U of A ROV Team

Spring 2004

Tech Report

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1 - *Executive Summary*

The purpose of the project is to design a remote controlled submersible that can easily maneuver around obstacles and perform seven different tasks. The reason for designing such a submersible is to enter it into a competition sponsored by MATE (Marine Advanced Technology Education Center). MATE's proposal is to design a remote operated vehicle (ROV) to efficiently complete the seven tasks. This is an exciting project that is both challenging and extremely rewarding.

A major challenge is that, our team is starting this design project with no previous prototypes to work from. The design will be completely original which means that we will have to work harder at narrowing design concepts and try to keep our time frame in mind. It will be important for us to stay focused on the main objective of designing and building a submarine to complete the seven tasks within the allotted time frame. Designing and constructing the biggest, most powerful, or best looking ROV is not a priority in this case. Please note that the team decided it would be beneficial to the project if we concentrated on designing of the retrieval system after a completed, functioning submersible is constructed. Decision making was difficult due to the range of different designs to choose from. Thus, the team chose to build a working sub first and then add the retrieval system to the working product. This does not mean that the team has forgotten the importance of the retrieval systems and how they relate to the initial design of the submarine. Throughout the design process it is important for us to take into consideration marine technology which is an unfamiliar area of study for us making the decisions even more challenging. By living in a desert climate we do not have access to ample resources that could aid us in our design, construction and testing. We do not have the luxury of testing the submersible in natural oceanic conditions; therefore, swimming pools will have to suffice. Aware of our obstacles, we are confident in creating a successful submersible that will be beneficial to marina technology.

A brief overview of the design requirements will give the reader an outline of the specifications of the project. The submersible must fit inside a 60 cm diameter circle and maneuver within an 80cm cube. The ROV must have a tether with a minimum length of 12m. The tether is used to control the submarine remotely. The maximum voltage is 13.5V and the maximum current draw is 25A. The ROV must withstand 150.36 kPa of pressure and also a camera must be used. The material of the sub has to be water-insoluble and cannot release any unsafe materials into the water or atmosphere.

Attached in this report is a projected timeline of the design process as well as an in-depth description of the task missions and preliminary design concepts. This Gantt chart displays the proposed dates for our progress this semester. We have designated key tasks to specific team members, but as always, the Gantt chart will be updated and modified when necessary.

2 - Project Specifications

The 2004 MATE Center ROV Challenge requires that our team complete seven tasks while staying within the design specifications. The whole competition will take place in a freshwater pool that will be up to 5 meters deep. The ROV will be flying in and around mystery reef, which is a structure made of ¾" PVC tubing and will be 3 meters wide by 3 meters long by 2 meters high. It will be covered in black landscaping cloth and will contain twisting and small passages as well as air leaks. The ROV will also be maneuvering outside mystery reef around a downed U-boat that will be represented by a 2 meter long and 1 meter in diameter PVC tube. The U-boat will be divided internally with bulkhead compartments.

It will be within the mystery reef and the U-boat that the team will have to complete the seven tasks. Task one requires that we locate and retrieve a lost towfish, which will be represented by a 2" diameter 1 meter long ABS pipe. There will be an eyehook attached to the tube, which we will always be oriented vertically. For task two we have to locate the captain's bell within the downed U-boat and then read the inscription on the bell. Task three asks us to patch a leaking barrel. We will be given a ten centimeter Velcro patch to cover a three centimeter hole, also made with Velcro. The barrel will be oriented upright and the hole will be on the upright, flat end. We will be judged on how accurately we place the Velcro patch. Task four has us finding and collecting five of a specific species of fish. We must locate the fish within the mystery reef or within the U-boat and then place them in the collection basket provided or in a collection basket of our own. Tasks five and six are very similar, in that we must find a methane leak and tag the tubeworm cluster next to the leak for task five, and we must find the mussel bed and tag it for task six. In both cases we will be given a tag that we must take down and use to attach to the respective objects. For the seventh and final task we must find five lava rocks and place them in the given collection basket or use one of our own.

These tasks provide us with wide and open-ended design possibilities; however the competition rules constrain the design to these guidelines:

- The ROV must be able to operate and withstand water pressure at a depth of 5m.
- The pool contains chlorinated, freshwater but should be considered conductive of electrical currents. Waterproofing the ROV components is preferable.
- The ROV should have at least 12m of tether in order to reach inside the mock-up from the control shack.
- The team must be able to set up the ROV system at the control shack within the 5-minute set up period.

- The team must be able to demobilize the ROV system and move it from the control shack within five minutes.
- The ROV must be able to fit through a circular opening of 60cm in diameter and maneuver in a space 0.8m x 0.8m x 0.8m.
- The ROV must be able to fly and operate in a bubble stream.
- The vehicle and all of its associated equipment, including the tether, must be either hand-carried or stowed on a wheeled cart (supplied by the team) and transported to the competition site.
- The vehicle must be launched and recovered by hand and only by the members of the team.
- The vehicle system (this includes carts and any other items used to operate or maintain the ROV) must not damage any part of the pool deck or bottom tiles.
- The ROV must have a video camera.
- The team may want to include a small light on the ROV. It will not be completely dark inside the mock-up, but light levels may be reduced.
- The team should devise a payload tool(s) to perform all the mission tasks.
- Only DC voltages are allowed to travel through the tether to the ROV. The maximum DC voltage the ROV can use is 13.5 volts.
- The maximum DC amperage the ROV can draw is 25 amps.
- The ROV's DC power system must be protected by a circuit breaker or a fuse(s).

While these guidelines will limit some of the design capabilities, we still have a many aspects of the sub that are very open ended. Perhaps the most open ended and most important aspect of the ROV will be the design of the retrieval system; the main component of the sub that will complete the seven tasks.

3 - Body Structure

3.1 - Introduction:

When designing and constructing the body of the submersible, many factors had to be taken into account to ensure the best and most efficient design. Not only did we have to consider the constraints set forth by the competition rules and regulations but also maneuverability, functionality, and aesthetics affected the design of the ROV. Many methods of analysis including Pugh, observational, and numerical analysis forced the team to go to the drawing board several times. In the end we were able to agree on a final design that was able to meet all of the requirements and most of our wishes.

3.2 - Constraints:

Many factors affected the final design of the submersible from different areas ranging from the MATE ROV Competition Rules to the preferences of the team members. Even though some constraints were more important than others, all were a factor in the geometry, size, and style of the ROV. Some of the major constraints that were taken into consideration are:

- The pool contains chlorinated, freshwater but should be considered conductive of electrical currents. Waterproofing the ROV components is preferable.
- The ROV must be able to fit through a circular opening of 60cm in diameter and maneuver in a space 0.8m x 0.8m x 0.8m.
- The ROV must be able to fly and operate in a bubble stream.
- The vehicle system (this includes carts and any other items used to operate or maintain the ROV) must not damage any part of the pool deck or bottom tiles.

3.3 – Structure Overall Design:

Through the course of the fall and spring semester, we were able to design and construct the structure of the submersible. Combining aspects of engineering analysis, competition constraints, subsystem incorporation, and creativity we finalized the design of the structure. As shown in the engineering drawing shown below, our open body system has a maximum length, width, and height of 17.22 inches, 16.85 inches, and 9.63 inches respectively.

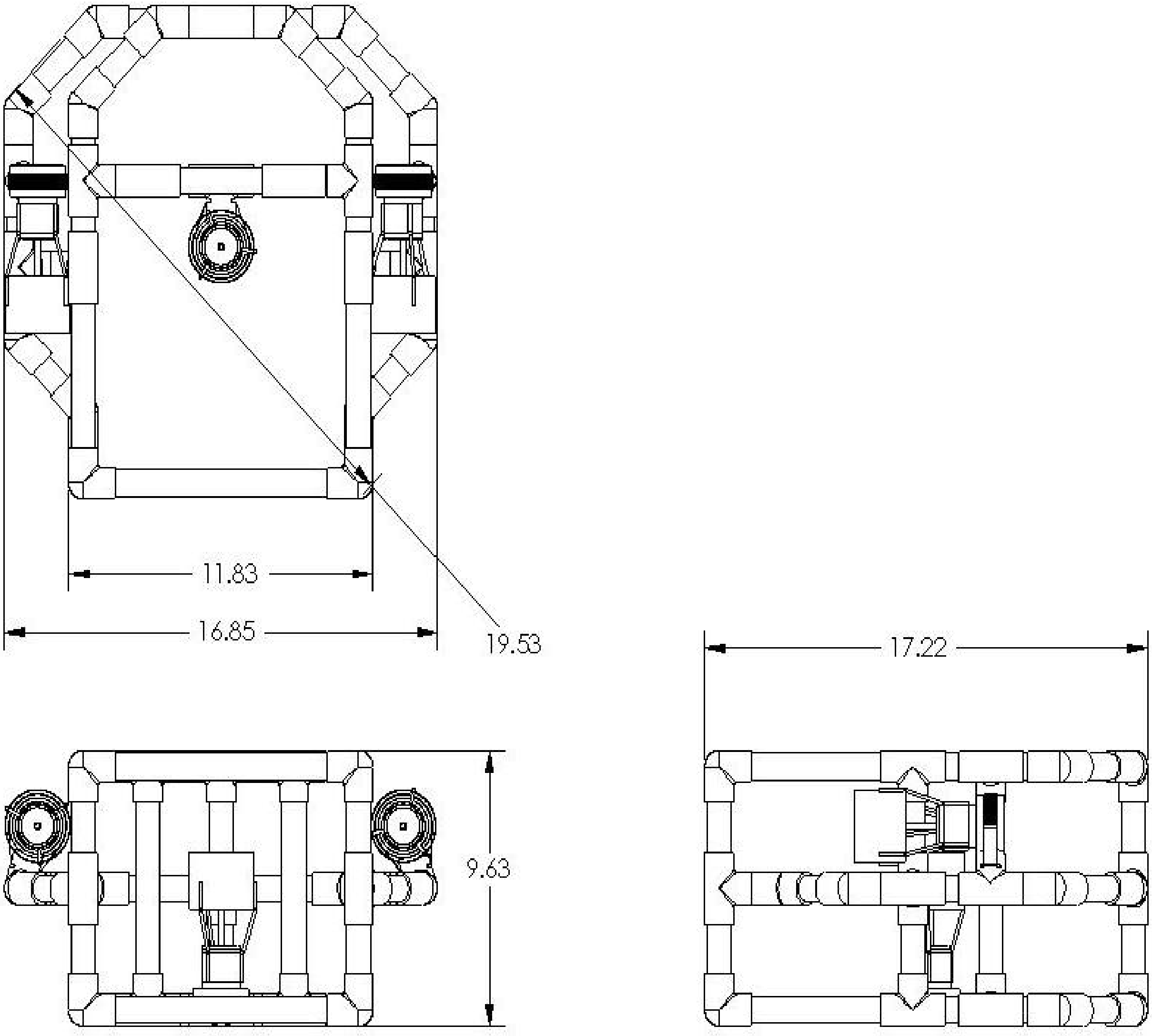


Figure 3.1 – Final Structure Design

3.4 - Analysis

DRAG

After finalizing the size and shape of the sub, we were able to perform analysis on the structure to make sure that it would be able to meet our needs. Before incorporating a propulsion system, it was important to find exactly what value of force we needed to overcome, thus calculating the drag force.

The drag force in the x and z directions were calculated by adding up all of the lengths of the pipes that were perpendicular to the flow. The parallel lengths were not used because they are positioned in the direction of flow, and therefore add negligible drag.

To calculate the drag force, Reynolds number first had to be found in order to find the drag coefficient. Reynolds number was found by using equation 3.1:

$$R_e = \frac{VD}{u} \qquad (3.1)$$

The velocity of the sub used was approximately 3.5 mph = 1.565m / s in the x-direction and about half that speed at 0.72 m / s, in the z-direction. This was due to the fact that there is only 1 motor in the z-direction as opposed to the two in the x-direction. The 3.5 mph is approximately a walking speed and is how fast we wanted the ROV to go underwater. The diameter of the PVC is 0.02064m. The kinematic viscosity used was found using Table A.8 in the Fox and McDonald *Introduction to Fluid Mechanics* texbook, assuming the water of the pool to be 68°F. The kinematic viscosity used was 1.00 x 10^{-6} m^2/s. Reynolds number was then found to be 32,302 for the x-direction and 14,860 in the z-direction.

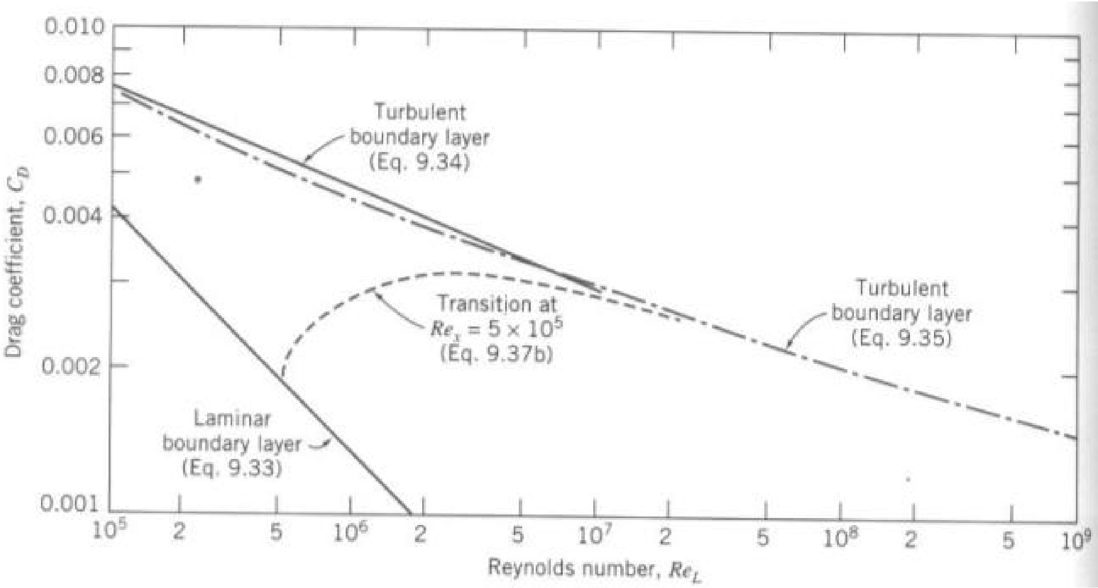


Figure 3.2 – Drag Coefficient Variation with Reynolds

Using the Reynolds number, the drag coefficient was found to be approximately 1.2 in the x-direction and 1.15 in the z-direction using figure 3.2, shown above. From the drag coefficient it was possible to find the drag force using the following equation 3.2:

$$F_D = C_D A \frac{1}{2} r V \qquad (3.2)$$

With ? = 998 kg / m^3, and an area of 0.08722m^2 for the x-direction and 0.09205m^2 in the z-direction, we found the drag force to be 8.65N in the x-direction and 3.97N in the z-direction. The difference in the numbers was mainly due to the fact that the velocity in the x-direction was double that in the z-direction.

MATERIAL SELECTION

Possibly the most obvious constraint, that is not stated, is the fact that the sub has to operate underwater. This was a large factor when deciding the material that we would use as the exterior of the sub. Being that this is the foundation of not only the structure but also for the system as a whole, we decided to use Pugh analysis to determine which would be the best material to use. The materials that we took into consideration included stainless steel, titanium, wood, aluminum, plastic, brass, and PVC piping. Comparing the materials to each other with aesthetics, weight, manufacturability, strength, waterproof, and cost at consideration we found PVC piping dominated the field. PVC provides us with a waterproof material that is extremely inexpensive, and durable enough to perform the tasks required by the MATE Center.

Table 3.1 – Specifications of PVC

Material	Brass	Steel (1020)	Polyvinyl Chloride
Yield Stress	75 MPa	200 MPa	53 MPa
Tensile Strength	60,000 psi	55,000 psi	7,300 psi
Modulus of Elasticity	130 GPa	210 GPa	1.5 GPa
Cost	2.20 $ / kg	.5 $ / kg	1 $ / kg
Density	8,400 kg / m^3	7,800 kg / m^3	1,300 kg / m^3

At this point, we were sure that we would use PVC piping, but the sizing of the pipes, and their structural orientation was to be determined later after other constraints were taken into consideration.

CENTER OF GRAVITY

An important value to know was the location of the center of gravity. This location would have a large impact on the incorporation of the other subsystems. As described later on, the placement of the motors would be directly related to the axis of the center of gravity in both the horizontal and vertical directions.

After designing the model in Solid Works, we used aspects of the program to calculate the center of gravity based on the density of the material used. We found the values to be 1.575 inches away from the center in the y-direction, 0 inches away from the center of the x-direction, and .188 inches away from the center of the z-direction. The location of the center of gravity with respect to the sub could be seen in Figure 3.3 and 3.4 shown below.

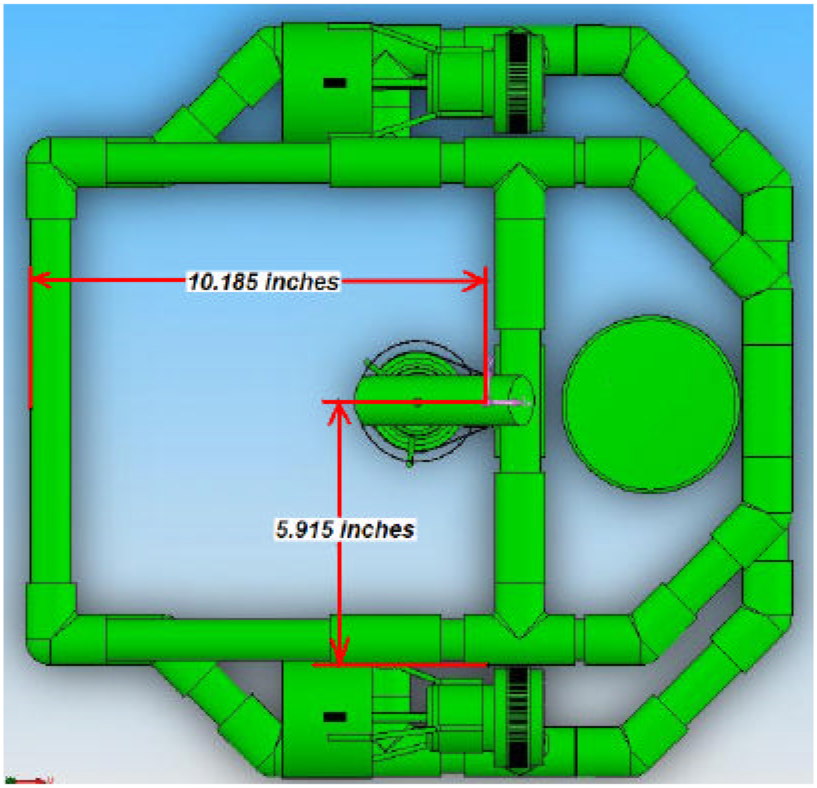


Figure 3.3 – Center of Gravity (x and y-direction)

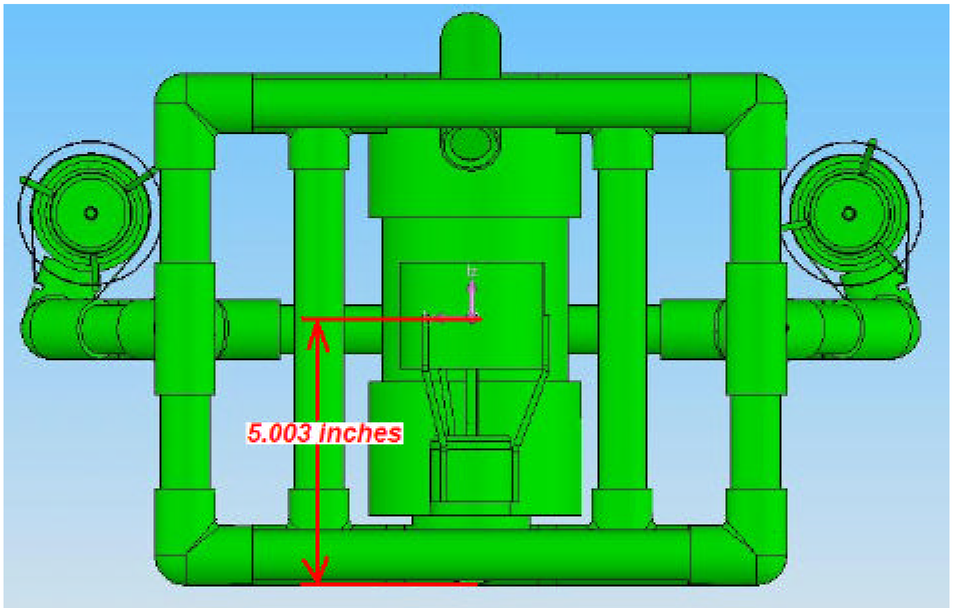


Figure 3.4 – Center of Gravity (z-direction)

BUOYANCY

One of the main desires requested by the team was to achieve neutral buoyancy of the submersible. This would prevent the sub from neither sinking nor floating. This way, as we maneuver the sub through the water we would not have to control the vertical motion of propulsion. It would also aid in the overall motion of the sub preventing it from unnecessarily pitching.

From fluids courses, we knew that if we were able to some how locate the center of buoyancy above the center of gravity, then we would prevent the sub from pitching and rolling. Therefore, we decided to cap off the ends of the top pieces of PVC trapping air inside. We also chose to drill holes in the rest of the pieces, allowing water to flow freely throughout the mid and lower sections of the sub. This in turn added more volume to the top of the sub increasing the buoyant force.

To find the buoyant force, we needed to first calculate the overall volume of the structure of the sub. Taking into consideration the added volume to the top section of the sub, we found the total volume that the structure would displace would be, 121.6 inches cubed. Then to find the buoyant force, we used equation 3.3, listed below.

$$F = r * V \qquad (3.3)$$

After converting the volume into metric units and using the density of water at 20 degrees Celsius to be 998 kg / m^3, we found the buoyant force to be 1.989 kg, which is equal to 4.384 lbs.

In order to find the total volume that we need to add to the sub in order to achieve neutral buoyancy, we need to know the total gravitational force acting upon the sub. This way we could find the difference between the gravitational and buoyant forces to find the force that we are working against. Therefore, knowing the total volume of PVC to be 114.27 inches cubed and using the same force equation that is listed above we were able to find the gravitational force. This time using the density of PVC which is 1300 kg / m^3 and once again converting the volume to metric units, we found the total force to be -2.434 kg, which is -5.367 lbs.

By taking the difference between the gravitational and the buoyant force, we found that our sub was experiencing a downward force of 0.98226 lbs, thus making it sink. At this point we needed to find the volume that we could displace that would add to the buoyant force, making the gravitational and buoyant forces the same. Therefore, we needed to manipulate the same equation that we used before, but now calculate for volume, as shown below in equation 3.4.

$$V = \frac{F}{r} \tag{3.4}$$

Converting the known downward force to metric units and knowing the density of water to be 998 kg/m^3, we found the volume to displace to be 4.4644 x 10^-4 m^3, which is equal to 27.243 in^3. By adding this volume both the gravitational and buoyant forces would be the same making the submersible to neither sink nor float. All buoyancy calculations and values can be found in the appendix.

CENTER OF BUOYANCY

To ensure stability of the submersible, it is important to know the location of the center of buoyancy in the x, y, and z – direction. The location of the center of buoyancy would help us understand how the sub would react underwater. It would also help us in determining the location of the motors.

To find the values, it was important to know the total volume of water the sub would be displacing, which is 96.548 inches cubed. From this total volume, I broke the sub into sections and found the volume in that section. To find the Z – Axis center of buoyancy, I divided the sub into 5 sections, the top, top-mid, middle, bottom-mid, and bottom. I found the volumes of each section to be 49.706, 6.0102, 19.693, 6.0102, and 15.128 inches cubed respectively. I then took the value of the volume and multiplied it by the density of water (.001122 slug/in^3). This gave me the buoyant force that would be acting on each member. I then averaged the distance of each section from the geometric center and multiplied that distance by the force to give me the buoyant moment. I summed the moments together, and then divided that value by the total volume of the sub.

From these calculations I found that the center of buoyancy is 1.635 inches above the geometric center in the z-direction. I also found the center of buoyancy to be 1.0032 inches behind the geometric center in the y-direction. From a basic understanding of buoyant force, I was able to determine that the axis of the center of buoyancy in the x-direction would be at the geometric center due to the symmetrical nature of the submarine in the x-direction. The volume displaced is the same on both the left and right side. All locations of the center of buoyancy locations can be referenced in relation to the geometric center in Figure 3.5 below.

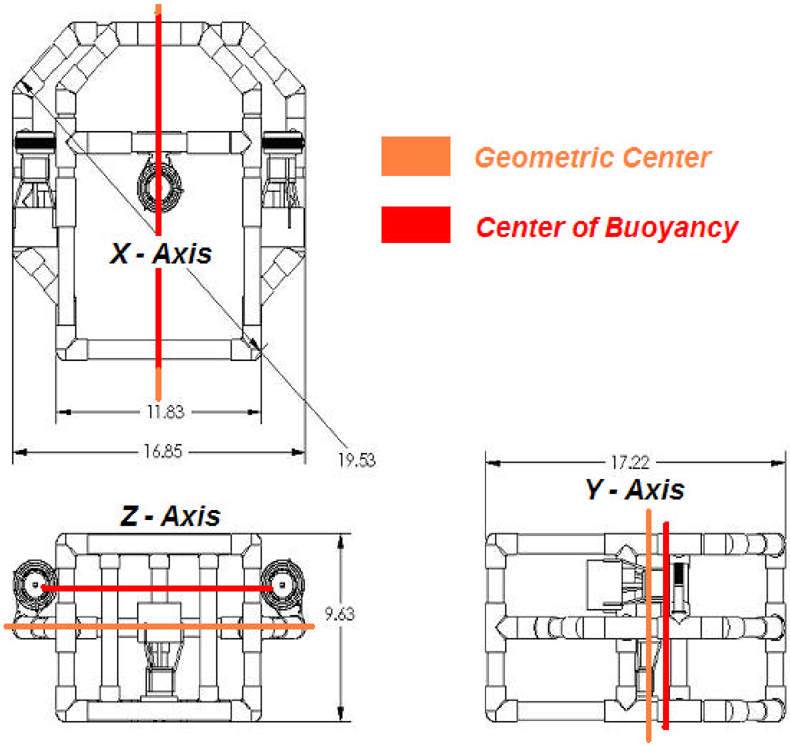


Figure 3.5 – Center of Buoyancy

3.5 – Fabrication:

After we finalized the design of the structure of the submarine, it was time to begin the construction. We purchased four 10' pieces of the ½ inch PVC piping. Using those pieces, we cut all of the pieces to the appropriate lengths listed in Table 3.2.

Final Design Pipe Number Reference Table										
Piece #	***Length***		***Piece #***	***Length***		***Piece #***	***Length***		***Piece #***	***Length***
1	8.75		*15*	2		*29*	2.65		*43*	1
2	8.75		*16*	2		*30*	2.65		*44*	1
3	3		*17*	2		*31*	3		*45*	1.6875
4	3		*18*	2		*32*	3		*46*	1.6875
5	3		*19*	3		*33*	4		*47*	1.6875
6	3		*20*	3		*34*	4		*48*	1.6875
7	5.8125		*21*	3		*35*	3		*49*	1
8	5.8125		*22*	3		*36*	3		*50*	1
9	5.8125		*23*	7.4		*37*	1		*51*	1
10	5.8125		*24*	7.4		*38*	1		*52*	1
11	2.5625		*25*	3.625		*39*	1		*53*	1
12	2.5625		*26*	3.625		*40*	1		*54*	1
13	2.5		*27*	2.65		*41*	1		*55*	1
14	2.5		*28*	2.65		*42*	1		*56*	1

Table 3.2 – List of PVC Structural Pieces

All of the pieces listed in Table 3.2 were cut, using a PVC pipe cutter, and put together using 4 different types of ½ inch PVC connectors that are listed in Table 3.3.

Table 3.3 – List of PVC Connectors

Slots	Shape	Diameter	Material	Pieces Used	Indiv. Weight*	Weight
2	45 degree	0.5"	Soft PVC Pipe	14	0.046875	0.65625
3	X, Y, Z axis	0.5"	Soft PVC Pipe	4	0.071875	0.2875
3	T shape	0.5"	Soft PVC Pipe	20	0.071875	1.4375
4	X shape	0.5"	Soft PVC Pipe	1	0.075	0.075

Total # of connectors	39	Total Weight	2.45625

Using the appropriate connectors in the proper fashion, we were able to construct the final design of the sub in the orientation as seen in Figure 3.6 shown below.

