FY17 RWDC State Unmanned Aircraft System (UAS) Challenge: Farmer's Companion

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Team Name: Andover Blueprints

Team Member:	*Age:*	*Grade:*
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All team members have filled out the surveys.
The team's objective function is: 0.7644.

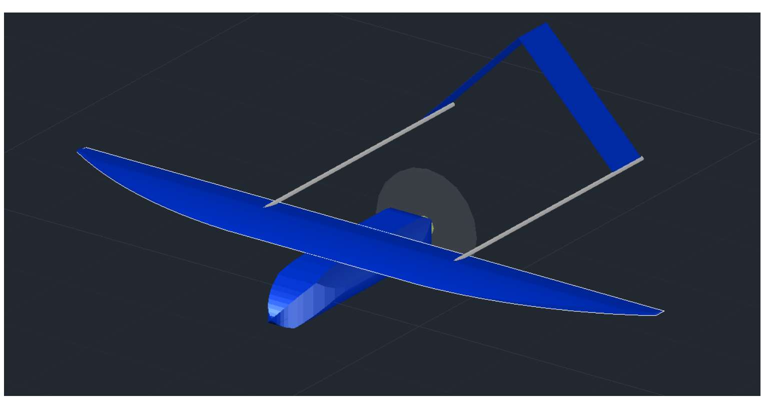


Figure 1: Final Design

Contents

List of Figures

List of Tables

Abstract

With an estimated additional two billion people on Earth by 2050, a food crisis is bound to emerge. As proposed in the FY17 Real World Design Challenge, the team has taken on the task of designing an unmanned aircraft system that can utilize current technology to be a multipurpose tool for farmers. This document presents a solution to the logistics, survey, and dash missions, along with providing the design of a multiuse UAS. The Andover Blueprints focused on three aspects of the challenge: payload, endurance, and speed. The logistics, survey, and dash missions test these aspects of the aircraft respectively. Thus, the team learned that maximizing each of these values produces the strongest solution. During the challenge, the Andover Blueprints created an ideal solution for the New England area and focused on two common food producing crops: corn and potatoes.

The team's research suggests that the strongest candidate for a multiuse UAS airframe is a fixed wing pusher plane called the Aerohawk. When equipped with a 55CC gas engine, the aircraft is capable of executing each mission with the highest degree of definitude and precision, while offering the variability required for the additional commercial and agricultural applications.

The designs of the Andover Blueprints' logistics, survey, and dash missions are briefly summarized in the following sentences. The UAV flies one mile under autopilot with an un-assembled 14.5 lb pest trap, 0.5 lbs of fuel, and five lbs of tools and returns with the five lbs of tools, 0.4 lbs of fuel, and 14.6 lbs of infested crops and soil samples in a detachable cargo hold to complete the logistics mission. To execute the survey mission, the plane flies for 210 minutes covering 5.5 square miles, while filming with a 1080p60 action camera and scanning for crop health with the Sequoia multispectral sensor. Finally, the dash mission involves the UAV flying 1.5 miles and back while utilizing the Sequoia sensor to scan for irrigational integrity.

The additional agricultural missions include scanning for moisture detection, infestation detection, creation of VRA and reflectance maps, biomass detection, and more. All follow a similar layout to the survey mission and carry the same payload. The additional commercial applications include pollution monitoring, structural scanning, monitoring of electrical lines and oil pipelines, and more. The team's UAS is an extremely versatile and multiuse device; thus, farmers or other customers have an increased incentive to purchase it.

The Sequoia sensor is an advanced multispectral sensor built by Parrot and MicaSense. Following a scanning mission conducted by the UAV, the raw data for the cameras and sensors is sent to the Andover Blueprints' corporate headquarters. There, professionals analyze the readings and convert it to useful data and suggestions for a farmer as part of a monthly subscription service. The system is sold with an insurance plan that allows farmers to return the UAS for a nominal fee, after which the system is quickly fixed and returned. The UAS is designed as a package to be a full, complete, and cost effective tool for the farmer.

Chapter 1

Team Engagement

1.1 Team Formation and Project Operation

Right from the beginning, there was a lot of thought and consideration as to who should be on the 2016-2017 RWDC Andover Team. The first step was recruiting members with varying skill levels in STEM. As a team of six people, the team was able to maximize everyone's skill levels by assigning roles for us all. Since this was a very detailed and comprehensive project, it took different types of people and their personalities. By doing this, the team knew that it would be successful. This is even true in the real world. In terms of leadership, Kunal took the role of general project manager, and he worked to help coordinate this project from start to finish. Kunal had previous experience in STEM from First Lego League (FLL), various summer camps, and leadership experience from leading other STEM projects before. Alex had experience in flying RC drones, various summer camps, and robotics competitions. Vishvesh (Vish) had experience flying drones and in robotics and using simulators and RC drones. Alex and Vish took on the roles of technological and design managers for the entire project and lead the creation of missions and the selection of system components to make the UAS function in a real life situation. With Alex's and Vish's knowledge, the team was able to identify the purpose of each of the three minimum-requirement missions (logistics, dash, and survey) and the expected payloads for each of those missions. The team used their knowledge to help determine the sensors, C3 equipment, and support equipment needed, not only for the three minimum-requirement missions, but also for the additional missions developed. Ruide (also written as Reader) brought his experience in flying drones and RC models, as well as his 3D modeling knowledge, to the team. As a result, he helped in a variety of tasks, including designing and creating both the UAV and flight plans, performing all of the analysis necessary for the UAV, and assisting Alex and Vish with the development of missions. Ruide and Alex also worked together to develop the 3D CAD models of the UAV and cargo hold. Steve was really interested in the business aspect of the challenge, so he helped the team with creating business plans for the missions, figuring out a strategy to make the most profit, and marketing. Sebastian had prior experience in a competition very similar to RWDC, called The Tech Challenge, so he knew what the engineering notebook should contain. Thus, he helped the team compile everything in this engineering notebook. He also made sure that any key ideas, notes, and analysis from the meetings were documented in this.

1.2 Acquiring and Engaging Mentors

The team primarily contacted and worked with four mentors, Sebastian's uncle, a fellow student, a patent lawyer from Covington and Burling, and Vish's grandfather. Although the team contacted Mr. Jeff Coppola with questions regarding the rules, Sebastian's uncle provided us with a significant amount of information concerning farming. Mr. Frankel works a variety of jobs, but he has experience raising livestock and working on a farm. Recently, he raised a large flock of sheep on a ranch in Napa, California. This made him an excellent resource when the team researched the options for the dash mission.

A fellow Phillips Academy student provided the team with valuable information on agriculture and livestock. Mr. Eli Newell is employed on a small farm during breaks and the summer. His experience in agriculture came to the team's attention as he began to push for a more aggressive farming program at Phillips Academy. The team then worked to leverage his knowledge throughout the challenge process. He manages the finances and taxes and works in the fields on a daily basis when not attending school. Therefore, he was able to offer the team key information on developing the logistics, dash, survey, and additional missions. Mr. Newell has been an employee of this farm for many years; thus, he helped narrow the options significantly by pointing out key flaws in many ideas. His experience in agriculture offered the team with insight into how to develop missions that would truly benefit the farmer and provided increased value to the UAS.

Sebastian's father works at a law firm called Covington and Burling, and he was able to contact a colleague, so the team could discuss patent law and the process and requirements for filing a patent. The lawyer, Mr. Winslow Taub, provided the team with pro bono assistance and helped the team understand patents, so the team could properly explain the plan to patent the design, including the process of submitting specifications and claims. This allowed the team to construct an accurate and effective patent section.

Vish's grandfather, Dr. Omkar Nath Dhar, is an agricultural consultant and farmer in India. He provided valuable insight into the needs of farmers and gave the team an idea of different ways that a company would be most efficient in helping a farmer. Dr. Dhar also helped the team understand how a farmer deals with infestation and why pest traps are so important to them.

In addition to these agricultural mentors, the team contacted farms in Massachusetts by phone to ask them a few questions and then went to visit Smolak Farms in North Andover. Smolak Farms is only a few minutes away from the school campus. When on the phone with different farmers and in person with a farmer from Smolak, the team asked them about what they would like to see in an agricultural UAV and whether they would buy our service for a given price. The team gained valuable information for the dash mission and other aspects of the drone's design and how the Andover Blueprints should run its business.

1.3 State the Project Goal

Many companies have recently started to experiment with UASs, given the potential applications that these vehicles can provide. Considering the uncountable uses of a UAS for a farmer, a drone must be designed with various "missions" in mind, and not just one use.

Due to the upcoming possibility of serious food shortages as population increases, a drone that provides farmers with solutions to many of their simple issues is essential. In order to clarify the variety of uses for a farm based UAS, as said in the challenge document, three categories are created: the logistics mission, the survey mission, and the dash mission. The logistics mission is about transferring a package eight pounds or heavier over a distance of one mile and then back. This allows a farmer to transport things like pest traps to specific areas of the field. The survey mission is about surveying an area greater than or equal to 0.25 miles. This allows a farmer to scan plants in a field for things like crop health. Finally, the dash mission is about traveling a distance of 1.5 miles at the fastest speed. This allows farmers to do things like determining the status of irrigation systems in the field. Furthermore, the UAS is to be capable of completing additional agricultural missions, to assist the farmer. Example additional agricultural missions include determining the moisture content of the crops, monitoring irrigation, biomass, infestation, and more. Finally, the system should have additional commercial applications, such as monitoring and assisting in oil spills, ground and water pollution containment, and more. As said in the challenge document, the objective function is a mathematical way to quantify the effectiveness of the solution.

$$Maximize\left\{mean\left\{\begin{array}{c} f_1 = \dfrac{W_p^2}{W_p^2 + 64} \\ f_2 = \dfrac{T_f}{T_f + 30} \\ f_3 = \dfrac{V_c^{0.5}}{87^{0.5}} \\ f_4 = \dfrac{N_m^{1.5}}{N_m^{1.5} + 3^{1.5}} \\ f_5 = \left(\dfrac{TR_{Year5} - E_{Year5}}{TR_{Year5}}\right) \end{array}\right\}\right\}$$

Figure 2: Objective Function

The team had to be able to design an unmanned aerial system that can demonstrate an efficient way to complete each of the logistics, survey, and dash missions. The logistics mission ($\frac{W_p^2}{W_p^2+64}$) allowed us to quantify how effective the total payload weight was. The team needed to show that the heaviest possible payload weight was used for the payload. Thus, the objective was to maximize the value of W_p, which is the payload weight for the logistics mission. While developing the logistics mission, the team calculated that once a payload of 20 lbs is reached, the objective function does not increase by much. Thus, the team decided to set a goal of 20 lbs for payload weight. The significance of this is to show that the UAV can handle heavy payloads without a detrimental change in performance.

The survey mission ($\frac{T_f}{T_f+30}$) allowed the group to quantify the endurance of the UAV. The team needed to show that the UAV with the largest endurance was used. Thus, the objective was to maximize the value of T_f, which is the time aloft for the survey mission. Since endurance is calculated based on how much fuel is onboard, the team decided to calculate the maximum possible fuel weight to get the highest endurance. To do this, the team took the maximum possible payload weight (because of the FAA restrictions, it must be 55 lbs), subtracted all of the weights of the necessary equipment needed onboard, and then calculated the remaining space for fuel. However, the team discovered that the remaining space for fuel was not enough to fit all the fuel. Thus, the team had calculated the maximum possible endurance of the UAV by filling the payload space with fuel. The significance of this mission is to show that the UAV can stay in flight for a considerable amount of time, in case of mid-flight emergencies during a particular mission, or if a farmer wants to check an additional thing while the UAV is in flight.

The dash mission ($\frac{V_c^{0.5}}{87^{0.5}}$) allowed us to quantify the speed of the UAV. The team needed to show that the UAV could go at the fastest speed. In this challenge, the maximum speed was set at 87 knots due to FAA regulations. Therefore, the objective was to have V_C, which is the cruise velocity for the dash mission, equal 87 knots. While searching for UAVs, the team discovered several with maximum speeds near or over 87 knots. Thus, the team focused on the previous two variables mentioned. Once the previous two variables were achieved, the team selected a UAV with a maximum cruising velocity of at least 87 knots. The significance of this mission is to show that the UAV can perform its missions quickly and efficiently.

The additional missions ($\frac{N_m^{1.5}}{N_m^{1.5}+3^{1.5}}$) allowed us to showcase the unique missions that the UAV could perform. The team needed to show that the team's UAV could perform multiple distinct missions. Therefore, the objective was to maximize the value of N_m, the number of unique missions developed. The team searched the Internet for present-day uses for drones and found several articles that listed many distinct uses. Then, the team debated whether each use was possible with the team's UAV and came up with a lengthy list of approved uses. The significance of this is for the UAV to be able to be deployed for a diverse portfolio of missions, thus showing that the team's UAV is a multipurpose tool suitable for actual customers in the market.

Maximizing business profitability ($\frac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}$) had the team minimize operational expenses to increase the team's overall profitability. The variable, TR_{Year5} , represents the total income received from running the business over a 5-year period, and the variable, E_{Year5} , represents the operating expense over a 5-year period. All of this was done by carefully selecting operational personnel and consumables and choosing an appropriate selling cost that was competitive in the market. The significance of this is to show that the team's UAV can help create a viable business and to demonstrate that the UAV is competitive in the market.

Ideally, the solution should reach an objective function approaching one. The team's solution is 0.7644.

1.4 Tool Set-up / Learning / Validation

Right from the beginning of the competition, the team decided to use Google Drive instead of Windchill because Google Drive made it easier for everyone to collaborate and share things with one another, and everyone was familiar with Google Drive. Also, the members lived in different time zones in and outside the US, and it was very difficult to communicate with one another during the school vacations. As a result, a Skype group was created, so that the team could hold Skype calls to continue working on the challenge. This is also when Google Drive became handy as the group was able to upload the files that anyone created and they could be accessed anytime and anywhere. Google Drive was also useful because multiple people could be on the same document at the same time.

Another challenge that the team had to face was learning the CAD modeling program. Rather than designing the 3D CAD model in Creo, the team decided to design it in AutoCAD 2014 since it offers more functions and it is more convenient. Also, AutoCAD 2014 was available for both Mac and Windows, whereas PTC Creo was only available for Windows. Since all of the team's members have Macs, the team members were able to share design ideas among each other instead of using the only Windows computer in the library, while the team's meetings were being held in the science center. Despite these challenges, the team worked together to overcome and persevere.

1.5 Impact on STEM

RWDC has taught the team that STEM requires a lot of thinking, brainstorming, and communication. Engineering requires collaboration, experience, and hard work in order to create a final product. At the beginning, the team jumped right into the research and started brainstorming designs, but the team did not have a clear plan to complete the challenge. As the group advanced in the challenge, answering one question lead to another, so the team started making more decisions and eventually finalized a design.

Each of the team's members has now found new passions in STEM that they had not had before, thanks to RWDC. RWDC has shown Kunal the complexity of the engineering process, and the numerous factors and steps needed to make even the simplest of decisions. Alex has experienced the intricacy of an engineering project specifically in the brainstorming, planning, and research processes. Vish learned how to prioritize equipment on drones, and this has given him an appreciation for each piece of C3 equipment. Vish and Alex have also gained a new understanding of the way the design process works, and how science, technology, engineering, and mathematics work together to make it thrive. Through the RWDC design process, Ruide realized the dependency of different design factors on each other and that these factors must be prioritized in order to reach a decision. He also learned that nothing in engineering is about solo work. One person cannot finish a project of this magnitude by himself or herself, and multiple viewpoints bring diverse opinions to an often better final product. Steve learned that there are multiple aspects to a business case that he did not know about before. Sebastian learned that it is important to establish strong connections with each member of the group in order to create a very strong final journal.

While looking for team members for the club, Kunal, Vish, Ruide, and Alex participated in Phillips Academy's biannual club rally. Using colorful posters depicting pictures of UAVs and CAD models on the RWDC website and online, along with their own shouts and yells, they were able to entice many students to sign up for the club. As each person approached the table, the members briefly introduced them to field of engineering and the competition. Although, in the end, the team was unable to take all of those people for the team due to the RWDC limitations, but the team's participation in the club rally brought the RWDC club, and also the field of engineering, into the minds of much of the school's population.

Chapter 2

Document the System Design

2.1 Mission Design

The following table was created to organize the basics of the minimum requirement missions.

	Logistics	Survey	Dash
Payload	To Location: 1 pest trap, tools, and fuel Back: Soil samples, infested crops, tools, and fuel	Sequoia sensor, Sequoia Gimbal, Wi-Fi Sports Action Camera, and fuel	Sequoia sensor, Sequoia Gimbal, and fuel
Purpose of Mission	To transport a pest trap	To measure crop health so that the farmer can scan for crop health	To determine if irrigation equipment is functioning correctly
General Flight Plan	1 mile and back	Survey 5.5 square miles (22 0.25 square mile fields)	1.5 miles and back

Table 1: Basics of the Logistics, Survey, and Dash Missions

All of the missions utilize the same drone, the Aerohawk, which has an empty weight of 33.07 lbs and a payload capacity of 30.86 lbs. Thus, a maximum of 21.92 lbs of payload can be utilized to comply with the FAA's drone regulation of a maximum takeoff weight of less than 55 lbs. This large capacity for the UAV provides more usefulness and an increased incentive to purchase it.

The team decided that an autonomous system would be implemented for all missions, using an autopilot. However, according to federal drone regulations, a pilot must always be behind the controls. The autopilot has full control of the UAV from takeoff to landing, although a farmer can transfer control from the autopilot system to manual in case of an emergency. Therefore, farmers do not have to intensely focus on piloting an aircraft for a significant amount of time and can just sit behind the controls.

Pests and invasive species that destroy crops are a common issue in the farming industry. Recognizing this, the Andover Blueprints worked to offer farmers a UAV that could help solve insect problems on the example logistics mission. A pest trap can be quickly delivered to farm workers one mile away if a pest "hotspot" is found in the field. This will be done with a drone flying one mile at 50 feet and 50 knots delivering the large pest trap (14.54 lbs), tools to set it up (5 lbs), and fuel (0.46 lbs). The system will then return with infested crops and soil samples (14.6 lbs) for analysis, along with the tools (5 lbs) and the remaining fuel (0.4 lbs). The team therefore has a total of 20 lbs and does not use the remaining 1.92 lbs available. This is because the team realized that farmers may want to add an additional thing last second. The drone completes the logistics mission in 2.1 minutes, thus quickly and efficiently supplying teams in the field with the pest traps and tools they need to properly treat the plants. The infested crops and soil samples, often full of small living bugs and biotic creatures, can also be quickly returned to the center of the farm for analysis. This will allow farmers to treat their fields properly with pest control devices and increase yield with precise amounts of pesticide.

For the example survey and dash missions, the same Sequoia sensor will be used. For the survey mission specifically, the previously mentioned Sequoia sensor (0.24 lbs), a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs), and a Wi-Fi Sports Action Camera (0.34 lbs) were chosen as the gear needed, for a total of 14.7 lbs. The Sequoia sensor is an advanced agricultural sensor designed and built by Parrot. The device is capable of identifying problem areas in a field, detecting symptoms of nutrient deficiencies to refine fertilization, estimate crop yield, control crop irrigation, and detect biotic stress. At 0.24 lbs, it is unbelievably light, yet also offers a sunlight sensor, which logs current lighting conditions to refine and calibrate other measurements from the system. The Wi-Fi Sports Action Camera is a GoPro type camera, purchased directly online for an ideal price. It records at 16MP and shoots 60 frames per second at 1080 by 1920 pixels with a 170° wide angle lens. The camera is housed in a waterproof and dust-proof case and Wi-Fi enabled, like the Sequoia sensor, so the information from a flight can be downloaded for analysis with ease.

The objective of the example survey mission, as stated in the table above, is to measure crop health, so a farmer is able to determine how to treat their crops. This example mission will be conducted over the course of 210 minutes, or 3.5 hours. The UAV is capable of extensive flights to maximize data collection. When the UAV is flown over the field, the Sequoia sensor is deployed to scan for crop health by detecting multiple telltale signs of unhealthy crops, including symptoms of nutrient deficiencies and biotic stress. A snakelike flight plan was designed, so the UAV will fly across 0.5 mi x 0.5 mi fields, making turns with 162.849 foot radii[1] while scanning the crops. This turn radius maximizes the area covered, because it ensures that area scanned by the Sequoia sensor will not be re-scanned when the plane returns. Flying at 50 knots with 13.23 lbs fuel at a height of 230 feet, 22 fields can be scanned (for a total of 5.5 square miles). The plane burns approximately 0.06 lbs of fuel per mile covered, so after covering the 5.5 square miles, the plane will have about 0.12 lbs of fuel remaining, which can be used for takeoff and landing and in case of emergencies.

