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

Team Name: Big Blue

Team Member:	*Age:*	*Grade:*
Kunal Vaishnavi	16	10th
Roshan Benefo	17	12th
Alex El Adl	14	9th
Vishvesh Dhar	15	9th
Ruide Wang	17	10th

School:	Phillips Academy Andover
State:	Massachusetts
Coach:	Dr. Clyfe G. Beckwith
Date:	April 4, 2016

Contact:

Kunal Vaishnavi	Roshan Benefo
978 609 7451	*201 396 4394*
kvaishnavi@andover.edu	*rbenefo@andover.edu*

All team members have filled out the survey.
Our objective function is: 0.764749774183612.

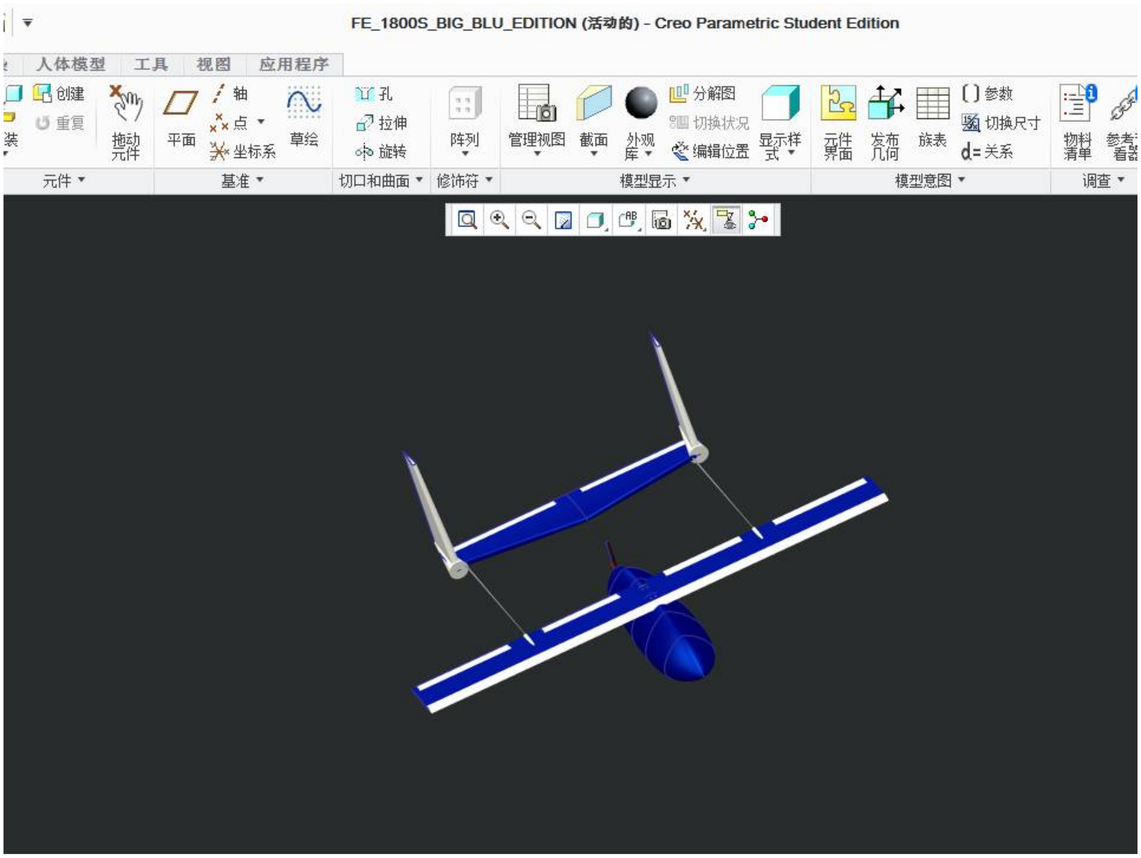

Figure 1: Our UAV

Contents

List of Figures

List of Tables

0.1 Abstract

With an 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 proposed in the FY16 Real World Design Challenge, the RWDC Andover team has taken on the task of designing an unmanned aerial vehicle (UAV) and associated unmanned aerial system (UAS) that uses current technology for moisture detection in precision agriculture. Our system has to efficiently detect moisture levels while keeping our costs at a minimum.

Water content in plant leaves is one of the most important factors that determines a plant's health and photosynthesis efficiency. A lack of water reduces a plant's productivity, and causes stomata to close, slowing transpiration as well as other normal functions of a plant. In order for a farmer to optimize their crop and accurately predict that year's yield, they must monitor crop moisture content and act accordingly. The team used the X5000 multispectral sensor to detect the moisture content of our crop because it fits our needs almost perfectly. A sensor with a high resolution was needed so moisture could be accurately detected at high altitudes and at all stages in the growth process. A sensor with a large field of view was also needed to decrease the amount of passes the UAV has to make over a field. A normal CCD/CMOS camera was not included because the UAV will be on autopilot most of the time.

In designing our solution, the team attempted to minimize cost by creating a semi-autonomous UAV that would allow us to minimize the operating team needed to use it. As the original UAV we found, the Penguin B, was not giving us a high enough value for airframe efficiency, the team decided to search for another UAV, and found the FE 1800S Aerobot.

While searching for a UAV, the team wanted something that could hold a payload of around eight pounds. The FE 1800S Aerobot worked well for our purposes. It can hold a payload of around eight pounds and stay in the air for about two hours. Furthermore, the FE 1800S was able to complete each flight in about 35 minutes, which allows for multiple flights per day.

To keep costs low, the team made sure that the flight plan was as efficient and quick as possible. This reduces the operational expenses of each mission by reducing the amount of time we need to hire operational personnel. In this way, the 5-year cost variable in the objective function is kept at a minimum to maximize the revenue.

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. Unfortunately, due to prior commitments, Jocelyn and Darcy had to resign from the team midway through the competition. The team really appreciates the time and effort that they both gave.

When it came time to work on the project, each meeting, we would take pictures of important things and calculations that we wrote down. This helped us to organize our work and so that everyone was on the same page in terms of what we were doing at that moment.

Figure 2: 1/24 Meeting

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. 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. One of our team members, Vish, was able to conduct an interview with his grandfather, Dr. Omkar Nath Dhar, an agricultural consultant in India. The interview helped the team understand the logistics behind growing, maintaining, and harvesting crops. This was crucial in fully comprehending how crop cycles work and finding the detection periods for corn and potato.

1.3 State 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 quantitatively evaluate the solution.

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

Figure 3: Objective Function

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 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. The variable, W_E, represents the empty weight of the aircraft. Early in, we determined that the main way we could increase our objective function would be to maximize our airframe efficiency. As such, we spent much of our time searching for a light airframe.Here is a table to compare what our previous airframe efficiency values were and what they are now:

	Previous Value	Current Value
Empty Weight of Aircraft	23.079 lbs	2.119 lbs
Maximum Takeoff Weight	25.123 lbs	6.297 lbs
Empty Weight/Maximum Takeoff Weight	0.919	0.336
Airframe Efficiency	0.081	0.671

Table 1: Comparison of Airframe Efficiency Calculations

As you can see, even though our maximum takeoff weight decreased, we were able to compensate for that by having a very low empty weight value.

Lighter airframes, for the most part, require less fuel to fly and usually 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. The variable, C_{AF} , represents the cost of the airframe. In comparison to other UAVs of similar ability, the UAV we found was relatively inexpensive, due in part to the material it is made of, EPO, or Expanded PolyOlefin foam. EPO's tough and durable nature makes it perfect for our UAV– it is normally used for consumer goods such as Crocs shoes, seat cushions, arm rests, and spa pillows.[1]

Along with a cheap airframe, the low cost of our UAV was also helped by the fact that it runs on batteries, unlike our previous solution, which ran on gas. Here is a table to compare what our previous airframe cost values were and what they are now:

	Previous Value	Current Value
Cost of Airframe	\$10,090	\$1,797
Total Cost of UAV at Maximum Takeoff Weight	\$20,320.61	\$7,606.10
Cost of Airframe/Total Cost	0.497	0.236
Airframe Cost	0.503	0.773

Table 2: Comparison of Airframe Cost Calculations

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. The variable, TR_{Year5} , represents the total income received from running the business over a 5-year period. To increase our total revenue, we increased the revenue cost because since there were two fields in the national competition, we could then charge double the price. This way, we were still maintaining the same cost-per-field, but increasing the amount we charged per each mission. On the other hand, the variable, OE_{Year5} , which represents the operating expense over a 5-year period, increased because the size of the field had changed. The operating expense was found by multiplying the flight cost per field by the number of fields. However, since our field was bigger (two 1 mile by 1 mile fields with a no-fly zone), the flight cost and the number of fields increased, which in turn, increased our operating expense. Here is a table to compare what our previous business profitability values were and what they are now:

[1]https://en.wikipedia.org/wiki/Polyolefin

	Previous Value	Current Value
Operating Expense	$261,053.76	$297,225.13
Total Revenue	$1,500,000	$1,924,000
Operating Expense/Total Revenue	0.174	0.154
Business Profitability	0.826	0.860

Table 3: Comparison of Business Profitability Calculations

Ideally, our solution should reach an objective function approaching one or higher. Our solution's objective function was approximately 0.7647.

1.4 Tool Set-up/Learning/Validation

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 Impact 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 lacked the amount of team members needed to get our numerous 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, 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 saw the dependency of different design factors on each other and 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 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. We later had each interested candidate explain their background in STEM and recruited people that would bring their individual skills and experience to work together in our team. 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.

Because Kunal and Roshan were relatively new running the competition at PA, we decided to only host one team from Andover. At the club rally however, we got fifty-five students to sign up for our club, and we were sorely disappointed to have to limit participation in the team to the seven person maximum stipulated by RWDC. Therefore, next year, to circumvent that, we'd like to create multiple teams at Andover, so that as many students who would like to participate will have the ability to participate. With this, we will be able to further build RWDCs presence on campus, and expose more students to the skills and experiences of the competition.

