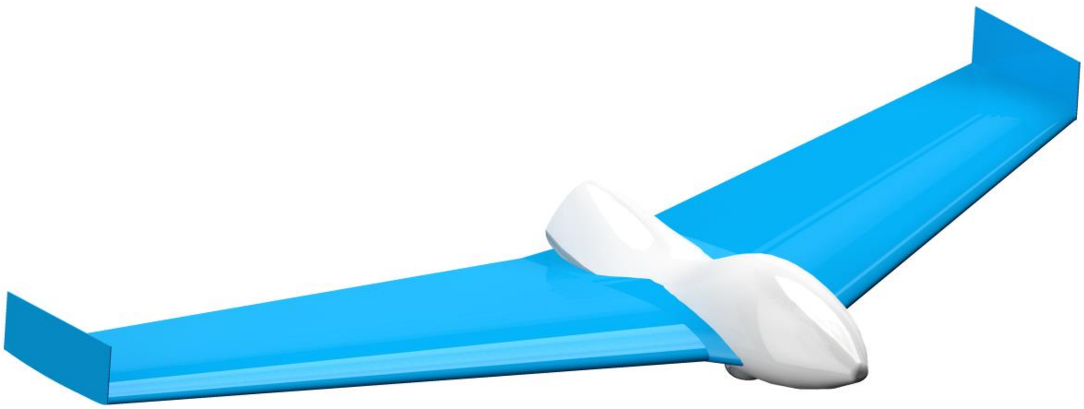
THE CRUISER

Precision Agriculture Moisture Detection
FY16 RWDC National Aviation Challenge

Submitted by

AERONAUTICAL DOLPHINS



Name	Age	Grade	E-mail	Phone Numbers (670)
Norcio, Ann	17	11	annmargaret.dn@gmail.com	234-1937
Nisola, Edna	17	12	nisolaedna@yahoo.com	785-8557
Alam, Masrur	17	12	masruralam@live.com	783-2345
Kim, Jun Young	18	12	junkim319@gmail.com	989-3535
Cao, Matthew	17	12	caomatthew0@gmail.com	989-0009
Malate, Robert	17	11	robert.jomarm@yahoo.com	783-7932
Villarmero, Daniel	16	10	danie4411@gmail.com	783-5055

OBJECTIVE FUNCTION: 0.8

Marianas High School

CNMI Public School System

PO Box 501370

Saipan, MP 96950

(670) 664-3800

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Advisor: John Raulerson

Team Leader: Ann Margaret Norcio

Marianas High School Mathematics Department and Aviation Department Chair

237-3258 / 235-2568

raulerson28@hotmail.com

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ABSTRACT

Introduction: Quickly developing in the United States, small unmanned aircraft systems (sUAS) are being utilized for the purpose of solving current problems that humans face. The integration of today's technological advances allow the conventional approach of dangerous and time consuming tasks to be conducted in a safer, faster, and more efficient manner. Furthermore, agriculture, being our primary source of food production, is at an all-time high worldwide. There is a call for a necessity to sustain crop produce availability in order to even out with the ever-growing human population. Unfortunately, recent droughts and the uncontrollable factors of nature have posed a dire need for water conservation. Thus, the inappropriate distribution of water to food-producing crops is evident to cause yield losses. Current UAV and conventional methods prove to be time-consuming, inefficient, highly costly, and poses risks to personnel on the field. Therefore, a need for a system that is capable of enhancing precision agriculture moisture detection in order to increase food production needed to be addressed. In purpose of creating a reliable solution, the team "Aeronautical Dolphins" has designed an unmanned aircraft system in regards to the challenge scenario. Moreover, in order to provide the necessary aspects of a UAS, our design was built around the variables of the sensor payload, overall aircraft efficiency, and business costs to complement the mission scenario. All in all, these factors have immensely impacted the team's design process and final design solution.

Conceptual Design: During the conceptual design phase, members of the team initiated to review the mission and define constraints that we were to adjust to. Upon familiarity with the challenge, the Aeronautical Dolphins followed the specific work method known as concurrent engineering to research and identify qualified design candidates. As a result, cucumbers, an indigenous crop to the CNMI, were chosen as our baseline crop in which our mission and design solution will revolve around. Produced at an abundance in the islands, the cucumber crop requires precise monitoring of its moisture content. Therefore, in the efforts of maintaining the precise moisture levels on crops and increasing the notion of water conservation, we have developed an unmanned aircraft system prototype solution. Lastly, considering all options available from the catalog and outside resources, the team identified baseline requirements that were analyzed during the following design phases.

Preliminary Design: The team down-selected options based on cost, time, reliability, and efficiency in regards to a preliminary performance analysis. This included specifying our air vehicle element, power plant system, airfoil selection, aerial equipment, and aircraft combination design. As a result, we considered a specified range of aircrafts and conducted research on current moisture detectors in the market. Heavily considering factors such as the application time, cost, and area of coverage of the specified mission led the team to utilize one superior UAS. For this reason, we selected the Darkwing FPV drone as our baseline air vehicle element, thus, the team decided to modify an existing and proven aircraft to fit the needs of the challenge. We ensure that the requirements of the aircraft weighing less than 55 pounds, a maximum speed of 100mph, maximum altitude of 500ft, and a limit load factor of 4g at the minimum and 6g maximum were adhered to.

Detailed Design: Approaching the final phase of our design process, the team continued to conduct detailed analyses on the airfoil, material, wings, sensor payload, and business assessment of our final design. Specifically, pros and cons were weighed out as the team finalized the air vehicle element, power plant system, airfoil selection, aerial equipment, and aircraft combination design. Our final design, the Cruiser, was modified from an existing Darkwing FPV drone and will weigh a total of 10.55 lbs. with a 79.55 inch wingspan. The aircraft is constructed out of balsa wood and will be run by LiPo batteries. The Cruiser will be flying 500ft. at a speed of 90mph, along with a 910 x 460 camera footprint coverage area at 100 frames per second. The final design of our system maximized the three core elements of airframe efficiency, airframe cost, and business profitability, resulting in the team's objective function value of 0.8.

1. Team Engagement

1.1 Team Formation and Project Operation

The team known as the Aeronautical Dolphins is composed of seven individuals with unique skills. Above all, these individuals worked cohesively during the completion of the FY16 National Challenge. As veteran participants of the Real World Design Challenge, members of the team served as student STEM ambassadors on the island of Saipan, which is the capitol of the Commonwealth of the Northern Mariana Islands. Likewise, both public and private schools were educated by peer advocates who encouraged participation in the 2015-2016 RWDC challenge.

Marianas High School has seen a drastic decline in student interest on STEM due to limited programs and resource availability. Thus, this resulted in the formation of only one core RWDC team. Nevertheless, to promote the importance of Science, Technology, Engineering, and Mathematics, an Aviation Club was revived on campus by the team members themselves. In addition, a STEM curriculum-based class is currently offered by Mr. John Raulerson, the team's coach, which takes place before school hours. Without doubt, the resources and knowledge provided through the STEM class, students are able to develop an interest within these career fields and possibly become a team member of the Aeronautical Dolphins. Many potential students were attracted upon advertisement. However, only a handful of dedicated students were prompted to stay for the rigorous tasks that followed.

All in all, each member worked in liaison with all other roles, constituting effective communication and collaboration as the key to the team's success. Consequently, teamwork and cooperation were an essential skillset the team practiced in order to complete the given tasks.

Table 1. National Challenge Dates

State Challenge Issued	*September 8, 2015*
National Challenge Issues	*January 19, 2016*
Webinar Dates	*January 16, 2016* *January 22, 2016*
Notebook Submission Deadline	*April 4, 2016*
National Challenge Presentation Deadline	*April 15, 2016*
National Challenge Event	*April 22-24, 2016*

The finalization of the team required that each member specialize in a profound role most acquainted by their interest.

The prospective roles are as follows:

TABLE 2. TEAM FORMATION

Name	Title	Responsibility
Ann Margaret Norcio	Project Manager/ Communicator	✓ Organize team schedules ✓ Distribute tasks ✓ Communicate with mentors ✓ Piece together engineering design notebook
Robert Malate	Design Engineer	✓ Document all designs considered ✓ Research materials and innovative concepts ✓ Configure (as well as organize) aircraft details
Masrur Alam	Mathematician	✓ Solve mathematical problems ✓ Verify and support excel worksheet calculations ✓ Provide measurements for aircraft and detection area
Jun Young Kim	Simulation Engineer	✓ Simulate 3D models to create the UAS designs ✓ Conduct analysis on MathCAD, Creo, and other software used
Edna Nisola	Marketing Specialist	✓ Identify targeted commercial applications ✓ Calculate costs ✓ Assess competitiveness of the system ✓ Conduct cost/benefits analysis and justification
Matthew Cao	Project Scientist/Mission Planner	✓ Creates possible mission plans with effective outcomes ✓ Specialize in the chosen detection pattern ✓ Conduct research and analysis on selected crop
Daniel Villarmero	Systems and Test Engineer	✓ Define the product architecture, its modules, and interfaces ✓ Ensures that various parts of the product will work together as a whole ✓ Reviews test cases generated by the team ✓ Provide suggestions on design improvements.

Time was a controllable yet limiting factor the team faced. Therefore, during the beginning of the school year, the team was under an ongoing design process of the FY15 National Challenge, which was subject to end on mid-November. Furthermore, to comply with the correlating school year, the FY16 State and National Challenge dates have been pushed further in order for senior students to participate in the National Challenge. As a result, this put the team in the position of working on two separate challenges in the same time frame.

The Aviation Club recruitment on campus took place in mid-September. In fact, the current members served as peer mentors to those who were interested in pursuing an engineering role. As a result, the national and state challenge overlapped each other. Overall, the engineering process and design phases have been put into a discreet, scheduled calendar that we adhered to in order to complete all aspects of the challenge.

Taskings	Start Date	End Date	September	October	November	December	January (2016)	February	March	April
FY15 National Challenge	Apr. 27	Nov. 15								
Conceptual Design Phase	Oct. 5	Oct. 25								
Indigenous Crop Research	Oct. 18	Oct. 31								
Preliminary Design Phase	Oct. 26	Nov. 19								
CAD Modeling	Nov. 20	Dec. 31								
Detailed Design Phase	Nov. 21	Dec. 12								
Review of FAA Regulations	Dec. 13	Dec.19								
Mission Plan	Dec. 13	Dec. 20								
Business Plan	Dec. 17	Dec. 31								
Notebook- Team Review	Dec. 31	Jan.8								
National Challenge Overview	Jan. 19	Jan. 26								
Conceptual Phase Refinement	Jan. 27	Feb. 8								
Indigenous Crop Refinement	Feb. 9	Feb. 16								
Preliminary Phase Refinement	Feb. 17	Mar. 2								
CAD Modeling	Feb. 17	Mar. 27								
Detailed Phase Refinement	Mar. 3	Mar. 12								
Review of FAA Regulations	Mar. 13	Mar. 15								
Mission Plan Refinement	Mar. 16	Mar. 22								
Business Plan Refinement	Mar. 23	Mar. 29								
National Notebook Review	Mar. 30	Apr. 3								

Calculations for webinar attendance dates were crucial due to differing time zones that put us 15 hours ahead of Eastern Standard Time. On occasions, the team had to meet up at six o'clock in the morning or earlier just to be able to attend the webinars. The team worked every day afterschool along with weekends and even during the holiday breaks in order to complete the challenge before the submission date. Having been struck and devastated by the strongest typhoon of 2015, namely Typhoon Soudelor, the members and our school has been greatly affected with the inability to access electricity or portable water for several weeks. As a result, this posed an immense threat to our national and state challenge work process, yet the team was able to complete the challenge despite these hardships.

Ann Margaret Norcio was the Project Manager and designated team leader of the Aeronautical Dolphins. She has furthered her knowledge from the past year to enhance her contributions during her second year on the RWDC team. Throughout the challenge, Ann Margaret has formulated the engineering design process timeline along with organizing the team's schedule, which, under several circumstances, took place outside the school environment such as the island's local café. Thereby, her ability to effectively communicate information to the team members, mentors, and research sources was a viable aspect in maintaining a steady workflow within the team. As the Project Manager, Ann Margaret served as a mentor to new and interested members.

Entering his second year of RWDC, Robert Malate maintained his engineering role as the team's Design Engineer. He has introduced numerous creative ideas along with supporting analysis that would improve the overall aerodynamic components of the team's design. Thus, Robert's ability to reason, and at certain occasions argue, with the team and mentors using thorough analysis proved highly essential in the selection process during each design phase. After all, he played a major role in performing the structural design analysis for the aircraft's load factors, which was an essential aspect of this year's challenge.

Masrur Alam took on the position as the team Mathematician, enhancing his contributions to the team as this marks his second year of taking on the challenge. As a novice to the team, he was able to comprehend the mathematical aspects of the challenge and express these calculations through the use of MathCad. Having recently been accepted into the Massachusetts Institute of Technology, Masrur proved mastery in his role by providing precise measurements and calculations in all aspects of the challenge. He was versatile and helped solve more than the mathematical problems that the team faced. By the way, Masrur is the first and only student in the history of our public school system to have been ever accepted into MIT.

Jun Young Kim, being his third year in joining RWDC, represented as the team's Simulation Engineer. Being the most experienced member of the team, Jun provided essential information and feedback on the team's steps towards the engineering design process. He served as the primary mentor in educating both rookie and veteran team members about how to use the integrated software provided to us by RWDC. Jun worked jointly with the design engineer throughout the creation of the system's 3D CAD models and performance of the structural design analysis. He maintains the team's Windchill updates along with the project manager as modifications were made to the aircraft design.

The designated team Marketing Specialist, Edna Nisola, held the responsibility of documenting the business case throughout the entire challenge scenario. Being her second year in RWDC, Edna has expressed competent skills in analyzing and justifying the marketable components of our system. As a result, she conducted extensive research on the current methods of moisture detection on crops, thereby, justifying the competitiveness of our system by proposing effective strategies that would satisfy both our customers and total business profitability. In addition, she ensured that our design was commercially acceptable. In particular, Edna played a crucial role in developing a centralized plan that would prove successful in the real world.

Matthew Cao conjoined roles as the team Mission Planner and Project Scientist. He took the lead in researching crops indigenous to the islands, providing the team with the base information needed in order to formulate our moisture detection method. As he enters his second year of RWDC, Matthew took on the challenge of additionally accepting the Mission Planner role. Thus, he was mindful in complying with the limitations and constraints addressed by the challenge, thereupon, working around such obstacles in order to conduct a practical, effective approach that strengthened the team's entire mission scenario.

It is Daniel Villarmero's first year as the team Systems and Test Engineer. Working cohesively from the beginning of the challenge, Daniel stood out from the group of interested members during the recruitment process. Therefore, he was able to familiarize himself with the duties that were accounted for the role, and far beyond that. Furthermore, Daniel performed extensive research and analysis on the detection system, defining all aspects of its product architecture, modules, and interfaces while tracking its effectiveness when working in conjunction with our system.

1.2 Acquiring and Engaging Mentors

Considering the lack of resources provided in our island, the team sought to obtain mentorship in areas such as the engineering and mechanical aspects of our design. The team selected mentors who were willing to provide us with technical feedback and respond within a reasonable amount of time.

Furthermore, having years of professional experience, our mentors were perceived as an invaluable resource to the team. For the most part, they aided in the forward momentum towards our engineering process, thereby, answering questions to the extent of their knowledge and providing us resources to obtain necessary information. Windchill was an effective tool in communicating the team's progress with the mentors. While the visuals were shown in that manner, the project manager maintained a method of communication with the mentors through email. As a result, each member had access to both communication tools, allowing direct access for specific or urgent inquiries.

After a successful relationship from mentors in the previous challenge, the team renewed mentorship from those available and willing to aid in our next design approach. The team also recognized that the RWDC Social Community site was a valuable tool in submitting technical support questions. However, a response would often be protracted by time, disallowing the team to articulate new notions and supportive ideas. Therefore, the mentors that we reestablished communication with were those who have worked with the Aeronautical Dolphins for consecutive years, along with new mentors obtained from the RWDC mentor list.

- Mr. Manoj Rahematpura from Pratt and Whitney specializes in aero-structures and has advised the team in the structural parts of the aircraft.

- Captain Christina Mastracchio was a mentor obtained after the previous team's tour at the Anderson Air Force Base located in Guam. As a pilot and an Air Force Academy and MIT graduate, she was able to provide the team with necessary feedback on our aircraft's aerodynamics.
- Douglass Brennan, general manager of Atkins Kroll Toyota based in Saipan, provided critical comments on our team's proposed business case. The team expresses great gratification for Mr. Brennan, who was always willing to provide us with a facility to work in even after the wake of Typhoon Soudelor.
- Emory Frink, one of our trusted mentors, advised the team to the best of his knowledge providing logical suggestions on the aircraft's maneuvers.
- Lastly, Mr. Roberto Malate was one of our newly obtained mentors who helped the team in proving the capabilities of our aircraft's power source.

Needless to say, although our mentors had busy schedules, it was in the team's courteous desire to respect their obligations. However, they did provide us with beneficial information from time to time that aided in the progress and development of our project.

Table 3. Mentors and Specialty

Name	*Company*	*Specialty*	*E-mail*
Manoj Rahematpura	Pratt & Whitney	Aero-structures	Manoj.rahematpura@pw.utc.com
Cpt. Christina Hart Mastracchio	Andersen Airforce Base	Aerodynamics	cm.cchio@gmail.com
Douglass Brennan	Atkins Kroll Toyota	Mechanical Engineering	Doug.brennan@aksaipan.com
Emory Frink	Self-Employed	Professional Pilot	Em.frink@gmail.com
Roberto Malate	Commonwealth Utilities Corporation	Civil Engineer	Malate.m.roberto@gmail.com

The Aeronautical Dolphins partnered with the Northern Marianas College-Cooperative Research Extension and Education Service (NMC-CREES) to conduct hands-on research and experimentation on our crop selection process. We collaborated with the program's dean, Dr. Timothy Kock, who aided the team in researching moisture problems that indigenous crops in the CNMI face presently.

1.3 State the Project Goal

The all-inclusive project goal is to design an unmanned aircraft system (UAS) that is capable of detecting moisture levels around two co-located food producing crops. The creation of a UAS that is capable of using current technology to perform moisture detection on crops can result in both monetary and water conservation. Furthermore, our final system must have the capability of performing additional commercial applications that vary from moisture detection. The justification of whether a crop contains too much, too little, or just enough water can aid in a potential increase in food production and start yet another revolution in precision agriculture.

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

Maximize Objective Function

We were given an objective function for the FY16 State Challenge. It constitutes the following three core elements of the challenge: airframe efficiency, airframe cost, and business profitability. Goals within the challenge include demonstrating through analysis an efficient detection method, effective air vehicle design, and end profitability for the business concept. As a result, the solutions reflected in our objective function value.

Airframe Efficiency

$1-\frac{W_E}{W_{TO}}$, The airframe efficiency value demonstrates the use of a light airframe that can support a large takeoff weight. To calculate this value, we had to subtract the empty weight of our aircraft from the maximum takeoff weight. The maximum takeoff weight includes the payload and battery. The more payload that our aircraft can carry, the higher the aircraft efficiency will be.

Airframe Cost

$1-\frac{C_{AF}}{C_{UAV}}$, The airframe cost value demonstrates the low fixed cost on the airframe. It is simply the cost of the airframe subtracted from the total aircraft cost at its maximum takeoff weight. It is essential to keep the cost of the airframe low as this will help our business plan. However, we still have to maintain the quality of the airframe.

Business Profitability

$\left(\frac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}\right)$ The business profitability value demonstrates profitability when exceeding the anticipated fifth year operating expense with total revenue for the year. To get this value, we subtracted the total expense for our business operation by the end of year 5 from the total revenue by the end of year 5. While it is important to make our aircraft reliable and efficient, we also have to make it highly marketable.

Detection Method

Providing an efficient detection method during the crop's growth cycle is the primacy of the mission scenario. The team conducted analyses on our selected sensor payload by calculating its camera footprint based on the given altitude and speed. The team also conducted analysis by simulating the program that comes with the sensor payload.

Design Elements

The design element is restricted to a small fixed-wing UAV, in which the team must demonstrate efficiency within the detection process as well as develop a high-end profitable business case. The design of the aircraft must be provided with analysis that the aircraft design is capable of handling the forces and weight during flight. The team focused on the wing analysis using JavaFoil and Creo Parametric in order to determine this subject.

System Design Approach

Choosing to utilize a single UAV rather than using multiple UAVs or a collaborative teaming with UGVs proved to be the most practical approach for the team. With this, our main focus point is directed towards maximizing its efficiency in terms of our theory of operation, detection flight pattern, and business case viability. This goes towards our goal to be in compliance with the Federal Aviation Administration (FAA).

Mission Scenario

Each team is given the opportunity to choose upon discretion its target crop in which they will perform the detection on a 1 mile x 1 mile field area. For this challenge, the team selected cucumbers, an indigenous crop in the CNMI, as our base crop in which our detection plan will take place. Although our mission is based on the cucumbers' growth cycle, we took in careful consideration that our detection method is capable of performing such operations on virtually any crop.

1.4 Tool Set-up/Learning/Validation

Software	Conceptual	Preliminary	Detailed
Windchill	2-3 hrs	2-3 hrs	2-3hrs
JavaFoil	1-2 hrs	2-3 hrs	2-3hrs
Creo Parametric	1-2 hrs	2-3 hrs	3-5 hrs
PTC MathCad	1-2 hrs	1-2 hrs	2-3 hrs

Lack of team motivation and STEM interest was never the issue with the Aeronautical Dolphins. Rather, it was the limited availability of resources that put a stall to our engineering approach. We considered ourselves lucky to have one desktop computer in which all provided software were installed. This is shared by all team members, each taking turns depending on the software that needed to be used. Another factor that the team faced was the additional obligations each member had outside of RWDC. Four of the seven members are currently seniors, who are in the process of college applications. On top of that, majority of the members live an active academic and extracurricular life. There were instances where communication and tasks had to be done through email and other social media. At the same time, living on an island that is merely twelve miles long, it was rare to experience that type of working process. Moreover, the team decided at some instances to meet in the afternoon until late night in order to complete our tasks.

Windchill
- Windchill significantly helped the team in documenting and updating our work, along with allowing us to share these documents with our mentors. While the project manager maintained the collaboration, each team member was able to access the account.

JavaFoil
- JavaFoil is an airfoil analysis software that the team obtained themselves. It allows us to visually analyze lift and drag coefficients and how it affects the wings of our aircraft. The team watched several tutorials in order to learn how to utilize this software.

Creo Parametric
- The installation of Creo Parametric 2.0 was relatively straightforward. Creo was the main tool the team utilized in performing the structural analysis of our aircraft design. It proved difficult to decipher what the number values and color codings meant. However, through numeral trial and error attempts, the team formulated an understainding of these values.

PTC MathCad
- PTC MathCad is a highly useful tool that the team frequently relied on. This, along with several Excel worksheets, were the sources used to calculate our objective function, mission time requirements, aircraft analysis values, and more.

The use of Creo Parametric 2.0 was a step-by-step process that the team enjoyed walking through. In order to perform an accurate analysis using the software, we had to ensure that all dimensions of the CAD models were accurate. We started by modeling our base aircraft and continued by modeling its modifications.

1.5 Impact on STEM

The members of the Aeronautical Dolphins are one of the few individuals that stand upon realization that even Saipan's limited resources and simple approach on life can lead to innovative success. Throughout the years, the Real World Design Challenge and Aviation program has gradually increased the number of students at Marianas High School who have expressed an interest in joining. As a result, STEM has become more competitive, thus creating an increase in innovative success. Therefore, the four graduating seniors on the team are currently following their paths to careers that fall under Science, Engineering, Technology, and Mathematics.

Ultimately, the involvement of the Aeronautical Dolphins in the Real World Design Challenge and STEM world encourages the CNMI Public School System to advocate the universal importance of STEM. This year, four seniors from the team will be graduating and pursuing their goals through higher education in the field of STEM. From the students' quotes, you will see how greatly STEM has impacted their future endeavors

ANN MARGARET:

"STEM is like a hook that was thrown into our school, reeling in only those who were courageous enough to take the bait, which, in this case, are those willing to take on the challenge. Fortunately, I was hooked from the very beginning. Marianas High School's biggest event in the sciences would be the STEM fair, a one-time event that had to be completed individually. Since the introduction to the Real World Design Challenge, opportunities and interest in the field of Science, Technology, Engineering and Mathematics in our school have greatly diversified. I was introduced to the notion of teamwork, leadership, and all things in academia. I've gained skills in diverse aspects that are bound to help me in the real world. This is my second year to take on the challenge, but I feel as if a load full of new information is still being presented. I am constantly left with the urge to learn more. I realized that that the greater challenge lay within the members and our ability to work as a team. I became aware of the many individuals who sacrificed their lives for the sake of innovation, and I am determined to make a change in which no lives will be the cost. Participating in RWDC has strengthened my aspiration of pursuing a career in biomedical engineering, putting my work in the hands of those who can help others."

ROBERT:

"I've always wanted to invent something innovative. I've watched numerous YouTube videos and read countless scientific articles, searching for ideas and possible projects. Unfortunately, none of them have even begun. Living here on the island of Saipan has prevented me from exploring my scientific interest. It's so hard to obtain the materials to even begin a project, and our school doesn't even have proper equipment to run a laboratory class activity. Fortunately, we had RWDC. Joining RWDC has enabled me to do the projects that I've longed to do. Even though we still don't have the formal equipment, the programs that RWDC have provided have enabled me to do real-life engineering. It provided me with the motivation and challenge to pursue my scientific interest. And my knowledge and experience I've gained from last year has allowed me to perform better this year as the team's design engineer, as well as seal my interest in taking engineering as I enter college."

MASRUR:

"This is my second year to compete in the Real World Design Challenge. Each year presents a new challenge for me and my fellow teammates and we have to utilize STEM in order to find a solution for this challenge. My participation in RWDC has greatly influenced my perspective on STEM. It made me realize the many benefits STEM can have on our society. Today, the field of STEM is being used to solve for many real-life problems in our world. After participating in this competition for the second time, I aspire to become a biomedical engineer and hope to contribute and help solve some of the world's problems, and I am overjoyed to be able to pursue this career while attending the Massachusetts Institute of Technology. RWDC not only influenced my perspectives on STEM, but also my fellow peers in school. It has influenced my school with its ongoing Aviation class, along with an added Physics class in our elective classes. There has been no other feat in the CNMI that can match winning two national championships. The success of our team serves as a role model to other students in the CNMI that are venturing into the field of STEM. In particular STEM can bring about many benefits for an individual and their community."

JUN YOUNG:

“This year is my third and last year joining the Real World Design Challenge. Being the longest veteran in the team, I was able to watch determined members come, go, and stay throughout the years. STEM played and still plays a significant role in my high school life, and I am proud of the decisions I made to stay with the program. Each year, my team and I gather around in excitement to face the rigorous challenge. Reminiscing back, my time spent in RWDC was the most defining, challenging, and exciting moments of my life. I encounter students of diverse grade levels who would love to join in, constantly reminding me the important impact STEM has on future engineers. It was my decision to take on the role of the Simulation Engineer for the entirety of my time, which was a general preference that transformed into my aspiration for a future career. STEM has affected my career path to become a Computer Programmer. As I work with models in Creo and MathCAD, I’m excited to see our thoughts evolving into a solution to a problem. STEM will always impact our daily lives in many ways and it will continue to do so.”

DANIEL:

“Ever since I talked to my dad about binary, I always have been fascinated by technology. At this time, I have started to learn programming and scripting. I used to study them every day just so I could make something new, but as time goes on, it began to grow stale. I told myself, “I want to try something new. I want a new challenge. I want to learn more about technologies I have not heard about.” RWDC gave me this chance to learn more about technology and the advancements humanity made to make our lives easier. In this program, I found out that something as simple as a camera could be genuinely difficult to find. There are many things to consider when looking for in a camera like its spectral band, weight, and power consumption. I did not know that these things mattered until I joined RWDC. The challenge and the opportunity to learn gave me the motivation to attend as much meetings as I can. The challenge grew even more as many more students in our school gained interest in the program. Technology and Engineering, specifically, became my focus as a future career. By joining RWDC, I learned new things I did not know about and one day I know I can use my knowledge from this program to advance my studies in technology and engineering.”

EDNA:

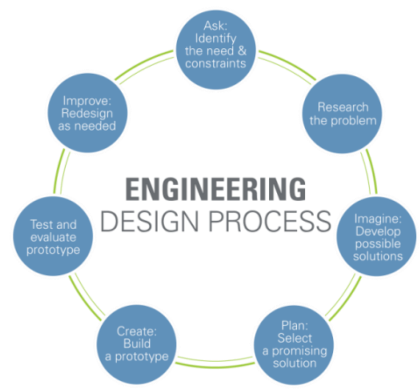
“I decided to join the Aviation program in my school quite reluctantly at first, not realizing that an immense interest would spark inside of me as a result. I was a newcomer then and yearned to try something new, expanding my opportunities in this remote island. I owe my greatest respect to my team members and coach who believed in my capabilities. This year marks my second year taking on the Real World Design Challenge, and that reluctance has long vanished. RWDC is greatly increasing my knowledge and interest in STEM, and I am enjoying the process. It gave me an awareness of my environment; which enabled me to appreciate STEM even more. I can say that it has been one of the best decisions I've made in my high school career. Furthermore, as the team’s marketing specialist, it gave me an opportunity to experience the field of business, which is a career that I decided to pursue after graduating high school. I am proud to say that these skills will be carried as I take on a marketing major at the Grand Canyon University. It isn't easy, as there are many components that are crucial that has to be done correctly, but it is nice to know that our work and ideas have a purpose and can be easily translated into the real world.”

MATTHEW:

“Joining the Real World Design Challenge was the biggest step I made towards communicating my ideas and working with others in an environment where each individual shares similar goals. This year marks my second time joining the challenge, and the many days I’ve spent throughout working on the challenge with my team members increased my knowledge regarding aeronautical aspects. Every afterschool, weekend, and holiday break was spent towards completing the project. As a graduating senior, STEM has strengthened my interest in applying to the Naval Academy, taking courses under aeronautical engineering, and pursuing a profession as a Naval Aviator. It was a blessing to recently be informed that I have been selected to attend the Naval Academy Preparatory School. The diverse knowledge that I gained from both challenges has influenced me to use this for the betterment of the people and to serve my country. I am starting now as my team and I advocate to students in our school and schools around the island about the huge role that STEM plays in our lives. I’ve learned that Real World Design is not just a yearly challenge, but an opportunity to gain something better for ourselves.”

2 Document the System Design

2.1 Conceptual, Preliminary, and Detailed Design



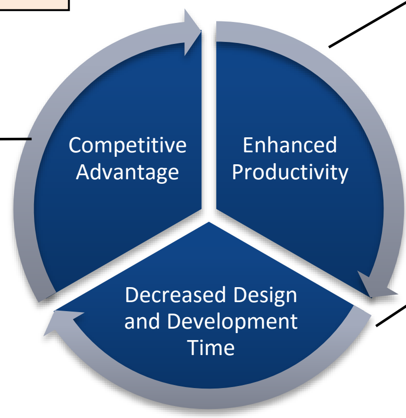
As the team propelled towards documenting our system design, further detail was added into the conceptual, preliminary, and detailed design phases. Careful research, analysis, and design decisions were made upon selecting our specific work method and throughout each design phase.

2.1.1 Engineering Design Process

At one point during the conceptual design phase, the team members realized the need to evenly distribute the time spent on each design phase, considering our short time frame. Apart from following the “general” engineering design process, the team considered numerous specific work methods that would prove both time efficient and advantageous for our company in the long term. We looked at new methods derived from computer aided method engineering, method tailoring, and situational method tailoring. As a result, the team came to a conclusion that **Concurrent Engineering** would result as the best specific work method.

Concurrent engineering, or simultaneous engineering, is a method of developing and designing products whereas different stages run simultaneously rather than consecutively. Most aircraft manufacturing industries integrate this method into its system reasonably for shortening design cycles and to meet the need of reducing risks. Additionally, it enables engineers to work on the same database at the same time, allowing effective cooperation and teamwork in order to identify constraints and the need for improvements. Implementing concurrent engineering in our design process will provide the following results:

Figure 1. Engineering Design Process



In regards to our specific work method, Our Product Lifecycle Management (PLM) overviewed the aspects of our initial concept to final design. The team was organized according to each member's role responsible for managing certain tasks, defining our Operation Process Management (OPM). This was an essential factor in creating a leading marketing strategy. The overall design process the team followed constitutes three main phases: the conceptual design phase, preliminary design phase, and detailed design phase.

Conceptual Design (First Phase)

- The problem is addressed. Limitations provided in the challenge are acknowledged.
- Ideas are brainstormed, requirements are assessed, and restrictions are noted.
- Assessment of the Objective Function sets values that the team must surpass or provide an exceptional value.
- Select a broad range of components, equipment, and basic outline of UAS.
- Conduct high complementary research to understand specifications, core concepts, and foundation principles.
- Determine the pros and cons that are significant to the selection of each design component.
- Identify existing methods including their cost, efficiency, and profitability.

