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An Unmanned Aerial System for the Detection of Crops with Undergraduate Project-Based Learning

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ABSTRACT

To keep pace with population growth, farmers are leveraging a host of new technologies to improve crop production, including genetically modified organisms (GMOs), along with increased chemical pesticides and fertilizer usage. These new techniques, however, have sometimes led to runoff problems for water systems and local watersheds. By using drone-based technologies the overuse of fertilizers, chemical sprays, and pesticides can be minimized, while preserving farm output and quality. This paper discusses lessons learned from and progress made in a year-long capstone research and development project performed by engineering and computer science students at York College of Pennsylvania. The project involves the study and use of multispectral camera technologies along with drones to survey farms growing corn in various climates. The technologies used to assess farms and modern farming practices are by their nature multidisciplinary. Students involved with this project have thus needed to draw on their engineering and scientific backgrounds while learning new and varied topics to tackle this real-world problem. This paper also examines some of the teaching challenges encountered when using project-based learning (PBL) techniques with engineering students to tackle a multidisciplinary problem similar to the types they will likely face in their professional careers. For example, the students have needed to apply best principles to design and build a drone system to assess crop health. Moreover, they have needed to understand the legal responsibilities of operating drones, farmer issues, and a host of technologies unfamiliar to them prior to this project. Student metrics and outcomes are also assessed to improve the process for future years.

Keywords: Unmanned aerial systems, modern farming practices, undergraduate students, project-based learning

1. INTRODUCTION

The crux of this project stems from a capstone program currently being conducted at the College. One of the main components of the project (an ABET stipulation[1]) is for the students to design and build a solution to a real world problem. The problem presented to students: many modern farm practices incorporate a “fertilize-everywhere, spray-everywhere, and use-pesticides-everywhere” approach, leading to excessive and harmful runoff into the environment. In addition, while these techniques often result in increased crop yields, they are also wasteful and expensive.

The design-and-build requirement has eliminated the possibility of a purchased solution, where students would have needed to worry only about operations, data collection and analysis (although the latter of which could have easily kept the students engaged for two semesters). Note that the purchased solution does exist, but it is expensive. When this program was started, a good existing system cost approximately $12,000 (minimum), with the extra needed materials costing approximately another $12,000. This amount far exceeded the allotted program budget (although these costs have continued to drop dramatically, and the same systems can now be purchased for approximately half the price).

One of the aspects that makes this problem so interesting is that it is multifaceted and multi-disciplinary. When the project was first started, it was assumed that the students would only be taught the following:

- How to design and build a flying wing.
- How to program and set up a modern-day autopilot.
- How to collect video data.

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[1] Abet Accreditation (http://www.abet.org/accreditation/).

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This paper provides a detailed description of student learning, as well as why this practice is not currently being followed on most farms. Furthermore, it provides examples of instrumentation of unmanned aerial systems (UAS), and its use for detecting healthy and unhealthy crops in fields.

2. UAS AIRFRAME DESIGN

On the surface, the design of a small autonomous airframe would not seem to be that difficult. However, the group of students involved in this program had no previous experience designing and or building small unmanned air system (UAS) platforms. These students included one highly motivated mechanical (ME) student, one extremely intelligent computer science (CS) student, and five other students with varying degrees of ability and interest in the project.

Before initiating this project, Wilkerson had the benefit of dozens of years working on these programs with the U.S. Army and was well-versed in the problems that occur when developing a UAS. In addition, for Army projects, we employed UAS hobbyists to help with designing basic drone airframes and flying them for Reconnaissance, Intelligence, Surveillance, and Target Acquisition (RISTA) purposes. Most radio control (RC) pilots know how to design and build aircraft that will fly and are stable. Proficient pilots can operate these systems without error. Little can set a program back faster than a flight crash or aerial mishap requiring the entire system be rebuilt. The practice of leveraging the expertise of RC hobbyists continues to be followed by both the military services and large universities. For example, Carnegie Mellon University and other similar academic programs have used RC hobbyist pilots to assist them with some of their programs.[2]

Meyers et al. (2009) discuss why unmanned aerial vehicles (UAVs) have been dominated by the defense industries. Kontogiannis et al. (2013) examines trends in creating innovative designs for small lightweight UASs to carry state-of-the-art photography and video equipment. Valavanis et al. (2014) offers a comprehensive handbook for the academic and research communities.

Figure 1 shows a typical UAS system that can be purchased for roughly $15,000. This eBee drone is capable of covering hundreds of acres in a single flight. This performance is more than 10 times greater than that of a typical quadcopter or multirotor drone. In addition, the system can operate completely autonomously and is quite efficient.

Figure 1. eBee Drone System provided by Parrot. This system is relatively easy to program and fly, and is able to take-off and land with minimal intervention.

The students working on this program needed to learn enough in two semesters to recreate this design. Moreover, they needed to operate (fly) the system manually during the design phases of the project. To assist them with some of these tasks, a local RC flying club was utilized,[3] whose members assisted the students in learning to fly and design flying aircraft. To learn some basic building techniques, students designed and built a series of foam board aircraft. In the process of building and flying these aircraft with instructor pilots, the students were able to understand the importance of balance, lift, and weight distribution; as well as the role of propulsion and control. Students also learned how to repair damaged aircraft.

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[2] CMU safety pilot Todd Dudek (https://www.cmu.edu/cmnews/010927/010927_chopper.html).

[3] York Area Radio Control Club in Manchester, PA (https://www.facebook.com/pages/York-Area-Radio-control-Club/263634823721298).

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Most fixed-wing airframe designs consist of a foam core with a reinforced surface. As presented in this paper, the foam profiles were made using a hot wire cutter. The design started with a wing profile; an example of which is shown in Figure 2. Wing profiles can be calculated using a wing profile designer.[4] Although there are many types and shapes that can be used, the students stuck to the basic designs.

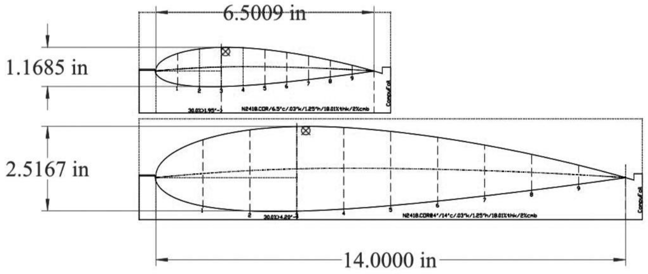
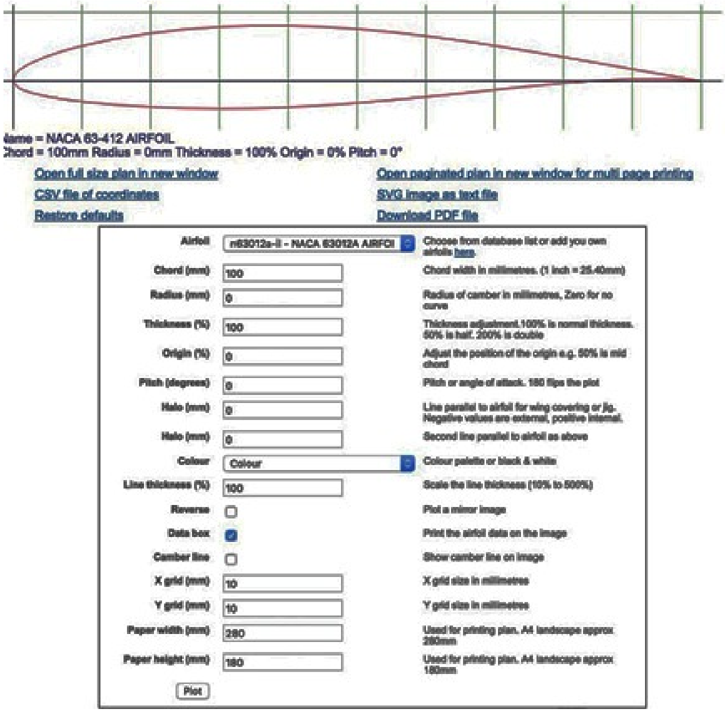