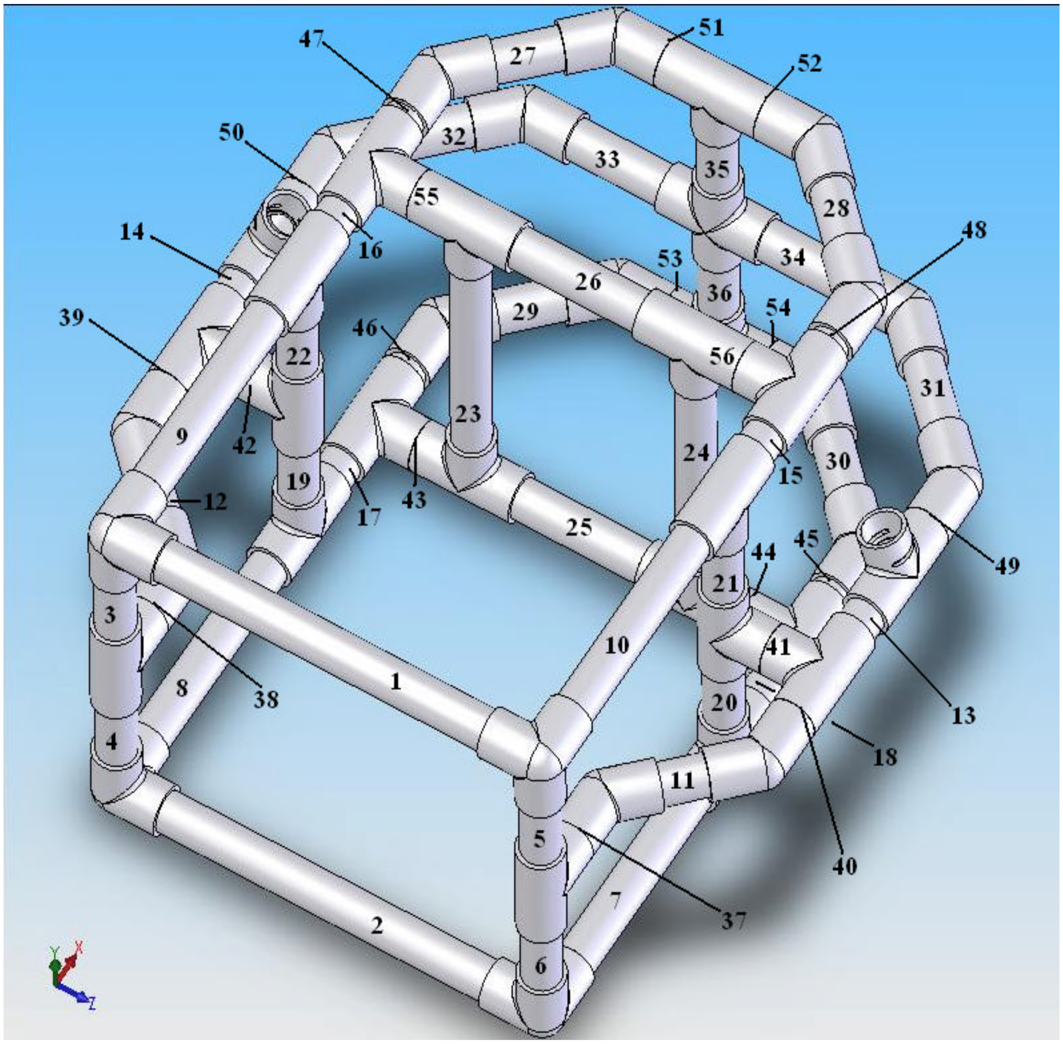


Figure 3.6 – Final Structure Design

3.6 Testing

BUOYANCY / STABILITY

One of the most important aspects of our submarine is to maneuver effectively and accurately, however this would never happen unless we were able to create a stable and buoyant vehicle. To test the structure's buoyancy we placed the structure into the water and found that our initial calculations were close and little extra foam was needed. We proceeded to add and remove foam in order to achieve the buoyancy that we wanted. Throughout this process no foam was added as to affect the center-of-gravity / center-of-buoyancy relationship. We always made sure that the center of gravity was below the center of buoyancy. Fortunately, our testing met our expectations by not pitching or rolling as the submersible was propelled through the water.

4 - Propulsion

4.1-Introduction

Decision analysis from the Pugh charts and the Linear Weighting came to the united conclusion of keeping things simple. The fewer parts and less complicated the propulsion system is, the easier it will be to control the sub through the movements needed. The decision analysis tools were based upon criteria of availability, cost, machine-ability, and adaptability. Ideas that were difficult to control, relatively expensive, difficult to attach to the sub, or were too big were eliminated. On researching the propulsion structure of commercially manufactured ROV's, it was noticed that the size and location of the propellers was crucial to the specific task being performed by the ROV. For specific tasks of exploration in open areas and the need for speed and covering large distances, the propellers were approximately the diameter of the width of the body structure. This means that with the large size diameter of the propellers there is a large pitch, thus increasing the torque and consequently the thrust of the ROV. For ROV's with tasks of search and rescue where the tasks performed are within tight quarters and maneuverability is of high importance than speed, the size and shape of the prop and shroud were quite smaller. Props of this size and structure are to increase the accuracy of direction of movement, not increase the speed. ROV's of this type are more relevant to our submarine and will be taken into consideration during the decision analysis.

4.2 - Constraints

The design specs for the ROV consist of a propulsion system that must operate with a maximum current of 25 Amps and 13.5 Volts. One limiting factor is that the ROV needs to be able to maneuver within an 80 cm cube. Taking the design constraints into consideration, priority is given to having a maneuverable ROV rather than having a fast ROV. Some preliminary brainstorming ideas consisted of propulsion via turbine engines, fans, propellers, flaps, and rudders.

4.3 - Design Results

DRIVE SHAFT

4.3.1 - Drive Shaft Overall Design

The drive shaft is a small diameter rod attaching the motor to the propeller. The length of a drive shaft is 2" and made out of brass rods. We were able to find a 3/16" solid brass threaded rod (Coarse Thread N182-899). The fit was perfect for the 3/16" inner diameter of the propeller. Taking into account that the plastic attachment to the motor is 3/16 inch and that the threaded rod is 3/16, a 7/32 diameter brass tube was attached over the top of the rod and plastic attachment to complete the drive shaft.

4.3.2 – Drive Shaft Analysis

Yellow brass rods were the best choice for the drive-shaft material because they have good machine-ability, great strength, and the best control for ductility to strength ratio. The brass rods were also easy to obtain and very inexpensive (~$0.75/foot). There was a consensus that the general rule for the length of a drive shaft should be no longer than the width of the propeller. The reason for the general rule of length is that if the length is any longer than the drive shaft it will be unstable and the propeller could create enough torque to become detached from the shaft. We do not want the shaft to be too much shorter than the length of the diameter of the propeller because then there will be a hindrance of flow over the propeller and over the motor. Since we are using a 2 7/16 inch diameter propeller we will create a drive shaft of 2 inches. Now that we have a length, we wanted to determine the force required to deflect the rod by 1/8 inch and determine the maximum force the rod could withstand. The purpose for determining the force that was required to deflect the rod 1/8" was because the clearance between the propeller and the shroud is 1/8 inch on each side. Therefore if the deflection was anything more than 1/8 inch, it would not be a tolerable design. For a length of 2 inches, and brass having a Modulus of Elasticity of 15.4 Mpsi, we performed the following calculations: (Exact equations are listed in Appendix A.2).

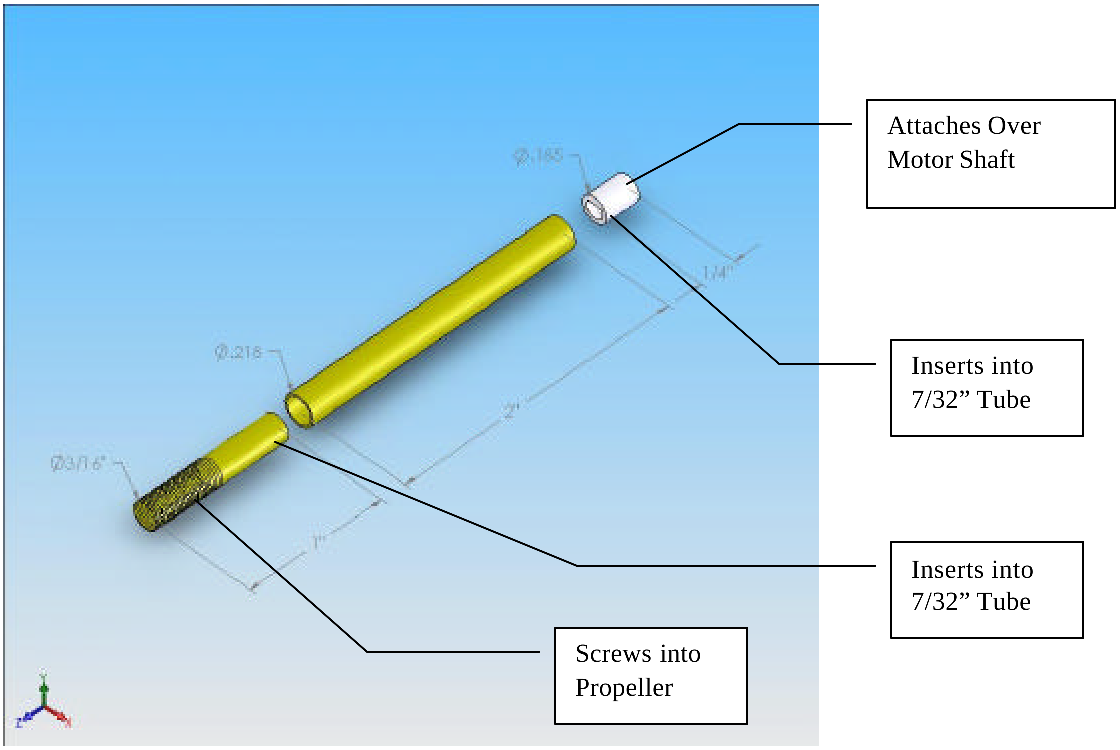
Table 4.1 - Results for preliminary deflection analysis

Maximum Deflection	1/8"
Maximum Force	62,995 lbs
Strain at Specified Deflection	0.0855
Stress at Specified Deflection	1.28 x 10^6 psi
Maximum Strength	40,000 psi
Maximum Normal Stress	3,421 psi
Maximum Strain	32.075
Maximum Pressure	167.98 psi

The calculations show that for the rod to be deflected by 1/8 of an inch there would have to be almost 63,000 lbs of force exerted upon it. Some more quick calculations are shown above, but since the submarine will experience forces considerably less than these, we do not need to continue with further detailed strength analysis. When considering the vibration of the system, we began with the maximum allowed deflection of 1/8”. Instead of calculating vibration of the system, we purchased a propeller balancer which was used to verify the accuracy of the system. By placing the propeller with the drive shaft attached, on the balancer, it was possible to analyze how centered it was. While testing, when one side began to wobble we were able to sand down the side until there was no vibration visible.

4.3.3 – Drive Shaft Fabrication

The next issue that came up was how to attach the drive shaft to the propeller and motor. The propeller that we decided on has a 3/16 inch diameter center for the insertion of a shaft. The motor we are using is a 500 gpm Rule Bilge Pump, which has a shorter built-in drive shaft that extends ½” out. The diameter for this drive shaft is 1/8”. This means that we are unable to connect the propeller to the motor using one rod with a single diameter because of differing geometric properties. The propeller has an opening of 3/16 inch for a rod to fit *inside*, whereas the motor has a drive shaft of 1/8-inch for a rod to fit *around*. The sizes of brass tubings that can be bought are a perfect fit for the drive shaft. They fit tightly within each other, without causing any vibrations (the solid 3/16 inch diameter threaded rod can fit inside the propeller and the 7/32 inch diameter tube (the next larger size) will fit over the drive shaft from the Bilge Pump). Since the tubings fit inside each other we can customize the length of the two rods and attach them via JB weld. Attaching the propeller to the drive shaft became quite simple. We were able to find a 3/16” solid brass threaded rod (Coarse Thread N182-899). The fit was perfect for the 3/16” inner diameter of the propeller. After screwing in the rod to the propeller, we used JB Weld to further secure the attachment. Since the fit was so tight, we were able to directly center it with reasonable accuracy. Taking into account that the plastic attachment to the motor is 3/16 inch and that the threaded rod is 3/16 inch, we used JB Weld to attach the two pieces within the 7/32” diameter brass rod. Figures 4.1 and 4.2 give a detailed representation of how the drive shaft is attached to the motor.



Attaches Over Motor Shaft

Inserts into 7/32” Tube

Inserts into 7/32” Tube

Screws into Propeller

Figure 4.1 - Exploded view of drive shaft

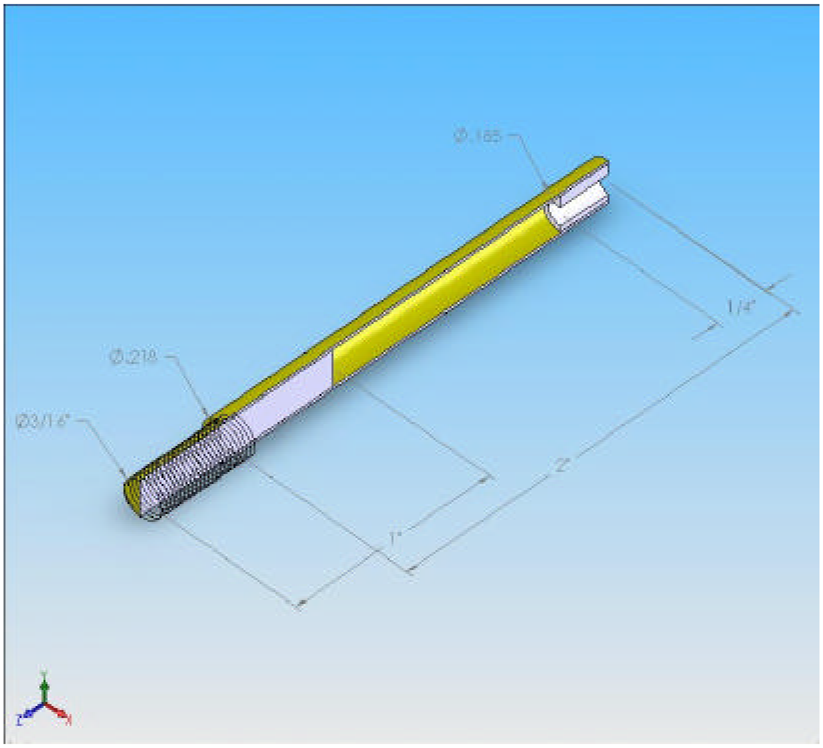


Figure 4.2 Cross-Sectional View of Drive Shaft

Detailed example calculations on the maximum stress and deflection of the drive shaft can be found in Appendix A.2. The design team has decided on three bilge pump motors for three degrees of freedom, placing two of them horizontally to give us forward/backward and yaw, and one in the center of gravity to ascend and descend. The team then chose a 2 7/16 inch diameter propeller with a 3/16 inch diameter for a drive shaft, a shroud with a diameter of a 1/8-inch greater than the propeller, and yellow brass tube fittings for the 2 inch drive shaft.

SHROUD

4.3.4 –Shroud Overall Design

Referring back to the main concern for the project that control of the system is more important than the speed, we have decided to employ the use of a shroud over the propellers. The reason for the shroud will lay more along the lines of increasing the amount of concentrated thrust in the desired direction. In other words, instead of water slipping off the ends of the propellers in several directions, the shroud directs the flow in a single direction across the whole propeller.

The material selection for the shroud was based upon consideration of cost, ease of machining, and at-hand supply. The decision was made to have a yellow brass sheet as the material for the shroud. The shroud will entirely surround each propeller and will have a diameter that is 1/8-inch greater than that of the propeller giving it a total diameter of 2 and 11/16-inches. The shroud is 2 inches in length and is made of a metal yellow brass sheet.

Each shroud is connected to their prospective bilge pump via three 1/16-inch diameter yellow brass rods. Each rod is placed 120° from each other around the shroud. There are two bends along the shroud that connect the larger diameter shroud to the smaller diameter bilge pump. Surrounding the bilge pump is another cylindrical yellow brass sheet. The rods were soldered to the shroud and the brass sheet surrounding the bilge pump.

4.3.5 – Shroud Analysis

After the complete structure was fabricated testing was done to ensure correct alignment for the propeller shroud and the bilge pump shroud. The purpose of the shroud is to enhance the direction of the thrust, not necessarily enhance the magnitude of the thrust. Since the incorporation of a shroud was needed to concentrate our thrust in a certain direction, it was imperative that the shroud be aligned with that of the motor. There was an understanding that the drive shaft attached to the motor would vibrate, thus making the propeller have a small deviation. Counting for this deflection we gave a 1/8” clearance between the tip of the propeller blade to the shroud.

For testing purposes we connected a battery to the motor and ran it at full throttle; for competition purposes we will never run our motor at full speed, this testing was just for maximum conditions. The first testing was done in air. At low speeds the propellers did have a small vibration but never came into contact with the shroud. When pushed to full speed the propellers did come into contact with the shroud, but it was noted that the contact was minimal. When placed in water, the water acted as a damper for the vibration of the propellers. There was no contact from the props to the shroud, even at full speed. In conclusion, the shrouds and attachments are adequate and durable for the purposes needed.

4.3.6 – Shroud Fabrication

The yellow brass sheet was purchased at ACE Hardware Store and came in 2”x 18” dimensions. Since the diameter of the shroud needs to be 2 $^{11}/_{16}$”, the metal sheets were cut into portions with lengths of 16.8” (from the equation for the circumference of a circle: $C=2pr$). Metal rollers were then used to form the sheets into full circles with radii of $2^{11}/_{16}$”. Using iron solder and a torch, the metal sheet was welded together (refer to Figure 4.3).

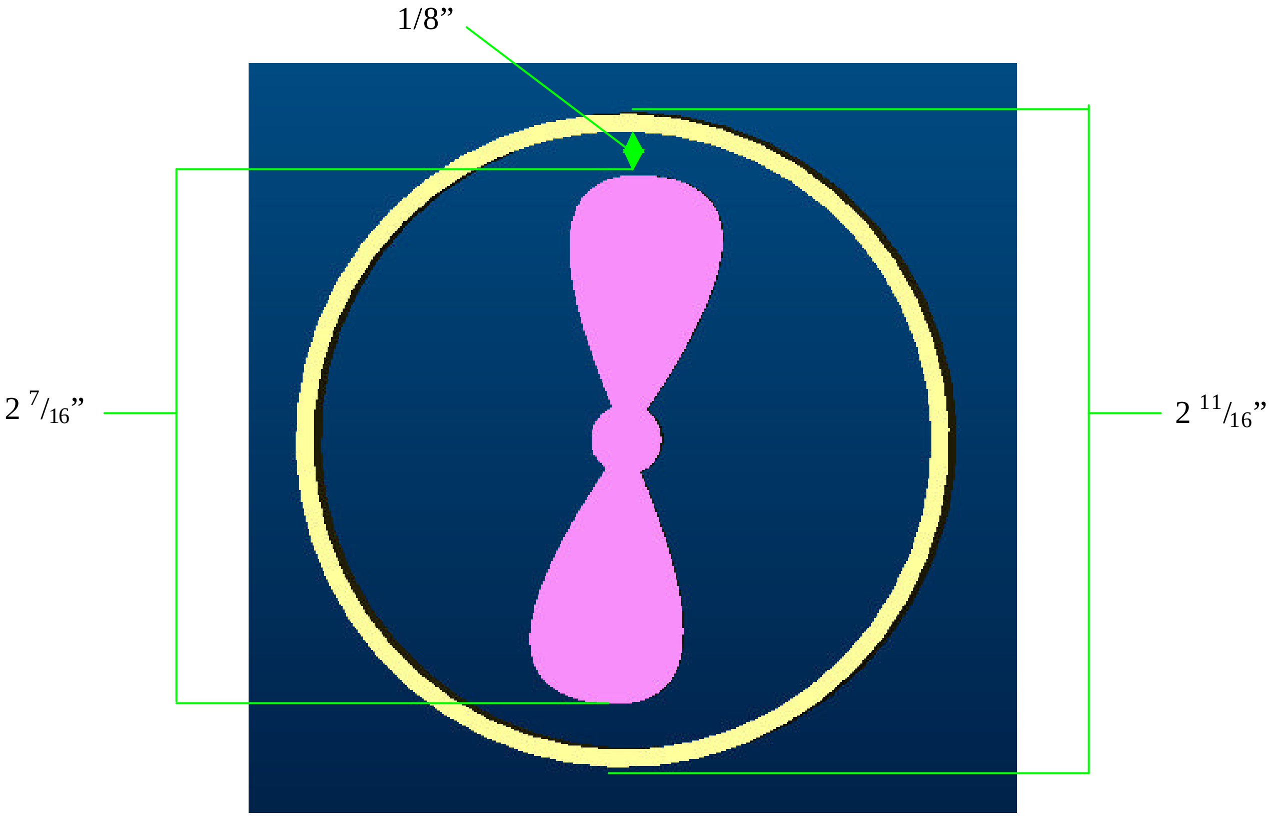
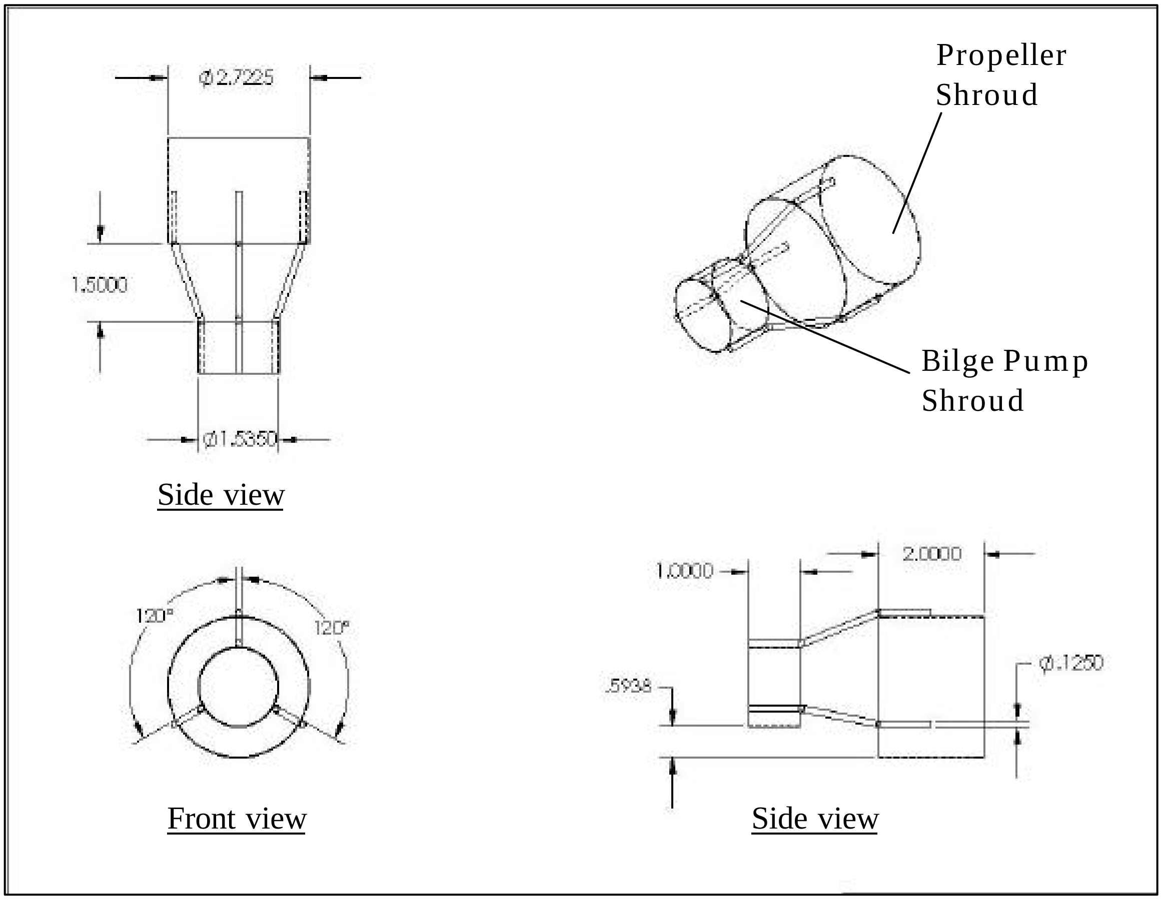


Fig. 4.3 – Propeller and Shroud system

Through this process, three shrouds were made for the submarine.

The brass rods were also purchased from ACE in dimensions of 1/16” in diameter by 18” in length. To ensure an adequate secure hold on to the shroud, a 1 inch length of rod was soldered to the shroud. Using a vise and a protractor, the brass rods were bent to an angle of 57° so as to line up with the outer diameter of the bilge pump. The length between the bilge pump and the shroud is 1.5” and since we know that the differences in diameters between the two are approximately 0.5” we can calculate the length of the angled rod between the pump and shroud. After the 1.58” length of rod, another bend was made in the rod to make it parallel with the surface of rod that is attached to the shroud (Figure 4.4)



Side view

Front view

Side view

Figure 4.4 –Design of Shroud and motor system

The attachment of the rod on the shroud was via solder, however the material of the bilge pump is plastic and soldering would not be adequate because it would melt the plastic and ruin the motor. Instead, a shroud was made for the bilge pump using the same material as the shroud for the propellers. The bilge pump shroud was made to almost the exact diameter of the pump, so close in fact that no glue or fastening connections were needed for the shroud to stay on the pump. The connecting brass rod was then soldered to the shroud on the bilge pump. Each rod was attached in this manner at 120° from each other so as to be equidistant from the other rods, thus there are three rods per bilge pump-shroud system. A diagram of the final shroud-pump system is shown in Figure 4.5.

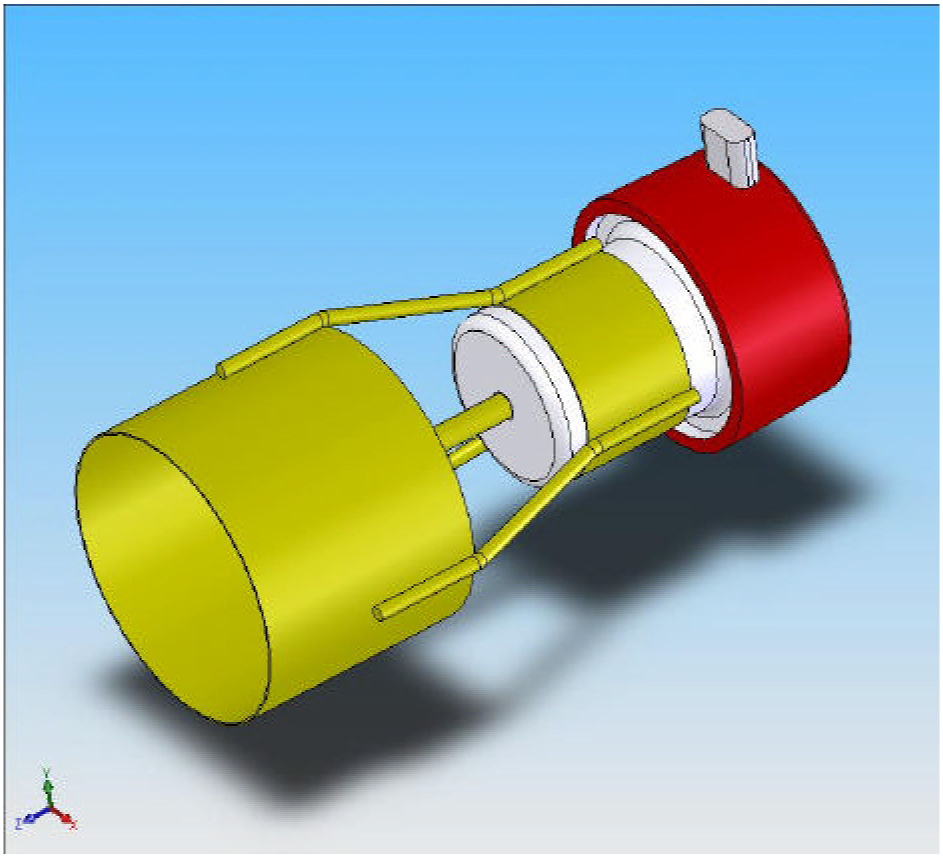


Figure 4.5 – Prototype of Shroud and motor system

4.3.7 – Shroud Revisions

Originally the shrouds were to be made of PVC tubing that would be cut to the correct length, however there were not enough variance in diameter sizes to fit the around the propellers. Therefore the decision was made to have a yellow brass strip as the material for the shroud. This allowed for bending of the brass strip into the diameter needed (2 11/16-inches) and welding it into place.

Since the shroud-pump systems are placed on the propellers at specific locations they do not affect the center of gravity. Two shroud-pump systems are placed on opposite sides of the sub, these masses act as counterweights and are neglected in the affects of center of gravity. The third shroud-pump system is placed at the exact center of gravity and will have no affect either. The only affect that the shrouds have on the submarine are with the center of buoyancy. Since mass is added and not necessarily volume, since water is flowing through and around the shroud-propeller system, we needed to add some positive buoyancy to counter it. The calculations for this amount are within the final calculations for center of buoyancy. The affect that the shroud had on system is not calculated, but rather the entire propulsion system (shroud, prop, drive shaft, and motor) are used in the calculations.

Originally the attachments from the shroud to the motor were aluminum; the change from the aluminum attachment rods to brass attachment rods was made for two reasons: 1) this stayed with the idea of keeping the entire system to the same material; 2) a more rigid material was also desirable. Since it is critical that the shroud and propellers stay a safe distance away from each other, much concern is taken regarding into the stiffness of the material for the attachment rods. Aluminum has an approximate Modulus of Elasticity of 36-41 GPa, whereas brass has an approximate Modulus of Elasticity of 96 GPa. The higher the modulus of elasticity (also known as Young’s Modulus) represents the higher order of stiffness of a material. For instance, rubber has a Modulus of Elasticity of 0.1 GPa and Diamond is 1000 GPa. To use the brass attachment rods, we will be using a stiffer material and thus decrease the chances of deflection and rule out the possibility of the shroud and propeller touching during motion.

