PECAM

Practical Engineering for Computations in Agricultural Models
Submitted in Response to the Real World Design Challenge

Submitted by

Flight 01890

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Tyler Clift	*Roy Xing*	

ABSTRACT

Introduction: With the notion that incorporating UAVs (Unmanned Aircraft Vehicles) or UAS (Unmanned Aircraft Systems) in agriculture provides efficient, convenient, and safe multipurpose tools to farmers, the market for these vehicles is quickly developing in the United States. In order to produce an optimal UAS, we designed our vehicles with efficiency in mind. We sought to produce a system of vehicles that could survey and apply SOLVITAL as quickly and thoroughly as possible. In order to maximize efficiency, we made a number of design decisions that would make the product more attractive to a typical farmer.

Conceptual Design: We began the design process by drafting a number of ideas, sharing amongst the team and assessing them for practicality. We were eventually able to slim down our portfolio to our three favorite designs and present them to our mentor. He offered suggestions, and we ultimately decided to pursue a design that would incorporate aspects from several different design drafts. From there, we determined which FAA regulations would be necessary to follow. After the state challenge, we decided to completely reevaluate our design, even investigating the possibility of pursuing a system of different vehicles. We started the design process over, developing new design ideas and proceeding to share and evaluate them for efficiency.

Preliminary Design:
During the preliminary design phase, we tested different propeller sizes, batteries and frame configurations. After running into an issue with insufficient thrust, we were forced to throw away our initial preliminary design. Another possible design consisted of a hollowed out frame containing SOLVITAL, which was distributed amongst the nozzles at each of the six motors. In selecting a propulsion system for our aircrafts, our analysis revealed that a gas-propulsion system would simply take up too much space with no increase in energy efficiency, so instead, we chose to use electric motors. For the State Challenge, we decided on a system of “Sentinel” hexacopter UAVs that would simultaneously survey and spray affected areas of the field. With the ability to hover and follow complex paths, we found that the hexacopter would be able to apply pesticides very efficiently. Our service would assess the farmer’s land to determine how many vehicles would be needed, then lease them to the farmer for a monthly price. For the National Challenge, we decided to add a new UAV to our fleet. Dubbed “Scout,” this fixed-wing plane would be solely responsible for surveying the field at maximum efficiency. We found that the fast-moving Scout would be able to survey much more quickly with a lower expenditure of energy. We could then take the survey data, run it through some programs to analyze affected areas, and use the resulting map to direct a pair of Sentinel units to distribute SOLVITAL.

Detailed Design:
Our final Sentinel design consists of a slide-in compartment that automatically opens and closes the valves in a tank that is partitioned into six regions, each feeding the nozzles located on the six rotors. Our electronics are all located in the airfoil enclosure that reduces drag at higher speeds. Our drones are completely autonomous with our proprietary software that is capable of tracking the aircraft, coordinating missions, saving battery by intelligently cutting out motors, and regulating speed to match the amount of thrust required for variable weight. The main function of the software, however, is to keep the workflow continuous and to facilitate communication between the different drones. Sentinel’s frame is 1.3 meters in length and carries a 25-kilogram payload, relying on six Tiger Motor U11 120kv U-Power Professional Motors to generate thrust. Each rotor has four blades, each being 0.343 meters in length and situated below the payload, allowing for gravity feeding of pesticide into the chambers above the nozzles. With this design, we were able to beat our primary competitor, the DJI Agras mg-1 by surpassing it in value and performance.

Scout’s wingspan of 1.2 meters, combined with the simple fuselage design, allows it to perform vertical takeoff and landing (VTOL). To provide for the best surveying results, the aircraft is equipped with a RedEdge-M camera with an 8 cm/px GSD and a variety of different options for a thorough assessment of crop health and infestation levels. An Intel NUC onboard computer is also included to facilitate all necessary calculations and image processing to determine, with the use of our algorithm, the shortest path for the sprayer drones to follow. Scout also features the implementation of an algorithm known as NanoMap that enables the aircraft to almost never crash, even if it begins to drift and uncertainty compounding arises from the continual use of its sensors.

Keywords: [VTOL, User-Friendly, Autonomous, Gravity Feed, Algorithms, Safety Protocols, Stabilization]

Specification Sheet

Survey Aircraft				
Criteria	Value	Regulations	Compliance	
			Yes	No
Takeoff Weight	8.933 kg	Unmanned aircraft must weigh less than 55 lbs. (25 kg).	V	
Wingspan (fixed-wing) or Max Width (other)	1.20 m			
Airspeed	16 - 32 m/s	Maximum airspeed of 100 mph (87 knots)	V	
Altitude	400 ft	Maximum altitude of 400 feet above ground level	V	
Time in Flight	64 min.			
Distance Traveled	~122.8 km			
Number of aircraft per operator	1	No person may act as an operator or VO for more than one unmanned aircraft operation at one time.	V	
		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.		V
		Small-unmanned aircraft may not operate over any persons not directly involved in the operation.	V	
		Daylight-only operations (official sunrise to official sunset, local time).	V	
		Must yield right-of-way to other aircraft, manned or unmanned.	V	
		Minimum weather visibility of 3 miles from control station.		V
		No operations are allowed in Class A (18,000 feet & above) airspace.	V	

Spraying Aircraft				
Criteria	Value	Regulations	Compliance	
			Yes	No
Takeoff Weight	24.251 kg	Unmanned aircraft must weigh less than 55 lbs. (25 kg).	V	
Wingspan (fixed-wing) or Max Width (other)	1.18 m			
Airspeed	15.823 m/s	Maximum airspeed of 100 mph (87 knots)	V	
Altitude	9.505 m	Maximum altitude of 400 feet above ground level	V	
Time in Flight	44 min			
Distance Traveled	41.773 km			
Number of aircraft per operator	2	No person may act as an operator or VO for more than one unmanned aircraft operation at one time.		V
		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.		V
		Small-unmanned aircraft may not operate over any persons not directly involved in the operation.	V	
		Daylight-only operations (official sunrise to official sunset, local time).	V	
		Must yield right-of-way to other aircraft, manned or unmanned.	V	
		Minimum weather visibility of 3 miles from control station.		V
		No operations are allowed in Class A (18,000 feet & above) airspace.	V	

1. Team Engagement

1.1 Team Formation and Project Operation

Our team is comprised of five students from Winchester High School, all of whom share an interest in applications of math, science, engineering, and technology in the real world context. Jennifer and Valeriy are returning to the challenge while Sam, Tyler, and Roy are new participants.

All team members are current seniors attending Winchester High School in Winchester, Massachusetts. Throughout the challenge, we have spent time both during and outside of school hours brainstorming ideas and working out solutions to problems. We had long weekly meetings, spent discussing viable design solutions, along with periodic conference calls to check on our progress and occasional extended work sessions which ranged from eight to twelve hours. We also used social networking to keep each other up to date on our progress.

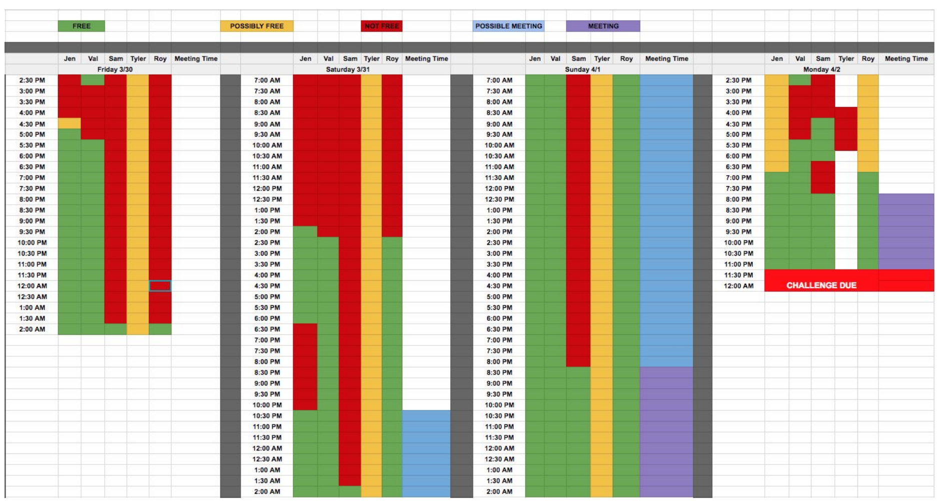


Figure 1: Spreadsheet to Organize Team Meetings

The team was divided into three different sub-groups to maximize productivity:

- <u>Design Team</u>: Focused on analyzing design parameters and designing the aircraft itself.
- <u>Engineering Team</u>: Focused on working with CAD to create and test designs.
- <u>Business Team</u>: Focused on calculating the cost, analyzed cost-efficiency, protected our ideas, and researched for additional applications of the aircraft.

Each member took on different roles to utilize his/her unique skill sets:

Jennifer is the team leader, a two-year veteran of the Winchester HS RWDC team, and an enthusiastic business analyst. As the most knowledgeable member of the team, regarding challenge procedures, she organized the logistics of the team and made sure every team member was involved in their assigned roles of the challenge. Also, as a business analyst, she utilized her experiences from various business competitions and projects, opting to write the business section and draft the market assessment. In addition, she utilized her programming skill in R -- programming language/software environment for statistical computing and graphics -- for the national challenge in order to add mathematical layers to the team's proposed operational algorithms. She also learned CAD modeling using Solidworks to help the team to create a new UAV that was added to our UAS.

Valeriy led the design team as the chief designer and returned to the challenge for a second time, participating for the first time in his freshman year. During the national round of the challenge, Valeriy was mostly involved in mathematical modeling and the development of the path-finding algorithms at the center of our detection plan. He combined concepts from many different disciplines of statistics, calculus, and graph-theory in order to drastically improve the efficiency of the mission. He frequently used Python scripts to make sense of large datasets with a variety of visualization tools. For the state challenge, he helped create different concepts for drone designs and tested their advantages. Coming from a computer science background, making the transition into material design seemed like an insurmountable challenge at first. However, as the challenge progressed, Valeriy utilized his experience in different disciplines of math and science, as well as the iterative development cycle that is critical to writing code, to create computer-animated renderings of the drones, mathematical and analytical interpretations of the mission, and innovative ideas that helped to perfect the design.

Sam was the head simulator and one of the engineers on the team. He was involved in conceptualizing UAV designs, determining the size and detailed information regarding flight (altitude, speed, etc.) as well as developing the airfoil specifications for the drones based on extensive simulation and testing. He was also responsible for most of the preliminary and conceptual sketches, as well as solving any of the design's physics problems such as determining the optimal spray radius for Sentinel (our spraying drone). Working together with Roy, he chose the most effective parts for the UAV and also ran calculations pertaining to the required RPM, number of propellers and other factors given the UAV's necessary payload and weight. With his knowledge of physics and penchant for novel ideas, Sam helped both with creating initial designs and running the numbers to turn PECAM into a competitive product within the industry.

As a business analyst and editor, Tyler focused on brainstorming and refining marketing strategies and alternative mission applications as well as editing documents and communicating with outside resources. He also developed ways to maximize revenue through different sales plans and was responsible for the more introductory portions of the document. Tyler organized the powerpoint for the National Challenge, taking the technical design notebook and reducing it to a comprehensive and cohesive summary of our product and its innerworkings. He was also really involved in providing other members feedback regarding their contributions and assisted them in overcoming design obstacles.

Roy was the engineer of the team, working on a variety of problems, ranging from figuring out how the drone would work from an electronics standpoint to the amount of thrust needed to lift it off the ground. He was responsible for the introduction of new ideas, such as the VTOL fixed wing drone and the advantages and disadvantages of such systems. Roy was also responsible for researching and implementing new algorithms and systems, such as NanoMap. Utilizing his familiarity and knowledge of electronics, Roy headed all related portions of the project, from figuring out how the motors and batteries would work to the function of IMUs. Working together with Sam, he chose the most effective parts for the UAV and also ran calculations pertaining to the required RPM, number of propellers, and other factors given the UAV's necessary payload and weight.

1.2 Acquiring and Engaging Mentors

Mentor 1 Name:	Joel Pedlikin
Company / Position:	COO of GreenSight (http://greensightag.com/)
Initial contact:	We communicated with Mr. Pedlikin via email back in August, expressing our interest in getting his help. We were initially connected with him through a contact from a robotic lab visited by Jennifer.
Follow up:	Mr. Pedlikin offered his entire team of engineers to assist and mentor the team.
Role:	When we were unsure of an answer to a prominent question in the design process, and could not solve it on our own, we reached out to Mr. Pedlikin for help. Although he had some useful answers, he was very slow to respond to our inquiries so we had to find alternative solutions ourselves or engage other mentors. We attempted to find a time to meet with Mr. Pedlikin and his team in person, but again were met with a late response and were unable to coordinate a time.
Questions:	• Can we lower the rotors below the payload? • What is the best battery for extended flight/ potential energy conservation options? • Nozzle pressure/gravity strain on the frame? • Cost of Production for DJI Agras mg-1 parts?
Final thoughts:	We found that Mr. Pedlikin was, at times, a good resource, but we had to find someone else who was more readily available to answer questions.

Table 1: Mentor 1

Mentor 2 Name:	Jaehyeok Kim
Company / Position:	Aerospace Engineering Major at Purdue University
Acquiring the Mentor:	Jaehyeok (Jefferson) is a Winchester High School alum and participated in the challenge in previous years. He is currently studying Aerospace Engineering at Purdue University (West Lafayette, Indiana). We asked him for assistance and clarification on a few points in the challenge and he was happy to help.
Role:	Jefferson provided assistance with Computed Aided Design. He also offered us his opinions when we had other questions that Mr. Pedlikin was unable to answer. Jefferson was studying in Indiana throughout the challenge, but was more readily available than Mr. Pedlikin to answer any quick questions that we had.

Table 2: Mentor 2

1.3 State the Project Goal

In this year's challenge, we were asked to develop a system of UAVs that would survey and apply pesticides to a plot of land for a typical farmer. Our goal was to create a design that would potentially ignore certain FAA regulations in order to be as efficient as possible. We also had to figure out what a typical Massachusetts farmer would want and need in a surveying service. We wanted to create a system of UAVs that was marketable to a typical farmer, but also scalable to be used commercially. This meant that we would make a minimalistic design, sleek and attractive in its construction, but impressively powerful in its performance; resulting from innovations to the conventional drone designs and protocols on the market rather than just more expensive components. We focused on making our drone user-friendly and reasonably priced, but also profitable for the firm. In short, the ultimate goal of our team was to build an incredibly capable product and provide an accompanying service, as detailed in this notebook, which will benefit our customers and generate revenue.

1.4 Tool Set-up/Learning/Validation

Software used: CATIA → SolidWorks

- With the help of one of our mentors, we were able to install and use CATIA to Computer Aided Design (CAD) our UAV designs.
- We had difficulty with compatibility between Macs and PCs, especially with CAD programs.
- CATIA does not allow multiple computers to collaborate simultaneously, so we were forced to work on one computer when working with this program. We ultimately resolved this problem by switching to SolidWorks.
- Shortly before the deadline, we ran into an issue with CATIA that forced us to switch our CAD program to SolidWorks. This was a major setback, as we were unable to transfer some of the details of our design to the new program.
- We were very inexperienced at the start of the challenge but learned a lot about CAD throughout by viewing tutorials and getting help from Jefferson when stuck.

1.5 Impact on STEM

Jennifer:

"The RWDC challenge helped me expand my knowledge in the STEM-related business field. I have been interested in this area since I was in 6th grade; however, I never had an opportunity to show or apply my skills. From this year and past years' experience, I learned how to apply my knowledge and skills to real life. Interactions and cooperation with the team members also helped me understand more about working with a small group to accomplish a common goal. Though we faced many challenges throughout the process, we were able to become self-sufficient, with some help from the mentor, and utilize each team member's specialties and interests. Overall, the RWDC was a great way to augment my interests and, with a real-life experience under my belt, ensure that I continue to pursue them in the future."

Valeriy:

"Throughout my participation in RWDC over the years, I have gotten to appreciate the scale of engineering projects and just how much goes into developing each aspect. The interdependence of each part and the weight of each decision in design is something that stood out to me in this challenge. RWDC and, by extension, other design projects allow you to directly see your progress and how, through each small problem that you solve, you get one step closer to creating your final solution. Seeing a variety of different disciplines come together in order to tackle exciting, non-traditional, and meaningful challenges was also a highlight of this experience. I consistently found myself utilizing concepts learned at school, previously labeled as "too abstract" or useless, and basing my solutions on them. Although aerospace engineering is most probably not going to be my primary concentration in college, I feel like the different components of the design process have reinforced my interest in STEM. Being able to create an elegant CAD design, applying mathematical concepts outside of a worksheet or test context, and writing a comprehensive business report are all takeaways from this challenge that will not only aid me in my future academic interests but also my career."

Sam:

"The Real World Design Challenge allowed me to both explore the world of STEM and gain a more in-depth understanding of the processes and details that go into design and engineering. I was able to apply my knowledge of physics and mathematics outside the classroom and explored a number of computer resources (SolidWorks, NASA Foilsim, etc.), both reinforcing my STEM education with real world applications and expanding my knowledge of the industry. RWDC was the vehicle through which all this was made possible, giving me an organized challenge, a clear goal, and a talented team of peers to work with. I learned what it took to put together such a large-scale project with a group. We had to delegate roles and workloads and meet preset deadlines. Organization was absolutely paramount and everyone had to carry their weight lest the whole project fall apart. Throughout this process, I learned about all the sides of working in STEM that were not covered in the classroom: the team building, documentation, communication and industry research that were key to our participation in this challenge. STEM never takes place in a vacuum and this could not have been more clearer through my experience with RWDC."

Tyler:

"The RWDC allowed me to see a number of different parts of STEM in action, and to consult with mentors who actually deal with engineering in real life. I learned how to collaborate with others more effectively by listening to ideas, expressing my opinion, and offering constructive feedback. The challenge also expanded my knowledge base in programs like CATIA, and made me interested in using CAD in the future. The challenge has taught me about the design process as well, and how to deal with failure in the world of design. RWDC has given me skills that I can apply in real life, as well as increasing my interest in the STEM field. What stood out to me the most, however, is the creative freedom that the challenge's logistical nature provides. Because there are no established, physical limitations to what your drone can and cannot accomplish, there are so many ways that a group could go about solving the challenge. This encourages the team to experiment and take risks without punishing consequences, allowing for many groups to come up with their own innovations and novel additions. Throughout the challenge, I gravitated towards certain aspects of the challenge more than others and this has helped me decide which avenues to pursue in my academic and professional future.”

Roy:

“The RWDC enabled me to tackle a problem from the real world and truly experience the number of calculations and pre-planning needed for engineering problems. By allowing me to fully experience and address such challenges head-on gave me a better insight into other aspects of engineering and solving problems that the people in the real world actually face. RWDC also taught me direct communication and working with people in charge of different aspects such as business. It was also my first time making a complete engineering notebook and being in charge of planning. In comparison to my experiences in other engineering challenges, I had the freedom in not worrying about extremely small budgets available to high school students, allowing me to develop my ideas and designs without monetary limitations. The experience is one that I will continue to refer to as a cornerstone in my path to becoming an engineer.”

