Team 12: REEF Subsonic Articulating Robotic Arm

Deliverable Title: Interim Design Report

Due Date: 12/08/2014

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REEF Subsonic WT Articulating Robotic Arm

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Acknowledgements

Team 12 would like to recognized sponsor Dr. Michael Sytsma and Dr. Kumar for exceptional guidance throughout the design phase of this project. The team is grateful for Dr. Sytsma's contributions and for allowing the team to visit the REEF center. Dr. Kumar has provided the team with a lot of help in regards to technical analysis of the system needed to finish he design process. Team 12 would also like to recognize the teaching staff of Dr. Gupta and Dr. Helzer for continued guidance throughout the semester.

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Abstract

The Aerodynamic Characterization Facility (ACF) of the Research and Engineering Education Facility (REEF) has requested a mounting and actuating mechanism in order to continue testing. This facility hosts an open subsonic wind tunnel with a maximum wind speed of 22 $m/_s$. The design must be able to adjust pitch (-5° to +30°) and yaw (-10° to +10°) while the tunnel is in operation and maintain the specimen in the center of the air flow. The design features 105 degrees of a 25 inch radial arc with a square shaped cross-section. The circular arc will be mounted in two locations in order to stabilize it during wind tunnel operation. Roller bearings with rubber coating will be used to reduce friction and help dampen vibrations. This arc will be actuated through the use of a flexible gear track fixed to the underside and a turn table as its base. A sting mount will be utilized to hold specimens. The procurement of the necessary components and materials for this design is underway and fabrication is expected to start at the beginning of spring semester.

I. Introduction

Due the removal of the current model mounting system, the Air Force Research Lab has requested the production of an articulating robot arm to be used in a subsonic wind tunnel. The arm would allow research conducted at the facility to continue and will enable the researchers to manipulate the pitch and yaw of aircraft models in an active flow. The articulation of the robotic arm will be dictated by a servo control unit that will be linked to a remote user interface. The yaw and pitch movements of the arm will be carried out through the use of two separate stepper motors. Any specimens held by the arm will be mounted utilizing a sting. The wind tunnel that the robot arm will be placed into is an open test section and is located at the Aerodynamic Characterization Facility (ACF) of the Research and Engineering Education Facility (REEF). The wind tunnel has the ability to generate wind speeds that can reach up to 22 m/s or approximately 50 mph. The inlet of the wind tunnel has a square cross-sectional area that is slightly larger than 1 m^2 (42” by 42”).

a) Background Information

Wind tunnels offer a cost effective way to test aerodynamic designs in a controlled environment. When a properly scaled model is placed in a wind tunnel, dimensionless numbers can be utilized to generate flows that are dynamically similar to conditions that would been seen by the full-size aircraft. The data recovered from testing would allow for modification and improvement before starting full-scale production. Wind tunnels operate by having a fan pull air into the entrance of the tunnel, often through screens and straighteners to help straighten the flow and reduce the turbulence. The cross sectional area of the tunnel is then reduced to increase the velocity of the incoming flow, which then proceeds to the test section. In an open circuit facility, once the flow has passed through the test section it continues to the diffuser and is discharged.

The facility that the robot arm will be utilized in is an open test section subsonic wind tunnel. In an open test section wind tunnel there are no walls bounding the flow immediately after the inlet contraction. This means that as the flow moves away from the test section entrance, the boundary layer of the flow will expand outward. This type of wind tunnel orientation is most often used for acoustic testing purposes. Figure 1 shows an example of an open test section open circuit wind tunnel that is housed at the same facility where the robotic arm will be used.

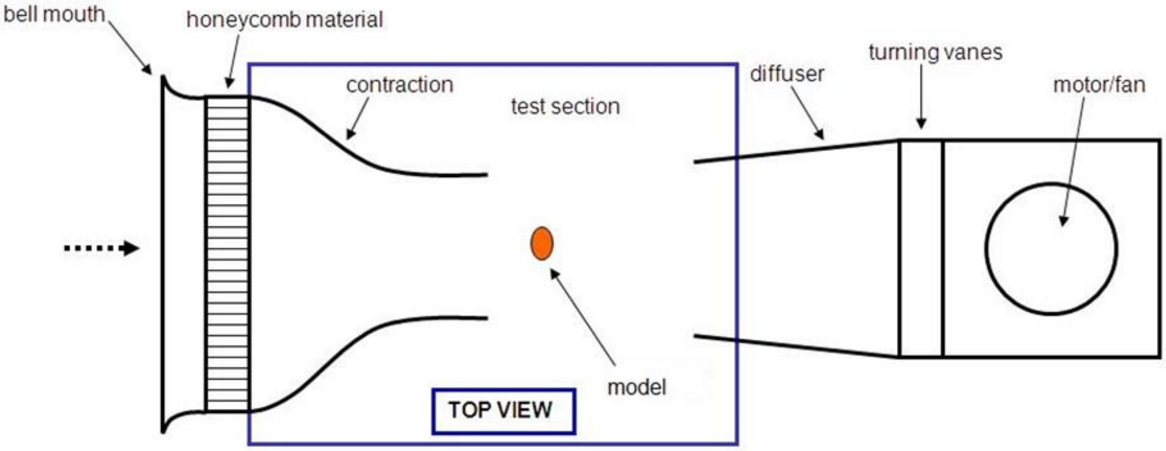


Figure 1: General representation of an open test section wind tunnel.

To achieve ideal results from testing, it is imperative that the model mounting system be minimally invasive. This is especially true for subsonic wind tunnels as the upstream adjusts to downstream objects and blockages. A common method of model attachment is the utilization of a sting mount. This type of mount attaches to the rear of a model and provides minimal interference to the flow approaching the model. Figure 2 shows a model held by a sting mount as well as representation of the flow direction. Measurement devices may be placed on the end of the sting, such as an internal balance or strain gage, to provide data on the specimen during experimentation.

