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X650F Power Enhancement

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AT497 Applied Research Project
X650F Power Enhancement
AT 497 Final Project Report Agreement

The X650F Power Enhancement Team has revised and concluded that the information contained within this proposal meets the objectives set forth in the project charter. This form is to serve as a binding agreement between the AT497 X650F Power Enhancement Team, the instructor, and team sponsor, stating that the research proposal as of the twenty-six of April, 2017 will serve as a finalized report showcasing the development of the completed design. The researchers are confident, and by signing this document, agree that the final fabricated product meets the project’s design requirements.

Signed and submitted April 26, 2017

AT 497: Prof. Dubikovsky
Project Sponsor: Prof. Kozak
Team Members: Daniel Ewell
Jessica Iglesias
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Donald Yu
AT497 Applied Research Project
X650F Power Enhancement

Team Members:
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Faculty Sponsor:
Brian Kozak

Spring 2017
Prof. Sergey Dubikovsky
April 26, 2017
Executive Summary

With the Unmanned Aerial Systems (UAS) program being new to Purdue’s Aviation Technology Department, a great deal of pressure is being placed on the founders’ shoulders of this program. More and more students are enrolling every year, and these numbers are anticipated to only grow. With expectations being set high, good first impressions are a must. Students that have enrolled in these courses are given all of the proper material and equipment necessary for their success in the program. However, as this is a newly developed program, there is always room for improvement.

The idea of developing a system that could double, if not triple the power supply of the UAV could have a major positive impact on the UAS program. Although it may take a substantial amount of time to finalize the end product of the quadcopter, with a system that could double or triple the amount of flight time could help the students achieve the goal of finishing all of the labs in a more timely manner. Through the team’s efforts, by enhancing the power of the X650F quadcopter, the results of this study have the potential of having a significant impact on community of the Aviation and Transportation Technology programs.

The final product delivered was a rectifier system that powers the drone via wall outlet power rather than a battery. The results are extremely positive, showing consistent flight times that are double to triple the capability of a single battery. With this design, several mock up boards can be manufactured inexpensively and simply. This will allow students throughout the UAS program to have reliable, extended use power supplies for testing and flying their quadrotor drones.
X650F Power Enhancement

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X650F Power Enhancement

I. Introduction

This proposal seeks to define the purpose, goals, and scope of the X650F Power Enhancement project. Five members of Purdue’s Aeronautical Engineering Technology program are leading this project as part of their senior capstone research course. The purpose of said project is to look into the many possibilities of enhancing the Unmanned Aerial Vehicle (UAV) power supply. This can open doors to several opportunities that can benefit both the Unmanned Aerial Systems (UAS) program here at Purdue University, as well as the all of the students expected to go into the industry. The ideas looked into include, but are not limited to; expanding the current battery life by purchasing new batteries for students within the program, charging the battery while the drone is in flight, or bypassing the battery completely and having the UAV run on a ground power source. After a concept design decision matrix was completed by the team, it was realized that the best design to fit the requirements was bypassing the battery completely and having the UAV run on a ground power source. All solutions and concepts were focused around the voice of the customer, Dr. Kozak, where the project group could define customer needs, and what is in and out of the scope of the group’s project.

This report contains the steps taken to date that have given this project purpose and direction. The problem is first presented, followed by the significance of why finding a solution to this problem can benefit the School of Aviation and Transportation Technology (SATT), along with the team’s goal and scope. Definitions and assumptions that the group defined at the beginning of the project are included as well. A review of applicable literature is provided which provides valuable sources to draw information from as the project progressed into the final
design. This project proposal also includes the project group’s procedures, results, and recommendations based on the results. Finally, there is a conclusion provided and lessons learned by each individual member of the group followed by a multitude of appendixes related to the project that were created throughout the work that the group completed.
II. **Statement of the Problem**

Although the Aeronautical Engineering Technology students majoring/minoring in UAS gain experience with their unmanned aerial vehicles, they still have room for improvement. Through experimentation, the team concluded that the unmanned aerial vehicles constructed in AT 219 typically has an average of 12 minutes of flight time. Currently, the class is designed around assembling and programming the UAV, with a nominal amount of focus on actual flight time for testing drone capabilities. The primary goal would be to take this 12-minute average battery life, and increase its capabilities by doubling, or possibly tripling its capacity, thus benefitting the students as the end result.

The Unmanned Aerial Systems major/minor are still in the early stages of development. Currently, there are nine courses, and this number is increasing dramatically as more students submit their applications for this particular major. Although the X650F quadcopter is only used in three classes, it is expected that this number will increase over the next few semesters. Thus, the end goal of this proposal is to not only benefit the program, but give the students the experience needed to find a career in the UAS industry.
III. **Significance of the Problem**

The UAS Program at Purdue University is still in the early stages of development, and it is growing rapidly. This industry and its technologies are improving every day. Purdue’s Aviation Technology Program has taken on the responsibility to prepare the students for the outside world. The problem is, the UAVs supplied for the UAS program are very cost effective for what they are going to be used for, but the power supply is nominal compared to what it could be. The idea of increasing the battery’s capacity could change the entire foundation of the program entirely. Although a 10 to 12-minute battery life is quite substantial for such a small UAV, the team believes this could be improved. By either increasing the battery life or bypassing the battery all together, the students is the UAV program can increase their flight experience and prepare for real life applications. There are nine courses that have currently been formed and this number will become larger as time goes on. The numbers have increased for the minor, and now that this is the second year that students have started the major, time is running short and the curriculums have to be made. Once all of the classes have been created, the more classes there will for the flight aspect of the program. More flight time equals more experience, and the more experience that the students have, the better off they will be in the long run. One of the project team members is majoring in this program, and he can state first hand that he wishes he had more flight experience in class. He flies for the one battery duration, and then for the rest of his two-hour lab, has to watch others complete their turn to fly. Dr. Brian Kozak was expecting his incoming students of the course to have the necessary skills and knowledge to perform adequately in AT 309. It is obvious there is an issue present when the professor has to change the structure of his course to compensate for the students lack of flight experience.
IV. **Goal of the Project**

This project is intended to provide a method of Purdue UAS students gaining more flight time during their UAS courses. This goal will be reached by providing the students with alternative methods of powering their drones that improves upon the current setup of waiting for batteries to charge. This setup should minimize the down time the students have during the lab sessions of AT 219, allowing the students to focus on fine-tuning the drones as well as gaining experience in piloting them. With the students becoming confident enough to pilot their drones, the later classes may require less emphasis on actual flight practice, allowing for a simpler, more fluid flow of the courses in the major. This may also result in the professors of the program being able to simplify their curriculum, focusing more on the theories and practical skills involved with UAS development and flight.

The Voice of the Customer is an important design requirement in developing the X650F Power Solution. The design requirements for this proposal were gathered from the sponsors of the project and observations gathered by the team. The proposal project is focused on UAS students gaining necessary experience and understanding of flight operations of their quadcopters. Through heavy discussion with the sponsor of the X650F Power Solution, the requirements that need to be fulfilled are to increase drone flight time two times longer than previous semesters, which was approximately ten minutes and lower battery recharge time from four hours to two hours by charging with an amperage rate increase. Further information about the Voice of the Customer can be found in Table 1.1 on the following page. In Table 1.2 on the following page, a House of Quality diagram illustrates how the team’s project is fulfilling the customer’s need. Several options are evaluated for meeting the customer’s needs like extra batteries, tethered system, etc.
### Table 1.1: Voice of Customer

<table>
<thead>
<tr>
<th>Options</th>
<th>Tethered System</th>
<th>Extra Batteries</th>
<th>Hot Swap Battery System</th>
<th>Higher Capacity Battery</th>
<th>Optimization of quadcopter aka lighter weight</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase drone flight time</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Lower time needed to recharge battery</td>
<td>5</td>
<td>10</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Operation in an enclosed environment</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Allow users more hands on experience</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>

### Table 1.2: House of Quality

<table>
<thead>
<tr>
<th>Needs</th>
<th>Drivers</th>
<th>Critical to Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Increase drone flight time</td>
<td>• Ease of use</td>
<td>• System is durable for up to 300 cycles</td>
</tr>
<tr>
<td>• Lower time needed to recharge battery</td>
<td>• Efficiency of lab time</td>
<td>• System directions are concise and easily understood</td>
</tr>
<tr>
<td>• Operation in an enclosed environment</td>
<td>• Cost to student</td>
<td>• Compatible with all student operated drones</td>
</tr>
<tr>
<td>• Allow users more hands on experience</td>
<td></td>
<td>• System does not hinder lab time</td>
</tr>
</tbody>
</table>
V. Definitions

The X650F Power Solution project uses the DMEDI process, simply because the solution focuses on a new development of a new product and service that still meets the customer's needs. The current base of measurement for this project is the cycle time of one flight for the X650F drone’s created in AT 219. This cycle time has a unit of minutes, with the current cycle time being around ten minutes. This cycle starts once the drone is turned on and begins flying, and the cycle ends when the battery runs too low, and the drone must be shut down so the battery can be recharged. For additional abbreviations used in this report, refer to Table 1.3. Refer to Table 1.4 to see a failure modes and expected analysis model for a better understanding or potential failures that may occur during the process of gaining more flight time. Refer to Figure 1 for the current AT 219 process. Lastly, in Table 1.4 is a SIPOC analysis, where the strengths, inputs, process, outputs, and customers are included.
<table>
<thead>
<tr>
<th>Abbreviation/Terms:</th>
<th>Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>X650F</td>
<td>Quadcopter Drone Used In UAV Minors and Majors</td>
</tr>
<tr>
<td>AT 219</td>
<td>A sophomore level class focused on the building of the UAV and test flying it</td>
</tr>
<tr>
<td>AT 309</td>
<td>A junior level class focused on the flying of the UAVs that were built in AT 219</td>
</tr>
<tr>
<td>SATT</td>
<td>School of Aviation and Transportation Technology</td>
</tr>
<tr>
<td>DMEDI</td>
<td>Define, Measure, Explore, Develop, Implement</td>
</tr>
<tr>
<td>DMAIC</td>
<td>Define, Measure, Analyze, Improve, Control</td>
</tr>
<tr>
<td>SIPOC</td>
<td>Suppliers, Inputs, Process, Outputs, Customers</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Modes and Effects Analysis</td>
</tr>
</tbody>
</table>

*Table 1.3 Abbreviations and Their Descriptions*
<table>
<thead>
<tr>
<th>Process Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>Severity</th>
<th>Potential Cause(s)/Mechanism(s) of Failure</th>
<th>Occurrence</th>
<th>Current Process Controls</th>
<th>Detection</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotorcraft Assembly</td>
<td>Manufacturing Error</td>
<td>Hinder Performance</td>
<td>7</td>
<td>Human Error</td>
<td>5</td>
<td>Repair Rotorcraft</td>
<td>10</td>
<td>350</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Inoperable Component</td>
<td>5</td>
<td>Human Error</td>
<td>5</td>
<td>Replace With New Component</td>
<td>10</td>
<td>250</td>
</tr>
<tr>
<td>Program Rotorcraft</td>
<td>Faulty Firmware</td>
<td>Incorrect Flight Mode</td>
<td>10</td>
<td>Error Occurred During Download</td>
<td>9</td>
<td>Redownload</td>
<td>10</td>
<td>900</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Inoperable For Flight</td>
<td>10</td>
<td>Incorrect Firmware Downloaded</td>
<td>9</td>
<td>Download Correct Firmware</td>
<td>10</td>
<td>900</td>
</tr>
<tr>
<td>N/A</td>
<td>Incorrect Coding Values</td>
<td>Unstable Flight</td>
<td>3</td>
<td>Rotorcraft Rejects Values</td>
<td>6</td>
<td>Access Flight Issue/Change Values of Incorrect Flight Condition</td>
<td>7</td>
<td>126</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Inoperable</td>
<td>10</td>
<td>Human Error</td>
<td>2</td>
<td>Recode Values</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>Battery Performance</td>
<td>Insufficient Charging</td>
<td>Shortened Battery Capacity</td>
<td>8</td>
<td>Human Error</td>
<td>10</td>
<td>Charge Battery</td>
<td>10</td>
<td>800</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Decrease in Flight Time/Lost Productive Lab Hours</td>
<td>10</td>
<td>Insufficient Battery Capacity</td>
<td>10</td>
<td>Charge Battery</td>
<td>10</td>
<td>1000</td>
</tr>
<tr>
<td>N/A</td>
<td>Depleted Battery</td>
<td>Inoperable Rotorcraft</td>
<td>10</td>
<td>Battery Cell Failure</td>
<td>2</td>
<td>Purchase New Battery</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Decrease in Flight Time/Lost Productive Lab Hours</td>
<td>10</td>
<td>Battery Cell Failure</td>
<td>2</td>
<td>Purchase New Battery</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>N/A</td>
<td>Incorrect Charging Cycle</td>
<td>Inoperable Battery</td>
<td>10</td>
<td>Human Error</td>
<td>1</td>
<td>Purchase New Battery</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>Drone Flight</td>
<td>Motor Overheat</td>
<td>Decrease in Flight Time/Lost Productive Lab Hours</td>
<td>10</td>
<td>Insufficient cooling</td>
<td>2</td>
<td>Running in controlled environment</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Destroying Motors of X650F</td>
<td>9</td>
<td>Insufficient cooling</td>
<td>2</td>
<td>Limited high power usage</td>
<td>10</td>
<td>180</td>
</tr>
</tbody>
</table>

*Table 1.4 Failure Modes and Expected Analysis Model*
Figure 1: AT 219 Process
<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Inputs</th>
<th>Process Steps</th>
<th>Outputs</th>
<th>Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT 219 Students</td>
<td>X650F Quadcopter</td>
<td>Rotorcraft FrameAssembly</td>
<td>Prolonged Battery Life</td>
<td>Professor Leasure</td>
</tr>
<tr>
<td>AT 309 Students</td>
<td>Hangar 5</td>
<td>Rotorcraft WiringAssembly</td>
<td>Substantial increase in flight time</td>
<td>Dr. Kozak</td>
</tr>
<tr>
<td>Aviation Professors</td>
<td></td>
<td></td>
<td>Increase flight experience</td>
<td>School of Aviation and Transportation Technology</td>
</tr>
<tr>
<td>Quadcopter Manufacturer’s</td>
<td>AC/DC Professional RC Battery Charger</td>
<td>Repairs</td>
<td></td>
<td>Prospective Students</td>
</tr>
<tr>
<td>School of Aviation and Transportion Technology</td>
<td>Replacement Parts</td>
<td>Test Flight</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instrumentation and Measurement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.5 SIPOC
VI. Assumptions

1. Students within the UAV major/minor will learn how to fly the drone build in AT 219.

2. It will take students at least 8 weeks to have the drone built and programmed before test flight.

3. School of Aviation and Transportation Technology (SATT) will continue to fund UAS majors and minors with the necessary resources to succeed including (but not limited to):
   a. Proper tooling for assembly of UAV.
   b. A controlled environment to fly UAVs in.