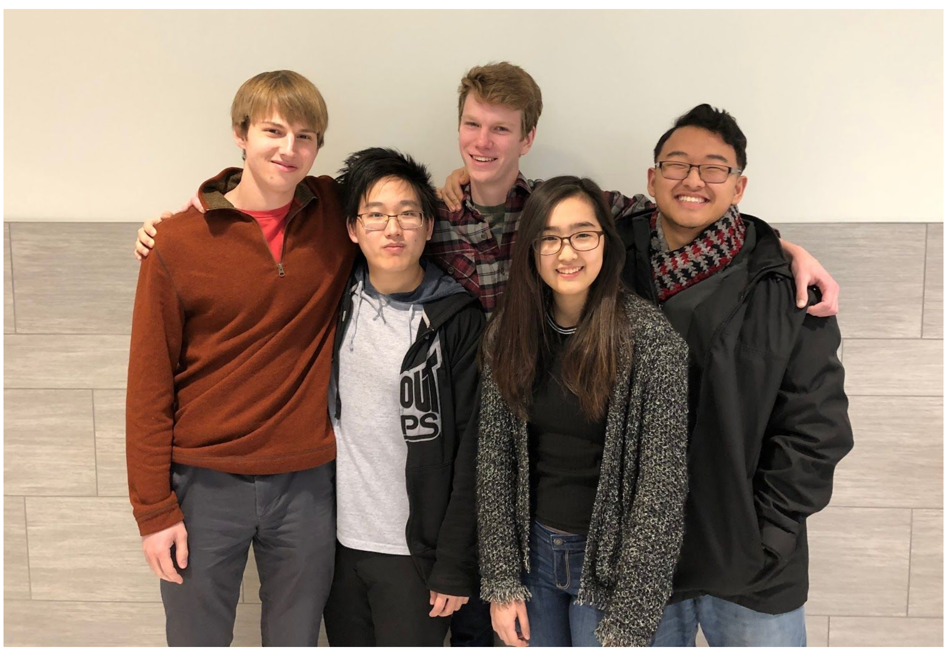


Figure 2: Members of Team Flight 01890

(From Left to Right) Valeriy, Roy, Tyler, Jennifer, and Sam

2. Document the System Design

2.1 Mission Design

2.1.1 Aircraft Compliance with Part 107

FAA Part 107 Regulations: Operational Limitations In Compliance | Not in Compliance | Not Applicable	**Team's UAS Design**
Unmanned aircraft must weigh less than 55 lbs. (25 kg).	**Scout**: Total mass for the drone is **8.933 kg** **Sentinel**: Total mass for the drone (including SOLVITAL payload) is **24.251 kg.**
Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within VLOS of the operator or visual observer.	Farmers are only responsible for replacing batteries and some initial setup. Our UAS is mostly autonomous and extremely user-friendly. However, it is required to go beyond the operator's range of visibility to fulfill its mission and maximize performance.
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.	
First-person view camera cannot satisfy "see-and-avoid" requirement but can be used as long as requirement is satisfied in other ways.	Our designs do not include a first person camera that captures the view in which the drone flies since our UAVs do not require any mid-flight intervention from the farmers. Scout does however have a camera mounted on its rear, pointing towards the ground when the drone is in a vertical position for landing purposes.
Small unmanned aircraft may not operate over any persons not directly involved in the operation.	Typically, corn fields are not located in residential areas. The sensors should also be able to recognize obstacles or hazards (such as people) when landing and actively avoid them.
Daylight-only operations (official sunrise to official sunset, local time).	The team agrees that daylight operations are safer and will provide more accurate results when surveying.

	Must yield right-of-way to other aircraft, manned or unmanned.	
	May use visual observer (VO) but not required.	The presence of a VO would not impact our UAS's performance as our system is designed to be fully autonomous in flight.
	Maximum airspeed of 100 mph (87 knots).	**Scout**: Our design's maximum cruising speed is **71.582 mph** (62.203 knots). **Sentinel**: Our design is able to attain a maximum speed of **35.395 mph** (30.757 knots)
	Maximum altitude of 500 feet above ground level.	**Scout**: Flies at **400 ft** above ground level. **Sentinel**: To ensure effective pesticide application, Sentinel will fly at a maximum of **9.507 m** (31.2 ft) above ground level.
	Minimum weather visibility of 3 miles from control station.	Both our UAVs are designed to operate only within one quadrant of the field at a time as given in the FY18 National Challenge field layout. Thus, the UAV would travel, at most, a distance of 1.4 miles from the farmer. The farmer will also be able to drive around the area if they wish to do so, keeping within the drone's flight range. Even though our drone will not be visible in poor weather conditions, our software always keeps a record of its last position, drastically simplifying the drone recovery process.
	No operations are allowed in Class A (18,000 feet & above) airspace.	Our drones do not benefit from or have the specifications to achieve flight above 18,000 ft.
	Operations in Class B, C, D and E airspace are allowed with the required ATC permission.	Typically, corn fields are not located near airports.
	Operations in Class G airspace are allowed without ATC permission	Our UAV will fly below 14,500 ft without Air Traffic Control permission since we will be operating in rural areas.
	No person may act as an operator or VO for more than one unmanned aircraft operation at one time.	For our design, we intend to have Scout survey one quadrant of the field, then survey the next as Sentinel sprays the first. Therefore, with the exception of Scout's first surveying flight, and depending on the intensity and distribution of infestation (which determines Sentinel's flight speed), much of our UAS's survey/spray process would involve both UAVs flying simultaneously.
	No careless or reckless operations.	

	Requires preflight inspection by the operator.	The farmer will have to check each UAV before flight, refilling the SOVITAL tank or changing batteries when required. The farmer will also have to calibrate the cameras on Scout and replace or charge its batteries when necessary.
	A person may not operate a small unmanned aircraft if he or she knows or has reason to know of any physical or mental condition that would interfere with the safe operation of a small UAS.	
	Proposes a microUAS option that would allow operations in Class G airspace, over people not involved in the operation, provided the operator certifies he or she has the requisite aeronautical knowledge to perform the operation.	Our team is targeting a demographic comprised of farmers that have a range of aeronautical knowledge and expertise. Considering that anyone can buy a commercial autonomous drone, the farmer should be able to supplement his/her agricultural or recreational purpose just like any other consumer. We do not believe in any barriers to purchase of our product as we have certified that PECAM is safe enough to be used within Class G airspace with minimal oversight.
	Pilots of a small UAS would be considered "operators".	

Table 3: FAA Part 107 Regulations vs. Team's Design

2.1.2 Justification of Regulatory Compliance

The first FAA guideline that we were not able to adhere to was the VLOS restriction. Our goal was to provide a smooth and novice-friendly user experience that did not hinder the user's everyday workflow. The farmer does not need to keep the drone within their line of sight except for maintenance, recharging, and refueling. Our proprietary software monitors the drones at all times with a live feed of their status and pinpoints their location. Therefore, we concluded that there was not sufficient justification to include additional functionality to allow the consumer to view our aircraft three miles away from the control tower. As part of our communications network between the user and the system of drones, everything that our consumers would need to know about the status of the aircraft and the completion of objectives can be easily found as part of the user interface. The only function that the farmer has to serve is to drive their car around the perimeter of the fields to intercept the drones for landing if need be. The UAVs' flight paths will be predetermined by our software. Furthermore, we deemed it sufficient to have only one farmer operate our system of drones (in which multiple drones will be in flight simultaneously). This would allow us to better reach out to our prospective demographic, which includes farmers working on smaller-scale agricultural plots and enterprises that do not have as many workers. We achieve this by having our drones be almost completely autonomous. The last restriction that we broke was bypassing the requirement for our customers to have certification in aeronautics. We strongly believe that if consumers can buy drones for purely recreational purposes, our customers that reside in rural areas should be able to use our drones for agricultural reasons. Operation is very streamlined and minimal instruction is needed, so to require official certification would create a deadweight loss of farmers who would clearly benefit from PECAM but would be deterred by the certification requirement.

2.1.3 Design Operations

We decided to utilize a system of drones consisting of one fixed-wing UAV for surveying and two hexacopters specialized for spraying to accomplish our mission. Initially, the surveying drone scans the field for areas of infestation and automatically processes the data collected with the help of proprietary software. As it returns to the ground vehicle to recharge, the onboard computer goes through several iterations of our distance-minimization algorithm [section 3.1.1]. Then, one of the sprayers is deployed at a starting position determined by the algorithm. The drone follows the pre-calculated path until only enough battery is left for the sprayer to fly back to the ground vehicle or the SOLVITAL reserve is effectively depleted. At that point, the first sprayer communicates its position to the second sprayer, which is on standby. Then, the second sprayer flies to the last position of the first sprayer and the mission is resumed with minimal interruption. Batteries are switched out by the user and recharged at the docking station located on the ground vehicle.

2.2 Conceptual, Preliminary, and Detailed Design

2.2.1 Engineering Design Process

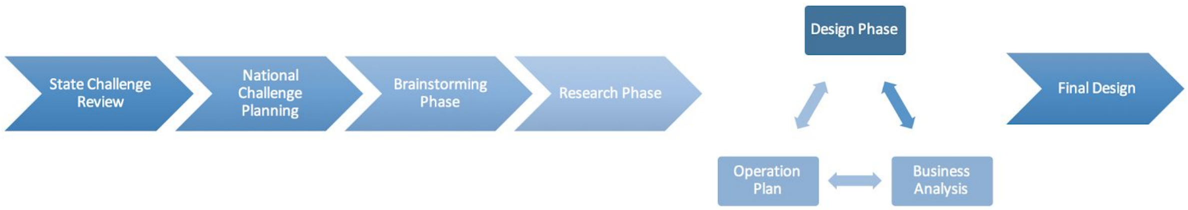


Figure 3: Team Flight 01890's Engineering Design Process

The team utilized the Engineering Design Process in order to design a UAS comprised of the most efficient, safe, user-friendly, and affordable UAVs. Each member of the team familiarized themselves with the key aspects of this year's challenge and researched a variety of drones already available on the market and the regulations that restrict their use. As the team worked through the brainstorming and research phase, we were soon faced with the dilemma of being stuck within the design phase, operation plan, and business analysis. This issue was largely due to the fact that certain values and variables were unable to be determined without knowing the other factors from different parts of the engineering design process, creating an unfortunate loop of inconvenience and an impasse in development. When the team faced this issue, we dealt with it by discussing possible solutions amongst the team and making executive decisions to simulate or run the numbers to test them out. During the design process, the members got together and proposed potential/conceptual designs, elaborating on each one and rejecting others to create a preliminary design. When these concepts were tested in theory and failed, we went back to see which adjustments were required or moved on to the next idea. Before finalizing and creating computer-aided renderings of the final design, the team verified that the system met the technical requirements and complied with the FAA regulations, justifying any violations. We made sure to double check the calculations and the execution of the theoretical operation during the detailed design phase.

2.2.2 Conceptual Design

During the state challenge, we initially considered a variety of different design options. At first, given the challenge's flexibility in allowing teams to determine the merit of FAA regulations, we thought that we could create a "no-compromises" design, selecting components regardless of price and the design philosophy revolving around producing as much power as possible. In short, we wanted to showcase an aircraft that was not held back by any restrictions. Our initial design ended up being an all-in-one, fixed-wing design, equipped with cutting-edge specs for both camera and spraying capabilities, that would be able to carry the whole payload in one flight without having to refuel. The idea completely disregarded cost-efficiency, was not a marketable product, and was not in the spirit of the challenge. The regulations are created for a reason, and we changed our goal to instead see where compromises could be made.

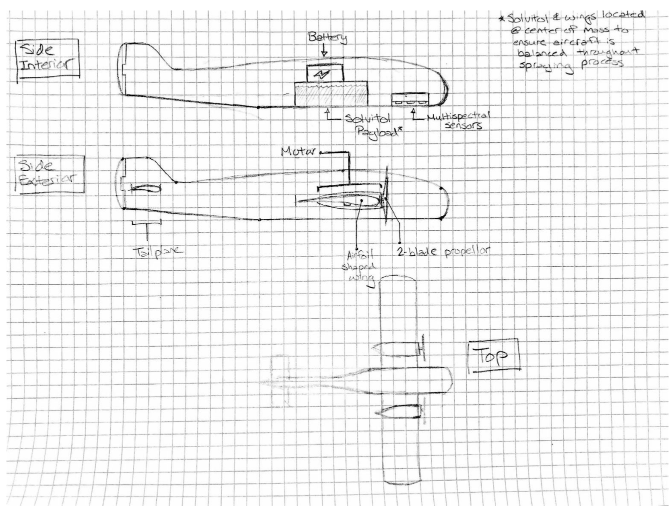


Figure 4: Fixed-Wing Conceptual Design

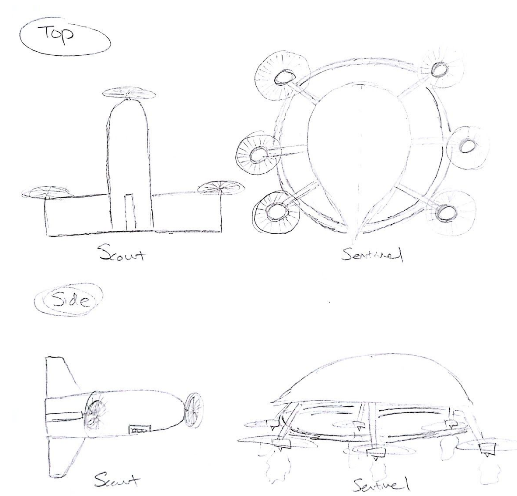


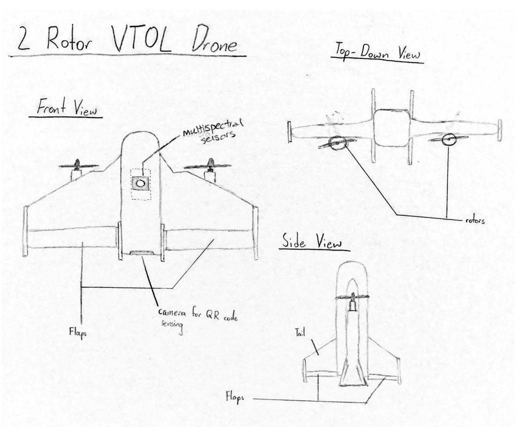
Figure 5: Both PECAM UAVs

With the changes made for the national challenge in mind, the team decided to redesign the UAS. Rather than having three identical multirotor drones that are tasked with surveying and spraying the field, we created a system comprised of two specialized drone types: one fixed-wing surveyor drone and two identical multirotor sprayer drones to complete the mission.

2.2.3 Preliminary Design

Surveying: After researching extensively, the team discovered that fixed-wing drones have an edge over mapping and Geographic Information System (GIS) compared to multirotor drones. Therefore, to increase efficiency -- in terms of speed, flight time, and other factors -- the team decided to design a new fixed-wing drone, now and hereafter referred to as “Scout,” for surveying purposes as part of the national challenge. To streamline the takeoff and launching mechanisms, the team decided on designing a Vertical Takeoff and Landing (VTOL), fixed-wing, drone for surveying. Scout’s capability of VTOL makes it a very portable and convenient method for surveying. Scout will take off vertically, perpendicular to the ground, and then turn, transforming its position to being parallel to the ground. It will complete its mission flying as a fixed wing aircraft and then, when landing, return to its perpendicular orientation with respect to the ground and descend as if it were a rotary drone.

We considered three different types of VTOL drone models with different numbers of rotors:

	Allows for the basic setup needed in order to perform vertical takeoff and landing, leading to a simple and elegant design. **Figure 6: 2 Rotor VTOL Drone**

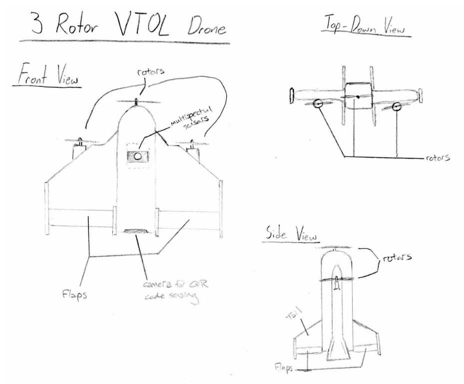
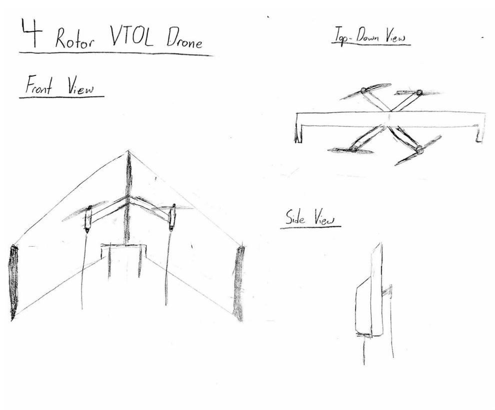
	Allows for more thrust when flying as a fixed-wing drone, but leads to difficulty when transitioning from vertical liftoff to parallel flight. **Figure 7: 3 Rotor VTOL Drone**
	Allows for, theoretically, the most stable takeoff and landing, but drains the battery more, resulting in a bulkier frame. **Figure 8: 4 Rotor VTOL Drone**

Table 4: Comparing VTOL Models

Considering these different types of VTOL models, we concluded that a 2 Rotor VTOL drone would be the most suitable base model, as we found the increased thrust provided by the third propellor would not be worth the drawback of decreased battery life. By adding more rotors, we also found that turning midair would prove to be marginally more difficult along with providing poor efficiency for the system. Our goal with the VTOL drone was speed, but most importantly efficiency and convenience for the farmer. We set out towards this goal initially with the concept of a VTOL drone itself, so that takeoff and landing would be streamlined and require very little input by the farmer him/herself. When the drone is running near the end of its 1.07-hour battery life, it will fly back to where the farmer and ground vehicle are; the farmer will then need to swap out its batteries with extra batteries (provided), allowing the drone to continue its surveying mission.

Spraying: For the distribution of pesticide, the team decided to use two hexacopters. With the aid of simulations, we carefully considered many models during the state challenge, concluding that a hexacopter design would provide enough thrust for our calculated payload and the precision necessary to spray pesticides efficiently; making it the most suitable solution.

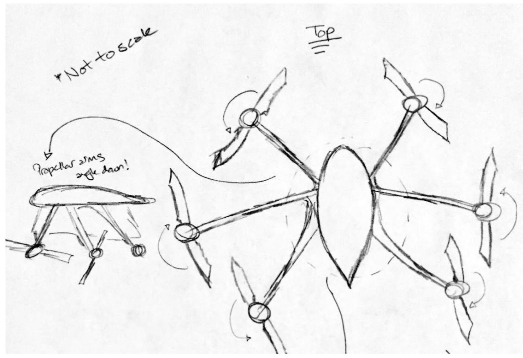


Figure 9: Preliminary Design-- Top and Side View

Elaborating on the hexacopter design, the team decided to use gravity feeding and gravity-assisted pumps to supply the SOLVITAL for spraying. The absence of a system wholly relying on a pump means that the fluid simply falls down the tubes to the nozzles, placed directly below the rotors to maximum spray coverage, and is accelerated by a pump with an extremely low energy cost of operation. To complement the simplified spraying protocol, the team developed a compartment that securely carries the payload, including the SOLVITAL container, three batteries, and other electronic parts above the rotors.