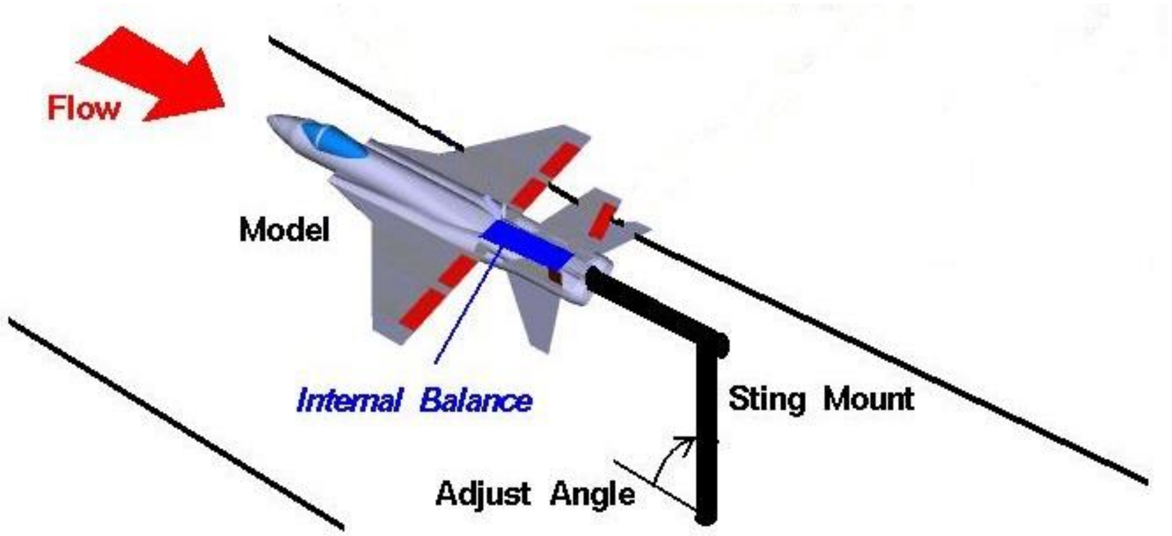


Figure 2: Example of a specimen held by a sting mount in a wind tunnel.

b) Goals and Objectives

The goal of the project given to Senior Design Group #12 is the design and production of a cost effective mechanism that can hold and adjust the orientation of a specimen being tested in a subsonic wind tunnel. The sponsor of the project presented a set of objectives to be achieved by the robotic arm. The arm must be structural sound enough to withstand the maximum forces generated by the wind tunnel, 22 m/s. The arm must also be able to manipulate the orientation of the mounted specimen while the tunnel is operating at maximum velocity. During the manipulation of the specimen, the position of the specimen (center of mass) must not change. The two aspects of the specimen's orientation that will be adjusted are the pitch (angle of attack) and the yaw (side slip). The pitch of the specimen should be able to be adjusted to any position between -5° below center and 30° above center. The yaw of the model should be able to adjust 10° left or right of center position. The final objective set forth was that when the model is in the desired position the model must not move.

Objectives list

- Arm able to withstand maximum force generated by wind tunnel
- Arm able to operate at maximum tunnel velocity
- Center of mass of specimen must not change
- Adjustable pitch range of -5° to +30°
- Adjustable yaw range of ±10°
- Model must not move when in set position

c) Constraints

While attempting to meet the objectives set forth by the sponsor multiple constraints had to be considered. The sponsor has requested that the user interface that will operate the robot arm will be run by a LabVIEW program. Using LabVIEW offers the opportunity to create an easy to use system, as well as having the ability for the system to report the angle that is actually at in comparison to the requested position. A second constraint in regards to the operation of the arm requires that the orientation of the arm should be within 0.25° of the requested orientation. When at any position the sting has the potential to deflect, the maximum deflection that is allowable is 0.25". To ensure validity of any results taken while using the system in addition to the structural integrity, the sponsor has required a factor of safety of 5. The final major constraint of the project is the operating budget; the team has been allotted $2,000 to complete the project. To assist with limitations of the budget and overall design, some components have already been provided by the sponsor.

Constraints list

- User interface involves LabVIEW
- 0.25° orientation accuracy
- Maximum Deflection of 0.25”
- Factor of Safety of 5
- $2,000 budget

II. Design and Analysis

a) Functional Analysis

The process by which the mechanism will operate can be broken down into three distinct sections; the structure, the user interface to the controller, and the controller to the stepper motors. The structural portion of the mechanism will be responsible for withstanding the wind tunnel forces and mounting the test specimen. This part will be designed to be as aerodynamic as possible in order to minimize forces and vibrations.

The mounting mechanism for the structural portion will be actively controlled by the user. Therefore a user interface will be required to enter commands for pitch and yaw that will feed into the servo controller. There will be a UI that consists of a command prompt in which the manipulations to the models alignment can be typed; these commands will be feed to the controller.

Once the commands have been passed from the servo controller to the stepper motors, they will initiate their operation. The two motors will be controlled independently, one changing the angle of attack and the other adjusting the yaw by controlling rotation of a turn table provided by the sponsor. The stepper motors will be connected to a force reducing system; increasing the torque produced by the motors; allowing them to easily adjust the pitch and yaw through their full range of desired motion. Table 1 summarizes the functional analysis.

Table 1: Functional Analysis

Equipment	**Function**
Controller	Used to pass command from user interface to respective stepper motors
Stepper Motor	Motor used to adjust the angle of attack (pitch) of the chosen mount design
Stepper Motor/Turn Table	A turn table (provided by sponsor) that has already been integrated with a stepper motor
Structure	Mounts the specimen and provides a structure for which the motors actuate to accomplish inputs

b) Initial Design Ideas

Our first design concept was a simple sting mount with a recessed portion to allow the base to rotate about the centroid of our model. This design is extremely simple to produce as some bent medal tube, or some separate straight portions screwed together would produce a satisfactory product. This design is shown in figure 3. It is a very useful design for yaw calculations, as the rotation about the models centroid would prevent any translation in the flow field, ensuring accurate data. However, this design is only advantageous for very low angles of attack. Once the model is adjusted to some angle of attack, the model will be moved in the flow field as well as no longer rotate about its centroid. This would skew the data to the point that it is no longer useful. With these considerations and the input from our sponsor this design would require extra actua*tion* in order to re-center the model in the air flow.

In order to maintain the model location within the flow field, a design incorporating a circular arc was developed. This design is shown in Figure 4. The arc design allows for the angle of attack, or pitch, to be changed within the flow field without translating the model in any direction. By placing the pitch center of rotation in line with the same axis as the yaw rotation, the model can be adjusted during operating conditions without data corruption. The arc design however is more complex to manufacture. The radius of the arc will have to be approximately 2 feet in order to stay out of the flow field. This will be very difficult to find off the shelf, and will probably have to be custom made. The arc will be mounted on a turn table with a built in servo motor.

