

Airfoil Testing Facility

ME424/426 Senior Capstone

June - December 2019

Client: Dr. Vibhav Durgesh

Lead Instructor: Dr. Steven Beyerlein

Graduate Student Mentor: Zachary Hacker

HotWings Team Members:

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Introduction

Problem Definition

Airfoil testing at the University of Idaho is a process that requires high need for operator intervention when it comes to set up and testing within the university wind tunnel. The stand that airfoils are mounted to is antiquated and has failing electronics. Angle of the airfoil must be adjusted manually with the accuracy not being as precise as laboratory experimenters need it to be. The HotWings team designed and manufactured an airfoil testing apparatus to fix these issues through rudimentary automation. Using National Instruments LabVIEW software to adjust the angle of attack as well as gather force data from a load cell.

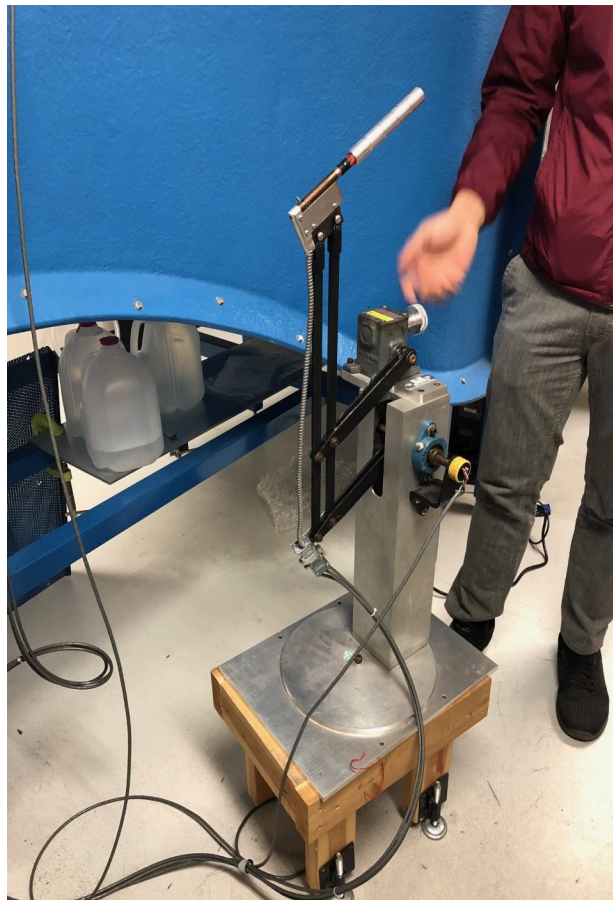


Figure 1. Current stand that is being used to hold and test airfoils in the wind tunnel.



Figure 2. Current data acquisition system that outputs lift force, drag force, pitching moment, velocity, and angle data.

Project Objectives

A multitude of objectives was given to the HotWings team at the beginning of the project. With Some being of higher priority than others. The team decided to split up these objectives into primary and secondary objectives. With primary being absolute necessities to fully completing the project. And

secondary being not project critical, but rather objectives that would be highly beneficial to get done.

Primary objectives are as follows:

1. Operate a stepper motor at 0.1° increments.
2. Design and manufacture airfoil.
3. Design and manufacture a modular stand with load cell placement as a primary consideration.

Secondary objectives are as follows:

1. Physically integrate load cell into the system.
2. Create a stand assembly process diagram for users.
3. Use load cell to achieve lift, drag, and zero angle of attack.

The HotWings team nearly hit all of the primary objectives and nearly all of the secondary objectives as the rest of the report will outline.

Design Requirements

Design requirements for this project were decided on and set from the first client interaction and changed slightly throughout June following subsequent client interaction and better understanding of client needs. Both the Primary and secondary objectives along with the design requirements document reflect the same goals to have uniformity within the project.

Functionality Requirements

Functional requirements are the ability for the system and user to operate practically within reasonable means. The operator shall not be required to push, lift, or carry any more than 50 lbf to move the apparatus. The operator shall be able to assemble/disassemble the apparatus under two hours.

The system should be capable of moving an airfoil at 0.1° increments. While also being designed to be updated in the future to automatically aligning the airfoil to a zero angle of attack. User should be able to simply change the angle of the motor through code. Standard tools that can be found in any hardware store shall be used to assemble/disassemble any part of the design.

Mechanical Requirements

Mechanical requirements encompass the ability of the system to handle static load, dynamic load, weight, and fit within certain spacing. The stand shall be able to carry a static load of at least 100 lbf while weight no more than 50 lbm while being able to stand on its own unaided. 8020 aluminum extrusions are to be used as the main stand material and are mounted together using brackets supplied from the client. The stand will fit within a 21"x21"x39" volume in order to fit within the wind tunnel test section. Mounting for the airfoil will be in the vertical position with the airfoil having an appropriately sized rod to connect itself to the system.

Electrical Requirements

Electrical requirements detail power needs of the system during operational use. During operation, the voltage of the encoder shall remain above 30V and below 80V with amperage remaining below 8.2A. The stepper motor shall remain below 2.6V and 6A. Both the motor and supporting electronics will be able to run off of a single power supply.

Software Requirements

Software requirements describe the ability of the software to perform during operation. Through the use of National Instruments LabVIEW software the motor will be able to move the airfoil 0.1° . Additionally, the system will be capable of being updated in the future to find zero angle of attack as well

as drag, lift, and pitching moment forces. The interface for the LabVIEW code will be easily controlled by the user.

Design Description

System Description

The complete system that the HotWings capstone team delivered to our client met the product requirements as well as hitting all of the primary objectives and all of the secondary objectives but the last one.

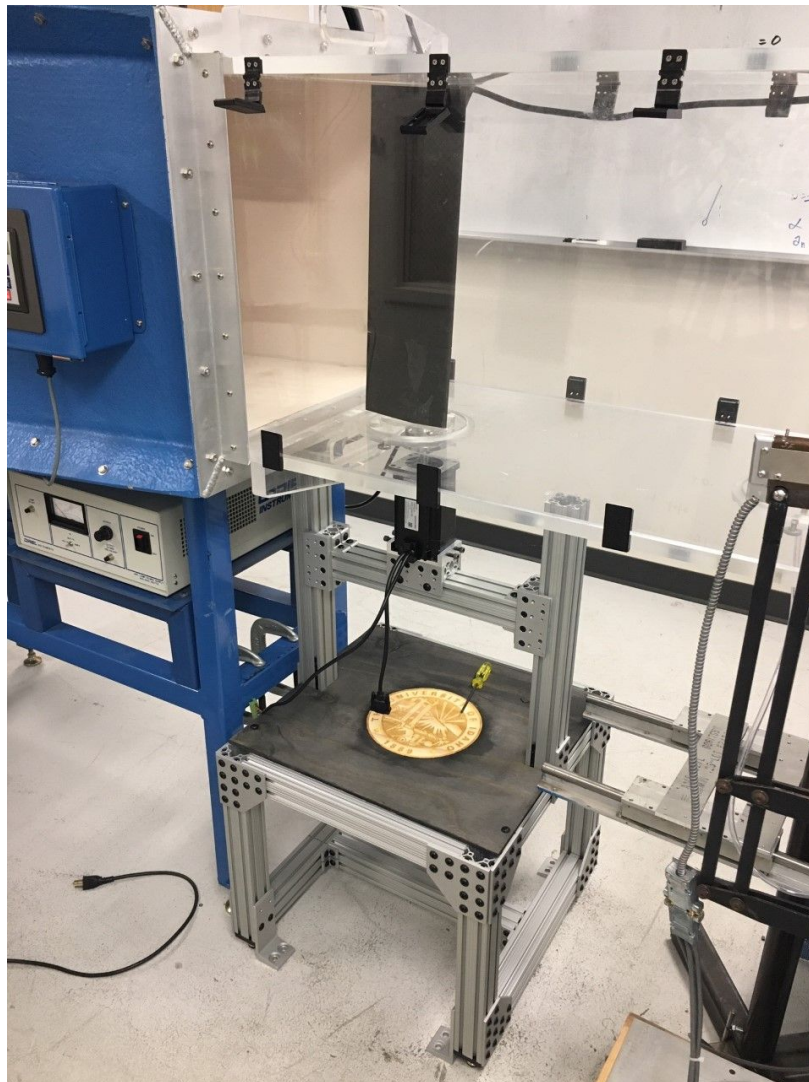


Figure 3. Full system delivered by HotWings capstone team sitting in university wind tunnel.

Detailed Mechanical Description

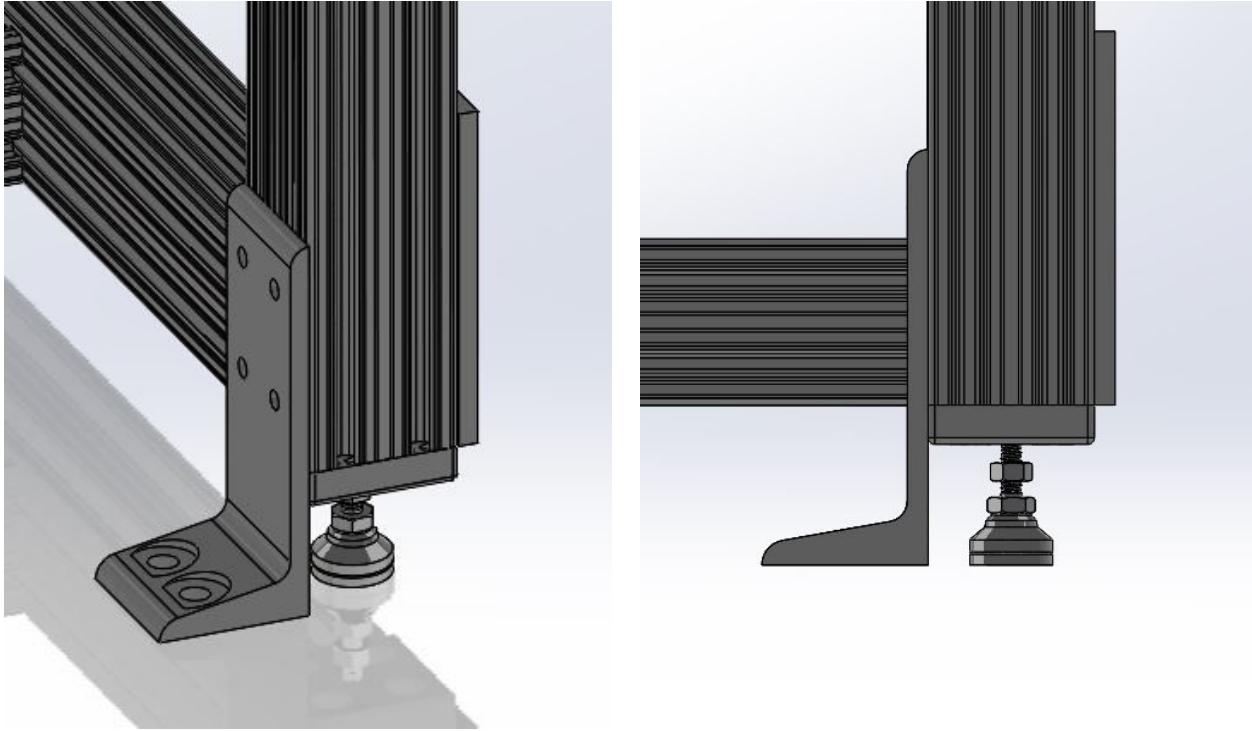
Stand Subassembly



Figures 4 & 5. The left figure (4) shows the final stand that was built. The right figure (5) shows a side view of the stand that emphasizes the upper sliding mechanism.