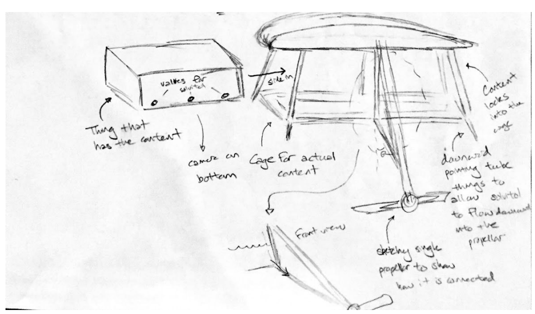


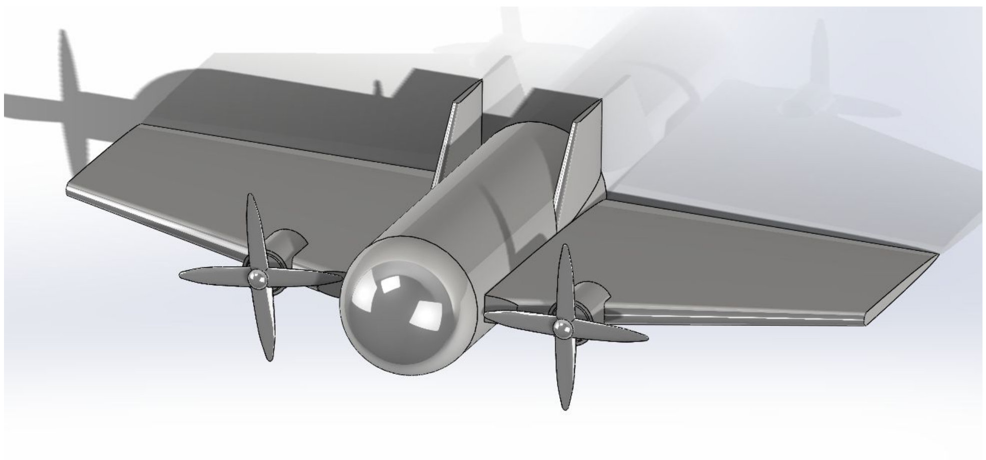
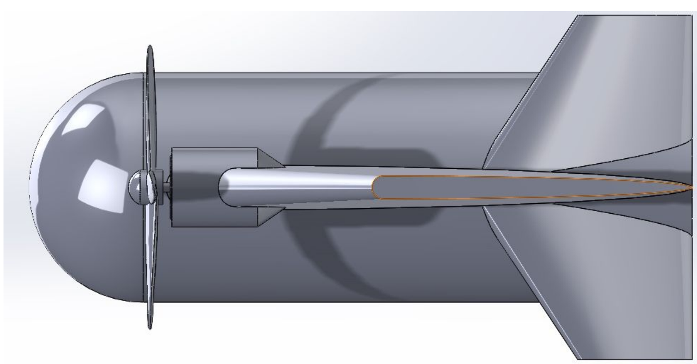
Figure 10: Elaborated Preliminary Design for the Payload Compartment

The team's redesign of the frame extended to the container housing the SOLVITAL reserve as multiple interior compartments were added to avoid the shifting of the center of gravity.

2.2.4 Detailed Design

Our finalized idea is an Unmanned Aircraft System (UAS) comprised of one VTOL fixed-wing drone for surveying and two hexacopters for spraying.

SCOUT: SURVEYING DRONE

<table>
<tr><th colspan="2">3-Views</th></tr>
<tr><td colspan="2">
[Front View]</td></tr>
<tr><td>
[Side View 1]</td><td>Unique motor mount design rather than embedding the rotor into the wing, maximizing aerodynamics while taking into account realistic wing design</td></tr>
</table>

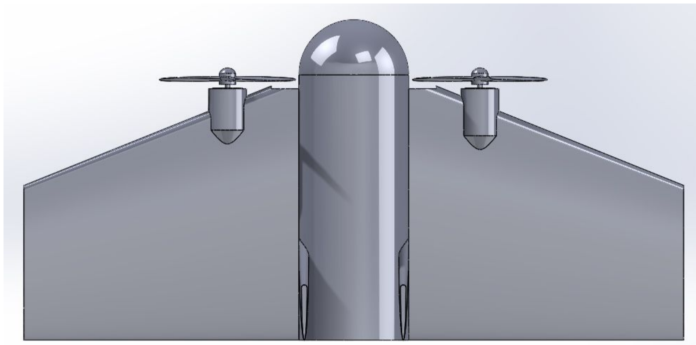
 [Top View]	*Following the general VTOL model shape, the motors are placed on the wings.*

Table 5: 3-View Diagram of Final Design of Scout

Payload (Cameras, Sensors, Computer): Scout will be outfitted with a top-of-the-line camera or the RedEdge-M from MicaSense, featuring a ground sample distance (GSD) of 8 cm per pixel (per band) at 120 meters and an adequate field of view of 47.2° HFOV. The RedEdge-M also provides a wide range of Spectral Bands — blue, green, red, red edge, near-IR— as well as a RGB color output of global shutter that is aligned with all of the previously mentioned bands. Scout will also feature a second camera, the X500 camera, on the back of its fuselage that will face the ground during vertical take off and landing. Its primary function is optical sensing of the landing pad, marked by a QR code that the onboard computer vision software will detect. Finally, Scout will house an Intel NUC computer, allowing it to run onboard calculations and process intaken data: dedicating most of its resources to finding the optimal spray path for Sentinel.

Rotors and Battery: Scout is outfitted with a Tiger Motor U11 120kv Heavy Lift Motor, which is rated at a higher rpm per volt than Sentinel's motors. To operate at our target level of efficiency, Scout needs to overcome the voltage limitations set by the LiPo 11,000 8S 29.6v Battery Pack as, normally, with a direct circuit, voltage output is not enough to generate enough thrust and sustain the motors: rated at 245 kv (kv ~ rpm per voltage). Because of this, we used a step-up DC-DC converter to increase the batteries' voltage output, allowing us to generate the ten kilograms of thrust needed to take off, maintain altitude mid-flight, and land safely.

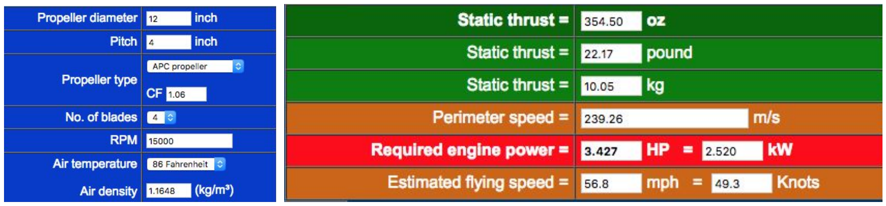


Figure 11: Static Thrust Calculation for Scout

The step-up DC-DC converter, also known as a boost converter, works with the use of a transistor switch, an inductor, diode, and a capacitor. By rapidly collapsing and recreating the magnetic field of the inductor by switching the circuit on and off, a voltage is generated and is forced to the rest of the circuit in parallel with the diode. The voltage is then stored in a capacitor connected in parallel to the circuit, thus stepping up the voltage.

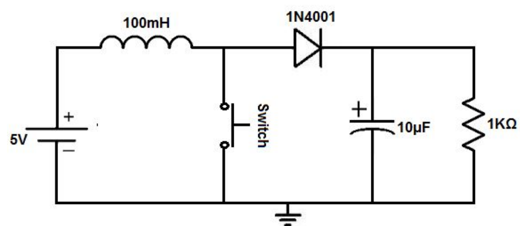


Figure 12: Basic Example Diagram of a Boost Converter

Unique Aspects of 2 Rotor Tail Sitter (VTOL) Transformer Drone: Scout is a VTOL-type aircraft, meaning that launching and landing are very convenient for the user. To launch, the farmer simply needs to set Scout vertically on the ground, and to land, the farmer uses a landing pad with a QR code that the drone can sense in order to land more precisely. Because of this, Scout requires a very small area for launch and, with how comprehensive the setup is (launching mechanisms and stands not required), the process is generally safer. It is also, by extension, made more portable as most elements required for takeoff are already integrated into the drone itself. Scout will begin its mission as if it is a rotary drone, utilizing its flaps to help stabilize it as it ascends. Then, using its flaps, the drone will flip itself from a vertical position to a horizontal one parallel to the ground, transitioning to its fixed wing mode. When Scout needs to land, it will use its GPS and IMU to roughly align itself in its landing location. It will then scan for a QR code using its X500 camera and use its flaps to reposition itself to its original vertical orientation; finally landing and stabilizing itself as it descends.

Frame: Scout's frame is made out of EPP (expanded polypropylene) foam, a durable, cheap, and light material that was a key factor in keeping Scout's weight as low as possible. EPP foam itself is physically flexible and has a been used in a number of different applications from drones to packing materials. For reinforcement, we used epoxy carbon fiber in strips and inner support frames along Scout's body. The fuselage houses all of our electronics such as the computer, IMU, electronic speed controller, and cameras. Scout's wings were designed based on optimal lift, with the help of an airfoil simulator, for when the drone is flying as a fixed wing aircraft. The wing is also where our rotors will be placed for thrust. The flaps not only control pitch, roll, and yaw, but also serve to physically stabilize Scout and keep the drone perpendicular to the ground during takeoff and landing.

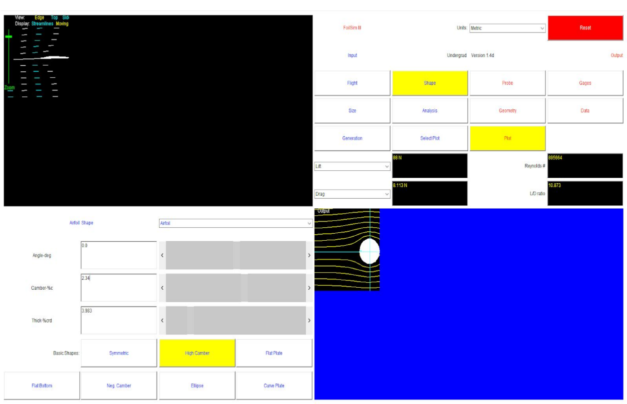
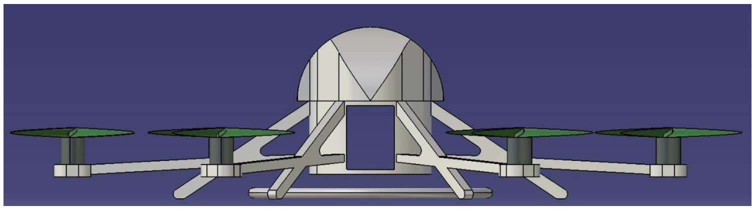
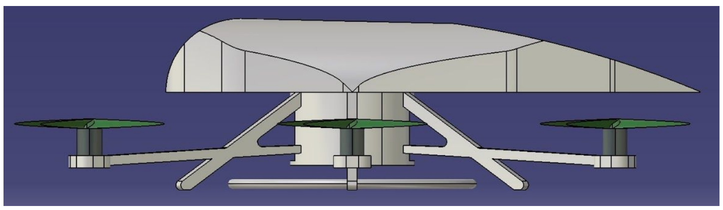
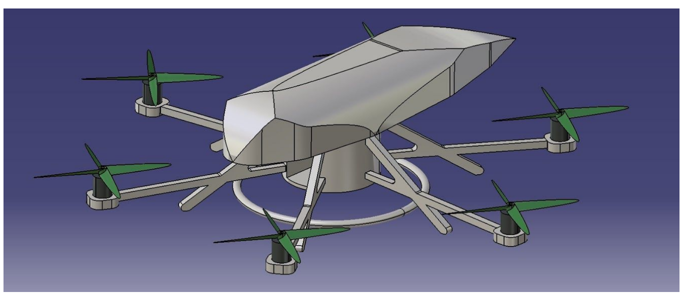
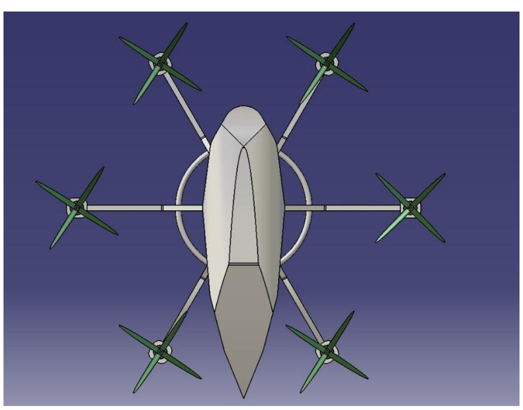


Figure 13: Size Specifications for the Airfoil

Figure 14: Shape Specifications for the Airfoil

SENTINEL: SPRAYING DRONE

4-Views	
 [Front View]	*The empty part shown is where the SOLVITAL and battery compartments are located.*
 [Side View]  [Isometric View]	*Payload is placed above the rotors, facilitating gravity feed spraying.*
 [Top View]	*Rotors are spaced apart in 60 degree increments*

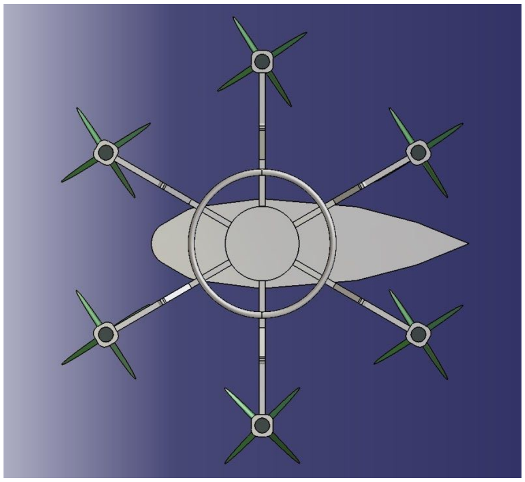
 [Bottom View]	*The circular frame at the bottom provides extra support for the rotor arms and acts as a landing platform.*

Table 5: 4-View Diagram of Final Design of Sentinel

The Compartment and Loading Mechanism: The modified payload compartment [Figure 15] slides into the main part of the drone and will hold three 5300mAh batteries and a tank capable of storing a maximum of nine liters of SOLVITAL. The implementation of an integrated circuit board and a built-in parallel connection for our batteries allows for the farmer to easily replace a new battery or tank when necessary. Since the batteries are in close proximity to one another, they will heat up with increased power draw. The case allows airflow in order to dissipate heat and prolong the battery's life cycle. The frame is custom-designed for the slide-in container and is primarily responsible for activating the valves that initiate the distribution of pesticide throughout the aircraft [Figure 16]. Each valve is activated by pushing in a switch, allowing the outflow of SOLVITAL. The frame itself is equipped with progressively deeper cuts starting from the innermost portion, much like a staircase, so that each valve is activated simultaneously. The smallest valve does not contact with the cage frame until it reaches its designated spot at the same time as all the other valves.

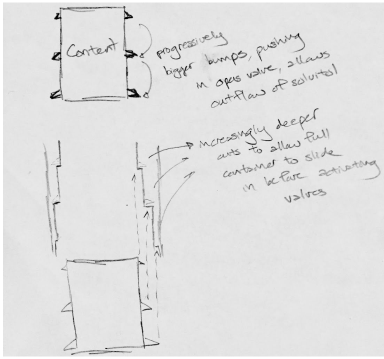


Figure 15: The Compartment & Loading Mechanism

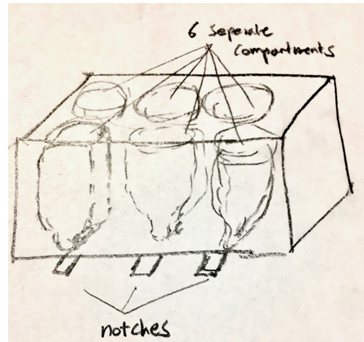


Figure 16: SOLVITAL Tank with Divided Compartments

This portion of the design emphasizes accessibility and makes the refueling procedure seamless and efficient. By including an intuitive access point to both battery and liquid-payload compartments, replacements are as easy as pressing a button. A spring-based mechanism then releases the batteries, allowing the user to manually rechamber new ones. To ensure that spraying is relatively equal across all 6 nozzles regardless of Sentinel's tilt in relation with the ground, we partitioned the SOLVITAL tank into 6 separate compartments. As a result of this, all nozzles will remain fully functional and maintain a constant spray area, as in no one part of the tank gets more SOLVITAL flow than another, drastically reducing the effect of mid-air instability on spraying performance.

Nozzles: The design features six nozzles located below each of the rotors in order to maximize spray coverage. Since the field offers various levels of infestation, the drone needed a way to regulate the amount of SOLVITAL dispersed throughout the mission and direct the intensity of spray. We decided that we would use a raindrop nozzle, which delivers liquid in a hollow cone distribution pattern. Furthermore, our spray protocol revolves around controlling the diameter of the nozzles' opening. Hovering for varying amounts of time above different sections of the field, depending on the level of infestation determined by the drone's surveying counterpart, is extremely inefficient and is a waste of energy. Therefore, we decided to regulate the SOLVITAL flow controlling the size of the nozzle's aperture with a servo. When the drone enters areas with no infestation, the servo blocks the opening and, when necessary, is released again to generate a stream. Individually, cone spray can miss the targeted area; however, with six nozzles all spraying at once, overlap from collective spray creates a uniform distribution. In order to assure that all intended areas are sprayed and properly covered, we chose the 0.25” diameter (0.75 oz) nozzle with the following dimensions: 0.9375” (L) x 0.5625”(W). With all of these features working together, our spraying protocol provides the user with a competitive level of precision and unparalleled performance.

Figure 17: Raindrop Nozzle

Rotors and Battery of Sentinel: One of the biggest shortcomings of the DJI Agras MG-1 design is its battery life. With a maximum of ten minutes of flight time per charge when fully loaded, we wanted to create an experience where our autonomous aircraft could do more work independently and not require as much maintenance. As such, it was imperative for us to extend our battery life beyond any of DJIs capabilities. To do this required a lot of raw power. We decided to invest in three 5300mAh batteries that, as part of a parallel configuration, would give us around 2.65 hours of battery under constant conditions and idle power draw from the motor. The diameter of our rotors combined with the fact that we only had two blades made it so that we were not able to get enough thrust to lift our aircraft off the ground. We, therefore, relied on a Step-Up DC-DC converter to increase the batteries’ voltage output, allowing us to generate the ten kilograms of thrust necessary for liftoff and maintaining altitude mid-flight as well as ensuring a safe landing. With a recharge time of four hours per battery, we would be able to maintain a constant workflow with a system of two spraying drones. However, in keeping with our vision of an aircraft with exceptionally long battery life, we did not stop with the inclusion of a cell with high capacity. We made it so that we placed ultrasonic sensors in our SOLVITAL tank in order to match the amount of thrust required to suspend a depleting amount of pesticide. When the volume of liquid reaches a certain point, two of the central rotors shut off, conserving a measurable amount of battery charge while not making any compromises in stability (since the distribution of weight remains the same).

Figure 18: Static Thrust Calculation for Sentinel

Rest of the Frame for Sentinel: The frame is hollow and made out of ABS plastic, ensuring that our aircraft was as light and cost-effective as possible while maintaining the rigidity necessary for a UAV with a relatively high payload. In order to maximize SOLVITAL capacity, while restricting ourselves to a weight manageable by the motors in our price range, we decided to aim for a maximum UAV mass of 25 kg. The top of the frame is an airfoil shape that allows our drone to withstand different weather conditions and to fly more efficiently, allowing for a faster maximum cruising speed. The airfoil compartment houses all of our electronics like the autopilot, IMU, and electronic speed controller.

