To: Dr. David Trevas

From: Tyler Darnell, Colton Farrar, Zachary S. Kayser, Thomas O'Brien, Daniel Varner

Date: February 26th, 2021

Subject: Implementation Memo

1 Introduction

The SAE Aero Micro competition challenges students to design and construct a micro airplane that can perform several tasks such as carrying a specified payload and completing a timed flight on the competition course. While the team is no longer partaking in the competition due to several changes in competition structure and schedule, the rules and regulations outlined by the competition have been the driving factor during design and construction. The customer requirements were derived from these rules, which drove the engineering requirements and their targets. The engineering and customer requirements have only changed slightly from the previous semester since the team is still using the competition rules as design guidelines, but slight changes have been made as the team learns more about the design and construction of micro airplanes. As the team worked to complete a prototype, several design alterations were made, and more changes will be made in the future of the project. This information is all discussed in detail below, along with an exhibit of the plans the team has for the future of the project.

2 Customer Requirements (CRs)

The SAE Aero Micro team derived customer requirements from the SAE Aero design rules. The SAE competition rules and regulations provides detailed descriptions of what functionalities the design is required to have. To summarize the SAE competition rules: A competition will be conducted where speed and payload weight/size capacity are contributing scoring factors [1]. In addition, the rules state that flights and landings must be successful for the flight score to count. Finally, the competition rules state that the aircraft must take off from a 4'x8' platform and land within a designated 200-foot landing strip. A complete list of the customer requirements derived from the competition rules is presented below along with a brief description. Additional requirements listed are due to limiting factors such as the budget provided by Northern Arizona University.

1. Wingspan Dimension (The wingspan cannot exceed 48")
2. Electric Motor (Only electric Motors are allowed for the propulsion)
3. Battery Limited to 4 Cell (The maximum battery size is limited to a 4-cell battery)
4. Power Limiter (The aircraft must incorporate a 450W power limiter in the electrical circuit)
5. Carries Metal Payload Plates (Part of the flight score includes the weight of payload plates)
6. Carries Payload Boxes (For each flight attempt at least one delivery box must be carried)
7. Carries Payload Plates in Cargo Bay (Payload plates must be fully enclosed in the fuselage)
8. One Fully Enclosed Cargo Bay (the number of cargo bays for the payload plates is limited to one)
9. Securable Payload Plates (Payload plates must be secured using an approved method)
10. Quick Payload Removal (Both payloads must be uninstalled within one minute)
11. Short Take-Off Distance (The aircraft must takeoff from a 4'x8' platform raised 1 foot)
12. Aircraft Range (The aircraft flight is scored based on the ability to complete the whole course)
13. Controllable in Flight (The pilot must always be able to maintain control of the aircraft)
14. Fast Aircraft (The aircraft flight is scored partially on the time it takes to complete the first leg)
15. Can Carry A Lot of Weight (The aircraft flight is scored partially on the additional weight carried)

16. Short Landing Distance (The aircraft must be able to land within the 200-foot landing strip)
17. Red Arming Plug (the aircraft must be equipped with a red arming plug to ensure safety)
18. Empty CG Markings (The aircraft must display the empty center of gravity location)
19. Gross Weight Limit (The aircraft cannot exceed 55 pounds)
20. 2.4 GHz Radio Control System (The aircraft must use a 2.4 GHz radio controller)
21. Spinners or Safety Nuts (The propeller must be properly secured to ensure safety)
22. No Metal Propeller (Metal propellers are prohibited for the competition)
23. No Lead (The material lead is prohibited from the competition)
24. No Structural Support from Payload (The installed payloads must not help support the structure)
25. Metal Payload Plate securing Hardware (Payload plates must be fastened with metal hardware)
26. Low Cost Build (The team is limited to a $1500 budget which includes registration fees)
27. Durable Design (The design and construction must be durable and reliable)

It is important to note that these CR's were derived from the SAE AERO competition and that the scheduled date for this competition was rescheduled weeks after graduation resulting in the withdrawal of the team's entry in the competition. This being the case, some customer requirements have been omitted from the physical design. The engineering requirements that have been ignored in the physical model include a 450-watt power limiter and spinners or safety nuts to fasten the propeller.

3 Engineering Requirements (ERs)

3.1 ER #1: Wingspan

3.1.1 ER #1: Wingspan Target = 47.5 Inches

The SAE AERO Micro competition rules have set a maximum wingspan value of 48 inches. The team has chosen a target value of 47.5 inches to maximize surface area contributing to the aircraft's lift as well as maintain a 0.5-inch buffer to be compliant with the SAE competition rules.