Figure 2. Basic profile of wing core and wing tip. Typical shapes are ear-drop with a height-to-length ratio of around 5 to 6.

This basic design was cut from a piece of luan using a laser engraver cutter. The foam was attached to the template, and then the hot wire cutter was drawn across the profile, making a smooth uniform wing section. The section was reinforced with either carbon fiber tubes or dowel wood along its upper and lower surfaces. Then the outside surface was coated with fiber-filled 3M tape, making the structure strong and durable. In fact, the wings can exceed many times the g-forces that a traditional aircraft could survive without failure. The outside of the structure was coated with another layer of colored tape, making it easy to see when in the air. The building technique used for this project are shown in Figure 4.



ame = NACA 63-412 AIRFOIL
hord = 100mm Radius = 0mm Thickness = 100% Origin = 0% Pitch = 0°

Airfoil	n63012a-il - NACA 63012A AIRFOI	Choose from database list or add you own airfoils here.
Chord (mm)	100	Chord width in millimetres. (1 inch = 25.40mm)
Radius (mm)	0	Radius of camber in millimetres, Zero for no curve
Thickness (%)	100	Thickness adjustment.100% is normal thickness. 50% is half. 200% is double
Origin (%)	0	Adjust the position of the origin e.g. 50% is mid chord
Pitch (degrees)	0	Pitch or angle of attack. 180 flips the plot
Halo (mm)	0	Line parallel to airfoil for wing covering or jig. Negative values are external, positive internal.
Halo (mm)	0	Second line parallel to airfoil as above
Colour	Colour	Colour palette or black & white
Line thickness (%)	100	Scale the line thickness (10% to 500%)
Reverse	☐	Plot a mirror image
Data box	☑	Print the airfoil data on the image
Camber line	☐	Show camber line on image
X grid (mm)	10	X grid size in millimetres
Y grid (mm)	10	Y grid size in millimetres
Paper width (mm)	280	Used for printing plan. A4 landscape approx 280mm
Paper height (mm)	180	Used for printing plan. A4 landscape approx 180mm

Figure 3. Snapshot of the wing foil designer.

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[4] There are many wing foil designers available (e.g., http://airfoiltools.com/plotter/index).

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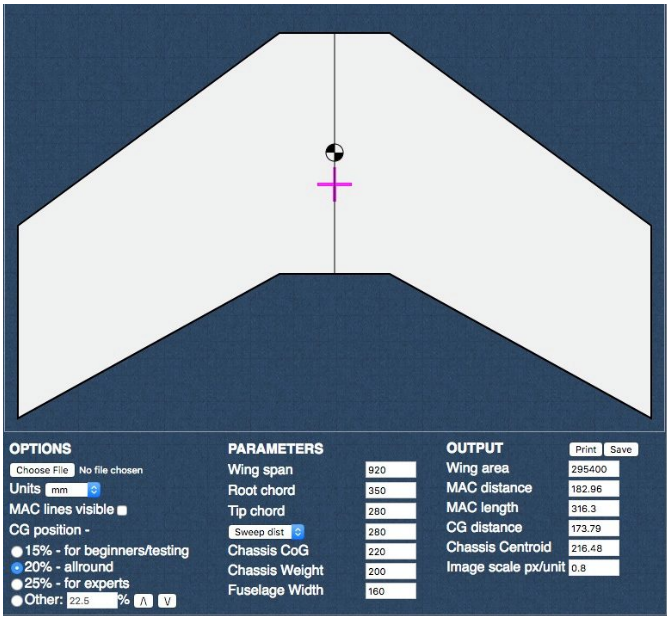
Figure 4. Basic foam wing core with tape reinforcement.

In the future, carbon fiber composite structures can be employed, but a traditional, proven technique was used for this first year. The center-of-gravity (CG) of lift for the aircraft is critical. These values were calculated using a standard wing tool. It is imperative that the location of the aircraft's CG be at or in front of the center-of-lift location. Tail-heavy aircraft are inherently unstable and difficult to control. For flying wings, this is critical. Hence, the students needed to build a complete three-dimensional Solid Works model of the airframe, with the location and weight of all of its components accounted for. These components include the motors, servos, batteries, flight control, cameras, global positioning system (GPS) units, electronics, control surfaces, and any other object of significant weight. Of no less importance is the propulsion system. The system must be lightweight and efficient, with sufficient reserves so as to make it easy to take off from rest. Therefore, it requires almost a 1-to-1 thrust-to-weight ratio at takeoff, but at no other times will it need that much thrust. Therefore, weight and efficiency are equally important. The largest weight components in the aircraft include the airframe, propulsion, camera system, and batteries. The remaining components are far less in weight but still must be accounted for in the location of the CG.



No file chosen
Units: mm
MAC lines visible ☐
CG position -
○ 15% - for beginners/testing
● 20% - allround
○ 25% - for experts
○ Other: 22.5 %

Wing span: 920
Root chord: 350
Tip chord: 280
Sweep dist: 280
Chassis CoG: 220
Chassis Weight: 200
Fuselage Width: 160

Wing area: 295400
MAC distance: 182.96
MAC length: 316.3
CG distance: 173.79
Chassis Centroid: 216.48
Image scale px/unit: 0.8

Figure 5. Basic center-of-lift calculator for a basic wing foil design.

