FY16 RWDC State Unmanned Aircraft System (UAS) Challenge: Moisture Detection in Precision Agriculture

Team Name: Big Blue

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Roshan Benefo	17	12th
Jocelyn Shen	15	10th
Alex El Adl	14	9th
Darcy Meyer	15	10th
Vishvesh Dhar	15	9th
Ruide Wang	17	10th

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All team members have filled out the survey.
Our objective function is: 0.470298.

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0.1 Abstract

With a estimated additional two billion people on Earth by 2050, a food crisis is bound to emerge. Furthermore, recent droughts in the United States have shown that a water crisis is imminent as well. As proposed in the FY16 Real World Design Challenge, we have taken on the task of designing an unmanned aerial vehicle (UAV) and associated unmanned aerial system (UAS) that can use current technology to help in moisture detection in precision agriculture. Our goal was to detect moisture levels in a local food bearing crop using our UAV and associated UAS. Our system had to efficiently detect moisture levels while keeping our costs at a minimum.

We used the X5000 multispectral sensor to detect the moisture content. We chose the X5000 multispectral sensor because it is a very high quality, yet cost and weight effective option, and it fits our needs almost perfectly. We needed a sensor with a high resolution so moisture could be accurately detected at high altitudes and at all stages in the growth process. We also needed a sensor with a large field of view to decrease the amount of passes the UAV has to make over a field to decrease operation time. We did not include a normal CCD/CMOS camera because the UAV will be on autopilot most of the time and the operator will always have a visual of the aircraft. The video camera would add extra weight and cost to our UAV and would not bring extra value to our product.

In order to achieve these goals, our team selected a UAV that could effectively detect moisture levels in corn from high altitude and medium speed. The UAV we found, the Penguin B, was produced by www.uavfactory.com. In designing our solution, we attempted to minimize cost by creating a semi-autonomous UAV, that would allow us to minimize the operating team needed to use it. We also avoided redesigning the UAV from the design produced by www.uavfactory.com. We felt that changing the design significantly would only add cost to the solution.

Initially, we estimated our flight time to be extremely high, in the order of around 3+ hours. Thus, while searching for a UAV, we wanted something that could not only hold our payload of around two pounds, but also one that could stay airborne for great lengths of time. The Penguin B was perfect for both needs - it is able to hold a payload of around 23 pounds, and stay in the air for over 10 hours. As we went through the design process, we realized that although we did not need nearly that much endurance, the Penguin B provided for a very fuel efficient platform - we could finish an entire mission

of three flights with under half a dollar of fuel. Furthermore, at a cruise speed of around 50 mph, the Penguin B was able to complete each flight in around 35 minutes, allowing for multiple flights per day.

To keep costs at a minimum, we made sure that the flight plan of the UAV was the most efficient because this would mean that flight time would be at a minimum, thereby reducing the amount of fuel carried during the flight. This would obviously reduce the cost of obtaining fuel, which helps lower our 5-year cost. This way, the 5-year cost variable in the objective function is kept at a minimum in order to maximize the revenue obtained, and make our UAV product a viable contender on the market.

Chapter 1

Team Engagement

1.1 Team Formation and Project Operation

Right from the beginning, we had to put a lot of thought and consideration as to who should be on the 2015-2016 Andover RWDC Team. The first step was recruiting members with varying skill levels in STEM. As a team of seven people, we were 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, we knew that we would create a successful team. This is even true in the real world. In terms of leadership, Kunal Vaishnavi and Roshan Benefo took the roles of project managers, and they worked together to coordinate this project from start to finish. Kunal had experience in STEM from First Lego League (FLL), various summer camps, and leadership experience from leading other STEM projects before. Roshan had experience in STEM from FLL and he brought his experience in maths and sciences to the team. Being the oldest member of the team, he was able to use his leadership experience to lead the team with Kunal. He helped the team in a variety of aspects, including designing/choosing the UAV and creating the business plan. Jocelyn had extensive experience in VEX Robotics, CAD design, and programming which helped the team in designing the UAV in PTC Creo, creating the flight plan, and choosing the UAV. Alex had experience in flying RC drones and planes and from attending robotics and programming summer camps. He focused on the way we would detect the moisture content of the food-bearing crop.

Darcy brought her 3D modeling, mechanics, and programming experience to the team. As a result, she helped in a variety of tasks, including designing/creating the UAV and flight plan and choosing the support equipment. Vishvesh (Vish) had experience flying drones and in robotics and using simulators and RC drones. With his knowledge, we were able to determine the C3 equipment we needed and ask him any questions about UAVs. Ruide had experience flying drones and RC models. This was useful to the team because we were able to ask him any questions about UAVs as well.

1.2 Acquiring and Engaging Mentors

On our team, Jocelyn's father was our main mentor. Jocelyn's father, Dr. Weixin Shen works as an aerospace engineer in Aerospace. He has also worked at MSC software and L3. Having Jocelyn's dad as our mentor has been beneficial in that we can conveniently ask questions and receive help when needed. Also, as a result of having a parent mentor, we did not need to reach out to identify and leverage mentors early and throughout the challenge process. During the last few days of the competition, we also contacted Mr. Bo Pollett, an aerospace engineer, to help us with our limit load and pitching moment coefficient calculations. After a short Skype call with Mr. Pollett, we were able to find the necessary materials and equations to calculate these values.

1.3 The Project Goal

Many companies have recently started to experiment with UAVs, given the potential applications that these vehicles can provide. Due to the upcoming food and water crisis that will impact the United States, the ability for farmers to increase crop yield and maintain profitability is crucial. The main goal of this project was to design a possible UAV that can detect moisture content in a food bearing crop in the most economical way. As said in the challenge document, the objective function is a mathematical way to quantify the solution.

We had to be able to design an unmanned aerial vehicle and associated unmanned aerial system that can demonstrate an efficient way to detect moisture levels, an effective way to build a UAV, and a business profit for

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

Figure 1.1: Objective Function

the company. Airframe efficiency (1- $\frac{W_E}{W_{TO}}$) allowed us to quantify how effective our airframe weight was. We needed to show that we used the lightest possible airframe for our payload. Lighter air frames require less fuel, and, for the most part, have a lower cost, thus allowing our business model to be more profitable. Cost effectiveness (1- $\frac{C_{AF}}{C_{UAV}}$) constrained us to purchasing the cheapest possible airframe that would allow us to carry out the mission. Maximizing business profitability ($\frac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}$) had us minimize operational expenses to increase our overall profitability. This was done by carefully selecting our operational personnel and consumables and choosing an appropriate service cost that was competitive in the market.

Ideally, our solution should reach an objective function approaching one or higher. Our solution's objective function was 0.47026117.

1.4 Pedagogy

Right from the beginning of the competition, as a team, we decided to use Google Drive instead of Windchill because Google Drive made it easier for everyone to collaborate and share things with one another. We ran into an issue, however, during our winter break. Jocelyn's computer's network adapter broke and she had both Mathcad and Creo on it. As a result, she was forced to use her parent's computer. This became a problem because if we needed to edit the files, we would not be able to do so because she lives on the West Coast so, while at school, she would not have access to her parent's computer. Thus, we had to obtain several licenses for Mathcad and Creo, one each for her parent's computer and one each for a school computer. This is also when Google Drive became handy as we were able to upload the files she created and download and edit them on a school computer. No matter what technical difficulty arose, we worked together as a team to overcome and persevere.

1.5 Our Perspectives on STEM

RWDC has taught us that STEM requires a lot of thinking, brainstorming, and communication. Engineering requires collaboration, experience, and hard work in order to pull off a final product. At the beginning, we jumped right into the research and started brainstorming designs, but we had a lack of team members to get all our tasks done. As soon as we got more team members, we started making more decisions and eventually pulled together a design.