Chapter 2

Our System Design Process

2.1 Conceptual, Preliminary, and Detailed Design

At our first meeting, the team 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. The team read over the rules and detailed background and then summarized these documents.

2.1.1 Engineering Design Process

Our airframe design was dependent on two factors: what payload the aircraft needed to carry, and how far it would need to fly. The team decided to tackle the payload issue first. Much of the UAV's payload weight is determined by the sensor it carries, and so, the team focused in on choosing a sensor. To do this, the team looked at the national challenge's requirement that our UAV had to have multiple uses, and realized that we could find multiple uses for the UAV, and look for a sensor(s) that could cover them all, or finding the most versatile sensor and selecting several uses for it. The team brainstormed many possible and practical uses for our UAV. To aid our process and ensure that our UAV would only need to hold one sensor, thereby reducing its cost, the team decided to choose the sensor first, and then choose the best uses from our list that could be preformed by the single

X5000 sensor. As such, the team decided to stick with the X5000 used in the state challenge due to its versatility as a multispectral sensor. Its multiple sensor bands allows it to have a wide range of uses, including completing our primary mission, crop moisture detection. These multiple filters consist of NiR, Green, and Red. After choosing our sensor, the team chose the airframe accordingly. The airframe decisions were limited based on the sensor's weight and field of view in addition to the other components needed on board the UAV, which contributed to the aircraft's payload and flight plan. During the last challenge, although the team had chosen a UAV with a phenomenal endurance and payload, we found late into the competition that we simply did not need all its endurance and payload capacity. As such, to improve our airframe efficiency score, the team created a rough estimate as to how much payload we would need, based off of the sensor the team had chosen, and selected airframes that had payload amounts that were just above that number. Our estimate, which, due to the fact that the team kept the same sensor, the team came up with by analyzing the payload components of our previous UAV submission, the Penguin B, was 5 pounds. As the team had done in the state challenge, the team once again began by researching and evaluating different types of UAVs, finally landing on the FE1800s Aerobot.

2.1.2 Conceptual Design

Based off our knowledge of the sensor's field of view, we could calculate the altitude and maximum velocity of our aircraft. The team then 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

Table 4: Pros and Cons of UAV Designs

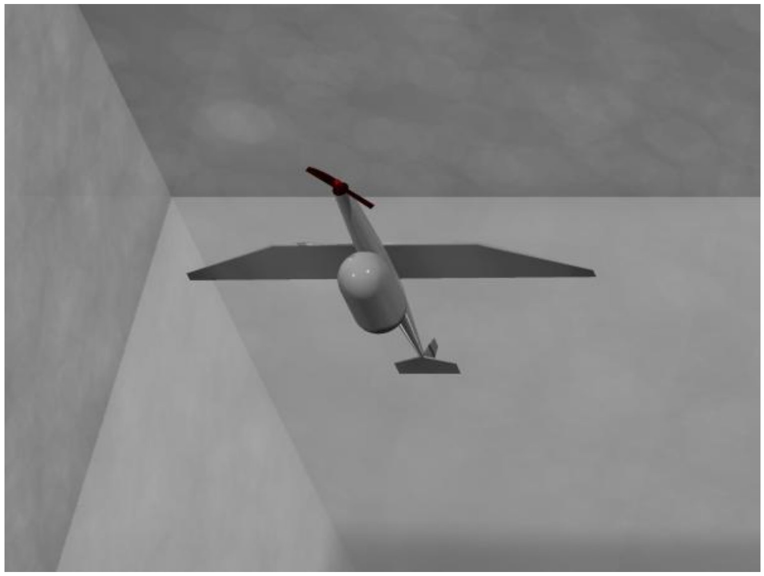

Figure 4: Tractor Design

After identifying all the restrictions our aircraft had, the team still had enumerable possibilities for our design. Having the 5 lb payload in mind, the team started a vast research of qualified airframes.

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. The cruise speed had to not be too fast as to prevent us from getting accurate measurements, but fast enough to complete the flight in a timely fashion)
- Cost (aircraft should be cost-efficient to ensure wider distribution, which increases our business profitability)
- Weight (a lightweight airframe would increase our airframe efficiency value)

- Landing method (the aircraft should be reusable, so it needs a safe landing)

- Takeoff method (affects the time of the operation)

At that point in the state challenge, the team had chosen the Penguin B UAV. However, the team realized that for the national challenge, to get the highest airframe efficiency, we could either scale down the Penguin B UAV model or find a new model. The pro of scaling down the Penguin B UAV model was that we could save the time of researching other potential models. The con was that it may be practically challenging for us to do so because Penguin B is a factory-made product. Furthermore, the high cost of the Penguin B would still be conserved. The pro of finding an entirely new model was that the team would avoid the hassle and cost of having to scale the Penguin B, along with the potential of finding a far cheaper airframe. The con was that the team may encounter an airframe that exactly fitted our specifications: one with a max payload of exactly 5 lb.

After thinking about the pros and cons of both methods, the team soon realized that the amount of time and labor it would take to scale down the Penguin and recalculate all of its aerodynamic values was far out of our reach. Furthermore, after some research, the team ended up finding several UAV designs that had around a 5 lb payload. Therefore, the team decided to use the second solution.

Having the 5 lb payload in mind, the team started our vast research of qualified airframes. Below are the choices that the team took into account:

Figure 5: ATIs Resolution UAS

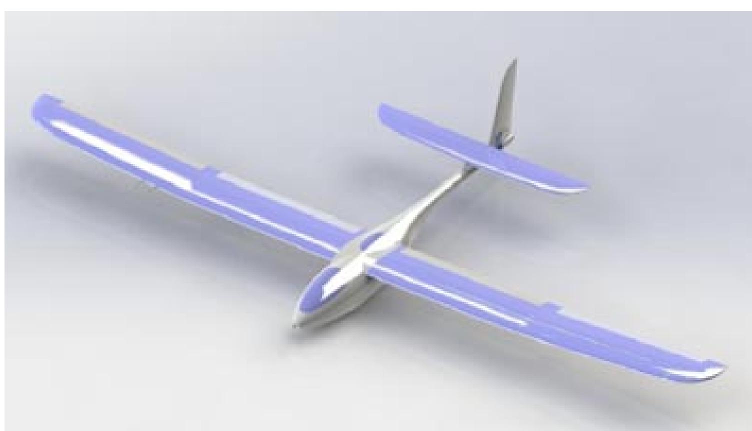

Figure 6: Applewhite Aero

Figure 7: FE 1720G Aerobot

Figure 8: FE 1800s Aerobot

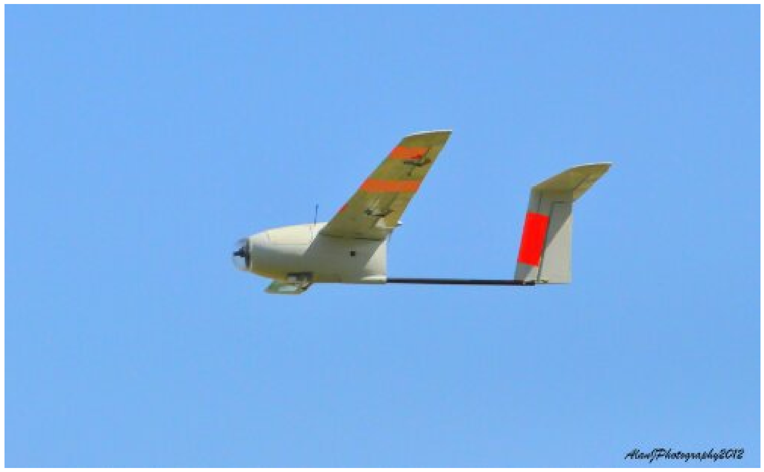

Figure 9: Techpod

Figure 10: Zephyr2 UAV

Figure 11: Recon UAS

2.1.3 Preliminary Design

The team then created a ranking system that would allow 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 ($)	Endurance (hr)
ATI Resolution UAS	8	7	n/a	n/a
Applewhite Aero	5	9	n/a	1.5
FE 1720G Aerobot	8	2.31	1,920	2
FE 1800S Aerobot	8	1.98	1,797	2
Techpod	2.25	2.75	n/a	1.5
Zephyr2 UAV	9	5	14,995	1
Recon UAS	5	6.8	n/a	1

Table 5: Comparison of Different UAV Options

While choosing our final design, the team was primarily influenced by each airframe's maximum payload and empty weight. The team first eliminated Techpod because its max payload did not meet our requirements. The team then roughly calculated the necessary endurance our UAV would need to have to complete the mission, a value of around 1.5 hours. Therefore, Zephyr2 UAV and Recon UAS were also out of our consideration. Due to their material (foam), the FE 1720G and the FE 1800S then captured our attention with their high payload / empty weight ratio and their low costs. The team finally selected the FE1800s due to its slightly lower weight, which would give us a higher airframe efficiency score, and cheaper cost.

2.1.4 Detailed Design

In designing our UAV, the team first determined the appropriateness of our sensor choice, the X5000 multispectral sensor. The sensor was a good choice because it offers excellent quality at a moderate price. 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

Table 6: X5000 Specifications

The team 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 342 ft laterally, which is roughly 113 rows of corn (each row being 3 feet).