Figure 4 shows the full stand has a wooden shelf built into the middle in order to consolidate electronics close to the motor. The exact amount of weight this shelf is able to support is unknown, however it is robust and can easily support the electronics that are needed to support motor operations. Figure 5 features the uppermost bar as a key design feature. This bar is where the motor, and subsequently the airfoil, is mounted. The bar is connected to the vertical members of the stand via one 2x2-8020 aluminum slider on either side. These sliders are specifically made to go onto the 8020 extrusions that the

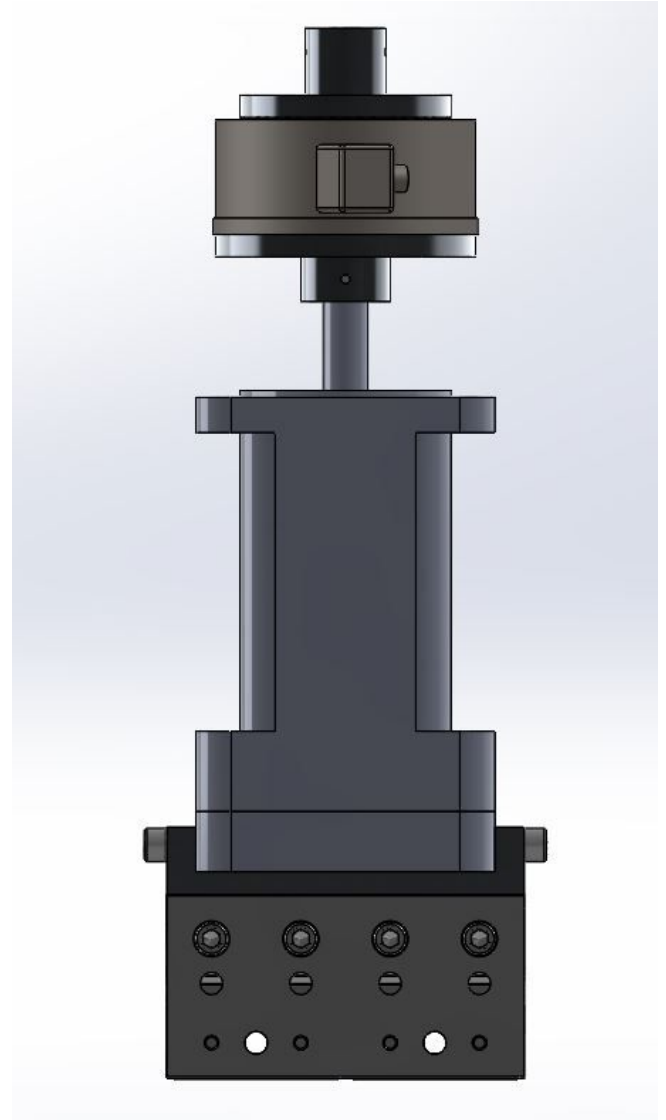
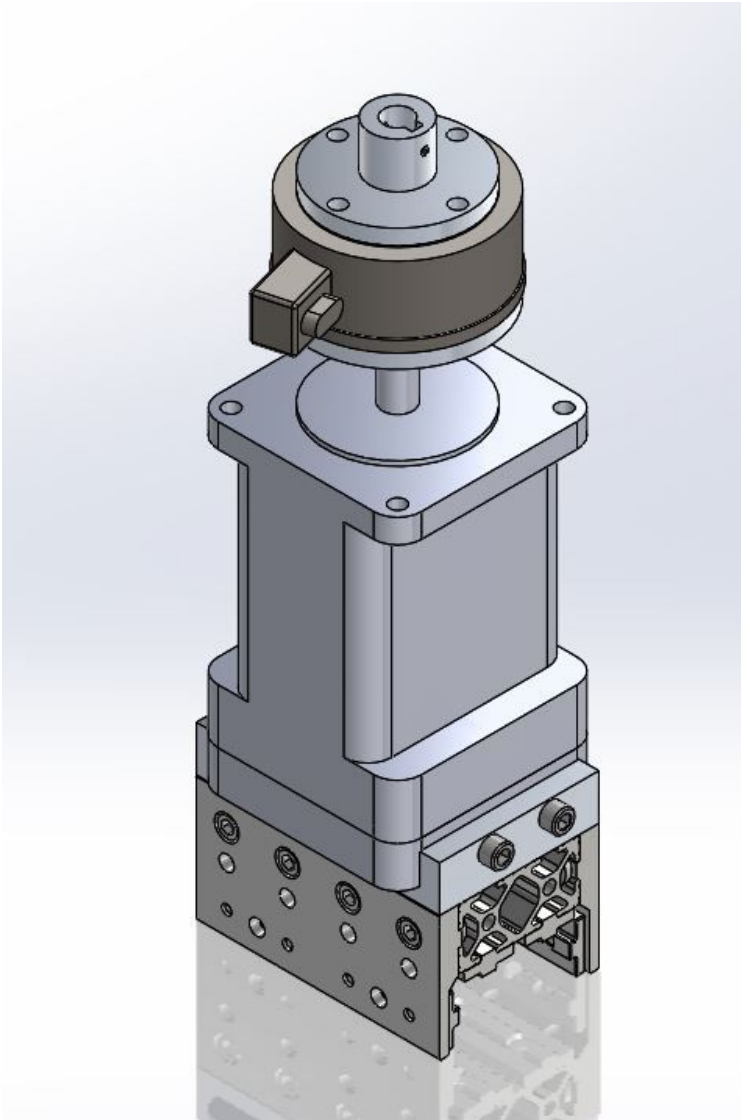
stand is mainly comprised of. The height of the bar on the slider is adjustable through the use of the sliders which allows the stand to be modular. The sliders can be fixed in place with the 1/4-20 screws that fit the aluminum extrusions together.



Figures 6 & 7. The left figure (6) shows a bottom corner of the stand where an adjustable leveling foot is alongside a floor mounting bracket. The right figure (7) is a side view of this.

Figure 6 and 7 show different views of the mounting and leveling feet on one of the bottom corners of the stand. These parts are present on all four corners of the stand as they are seen in these images. The stand motor can be leveled using the leveling feet at the bottom of the stand and during testing, the stand will remain completely stationary if the mounting feet are utilized. The mounting feet can be bolted into the floor beneath the wind tunnel test section which will make the stand resistant to any type of moment force that would want to turn or move the stand during testing.

Motor Subassembly



Figures 8 & 9. The left figure (8) shows the final motor assembly that was built for the project. The right figure (9) shows a side view of this.

The motor subassembly sits atop the crossbar that can be seen in figures 4 and 5. The bottom most part of this subassembly is another 8020 aluminum 2x2 slider. This slider allows for the motor to be correctly situated on the stand and in the wind tunnel test section so no parts of the system touch the section walls.

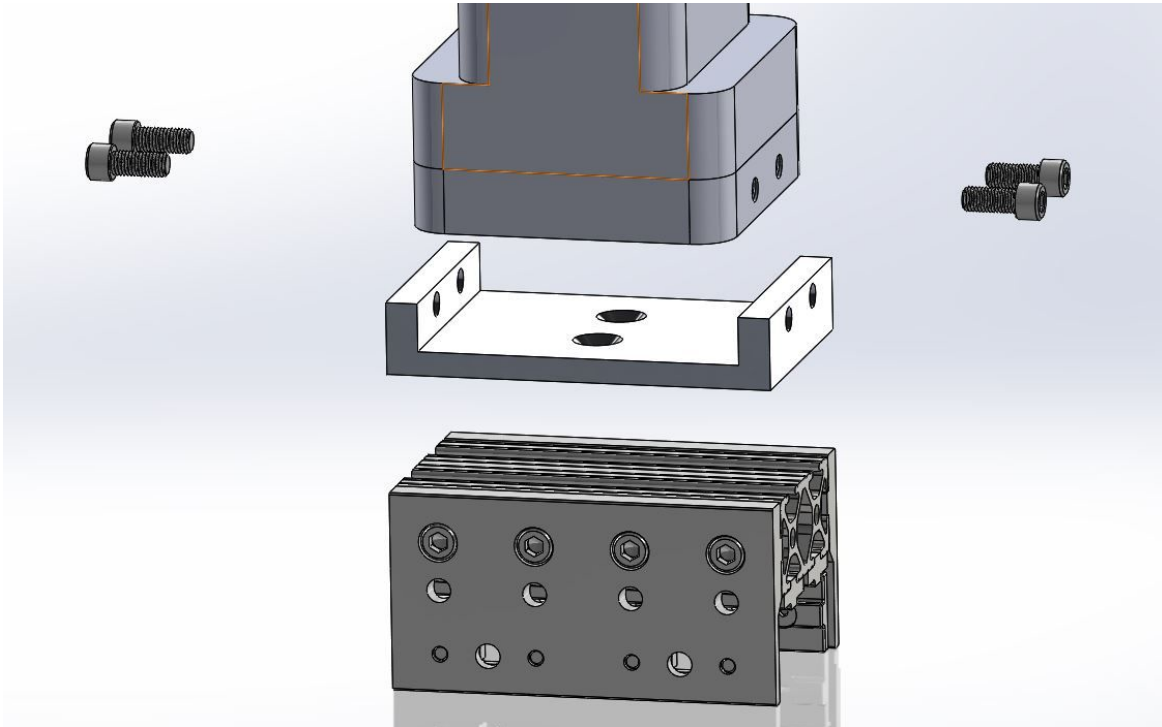
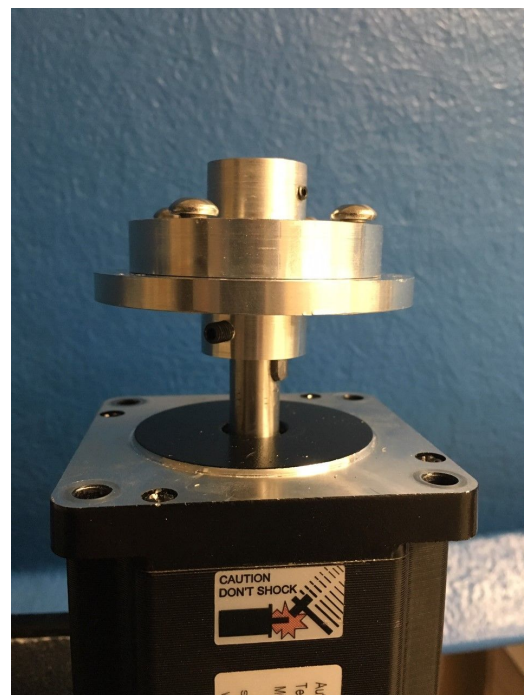


Figure 10. Exploded view of bottom portion of motor subassembly.

A connector plate was made of aluminum and needed to be manufactured in order to attach the motor to the 2x2 slider that sits atop the crossbar of figures 4 and 5. The plate is attached to the slider via the same 1/4-20 screws that hold together the stand. The base of the motor had to have four holes drilled in order to connect the motor to the plate.



Figures 11 & 12. Connector plates can be utilized with or without load cell integrated.

The plates shown in figures 11 and 12 were designed to be able to hold a load cell or operate without a load cell. The load cell shown in Figure 11 is an ATI Gamma Load cell. The bottom plate is keyed into the motor shaft and secured with a set screw. The bottom plate also features tapped holes to allow the top plate to connect to it .

Both plates are made of aluminum and were designed to specifically hold the ATI Gamma load cell. If another load cell was to be implemented within the system a redesign of these plates may be required to accommodate for the new load cell, see appendix A for drawing sheets of the plates.

Airfoil Creation



Figure 13. Airfoil Drawing

The airfoil choices for this project were between the NACA 0009 and the NACA 0021. The numbers correspond to the relative percent thickness of the airfoil. To make sure and cover all the bases for the design, the NACA 0009 was chosen since it was the thinnest option and our design would, therefore, satisfy whatever would be needed for an airfoil of a higher percent thickness.