Each of our team members has now found new passions in STEM that they had not had before, thanks to RWDC. For example, Jocelyn, who had previously not enjoyed CAD because of its many restrictions, has discovered that there are no limits to a design. RWDC has also shown Roshan and 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 opened up a new appreciation for the creative and understanding for each piece of C3 equipment in order to increase the UAV's efficiency. Through the RWDC design process, Darcy has seen the dependency of different design factors on each other and has realized that these factors must be prioritized in order to reach a decision. Last, but not least, Ruide also learned that nothing in engineering is about solo work. One person cannot finish a project of this magnitude by themselves and multiple viewpoints bring diverse opinions to an often better final product.

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

Chapter 2

Our System Design Process

2.1 Conceptual, Preliminary, and Detailed Design

At our first meeting, we started considering which airframe to use, which sensor to use in order to detect moisture content most accurately, and which crop to chose. Our first step was to analyze the challenge. We read over the rules and detailed background and then summarized these documents.

2.1.1 Engineering Design Process

Our next step was to chose a crop. We did some research on several crops commonly grown within the United States: oranges, corn, wheat, and apples.

Crop	Crop Dimensions	Location	Growth Cycle
Apples	15'	Michigan and Washington	3 years
Corn	5'	Midwestern America	3 months
Wheat	4'	Great Plains	8 months
Oranges	18'	Florida	3 years

We chose to use corn because it grows quickly and is one of the most cultivated crops in the world. After looking at the different possibilities, we chose the X5000 multispectral sensor. After choosing our sensor, we chose our airframe accordingly. We limited our airframe decisions based on the sensor's weight and field of view, which contributed to the aircraft's payload and flight plan. When we chose our airframe, we took into consideration the design's cost, maximum payload weight, and endurance. In order to find an airframe, we first did research on all UAVs in general. Then, we looked at specific designs that fit our sensor choices. In order to narrow down our choices, we made a table of separating the pros and cons of tractor verses pusher airframe designs and a table of different types of potential landings (belly, vertical, parachute, or wheels-down). In choosing a landing, we searched for one that would be safe, cost-efficient, and would allow us to mount the sensors on the bottom of the plane. After selecting a wheeled landing, along with a pusher design, we pulled together a collection of designs that fit our requirement and chose an airframe.

2.1.2 Conceptual Design

After identifying all the restrictions our aircraft had, we still had enumerable possibilities for our design. We separated the designs into two groups: group 1 (weighing under 20 lbs, operating under 1200 ft above ground level, and unable to fly above 100 knots (KTS)) and group 2 (weighing between 21 lbs and 55 lbs, operating under 3500 feet above ground level, and unable to fly above 250 KTS). These are the two designs that we narrowed down through extensive research:

1. *Group 1*: Trimble UAS [1]

Weight	2.5 kg
Endurance	50 minutes
Cruise Speed	22.352 m/s kg
Takeoff Method	catapult
Type of Landing	belly
Other	Autoflight; made of impact resistant foam

[1] http://uas.trimble.com/ux5

2. *Group 1*: eBee [2]

Weight	0.69 kg (empty), 21.5 kg maximum takeoff
Endurance	50 minutes
Cruise Speed	11-25 m/s
Takeoff Method	hand-thrown
Type of Landing	belly
Other	battery powered

3. *Group 2*: Penguin B UAV [3]

Weight	10 kg (empty), 21.5 kg maximum takeoff
Endurance	10+ hours
Cruise Speed	22 m/s kg
Takeoff Method	car launch
Type of Landing	wheeled
Other	gas engine

Our conceptual designs were influenced by:

- Payload capacity (our aircraft has to be able to carry our chosen sensor)
- Endurance time (the aircraft must finish its mission)
- 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 our business profitability)
- Weight (this affects the bank angle of the aircraft, which in turn affects the turning radius, and reduces our airframe efficiency)
- Landing method (the aircraft should be reusable, so it needs a safe landing)
- Takeoff method (affects the time of the operation)

[2] https://www.sensefly.com/drones/ebee.html
[3] http://www.uavfactory.com/product/46

The final design we chose was the Penguin B. While choosing our final design, the Penguin B, we were primarily influenced by the air frame's long endurance. Marketed as having an endurance of over 10 hours, we soon realized that this aircraft was the only one on our list that would be able to complete the mission without needing to land, refuel, and take off again.

2.1.3 Preliminary Design

Based off our knowledge of the sensor's field of view, we could then calculate the altitude and maximum velocity of our aircraft. We researched the pros and cons of using a tractor design versus a pusher design for our airframe.

	Pros	Cons
Tractor	Propeller receives direct, undisturbed airflow Doesnt require long takeoff and landing space More maneuverability	Slower
Pusher	Fast Easy to belly land	Requires long runway Less maneuverable

After going through the two types of designs above, we decided that the Penguin B model most fit our payload and endurance requirements. Because it is a pusher design, it is faster, thus reducing our mission time. It also uses a wheeled landing, which is a safer landing. The Penguin B is lightweight but still able to have a payload capacity great enough to carry the cameras. One of the disadvantages of this design is that its high cruise speed causes the aircraft to have a larger turning radius, making our flight plan longer and more complicated. We chose not to use the Trimble design because it has a belly landing, not a wheeled landing, and also because its payload capacity ended up being too small to carry our payload. Its endurance of 50 minutes is also significantly shorter than the Penguin B's. The advantage of the Trimble was that it was much lighter than the Penguin B.

2.1.4 Detailed Design

First, we determined the appropriateness of our sensor choice, the X5000 multispectral. The multispectral sensor was appropriate because its quality is excellent and the cost is appropriate. The X5000 specifications are:

Cost	$5,500
Size	63.5mm x 63.5mm x 50.8mm
Field of View	40 x 20 degrees
Resolution	2048 x 1536
Weight	1.4 lb
Stabilization	Excellent
Roll Limit	30 degrees
Pitch limit	30 degrees

We also drew some diagrams of the X5000's field of view. These drawings showed us that the X5000's field of view was sufficient to measure 340 ft laterally, which is roughly 113 rows of corn (each row being 3 feet). However, to make sure that our detection is accurate, we are using a field of view of 330 ft across, which is 110 rows of corn.

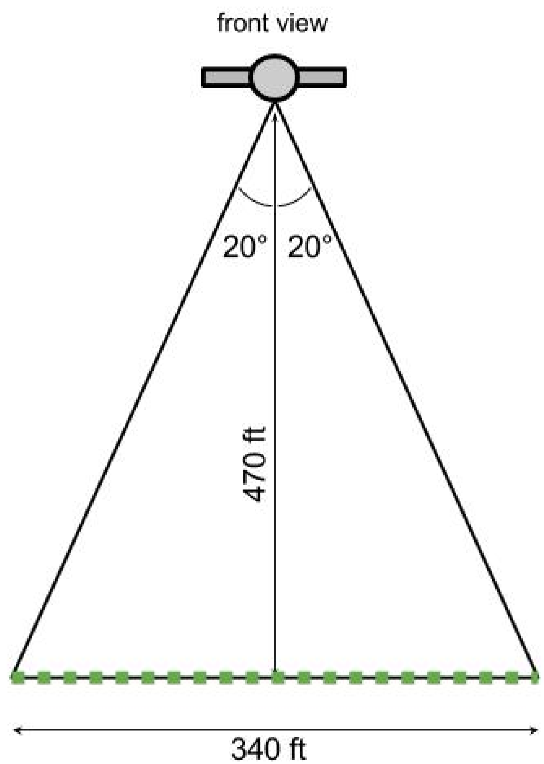

Figure 2.1: Camera visualization

At an altitude of 470 ft (within FAA regulations), our camera can view 340 ft in the x direction:

$$tan(20) = \frac{\frac{1}{2}x}{470ft}$$

After choosing the Penguin B airframe, we calculated the maximum bank angle the aircraft could safely sustain in a turn. Calculating our bank angle (in section 2.7) allowed for us to calculate the minimum turning radius of our aircraft, which was essential in determining the most efficient flight plan.