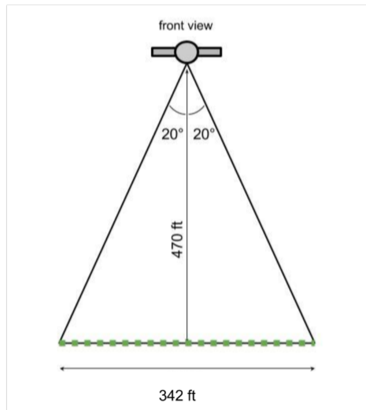

Figure 12: Camera Visualization

At an altitude of 470 ft (within FAA regulations), our camera can view 342 ft in the x direction:

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

Other categories of sensors the team had considered were CCD/CMOS cameras (digital imaging sensors), thermal (sensors used to measure and image heat), LiDAR sensors (measures distance and contours of remote bodies (e.g. terrain) through the use of reflected laser light), Synthetic Aperture Radar (SAR) (sensor that measures distance and contours of remote bodies (e.g. terrain) through use of reflected radio waves), and lastly, Multispectral cameras (all-encompassing visual sensor for capturing image data across the electromagnetic spectrum). The team chose the X5000 because of its range, affordability, and simplicity in reading moisture content. The X5000 also has many other functions, which include:

- Detecting deep water vegetation (30 meters depth)
- Detecting man-made objects (9 meters depth)
- Oil detection

- Detecting dead foliage, vegetation types, soil, urban features
- Can detect plant health
- Gas detection
- Mapping shorelines and biomass content

After choosing the FE 1800S Aerobot airframe (as explained before), 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, the team learned how to organize our decisions and prioritize factors of the design. Because so many calculations depended on one another (i.e. cruise speed affected turning radius, which affected the flight plan), the team needed to communicate efficiently as a team. Since our team is based in a boarding school, it was very difficult communicating over the break when everyone was at home in different countries and states. 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 it is always better to have more options than less options, choose from those, and modify them, rather than have very few designs to choose from. This is how the team was able to choose the new airframe that we wanted as well as the second crop for the second 1 mile by 1 mile field. The team also learned how to make tables of pros and cons of a certain designs to help us with the elimination process.

Preliminary Phase

During the preliminary phase, the team learned that it is impossible for us to choose an absolutely perfect design. The team focused too much on each positive aspect of each design. In the end, the team learned that it is important to prioritize design choices.

Detailed Phase

During the detailed phase, the team learned how to make specific modifications to improve our design. The team also learned how to use PTC Mathcad to do calculations and visualize our design using PTC 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. To do this, the team assigned roles to each member. For example, we assigned one person to work on the CAD and Mathcad projects and others to handle the flight plan. This was soon thrown off after two team members were forced to drop out due to other commitments, after which were forced to redistribute the workload. 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 FE 1800S Aerobot, 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. However, after the state challenge, we realized that the biggest way for our team to increase our objective function is by redesigning the airframe of the UAV. As a result, we scrapped the Penguin B, and started searching for better airframes. We then encountered the FE 1800S Aerobot. In all, in each design phase, we went through 2-3 iterations.

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, the team created tables on Google Drive to compare each possible candidate. The 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 the team first began to conceptualize the most effective strategy to measure the amount of moisture located in the plant leaves and soil, the team looked at the different sensors available to remotely sense the overall moisture content and health of the crop. The team 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, the team 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, the team realized that this would be a highly unreliable and inaccurate option so the team decided on mounting a sensor or multiple sensors.

By separating the possible sensors into two categories, direct (radar and infrared) and indirect (cameras), the team was able to start going through these categories. The team realized that an indirect sensor (camera) would not be useful because the team needed to measure the moisture content accurately, which would require a direct sensor to measure it. With a normal CCD/CMOS camera it would be extremely difficult and tedious for our employee or farmer to identify areas lacking water from the footage. Also, the team would not get exact numbers. Thus, the team researched direct sensors specifically. The team took into consideration the field of view of each sensor, its accuracy, and its cost. To make the selection process easy, the team 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°

Table 7: 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 8: Comparison of Sensors Without CCD/CMOS

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 171 feet. This would mean that our UAV cannot travel faster than 171 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 108 feet per second.

We were thinking of including a normal video camera so the user could view their field from above. In the end, the team 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 13: X5000 Multispectral Sensor

2.2.2 Air Vehicle Element Selection

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

- Composite airframe
- Two vertical stabilizers
- High-mounted wing with ailerons
- Electric brushless motor

It contains the following sensors and electronics:

- GPS system
- 900 MHz Data Transceiver
- Autopilot
- Multiplexer Analog/Linear
- Serial 10 Servo Controller
- 10,000 mAh, 22.2 Volt Lipo Battery
- 500 mAh 11.1 Volt Lipo Battery.

The reason the team chose a pusher design in the end is because it is more energy efficient than tractor air crafts. Fixed wing pushers are also much stronger and more stable than many other designs, allowing us to carry enough payload to carry out the operation. The team chose to use skid landing because it uses much less landing space. Also, fixed wing pushers are much more energy efficient than other designs.

Our UAV uses a X5000 multispectral camera because of its high resolution, field of view, and reasonable cost. Our design also uses a Raspberry Pi for data logging. The team used a Raspberry Pi because it a cheap, practical, and powerful way to capture data and transmit it to a computer. Rather than having all of this done on the UAV itself, the team 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 Sunny Sky X2820, 800kv brushless motor because of its low weight and high efficiency. The engine weighs 140g, and generates the power of 700W, 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 $1797. With the electronics, sensors, and powerplant, the airframe costs $7606.

2.2.3 Command, Control, and Communications (C3) Selection

When the team was 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.

The team 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.

After launching the UAV by hand, the PC will send a signal to the multiplexer that will turn the UAVs autopilot on, thus disengaging the SSC from manual control. Using the GPS, the UAV orients itself to the starting position of its path and then the pre-programmed flight plan will then 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 micro-controller ($100) that are connected to the PC. The operator will take these controls and land the UAV on the 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 the team's 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, the team 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, the team 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, the team 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, the team 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, 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 with the joystick. After Big Blue looked in the catalog and on other external websites, it decided to use the 900MHz High Range Data Transceiver Set from the catalog because it 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, the team 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 our operation plan includes only one UAV, the team did not need any support beyond these options, and this strategy helped us conserve the amount of money spent on support equipment.

The team chose a utility trailer, priced at $200, 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 FE 1800S Aerobot. The team 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, because Big Blue has an electric brushless motor, the team no longer requires the Internal Combustion Flight Line Kit, which reduces our costs by $130.

2.2.5 Human Resource Selection

For on-field operation, the team decided to hire a Safety Pilot, a Data Analyst, and Range Safety/Aircraft Launch and Recovery/Maintenance officer. The Safety Pilot, and Range Safety Officer are hired for $35 per hour, and the Data Analyst for $50 per hour. As our UAV is autonomously controlled and does not transmit data while in flight, Big Blue is 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 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 and alert the Safety Pilot. 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 of any deviations from the mission plan. At the beginning of the flight, the Range Safety officer will help set up the launch of the aircraft, and, at the end of each flight, he/she will recover the aircraft. After the aircraft lands and is recovered, the Data Anaylyst will analyze the flight data. Our three operational personnel will cost \$120 per hour, at a cost of \$240 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 the team was able to fly above 500 ft, our camera could have a wider field of view in the x-direction. In this way, the team could have detected more rows of corn and reduced our operational time. The UAV weight restriction of 55 lbs didn't seem to be too much of an issue, as the team realized that in order to increase our airframe efficiency, the team needed a UAV airframe that weighed the least amount possible, which directed us towards lightweight airframes that were far under 55 lbs. The maximum airspeed requirement also did not affect our UAV too much; the small, lightweight UAVs that Big Blue found were unable to travel at nearly 100 mph.

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

2.4 Component and Complete Flight Vehicle Weight and Balance

The total empty weight of the UAV is 2.069 pounds, and at maximum takeoff weight, the UAV is 6.297 pounds. 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	19.68	33.06	1.68
Engine	25.59	7.68	0.3
GPS System	12.80	0.256	0.02
Multiplexer	12.80	0.422	0.033
High Power Data Transceiver	12.80	0.32	0.025
Serial 10 Servo Controller	12.80	0.1408	0.011
Total Empty Airframe	20.24	41.87	2.069

Table 9: Details of Airframe

Our empty UAV has a center of mass located at 20.24 inches from the nose. The UAV's payload data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
X-5000	12.80	17.92	1.4
Raspberry Pi Zero	12.80	0.8	0.064
Sandisk 8 GB Class4 TF MicroSDHC Memory Card	12.80	0.5632	0.044
Total Payload	12.79	19.28	1.51

Table 10: Details of Payload

Our UAV payload has a center of mass located at 12.79 inches from the nose. The UAV's power source data is below.

Component	Fuselage Station (in)	Moment (inch-lbs)	Weight (lbs)
GENS ACE Battery Pack	12.80	1.28	0.10
Multi Rotor LiPo Pack	12.80	33.54	2.62
Total Power Source	12.80	34.82	2.72

Table 11: Details of Power Source

Our UAV power source has a center of mass located at 12.80 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	20.24	41.87	2.069
Total Payload	12.79	19.28	1.51
Total Power Source	12.80	34.82	2.72
Total UAV	23.32	95.97	6.297

Table 12: Details of Weight of UAV

Our UAV's center of mass at maximum takeoff weight is located 23.32 inches from the nose.

2.5 Design Analysis

Our aircraft, at maximum takeoff weight, weighs 6.297 lbs, which is less than the FAA weight cap of 55 lbs. It flies at a speed of 108 ft/s, which is less than the FAA cap of 146.7 ft/s, and at an altitude of 470 feet, less than the FAA restriction of 500 feet. 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 FE1800s' maximum flying weight is 4.5 kg, or 44.145 Newtons. The lift force provided by the wings must be equal to this, to allow the plane to fly. Therefore, the team estimated the lift force to be 44.145 N. The team was unable to accurately find the density of the air the aircraft would be flying through, so the team used the air density at sea level of $1.225 kg/m^3$. [3] The aircraft's wing area is $0.432 m^2$ (1.8 m by 0.24 m, as provided by the UAV website.) [4] To get C_L, Big Blue used the aircraft's flight velocity of 108.5 m/s.

Once all of these were inputted, the team calculated the lift coefficient of the aircraft to be 0.014, when the aircraft is at 0 degrees angle of attack.

