The X181-NR

Submitted in Response to the FY18 National Real World Design Challenge

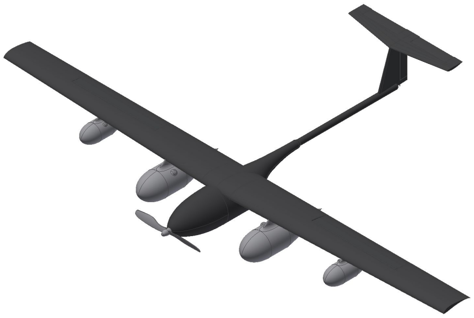

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Table of Contents

List of Figures

List of Tables

ABSTRACT

By the year 2050, it is estimated that there will be an additional 2 billion people on the Earth. To address this massive surge in population, humans will have to produce about 70% more food. Through technological development, it is possible to address this issue. Even today, Unmanned Aircraft Systems (UAS) are developed which enable a modern farmer to achieve greater crop yield. Through the Real World Design Challenge, which continually seeks to promote the development of these types of precision agriculture solutions, the Xaverian Engineers were tasked with developing a functional and profitable Unmanned Aerial Vehicle (UAV) design for use by a farmer.

In this scenario, this aircraft had to be capable of surveying and spraying better than two other competing aircraft in the market, the DJI Agras MG-1 (for spraying) and the eBee SQ (for surveying). Within this context, the challenge stipulates that a case must be made as to whether or not the part 107 regulations restrict the ability to improve crop yield while simultaneously minimizing profits. The design solution may operate outside of the part 107 regulations given that safety is not compromised and the deviations help increase operational efficiency.

The design solution, the X181-NR, operates more efficiently than the two given systems while deviating safely from part 107 in some instances. Nonetheless, the decision to use modularity to carry out both cornfield billbug infestation detection and application of pesticide to these infested areas—within a single aircraft—ultimately renders a system that is both affordable for farmers and profitable for the system operator.

The aircraft that is employed by the X181-NR, a single combustion engine, fixed wing aircraft with a carbon fiber fuselage and wing is able to treat the infested field at a significant time and cost savings compared to traditional methods and the competing UAS. The versatility of this aircraft allows it to be operated profitably at most any field size, through an optimal field size of 4,200 square acres was determined based on the time it can accrue revenue working on fields of that size. Nonetheless, the aircraft fits in a market that is occupied by both small and large farmers, and the relatively low initial cost of the X181-NR make its costs closely proportional to field size.

Ultimately, the importance of the X181-NR becomes most relevant when considering how its use will positively affect farmers. Corn crops can be used in a variety of different ways: for fuel, feed, sugar, or food, and it is thus a very important crop to the American economy. The X181-NR is able to protect the investment American farmers make in their corn crops by ensuring that it is not damaged by pests and parasites. By doing this more economically than competing systems, the X181-NR provides a service that both benefits the operator of the system in the long run, thus allowing the system to treat a greater number of farms over the span of many years, while also benefiting the farmer by preserving his or her corn crops at a low cost.

The use of the X181-NR as a precision agriculture solution to corn infestation has implications that reach far beyond its use on an individual field. By maximizing airframe efficiency, optimizing field size, and reducing costs for farmers, the X181-NR helps protect a crop that is vital to the American economy.

Specification Sheet

SURVEY CONFIGURATION OF AIRCRAFT				
Criteria	**Value**	**Regulation**	**Compliance**	
			Yes	**No**
Takeoff Weight	~64 lbs	Unmanned aircraft must weigh less than 55 lbs (25 kg)		No
Wingspan (fixed-wing) or Max Width (other)	14 ft			
Airspeed	18.1 m/s	Maximum airspeed of 100 mph (87 knots)	Yes	
Altitude	~400 ft	Maximum altitude of 400 ft above ground level	Yes	
Time in Flight	47.6 min			
Distance Traveled	~36 mi			
Number of aircraft per operator	1	No person may act as an operator or VO for more than one unmanned aircraft operation at one time	Yes	
		Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within VLOS of the operator or visual observer. At all times the small unmanned aircraft must remain close enough to the operator for the operator to be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.	Yes	
		Small-unmanned aircraft may not operate over any persons not directly involved in the operation	Yes	
		Daylight-only operations (official sunrise to official sunset, local time)	Yes	
		Must yield right-of-way to other aircraft, manned or unmanned	Yes	
		Minimum weather visibility of 3 miles from control station	Yes	
		No operations are allowed in Class A (18,000 feet & above) airspace	Yes	

SPRAYING CONFIGURATION OF AIRCRAFT				
Criteria	**Value**	**Regulation**	**Compliance**	
			Yes	**No**
Takeoff Weight	251 lbs (max 311 lbs)	Unmanned aircraft must weigh less than 55 lbs (25 kg)		No
Wingspan (fixed-wing) or Max Width (other)	14 ft			
Airspeed	18.1 m/s	Maximum airspeed of 100 mph (87 knots)	Yes	
Altitude	25 ft	Maximum altitude of 400 ft above ground level	Yes	
Time in Flight	35.9 min			
Distance Traveled	optimal flight path determined by software			
Number of aircraft per operator	1	No person may act as an operator or VO for more than one unmanned aircraft operation at one time	Yes	
		Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within VLOS of the operator or visual observer. At all times the small unmanned aircraft must remain close enough to the operator for the operator to be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.	Yes	
		Small-unmanned aircraft may not operate over any persons not directly involved in the operation	Yes	
		Daylight-only operations (official sunrise to official sunset, local time)	Yes	
		Must yield right-of-way to other aircraft, manned or unmanned	Yes	
		Minimum weather visibility of 3 miles from control station	Yes	
		No operations are allowed in Class A (18,000 feet & above) airspace	Yes	

1. Team Engagement

1.1 Team Formation and Project Operation

The roles and responsibilities of Project Manager were split equally between Senior and three-year member Roham Hussain and Senior and four-year member Noah McGuinness. Both were chosen for their unique backgrounds in design and engineering and for proficiencies in leadership and team management. Half of the team this year was replaced by newer members, so proper team leadership and designation of tasks was important. To this end, senior members were designated "Directors" of their respective positions, each in charge of leading a new team member within their sphere of influence. At the helm remained the co-project managers, concentrating on the overall management of the team.

Each member brought their own unique skill-sets and expertise, all of which were integral towards the completion of the notebook. The individual roles, responsibilities, and backgrounds of the members are detailed below.

Carter Chase - Theory of Operation [Sophomore]

Carter Chase is a Sophomore at Xavier High School. This year, he is taking all honors and Advanced Placement classes. In school, Carter works to the best of his ability and will always try his best no matter the task at hand. Carter has had a very high interest in engineering ever since his grandfather used to build lego sets with him since he was younger. Outside of the school environment, Carter spends his free time playing sports including baseball and basketball where he has developed high quality social skills and has learned to be a team player. Carter loves working with other people and is glad to do whatever benefits the team, including various aspects of this year's design challenge. These abilities will help the Xavier engineering team succeed in the long run and create a fun, creative environment. Over the summer Carter interns at ACMT (Adchem Manufacturing Technologies) in Manchester, CT working with composites and adhesives in aerospace.

Roham Hussain - Graphic Designer [Senior]

Roham Hussain is a senior at Xavier High School, and is this year's graphic designer. Over the past few years, he has become deeply integrated with every aspects of the Engineering Team. On a daily basis, he is able to maintain a rigorous six-AP school schedule and a stable tutoring position at the Kumon School of Learning. Even with this busy schedule, he manages to hold leadership positions in multiple extracurricular activities including Model UN and a specialized advisory committee for the Department of Motor Vehicles. Over the summer time period, Roham has worked as an intern for an accomplished graphic design firm as well as taken part in numerous engineering-based programs and leadership forums. From these experiences, Roham has achieved proficiency in leadership, collaboration, design, academics, and more—all of which enable him to be a better leader for such a diverse team.

Akshay Khunte - Design [Sophomore]
Akshay Khunte is a Sophomore at Xavier High School, and is mainly focused on the Design Aspect of the project. Currently, he is enrolled in all honors and Advanced Placement classes, including H Algebra II and H Engineering I. He has also received the distinction of High Honors throughout his Freshman Year and his first quarter of Sophomore Year. Akshay is involved both in and outside the classroom; beyond the Engineering Team, Akshay also participates in his school's Math and Model UN Teams, and is a coxswain on the Crew Team. He is also a Boy Scout and has achieved the Eagle Scout rank. His advanced academics paired with his leadership experience both in sports and scouting make him a well-rounded individual who adds much to the team. Most of his efforts are concentrated on the designing aspect of the challenge. He has experience with using modeling software such as SketchUp. These assets make him a versatile team member, especially when coupled with the leadership skills he has learned as part of earning the rank of Eagle Scout.

Noah McGuinness - Co-Project Manager and Director of Design and Analysis [Senior]
Noah McGuinness is the Director of Design and Analysis for Xavier High School's Real World Design Challenge solution. With three years 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. Further, working with the aerodynamic and mechanical elements of past challenges has allowed him to apply a more comprehensive understanding of unmanned aircraft systems. As the leader of the design team, it is his responsibility to oversee many aspects of the development process. In order to create an efficient, comprehensive, and technically viable solution, he has applied these experiences and skills to the project with the goal of benefitting the team to the best of his ability.

Alexander Pralea - Business [Sophomore]
Alexander Pralea is a sophomore at Xavier High High school who focuses on the business portion of the project. As he is enrolled in all honors classes and Advancement Placement classes, from H Algebra II to H Engineering I, he can bring a diverse skillset and the hard work necessitated by a project of this magnitude. From freshman year to now, Alex has received High Honors and the Brother Celestine Award for his academic achievement. Furthermore, Alex has evinced his commitment to extracurricular activities in his vital role in the varsity tennis team, math team, Model UN, Italian club, and school ambassadors. He has attained the leadership role of Editor within the school newspaper, and is also involved in leadership within the school community as a homeroom representative. Outside school, Alex trains to become a ski instructor in Stratton, Vermont, and he also assumes an important role at his church, First Church of Christ, where he not only assists in organizing some day-to-day activities but volunteers and serves in mission trips. With his flexibility and acuity, he offers the well-roundedness and acumen for this position. Alex's experience in a variety of topics, from mathematics to engineering and leadership, makes him perfect for solving this year's Engineering challenge, for which he aspires to create a feasible and effective solution.

Vincent Salabarria - Director of Business [Senior]
Vincent Salabarria is the team's Director of Business for this year's challenge. He is a senior at Xavier High School. The experiences Vincent has in his honors and AP classes, including mathematics, English,

and environmental science, and his recognition as a Distinguished Scholar are important to the success of the team. Vincent has also accumulated about 120 hours of flight training and experience and holds a private pilot certificate. The knowledge that he has acquired regarding federal aviation regulation, flight dynamics, and flight operations have been integral to the team's successful completion of the challenge. Furthermore, this is Vincent's fourth year as a team member. The past three years, he has been the director of the Business Case, and he was the Project Manager from 2016 to 2017. His prior experiences as a pilot, Project Manager, and director of Business have helped him guide the team to produce a successful and effective solution to the challenge.

Anthony Tedeschi - Director of Theory of Operation [Senior]
Anthony Tedeschi is a senior at Xavier High School and is the Director of Theory of Operation. This is his fourth year of participating in the Real World Design Challenge. At Xavier, he is involved in honors and accelerated classes and three of those classes are stem related. He has an interest in mechanical engineering and has had this interest ever since he was young. Over the four years that he has participated in the RWDC he has gained a vast knowledge about the subjects of precision agriculture and design development.

1.2 Acquiring and Engaging Mentors

The team found the mentors to be an invaluable resource in completing the project. The diverse backgrounds and years of professional work experience of the mentors enabled the team to solve the complex problems offered by this challenge. After the National Challenge was announced, the team met with the mentors at Pratt and Whitney and discussed strategies to meet the standards required for excelling at the national level of the competition. The mentors and the team decided to split the project timeline into two sections. The first portion of the project would consist of planning and executing the project by completing the notebook. The team then entered into the second phase of the project: the revision and fine-tuning stage. The team leveraged the mentors as a resource by asking the mentors to review the notebook. Through their feedback, tips, and suggestions on how to improve the work, the team was able to further enhance the content of the notebook. 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 "CM" and thus contacted the mentors in order to understand the concept. Lastly, the mentors were instrumental in regards to the presentational aspect of the challenge. They provided the team with feedback regarding both the style and content of the presentation and helped improve the overall design and strategy of it, as a whole.

1.3 State the Project Goal

This year's national challenge requires both the determination of whether or not the FAA's part 107 regulations limit the ability to improve crop yield while minimizing profits and the development of a UAS (Unmanned Aerial System), with the possibility of multiple aircrafts, designed to perform one or both of two main functions in an agricultural environment. According to the Challenge, the UAS must be capable of spraying and/or surveying better than one or both of the aircrafts given. Furthermore, the challenge details that if either surveying or spraying is to be done using traditional methods, how the traditional methods are carried out and the cost of such methods in comparison to using a UAS.

There are four, primary subjects that each team must document. These subjects relate to the missions the UAS or the UAS in combination with traditional methods is supposed to complete. 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, the UAS design, 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, though an integral part of the challenge is to provide a number of uses within the agricultural industry.

The challenge, which must be completed with the UAS, is to initially survey a corn field for infestation by billbugs and then to spray infested areas with the challenge-specific compound Solvitol. The testing field, composed of four 1 mile by 1 mile sections, must be able to be surveyed and sprayed by the UAS designed by the team. The UAS given by the challenge as competitors to the team’s UAS are the DJI Agras MG-1 (spraying) and the eBee SQ (surveying). The UAS, and by extension the full solution, must be better than one or both of these drones at their respective tasks.

Another important part of the Challenge is its focus on aircraft safety. Because of this, the ideal aircraft would have the ability to avoid ground and air obstacles while providing the pilot with maximum situational awareness. The contingency responses and aircraft safety equipment ensure that the aircraft provide the farmer with a safer, more reliable system. By ensuring the safety of the UAS the team will be able to cut down on the possibility of losing the UAS which will help cutting down on profit loss. Furthermore, the aircraft must be equipped with procedures to follow in case of signal loss from the pilot and GPS, another way to lessen the chance of losing the UAS.

For the business portion of the challenge, the team must produce a method of selling the services of spraying and detection to farmers. Furthermore, the team cannot market the aircraft itself as what will be sold. The teams must also see if they can make a case that their designs outside of part 107 regulations will lead to an increased opportunity for profit. This profit must come from reduction of costs or increases in revenue without making the price unreasonable for farmers.

1.4 Tool Set-up/Learning/Validation

In order to successfully complete the project, the team had to use various software such as Autodesk Inventor, Autodesk Flow Design, Desmos Graphing Calculator, Microsoft Excel, and Google Drive.

Autodesk

Noah and Akshay 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 software that proved to perform many of the required tests that allowed for the refining of the model. Programs such as Autodesk Flow Design were used to make adjustments to the airframe and analyze the aerodynamic properties of the craft, while other functions of Autodesk Inventor allowed for structural analysis and design of key parts of the Unmanned Aerial Vehicle (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 Suite
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 seamlessly. 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. To better facilitate this process, and to accommodate busy schedules, Google Hangouts was also implemented. Through this program, the team was able to work effectively and in harmony with other team members in a video-call style environment.

1.5 Impact on STEM

Carter Chase [Sophomore]
Ever since Carter was young he took an interest in building and problem solving mostly due to the influence of his grandfather. He participated in many engineering oriented tasks ranging from building lego sets, airplane models, and constructing real airplane engines. Participating in the RWDC challenge allows him to bring all of the knowledge he has obtained over the years and focus it on a single project. His perspective on STEM has altered while participating in the RWDC challenge due to an inclusion of teamwork and a strong Xaverian core that connects him and the team together into a family. The team as a cohesive whole is able to conquer any hurdle that comes at them, whether there is a fault in the project or even if a group member is falling behind. Along with his perspective on STEM, Carter has obtained an interest in engineering as a future because of the RWDC challenge. He has developed a fixed mindset, focused on finding opportunities to absorb the highest possible amount of knowledge on STEM. Throughout the school, students begin to realize the great success of the engineering team and are eager to learn more. The team spreads the news about STEM, sparking interests in many of the students. Many students have heard of the extreme success of the school in recent years in the challenge, and because of their interest in competition, love hearing about the STEM oriented technologies they use.

Roham Hussain [Senior]
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. The experiences he has gained since then, from various engineering summer camps as well as an internship at a professional-level graphic design firm, have only furthered this passion. The Engineering Team at Xavier High School seemed to him to be

the perfect extension of these interests. Participation in the RWDC challenge over the past few years have been instrumental in shaping his own career, as they have, even now, encouraged him to apply for STEM majors in college. His time on the Engineering Team has been so meaningful that, even at his own school, he seeks, through his managerial role on the Engineering Team, to further promote STEM education by bringing 3D printers and other great engineering-based opportunities to the school that were previously not there.

Akshay Khunte [Sophomore]

Akshay has always been interested in how things work and how they are designed. Ever since he was a child, he would always take his toys and other items apart to see how they work and find out if he could put them back together. Since a young age, he has also always been interested in technology and experimentation with it. Akshay finally realized his true passion for creation during his Eagle Project, in which he designed and led the construction for a large aviary. He has also realized this passion because of the engineering team. The RWDC Challenge is a great way for Akshay to utilize his interest for engineering and creating something that is applicable in the real world. Furthermore, RWDC is leading to the cultivation of an interest in the STEM field for others in his school, by leading to the creation of our engineering team and inspiring others to try Engineering. Akshay believes that he would eventually like to go into the STEM field, especially in biomedical engineering, and RWDC really helps him see himself in that kind of a position. Engineering team is a great place for Akshay and his fellow classmates to follow their passions and see the places these passions could take them.

Noah McGuinness [Senior]

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 not only introduced to design processes, but was also able to expand his 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 software. The project's requirement for a tested and analyzed UAS model allowed Noah to increase his 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.

Alexander Pralea [Sophomore]

Growing up in a medical household has aided Alex in cultivating his interest in science, technology, and engineering. From a young age, he has manifested his interest in working with his hands and designing various projects. He has always loved tinkering with legos, which extends to his current love of tinkering with computers. This evident interest in engineering has lead him to join the many STEM programs offered at Xavier. In the Engineering team's Real World Design Challenge, Alex hopes to utilize his love of design and communication to benefit the team. Since joining the team this year, Alex has witnessed the various opportunities afforded by engineering, and is excited to utilize all the skills he has accumulated in applying aviation to the real world. Becoming a member of the Engineering Team has imbued Alex with an enhanced love of STEM, which he has come to view as a career option. In the future, Alex hopes to become an oncologist with a focus on research, where he can use the skills and passions developed in his tenure in Xavier's Engineering team.

Vincent Salabarria [Senior]
Science, technology, engineering, and mathematics have always interested Vincent. However, applying these topics is where he finds the most interest and value. The RWDC supports Vincent's interest in aircraft operation and design. As a member of the team, Vincent has the opportunity to thoroughly research and develop aviation technology. While working on the Business Case, Vincent uses Microsoft Excel. He also must effectively communicate meeting dates and important information to the entire team, utilizing communication technologies. Finally, the entire Challenge is conducted using 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, as a commercial pilot, flight instructor, or air traffic controller.

Anthony Tedeschi [Senior]
Ever since Anthony was young he was always interested in taking things apart and putting them back together in order to find out how something works. As he got older he gained an increased interest in science and math and realized that he wants to study mechanical engineering. The Xavier High School Engineering Team was one of the things that had influenced Anthony to want to study engineering. While on the Engineering Team he was able to learn about and apply the four aspects of STEM. He would like to pursue a career in the United States Navy and has been accepted into Norwich University Corps of Cadets and their mechanical engineering program.

2. Document the System Design

2.1 Mission Design

2.1.1 Aircraft Compliance with Part 107

Inside Regulation

The proposed theory of operation for the UAS solution documented in this design notebook complies with the following elements of the part 107 regulations:

-The vehicle may only operate in daylight or twilight
-The vehicle must stay within 400 feet of the ground
-The vehicle must not exceed an airspeed of 100 mph (87 knots)
-The vehicle may not be flown over anyone not participating in operation
-The vehicle may not be flown under covered structures or vehicles
-The vehicle may operate in Class G airspace without air traffic control (ATC) permission.

-The vehicle may carry an external load that is securely attached and does not unreasonably affect the flight characteristics or controllability of the aircraft.

-NOTE: Although the spraying vehicle has four detachable pesticide tanks that are suspended from the wings, they have not been found to cause stability issues, unreasonable drag, or harm the structural integrity of the wings (see section 2.2.4).

Outside Regulation

The proposed theory of operation for the UAS solution documented in this design notebook does not comply with the following regulations to the extent stated:

-The vehicle and payload must not exceed 55 pounds in total weight

-The X181-NR will have a maximum operating weight of 311 total pounds (64 pounds of airframe and operational components, 247 pounds of possible payload), but will operate at 251 with 187 pounds of pesticide for the application mission. Thus the vehicle will be operating 196 pounds above of the current part 107 regulations.

2.1.2 Justification of Regulatory Compliance

The only part of the design which is not inside FAA part 107 regulations is the weight. In this year's challenge, the mission is to spray pesticide over 10% of 2560 acres (256 acres) with .35 gallons, or 2.93 lb of Solvitol, per acre. This means that in total, approximately 749 lbs of Solvitol must be carried and sprayed using a number of trips. If the design was inside regulations, assuming a 1:1 payload to body weight ratio, the drone would be able to carry only 22.5 lbs per carry, and would thus take 34 trips to completely spray the infected areas in the field. The only way to reduce this number and thus dramatically reduce costs and time needed for the aircraft to constantly come back and refill its tank of Solvitol is to increase the payload size drastically, and thus increase the overall weight. In order to achieve a design which can carry a very large payload, the team had to exceed the weight set by the part 107 regulations and have a pesticide mission weight of 251 pounds including payload (with 311 pounds maximum calculated lift capacity). With 187 lbs of pesticide (22.37 gallons), the drone can spray all the infested portions of the field in just 4 trips, one per each 1 mi x 1 mi field, a small number compared to the 34 trips a drone inside regulations would need to spray the infested areas. In total, the X181-NR, from the beginning to the end of the mission, requires two hours. This ultimately saves thousands of dollars in labor and operational costs by reducing the time it takes to complete the mission.

As a result of the massive decrease in number of trips necessary to complete the mission and thus large reduction in cost, the team decided that it would make sense to go outside of part 107 in terms of the weight of the design. Furthermore, after numerous tests and analysis of the design, it has been found that the drone is still safe even with its high weight and does not pose a threat (see safety analysis in section 2.2). The operating costs of the X181-NR $26,818 less per mission than that of a comparable system that operates within this part 107 regulation. This is outlined in section 4.3 of the notebook. This increased efficiency due to operations outside of the weight limitations allows profit to be maximized and costs for the farmer to be reduced.

2.1.3 Design Operations

The UAS will be used for both the surveying and spraying missions. To minimize unnecessary cost, the sprayer aircraft design was modularized to allow for detection capabilities. (For more information, visit Section 2.2.2.)

For the surveying mission, the detection will take place with the use of a camera with the capability to detect Near Infrared Radiation (NIR) and the visual spectrum. This capability will allow for the generation of Normalized Difference Vegetation Index (NDVI) maps which can determine whether or a plant is infested based on its overall health. This map will then be fed into the flight plan for the spraying drone which will use it to determine the infested areas which need spraying. (More information can be found in Section 2.2.2 and 3.1.)

Two flat fan nozzles and five spray tanks allow for the completion of the spraying mission (Section 3.2).

As for the part 107 regulations, the goal was to follow as many of the regulations as possible. In this pursuit, only one part 107 regulation was violated. In order to perform the application mission in a feasible amount of time (to prevent the UAV from having to make unnecessary trips back to the base of operations), the UAS system had to be able to carry a significant payload of pesticide. As a result, the weight restriction was surpassed (the regulation stipulated no more than 55 lbs, but the UAV weighs 251 lbs in total).

2.2 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, hybrid, etc.), 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.

2.2.1 Engineering Design Process

The team followed the Engineering Design Process as seen below for the Challenge:

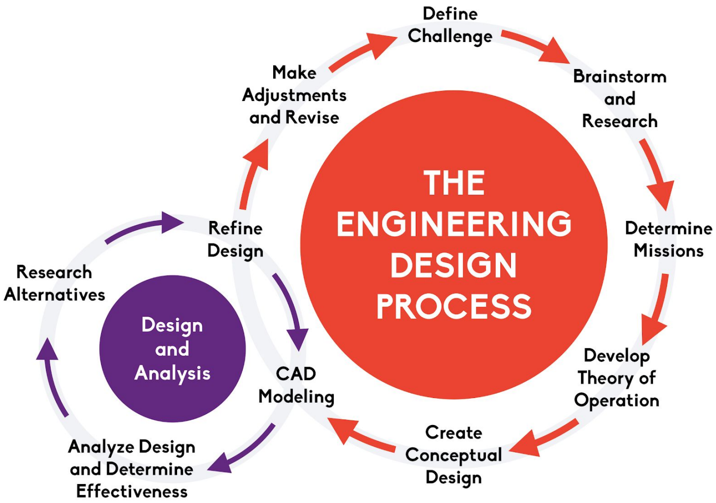


Figure 1: The Engineering Design Process

The team's first step in the design process was to define the challenge. In order to do this, each team member read the detailed background and challenge statement in order to understand what the goal of the operation was. The team also began considering what the solution of the challenge should contain.