Preliminary Design (Second Phase)

- Validate feasible functions of product(s).
- The major components of different designs, performance requirements, system elements, and reliability are discussed by the team.
- Diagrams, layouts, and models are created to visualize the conceptual designs.
- Precise configurations such as mathematic and systematic requirements are measured and tests are conducted to ensure the reliability and qualities of each design
- Systems & Test and Simulation Engineers work together to generate a visual of the aircraft archetype.
- If there are insufficient elements present, modifications of the design must be updated.
- The range of options are narrowed down and further analyzed in a selection of beneficial output.
- Items are specified through requirements of the challenge, thus rendered to the baseline requirements of the team.

Detailed Design (Third Phase)

- The team disregards inferior proposed designs and favors one final concept that will be integrated into the project goal.
- All aspects of the final design are stated.
- Favorable concepts developed during the previous phases are brought back to help improve the final design solution.
- High-order analysis is conducted to ensure viability of the final design solution.
- Communicate results of analysis that the system is operative.
- Document a business case with the cost analysis and cost/benefit justification.

- Prescribe a plan that will raise financial resources for covering initial costs.

2.1.2 Conceptual Design

As a team, the Aeronautical Dolphins reviewed the requirements expected in the national detection mission scenario. The Federal Aviation Administration Rules and Regulations were an important factor we sought to conform with. This was the team's first step towards refining our state challenge product that would operate in our system. Additions to the national challenge included an increase in field size, a designated "No Fly Zone," and

Once the team was well acquainted with the national challenge, our initial ideas were greatly influenced by the scope of research we had done. With the knowledge obtained, we then proceeded to form a basic outline of what we wanted in our design system. The team researched numerous types of air vehicle element and airframe configurations on existing UAVs as well. We examined, researched, and debated on improving our current UAS system design. This aircraft would have to be efficient as well as cost effective, as compared to existing UAV detectors today. The conceptual design would list down all our candidates for this solution.

Although the RC F-14 Tomcat, our baseline model for the state challenge, performed the state mission exceptionally, the team decided that it was not optimized and designed specifically for the national challenge. As a result, we searched for an aircraft that contained a form that fit its function. The RC F-14 Tomcat's design for aerobatics and high-speed speed flight reduced our system's total airframe efficiency, which is a major factor in our objective function outcome. As a result, the team opted

Initially, the team was reliant on modifying an aircraft that has a high payload capacity and is able to fly at speeds above 70 miles per hour. We investigated the flying wing designs and compared them to our state challenge UAV design along with conventional aircraft designs provided in the market. Described below are the aircraft designs pre-selected for the national mission.

<u>Baseline UAV</u>

The team wanted to select an aircraft that would serve as a baseline design for our UAV. Specifically, the team researched existing aircraft that is already aerodynamically proven and capable of flying. While searching for aircraft, the team ensured that the aircraft will meet the challenge requirements and restraints; weigh less than 55 lbs., be a tractor or pusher design, have a limit load factor of 4g, and an ultimate load factor of 6g. Additionally, we selected aircraft designs that possess traits that are advantageous to our mission. In order to further analyze our aircraft candidates, the team calculated each plane's potential airframe efficiency. We calculated these values by dividing the potential payload weight by the maximum weight given the specifications provided for each aircraft. The team conducted wing analyses and discovered that the airframe efficiency is optimized by the sensor payload and batteries. The conceptual design would list down all our candidates for this solution.

The Darkwing FPV Drone is a composite flying wing that is designed specifically for First Person View. Its winglets and central fuselage are constructed of durable fiberglass and sheeted construction balsa. In relation to its size, the Darkwing provides an extensive amount of space under its canopy and provides a large payload capacity. Its efficient and sleek aerodynamic design allows for exceptional stall and glide characteristics. The Darkwing is characterized to fit both form and function- making it a high contender against the team's state challenge aircraft.

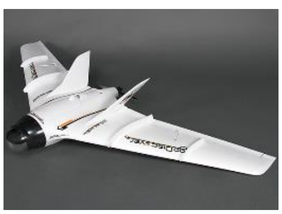
SPECIFICATIONS

Figure 2. Darkwing FPV Drone

- Aircraft composed entirely of balsa wood
- Wingspan of 68 inches
- Empty weight of aircraft is 3.09 lbs.

Initial airframe cost:

$167.44



SPECIFICATIONS

Figure 3. Go Discover FPV

- Aircraft composed of EPO foam
- Wingspan of 63 inches
- Empty weight of 3.97 lbs.

Initial airframe cost:

$136.13

To accommodate the needs of our sensor payload, the team took into consideration several aircraft that contained large payload capabilities. The team came across the Go Discover FPV, a drone that is characterized with a 63-inch wingspan that allows it to have excellent lift capabilities. The Go Discover was designed specifically to accommodate an FPV platform with its integrated pan and tilt system located at the nose. A strong candidate for the challenge, this aircraft has a straightforward layout as well as fast reflexes. It is equipped with an 800 kv motor and an acrylic FPV-protecting dome.

The F-14 Tomcat Twin Ducted Fan EPO 1000mm is an RC aircraft that was modified to be part of our UAS system in the FY16 State Challenge. It is powered by a pair of 50mm ducted fans, giving it the capability to outperform other aircraft in terms of mobility during flight. It is constructed from EPO foam and has fixed landing gear that can be removed for hand launching. The F-14 is equipped with an easy-to-maintain sweep mechanism that can be simply controlled through a transmitter. The wings are able to sweep back during mid-air flight, allowing it to perform quicker with precision. The F-14 Tomcat's fast, lightweight, and exceptional payload capabilities make it a strong contender

SPECIFICATIONS

Figure 4. F-14 Grumman Tomcat

- 1000mm extended with 620mm swept
- 980 mm length

1100g weight

against the other aircraft candidates. The team opted to compare this aircraft with candidates that will ultimately increase our airframe efficiency in the national challenge.

 **SPECIFICATIONS** **Figure 5. Skua FPV**	▪ Aircraft composed of EPO foam ▪ Wingspan of 82.68 inches ▪ MTOW: 6.61 lbs. Initial airframe cost: **$129.78**

In an effort to emphasize the notion of "form fits function," the team looked closely into the Skua FPV Plane from X-UAV. Its utilitarian platform is designed specifically to maintain long duration FPV duty, which is a crucial component for the national challenge. This drone ultimately allows easy access to cameras, FPV transmitters, batteries, or any other equipment because of its all-molded EPO airframe. Considering the challenge constraints, the team was convinced that this aircraft would maximize space in the fuselage area and increase our overall airframe efficiency. We estimated its maximum speed to be less than 60 mph and potential airframe efficiency between 50-65%.

The selection of the proper air vehicle element would be able to determine the operational flight mission. Offered in the catalog were three baseline air vehicle element options: Fixed-wing Tractor Propeller, Rotary-wing/helicopter, and Hybrid (Fixed-wing/Quadrotor). Each option presented differing characteristics. It was up to the team's accountability to examine all trade-offs that outweighed each other as we were to choose a complementing air vehicle element that would best conduct the mission. Specifically, we wanted to form a vehicle that submitted to maneuverability and efficiency both in time and cost. An exceptional air vehicle element would be able to sustain flight with different types of payloads onboard while still having the capability to conduct safe operations when performing moisture detection on specific crop areas.

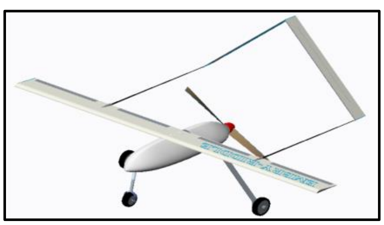


Figure 6: Fixed-Wing Pusher Propeller Design

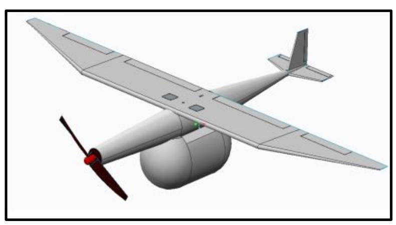


Figure 7: Propeller Design

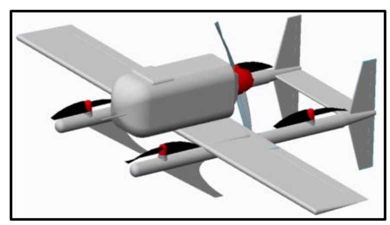
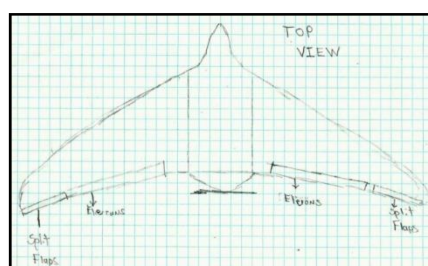


Figure 8: Hybrid (Fixed-Wing/Quadrotor) Design

Conceptual Design Phase Aircraft Drawings

Additionally, the team furthered to conceptualize other air vehicle elements. As we assembled our ideas, we developed our baseline requirements which advanced us to theoretically provide a basic arrangement of general components and measurements.



Drawing 1: *First rough draft sketch of the Darkwing FPV Drone (not modified)*

After conducting extensive research on our air vehicle element and UAV baseline, the team leaned toward the Darkwing FPV Drone 1727mm Composite (ARF) and started with conceptual drawings of the aircraft.

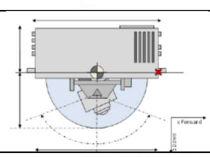
Sensor Payload

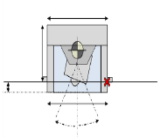
One of the first concerns of the team was the sensor payload selection. Based on our research, utilizing a multispectral or hyper spectral camera would be the best option to approach this mission. A research team from the University of Alabama utilized thermal cameras to conduct soil moisture research.

The team analyzed the specifications of the sensor payloads provided in the RWDC catalog. Referencing their standard specifications gave us a baseline to form ideas off of. The X6000 and X5000 are, in our opinion, the top prospects from the provided options. Weighing in at 3.2kg and .65kg respectively, both cameras are heavyweight, a factor the team kept in mind from the beginning. The X6000 uses between 5.6-8 watts and the X5000 uses between 2-3 watts for power. For the most part, we were able to work with those numbers; however, the cameras were inefficient overall because they both only operate with green, red, and NIR bands. The table below depicts the team's conceptual sensor payload options.

We looked for a camera that would prove both lightweight and efficient. It would also need to have excellent stabilization, sufficient rolling limits, and adequate zooming capabilities, as well as having the most suitable imaging method to maintain proper sight of the infested crop area. We reviewed the catalog options as well as cameras obtained from outside sources.

Table 4. Sensor Payload Selection

Sensor Payload	Lateral	Weight	Battery Usage	Resolution	Images Produced	Cost
Rikola 	348 ft.	1.587 lbs.	7.9 V (5.3 W avg.) (10.5 W mom.)	1010 x 1010	Hyper spectral (100 bands) VIS-VNIR	$42,000
ADC Snap (Tetracam) 	352 ft.	0.198 lbs.	9.0-14.7 V DC (2 W. nominal)	1280 x 1024	Multispectral (10 bands) NIR	$4995
Flir Vue Pro 	660 ft.	0.203-0.25 lbs.	4-6 V (<1.2 W)	640 x 512	Thermal	$4000-$5000
Tau 2 	1214 ft.	0.203 lbs.	4-6 V	640 x 512	Thermal	$4000-$5000
X6000 	370 ft.	7 lbs.	9-12 V (5.6 W nom.) (8 W max)	1280 x 1024	Multispectral NIR	$15000
ICI SWIR 640 	See Camera Footprint	120g (320g with lens)	>1 watt	640x512	Hyper spectral	$19,995

X5000 	See Camera Footprint	65kg	2-3 watts	2048x1536	Multispectral	$5,500
Mini-Nyx-S 640 	See Camera Footprint	1.3lb or 600g	5w 5VDC is required for the cooler and 12VDC	640x512	Hyper spectral	$60,000
Saturn VISIR 	See Camera Footprint	3kg or 6.55lb	5w 5VDC is required for the cooler and 12VDC	1000x256	Hyper spectral	N/A
Zephir 2.5 	See Camera Footprint	4kg or 8.82lb	12 VDC @ 5 A	320x256	Hyper spectral	N/A

As part of our sensor payload analysis, the team inputted each sensor payload's viewing specifications into a camera footprint that was provided in the FY14 Real World Design Challenge. The team mainly considered each camera's coverage area and resolution, each at the maximum height of 500ft.

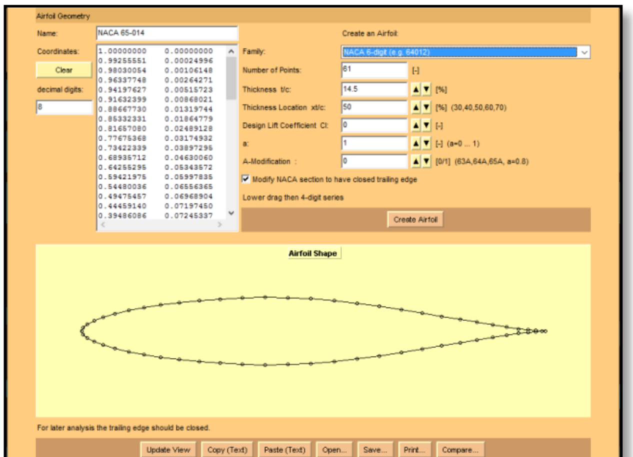
For the aircraft's material selection, the team debated on using balsa wood or expanded polyolefin (EPO) foam for the majority of its framework. The team found it incredibly challenging to conduct an analysis on EPO foam as its option was not provided in the Creo Parametric program. Realizing this during the conceptual design phase provided the team with sufficient time to conduct trial-and-error analyses on the EPO foam. As time passed, we discovered an option to input the values of EPO foam ourselves and simulate it through Creo Parametric. Further speaking, this was done to compare wing analyses with balsa wood material.

In regards to the ground system, the team had to select components that would work in conjunction to full operate the system. We initially looked into each of the various components and started with the C3—command, control, and communications. We looked through the catalog and noted all of the control systems as well as the additional equipment. We considered the price, mandatory equipment, and function of each component. It was clear that we needed to carefully select our components for our ground control station in order to meet all requirements.

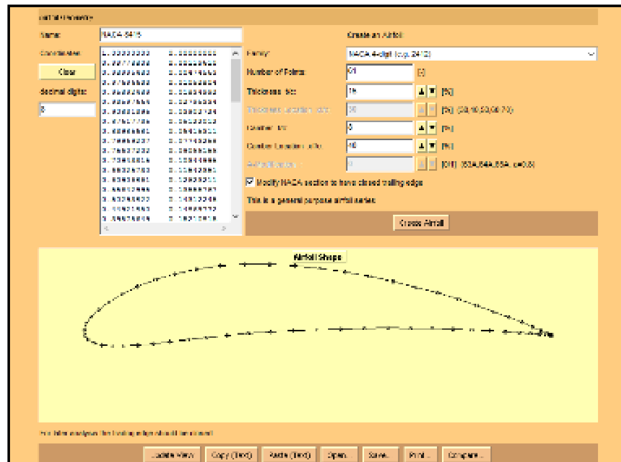
The next aspect the team considered was the system's support equipment. The catalog provided a selection variety of trailers, launchers, and items that aided the aircraft's propulsion system. Initially, the team wanted a trailer that was suitable for the size of our aircraft and is capable of serving as equipment storage as well as a workplace for our operational personnel. The team heavily considered that our final aircraft design will have no landing gear, which resulted in various ideas for efficient landing and takeoff approaches. We wanted a launching system that was compatible with a fixed-wing aircraft, at least 23 m/s, reliable, and simple to set up.

Airfoil

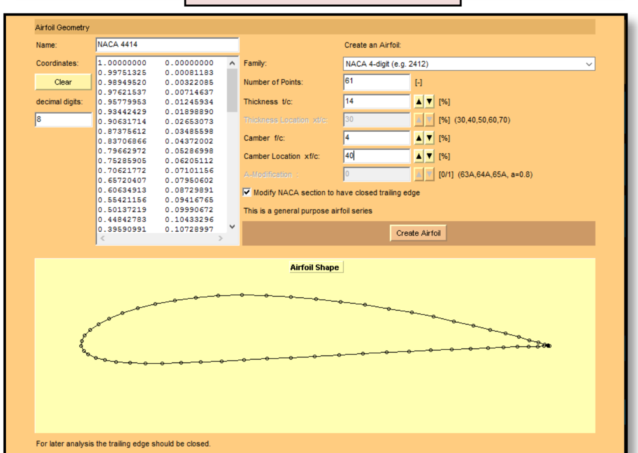
Moving on to our UAV's wing characteristics, the team speculated on selections of an airfoil type. *Bernoulli's principle* applies to how an airfoil works because the increase of a moving fluid works in conjunction that decreases the pressure within the fluid. The main question at hand was which airfoil would prove the most efficient for this mission. Furthermore, air is moving at a faster speed on the top of the airfoil as compared to the bottom. This allows it to be lifted by the higher pressure created beneath the wing; thus, creating lift. After brainstorming and considering the challenge, we generally decided that the airfoil needed to have a thin shape in order to reduce its drag. Because having a high lift capacity was not so crucial, a thick-shaped airfoil would not be needed. We factored the mission requirements and aircraft behavior characteristics upon choosing airfoil candidates (Johnson, About Airfoils for Flying Model Aircraft, 2015). All in all, the team was looking for an airfoil that had high lift capabilities that allowed the aircraft to be easily controlled. The team came up with several airfoil selections: NACA 65-014, NACA 8415, NACA 4414, and the NACA 25112.



NACA 65-014



NACA 8415



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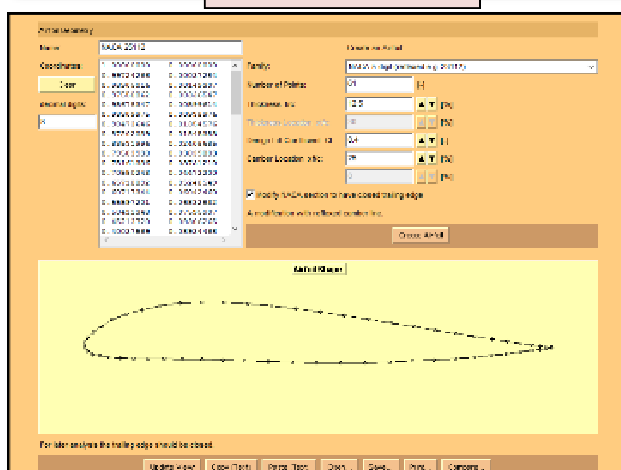


NACA 25112

Detection Pattern (Conceptualized)

After several detection pattern attempts, the team formulated that the lawnmower pattern serves as the best candidate in regards to the mission scenario. It significantly improves the aircraft's efficiency while enabling it to perform less turns while still maintaining a large coverage area. Our first conceptual pattern is depicted, in which we will be using two UAVs to perform moisture detection over crops on two, co-located 1 x 1 mile fields with nine turns for each field. The team considered other patterns such as the Spiral pattern, Zamboni pattern, and Dubin's Path.

Consequentially, we avoided options that included too many turns due to our UAV having to slow down, increasing the mission time. The team would have to consider turn radius, angle of bank, elevation, and speed upon implementing these ideas into the scope of our pattern. The team's mission planner monitored all possible detection patterns. The team started off by experimenting several search patterns utilizing the Cruiser. As we moved on further with the challenge, we decided to eliminate all single aircraft patterns, as it would consume too much time and turns.

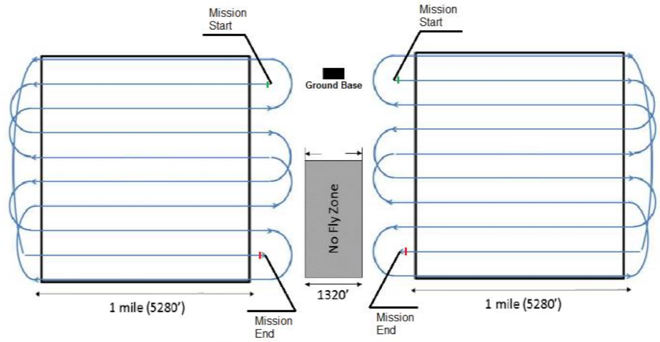
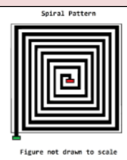
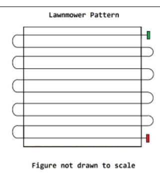
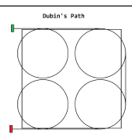
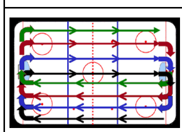


Figure not drawn to scale

Detection Pattern Considerations

Table 5. Detection Pattern Considerations	
	Because of its potential to detect an entirety of a field, the Spiral Pattern stood as a candidate for our detection pattern. This pattern, however, required additional and unnecessary turns as compared to the other application patterns. As a result, the team decided that this candidate would later be disregarded due to its low productivity in terms of turning.
	Similar to that of a lawnmower's, the Lawnmower Method goes in long lanes with 180° turns. It can have a straight, forward, up and down, or back and forth motion that is easy to apprehend. The pattern's efficiency depends on the number of turns; the more turns, the more precise. Furthermore the sweep of the pattern results the number of turns in a same area, the sweep can be erected up and down or side to side.
	Dubin's Path is a continuous circular motion which proved ineffective towards our requirements. The circular pattern does not have precision and will not cover the field promptly. Therefore, we did not choose utilize this search pattern.
	The Zamboni pattern is a complicated pattern with many repetitions of strides within a circular motion turn. Hence if we were to use the Zamboni pattern, it would require the aircraft to fly over pointless locations. Furthermore, the overall pattern will leave several parts of the area uncovered which is inaccurate. This would decrease our time efficiency and productivity towards the mission because the aircraft would be required to make additional unnecessary turns decreasing our mission rate, hence the team decided not to use this pattern.

Battery Selection (Conceptual)

The battery selection was of utmost importance in regards to the stability and power of the aircraft. The team opted to select a battery that would provide an optimal amount of power for our UAV. Thus, we considered power consumption of the motor as our baseline as it consumed more power as compared to the other components of the aircraft. In addition, the other components consumed significantly less amounts of power than the motor. As a result, due to the lower power consumption of the motor compared to twin EDFs, the team decided that we would be able to use batteries available on the market instead of fabricating our own.

Factors such as voltage, discharge rate, weight, and milliamp rating were heavily weighted during our selection process. Since the motor would need to run on a five-cell set-up to perform optimally, a 22.2volt battery was needed. According to our research, discharge rate was the amount of amps a component is able to pull from the battery (Salt, n.d.). The team decided that a C-rating of 20 to 25 was safe for our system, and anything beyond that was acceptable. Because of the size of the aircraft, we wanted to ensure that the energy density of the battery was worth its weight penalty. In general, we decided that any battery above one kilogram (2.2 lbs) would not be selected. That is to say, the milliamp rating of the battery ultimately dictated the flight time of the aircraft. Based on our identified needs in reference to the current batteries on the market, the team had to decipher between batteries that had a milliamp rating from 4000 to 8000.

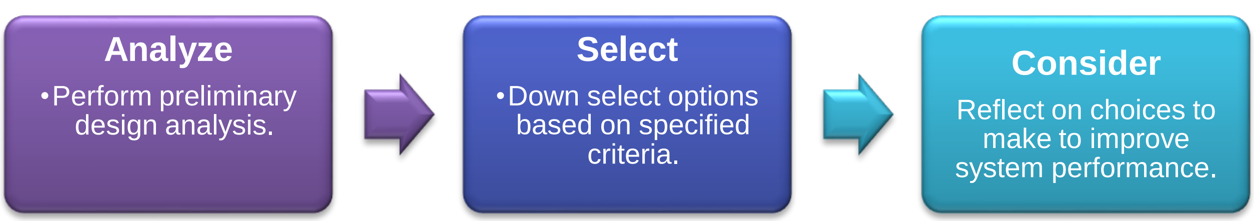
<u>Support Equipment (Catapult)</u>

The team considered getting a catapult via from the RWDC catalog or outside marketing sources. Likewise, we also considered designing our own catapult. For example, the pneumatic catapult from the catalog has a force of 6 kJ and it is capable of launching an aircraft at a maximum speed of 23 meters per second (51.4 mph). It includes an integrated compressor with reverse polarity protection, thermal shutdown and pressure relief valve. The total cost for the pneumatic catapult was a sizable $28,000.

The Micro-pilot MP Cat has a force of 6 kJ and a maximum launch speed of 26.3 meters per second (58.8 mph). It is easy and quick to install. Its compressor is powered by 14 4V Li-ion battery cartridges. Furthermore, it weighs 55 pounds and costs a whopping $35,000.

On the other hand, for our custom-designed catapult, we decided to build it out of light- weight aluminum since it proved to be feasible, strong and light. The catapult will be utilizing bungee cords in order to create enough force to launch the aircraft. The chord will be attached from the front of the catapult to the crate and the crate will be pulled back to create force in which we will calculate using Hooke's Law. The crate will be specifically designed to incorporate walls which will fall down after the crate reaches the take-off speed to ensure the aircraft launches safely and properly. Additionally, our catapult will have clearances incorporated that are specifically-designed for our aircraft in order to ensure a safe and reliable launch. Furthermore, the estimated cost was about $1500.

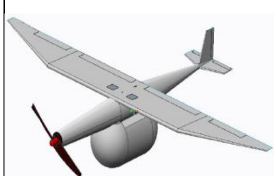
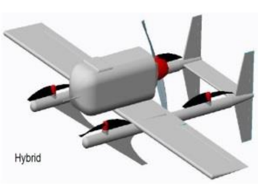
2.1.3 Preliminary Design



The next step towards finalizing our design concept was the preliminary design phase. The team recognized the need to narrow down our options based on each candidate's merit.

The air vehicle element selection played an immense role during this design phase. Important aspects such as cost, weight, performance ability were carefully considered by the team. The catalog provided the team with three options to choose from.

TABLE 6. Air Vehicle Elements

Option	Airframe	Flight Controls	Propulsion	Metrics
C. Fixed-wing Pusher Propeller 	• Composite airframe • V-tail • High-mounted with w/ ailerons • Tricycle landing gear	• Push-pull connectors • (2) ailerons, (2) mixed-elevator/rudder (v-tail), (1) steerable nose gear • Electronic speed control • BEC	• Electric Brushless Motor (7.7;1 geared drive) • Propeller (pusher, 19 x 11, efficiency 80%) • Battery (640 Wh 44.4V, Lithium Polymer [Li-Po])	• $15,000 • Empty weight: 32.85 lbs. • Wing span: 129" • Length: 89.37" • Max payload: 14.55 lbs. • Endurance: 110 mins. • Cruise speed: 42.76 knots (49.21 mph)
B. Fixed-Wing Tractor Propeler 	• Reinforced carbon fiber airframe • Fiberglass payload bay module • Conventional tail (elevator and rudder) • High-mounted wing with ailerons	• (2) ailerons, (1) rudder, (1) elevator • Push-pull connectors • ESC • Independent 1300 mAh Li-Po battery (for servo power)	• Electric motor (brushless) • (2) 5000 mAh Li-Po batteries (for motor) • Propeller (folding tractor, 10 x 6, efficiency 78%)	• Cost: $5,000.00 • Empty Weight: 2.78lbs • Wing span:78.74" • Length: 47.24" • Maximum payload: .88lbs/14.12oz • Endurance: 55 minutes with .88lbs/14.12oz payload • Cruise speed: 32.39 knots (37.28mph)
C. Hybrid (Fixed-wing/Quadrotor) 	• Composite materials	• Quadrotor: multirotor flight controller w/ autopilot functionality, ESC • Fixed-wing: (2) ailerons, (1) rudder, (1) elevator, push-pull connectors, (1) ESC	• Fixed-wing: Electric Brushless Motor; Propeller (pusher); Li-Po battery • Secondary (quadrotor): Electric Brushless Motor; (4) propellers (carbon fiber)	• $25,000 • Empty Weight: 25 lbs. • Max payload: 5 lbs. • Wing span: 127.95" • Length: 88.58" • Endurance (forward flight): 60 mins. • Endurance (hover): 5 mins. • Cruise speed: 35 knots (40.28 mph)

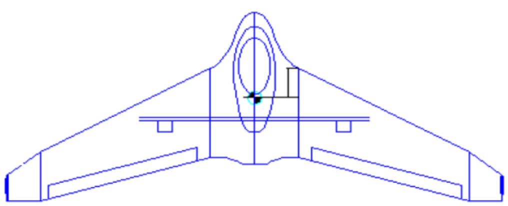
We searched numerous battery options that would test powerful enough to sustain our aircraft in order to perform the mission.

Majority of the RC aircraft design candidates were capable of carrying the payload required for this year's mission. The team, however, yearned to select an aircraft that will be able to complete the mission in less time, still while maintaining an exceptional payload capacity. Below are the main specifications of each aircraft candidate that we obtained from sources outside the RWDC catalog.

Table 6. **Aircraft**	**Specifications**
 **Darkwing FPV Drone 1727mm Composite (ARF)**	• Wingspan: 1727mm • Length (fuselage): 762mm • Dry Weight: 1400g
 **F-14 RC Aircraft**	• Wingspan: 61 in. • Length: 60.6 inn • Empty Weight: 9.56 lbs.
 **HobbyKing® ™ Go Discover FPV Plane EPO 1600mm (PNF) (EU Warehouse)**	• Wingspan: 1600mm • Length: 737mm • Weight: 1800g
 **Skua FPV Plane EPO 2100mm (KIT)**	• Wingspan: 2100mm • Length: 1150mm • Flying Weight: 2500-3000g

Majority of the following RC aircraft design candidates were capable of handling the payload requirements provided by the National Challenge.

Darkwing FPV Drone		**F-14 Grumman Tomcat RC**	
Pros	**Cons**	***Pros***	**Cons**
▪ Higher Payload Capacity ▪ Reduced Drag ▪ Higher Airframe Efficiency ▪ Low Cost	▪ Lower Speed ▪ Unconventional Flight Controls ▪ Need Modification	▪ High Speed Capability ▪ Variable Wing Geometry	▪ Lower Payload Capacity ▪ High Power Consumption ▪ High Cost



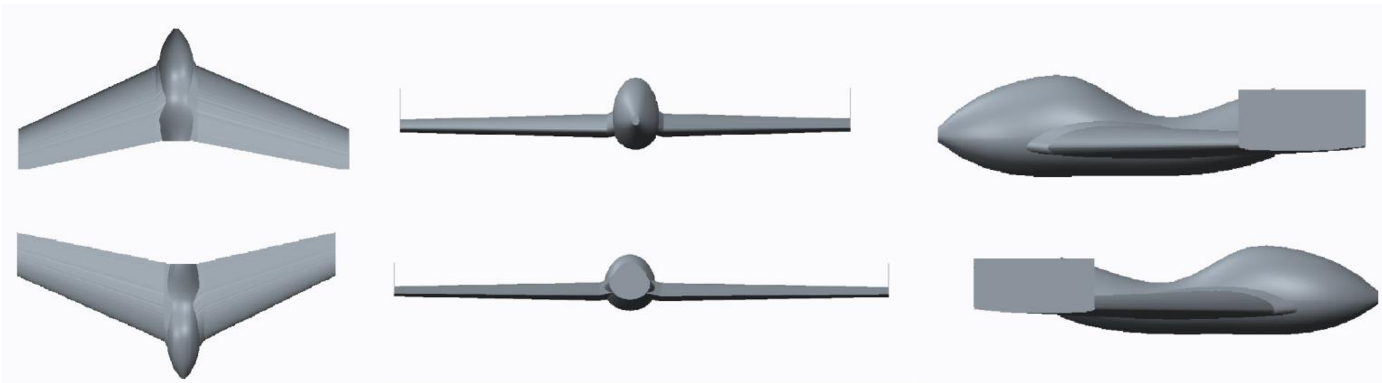
Specifications (Pre-modification)
Wingspan: 68 in. **Fuselage length: 30 in.** **Empty Weight: 3.08 lbs.** **MTOW: 6.6 lbs.** **Wing area: 5.31 sq. ft.** **Flight Controls: Elevons**

Compared to the existing aircraft candidates, the team decided that the Darkwing FPV's abilities were most suitable for this mission. Ultimately, the team developed a plan to modify the Darkwing to fit the need of the challenge specifications. It has the capability to reach the high speeds that we need in order to complete the mission in a short amount of time. On another note, the Go Discover FPV was a strong contender. It is equipped with a large compartment located in the forward section of the fuselage for a sensor payload. We predicted, however, that the center of gravity (CG) configurations would pose complications due to the weight of our sensor payload. Additionally, this aircraft contains a lower payload capacity compared to the Darkwing. The Skua FPV, on the other hand, had a high payload capacity but lacked essential speed capabilities. It compartment located below the aircraft added unwanted drag. In comparison to the F-14 RC aircraft, the Darkwing provides a higher payload capacity, greater airframe efficiency, and constitutes an overall low initial and modification cost. Unlike the F-14 who is characterized with high power consumption, the

Darkwing is able to withstand longer flight times during detection or other commercial application flights.

Confident that the team will stay with this aircraft, our Simulations Engineer started simulating CAD models of the original Darkwing as the team made constant modifications. These models were needed at an early phase in order to conduct the wing and structural analyses in Creo Parametric. Modifications were made as the team approached the detailed design phase.