3.1.2 ER #1: Wingspan Tolerance = +/- 0.5 Inches

The wingspan tolerance has been set to maintain compliance with the SAE AERO Micro competition rules. The upper tolerance will bring the wingspan length to the specified maximum value but no greater. These tolerances have been set keeping in mind that the laser cutting process has its own error associated with tolerance. The +/- 0.5-inch tolerance is large enough to account for this manufacturing process as well as imperfections in the airfoil assembly.

3.2 ER #2: Cargo Bay Volume

3.1.3 ER #2: Cargo Bay Volume - Target = 175 Cubic Inches

For the SAE AERO Micro competition during each flight attempt the aircraft must attempt to carry one of two size delivery boxes. The size delivery box the team has chosen to use has upper tolerance dimensions of 6.25 x 6.25 x 4.25 inches. The target cargo bay volume is large enough to fit this delivery box and up to a 6.25 x 3 x 0.75-inch delivery plate. This cargo bay volume includes room for a 0.25-inch-thick reinforcing plywood base in which to secure the payload plates and the rear landing gear.

3.1.4 ER #2: Cargo Bay Volume - Tolerance = +/- 10 Cubic Inches

The cargo bay volume tolerance was set keeping in mind that the delivery box would be housed inside the fuselage along with the payload plate. While the payload plate must be located inside the fuselage it was a design choice that the delivery box also be housed inside the fuselage. This design decision eliminates the variable drag force that would be caused by an exterior mounted delivery box.

3.3 ER #3: Quick Payload Removal

3.3.1 ER #3: Quick Payload Removal - Target = 1 minute

For the SAE competition, the required time to add and remove the payload was no more than 1 minute. Although the team is no longer participating in this competition, the requirements are still the basis for the team's design. If the team were to not remove the payload within 1 minute, they would be docked points in the competition or even disqualified. With this in mind, the team strives to be able to still remove the wing and payload within the 1-minute timeframe.

3.3.2 ER #3: Quick Payload Removal - Tolerance = - 0.5 minutes

Because the 1 minute maximum of removing the payload was a competition requirement, the tolerance only has a lower limit. With the target value of 1 minute, the tolerance the team hopes to achieve this value or 30 seconds less. In other words, the team expects to remove the payload within the range of 30s to 60s.

3.4 ER #4: Short Takeoff Distance

3.4.1 ER #4: Short Takeoff Distance - Target = 8 feet

One of the requirements of the competition is that the airplane must take off from a platform that is 8 feet long and elevated two feet above the ground. This requirement is mandatory by the competition rules, and a failure to comply with the target would result in a disqualification of that flight. The airplane can leave the ground before reaching the eight-foot mark and may touch the launch pad after leaving but may not touch the ground until coming back to land. Finally, the plane can be held and the backside can hang off the launch platform before launch.

3.4.2 ER #4: Short Takeoff Distance - Tolerance = - 2 feet

The tolerance for the takeoff distance is negative two feet, since the plane can take off before leaving the launch platform but may not touch the ground after leaving. Taking off between the six and eight foot mark is ideal, since too much thrust/lift forcing the plane off the ground too early could result from overcompensation in the motor or wing lift, which would result in more dry weight and less stable flights.

3.5 ER #5 (changed from fall): Cost Under $300

3.5.1 ER #5: Cost under $300 - Target = $299

Due to the high costs of the registrations for the SAE competitions, the team has been left with only a fraction of the budget that was awarded in the Fall semester. For this reason, the team has only a small budget of around $300 for the purchasing of parts and manufacturing of the craft. Fortunately, the team can acquire many parts and components for free from the NAU Machine Shop as well as from Tim Kelly from the Flagstaff Flyers. Additionally, most of the manufacturing has taken place at Tim Kelly's workshop and allowed us to use his tools and building equipment for no charge. There are still components that the team wishes to purchase for the testing and manufacturing of the craft and the team remains vigilant about the budget and spending.

3.5.2 ER #5: Cost under $300 - Tolerance = +/- $150

Most of the budget for the team was used for competition registration fees, therefore the team had only a small budget to use for the manufacturing of the craft. The team has been working diligently and have been resourceful in methods to minimize costs, wherever possible. However, the potential for running over budget due to unseen forces remains a possibility. The team decided that a tolerance of $150 was a suitable value to cover any unforeseen costs that causes the team to go over-budget.