Once the problem was accurately defined and each member had an understanding of what the challenge entailed, the team moved into the Brainstorm and Research phase of the project. In this phase, the members of the team split up, researching all of the various aspects of the project and summarizing the data they collected in documents which served as resources in the future phases. Likely the most critical aspect to creating a viable design, the team contacted local farmers and received suggestions for the capabilities of the drone. By utilizing this invaluable resource, the team could design the drone designed specifically based on the intended consumer's wishes. For brainstorming, the team conducted numerous video calls and in-person meetings to produce various ideas for the design of the drone. Although some ideas did not seem feasible, the team did not reject any propositions, recognizing that all ideas should be considered during the brainstorming period and thus not inhibiting creativity. Furthermore, the more outlandish ideas could be used as the base of finding more viable ideas for the drone.

Once brainstorming was completed, the team created a conceptual design. The team 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 create the 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. After a design was created, it was heavily analyzed and redesigned several times. This phase continued for the majority of the project's duration. As the design portion of the team worked to design the UAV, the members working on theory of operation worked to decide how the spraying and surveying would be completed and what methods could and would be used.

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

2.2.2 Conceptual Design

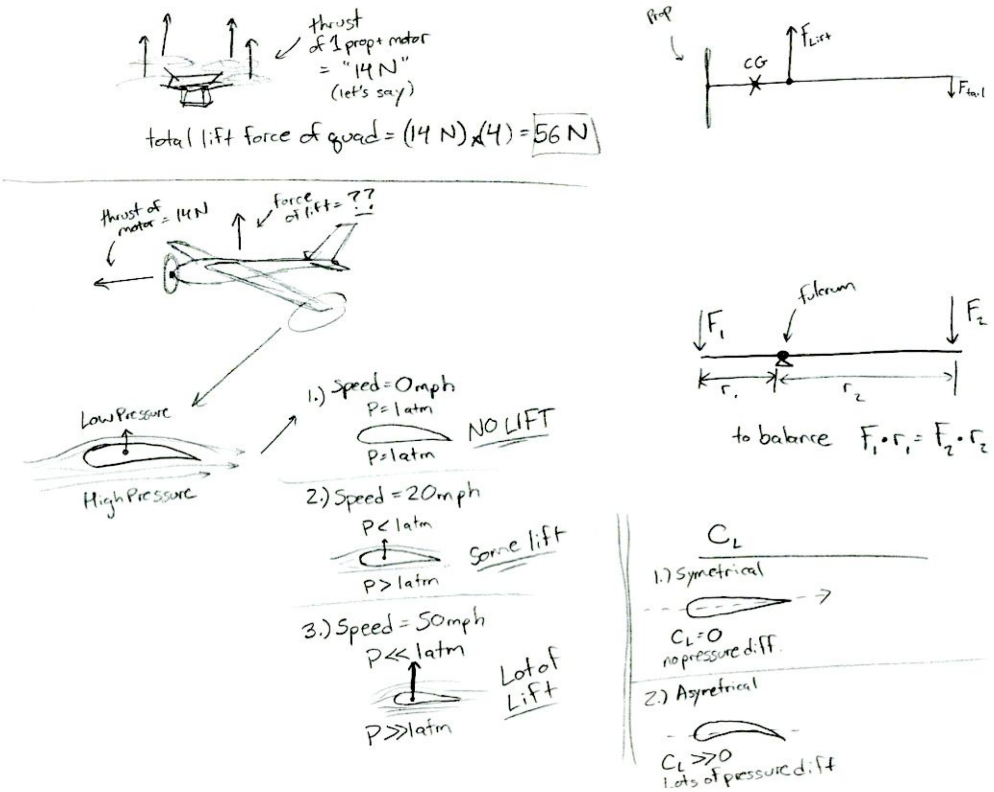


Figure 2: Configurations Sketch (1)

(Hypotheticals used to explain the basics of UAV configurations to new team members)

Spraying Vehicle

Initial Considerations - UAV Configuration

The first step in narrowing down the many variables involved in UAS design was determining the configuration that was best suited for the mission requirements. Of the three options considered (fixed-wing, multi-rotor, and hybrid) it was determined that a fixed-wing tractor would be the most efficient design considering the heavy payloads and long distances involved in pesticide spraying. The multi-rotor option was primarily at a disadvantage due to fact that all lift for the design would need to constantly be supplied in a form of vertical thrust solely from the rotors. The energy required for not only lifting the craft, but maneuvering it smoothly (requiring a safe ratio of 2:1 or 3:1 for thrust to weight of the UAV) significantly hindered payload weight, flight speed, and time. Sources revealed that the relatively simpler structure of a tractor allowed for easier user maintenance and lift produced by wing surfaces allowed for longer flight times and carrying capacities. To better understand how different designs would fare, a series of more complete conceptual designs were established (discussed in 2.2.3 - Preliminary Design).

Conceptual Design 1 & 2 - Multi-Rotor and VTOL Hybrid

Market research of pesticide drones, including the DJI-Agras, revealed a large number of vehicles that were multi-rotor rather than fixed wing for spraying which led the team to conduct additional research regarding the practicality of using such a configuration for this year's challenge. Controllability, stability, and low speeds were all factors that originally made the multi-rotor an appealing option for consideration.

With further research, however, the primary concerns that were noted against this design were the severe payload and duration limitations that are associated with using quadrotor or hexrotor. During the preliminary design phase, these concerns were quantified through calculated power consumption estimates (see 2.2.3).

While the VTOL option had the potential to combine the best of both the fixed-wing design and the multi-rotors, the same limitations that applied to the multi-rotor were weighed against the minimal benefit of being able to take off and land vertically; however, this option was investigated for the potential to develop workarounds for these limitations.

Conceptual Design 3 & 4 - Fixed-Wing Pusher or Tractor

The aerodynamic and logistic capabilities of a fixed-wing were originally the main points that attracted the team to this conceptual design. Overall, it was believed that given the stipulations of the current challenge, a tractor or pusher would provide the most useful means of applying the modularity required for the transport of a large liquid payload. The ability to generate lift from air flowing over the horizontally moving wing surfaces as opposed to just the direct vertical power of motors creates a configuration that is optimized for long ranges with dead-weight payload.

Detection Vehicle and Detection Methods

Detection with Traditional Methods

Detection with traditional methods is a relatively cost-effective means of surveying the field. Not only can surveying be completed at a much lower cost compared to the eBee SQ (see section 4.1.1), utilizing traditional methods also means that an additional UAV need not be created for the surveying mission, a potential source of significant savings. Furthermore, utilizing traditional methods for surveying increase the accuracy of detection, given the inclusion of an Agricultural Specialist in the detection component. The National Challenge, however, stipulates that detection of billbug infestation must be completed from the Air with a UAS, meaning that Traditional Methods may not be used.

Detection from the Air

Detection from the air certainly has many positives which must be considered when making the decision of the method of detection of the billbug infestation. One of the biggest advantages of detection from the air is speed of detection. Although traditional methods can detect the infestation in the same amount of time as, for example, the given eBee surveyor UAS, a fixed wing aircraft with optimized propulsion and a higher speed camera could complete the detection faster than an individual. A surveyor UAS can pinpoint areas which are infected by the acre, instead of larger regions marked by manual inspection. This allows for maximizing the effect of each gallon of Solvital; no uninfected regions would be marked for the spraying UAS to cover. This would decrease the cost and time of each spraying mission. Furthermore, a UAS for surveying could be designed with maximum flight time and distance in mind. This would allow the surveying mission to be done faster than manual detection or the eBee drone.

➔ **Detection using Machine Learning**

One of the methods the team considered for detection of the billbug infestation is machine learning. Utilizing machine learning means having the camera in the plane record video of the plants below at a high level of zoom, and running the video through a program which would analyze each frame for the visual signs of billbug infestation, such as the small holes in the plants. In the process of developing this program, thousands of frames must be captured by the UAS on the sample field of both infected and healthy plants which would then be manually defined as infected or uninfected. These frames would be utilized as test files for the program to use as it teaches itself to correctly identify the indicators of billbug infestation. This method of detection, however, poses many problems. First and foremost, the height of the plane (400 ft) means that the focal length of the camera would have to be quite large to attain the close view of the plant necessary to determine if the less than one inch wide holes are present. Such a large focal length would equate to many more passes necessary during the detection mission given the smaller amount of area captured during each pass. This would drastically increase the time of each mission and thereby increase the cost. Secondly, machine learning is not a foolproof means of detection. Not only is the practice not completely developed, machine learning as a whole is a teaching process in which the program teaches itself only based on what it sees and is not flexible with slightly different images. This means that the process could potentially be extremely inaccurate once used on a farmer's field since the program would be "trained" based on the sample field. Machine learning, although it would work most of the time if many test frames were captured, is quite expensive and has potential for inaccuracy.

➔ **Detection using Normalized Difference Vegetation Index (NDVI) Camera Technology**

A second method for detecting billbug infestation is using NDVI Camera Technology to determine the healthfulness of a plant. This process, which requires the use of a camera equipped with the NDVI technology, generates an image of the field which based on the amount Near Infrared Radiation (NIR) and red light absorbed by the sensor on a pixel-by-pixel basis. This maps allows the computer to determine which areas of the field are infected by noting the portions with a lower NDVI value compared to the rest of the field. This method allows for a significantly higher field of view in the camera, meaning that fewer passes, less time, and less money are required per mission. Since the visual signs of infestation are usually hidden beneath the head of the corn stalk and covered by foliage, this method overcomes this issue and detects infestation regardless of the ability to see visual signs. Overall, NDVI technology is one which has a high level of accuracy and one which allows for the high altitude of flight required as a result of the no-fly zone without sacrificing the ability for detection. It also decreases cost given its ability to determine the health of a plant without using a high focal length which only captures a small number of plants in a frame, decreasing the number of passes per mission.

Two Separate UAVs for Spraying and Detection

One option for the UAV for detection would be to create a new UAV specifically designed for surveying which is lighter and more maneuverable than the spraying UAV. This method would likely increase the efficiency of the Surveyor, given that it would be designed specifically for surveying. This option, however, would be incredibly expensive. Building and maintaining two separate drones would vastly increase cost. This large expense would serve to only minimally increase the surveyor's capabilities. This option, while it would increase the ability of the surveyor to some extent, would be very costly for both the business and the consumer.

Modularizing the Sprayer Design for Detection

A second option for the UAV detection mission would be to utilize the Spraying UAV for the detection mission. By modularizing the components unique to each mission, the cost of new computational and material components would be saved. Furthermore, this would allow for a decrease in overall cost. This UAV could potentially be slightly less capable than a dedicated surveyor, but this can be overcome by optimizing the flight path based on the Spraying UAV and also removing all components unique to the sprayer to streamline the vehicle and make it as capable as a dedicated surveyor. Given the vast savings, modularizing the components unique to the two missions would make the X181-NR a much more financially feasible purchase.

2.2.3 Preliminary Design

Spraying Vehicle

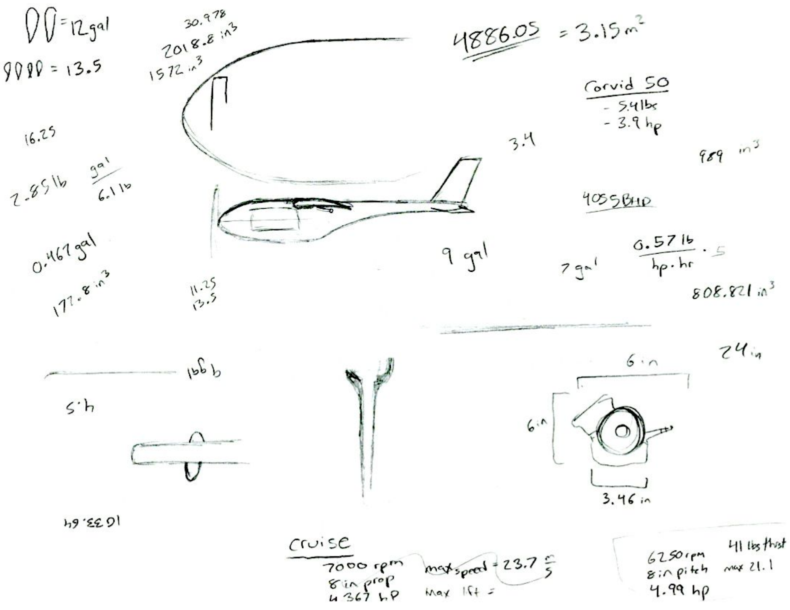


Figure 3: Preliminary Sketch (2)

Conceptual Designs 1 & 2

One of the first decisions made regarding the part 107 regulations was that the weight limit would need to be exceeded in order to cut down the large number of trips associated with the total of 749 pounds (89.6 gallons) of SOLVITAL that were necessary for the field area specified. Conservatively assuming a vehicle with an approximate 1:1 weight to payload capacity ratio, such a drone would have a minimum of about 30 trips to make to complete the pesticide application. Thus the team considered the UAV's power consumption in light of this decision.

Conceptual designs 1 and 2 were ruled out primarily for this reason. To consider power consumption for both vertically oriented designs, the team originally determined that the power supply would have to be electric due to the high unreliability of using an electronic fuel injection engine for precise speed control at this scale. In addition, even with a gas motor, the same concerns about the downsides to multirotors for use in payload transportation were still applicable, but the calculations with electric motors further solidified these concerns.

Recommended with a minimum of 2:1 or 3:1, a 1:1 ratio would lead to a completely useless design that only had vertical lifting capacity. When considering the lift required for a 2:1 design, the numbers required for energy consumption were daunting and unreasonable (discussed below).

Research regarding the various configurations had revealed that multirotor designs were not ideal for large payloads. To determine the validity of these results, a systematic approach to the issue was taken. First, the required primary elements for propulsion were determined: Propellers, motors, batteries. (While other components such as the flight controller, speed controllers, battery eliminating circuits, and other precise control instruments are required, they were not considered for the rough approximations done in this early stage of the process). With the knowledge that at the minimum, about 150 pounds of payload were required (for a minimum of 5 trips), a rough and generous approximation of a 75-pound frame was added. With a target goal of approximately 2.5:1 lift to weight ratio at the minimum for this theoretical example, the rough lifting capability of the craft was calculated by multiplying the total weight by 2.5. The result was a lift requirement of 526 pounds. Both hexa-rotor and quadrotor designs were considered, leaving the first at an approximate 87.7 pounds required per propeller (526lbs/6 props) against the 131.5 lbs/prop (562lbs/4 props). While the hex-rotor provided a lower result, both amounts are generally considered unreasonably high for motors. For the first option of 87.7 per motor (~40,000 g), not a single electric motor could be found that produced more than an absolute maximum of 9000 grams of thrust per motor.

Conceptual Designs 3 & 4

A number of factors were considered once it was determined that the vehicle would be fixed wing. The two primary categories were propulsion configuration (pusher or tractor) and wing placement (high, mid, or low-wing).

- ➔ **Wing Placement**

  The following pros and cons list was created to aid this selection process.

Wing-Type	Pros	Cons
High	-High center of lift for lateral stability (good for wing tanks) -No storage space lost in fuselage -Higher ground clearance	-In the event of a crash the main body and prop take the impact -Not practical to have long landing gear on the wings
Low	-Easier to maneuver in crosswinds (not applicable for this challenge) -Little space taken up by wing in main fuselage -Distribution of force in a crash landing -Shorter landing gear	-Less lateral stability -Wings may catch on ground debris -Higher ground effect -More airflow interference for empennage

Due to the high payload stored in the wing tanks and the necessity to have high stability with the larger aircraft, the high wing was selected. In addition, the higher ground clearance was seen as a major positive factor seeing as it would increase the capability for more pesticide capacity.

➔ **Propulsion: Pusher or Tractor**

The debate over whether pushers or tractors are theoretically more efficient is largely unresolved, as the pros and cons vary based on the intended use of the aircraft.

The first factor considered was that of aerodynamic efficiency. Due to the placement of the propeller on tractors, the flow of air comes uninterrupted into the blades, allowing for smoother airflow and more effective propulsion. In pusher designs, however; the airflow has travelled over the frame and may thus be turbulent or obstructed by the time it reaches the propeller, reducing efficiency.

Next came the considerations for propulsion. Engines positioned in the front of the craft often receive better airflow (the intake vent and the exhaust on the X181-NR were positioned just to the sides of the propeller), and thus better cooling. However, pushers often have the advantage when it comes to gas engines, as the entire structure may often be left exposed to open air for ease of exhaust expulsion, maintenance, and fueling, and this does not adversely affect drag due to the lack of direct, blunt air contact with the engine in the back. However, one important factor specific to the X181-NR was the necessary consideration of pesticide application. An engine and propeller in the back would potentially accumulate pesticide in its mechanisms or intake vents, creating maintenance issues and potentially affecting the even distribution of pesticide droplets with the turbulence from the UAV’s wake.

For these reasons, it was decided that a tractor was a better option, and access hatches were accounted for in order to facilitate maintenance or removal of the engine if necessary despite its restrictive housing.

Detection Vehicle

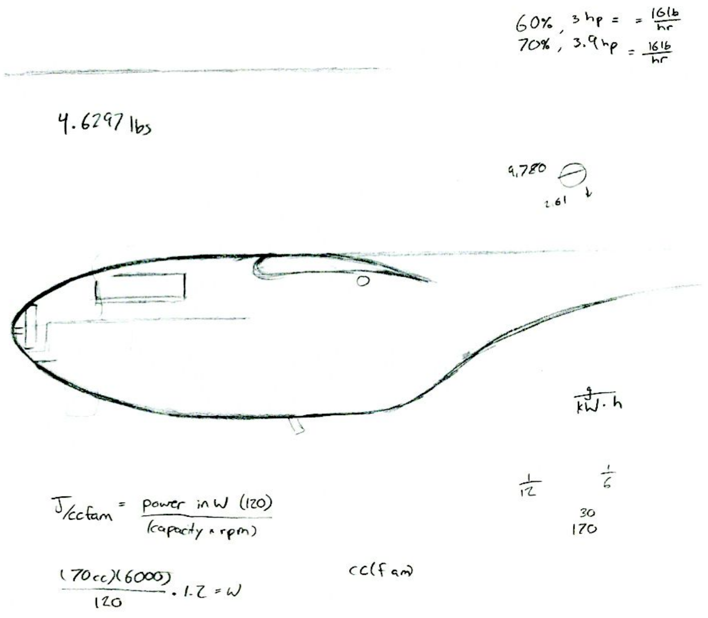


Figure 4: Preliminary Sketch (3)

Detection from the Air

Detection from the air, although it has a multitude of positives such as identification by acre, is unpractical mainly for one reason: cost. Utilizing a drone to complete the surveying mission is simply too expensive compared to manual detection. As explained in section 4.1.1, using a drone is costly and manual detection has the potential to use the same amount of time as aerial detection at a much lower cost. Simply stated, although it provides some benefits over traditional methods, it is not the best option as manual inspection allows for significantly cheaper detection, a priority of farmers.

However, the national challenge stipulates that both detection and spraying must be accomplished by an unmanned vehicle, and thus traditional methods are not permissible.

Limited by this stipulation, the team determined that the best solution to offset the costs would be to modularize the spraying vehicle to be fit for aerial detection as well, despite its large size, rather than constructing a separate, expensive, independent vehicle solely for the purpose of detection.

Initially, it was believed that the large size and build of the X181-NR would make it unfit for the quick speeds and maneuverability associated with drones such as the eBee; however, by developing a suitable flight plan and adding the ability to remove heavy components of the drone that would not be required for the survey mission, the benefits of speedy UAV travel as opposed to manual detection shone through.

- ➔ **Machine Learning - Visual Spectrum**

  Machine Learning is a means of detection which, although it is usable, may be prone to errors and also is expensive. This method records video of the field in the Visual Spectrum and the proceeds to search for the visual effects of billbugs on a frame by frame basis. Due to the need for a high level of zoom on the camera, many more passes (compared to NDVI Camera Technology, for example) must take place to completely scan the entire field. Furthermore, this technology is prone to errors in that a slight change in the conditions of a farmer's field compared to the sample field could lead to inaccuracy or inability to properly scan. Due to the high cost and questionable accuracy, this option for detection is not feasible in providing a cost effective and capable product.

➔ **NDVI Camera Technology - Visual and NIR Spectrum**

A second means of detecting billbug infestation is NDVI technology. This technology calculates the health of a plant based on the light on both the Visual and NIR spectrum the plant reflects and absorbs. This method allows for a significantly higher field of view (FOV) per picture as well as a greater accuracy given the ability to detect infestation without the presence of visual cues. Furthermore, this large FOV allows for fewer passes compared to when Machine Learning is used, translating to significantly lower amounts of time and money required for each mission.

2.2.4 Detailed Design

The Design Process - An Overview

The design of an entire aircraft system is a complex problem of systems engineering, involving the optimized interaction of a number of major categories of flight components. To break down this process at the very start, the team considered many of the systems one by one, using information from the previous component to determine the next. Once each category had been completed, further optimization was conducted to then refine the interactions of these systems to a design that would be efficient and effective. These categories were as follows: Wings and Lift, Propulsion and Power, Control and Electronics, Fuselage and Structure. This section is intended to show the process of designing the UAV and many of the subsections describe early iterations of vehicle components. For a list of the final vehicle's capabilities, see the end of 2.2.4.

The spraying vehicle was designed first, as it posed much more of a technical challenge as a result of the need to carry an unusually high payload. Since it was determined that the detection vehicle would likely be a modification of the sprayer and its airframe, the team determined that the best course of action was to complete the vehicle with higher weight requirements first, as it would be easier to convert into a UAV for lighter weights than it would be to convert a small drone into a heavy-lifting vehicle.

Spraying Vehicle Design

Wings and Lift

To begin, the team first collected as much data as possible about what functions would be required of the aircraft such as the total field size, the weight and volume of SOLVITAL to be transported, and the performance specifications of the baseline drone provided. This information allowed the team to determine what the desired payload size would be in comparison to the capabilities of the DJI-Agras and the limits of what could be reasonably transported by an unmanned agriculture drone. To determine what the approximate payload goal was as a first step, the information provided about SOLVITAL (density of 8.36 lb/gal and requirement of 0.35 gal/acre) was used to calculate the total weight and volume needed per trip given increasing numbers of trips.

First, 10% of the 2560 acres yielded 256 affected acres, which at 0.35 gal/acre totals to about 89.6 gallons of SOLVITAL, or 749 pounds. This was then placed into a chart that listed volume per trip, pounds per trip, and two values “x” and “2x” that represent the dimensions of a theoretical payload tank in the shape of a rectangular prism with a square base (x by x) and a length of 2x needed to transport the given volume. These last two values were just intended to provide a preliminary sense of what size tank would be required for such a volume in more tangible terms.

Trips	**Vol/Trip**	**Lbs/Trip**	**X** (ft)	**2X** (ft)
1	11.98 ft^3	749	1.82	3.63
2	5.99 ft^3	374.5	1.44	2.88
3	3.99 ft^3	249.6	1.26	2.52
4	2.99 ft^3	187.25	1.14	2.29
5	2.40 ft^3	149.8	1.06	2.13

Table 1: Preliminary Analysis of Trips

Considering the DJI-Agras’s spraying time of about 35 trips, the team determined that a desired number would be between 3-5 trips, as to not result in an aircraft that was too heavy to safely maneuver in the event of a crash. Although a large craft could have been designed to carry all 749 pounds in one trip, such a vehicle’s size and weight would make it extremely unwieldy for usage on a smaller farm, and in addition would present safety risks, as a vehicle over 1000 pounds travelling at high speeds could be a significant threat in the event of control loss.

With a weight range in mind, the design team could begin development by searching for airfoils. After conducting research for airfoils ideal for for small-scale flight, stability, and maximum payload capacity, a list was compiled. Each airfoil was then analyzed in Xfoil and compared based on the following criteria: Coefficient of lift, (C_L), Pitching Moment (C_M), and approximate Stall Angle. (The Drag Coefficient was also considered between the final candidates, but was not included in the initial testing chart due to a low variance in the Cdp). All values were taken with an approximate reynolds number of 225,000 based on preliminary velocity estimates.

Airfoil	**C_L @ 0°00 AoA**	**C_M**	**Stall Angle (apx)**
NACA 2412	0.2555	-0.0558	20°
NACA 4412	0.5100	-0.1113	16°
NACA 4424	0.5538	-0.1153	14°

NACA 6412	0.7626	-0.1664	11°
NACA 2410	0.2512	-0.0554	19°
S1223	1.1829	-0.2704	13°
S1210	1.0549	-0.2454	12°
S1221	0.6759	-0.1661	14°

Table 2: Airfoil Data

Because of the significance of carrying large amounts of SOLVITAL, the coefficient of lift was a heavily weighted factor in the decision process, which made the Selig 1223 an attractive choice. Initially, due to the high CL, there were concerns of stability; however, further research into the foil's stability presented the only drawbacks of a relatively low maximum angle of attack and a thin trailing edge which could present structural concerns. (Note: These concerns are later resolved through structural analysis, see section 2.2.4).

Due to the fact that the X-181NR was not intended for acrobatic flight, but rather only minimally strenuous maneuvers over relatively level fields, the 13° stall angle was considered a reasonable sacrifice for doubling the lift capacity compared to the second competitive foil, the 4412. Thus, the Selig 1223 was selected as the root foil. The following figure demonstrates the usage of Xfoil for viscid analysis of the Selig 1223.