In the example dash mission, the payload consists of fuel (1.36 lbs), the Sequoia Sensor (0.24 lbs), and a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs) to balance and attach the sensor, for a total payload weight of exactly 2 lbs. In this instance, the Sequoia sensor is employed to determine if irrigation equipment is functioning properly. The sensor is able to identify places where water stress is suspected, along with areas with excessive moisture content in the soil, so the farmer can head out into the field to adjust or fix their equipment. The UAV will fly out for 1.5 miles at 87 knots at 230 feet. When flown 1.5 miles, 0.09 square miles are scanned. Irrigation pipes travel along specific areas of a field, so this scan provides significant information to determine their status. Because of the high speed at which this mission is conducted, it only takes 1.91 minutes to complete. These scans prevent a pipe from bursting, save significant amounts of water, and also prevent the over watering of plants, thus increasing yield and maximizing savings.

The team designed ten additional agricultural missions, all of which fly at 230 feet and 87 knots to minimize time and maximize the quality of the scans. The optimal altitude for the Sequoia is 230 feet and 87 knots is the max speed. The Sequoia sensor, the Wi-Fi Action

[1]Section 2.7 explains the derivation of this

Sports Camera (WASC), the 2 Axis Parrot Stabilized Gimbal, and fuel make up the total payload, for a total of 14.7 lbs. The farmer uses the survey mission flight plan to increase scanning power. Each mission utilizes 13.23 lbs of fuel so the farmer can scan for up 3.5 hours. Up to 5.5 square miles can be thoroughly covered, depending on a farmer's preference. Details of how each mission assists the farmer are as follows:

Mission	**Payload**	**Purpose of Mission**	**General Flight Plan**
Moisture Detection	Sequoia sensor, Parrot gimbal, WASC, and fuel	To determine the moisture content of the crops	Snake-like pattern
Infestation Detection	Sequoia sensor, Parrot gimbal, WASC, and fuel	To find any crops that have been infested	Snake-like pattern
Weeds Detection	Sequoia sensor, Parrot gimbal, WASC, and fuel	To detect any weeds growing within the crops	Snake-like pattern
Creating VRA Maps	Sequoia sensor, Parrot gimbal, WASC, and fuel	To determine the strength of nutrient uptake in a single field	Snake-like pattern
Time-Series Animation	Sequoia sensor, Parrot gimbal, WASC, and fuel	To take multispectral images in a single field	Snake-like pattern
Creating Reflectance Maps	Sequoia sensor, Parrot gimbal, WASC, and fuel	To create a map that would help the farmer with increasing yields	Snake-like pattern
Biomass Detection	Sequoia sensor, Parrot gimbal, WASC, and fuel	To find biomass in crop residues in order to produce energy	Snake-like pattern
Harvest Yield Estimation	Sequoia sensor, Parrot gimbal, WASC, and fuel	Count plants and size/number of product to predict income for that season	Snake-like pattern
Scouting Fertile Land	Sequoia sensor, Parrot gimbal, WASC, and fuel	To find fertile land	Snake-like pattern
Livestock Monitoring	Sequoia sensor, Parrot gimbal, WASC, and fuel	To track the livestock in a field	Snake-like pattern

Table 2: Basics of the Additional Missions

Mission	**Explanation of Assistance**
Moisture Detection	Allows farmer to adjust irrigation practices to cater to plants needs, thus increasing yield
Infestation Detection	Identifies pest "hotspots" so they can be dealt with, thus increasing yield
Harvest Yield Estimation	Allows farmers to estimate labor and time need when it's time to harvest crops
Creating VRA Maps	Allows farmers to recognize unhealthy plants so they can treat individually to increase yield
Time-Series Animation	Shows farmers ongoing trends so they can adjust their farming practices to increase yield
Creating Reflectance Maps	Allows farmers to understand current trends to adjust current farming practices
Biomass detection	Reduces disposal costs, pollution, increases energy independence, and "eco-friendliness"
Scouting Fertile Land	Allows farmers to expand effectively onto fertile land to maximize yield
Livestock Monitoring	Allows farmers to recognize and track current livestock to keep track of them
Weed Detection	The detection of weeds prior to harvest prevents damaging invasions from increasing in size

Table 3: Explanation of Assistance for Additional Missions

2.2 Conceptual, Preliminary, and Detailed Design

To design this drone, a clear plan for research and analysis was needed. Also, being a team effort, communication was critical to understand the collective mindset towards the design process. So, the team first created a strategy for how to attack the challenge, then established means of communication through Skype, Google Docs, and group chats. This system not only allowed decisions to be made efficiently, but also allowed research to be shared quickly, which in turn aided the design process.

In the first two weeks, the team started considering which airframe to use, which crop to chose, and what payloads would be useful for a farmer. The first step was to analyze the challenge. The team read over the rules and the detailed background and then summarized these documents. At every weekly meeting, the team collectively went over these documents again, so that everyone was on the same page about each of the missions. Then, each person was assigned a task, such as analyzing the objective function to see what factor was most important for each mission, comparing airframes to find the most well-rounded one, or finding a useful payload for each mission.

2.2.1 Engineering Design Process

In order to solve a problem or create a novel product, engineers and designers use the engineering design process. Though the process can vary depending on the industry, commercial application, or the invested capital, the team stuck to the basic engineering process as follows:

1. Define the Problem
2. Do Background Research
3. Brainstorm Solutions
4. Select the Best Solution
5. Develop the Idea
6. Construct a Model (CAD Model / Business Plan)
7. Assess Viability
8. Refine the Design (Redesign)

To define the problem, the team read over the rules and detailed background, and identified the minimum requirements and any important regulations. Also, the logistics, survey, and dash missions were summarized so that everyone had a comprehensive understanding as to what each mission's goal was. Then, background research was done to identify crops in the area and find payloads that are the most beneficial for a farmer. The team took this research and began brainstorming solutions for each mission. Once a sizable list of potential resolutions was created, each one was scrutinized and evaluated. In this process of narrowing down solutions, the team first tackled the issue of payload. With each main mission having a different minimum payload, individualized solutions for each mission were selected, rather than one payload that satisfies all missions. This decision gives farmers variability and allows them to be resourceful by using one drone for many different applications. The final payload decisions were:[2]

- Logistics Mission: Pest Traps, Tools, Crop Samples, Soil Samples, and Fuel
- Survey Mission: Sequoia Sensor, Sequoia Gimbal, HD Camera, and Fuel
- Dash Mission: Sequoia Sensor, Sequoia Gimbal, and Fuel

While choosing payloads, the team also gauged their value to the farmer in order to make sure that they were efficient as well as useful.

Next in the process of narrowing down solutions, the team addressed the UAV's airframe. Because of the need to satisfy the logistics, survey, and dash missions as well as have the flexibility for additional applications, the airframe had to maximize on three things: speed, flight time, and payload capacity. These three considerations were extremely important for the UAV, so much time was spent mathematically analyzing the objective function to find their maxima and minima. Once the team understood the baseline speeds, flight times, and payloads that needed to be reached, an airframe was found that matched that criterion.

[2] Sections 3.1, 3.2, and 3.3 give details about the reasons for each payload

After developing the idea a little more, the Andover Blueprints continued on to create a CAD model, so the team could physically see the concepts that were being visualized. Even more importantly, the business model was then discussed and created around the team's vision (Chapter 4 elaborates). This was the phase of the engineering design process where the team finally had a comprehensive view of the product and business.

With this in-depth perspective, the team took a step back from the details to assess the viability of solutions as a whole. Each mission was once again reviewed and then the whole team scrutinized the solutions.

Throughout the whole engineering design process, almost all decisions, solutions, calculations, etc. were reconsidered and revised. This iterative process is why engineering is such a great method to design and create something. If a decision doesn't satisfy the team: reconsider all the options! If a solution seems feeble and hollow: redesign! If the business is not viable in the market: rethink and redesign! Because this UAS went through much iteration as such, the team is confident in its integrity and ability.

2.2.2 Conceptual Design

After identifying all the restrictions the aircraft had, both legal and those imposed by RWDC, the team still had enumerable possibilities for the design. It was quickly decided that creating an airframe from the ground up would be close to impossible within the time given, so the team researched, examined, and compared countless UAVs from various companies across the world.

Rotorcraft, hybrid, and fixed wing aircraft were considered as designs for the airframe. The pros and cons are shown below:

Considerations	**Rotorcraft**	**Hybrid**	**Fixed Wing**
Speed	Rarely higher than 50 knots	Scattered	Up to 87 knots
Endurance	Very low	Moderate	Extensive
System cost	Moderate ($5000 - $15,000)	Expensive (upwards of $10,000)	Moderate (Most are less than $10,000)
Fuel Efficiency	Very poor	Poor to moderate	Adequate/Very good
Payload Capacity	15 lb maximum	Moderate– less that 20 lbs	Typically high (20 lbs or higher)
Maneuverability	Very good	Good	Poor
Availability	Widely manufactured and available	Rare	Moderate availability

Table 4: Pros and Cons of Rotorcraft, Hybrid, and Fixed Wing Aircraft

Despite lacking maneuverability, a fixed wing aircraft maximizes flight time, payload capacity, and speed. Thus, the team chose to utilize a fixed wing airframe. From there, the Andover Blueprints then had chosen between a pusher and tractor design. The pros and cons are listed below:

	Pros	Cons
Tractor	Propeller receives direct, undisturbed airflow Doesn't require long takeoff and landing space More maneuverability	Slower
Pusher	Extensive endurance High payload capacity and speed	Requires runway Only moderately maneuverable

Table 5: Pros and Cons Tractor and Pusher Designs

A fixed wing pusher design was ultimately chosen as the ideal airframe because it is more energy efficient than an airframe with rotors. Fixed wing pushers are also significantly stronger and more stable than other designs, allowing them to carry enough payloads to execute the operation. The team chose to use a wheeled landing because it is safer, cheaper, and more energy efficient than the other landings (parachute and belly). For example, a parachute landing often fails to prevent expensive airframes from hitting the ground hard, and belly landings can damage a UAV. Additionally, belly and parachute landings can require large and expensive towed launchers.

After the landing mechanism was decided, the propulsion needed to be determined. The team chose a gas engine because of its efficiency and cost. Batteries are heavy, expensive, and can take hours to charge, while gas is cheap, offers much longer range and flight time, and can be refueled in an instant. Thus, a gas engine was an obvious choice.

After determining the above, the conceptual designs were picked out. The conceptual designs were influenced by:

- Payload capacity (the aircraft has to be able to carry the chosen sensor and payload)
- Endurance time (the aircraft must finish its missions)
- Cruise speed (this affects the turning radius of the aircraft, which in turn affects the flight plan)
- Cost (aircraft should be cost-efficient to ensure wider distribution, which increases the business profitability)
- Weight (this affects the bank angle of the aircraft, which in turn affects the turning radius, and reduces the airframe efficiency)
- Landing method (the aircraft should be reusable, so it needs a safe landing)
- Takeoff method (affects the time of the operation)
- Regulation (the aircraft should meet all FAA drone regulations)

Seven designs were ultimately considered. Specifications and images are shown below:

Consideration 1: Theia Operational UAS[3]

[3]http://www.threod.com/products/uas-theia/theia-description

Figure 3: Theia Operational UAS Image

Payload	55.12 lbs
Weight	110.24 lbs
Cost	N/A
Speed	48.59 knots min, 81.00 knots max
Endurance	Up to 24 hours
Engine	4-stroke 110cc fuel injected gasoline engine
Takeoff/Landing	Wheel/Wheel

Table 6: Theia Operational UAS Specifications

Consideration 2: UAV Strix[4]

[4] http://www.aerodreams-uav.com/es-uav-strix.html

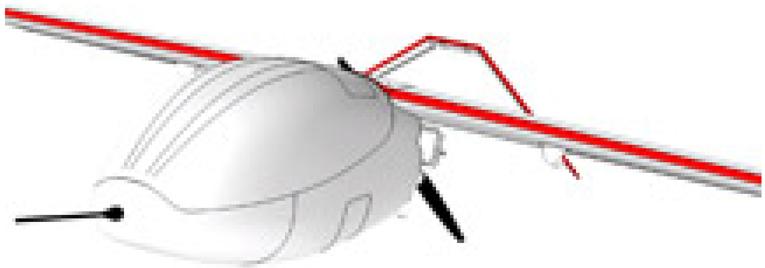


Figure 4: Strix UAV Image

Payload	39.7 lbs
Weight	66.1 lbs
Cost	N/A
Speed	86.39 knots
Endurance	15+ hours
Engine	10 HP, 100 CC, 2T Electronic Injection
Takeoff/Landing	Launched by hand via moving car or pneumatic platform/manual

Table 7: UAV Strix Specifications

Consideration 3: HAVOC[5]

Figure 5: HAVOC Image

[5]http://www.brocktekus.com/havoc

Payload	45 lbs
Weight	84 lbs
Cost	N/A
Speed	102.54 knots
Endurance	18 hours
Engine	N/A
Takeoff/Landing	Manual or auto rolling/Manual or auto rolling

Table 8: HAVOC Specifications

Consideration 4: SPEAR[6]

Figure 6: SPEAR Image

Payload	10 lbs
Weight	21 lbs
Cost	N/A
Speed	64.00 knots
Endurance	2.8 hours ICE, 1 hour electric
Engine	Basic internal combustion engine preferred over electric
Takeoff/Landing	Manual/Belly skid

Table 9: SPEAR Specifications

Consideration 5: BOREAL[7]

[6]http://www.brocktekus.com/spear
[7]http://www.xamen.fr/index.php/fr/produits/boreal.html

Figure 7: BOREAL Image

Payload	11 lbs
Weight	55 lb MTOW
Cost	N/A
Speed	97.33 knots
Endurance	10 hours
Engine	100W, 12V regulated electric power supply
Takeoff/Landing	Automatic take off, RTK aided landing, or full manual control

Table 10: BOREAL Specifications

Consideration 6: InSitu Group Scaneagle A-15[8]

[8]http://www.barnardmicrosystems.com/uav_list/scaneagle.html

Figure 8: InSitu Group Scaneagle A-15 Image

Payload	13.2 (fuel is part of it)
Weight	26.5 lbs
Cost	Less than $100,000
Speed	69.52 knots
Endurance	28 hours
Engine	2.5hp (2kW) single-cylinder, two-stroke 3W-28 gasoline engine
Takeoff/Landing	Company built launcher (towed by truck)/belly landing

Table 11: InSitu Group Scaneagle A-15 Specifications

Consideration 7: Aerohawk[9]

[9] http://www.asiatechdrones.com/_p/prd1/4554854371/product/aerohawk-*-bare-airframe

Figure 9: Aerohawk Image

Payload	33.86 lbs
Weight	33.07 lbs with engine
Cost	$5,200 w/ 55CC gas engine
Speed	87 knots
Endurance	w/ fuel in cargo bay: 4.5 hours | w/o fuel in cargo bay: 3.5 hours
Engine	55CC gas engine
Takeoff/Landing	Wheel/Wheel

Table 12: Aerohawk Specifications

2.2.3 Preliminary Design

The team then created a ranking system that allowed us to quantitatively evaluate each airframe. The ranking system evaluated each airframe for the following categories: maximum payload, empty weight, cost, and endurance. Here is the ranking system:

Name of UAV	**Max Payload (lb)**	**Empty Weight (lb)**	**Cost ($)**	**Max Speed (knots)**	**Endurance (hr)**
Theia Operational UAS	55 lbs	110 lbs	n/a	81 knots	24 hrs
UAV Strix	39 lbs	66 lbs	n/a	86 knots	15 hrs
HAVOC	45 lbs	84 lbs	n/a	103 knots	18 hrs
SPEAR	10 lbs	21 lbs	n/a	50 knots	Electric: 1 hr Gas: 2.8 hrs
BOREAL	11 lbs	44 lbs	n/a	100 knots	10 hrs
InSitu Group Scaneagle A-15	13.2 lbs	26.5 lbs	< $100,000	70 knots	15 hrs
Aerohawk	30.86 lbs	33.07 lbs	$5,200	87 knots	10 hrs

Table 13: Comparison of Different UAV Options

While choosing the final design, the team was primarily influenced by each airframe's maximum payload and empty weight. The team first eliminated SPEAR because its max speed was way too low for it to be used in the dash mission and because its endurance was too low for the survey mission. Then, the team eliminated Theia Operational UAS, UAV

Strix, HAVOC, and BOREAL because their empty weights were so high that having a heavy payload weight for the logistics mission would not be realistic or not possible. This left the team between InSitu Group Scaneagle A-15 and the Aerohawk. The team finally selected the Aerohawk due to its higher maximum payload weight and because the max speed of InSitu Group Scaneagle A-15 was not high enough for the dash mission (exactly 87 knots). The Aerohawk also carries a 55CC gas engine, which allows it to stay aloft for an increased period of time. It met all federal drone regulations and was at a reasonable price.

2.2.4 Detailed Design

First, the Andover Blueprints picked the UAV platform to be able to successfully execute the selected missions and be suitable for any additional applications for a real customer in the field. The team looked for fixed wing pusher UAVs and decided to go with a gas engine for increased speed and endurance to satisfy the Andover Blueprints' high performance standards. The team primarily focused on the dash, survey, and logistics missions so the top three priorities while choosing the drone were speed, maximum flight time, and the payload it can carry (volume as well as weight). The group also took into account the price of the UAV to deliver the cheapest possible product to the farmer while retaining the greatest quality specifications. The options given in section 2.2.2 were narrowed down to the InSitu Group Scaneagle A-15 and the Aerohawk by Asia Tech Drones. During the process of choosing a drone, the team looked for the most well rounded, most powerful, and best suited UAV for our applications. The Andover blueprints finally decided to use the Aerohawk because of its high maximum payload weight and because the Scaneagle can not fly fast enough for the dash and additional missions.

The Aerohawk UAV is perfect for the business because it is fast, durable, agile, able to complete long missions, can carry over 30 pounds of payload with our innovative detachable cargo bay, and is cost effective. It can be applied for data collection missions (the primary focus of the Andover Blueprints' business) and transport missions such as the logistics portion of the challenge.

After choosing the Aerohawk, the team calculated the maximum bank angle the aircraft could safely sustain in a turn. Calculating the bank angle (in section 2.7) affected the mount the team later chose and allowed the team to calculate the minimum turning radius of the aircraft. This was essential in determining the most efficient flight plan for a range of application in agriculture and beyond.

Next, the team deliberated over an appropriate sensor (section 2.3.1). In the end, the group chose the Sequoia multispectral sensor from Parrot and MicaSense. This multispectral sensor was appropriate because of its excellent quality is and relatively low cost. It is over $2,000 dollars cheaper than the X5000 sensor, the team's original pick from the detailed background, and includes an irradiance sensor as well as more flexibility in terms of bands of light and lenses. The sensors' specifications are:

Sensor	X5000 Multispectral Sensor	Sequoia Multispectral Sensor
Cost	$5,500	$3,500
Multispectral Sensor Size	2.5 in (width) x 2.5 in (length) x 2.0 in (height)	1.6 in (width) x 2.3 in (length) x 1.2 in (height)
Irradiance Sensor Size	n/a (no irradiance sensor)	1.6 in (width) x 1.9 in (length) x 0.7 in (height)
Weight	1.4 lbs	0.24 lb
Field of View	40° (horizontal) x 20° (vertical)	70.6° (horizontal) x 52.6° (vertical)
Resolution	3.15 MPX	16 MPX
Bands of Light	Green, Red, NiR	Green, Red, Red Edge, NiR, RGB
Maximum Range	500 feet	500 feet

Table 14: X5000 vs Sequoia Sensor Specifications

The group also needed a mount to stabilize the sensor and keep it pointing down when the UAV turns. The team decided to use a 2 Axis Parrot Sequoia Stabilized Gimbal ($60). The team decided to use this cost effective option over a GoPro mount that could be modified to fit the Sequoia sensor. The GoPro mount would require set up and even with the necessary modifications the gimbal would not have perfect integration, thus reducing the quality and consistency of the data gathered. The gimbal that the group chose is specifically designed for the Sequoia sensor and ensures excellent stabilization as well as good pitch and roll limits for the product. Here are the mount's specifications:

Cost	$60
Stabilization	Excellent
Size	3.7 inches (width) x 3.9 inches (length) x 4.0 inches (height)
Weight	0.397 lbs
Roll Limit	45°
Pitch Limit	45°

Table 15: Parrot Sequoia Mount Specifications

Additionally, the team calculated the Sequoia's field of view. These drawings showed that the sensor's horizontal field of view was sufficient to measure 325.698 feet laterally, which is roughly 108 rows of corn (each row being 3 feet). However, to make sure that the detected data is accurate, the solution senses overlapping images.

