Senior Capstone Project Final Report: Compliant Flap

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Submitted to Professor Xiaobin Le PhD.

MECH5000-03 Mechanical Capstone Analysis

Mechanical Engineering Program

School of Engineering

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Summary of Project

The flap system used on a Cessna 172, the most widely used personal aircraft, suffers from heavy components, surface discontinuities, and complex hardware configurations that necessitate the design of a compliant flap, which will change shapes from the default NACA 2412 geometry to improve wing performance during take-off, cruising, and landing, while reducing surface discontinuities and mechanism weight. Compared to other attempts at compliant wings, the flap system is the focus of this design because full-wing designs lack the structural rigidity needed to be feasible, and other novel approaches such as material selection and actuation method are adopted. The goal of this design project is to fabricate an internally powered scale model that is servo-actuated by an Arduino and will be placed on an unhinged, double-pylon test structure for wind tunnel testing the transition between three different configurations for specific flight events, which will validate computational fluid dynamics analysis of the system.

Executive Summary

The success of this project hinges on equal participation and effort from each team member. In order to ensure all necessary work is completed, we break down tasks week by week. As Project Manager, Jacob takes notes at each meeting and separates work into equal chunks. This is communicated to all team members via a weekly email. He also assisted with the design options for flap actuation and the test stand. Both subsystems required multiple people to brainstorm, sketch, and consider the relative difficulty of each. Once detailed design begins, Jacob will work heavily on the actuator and airfoil skin design.

Nial worked primarily on the flap actuation design, coming up with ideas, sketching potential geometries, and researching the pros and cons of various actuators. He is also responsible for creating a manufacturing plan so we can begin building once design is finished and will assist in the detailed design of the actuators and airfoil skin.

Tito worked heavily on the design for the test stand. This required multiple ideas to be generated, sketches drawn, and pros and cons to be determined for each. He researched various wind tunnel options for testing, including one owned by Wentworth and some from outside sources. He will also be responsible for test stand design (mechanical and control systems) once basic design parameters are finalized.

Andrew specializes in the computational fluid dynamics aspect of the project. Having worked with complex CFD programs in the past, he has expertise in this field that the rest of the group does not. He generated a list of potential airfoil shapes for our project and researched how each of these would affect flight parameters. He also researched how to properly use a wind tunnel in order to get accurate data by speaking with professors and industry professionals. Once our detailed design is complete, Andrew will use CFD programs to validate wind tunnel data.

We feel that each group member has contributed equally to the project and brings a unique set of skills to aid in our success. All team members contributed to the initial ideas brainstorming and work equally on deliverables (presentations, reports, weekly assignments). While not all aspects of the project happen in parallel, group members that have a lighter work load during a given week assist where needed.

PROJECT MANAGER:	Jacob Willette	SIGNATURE:	Jacob Willette	DATE:	3/4/22
TEAM MEMBER:	Tito Bermudez	SIGNATURE:	MisaelB	DATE:	3/4/22
TEAM MEMBER:	Andrew Lanzrath	SIGNATURE:	[illegible]	DATE:	3/4/22
TEAM MEMBER:	Nial McInally	SIGNATURE:	nial McInally	DATE:	3/4/22
TEAM MEMBER:		SIGNATURE:		DATE:	

Compliant Flap Project

Introduction

Modern aircraft utilize flap structures to increase wing length for increased lift during take-off, retracted flaps for cruising, and deploy flaps in a downward position for increased drag during descent and landing.


As seen in the figures above, the flaps have multiple points of surface discontinuity. In addition, the components needed to operate the flaps are heavy. These flaps are fundamental to flight, so they are used on small and large aircraft alike. Opportunities abound to make flight more efficient by reducing mechanism density to increase fuel efficiency and or reducing drag on key parts of the aircraft such as the wing by removing surface discontinuities.

The application of compliant design to wing structures is a candidate that has the potential to take advantage of both design opportunities enumerated above. The first compliant wing was on the plane designed by the Wright brothers, but contemporary research on compliant wing design started in the 2000s. Prior designs have attempted to make the entire wing a compliant mechanism. This almost completely eliminates surface discontinuities along the entire surface area of the wing. Also, the lack of joints reduces the amount of hardware needed, and thus the overall weight of the wing is reduced.

Despite those advantages gained from compliant wing designs, a whole wing being compliant is not feasible. The flexible properties of compliant mechanisms utilized over an entire wing bring about serious concerns over the strength and reliability of the wing under strong aerodynamic loads. Second, the number of actuators needed to make a compliant wing create multiple failure points any one of which could severely reduce the function of the wing if failure occurs. These reasons have stopped compliant applications to wing design from being commercially viable, but no research has been conducted on making only a portion of the wing compliant, specifically the flap system, which undergoes the most significant geometry changes over a typical flight course. Designing only the flap as a compliant mechanism resolves the two issues stated above related to the prior compliant wing designs. Fewer actuators reduces the effect of a failed actuator, which increases the overall reliability of the wing, and having only the flap be compliant means that the rest of the wing can act as a rigid structural body. Thus the advantages gained from compliant design can be applied to a wing system without reductions to the structural or operational integrity of the wing, which makes it a feasible concept.

The objective of the proposed project is to design a compliant flap that is optimized for various stages of flight (i.e., cruising, take-off, landing). The flap would be modeled after the flight conditions and airfoil of a Cessna 172 but as mentioned before this technology has applications and benefits for all aircraft. The 172 was chosen as a model because it is the most constructed plane in the world (there are four times more 172s then Boeing 737s) and because its fuel efficiency is relatively low at approximately 14 mpg (McIver).

The end result of this project will be a fully actuated, testable, compliant flap that yields results when tested in a wind tunnel. Success will be measured by the flaps ability to accurately conform to the three pre-determined airfoil shapes within a few seconds, without the need for discontinuities in the airfoil skin. Because this is a scaled down model of a 172 airfoil, the test results will likely vary from a full scale 172 airfoil.

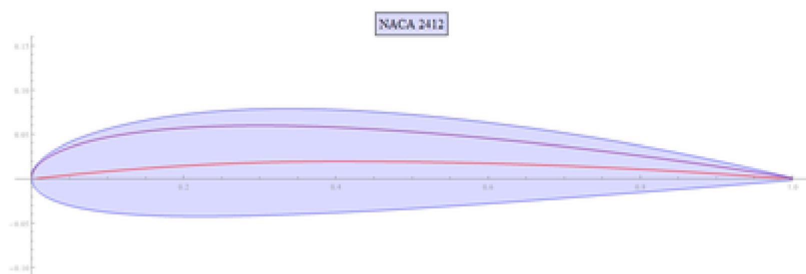
This project is feasible for a two semester capstone course because we have experience with fluid mechanics and computational fluid dynamics (CDF) in addition to having outside resources for validation. Another factor that contributes to this project’s feasibility is the type of resources available to us at Wentworth. Wentworth already has a wind tunnel and an additive manufacturing lab which will reduce the lead time of this project drastically versus having to hire outside manufacturers and test engineers.

Needs Assessment

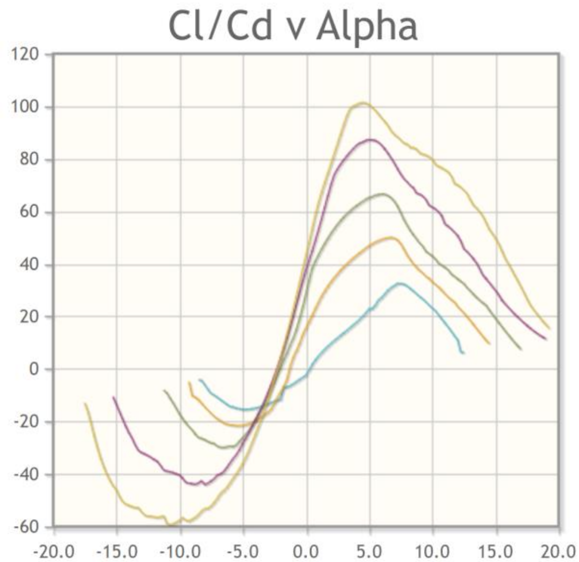
A typical airfoil utilizes a significant number of flaps to alter flight characteristics, for takeoff, landing, and some cruising situations. Each of these flaps and their associated hardware creates discontinuities in the skin of the airfoil, causing unnecessary and unplanned drag. Because of this, there is a significant loss to flight efficiency and fuel economy. NASA reports that just a 1% decrease in drag on the US fleet of wide-bodied aircraft would save $140 million annually so even the smallest optimization has the potential to save a fortune as well as help reduce carbon emissions (Kota). The discontinuities in some designs also cause a gap in the wing that bridges the high-pressure and low-pressure zones, leading to further inefficiency (Sadraey). Additionally, every moving part of a flap and control surface must be fixed to the wing, move on a joint, and be actuated causing a build up of hardware like nuts and bolts, increasing weight. All of these factors contribute to a given flights efficiency, so replacing traditional flaps with a compliant flap will have a significant impact on the flight quality and will save plane owners money.

Specifications

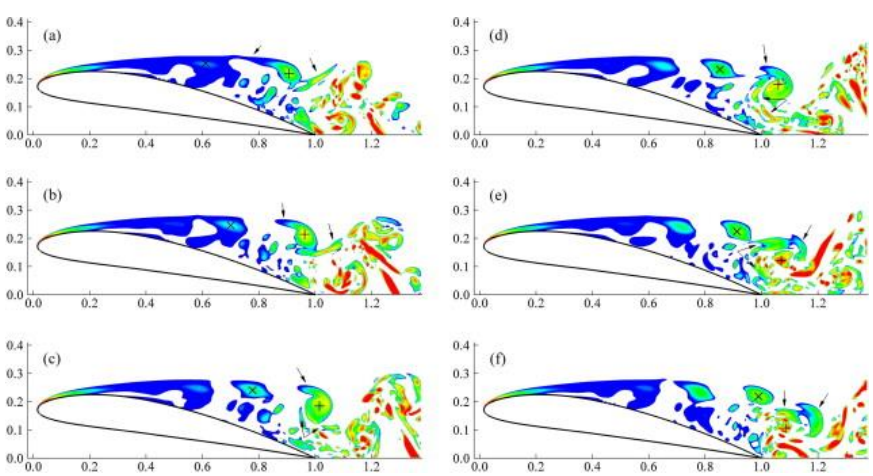
There are three categories of technical specifications. First, the design must be applicable to a currently produced aircraft. The target application will be the Cessna 172 flap system since it is the most mass-produced aircraft in existence. Additionally, the 172 has poor fuel efficiency averaging 12 nautical miles per gallon so efficiency gains made by decreasing drag and decreasing weight improves the vehicle efficiency for the large number of Cessna 172 owners. The airfoil and flap system employed on the 172 is the NACA 2412, which is shown below.



The flap design must at least meet the standards set by the aerodynamic properties of the NACA 2412, which is the airfoil design used by the Cessna 172, but improving the aerodynamics of the NACA 2412 is certainly a secondary goal to be pursued after the current properties have been matched. The aerodynamic comparison of the NACA 2412 airfoil to the new flap design will be quantitatively assessed by comparing drag-lift ratios, drag-angle of attack ratios, lift-angle of attack ratios, and other standard metrics used in aerodynamic design. An example plot of the ratio of the lift to the drag coefficients versus alpha, the angle of attack, at Reynolds numbers between 50,000 and 1,000,000 is provided.



Additionally, the flow over the compliant flap design must not have points of boundary layer separation at any region on the flap surface since separation increases pressure drag and reduces lift, which decreases efficiency. Airfoils in use have been designed and rigorously tested to ensure that at operating speeds and angles of attack, there is no boundary layer separation. The figure below is a visual representation of boundary layer separation.



Another part of the first preliminary specification is that the compliant flap design must weigh less than the current flap on the NACA 2412. The wing group of a Cessna 172 weighs 236 pounds with a wing group density of 2.489 pounds per cubic foot. (McIver) The final component of the first preliminary specification of the compliant flap design that specifically relies on the Cessna 172 as the model application is the transition speed between flap geometry configurations, which must be determined with the 172's optimal operating altitude and speed as well as take-off and landing angles of attack in mind. Also, the lifespan of the compliant flap must match that of the Cessna 172's default design. A Cessna 172 must be inspected every 30,000 flight hours, and within any given flight operation, the current NACA2412 flaps are actuated about four to five times so the current flaps undergo approximately 120,000 to 150,000 cycles per inspection period.

The second specification is that a scaled model of the final design must be able to fit in one of the wind tunnels at the team's disposal to test the program-controlled actuators and provide experimental aerodynamic data of the flap behavior in each of the four configurations (take-off, cruising, and landing) as well as the aerodynamics of the transition between any two configurations. The use of the Cessna 172 as the main application for this project plays an indirect, but important role in this specification too. It would be very difficult to properly scale up a compliant mechanism with actuators from a small model to the size of a passenger aircraft such as a Boeing 737. The small size of the Cessna 172 allows for a smaller scaling factor between the model and the actual flap size. Both available wind tunnels have dimensions of twelve 24 inches long by 12 inches wide by 12 inches tall. Models in wind tunnels must not have a projected frontal area normal to the flow inlet that is greater than ten percent of the cross-sectional area of the wind tunnel test section normal to the flow inlet so for the given wind tunnel dimensions, the model's projected frontal area must not exceed 14.4 square inches. Based on this dimension restriction, the Reynolds number regime used to test the flap in all potential flight situations is between zero and 5.75 million. Additionally, the test stand must be designed such that it can interface with the wind tunnel that will be used for testing.

The final specification is that the system must actuate upon command by a programmed electrical control system with an internal power source. It will not be sufficient to have an actuator system that requires manual intervention or an external power supply. At the same time, this design team does not have any electrical engineers, so the control system must take on a simple form that achieves the specification without requiring specific electrical engineering expertise.

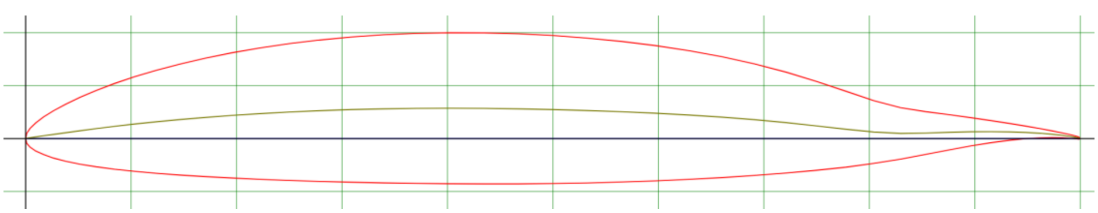
Conceptual Design

Design Options

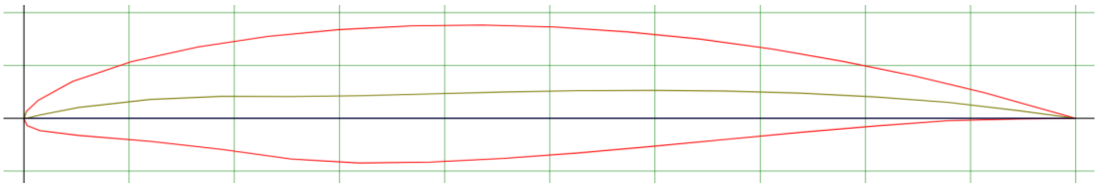
To generate three design options, the subsystems of the flap were analyzed to generate design option feature lists.

Subsystem 1: Airfoil Shapes

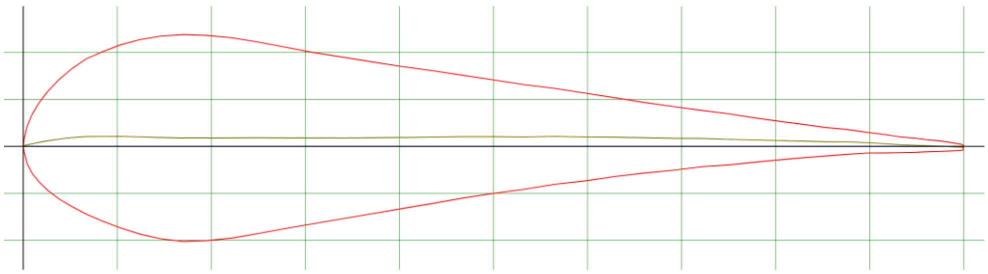
For subsystem 1, airfoil shapes were selected based on their characteristics at different Reynold's Numbers. For the takeoff and landing scenarios, two airfoils were presented as options. For takeoff, the group was looking for high lift characteristics at lower Reynolds numbers, while for landing higher drag was required. Below are images of the airfoil options:



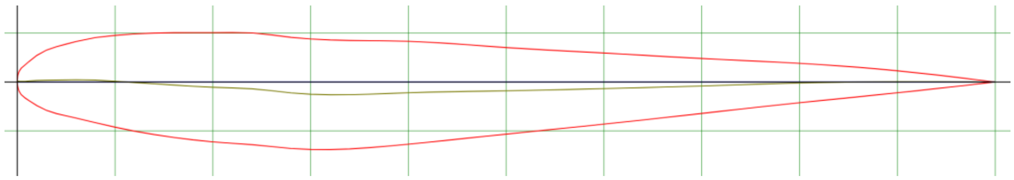
AH-79-K-143/18 (takeoff)



APEX 16 (takeoff)



AH-81-K-144 W-F KLAPPE (landing)



BOEING 707 0.08 SPAN (landing)

Subsystem 2: Actuators

Subsystem 2 was dedicated to the actuation mechanism of the flap. The four options that were considered by the group are electric servos, pneumatic pistons, stepper motors, and memory materials (the latter not being an entirely serious consideration but one the group though was worth investigating).

Subsystem 3: Test Stand

Subsystem 3 comprised of two parts, the control system and the frame design. For the controller, the Arduino and Raspberry Pi microcontrollers were considered. The next part of subsystem 3 was the frame design. The frame was to have either a single pylon entering through the bottom of the flap or a double pylon attaching to both sides of the flap (see images below). Additionally, whichever pylon was chosen would either be fixed or have a hinge to change the angle of the flap.

The following design options were developed for the assessment of the group's final design decision. It was determined that the test stand's frame had to be a double pylon system to achieve the groups initial design constraints.

Design Option 1

Design option one consists of the following:

- BOEING 707 0.08 SPAN as the landing airfoil
- AH-79-K-143/18 as the takeoff airfoil
- Electric servos as the actuator
- Raspberry Pi as the micro controller

The object of this design is to achieve more complex airfoils via the means of more complex control systems. The complex airfoils could yield better flight characteristics such as drag and lift as a trade of for their difficulty.

Design Option 2

Design option two consists of the following:

- AH-81-K-144 W-F KLAPPE as the landing airfoil
- APEX 16 as the takeoff airfoil
- Electric servos as the actuator
- Arduino Uno as the micro controller

This design is meant to have simpler airfoils that could be achieved through simpler actuation and mostly linear displacements. A simpler and better documented micro controller can be used in this design option.

Design Option 3

Design option three consists of the following:

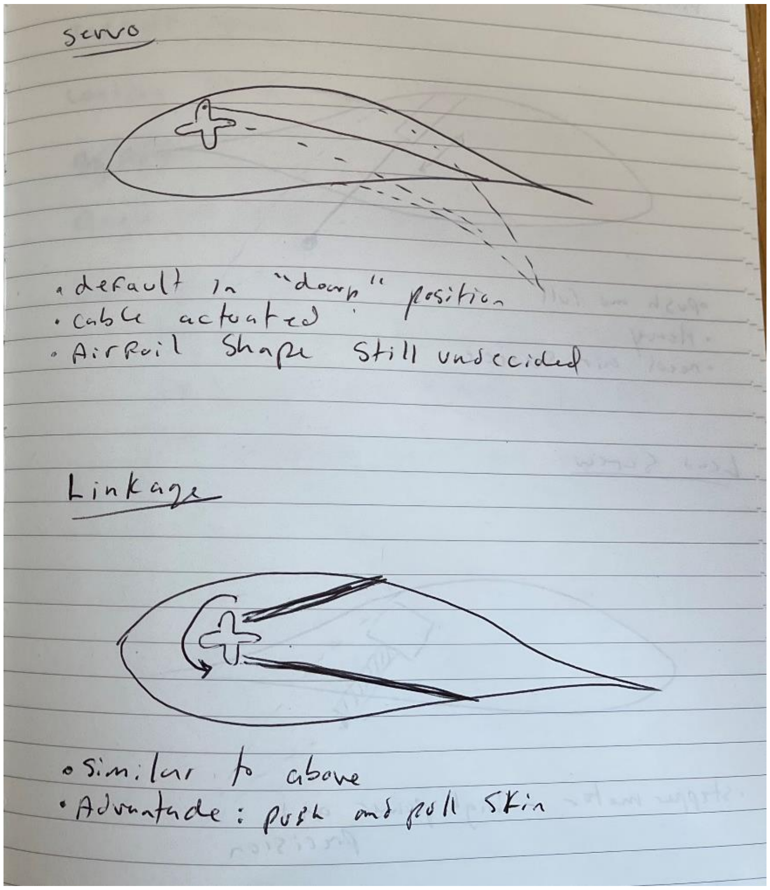
- AH-81-K-144 W-F KLAPPE as the landing airfoil
- APEX 16 as the takeoff airfoil
- Pneumatic Pistons as the actuator
- Arduino Uno as the micro controller

Design three has all the simplicity of design two but is achieving it's actuation through the use of pneumatics rather than servos. Pneumatics can provide higher power actuation to the design but also usually require more space and auxiliary systems like air compressors.

Analysis of Design Options

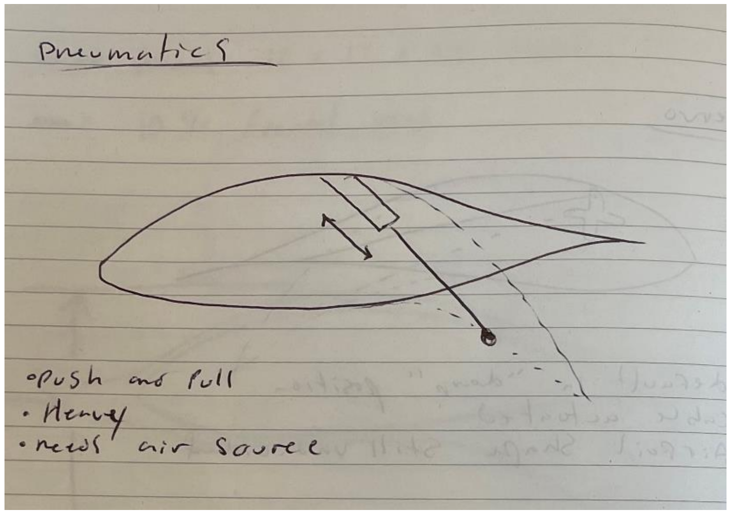
Experimental Results and Analysis

The group considered two options to actuate the deformation of the airfoil skin. Design options one and two utilized electric servos for this purpose. Servos are a very common actuator for all applications, meaning they can be found in a variety of sizes, with a range of specs for power, range of motion, and interface type. Due to the scale of our project, most hobby servos will be in the correct range of specs for our need, but more powerful ones can be used for a full-scale mechanism. Due to their rotary motion, servos also provide a lot of options for actuation method (cam, linkage, cable, etc.).



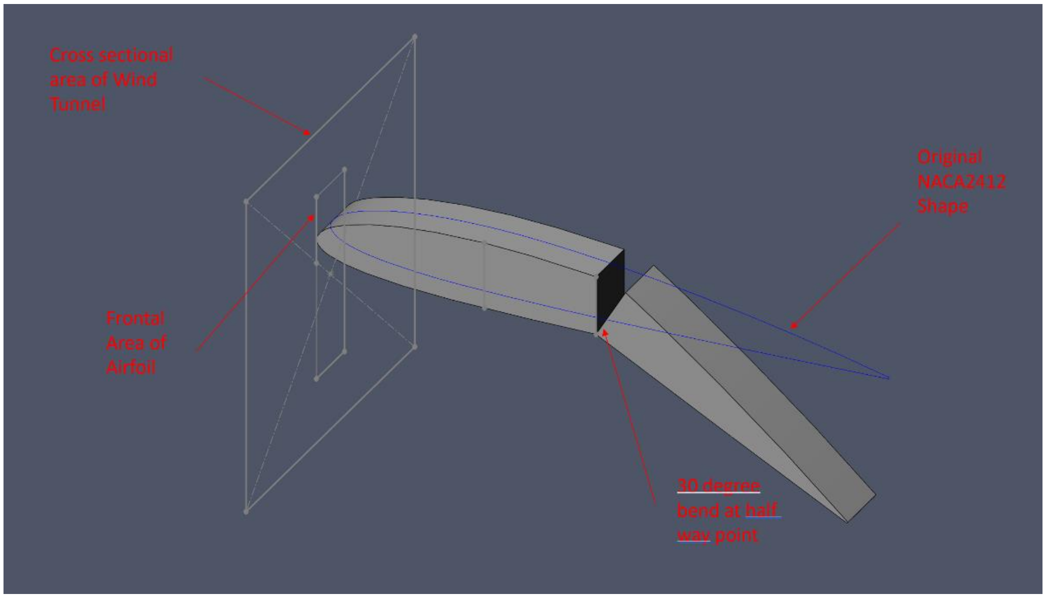
Conceptual Application of Servo

Design option three considered the use of pneumatic pistons for skin deformation actuation. Pneumatics offer a lot of power at high speeds with two well defined positions. While smaller pneumatics are more difficult to come by than servos, there are several options on the market in the size and power range needed. Pneumatics, however, pose some challenges in regard to mobility. With only two fixed positions, multiple cylinders would be needed for each location to achieve three different airfoil shapes. They are also heavier than servos and only come in standard stroke lengths.

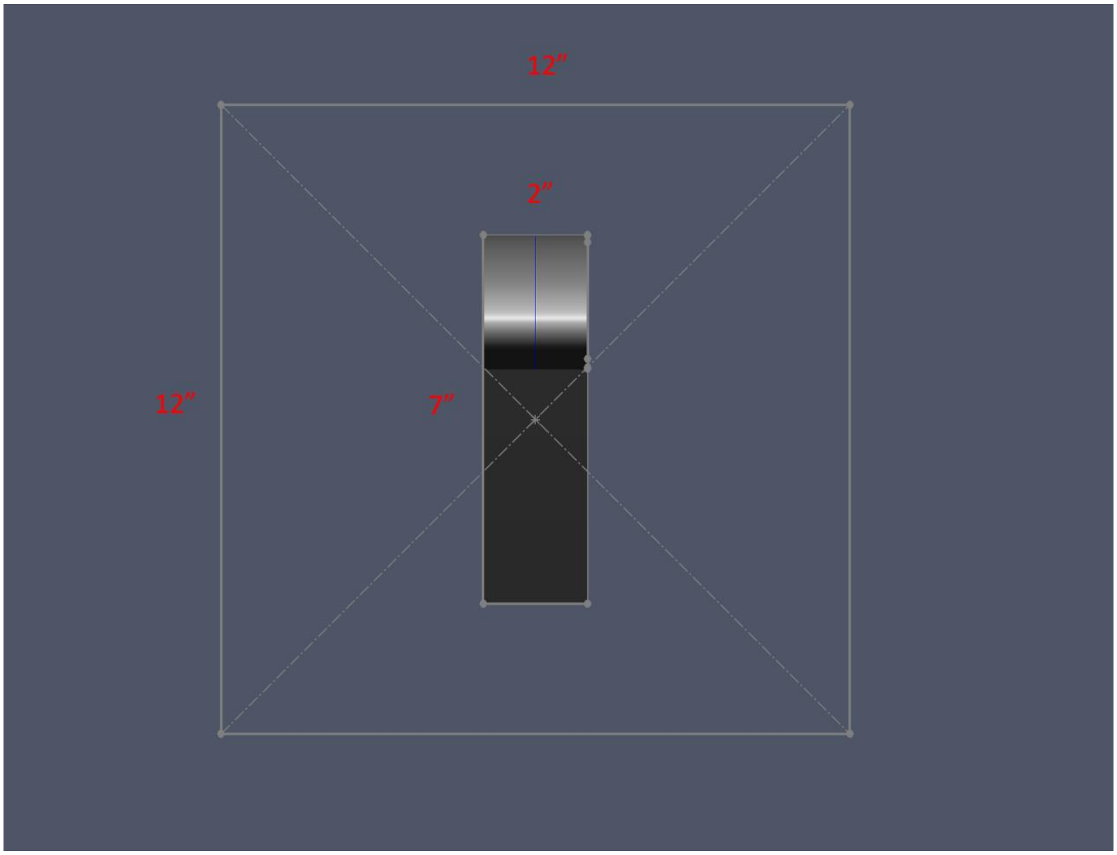


Conceptual Application of Pneumatic Piston

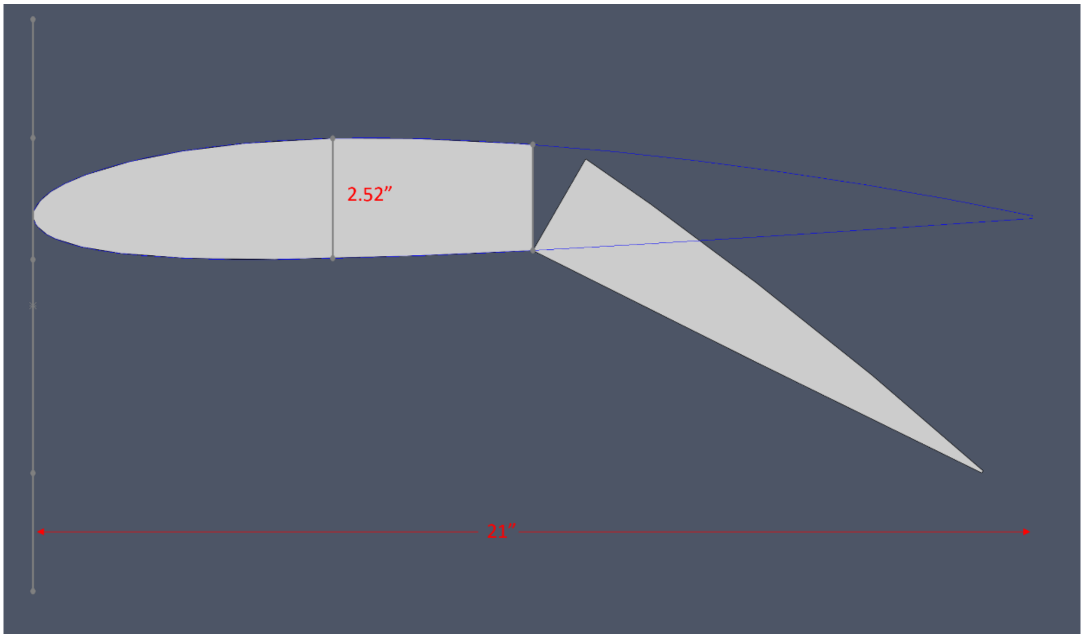
To help make preliminary design options, the group needed to have a preliminary set of dimensions. The driving factor in the size of the flap is its ability to fit inside the wind tunnel and collect useful data. From research, the group found that the frontal cross section of the flap needed to be at most 10% of the working cross section of the wind tunnel. The group took the default NACA2412 airfoil and bent it at a 30-degree angle halfway along the test flap to approximate the largest frontal area. Then, the flap was scaled up to meet the 10% requirement. Through this preliminary analysis, the group now had geometry to determine the available space inside the flap for actuators and other components. The maximum thickness of the flap would be approximately 2.52” and the maximum length would be 21”.



Preliminary Size Analysis Terms



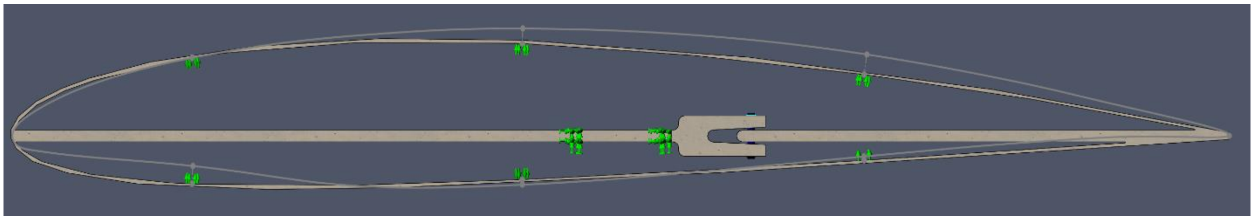
Preliminary Frontal Dimensions



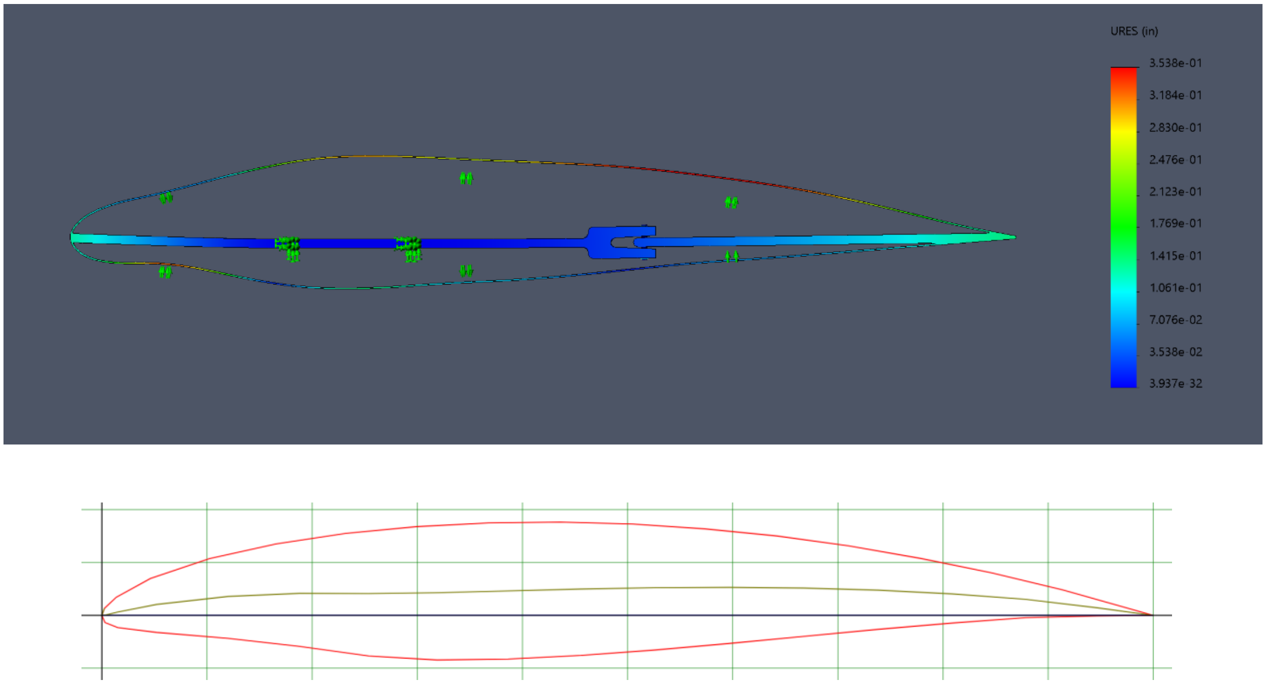
Preliminary Side Dimensions

The next set of experiments were to determine the distribution and force requirements to deform the default airfoil to the target airfoil. For this analysis, the group decided to use the NACA2412 as the default airfoil, the APEX16 as the takeoff airfoil, and the AH81-K-144 W-F KLAPPE (abbreviated to AH81 in this document) as the landing airfoil. The group chose an initial skin thickness of 0.03” and an initial material of 3D printed ASA plastic.

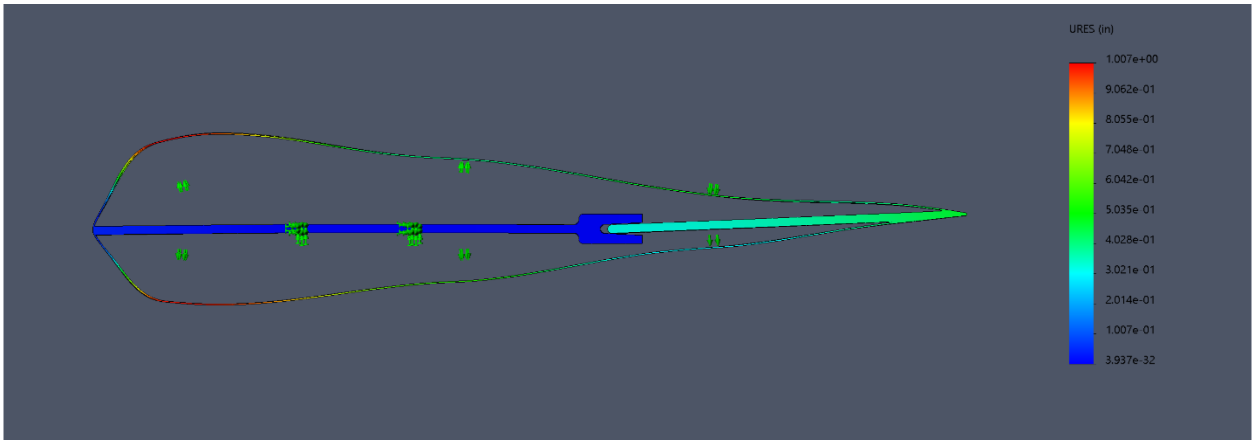
The skin was segmented to have six discrete flat areas on which to apply forces perpendicular to the skin’s contours. The process of guessing what forces to apply to the skin commenced but was found to be very sensitive and mostly unreliable to get accurate deformation. The ultimate solution that yielded the best results was the use of Solidworks Simulation Suite’s “prescribed displacement” load. This tool was used to move the flat regions of the skin the distance from the default airfoil to a perpendicular point on the desired airfoil. In effect, this load acts similarly to a rotating cam if the skin is being pushed or a cable in tension if the skin is being pulled.