2.1.5 Lessons Learned

In each design phase we learned how to organize our 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), we needed to communicate really well as a team. Since our team is based in a boarding school, it was very difficult communicating over the break. Eventually, we 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 we learned that it is always better to have more options than less options. We learned that we should not just conceptualize a few designs, because each design has its flaws. It is better to think of as many designs as possible, chose from those, and modify them, rather than have very few designs to chose from.

Preliminary Phase

During the preliminary phase we learned that it is impossible for us to choose an absolutely perfect design. We could not pick a design because each of us wanted an absolutely perfect design. We focused too much on each positive aspect of each design. In the end, we learned that it is important to prioritize design choices.

Detailed Phase

During the detailed phase we learned how to make specific modifications to improve our design. We learned how to use Mathcad to do calculations and visualize our design using Creo.

2.1.6 Project Plan Updates and Modifications

One of the changes in our project plan involved adding more team members in order to split the jobs. We assigned roles to each member. For example, one person to work on the CAD and Mathcad projects and others to handle the flight plan. Also, at first our research was very disorganized and hard for other team members to understand. We reorganized the research on Google Drive by sorting it into tables and outlines. In this way, each team member could reference all of our research more quickly. Before we chose the Penguin B, we ran through several designs: our first design was a hybrid design but in order to reduce complexity, we changed our design to a fixed wing pusher. Once we conceptualized the fixed wing pusher design, we changed our design again to the Penguin B.

2.2 Selection of System Components

Selection of our aircraft's components was the most important step in our design process. Choosing our payload gave us a distinct idea of which airframe to use, because the airframe type is very dependent on the payload it needs to carry. When choosing our system components, we created tables on Google Drive to compare each possible candidate. Our team split into groups to focus on each component and write out all the pros and cons of our decisions.

2.2.1 Payload Selection

When we first began to conceptualize the most effective strategy to measure the amount of moisture located in the plant leaves and soil, we looked at the different sensors available to remotely sense the overall moisture content and health of the crop. We wanted to mount a sensor or multiple sensors onto the bottom of our UAV. A sensor had to be light, cheap, but most of all, accurate, so we could receive accurate data. A high resolution sensor would be needed to inspect corn plants at all stages of the growth cycle while still being able to fly high.

We looked at some different ways to remotely observe moisture content:

1. Direct

- Thermal Sensor
- Multispectral Sensor

- Synthetic Aperture Radar
- LiDAR

2. **Indirect**
   - Indicator Crops
   - Crop Color
   - Growth Rate
   - Amount Of Chlorophyll In Leaves
   - CCD/CMOS Camera

At first, we considered utilizing an indicator crop as a way to determine the amount of water in the soil and plant, as it would be the simplest solution to the problem. Soon after, we realized that this would be a highly unreliable and inaccurate option so we decided on mounting a sensor or multiple sensors.

By separating the possible sensors into two categories, direct (radar and infrared) and indirect (cameras), we were able to start going through these categories. We realized that an indirect sensor (camera) would not be useful because we needed to measure the moisture content, which would require a direct sensor to measure it. Thus, we researched direct sensors specifically. We took into consideration the field of view of each sensor, its accuracy, and its cost. To make the selection process easy, we made two tables, one table with CCD/CMOS sensors and one table without CCD/CMOS sensors.

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°

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°

Our superior aircraft combined with this exceptional camera makes an extremely effective tool for precision agriculture. The X5000 sensor measures the moisture content in leaves remotely by sending various wavelengths of light. The sensor picks up the reflected light and analyses it. Depending on the wavelengths of light that come back, it computes the water found in the crop or soil. It then stores this data in our Raspberry PI module aboard the aircraft. The data is later uploaded onto a computer and analyzed to increase crop turnout rates immensely by telling the farmer the exact state of his crop. Our product reduces water use and increases profits for the farmer.

The large field of view from the X5000 (see section 3.1) increases the speed at which our aircraft can fly because the camera only shoots at one frame per second. The X5000 multispectral sensor has a vertical field of view of 20 degrees. At our altitude of 470 feet this would translate into a vertical viewing area, on the ground, of 176 feet. This would mean that our UAV cannot travel faster than 176 feet per second so that we cover all of the crop field with no gaps in our data. According to our flight plan, the UAV will travel at around 72 feet per second.

We were thinking of including a normal video camera so the user could view their field from above. In the end we decided against including a "normal" CCD/CMOS camera because the UAV is on autopilot most of the time and the operator will always have a visual line of sight of the aircraft. The video camera would add extra weight and cost to our UAV (which we are trying to reduce) and would not bring extra value to our product.

Our UAV will be the best option on the market for precision agriculture drones because of its high quality yet cost effective design and will help grow food more effectively for the rapidly growing population.

Figure 2.2: X5000 Multispectral Sensor

2.2.2 Air Vehicle Element Selection

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

- Composite airframe
- V-tail
- High-mounted wing with ailerons
- Tricycle landing gear

It contains the following sensors and electronics:

- GPS system
- 900 MHz Data Transceiver
- Autopilot
- Multiplexer Analog/Linear
- Serial 10 Servo Controller

- 500 mAh, 22.2 Volt Battery

The reason we chose a pusher design is because it is more energy efficient than air crafts with rotors. Fixed wing pushers are also much stronger and stabler than many other designs, allowing us to carry enough payload to carry out the operation. We chose to use a wheeled landing because it is safer than the other landings (parachute and belly). Also, fixed wing pushers are much more energy efficient than other designs.

Our UAV uses an X5000 multispectral camera because of its high resolution, field of view, and reasonable cost. Our design also uses a Raspberry Pi for data logging. We used a Raspberry Pi because it a cheap and very efficient way to capture data and transmit it to a computer. Rather than having all of this done on the UAV itself, we decided to let all of the processing occur on the computer so as to make the UAV need as little electronics as possible and as light as possible.

Our choice of power plant is a 3W 28i engine because of its low weight. The engine weighs 2.64 pounds, and generates 3.35 hp, producing an excellent power output to weight ratio.

The servo controller, battery, gps, 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 cost of the bare airframe is $10,090. With the electronics, sensors, and powerplant, the airframe costs $14,812.

2.2.3 Command, Control, and Communications (C3) Selection

When we were deciding the structure of the C3 system, there were three distinct strategies we took into consideration: autonomous, semi-autonomous, or manual C3 systems. Each of these strategies would require 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 amount of error in the flight path due to human error. This altered flight plan will reduce efficiency and will require a more trained operator than an average farmer.

- Semi-autonomous systems have the ability to fly without human control by utilizing a computer that executes a preprogrammed flight course. These systems allow for human intervention as well in case of 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, they are least flexible when it comes to mission execution. These systems fly themselves by executing a preprogrammed flight path in a flight computer without any human control. All cruise maneuvers would have to be programmed into the flight computer, along with takeoff, landing, and stall recovery.

We ultimately selected a semi-autonomous system because it offered the most robust solution. It gave us more flexibility when it came to takeoff, landing, and recovery control. It also allowed us to fly an exact flight path. The semi-autonomous system also provides a safer alternative than an autonomous system because it can always be brought under manual control if issues arise. The aircraft will be flying autonomously most of the time along our preprogrammed flight path until the operator wants to switch to his or her remote control.

Selecting the Command System

In order to implement our semi-autonomous system, the ground controller has a Panasonic Toughbook PC ($320) outfitted with software to constantly monitor the UAVs autopilot movement and flight data. As the UAV continues its path, it relays information back to the operator.

