REEF Subsonic WT Articulating Robotic Arm

Deliverable: Project Plan and Product Specification

Team Number: 12

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Submitted To: Dr. Helzer and Dr. Gupta

Authors:

Jacob Kraft

Andrew Baldwin

Justin Broomall

Caitlan Scheanwald

Table of Contents

Table of Figures

Table of Tables

Abstract

The goal of the REEF WT Articulating Robotic Arm project is to create a robotic arm capable of mounting, pitching, and yawing a specimen during operation of the wind tunnel. During operation, the mounting mechanism must keep the specimen in the center of the $42in^2$ test section. The previous arm for the wind tunnel was relocated to another research facility, and a new one is required to carry out further testing of specimens. A sting mount will be utilized in order to minimize flow disruption around the specimen. The joints and base of the arm will be moved using stepper motors. Per the sponsor's request, the material for the arm will be comprised mostly of 80/20. Design constraints, performance specifications, and a schedule have been created. A Gantt chart will tentatively plan out the remainder of the semester. Design ideas will now be drafted with respect to the constraints and specifications. Next deliverable will offer the final design ideas.

1 Introduction

The objective of this project is to create a mechanism to mount a specimen in the center of the wind tunnel test area. This mechanism must be able to adjust the pitch and yaw of the specimen while the wind tunnel is operational. The building material was specified to be 8020 by the sponsor. A servo control unit will be provided to be programmed with the purchased stepper motors and the user interface. These stepper motors will be the source of movement for the mechanism. The wind tunnel has a maximum speed of 22 m/s, or approximately 50 mph, with a $42in^2$ test section. A sting mount will be used to hold the specimen in place. Multiple mechanisms of this type exist. The background analyzes a few different mounting types used for research in large wind tunnels.

Numerous problems remain to be solved in this project. First, a design must be created in order to best adjust orientation of the specimen while keeping it located in the center of the test section. Changes of the model location within the flow could lead to undesirable results. The team will have to decide on an angle of attack as well as design the mechanism to move the specimen in pitch and yaw. Second, forces from the wind tunnel must be analyzed in order to build a structure that can withstand maximum speeds. A high factor of safety will be used for this design portion, so that the integrity of the structure is ensured. Third, a force reducing mechanism such as a gearbox or chain drive must be designed in order to move the mounting mechanism during wind tunnel operation. This will also incorporate the force analysis on the tunnel. The final problem lies in pricing. Given a material, motor type, and size constraints, a design must be formulated to keep within the budgeted $2000.

2 Project Definition

2.1 Background research

Wind tunnels have proven to be a cost effective means to test an aerodynamic design in a controlled environment. Small scale aircraft models will have the same drag, life, and side force coefficients as full scale aircraft in flight. In order to properly test an object in a wind tunnel, a device must be constructed to hold the model in place and measure the forces acting on it. Depending on the desired data, model size, and wind tunnel test section, the mount could be very robust, or be very discreet to reduce impact on the acquired data. There are several types of mounts that have been developed for wind tunnel testing. Four commonly used mounts are single strut, two strut, three strut, and sting mounts[2] as shown in figure 1.

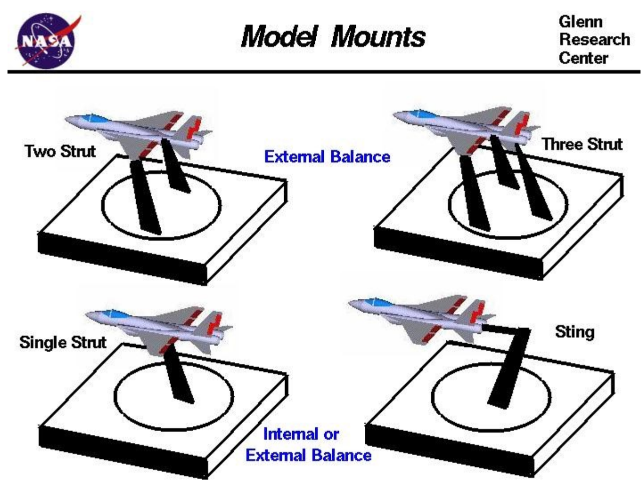


Figure 1: Model Mounts[2]

Per suggestion of our sponsor, the mount we will utilize is a sting mount. The benefit of the sting mount is there is little areodynamic interference until the flow reaches the wake. This means the lift and side forces will be unaffected, however, the drag force will be slightly impacted by the mount geometry itself. Sting mounts also provide an easy method to run wires or tubes through the mount and to the control room.