At an altitude of 230 feet (the ideal altitude for the Sequoia sensor and within FAA regulations), the camera can view 325.698 ft in the x direction:

$$tan(35.3) = \frac{\frac{1}{2}x}{230ft}$$

2.2.5 Lessons Learned

In each design phase, the team learned how to organize its decisions and prioritize factors of the design. Because so many calculations depend on one another (i.e. cruise speed affects turning radius, which affects the flight plan), the team needed to communicate really efficiently. Since the team is based in a boarding school, it was very difficult communicating over the break. Eventually, the team set up several Skype meetings and productively worked together. This design process taught us that collaboration is the key to success.

Conceptual Phase

During the conceptual phase, the team learned that conducting research does not mean clicking and reading links on the first or second pages of a web search and then coming to a conclusion; but rather, conducting research means going to the fourth, fifth, sixth (etc.) pages of a web search and perusing content to extract important information to come up with a logical conclusion. It also means using resources like books, articles, newspapers, scholarly articles, research papers, etc. to gather further information, rather than just relying on web searches. The team found several articles about drones from places such as Business Insider, The Huffington Post, The New York Times, etc. to help us with decision-making. All of this research helped the team consider many different conceptual designs and exhaust all of the options.

Preliminary Phase

During the preliminary phase, the team learned to manage time efficiently. At the beginning of the challenge, the team was taking lots of time to finalize things. To prioritize, the team created a "tasks to do" schedule to figure out what needed to be accomplished each meeting. At the beginning of every meeting, the team projected the schedule on the projector (so that everyone was on the same page) and eliminated each task as it was completed. This helped the team manage its time to maximize the value of each meeting, while not wasting any precious time.

Detailed Phase

During the detailed phase, the team learned that even though certain decisions were agreed upon by all team members, things could still change, depending on the situation. For example, early on, the team agreed on the basics of the three minimum-required missions (logistics, dash, and survey), like the payload and the purpose of the mission. However, as the team progressed and better understood the challenge, the team identified many flaws with the payloads that were originally agreed upon, and so, the payloads were changed, which in turn, changed the purposes of the missions.

2.2.6 Project Plan Updates and Modifications

One of the original things that the team did was assign roles to each member: for example, one person to work on the CAD and design analysis and others to handle the flight plan. At first, the team's research was very disorganized and hard for other team members to understand. The team reorganized the research on Google Drive by sorting it into tables and outlines. In this way, each team member could reference the team's research more quickly. Before the team chose the Aerohawk, the team ran through several designs: the team's first design was the Theia, but its payload was 55 lbs, which is the exact limit specified by the FAA. The team wanted to significantly reduce the payload weight, so the team changed its design to the Spear. However, the payload weight of the Spear was 10 lbs, and after some analysis on the objective function, the team realized that the ideal payload weight would be around 20 lbs. Thus, the team changed its design again to the Aerohawk. During each design phase, the team went through four iterations to develop the best possible UAS.

2.3 Selection of System Components

Selection of the aircraft's components was the most important step in the design process. Deciding what the UAV should do for the customer and choosing the payloads gave the team a distinct idea of which airframe to use. The airframe type was very dependent on the payload; it needed to be able to carry out each mission and had to be extremely adaptable to fit all of the needs the team laid out. When choosing the system components, the team created tables on Google Drive to compare each possible candidate, while keeping price and functionality in mind. The team split into groups to focus on each component and discuss the pros and cons of each decision. Later, the group made sure to review, discuss, and finalize everything together to look at other ideas and really make sure that the product made sense and can serve farmers in real world commercial applications.

2.3.1 Payload Selection

After the team began to conceptualize the logistics, dash, and survey missions, the group began brainstorming effective strategies to let farmers complete each mission.

Logistics Mission

For the logistics portion of the challenge, the team wanted to transport a pest trap as well as tools to a location 1 mile away and return farm materials such as deceased crops, soil samples, old pest traps, and tools. The group decided to transport pest traps after Vish's grandfather mentioned that farmers often have to carry many large pest traps around on their trailers but can't reach remote parts of the field without running over crops or wasting much time and effort. The team originally wanted to use small plastic pest traps, of which the team would have to use over 200, to meet the set payload goal of 20 lbs. This was not possible because of their large volume, so the Andover Blueprints later chose to transport a reusable and commonly used large metal pest trap. Since the UAV cannot hold the pest trap while assembled, it is transported while dissembled. On the return trip of the logistics mission, the team decided to transport infected crops and soil samples to further investigate the infestation and prevent it from spreading and destroying the crop. The tools also have to be transported back, along with any other materials the farm workers desire to add. The next challenge the team had to overcome was how the cargo would be attached to the UAV, so a list of possible solutions was created:

- Attach an additional cargo hold to transport extra fuel and farm materials
- Strap the payload to the bottom of the airframe with bands
- Carry a small payload that fits in the airframe hull
- Attach a rig to drop small pest traps at given intervals throughout the flight

After weighing all of the possibilities, the group ruled out the second option because it would affect the aerodynamics of the UAV and the third option because it would not be able to carry a heavy or large enough payload. The fourth option would introduce a varied payload and would require a complicated pest trap-dropping rig. However, this design could only drop small pest traps that cannot unfold by themselves and later have to be removed by a farm worker. In the end, the team decided to use the first option and design and construct an additional cargo hold that would be included with the UAV. It can easily be attached to the bottom of the Aerohawk with lag screws, which can sustain the weight.[10] This additional cargo hold has maximum dimensions of 30 in (length) x 8.98 in (width) x 5 in (height). Its volume is 1,110.40 in^3.

The team decided to use this payload option because this modular design, with a detachable cargo hold, allows the farmer to switch the UAV from transport mode to sensing mode, depending on if the cargo container is attached and what mission the customer wishes to execute. The cargo hold can be added or removed to the UAV and does not impede the aerodynamics of the aircraft. It is extremely streamline and was specifically designed for the Andover Blueprints' UAV, so it weighs only 0.75 lbs to maximize the amount of material the UAV can carry. This container can hold the entire 20 lb and 235 in^3 pest trap with room to spare. Fuel and extra payload items can also be stored aboard the hull of the aircraft. This solution is much better than the other options.

Survey Mission

For the survey mission, the group decided to monitor overall crop health. This was deemed a useful primary mission because a farmer can execute the survey mission. If the crop efficiency and health is not optimal, customers can perform other applications of the UAV such as monitoring moisture content, weed detection, measuring nutrient levels in the soil, and more. To perform this task, the team narrowed the payload possibilities down to the following categories of sensors and approaches to the problem at hand:

- Indicator Crops
- Monitor Crop Color
- Monitor Growth Rate
- Monitor Amount of Chlorophyll in Leaves
- Thermal Sensor
- Multispectral Sensor
- Hyperspectral Sensor
- Synthetic Aperture Radar
- LiDAR
- CCD/CMOS Camera

[10] http://countryplans.com/smf/index.php?topic=5268.0

To decide what approach to use to detect overall crop health, the team used a rigorous decision making process (which was also employed to choose the sensor for the dash mission). The sensor was selected through many stages of eliminating unfit options, while keeping in mind the other functions of the UAV.

At first, the team considered utilizing an indicator crop as a way to determine the overall health of the useful crop, as it would be the simplest solution to the problem. Soon after, the members realized that this would be a highly unreliable and inaccurate option because the crops would be different and there is no precise correlation between the plants; so it was decided that mounting a sensor or multiple sensors would be a better plan.

The group began by compiling all of the different sensors that had been researched by the team members. By separating the possible sensors into two categories, direct (radar, infrared, thermal) and indirect (cameras), the team members were able to start evaluating and comparing the sensors given in the detailed background.

With CCD/CMOS sensors:

	X250 Sensor	X500 Sensor	X1000 Sensor	X2000 Sensor	X3000 Sensor
Cost	$30	$50	$5,000	$15,000	$17,000
Size (*l* x *w* x *h* in mm)	24 x 18 x 10	22.5 x 11.5 x 8	63.5 x 63.5 x 50.8	102 x 102 x 25.4	127 x 127 x 57.2
Field of View (horizontal x vertical [FOV])	62°x 30°	90°x 80°	40°x 20°	55°x 5.5°	25°x 19°
Resolution (horizontal x vertical [px])	656 x 492	656 x 492	640 x 480	640 x 480	640 x 480
Weight	0.18 oz	0.18 oz	0.5 lb	2.1 lb	3.5 lb
Stabilization	poor	poor	good	excellent	excellent
Zoom	n/a	n/a	n/a	10x	4x continuous zoom IR 3x continuous zoom visual
FOV When Zoomed In	n/a	n/a	n/a	41.25 x 4.125	n/a
Roll Limit	n/a	n/a	30°	80°	85°
Pitch Limit	n/a	n/a	30°	80°	85°

Table 16: Comparison of Sensors With CCD/CMOS

Without CCD/CMOS sensors:

	X4000 Sensor	X5000 Sensor	X6000 Sensor
Cost	$20,000	$5,500	$15,000
Size (*l* x *w* x *h* in mm)	102 x 102 x 25.4	63.5 x 63.5 x 50.8	12.5 x 12.5 x 4.75
Field of View (FOV)	30°x 25°	40°x 20°	40°x 20°
Resolution (px)	640 x 480	2048 x 1536	1280 x 1024
Weight	3 lb	1.4 lb	7 lb
Stabilization	excellent	excellent	excellent
Zoom	8x continuous zoom	n/a	n/a
FOV When Zoomed In	n/a	n/a	n/a
Roll Limit	80°	30°	70°
Pitch Limit	80°	30°	70°

Table 17: Comparison of Sensors Without CCD/CMOS

The Andover Blueprints soon realized that an indirect sensor (CCD/CMOS camera) is not useful because the product has to accurately measure the health of the crop, not just through appearance. A direct sensor is much more suitable to measure plant health because it produces specific data. Thus, the team researched direct sensors specifically. The field of view of each sensor, its accuracy, and its cost were all taken into account in the decision making process.

The team then decided that from the given sensors in the detailed background, the best option is the X5000, due to its great versatility, relatively low price, accuracy, and how well suited it is for the groups needs. Last year, the team used the X5000 multispectral sensor as well, but this year, the team decided to continue to search for a cheaper and more effective sensor to hopefully find a better option.

The team focused on the UAS's sensing capabilities, and after much research, the Sequoia multispectral sensor ($3,500) from Parrot and MicaSense and the 2 axis gimbal for the Sequoia ($60) were chosen for the survey mission. The gimbal allows for a great turning radius with its 45 degree roll and pitch limits. The Sequoia sensor is designed and built for use on agricultural drones. It is cheap, accurate, and versatile. It weighs 0.24 lbs and includes an irradiance and multispectral sensor. The multispectral sensor features four bands: a 1.2 Mpx red camera, a 1.2 Mpx green camera, a 1.2 Mpx near infrared camera, a 1.2 Mpx red edge camera, along with a 16 Mpx RGB reflectance camera. It features a built in 64 gigabyte memory and is Wi-Fi enabled. It also contains a memory card slot to supplement the internal storage in the multispectral sensor. The additional irradiance sensor is mounted on the top of the UAV to collect data on current lighting conditions to refine and recalibrate measurements from the multispectral sensor. It also features an IMU enabled GPS device to geotag sensor readings and track the aircraft's current location. The X5000 does not have any of these additional functions and is much more expensive. In this mission, the Sequoia sensor measures immense amounts of data in the plant leaves and soil remotely by sending various wavelengths of light and measuring reflected light. Based on reflected light, the sensor computes and stores data on all aspects of the crop or object below. This data is uploaded to a computer and the company website, once the UAV lands, and is analyzed by the farmer or trained professional that the company will employ.

Dash Mission

For the dash portion of the challenge, the team decided to monitor a farm's irrigation system. The Andover Blueprints decided to apply the UAV in this way after speaking to actual farmers. The group spoke to a local farmer, who pointed out that farms often have large irrigation systems and pipelines that are hard to oversee and tend to break, rust, leak, and weaken over time in the elements. These irrigation, fertilization, and pesticide distribution systems are essential for the smooth operation of large industrial farms, and a leak can lead to a large loss in money and efficiency of the farm. Without a functioning irrigation system, there is no purpose in a UAV that detects moisture content in a field! To detect leaks or irregularities in a large farm's irrigation system, the UAV can use any of the following sensors:

- Thermal Sensor
- Multispectral Sensor

- Hyperspectral Sensor
- Synthetic Aperture Radar
- LiDAR
- CCD/CMOS Camera

The group followed the same rigorous research, elimination, and comparison plan that was successful in finding a sensor for the survey mission. The team ended up sticking with the Sequoia multispectral sensor by Parrot and MicaSense ($3,500), in conjunction with a 2 axis gimbal for the Sequoia ($60). Because of its versatility, the team employs this sensor and gimbal in all other missions besides logistics. This particular mission can be applied to irrigation, fertilization, and pesticide distribution systems on farms and in many other pipelines in non-agricultural settings.

The Sequoia senses leaks and weak spots in irrigation pipelines with redundancy. The sensor has near infrared, green, red, red-edge, and RGB reflectance lenses to ensure broad and deep data for farmers to utilize and feed to their irrigation, pesticide, or fertilization systems to optimize farm efficiency, while decreasing wasted resources. With this technology, the Sequoia measures the thickness of the metal in the pipeline and its composition (ex: rust or steel) based on the reflected light. The sensor also detects area with raised amounts of water around the irrigation system to detect a leak. All these irregularities show up as discolorations and altered values on the final image. The trained data analysts and business strategists can then analyze these discrepancies, once customers upload their data on the Andover Blueprints' secure web-portal to ensure data privacy, while offering the best service to the customer.

In the dash mission, where speed is paramount, the large 70.6° x 52.6° field of view from the Sequoia[11] increases the maximum speed at which the aircraft can fly because almost all multispectral sensors, including the Sequoia, shoot at one frame per second. The Sequoia multispectral sensor has a vertical field of view of 52.6°. At the determined optimal altitude of 230 feet, this translates into a vertical viewing area, on the ground, of 227.346 feet. This means that the UAV cannot travel faster than 227.346 feet per second, so that the UAV covers the entirety of the field with no gaps in the data. According to the flight plan, the UAV will travel at max allowed speed per FAA guidelines or 87 knots, which converts to 146.839 feet per second while covering 325.698 feet horizontally in one sweep.

In conclusion, the aircraft, the Sequoia, and the cargo hold make the solution extremely effective. All of the missions allow farmers to quickly, easily, and efficiently transport equipment. Thus, the Andover Blueprints' UAV will be the best option on the market.

2.3.2 Air Vehicle Element Selection

The Aerohawk, built by Asia Tech Drones and coupled with a 55cc gas engine, was an outstanding choice for the UAV. The extended range, large payload capacity, cost, and integrated engine influenced the selection of this platform.

[11] See section 3.1 for more information

The fixed wing pusher UAV is made of the following components:

- Aerohawk ($4,000)
- 55cc engine with support peripherals ($1,200)

It contains the following sensors and electronics (C3):

- Micro-controller ($100)
- 900MHz data transceiver set ($135)
- Autopilot ($149.99)
- Multiplexer ($0.45)
- Lipo Battery Pack Charger ($8.50)
- Serial servo controller ($18)
- GENS ACE 450 mAh 11.1 25 C 3S1P Lipo Battery Pack ($5.29)
- IMU (Inertial Measurement Unit) ($40)
- GPS ($50)
- Sequoia sensor ($3500)
- Wi-Fi Sports Action Camera ($50)
- 2 Axis Parrot Sequoia Stabilized Gimbal ($60)

It requires the following support equipment:

- Panasonic Toughbook PC ($320)
- Thrustmaster joystick ($50)

A 55cc gas engine with support peripherals was chosen because of a variety of factors:

(a) Integration: Asia Tech Drones offers multiple engines for the Aerohawk. If the team decided to use a third party engine, integration would be challenging. Securing the engine and ensuring a proper fit would be a challenge in the conceptual phase. Finding the area within the aircraft for an engine was also not available on the site. Therefore, it made significantly more sense to buy the integrated engine.

(b) Cost: Buying directly from Asia Tech Drones presented major perks. Asia Tech Drones is a wholesaler; thus, its prices are significantly lower than major brands that purchase from exporters, who purchase the drones from a manufacturer. Consequentially, their engines are also cheaper. 55cc gas engines built for drones can be quite expensive; therefore, it's cheaper to buy directly from a wholesaler.

(c) Gas versus electric: A gas engine is preferable over an electric because it can be refueled quickly, offers longer endurance, and has a significantly better weight to power ratio.

The UAV uses the Sequoia sensor by Parrot and MicaSense. The data analysis that comes with it is valuable, and it is Wi-Fi enabled so transferring data is easy. It was chosen because of its small size, sunlight sensor, built in GPS, strong range, high resolution, and ease of use. It is attached to a gimbal built by Parrot. The sensor is designed for agricultural drones, so it is prepared to survive the conditions expected when growing crops. A Wi-Fi Sports Action Camera is used on the example survey mission. It captures 1080p 60 fps video in high definition at a fraction of the price of a GoPro because it is bought directly from the manufacturer. The camera is in a waterproof, dust-proof case, making it well suited for use on a farm.

The servo controller, battery, and data transceiver are all necessary for the functioning of the autopilot, and the transmission of its data to the ground station computer. The multiplexer is necessary to put the safety pilot in control of the UAV should the autopilot fail.

The Sequoia sensor features an IMU and GPS, but is not carried on the example logistics mission. Thus, a separate IMU and GPS were purchased to aid with navigation and positioning.

All electronics, payloads, and machinery are housed inside either the additional cargo hold or the main fuselage of the UAV. Therefore, dust and precipitation will rarely be an issue. Should that problem arise, the included Internal Combustion Flight Line Kit allows for fixing of the engine by the farmer. The computer duster will clean out the components, which are already sealed off from grime by the hull. Finally, the maintenance plan provides added financial protection against issues with the UAS.

The cost of the bare airframe is $4,000. With the electronics, sensors, support equipment, and engine, the system costs $6,047.23.

2.3.3 Command, Control, and Communications (C3) Selection

When the team was deciding the structure of the C3 system, there were three distinct strategies taken into consideration: autonomous, semi-autonomous, or manual C3 systems. Each of these strategies requires a different set of hardware and operational costs. Here are the explanations of each strategy:

- Manual systems give the operator the greatest flexibility and control over the aircraft. This greater amount of control comes with a high cost, due to the need for more onboard sensors and telemetric hardware, as well as extra personnel. Manual control would consist of an operator or operators and a remote control. Manual control also increases the possibility of human error in the flight path. This altered flight plan will reduce efficiency and will require a more trained operator than an average farmer.

- Semi-autonomous systems fly with some element of human control and some element autonomous by utilizing a computer that executes a pre-programmed flight course. These systems allow for manual control in case of an emergency or when more freedom is needed. These systems retain some of the flexibility of manual systems, while greatly reducing the operational cost and increasing accuracy, efficiency, and ease of use.

- Autonomous systems provide for the least expensive and most accurate C3 system, however, and are somewhat flexible when it comes to mission execution. These systems fly themselves by executing a pre-programmed flight path in a flight computer without any human control, but still have the option to switch to manual control in case of an emergency. All cruise maneuvers have to be programmed into the flight computer, along with takeoff and landing.

The team ultimately selected the autonomous system because it offered the most robust solution. It gave us a pre-programmed takeoff and landing and also allowed us to fly an exact flight path. The autonomous system sometimes brings up the question of safety, but the ability to switch into manual provides a safe control method if issues arise. The aircraft will be flying autonomously along the pre-programmed flight path until the operator needs to switch to his or her remote control.

Selecting the Command System

In order to implement an autonomous system, the ground controller has a Panasonic Toughbook PC ($320) outfitted with software to constantly monitor the UAV's autopilot movement and flight data. This computer is also connected to the joysticks that pilot the UAV during emergency manual flight. As the UAV continues its path, it relays flight information back to the operator through a data transceiver set. The team chose this command system due to its quick autopilot to manual transition time, ease of use, and ability to display in-flight information. Though a tablet or RC remote would be a little easier for a farmer to learn in the beginning, it would by no means be able to match the flexibility, speed, and information that the Panasonic Toughbook provides.

Selecting the Control System

There are two situations for the control system: one for missions with the Sequoia sensor and one for the missions without it.