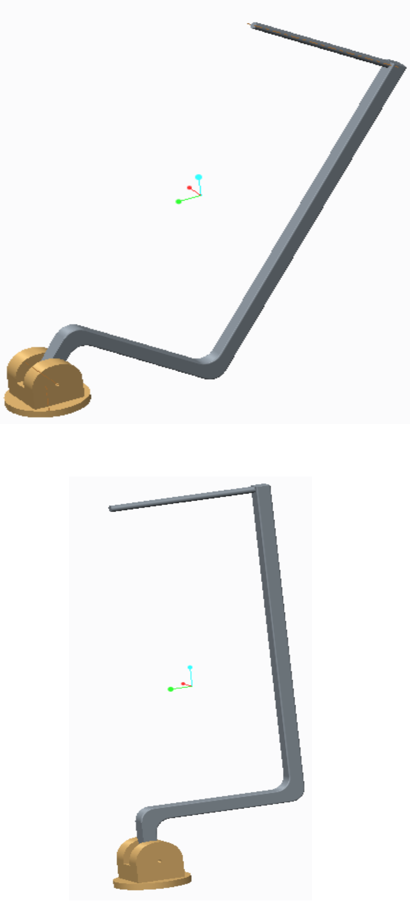


Figure 3: Design 1

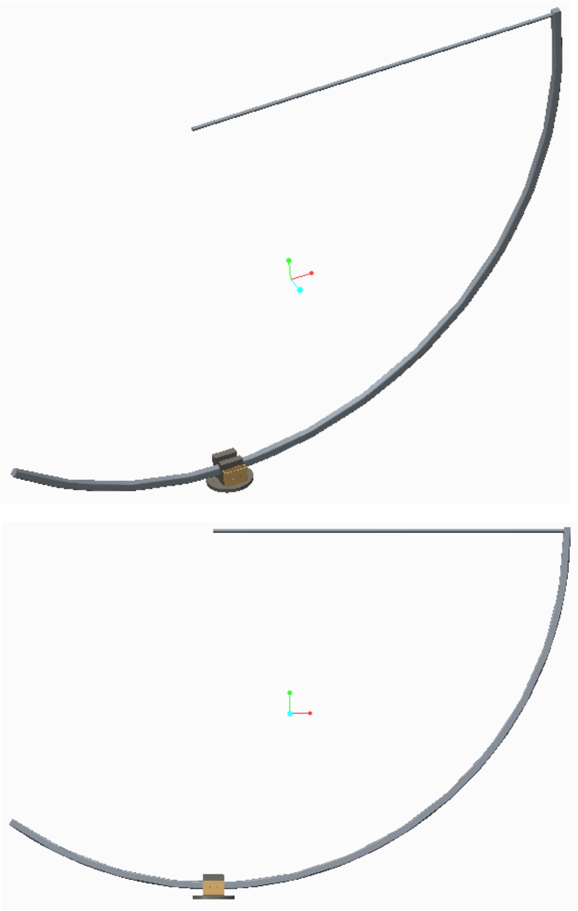


Figure 4: Design 2

This will turn the arc on the horizontal plane, or the yaw. The pitch will be adjusted by a stepper motor and a gear train, utilizing a worm gear against the arc. The worm gear will allow a fine degree of control as well as, being non-back drivable, maintain its position under a load.

Similar to design two, design three utilizes an arc to maintain the model location during dynamic testing conditions. This design, shown in Figure 5 was developed to help mitigate the amount of material in front of the model, and maintain designed flow conditions upstream. By placing the arc mounting mechanism at the rear of the arc, the amount of material in the arc is reduced. This reduction in the amount of arc used could result in significant cost savings if it must be custom manufactured. The arc mounting mechanism would have to be moved in both the horizontal plane and vertical plane by the at least the radius of the arc itself. By translating the mounting mechanism by three to six feet, huge moments are created. This would require more materials, resulting in larger motors, higher costs, and overall lower efficiency.

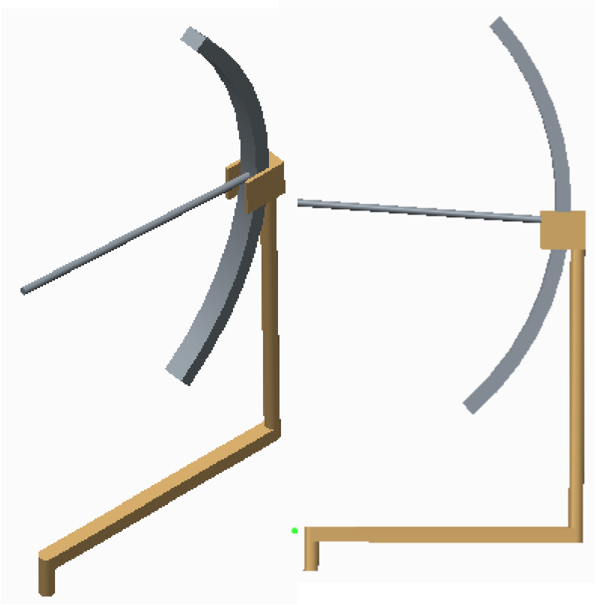


Figure 5: Design 3

c) Selection of Optimum Design

The criteria we chose to judge our different designs upon are shown in the decision matrix. The decision matrix is shown in table 2. Strength, cost, efficiency and complexity were the main evaluating factors. The strength of the design was determined through use of the equations shown above and based on the geometric properties of the models. For example, design #3 shows a high potential for bending at most of the weight is being supported by a single rod that extends away from the center of the design; resulting in its low score. The strength of the design was given a high weighting as the sponsor has requested a factor of safety on the design of 5, meaning that under no circumstances should the mount ever come close to failing.

Table 2: Decision Matrix

Criteria	**Strength**	**Cost**	**Efficiency**	**Complexity**	**Total**
Weight	9	6	9	6	30
Design #1	50	75	75	80	68.5
Design #2	80	65	90	75	79
Design #3	60	50	80	50	62

The cost portion of the score was mainly determined by the section of the design that will shift the pitch, as the yaw of all three designs will be adjusted in the same manner. Designs #2 and #3 would require a very precise arc to be purchased or fabricated which could potentially cost double to triple what the sting mount for design #1 would be comprised of. The complexity of the design and the cost of the design are interrelated and share the same general trend in the decision matrix; design #3 scoring the lowest and design #1 scoring the highest.

The efficiency component of the decision matrix took multiple factors into account to produce its score. The amount of moving parts required for the design was one factor in which all three design scored the same as the all have few moving parts. Another consideration was the amount of flow interruption in comparison to stability. The mount must refrain from interrupting the flow before it reaches the test model and must maintain a stable unmoving position. Design #2 scored the highest on this portion as it is completely out of the flow, as well as being mounted directly to the turn table will be very stable.

The cost was analyzed based on the amounts of material and additional equipment required. Designs 1 and 2 have more material due to the moment arm that extends to attach behind the object. Also, design 1 requires more motors in order to keep the objects center of mass stationary. This would require significant more costs due to the stepper motor and encoder combination. For this reason, design 2 scored the best. It would only require one additional stepper motor and would require material just for an arc.