Sting mounts are very versatile and have the benefit of providing internal or external balance testing. With internal testing, strain gages are placed within the sting assembily inside the aircraft model. These strain gages will measure the forces

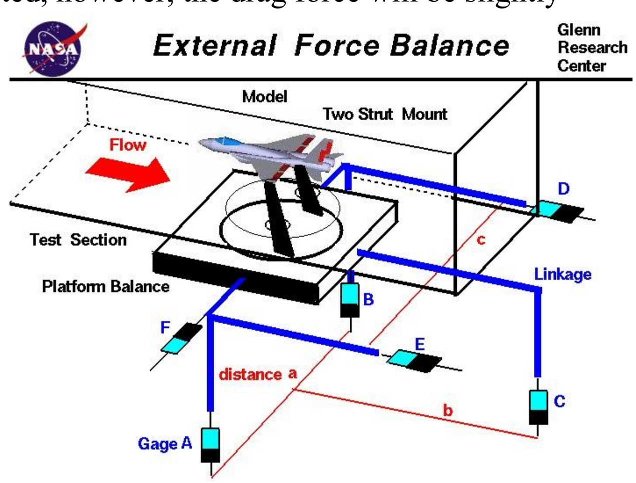


Figure 2: External Force Balance[4]

and moments acting on the model. The lift, drag, and pitch can be determined. However, the side forces (roll or yaw) can't be determined with internal balance testing[3]. In order to measure the side forces, the mount must be able to preform an external balance. The external balance encorporates mulitple strain gages within the base of the model itself. In figure 2, boxes A through F represent the different strain gages within the base of the mount. These gages measure six different components, lift, drag, and side forces, as well as pitch, yaw, and roll moments[4].

2.2 Need Statement

The sponsor for team 12, the REEF Subsonic WT Articulating Robotic Arm project, is the Air force research lab. Mike Systma is the air force research lab representative for this project. The facility has a subsonic wind tunnel with a test section of 42 in^2. The wind tunnel reaches a maximum speed of 22 meters/second. The existing robotic arm mount was removed and placed in a different wind tunnel. A new robotic arm must be designed in order to mount test specimens. The test specimens must be able to adjust in pitch and yaw within the center of the wind tunnel test section.

Need Statement: There is no mounting mechanism in the wind tunnel to hold the specimen.

2.3 Goal Statement & Objectives

Goal Statement: Design a mounting mechanism in order to mount and adjust test specimen to desired orientations during wind tunnel operation.

Multiple objectives have been set forth to be achieved in the design of the mounting mechanism. While a test specimen is being held in the active flow of the wind tunnel the mechanism must be able to manipulate the orientation of the specimen. The angle of attack (pitch) of any specimen must be able to be adjusted 30° above or below a sitting position of completely level. The yaw (side slip) of the specimen must also be able to be adjusted 20° to the left or right of an initial position of being directly aligned with the flow. While the orientation of the specimen is being shifted the location of the model; the middle of the test section; must remain the same so that consistent results may be achieved. Once the specimen has been shifted to a desired orientation it is pivotal that the model remain still and refrain from moving or swaying. For this to be achieved the mechanism should be designed to withstand the maximum velocities that can be produced by the wind tunnel, 22 meters per second. The mechanism must be made to be mobile, allowing easy movement and alignment in regards to its physical position in the open wind tunnel facility.