[2] https://www.grc.nasa.gov/www/k-12/airplane/liftco.html
[3] http://scipp.ucsc.edu/outreach/balloon/atmos/1976%20Standard%20Atmosphere.htm
[4] http://fliteevolution.com/product/fe-1800s/

As the team was unable to find the exact airfoil type of the FE 1800s UAV, after a little bit of online research, the team was able to estimate it to be the NACA 12012 airfoil. Once the team had found the 12012 airfoil, the team confirmed our guess with an analysis of the airfoil with Javafoil, an online aerodynamics tool. Below is the graph Javafoil produced of the wing's C_L values.

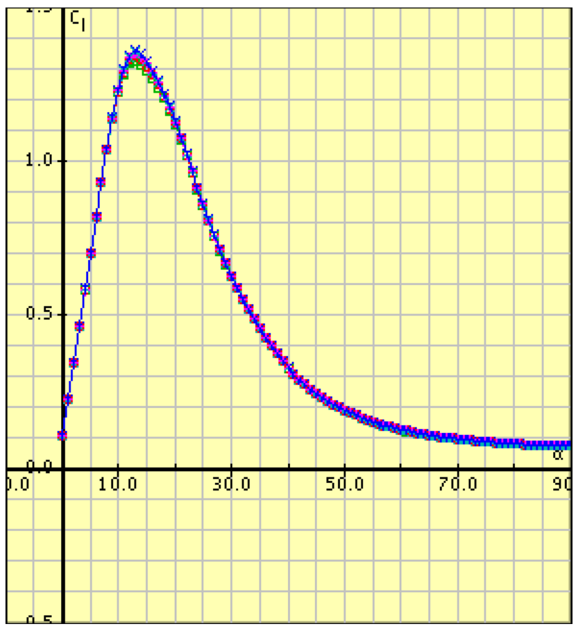

Figure 14: Lift Coefficient Graph

To calculate the C_d value of the aircraft, the team used the C_d of an streamlined body: 0.04. Using JavaFoil, the team was able to come up with a list of C_M values against their respective angle of attacks. The team cut the table off after the critical angle of attack of around 11 degrees, as provided by the Javafoil graph above.

Alpha (Angle of Attack in degrees)	C_M 0.25
0	-0.008
5	-0.012
10	-0.020

Table 13: List of C_M Values vs Angle of Attack

2.6 Structural Analysis

The FE1800s wing spar is a carbon fiber rod that is 0.47 in by 0.39 in by 47.27 in. From talking with Mr. Bo Pollett, one of our mentors, the team was able to determine that during loading, 90 percent of the load is taken by the carbon fiber. As such, the team decided to find the amount of load on a carbon fiber tube at 6 gravities:

- Weight of UAV: 6.297 pounds
- At 6 g: 37.782 pounds
- Each wing will be taking 18.891 pounds of force (37.782/2)
- Length of carbon fiber: 47.27 inches
- Carbon fiber height: 0.47 in
- Carbon fiber width: 0.39 in

Using this tool [5], the team was able to find that the bending stress would be 87,608.67 psi. Carbon fiber has an ultimate strength of 8,129,365.2 psi, which is greater than 87,608.67 psi. Therefore, our wing will remain functioning even at 6g, which satisfies our load requirement.

The aircraft will undergo the highest stress during its coordinated turns. To find how much the aircraft will be stressed during each turn, the first calculated the maximum bank angle of the UAV, to find the tightest turn it can make. The team then proved that even at a maximum bank angle,

[5] http://www.meracalculator.com/engineering/deflection-round-tube-beams.php

the aircraft will not exceed the load factor requirements of the competition. Finally, Big Blue calculated the turn radius at maximum bank angle.

$\cos\theta = \frac{W}{L}$

Where θ is the bank angle, W is the weight of the aircraft in Newtons, and L is the lift force provided by the wings. As the weight of the aircraft is 6.297 pounds, or 28.01 Newtons, using the estimated lift force the team found in section 2.5, the team finds θ to be 50.6 degrees.

As mentioned in the next section, our smallest coordinated turn is of radius 342 feet. The equation to find the aircraft load factor as it turns is below:

$n = \frac{L}{W}$

where n is the load factor, measured in gravities, L is the lift force provided by the wings in Newtons, and W is the weight of the aircraft in Newtons.

From this, the team plugged in L into the equation $n = \frac{L}{W}$ and find n to be 1.58 gravities. Therefore, in the UAV's turn, the load factor the aircraft will experience of around 2 gravities is less than the mandated maximum of 4 gravities.

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 342 feet. 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 ($L_{horizontal}$) which is the portion of lift that provides the centripetal force. After that, the team looked at the equations used to calculate $L_{horizontal}$. The total lift force formed the hypotenuse of a right triangle, with $L_{horizontal}$ being the opposite side with respect to the bank angle theta, and W being the adjacent side. Therefore, the team can calculate $L_{horizontal}$ by using the Pythagorean Theorem:

$L_{horizontal} = \sqrt{L^2 - W^2}$

Since $n = \frac{L}{W}$, $n\,W = L$.

So, $L_{horizontal} = \sqrt{(nW)^2 - W^2}$.

So, $L_{horizontal} = \sqrt{(n^2 - 1)(W^2)}$

So, $L_{horizontal} = W\sqrt{n^2 - 1}$

$L_{horizontal}$ also provides the centripetal force of the aircraft, or $\frac{mv^2}{r}$. This is equal to $\frac{Wv^2}{gr}$ and $W\sqrt{n^2 - 1}$.

So, $r = \frac{v^2}{g\sqrt{n^2-1}}$.

Since the aircraft travels 74 mph during the turn, Big Blue calculates r to be 297.97 feet.

The team was able to calculate that the UAV could sustain a coordinated turn of a minimum of 300.7 feet. As the team's flight plan calls for a turn radius of 342 feet, its UAV will be able to fly our flight plan.

The turning radius that the team calculated by hand, along with the acceleration gravity found in section 2.6, is around equal to the data provided by the online calculator tool that the team found.[6] The online calculator gave the team a turning radius of 302.0 feet and an acceleration gravity load of 1.6 g's. The slight discrepancies between the hand calculated and online calculated values can be attributed to differences in rounding.