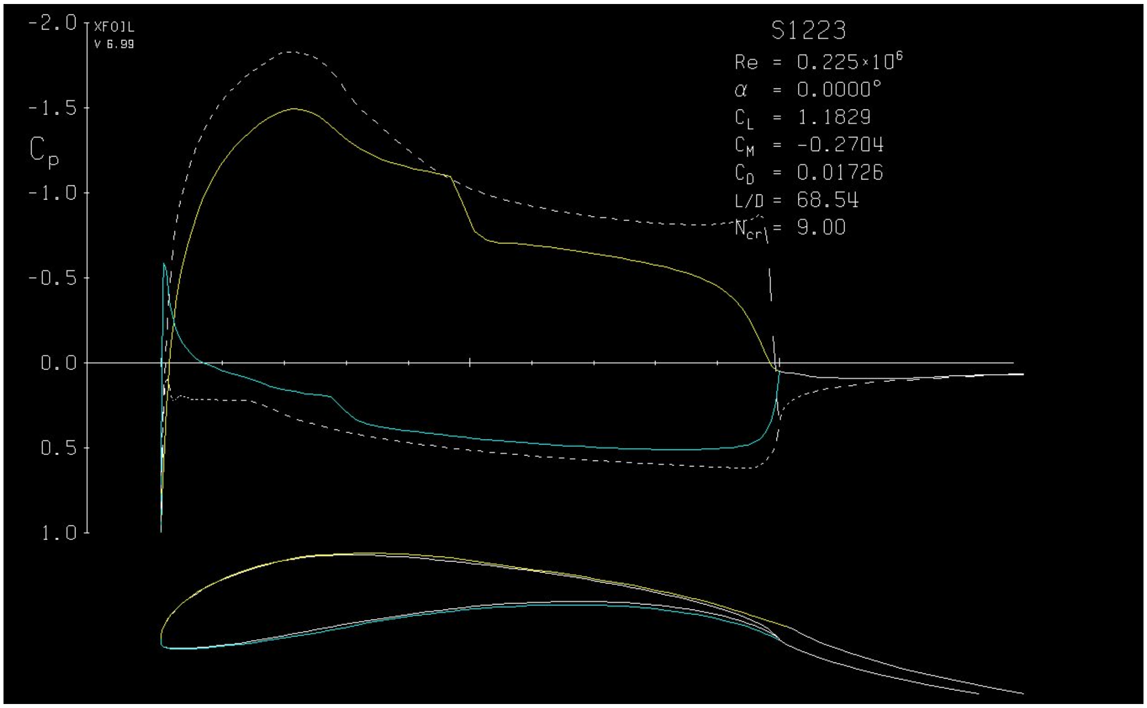
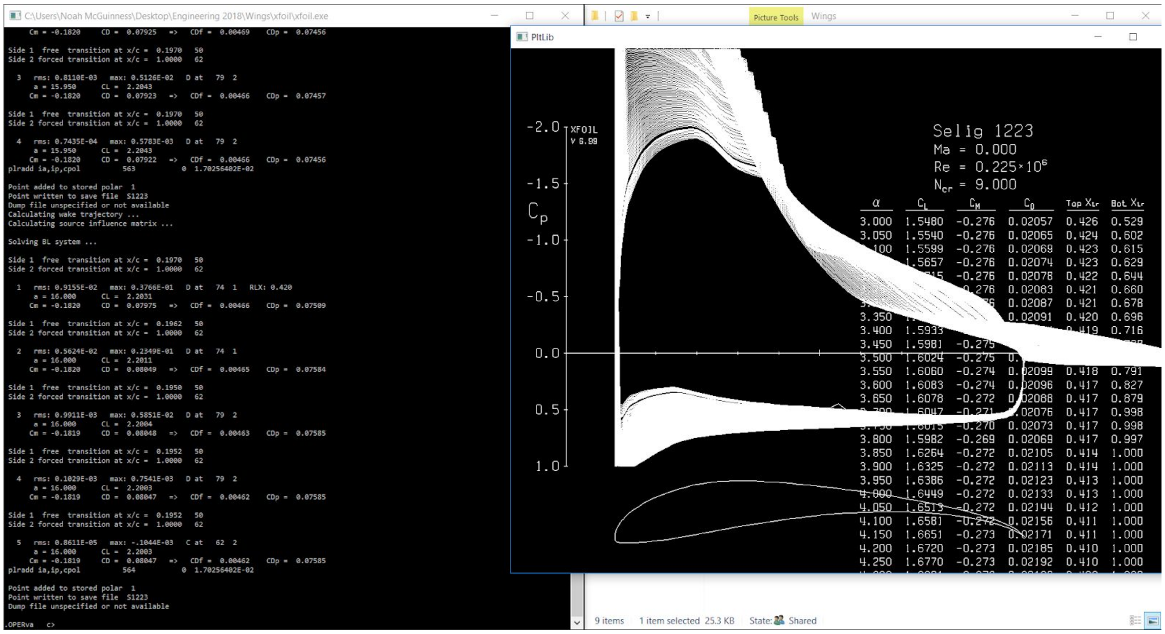


Figure 5: Viscid Analysis of S1223 at 0°00

The maximum stall angle was also determined through this software. A chart of thousands of iterations of angles in the range 0 to 20 degrees was compiled into a polar chart of Angle of Attack vs Coefficient of Lift and then interpolated in Microsoft Excel. The interpolated result was the derived to find the peak, and thus the approximate angle.



```
    Cm = -0.1820     CD =  0.07925   =>   CDf =  0.00469    CDp =  0.07456

Side 1  free  transition at x/c =  0.1970   50
Side 2 forced transition at x/c =  1.0000   62

  3   rms: 0.8110E-03   max: 0.5126E-02   D at   79  2
     a = 15.950      CL =  2.2043
    Cm = -0.1820     CD =  0.07923   =>   CDf =  0.00466    CDp =  0.07457

Side 1  free  transition at x/c =  0.1970   50
Side 2 forced transition at x/c =  1.0000   62

  4   rms: 0.7435E-04   max: 0.5783E-03   D at   79  2
     a = 15.950      CL =  2.2043
    Cm = -0.1820     CD =  0.07922   =>   CDf =  0.00466    CDp =  0.07456
plradd ia,ip,cpol          563           0  1.70256402E-02

Point added to stored polar  1
Point written to save file  S1223
Dump file unspecified or not available
Calculating wake trajectory ...
Calculating source influence matrix ...

Solving BL system ...

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Side 2 forced transition at x/c =  1.0000   62

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Side 2 forced transition at x/c =  1.0000   62

  2   rms: 0.5624E-02   max: 0.2349E-01   D at   74  1
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    Cm = -0.1820     CD =  0.08049   =>   CDf =  0.00465    CDp =  0.07584

Side 1  free  transition at x/c =  0.1950   50
Side 2 forced transition at x/c =  1.0000   62

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    Cm = -0.1819     CD =  0.08048   =>   CDf =  0.00463    CDp =  0.07585

Side 1  free  transition at x/c =  0.1952   50
Side 2 forced transition at x/c =  1.0000   62

  4   rms: 0.1029E-03   max: 0.7541E-03   D at   79  2
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Side 2 forced transition at x/c =  1.0000   62

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Point added to stored polar  1
Point written to save file  S1223
Dump file unspecified or not available

.OPERva   c>
```

```
Selig 1223
Ma = 0.000
Re = 0.225×10^6
Ncr = 9.000
  α       CL       CM       CD      Top Xtr  Bot Xtr
3.000   1.5480   -0.276   0.02057   0.426   0.529
3.050   1.5540   -0.276   0.02065   0.424   0.602
  100   1.5599   -0.276   0.02069   0.423   0.615
        1.5657   -0.276   0.02074   0.423   0.629
           15    -0.276   0.02078   0.422   0.644
                   .276   0.02083   0.421   0.660
                    76    0.02087   0.421   0.678
3.350                     0.02091   0.420   0.696
3.400   1.5933                        419   0.716
3.450   1.5981   -0.275
3.500   1.6024   -0.275   0.
3.550   1.6060   -0.274   0. 02099  0.418   0.791
3.600   1.6083   -0.274   0. 02096  0.417   0.827
3.650   1.6078   -0.272   0  02088  0.417   0.879
        1.6047   -0.271    .02076   0.417   0.998
                 -0.270   0.02073   0.417   0.998
3.800   1.5982   -0.269   0.02069   0.417   0.997
3.850   1.6264   -0.272   0.02105   0.414   1.000
3.900   1.6325   -0.272   0.02113   0.414   1.000
3.950   1.6386   -0.272   0.02123   0.413   1.000
4.000   1.6449   -0.272   0.02133   0.413   1.000
4.050   1.6513   -0.272   0.02144   0.412   1.000
4.100   1.6581   -0.272   0.02156   0.411   1.000
4.150   1.6651   -0.273   0.02171   0.411   1.000
4.200   1.6720   -0.273   0.02185   0.410   1.000
4.250   1.6770   -0.273   0.02192   0.410   1.000
```

Figure 6: Viscid Aseq Analysis of S1223

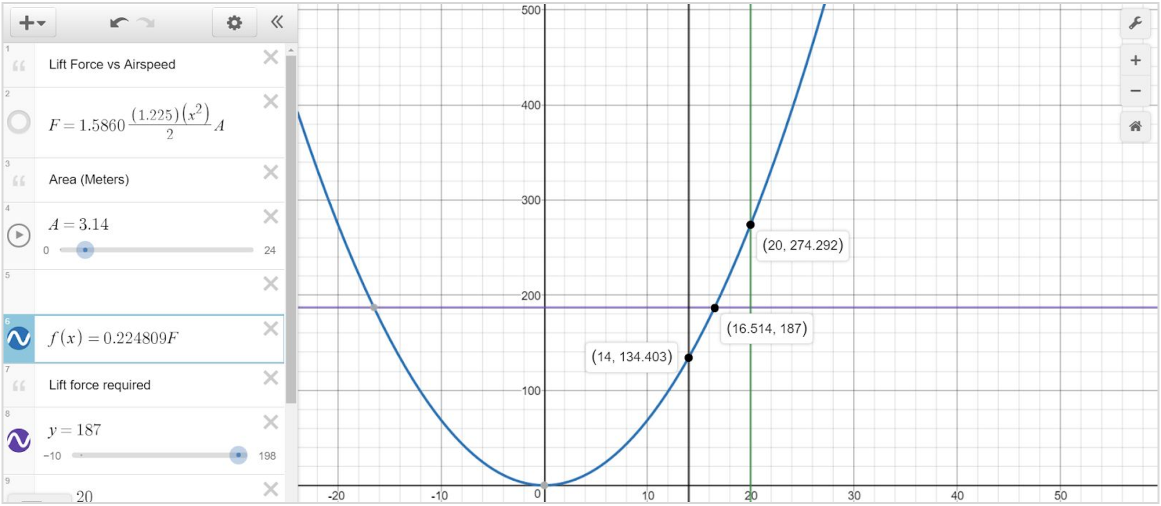
Figure 7: Interpolated Cl vs AoA and its Derivative (S1223)

With the lift coefficient determined, the team began by modelling a variety of wings with the Selig 1223 as the root foil. Of all components, the most iterations were created of the wings. Initial models were created to fit within the 9 foot limit and the following design variables were considered: Sweep, span, chord, and dihedral angle. Approximately 7 different variations were created in the <9 ft range. After recording the area for each wing, the .stl files were tested through Computational Fluid Dynamics (CFD) analysis in Autodesk Flow Design to obtain values for drag. These were then compared to the Lift Force vs Velocity graph generated with the lift equation shown below.

$$Lift = Coefficient \times \frac{Air\ Density\ \times Velocity^2}{2} \times Wing\ Area$$

$$F = Cl \times \frac{\rho \times v^2}{2} \times A$$

With Desmos Graphing Calculator, the team was able to visualize the amount of lift that would be produced at velocities in the reasonable airspeed limits of many UAV motors investigated (a range of about 12-23 m/s or about 27-50 mph). Alternatively, the velocities necessary to carry payloads of weights determined in table 3 for a given number of trips were investigated by finding points where the lines intersected.



1 Lift Force vs Airspeed

2 $F = 1.5860 \frac{(1.225)(x^2)}{2} A$

3 Area (Meters)

4 $A = 3.14$

5

6 $f(x) = 0.224809F$

7 Lift force required

8 $y = 187$

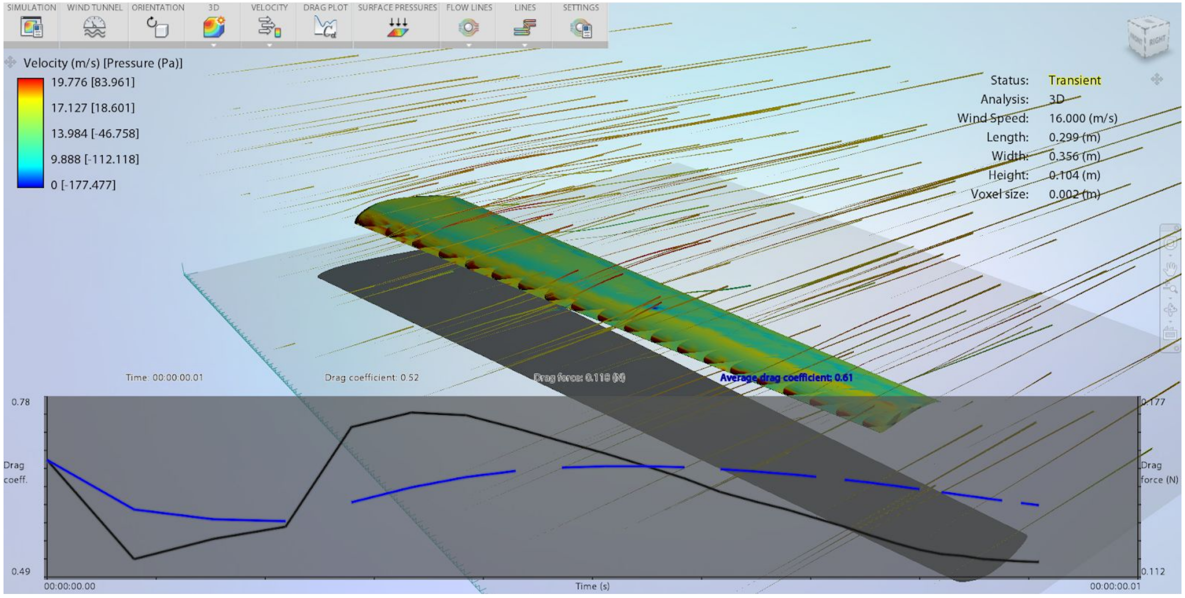
9 20

Figure 8: Desmos Lift Calculations Example for a Wing Iteration

Iteration	***Leading:Root* Chord Ratio**	**Sweep Angle**	**Drag Coefficient**	**Lift (lbs)**
1	1.0	0	0.74	98
2	1.0	10	0.61	89
3	0.83	8.2	0.56	80
4	0.79	11	0.47	78
5	0.77	9.5	0.49	79
6	0.76	0	0.56	81
7	0.76	7.9	0.45	78

Table 3: First Wing Iterations (9 feet span, lift calculated at 17 m/s)

After testing the initial 7 iterations, approximately 4 more of a wingspan that exceeded 9 feet were tested in order to further increase the area of the wings, as the amount of pesticide that could be carried was limited by the lifting capacity. Using the calculation method above, the merits of greater area were weighed against the additional drag, material weight, and structural complications of long wings. An example of wind tunnel analysis on one of these iterations is shown below.



Status: Transient
Analysis: 3D
Wind Speed: 16.000 (m/s)
Length: 0.299 (m)
Width: 0.356 (m)
Height: 0.104 (m)
Voxel size: 0.002 (m)

Time: 00:00:00.01
Drag coefficient: 0.52
Drag force: 0.118 (N)
Average drag coefficient: 0.61

Figure 9: Sample of CFD Analysis for Wings (NOT Final Iteration)

The final version of the wing had a wetted area of 3.2 m^2 and was capable of producing 169 lbs of force at 18 m/s. Its average drag coefficient was 0.54. A coefficient of lift of 1.1832 was used for the S1223 for 0.0 degree flight based on XFOIL viscid analysis at a reynolds of 250,000.

Straight and Level Flight - A Trimmed Approach

Restricted by the 14 foot wingspan, limiting the area of the wings after an efficient aspect ratio was narrowed down through CFD analysis, the team had to look elsewhere for increasing the total lift of the UAV to improve its number of trips. After further optimising the propulsion configuration to favor RPM over pure thrust (beneficial for increasing the maximum theoretical speed of the aircraft according to Max Velocity (m/s) = RPM/60 * Propeller_Pitch (m)), further research was conducted on how to safely maximize the vehicle's lift.

Analyzing the XFoil data, the team determined that a potential method would involve increasing the angle of attack of the airfoil minimally (to ensure the Lift/Drag ratio did not drop and that stall was safely avoided) to raise the coefficient of lift. After conducting research it was determined that trimming methods on both high altitude commercial and low altitude private aircraft frequently will fly at an angle of attack other than 0 to balance lift and weight at the cost of some additional drag. Further calculations were conducted using the AoA sequencing tool in XFoil to determine that a 5.0 degree angle of attack would provide for a significant margin of extra lifting capacity while still maintaining a safe L/D ratio of approximately 78, and keeping well below the stall angle of 13 degrees. In addition, this modification to flight procedure was welcomed, as the pesticide makes up the majority of the vehicle's extra weight, which is rapidly dispersed over the course of the flight plan, rapidly reducing the UAV payload from 251 pounds to 64 over a single flight. This reduction is weight is countered by an automated decrease in AoA to maintain a constant altitude. With a 5.0 degree AoA, the new Cl is 1.7535 and produces about 251 pounds of force at 18 m/s.

Propulsion

Initially, the team was biased towards choosing an electric motor for the system as a result of both past year challenges and the research conducted. Because electrics do not require fuel, there are fewer concerns about the accumulated cost of gasoline, the pollution caused by exhaust, and the weight and size of many electronic fuel injection (EFI) engines. As a result, a significant portion of time was spent assuming that the craft would run off of batteries; however, as further calculations were run, it became apparent that a gas engine possessed much greater potential for the scope of this year's challenge and the magnitude of the payload.

Market research was conducted for a wide variety of electric motors, and their various merits were compared on the basis of amperage draw at 85% throttle, thrust, and most importantly for the challenge, the top practical speed achievable by the propeller and motor combination as estimated by: *Propeller Pitch (m) x RPM/60*. The results were compiled below.

The U13 out-performed all of the other motors in nearly every category, at the expense of higher energy consumption, which was to be expected. In the final stages of the process, the decision was between the U13 kV100 with the 36*11.5 propeller, the 32*11 propeller, yet the higher velocity was favored over the slight thrust decrease and amperage increase due to the significance of velocity as a squared quantity in the lift equation.

Motor	Voltage	Propeller	Pitch (in)	Amps	Thrust (g)	RPM	Speedmax (m/s)	Mass (g)
U13 (kV100)	32	36*11.5	11.5	38.1	10201	2432	11.83477	1280
	40	34*11	11	47.4	12847	2971	13.829095	1280
	40	36*11.5	11.5	53.7	14454	2906	14.141383	1280
	48	30*10.5	10.5	43.8	13007	3722	16.53728	1280
	48	32*11	11	51.6	14410	3580	16.663803	1280
U13 (kV85)	40	36*11.5	11.5	33.5	10969	2529	12.306798	1300
	48	32*11	11	33.4	11346	3140	14.615738	1300
	48	34*11	11	41.2	13381	3035	14.126995	1300
MN701-S (kV280)*	~22	24*7.2	7.2	35.3	5398	4206	12.814456	355
	~22	26*8.5	8.5	48.8	6860	3773	13.570759	355
MN701-S (kV135)*	~48	24*7.2	7.2	16.3	5561	4221	12.860157	350
	~48	26*8.5	8.5	22.9	7194	3869	13.916053	350

MN705-S (kV260)*	~22	26*8.5	8.5	45.9	7041	3772	13.567163	450
	~22	27*8.8	8.8	50.6	7542	3741	13.930567	450
MN705-S (kV125)*	~48	26*8.5	8.5	20.6	7103	3841	13.815342	450
	~48	27*8.8	8.8	22.8	7710	3772	14.046004	450

Figure 10: Electric Motor Comparisons
*values taken at 80% due to unavailability of 85% testing

After determining that the U13(kV100) was one of the only motors that could come close to supplying a velocity necessary for achieving a high-lift flight, a battery that could supply a sufficient amount of energy for at least an hour of flight time was searched for. In order to figure out the approximate capacity of candidates, the equation:

Capacity (Amp Hours) = Duration (Hours) x Current Drawn (Amperes)

Ah = (hrs)(A)

which indicated that for one hour of flight time at a draw of approximately 51.6 Amperes, a 48 V battery of approximately 50-60 Ah would be required. Unfortunately, the majority of batteries with a stated output at this level weighed upwards of 20 pounds and occupied spaces up to several cubic feet. They could simply not supply enough power in a reasonable amount of compact space and weight.

Whereas in the past, the extra weight of the large metal engines and their associated fuels had been deterrents, as the craft only weighed up to 50 pounds at the most, the low energy density lithium ion batteries in comparison to gasoline made operating even under the best motors an inefficient task for such a heavy vehicle due to the weight and size of the battery required for any degree of sustainable flight. Thus, gas motors were investigated. In order to ensure accurate calculations, due to the wide presence of overstated engine performance in deceptive “theoretical” terms, motors were preferred that listed charts with live performance data and fuel consumption values. In addition, to maximize throttle control, an EFI engine was preferred.

Through the use of research and the static thrust calculator, the influence of horsepower, our desired propeller, and static thrust were considered on the vehicles performance. Eventually, the AIE 40S 5BHP engine was selected in a nearly unanimous decision over the other candidates such as the Desert Aircraft DA-50, or its EFI version, the Corvid-50.

The AIE 40S 5BHP engine provided a lightweight, compact, and fully electronically pre-integrated engine system that would serve the team’s propulsion needs. In addition, a major attraction of this motor was the pre-installed electronic engine control system, including engine software for full engine management, actuators, a fuel pump/mixing mechanism, and easy attachments for the onboard autopilot hub.

Further optimization with the thrust calculator allowed for the pairing of a propeller that would keep the engine at its limit of just above 5 HP at its maximum while achieving a velocity that would allow for significant lift, still maintaining a decent ratio of thrust to predicted weight. It is important to note that the data below reflects the performance of the system at 100% throttle, which runs the engine at 6818 RPM.

Propeller diameter [illegible] inch
Pitch 7 inch
Propeller type Choose!
CF 1
No. of blades 2
RPM [illegible]
Air temperature Choose!
Air density 1.225 (kg/m³)

Static thrust = [illegible] oz
Static thrust = 42.77 pound
Static thrust = [illegible] kg
Perimeter speed = [illegible] m/s
Required engine power = 5.000 HP = 3.677 kW
Estimated flying speed = mph = Knots

Figure 11: Godollairport Thrust Calculator

Fuel and Fuel Consumption

The AIE 40S 5BPH is rated between 0.51 and 0.57 lb/hp/hr, so for the sake of safety, the team conservatively used the upper limit, 0.57, for calculations. Unlike electric vehicles, the capacity of a gas powered UAV is limited by how much fuel it can carry, thus the fuel tank was designed with the capability to maintain 2 hours of flight on full throttle, even though the craft would not be operating at this extreme capacity during regular missions.

For the 100% throttle calculations, a value of 5.000 HP was used to determine that the fuel consumption rate would be 2.85 lb/hr, or 5.7 pounds of fuel for a total of two hours of flight on full throttle. Using the standard density of 6.1 lb/gal for the ethanol mixture, this would equate to a 0.93 gallon tank for fuel. Already the benefits of the energy density of gasoline over lithium ion or polymer may be seen for this larger scale UAV, as the previously calculated immense battery weight for similar durations would well outweigh their worth in energy.

Airframe and Fuselage

Up to this stage in the design process, a great deal of initial decisions were based on Research and approximations. The majority of final adjustments would require concrete values. In order to get to this stage, initial measurements were based on rough calculations until more data could be gathered and definitive values could be adjusted and applied. For instance, the initial length of the fuselage sketch was approximated by taking into account the counter lift that would need to be produced to balance forces around the center of mass. The lift force produced by the horizontal stabilizer in level flight must provide an equal moment force on the center of mass to the moment force produced by the lift of the wings. This placed the initial length of the fuselage past the wings by 75 inches to leave room for further flexibility of the stabilizer size in future steps (given a significant lever arm, less lift force need be applied). The main fuselage was defined by series of independent ribs that were primarily adjusted to accommodate for key payload components such as the engine, fuel tank, and center fuel tank. Figure 9 displays the wireframe that served as the structural base for the modelling of the rest of the body. To edit the shape of the airframe, adjustments could be made to the dimensions of individual ribs or segments.