Objectives:

- Adjust pitch (angle of attack) of specimen ±30º
- Adjust yaw (side slip) of specimen ±20º
- Must be a mobile mounting mechanism
- Keep specimen in center of test section
- Withstand maximum wind speeds of the tunnel
- Hold specimen still

3 Constraints

There are multiple constraints that need to be acknowledged and adhered to for the production of a robotic arm for use in a subsonic wind tunnel. The arm is required to alter the pitch and either the roll or yaw of a given model as it is studied in a wind tunnel, based on parameters inputted by researchers that will be carried out by the mechanism’s stepper motors. There will be two stepper motors to adjust the pitch and yaw. The model must maintain a position in the center of the flow while the pitch and yaw are changed. The power source for the robot would come from a standard wall socket and converted into a DC current via a power supply. This power demand will depend on the selected stepper motors.

The first main constraint is the budget that has been allotted for the project, a total of $2,000, for the procurement of materials and construction of the arm. The major expenditures come from the purchase of stepper motors and encoders, as well as the 80/20 building materials for the structure. This material was requested by the sponsor. The most expensive part, the servo controller unit, will be provided by the sponsor. A preemptive break down of the budget is shown in Table 1. 8020.net[5] was used by our sponsor to give an approximation of the pricing for the building materials.

Since there is a potential for deformation and even damage to the structure due to the forces produced by the wind tunnel, a high factor of safety is needed. The supporting structure and the arm must be able to withstand the forces produced by the wind tunnel blowing directly onto both, as well as not tip over due to the previously mentioned forces and lift generated due to the model. All of these forces must be accounted for while minimizing the total weight of the system. The structure holding the arm must be able to be moved easily and once in its desired location, locked into place. The structure have adjustable feet to ensure the model will be perfectly level. The vertical position of the model held by the arm needs to be placed in the center of a 42”x42” square inlet; the centroid of the opening being approximately 84” in height.

Table 1: Estimated Budget

Item	Estimated Costs
80/20 Frame Structure	$500-$600
Stepper Motor/Encoders	$400
Raw Materials	$200-$300
Shop Time/Fabrication	$200
Total	**$1500**

3.1 Design Specifications

The mounting device must be able to adjust both its angle of attack (α) and angle of side slip (β) during operation of the wind tunnel at maximum speed of 22 m/s. The angle of attack and angle of side slip must be able to adjust ±30º and ±20º respectively. Because the wind tunnel will be applying a dynamic force to the face of the mounting mechanism, a bending moment and torque would be induced. Using the bending moment and torque, a minimum diameter can be calculate for the bar structure through use of the max shear stress and yield stress of aluminum. The applied moment would also torque the motor additionally. The motor must overcome this torque in order to be able to adjust the angle of attack during wind tunnel operation. Together, this aluminum structure along with accessories will add together for a total weight. This weight must be approximately 50kg maximum to ensure portability. All calculations will be shown in the appendix. The list below summarizes the specific design specifications:

- Must have less than $2.751*10^8$ Pa in bending stress
- Shear stress must not exceed $2.048*10^8$ Pa
- Angle of attack must traverse ± 30º
- Side slip must traverse ±20º
- Bearing must support a total weight of 50kg
- Structure must stay standing under 230N*m of torque
- Structure must have zero movement in the X and Y direction during operation
- Motor must supply a steady torque of 112 N*m
- Stepper motors must be able to move over 30º range

3.2 Performance Specifications

The mounting mechanism should be able to shift the orientation of the test specimen; either the angle of attack or yaw; at a rate of 0.5° per second until its desired orientation is achieved. All changes in specimen orientation will be feed to the mounting mechanism through a wired data transmission; any additional sensors on the model will transfer data in the same fashion. All power that will be provided to the mechanism will come from a standard grounded 120V wall socket. The wind tunnel is active the mechanism must be portable, either for shifting its position in the open wind tunnel or so that it be stored elsewhere.

Performance Specs

- Shift alpha and beta respectively at a rate 0.5 deg/s
- Portability while wind tunnel not in operation
- Wired data transmission to control orientation
- Use of standard US wall socket (grounded, 120V) for power

4 Methodology

The first objective of the project will be to visit the site and take necessary measurements and evaluate the space for the mounting mechanism. During the site visit, the team will discuss possible ideas and problems that may be encountered with the sponsor. Based on this discussion, a design will be formulated that can theoretically manage all of the project constraints and specifications. With the measurements from the facility, the dimensions and weight of the overall structure can be estimated. The team will assume a high factor of safety for all calculations. Once force analysis and the design of individual, vital components is completed, drawings will be made. These drawings and the calculation and modeling results will be submitted to the sponsor.