Figure 9. Preliminary CAD Models (During Modification Process)



Battery Selection

In order to determine the estimated flight time, the team consulted with our mentors for assistance. Towards the process, we were able to come up with a way to calculate the potential flight time that each type of battery would produce. The results are shown below:

Battery Analysis		
Milliamp Rating	Estimated Flight Time	Weight of Battery
8000 mAh	13 minutes	>=2.2 lbs.
6000 mAh	9.67 minutes	1.8-1.9 lbs.
5000 mAh	7.97 minutes	1.6-1.7 lbs.
4000 mAh	6.262 minutes	1.3-1.5 lbs.

Upon completing our analysis, the team verified our research that states the higher the milliamp rating correlates to how much longer an aircraft can fly. However, the weight of the battery increases as a result. In order to decipher accurately, the team needed to calculate the estimate mission time for a single aircraft. With a result of seven minutes, we decided that the 6000 mAh battery would stand as the optimal candidate. Compared to the 8000, the 6000 mAh battery generates a lighter weight and costs less. The 4000 and 5000 mAh were excluded from our selection process because they failed to provide sufficient power to enable the aircraft to complete one mission flight.

The following table depicts our battery selection candidates.

Table 8. Battery		Specifications
MaxAmps LiPo 5450 6S 22.2v Battery Pack		• Milliamp Rating: 5450 mAh • Weight: 1.5278 lbs. • Estimated flight time: 10.07 minutes • Dimensions: 5.39 in. x 1.77 in. x 2.04 in. • Cost: $249.99
Glacier 30C 6000mAh 6S 22.2V LiPo Battery		• Milliamp Rating: 5800 mAh • Weight: 1.8125 lbs. • Estimated flight time: 10.85 minutes • Dimensions: 6.299 x 1.85 x 1.85 in. • Cost: $122.95
MaxAmps LiPo 6000XL 22.2V Battery Pack		• Milliamp Rating: 6000 mAh • Weight: 1.85 lbs. • Estimated flight time: 9 minutes • Dimensions: 6.38 in. x 1.77 in. x 2.13 in. • Cost: $264.99

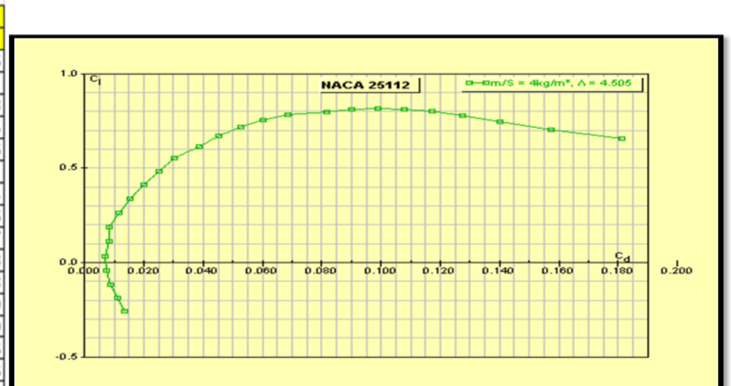
Because it provided the greatest energy density in terms of milliamps to grams, the team selected the Glacier 30C 6000mAh 6S 22.2V LiPo Battery. The team accepted its cost tradeoff based on the overall factor that this battery provided an ample amount of flight time as compared to its other candidates.

Airfoil Selection

For better modifications that would help increase stability during lift, we contemplated that our camber would be thicker in order to complement the size of the fuselage. A right amount of thickness in our camber would emphasize Bernoulli's principle, which states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. Air is moving at a faster speed on the top of the airfoil as compared to the bottom, which allows it to be lifted by the higher pressure created beneath the wing; thus, creating lift. Stemming from our conceptual choices, the team conducted an analysis for each airfoil using the JavaFoil software. Below are the analyses the team conducted that later to our primary airfoil selection.

NACA 25112

α	Re	Cl	Cd	Cm 0.25	TU	TL	SU	SL	L/D	A.C.	C.P.
[°]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-5	473948	-0.26	0.0136	0.002	0.488	0.018	0.993	0.99	-19.052	0.256	0.26
-4	548573	-0.19	0.011	0.002	0.459	0.021	0.994	0.991	-17.303	0.256	0.261
-3	698255	-0.118	0.0089	0.002	0.432	0.025	0.995	0.992	-13.263	0.257	0.263
-2	1.16E+06	-0.043	0.0072	0.001	0.405	0.031	0.995	0.993	-5.93	0.257	0.275
-1	1.31E+06	0.033	0.007	0	0.377	0.047	0.995	0.995	4.777	0.258	0.236
0	727537	0.11	0.0084	0	0.369	0.099	0.995	0.995	13.134	0.258	0.251
1	559805	0.186	0.0084	-0.001	0.351	0.875	0.995	0.991	22.238	0.259	0.254
2	471156	0.262	0.0115	-0.002	0.329	0.89	0.994	0.99	22.835	0.26	0.256
3	416084	0.337	0.0153	-0.002	0.311	0.903	0.994	0.99	22.086	0.261	0.257
4	376677	0.41	0.0199	-0.003	0.292	0.911	0.992	0.99	20.596	0.261	0.258
5	347327	0.482	0.0253	-0.004	0.271	0.92	0.99	0.99	19.068	0.262	0.258
6	325491	0.55	0.0304	-0.005	0.253	0.929	0.981	0.991	18.082	0.263	0.259
7	307828	0.615	0.0387	-0.006	0.23	0.937	0.96	0.992	15.864	0.265	0.259
8	294448	0.671	0.0454	-0.007	0.209	0.943	0.914	0.996	14.782	0.267	0.26
9	285182	0.717	0.0525	-0.008	0.182	0.95	0.845	0.998	13.667	0.27	0.26
10	277601	0.756	0.0601	-0.008	0.152	0.958	0.769	0.998	12.579	0.275	0.261
11	272293	0.784	0.0687	-0.009	0.108	0.963	0.691	0.998	11.417	0.287	0.262
12	270020	0.797	0.0816	-0.01	0.016	0.969	0.584	0.999	9.765	0.307	0.262
13	267674	0.811	0.0903	-0.011	0.012	0.978	0.539	0.999	8.983	0.339	0.263
14	266857	0.817	0.0989	-0.012	0.009	0.998	0.499	0.999	8.255	1.817	0.264
15	266787	0.812	0.1077	-0.012	0.006	0.999	0.462	0.999	7.541	0.154	0.265
16	267885	0.799	0.117	-0.013	0.004	0.999	0.425	0.999	6.826	0.205	0.267
17	271670	0.776	0.1274	-0.014	0.004	0.999	0.385	0.999	6.091	0.224	0.268
18	277878	0.744	0.1399	-0.015	0.003	0.999	0.336	0.999	5.317	0.235	0.27
19	285675	0.703	0.1574	-0.015	0.003	0.999	0.271	0.999	4.466	0.247	0.272
20	295795	0.655	0.1814	-0.015	0.003	0.999	0.189	0.999	3.61	0.252	0.273

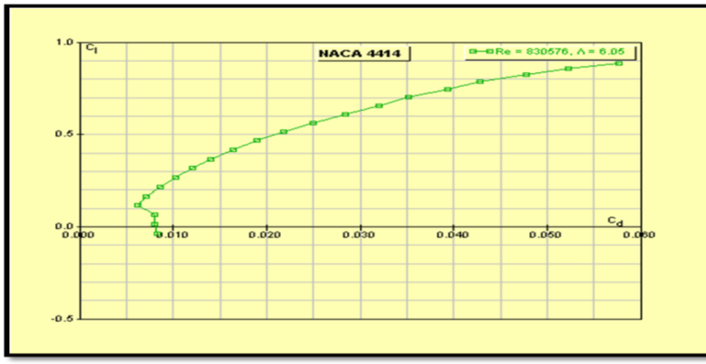


NAC25112

Ultimately, the team decided to select the NACA 25112 as our aircraft's airfoil. This airfoil was unique compared to the other selections because it had a reflexed trailing edge, which was suitable for flying wing aircraft (Johnson, About Airfoils for Flying Model Aircraft, 2015). It provided the desired amount of lift required for this mission. In addition, its flat-bottomed design allows it to fly without extensive RC piloting experience. Furthermore, because of the thickness of the airfoil, we were able to place components inside the wing.

NACA 4414

α	Cl	Cd	Cm 0.25	T.U.	T.L.	S.U.	S.L.	L/D	A.C.	C.P.
[°]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-5	-0.037	0.0083	-0.028	0.749	0.089	1	1	-4.456	0.26	-0.493
-4	0.013	0.0081	-0.028	0.707	0.124	1	1	1.65	0.26	2.355
-3	0.064	0.008	-0.029	0.662	0.205	1	1	7.994	0.261	0.697
-2	0.115	0.0062	-0.029	0.609	0.875	1	1	18.539	0.262	0.505
-1	0.166	0.0072	-0.03	0.551	0.917	1	1	23.022	0.264	0.431
0	0.216	0.0086	-0.031	0.484	0.94	1	1	25.027	0.265	0.392
1	0.267	0.0103	-0.031	0.436	0.957	1	1	26.002	0.266	0.368
2	0.317	0.012	-0.032	0.416	0.964	1	1	26.357	0.267	0.352
3	0.367	0.0141	-0.033	0.398	0.973	1	1	26.106	0.268	0.34
4	0.417	0.0164	-0.034	0.378	0.978	1	1	25.42	0.269	0.332
5	0.466	0.019	-0.035	0.361	0.982	1	1	24.529	0.27	0.325
6	0.515	0.0218	-0.036	0.347	0.986	1	1	23.571	0.271	0.32
7	0.563	0.0249	-0.037	0.325	0.989	1	1	22.584	0.273	0.316
8	0.61	0.0284	-0.038	0.304	0.992	1	1	21.507	0.274	0.313
9	0.657	0.032	-0.039	0.283	0.994	1	1	20.548	0.275	0.31
10	0.702	0.0351	-0.04	0.261	0.997	1	0.999	19.985	0.277	0.308
11	0.747	0.0393	-0.042	0.238	0.998	1	1	18.994	0.278	0.306
12	0.789	0.0428	-0.043	0.215	0.998	0.994	1	18.417	0.279	0.304
13	0.826	0.0478	-0.044	0.19	0.998	0.968	1	17.281	0.279	0.303
14	0.858	0.0523	-0.045	0.161	0.998	0.923	1	16.394	0.278	0.302
15	0.883	0.0577	-0.046	0.127	0.998	0.858	1	15.304	0.277	0.302

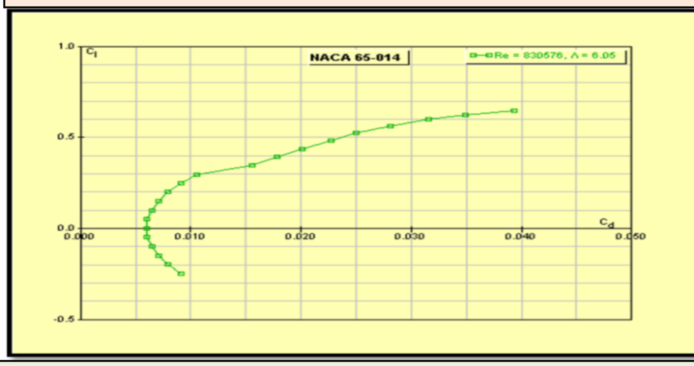


NACA 4414

Under-cambered airfoils, like the NACA 4414, were recommended for an aircraft that would be carrying a high-payload while travelling at high-speeds (Picking the "right" airfoil for model aircraft, 2012). However, the shape of this airfoil did not provide a sufficient amount of room for components to be placed inside. Although it produced more lift than the NACA 25112, the team determined through h MathCad calculations that the NACA 25112 provided right amount of lift without making the aircraft fly at a negative angle of attack, thereby allowing it to fly leveled.

NACA 65-014

α	Cl	Cd	Cm 0.25	T.U.	T.L.	S.U.	S.L.	L/D	A.C.	C.P.
[°]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-5	-0.248	0.00912	0.006	0.745	0.504	1	1	-27.163	0.273	0.273
-4	-0.199	0.00796	0.005	0.706	0.519	1	1	-24.958	0.273	0.273
-3	-0.149	0.00708	0.003	0.67	0.536	1	1	-21.099	0.273	0.273
-2	-0.1	0.00644	0.002	0.638	0.552	1	1	-15.486	0.273	0.273
-1	-0.05	0.00606	0.001	0.611	0.569	1	1	-8.232	0.273	0.273
0	0	0.00594	0	0.587	0.587	1	1	0	0.273	0.25
1	0.05	0.00606	-0.001	0.569	0.611	1	1	8.232	0.273	0.273
2	0.1	0.00644	-0.002	0.552	0.638	1	1	15.486	0.273	0.273
3	0.149	0.00708	-0.003	0.536	0.67	1	1	21.099	0.273	0.273
4	0.199	0.00796	-0.005	0.519	0.706	1	1	24.958	0.273	0.273
5	0.248	0.00912	-0.006	0.504	0.745	1	1	27.163	0.273	0.273
6	0.296	0.01056	-0.007	0.486	0.79	1	1	28.029	0.273	0.273
7	0.344	0.01554	-0.008	0.024	0.828	1	1	22.119	0.274	0.273
8	0.391	0.01777	-0.009	0.02	0.872	1	1	21.98	0.274	0.273
9	0.436	0.02013	-0.01	0.019	0.912	1	1	21.687	0.274	0.273
10	0.481	0.02276	-0.011	0.017	0.939	1	1	21.122	0.275	0.273
11	0.523	0.02501	-0.012	0.016	0.966	1	1	20.919	0.276	0.274
12	0.563	0.02805	-0.013	0.015	0.977	1	1	20.083	0.277	0.274
13	0.597	0.03151	-0.014	0.015	0.982	0.966	0.999	18.943	0.279	0.274
14	0.623	0.03491	-0.015	0.014	0.983	0.897	0.999	17.836	0.282	0.274
15	0.644	0.03934	-0.016	0.013	0.986	0.824	1	16.366	0.284	0.275

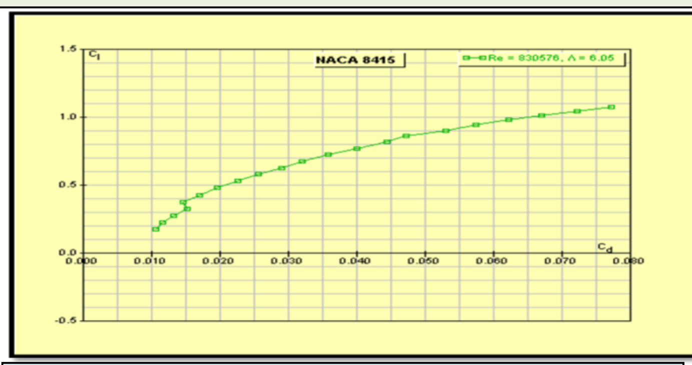


NACA 65-014

The NACA 65-014 was the airfoil of the Northrop YB-49 flying wing bomber. Because the team adopted the split-flap technology of this aircraft, we considered this airfoil as a possible candidate. Based on the JavaFoil results, however, it constituted a low lift coefficient which makes it unsuitable for mission. Additionally, because of its near-symmetrical design, this airfoil can increase the difficulty of piloting the aircraft.

NACA 8415

α	Cl	Cd	Cm 0.25	T.U.	T.L.	S.U.	S.L.	L/D	A.C.	C.P.
[°]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-5	0.169	0.0106	-0.056	0.6	0.052	1	1	15.923	0.26	0.58
-4	0.221	0.0117	-0.056	0.56	0.064	1	1	18.794	0.261	0.505
-3	0.272	0.0133	-0.057	0.515	0.078	1	1	20.489	0.263	0.459
-2	0.323	0.0152	-0.058	0.45	0.139	1	1	21.228	0.265	0.428
-1	0.374	0.0148	-0.058	0.436	0.983	1	1	25.282	0.267	0.406
0	0.425	0.0171	-0.059	0.424	0.987	1	1	24.795	0.269	0.39
1	0.475	0.0198	-0.06	0.415	0.99	1	1	24.075	0.271	0.377
2	0.525	0.0226	-0.061	0.406	0.991	1	1	23.235	0.273	0.367
3	0.575	0.0258	-0.063	0.399	0.993	1	1	22.326	0.275	0.359
4	0.624	0.0291	-0.064	0.388	0.995	1	1	21.451	0.278	0.352
5	0.673	0.0321	-0.065	0.378	0.997	1	1	20.98	0.28	0.347
6	0.721	0.036	-0.067	0.369	0.998	1	1	20.023	0.282	0.343
7	0.768	0.0401	-0.068	0.362	0.999	1	1	19.151	0.285	0.339
8	0.814	0.0445	-0.07	0.356	0.998	1	1	18.316	0.286	0.336
9	0.858	0.0472	-0.072	0.35	0.998	0.989	1	18.173	0.287	0.334
10	0.9	0.053	-0.073	0.344	0.999	0.972	1	16.97	0.289	0.331
11	0.939	0.0576	-0.075	0.333	0.999	0.948	1	16.308	0.29	0.33
12	0.976	0.0623	-0.076	0.322	1	0.917	1	15.669	0.292	0.328
13	1.01	0.0672	-0.078	0.312	1	0.885	1	15.046	0.295	0.327
14	1.043	0.0722	-0.079	0.304	1	0.852	1	14.437	0.3	0.326
15	1.071	0.0774	-0.081	0.295	1	0.818	1	13.841	0.304	0.326



NACA 8415

The NACA 8415 had a similar case to the NACA 4414. Its high camber enables the airfoil to produce a large amount of lift at small angles of attacks. Like the NACA 4414, the lift provided was too great and would pose a problem when the aircraft is descending. Additionally, the components would not be able to fit inside the wing because of this overall design.

Support Equipment Selection

For the support equipment selection, deviations of any additional equipment or components that would help operate the functional requirements of the UAS were required. Our selection of potential candidate solutions are based on reliability, maintenance, and test features that would verify its performance to be considered in the next step of the design phase. Ultimately, the team decided to select our support equipment from resources outside the catalog due to their reasonably high prices. Further speaking, the team opted to design a catapult as part of our launching support system.

Sensor Payload (Analysis)

By using the camera footprint sheet provided, the team was able to successfully analyze the lateral, coverage area, and possible resolution of our sensor payload candidates.

The team's attention first turned to the Tau 2, a thermal imaging camera. This option was acceptable in some regards; 4-6 VDC, and 112-479g depending on the lens that we selected. This camera produces images with a resolution of 640x512 and has a frame rate of 7 frames per second. Furthermore, its supporting rationale is that its thermal capabilities are able to identify and determine the temperature rates of both plant and soil. However, it failed to meet our requirements due to a certain lack of information--notably the cost--and the spectral range being too high for our purposes (7.5-13.5μm).

The ADC Snap, the first multispectral camera that we looked at instead of thermal imagers, subsequently, was our next choice. The ADC Snap is 90g--very lightweight--and had a power consumption of 9-14.7 VDC, therefore, it fit our parameters. This camera had the following qualities listed as followed: captures images in the red, green, near IR range, produces images with a resolution of 1280x1024, costs $4,995, captures images with a trigger, and weighs 0.198 lbs. Indeed,this was when we switched our focus from thermal imaging to multispectral imaging. Furthermore, the team learned that multispectral cameras are more commonly used in precision agriculture in reference to crop health. As a result, this was also the point where we learned about indices like NDVI.

Furthermore, the RedEdge looked to be a very promising option because it gave us very reliable data due to the multiple sensors it held, compared to similar filters. In addition, it was light enough (150g) for our purposes, and at 5 VDC, would not have been a strain on our battery. Eventually, the large lateral range convinced the team to put this camera as one of our strongest candidates, until we started searching for other options due to our spectral band needs that the RedEdge .45-.88μm did not satisfy.

The FLIR Vue Pro's specifications are similar to that of the Tau 2, however, this camera contains a higher frame rate of 30 frames per second. Likewise, the rationale behind this is the same as the Tau 2. Thus, we needed a thermal camera to determine the temperature of the soil and use the temperature to determine the moisture content.

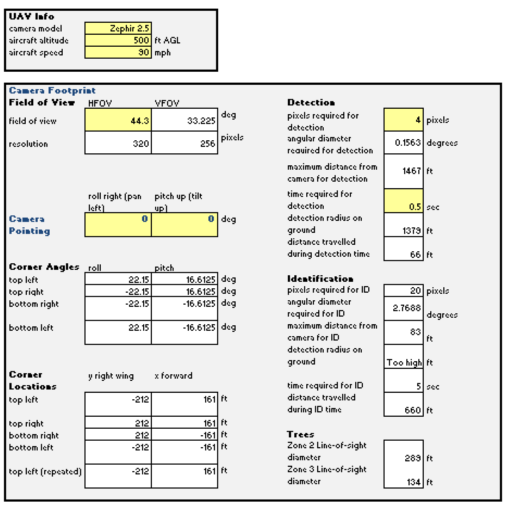
As produced in the RWDC catalog, the x5000 sensor payload captures images in the same range as the ADC Snap. It produces images with a resolution of 2048x1536 and has the ability to pitch and roll, capturing one frame per second and weighing at 1.41 lbs.

The x6000 is another sensor payload provided by the RWDC catalog. It captures images at the same range as the x5000 and ADC Snap, along with producing images with a resolution of 1280x1024. This camera has the ability to pitch and roll more sufficiently and captures two frames per second. Its weight, however, is up to seven lbs.

Unlike other sensor payloads, the Rikola Hyperspectral camera features a hyperspectral imager that captures images in the range of 0.5-0.9 micrometers. Costing $42,000, the Rikola has an image resolution of 1010x1010 and captures 30 frames per second. Furthermore, it captures in many spectral bands, which allow us to use indices that are more specialized for this challenge.

<u>NATIONAL CHALLENGE CANDIDATES</u>

Utilized in the state challenge, the ICI SWIR 640 is a hyperspectral imager that fit the requirements of the challenge in terms of detection. It captures images in the range of 0.9 – 1.7 micrometers with a resolution of 640x512. This sensor is capable of capturing 60 frames per second weighing at only 0.26 lbs. It was this camera that shifted the team's attention towards hyperspectral imaging. Through research, the team learned about the indices required to specifically detect soil and canopy moisture. Therefore, by using indices that incorporated SWIR bands, we would be able to achieve higher accuracy. All in all, the difference between this camera and the Rikola was that this camera was lighter, had longer a spectral response, a higher frame rate, and lower cost. The drawback with this sensor payload is its lower resolution when compared to other cameras.

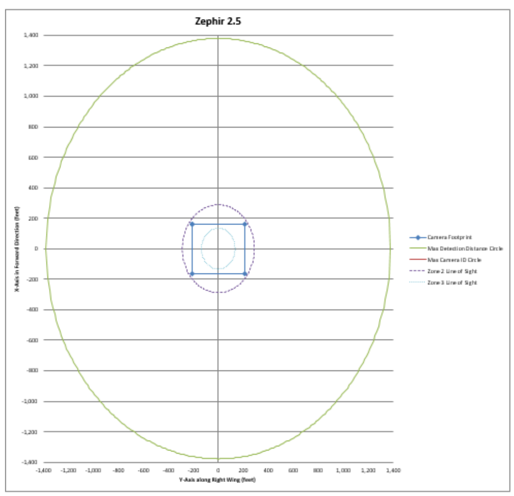


UAV Info		
camera model	Zephir 2.5	
aircraft altitude	500	ft AGL
aircraft speed	90	mph

Camera Footprint

Field of View	HFOV	VFOV	
field of view	44.3	33.225	deg
resolution	320	256	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	0	0	deg
Corner Angles	roll	pitch	
top left	22.15	16.6125	deg
top right	-22.15	16.6125	deg
bottom right	-22.15	-16.6125	deg
bottom left	22.15	-16.6125	deg
Corner Locations	y right wing	x forward	
top left	-212	161	ft
top right	212	161	ft
bottom right	212	-161	ft
bottom left	-212	-161	ft
top left (repeated)	-212	161	ft

Detection		
pixels required for detection	4	pixels
angular diameter required for detection	0.1563	degrees
maximum distance from camera for detection	1467	ft
time required for detection	0.5	sec
detection radius on ground	1379	ft
distance travelled during detection time	66	ft
Identification		
pixels required for ID	20	pixels
angular diameter required for ID	2.7688	degrees
maximum distance from camera for ID	83	ft
detection radius on ground	Too high	ft
time required for ID	5	sec
distance travelled during ID time	660	ft
Trees		
Zone 2 Line-of-sight diameter	289	ft
Zone 3 Line-of-sight diameter	134	ft

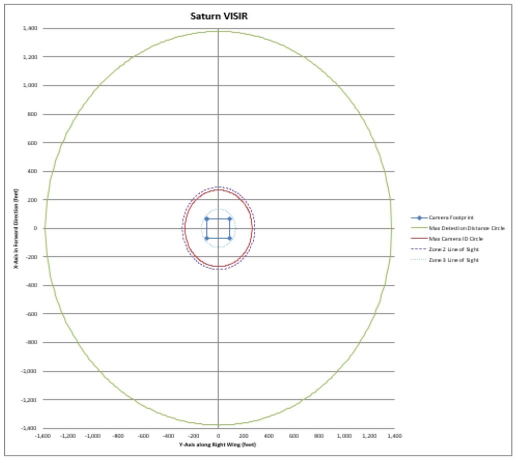


The Zephir 2.5 is a hyperspectral camera that the team considered for use in the national challenge. This imager captures images in the spectral range of 0.85 – 2.5 micrometers, a 320x256 resolution, and at 345 frames per second. This camera, however, weighs a total of 8.82 lbs. The rationale behind this camera was that we decided to use much more accurate indices to detect soil and canopy moisture, which required a wider spectral range response. An example was the Normalized Multiband Drought Index, which required images contained in the 0.8 – 2.5 micrometer range. The differences between the other two cameras was that it had a wider spectral range response and frame rate. On the other hand, it was heavier and produced lower resolution images than the other cameras.

UAV Info		
camera model	Saturn VISIR	
aircraft altitude	500	ft AGL
aircraft speed	90	mph

Camera Footprint			
Field of View	HFOV	VFOV	
field of view	20.2	15.15	deg
resolution	1000	256	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	0	0	deg
Corner Angles	roll	pitch	
top left	10.1	7.575	deg
top right	-10.1	7.575	deg
bottom right	-10.1	-7.575	deg
bottom left	10.1	-7.575	deg
Corner Locations	y right wing	x forward	
top left	-90	68	ft
top right	90	68	ft
bottom right	90	-68	ft
bottom left	-90	-68	ft
top left (repeated)	-90	68	ft

Detection		
pixels required for detection	4	
angular diameter required for detection	0.1563	degrees
maximum distance from camera for detection	1467	ft
time required for detection	0.5	sec
detection radius on ground	1379	ft
distance travelled during detection time	66	ft
Identification		
pixels required for ID	20	pixels
angular diameter required for ID	0.404	degrees
maximum distance from camera for ID	567	ft
detection radius on ground	268	ft
time required for ID	5	sec
distance travelled during ID time	660	ft
Trees		
Zone 2 Line-of-sight diameter	289	ft
Zone 3 Line-of-sight diameter	134	ft

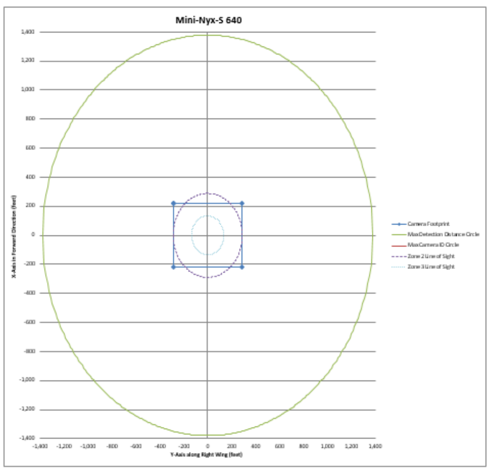


The next sensor payload candidate was the Saturn VISIR. . Like the Zephir 2.5, its features are listed as followed: it is a hyperspectral camera that captures images in the spectral range of 0.8 – 2.5 micrometers, captures images with a resolution of 1000x256, captures 250 frames per second, and weighs approximately 6.55 lbs. The rationale behind this camera was that this camera had a higher resolution than the Zephir, while keeping the spectral range. The difference between this camera and the Zephir 2.5 was that this camera was lighter and produced higher resolution images. In addition, it had a wider spectral range, sterling cooler and lower frame rate.

UAV Info		
camera model	Mini-Nyx-S 640	
aircraft altitude	500	ft AGL
aircraft speed	90	mph

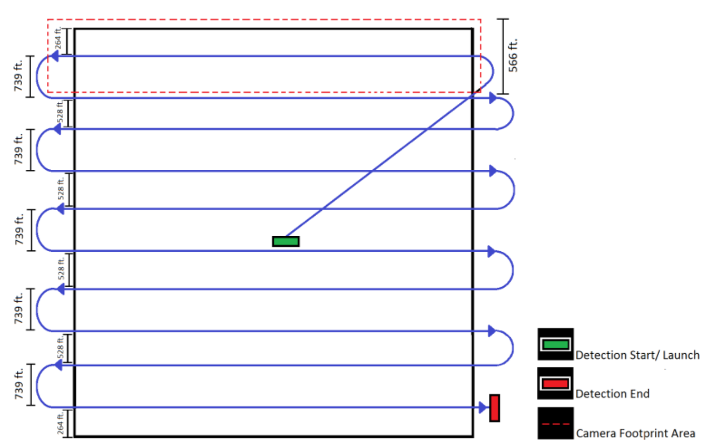
Camera Footprint			
Field of View	HFOV	VFOV	
field of view	55.6	42.5	deg
resolution	640	512	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	0	0	deg
Corner Angles	roll	pitch	
top left	27.8	21.25	deg
top right	-27.8	21.25	deg
bottom right	-27.8	-21.25	deg
bottom left	27.8	-21.25	deg
Corner	y right wing	x forward	
top left	-283	220	ft
top right	283	220	ft
bottom right	283	-220	ft
bottom left	-283	-220	ft
top left (repeated)	-283	220	ft

Detection		
pixels required for detection	4	pixels
angular diameter required for detection	0.1563	degrees
maximum distance from camera for detection	1467	ft
time required for detection	3	sec
detection radius on ground	1379	ft
distance travelled during detection time	396	ft
Identification		
pixels required for ID	20	pixels
angular diameter required for ID	1.7375	degrees
maximum distance from camera for ID	132	ft
detection radius on ground	Too high	ft
time required for ID	5	sec
distance travelled during ID time	660	ft
Trees		
Zone 2 Line-of-sight diameter	289	ft
Zone 3 Line-of-sight diameter	134	ft



The final camera candidate is the Mini-Nyx-S 640. This hyperspectral imager captures images in the spectral range of 0.8 – 2.5 micrometers. This potential sensor payload captures image resolutions of 640x512 at 100 frames per second. With a cost of $60,000 and weighing at only 1.3 lbs., the Mini-Nyx-S 640's specifications were the best of both worlds. It met the challenge's spectral range requirements while keeping its specifications of being lightweight, capturing images quickly, and maintaining high quality resolution.

At this point, the team started to stray from the basic method of camera detection, which requires that the sensor payload face straight down on the crop with no panning or tilting. The team then looked at the Mini-Nyx-S 640 and conducted a camera footprint analysis on it. We later discovered that sweeping the camera to the left and right during detection will not only increase our coverage area but decrease our total mission time. This led to a change in our detection approach and provided us with a new frontrunner for our sensor payload selection.



Preliminary Detection Patterns

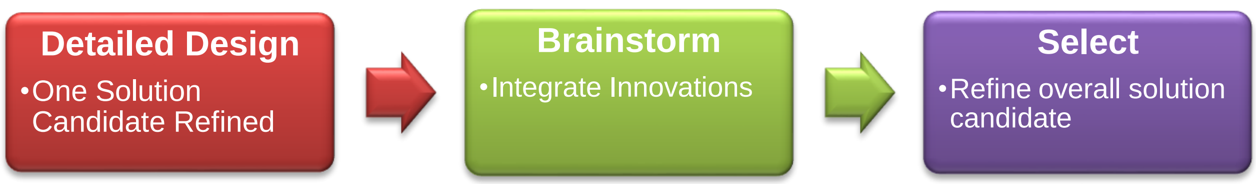
Based on the camera footprint analysis on our sensor payload candidates, the team decided to include a pan and tilt mechanism to the sensor payload.

This will allow the camera to sweep to the left and right, allowing a large coverage area of the field. This, however, significantly changed our detection pattern. As depicted on the right, our detection pattern will lessen to six turns instead of ten.

Support Equipment (Catapult)

Our aircraft selection played a major role into narrowing the candidates down. We ultimately decided to design our own catapult in order to meet the specific needs of our aircraft. While the other catapults can generate the appropriate lift to launch our aircraft, they are generic, and not specifically designed for our unique UAV. As a result, our catapult will be able to launch our aircraft with precision and reliability, since we will build it based on the needs of our aircraft alone. There will also be clearances maintained to ensure that the pusher propeller clears the supportive structure, as the aircraft lifts off. Additionally, we were able to save $26,500.00 by designing our catapult within the company, thus saving money while utilizing the talents of our very own employees. Particularly, we used the same philosophy as the Wright Brothers.