4. The Unmanned Aerial Systems major and minor will continue with assembling and testing of supplied UAV.

5. Cooperation with Doctor Kozak in defining customer needs.

6. Cooperation with Professor Eismen in developing the electrical power.
VII. Scope and Applicability

The solution of this project will focus on the lab sessions of AT 219. These sessions take place inside Hangar 5 of the Purdue Airport, as it is not being occupied by the Phenom jets at the time of the lab. Since the hangar is large enough for multiple drones to be operating simultaneously, the solution will be designed so that it can be used by several students at once in a relatively clean, climate controlled environment. The final solution will be used primarily by the students and instructors of AT 219, with the potential of usage within other courses of the UAS program as they develop. Due to this, students within the program will become more marketable within the industry, causing this solution to impact potential companies, as well as the university. The solution will likely be highly portable, capable of operating from any location suitable for drone flight.

Since the solution is intended to be used within Hangar 5, weather protection will likely be unnecessary as the environment within the hangar is controlled. With this in mind, any protection that can be implemented with minimal financial or functional impact will likely be included. This added durability will allow the solution to possibly be utilized outside of the intended purpose, providing the end uses with a more versatile product.
VIII. Review of Applicable Literature

As technology makes further advances, the technology of Unmanned Aerial Systems (UAS) and Unmanned Aerial Vehicles (UAV) are reaching new markets and finding new applications. With the growing market for UAS’s, the market is in need for experienced pilots who have a deep understanding of the system’s operation and piloting the UAV. As a result, universities such as Purdue are developing UAS related majors for meeting this new demand. The School of Aviation and Transportation developed the UAS major to prepare students for the growing needs of the industry. The main impediment for teaching students the project team has observed in the UAS laboratory sessions is the duration of drone flight. Drone flight provides students hands-on experience in the operation of the drone. The drones are battery powered and the recharge time for the batteries are lengthy, which severely limits the amount of time the drone can fly. The project team goal is to increase the amount of hands-on experience on the drone for UAS students. To achieve this, the project team is researching ways to increased drone flight time. As a result, the project team researched and referenced online articles and scholarly journals to better understand UAS systems and innovative ideas to increase drone flight time.

In order to develop a system that can improve hands-on experience on a drone, the project team needed to gain knowledge on how an UAV operates. The project team studied various different online articles and scholarly resources to further the team’s understanding of UAVs. *Quadcopter Flight Dynamics* (2014) by M., Khan focuses on the flight dynamics on unmanned aerial vehicles. The physics involved in flying a quadcopter is explained in depth in this journal. The journal was beneficial in determining how the powered tethering unit affects drone flight. The team learned the factors that go into producing thrust and overall motion of the UAV, and it details the math equations used to calculate outputs from different motions the
quadcopter can perform. The *Unmanned Aviation Systems: the Definitive Guide* (2015) by M. Leasure and M. Nolan was another resource utilized by the team. The entire book can be used every day throughout the program’s classes; whether that involves the electronics of the UAV, the aircraft structure, or even airspace operations and flight regulations. The biggest takeaway that is going to be applied to the limitations of flight time with the use of a lipo battery is the chapter regarding Electricity, Electrical, Communications, and Navigation systems. It presents information in a way that helps the team understand how to calculate different measurements, which include wattage, amperage, volts, and current.

For the concept design analysis, the project team studied the different approaches researchers took to address increasing drone flight time. Researchers from the Massachusetts Institute of Technology and the Boeing Research and Technology organizations published the *Automated Battery Snap and Recharge to Enable Persistent UAV Missions* (2011) paper regarding to developing a platform for automated battery changing and charging. The researchers aimed to find a solution to UAV delays and shutdowns. The goal of their project was to increase UAV flight time and mission operations due to growing need for UAVs to stay in the air. Another source that provided insight in achieving longer flight is by the researchers from the University of Agder, Norway published the *Multicopter UAV Design Optimization* (2014) paper that describes the development of optimizing the multi-rotors’ efficiencies to get the best flight performance out of the UAV. This paper displays problem solving techniques using software aided optimizers and design analysis for selecting the best set of hardware for increasing performance. These sources were beneficial in the concept design analysis. It assisted in determining what concepts are feasible and practical for the UAS students and what the project team itself can develop in the time constraint of the project. For example, the project team may
not have the resources or time to develop a battery-swap system, but it may have had the time
conduct tests on how to optimize hardware on the drone.

During the testing of the powered tethering system, an issue concerning the heat
dissipation of the motors used to drive the propellers. The cause for concern is that the motors
showed signs of high heat and were hot to touch. Due to this concern, the project team
researched brushless motor designs and the safe to touch temperatures. The Brushless Motors -
How they work and What the Numbers Mean (2016) on the Drone Test website covers the design
and function of DC brushless motors. A detailed description of the power intake and outputs of
brushless motors is explained in the article, along with miscellaneous calculations that determine
various wearing over time of brushless motors. With this information, the project team was able
to determine the operating temperature range of motors used on drones. Next, the project team
studied the Safe touch temperatures for hot plates paper by B. Subramanian and J. Chato. The
researchers found that the safe touch temperature for metallic materials is 56°C–100°C
(Subramanian, 1998). The motors’ operating temperature range were within limits and the
temperature of the motors after 30 minutes of flight was determined to be safe to touch; this is
further explained in the procedures section.

The knowledge gained in the literature were fundamental in developing the proposed
design. The project team studied how a drone operates and were able to identify areas that could
be improved to increase drone flight duration. Several scholarly sources were examine to assist
in the concept design analysis, in which it assisted in determining in what methods the project
team is capability of achieving and what could better benefit UAS students. Also during the
testing of the powered tethering system, a safety concern arose from the heat dissipated by the
motors. Through literature review, the project team was able to address the safety concern.
IX. Procedures

The procedures taken in the development of the X650F Power Solution involved a complicated process, and thus was broken into different sections. The first section describes the concept design analysis, in which several concept designs were conceived and evaluated. After each concept was evaluated, a concept was inserted into a decision matrix and ranked against the other concepts. The highest-ranking concept, which resulted in concept 1, was then used to address the issue. A set of procedures in the form of either DMAIC or DMEDI improvement process were generated to develop the product. The second section serves for as summary of procedures taken to complete the project in a table format. This section uses the DMEDI style of Lean Six Sigma improvement process for the development of the new product. The third section reviews the measured data and experiments conducted by team on the prototype of concept design one.

Section 9.1: Concept Design Analysis

During the concept design analysis, several concepts of the product were conceived. The first design concept generated was a powered tethering unit that powers the drone without the battery installed. The design requirements necessitates drone flight should achieve at least three times the amount of flight time generated by the battery. The powered tethering unit will allow the drone to fly for an indefinite amount of time; specifically it will meet the design requirement of increasing drone flight time when compared to battery-powered flight. There are several advantages to this design that includes guaranteed increased flight time, removal of the weight of battery, no charge times required, portable design, appealing to stakeholders, and relatively cheap to implement. The disadvantages to this design includes limited range of the drone,
environment sensitive, additional startup work to implement, and difficult to have multiple systems operating. This concept uses a DMEDI process improvement, because the concept it focuses on the development of a new product and service that meets the needs of the customer.

The second concept design was supplying additional batteries to the students in the UAS courses. The concept suggests purchasing at least four batteries for each student and purchasing additional charging units for the lab. The reason for four batteries is that the average battery powered flight achieves approximately twelve minutes of flight. The design requirements necessitates drone flight should achieve at least two times the amount of flight time generated by the battery. Having four batteries allows the student to fly for roughly an hour. There are several advantages to this design that includes: ease of implementation, operation in both enclosed and open environments, ability to use equipment outside of laboratory time, and all students have access to the additional supply of batteries. The disadvantages to this design includes: high cost for purchasing both batteries and charging units, potential to increase battery recharge time due to increased amount of batteries, and not as appealing to stakeholder when compared to other designs. This concept uses a DMAIC process improvement, because improvements and process evaluations were made to the lab to eliminate weaknesses in current processes in the lab structure.

The third concept design was to charge the battery of the drone during flight. The design suggests using a rectifier and wires to charge the batteries while flying. It will allow the battery to be charged at or close to full charge at all times. This is different from the concept design one in which the battery is still installed on the drone. In concept one, the battery is removed. Having the battery during flight operations will allow the students not having to change weight and balances on their drone. There are several advantages to this design that includes: potentially
unlimited flight time in which it allows for at least thirty minutes of flight, no battery charge times required, portable design, and relatively cheap to implement. The disadvantages to this design is similar to concept one, however, there are more traits that includes difficulty to maintain proper amps and volts necessary to charge battery and risk of destruction of the battery. This concept uses a DMEDI process improvement, because the concept it focuses on the development of a new product and service that meets the needs of the customer.

For determining the strengths and weaknesses of each concept design, a Pugh Matrix was generated to compare each concept. Figure 2 illustrates the Pugh matrix. As shown in Figure 2, the datum is the Tethered System and the other two concepts were weighed against this concept. The criteria were derived from the design requirements and the voice of the customer.. Each criteria was given a rank between 1 to 5, with 1 as ‘partially satisfies the need’ and with 5 as ‘fully satisfies the need.’ Each concept was given a rating that ranges between -3 to +3, and with -3 as ‘does not satisfy the need when compared to the datum’ and with +3 as ‘fully satisfies the need when compared to the datum.’ The rating metrics were given to the concepts were based on preliminary studies and suggestions made by the project sponsor. The end rankings resulted in the concept 1 placing first, concept 2 placing second, and concept 3 placing third.
Section 9.2: Summary of Procedures in DMEDI

In the table below, Table 1.6, is a set of procedures in the form of DMEDI improvement process. These procedures were generated to develop the product and implement the design. This serves for as summary of procedures taken to complete the project in a table format. This section uses the DMEDI style of Lean Six Sigma improvement process, because the concept focuses on the development of the new product eliminate weaknesses in the UAS course processes.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Purpose</th>
<th>Deliverables</th>
<th>Tools Used</th>
</tr>
</thead>
</table>
| Define | Discussed with the sponsor about the requirements that need to be fulfilled. Identified the needs to be: increase drone flight time two times longer than previous semesters which was approximately ten minutes, lower battery recharge time from four hours to two hours by charging with an amperage rate increase, operate the quadcopter in an enclosed environment, and allow students to gain more hand-on experience on the drone. | 1. Identification of problem in the UAS course that could be improved  
2. Development of project scope and plan  
3. Create a draft project charter  
4. Identified the Voice of Customer  
5. Consulted sponsors of the proposal | 1. Gantt chart  
2. Project charter |
| Measure | Benchmarked the capabilities of the X650F quadcopter and hypothesized possible solutions that can improve flight time | 1. Benchmarked information for design | 1. Data analysis tools via Excel  
2. Voltage and Amperage readouts via voltmeters and ammeters  
3. Flight cycle measured via timer |
| Explore | Assessed the current condition of the UAS classes that use the X650F quadcopter. Explored the causes of the problem and | 1. Product design concepts  
2. House of Quality  
3. Evaluate several | 1. Pugh Matrix  
2. House of Quality  
3. SATT Faculty |
| Develop        | examined how it drives the customer’s needs. A House of Quality diagram is developed to illustrate how to fulfill the customer’s need. Several options are evaluated for meeting the customer’s needs like extra batteries, tethered system, etc. | conceptual alternatives |
|               |                                                                                                                     | 4. Pugh Matrix          |
|               |                                                                                                                     |                           |
| Develop       | Develop different product designs such as a mockup board and a spool designs. The different product designs were evaluated and shared with project sponsor in order to best understand how to approach the powered tethering unit. After the product design was picked, the parts for the designed design was ordered and then fabricated. The fabricated prototype was then tested to for operational checks and limits. The team used the Aviation Department’s facilities to test the prototype. The team also used progressive testing methods to test the limits and other characteristics of the prototype. |                           |
|               | 1. Detailed product design                                                                                         | 1. Progressive Testing Analysis tools |
|               | 2. Detailed production process                                                                                     | 2. Aviation Technology’s Avionics Lab |
|               | 3. Prototype and Pilot of powered tethering system                                                                | 3. Purdue Airport’s Hangar 5 |
| Implement     | After the prototype has been validated and operational capable by the project’s sponsor, the                      |                           |
|               | 1. Operational directions                                                                                         | 1. Dr. Kozak’s resources |
|               | 2. Final product                                                                                                | 2. UAS                  |
The project will be ready for implementation. The implementation step would include employing the powered tethering unit in the UAS courses. The students will be using the created product during their lab time.

<table>
<thead>
<tr>
<th>design</th>
<th>laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Use in UAS course</td>
<td></td>
</tr>
</tbody>
</table>

Table 1.6: Procedures for Concept 1, Tethered System

Section 9.3: Review of Measurements and Experiments

In this section, data collection procedures and the conducted experiments throughout the project’s development are reviewed. A series of tests were conducted to collect the tether unit’s operational data and its effect on the X650F drone. The powered tethering unit were tested against the design requirements, such as flight time increase and use in an enclosed environment, that were set forth by preliminary studies and the voice of the customer. During the experimental phase, several issues were observed that are a cause for concern such as flight characteristics and heat dissipation. The methodology of the conducted tests were to determine the power capabilities of the power supply, administer time trials of powered flight with the tethering unit, measure thermal behaviors of the drone and tethering unit system, and evaluate payload capabilities. Below are the series of tests conducted by the team to evaluate the prototype's design and the issues that were a cause of concern.