Efficiency grading was developed based on how easily the mechanism will move. In design 2, one movement covers both translation and centering. It also has just the sting mount in the flow. Design 3 has similar efficiency but has a large arc in the flow. Since the tunnel is subsonic, this would change results due to the fluid being able to adjust to the upcoming boundary. Design 1 had the lowest efficiency because it would require 4 movements to accomplish the same task as designs 2 and 3 accomplish with 2 movements. This also ties into the complexity grading. Although design 1 is extremely simple, it has complexity in terms of keeping the mount centered in the flow. Design 2 has complexity about its arc, but generally does not interrupt the flow patterns. Finally, design 3 has a relatively large object in the flow. This would be hard to analyze and would require many assumptions. It would also require research beyond what is known. For this reason, it scored low.

Overall, design 2 was the final selection. This was because it was the most optimized case of strength, cost, efficiency, and complexity. The next section will further analyze this design. Since selection of the optimum design, dimensioned drawings, actuation methods, mounting methods, and stress analysis has been completed. These will be discussed and presented in the following section.

d) Evaluation of Optimal Design

In the initial stages of the design phase, it was known that the device must be able to withstand wind speeds of up to 22 m/s. The device must also be able to actuate through some electrical-mechanical method while maintaining the mounted specimen in the center of the airflow. A few different design concepts associated with accomplishing these tasks were stress analysis, deflection analysis, flow around a body, motor analysis and a geometric analysis. The final design currently drafted and analyzed is shown in Figure 6.

Figure 6: Final Design

Before any other analysis could be completed, geometric analysis had to be completed in order to size the mechanism correctly. It was a constraint to have most of the mechanism outside of the flow. Since an arc was the mounting mechanism chosen, this means that throughout its entire actuation motion (-5 to 30 degrees), it must not imping on the flow field. The arc was analyzed in its most extreme condition of 30 degrees since this would place part of the arc into the flow as shown in Figure 7. Using (1), and a jet half-width of 20 inches, the radius of the arc was calculated to be 24.4inches. This was rounded up to 25 inches for simplicity and clearance.

$$radius = \frac{l}{\cos(35)} = 24.4\ inches \sim 25\ inches \tag{1}$$

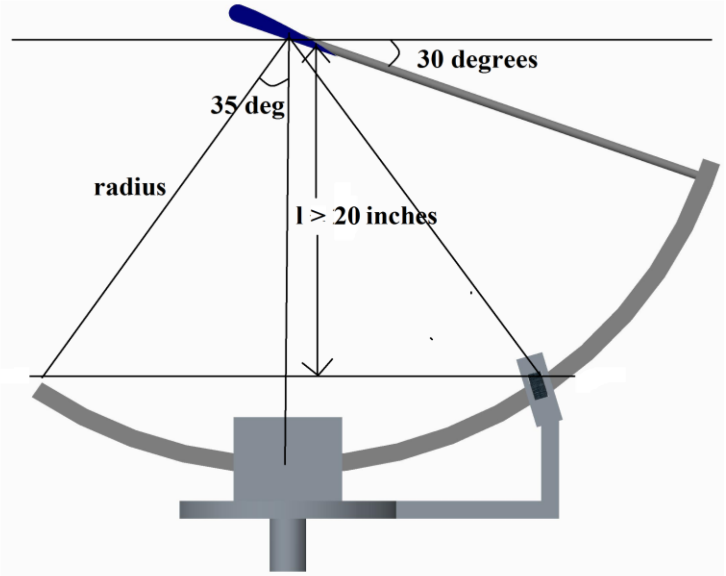


Figure 7: Geometric Analysis

Before any of the structural analysis could be completed, the flow around the body had to be analyzed. Utilizing some conservative assumptions, the flow around the body could be analyzed in order to obtain lift and drag forces. The assumptions used to obtain the lift and drag forces are shown in Table 3. Appendix A shows all of the Mathcad calculations completed to arrive at maximum lift and drag forces. Results of the flow analysis are shown in Table 4.

Table 3: Assumptions

#	Assumptions
1	-Maximum flow blockage of 10%
2	-Coefficient of lift (CL) = 2
3	-Coefficient of drag (CD) = 1
4	-Multiplication factor of 1.5 for unsteady loads

Table 4: Calculation Results

Variable	Value (units)
Max Lift	12 (N)
Max Drag	60 (N)
Max Moment	38 (N*m)

Following the sizing and calculation of maximum forces on the arc structure, stress and deflection calculations could be completed. Using a properly sized model of the arc in Creo, combined with the maximum drag and lift forces acting on the structure, Von Mises stresses and maximum deflection were calculated. Figure 8 shows the maximum stresses in a gradient diagram. The maximum stress occurs in the red area on top of the sting. Compared to the maximum allowable stress of Aluminum 6061, the maximum stress seen by the mechanism of 37 MPa results in a factor of safety of approximately 10. This satisfies the minimum factor of safety constraint put in place by the project sponsor.

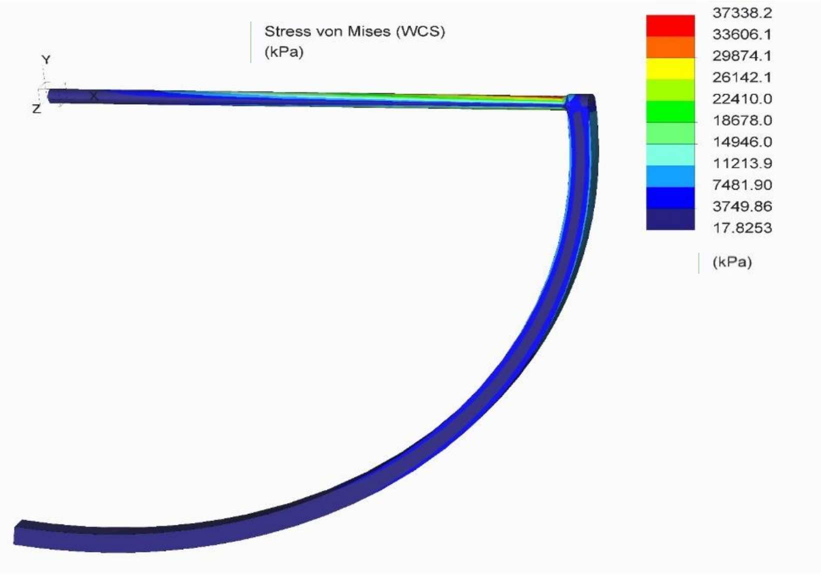


Figure 8: Stress Analysis

The other constraint put in place by the sponsor was a maximum deflection no greater than a quarter of an inch (0.25in). Figure 9 shows the gradient chart of the deflection. The red area at the tip of the sting shows the spot of maximum deflection. This maximum deflection was approximately 0.14 inches, which satisfies the sponsor's constraint. This deflection at the tip will be reflected by an inclinometer, which will provide feedback.