[6] http://www.csgnetwork.com/aircraftturninfocalc.html

2.8 CAD Models

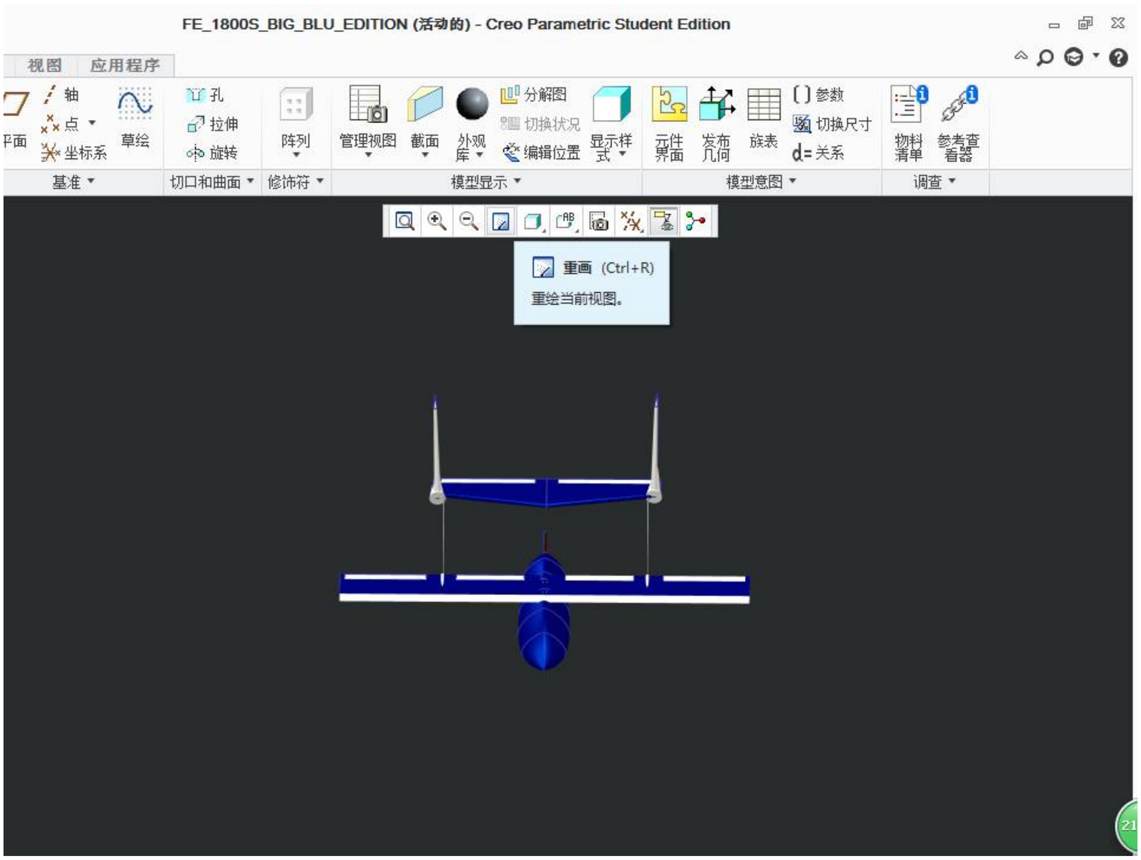

Figure 15: 3D CAD Model of UAV

Figure 16: X5000 Multispectral Sensor

2.9 Three View of Final Design

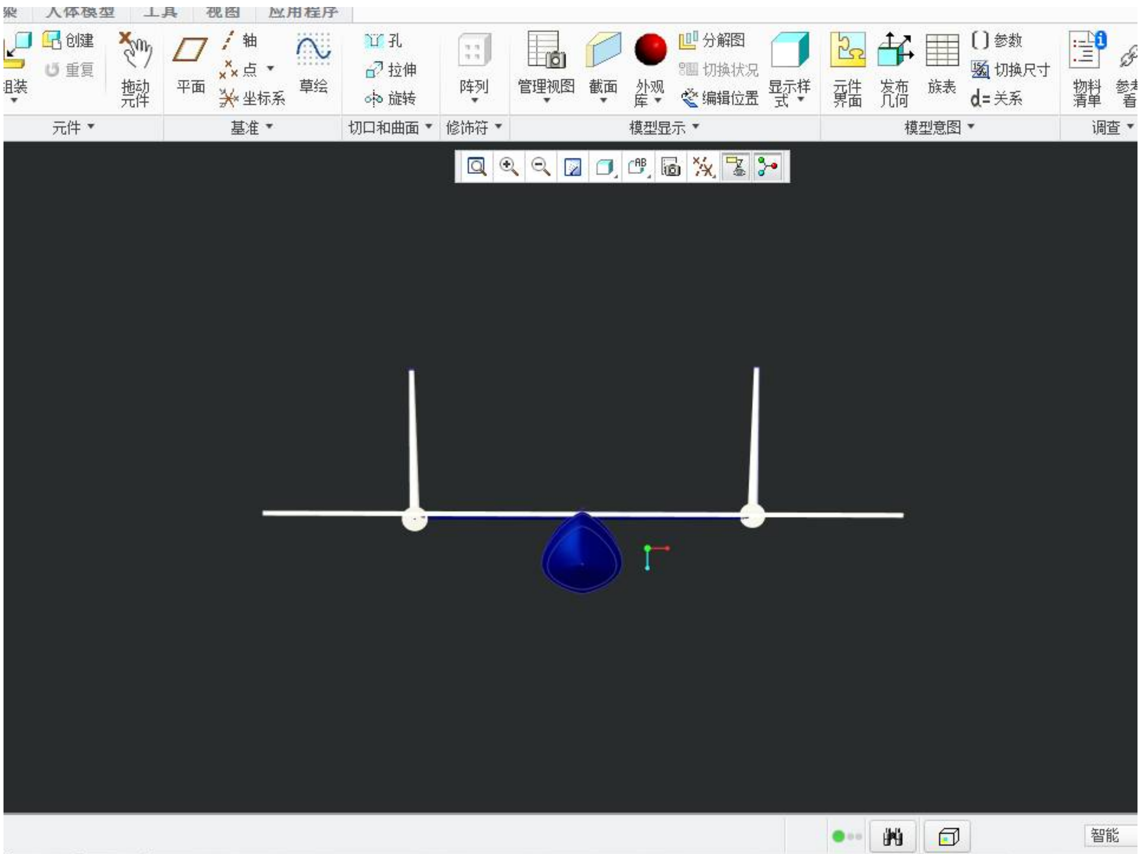

Figure 17: XY View of 3D CAD Model

Wingspan: 1800 mm
Wing string: 240 mm
Body length: 650 mm
Body Width: 160 mm
Body Height: 150 mm

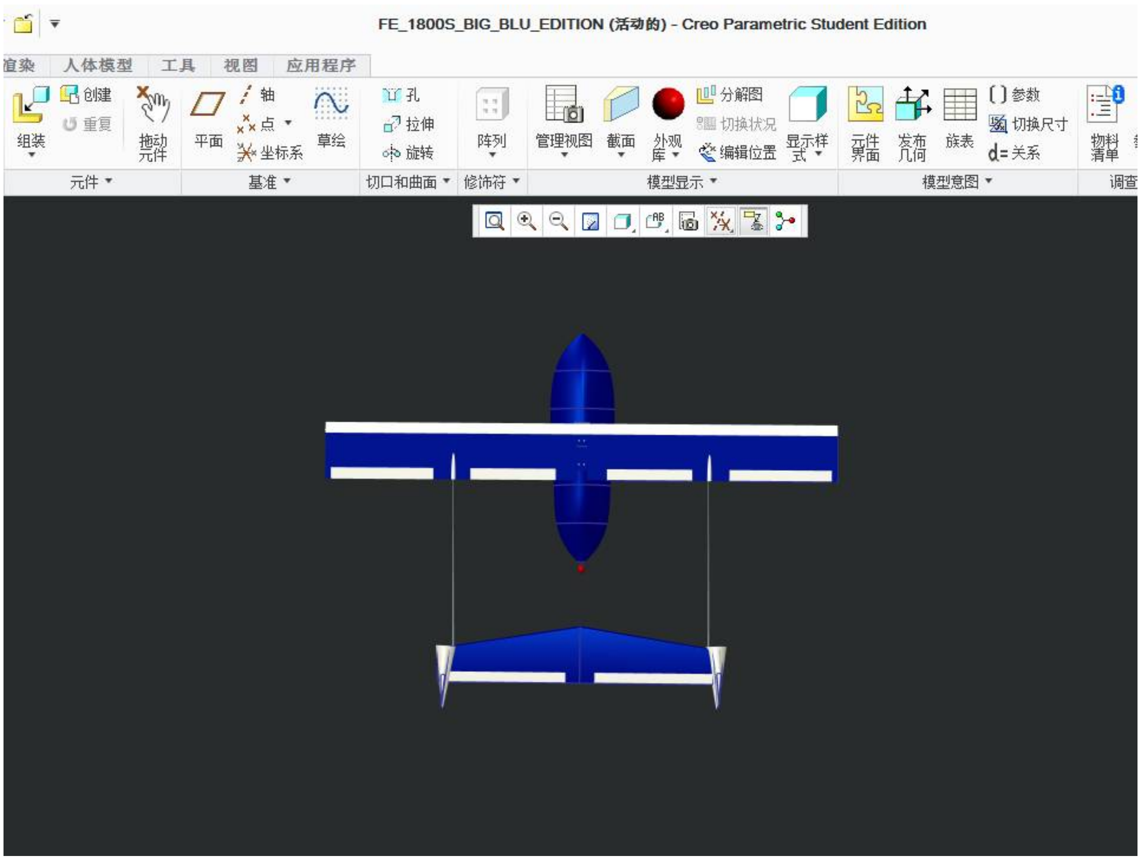

Figure 18: XZ View of 3D CAD Model

Wingspan: 1800 mm
Wing String: 240 mm
Body Length: 650 mm
Body Width: 160 mm
Body Height: 150 mm

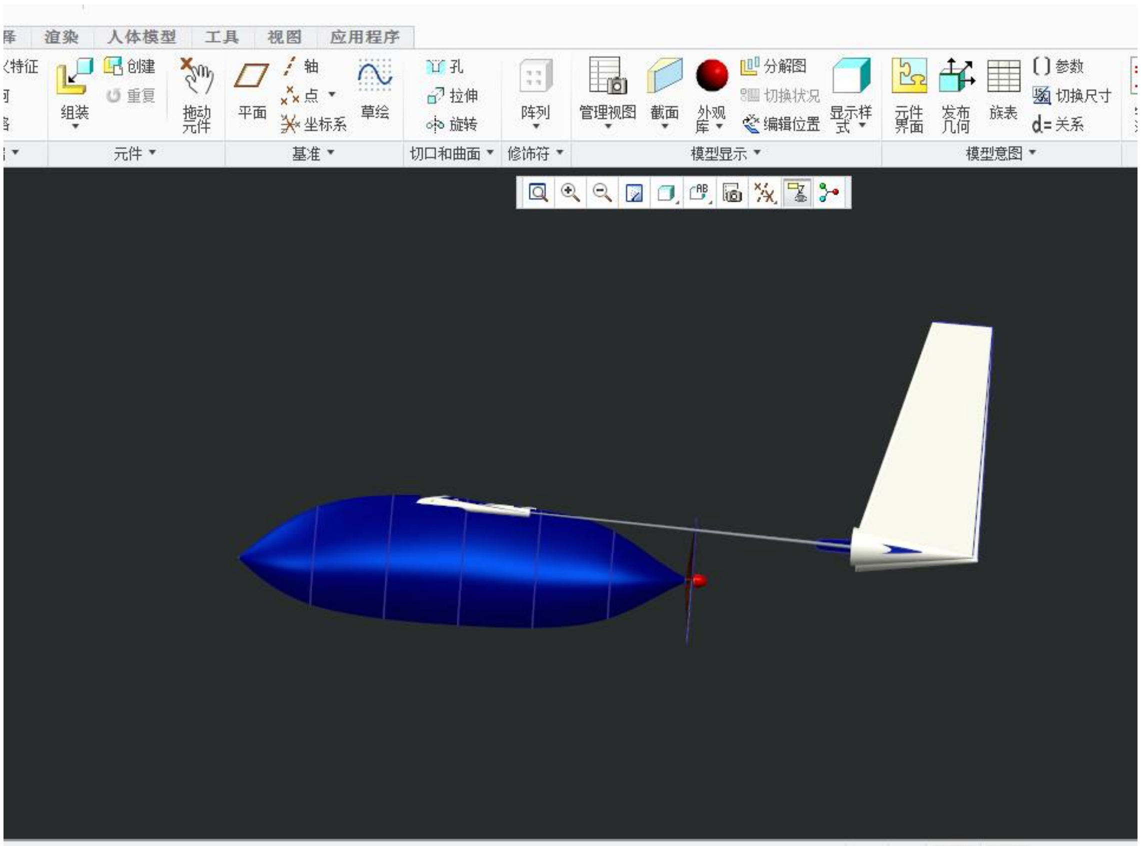

Figure 19: YZ View of 3D CAD Model

Wingspan: 1800 mm
Wing String: 240 mm
Body Length: 650 mm
Body Width: 160 mm
Body Height: 150 mm