Section 9.3.1: Power Operational Check

This test entails an operational check on the

Figure 3: Output Voltage
powered tethering unit to determine if it is operating normally. The powered tethering unit consists of two major systems: the tethered power supply and the tethering cables. Normal operation is defined by the tethered power supply being able to supply an output voltage of 13 volts to a circuit. Normal operation of the tethering cables is defined by the cable having no opens and having continuity between the two ends of the cable. The procedures for this check was to measure the output voltage of the tethered power supply, connect the power supply to a mockup circuit, check the tethering wire for continuity, and connect the powered tethering unit to the drone if all of the preceding steps were successful.

The power operational check occurred after the fabrication of the first iteration of the tethered powering system. After the fabrication of the cable, power supply switch, and cable connectors, the output of the tethered power supply was measured across the cable as shown in Figure 3. A multimeter, which was supplied by the AT Avionics Lab, was connected to the output connections of the tethered power supply. A measurement of an output voltage of 13 volts with a +/- 0.2 volts tolerance was observed. This matched the tethered power supply’s product specifications. With the tethered power supply operating normally, it was then used to power one of the Avionic Lab circuits, as shown in Figure 4. The lab mockup circuit functioned successfully with the tethered power supply driving it. Next, the continuity of the tethering cable was check by using the multimeter, and the readings from the multimeter showed no indications of opens in the tethering cables. The powered tethering unit was then assembled by linking the
power supply to the tethering cable. Since the preceding steps were successful, the powered tethering unit prototype could now be tested with the X650F drone. The X650F drone powered on successfully with the powered tethering unit supplying it energy.

The Power Operational Check resulted in a success. The powered tethering unit displayed no signs of faults and the checks indicated the system was operating normally. This test section only assesses if the tethered powering unit could power the drone, not whether the unit could supply drone flight. As a result, the drone was not flown during this test. The following test sections covers drone flight assessments.

Section 9.3.2: 20 minute Operational Check

In this test section, the X650F drone operationally check by a 20-minute flight with the powered tethering unit connected. An operational check in this test involves determining if the drone is operating in normal flight. Normal flight is defined as flight duration of at least 10 minutes, distance range of 25 ft from the pilot, and light flight maneuvers. Light flight maneuvers is described as leveled flight and no turns or movements with excessive pitch angle. A specified time of 20 minutes was chosen due to meeting the design requirements and testing methods. The design requirements necessitates that powered tethering unit must be able supply power to the drone longer than a battery power flight, which averages 12 minutes of flight. The 12 minutes were derived from preliminary tests and calculations, which measured how long the battery can supply power to the drone. Also, the testing methods for drone flight suggested 20 minutes, because the testing methods was designed to take a form of progressive testing to better observe operational data and not to overstress the prototype. The procedures for this check was to operate the drone for 20 minutes with it being powered by the tethering unit, observe any
notable flight characteristics, and monitor heat dissipation from the prototype and drone.

The testing environment was conducted in Hangar 5 at Purdue Airport. However, due to weather conditions, the hangars were filled with aircraft. The team decided to use the limited space to work with the prototype. Before the testing, there were pre-adjustments and modifications that took place. The propellers of the drone were rebalanced with adding strips of tape to the propeller. The battery was removed as well. After the re-balancing, the tethered powering unit was powered and connected to the drone. The drone was then flown for 20 minutes, performed light maneuvers, and operated within 25 ft of the pilot, as shown in Figure 5.

During the test, minimal heat was dissipated by the power supply, wiring, motors, and the electronic controllers. The tethered powering unit did not show any signs of overheating for 20 minutes. The collected data and notes are shown in Table 1.7. Overall, the test flight was a success for determining the functionality and operations.

However, there were some concerns that arose from the testing. The tethering cable from the prototype had an effect on the flight on the drone, in which the tension of the wire pulled the drone in the direction of which the power supply was place. At certain times, the propellers on the drone were experiencing a ‘wobble’ effect, which caused the drone to shift out of level flight for a minor. The main theory is that there were improper propeller balancing, which led to the ‘wobble.’ However, the removal of the battery may have caused this effect, since it may have shifted the weight and balance of the drone.
Table 1.7: Data collected during Test 3.2

<table>
<thead>
<tr>
<th>Design</th>
<th>Flight Time in minutes</th>
<th>Charge Time for Battery in hours</th>
<th>Weight of drone in lbs</th>
<th>Notes 1</th>
<th>Notes 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>12 min</td>
<td>1 hr 30 min</td>
<td>3.29</td>
<td>Minimal heat dissipated by the power supply</td>
<td>Tested at 15-20ft</td>
</tr>
<tr>
<td>Powered Tethering Unit</td>
<td>20 mins</td>
<td>NA</td>
<td>2.56</td>
<td>Tension on cable pulls the drone</td>
<td>Minimal heat dissipated from the motors and the ECs</td>
</tr>
</tbody>
</table>

Section 9.3.3: 30 minute Operational Check

In this test section, the X650F drone operationally check by a 30-minute flight with the powered tethering unit connected. The operational check follows the same experimental approach as Section 3.2: 20 minute Operational Check, where it involves determining if the drone is operating in normal flight. A specified time of 30 minutes was chosen due to meet the design requirements by assessing if the powered tethering unit could supply powered flight longer than a battery powered flight. Since the previous test powered the drone for 20 minutes, a 30-minute flight will be beneficial in understanding the limits of the design. The procedures for this check was to operate the drone for 20 minutes with it being powered by the tethering unit, observe any notable flight characteristics, and monitor heat dissipation from the prototype and drone.

The testing environment was the same as the previous test, which was located in Hangar 5 at Purdue Airport. The hangars were still filled with aircraft due to the weather conditions. The
team decided to use the limited space to work with the prototype. During the test, the team monitored the flight characteristics of the drone and the heat dissipated by various components of the drone and the tethered system. Minimal heat was dissipated by the power supply, wiring, and the electronic controllers. The tethered powering unit did not show any signs of overheating for thirty minutes. The collected data and notes are shown in Table 1.8. Overall, the test flight was a success for meeting the 30 minutes of flight limit. However, some issues arose during the testing. One cause of concern was that the motors that drive the propellers showed signs of high heat and were hot to touch. Due to these indications, thermal readings of the motors and essential flight components will be evaluated in the next section, Section 3.4. In addition, the flight controller, KK2 board, started beeping shortly after the thirty-minute mark. There were two theories that could explain this. The beeping from the flight controller could have signified the motors overheating. Another theory is the flight controller board has a built-in flight time limit to protect the drone. This theory better supports the beeping from the flight controller, because most X650F drones do not operate for prolonged periods.
Section 9.3.4: Thermal Measurements

Due to the signs of high heat dissipated from the motors of the X650F drone, the project team judged that an accurate thermal reading of the motors would be needed to assess the safety of operating the powered tethering unit longer than 30 minutes. A thermal camera, which was provided by the UAS faculty, was used to measure the temperatures of the various components of the system. The thermal camera used was a Flir Vue Pro R, and the maximum and minimum readings the camera was express is 275 F and -13 F respectively.

The procedures for the thermal measurements was to check the temperatures of various components of the powered tethering unit during flight.

Table 1.8: Data collected for 30 minute Operational Check

<table>
<thead>
<tr>
<th>Design</th>
<th>Flight Time in minutes</th>
<th>Charge Time for Battery in hours</th>
<th>Weight of drone in lbs</th>
<th>Notes 1</th>
<th>Notes 2</th>
<th>Notes 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>12 min</td>
<td>1 hr 30 min</td>
<td>3.29</td>
<td>Minimal to medium heat dissipated from the power supply</td>
<td>Tested at 15-20ft</td>
<td>High heat dissipated from the motors</td>
</tr>
<tr>
<td>Powered Tethering Unit</td>
<td>30 mins</td>
<td>NA</td>
<td>2.56</td>
<td>Knotted cable during flight</td>
<td>KK2 board beeping after 30 minute flight</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6: Snapshots of the different time intervals of drone flight
tethering unit and the X650F drone. The checks for temperatures were conducted in three
different time intervals of drone flight: 10 minutes, 20 minutes, and 30 minutes. In figures 6,
illustrate snapshots of the different time intervals the drone was flown. A thermal measurement
on the drone in the OFF position was conducted to illustrate the difference of temperatures from
OFF position to 30-minute flight operations. The thermal measurements were taken after the
drone has flown after the designated time interval and once the drone landed on the ground. The
reason for taking the measurements when the drone landed was due to safety concerns and
concern with damaging the drone. As a result, the temperatures were taken a minor, less than 10
seconds, after the drone has landed, which may have skewed the temperatures to the low end.
However, this is satisfactory data because the operators of the drone would only be touching the
components when the drone is grounded.

The powered tethering unit and the drone components were thermally check at different
flight time intervals. The collected thermal measurements were compiled into two different
tables, as shown in Tables 1.9 and 1.10. In Table 1.9, the temperature of tethering unit and drone
components were collected. In Table 1.10, the temperature of tethering unit and drone
components were collected. The reason the drone motors were sorted into different table is that
the temperatures of the motors averaged higher temperatures than the temperature of tethering
unit and drone components. In addition, the motors provide the essential thrust to lift the drone
and thus need further inspection. The highest temperature range were dissipated by the motors in
all time intervals when compared to the tethering unit and drone components. The reason for this
test was to determine if the motors were safe to touch after operation. As shown, the highest
temperature collected was 178 F and were hot to touch. The project team studied the *Safe touch
temperatures for hot plates* paper by B. Subramanian and J. Chato. The researchers found that
the safe touch temperature for metallic materials is 56°C–100°C, 133 F-212 F, for a contact time of 5 seconds (Subramanian, 1998). The researchers concluded that “if the surface did not feel ‘too hot’ for 5 seconds, the person had sufficient time to release contact without either physiological damage or dropping the part, even if the temperature remained relatively high for a longer period” (Subramanian, 1998). As a result, even though the motors temperature was 178 F, it is safe to touch if the contact time is below 5 seconds.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Off position</td>
<td>81</td>
<td>73</td>
<td>81</td>
<td>73</td>
<td>81</td>
<td>73</td>
<td>81</td>
<td>73</td>
</tr>
<tr>
<td>10 minutes</td>
<td>90</td>
<td>74</td>
<td>88</td>
<td>74</td>
<td>89</td>
<td>72</td>
<td>89</td>
<td>70</td>
</tr>
<tr>
<td>20 minutes</td>
<td>92</td>
<td>73</td>
<td>86</td>
<td>74</td>
<td>92</td>
<td>72</td>
<td>94</td>
<td>77</td>
</tr>
<tr>
<td>30 minutes</td>
<td>93</td>
<td>78</td>
<td>90</td>
<td>74</td>
<td>86</td>
<td>74</td>
<td>96</td>
<td>85</td>
</tr>
</tbody>
</table>

Table 1.9: Temperature of Tethering Unit and Drone Components in Fahrenheit

<table>
<thead>
<tr>
<th>Flight Time using Ground Power Tether</th>
<th>Front Left Motor (Max)</th>
<th>Front Left Motor (Min)</th>
<th>Front Right Motor (Max)</th>
<th>Front Right Motor (Min)</th>
<th>Back Left Motor (Max)</th>
<th>Back Left Motor (Min)</th>
<th>Back Right Motor (Max)</th>
<th>Back Right Motor (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off position</td>
<td>81</td>
<td>73</td>
<td>81</td>
<td>73</td>
<td>81</td>
<td>73</td>
<td>81</td>
<td>73</td>
</tr>
<tr>
<td>10 minutes</td>
<td>131</td>
<td>73</td>
<td>150</td>
<td>79</td>
<td>138</td>
<td>73</td>
<td>136</td>
<td>78</td>
</tr>
<tr>
<td>20 minutes</td>
<td>153</td>
<td>74</td>
<td>156</td>
<td>73</td>
<td>147</td>
<td>74</td>
<td>158</td>
<td>73</td>
</tr>
<tr>
<td>30 minutes</td>
<td>168</td>
<td>74</td>
<td>178</td>
<td>82</td>
<td>162</td>
<td>76</td>
<td>158</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 1.10: Temperature of motors in Fahrenheit

Section 9.3.5: Payload Measurements

In this test section, the payload capacity of the X650F drone is evaluated and its effect on the flight characteristics of the drone. The reason for this testing is to further showcase that the powered tethering unit can increase hands-on experience for the user. Since the drone has the battery removed during the operation of the powered tethering unit, the is capable of the
supporting a higher payload capacity. With a higher payload capacity, students may learn more about flight characteristics with a heavier payload.

The procedures done to evaluate the payload capacity was to incrementally add weight to the drone when it is being powered by the battery or by the tethering unit. After the weight was added, the flight characteristics of the drone is examined. The weight added was done in one-pound increments. From previous measurements and calculations, the maximum calculated payload of the battery-powered operation is 3.53 lbs and 4.26 lbs when powered by the tethering system. For each weight increment, the drone flight was given a score between 1 to 5. This score assesses the performance of the drone with the weight added. A score of 1 equates to the drone struggling to maintain altitude, sluggish maneuvers, and heavy strain on the motors. A score of 5 equates to the drone easily maintaining altitude, agile maneuvers, and capable of carrying the load. The scoring of each powering system is showcased in Table 1.11. Both battery powered and tethering system were able to support the drone’s payload capacity up to 3 lbs. However, the battery powered drone suffered severe performance issues when 4 lbs of weight were added. This was expected since the calculated payload of a battery powered X650F drone is rated to be 3.53 lbs. The powered tethering unit was able to support 4 lbs of weight, however the drone was straining to maintain altitude. Even with the strain on the drone with 4 lbs of added weight, this will still provide an increase of hands-on experience to the drone pilot in which the pilot will be able to learn more about how to operate a drone with added weight.
<table>
<thead>
<tr>
<th>Design</th>
<th>No Weight Added</th>
<th>Weight added, 1 lb</th>
<th>Weight added, 2 lb</th>
<th>Weight added, 3 lb</th>
<th>Weight added, 4 lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Powered</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Powered Tethering Unit</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

*Table 1.11: Payload capacity scoring of each powering system*
X. Results (DMAIC or DMEDI)

The results of the development of the X650F Power Solution is modeled after the DMEDI process improvement, and thus was broken into the individual sections. The project is modeled after the DMEDI, because it focuses on the development of a new product and service that meets the needs of the customer. In the define section, a comparison of the design requirements and the results are assessed. The measure section examines the existing processes in the UAS coursework and the design requirements to gain a better understanding of the service the customer needs. In addition, the role of the FMEA in the development of the powered tethering unit is presented in the measure section. The explore section discusses the concept design analysis and how the voice of the customers affected the development of the design. The develop section compares the estimated resources and the actual resources of the project. The powered tethering unit’s limits and optimization are reviewed in the development section. Also in the develop section, the design evolution of the powered tethering unit is showcased. In the implementation section, descriptive statistics and T-tests are also conducted in the implementation section to evaluate the before and after processes.