To design the airfoil in SOLIDWORKS, the *Selig format dat file* was needed. This was obtained from the NACA website and contained the coordinates that could be converted to a text file and uploaded into the SOLIDWORKS software to create the drawing seen in figure 6. After the drawing is made it's as simple as extruding the part to the proper dimensions. In order for the airfoil to be considered a theoretically infinite wing we needed it to be within $\frac{1}{8}$ in from the top and bottom of the wind tunnel test

section. With our test section being 18in x 18in we went with an airfoil height of 17-13/16 in. Another stipulation in regards to the airfoil size comes in relation to the chord length. As a rule for testing airfoils, the projected airfoil area could not exceed 10% of the testing area at any given time. With the test section area being 324in² and our max angle of attack being 18° the following equations governed our chord length.

$$x * 17.8125(in) = .1 * 324(in^2) \quad \text{Equation 1}$$

$$Cl \sin(18^\circ) = x \quad \text{Equation 2}$$

In the above equations, x is equal to the maximum length that the airfoil can be to contribute to the overall projected area at the max angle of attack. Once that number was found to be 1.8in, we could then use equation 2 to solve for the chord length using the proper trigonometric relationship.

Airfoil Creation

Once the height and chord length were determined, the task of how to manufacture such a precise geometric shape needed to be determined. Initially, machining the part with the CNC machine at the University seemed like it would be a viable option. Once that plan was deemed impossible by the shop manager, a different route needed to be considered. Ultimately, the decision to 3-D print the airfoil as a means of validation for our system became unanimous amongst the team members. Since the printer can only print parts at a specific maximum height, the airfoil needed to be pieced together in 4 parts. Figure 14 shows how the individual parts were designed to fit together with hopes of minimizing the offset of the leading and trailing edges and Figure 15 shows the airfoil as a full assembly.

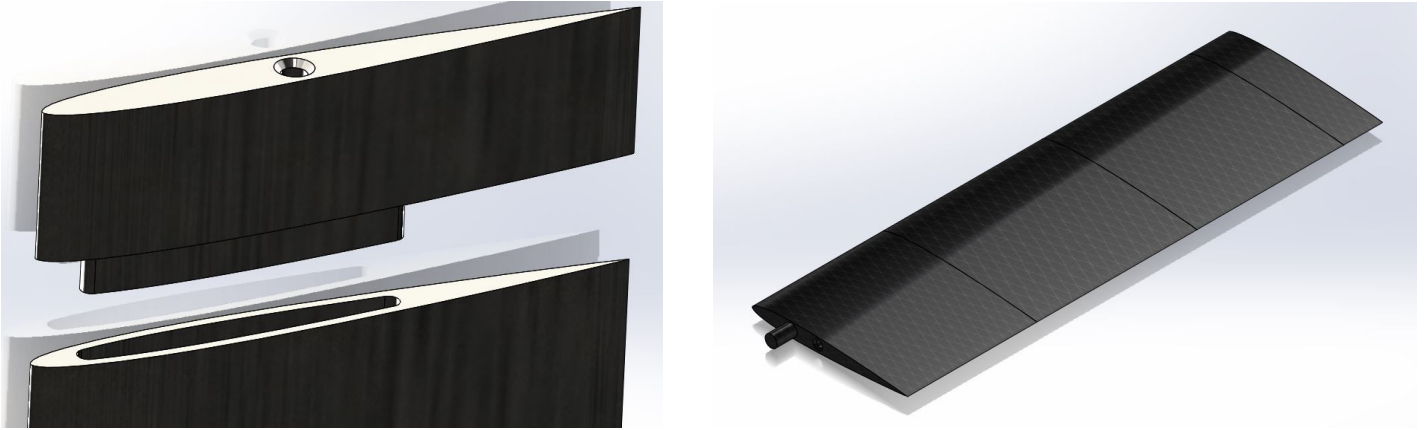


Figure 14 & 15. Connecting the airfoil together (14) and full Airfoil Assembly (15)

The airfoil is simply a prototype used for validation of the stand design. Later in the report, in the recommendations portion, there are some suggestions for taking this airfoil from the prototype phase to the final phase. The need to eliminate the seams and make the airfoil look as if it was one piece was a problem that the team did consider. A black plastic weld for seam connection and a smooth-on XTC-3D coating for surface finish were tested, however, with time constraints, they were not able to be implemented into the final prototype.

Detailed Electrical Design

For hardware a NEMA 34 Stepper Motor to control the airfoil's angle with a KL-8082H Hybrid Servo Drive to control it. This motor and driver allows for digital control of angle of attack through software along with a built in encoder for angle reading in our LabView software.



Figure 16. NEMA 34 Motor and KL-8082H Driver

The other benefit of this motor is a relatively high holding torque to prevent movement from the air stream that is not desired. The driver connects the encoder, direction, and pulse channels to the data acquisition device through a breakout board. We used a NI PCIe DAQ with a breakout board for motor control and angle collection. This breakout board takes the PCIe DAQ channels and turns them into the physical connections we need to connect the driver to the DAQ. For force collection, we used an ATI FT06889 SI-130-10 load cell. This is a 6 axis load cell with high accuracy.

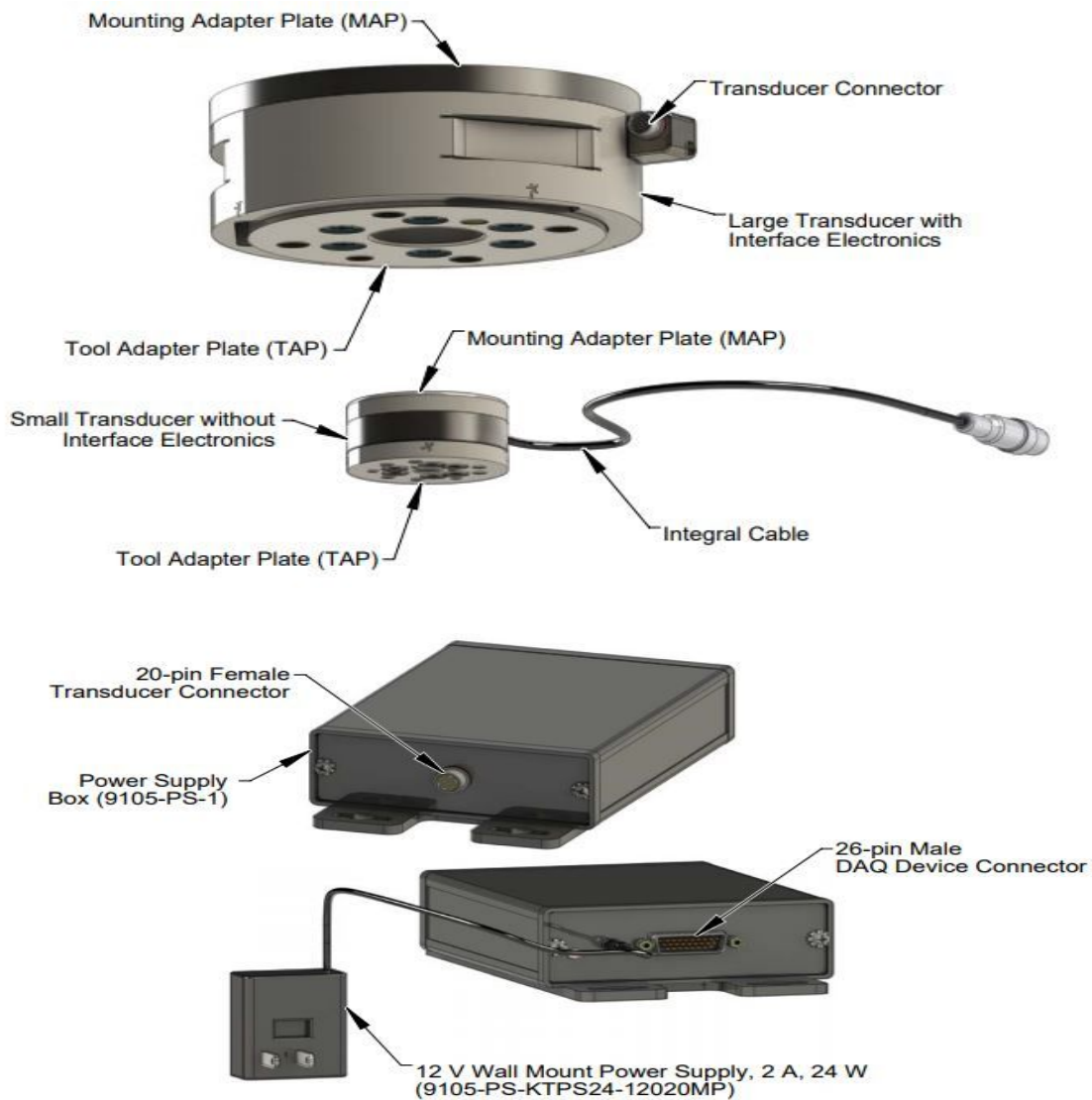


Figure 17. ATI FT06889 SI-130-10 load cell with transducer DAQ connector

Through some initial testing using high precision masses in the Z-axis, we found it read 0.02N off of the force the high precision mass should be creating. This load cell connects to a transducer DAQ connector device that is included with the load cell. This device then plugs directly into the PCIe DAQ without the need for a breakout board. Finally, this DAQ plugs directly into our data collection computer's PCI port that interfaces with LabView on the PC. Below is figure 18 showing the system we used to do testing for the load cell data collection and motor movement.

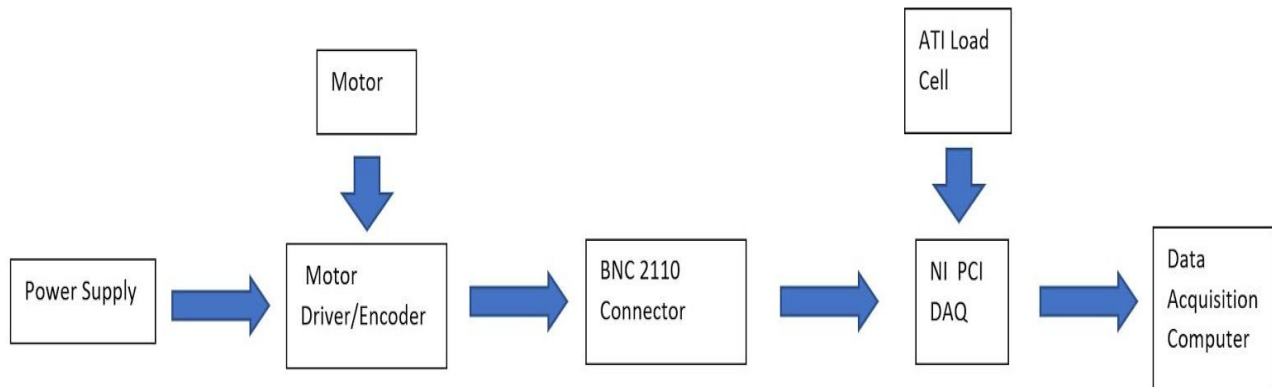


Figure 18. Block diagram of hardware connections

Some important notes are that we used a BNC 2110 breakout board with a PCIe 6351 DAQ for motor control and load cell testing. This current system does not allow for simultaneous load cell data collection in tandem with motor movement and angle reading. These were used in combination with a computer in the fluids lab that is used by a graduate student and are not the long term hardware for this system in the future. Refer to the electronics section of recommendations for future hardware design and selection. Additionally, refer to appendix C for all data sheets and links for the hardware.