2.1.4 Detailed Design



The team approached the last step of the engineering design process to further refine the UAS. Extensive calculations were done to ensure that the aircraft would perform optimally.

Specifications (Post-modification)

- Wingspan: 79.55 in.
- Fuselage length: 35.1 in.
- Empty Weight: 5.4765 lbs.
- MTOW: 10.55 lbs.
- Wing area: 9.755 sq. in.
- Wing loading: 14.33 oz/sq. ft.
- Wing cube loading: 4.6
- Flight Controls: Elevons, Split Flaps
- Max speed: 90 mph.

After selecting the Darkwing FPV Drone as our final aircraft, the team made several modifications to it in order to refine it for the mission. In order to make the Darkwing suitable for the mission, the team had to increase the aircraft's size. After determining our payload requirements, we resized the aircraft in a way that would increase its efficiency while enabling it to carry all necessary components. The team determined that enlarging the aircraft by 17% would optimize it for the mission and the challenge. The stress-test results confirm that the aircraft would be able to handle the loads of the aircraft. Furthermore, we modified the wings and added split flaps as a vertical axis flight control. Because we will be launching our aircraft from a catapult and will be catching it in a net, there was no need to implement landing gears. We conducted a stress analysis on the wings to make sure that the aircraft was capable of carrying the load of the aircraft.

Sensor Payload (Detailed Selection)

In order to select our sensor payload, we had to keep in mind of the

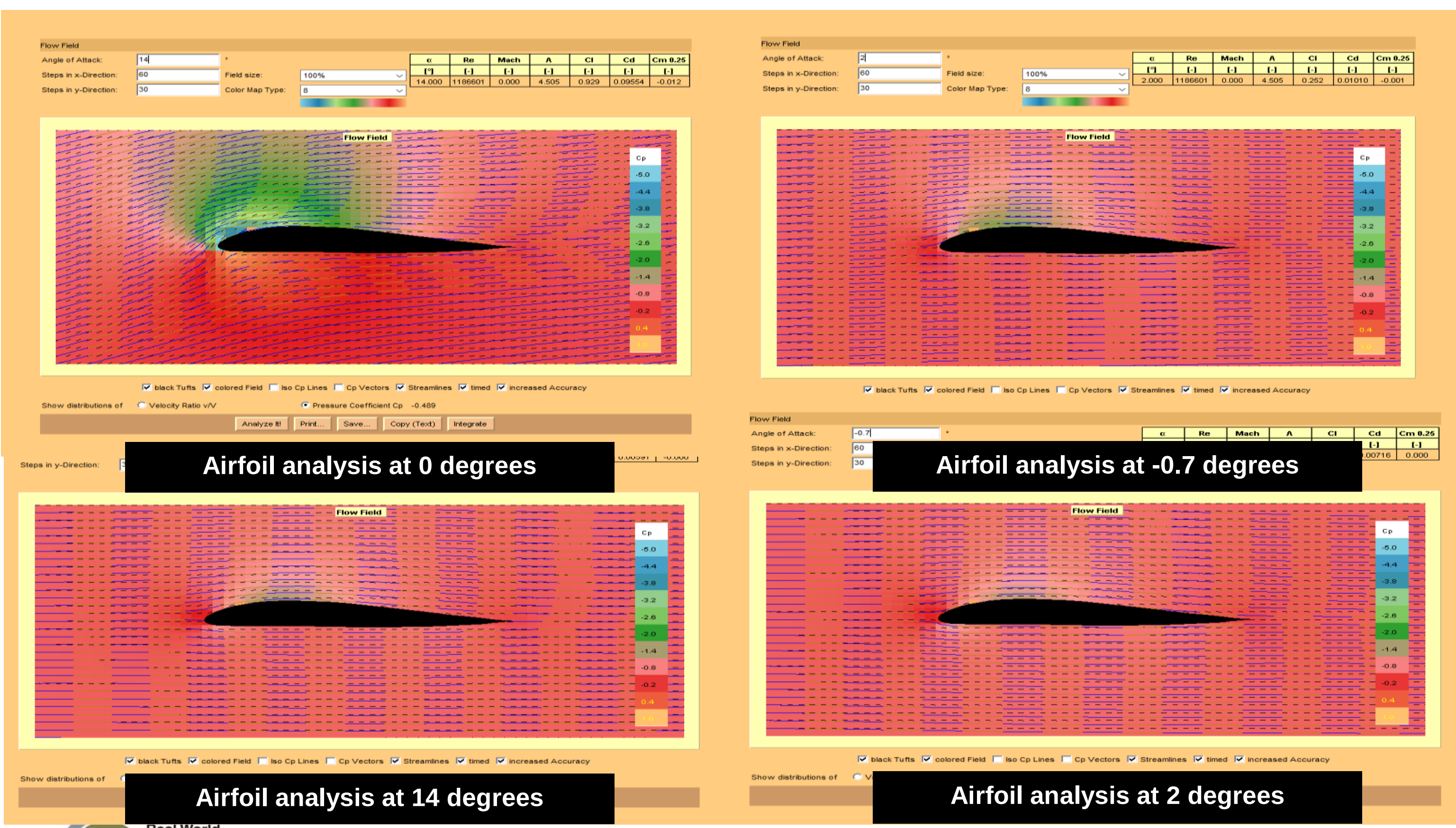
- OEM integrated detector cooler assembly (IDCA)
- Extended wavelength (0.9 - 2.5um) high performance IRFPA
- AIRS customized optical interface, hyperspectral filter mounting and packaging
- Smart IDCA - A/D and uncorrected Camera Link video interface
- High resolution 15 um pixel
- Designed for ease of integration into hyperspectral instruments, gimbal payloads, and other OEM systems

AIRS AMERICAN INFRARED SOLUTIONS

mission scenario. At first, we thought that thermal imaging would be enough for moisture detection. As a result, the Tau 2 was our initial leading candidate. However, there were many questions as to how to measure the moisture content for the soil and the crop. Upon further investigation, we thought that multispectral imaging would be sufficient to measure the moisture content since we would be using the Normalized Difference Vegetation Index (NDVI) to measure the moisture level. The Micasense RedEdge was our next leading candidate with a spectral band of 450-950 nanometers (nm). Later on, we realized that the NDVI was not appropriate for our mission since it measures only the photosynthetic activity of plants; however, we needed to measure the moisture level of crops as well. After researching for another index, we came upon the Water Band Index (WBI) and the Water Index Soil (WISOIL), which measured the moisture content for the crop and soil, while utilizing a spectral band of 900-1450 nm. Thereby, after searching for a new sensor payload, we found the Mini-Nyx-S 640.

After the preliminary phase, we rejected many cameras. First, the FLIR Vue Pro and the Tau 2 were rejected because the process of detecting moisture with a thermal imager wasnot efficient compared to the other cameras.Thus, it took too much time to acquire the needed data to be viable. Secondly, the ADC Snap, X5000, X6000, Rikola Hyperspectral Camera, and the ICI SWIR 640 were rejected because they did not cover the spectral range needed to acquire accurate results. Thirdly, the Saturn VISIR and the Zephir 2.5 were rejected because they were too heavy and did not produce image resolutions compared to the Mini-Nyx-S 640.That is tosay, the camera we decided to use was the Mini-Nyx-S 640 because it met our spectral range requirements, was lightweight, and met our image resolution requirements.

NACA 5410 Airfoil (Detailed Analysis)



Airfoil analysis at 0 degrees

Airfoil analysis at -0.7 degrees

Airfoil analysis at 14 degrees

Airfoil analysis at 2 degrees

After selecting our final airfoil, the team conducted an in-depth analysis of the NACA 25112. The figures below compiles the main data points we obtained from the analysis using JavaFoil. Utilizing MathCad, the team was also able to calculate its angle of bank and use this data as aid in conducting our wing and structural analysis.

Later in the design phase, the team discovered a way to input the values of regular balsa wood material and form it into Creo Parametric. This was a difficult decision process as balsa wood and EPO foam have very similar characteristics, and are both strong candidates when analyzing the aircraft's efficiency. As we entered the detailed design phase, the team decided to use balsa wood, the original material of the Darkwing FPV Drone.

Table 9. **Material Selection**

Type	Advantages
Balsa Wood	• High strength • Lightweight • Low maintenance • Easily assembled

Indigenous Crop Selection (Detailed Research)

The selection of indigenous and local crops was a rather difficult process for the team. We wanted to select a crop that had a variety of uses, as well as it being highly marketable and nutritional in the islands. Cucumbers and squash are water-containing crops that are indigenous to the CNMI. Due to its adequate shelf life, low cost, same-family categorization, and fast-growing capabilities, these crops have been an essential food crop that can be available year round, especially in a tropical island like Saipan. The increase in crops will not only bring monetary gain, but nutritional value as well. The team conducted research on both crops, as shown below.

In the islands, we have three main varieties of cucumber consumption; slicing, pickling, and burpless. Slicing is the eating of fresh, raw, unripe cucumbers. They are eaten unripe because when they ripen and turn yellow they are extremely bitter. In this form, cucumbers provide a good source of Vitamin A, Pantothenic Acid, Magnesium, Phosphorus and Manganese, and a very good source of Vitamin C, Vitamin K and Potassium. Cucumbers are therefore very easily a healthy food product and also very moist for those who have low water intake.

In pickling form, cucumbers retain their high fiber, are full of healthy antioxidants, and probiotics. Probiotics are a type of live bacteria that is extremely healthy, particularly for the digestive system. This is important because the only other common source of probiotics is yogurt (other options including kimchi and sauerkraut), which goes off very quickly and is therefore hard to transport to all corners of the world. Probiotics are considered to be of vital importance since they allow your body to absorb vital minerals and vitamins. Include the long-lasting properties of pickled products, and cucumbers have the ability to feed many in poor, hard-to-reach areas.

Thirdly, burpless cucumbers are a type that are thinner skinned and sweeter than other cucumbers. They're eaten fresh and often renowned for the ease with which they digest. There are also other ways in which cucumbers can be eaten and preserved, making them a versatile product that is found attractive by cultures all over the world. Additionally, their short growth period (65 days) and large yield when properly cared for, makes them an ideal crop for mass production.

Squash, also known as cucurbita and pumpkin, are a produce found worldwide. Although originally cultivated in the Americas, squash spread throughout Europe during the Colombian Exchange. The top five pumpkin producing countries in the world are China, India, Russian Federation, United States, and Egypt. The US produced 786, 980 metric tons of pumpkin in 2008. Besides the significance in many cultural and religious practices held by squash, the health benefits and it's popularity with consumers on a daily level make it an important crop with high demand.

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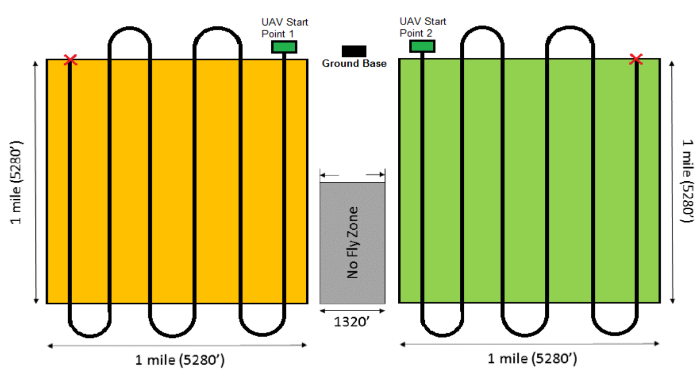
Squash provide many necessary minerals and vitamins. For example; spaghetti squash, which lasts for over a month uncut, contains vitamin A (457% the RDI), vitamin C (52% of the RDI), antioxidants (beta-carotene, lutein, and zeaxanthin), B vitamins (riboflavin, niacin, and thiamin), folate, minerals (potassium, manganese, calcium, iron, phosphorus, and zinc), omega-3, and omega-6. is often recommended to those who are pregnant or soon will be (folate), eye health (antioxidants), heart diseases, joint issues, blood issues, muscle or bone issues, and for types of cancer (omegas). All of these important and healthy vitamins and minerals found in spaghetti squash make it a versatile, well-rounded food choice. It is often recommended to those who are pregnant or soon will be (folate), for eye health (antioxidants), heart diseases, joint issues, blood issues, muscle or bone issues, and for types of cancer (omegas).

Overall, squash is considered a healthy choice for a well-balanced diet, and has an extremely large variety of ways it can be prepared; boiled, steamed, heated, fried, raw. Additionally, squash generally keep for long periods of time, meaning they can be sold all over the world. They also have high water content.

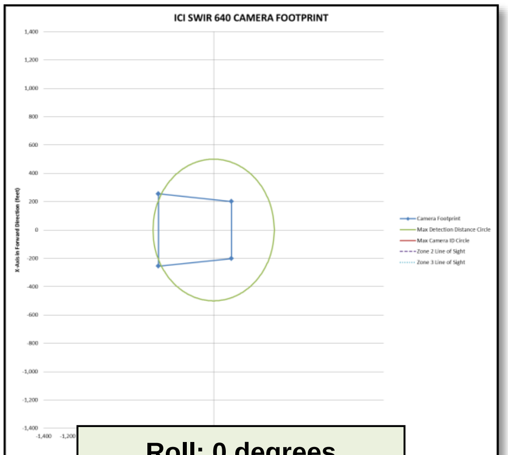
Squash have large yields, with winter and summer varieties. This means squash can be a year round product. Seeds should be planted one inch deep and 2-3 feet apart in rows 4-6 feet apart. The numbers of fruits produced per plant vary depending on the type of squash, as do the size of the fruit. Acorn squash have an average yield of 5 fruit per plant (1-3 pounds/fruit), butternut have 3-4 (2-4 pounds/fruit), and pumpkin have 1-2 (6-18 pounds/fruit). As of March 11th, 2016, New York's Park Slope Food Coop listed squash as costing \$1.11-\$2 per pound (butternut-zucchini).



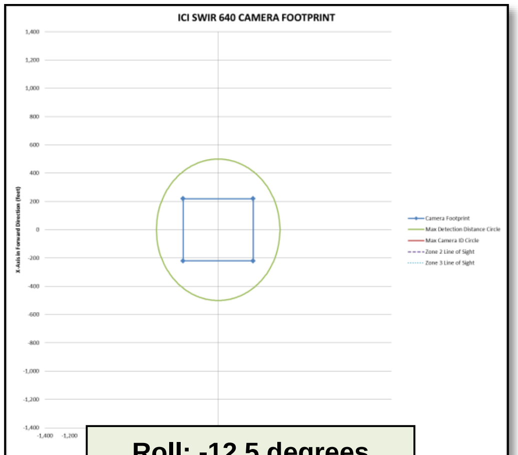
The care of squash is relatively simple in many ways. However, they do require a lot of sun, rich fertilized soil, and consistent watering patterns. The suggested amount is deep watering of at least 1 inch per week. As the crop nears harvest, specifically around flowering, it must be watered and monitored even more diligently. Squash is usually harvested at around fifty days.

Detection Pattern (Detailed)

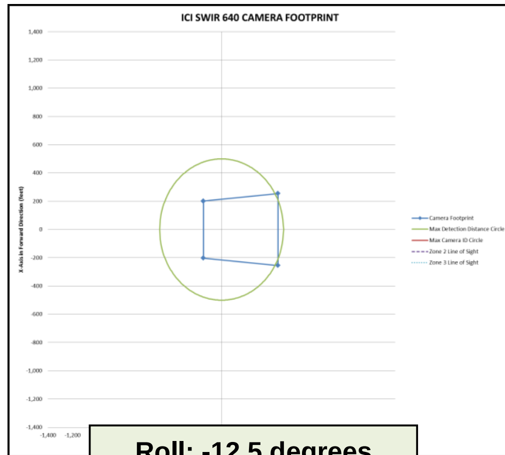
As a result of our sensor payload's ability to sweep left and right during the detection process, the team was able to significantly decrease the amount of turns we take, from nine to five turns. Depicted above is the detection pattern the formulated during the detailed design phase. To maintain visual line of sight, the operational pilot will be stationed at the center of the field. The aircraft will be launched at the center of the field by a catapult and will make its way to the most upper left section of the field. The aircraft will begin its detection from that point on. The team calculated the sensor payload's coverage area with the provided camera footprint sheet.



Roll: 0 degrees



Roll: -12.5 degrees



Roll: -12.5 degrees

Battery Selection (Detailed)

In order to calculate the flight time that the battery can produce, the team worked with our mentors to develop a formula. We calculated the amount of power that we could draw from the battery. After doing so, we then calculated that we could obtain approximately 9.5 minutes of flight time from our battery. Because our mission time is exactly seven minutes, there will be about 26% of battery life remaining upon completion of a mission. This ensures that the aircraft will have enough power to fly back to the ground case in the event of a discrepancy.

Support Equipment Selection (Catapult)

The materials and parts that the team used to construct our catapult included as followed: pistons, springs, bungee cords, wheels, and light-grade aluminum which will also serve as the launch pedal. The aluminum served as the structure, while the pistons and springs are designed to hold the aircraft in place before depressing and collapsing respectively. We specifically designed a unique crate attachment to our catapult system, which will be described in detail in the following sections.

2.1.5 Lessons Learned

<u>Conceptual Design Phase Duration</u>

We learned that the higher the aircraft flies above the ground, the lower the resolution of our sensor payload will likely be.

The team recognized the need to choose a fast-growing crop in order to increase our missions per day.

We recognized the positive effects of placing antennas being placed on the outboard wings. These antennas, when placed parallel and attached to the spar, serves as anti-torque that devises structural reinforcement for the spar, as well as improving communication.

We learned that certain cameras have ITAR regulations due to the ways that they could be used for military purposes.

The term “G” is how many times the plane weight is to itself (ex. 3g equals three times the weight of the aircraft).

We learned that the closer we want to be able to precisely detect the moisture of plants and soils with one camera, the wider the spectral range of our camera needs to be.

We learned that detecting moisture is based on how much the plant or soil reflects a certain wavelength.

We learned that different moisture indices need different and specific spectral bands.

We learned that cameras that don’t list a field of view do not come with a lens. Interaction with the providing companies should always be made before use.

<u>Preliminary Design Phase Duration</u>

We are now aware of the additional FAA regulations that have to be complied with requiring experience, special certification, inspection and approval of the aircraft, and specific qualifications to be able to legally fly the aircraft for agricultural use.

We learned that our communications, control and telemetry are activated by the data transceiver set that allows us to activate the servo receiver. This allowed data from our sensor payload and servos to be transmitted to our ground station.

We recognized the need to decrease our UAV’s speed in addition to lowering our flaps before turning in order to increase drag and stabilize our airspeed in that time duration.

The team learned that a battery with a high amp-hour capacity will make our aircraft fly longer.

We learned about how setting a battery in a series and parallel circuit increases the voltage and its amp-hours.

<u>Detailed Design Phase Duration</u>

The team learned that the cucumber and squash crop’s growth cycle has an approximate 3-week time gap between each stage, thus affecting our mission detection approach.

The team learned that Creo simulate could be used to conduct a structural analysis of the wings and the aircraft’s load factors.

We recognized the importance of making our trailer multifunctional, utilizing it for the following: a storage area for components, work space for personnel and area for data analyst, and a mobile tower. We recognized the need of a truck in order efficiently move equipment and carry the refueling system while acquiring an efficient mission time.

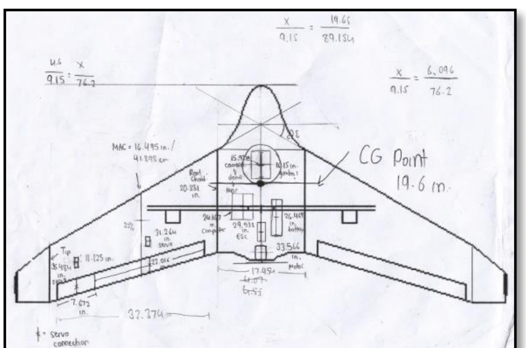
<u>Throughout Entire Design Phase</u>

The team learned the importance of communication, teamwork, and patience throughout the challenge. Despite the lack of resources and inability to directly print or copy material, along with extended times of wait for responses, we learned how to maintain our goal of completing the mission scenario no matter what our limitations were.

2.1.6 Project Plan Updates and Modifications

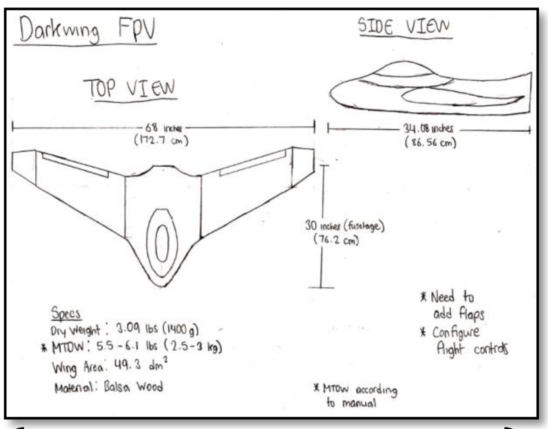
Project plan updates and modifications were made with careful consideration throughout the conceptual, preliminary, and detailed design phases. The team had to perform several modifications in order to significantly increase the airframe efficiency and payload capacity of the aircraft.. As a result, the team decided to increase the size of the aircraft by 17%. Since this is an RC aircraft, there is no need to store any additional components in the nose. In addition to that, the team removed the landing gear to further reduce the weight of the aircraft. This all works in conjunction to increasing our aircraft efficiency, overall business case, and our objective function value.

The following drawings depict the team's updates and modifications regarding the UAV design.



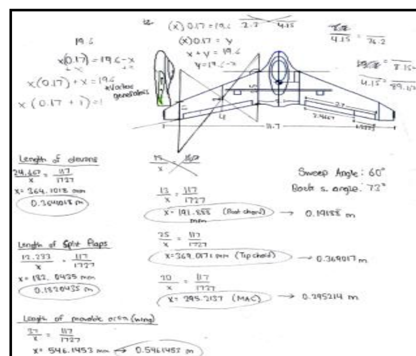
Drawing A: Aircraft Dimensions

This drawing shows the top view of the aircraft with calculations made to manually calculate the aircraft's center of gravity and aircraft dimensions.



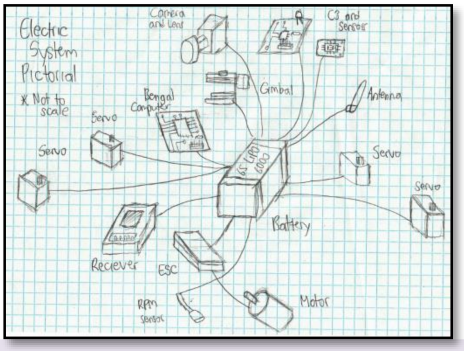
Drawing B: Top & Side View of the Aircraft

This drawing depicts the overall top and side view of the fully modified Darwing FPV Drone, which the team names the Cruiser.



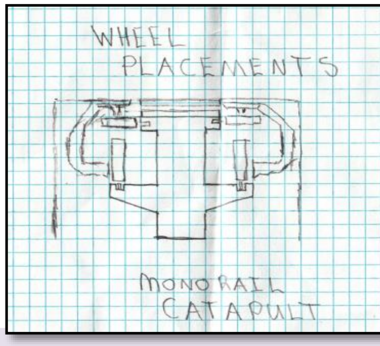
Drawing C: Flight Control Calculations

The team calculated the angles, chords, and other supporting values that quantify the use of our added flight controls. These include our split flaps and elevons.



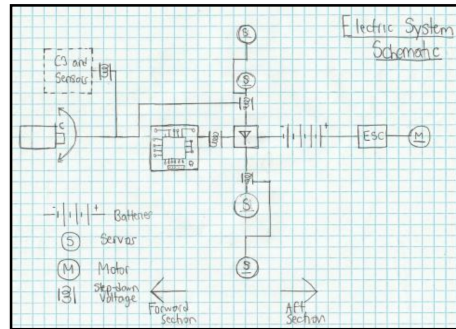
Drawing D: Pictorial Diagram of Electric System

The team wanted an easy, general picture of the electrical system of the aircraft. Having a pictorial diagram enables us to visualize the electric system in 3D. This also goes towards placing and aligning



Drawing E: Monorail Catapult Drawing

Since we will be designing our own catapult that will be specified for the chosen aircraft, the team sketched the parts and wheel placements of our catapult.



Drawing F: Electric System Schematic

The drawing above illustrates the aircraft's electric system schematic, which includes the placement of our batteries, servos, motor, antennas, and more.

In addition to enlarging the aircraft's size, the team modified majority of the inside fuselage and the components that align inside it. We modified the electric system and inputted the C3 components that were needed to maintain communication between the aircraft and the ground system during detection. The team modified our battery with power cells that will provide more than enough energy to fly the aircraft over a 1x1 mile field area.

Numerous modifications were made to our conceptual ideas for both the aircraft, mission plan, support equipment, and business approach. In order to increase productivity, the team made the biggest modification on our system and its workers. Ultimately, the team decided to utilize two UAVs to complete the mission in less time, however, gaining more value for both workers and customers. This significantly increased our operational personnel, initial and per hour costs, and business approach. On the same note, the team switched gears on both our airframe baseline and sensor payload in pursuant to marketing the best and unmatched materials that our company can offer in the business world.

2.2 Selection of System Components

2.2.1 Payload Selection

Sensor Payload Selection

The sensor payload that would be used for this challenge was the Mini-Nyx-S 640. This hyperspectral camera has a spectral range of 0.8 to 2.5 micrometers. With this spectral range, the sensor would be able to capture images that could be used with our indices. Therefore, the camera achieved its spectral range by using a Mercury Cadmium Telluride (HgCdTe) camera sensor cooled to 180Kelvins, or -93.15 Celsius. Furthermore, to cool it down to 180K, it utilizes a sterling cooler that was integrated to the camera. The sterling cooler added a significant weight increase to the camera. For the camera to endure abuses, its housing was mostly made of metal. With the material of the housing and the addition of a sterling cooler, the camera's weight added up to 600g, or 1.3lbs. As a result, this camera was expensive to produce, and it costs $60,000. Because of its low power consumption, our system is able to achieve a longer flight time, which will enable us to perform more missions per charge. It is capable of capturing images in various spectral ranges, which in this case are the ranges needed to detect the cucumber crop's soil and canopy moisture content. Finally, the company that sells this camera gives great support to its customers. ICI SWIR is the only camera company that answered our questions in a timely and efficient upon addressing the question. Depicted below are the camera specifications.

IR FOCAL PLANE ARRAY

Sensor Type	MCT
Array Format	640 (h) x 512 (v)
Pixel Pitch	15 µm
IRFPA Spectral Band	Extended SWIR (0.9- 2.5 µm)
FPA Operating Temperature	180°K typical

OPTICAL INTERFACE (CUSTOMIZABLE)

Cold shield	matched for system design
Cold Filter Bandpass	per customer requirements
Hyperspectral options	order blocking or sorting filter mounted in dewar cold space to customer requirements

COOLER - INTEGRAL STIRLING

Integral Stirling	K561 or other
MTTF	> 10,000 hours
Split Stirling	Optional

READ OUT INTEGRATED CIRCUIT (ROIC)

Modes	Snapshot in IWR (Integrate While Read, ITR (Integrated Then Read) or RS (Rolling Shutter)
Input Stage	Capacitance Transimpedance Amplifier (CTIA)
Sub-frame capability	any size in steps 4 hor. and 1 vert.
	row deselction for individual lines (e.g. spectral channels)
Outputs	4
Max. Full Frame Rate	100Hz IWR (640x512)
	variable (higher) with windowing

ELECTRICAL

Voltage	12 VDC and 5 VDC
Power Dissipation @ 25°C	4 W typical steady state

COMMAND AND CONTROL ELECTRONICS

Communications	RS-232
Video Output	Uncorrected Camera Link
A/D converter	16 bit
Frame Sync	external or internal

After shifting our attention from thermal cameras to multispectral and hyper spectral cameras, the team started to research indices that would deem appropriate for our mission, along with it being compatible with our camera. The first index we found was the Normalized Difference vegetation Index (NDVI). This index uses the following bands to determine the health of the vegetation: Red, Blue, Green, and Near Infrared. The Normalized Multiband Drought Index was selected to determine if the soil is too dry or too wet. This index used images captured in the 860 nm, 1640 nm, and 2130 nm bands to achieve its goal. These bands were selected by this index because they are sensitive to moisture changes in the soil. Dry soil will give a value between 0.7 and 1, soil with intermediate moisture will give a value between 0.6 and 0.7, and wet soil will give a value less than 0.6. We decided to use this index to detect the moisture content of the soil because the results produced by this index have been reliable to many other researchers.

At first, the team thought that this index would serve our purpose; but with more research, we found that it detects merely the "greenness" or photosynthetic activity of a crop, not its moisture content. The next indices we found were the Moisture Stress Index (MSI) and the Normalized Multi-band Drought Index.

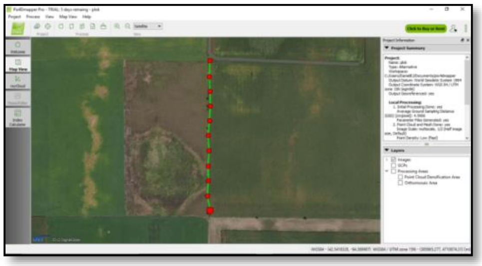
The Moisture Stress Index uses the strength of absorption of the leaf in the 1599nm range and divides it by the strength of absorption in the 819nm range. The value from this equation will determine the water stress of the leaves by giving it a value between the 0 and 3. Usually, the value of healthy vegetation is between 0.4 and 2. The Normalized Multi-band Drought Index uses the differences between two liquid-water absorption bands to determine if the soil is too wet or too dry. Dry soil will give a value between 0.7 and 1, soil with intermediate moisture will give a value between 0.6 and 0.7, and wet soil will give a value less than 0.6. The issue we found with these indices is that its spectral range is too long. If the spectral range is too long, it may result in a larger and heavier camera. As a result, the indices that the team decided to utilize were the Water Band Index (WBI) and the Water Index Soil (WISOIL). The Water Band Index determines the water stress of our plants and the Water Index Soil determines the moisture content of the soil. The team chose both indices because it falls within our camera's spectral range; between 900nm and 1700nm. The Water Band Index uses the strength of absorption in the 900nm and 970nm range, and the Water Index Soil uses the strength of absorption in the 1300nm and 1450nm range. This helped us choose a lighter and smaller camera.

The Moisture Stress Index was selected to determine if the leaves are experiencing moisture stress. This index uses the strength of absorption of leaf water in the 1599nm range and divides it by the strength of absorption in the 819nm band as a reference. The values of this equation will determine the water stress of the leaves by giving it a value between the 0 and 3. The higher the value, the less stress the plant is experiencing. Usually, the value of healthy vegetation is between 0.4 and 2. We decided to use this index to detect the moisture content of the crop because reputable organizations, like NOAA, continue to use this index.

Images that are captured during flight will be simultaneously transmitted to our ground system, or, in other words, real time. While receiving the images, our ground-based program will begin its processing of data. As a redundant and safety procedure, all images captured by the sensor payload will be stored on a USB Drive that is connected to the onboard computer that comes with the camera. All images that were captured are uncompressed and stored as .RAW files. This makes sure we have the most data we could possibly collect, but it will take a significant amount of space in the drive. The USB Drive is 8GB which will enable us to take 2000 images in the spectral bands we need. After every mission, the USB drive will be removed from the onboard computer and the images stored on the USB will be copied to another computer for processing.

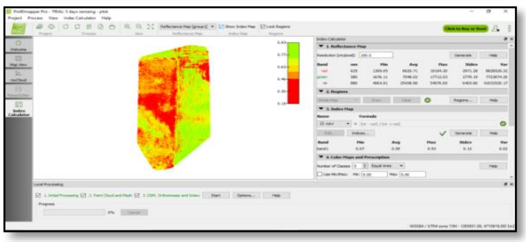
The images that are captured by the sensor payload will be geo referenced. It will acquire its coordinates by the GPS receiver embedded on the onboard computer. Each image after first being processed by IR-Flash, a program to process the images from the sensor payload, will be converted to .jpg images containing the necessary metadata needed for referencing and further image processing. The data will include spectral data and coordinates.

There will be two programs that will be used for the processing of the images. The first program will be IR-Flash. This program, provided by Infrared Cameras Inc., will convert the .RAW files from the USB Drive into .jpg images with coordinates and spectral information. These images will then be imported to Pix4DMapper. This program will take the information from the .jpg images and generate a color map based on the indices we use to detect moisture of the soil and plant. With easy to understand color maps, it will be easy to interpret the data to our customer. Pix4DMapper costs $8,700 to own forever, but it also offers a rental plan of $350 per month. The company that developed this program provides resources to help you learn the program. IR Flash comes free with the sensor payload package. In the company's website, they provide a user manual to help you get started on using their program.

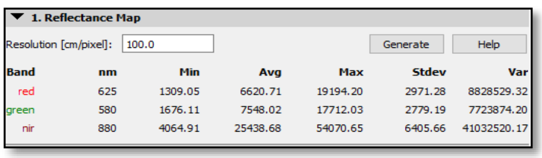


Detection System Software

All images that have been imported and contain the coordinates of where it is captured will be referenced by a red dot in map view. It will also show the progress of each image in processing.