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3. FLIGHT OPERATIONS

The importance of flight operations to this program cannot be understated. Murphy et al. (2008) explained the importance of small unmanned aerial system (SUAS) operations that were conducted during an eight-day structural inspection task. Freeman et al. (2014) examined the ramifications of small drone use in the agriculture industry and the policies restricting their use. Since the time of Dr. Murphy's assessment, numerous regulations have been passed to control the use of drones in commercial airspace. Drone operations are now federally regulated, and flying them in U.S. airspace requires a license. This fact presented a new problem for this project in that we needed at least one of the students to have a Remote Pilot In Charge (RPIC) license. Currently, to obtain a license, an applicant must have knowledge of the following:

- Federal Aviation Administration (FAA) rules and regulations
- Airspace, including being able to read a sectional chart and knowing all of the symbols
- UAS weather and weather sources
- UAS loading and performance
- Crew resources and management
- Airport and airfield operations
- Radio communications and rules
- Emergency procedures
- Preflight and maintenance
- A waiver request

The licensing exam is a two-hour closed book, closed notes, and no Internet test. An RC pilot would have a head start on this exam, but the project's students were starting from ground zero. Therefore, one of the students enrolled in an online course that had proven results.[5] The course consists of 10 sections, each with approximately 10 subsections with videos and exams. The course also provides useful links, including the following:

- Visual Flight Rules (VFR) Aeronautical Chart Symbols
- Chart Supplement Search
- Sample – KOCF Chart Supplement
- SkyVector (Sectional Charts)
- Weather Chart Symbols
- Meteorological Aerodrome Report (METAR) Cheat Sheet
- Phonetic Alphabet
- Remote Pilot Handbook
- Part 107 Regulation

A complete set of links is provided in Appendix A of this report to help anyone wanting to duplicate this study. The RPIC is responsible for virtually every aspect of flight operations, including crew management, weather conditions, UAS maintenance, flight insurance, and airspace management. A complete set of records needs to be maintained, and flight safety is paramount. Under FAA regulations, flights are possible nearly anywhere with the proper paperwork. For this initial season, we chose a farm to survey (with permission from the farmer) that had a local flying field at the site, as well as crops of corn, hay, and soybeans. Figure 6 shows a sectional chart of the area with subplots from Google Earth. As can be seen, this is class "G" airspace; therefore, no paperwork is required for UAS operations. Nonetheless, all FAA rules and regulations still apply. In the coming semester, we plan to expand our operations to include additional farms.

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[5] The service we used was https://remotepilot101.com/.

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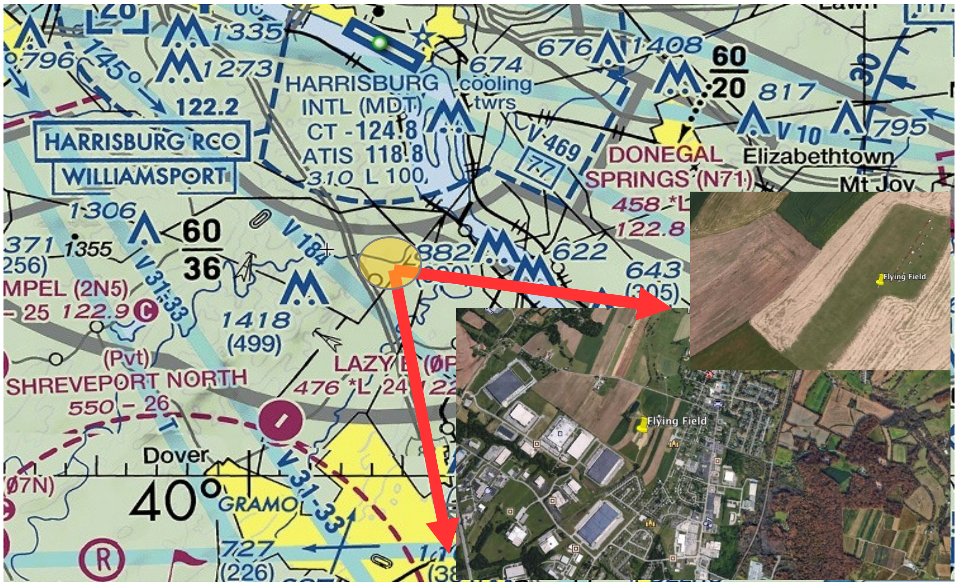

Figure 6. Primary survey area for year one. This area is classified as class "G" airspace, which indicates that no paperwork is required for UAS flight operations.

4. AUTOPILOTS

Autopilot systems have rapidly changed in the past 10 to 12 years. When Wilkerson first started looking at RISTA operations for the U.S. Army, an autopilot cost approximately $5,000. At that time, there were few available, and we were using the MicroPilot system.[6] Today, there are dozens of autopilots on the market, including multiple open source projects. Current costs range from $25 to several hundred dollars. The system we chose for this project was the Pixhawk PX4 autopilot system.[7] The system is low cost, reliable, and vastly superior to the system we used some 15 years ago. The system features a 32-bit ARM Cortex M4 core with floating point unit (FPU) and a 32-bit fail-safe coprocessor. A typical system comes with a main accelerometer gyro, an additional accelerometer and gyroscope, an accelerometer/compass (magnetometer), and a barometer. Figure 7 shows the PX4 Pixhawk system and some of the connections.[8] The Pixhawk system is ideally suited for this program.

Ristorto et al. (2015) explored using the Pixhawk system to monitor farm applications. Using a Pixhawk system, Lum et al. (2016) examined an operational and analytical workflow of incorporating UASs for surveying and assessing farm crops. Also using the Pixhawk system, Valasek et al. (2016) looked at stress in corn and cotton crops. Likewise, Valasek et al. (2017) examined the importance of lightweight, stable, inexpensive, and reliable systems, such as the Pixhawk. Additionally, the authors had experience with autonomous flight testing of quad rotor systems using the Pixhawk flight system. However, the authors had never used the system in a fixed-wing system. The rotary systems offer some advantages. Because rotorcraft take off and land vertically, one need not consider forward speed during those operations. With a fixed-wing aircraft, the complexity of takeoff and landing operations is greatly increased. Waypoint navigation is also equally complicated. Figure 8 depicts a typical autonomous takeoff. Using this technique, the complexities of an aircraft's takeoff is removed from the pilot.

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[6] MicroPilot has been providing professional UAV products since 1994 (https://www.micropilot.com)/.

[7] PX4 autopilot is an open source system used in inexpensive autonomous aircraft (https://en.wikipedia.org/wiki/PX4_autopilot).

[8] Pixhawk autopilot system (https://pixhawk.org/modules/pixhawk).

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Figure 7. PX4 Pixhawk flight control system.

The Pixhawk autopilot can be used with several different ground control stations. Because Wilkerson primarily use an Apple Mac computer, Wilkerson chose the APM Planner version 2.0.20, which has proven to work well on the Mac system. Figure 9 shows the APM planner while connected to the Pixhawk system and with an initial flight plan.[10] Planning includes takeoff, waypoint navigation, altitudes, speeds, and landing. The Pixhawk also collects data during the flight. These data include power drains, flight parameters, and a complete monitoring system, allowing engineers to optimize flight parameters and troubleshoot issues as they arise. Flight telemetry is also possible using a separate transmitter and receiver connected to the controlling computer.

Figure 8. Autonomous takeoff of a fixed-wing aircraft.

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[10] Mission Planner is a ground station application for the ArduPilot (Pixhawk) open source autopilot project (http://ardupilot.org/ardupilot/index.html).