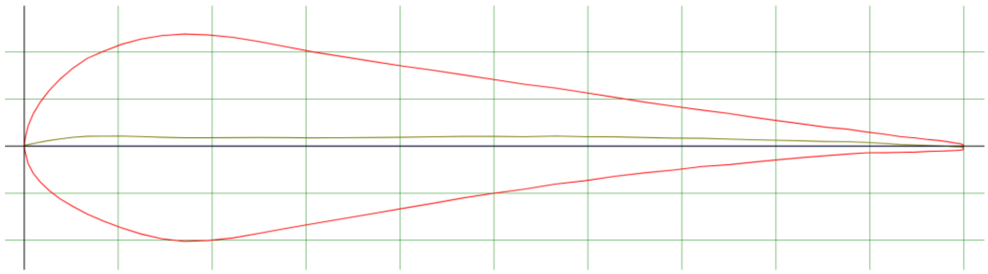


The NACA2412 skin showing the locations of the prescribed displacements and the magnitudes of said displacements



The initial APEX16 simulation and it’s target airfoil





The initial AH81 simulation and it's target airfoil

It's worth noting that the AH81 airfoil has a shorter overall length than the other two airfoils to maintain the same perimeter, so a small relief joint had to be added to the rib section to accommodate this difference.

This initial simulation gave the group two major takeaways: 1. The skin was smoother when deformed if the skin was thicker but required more force to deform and 2. The fore-most displacement was more useful to an even shape if it was moved back several inches because of the skin-rib connection.

To test a final skin thickness, the group 3D printed three sets of ASA test circles. Each set had a different wall thickness (0.03", 0.06", and 0.12") and two different outer diameters (3" and 4"). From these prints, it was determined that an increase in diameter decreased overall stiffness of the circles and increased wall thickness increased the overall stiffness amongst the same diameter circles. It was also found that the 0.03" circle was 1 layer of plastic thick while the 0.06" sample was 3 layers thick. The group decided that based on these tests the best wall thickness to use was at a two-layer thickness, or approximately 0.045". In the simulation, this new thickness smoothed out the deformed airfoil desirably.

This initial simulation was only designed to check for deformation shape and could not be used to accurately determine factors of safety or fatigue capabilities. Future simulations with a complete 3D model will be used to determine these factors and finish verifying the design.

Assembly Tolerance and Part Dimensions

During design, specific part tolerance must be considered in order to design within spec. The group considered the manufacturing tools and equipment available when deciding part tolerance. Most parts, including the skin of the airfoil, will be 3D printed on the Fortus 450 at Wentworth which can hold a tolerance of +/- 0.005. Individual dimension tolerance is outside of our control with 3D printed parts, so all dimensions of 3D printed parts will be held to +/- 0.005. Some parts will be machined on a standard 2 axis lathe. The only interface with each of these parts will be a press or clearance fit inside of a 3D printed hole. As the printer holds a tolerance of +/- 0.005, turned parts will be held to a tolerance of -0.005, +0.000 to ensure that they fit inside the printed holes.

Manufacturing Routing

Additive Manufacturing

1. Design part in Solidworks.
2. Save as STL file.
3. Order part through WIT Additive Manufacturing Center.
4. Remove leftover support material.
5. Sanding and finishing as needed.

Test Stand Spine

1. Cut to 2.75” length.

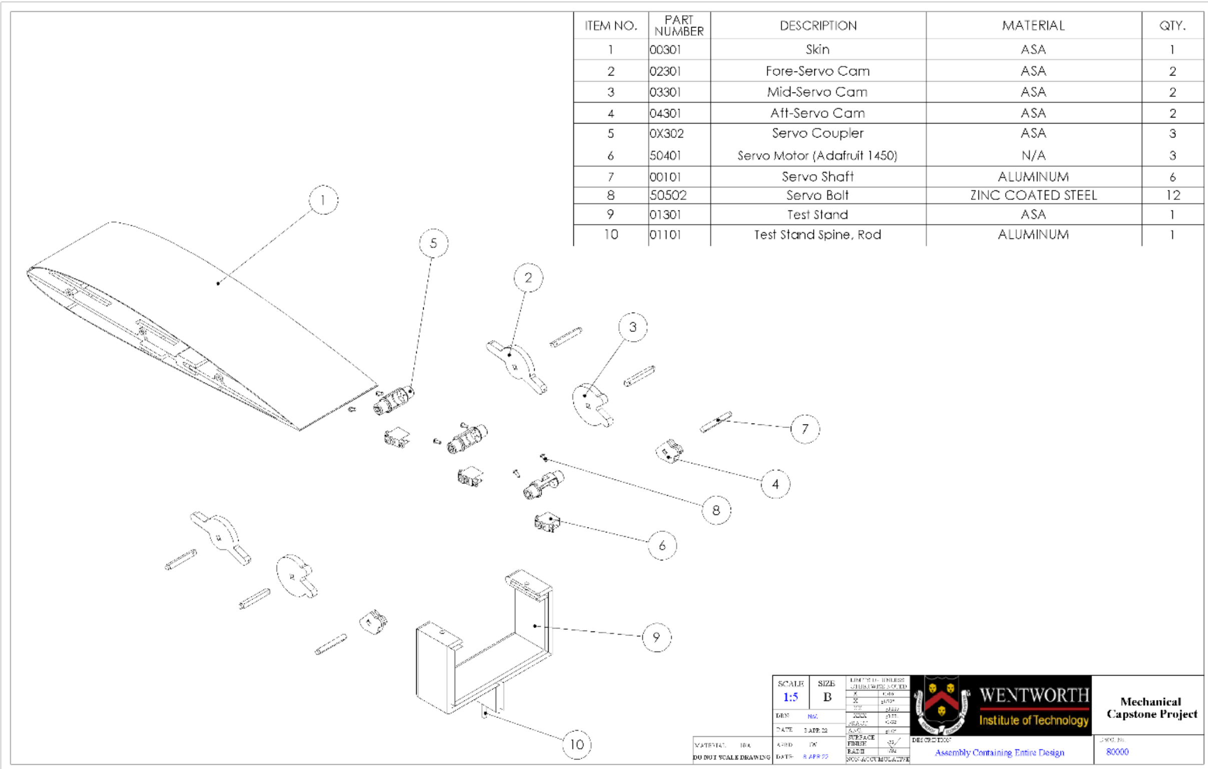
Servo Shaft

1. Cut shaft to 2.15" length.
2. Turn 0.25" diameter circular feature to a depth of 0.125" on lathe.
3. Drill 0.1065" diameter hole using mill.
4. Tap hole using #6-32 UNC tap.

Cost of Parts

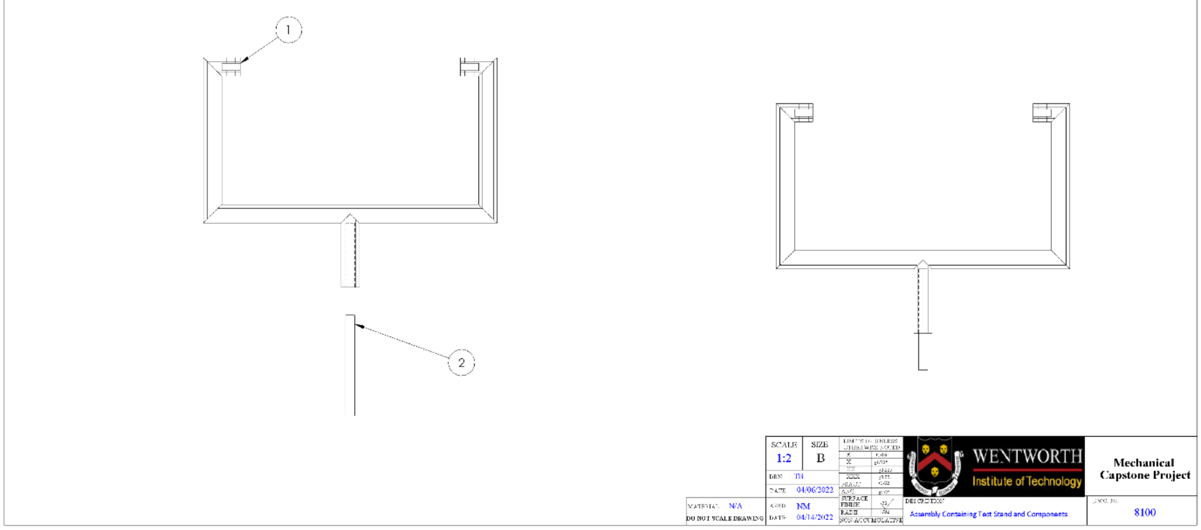
Budget			
		Per Item	Subtotal
Control System			
	Arduino	N/A	$30
	Wiring	N/A	$5
	Breadboard	N/A	$10
Actuators			
	Servos	$15	$45
	Power Supply	N/A	$20
	M4 Bolts	$0.16	$2.24
	M4 Nuts	$0.08	$0.48
	1/8" Paracord		$4
Manufacturing			
	Airfoil	$90	$270
	Test Stand	N/A	$50
	Test Stand Spine	N/A	$6
	Fore-Servo Cam	$4	$4
	Mid-Servo Cam	$4	$8
	Aft-Servo Cam	$2	$2
	Servo Coupler	$3	$9
	Servo Shaft	N/A	$14
Total			**$480**

Assembly and Detailed Drawings

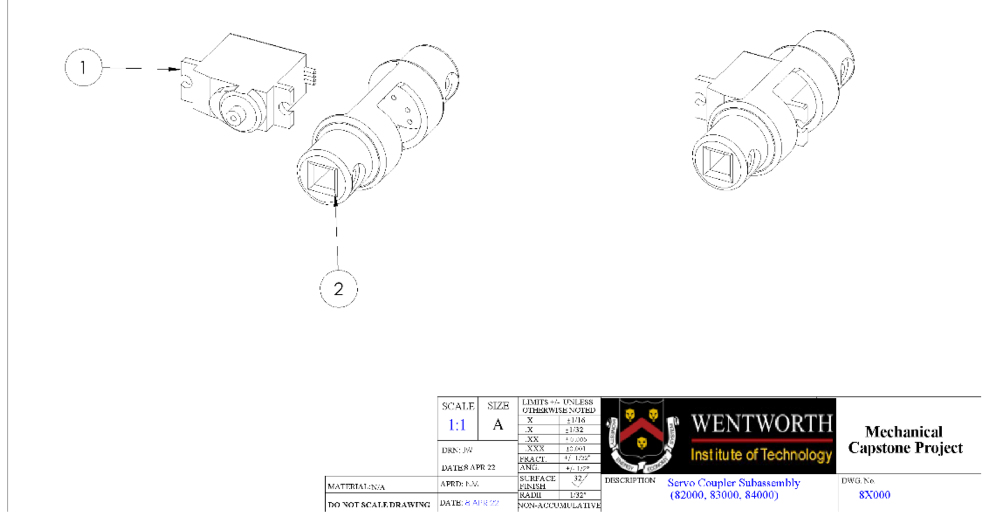


ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	00301	Skin	ASA	1
2	02301	Fore-Servo Cam	ASA	2
3	03301	Mid-Servo Cam	ASA	2
4	04301	Aft-Servo Cam	ASA	2
5	0X302	Servo Coupler	ASA	3
6	50401	Servo Motor (Adafruit 1450)	N/A	3
7	00101	Servo Shaft	ALUMINUM	6
8	50502	Servo Bolt	ZINC COATED STEEL	12
9	01301	Test Stand	ASA	1
10	01101	Test Stand Spine, Rod	ALUMINUM	1

ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	01301	Test Stand	ASA	1
2	01101	Test Stand Spine, Rod	Al-6063-T5	1



ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	50401	Servo Motor (Adafruit 1450)	N/A	1
2	0X302	Servo Motor Coupler	ASA Plastic	1



Decision Matrices

Goals and Rating

A list of five design goals were created based on the group's design specifications:

- Rigidity – The ability of the design to be secure under all forms of testing and displacements
- Compactness – The relative density of the designs components and ability to fit in small spaces
- Scalability – The ability of the design to be blown up to a full scale design after being fully developed
- Controllability – The easy with which the actuators and controllers can control the movement of the flap's skin.

These goals were then ranked against each other in a ranking matrix. The goals in the row title were compared to the goals in each column title. A score of 0 means that the goal is less important, a score of 0.5 means that the goal is equal in importance, and a score of 1 means the goal is more important. The sum of these scores is the design goal's final score and is used to rank the goals in order of importance.

Goals	**Rigidity**	**Compactness**	**Scalability**	**Controllability**	**Score**
Rigidity	X	0.5	1	0.5	**2**
Compactness	1	X	0.5	1	**2.5**
Scalability	0	0	X	0.5	**0.5**
Controllability	0.5	0	0.5	X	**1**

Goal Rating Matrix

Goal Weighting

A weight was assigned to each goal to further differentiate their relative importance

Goals	Compactness	Rigidity	Controllability	Scalability
Weight	100%	90%	75%	50%

Goal Weight Table

Design Option Assessment

With relative weights assigned to the goals, the three design options could now be rated. Each design option was scored from zero to ten on it's ability to reach each design goal. The rating was then multiplied by the corresponding goal's weight in order to calculate a weighted score of each design option.

Goals	Compactness	Rigidity	Controllability	Scalability	Weighted Total
Option 1	10	8	4	5	22.7
Option 2	8	8	9	6	25.0
Option 3	4	10	5	7	20.3

Final Design Matrix

From this calculation, the group found that design option 2 was the best design option to pursue for this project. It's score of twenty-five points makes is a clear winner compared to the other two scores.

Final Design Option

Part List

The project's parts are numbered by the convention outlined below:

Manufactured Part	0XXXX
Purchased Part	5XXXX
Assembly	8XXXX
Technical Drawing	DXXXXX
Manufacturing Procedure	PXXXXX
Top Level Assembly	80XXX
Test Stand Assembly	81XXX

Fore-Servo Assembly	82XXX
Mid-Servo Assembly	83XXX
Aft-Servo Assembly	84XXX
Metal Part	XX1XX
Plastic Part	XX2XX
3D Printed Part	XX3XX
Electronics	X04XX
Fastener	X05XX
Other	XX6XX

Bills of Materials

Part Number	Name	Material	Description	QTY
101	Servo Shaft	Aluminum	modified 0.25” keystock	6
301	Skin	ASA	3D printed airfoil skin with internal rib	1
1101	Test Stand Spine	Aluminum	Rod of aluminum to stiffen the test stand	1
1301	Test Stand	ASA	3D Printed test stand structure	1
2301	Fore-Servo Cam	ASA	3D Printed CAM for 82000	1
2302	Servo Coupler	ASA	Servo to shaft coupler	1
2601	Fore Servo Cord	Paracord	1/8” Paracord	1
3301	Mid-Servo Cam	ASA	3D Printed CAM for 83000	1
3302	Servo Coupler	ASA	Servo to shaft coupler	1
4301	Aft-Servo Cam	ASA	3D Printed CAM for 84000	1
4302	Servo Coupler	ASA	Servo to shaft coupler	1
4601	Aft Servo Cord 1	Paracord	1/8” Paracord	1
4602	Aft Servo Cord 2	Paracord	1/8” Paracord	1
50401	Servo	N/A	Adafruit 1450 Electric Servo	3
50501	Servo Nut	Zinc Coated Steel	M4 Nut	6
50502	Servo Bolt	Zinc Coated Steel	M4 bolt	12
51401	Microcontroller	N/A	Arduino Uno Rev 3	1
51502	Test stand Bolt	Zinc Coated Steel	M4 Bolt	2

Purchased Parts

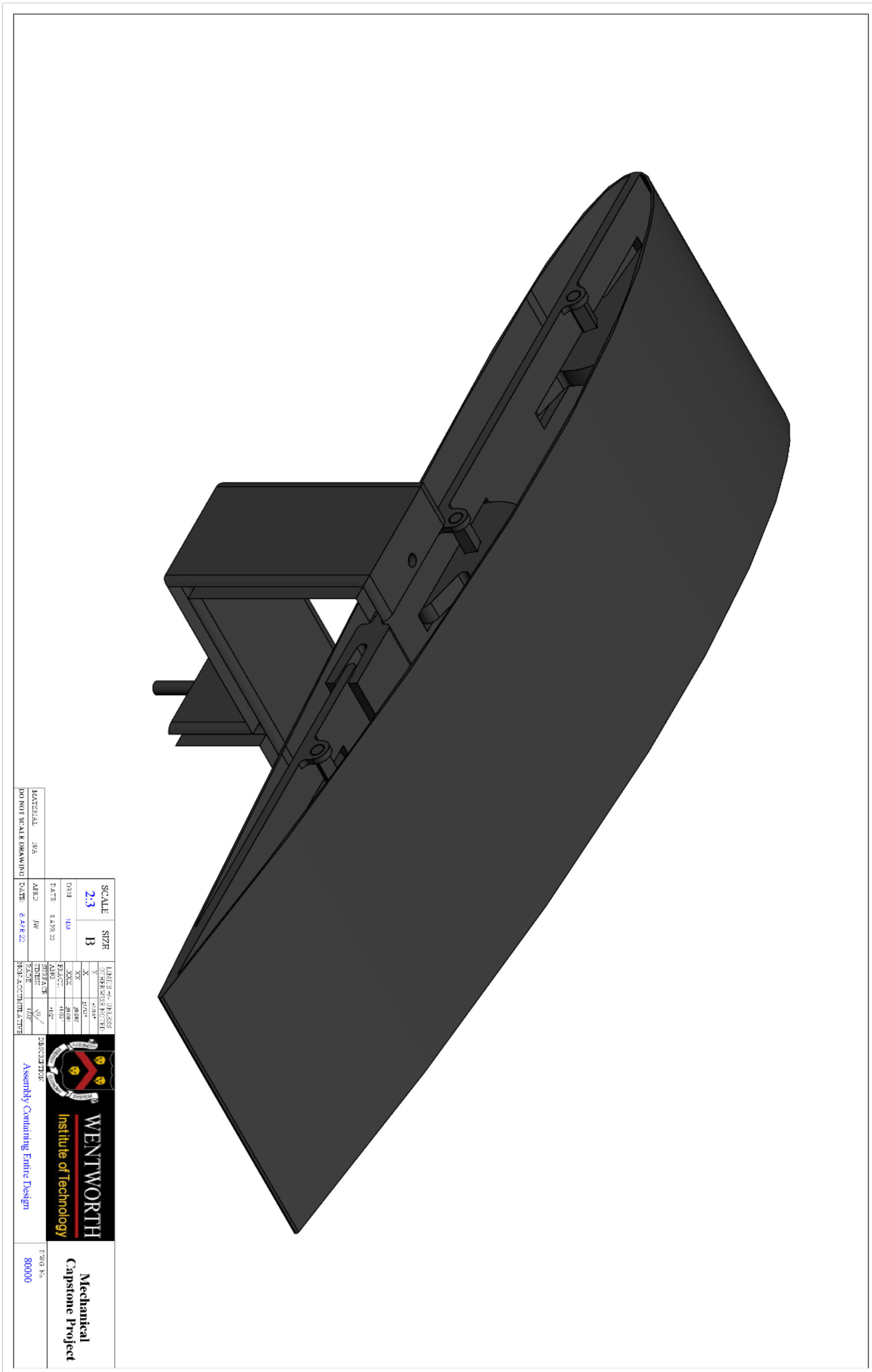
Part Number	Name	Description	Source
50401	Servo	Adafruit 1450 Electric Servo	Adafruit
50501	Servo Nut	M4 Nut	Bolt Depot
51401	Microcontroller	Arduino Uno Rev 3	Arduino
51502	Test stand Bolt	M4 Bolt	Bolt Depot
50502	Servo Bolt	M4 bolt	Bolt Depot

Manufacturing Parts

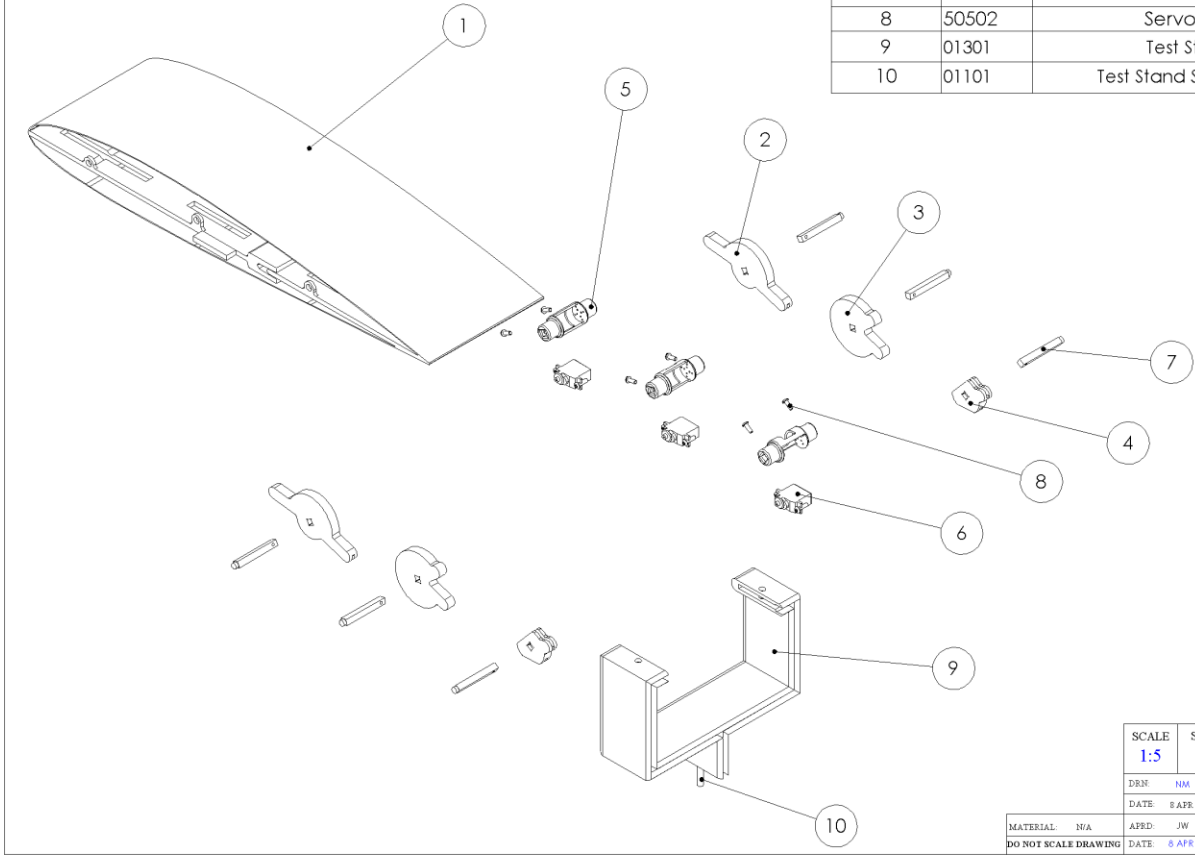
Part Number	Name	Description
00101	Servo Shaft	modified 0.25” keystock
00301	Skin	3D printed airfoil skin with internal rib
01101	Test Stand Spine	Rod of aluminum to stiffen the test stand
01301	Test Stand	3D Printed test stand structure
02301	Fore-Servo Cam	3D Printed CAM for 82000
02302	Servo Coupler	Servo to shaft coupler
02601	Fore Servo Cord	1/8” Paracord
03301	Mid-Servo Cam	3D Printed CAM for 83000
03302	Servo Coupler	Servo to shaft coupler
04301	Aft-Servo Cam	3D Printed CAM for 84000
04302	Servo Coupler	Servo to shaft coupler
04601	Aft Servo Cord 1	1/8” Paracord
04602	Aft Servo Cord 2	1/8” Paracord

Drawings

Assembly Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	00301	Skin	ASA	1
2	02301	Fore-Servo Cam	ASA	2
3	03301	Mid-Servo Cam	ASA	2
4	04301	Aft-Servo Cam	ASA	2
5	0X302	Servo Coupler	ASA	3
6	50401	Servo Motor (Adafruit 1450)	N/A	3
7	00101	Servo Shaft	ALUMINUM	6
8	50502	Servo Bolt	ZINC COATED STEEL	12
9	01301	Test Stand	ASA	1
10	01101	Test Stand Spine, Rod	ALUMINUM	1



MATERIAL: N/A
DO NOT SCALE DRAWING

SCALE 1:5 | SIZE B
DRN: NM
DATE: 8 APR 22
APRD: JW
DATE: 8 APR 22

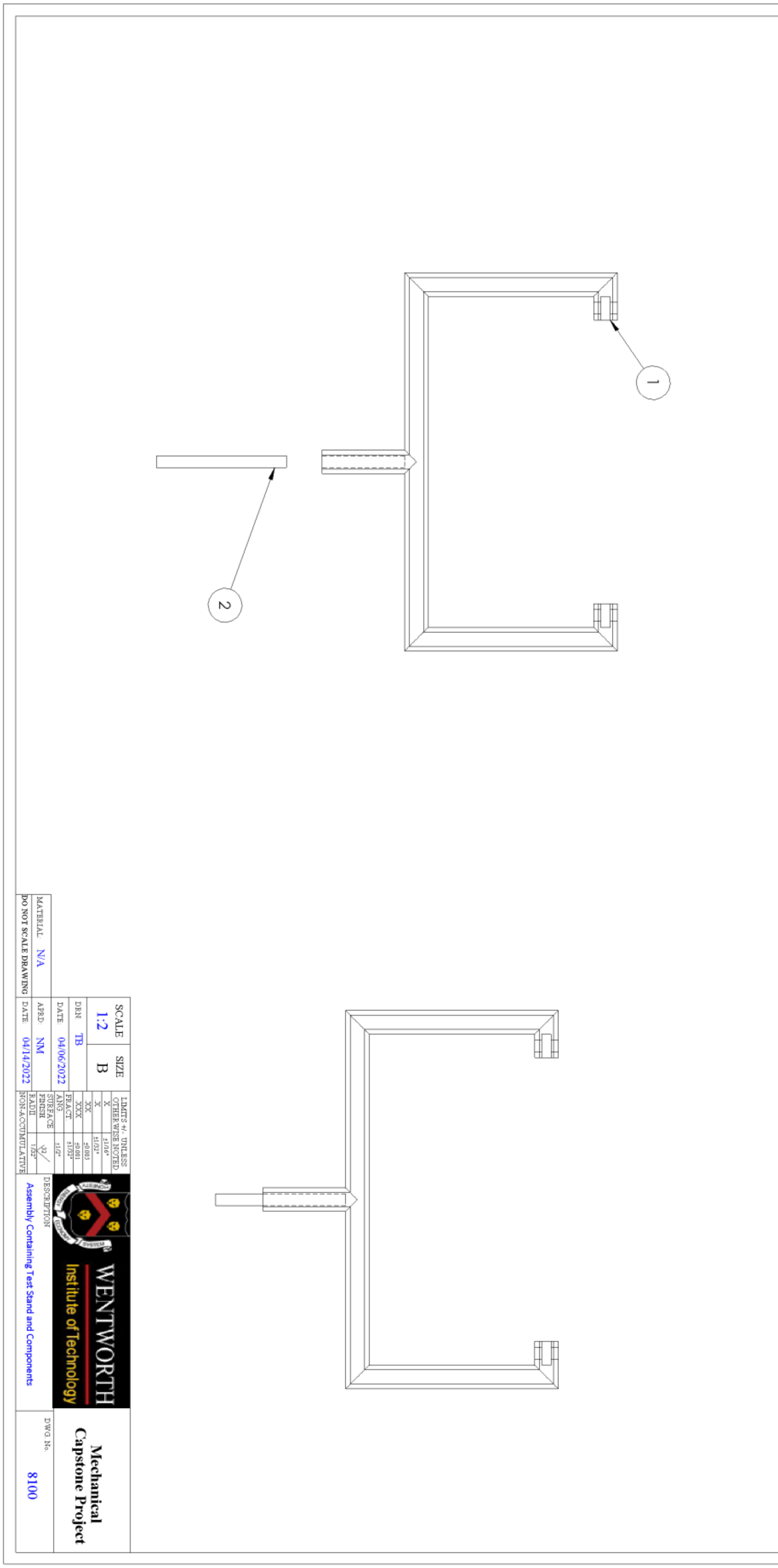
LIMITS +/- UNLESS OTHERWISE NOTED
X ±1/16"
X ±1/32"
XX ±0.005
XXX ±0.001
FRACT ±1/32"
ANG ±1/2°
SURFACE FINISH 32
RADII 1/32"
NON-ACCUMULATIVE

WENTWORTH Institute of Technology

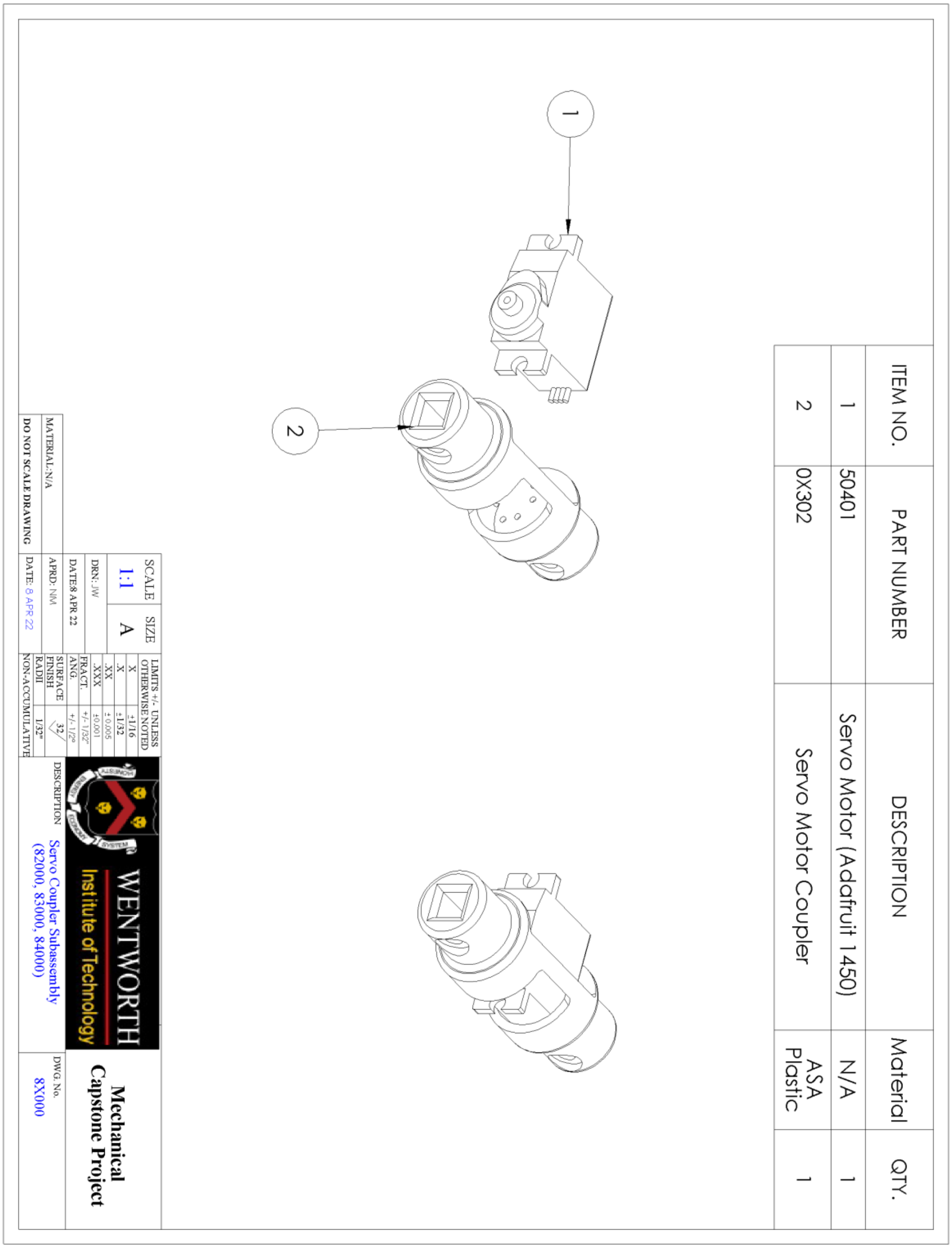
DESCRIPTION: Assembly Containing Entire Design

Mechanical Capstone Project

DWG No. 80000

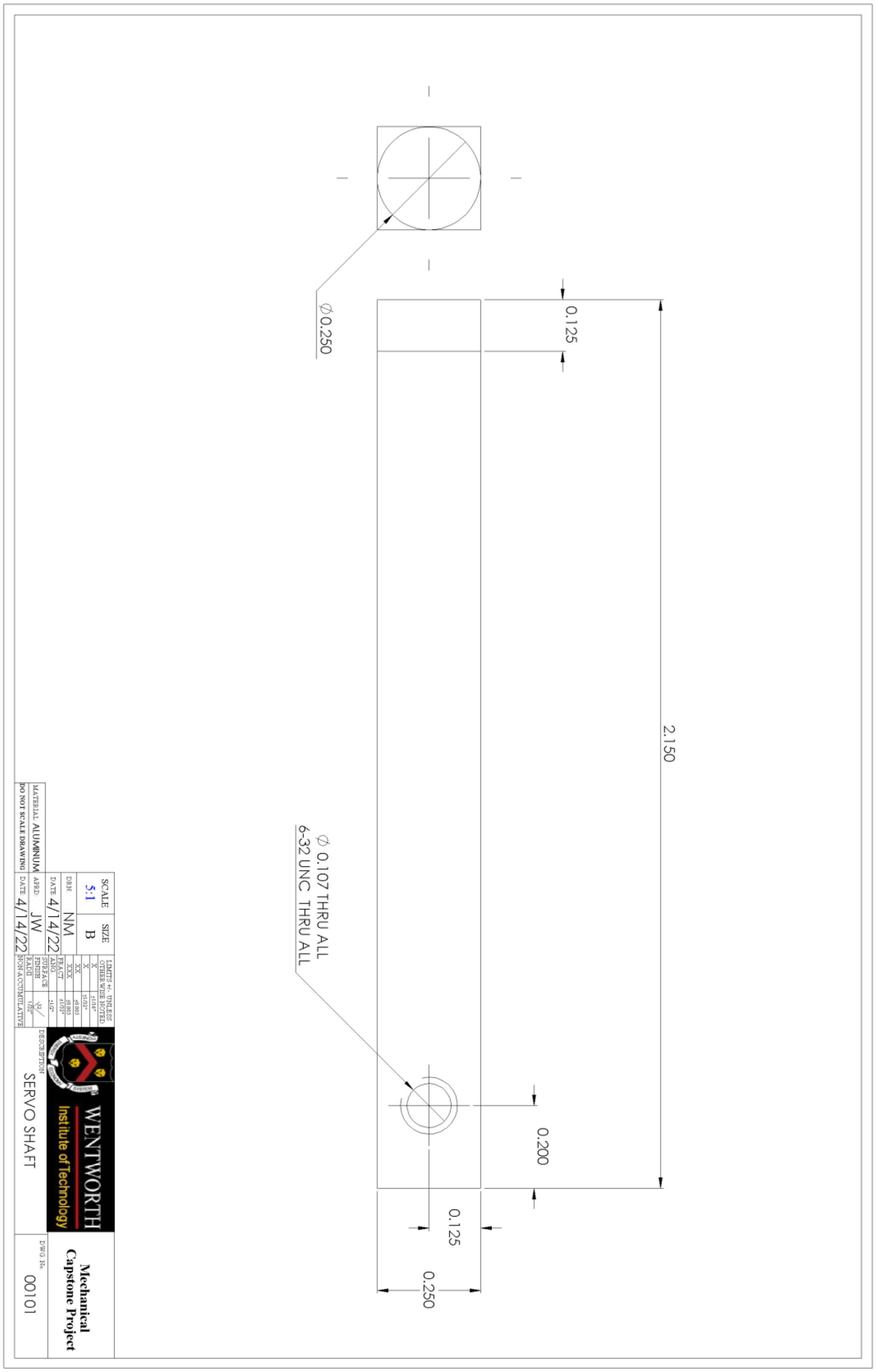


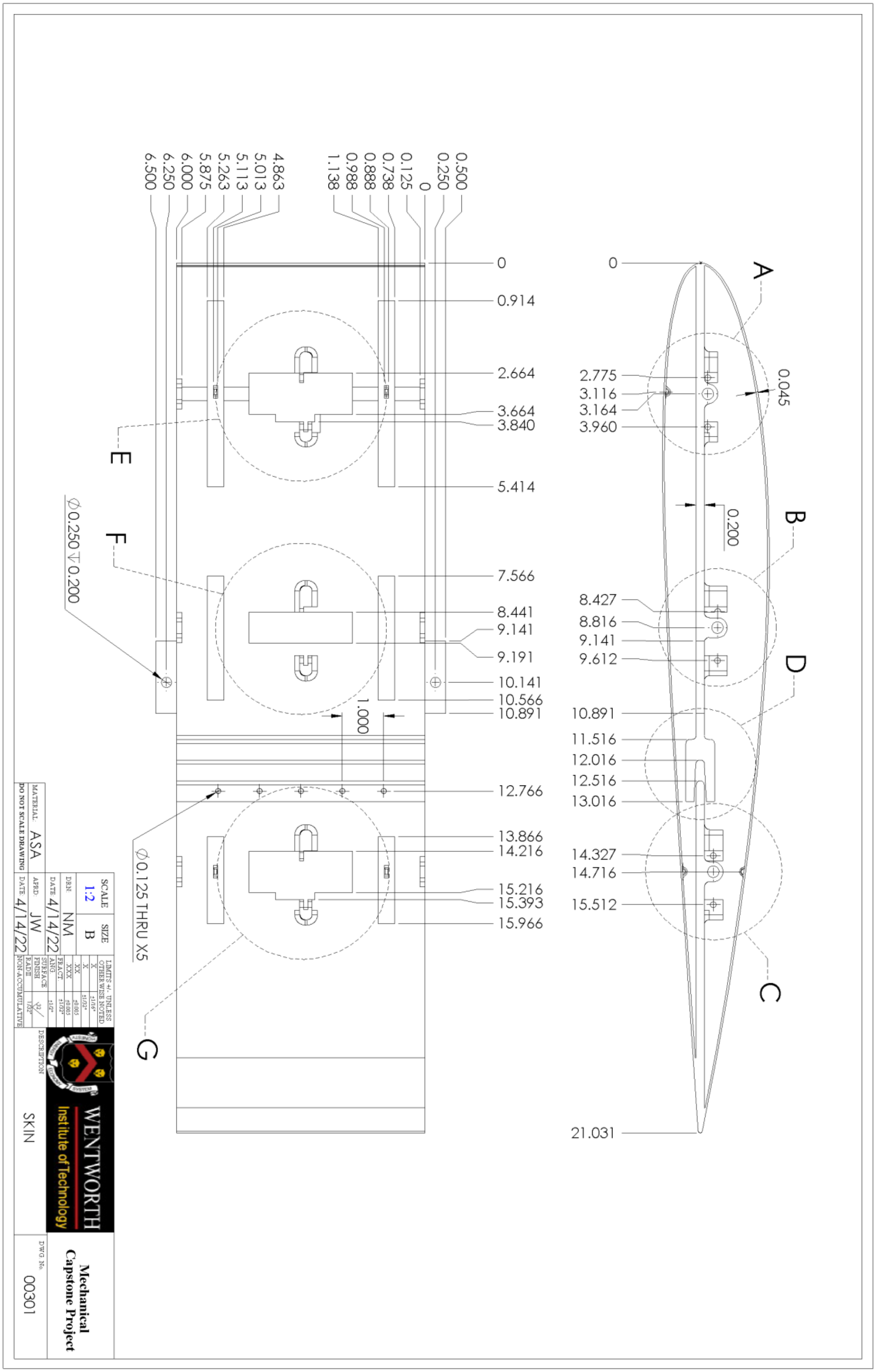
ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	01301	Test Stand	ASA	1
2	01101	Test Stand Spine, Rod	Al-6063-T5	1