The other revision we made to the shroud-pump system was adding a shroud to the bilge pump since it was infeasible to solder brass to plastic. Originally it was thought to use a hose clamp, but again, it is not desirable to solder two different materials together. To get the best attachment we wanted to solder brass to brass, hence creating a brass shroud for the pump extension. The pump shroud was created in the same manner as the shroud for the propeller. The only difference was that the pump shroud only had a diameter of 1.53” and a width of 0.5”.

MOTORS

4.3.8 - Motors Overall Design

The ROV has three motors. The motors are 500 gpm bilge pump motors. Two of the motors were placed horizontally on the outsides of the frame, to provide forwards, backwards and yawing motions. (Fig 4.6) The other motor was placed approximately at the center of gravity of the ROV in the vertical direction. This placement enables the sub to ascend and descend. By finding the center of gravity, we were able to get an exact placement for the center motor. This was found by determining the center of gravity in the x and y directions. This will be the center of gravity when looking at the sub from above. For example the length of the sub will be the x direction, the width the y direction and the height the z direction. We are not concerned with the center of gravity in the z direction for the third motor.

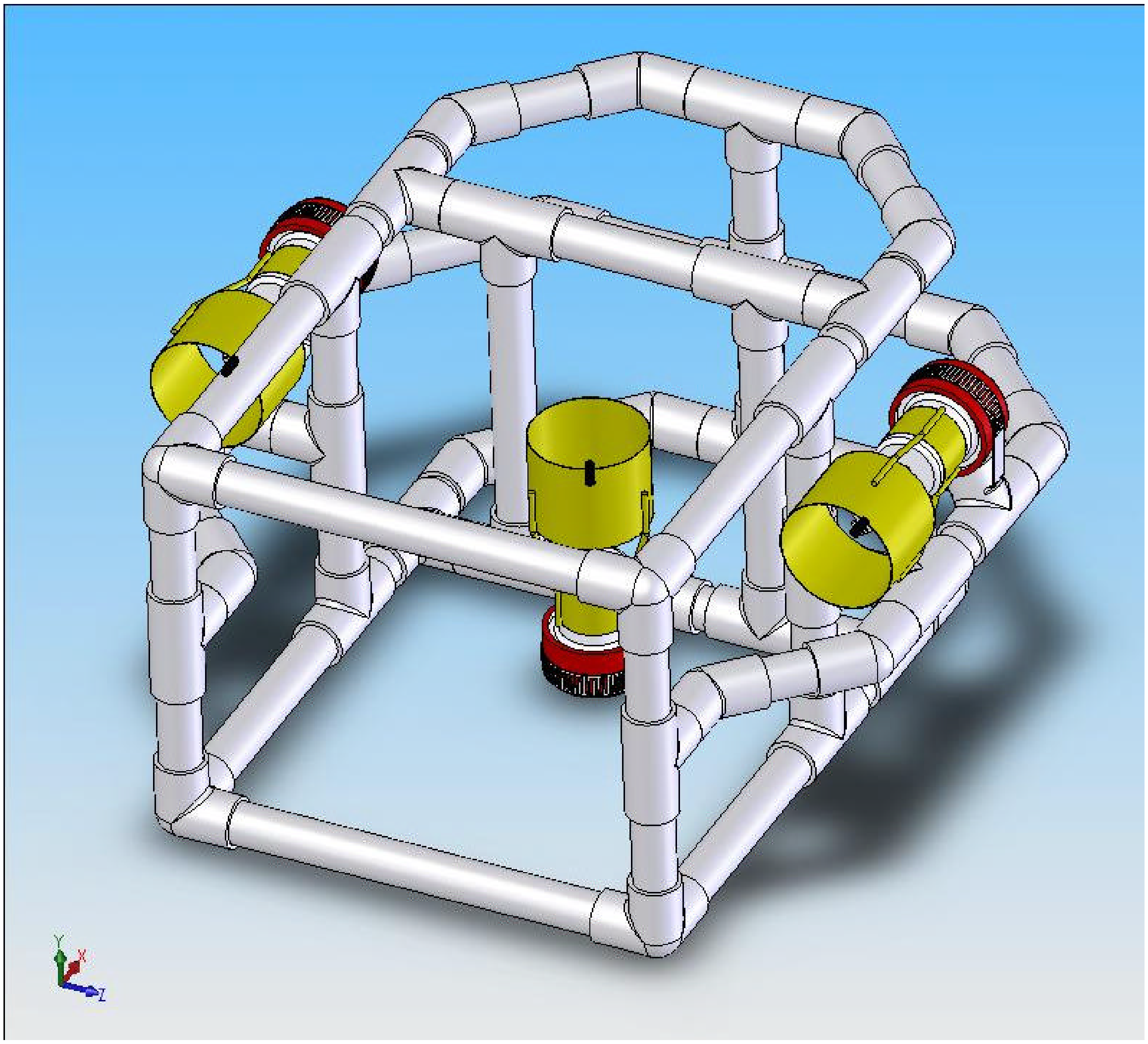


Figure 4.6 – Placement of Motors

4.3.9 – Motor Analysis

Our biggest dilemma in designing the propulsion system was to determine how many motors we were going to have, what kind of motors to use and where we were going to place them. We were looking at getting a standard DC motor and building a cowling to cover and waterproof the motor. Our other option was to use a bilge pump, which is already covered and sealed. It was an obvious decision because if we used the standard motor, we would have to not only, seal the entire motor but also, try to seal the drive shaft while allowing it to spin. The bilge pump is already completely sealed and would cut down on our build time tremendously. We chose bilge pumps based on the fact that we did not want to have to waterproof the other motor. There is a higher percentage of having problems the more complicated the design gets. The cost of each bilge pump motor was around $20.00.

Next we had to decide on the number of motors we would use. We found that the majority of working subs have three stationary motors giving them three degrees of freedom. We could have easily used four or more motors which would give us more degrees of freedom. We decided that by increasing the motors, we would get pitch if we placed another motor in the vertical direction. This degree of freedom is not necessarily needed. We are able to do all of our tasks without pitch. Being able to ascend and descend along with our ramp on the bottom of the sub, is an easy substitute for another degree of freedom. Another reason to help us make the decision to eliminate the extra degree of freedom was that we want to eliminate all the extra controls that we can. The fewer amount of controls that we have, the better. With a smaller number of motors, we are able to use less power which will let us direct more power into our retrieval system. By strategically placing the motors as stated, we have given the best stability to the sub.

We now had to calculate the thrust force given by each propeller to make sure that our choice of motor would work. This began by finding the RPM on land. The RPM were found to be ˜ 5600. When put in the water we estimated the RPM to be ˜ 4000. This comes out to be 66.7 revolutions per second. The analysis of the speed of the bilge pump was conducted by running the pump at full speed in the setup below, shown in Figure 4.7. The sound of the motor can be recorded and manipulated accurately.

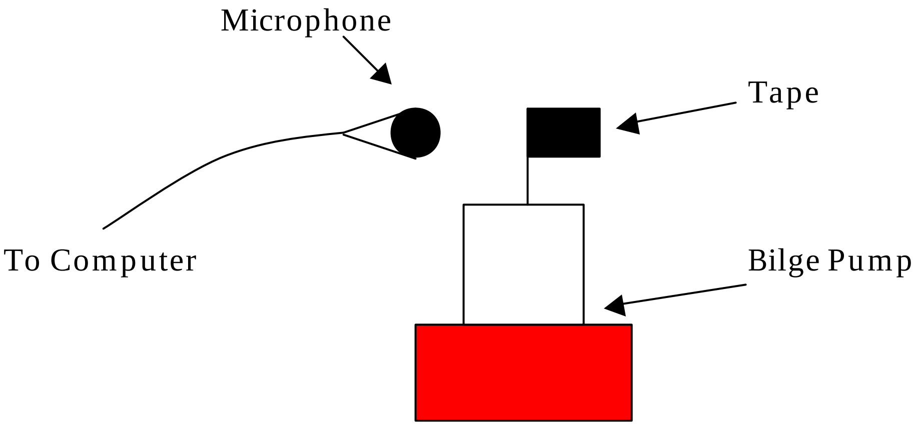


Figure 4.7 – Testing of Speed of Bilge Pump

In a five (5:00) second audio clip at full speed, the sound is too fast to be counted. The sound clip can be “stretched” to 160 seconds by multiplying a factor of 2^5 by the five seconds. Within 60 seconds, the computer counted 175 beats. Thus, 175 beats times the factor of 2^5, we get 5600 beats per minute, also known as 5600 revolution per minute. An example of the calculations is shown below in Equations 4.1 and 4.2.

$$5\,\text{seconds} \times 2^5 = 160\,\text{seconds} \qquad \text{Eq. (4.1)}$$

$$175\frac{\text{beats}}{\text{minute}} \times 2^5 = 5600\frac{\text{beats}}{\text{minute}} = 5600\frac{\text{revolutions}}{\text{minute}} = 93.33\frac{\text{revolutions}}{\text{second}} \qquad \text{Eq. (4.2)}$$

4.3.10 – Motor Fabrication

The last aspect to look at for the motors was how to attach them to the PVC body structure of the sub. This was done by attaching a PVC T-connector to the motor and using a hose-clamp to attach the motor to the T-connector. This assembly is detailed in Figures 4.8 and 4.9.

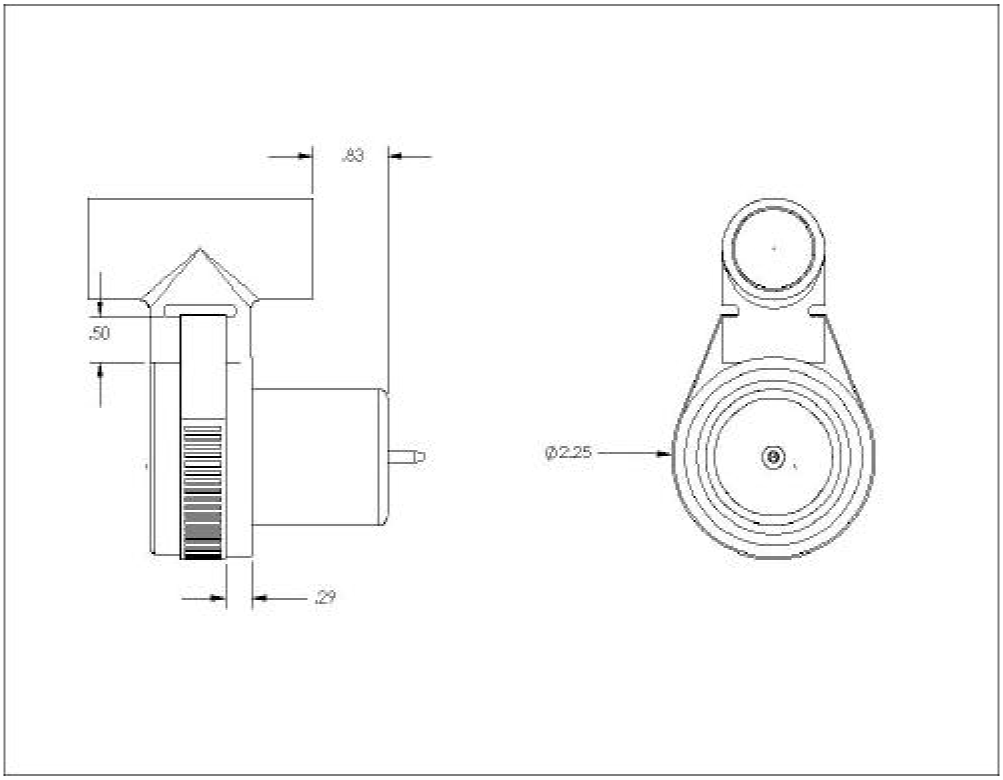


Figure 4.8 – Motor attachment

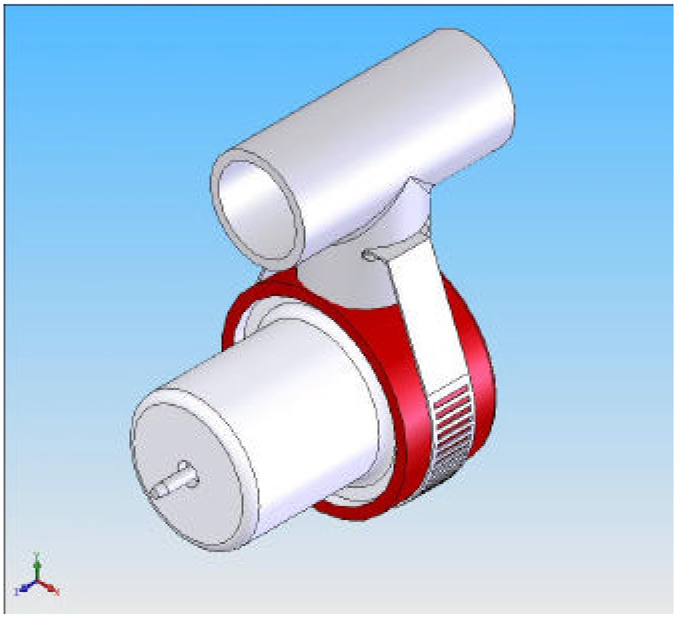


Figure 4.9 – Motor Attachment

PROPELLERS

4.3.11 - Propeller Overall Design

The other half of the propulsion component is the propeller. We chose a propeller with a diameter of $2^{7}/_{16}$-inches. The propellers are designed to propel in both the forward and backward motion. The pitch of our propellers is 1.5 inches, meaning with each revolution the propellers move 1.5 inches forward. Each propeller is attached to a drive shaft and connected to the motor. Each propeller also has a shroud surrounding it connected to the motor.

4.2.12 - Propeller Analysis

All testing on the propeller was done when the propellers were attached to the drive shaft and the shroud was place around the props. Although the drive shaft had some slight vibrations, which caused vibrations on the propellers, there was enough clearance within the shroud that the propellers did not touch the shroud in water. The propellers performed exactly as planned and required no alterations or further analysis.

The pitch of the propeller is 1.5 inches with a diameter of $2^{7}/_{16}$ inches. The speed of advance coefficient, J was then found.

$$J \equiv \frac{V}{ND} \qquad \text{Eq. (4.3)}$$

In Equation 4.3, N refers to the number of revolutions per second, D is the diameter and V is the velocity. J was found to be 0.059 for the x-direction and 0.027 for the z-direction.

The thrust coefficient, C_T, was then found to be 0.43 in the x-direction and 0.45 in the z-direction, using Figure 4.10.

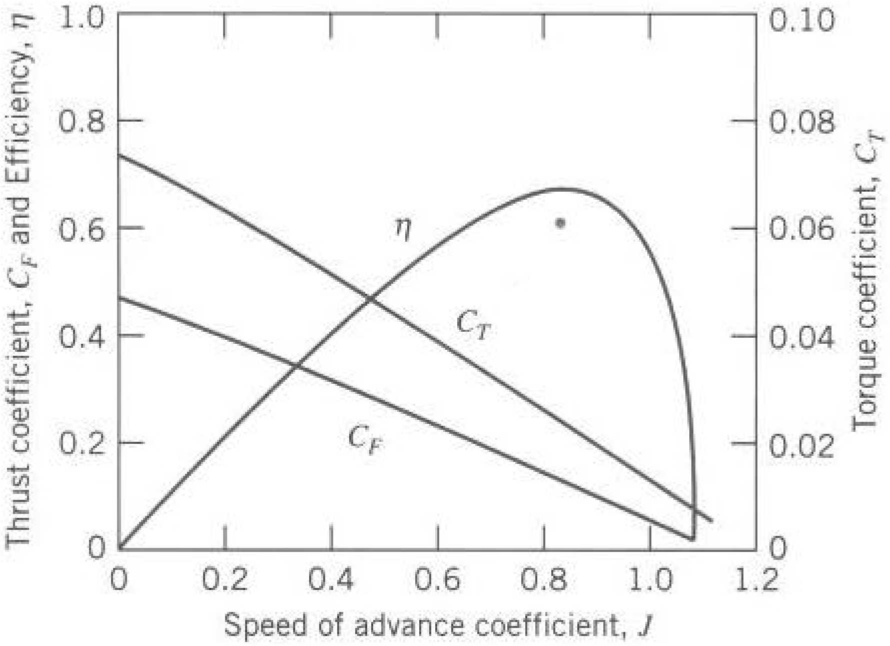


Figure 4.10 – C_T VS. J

The thrust force was calculated using Equation 4.4:

$$F_T = C_F r n^2 D^4 \qquad \text{Eq. (4.4)}$$

The thrust force was found to be 13.652N per propeller in the x-direction and 14.29N in the z-direction.

Comparing the thrust force against the drag force respectively, in the x-direction being 13.625N and 8.65N, and in the z-direction being 14.29N and 3.97N, it is easy to tell that the thrust force greatly outdoes the drag force in both directions.

4.3.13 - Propeller Fabrication

Propellers were purchased from Competition Hobbies. The material of the propellers is plastic. The propeller size was determined based on our main size requirement, that we did not want the prop to be too large. The size constraints come from the closeness that the propeller must be to the submarine itself. There is only a 4 inch clearance between the edge of the submarine and the edge of the maximum width our submarine can be given to us by the competition rules. . An image of our propeller is shown in Fig. 4.11.

Figure 4.11 - Propeller

The pitch determines whether the sub has more speed or is more maneuverable. The higher the pitch, the faster the sub will go, getting more thrust per rotation therefore increasing the speed. The lower the pitch, the easier it is to maneuver the sub. If the pitch is lower, you get less thrust per rotation, which allows the sub to have easier handling. We decided to go with the smallest pitch that is available for the size diameter of prop we are getting. For the 2 7/16 inch prop, the smallest pitch that was available was 1.5 inches. . The pitch of the propeller is known from the manufacturer. These decisions were made based on the fact that for our mission, we need to be able to manipulate our ROV efficiently, making our sub more maneuverable. After all, we are more concerned with control than speed.

<u>4.4 – Propulsion and Maneuverability Testing</u>

With a submarine that is extremely maneuverable we will be able to more accurately and quickly complete the tasks required of us. Once the motors and shrouds were placed on the structure and the electronics hooked up we were able to drop the sub into the water and test its full functionality. The testing consisted of piloting the ROV and making sure that all three degrees of freedom were attainable. The only major problems encountered during operation were related to the radio controller. All three motors worked perfectly and all three degrees of freedom were attainable, however the setup and configuration of the directions traveled with the control sticks did not work correctly. This was easily overcome through programming of the radio.

5 – Control System

5.1 – Introduction

The primary purpose of the control bay is to provide shelter for the three speed controller's and a radio controlled (RC) receiver so that the user of the ROV may effectively operate the movement of the ROV. For the design of the control bay for the control system of the ROV, the underlying theme was 'meeting our necessities without making our own work too difficult.' As this report will depict, the process was extremely procedural to prevent delving into fields of study that were to complex for our team. By carefully weighing which decisions were most vital to the bay's success, and structuring other designs around those key elements, the team feels that the final design will be successful due to its simplicity and confidence in its design factors.

5.2 – Constraints

As far as electricity goes, there are numerous constraints set by the competition rules. Some are in regards to actual design specifications, while others are merely for safety reasons. These restraints are:

- Maximum DC voltage is 13.5 volts
- Maximum amperage is 25 amps.
- Any AC to DC power supplies must be located at least 3m from the pool's edge and elevated to eliminate the possibility of standing water, i.e. Electrical hazard.
- Only DC voltages are allowed to travel through the tether to the ROV.
- A circuit breaker or a fuse(s) must protect the ROV power system.

5.3 - Electronic Speed Controller (ESC)

5.3.1 – Overall Design

Shown below in Table 5.1 is a picture and specifications of the Super Rooster, by Novak. It is an ESC that is bi-directional, thermally protected, and operates at 12 Volts, the competition voltage. Three of these speed controllers are necessary to regulate the amount of thrust per bilge pump.

Table 5.1 – The Super Rooster Specifications

	**Super Rooster (ESC) by Novak** Input Voltage: 7.2-12 Volts Case Size: 1.63 x 2.02 x 1.22 inches Weight: 4.0 ounces On-Resistance: 0.0020 Ohms Wire Size: 14 gauge Reversible: Yes Dual Stage Thermal Protection

5.3.2 – Analysis

After careful research, the most fitting of radio controlled speed controllers (ESC) is the “Super Rooster” by Novak. This ESC is reversible which is needed for rotating the ROV back and forth (full range of motion per degree of freedom), yet it also can handle 12 Volts of direct current, which is the quantity that will be supplied at the MATE competition in June. Most ESC were unable to satisfy both of these design requirements. The Super Rooster comes with heat sinks to distribute any internal heat generation away from the electronics. Aside from that they also come with a built in two-stage thermal protection that slows the current at a given temperature, and stops all flow at another. In looking at the “Super Rooster”, a known heat generation was pre-calculated based on given specifications, to insure that the heat would not have adverse effects on the rest of the control bay. This calculation can be found in the Appendix: Figure A.3.1. The resulting heat generation calculated was .0375 Watts. We determined this value to be insufficient heat to harm any innards of the control bay. All in all, these ESCs are exactly what our ROV needs to function according to our design specifications. Many other features and statistics about the Super Rooster are available, but the notes listed in Table 5.1 above are the key reasons that we chose this ESC.

5.3.3 – Fabrication

No fabrication is necessary; the Super Rooster is pre-assembled by Novak. A few simple modifications were made such as: the brake wires were trimmed as to not interfere with the other important connections (spatially), and the power switches were shorted to allow use of the ESCs by simply connecting the power cables to the battery on the surface by the operator without opening the sealed control bay. A special adhesive was used to attach the ESC to the mounting plate to provide for sufficient heat transfer (dissipation) and grip. After looking through several methods of attaching the ESC, 3M Heavy Duty Double-Sided Tape proved to be the most effective and efficient. This material can be seen here in Figure 5.1. Statistics for this material can be found in the Appendix: Figure A.3.2.

Figure 5.1 - 3M Heavy Duty Double-Sided Tape

5.3.4 – Testing

A heat test was conducted to determine if the heat generation of three ESCs will be hazardous to the overall design of the control bay. Data from this test can be found in the Appendix: Figure A.3.3, the Speed Controller Heat Test. In this test, a simple household thermometer was held against an ESC for 10 minutes in ambient temperature and pressure to record the varying temperature emitted from the ESC. The results show, as does the analysis, that the heat generated is far too miniscule to deteriorate any components within the control bay.

5.4 - The Radio Controlled (RC) Receiver

5.4.1 – Overall Design

The JR – R700 was chosen for our control system. It can be seen here in Figure 5.2, alongside its specifications that were important to our design.

Table 5.2 – The JR – R700 Specifications

Futaba JR – R700 receiver
Case Size: 1.81 x.94x.50 inches
Weight: .64 ounces
Frequencies: 72 MHz
6 Channels

5.4.2 – Analysis

The RC receiver that will be used is basic in its design requirements. It will only need to communicate effectively with three separate channels of transmission with the radio for proper movement, be light, and small. Since the receiver requirements are not as crucial as other aspects of the control bay, there was more freedom in deciding which receiver to use on the ROV. After looking at several receivers, we decided that the JR – R700 is more than sufficient in meeting these design needs. It has 6 channels of transmission and is small and light.

5.4.3 – Fabrication

As before, with the ESCs, the JR - R700 is pre-assembled, and the only detail is again, how to attach it to the mounting plate within the bay. Simplistically, our team decided it would be best to use the same material as used for the ESCs. Since it works for the speed controllers, it should work for the receiver.

5.4.4 – Testing

Testing the range of the receiver was a meager, but important part of the design process. Since the signal was being transmitted and received within an extremely close proximity, it was doubtful that any flaw would occur. For sake of security however, we proceeded. This premise was tested during the initial testing of the signal conductivity of the coaxial cable. As similar range of approximately 5 inches was used in the prototype Parmesan canister (see Coaxial Cable). This range worked perfectly!

5.5 – Coaxial Cable

5.5.1 – Overall Design

General purpose RG-6, 75 Ohms coaxial television cable will be used to conduct the radio signal to the control bay. Having a diameter is 13/64 inches; a length of 50 feet was cut for the length of our tether to the ROV.

5.5.2 – Analysis

A diagram of coax can be seen below in Figure 5.2. The design requirements of our communications wire only demand that the wire be ductile enough to allow movement of the ROV, yet efficiently transmit the intended signal of the operator. Coaxial Cable is well insulated, magnetically shielded, and electrically protected. In searching for a material that could hold a signal through 50 feet of tether without losing integrity, radio shielding became a necessity. Due to its easy of accessibility in large quantities and its cost, coax cable became our “underwater antenna” of choice.

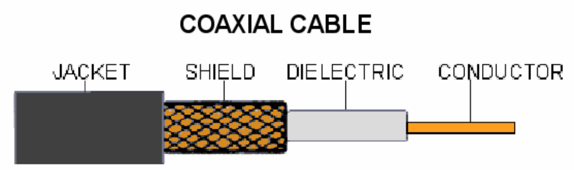


Figure 5.2 – Coaxial Cable Cross Section

5.5.3 – Fabrication

The only aspect of coaxial cable that necessitated any fabrication at all is per end of the wire. The radio (see Radio) end of the coax was stripped of all layers excluding the copper conductor within. This bare wire was then wrapped within an eyelet connector as seen in Figure 5.3 here. This could then be bent and fastened within the radio as if it were the original antenna. The control bay side of the coax was simply sheared to see if transmission was still effective. Since it was, no further stripping was needed to better the radio signal through the coaxial cable.

Figure 5.3 - Radio Eyelet Connector

5.5.4 – Testing

The first test that was ever conducted on this project was to determine if the radio signal through a 50-foot length of our coaxial cable was sufficient enough to generate a desired response, and if the coaxial cable was waterproof not allowing any water to seep into the bay. Since the design of the control bay had not yet taken place, the control bay consisted of a used Parmesan Cheese canister. A schematic of the test can be seen in Figure 5.4, while the actual test Parmesan Cheese canister can be seen in Figure 5.5. The testing apparatus can be seen in Figure 5.6. This system used only a 9.6-volt battery, demonstrating that if such a test could be run at a lower voltage, then a 12-volt experiment would surely work as well.

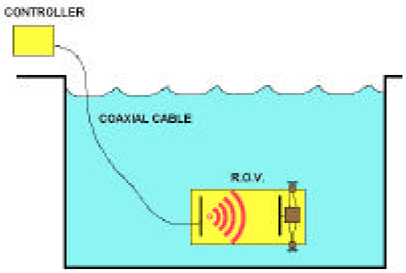


Figure 5.4 – Coaxial Cable Signal Transmission Test Schematic

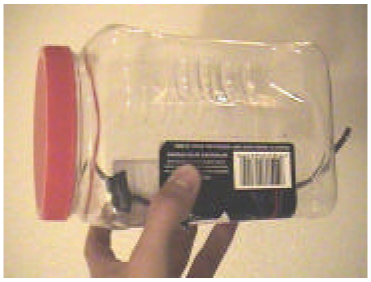


Figure 5.5 – Parmesan Prototype Canister

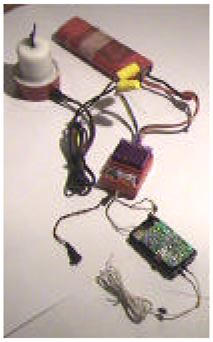


Figure 5.6 – Test Assembly

Figure 5.7 – Liquid Nails

As shown in Figure 5.5, the control bay for the test module was a Parmesan cheese canister. The reasoning for this test body is simple: the canister was water tight as proven by keeping Parmesan cheese moist, and secondly, as pre-tested before our coax testing, could be sunk to the bottom of an 8-foot deep pool and still stay air tight. The components as shown in Figure 5.6 were packed into the canister and sealed tightly. The coax cable, which was the only attachment to the canister (excluding the nylon rope used for submersing the ROV) was punched through the bottom of the canister and then sealed with Liquid Nails, shown here in Figure 5.7, a water resistant silicone used for sealing such holes. By submerging a large bucket of rocks and running the nylon rope through the handle of the bucket to vary the depth of the floating Parmesan Canister, this test was conducted. A photograph of this can be seen in the Appendix: Figure A.3.4, showing how the controls for the ROV worked! The radio signal was effectively broadcasted from the modified Futaba Radio, transmitted through 50-feet of coax, sent and received within the submersible, and correctly translated into the motions desired of the bilge pump, and the wire correctly sealed the Parmesan Canister, insuring proper watertight insulation.

5.6 - Wiring and Connections

5.6.1 – Overall Design

A wiring diagram shown in Figure 5.8 depicts a layout of the wiring for the system. The four wire colors (red, black, yellow, and blue) from the speed controllers are 14-gauge. Two of these will connect to the power supply, the other two to its respect bilge pump (motor). Each of these connections are fixed with a detachable connector to allow for alterations in the electronics if something were to fail or malfunction. A photo of these connectors can be seen in

Figure 5.9. The ESCs are connected in parallel as to allow consistent voltages per “Super Rooster.” The external proof wires will connect to the 14-guage internal wires, preventing any harm to the electronics within the bay. This external wire is simple 16 gauge, general-purpose waterproof wire, fully intended for outdoor (underwater) use. This gauge will also be used in conducting the 12 Volts of DC to the control bay (power cables).