Once the design of the structure is 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.

4.1 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 3 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 in the Spring.

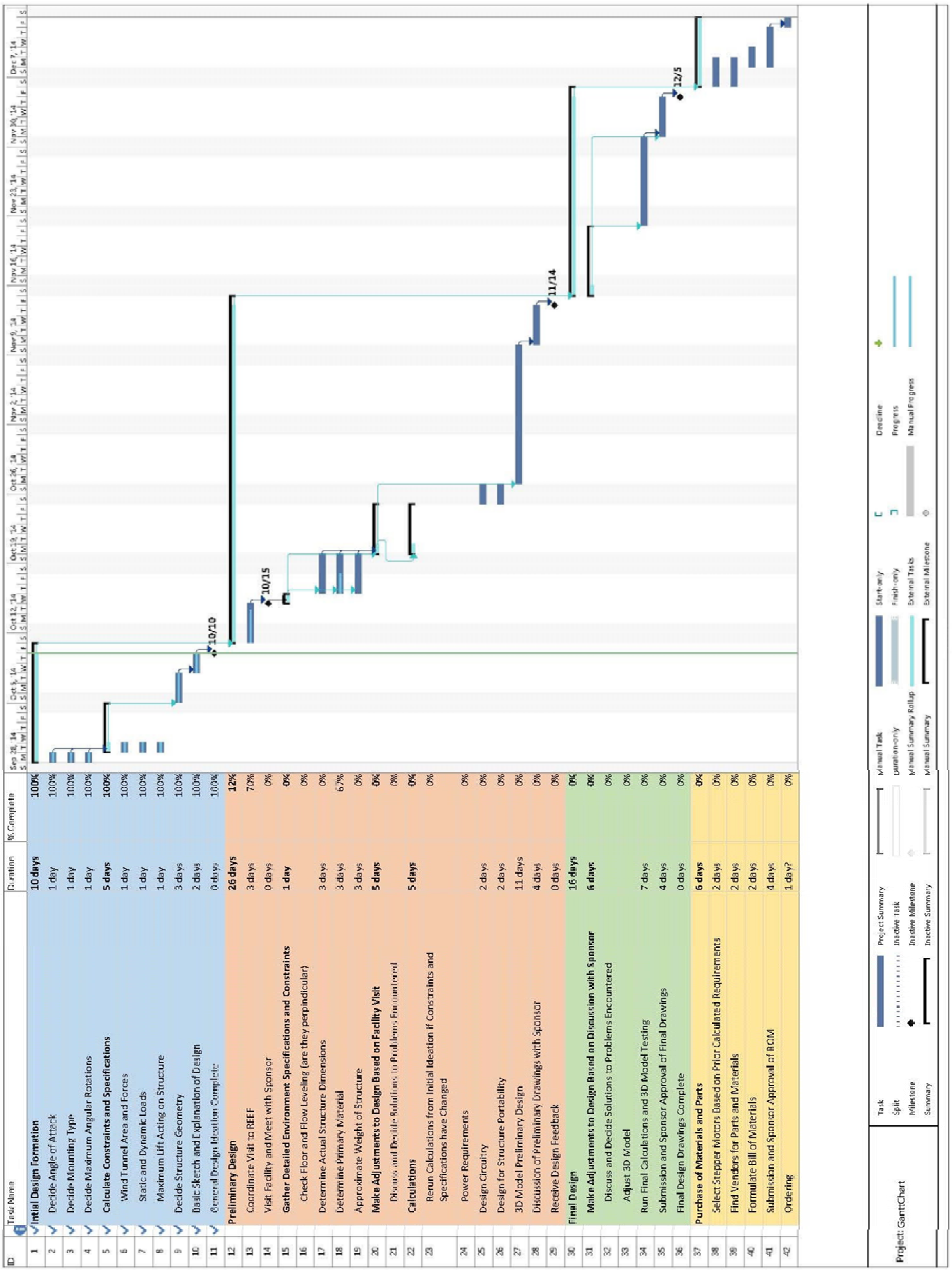


Figure 3: Team 12 Gantt Chart

4.2 Resource Allocation

The initial design ideation has been 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. Calculations are primarily performed by the team leader, Jacob Kraft. He is in charge of running mathematical scenarios to fit each idea so that the team can identify which ideas do not fit the project constraints. 3D modeling and drawings are completed by Justin Broomall. Justin also works with Jacob because many of the 3D models are needed for testing simulations. All circuitry and programming needs are handled by Caitlan Scheanwald. She is in charge of choosing the stepper motors that will be vital to the design, as well as programming them along with the servo unit later during fabrication. Until then, it is her responsibility to keep the group informed of power requirements for the structure as the design evolves. All purchases and design decisions based on cost are handling by Andrew Baldwin. It is his duty to research parts and vendors to help the team keep costs low. If a design idea is too costly he must inform the team and attempt to provide an alternate design solution.

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.

5 Conclusion

The previous robotic arm used for this wind tunnel was relocated to another research area, and the tunnel can no longer be used to carry out tests without a mounting mechanism. The goal of this project is to creating a mounting mechanism that can also adjust the pitch and yaw of the specimen during wind tunnel operation. During operation, the specimen must remain located in the center of the 42 in^2 test section. It is intended that the mounting mechanism be made with 8020 material per the sponsor's request. The mechanism will also utilize stepper motors with encoders and a servo control unit. Per the sponsor's suggestion, the design will feature a sting mount. This will minimize flow disruption around the test specimen and therefore impact the majority of test results the least.