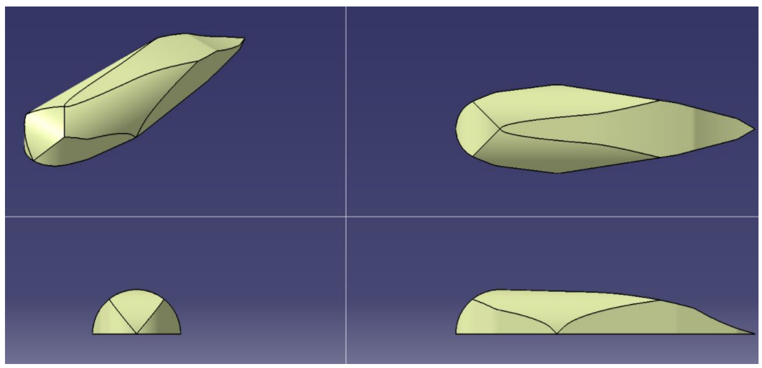


Figure 19: 3-Views of the Top Frame

The bottom of the frame is connected to several feeder pipes that, through the lock-on loading mechanism, transfer the pesticide from the tank to the nozzles under the rotors. Constant feeding of pesticide, with the help of a gravity assisted pump, creates the pressure required to expel the liquid as a thick mist. Because we are employing gravity feeding to distribute pesticide, we need a restrictive device to regulate the flow of the pesticide, taking the form of a servo that simply restricts or allows the SOLVITAL to leave the nozzle.

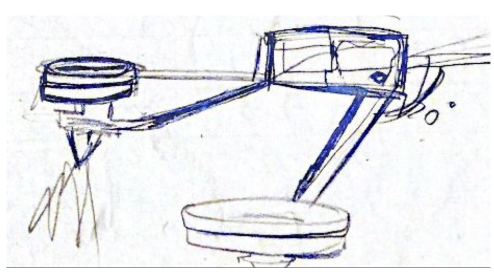


Figure 20: Frame + Rotor and Nozzle Placement

Ground Transport: In order to transport the UAV from one quadrant to the next, we will utilize one ground vehicle. With the notion that we are allowing farmers to oversee the operation, the truck is going to be in constant communication with the system of drones: exchanging data regarding coordinates (future land sites and checkpoints) and figures regarding objective completion. Radio will facilitate all communication within the UAS.

PECAM Premium: For customers more interested in keeping track of their crops throughout time and having an updated history of missions, our service will provide a subscription-based service, called PECAM Premium. We offer 24/7 assistance with our professionals that will, with the user's permission, analyze the scans of their plot and provide suggested missions schedules and a more comprehensive breakdown of every mission. We will also compile a complete database for the user to view the progression in crop health and infestation patterns, allowing the farmer to make sense of their field and smartly allocate resources to areas of most importance. The package also includes priority for online and over-the-phone support with the consumer's drone. While non-subscribers have to send damaged drones back to the company and wait a period of up to seven days for repairs, Premium members will be able to quickly schedule a session with a certified technician and have a functional drone back in their hands after a waiting period of 1-2 days. The service also extends to computational resources as it unlocks access to our computing center where we have hardware dedicated to processing PECAM device data. Although the computer already included as part of the Scout design is perfectly capable, there will be a period of time dedicated to the interpretation of data and the running of several algorithms. If the user wants another boost to their efficiency and eliminate all interruptions of workflow, this is a great option. Lastly, to bring all of these features into one, convenient, and accessible place, we have the PECAM mobile application that effectively serves as the user interface for the UAS. Non-subscribers also have access to the application itself but have restricted access to its features. Basic necessities like a mission timer, battery/payload level indicator, and safety features are, of course, available for all customers. For enthusiasts and farmers certified to operate aerial vehicles, the app can also function as an autopilot override. The mobile device acts as the display that shows a live video feed of the drone's flight, shot through the cameras on Scout, while virtual joysticks allow full control over the drone. Members will also get open access to testing stages of new software updates to algorithm efficiency, UI, and other software-dependent features.

2.2.5 Lessons Learned

1) This was a lesson that resounded all the way through the project. We always had a vision of what we wanted to accomplish but were held back by the interdependent nature of the design process. Some decisions cannot be made without making some assertions and agreeing on, albeit temporary, hard numbers so that the rest of the project can move forward.
2) While we were working on creating a compartment to house the battery and tank of SOLVITAL, we struggled to figure out how many batteries we should include since two did not give us quite enough flight time to maintain a steady workflow and three was a more expensive solution: from the perspectives of business and simple mass restriction. What we realized is that in aerospace design, you cannot deliver the perfect solution and need to instead aim to find the most optimal one given the circumstances. You need to measure your choices against one another and choose the solution that perhaps sacrifices a less significant aspect of the design but is overwhelmingly beneficial to one of greater importance.
3) Creating a computer rendering of the design is almost impossible without knowing the dimensions and even if you somehow make one, the potential issues with the design manifest later on.
4) One of our first ideas was to create pressure within the frame of the drone and to stabilize it by keeping the hollow interior filled with SOLVITAL at all times. We decided to not follow through with this since we do not know if SOLVITAL is corrosive or not and keeping it in constant contact with the framework of our design might compromise the integrity of the design. Additionally, the framework is at a high risk of getting deformed from being under constant strain and potentially bursting mid-flight.
5) The onset of Nationals brought with it a new wave of challenges. We had not anticipated that we would be responsible for funding most of our trip. Our school had no remaining

budget so we were forced to reach out to other organizations in order to raise enough funds.

6) We also had difficulty finding an adult advisor to come to Nationals with us. Our Faculty Advisor for the State-level challenge, Ms. Grace, was unable to make the trip so we had to reach out to our community to find someone. We ultimately found a member of the school administration who was more than happy to join us on our trip.
7) There were three big snowstorm in the new england region that made it impossible to collaborate in person as we approached the deadline. We utilized Skype and social media to communicate despite the storm.

2.2.6 Project Plan Updates and Modifications

DOCUMENT STATUS UPDATE

Done	TYLER PLEASE EDIT AGAIN :)						WHEN YOU'RE DONE WITH A SECTION CHANGE (ONLY) YOUR COLOR IN YOUR COLUMN TO GREEN		PRIORITY
Edit!	TYLER PLEASE EDIT :)						SECTION TURNS GREEN WHEN EVERYONE GETS GREEN		
Nope									
		Jen	Val	Ty	Sam	Roy			
Status	Section	Responsibility					Comment1	Comment 2	Comment 3
	0. Organization								
	Document Organization								
	Title Page						Add Final CAD Pictures	Name UAS	
	Table of Contents						Make sure page #s match w/ doc	Do these at the end as they are subject to change	
	List of Figures						Make sure figure #s match w/ doc	"	
	List of Tables						Make sure table #s match w/ doc	"	
	Team Survey						See if we need to fill out a survey again		
	Abstract						Make sure it includes both Scout and Sentinel	Add more to keywords	
	Specification		J		J	J	Fill it out	Jen: We need dimensions of Scout and front-facing surface area of Sentinel	
	1. Team Engagement								
	1.1 Team Formation and Project Operation						Add more to personal role + edit		
	1.2 Acquiring and Engaging Mentors								
	1.3 State the Project Goal								
	1.4 Tool Set-up/Learning/Validation						Some of the things should not be in this section, move them		
	1.5 Impact on STEM						We better win that Impact on STEM award		
	2. Document the System Design								
	2.1 Mission Design				J	J			
	2.1.1 Aircraft Compliance with Part 107				J	J	Check and Update the Chart	Make sure it includes both Scout and Sentinel	Jenn: Get the surface area of Sentinel from the CAD model so we can finish th
	2.1.2 Justification of Regulatory Compliance				J	J	This info should match the chart in 2.1.1	Make sure it includes both Scout and Sentinel	Needs completion of 2.1.1
	2.1.3 Design Operations								
	2.2 Conceptual, Preliminary, and Detailed Design						Scout info add, Sentinel is done		
	2.2.1 Engineering Design Process								
	2.2.2 Conceptual Design						Sam draw a conceptual drawing for Scout.		
	2.2.3 Preliminary Design						Add more descriptions		
	2.2.4 Detailed Design						Jen: Add CAD Stuff	Rest: Add details, figure out Sentinel Premium	Sam: add spraying physics stuff to detailed design for sentinel
	2.2.5 Lessons Learned								
	2.2.6 Project Plan Updates and Modifications						Make new Gantt Chart	Update meeting chart and elaborate	
	2.3 Selection of System Components								
	2.3.1 Payload Selection								
	2.3.2 Air Vehicle Element Selection						Make sure all the info is correct / finish it off		
	2.3.3 Command, Control, and Communications (C3) Selection						Elaborate		
	2.3.4 Support Equipment Selection						Elaborate		
	2.3.5 Human Resource Selection								
	2.4 Component and Complete Flight Vehicle Weight and Balance					J	Jen: Analyze CAD model	Roy: Comfirm Jen's numbers	
	2.5 Operational Maneuver Analysis						Elaborate		
	2.6 Three View of Final Design					J	Jen: Add CAD stuff	Roy: Write all the stats	
	3. Document the Missions								
	3.1 Detection Plan								
	3.1.1 Detection Theory of Operations						Jen: Stats model with R	Val: Add explanation	
	3.1.2 Detection Considerations						Elaborate		
	3.2 Application Plan								
	3.2.1 Application Theory of Operations						Jen: Stats model	Val: Add explanation	Sam: Add spraying model
	3.2.2 Application Considerations						Jen: Fix the diagram	Sam + Roy: Elaborate	
	3.3 Overall System Performance								
	3.4 Safety						Elaborate		
	4. Document the Business Case								
	4.1 Market Assessment					J			
	4.1.1 Market Comparison					J	Jen: Compare our model with the others	Roy: Fill out all the stats	
	4.1.3 Target Market Assessment								
	4.2 Profitability Analysis					J			
	4.2.1 Fixed (Initial) Costs					J			
	4.2.2 Operational Cost					J			
	4.2.3 Pricing Analysis					J			
	4.2.4 Regulatory Analysis					J	Jen: Write	Roy + Tyler: Check the #s (especially regarding weight and material costs)	
	4.3 Cost / Benefits Analysis and Justification						Talk about the algorithms		
	5. Conclusion								
	5. Conclusion						Rewrite		
	6. Reference								
	6. Reference						Include all reference links here and make sure they're properly cited		

Figure 21: Team Organization / Delegation of Work

Screenshot of the spreadsheet that the team utilized to delegate work during the National Challenge

2.3 Selection of System Components

2.3.1 Payload Selection

Sentinel's SOLVITAL tank contains six compartments in order to minimize the splash and, in doing so, reduces the momentum and the shifting of the center of gravity. The battery chamber is designed to be very accessible as pulling the payload compartment out of the drone's frame reveals a button that, when pressed, releases the batteries for an easy replacement. The airfoil compartment on the top of the drone is where all the electronics are stored, resulting in a compact and minimalistic design.

Scout's fuselage body contains the RedEdge-M camera, the Intel NUC computer, and the rest of the electronics and sensors. The batteries will be in the front of the fuselage due to their weight and accessibility for replacement: accomplished by opening the dome and changing the batteries. The RedEdge-M will be placed on the middle of the fuselage as that is the drone's center of mass. The IMU and GPS will also be placed at the same location so that their sensor outputs will be more convenient in calculating pose and location. On the bottom/end of the fuselage, the X500 camera will be placed for landing purposes.

2.3.2 Air Vehicle Element Selection

Fixed-Wing Tail-Sitter VTOL Transformer Survey Drone (Scout)

#	Name	Description	Justification	Cost
2	**Tiger Motor U11 120kv Heavy Lift Motor (10 kg of Thrust)**	This is the high thrust motor that we are using to generate the thrust for the drone. Each one of these motors have a mass of 0.73 kg.	Our design features 2 motors. Thus, in calculating the thrust needed per motor we found that we needed 8.11 kg per motor. The Tiger Motor U11 120kv Heavy Lift Motor not only provides the amount of thrust that we were looking for but also a reasonable price and compatible ESC (electronic speed controller) that is sold separately.	Each: $349.99 Total: $699.98
1	**RedEdge-M MicaSense**	This is the multispectral camera that we will be using to map and survey the field.	The RedEdge-M sensor is is going to be used to fully map and survey the field. The RedEdge-M sensor is one of the best	Total: $4900.00

		The RedEdge-M has the ability of creating RGB color images aligned with 5 specific spectral bands. The mass of one RedEdge-M is 0.173 kg.	precision cameras available on the market.	
1	**Tiger Motor Flame 80A ESC**	This is the electronic speed controller (ESC) we are going to use to control the motors, with a mass of 94g.	We need an electronic speed controller that was capable of handling a high current due to the requirements set by the motors. This ESC is also already confirmed to be compatible with the Tiger Motor U11 120kv Heavy Lift Motor.	Total: $140
1	**X500 Camera**	This is the standard camera that we use for Scout's autonomous vertical landing feature. This camera's mass is 0.05 kg.	This standard camera is effective and yet cheap, which fits our requirements. We do not need it to be high resolution nor particularly advanced as we are only using it for low altitude landing.	Total: $50
1	**Intel NUC**	The Intel NUC is Scout's main computer used for data processing and calculating flight plans. The mass for the Intel NUC is 0.52 kg.	This small and yet powerful and customizable computer fits our needs in terms of processing power and speed.	Total: $750
2	**LiPo 11,000 8S 29.6v Battery Pack**	This is the battery that we are using to power our drone. Each battery has a mass of 1.690 kg.	This battery's immense mAh, given its size, is exactly what we need. Along with being able to fit our standards and needs in terms of number of battery cells and voltage, it is quite optimal for our design.	Each: $500 Total: $1000
1	**MPU-9250 Inertial Measureme nt Unit**	IMUs are self-contained sensors that use gyroscopes and accelerometers in order to measure linear and angular motion, which can then be used to calculation position and orientation of the drone. As this is a small unit, the weight is negligible.	We thought about using the MPU-6050 IMU, utilizing the gyro and accelerometer sensor fusion. However, we found that the MPU-9250 has more features than the MPU-6050 while retaining the features of the MPU-6050 with a magnetometer and a compass.	Total: $14.95
6	**TowerPro SG90 9G Mini Servo**	This is a mini servo that will be used for controlling the valves in the nozzle system of a drone. Each has a mass of 0.009 kg.	We needed a way to control the opening and closing of the nozzle of the gravity fed SOLVITAL spray. These mini servos were both inexpensive and provided sufficient power for our purposes.	Each: $3.79 Total: $22.74

1	**Radiolink PixHawk Advanced Autopilot w/ SE100 GPS**	This is an autopilot unit that will allow our UAV to navigate itself autonomously. As this is a small unit, the weight is negligible.	The Radiolink PixHawk Advanced Autopilot w/ SE100 GPS will allow our UAV to be more autonomous and keep itself upright, taking some things off the farmer's plate.	Total: $139.99

Table 9: Air Vehicle Elements (Scout)

Multi Rotor Spraying Drone (Sentinel)

#	Name	Description	Justification	Cost
6	**Tiger Motor U11 120kv Heavy Lift Motor (10 kg of Thrust)**	This is the high thrust motor that we are using for the thrust of the drone. Each one of these motors have a mass of 0.73 kg.	Our design features 6 motors due to a hexacopter being a unique and effective way to fly: the ability to disable motors along the flight to save power. Thus, in calculating the thrust needed per motor we found that we needed 10 kg per motor. The Tiger Motor U11 120kv Heavy Lift Motor not only provides the amount of thrust that we were looking for but also a reasonable price and compatible ESC (electronic speed controller) that is sold separately.	Each: $349.99 Total: $2100.00
1	**Vu8 LiDAR sensor**	This is a LiDAR system that uses lasers to map the environment by bouncing the light off of an object and measuring the time the laser takes to return to the source. The LiDAR weighs only 75 grams.	The Vu8 LiDAR sensor is going to be used for mapping the field. The sensor has a large range of 215 meters and light weight of 75 grams, making it ideal for our needs.	Total: $475.00
10	**HC-SR04 Ultrasonic Distance Sensor Module**	This is a sensor that uses ultrasonic waves to determine the distance from the sensor to a surface (in this case, the surface of the remaining SOLVITAL in our tank). The module. As this is a small unit, the weight is negligible.	We believe this is the ideal ultrasonic sensor for our UAVs, considering its price point and the relatively simplistic job we have for it to do, which is to measure the level of SOLVITAL left in our UAV's tank. We also use the same type of ultrasonic sensor in order to detect obstacles while we fly to avoid crashing into them.	Each: $2.99 Total: $29.99
1	**MPU-9250 Inertial Measureme nt Unit**	IMUs are self-contained sensors that use gyroscopes and accelerometers in order to measure linear and angular	We thought about using the MPU-6050 IMU, utilizing the gyro and accelerometer sensor fusion. However, we found that the MPU-9250 has more features than the	Total: $14.95

		motion, which can then be used to calculate position and orientation of the drone. As this is a small unit, the weight is negligible.	MPU-6050 while retaining the features of the MPU-6050 with a magnetometer and a compass.	
6	**TowerPro SG90 9G Mini Servo**	This is a mini servo that will be used for controlling the valves in the nozzle system of a drone. Each has a mass of 0.009 g	We needed a way to control the opening and closing of the nozzle of the gravity fed SOLVITAL spray. These mini servos were both inexpensive and provided sufficient power for our purposes.	Each: $3.79 Total: $22.74
3	**Gens ace 5300mAh 44.4V 30C 12S1P Lipo Battery Pack**	This is the battery that we are using to power our drone. Each battery has a mass of 1592g.	By employing multiple batteries, we maximize potential battery life, thus increasing our margin of error for dealing with volatile variables such as wind and other weather conditions.	Each: $252.38 Total: $757.14
1	**Tiger Motor Flame 80A ESC**	This is the electronic speed controller (ESC) we are going to use to control the motors, with a mass of 94g.	We need an electronic speed controller that was capable of handling a high current due to the current required of the motors. This ESC is also already confirmed to be compatible with the Tiger Motor U11 120kv Heavy Lift Motor.	Total: $119.99
1	**Radiolink PixHawk Advanced Autopilot w/ SE100 GPS**	This is an autopilot unit that will allow our UAV to navigate itself autonomously. As this is a small unit, the weight is negligible.	The Radiolink PixHawk Advanced Autopilot w/ SE100 GPS will allow our UAV to be more autonomous and keep itself upright, taking some things off the farmer's plate.	Total: $139.99

Table 6: Air Vehicle Elements (Sentinel)

The aircraft is suitable for farm conditions. The parts we chose allow for a reasonable range of operation. Given that we are already dividing the field into four smaller quadrants, this will allow our aircraft to be able to operate well across the entire service area. Additionally, the parts we chose can operate in a wide range of temperature and humidity conditions.