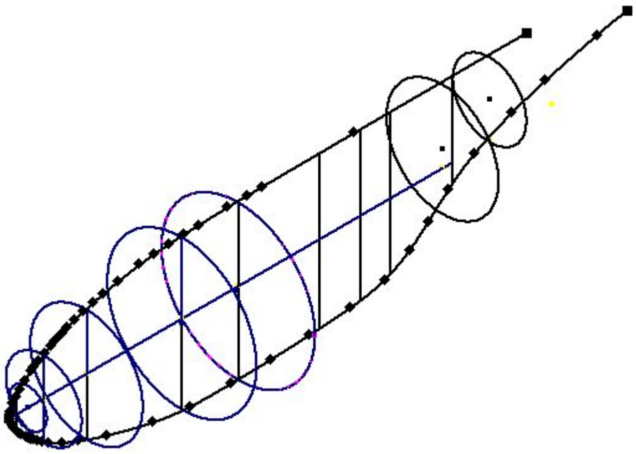


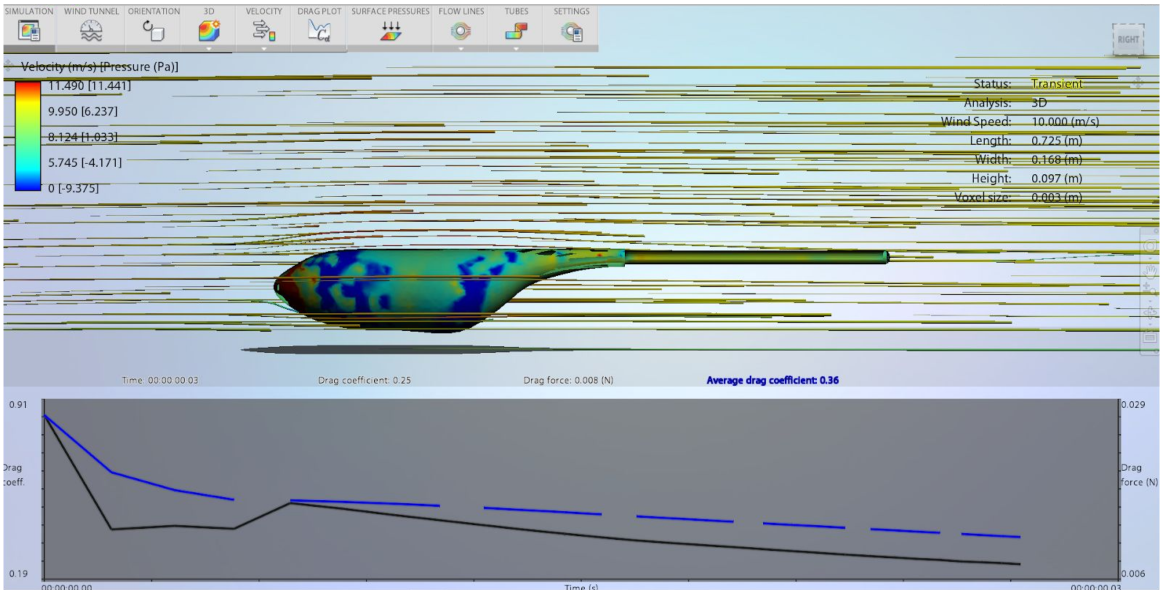
Figure 12: Fuselage Frame with Ribs

Early iterations of the fuselage were not streamlined due to the fact that they were the first representation of a solid-body sweep over the initial frame. Sub-Figure s1 is one of the first iterations developed. To progress to the optimized form of the frame, the minimum space requirements set by payload items were strictly followed while the rest of the face was rounded and smoothed. After developing multiple iterations of the frame, each was run through Autodesk Flow-Design, a wind tunnel testing software that provides drag plots and data for given airspeeds. Comparing the results of the analysis aided the gradual refinement process led to the final design (shown in Sub-Figure s4). To demonstrate the effectiveness of the process, the results of the tests for both designs may be seen in the tabular figure below, which compares the wind tunnel results of three iterations of the design. Due to the size differences between the first and last iteration, the unitless drag coefficients are used for comparison as the drag force would not provide a consistent for comparison. (images of the testing environments themselves are labeled by the "sub figure" that corresponds to the iteration).

Iteration*	**Average Drag Coefficient**	**Sub-Figure**
1	0.36	s1
2	0.29	s2
3	0.19	s3

Figure 13: Fuselage Iterations

*More than 3 iterations were created; however, for the purpose of this chart, the three that were selected for demonstration are labeled 1, 2, and 3. Sub-Figure s4 is just to demonstrate analysis on the full body.

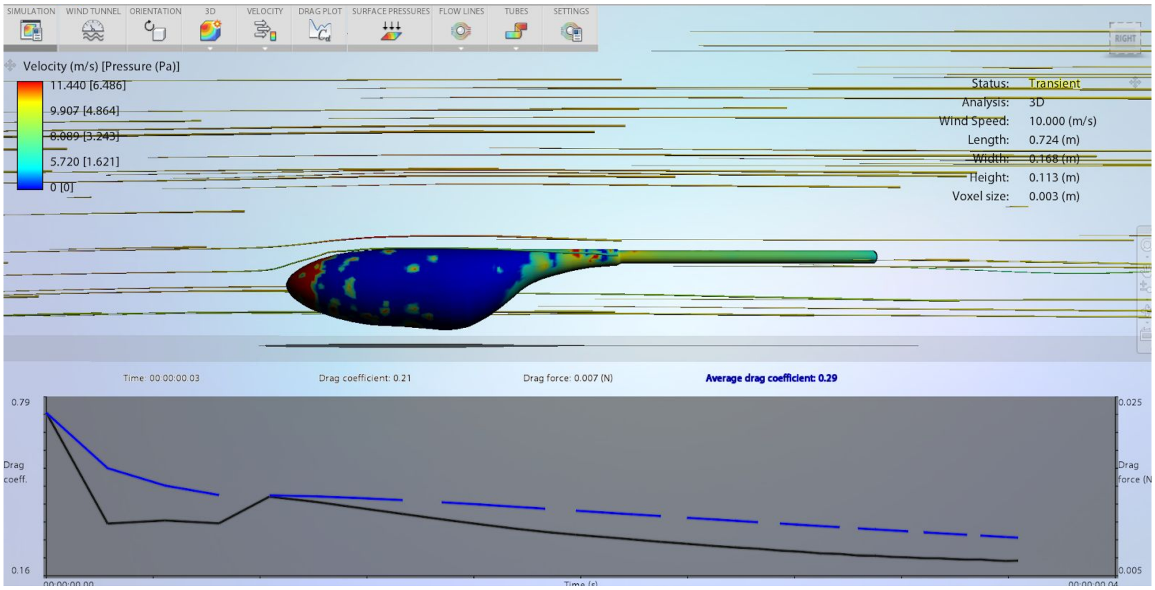


Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 0.725 (m)
Width: 0.168 (m)
Height: 0.097 (m)
Voxel size: 0.003 (m)

Time: 00:00:00:03 Drag coefficient: 0.25 Drag force: 0.008 (N) **Average drag coefficient: 0.36**

Sub Figure s1

(Text Clarification - Drag Coefficient: 0.25 Drag Force: 0.008 (N) Average Drag Coefficient: 0.36)

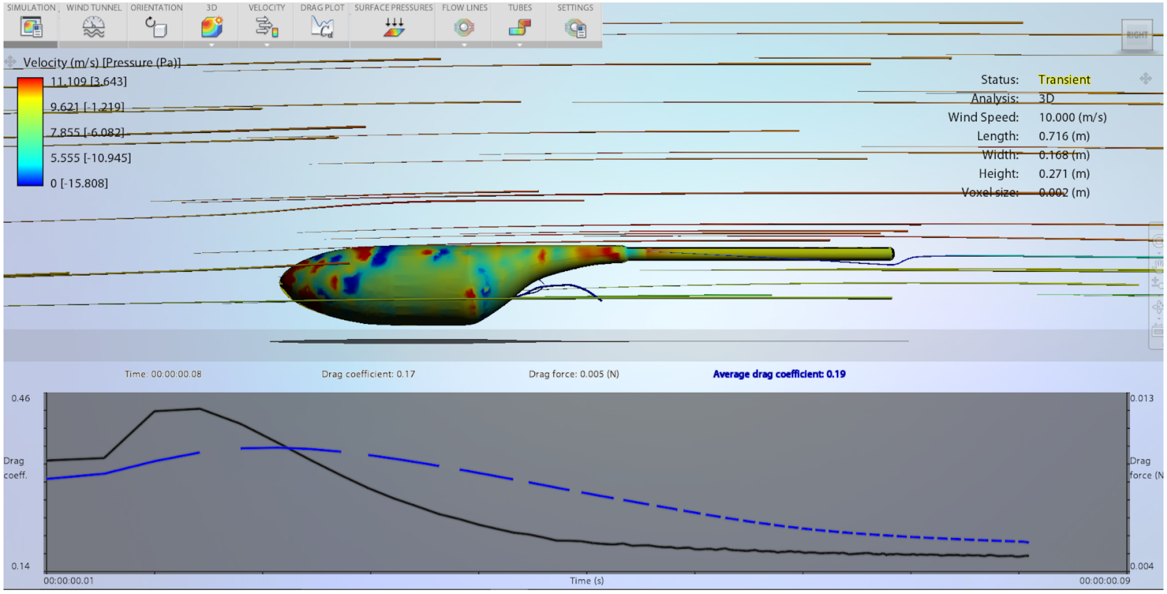


Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 0.724 (m)
Width: 0.168 (m)
Height: 0.113 (m)
Voxel size: 0.003 (m)

Time: 00:00:00:03 Drag coefficient: 0.21 Drag force: 0.007 (N) **Average drag coefficient: 0.29**

Sub Figure s2

(Text Clarification - Drag Coefficient: 0.21 Drag Force: 0.007 (N) Average Drag Coefficient: 0.29)

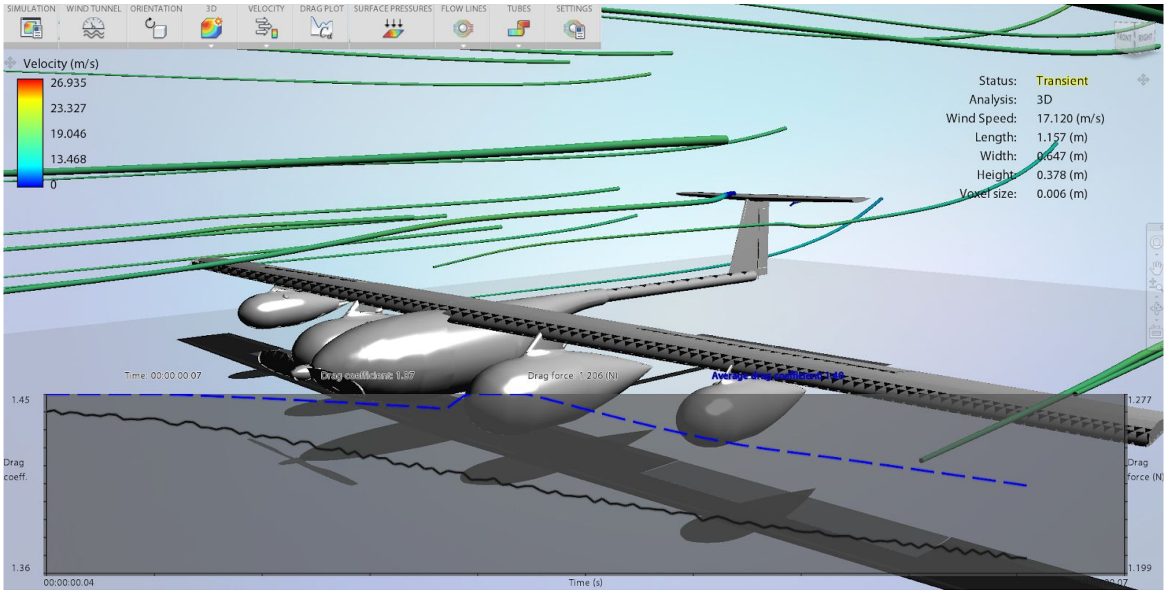


Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 0.716 (m)
Width: 0.168 (m)
Height: 0.271 (m)
Voxel size: 0.002 (m)

Time: 00:00:00.08 Drag coefficient: 0.17 Drag force: 0.005 (N) **Average drag coefficient: 0.19**

Sub Figure s3

(Text Clarification - Drag Coefficient: 0.17 Drag Force: 0.005 (N) Average Drag Coefficient: 0.19)



Status: Transient
Analysis: 3D
Wind Speed: 17.120 (m/s)
Length: 1.157 (m)
Width: 0.647 (m)
Height: 0.378 (m)
Voxel size: 0.006 (m)

Time: 00:00:00.07 Drag coefficient: 1.37 Drag force: 1.206 (N) **Average drag coefficient: 1.40**

Sub Figure s4: Final Design

Weight Optimization and Structural Safety:

Weight was also another important consideration in the design of the fuselage. Excess weight would waste materials, space, and energy. The primary process used to reduce total mass was the thinning of the fuselage. The shell feature that formed the hollow internal of the original fuselage was incrementally increased. In order to ensure the fuselage could still withstand forces of flight or extreme stresses, structural analysis involving forces of two (2) times the estimated weight of the craft at its heaviest payload were performed after each iteration. By the end of the process, approximately 2.1 lbs were removed from the total weight of the frame (including wings, tail, and fuselage), bringing it from 10.78 to 8.68 lbs. The three main locations of focus for the analysis were the control surface joints, the tail boom, and the tail itself.

Such analysis also brought weak points to the team's attention. While thinning the fuselage was integral to decreasing the dead-weight, often after shelling a feature, structural testing would reveal an area that needed reinforcement as shown below. In one of the final iterations of the wings, the most strenuous moment (283 pounds of force that would be experienced at liftoff) was simulated on the wings, revealing a weak point at only 1.01 safety factor.

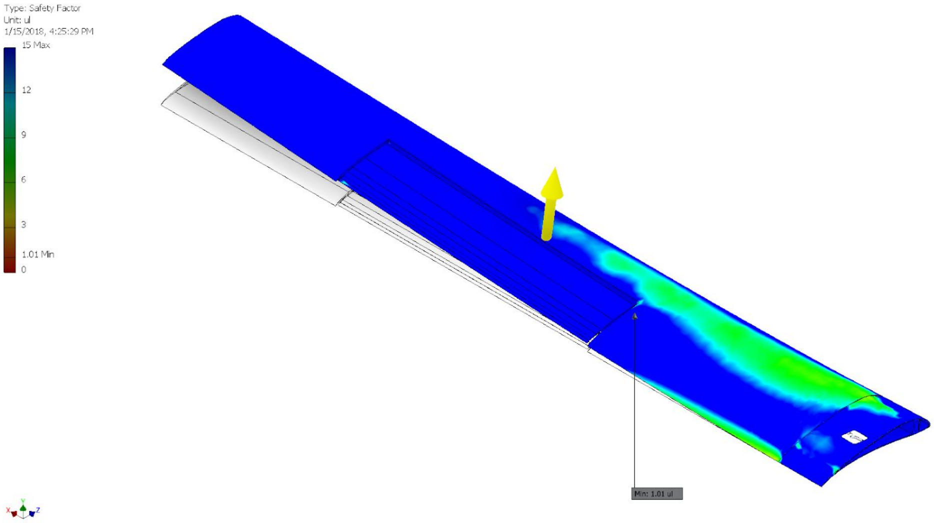


Figure 14: Wing Safety (1)

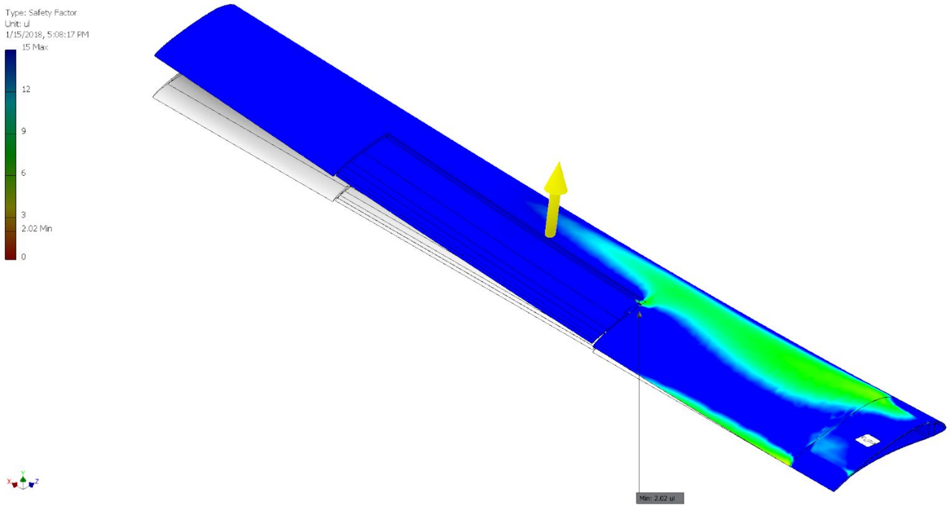


Figure 15: Final Wing Analysis (2) (min: 2.02)

As it can be seen from the final iteration, the wings are structurally capable of carrying the weight of the vehicle up to 2x the anticipated force of 282 lbs of force. The wing as shown in (figure 15) was only 2.02 at its lowest point, indicating a significant level of support beyond what is expected in the field.

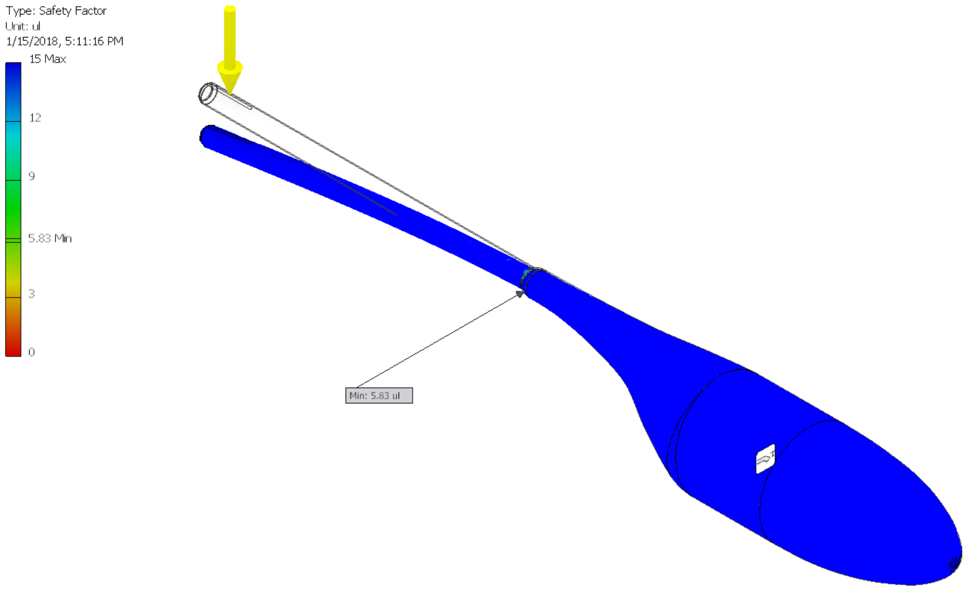


Figure 16: Final Fuselage Testing (5.83 safety)

The 30 pounds applied to the boom, although it was twice the force (figure 13) yielded a minimum of safety factor of 5.83, a number still well over a recommended minimum. In the interest of product durability and quality, it was decided to end the thinning process at this point.

Stabilizer Design

The tail was one of the last elements to be finalized in the design due to the delicate balancing of forces between the moments on the center of gravity from the wings and the tail. A high wing was chosen to minimize interference with pesticide spraying and to minimize drag from wing and fuselage. Once it was determined that the center of lift was 4.6 inches behind the center of mass, the lever arm to the proposed center of lift for the tail was measured to be 75 inches. Assuming a constant speed of approximately 18 m/s for average flights, the force produced by the wings would sum to 250 pounds at the center of lift at the specified angle of attack for the majority of straight and level flight. To calculate this lever arm length after the negative lift was calculated from the NACA 4412 airfoil data and the assumed 18 m/s flight speed the following equation was used. At different velocities, the lifts produced by the horizontal stabilizer and wings will not remain in this constant balance, which is where automated elevator control will trim the vehicle to maintain a net torque of 0 - these calculations are to establish a stable setting for the most common flight conditions likely to be encountered by the vehicle.

Force1 (lbs) x Distance1 (in) = Force2 (lbs) x Distance2 (in)
(250) (4.5) ÷ (15.0) = D

It was determined that the lift supplied was 17.8 pounds to be applied at 75 in behind the center of mass. Using the NACA 4412 airfoil at a fixed angle of attack of -2.40° at the specified speed produces the lift required. These calculations were made using the lift equation (previously stated) as well as XFoil data for the 4412, as shown below.

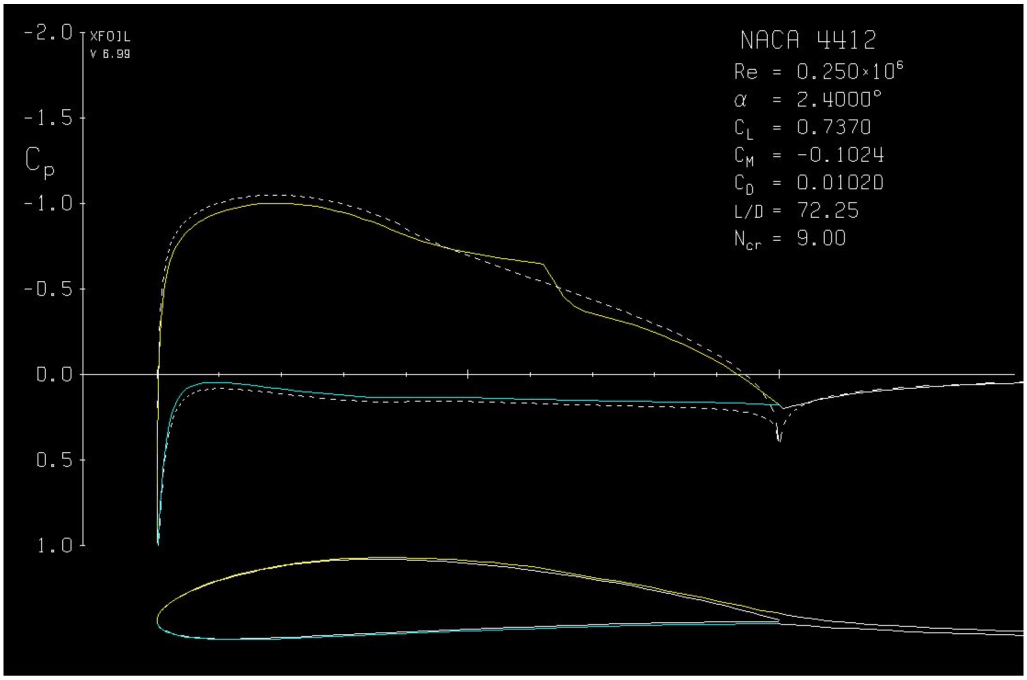


Figure 17: NACA 4412 Tail

The same thinning for weight reduction method that was applied to the wings and body was also applied to the tail in order to reduce weight. Below, it can be seen that despite this, the stabilizers still demonstrate an astounding level of safety, with a minimum factor over 15x the recommended value for normal flight.

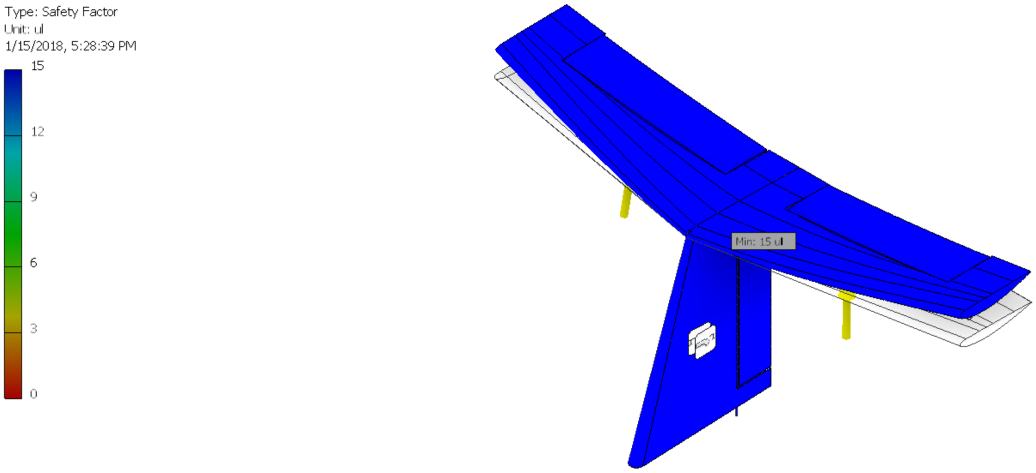


Figure 18: Final Tail Iteration Analysis (15x)

Additional Final Operational Information

Below is some information taken from analysis of the final design.

Total Runway Required for Full Payload: *630 ft*

-With an acceleration of 1.67 m/s^2 from the 42.8 lbs of thrust on the 251 lb loaded UAV

Total Runway Required for Empty Payload/Detection: *66 ft*

-With an acceleration of 6.58 m/s^2 from the 42.8 lbs of thrust on the 64 lb unloaded UAV

Thrust (100% Throttle): *42.8 lbs*

Top Speed: *45.2 mph (20.20 m/s)*

Operational Weight (no payload): *64 lbs*

Maximum Lift: *311 lbs at 45.2 mph*

Fuel Capacity: *0.93 gal*

Flight Time (full payload): *2.0 hours**

Flight Time (no payload): *10.0 hours***

Stall Speed (full payload): *40.1 mph* (decreases exponentially as pesticide is released)

Stall Speed (no payload): *20.4 mph*

Stall Angle: *13.2°*

*To err on the side of caution, the 100% throttle value was used to calculate the full payload flight time.
**The speed required to keep the empty craft aloft at 0.0 degree angle of attack is 25 mph, which according to the Godolloairport Static Thrust calculator requires an RPM of 3922 which strains the engine approximately 1 HP. This yields a lb/hr rate of (0.57 lb/hp/hr)(1 hp) = 0.57 lb/hr. With 5.7 pounds of fuel, this results in a 10 hour flight time.