3.6 ER #6 (changed from fall): Lift Force

3.6.1 ER #6: Lift - Target = 5 pounds

A requirement of the competition is for the craft to have the ability to transport weighted cargo and a large portion of the scoring would be based on the amount of cargo that the craft would be able to carry. In order to meet this requirement, the team will design the craft to be able to generate five pounds of lift so the plane will be able to carry a significant amount of weighted payload and score points from this, as a result. The lift force that was originally designed for the craft in the Fall semester was 30 lbs. The lift has been substantially cut down to and is now designed to achieve a lift of five pounds. This redaction has been implemented as the team gained further experience with the design and realized how light the plane would actually be and what little lift was actually needed for successful flight.

3.6.2 ER #6: Lift - Tolerance = +/- 1 pounds

The goal of this project is to create a plane that is to carry a substantial amount of payload, though this is only possible if the craft has a large amount of lift. However, due to competition constraints regarding the size of the wings, the team designed the wings to fit within the set wingspan size of 48 inches, but also with a large surface area where a large amount of lift can be generated. The tolerance of +/- 1 lb. can be attributed to the angle of attack of the craft as the upward angle of the craft during takeoff and ascent elevates lift and a downward angle of attack during descent decreases the lift force.

3.7 ER #7: Thrust Force

3.7.1 ER #7: Thrust Force - Target = 10 pounds

The overall goal of the competition is to design a plane that can transport a significant amount of weighted payload. To accomplish this, the plane must have a high thrust force to be able to take off from the short distance of the craft and fly successfully while carrying a payload. The thrust force of 10 pounds has been designed for the craft as it is the near the maximum thrust that the craft can achieve with the motor and propellor combination that have been chosen for the craft. The thrust force of 10 lbs. is enough to launch the craft from a small takeoff platform, while being loaded with a weighted payload.

3.7.2 ER #7: Thrust Force - Tolerance = +/- 3 pounds

The tolerance of the thrust is +/- 3 pounds as the thrust can vary depending on the throttle that is applied to the motor as well as the overall electrical load. This tolerance has been implemented as the craft itself is limited to only operating at 450-watts at any time and the motor takes up 400-watts. Depending on the overall electrical demands of the craft at a given moment, the power routed to the motor may be partially hindered and therefore result in a loss of thrust provided by the motor.

3.8 ER #8: Drag Force

3.8.1 ER #8: Drag Force - Target = 2 pounds

With the implementation of a scoring system that was also based on the time it would take for the craft to complete the course, the drag force acting on the craft in flight would need to be addressed in order to maximize its velocity and power efficiency. The plane has a large surface profile due to the large wings that is required in order to generate a large amount of lift as well as the enlarged fuselage that is required in order to have the ability to transport the cargo containers. These factors degrade the craft's aerodynamic profile and enhance the drag forces upon it and ultimately decrease the velocity and power efficiency of the craft. The drag force is set to be limited to two pounds cause the plane to experience a loss in velocity and power efficiency, but the high thrust force of the motor will still allow the craft to fly at a desirable velocity with a large payload.

3.8.2 ER #8: Drag Force - Tolerance = +/- 0.5 pound

The tolerance of the drag force was set to a range of +/- 0.5 pounds as the team expects the drag on the craft to change based on the conditions that the team is flying in. For example, the team is willing to travel to an area of lower elevation to test the craft. The higher air density that is present at lower elevations will induce higher drag forces upon the craft, while the high elevations that the team is accustomed to flying has induced less drag forces due to the lesser density of air.

3.9 Flight Durability

3.9.1 ER #9: Flight Durability - Target = 4 flights

The competition rules state that a total of three flights will be performed to earn points for the competition. Therefore, to ensure the durability of the plane, the target value for continuous flights flown in four flights. This target ensures that the airplane can handle the aerodynamic forces of flight, as well as the stresses associated with takeoff and landing. The battery may be changed between flights, but the structure of the aircraft should be durable enough to withstand all four flights without any repairs.

3.9.2 ER #9: Flight Durability - Tolerance = +/- 1 flight

The tolerance for the testing is +/- one flight since the minimum number of successful flights needed per competition rules is three, and five flights is the maximum number desired to make sure the batteries don’t run to low and the airplane is not overstressed in such as limited time. If the plane can complete 3-5 test flights without issue, it will handle well in competition where the flight conditions and pattern are much less strenuous than what is will perform through the team’s testing.