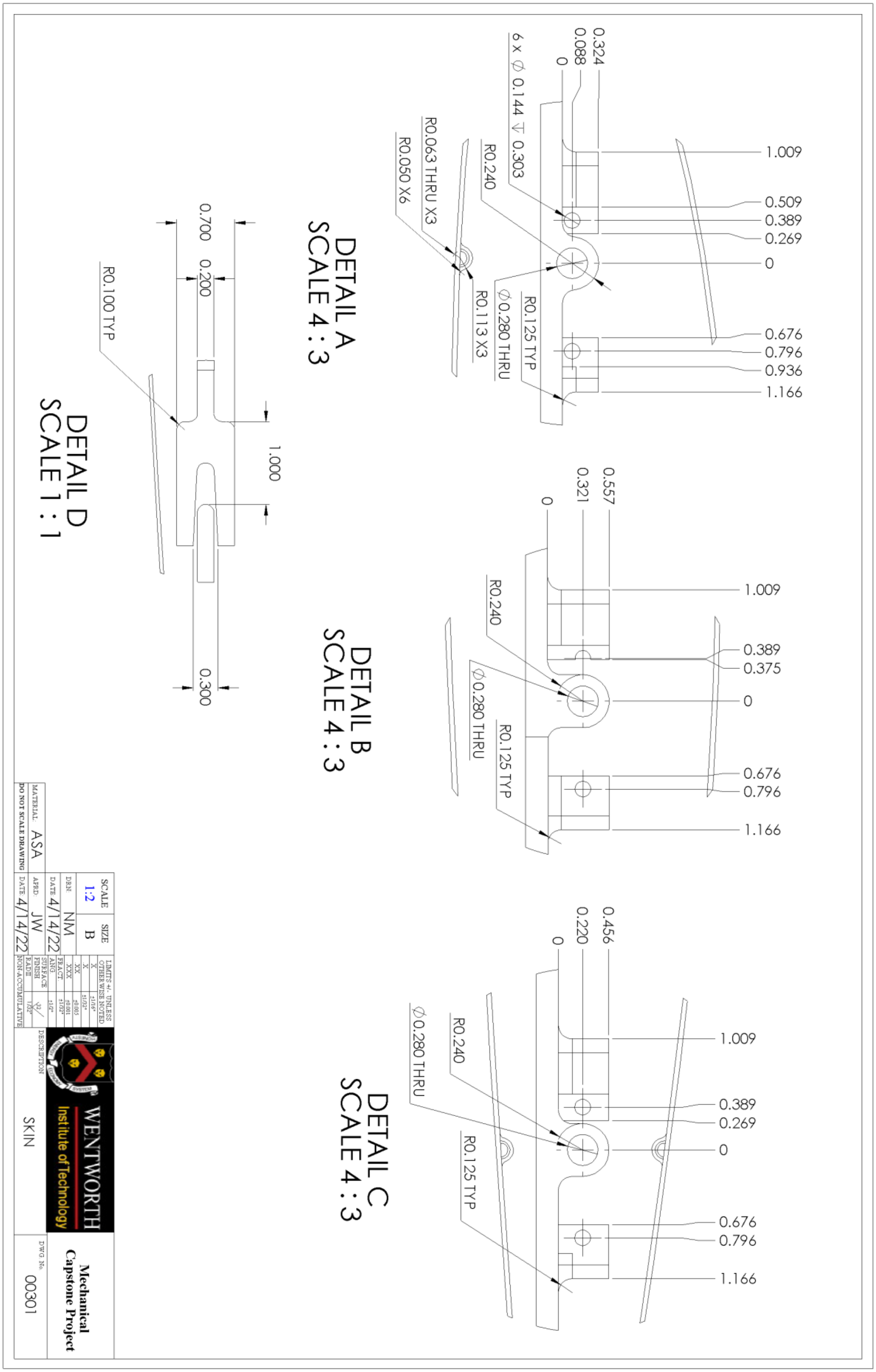


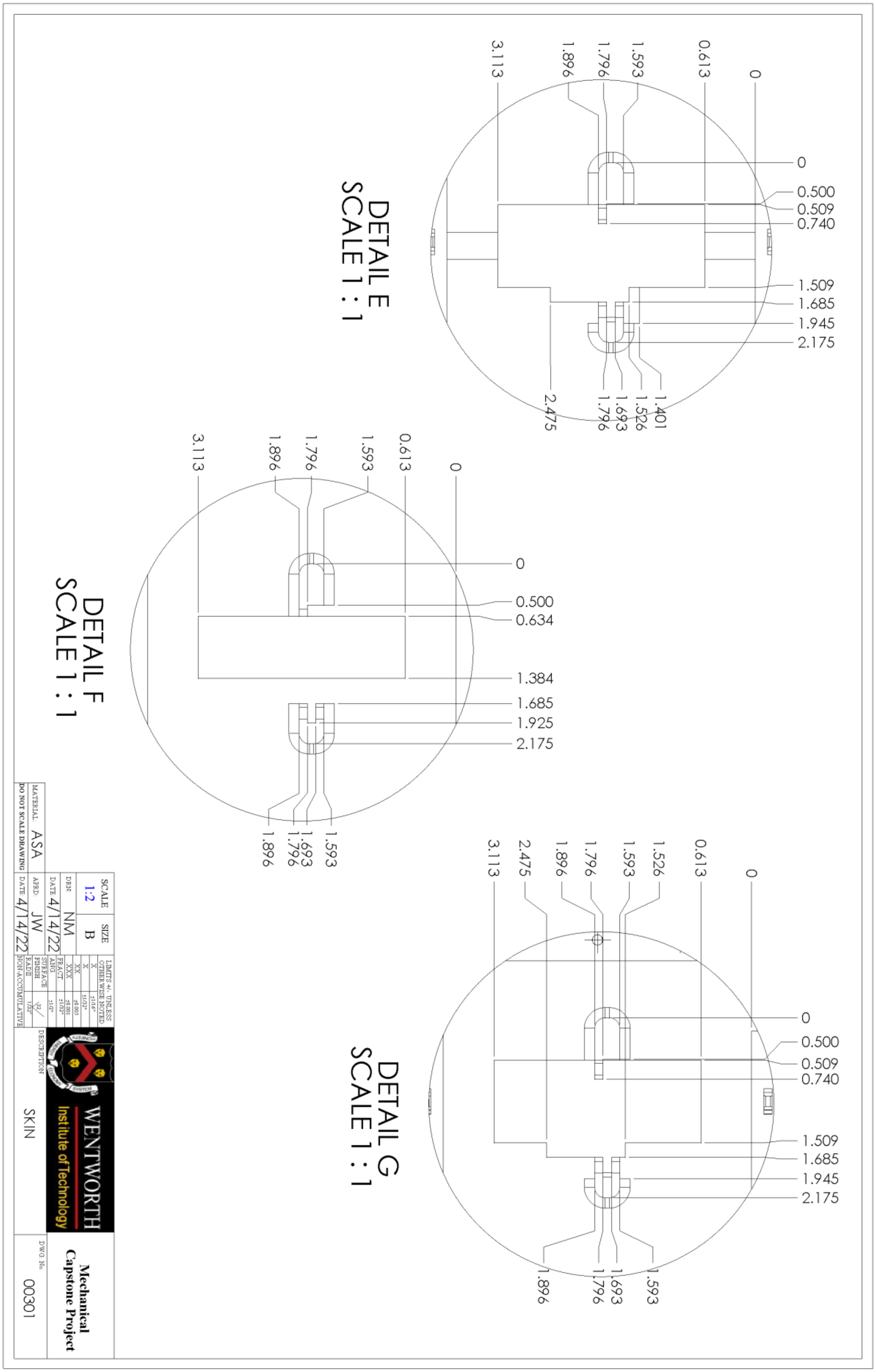
ITEM NO. | PART NUMBER | DESCRIPTION | Material | QTY.
1 | 50401 | Servo Motor (Adafruit 1450) | N/A | 1
2 | 0X302 | Servo Motor Coupler | ASA Plastic | 1
1
2
SCALE
1:1
SIZE
A
DRN: JW
DATE:8 APR 22
APRD: NM
DATE: 8 APR 22
MATERIAL:N/A
DO NOT SCALE DRAWING
LIMITS +/- UNLESS OTHERWISE NOTED
X ±1/16
.X ±1/32
.XX ± 0.005
.XXX ±0.001
FRACT. +/- 1/32"
ANG. +/- 1/2°
SURFACE FINISH 32
RADII 1/32"
NON-ACCUMULATIVE
WENTWORTH
Institute of Technology
DESCRIPTION
Servo Coupler Subassembly
(82000, 83000, 84000)
Mechanical
Capstone Project
DWG. No.
8X000

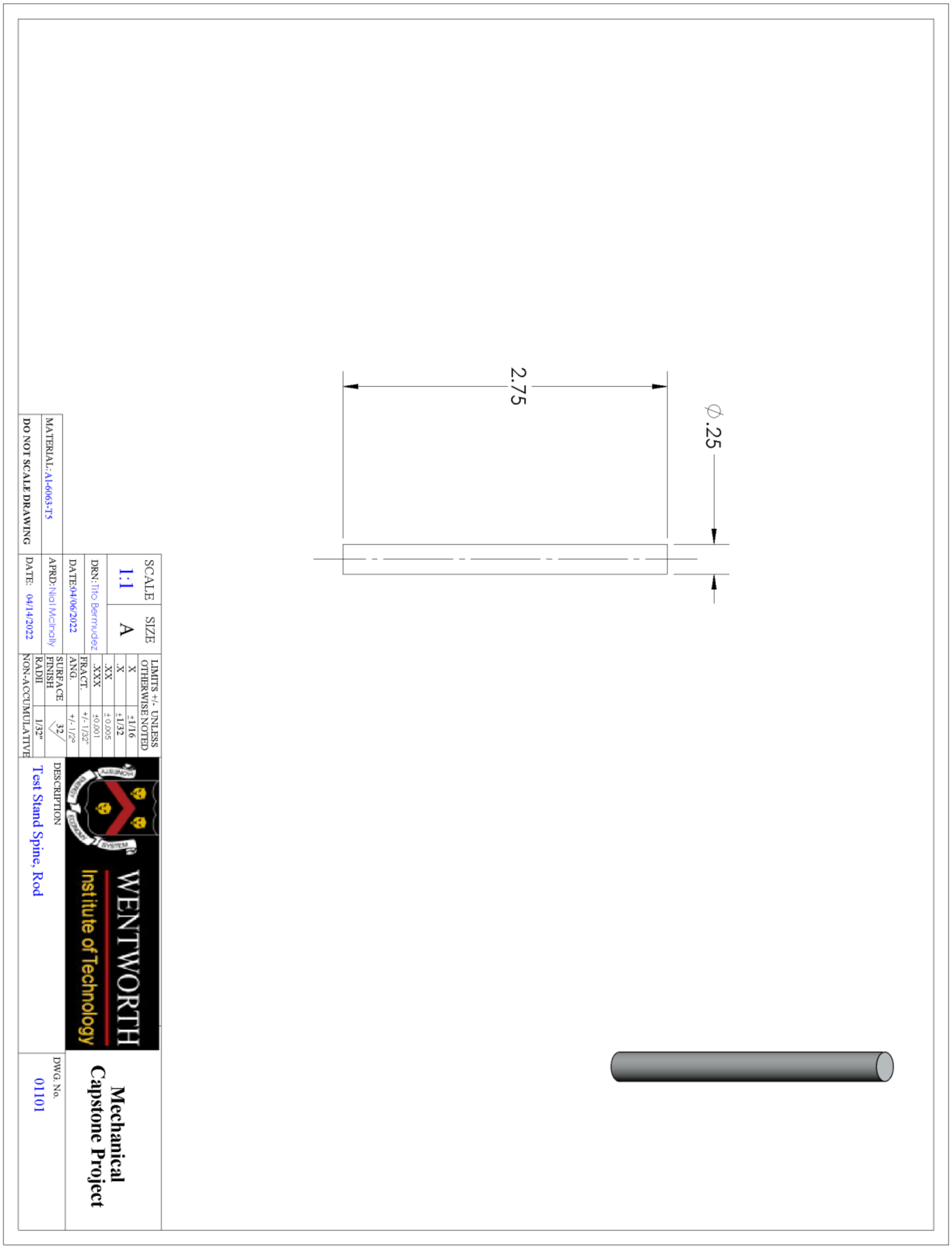
Part Drawings

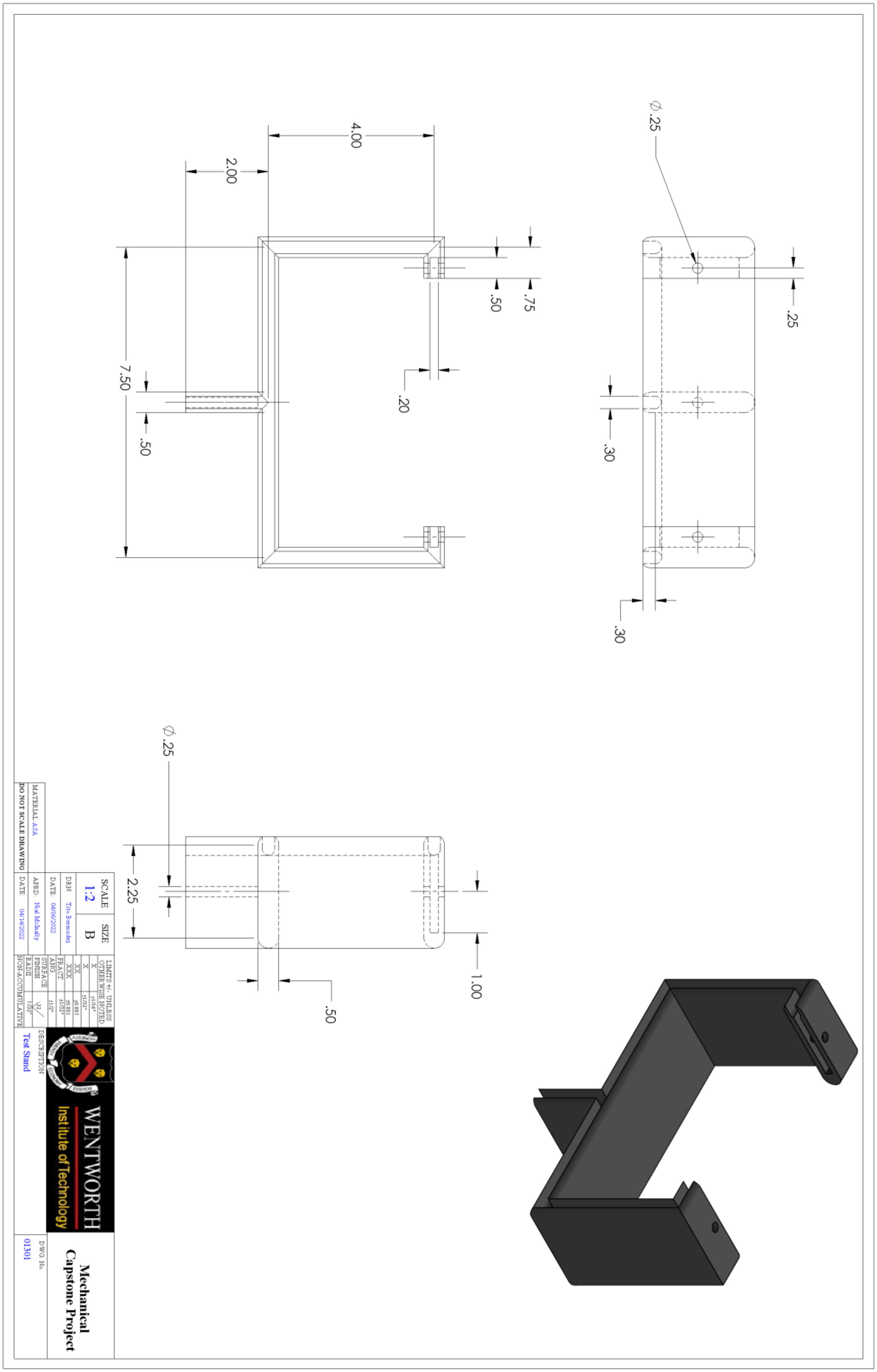


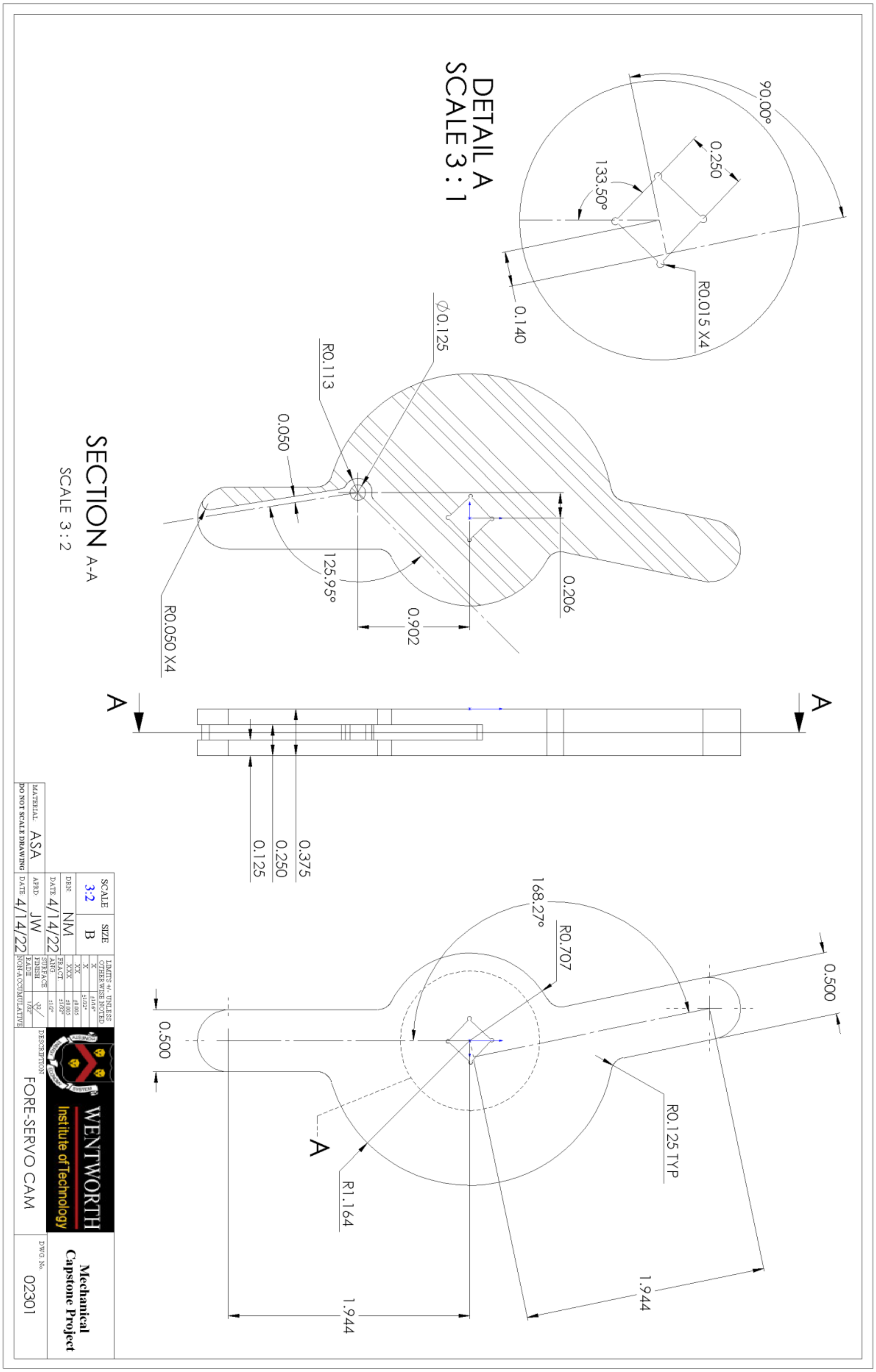

A
B
C
D
E
F
G
Ø0.250 ⟂ 0.200
Ø0.125 THRU X5
0.045
0.200
1.000
MATERIAL ASA
DO NOT SCALE DRAWING
SCALE 1:2
SIZE B
DRN NM
DATE 4/14/22
APPD JW
DATE 4/14/22
WENTWORTH
Institute of Technology
DESCRIPTION SKIN
Mechanical Capstone Project
DWG No. 00301

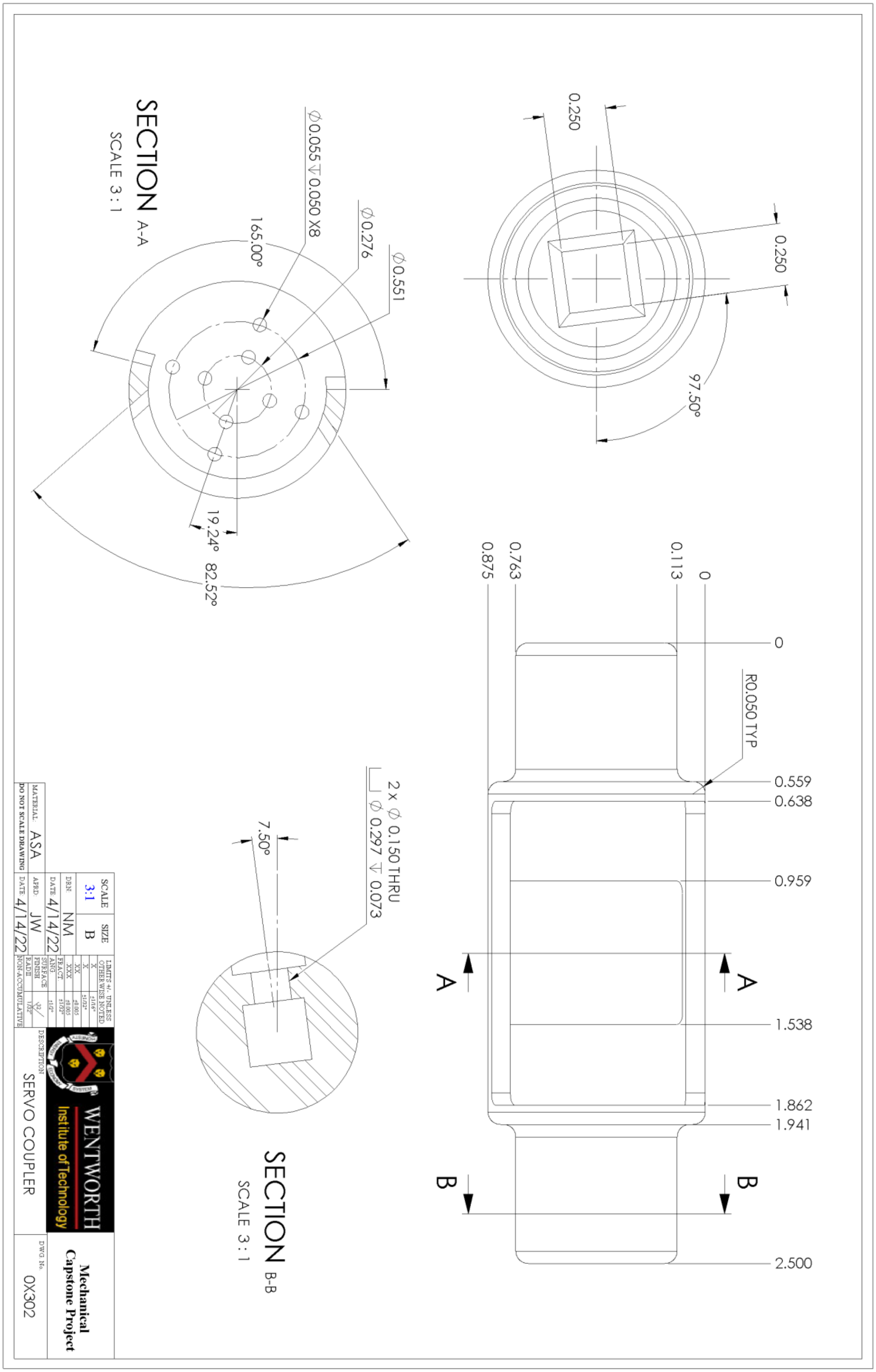

DETAIL A
SCALE 4 : 3
DETAIL B
SCALE 4 : 3
DETAIL C
SCALE 4 : 3
DETAIL D
SCALE 1 : 1
6 x ∅ 0.144 ↧ 0.303
R0.063 THRU X3
R0.050 X6
R0.240
R0.113 X3
∅0.280 THRU
R0.125 TYP
R0.100 TYP
0.700
0.200
1.000
0.300
WENTWORTH
Institute of Technology
Mechanical Capstone Project
MATERIAL ASA
DO NOT SCALE DRAWING
SCALE 1:2
SIZE B
DRN NM
DATE 4/14/22
APPD JW
DATE 4/14/22
DESCRIPTION SKIN
DWG No. 00301

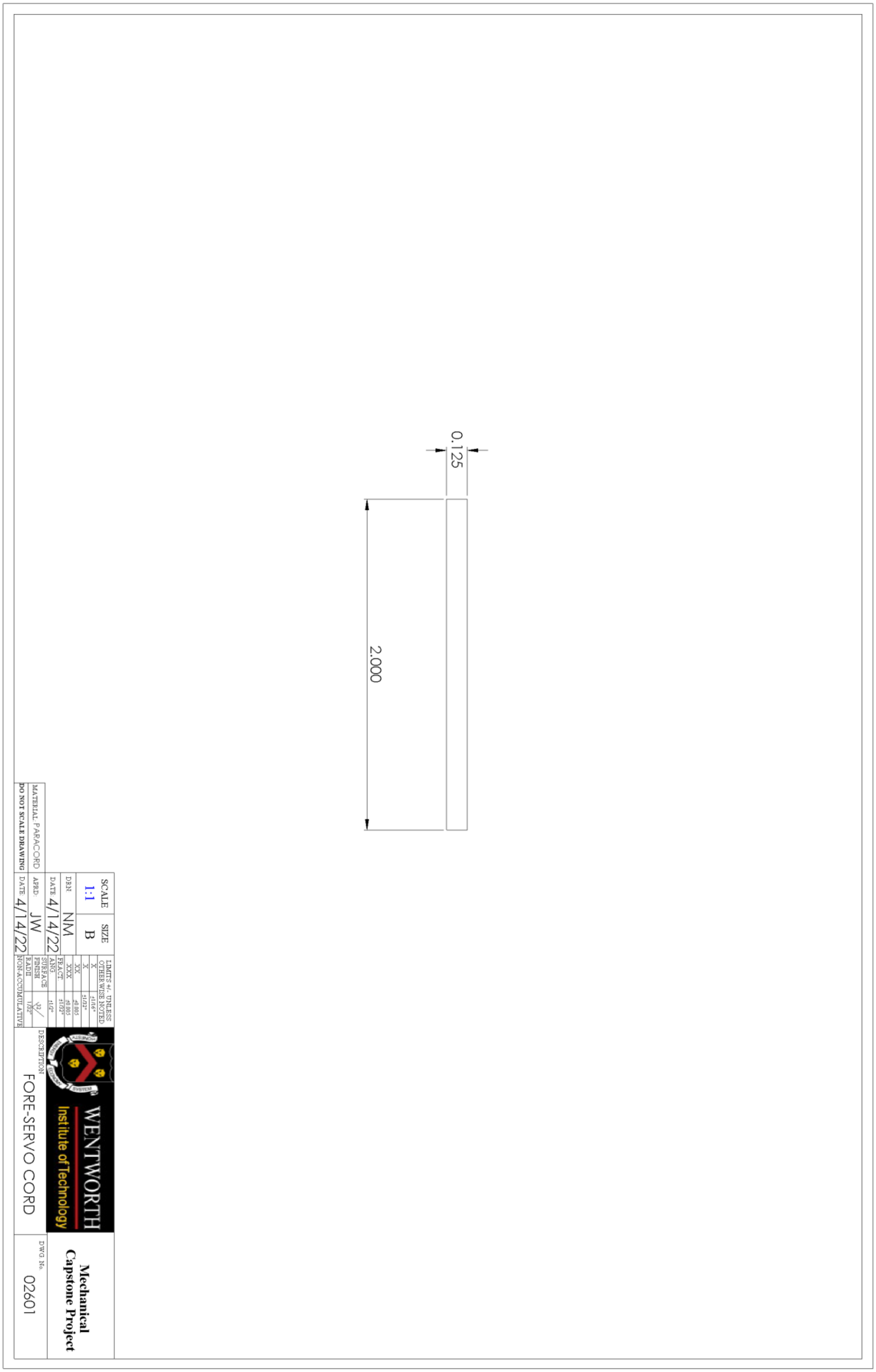

DETAIL E
SCALE 1 : 1
DETAIL F
SCALE 1 : 1
DETAIL G
SCALE 1 : 1
SCALE 1:2
SIZE B
DRN NM
DATE 4/14/22
APPD JW
DATE 4/14/22
MATERIAL ASA
DO NOT SCALE DRAWING
DESCRIPTION SKIN
WENTWORTH
Institute of Technology
Mechanical Capstone Project
DWG No. 00301

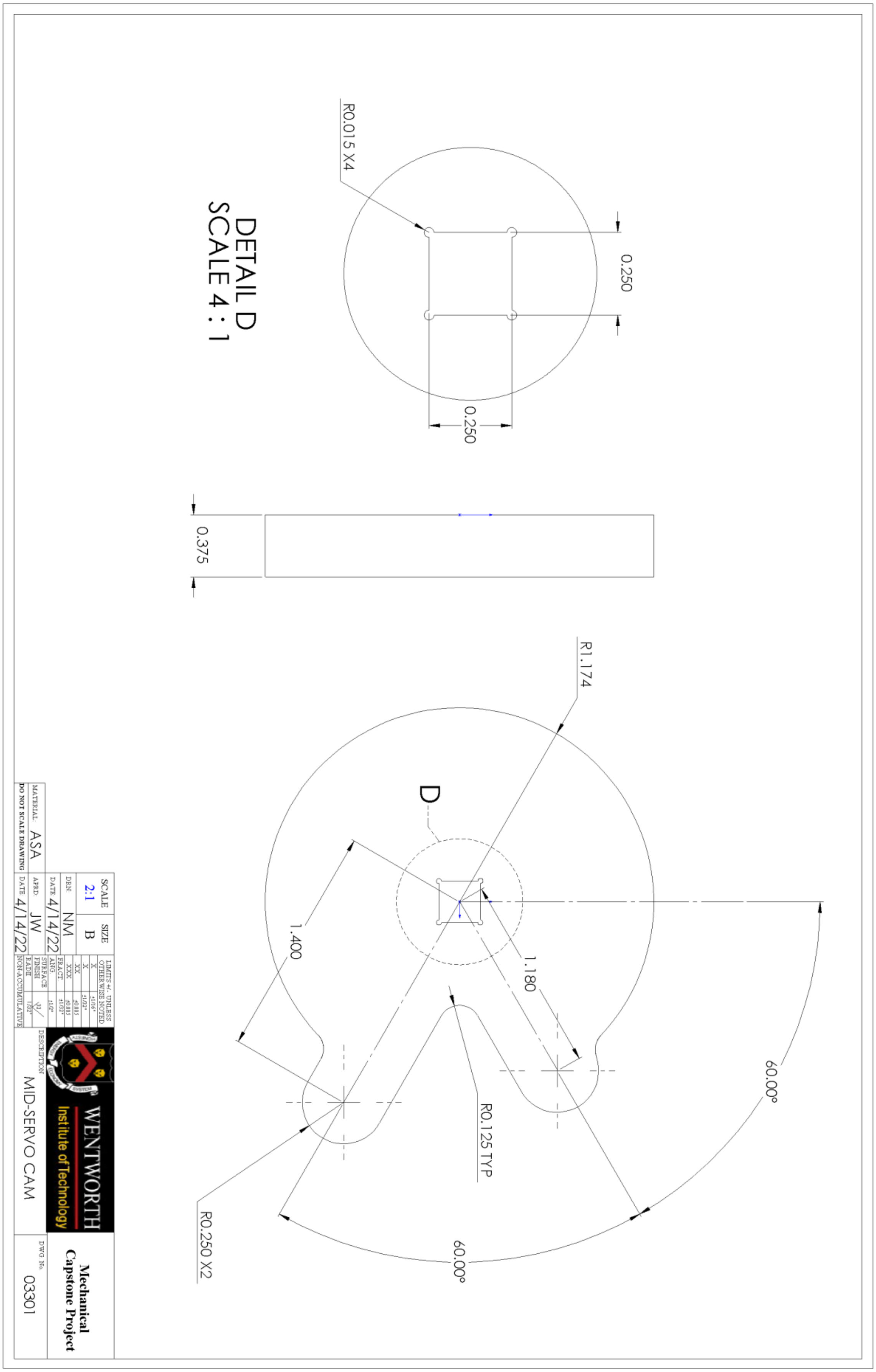

2.75
⌀.25
DO NOT SCALE DRAWING
MATERIAL: Al-6063-T5
SCALE
1:1
SIZE
A
DRN: Tito Bermudez
DATE: 04/06/2022
APRD: Nial McInally
DATE: 04/14/2022
LIMITS +/- UNLESS OTHERWISE NOTED
X ±1/16
.X ±1/32
.XX ± 0.005
.XXX ±0.001
FRACT. +/- 1/32"
ANG. +/- 1/2°
SURFACE FINISH 32
RADII 1/32"
NON-ACCUMULATIVE
WENTWORTH
Institute of Technology
DESCRIPTION
Test Stand Spine, Rod
Mechanical Capstone Project
DWG. No.
01101

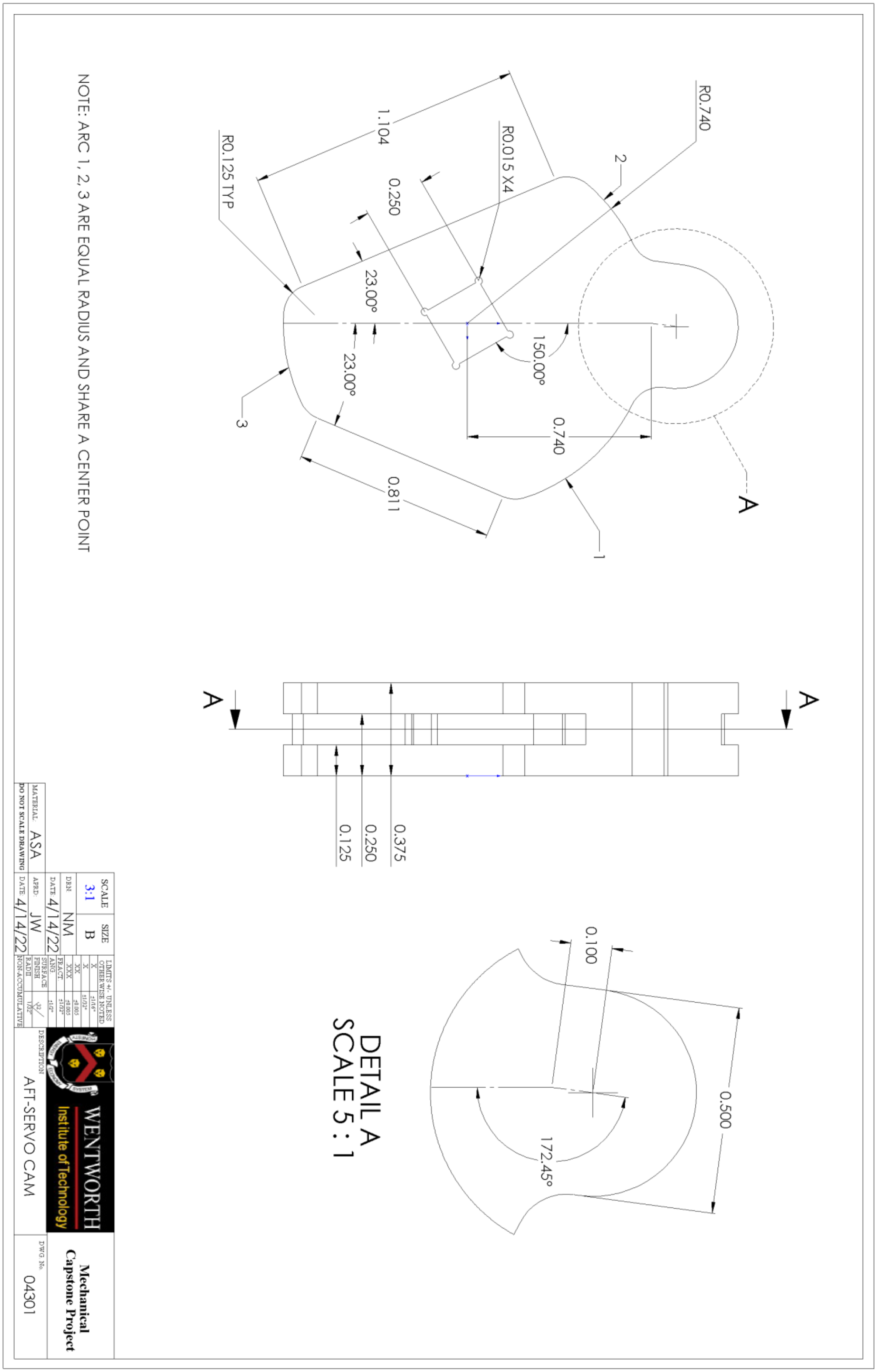

4.00
2.00
7.50
.50
.75
.50
.20
Ø .25
.25
.30
.30
Ø .25
2.25
1.00
.50
SCALE
1:2
SIZE
B
DRN Tito Bermudez
DATE 04/06/2022
DATE 04/14/2022
MATERIAL ASA
DO NOT SCALE DRAWING
WENTWORTH
Institute of Technology
DESCRIPTION
Test Stand
DWG No.
01301
Mechanical
Capstone Project