Detection Vehicle Design

Extension of the X181-NR

As mentioned in the sections of 2.2.2 and 2.2.3, the detection plan originally relied on the ability of a manual inspector to perform the analysis of the field in a comparable time, and lower cost than the eBee competitor drone. This plan was deemed favorable, as the expense of designing, maintaining, and manufacturing a separate UAV would raise the cost of billbug identification for the team. The versatility and speed of an aerial surveyor, as well as the possibility for expansion into additional applications of the multispectral camera began to reveal the potential benefits of simply modifying the X181-NR sprayer by modularizing the components that were only required for pesticide application. Spraying equipment, tubing, and pumps positioned within the fuselage were compartmentalized into an easily removable “unit” that the team could easily disconnect or reconnect to the UAV. Further, the removable pesticide tanks could be separated while the X181-NR is prepared for a detection mission. In order to ensure that the sprayer could be appropriately adapted for detection, the following factors were considered.

Field Maneuvers

One of the most pressing concerns regarding the use of the spraying vehicle for detection was its large size intended for the pesticide transportation, making tight maneuvers difficult within the field boundaries to ensure full coverage of the field. However, the camera chosen for the X181-NR detects from 400 feet, above the No-fly-zone boundaries, allowing the UAV to travel outside the field to perform wider turning maneuvers while still properly aligning field passes for full coverage. See section 2.4 and 2.5 for further analysis of the turning maneuvers, and section 3 for details on the detection plan.

Balance Complications

The removal of the heavily weighted pesticide tanks posed the possibility of shifting the center of mass to an unstable position; however, the tanks had been purposely lined up with the unloaded vehicle's Z axis position, to minimize this effect. See section 2.4 and 2.5 for this analysis.

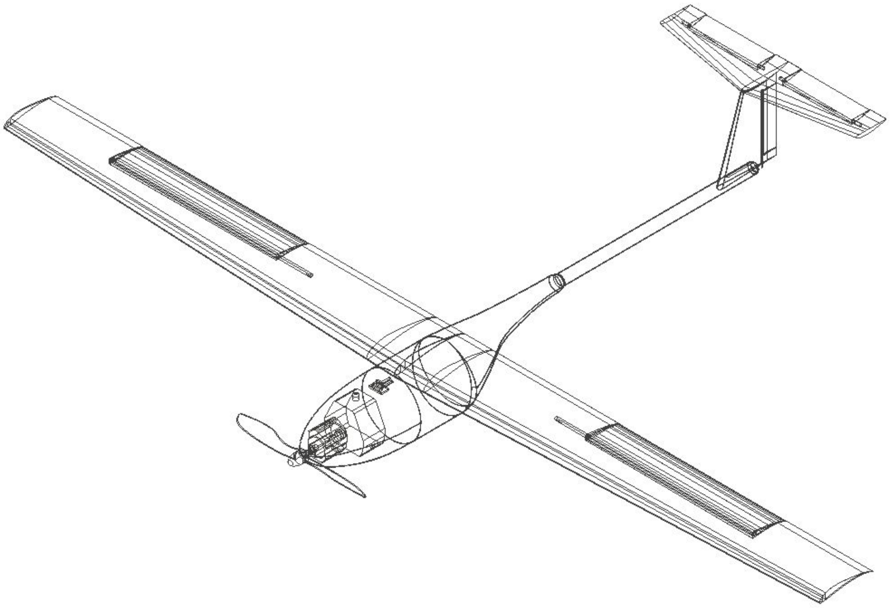


Figure 19: Detection Vehicle (X181-NR without pesticide tanks, and added camera)

Camera Selection and Payload

The camera selected for the detection mission is the Mapir Survey2 Camera with NDVI Red + NIR capabilities. This camera has the ability to detect NIR light and therefore creates the NDVI images necessary for detecting the health of the plants in the field. In addition to these capabilities, the Survey2 also has multiple other attractive features. Perhaps most importantly, the Survey2 has a high, 82° FOV. This translates to the camera having the ability to capture an area of approximately 4.04 acres in each picture at an altitude of 400 ft. Furthermore, the camera has a high, 16 megapixel resolution which allows for quality maps to be developed, further optimizing the camera's ability to detect unhealthy plants. The Survey2 is also quite inexpensive compared to other NDVI survey cameras. At $280, it is a well-worth it expenditure which captures a large region and produces quality NDVI maps for detection of plant disease/infestation. The Mapir Survey2 is a camera which combines NDVI technology, a high FOV, and a low price into a package which is a capable of producing high-resolution images for the detection of billbug infestation.

2.2.5 Lessons Learned

In the first stage of the design phase, the team learned how to brainstorm quality solutions. The presentations made 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. This period of brainstorming was important for the team because it served as a medium to discuss both the advantages and limitations of each solution. Through this reflection, the team was able to reach a more advantageous design.

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 then 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 together loose information and use self-knowledge to find solutions to the challenge. The team used these skills during the entire project in places such as creating the flight plan or choosing the appropriate safety sensors.

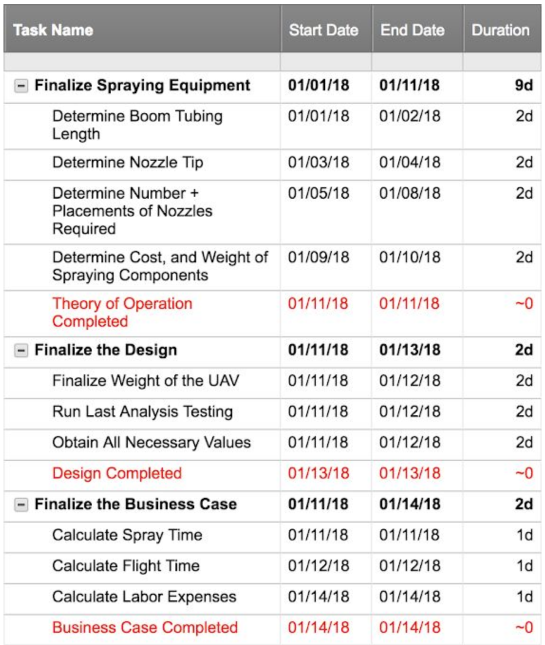
When it came to determining multiple solutions and picking the best solution, the team learned how to effectively use the solution selection matrix. The solution selection matrix is a spreadsheet that helps determine the effectiveness of a product using a weighted rating system in different categories. 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. Deadlines were created to make 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. Through detailed planning (in which every person was assigned tasks to complete), the team also able to work more efficiently than it had in years previously. During the challenge, the team used email and text messaging 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.

2.2.6 Project Plan Updates and Modifications

Overall team management was directed by Noah McGuinness and Roham Hussain, the project managers chosen by this year’s group. To this end, Google Calendar was instituted as a way to streamline time management for the team. With the ease of use and the widespread accessibility of the program, the team was easily able to set dates and times for weekly video calls, as well as set deadlines for tasks in order to proceed efficiently with the project.

A sample Gantt chart (shown in table 4 and figure 20 below) shows how tasks were broken up among the three phases of the project (Theory of Operation, Design, and lastly, the Business Case). Before the final design could be completed, and before the final wages/expenses could be calculated, information from the Theory of Operation needed to be completed (the spraying equipment components needed to be finalized). By breaking up these sections into small manageable parts, the team was able to proceed rapidly through the project timeline.



Task Name	Start Date	End Date	Duration
⊟ **Finalize Spraying Equipment**	**01/01/18**	**01/11/18**	**9d**
Determine Boom Tubing Length	01/01/18	01/02/18	2d
Determine Nozzle Tip	01/03/18	01/04/18	2d
Determine Number + Placements of Nozzles Required	01/05/18	01/08/18	2d
Determine Cost, and Weight of Spraying Components	01/09/18	01/10/18	2d
Theory of Operation Completed	01/11/18	01/11/18	~0
⊟ **Finalize the Design**	**01/11/18**	**01/13/18**	**2d**
Finalize Weight of the UAV	01/11/18	01/12/18	2d
Run Last Analysis Testing	01/11/18	01/12/18	2d
Obtain All Necessary Values	01/11/18	01/12/18	2d
Design Completed	01/13/18	01/13/18	~0
⊟ **Finalize the Business Case**	**01/11/18**	**01/14/18**	**2d**
Calculate Spray Time	01/11/18	01/11/18	1d
Calculate Flight Time	01/12/18	01/12/18	1d
Calculate Labor Expenses	01/14/18	01/14/18	1d
Business Case Completed	01/14/18	01/14/18	~0

Table 4: Gantt Chart

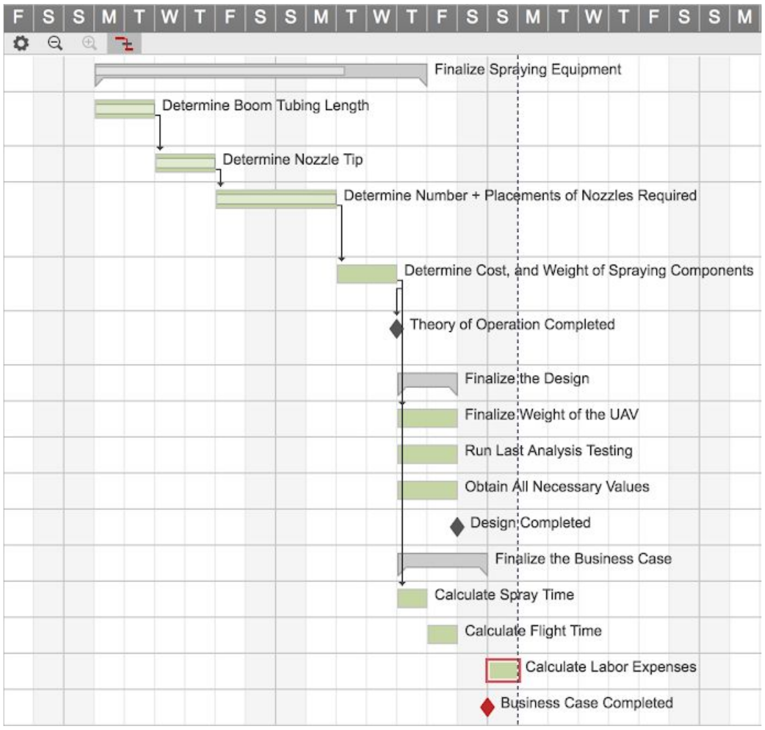


Figure 20: Gantt Chart

2.3 Selection of System Components

Key equipment for this design challenge was selected by researching what would work best based on efficiency, effectiveness, and cost. The key items that were selected for the design included sensors, nozzles for spray, and controls for the design. The equipment that and design decision are essential to designing a UAS that is low cost but efficient at the same time.

The selection process for key items for the aircraft includes research and calculations into various parts needed for the aircraft and the mission. After careful research and analysis the team decided on what would be the most efficient at a reasonable cost which would make the design practical and economical.

A great deal of the components are discussed in section 2.2 as part of the design process. For the sake of avoiding redundancy, they have been omitted here.

2.3.1 Payload Selection

The payload selection for the design includes spraying equipment, detection equipment, and control equipment. For the spraying equipment, the flat fan nozzle has been chosen due to its high efficiency. The nozzle allows for a wide spray pattern that assists in maximizing the area the drone can spray. This wide spray pattern will allow the drone to save energy and have longer flight time by performing fewer passes while still releasing drop volumes large enough to adequately cover the affected areas. The flat fan nozzle that has a quarter-inch diameter costs $2.50 per unit.

The spraying equipment for the UAS includes boom tubing and the use of spray nozzles. Since the wingspan of the UAS is 15 feet this allows for multiple nozzles to be used. The spray tank in the fuselage is attached to the boom tubing. The tubing includes two different tubes that run 6 feet each. There are two nozzles with two on each of the wings which would allow for maximum coverage while still maintaining maximum efficiency. The wingspan is what allows for maximum coverage in terms of the spraying mission. This also allows for a stable flight during the mission and provides excellent control when it comes to turning in flight.

Cost is one of the most important aspects of the design and payload selection for the design. There are multiple components needed for the application mission which includes spraying equipment and also controls for the spraying equipment in the UAS. The nozzles that were selected for the design are beneficial to the design since the wide angle of the spray calls for less of these nozzles to be needed. Even though the UAS motor is powered by gas, there is still a need for a battery to power the systems within the UAS. These systems include sensors, boom tubing, control box, and spray pump. The boom tubing cost completely depends on the dimensions of the aircraft and how much pesticide is being applied to the field. The boom tubing that was selected has a total cost of $18.00 which is $0.15 per inch across the wings of the aircraft. The tubing for the design is made of a hard plastic and is attached to the wings and the external spray tanks. The four flat fan nozzles have a 110 degree spray which allows for four nozzles in total for the whole the design. The total nozzle cost for each is $2.50 which comes out to $10.00.

The other key elements of the spraying equipment include the spray tank, spray pump, and control box. The spray tanks are custom designed to the aircraft and can hold 24.25 gallons. The spray pump and the control box will be able to connect to the boom tubing on each of the wing. In terms of spraying equipment, the only internal parts are the spray pump and the control box. The Spray pump costs $20.00 and with a weight of about 14 oz which allows for the aircraft to stay within the weight limit of Part 107. The control box is the most important part of the payload selection as it allows for the team on the ground to oversee how much of the payload is being sprayed and how much is needed. The total cost of the control box is $10.00 and is very affordable for the aircraft.

2.3.2 Air Vehicle Element Selection

In order to ensure that the aircraft could meet optimum performance in the agricultural environment, certain air vehicle elements proved to be more useful and effective than others. All of the justifications for the following decisions that are not listed in this section were described in the Detailed Design portion of Section 2.2 (See 2.2 for the decision process). The following is a compiled chart of the chosen components selected for the air vehicle element:

Airframe

Component	Quantity	Price	Weight
Flat Nose Nozzle (0.25” diameter)	2	$2.50	3.0 oz
Boom Tubing (0.25” diameter)	2 (6 ft each)	$18.00	19.20 oz
Control Box	1	$10.00	10.72 oz
Spray Pump	1	$20.00	14.24 oz
Max Amps LiPo 13500 XL 2S 7.4v Battery Pack	1	$210.00	21.59 oz
	Total:	$286	68.65 oz

➔ **Flat Nose Nozzle**
Cost Per Unit: $2.50
Number Required: 2
Justification: The Flat Nose Nozzle is used for broadcast spraying of pesticides and herbicides. This nozzle produces tapered-edge spray pattern (flat fan) and has an ideal range of 30-40PSI. In this case the 0.25” diameter nozzles are utilized - 0.75 oz – 0.9375” (L) x 0.5625” (W). This nozzle is necessary to the project due to its wide broadcast of pesticide which allows for utmost efficiency.

➔ **Boom Tubing**
Cost Per Unit: $18.00
Number Required: 1
Justification: The Boom Tubing provides structural support and conveys pesticide mixture to nozzles. In this case the 0.25” diameter tubing is used which has a linear density of 0.1466 oz per inch. The Boom Tubing is necessary to the project do its ability to swiftly distribute pesticide from the spray tank to the nozzles.

- ➔ **Control Box**
  Cost Per Unit: $10.00
  Number Required: 1
  Justification: The Control Box is necessary for control over the spray pump. It requires one servo input for on/off functionality, and it does not vary speed or pressure. Weight - 0.67 lb (10.72 oz)

- ➔ **Spray Pump**
  Cost Per Unit: $20.00
  Number Required: 1
  Justification: The spray pump is necessary for the control of how much pesticide is sprayed over the field. This component is able to provide 40 PSI of pressure from the spray tank which is works well with the nozzles as the pressure of the nozzles used is between 30-60 PSI.

- ➔ **Max Amps LiPo 13500 XL 2S 7.4v Battery Pack**
  Cost Per Unit: $210.00
  Number Required: 1
  Justification: The Max Amps battery pack will be the source of energy for all components of the UAV which need power other than the motors, using a parallel circuit.

Flight Controls

Component	Quantity	Price	Weight
Universal battery-elimination circuitry (U-BEC)	2	$20	0.26 oz
3DR Pixhawk Mini Autopilot	1	$92	0.56 oz
Multiplexer	1	$25	0.53 oz
	Total:	$157	1.35 oz

- ➔ **Universal battery-elimination circuitry (U-BEC)**
  Cost Per Unit: $40
  Number Required: 2
  Justification: The device 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. 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 option is necessary in case of an emergency to prevent the plane from crashing.

- ➔ **3DR Pixhawk Mini 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. This device is needed to autonomously fly.

- **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 (e.g., servo RX or servo controller). This is needed to send data to the servos.

Sensors

Component	Quantity	Price	Weight
Digital Compass Sensor	1	$45	0.03 oz
9-Degree of Freedom (DOF) Inertial Measurement Unit (IMU)	1	$40	0.02 oz
Global Positioning System (GPS) Sensor	1	$50	Negligible
Microcontroller	1	$100	0.35 oz
	Total:	$235	0.40 oz

- **Digital Compass Sensor**
  Cost Per Unit: $45
  Number Required: 1
  Justification: This sensor measures magnetic heading (single-axis) with 0.1 degree resolution (3 to 4 degrees accuracy). This provides the UAS with a direction of travel.

- **9-Degree of Freedom (DOF) Inertial Measurement Unit (IMU)**
  Cost Per Unit: $40
  Number Required: 1
  Justification: It is 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. This unit provides the data to the autopilot component needed to correctly guide the UAV 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 assists the autopilot in knowing the exact coordinates of the UAS.

- **Microcontroller**
  Cost Per Unit: $100
  Number Required: 1
  Justification: One of the suggestions of a farmer was to include the capability for the drone to log its flight data. This device is a high-fidelity/onboard sensing option that can be connected to a communication device (i.e., telemetry radio) using a serial interface to transmit analog and digital sensor data to a PC.

2.3.3 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	$4000
Data Transceiver Set (900Mhz) – High Range (Communication)	1	$135
	Total:	$4135

Command/Control

The team chose the PC Laptop Control which costs $4000. This system will be able to communicate with the UAV 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 UAV 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.

COM3 115200

Distance: 0.7989 km
Prev: 522.46 m AZ: 67
Home: 462.94 m

GEO -35.040907 117.832747 11.40

GoogleSatelliteMa
Status: loaded tiles

Home Location
Lat -35.04173272
Long 117.8277683
Alt (abs) 38

Waypoints

WP Radius 2 Loiter Radius 60 Default Alt 100 ☐ Absolute Alt ☐ Verify Height Alt Warn 20

	Command					Lat	Long	Alt	Delete	Up	Down	Grad %	Dist	AZ
1	WAYPOINT	0	0	0	0	-35.0407928	117.8277898	100	X	⬆	⬇	95.7	104.5	1
2	WAYPOINT	0	0	0	0	-35.0406786	117.8260410	100	X	⬆	⬇	0.0	159.7	275
3	WAYPOINT	0	0	0	0	-35.0417239	117.8251612	100	X	⬆	⬇	0.0	141.2	215
4	WAYPOINT	0	0	0	0	-35.0428395	117.8259873	100	X	⬆	⬇	0.0	145.1	149
5	WAYPOINT	0	0	0	0	-35.0427165	117.8274572	100	X	⬆	⬇	0.0	134.5	84

Figure 21: Command/Control Visualization

Communication

The team needed to design the last aspect of the communication system ("C3"). 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 1.5 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 2.25 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 only 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.

In summary, the system communication updates consists of the use the PC Laptop Control costing $4000 and the Data Transceiver Set (900Mhz) – High Range costing $135. This results in a total of $4135 for all communication devices. The following is a chart that illustrates the purpose of each component.

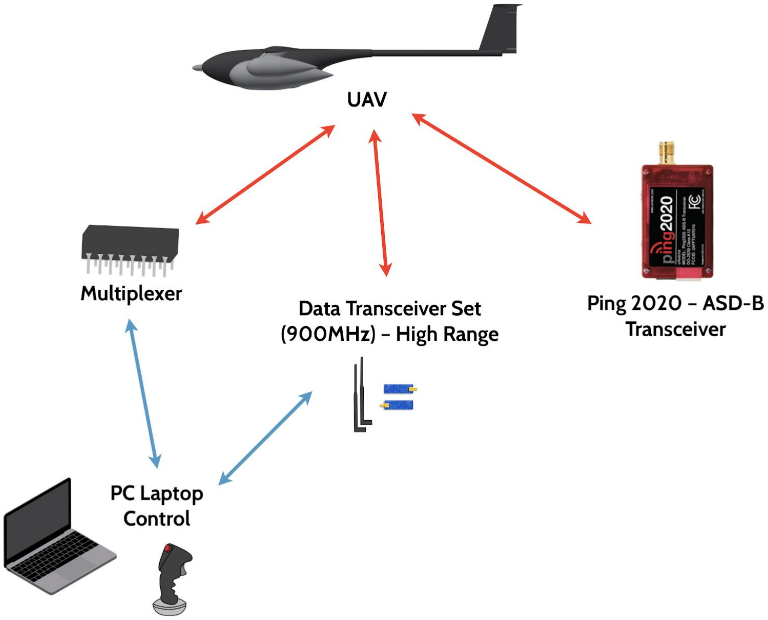


Figure 22: Communication System Components

2.3.4 Support Equipment Selection

Support equipment is necessary for the movement and storage of the pesticide SOLVITOL. It is important to note that the SOLVITOL comes in a container, which is included in the $45 cost to acquire the pesticide. However, a method to move the pesticide from the container to the aircraft is needed. Because of this, a liquid feeder bottle, for $29, is needed.

In addition, the laborer must be well-equipped to deal with the incurred chemical risks. As a result, he or she must wear a hazmat suit with gloves, a faceshield, and boots, all of which are chemically resistant. The cost for the gear, $353, encompasses all of these requirements.

Component	Cost ($)
Hazmat Suit	136
Gloves	38
Faceshield	20
Boots	130
Container (long term)	*included in initial cost*
Liquid Feeder Bottle	29
TOTAL	**353**

Table 5: Support Equipment Selection

In order to fill the aircraft with gasoline, a tank is necessary. A five gallon, or twenty liter, tank is $72.

Transporting the aircraft is achieved by using the Streamline trailer provided in the catalogue. This costs $5,000 and provides storage both for the airframe and the other system components, such as the laptop control module.

2.3.5 Human Resource Selection

Personnel	Cost ($ Per Hour)	Quantity
Range Safety/Aircraft Launch & Recovery/Maintenance	$35	1
Safety Pilot	$35	1
Operational Pilot	$35	1
Total:	$105	3

- **Range Safety/Aircraft Launch & Recovery/Maintenance Officer**
  Cost (per hour): $35
  Number Required: 1
  Justification: This individual is a highly skilled technician. Range safety includes ensuring frequency deconfliction 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 will 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
  Number Required: 1
  Justification: This individual is responsible for bringing the aircraft safely in for recovery. For this competition, we will assume line-of-sight (LOS) operation 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.

- **Operational Pilot**
  Cost (per hour): $35
  Number Required: 1
  Justification: In the case of autonomous or semi-autonomous 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.

2.4 Component and Complete Flight Vehicle Weight and Balance

Autodesk was able to be used to calculate the center of gravity for all of the material components such as the carbon fiber wings, tail, and fuselage, or the polyethylene tanks; however, components such as the engine and electronics needed to be manually overwritten to simulate the unique weights of these parts. Thus a separate "components" part was created to simulate these weights individually before totalling them into the images and coordinates shown below.