Without the Sequoia sensor onboard, the Panasonic Toughbook PC will converse with the UAV's MHz data transceiver set ($135), micro-controller ($100), IMU ($40), and GPS ($50) for proper positioning. The data transceiver set and micro-controller work in tandem to relay the GPS and IMU's information to the ground station. This communications unit will also converse with the multiplexer ($0.45) and serial servo controller (SSC) inside the UAV's hull. The multiplexer is the piece of equipment that switches the UAV between autopilot and manual flight mode and directs the SSC ($18) to manage the movement of the ailerons and rudders.

With the Sequoia sensor onboard, the GPS and IMU are not needed, as they are built into the sensor itself. In this case, the Panasonic Toughbook PC will converse with the UAV's MHz data transceiver set, micro-controller, and Sequoia sensor. The data transceiver set and micro-controller work in tandem to relay the Sequoia's information to the ground station. This communications unit will also converse with the multiplexer and serial servo controller (SSC) inside the UAV's hull.

At launch, for all missions, the PC will send a signal to the multiplexer that will turn the UAV's autopilot ($150) on, thus disengaging the SSC from manual control. The pre-programmed flight plan will be executed thus giving full control to the autopilot. Unless the autopilot is disengaged, the SSC cannot be controlled manually. This feature is so that manual control is available in case a failure occurs with the autopilot system. This feature is also in place for the landing of the UAV. Although the UAV will land during normal operation with the autopilot, in case the autopilot fails, the UAV can land manually. To do this, the multiplexer re-routes the signal from the pre-programmed course to the joystick ($50) that is connected to the PC. The operator will take these controls and land the UAV on the dedicated landing strip.

Selecting the Communications System

When selecting the communications system, it was mostly a question of ease of use, ease of setup, reliability, cost, and signal range of the data transceiver from the ground to the receiver on the UAV. Before choosing a radio video transmitter, the team calculated the maximum possible range between the ground station and aircraft. For this minimum range, for all missions, the assumption was made that the controller would be at the edge of the takeoff landing strip with the aircraft at the maximum possible cruising altitude of 400 feet (0.0757576 miles) at the opposite corner. Using the Pythagorean Theorem, the team calculated that the drone would be no more than 1.5 miles from the ground station.

If the ground station is at one edge of the field, the farthest the drone can be away is 400 ft above the opposite edge of the field. To calculate this distance, the team used the Pythagorean Theorem, setting up the sides of the triangle as 1.5 miles (the distance from the edge of the field to the furthest destination), and 0.0757576 miles (the maximum height): $\sqrt{1.5^2 + 0.0757576^2} = 1.50191$ miles.

With this calculation in mind, the team looked for a radio that had a long enough range so it could meet, and, hopefully, surpass this constraint. It also had to be robust enough for the pilot to reliably control the plane in case of an emergency. After looking in the catalog and on other external websites, the team decided to use the 900MHz High Range Data Transceiver Set from the catalog, as it was best suited for the purposes. It proved to be an economical and complete solution with a more than apt range of 6.3 miles and a cost of $135.

2.3.4 Support Equipment Selection

While choosing support equipment for the UAV, the Andover Blueprints considered how best to maximize the support equipment's usefulness while maintaining a low cost. The team decided to select minimalistic equipment that provided enough support for one UAV only. Given that the operation plan includes only one UAV, there was no need for any support beyond these options, and this strategy helped the team conserve the amount of money spent on support equipment.

The team chose a utility trailer, priced at $299, to provide necessary transportation of the UAV and other support equipment. This is the best option for the team's design because it was the least expensive and also has enough space inside to carry the UAV. The team included the Internal Combustion Flight Line Kit for $130 in order to recover from any engine malfunctions on the UAV that could happen while it is at the farm. This kit is not strictly necessary for the daily operation of the UAV, but if the UAV ever experiences malfunctions while on the farm, the kit will allow the UAV to be repaired immediately and continue with its operation.

The support equipment and resulting cost was significantly abridged due to the team's business model. For example, there is no need for a generator, as farmers can charge the UAV's battery at their own homes, instead of having to charge it in the field.

2.3.5 Human Resource Selection

The Andover Blueprints' company consists of three major divisions: training, maintenance, and analysis. The training section is a 30 hour comprehensive training program costing $720 and is designed so that farmers can operate the UAS legally, safely, and efficiently. To ensure the success of this goal, the team chose to employ a FAA Compliance Trainer ($20 per hour for 3 hours), a Flight Trainer ($25 per hour for 10 hours), Systems Trainer ($20 per hour for 7 hours), and a Safety Trainer ($20 per hour for 10 hours). Using the skills that each of these individuals brings to the table, the company designed a comprehensive plan for instructing operators on how to use the UAS. The flight trainer will instruct the farmer how to fly the UAV, by starting instruction on a very basic level but then progress to more complicated maneuvers. Then, the safety trainer will teach the operator how to control the drone safely. Immediately after the customer knows how to fly the UAV safely, the FAA Compliance Trainer will work with the customers to teach them the legal regulations. The systems trainer will give the farmer a complex breakdown of the specifics of the UAS.

Despite all of this training, the UAS may still break. In order to prevent farmers from worrying about this, the maintenance division was created. This division consists of repair ($25 per hour), electronic ($25 per hour), and support systems technicians ($30 per hour). Despite the UAV being very durable, there is a small chance that parts like the landing gear orienter may malfunction after repeated usage. In order to repair physical parts, the team employs repair technicians that can quickly fix damaged UAV parts. If the Sequoia sensor, which is essential for many of the missions, breaks, a repair technician will not have the necessary knowledge to fix it. So, if this happens, an electronic engineer will fix the sensor as soon as possible. Furthermore, even with an intuitive C3 design, a customer may break something, such as an antenna. To ensure that the drone is not limited by the durability of the controls, the Andover Blueprints will hire support system technicians that are trained to fix the C3 support equipment.

Finally, the analysis division is made up of data analysts (costing $35 per mission– 1 hour of work) and agricultural advisers ($40 per mission– 2 hours of work), and this division is responsible for helping farmers use the UAS to improve their profitability. Data analysts interpret raw data from the UAS, and then send it to agricultural advisers, who create a comprehensive plan that the customers can carry out to fix any problems they encounter.

2.4 System and Operational Considerations

The final objective function value was 0.7644. In order from highest to lowest, the values for the function's different parts were: 1.000 for the dash speed, 0.9002 for the additional missions, 0.8750 for the survey time, 0.8621 for the logistics weight, and 0.1847 for the business profitability.

In order to get these values, the team attempted to balance the objective function while minimizing the cost needed to obtain high values in all criteria. This was done because the function takes an average of all of the values, so the team decided that in order to maximize its value, all the individual components would need to be maximized as well. To achieve this goal, the team created a table of values for the objective function and saw which drone specifications were needed to get high function values. For example, it was decided that having a maximum payload weight of twenty pounds was large enough to carry significant objects such as pest traps, tools, and any other materials that a farmer desires, but small enough that building a drone that met this specification would not cost too much. Twenty pounds was determined by the researchers to be the most viable and useful payload for a farmer. This is also one of the highest realistic weights a cost effective UAV can carry with regard to the FAA's fifty five pound weight limit. The team designed a drone that could fulfill the team's specified requirements, without going too far over them. This way, the team did not spend extra money on a UAV that flying at ninety knots or launching with more than fifty five pounds, when the FAA regulations prohibit this. Also, at a certain point, a difference of one changes the objective function so little that it is more efficient to save money on parts than to try and get the drone to fly for an extra few minutes or takeoff with twenty one pounds instead of twenty. Such considerations kept the cost of the drone and its parts as low as possible while still keeping the objective function value high.

2.5 Component and Complete Flight Vehicle Weight and Balance

The total empty weight of the UAV is 34.08 pounds, and the maximum takeoff weight varies with the mission. For every mission, in order to find the center of mass of the entire UAV at maximum takeoff weight, the team split it into three components: empty airframe, payload, and power source. The moment and center of gravity calculations for the empty airframe are below. The datum point used for the fuselage station measurement is at the tip of the nose of the plane.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Airframe	21.87	618.48	28.28
Engine	28.15	164.96	5.86
900MHz data transceiver	25.59	0.64	0.025
Multiplexer	25.59	0.84	0.033
Autopilot	25.59	1.31	0.051
Serial servo controller	25.59	0.28	0.011
Micro-controller	25.59	0.56	0.022
Total Empty Airframe	23.09	787.07	34.08

Table 18: Details of Empty Airframe

The empty UAV has a center of mass located at 23.09 inches from the nose for all missions. The UAV's payload, power source, and the total weight data for each mission are below.

2.5.1 Logistics Mission

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Pest trap	13.78	200.36	14.54
Tools	15.78	78.9	5.00
Inertial Measurement Unit	25.59	0.26	0.01
GPS	25.59	0.51	0.02
Total Payload	14.31	280.03	19.57

Table 19: Details of Payload in Logistics Mission

The UAV payload has a center of mass located at 14.31 inches from the nose in the logistics mission. The UAV's power source data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
GENS ACE Battery Pack	23.62	2.36	0.10
2c Gas mixed 30:1	23.62	10.87	0.46
Total Power Source	23.62	13.23	0.56

Table 20: Details of Power Source in Logistics Mission

The UAV power source has a center of mass located at 23.62 inches from the nose in the logistics mission. Below is a compilation of all the UAV data for a calculation of the UAV's overall center of mass at maximum takeoff weight in the logistics mission.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Total Empty Airframe	23.09	787.07	34.08
Total Payload	14.31	280.03	19.57
Total Power Source	23.62	13.23	0.56
Total UAV	19.93	1080.33	54.21

Table 21: Details of Weight of UAV in Logistics Mission

In the logistics mission, the team's UAV center of mass at takeoff weight is located 20.26 inches from the nose.

2.5.2 Survey Mission

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Sequoia Sensor	7.87	1.89	0.24
2 Axis Parrot Sequoia Stabilized Gimbal	7.87	3.15	0.40
Wifi Sports Action Camera	7.87	2.67	0.34
Total Payload	7.87	7.71	0.98

Table 22: Details of Payload in Survey Mission

The UAV payload has a center of mass located at 7.87 inches from the nose in the survey mission. The UAV's power source data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
GENS ACE Battery Pack	23.62	2.36	0.10
2c Gas mixed 30:1	15.75	208.37	13.23
Total Power Source	15.81	210.73	13.33

Table 23: Details of Power Source in Survey Mission

The UAV power source has a center of mass located at 15.81 inches from the nose in the survey mission. Below is a compilation of all the UAV data for a calculation of the UAV's overall center of mass at maximum takeoff weight in the survey mission.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Total Empty Airframe	23.09	787.07	34.08
Total Payload	7.87	7.71	0.98
Total Power Source	15.81	210.73	13.33
Total UAV	20.78	1005.51	48.39

Table 24: Details of Weight of UAV in Survey Mission

In the survey mission, the UAV's center of mass at takeoff weight is located 20.78 inches from the nose.

Since all additional missions developed contain the same components, the tables containing the details of payload, power source, and weight of UAV are the same.

2.5.3 Dash Mission

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Sequoia Sensor	7.87	1.89	0.24
2 Axis Parrot Sequoia Stabilized Gimbal	7.87	3.15	0.40
Total Payload	7.87	5.04	0.64

Table 25: Details of Payload in Dash Mission

The UAV payload has a center of mass located at 7.87 inches from the nose in the dash mission. The UAV's power source data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
GENS ACE Battery Pack	23.62	2.36	0.10
2c Gas mixed 30:1	23.62	32.36	1.37
Total Power Source	23.62	34.72	1.47

Table 26: Details of Power Source in Dash Mission

The UAV power source has a center of mass located at 23.62 inches from the nose in the dash mission. Below is a compilation of all the UAV data for a calculation of the UAV's overall center of mass at maximum takeoff weight in the dash mission.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Total Empty Airframe	23.09	787.07	34.08
Total Payload	7.87	5.04	0.64
Total Power Source	23.62	34.72	1.47
Total UAV	22.85	826.83	36.19

Table 27: Details of Weight of UAV in Dash Mission

In the dash mission, the UAV's center of mass at takeoff weight is located 22.85 inches from the nose.

2.6 Design Analysis

The aircraft, although capable of carrying more, has a maximum takeoff weight of 55 lbs due to the FAA weight cap. It is also able to fly at a speed of 146.8 ft/s (87 knots), which is the FAA cap for UAV velocity, and at an altitude of 400 feet, also the FAA restriction limit. Using the maximum weight the aircraft could fly at, which was provided by the UAV website, the team was able to calculate the lift coefficient of the aircraft:[2]

$C_L = \frac{L}{0.5rAv^2}$

Where C_L is the lift coefficient, L is the lift force in Newtons of the wings, r is the air density in $\frac{kg}{m^3}$, A is the wing area in m^2, and v is the aircraft velocity in m/s.

The Aerohawk's maximum flying weight is 55 lbs, 24.95 kg, or 244.76 Newtons. The lift force provided by the wings must be equal to this, in order to allow the plane to fly. Therefore, the team estimated the lift force to be 244.76 N. The team was unable to accurately find the density of the air the aircraft would be flying through, so they used the air density at sea

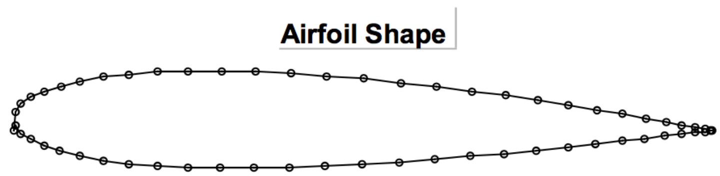
[2]https://www.grc.nasa.gov/www/k-12/airplane/liftco.html

level of $1.225kg/m^3$.[3] The aircraft's wing area is $12.1ft^2$, or $1.125m^2$ (3 m by 0.375 m). To get C_L, the team used the aircraft's flight velocity of 146.8 ft/s, or 44.76m/s.

Once all of this data was inputted, the team calculated the lift coefficient of the aircraft to be 0.18, when the aircraft is at 0 degrees angle of attack.

Once the team identified the lift coefficient of the wing, it was easy for the team to find the ideal airfoil type. The team decided to adapt the NACA 1714 wing as the airfoil of Aerohawk. Below is the shape and the geometry of the airfoil.

NACA 1714



x	y	x	y
1.00000000	0.00000000	0.06688076	-0.02981375
0.99732594	0.00054430	0.09531723	-0.03673816
0.98918293	0.00216096	0.12816795	-0.04258625
0.97570782	0.00480173	0.16507457	-0.04727388
0.95704464	0.00838986	0.20563567	-0.05075100
0.93339324	0.01282488	0.24941097	-0.05300743
0.90500754	0.01798810	0.29592565	-0.05407425
0.87219308	0.02374814	0.34467519	-0.05402109
0.83530405	0.02996562	0.39513037	-0.05294989
0.79473965	0.03649638	0.44674271	-0.05098644
0.75093995	0.04319315	0.49895017	-0.04827082
0.70438117	0.04990574	0.55118314	-0.04494834
0.65557059	0.05648031	0.60287061	-0.04116194
0.60504108	0.06275844	0.65344641	-0.03704686
0.55334532	0.06857699	0.70235548	-0.03272802
0.50104983	0.07376944	0.74906005	-0.02831964
0.44872883	0.07816931	0.79304560	-0.02392678
0.39695794	0.08161590	0.83382656	-0.01964783
0.34630781	0.08396184	0.87095175	-0.01557691
0.29733771	0.08508193	0.90400946	-0.01180559
0.25058903	0.08488197	0.93263217	-0.00842301
0.20657907	0.08330640	0.95650082	-0.00551446
0.16579483	0.08034322	0.97534869	-0.00315837
0.12868722	0.07602547	0.98896467	-0.00142228
0.09566578	0.07042820	0.99719596	-0.00035847
0.06709383	0.06366129	1.00000000	0.00000000
0.04328440	0.05585831		
0.02449678	0.04716277		
0.01093383	0.03771328		
0.00274001	0.02762941		
0.00000000	0.00000000		
0.00273810	0.00637035		
0.01091857	-0.00371729		
0.02444670	-0.01318304		
0.04317014	-0.02192173		

Figure 10: NACA 1714 Airfoil Geometry

[3] http://scipp.ucsc.edu/outreach/balloon/atmos/1976%20Standard%20Atmosphere.htm

Once the team identified the NACA 1714 airfoil, the team came up with a complete analysis of it with JavaFoil, an online aerodynamics tool. Below is the graph JavaFoil produced of the wing's C_L values vs Alpha, the angle of attack.

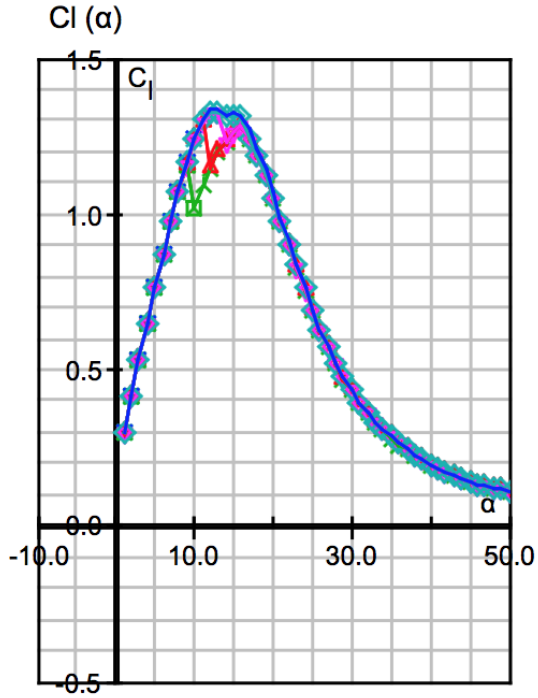


Figure 11: Lift Coefficient Graph

From the graph, the team discovered that the stall angle of 1714 is around 11°. To calculate the C_d and the C_M values of the aircraft, the team put the 1714 airfoil under a simulation provided by JavaFoil. It is able to come up with a list of C_d and C_M values against their respective angle of attacks (Alpha). The team cut the table off after the critical angle of attack of around 11°, as provided by the chart below.

Alpha	C_L	C_d	$C_M 0.25$
0	0.183	0.014	-0.014
1	0.298	0.013	-0.016
2	0.415	0.014	-0.017
3	0.530	0.015	-0.019
4	0.644	0.016	-0.021
5	0.754	0.018	-0.022
6	0.859	0.020	-0.024
7	0.957	0.022	-0.025
8	1.054	0.023	-0.027
9	0.949	0.051	-0.010
10	1.022	0.057	-0.011

Table 28: List of C_L, C_d, and C_M Values vs Angle of Attack

The team was also able to identify the pressure coefficient distributions at different angles of attack on top of C_L, C_d, and C_M and generate the Flow Field of the 1714 airfoil under three angles of attack: 0, 5, and 10 degrees. The graphs are below.

