

Human Powered Submarine

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MEE 488

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1.0 Problem Definition

1.1 Overview

The Human Powered Submarine has been a part of the senior design program for the last six years. This project is lead by Professor Michael Peterson and was started because of a semiannual human powered submarine competition held by the San Diego chapter of the ASME. This project exposes young mechanical engineers to the troubleshooting/design situations that are commonplace in the field and prepares them for working in teams with strict deadlines and deliverables.

Although there have been many advances in the sub's design over the years, several areas still were in need of improvement. The main focus of the team this year was to upgrade the control systems and the linear actuators. The control systems, both manual and electronic, needed a complete overhaul. In a previous year's competition, there had been an electronic failure, and the team added the current manual controls at the last minute in order to complete the competition. More care would be needed in their design this time around. The electronic or "Fly-by-Wire" controls also were in need of an update. The electrical components were poorly assembled and occupied too much valuable space in the rear of the sub. In addition, issues with stability needed to be addressed if time permitted. Previous groups had formed bow planes but had not mounted them, so an effective mechanism for connecting the bow planes was needed. To test the effects of the bow planes, the sub would need to be pulled through the university's tow tank, so a towing connector at the front of the sub was also needed. Lastly, a few issue with safety needed to be corrected in order to be in compliance with the rules of the competition. The two main safety issues were the broken lower window and the safety bouy.

1.2 Fly-by-Wire

One of the biggest problems facing the design team this year was the Fly-by-Wire control system. This is intended to be the primary mechanism for steering the sub, so it is critical that it works correctly.

The control systems of the previous years had a few technical problems. Though the control system was comprised of an analog joystick, the programming made it so that it was only read as digital. This made the steering turn in steps which caused the rotation of the servos to be somewhat jerky.

By making the program fully analog, small fluctuations in the joystick will result in small fluctuations in the servos. This can help when making slight turns. Instead of having the servos turn at discrete intervals, the servos position controlled by an analog stick would be smooth and continuous.

A new problem arises in changing the controls of the submarine to true analog; the microcontroller (BASIC® Stamp, by Parallax Inc) used to interpret joystick inputs and send signals to the servos does not directly read analog inputs. The BASIC® Stamp will accept inputs of a certain magnitude but not varying magnitude. This problem will need to be addressed with additional hardware

The previous year's team also had spatial issues in the rear of the submarine. The microcontroller for controlling the servos was placed in a box that occupied most of the room in the rear of the sub. This left very little room for manual controls and various hookups. This was because the box that housed the microcontroller also contained the servos. The carrier board was also much larger than it needed to be, so it took up much of the space in the box, making the box even larger. Since this box was made from aluminum, it added significant weight to the back end of the sub, worsening an already poor weight distribution.

The new design would solve these problems by being small enough to eliminate the need for the large aluminum box that housed the electrical components and servos. Also, the new design would eliminate the long and cumbersome program that was used to control the sub with a simpler, more elegant one. Lastly, the program and hardware in combination would allow for fully analog control of the control surfaces.

1.3 Linear Actuators

The human powered submarine's linear actuators are an essential mechanical component to make the submarine a competitor in the competition and for perhaps achieving a possible world record. The linear actuators are the components that convert the electronic signals from the joystick (steering input) into the mechanical movement of the control surfaces. This control system consists of a servomotor and various linkages to the control surfaces. The design of such a system converting an electrical signal to mechanical motion would be a relatively elementary engineering problem. However, designing such a system to be entirely submersible and to operate in tight space constraints has proved to be a much more difficult feat, and as such was the primary downfall of the submarine in previous competitions.

The initial design consisted of a single, waterproofed aluminum box located in the rear of the submarine that housed all of the servomotors involved in controlling the submarine. This design turned out catastrophic to the sub, because when the waterproofing of the single box failed, the entire sub was immobile. The control surfaces protruded through the walls and connected directly in line with the shaft of each servo without the use of control arms, gears, or any form of linkage. In addition to the box waterproofing, the servomotors were filled with grease in order to act as a second line of defense against water entry. However, instead of providing water protection, as water entered through the failed waterproofing of the box, the grease

became highly viscous and caused the servos to move at different speeds than they were originally programmed to, making steering impossible.

The new design targets the problem areas of the old design. Two systems were developed, electronic controls and a backup manual system. First, the new electronic control system includes individual waterproofed boxes to house the servos controlling each control surface. Therefore, if the waterproofing on one box fails, three other control surfaces should still be functional. Another feature of the new design is adding control arms to the shafts of the control surfaces that attach to the servomotors by means of a push rod. This allows for greater leverage for the servo over the control surface, resulting in more precise control and less strain on the servos. In the new design, the internals of the servos are not filled with grease because its viscosity is too dependent on temperature.