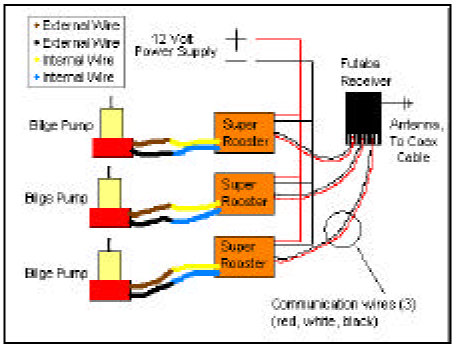


Figure 5.8 – Control System Wiring Diagram

Figure 5.9 – Detachable Connectors

5.6.2 – Analysis

The wires of these components, though insulated, may not fair well against the effects of water and high pressure. It is for this reason that these internal wires will be connected to external wires (or better, water proof). The wires that came with the Bilge pumps are waterproof and are long enough to reach from the respective locations on the ROV into the control bay.

Though thin, the number of wires will occupy a fair amount of volume within the control bay relative to the amount of space available. The thinnest wires must be used, without selecting too thin of a gauge of wire, and overheat a connection. By pre-determining the currents and voltages run through the system, we assured ourselves that nothing would overheat or melt any wires. Checking the gauges on all wires, 16 gauge external wires (bilge pump wires), in conjunction with 14 gauge internal wires (Super Rooster wires) both satisfied 2.5 amps at 12 volts (Bilge pump Maximums) according to wire tolerances. The inputs and outputs for the Communication wires, as seen in Figure 5.8, were simple and should not incur any form of modification or transformation.

5.6.3 – Fabrication

Soldering was the method of attaching most all wires. This not only provides sufficient electrical connection, but an added rigidity to the wires themselves also makes soldering beneficial to our intent. These wires were then wrapped in either electrical tape or dipped in Liquid Electrical Tape, a paint on version of the same material. A vile of this can be seen here in Figure 5.10. This proved helpful for electrically sealing some connections from others while working and operation in extremely tight spaces.

5.6.4 – Testing

Simply put, the testing of the entire electrical system consisted of connecting all components to see if each worked as planned. This setup has been tested for use with all three bilge pumps, full voltage, and max current, and it proved successful! Doubly, to insure that the gauges of the wires were not too thin, each wire was observed for any extreme increase in temperature. Nothing of this matter was noticed.

Figure 5.10 – Liquid Electrical Tape

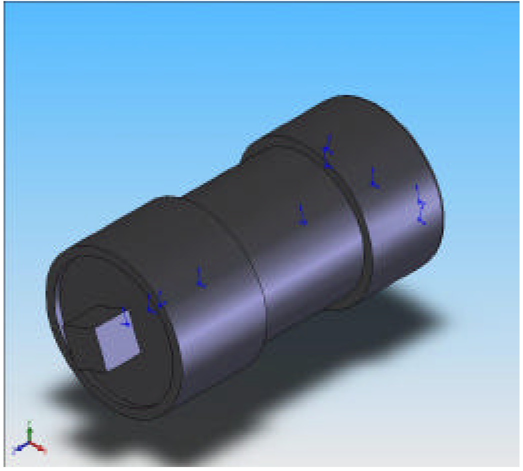
<u>5.7 - The Casing</u>

5.7.1 – Overall Design

The Control Bay is made of 3-inch diameter general-purpose black Acrylonitrile-Butadiene-Styrene (ABS) pipe. The ends are fitted with both a butted end and a female screw end, respectively. An image of the casing, as well as design specifications is shown here in Table 5.3. The female threaded-end will be sealed by a male threaded-end. This “lid” is crucial to the design of the control bay, including the small square knob that juts out 1 inch from the bottom of the bay. Its importance will be discussed subsequently (see **platform** and **hole**).

Table 5.3 – The Control Bay Housing Specifications

Dimensions
Length: 8.0 inches
Butted-end Length: 2.25 inches
Threaded-end Length: 3.0 inches
Knob length: 1.0 inch
Inside Diameter: 3.0 inches
Actual Pipe Length: 6.25 inches
Thermal Conductivity: 0.18 W / m*K



5.7.2 – Analysis

The bay itself needs to conceal all of the electronics, as well as be water tight, yet be functional in allowing our team to get to the electronics in case something goes wrong. Rule number one, electricity and water don't mix. One of the biggest accomplishments of this project was making a re-sealable capsule that was water tight. Due to its attainability, cost, and sufficiency in our design requirements, the material selected to case the control bay is of a general-purpose thermoplastic resin called ABS. ABS is made to sustain high pressures and has an average of 50 MPa tensile strength and an average compressive strength of 68 MPa. At a depth of 3 meters, the maximum depth of the competition pool, the pressure at the bottom will only be 4.25 psi. These calculations can be found in the Appendix: Figure A.3.5. The horizontal drag of the bay was also determined relative to apparent velocities. These values can be seen in tabular form in the Appendix: Figure A.3.6.

A brief heat transfer analysis was conducted on the ABS pipe to determine if the heat generated within the bay by the ESCs would accumulate, and endanger any controls within the bay. This analysis can be found in the Appendix: Figure A.3.7a,b showing that the maximum internal temperature that could be hazardous to the controls is at 142.8 degrees Fahrenheit. Knowing full well that this temperature is unattainable by the ESCs, the ABS pipe proved sufficient for heat transfer.

5.7.3 – Fabrication

As can be seen here in Figure 5.11, the butted end will be cleaned with ABS primer, and then glued with ABS cement to prevent any leakage at all. The female threaded-end will be treated similarly. Each piece will be pushed on over the 3-inch pipe until the inside is flush with the end caps. This provides a better seal. An auxiliary bead of ABS cement was then run between the connecting parts to insure a good seal.

Figure 5.11 – ABS Primer and Cleaner

Figure 5.12 – PTFE High Density Teflon Tape

The threaded lid will fit well into the female threaded end. The threading around the lid is tapered, and on its own, does not make a perfect watertight seal. With the introduction of high density Teflon tape (PTFE) shown here in Figure 5.12, that is made for sealing similar junctions in gas flow for air ducts; the seal can be kept in tact throughout all pressures that will be induced during competition. This tape is wrapped twice around the lid in a fashion that stretches the tape while tightening the lid. A special adjustable wrench is used to tighten the lid to the extent that we need to achieve a good seal. This wrench can be seen here in Figure 5.13.

Figure 5.13 – Adjustable Sealing Wrench

5.7.4 – Testing

By sealing the bay with the Teflon tape the control bay was tested on factors of time and pressure, to see when and where (if) the bay leaks. Using the same procedure to sink the Parmesan Cheese Prototype (as mentioned in section 5.5), the depth of the bay was controlled, as was the time of the test. As a result, the pressure could be varied to determine test results. A control of 25 minutes was used, since it is the maximum time allotted for competition by MATE. The results can be seen in the Appendix: Figure A.3.8. The bay did not leak at any of the depths recorded.

5.8 - The Platform

5.8.1 – Overall Design

As can be seen here in Figure 5.14, a 1/8-inch thick plate of 6061 Aluminum was used to suspend the components. The plate is 5.5 inches long by 2.8 inches wide to allow a small gap for clearance, per side within the 3-inch inside diameter ABS pipe. As far as positioning, the three ESCs will sit side by side on the topside of the aluminum plate, while the receiver will be attached on the other side. The wires and the slack provided for detachment of the plate, will consume whatever space is unoccupied.

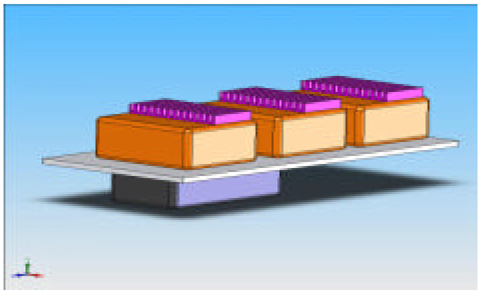


Figure 5.14 – 6061 Aluminum Plate with Electronic Components

The end of this plate will be attached to the Male Threaded-End / "Lid" of the control bay using a simple steel L-Bracket and a #10 screw and nut. A photo of this can be seen here in Figure 5.15. This method anchors the plate to the lid. This whole assembly is rotated as it is being sealed to the control bay casing (section 5.7).

**Figure 5.15 –
Screw and Nut with L-Bracket**

5.8.2 – Analysis

A method of holding all the electronic components within the control bay was necessary in our design. It needed to be rigid enough to withstand any stress implied by the weight of the electronics within the bay, yet thin enough to not consume too much volume of the bay itself. It had to provide easy access to the electronic components, yet protect them from the open environment. High heat conductivity would also benefit our design to prevent the damage of any electronics. The key component however is rigidity. It is for this reason that we selected 6061 Aluminum. Aluminum in general, at the thickness of 1/8-inch is plenty sufficient to withstand the stress of not only the weights of the electronic components, but also the bending stress that will be induced by sealing the bay. A quick stress analysis of this can be found in the Appendix: Figure A.3.9. This shows that unless forces of extreme magnitude twist the plate, it will not deflect or mutate at all. Any heat created by the ESCs would quickly dissipate into the plate, and then into the ambient air within the bay.

5.8.3 – Fabrication

The electronic components can be attached using the 3M Heavy Duty Foam Adhesive, as seen before in Figure 5.1. By placing the three ESCs on the same side of the plate, this will provide less confusion and added simplicity by running all wires of the same kind, on the same side of the bay. A small hole was drilled through the plate, as seen in Figure 5.16, to thread the screw and nut through the plate / L-Bracket assembly. A ¼-inch hole was drilled, and a lock washer holds the nut in place to prevent unwanted

Figure 5.16 – Hole in Aluminum Plate

Figure 5.17 – 30 min. epoxy

loosening. A special epoxy known as "30 minute" slow-cure was used to adhere the L-Bracket to the lid of the control bay. A photo of this material can be seen here in Figure 5.17. The lid of the bay was then milled per side to where the plate could rest on the interior surface of the lid. This not only provided added rigidity, but also better seeded the plate to the lid.

5.8.4 – Testing

The only testing conducted for the platform was the rigidity test…how well did the milling, 30-minute epoxy, and the L-Bracket assembly, secure the plate to the lid. A simple hand test was conducted by twisting the plate to see if any obvious failure occurred. The first of these tests actually broke the epoxy straight off from the lid. Later evaluation determined that the epoxy mixture was imbalanced, and a second test of similar manner proved sufficient in providing the desired results. The plate was secured to the lid, yet still detachable by unscrewing the screw and nut.

5.9 – The Hole

5.9.1 – Overall Design

In order to transmit all electrical wires from the outside of the control bay in, and vice versa, a small ½ inch diameter hole was drilled in the male threaded screw end to run all wires through. This hole was sealed with the 30-minute epoxy, as used before and as seen in Figure 5.17. A cubic inch plug was made to insure the integrity of the watertight hole. This hole can be seen here in Figure 5.18a,b.

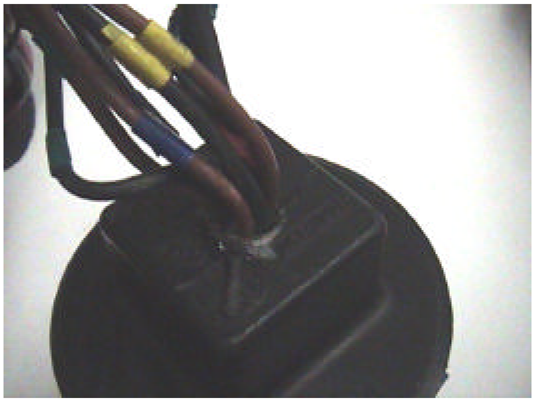


Figure 18a – Lid hole external view

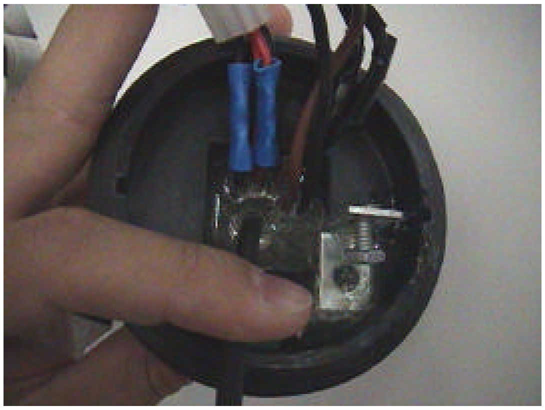


Figure 18b – Lid hole internal view

5.9.2 – Analysis

After looking at several epoxies to seal the hole for our wires, it was determined that the longer the substance was able to set, the more waterproof the seal would become. In knowing this, we found the longest sitting epoxy (without changing composition) to insure the best seal. Again, making an air capsule be watertight has proved to be one of the most difficult tasks of this project. By using the epoxy, it would fall between all wires and connections, and make a perfect surface seal between the ABS pipe surface and the wires themselves. By using the quantity of epoxy that we did, the seal was to be guaranteed. Of course, this needed to be tested to make sure.

5.9.3 – Fabrication

Since the epoxy takes 30 minutes to harden, after mixing the two components, the first batch was allowed to set for around 20 minutes. This gave our team time to apply the epoxy in the necessary areas without running epoxy in undesirable areas. Once a preliminary seal was made in the hole, the cubic inch of epoxy was dumped into the hole, making sure to run between and around all wires individually.

5.9.4 – Testing

Since the electronics plate is detachable due the connectors shown in Figure 5.9, the bay was then leak tested again, just as any test before. The high density Teflon tape was applied, the casing was secured, and the whole assembly was sunk to the bottom of a test pool. As the bay was pressure tested before, this test was run once for 25 minutes (length of competition). Maintaining the bay at 9 feet under water for this time, after the test, the bay had shown no signs of flooding or leakage.

<u>5.10 – Counterbalance & Buoyancy</u>

5.10.1 – Overall Design

The intentions of our design are to make a bay that is not only watertight, but neutrally buoyant as well. In initial designs, the bay needed additional weight to balance the forces. In all actuality, now that the overall length of the bay has been shortened and no supplemental weight is necessary to equalize the forces. Their magnitudes are approximately equal; therefore, the rest can be equated with the rest of the ROV.

5.10.2 – Analysis

The knob shown on the end of the bay above was incorporated into design as a perfect location to place the counterbalance for the bay. The overall displacement of water due to the bay's volume (Archimedes Principle) gives a buoyancy force of 2.975 lbs. Before modifications to the length of the bay, this value was at around 4 lbs. This calculation can be seen in the Appendix: Figure A.3.10a. The analyzed weight of the gear within the bay, including the weight of the bay itself can also be found in the Appendix: Figure A.3.10b. The overall weight of the bay and all of its gear weighs about 2.300 lbs. This leaves a difference of around 0.675 lbs. This weight was to be originally added to the bay to establish approximate neutral buoyancy. Using hypothetical values for whatever material was to be used to weight the bay down, the mass and volume of this was determined. This can be seen in Appendix: Figure A.3.10c. In using such items as electrical connectors, a thicker aluminum plate, and a cubic inch of epoxy, it is to no surprise that the bay can balance itself out without the addition of any auxiliary material.

The other benefit of balancing the bay as we did was that the forces of buoyancy and weight in opposing directions proved to have a short distance between the centers. This discrepancy creates a natural form of static stability, and in most cases, allows the ROV to upright itself if flipped over.

5.10.3 – Fabrication

Since no additional weight was added, no fabrication was necessary.

5.10.4 – Testing

To insure the approximate neutral buoyancy, the sealed bay with all components inside was cast into water to determine its overall buoyancy and its vertical stability. By slightly floating and up righting itself, it satisfied both of these conditions.

5.11 – Radio

5.11.1 – Overall Design

The XP662 by JR is our ideal radio for what we need. It can communicate with up to 6 channels simultaneously, and its digital setup allows mixing. Its output power of the signal is approximately 1 watt, but this value is not

Figure 5.19 – XP662 JR Radio Transmitter

important since this signal will only travel a short range (approximately 3 inches). It uses 50/72 MHz frequencies to correspond with the receiver.

5.11.2 – Analysis

The only design requirements that the radio needed to meet were to be able to effectively communicate with the receiver, have a feature known as digital mixing, and be as cheap as possible. Most hobby radios used for what we needed it for are in the order of $300. Mixing is what allows the forward/back, right/left motion to be controlled by one of the sticks on the radio. It actually “mixes” the signal between two different channels to allow the full right command to respond by left forward, right backward. Otherwise, straight and forward would be careful calibration of two thumb throttles which would be very difficult.

5.11.3 – Fabrication

Just the same as the ESCs and the receiver, the radio needs no fabrication. The only adjustment that need be mentioned is of the eyelet connector as seen in Figure 5.3, and previously described. The trim (digital error correction) of the radio can be corrected manually using the computer in the radio.

5.11.4 – Testing

The only testing required was that of assembling the control bay, attaching the radio to the end of the coaxial cable, and determining whether or not the system functions as desired. This test was conducted, and succeeded!

5.12 - Tether

5.12.1 – Overall Design

The tether consists of the coaxial cable, two 16 gauge wires for power to the control bay, and the RCA cable as extended from the underwater camera. The overall cross section of the tether is approximately .5 cm^2. A photo of the tether can be seen here below in Table 5.4. The length of the tether is 50 feet, which is sparing for the actual length required by the competition. Also listed in Table 5.4 is each wires diameter as measured using vernier calipers and the total volume of wire.

Table 5.4 – Tether Specifications

5.20 – Image of the Tether with buoyant foam

	Diameter (in)	Area (in^2)	Volume (in^3)
Power Wire 1	0.21	0.034619	20.7711
Power Wire 2	0.2	0.0314	18.84
Coax Cable	0.1	0.00785	4.71
RCA Cable	0.1	0.00785	4.71
		Total Vol.	49.0311

5.12.2 – Analysis

By determining the volume and the weight of the tether, the amount of buoyant foam can also be found to make the tether neutrally buoyant. These calculations are summarized below, but they can also be found in the Appendix: Figure A.3.11. The weight of the tether was measured to be 5.816 lbs using a scale.

Table 5.5 – Buoyant Force (Tether)

Buoyant Force – Tether								
Vol. in^3	**cm/inch**	**Vol. cm^3**	**cm/m**	**Vol. m^3**	**Density H2O**	**Force kg**	**kg/lb**	**Force lbs**
49.0311	2.54	803.4757737	100	0.000803476	998	0.801868822	0.45359237	1.767818145

In the above chart, the volume is converted to m^3, and the buoyant force of the tether is determined based on the density of water and the force of gravity.

Table 5.6 – Volume Displacement

Total Volume for Tether to Displace							
Sum of Forces lbs	**kg/lb**	**Force kg**	**Density H2O**	**Vol. m^3**	**m/cm**	**Vol. cm^3**	**Vol. in^3**
-4.048181855	0.45359237	-1.836224402	998	0.001839904	0.01	1839.90421	112.2778437

In the above chart, The 5.816 – 1.767 lbs yields a net downward 4.04 lbs. Assuming the foam to be weightless, the volume needed to be displaced by the foam is then determined to be 112.27 in^3. Using cross sectional areas, the overall length of the foam required to make the tether neutrally buoyant can be determined. This length is approximately 6 feet of foam.

Table 5.7 – Foam Displacement Length

Foam Cross Sec. Area	**Displacement Volume**	**Foam Length (in)**	**Foam Length (ft)**
1.57	112.2778437	71.51455012	5.959545843

5.12.3 – Fabrication

The foam was cut into small 2~3 inch lengths and wrapped using electric tape to fasten the foam to the tether. All 6 feet of foam was used spaced accordingly throughout the length of the 50 feet.

5.12.4 – Testing

The buoyancy of the tether was tested, again, by placing in the water to see if it floated or sank. After a few minor adjustments, the tether actually suspended itself at mid-depth of the pool.

5.13 – Attaching the Bay

5.13.1 – Overall Design

As can be seen in Figure 5.22, the control bay has been fastened with two post clamps. Each post has two screws jutting outward. These are the fasteners for the C-Clamps seen in Figure 5.21. The C-Clamps loop around the PVC pipe used in the structure of the ROV to secure the control bay.

Figure 5.21 – C-Clamps

Figure 5.22 – Fastened Control Bay

5.13.2 – Analysis

From rubber bands, to O-rings, to Velcro, to glue, the best fit way that we determined to attach the control bay was using these cheap, rigid, C-clamps. Simplistic in manner, they are effective in locking down the control bay, and eliminating motion thereof.

18

5.13.3 – Fabrication

By drilling small 1/8 inch diameter holes through the post clamps, the matching nuts can easily be fixated on the threaded end after the C-clamps are positioned on the screws. The post clamps stay fastened by a screw used to tighten the clamp horizontally.

5.13.4 – Testing

No testing is necessary other than whether or not the nuts lock on the screws and the bay fastens itself to the ROV.

6 –Retrieval

6.1 - Introduction

The retrieval system needs to combine all of the elements that will enable us to complete the seven tasks of the competition. These include holding, carrying, picking up and releasing objects.

6.2 - Constraints

A majority of the design for the retrieval system was left open due to the creative nature of the competition and the tasks. Therefore, many of the ideas are innovative and open-ended. Even though the MATE Center did not provide any specifications regarding the construction and design of the retrieval system, there were constraints that we needed to take into account when designing, such as those listed below.

- The pool contains chlorinated, freshwater but should be considered conductive of electrical currents. Waterproofing the ROV components is preferable.
- ROV should provide a source of visibility underwater
- Should provide a payload tool to perform all tasks

6.3 - The Claw

6.3.1 - Overall Design

The claw is a basic robot claw that is available at Toys R Us. The connector rod is long and thick. It is attached to a pushrod connector which in turn connects the claw to a servo. The exact design is shown in Figure 6.1. with the dimensions shown in the appendix.

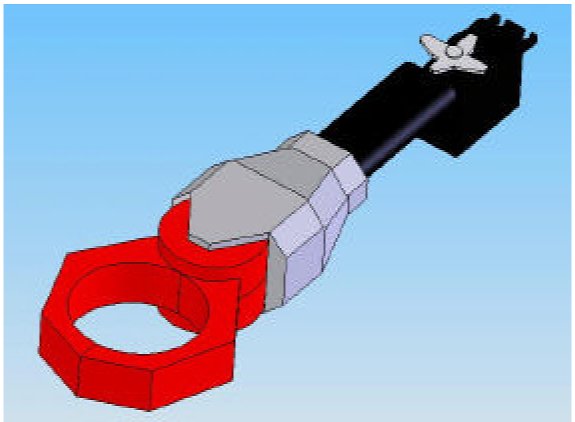


Figure 6.1 – The Claw

6.3.2 - Analysis

The claw was purchased and then taken apart. The connecting rod was shortened to the desired overall length. This length was determined by how we wanted to mount it, there were no constraints as far as the claw was concerned. We chose a length of 5 inches based on the fact that we wanted to mount it on the top of the sub. We did not want it to be in the way of the camera but we did want it as closely lined up with the camera as possible. Having the two lined up would enable us to more efficiently line the sub up for the retrieval tasks. Next we had to determine the amount of force that was required to close the claw. This was found by using a spring loaded force meter and attaching weights to the connecting rod. The force needed to close the claw came to 17 Newtons. Using the specifications provided by the servo company as shown in Figure 6.2, we found the torque to be 43 ounce-inch at 4.8 volts. With the length of the servo arm that we are using at .5 inches, we get at output torque of 86 ounces. This is the equivalent of 23.91 Newtons, which exceeds the required 17 Newton force to close the claw. This gives us a factor of safety of 1.41, which more than meets our needs.

NES-537 Specifications

Torque	43 ounce inch @ 4.8 volt
Speed	.25 sec 60deg @ 4.8 volt
Weight	1.58 oz
Size	1.52 x .73 x 1.32
Motor	3-pole ferrite
Gears	Plastic
BB	Single

Figure 6.2 – Servo Specifications

6.3.3 - Fabrication

The first thing done was to shorten the length of the claw. It was approximately cut so that the connecting rod is 5 inches long. This length was chosen simply because of where we wanted to mount it on the sub. Then the pushrod was connected to the connecting rod and tightened down. This was then inserted into the servo, shown in Figure 6.3, and the servo wires were attached to the control bay. The claw was mounted on the sub by attaching the connecting rod cover to the top of the sub with screws.

Figure 6.3 – JR Servo NES 537

6.4 - The Scoop

6.4.1 - Overall Design

The scoop was designed to fulfill one of the task requirements. Being that we need to pick up 1 lava rock, that weigh less than 1 Newton, off of the bottom of the pool, we chose to use a static object to complete the task. Using the speed provided by the propulsion, we plan to propel the rocks up the scoop into the submersible.

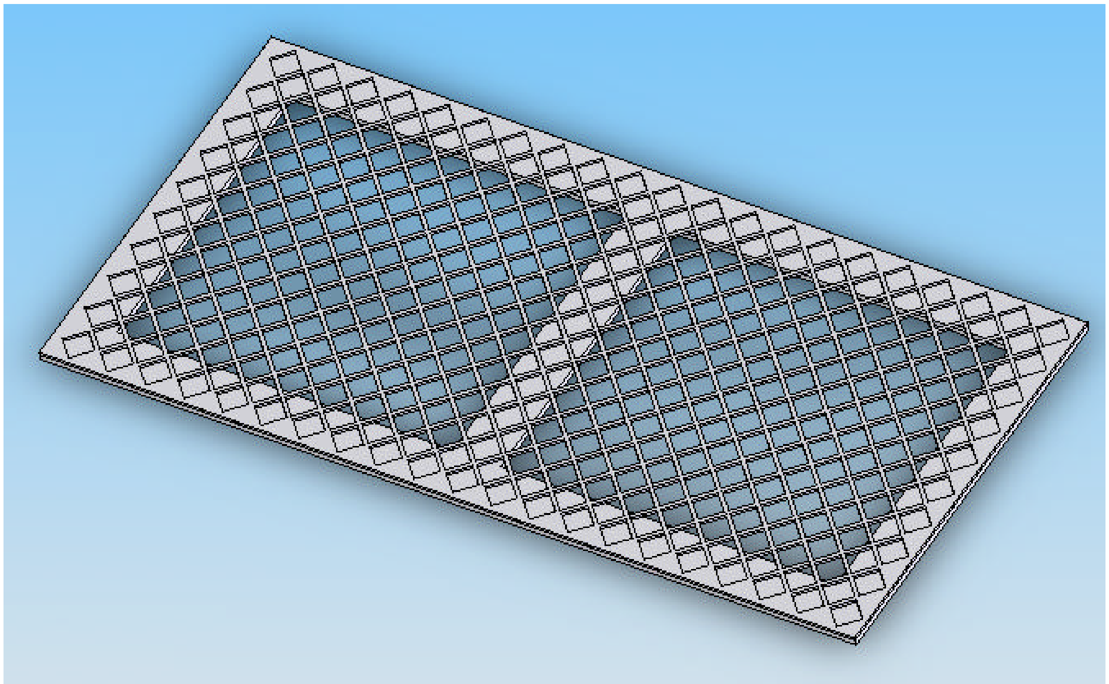


Figure 6.4 – Scoop

6.4.2 - Analysis

The analysis for this object is extremely complex to provide an appropriate answer. The only way to give accurate results is through the use of a computer program such as Ansys. Unfortunately, none of the team members are proficient in this program, and none of the students within the department were willing to help us with this aspect of the analysis. Therefore, we chose to test it to check the durability and make sure that it can withstand the appropriate pressure.

After attaching the scoop to the sub, we propelled the sub directly downward and allowed the scoop to collide with the bottom of the pool. After several attempts, we found no deformation in the aluminum sheet. Then we chose to drive directly into a drain filter at the bottom of a pool. At full throttle, we drove the aluminum scoop directly into the filter which protruded vertically from the bottom of the pool. We noticed there to be slight buckling, but the sheet did not break, or deform exceptionally. Therefore, crashing it at maximum velocity in both the horizontal and vertical directions, and noticing little to no deformation, we are comfortable that the scoop will withstand the forces and perform the required tasks set forth by the MATE Center

6.4.3 - Fabrication

We chose to use a sheet of 6061 aluminum that we initially cut to fit the width of the opening in the front of the sub, which is 8.5 inches. We decided to keep the length of the sheet to be 4 inches providing us with a long enough ramp at a shallow angle.

At this point, we knew that if we were to put this sheet on the front of the sub, we would be producing a large amount of drag. Therefore, we decided to cut out two identical squares sized at 3.5 inches by 3 inches, oriented symmetrically. We were able to cut these out without cutting through any other pieces of aluminum with the use of a Dremel Tool. After the squares were cut, we knew that we could not leave the scoop at this point. Therefore, we chose to use an aluminum meshing and wrapped it around the sheet. This would allow the water to flow through the squares, and not letting the rocks to fall through.

6.5 - The Netting

6.5.1 - Overall Design

The main idea of our structure design was the incorporation of a mouth type opening which would allow us to hold the scooped up rocks and capture the floating fish. However, in order for the mouth system to work we had to place netting around the open end to create an enclosed area where the various objects could be held. The netting chosen was a general purpose bird netting found in any local hardware store. This netting was chosen for its large square holes which would allow water to easily pass through and cause very little extra drag as seen in Figure 6.5.