Chapter 3

The Detection Plan

3.1 Moisture Detection Pattern

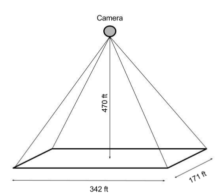

Figure 20: Sensor 3D View

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

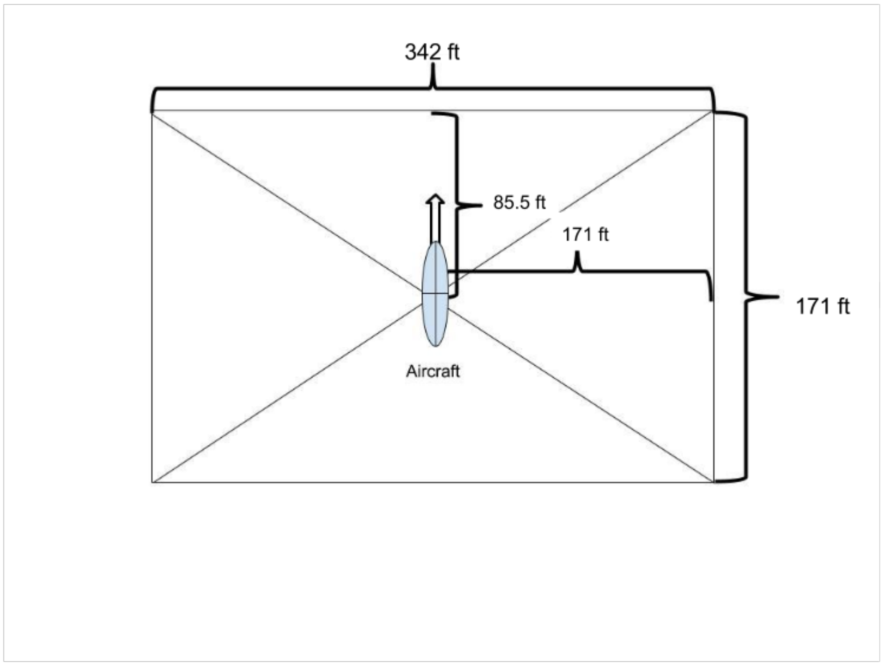

Figure 21: Viewing Box

Because the team's aircraft can detect around 342 ft of land across, it is able to view 113 rows of corn at a time (each row of corn being 3 feet apart). Big Blue used a turning radius of around 342 ft. Based on these specifications, the team designed its flight plan accordingly:

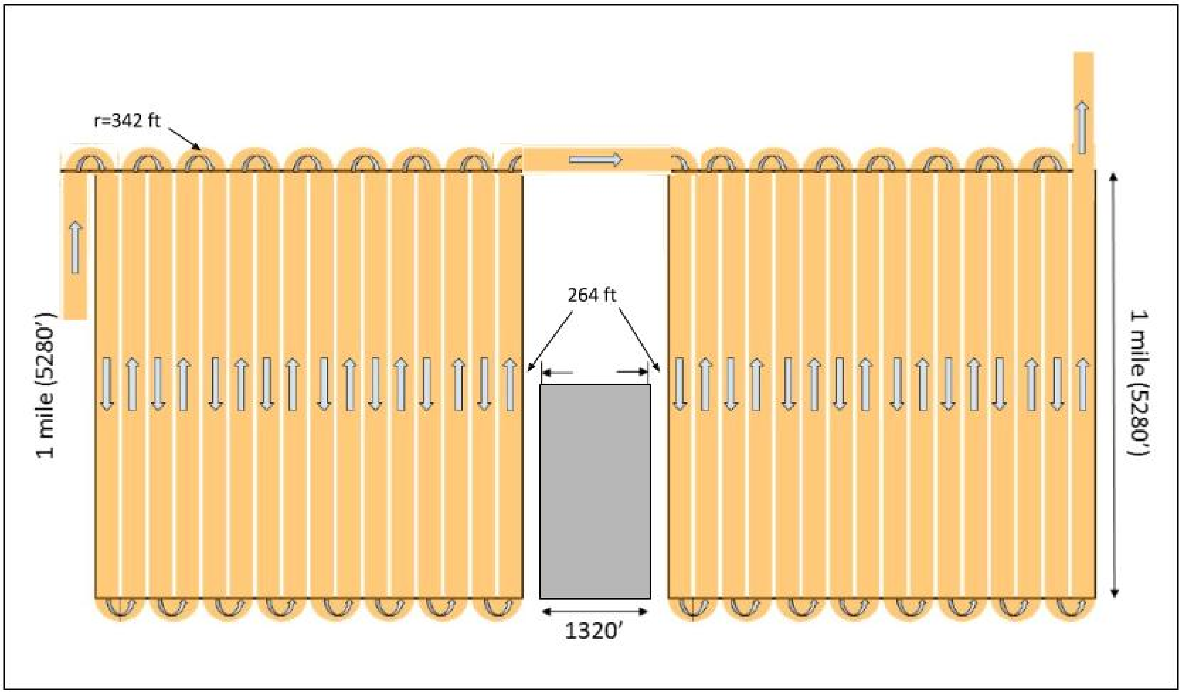

Figure 22: Current Flight Plan

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 below. $Portion_a$ consists of all the coordinated half-circle turns the UAV will make. $Portion_b$ consists of the straight flight the UAV will make up and down the field. $Portion_c$ consists of the straight part of the journey the UAV will take between fields, and $Portion_d$ is distance the UAV will travel during the two quarter-circle coordinated turns it will take as it flies from field to field.

$Portion_a$ = 2 (16×π×342 = 17,190.79 ft) = 34,381.59 ft

$Portion_b$ = 2 (84,480 ft) = 168,960 feet

$Portion_c$ = 264 ft + 1320 ft + 264 ft = 1,848 feet

$Portion_d$ = 342π ft = 1,074.42 feet

$Total$ = 34,381.59 ft + 168,960 ft + 1,848 ft + 1,074.42 ft = 206,264 ft or 39.06 mi

At 74 mph, this is 31 minutes.

Our sensors will detect moisture every 1.58 seconds.

74 mph (cruise speed) = 108 ft/s

$\frac{171ft}{108ft/s}$=1.58

At 470 feet, the X5000 will have a resolution of around 2 inches by 1 inch. The calculations for this are below:

Field of view/Pixel count = Resolution

Horizontal (left and right the field): 342 ft/2048 pixels = 2 inches per pixel

Vertical (up and down the field): 171 ft/1536 pixels = 1 inch per pixel

3.2 Theory of Operation

Preflight

The UAV will be transported by the Range Safety Officer to a suitable section of clear ground on the farmer's property right behind the takeoff position. The ground control station will be situated in the middle of the two crop fields, in line with the edge of these fields (opposite of the no-fly-zone). The UAV will be reassembled at the takeoff position, turned on, and the Range Safety pilot will calibrate and check the autopilot as well as other systems vital for the UAV's function.

Takeoff

The Range Safety pilot throws the UAV and monitors the sky as it takes off. The Safety pilot, who will be standing at the ground control station, monitors the UAV as it takes off and in an emergency, he/she will use the joystick to bring the UAV under control until the autopilot can take over once again.

Flight

The UAV's autopilot will then make sure the aircraft travels on its pre-programmed flight plan. The safety pilot will make sure the aircraft is flying on its designated flight path and that the autopilot is working properly. The range safety pilot will make sure that sky is clear of all obstacles. In case the autopilot malfunctions or the UAV loses control, the safety pilot always has the joystick and can switch from the autopilot to manual mode so he can redirect the plane and bring it under control or safely land it.

Landing

The UAV will belly land according to its landing autopilot on a strip of clear ground just outside of the farmer's. There will be no difference in flight plans between the detection periods.

Postflight

After the UAV lands, the data analyst will remove the Raspberry Pi with the SD card from the UAV and plug it into the Panasonic Toughbook to retrieve and analyze the data that has been collected by the X5000 sensor during the flight. This information then will be relayed to the customer.

3.3 Detection Considerations

A challenge Big Blue ran into was in choosing a crop. The team did some research on several food bearing crops commonly grown within the United

States: oranges, corn, wheat, potatoes, and apples. The team then narrowed the choices down to crops grown in its area to best serve its local farmers.

Crop	Crop Dimensions	Primary 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
Potatoes	1'	Idaho	4 months

Table 14: Crops Considered

In the state challenge, Big Blue decided to use corn because it grows quickly and is one of the most cultivated crops in the world. The team also took into consideration lots of other factors such as the crop size, amount of food it produces to feed people or animals, and crop density on a field. Crop and leaf size was especially important because the larger the surface area of the crop is the easier it is to detect moisture content. Crops with large leaves allow us to sacrifice some resolution and fly higher but still obtain an accurate reading.

When the team started working on the national challenge, the first thing the team did was choose its second crop. Again, the team wanted a common food bearing crop that is grown in Massachusetts. Big Blue looked at the same crops the team had researched earlier and picked potatoes because of their growth time, food production, and size. The team's crop choices affected its detection strategy. The team had to pay particular attention to the size of the plant leaves to make sure the X5000 sensor could detect moisture in them. Corn and potatoes are also harder to detect at the beginning of the season, before any leaves have sprouted, so in this case the sensor would be measuring the moisture content of the soil instead. This would give the farmer a good estimate of how wet his land is to ensure the germination of the seeds. This information was another factor as to why Big Blue stuck with a high resolution camera during the national challenge so the team can offer a more versatile product that can be used in a variety of ways in various stages of the growth process.

In the beginning stages of the state challenge, the team had a different flight plan that would cross the horizontal distance of the field twice in order to maximize detection accuracy. However, since Big Blue decided on using the X5000, whose detection is very accurate, the team was able to simplify our flight plan and reduce the total travel distance. The team's original flight plan was:

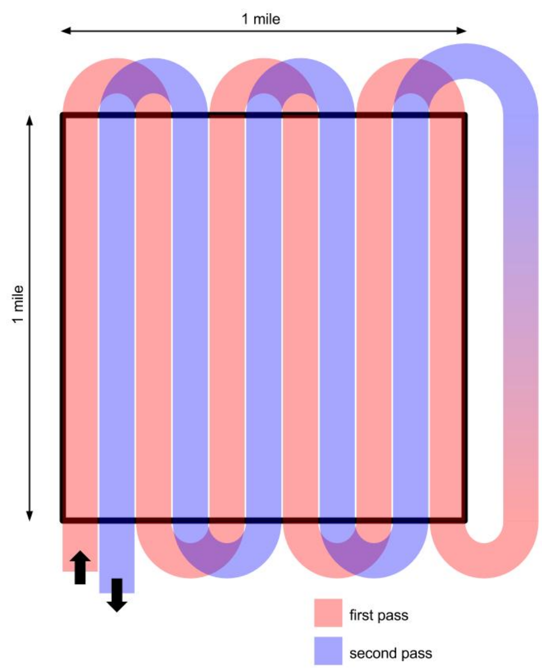

Figure 23: Original Flight Plan

The team kept its revised flight plan during the national challenge, as the team found that it were able to think of the new field setup as two fields from the state challenge.