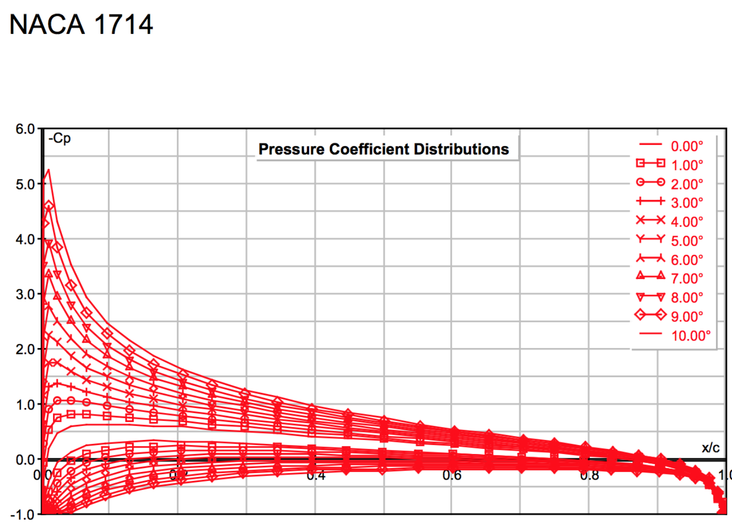


Figure 12: Pressure Coefficient Distribution of 1714

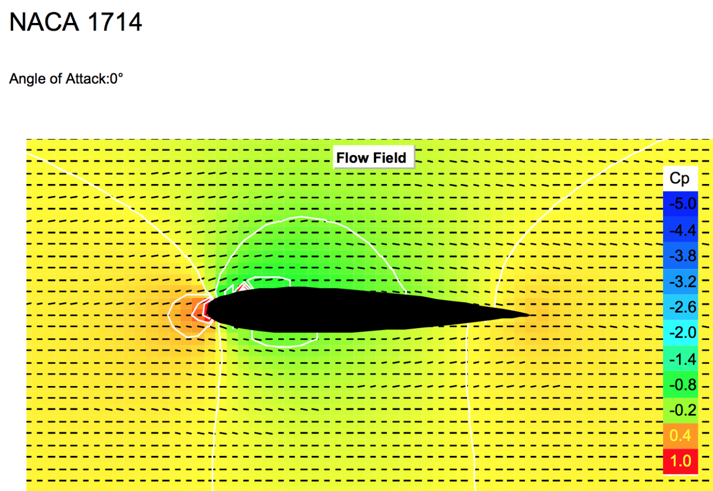


Figure 13: Flow Field at 0° of Attack

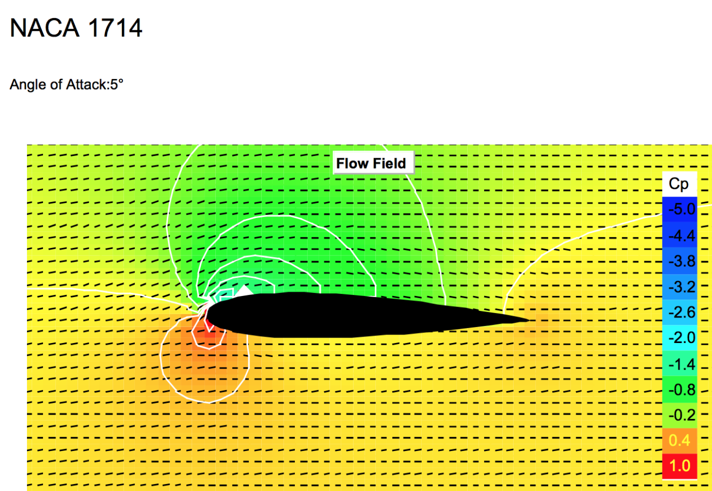


Figure 14: Flow Field at 5° of Attack

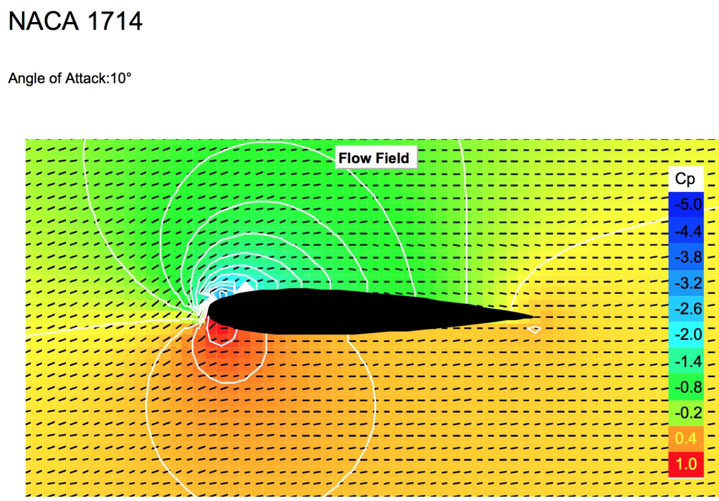


Figure 15: Flow Field at 10° of Attack

2.7 Operational Maneuver Analysis

Then, the team calculated the minimum turning radius the aircraft will have, given the maximum bank angle, to prove that it can make the planned coordinated turn radius of 162.849 feet in survey and additional missions. To do this, the team split the lift force into two components, the vertical component, which is equal to the weight of the aircraft, and the horizontal component (L_h), which is the portion of lift that provides the centripetal force. After that, the team looked at the equations used to calculate L_h. The total lift force formed the hypotenuse of a right triangle, with L_h being the opposite side with respect to the bank angle θ, and W being the adjacent side. Therefore, the team can calculate L_h by using the Pythagorean Theorem:

$L_h = \sqrt{L^2 - W^2}$

Since $L_h = \frac{mv^2}{r}$,

So, $\frac{mv^2}{r} = \sqrt{L^2 - W^2}$.

So, $r = \frac{mv^2}{\sqrt{L^2 - W^2}}$

Since m, v, and W are fixed in this case, in order to minimize r, the team has to maximize L. According to the calculations in section 2.6, L is maximized when the angle of attack is approaching the stall angle of 11°, resulting in C_L approaching 1.05. From the definition of C_L in section 2.6, the team was able to calculate L_{max}, which is 478.62 Newtons. According to the survey mission flight plan, the UAV will be traveling at 50 knots (58.54 mph). The team then calculated r_{min} to be 32.50 feet.

In this case, the aircraft with be preforming a banking angle of 63.26° and an angle of attack at 11°. The minimum turning radius of the aircraft, 32.50 feet, is far under the planed turning radius, 162.849 feet, which the team called. Therefore, the aircraft will not only be able to fly the team's plan, but to do it comfortably.

2.8 CAD Modeling

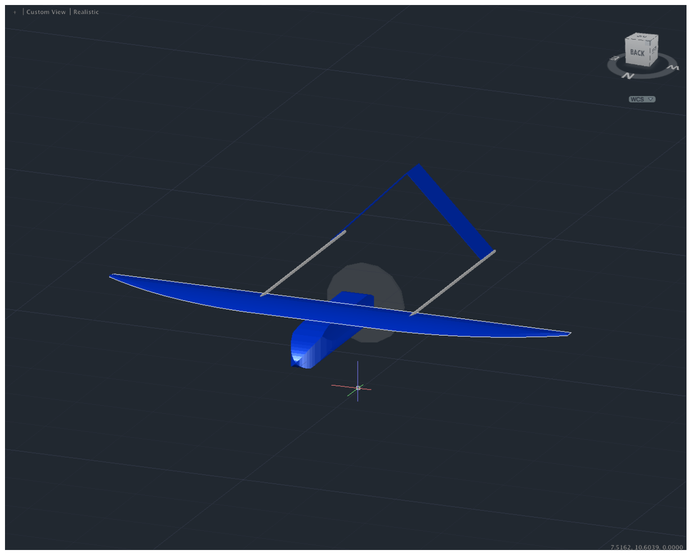


Figure 16: Aerohawk

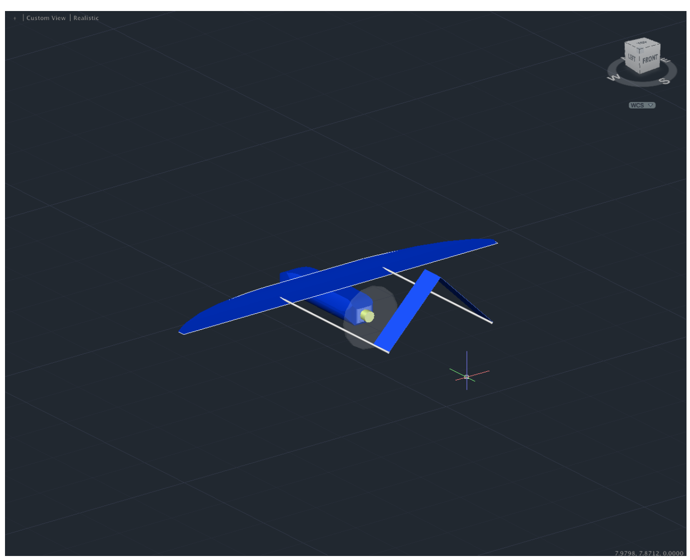


Figure 17: Aerohawk from Another View

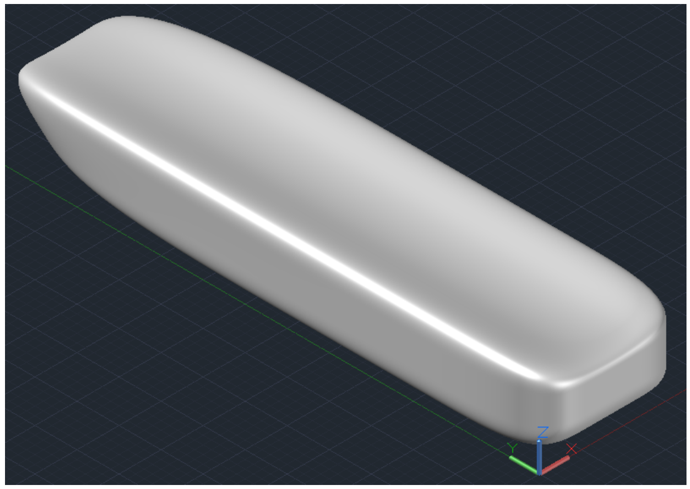


Figure 18: Cargo Hold

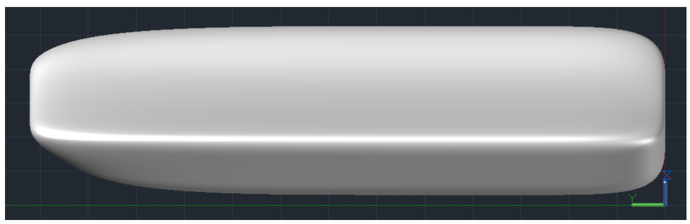


Figure 19: Cargo Hold from Another View

2.9 Three View of Final Design

2.9.1 Aerohawk

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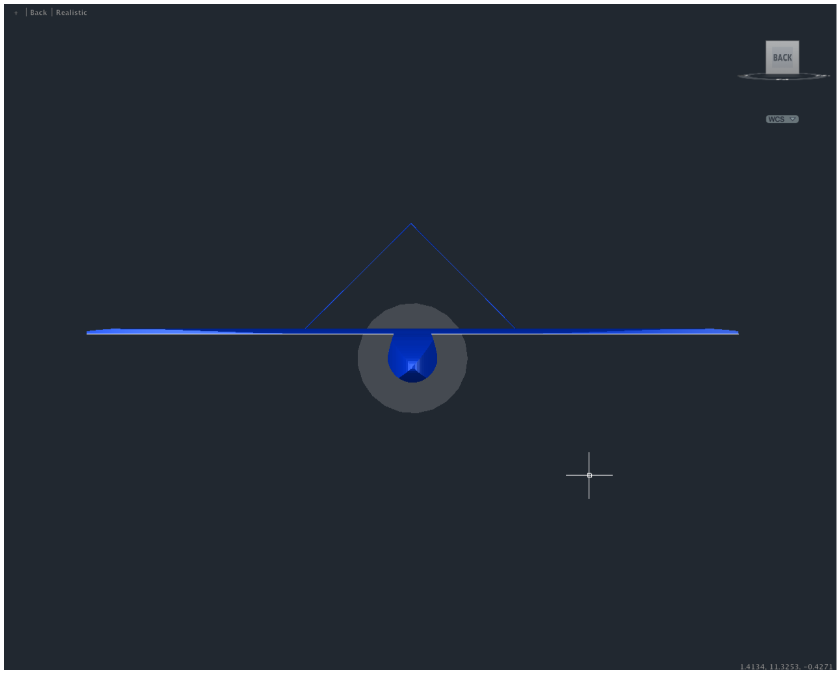

Figure 20: XZ View of Airframe

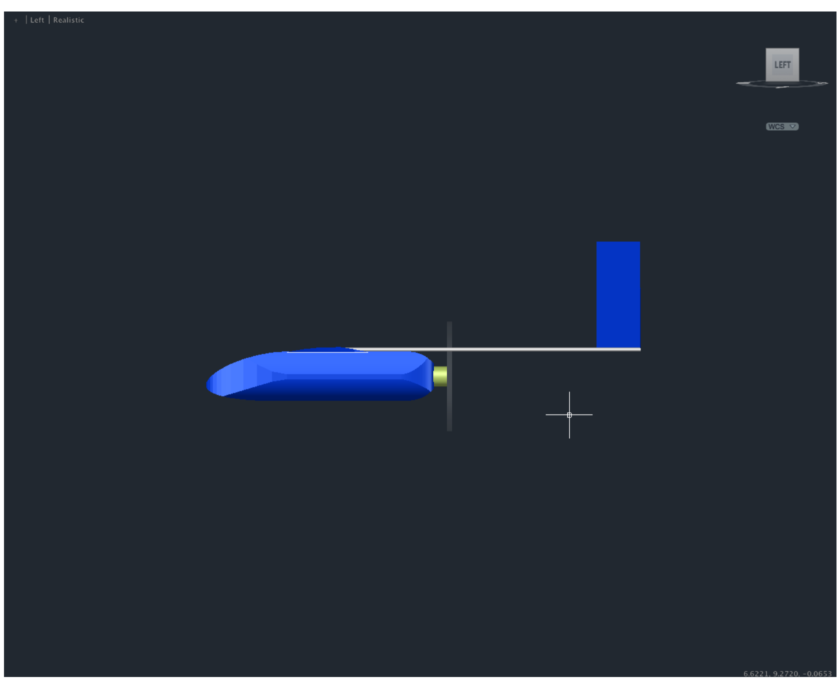

Figure 21: YZ View of Airframe

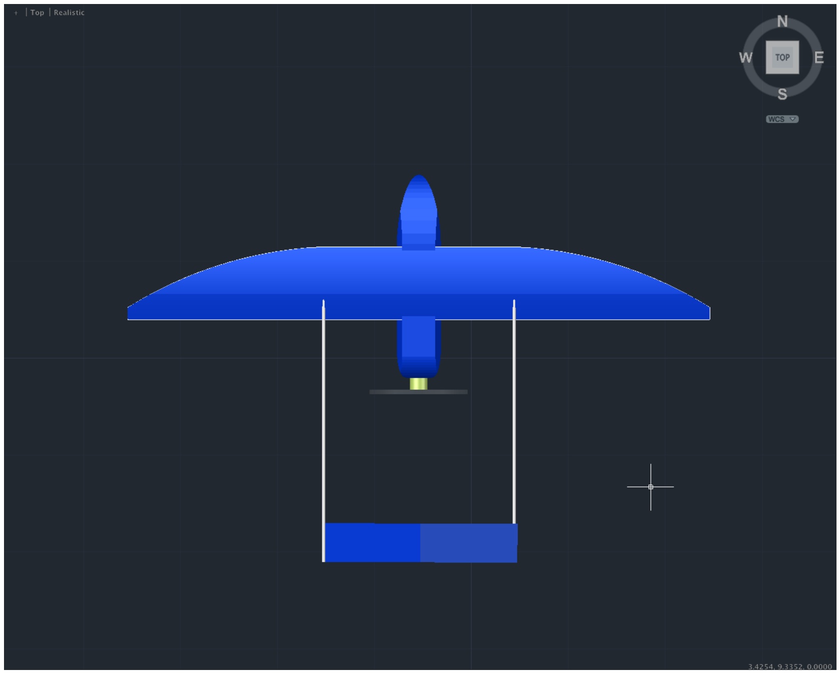

Figure 22: XY View of Airframe

Dimensions of the Aerohawk:
- Airframe Wingspan: 118.11 in (3.000 m)
- Airframe Length: 75.59 in (1.920 m)
- Airframe Height: 28.66 in (0.728 m)

2.9.2 Cargo Hold

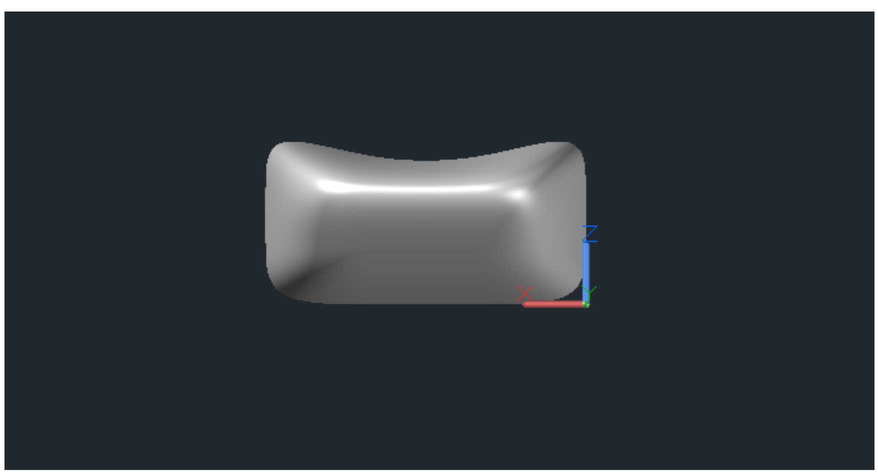

Figure 23: XZ View of Cargo Hold

Figure 24: YZ View of Cargo Hold

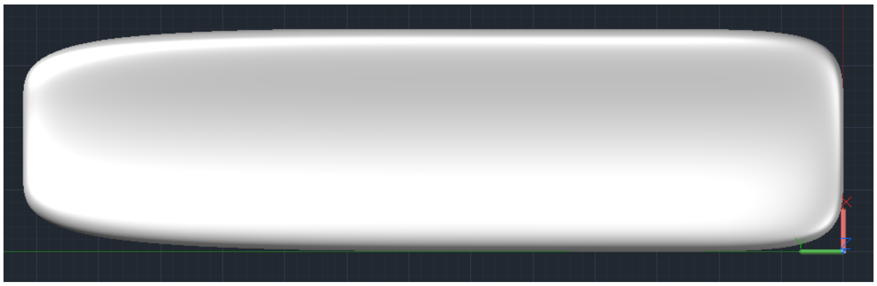

Figure 25: XY View of Cargo Hold

Dimensions of the Cargo Hold:
- Cargo Hold Length: 33.07 in (0.84 m)
- Cargo Hold Width: 8.98 in (0.23 m)
- Cargo Hold Height: 5.00 in (0.13 m)

Chapter 3

Document the Missions

3.1 Logistics Mission

The logistics mission is outlined as a minimum-requirement mission in which the UAV must be able to transport a payload of 8 lbs to a location 1 mile away and then return with a payload of 8 lbs without recharging batteries or refueling.

The team decided to utilize the UAV in this mission to transport objects across a farm. The group then deliberated over the types of payloads that an actual farmer will need out in the field for such a mission, and the final decision was that the payload will consist of pest traps, tools, soil samples, and crop samples. The team chose these because they are all related to infestation management, which is important for any farmer with a sizable crop.

Pest traps are an important part of large crops such as corn, which is susceptible to many pests, such as the European Corn Borer, Brown Stink Bug, and the Brown Marmorated Stink Bug. Pest traps are an extremely efficient way to manage these pest populations, and they are fairly cheap, which makes them popular among farmers. When a farmer comes across a problem area on his or her field, rather than driving a truck or tractor back to pick up a pest trap, a drone can be deployed to expedite the transportation process.

Because dropping off the pest trap is a one-way payload, the team needed to fill the payload on the way back. A natural solution to that problem was to have the farmer fill the return payload with soil samples and infested crop samples, which would need to be analyzed anyways to understand the scope of the infestation. This dual-payload system allows us to allocate resources efficiently and accelerate a tedious process for the farmer.

3.1.1 Theory of Operation (Example Logistics Mission)

The UAV that the team designed will take off from a short airstrip near the field, take the shortest route to its destination 1 mile away, land, have its pest traps and tools removed, then have the payload replaced with infected crop samples and soil samples, add the tools back on, and finally return to its starting location. In order to complete this mission, there needs to be at least to two human resources (two trained farmers), one at the drone's starting location (Farmer-1) and one at its destination (Farmer-2). The ground control station is at the edge of the takeoff strip.

To start, Farmer-1 will place the UAV on its dedicated takeoff strip and then execute the command to initiate the flight plan using the ground station. Farmer-1 will watch to make sure it maintains line of sight, while also being ready to switch to manual control using the ground control station in case of an emergency. The UAV will then follow the flight plan and land in a clearing near the destination. Farmer-2 unloads the pest traps, then refills the payload with soil samples and infected crop samples. The UAV will finally take off once again and follow the flight plan back to its starting location, where it will land back on the landing strip and refuel to be prepared for any future missions.

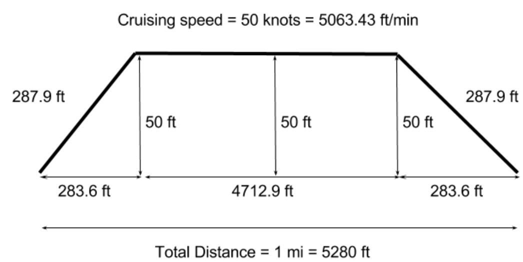

Figure 26: Logistics Mission Flight Plan

The whole mission itself will take about 7.6 minutes, out of which 2.1 minutes is actual flight time and 5.5 minutes is loading and unloading the UAV's payload. Reference the picture below to see the calculation of flight time.