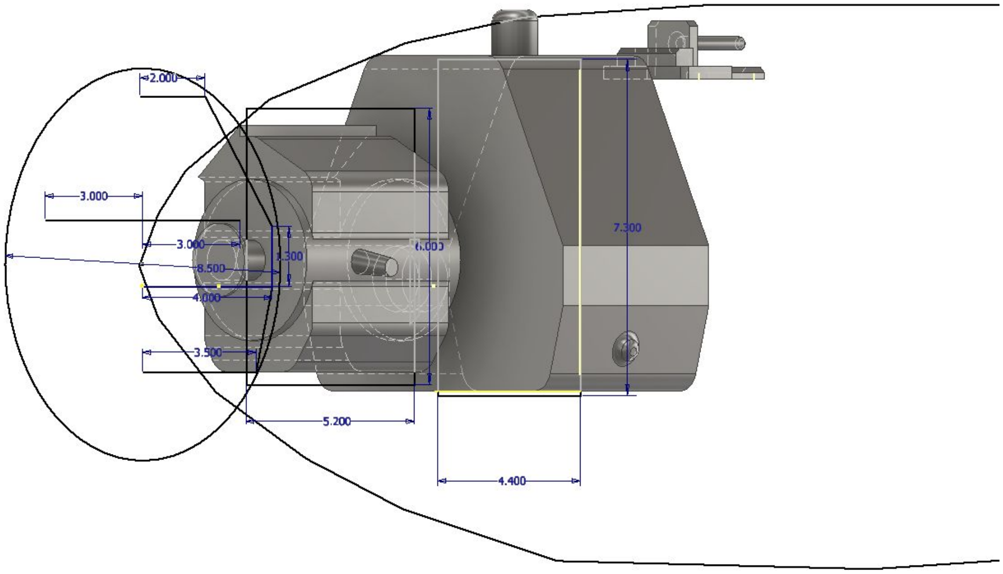


Figure 23: Engine, Fuel Tanks, and Electronics for Weight Analysis

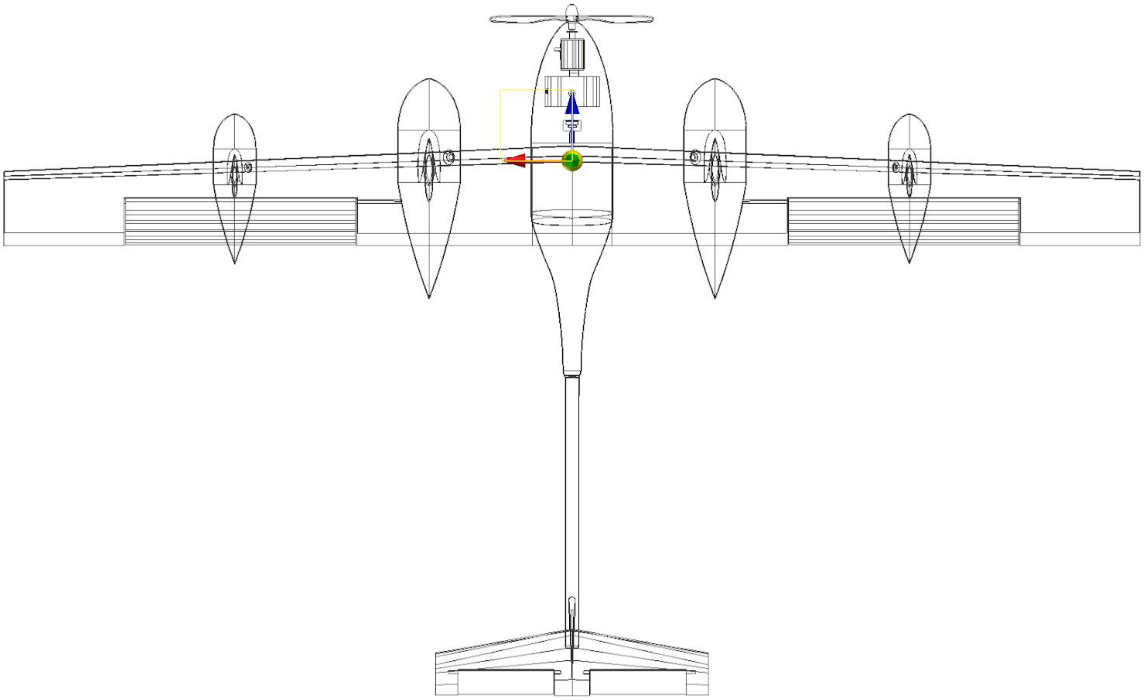


Figure 24: Center of Gravity Top View (visual)

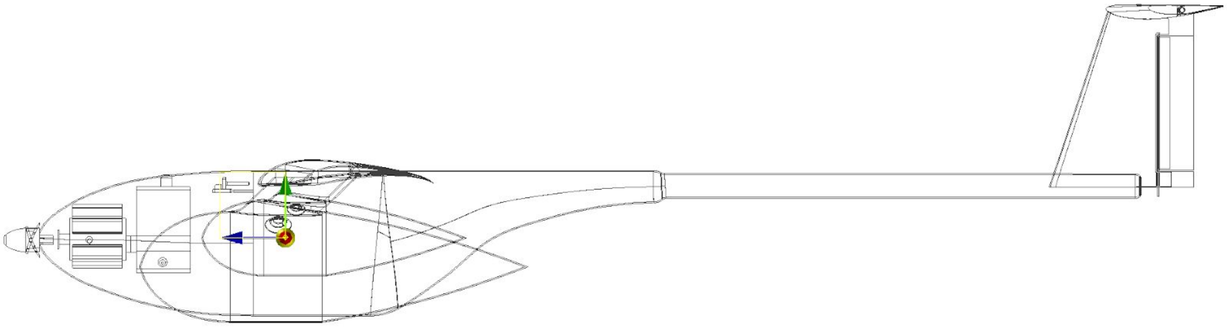


Figure 25: Center of Gravity Side View (visual)

The visual center of gravity location has been plotted in both of the images above for reference. The coordinate system uses the propeller as the (0,0,0) point, with ***x*** being the axis parallel to the wings, ***y*** being the top-to-bottom axis, and ***z*** being the front-to-tail axis perpendicular to the wings. (x, y, z). The coordinates are as follows in inches.

<u>Center of Gravity</u> = (0, 0.4, 21.5)

X increases negative to positive from left to right in figure 24

Y increases negative to positive from top to bottom

Z increases negative to positive from left to right in figure 25

(Remains unchanged when pesticide tanks are removed and camera is added)

2.5 Operational Maneuver Analysis

Three primary components (as discussed in section 3.1) make up the flight plan for the detection mission: Liftoff/Landing, Scanning Pass, Maneuver A, and Maneuver B.

The requirements for takeoff and landing are outlined in section 2.2.4 using the weight of the vehicle for the detection mission (65 lbs), thrust, and the resulting acceleration according to Newton's Second Law. Takeoff and landing are performed at a 0.0 degree angle of attack at full throttle until the climb, which is performed at 40 miles per hour up to 400 feet.

The scanning pass, as a straight and level procedure, simply involved calculating the lift produced by the vehicle under the given conditions, ensuring that it equaled the weight of the UAV. The outline of the scanning pass involves 42.5 mph flight, with a downward trim of 3.0 degrees to reduce the additional lift produced by the increased airspeed. The new Cl at this angle was determined through viscid XFoil analysis of the S1223.

Maneuver A was developed with the assistance of the csgnetwork turn calculator. With the given turn radii known for the flight plan based on camera footprints, the team was able determine the conditions required to make the turn for this maneuver. Maneuver A involves decelerating to 30.22 mph and banking at a 10.0 degree angle to turn 180 degrees with a radius of 347.7 feet. The results of these calculations are shown below. As it can be seen, the stall speed for the turn is below the airspeed of the vehicle during the maneuver, and the G load does not exceed 1.0, producing no additional strain on the frame. See section 2.6 for this structural analysis.

Maneuver A – Operational Analysis		
Aircraft Speed Entering Turn	30.22	mph
Turn Radius	347.8	feet
Turn Bank Angle	10	degrees
Turn Diameter	695.6	feet
G Load	**1.0**	**Gs**
360° Turn Time	49.2	seconds

Table 6: Operational Analysis for Maneuver A

Maneuver B was significantly tighter than Maneuver A but still manageable with the lighter payload for detection. It involves decelerating to 32.6 mph and banking to 45.0 degrees to complete a 180 degree turn in a radius of 71.3 feet. The analysis is shown below.

Maneuver B – Operational Analysis		
Aircraft Speed Entering Turn	32.6	mph
Turn Radius	71.4	feet
Turn Bank Angle	45	degrees
Turn Diameter	142.8	feet
G Load	**1.4**	**Gs**
360° Turn Time	9.4	seconds

Table 7: Operational Analysis for Maneuver B

2.6 Three View of Final Design

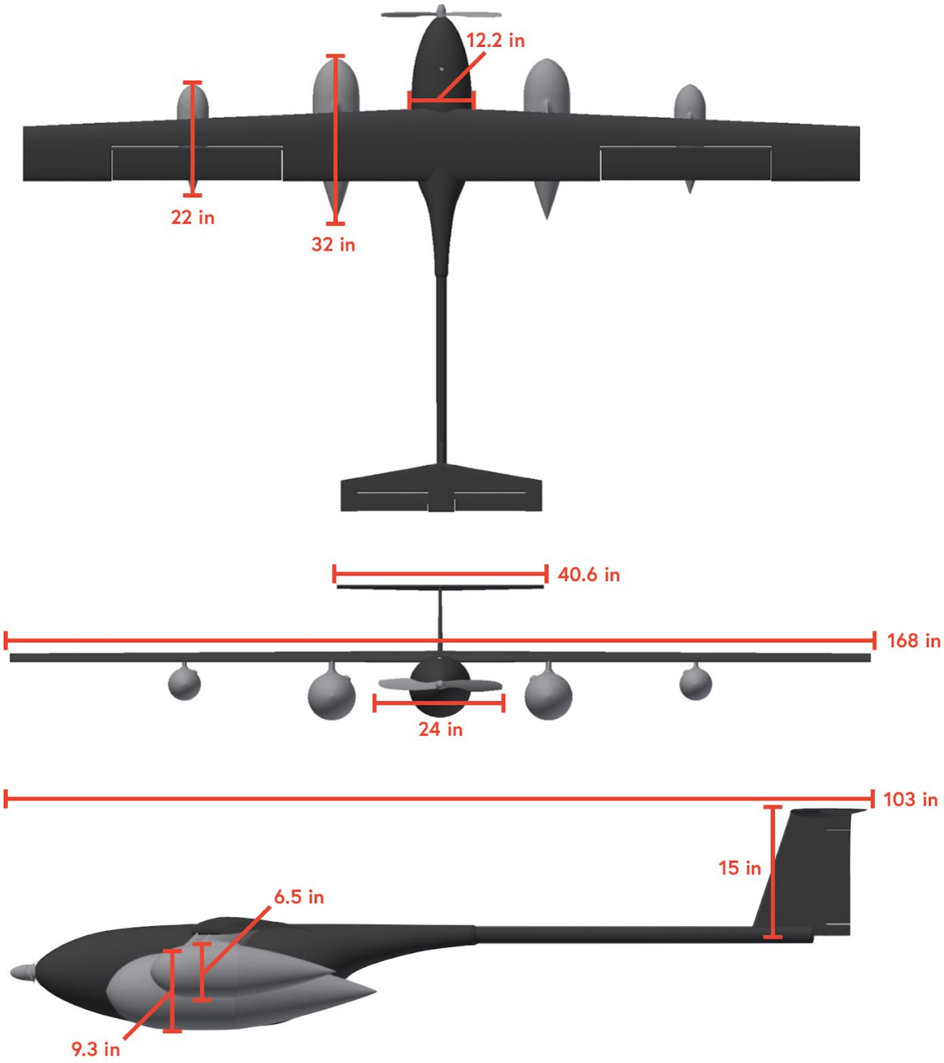


Figure 26: Three View of Final Unmanned System Design

3. Document the Missions

3.1 Detection Plan

In order to detect the infested areas of the field, NDVI Camera Technology will be applied to accurately detect infestation with a relatively amount of time necessary for each mission. This relies on NDVI calculations to determine plants in the field which are infected based on the overall health of the plant. NDVI technology allows for crop damage to be easily identified without the need for an agricultural specialist.

3.1.1 Detection Theory of Operations

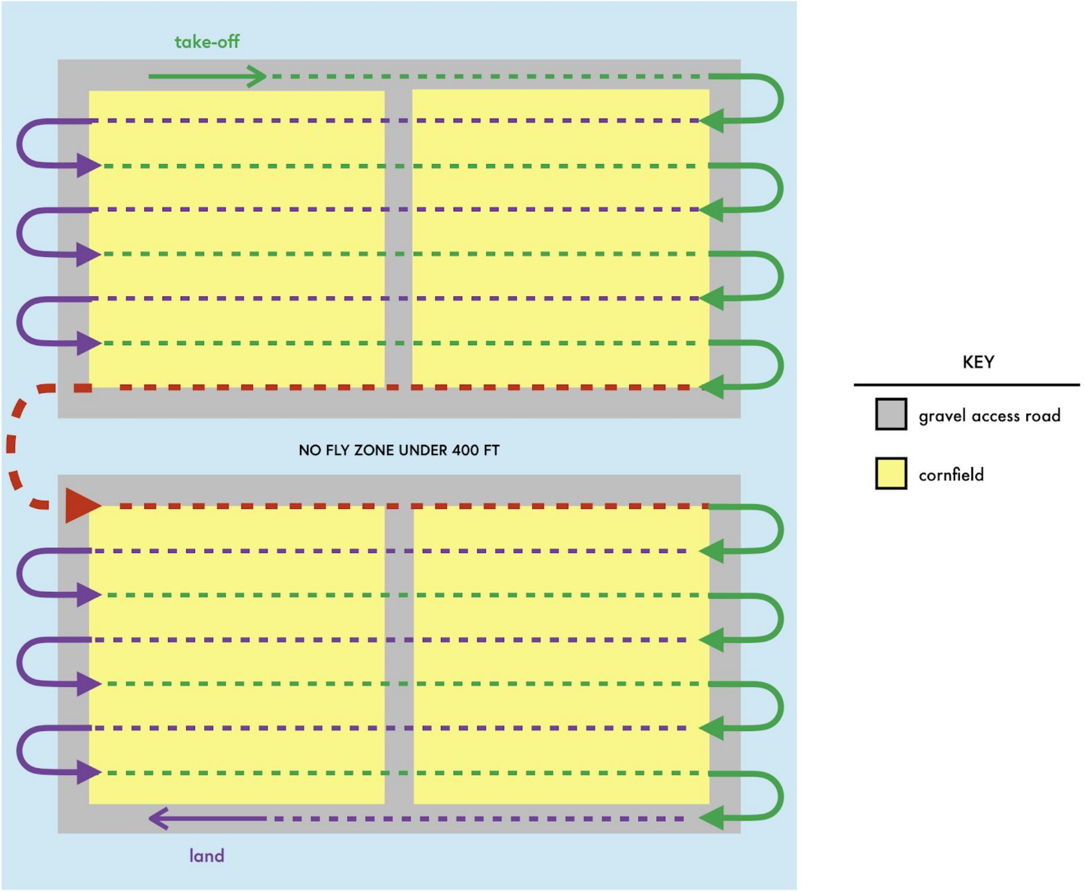


Figure 27: Flight Plan for Detection

Detection Plan Overview

1.) Launch from the long outside access road with camera and gimbal payload

-66 feet required at an acceleration of 6.58 m/s^2 (see 2.2.4 thrust analysis)

-1.7 seconds until liftoff

-2.8 seconds to climb to 400 feet cruising altitude with a net upward thrust of 104 lbs at a 0.0 degree angle of attack, 40 mph airspeed

2.) Maneuver A

-Decrease airspeed to 30.22 mph to conduct Maneuver A (10 degree bank, 347.7 ft turn radius)

-Turn takes 24 seconds to complete. See section 2.5.

3.) Scanning Pass

-Increase airspeed to 42.5 mph and trim nose down to -3.0 degree angle of attack to decrease coefficient of lift to 0.402, creating a lift equal to the UAV weight

-Adjust camera gimbal by 3 degrees to be perpendicular with the ground

-Single pass time = 2.82 minutes at 42.5 mph (2 mile strip)

4.) Repeat Maneuver A and Scanning Pass (7 additional times)

-Total time for 8 Maneuver A's and Scanning Passes = 25.7 minutes.

5.) Maneuver B

-Decrease airspeed to 32.6 mph to conduct Maneuver B (45 degree bank, 71.3 ft turn radius)

-Turn takes 4.7 seconds to complete and crosses above the restricted area of the no-fly zone. See section 2.5 for analysis.

6.) Scanning Pass

7.) Maneuver A

8.) Scanning Pass

9.) Repeat Maneuver A and Scanning Pass (7 additional times)

-Total time for second half of the field (8 maneuver A's and passes) is 25.7 minutes

10.) Maneuver A

-Land on access road.

Image and Data Capture and Analysis:

The camera selected for this mission was the Mapir Survey2 Camera with NDVI Red + NIR capabilities. NDVI technology enables the calculation of the level of health of a plant based on the amount of NIR and red light the leaves absorb and reflect. The Survey2 can operate at the detection altitude of 400 ft and captures approximately four acres in every picture, taking one picture every second. When a plant is infected, its overall health is worsened (this is why infestation is bad for plants). This means that if the overall health of a plant can be detected, this can be used to determine which plants have been infested with corn billbugs. This camera has this ability as a result of NDVI technology, and generates health maps of the captured areas which indicate the plants in each picture whose health has been compromised. This method is completely non-invasive for the plant and does not rely on the visibility of the small holes created by the billbugs. Instead, the camera can detect the overall health of each plant with NIR and red light sensors to determine the water content of leaves. The camera creates 'health maps' of the field with these values which the computer can process to distinguish the infested and non-infested plants. These maps are then stitched together based on the flight plan to create a full map of the given field with infested areas marked by the low health of the plants.

3.1.2 Detection Considerations

Strategy Formation

The flight plan was developed almost entirely around the footprint of the camera, the altitude limitations of the no-fly zone and the UAV's capabilities. First it was determined that the detection would need to be completed from 400 feet, as any lower height would present maneuverability issues with the no-fly zones. This height, along with the field of view of the camera, was used to determine the horizontal footprint, and thus the width of each pass on the field. To maximize efficiency and coverage, a creeping line pattern was the first option considered. Fortunately for the team, the turning radius required for detection widths of 695 feet (347 feet radius) was well within the maneuverable capabilities of the X181-NR (see section 2.5).

To bridge the gap between the two 2x1 mile strips of field separated by the no-fly zone, a significantly tighter radius of 71.3 feet was required, but easily attainable with the small payload as shown in the section 2.5 analysis.

After developing maneuvers A and B, the team began to brainstorm on the best method for increasing the speed of detection, while decreasing detection time, on the straight passes. Initially, it was determined that approximately 24 mph would be the maximum, as any higher airspeed at 0.0 degree angle of attack would cause the vehicle to increase in altitude. Thus it was determined that the speed of the vehicle could be increased to approximately 43 mph on the straightaways with the same lift force if the nose was trimmed to a pitch of -3.0 degrees, dropping the coefficient of lift to 0.402 from its 0.0 degree AoA value of 1.18. This drastically improved the speed of detection from 1.3 hours to about 50 minutes. In addition, the 60 fps capabilities of the multispectral camera allowed for these speeds while still maintaining sufficient image quality.

Benefit to the Farmer

The X181-NR provides both monetary benefits and time savings to the farmer. Whereas the use of the DJI Agras MG-1 and the SenseFly eBee SQ would result in the farmer paying 35% of the value of his or her cornfield to prevent crop loss (how this figure is calculated can be found in section 4.3), the X181-NR can provide the same service while only costing the farmer 10% of the value of the field. In terms of time spent, the X181-NR can detect and treat a field, including set-up and breakdown for a 2560 acre field (of which 10% needs to be treated) within three hours. The combination of using the MG-1 and eBee would take over three days to accomplish the same task. Therefore, the farmer is not paying for excess manpower and resources, and the farm is not occupied by the treatment company for as long a time. The choice of a NDVI camera also benefits the farmer. This allows for the extra feature of being able to scan the field for any infestation without being limited to only one resulting from billbugs. This equates to the X181-NR being more valuable to the farmer, as it is a tool which can detect decreases in plant health in general in addition to billbug infestations.

Benefit to the Company

The low operating costs of the X181-NR make it an ideal solution for the company to make a profit while treating infested cornfields. Much like the low-time requirement of the X181-NR benefits the farmer, it also benefits the company by reducing operating costs and allowing for a maximization of profits. As detailed in section 4.3, the operational costs of the X181-NR are 12% of those of the MG-1 and eBee to treat a 2560 acre field. Ultimately, this allows for a 46% greater profit margin for the company when comparing the two potential systems, all while still proving beneficial to the farmer.

Comparison

In comparison to the eBee, the detection performance of the X181-NR in the areas of time, money, and manpower is superior due to the adoption of efficiencies. First, the eBee takes a significant amount of time to carry out the mission: five hours in total. This results in a total of nearly $180 of operational and personnel costs. However, the real cost comes from the fact that the data analysis software costs $1,500 to operate, driving the operational cost of the eBee significantly higher. Moreover, checking the field for pesticides lasts 5 hours for the eBee, but only 47.6 minutes for the X181-NR, so the X181-NR provides a significant savings in time. In fact, in the time that it would take for the eBee to detect the field, the X181-NR could have already detected and treated it. The X181-NR attains savings because it eliminates the amount of manpower required and automates certain portions of the process, while the eBee maintains unnecessary positions and costly software programs. Overall, the X181-NR is a better UAS because it is more efficient, cost-effective, and is faster.

3.2 Application Plan

3.2.1 Application Theory of Operations

[Detail how your system would conduct the application mission from beginning to end. Calculate the time and manpower (human resource element) requirements. Show the operational profile for your system to complete the example application.]

General Overview

The challenge stipulates that each of the 4 1x1 mile fields will be 10% infested with billbugs. Since each field is 640 acres (2560/4), and 64 acres, or 10% of this 640 acres is infested, and each acre must be sprayed with 0.35 gallons of pesticide, this amounts to 22.4 gallons per each of the 4 fields. Since the total capacity of the vehicle is 24.25 gallons of pesticide, the UAV can sufficiently carry this payload and will carry out each of the applications for the 4 fields separately, landing in between to be refueled and resupplied with Solvitol.

Detailed Plan

Unlike detection, the application plan will vary based on the distribution of pests in each unique field. Detection missions require the coverage of the entirety of a field, and thus may employ the same flight plan in each given situation; however, based on the results of this analysis, the location of the 10% in need of application will vary in distribution. To account for this, the team researched the capabilities of the Ardupilot software installed in the Pixhawk flight controller. The open source flight planning software that is included with this payload allows for algorithmically optimized waypoint targeting. Waypoints will be set to the locations in need of application, and the software will automatically determine the following: Best position for takeoff along the gravel roads, turns and maneuvers *within* the calculated limits of the vehicle (see section 2.5), overall course of flight, landing.

These 4 categories must be within the operational limits of the vehicle as analyzed in the final sections of Section 2 of this notebook. Thus, the software will be programmed to account for the 630 feet required for full-payload liftoff, and the high stall speed of the loaded vehicle to ensure that the increased stall speed is not above the vehicle's capability when performing banked turns. However, as the pesticide is the heaviest component of the payload, and it is dispersed as the flight progresses (at a rate of 2.49 gallons per minute while spraying), the vehicle's maneuverability rapidly increases throughout the duration of the flight. Thus the software will account for the projected weight of the vehicle after each dispersion, and adjust the limitations on the flight plan accordingly to maximize efficiency. The software will appropriately avoid the no fly zones, and maintain an altitude of 25 feet above the crops while spraying to maintain the 87 foot application span with a droplet size that sufficiently supplies 0.35 gallons per acre covered.

While each individual flight path will be unique, a few known statistics were calculated and are shown below:

Spraying Speed: 18.1 m/s
Swath Width at 25 feet: 87 feet
Flow Rate: 2.49 Gallons/min
Amount of Time Spraying per 1x1 mi field: 8.98 minutes
Amount of Time Spraying Total: 35.92 minutes

Beyond the flight plan, the application will be carried out by the nozzles that are fed by boom tubing from the 5 spray tanks located on the UAV. (4 external, 1 internal). The design is able to accomplish the pesticide application mission through the use of different components that were selected throughout the design process. To make the application mission the most economical and efficient as possible for the farmer, some components were even designed from the ground up. The most prominent example of this is with the five spray tanks located on the UAV: they were specifically designed to complement the streamlined design of the system while also providing the largest amount of possible payload storage for the SOLVITAL.

As stipulated by the challenge, only 10% of the total 2560 acres is considered infected, and so only 10% of the field needs to undergo the spraying application. Since the total capacity of the spray tanks is about 25 gallons, and the two flat fan nozzles have a spray angle of 110 degrees (amounting to a spray width of approximately 87 feet), it is estimated that the total application time would be 2 hours. This would amount to $4,242 for the operational cost of the mission. (See section 4.2.2 for more information with these calculations.)

3.2.2 Application Considerations

[What are the major considerations necessary to support your theory of operation and application strategy? What did you do to maximize your design efficiency? Include at least: (a) How is your system beneficial to the farmer (time, resources, etc.)? (b) How is your system beneficial to your company? (c) Compare the spraying performance of your system to the performance of the DJI Agras MG-1 (time, money, manpower, etc.).]

Benefit to the Farmer

The X181-NR is a beneficial option for the farmer in regards to pesticide application for a couple of reasons. First, the same aircraft is able to perform both the detection and application missions, thus reducing time between finding the pests and treating for them. Because of this, the farm is occupied for less time with detection equipment than it otherwise would be, thus allowing for an increase in farmer productivity. Another benefit of utilizing the X181-NR is financial. That is, for a 2560 acre field like the one used as a baseline in the RWDC, only 10% of the value of the infested sections is dedicated to detecting and treating pests. The competing system, the MG-1 (excluding the detection costs), requires 34% of the value of the infested area to be paid (see section 4.3 for further details). Therefore, the time-savings that the X181-NR provides also translates into a financial savings for the farmer. Because of this, the X181-NR operates more efficiently and requires less of the farmer's resources to be dedicated to treating the field for pests.

Benefit to the Company

The X181-NR is useful for the company because of the profit margins that it is able to provide. Because of its lower operational costs, the X181-NR make is able to provide the company a profit while treating the infested fields at a competitive price. As detailed in section 4.3, the operational costs of the X181-NR are 12% of those of the MG-1 and eBee to treat a 2560 acre field. Ultimately, this allows for a 46% greater profit margin for the company when comparing the two potential systems, all while still proving beneficial to the farmer.

Comparison to the DJI Agras MG-1

Compared to the MG-1, the X181-NR is able to significantly reduce the time that it takes to spray the field, thus reducing operational costs. The reduction in operational costs allows the company to produce a larger profit margin and for the farmer to pay a smaller percentage of the value of the field to treat the field. This comparison is shown in detail in section 4.3, but a brief overview regarding the comparison of the two UAS will be discussed here. Whereas the MG-1 requires multiple flights to refuel and refill with SOLVITOL, the X181-NR can complete the spraying mission in one flight. Because of this, while the MG-1 requires over thirty-six hours to complete the mission, the X181-NR can complete the mission in under two. Therefore, using the same personnel to complete the mission, the X181-NR accrues one-eighteenth of the personnel cost of the MG-1 over the course of the mission. Ultimately, the X181-NR's increased capacity and endurance allow it to complete the treatment mission more speedily and more cost-effectively than the MG-1.