The second control system includes the manual hand controls. Unlike the electronic control system where each control surface functions independently, the manual controls link together the horizontal control surfaces as well as the vertical control surfaces. The horizontal control surfaces, which control the pitch of the submarine, are linked together by a bar and are controlled by a single control arm. The vertical control surfaces, which control roll, are a bit more complicated. In order for the submarine to roll, the two surfaces must move opposite of each other. For this to occur, a differential gearing system was designed linking the surfaces together allowing for both to be controlled through one control arm. Both the manual and electronic control systems were designed to be quickly interchangeable and fully removable, if necessary for any repairs or other maintenance.

1.4 Manual Control System

The manual control system was a large problem for the design team. The original

controls were thrown together when the electronic controls failed in a previous competition. For future competitions, however, this system must perform to the same specifications as the electronic control system, so in the event of an electronic failure, the pilot can rely on the manual controls to perform with the same level of certainty. The problems the sub team addressed this year were the poor placement of the handles, gloves being caught on exposed bolts, throttle cables not reaching their hook-up, and loose throttle cables.

Through in-water testing, the team found the original placement of the handles to be very awkward for the diver (Figure 1.4.1). In order for the diver to reach the handles, he would have to bend his elbows considerably making precise turns all but impossible. Another existing problem from last year was the exposed bolts that easily caught on the diver's gloves. The handles new design needed to minimize the rough surface area.



Figure 1.4.1 – Modified handle placement

In fixing the problem of awkward placement of the handles, a new problem arose when the throttle cables no longer reached to the back of the submarine. The links that were initially used with the new design of the handles were small 1-inch links, which were not long enough to make up the difference in the new position of the handles. As a result, moving the handles forward roughly three inches caused the throttle cables to be two

inches too short.

The last major issue with the manual controls was that the throttle cables had not been attached to the walls of the submarine, and the loose cables could potentially interfere with the driver's operation of the sub. A design had to be created that would hold the cables in place. Whatever material was used had to be water resistant and not allow the cables to slip.

1.5 Tow Cone

Since it takes considerable time for the necessary team members to achieve the required scuba certification, some testing of the sub would need to be done in the U.M. tow tank without an operator. In the fall, the group noticed that there was no way to attach a towing line to the sub so that it could be towed underwater with no one in it. This was significant, since the sub would have to be tested in a tow tank without an operator aboard.

The solution would be to design and fabricate a tow cone to be permanently attached to the front of the sub. The tow cone would have the added value of providing extra weight in the front of the sub. This would be helpful, since in previous competitions, the team found that the sub has a tendency to point up while traveling underwater.

1.6 Bow Planes

Last time the submarine was entered in competition, it had a tendency to nose up and head directly to the surface. The control surfaces at the rear would try to counter act this movement, but they simply were not enough. Most conventional submarines have two sets of control surfaces. They have bow planes in the front, and a rudder and trim planes in the back. In this configuration, the bow planes control the majority of the pitch control, while the trim planes provide an additional effort to reduce the stress on the

bow planes. This is similar to using trim tabs to take effort off the control surfaces of an airplane.

Since our sub has all of the control surfaces at the rear, we would not be able to follow the traditional set up. Instead, we would have the fully functional control surfaces at the rear of the sub. In front, we will install two small bow planes. They will be stationary control surfaces meant to counteract the rising nature of the sub. Using these bow planes, we should be able to allow the control surfaces to focus on piloting the sub rather than just keeping it level.

1.7 Window

At some point during competition, testing, or transportation, the sub sustained damage to the lower window. The Plexi-glass was shattered, so the entire window needed to be replaced. In order to do this we needed to remove the rest of the remaining old window. We were also responsible for creation of the new window to replace the old one.

1.8 Safety Buoy

One of the components of the submarine competition is the safety award, which is given to the group that demonstrates the greatest safety ability incorporated into their sub. The previous submarine team had a safety buoy in place, but the mechanism to make the buoy functional was broken. Also with regards to the rules and regulations of this year's submarine competition, we must paint the safety buoy a bright visible color, instead of its original blended color to the submarine. The safety line must also be replaced by something 1/16" thick and fluorescent in order for it to be plainly visible to safety divers. So with this in mind, a new and improved release mechanism must be created for the safety buoy, along with minor cosmetic alterations.