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1	Waypoint	Rel.Alt	lat 40.0513735°				5.00 m	0.00 s
2	Waypoint	Rel.Alt	lat 40.0512051°	lon -76.7318898°	alt 20.00m	0°	5.00 m	0.00 s
3	Waypoint	Rel.Alt	lat 40.0513406°	lon -76.7326301°	alt 20.00m	0°	5.00 m	0.00 s
4	Waypoint	Rel.Alt	lat 40.0514843°	lon -76.7320079°	alt 20.00m	0°	5.00 m	0.00 s
5	Waypoint	Rel.Alt	lat 40.0518867°	lon -76.7308760°	alt 20.00m	0°	5.00 m	0.00 s

WP Radius 0.00 m

Alt 20.00 m

Figure 9. Screenshot of the APM mission planner.

Mission Planner allows the autopilot to be programmed to follow waypoints. It also allows for the autopilot to be set up for various platforms and flight modes along with the associated transmitter system. For this project, the authors chose the Taranis Q X7 2.4-GHz, 16-channel transmitter.[11] Figure 9 shows the primary flight display, waypoint editor, and flying field used for our experiments. The waypoint editor allows for altitude, location, and speed to be specified. The red R symbol in the box specifies that the aircraft should return to where it was launched from and land. As mentioned, the landing sequence for a fixed-wing aircraft requires more planning and thought than a quad rotor. However, the fixed-wing aircraft will enable a survey of a typical Pennsylvania farm to be done in one flight. The typical Pennsylvania farm is approximately 135 acres, and for most farms, the actual fields are broken up into smaller parcels. One particularly interesting part of this project turned out to be the farm itself, as well as understanding the overreaching problem that we were trying to solve. Thus, the following review of some basic modern farming practices is provided to help the reader appreciate the economics of a modern farm, as well as the potential benefits of multispectral analysis of farmer fields.

5. THE FARM (CROP SURVEYS)

The purpose of this project was to research how to reduce the amount of fertilizers, pesticides, fungicides, and other chemicals that farmers routinely use in the York County, PA area. The data will enable the farmers to reduce their use of chemical and natural pollutants while maintaining and, in the future, even increasing crop/acre yield. The project has numerous benefits, including reduced farm field runoff into the York Codorus and Chesapeake Bay watersheds and surrounding area water systems, educational research benefits for the College, and potential new business areas and opportunities for the greater York area. The initial focus of the project will be on corn and associated crops in the York area. Therefore, our surveys will include soybeans, wheat, hay, and straw crops.

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[11] The name Taranis is from the Celtic mythical God of Thunder. The transmitter is a good example of how fast things are changing and includes a telemetry system that will warn the operator when single strength is getting low or when other issues arise. It can be purchased for approximately $100 and is a product of FrySky (https://www.frsky-rc.com/).

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Since 1960, farm corn production has risen every year, from ~40 bushels/acre to currently nearly 200 bushels/acre (see Figure 10). Other York area crops have also seen similar gains. To produce these increases, the modern farmer has employed numerous technology-based measures, many of which involve chemical and aggressive fertilization. These include the application of Roundup® (a glyphosate herbicide), pesticides, fungicides, fertilizers, and (for corn) lots of nitrogen. Many of these chemicals and fertilizers produce unwanted runoff byproducts, which find their way into York area streams, reservoirs, and ground water and thereby produce undesirable results. This project is a first step to using modern technologies to mitigate the unwanted results of modern farming techniques.

The way the technology is applied is relatively simple. Drones are flown over farm fields, collecting video data using green, red, red edge visible, and near infrared light. Images are stitched together to form a GPS-anchored mosaic of the farm field. Data analysis of the light produces intricate information about the condition of the soil and crops. These data contain information about nutrients, weeds, pests, and other items that would otherwise require chemical and other additives being added to the entire farm field. In other words, the drones provide concise locations and data of where treatments are needed. This information allows the farmers to focus their field treatments, thereby reducing current levels of unwanted chemical byproducts while maintaining the beneficial aspects these products provide. Ultimately, this activity can save the farmer money and time (although the economics of drone use are admittedly still not fully understood with regard to smaller farm sizes, which are typical of York area farming). Nonetheless, these technologies are currently being used on larger midwestern farms where typical acreage is closer to a 1,000 acres/farm. For example, Nebraska farms currently average 934 acres, and Kansas farms are approximately 747 acres in size.

Modern farming has undergone an evolution, resulting in higher yield per acre than what was thought possible. As previously stated, the average yield per acre of corn in 1950 was roughly 40 bushels per acre.[12] Today, the yield from an average acre can be more than 160 bushels, a fourfold increase. But, this increase has also come with its own associated costs.

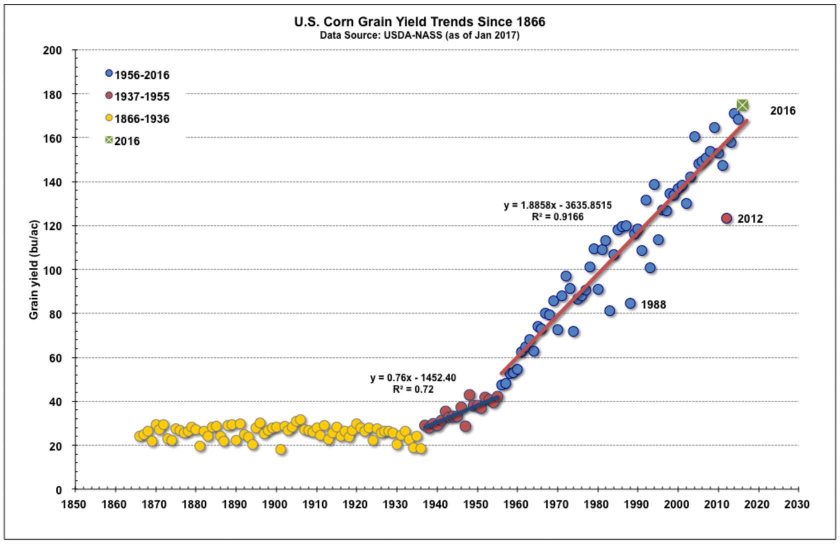

Figure 10. Historical U.S. corn grain yields.[13]

A modern farm has little resemblance to the farms of 70 years ago. Techniques and technology play a big role in modern farming. Most farmers routinely rotate their crops between corn and soybeans to help increase the yields. For the most part, the corn grown on farms in the York area is "dent corn" and is used for cattle feed. Many of these farms are no-till farms (i.e., crops are planted and grown without plowing or turning the soil), and since 2002, the percentage has grown.[14] No-till farming is good for the environment as it helps to reduce soil erosion and runoff into area streams and

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[12] Average Crop Yields, U.S. and Missouri, 1950–2011, Source: USDA, National Ag. Statistics Service (http://agebb.missouri.edu/mgt/cropyldsmous.pdf).

[13] Source: Purdue University (https://www.agry.purdue.edu/ext/corn/news/timeless/yieldtrends.html).