3.3 Overall System Performance

Compared to the eBee or the use of traditional detection methodologies the X181-NR provides a significant cost-savings to the farmer. Many variables illustrate this point, such as operational and initial costs. In a four square mile field, the eBee and traditional detection methods both take five hours to complete the detection, while the X181-NR takes 47.6 minutes. In fact, compared to the eBee, the X181-NR saves $62,761 and compared to the traditional manual method of detection it saves $12,499. (For more information, visit Section 4.3.)

The X181-NR is able to apply pesticides for a considerable cost savings for the farmer compared to the MG-1. Much of the monetary savings that the X181-NR allows for comes from its ability to reduce the amount of time needed to complete the spraying mission. Whereas the MG-1 requires three whole days to apply pesticide to a field, the X181-NR can complete the same mission in one hour. Because of this, the manpower requirements for the X181-NR are drastically reduced. The X181-NR is able to do this because of its increased capacity to carry pesticides; that is, it does not need to refill its tanks as many times as the MG-1. Because of the decreased operational cost, the X181-NR produces an additional 46% in profit margin than the MG-1 for a fraction of the value of the field.

In terms of part 107 regulations, the X181-NR only breaks away from the total weight constraint of not exceeding beyond 55 pounds. Allowing for the transport of a larger payload greatly reduces the number of trips that would be needed for the aircraft to completely spray 10% of the 2560 acres. Complying with part 107 would require 34 of such trips which is simply not economically feasible for the farmer or for the operator. By increasing the total weight to 251 pounds with 187 pounds payload (max. 311 pounds), the X181-NR is able to complete the application mission in only four trips, one per each 1 mile x 1 mile field, greatly reducing operational cost in the process. (For more information, visit Section 2.1.2.) The other part 107 regulations could be feasibly met without any significant drawbacks.

3.4 Safety

Safety Components	Quantity	Price
LeddarVu - 8 segment LiDAR Sensor Module	1	$690
Ping2020 ADS-B Transceiver	1	$1200
	Total:	$1890

The LiDAR (Light Detection and Ranging) is used for terrain avoidance in abnormal and normal operating conditions. It is especially useful in the event of signal loss from the pilot, as the aircraft is able to “see and avoid” on its own; that is, it is able to avoid hazardous terrain and structures.

When combined with programmed flight plans for both normal cases and during loss of signal, the LiDAR will allow the UAS to conduct operations while avoiding obstacles and also allow it to return to the GCS without needing to be manually controlled and outside of the normal flight plan. This safety feature is crucial in preventing the loss of the UAV in potentially hazardous situations.

Although LiDAR technology typically requires heavy post- and pre- processing, the UAS will not need to complete this processing as the LiDAR will be used only by the UAV autopilot system for obstacle avoidance. This processing would be only necessary if the data was to be visualized for a human operator. Furthermore, in order to prevent the need to store large amounts of data included in the LiDAR data maps, the sensor will only store data for a very limited period; essentially, the autopilot sensor will continually receive data from the LiDAR sensor and the now-old data will be deleted.

The X181-NR also features ADS-B in and out capabilities. This contributes to the the operating pilot’s situational awareness, in that he or she is fully aware of traffic in the vicinity of the UAS’s operational area. ADS-B is a satellite system that triangulates the position of aircraft, using the aircraft’s pre-existing navigational equipment. Essentially, ADS-B provides the X181-NR with traffic avoidance capabilities. Not only does the ADS-B assist the operational pilot, but it also ensures that the aircraft will maintain FAA compliance in variance types of airspace in 2020 and beyond, when it becomes a requirement in order to operate in the National Airspace System (NAS). The team requires the use of the Ping2020 ADS-B transceiver because according to Federal Regulation 14 CFR § 91.225 and 14 CFR §

91.227 starting January 1, 2020, any aircraft operating in airspace defined in 91.225 are required to have an Automatic Dependent Surveillance – Broadcast (ADS-B) system. Although the choice could have been made to operate outside of this regulation, the traffic collision avoidance capabilities that ADS-B provides help maintain the operational integrity of the aircraft in the long term in any environment. Moreover, incidents between commercial airliners and UAS operations interfering with one another have become more prevalent in recent months. Therefore, in the interest of protecting the safety of others and maintaining the UAS in the long term, it was deemed necessary to equip it with ADS-B.

Since the aircraft operates outside of part 107 compliance in that it weighs more than 55 pounds, extra precautions were put in place when designing the aircraft in order to maintain operational safety. Presumably, the goal of the part 107 regulation that sets the weight limit is to prevent high-speed traffic with little maneuverability from operating near the ground. That is, in order to comply with the other part 107 regulations, the aircraft should be a certain size. The X181-NR ultimately operates safely because of its compliance with the other regulations. The aircraft's stall speed is 30.5 miles per hour, which ensures safe operations well below the actual operating speed of the aircraft in normal flight conditions. The main contributing factor that allows the X181-NR to deviate from the regulation is its wing design. The wing can lift a heavy weight even at low speeds, which allows the X181-NR to operate like more lightweight aircraft under the given operating conditions. Therefore, the X181-NR can be operated just as safely as other, smaller UAS under the same operating conditions.

4. Document the Business Case

4.1 Market Assessment

4.1.1 Market Comparison

The DJI Agras MG-1 (MG-1), a competitor to X181-NR, provides a variety of features that make it a serious contender. This UAV can conduct the treatment of a 256 acre field in around 36.6 hours over the course of 3 days. Therefore, 36.6 hours of labor are required and the entire piloting process costs a grand total of $1,281, or $35 per hour. Refilling the pesticide costs $549, as launch recovery assistance is employed. Charging the batteries of the UAV costs $30.02, which considers the fact that the cost per gallon of Diesel is $2.05 (.4 gallons of which can be used to charge per hour) and that the entire charging process takes 36.6 hours. A constant cost, though an important one, is the cost of SOLVITOL to cover the 256 acres, which is $4,032. The overall cost of the aircraft amounts to $1,500, which includes the UAV's ability to apply pesticides. A more in depth comparison between the MG-1 and X181-NR is shown in section 4.3. However, the reduced time that it takes for the X181-NR to complete the field detection is ultimately what makes it competitive against the MG-1. The initial cost to acquire the MG-1 is $15,000, while the X181-NR costs $14,447.

The eBee SQ (eBee), another one of the given competitors to the X181-NR, is able to complete the detection in five hours. Because of this, five hours of labor are needed to operate the system, and five hours of diesel generator use are required to charge the batteries. The cost of detecting the field is $175, assuming the operational personnel are paid $35 per hour, and the cost to charge the batteries for each detection is $4.10. This means, operationally per hour, the eBee costs $179.10. In addition to this cost, data analysis is performed real-time at a cost of $1,500. The initial cost to purchase the aircraft is

$10,490. However, the system is limited in that it is unable to perform pesticide application. Rather, traditional methods must be used in addition to the eBee system.

Aside from the methods employed by the DJI Agras MG-1, conventional methods for the application of pesticides include the use of insecticides at the time of planting and preventative control. As per Bayer Global, preventing pests begins before one even plants a crop. Doing so results in a healthy, mature plant that does not suffer from insect infestations, as insects arise when a plant is just planted. Various insects, foremost in importance being maggots, grubs, larvae, and multifarious worms, pester corn plants, so tests must be undertaken to determine if the amount of insects is below a certain level per region. Tests denoting excess insects must result in the meticulous foliar application of insecticides. In addition to the use of insecticides, judicious seed treatment ensures a good yield.

Beginning before the planting stage, seed treatment consists of the treatment of seeds via chemicals that protect the seed from not only insects but also disease, nemadtoes, and more. From then on, pesticides must be applied from the roots up, covering every inch of the plant. By dressing the seeds early on, one can assure that the seeds grow and prosperity to their full potential. Applying pesticides allows for a more uniform crop which generates a greater yield.

The cost of this process, however, adds up quickly. According to the University of Chicago, published in 2004, the average cost per acre of pesticide application is $32. Adjusted for inflation, this number reaches $45. As a result, spraying a 2560 acre corn field costs $81,920, an expensive proposition.

According to the National Agricultural Aviation Association (NAAA), the initial cost of a crop dusting aircraft is between $100,000 and $1,400,000. Although these aircraft can apply pesticides relatively quickly, this initial cost may be prohibitive for some farmers and, over a five year period, is more difficult to make up than less costly alternatives. Moreover, operating these aircraft is also expensive. Given that aviation gasoline (Avgas, 100 octane, low lead gasoline) costs between $5 and $7 per gallon regionally and these aircraft can consume between seven and twelve gallons of fuel per hour, the operational costs are relatively high. Moreover, if the field is not located next to a suitable landing area for the aircraft, additional flight time during which pesticide is not being applied is acting as an additional cost. The hourly pay for a crop dusting pilot is typically between $35 and $40 per hour, according to the Bureau of Labor Statistics (BLS), and these pilots require a commercial license. This means that these pilots require significant training, which justifies the higher salary. Between the initial costs and operational costs of conventional crop dusting aircraft, pesticide application using this traditional method is rather costly compared to more precise methods.

Aside from the eBee, another way to detect parasitic infestations in fields is to collect a sample from a single plant in the field that is assumed to be infected. According to Iowa State University, although this is a useful method to determine if a field is infested, it is not advisable to apply pesticide to the entire field. The university states that the pests often occur in localized areas, and “consequently, fieldwide application of these pesticides might not be necessary or economical.” Even so, the cost to send a sample for evaluation is $30, which provides conclusive evidence regarding the presence of a parasite. Regardless, the conventional methodology that is used to determine billbug infestation in corn crops is manual investigation. This conventional method has many faults: it is relatively cost-intensive, at $475 per detection, including labor for physical detection and information synthesis, and requires a relatively significant amount of time. According to North Carolina State University (NCSU), ten samples should be taken per field to determine where the billbug has infested. If, however, after four samples are taken it is determined that there is a significant infestation in the field, the university states that sampling can be discontinued and that treatment can begin. While the eBee takes five hours to do a complete detection of the field and costs $1,500 for data analysis, only sending in ten samples from areas that are clearly infested is a significant savings. At $300, it would need to take the farmer five times the amount of time to do the detection on foot than with the UAS to make it a less economical option. Therefore, even if the farmer were to dedicate 25 hours of labor to collecting ten samples from the fields, then the UAS costs would just break even. Assuming that it takes one half of an hour to walk a mile in a corn field, a twenty five hour walk would be twenty five passes through the two mile field. However, according to NCSU, this is not necessary. Another potential option is using a “zig-zag” pattern through the field to provide enough coverage to determine if a field is infested or not. Still, though, this possibility presents some drawbacks: this pattern takes a little over five hours to complete on foot, which is the same amount of time it takes the eBee to complete the detection. The cost does present some advantages, as completing the detection on foot rather than by air saves two-thirds of the original cost. Nonetheless, a third option exists that is more practical than either of the aforementioned possibilities, the camera method, which the team decided to use. The X181-NR employs a camera that inspects, without the aid of humans, a field, and can easily detect infected regions. Furthermore, this process eliminates much of the unnecessary spending that the eBee and zig-zag methods incur. Costing $162.54, the operational costs of the X181-NR are far lower than that of the alternatives in part because no additional labor is needed and the time the detection takes (47.6 minutes) is also far lower. Another advantage of this method is that it allows detection to be undertaken much later in the corn’s development; manual investigation must occur early in the crop’s growth (up to the sixth to eighth leaf stages, according to the NCSU report. This leaves a possibility for future infiltration by pests, which the X181-NR’s ability to scan fields much later in their development without harming the plant prevents. As a result, the X181-NR offers a versatility that reduces the costs and times of the competing designs.

The X181-NR operates outside of the weight limit that is set forth by part 107 regulations. Part 107 requires that aircraft weigh less than 55 pounds, while the X181-NR weighs 64 pounds filled with fuel without a payload. When the X181-NR is filled with pesticide, it weighs 251 pounds. Exceeding the part 107 weight limit reduces the time that it takes to complete the missions, thereby decreasing operational costs. Whereas it takes the MG-1 over 36 hours to complete the field spraying, the X181-NR can complete the spraying routine in two hours. Over many fields, this leads to a significant cost savings, and the X181-NR is ultimately able to do this because of its capacity.

4.1.2 Field Size

[Explain how treating multiple smaller fields affected the profitability of your system.]

While these baseline calculations were completed with a four square mile field with a ten percent infestation of bill bugs, the X181-NR can also operate in fields of other sizes. The X181-NR can spray seven acres each minute. This also means that, for each minute of flight, 2.49 gallons of SOLVITOL is used, or $112.05 per minute. Over the course of one hour, 420 acres can be sprayed, which results in a total of $6,615 of SOLVITOL being spent. This is also the maximum value for three hours of labor time. Additionally, before each application of SOLVITOL, a detection mission is carried out. In the baseline mission, 2560 acres are detected in 47.6 minutes (discounting maneuvering time not related to detection, since this will change depending on the field), resulting in an actual detection rate of 53.78 acres per minute, or 3226 acres per hour. Hourly paid wages and other operation costs are rounded up to the whole hour for the purposes of this challenge, both to account for labor and safety. Therefore, both the standard 256 acre infestation and a 420 acre infestation require two work-hours to be completed. In a more literal sense, it actually takes 83 minutes to complete the 256 acre field and 120 to complete the 420 acre field. Note that, in order to standardize values in this section, set-up and break down are not considered. Similarly, the 420 acre field takes the same amount of time in terms of labor. Using the unit productivity rates of 420 acres of application per hour and 3226 acres of detection per hour, the following costs are accrued for different field sizes with 10% infestations: for a 2560 acre field, $4,242; for a 4,200 acre field, $6,825; for a 12,600 acre field, $20,265; and for a 2,100 acre field, $3,412.

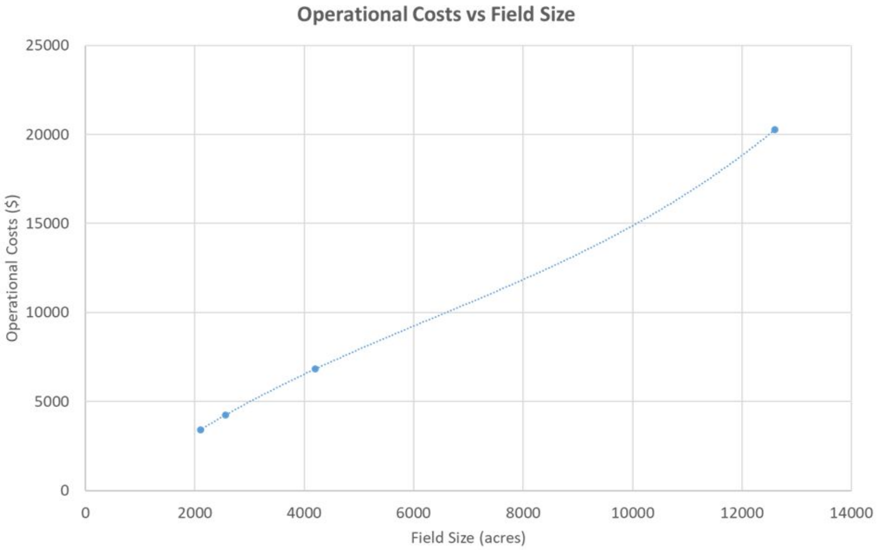


Figure 28: Operational Costs vs. Field Size

Figure 29: Field Size vs. Profit Margin

Ultimately, the factor that affects operational costs the most over differently sized fields is the amount of time needed to complete the application. The costs for SOLVITOL increases in a linear fashion as field size increases, and fuel costs increase linearly as flight time increases. Labor costs, however, remain constant over hourly time frames, and then increase by the hour as flight time surpassses the next hour mark. Essentially, the number of "smaller" fields treated does not greatly affect the operation costs of operating the aircraft; rather, the time spent treating the field is what ultimately affects operational costs. Ultimately, so long as the total time spent operating over a greater number of smaller fields is the same, operation costs will not be affected. A way to increase the price, for example, would be to require the aircraft to treat more, large-scale fields. However, the challenge's stipulation, which ultimately results in the same total area being treated and time spent treating it, does not adversely affect operational costs.

Finally, considering both field size and number of fields treated, expected profits can be mapped over a five year period. The following table shows the expected profit, which takes into account market size, the number of fields that can expect to be treated, and the revenue and operational costs of using the system.

Year	Profit ($)
1	59,820
2	179,460
3	177,220
4	223,360
5	290,980
TOTAL	**$ 930,840**

Table 8: Expected Yearly Profit

4.1.3 Target Market Assessment

Although the state of Connecticut does not have the large-scale farms that are found in other parts of the country, the X181-NR is able to operate both locally and across the country if more suitable regional markets are found.

According to the 2012 Census of Agriculture, carried out by the USDA, approximately 435,000 acres, or about 680 square miles, of land in Connecticut are dedicated to agricultural uses. The report also states that the average size of each farm is 73 acres, or about one tenth of a square mile. As a result of development, although Connecticut as seen an increase in farmed land since 1982, the first year the census reports, and 2012, that farmed land has become more fragmented. Therefore, a two square mile corn field like the one used to compare the X181-NR to its competitors is not likely to be found in Connecticut. More specifically, the census reports the amount of land used to raise corn crops in the state. In total, about 28,000 acres, or 44 square miles, of land are used to raise corn crops in Connecticut.

Despite the fact that Connecticut's farmland is fragmented and accounts for only nine percent of the the state's land, the state's farm sales are the third highest in New England, totaling $574 million in 2015 according to a University of Connecticut (UCONN) study (*Economic Impacts of Connecticut's Agricultural Industry*). About $20 million dollars of this is attributed to the growth of grains. (NB: The USDA typically categorizes dent corn, the corn used in this challenge, as a grain.) Moreover, between 2007 and 2015, the study reports an 821% increase in grain sales from Connecticut, which has resulted in a 246% increase in job availability in that sector. This study helps to demonstrate that agriculture and, in particular, grain crops are vital to Connecticut's economy. As a result of this, the X181-NR does have a market in Connecticut and could play a vital role in the protecting the state's economy.

The largest corn producing state in the United States is Iowa. According to the USDA census, there are over 1,500 farms in Iowa that are greater than 2,000 acres in size. Because of this, Iowa has the market of two square mile fields that Connecticut lacks. In Iowa, over 14,100,000 acres of land are dedicated to growing corn, which results in a total value of over $5.5 billion at the $3 per bushel that is used by the RWDC to standardize comparisons. Therefore, the value of corn to the country as a whole is significant. A ten percent loss off of $5.5 billion is a $550,000,000 loss. Wide scale use of the X181-NR would help to significantly reduce potential agricultural losses.

The X181-NR is a versatile aircraft, in that its profit margin remains constant over differently sized fields. However, larger fields ultimately provide more revenue, which is an asset and a sort of insurance policy if the projected number of detections and applications is not met. Nonetheless, the optimal field size for the X181-NR is a 4,200 square acre field, as this is the largest sized field that can be treated in a two hour time span. Although larger field sizes can be accepted by the X181-NR, the additional manpower requirements and time needed to work with larger fields reduces the number of fields that can be treated in the season. Therefore, the 4,200 square acre field balances a maximized revenue value while operating under a minimized time table.

Ultimately, the operational outline determines that, essentially, a maximum of forty fields could feasibly be treated in a year. This is specifically outlined in 4.2.3, but, to summarize the decision to treat this many fields resulted from a few factors. First, there need to be enough fields to treat. Second, the size of the fields treated should be a size that maximizes profitability (even if time allowed five hundred detections of a single square mile field, it would not be viable). Third, the treatments must take place during the growing season.

4.2 Profitability Analysis

To maximize profitability, the X181-NR ultimately does two things which work in conjunction with one another. First, the X181-NR reduces the time needed to carry out the detection mission. In a similar fashion, the system reduces the amount of time needed to carry out the pesticide application mission in order to reduce operational costs, most notably those related to manpower. Ultimately, the system's efficiency stems from its ability to reduce operational costs and time, which is the keystone to its ability to produce a profit.

4.2.1 Fixed (Initial) Costs

The initial costs of the system are those costs associated with manufacturing the aircraft. Since the use of the X181-NR is meant to replace more costly traditional methods of spraying, these costs must be absorbed by the spraying company, the owner and operator of the X181-NR, over time. Because of this, the farmer will not see these costs up-front; rather, the company defrays the initial costs over time by charging a certain fee for spraying the infested field.

The initial costs of the aircraft can be categorized in order to provide an overview as to how an investment in the X181-NR as a system is related to its use on the farm. That is, by investing in more costly equipment in certain categories of equipment and saving money in others, each cost can be individually justified. The following categories will be used to break down the initial costs: airframe; aircraft construction labor; command, control, and communications (C3); and support equipment costs.

The airframe components of the X181-NR each contribute to the its efficiency, celerity, and safety. The cost of the carbon fiber, of which the body of the aircraft is composed, amounts to $267. Carbon fiber was chosen because of its reliability in operation and its lightweight. The cost of the propeller, essential to the movement of the vehicle, amounts to $100. For taking off and landing, a landing gear mechanism was designed, which costs $62. In order to power the electrical components of the aircraft, an alternator and battery are necessary, which cost $281 combined. A gasoline combustion engine is used in order to maximize flight time and range. In order to complete the detection mission, a $280 camera must initially be purchased. Finally, $18 of tubing is needed to transport pesticide from the tanks to the spraying release nozzles.

Airframe Component	Cost of Component ($)
Carbon Fiber	267
Propeller	100
Engine	649
Landing Gear	62
Alternator	71
Battery	210
Tubing for Pesticide	18
Camera	280
TOTAL	**1657**

Table 9: Airframe Components

There are two main labor roles associated with building the X181-NR: the assembly technician and the electronics technician. The assembly technician constructs the airframe itself and is also able to build the fuselage and other control surfaces. Because of this dual-nature, time is added to this person's role when considering how much he or she works on the aircraft. The RWDC catalogue and the Bureau of Labor Statistics (BLS) both suggest that this position be paid $25 per hour. The electronics technician is able to install the electronic equipment in the aircraft. A full list of this equipment can be found in the next paragraph. Since the aircraft uses ADS-B and other advanced C3 technologies, many of which are necessary to ensure aircraft safety, this role requires substantial training. Beyond a standard Federal Communications Commission (FCC) certification, this role must be filled by an aircraft electronics technician (AET) who has experience in advanced aircraft electronics. The BLS states that the hourly pay for an AET is $29, a slight increase over the catalogued amount by the RWDC. However, this additional pay is necessary for the aircraft to operate safely. It is estimated that, due to the complexity of the aircraft, a total of twenty four hours of labor will be needed by the assembly technician to build the airframe and an additional twelve hours by the electronics technician. This results in a total of $948 in order to build the aircraft.

The C3 components are used to control and communicate with the aircraft. They serve as systems that are vital to normal aircraft operation, aircraft operational safety, and in the reduction of pilot workload. Because of this, C3 components make up a significant portion of the initial costs of the system. The table below gives a detailed list of the C3 components.

C3 Component	Cost of Component ($)
LeddarVu - 8 segment LiDAR Sensor Module	690
Ping2020 ADS-B Transceiver	1200
ArduPilot	0
PC Laptop Control	4000
Data Transceiver Set (900Mhz) – High Range	135
Microcontroller	100
Global Positioning System (GPS) Sensor	50
9-Degree of Freedom Inertial Measurement Unit	40
Digital Compass Sensor	45
Multiplexer	25
Autopilot	92
Universal Battery-Elimination Circuitry (U-BEC) (x2)	40
TOTAL	**6417**

Table 10: Command, Control, Communications (C3) Components

In order for the X181-NR to operate effectively not only as an aircraft but also as a system, support equipment is integral to the initial investment that must be made in the aircraft. The support equipment primarily serves a few purposes: it facilitates the storage and transferral of gasoline and SOLVITOL to the aircraft, provides storage for the aircraft itself, and provides safety equipment for the person who moves the SOLVITOL from storage to the aircraft. SOLVITOL is hazardous to humans, so moving it in a controlled and safe manner is vital to successfully completing each mission. The liquid feeder bottle allows the SOLVITOL to be transported from its storage container to the aircraft without leakage. It is also necessary for the aircraft to be stored in a safe and controlled environment between missions, which necessitates the purchase of the Streamline trailer. Finally, since the aircraft uses a gasoline combustion engine, a tank is needed to fill the aircraft with gasoline. The table below outlines these costs.

Support Equipment	Cost of Component ($)
Container (long term)	*included in initial cost*
Liquid Feeder Bottle	29
Gasoline Tank	72
Streamline Trailer	5000
DuPont Coverall	136
Shoulder Length Gloves	38
Googles and Face-Shield	20
Protective Boots	130
TOTAL	**5425**

Table 11: Support Equipment Components

The costs of components relative to each other were maximized in order to make the X181-NR a financially viable choice in precision agriculture. The primary acquisition costs for the X181-NR result from C3 components and support equipment. The C3 components make up 44% of the initial costs but are integral to controlling and communicating with the aircraft, the situational awareness of the pilot, and traffic avoidance. These all help ensure that the aircraft operates effectively and reliably over time.The support equipment makes up the next greatest piece of the initial costs. However, the majority of this value comes from the need for a trailer to transport the system. Next, the airframe components make up eleven percent of the initial costs. The use of a gasoline combustion engine makes up a significant portion of this, but allows for greater flight endurance. Similarly, the choice of carbon fiber for the airframe maximizes efficiency. Finally, labor makes up seven percent of the initial costs. Initial investment in professional labor ensures that the system functions well in the future. The total sum of the initial costs for the system is $14,447.