2.0 Concept Design

2.1 Overview

After the team determined the major flaws with the original design, it was time to address their resolution. At this point the team was divided into smaller groups to better focus on solving the issues at hand. One group focused on the Fly-by-Wire design. This involved constructing the circuitry, controller, and programming the microcontroller to accept joystick inputs and send servo outputs. A second group worked on the linear actuators. They were responsible for making the actuators water tight, finding a suitable mounting location, and integrating them smoothly with the manual controls. The third group focused on manual controls, bow planes, safety buoy, and various other repairs and loose ends.

2.2 Fly-by-Wire

The team was faced with several possible approaches in the design of the fly-by-wire control system. Three choices in particular were among those deemed most practical for our desired application. Option 1 was to upgrade the existing control system and attempt to diagnose errors in the wiring and programming. Option 2 was to employ the *Parallax Inc Board of Education (BOE)* carrier board used to load test programs onto the microcontroller and to become familiar with the programming language. The third option was to design our own version of the *Parallax Inc Board of Education* carrier board that would be more condensed, since it would not have features we did not need. We weighed these options against one another by using a decision matrix as shown in Table 2.2.1 below.

Table 2.2.1 Decision Matrix for Fly-by-Wire Control System

	Size	Difficulty	Time	Cost	Customization	Total
Update existing system	1	1	1	4	3	10
Adapt <i>BOE</i> for use	3	4	3	3	2	15
Design new carrier board	4	2	2	3	5	16

(Rating: 1-Very negative or unknown trait, to 5-Very positive trait)

From the above decision matrix, it was clear that designing a new carrier board would be the best option. Although it would be difficult and time-consuming relative to the other options, the benefits from its small size and the ability to customize it to exact specifications make it the clear winner. By choosing this route, the team would be able to add only the features that were needed, like analog controller interaction and four independent servo outputs, while avoiding having extra features that would be useless in our situation, AC power for instance.

One major drawback to choosing this design was, of course, the amount of electrical engineering that is involved. Since the team had limited training in this field, extensive research was needed before and during the design and construction of this board.

Once the design of the electronic hardware was determined, the team addressed the design of the joystick. After discussing several options, it was finally decided to go with a design similar to that of years past. This design consisted of an analog control stick salvaged from a PlayStation2 controller. These controllers are ideal for this use since they are relatively inexpensive, very easy to find, and have simple wiring.

2.3 Linear Actuators

The design of the linear actuators was originally based upon a rough sketch from the sub team the previous year. The sketch consisted of a push rod with one end attached as to create a moment on the control surface. The other end of the push rod was a rack gear that was meshed with a pinion gear from a servo. A push/pull wire system had already been installed to throttle-style grips in the submarine, so we wanted to use this system for the manual controls.

The first thing that was changed from this design was to integrate this manual control system. We wanted to use the original idea for the electronic controls, but also be able to change over to manual controls quickly if necessary. For this reason, we extended the lever on the control surface rods in both directions, with the push rod from the electronic actuators attached to one side and the push/pull wire from the manual controls attached to the other side (See Figure 2.3.1)