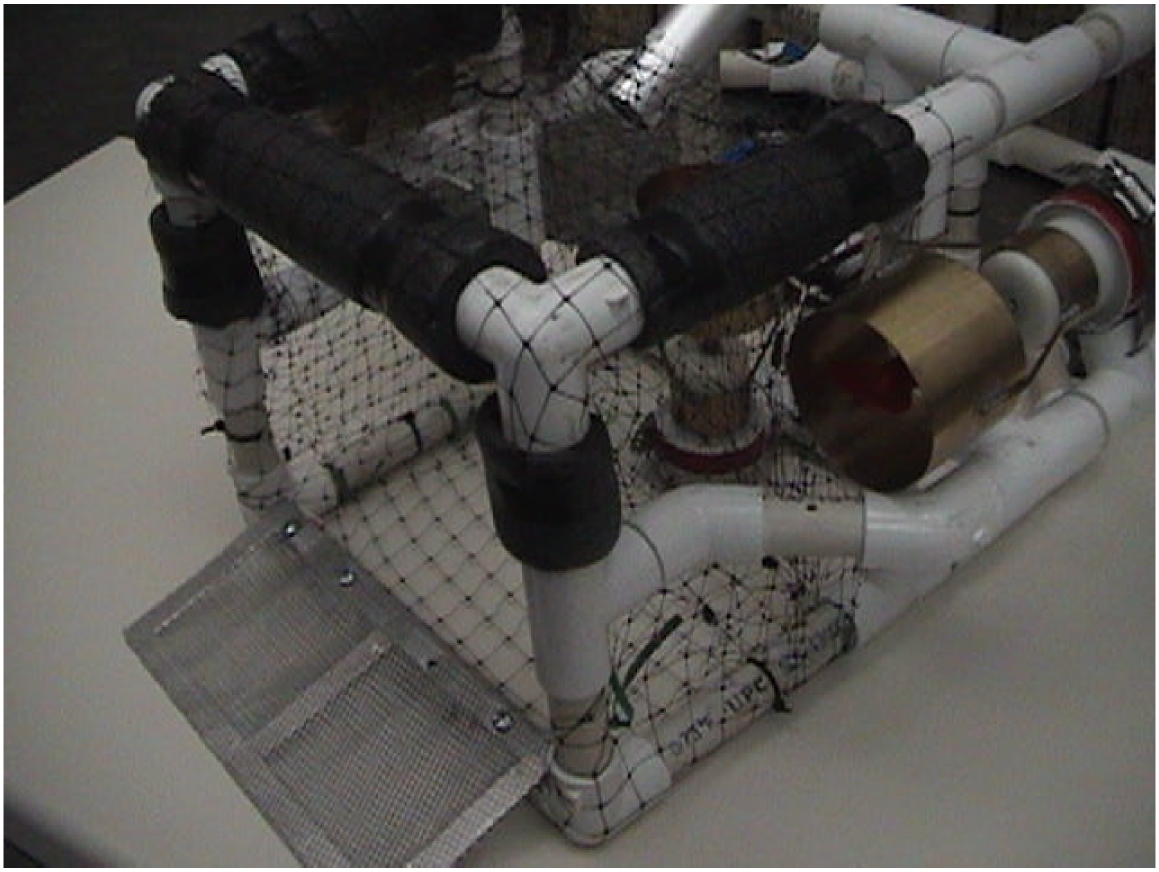


Figure 6.5 – Netting and Scoop Assembly

6.5.2 - Analysis

Considering that the maximum load that the netting will experience is only 1N (roughly .2 lb), we decided that there is no analysis needed for netting.

6.5.3 - Fabrication

To put the netting on the sub, we used the bird netting, and cut it to an appropriate size. We ended up cutting a T-shape in the netting, and used that length to cover the top, bottom, both sides, and the back without breaking the netting. This way, there are no holes, or cracks that the rocks or fish can escape from within the netting. We were able to attach the netting through the use of zip-ties that wrapped around the netting and was connected through the drilled holes in the PVC pipes. This way, we made sure that we had a secure hold on the netting itself.

6.6 - The Camera

6.6.1 - Overall Design

The camera we chose is a Lorex Pro CVC6990 black and white submersible video camera. The camera shown with dimensions in Figure 6.6 was chosen for its depth rating of 90’, its 0lux video capabilities and its simple RCA video output. The camera runs off of 12V DC and runs at 200mA, therefore only consuming 2.4W of power.

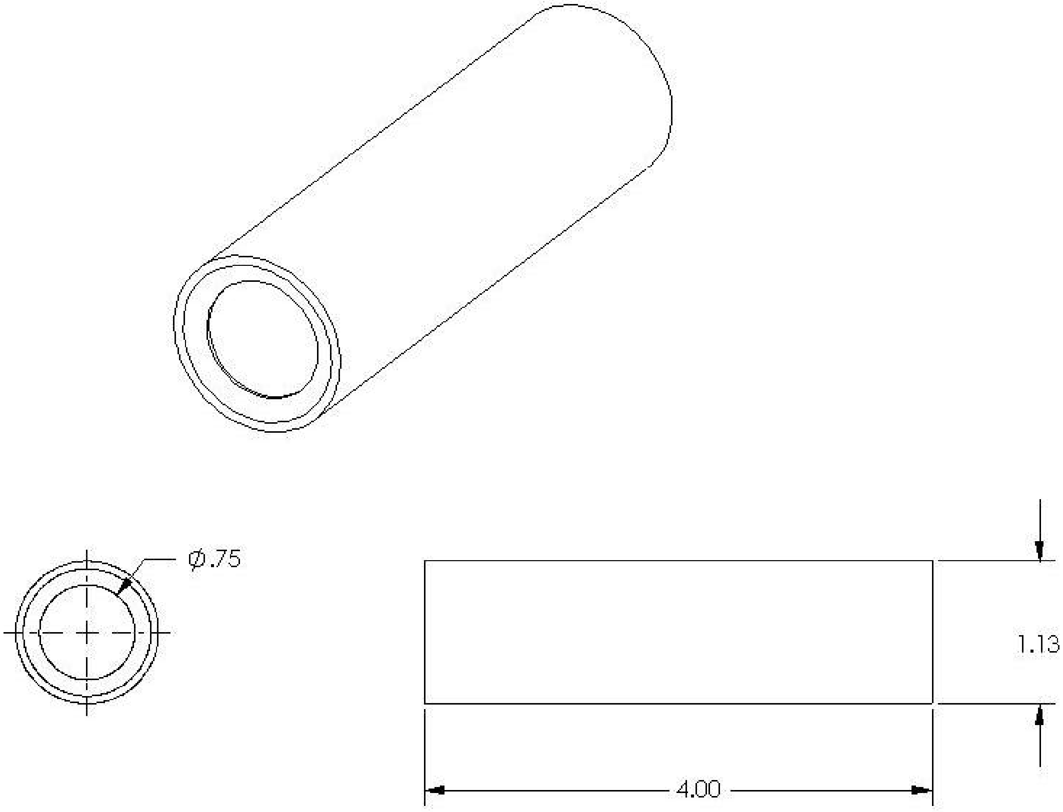


Figure 6.6 – Camera Engineering Drawing

6.6.2 - Analysis

Since the cameras are manufactured and will not sustain any sort of forces or loads and the pressure testing has been ensured by the manufacturer, we determined that no numerical analysis was needed for the camera. However, in determining which camera to buy we did compare the Lorex (which we bought) to another, similar camera made by CSI. The CSI camera was very similar as far as performance, however the CSI camera was bigger and more expensive than the Lorex, which made the decision easy.

6.6.3 - Fabrication

Being that we purchased a prefabricated camera that came with a camera mount, we were forced to put forth little effort to assemble it. We decided to use a hose clamp that we drilled a mounting screw through. We then attached that hose clamp to the mid-center PVC tube on the top of the sub. This location provided us with a bird’s eye view of the scoop and claw making it easy to remotely operate those objects. It was also far enough away from the front to view through the PVC square frame, giving us an unobstructed view.

7 - Bill of Materials

7.1 – Purchased Materials

Part	Model	Assembly	Supplier	Cost ($)	Number	Updated Cost ($)
Motor	Bilge Pump	Propulsion	Rule	$ 20.00	5	$ 100.00
Speed Controller	Super Rooster	Controls	Novak	$ 129.00	3	$ 387.00
Aluminum Plate	Aluminum	Controls	E&S Hobbies	$ 4.25	1	$ 4.25
Brass Rods	3/16” Brass Rods	Controls	E&S Hobbies	$ 1.69	4	$ 6.76
Pipe	3” ABS Pipe	Controls	Ace Hardware	$ 1.89	2	$ 3.78
Tubing endcap	3” Butted ABS endcap	Controls	Ace Hardware	$ 1.73	4	$ 6.92
Threaded endcap	3” Threaded ABS endcap	Controls	Ace Hardware	$ 2.25	4	$ 9.00
Brass Strip	12X.016X2” Brass Strip	Propulsion	Ace Hardware	$ 2.89	3	$ 8.67
Propeller	2 7/16” Wildcat/Stinger	Propulsion	Hobby Barn	$ 1.00	3	$ 3.00
Brass Rods	1/8"-Brass	Propulsion	Hobby Town	$ 0.75	9	$ 6.75
PVC Fitting	0.5"-Straight Connector	Body Structure	Home Depot	$ 0.25	21	$ 5.25
PVC Fitting	0.5"-90° Elbow	Body Structure	Home Depot	$ 0.42	11	$ 4.62
PVC Fitting	0.5"-T	Body Structure	Home Depot	$ 0.19	2	$ 0.38
PVC Fitting	0.5"-Cross	Body Structure	Home Depot	$ 0.73	1	$ 0.73
Elbows	0.5"-45° Elbow	Body Structure	Home Depot	$ 0.97	8	$ 7.76
PVC tubing	1/2 PVC 40	Body Structure	Home Depot	$ 0.98	3	$ 2.94
RC Connector	9.6V-RC Connector	Controls	Radio Shack	$ 2.99	1	$ 2.99
RC Combination	9.6V-RC Combo	Controls	Radio Shack	$ 24.99	1	$ 24.99

JR Radio	SP662	Controls	Hobby Town	$ 250.00	1	$ 250.00
Connecting Wire	RG58 UL Coax	Controls	Radio Shack	$ 0.23	50	$ 11.50
Claw	Robot Claw	Retrieval	Toys R Us	$ 6.50	1	$ 6.50
Pushrod Connectors	Great Planes	Retrieval	Competition Hobbies	$ 1.68	1	$ 1.68
Sheet Metal	Aluminum	Retrieval	Ace Hardware	$ 2.50	1	$ 2.50
Mesh	Aluminum	Retrieval	Michael's	$ 5.00	1	$ 5.00
Mesh	Bird Netting	Retrieval	Ace Hardware	$ 7.50	1	$ 7.50
Camera	CVC6990	Controls	Wild West Electronics	$ 150.00	1	$ 150.00
Total Cost	**$ 1,020.47**					

Table 7.1 – Bill of Materials

The Bill of Materials reflects the products that have been purchased for use in the final design. The **Part** reflects the type of product that we are using, as the **Model** describes the exact model number that was purchased. The **Assembly** categorizes which sub-system the part is used for and the **Supplier** is where we purchased the product. The **Cost ($)** can be understood as either the dollar price per part, or dollar price per foot, and the **Number** reflects the number of each part or the number of feet purchased. The **Updated Cost ($)** reflects the total price for each part/foot purchased. This chart was used to keep track of all expenses for our design.

8 - Environmental Statement

8.1 – Product Properties

- Number made: 1.
- Life Cycle: 6 months to 1 year.

8.2 - Materials of Product:

Table 8.2 – Materials Listing

Part	Model	Number
Motor	Bilge Pump	3
Propeller	1.5*1.5 Wildcat/Stinger	3
Aluminum Rods	1/8"-Aluminum	15
PVC Fitting	0.5"-Straight Connector	21
PVC Fitting	0.5"-90° Elbow	11
PVC Fitting	0.5"-T	2
PVC Fitting	0.5"-Cross	1
Elbows	0.5"-45° Elbow	8
PVC tubing	1/2 PVC 40	3
RC Connector	9.6V-RC Connector	1
Battery	9.6V-RC Battery	1
Connecting Wire	RG58 UL Coax	50
Brass Rods	1/8"D-Yellow Brass Rod	3
Brass Rods	3/5"D-Yellow Brass Rod	3
Camera	??	1
Speed Controllers	Futaba	3
PVC Fitting	1.5"-Straight Connector	3
Metal Clamps	Aluminum Hose Clamp	6
RC Controllers	Futaba	2

8.2.1 - By-products During Use

- Rust – The metal pieces that sit in water will slightly rust after extended periods of time.
- Environmentally friendly, not many by-products.

8.2.2 - Recyclable or Re-usable Materials After Use

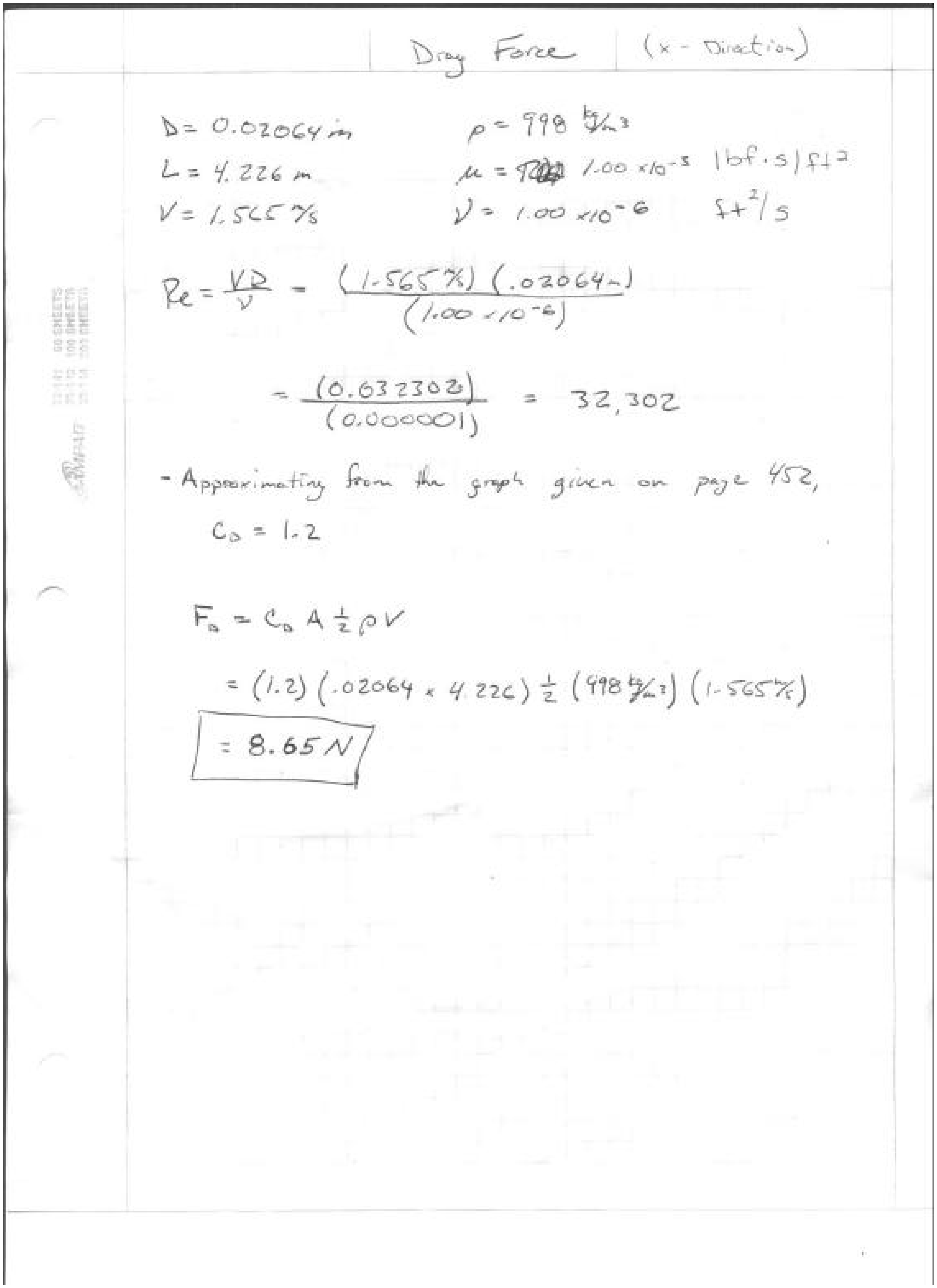
- Camera
- Bilge Pumps
- Propeller
- Wires

- The Manipulator (mechanical arm)
- Aluminum / Brass Rods
- PVC is not completely recyclable as chlorine is harmful to the environment.

9 – Appendix

A.1 - Structural Calculations

A.1.1 – Drag Force (x-direction)



Drag Force (x - Direction)

$D = 0.02064\ m$

$L = 4.226\ m$

$V = 1.565\ m/s$

$\rho = 998\ kg/m^3$

$\mu = 1.00 \times 10^{-5}\ lbf \cdot s / ft^2$

$\nu = 1.00 \times 10^{-6}\ ft^2/s$

$$Re = \frac{VD}{\nu} = \frac{(1.565\ m/s)(.02064\ m)}{(1.00 \times 10^{-6})}$$

$$= \frac{(0.0323032)}{(0.000001)} = 32,302$$

- Approximating from the graph given on page 452,

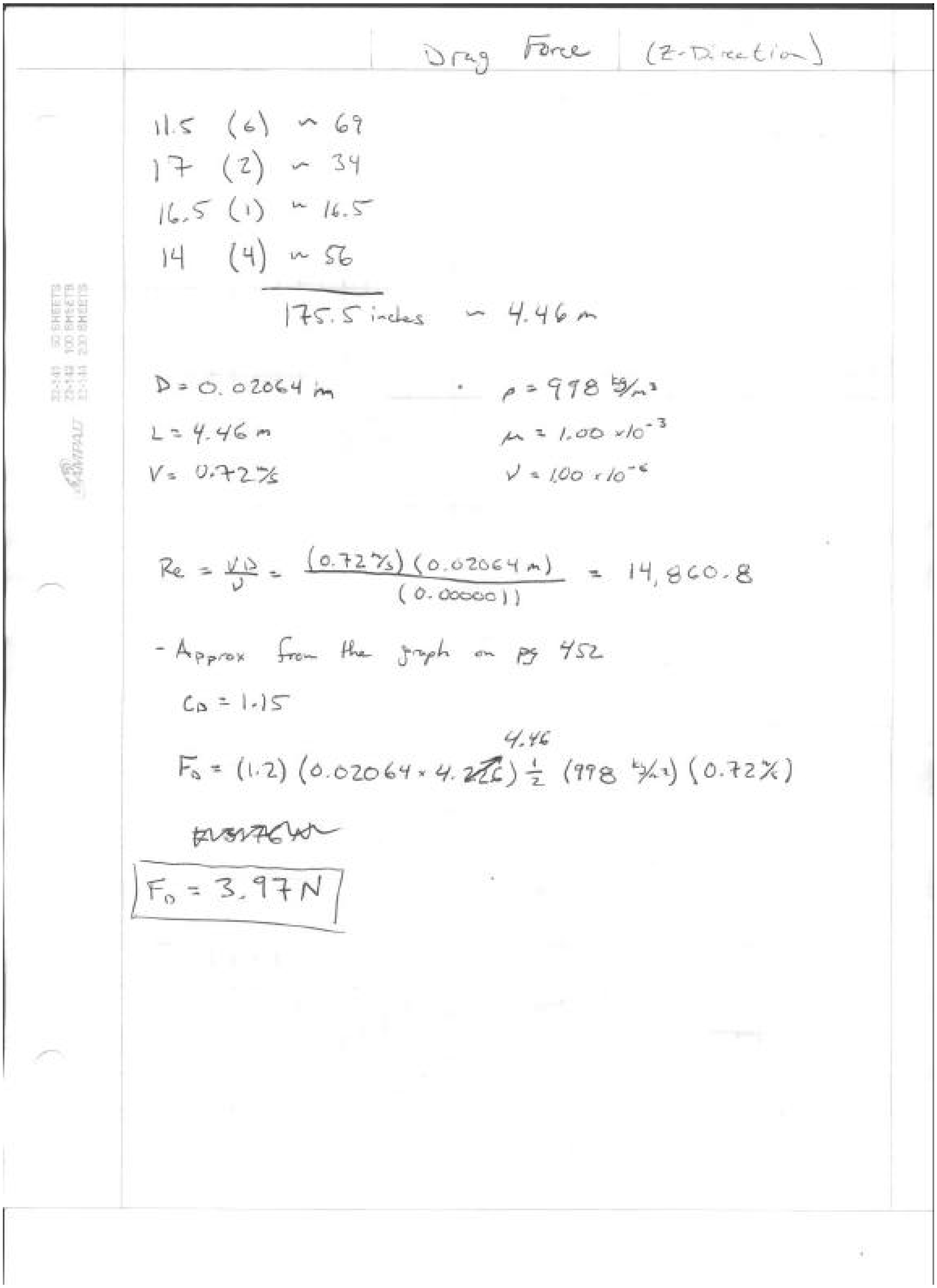
$C_D = 1.2$

$$F_D = C_D A \tfrac{1}{2} \rho V$$

$$= (1.2)(.02064 \times 4.226)\tfrac{1}{2}(998\ kg/m^3)(1.565\ m/s)$$

$$\boxed{= 8.65\ N}$$

A.1.2 – Drag Force (z-direction)



Drag Force (Z-Direction)

11.5 (6) ~ 69
17 (2) ~ 34
16.5 (1) ~ 16.5
14 (4) ~ 56

175.5 inches ~ 4.46 m

$D = 0.02064\ m$
$L = 4.46\ m$
$V = 0.72\ m/s$

$\rho = 998\ kg/m^3$
$\mu = 1.00 \times 10^{-3}$
$\nu = 1.00 \times 10^{-6}$

$$Re = \frac{VD}{\nu} = \frac{(0.72\ m/s)(0.02064\ m)}{(0.000001)} = 14,860.8$$

- Approx from the graph on pg 452

$C_D = 1.15$

$$F_D = (1.2)\left(0.02064 \times 4.\overset{4.46}{\cancel{226}}\right)\frac{1}{2}\left(998\ kg/m^3\right)\left(0.72\ m/s\right)$$

~~[illegible]~~

$$\boxed{F_D = 3.97 N}$$

A.1.3 – Calculation Tables

Table A.1.1 – List of Connectors

Slots	Shape	Diameter	Material	Pieces Used	Indiv. Weight*	Weight
2	45 degree	0.5"	Soft PVC Pipe	14	0.046875	0.65625
3	X, Y, Z axis	0.5"	Soft PVC Pipe	4	0.071875	0.2875
3	T shape	0.5"	Soft PVC Pipe	20	0.071875	1.4375
4	X shape	0.5"	Soft PVC Pipe	1	0.075	0.075

Total # of connectors	39

Table A.1.2 – List of PVC Pipes

Length	Diameter	Material	Pieces Used
8.75	0.5"	Soft PVC Pipe	2
3	0.5"	Soft PVC Pipe	10
1.6875	0.5"	Soft PVC Pipe	4
1	0.5"	Soft PVC Pipe	16
2.5625	0.5"	Soft PVC Pipe	2
2.65	0.5	Soft PVC Pipe	4
3.625	0.5"	Soft PVC Pipe	2
7.4	0.5"	Soft PVC Pipe	2
2	0.5"	Soft PVC Pipe	4
5.8125	0.5"	Soft PVC Pipe	4
2.5	0.5"	Soft PVC Pipe	2
4	0.5"	Soft PVC Pipe	2
3	0.5"	Soft PVC Pipe	2

Total # of pipes	56

Table A.1.3 – Buoyancy Volume Top Caulked Pieces

Radius^2	Length	Pi	Indiv. Volume	Pieces Used	Volume Total
0.191406	8.75	3.14	5.258886719	1	5.258886719
0.191406	5.8125	3.14	3.49340332	2	6.986806641
0.191406	2	3.14	1.20203125	2	2.4040625
0.191406	3	3.14	1.803046875	2	3.60609375
0.191406	1.6875	3.14	1.014213867	2	2.028427734
0.191406	3.625	3.14	2.178681641	1	2.178681641

Total volume displaced	22.46295898

Table A.1.4 – Volume PVC Pieces (Bottom Section)

Radius^2	Length	Pi	Indiv. Volume	Pieces Used	Volume Total
0.128906	8.75	3.14	3.541699219	1	3.541699219
0.128906	3	3.14	1.214296875	10	12.14296875
0.128906	1.6875	3.14	0.683041992	2	1.366083984
0.128906	1	3.14	0.404765625	16	6.47625
0.128906	2.5625	3.14	1.037211914	2	2.074423828
0.128906	2.65	3.14	1.072628906	4	4.290515625
0.128906	3.625	3.14	1.467275391	2	2.934550781
0.128906	2	3.14	0.80953125	2	1.6190625
0.128906	5.8125	3.14	2.352700195	2	4.705400391
0.128906	2.5	3.14	1.011914063	2	2.023828125
0.128906	4	3.14	1.6190625	2	3.238125
0.128906	3	3.14	1.214296875	2	2.42859375

Total Volume Displaced	46.84150195

Table A.1.5 – Volume PVC Pieces (Top Section)

Radius^2	Length	Pi	Indiv. Volume	Pieces Used	Volume Total
0.128906	8.75	3.14	3.541699219	1	3.541699219
0.128906	5.8125	3.14	2.352700195	2	4.705400391
0.128906	2	3.14	0.80953125	2	1.6190625
0.128906	3	3.14	1.214296875	2	2.42859375
0.128906	1.6875	3.14	0.683041992	2	1.366083984
0.128906	3.625	3.14	1.467275391	1	1.467275391

Total Volume Displaced	15.12811523

Table A.1.6 – Buoyant Force

Vol. in^3	cm/inch	Vol. cm^3	cm/m	Vol. m^3	Density H2O	Force kg	kg/lb	Force lbs
69.30446	2.54	1135.697	100	0.001135697	998	1.133425	0.45359237	2.498775
52.29905	2.54	857.0279	100	0.000857028	998	0.855314	0.45359237	1.885644

Summed Buoyant Force	4.384419137

Table A.1.7 – Gravitational Force on the Sub

Vol. in^3	cm/inch	Vol. cm^3	cm/m	Vol. m^3	Density H2O	Force kg	lb/kg	Force lbs
61.96962	2.54	1015.5	100	0.0010155	1300	-1.32015	0.45359237	-2.91043
52.29905	2.54	857.0279	100	0.000857028	1300	-1.11414	0.45359237	-2.45625

Summed Gravitational Force	-5.366682758

Table A.1.8 – Total Volume to Displace

Sum of Forces lbs	kg/lb	Force kg	Density H2O	Vol. m^3	m/cm	Vol. cm^3	Vol. in^3
-0.982263621	0.453592	-0.445547284	998	0.00044644	0.01	446.4401641	27.24345

Table A.1.9 – Center of Buoyancy Location (Z-Axis)

Section	Volume (in)	Density	Force	Distance from Center (in)	Buoyant Moment
Top	49.70640931	0.001122685	0.055804649	4.565	0.254748224
Top Mid	6.0102	0.001122685	0.006747563	2.2825	0.015401311
Mid	19.69299	0.001122685	0.022109028	0	0
Bottom Mid	6.0102	0.001122685	0.006747563	-2.2825	-0.015401311
Bottom	15.12811523	0.001122685	0.016984111	-4.565	-0.077532466
Totals	96.54791455		0.108392913		0.177215758
				Distance from Center	1.634938602

Table A.1.10 – Center of Buoyancy Location (Y-Axis)