[14] Since 2002, no-till adoption in Pennsylvania has increased, from just over 20% of planted acres

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water systems; however, it also often leads to farmers relying heavily on spraying chemical fertilizer and pesticides uniformly. More recently, numerous other technologies have become available that will help farms be more productive while reducing their footprint on the local water systems. The following paragraphs review some of the planting and farming techniques and examine how emerging technologies might further aid the modern farm.

Preparation: Cornfields are typically prepped with a version of Roundup herbicide, which suppresses the weeds that can significantly affect/decrease crop yield. To protect the crops from being killed by Roundup, farmers also use genetically modified corn seeds that are resistant/immune to glyphosate. In addition, corn is typically planted along with a nitrogen spray to accelerate the growth. Corn can take up to half the soil's nitrogen supply in only 30 days,[15] which is relatively early in corn's growth phase. Therefore, farmers typically apply additional nitrogen when the corn is about two feet tall. Figure 11, taken from the Dupont Pioneer website, shows the huge dependency corn has on nitrogen.

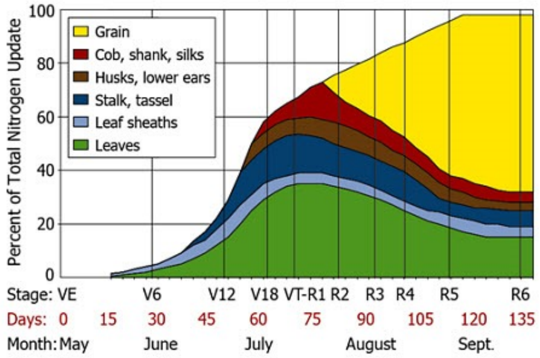

Figure 11. Corn dependency on Nitrogen (taken from the DuPont Pioneer website).

While crop rotations have mitigated the nitrogen issue, not all fields are rotated every year. Nonetheless, there are numerous publications that evaluate corn growth and crop yield due to nutrients, (see Scharf et al. [2005] and Martin et al. [2005]). Corn crops also have other needs, including favorable soil pH levels. According to the National Gardening Association,16 pH levels work best when they are between 5.8 and 6.8. This fact can lead to farmers applying additional treatments (such as lime) to the fields to adjust the pH and prepare the soil for corn production. In addition to having favorable pH levels in the soil, good drainage can also be important. Often, farmers will mix in compost manure in the fall and apply it to their fields. Such practices, while beneficial to the soil, can also lead (especially in the winter or during rainy seasons) to increased runoff into the local stream systems that feed the local water supply and Chesapeake Bay watershed.

Weeds: Another factor affecting corn yield are weeds. It is well known that weeds competing with corn, particularly early in the growing season, can affect yield. In fact, it has been estimated that weeds alone can reduce yield by 20–40 bushels/acre.[17] Grasses and broadleaf weeds are the most damaging weeds in Pennsylvania cornfields. Typically, these weeds are controlled by pre-plant, pre-emergence, or post-emergence chemicals. When considering weed control, the farmer must consider a variety of factors, including weed size, temperature, rainfall, soil moisture, soil type, and soil pH. In addition, early weed infestation has a larger effect when the crop is under stress (e.g., from drought, excessive moisture, and/or periods of cold weather).

This, in part, is why farmers typically use Roundup (or equivalent) herbicides on the fields to reduce weed growth. The glyphosate in Roundup inhibits plant enzymes through their roots and is effective only on actively growing plants. Around 1996, however, genetically modified organism (GMO) corn seeds were made immune to Roundup.[19] Thus,

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(https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/pa/soils/health/?cid=nrcseprd1221425).

[15] Data taken from the DuPont Pioneer website (https://www.pioneer.com/home/site/us/agronomy/library/nitrogen-application-timing/).

[16] Source can be found at http://homeguides.sfgate.com/ph-corn-need-104650.html.

[17] Source: Mark Rosenberg, formerly SDSU Weeds Field Specialist (http://igrow.org/agronomy/corn/effect-of-weed-competition-on-corn/).

[19] Roundup is a brand name for glyphosate, a herbicide developed by Monsanto (https://en.wikipedia.org/wiki/Glyphosate).

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spraying a field with Roundup kills the weeds but has no effect on a "Roundup-ready" corn crop. This allows farmers to use Roundup even as a post-emergence herbicide against weeds that could affect crop yield.

Unfortunately, the effects of Roundup have not all been positive. One analysis by Schinasi et al. (2014) has claimed an increased risk of non-Hodgkins lymphoma (NHL) in workers exposed to glyphosate formulations. Also, in 2015 the World Health Organization classified glyphosate as a probable carcinogenic in humans. In addition, certain weeds have started to develop a resistance to weed control sprays, including glyphosate. This finding has led to an evolution of weed control measures on farms (Heap et al. 2014).

Insect Control: Another issue faced by farmers is pest control. GMO seeds have been engineered to be resistant to certain pests, however, more often than not, additional measures are necessary. A typical Pennsylvania farm must deal with the following insect pests, including:

- Army-worm
- Corn root-worm (northern and western)
- European corn borer
- Cutworm
- Wireworm
- Common stalk borer
- Seed corn maggot

Note that Pennsylvania farmers rarely use an insecticide to control corn borers. For other pests, however, additional methods are sometimes required. Crop rotation also helps with specific pests.

Diseases: Another problem for Pennsylvania farms is plant diseases. Although corn diseases in Pennsylvania are not widespread, they remain a concern because, in part, of the successful breeding programs for seeds, which have some disease resistance to a variety of corn issues, including:

- Northern leaf spot
- Bacterial leaf blight
- Anthracnose
- Gray leaf spot
- Stalk rot
- Ear molds

Selective seed breeding helps modern farmers resist many diseases in Pennsylvania cornfields. Nonetheless, seeds are typically treated by the seed company or by the planter box with a protective fungicide. In general, there are several seed box treatments that are relatively inexpensive and easily applied while planting. Much of the information presented in this paper on weed, insect, and disease control was obtained from Penn State's Department of Agronomy.[20]

Corn Economics: Corn production costs vary from region to region and are dependent on many factors, including seeds, fertilizers, chemicals, fuel, machinery, land, and labor.[21] Fertilizer, chemical, and fuel costs for corn can significantly affect the farmer's potential gross income. For instance, variable costs can account for just over 50% of the total costs of growing corn. In addition, for corn, seed and fertilizer costs exceed the cost of the capital recovery a farmer must pay on machinery. These are important statistics since this is the most likely beneficiary of multispectral analysis of

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[20] Source: National Agricultural Statistics Service, U.S. Department of Agriculture – National Agricultural Statistics Service Website (http://www.nass.usda.gov/) (2001) and https://ipmdata.ipmcenters.org/documents/cropprofiles/PAcornfield.pdf.

[21] Source: Agricultural Economic Insites (https://ageconomists.com/2017/05/01/usda-cost-of-production-estimates-show-little-change-from-2016/).