Section 10.1: Define

The define phase of the DMEDI process improvements involves determining the project scope, objectives, and design requirements. With the completion of the project, the powered tethering unit meets all of the project’s design requirements. The design requirements are defined as increasing drone flight time, decreasing the time needed to recharge battery, and ensuring more hands-on experience with the drone. These design requirements were the drivers in the development process, and all actions taken to fabricate the powered tethering unit linked back to
the design requirements. As a result, these requirements were not changed throughout the project's development. One requirement that may have changed in the development process was the compatibility of the powered tethering unit to other types of drone frames. The powered tethering unit fabricated in this project is limited to only the X650F drone; however, the project’s sponsor was interested if the unit could be compatible to other types of drones. The project’s sponsor tasked the group to installing voltage and amperage measuring instruments to the powered tethering unit in order to monitor the voltage and amperage draw of the system. In addition, the power supply unit in the powered tethering system has a built-in potentiometer that adjusts the electrical output to meet the demands of the attached device. The project group did not conduct tests for compatibility for other drone frames due to being out of scope. However, in theory, the powered tethering unit should be able to power any drone frames that are within the limits of the electrical output of the power supply unit.

**Section 10.2: Measure**

The measure phase of the DMEDI process improvement involves defining the voice of the customer. The difference between the define phase and the measure phase is that the define phase focuses on the scope and objectives of the project. The measure phase focuses on understanding the voice of the customer and who may be the customers of the final deliverable. In this measure section, the examination of the existing processes in the UAS coursework and the design requirements occurred to gain a better understanding of the servicing the customer needs. The stakeholders for the final deliverable were identified to be UAS department’s students and faculty, prospective students, industry contacts, and the SATT department. The existing UAS class is designed around assembling and programming the UAV, with a nominal amount of focus on actual flight time for testing drone capabilities. The process the project team is improving is
the drone flight operations. The main handicap in this process is the battery powered drone flight that has a flight ranging 10-12 minutes with a recharge time that is longer than an hour. In addition, the role of the FMEA in the development of the powered tethering unit is presented in this measure section. One of the issues that arose during the testing of the high heat dissipation from the motors. The project team accounted for this issue in the FMEA in Table 1.4. Motor overheat was anticipated during the development and it proved beneficial for assessing the potential effects of failure. If the motors were to overheat, there would be a decrease in flight time and loss of productive laboratory hours. Since this failure mode had a severity rating of 10 and a detection rating 10, the project team conducted thermal measurements and literature review to provide an assessment of the issue. As shown in Table 1.10, the highest temperature collected was 178 F and were hot to touch. The project team studied the *Safe touch temperatures for hot plates* paper by B. Subramanian and J. Chato. The researchers found that the safe touch temperature for metallic materials is 56°C–100°C, 133 F-212 F, for a contact time of 5 seconds (Subramanian, 1998). As a result, the project team concluded that no action needs to be taken since the motors temperature was 178 F; it is safe to touch if the contact time is below 5 seconds.

**Section 10.3: Explore**

The explore phase of the DMEDI process improvement focuses on developing several design concepts that address the project’s issue. The project team generated three different concept designs that could potentially satisfy the customer’s needs and the design requirements. The first design concept generated was a powered tethering unit that powers the drone without the battery installed. The powered tethering unit will allow the drone to fly for an indefinite amount of time; specifically it will meet the design requirement of increasing drone flight time
when compared to battery powered flight. The second concept design was supplying additional batteries to the students in the UAS courses. The concept suggests purchasing at least four batteries for each student and purchasing additional charging units for the lab. The reason for four batteries is that the average battery powered flight achieves approximately twelve minutes of flight. The third concept design was to charge the battery of the drone during flight. The design suggests using a rectifier and wires to charge the batteries while flying. It will allow the battery to be charged at or close to full charge at all times. This is different from the concept design one in which the battery is still installed on the drone. In concept one, the battery is removed. Having the battery during flight operations will allow the students not having to change weight and balances on their drone. A Pugh Matrix was used to determine which concept design the project team will develop. In addition, the Pugh Matrix was used to assess the strengths and weaknesses of each concept design, which were weighed on how effective each concept satisfied the design requirements. The voice of the customer affected the development of the design, in which the concepts were weighed on the design requirements. The design requirements were derived from the voice of the customer. Concept one, the powered tethering unit, ranked first in the Pugh Matrix, and the project team chose to develop concept one for the final deliverable.

Section 10.4: Develop

The develop phase of the DMEDI improvement process demonstrates the project group’s development of the final deliverable. The project team’s final deliverable is the fabrication of concept one, powered tethering unit. The design evolution of the powered tethering unit is shown in Figure 7. The powered tethering unit underwent different iterations of mockups in order to
better meet the design requirements and satisfy the customer. The final stage of the powered tethering unit is shown in Figure 8. The final product features a electrical readouts from the power supply to assist the user in determining the amperage and voltage draw of the drone. A mockup board was used to mount the core components: power supply, power supply cable, and tethering wire. Hooks, cleats, and handles were installed to the mockup to increase the ergonomics and ease of use when operating the powered tethering unit. With all the benefits of the powered tethering unit does has several limitations for drone flight operations. One of the limitations is that the drone may only be operated within 25ft from the powered tethering unit. The system may only be used in an enclosed environment and away from open weather in order to prevent water or weather damaged to the system.

Also in this section, a comparison of estimated resources and the actual resources are evaluated. A complete parts list is shown in Appendix F. The parts list documents all of the parts the project team has ordered and used for the project. However, some parts were not used in the final deliverable due to changing of design when developing the powered tethering unit. The project’s budget was $680 and the project group used only $309.58 throughout the completion of the project. The project team had a remaining budget of $370.42. One of the reasons why the project group was under the budget is that the group anticipated a chance of the drone becoming inoperable, which will lead to a purchase of a new drone. Luckily, this did not occur in the project’s development. This further supports the proof of success of the project team by how the team was saved budget money and failures that may accrue high costs did not occur.
Design 1: Use of a spool to unwind the tether. Power supply and power cable rests on floor.

Design 2: Powered tethering unit is installed onto a board to consolidate all components. Electrical readouts are installed to the board. Power supply cable and tethering cable are wound onto the board and spool instead of resting on.

Design 3: Powered tethering unit is installed onto a board to consolidate all components. Electrical readouts are installed to the board. Power supply cable and tethering cable are wound onto the board. The spool is removed.

Figure 7: Design evolution
Section 10.5: Implement

In the implementation section, descriptive statistics and T-tests are also conducted in the implementation section to evaluate the before and after processes. A t-test was conducted to determine whether the gathered data were significant to each other. A two-sample assuming unequal variances t-test was used to evaluate the before and after processes. Three different t-tests were conducted to measure the improvements gained from the powered tethering unit. Duration of flight, duration of charge time, and payload capacity were the data-sets used to conduct the three separate t-tests. The statistical analysis data tables are found in Appendix C. The mean, variance, one tail, and two tail calculations are further found in Appendix C. For the Duration of Flight data set, the battery powered and powered tethering unit had a T-Stat of -2.77. Both the Duration of Flight and Charge Time data sets were collected over a series of six tests. For the Duration of Charge Time, the powered tethering unit was given a time of one, because the tethering unit did not charge the battery and to make the calculations easier to read. The T-
stat for the Duration of Charge is equated to by 89.69. The T-stat for the Payload Capacity data set was equated to be -0.87. The Payload capacity data set was collected over a series of five tests.

<table>
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<th>Test</th>
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<tr>
<td>Improvement</td>
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</table>

### Figure 9: Data sets used for the T-test

Also for the implementation phase, a job card or operating instructions were developed for student use in laboratory. A job card details the directions, materials needed and cautions when operating the powered tethering unit. The set of instructions is found in Appendix G. A job card was developed in order for it to be implemented into laboratory sessions. This job card will decrease the instructor’s workload when instructing their students on how to operate the powered tethering unit.

The project team also wanted to find a volunteer from this semester’s AT 219 course to
help further support the proof of concept and how it can be implemented later. A coworker and friend of Joseph Reed’s named Todd Horn stepped up to take on the task of testing his quadcopter on the powered tethering unit. Once a waiver was signed on behalf of the team, he started up his UAV and flew it for approximately 17 minutes, which was 5-7 minutes more than the average flight time. Unfortunately, due to his own personal programming errors, he was unable to fly for the full 20 minutes that would have given the team the results of doubling his average flight time. However, the results the team were able to collect was that his flight percentage average increased from 50% to 64.71%. He concluded that this tethering unit could be very beneficial for the UAV program, and that there are several labs in some of his UAV courses that this system could have come in handy for. When asked if he would want to use a system like this more often, he said 100% yes.
XI. Recommendations

Throughout the team’s project development, there have been numerous recommendations given to the team, as well as recommendations that the team can give about the power enhancement of the X650F. First of all, the team was given the recommendation of creating a tethered unit, rather than purchasing extra batteries, which was a different concept the group had in mind. Additionally, the group was given the recommendation of making the solution viable in an enclosed environment, which was defined by the needs of the customer, Doctor Kozak. Some other recommendations based on the results of the X650F Power Enhancement project is to ensure that quadcopter is in the correct operating condition before applying power from the power unit to it. This is important because unlike a normal UAV drone flight, the system would now be tethered, which limits the range of the UAV. Additionally, when the quadcopter is being prepared to fly with the tethered unit the team has designed, it is vital to ensure that the quadcopters’ blades are out of the range of the wire. If the wires were to be caught in any of the blades, it could result in a crash or damage to the quadcopter itself. Lastly, another recommendation based on the results of the project, it is important to place the power unit in a central location underneath where the quadcopter will be flying. The reason for this is so that they wire does not pull the quadcopter in the direction of where the power unit is due to the weight of the wire. Overall, these recommendations based on the results of the project, and what the team has learned throughout the project are important for how the power unit was designed, as well as for when operating the unit.
XII. Conclusion

Throughout the project of the X650F Power Enhancement, the team has had many goals set, and overcome. The main overall goal that the team had was to overcome the issue of more flight time needed within the UAS major and Minor in the School of Aviation and Transportation Technology at Purdue University (SATT). The average flight time of X650F drones were around 10-12 minutes with the battery at full charge. After many different conceptual designs, and a decision matrix completed, the group realized it would be best to create a tethered drone system that utilized a ground power source for potentially unlimited flight. Another goal that the group had for this project was to meet all customer requirements from the group’s sponsor, Dr. Kozak. He defined the groups’ customer needs as increasing the drone flight time, lowering the drone battery recharge time, the final design to be operable in an enclosed environment, and lastly for users to get more hands on experience. All of these goals from the groups sponsor were met from the final design concept of a tethered drone system.

After gathering data and results from multiple test-runs, there were some concerns the group needed to address. One of the main concerns was that each motor from the X650F quadcopter was beginning to get hot, due to the longer flight times that the tethered unit could provide rather than compared to the battery. The group analyzed this concern by monitoring the motor heat with a thermal camera to ensure that there were no overheat conditions that could result in damage to the X650F quadcopter. In conclusion, the group was able to improve the average flight time of the quadcopter by 54.81%, while also managing to improve the battery recharge time by more than 100%, because no batteries were used in the groups’ final design.
XIII. **Summary of Lessons Learned**

*Joseph Reed*

The main lesson learned regarding this project is how complex the problem really is. As a group, we sat down to think about what we could do to increase the battery life for the X650F quadcopter for the UAV major and minor. Alternatively, maybe even bypassing the battery completely. It all started after seeing an article that was published by Berkley University. Essentially, the UAV company DJI funded a project to the students of Berkeley to create a powered tethering system that was specific to the company's merchandise. Our group loved this idea, and decided that we wanted to try to create a similar system that was specific to the UAVs utilized in our program. After looking into the idea a little further, I thought that this solution could easily be achieved by taking 1. a battery charger with dc power with an ac converter built in the unit so that it may be plugged into a wall outlet, 2. a Y charging cable with two male leads and one female lead so that one end could be plugged directly into the UAV, and the other two ends would connect the battery to the UAV and the battery to the charging station, and 3. Buying the proper amount of cable wire so that we would have approximately 25 ft. for the tethering system. This unit could benefit the program by increasing the battery life substantially and giving the students the experience they will need to succeed in this industry.

After looking into this possible solution more in depth, we noticed quickly that it is not as simple as we perceived. It was going to take so much to get a unit like this operational that we decided to shift our thoughts in a different direction. Rather than creating a tethering unit that charges a battery midflight, create a system that can bypass the battery entirely. However, even this plan was going to make our group push ourselves harder than we expected. We never took into consideration all of the different variables such as what size wire, how much voltage will be
passing through the wire, how much heat can the motors and electronic speed controllers handle before the it damages the components, how many amps will we need to charge the UAV at so the it can hold the charge, etc. This list can go on. This was the lesson that we all learned, that we are going to have to put a lot more thought and work into this project in order to achieve our primary goal: increase flight time for the students. Once we realized it was not as simple as we expected, this did not sway us at all, it encouraged us to keep pushing forward with this possible solution. It was definitely a struggle, but five minds are better than one and with the help and guidance of our sponsor, we were able to create a fully functioning powered tethering unit for the X650F quadcopter.