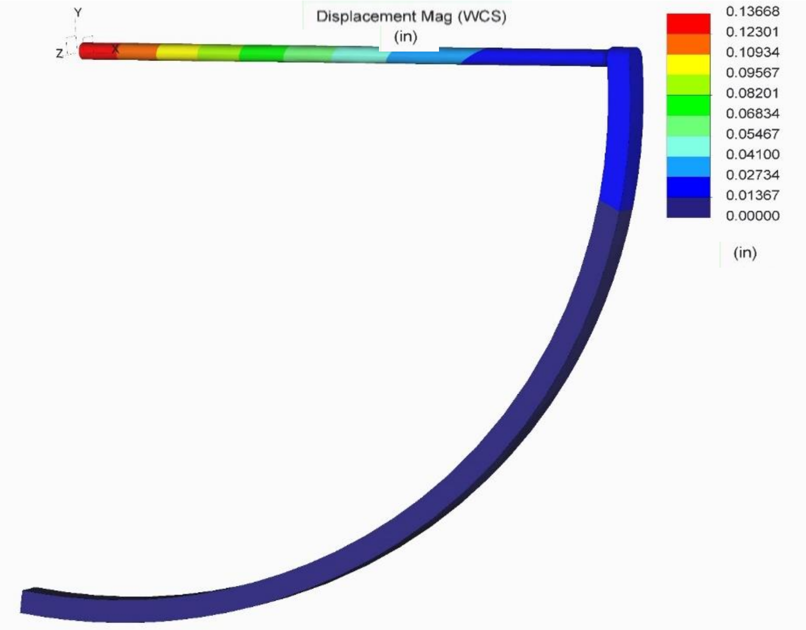
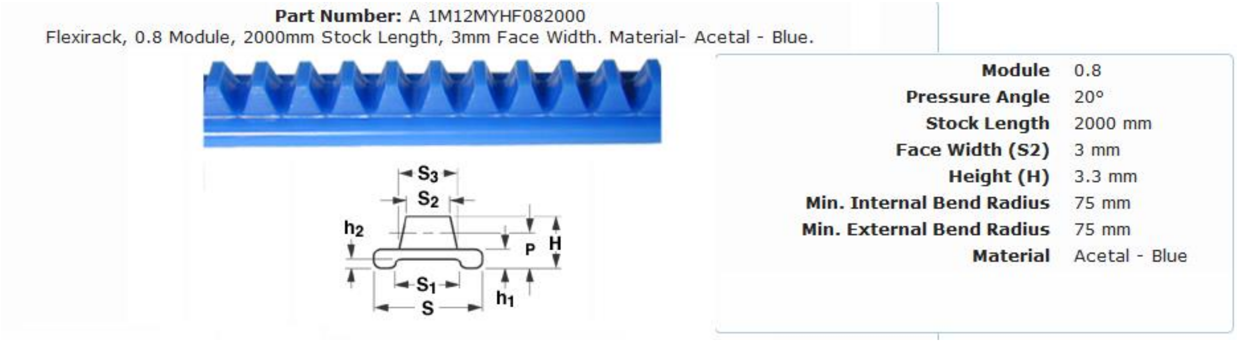


Figure 9: Displacement Analysis

In addition to the stress and deflection calculations, the maximum drag and lift forces allow for analysis to select a motor. In appendix A, the calculations under motor selection show the maximum torque the motor must be able to withstand in order to actuate. Maximum torque was calculated to be 7098 N*mm. Because of the provided budget, a motor with this amount of torque will not be able to be purchased. Instead, a motor gearbox will be purchased in order to increase torque provided by the purchased motor. Torque adjustment through a gearbox is another mechanical engineering concept utilized in this project. The motors currently under selection will be purchased with a driver, controller, and optical encoder. The optical encoder will provide feedback in order to ensure accuracy during actuation. A motor and included components will be purchased at the start of the spring semester.

A gear track will be mounted on the back of the arc in order to mate with the spur being driven by the motor. This will provide actuation. The track being placed onto the back of the arc is called “Flexi-rack”. It is an Acetal track made to bend to a specific radius range. A 25 inch radius is well within the specification of the flexi-rack. Purchasing flexi-rack with a face-width of 0.118in and a module of 0.8 yields an allowable transmission force of 100N. The maximum force needed to withstand is 69N as shown in appendix A under gear forces. Figure 10 shows the flexi-track that the team intends to purchase.



Part Number: A 1M12MYHF082000

Flexirack, 0.8 Module, 2000mm Stock Length, 3mm Face Width. Material- Acetal - Blue.

Module	0.8
Pressure Angle	20°
Stock Length	2000 mm
Face Width (S2)	3 mm
Height (H)	3.3 mm
Min. Internal Bend Radius	75 mm
Min. External Bend Radius	75 mm
Material	Acetal - Blue

Figure 10: Flexi-rack

In order to support the arc and reduced vibration, roller bearings will be used in the base design to support the normal force and moment induced when locked into a static mode. The bearing design can be seen in Figure 11. A follower on the back was also placed outside of the flow to help reduce the moment on the arc. Bearings will be purchased at the start of the spring semester of senior design. Detailed drawings and dimensioning of the base and follower are provided in appendix B.

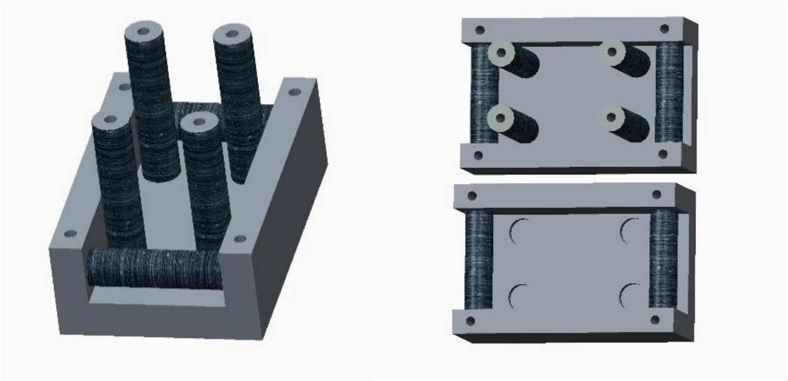


Figure 11: Bearing and base structure

III. Risk and Reliability

A few different risks are associated with the operation of this mechanism. Possible failures include fatigue failure in the sting, gear tooth failure, and motor failure. Fatigue failure could occur in the sting to the shedding of asymmetrical vortices at high tunnel speeds. The vortices will cause vibrations that could eventually cause sting failure or attachment failure in the bolt. This failure would occur in an isolated room, so chances of injury is zero percent. Also, the sting is a cheap metal rod that could be purchased and reattached for a cheap cost.

Gear tooth failure is another possibility. Because the chosen material for gear mating was Acetal plastic, wearing is going to occur. Accuracy would be sacrificed if a gear tooth failure occurred as the motor could skip steps.