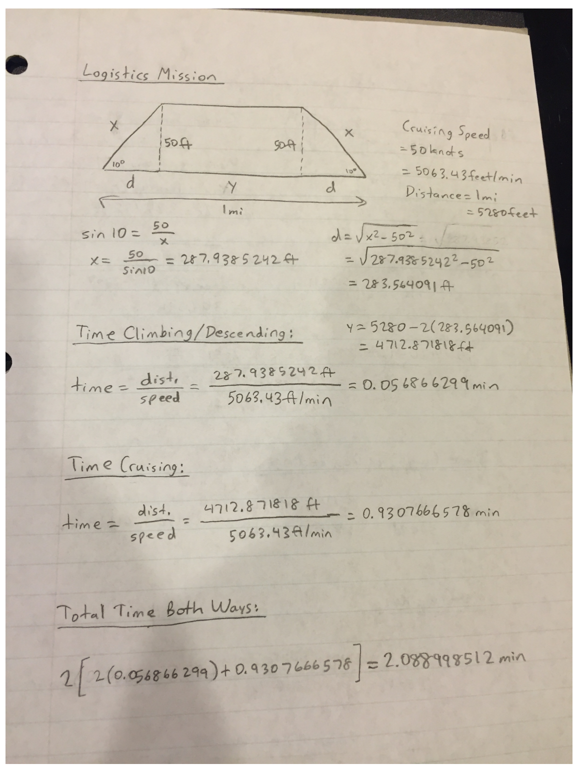

Figure 27: Flight Time Calculations for Logistics Mission

Throughout this whole process, Farmer-2 will be in contact with Farmer-1 so that whenever the UAV lands or takes off, there is always a person maintaining line of sight. This process is designed to be compliant with FAA regulations and allows farmers to have flexibility over the destination of the UAV.

The overall purpose of the mission is to provide farmers with a way to expedite the process of attacking and analyzing crop infestation. By delivering pest traps straight to the farmer and allowing him or her to send samples back, the farmer does not have to leave the field in order to address crop infestation. Not only does this save a lot of time, it saves the gas that the farmer's truck would use, allows infestation to be addressed much faster, and gives farmers more time to tend to their crops– time which would otherwise be spent driving back and forth to gather materials.

3.1.2 Logistics Mission Design Considerations

Because of the nature of the engineering design process, the Andover Blueprints went through many iterations of designs and, specifically for the logistics mission, many payloads. At first, the team thought that using the UAV to drop off tools or the farmer's lunch would be an effective use of payload space, but after careful consideration it seemed rather foolish to buy a \$10,000 drone for the purposes of transporting tools and food. The payload was then changed to soil samples, but even this was not efficient enough. The team regarded this new payload as inefficient for two reasons: 1) soil samples are a one-way payload; therefore, fuel would not be economized, 2) soil samples take time to analyze, so having a drone expedite the process makes no difference, and also farmers could always bring soil samples back with them at the end of their work day.

At this point, the Andover Blueprints began to do research on its choice of farm, corn and potatoes, to understand what problems a drone could solve on those types of fields. The team found that both corn and potatoes are susceptible to many types of pests, and farmers often have to deal with infestations. Because of the vast number of possible pests and pest solutions with these two crops, the focus was narrowed down to just corn. The team then did research on harmful pests to corn and found that the European Corn Borer, Brown Stink Bug, and the Brown Marmorated Stink Bug are some of the most damaging. One solution that repeatedly showed up for all of these insects was pest traps.

Although the team understood that pest traps were the best payload option, there was still the need to find which type of pest trap was best for the UAV. The selection process eventually narrowed down to two types of pest traps, the light, one-time-use pest traps, or the large, reusable pest traps. The light pest traps are very small and would be easy for a farmer to carry into the field manually, but many of them need to be deployed in order to deal with infestation. On the other hand, the large, heavier pest traps are difficult for a farmer to transport, but they are very effective in dealing with infestations. This reusable pest trap, known as the Texas Style Cone Trap, was the one chosen. The team realized that the UAV would be most effective carrying this type of pest trap, because it would actually solve a farmer's problem of trying to transport such a large, heavy product. Then, in order to make the design as beneficial as possible to the farmer, the team decided to fill the return payload with soil samples and crop samples, which would need to analyzed anyways to determine the scope and effect of an infestation. This dual-payload system allows the team to distribute resources methodically and expedite the transportation process.

As outlined in 3.1 & 3.1.1, the designed mission is beneficial to farmers because they don't have to leave the field in order to address crop infestation. Time is saved, the gas the farmer's truck would use is saved, and infestation can be addressed much faster.

In order to make the team's UAV capable of meticulously completing the survey mission and dash mission, the Andover Blueprints had to compromise on the payload weight for the logistics mission. This was a result of the team selecting an airframe that can hold a moderate amount of payload, but can travel very fast. This airframe was chosen to make sure that the team's UAS would be well-rounded. That said, to balance this compromise, the team created a strong link between the survey and logistics mission to ensure an advantage for the farmer. In the survey mission, which is designed to analyze crop health, if an infestation is detected, the logistics mission's strategy of transporting pest traps can be used. This means that farmers will not only detect a problem with the UAV, they will address the problem with the UAV as well.

3.2 Survey Mission

The survey mission is outlined as having the aircraft survey 0.25 square miles over at least 30 minutes while recording with a 1080 pixel and 60 frames per second video camera. The Andover Blueprints chose to attach a powerful multispectral and sunlight sensor and an action camera to the UAV to meet the specifications of the mission.

In order to meet the requirement of having a high definition 1080p 60 fps camera on the UAV, the team researched multiple cameras to use for the survey mission. Cameras were judged based on the following factors:

- Cost (the team wanted a camera that was as cheap as possible)
- Size (ideal to minimize size)
- Versatility (the camera has to be able to survive farming conditions)
- Frames per second (60 fps minimum)
- Quality (1080p HD or higher)
- Weight (less than one pound)

The team narrowed the options down to a GoPro Hero 5 and the Wi-Fi Action Sports Camera. Both are built for rugged conditions, record in the quality required, and have a reasonable weight and size. The Wi-Fi Action Sports Camera is similar to a GoPro, but bought straight from the wholesaler. Though lacking the brand name, it is $\frac{1}{8}$ of the cost of a GoPro. Therefore, it was chosen over the GoPro to be utilized on the survey mission.

Following extensive research, the Sequoia sensor, built by Parrot and MicaSense, was chosen to be used for the survey mission. Built for use on agricultural drones, it can detect water stress, symptoms of nutrient deficiencies, biotic stress, identify problems in the field, and estimate crop yield. A sunshine sensor is mounted upon the top of the UAV to collect data on current lighting conditions to refine and recalibrate measurements from the multi-spectral sensor. It also features an IMU enabled GPS device to geotag sensor readings and track the aircraft's current location. These features make it an excellent choice to scan for crop health on the survey mission.

(a) Sequoia Multispectral and Sunlight Sensor

(b) Wi-Fi Action Sports Camera

Figure 28: Survey Mission Main Payload

The crop health mission was chosen as the survey mission after intense evaluation. An extended flight time is ideal because it allows farmers to scan more of their field. The team's drone therefore scans 5.5 miles to maximize the usefulness for a farmer.

3.2.1 Theory of Operation (Example Survey Mission)

The farmer conducting the survey mission will have the following payload on the Aerohawk:

- Sequoia Sensor (0.24 lbs)
- Two Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs)
- Wi-Fi Sports Action Camera (0.33 lbs)

The fuel tank is then filled with 13.23 pounds of fuel. This accounts for a 14.2 lbs payload. The flight time for the survey mission was calculated with the assumption that the farmer would only fill the main fuel tank in the hull of the UAV with fuel and the ground control station at the edge of the takeoff strip. However, if farmers want to greatly extend the flight time by approximately one hour, they can outfit the separate cargo hull that's sold with the UAS with another fuel tank connected to the main airframe. All missions can be modified in such a way. This provides increased variability, so the UAS works for any farmer.

The purpose of the example survey mission is to measure crop health so a farmer is able to recognize which areas of the field to treat for pests, dehydration, or a lack of nutrients. The Sequoia sensor is utilized to scan and quantify crop health over an area of 5.5 square miles (by scanning 22 0.25 square mile fields). An agricultural mentor pointed out that farmers operate on fields of different sizes and dimensions. Thus, the mission was designed to be applicable to nearly all fields. The 22 0.25 square mile scanning areas can be rearranged to fit any sized field. However, to maximize efficiency and minimize confusion, the team organized these plots of land into a 5.5 mi by 1.0 mi rectangle:

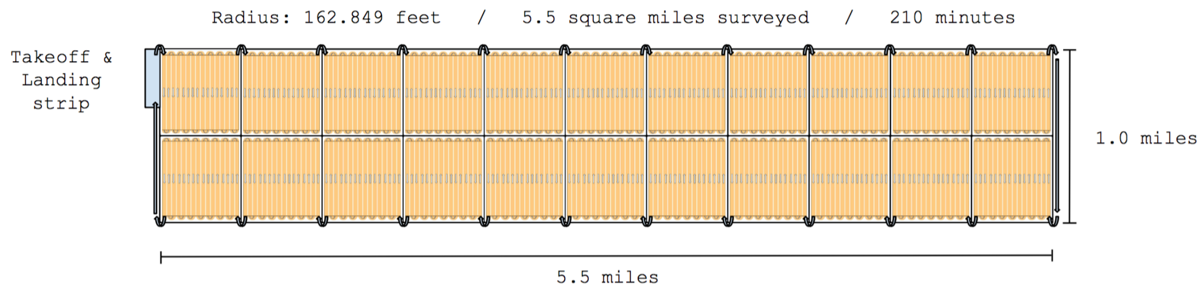

Figure 29: Survey Mission Full Flight Pattern

Each yellow square is 0.25 square miles. In one square, the UAV follows the following flight plan:

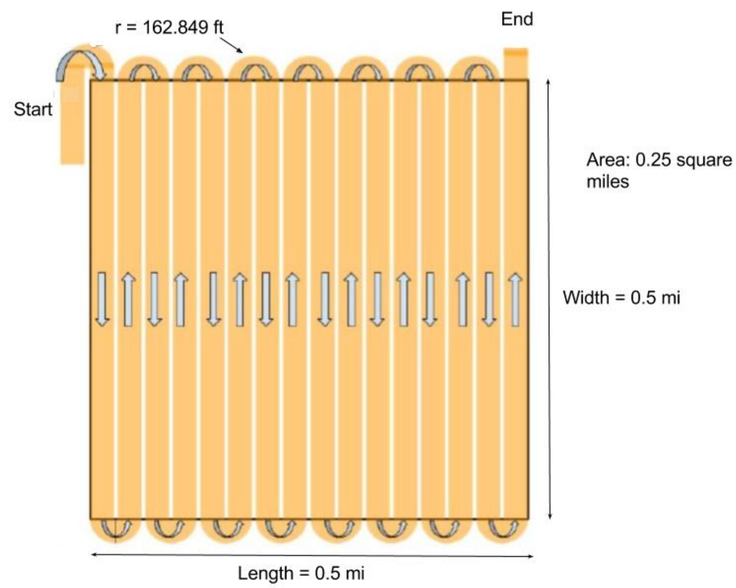

Figure 30: Survey Mission Flight Plan

To launch the UAV, the farmer places it on a small takeoff strip. The farmer then conducts a pre-flight inspection and then flips on the autopilot, which launches the UAV at an angle of ten degrees. Once the system reaches 230 feet, the UAV levels out. According to US Federal Drone Regulations, a person still has to be at the controls, but the aircraft can scan the fields for 3.5 hours without having to be flown manually. This significantly decreases the labor required to scan the fields for crop health. The pilot ensures that the plane is flying at 50 knots to increase fuel efficiency and flight time. 5.5 square miles are then scanned over the following 3.5 hours. An additional surplus of fuel allowing the UAV to cover 1.9 miles is left over for landing, takeoff, and emergencies. Refueling is done once the UAV lands.

When the UAS returns and lands autonomously, the farmer detaches the Sequoia sensor and Wi-Fi Sports Action Camera. The devices then connect to the Panasonic Toughbook PC via either Wi-Fi or cable, and the data and video from the flight is submitted to the Andover Blueprints' online portal to be analyzed, so the farmer can get a proper conclusion on which specific areas require attention, increased analysis, or treatment. The IMU and GPS readings from the Sequoia sensor can be overlaid to tag and provide location for the Wi-Fi Action Sports Camera video. The purpose of the mission, to capture crop health, has been fulfilled, as 5.5 square miles of plants has been scanned and videoed at 1080p 60 fps to determine their well being.

3.2.2 Survey Mission Design Considerations

When farmers are able to accurately measure crop health, it allows them to understand the current growth rate, reevaluate their farming practices, adjust pest control, and increase yield. The choice of farm, method of collection, and ease of use are all key factors when designing a mission to collect details on current crop health. The team considered the ideal situation to collect data while creating a versatile UAS for a farmer.

Although many applications were suggested, the team, working with the mentors, eventually decided to either scan for moisture detection or crop health. Both data points often vary across a field, so utilizing a UAV to scan for them would allow a farmer to adjust their farming practices accordingly across a field and therefore maximize yield. After extensive research, the practical uses of a crop health mission became increasingly clearer. Farmers can weed out and understand issues in their growing cycle and overlay scans over periods of time to recognize prevalent problems. Thus, crop health is scanned for on the survey mission.

The team found that the Sequoia sensor works best on plants with low variation in height. Thus, scanning for crop health on plants such as corn or potatoes is ideal. This is because the Sequoia sensor detects biotic stress when pests attack plants. To provide variability to the farmer, the team does not specify the type of crop scanned for on the example survey mission, as the mission works for all types of crops, but heavily suggests scanning either corn or potatoes.

This system presents a unique and cost effective solution to allow a farmer to scan for crop health. It only employs one person to operate for 210 minutes at a cost of $11 per hour, so $38.50 in total. Tractors operate at a maximum speed of 30 miles per hour, and a typical pace between 5 and 15 miles per hour. Other methods such as individual scanning and satellites cost unaffordable sums. Thus, this UAS presents a time and cost effective solution for a farmer when scanning for crop health. It also only requires fuel and a human operator, with little to no outside help. Farmers can therefore collect key data on their own with little resources involved.

Farmers in the past had four main options for collecting data: manned aircraft, satellites, application booms, and employee sweeps. The creation of UAVs presents a revolutionary, cost effective, and time efficient way to collect crop health data. Manned aircraft risk the life of the pilot, are expensive to operate and own, and present serious environmental issues. Only large farms can afford to utilize satellites. They're incapable of offering crop health data and must be retasked between multiple farms to be worth the price. Application booms and hiring workers to sweep the fields with sensors are both widely available and implemented solutions to gathering agricultural data. However, these operations are expensive, and take significant amounts of time to scan. Thus, the use of a UAV equipped with a singular multispectral sensor eliminates all risk while decreasing expenses and manpower.

A rotorcraft or helicopter type UAV is incapable of fulfilling this mission because they're not aerodynamic and therefore use a significant amount of fuel per minute of flight. This prevents them from staying in the air long enough to scan for crop health. Hybrid designs are rare, utilize significant amounts of fuel for takeoff and landing, and have little apparent upside for the agricultural market. This design is mostly used by companies that try to do everything, thus sacrificing quality of the missions performed for quantity. But, the Andover Blueprints stayed focused on the agricultural UAV market to provide the highest quality service for customers, therefore making a better business. If the company utilized a hybrid drone, more missions would have been feasible, but each mission would not be as helpful to the farmers, which would lead to a low customer satisfaction and inevitable failure. Companies must focus on their market and customer base and not try to do everything. So, using a fixed wing design is ideal because it can carry out the missions that the team designed without sacrificing any of its core capabilities. It has great endurance, fuel efficiency, and payload capability despite lacking the maneuverability that rotorcrafts and hybrids have.

The team decided that a fixed wing plane is the only UAV design that is capable of accomplishing the logistics, survey, and dash missions. Extended flight time was ideal, so to reach that requirement, it became obvious that the mobility of a rotorcraft would have to be sacrificed for a fixed wing design to extend the range. However, fixed wing aircraft are faster, so this design increased the effectiveness of the dash mission. Thus, few compromises were made in the designs of the other missions.

3.3 Dash Mission

The dash mission minimum requirement is outlined as having the UAV fly a payload of at least two pounds to a location 1.5 miles away and then return back to the starting position. In the dash portion of the challenge, speed is the top priority, so the team can produce results for the customer in seconds. This type of mission can be useful for a quick sensor reading or a small payload drop.

The Andover Blueprints brainstormed logical, useful, and efficient applications that meet the dash mission requirements through extensive online research and conversations with the mentors. The team contacted multiple farms and farmers through email, phone, and in person to gather useful, real world insight.

The team chose to apply the dash mission to monitor irrigation systems on farms to pinpoint weak spots and leaks. Irrigation systems are often extremely vast and contain many pipelines that must be in pristine working condition to ensure the most efficient operation of the farm. The pipelines can break and cause many problems, so the UAV uses the Sequoia multispectral sensor to predict breaks by sensing weak spots or rapidly identifying problem areas after a malfunction has occurred. The Andover Blueprints identified the customer base as larger farms and any sizable farm will require this mission to ensure a properly functioning irrigation pipelines. When customers are not monitoring irrigation pipelines, they can also use the versatile applications of this UAS to monitor pesticide spreading and fertilization systems or other infrastructural components on their farm.

For the dash mission, speed is critical to ensure the fastest possible data collection for the customer. The FAA regulations state that the UAV can fly at a maximum speed of 87 knots or 100.12 miles per hour. The team kept this speed in mind when searching for a suitable UAV, and the Aerohawk airframe was chosen, in part due to the fact that it can fly at and even above the target speed of 87 knots.

The UAV produces data during this mission with the Sequoia multispectral sensor by Parrot and MicaSense. The Sequoia senses leaks and weak spots in irrigation pipelines with redundancy. The sensor measures the frequency of reflected light to create multiple multispectral images while it also produces RGB images. With this technology the Sequoia measures the thickness of the metal in the pipeline and its composition (ex: rust or steel) based on the sensed light. The sensor also detects area with raised amounts of water around the irrigation system to detect a leak. With this technology the system can also detect breaks in underground pipelines. All these irregularities show up as discolorations and altered values on the final image. These discrepancies will then be analyzed by the team's trained data analysts and business strategists once the customer uploads their data on the Andover Blueprints' secure web-portal that ensures complete data privacy, while offering the best data analysis and decision support service to the customer.

3.3.1 Theory of Operation (Example Dash Mission)

The purpose of the dash mission is to monitor the structural integrity of an irrigation system or detect leaks in pipelines so the customer is able to very quickly locate and fix that portion of piping in a large irrigation rig. The Sequoia sensor on the UAV is utilized to scan and assess weak spots in an irrigation pipeline in an agricultural setting to ensure that an irrigation system will function perfectly. Irrigation is a key aspect of farms in the United States, especially in drought ridden areas. Thus, the interest in systems that are capable of performing irrigational status missions creates a larger market for the UAS. The mission is executed periodically or after a pressure drop in an irrigation pipeline is detected.