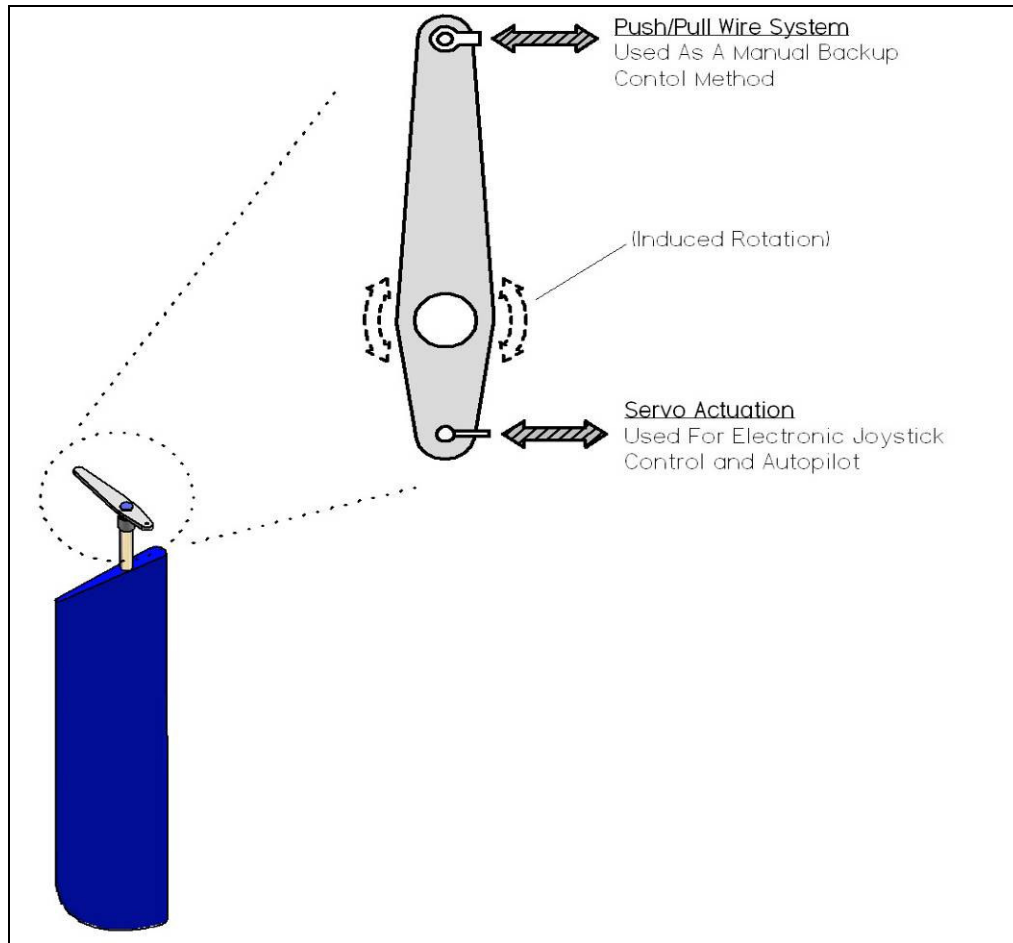


Figure 2.3.1 – Control arm

Next, we designed a way to waterproof the original design system. The servos were to be housed in individual waterproof boxes, machined out of a single piece of material with a acrylic lid (for viewing and easy troubleshooting) attached and sealed with an o-ring. Initially, a bellows design was used around the push rod (See Figure 2.3.2). This eliminated any motion across sealed surfaces, which had been a major problem in the past designs. Instead, each end of the bellows could be permanently sealed, and the expansion and contraction of the bellows would still allow movement of the control system. Using fork boots from a bicycle suspension system, a mock-up of the waterproofing system was fabricated for underwater testing.



Figure 2.3.2 – Box with initial bellows design

After testing the waterproofing mock-up, there were two main problems that needed to be addressed. First, epoxy was used as a sealant in all interfaces, but it proved to be too brittle. and when the rubber moved it cracked and let in water. To correct this, we changed the design to use gasket maker instead of epoxy, since the gasket maker was much more flexible. Similarly, gasket maker replaced the o-ring as the lid waterproofing component. The second problem was that when the push rod was in motion, the bellows movement created an internal change in volume. Since we had sealed up the fork boot's vent holes to waterproof them, the air inside was trying to compress and expand. This made it very hard to move the push rod. The first solution to this problem was to install a latex diaphragm surface on one of the other walls of the box, so the wall could expand or contract to account for the change in volume of the bellows – keeping the overall internal volume the same. This idea, however, was abandoned in exchange for a simpler approach. Finally, the fork boot bellows was replaced with surgical latex tube attached with gasket maker and hose clamps on either end (See Figure 2.3.3). This latex tube still allowed the axial motion of the push rod and had the same waterproofing qualities of the fork boot, but the tube itself was thin enough to be able to expand and contract radially, keeping the volume inside the box constant without introducing another mechanical component.