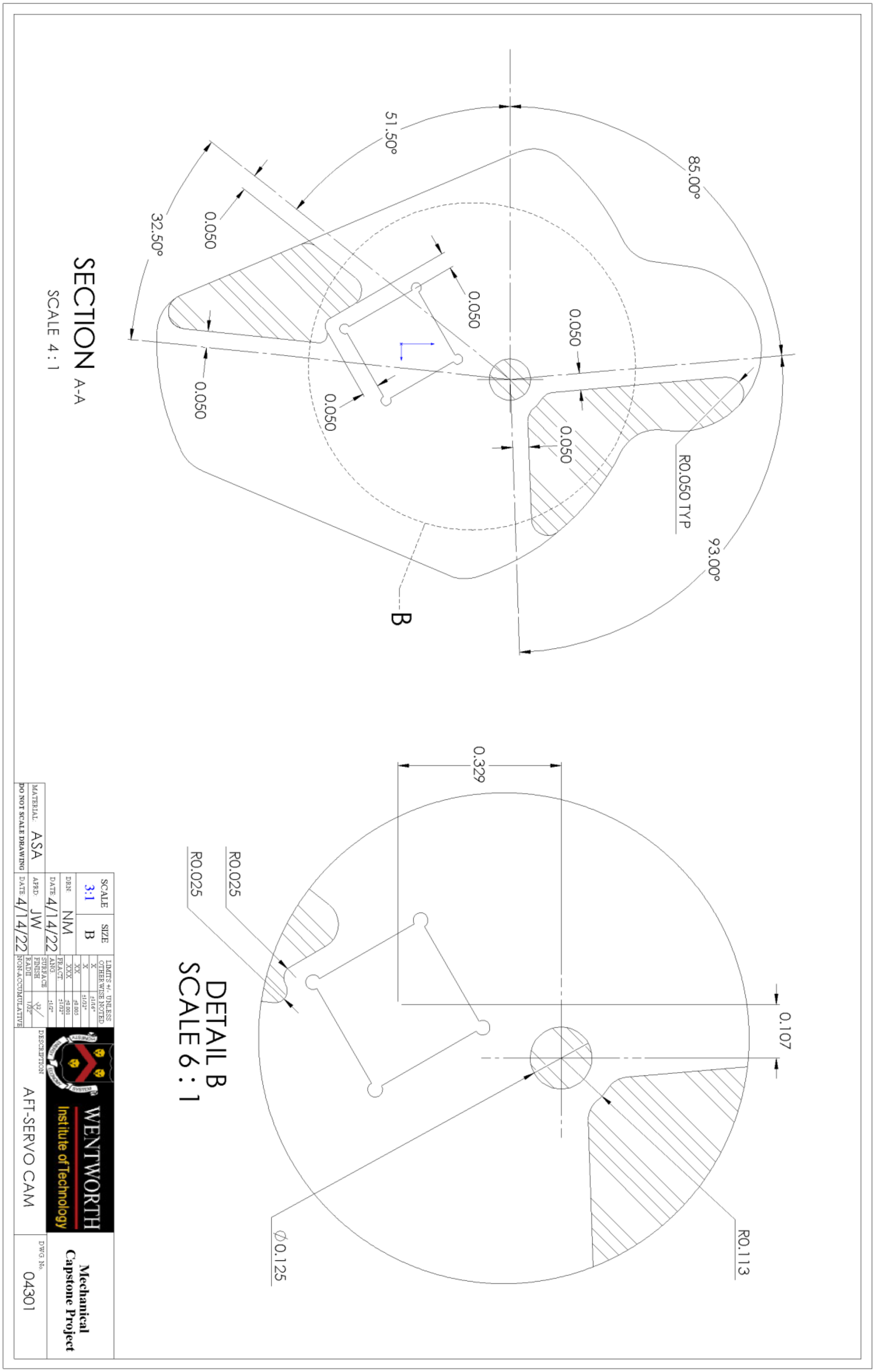

DETAIL A
SCALE 3 : 1
90.00°
0.250
133.50°
R0.015 X4
0.140
∅0.125
R0.113
0.050
SECTION A-A
SCALE 3 : 2
125.95°
0.206
0.902
R0.050 X4
A
A
0.375
0.250
0.125
168.27°
R0.707
0.500
0.500
R0.125 TYP
A
R1.164
1.944
1.944
MATERIAL ASA
DO NOT SCALE DRAWING
SCALE 3:2
SIZE B
DRN NM
DATE 4/14/22
APP'D JW
DATE 4/14/22
WENTWORTH
Institute of Technology
Mechanical Capstone Project
DESCRIPTION
FORE-SERVO CAM
DWG No.
02301

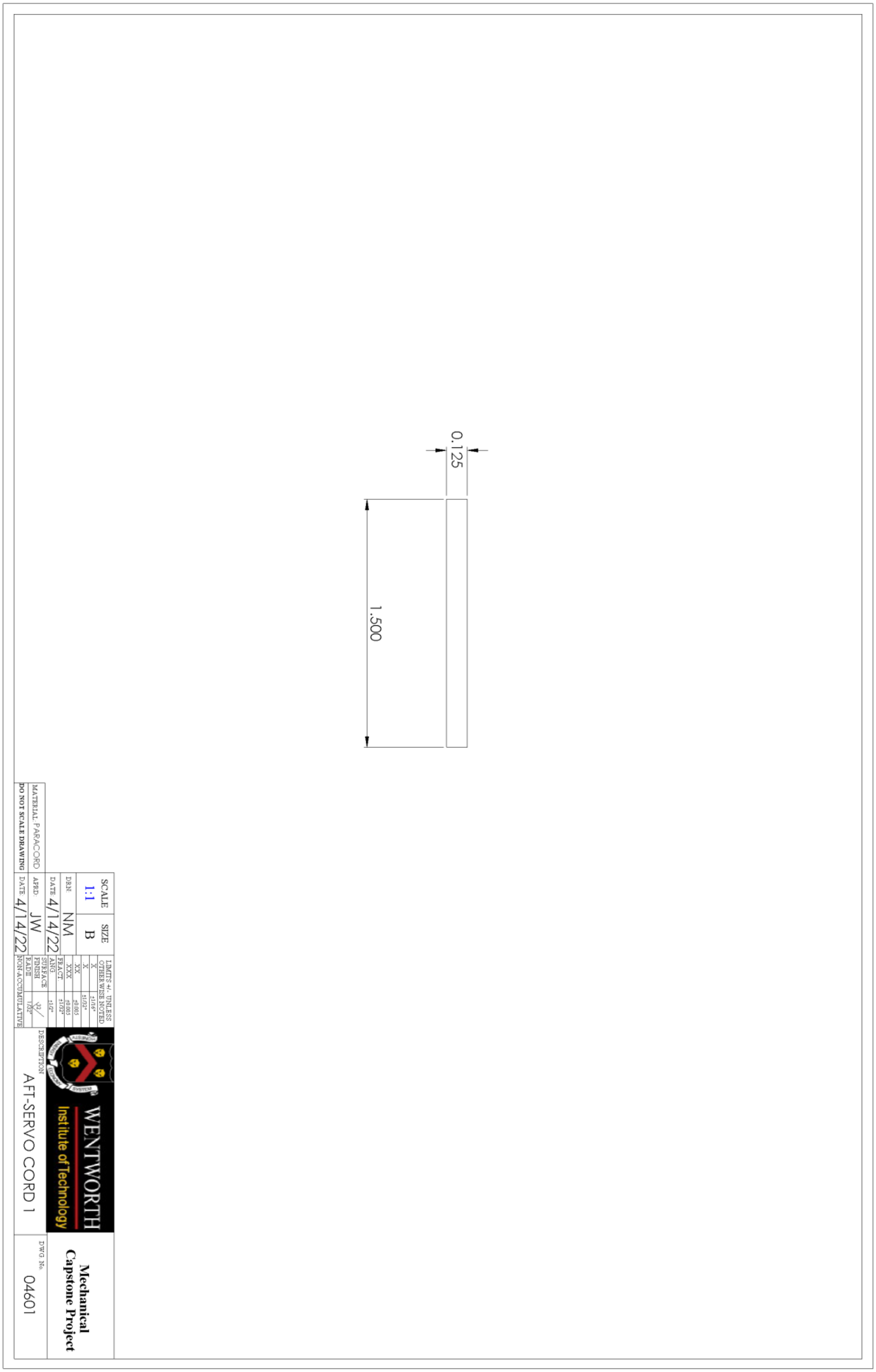

SECTION A-A
SCALE 3 : 1
SECTION B-B
SCALE 3 : 1
⌀0.055 ↧ 0.050 X8
⌀0.276
⌀0.551
165.00°
19.24°
82.52°
0.250
0.250
97.50°
R0.050 TYP
2 x ⌀ 0.150 THRU
⌴ ⌀ 0.297 ↧ 0.073
7.50°
0
0.113
0.763
0.875
0
0.559
0.638
0.959
1.538
1.862
1.941
2.500
A
A
B
B
MATERIAL ASA
DO NOT SCALE DRAWING
SCALE 3:1
SIZE B
DRN NM
DATE 4/14/22
APPD JW
DATE 4/14/22
WENTWORTH
Institute of Technology
DESCRIPTION
SERVO COUPLER
Mechanical Capstone Project
DWG No.
0X302

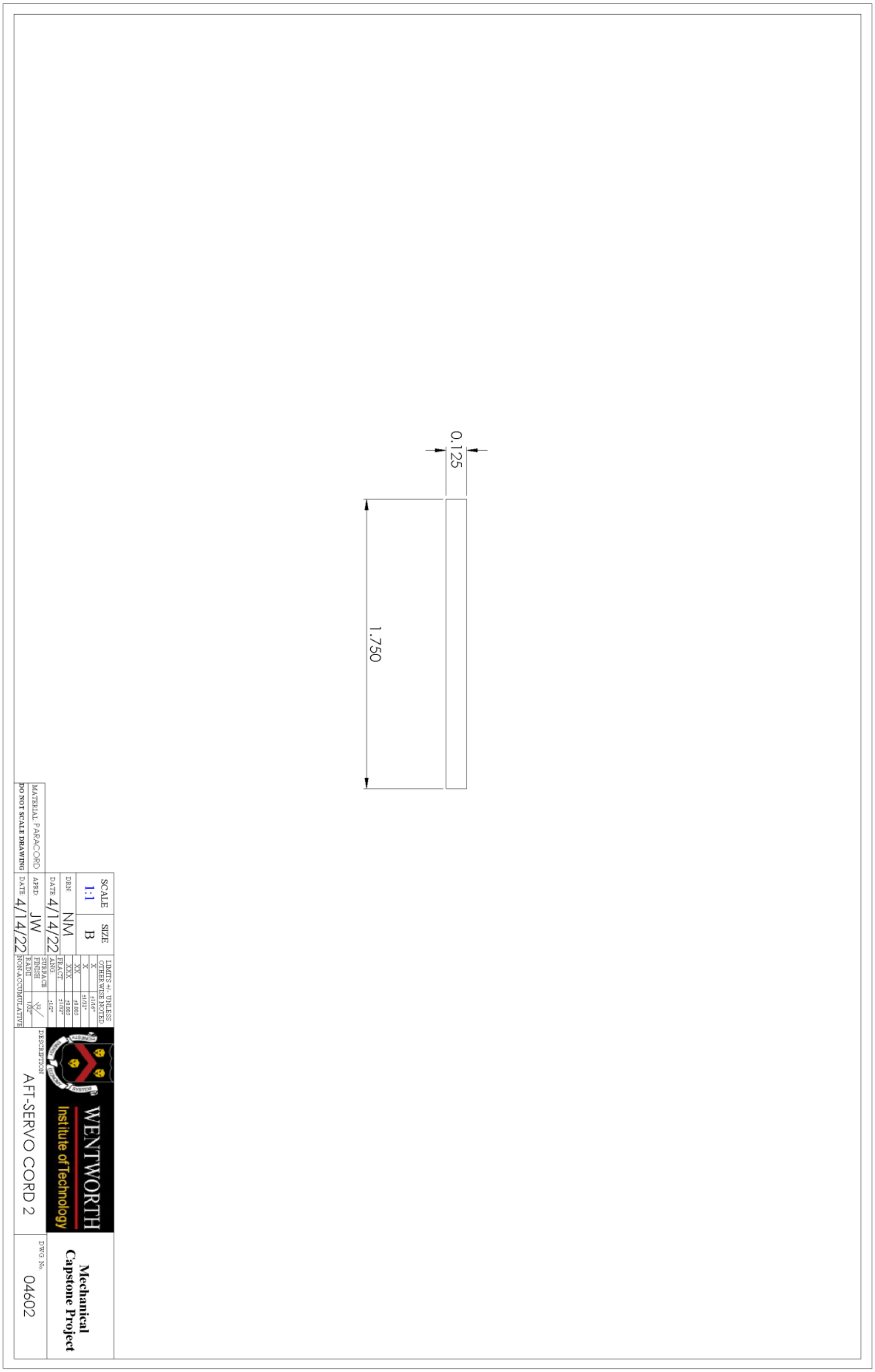

0.125
2.000
SCALE
1:1
SIZE
B
DRN
NM
DATE
4/14/22
APPD
JW
DATE
4/14/22
MATERIAL PARACORD
DO NOT SCALE DRAWING
WENTWORTH
Institute of Technology
DESCRIPTION
FORE-SERVO CORD
Mechanical
Capstone Project
DWG No.
02601


R0.015 X4
0.250
0.250
DETAIL D
SCALE 4 : 1
0.375
R1.174
D
1.400
1.180
60.00°
R0.125 TYP
R0.250 X2
60.00°
SCALE
2:1
SIZE
B
DRN
NM
DATE
4/14/22
APPD
JW
DATE
4/14/22
MATERIAL
ASA
DO NOT SCALE DRAWING
WENTWORTH
Institute of Technology
DESCRIPTION
MID-SERVO CAM
Mechanical
Capstone Project
DWG No.
03301


NOTE: ARC 1, 2, 3 ARE EQUAL RADIUS AND SHARE A CENTER POINT
R0.740
R0.015 X4
R0.125 TYP
1.104
0.250
23.00°
23.00°
150.00°
0.740
0.811
1
2
3
A
A
A
0.375
0.250
0.125
DETAIL A
SCALE 5 : 1
0.100
0.500
172.45°
SCALE
3:1
SIZE
B
DRN
NM
DATE
4/14/22
APPD
JW
DATE
4/14/22
MATERIAL
ASA
DO NOT SCALE DRAWING
WENTWORTH
Institute of Technology
DESCRIPTION
AFT-SERVO CAM
Mechanical
Capstone Project
DWG No.
04301


SECTION A-A
SCALE 4 : 1
DETAIL B
SCALE 6 : 1
51.50°
85.00°
32.50°
93.00°
0.050
R0.050 TYP
B
0.329
0.107
R0.025
R0.025
R0.113
∅0.125
MATERIAL ASA
DO NOT SCALE DRAWING
SCALE 3:1
SIZE B
DRN NM
DATE 4/14/22
APPD JW
DATE 4/14/22
WENTWORTH
Institute of Technology
DESCRIPTION
AFT-SERVO CAM
Mechanical Capstone Project
DWG No.
04301


0.125
1.500
SCALE
1:1
SIZE
B
DRN
NM
DATE
4/14/22
APPD
JW
DATE
4/14/22
MATERIAL PARACORD
DO NOT SCALE DRAWING
WENTWORTH
Institute of Technology
DESCRIPTION
AFT-SERVO CORD 1
DWG No.
04601
Mechanical
Capstone Project


0.125
1.750
SCALE
1:1
SIZE
B
DRN
NM
DATE
4/14/22
APPD
JW
DATE
4/14/22
MATERIAL PARACORD
DO NOT SCALE DRAWING
WENTWORTH
Institute of Technology
DESCRIPTION
AFT-SERVO CORD 2
Mechanical
Capstone Project
DWG No.
04602

Final Design Plan

Purchasing Plan

All parts will be purchased with the aid of Herb Connors, the head of laboratories in the school of engineering at Wentworth Institute of Technology. The bolts and nylon lock nuts will be purchased from Bolt Depot. The Arduino will be purchased as part of a kit that includes all of the necessary parts to set up basic Arduino systems. Only three servos are needed to successfully complete the design, but a fourth servo will be purchased as back-up in the event one of the servos breaks. The cord and aluminum stock will be purchased from McMasterCarr. Finally, 3D printing orders for the Additive Manufacturing Center will be processed through Wentworth Institute of Technology's PaperCut printing service.

Manufacturing Plan

The majority of the manufacturing for this project is 3D printing. The machining required for the test stand is minimal, not even requiring the lathe station or milling machine. There is no challenging materials to machine as aluminum will be the primary material for parts not 3D printed. The benefit to 3D printing a majority of the components is that it allows for rapid changes to be made to the design when problems are encountered with less cost compared to using other materials and manufacturing methods.

Experimentation Plan

Computational fluid dynamics simulations will be used to predict the turbulence created by the test stand. The primary experimental test will be the wind tunnel. The Wentworth wind tunnel has a maximum air speed of 60 miles per hour, and the wind tunnel at Baxter Academy in Maine has a maximum air speed of approximately 200 miles per hour. The Wentworth wind tunnel uses smoke as the primary optical evaluation technique, while the Baxter Academy uses sublimating carbon dioxide as the optical tracing technique. The Wentworth wind tunnel will be a good quick iteration tool because of its proximity to the school's 3D printing services, but the Baxter wind tunnel will provide more realistic operating conditions for the airfoil since high wind speeds approach the similarity solution's required air speed.

Final Documentation Plan

The complete documentation package will contain the final report, the technical poster, all part and assembly drawings, part and assembly manufacturing procedures, and the experimental test plan.

Conclusions

The final design has been presented. The small and lightweight servos allow for the actuation between simple airfoil geometries meeting the design specifications of a flap that is less dense than the original and more aerodynamically efficient. Simulations will determine if the servos are strong enough to withstand aerodynamic loads. The servos will be actuated by an electrically contained system controlled by a simply programmed Arduino. Moving forward, a securing mechanism for the cams will be developed, and fatigue simulations to determine the total number of cycles for the lifetime of a compliant flap.

Works Cited

"A Morphing Fractal Vise Pivots to Grasp Irregular Shapes for Engraving." Kapi News, 1 July 2021, https://www.kapinews.com/2021/07/01/a-morphing-fractal-vise-pivots-to-grasp-irregular-shapes-for-engraving/.

Kota, Sridhar et al. "Mission Adaptive Compliant Wing – Design , Fabrication and Flight Test." (2009).

McIver, John. "Cessna Skyhawk II/100 (172) Performance Assessment." 23 Jan. 2003, www.temporal.com.au/c172.pdf.

Pecora, Rosario. "Morphing Wing Flaps for Large Civil Aircraft: Evolution of a Smart Technology across the Clean Sky Program." Chinese Journal of Aeronautics, vol. 34, no. 7, 2021, pp. 13–28., https://doi.org/10.1016/j.cja.2020.08.004.

Previtali, Francesco, et al. "Compliant Morphing Wing." Proceedings ICAST2011: 22nd International Conference on Adaptive Structures and Technologies, Oct. 2011.

Previtali, Francesco. "Morphing Wing Based on Compliant Elements." Diss., Eidgenössische Technische Hochschule ETH Zürich, Nr. 2, ETH-Zürich, 2015.

Sadraey, Mohammad H. "Wing Design." Aircraft Design – A Systems Engineering Approach, Wiley, 2013, pp. 161–264.

Appendices

Appendix 1: Team Qualifications

Tito Bermudez

Tito has taken classes in the manufacturing minor at Wentworth and is more than qualified to help with the fabrication of parts for this project. Additionally, Tito has experience working with Wentworth facilities while on his first Co-Op experience so he will be able to help the group interface with the school's resources.

Nial McInally

Nial has had two Co-Ops in the manufacturing engineering field, taken Wentworth's manufacturing minor classes, and used Solidworks extensively. Along with Tito, Nial will be an asset to the group's manufacturing capabilities and will be a key part of the groups 3D modeling and document control system management.

Andrew Lanzrath

Andrew is the group's computational fluid dynamics and thermos-fluids expert. He has worked on various CDF projects in his free time and in collaboration with Wentworth's professors. His code will be required to test the groups final products against wind tunnel data.

Jacob Willette

Jacob has manufacturing and design experience from his Co-Ops that will be implemented in this project. He has over five years of experience in Solidworks in addition to a Solidworks CSWP certification which will be valuable to the 3D modeling and mechanical design aspects of this project.

Appendix 2: Resumes of Team Members

Tito Bermudez

Misael Bermudez (Preferred name: Tito)

bermudezm1@wit.edu | 617-676-8616 | Newton, MA

EDUCATION

Wentworth Institute of Technology | Boston, MA — Expected December 2022
Bachelor of Science in Mechanical Engineering

University of Massachusetts, Boston | Boston, MA — Jan 2018-Dec 2019
Physics Major

Related Courses: Engineering Thermodynamics, Mechanics of Materials, Additive Manufacturing, Engineering Graphics, Fundamentals of CAD & CAM, Computer Science, Multivariable Calculus

SKILLS

Software: SolidWorks, AutoCAD, Java, MATLAB, Microsoft Office (Excel, PowerPoint, Word)
Engineering: Material Testing with Instron Equipment, Stress Analysis, Finite Element Analysis (FEA)
Certification: Stratasys Additive Manufacturing

LEADERSHIP EXPERIENCE

United States Marine Corps — December 2013 – December 2017
Team Leader – Camp Pendleton, CA

- Led a demolitions team through training exercises in the successful employment of explosive charges while always maintaining safety standards.
- Communicated with higher leadership on which obstacles to prioritize for successful completion of the mission.
- Trained team members in the construction of demolition charges and the calculation of standard safe distances in accordance with safety practices.
- Conducted quarterly performance reviews on team members.
- Delegated tasks to other team members when needed.

Additional Work Experience

Whole Foods — May 2011 – December 2013
Prepared Foods Team Member – Newton, MA

- Weighed, priced, and packaged customer selections.
- Prepared sandwiches and other prepared foods behind the counter for customers, which included slicing meats and cheeses.
- Ensured a fresh and appealing display by keeping cases and salad/ hot bars clean and well stocked and properly rotated, while checking and ensuring freshness and quality of products.

Nial McInally

Nial McInally

Mechanical Engineering Student

Greater Boston Area
508 736-1777
mcinallyn@wit.edu

EDUCATION

Wentworth Institute of Technology — GPA: **3.66/4**
B.S. in Mechanical Engineering, Minor in Manufacturing — Junior | Expected Graduation: August 2022

Relevant Courses: Design of Machine Elements, Thermodynamics I & II, Heat Transfer, Fluid Mechanics, Dynamics

SKILLS & CERTIFICATIONS

Design: Certified SolidWorks Associate (CSWA), Autodesk Suite (Inventor/Fusion 360)
Manufacturing: CNC milling, lathe working, 3D printing, calipers/micrometers, basic GD&T, comfortable with power tools
Other: Microsoft Office (Excel, PowerPoint, Word), OSHA 10-Hour General Industry certified, Project Data Management (PDM)

WORK EXPERIENCE

Methods Machine Tools, Inc
Design Co-op
Sudbury, MA
January – May 2021

- Used SolidWorks to design custom machine options for CNC equipment
- Designed automation cell layouts based on customer request
- Created SolidWorks drawings to supplement machine installation documentation
- Communicated with vendors to request quotes for automation cell components

Vangy Tool Company, Inc
Entry Level Machinist
Worcester, MA
May – August 2019

- Read and executed operations from engineering drawings for custom parts
- Created work-holding setups and CNC machine programs for mills/lathes
- Performed tolerance checks for manufactured parts
- Packed and verified orders before shipment

Shrewsbury Robotics
Engineering Camp Counselor
Shrewsbury, MA
2014 – 2018 (Summers)

- Taught middle school students mechanical design and coding using LEGO MINDSTORMS
- Lead students through the engineering design process
- Collaborated with other counselors to organize each day's activities
- Used knowledge and experiences to make engineering fun

LEADERSHIP & ACTIVITIES

Wentworth Chapter of ASME
Co-President
September 2020 – Present

Collaborate with other members of the Executive Board to:
- Plan and run weekly meetings
- Organize demonstrations of campus technical resources
- Create budget and schedule for future projects

FIRST Robotics (FRC 467)
Alumnus and Mentor
Fall 2013 – Present

Mentor | Fall 2018 – Present
- Guided students through the engineering design process
- Taught class on the basics of CAD using Autodesk Fusion 360

Student | Fall 2013 – Spring 2018
- Designed and manufactured parts for each year's robot
- Analyzed game elements and implemented strategic design
- Led the team as Lead System's Engineer to two championship events

HONORS & AWARDS

Wentworth Engineering Honors Society | *Member*
July 2020 – Present
- Accepted into a society for high achieving engineering students

FIRST Dean's List Finalist
2017 Season
- Awarded to FIRST students for outstanding leadership and community service
- Received in recognition of hard work with FRC Team 467 and commitment to spreading STEM in Central Massachusetts (one of six recipients in New England)

Andrew Lanzrath

Andrew Thomas Lanzrath

lanzrath@mit.edu ● (619) 495-8044 ● Boston, MA

Research Interests

HTS magnet technology, plasma fusion, nuclear materials science, particle accelerators, computational fluid dynamics, thermal convection, numerical simulation of magnet quench events, high energy density physics, nuclear material irradiation, Van der Waals heterostructures, strongly correlated electron transport solid state physics.

Education

MASSACHUESETTS INSTITUTE OF TECHNOLOGY — Cambridge, MA
Master of Science, Nuclear Science and Engineering — May 2024
Focus: *In-situ* analysis of nuclear irradiated high temperature superconducting magnet material properties within a magnetic field under cryogenic conditions using fission reactor neutron and low energy proton accelerator irradiation sources.

WENTWORTH INSTITUTE OF TECHNOLOGY — Boston, MA
Bachelor of Science, Mechanical Engineering. GPA 4.0/4.0 — August 2022
President's List: 2019 – 2021. Tau Alpha Pi
Relevant Coursework: Heat Transfer, Dynamics, Mechanics of Materials, Materials Science, Circuit Theory, Thermodynamics, Fluid Mechanics

GROSSMONT COLLEGE — El Cajon, CA
Associate of Science, Physics. GPA 4.0/4.0 — August 2019
Associate of Science, Mathematics. GPA 4.0/4.0
Dean's List: 2017 – 2019. Phi Theta Kappa

ST. AUGUSTINE HIGH SCHOOL — San Diego, CA
Principal's List: 2013-2017. GPA 4.24/4.0 — June 2017
National Honors Society: 2015 – 2017
California Scholastic Federation 2013 – 2017

Research Experience

MASSACHUSETTS INSTITUTE OF TECHNOLOGY: FRANCIS BITTER MAGNET LABORATORY – PLASMA SCIENCE AND FUSION CENTER — Cambridge, MA, July 2021 – Present
Undergraduate Research Intern

- Fabricated and tested REBCO lap joints and reinforced double pancake crossover sections of various lengths using different fabrication processes for 1.3GHz NMR HTS insert.
- Designed an experiment to simulate conductor wire motion and resultant heating during quenches of LTS magnets with a heater and applied mechanical forces to assess SN2 impregnation as a replacement for complex coil impregnation with epoxy or paraffin.
- Modeled quench events using simplified schemes for early-stage magnet design quench protection requirements in MATLAB.
- Constructed and tested a single-pancake REBCO coil to determine turn-to-turn contact resistance and over-current properties of no-insulation, metal-insulation, and indium shunted HTS coils.
- Designed a test-fixture for testing a small BSCCO 2212 coil for critical current performance below 63K including mount, shunt, and current leads for a conduction-cooled/SN2 system.

Andrew Thomas Lanzrath

lanzrath@mit.edu ● (619) 495-8044 ● Boston, MA

WENTWORTH INSTITUTE OF TECHNOLOGY Boston, MA
Undergraduate Research Intern January 2021 – Present

- Computational Fluid Dynamics
    - Tested the Solidworks embedded CFD solution to assess the validity of simulation results compared to experimental data and analytical solutions of the Navier-Stokes equations.
    - Developed a report on maximizing solution accuracy using the Solidworks Flow Simulation for unsteady, incompressible, viscous flow over a circular cylinder at low Reynolds numbers for use in the educational environment.
    - Constructed an implicit finite difference algorithm to solve the two-dimensional, compressible Navier-Stokes equations using Beam-Warming approximate factorization and Steger-Warming flux vector splitting.
- Aerosol Transport and Deposition
    - Designed a program to analyze photometric aerosol deposition data in MATLAB.
- Condensed Matter
    - Developed alternative methods to electron beam lithography for electrically connecting to graphene for four-probe measurements.
    - Designed and constructed a dual-function machine for low-dimensional material micro-soldering and stamp transfer stacking of Van der Waals heterostructures.

Work Experience

LAW OFFICE OF ERIC ALAN ISAACSON San Diego, CA
Legal Aid June 2020 – January 2021

- Researched relevant statutory and case law for complex, securities class action and constitutional law cases.
- Edited legal fillings (memoranda of law, appellate briefs, etc.) for various state courts and the Federal district and appellate courts.

DI DONATO ASSOCIATES San Diego, CA
Architectural Design Intern June 2017 – August 2019

- Assembled construction documents for commercial, residential, and telecom projects.
- Designed 3D models and renderings for residential, commercial, and mixed-use project visualization.
- Performed field measures and construction administration site visits for residential, commercial, mixed-use, telecom, and educational projects.

Technical Skills

Programming: MATLAB, C++, Modern Fortran, R
Software: Solidworks, LabView, Comsol, LaTeX, AutoCAD, Microsoft Office

Publications

CONFERENCE POSTERS

1. "Stability of Two Impregnated NbTi Coils Operated in the 4.2-6K Range, Paraffin v. Solid Nitrogen," W. Lee, A.T. Lanzrath, D. Park, J. Bascuñán, Y. Iwasa, 27th International Conference on Magnet Technology, Fukuoka, Japan, November 15-19, 2021.

Jacob Willette

Jacob C. Willette

Maine/Boston/San Francisco Areas • 207- 577-1845 • ME@jcwillette.engineer • jcwillette.engineer (website /portfolio)

Education

Wentworth Institute of Technology | Boston, MA **Class of 2022**
Bachelor of Science **GPA: 3.81/4.00**
Majoring in Mechanical Engineering
Dean's list for all semesters
Classes: Design Process, Statics/Dynamics, Circuit Theory, Thermodynamics I-II, Heat Transfer, Materials Science, Graphics (Introductory GD&T), Mechanical Vibrations, Simulation Based Design

Skills

Software: SolidWorks, Creo ProE, Microsoft Office Suite, Trello, Various Project Management Tools
Manufacturing: Additive Manufacturing (FDM, SLA, Resin, etc.), CNC milling, G-Code, Lean Training, Injection Molded Part Design

Experience

Mechanical Engineering Co-Op **September 2021 – January 2022**
Savant Systems Inc. | Hyannis, MA
Assisted mechanical engineers with product design initiatives with the use of 3D modeling. Researched and assisted in the development of new and innovative ideas, material selections and processes through prototyping and analysis. Made engineering change orders and documented mechanical BOMs. Interfaced with contractors and design consultants outside of the company.

Quality & Continuous Improvement Co-Op **January 2021 - May 2021**
ABB Inc. | Auburn, ME
The purpose of this role is to expand the Co-op's knowledge on how to implement lean manufacturing and deliver strong projects for the plant with results that will help improve safety, quality, and productivity for the department. Made spreadsheets to collect data for the quality department and helped improve quality practices.

Manufacturing Work Study | Boston, MA **Spring 2019 – Spring 2020**
Assisted professors in Wentworth's Manufacturing center teaching the intro CAM class.

Leadership / Activities

Co-President of ASME | Boston, MA **Fall 2018 – Present**
President and member of Wentworth's chapter of the American Society of Mechanical Engineers. In charge of directing the group's vision and managing the club in general.

Academic Affairs Officer, Wentworth Student Government | Boston, MA **Fall 2020 – Summer 2021**
The interface between faculty and students at Wentworth, responsible for addressing student needs and views at monthly Faculty Senate meetings and helping students interface with the school in general.

Calculus I Teacher's Assistant (Supplemental Instructor) | Boston, MA **Fall 2019 – Spring 2021**
Assisted the professor in teaching calculus I for three classes a week and tutored students during evening drop-in sessions

Interests

Short Literature, Rock Climbing, National Geographic, 60's Music (Grateful Dead, Dylan, Hendrix, etc.), Archaic technologies: typewriters, turntables, floppy disks

Jacob C. Willette

Maine/Boston/San Francisco Areas • 207- 577-1845 • ME@jcwillette.engineer • jcwillette.engineer (website /portfolio)

References

Jonathan Amory, Former Boston Dynamics Engineer, Engineering Teacher/Mentor
Baxter Academy for Technology and Science
207-838-1614
jon.amory@baxter-academy.org

Peter Corsini, Dir. Mechanical Engineering, Former Manager
Savant Systems Inc.
508-683-2518
peter.corsini@savant.com

Jeramy Lord, Quality Technician, Former Direct Supervisor
ABB Inc.
207-786-5117
jeramy.lord@us.abb.com

Richard Bourgeois, Quality Manager, Former Manager
ABB Inc.
207-786-5168
richard.bourgeois@us.abb.com

CSWP

Appendix 3: Weekly Working Notes

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

PROJECT TITLE

Group number #: 1 **Week number #:** 3

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:2/1/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:2/1/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:2/1/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:2/1/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 3

- **Meeting minutes**

Meeting time: 1/27/22 3pm-5pm		Location: KNGMN202	
Attendance: All Present			

Activities:

Discussed 4 design project options for Assignment 2. Narrowed 4 options down to our top 2: Compliant airfoil and A UV Cleaner module for waterbottles.

It was later found that the UV Cleaner would not be fiesable for our capstone project as it was too electrically focused.

The next day we determined that our new backup project would be a Compliant Vise mechanism to hold strangly shaped one-off parts where creating a jig is too expensive.

Tasks for Next Week:

We need to flesh out our top two ideas for assignment 3 and adapt one of those ideas to a pre-proposal presentation.

After the presentation we should have a good idea of how we want to procede with Assignment 4 and can hopefully start that on 1/3/22

2

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

PROJECT TITLE

Group number #: 1 **Week number #:** 4

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:2/7/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:2/7/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:2/7/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:2/7/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 4

- **Meeting minutes**

Meeting time: 1/31/22 3pm-5pm		Location: Library	
Attendance: All Present			

Activities:

Created an outline for Assignment 3/Pre-proposal Presentation and identified additional research needs.