To conduct an example dash mission, the Aerohawk is filled with 1.37 lbs of fuel; and a farmer attaches the Sequoia Sensor (0.24 lbs) and a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs), so the image remains clear and the UAV can turn sharply when necessary. These components add up to a total of a two-pound payload. A farm worker places the drone on the landing strip (preferably an open grassy area). This starting location is near the beginning of the irrigation pipeline or agricultural infrastructure being monitored. One farmer stays at this position on the runway during the execution of the mission. He or she will maintain line of sight and be ready to use the Thrustmaster joystick and Panasonic Toughbook, which are at the ground control station, which is at the edge of the takeoff strip, to take over manual control over the UAV in case of an emergency. The farmer also sets the flight plan along the pipeline and starts the UAV. The UAV will fly completely autonomously and collect data with its Sequoia multispectral sensor. The UAV completes the mission in only 1.914 minutes and lands on the same landing strip it took off from. Refueling is done once the UAV lands. The derivation of flight time is below:

Time Taken During an Entire Turn: $\frac{162.849\pi ft}{8810.37ft/min} = 0.05806852857\ min$

Time Taken During Straight Line: $\frac{7920ft}{8810.37ft/min} = 0.8989406801\ min$

The flight plan works as follows. The UAV takes off in a negligible amount of time, makes a 90° turn, and then goes in a straight line for 1.5 mi. Then, it makes a 180° turn and comes back for 1.5 mi above other pipelines in an adjacent path to the first one to maximize sensed area. Finally, it makes another 90° turn and lands in a negligible amount of time. Thus, in total, the UAV traverses the 1.5 mi straight line twice and makes two entire turns. Therefore, the two above numbers are multiplied twice and then added to one another: $2 \times 0.05806852857\ min + 2 \times 0.8989406801\ min = 1.9140184173\ min$. Below is a diagram of the dash mission's flight plan:

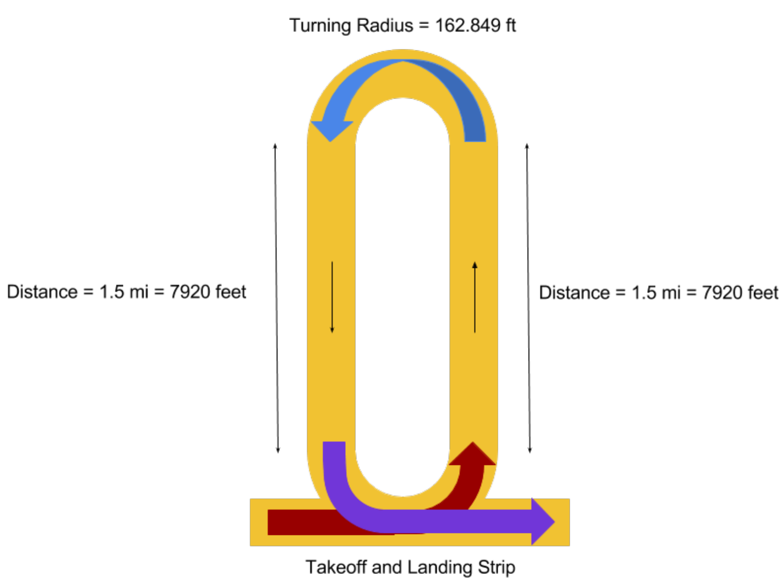

Figure 31: Dash Mission Flight Plan

The farm worker can then plug the Sequoia sensor into the Toughbook to view the collected data and images the camera produced during the flight. This data can then be uploaded on the Andover Blueprints' website and be sent to the data analysts and business decision experts (agricultural advisers) in the company headquarters. With the company's rapid decision support system, the farmer can then take immediate action based on the UAS's findings.

3.3.2 Dash Mission Design Considerations

Because of the nature of the engineering design process, the Andover Blueprints went through many design iterations. The team spoke extensively to the agricultural advisers to inspire ideas. This really gave the team a good idea of what farmers need from a UAS such as the one the group was designing. This made the UAV viable on the market and let the team list multiple possibilities for the dash mission. Here are some of the final options the group considered:

Final List of Possible Dash Missions

- Swiftly carry soil samples, tools, emergency medical equipment, dead plants, or pest traps across farmland
- Quickly monitor crop health, moisture, nutrients, or another data point of a swath of farmland and if there is a problem fly over the entire field in another mission
- Rapidly fly along irrigation pipelines or other agricultural systems and ensure they are in smooth working order

First, the members began by deliberating over missions and ruling out options that would not be reasonable or benefit the customer. The Andover Blueprints chose to focus on corn and potato fields so the team kept this in mind as the group deliberated over the most optimal mission to implement. The first mission in the list was ruled out because it is not useful in a real agricultural scenario. Transporting light items (two or more pounds) is not reasonable as they can usually be carried or driven around. It is not useful for the UAV to carry around medical kits or sandwiches, as this might not be done often enough to be important and operating the UAV for this use would be too expensive or complicated to be realistic. The logistics mission already transports objects such as pest traps, but it is useful because it is meant to carry much more weight with the additional cargo hold into areas that can not be easily accessed by a tractor. The team also deemed it would be better to expand on the data collection capabilities of the UAS. The second option was also deemed unfit because the dash mission states that the UAV must fly 1.5 miles to a location and then fly back. If the UAV was to monitor a swath of crop at the altitude of 230 feet, it would only cover a maximum of 651.40 feet by 1.5 miles which is only a small portion of most corn or potato fields. The average size of corn field in the US is 333 acres, and potato field are usually about 258 acres. Since both crops, but especially potatoes, have incredibly varied yields between fields and even individual acres, a UAV would have to scan the entire area to produce precise results. This would not give the full picture of the field to a farmer and would undermine the purpose of the UAS.

Finally, for the dash mission, the group decided to monitor agricultural irrigation pipelines. This idea was inspired by a talk with a local farmer who spoke of her experience on multiple farms in a conversation with us. She gave us much information of what real life farmers need and what makes a good precision agriculture UAS solution for the market. The pipeline monitoring application is very useful for the farmers, as irrigation pipelines are extremely common on farms, especially in large operations. These pipelines often break with constant use in the harsh environment they are located in. Without a working irrigation system, many of the other data collection missions, such as moisture detection, will not benefit the farmer, especially because collected data from the UAS's Sequoia sensor can be directly plugged into many modern irrigation, fertilization, or pesticide spraying systems. Since farmers cannot afford to lose any time or money on system malfunction, the UAV solution will fly over the irrigation pipeline for 1.5 miles and then fly back along another part or side of the system, while the Sequoia multispectral sensor is using multiple lenses and bands of light to check for weak spots and leaks in the rather large agricultural system. This mission was designed specifically for irrigation pipelines on farms, but can just as well be used on oil pipelines and electrical lines outside of farms and fertilization and pesticide spraying systems in an agricultural setting. This makes the team's UAV and this mission very versatile and useful to a real farmer.

Although the team understood that a multispectral, hyper-spectral, or thermal sensor would be the best payload option, there was still the need to find which specific sensor would be best for the UAS. The selection process eventually narrowed down to just multispectral sensors because of their versatility through their multiple lenses that sense different bands of light. They also fit better into the team's budget than the other two options. The team decided to stick with the Parrot Sequoia multispectral sensor because it is ideal for this mission and therefore the UAS does not need an additional sensor.

Another consideration was the height of the UAV and the area the sensor can cover on the ground. In order to make the UAV capable of meticulously completing the survey and logistics missions, the Andover Blueprints had to compromise on the airframe. The team needed a fast UAV that can hold a large payload and fly for a extended period of time. Even though the Aerohawk is so large, the cargo hold was designed so that it will be removed during the dash mission and the UAV can still fly at the maximum allowed speed of 87 knots. Because of the UAV's speed, the team had to adjust its altitude to the optimal height for the Sequoia sensor or 230 feet. If the UAV operated at a much lower altitude, there would be gaps in the data.

The designed mission is extremely beneficial to farmers because they don't have to leave the field and walk along a sometimes massive irrigation, fertilization, or pesticide spraying system. Time, water, and money are saved because a leak in an irrigation pipeline can be addressed much faster or they can be prevented as the sensor can detect weak spots before they become a problem. These farmers will have access to data very quickly and will be able to share their data with the trained professionals to be advised on their following decisions to maximize farm efficiency and profit.

3.4 Additional Farm Missions

The team designed ten additional agricultural missions:

- Moisture Detection Mission:

  This mission was designed to determine the moisture content of the crops and soil. Using the Sequoia sensor, the drone would fly over a plot of land and calculate the moisture content. According to farmers, moisture content in the soil varies across a field, so having a drone calculate it would be extremely helpful because it allows the farmer to customize irrigation equipment based on the climate.

- Infestation Detection Mission

  This mission was designed to discover infestation in a field. Using the Sequoia sensor, the drone would utilize powerful infrared technology to scan for infestation. This allows a farmer to detect increased infestation and deploy pesticide and/or pest traps as necessary, thus maximizing yield and minimizing damage early on.

- Harvest Yield Estimation

  To calculate harvest yield, a program is downloaded to the Sequoia sensor that allows it to count plants and size/number of product then calculate estimated harvest and yield to monitor over the years and predict income for that season depending on the plant. The Sequoia sensor is calibrated for that specific crop and the drone is flown over the field. This identifies and numbers the crops over a desired field size for a desired and calibrated crop type.

- Creating VRA Maps Mission

  VRA maps are a way of showing the strength of nutrient uptake in a field. To create them, UAV employs the Sequoia sensor to create a map that indicates where plants may need increased nutrients, are diseased, or lack sufficient water and/or sunlight.

- Time-Series Animation Mission

  A time series animation is a series of images that can be stitched together to find differences between healthy and unhealthy plants over a period of time. The animation can be used to show changes in the crop and reveal any trouble spots or opportunities for crop management. By launching the drone with the Sequoia sensor attached, the UAS could compile a time series animation.

- Creating Reflectance Maps Mission

  The purpose of creating reflectance maps is to allow a farmer to create a map that would help them with increasing yields, cutting costs, and increasing business profitability. It also helps with determining which crops need to be looked at more closely and more frequently. The Aerohawk is launched with the Sequoia sensor attached to scan the fields to develop this map.

- Biomass Detection Mission

  The drone would be launched with the Sequoia sensor attached to find biomass in crop residues in order to produce energy. This allows the farmer to reduce disposal costs and pollution, increases energy independence, and helps protect ground and surface water from poisons and excessive aquatic plant growth. With the heavy pressure for farms to be increasingly eco-friendly, this is an excellent way to make steps toward achieving that.

- Scouting fertile land suitable for farming (measure nutrients in ground)

  According to the agricultural mentors, farms often buy more land than they plan to farm on in one year. However, as they grow and prosper, they expand and hope to utilize land that currently goes unused. Seeking out the areas that have greater nutrients and better soil can allow farmers to make smarter choices about where their plants go. The Sequoia sensor is capable of measuring nutrients and moisture content in the ground; therefore, land would be scanned by the Aerohawk, using this sensor, in order to discover the ideal place to grow crops.

- Livestock Monitoring

  Livestock are often scattered across a large grazing pasture. Therefore, the team designed an additional agricultural mission to track animals with a simple UAV flight. The farmer modifies their field size to fit the needs of the farm. This allows a farmer to know when livestock are traveling away from the main barn or straying out of the pasture.

- Weed Detection Mission

  The final additional mission is intended to allow the farmer to seek out the specific areas with large amounts of weeds. Instead of employing hundreds of workers to comb the fields in an effort to eliminate weeds and invasive plants, the drone could be flown over to scan for hot-spots of growth. The farmer could then send employees out to specific parts of the field to target large invasive growths. Many farmers do not realize how bad their weed problem is until harvest time comes, so being able to scan for specific yield damaging invasions proves valuable.

Every additional agricultural mission utilizes the survey mission flight plan (see Figure 28). However, the farmers can rearrange 22 of these 0.25 square mile squares to perfectly fit their field, rather than having a set plan as used in the survey mission.

Each flight is conducted at 230 feet to maximize the ability of the sensor. The payload for each additional agricultural mission is: the previously mentioned Sequoia sensor (0.24 lbs), a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs), and a Wi-Fi Sports Action Camera (0.34 lbs). The plane will fly at 50 knots to maximize speed and quality of scans, for 210 minutes to provide an extended flight time. This allows increased area to be scanned. Just over 5.5 square miles can be scanned in the 210 minutes allotted.

Similar to the survey mission, autopilot is utilized in this mission. The pilot rearranges each of the 22 0.25 square mile squares so that he or she scans the areas that require attention. The pilot does not need to pilot the aircraft during takeoff, landing, or flight. The ground control station is at the edge of the takeoff strip.

Throughout the entirety of these additional agricultural missions, there is a minimal amount of manpower used. The first and most important person involved in this process is the farmer, who will be on standby in case any aerial intrusions or obstacles appear. In this case, the farmer will simply take control of the drone and guide it to a safer area so that no damage is done to either the intrusion or the UAV. The length of each flight varies upon the mission, but since the farmer is not being paid by the Andover Blueprints, the average mission time is irrelevant to the cost of manpower. After the UAV has collected data during the mission, it can be sent to a data analyst who can compile all the raw data into a readable form. Due to the fact that data analysis is mainly compiling data rather than interpreting it, and the process is heavily augmented by computer programs, the team expects this process to take no more than one hour per mission. This costs the team \$35. The only other people involved in the missions are the agricultural advisers. Since the problems farmers encounter are generally similar, a pest infestation for example, the advisers will have a general template on how to fix each agricultural problem. Whereas the specific details might change, there are only so many ways to efficiently fix an irrigation leak. So, the team assumes that it will take no more than two hours per mission for an agricultural adviser to draft a plan for action for the farmer to use, and this will cost \$40. That makes the total manpower cost for one mission \$75.

Because these missions are similar to the survey mission, no compromises were made in the process of designing these missions. Thus, both the three main missions and the additional agricultural missions are executed to the highest degree of precision and quality.

Chapter 4

The Business Case

4.1 Patenting Your Idea

Due to the fact that the UAS qualifies as a machine, the company needs to file for a utility patent in order to protect the idea from intellectual theft. After the team did an in depth search to find out if the UAS system was patentable, the team found no results that were the same as Andover Blueprint's UAS, which means the probability of the patent being accepted is high. In addition, the UAS is a summation of all of its premade parts, so it will qualify as a single invention and thus be patentable as specified by USPTO regulations. However, in order to make sure of this, the company needs to do a patent search. This will cost $300 because the business qualifies as a "small entity" since the team will only employ around 30 people, and has no legal obligation to sell the patent to another larger company. After the patent search has been finished, the fee for the actual patent examination will be $360. These fees, combined with the small entity electronic utility patent filing fee of $70, makes the total cost of obtaining a patent $730. Then, after 3 years, the team will be charged a fee of $800 for a small entity patent. The team can file this patent without employing a patent attorney, because the team's adviser has experience in patent applications and will guide us along the way.

The Andover Blueprints also connected with an experienced patent lawyer to provide key information on the actual process of filing a patent. The lawyer, Winslow Taub, specializes in patent law and was therefore able to provide extensive background on filing a patent and issues that may arise. In order to file for a patent, a set of specifications and 20-22 claims must be submitted to the US Patent Office. Specifications are drawings, writings, diagrams, images, etc. that cover the "invention" that you've created. In this case, diagrams detailing the modified Aerohawk plane along with the implemented sensors, fuselage, and payloads would be submitted in addition to writings detailing the "invention" that was created. Claims are one sentence "claims to fame" that cover the key components or uses of this invention that the team hopes to patent. For example, a claim covering the uses for the survey mission might be:

"A fixed wing drone aircraft that couples:

(a) A multispectral sensor with an HD camera attached to a gimbal to provide an individual with clear imagery and scans in order to indicate

(b) A Wi-Fi enabled multispectral sensor and a Wi-Fi enabled HD camera attached to the aircraft to upload data to a separate computer entity allowing immediate analysis following airborne data collection.

(c) A snakelike flight plan featuring back and forth turns across an agricultural plot of land with data collection through a multispectral sensor in order to provide an individual with data concerning the status of crops."

With pro bono assistance from the patent lawyer, claims and specifications would be submitted as a new and unique design because existing components are combined into a new unparalleled design featuring novel ideas.

4.2 Market Assessment

Agriculture has been the target field for a variety of new products claiming to help increase crop yield through data. Two notable contenders are satellites and airplanes, but due to their costs and inaccuracies, no other technology stacks up against the agricultural UAV. Satellites can cost up to $20 per acre, and aircraft photography can cost $15 per acre, and the data gathered is still full of inconsistencies. Plus, after the data is gathered, it is given to farmers without any analysis, which could be useless unless the farmer knows how to analyze satellite data.

With low upkeep costs, often just costing that of fuel, as well as precise data gathering tools, any farmer would be wise to choose a UAV over other means of technology. And, many farmers do. They buy so many agricultural drones that agricultural UAS's make up 80% of the commercial drone sales. So, there is quite a large market for agricultural drones, and thus numerous competitors, despite the high barriers for market entry. As such, the agricultural drone market has split into two groups: the cheap but ineffective UAS's and the expensive but versatile ones. Unsurprisingly, the range of costs for agricultural drones is wide with a low being around $300 and a high being around $25,000. The Andover Blueprints' UAS is oriented into the versatile but expensive category, but even within this category it is an outlier. For one thing, it costs $13,275.71, placing it almost $2,000 lower than the nearest agricultural drone with similar capabilities. Despite its low cost, the Andover Blueprints' UAV can perform more missions than many of its more expensive competitors. Some missions that the Andover Blueprints' UAV can do that others cannot are weed, biomass, and infestation detection, as well as livestock monitoring. Also, the Andover Blueprints' drone has better physical capabilities than more expensive competitors. For example, most other drones similar the Andover Blueprints' are limited to a maximum speed of 60 knots, whereas the Andover Blueprints' UAV can go up to 87 knots, a limit only due to FAA regulations. Also, with a 2 hour flight time, the Andover Blueprints' UAV can out last most competitors, with their average flight time being around an hour.

However, this is just the market for purchasing drones. Many companies have farmers pay for a service in order to have someone else fly a drone over their fields. The main benefit to this is that it saves time for the farmer, but it is overpriced to be quite frank, with one mission consisting of all the farmer's land costing around $500, depending on the service provider and size of the land photographed. If a farmer buys the team's UAS instead, they will be able to do as many missions as they want, for one low monthly cost of \$360.[1] And, when you pay for data analysis from other services, customers receive raw unprocessed data, which they may not be able to understand. But, with the Andover Blueprints' data analysis service, agricultural advisors are provided with no extra cost to the farmer.

So, with all of this considered, the team projects that the UAS will become the standard choice for high quality agricultural drones, due to its physical durability and its sensor versatility. Both of these factors enable customers to collect more data about their farms than they could with the team's competitors. Also, the market for agricultural drones themselves will likely increase, seeing as it is consistently out classing competitors such as satellite imaging in both accuracy and usage cost. As a result, the team believes that the Andover Blueprints' drone will be able to beat the competition.

4.2.1 Company Timeline

Year 1 Company Timeline

- Day 1- The company starts getting investors in order to obtain initial capital.
- Day 7- The team begins creating the patent application
- Day 20- The team obtains a working location to house all data analysts, agricultural advisors, and mechanics.
- Day 21- The company begins hiring workers for maintenance, training, and data analysis.
- Day 25- Drone production will begin.
- Day 30- The team will begin selling drones and providing additional services to customers with ample time for farmers to prepare for the growing season.
- Day 32- The team will file their patent application, while paying relevant fees for doing so.
- Day 101- The team will meet a 20 drone sale quota.
- Day 170- The team will meet a 30 drone sale quota.
- Day 239- The team will meet a 20 drone sale quota.
- Day 308- The team will meet a 15 drone sale quota.
- Day 377- The team will meet a 15 drone sale quota.

The standard UAS sale quota is 20 drones and it is assumed that day 1 is January 1. Also, the team projects that the drone sales to vary upon the season, with right before and during the growing season having the highest sales. For the first quota, it is expected that

[1]See section 4.4.3 for details.

Day 101 will be under the quota simply because it is a new company, and has not had time to get the public attention needed to draw in customers. However, day 101 aligns with the beginning of the annual sale boom, so the company still expects to sell at least 30 units. Day 102-170 covers the majority of the annual boom, so the sales are estimated to be 10 units higher than the normal sales. Day 171-239 covers the end of the sales boom and into the "dry season" where sales decrease dramatically because the growing season has ended. So, the team expects these factors to essentially cancel out, and that 20 units, the standard, will be sold. After the growing season has completely ended, sales will definitely decline, making the quotas for days 240-308 and 309 -377 much lower than the standard drone sale quota. This cycle will repeat for the rest of the 5 years of the company, but around 25 extra sales will be made each year as the company becomes more publicly known, thus bringing in more customers.