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farm crops. Admittedly, the current economic realities in corn farming are unattractive. The U.S. Department of Agriculture (USDA) estimates of costs, yields, and prices for corn, soybeans, and wheat currently all show negative returns. A USDA cost-of-production forecast for 2017 is given in Figure 12. (Note that these projections will vary from region to region.) A typical modern farmer has far more things to consider than his ancestors did just 70 years ago. Technology is paramount in every decision and method on a modern farm. Corn requires a larger investment but can also offer similar rewards. As pointed out in this article, "With respect to corn production, the total cost of producing corn is now $3.92 per bushel. Just a couple of years ago, the cost of production estimate at trend yields was $4.11, so forecast costs have come down $0.19 per bushel since 2015. This is a rather substantial amount. At the 2017 trend yield, this amounts to $32 per acre." These estimates will, of course, vary with corn prices per bushel and yield per acre, but the margin under which the farmer is working is slim.

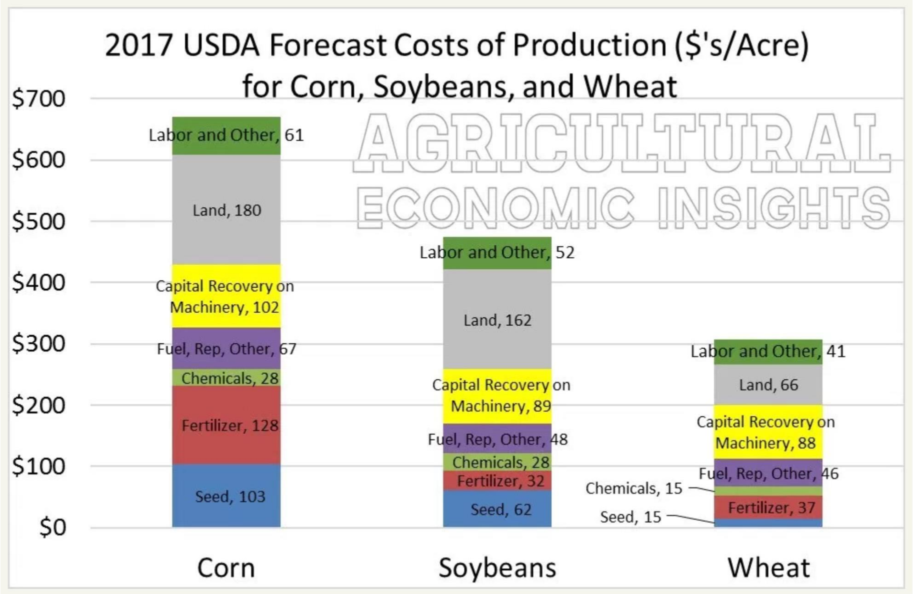

Figure 12. 2017 costs of production estimates for corn, soybean, and wheat.

Fertilizers: Fertilizers and animal manure both have significant amounts of nitrogen and phosphorus in them. These nutrients are the primary sources of pollution from agricultural. Excess nutrients impact water quality. They turn up in water systems and also filter themselves into the ground water systems. Excessive nitrogen in the water causes algae to grow, and too much algae will overwhelm the ecosystems and harm water quality. Furthermore, large growths of algae, often called algal blooms, reduce or even eliminate oxygen in the water. This can cause the death of fish and facilitate elevated toxins and bacterial growth in the water system. Not surprisingly, people can also become sick if they come into contact with this contaminated water.

Multispectral Analysis (MSA): Multispectral analysis has been shown as an excellent tool for mitigating overuse of fertilizers and pesticides (Goel 2003, Miao 2009, Pinter et al. 2003, Hatfield et al. 2008). Multispectral sensors can be placed on agricultural drones that will allow farmers to manage their fields more effectively. The analysis can give valuable insights into soil conditions, fertilizers, and, in some cases, plant stress due to insect and weed infestation. Moreover, there are potential benefits for the environment by reducing the need for certain fertilizers and pesticide sprays. As mentioned, the multispectral cameras use visible, green, red, red-edge, and near infrared wavebands to capture visible and invisible images of vegetation. The images taken from the video camera are stitched together and then anchored to specific GPS locations. This imagery provides a map for various plant needs based on location, and it can help mitigate overuse of fertilizers and other chemical sprays. We use this imaging technology with the associated reflectance and wavebands to provide insights into the health of the farmer's soil and plants. Initially, we used existing systems and software to provide this information, but eventually we intend to contribute to the growing body of methods and tools that a farmer has at his disposal using this relatively new technology.

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There are a variety of indices that have been derived from ratios of light from reflectance at specific wavelengths that can be used. One method of looking at crops is to analyze the normalized difference vegetation index (NDVI). The NDVI can be found from the individual measurements as follows:

$$NDVI = \frac{(\text{NIR - Red})}{(\text{NIR + Red})} \tag{1}$$

NDVI can be used to evaluate plant nitrogen, chlorophyll, and possibly grain yield (Freeman et al. 2007, Ma et al. 1996, Shanahan et al. 2001; Shanahan et al. 2003). Nitrogen use and fertilizer will be our primary focus during the first season. The multispectral camera we will be using is the Parrot Sequoia camera system, shown in Figure 13.

Figure 13. The Parrot Sequoia camera system.

At 120 m (~394 ft), Sequoia has a ground sampling distance (GSD) of 11 cm/pixel. The Sequoia camera captures images across four multispectral bands, plus red/green/blue (RGB) imagery. Coupled with accurate GPS anchors, the camera will yield a high-resolution picture of a farm field. Sequoia uses a standard GoPro mount. The unit requires an external 5-volt, 2.4-amp power supply, which makes it easy to mount and use on a flying drone. A typical NDVI index map of a field using the Sequoia camera is given in Figure 14.[22] This image captures green, red, red edge, and near infrared wavelengths. The video stream consists of a composite of still images. The images are then stitched together to yield a view of the entire field, such as shown in Figure 15. Typically, specific locations are GS-anchored, thereby yielding information about the crop in different locations with a high degree of accuracy. This capability is critical, as it can help enable farmers to apply differing amounts of fertilizers, pesticides, and other chemicals specifically where they are needed, rather than uniformly around the entire field. This information will also enable farmers to see a clearer picture of their crop needs without the need for multiple soil samples.

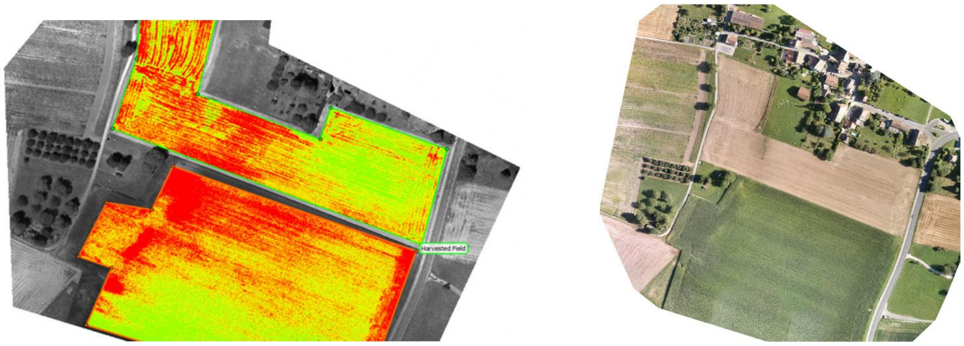

Figure 14. NDVI and Visible Image from Parrot Sequoia camera.