Selecting the Control System

The Panasonic Toughbook PC ($320) will converse with the UAVs MHz data transceiver set ($135) and GPS ($50) for proper positioning; the data transceiver will also converse with the multiplexer ($0.45) and serial servo controller (SSC) inside the UAVs 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.

At launch, the PC will send a signal to the multiplexer that will turn the UAVs autopilot on, thus disengaging the SSC from manual control. The pre-programmed flight plan will be executed thus giving full control to the autopilot. As the UAV scans the fields, it will store all visual data in the Raspberry Pi Zero (\$5), aboard the aircraft. 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 via a manual signal. To do this, the multiplexer re-routes the signal from the pre-programmed course to the joystick (\$50) and microcontroller (\$100) that are 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 our method of manual control, it was mostly a question of ease of use, ease of setup, reliability, cost, and signal range of our data transceiver from the ground to the receiver on the UAV. Before choosing a radio video transmitter, we calculated the maximum possible range between the ground station and aircraft. For this minimum range, we made the assumption that the controller would be in the middle of one edge of the field with the aircraft at the maximum cruising altitude of 500 feet at the opposite corner. Using the Pythagorean Theorem, we calculated that the drone would be no more than 1.4652 miles from the ground station.

If the ground station is in the middle of one side of the field, the farthest the drone could be away is at one of the opposite corners. To calculate this distance, we used the Pythagorean Theorem, setting up the sides of the triangle as 0.5 miles (the distance from the middle of the field to one of the edges), and 1 mile (the distance from one of the edges of the field to the other): $\sqrt{0.5^2 + 1^2} = 1.118$ miles. Then, we took into consideration that the UAV would be 470 feet high (30 feet below the regulated maximum altitude of 500 feet, for safety): $\sqrt{0.094697^2 + 1.118^2} = 1.4652$ miles. With this calculation in mind, we 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 with the joystick. After we looked in the catalog and on other external websites we decided to use the 900MHz High Range Data Transceiver Set from the catalog was best suited for our 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.

2.2.4 Support Equipment Selection

While choosing support equipment for the UAV, we considered how best to maximize the support equipments usefulness while maintaining a low cost. We decided to select minimalistic equipment that provided enough support for one UAV only. Given that our operation plan includes only one UAV, we did not need any support beyond these options, and this strategy helped us conserve the amount of money spent on support equipment.

We chose a Utility trailer, priced at $1099, to provide necessary transportation of the UAV and other support equipment. This is the best option for our design because it was the least expensive and also has enough space inside to carry the UAV. This model has one UAV rack, which will fit the Penguin B UAV. We also decided to include a small power generator, which costs $69, to power the trailer. This power option was the least expensive, and it can still provide a sufficient amount of power to sustain our single UAV and the computer systems aboard the trailer. Lastly, we 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.

2.2.5 Human Resource Selection

For on-field operation, we decided to hire a Safety Pilot, Operational Pilot, and Range Safety officer. All three of these people are hired for $35 per hour. As our UAV is autonomously controlled and does not transmit data while in flight, we are permitted to use a skeleton crew for control. The three operators will work in tandem to ensure the safe and efficient operation of the vehicle. The Operational Pilot will monitor the autopilot, and the Range Safety pilot will keep in contact with local ATC and constantly scan the sky for any potential obstacles, such as birds or other planes. The Safety Pilot will maintain visual contact with the UAV, thereby satisfying the FAA regulation of constant visual line of sight (VLOS), and it will be ready to take over with our joystick should he or she see or hear from the Range Safety officer or the Operational Pilot of any deviations from the mission plan. Our three operational personnel will cost \$105 per hour, at a cost of \$183.75 for each 1.75 hour mission.

2.3 System and Operational Considerations

FAA regulations impacted our design in that our UAV has to fly lower than 500 ft. If we were able to fly above 500 ft, our camera could have a wider field of view in the x-direction. In this way, we could have detected more rows of corn and reduced our operational time.

While analyzing the objective function, we noticed that to get our objective value closer to one, we had reduce the empty airframe weight, while increasing the payload weight. As such, we scoured our empty airframe component list and removed all unnecessary equipment. In terms of maximizing business profitability, we tried to reduce the operating expenses over five years.

2.4 Component and Complete Flight Vehicle Weight and Balance

Fuel burn rate:	$F := \frac{7.5\ L}{13.5\ hr} = 0.556\ \frac{L}{hr}$
Density:	$p_g := 0.755\ \frac{kg}{L} = 755\ \frac{kg}{m^3}$
Expense:	$2.1\ kW$
Flight time:	$t := 35\ min = 0.583\ hr$
Cost:	$\frac{\$1.95}{gal}$
Gas/Oil Ratio:	$\frac{50}{1}$
Gallons gas:	$G_g := 0.083\ gal$
Gallons oil:	$G_o := 0.0017\ gal$
Oil density:	$p_o := 3.35\ \frac{kg}{gal}$
$F \cdot t = 0.086\ gal$	
Mass gas:	$m_g := p_g \cdot G_g = 0.237\ kg$
Mass oil:	$m_o := p_o \cdot G_o = 0.006\ kg$
Total mass:	$m_g + m_o = 0.243\ kg$

Figure 2.3: Fuel Calculation

The total empty weight of the UAV is 23.2555 pounds, and at maximum takeoff weight, the UAV is 25.123 pounds. To find the center of mass of the entire UAV at maximum takeoff weight, we 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	34.99	655.71	18.74
Engine	50.98	134.59	2.64
GPS System	15.08	3.016	0.02
Autopilot	15.08	0.754	0.05
Multiplexer	15.08	0.498	0.033
High Power Data Transceiver	15.08	0.1658	0.011
Serial 10 Servo Controller	15.08	0.377	0.025
Battery	15.08	23.53	1.56
Total Empty Airframe	35.550	820.46	23.079

Our empty UAV has a center of mass located at 35.550 inches from the nose. The UAV's payload data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
X-5000	15.08	21.72	1.4
Raspberry Pi Zero	15.08	0.9651	0.064
Sandisk 8 GB Class 4 TF MicroSDHC Memory Card	15.08	0.6635	0.044
Total Payload	15.48	23.349	1.508

Our UAV payload has a center of mass located at 15.48 inches from the nose. The UAV's power source data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Fuel	34.99	18.75	0.5360
Total Power Source	34.99	18.75	0.5360

Our UAV power source has a center of mass located at 15.08 inches from the nose. Below is a compilation of all the UAV data, for a calculation of the UAV's overall center of mass at maximum takeoff weight.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
Total Empty Airframe	35.550	820.46	23.079
Total Payload	15.48	23.349	1.508
Total Power Source	34.99	18.75	0.5360
Total UAV	37.30	862.559	25.123

Our UAV's center of mass at maximum takeoff weight is located 37.30 inches from the nose.

2.5 Design Analysis

Our aircraft, at maximum takeoff weight, weighs 25.123 lbs, which is less than the FAA weight cap of 55 lbs. It flies at a speed of 22 m/s, which is less than the FAA cap of 44.7 m/s, and at an altitude of 470 feet, less than the FAA restriction of 500 feet. Using this weight, we were able to calculate the lift coefficient of the aircraft:

LIFT COEFFICIENT

Weight: $W := 11.3956\ kg \cdot 9.81\ \frac{m}{s^2} = 111.791\ N$

Lift force: $L := W$

Surface area of the wing: $A := .79\ m^2$

Air pressure $r := 1.21\ \frac{kg}{m^3}$

Aircraft velocity: $v := 22\ \frac{m}{s}$

$$C_L := \frac{L}{A \cdot 0.5 \cdot r \cdot v^2} = 0.483$$

Figure 2.4: Lift Coefficient Calculations

This lift coefficient of 0.483 is less than then maximum lift coefficient provided by UAV Factory, the makers of the airframe, which is 1.3.