In the next portion of this project, design ideas must be evaluated. The sponsor will take part in this ideation and invention part. Once a design is formulated, force and weight analysis will be completed. The mechanism must withstand the maximum air speed of 22 m/s while being fully operational. Being able to already define a number of parts required for the project, an approximate budget was created, totaling about $1500 dollars. The excess $500 dollars is a rough estimate but should cover miscellaneous costs.

In the days leading up to the next deliverable due date, the team will hold staff meetings and make a site visit in order to confirm design details and constraints and evaluate progress. A site visit will allow the group to examine the surroundings, see other mounting mechanisms, and take essential measurements for the ideation and invention portion of the project. A schedule is now provided in the form of a Gantt chart in order to tentatively plan out future and upcoming deliverables/milestones.

The next steps of the project include coming up with various designs for the mounting mechanism. These designs will be analyzed individually with respect to the design constraints. During this process, ideas will be eliminated. The goal by the next deliverable is to have a design that can begin to be drafted in a CAD software. Following the drafting, drawings will be submitted before the end of the semester in order to begin the next stage of production for the project.

6 References

1) Dunbar, Brian. "Unitary Plan Wind Tunnel 11-by 11-foot Transonic Test Section." NASA. NASA, n.d. Web. 23 Sept. 2014.
2) Benson, Tom. "Model Mounts." Model Mounts. NASA, 12 June 2014. Web. 23 Sept. 2014.
3) Benson, Tom. "Internal Force Balance." Internal Force Balance. NASA, 12 June 2014. Web. 23 Sept. 2014.
4) Benson, Tom. “External Force Balance.” External Force Balance. NASA, 12 June 2014. Web. 23 Sept. 2014
5) "8020.net 80/20® Inc. - The Industrial Erector Set®." *CoolSocial RSS*. N.p., n.d. Web. 26 Sept. 2014.