Tasks for this week:

1. Major Tasks
   a. Create, Practice, and deliver Preproposal Presentation
   b. Create and Submit preproposal
2. Individual Tasks
   a. Tito
      i. Validate need (bullet 1 on A3) for Airfoil
   b. Nial
      i. Validate/Expand on Costs
      ii. Create Presentation Slides and Format
   c. Andrew
      i. Select a spesific plane to model our airfoil after
   d. Jacob
      i. Research existing compliant wing designs and assess their pros and cons
      ii. Create Gantt Chart
      iii. Fill out reports 3 and 4

Tasks for Next Week:

1. Major tasks
   a. Assignment 4 (Design Spesifications)
   b. Conceptual Design and design options

2

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

PROJECT TITLE

Group number #: 1 **Week number #:** 5

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:2/14/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:2/14/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:2/14/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:2/14/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 5

- **Meeting minutes**

Meeting time: 2/7/22 3pm-5pm		Location: Library	
Attendance: All Present			

Meeting Notes:
- Started to fill out the first part of assignment 4
- Got as far as we could before breaking off to do individual work
- Meeting again Wednesday to finish assignment and develop design options

Tasks:
- Determine rough Airfoil Shapes for Takeoff and Landing (we don't have to do this yet, this is part of the design option investigation phase)
- Approximate dimensions of the final airfoil (Andy, Willette 2/9/22)
- Investigate WIT wind tunnel specs (Tito 2/9/22)
  - Find as much info as you can (try and source a manual?) from Herb Conners, connersh@wit.edu
  - If you can get more info that is preferred but at least answer the following questions:
    - What is the working volume?
    - What is the max speed?
    - Does it have smoke line capabilities?
    - How does it hold test samples?
    - How do we get permission to use it ?
- Find relevant Cessna 172 stats (Nial, 2/9/22)
  - The first citation in works cited is a good starting place
  - If you can get more info that is preferred but at least find the following information:
    - Speeds at different times (cruising, landing, takeoff)
    - The angle of attack range (max decent angle to max ascent angle)
    - Fatigue Info
      - the life span of plane
      - The expected number of cycles on a flap (they do preflight and postflight checks so it may be different from just the number of take-offs and landings)
    - How do the plane's current flaps actuate? (more details the better here)
- Design Options (everyone, 2/14/22)
  - We need a few options on how to design the following:
    - Actuators
    - Airfoils
    - Test Stand
    - Controls System (may be hand in hand with test stand)
  - We'll talk more about this Wednesday but it's good to think about while we're researching

2

Tasks for Next Week
- Finish and submit assignment 4
- Start investigating design options
- Start Writing Formal Preproposal

3

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

PROJECT TITLE

Group number #: 1 **Week number #:** 6

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:2/21/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:2/21/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:2/21/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:2/21/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 6

- **Meeting minutes**

Meeting time: 2/14/22 3pm-5pm		Location: Library	
Attendance: All Present			

Meeting Notes:

- Finished assignment 4
- Broke out research tasks for design options

Tasks:

- Next Monday we want to make an informed final design choice with a design matrix. Below is the research that each of us needs to do in order to come to a conclusion. Design matrices are based on relative metrics and gut instincts so in many cases the questions we need to answer don't require exact numbers. If we don't all contribute to this we will have a very bad time next week, so please come to the meeting next Monday with information and answers from your research.
  - Research options for airfoil target shapes **(Andy, 2/21/2022)**
    - Get two airfoils for take-off and landing configurations (4 total airfoils)
  - Research Actuation Method **(Nial, 2/21/2022)**
    - Look into the following
      - Electric Servos
      - Pneumatics
      - OTHER, Undetermined
    - Find the following:
      - Aprox. weight
      - Power requirements
      - Space in wing
      - Actuation strength
  - Research Control System **(Tito, Willette, 2/21/2022)**
    - Controller **(Tito)**
      - Options
        - Arduino
        - Raspberry Pi
        - Other?
      - Find out the following:
        - Relative complexity (relating to software and electronics)
        - ability to control the actuators above
        - ability to use sensors
        - price

2

- Stand **(Willette)**
  - Options
    - Single Pylon
      - Hinged
      - Unhinged
    - Double Pylon
      - Hinged
      - Unhinged
  - Find out the following:
    - Feasibility in the wind tunnels
    - Pros and Cons
- Start Formal Proposal **(Everyone, 2/25/2022)**
  - Do what you can to start but some of these may require a final design option
  - Work break out
    - Abstract **(Andy)**
    - Intro **(Andy)**
    - Need **(Nial)**
    - Objective **(Nial)**
    - Product Specs **(Andy)**
    - Design Options **(Willette)**
    - Work Plan **(Willette)**
    - Member Qualifications **(Willette)**
    - Budget **(Tito)**
    - Project's Future **(Tito)**

Tasks for next week:

- Finish Formal Proposal
- Begin Midterm Report
- Fill out Design Matrix

3

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 7

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:2/28/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:2/28/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:2/28/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:2/28/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 7

- **Meeting minutes**

Meeting time: 2/21/22 3pm-5pm		Location: Library	
Attendance: All Present			

Meeting Notes:

- Filled out design matrix and determined best design option
- Distributed work for the preproposal assignments

Tasks:

- Finish Formal Proposal **(Everyone, 2/25/2022)**
  - Details for exactly what he wants are in lecture 6. Some stuff we can copy from our preproposal and others we can't
  - Section break out
    - Abstract **(Andy)**
    - Intro **(Andy)**
    - Need **(Nial)**
      - this may be exactly the same but double-check
    - Objective **(Nial)**
    - Product Specs **(Andy)**
      - this will likely be the same but you need to mention all the design specs from assignment 4… maybe do a bulleted list but it's up to you
    - Design Options **(Willette)**
    - Work Plan **(Willette)**
    - Member Qualifications **(Willette)**
    - Budget **(Tito)**
      - we should have a good idea of what we're buying once we do the design matrix. You should be able to get a more fleshed-out budget than last time.
    - Project's Future **(Tito)**
- Finish Formal Proposal Presentation
  - Slide break out
    - Outline **(Willette)**
    - Intro **(Nial)**
      - summary of our project
    - Need Assessment **(Nial)**
      - summary of need. I copied your notes and pictures from last time on one slide

2

- Specifications **(Andy)**
  - briefly go over our design specs from assignment 4
- Existing Products **(Willette)**
  - mention trends in existing products and how ours is different
- Skills and Analysis **(Tito)**
  - Mention each of the types of analysis we have to do and what technical skills are required to do them
- Subsystem 1 **(Andy)**
  - Show each airfoil. Mention what we were looking for when we picked them out
- Subsystem 2 **(Nial)**
  - You can use sketches from assignment 4. Explain each actuator and how it would interact with the flap. One major pro and con for each.
- Subsystem 3A **(Tito)**
  - Show the two controllers. Mention their differences and try to say at least one major pro and con for each.
- Subsystem 3B **(Willette)**
  - Use sketches from assignment 4. Explain the difference and major pros and cons.
- Design Matrix **(Willette)**
  - Explain the top three design choices and what we are going with

Tasks for Next week:

- Complete midterm report

3

.MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 10

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:3/21/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:3/21/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:3/21/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:3/21/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 10

- **Meeting minutes**

Meeting time: 3/14/22 3pm-5pm		Location: CEIS	
Attendance: All Present			

Meeting Notes:

- Broke out Design Work

Tasks:

- Tito
  - Design Test Stand
- Nial
  - Design servo-skin interface mechanism
- Andy
  - Study Wentworth's wind tunnel and give feedback to Tito
- Willette
  - Run FEA sims to determine desired force vectors on skin

Next Week's Tasks:

- Continue above tasks

2

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 8

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:2/28/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:2/28/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:2/28/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:2/28/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 8

- **Meeting minutes**

Meeting time: 2/28/22 3pm-5pm		Location: Library	
Attendance: All Present			

Meeting Notes:

- Broke out work for Midterm Report

Tasks:

- Tito
  - Cost of parts (under "analysis of design options")
    - Try to go as detailed as you can
- Nial
  - Copy over from Formal Proposal:
    - Abstract into Summary of Project
    - Introduction
    - Needs Assessment
    - Specifications
    - Design options, underneath conceptual design (Wait until I verify I did that right)
    - Schedule into Appendix 6
- Andy
  - Editor-in-chief
- Willette
  - Analysis of design options
    - add stuff for geometry calcs in Solidworks
  - Decision Matrices
  - Any other section that has to do with concept design and schedule

Next Week's Tasks:

- NO MEETING, SPRING BREAK

2

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 12

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:4/4/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE: 4/4/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE: 4/4/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE: 4/4/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 12

- **Meeting minutes**

Meeting time: 3/28/22 3pm-5pm		Location: CEIS	
Attendance: All Present			

Meeting Notes:

- Continued design work

Tasks:

- Tito
  - Finish test stand CAD
- Nial
  - Finish designing servo-skin interface mechanism
- Andy
  - Work on application for money from Wentworth
- Willette
  - Continue to optimize skin
  - CAD final interfaces

Next Week's Tasks:

- Finish 2D Drawings
- Submit Budget request
- Finish Final Presentation

2

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 13

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:4/9/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE: 4/9/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE: 4/9/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE: 4/9/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 13

- **Meeting minutes**

Meeting time: 4/4/22 3pm-5pm		Location: CEIS	
Attendance: All Present			

Meeting Notes:

- Finished CAD
- Moved on to creating technical drawings
- Began writing budget request

Tasks:

- Tito
  - Finish test stand Drawings
- Nial
  - Finish designing servo-skin cam drawings
- Andy
  - Finish application for money from Wentworth
- Willette
  - Skin and servo coupler drawings
  - Set up final submission folder

Next Week's Tasks:

- Finish and practice final presentation
- Finish Technical Poster
- Finish Final Report and other submissions

2

MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 11

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:3/28/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE:3/28/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE:3/28/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE:3/28/22

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Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 11

- **Meeting minutes**

Meeting time: 3/21/22 3pm-5pm		Location: CEIS	
Attendance: All Present			

Meeting Notes:

- Continued design work

Tasks:

- Tito
  - Finish test stand CAD
- Nial
  - Finish designing servo-skin interface mechanism
- Andy
  - Work on application for money from Wentworth
- Willette
  - Continue to optimize skin
  - CAD final interfaces

Next Week's Tasks:

- Finish Final 3D and 2D work

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MECH5000 MECHANICAL CAPSTONE PROJECT, SPRING 2022

Weekly report

Compliant Flap

Group number #: 1 **Week number #:** 14

PROJECT MANAGER: Jacob Willette

SIGNATURE: DATE:4/18/22

TEAM MEMBER: Tito Bermudez

SIGNATURE: DATE: 4/18/22

TEAM MEMBER: McInally Nial

SIGNATURE: DATE: 4/18/22

TEAM MEMBER: Andrew Lanzrath

SIGNATURE: DATE: 4/18/22

Mechanical Engineering Program
School of Engineering
Wentworth Institute of Technology
550 Huntington Ave, Boston, MA 02115
Spring 2022

1

Weekly report for MECH5000-Mechanical Capstone Project, Spring 2022

Week No: 14

- **Meeting minutes**

Meeting time: 4/11/22 3pm-5pm		Location: CEIS	
Attendance: All Present			

Meeting Notes:

- Broke out Final Report and Final Presentation Assignments

Tasks:

- Tito
  - Report:
    - Update budget (should be able to estimate costs pretty accurately now since we know exact parts and 3D print volumes)
    - Use procedures in grabcad to write "Analysis of Design Options > Manufacturing Routing" (you don't need to write about every individual part, I would make a section that describes the process for every 3D printed part for example. See how condensed you can make it)
  - Presentation:
    - Final Design – Electrical (hit the specs "Electrically self-contained" and "Test stand interfaces with wind tunnel
    - Conclusion (Wrap up by briefly covering why the final design fits all our design specs)
- Nial
  - Report:
    - Add sketches and overview of other actuator options to "Analysis of Design Options > Experimental Results and Analysis"
    - Import Drawings to "Final Design Option > Drawings"
    - Write section "Analysis of Design Options > Assembly Tolerance and Part Dimensions"
  - Presentation:
    - Compliant Flap (literally the same summary as before)
    - Needs Assessment (Also the same as before)
    - Final Design-Mechanics (hit the specs "wing density" "wind tunnel volume" and "actuator strong enough to resist aerodynamic loads")
- Andy
  - Report:
    - Update Summary of Project as needed
    - Write paragraphs in "Final design plan", Final Documentation plan, and conclusions

2

  - Presentation:
    - Design Spesifications (same as last time)
    - Final Design – Flow Simulations (hit the specs "No Flow Separation")
- Willette
  - Report:
    - Add Initial Flexing Sim results to "Analysis of Design Options > Experimental Results and Analysis"
    - Add last weekly reports
    - Update Design Matrices
    - Write Appendix 5
    - Add Part List
  - Presentation:
    - Intro
    - Outline
    - Final Design – actuation simulations (Skin/rib has acceptable lifespan)

Next Week's Tasks:

- SEMESTER OVER

3

Appendix 4: Samples of Group's Engineering Notebooks

Tito Bermudez

1/26

- Moved to Team 1
- Talk about general scope of project

1/31

Research

- Looking for information that validates the intent of the project.
- Found articles that can be used as reference for pre-proposal

1) Sadney, Mohammad "Wing Design"
2) Previtali, Francesco "Morphing Wing Based on Compliant Elements"

Rough Cost Analysis

3D Printing /Manufacturing - $200

Actuation - $200
↳ dependend on selection

Control System - $150

Unknown Costs - $200

2/2

Meeting Notes

- Finishing touches on Pre-Proposal Presentation
- Practice Pre-Proposal Presentation as a group

2/7

Meeting Notes

- Investigating air foil design
  - ↳ for general size considerations
- Investige specifications of WIT wind tunnel
  - max speed?
  - volume?
  - smoke capabilities?
  - holding test samples?
  - How to shedule use?

2/9

Research

- Met with lab tech in charge of wind tunnel
- Dimensions - approx. 12" x 12" x 36"
- ~ 60 mph max speed
- smoke - 1 line of smoke
  - glycol based smoke
- Holds sample w/ metal rod placed in drill style chuck
  - ↳ need metal rod to be attached to prototype
- Need to write-up procedure for experimentation
  - ↳ get approved by prof.

2/14

Meeting Notes

- start to research control systems
  - Arduino
  - Raspberry Pi
  - Other?
- Can the control system be used to actuate the selected actuators?
- Cost?
- Materials needed to operate?
- Relative complexity?
- Software considerations?
- Start Working on Formal Proposal

2/15

Research

Arduino

- $23 for newest board
- only programmed using C/C++
- can control a variety of components
- Only used for ~~simple~~ small number of simple tasks
- Less powerful processor
- cannot run many complex tasks simultaneously
- Only basic programming is needed to run

Raspberry Pi

- $35 for newest generation (possibly cheaper if used)
- can use multiple languages to program (Python, Scratch, Ruby, C, C++)
- faster processor (can handle more ~~can induce latency~~ complex tasks)
- uses a full operating system (can induce latency in some operations)

	Arduino	Raspberry Pi
Complexity (learning curve)	1	2
Actuation Control	1	2
Sensor Abilities	1	2
Price	1	2
total	(4)	8

* lower is better

Arduino will be used for the controller

2/21

Meeting Notes

- Finish formal proposal
  (Details in Lecture 6)
  - Work on budget (detailed)
  - Used design matrix to select subsystems, so budget can be more accurate
  - Also future of project
- Finish formal proposal presentation
  Slides to do:
  1) Skills and Analysis
     - Mention each type of analysis needed and techinical skills required
  2) Sub-system 3A
     - Controllers
     - Arduino vs. Raspberry Pi
     - Show images
     - at least one pro and con for each

2/23

Research

Budget

Control system
- Arduino — $25
- Wiring + Accesories — $25

Actuator
- Servos — $30
- Power supply — $20

Manufacturing
- Test stand — $50
- 3D Printing — $150

Buffer Costs — $200

Total — $500

3D Printing costs will use money from school in Paper Cut accts.

2/25

Research

Projects future

Goals:
1) Have a live (working) model
2) Have wind tunnel data to prove efficacy of the flap
3) Have an "action plan" for how to scale up design for a real Cessna 172

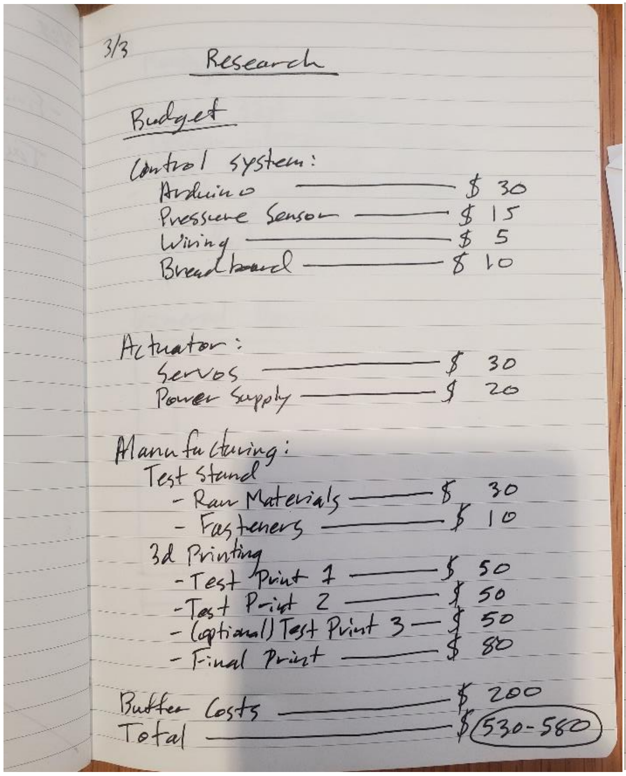
Future
- can be used to advance the exploration of compliant air foils

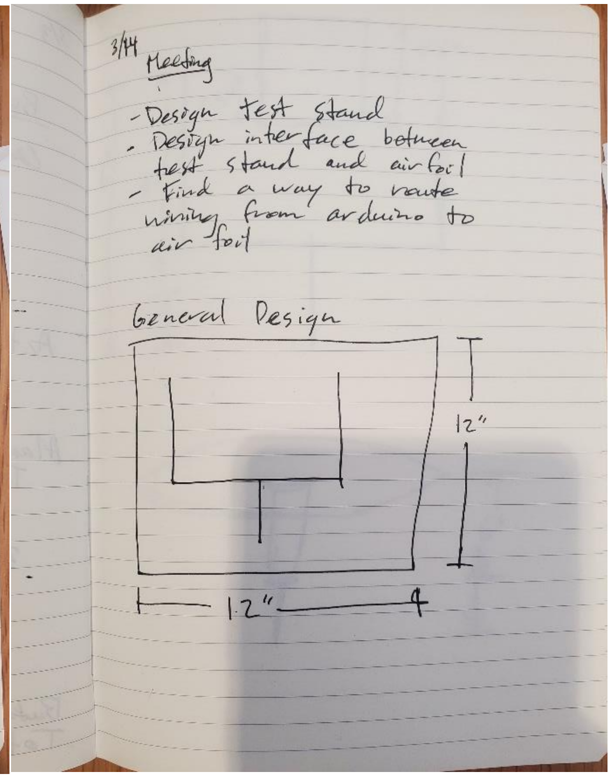
2/28

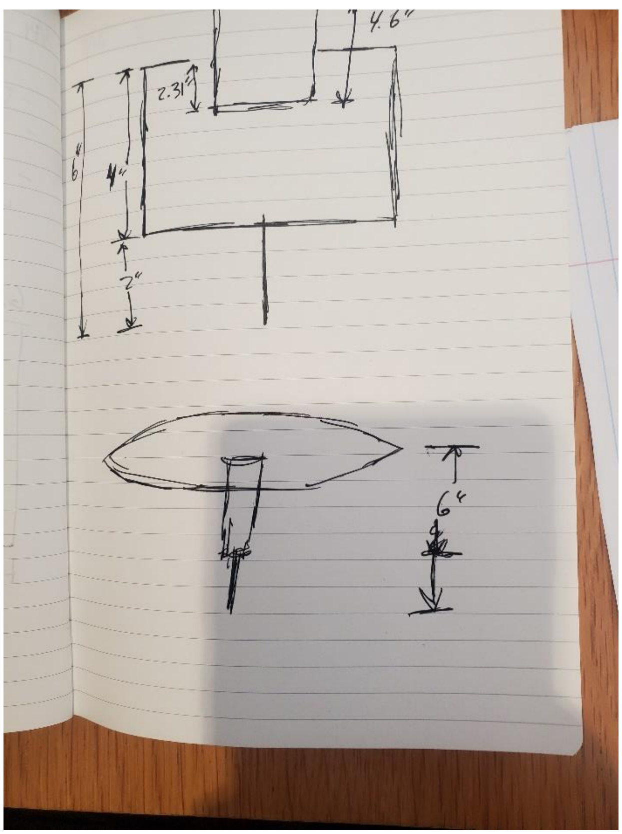
Meeting

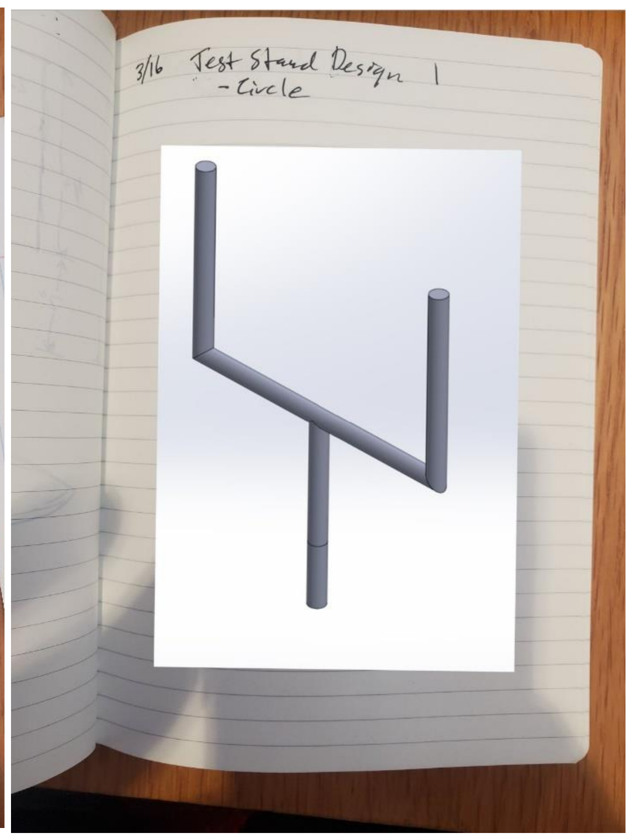
- Finish Midterm Report

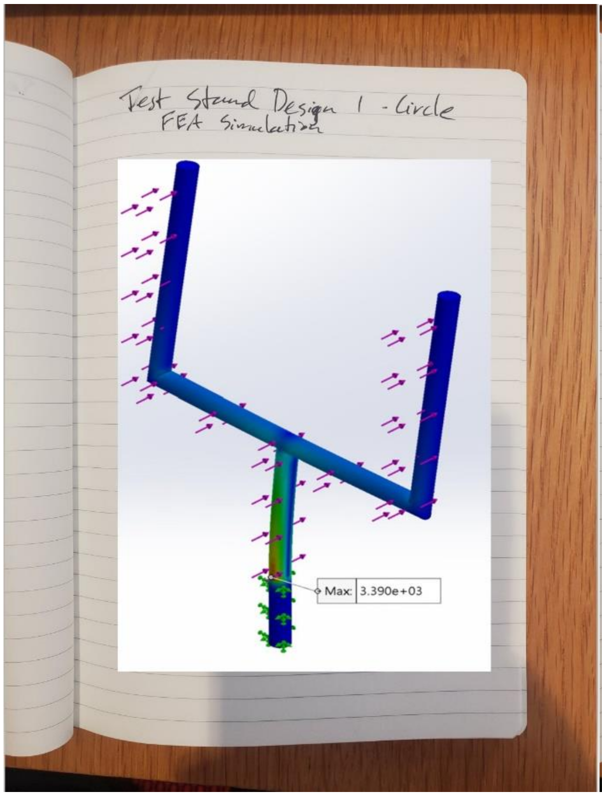
Tasks:
- Cost of parts
  (Under "analysis of design options")
- try to be as detailed as possible

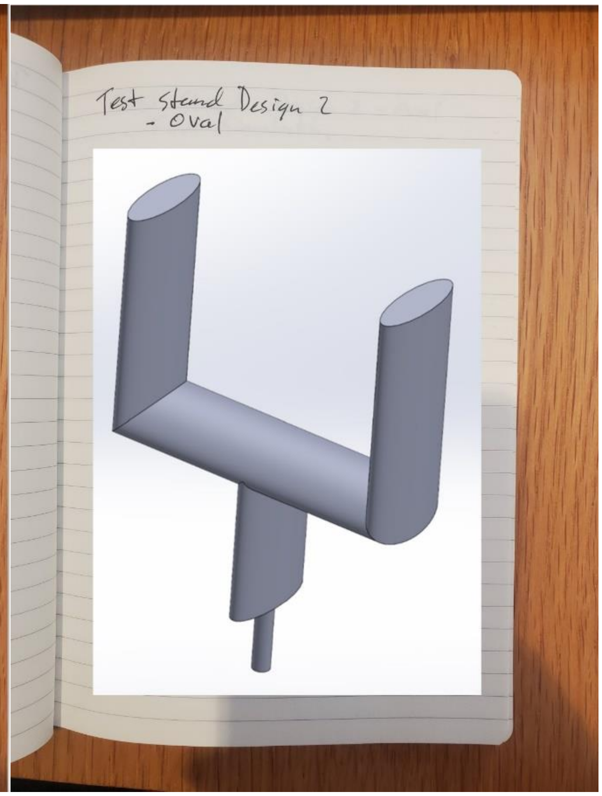

3/3
Research
Budget
Control system:
Arduino $ 30
Pressure Sensor $ 15
Wiring $ 5
Breadboard $ 10
Actuator:
Servos $ 30
Power Supply $ 20
Manufacturing:
Test Stand
- Raw Materials $ 30
- Fasteners $ 10
3d Printing
- Test Print 1 $ 50
- Test Print 2 $ 50
- (optional) Test Print 3 $ 50
- Final Print $ 80
Buffer Costs $ 200
Total $ 530-580

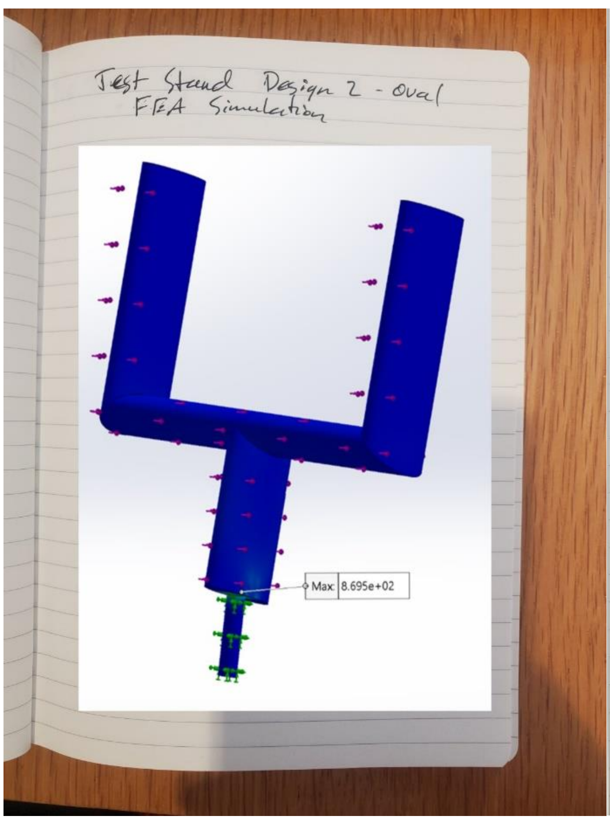

3/14
Meeting
- Design test stand
- Design interface between test stand and air foil
- Find a way to route wiring from arduino to air foil
General Design
12"
12"

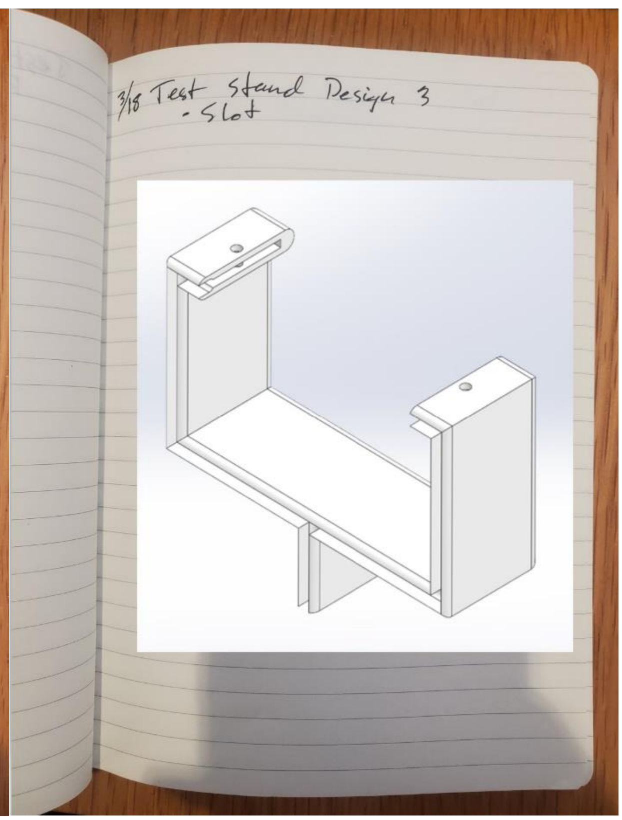

4.6"
2.31"
6"
4"
2"
6"

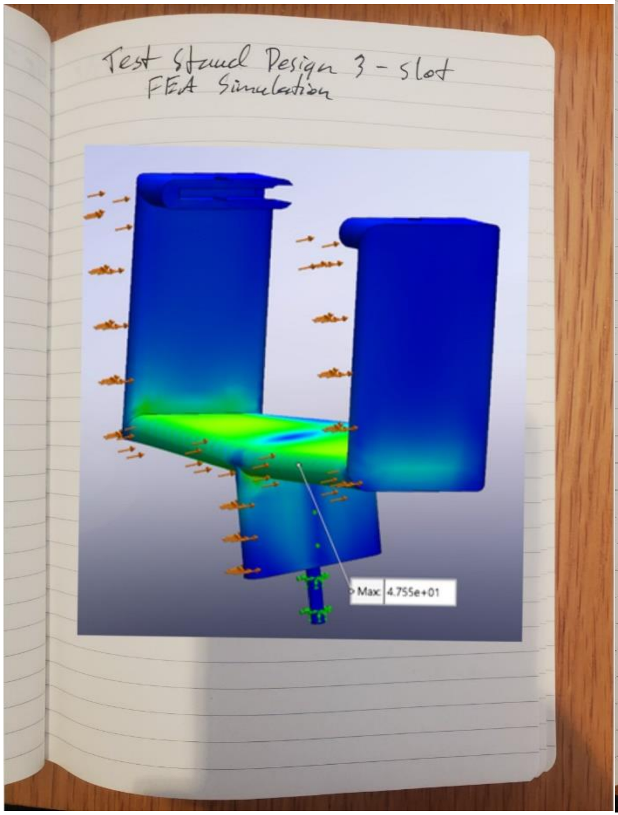

3/16 Test Stand Design 1
- Circle

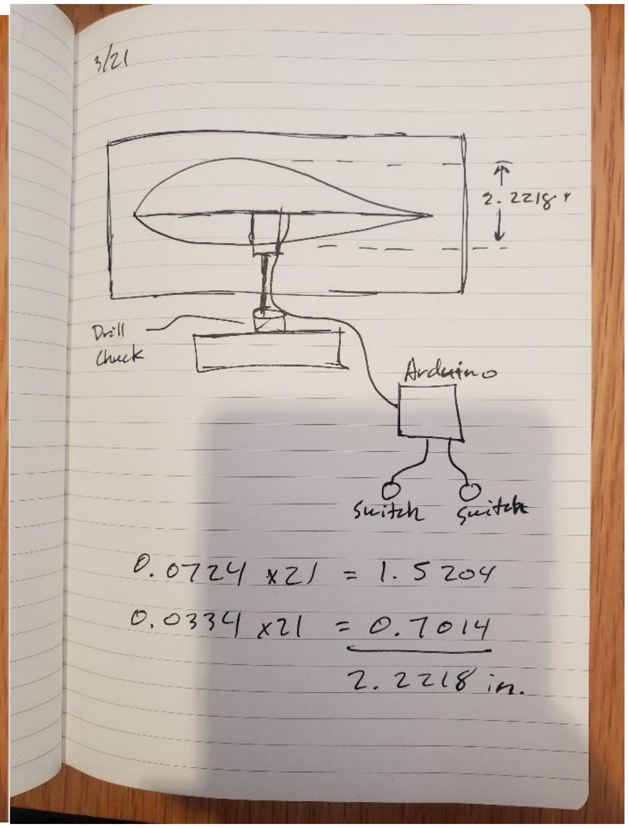

Test Stand Design 1 - Circle
FEA Simulation
Max: 3.390e+03


Test Stand Design 2
- Oval

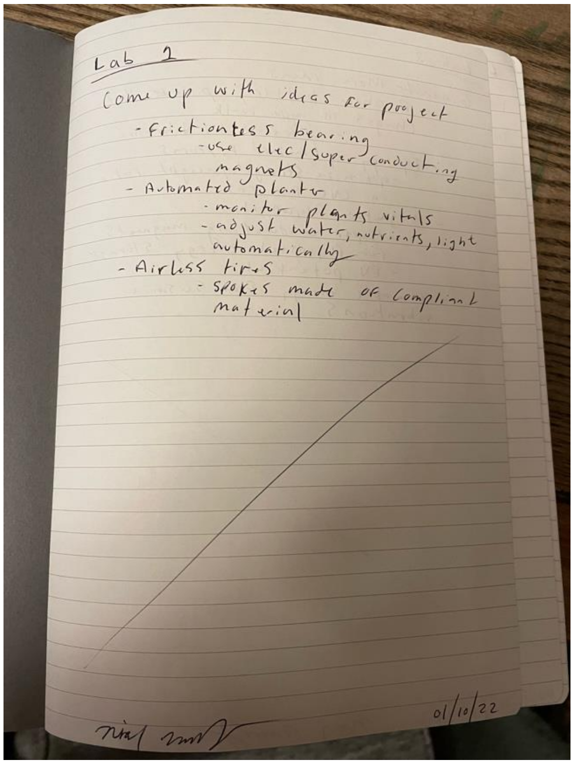

Test Stand Design 2 - Oval
FEA Simulation
Max: 8.695e+02

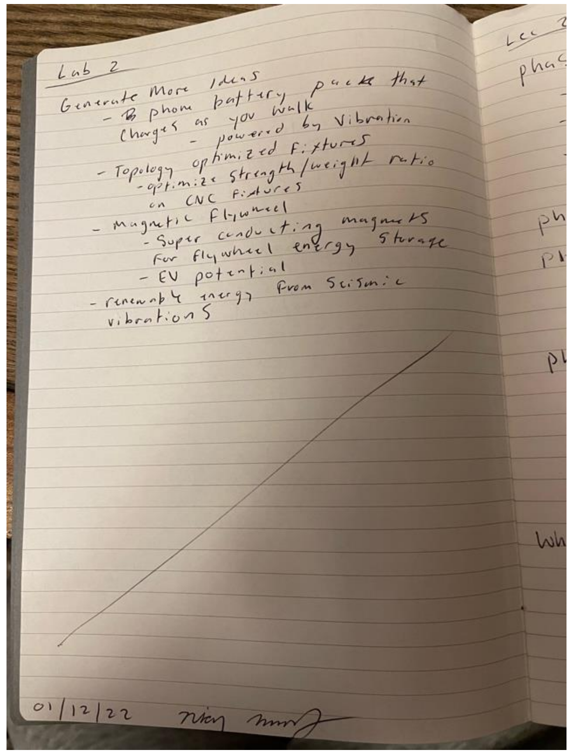

3/18 Test Stand Design 3
- Slot

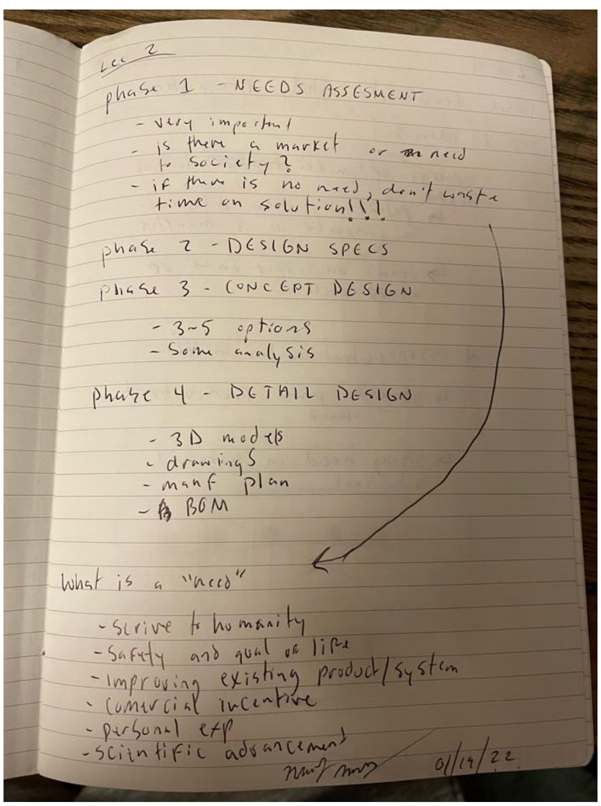

Test Stand Design 3 - slot
FEA Simulation
Max: 4.755e+01

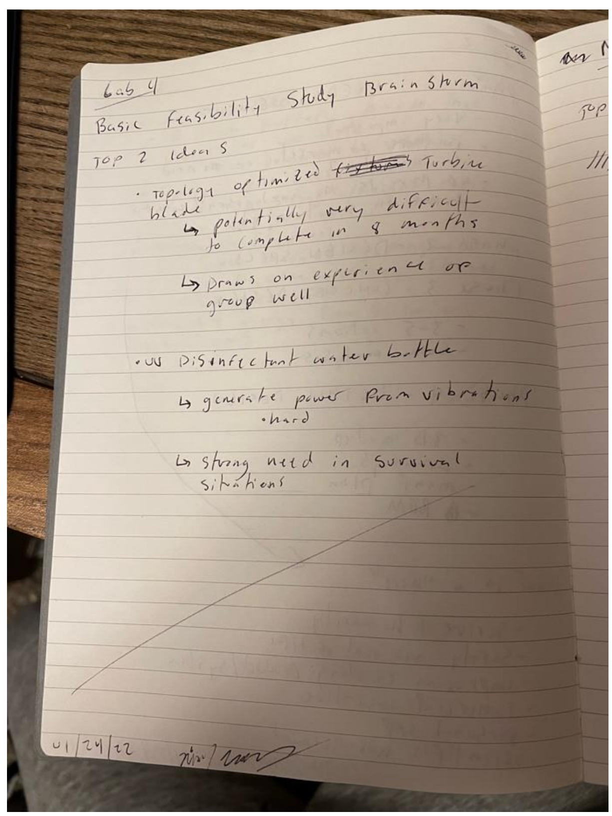

3/21
2.2218 in
Drill Chuck
Arduino
Switch
Switch
0.0724 x21 = 1.5204
0.0334 x21 = 0.7014
2.2218 in.