To calculate the Cd value of the aircraft, we used the Cd of an streamlined body: 0.04. As we were unable to find the exact airfoil type of the Penguin

B UAV, after a little bit of online research, we were able to estimate it to be the NACA 23015 airfoil. Using JavaFoil, an online aerodynamics tool, we were able to come up with a list of Cm values against their respective angle of attacks:

Alpha (Angle of Attack in degrees)	Cm 0.25
0	-0.008
5	-0.021
10	-0.033
15	-0.041
20	-0.046
25	-0.047
30	-0.050
35	-0.053
40	-0.054
45	-0.050

2.6 Structural Design

After some research online, we realized that the Penguin B UAV's wing spars are made out of carbon fiber. From talking with Mr. Bo Pollett, one of our mentors, we were able to determine that during loading, 90 percent of the load is taken by the carbon fiber. As such, we decided to find the amount of load on a carbon fiber hollow tube at 6 gravities:

- Weight of UAV: 25.123 pounds
- At 6 g: 150.74 pounds
- Each wing will be taking 75.37 pounds of force (150.74/2)

- Length of carbon fiber: 64.95 inches

We assumed a 1 inch diameter and 0.1 inch thickness for the fiber, as we were unable to find the actual values.

Using this tool: http://www.meracalculator.com/engineering/deflection-round-tube-beams.php, we were able to find that the bending stress would be 168,910.116 psi. Carbon fiber has an ultimate strength of 8,129,365.2 psi, which is greater than 168,910.116 psi. Therefore, our wing will remain functioning even at 6g, which satisfies our load requirement.

2.7 Operational Maneuver Analysis

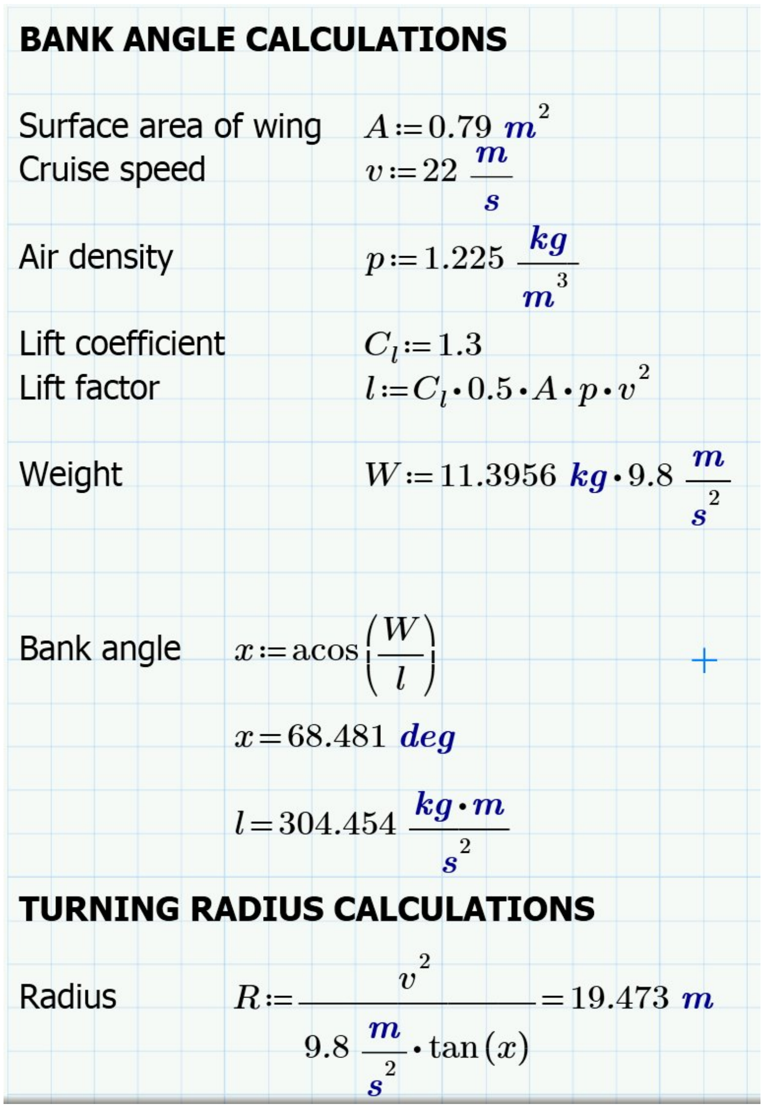

Figure 2.5: Bank Angle Calculations

We were able to calculate that the UAV could sustain a coordinated turn of a minimum of 63.9 feet. As our flight plan calls for a turn radius of 165 feet, our UAV will be able to fly our flight plan.

2.8 CAD Modeling

Figure 2.6: UAV

Figure 2.7: Bottom view

Figure 2.8: X5000 Multispectral Sensor

2.9 Three View of Final Design

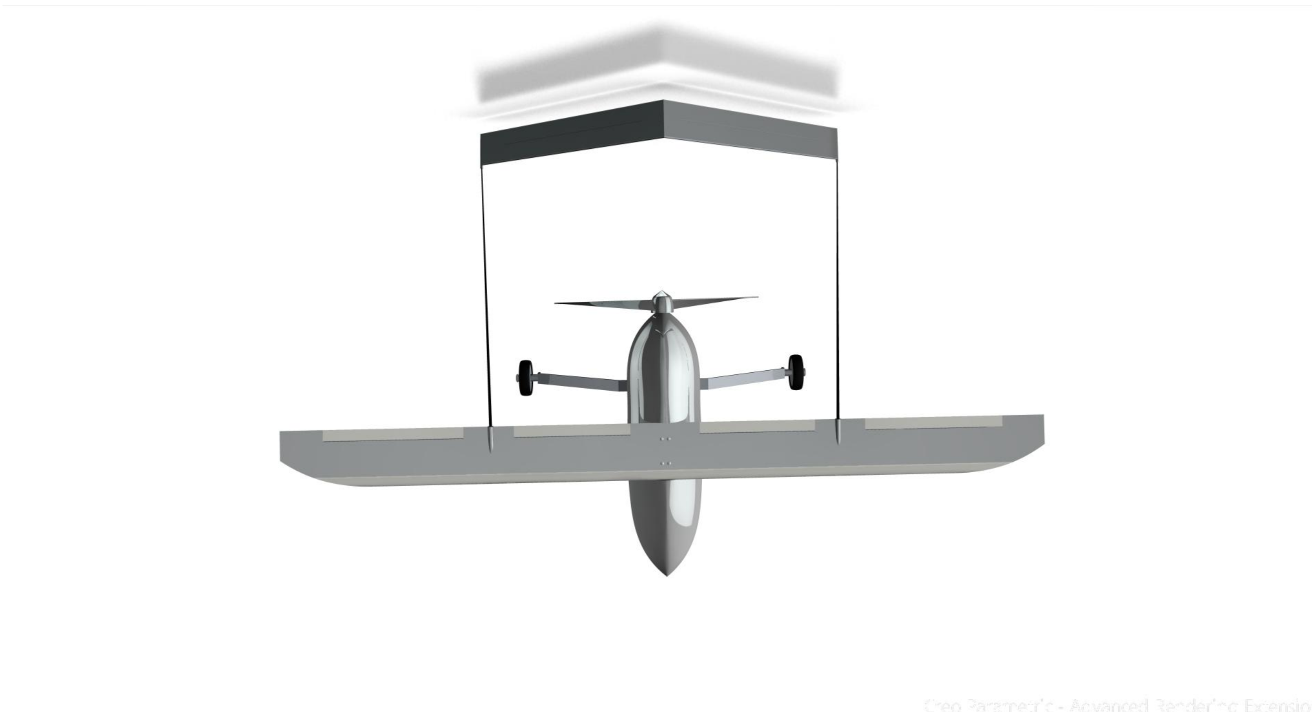

Figure 2.9: XY view

Wingspan: 3.3 m

Airframe length: 2.27 m

Figure 2.10: XZ view

Airframe length: 2.27 m

Airframe height: 0.907 m

Figure 2.11: YZ view

Wing span: 3.3 m

Airframe height: 0.907 m

Chapter 3

The Detection Plan

3.1 Moisture Detection Pattern

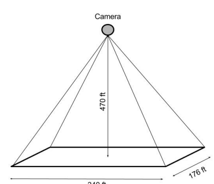

Figure 3.1: Sensor 3D View

This is the viewing box of our X5000 sensor on our aircraft at an altitude of 470 feet:

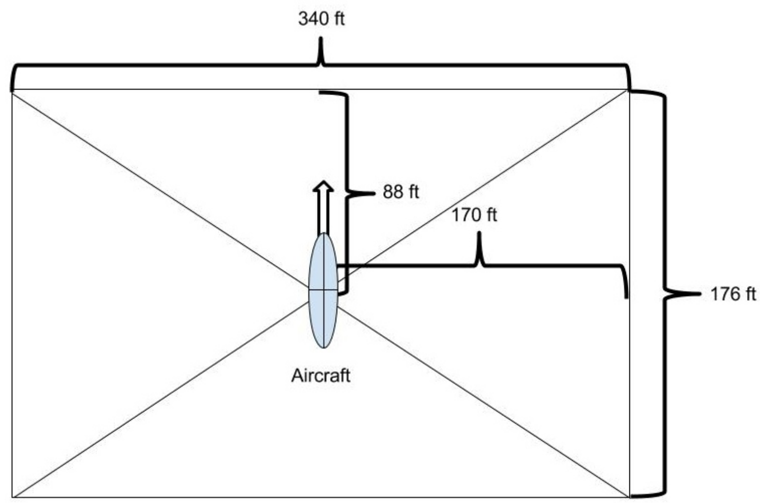

Figure 3.2: Viewing box

Because our aircraft can detect 340 ft of land across, it is able to view 113 rows of corn at a time (each row of corn being 3 feet apart). We used a turning radius of 165 ft. Based on these specifications, we designed our flight plan accordingly:

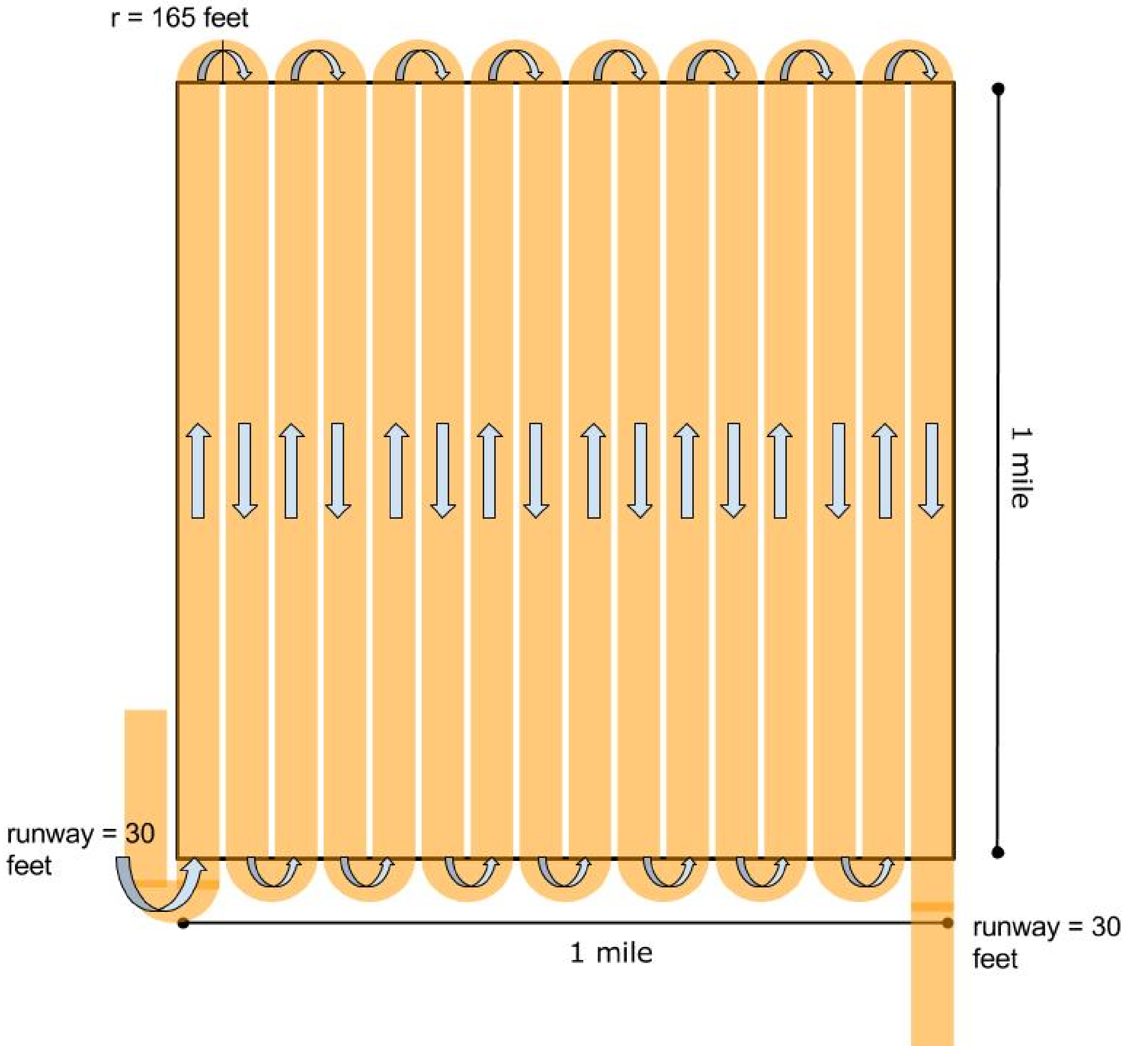

Figure 3.3: Flight plan

This plan does not use our minimum turning radius, because the X5000 has such a wide field of view. This also effectively reduces our mission time. Our total calculated distance for this flight plan is:

$distance = 16 \text{ mi} + 16 \text{ x } \frac{1}{2} \text{ x } 2 \text{ x } \pi \text{ x } (165 \text{ ft } \frac{1mi}{5280ft}) + 2 \text{ x } 30 \text{ ft}\frac{1mi}{5280ft}$

$distance$ = 17.58 mi

Our sensors will detect moisture every 2.25 seconds.

50 mph (cruise speed) = $73\frac{1}{3}$ ft/s

$\frac{165ft}{73\frac{1}{3}ft/s}$=2.25 s

3.2 Theory of Operation

Preflight

The UAV will be transported to a 30 meter strip of clear ground on the farmer's property. It will be assembled and positioned at the end of the strip to be ready for takeoff.

Takeoff

The Operational Pilot monitors the UAV as it takes off.

Flight

The UAV's autopilot will then make sure the aircraft travels on its programmed flight plan. The Operational Pilot will man the laptop where all the data from the autopilot being relayed. The Safety Pilot will make sure the aircraft is flying on its designated flight path and that the sensor is working properly. The Range Safety Pilot will make sure that sky is clear of all obstacles.