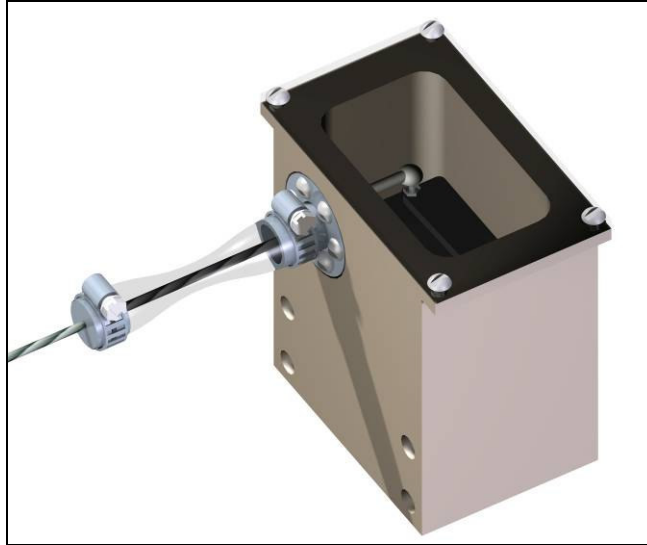


Figure 2.3.3 – Final box design

The manual controls were created anew, with no reference to last year's model. The initial design consisted of linking the two horizontal control surfaces together as well as the two vertical controls. The horizontal control surfaces were set to move in tandem in order to control pitch. The vertical control surfaces were set to move opposite one another in order for the sub to perform a controlled roll. The combination of these allows the sub to be controlled in a way similar to a fixed wing aircraft. The horizontal controls were linked with a basic clamp fixture, while the vertical surfaces were rigged with a gear and bracket assembly.

2.4 Manual Controls

The manual controls needed to be repositioned forward in the sub for ease of use for the diver. The initial plan was to simply move the position of the handles, but this resulted in the need to redesign the links attached to the handles. When the new longer links were tested, however, it was found that they did not offer the range of motion needed to operate the sub. After testing different options for correcting the problem, the best solution to this problem was found through attaching the throttle cables to the side of the sub close to the connectors as shown below in Figure 2.4.1.

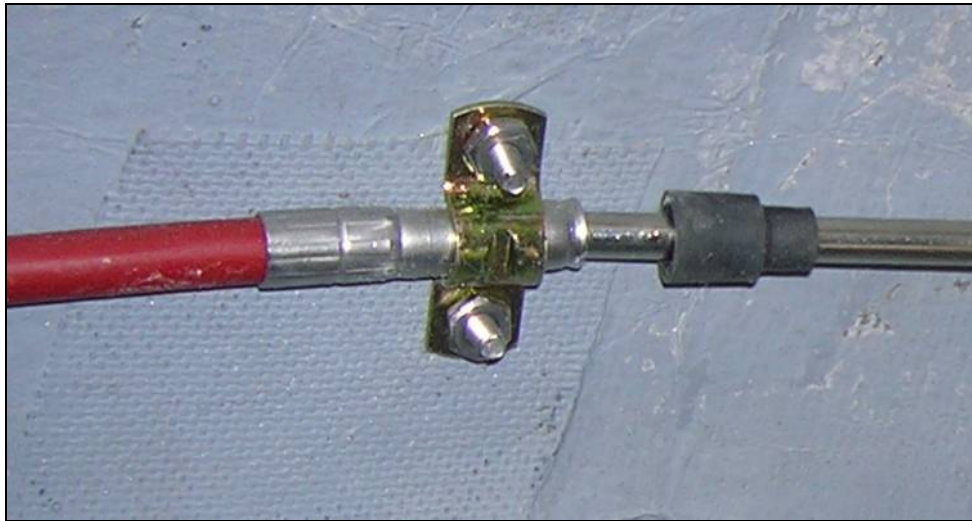


Figure 2.4.1 – Attachment of throttle cable

This proved to solve the problem of limited rotation of the controls. Another major area of concern was the old design of the handles, which allowed the diver's gloves to be snagged on the control surface. After the team had designed different alternatives to fixing the problem, the easiest and most efficient design was chosen. The bolts were countersunk into the handles providing a smooth surface.

2.5 Tow Cone

Three options were available for the material of the tow cone. The tow cone could be made out of rubber, plastic or metal. Silicone rubber does not have adequate mechanical properties to be used as a mechanical part. The rubber has an ultimate strength of 240 PSI, and it is also very soft (a shore hardness of 30A). This would mean that the tow cone would not last very long if it were made of this material. The rubber is also quite heavy, with a specific gravity of 1.34 g/cc, which means that it will sink when underwater.

Another option is urethane plastic. The plastic is impact resistant and very hard, with a Shore hardness of 70D. It is also resistant to moderate heat changes and moisture. The

ultimate tensile strength of the plastic is 3,000 psi. A tow cone constructed of plastic would have a specific gravity of 1.05 g/cm³, which means that it will sink when under water.

The last option would be metal. Metal is very hard and is extremely strong (ultimate tensile strength is usually around 60 MPA for steel and 40 MPA for Aluminum). The metal would have to be aluminum or stainless steel so the tow cone will not corrode. Metal, however, is too heavy. To compensate, the cone could be made smaller, but that would concentrate the forces of towing the sub in a smaller area, which could damage the nose of the sub. Metal is also harder to machine than plastic and/or rubber.