3.10 Aircraft Reliability

3.10.1 ER #10: Aircraft Reliability - Target = 95% Successful Flights

The competition rules state that per flight round each team is allowed only 60 seconds to prepare the aircraft for take-off. The rules also state that only on attempt per round is allowed even if the time limit has not expired. A 95 percent reliability value has been exceeded thus far during flight testing but is necessary to ensure scoring flight attempts can be completed during competition. Failure to be considered reliable is defined as any unforeseen circumstance that disables the aircraft’s ability to fly.

3.10.2 ER #10: Aircraft Reliability - Tolerance = +/- 5% Successful Flights

The tolerance for the reliability of the aircraft has been set at 5% because the rules do not allow for multiple flight take-offs for the Micro class. The team has set the tolerance to 5% of flights to be unsuccessful in order to minimize the potential of a failed flight or take-off during the competition. The 5% tolerance was established as the team believes that at least 19 out of 20 flights and take-offs attempted should be successful. So far, the team has been 100% successful with all of the test flights and take-offs performed.

4 Design Changes

The team made two primary design changes during the construction process and then an addition. The first being adding dihedral to the airfoil. Second the team adjusted the access to the cargo hold. Finally adding bulkheads to the fuselage. The driving factors for changes were stability and ease of access. During the competition the team between flights would need a quick and easy way to access the cargo hold to adjust the weight the craft was carrying.

4.1 Design Iteration 1: Change in Airfoil

The original design for the airfoil had no dihedra. After consulting and receiving feedback from the flagstaff flyers along with research conducted by the group. The team made the decision to add dihedral to the design of the airfoil. The reason for the adjustments was the increased stability that the dihedral would add to the aircraft. Since part of the function for this aircraft is to be a cargo carrier the extra stability would assist in carrying this weight. As seen in the Figure 1 the completed airfoil with dihedral. The team added overall a five-degree angle to create the dihedral for this airfoil iteration.

Figure 1 - Airplane wing with dihedral

4.2 Design Iteration 2: Change in Fuselage Cargo Hold

The second design change adjusted the method for which the team would access the cargo hold. This change required a secondary modification to the aircraft. The first change as seen in Figure 2 was the cut for the flap. As a result of this adjustment the team needed to decide how the airfoil would be secured to fuselage. The team opted to secure the airfoil via rubber bands that go around wooden dowels that are attached to the fuselage. The reason for this flap adjustment was for time and ease of access. Originally during competition, the team would have limited time between flight to adjust the payload of the craft. Thus, the team needed a quick and efficient method for which to adjust the weight of the aircraft

Figure 2 - Cargo hold access and dowels used to secure wings

4.3 Design Iteration 3: Change in Fuselage Structure

After completing construction of the fuselage, the team noticed some issue with the overall integrity. After consulting the flyers and deliberating over some options the team opted to add bulkheads to the craft to increase the integrity of the craft. The team simply adjusted for the bulkhead to be slightly smaller than the current fuselage along with a large enough hole in the center to allow for wires to be ran through as seen in Figure 3. The bulkheads are the foam window shaped cutout seen at the bottom of the figure.