Landing

The UAV will land according to its landing autopilot on a strip of ground in front of its flight path. There will be no difference in flight plans between the detection periods.

3.3 Detection Considerations

Our choice of crop, corn, affected our detection strategy. Because the leaves of corn are thinner and oriented more vertically, making them harder to detect, we had to change our sensor payload in order to make sure we were detecting the moisture content accurately.

Corn is harder to detect at the beginning of the season, before any leaves have sprouted. After corn has sprouted, it is vulnerable after pollination and if it is not in environmentally favorably conditions, the leaves will shrink. This information was another factor as to why we chose a high-resolution camera.

Originally, we had a different flight plan that would cross the horizontal distance of the field twice in order to maximize detection accuracy. However, since we decided on using the X5000, whose detection is very accurate, we could simplify our flight plan and reduce the total travel distance. Our original flight plan was:

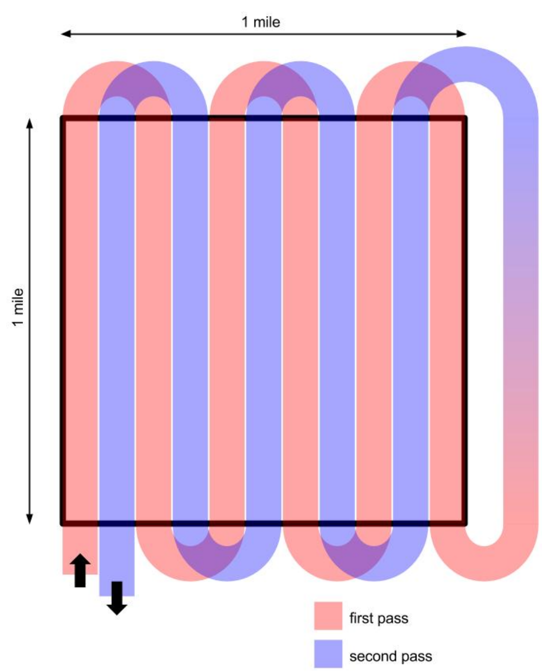

Figure 3.4: Original Flight plan

Our choice of our moisture detection sensor, the X5000 heavily influenced our design. At first, our plan was to fly over each the field and read each row of corn. However, after choosing the X5000, which has a high resolution and field of view, we changed our design. If we had used a sensor with a smaller resolution, we would have had to make smaller turns, which would be much harder and more inefficient.

When considering how to find a balanced approach to maximizing the three components of the challenge, we wrote a program using IPython Notebook to analyze the objective function:

In [8]:
```
w_e = 10 kg
w_t = 33.68
c_a = 2000.0
c_u = 4000.0
oe = 10000.0
tr = 50000.0

airframe_efficiency = 1-(w_e/w_t)
airframe_cost = 1-(c_a/c_u)
business_profitability = (tr-oe)/tr

mean = (airframe_efficiency+airframe_cost+business_profitability)/3

print airframe_efficiency
print airframe_cost
print business_profitability
print mean
```

```
0.5
0.5
0.8
0.6
```

Figure 3.5: Objective Function Program

We focused on minimizing the empty weight of our aircraft. We also chose an airframe that has a high cruise speed (22 m/s), but still allows us to make a turn that is small enough to measure moisture content in all the rows of corn. Cost was taken into consideration when we chose our airframe because we wanted to choose a design that had a high endurance but would use less fuel. By using less fuel, we were able to reduce the cost of the UAV. We reduced our operating expenses (see section 4.4) to maximize business profitability.

3.4 Detection Time and Resource Requirements

Our design requires three people to operate the UAV. This includes an Operational Pilot to fly the UAV, who will control the UAV in flight and initiate the autonomous takeoff and landing. There will also be a Safety Pilot, who will continuously maintain visual contact with the UAV and monitor the sensor. Finally, there will be a Range Safety Pilot to observe the sky surrounding the UAV and warn the Operational Pilot of any threats that may be approaching the UAV.

The timescale of this mission is very short. The UAV will spend approximately 25 minutes scanning the cornfield, with an additional time period of launching and landing the plane and flying it to the cornfield. We estimated a total time of around 35 minutes per flight. This time period varies due to the location of a suitable strip of land to launch the plane located on the farmers property. Our UAV will need to complete three flights per mission: once in the spring, once in the summer, and once in the fall. Therefore, total mission time is around 105 minutes.

Chapter 4

The Business Case

Operational Costs Per Hour	Year 1	Year 2	Year 3	Year 4	Year 5
Operational Personnel	$ 105.00	$ 105.00	$ 105.00	$ 105.00	$ 105.00
Consumables	$ 0.40	$ 0.40	$ 0.40	$ 0.40	$ 0.40
Operations and Support Costs	$ 319.40	$ 105.40	$ 314.40	$ 105.40	$ 314.40
Total UAS Cost Per Hour (over specified number of applications)					
System Initial Cost ($AcqCost_i$)	$ 5,850.68	$ 5,850.68	$ 5,850.68	$ 5,850.68	$ 5,850.68
Number of Fields Per Year (N)	100	100	100	100	100
Time to Complete Field (T) [in	2.0000	2.0000	2.0000	2.0000	2.0000
Acquisition Cost Per Hour	29.25342	$ 29.25	$ 29.25	$ 29.25	$ 29.25
Total Cost Per Hour ($FCPH_{RWDC}$)	$ 348.65	$ 134.65	$ 343.65	$ 134.65	$ 343.65
Total Cost per Field	$ 697.31	$ 269.31	$ 687.31	$ 269.31	$ 687.31
Total Revenue Per Field	3000	3000	3000	3000	3000
Total Revenue Per Year	$ 300,000.00	$ 300,000.00	$ 300,000.00	$ 300,000.00	$ 300,000.00
Total Cost Per Year	$ 69,730.75	$ 26,930.75	$ 68,730.75	$ 26,930.75	$ 68,730.75
Total Profit (Loss)	$ 230,269.25	$ 273,069.25	$ 231,269.25	$ 273,069.25	$ 231,269.25
Cumulative Net Cash Flow	$ 230,269.25	$ 503,338.50	$ 734,607.75	$ 1,007,677.00	$ 1,238,946.25

Figure 4.1: Total Costs

4.1 Additional Commercial Applications

Due to the long endurance of the Penguin B, the UAV could potentially service a much larger crop area. If we filled the UAV's fuel tank to its maximum capacity, the UAV could fly for over 10 hours, servicing 30 square miles of fields in one flight. Furthermore, it could potentially carry far more payload, if needed for the mission. According to www.uavfactory.com, the Penguin B can hold up to 25 pounds of payload. Lastly, if the FAA flight cap of 500 feet were removed, our UAV, equipped with its current sensor, could potentially fly higher, to gain a far greater sensor coverage area and cover more crops in less time.

4.2 Amortized System Costs

As the United States is one of the leaders in world corn production, demand for our product will be high. We estimated that we can service over 100 fields per year. Using the cost calculator, we found that the total cost for 100 missions, with three detection flights per mission, would be around \$98,984. This was calculated by multiplying the cost per field, \$697.31, by 100, and adding the total acquisition cost, which was \$29,253. The extra \$214 registration fee was be added for FAA UAV registration fees. Every other year, an additional \$209 dollars was added for the FAA Knowledge Test fees.

$$\$697.31 * 100 + \$29,253 = \$98,984$$

4.2.1 Initial Costs

We calculated our assembly cost to be \$27,320 (\$20,320 for the UAV system, and \$7,000 for the engineering and construction labor.)