Another lesson learned that our team learned the hard way was that just because there are several people working in the same department with similar goals, does not mean that they are going to agree on things. Our group spoke to Professor Leasure at the beginning of this school year in 496 about this project idea, and he originally stated that it seemed like a fun project, but his schedule is always busy, so he asked us to seek out a different sponsor within the UAS department, and he would act as only a consultant. Our team was completely fine with that, so we sought out Dr. Kozak. We pitched our idea to him and he thought it was a fun project as well, and accepted the responsibility of being our official sponsor. A semester has passed, and with his help, our team now has a fully functioning and operational prototype for the powered tethering unit. Along this long and dusty road, we hit some roadblocks. Therefore, we did what we were asked to do, and we sought out the guidance from professor Leasure. An email was sent to him simply requesting some time out of his busy schedule to sit down with him and discuss the parameters of our prototype and how it can be implemented into his courses, as well as the other courses that had been created, and the future courses to come. In a very blunt manner, he told our
group that he does not agree with our project, and wants nothing to do with it. Not knowing what had changed his mind, or if this was his reaction by maybe accidently misinterpreting our intentions to further better the program, one thing was for sure and that was how uneasy the team had felt afterwards. Our primary goal was to implement this system in the nine current courses that have been developed. Everyone was afraid that if Leasure didn’t agree with the project anymore, that we had no project. However, Professor Kozak agreed that the students in the program had not been as prepared for his level three course as he would have hoped, and thought that a system like such could be a fun a new way to gain the experience needed to proceed through the program. In addition, this can be looked at as a real world UAS technology application. There is a civil engineering company in Indianapolis that is currently researching a project almost identical to ours, by creating a powered tethering unit for a small-unmanned aerial system so that it can be powered long enough to complete indoor surveying and inspections of the terminal building at Indianapolis International Airport.

Dr. Kozak being our official sponsor, he told us to proceed with the prototype. The lesson learned here was that minds can easily change and just because people work together in the same department, does not mean that they are going to agree with one another. The UAS team was assured that there is still work to be done, and there is still a good project here. Just because one professor threw our idea out into the cold, does not mean he would too.

**Donald Yu**

Different types of processes used for data collection for the drone were learned used in this project. These processes were beneficial in understanding the project design's operational characteristics and the limits of the design. Some of methods learned were observational techniques, measurement tools, and experiments. Performing experiments on the powered
tethering design allowed the team to study the functionality of the drone with the design. Data collection tools such as a thermal camera and timers were used to measure several characteristics of the design. If the team had planned on what to observe during the operational testing of the design, it would have decreased the amount of time needed to test the design. During the testing sessions, most of the characteristics that the team wanted to discuss occurred when the drone was in flight. However, it was a great learning experience for the team in retrieving and helped the team understand the functionality of the powered tethering unit.

Progressive testing methods were used when testing the powered tethering unit design. The team learned that progressive testing on the unit would be beneficial in understanding the powered tethering unit’s capabilities. This testing method helped accommodate each team member’s busy schedule. Conducting small tests at a time helped the team study the prototype with each of the team’s limited time in mind. If the team had to do the project over, knowing how to effectively conduct testing methods would have been useful. The first couple testing sessions took too much time studying the functionality of the design. After the team realized that they could not accommodate this lengthy process in their schedule, the team realized they could break down the testing into smaller and manageable experiments. This was a good learning experience for learning how to manage time constraints and team experiments on the prototype unit.

Joe Lund

Throughout AT 496 in the Fall semester and AT 497 in the Spring semester I have learned numerous lessons about project proposals, designing, and manufacturing solutions. The biggest thing that I have learned is how to write an effective problem statement. When our group first got together in the semester to begin writing, a problem statement we were not sure of what
to include and how to word our problems statement. The first statement we wrote was very negative and focused on the lack of flight experience for UAV majors and minors who are enrolled in the AT 219 course. After getting feedback from other groups in the class, I learned that it was necessary to turn the negatives of the problem statement into positives. In addition, it helped me learn about problem statements by reading other groups’ problem statements during their presentations. That helped me because it helped give an example of either what other groups were doing wrong or what other groups were doing correctly.

A second lesson that I have learned is to expect the unexpected. We have ordered numerous parts in order to make the solution meet the customer's’ needs. One particular thing that we did not think we would need to modify, which took up a lot of our time, is taking off a plastic shielding around our wire that leads up to the X650F. This was a mistake in the ordering process because we bought wire that is supposed to be oil resistant, and it added extra weight to the wire. Additionally, the extra plastic coating made our wire very rigid, which was not good for when we wanted to test out our prototype. Overall, we overcame this problem by setting extra time in our group meetings in order to properly get all of the plastic shielding off.

Another lesson that was learned throughout the process of designing, manufacturing, and testing our X650F quadcopter power solution was the importance of ordering our parts early. Luckily enough, we knew exactly what we needed to purchase for the project going into the semester, and we were able to buy these parts early instead of being pressed for time on the final product. Lastly, I learned the importance of creating an estimated budget. This was especially important because of the fact that we were actually under budget for our project, which made things go expected. If our group was to not create a budget at all, then we would have been surprised at how much money the project was actually going to take. Overall, these lessons
learned are very important to the overall success of our project and how I will go about my professional career.

Daniel Ewell

The lessons learned during this process was how complex our problem truly was. There were several variables and concepts that we did not realize were relevant until we began analyzing a possible solution. When we looked at a power tether system factors such as the required wire gauge, the weight associated with the wires, and the fact that the drone requires a very specific, unique power current to operate. The core lesson learned during the initial stages of the process is that design problems such as these are often much more complex than they initially appear, and initial research must be done before any solutions are considered.

The second lesson was one I learned personally. I learned that, while considering details throughout the process can prevent delays, it will prevent progress on the issue if done excessively. During the early meetings I would focus too intensely on the “what if’s” of the problem, and would prevent progress from being made on the proposal section of the project. I had to change my method of thinking for the project, and learn that focusing too much on the fine details will prevent progress rather than help it.

As the project continued into the second semester, the importance of following up communications with potential sponsors was made apparent. The team assumed that more support was behind the project, and this was due to assumptions and miscommunication. If the team were to start again, they would most certainly make sure that all prospective sponsors have stated their stance on the project clearly, and all communications are clear.

Jessica Iglesias
One of the lessons learned this semester is the importance of design analysis. At first, we didn’t know how we were going to design our prototype. Then we got on CATIA and brainstormed a few ideas and through that, we knew what dimensions we could and couldn’t work with. After designing the CATIA model, that made is much easier to visualize how our prototype would look. After receiving our parts, we ran into another problem. It was so inconvenient to carry all the parts, especially since they were wired together. Therefore, we got back on CATIA and came up with a potential layout to have everything fit nicely on a board. In turn, we lost a lot of time because we didn’t start with a design and had to order many unexpected parts later in the semester. Luckily, everything came in on time and worked out but this could have been more efficient and less costly if we designed a software model in the first place.

Another lesson learned was the importance of identifying customer needs. One setback we encountered was, after creating the first prototype, we had a meeting with our sponsor to review the results and he raised many questions that we didn’t even consider. He asked about our voltage and amperage inputs/outputs. How we could improve the second prototype from the first, the temperature of the motors after running them for a certain time, etc.

If we had met with him and discussed what specifically he was looking for, we could have saved more time testing for all of these different objectives instead of having to go back and run another test. Therefore, we meet more frequently and keep out sponsor in the loop even more so everyone is on the same page. In meeting with him, we have come up with a nice design to improve our second prototype presentation and implementation purposes.
Appendix A: Weekly Project Reports

On the following pages, weekly project reports are documented. Each weekly project report contains weekly objectives, achievements, and deliverables.
AT 497 Weekly Team Report
Week Ending Date: 1/24/2017

Accomplishments:

- Finalized project proposal
- Set a dedicated meeting schedule
- Started measurements initial power requirements and payload capabilities

Plan for Next Week:

- Finalized Project Proposal
- Finished Initial CATIA Design Model and Engineering Drawing
- Meet with Dr. Kozak to discuss project progress and presentation of initial design
- Meet with Prof. Dubikovsky to discuss funding

Issues or Concerns:

- Finding funding for the project
- Finding a time to meet with Dr. Kozak that will allow all team members to attend

Team Members and Hours on Project:

- Daniel Ewell, Jessica Iglesias, Joe Lund, Joseph Reed, and Donald Yu attended the meeting
- Week 3 hours: 2 hours
- Cumulative hours: 3 hours
AT 497 Weekly Team Report  
Week Ending Date: 1/24/2017  
Date Due: 1/25/2017

### Accomplishments:

- Finalized project proposal
- Set a dedicated meeting schedule
- Started measurements initial power requirements and payload capabilities

### Plan for Next Week:

- Finalized Project Proposal
- Finished Initial CATIA Design Model and Engineering Drawing
- Meet with Dr. Kozak to discuss project progress and presentation of initial design

### Issues or Concerns:

- Meet with Prof. Dubikovsky to discuss funding
- Finding funding for the project
- Finding a time to meet with Dr. Kozak that will allow all team members to attend

### Team Members and Hours on Project:

- Daniel Ewell, Jessica Iglesias, Joe Lund, Joseph Reed, and Donald Yu attended the meeting
- Week 3 hours: 2 hours
Accomplishments:

- Initial visual design made in CATIA
- Set a dedicated meeting schedule with Dr. Kozak, meetings occur biweekly

Plan for Next Week:

- Finalize Budget
- Begin to order parts

Issues or Concerns:

- Dr. Leasure disagreement with project

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, and Donald Yu attended the meeting
- Week 4 hours: 1 hour 30 minutes
- Cumulative hours: 4 hours 30 minutes
AT 497: Team 2-X650F Power Enhancement Weekly Team Report
Week Ending Date: 02/07/2017

Accomplishments:
- Finalized Budget and Found Suppliers

Plan for Next Week:
- Turn in Form 12 to Dr. Kozak
- Prepare Conceptual Design

Issues or Concerns:
- Did not take into account long shipping time, which may push Gantt chart back
- Adjusted Gantt Chart

Team Members and Hours on Project:
- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 4 hours: 2 hours
- Cumulative hours: 6 hours 30 minutes
Accomplishments:

- Dr. Kozak approved budget
- Submitted Form 12
- Finalized project proposal presentation

Plan for Next Week:

- Status check on the parts order
- Prepare Conceptual Design

Issues or Concerns:

- Shipping time for the ordered parts

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 6 hours: 1 hours
- Cumulative hours: 7 hours 30 minutes
Accomplishments:
  - Received majority of components
  - Submitted Form 12

Plan for Next Week:
  - Order power supply cable
  - Status check on the parts order
  - Prepare Conceptual Design Draft

Issues or Concerns:
  - Shipping time for the power supply cable

Team Members and Hours on Project:
  - Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
  - Week 7 hours: 4 hours
  - Cumulative hours: 11 hours 30 minutes
Accomplishments:

- Completed all part orders
- Developed Conceptual Design Draft
- Started subassembly of design

Plan for Next Week:

- Status check on the parts order
- Finish constructing subassemblies in order to decrease build time

Issues or Concerns:

- Shipping time for parts
- Completion of design is dependent on the shipping time

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 8 hours: 3 hours 30 minutes
- Cumulative hours: 15 hours
Accomplishments:

- Received all but one component for assembly
- Finished and presented conceptual design project.
- Applied changes to presentation and sent final draft to Dr. Kozak
- Started subassembly of design

Plan for Next Week:

- Status check on the parts order
- Finish constructing subassemblies in order to decrease build time

Issues or Concerns:

- Shipping time for last remaining part before break
- Completion of design is dependent on the shipping time. For we are anticipating to have an active prototype after we get back from break

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 9 hours: 2 hours 30 minutes
- Cumulative hours: 17.5 hours
Accomplishments:

- Completed prototype of design
- Achieved initial powering of the drone using the tether

Plan for Next Week:

- Additional modifications and testing of prototype
- Data collection and benchmarking of prototype
- Flight characteristics adjustments
- Meet with Dr. Kozak after benchmarking

Issues or Concerns:

- Finding an enclosed area with sufficient room to test the design
- Comparing flight characteristics of the drone with the tethering design versus the battery

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 11 hours: 4 hours 30 minutes
- Cumulative hours: 22 hours
Accomplishments:
- Completed first round of testing
- Achieved 20 minutes of flight time with tethering unit
- Attained crucial drone flight characteristic data

Plan for Next Week:
- Additional modifications and testing of prototype
- Additional data collection and benchmarking of prototype
- Flight characteristics adjustments, especially on propeller
- Send part orders for additional parts like the voltmeter and ammeter

Issues or Concerns:
- Comparing flight characteristics of the drone with the tethering design versus the battery
- Improper propeller balancing lead to minor offset of directional flight
- Building ceiling did not permit full 25ft operations

Team Members and Hours on Project:
- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 12 hours: 2 hours
Accomplishments:

- Completed second round of testing
- Achieved 30 minutes of flight time with tethering unit
- Attained crucial drone flight characteristic data
- Started the final project report

Plan for Next Week:

- Additional modifications and testing of prototype
- Additional data collection and benchmarking of prototype
- Flight characteristics adjustments, especially on propeller
- Finish individual group member’s part on the final project report

Issues or Concerns:

- Flight control board started making beeping noises shortly after the 30-minute mark
- High heat dissipated by the motor
- Drone experienced fluttered flight
  - May be due to improper balancing
- Building ceiling did not permit full 25ft operations

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 13 hours: 3 hours
- Cumulative hours: 27 hours
# AT 497: Team 2-X650F Power Enhancement Weekly Team Report

**Week Ending Date:** 04/11/2017  
**Date Due:** 04/12/2017

## Objectives

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<tr>
<td>Working with Professor Kozek with Implementation</td>
<td></td>
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<td>Final submission of written solution</td>
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</tr>
</tbody>
</table>

## Accomplishments:

- Completed third round of testing  
- Achieved a second 30 minutes of flight time trial with tethering unit  
- Attained motor operating temperature at 30 minutes of flight  
- Started the final project report

## Plan for Next Week:

- Send another part order for the mock up board prototype  
- Obtain operating temperature of the motors for different time trials  
- Fabricate the mock up board prototype with ammeters and voltmeters

## Issues or Concerns:

- Flight control board started making beeping noises shortly after the 30-minute mark  
- High heat is still being dissipated by the motor  
- Time constraints on completing the mock up prototype due to waiting on parts

## Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting  
- Week 14 hours: 6 hours  
- Cumulative hours: 33 hours
Accomplishments:

- Finished fabricating the designed system on two mockup boards
- Completed the voltage and amperage wiring to the power supply
- Finished majority of the final project report

Plan for Next Week:

- Obtain operating temperature of the motors for different time trials
- Complete testing on the new mockup boards
- Collect voltage and amperage during drone flight
- Finish individual group member’s part on the final project report

Issues or Concerns:

- Mockup boards may not be ergonomic
- Group scheduling constraints when completing the project report
- Time constraints on completing testing and data collection

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 14 hours: 7 hours
- Cumulative hours: 40 hours
Accomplishments:

- Finished fabricating the designed system on two mockup boards
- Finished the final project report

Plan for Next Week:

- Submit Final project report
- Submit poster and presentation

Issues or Concerns:

Team Members and Hours on Project:

- Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias and Donald Yu attended the meeting
- Week 14 hours: 12 hours
- Cumulative hours: 52 hours
Appendix B: Reference List


Khan, M. (2014). *Quadcopter Flight Dynamics*. 3(8), 01-06. Retrieved from ISSN 2277-8616


Biomechanical Engineering, 120(6), 727-36.