4.3 Cost/Benefits Analysis and Justification

5 YEAR BUSINESS PLAN					
Additional Services	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Maintenance Costs	$ 8,000.00	$ 18,000.00	$ 30,000.00	$ 44,000.00	$ 60,000.00
Profit From Maintenance	$ 2,000.00	$ 4,500.00	$ 7,500.00	$ 11,000.00	$ 15,000.00
Total Maintenance Revenue	$ 10,000.00	$ 22,500.00	$ 37,500.00	$ 55,000.00	$ 75,000.00
Data Analysis Costs	$ 360,000.00	$ 810,000.00	$ 1,350,000.00	$ 1,980,000.00	$ 2,700,000.00
Profit From Data Analysis	$ 72,000.00	$ 162,000.00	$ 270,000.00	$ 396,000.00	$ 540,000.00
Total Data Analysis Revenue	$ 432,000.00	$ 972,000.00	$ 1,620,000.00	$ 2,376,000.00	$ 3,240,000.00
Total Revenue from Additional Services	$ 442,000.00	$ 994,500.00	$ 1,657,500.00	$ 2,431,000.00	$ 3,315,000.00
Total UAS Cost					
Number of Systems Sold	100	125	150	175	200
Total UAS sold	100	225	375	550	750
Total Cost of UAS	$ 1,062,057.08	$ 1,327,571.35	$ 1,593,085.62	$ 1,858,599.89	$ 2,124,114.16
Total Profit from UAS	$ 265,514.27	$ 331,892.84	$ 398,271.41	$ 464,649.97	$ 531,028.54
Total Revenue From UAS Sales	$ 1,327,571.35	$ 1,659,464.19	$ 1,991,357.03	$ 2,323,249.86	$ 2,655,142.70
Overview of Revenue					
Total Costs	$ 1,430,057.08	$ 2,155,571.35	$ 2,973,085.62	$ 3,882,599.89	$ 4,884,114.16
Total Profit	$ 339,514.27	$ 498,392.84	$ 675,771.41	$ 871,649.97	$ 1,086,028.54
Total Revenue	$ 1,769,571.35	$ 2,653,964.19	$ 3,648,857.03	$ 4,754,249.86	$ 5,970,142.70
Cumulative Total Revenue	$ 1,769,571.35	$ 4,423,535.54	$ 8,072,392.56	$ 12,826,642.43	$ 18,796,785.13
Cumulative Net Cash Flow	$ 339,514.27	$ 837,907.11	$ 1,513,678.51	$ 2,385,328.49	$ 3,471,357.03

Figure 32: 5 Year Business Plan

In order to increase business profitability, the team decided to find a niche in the market and then do everything possible to corner it. After much deliberation over which part of the agricultural UAS industry was the most undeveloped, one of the team's members noticed that there was a rift between extremely cheap drones and expensive but exceedingly durable ones. Cheap drones, although easier to sell to the common farmer, is a highly developed industry with many well known competitors dominating the market, so the team decided to avoid making one of these drones. Instead, the team wanted to become the low cost provider for durable drones, a market that is almost nonexistent as of the making of this project. By doing this the team could sell to the farmers who wanted an agricultural UAV to help them with their work, but are not willing or able to pay $20,000 for one. To do this, the team looked for a drone with high carry capacity, speed, and flight time so that customers can perform a wide range of missions and that costed no more than $6,000. With these requirements the team would necessarily find a drone that could maximize the minimum requirement parts of the objective function, and still be sold at a low cost. The ultimate business goal was to sell the drone at $13,000, so that the team's drone would clock in at

$2,000 less than its nearest competitor. After much research was conducted, the Aerohawk was chosen, because its relatively low cost of $5,200 including the 50cc engine and high durability, thus helping the team accomplish their goal of becoming the low cost provider for durable UAS's. Furthermore, unlike many other options, the Aerohawk did not come with a sensor of its own, which allowed the team to find its own sensor that could fulfill all of the missions the team had created. This way the team did not waste money for something they were not planning on using. While the drone was being chosen, the team was also researching sensors, eventually deciding on the Sequoia. Choosing the Sequoia was quite possibly the easiest decision made as the team created the UAS, seeing that it had all of the capabilities needed to finish the specified missions, as well as costed less than its competitors, namely the X5000. The Sequoia sensor costed $3,500, which made the total cost of the core UAV components equal $8,800, giving the team $1,600 to work with, in order to make a 25% profit on the UAV and still only charge $13,000 per unit. From this moment onward, the team created and utilized a versatility function to determine if a part was worth including in the overall system. It was quite a simple yet profound tool, giving outputs by simply dividing component cost by the number of missions utilized, and then dividing one by that number. The higher the versatility function value, the more cost effective the component. For example, the autopilot was used in all of the agricultural missions, and only costs $149.99. Its versatility function value is around .079, which may seem small at first, but is actually an exceedingly high output for the function. This made autopilot a must have for the UAS, and thus made it easy for the team to a lot necessary money to paying for it. After running all of the proposed parts through the function, the team decided on the ones mentioned in section 2.3.2. Unfortunately the total UAS cost was $220.57 over the preferred budget, but since every component was either absolutely necessary for the UAS to function or had an extremely high versatility function value, the team decided to increase the price of the UAV. The end price of the UAS is $13,275.71, which still fits into the market niche that the team is trying to corner.

$13,275.71 may seem like a big investment at first glance, but it is definitely worth it for full time farmers. According to the USDA, slightly more than 80% of farms make the majority of their income from off farm sources, but these farms only account for 12% of all farm sales. For these businesses, buying an agricultural UAS is a waste of money, because the cost of the UAS is higher than the cost in time in resources to simply do the work manually. This is not the case for the largest farms, however, which produce 88% of the farm sales and they typically make a net profit of over $100,000 annually, according to a recent survey from Iowa State University. So, due to the drone's cost of around $13,275.71, it is necessary for the team to focus on selling to the owners of the largest farms in the U.S., who have the farm revenue to buy the UAS. This means that the team's agricultural drone market has approximately 500,000 customers. Although these targeted customers could afford it, in some cases the drone costs 15% of their annual income. As bad as this may seem, the drone will actually more than pay for itself over the course of a few years by utilizing its data to help farmers increase their annual crop yield dramatically.

One such of these abilities is the drone's mission to detect pests, thus helping farmers swiftly remove them before they do too much damage. Assume for the sake of this example that, with the help of the team's agricultural advisors, only 5% of the harvest's crops are destroyed by pests. This is a reasonable number seeing that the pest control sensor only works when the actual crop has already been damaged, but it is sensitive enough that only small portion of the crop must be damaged before pest detection. Studies disagree on exactly what percent of crops are destroyed by pests annually, but the most consensus seems to be around the 20% mark. Using this number with the data from a USDA study that said an average of 118.5 bushels of corn were harvested per acre, it is clear that the actual number of crops originally planted is 148.1 bushels per acre. Had the farmers been using the team's UAS thus reducing crop pest damage to 5% of crop yield, they would have harvested 140.6 bushels of corn per acre, which is a 15% increase in crop yield and therefore an equal percent increase in profit.

Another helpful mission that the UAS can perform is the weed detection mission. Often times farmers believe that if they simply apply weed remover to their crops 2-3 weeks after corn crop emergence, they will minimize the damage weeds have on their crops. Studies have proven this to be false, with weed damage still causing around 15% of corn to be lost per acre due to weeds. Now, obviously, the weeds are not distributed evenly throughout the field, but in a handful of concentrated areas. With the help of the Andover Blueprints' UAV, farmers can locate these areas and concentrate herbicides to combat weeds there, thus reducing both waste and the environmental impact of using herbicides to increase crop yields. This will cause an increase of 20 bushels per acre, or a 10% increase in corn crop yield. These are just two missions out of fifteen that the team's drone can do, and they have already increased corn crop yield per acre by 25%, thus making the drone pay for itself and then some over the course of one year.

4.4 Additional Services

The Andover Blueprints' company, although mainly selling high quality drones, also provides a wealth of extra services to maximize the amount the consumer benefits from our service. These services are UAS training, data and agricultural analysis, and maintenance. None of these services are required for the consumer to use, but many are very helpful and highly recommended for increasing farm production and taking care of the UAS. These services are also offered so the farmer can generate more revenue and use our UAS to its fullest potential. This business support network behind our product is really where our team is ahead of the competition. The team did not simply strap a camera to a drone but the team kept real farmers in mind and built a innovative as well as useful service around them.

4.4.1 Training

Role	Hours	Cost Per Hour	Subtotal
Flight Trainer	10	$ 25.00	$ 250.00
FAA Compliance Trainer	3	$ 20.00	$ 60.00
Systems Trainer	7	$ 30.00	$ 210.00
Safety Trainer	10	$ 20.00	$ 200.00
Total Trainer Hours (not to exceed 50)	30		
Total Trainer Labor Cost			$ 720.00

Figure 33: Trainer Labor Costs

One of the most important services the company offers to its customers is UAS training. This training makes use of the training division's UAS safety and legal experts[2] to give customers new to operating drones a 30 hour comprehensive learning plan. As any UAV pilot will tell you, learning how to fly a drone is no easy task. In order to ensure that potential buyers do not shy away from UAS agriculture, the company includes the $720 training cost within the cost of the UAS. So, simply by buying a UAS, anyone can learn how to use it for no additional cost. The training program teaches customers how to safely pilot the UAV, a course on understanding the mechanisms of the drone, and how to deal with any emergencies that may arise while the UAV is in flight. This course will more than prepare customers to pass the practical section of the Airman Certificate Examination. Also, the training includes a special FAA compliance trainer which will teach customers things like the Line of Sight Rule and prepare them for the knowledge section of the Airman Certificate Examination, seeing that the drone qualifies as a business UAV.

4.4.2 Maintenance

Role	Hours	Cost Per Hour	Subtotal
Maintenance/Repair Technician	1	$ 25.00	$ 25.00
Electronics Technician	1	$ 25.00	$ 25.00
Support Systems Technician	1	$ 30.00	$ 30.00
Total Maintenance Labor Cost			$ 80.00
Profit (For this piece type in the % profit you want to make on the sale of your system and training into the white box to the right. You may not exceede 25% profit)		**25%**	$ 20.00
Total Maintenence Price			$ 100.00

Figure 34: Maintenance Labor Costs

Accidents happen. Whether a customer accidentally crashes a UAV or the drone's parts simply stop working after lots of repeated wear and tear, some maintenance will inevitably be necessary. Because of this, the company strongly encourages customers to buy an insurance policy for $61.08 per year on their UAS. This service is even necessary in some territories that have changed or are changing their guidelines to make drone insurance mandatory. This policy works much like car insurance, where every month a customer will pay a small amount, regardless if the drone has been repaired or not that month. Then, if the UAV does malfunction, the insurance policy will cover any necessary costs. This is both economical on the part of the buyer and the insurer. From the buyer's perspective, many of the parts on the UAV are sensitive and expensive when bought one at a time by them. So, if a UAV crashes or a malfunction does occur, replacement parts and specialized repair labor will total to a very large cost on the farmer. The team estimates that one physical UAV crash will cost take 25 hours to repair fully and the labor will cost $625. A sensor malfunction will take 15 hours to repair and cost $375 in labor costs, and a support systems breakdown will take 12 hours of work and cost $390. Also, it was concluded that in an accident, both the UAV and the sensors would need repair, so the total cost of one accident will be $1000.

[2]See section 2.3.5 for more details.

This number is so high that its cost is more than 16 years worth of insurance, making the insurance plan far superior for customers than a pay-as-it-breaks plan. On the insurer side of things, this system works because it distributes risk, and therefore cost, over a large amount of people. Additionally, because the UAV is automatic, unless there is a safety concern and the operator must take over, the team does not anticipate many crashes, making the risk of having to pay the maintenance bill relatively low. And, as more people join the service, the amount of insurance income to pay for any potential accidents increases, thus, "distributing the risk" of crashes over a greater population.

4.4.3 Data Analysis

Role	Hours	Cost Per Hour	Subtotal
Data Analysis	48	$ 35.00	$ 1,680.00
Agricultural Advisors	96	$ 20.00	$ 1,920.00
Total Data Analysis Labor Cost			$ 3,600.00
Profit (For this piece type in the % profit you want to make on the sale of your system and training into the white box to the right. You may not exceede 25% profit)		**20%**	$ 720.00
Total Data Analysis Price			$ 4,320.00

Figure 35: Data Analysis Labor Costs

Whereas the Andover Blueprints' UAV can carry large payloads, its main feature is its Sequoia sensor that can help the farmer get critical information to help increase crop yield. The UAS is an extremely powerful data solution so data analysis is essential for all of the missions except for logistics. Seeing as the team expects the farmers to use the UAS for this purpose, having a pay-as-you-go data analysis service seems inefficient and costly for customers. In order to solve this problem, the team offers a monthly subscription service for data analysis and agricultural advising. This subscription based approach also happens to provide a flow of revenue for the team's company rather than a one time fee. It is projected that each individual mission will require 3 hours of labor from experienced employees which costs \$75, and that on average, a farmer performs four missions per month. This costs the company \$300 in labor per month, making the monthly price for the service \$360. Such a monthly bill may seem expensive at first, but because all of these analyses provide useful data to help improve crop yield, the service actually pays for itself and then some. For example, the UAS can scan for pests that can destroy 15%-47% of crops, depending on the study. However, with the expert advice from the agricultural advisers, this number will be greatly reduced to an estimate 5%, thus increasing the profit that the farmer will make. What really sets the Andover Blueprints' solution apart from the competition is that it is not just a UAV with a sensor strapped to it. The team has designed an entire package solution for the customer. Employees will analyze data collected by the UAV and will guide the farmer to make the best decisions to increase efficiency making the UAV a fantastic catalyst for their business. To provide this service our expert employees will utilize machine learning algorithms and other features such as daily weather reports and the time in a crops growth cycle to provide up to date real time data and the smartest advice for the customer to take the best decision for their interests/business. As previously mentioned in section 4.2, the upfront cost of this state of the art data analysis service is much cheaper than its competitors. They can charge up to $500 for gathering data on an 100 acre field, whereas the team's data analysis costs $140 less than that. Due to this and the fact that most farmers are not accustomed to doing complex data analysis themselves, the team expects nearly all customers to use the data analysis service provided. Assuming that the sells the same number of units as projected in section 4.2.1, the total revenue from the first year of data analysis will be $432,000 with a profit of $72,000. It should be noted that these number will increase as more units are sold and more customers join the service, eventually reaching a yearly revenue of $3,240,000 and a yearly profit of $540,000 after 5 years.

4.5 Additional Commercial Applications

Other than agriculture, there are many markets where the Andover Blueprints' UAS is incredibly beneficial. Even though the Andover Blueprints is a very focused company and the main industry the company operates in is agriculture, these additional missions are necessary for our business because of the lack of agricultural revenue during the New England winter. The strength of the UAS the team has created is that it is exceptionally versatile. This advantage sets this UAS apart from the competition on the market. It is incredibly useful in a real world scenario for an actual customer. The Sequoia sensor is used in almost all of the UAS's missions allowing a customer to complete many diverse objectives without changing the sensor. The Sequoia multispectral sensor is incredibly powerful because of its five lenses (red, green, NiR, RedEdge, and visual spectrum) and its sunlight sensor which ensures impeccable accuracy when measuring reflected light. It can be utilized in hundreds of missions ranging from agriculture to renewable energy. For example, the UAS's wide sensor array makes it great for geographical survey missions. A combination of green, red, and NIR filters allow for imaging natural vegetation, surveillance of man-made objects, and even beneath the water. This expands the consumer market for the product to large data companies, such as Landpoint, that collect and process the relevant data of the land to determine where and how they should be working both in urban and undeveloped areas. Also, as previously noted, the UAV's Sequoia sensor is able to monitor man made objects, including electrical lines, oil pipelines, and solar farms. This can in turn help construction companies spot defects with buildings that are viable to collapse. Not only that, but the UAS can even aid corporations like National Grid preemptively spot structural problems in their electrical lines and fix them before they cause a loss of power. The same goes for large oil companies that do not want to lose their cargo because of pipeline leaks or even full on oil spills. In the unfortunate event that an oil spill or any other sort of pollution begins to spread, the Sequoia's ability to detect disturbances both on land and water could assist environmental agencies in determining a strategy to quarantine the spill zone. Additionally, the drone's NIR and green light sensor can be used to find invasive species of algae and give local environmental agencies an idea of how restore the ecosystem to its most natural state. With the Wi-Fi Action Sports Camera on the UAS, the team's drone can also work for industries such as law enforcement, by performing routine surveillance missions on city streets, thus allowing on duty cops to spend their time elsewhere. For more suburban or rural areas, local governments can use drones to determine the ice thickness on lakes and ponds to see if it is safe for ice skating.

One final non-agricultural use of the UAS would be for the U.S. military. The military is one of the largest UAS consumers in the market, making it an ideal business partner. The team's UAS will be able to perform reconnaissance missions using its multispectral sensors, as well as deliver payloads to various destinations as needed, using the UAS's internal GPS. None of these stated applications require any changes to the original drone's sensor array or physical aspects, which makes entering these markets highly feasible for the team.

Because the team did not want to waste money paying for extra abilities that would be illegal to the common consumer, even without the FAA regulations the drone's capabilities would be the same. For example, the UAV cannot fly much faster than 87 knots. This is due to the fact that when the team decided on a engine, they chose one that was as cost effective as possible, instead of spending extra money to have the drone's max speed be higher than the legal limit. This lack of necessity to alter the UAS holds true even in foreign markets as well, because the U.S. is spearheading the drone regulation initiative. As a result, foreign countries have relatively light regulations placed on UASs, so it is easy to sell drones globally. In fact the only main difference between the U.S.'s drone policies and those of other countries is how to actually get the pilot's permit. For example, if the drones were to be sold in Canada, owners of the team's UAS needs to apply for a Special Flight Operations Certificate (SFOC), but in countries like China no such certification is required. Other countries like India, simply restrict UAS operations over public places, with few regulations about how they are flown in private airspace. To ensure that every customer can obtain their permit if necessary, FAA compliance trainers will be trained for the regulations of other countries too, so that the team's company can easily expand into other markets as needed.

Chapter 5

Conclusion

Following months of meetings, reiterations, and teamwork, the Andover Blueprints completed an engineering design notebook that thoroughly documents the plan for the creation of a multi-use UAS for farming and other applications as well as the elaborate business case and extensive services behind the product. New and returning team members collaborated on the design of an agricultural drone and the numerous UAS missions to increase crop yield in the Northeast.

The team recognized that each mission was designed to test the UAS's capabilities in a different manner. The logistics mission tests payload capacity, the survey mission tests endurance, and the dash mission tests speed. With this in mind, the team crafted solutions for each mission that maximized these values so that the final product was as versatile as possible, in order to give farmers the most use for their investment.

The logistics, survey, and dash missions bring pest traps, fuel, and tools to farmers in the field, scan for crop health, and monitor irrigation equipment respectively. After the team brainstormed the concepts for these and 10 other missions, consideration and calculation of variables such as flight speed, height, route, and time was needed. Inquiry into these questions led to more complex analysis, causing the team members to find things like the quantity and weight of fuel needed for the UAV to finish the mission and how wide the UAV's turns were going to be. Similar to the last step, to calculate those variables, the team needed to find if the payload weight with fuel would overload the UAV and if the turn radius would cause capture too much or too little of the field being measured. Throughout this process, the team had to adhere to FAA regulations and economic restrictions to make the UAS legal and affordable to potential consumers. Additionally, they had to consider the cost and process of patenting the UAS.

The success of final design was mathematically quantified using the objective function calculator, as shown below:

Objective function	
Mission 1 (Logistics)	
Payload weight	20
Objective Function 1	0.8620689655
Mission 2 (Survey)	
Time aloft (minutes)	210
Objective Function 2	0.875
Mission 3 (Dash)	
Cruise velocity (knots)	87
Objective Function 3	1
Additional Missions	
Total Number of Missions	13
Objective Function 4	0.9002051051
Business	
Total revenue minus expense for five-year period	$ 3,471,357.03
Total revenue for five-year period	$ 18,796,785.13
Objective Function 5	0.184678231
Objective Function	
Total Objective Function	0.7644

Figure 36: Objective Function Values

Although the team felt that the objective function was only a partial measure of success, it worked hard to maximize values in order to prove that the challenge statement was fully understood and addressed. For the logistics mission, the key objective function value was the payload weight. This shows that the challenge is emphasizing the value of being able to transport a large payload for the farmer using the UAV. Thus, the team worked to design a UAV with a large payload capacity. When designing the UAV to conduct the survey mission, the team worked to increase the endurance. The flight time was the main variable in the survey mission objective function, indicating that the purpose of the mission was to demonstrate the time aloft that the UAV could withstand. For the dash mission, the cruise velocity of the aircraft has a significant effect on the mission objective function. This indicates that maximizing the speed of aircraft on this mission produces a stronger solution and therefore a better multiuse UAS for a farmer. The number of additional missions has the potential to notably increase the additional missions objective function. It can be assumed that this indicates that increasing the variability of the UAS increases its helpfulness to a farmer and is therefore a better solution, thus a higher objective function as a result of it. With this in mind, the team worked to increase the number of additional missions that the drone could create. Finally, the average percent profit that the team hypothetically makes on the services and products offered is the single-most effective value to increase the objective function for the business case. This indicates that the competition values this aspect of the business case, so increasing it allows the UAS to be a better product. However, the competition limited this value to 25%; therefore, the possible objective function for the business case is limited to 0.20. In essence, the objective function allowed the team to quantify the effectiveness of the solution and better understand the purpose of the challenge.

All in all, this competition shined a light on the detail required to create a feasible tech startup and equipped the team members with skills they will carry on in their STEM careers. The Andover Blueprints are grateful to RWDC for providing a program that has inspired them to continue being intrigued by engineering and design.

Chapter 6

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