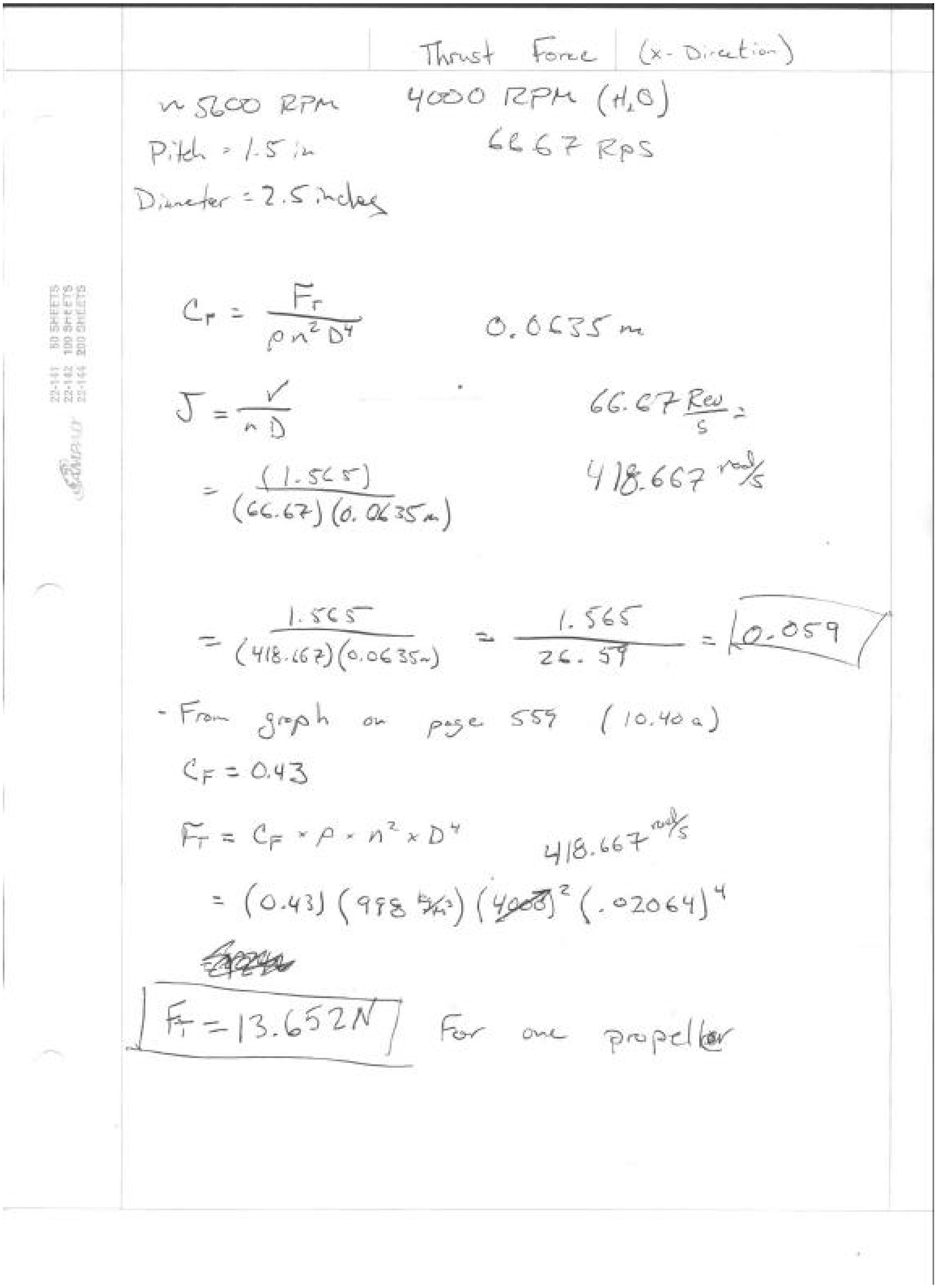
Section	Volume (in)	Density	Force	Distance from Center (in)	Buoyant Moment
Front	15.44766633	0.001122685	0.017342866	8.36	0.144986361
Front Mid	16.41314547	0.001122685	0.018426795	4.18	0.077024004
Mid	20.27506206	0.001122685	0.022762512	0	0
Back Mid	18.34410376	0.001122685	0.020594654	-4.18	-0.086085652
Back	26.06793693	0.001122685	0.029266087	-8.36	-0.244664484
Totals	96.54791455		0.108392913		-0.108739771
				Distance from Center	-1.0032

Table A.1.11 – Center of Buoyancy Location (X-Axis)

Section	Volume (in)	Density	Force	Distance from Center (in)	Buoyant Moment
Left	48.27395727	0.001122685	0.054196457	5.665	0.307022927
Right	48.27395727	0.001122685	0.054196457	-5.665	-0.307022927
Totals	96.54791455		0.108392913		0
				Distance from Center	0

A.2 – Propulsion

A.2.1 – Thrust Force (x-direction)



Thrust Force (x-Direction)

~5600 RPM   4000 RPM (H_2O)

Pitch = 1.5 in   66.67 RPS

Diameter = 2.5 inches

$$C_F = \frac{F_T}{\rho n^2 D^4}$$ 0.0635 m

$$J = \frac{V}{nD}$$ 66.67 $\frac{Rev}{s}$ =

$$= \frac{(1.565)}{(66.67)(0.0635 m)}$$ 418.667 rad/s

$$= \frac{1.565}{(418.667)(0.0635 m)} \approx \frac{1.565}{26.59} = \boxed{0.059}$$

- From graph on page 559 (10.40 a)

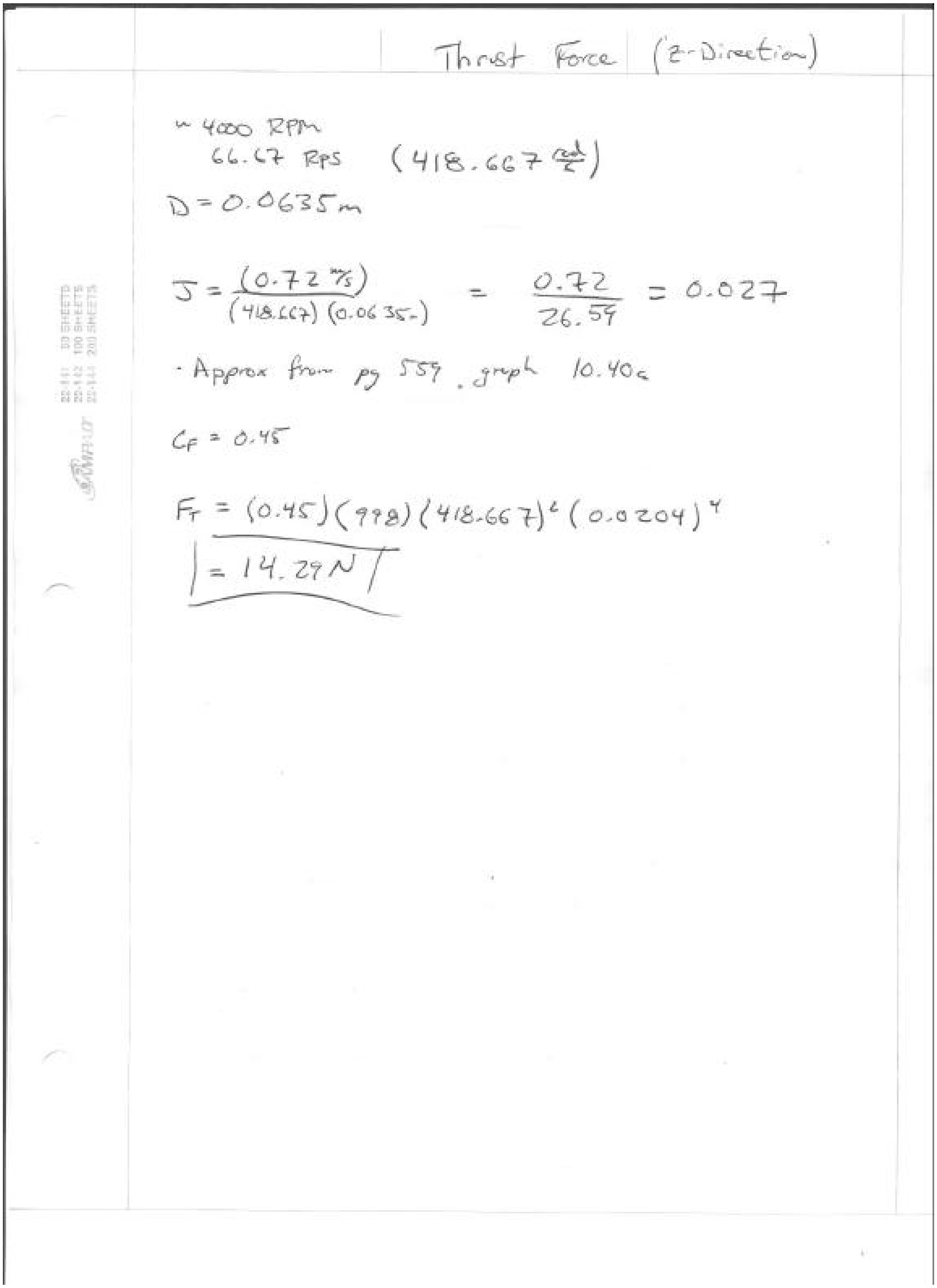
$C_F = 0.43$

$F_T = C_F \times \rho \times n^2 \times D^4$

$$= (0.43)(998\ kg/m^3)(\overset{418.667\ rad/s}{\cancel{4000}})^2(.02064)^4$$

$\boxed{F_T = 13.652 N}$ For one propeller

A.2.2 – Thrust Force (z-direction)



Thrust Force (z-Direction)

~ 4000 RPM

66.67 RPS $\left(418.667 \frac{rad}{s}\right)$

$D = 0.0635 m$

$$J = \frac{(0.72 \, m/s)}{(418.667)(0.0635 m)} = \frac{0.72}{26.59} = 0.027$$

· Approx from pg 559 . graph 10.40c

$C_F = 0.45$

$$F_T = (0.45)(998)(418.667)^2(0.0204)^4$$

$$\boxed{= 14.29 N}$$

A.2.3 – Drive Shaft Calculations

$$d = \frac{F\lambda}{AE} => \frac{1}{8} = \frac{F\cdot 1.5}{\left(p\left(\frac{1}{8}\right)^{2}\right)\cdot\left(15.0\times10^{6}\right)} \qquad \text{(Maximum Deflection)}$$

$$F = \frac{\left(p\left(\frac{1}{8}\right)^{2}\right)\cdot\left(15.0\times10^{6}\right)}{8\cdot 1.5} = 62{,}995 lbs \qquad \text{(Maximum Force)}$$

$$s = \frac{F}{A} = \frac{6.3\times10^{4}}{\left(p\left({}^{1}\!/_{8}\right)^{2}\right)} = 1.28\times10^{6}\left({}^{lbs}\!/_{in^{2}}\right) = 1.28\times10^{6}\, psi \qquad \text{(Stress at deflection)}$$

$$e = \frac{s}{E} = \frac{1.283\times10^{6}}{15\times10^{6}} = 0.0855 \qquad \text{(Strain at deflection)}$$

$$S = \frac{s}{e} = \frac{1.283\times10^{6}}{0.0855} = 40{,}000 psi \qquad \text{(Maximum Strength)}$$

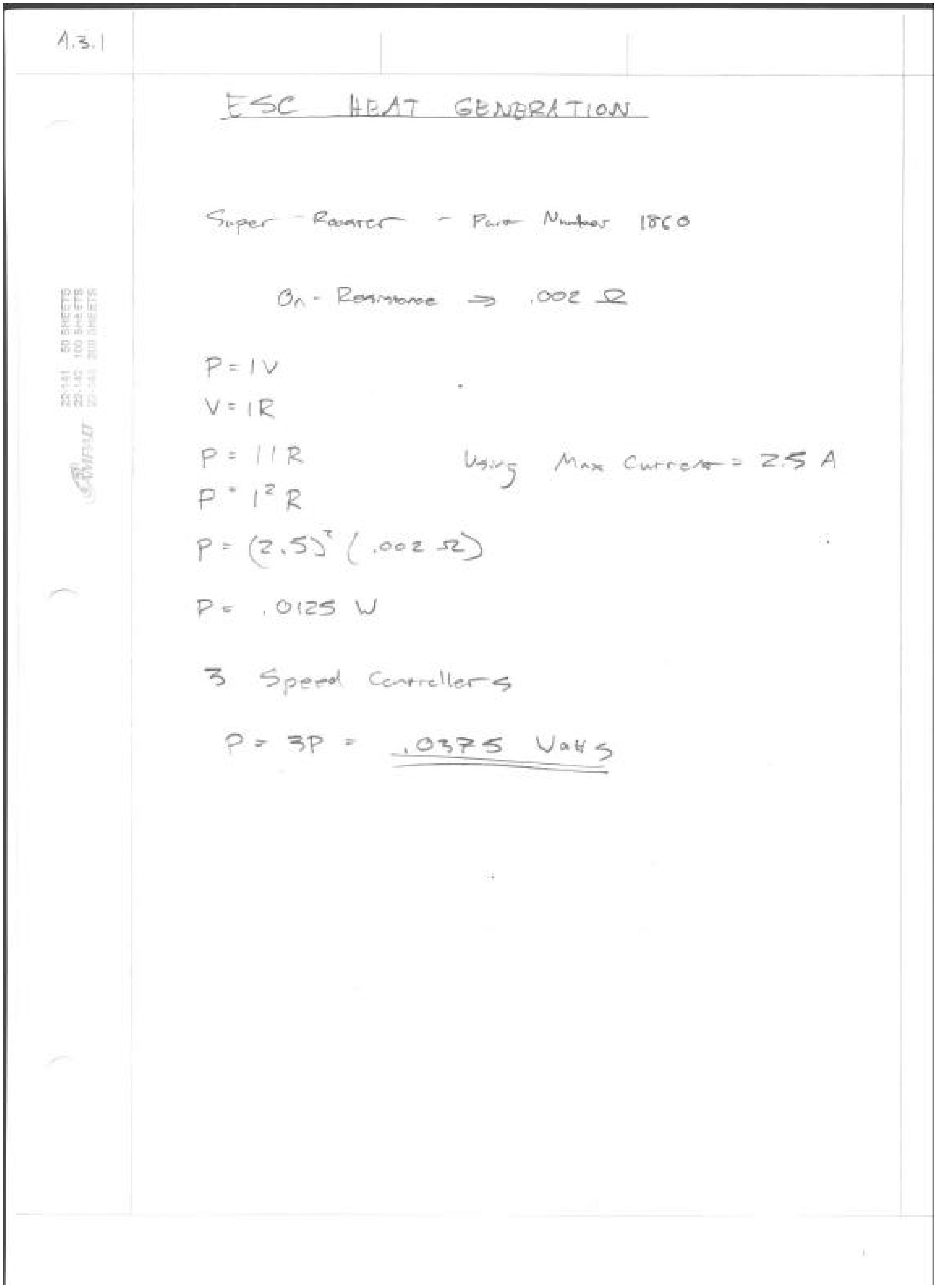
$$\frac{s}{S} = e_{\max} = \frac{1.283\times10^{6}\, psi}{40{,}000 psi} = 32.075 \qquad \text{(Maximum Strain)}$$

$$s_{out} = \frac{S\cdot s}{E} = \frac{(40000 psi)\left(1.283\times10^{6}\right)}{15\times10^{6}} = 3{,}421 psi \qquad \text{(Maximum Stress)}$$

$$P = s \cdot A = (3{,}421 psi)\left(p\left({}^{1}\!/_{8}\right)^{2}\right) = 167.98 lbs \qquad \text{(Maximum Pressure)}$$

A.3 – Controls

A.3.1 – ESC Heat Generation



A.3.1

ESC HEAT GENERATION

Super Rooster – Part Number 1860

On - Resistance ⇒ .002 Ω

$P = IV$

$V = IR$

$P = IIR$ Using Max Current = 2.5 A

$P = I^2R$

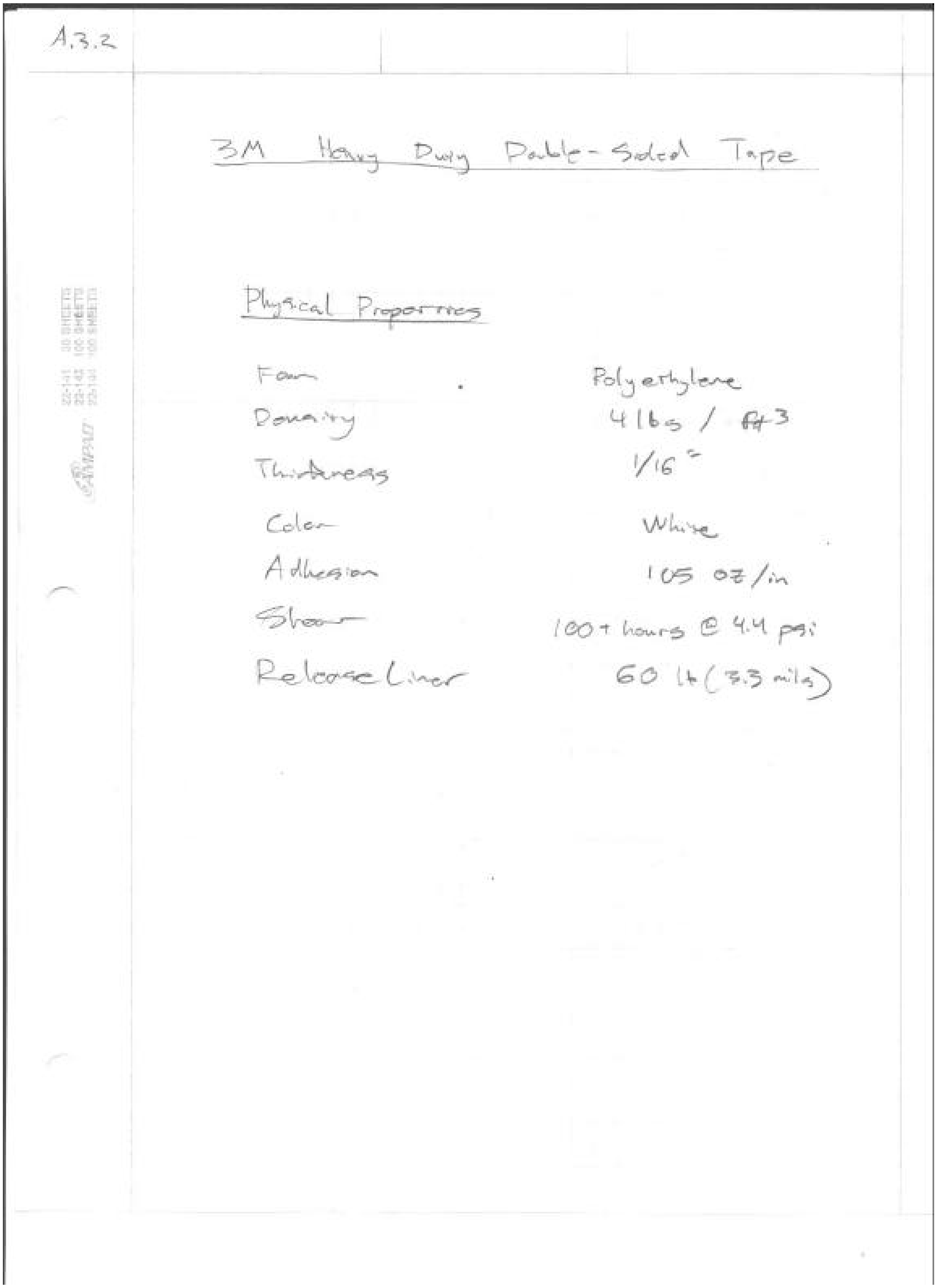
$P = (2.5)^2(.002\ \Omega)$

$P = .0125$ W

3 Speed Controllers

$P = 3P = $ .0375 Watts

A.3.2 – Heavy Duty Double-Sided Tape



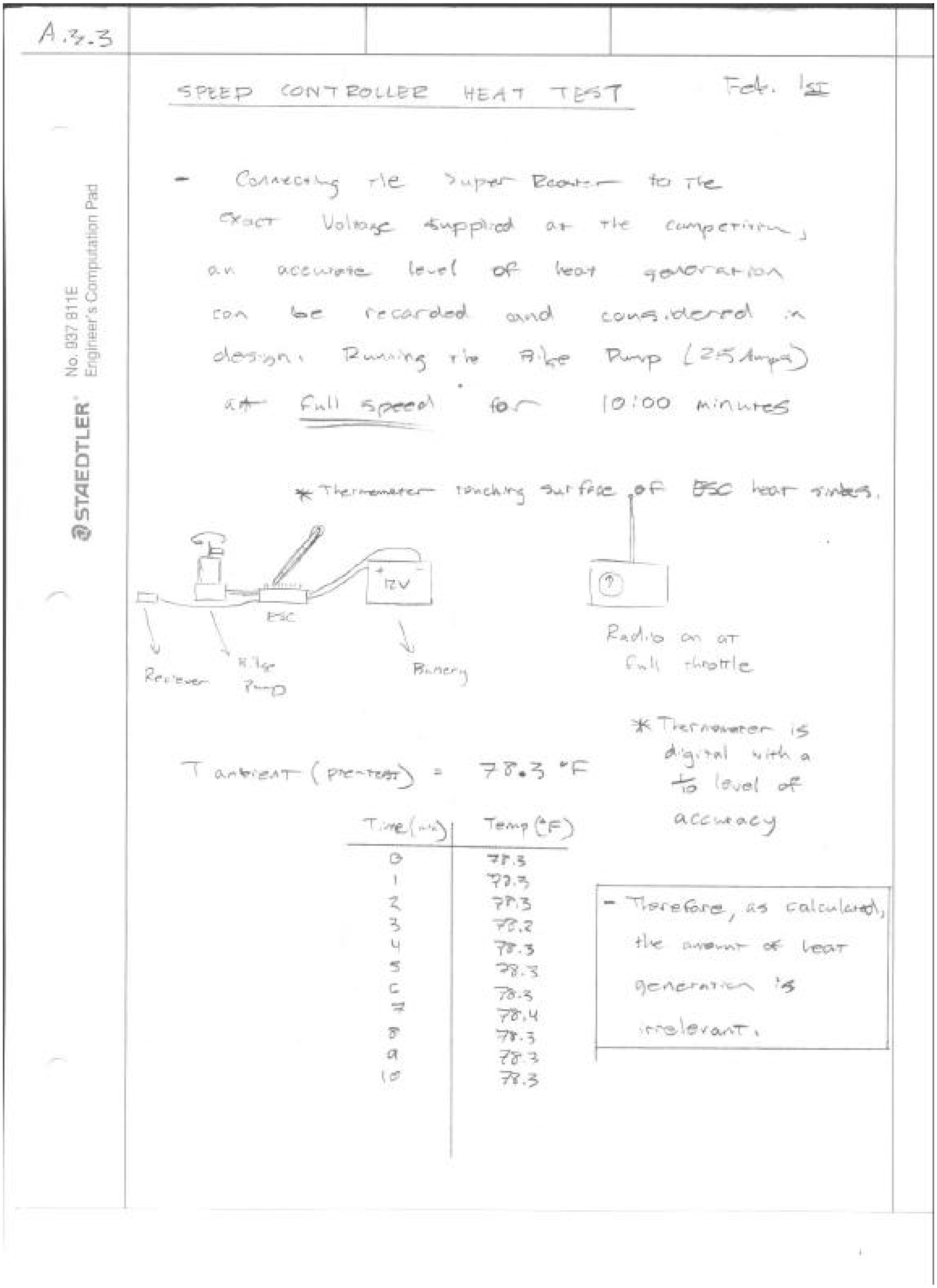
A.3.2

3M Heavy Duty Double-Sided Tape

Physical Properties

Foam	Polyethylene
Density	4 lbs / ft^3
Thickness	1/16"
Color	White
Adhesion	105 oz/in
Shear	100+ hours @ 4.4 psi
Release Liner	60 lb (3.3 mils)

A.3.3 – Heavy Duty Double-Sided Tape



A.3.3

SPEED CONTROLLER HEAT TEST Feb. 1st

- Connecting the Super Booster to the exact Voltage supplied at the competition, an accurate level of heat generation can be recorded and considered in design. Running the Bilge Pump (2.5 Amps) at full speed for 10:00 minutes

* Thermometer touching surface of ESC heat sinks.

Reciever
Bilge Pump
ESC
12V
Battery

Radio on at full throttle

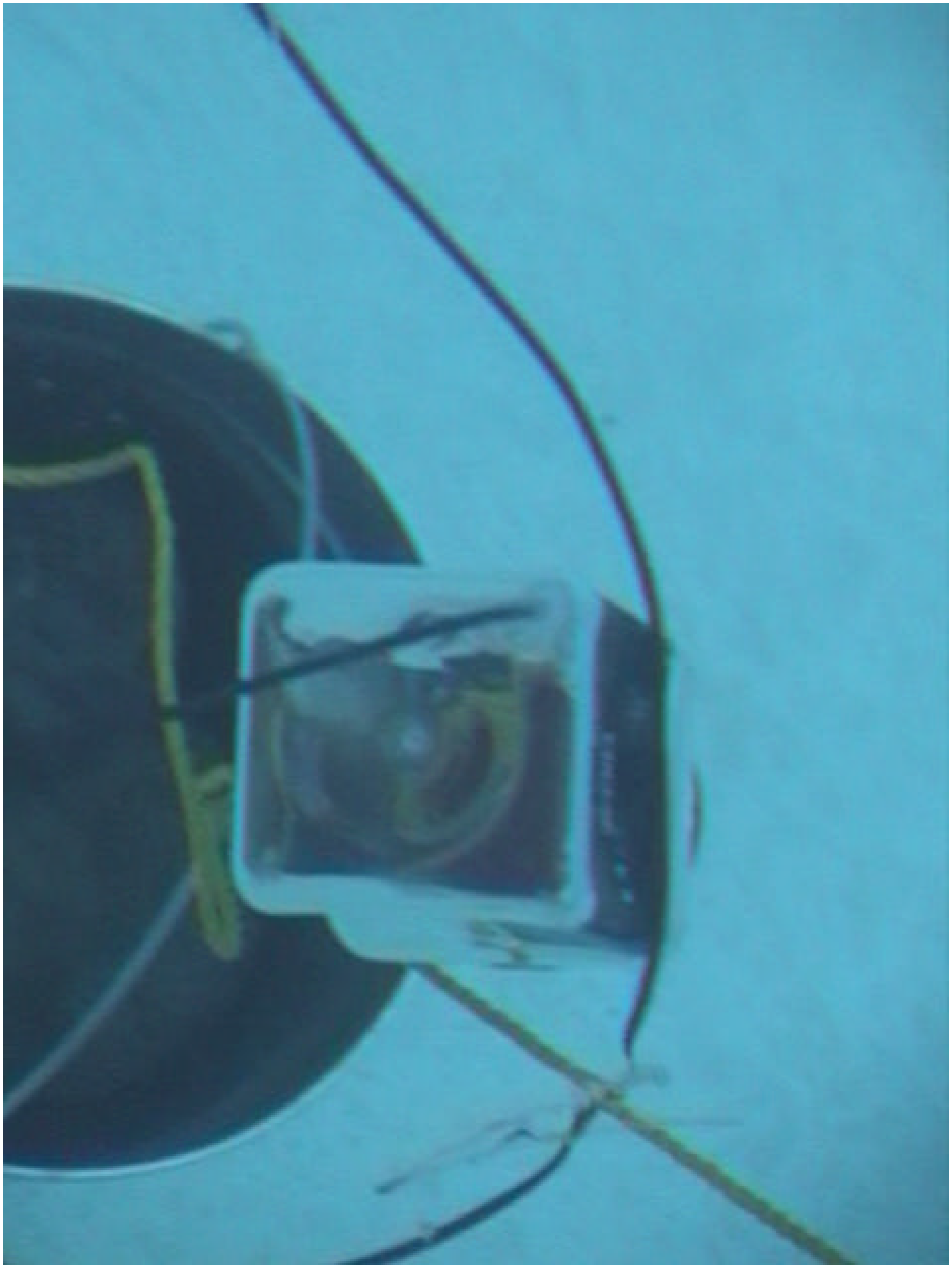
* Thermometer is digital with a $\frac{1}{10}$ level of accuracy

T ambient (pre-test) = 78.3 °F

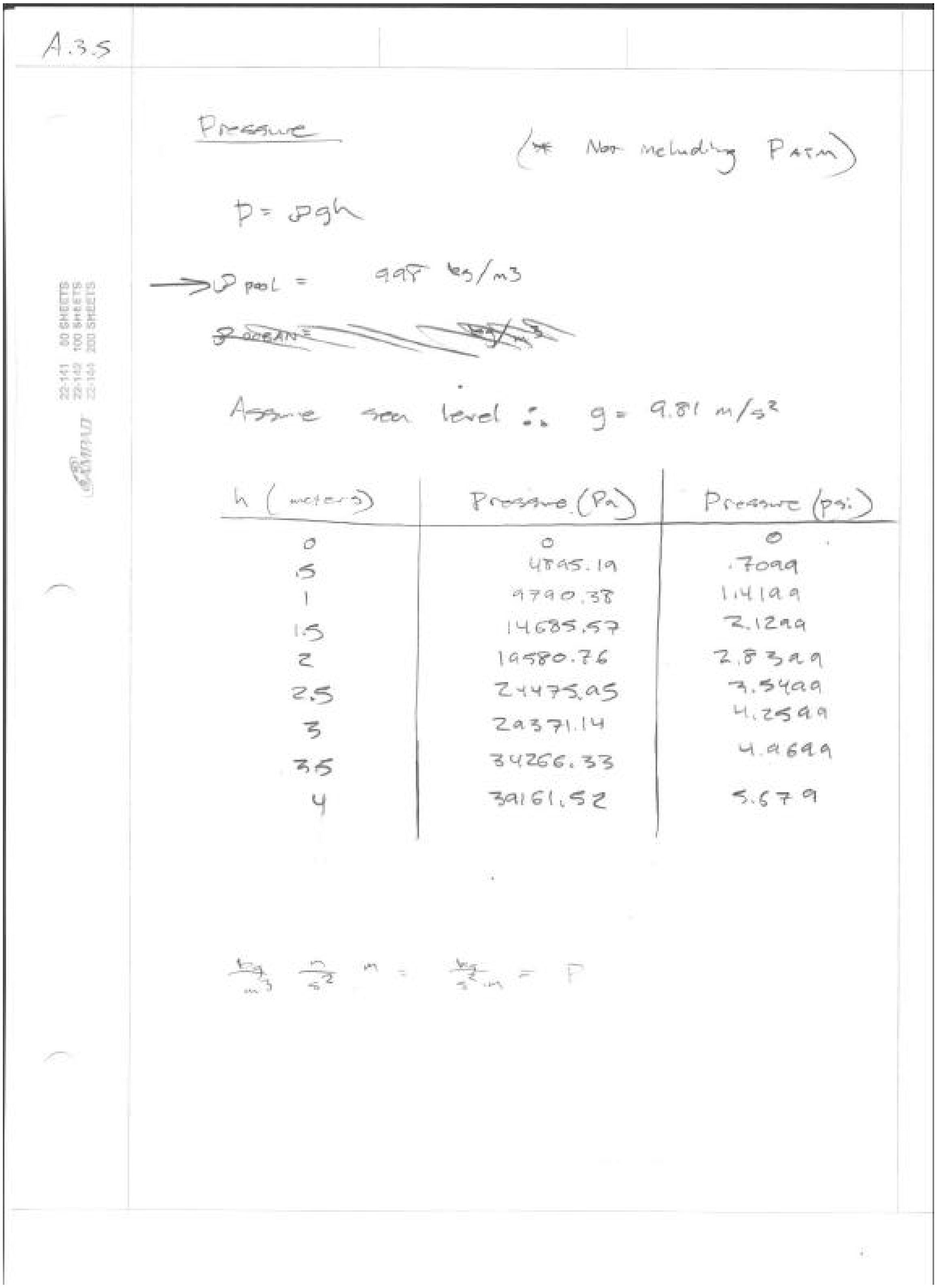
Time (min)	Temp (°F)
0	78.3
1	78.3
2	78.3
3	78.2
4	78.3
5	78.3
6	78.3
7	78.4
8	78.3
9	78.3
10	78.3

- Therefore, as calculated, the amount of heat generation is irrelevant.