### Appendix C: Statistical Analysis

#### Duration of Flight (rounded to nearest minute)

<table>
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<th>Powered Tethering Unit</th>
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<td>30</td>
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<tr>
<td>6</td>
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<td>30</td>
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<tr>
<td><strong>Totals</strong></td>
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<td><strong>Improvement</strong></td>
<td><strong>54.81%</strong></td>
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#### t-Test: Two-Sample Assuming Unequal Variances

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#### Payload Capacity (in pounds)

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#### t-Test: Two-Sample Assuming Unequal Variances

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Appendix D: Presentation Slides

X650F Power Enhancement

Daniel Ewell
Jessica Iglesias
Joseph Lund
Joseph Reed
Donald Yu

Introduction

This proposal seeks to define the purpose, goals, and scope of the X650F Power Enhancement project. Five members of Purdue’s Aeronautical Engineering Technology program are leading this project as part of their senior capstone research course. The purpose of said project is to look into the many possibilities of enhancing the Unmanned Aerial Vehicle (UAV) power supply. This can open doors to that can benefit both the Unmanned Aerial Systems (UAS) program here at Purdue University, as well as the all of the students expected to go into the industry. The ideas currently being looked into include, but are not limited to: expanding the current battery life, making the battery changing process more efficient, or bypassing the battery completely and having the UAV run on a ground source.
Statement of Problem

Although the Aeronautical Engineering Technology students majoring/minoring in UAS gain experience with their unmanned aerial vehicles, they still have room for improvement. Through observation and research, we concluded that the unmanned aerial vehicles constructed in AT 219 typically has an average of twelve minutes of flight time. Currently, the class is designed around assembling and programming the UAV with a nominal amount of focus on actual flight time for testing drone capabilities. The primary goal would be to take this twelve minute average battery life, and increase its capabilities by doubling, or possibly tripling its capacity, thus benefitting the students as the end result.
Statement of Problem cont.

The Unmanned Aerial Systems major/minor are still in the early stages of development. Currently, there are nine courses, and this number is increasing dramatically as more students submit their applications for this particular major. Although the X650F quadcopter is only used in three classes, it is expected that this number will increase over the next few semesters. Thus, the end goal of this proposal is to not only benefit the program, but give the students the experience needed to find a career in the UAS industry.

Significance of Problem

The UAS Program at Purdue University is still in the early stages of development, and it is growing rapidly. This industry and its technologies are improving every day. Purdue’s Aviation Technology Program has taken on the responsibility to prepare the students for the outside world. Our problem is, the UAVs supplied for the UAS program are very cost effective for what they are going to be used for, but the power supply is nominal compared to what it could be. The idea of increasing the battery’s capacity could change the entire foundation of the program entirely. Although a 10-12 minute battery life is quite substantial for such a small UAV, our team feels as if we could do better. By either increasing the battery life or bypassing the battery all together, the students is the UAV program can increase their flight experience and prepare for real life applications.
Significance of Problem cont.

There are nine courses that have currently been formed and this number will become larger as time goes on. The numbers have increased for the minor, and now that this is the second year that students have started the major, time is running short and the curriculums have to be made. Once all of the classes have been created, the more classes there will for the flight aspect of the program. More flight time equals more experience, and the more experience that the students have, the better off they will be in the long run. One of our team members is majoring in this program, and he can state first hand that he wishes he had more flight experience in class. He flies for the one battery duration, and then for the rest of his two hour lab, has to watch others complete their turn to fly. Dr. Brian Kozak was expecting his incoming students of the course to have the necessary skills and knowledge to perform adequately in AT 309. It is obvious there is an issue present when the professor has to change the structure of his course to compensate for the students lack of flight experience.

Goal of the Project

This project is intended to provide a method of Purdue UAS students gaining more flight time during their UAS courses. This goal will be reached by providing the students with alternative methods of powering their drones that improves upon the current setup of waiting for batteries to charge. This setup should minimize the down time the students have during the lab sessions of their courses, allowing the students to focus on fine-tuning the drones as well as gaining experience in piloting them. With the students becoming confident enough to pilot their drones, the later classes may require less emphasis on actual flight practice, allowing for a simpler, more fluid flow of the courses in the major. This may also result in the professors of the program being able to simplify their curriculum, focusing more on the theories and practical skills involved with UAS development and flight.
### SIPOC

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Inputs</th>
<th>Process Steps</th>
<th>Outputs</th>
<th>Customers</th>
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<tr>
<td>AT 219 Students</td>
<td>X650F Quadcopter</td>
<td>Rotorcraft Frame Assembly</td>
<td>Prolonged Battery Life</td>
<td>Dr. Kozak</td>
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<td>AT 309 Students</td>
<td>Hangar 3</td>
<td>Rotorcraft Wiring Assembly</td>
<td>Substantial increase in flight time</td>
<td>School of Aviation and Transportation Technology</td>
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<td>Aviation Professors</td>
<td>AC/DC Professional RC Battery Charger</td>
<td>Repairs</td>
<td>Increase flight experience</td>
<td>Prospective Students</td>
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<td>Quadcopter Manufacturer’s Replacement Parts</td>
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<td>Instrumentation and Measurement</td>
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</table>

### Process Flow Chart

1. Event at AT 219
2. Rotorcraft assembly
3. Repairs
4. Program the controller
5. Charge it
6. Is the battery charged?
   - Yes
   - No
7. Is the research performed yesterday?
   - Yes
   - No
8. Did the research perform as intended?
   - Yes
   - No
9. Return test flight
10. Access data
    - Yes
    - No
11. Purchase a new drone
    - Yes
    - No
12. Complete mission on location
    - Yes
    - No
Definitions

The X650F Power Solution project uses the DMEDI process, simply because the solution focuses on a new development of a new product and service that still meets the customer’s needs. The current base of measurement for this project is the cycle time of one flight for the X650F drone’s created in AT 219. This cycle time has a unit of minutes, with the current cycle time being around ten minutes. This cycle starts once the drone is turned on and begins flying, and the cycle ends when the battery runs too low, and the drone must be shut down for charging.

Assumptions

1. Students within the UAV major/minor will learn how to fly the drone build in AT 219.
2. It will take students at least 6 weeks to have the drone built and programmed before test flight.
3. School of Aviation and Transportation Technology (SATT) will continue to fund UAS majors and minors with the necessary resources to succeed including (but not limited to):
   a. Proper tooling for assembly of UAV.
   b. A controlled environment to fly UAVs in.
4. The Unmanned Aerial Systems major and minor will continue with assembling and testing of supplied UAV.
5. Cooperation with Professor Eismen in developing the electrical power solution.
**Scope and Applicability**

The solution of this project will focus on accepting classes within the UAS major and minor. These sessions take place inside Hangar 5 of the Purdue Airport, as it is not being occupied by the Phenom jets at the time of the lab. Since the hangar is large enough for multiple drones to be operating simultaneously, the solution will be designed so that it can be used by several students at once in a relatively clean, climate controlled environment. The final solution will be used primarily by the students and instructors in UAS majors and minors. Due to this, students within the program will become more marketable within the industry, causing this solution to impact potential companies, as well as the university. The solution will likely be highly portable, capable of operating from any location suitable for drone flight.

**Design Requirements**

The Voice of the Customer is an important design requirement in developing the X650F Power Solution. The design requirements for this proposal were gathered from the sponsors of the project and observations gathered by the team. The proposal project is focused on UAS students gaining necessary experience and understanding of flight operations of their quadcopters. Through heavy discussion with the sponsor of the X650F Power Solution, the requirements that need to be fulfilled are to increase drone flight time two to three times longer than previous semesters which was approximately twelve minutes and lower battery recharge time from four hours to two hours by charging with an amperage rate increase. Further information about the Voice of the Customer can be found in Table 1.3 on the following page. In Table 1.4 on the following page, a House of Quality diagram illustrates how the team’s project is fulfilling the customer’s need. Several options are evaluated for meeting the customer’s needs like extra batteries, tethered system, etc.
Voice of Customer

<table>
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<tr>
<th>Needs</th>
<th>Drivers</th>
<th>Critical to Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Increase drone flight time</td>
<td>• Ease of use</td>
<td>• System is durable for up to 300 cycles</td>
</tr>
<tr>
<td>• Lower time needed to recharge battery</td>
<td>• Efficiency of lab time</td>
<td>• System directions are concise and easily understood</td>
</tr>
<tr>
<td>• Operation in an enclosed environment</td>
<td>• Cost to student</td>
<td>• Compatible with all student operated drones</td>
</tr>
<tr>
<td>• Allow users more hands on experience</td>
<td></td>
<td>• System does not hinder lab time</td>
</tr>
</tbody>
</table>

Table 1.3

House of Quality

[Diagram showing relationships and ratings between needs, drivers, and quality criticality]
 Procedures

The procedures taken in the development of the X650F Power solution is modeled after the DMEDI process improvement. The DMEDI improvement process involves the following steps: Define, Measure, Explore, Develop, and Implement. The proposal is modeled after the DMEDI, because it focuses on the development of a new product and service that meets the needs of the customer.

Time Action Plan of the Spring Semester
Anticipated Impact and Resources Required

For this project, it is an estimated cost of $680 towards the improvement of flight time. This cost estimate was established due to taking potential problems into account such as a new battery costing approximately $100, a new quadcopter case costing $400, a power supply regulator costing $100, a charging 10 gauge wire costing $50, and lastly a wire spool costing roughly $30 with room for unanticipated modifications. Four weeks will be dedicated towards building, testing, and refining the proposed solution. If it is successful, additional time will be spent with Professor Kozak working on refinements and implementing the solution in the UAS program. The impact that the solution will have an increased flight time for students to gain experience, thus preparing the students for future courses within the UAS program.

Parts List

As you can see, we spent well below our anticipated cost due to parts running smoothly with each other.
Review of Applicable Literature

The project team studied various different online articles and scholarly resources to further the team's understanding of UAVs. "Quadcopter Flight Dynamics (2014) by M. Khan focuses on the flight dynamics of unmanned aerial vehicles. The physics involved in flying a quadcopter is explained in depth in this journal. For the concept design analysis, the project team studied the different approaches researchers took to address increasing drone flight time. Researchers from the Massachusetts Institute of Technology and the Boeing Research and Technology organizations published the "Automated Battery Swap and Recharge to Enable Persistent UAV Operation (2011) paper regarding to developing a platform for autonomous battery changing and charging. During the testing of the powered differential system, an issue concerning the heat dissipation of the motors used to drive the propellers. The cause for concern is that the motors showed signs of high heat and were hot to touch. Due to this concern, the project team researched brushless motor designs and the safe to touch temperatures. "The Brushless Motors - How they work and What the Numbers Mean (2016) on the Drone Ter website covers the design and function of DC brushless motors. It offers the general design of the motor, going over the concept of the rotor and stator within them. The knowledge gained in the literature were fundamental in developing the proposed design. The project team studied how a drone operates and were able to identify areas that could be improved to increase drone flight duration.

Procedures

The procedures taken in the development of the X650F Power Solution involved a complicated process, and thus was broken into different sections. The first section describes the concept design analysis, in which several concept designs were conceived and evaluated. After each concept was evaluated, a concept was inserted into a decision matrix and ranked against the other concepts. The highest ranking concept, which resulted in concept 1, was then used to address the issue. A set of procedures in the form of either DMAIC or DMEDI improvement process were generated to develop the product. The second section serves for as a summary of procedures taken to complete the project in a table format. This section uses the DMEDI style of Lean Six Sigma improvement process for the development of the new product. The third section reviews the measured data and experiments conducted by team on the prototype of concept design one.
DMEDI

Our group decided to use the DMEDI methodology because we created a new design for the existing process. In our proposal, Table 1.6, is a set of procedures in the form of DMEDI improvement process. These procedures were generated to develop the product and implement the design. This serves for as summary of procedures taken to complete the project in a table format. This section uses the DMEDI style of Lean Six Sigma improvement process, because the concept focuses on the development of the new product eliminate weaknesses in the UAS course processes.

Results:

<table>
<thead>
<tr>
<th>Test</th>
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<th>Test</th>
<th>Battery Powered</th>
<th>Powered Tethering Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
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</tr>
<tr>
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<td>2</td>
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<tr>
<td>Improvement</td>
<td>60.83333333</td>
<td></td>
</tr>
</tbody>
</table>
Appendix E: Proof of Success

On the following pages, the proof of success is expressed through weekly meeting minutes. Each meeting minutes contains weekly objectives, achievements, and deliverables.
Team 2: X650F Power Enhancement
Date: 1/23/17@ 1:30pm-3:30pm
Attendance: Daniel Ewell, Jessica Iglesias, Joe Lund, Joseph Reed, Donald Yu

Meeting Minutes:

Our team revised our project proposal in accordance with the corrections made by the instructor and the updated project proposal guidelines. The revisions were made to address unclear scope, potential customers, the ability to measure improvement, and the quantification of negative impacts of problems. Jessica I. was tasked finalizing the project proposal and the presentation after the group members finished adding revisions.

Another topic our team discussed was the initial prototype assembly of our solution. Joe Reed briefed the team on key points of the initial design. The initial design consists of a power supply, electrical wire, fly reel for dispensing the wire, and a power regulator. Joe R. calculated the amount of electric current needed to power the initial design and determined that a 10-gauge wire was capable of carrying the electric current in a safe manner. Joe L. presented his findings for an appropriate power supply. He found a 480W AC-DC power supply that could provide sufficient power to the initial design. After the measurements and initial designs were discussed. Daniel E. was tasked on making a visual design using CATIA V5, since he has the most experience in working with the software.