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, the team changed its design. If Big Blue had used a sensor with a smaller resolution, the team 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, the team 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 24: Objective Function Program

Big blue focused on minimizing the empty weight of its aircraft. The team also chose an airframe that has a high cruise speed (74 mph), 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 Big Blue chose our airframe because the team wanted to choose a design that had a high endurance but low operational cost. By using a UAV that was battery powered, the team were able to reduce the cost of the UAV by eliminating the need for gasoline/petroleum fuel. The team reduced its operating expenses (see section 4.4) to maximize business profitability.

Conventional detection methods use soil moisture sensors which require samples of soil or must be installed under the topsoil. This is inefficient as one must gather data from all sections of the field separately. In addition, certain other conventional methods require a farmer to cut off leaves or yields from certain sections of the plants and then analyze them to find the moisture content. This is very time-consuming and only gives the farmer a small snapshot of what areas must be watered more. This also harms plant which could reduce crop efficiency. Our UAV's multispectral sensor is much quicker and cheaper in detecting moisture than conventional methods as it uses NiR spectroscopy to detect the amount of water in an individual plant. Spectroscopy is the interaction between matter and electromagnetic waves. The sensor detects 400-1100 nm (NiR) waves of light that are reflected from a leaf back to the sensor. Using this information it stitches together a map of the areas of high and low moisture using varying colors. Much like on a precipitation map, a farmer can view this moisture map and make decisions on which areas need more water, even down to the exact plants.

3.4 Detection Time and Resource Requirements

The design requires three people to operate the UAV. This includes a Safety Pilot, who will continuously maintain visual contact with the UAV and monitor the sensor. There will also be a Range Safety Pilot to observe the sky surrounding the UAV and warn the Safety of any threats that may be approaching the UAV. Lastly, there will be a Data Analyst to analyze the UAV's data once it has landed.

The timescale of this mission is very short. Since the total distance for the UAV to travel is 39.06 miles, and the UAV travels at 74 mph, the UAV will spend approximately 31 minutes scanning the cornfield, with an additional time period of 4 minutes for 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	$ 120.00	$ 120.00	$ 120.00	$ 120.00	$ 120.00
Consumables	$ 15.16	$ 15.16	$ 15.16	$ 15.16	$ 15.16
Operations and Support Costs	$ 349.16	$ 135.16	$ 344.16	$ 135.16	$ 344.16
Total UAS Cost Per Hour (over specified number of applications)					
System Initial Cost ($AcqCost_i$)	$ 2,422.46	$ 2,422.46	$ 2,422.46	$ 2,422.46	$ 2,422.46
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	12.11229	$ 12.11	$ 12.11	$ 12.11	$ 12.11
Total Cost Per Hour ($FCPH_{RWDC}$)	$ 361.27	$ 147.27	$ 356.27	$ 147.27	$ 356.27
Total Cost per Field	$ 722.55	$ 294.55	$ 712.55	$ 294.55	$ 712.55
Total Revenue Per Field	3884	3884	3884	3884	3884
Total Revenue Per Year	$ 388,400.00	$ 388,400.00	$ 388,400.00	$ 388,400.00	$ 388,400.00
Total Cost Per Year	$ 72,254.80	$ 29,454.80	$ 71,254.80	$ 29,454.80	$ 71,254.80
Total Profit (Loss)	$ 316,145.21	$ 358,945.21	$ 317,145.21	$ 358,945.21	$ 317,145.21
Cumulative Net Cash Flow	$ 316,145.21	$ 675,090.41	$ 992,235.62	$ 1,351,180.82	$ 1,668,326.03

Figure 25: Total Costs

4.1 Regulatory Restrictions

The FAA imposed several restrictions on Big Blue's UAV including a maximum flight height of 500 feet, a maximum UAV weight 100 mph, and a maximum weight of 55 lbs. This constrained the UAVs that were available to relatively lightweight and slow UAVs. Furthermore, the FAA requires operators to register their UAV every couple of years, at a total $214.

4.2 Amortized System Costs

As the United States is one of the leaders in world corn production, demand for Big Blue's product will be high. The team estimated that it can service over 100 fields per year. Using the cost calculator, the team found that the total cost for 100 missions, with three detection flights per mission, would be around $84,581. This was calculated by multiplying the cost per field, $722.55, by 100, and adding the total acquisition cost, which was $12,112. 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.

$$\$722.44 * 100 + \$12,112 + \$214 = \$84,581$$

4.2.1 Initial Costs

The team calculated its assembly cost to be $12,112 ($8,387.29 for the UAV system, C3, and Support Equipment, and $3,725 for the engineering and construction labor.)

System Costs		
Total Vehicle Cost	$	7,508.44
C3 Cost	$	370.00
Support Equipment Cost	$	508.85
Engineering Labor Cost	$	3,725.00

Figure 26: UAV Initial Cost

Role	Hours	Cost Per Hour	Subtotal
Project Manager	30	$ 75.00	$ 2,250.00
Simulation Engineer	12	$ 50.00	$ 600.00
Systems and Test Engineer	5	$ 50.00	$ 250.00
Project Scientist	5	$ 50.00	$ 250.00
Electronics Technician	5	$ 25.00	$ 125.00
Aircraft Maintenance Technician	10	$ 25.00	$ 250.00
Total Eng/Construction Labor Cost			$3,725.00

Figure 27: 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. During this time, the portable generator on the ground will consume $1.95 worth of fuel. The batteries on board the UAV, in the mission time (around 1.5 hours,) will take around 1781.5 mAh of electricity, which, using a standard US 120 Volt power outlet, will take 231.78 kWh of electricity. The average price of electricity in the US is 0.12 cents per kWh, resulting in a $25.65 cost for UAV electricity. On the field, our three Operational Personnel will cost $240 for each (rounded) 2 hour mission.

The total cost calculation is below:

$240 + $25.65 + $1.95 = $267.6

4.2.3 Amortization

The total cost per mission was calculated to be $831.57 dollars.

To calculate this, the team added the initial system cost and the total operational cost per mission for the anticipated number of missions per year (100), and divided the sum by the number of missions per year.

Total acquisition cost:

Total Vehicle Cost ($7,508.44) + C3 Cost ($370.00) + Support Equipment Cost ($508.55) + Engineering Labor Cost $3,725.00 = $12,112.29
Operational cost per mission: $692.45

($12,112+ $692.45*100)/100 = $813.57

4.3 Market Assessment

Big Blue's UAV is competitive in the market in three ways: its low cost and fuel efficiency, quick mission completion time, and its high resolution. Against other UAVs of similar cost, the main advantage the FE1800s has is its superb fuel efficiency. Able to complete each mission of three flights with less than $20 worth of electricity, the FE-1800S is an economically sound option for the team's 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. Big Blue's UAV can complete the task in around 35 minutes.

Other services use satellites. In the team's research, it stumbled upon one such service, "Cropio." Cropio's service is priced at a similar cost as mine, at around $3884 for a two square mile area, but provides more consistent updates (they provide daily updates). However, research has proven that satellite imagery simply cannot stand up against UAV detection. UAV detection, including those offered by our service, offers a far greater resolution than can be provided by satellite imagery. [7] [8] [9] [10] The team's service provides a resolution of around two inches by one inch, while satellite resolutions range from several feet to several miles. As such, although there are satellites that can potentially measure soil moisture, the service will allow a farmer to specifically pinpoint, to the exact plant, which crops need more moisture.

4.4 Cost / Benefits Analysis and Justification

While designing the aircraft, the team paid close attention to minimizing the costs of the sensors and payload on board the UAV, along with reducing the cost of the airframe itself. The team always chose the cheapest equipment that would achieve our intended goal. The batteries the team chose are far cheaper than on board generator systems, and yet hold enough electricity to power our on board systems and UAV during the entirety of a flight. Instead of having an expensive and large trailer, since the team has very little ground support equipment, the team went for a minimalistic approach and chose the Utility Trailer, and open trailer that allowed the team to store the UAV, generator, computer, and battery recharger. Since the competition rules state that the team is to expect good weather conditions, there is no possibility of rain damaging our electronics. Furthermore, the system is designed to use as few operational personnel as possible. The team decided to only have three

[7] http://www.cropquest.com/precision-ag/uas-aerial-satellite_imagery/
[8] http://www.senteksystems.com/2015/11/30/satellite-imagery-versus-uav-imagery/
[9] www.mdpi.com/2072-4292/7/3/.../remotesensing-07-02971.pdf
[10] http://arxiv.org/pdf/1307.2434.pdf

people on site: the Safety Pilot, Range Safety Pilot, and Data Analyst. The semi-autonomous design of the UAV, and the fact that it transmits no data while in flight, makes all other roles redundant, allowing the company to offer its service for a lower cost, while still maintaining business profitability. The system is also easy to use for the consumer; as the team 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 the operators. Lastly, the 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, the team will be able to service multiple fields per each growing period.

During the state challenge, the UAV our team used turned out to have too much capacity for our needs. As such, the team researched UAVs again and found a far cheaper and lighter UAV that would be suitable for its needs. With this, the team was able to maximize the cost and payload efficiency of the airframe.

In order to maximize the sensor coverage of our UAV, the team decided to fly it near the maximum FAA approved height of 500 feet, leaving 30 feet of leeway for safety. The team calculated that it would receive a suitable sensor resolution at this height. The team decided that the higher the UAV flew, the shorter flight path the UAV could have. As shown in section 3.1, the X5000 , at 470 feet, produces pixels that are 2 inches by 1 inch in size. At this size, the UAV will be able to obtain its data. As such, the UAV 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.