2.3.3 Command, Control, and Communications (C3) Selection

All the drones will be autonomous in-flight as they are surveying and spraying. However, the farmer will supervise and assist the drones in other tasks that are needed in order for them to function, such as battery charging. In order to transport the UAV from one quadrant to the next, we will utilize one ground vehicle, a truck, which the farmer will drive and operate. The user may also choose to use a landing pad for Scout and specify a particular location for landing instead of the vehicle's coordinates: the default. With the notion that we are allowing farmers to oversee the operation, the truck is going to be in constant communication with the system of drones, exchanging coordinates data (future land sites and checkpoints) and figures regarding objective completion. To add on to the autonomy of the drones, we will utilize the *Radiolink PixHawk Advanced Autopilot w/ SE100 GPS*. Each aircraft is equipped with one of these devices, which is an autopilot unit that will allow our UAV to navigate itself autonomously and keep itself upright. All control of the drones will be done without user intervention, instead, utilizing various algorithms and frameworks from Nanomap and Robot Operating System. Once the farmer launches the drones from a particular location, the aircrafts will then rely on their own sensor inputs and actuator outputs in order to achieve their goals. Data will be communicated between the drones wirelessly with the help of radio waves. Even large video and graphics intensive files will be able to be transferred with the help of video modulation and similar modes of broadcasting. For example, after Scout calculates the optimal flight path, it will then send that information to the Sentinel units. This allows for the quick and efficient transfer of data that later facilitates a smooth transition from surveying to spraying.

2.3.4 Support Equipment Selection

The support equipment will primarily consist of the vehicle that the farmer owns, which will act as the functional mission base. The car will be moving along the perimeter to intercept drones as they return for a battery recharge or SOLVITAL refill. The farmer will also be carrying a charger for the batteries, replenishing depleted units with a generator or vehicle battery as a source for a charge. Extra batteries can be charged before the start of the mission and used for quick redeployment or a temporary solution in the case of a charging malfunction. There is also a landing pad that is a flat and lightweight square with a QR code printed on it. If the user wants to specify Scout's landing location or desires a more precise landing, the pad can aid in fulfilling those requirements. Since most of the support equipment is already owned by the farmer, it carries a relatively low cost.

2.3.5 Human Resource Selection

Our user-friendly UAS will include a comprehensive guide detailing all the specifics of operations. Because of the system's autonomous nature, the explicit cost of utilizing it is zero, with the exception of the initial installation and pick-up assistance: taking approximately an hour each to complete. The cost to hire assistance for the aforementioned services is $25 per hour and is covered by the security deposit made when renting one of our products. Initial services also include on-site training led by our technicians, covering the basics of operation, maintenance, as well as safety concerns and protocols. Technicians will answer questions during the training and all future concerns will be handled by our offices for tech support. Due to minimal reliance on a human operator, the user will be able to operate the whole system on their own.

2.4 Component and Complete Flight Vehicle Weight and Balance

Surveying Drone:

Due to Scout's bilateral symmetry and weight distribution of its electronics, the center of gravity is located in the middle of the fuselage. This allows the UAV to be more stable and have an easier time transforming from vertical takeoff to flying and then back to vertical landing. The main camera, the RedEdge-M, will also be placed at the center of gravity. The heavier electronics, such as the batteries, will be distributed across the fuselage to maintain the center of mass. To maintain balance on the ground, before and after takeoff/landing, the tailfins will be used to prop up the whole drone.

Spraying Drone:

Because our UAV design is radially symmetrical, the center of gravity is located in the middle of the main compartment, as labeled in the top view of the 3-view of the design in Section 2.6. This allows the UAV to be much more stable. Our main payload, SOLVITAL, will be divided up and placed into six smaller compartments within the main container. The outflow of SOLVITAL is exactly the same across each of the six nozzles, meaning that there is a uniform change in mass across the system. The hexacopter design also maintains an equal distribution of mass, allowing the UAV to experience minimum variation in the center of gravity throughout each mission.

2.5 Operational Maneuver Analysis

The motors on Scout and Sentinel are able to meet the rpm requirements to produce the thrust we need. However, the batteries that we used for each drone could not, on their own, provide the voltage needed to overcome gravity. The motors are rated at 120 kv (kv ~ rpm per voltage) for Sentinel and 245 kv for Scout. Therefore, we have to use a boost converter to increase the system's voltage in order to generate the rpm we needed to hover and fly.

Sentinel will be able to determine its optimal spraying altitude based on wind speed, which is calculated by analyzing how far it deviates from its own intended flight path, due to wind, using its IMU and drift. Once determined, Sentinel will utilize the following equation:

$$2 = 0.5159 + 0.1561h + 0.1369{v_{wind}}^2(0.3305 + 0.1h)^2$$

where h is the craft's altitude and v^2_{wind} is the wind speed. This model's derivation began with determining an acceptable deviation of spray application (we decided to settle on a possible margin of 2 meters, allowing a generous altitude range while minimizing the effect of spraying overlap because of inaccuracy). We first determined the initial velocity of the spray using equations for flow rate based on our nozzle's dimensions, namely diameter and rated pressure. Then, we incorporated other factors such as the spray's terminal velocity, the angle of spray, and spray droplet radius (3.175 mm, minimizing horizontal acceleration due to wind) in order to relate the wind speed with Sentinel's optimum spraying height. Though the model does not technically apply to situations where there is absolutely no wind, it can be used to approximate the optimum altitude in this situation by assuming that the y-intercept (see graph) is equivalent to the upper limit of the function as wind speed approaches 0. To further minimize inaccuracies due to wind, Sentinel will overcompensate whenever it drifts offcourse, moving laterally against the wind so that the wind blows the SOLVITAL into its intended spray zone (e.g. if the wind blows Sentinel a certain distance off course to the right, Sentinel will move left until it is offset enough that the rightward wind will correct the now left-leaning spray zone).

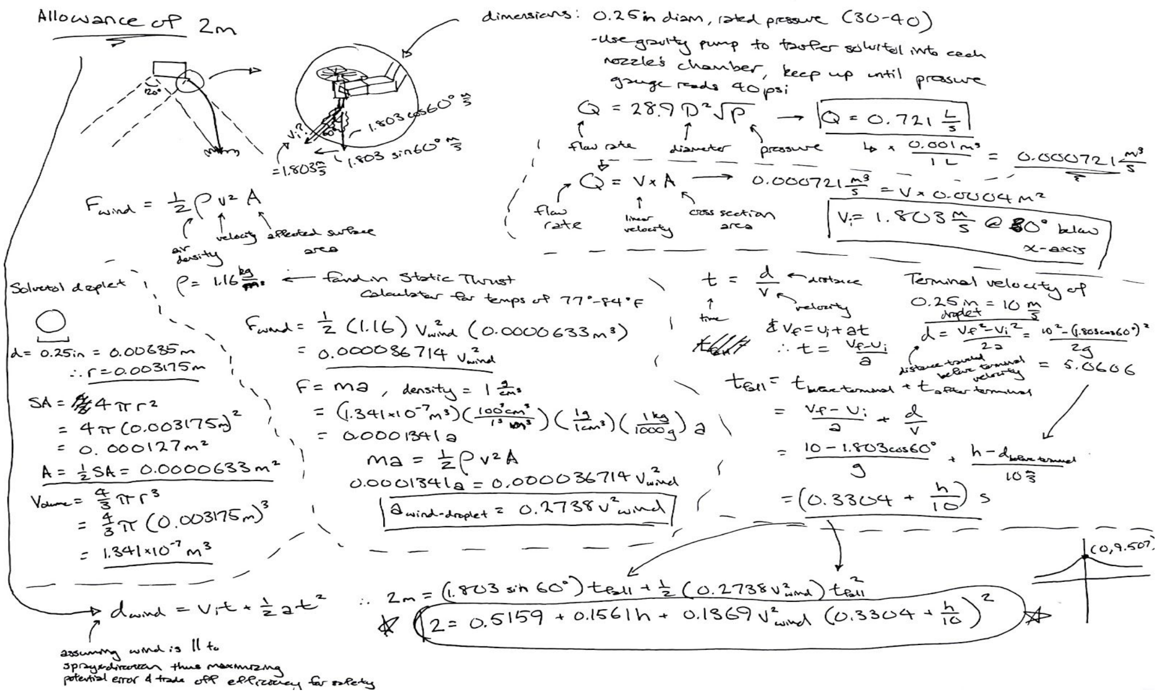


Figure 22: Mathematical Calculation Brainstorming

Figure 23: Altitude Model

As shown, the maximum altitude for a 2 meter allowance is 9.507 meters. This functions is the upper limit that optimum altitude approaches as wind speed approaches 0 m/s. Because of this, we can utilize it as a reasonable approximation of altitude when wind speed is 0 m/s.

2.6 Three View of Final Design

Figures 24 and 25, depict the three view of the final unmanned system design:

Scout: Full Aircraft Dimensions (Rounded to three decimals)

- Empty Weight: 1.4 kg (3.086 lbs)
- Wingspan: 1.2 m (3.937‘)
- Width (including rotors): 0.3 m (0.984‘)
- Height: 0.6 m (1.969‘)
- Payload (supports up to): 8.933 kg (19.694 lbs)
- Maximum Endurance: 64 min
- Maximum horizontal speed: 32 m/s (71.582 mph or 62.203 knots)
- Flight altitude: 122 m (400’)

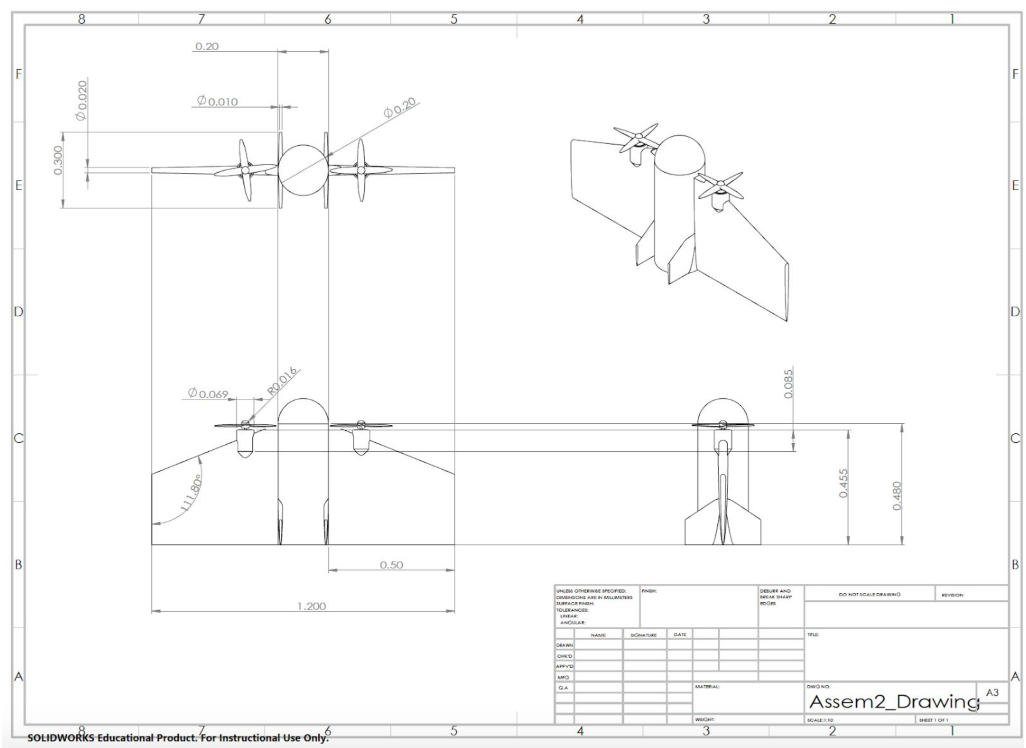


Figure 24: Three View of Final Unmanned System Design - Scout

Sentinel: Full Aircraft Dimensions (Rounded to three decimals)

- Empty Weight: 15.251 kg (33.623 lbs)
- Diagonal span: 0.5 m (1.64')
- Frame arm length: 0.13 m (0.427')
- Length (including rotors): 1.296 m (4.252')
- Width (including rotors): 1.18 m (47.46')
- Height: 0.348 m (1.142')
- Payload (supports up to): 25 kg (55 lbs)
- Maximum Endurance: 44 minutes
- Maximum ascent/descent speed: 15.823 m/s (35.395 mph or 30.757 knots)
- Flight altitude: 50 m (3.281')

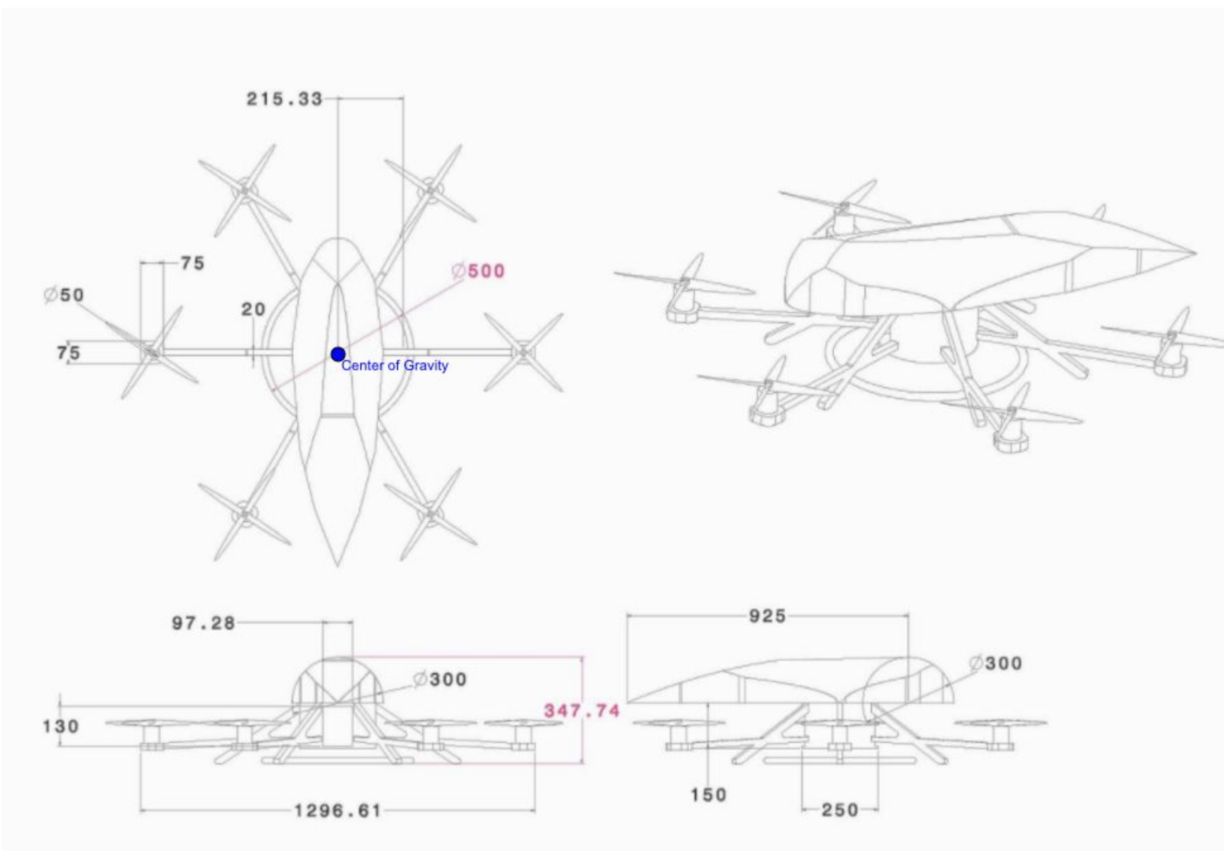


Figure 25: Three View of Final Unmanned System Design - Sentinel

3. Document the Missions

Software is an essential component in bridging the gap between a technically powerful design and an accessible, usable tool. The software included in our design is built upon the Robot Operating System (R.O.S.), an industry standard framework in the robotics field. The user taps into this system through a simplified and condensed interface in the form of the PECAM mobile application. They will be able to view, among many other things, the status of their land, a computer rendering of the current flight path, mission progress, a constant feed coming from the active drone, updates on location, SOLVITAL quantity remaining, battery charge, and active rotors (the Sentinel drone will deactivate its rotors to conserve battery if needed). There are many variables in precision spraying such as variance in the level of infestation, weather conditions, and electronic failure. The way that we bypassed what seemed like an endless list of potential issues is a number of novel workarounds as part of our proprietary software.

3.1 Detection Plan

3.1.1 Detection Theory of Operations

The first, and most sophisticated, part of our software package is a path minimization algorithm. For each quadrant, the sprayer drones will follow a pre-calculated shortest path as generated by Scout's onboard computer. A main focus of our design was to maximize battery life and a direct, brute forced path would conflict with this goal. Simply connecting each infestation point in some random way is a solution but not a very elegant one as displayed in [Figure 26].

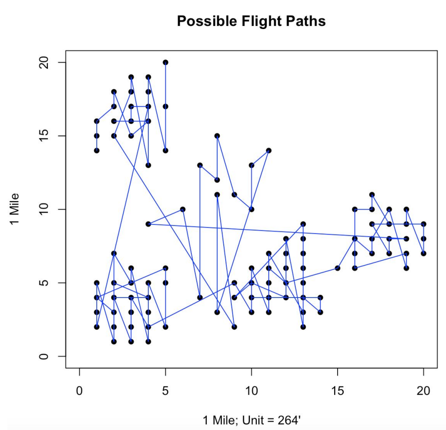


Figure 26: Sample Flight Path Mode

Since there is way too much variance in the distribution of infestation areas and their severity, it would be very difficult to, analytically, produce one path that fits every scenario. Because of this, we decided to have our algorithm evaluate three separate paths.

First, we had to consider the brute force method or the parallel search pattern [Figure 27] where the sprayer travels from one side of the field to another, sweeping the area strip by strip, and restricts itself to a turn radius equal to its wingspan. The distance traveled is then calculated with the formula $2d^2/w + d/2$ where d is the dimension of a square field and w is the wingspan of the aircraft. Mathematically, this is the simplest method; however, it could prove to be the shortest path given a particular distribution of infestation points.

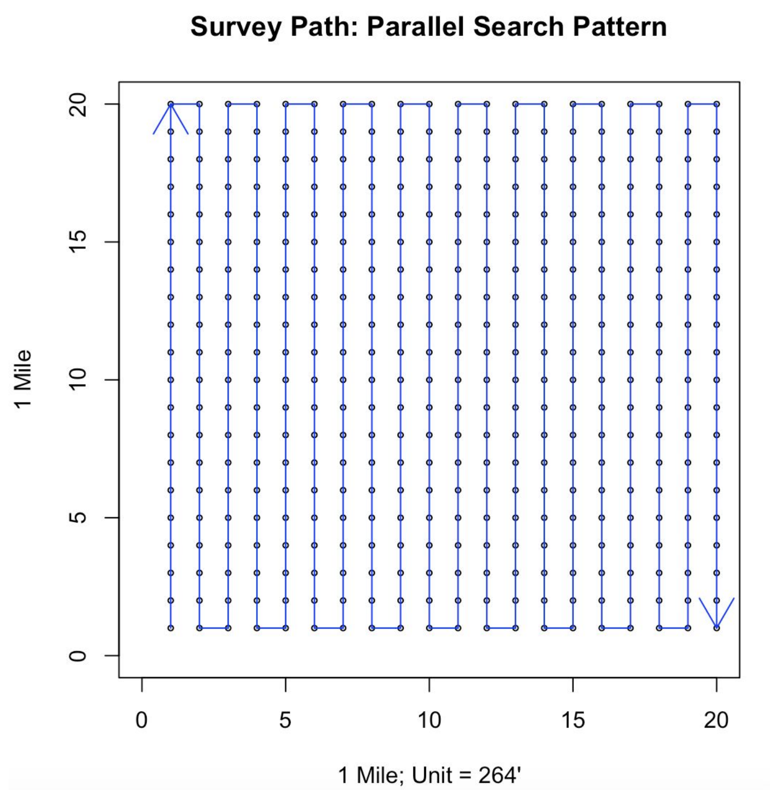


Figure 27: R generated Parallel Search Pattern Model

When one UAV runs out of battery or SOLVITAL, the next UAV resumes the mission at the point where the first sprayer left off. This method is used when infestation points are so scattered that other parts of our algorithm necessitate extensive backtracking and the path will, therefore, end up being longer and less efficient.