The meeting concluded with discussing group meeting schedules, consulting with Dr. Kozak, and finding funding for the project. Our group agreed to meet every week at the scheduled AT497 laboratory class time to work on our project. Within the next week, our team will try to meet with Dr. Kozak to provide him an update on our group’s progress and to present him an initial visual design of our project. Our group will consult with different faculty to find more information about finding funding and the process to receive funding for the project.

Deliverables by next meeting @ possible date 1/30
Finalized Project Proposal
Finished Initial CATIA Design Model and Engineering Drawing
Meet with Dr. Kozak to discuss project progress and presentation of initial design
Meet with Prof. Dubikovsky to discuss funding

Individual Deliverables:
Daniel Ewell: Initial CATIA Design Model
Joe Lund: Initial budget and information about funding
Joe Reed: Measure drone power requirements and payload capabilities
Jessica Iglesias: Final revision of project proposal
Donald Yu: Weekly status reports and meeting minutes. Aid Joe R. with measurements
Team 2: X650F Power Enhancement
Date: 1/30/17@ 1:30pm-3:00pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Donald Yu

Meeting Minutes:

Our team had a brief meeting discussing the initial CATIA design made by Dan, budget costs, and meeting schedule with Dr. Kozak. Dan completed the initial visual design, which is attached to the sheet. The budget cost is estimated to be $150 for the 10-gauge wire, wire reel, power supply, and switch. The prices were retrieved from several hardware stores such as Home Depot and Ace hardware. We had concluded the meeting with Dr. Kozak discussing the practical applications of the project. Also, we were able to set up a scheduled meeting with Dr. Kozak every other week on Mondays. This will be beneficial in the development and implementation stage of the project.

An issue occurred during this meeting that is a cause for concern. We were emailing Prof. Leasure for a meeting to discuss the progress of our project, and he responded with disagreement with the premise of our project. Since the X650F Power Enhancement project is being developed for his classes, our group were concerned with the potential customer aspect of the project and whether our project could be implemented. However, we were able to meet with Dr. Kozak to express our concerns. He assured our team that our project was still viable, and we may need to broaden our potential customers. For the next couple days, our team will converse with each other to examine what specifically needs to be adjusted to meet project objectives.

Deliverables by next meeting @ possible date 2/06
Finalize Budget
Begin to order parts
Team 2: X650F Power Enhancement
Date: 02/06/17@ 1:00pm-3:00pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team discussed the project process flowchart, conceptual design, and the Form 12. The project process flowchart was created to coordinate the steps needed to prepare a conceptual design and execute the respective design. Attach to this sheet is the process flow chart. Many items on this flow chart were taken from the Gantt chart. The team decided to start thinking about conceptual designs that could be applied to this project in forms of both DMEDI and DMAIC.

The team had its scheduled meeting with Dr. Kozak as well. The subject of the meeting was the funding of the project. Dr. Kozak clarified certain aspects of the Form 12 that were confusing to the team members. He explained to the team on how to correctly complete the Form 12 and the process of ordering parts. One issue occurred during our meeting with Dr. Kozak, which were the delivery times for the team’s parts. The team did not take into account the bureaucracy of the department. The team was just informed that it’ll take about a week to for the Form 12 to be processed and for the parts to be ordered. This results in a pushing the team’s Gantt chart a week behind. The team decided to update the Gantt chart according.

Deliverables by next meeting @ possible date 2/13
Submit Form 12 to Dr. Kozak
Begin to order parts
Team 2: X650F Power Enhancement
Date: 02/15/17 @ 1:00pm-2:00pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team discussed the project process flowchart, conceptual design, and the Form 12. The project process flowchart was created to coordinate the steps needed to prepare a conceptual design and execute the respective design. Attach to this sheet is the process flow chart. Many items on this flow chart were taken from the Gantt chart. The team decided to start thinking about conceptual designs that could be applied to this project in forms of both DMEDI and DMAIC.

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Deliverables by next meeting, date 2/20
Draft of conceptual design
Status check on parts order
Team 2: X650F Power Enhancement
Date: 02/20/17 @ 1:00pm-3:00pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team discussed the part orders, power supply discrepancy, and conceptual design presentation. Over the week, most of the parts that were ordered arrived, which include 10-gauge wire, power supply, and the PLA plastic. The team did have a minor issue when filling the Form 12 in terms of incorrect addresses. The issue was corrected by properly revising the company address. The other parts are still in route are the switches, spools, and power supply cable. One issue that has arisen was the power supply cable. The team initially thought the power supply came with a power cable. However, the part arrived without a power cable. The team calculated the correct cable gauge and length needed for a power cable to be compatible with the power supply. The calculations resulted in a length of 15ft. and 12-gauge. This is an issue of concern, because the team needs to submit another Form 12 for the power cable. This may push our gantt chart back. The team decided to start constructing sub-assemblies of the design for the time being. The sub-assemblies will be built from the parts that arrived. This will allow the team to be able to work on the design without losing time waiting for the remainder of the parts.

The team had its scheduled meeting with Dr. Kozak as well. The subject of the meeting was the power supply cable and timeline of the project. The team communicated to Dr. Kozak about the power supply order did not have a power cable. The team explained to Dr. Kozak that another Form 12 has to be submitted for the power cable. He expressed that another Form 12 will not be an issue, but he was worried that it may negatively affect the team’s gantt chart. He also explained that he wants an operational prototype of the design and asked when it can be expected. The team deliberated with each other on the topic. The team decided that an operational prototype could be assembled for Dr. Kozak by the end of the first week back from spring break, 3/24/17.

Deliverables by next meeting, date 2/27
Submit Form 12 for power supply cable
Start subassembly of design with current parts
Prepare a Conceptual Design Draft
Team 2: X650F Power Enhancement
Date: 02/27/17 @ 1:00pm-3:00pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team discussed the part orders, power supply discrepancy, and conceptual design presentation. The project parts that are still in route are the switches, spools, and power supply cable. The team also made a trip to Home Depot and Lowes to correct an issue with the Form 12 order, in which a revision to the part number had to be added. The part number did not match with the part the team was looking to buy. The trip to these two stores provided the corrected part numbers. After the trip, the team revised the part orders and submitted it to Dr. Kozak. The current concern is the shipping time of the part orders. The gantt chart of the project is a couple weeks behind. However, the team is managing this issue by starting to create subassemblies of the tethered system with the current parts at hand. This will allow for decreased build time and testing in the future when the parts arrive. This will allow the team to be able to work on the design without losing time waiting for the remainder of the parts.

The team developed their conceptual design presentation throughout the week and finalized it during the meeting. The three concepts that are being proposed are purchasing additional supply of batteries and chargers, ground powered tethered system, and ground powered charging tethered system. A decision matrix was developed that featured the customer needs and criteria the design needs to meet. This matrix provided additional understanding of the best course of action in forming a solution to the problem.

Deliverables by next meeting, date 2/27
Status check on the parts order
Finish constructing subassemblies in order to decrease build time
Team 2: X650F Power Enhancement  
Date: 03/07/17 @ 1:00pm-3:00pm  
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team discussed the final part orders, which unfortunately is still the power supply. It is supposed to be here no later than Thursday and Dr. Kozak will not be here to collect the specified part, so he granted Joseph Reed permission to pick that up from the front office. The rest of the desired components have been received and are ready for prototype assembly. Our team also finished the conceptual design presentation, presented it to the class, and took notes on the desired changes expressed by both the class and Dr. Kozak for a final draft, which was then emailed to Dr. Kozak for record. The gantt chart of the project is a couple weeks behind. However, the team is managing this issue by starting to create subassemblies of the tethered system with the current parts at hand. A working day has been assigned for this next coming week before break starts so we do not fall much more behind from our schedule. This will allow for decreased build time and testing in the future when the parts arrive. This will also allow the team to be able to work on the design without losing time waiting for the remainder of the parts.

Deliverables by next meeting, date 3/20
Active prototype of Powered Tethering System  
Visual data collection and analysis of built prototype  
Avionics Aircraft Testing and Measurements
Team 2: X650F Power Enhancement
Date: 03/20/17 @ 1:20pm-2:30pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team tried to use one of the hangars for testing the completed prototype. However due to weather conditions, the hangars were filled with aircraft. The team decided to postpone and reschedule testing for another date. The team discussed how the benchmarking and measurements during the testing will take place. The design requirements were considered to be the top measurements needed, which include: flight time, enclosed environment operations, etc. Flight characteristics were taken into consideration, due to removing the battery of the drone will change how the drone flies. Also, supplementary material for the use of the prototype was brought up like a set of instructions for operating the prototype. Below is a summary of the fabrication process of the prototype.

The team met on Wednesday, March 8, 2017 to finish constructing the first prototype iteration of the tethered powering system. The power supply finally arrived at the airport and was delivered to us. The team met in the avionics lab to take advantage of the readily available equipment, and to receive technical support from the lab instructor, Corrine Neidig. The two spools of fifty-foot wire was cut into twenty-five foot lengths. The two twenty-five foot wires had plug and ring connections crimped onto it, and the wires were zip-tied together to make a singular cable. A switch was installed onto the power supply to easily facilitate energizing the design. The power supply cable had ring connectors crimped onto the wires, and were connected to terminals on the power supply. The result is shown in figure 1. After the fabrication of the cable, power supply switch, and cable connectors, the team measured the output of the power supply across the cable. After, the team used the design to power one of the lab circuits to test its operability, as shown in figure 2. The prototype was able to power the lab circuit, which allowed the team to take the prototype to the drone. The team then connected the tethered power system to the drone to assess if the tether could power the drone. The tethered power system was able to power the drone. The drone was not flown on that day, and further testing will take place during the week of 03/20/2017.

Deliverables by next meeting, date 3/27
Additional modifications and testing of prototype
Data collection and benchmarking of prototype
Flight characteristics adjustments
Meet with Dr. Kozak after benchmarking
Team 2: X650F Power Enhancement
Date: 03/27/17 @ 1:30pm-3:30pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team used Hanger 5 for testing the completed prototype. However due to weather conditions, the hangars were filled with aircraft. The team decided to use the limited space to work with the prototype. Before the testing, there were pre-adjustments and modifications that took place. The propellers of the drone were rebalanced with adding strips of tape to the propeller. The battery was removed as well. While the propellers were being re-balanced, the team discussed how the benchmarking and measurements during the testing will take place. After the re-balancing, the tethered powering unit was powered and connected to the drone. Joe Reed piloted the drone. The team decided to fly the drone for twenty minutes to achieve doubling the flight time compared to the battery. The team wanted to do progressive testing, like twenty minutes now and then thirty minutes for the next test, to be able to monitor several components of the prototype and drone. During the test, minimal heat was dissipated by the power supply, wiring, motors, and the electronic controllers. The tethered powering unit did not show any signs of overheating for twenty minutes. Overall the test flight was a success for determining the functionality and operations. However, there were some concerns that arose from the testing. Comparing flight characteristics of the drone with the tethering design versus the battery will need to be examined for determining the practical and benefit analysis of the design. There were times where the drone did not operate as intended by the pilot. The main theory is that there were improper propeller balancing, which lead to minor offset of directional flight. The wire from the prototype had an effect on the flight on the drone, in which the tension of the wire pulled the drone in the direction of which the power supply was place. Also, to be able to fully test the design, the team needs to find a building with a ceiling height greater than 35 ft to be able to comfortably fly the tethering unit to the full 25 ft.

After the testing was completed, the team met with Dr. Kozak to discuss our findings and where the design can be further improved. Dr. Kozak expressed that he was satisfied that the team was able to fabricate an operating prototype with at least one round of testing completed. Dr. Kozak advised the team that the prototype can be more versatile if the team could vary the output voltage of the power supply to be able to supply power to other types of drones. The team stated that the power supply has a built-in potentiometer in which the output voltage can be adjusted. However, the potentiometer has no readout of the output voltage and has to be read from a voltmeter. Dr. Kozak suggested of acquiring a small voltmeter and bus bar with an ammeter to be able to receive the readouts of the voltage and amperage. Mounting the two meters to the power supply will allow for portability and ease of use. The team is planning to submit part orders for the additional parts.

Deliverables by next meeting, date 4/03
Additional modifications and testing of prototype
Additional data collection and benchmarking of prototype
Flight characteristics adjustments, especially on propeller
Send part orders for additional parts like the voltmeter and ammeter
Team 2: X650F Power Enhancement
Date: 04/03/17 @ 1:30pm-4:30pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team used Hanger 5 for the second test of the completed prototype. Before the test flight, pre-adjustments to the propellers took place. The same procedures that occurred last testing took place at this testing. The battery was removed. The wire tethered was unwound from the cable roller. The power supply was placed in a low traffic area, and it was connected to the outlet. The wire was then connected to the drone and was then energized. Joe Reed piloted the drone. For this test, the team decided to fly the drone for thirty minutes to achieve tripling the flight time compared to the battery and as required by design requirements. This is the second part of the progressive testing, in which thirty minutes of flight will occur. It is a ten minute increase from the previous testing. During the test, the team monitored the flight characteristics of the drone and the heat dissipated by various components of the drone and the tethered system. Minimal heat was dissipated by the power supply, wiring, and the electronic controllers. The tethered powering unit did not show any signs of overheating for thirty minutes. However, the motors that drive the propellers showed signs of high heat. Further research on the motor specifications need to be retrieved, such as the temperature range. The flight controller, kk2 board, started beeping shortly after the thirty-minute mark. The beeping from the flight controller could have signified the motors overheating. Another theory was that the board as a built-in flight time limit. From a quick troubleshooting search, the board may have started beeping due to a low voltage error. Overall the test flight was a success for determining the functionality and meeting the design requirements of meeting thirty minutes of flight time. The drone experienced fluttering at the beginning of the test, which may be due to the drone not being balanced.

After the testing was completed, the team discussed the project final report. The team completed several sections of the report during this time of the meeting. The remaining sections of the report was divided up between the team members. A couple of appendixes were added to the report, such as “Instructions on operating the system” and “Collaborations and Consultations,” to further detail the success of the project.