Givens

Design Properties

$h\_max := 82in = 2.083m$

$Vmax := 22\frac{m}{s} = 49.213mph$

$rho\_air := 1.2\frac{kg}{m^3}$

$alpha\_max := 30deg$

$beta\_max := 20deg$

$Amax := 4ft^2 = 0.372m^2$

$L\_sting := 5ft$

$L\_base := 4ft$ $\quad t := .25in$

$W\_base := 2ft$

$H\_base := 2ft$

Aluminum Properties

$rho\_alum := .0975\frac{lb}{in^3} = 2.699\times 10^3 \cdot \frac{kg}{m^3}$

$UTS\_alum := 45ksi = 3.103\times 10^8 Pa$

$USS := 29.7ksi = 2.048\times 10^8 Pa$

$YS := 39.9ksi = 2.751\times 10^8 Pa$

$E := 10000ksi = 6.895\times 10^{10} Pa$

$G := 3770ksi = 2.599\times 10^{10} Pa$

Force and Moment Calculations

$F\_max := \frac{1}{2}\cdot rho\_air\cdot Vmax^2\cdot Amax = 107.916N$

$Moment\_max := F\_max\cdot h\_max = 224.768N\cdot m$

$Torque\_max := L\_sting\cdot cos(beta\_max)\cdot F\_max = 154.546N\cdot m$

$Moment\_motor := F\_max\cdot\frac{h\_max}{2} = 112.384N\cdot m$

$Flift := \frac{1}{2}\cdot rho\_air\cdot Vmax^2\cdot sin(alpha\_max)\cdot Amax = 53.958N$

Structural Calculations

-Assuming full aluminum rods as structure base

$Shear\_force := F\_max = 107.916\,N$

$$d\_min\_shear := \sqrt{\frac{3\cdot Shear\_force}{\pi\, USS}} = 0.028\cdot in$$

-Bar diameter must be greater than 0.028 inches if only shear is considered

$$d\_min\_bend := \sqrt[3]{64\cdot\frac{Moment\_max}{\pi\cdot YS}} = 0.026\,m$$

-Shear diameter is larger, so minimum diameter is 0.028in

$d\_min := 0.25in$

-Select quarter inch bar as material diameter

$Volume\_base := 2\cdot L\_base\cdot W\_base\cdot t + 2\cdot W\_base\cdot H\_base\cdot t = 0.014\cdot m^3$

$mass\_base := rho\_alum\cdot Volume\_base = 38.211\cdot kg$

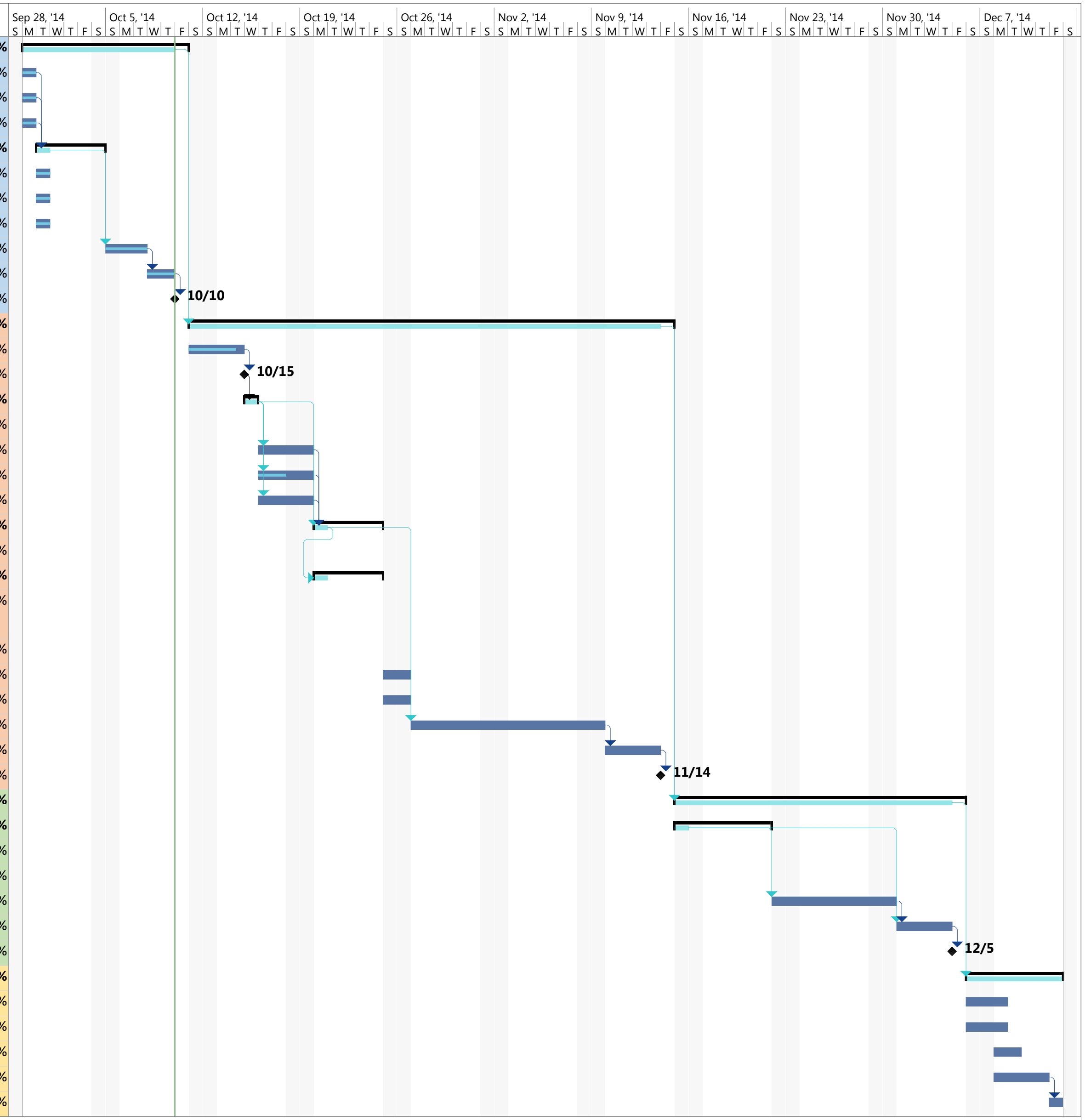
$$mass\_structure := \frac{\pi}{4}\cdot d\_min^2\cdot h\_max\cdot rho\_alum = 0.178\,kg$$