The second part of our algorithm is the path generated by running the renowned Dijkstra's Algorithm while all infestation points or "nodes" are considered in the calculation of the shortest path. The algorithm requires a start node, which is easily calculated by considering the closest area of infestation to the ground vehicle, which serves as the launch site for the drones. The final or end-node is therefore the node that is diagonally farthest away from its starting counterpart. After those are established, we need to generate the total number of paths, which will be referred to as edges. The computer can create connections between every infested node in the field by employing a modified version of Hamiltonian and Euler Paths; in this case, paths or edges can intersect one another and there is more than one way to get to any single node. The first step is to find all of the lengths for every edge starting in the initial node. Then, the computer remembers which node yields the shortest distance and finds all possible paths branching out from the recorded node. This continues as the algorithm iterates over and over until the end node is reached. Dijkstra's worst case performance is outlined by $O(|E|+|V|\log|V|)$ where E represents the number of edges and V, the number of vertices. Since the algorithm takes logarithmic time to complete, the sheer number of data and coordinates that the computer has to work with do not significantly impact the algorithm's efficiency. The algorithm returns the length for the shortest path and is recorded by the computer to be compared to the results of the other two steps in our path-minimization model. In certain distributions of infestation, a slight complication arises in that certain edges have a negative cost or reverse the efforts of previous steps of the algorithm. If this is the case, our algorithm will substitute Dijkstra's with the Bellman-Ford algorithm that is able to work around this scenario at the expense of efficiency: worst case performance is $O(|E||V|)$.

The third portion of our algorithm is a very thorough and holistic review of multiple parameters collected as part of the surveyor drone's data. First, the whole quadrant of the field undergoes density-based clustering, which takes concentrated areas of infestation and groups them together.

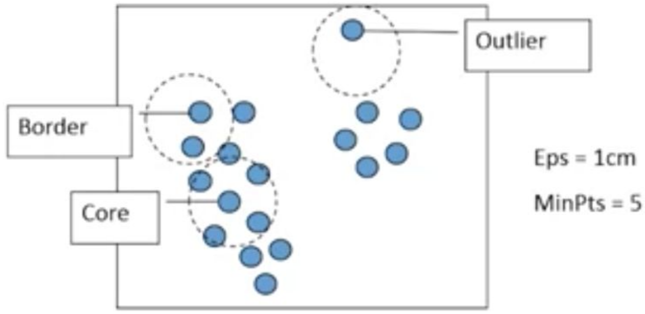


Figure 28: Density-Based Clustering

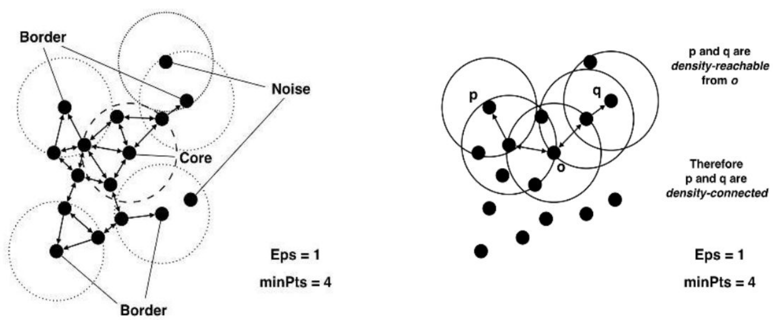
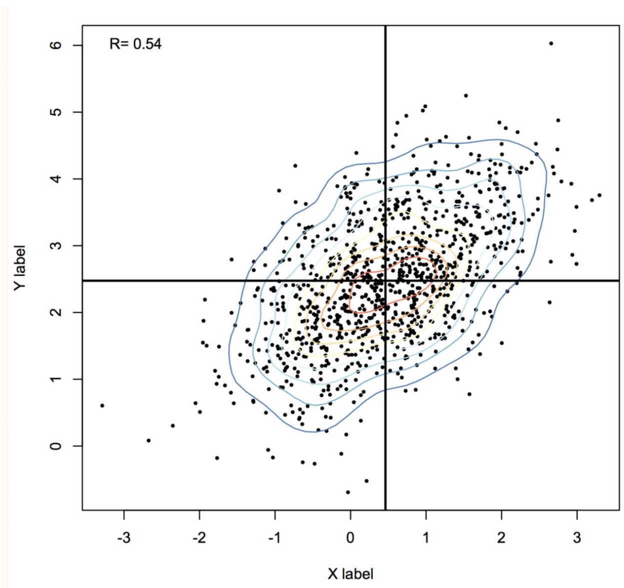


Figure 29: dbscan's implementation of DBSCAN - Density-based Clustering with R

However, this method is not completely foolproof as some nodes that are really far away from dense clusters are still included in a particular grouping. With the use of two-dimensional kernel density estimations [Figure 28], each node will fall into a certain range from the center node, determined by looking at which point is the most highly and densely infested. A node's inclusion within a certain range will assign it an arbitrary "gravitational constant" that, with the use of machine learning, will aid the computer in differentiating between actual members of dense groupings and anomalies.



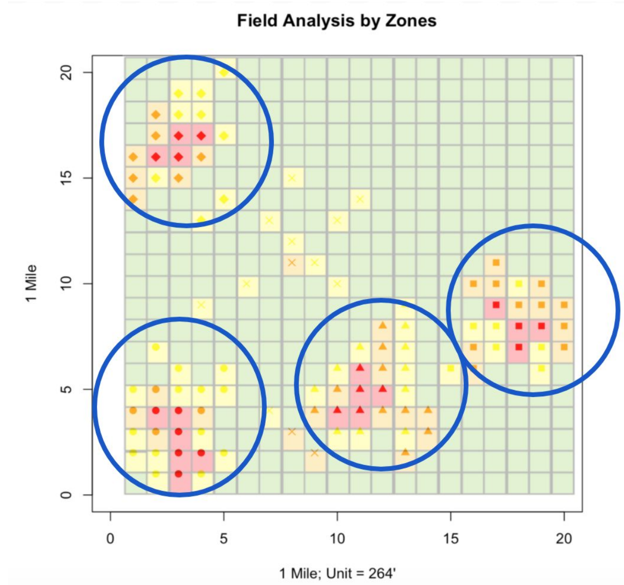


Figure 30: Kernel Density Estimations

Figure 31: Finalized Grouping

Anomalies will become their own group that will be dealt with later in the algorithm. In the meantime, now that the computer has established which areas of the field are parts of infestation groupings, the next part of the algorithm is to run Dijkstra's on a more localized scale: within each division or grouping. The same steps are followed as those detailed in the description of the second part of our algorithm. However, when a shortest path is found within one division, and Dijkstra's is done running the first time, there needs to be a transitory path between groupings. What we have decided to do is to assign weights to each possible path between the divisions and rate them based on how many nodes can be covered for the minimum distance that needs to be traveled. Going forward, the team considered an infestation field model from the 2015 State Challenge in order to create a base analysis model. For each square, green areas are unaffected (0%), yellow stands for low infestation (< 20%), orange areas indicate medium infestation (20-50%), and red areas are highly infested (>50%).

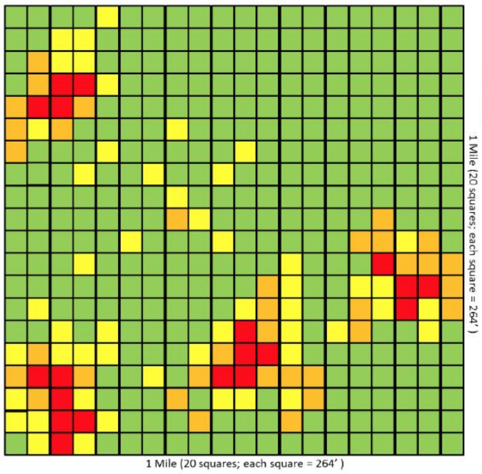


Figure 31: Sample Infested Field Model

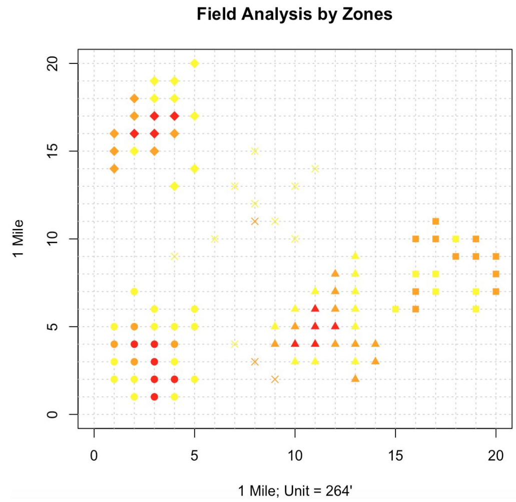


Figure 32: R generated Analysis Model

The team transferred each square as a plot onto a 20 by 20 unit coordinate plane within R's development environment in order to generate a field analysis model. Using this model and principles of density-based clustering, we then identified and grouped the plots into four zones and outliers were designated to be the "Non-Zone" area. Although this example was taken from 2015 RWDC challenge, the cluster pattern shown above is observed in real life, as billbugs' infestation spatial patterns on corn, among many other infested plants, resemble this model.

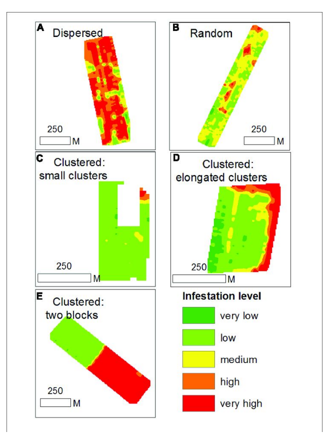


Figure 33: Examples of Infestation Spatial Patterns in Sampled Tomato Fields

Going back to the algorithm, the weights are calculated by looking at the maximum area that the drone can spray without overlapping the divisions.

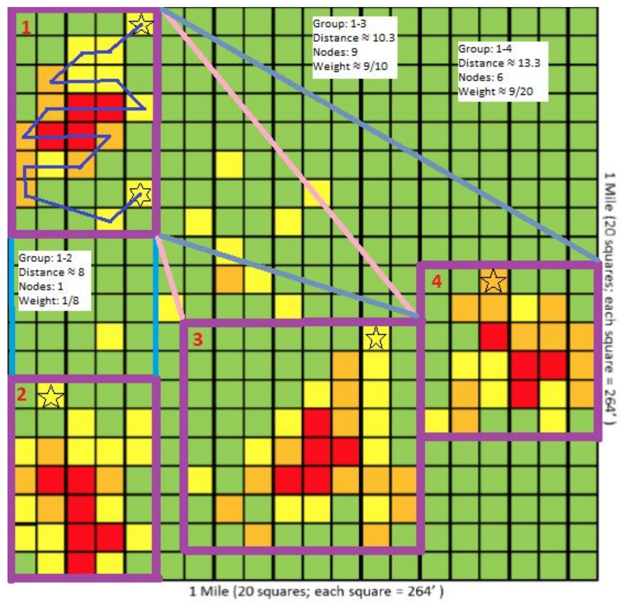


Figure 34: Visual Aid For Weight Calculation

The way these areas are established is dependent on the fact that every division is comprised of square nodes as each concentrated area is also bounded by a rectangular outline (as shown above). Once Dijkstra's is done calculating the path through one grouping, lines are drawn from the completed area's bounds, specifically from the corner closest to the end node, to the corners of the other groupings' bounds closest to their starting nodes, which are always the closest nodes within a grouping to the previous division's end node. After these areas are outlined, the computer can easily find how many complete and partial nodes are contained within the area. Distance is calculated with the pythagorean theorem and distance formula. Since our sprayer drones' primary concern is battery life, we decided to prioritize distance over the amount of nodes covered, meaning that our weight would have to be inversely proportional to distance. As such, our weight is calculated with the following equation, N/D, where N is the number of nodes and D is the distance. The algorithm chooses which grouping to visit next based on the weight, prioritizing divisions with greater values for weights as this signifies an analytically more efficient route.

The last part of this algorithm is the pathfinding in the transition stages, linking sequential Dijkstra's runs, as the drone is moving between two groups. Instead of backtracking or covering all previously identified anomalies at the end of the mission, the overall path will integrate the coverage of these nodes into the smaller-scale paths between divisions in order to maximize efficiency. In some instances, this could be accomplished by once again employing Dijkstra's; however, if there is excessive backtracking or a negative weight to the paths, the algorithm will not yield the actual shortest path or will not work at all. The alternative Bellman-Ford Algorithm is much less efficient and will push the limits of our computing resources. In the case that these two algorithms do not work, we have implemented the final part of our algorithm: curve fitting and regression analysis. The computer has all the coordinates of the "anomaly" nodes and will draw a variety of regressions through those points: exponential, power, and polynomial. Of course, as the degree or complexity of the function increases, the length of the curve tends to increase as well, as does the overall quality of the curve's fit. This calls for a method to evaluate which curve is the most efficient and, in our case, this took the form of another weight value. There are two components that contribute to the weight's evaluation. The first is the coefficient of determination (R^2) of the convolution between the previously evaluated regressions and two other piecewise functions drawn through the anomaly points. The second is the length of the convolution.

Convolution is an integral transformation applied to two functions in order to create a third, original representation of the overlap between the two original functions. In our case, this is particularly useful because the regressions that we have generated are not as close to the data as we would like them to be: they are, after all, supposed to be the path that our drone takes to cover the infestation areas. They come close to fitting through the data; however, the drone will have to make small deviations in its path. These adjustments are unavoidable, but, with convolution, we can minimize them.

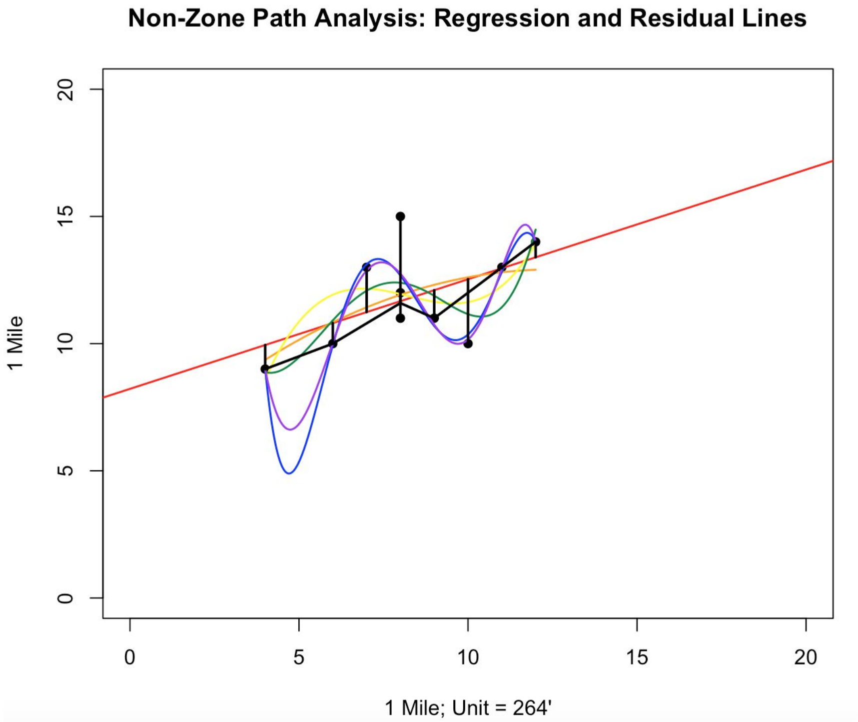


Figure 35: Regression and Residual Lines of Non-Zone Path Analysis

In our case, there are three possibilities. If a function's frequency exceeds the average and the curve deviates too much (low R^2 value), then the regression will be combined with the Lowess Line (Figure 36: right), the piecewise representation of the overall trend for a dataset, for convolution, effectively bringing the resulting curve closer to the data points and providing for a better fit. Similarly, if the curve has a low R^2 value, because it has an extremely low frequency and does not fluctuate at all, then it will be paired with the noiseless data path analysis (the brute force path through a dataset - Figure 36: left) for convolution, opening up the regression and, once again, creating a better fit. Lastly, if the coefficient of determination is really high (.95 >), the regression can remain unchanged.

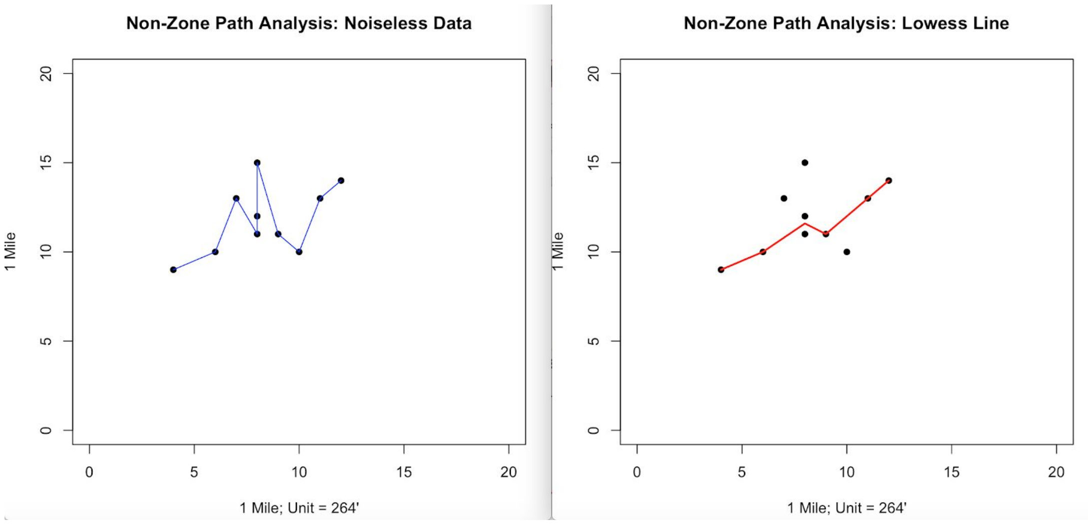


Figure 36: Comparison of Noiseless and Lowess Models

Convolution effectively forces a regression to, in some ways, fit the data better and is more representative of what a path, as generated by our algorithm, would look like. The red line in the figure below is a ninth degree regression through the data points; it doesn't go through several of the points and leaves a lot of guesswork as to how much the drone will deviate from the path. The blue is the noiseless data path analysis and the purple is the combination of the two after convolution.