Deliverables by next meeting, date 4/10
Additional modifications and testing of prototype
Additional data collection and benchmarking of prototype
Flight characteristics adjustments, especially on propeller
Team 2: X650F Power Enhancement
Date: 04/11/17 @ 1:30pm-4:30pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team discussed the fabrication of the second prototype. The team browsed different hardware stores such as Lowes for several different parts. The plywood, handles, and hooks were found on the hardware store’s site to be suitable for the second prototype. The second prototype was designed to be a mock-up board design. The mock-up board design was favorable due to its organization traits. The spool design was found to be a poor performance issues due to not being able to spool the wire in flight effectively. The final project report was discussed as well. The lessons learned section of the final report was divided up between the team members. Several lesson learns were discussed and each member was tasked to write about the lessons learned. The literature review was discussed on who was to write it. Also, the team determined several dates for the fabrication of the second prototype. However, the dates are tentative due to waiting on the parts to be shipped.

The team had its scheduled meeting with Dr. Kozak as well. Dr. Kozak confirmed our parts order for the plywood, hooks, and cleats for the mock up board. He told the team to deliver the part order form by the end of the day. The team presented the mockup board design to Dr. Kozak via sketches from Catia software. He noted that the team should add the spool next to the mockup design for added convenience. The team asked to use a thermal camera from Dr. Kozak’s lab to help facilitate the testing of the drone. The thermal camera will aid in monitoring the temperatures of the motors and power supply. Dr. Kozak also stated that he wanted the final report and design by April 26, which will be convenient, since it is the same due date for the final submission for AT 497.

Deliverables by next meeting, date 4/17
Send another part order for the mock up board prototype
Obtain operating temperature of the motors for different time trials
Fabricate the mock up board prototype with ammeters and voltmeters
Finish individual group member’s part on the final project report
Team 2: X650F Power Enhancement
Date: 04/17/17 @ 1:30pm-4:30pm
Attendance: Daniel Ewell, Joe Lund, Joseph Reed, Jessica Iglesias, and Donald Yu

Meeting Minutes:

During the meeting, the team consolidated all of the ordered parts and fabricated the second project design. The UAS laboratory was used as a work area to fabricate the mockup board. The design the team is constructing is illustrated in figure 1. The plywood was cut into the necessary size using a circular saw provided by Dr. Kozak. The hooks, cleats, and handles were fastened to the plywood with wood screws. The power supply unit and electrical meters were fastened with double-sided tape and velco strips. The tethering cables were construction process was similar to the first iteration of the design. The two spools of fifty-foot wire was cut into twenty-five foot lengths. The two twenty-five foot wires had plug and ring connections crimped onto it, and the wires were zip-tied together to make a singular cable. A switch was installed onto the power supply to easily facilitate energizing the design. The power supply cable had ring connectors crimped onto the wires, and were connected to terminals on the power supply. During the construction of the tethering cable, the team received technical support from the avionics lab instructor, Corrine Neidig. After all of the components were fastened to the plywood, the team wired the electrical meters to the power supply unit and tested the electrical meter readings to determine whether meters were operational or not. The results showed the meters were operating normally, but the system was not connected to the powered tethering system why suppling power to the drone. This test will be conducted at a later date. There were several causes of concern when constructing this mockup design. The plywood had areas of decay, which made some of the fastens loose when screwing it to the board. This was remedied by using longer fasteners and strategically choosing areas for component placement. After the cuts were made to the wood, the edges of the plywood were sharp. This indicated the edges needed to be sanded to achieve smoothness. Another issue was the ergonomics of the board, the spool design, as illustrated in figure 2, may decrease the ease of use when handling the mockup board.

Deliverables by next meeting, date 4/24
Obtain operating temperature of the motors for different time trials
Complete testing on the new mockup boards
Collect voltage and amperage during drone flight
Finish individual group member’s part on the final project report
## Appendix F: Parts List

<table>
<thead>
<tr>
<th>Part no.</th>
<th>Part Name</th>
<th>Part Serial Number</th>
<th>Description of Part</th>
<th>Units per Assembly</th>
<th>Vendor</th>
<th>Price per part</th>
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</thead>
<tbody>
<tr>
<td>1001</td>
<td>Gatehouse 4.75-in Screen Door Pull Handle</td>
<td>803446</td>
<td>Cold-rolled steel handle</td>
<td>4</td>
<td>Lowe's</td>
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<tr>
<td>1002</td>
<td>Stanley-National Hardware 2053BC Tarp/Rope Hook</td>
<td>20772</td>
<td>Medium weight hook with blunt ends</td>
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<td>Lowe's</td>
<td>$0.73</td>
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<tr>
<td>1003</td>
<td>Gatehouse Rope Cleat</td>
<td>311988</td>
<td>2-IN inside diameter ring, #0 wire, welded</td>
<td>2</td>
<td>Lowe's</td>
<td>$1.98</td>
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<tr>
<td>1004</td>
<td>23/32-in Common Pine Sanded Plywood, Application as 2 x 4</td>
<td>7710</td>
<td>Pre-cut panels of plywood</td>
<td>2</td>
<td>Lowe's</td>
<td>$10.84</td>
</tr>
<tr>
<td>1005</td>
<td>Scotch 1-in W Two-Sided Tape</td>
<td>488024</td>
<td>Indoor/outdoor tape and is UV-resistant</td>
<td>1</td>
<td>Lowe's</td>
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<tr>
<td>1006</td>
<td>16 Amp Single Pole Rocker Switch</td>
<td>1001-385-753</td>
<td>.250&quot; spade terminal</td>
<td>2</td>
<td>Home Depot</td>
<td>$4.97</td>
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<tr>
<td>1007</td>
<td>Southwire 10-3 NMWG Wire</td>
<td>7411129</td>
<td>Spool length: 25 ft., temp. rating: 194 degrees f, voltage: 600v</td>
<td>1</td>
<td>Home Depot</td>
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<tr>
<td>1008</td>
<td>12-10 AWG Vinyl Butt Splices 10pk</td>
<td>000-277-938</td>
<td>Vinyl insulated (600 V) Max. Temp. 75 C (167 F)</td>
<td>1</td>
<td>Home Depot</td>
<td>$1.99</td>
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<tr>
<td>1009</td>
<td>Heat Shrink Tubing Black 1/4 96IN</td>
<td>0000-956-958</td>
<td>2:1 shrink ratio 600V tubing</td>
<td>1</td>
<td>Home Depot</td>
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<tr>
<td>1010</td>
<td>Ring Vinyl 12-10 AWG, STUD 8-10, 10</td>
<td>0000-288-102</td>
<td>Vinyl insulated (600 V) Max. Temp 75 C (167 F)</td>
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<td>1012</td>
<td>10 Stranded Thhn Black - 50ft</td>
<td>0000-200-158</td>
<td>Gasoline and oil resistant. Rated 105 Degrees C</td>
<td>1</td>
<td>Home Depot</td>
<td>$14.27</td>
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<tr>
<td>1013</td>
<td>10 Stranded Thhn Red - 50ft</td>
<td>0000-201-563</td>
<td>Gasoline and oil resistant. Rated 105 Degrees C</td>
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<tr>
<td>1014</td>
<td>Cord Storage Reel with Stand</td>
<td>1000-281-770</td>
<td>Holds up to 150 ft. of 16/3 extension cord. Can be used inside and outside</td>
<td>2</td>
<td>Home Depot</td>
<td>$9.97</td>
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<tr>
<td>1015</td>
<td>12-10 AWG Nylon Female Disconnects 10pk</td>
<td>000-277-935</td>
<td>Fully insulated Nylon (600 V) Max. Temp. 105 C (221 F)</td>
<td>1</td>
<td>Home Depot</td>
<td>$1.99</td>
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<td>Item</td>
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<tr>
<td>1016</td>
<td>DROK 2 Wires DC 0-50A Digital Current Meter Blue LED Amp Meter-Amperage Shunt Resistance</td>
<td>1</td>
<td>Amazon</td>
<td>$9.92</td>
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<tr>
<td>1017</td>
<td>Superior Electric EC 123-15 Replacement Power Tools Electrical Cord 3 wire-12AWG, 300V, 15 ft</td>
<td>2</td>
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<tr>
<td>1018</td>
<td>The Hillman Group 25-Count #8 x 0.675-in Beige Self-Drilling Interior/Exterior Standard (SAE) Sheet Metal Screws</td>
<td>1</td>
<td>Lowe's</td>
<td>$6.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1019</td>
<td>Aerfas 3/4-in x 8 yards Cable Tie Roll Fastening Tape Roll Hook &amp; Loop Sticky Cable Cord Wire Tie Strap (Black)</td>
<td>1</td>
<td>Amazon</td>
<td>$7.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Cost: $309.58

Project Budget: $680

Remaining Budget: $370


**Appendix G: Instructions on Operation**

<table>
<thead>
<tr>
<th>Purdæ University Unmanned Aerial Systems</th>
<th>Ref: 04/28/17</th>
</tr>
</thead>
</table>

**Purpose Statement:** The purpose of this job card is to fully demonstrate how to safely operate the powered tethering unit mockup.

<table>
<thead>
<tr>
<th>UAV Registration Number</th>
<th>Date:</th>
<th>Mockup Assigned:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Signature</th>
<th>Remote Pilot Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Equipment List:** X650F V4 quadcopter or your AT 219 Unmanned Aerial Vehicle, Powered Tethering Unit Mock Up Board 1 or 2.

**Damages or incidents:**

![Diagram of equipment]
<table>
<thead>
<tr>
<th>Purdue University Unmanned Aerial Systems</th>
<th>Ref: 10/27/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lay out your UAV in the designated flight area and extend the arms and prepare for flight.</td>
<td></td>
</tr>
<tr>
<td>2. Clear the area. CAUTION: If you do not clear the area, this could result in damaging your UAV or your surroundings.</td>
<td></td>
</tr>
<tr>
<td>3. Layout the mock up flat on the ground. Refer to Figure 1.</td>
<td></td>
</tr>
<tr>
<td>4. Unwind the powering cable and plug it into the wall. Refer to the blue arrow.</td>
<td></td>
</tr>
<tr>
<td>5. Unravel the desired or assigned length of tether from the mockup. Refer to the red arrow.</td>
<td></td>
</tr>
<tr>
<td>6. Turn on your transmitter.</td>
<td></td>
</tr>
<tr>
<td>7. Plug the tether into the UAV.</td>
<td></td>
</tr>
<tr>
<td>8. Flip the switch on the mockup to apply power. Refer to the green arrow.</td>
<td></td>
</tr>
<tr>
<td>9. Fly the desired or assigned amount of time. Note: Safety is key, so make sure there is enough slack in the cable so that there is not too much tension.</td>
<td></td>
</tr>
<tr>
<td>CAUTION: Too much tension can lead to the crashing of the UAV.</td>
<td></td>
</tr>
<tr>
<td>CAUTION: After your flight, you always want to take a temperature reading of the motors to make sure they are not overheating.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.
10. Once the mission has been completed, and you have disarmed the UAV, turn off the transmitter and begin to put away the mock up.

11. Turn the switch to off to power down the power supply.

12. Unplug the tethering cable from the UAV.
   
   CAUTION: Failure to power down correctly could result in electrocution.

13. Wrap tethering cable back around the appropriate hooks.

14. Unplug the powering cable from the wall and begin to wrap it around the mock up board.

15. Put away the mockup board where you initially found it.

16. Log your flight time in your log books with a brief description of your mission.

17. Make sure you record any incidents that may have occurred in your unmanned system logbook.
Appendix H: Consultation and Collaboration

Dr. Brian Kozak: The primary consultant and sponsor of the project. He gave the team the desired parameters of the final product. Input was continuously given throughout the design and prototyping process in order to achieve the desired final product.

Prof. Thomas K Eismin: Consulted the team on the aspects of electrical circuits and their limitations and formulas. This information was critical for ensuring that the electrical components were designed in a way to function properly without damage.

Corinne Neidig: Collaborated with the team to provide the tools and equipment necessary to assemble the first prototypes.

Michael Reed: Consulted the team on examples of equipment that could be purchased to meet the needs of the customers.

Todd Horn: Volunteered to utilize his personal UAV that he constructed in AT 219 to help provide better results for our proof of concept. He flew for 20 minutes which was well above the average flight time of 10-12 minutes.

Will Weldon: Operated the Flir Thermal Camera in order for us to acquire the temperature readings on the motors of the UAV.

Jonathan Lorenzini: Was ever so kind to help us wire up our ammeter to the mockup board so that when the UAV was being operated, we could record real time amperage readings.
Appendix I: Waivers of Liability

A waiver was included within this report because the project team wanted to have a student from the current AT 219 course come in and utilize his UAV with our tethering unit. But if anything the team to happen to his quadcopter during operations, the team did not want to be held liable for any damage that may have occurred. His signed the the document knowing ahead of time the risks of safety and operations. He concluded that this tethering unit could be very beneficial for the UAV program, and that there are several labs in some of his UAV courses that this system could have come in handy for. When asked if he would want to use a system like this more often, he said 100% yes.
Waiver of Liability

This agreement releases The AT 497 Senior Design Group, which includes Joseph Reed, Donald Yu, Jessica Iglesias, Joe Lund, Dan Ewell, and the official sponsor Dr. Brian Kozak, from all liability relating to injuries that may occur during the testing of the powered tethering unit. By signing this agreement, I agree to hold The AT 497 Senior Design Group entirely free from any liability, including financial responsibility for injuries incurred, regardless of whether injuries are caused by negligence.

I also acknowledge the risks involved in participating in the use of the Powered Tethering Unit. These include but are not limited to injury, damage to any equipment, damage to any aircraft, or even anything in the general vicinity of the environment. I swear that I am participating voluntarily, and that all risks have been made clear to me. Additionally, I do not have any conditions that will increase my likelihood of experiencing injuries while engaging in this activity.

By signing below I forfeit all right to bring a suit against The AT 497 Senior Design Group for any reason. In return, I will receive experience with the Powered Tethering Unit. I will also make every effort to obey safety precautions as listed in writing and as explained to me verbally. I will ask for clarification when needed.

I, [signature], fully understand and agree to the above terms.

[Participant]  [04/24/2017]  [Date]