Detailed Software Description

For our software we used LabView due to its ability to work well with NI DAQ devices as well as having built in components to make tasks such as reading the motor angle from the encoder much easier. The first task was to get motor movement using the LabView interface. A graduate student named Rodrigo who had worked on a very similar project with our client was a massive help as he had some LabView code that only needed to be slightly modified to work for the purposes of our project. The front panel of this code can be seen below in figure 19 with the full back panel available in the LabView folder. This file path can be found in appendix D.

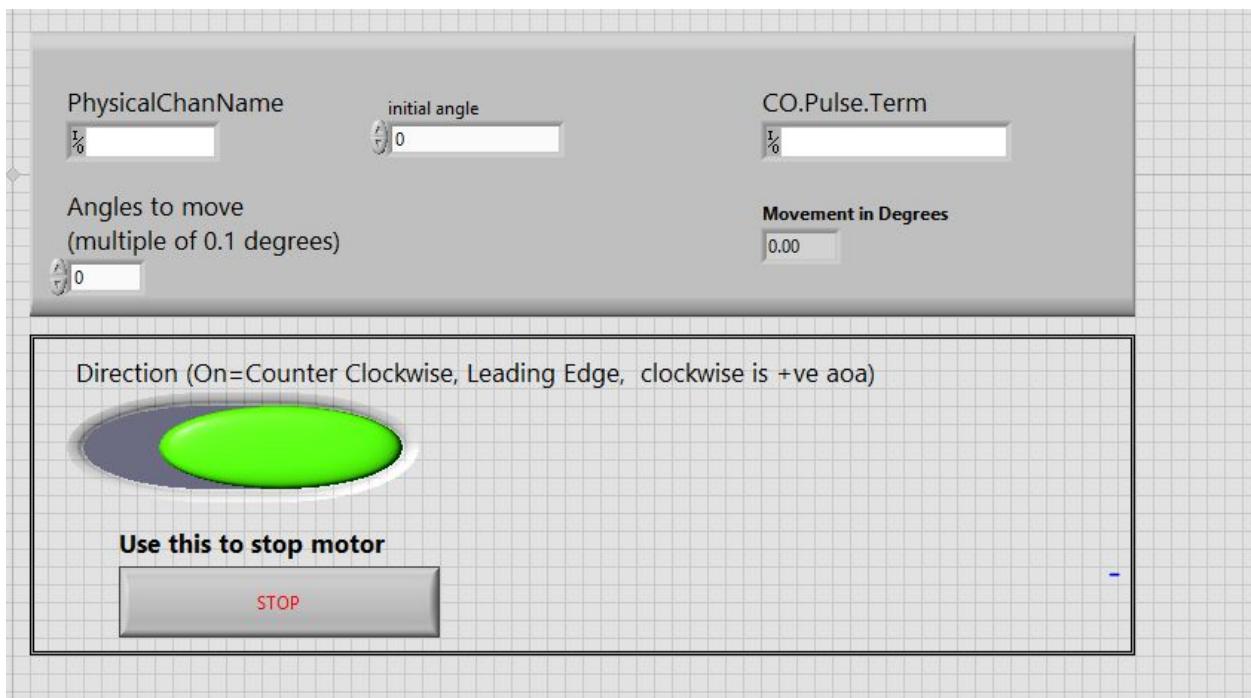


Figure 19. Motor movement front panel

Some key points about this is that both the encoder and motor control pulse block need to interface with counter outputs from a DAQ. The reason for this is that counters have much higher precision and accuracy compared to other signaling. For the motor movement pulse term, the type,

amount, and timing of the pulsing can be modified based on need. This was adjusted to get the 0.1° accuracy for motor movement based on the amount of pulses it needs. The resolution for this can be further increased by adjusting the white tabs on the side of the motor driver up to 40,000 pulses per revolution. For the encoder, the A and B input that can be seen in the code come from the A and B encoder pins on the driver. These can be plugged into any PFI port on the breakout board as long as they match when it is selected in the LabView code. However, we were finding the angle readings to be fairly inaccurate and infrequent especially at lower angle changes. We are unsure if this was due to a wiring or software error and did not have the time to finalize its accuracy. Finally, the direction pin can be plugged into any digital port on the breakout board which can be selected in the direction block at the top of the back panel. For load cell data collection, a different LabView code was used that can be seen below in figure 20. The full code and back panel can be found in the file path found in appendix D.

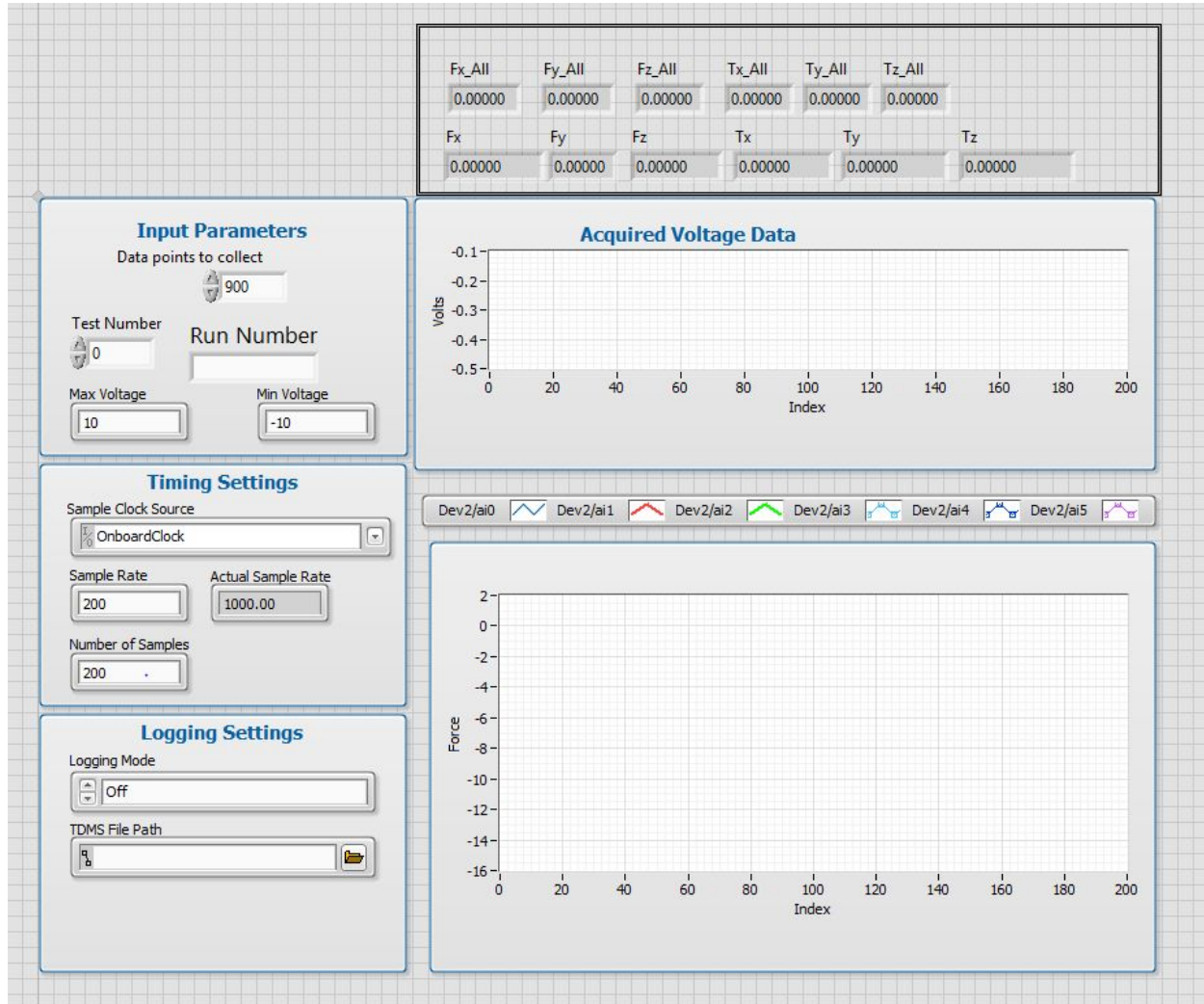


Figure 20. Front panel of load cell code

The load cell plugs directly into the PCIe DAQ and as seen in the LabView code it pulls the correct channels required for the Fx, Fy, Fz, Tx, Ty, and Tz force and moment readings. The code also pulls information from a text file named after the load cell. This text file contains a six by six calibration matrix provided by ATI. Although this gets the load cell reading accurately, the readings are not zeroed out and could be made more accurate. Both of these issues can be solved through a linear calibration. Getting to this step is as far as our team got due to time constraints but both motors movement, angle reading, and the load cells capability to read force were validated to be working. However, much more work needs to

be done in the future to make these as accurate as possible and to get the lift, drag, and moment forces along with then zero angle of attack. Additionally, the file path for the LabView codes can be found in Appendix D.

Design Validation

The main tool used in the design validation process was the design validation plan. The design validation plan (DVP) is a matrix of small and large requirements and corresponding tests used to achieve the design requirements.

Requirement	Test	Test Subject	Target Date	Result	Recommendation
Airfoil needs to have a chord length such that no more than 10% of the test section area will be taken up at maximum the angle of attack	Do mathematical calculations and figure out what that chord length needs to be	Airfoil Model	7/18/19	Chord length needs to be 5.825 inches with a max angle of attack of 18°. Test Passed (7/2/19)	Re-design the airfoil in SolidWorks and make the chord length the proper dimension.
Airfoil needs to follow the profile of the NACA 0009 model	Research where NACA airfoil coordinates can be found and how to create a SolidWorks model	SolidWorks Model	9/21/19	Test Passed (7/10/19)	
Airfoil needs to fit together with smooth edges from 3D printer	Place the pieces together and ensure proper connection.	Airfoil Prototype parts	11/22/19	Test Passed 11/22/2019	The airfoil fits together as expected but needs to be glued together with an epoxy to give smoother edges.
Airfoil needs to have a surface finish with a K value of 4 or less.	Use a test guage, if available and measure the surface finish of 3-D printed airfoil.	airfoil	12/4/19		
Airfoil needs to fit into the wind tunnel test section but be as close to the top and bottom as possible to maintain infinite airfoil application. (Within 1/8 in)	Measure wind-tunnel and design airfoil to be proper height to accomplish the infinite airfoil need.	Airfoil, wind tunnel test section	12/3/19	Test Failed (12/3/2019)	The connector on the bottom of the airfoil needs to be longer. We did not take into account the size of the screw heads that connect the load cell to the connector plate so there was not enough clearance for the airfoil to fit.

Figure 16. Example of DVP

Figure 16 shows a small snapshot of the DVP used. Green indicates that the test passed, yellow indicates that the test passed but there was something that could be improved upon, and red indicates that the test failed. The DVP was constantly updated with new requirements and tests that were needed for new and different designs. It was also constantly updated by removing requirements and tests that were no longer needed for a failed design. The full DVP can be found in appendix B. Some of the tests were not

met in the DVP, this is due to the project running out of time, however, these tests are not primary objectives that were needed to complete the project.

Conclusion and Recommendations

Lessons Learned

The HotWings team was a team comprised of solely mechanical engineers and one of the main centerpieces of the design and system usability was the load cell. If engineering students in the future decide to change the load cell or modified the system in a way the move the position of the load cell it must be known that the load cell needs to be fixed. Fixed for a load cell means that the load cell can not be free moving in multiple axes. If a load cell is not fixed it will not properly sense data.

A load cell needs to be fixed in order for it to have a reference frame for sensing forces that are input to it. In the HotWings design, see figure 11, it can be seen that the load cell is fixed to the bottom plate that is keyed onto the shaft of the stepper motor. During testing the load cell will be fixed in this reference frame and be allowed to collect force measurements.