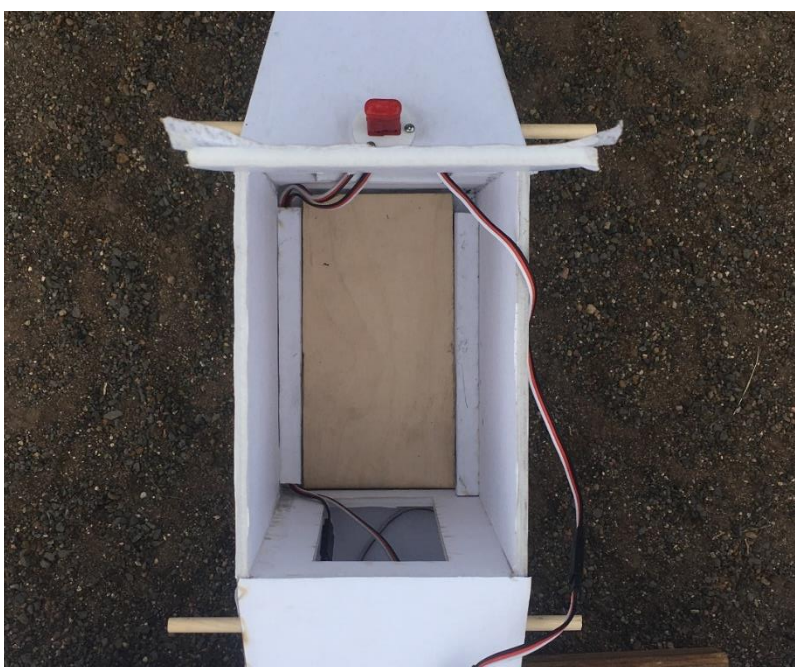

Figure 3 - Completed bulkheads within the fuselage

4 Future Work

The first test flight of the airplane was performed on February 21st at the Flagstaff Flyer's airfield and was a resounding success. A total of three complete flights were performed, with one successful landing, and two nose overs during the other two landings. To ensure the team designs the best plane possible and address some of the issues seen during the test flight, the team will continue to iterate and improve on the design.

The team fully expects to redesign several components of the plane, such as increasing the range of motion of the ailerons to allow for more control while in the air, moving components backwards to lessen the weight at the nose of the plane, and more. The team also hopes to make any design changes to the fuselage to optimize the center of gravity and increase the amount of payload that can be carried. Finally, due to the withdrawal from competition, the team now has time to focus on purchasing and constructing test stands to measure motor and wing properties. These design changes are further discussed below along with a section describing the future design of the test stands and a breakdown of the team's schedule for the remainder of the semester.

4.1 Further Design - Airplane

The team is currently considering several design changes to the airplane that will be implemented in the future. The first and most major design change the team is considering is adding a first-person view (FPV) camera to the front of the plane to make flying much easier. This would allow the team and future capstone teams to test fly their airplanes and assess their performance without the added risk of line of sight flying. A second major design change the team is considering is working on methods to increase the structural integrity and size of the cargo bay to carry more payload. While the team has dropped out of competition, the team is still using the rules as a basis of design, and this change would increase the scores seen at competition.

The penultimate design change is changes related to increasing the thrust and lift of the aircraft. While the team believes the airplane can take off from the designated test stand specified by the rules, this only includes the dry weight of the airplane and no payload plates. The team needs to consider whether changes must be made to increase the thrust and lift, or if the plane would function well enough at sea level conditions rather than higher up in Flagstaff. Finally, a fourth and very important design change to the aircraft is to move the front nose wheel forward and some of the electronics backwards. The aircraft is currently nose heavy, which caused the nose overs seen in the flight test.

In terms of manufacturing, the team will continue to design and construct the plane at the residence of Tim Kelly and the NAU machine shop. Both locations provide tools and plenty of space to construct the various components of the plane. However, most of the components are laser cut using Tim Kelly's laser cutter. Thus, much of the designing and manufacturing of the plane will continue to take place at his residence. The team also plans to manufacture many of the components individually at home to accommodate for any COVID-19 related concerns. This will allow for each student to do the fair amount of manufacturing, while also ensuring their safety and wellbeing.

4.2 Further Design - Test Stands

Due to the team dropping from competition, our faculty advisor, David Trevas, has recommended looking into purchasing and building test stands to measure motor and wing properties. The team believes that this recommendation is well thought and could provide the team and future capstone teams with the necessary tools to test their design and prepare competitive reports in the future. The team is currently looking at purchasing a prefabricated test stand to measure motor thrust and is brainstorming ideas as to how the properties of the wings could be measured. The current and most feasible idea is to create a roof mounted car test stand. This test stand would attach to the roof of a car and use strain gauges or load cells to measure the lift and drag of the wing, outputting the read data to a computer where it could be analyzed. As the team finishes the redesigns discussed on the plane, this new project will become the main priority as the team wraps up the project.

4.3 Schedule Breakdown

The entire schedule can be viewed in the Gantt chart in Appendix A. Due to the size of the Gantt chart, the tables provided in the appendix are a bit difficult to read. To accommodate, the team has attached the Gantt chart excel file to this document for further review should the Appendices prove overly difficult to read.

The team has made significant changes to the Gantt chart from what was submitted last semester to accommodate for the issues of COVID-19 and the ever-changing design requirements of the capstone project. Firstly, the construction of the plane took much longer than anticipated, and testing was pushed back approximately a month to accommodate for the longer than anticipated construction times. However, the team is now caught up and finished with the Design and preconstruction, construction, and testing that was laid out in the previous semester, and will being transitioning into the next phase of the capstone project which is split into three distinct sections: the design improvement section, the test stand section, and the capstone reports/requirements section.