A.3.4 – Underwater Picture



A.3.5 – Pressure



A.3.5

Pressure

(* Not including PATM)

$P = \rho g h$

→ ρ pool = 998 kg/m3

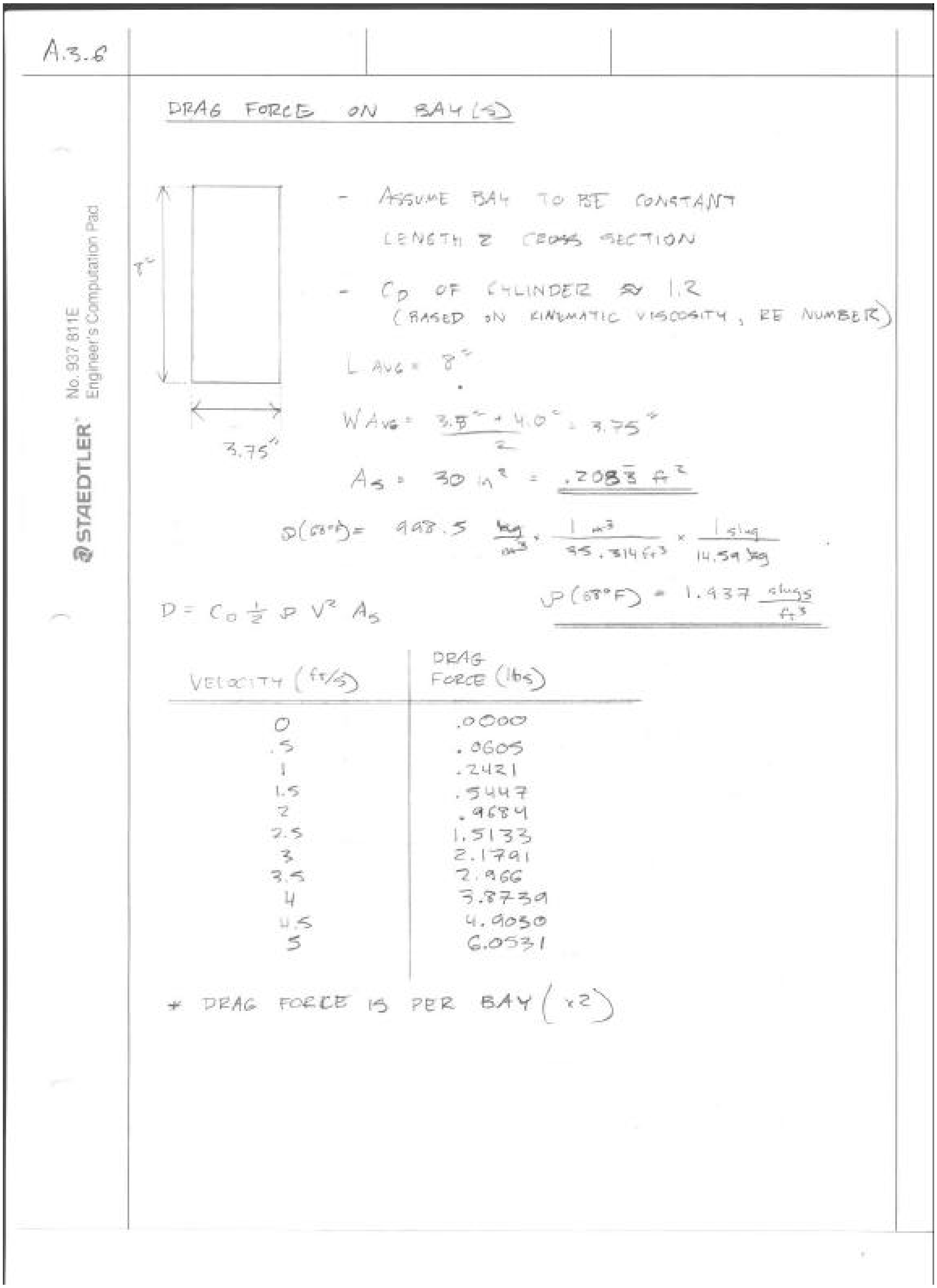
~~ρ ocean =~~

Assume sea level ∴ $g = 9.81\ m/s^2$

h (meters)	Pressure (Pa)	Pressure (psi)
0	0	0
.5	4895.19	.7099
1	9790.38	1.4199
1.5	14685.57	2.1299
2	19580.76	2.8399
2.5	24475.95	3.5499
3	29371.14	4.2599
3.5	34266.33	4.9699
4	39161.52	5.679

$\frac{kg}{m^3} \frac{m}{s^2} m = \frac{kg}{s^2 \cdot m} = P$

A.3.6 – Drag Force



A.3.6

DRAG FORCE ON BAY(S)

- ASSUME BAY TO BE CONSTANT LENGTH & CROSS SECTION
- C_D OF CYLINDER ≈ 1.2 (BASED ON KINEMATIC VISCOSITY, RE NUMBER)

8"

3.75"

$L_{AVG} = 8"$

$W_{AVG} = \frac{3.5" + 4.0"}{2} = 3.75"$

$A_S = 30\ in^2 = \underline{.208\bar{3}\ ft^2}$

$\rho(68°F) = 998.5\ \frac{kg}{m^3} \times \frac{1\ m^3}{35.314\ ft^3} \times \frac{1\ slug}{14.59\ kg}$

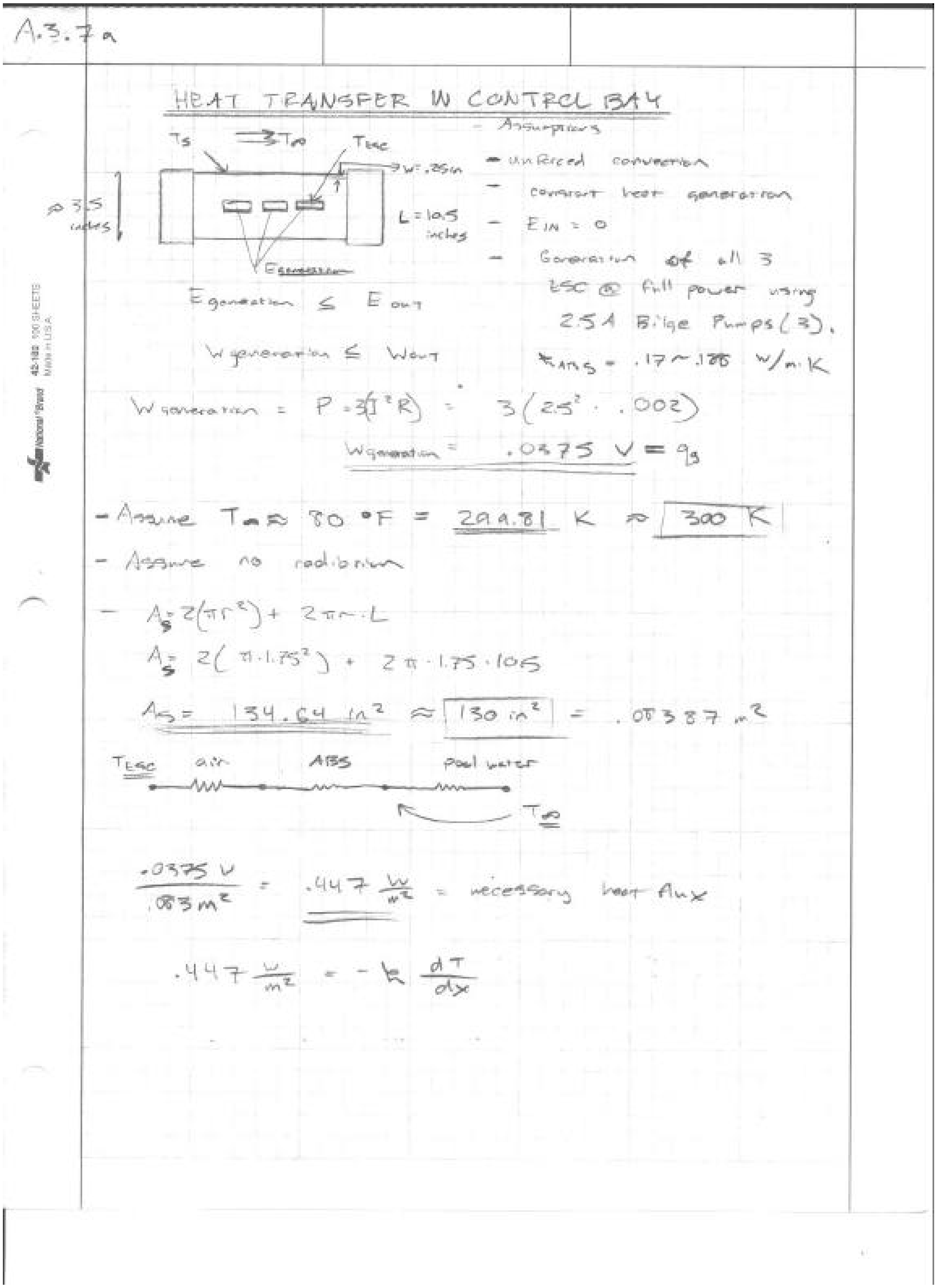
$D = C_D \frac{1}{2} \rho V^2 A_S$

$\rho(68°F) = 1.937\ \frac{slugs}{ft^3}$

VELOCITY (ft/s)	DRAG FORCE (lbs)
0	.0000
.5	.0605
1	.2421
1.5	.5447
2	.9684
2.5	1.5133
3	2.1791
3.5	2.966
4	3.8739
4.5	4.9030
5	6.0531

* DRAG FORCE IS PER BAY (x2)

A.3.7a – Heat Transfer in Control Bay



A.3.7a

HEAT TRANSFER IN CONTROL BAY

- Assumptions
- unforced convection
- constant heat generation
- $E_{IN} = 0$
- Generation of all 3 ESC @ full power using 2.5A Bilge Pumps (3).

$k_{ABS} = .17 \sim .185$ W/m·K

$E_{generation} \le E_{out}$

$\dot W_{generation} \le \dot W_{out}$

$$\dot W_{generation} = P = 3(I^2 R) = 3(2.5^2 \cdot .002)$$

$$\underline{\underline{W_{generation} = .0375\ V}} = q_g$$

- Assume $T_\infty \approx 80$ °F = $\underline{299.81}$ K ≈ $\boxed{300\ K}$
- Assume no radiation
- $A_s = 2(\pi r^2) + 2\pi r \cdot L$

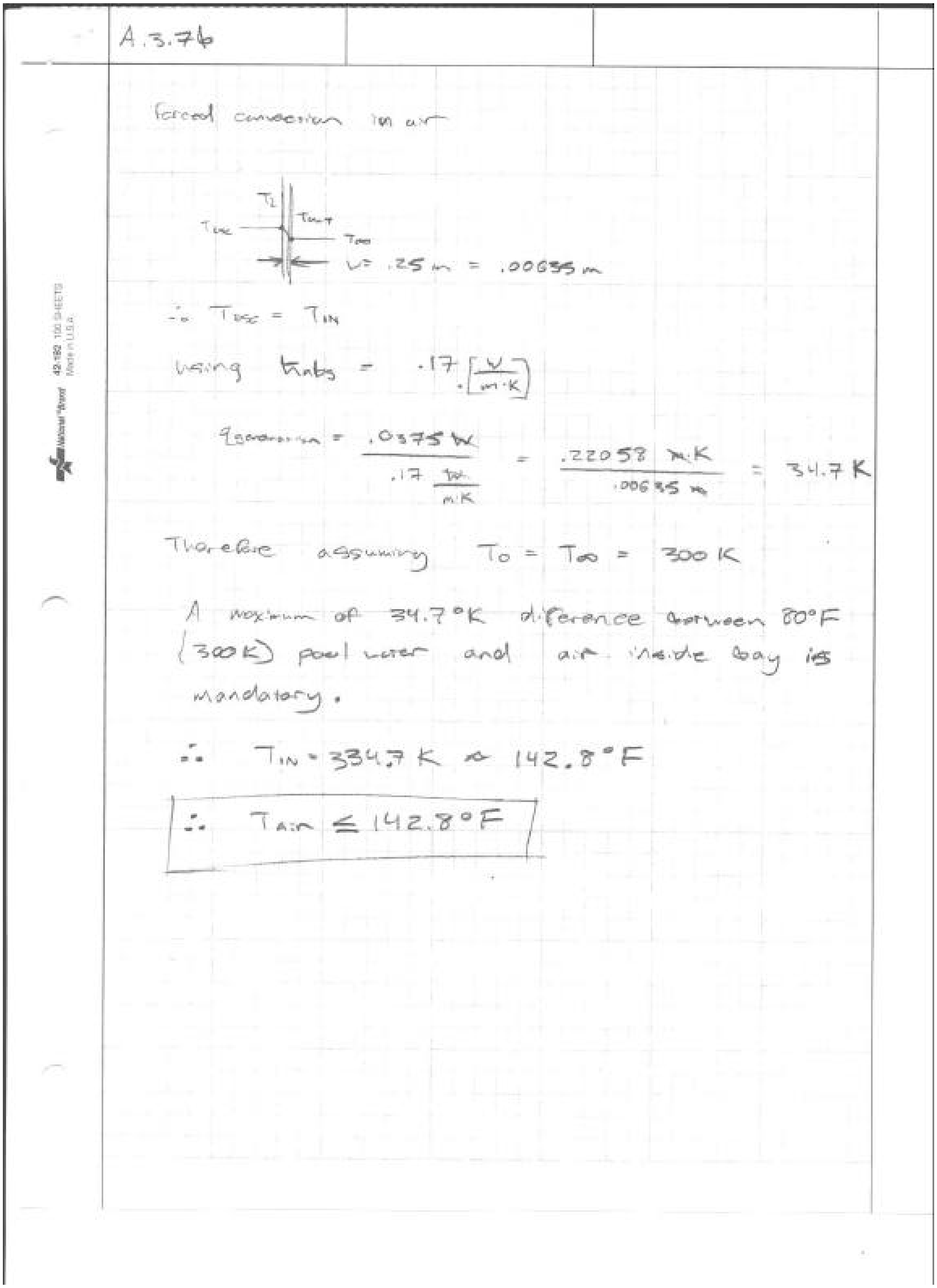
$A_s = 2(\pi \cdot 1.75^2) + 2\pi \cdot 1.75 \cdot 10.5$

$\underline{\underline{A_s = 134.64\ in^2}} \approx \boxed{130\ in^2} = .08387\ m^2$

$$\frac{.0375\ V}{.083\ m^2} = \underline{\underline{.447\ \frac{W}{m^2}}} = \text{necessary heat flux}$$

$$.447\ \frac{W}{m^2} = -k\frac{dT}{dx}$$

A.3.7b – Heat Transfer (Cont.)



A.3.7b

forced convection in air

$L = .25 \text{ in} = .00635 \text{ m}$

$\therefore T_{osc} = T_{IN}$

using $k_{abs} = .17 \left[\frac{W}{m \cdot K}\right]$

$$q_{conduction} = \frac{.0375 \, W}{.17 \, \frac{W}{m \cdot K}} = \frac{.22058 \; m \cdot K}{.00635 \; m} = 34.7 \, K$$

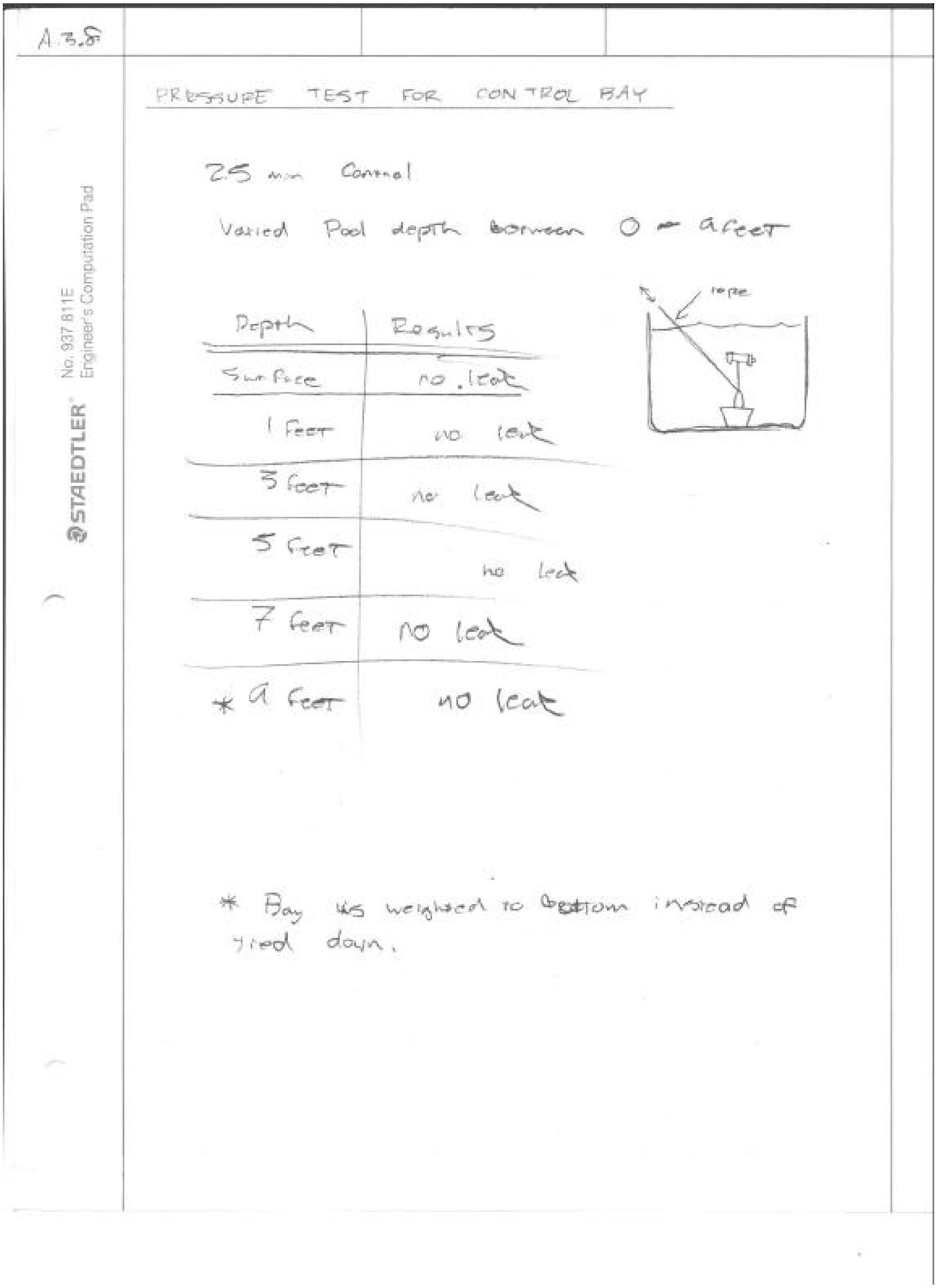
Therefore assuming $T_0 = T_\infty = 300 \, K$

A maximum of 34.7 °K difference between 80°F (300K) pool water and air inside bay is mandatory.

$\therefore \quad T_{IN} = 334.7 \, K \approx 142.8 °F$

$$\boxed{\therefore \quad T_{air} \leq 142.8 °F}$$

A.3.8 – Pressure Test for Control Bay



A.3.8

PRESSURE TEST FOR CONTROL BAY

25 min Control

Varied Pool depth between 0 - 9 feet

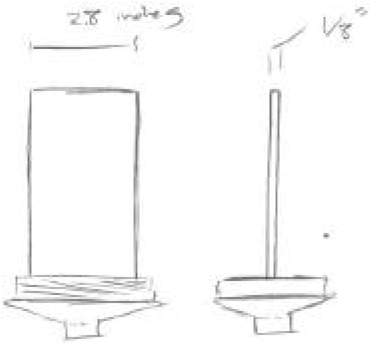
Depth	Results
Surface	no leak
1 feet	no leak
3 feet	no leak
5 feet	no leak
7 feet	no leak
* 9 feet	no leak

* Bay was weighted to bottom instead of tied down.

A.3.9 – Aluminum Stress Analysis

A.3.9

Aluminum Stress Analysis



Stress comes from friction on inside of Control Bay. If Plate catches, and an assumed applied torque of 50 lbs-in twists the plate....

Friction Force is negligible.

NO STRESS

A.3.10a – Buoyancy of Control Bay

A.3.10a

CONTROL BAY BOUVANCY FORCE

- Archimedes Principal

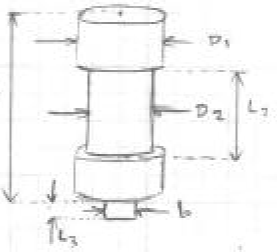
B = volume of fluid displaced.

VOLUME

$$V = \frac{\pi D_1^2}{4} L_1 - \left(\frac{\pi L_2}{4}\left(D_1^2 - D_2^2\right)\right) + L_3 b^2$$

$$= \frac{\pi \cdot 4^2}{4} 7 - \left(\frac{\pi \cdot 2.75}{4}\left(4^2 - 3.5^2\right)\right) + 1 \cdot \left(1\tfrac{5}{16}\right)^2 \quad 4$$

$$V \approx 82.31\ in^3 = \underline{\underline{.001347\ m^3}}$$



GRAVITY

$$g = \frac{G M_E}{(R_E + h)^2}$$

$G = 6.67E^{-11}\ N \cdot m^2/kg^2$

$M_E = 5.98E24\ kg$

$R_E = 6.37E6\ m$

$h_{TUCSON} = 2400'$

$h_{UCSB} = 0'$

$g_{UCSB} = 9.829\ m/s^2$

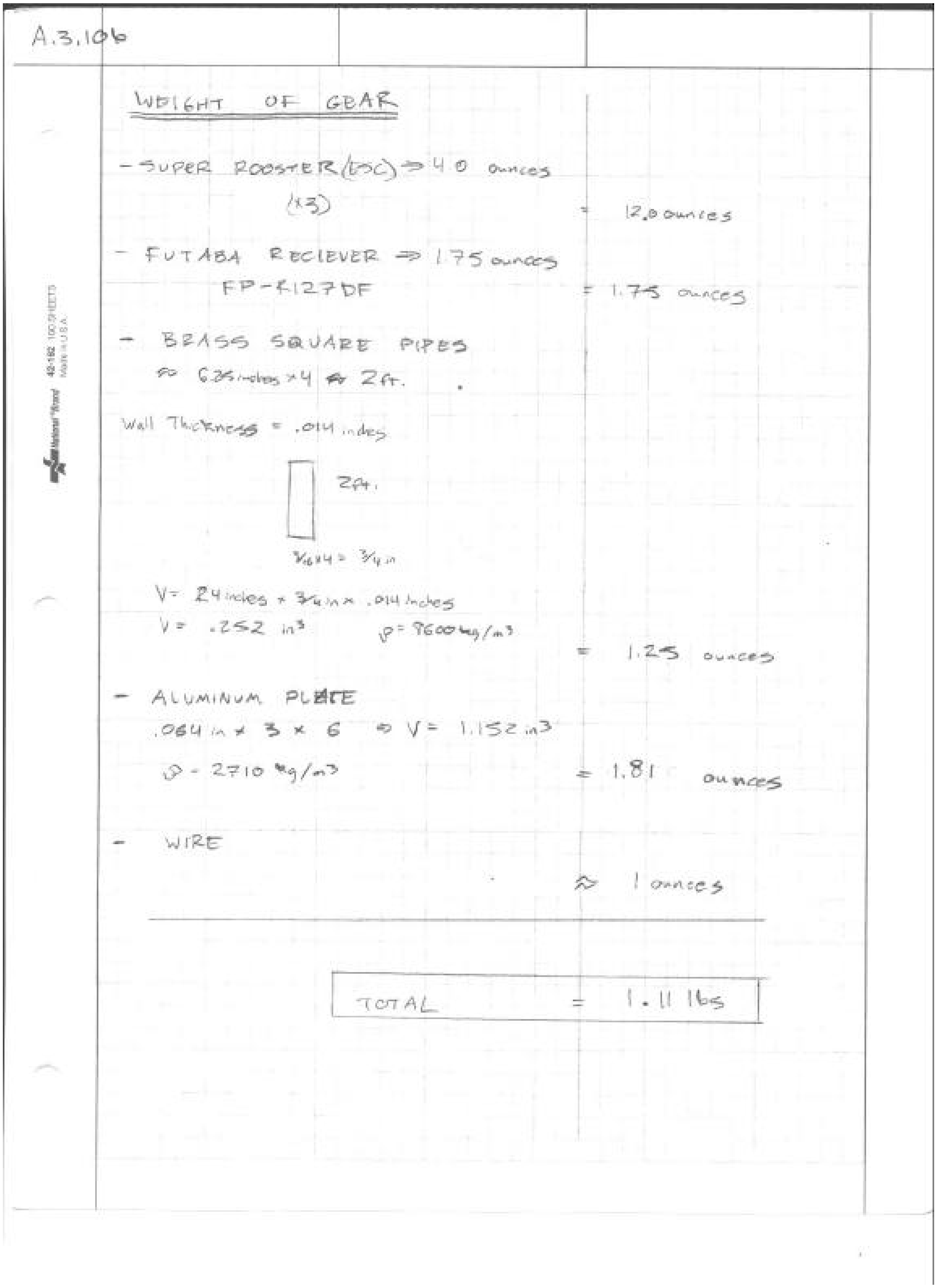
$g_{TUCSON} = 9.827\ m/s^2$

$\therefore\ \underline{g = 9.828\ m/s^2}$

ρ_{H_2O} @ $\underline{68°F}$; $v = 995.02\ \frac{m^3}{kg}$ $\quad \underline{\underline{\rho(68°F) = 998.5\ \frac{kg}{m^3}}}$

$$B = \rho g V = 13.2357\ N = \boxed{2.975\ lbs}$$

A.3.10b – Weight of Internals



A.3.10b

WEIGHT OF GEAR

- SUPER ROOSTER (ESC) ⇒ 4.0 ounces
(×3) = 12.0 ounces

- FUTABA RECIEVER ⇒ 1.75 ounces
FP-R127DF = 1.75 ounces

- BRASS SQUARE PIPES
≈ 6.25 inches ×4 ≈ 2ft.

Wall Thickness = .014 inches

2ft.