The current design has the load cell and airfoil directly atop each other and directly linked to the shaft of the motor. This allows for the whole motor system with load cell and airfoil integrated to be able to turn as essentially one unit. During the course of this project a design was heavily considered that used helical bevel gears to link the shaft of the motor to a rod that would subsequently turn the load cell and airfoil. During a design review this design was negated by multiple professors, client included, and graduate student mentor. This is because gears in the system would impart a continuous force on the load cell that would be nearly impossible to quantify. Avoiding the use of any gears is highly recommended in this system.

The HotWings design team was tasked with design and manufacturing an airfoil which was successfully completed, however, the methods used to achieve this airfoil should be avoided in the future. The final airfoil produced for this project was done using the Markforged Mark Two overseen by Dr. Joel Perry. As explained in the airfoil creation section it had to be printed in four parts. The material used to print the airfoil was Onyx, which is a mix of Nylon and chopped Carbon Fiber. The combination of 3D printing, material selection available for the printer, and printer dimension restrictions lead to the production of an airfoil that is less than desirable for accurate testing.

Coming off the printer the airfoil needed to be much smoother and have a mirror finish. Smooth-On XTC 3D High Performance Print Coating was an epoxy purchased by the team to attempt to achieve a surface finish that was desirable to test with. This epoxy did not work as advertised on the onyx material. It is recommended to avoid 3D printing an airfoil on any university 3D printer and to avoid using the aforementioned epoxy on a 3D print.

Recommendations for Future Designers

The project goals for the first capstone series of this legacy project were broad and plentiful. The Hot Wings Team reached most of these goals but there is room for improvement in future years. To really address each recommendation it would be best to go through each objective individually.

Stand

For the stand itself the recommendations are minimal. The most crucial addition would be to have holes installed in the floor of the wind tunnel lab which will hold the stand in place via the mounting feet seen in figures 6 and 7.

Airfoil

The airfoil needs to be redesigned and manufactured using a different process. Deciding how to move forward with the design of a new airfoil is a project all to itself and it is the one objective that

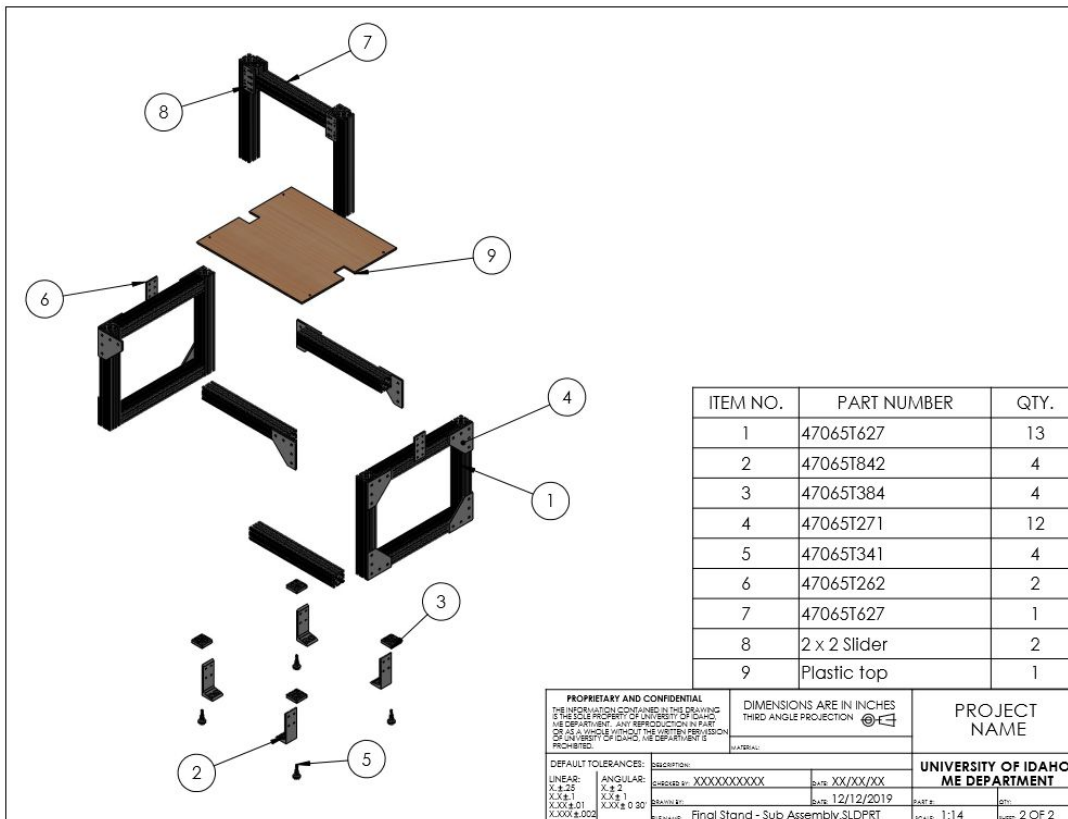
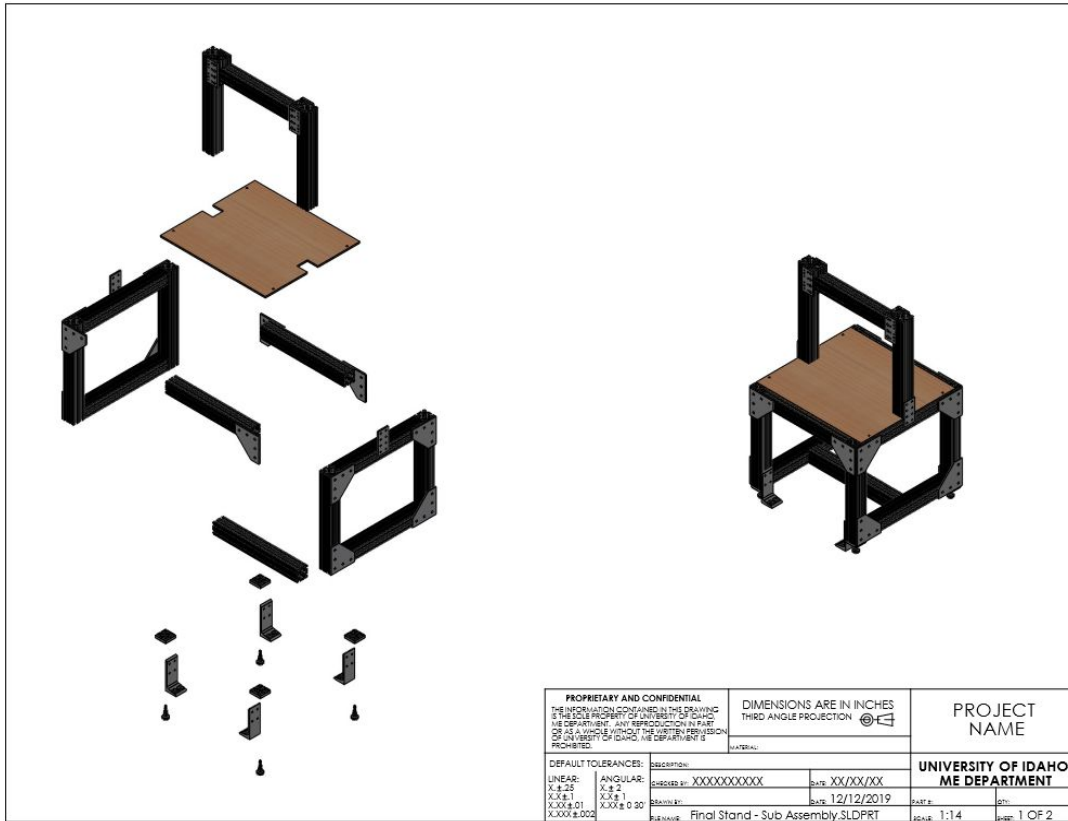
HotWings could not accomplish outside of the prototype phase. More research needs to be done on outsourcing the current model to a machining company and getting quotes on what that would cost. Producing the airfoil out of a 6000 series aluminum would be ideal as this is an aircraft grade aluminum. The option to outsource to a 3-D printing company is an option but it would need to be able to print the full height and the issue with the surface finish would need to be addressed. Discussions with the future client of this project may determine that the NACA 0009 airfoil is not viable to get to a quality desired by the client. Concerning the current airfoil, the cylinder piece that connects into the stand did not print as expected. The Markforged can print two separate materials with one as a support material and the hope that adding the carbon fiber support to the connector piece to help with strength seems to have affected the print quality. Re-printing that bottom piece without the reinforcement might solve this problem. In conclusion, the airfoil needs to be taken from the current prototype and transformed into something beautiful that can actually validate the lift and drag coefficients of the NACA-0009.

Electronics and Software

For our electronics and software, there needs to be some improvements to the hardware itself as well as the LabView code. First of all, there needs to be a DAQ that can take data simultaneously for both the load cell and the motor since currently these two sub systems are being validated independently and not running together at the same time on the same DAQ. After our research, we currently recommend the NI 6323 PCIe DAQ with an accompanying breakout board since it has two ports that a breakout board and the load cell could connect to. However, its capability to sample at the same time as well as its sample rate still need to be verified. Secondly, the wiring itself needs to be adjusted and upgraded. Since there will be a change in DAQ and breakout boards in the future, the wiring will change to what exact port it plugs into. However, it is fundamentally the same as the pulse signal wire still needs to go into a counter output port and so on for the other wired connections. The wires themselves need to be upgraded as well to longer and possibly thicker gauge wiring. For the power supply, we are currently using a variable power supply unit with plug in connections. Although this works, it is quite large and it could be used

elsewhere in the university and we purchased a more permanent switching power supply. However, this did not come with a connecting wire to plug into the wall. This is a fairly simple fix since all that needs to be purchased is an appropriate connector which can be found on any basic site such as Amazon. This project also lacks a dedicated data collection computer setup. Although we have acquired a cart, tower PC, and keyboard, we still lack a mouse and monitor. This PC has LabView downloaded but has not been validated with all of our system parts and will need to make sure it all works once it is all put together with an internet connection. Internet ethernet plug ins can be found in the fluids lab next to the sink and the wind tunnel test section. For the load cell, there is also possibly a cord that needs to be purchased to connect it to the PCIe DAQ. Dr. Durgesh said there was one for it but we could never find it so we had been using one that Rodrigo used for his test set up. If this is not available, one needs to be purchased for our system. As for the software, we were using a modification of Rodrigo's code to get our system working and although it was good for validation, we recommend either starting from scratch or making further modifications as necessary to get the system working as intended. Further work needs to be done especially when it comes to reading the motor's encoder for the angle, as well as fixing the offset issue with the load cells force collection. The force data can be output as a DAT file for collection, but the motors angle cannot currently. Making the motors angle readout able to be output as a DAT file would be helpful for data collection so the force data and angle reading can be shown together so the forces at specific angles can be read much easier. Additionally, Rodrigo had some code for finding zero angle of attack but our team never reached this part. His recommendation was to do that part from scratch for more optimal results but the code is available for reference. All recommended products can be found in Appendix D as well as the file path for LabView codes.