$mass\_extra := 10kg$

$mass\_total := mass\_base + mass\_structure + mass\_extra = 48.389\,kg$

$bearing\_normal\_force := mass\_total\cdot g - Flift = 420.572\,N$

ID	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	0 days	100%
12	Preliminary Design	26 days	12%
13	Coordinate Visit to REEF	3 days	70%
14	Visit Facility and Meet with Sponsor	0 days	0%
15	Gather Detailed Environment Specifications and Constraints	1 day	0%
16	Check Floor and Flow Leveling (are they perpidicular)		0%
17	Determine Actual Structure Dimensions	3 days	0%
18	Determine Primary Material	3 days	67%
19	Approximate Weight of Structure	3 days	0%
20	Make Adjustments to Design Based on Facility Visit	5 days	0%
21	Discuss and Decide Solutions to Problems Encountered		0%
22	Calculations	5 days	0%
23	Rerun Calculations from Initial Ideation if Constraints and Specifications have Changed		0%
24	Power Requirements		0%
25	Design Circuitry	2 days	0%
26	Design for Structure Portability	2 days	0%
27	3D Model Preliminary Design	11 days	0%
28	Discussion of Preliminary Drawings with Sponsor	4 days	0%
29	Receive Design Feedback	0 days	0%
30	Final Design	16 days	0%
31	Make Adjustments to Design Based on Discussion with Sponsor	6 days	0%
32	Discuss and Decide Solutions to Problems Encountered		0%
33	Adjust 3D Model		0%
34	Run Final Calculations and 3D Model Testing	7 days	0%
35	Submission and Sponsor Approval of Final Drawings	4 days	0%
36	Final Design Drawings Complete	0 days	0%
37	Purchase of Materials and Parts	6 days	0%
38	Select Stepper Motors Based on Prior Calculated Requirements	2 days	0%
39	Find Vendors for Parts and Materials	2 days	0%
40	Formulate Bill of Materials	2 days	0%
41	Submission and Sponsor Approval of BOM	4 days	0%
42	Ordering	1 day?	0%



Project: GanttChart

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			