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[22] Source: https://pix4d.com/sequoia-faq/.

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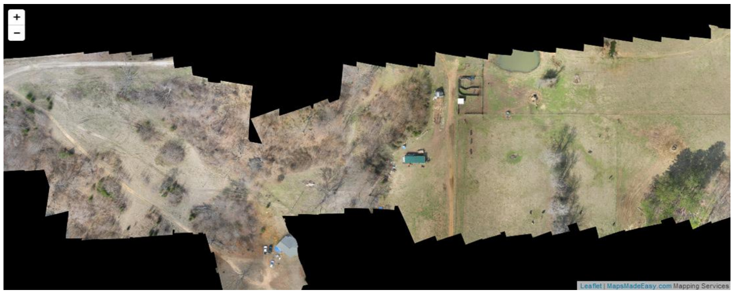

Figure 15. Image stitching example.[23]

Data Analysis: Soil and crop analysis can be accomplished using the Pix4D analysis technique. This could also be accomplished by satellite, but the data would need to be current, which is not always possible. The Sequoia camera system provides a wealth of information that can be analyzed using proven techniques. Soil nutrients can be found from a variety of data from both the soil imagery and the imagery of the crop foliage.

6. PRELIMINARY RESEARCH

The primary focus of this project was to assess the use of fertilizers and chemical sprays on farms in the York Codorus watershed area. The authors looked at typical use versus agriculture needs to maintain current production levels. The data analysis and findings will be focused on attempting to limit the amount of runoff into local streams without impacting the farmer's bottom line: production. As mentioned, the crop of choice is corn, but because most farms in Pennsylvania are no-till farms and the farmers typically rotate crops between corn, soybeans, and wheat, we will examine all three crops. Farm size and field distribution are of concern, but initially we will focus on specific areas in York county. According to the 2012 Census of Agriculture, York County, PA, had 2,171 farms with an average size of 121 acres. Approximately 75% of the land was being used as cropland at that time. The top crop items were corn, soybeans, and wheat. Figure 16 shows the location of York County with a usage subplot.

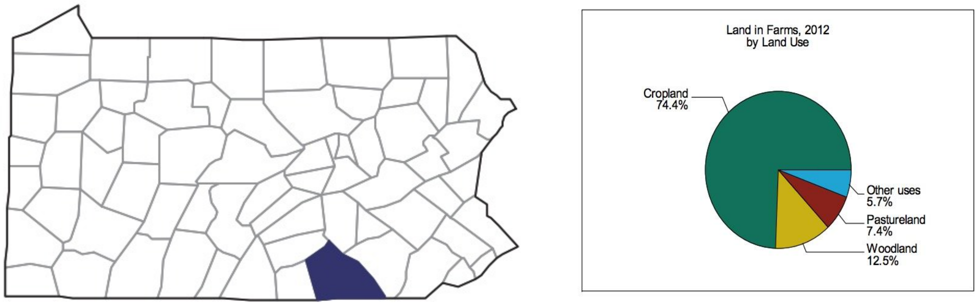

Figure 16. York County, PA and corresponding land use.

There are two major reservoirs in the southern part of the county: Lake Williams and Lake Redman. Both reservoirs have numerous farms that are in the south, where runoff is possible. These will be the initial farms we approach to get permission for gathering information on the soil and plant nutrient conditions. The data will ultimately benefit the farmer but should also serve as a first step of reducing harmful runoff into these two reservoirs. Figure 17 shows some of the farms occupying the southern waterways feeding Lake Redman along the East Branch of Codorus Creek. Figure 18 shows an overview of the greater Redman and Williams Lake area.

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[23] Source: Google Images. https://www.google.com/search?biw=1263&bih=737&tbm=isch&sa=1&q=aerial+image+stitching+&oq=aerial+image+stitching+&gs_l=psy-ab.3...2795.2795.0.3089.1.1.0.0.0.0.286.286.2-1.1.0....0...1.1.64.psy-ab..0.0.0....0.G0mCnuOGM4A#imgrc=-eHWHcX43FE3VM:

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Figure 17. Southern approach to Lake Redman along the Codorus Creek.

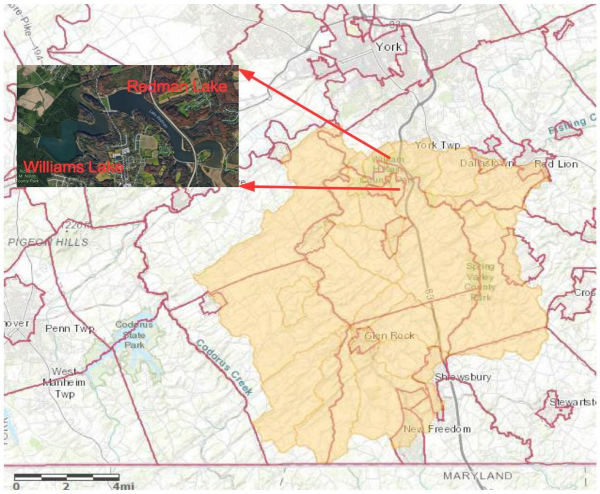

Figure 18. Runoff areas feeding the Williams and Redman Lakes.

Many of the local farms in this area are rotating crops between corn, soybeans, and wheat. At the heart of project is the data analysis of drone multispectral imaging. To get to this point, there are several critical steps that must be completed first. These include buying the equipment, training, use of and experimentation with the equipment. Critical in this timeline are the design and building of a functional drone system that the students can operate and an ability to analyze multispectral data.

7. LEARNING OUTCOMES

Wirkala et. al. (2011) Pointed out that there is widespread enthusiasm for PBL in K12 educational programs. Ravitz (2009) used nearly three decades of data understanding the impact of PBL when compared to traditional programs. Wilkerson et. al. (2017) showed that advanced topics in Engineering and Robotics, normally reserved for graduate studies, could also be used in undergraduate PBL studies. Notwithstanding, assessing these PBL study impacts on students is not always easy or quantifiable. Not surprisingly, Prince (2004) discovered that, even if PBL works, educational outcomes are often not quantifiable, making overall assessment difficult. Further, Prince pointed out that even when data was

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available, ascertaining if a specific technique worked becomes a matter of opinion. Nonetheless, some form of assessment needs to be gathered in order to estimate the impact of the PBL techniques. To that end, our initial assessment was based on exposing students to topics that they had little or no prior knowledge of, to see if they could make notable progress using PBL and Active Learning techniques within their capstone course. As a measures of merit, we included an initial survey of prior knowledge of the topics they would need to learn and then an exit survey, asking the same questions. In general all of the students knew very little about, drone aircraft, radio control, farming, multispectral analysis or any of the other topics they were about to be exposed to.