The index calculator is where majority of the processing of the images will take place. It contains the necessary tools for processing images to color maps.

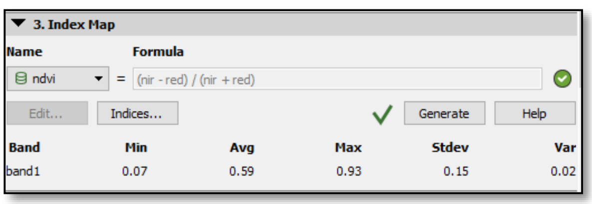


1. Reflectance Map

Resolution [cm/pixel]: 100.0 Generate Help

Band	nm	Min	Avg	Max	Stdev	Var
red	625	1309.05	6620.71	19194.20	2971.28	8828529.32
green	580	1676.11	7548.02	17712.03	2779.19	7723874.20
nir	880	4064.91	25438.68	54070.65	6405.66	41032520.17

The reflectance map that will be used for processing will be generated here. All the spectral bands that are available in the image for processing are listed here as well.



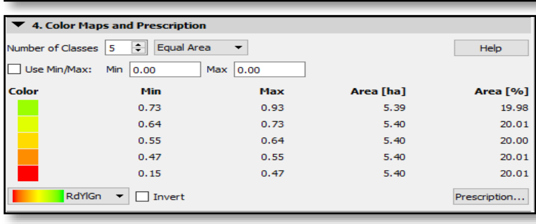
3. Index Map

Name: ndvi Formula: = (nir - red) / (nir + red)

Edit... Indices... Generate Help

Band	Min	Avg	Max	Stdev	Var
band1	0.07	0.59	0.93	0.15	0.02

All indices that will be used for detection will be stored on a database that could be accessed from this window. The color map will also be generated from this window.



4. Color Maps and Prescription

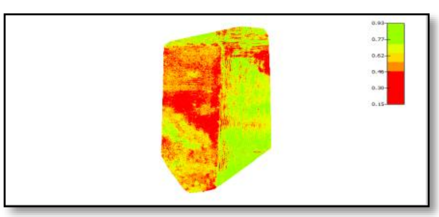
Number of Classes 5 Equal Area Help

Use Min/Max: Min 0.00 Max 0.00

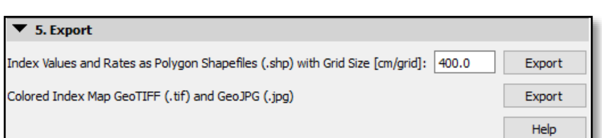
Color	Min	Max	Area [ha]	Area [%]
	0.73	0.93	5.39	19.98
	0.64	0.73	5.40	20.01
	0.55	0.64	5.40	20.00
	0.47	0.55	5.40	20.01
	0.15	0.47	5.40	20.01

RdYlGn Invert Prescription...

The color will be assigned values based on the index and prescriptions based on what the color signify.



The map displayed here is a generated color map based on the data that has been loaded to the program.



5. Export

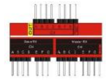
Index Values and Rates as Polygon Shapefiles (.shp) with Grid Size [cm/grid]: 400.0 Export

Colored Index Map GeoTIFF (.tif) and GeoJPG (.jpg) Export

Help

All color maps that have been generated by Pix4DMapper could be exported and used to other popular GIS software (ex. ArcGIS).

Component	Weight (lbs.)	Dimensions (inches)	Cost per Component	Quantity	Total Cost	Total Weight
Glacier 30C 6000mAh 6S 22.2V LiPo Battery 	1.8125	6.299 x 1.85 x 1.85	$122.95	1	$122.95	1.8125
13 x 13 APC Propeller 	0.132	Diameter: 13 Pitch: 13	$10.90	1	$10.90	0.132
80-Amp Pro Switch-Mode BEC Brushless ESC, EC5 (V2) 	0.234	3 x 1.6 x 0.62 (L x W x H)	$74.99	1	$74.99	0.234
Power 60 Brushless Outrunner Motor, 470Kv 	0.8125	Overall diameter: 2 Shaft Diameter: 0.24 Overall length: 2.4	$109.99	1	$109.99	0.8125
A6150 HV High Torque Metal Gear Servo 	0.12	57 x 0.79 x 1.51 (L x W x	$36.99	2	$73.98	0.24
A6220 HV Dig Low-Profile Hi-Torque MG Aircraft SX 	0.1	1.58 x 0.79 x 1.02 in (L x W x H)	$84.99	2	$169.98	0.2
Airspeed Sensor 	0.009	1.1 x 0.62 x 0.4	$45	1	$45.00	0.009
RC Radio Reciever (Servo) 	0.045	2.06 x 1.48 x 0.63	*Shares cost with radio control	1		0.045

Component	Weight (lbs.)	Dimensions (inches)	Cost per Component	Quantity	Total Cost	Total Weight
Autopilot 	0.05	2.63 x 1.6 x0.26	$250	1	$250.00	0.05
Multiplexer 	0.03	1.69 x 0.7 x 0.25	$25	1	$25.00	0.03
Altimeter Sensor 	0.009	1.1 x 0.62 x 0.4	$40	1	$40.00	0.009
3-axis accelerometer 	0.009	1.1 x 0.62 x 0.4	$30	1	$30.00	0.009
Servo Current Monitor 	0	Negligible	$25	4	$100.00	0
Temperature Sensor 	0	Negligible	$10	1	$10.00	0
RPM Sensor (optical) 	0	Negligible	$15	1	$15.00	0
Onscreen Display (OSD) and Datalogger with Limited Telemetry Reporting 	0.106	OSD:0.5 x 1 x 0.25 Data Logger:0.75 x 1 x 0.25 GPS: 0.5 x 0.5 x 0.25	$250	1	$250.00	0.106

Component	Weight (lbs.)	Dimensions (inches)	Cost per Component	Quantity	Total Cost	Total Weight
Mini-Nyx-S 640 	1.323	4.37 x 1.49 x 2.325	$60,000	1	$60,000.00	1.323
Lens 	0.441	Length:2.604 Diameter:2.224	$1,236	1	$1,236.00	0.441
Bengal PC/104 Format Single Board Computer 	0.282	4.23 x 3.77	$621	1	$621.00	0.282
OBG-600L 2-Axis Brushless Gimbal 	0.95	4.835 x 3.583 x 3	$1,193.54	1	$1,193.54	0.95
Lexan Dome (Clear) 	0.11	Diameter: 7 Height: 7	$112.95	1	$112.95	0.11
DJI Lightbridge 	0.16	2.68 x 1.89 x 0.83	$999	1	$999.00	0.16

Aircraft Components

Total Cost: $1,987.48

Total Weight: 3.689

Payload Components

Total Cost: $63,163

Total Weight: 3.266

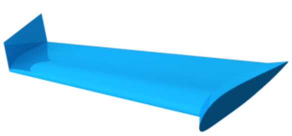
The payload components are divided evenly inside the fuselage, which has been carefully placed to maximize aerodynamics and reduce parasitic drag within the aircraft. The team calculated the aspect ratio and planform of the wings to variably predict a high aerodynamic performance of our wings. This was of particular significance due to concerns from the recent RWDC webinar regarding limit load factors. The aircraft's components have been aligned in a small and efficient manner, minding the location of the sensor payload will be located in the mid-fuselage. The major C3 components such as the Data Transceiver, Video System, Servo Receiver, and Autopilot will be located at the forward section of the fuselage. Antennas and actuators that transmit and receive data are located inside the fuselage, respectively positioned at a specific distance as notified by the FAA regulations.

2.2.2 Air Vehicle Element Selection

Throughout the challenge, the team worked on modifying the Darkwing FPV Drone to be suitable for our mission. We specifically wanted our aircraft to be able to not only fulfill the mission requirements, but at an equally important capability to complete the detection at the shortest time possible. Below are the aircraft configurations:

Airframe Configuration

The flying wing design of the UAV merges the fuselage and wings of the aircraft into a single structure. The wings are connected to the fuselage through a rod. The entire airframe is composed of balsa wood. Majority of the components are located in the fuselage area. They are the following: the battery, the ESC, the motor, the computer, the C3 components, the altimeter sensor, the airspeed sensor, the temperature sensor, the RPM sensor, the camera and lens, the gimbal, and the dome. The camera and lens, dome, and gimbal is located at the section of the fuselage before the nose cone. The camera will be protruding from the fuselage because of its pan-and-tilt mechanism and capabilities during flight. The dome would protect the camera and reduce the drag that the camera would add on the aircraft.



The wings of the aircraft have been modified to have split flaps as an additional flight control. Servos would be placed in the wings to help move the flight controls. The airfoil for the aircraft is the NACA 25112. The NACA 25112 has a high lift-to-drag ratio, an optimal lift capacity for our aircraft and mission. It allows our aircraft to travel at a high speed in reference to its size. Based on our structural analysis, the wings are more than capable of handling the required limit loads (limit load factor 4g, ultimate load factor 6g).

Flight Control Configuration

Because of the flying wing design, the team had to configure the aircraft in a way that made it easily controllable. Additionally, because there is no empennage on the aircraft, we had to use different flight controls not normally used on a standard aircraft. The team would be using elevons and split flaps as the flight controls of the aircraft. The elevons are a combination of elevators and ailerons. They would be giving the aircraft roll and pitch control. We modified the wing section to have split flaps. The split flaps function as regular flaps and provided yaw control. It does this by creating asymmetric drag. For example, when the left split flap is opened, more drag is created on the left side of the aircraft. Thereby, making the aircraft turn to the left. The A6150 HV servos would control the elevons while the A6220 HV servos would control the split flaps.

Power Plant Configuration

The team worked towards creating a propulsion system that would not only be efficient, but environmentally-friendly as well. It is relatively simple to set up the power plant for an aircraft; requiring only a power source (ex. a battery); a motor and propeller configuration; and an electronic speed controller (ESC) (Reid, 2011). However, it was difficult to find the right components that would optimize our aircraft for our mission. We utilized the tools provided by RWDC such as MathCad and online calculators in order to select the best components for our power plant configuration.

Battery 	• Type: Lithium Polymer • Milliamp Rating: 6000 mAh • Voltage:22.2 V (6-cells) • Discharge Rate: 120 C • Weight: 1.8125 lbs. • Dimensions: 6.299 x 1.85 x 1.85 in. • Cost: $122.95
Motor 	• Power 60 Brushless Outrunner Motor • Voltage: 22.2 V • kV: 470 • Max Amps: 80 amps for 15 seconds • Weight: 13 oz • Dimensions: 2.4 in (case length), 2 in (diameter) • Cost: $109.99
Propeller 	• 13 x 13 APC Prop • Type: APC Propeller • Diameter: 13 inches • Pitch: 13 inches • Weight: 0.132 lbs. • Cost: $10.90
ESC 	• 80-Amp Pro Switch-Mode BEC Brushless ESC, EC5 (V2) • Weight: 0.234 lbs. • Dimensions: 3 x 1.6 x 0.62 in. • Cost: $74.99

The battery that would power the entire aircraft is the Glacier LiPo 6000. When factoring the power consumption for the motor, we had an estimated flight time of 9.5 minutes. This was more than enough for our UAV to complete its mission, but the team wanted to ensure that the aircraft would have extra power as a precautionary measure, with about 26% of battery life left. Additionally, this battery has been selected to meet the entire power demand of our UAV, such as the C3 and the sensor payload.

We will be using the Power 60 Brushless Outrunner Motor with a 13 x 13 APC propeller. According to a static thrust calculator, this configuration with the motor running at 7350 RPM will enable our aircraft to fly at 90 miles per hour while producing 4.53 lbs. of thrust (Füzesi, n.d.). Furthermore, the motor consumes about 780 watts during cruise flight, which does not put a huge strain on the battery and motor.

The ESC we selected for our aircraft will be the 80-Amp Pro Switch-Mode BEC Brushless ESC. It was selected because it provided the control for our aircraft, providing a smooth and quick control. Furthermore, it was also programmable, enabling us to modify it to fulfill requirements of the mission.

Airframe

- Balsa Wood
- Flying Wing Design

Flight Controls

- Elevons
- Split Flaps

Power Plant Configuration

- Power 60 Brushless Outrunner Motor, 470 Kv
- Glacier 30C 6000mAh 6s LiPo
- ESC

Required Equipment/Sensors

- C3
  - RC Radio Reciever
  - Autopilot
  - OSD and Datalogger
  - Multiplexer
- Sensors
  - Altimeter Sensor
  - Temperature Sensor
  - Airspeed Sensor
  - RPM Sensor
  - 3-axis accelerometer
- Misc.
  - Antennas
  - Ground Control Equipment
- Payload
  - Mini-Nyx 640 Camera and Lens
  - Gimbal
  - Bengal Computer

2.2.3 Command, Control, and Communications (C3) Selection

After thoroughly analyzing the challenge scenario in relation to our theory of operation, the team identified that data transmission plays a vital role in communications. We considered all candidates for components for the C3 selection- command, control, and communications. Careful observations and additional research were made in order to select which components best fit the requirements of our theory of operation. The team considered various components using the provided RWDC C3 selection catalog and outside research. The command, control, and communications equipment provided in the catalog fit the team's criteria of maintaining data during our operation. Our C3 selection was vital towards calculating our overall weight and balance as we placed these components in the most appropriate areas of the aircraft. Each component that added to the weight of the aircraft affected its overall aircraft efficiency and limit load factors.

Our control commands and telemetry equipment will consist of using a Hobby-grade Remote Control (R/C) radio to associate both autonomous and control switching operations, which will purposefully deviate a pre-established flight when planning to move to specific areas. The handheld R/C radio and switch will also be used to utilize secondary controls to improve the system's safety precautions. This allows the operational personnel to have a redundant control system, allowing semi-autonomous control for both autonomous and pilot-controlled operations.

According to the RWDC Catalog, the 900MHz Video System and other video system choices were not compatible with use of high quality sensor payloads, which was exactly our case for this challenge. The disregarding of this option led the team to remove the 900MHz Data Transceiver set as well. As a result, the team contacted the SWIR Company and asked for a system that would deem compatible with our sensor payload.

Our system will support the live transmission of images to our ground PC by using the DJI Lightbridge Video Transmitter System. This module is separated into two parts. The first part is the air system. The air system section of the module will be located onboard the aircraft. The weight of the module is 70g (without antennas), and it consumes 650mA at 12v. The second section is the ground system. Furthermore, the new revision, the system itself is now combined with a controller, which eliminates the need for a separate controller. Therefore, the maximum range of the module will result in 3.1 miles when it is FCC compliant. As a result, this assures our company that we will not go out of range of the module. The controller will connect to a laptop that will store all the images being transmitted. Generally speaking, IR-Flash will be stored on the laptop connected to the controller. After all the images are transmitted and stored to the laptop, we will begin the first phase of processing the images.To maintain communication, we will use a set of Data Transceivers that come with antennas, capable of maintaining an outdoor line of sight range of up to 6.3 miles while airborne. Since our aircraft will be caught by a net upon landing, the team decided to place the antennas in ide the fuselage: one antenna in the forward section and one in the aft section, both 18 inches apart. Even if it is provided that the mission field will have no obstructions concerning visual flight, the aircraft will have minimal to no interferences regarding communication as we are only using one small UAV to detect the field.

CONTROL/DATA PROCESSING & DISPLAY OPTIONS			
Component	Quantity	Cost Per Item	Subtotal
Hobby-grade Remote Control (R/C) Radio	1	$750.00	$ 750.00
Post Processor PC (Laptop)	1	$3,500.00	$ 3,500.00
LCD Display	1	$200.00	$ 200.00
C3.4xLarge Server	4	$ 8,116.00	$ 32,464.00
Total Ctl/Data Process/Display Cost			$36,914.00

Control/Data Processing & Display: $36,914.00

COMM EQUIPMENT OPTIONS			
Component	Quantity	Cost Per Item	Subtotal
DJI Lightbridge Video Transmitter System	1	$999.00	$ 999.00
Total Comm Equip Cost			$999.00

Communications Equipment: $999.00

ADDITIONAL C3 EQUIPMENT OPTIONS			
Component	Quantity	Cost Per Item	Subtotal
YAGI-Directional Antenna (2.4GHz) - Ground Based	1	$60.00	$ 60.00
Total Additional C3 Equip Cost			$60.00

Additional C3 Equipment: $60.00

Table 11. Total C3 Cost

Component	Quantity	Total
Total Ctl/Data Process/Display Cost	7	$36,914.00
Total Comm Equip Cost	1	$999.00
Total Additional C3 Equip Cost	1	$60.00
Total C3 Cost	**9**	**$37.973.00**

Total C3 Cost: $5,909

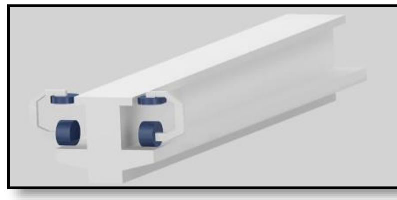
2.2.4 Support Equipment Selection

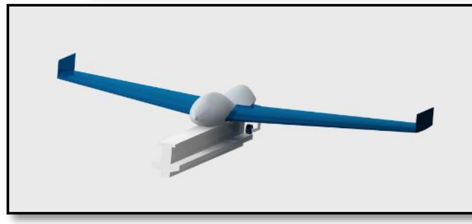
SUPPORT EQUIPMENT			
Component	Quantity	Cost Per Item	Subtotal
Catapult (Custom Made)	2	$1,500.00	$ 3,000.00
12ft x 16ft Soccer Net (Landing Net)	2	$10.44	$ 20.88
5000W Solar PSW Split Phase Power Inverter with 3500W DC 24V Smart Generator	2	$1,800.00	$ 3,600.00
24V Solar Panels	20	$187.99	$ 3,759.80
2016 7ft x 16ft Enclosed Cargo Trailer	2	$2,850.00	$ 5,700.00
2015 Nissan Frontier	2	$17,990.00	$ 35,980.00
Total Support Equipment Cost			$52,060.68

The team recognized the need to provide a shelter for the Cruiser as we travel to and from our future mission sites. Thus, we decided on utilizing a 7ft by 16ft-enclosed trailer with a cost of $2,850. The trailer would accommodate the following: our workstations (laptops and communication equipment), tools (catapult and landing net), and our generator and solar panels – providing our personnel a portable work area and storage for our aircraft and equipment. By choosing an aircraft that is battery powered, the team also recognized the need for our entire system to be environmentally friendly. In addition, we are positioning ourselves to take advantage of future battery technology such as the Lithium Air. Our ground workstation must be operated with a power source, and one unique way would be purchasing a fuel-powered generator. With the environment and our per hour costs in mind, the team decided to invest on a $1,800.00 smart generator that would be powered by solar energy. We also purchased ten solar panels that equate to $188.00 each, in which would be charged one day before our mission. We need not to worry about bad weather conditions or operating after the sun sets, because FAA regulations limits us anyway from conducting our missions during bad weather conditions and at night. Besides, FAA regulations prohibit operations during inclement weather as well as night. Accordingly, due to our smart generator and solar panels, the team limited our costs per hour with only our operational personnel, because we did not need to purchase consumables for our aircraft and workstation.

The team also needed to design a catapult that would aid in the aircraft's launching system. By the same token, the catapult available on the catalog was extremely costly, therefore, our team decided to design our own catapult that would complement our aircraft's specific needs at a fraction of the cost. We also chose to have a landing net that would secure our aircraft during its landing phase. The team anticipated that possible damages that could be inflicted on our aircraft due to its force, therefore, we covered the revealed area by purchasing a dome to protect our sensor payload. The team would also be utilizing a 2015 Nissan Frontier to carry and transport our trailer to our mission site. Compared to the support equipment provided in the catalog, our selection proved to be cost-efficient as well as guaranteed to provide quality and reliability to the system.

<u>Launching System</u>





The team decided to design a catapult rather than purchase one from the catalog. We specifically designed a unique crate attachment to our catapult system. Incidentally, our catapult has four collapsing walls that work in conjunction with a forward positioned piston. These walls will be placed in a descending manner in which the first wall is the tallest and the remaining walls decrease in height. This will allow the aircraft to have an eight degree angle of attack. Furthermore, once the catapult reaches a pre-determined takeoff speed, the collapsing walls will collapse forward while the forward piston depresses simultaneously. As a result, the aircraft at said moment will have the speed and clearance to takeoff safely. In particular, the walls of the catapult will be constructed of light aluminum with lighten holes. The holes are drilled in the aluminum to lighten to overall weight of the catapult without compromising structural integrity. Chiefly, the walls will support the aircraft horizontally and the forward piston will prevent forward movement until the aircraft reaches a pre-determined takeoff speed. The crate will be travelling on a monorail which will ensure stability as the crate is moving forward.

Furthermore, once the crate reaches the end of the track, it will have achieved takeoff speed and a built-in sensor located at the end of the track, which will activate the sensors on the crate. For the most part, these sensors will allow the aircraft to take off on its own, after the crate reaches the targeted speed. These sensors will be located three feet from the starting point of the crate. Once when the crate passes over these sensors, which will take 82 milliseconds, the sensors will signal the forward piston to depress immediately causing the other walls to collapse forward simultaneously. The aircraft will already have a take-off speed of 25 miles per hour which will allow the aircraft to take off smoothly.

The bungee cord will be stretched from the front of the crate, and terminate all the way to the front bulkhead of the catapult. After calculating the pounds of force needed to launch the aircraft at a speed of 25 mph via Hooke's Law, the bungee cord will be stretched to produce 15.52 pound-force. Additionally, there will be a decelerating bungee cord attached to the back of the crate from the back of the catapult which shall serve as the brake once when the crate passes the sensors. This will prevent the crate from damaging the front bulkhead of the catapult. There will also be a launch pedal near the third leg of the catapult made out of light-grade aluminum. Once the pedal is stepped on or actuated, it will release a piston holding the tension chord, thereby, allowing the crate to accelerate from 0 to 25 mph is less than one second.

Initial Engineering Role	Engineering Specifications	Career Qualifications
Marketing	Documents business costs and conducts cost/benefit analysis	B.S. in Marketing
Systems & Test Engineer	Tests design prototypes and pre-production products	B.S. in Engineering
Design Coordinator	Integrates new or modified design data into the overall product design	B.S. in Engineering
Simulations Engineer	Develops simulations and models for project designs	B.S. in Engineering
Project Mathematician	Translates and applies mathematical principles into the project designs and plans	B.S. in Engineering
Mission Planner	Develops and coordinates overall mission plan	B.S. in Engineering
Project Manager	Manages the project plan and deliverables	B.S. in Engineering

2.2.5 Human Resource Selection

When selecting the crewmembers of our design system, it was crucial for each team member to identify their strengths, experiences, and observations for the overall engineering design effort. We noted that the variety of skills each member possesses plays an important role when considering the cost, time, and the number of people needed for the mission. In our efforts to reduce the total number of man hours, the team decided on a rationale consisting of each member being multi-qualified in order to support the mission provided by the challenge. Each team member will be responsible for two professional jobs in order to coordinate and assist in the efficient operations of our system. The team members made up of the project manager ($75.00/hr), design coordinator ($50.00/hr), systems and test engineer ($50.00/hr), simulation engineer ($50.00/hr), project mathematician ($50.00/hr), mission planner/project scientist ($50.00/hr), and marketing specialist ($50.00/hr), will have a dual responsibility as the operational crew. The crew consists of one of each role: payload operator ($35.00/hr), data analyst ($50.00/hr), range safety launch and recovery maintenance ($35.00/hr), launch and

Initial Engineering Role	Dual Responsibility (Operational & Support Personnel)	Approved FAA Certification/Training License	Specifications
Marketing	Safety Pilot	FAA Private Pilot's License	Monitors the aircraft's telemetry and safety operations
Systems & Test Engineer	Operational Pilot	FAA Private Pilot's License with a Visual Flight Rule Rating, Agricultural Aircraft Operator Certificate	Operates and adjusts the aircraft's programming
Design Coordinator	Range Safety/Aircraft Launch & Recovery/Maintenance	FAA certified with A&P ratings	Coordinates air traffic management and ensures safety operations
Simulations Engineer	Launch and Recovery Assistant	FAA certified with A&P ratings	Coordinates air traffic management and ensures safety operations
Project Mathematician	Data Analyst	Special Airworthiness Certificate – Restricted Category (SAC-RC)	Analyzes data collected from the mission
Mission Planner	Payload Operator	Special Airworthiness Certificate – Restricted Category (SAC-RC)	Monitors sensor payload and scopes the area
Project Manager	On-watch Personnel	FAA Pilot's License	Observes overall mission and operation

recovery assistant ($15.00/hr), safety pilot ($35.00/hr), and operational pilot ($35.00/hr). This would then total to six operational personnel. The purpose of this selection is to minimize our costs and maximize our efficiency towards our business case. Additionally, our company hired an assembly technician ($25.00/hr), electronics technician ($25.00/hr), and an aircraft maintenance technician ($25.00/hr), that will assemble and add modifications to our UAV. Easy to assemble, it will take approximately 80 hours for these personnel to build our aircraft.

2.3 System and Operational Considerations

Throughout the project development, the team had to face many decision making processes. Each decision the team made would significantly impact our aircraft's final design. Furthermore, we recognized the importance between a balance of costs and benefits that were also taken into further examination. The team recognized various tradeoffs that helped us towards increasing our object function value, justifying core elements that increased the overall efficiency of our design solution. One of the major tradeoffs the team encountered was that of our objective function. In order to achieve an objective function value of one or greater, the team had to maximize the values of the aircraft efficiency, airframe cost, and business profitability. The team worked towards achieving an airframe efficiency value of at least more than 50%, which was presented as a challenge due to small, fixed wing aircraft not generally having a large payload capacity. In order to increase this value, the team considered many factors that would lower the empty weight while increasing our maximum takeoff weight of our aircraft. The team counted for this by selecting a sensor payload that was of high quality and lightweight, weighing at only 1.3 lbs. with its lens, being six pounds lighter than the X5000 and X6000 provided in the RWDC catalog. This allowed more components to be added into the aircraft, as well as the opportunity to improve our battery, increasing its flight time before it needs to recharge.

Objective Function

$W_{Empty} := 5.4765$ $\quad C_{AF} := 1504.84$ $\quad TR_{Year5} := 174000000$

$W_{MTOW} := 10.555$ $\quad C_{UAV} := 64791.28$ $\quad OE_{Year5} := 9978370.34$

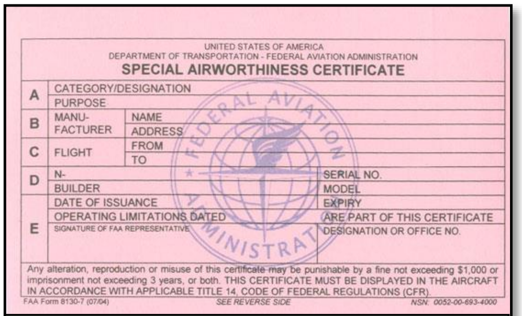
$$AE := 1 - \frac{W_{Empty}}{W_{MTOW}} \qquad AC := 1 - \frac{C_{AF}}{C_{UAV}} \qquad BP := \frac{TR_{Year5} - OE_{Year5}}{TR_{Year5}}$$

$AE = 0.481$ $\quad AC = 0.977$ $\quad BP = 0.943$

$$ObjectiveFunction := \frac{AE + AC + BP}{3}$$

$ObjectiveFunction = 0.8$

Our company will have to apply for numerous certifications such as the Section 333 exemption. The operational limits, as stated in the provided "Overview of Small UAS Notice of Proposed Rulemaking," have been carefully understood by the team. We made sure that our system adhered to these limitations and (proposed) rules.



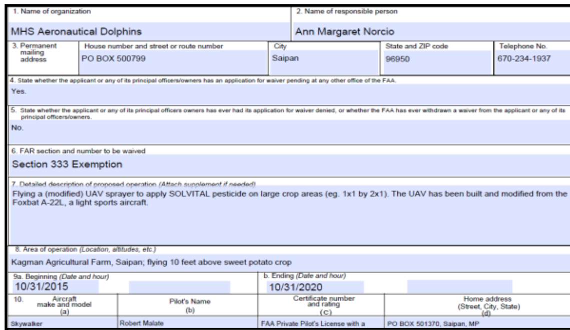
UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION - FEDERAL AVIATION ADMINISTRATION
SPECIAL AIRWORTHINESS CERTIFICATE

A	CATEGORY/DESIGNATION			
	PURPOSE			
B	MANU-FACTURER	NAME		
		ADDRESS		
C	FLIGHT	FROM		
		TO		
D	N-		SERIAL NO.	
	BUILDER		MODEL	
E	DATE OF ISSUANCE		EXPIRY	
	OPERATING LIMITATIONS DATED		ARE PART OF THIS CERTIFICATE	
	SIGNATURE OF FAA REPRESENTATIVE		DESIGNATION OR OFFICE NO.	

Any alteration, reproduction or misuse of this certificate may be punishable by a fine not exceeding $1,000 or imprisonment not exceeding 3 years, or both. THIS CERTIFICATE MUST BE DISPLAYED IN THE AIRCRAFT IN ACCORDANCE WITH APPLICABLE TITLE 14, CODE OF FEDERAL REGULATIONS (CFR).

FAA Form 8130-7 (07/04) SEE REVERSE SIDE NSN: 0052-00-693-4000

Special Airworthiness Certificate



1. Name of organization: MHS Aeronautical Dolphins
2. Name of responsible person: Ann Margaret Norcio
3. Permanent mailing address — House number and street or route number: PO BOX 500799; City: Saipan; State and ZIP code: 96950; Telephone No.: 670-234-1937
4. State whether the applicant or any of its principal officers/owners has an application for waiver pending at any other office of the FAA.
Yes.
5. State whether the applicant or any of its principal officers owners has ever had its application for waiver denied, or whether the FAA has ever withdrawn a waiver from the applicant or any of its principal officers/owners.
No.
6. FAR section and number to be waived
Section 333 Exemption
7. Detailed description of proposed operation *(Attach supplement if needed)*
Flying a (modified) UAV sprayer to apply SOLVITAL pesticide on large crop areas (eg. 1x1 by 2x1). The UAV has been built and modified from the Foxbat A-22L, a light sports aircraft.
8. Area of operation *(Location, altitudes, etc.)*
Kagman Agricultural Farm, Saipan; flying 10 feet above sweet potato crop
9a. Beginning *(Date and hour)* 10/31/2015 b. Ending *(Date and hour)* 10/31/2020

10. Aircraft make and model (a)	Pilot's Name (b)	Certificate number and rating (c)	Home address (Street, City, State) (d)
Skywalker	Robert Malate	FAA Private Pilot's License with a	PO BOX 501370, Saipan, MP

Section 333 Exemption

Currently speaking, the FAA is developing new policies that will later affect operators' access to airspace, whether it is for commercial or other operations. In order to gain access to information on certificates and applications forms, the team created an account under the FAA website. The time it takes to process and gain certification was a realistic factor that we had to incorporate during our final design phase. In the Northern Marianas Islands (specifically Saipan), the integration of UAS is at a bare minimum. Majority of the operations conducted in our area fall under the public sector. The team's compliance within local regulations was another limiting factor. Civil operators such as private companies are generally uncommon in the CNMI. Thus, the team had to conduct extra research and asked for advice from nearby FAA personnel.

FAA Operational Limitations

- Unmanned aircraft must weigh less than 55 lbs. (25 kg).
- Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within VLOS of the operator or visual observer.
- At all times the small unmanned aircraft must remain close enough to the operator for the operator to be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.
- Small unmanned aircraft may not operate over any persons not directly involved in the operation.
- Daylight-only operations (official sunrise to official sunset, local time).
- Must yield right-of-way to other aircraft, manned or unmanned.
- May use visual observer (VO) but not required.
- First-person view camera cannot satisfy "see-and-avoid" requirement but can be used as long as requirement is satisfied in other ways.
- Maximum airspeed of 100 mph (87 knots).
- Maximum altitude of 500 feet above ground level.

Using MathCad, the team calculated our objective function value. Our reasonable tradeoff of our airframe efficiency value of 0.48 resulted in an airframe cost value of 0.98 and a business profitability of 0.94, resulting in a total objective function of 0.8.

In regards to our detection plan, the team had to make a final decision as to how many detections we will perform during each phase of the cucumber crop's growth cycle. Based on our research, the conventional number of moisture detections per growth cycle is three. Because cucumbers and squash grow at an approximate nine-and-a-half week span, the team decided to offer our customers a deal by detecting four times during its growth phases. Detection will occur right when the seeds are planted, during germination, its flowering phase, and just before harvest. This not only allows marks our stance in precision agriculture but also provides a competitive edge to other companies.