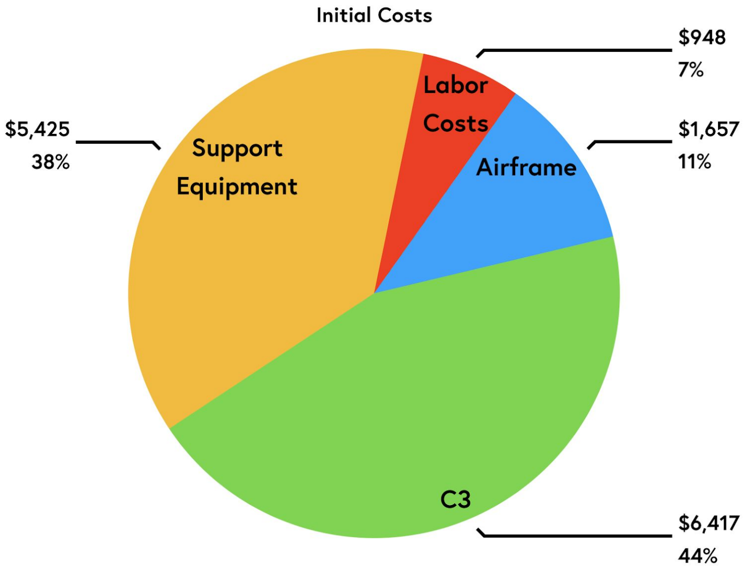


Figure 30: Cost Per Each Component

Ultimately, exceeding the part 107 regulations allows the X181-NR to complete the mission in a reduced amount of time. Although the initial costs themselves essentially fall within the regulations, the large size of the aircraft, greater than 55 pounds when loaded, allows it to carry out its missions continuously. Because of this, it does not have to refuel or load more pesticide, which would ultimately cause an increase in time, thus increasing operational costs and manpower requirements. Thus, the size of the airframe itself, which allows the aircraft to operate outside of the part 107 regulations, is what allows the system to be a cost-effective system application in precision agriculture.

4.2.2 Operational Cost

The costs related to operating the X181-NR include personnel costs, maintenance costs, and fuel use. Each component to the cost plays an important role in the operation of the aircraft, though the each operational cost was mitigated in order to make the system a cost-effective way to apply pesticides in the long term.

The personnel costs ultimately translate into the amount each person who is associated with operating the system gets paid. A Range Safety/Aircraft Launch & Recovery/Maintenance, Safety Pilot, and Operational Pilot are required to carry out the missions. Each of these personnel are paid $35 an hour, based on BLS guidelines, and work for the duration of each mission. A significant savings was made possible by replacing the role of an agricultural specialist with that of an open-source program that allows the pilot to recognize where the infected areas are located, which allows for a saving of $35 to be made. Moreover, the two hours that would later be spent on paying an agricultural specialist to create a report on the billbug infestation are no longer necessary. This brings the total amount of money saved by substituting the software instead of the specialist to $245 over the course of the mission. An additional $525 in labor costs is saved by not requiring the aircraft to carry out this portion of the mission. In order to operate the aircraft during the detection mission, three personnel are needed, the Range Safety/Aircraft Launch & Recovery/Maintenance, Safety Pilot, and Operational Pilot. In total, for the 47 minutes that it takes to carry out the mission, these three individuals are paid $105. Next, the personnel costs related to pesticide application must be considered. Assuming that 10% of the field is infested, or 256 acres, the mission flight time is a little under forty minutes. Therefore, during the time that the field is actually being treated with pesticide, $105 is spent in labor. However, an additional hour is allocated to set up and break down the aircraft, so an additional $105 is spent in labor between the two missions. The Range Safety/Aircraft Launch & Recovery/Maintenance officer, the Safety Pilot, and the Operational Pilot are all paid $35 an hour during for operating the aircraft. In total, $315 is needed to pay for labor each mission, including the detection phase, the pesticide application phase, and the set-up and break-down of the aircraft.

The operational cost of the UAS also considers the cost of the gasoline necessitated to power it. The aircraft burns fuel at 2.85 gallons per hour, and gasoline costs $2.52 per gallon. For the detection mission, this results in the need to pay for $7.18 of fuel, since the flight is 54 minutes long. Covering the corn field at a 10% rate of pest infestation means that the duration of the spraying is 36 minutes. In order to complete the 36 minute application mission, 1.55 gallons should theoretically be necessary. However, this number fails to account for safety factors and a potentially imperfect engine efficiency; with those factors considered, 2 gallons is the necessary amount. This number is also used as a safety factor for the detection mission. Therefore, the cost of the gasoline needed to power the UAS to detect pests and apply pesticides using four gallons of fuel is $10.08.

Another cost that must be considered during the spraying phase of the mission is related to SOLVITOL use. Each acre of the field requires 0.35 gallons of SOLVITOL to be applied to eliminate the infestation. The fixed price of SOLVITOL is $45 per gallon, so spraying 0.35 gallons per acre of 256 acres, the infested land, costs $4032. It is important to note, however, that this is a fixed cost between all systems. Traditional methods, competing UAS, and the X181-NR all use this quantity of SOLVITOL to treat the field. Nonetheless, it is an important factor to consider when discussing operational costs. Over time, the aircraft also experiences what is considered "normal" wear and tear. That is, the aircraft needs to be serviced from time to time and may need to be repaired in order to maintain operational efficiency in the long term. The engine requires an overhaul after every five hundred hours of flight. Typically, this costs between $100 and $200 to complete. This must be carried out after every 500 missions for the ten percent infestation of the two square mile field. An additional routine maintenance check must be completed on the airframe itself at this time in order to operate the aircraft safety, and an additional $150 is allocated to this, or about a quarter of the airframe cost. Therefore, assume that every 500 missions results in a total of about $300 in maintenance. Therefore, each individual mission accrues a cost of $0.60 in maintenance.

When encompassing each portion of the operation, as in detection and spraying, the operational cost of the vehicle per mission is just $4,357.08. This cost considers the maintenance fees accrued, as well as the costs for the SOLVITOL, sampling, and labor. Sampling the field is nearly exclusively made up of operating costs, at $162.54. On the other hand, the spraying portion of the mission proves far more costly, primarily because of the SOLVITOL cost, and totals $4,194.54.

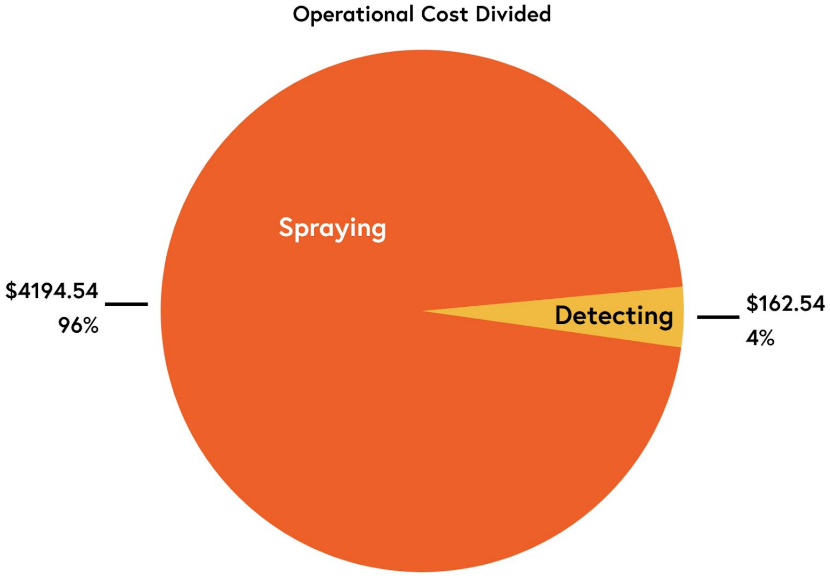


Figure 31: Operational Cost Divided

Another factor that affects operational cost of the UAS is field size. Due to fact that the time spent detecting and spraying depends on field size, certain field sizes are more efficient than others in terms of how many costs are incurred. Calculations prove that the optimal field size is 4,200 acres, which costs $6825 for a full detection at a rate of 10% application. It must be noted that the solvitol cost remains constant as the cost is determined by quantity.

The UAS can fly four fields at once to no loss to its operational costs. This is because the UAS handles four smaller fields as one, larger fields, which limits overall expenditure.

In total, the operational cost of the UAS was optimized by reducing labor times, trips, and gasoline costs. Although the X181-NR does operate outside of certain part 107 regulations, it does so while maintaining a safe operating environment with the goal of maximizing efficiency. The UAS failed to stay within the part 107 weight limit in an attempt to limit the amount of trips taken. Part 107 limits the weight of the aircraft to 55 pounds. The operating empty weight of the X181-NR is 48.2 pounds, while the maximum gross weight during the pesticide application mission is 311 pounds, with the actual weight of 251 pounds. However, due to the high efficiency of the aircraft's wing, it is able to operate within the part 107 speed limit of 87 knots. The fact that the X181-NR exceeds the weight limit is the most important money-saving factor in terms of the aircraft's non-compliance with the part 107 regulations. By reducing mission time, labor, gasoline, and maintenance costs are all reduced because each mission takes less time to complete. Another way that the X181-NR reduces labor, gasoline, and maintenance costs is through the automation of the pest detection in the field. Instead of using an agricultural analyst, the use of software allows the synthesis of data to be completed free of charge. Therefore, ultimately, only labor and operating costs are needed to detect the field, costing only $162.54, since it takes less than an hour to carry out the mission. Whereas the price of both operating the eBee and completing data analysis is $2,395.50, the X181-NR completes this task at a fraction of the price, mostly because of its ability to reduce operating time. Therefore, the X181-NR saves money because of its increased carrying capacity and the decision to minimize labor and operational costs for field detection.

4.2.3 Pricing Analysis

The field size used was calculated through a detailed comparison with existing corn fields all across the United States.

The field size used was determined through a detailed comparison with existing corn fields all across the United States. In Connecticut, as mentioned in section 4.1.3, 28,000 acres, are used for the growing of corn crops. Though this fact limits the availability of 2,560 acre fields, the baseline RWDC field size, the UAS could still be effective with smaller fields. For the sake of clarity, the smallest field size that will be considered is 2,100 square acres, or a 210 square acre infestation. The feasible task of detecting and spraying pests and pesticides on Connecticut's field would occur at a rate of 1.5 per week for 10 weeks during the first year of the aircraft's operation, for a total operation cost of $52,680. In the first year, fifteen fields could be detected, and helps estimate gaining market share over the early years of operation. Moving onwards, the X181-NR could expand its production outwards to where larger, more valuable corn fields lie. It is foreseeable that by the second year, the X181-NR could cover corn fields in other New England states, where 186,000 acres of corn fields in total are. The UAS would cover 45 2,100 acre fields at a rate of four detections and sprayings per week for 11.25 weeks, and thus would accrue an operational cost of $158,040. The third year would permit the introduction of the X181-NR to the Mid-Atlantic states of New Jersey, New York, and Pennsylvania, which would augment the operated areas to 44,800 acres and an operational cost of $147,780. During this year, 30 2100 acre fields and 10 2560 acre fields would be detected. This would need a rate of detection and spraying of four fields per week for ten weeks. The fourth year would coincide with expansion to the Southern United States, where the X181-NR would continue its previous rate of 4 fields per week for 10 weeks. However, the amount of acres covered would increase to 103,700 acres. 15 2100 acre fields, 20 2560 acre fields, and five 4200 acre fields would be detected. The operational cost would grow to $171,645. The fifth year would result in the proliferation of the X181-NR in the Midwest. There, the UAS would cover 10 2100 acre fields, 10 2560 acre fields, and 20 4200 acre fields, or 130,600 acres in total. The rate of the UAS's detections and spraying would maintain itself at four fields per week, though the operational cost would rise to $213,040. The tables that follow outline the five year detection and application plan and operational costs per field size.

Year	2100 Acre Fields	2560 Acre Fields	4200 Acre Fields	12600 Acre Fields
1	15	0	0	0
2	45	0	0	0
3	30	10	0	0
4	15	20	5	0
5	10	10	20	0

Table 12: Five Year Detection and Application Plan

Field Size (Acres)	Operational Costs ($)
2100	3517
2560	4247
4200	6825
12600	20265

Table 13: Operational Costs per Field Size

The profit that the company makes over the five year period is an important factor in the pricing analysis. The estimated profit values are take into account a number of different variables and are standardized for a given number of fields being treated each year. Nonetheless, given the number of fields that are to be treated each year, the company profit will increase as follows: In the first year, $21,330 will be accrued, $63,990 in the second year, $80,360 in the third year, $119,400 in the fourth year, and $142,600 in the fifth year. These values are the result of maximizing the number of different types of fields that are treated each year based on the system's optimal field size.

An important decision that was made regarding how the system is priced for farmers' use is related to the type of cornfield that it detects. As the challenge states, by 2050, the Earth's population will have significantly increased, thus increasing demand for food crops, such as corn, as well. However, a major use of corn is also to create ethanol, an alternative energy source to fossil fuels. Ethanol and biofuels are, in fact, beneficial in many ways. Not only will biofuels not be depleted if used sustainably, unlike fossil fuels, but they also do not result in a net carbon release into the atmosphere. That is, photosynthesis from the plants removes carbon from the atmosphere, and that same carbon is released by combustion. A major issue with corn ethanol, however, is that it ultimately competes with food crops and drives food prices higher. Moreover, the amount of land needed to replace conventional fossil fuels with biofuels sourced from corn would exceed the combined amount of land currently dedicated to the growth of corn for human consumption and fuel use.

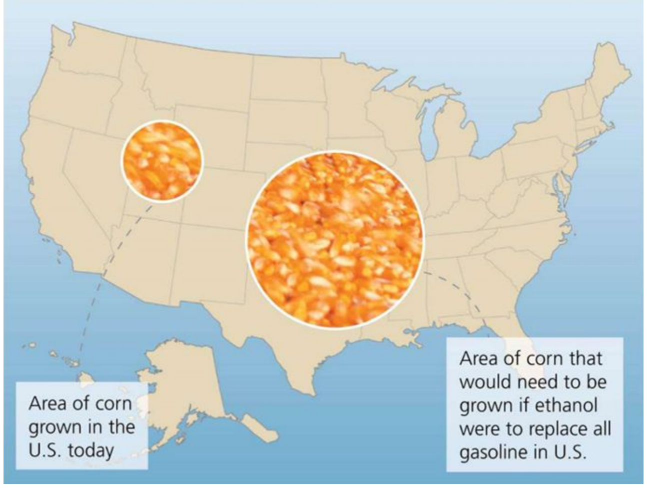


Figure 32: Ethanol Effects on Corn Growth in the U.S.

Because of the competition ethanol producing corn creates with food producing corn, the company charges a 10% premium on treating fields used for growing ethanol corn. Note that all figures that are used in this section are using the food-crop related profit margin. This provides a more conservative estimate of the profit along with keeping to the RWDC's focus on helping support food-producing crops.

To begin outlining revenue and profitability, an additional aspect must be added to the operation costs that are accrued each year. Previously, the breakdown of operation costs per year were stated as follows: year one, $52,680; year two: $158,040; year three: $147,780; year four: $171,645; year five: $213,040. However, one additional aspect must be considered when calculating yearly costs: the amortization of the initial costs over the five years. The calculation is simple, an additional $2889.40 is added to each year (this is $14,447 divided by five years).

In order to evaluate the feasibility of turning of profit, certain values, national averages, were used in order to determine the value of corn crops. These values are 100 bushels per acre of production and $3.88 per bushel. Thus, each acre of corn is valued at $388. By multiplying this by ten percent of the value of a full field's worth of corn (since only ten percent is infested), the potential loss of corn is outlined as follows for the different field sizes: a 2100 acre field could lose $81,480; a 2560 acre field could lose $99,329; a 4200 acre field could lose $162,960; and a 12,600 acre field could lose $488,880 worth of corn.

The competing aircraft systems cost $34,874, or 35% of the 2560 acre field's value, in order to save the infested corn. The profit of this system is 10%. Therefore, in order to optimize the X181-NR against competition, provide a viable option for farmers, and create a reasonable company profit, these values must be optimized.

In a 2560 acre field with a ten percent infestation, the company starts with a baseline of $10,000 of revenue. That is, the farmer pays $10,000 for the full detection and treatment of the field. This principal is used for all of the different field sizes, and a summary of the revenues, profit margins, and farmer costs can be found in the table below.

Acres	Infested Value	Operational Costs	Revenue	Revenue Percent Value of Field	Profit	Profit Margin
2,100	$81,480	$3,512	$7,500	9%	$3,988	53%
2,560	$99,329	$4,242	$10,000	10%	$5,758	58%
4,200	$162,960	$6,825	$16,500	10%	$9,676	59%
12,600	$488,880	$20,265	$40,000	8%	$19,735	49%

Table 14: Summary of Revenues, Profit Margins, and Farmer Costs for Different Field Sizes

For the farmer, depending on field size, no more than 10% of the value of the infested and potentially lost crop is paid when using the X181-NR. That is, the out-of-pocket cost for the farmer does not exceed ten percent of the revenue that they will eventually make off of the corn. Again, flying over multiple fields does not adversely affect profitability. In essence, the column called "acres" in the table above could just as easily be replaced with the word "time". That is, the operational costs that are accrued really actually result from the time spent operating the system. Thus, one 4,200 acre field; a 2,100 and 2,100 acre field combined into a 4,200 acre field for one detection; or four 1,050 acre fields, so long as they are considered "one mission", would all result in the company charging the farmer $16,500.

At its core, the X181-NR reduces time spent carrying out missions to reduce the cost for farmers and optimize profits for the company. Therefore, the primary strategy that the business case employs maximizes profit margins while mitigating costs.

4.2.4 Regulatory Analysis

14 CFR 107 provides a comprehensive outline of safety considerations regarding UAS operations. The X181-NR's compliance with federal aviation regulations ensures safe flight, and its operations outside of the current boundaries help achieve peak efficiency in the precision agriculture setting without compromising flight safety. From the perspective of the FAA, the current regulations help integrate UAS operations into the current airspace system. As with any new technology, UAS safety standards are an imperative element for the long-term commercial success of the product. However, commercial viability also requires that new uses for technologies be pioneered in new ways. Therefore, for optimal use of UAS technologies in precision agriculture, certain regulations need to be reviewed and solutions need to be produced that expand potential uses of these technologies without compromising safety. To achieve maximum profitability, the X181-NR adheres to certain federal aviation regulations in order to maintain a safe operations in the National Airspace System (NAS) while also expanding upon the current regulations to allow an abundance of uses in agricultural markets.

To operate the UAS, the pilot must comply with federal law and take an exam certifying competency in a variety of fields, including regulations regarding airspace requirements, weather, loading and performance, and aircraft operations and flight characteristics. This vital test, the content of which is determined by the Airman Certification Standards (ACS), emphasizes knowledge relating to all facets of 14 CFR 107. Moreover, it also helps ensure pilot and aircraft competency in emergency situations.

Additionally, federal regulations require specific standards for weight, speed, fuel, and size. The unmanned aircraft cannot exceed 87 knots in speed and 55 lbs. As for size, the aircraft's registration markings must be legible, as they are subject to routine inspections Furthermore, the aircraft must receive permission from Air Traffic Control prior to any operation, during which the aircraft needs a camera to maintain sight for three miles.

The carriage and transport of hazardous materials, including fertilizers and pesticides, by UAS is prohibited under 49 CFR 171.8. This regulation protects both the environment and the public by eliminating the potential release of hazardous chemicals from the air. However, over farmland, these concerns are substantially mitigated. In fact, the timely transport of fertilizers in secure aircraft over farmland ensures that the fertilizer will not be released outside of the farm itself. Moreover, aircraft are currently used to spray pesticides and fertilizers on crops by the common practice of crop dusting. Therefore, the waiver of this regulation for UAS over farmland is neither un-reasonable nor unsafe if proper safety precautions and protocols are put in place.

The X181-NR also operates outside of the part 107 regulations that limit aircraft weight to 55 pounds. The weight of the aircraft with full fuel and without a payload is 64 pounds while it weighs 251 pounds with a full pesticide load. The profitability strategy that the X181-NR ultimately employs is one that maximizes the amount of pesticide that can be sprayed over a given unit time. By reducing the amount of time it takes to complete each mission, operational costs are mitigated. Ultimately, operating outside of the weight limit that is imposed by part 107 is integral to the reduction in mission time.

4.3 Cost / Benefits Analysis and Justification

The X181-NR is ultimately a highly efficient and profitable system to detect and mitigate pests in the agricultural setting. By reducing the amount of time needed to carry out different missions and reducing manpower requirements, the X181-NR is a competitive system in precision agriculture. Not only is it an attractive choice for farmers, but it also produces a substantial profit for the operators, as well.

Compared to the eBee or the use of traditional detection methodologies the X181-NR provides a significant cost-savings to the farmer. Many variables illustrate this point, such as operational and initial costs. In a four square mile field, the eBee and traditional detection methods both take five hours to complete the detection, while the X181-NR takes 47.6 minutes. For the eBee and traditional methodology, the operational Pilot of and Agricultural Specialist are each paid $35 per hour to complete the detection, so the labor cost is $175, whereas the X181-NR only charges $35 for the operation personnel for one hour. The cost to charge the batteries of the eBee is an additional $4.10, and the real time data analysis costs $1,500. The ten samples that the traditional method uses are available after 72 hours of being sent to the lab, but only costs $300 to be completed. In contrast, the X181-NR’s open-source software ensures that results are given instantaneously and gratis. Moreover, the initial cost of the eBee is $10,490, while the manual system does not require that this cost be paid off. Assuming that forty detections are completed a year, the operational costs related to using the eBee is $69,262. Forty uses of the Agricultural Specialist and data analysis method costs $19,000. The use of the X181-NR costs $6,501 for forty detections. Thus, compared to the eBee, the X181-NR saves $62,761 and compared to the traditional method it saves $12,499.

The X181-NR is able to apply pesticides for a considerable cost savings for the farmer compared to the MG-1. Much of the monetary savings that the X181-NR allows for comes from its ability to reduce the amount of time needed to complete the spraying mission. Whereas the MG-1 requires three whole days to apply pesticide to a field, the X181-NR can complete the same mission in one hour. Because of this, the manpower requirements for the X181-NR are drastically reduced. The X181-NR is able to do this because of its increased capacity to carry pesticides; that is, it does not need to refill its tanks as many times as the MG-1. Because of this, the MG-1 costs the farmer $32,500 in spraying for pests but only yields a 12% profit for the operator (note that this is not reflected in the table that follows because of the addition of the eBee into the consideration of profit). The X181-NR only costs the farmer $4,242 to detect and remove pests and yields the company a 58% profit. Therefore, the X181-NR produces an additional 46% in profit margin for a fraction of the value of the field.

The following table compares the capabilities of the X181-NR to treat (detect and remove pests) a field. In order to conduct of comparison between the capabilities of the X181-NR to do this full treatment and the other two UAS, the MG-1 and eBee were combined into one "system" that could detect and remove pests from a field.

Aircraft/System	Value of Field	Treatment Cost	Treatment Percent of Field Value	Raw Value of Operator Profit	Percent Operator Profit
DJI Agras MG-1 and SenseFly eBee SQ (combined)	$99,329	$34,874	35%	$3,470.88	10%
X181-NR	$99,329	$4,242	10%	$5,758.00	58%

Table 15: Comparison of the Two Systems

Ultimately, the X181-NR is a cost effective way for farmers to boost crop yield and protect their investments in their farm. The aircraft's ability to transport large payloads is the primary reason that it can operate efficiently on the farm. Ultimately, this allows the number of trips that need to be taken by the aircraft to be mitigated, which reduces operating costs. Even though the initial cost of the X181-NR is comparable to other precision agriculture UAS, the X181-NR is able to operate more efficiently on a day to day basis. The aircraft's wing not only facilitates a substantial payload, but also allows the aircraft to use a gasoline combustion engine and carry its fuel during flight. This helps to increase the aircraft's endurance significantly. As a result of the focus on reducing flight time, boosting endurance, and reducing operating costs, the X181-NR acts both a cost-effective aircraft for the farmer and provides its operator with a substantial profit.

5. Conclusion

The design solution, the X181-NR, a single combustion engine, fixed wing aircraft with a carbon fiber fuselage and wing, presents an effective low-cost alternative to other conventional spraying vehicles such as the DJI-Agras MG-1. The versatility of this aircraft allows it to be operated profitably at most any field size, through an optimal field size of 4,200 square acres was determined based on the time it can accrue revenue working on fields of that size. Nonetheless, the aircraft fits in a market that is occupied by both small and large farmers, and the relatively low initial cost of the X181-NR make its costs closely proportional to field size. Furthermore, the decision to use modularity to accommodate the need to carry out cornfield billbug infestation detection within the same aircraft ultimately results in a system that is both affordable for farmers and profitable for the system operator. The importance of the

X181-NR becomes even more relevant when considering how through its use it can ensure the long-term viability of agriculture for the needs of a continually growing world population. By maximizing airframe efficiency, optimizing field size, and reducing costs for farmers, the X181-NR helps protect a crop that is both vital to the American economy and to the future of the whole world.

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