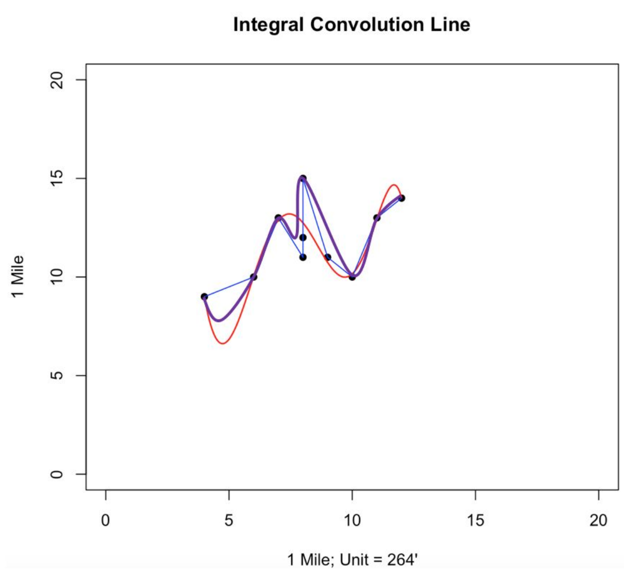


Figure 37: R generated Flight Path Comparison

Convolution is an incredibly valuable tool and, for our purposes, the third function that it produces can be derived by the following equation, where x is a point along the horizontal axis and τ represent a shift along that axis:

$$(f * g)(x) = \int_0^x f(x - \tau)g(\tau)\, d\tau$$

After we establish which function is going to be our path (convolution function or the same regression), we need to evaluate our weight. As mentioned previously, length is the second component and, fortunately, it can be found by taking the arc length. It is represented by the following equation where x_1 and x_2 are the coordinates of the bounding anomaly coordinates along the horizontal axis and f' is the derivative of the regression function with respect to x:

$$d = \int_{x_1}^{x_2} \sqrt{1 + (f')^2 dx}$$

Again, we are trying to minimize distance traveled so our weight will be inversely proportional to arc length and directly proportional to the coefficient of determination. The greatest value translates to the most efficient arc-based path.

All parts of the algorithm as well as their respective subdivisions will return a minimum length for the path calculated using that particular method. The sprayer drones will end up following the shortest one.

3.1.2 Detection Considerations

a. Our system is beneficial to the farmer in that it requires very little effort to operate. The farmer's sole role in the process of surveying is the initial setup, launch, as well as the receipt and recharge of the batteries of the UAVs (once trained). The only resources needed to operate our system are time and an existing vehicle (thus, nearly no explicit costs beyond the initial payment to rent our system). All this requires very little work on the farmer's part. Both the time and effort spent by said farmer would spend on this task would be far less than if they were to do so manually, thus allowing for a far more efficient process.

b. Our system would be highly competitive in the precision agriculture industry, creating high demand amongst farmers in need of precision agriculture services. Our spraying drone and surveying drone are respectively cheaper than the DJI Agras and Ebee SQ, along with being at least on par or exceeding their capabilities. Thus, we would be able to turn a good profit for our company while maintaining good customer relationships.

c. We are able to match the speed of the Ebee SQ and slightly exceed the surveying resolution. Sentinel's advanced design allows it to also outperform the DJI in general, from spraying to operating time. By being able to provide superior capabilities than those of our competitors, our service will be exceptionally efficient and an appealing purchase to consumers.

3.2 Application Plan

3.2.1 Application Theory of Operations

Considering the size of the given field, our drones are expected to require a number of recharges/refills throughout the mission. Our solution is to have a system of multiple specialized aircraft constantly working to cover all infestation points.

The system is first be transported to the field by the farmer with the batteries fully charged from the night prior. The user then calibrates the sensors of the drones so that they are orientated correctly before liftoff. For initial set-up, the farmer inputs the size of the field, places the drones on the back of his truck, drives towards one of the corners, and presses start.

Scout is deployed first, taking off vertically and transitioning into its fixed-wing phase, proceeding to collect all of the data regarding crop health and infestation severity. The onboard computer then internalizes the information and analyzes it to create the path that the Sentinel units follow until the mission's end. Utilizing its IMU sensor, the drone easily lands at the default truck location or a specified, QR-marked coordinate. The drone will use a fusion of GPS sensors and computer vision in order to orientate itself over the target landing zone and touchdown safely and accurately. Directions for the mission are shared with the sprayer drones via radio waves and the surveying stage is complete. Depending on the volume of data collected, Scout may be able to relay information before landing.

A Sentinel unit will then set out and continue working until it needs a SOLVITAL refill or has just enough battery left for a return trip to the ground vehicle. When a sprayer needs to return to base, it relays its location to the second sprayer, which is immediately launched to maintain workflow and makes the transition as seamless as possible. The two sprayers will thus alternate in this manner until the whole mission is completed. Landing paths are always a perpendicular path to the closest edge of the field, allowing the ground vehicle to intercept the drones at the landing coordinate; effectively minimizing the distance that the next UAV has to travel before resuming the mission. The way that our drones determine the closest location for a landing is that, as part of our program's initial setup, the consumer has to specify the area of their plot and calibrate the orientation sensor. From there, the drone handles all calculations and finds the closest perpendicular distance. However, it also takes into account where the farmer is located when starting to plan its landing as to avoid making the farmer drive to the other side of the field only to save a meter of travel for example.

When a drone arrives to the truck landing pad, the farmer will replace/charge the batteries and refill SOLVITAL after deploying the other Sentinel unit. The time it will take to complete the mission depends on, among other factors, the size of the field (for the sake of scalability) and the concentration of the infested areas. The manpower is limited to the farmer setting up and collecting the drones once the tasks are finished as well as replacing their batteries.

While Scout will be flying at a set altitude of 400 feet, Sentinel's altitude will be heavily dependent on environmental factors, namely wind. To do this, it will follow a model we derived as described in [section 2.5].

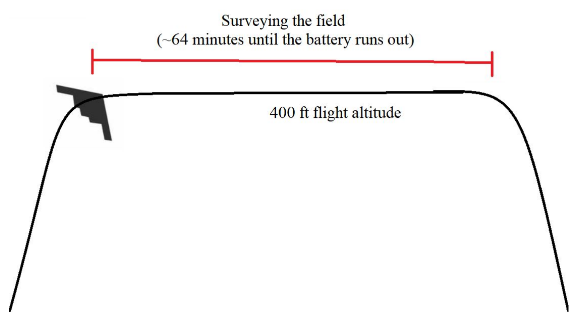


Figure 38: Operational Profile for Scout

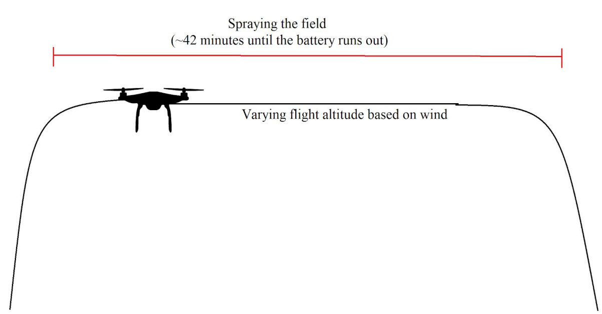


Figure 39: Operational Profile for Sentinel

3.2.2 Application Considerations

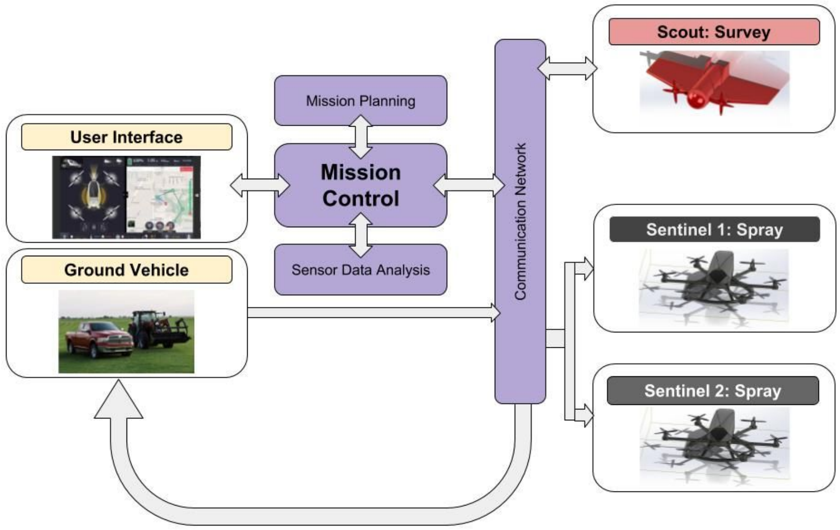


Figure 40: Application Plan of Our UAS Base Model

a. Our system is beneficial to the farmer in that it requires very little effort to operate. The farmer's sole role in the process of surveying would be setting up, launching, receiving and recharging the batteries of the UAVs once they have been trained in doing so. The only additional resources needed to operate our system are time and an existing vehicle (thus, nearly no explicit costs beyond the initial payment to rent our system). All this requires minimal work on the farmer's part as the drone is integrated into their workflow. Both the time and effort spent by the said farmer would be far less than if they were to survey and spray their field manually, thus allowing for a far more efficient process.
b. Our system would be highly competitive in the precision agriculture industry, creating high demand amongst farmers in need of services of this class. With our subscription-based model and the variety of different packages that we can offer, all specialized for individual customers, we are able to offer exceptional service while leaving our customers satisfied and coming back.
c. The advanced sensors and software that we use also ensure a high quality of safety and autonomy for the user even if they are novices or do not know much about drones in general, allowing for a smooth user experience with our service.

3.3 Overall System Performance

Compared to the DJI, our battery life, spraying, and surveying capabilities are quantitatively superior. Also, because of the fact that we utilize a number of UAVs in our system that specialize in surveying and spraying separately, our product is much more scalable to larger plots of land and missions of higher complexity. Cost efficiency and user experience are aspects of this product that are unmatched by any of our competitors. Flexibility of use and safety of the VTOL design, combined with sensory awareness that ensures a safe landing, are a foundation for a very appealing and powerful product. Even though our design philosophy hinges on innovation and novel approaches to solve problems, the hardware that we were able to pack into our designs outmatches that of the competition. Scout, for example, easily competes with other surveying drones of its class as it has the RedEdge-M camera, which has a higher resolution than the Ebee SQ’s camera (their 12 cm/px Ground Sample Distance Resolution to our 8 cm/px Ground Sample Distance Resolution). Taking unparalleled performance and integrating it into an intuitive and sleek design is what distinguishes PECAM products from the rest of the precision-spraying market.

3.4 Safety

The implementation of NanoMap (an open source motion planning framework from MIT running on R.O.S. NanoMap using a sequence of 3D snapshots) allows our drones flying up to 10 m/s to safely navigate around obstacles; even if the drone is not sure where it is based on its sensor readings.

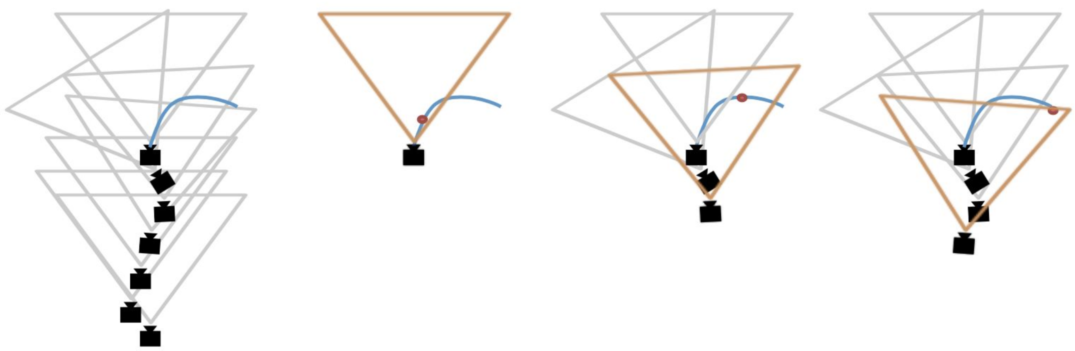


Figure 41: NanoMap 3D Snapshots

NanoMap essentially works so that when the drone moves forward, it continuously takes depth sensor snapshots of the terrain around it. The drone will then start looking at its collected snapshots until it finds one that depicts the area that it is in. The NanoMap algorithm will alleviate the problem of inaccurate sensor readings as drones continue flying, which results from the uncertainty of the accuracy of IMU acceleration measures.

Other safety features include:

a. In the event that our UAS loses signal from the user, it is programmed to stop all lateral motion and gradually slow its rotors until it lands. For Sentinel, this means that it will simply start to slowly descend whilst using its LIDAR sensor to make sure nothing is underneath it. Scout, on the other hand, will reposition itself to be vertically orientated and then also start to slowly descend whilst using its bottom X500 camera to optically detect any hazards underneath it. The user will be notified via the user interface with additional information, such as sensor readings. The user will be able to see the last coordinates of the drone before it lost signal and will have to manually find the drone and reconnect. However, the user will then have the option to have the drone fly autonomously back to where it launched or to continue its original task and or path.

b. Sentinel will be equipped with lateral four ultrasonic sensors, providing a quasi-360 view around the UAV to detect any obstacles in front or around it. Should the UAV detect an obstacle, it is programmed to approach it from different angles and determine the optimal path around said obstacle. The VTOL fixed-wing drone will also be equipped ultrasonic sensors so that it will also have this functionality. The ultrasonic sensors will be integrated around the fuselage and at the tips of the wings, covering a wide range of detection around the more vital parts of the drone. The NanoMap algorithm will also enable the drones to not fall off course more than 90% of the time even if the sensor readings from the IMU are inaccurate.

c. Because the majority of the drone’s flight is autonomous, the pilot will not need to worry about physically keeping an eye on the UAV. Should the UAV encounter issues (detailed in parts a and b), it is programmed to handle them autonomously.

d. Scout is inherently more safe than most fixed wing drones as it does not need any form of bulky or unwieldy launching apparatuses. Due to Scout’s vertical takeoff and landing, it can be safely launched and land anywhere. With all of Scout’s sensors it will be able to accurately detect if the user and or other objects are around it during takeoff and landing, thus being able to almost always guarantee a safe takeoff and landing for itself and its user.

4. Document the Business Case

4.1 Market Assessment

4.1.1 Market Comparison

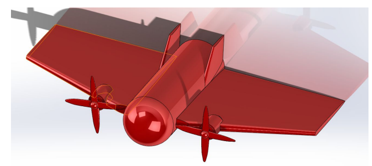
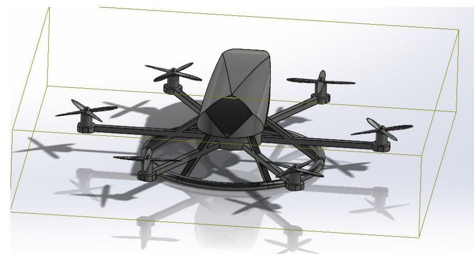
Comparison 1: eBee SQ vs Scout		
eBee SQ		**Scout**
	**Design**	
$10,490.00	**Price**	$7690.11
1.1 kg (2.42 lbs)	**Weight**	8.933 kg (19.694 lbs)
1.1 m (3.608')	**Wing Span**	1.20 m (3.937')
- Sensors: - 12 cm/px (4.72 in/px) Ground Sample Distance (GSD) resolution for the multispectral - 3.1 cm/px (1.22 in/px) RGB	**Survey**	- Sensors: - 8 cm/px (3.15 in/px) Ground Sample Distance (GSD) resolution for the multispectral
11-30 m/s (35-68 mph)	**Cruise Speed**	16-32 m/s (35.791-71.582 mph)
120 m (393.701 ft)	**Flight Altitude**	122 m (400 ft)
- 55-min flight to cover 500 acres at a 400-ft altitude for a single aircraft - 5 hr for a single aircraft to cover the full 4-mi^2 (2560-acre) field	**Flight Time**	- 64-min flight to cover 640 acres at a 400-ft altitude - Marginally under 5 hr for a single aircraft to cover the full 4-mi^2 (2560-acre) field
- Low weight	**Competitive Edge**	- Safety and convenience for landing and launching - Long flight time - Precision - Coverage

Table 7: Market comparison-- eBee SQ vs Scout

Comparison 2: DJI Agras MG-1 vs Sentinel		
DJI Agras MG-1		**Sentinel**
	**Design**	
$14,999.00	**Price**	$3737.09
Maximum 24.5 kg (54 lbs)	**Weight**	Maximum 25 kg (55 lbs) w/ payload
1.52 m (4.99’)	**Diagonal Span**	0.5 m (1.64’)

- Camera: Parrot Sequoia Camera	**Survey**	- “Divide-and-conquer” approach
		- Sensors for detection:
		  - Vu8 LiDAR sensor
		  - HC-SR04 Ultrasonic Distance Sensor Module

22 m/s	**Cruise Speed**	15.823 m/s
3.00 m	**Flight Altitude**	9.507 m
10L spray capacity	**Spray**	9L spray capacity
Up to 10-24 min (depending on load)	**Flight Time**	Up to 44 min
- Resist wind up to 45km/h (12m/s or 28mph) - Customization abilities - Portability (foldable) - Speed - Spray capacity	**Competitive Edge**	- Advanced algorithm to counteract drift and prevent crashes - User-friendly - Long battery life - Comprehensive algorithm to minimize the length of each flight path

Table 8: Market comparison-- DJI Agras MG-1 vs Sentinel

4.1.2 Field Optimization

Following the challenge rules, we created our base model UAS around the 2 mile by 2 mile field.

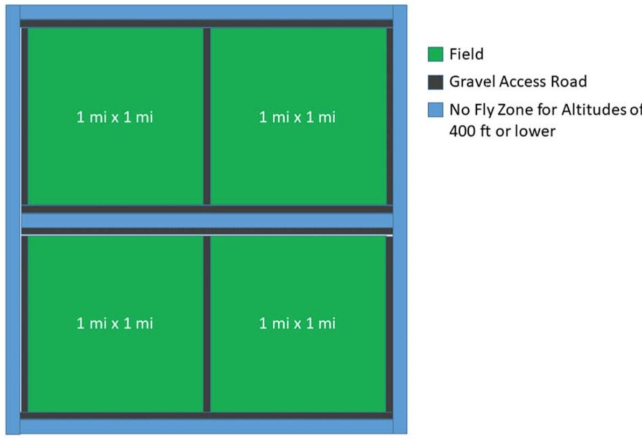


Figure 42: Field Layout for FY18 National Challenge (not to scale)

Equipped with our comprehensive algorithm mentioned in [section 3], the PECAM UAS can easily be scaled up or down and tailor each mission to the given field size. In fact, the system profitability will remain the same regardless of the field size because of our "divide-and-conquer" method to approach each mission that was used since the state challenge (originally given a 1 mile by 1 mile field, we divided the large field into 1/20 mile by 1/20 mile nodes). Then, using our unique algorithm, the field will be divided into zones and the UAV will have all the information to perform its given mission with the shortest flight path. This allows our system to be applied to field of any sizes, easily scaling down or expanding the mission strategy.

Our UAS will maintain a continuous workflow with a system of three drones that will actively communicate between each other and use a "tag-in" system, switching off when refill or recharge is needed.