However, with an optical encoder, it would detect these missed steps and be able to adjust. A second mode of failure due to a failed tooth would be that the mechanism would no longer be able to operate until fixed. The advantage of using a plastic flexi-track is that it could be cheaply replaced. This failure would be more costly as partial disassembly would need to occur in order to put the new track on.

A final failure mode could occur in the motor. Motor stall could occur through misalignment or unexpected forces in the tunnel. This could cause the motor to burn out. This would cause risk of injury as the motor could be extremely hot and with a high voltage. Also, replacement of the motor would require almost complete disassembly and purchase of a new motor. Motor compatibility with the encoder and controller would also need to be checked. Buying a new motor would be both costly and timely. This is the worst type of failure that could occur in this system and the motor calculations will be carried out with several factors of safety.

IV. Procurement

With the design process in its final stages the group has begun to place purchase orders for raw materials to be machined and stock parts from manufacturers. After speaking to multiple vendors, an estimate of approximately $300 has been provided for the raw aluminum 6061 that will comprise the arc. The machining of the arc will be done by the High-Performance Material Institute (HPMI) in Innovation Park. A request for a quote on the aluminum 6061 rod being used for the sting has been sent to vendors. The other components that will require machining are base and the follower; once the designs have been finalized for these components vendors will be contacted.

The rest of the components needed for the design all have the ability to be purchased from manufacturers and will require not extra machining or major alteration to be implemented. To achieve arc translation, a flexible gear track is being added to backside of the arc which will mesh with gears. The flexible track will be purchased from Stock Drive Products and will be $40 before the cost of shipping. The proper gear train is still being determined along with the motor that the will drive the arc translation, once the calculations have been completed the proper gear set will be purchased. The stepper motor that will drive the gear train will be approximately $200-$250, ordered from Anaheim Automation. Between the base piece and the follower to assist with alignment and stability there will be eleven rollers, these rollers will be metal with a rubber overlay to generate friction between the roller and arc. The specific materials for the rollers and the bearings that will be on the roller shafts have not been selected.

The mechanical pieces for the mechanism should tentatively cost between $800-$1,100; leaving at least $900 for the electrical components to be purchased next semester. All designs will be finalized before the end of the semester and all corresponding purchase orders will be placed. A comprehensive budget for components purchased in the fall semester will be provided in the spring. Table 5 summarizes the budget.

Table 5: Rough Budget

Component	Price (Estimated)
Raw Metals	$500
Motor	$250
Track	$40
Gears	$60
Rollers/Bearings	$100
Total	**$950**

V. Conclusion

The goal of this project is to create a mounting mechanism for AFRL's REEF center in Shalimar, FL. This mounting mechanism must be able to adjust a specimen's pitch and yaw in a low speed, open test-section, wind tunnel with maximum speeds pf 22 meters per second. The pitch and yaw must be able to achieve a range of -5 to 30 degrees and -10 to 10 degrees respectfully. The specimen must remain in the same 3 dimensional location at the end of actuation. The mechanism must be a cost effective solution since the maximum budget allotted is 2,000.

Several other designs were considered and analyzed for feasibility. The decision matrix helped the team decide that the best option for actuation was a circular arc with an attached sting mount for holding the mechanism. This design was chosen because it was able to actuate pitch while maintaining the central location of the model. Adjusting the yaw through use of a turn table beneath the body's center of mass allowed the location to remain the same as well. The issues with this design were fabrication and actuation methods.

Analyzing the optimum chosen design allowed the team to design an effective mounting system, choose actuation system, and select a material. The arc was designed to be 105 degrees of a circle with a radius of 25 inches. This allows the arc to be actuated outside of the flow while maintaining its capability to operate the full range of motions. Aluminum 6061 was chosen upon stress and deflection analysis. The stress and deflection analysis in Creo illustrated a factor of safety of approximately 10 and a deflection less than the quarter inch constraint. Max deflection was shown to be approximately 0.14in. Drawings and dimensioning of the design are shown in appendix B. An estimated cost analysis showed that the project is still within budget. Future plans of the mechanism include design of the control system.

VI. Environmental and Safety Issues and Ethics

Because this model has several moving parts and is in a very dynamic environment, there are always associated risks. Ensure the gears and rollers are clear of any obstructions, and hands are not on the mechanism during operation. The rollers and gears could produce a pinching/ crushing hazard that could result in injury. While the tunnel is in operation if any point on the mechanism were to fail, the sting, support arm, base plate, it could result in a loss of control of the model and mechanism. In the event of a catastrophic failure where a total separation of the model from the arc were to occur, the model and resulting broken pieces would create a projectile hazard. The group has also been given several thousand dollars' worth of equipment. These items must be incorporated in the design, or be returned to the sponsor.

VII. Future Plans

The next semester will focus on sending out part orders, machining, and design of the control system. Once the designs are approved, an official budget and bill of materials will be formulated. While the design was formed with budget in mind, this portion will gauge actual prices. If the design exceeds the budget provided, it will be re-evaluated for aspects that can be adjusted or redesigned to lower the cost. If changes are made, the analysis process must be completed again. If the design can't be changed, further funding will be requested from the sponsor.

Figure 12 displays the basic processing and functions that the design will incorporate. The user will input desired values for the pitch and yaw of the test specimen. If the desired angles do not match the current position of the specimen, the motors will turn on to move the specimen. It is important to note that only one angle (pitch or yaw) will change at a time. Also, a new angle cannot be entered until the motors have completed their current movements. Once the specimen reaches the desired position, the user will be able to input new angle values. The list below summarizes the next semesters plans:

- Check specifications of sponsor provided components against design requirements
- Selection of appropriate stepper motor
- Completetion of procurement for all components and materials required for design
- Design the circuitry for electrical componenets
- Programming of user interface using LabView