2.4 Component and Complete Flight Vehicle Weight and Balance

Weight and Balance

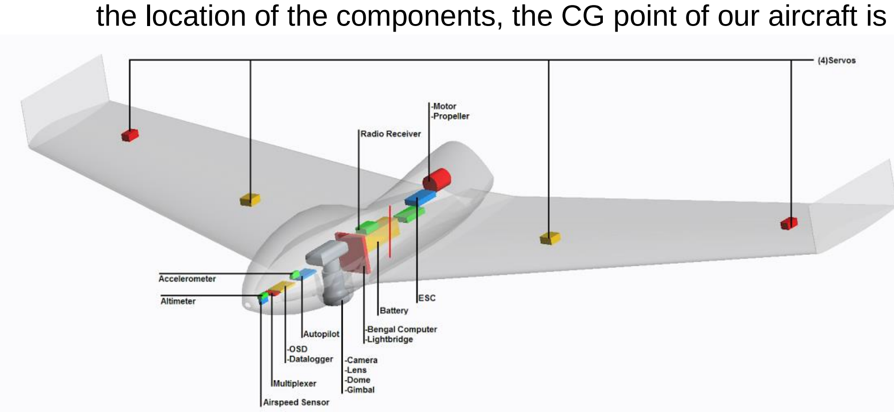
No.	Weight Category	Component	Sub-Category	Weight (lbs	Fuselage Station (in	Moment (lbs-inches)
1	**Power Plant**	Power 60 Brushless Motor		0.81	33.57	27.27
		80-amp Pro ESC		0.23	28.00	6.55
		Propeller		0.13	35.29	4.66
		Battery		1.81	20.00	36.25
						0.00
						0.00
2	**Payload**	Mini Nyx Camera		1.32	14.00	18.52
		Lens		0.44	14.00	6.16
		Dome		0.11	14.00	1.54
		Gimbal		0.95	14.50	13.78
		Bengal Computer		0.28	23.00	6.49
						0.00
3	**Controls and Sen**	Altimeter Sensor		0.01	3.00	0.03
		Airspeed Sensor		0.01	3.00	0.03
		Multiplexer		0.03	4.00	0.12
		RPM Sensor		0.00	35.00	0.00
		3-axis accelerometer		0.01	9.00	0.09
		Data Transciever (900 Mhz)		0.03		0.00
		Video System (900 Mhz)		0.19		0.00
		Autopilot		0.02	10.00	0.20
		OSD, Datalogger		0.11	6.50	0.72
		Reciever		0.05	22.00	0.99
		Elevon Servo		0.24	30.00	7.20
		Split Flap Servo		0.20	34.00	6.80
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
Total Weight (lbs)				**6.99**	**352.86**	**137.39**
C.G Location from the nose of the aircraft (inches)						19.65

Weight has become a major factor in designing the aircraft, especially since the Cruiser weighs much less than 55 pounds. The team focused on selecting materials that had a low density as well as containing high strength characteristics for continuity and reliability throughout the years. We chose a material the proved to be feasible, strong, and light weight thus making this a perfect candidate for our air craft design.

In order to make the plane as aerodynamic as possible, the team recognized the need to reduce the weight of our aircraft. This would allow more room for additional payload components to be added into the fuselage. Because of the modifications made to our aircraft, the team had to recalculate its CG point. Through our research, we learned that the general CG range for most aircraft is 25-30% of the mean aerodynamic chord (MAC) (Stengel, 2014) (Aircraft Center of Gravity Calculator). Once we knew our MAC, we were then able to calculate the CG of our aircraft.

$$MAC := rc \cdot \frac{2}{3} \cdot \left(\frac{\left(1+t+t^2\right)}{(1+t)} \right)$$

We used the formula on the right to calculate the MAC of our aircraft, where *rc* equals the root chord length and *t* equals the taper ratio (Johnson, 2015) by utilizing MathCad.. The team took 25 and 30 percent of the MAC and found range of the MAC that the optimal CG point should lie in. Because the aircraft was enlarged by about 17%, the team had to recalculate the CG point of the aircraft. We based the CG point of the aircraft on the manual. According to the manual, the original CG point of the aircraft is 16.75 inches from the datum line. When we recalculated it based on proportion, the CG point is located about 19.6 inches from the datum line. By using the weight and balance calculator provided by RWDC, the team was able to quickly calculate and calibrate the CG point of our aircraft. Based on the location of the components, the CG point of our aircraft is 19.6 inches from the datum line.



2.5 Design Analysis

Our final UAS design, which the team named as the Cruiser, complies with all design requirements listed in the design variables, UAS constraints, and assumptions in the detailed background information. Therefore, our RC base model aircraft choice proved the most suitable for the challenge including all air vehicle design parameters. A distinct process was conducted before the team reached our final design analysis point. Thus, throughout the challenge, we wanted to make sure our system was fully capable of completing the mission while complying with the restrictions and requirements given.

By selecting a flying wing design for our UAV, we were able to reap the benefits of it. Because the entire aircraft produces lift, less structural reinforcement is needed. Furthermore, this enables the aircraft to have a higher payload capacity than conventional aircraft. As a result, drag is reduced from this design because the empennage is removed from the aircraft.

Furthermore, the Cruiser was modified from the Darkwing RC aircraft. It weighs 10.55 lbs. with a 79.55 inch wingspan. The entire aircraft is constructed out of balsa wood, a popular material that is immensely popular among the RC aircraft community. The components have been placed in order to attain the proper CG site of our aircraft, which in this case is 19.6 inches from the datum line. The batteries, C3 components, sensors the sensor payload, pan-and-tilt mechanism, and clear dome covering are located at the forward section of the aircraft. Furthermore, the ESC, motor, and propeller are located at the aft section of the aircraft. Additionally, the servos are located where they are in use. Likewise, the flight controls that will be used in conjunction to the aircraft are elevens which includes split flaps.

The battery, however, is constructed just for these components along with the motor. The wings are fully capable of handling the load factors required by RWDC, which consist of a limit load of 4g and an ultimate load of 6g. By the same token, balsa wood can take about 2840 psi before breaking, and the highly-stressed parts have been analyzed to ensure that our wings can take the load. Thus, using Creo Simulate, the team was able to successfully analyze the load applied on the wing and prove that our aircraft complies with the load requirements. We also calculated several of the aerodynamic coefficients for our aircraft.

Thanks to Mathcad, we were able to quickly and neatly conduct our calculations. The coefficient of lift of our aircraft is 0.052. The coefficient of drag was much harder to find, but through our research, we found that for light-weight, single-engine aircraft, they have a coefficient of drag of 0.024. It has been modified and optimized for conducting our mission. The flight controls will be controlled with the autopilot, by which the mission will be ultimately carried out. The autopilot is programmed with waypoints and data on the level of infestation.

Our mission control equipment selection includes the following: PC (laptop), Hobbygrade remote control (R/C) radio), DJI Lightbridge 2 Transceiver and Video System Set, Servers, Additional LCD Display, Global Positioning System (GPS) Sensor, and autopilot. Our antenna, processor, controllers, and displays cover all system's need in order to complete the mission.

Our sensor payload, the Mini-Nyx-S 640 also includes a program that will aid in the processing of data as well as maintaining images captured from the onboard camera. Furthermore, customers will be able to conveniently complete post-processing and routine maintenance.

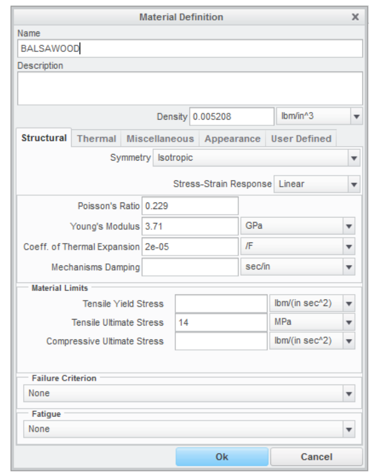
Having cucumber and squash as our selected crops, our detection strategy is able to commence at the same time for both crops. The ground-control personnel are able to maintain a visual line-of-sight on the UAV.

The antennas will be place inside the fuselage at more than 18 inches apart. This will prevent any destructive interference.

The team has created a contingency response in the possibility of problems occurring within the UAV system. In the event of such happenings, the detection process will automatically be stopped. Flight controls will be shifted to manual mode, in which the ground control pilot will fly the UAV back to base. Once at the base, the on-sight dual-qualified technicians will troubleshoot any problems within the UAV.

2.6 Structural Analysis

As part of the challenge, we were required as a team to conduct an analysis proving that our aircraft is capable of handling a limit load factor of 4g and an ultimate load factor of 6g. Initially, the team conducted background research on g-forces and methods of stress analysis.



By definition, "*g*" is the ratio of the lift needed over the weight of the aircraft *(Cavcar, 2004)*. Because lift is simply the weight of the aircraft (in terms of achieving flight), *g* could be thought of as how many times extra of the weight of the aircraft. In this case, we needed to make sure that our wings can handle a minimum weight of 42.2 lbs. (4g) and a maximum weight of 63.3 lbs. (6g).

The main method of conducting wing loading analysis is placing the wing upside-down, elevating and leveling it and placing sandbags on the wings. Because we are using a flying wing as a baseline design for our aircraft, the load is distributed throughout the entire aircraft. Aside from the nose, all parts of the aircraft produce lift, including the fuselage. About 80% of the weight is carried by the wings, while 20% is carried by the fuselage.

Structural Analysis

$WingArea := 524.91$ sq. in.

$MaxStrength := 2840$ psi.

$$Load_{Maximum} := \frac{MaxStrength}{WingArea}$$

$Load_{Maximum} = 5.41$ psi.

$Area_{Affected} := 17$ sq. in.

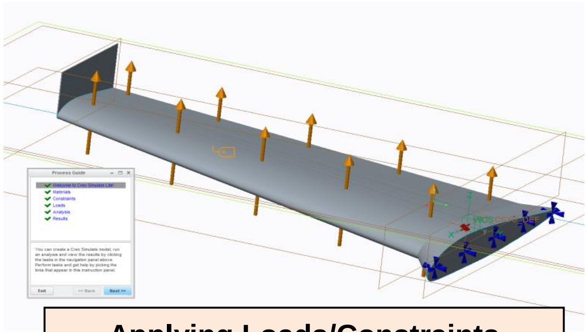
$Stress_{4g} := 24.2007$ $\quad Load_{4g} := \dfrac{Stress_{4g}}{Area_{Affected}}$

$Load_{4g} = 1.424$ psi.

$Stress_{6g} := 36.3011$ $\quad Load_{6g} := \dfrac{Stress_{6g}}{Area_{Affected}}$

$Load_{6g} = 2.135$ psi.

After consulting our mentors, we came to a conclusion that a computer-simulated stress test will be the best method to conduct our analysis. The team learned that the Creo software provided by RWDC had a stress-test simulation capability. In the meanwhile, after learning what to do and how to use it, we utilized the program to analyze the wings of the aircraft. As a result, the team conducted a cantilever-stress test (Cantilever Beams, n.d.). Since the wing will be attached to only one point of the aircraft and the force is applied on the other end (which in this case is the entire wing), we concluded that conducting a cantilever-stress test would be the best way to analyze our wings.



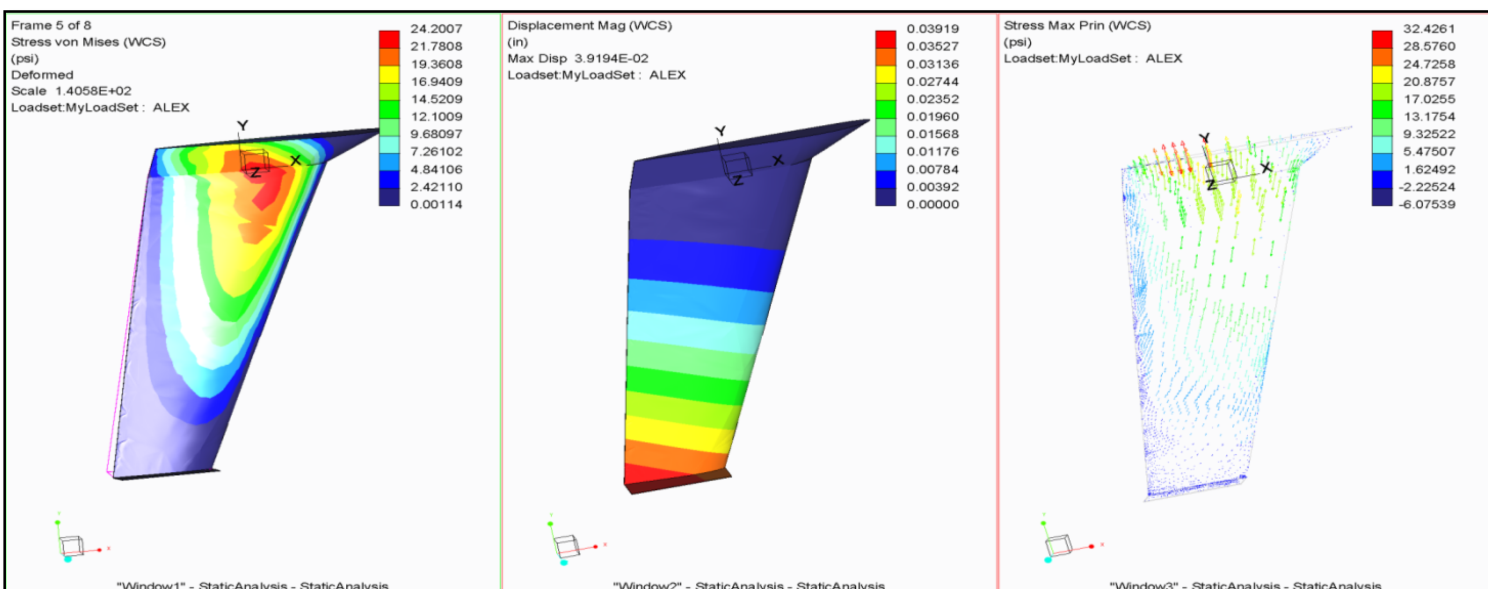
Applying Loads/Constraints

The wings of the aircraft will be constructed out of balsa wood. When assigning the material to the aircraft, we had to create a material file in the simulations program. Based on our research, we came up with several values for the balsa wood material (JSP International). We placed the constraint on the part of the wing that will be attached to the fuselage. The load was distributed across the two parts of the wing based on the percentage of the area that it had. For example, the trapezoid-shaped section, can contain 76.66% of the wing area, while the lower, rectangular section can cover 23.33% of the wing area. These percentages determine how much load that a specific area will be put under. For the trapezoidal section, it will be under 19.9316 lbs. of force for 4g, and 29.8974 lbs. of force for 6g. The results of the analysis greatly helped the team in understanding and calculating whether or not our aircraft complies with RWDC's limit load factor requirements. These results were displayed. We consulted our mentors on how to interpret the results from the Creo Simulate test. We followed the procedures below in order to interpret the data:

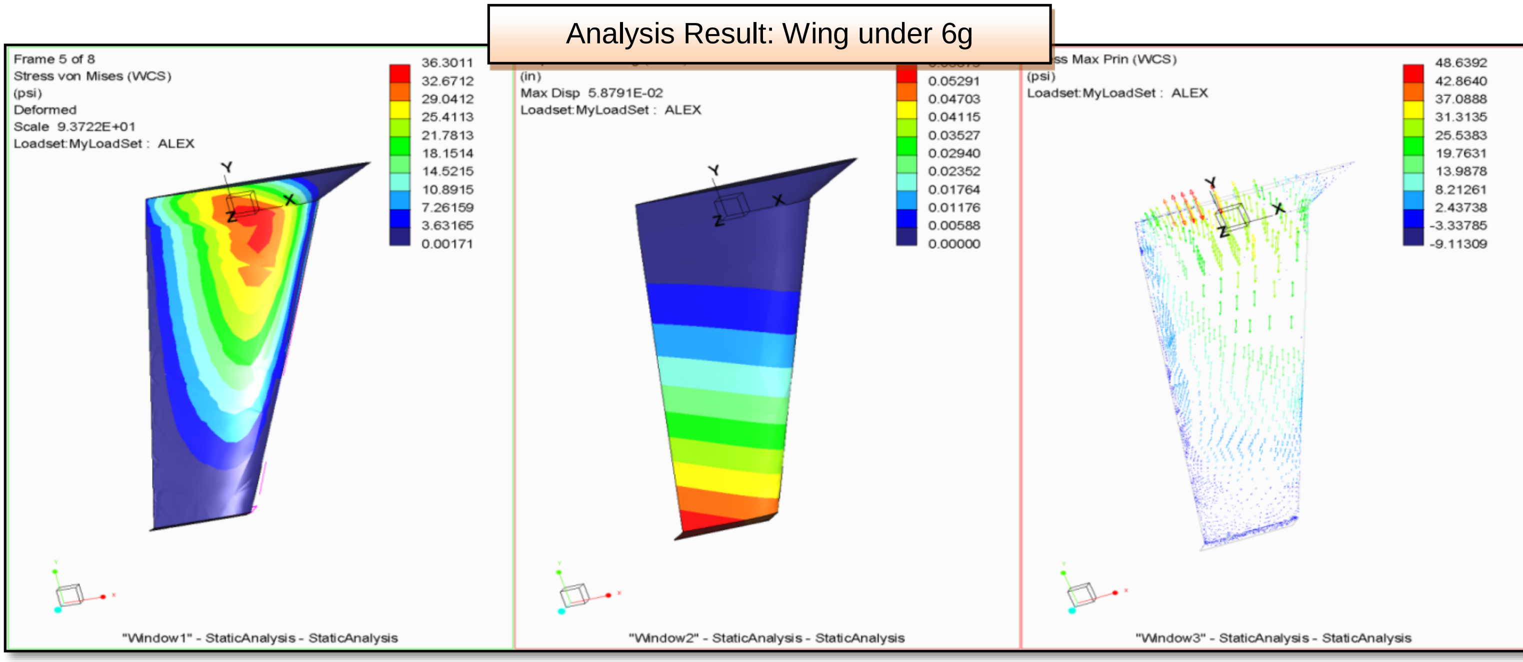
1) Determine the area of the "most-stressed" part of the wing. In the Creo analysis, the most stressed area is displayed in the colors orange and red.

2) Determine how many pounds per square inch (psi) one sq. inch of the EPO foam can withstand before it breaks (modulus of rupture). Divide that by the area determined in the first step. Based on the information, one square inch of EPO foam can take 12.4662 psi before its possibility to break.

3) Look at the data and match the given numerical values to the color. Then repeat step two, this time inputting the psi under that g condition.



Analysis Result: Wing under 4g



Based on the information, one square inch of the wing can take about 5.41 psi before it ruptures. Under 4g and 6g conditions, the area under the most stress is about 17 square inches. Under 4g, the most affected area is under 1.424 psi. Under 6g, the most affected area is under 2.135 psi. Because the rupture force for balsa wood is 5.41, and at 6g the aircraft will be experiencing 2.135 psi, the wings of the aircraft are more than capable of dealing with the stresses of flight.

2.7 Operational Maneuver Analysis

The team analyzed the aircraft at the four main points of the mission: launching, cruise flight, turning, and landing. This was executed to ensure that our aircraft will work accordingly during these critical moments of the mission. To summarize, the Darkwing is more than capable of handling the stress it will be under during throughout the entire mission duration. Below is our analysis at every point of the mission.

Force for Catapult

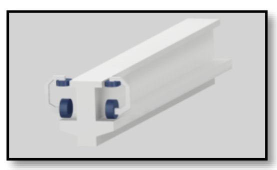
$weight := 12.49$ pounds
$speed_{takeoff} := 57.2$ feet per second
$time := 1$ second(s)

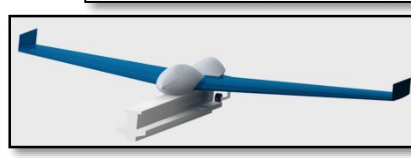
$$F := \frac{1 + weight}{32} \cdot \frac{speed_{takeoff}}{time}$$

$F = 24.113$ pound-force

Launching

The main forces that the aircraft would experience are the launch force and acceleration. The team used Hooke's Law to calculate the amount of force needed by the catapult in order to be able to launch the aircraft. The result was 15.526 pounds of force. When this force is applied to our aircraft, it would be accelerating from 25 mph to 63.7 mph in five seconds. Thereabout, it would ascend at 10 feet per second until it reaches an altitude of 500 ft.





G-calculation during turning

$Lift := 14.556$ pounds
$Weight := 12.49$ pounds
$angle := 30.9$

$$Turning_{gs} := \frac{Lift}{Weight} \, \mathrm{g}$$

$Turning_{gs} = 1.165$ g

Maximum Bank Angle Calculation

$Lift := 79.94$
$Weight := 12.49$

$$Angle_{MaxBankRadians} := \mathrm{acos}\left(\frac{Weight}{Lift}\right)$$

$Angle_{MaxBankRadians} = 1.414$ radians

$$Angle_{MaxBankDegrees} := \frac{180 \cdot Angle_{MaxBankRadians}}{\pi}$$

$Angle_{MaxBankDegrees} = 81.011$ degrees

Cruise Flight

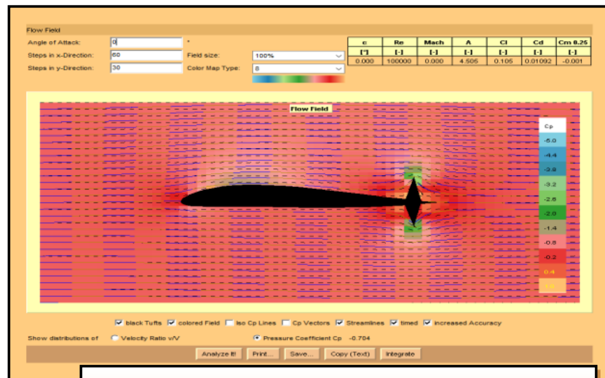
The cruise flight will be the main course of flight that the aircraft will be going through for majority of the mission. The entire detection process will occur during this phase. The Darkwing would be flying at 90 mph at an altitude of 500 feet. The aircraft would start decelerating once it approaches the perimeter of the scouting area in order to facilitate turns.

Turning

The aircraft would turn at the specified turning points detailed in the mission plan. The aircraft would slow down at a rate of 9.1 mph per second until it reaches airspeed of 63.7 mph. At this time, the wings would be swept forward to increase the wing area, which in turn would increase our lift capacity. When turning, the aircraft would be at a bank angle of 30.96 degrees, which is safe with our aircraft based on its load calculations. While turning at the 30.96 degrees, the aircraft would experience 1.166 g.

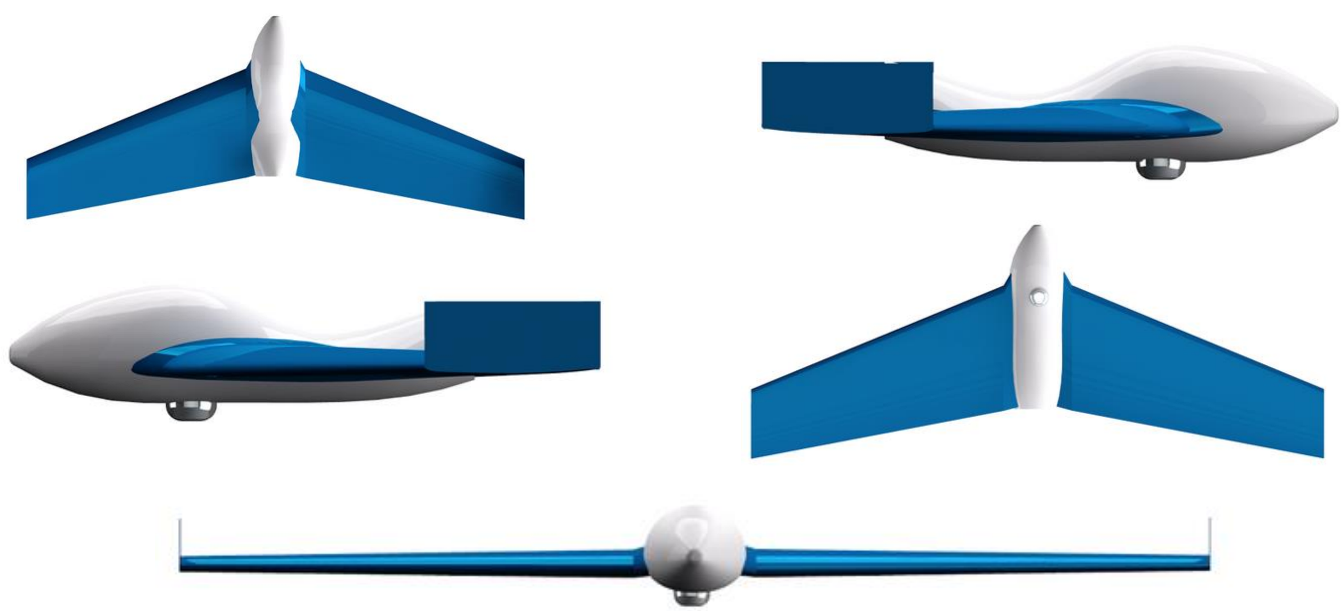
Landing

At the final row of the field (based on the mission plan), the aircraft will begin to descend from 500 ft. until it reaches 5 ft. where it will be secured in a net. The aircraft would descend at a rate of 10.1 feet per second. The airspeed of the aircraft would decelerate at a rate of 12 mph per second until it reaches 25 mph. The split flaps will be opened in order to allow our aircraft to stay in the air at a much slower speed. In order to form the needed turns and to slow down, the team added split flaps as a vertical axis flight control.



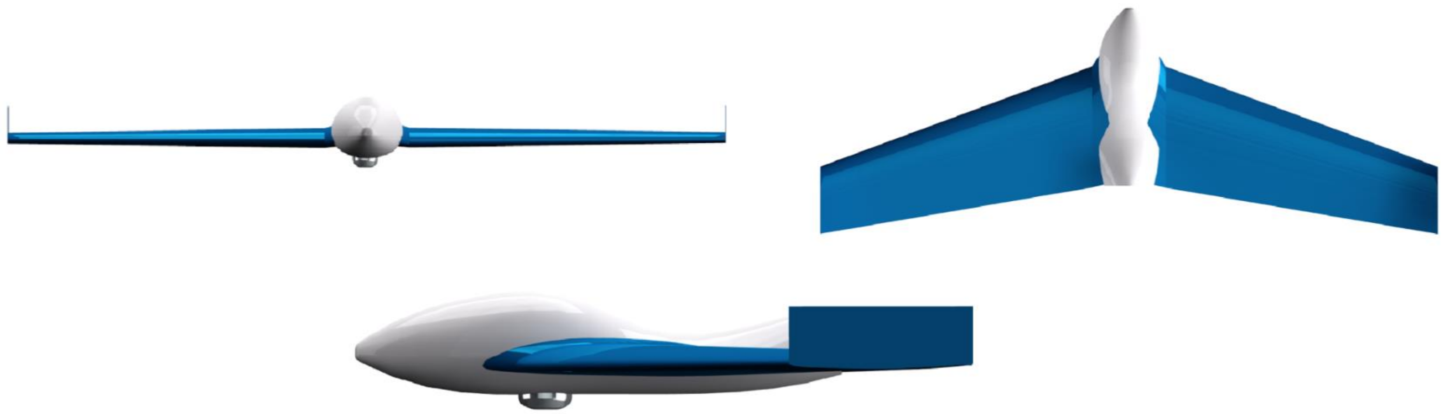
Split Flaps Analysis (Java Foil)

2.8 CAD models



2.9 Three View of Final Design

The following, **Figure 12**, depicts the three view of the final unmanned system design.



Wings
Wingspan: 79.55 in.
Semispan: 33.374 in.
Wing Area: 9.755 sq. in.
Wing Loading: 14.33 oz/ sq. ft.
Root Chord: 20.331 in.
Tip Chord: 11.125 in.
Mean Aerodynamic Chord: 16.495 in.
Max Wing Thickness: 1.9794 in.
Wing sweep: 30 degrees
Aspect Ratio: 4.505

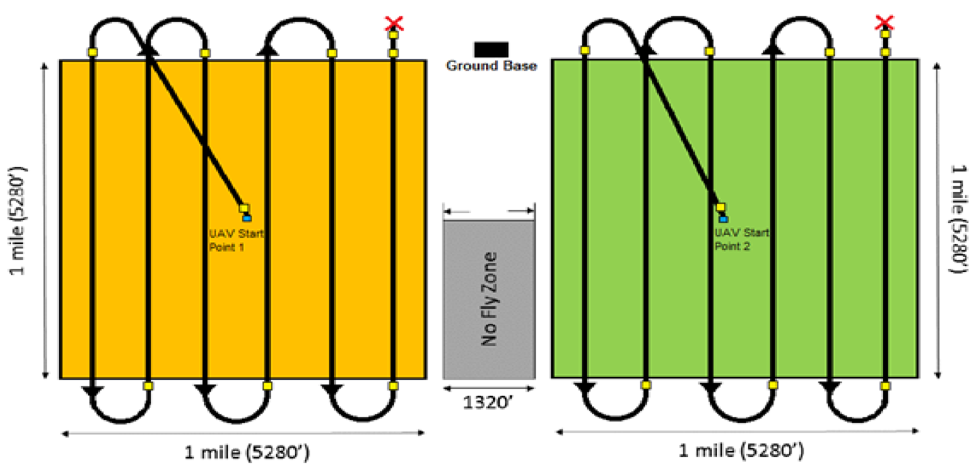
Fuselage
Length: 35.1 in.
Area: 4.92 sq. ft.
Empty Weight: 5.4765 lbs.
MTOW: 10.555 lbs.
sq. in.

Winglets
Height: 5 in.
Airfoil: NACA 25112
Chord Length: 11.125 in.

Airfoil: NACA 5410
Coefficient of Lift: 0.033-0.817 (depends on AoA)
Coefficient of Drag: 0.00696-0.09893 (depends on AoA)
Max L/D Ratio: 22.835 at 2 degrees AoA

2. Document the Detection Plan

3.1 Moisture Detection Pattern



Cucumbers and squash are of regional importance in the Northern Mariana Islands. Being a tropical island, an abundance of these crops are grown and marketed each year in the CNMI. Due to Saipan's crop areas being immensely smaller when compared to farm fields in the United States, the team has manipulated its largest cucumber and squash crop field into that of a 1 x 1 mile field. Later specified in the following sections, our detector aircraft will fly over the crop area following a constant detection pattern four times during the cucumber's growth cycle. We will be detecting the soil right after planting, soil and plant during germination, the plant only during its flowering stage, and the full-grown plant just before harvest.

The FY16 mission scenario states that our UAS design must perform moisture detection on our selected crop over a 1 x 1 mile field area. One of the initial decisions the team made was locating the Cruiser's starting point in the middle of the field area. Furthermore, the premise that supports this placement was created by the maximum length of the hypotenuse. The length of the hypotenuse, being longer than the longest leg, will be the horizontal distance of 5,280 feet. Subsequently, 5,280 feet is the limit of our line of sight. Based on our calculations, the hypotenuse would be greater due to the Pythagorean Theorem if we started at one end of the mission area and terminated at the opposite end.

The mission starting point would commence with the launching of our aircrafts using two catapults for each respective mission field. Our ground base will be located between both crop fields, adjacent to the No Fly Zone. Ultimately, the team chose to enhance the use of the lawnmower method in order to increase our productivity during its performance. This workplace was situated in this particular location because it proved the most practical and is easily accessible for the operational personnel. With this, we are able to complete the mission in a uniformed method along with being able to maintain a clear visual line of sight for both aircraft. Launching our aircrafts at 25 mph with a catapult allows us to eliminate the necessary takeoff and landing procedures of aircraft with landing gear. Upon launch, the Cruiser will climb to its maximum altitude of 500 ft. in approximately 39 seconds the aircrafts will begin moisture detection at a cruise speed of 90 mph.

The Cruiser's speed was strategized so that the camera footprint would work in conjunction to its speed. Furthermore, with a wingspan of 79.55 inches, our aircrafts would be required to perform 5 turns in one 1x1 mile mission field. This is equivalent to detecting approximately 6 rows. When the aircraft arrives at a specific turn in the mission field, it will begin to slow down at a rate of 9 mph/sec until it reaches its turning speed of 62.7 mph with an angle of bank of 60.96°. The Mini-Nyx-S 640 will be the sole sensor payload that will be utilized for our detection mission scenario. During the detection, the Cruiser will not be required to perform any stops or refueling due its high battery life. After completing the mission, the Cruiser will then decelerate and be caught by a net as its landing process. Throughout the entire mission scenario, images captured by the sensor payload will be sent to our ground base, which will process the data upon receiving the information.

Detection Cycles per Mission

Cucumbers and squash are heat seeking plants that require warm, moist, fertile soil at a pH of 6.0 or higher to germinate. The soil should be evenly moist across the entire field. Our mission would be to check if any of the soil is too dry or outright wet, which would prevent the germination of cucumber seeds. Using the Water Index SOIL (WISOIL), our data analyzer will determine inconsistencies in the moisture levels of the soil. This will be detected using the reflective properties of the soil in certain spectral bands. Additionally, the loamy soil that cucumbers and squash are planted in is ideal for the WISOIL, as it was originally modeled with sandy loam soil. Furthermore, we would do an analysis of the cucumber fields either before planting or just when it occurs.