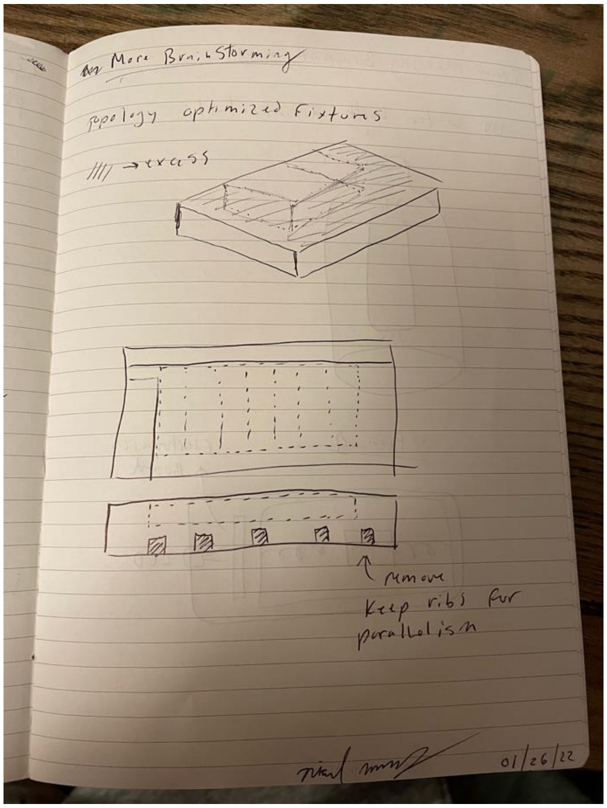
Nial McInally

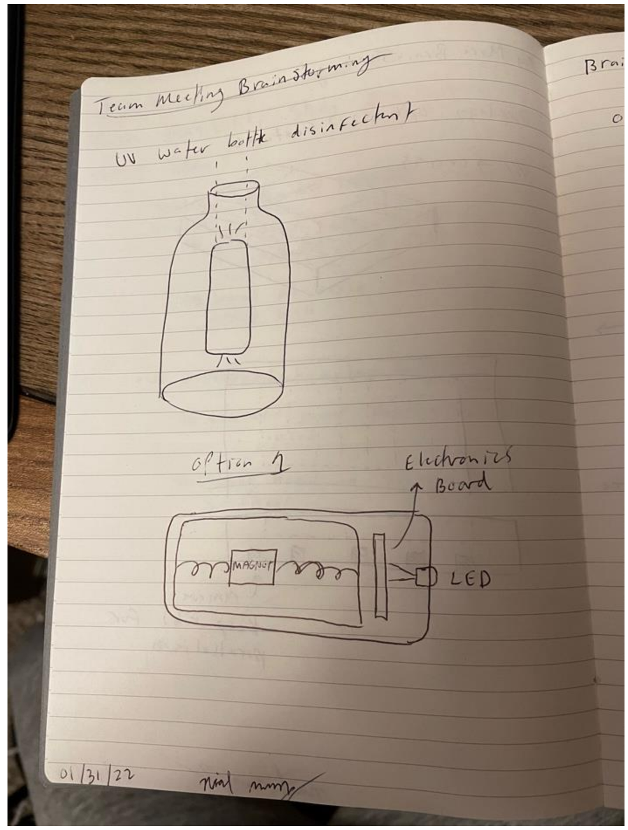


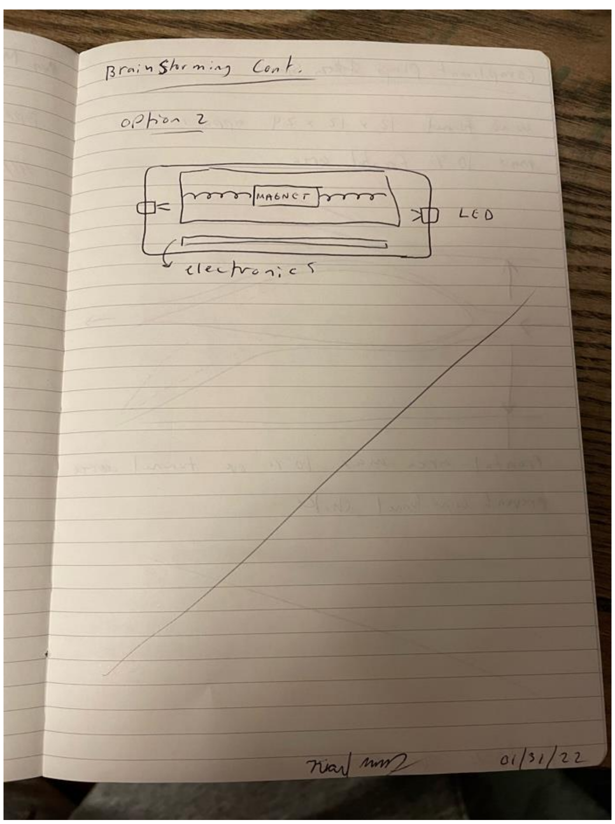


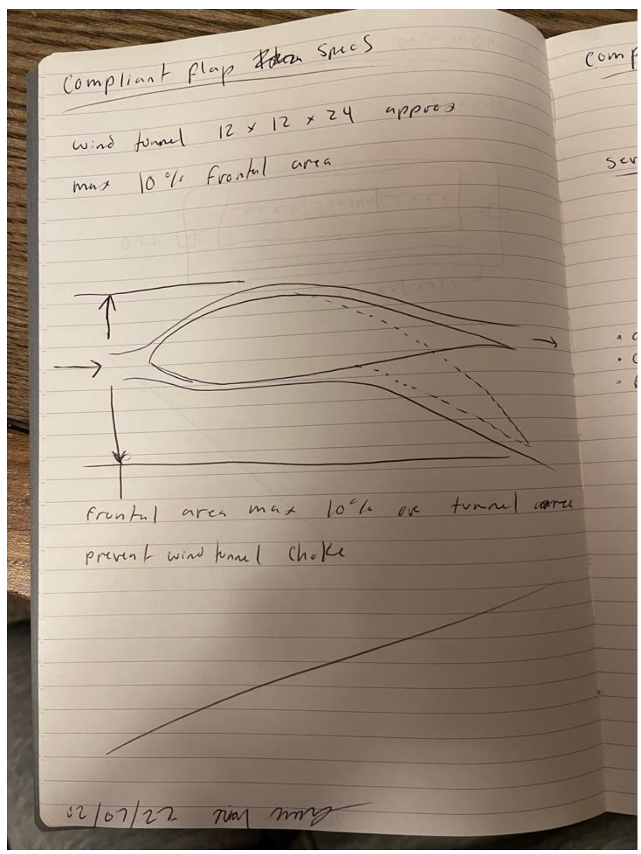


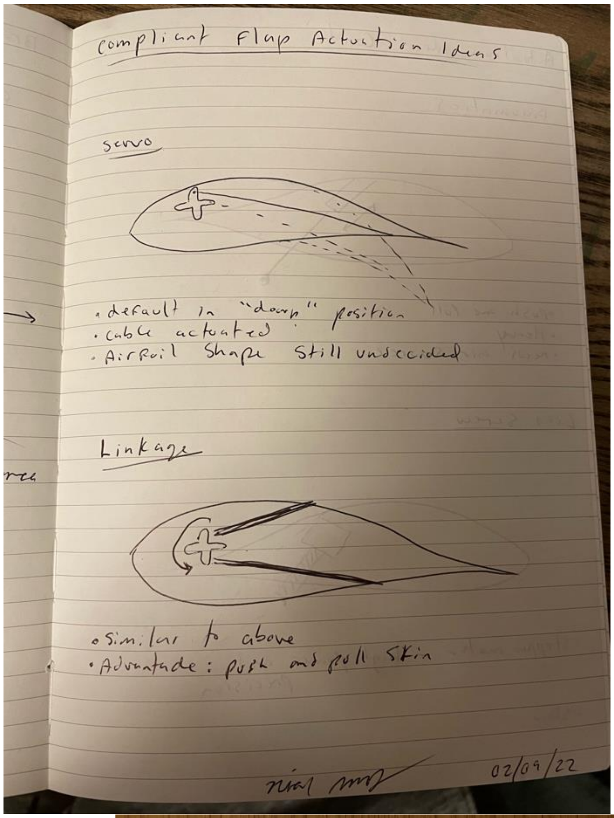


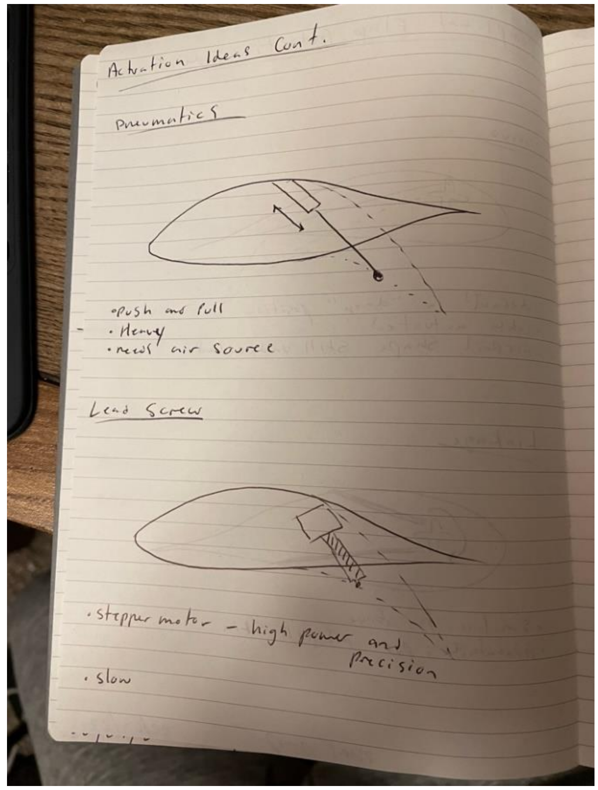

More BrainStorming
Topology optimized Fixtures
excess
remove
Keep ribs for
parallelism
01/26/22

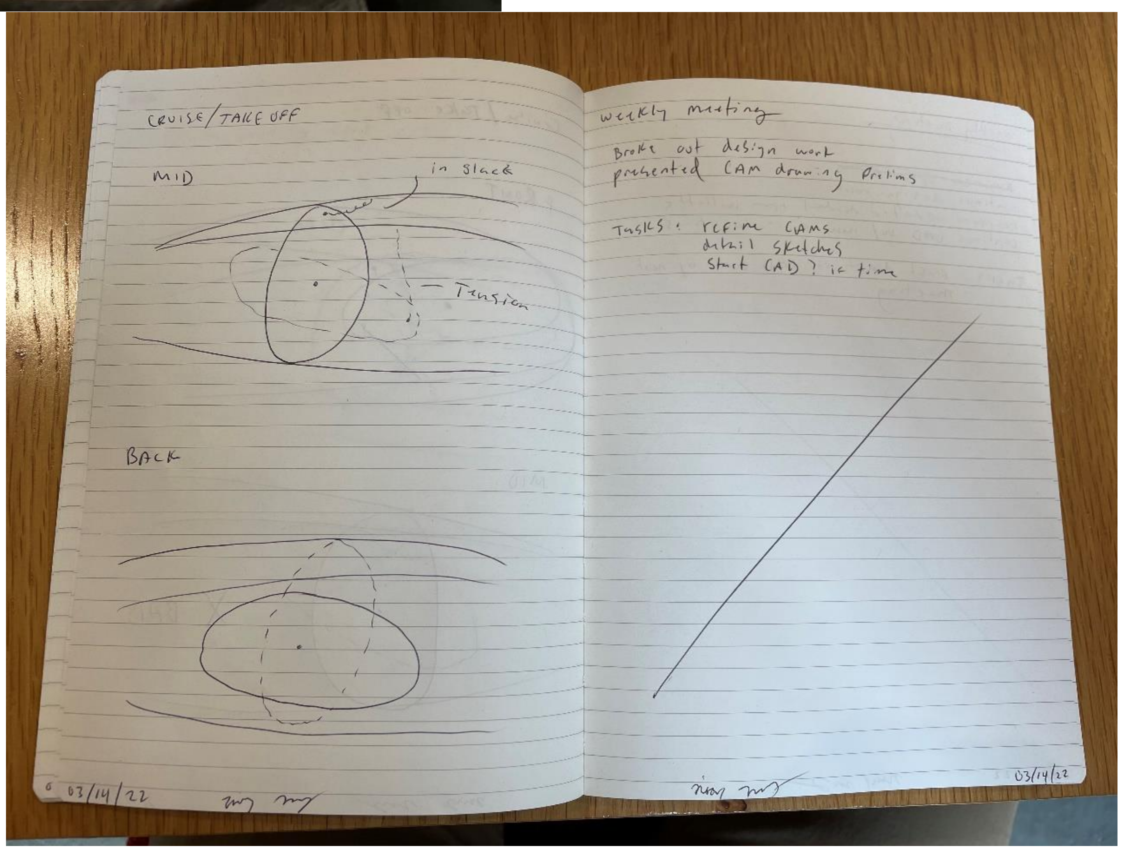

Team Meeting Brainstorming
UV water bottle disinfectant
Option 1
Electronics
Board
MAGNET
LED
01/31/22

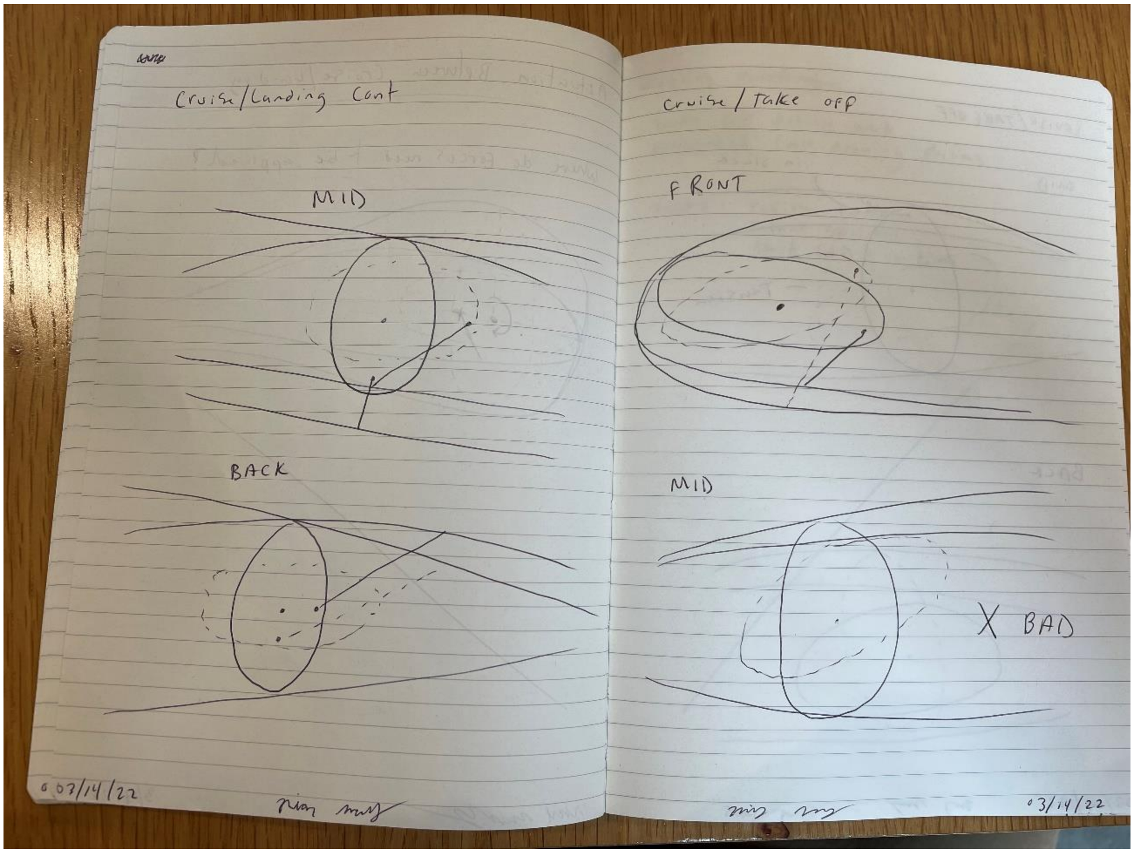

BrainStorming Cont.
Option 2
MAGNET
LED
electronics
01/31/22

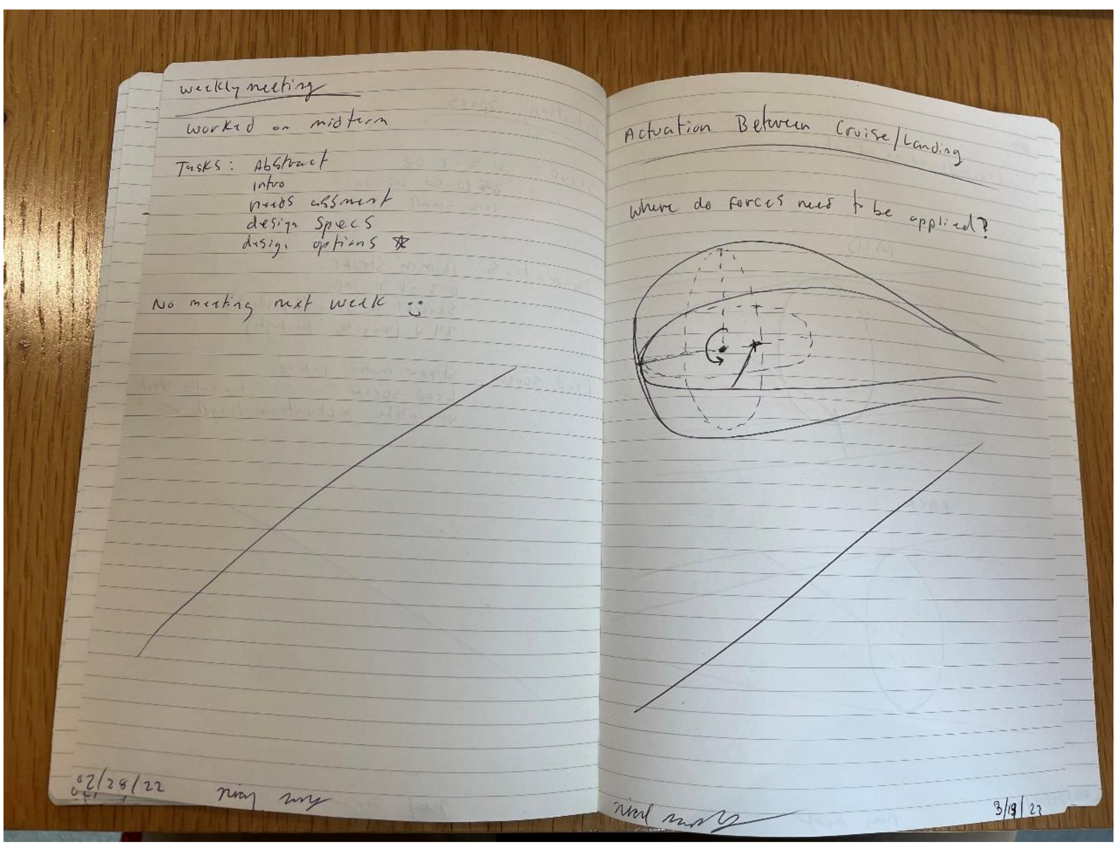

Compliant Flap Specs
wind tunnel 12 x 12 x 24 approx
max 10% frontal area
frontal area max 10% of tunnel
prevent wind tunnel choke
02/07/22

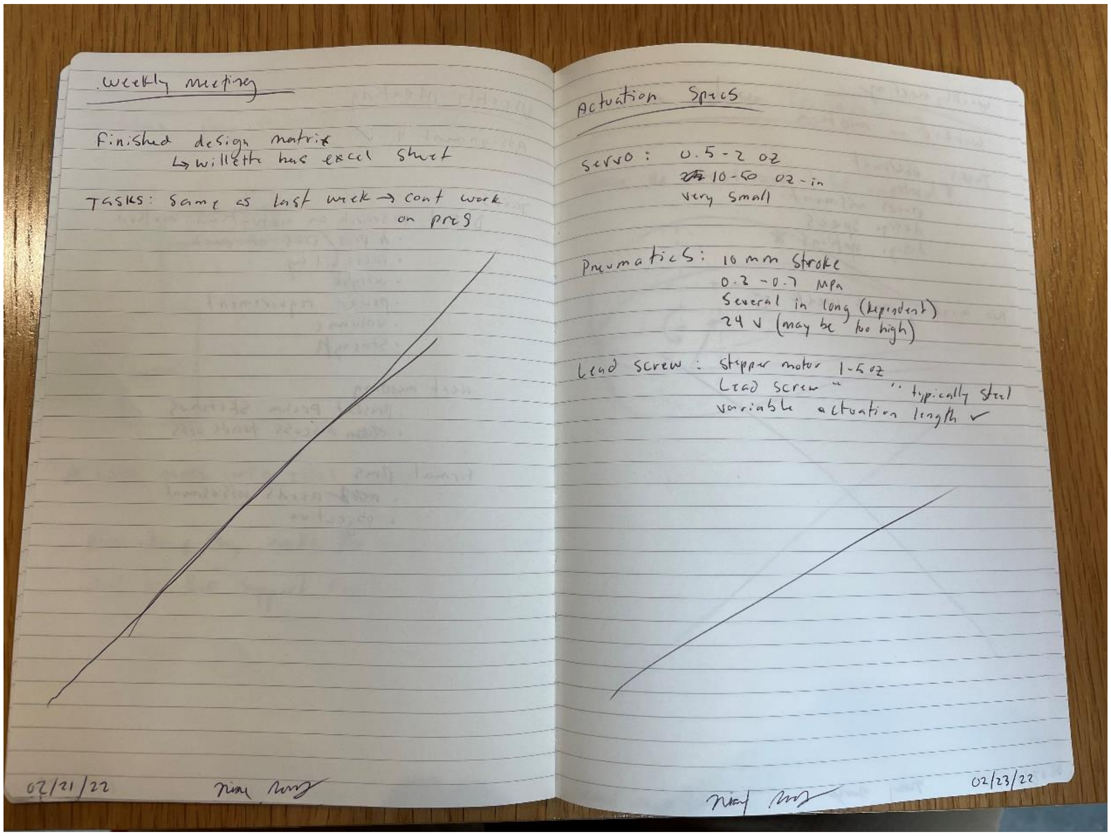

Compliant Flap Actuation Ideas
Servo
• default in "down" position
• cable actuated
• Airfoil Shape still undecided
Linkage
• Similar to above
• Advantage: push and pull skin
02/09/22

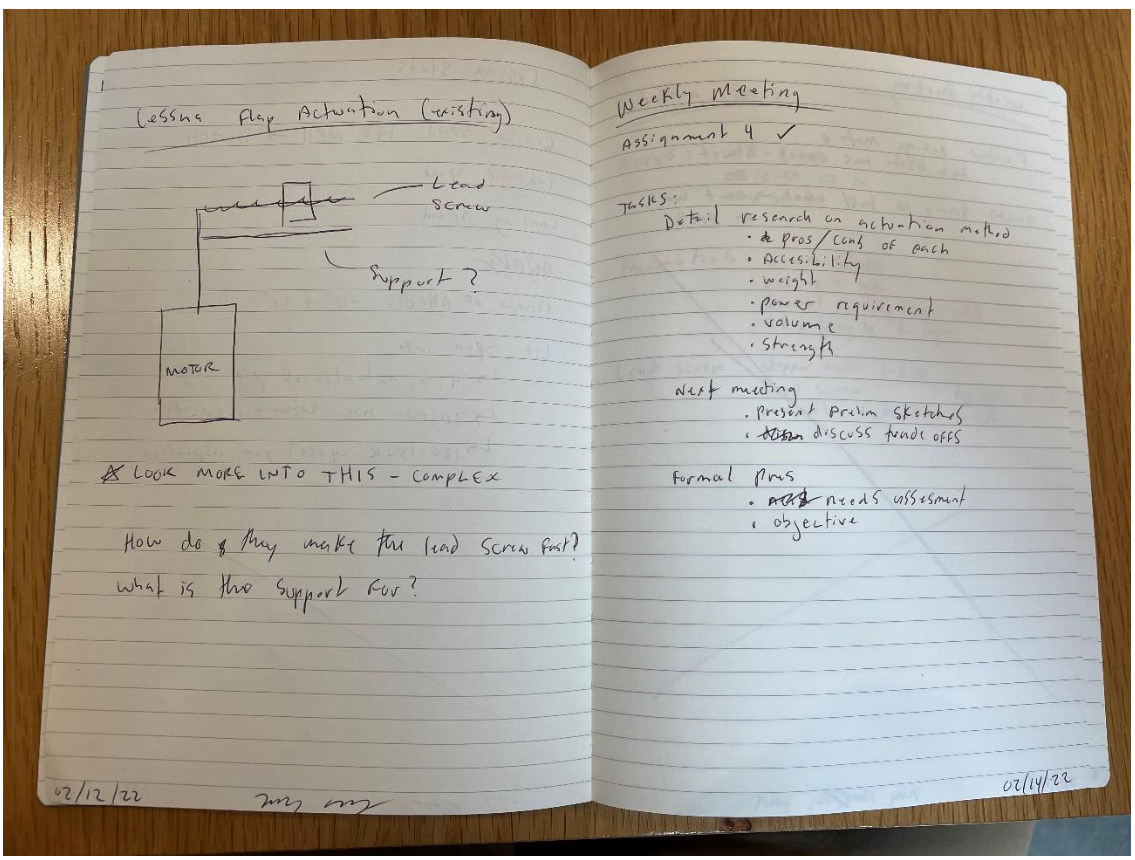

Actuation Ideas Cont.
Pneumatics
• push and pull
• Heavy
• needs air source
Lead Screw
• stepper motor - high power and precision
• slow


CRUISE/TAKE OFF
MID
in slack
Tension
BACK
03/14/22
weekly meeting
Broke out design work
presented CAM drawing prelims
Tasks: refine CAMS
detail sketches
Start CAD? if time
03/14/22

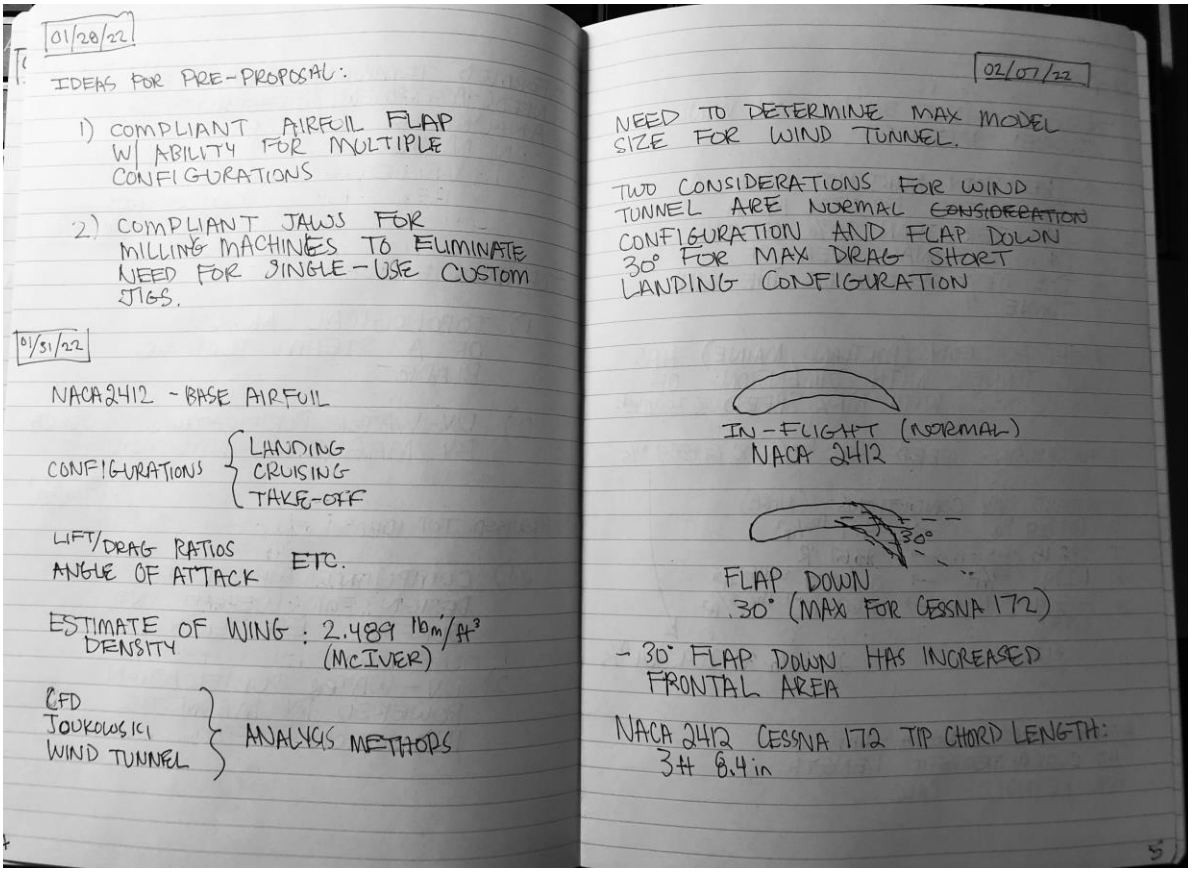

Cruise/Landing Cont
MID
BACK
03/14/22
Cruise/Take off
FRONT
MID
X BAD
03/14/22


weekly meeting
worked on midterm
Tasks: Abstract
intro
needs assment
design specs
design options
No meeting next week
02/28/22
Actuation Between Cruise/Landing
Where do forces need to be applied?
3/8/22


Weekly meeting
Finished design matrix
Willeth has excel sheet
TASKS: Same as last week → cont work on pres
02/21/22
Actuation Specs
Servo: 0.5-2 oz
10-50 oz-in
very small
Pneumatics: 10 mm stroke
0.2-0.7 MPa
Several in long (dependent)
24 V (may be too high)
Lead screw: stepper motor 1-5 oz
Lead screw " " typically steel
variable actuation length
02/23/22


Cessna Flap Actuation (existing)
Lead Screw
Support ?
MOTOR
LOOK MORE INTO THIS - COMPLEX
How do they make the lead screw fast?
What is the support for?
02/12/22
Weekly Meeting
Assignment 4 ✓
Tasks:
Detail research on actuation method
• pros / cons of each
• Accessibility
• weight
• power requirement
• volume
• strength
Next meeting
• Present prelim sketches
• discuss trade offs
Formal pres
• needs assessment
• objective
02/14/22

Andrew Lanzrath



01/28/22

IDEAS FOR PRE-PROPOSAL:

1) COMPLIANT AIRFOIL FLAP W/ ABILITY FOR MULTIPLE CONFIGURATIONS

2) COMPLIANT JAWS FOR MILLING MACHINES TO ELIMINATE NEED FOR SINGLE-USE CUSTOM JIGS.

01/31/22

NACA2412 - BASE AIRFOIL

CONFIGURATIONS { LANDING, CRUISING, TAKE-OFF

LIFT/DRAG RATIOS
ANGLE OF ATTACK
ETC.

ESTIMATE OF WING DENSITY : 2.489 lbm/ft³ (McIVER)

CFD
JOUKOWSKI
WIND TUNNEL
} ANALYSIS METHODS

02/07/22

NEED TO DETERMINE MAX MODEL SIZE FOR WIND TUNNEL.

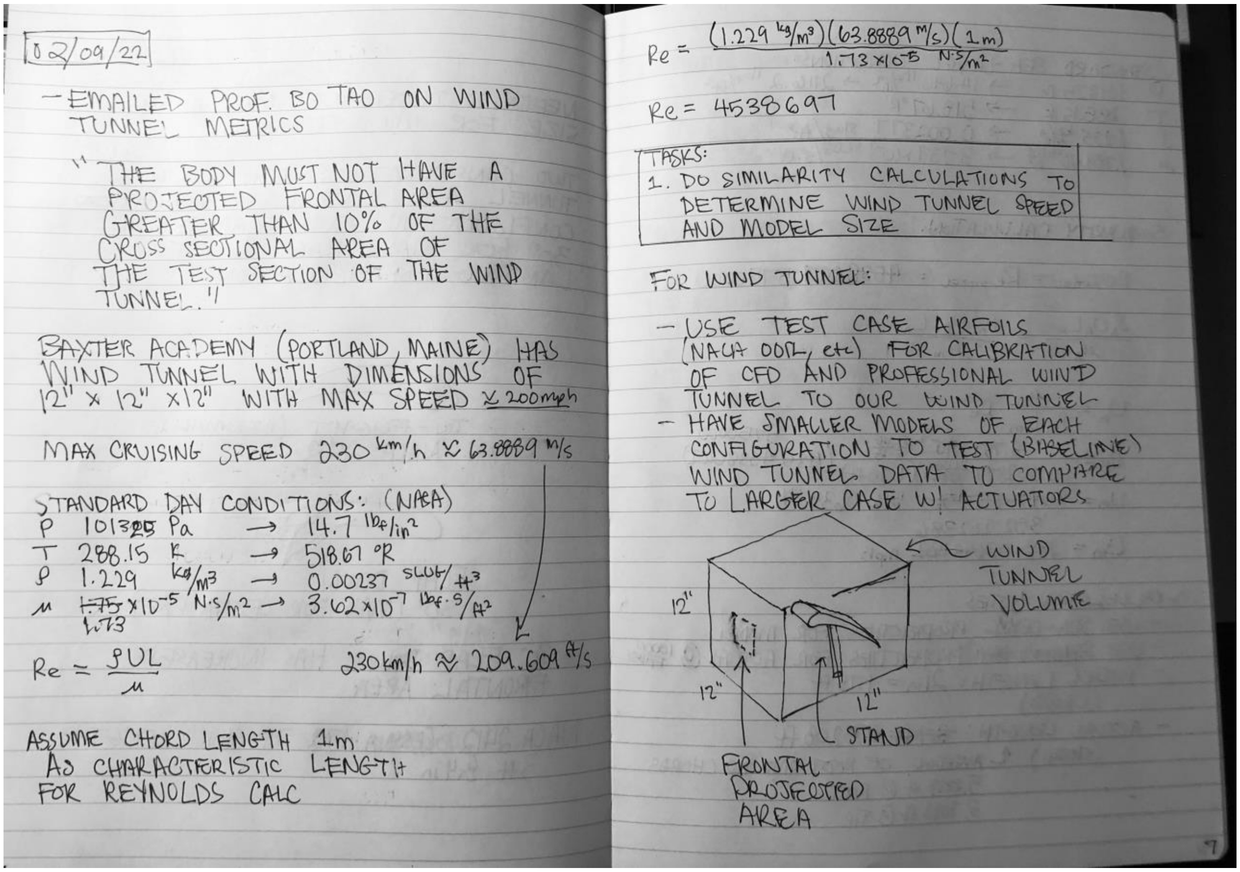
TWO CONSIDERATIONS FOR WIND TUNNEL ARE NORMAL ~~CONSIDERATION~~ CONFIGURATION AND FLAP DOWN 30° FOR MAX DRAG SHORT LANDING CONFIGURATION

IN-FLIGHT (NORMAL)
NACA 2412

30°
FLAP DOWN
30° (MAX FOR CESSNA 172)

- 30° FLAP DOWN HAS INCREASED FRONTAL AREA

NACA 2412 CESSNA 172 TIP CHORD LENGTH:
3ft 8.4 in



02/09/22

- EMAILED PROF. BO TAO ON WIND TUNNEL METRICS

"THE BODY MUST NOT HAVE A PROJECTED FRONTAL AREA GREATER THAN 10% OF THE CROSS SECTIONAL AREA OF THE TEST SECTION OF THE WIND TUNNEL."