As can be seen in this paper's review of required materials; this is a diverse collection of technologies. Foremost for this class was the ABET requirement of: Build and Design. However, that alone does not tell the whole story. What was required to make this program meaningful for the students required students to research, learn and in some cases master technologies where they had little background. The question is, is this project possible or will this result in a failed capstone. This being our first attempt at this particular project with PBL/Active Learning techniques has proven challenging and extremely interesting. Much to our surprise the interesting part of this project was not limited to the instructors, rather the students also bought into the program and this resulted in some promising results. Students seemed more than willing to put in extra effort to move this project forward. The approach centered on teaching them what they needed to know so that they could do the work, rather than showing them how to do the work. To this end the first semester centered on:

- Learning about aviation
- Learning about aviation safety
- Learning how to fly RC aircraft ("the fun part")
- Learning how to build aircraft
- Learning how autopilots work
- Learning a specialty area while teaching it to the other members

Since testing and flying these aircraft is critical to the project success, the students were required to spend a fair amount of extra time going to a flying field and learning to fly as well as learning how other people build aircraft. As a first step, students built an aircraft based on a known design and test flew it during the first semester. During the second semester the aircraft was outfitted with an autopilot so that autonomous take off and landings could be done with an aircraft that could be rebuilt easily. Figure 19 shows that aircraft. The aircraft is based on a paper foam board construction that is easy to repair and inexpensive. Reinforced tape and a simple glue gun is used in its construction. The design was based off a Flight Test Blunt Nose Versa Design.

Figure 19. Flight Test design Versa Blunt Nose with student installed Pixhawk autopilot.

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The final aircraft is still under development but will be tested with the knowledge gained from the experiments on the know design. That aircraft is shown in Figure 20. In this aircraft the design was based off the student's design. The model is built from a foam core cut out of a foam block using a hot wire cutter. The wing is reinforced using a main spar and employs the same autopilot used in the paper wing design. This allowed the students to transfer their code to launch, fly and land autonomously from one to the other without major modifications. The design was completed using some of the tools listed earlier in this paper and Solid Works program.

Figure 20. Student foam core design nearing completion with autopilot installed.

The wing design allows the aircraft to be flown for approximately an hour which is sufficient to survey a farm comprising multiple acres. The design has the following requirements.

- Aircraft must fly for approximately one hour.
- Must have sufficient power to operate motors, autopilot, transmitters and receivers and the camera.
- Must have telemetry and tracking.
- Must fly autonomously and be programmable to fly a lawnmower pattern.
- Must be capable of autonomous take offs and landings.
- Must be reliable.

The final requirement is paramount. The camera costs $3,500 and a hard landing or a lost aircraft due to a fly off (worst case scenario) would be catastrophic. Hence, as an interim measure two quad copters were also developed. This design restricted the flight time, but made the reliability efforts easier. These two aircraft are shown in Figures 21 and 22. Using these vehicles proved invaluable in gaining experience with autopilot programming, planning, flight data analysis and post processing of the camera images.

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Figure 21. DJI quadrotor aircraft.

One of the initial flights over the school is artificial turf soccer field is shown in Figure 22. This flight took approximately six minutes to completed, and consisted of nearly 1,800 individual images. Since the aircraft was flown at a low altitude, only a limited area could be covered. The six minute flight nearly exhausted the entire battery that was used (4,000 mAh lithium polymer battery). While the quadcopter was capable of carrying a battery twice that size, this aircraft would prove difficult for surveying large farm fields. At each step in the process, the students were urged to move slowly and cautiously, thereby avoiding costly mistakes that might result in the loss of an aircraft. Multiple flights where performed with each aircraft prior to employing any data analysis techniques (which requires the camera to be on board). Other precautions were taken to protect the camera in the event of a mistake as well as methods to recover a lost aircraft.

Figure 22. 3D Robotics DIY multi-rotor aircraft.

Regardless of these outcomes, as educators we are trying to imbue the students with the ability to tackle real world problems and issues using the scientific and engineering approach. Our observation of the students and their motivation using PBL techniques versus our experiences teaching traditional topics is also relevant. In this regard, it was self-evident that the students got far more out of this program than what could have been found in a traditional classroom environment. However, it would be hard to argue that this was any more effective than our capstone Baja, Formula, or for that matter any of the capstone programs. What was evident in this program was that for these students this program motivated and inspired those to work harder and longer than what one might find in a traditional science course.

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8. RECOMMENDED FUTURE WORK

The overall goal of the project was to make a meaningful contribution to farmers in the York area (Pennsylvania, USA) while conforming to the ABET and school requirements. The findings could be extrapolated to other universities, colleges, and geographical areas. There are over 2,000 farms in York County alone and about three-quarters of these are crop farms. The average farm size is about 120 acres per farm. Surveying farms of this quantity with efficiency requires a proficient aircraft. Multi-rotor drones cannot cover large areas due to battery requirements and doing just one farm with a multi-rotor will take multiple flights. Additionally, video files from multiple flights would need to be merged resulting in an increased amount of time per farm. This was paramount in the thinking of developing a fixed wing design. Buying a system would cost at least ten-thousand dollars and may not meet the farmer's or ABET requirements. However, undergraduate students can make a meaningful contribution to farms in the York area and to the larger community as a whole.

9. CONCLUSIONS

Without question, the described project is an ambitious PBL undertaking. However, this is a real-world problem, and one that will likely not be solved in a single decade, much less a year. In addition, the students are provided the opportunity to move out of their comfort zones and into areas where they have had little prior training which will require the acquisition of and honing critical skills – transferable beyond the scope of this project. Students will research a problem and build that into their solution. The solution needed to include a design and build portion, or the process could have been shortcut by simply purchasing existing systems. The coming semester will further demonstrate whether having engineering and computer science students tackle a problem such as this will be fruitful. This paper lays a reasonable foundation of knowledge that others may use to facilitate similar farming studies with engineering and computer science undergraduate students where a system needs to be designed and built.

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APPENDIX

A list of flight operations resources:

- Chart Supplement Search: https://www.faa.gov/air_traffic/flight_info/aeronav/digital_products/dafd/search/
- SkyVector (Sectional Charts): https://skyvector.com/
- Weather Chart Symbols, How to Read: https://www.thoughtco.com/symbols-on-weather-maps-3444369
- METAR Cheat Sheet: http://www.wrh.noaa.gov/wrh/metar_decode_key.pdf
- Phonetic Alphabet: https://en.wikipedia.org/wiki/NATO_phonetic_alphabet.
- Remote Pilot Handbook: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf
- Part 107 Regulations: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_107-2.pdf
- Drone Registration: https://registermyuas.faa.gov/
- Airspace Restrictions: https://www.faa.gov/uas/where_to_fly/airspace_restrictions/
- FAA Waivers: https://www.faa.gov/uas/request_waiver/
- Flight Services: https://www.1800wxbrief.com/Website/#!/
- Verifly Insurance: https://verifly.com/?utm_source=rp101&utm_medium=email&utm_campaign=sept2016

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