4.1.3 Target Market Assessment

The team used the sales funnel to narrow down our target market:

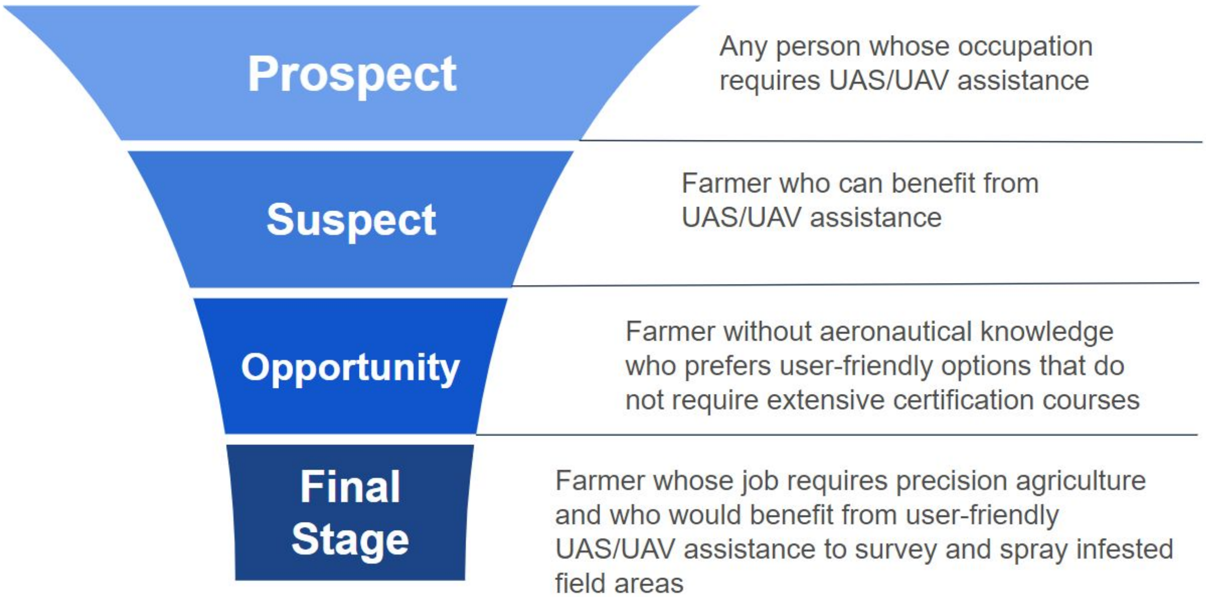


Figure 43: Sales Funnel

Our UAS can operate in fields of any size, as we approach the field with our "divide-and-conquer" method to break up the field into smaller sections, and then use the zone analysis algorithm to address infested areas to survey and spray. Our base model is programmed to survey and spray a 640-acre field subdivided into nodes, but considering our approach, the path can be scaled down or up to target smaller or bigger fields — the average corn field in the US is approximately 333 acres, but larger plantations have bigger acreage.

Corn Production:

2016 U.S. Corn Production by State

	Acres Planted (1,000s)	Acres Harvested for Grain (1,000s)	Average Yield bu/acre	Total Production 1,000 bushels
AL	330	315	120	37,800
AR	760	745	171	127,395
AZ	95	50	215	10,750
CA	420	100	185	18,500
CO	1,340	1,170	137	160,290
CT	25	NA	NA	NA
DE	170	164	170	27,880
FL	80	40	145	5,800
GA	410	340	165	56,100
IA	13,900	13,500	203	2,740,500
ID	340	100	188	18,800
IL	11,600	11,450	197	2,255,650
IN	5,600	5,470	173	946,310
KS	5,100	4,920	142	698,640
KY	1,500	1,400	159	222,600
LA	620	550	165	90,750
MA	16	NA	NA	NA
MD	460	400	152	60,800
ME	31	NA	NA	NA
MI	2,400	2,040	157	320,280
MN	8,450	8,000	193	1,544,000
MO	3,650	3,500	163	570,500
MS	750	720	166	119,520
MT	115	55	100	5,500
NC	1,000	940	129	121,260
ND	3,450	3,270	158	516,660
NE	9,850	9,550	178	1,699,900
NH	15	NA	NA	NA
NJ	80	71	145	10,295
NM	120	41	150	6,150
NV	11	NA	NA	NA
NY	1,100	570	129	73,530
OH	3,550	3,300	159	524,700
OK	400	350	121	42,350
OR	80	39	230	8,970
PA	1,400	950	129	122,550
RI	2	NA	NA	NA
SC	375	350	127	44,450
SD	5,600	5,130	161	825,930
TN	880	830	151	125,330
TX	2,900	2,550	127	323,850
UT	80	29	175	5,075
VA	490	340	148	50,320
VT	90	NA	NA	NA
WA	170	85	235	19,975
WI	4,050	3,220	178	573,160
WV	49	35	145	5,075
WY	100	69	147	10,143
U.S.	94,004	86,748	175	15,148,038

Source: USDA, NASS, Crop Production 2016 Summary, Jan. 12, 2017

Figure 45: U.S. Corn Production by State. Ibid.

While there are only a few large corn plantations in the state of Massachusetts, analyzing the US corn acres planted and US corn production, there are many other states within the United States that we will be able to successfully target.

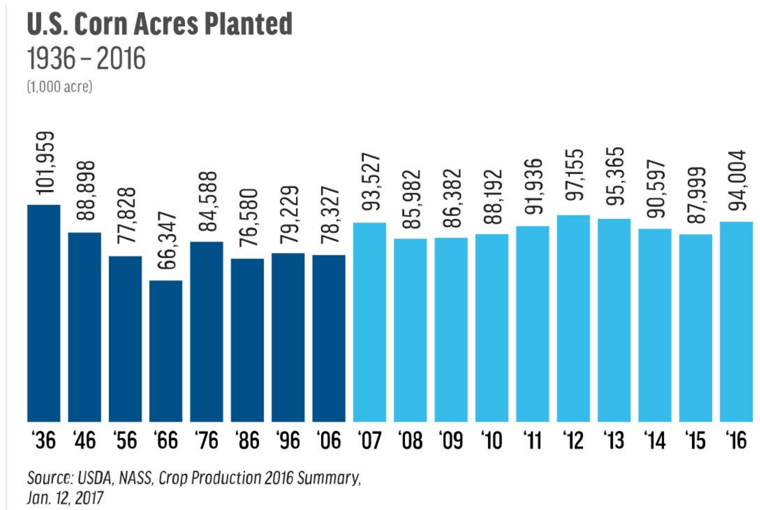


Figure 44: US Corn Acres Planted. Adapted from World of Corn by National Corn Growers Association, 2017.

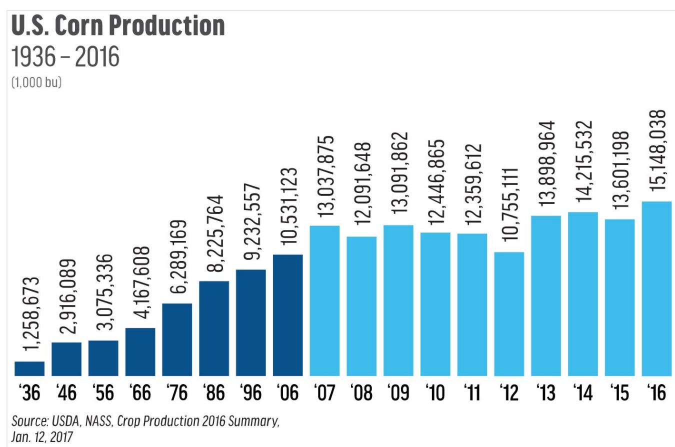


Figure 46: US Corn Production. Ibid.

Relevance of Technology:

According to the “Gartner Hype Cycle for Emerging Technologies, 2017,” commercial UAVs (drones) are currently in the peak of inflated expectations. Furthermore, UAV markets are expected to reach the plateau in 2 to 5 years, entering mainstream adoption. This chart shows that our UAS will remain a viable product in the near future and will have broad market applicability and relevance.

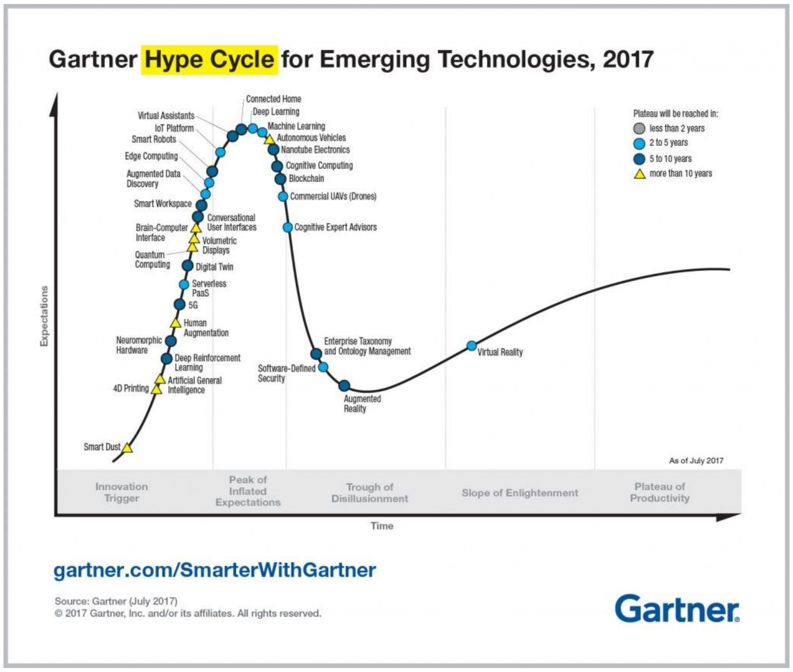


Figure 47: Technology Hype Cycle. Adapted from Top Trends in the Gartner Hype Cycle for Emerging Technologies by C. K. Panetta, 2017: Gartner

Precision Agriculture:

Among the many benefits — both economic and environmental — of precision agriculture, the primary ones result from reduced or targeted placement of crop inputs such as nutrients, pesticides, and water. These benefits of precision agriculture are well known to the USDA (United States Department of Agriculture) and to farmers themselves. This notion will allow our system to be highly competitive in the market, due to its high societal benefit and efficacy as a capital investment for agricultural firms.

4.2 Profitability Analysis

4.2.1 Fixed (Initial) Costs

Material Cost:

Our UAS consists of three UAVs — one surveying drone and two identical spraying drones. Because our UAS consists of two different models of UAVs, both models were calculated separately and were accounted for as a system in the end to calculate the total cost of the base model UAS.

Quantity	Prodct	Cost	Total Cost
1	Micasense	4900	4900
2	Tiger Motor U11 120kv Heavy Lift Motor	350	700
1	Radiolink PixHawk Advanced Autopilot w/ SE100 GPS (Autopilot)	140	140
1	Tiger Motor Flame 80A ESC	120	120
4	TowerPro SG90 9G Mini Servo	3.79	15.16
1	MPU-9250 Inertial Measurement Unit	14.95	14.95
1	X500 camera	50	50
1	Intel NUC	750	750
2	LiPo 11,000 8S 29.6v Battery Pack	500	1000
	TOTAL FOR SCOUT		**7690.11**

Quantity	Prodct	Cost	Total Cost
6	Tiger Motor U11 120kv Heavy Lift Motor	350	2100
3	Gens ace 5300mAh 44.4V 30C 12S1P Lipo Battery Pack	252.38	757.14
1	Tiger Motor Flame 80A ESC	120	120
1	Radiolink PixHawk Advanced Autopilot w/ SE100 GPS (Autopilot)	140	140
4.08	Frame 45.72 cm wingspan	18.96	77.36
10	ultrasonic sensors	2.99	29.9
1	LIDAR Vu8	475	475
1	MPU-9250 IMU	14.95	14.95
6	TowerPro SG90 9G	3.79	22.74
	TOTAL FOR SENTINEL		**3737.09**

TOTAL FOR BASE MODEL UAS	**15164.29**

Figure 48: Material Cost Calculation

The cost of the premium model may vary depending on the farmer's selection of additional services that our company can provide, but there is no fixed cost difference.

Project Management Cost:

The total cost of the Sentinel UAS also includes labor costs to design and produce the UAVs.

Title	Cost per Hour	Hours Needed	Total Cost
Project Manager	75	30	2250
Design coordinator	50	20	1000
System & Test Engineer	50	10	500
Simulation Engineer	50	5	250
Project Scientist	50	20	1000
Project Mathematician	50	10	500
Project Communicator	50	15	750
Assembly Technician	25	15	375
Electronic Technician	25	15	375
TOTAL PROJECT MANAGEMENT COST			**7000**

Figure 49: Project Management Cost Calculation

Hours are estimates of the time that members responsible for specific role spent on the project.

4.2.2 Operational Cost

Our service will include an initial installation and pick-up service, which will take approximately an hour each. During the initial installation, the farmer will have an opportunity to ask questions regarding the UAS operation. Thus, the short-term operational cost will be $50 with 2 hours of service provided by the aircraft maintenance technician.

Title	Cost per Hour	Hours Needed	Total Cost
Aircraft Maintenance Technician	25	2	50
TOTAL OPERATIONAL COST			**50**

Figure 50: Operational Cost Calculation

Our user-friendly and comprehensive UAS allows our user, the typical farmer, to operate the system by him/herself on the field without the necessity of other human assistance. Therefore, there is no accounted long-term operational cost. However, since the farmer must be out in the field with the UAVs to recharge the batteries and refill the SOLVITAL tank, the economic cost will be the time that the farmer must dedicate to operate the UAS during the day-operation as well as ground vehicle operation costs.

The total cost of hiring the data analyst varies ($50 per hour), as this service is only available to the users of PECAM Premium, our subscription-based upgrade version. This additional operation cost will be part of the subscription fee for the premium model, and thus is not factored into the base model. This option will be beneficial to the users who desire to keep the survey data throughout the field operation period and have an updated history of missions. This option will also offer unlimited access to our professionals who will help the farmers to analyze the scanned data from their field and provide suggestions to improve their crops. This additional service will also provide onsite instant help for the field operators / users in need.

4.2.3 Pricing Analysis

PECAM Base Model:

Our UAS plan is to approach any field with a “divide-and-conquer” method of surveying and spraying, where the given field is to be split up into several smaller pieces to tackle individually. Thus, the field size is not a constraint for Sentinel UAS, allowing us to significantly expand our market.

The farmers will be required to pay a security deposit for damages and the cost of the service. Our service will be subscription-based, and our base model will include the three UAVs as a complete UAS, as well as necessities such as a mission timer, battery/payload level indicator, and safety features. While this base model UAS will be sufficient for the farmers to perform needed surveying and spraying operations, they are also given an option to purchase our premium model, PECAM Premium. This upgrade will provide additional services to aid the farmers to analyze their field condition in detail. A discounted rate for longer rent will be available to incentivize the users to stay with our system.

PECAM Premium:

Customers will have an option to upgrade their UAS to PECAM Premium. This premium package will not only offer enhanced and more in-depth analysis of the field, but also additional services that will provide assistance from our trained professionals. Furthermore, the service includes extended computational resources, providing direct access to our computing center where all of the data collected is centralized. The time to interpret and communicate the data will dramatically decrease with the data center’s capability to process multiple algorithms and increase the fluidity between each operation. Extra safety measures, such as autopilot override, will also be available to certified farmers through the premium package. These additions will build upon our already capable UAVs’ performances.

4.2.4 Regulatory Analysis

Not complying with the part 107 regulation, our system allows the farmers to undertake the role of payload operator and provide launch and recovery assistance. The PECAM UAS also allows farmers to serve many roles that would otherwise require hiring of specialized personnel. This dramatically reduces the total operational cost, by approximately $170 per hour and approximately $1070 per mission, and increases affordability.

Title	Cost per Hour
Assembly Technician	25
Electronics Technician	25
Payload Operator	35
Launch and Recovery Assistants	15
Safety Pilot	35
Operational Pilot	35
TOTAL REDUCED OPERATING COST	**170**

Title	Cost per Hour	Hours Needed	Total Cost
Assembly Technician	25	10	250
Electronics Technician	25	3	75
Payload Operator	35	10	350
Launch and Recovery Assistants	15	3	45
Safety Pilot	35	10	350
Operational Pilot	35	10	350
TOTAL REDUCED OPERATING COST			**1070**

Figure 51: Estimated Total Reduced Operating Cost per Hour

4.3 Cost / Benefits Analysis and Justification

PECAM UAS:

Rather than just focusing on the UAV during the operation, the farmer can utilize the time to move the ground vehicle to allow the current UAV in operation to land, refill SOLVITAL, and change battery, and also allow the next one to take off. This not only reduces the total operational cost, but also reduces the stress that the farmer may experience in scheduling an appointment with the field operators and assistants.

Fluidity between drones is possible because of our proprietary communication and operational systems. Comprehensive algorithms to minimize the flight time and battery optimization with a mini-system of drones for spraying also reduces the overall price and efficiency of the system.

Scout - Surveying:

With the tailsitter VTOL transformer design, the UAS does not require the farmers to build a separate landing strip on their field. Rather, the user simply has to place a QR code on the desired spot or on their ground vehicle in order to assist the drone for accurate landing. This serves as a safety feature and adds to the convenience of the user.

Sentinel - Spraying:

Our spraying drones will use gravity feeding of pesticide into the chambers above the nozzles. This minimalistic design of gravity feed with a gravity assisted pump is a system that does not require much maintenance or complicated inner workings that could be a source for malfunction.

Ground Vehicle:

The ground vehicle will not be an additional cost for the farmer as it can be any type that a farmer owns, which will most likely be a vehicle large enough to transport all three UAVs. This will prevent farmers from spending additional money to purchase necessary equipment.

Premium Option:

While range safety, aircraft launch, and recovery are up to the farmers, maintenance is provided in the form of installation and pick-up. If farmers desire detailed analysis of their field condition, they can also purchase the premium service to add an additional team of experts to the mission.

5. Conclusion

In summary, we believe that our design efficiently accomplishes the tasks set out by the challenge in a reasonable and marketable package. Although we began with a number of different ideas, some of which were completely noncompliant both with FAA regulations and RWDC guidelines, we eventually narrowed down our system to two types of UAVs. Scout, a tail-sitter, VTOL, transformer, fixed-wing drone was optimized for surveying. Sentinel, a hexacopter that operates in groups of two or more to maximize efficiency and minimize time spent, was used for pesticide application.

The base PECAM UAS model is comprised of three UAVs, equipped with our unique comprehensive flight path calculation algorithm, that communicate with each other throughout the mission, allowing smooth and continuous operation. We also offer the PECAM premium subscription for farmers who desire to have professional assistance to get a detailed and more accurate analysis of their infested field area.

After narrowing down our target market to farmers whose jobs would benefit from precision agriculture in the form of user-friendly UAS assistance to survey and spray, many unique aspects were introduced to our UAS and its software to maximize its utility. To make sure that our product is marketable to our target market, our UAS completes each field mission with the “divide-and-conquer” method, where bigger fields are split into smaller sections, allowing easy scalability. To conserve battery life, we implemented a system in our software to cut off two of the six rotors when the battery life is low, essentially turning our hexacopter into a quadcopter. To further improve our system, we hollowed the airframe of the UAVs to reduce mass and overall production cost.

Our drone design does not comply with 5 out of 21 FAA Part 107 Regulations’ operational limitations. By designing our UAS outside of these constraints and allowing farmers to become an independent operator, we were able to significantly reduce the operational cost. We also utilize a ground vehicle that is already owned by the farmer as a functional base to allow for continuous workflow when recharging UAVs and refilling SOLVITAL.

Ultimately, we hope to expand the precision agriculture UAS market and thus become a truly user-friendly platform that will allow our users to perform their tasks with ease.

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