BAXTER ACADEMY (PORTLAND, MAINE) HAS WIND TUNNEL WITH DIMENSIONS OF 12" x 12" x 12" WITH MAX SPEED ≈ 200mph

MAX CRUISING SPEED 230 km/h ≈ 63.8889 m/s

STANDARD DAY CONDITIONS: (NASA)

P 101325 Pa → 14.7 lbf/in²

T 288.15 K → 518.67 °R

ρ 1.229 kg/m³ → 0.00237 slug/ft³

μ ~~1.75~~ 1.73 x10⁻⁵ N·s/m² → 3.62x10⁻⁷ lbf·s/ft²

$Re = \frac{\rho U L}{\mu}$

230 km/h ≈ 209.609 ft/s

ASSUME CHORD LENGTH 1m AS CHARACTERISTIC LENGTH FOR REYNOLDS CALC

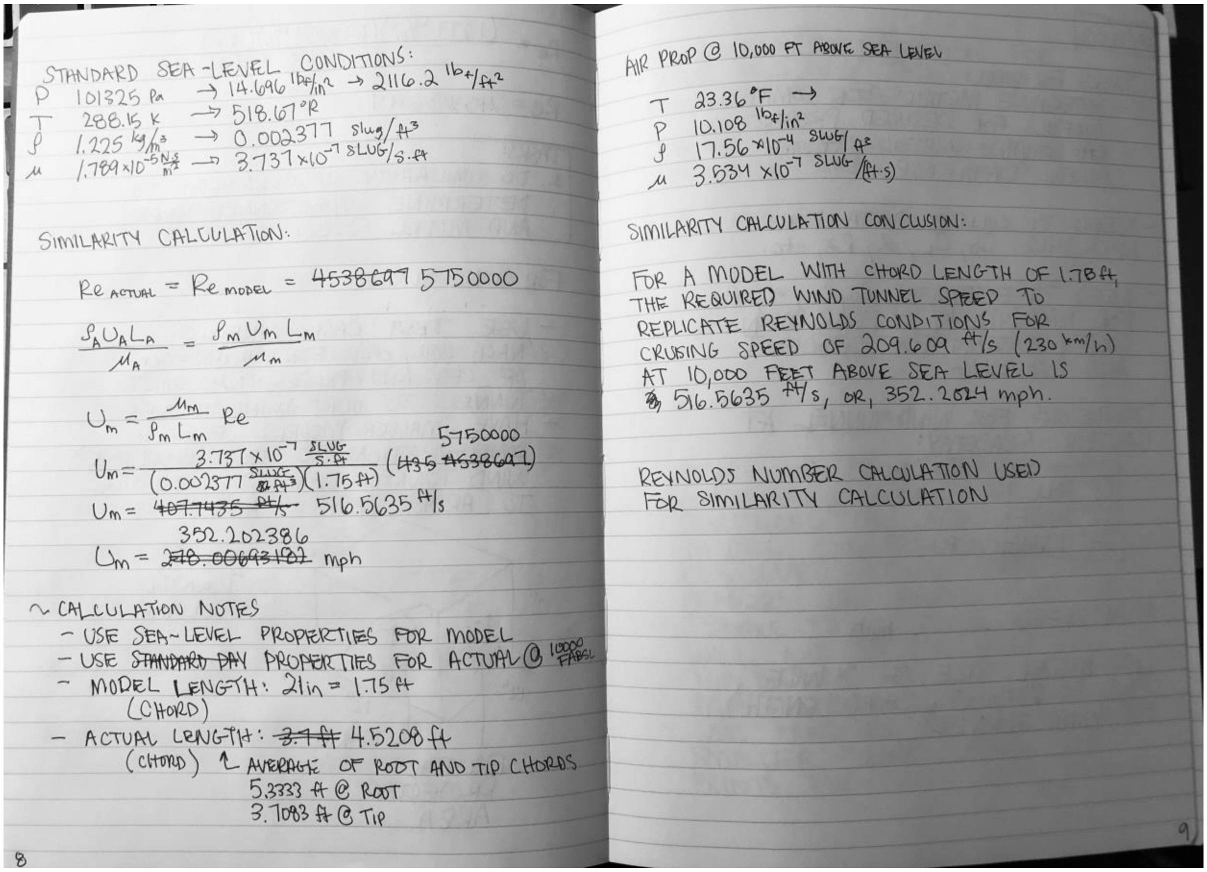
$Re = \frac{(1.229\ kg/m^3)(63.8889\ m/s)(1\ m)}{1.73\times10^{-5}\ N\cdot s/m^2}$

Re = 4538697

TASKS:
1. DO SIMILARITY CALCULATIONS TO DETERMINE WIND TUNNEL SPEED AND MODEL SIZE

FOR WIND TUNNEL:

- USE TEST CASE AIRFOILS (NACA 0012, etc) FOR CALIBRATION OF CFD AND PROFESSIONAL WIND TUNNEL TO OUR WIND TUNNEL
- HAVE SMALLER MODELS OF EACH CONFIGURATION TO TEST (BASELINE) WIND TUNNEL DATA TO COMPARE TO LARGER CASE W/ ACTUATORS



STANDARD SEA-LEVEL CONDITIONS:

P 101325 Pa → 14.696 lbf/in² → 2116.2 lbf/ft²

T 288.15 K → 518.67 °R

ρ 1.225 kg/m³ → 0.002377 slug/ft³

μ 1.789×10^{-5} N·s/m² → 3.737×10^{-7} SLUG/s·ft

SIMILARITY CALCULATION:

$Re_{ACTUAL} = Re_{MODEL} =$ ~~4538697~~ 5750000

$$\frac{\rho_A U_A L_A}{\mu_A} = \frac{\rho_m U_m L_m}{\mu_m}$$

$$U_m = \frac{\mu_m}{\rho_m L_m} Re$$

$$U_m = \frac{3.737 \times 10^{-7} \frac{SLUG}{S \cdot ft}}{(0.002377 \frac{SLUG}{ft^3})(1.75 ft)} (5750000)$$

(~~435~~ ~~4538697~~)

$U_m =$ ~~407.7435 ft/s~~ 516.5635 ft/s

$U_m =$ ~~278.00693182~~ 352.202386 mph

~ CALCULATION NOTES

- USE SEA-LEVEL PROPERTIES FOR MODEL
- USE ~~STANDARD DAY~~ PROPERTIES FOR ACTUAL @ 10000 FABSL
- MODEL LENGTH: 21 in = 1.75 ft (CHORD)
- ACTUAL LENGTH: ~~3.1 ft~~ 4.5208 ft (CHORD) ↑ AVERAGE OF ROOT AND TIP CHORDS
  - 5.3333 ft @ ROOT
  - 3.7083 ft @ TIP

8

AIR PROP @ 10,000 FT ABOVE SEA LEVEL

T 23.36 °F →

P 10.108 lbf/in²

ρ 17.56×10^{-4} SLUG/ft³

μ 3.534×10^{-7} SLUG/(ft·s)

SIMILARITY CALCULATION CONCLUSION:

FOR A MODEL WITH CHORD LENGTH OF 1.75 ft, THE REQUIRED WIND TUNNEL SPEED TO REPLICATE REYNOLDS CONDITIONS FOR CRUISING SPEED OF 209.609 ft/s (230 km/h) AT 10,000 FEET ABOVE SEA LEVEL IS 516.5635 ft/s, OR, 352.2024 mph.

REYNOLDS NUMBER CALCULATION USED FOR SIMILARITY CALCULATION

9

02/14/22

TASKS FOR WEEK:
- DETERMINE METRICS FOR COMPARING AIRFOILS FOR DESIRED PROPERTIES
- ~~CA~~ COMPARE AIRFOILS FROM AIRFOIL DATABASE

- NEED TO COLLECT DATA FOR NACA2412 C_D, C_L, α, Re, etc.

- NEED TO ESTIMATE C_D, C_L, α, Re FOR NACA2412 W/ 30° FLAP DOWN CONFIGURATION FOR DESCENT AND LANDING

DIMENSIONS FOR WIND TUNNEL AT BAXTER ACADEMY:

12" TALL
12" WIDE
24" LONG

MAX SPEED: ______ mph

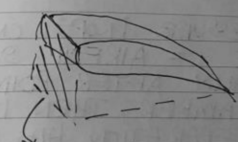
USE MODEL SIZE OF 2" WIDE AND ≈ 6" ~~LONG~~ TALL (CHORD LENGTH) FOR WIND TUNNEL

10

METHODOLOGY/JUSTIFICATION FOR 2" WIDE AND ≈ 6" TALL WIND TUNNEL TEST MODEL:

- BAXTER WIND TUNNEL HAS CROSS SECTIONAL AREA OF 144 in^2

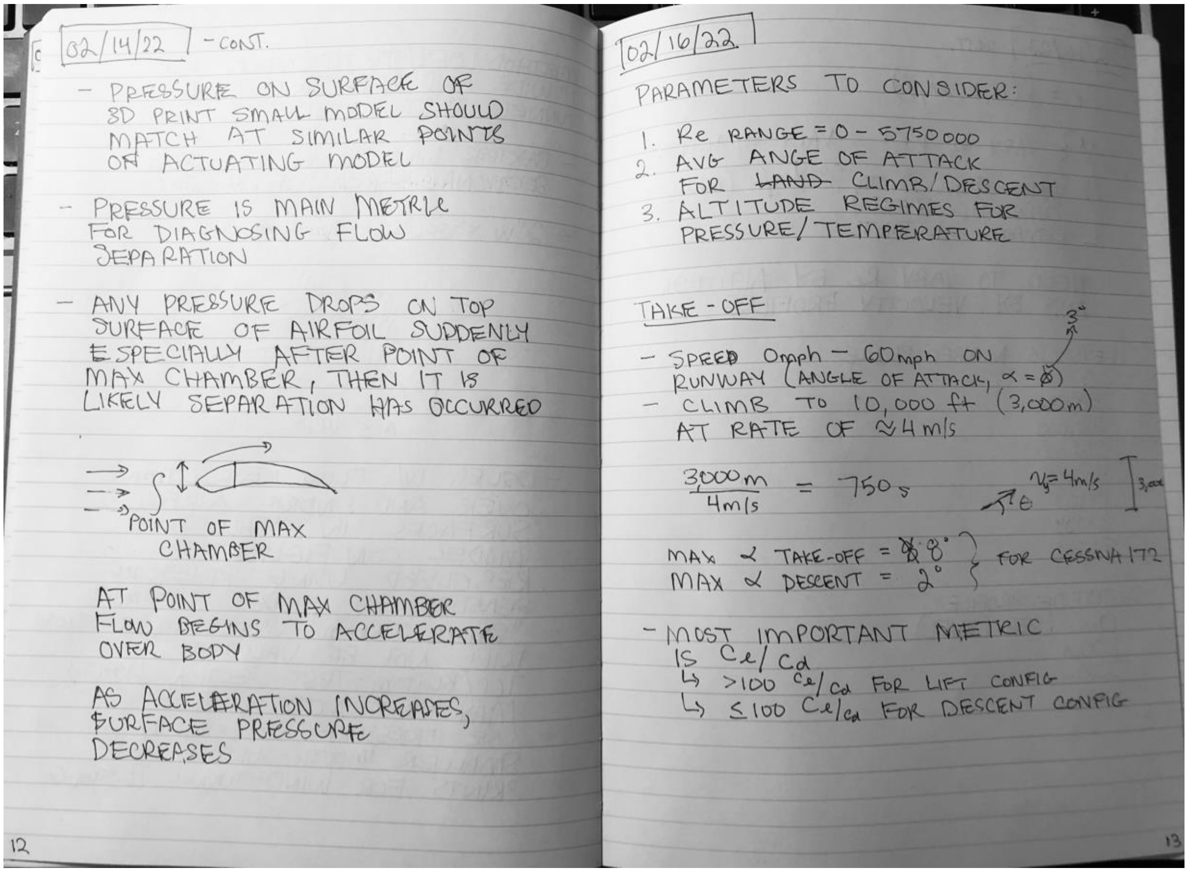
- $2"W \times \approx 6"H = 12 \lesssim 14 in^2$



$A \leq 14 in^2$

- ISSUES W/ FLOW RESOLUTION OVER AND UNDER AIRFOIL SURFACES IN "TALL-THIN" MODEL CONFIGURATION RESOLVED USING PRESSURE SENSORS ON MODEL SURFACE
- "SMOKE STREAM" VISUAL DIAGNOSTICS WILL NOT BE VALID AS TOP/BOTTOM TEST SECTION WALLS MAY INTERACT W/ FLOW
- USE PRESSURE SENSORS IN SMALLER SMOOTH-SURFACE 3-D PRINTS FOR WIND-TUNNEL TESTING

11



02/14/22 - CONT.

- PRESSURE ON SURFACE OF 3D PRINT SMALL MODEL SHOULD MATCH AT SIMILAR POINTS OF ACTUATING MODEL
- PRESSURE IS MAIN METRIC FOR DIAGNOSING FLOW SEPARATION
- ANY PRESSURE DROPS ON TOP SURFACE OF AIRFOIL SUDDENLY ESPECIALLY AFTER POINT OF MAX CHAMBER, THEN IT IS LIKELY SEPARATION HAS OCCURRED

AT POINT OF MAX CHAMBER FLOW BEGINS TO ACCELERATE OVER BODY

AS ACCELERATION INCREASES, SURFACE PRESSURE DECREASES

12

02/16/22

PARAMETERS TO CONSIDER:

1. Re RANGE = 0 - 5750000
2. AVG ANGE OF ATTACK FOR ~~LAND~~ CLIMB/DESCENT
3. ALTITUDE REGIMES FOR PRESSURE/TEMPERATURE

TAKE-OFF

- SPEED 0mph - 60mph ON RUNWAY (ANGLE OF ATTACK, $\alpha = 0$) 3°
- CLIMB TO 10,000 ft (3,000m) AT RATE OF ≈4 m/s

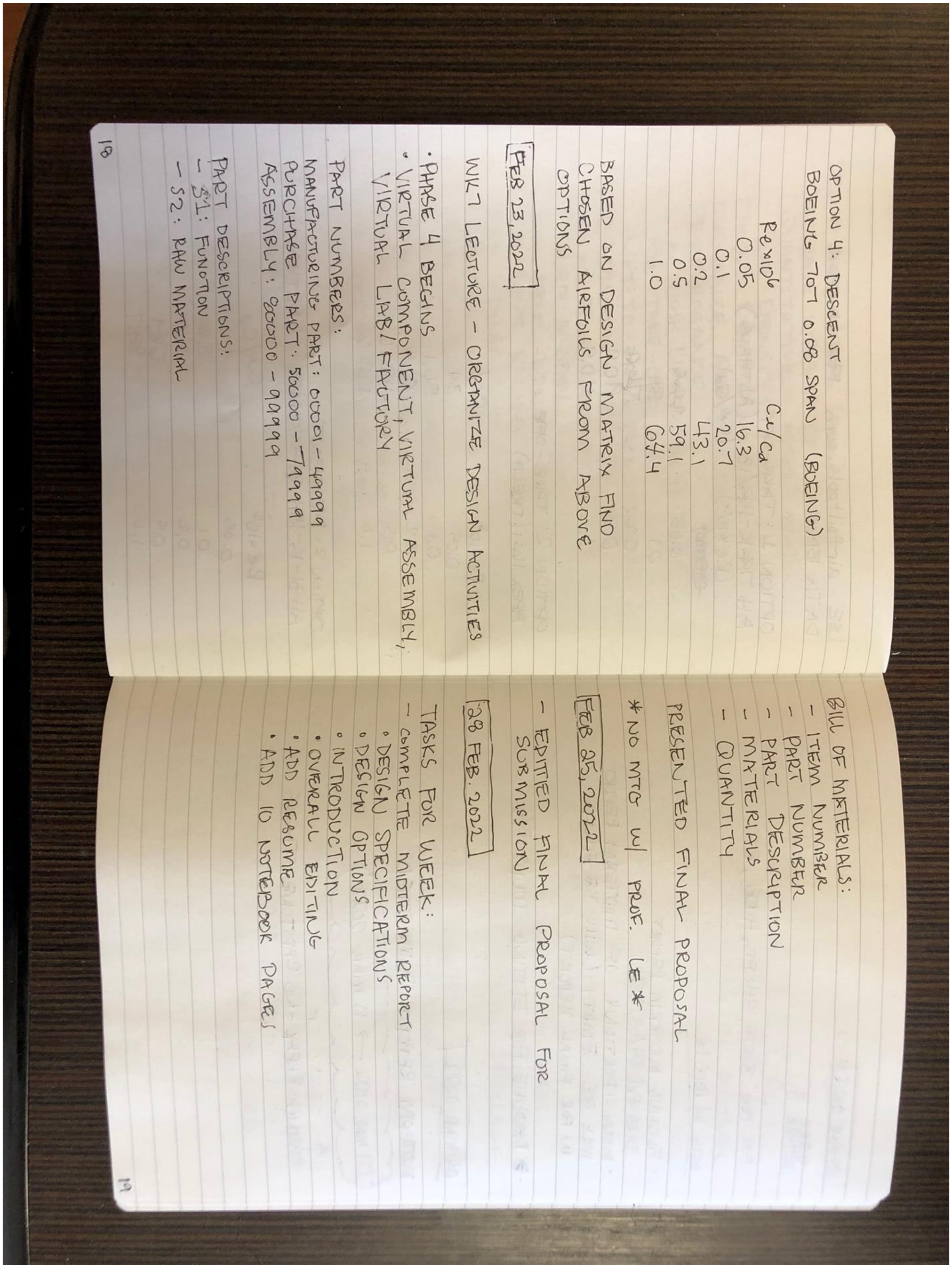
$$\frac{3000\,m}{4\,m/s} = 750\,s$$

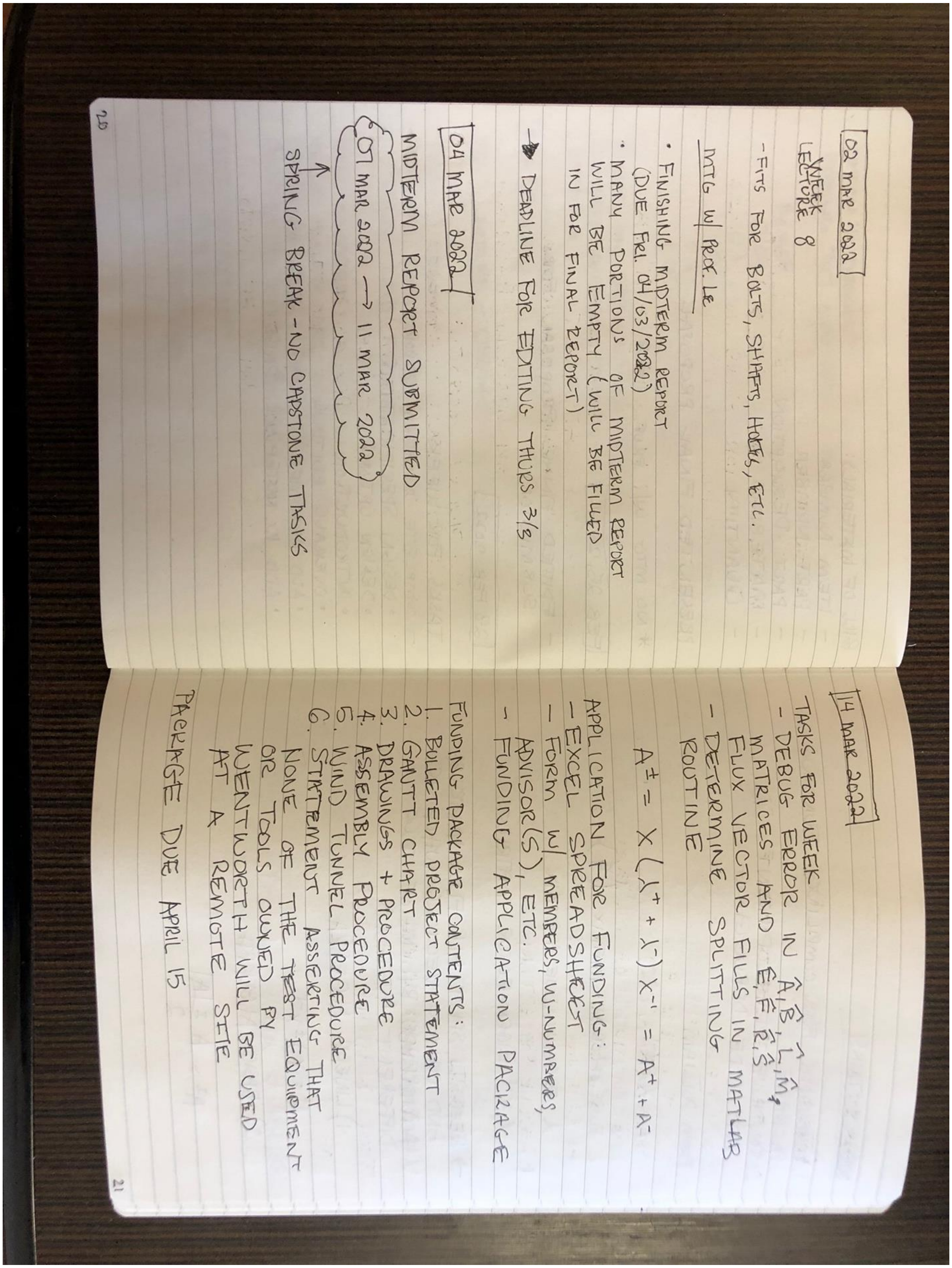
$V_y = 4\,m/s$, θ, 3,000

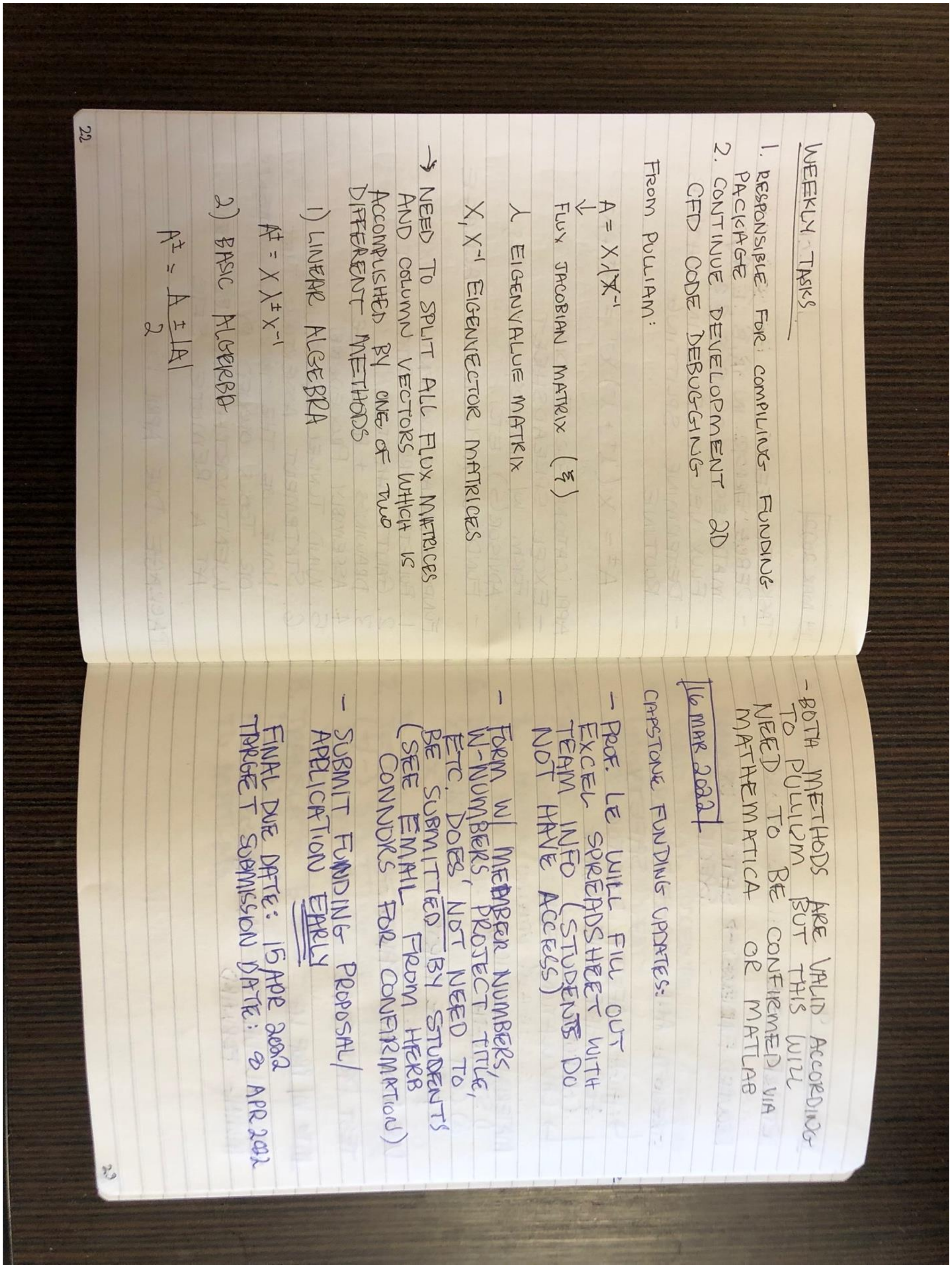
MAX α TAKE-OFF = ~~8~~ 8°
MAX α DESCENT = 2°
} FOR CESSNA 172

- MOST IMPORTANT METRIC IS C_l/C_d
  - ↳ >100 C_l/C_d FOR LIFT CONFIG
  - ↳ ≤100 C_l/C_d FOR DESCENT CONFIG

13


OPTION 4: DESCENT
BOEING 707 0.08 SPAN (BOEING)
Re x10^6 Cl/Cd
0.05 16.3
0.1 20.7
0.2 43.1
0.5 59.1
1.0 64.4
BASED ON DESIGN MATRIX FIND CHOSEN AIRFOILS FROM ABOVE OPTIONS
FEB 23, 2022
WK7 LECTURE - ORGANIZE DESIGN ACTIVITIES
• PHASE 4 BEGINS
• VIRTUAL COMPONENT, VIRTUAL ASSEMBLY, VIRTUAL LAB/FACTORY
PART NUMBERS:
MANUFACTURING PART: 00001 - 49999
PURCHASE PART: 50000 - 79999
ASSEMBLY: 80000 - 99999
PART DESCRIPTIONS:
- S1: FUNCTION
- S2: RAW MATERIAL
18
BILL OF MATERIALS:
- ITEM NUMBER
- PART NUMBER
- PART DESCRIPTION
- MATERIALS
- QUANTITY
PRESENTED FINAL PROPOSAL
* NO MTG W/ PROF. LE *
FEB 25, 2022
- EDITED FINAL PROPOSAL FOR SUBMISSION
28 FEB. 2022
TASKS FOR WEEK:
- COMPLETE MIDTERM REPORT
° DESIGN SPECIFICATIONS
° DESIGN OPTIONS
° INTRODUCTION
• OVERALL EDITING
• ADD RESUME
• ADD 10 NOTEBOOK PAGES
19


02 MAR 2022
WEEK LECTURE 8
- FITS FOR BOLTS, SHAFTS, HOLES, ETC.
MTG W/ PROF. LE
• FINISHING MIDTERM REPORT (DUE FRI. 04/03/2022)
• MANY PORTIONS OF MIDTERM REPORT WILL BE EMPTY (WILL BE FILLED IN FOR FINAL REPORT)
→ DEADLINE FOR EDITING THURS 3/3
04 MAR 2022
MIDTERM REPORT SUBMITTED
07 MAR 2022 → 11 MAR 2022
SPRING BREAK - NO CAPSTONE TASKS
20
14 MAR 2022
TASKS FOR WEEK
- DEBUG ERROR IN $\hat{A}, \hat{B}, \hat{L}, \hat{M}$, MATRICES AND $\hat{E}, \hat{F}, \hat{R}, \hat{S}$ FLUX VECTOR FILLS IN MATLAB
- DETERMINE SPLITTING ROUTINE
$A^{\pm} = X(\Lambda^{+} + \Lambda^{-})X^{-1} = A^{+} + A^{-}$
APPLICATION FOR FUNDING:
- EXCEL SPREADSHEET
- FORM W/ MEMBERS, W-NUMBERS, ADVISOR(S), ETC.
- FUNDING APPLICATION PACKAGE
FUNDING PACKAGE CONTENTS:
1. BULLETED PROJECT STATEMENT
2. GANTT CHART
3. DRAWINGS + PROCEDURE
4. ASSEMBLY PROCEDURE
5. WIND TUNNEL PROCEDURE
6. STATEMENT ASSERTING THAT NONE OF THE TEST EQUIPMENT OR TOOLS OWNED BY WENTWORTH WILL BE USED AT A REMOTE SITE
PACKAGE DUE APRIL 15
21



WEEKLY TASKS

1. RESPONSIBLE FOR COMPILING FUNDING PACKAGE
2. CONTINUE DEVELOPMENT 2D CFD CODE DEBUGGING

FROM PULLIAM:

$A = X \lambda X^{-1}$

↓

FLUX JACOBIAN MATRIX (ξ)

λ EIGENVALUE MATRIX

X, X^{-1} EIGENVECTOR MATRICES

→ NEED TO SPLIT ALL FLUX MATRICES AND COLUMN VECTORS WHICH IS ACCOMPLISHED BY ONE OF TWO DIFFERENT METHODS

1) LINEAR ALGEBRA

$A^{\pm} = X \lambda^{\pm} X^{-1}$

2) BASIC ALGEBRA

$A^{\pm} = \frac{A \pm |A|}{2}$

22

- BOTH METHODS ARE VALID ACCORDING TO PULLIUM BUT THIS WILL NEED TO BE CONFIRMED VIA MATHEMATICA OR MATLAB

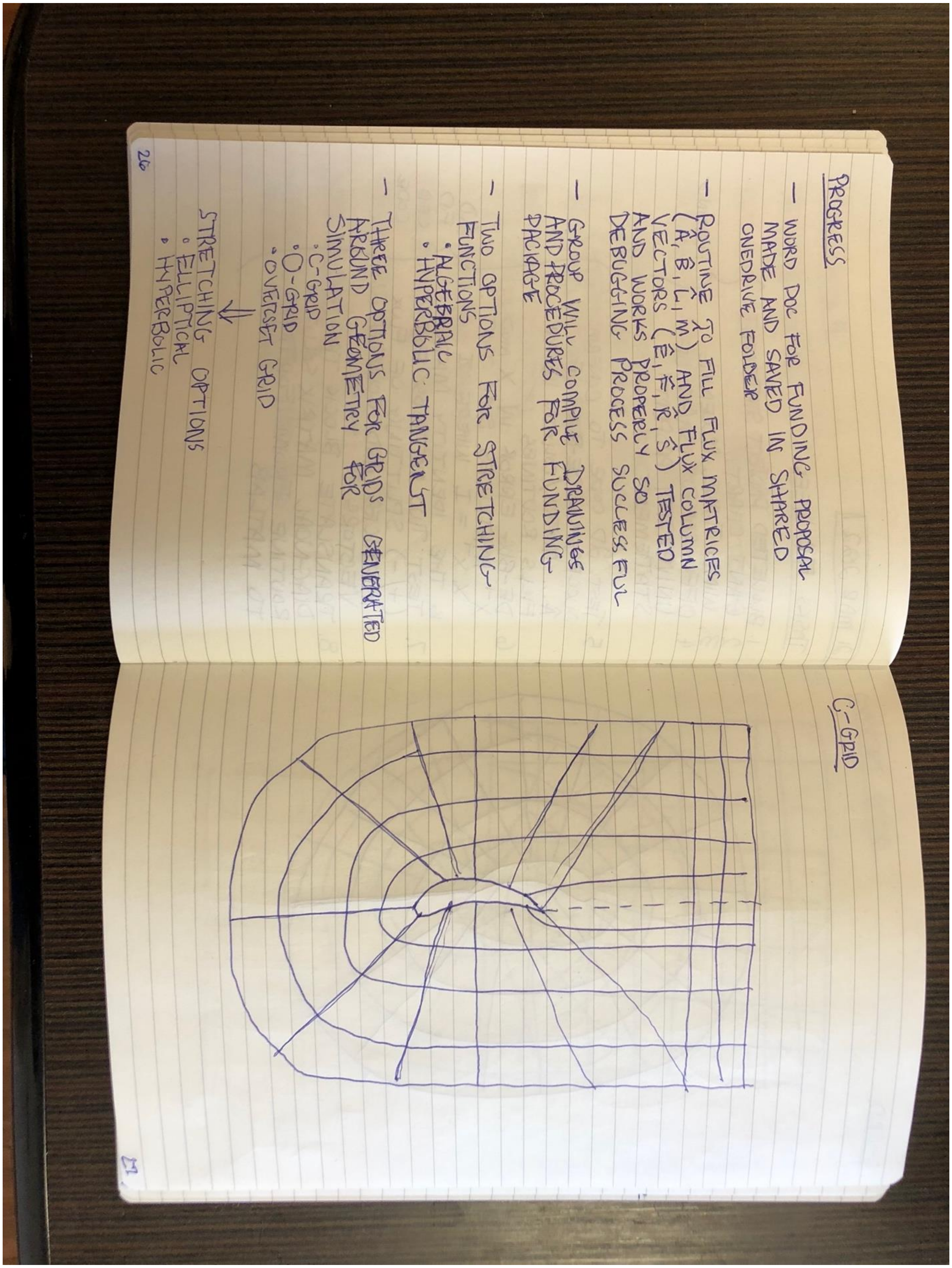
16 MAR 2022

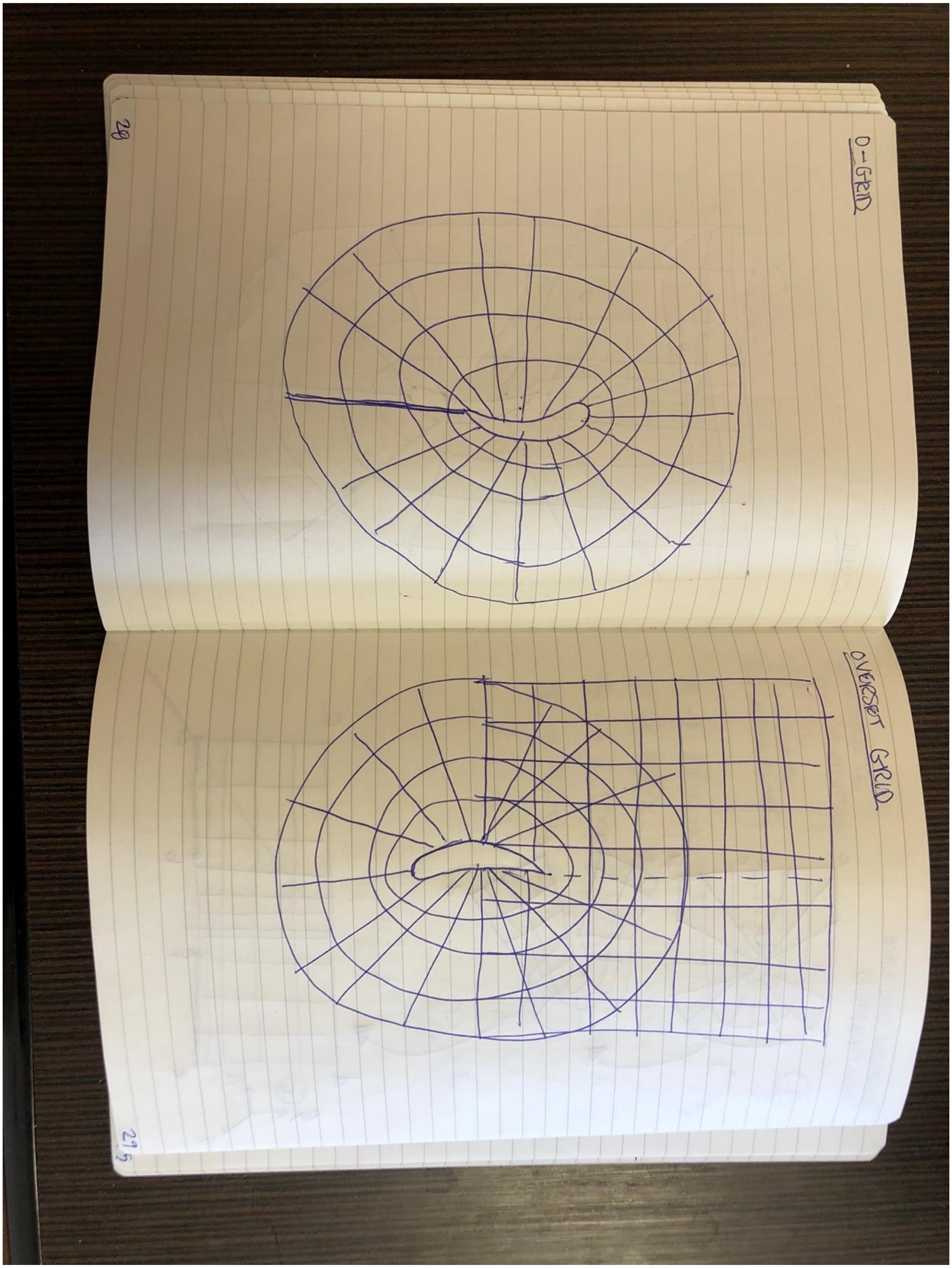
CAPSTONE FUNDING UPDATES:

- PROF. LE WILL FILL OUT EXCEL SPREADSHEET WITH TEAM INFO (STUDENTS DO NOT HAVE ACCESS)
- FORM W/ MEMBER NUMBERS, W-NUMBERS, PROJECT TITLE, ETC. DOES NOT NEED TO BE SUBMITTED BY STUDENTS (SEE EMAIL FROM HERB CONNORS FOR CONFIRMATION)
- SUBMIT FUNDING PROPOSAL/ APPLICATION EARLY

FINAL DUE DATE: 15 APR 2022
TARGET SUBMISSION DATE: 8 APR 2022

23


PROGRESS
- WORD DOC FOR FUNDING PROPOSAL MADE AND SAVED IN SHARED ONEDRIVE FOLDER
- ROUTINE TO FILL FLUX MATRICES (Â, B̂, L̂, M̂) AND FLUX COLUMN VECTORS (Ê, F̂, R̂, Ŝ) TESTED AND WORKS PROPERLY SO DEBUGGING PROGRESS SUCCESSFUL
- GROUP WILL COMPILE DRAWINGS AND PROCEDURES FOR FUNDING PACKAGE
- TWO OPTIONS FOR STRETCHING FUNCTIONS
• ALGEBRAIC
• HYPERBOLIC TANGENT
- THREE OPTIONS FOR GRIDS GENERATED AROUND GEOMETRY FOR SIMULATION
• C-GRID
• O-GRID
• OVERSET GRID
STRETCHING OPTIONS
• ELLIPTICAL
• HYPERBOLIC
26
C-GRID
27


O-GRID
OVERSET GRID

Jacob Willette

27 Jan 2022

Summary of weeks 1 – 3

- Week 1
  - Posted to brightspace discussion board several capstone project ideas
  - Adapted these ideas to Assignment 1 (Assignments will now be refered to by A1, A2, A3, etc.)
- Week 2
  - Formed preliminary design group with Nial ~~Mc~~ McInally and Andrew Lanzara
  - Created several new ideas for capstone design
- Week 3
  - Generated 4 ideas for A2:
    - Topology Optimization of Turbine blade
      - Found this to be too hard to scale to a level where it can be evaluated
    - Compliant endoscope
      - While the idea was sound in principle, we determined it would require knowledge and intrest in the Biomedical engineering field (neither of which we posses)
    - UV disinfectant water bottle capsule
      - Our favorite idea, very practical for our timeframe and budget

cont. →

required moderate knowledge of Electrical engineering.