FE1800s– the team's superior aircraft, combined with our X5000 multi-spectral 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	$ 7,508.44
C3 Cost	$ 370.00
Support Equipment Cost	$ 508.85
Engineering Labor Cost	$ 3,725.00
Operational Costs per Hour	
Operational Personnel	$ 120.00
Consumables	$ 15.16
Operations and Support Costs ($O\&S_{hr}$)	$ 135.16
Revenue and Profit	
Total Acquisition Cost	$ 12,112.29
Cost Per Field	$ 722.55
Revenue Per Field	3884
Profit Per Field	$ 3,161.45

Figure 28: Total Revenue Assessment

4.5 Additional Commercial Applications

In addition to detecting plant moisture content, the UAV is also equipped to detect crop infestation, measure algae blooms in lakes or at beaches, and monitor climate change through thermal mapping. The UAV needed to be extremely versatile to perform different functions to be able to maximize our profits. Moisture detection in corn and potatoes is performed three times during each crops growth cycle. With multiple customers and different growth periods (ex. early corn and late corn). This main function will generate the most money but as corn and potato do not grow in the winter in Massachusetts a new solution was needed for the winter and between the three detection times at the beginning, middle, and end of the crops' lifespan. To generate more profits for our company and our investors, Big Blue added these three additional functions to our UAS system as well as keeping our UAV open and modular so the team can at any time change out a sensor to allow it to preform a new task as the market changes. This will allow the business to expand and conform to demands in the future and have longevity. While choosing out airframe, the team kept this in mind and picked a UAV that fit very well to our current business objectives to get our company off the ground but could also handle different functions that may arise in the future.

Out of the three extra uses, detecting crop infestation will be the primary source of revenue. Crop infestation is a major issue in mass agriculture as a single pest could ruin an entire year's harvest. At the same time, too much pesticide could make the food dangerous too eat and is very expensive. Our UAS solution for this would monitor a farmer's field and alert them of an infestation so the can act accordingly and use pesticide. The UAV will use its built-in X5000 multispectral sensor to detect a lack of chlorophyll in plant leaves. It does this with the green filter of the sensor. A reduced amount of chlorophyll in a plant is an indicator of stress often caused by damage done by pests. The sensor can also more accurately detect individual egg clusters on leaves that have been left by some types of pests. Big Blue would preform this detection in the summer on the days the team is not monitoring moisture or simultaneously to make more money. The package will be sold to the farmers who have already purchased a subscription for plant moisture detection. This way, the company will not have to establish a new customer base and can make much more money from the same farm.

Another use for the UAV is algae detection in lakes or near beaches. In

Massachusetts, there are many beaches on the Atlantic Ocean and many lakes for fishing or swimming. In the summer months between June and October toxic algal blooms, such as the red tide, plague these bodies of water so beaches and fishers often have to be closed. Fish can become contaminated and people can be poisoned by these toxic algal blooms. The UAV will use the green filter of the X5000 sensor to detect underwater algae. The UAV perform regular flights over the shoreline and notify the company's customer (the owner of the beach) of a high algae concentration. This will be faster, more accurate, and more efficient than having to dive in the water and collect water samples from many spots along the vast shoreline. In addition, the UAV can reach farther into the body of water to detect algal tides that have not yet reached the shore, but soon will.

In the winter, the UAV will be used to detect ice thickness in lakes and rivers to obtain revenue while crops are not growing. This is vital to the success and sustainability of our business. In New England, ice fishing is an extremely popular activity during the winter months. This requires people to bring their huts, drills, fishing supplies, and sometimes even trucks onto the the ice. Unfortunately, people and their supplies sometimes fall through ice that is too thin. This causes many deaths every year and countless injuries. Currently there is no accurate, efficient, or practical way to detect the thickness of the ice. Now, the most popular way to determine if lake or river ice is safe is to approximate based on the amount of days the temperature has been under freezing. People also use drills to see the thickness of the ice but this requires stepping on the ice. These methods are inaccurate and dangerous. The drone will use its X5000 multispectral sensor to sense the amount of light being reflected off the ice. This way it can tell the thickness and whether the surface is wet (melting) or dry (frozen). The service can be purchased by the local government or private ice fishing companies or businesses that operate on ice. The product ensures the saftey of any employees or visitors and will help prevent any costly accidents. The UAS will also store previous years' data create thermal maps to monitor global warming and how the ice changes over time.

Chapter 5

References

Here are all of the sources that Big Blue used to conduct its research throughout the competition:

1. http://ftp.fao.org/agl/agll/docs/sb79.pdf

2. http://www.provident-living-today.com/Types-of-Soil.html

3. http://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/massachusetts/franklinMA1967/

4. https://www.grc.nasa.gov/www/k-12/airplane/liftco.html

5. http://www.csgnetwork.com/aircraftturninfocalc.html

6. http://turbineair.com/wp-content/uploads/2013/08/Bank-Angle-vs-stall-speed-2013.pdf

7. http://www.aerospaceweb.org/question/performance/q0146.shtml

8. http://www.meracalculator.com/engineering/deflection-round-tube-beams.php

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

10. http://www.nature.com/news/2008/080318/full/news.2008.680.html

11. http://igett.delmar.edu/Resources/Remote%20Sensing%20Technology%20Training/Landsat sm.pdf

12. https://www.spacetelescope.org/about/general/instruments/nicmos/

13. http://education.seattlepi.com/spectroscopy-identify-elements-3503.html

14. https://en.wikipedia.org/wiki/Multispectral_image#Classification

15. http://www.fsa.usda.gov/Internet/FSA_File/fourband_infosheet_2012.pdf

16. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.475.6832&rep=rep1&type=pdf http://dronelife.com/2014/10/01/best-agricultural-drones/

17. http://dronelife.com/2014/10/01/best-agricultural-drones/

18. http://www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/beaches-algae/algae-information.html

19. http://ehp.niehs.nih.gov/122-a206/#r1

20. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact= poster.ppt&usg=AFQjCNHviTUYiLV9VK3iY1Gezm92MfEP8A&sig2=m8DxRq_ApyUFO4

21. http://ocean.si.edu/ocean-news/scientists-work-predict-and-prevent-algae-blooms

22. http://www.popularmechanics.com/science/environment/a8995/mobile-robotic-laboratory-will-track-ocean-toxins-15496532/

23. http://www.mbari.org/technology/emerging-current-tools/instruments/environmental-sample-processor-esp/

24. http://ehp.niehs.nih.gov/122-a206/#r1

25. http://www.whoi.edu/sbl/liteSite.do?litesiteid=7993&articleId=11906

26. http://www.mclanelabs.com/master_page/product-type/samplers/imaging-flowcytobot

27. http://www.analistgroup.com/en/new-solutions-with-drones/uav-multispectral

28. https://directory.biomassmagazine.com/listings/company/

29. http://www.cbsnews.com/news/oil-gas-industry-spills-happen-all-the-time/

30. http://www.itopf.com/knowledge-resources/data-statistics/statistics/

31. https://www.sensefly.com/drones/ebee.htmlr

32. http://air-vid.com/wp/20-great-uav-applications-areas-drones

33. http://www.zoeticaenvironmental.com/zoetip/2014/12/15/swimming-drones-that-can-target-and-treat-green-algal-blooms

34. http://www.hindawi.com/journals/jspec/2012/276795/

35. https://www.ghorganics.com/page2.html

36. http://www.theatlantic.com/health/archive/2014/06/the-most-popular-vegetable-in-america-is-the-potato/372502/

37. http://lifeofplant.blogspot.com/2011/03/north-american-agriculture.html

38. http://www.ncausa.org/About-Coffee/Coffee-Around-the-World

39. http://www.starkbros.com/growing-guide/article/how-many-years/

40. http://www.ask.com/home-garden/long-wheat-grow-5dc7d250b6f8358b

41. http://fas.org/irp/imint/docs/rst/Sect3/Sect3_1.html

42. https://surfaceoptics.com/applications/precision-agriculture-hyperspectral-sensors/

43. http://homeguides.sfgate.com/close-together-can-plant-rows-corn-60020.html

44. http://skyrcee.lot.my/index.php?route=information/information&information_id=1526

45. https://en.wikipedia.org/wiki/Polyolefin

46. http://www.hobbyking.com/hobbyking/store/_64439_Multistar_High_Capacity_6S_10000mAI

47. http://www.hobbypartz.com/98p-imars-charger-6s-50w.html

48. http://www.genstattu.com/ga-b-25c-450-3s1p-jst.html

49. http://www.amazon.com/Battery-Balance-Charger-Li-ion-Batteries/dp/B005EF15Q4/ref=s
and-games&ie=UTF8&qid=1459717018&sr=1-6&keywords=Lipo+charger

50. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3436001/

51. http://about.cropio.com/#press

52. http://www.mh-aerotools.de/airfoils/javafoil.htm

53. http://www.cropquest.com/precision-ag/uas-aerial-satellite_imagery/

54. http://www.senteksystems.com/2015/11/30/satellite-imagery-versus-uav-imagery/

55. www.mdpi.com/2072-4292/7/3/.../remotesensing-07-02971.pdf

56. http://arxiv.org/pdf/1307.2434.pdf

57. http://www.livescience.com/53536-drones-record-sea-ice.html

58. http://www2.bren.ucsb.edu/d̃ozier/Pubs/Chylek_2007JD008742.pdf

59. http://www.atiak.com/products/resolution-3-airframe/

60. http://www.applewhiteaero.com/documents/MILO-SPEC-SHEET_b.pdf

61. http://fliteevolution.com/product/fe-1720g/#more-1348

62. http://fliteevolution.com/product/fe-1800s/#more-331

63. http://hobbyuav.com

64. http://www.marcusuav.com/Marcus_UAV_Zephyr_3_Brochure.pdf

65. http://www.uasusa.com/images/PDFs/RECONSpecs.pdf

66. http://www.uavglobal.com/commercial-uav-manufacturers/