Most of the remaining time in capstone will be spent working on design improvements on the airplane and the design and construction of the test stands. While the team is happy that the plane flew, it still requires some modifications to make it ready as if it were going to compete in the competition. However, since the team is no longer competing in the competition, the focus has also shifted to preparing future aero micro capstone teams for this project. To do so, the team will be purchasing/constructing test stands as outlined in the chart in Appendix X. Additionally, the team will also be taking inventory of the aero micro inventory and organizing the closet in order to ensure future capstone teams have a better chance at competing.

Finally, the last responsibilities of the team are compiling the final reports, presentations, posters, and website that remain in the class. The dates on these are not finalized yet, so the team will update the Gantt chart when the start and end dates can be better approximated.

5.0 References

[1] "2021 - SAE Aero Design - Rules," SAE International, 21 Sept. 2020. [Online]. Available: https://www.saeaerodesign.com/cdsweb/gen/DocumentResources.aspx (Accessed: Feb. 10, 2021).

6.0 Appendices

6.1 Appendix A – Gantt Chart

SAE Aero Micro

Team 20F12 Aero Micro
Tyler Darnell

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project Start: Fri, 8/21/2020
Display Week: 18

TASK	ASSIGNED TO	PROGRESS	START	END
Design and Pre-Construction				
Black Box and Functional Decompositio	Tyler Darnell	100%	8/21/20	9/2/20
Wing Design	Colton Farrar	100%	9/2/20	11/4/20
Fuselage Design	Zachary Kaiser	100%	9/2/20	11/4/20
Landing Gear Selection	Thomas O'Brien	100%	9/2/20	10/14/20
Motor and Propellor Selection	Daniel Varner	100%	9/2/20	11/4/20
CAD Package	Colton Farrar	100%	10/14/20	11/14/20
Purchasing	Thomas O'Brien	100%	11/14/20	12/16/20
Construction				
Wing Construction	Colton Farrar	100%	11/4/20	12/31/20
Fuselage Construction	Thomas O'Brien	100%	11/4/20	12/31/20
Motor and Propellor Insertion	Daniel Varner	100%	12/16/20	1/22/21
Landing Gear Installation	Thomas O'Brien	100%	12/16/20	1/22/21
Avionics Installation	Zachary Kaiser	100%	12/16/20	1/22/21
Assembly	Tyler Darnell	100%	12/16/20	1/22/21
Final Assembly and Pre-Test	Tyler Darnell	100%	1/6/21	1/31/21
Testing				
Preliminary Flight Testing	Thomas O'Brien	100%	1/31/21	2/21/21
Landing and Takeoff Testing	Daniel Varner	100%	1/31/21	2/21/21
Durability Testing	Colton Farrar	100%	1/31/21	2/21/21

6.1 Appendix A – Gantt Chart (continued)

SAE Aero Micro

Team 20F12 Aero Micro
Tyler Darnell

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project Start: Fri, 8/21/2020

Display Week: 27

TASK	ASSIGNED TO	PROGRESS	START	END
Design Improvements				
FPV Installation	Zachary Kaiser	10%	2/21/21	3/31/21
Improve Center of Gravity	Thomas O'Brien	10%	2/21/21	3/31/21
Change Nose Plate Placement	Daniel Varner	0%	2/21/21	3/31/21
Lift and Drag Considerations	Tyler Darnell	10%	2/21/21	3/31/21
Test Stand Design				
Research Lift and Drag Stands	Tyler Darnell	90%	2/15/21	2/22/21
Purchase Thrust Stand	Thomas O'Brien	90%	2/22/21	2/24/21
Draw Initial L&D Designs	Tyler Darnell	30%	2/22/21	3/1/21
Obtain Design Validation	Colton Farrar	0%	3/1/21	3/1/21
Purchase L&D Stand Components	Thomas O'Brien	0%	3/1/21	3/8/21
Test Stand Construction and Testing				
Begin Test Stand Construction	Zachary Kaiser	0%	3/8/21	4/8/21
Begin Test Stand Testing	Daniel Varner	0%	4/8/21	4/15/21
Capstone Reports				
Implementation Memo	Colton Farrar	100%	2/22/21	2/26/21
Midpoint Presentation	Zachary Kaiser	70%	2/22/21	2/28/21
Final Capstone Report	Tyler Darnell	0%	TBD	TBD
Final Capstone Presentation	Thomas O'Brien	0%	TBD	TBD
Team Poster	Colton Farrar	0%	TBD	TBD
Final Website Checks	Daniel Varner	0%	TBD	TBD