Air Vehicle Element (UAV) Design-1 (required)	
Number of Vehicles, N_{UAV1}	1
Empty Weight, W_{E1}	23.079
Power Weight, W_{pow1}	0.536
Payload Weight for Max Takeoff Configuration, W_{pay1}	1.508
Maximum Takeoff Weight, W_{TO1}	25.123
Total Empty Cost, C_{E1}	\$ 14,812.45
Airframe Cost, C_{AF1}	\$ 10,090.00
Power Cost, C_{pow1}	\$ 0.17
Payload Cost for Max Takeoff Configuration, C_{pay1}	\$ 5,507.99
Air vehicle cost at W_{TO}, C_{UAV1}	\$ 20,320.61
Air vehicle cost at WTO w/o fuel, $C_{UAVwof1}$	\$ 20,320.44
Additional Component Cost, C_{add1}	\$ -00
Single Design-1 Cost, C_{Tot1}	\$ 20,320.44
Total Design-1 Cost, C_{Tot1}	\$ 20,320.44

Figure 4.2: UAV Initial Cost

Role	Hours	Cost Per Hour	Subtotal
Project Manager	40	$ 75.00	$ 3,000.00
Simulation Engineer	25	$ 50.00	$ 1,250.00
Systems and Test Engineer	25	$ 50.00	$ 1,250.00
Project Scientist	10	$ 50.00	$ 500.00
Project Mathmetician	10	$ 50.00	$ 500.00
Electronics Technician	5	$ 25.00	$ 125.00
Aircraft Maintenance Technician	10	$ 25.00	$ 250.00
Assembly Technician	5	$ 25.00	$ 125.00
Total Eng/Construction Labor Cost			$7,000.00

Figure 4.3: Engineering Labor Cost

4.2.2 Direct Operational Cost Per Mission

The flight time of the UAV for every scan will be approximately 35 minutes. This includes takeoff, landing, cruise, and all coordinated turns. As our UAV consumes approximately 0.55 liters of fuel per hour, we will need to purchase 0.323 liters of fuel per flight. The UAV fuel consists of a 50:1 gas to oil ratio, and an estimated price for 0.323 liters of 50:1 gas to oil is around \$0.17. Multiplied by three for the three flights per mission, this calculates to be \$0.51. On the ground, we will need fuel for our power generator– this consumes 0.06 gallons of gasoline per each 35 minute flight, with a total of 0.18 gallons of gasoline per mission. This would cost \$0.351 per mission. Manpower for the each 35 minutes of flight will cost \$61.25, which multiplies to \$183.75. Therefore, the estimated operational cost per mission is \$184.611.

$$\frac{0.55 liters}{60 minutes} = \frac{0.323 liters}{35 minutes}$$

$$\$0.51 + \$0.351 + \$183.75 = \$184.61$$

4.2.3 Amortization

The total cost per mission was calculated to be \$457.81 dollars.

$$(\$27,320 + \$184.611 * 100)/100 = \$457.81$$

4.3 Market Assessment

Our UAV is competitive in the market in two ways: its low cost and fuel efficiency, and quick mission completion time. Against other UAVs of similar cost, the main advantage the Penguin B has is its superb fuel efficiency. Able to complete each mission of three flights with less than half a dollar of fuel, the Penguin B is an economically sound option for our project.

Other services that measure moisture levels in fields usually involve farmers going out and measuring the field by placing devices into the ground, or by taking soil samples and sending them to be analyzed. Both of these methods are incredibly time consuming: to achieve an accurate representation of the field's moisture levels, the density of soil samples or device placements would need to be high, needing the farmer to spend incredible amounts of time. Our UAV can complete the task in around 35 minutes. Other services use satellites. For example, we investigated one such service, "Cropio," which charges around $1,280 to survey an entire field, or $3,840 to complete the three needed field surveys per mission. This is not comparable to our UAV, which can complete a mission with a cost of $3000.

4.4 Cost / Benefits Analysis and Justification

While designing the aircraft, we paid close attention to minimizing the costs of the sensors and payload on board the UAV. We always chose the cheapest equipment that would achieve our intended goal. Our battery is far cheaper than on board generator systems, and yet holds enough electricity to power our on board systems during the entirety of a flight. Instead of having an expensive and large trailer, since we have very little ground support equipment, we went for a minimalistic approach and chose the Utility Trailer, and open trailer that allowed us to store our UAV, generator, computer, flight line kit, and battery recharger. Since the competition rules state that we are to expect good weather conditions, there is no possibility of rain damaging our electronics. Furthermore, our system is designed to use as few operational personnel as possible. We decided to only have three people on site: the Operational Pilot, Safety Pilot, and Range Safety Pilot. The semi-autonomous design of our UAV, and the fact that it transmits no data while in flight, makes all other roles redundant, allowing us to offer our service for a lower cost, while still maintaining business profitability. The system is also easy to use for the consumer; as we are offering it as a complete service package, the consumer will need to do nothing (including taking FAA certification tests, which will be taken by our operators); all necessary tasks will be performed by our operators. Lastly, our UAV is able to complete a mission of three flights in under 105 minutes; each flight being around 35 minutes. This allows for multiple flights per day. Given the high demand for this service, as mentioned previously in the engineering log, we will be able to service multiple fields per each growing period.

In order to maximize the sensor coverage of our UAV, we decided to fly it near the maximum FAA approved height of 500 feet, leaving 30 feet of leeway for safety. We calculated that we would receive a suitable sensor resolution at this height. We decided that the higher we flew, the shorter flight path the UAV could have.

X5000 resolution: 2048 pixels

X5000 field of view: 40 degrees by 20 degrees

$$\frac{2048 pixels}{tan(20)} \text{ x } 500 \text{ feet} = 11.25 \text{ pixel/feet}$$

At 11.25 pixels per feet, we will be able to obtain our data. Since we get 11.25 pixels per feet at 500 feet, we will be able to fly at 470 feet.

The UAV is also easy to disassemble, allowing for easy transportation to and from fields.

This more modular system allows the user to replace separate parts and not the entire system. Also, this approach makes the electronics significantly more compact, leaving room for extra equipment if needed.

Our superior aircraft, combined with our X5000 multispectral camera, is an extremely effective tool for precision agriculture. The X5000 camera measures the moisture content in leaves, remotely, by sending various wavelengths of light. The sensor picks up the reflected light and analyses it. Depending on the wavelengths of light that come back, it computes the water found in the crop or soil. It then stores this data in our Raspberry PI module aboard the aircraft. The data is later uploaded onto a computer and analyzed to increase crop turnout rates immensely by telling the farmer the exact state of his crop. Our product reduces water use and increases profits for the farmer. Our UAV will be the best option on the market for precision agriculture drones because of its high quality, yet cost effective design, and will help grow food more effectively for the rapidly growing population.

Cost for Missions	
Mission Parameters	
Note: Each field is required to have at least 3 detection flights per crop growth cycle. For the total time of detection, use the total time for all the detection flight (at least 3) for each field. For the number of fields, this is the number of crop fields that have all the detection flights (at least 3). Setup/Travel Time will not be calculated; it is assumed the system is available on site and configured for operation. Time must be calculated in whole numbers (no decimals), always round up. For example, 1.15 hours should be entered as 2 hours.	
Number of Fields Per Year (N)	100
Time to Complete Average Field (at least 3 detections) (T) [in hours]	2
System Costs	
Total Vehicle Cost	$ 20,320.44
C3 Cost	$ 370.00
Support Equipment Cost	$ 1,562.98
Engineering Labor Cost	$ 7,000.00
Operational Costs per Hour	
Operational Personnel	$ 105.00
Consumables	$ 0.40
Operations and Support Costs ($O\&S_{hr}$)	$ 105.40
Revenue and Profit	
Total Acquisition Cost	$ 29,253.42
Cost Per Field	$ 697.31
Revenue Per Field	3000
Profit Per Field	$ 2,302.69

Figure 4.4: Total Revenue Assessment