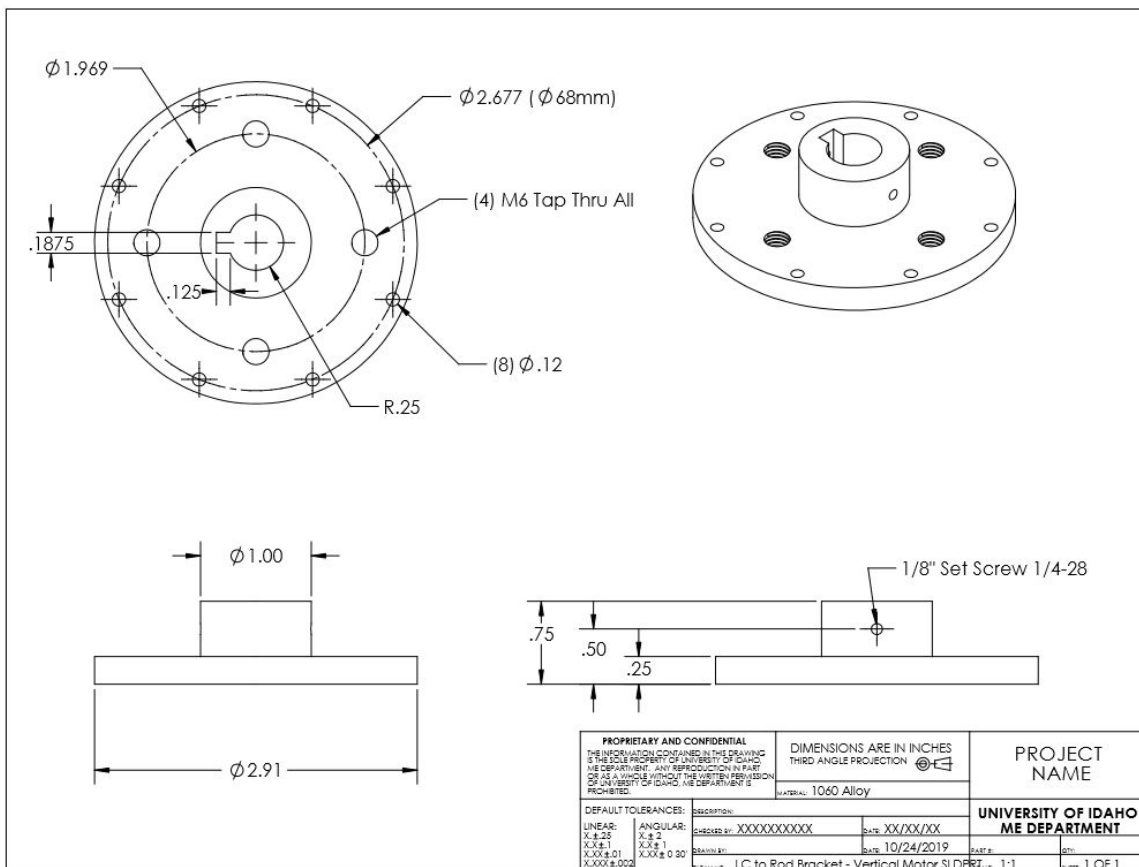
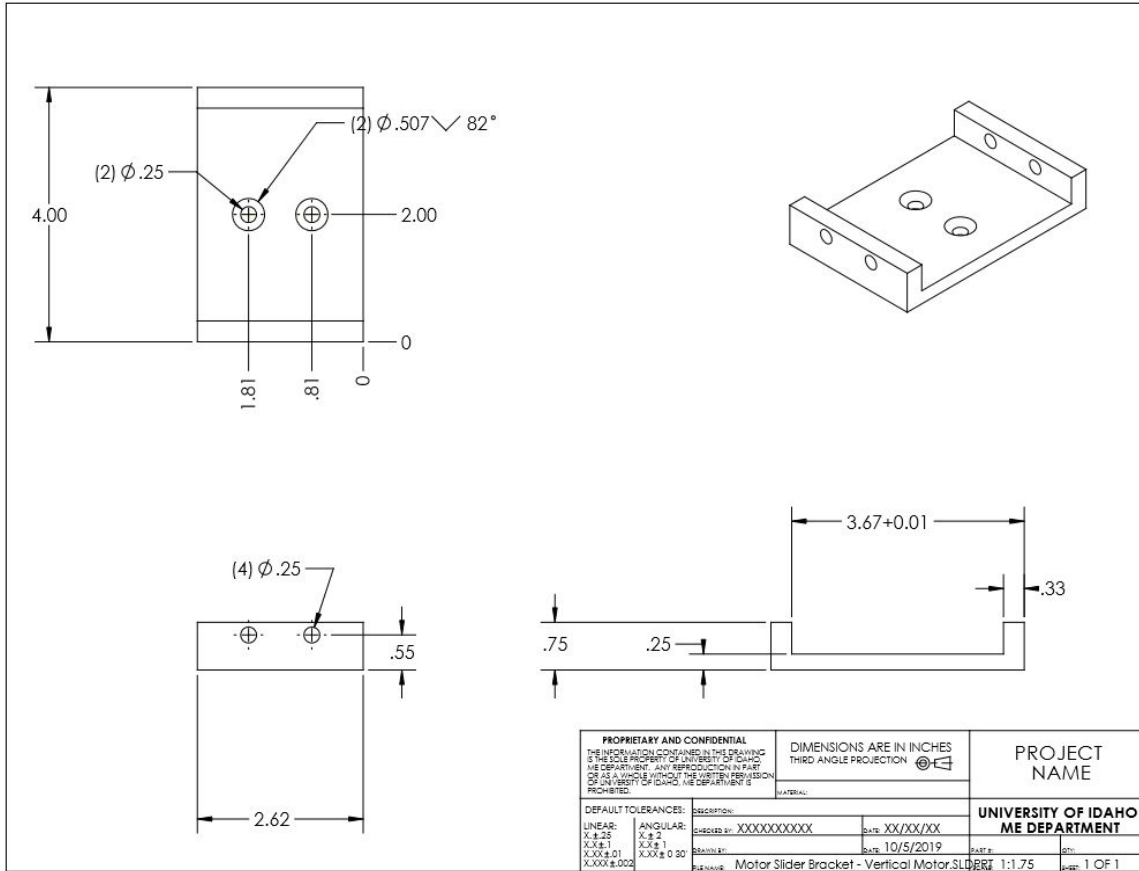
Appendix A

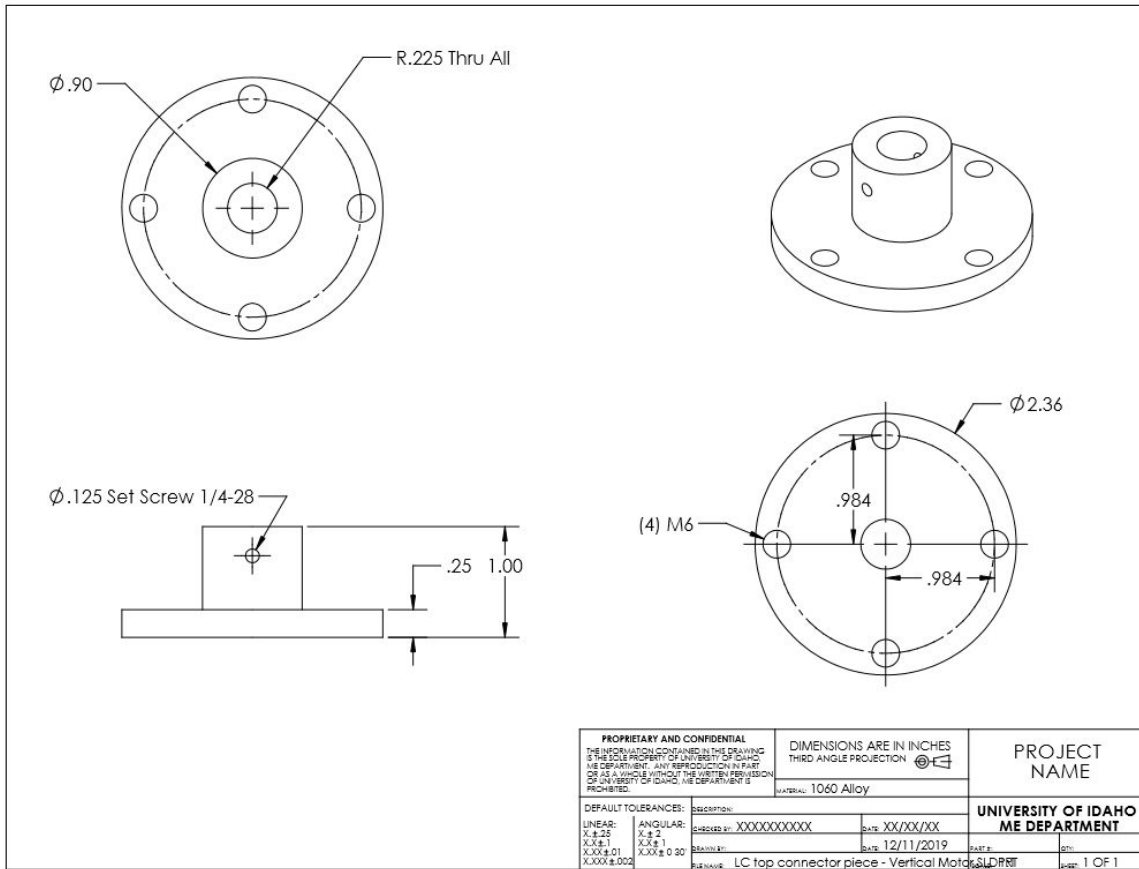


ITEM NO.	PART NUMBER	QTY.
1	NEMA 34 Stepper Motor	1
2	Gamma ATI LC	1
3	2 x 2 Slider	1
4	LC to Rod Bracket - Vertical Motor	1
5	Motor Slider Bracket - Vertical Motor	1
6	LC top connector piece - Vertical Motor	1
7	91864A047	4
8	Airfoil Assembly	1

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MATERIAL: _____ PART # _____ DATE: 12/12/2019 FILENAME: Motor_Airfoil - Sub Assembly - Vertical Motor.SLDPRT			sheet: 1 OF 1

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DEFAULT TOLERANCES: LINEAR: X.XX X.XX.1 X.XX&0.01 X.XX&0.002	ANGLUAR: X.2 X.2.1 X.2.1 X.2.1	description: XXXXXXXXXXXX date: XX/XX/XX 12/12/2019	UNIVERSITY OF IDAHO ME DEPARTMENT
MATERIAL: _____ PART # _____ DATE: 12/12/2019 FILENAME: Airfoil Assembly.SLDPRT			sheet: 1 OF 1





PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF UNIVERSITY OF IDAHO ME DEPARTMENT. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF UNIVERSITY OF IDAHO, ME DEPARTMENT IS PROHIBITED.		DIMENSIONS ARE IN INCHES THIRD ANGLE PROJECTION		PROJECT NAME	
DEFAULT TOLERANCES:		DESCRIPTION:		MATERIAL: 1060 Alloy	
LINEAR: X.XX±.05 X.XX±.01 X.XXX±.002	ANGULAR: X.X°± X.XX°±1 X.XXX°±0.20	DRAWN BY: XXXXXXXXXXXX	DATE: XX/XX/XX	UNIVERSITY OF IDAHO ME DEPARTMENT	
REVISIONS:		DATE: 12/11/2019	PART #:	DRAWN BY: LDPR	
REVISIONS:		REVISION: LC top connector piece - Vertical Mot	DATE:	PAGE: 1 OF 1	

Appendix B

Senior Capstone Design

Project: Aerodynamic Test Facility
Team: Hotwings

Date Updated: 12/4/19

Design Validation Plan & Results (DVP&R)

Requirement	Test	Test Subject	Target Date	Result	Recommendation
Mechanical Requirements					
Stand					
The stand will fit within an 21in X 21in x 39in volume	Analyze volume within Solidworks	Solidworks model	8/1/19	Passed (10/15/19)	
The stand will fit below the test section of the wind tunnel			12/3/19	Passed (12/3/2019)	
Stepper Motor fits into the stand connector plate.	Place stepper motor onto the plate.	Machined plate and stepper motor.	10/22/19	Passed (10/22/19)	
Stepper motors keyed shaft fits into lower machined connector plate.	Slide female end of lower connector plate onto stepper motors shaft.	Stepper Motor and Lower Connector Plate	11/1/19	Passed (11/6/19)	
Load Cell will fit onto lower machined connector plate.	Connect load cell to lower plate using M3-0.5 screws.	LC and Lower Connector Plate	11/1/19	Passed (11/1/19)	
Load Cell will fit onto upper machined connector plate.	Connect load cell to upper plate using M6-1 screws.	LC and Upper Connector Plate	11/1/19	Passed (11/1/2019)	
The stand shall be able to withstand a vertical static load of 100lbf	Place 100lbs on the top portion of the stand.	Full Stand	10/10/19	Passed (10/22/19)	
The stand will remain level during testing.	Small bubble levels will be placed on the stand to ensure it is evenly placed in the test section area. The stand will be able to be adjusted using adjustable legs attached to the bottom of the stand.	Adjustable Legs / Bubble Levels	12/5/19	Passed (12/5/2019)	