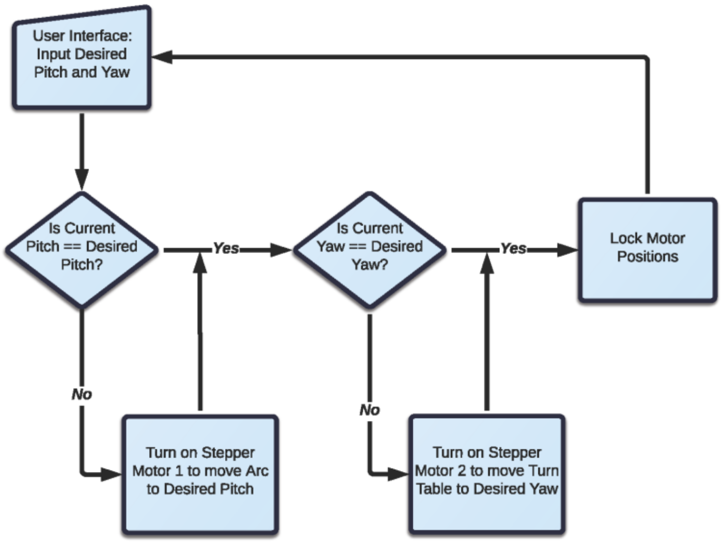


Figure 12: Processing and functions

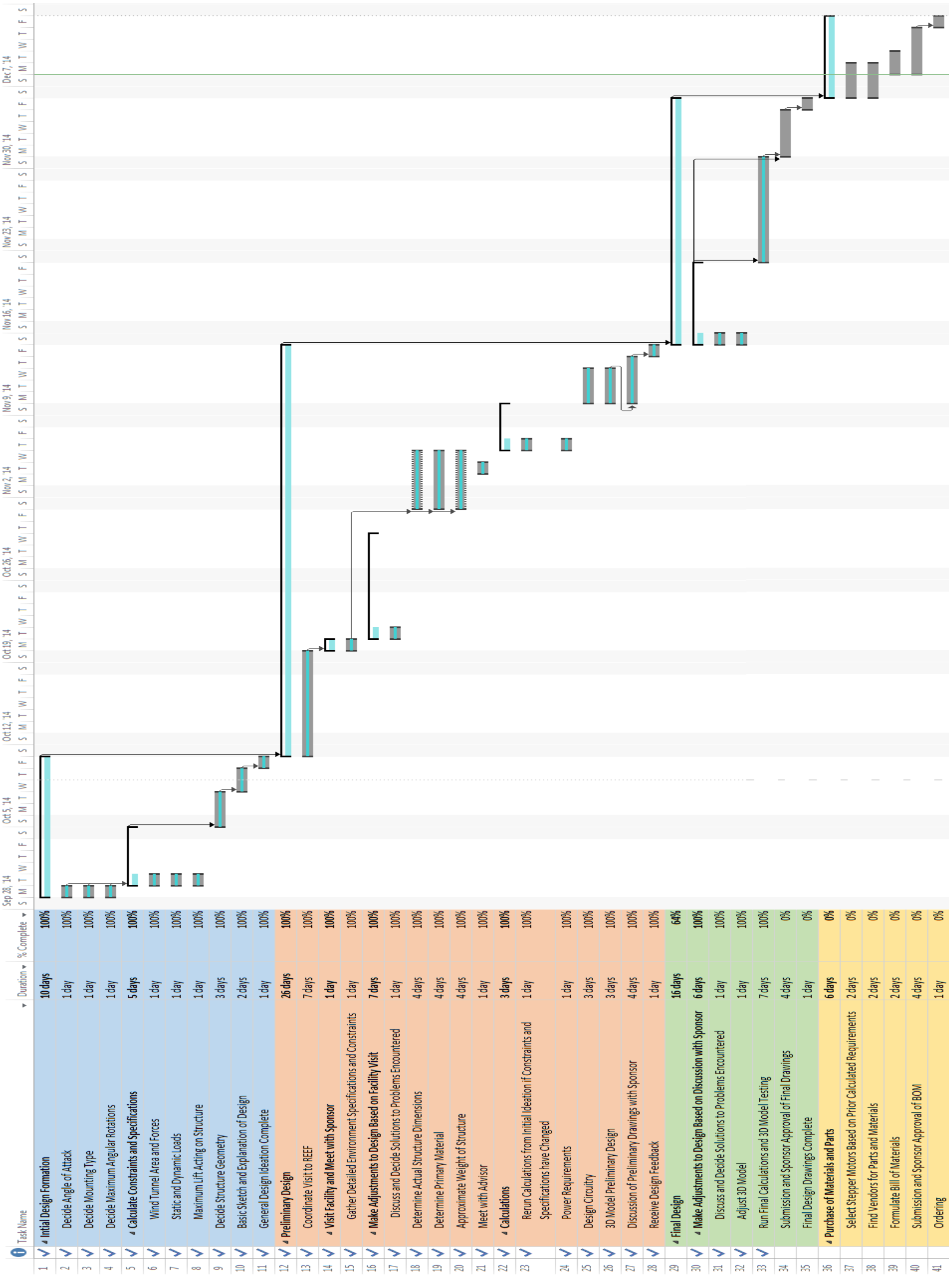
VIII. Gantt chart and Resources

The team has come together to review a schedule for the Spring semester as well as to assign tasks. This schedule and allocation of tasks to individual members will help ensure the team completes this project in time.

a) Schedule

To help keep track of this project and the many design decisions that must be made in order to proceed, the team has formulated a Gantt chart displayed in Figure 13 accompanied by a detailed breakdown. This will enable the team to keep track of progress and make sure that we complete milestones in a timely manner, so as to best prepare us for fabrication and control system design in the spring. The Gantt chart is displayed on the next page. It is also shown in appendix C.

b) Gantt Chart



		Task Name	Duration	% Complete
1	✓	**Intial Design Formation**	**10 days**	**100%**
2	✓	Decide Angle of Attack	1 day	100%
3	✓	Decide Mounting Type	1 day	100%
4	✓	Decide Maximum Angular Rotations	1 day	100%
5	✓	**Calculate Constraints and Specifications**	**5 days**	**100%**
6	✓	Wind Tunnel Area and Forces	1 day	100%
7	✓	Static and Dynamic Loads	1 day	100%
8	✓	Maximum Lift Acting on Structure	1 day	100%
9	✓	Decide Structure Geometry	3 days	100%
10	✓	Basic Sketch and Explanation of Design	2 days	100%
11	✓	General Design Ideation Complete	1 day	100%
12	✓	**Preliminary Design**	**26 days**	**100%**
13	✓	Coordinate Visit to REEF	7 days	100%
14	✓	**Visit Facility and Meet with Sponsor**	**1 day**	**100%**
15	✓	Gather Detailed Environment Specifications and Constraints	1 day	100%
16	✓	**Make Adjustments to Design Based on Facility Visit**	**7 days**	**100%**
17	✓	Discuss and Decide Solutions to Problems Encountered	1 day	100%
18	✓	Determine Actual Structure Dimensions	4 days	100%
19	✓	Determine Primary Material	4 days	100%
20	✓	Approximate Weight of Structure	4 days	100%
21	✓	Meet with Advisor	1 day	100%
22	✓	**Calculations**	**3 days**	**100%**
23	✓	Rerun Calculations from Initial Ideation if Constraints and Specifications have Changed	1 day	100%
24	✓	Power Requirements	1 day	100%
25	✓	Design Circuitry	3 days	100%
26	✓	3D Model Preliminary Design	3 days	100%
27	✓	Discussion of Preliminary Drawings with Sponsor	4 days	100%
28	✓	Receive Design Feedback	1 day	100%
29	✓	**Final Design**	**16 days**	**64%**
30	✓	**Make Adjustments to Design Based on Discussion with Sponsor**	**6 days**	**100%**
31	✓	Discuss and Decide Solutions to Problems Encountered	1 day	100%
32	✓	Adjust 3D Model	1 day	100%
33	✓	Run Final Calculations and 3D Model Testing	7 days	100%
34		Submission and Sponsor Approval of Final Drawings	4 days	0%
35		Final Design Drawings Complete	1 day	0%
36		**Purchase of Materials and Parts**	**6 days**	**0%**
37		Select Stepper Motors Based on Prior Calculated Requirements	2 days	0%
38		Find Vendors for Parts and Materials	2 days	0%
39		Formulate Bill of Materials	2 days	0%
40		Submission and Sponsor Approval of BOM	4 days	0%
41		Ordering	1 day	0%