By the same token, in comparison to other annual crops, cucumbers and squash have a phonological process in which developmental processes overlap. On average, the cucumbers and squash vegetation growth period is 65 days, or 9 weeks and 2 days, long. Therefore, after the initial detection before or at planting, the team will evaluate the cucumber and swuash canopy moisture at 3, 6, and 9 weeks; roughly planting, sprouting, blooming, and harvest. Likewise, at 3 weeks, germination will have already occurred and the cucumber and squash plants will have numerous leaves. The plants should at this time be receiving 1 inch of water per week, assuming the climate is temperate, as best suited to cucumbers and squash. In particular, using the Moisture Stress Index (MSI), we will detect the canopy moisture content of the fledgling plants, and the Normalized Multiband Drought Index (NMDI) to determine the soil's moisture. Usually, wet soil will give a value of less than 0.6 for wet soil on the NMDI.

In the third growth stage of cucumbers and squash, which is in the 6th week, we will be using the MSI for canopy moisture detection. We will use this index because of how dense the canopies of these plants are, which eliminates soil detection. The severe density of the canopy comes from the ability of our crops to be planted close together (either 3-5 feet apart or 1 foot apart on trellises). We can gather much more accurate data because our index relies on the leaves' strength of absorption in certain spectral bands to detect if the crop is receiving enough moisture for healthy growth. We chose to detect in the third growth stage because we want to continue monitoring the moisture of the plant throughout its growing cycle. As a rule, cucumber and squash have a rapid growth period, so problems can arise quickly with the crops. Usually, healthy green vegetation will give a value between 0.4 and 2 on the MSI. As long as the values from the dataset stay within this range, our cucumber crop at the time of detection is healthy.

In the fourth growth stage of cucumbers and squash, which is in the 9th week, we will continue to use the MSI for moisture detection of the crop. This part of the crops' growth cycle will be around the time they are ready for harvest. We will detect the area around five days before the farmers are going to start harvesting the cucumber and squash. At this point both crops will be developed, but they will not interfere with detection because they are covered by the plant's leaves.

Cucumber Information

During the cucumber's growing season, it needs to be watered once a week with one inch of water in order for the soil to be consistently moist. If water is not properly applied, then the crop yield will result as strangely shaped, peculiar in taste, and not as plentiful as possible. The plants are planted 3-4 feet apart, or one foot apart depending if the cucumbers are hung on a trellis. If the crops are grown using trellises, they would reach a height around 4 or 5 feet. Cucumbers have the ability to be extremely prolific, and with an expiration date of 7-10 days when fresh, and 1-2 years when pickled, they can be a year-long product.

If the cucumber is fresh, it can cost between \$0.30-\$1.00 depending on variety type, freshness, size, and area that it is being sold in. We noted that organic cucumbers are \$1.50-\$2.00 per pound, but they are an uncommon variety. Pickles cost \$2.28-\$3.34 per jar, and are often made by cucumber farmers themselves (larger direct profit margin). Cucumbers are a cheap fresh produce product (technically a fruit, but grouped as a vegetable), so the profit margin per cucumber is small, making the fact that they are mass produced key to the cucumber industry.

In 2011, 18,860 tons of cucumbers were sold from South Africa (local and exported). Compared to the 15,307 tons sold two years previously, the increase in demand for cucumbers is clear. The top five cucumber producing countries in the world are currently China, Iran, Turkey, the Russian Federation, and the U.S. In 2007, the United States produced 930,970 metric tons of cucumbers. Though it originated in a small section of India, cucumbers are now grown and sold worldwide and have been considered a competitive crop for over 3,000 years.

For countries such as South Africa, cucumber production is an important issue because many of the cucumbers produced are sent to extremely impoverished countries (Zimbabwe receives 32.4% of the yearly cucumber yield). In countries that suffer from starvation and dehydration, moist, plentiful, vitamin and mineral heavy and cheap produce such as cucumbers, which can be preserved for long periods of time, can greatly influence and improve the lives of the very large population. Cucumbers also have properties that cool blood temperatures and are 95% water, which are helpful to those living in deserts or dry areas.

Squash Information

Squash contains a huge amount of vitamins A, C, E, B6, niacin, thiamin, pantothenic acid, and folate. They are also incredible sources of carotenoids and important anti-inflammatory and antioxidant compounds. These all contribute to the impressive health benefits of squash. One of these is boosting the immune system. Squash's high levels of vitamin A, C, magnesium, and other antioxidant compounds, helps the body boost its immune response and its defense against foreign substances.

Squash can also aid in managing diabetes and in improving bone and eye health. It contains pectin, an essential element in blood sugar regulation that ensures the insulin and the glucose activities within the body are in check, which is essential for managing diabetes. It also contains an incredible amount of beta-carotene, which is an antioxidant compound essential for good eye health. This could reduce the chances of glaucoma, cataracts, and other vision issues.

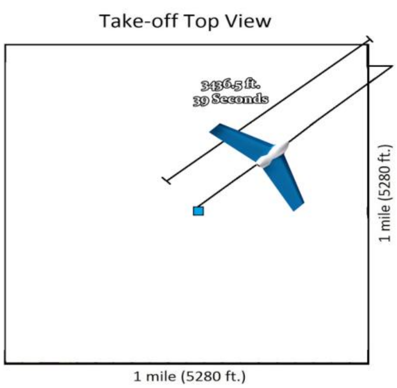
Squash is also capable of improving blood circulation and preventing cardiovascular diseases. Squash contains high levels of iron and copper, which can reduce the chances of developing anemia, and an increase in blood circulation can increase oxygenation and brain function. It also contains magnesium and potassium that can help increase blood flow and reduce stress on the heart. Its pectin can also reduce the chances of heart attacks and strokes, because it is capable of scraping excess cholesterol from the artery walls. Reducing the risk of lunch cancer and providing relief from asthmatic conditions are also other health benefits associated with squash.

The prices of squash can range from $1.07 per pound up to $3.85 per pound. Native squash is an important source of the astounding genetic variety that people can benefit from today.

The explanation behind the selection of squash as a second crop was based off many factors. The team met up with the Northern Marianas College CREES and Department of Land and Natural Resources in order to directly assess the problems these crops face along with their similarities in growing needs. In the same family as cucumbers, squash has multiple uses along with a long shelf life and affordable cost in the market. It promised all the aforementioned factors which conclude that squash is a very affordable and transportable crop with a fast growth cycle of only 50 days. Furthermore, because squash and cucumbers are in the same family (cucurbits), their growth cycles are virtually the same, hence we can perform moisture detections at the same time for both fields.

It takes cucumbers 65 days to be fully grown ready to harvest while squash takes approximately 50 days or more. Although there is a small sign of date delay, our agricultural mentors say this is not significant enough to deter our mission productivity. Squash is a worldwide enjoyed crop with high demands due to its fast growth cycle and affordable price. It is also an indigenous crop in CNMI, where majority of the farmers grow squash at high demands on the local markets. Squash also provides a great source of vitamins despite their cheap price on the market. It provides a rich source of vitamin A and C, magnesium, fiber, folate, riboflavin, phosphorus, potassium and vitamin B6. The primary purpose of our specific crop selection was also greatly influenced by our goal of providing affordable mass production of food for the poor mainly targeted at the people of Africa. Our crop selection solely lied on the cost of the crop, its growth cycle and its overall benefits. Both the cucumber and squash are packed with nutrition for consumers, and, since we are targeting those who suffer from lack of food, these easy-to-grow affordable crops can provide them with sufficient nutrients to survive.

3.2 Theory of Operation (Example Detection)



<u>Launching Scenario</u>

Depicted on the diagram is the launching process of the Cruiser. Upon arriving at the mission area, the team will locate the aircraft and its catapult in the center of the field in preparation for launching. Other than decreasing the weight of the aircraft, utilizing a catapult allows the Cruiser to gain altitude and speed quickly compared to when taking off at a runway. When this force is applied to our aircraft, it will be accelerating from 25 mph to 63.7 mph in five seconds. Thereabout, it would ascend at 10 feet per second until it reaches an altitude of 500 ft.

<u>Camera Footprint Detection Scenario</u>

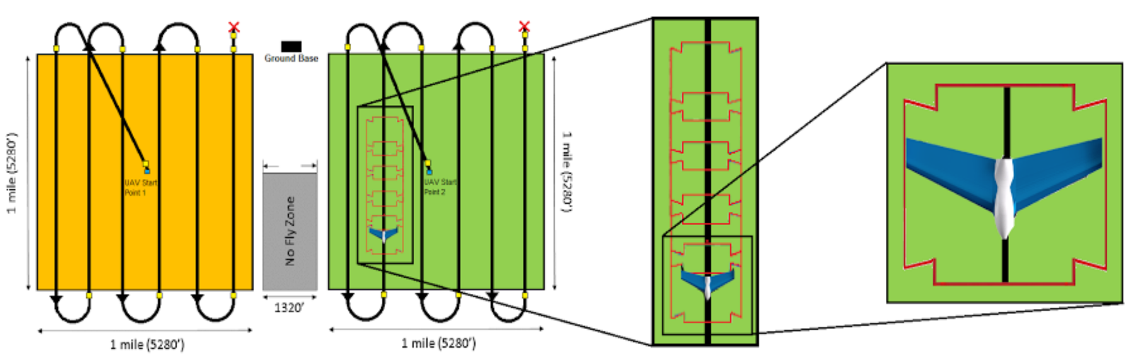
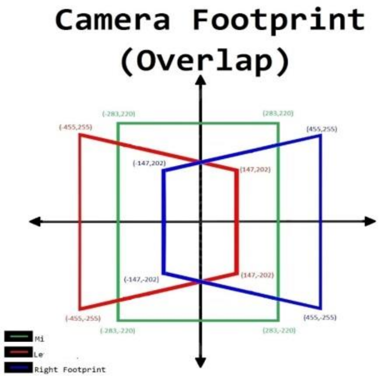


Figure not drawn to scale

The image depicted on the right is an example of the detection scenario with our sensor payload's camera footprint. The sensor payload will be continually capturing images at a frame rate of 100 frames per second. The team calculated and adjusted our camera's settings to ensure that the imaging footprints will overlap, leaving no gaps or holidays throughout the detection process. Once the mission is commenced, our data analyst will survey the data while it is being processed. The Cruiser will be flying at an altitude of 500 ft. and a cruise speed of 90 mph. Its ability to fly such an altitude allows it to perform less turns, which contributes decreasing the total mission time.

To accurately quantify the coverage area of our sensor payload, the team graphed the coordinates of the images overlapping each other based on the results provided by the camera footprint. Within our flight time interval, the camera will capture images of the left, right and middle footprint. Furthermore, the footprints are indicated in the red, green and blue colors. As a result, these camera footprints will be combined to create a single picture, which will represent a complete camera footprint. All in all, one footprint will cover 910 ft. in width and 460 ft. in length.



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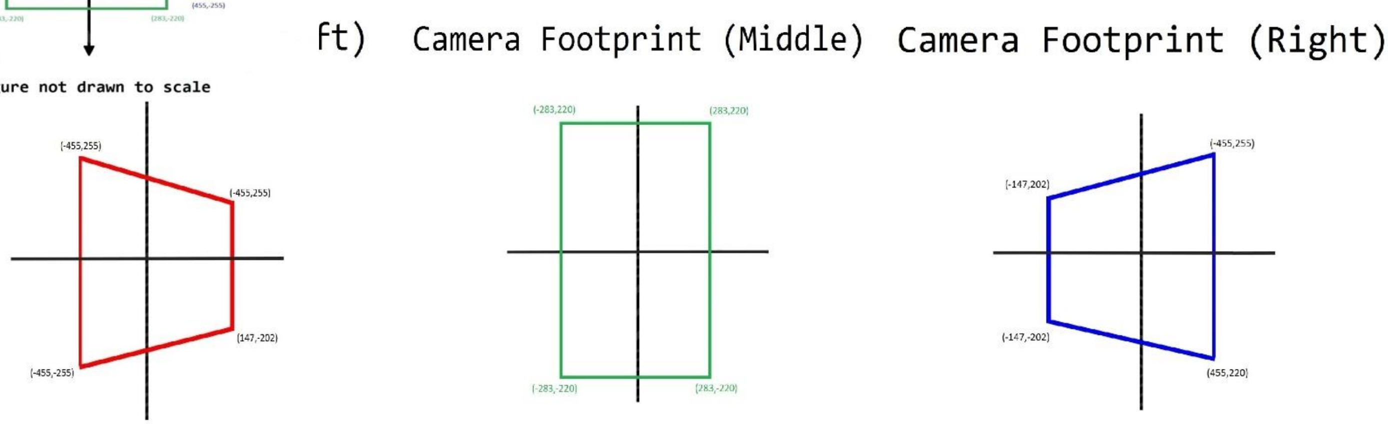


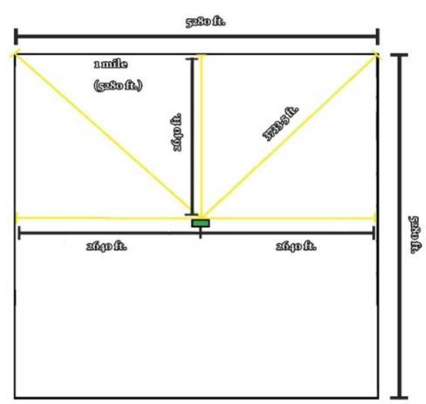


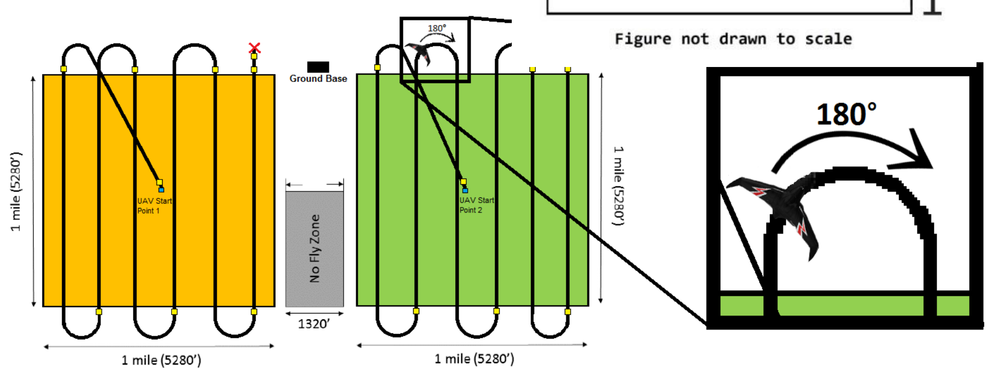
Figure not drawn to scale

Visual Line of Sight

Because the aircraft requires a one mile visual line of sight, the team decided to launch our aircraft from the middle of the field. The operational pilot will be monitoring the aircraft throughout the mission from the middle of the field. Hence, this allows the pilot to maintain a line of sight in a 360° field of view.

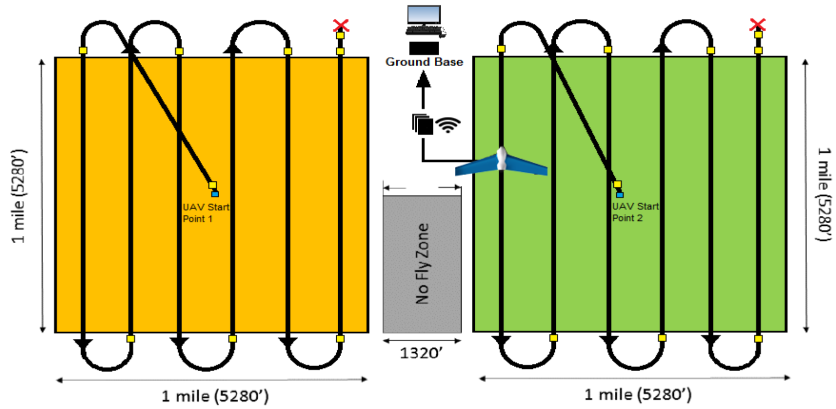
Turning

When our aircraft approaches its turning point from 315.92 ft., it will begin to reduce its speed at 9.1mph/sec and perform a 180° at 62.7 mph. Our aircrafts will repeat this process per each turn in the mission field. The total turns calculated for this mission is 10 (5 for each field) and the total time to complete the mission is approximately seven minutes.



Data Transfer

During detection, the Cruiser will automatically transmit the data collected to our ground base. Made possible by our C3 equipment, live transmission of images can occur along with the processing of data once the images are received.



Interference

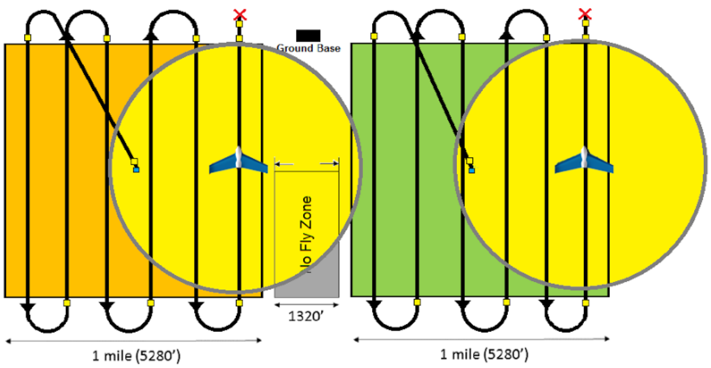
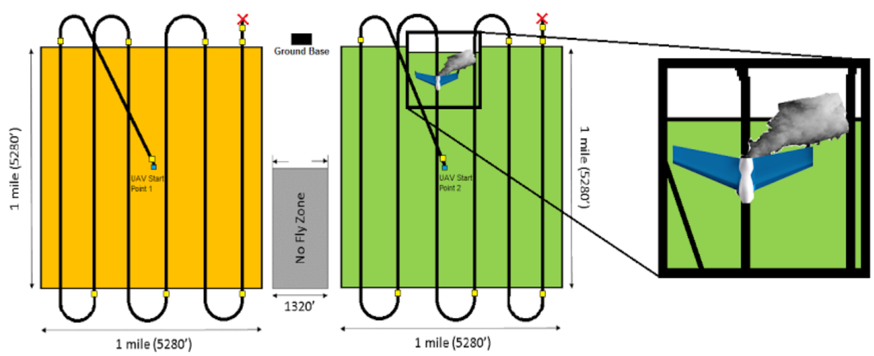


Figure not drawn to scale

In order to avoid any possible signal interference between the aircrafts, the team modified the mission plan in a matter where both planes will fly in a symmetrical pattern. This allows us to have a redundant precautionary measure to ensure that there is at least a one-mile distance of separation between the UAV signals. As demonstrated in the figure, both aircrafts will conduct the detection simultaneously in their respective fields. In compliance with the RWDC detailed background, the team ensured a 6,240 ft., or 1.18 mile separation between both aircraft. The distance between the one-mile diameter of aircraft 1 and 2 is 1,760 ft.

Contingency Plan



In case of a malfunction occurring to aircraft during flight operations, the Cruiser will switch from autopilot mode to manual control mode. Afterwards, the pilot will manually fly the aircraft back to ground base. The aircraft will be caught by a net and thereby, be tended to by our technical engineers. Once we troubleshoot and repair the aircraft, it will be re-launched to resume its mission where it discontinued scouting.

Mission Complete/Recovery Scenario

Upon completion of the mission, the Cruiser will head towards its point of origin. While in the process of landing, the aircraft will slowly decrease its speed and altitude. Meanwhile, when the aircraft arrives closer to the ground, it will eventually, be caught by the use of a net.

3.3 Detection Considerations

Indigenous Crop Choice- Detection Approach

The team strategized in choosing crops that had moisture problems or required close monitoring for moisture content. During our conceptual design phase, we considered numerous fruits and vegetables such as corn, wheat, watermelons, and tomatoes. Although these crops met the requirement of growing on moist areas, their short shelf life did not pose a great impact on increasing food productivity for the growing population. In the preliminary and final design phase, the team decided to choose cucumbers and squash as our crop of choice. The moisture requirements of these crops made it an optimal choice for our detection process. Furthermore, cucumbers and squash worked in conjunction with our mission objective. In general, they are highly marketable all over the world, and have a rather long shelf life. In other words, when transported, these crops can last for an adequate amount of time before starting to rot. In addition to that, cucumbers are popular worldwide for its low cost, also working in conjunction with our mission objective of saving world hunger. Because of our selection, our team strategized a mission plan in which we will detect four times over the growth cycle of the both crops. Our aircraft will detect once in the germination process of the plants, once when it sprouts, a third time when the crop produces flowers, and lastly when the crop is ready to harvest. Because they are fast growing crops, we will be able to perform our detection relatively quickly, resulting in financial benefits. In terms of the mission itself, the aircraft will be detecting the cucumbers and squash using a hyper spectral camera at an altitude of 500 ft. with a top speed of 90 mph.

Effects on Detection Strategy

The four detection periods over the crop's growth cycle was drastically dependent on the crop selection. For our crop selection, we chose cucumbers and squash, fast growing crops that are highly marketable and require a lot of water attention. Because they are fast growing crops, our detections will be made quicker compared to crops with longer growth cycles. The team formulated a mission plan in which the crop field will be detected once in the germination process of the cucumber, during its sprouting, then the flowering process, and finally its harvesting time. We balanced our four detecting times so that we will be able to monitor the crop as productively as possible. Furthermore, of the short growth period, we will be able to perform 4 missions in every nine week period, performing detection every 3 weeks. This provides our customers with an affordable deal, as we will be charging at a low price while performing top of the line detection on our chosen crop.

Sensor Payload Selection

The team chose the Mini-Nyx-S 640 hyper spectral camera due to its light weight and capability to produce high resolution images at numerous spectral bands. The challenge scenario required us to detect moisture in a field of a chosen crop, which included detecting the soil and crop moisture levels. Hence, to reduce the usage of multiple cameras, we chose a single hyper spectral camera that was capable of all detection levels from soil to crop, as well as additional commercial applications.

Objective Function Considerations

To maximize our airframe efficiency in regards to our objective function, the team chose the Darkwing FPV Drone, a lightweight UAV, with an exceptional payload capacity and speed characteristics. To further reduce the aircraft's weight, the team chose components that were lightweight yet high quality. The selection of a lightweight camera allows us to fit more components into the fuselage, making the efficiency of our airframe highly exceptional. As for our cost and business profitability, our company is set to breakeven by the first year of business. Because the total mission time to complete on field is seven minutes, our company is able to maximize the missions we complete each work day.

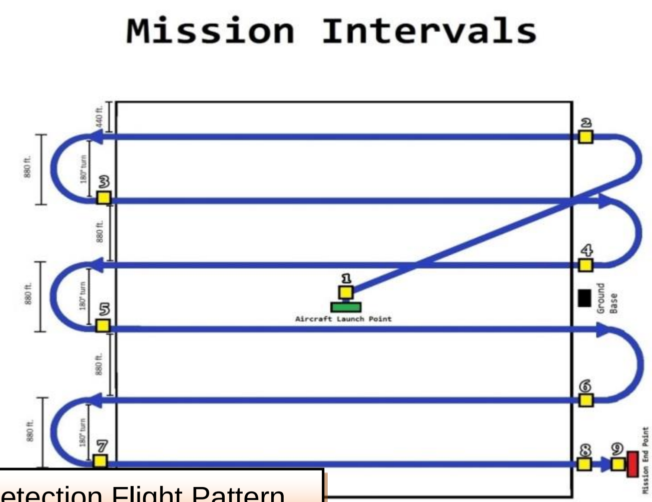
Conventional Moisture Detection Methods- Competitiveness Assessment

Table 12a. Current Methods of Moisture Detection
Crop Scouting Crop scouting is an action of traveling through a crop field, during its growth season, while making frequent stops for observations. The traditional methods of crop scouting were to have the farmer walk through the field while observing plants manually, which entails taking field notes and samples. Furthermore, regular crop scouting through the crop's life could reveal pest issues, soil moisture issues, and other risks that could affect the crop revenue as well as other uses. Nevertheless, it provides single point coverage, which proved not to be efficient enough to scout for both soil and plant conditions. Subsequently, this prevented farmers from monitoring trends in the growth cycle. Manually scouting an entire field could take an ample amount of time; and time of course, in a business perspective, is revenue. Unfortunately, it is tiring and tedious, but scouting itself is necessary. It is also highly inaccurate – there is a plethora of information that humans cannot see with the naked eye, including moisture content. The inefficiency and inaccuracy of this method negatively affects the business's productivity.
Remote Sensor Technology Remote sensors vary in accordance with the type of platform that they are mounted on. Thus, enabling us to have the ability to observe and collect information on crop and soil conditions using devices attached to aircrafts, satellites, as well as agricultural equipment.
Satellites and Manned Aircrafts Passive sensors are mounted on satellites and aircrafts, which measures the amount of sun energy reflected from an object. By the same token, passive sensors rely heavily on sun light, meaning that its maximum performance can only be during the time when the sun is illuminating the target area. As a result, this would be based as inefficient, because this technology will limit us to daylight operations only. As mentioned earlier, inefficiency negatively affects productivity and profitability.
High-Clearance Tractors (Manned) Active sensors are used on ground vehicles such as manned tractors. Active sensors use its own modulated light at fixed wavelengths. Instead of relying on sunlight, it illuminates the object itself and measures it. As a result, it has the ability to obtain data at any period, regardless of the time of the day or the amount of sunlight available. However, the tractor requires human operator, who cannot precisely drive through fields without damaging crops in its path. Besides, being on the ground has its disadvantages; it would be time consuming and could also pose risks for the operator.
Hand Carts Hand carts are less expensive versions of the tractor, together with the active sensor technology. Unlike the tractor, it reduces the risk of damaging the crops because of the close manual operation done by a person pushing the cart through a field. However, though it is more accurate than the traditional crop scouting method, it is still inefficient. It would be extremely time-consuming, and physically demanding for the operator, which would again affect the business's productivity and profitability.

Compared to conventional moisture detection methods for crops, the precision and productiveness offered by our system brings it to the top of the list. A conventional moisture detection method consists of multiple processes which are time consuming and virtually unproductive. In terms of farm fields that are hundreds of miles in width and length, repeating this technique by covering small areas at a time will require tedious work as well as a large number of personnel. On the other hand, our UAV moisture detection plan uses a UAV which is equipped with a SWIR hyper spectral camera that is capable of multiple arrays of detection. Our aircraft will fly at an altitude of 500 ft. at a top speed of 90 mph, allowing the aircraft to detect the field in a larger scale, resulting in faster completion of the mission. Our hyper spectral camera has a 910 ft. width and 460 ft. length foot print. With all these factors assimilated, the aircraft is calculated to complete a 1x1 mile field in seven minutes. To assess the competitiveness of our aircraft to the marketplace, the team conducted research on current and over-the-years methods of moisture detection.

3.4 Detection Time and Resource Requirements

In order to calculate the total mission time and total battery consumption, the team broke down the entire mission scenario into nine different sections. These sections were used to calculate the total mission time as well as battery consumption. As a result, we calculated the total mission time to take exactly seven minutes. The total cumulative distance traveled is calculated to be 44962 ft. Furthermore, the yellow squares represent the mission interval checkpoints. The team created a Flight Pattern chart that determines the distance, time, and battery consumption during each checkpoint.



Manpower Requirements:

- 1 x Payload Operator
- 1 x Data Analyst
- 2 x Range Safety/ Aircraft Launch & Recovery/Maintenance
- 1 x Safety Pilot
- 1 x Operational Pilot

Aircraft 1: Detection Flight Pattern

Position	Distance (ft)	Cumulative Distance	Time (sec)	Cumulative Time	Power Usage
1 (Launch Area)	0	0	0	0	100%
2	3436.5	3436.5	48.6	48.6	91.4736842
3	6662.3	10098.8	56.245	104.845	81.60614035
4	6662.3	16761.1	56.245	161.09	71.73859649
5	6662.3	23423.4	56.245	217.335	61.87105263
6	6662.3	30085.7	56.245	273.58	52.00350877
7	6662.3	36748	56.245	329.825	42.13596491
8	5280	42028	41.21	371.035	34.90614035
9 (Landing)	2934	44962	49	420.035	26.30964912

Aircraft 2: Detection Flight Pattern

Position	Distance (ft)	Cumulative Distance	Time (sec)	Cumulative Time	Power Usage
1 (Launch Area)	0	0	0	0	100%
2	3436.5	3436.5	48.6	48.6	91.4736842
3	6662.3	10098.8	56.245	104.845	81.60614035
4	6662.3	16761.1	56.245	161.09	71.73859649
5	6662.3	23423.4	56.245	217.335	61.87105263
6	6662.3	30085.7	56.245	273.58	52.00350877
7	6662.3	36748	56.245	329.825	42.13596491
8	5280	42028	41.21	371.035	34.90614035
9 (Landing)	2934	44962	49	420.035	26.30964912

In conclusion, the total time to complete the detection patter is seven minutes.

4. Document the Business Case

4.1 Regulatory Restrictions

The team's UAS, the Cruiser, is designed specifically to be that needed precision agriculture tool. The Cruiser is capable of being programmed without a pilot onboard; decreasing the threat of loss of human lives if this was a manned aircraft. After rigorously studying the FAA Rules and Regulations, we concluded that the Cruiser is able to accomplish multitudes of missions that vary from precision agriculture. If regulatory restrictions were to come at an ease, the Cruiser will be able to perform missions that include, and are not limited to, search and rescue operations in large areas, as well as assisting in firefighting and nonmilitary applications. The Cruiser is able to fly at speeds of 100mph or more without loud noise, completing needed commercial applications that would take less than an hour. Equipped with a sensor payload that can process a variety of images in different spectral bands, the Cruiser is able to switch programs and monitor and detect other aspects of agriculture such as pest detection. Our operational personnel will be as multi-qualified as our aircraft, making modifications to the Cruiser easy and possible to do.

To stay in accordance with the regulations, the Aeronautical Dolphins thoroughly analyzed the need to obtain such permission to conduct these additional applications in a safe and efficient manner. The SAC-RC is available to civil UAS operators that will permit our system design to perform missions that include the following: search and rescue, reconnaissance, agricultural monitoring, news media operation, firefighting and nonmilitary applications. This certification will not only permit authorization for our UAS, but also increase our company's market size and productivity while utilizing our manpower and maintaining efficient and low cost performances. An ease to the regulations would allow our aircraft to fly at night to conduct search and rescue missions for emergency purposes, also not limiting the aircraft to weather and night operations unless safety is at risk. Come together, these additional applications will increase our overall profit.

Our UAS can be used by private aerospace companies and organizations who strive to improve and develop UAS technology. Notwithstanding, our aircraft is able to expand new ideas for further research and commercialization of unmanned aircraft vehicles for educational purposes. The United States is currently competing in the global market with the use of UAVs for military use. As our aircraft is capable of a large payload capacity, development and research of our UAS will be of consideration within this area. If regulatory restrictions were at ease, the Aeronautical Dolphins will be capable of exploring beyond our borders that will enable us to achieve problem solving, critical thinking, research analysis, and provide special services for customers.

Our company will have to apply for numerous certifications such as the Section 333 exemption.The operational limits, as stated in the provided "Overview of Small UAS Notice of Proposed Rulemaking," have been carefully understood by the team. We made sure that our system adhered to these limitations and (proposed) rules.Currently speaking, the FAA is developing new policies that will later affect operators' access to airspace, whether it is for commercial or other operations. In order to gain access to information on certificates and applications forms, the team created an account under the FAA website. The time it takes to process and gain certification was a realistic factor that we had to incorporate during our final design phase. In the Northern Marianas Islands (specifically Saipan), the integration of UAS is at a bare minimum. Majority of the operations conducted in our area fall under the public sector. The team's compliance within local regulations was another limiting factor. Civil operators such as private companies are generally uncommon in the CNMI. Thus, the team had to conduct extra research and asked for advice from nearby FAA personnel.

The team must obtain a Special Airworthiness Certificate prior to our operation. We will have to comply with rules under the restricted category for agricultural use. There are, however, exceptions along with extra certifications needed as we plan to use the Cruiser for other commercial applications. In order to obtain the SAC under the experimental category, the company must comply with the rules regarding research and development, crew training, exhibition, air racing, and market surveys. The system must be inspected in order to be "in a condition for safe operation." Additional design requirements that follow our registration include field approval, human factors in aviation safety, original design approval, and approval of safety enhancing non-required equipment under 14 CFR 21.8(d). Our personnel crew will consist of experienced pilots that already fit the certification criterion- owning an FAA airman certificate. Time and operational cost will be a tradeoff as both personnel and the aircraft have to comply with the FAA regulations.

Table 12. FAA Rules and Regulations
Special Airworthiness Certification (SAC): Certification for Civil Operated Unmanned Aircraft Systems (UAS) and Optionally Piloted Aircraft (OPA)
Special Airworthiness Certification: Condition For Safe Operation
Civil Operations (Non-Governmental): Section 333 Exemption
Special Airworthiness Certificate-Experimental Category (SAC-EC)
SAC-Restricted Category (SAC-RC)
Certificate of Authorization or Waiver (COA)

In order to operate our UAV in the National Airspace System, we must be granted through an approval process under relevant parts of Title 14 of the Code of Federal Regulations. Therefore, must request for authorization to conduct UAS operations in the NAS of approved Prohibited Area or active Restricted and Warning Areas designated for aviation use.

A Special Airworthiness Certificate- Restricted Category will also be in compliance with our system for the special purpose of precision agricultural detection under § 21.25. As of March 23, 2015, the FAA granted a "blanket" COA for flights at or below 200 feet to aircrafts below 55 pounds. The team will apply for the SAC-RC upon receiving our COA. This will be at least 120 days before our operation is executed. Obtaining this certificate will also take place before we execute full operations. This process will provide us a legal entry into the NAS, providing us a competitive advantage in the UAS marketplace. The exemption discourages illegal operations, improves safety, and will result in significant economic benefits.