Senior Capstone Design

Project: Aerodynamic Test Facility
Team: Hotwings

Date Updated: 12/4/19

Design Validation Plan & Results (DVP&R)

Requirement	Test	Test Subject	Target Date	Result	Recommendation
The stand will remain still while the wind tunnel is operating.	The stand will be bolted to the floor using floor mount brackets.	Full Stand	11/22/19	Not performed	Holes need to be drilled into the lab floor
The stand will not weigh more than 50 lbs without the the test equipment attached	The full stand design will be weighed together on the scale in G.J. 126 after manufacturing has been completed. Before the scale can be used to verify the weight, the stand will be assembled in SolidWorks and the weight will be evaluated in the software	SolidWorks Model/Manufactured Stand	9/24/2019 (Model) 10/8/19 (Manufactured)	Passed (10/15/19)	
Stand will have shelf built in to hold all electronics needed to power the load cell. (i.e. Power supply, encoder, cables, DAQ)	Measure area of each component to be placed on shelf. Adjust shelf area accordingly.	Electronics being placed on shelf. Large piece of wood that will become the shelf.	11/12/19	Passed (11/12/2019)	
Shelf capable of holding all the electrical components without large displacement.	Place electronics equipment on the shelf and visually inspect displacement.	Electronics being placed on shelf. Large piece of acrylic that will become the shelf.	11/12/19	Passed (11/12/2019)	
Airfoil					
Airfoil needs to have a chord length such that no more than 10% of the test section area will be taken up at maximum the angle of attack	Do mathematical calculations and figure out what that chord length needs to be	Airfoil Model	7/18/19	Passed (7/2/19)	

Senior Capstone Design

Project: **Aerodynamic Test Facility**
 Team: **Hotwings**

Date Updated: **12/4/19**

Design Validation Plan & Results (DVP&R)

Requirement	Test	Test Subject	Target Date	Result	Recommendation
Airfoil needs to follow the profile of the NACA 0009 model	Research where NACA airfoil coordinates can be found and how to create a SolidWorks model	SolidWorks Model	9/21/19	Passed (7/10/19)	
Airfoil needs to fit together with smooth edges from 3D printer	Place the pieces together and ensure proper connection.	Airfoil Prototype parts	11/22/19	Passed (11/22/2019)	The airfoil fits together as expected but needs to be glued together with an epoxy to give smoother edges.
Airfoil needs to have a surface finish with a K value of 4 or less.	Use a test guage, if available and measure the surface finish of 3-D printed airfoil.	airfoil	12/4/19	Failed (12/4/2019)	The epoxy did not cure as expected. A second coat might help with this however, time will not allow us to continue testing this particular phase of the project.
Airfoil needs to fit into the wind tunnel test section but be as close to the top and bottom as possible to maintain infinite airfoil application. (Within 1/8 in)	Measure wind-tunnel and design airfoil to be proper height to accomplish the infinite airfoil need.	Airfoil, wind tunnel test section	12/3/19	Failed (12/3/2019)	The connector on the bottom of the airfoil needs to be longer. We did not take into account the size of the screw heads that connect the load cell to the connector plate so there was not enough clearance for the airfoil to fit.
Airfoil needs to fit into the wind tunnel test section but be as close to the top and bottom as possible to maintain infinite airfoil application. (Within 1/8 in)	Measure wind-tunnel and design airfoil to be proper height to accomplish the infinite airfoil need.	Airfoil, wind tunnel test section	12/10/19	Passed (12/10/2019)	Note: The wind-tunnel should not be run at high speeds.
Hardware Requirements					

Senior Capstone Design

Project: **Aerodynamic Test Facility**
 Team: **Hotwings**

Date Updated: **12/4/19**

Design Validation Plan & Results (DVP&R)

Requirement	Test	Test Subject	Target Date	Result	Recommendation
Motor/Encoder Circuit will work with basic arduino code validating circuit design	Build prototype circuit and code to perform basic movement	Motor/Encoder	9/10/19	Passed (9/10/19)	Motor works well with arduino. Is not the best for the purposes of this design but was a familiar controller to do a basic validation that our circuit is correct and will move forward with LabView
Motor/Encoder Circuit will work using LabView interface for motor movement	Build circuit with DAQ and use software to achieve basic motor movement	Motor/Encoder	10/4/19	Passed(10/22/19)	We achieved basic motor movement using the labview interface using a motion study in a single direction
Software will be able to interface with load cell/s chosen for use	Set up a simple test with load cell/s and software that allows testers to visually see load cell is acquiring data	Software, load cell/s	11/22/19	Passed (11/20/19)	Load Cell was reading within 0.2 N of what the "true" force reading was. However was not zeroed out
Software Requirements					
LabView software will be able to turn stepper motor	Hook up motor to software and run simple code to turn motor stem	Software, Stepper Motor	10/4/19	Passed (10/30/2019)	
Software should be able to operate stepper motor at 0.1° steps sizes	Connect stepper motor to software with code to verify 0.1° movement	Software, Stepper Motor	10/25/19	Passed (10/30/2019)	
Motor angle will be read by software				Passed (12/2/19)	Outputs angle movement but is not doing it accurately. Needs more testing and tweaking to fine tune
Software will be able to interface with NI DAQ that is available for use	Run software and DAQ together to verify that they are speaking to each other to	Software, DAQ	10/13/19	Passed (10/22/2019)	

Senior Capstone Design

Project: Aerodynamic Test Facility
 Team: Hotwings

Date Updated: 12/4/19

Design Validation Plan & Results (DVP&R)

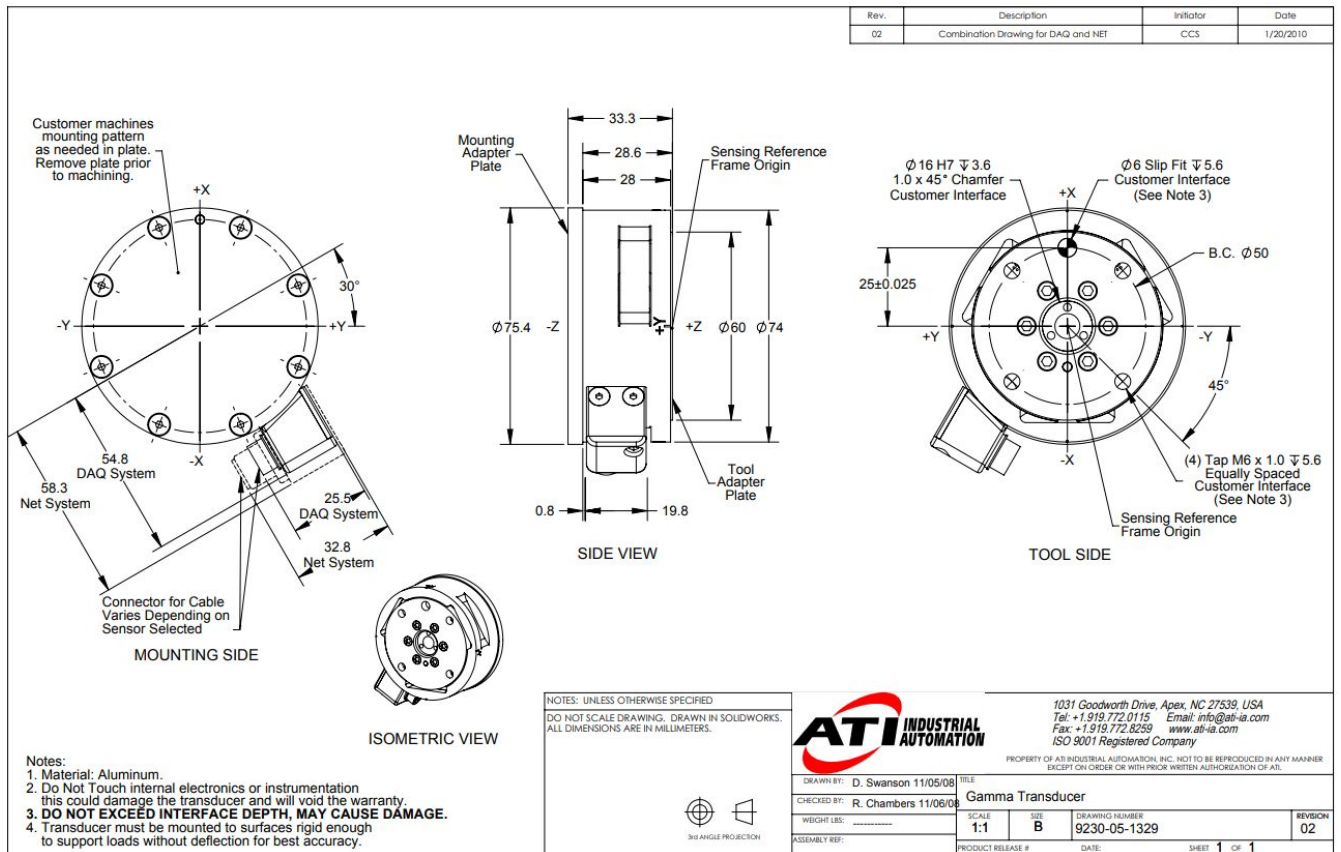
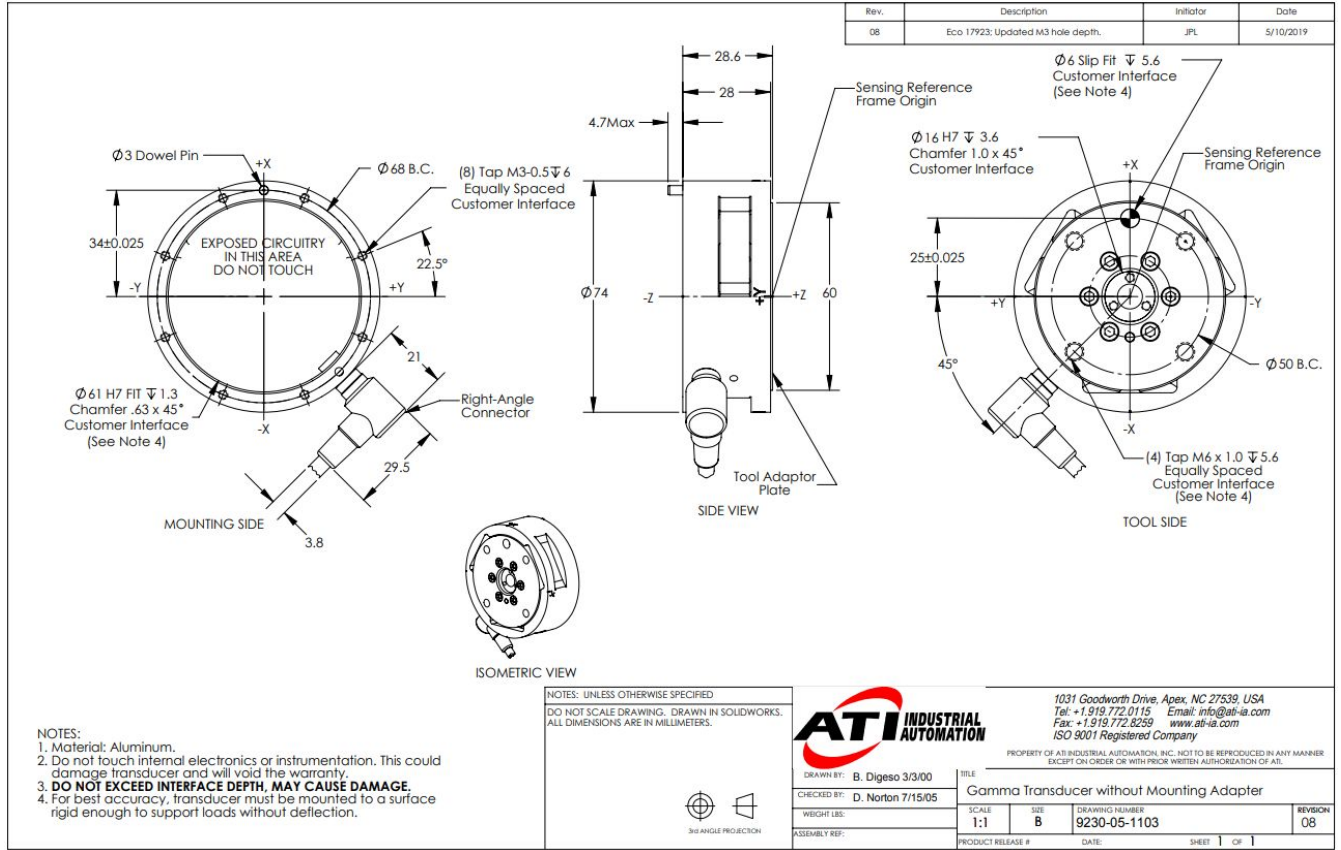
Requirement	Test	Test Subject	Target Date	Result	Recommendation
Software UI will be easy to understand and contain the appropriate labels that help describe what each function accomplishes.	Do small focus groups with client, instructor, and other team members to gauge UI intuitivness	Software UI	11/21/19		
Labview will move motor in relation to its starting angle position	write labview code that shows the motors current position and can be manually changed by the UI that can be validated using a protractor	software, motor	11/21/19	Passed (12/2/2019)	Moves in relation to its starting angle but angle readout is not accurate
Load cells should be calibrated to read correct lift and drag output (Secondary Objective)	Apply 5 different loads for LC calibration, then apply load and verify accuracy of force measurement	Load Cells	11/8/19	Passed (11/20/19)	Reads force but not necessarily the lift/drag force, need more testing to fully validate