$3/16 \times 4 = 3/4$ in

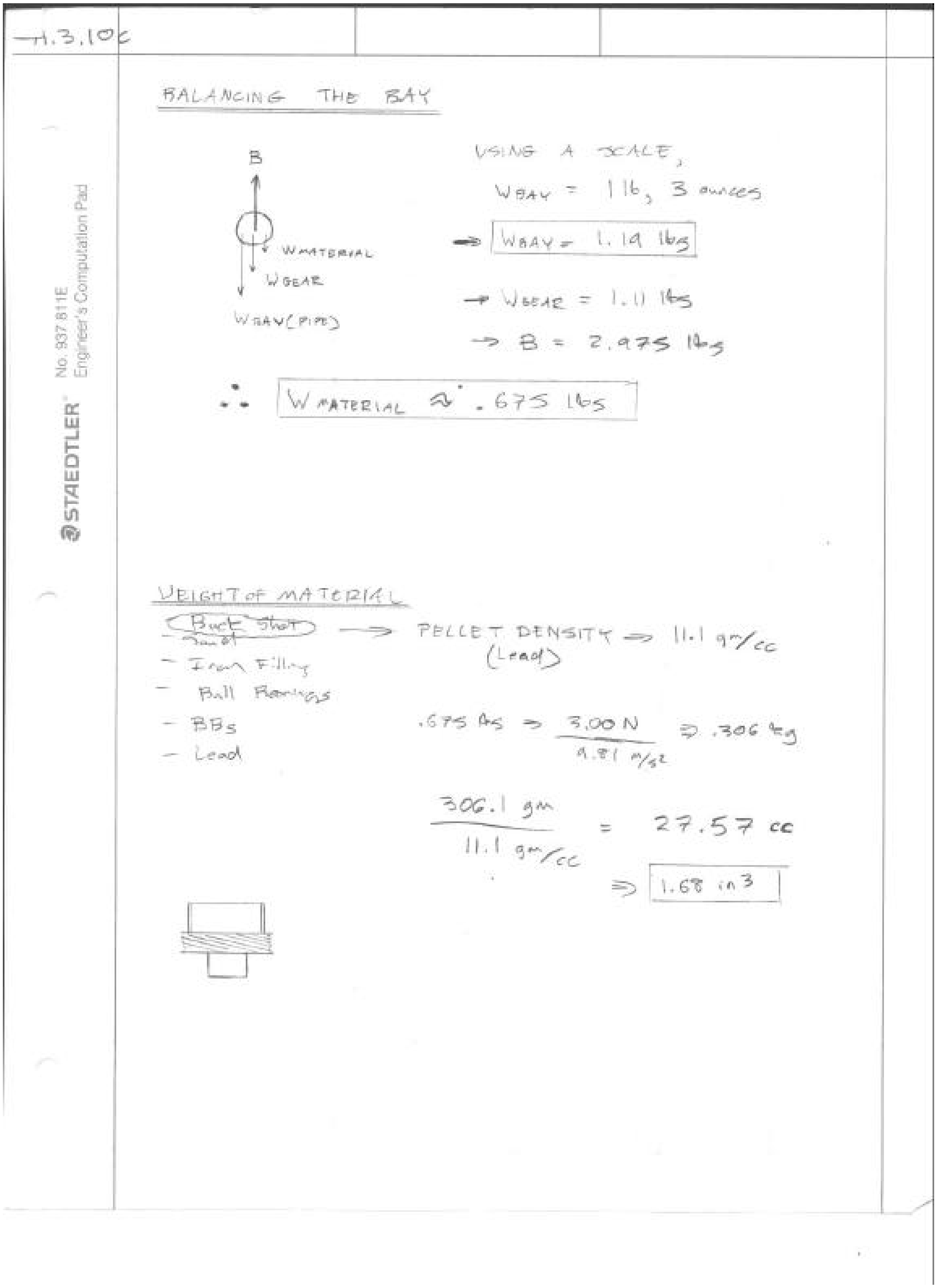
V = 24 inches × 3/4 in × .014 inches
V = .252 in³ ρ = 8600 kg/m³
= 1.25 ounces

- ALUMINUM PLATE
.064 in × 3 × 6 ⇒ V = 1.152 in³
ρ = 2710 kg/m³ = 1.81 ounces

- WIRE
≈ 1 ounces

TOTAL = 1.11 lbs

A.3.10c – Control Bay Calculations



A.3.10c

BALANCING THE BAY

USING A SCALE,

W_{BAY} = 1 lb, 3 ounces

⇒ $\boxed{W_{BAY} = 1.19 \text{ lbs}}$

→ W_{GEAR} = 1.11 lbs

→ B = 2.975 lbs

∴ $\boxed{W_{MATERIAL} \approx .675 \text{ lbs}}$

WEIGHT OF MATERIAL

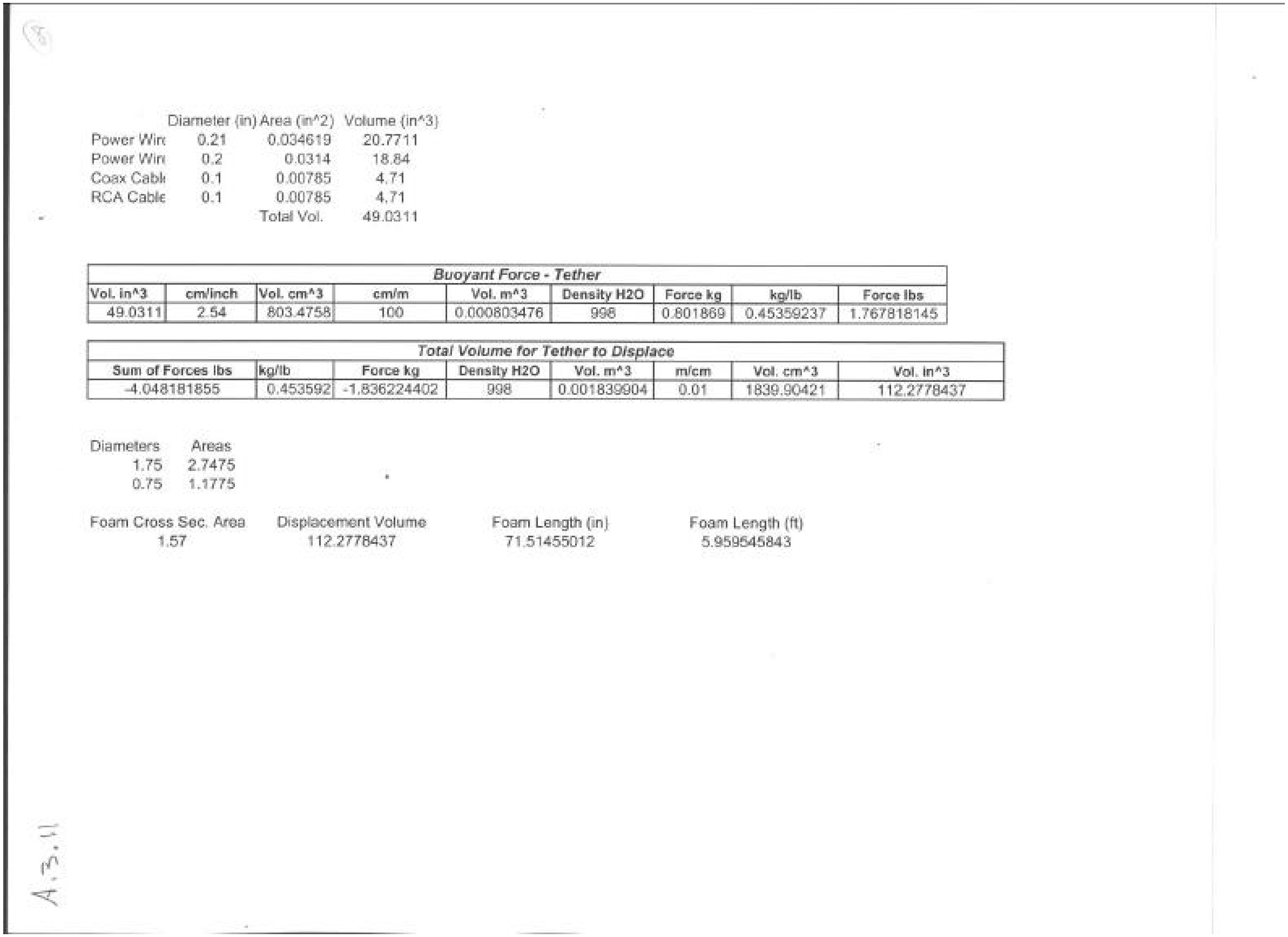
- Buck Shot ⟶ PELLET DENSITY (Lead) ⇒ 11.1 gm/cc
- Sand
- Iron Filling
- Ball Bearings
- BBs
- Lead

$.675 \text{ lbs} \Rightarrow \frac{3.00 \text{ N}}{9.81 \text{ m/s}^2} \Rightarrow .306 \text{ kg}$

$\frac{306.1 \text{ gm}}{11.1 \text{ gm/cc}} = 27.57 \text{ cc}$

⇒ $\boxed{1.68 \text{ in}^3}$

A.3.11 – Tether Calculations



A.3.11

	Diameter (in)	Area (in^2)	Volume (in^3)
Power Wir	0.21	0.034619	20.7711
Power Wir	0.2	0.0314	18.84
Coax Cabl	0.1	0.00785	4.71
RCA Cable	0.1	0.00785	4.71
		Total Vol.	49.0311

Buoyant Force - Tether								
Vol. in^3	cm/inch	Vol. cm^3	cm/m	Vol. m^3	Density H2O	Force kg	kg/lb	Force lbs
49.0311	2.54	803.4758	100	0.000803476	998	0.801869	0.45359237	1.767818145

Total Volume for Tether to Displace							
Sum of Forces lbs	kg/lb	Force kg	Density H2O	Vol. m^3	m/cm	Vol. cm^3	Vol. in^3
-4.048181855	0.453592	-1.836224402	998	0.001839904	0.01	1839.90421	112.2778437

Diameters	Areas
1.75	2.7475
0.75	1.1775

Foam Cross Sec. Area	Displacement Volume	Foam Length (in)	Foam Length (ft)
1.57	112.2778437	71.51455012	5.959545843

A.4 – Engineering Drawings

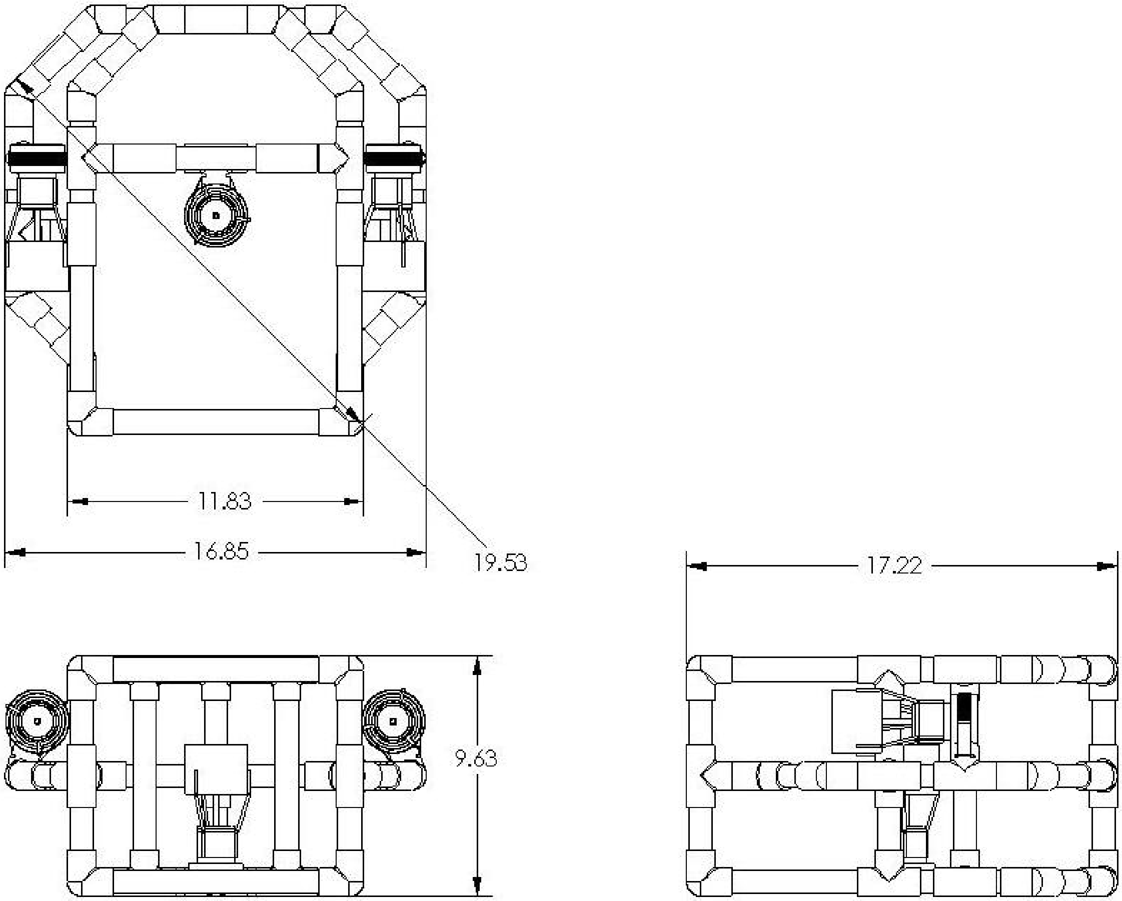


Figure A.4.1 – Drawing of Structure

This is the final drawing of the sub with the attached propulsion system displaying the location of each of the three motors. This drawing displays the greatest dimensions in the length, width, and height. It also shows the length diagonally, which also must be taken into account being that one of the requirements is to maneuver in a 60 cm cube. Through the process of the design and construction, we were able to create a structure that met the sizing requirements in all directions as shown in Figure A.4.1.

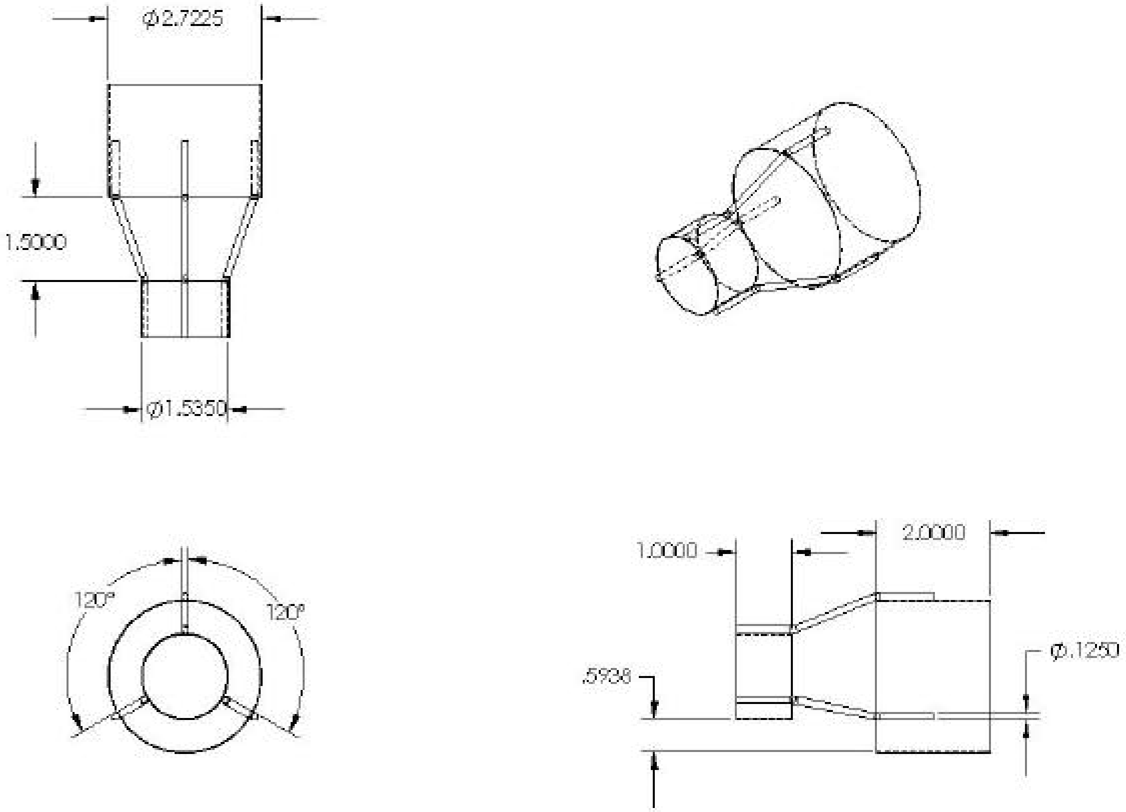


Figure A.4.2 – Drawing of the shroud

This drawing of the shroud shows the exact sizing and dimensions of each piece used in the assembly this part. Unfortunately we came up with this design after the drive-shaft and propellers were assembled to the bilge pump (motor). Therefore, we were forced to remove each drive shaft because the smallest diameter of the shroud assembly, being 1.535 inches, is much less than that of the propeller at 2.5 inches. Fortunately, started the assembly of the propulsion early, providing us plenty of time to correct our mistakes.

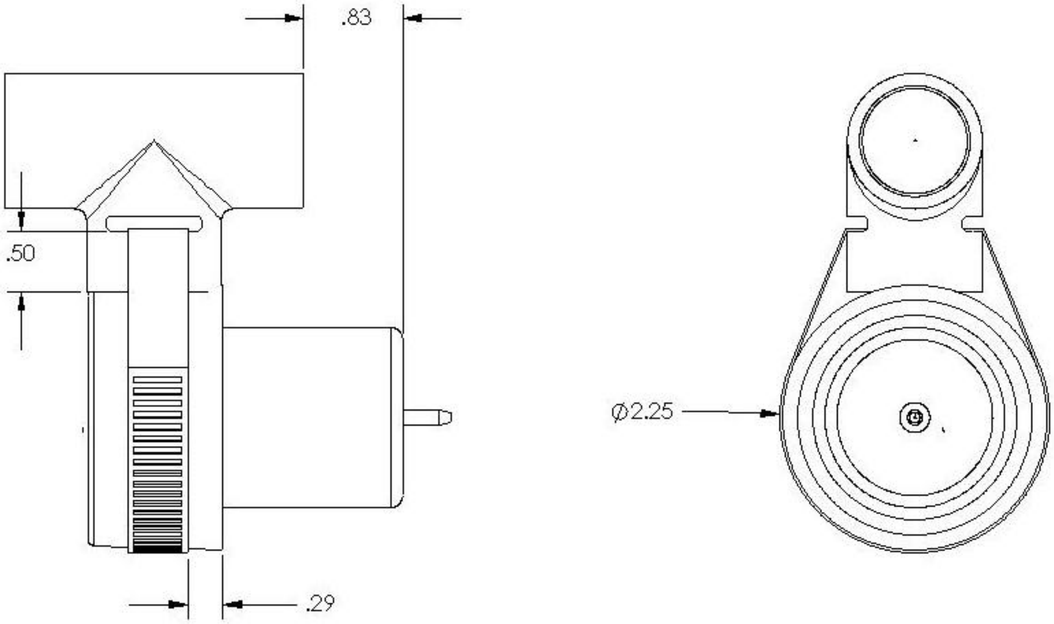


Figure A.4.3 – Drawing of Motor Attachment

One of the most challenging aspects of the project was the attachment of the motors. Being that the bilge pump is a cylinder, we were faced with a challenging task of attaching a cylinder to a cylindrical PVC pipe. Through the course of brainstorming, we decided to use a three way (T-shape) PVC connector and a hose clamp to attach the bilge pump as shown in Figure A.4.3. We found this to be a very stable solution providing us with the ability to easily adjust the placement of the motors and their orientation by moving the connector to a different location on the structure.

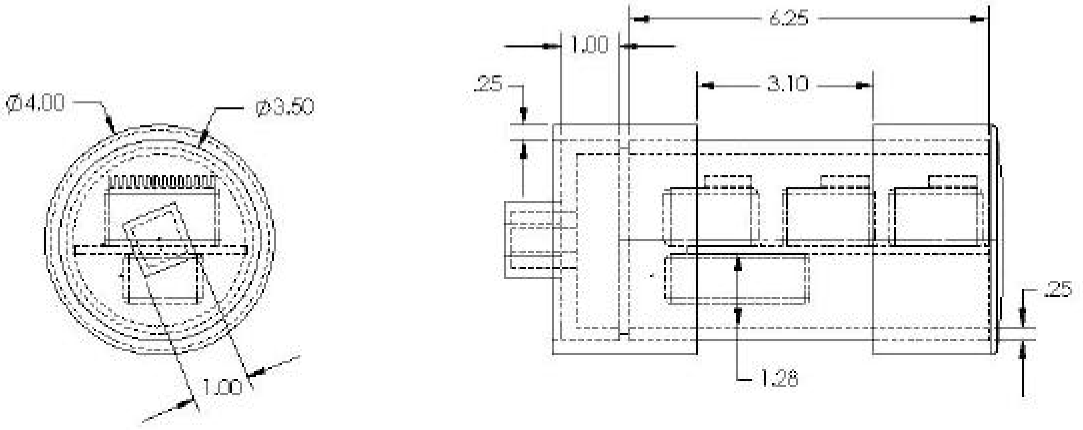


Figure A.4.4 – Drawing of Control Bay

The control bay shown in Figure A.4 was one of the most important aspects of the design. Being that the control bay would house all of the electronics for the sub, we needed to make sure that we could provide a dry climate within the bay. Through the process of design, another criterion was the organization of the electronics within the bay. By attaching all of the electronics to one aluminum plate we were able to orient our speed controllers and receiver to fit within the bay. We also used Figure A.4.4 to provide us with the appropriate values to calculate the buoyancy of the control bay.

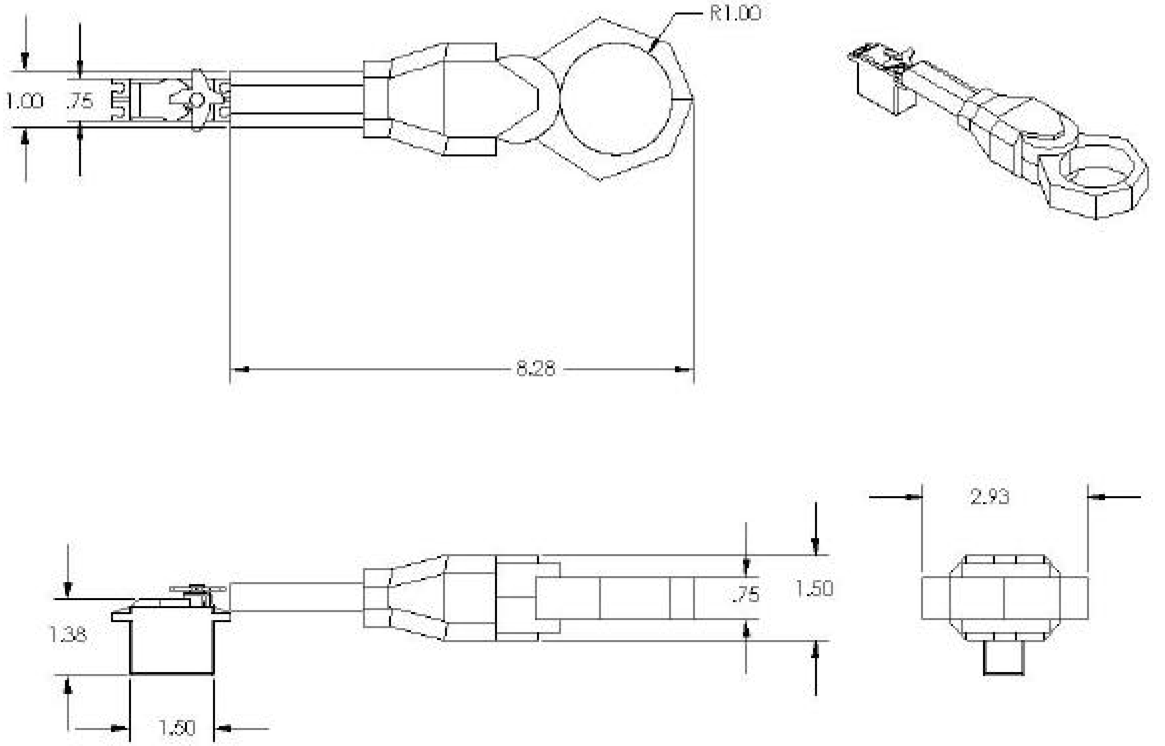


Figure A.4.5 – Drawing of Claw

Figure A.5 is a detailed drawing of the mechanical aspect of our retrieval system. With many ideas and a limited amount of time to work with, we were forced to be creative with our retrieval system. We found that we were able to accomplish most of the tasks of the competition with the use of one mechanical claw. Through the use of an avionic servo, attached to a toy claw, we were able to mechanically operate this device remotely.

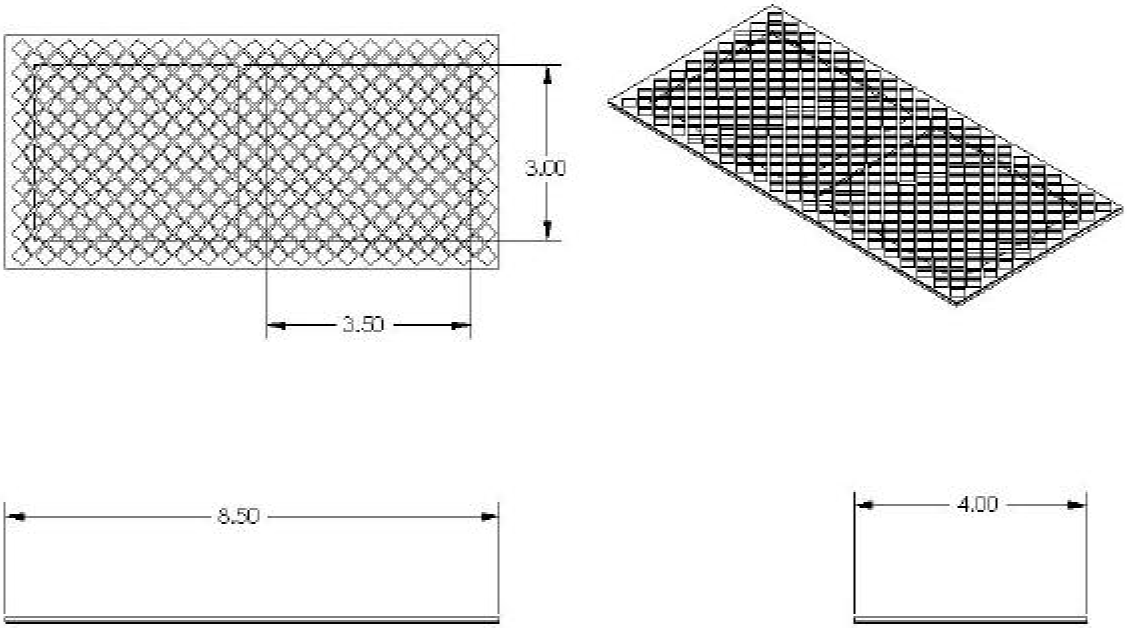
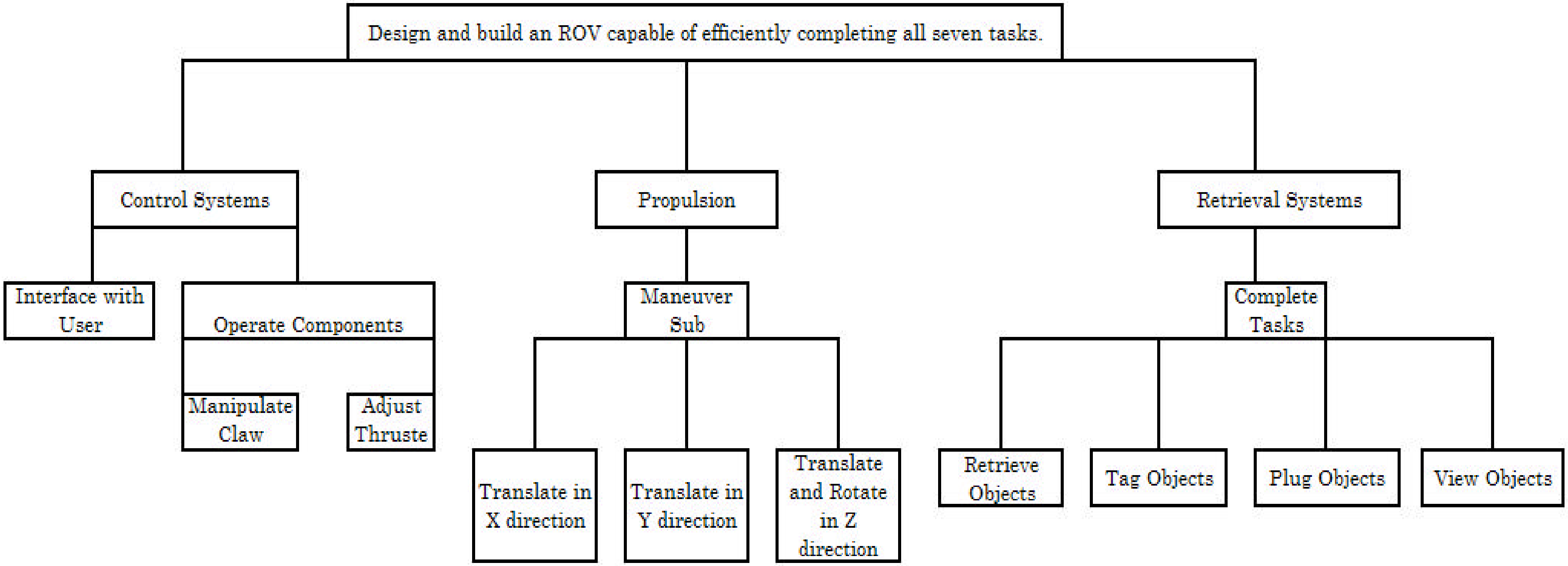


Figure A.4.6 – Drawing of Scoop

The drawing displays all dimensions of the scoop, which turned out to be one of the most challenging parts to machine. Attempting to cut two, identically shaped squares out of a solid piece of aluminum turned out to be extremely challenging with the rugged tools we had access to. With much patience, and plenty of precision, we were able to accurately cut out the squares using a Dremel Tool.

B.1 – Function Structure



B.2 – References

Tower Hobbies, "Great Plane Prop 1.5X1.5 Wildcat/Stinger", http://www2.towerhobbies.com/cgi-bin/wti0001p?&I=LXJ761&P=0.

Tower Hobbies, "Kyosho Propeller D35xP1.4 Vipers/Hydrojet/Streamliner", http://www2.towerhobbies.com/cgi-bin/wti0001p?&I=LXT033&P=0.

Novak Electronics Inc., "Quality Electronics for your Radio Control Car", http://www.teamnovak.com.