Figure 13: Gantt Chart

c) Resource Allocation

Design ideation was a team effort. All major design decisions are discussed by the team and each member contributes ideas to accomplish specifications within the project constraints while also being aware of possible problems that may occur with each idea or change. Table 6 shows the upcoming tasks that require completion for the project to move forward. Each team member has been assigned tasks based on their areas of expertise and has estimated the hours they require to complete those tasks.

Table 6: Resource Allocation

Task	Responsible Party	Estimated Days
Circuit Design Calculations	Caitlan Scheanwald	3
Circuit Drawings	Caitlan Scheanwald	2.5
Research Stepper Motors	Jacob Kraft	2
Research Servo Unit	Jacob Kraft	2
Design Gear Train/System	Justin Broomall	4
Calculate Necessary Gear Ratios	Justin Broomall	3
Submit Purchase Orders	Andrew Baldwin	1

Primarily, this group intends to function as a team. While we have assigned specific responsibilities to each member, we also recognize that it is beneficial to work together, especially when certain portions of the design process may be heavier on one team member than on another. Team 12 will work together to complete this design and its fabrication to the satisfaction of the sponsors and advisors.

IX. References

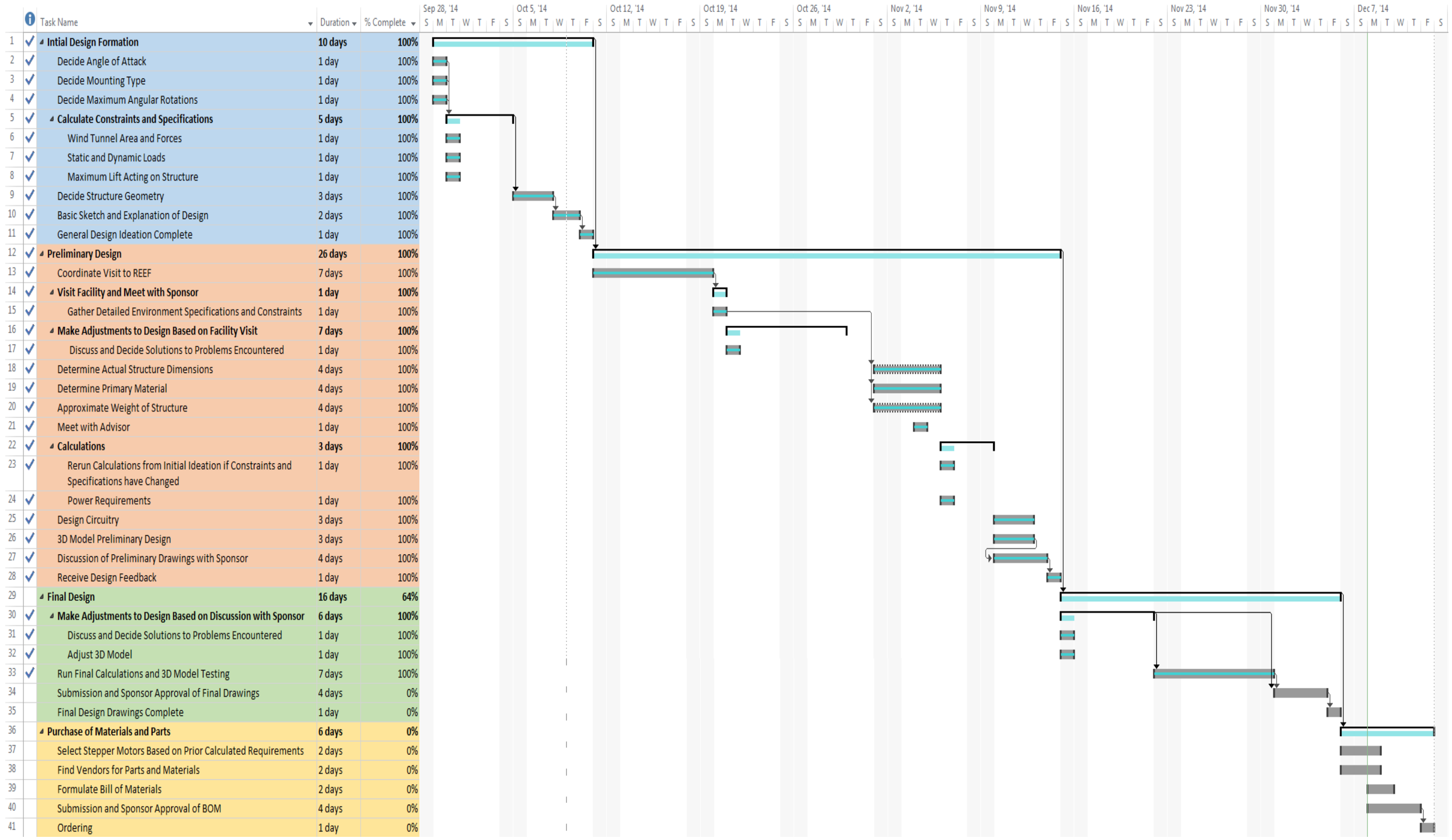
1. Dunbar, Brian. "Unitary Plan Wind Tunnel 11-by 11-foot Transonic Test Section."
2. NASA. NASA, n.d. Web. 23 Sept. 2014.
3. Benson, Tom. "Model Mounts." Model Mounts. NASA, 12 June 2014. Web. 23 Sept. 2014.
4. Benson, Tom. "Sting Mount Example." Internal Force Balance. NASA, 12 June 2014. Web. 23 Sept. 2014.
5. Benson, Tom. “External Force Balance.” External Force Balance. NASA, 12 June 2014. Web. 23 Sept. 2014

X. Appendix

a) Appendix A: Mathcad Calculations

b) Appendix B: Detailed Drawings

c) Gantt Chart



		Task Name	Duration	% Complete
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2	✓	Decide Angle of Attack	1 day	100%
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