- Table top injection molder
  - Our interest in this idea dwindled when we found other very similar products. The only path to take with this project would be to improve it's safety.
- Generated top ideas for A3
  - initially kept the UV disinfectant water bottle capsule, however, Proffessor Le (who will now be refered to as Prof. Le) thought the idea was not mechanical enough for this class. Personally, I ended up agreeing with him but my other members still think it is salvageable...
  - Compliant ~~AE~~ Airfoil mechanism
    - Prof. Le thought this idea was very suitable for this course and wanted us to keep it for A3.
- Added Tito Bermudez to the group
- Action Items for the rest of the week and next week
  - Add Tito to team contract
  - get Tito Engineering Notebook
  - Find preproposal idea to replace UV disinfectant capsule by 28 Jan22.
  - Finalize preproposal
  - Create and practice preproposal presentation

left intentionally blank

1 Feb22

Summary of Yesterday's meeting

- Started answering questions associated with A3 surrounding the compliant airfoil
  - After the meeting we needed to know:
    - How can we back up our need claim? i.e. ~~and~~ can we support it with evidence?
    - Can we flesh out the cost analysis?
    - More research into existing compliant airfoils
    - What plane can we model our airfoil after
- established that we needed to answer these questions before moving on with A3
  - divided them to Tito, Niall, myself, and Andrew research
- Assigned the task of making the presentation slides / format to Niall

Summary of research on compliant airfoils

- Found 3 research papers on compliant airfoils (titles will be added to notebook ~~later~~ post script)
- Most compliant foils are designed with the intention of making the whole wing compliant
- A primary design challenge is the strength of the wing
- A main drawback of compliant airfoils is the amount of potential failure points and this almost exclusivity is why they aren't wide spread in industry/production yet.

cont. →

- Many designs use carbon fiber for the "skin" of the wing

7 Feb 22

Meeting notes:

- Started to fill out the first part of A4
- Got as far as we could in A4 before breaking off individually
- meeting again on 9 Feb 22 to finish A4 and develope design options

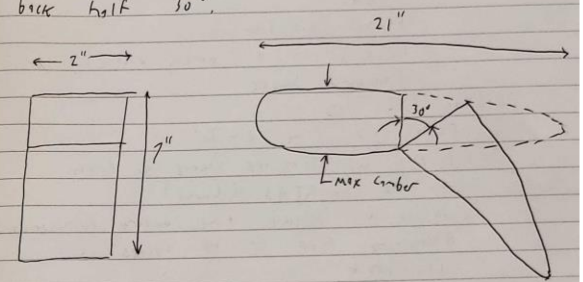
Tasks

- Approximate dimensions for final airfoil (Andrew, me 2/9/22)
- investigate windtunnel specs (tito 2/9/22)
  - What is the working volume?
  - What is the max speed?
  - does it have smoke?
  - how does it hold test samples
  - how do we get permission to use it
- find relevant Cessna 172 stats (Nial 2/9/22)
  - Speed at different times
  - Angle of attack range
  - Fatigue info
    - life of plane
    - # of cycles on flap
  - Flap Actuation

8/ Feb 22

Through Solidworks approximations we were able to find a rough airfoil size in order to begin checking the feasability of different actuators.

Below is a sketch of the Solidworks model. To approximate an airfoil with the flaps engaged, we split the Naca air foil in half and tilted the back half 30°.



The frontal area of the airfoil is designed to be ~10% of the area of flow in the wind tunnel (144 in²). The rest of the dimensions are driven by the shape of the Naca2412 airfoil.

7 Feb 22

The following information was gathered from our research:

- See previous page for airfoil specs
- Wind tunnels
  - Baxter ~~the~~ academy
    - 230 mph top speed
    - 12" x 12" x 24" working ~~area~~ volume
    - Dry ice smoke
  - Wentworth
    - 60 mph top speed
    - 12" x 12" x ~24" working volume
    - Standard smoke
- Cessna 172 stats
  - Flaps vary from 0° – 30°
  - landing and take off speeds go from 56 to 60 KIAS (knots)
  - 30,000 hr flight time before reinspection
  - Approximate flap # of cycles is 120 ~ 150 k

14 Feb 22

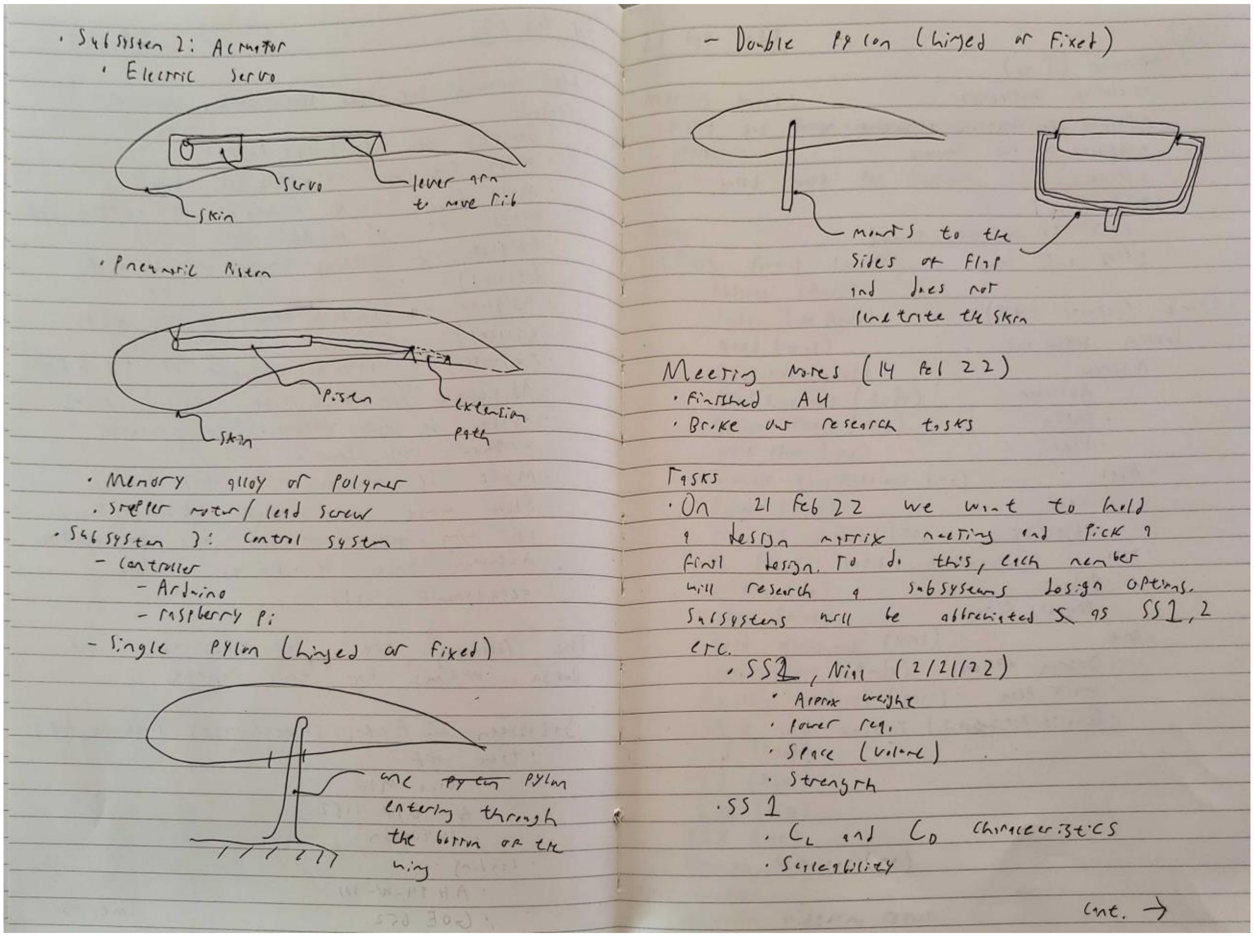
The following are the specifications for our project:

- Density of ≤ 2.487 lb/ft³
- Must fit in 12" x 12" x 24" volume
- Must have similar properties of existing 172 flaps at 0° to 30°
- Adequate for cruising speeds of 140 mph (scaled)
- Adequate at landing speeds of ~~56~~ 61 KIAS (scaled)
- Adequate at take off speeds of 56 KIAS
- Adequate for at least 150,000 cycles.
- Must be self contained (i.e. operable without wall power)
- Must be mountable in wind tunnel
- Flow must not separate after surface of wing ~~at~~ ~~...~~ in any configuration.
- Actuation must be able to withstand aerodynamic loads

The following are the subsystems and design options for this project.

- Subsystem 1: Airfoil shape (images found in A4)
  - take off
    - NACA M20
    - ~~Ah~~ DGA 1182
    - dh4009sm
  - landing
    - AH 94-W-301
    - GOE 652

cont. →



- Subsystem 2: Actuator
  - Electric servo

    servo

    lever arm to move rib

    skin
  - Pneumatic piston

    piston

    extension path

    skin
  - Memory alloy or polymer
  - stepper motor / lead screw
- Subsystem 3: control system
  - controller
    - Arduino
    - raspberry pi
  - Single pylon (hinged or fixed)

    one ~~pylon~~ pylon entering through the bottom of the wing
  - Double pylon (hinged or fixed)

    mounts to the sides of flap and does not penetrate the skin

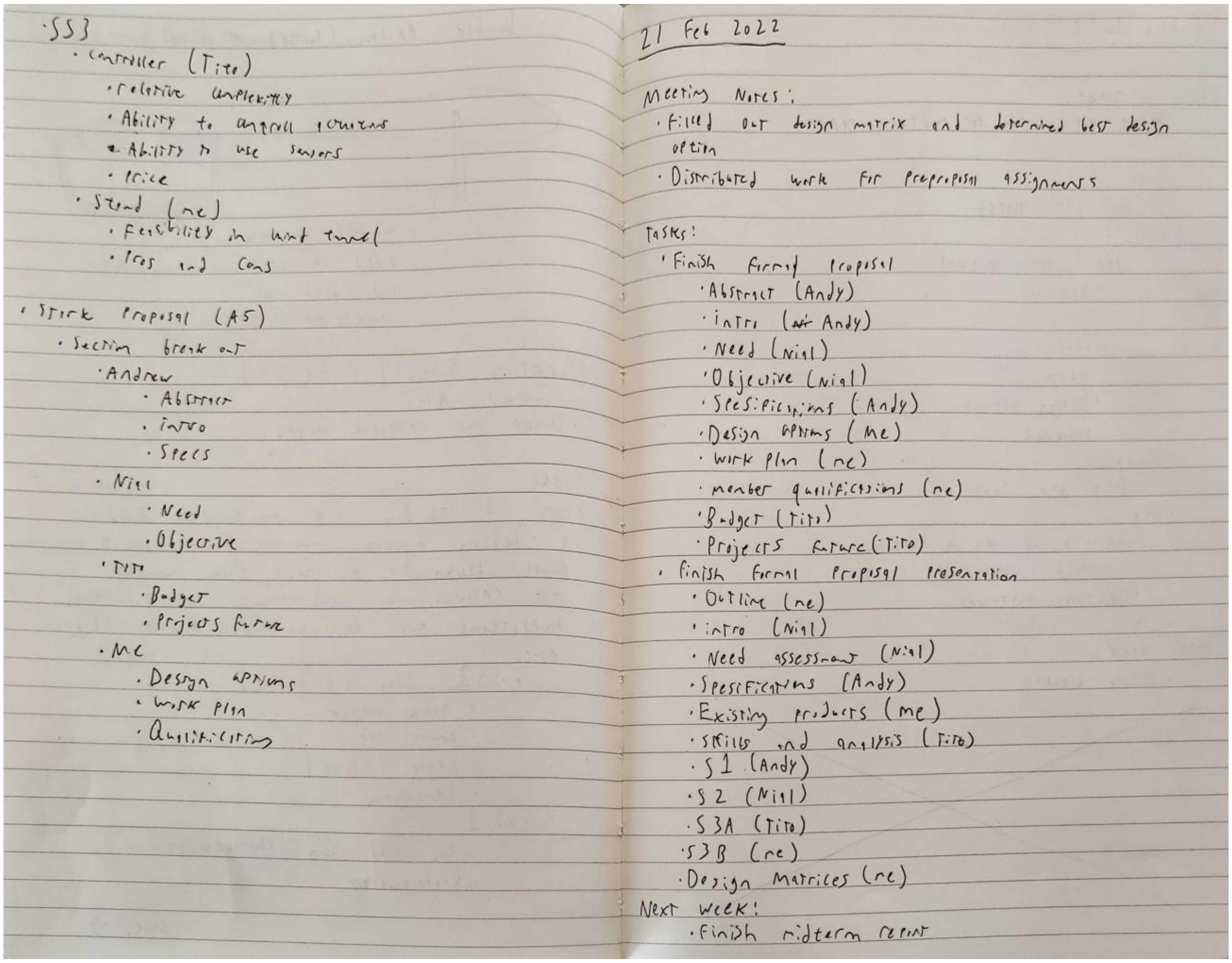
Meeting notes (14 Feb 22)

- Finished A4
- Broke out research tasks

Tasks

- On 21 Feb 22 we want to hold a design matrix meeting and pick a final design. To do this, each member will research a subsystems design options. Subsystems will be abbreviated as SS1, 2 etc.
  - SS2, Nial (2/21/22)
    - Approx weight
    - power req.
    - Space (volume)
    - Strength
  - SS 1
    - C_L and C_D characteristics
    - Scalability

cont. →


- SS3
  - Controller (Tito)
    - relative complexity
    - Ability to control routines
    - Ability to use sensors
    - Price
  - Stand (me)
    - Feasibility in wind tunnel
    - Pros and Cons

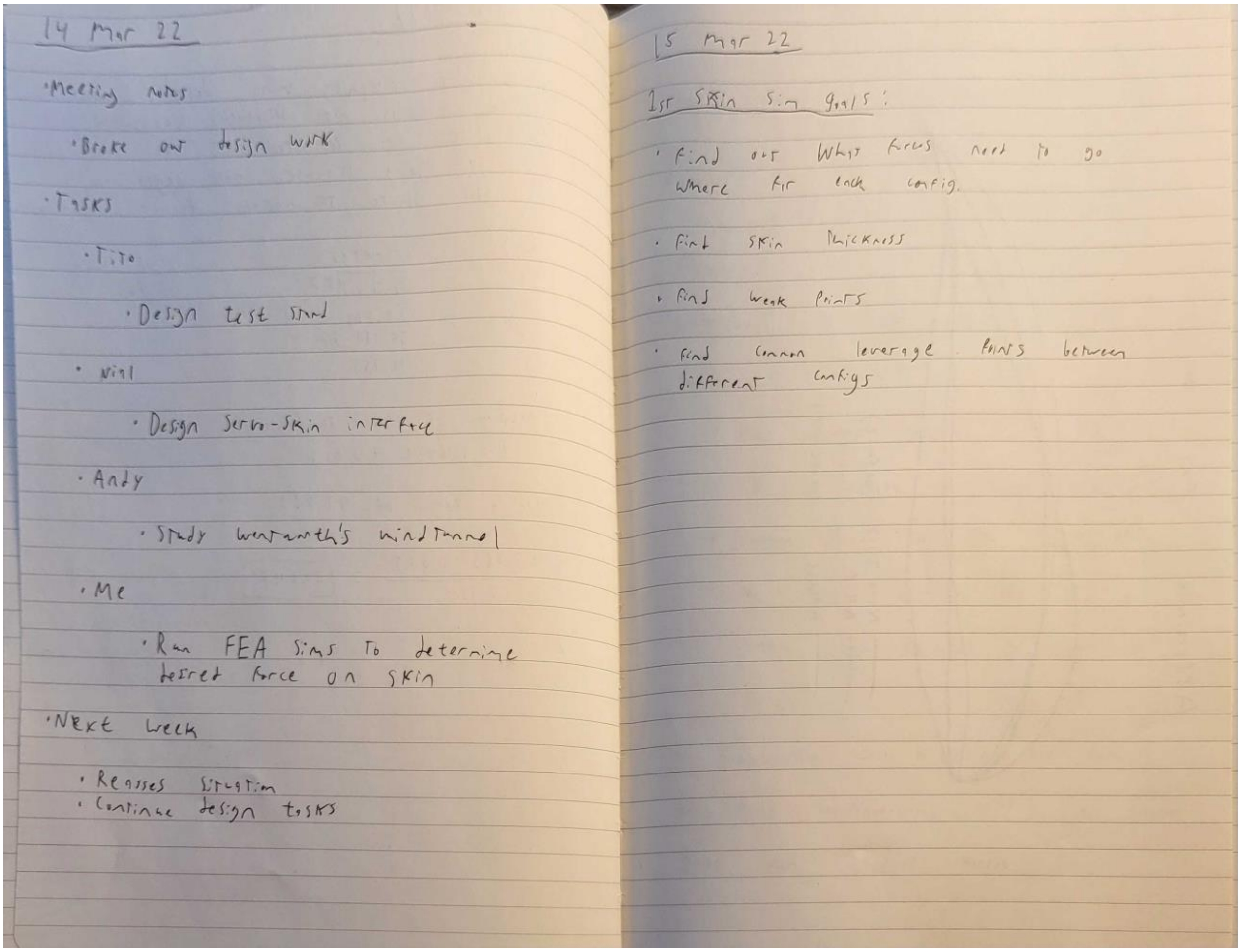
- Start Proposal (A5)
  - Section break out
    - Andrew
      - Abstract
      - intro
      - Specs
    - Nial
      - Need
      - Objective
    - Tito
      - Budget
      - Projects future
    - Me
      - Design options
      - work plan
      - Qualifications

21 Feb 2022

Meeting Notes:
- Filled out design matrix and determined best design option
- Distributed work for preproposal assignments

Tasks:
- Finish formal proposal
  - Abstract (Andy)
  - intro (Andy)
  - Need (Nial)
  - Objective (Nial)
  - Specifications (Andy)
  - Design options (me)
  - work plan (me)
  - member qualifications (me)
  - Budget (Tito)
  - Projects future (Tito)
- Finish formal proposal presentation
  - Outline (me)
  - intro (Nial)
  - Need assessment (Nial)
  - Specifications (Andy)
  - Existing products (me)
  - Skills and analysis (Tito)
  - S1 (Andy)
  - S2 (Nial)
  - S3A (Tito)
  - S3B (me)
  - Design Matrices (me)

Next week:
- Finish midterm report



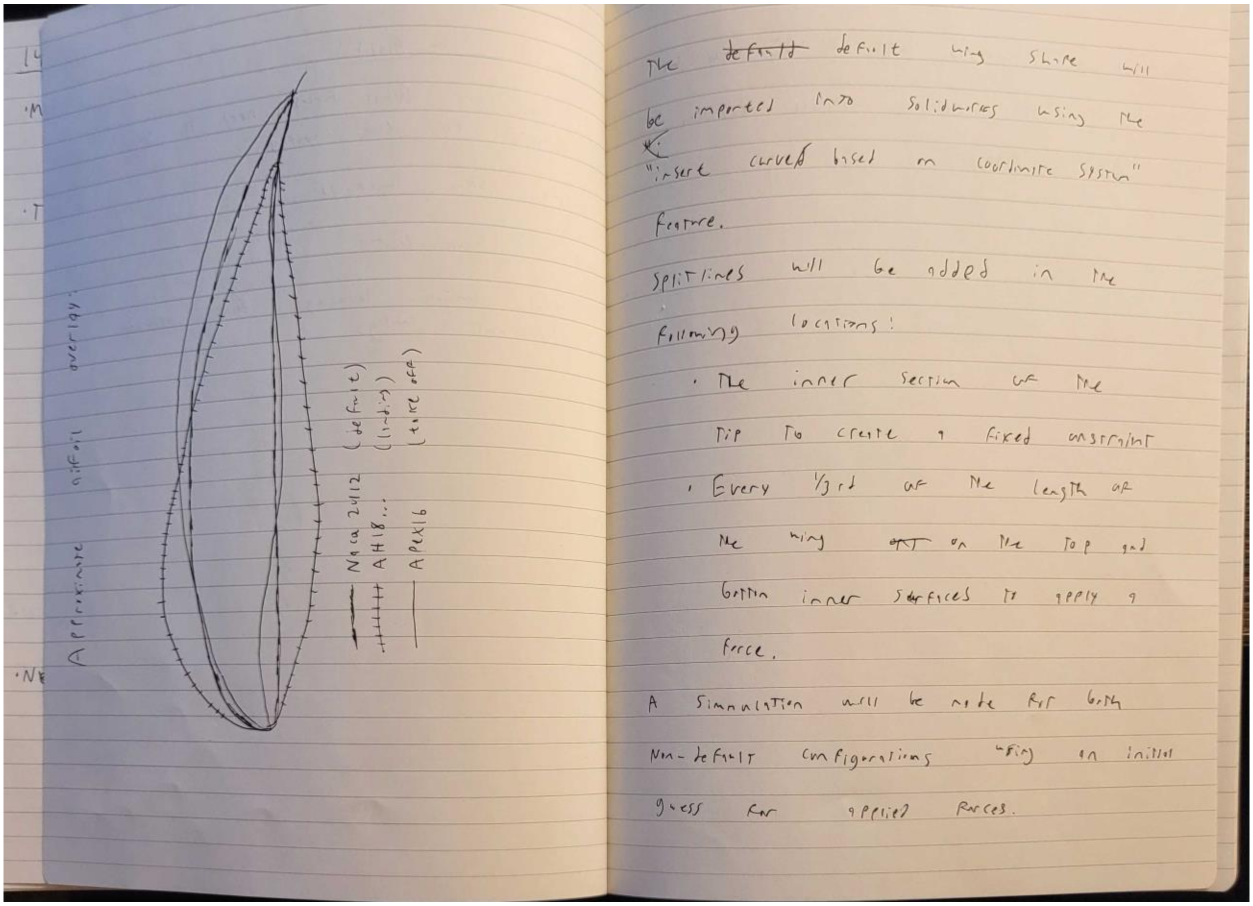
14 Mar 22

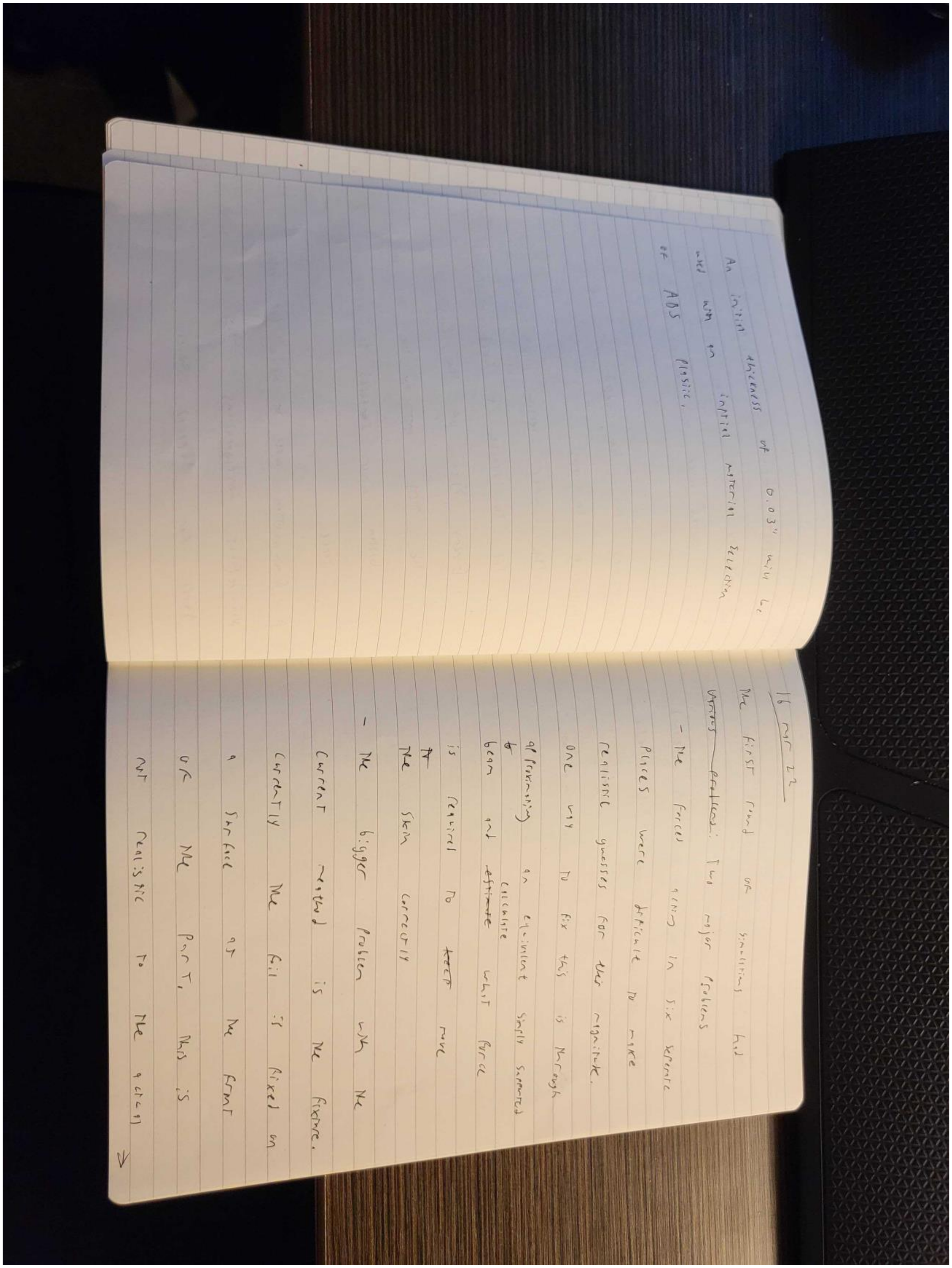
- Meeting notes
  - Broke out design work
- Tasks
  - Tito
    - Design test stand
  - Nial
    - Design Servo-Skin interface
  - Andy
    - Study Wentworth's wind tunnel
  - Me
    - Run FEA sims to determine desired force on skin
- Next week
  - Reasses situation
  - Continue design tasks

15 Mar 22

1st Skin Sim goals:

- Find out what forces need to go where fir each config.
- Find skin thickness
- Find weak points
- Find common leverage points between different configs


Approximate airfoil overlay:
Naca 24112 (default)
AH18... (landing)
APEX16 (take off)
The default wing shape will be imported into Solidworks using the "insert curves based on coordinate system" feature.
Split lines will be added in the following locations:
· The inner section of the tip to create a fixed constraint
· Every 1/3rd of the length of the wing on the top and bottom inner surfaces to apply a force.
A simulation will be made for both non-default configurations using an initial guess for applied forces.

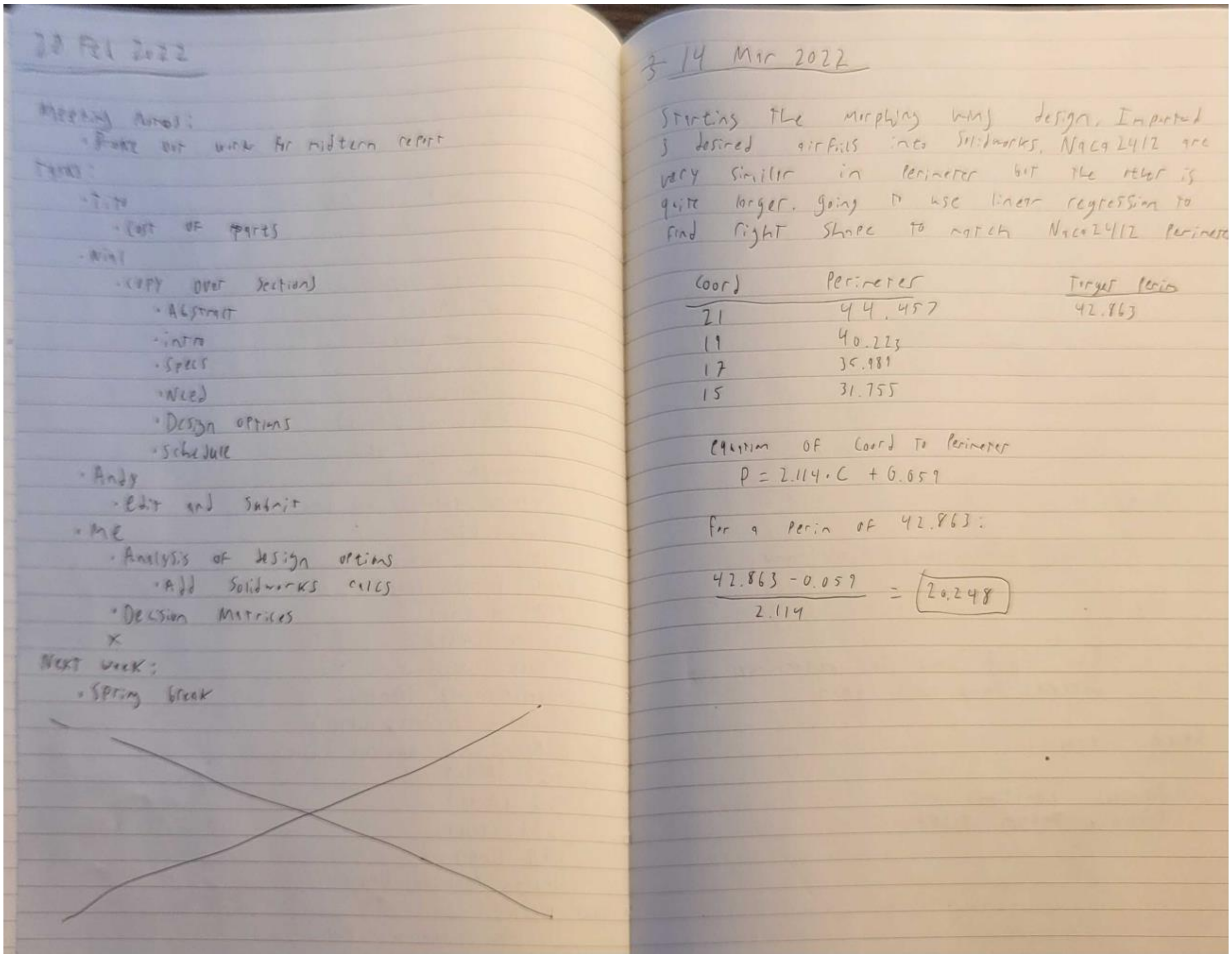


An initial thickness of 0.03" will be used with an initial material selection of ABS plastic.

16 Mar 22

The first round of simulations had ~~various problems~~: Two major problems

- The forces acting in six separate places were difficult to make realistic guesses for their magnitude. One way to fix this is through approximating an equivalent simply supported ~~to~~ beam and ~~estimate~~ calculate what force is required to ~~keep~~ move ~~At~~ the stem correctly
- The bigger problem with the current method is the fixture. Currently the foil is fixed on a surface at the front of the part, this is not realistic to the actual →


28 Feb 2022
Meeting notes:
• out work for midterm report
Tasks:
• Tito
• Cost of parts
• copy over sections
• Abstract
• intro
• Specs
• Need
• Design options
• Schedule
• Andy
• Edit and Submit
• Me
• Analysis of design options
• Add Solidworks calcs
• Decision Matrices
Next week:
• Spring break
14 Mar 2022
Starting the morphing wing design. Imported 3 desired airfoils into Solidworks. Naca 2412 are very similar in perimeter but the other is quite larger. Going to use linear regression to find right shape to match Naca 2412 perimeter
Coord
Perimeter
Target Perim
21
44.457
42.863
19
40.223
17
35.981
15
31.755
Equation of Coord to Perimeter
P = 2.114 · C + 0.059
For a Perim of 42.863:
42.863 - 0.059
2.114
= 20.248

Appendix 5: Breakdown of Tasks

- Tito Bermudez
    - Primary Duties
        - Design Test Stand and relevant interfaces
        - Provide Drawings and 3D models for Test Stand
        - Chief Manufacturing Engineer
            - Provide manufacturing insight for whole project
- Nial McInally
    - Primary Duties
        - Design Servo Cam mechanisms and relevant interfaces
        - Chief Technical Drafter
            - Provide Drawings and 3D models for Servo Cam mechanisms
            - Provided Assembly Drawings for all assemblies
- Andrew Lanzrath
    - Primary Duties
        - Chief Aerodynamicist and Computational Fluid Dynamics Expert
            - Assessed CFD codes and developed accurate testing models
        - Editor-in-chief of all major reports and presentations
- Jacob Willette
    - Primary Duties
        - Design flap's skin and relevant interfaces
        - Chief Finite Element Analyst

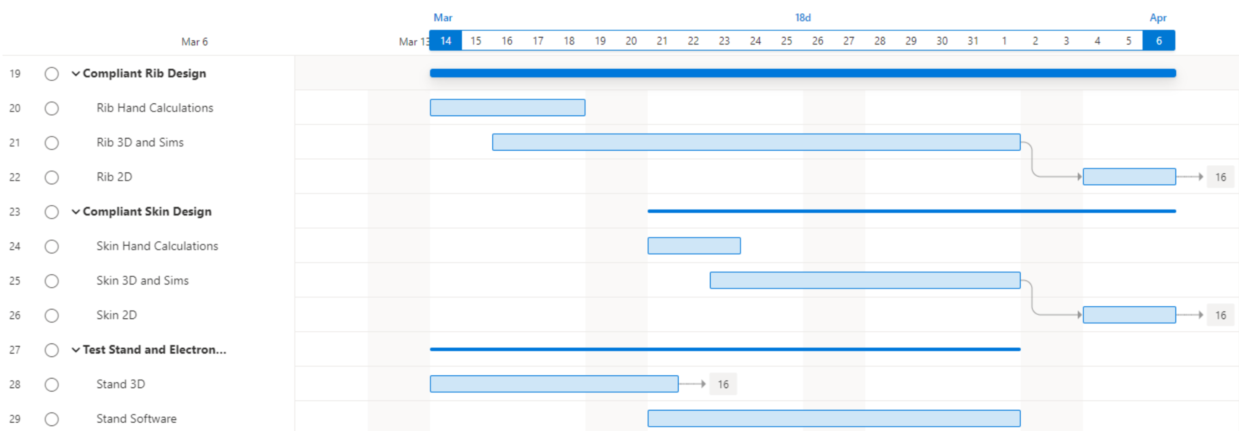
- Ran all solidworks simulations that were out of the purview of aerodynamics

- Project Manager
  - Organized all tasks
  - Organized the submission of assignments and work distribution
  - Created Gantt charts and organized team vision

Appendix 6: Schedule and Progress

Sprint 2 (3/14-4/20)

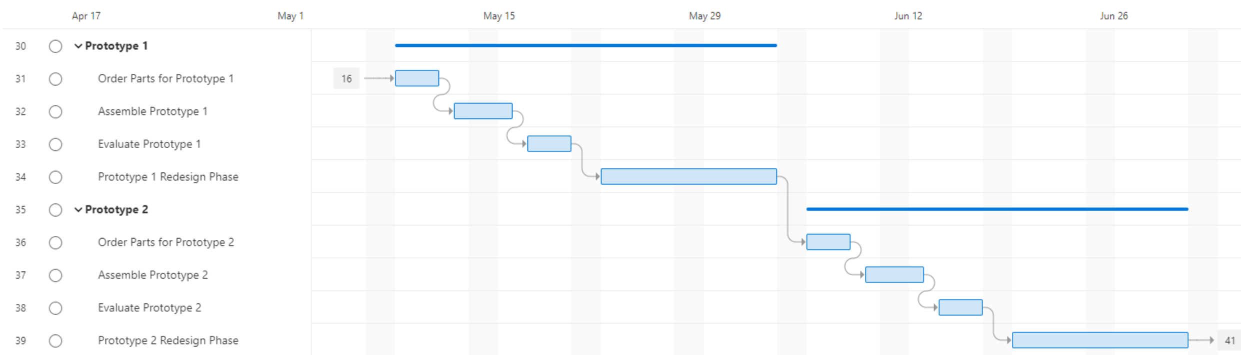
Sprint 2 picks up after spring break and lasts until the end of the spring semester. The primary goal of this sprint is to finish the initial design of the flap to a point where it is ready to be constructed when the summer semester begins. Along side this, the group will be completing the formal report and other end of semester assignments.



Sprint 2 Gantt Chart

Sprint 3 (5/11-7/1)

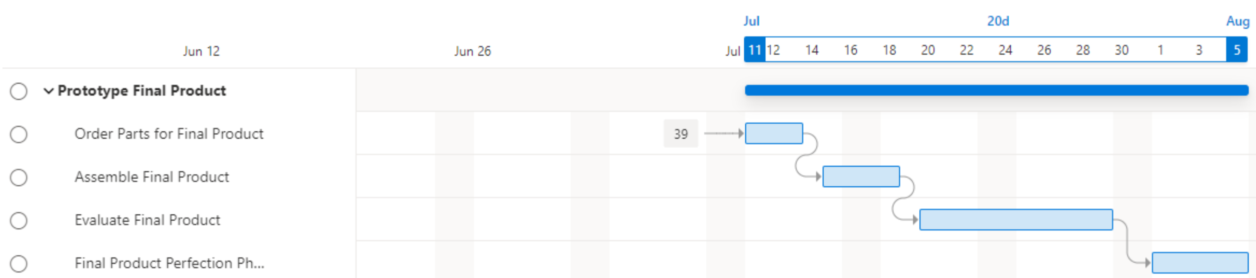
Sprint 3 occurs from the beginning of the summer semester and lasts until 4th of July break. During this period the group will create two working prototypes of their design to evaluate and iterate upon. This will be the main period for wind tunnel tests.



Sprint 3 Gantt Chart

Sprint 4 (7/11-8/10)

In the period after 4th of July break to the end of the summer semester, the group will assemble their final product, employ any last-minute changes, and do any end-of-semester work. Windtunnel tests will be done on the final product to ensure it’s efficacy.



Sprint 4 Gantt Chart