To accommodate the visual line of sight we have to maintain of our aircraft over two 1x1 mile fields, the team decided to get the FCC Amateur Radio License which enables us to achieve a greater control range of 20-30 miles. With this license, our company will be able to incorporate other FPV systems which has a long range radio frequency that requires a license to operate.

In terms of obtaining the FCC license, the team will obtain the Technician License through a process of passing an examination administered by a team of volunteer examiners (VEs). The examination requirements include 35 questions on radio theory, regulations and operating practices. The VEs will determine the license operator class for which we are qualified through a testing of skills and abilities in operating an amateur station. The privilege of getting the technician class license are all VHF/UHF amateur bands, along with frequencies above 30 MHz.

Compliance with the aforementioned FAA regulations will allow our UAS to complete its moisture detection mission with ease. Our aircraft design, the Cruiser, was modified to ensure precision moisture detection.

4.2 Amortized System Costs

In the first year of our business, the team calculated that we would be able to conduct 1,200 missions in total. The Cruiser's detection flight time is approximately 7 minutes, however we took into great consideration the very purpose of our system – that is to analyze the data our sensor payload collected. This would take approximately 40 minutes, making one detection flight and data analysis 47 minutes. We would need to conduct a total of four detection flights and data analysis throughout all four of our crop's growth cycle, thus placing our mission time at 188 minutes or 3.13 hours. We determined the number of missions for our first year by initially deciding upon conducting 20 detection flights, or (20 fields / 4 detection flights = 5 missions) 5 missions per day. We also took into consideration the federal holidays in 2016 and a two-week vacation time for our personnel. In essence, the personnel would be working for 8 hours a day and for 5 days a week, which ultimately results into a total of 1,200 missions for our first year in business. This would cost our company $1,683.56 per field and $2,020,274.07 per year.

4.2.1 Initial Costs

System Initial Cost: $261,37

Airframe Cost: $1,504.84

Empty Aircraft							
Component	Quantity per vehicle	Cost per component	Weight per component (lb)	Cost per vehicle	Weight per vehicle (lb)	Airframe? (YES/NO)	Airframe Cost
13 x 13 APC Propeller	1	$10.90	0.132	$10.90	0.132	YES	$10.90
80-Amp Pro Switch-Mode BEC Brushless ESC, EC5 (V2)	1	$74.99	0.234	$74.99	0.234	YES	$74.99
Power 60 Brushless Outrunner Motor, 470Kv	1	$109.99	0.8125	$109.99	0.8125	YES	$109.99
A6150 HV High Torque Metal Gear Servo	2	$36.99	0.12	$73.98	0.24	YES	$73.98
A6220 HV Dig Low-Profile Hi-Torque MG Aircraft SX	2	$84.99	0.1	$169.98	0.2	YES	$169.98
Airspeed Sensor	1	$45.00	0.009	$45.00	0.009	YES	$45.00
RC Radio Receiver (Servo)	1	$0.00	0.045	$0.00	0.045	YES	$0.00
Autopilot	1	$250.00	0.05	$250.00	0.05	YES	$250.00
Multiplexer	1	$25.00	0.03	$25.00	0.03	YES	$25.00
Altimeter Sensor	1	$40.00	0.009	$40.00	0.009	YES	$40.00
3-axis Accelerometer	1	$30.00	0.009	$30.00	0.009	YES	$30.00
Servo Current Monitor	4	$25.00	0	$100.00	Enter W per comp	YES	$100.00
Temperature Sensor	1	$10.00	0	$10.00	Enter W per comp	YES	$10.00
RPM Sensor (optical)	1	$15.00	0	$15.00	Enter W per comp	YES	$15.00
Onscreen Display (OSD) and Datalogger with Telemetry Reporting	1	$250.00	0.106	$250.00	0.106	YES	$250.00
Darkwing Airframe	1	$300	3.6	$300.00	3.6	YES	$300.00
Empty Weight, W_E					5.4765		
Total Empty Cost				$1,504.84			
Airframe Cost, C_{AF}							$1,504.84

Power source							
Component	Quantity per vehicle	Cost per component	Weight per component (lb)	Cost per vehicle	Weight per vehicle (lb)	Fuel? (YES/NO)	Cost without Fuel
Glacier 30C 6000mAh 6S 22.2V LiPo Battery	1	$122.95	1.8125	$122.95	1.8125	YES	
Total weight					1.8125		
Total Cost				$122.95			$0.00

Power Source: $122.95

Payload					
Component	Quantity per vehicle	Cost per component	Weight per component (lb)	Cost per vehicle	Weight per vehicle (lb)
Mini-Nyx-S 640	1	$60,000.00	1.323	$60,000.00	1.323
Lens	1	$1,236	0.441	$1,236.00	0.441
Bengal PC/104 Format Single Board Computer	1	$621.00	0.282	$621.00	0.282
OBG-600L 2-Axis Brushless Gimbal	1	$1,193.54	0.95	$1,193.54	0.95
Lexan Dome (Clear)	1	$112.95	0.11	$112.95	0.11
DJI Lightbridge Video Transmitter	1	(Included with transmitter system in C3)	0.16	$0.00	0.16
Total weight					3.266
Total Cost				$63,163.49	

Payload: $63,163.49

CONTROL/DATA PROCESSING & DISPLAY OPTIONS			
Component	Quantity	Cost Per Item	Subtotal
Hobby-grade Remote Control (R/C) Radio	1	$750.00	$ 750.00
Post Processor PC (Laptop)	1	$3,500.00	$ 3,500.00
LCD Display	1	$200.00	$ 200.00
C3.4xLarge Server	4	$ 8,116.00	$ 32,464.00
Total Ctl/Data Process/Display Cost			$36,914.00

Control/Data Processing & Display Options: $36,914.00

COMM EQUIPMENT OPTIONS			
Component	Quantity	Cost Per Item	Subtotal
DJI Lightbridge Video Transmitter System	1	$999.00	$ 999.00
Total Comm Equip Cost			$999.00

Communication Equipment Options: $999.00

ADDITIONAL C3 EQUIPMENT OPTIONS			
Component	Quantity	Cost Per Item	Subtotal
YAGI-Directional Antenna (2.4GHz) - Ground Based	1	$60.00	$ 60.00
Total Additional C3 Equip Cost			$60.00

Additional C3 Equipment Options: $60.00

SUPPORT EQUIPMENT			
Component	Quantity	Cost Per Item	Subtotal
Catapult (Custom Made)	2	$1,500.00	$ 3,000.00
12ft x 16ft Soccer Net (Landing Net)	2	$10.44	$ 20.88
5000W Solar PSW Split Phase Power Inverter with 3500W DC 24V Smart Generator	2	$1,800.00	$ 3,600.00
24V Solar Panels	20	$187.99	$ 3,759.80
2016 7ft x 16ft Enclosed Cargo Trailer	2	$2,850.00	$ 5,700.00
2015 Nissan Frontier	2	$17,990.00	$ 35,980.00
Total Support Equipment Cost			$52,060.68

Support Equipment: $52,060.68

ENGINEERING & CONSTRUCTION LABOR			
Role	Hours	Cost Per Hour	Subtotal
Project Manager	80	$ 75.00	$ 6,000.00
Design Coordinator	80	$ 50.00	$ 4,000.00
Systems & Test Engineer	80	$ 50.00	$ 4,000.00
Simulations Engineer	80	$ 50.00	$ 4,000.00
Project Mathematician	80	$ 50.00	$ 4,000.00
Project Scientist/Mission Planner	80	$ 50.00	$ 4,000.00
Marketing Specialist	80	$ 50.00	$ 4,000.00
Assembly Technician	160	$ 25.00	$ 4,000.00
Electronics Technician	160	$ 25.00	$ 4,000.00
Aircraft Maintenance Technician	160	$ 25.00	$ 4,000.00
Total Eng/Construction Labor Cost			$42,000.00

Engineering & Construction Labor: $42,000.00

Air Vehicle Element (UAV) Design-1 (required)	
Number of Vehicles, N_{UAV1}	2
Empty Weight, W_{E1}	5.4765
Power Weight, W_{pow1}	1.8125
Payload Weight for Max Takeoff Configuration, W_{pay1}	3.266
Maximum Takeoff Weight, W_{TO1}	10.555
Total Empty Cost, C_{E1}	$ 1,504.84
Airframe Cost, C_{AF1}	$ 1,504.84
Power Cost, C_{pow1}	$ 122.95
Payload Cost for Max Takeoff Configuration, C_{pay1}	$ 63,163.49
Air vehicle cost at W_{TO}, C_{UAV1}	$ 64,791.28
Air vehicle cost at WTO w/o fuel, $C_{UAVwof1}$	$ 64,668.33
Additional Component Cost, C_{add1}	$ -
Single Design-1 Cost, C_{Tot1}	$ 64,668.33
Total Design-1 Cost, C_{Tot1}	$ 129,336.66

Revenue and Profit		
Total Acquisition Cost	$	261,370.34
C3 Cost	$	37,973.00
Support Equipment Cost	$	52,060.68
Engineering Labor Cost	$	42,000.00

Summary: $261,370.34

4.2.2 Direct Operational Cost per Mission

Direct Operational Cost per Mission: $236.06

OPERATIONAL PERSONNEL			
Role	Number Req	Cost Per Hour	Subtotal
Payload Operator	2	$ 35.00	$ 70.00
Data Analyst	2	$ 50.00	$ 100.00
Range Safety/Aircraft Launch & Recovery/Maintenance	2	$ 35.00	$ 70.00
Launch and Recovery Assistant	2	$ 15.00	$ 30.00
Safety Pilot	2	$ 35.00	$ 70.00
Operational Pilot	2	$ 35.00	$ 70.00
Total Operational Personnel Cost			$410.00

Operational Costs per Hour		
Operational Personnel	$	410.00
Consumables	$	-
Operations and Support Costs ($O\&S_{hr}$)	$	410.00

Our company has an unmanned aircraft system that is equipped with extremely qualified personnel that will operate the entire system for the mission scenario. Our mission time for each detection flight is 7 minutes with a data analysis time of 40 minutes. An entire field that would be detected four times will have a sum of 188 minutes or 3.13 hours for its mission time. Our costs per hour consists entirely of our operational personnel, due to our team's decision on powering our entire system with solar energy, thus decreasing our operational costs per hour and most importantly, impacting our environment positively in the long run. Two payload operator, data analyst, range safety/aircraft launch and recovery maintenance, launch and recovery assistant, safety pilot, and operational pilot will operate our system. The system's per hour costs are defined below:

Total per Hour Cost: $410.00

Time to Complete Mission (4 Detection Cycles): 188 minutes (4 hours as estimated in the RWDC Calculator)

Time to Complete Mission (1 Detection Cycle): 47 minutes (including data processing time)

Total Flight Time for 1 Mission Scenario: 7 minutes

Total Data Processing Time for 1 Mission Scenario: 40 minutes

Assuming a system initial cost of $261,370.34 and 1,200 missions for year 1, a Total Acquisition Cost per Hour of $10.89, and the Time to Complete Mission of 4 hours (rounded up), our total costs are shown below:

Total Flight Cost per Hour: $420.89

Total Operational Cost per Mission: $1,683.56

4.2.3 Amortization

The team utilized the RWDC cost calculator to find The Cruiser system's amortization costs. First, we added our system initial cost ($261,370.34) and the total operational cost per year ($2,020,274.07), then divided this total cost ($2,281,644.41) by 1,200 missions we will be expecting for year 1. The team decided that we would be able to conduct 5 missions per day. We then multiplied this by 5 because we will be working for 5 days a week, totaling to 25 missions per week. We then multiplied this by 52 weeks, which is the amount of weeks there are in a year, equaling 1,300 fields per year. Then we took into consideration the federal holidays and the allotted vacation time for our personnel, which would equal to 20 working days or 100 missions, and subtracted that from the 1,300 fields per year that we could conduct for the entire year if there were no day offs, thus equaling into 1,200 fields per year. Our amortization cost is $1,901.37.

System Initial Cost	**$261,370.34**
Total Operational Cost per Mission	**$1,683.56**
Total Operational Cost per Year	**$2,020,274.07**
Initial Cost and Operational Cost per Year	**$2,281,644.41**
Total Cost divided by 480 Missions	**$1,901.37**

Operational Costs Per Hour	Year 1	Year 2	Year 3	Year 4	Year 5
Operational Personnel	$ 410.00	$ 410.00	$ 410.00	$ 410.00	$ 410.00
Consumables	$ -	$ -	$ -	$ -	$ -
Operations and Support Costs ($O\&S_{hr}$)	$ 410.00	$ 410.00	$ 410.00	$ 410.00	$ 410.00
Total UAS Cost Per Hour (over specified number of applications)					
System Initial Cost ($AcqCost_i$)	$ 52,274.07	$ 52,274.07	$ 52,274.07	$ 52,274.07	$ 52,274.07
Number of Fields Per Year (N)	1200	1200	1500	2400	4800
Time to Complete Field (T) [in hours]	4	4	3	2	1
Acquisition Cost Per Hour	10.89043083	$ 10.89	$ 11.62	$ 10.89	$ 10.89
Total Cost Per Hour ($FCPH_{RWDC}$)	$ 420.89	$ 420.89	$ 421.62	$ 420.89	$ 420.89
Total Cost per Field	$ 1,683.56	$ 1,683.56	$ 1,264.85	$ 841.78	$ 420.89
Total Revenue Per Field	10000	10000	12,000	15,000	20,000
Total Revenue Per Year	$ 12,000,000.00	$ 12,000,000.00	$ 18,000,000.00	$ 36,000,000.00	$ 96,000,000.00
Total Cost Per Year	$ 2,020,274.07	$ 2,020,274.07	$ 1,897,274.07	$ 2,020,274.07	$ 2,020,274.07
Total Profit (Loss)	$ 9,979,725.93	$ 9,979,725.93	$ 16,102,725.93	$ 33,979,725.93	$ 93,979,725.93
Cumulative Net Cash Flow	$ 9,979,725.93	$ 19,959,451.86	$ 36,062,177.80	$ 70,041,903.73	$ 164,021,629.66

Our company's revenue proved to be greater than our costs, though our system costs were high due to investments for superior equipment and environmentally conscious resources.

In the first year of our market analysis, though our system costs were high due to our investments for superior equipment and environmentally conscious resources, our revenue proved to be greater than our costs, providing us a total profit of $9,979,725.93. Though it is possible to greatly maximize the missions we could perform, we chose to start our business with plenty of room to improve our system, and examine our performance as our business grows. It is also noted that we would be paying for our entire system initial cost in a span of five years, which would be $52,274.07 yearly. In the third year of our business case, the team saw this as an opportunity to improve our system, by decreasing our mission time to 3 hours. Thus resulting in a total of 1,500 missions per year, and a total profit of $16,102,725.93.

By the fourth year of our business case, the team knew that we could further maximize the Cruiser's capabilities, and decrease our mission time to 2 hours totaling to 2,400 missions per year. From this improvement, we could make a profit of $33,979,725.93 and a cumulative net cash flow of $70,041,903.73.

As year five unfolds, we will continue to further maximize our system and decrease our mission time to less than one hour (as rounded by the RWDC calculator), resulting to a total of 4,800 fields that year. We determined that through these stellar improvements, it would be appropriate to maximize our revenue to $20,000, still without surpassing the high costs of nearly $35,000 for conventional or other UAV solutions.

4.3 Market Assessment

The traditional way of detecting moisture in crops is the time-consuming method of crop scouting. This provides only a single point of coverage, for it is done merely by the farmer's observations, and it cannot provide the exact conditions of the soil and plants, thus preventing farmers from monitoring trends in the production for effective crop management decisions. Our system, however, has a superior sensor payload that is capable of gathering data of various spectral bands for a professional analyst in our personnel to analyze.

Manually scouting an entire field could take an ample amount of time; and time of course, in a business perspective, is revenue. It is tiring and tedious, but scouting itself is necessary. It is also highly inaccurate – there is a plethora of information that humans cannot see with the naked eye, including moisture content. The inefficiency and inaccuracy of this method negatively affects the business's productivity. Our system can perform incredibly fast, but still without losing keen accuracy. It also provides a stellar performance on not only moisture detection, but also other information that could result in healthier crops and a larger crop yield.

The use of satellites and manned aircrafts is another option on crop moisture detection, and both methods rely heavily on passive sensors. Passive sensors rely heavily on sun light, meaning that its maximum performance can only be during the time when the sun is illuminating the target area. This again, would be inefficient, because by using this technology, one would be limited to working only when there is sun light on the target area. As mentioned earlier, inefficiency negatively affects productivity and profitability. Our aircraft's unmatched sensor payload is capable of detecting even on low light, and still without losing accuracy and productivity.

There are, of course, many rising unmanned aerial vehicles in the market for agriculture – and more specifically, moisture detection. The eBee is a UAV that flies at 45 km per hour, or just below 30 mph, and can cover 100 acres in 20 minutes. Our aircraft, on the other hand, can easily fly at 90 mph and can cover 640 acres in only 7 minutes! The eBee also charges $5.00 for an acre, meaning that if the eBee were to conduct our mission scenario, it would cost about $6,400 for one detection flight – and we would need it to detect four times throughout the crop's growth cycle, so the total cost would be $25,600. We would only be charging $6,000 per field during our first two years, well below the price compared to this UAV out on the market. Also, even as we improve our system we would be charging a maximum of $6,000 – still without surpassing the cost of our competition. Not only is our system incredibly feasible, but it can also perform with extraordinary excellence- a true innovation towards precision agriculture.

4.4 Cost / Benefits Analysis and Justification

Constantly consulting our mentors and retrieving answers from all available resources, the team made its biggest decisions towards increasing the efficiency of our aircraft and profitability of our business case. As a result, the team came across various tradeoffs and beneficial decisions that affected our final objective function cost value. The team recognized that a low airframe empty weight value along with a high maximum payload capacity will result in a higher airframe efficiency value. This is the core challenge not just within RWDC but existing fixed-wing RC aircraft worldwide. We recognized that, compared to conventional methods, time and accuracy was an essential factor in assessing our system's competitiveness in the market.

Customer Value

While many consumers attempt to purchase their own RC detector UAVs, whether it be for commercial or other purposes, they find themselves amused yet lacking productivity and accuracy when it comes to agricultural detection. On average, a regular UAV detector would cost over $25,000, at the least. Unequipped with a detection and communications system, proper sensor payload, and long lasting propulsion system, these UAVs would leave consumers spending more for factors that provide less value. As mentioned earlier, the Cruiser and our company's system is fully equipped specifically for agriculture detection purposes. For the price of only $6000, a customer's farm is able to experience direct quantification of moisture in both the soil and plants on his/her crop in exactly seven minutes for two, co-located 1x1 mile fields.. During the detection process, images are automatically processed and transmitted to our ground base system, in which our data processing program will compile the images along with a report indicating the high or low moisture levels in each acre. An entire detection mission provided by our company alone defeats the cost and outcome of a conventional moisture detection method or UAV.

Sensor Payload Selection

Compared to the "basic" method of having the sensor payload point only downwards during the detection, our system's sensor payload, the Mini-Nyx-S 640, is able to maintain high resolution images while it sweeps to the left and right, allowing a large coverage area of detection. All in all, one sweep of the camera will be able to cover 910 ft. in width and 460 ft. in length in a span of one full pan and tilt. Having consulted the camera provider's company and performed several analyses, this execution is possible with the speed of our aircraft. Our use of a SWIR hyperspectral camera allows our UAS to directly quantify the moisture levels of crops, using several indices and programs that will allow us to determine through color maps and ratios the moisture level of both the soil and plants of crops. Our company will utilize the IR-Flash and Pix4DMapper in conjunction with our sensor payload to process information and images in which we will provide to our customers.

Mission Plan

The team challenged one another to come up all possible search patterns during the entire mission process. Ultimately, the choice of utilizing two superior UAVs for the national challenge proved the most beneficial in terms of our initial and yearly costs. The use of two aircrafts enable our company to keep a core operational personnel team, while minimizing our labor costs. This also disregards additional implications on avoiding interference with multiple UAVs except for those encountered that are not part of our system. The engineering team is then able to advertise and further improve this system in the following years. For customers in the United States who own large acres of cropland, our company will provide affordable deals for detecting each 1 x1 mile field in the crop area. This will allow our company to maintain long term partnerships with farms that have large field areas, minimizing the cost of our travel time as well as getting our system involved in the larger agricultural marketplace.

Breakeven Analysis

Our company's breakeven analysis was greatly affected by our system initial cost and total profit we will be gaining throughout year one to year five. There is an indicated profit gain by the first year of our business case. Our yearly revenue ($12,000,000) is much greater than our operational cost per year ($2,020,274.07), resulting in a total profit of $9,979,725.93. The company's costs and profits will improve as we approach year five, making additional modifications to improve and expand our system as a whole. This results in an increase of revenue per mission for the following years, still providing a large gap between the cost of conventional moisture detection methods.

Finally, the unique design of our system enables us to achieve much more in addition to achieving top of the line moisture detection on crops. Our system is capable of detecting factors other than moisture, along with the capability to detect over fields of virtually any crop, depending on present visual obstructions. The team has learned that innovating strategies using advanced existing technology will effectively increase precision in moisture crop detection and food production, all of which the Cruiser and our system has accomplished throughout the FY16 Real World Design National Challenge

4.5 Additional Commercial Applications

Our world is ever changing and ever growing. Therefore, in order to compensate for the population growth in the future years, food production has to be more efficient and productive than ever. Additionally, it is predicted that by the year 2050, two billion more people will be added to the world's population, thus the requirement for food production will gradually increase. Farmers are now opted to innovate ways to do the following: increase food production, reduce toxic chemical exposure to their own crops and the surrounding environment, and to reduce costs of maintaining their crops, so as to provide more food while increasing their profits.

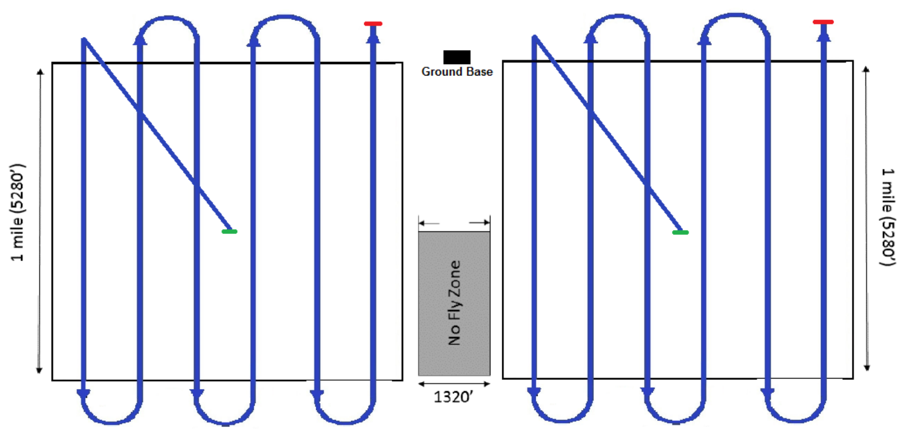
As our primary service, the team formulated a systematic and efficient approach towards performing moisture detection on crops. Going beyond the National Challenge mission scenario, our company aims to provide services to farms both large and small. In reference to large agricultural businesses who utilize thousands of acres of land, the Aeronautical Dolphins aim to extend our services to large-scale crops. This will allow us to maximize our mission productivity each day. Ultimately, our UAV is capable of detecting virtually any crop, including their soil and crop canopy content. Our company is able to perform moisture detection for large-scale crops; focusing, for example, on one entire area of land per day. The following days of the week, for example, would consist of our company providing services to another "large" customer. Theoretically, this will allow us to focus on entire areas of land, which equates to numerous national challenge crop fields combined.

There are, however, times in between crops' growth cycles where our company does not have to perform a detection. In this case, the team formulated detailed plans on additional commercial applications.

Consequently, the Cruiser has also been proven to accomplish a multitude of missions other than precision agriculture. In addition, if regulatory restrictions were to come at an ease, our aircraft will be able to perform missions that include search and rescue operations in large areas, as well as assisting in firefighting and nonmilitary applications. Above all, in order to stay in accordance with the regulations, the Aeronautical Dolphins thoroughly analyzed the need to obtain such permission to conduct these additional applications in a safe and efficient manner. The SAC-RC is available to civil UAS operators that will permit our system design to perform missions that include the following: search and rescue, reconnaissance, agricultural monitoring, news media operation, firefighting and nonmilitary applications. Thus, this certification will not only permit authorization for our UAS, but also increase our company's market size and productivity while utilizing our manpower and maintaining efficient and low cost performances. An ease to the regulations would allow our aircraft to fly at night to conduct search and rescue missions for emergency purposes, also not limiting the aircraft to weather and night operations unless safety is at risk. The aircraft's nozzles are positioned specifically in a way that allows it to adjust to any crop spacing, as well as making it detachable for other commercial purposes. In short, these additional applications will increase our overall profit.

All in all, little to no modifications are needed in order for the Cruiser to perform additional applications. Because of our unmatched sensor payload, our UAV is able to perform optimally in terms of surveillance.

The first and optimal application that the team decided to perform is pest detection. This, overall, provides both our company and customers a deal that cannot be rejected. By changing our camera's index, our UAV is capable of directly and indirectly detecting signs of pests on crops. Apart from obtaining new customers, our company has set a deal of \$12,000 for a full pest detection in addition to a four-cycle moisture detection. An individual 1x1 mile field will cost \$6,000.



In addition to our alternative additional applications, this pest detection additional application can be used as an alternative way to earn profit for our investors.

Prior or post to moisture detection, our aircrafts are capable of mapping a particular field and detecting for damages in crops which indicate pest infestation. In this scenario, the same 1x1 mile fields from the national mission scenario are shown as an example crop. The aircrafts will be performing a lawn mower pattern to detect damages in the crop field, still while flying at an altitude of 500 ft. and at a speed of 90 mph. The aircrafts will be flying simultaneously in a symmetrical method to avoid the one-mile signal interference between the aircrafts. The purpose of this mission would be to detect signs of pest life by identifying holes or physical damages on crops as well as directly identifying living pests.

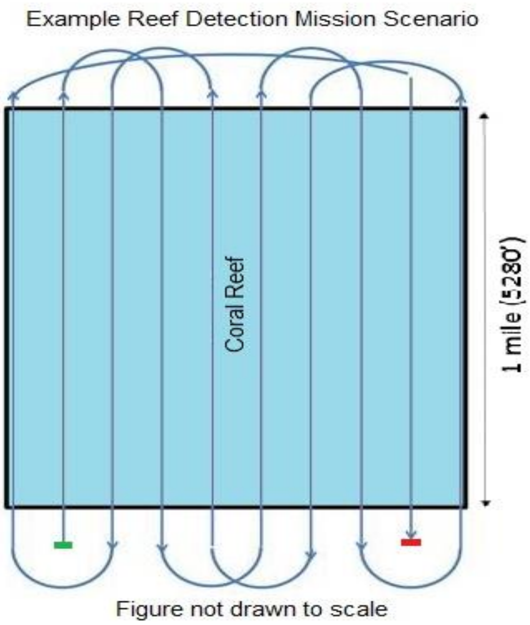
Operational Costs Per Hour	Year 1
Operational Personnel	$ 410.00
Consumables	$ -
Operations and Support Costs ($O\&S_{hr}$)	$ 410.00
Total UAS Cost Per Hour (over specified number of applications)	
System Initial Cost ($AcqCost_i$)	$ 52,274.07
Number of Fields Per Year (N)	600
Time to Complete Field (T) [in hours]	1
Acquisition Cost Per Hour	87.12344667
Total Cost Per Hour ($FCPH_{RWDC}$)	$ 497.12
Total Cost per Field	$ 497.12
Total Revenue Per Field	6000
Total Revenue Per Year	$ 3,600,000.00
Total Cost Per Year	$ 298,274.07
Total Profit (Loss)	$ 3,301,725.93
Cumulative Net Cash Flow	$ 3,301,725.93

This advantageous detection strategy can be used to obtain information at an early stage where pesticide can be applied to infected crops. Aside from the moisture detection, the pest detection can be a crucial application that can be used to preserve fields. Majority of crop fields are targeted by pests year-round and grow to adapt to the pesticide that is applied, making early application efforts crucial for crops' survival. Our approach of pest detection allows the investors to gain insight on what part of their field is being targeted the most and the level of pest infestation based on our data of crop damage. During the flight, our aircrafts will be capturing images which will be wirelessly transmitted to our ground base, in which our data analyst will begin the data processing. Our total mission time is calculated to be approximately 7 minutes- just under 10 minutes. Ultimately, our sensor payload is capable of detecting both moisture and pest presence in one mission fly through. With the data obtained from the aircrafts mission, we can reuse the same data images to distinguish both pest with the usage of a separate program. (The Unscramble 9.1)

As for our business case, the system initial costs would remain the same. The total mission flight and processing time will also remain at seven minutes. The team calculated the total revenue, profit, and missions per year for our first year using the breakeven analysis calculator. We estimated a total completion of 600 fields per year, charging total revenue of $6,000 for every 1x1 mile field. This alone results in a total cumulative net cash flow of approximately $3,000,000.000!

Our secondary commercial application is one that is beneficial not just for the CNMI, but also for the environment and the world that surrounds us. This commercial application is coral reef monitoring and security.

For many years, marine biologists and government-funded and private environmental organizations spend countless hours, days, and weeks physically monitoring coral reefs, seagrass, and other wildlife. For many,



however, this is the only way that humans can assess the deterioration of our coral reefs. A growing issue in the CNMI, the team met with the CNMI Department of Environmental Quality and interviewed marine biologists who perform these reef monitoring jobs. Each time a mission was to be performed, workers had to physically dive down the reefs and collect samples of corals and seaweed to assess their health. With the purpose of improving coral reef and seaweed monitoring, the Aeronautical Dolphins made this type of monitoring using a UAV possible. The team consulted with the Mini-Nyx-S 640 SWIR camera's manufacturing company and developed agreements on modifications that can be made with the camera lens, indices, and bands. The mapping of coral reefs and localization of reef areas that are affected by degradation is a mission the team sought to perform. The following figure consists of a 1x1 mile ocean reef area. In regards to the detection plan, the team decided that only one aircraft will be needed to complete this mission. In addition, it will be following a pattern that is similar to the Zamboni pattern. Since the aircraft is performing both mapping and searching for degradation, its detection pattern has been modified significantly in order to maximize its capturing accuracy. Due to constant changes in water movement, the team decided that overlapping images would be the optimal option in regards to gathering the most accurate data.

Current coral reef monitoring techniques range from satellite data gathering to underwater transect monitoring. Although the idea and traditional approach would be through multilevel sampling which is detailed to an extent, remote sensing through the usage of UAVs can offer opportunities to gather information over larger areas effectively and time-efficiently compared to mainstream on-the-spot surveying of coral reefs, where only limited information can be collected in specific areas. Through remote sensing, data from observation can be used to help monitor changes in the coral reef and distinguish between anthropogenic and natural effects in the health of corals. Ultimately, remote sensing is a productive and efficient method for monitoring coral reef areas that are distant or intensively used. This also offers a more cost-effective method when compared to a conventional, intense labor field survey approach.

Another innovative way of approaching this problem could be through the usage of satellite imaging, but the truth behind satellite imaging is that it is lacking either the spatial or spectrum resolution aspect of precision and productive detection for mapping coral reefs and monitoring the health status and vitality of coral reefs. However, hyperspectral UAV sensors have both the capability of high spatial and high spectral resolution, which contribute to the general UAV approach of not only mapping coral reef areas but also identifying damages in coral reefs. As an addition, the Cruiser is also able to survey areas along the coast or beaches where humans are not allowed to fish, dispose waste, or be using any form of water transportation. The team calculated an approximate cost of $3,500 per 1x1 mile area of detection that is conducted.

The final commercial application that can be conducted by the Cruiser is forest fire monitoring and search and rescue. Since the system requirements and costs remain the same, the team decided to combine these closely-related applications. The Normalized Multiband Drought Index that is equipped by our sensor payload allows the Cruiser to both moisture and solid content even through visual obstructions. Because of the IR Flash and Pix4DMapper programs and our communication/data transmission equipment, images and videos that are captured under the SWIR spectral range are able to be transmitted directly to the team's ground base and servers during real-time. This will provide extreme aid in preventing forest fires as well as indicating specific areas in which the fire started. Like forest fire monitoring, which occur only at some time, the team wanted to utilize the Cruiser to not only come to the rescue for the environment but for humans as well. The original Cruiser, without any modifications from this challenge, is able to provide humanitarian aid such as performing search and rescue missions that is in compliant with FAA regulations.

In terms of its versatility, the Cruiser is an aircraft that is unmatched when compared to existing UAVs or conventional methods done for agriculture, research analysis, or even humanitarian aid. Its large payload capacity in terms of its weight, low vehicle cost, and superior sensor payload allows it to achieve more than the RWDC challenge statement. It constitutes an understanding of the many possibilities that can be performed by a single innovation. With the Cruiser, solutions beyond water conservation and food production can be addressed and solved.

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