Appendix B-a

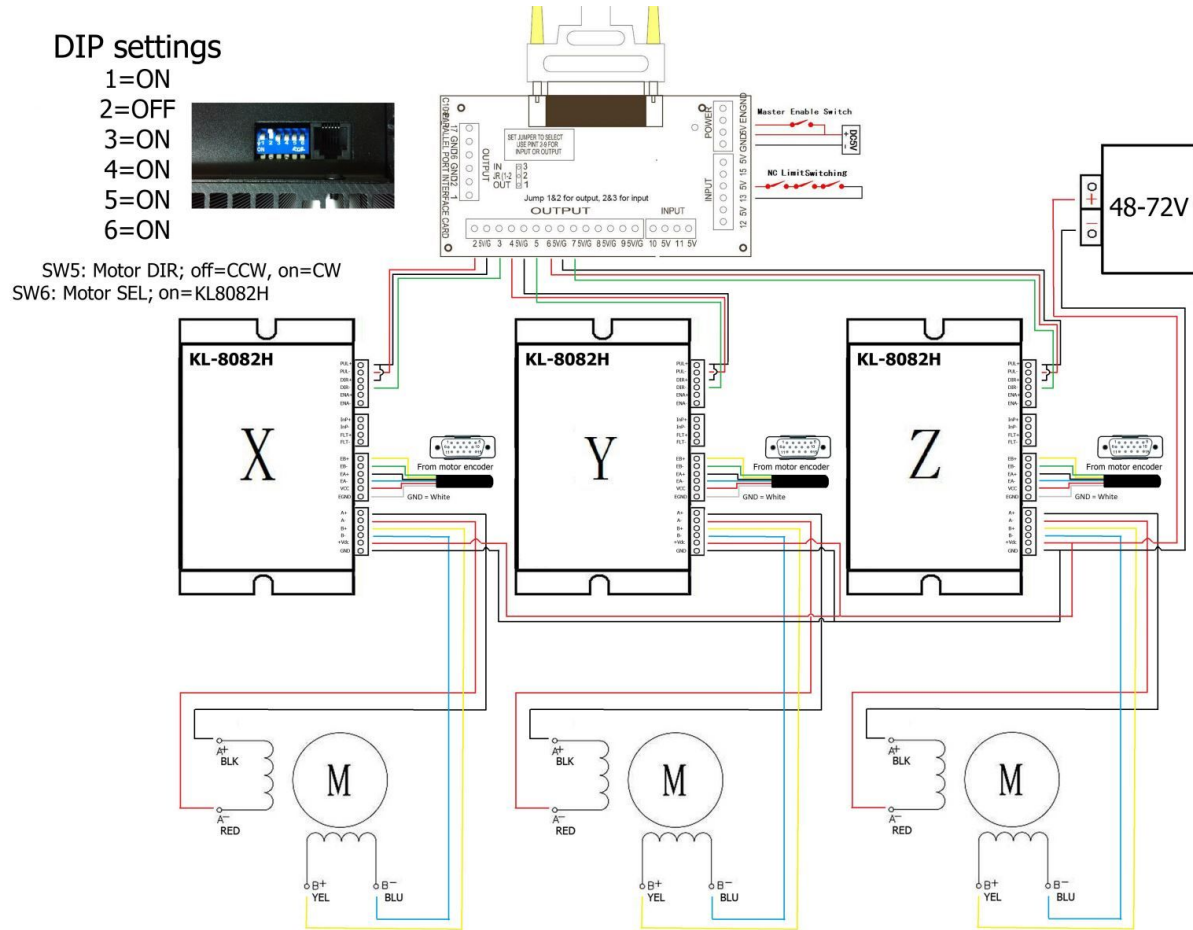
Hot Wings Capstone Project Budget - Summer/Fall

Expense Items	Vendor	Documentation to Office	2019						Item Total	
			June	July	Aug	Sept	Oct	Nov		Dec
Supplies / Parts / Services:										
<i>McMaster Carr Parts</i>										
80/20 2X2 AL (16ft)							\$117.63		\$ 118	
Stand Legs x4							\$24.40		\$ 24	
Floor Fasteners x 4							\$63.00		\$ 63	
End Caps x 4							\$60.76		\$ 61	
1/4"-28 Screw (10 pack)							\$7.15		\$ 7	
Bearing x2							\$27.14		\$ 27	
Helical Gears (pair)							\$157.08		\$ 157	
Corner Brackets x14								\$206.78	\$ 207	
Drop-In Fastener x50								\$113.50	\$ 114	
Straight Bracket x2								\$18.52	\$ 19	
Pre-Purchased										
8020 2x2 (12ft)									\$ -	
Aluminum Fasteners	Sun Source								\$ -	
Sliders x 3	Sun Source								\$ -	
Aluminum Brackets	Sun Source								\$ -	
NI DAQ	National Instruments								\$ -	
6-axis Load Cell (temp)	ATI								\$ -	
IFPS Converter Box	ATI								\$ -	
Nema 34 Stepper Motor	Automation Technologies Inc								\$ -	
KL-80R2H Hybrid Driver	Automation Technologies Inc								\$ -	
Connecting Wires									\$ -	
Data Collection PC	University of Idaho								\$ -	
3-D Print										
3-D Print Cartridge	Sindoh/Amazon	yes		\$30.00					\$ 30	
3-D Print Cartridge 2	Sindoh/Amazon	yes			\$ 30				\$ 30	
Mark Forge Parts							\$35.00		\$ 35	
Electronics										
VGA Cable	Automation Technologies Inc	yes		\$25.00					\$ 25	
Pin for Encoder	Amazon	yes			\$ 8				\$ 8	
PSU	Automation Technologies Inc						\$ 30		\$ 30	
Airfoil										
XTC-3D epoxy							\$ 28		\$ 28	
Black Mold							\$ 6		\$ 6	
3-D printing								\$ 153	\$ 153	
ME Shop Usage (est. Hrs):										
Stand Design							\$ 5	\$ 10	15	
Design Tweaks							\$ 1		1	
									0	
									0	
									0	
									0	
Graduate Student Support									\$ -	including fringe
Shop Overhead									\$ -	
University Overhead									\$ 55	5% of all expenses
Totals									\$ 1,107	\$ - \$ (1,107)
									Budget	Excess

Appendix C



https://www.ati-ia.com/products/ft/ft_models.aspx?id=Gamma (Link to ATI SI-130-10 Load Cell for further spec sheets and documentation)



<https://www.automationtechnologiesinc.com/products-page/hybrid-servo-system/nema-34-hybrid-servo-motor-kl34-8n-1000-rated-torque-1128-oz-in/> (Link to NEMA 34 Motor and KL-8082H Driver product page with further documentation and spec sheets at the bottom of the product page)

Appendix D

File Path for documentation and codes

On the shared drive, Shared/Engineering/SeniorDesign/-Senior Design/2019 Summer & Fall/Hot Wings - Capstone/

Link to PCI 6323 recommended new DAQ

http://www.ni.com/sic/configurator/configure.action?sflid=NI&wcs_l=en-us&wcs_k=multifunction-io-device&wcs_s=23287

Link to Power Supply Cable

https://www.amazon.com/Pinfox-Replacement-Pigtail-Universal-Appliance/dp/B07QYRMD6D/ref=sr_1_22_sspa?keywords=power+supply+cable&qid=1576206443&sr=8-22-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEExOFFPWk1YUk0zQlJPJmVuY3J5cHRlZEIkPUEwOTUyNjY4MIU4N1pDUERIREtTJmVuY3J5cHRlZEFkSWQ9QTAzMTEwNDEwVTRMWFJBUVZQT1FUIndpZGdldE5hbWU9c3BfYnRmJmFjdGlvbj1jbGlja1JlZGlyZWNoJmRvTm90TG9nQ2xpY2s9dHJlZQ==

References

<https://pdfs.semanticscholar.org/365c/e6a5f149b900ba393c57997c5dcf8aa80cd7.pdf>

Good technical document for calculating drag forces, includes lots of equations that may prove useful

<https://m-selig.ae.illinois.edu/pubs/SeligMcGranahan-2004-NREL-SR-500-34515-SixNRLAirfoils.pdf>

Technical document using two load cells to calculate lift, grad, and pitching moment for an airfoil

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKewjmu6p0YXjAhUhiFQKHaZtCH0QFjAAegQIAhAC&url=http%3A%2F%2Fuser.engineering.uiowa.edu%2F~fluids%2Fposting%2FHome%2FEFD%2FEFD_Lab3%2FLab3-Exercise_Note_old.doc&usq=AOvVaw1-VcrqoJ59yXuv8MO4Wx

(Downloadable Windows Doc). using two load cells in a horizontal orientation to find lift and drag forces.

<http://www.sjsu.edu/people/nikos.mourtos/docs/Blackwell.S11.pdf>

Research paper with some information about airfoil orientation

<https://www.automationtechnologiesinc.com/products-page/hybrid-servo-system/nema-34-hybrid-servo-motor-kl34-8n-1000-rated-torque-1128-oz-in/>

Link to motor/driver product page. Spec sheets can be found at the bottom of the page and includes a video of it being wired up to an acorn controller(not exact for our project but helps show how it would be wired to a similar controller)

<http://bioeng.nus.edu.sg/mm/wp-content/uploads/2012/07/MotorControl-1japwem.pdf>