Of the options available, plastic was chosen for the material to be used. The name of the plastic that was used is Smooth-Cast 300. It came with mold making and casting starter kit from Smooth-On. The Silicone rubber also comes with the starter kit.

2.6 Bow Planes

The bow planes that were to be used on the submarine were already cast by a previous design group. Therefore, there was not much that we were able change with their design. We would, however, need to design a system for mounting the bow planes to the sub itself. Because it would have been too complicated for the sub pilot to control manually both the rear steering and the bow plane trim, a static mounting system was selected. With this system, the bow planes would stay in a fixed position that could be adjusted when the sub was not being operated. This fixed position is possible, because the bow planes are not meant for maneuvering. They are instead intended to counteract the tendency of the sub to nose up toward the surface.

Although the bow planes needed to be fixed, we did not want the mounting to be totally static, since the sub tends to level out once operational speed is attained.

Therefore, we wanted some sort of bushing that would allow for slight movement of the bow planes. This bushing would also have to be something that was removable, so that it could be adjusted or altered. Initial designs used a spring that would be welded to a mounting plate that would then be secured in position. This design was abandoned in favor of using a rubber bushing, such as surgical tubing, which would stand up well to corrosion and be easily replaced.

2.7 Window

The design of the previous window was sufficient as is, but was in need of repair. Upon group discussion, we decided to simply remove the existing window and replace it with a window of equal dimensions and strength.

2.8 Safety Buoy

The safety buoy used in years past was broken. The cable used to deploy it was severed and the release mechanism did not function smoothly. We decided to revamp the design of the safety buoy to make it easier to deploy by the driver of the submarine. To do this, a release mechanism would need to be created and placed in a location that allowed for easy access, but that would not accidentally be triggered through normal operation. The new design is based on the original with minor modifications to comply with safety regulations. This design will be discussed more in depth in the following section. We believe that the new design of the safety buoy will not only be in compliance with the safety regulations of the competition, but will also make the submarine safer for the operator as well.

3.0 Design Description & Construction

3.1 Fly-by-Wire

The layout of the Fly-by-Wire system has three major components; the joystick, the carrier board, and the waterproof box used to house the carrier board. The heart and soul of the Fly-by-Wire system is the carrier board that holds the microcontroller. This was customized to be as small as possible since room in the rear of the submarine was minimal. By studying previous year's attempts at creating a carrier board, it was noted that using smaller breadboards and optimizing the space used on them would be a good way to minimize the system size. By stacking 1¼" X 1¼" breadboards on top of each other, we achieved a small stack that would fit nicely in the rear of the sub.

Microcontroller Selection & Description

It was determined that the team would continue to use the same model microcontroller as many of the previous teams had. This was the BASIC Stamp 2p 24 pin (BS2p24) module made by Parallax Inc shown in Figure 3.1.1. Several favorable traits made staying with this model a good idea. First, the module had 16 input/output (I/O) pins, which meant that there would be plenty of locations to attach servos and joysticks, while still being expandable for future teams. Secondly, this microcontroller was fast. At nearly 12,000 calculations per second, it was blazing in comparison to other modules. Lastly, this module had a significant increase in memory over previous versions of modules available.

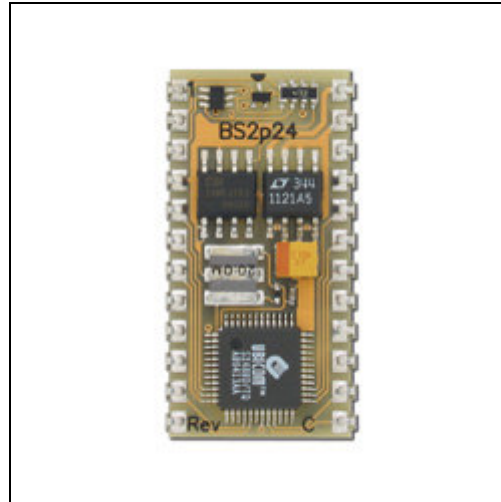


Figure 3.1.1 – Image of BS2p24 module, from <http://www.parallax.com>

Figure 3.1.2 below is showing the schematic of the microcontroller and what each of the pins that it has is used for.

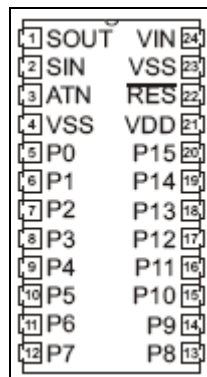


Figure 3.1.2 – Pin layout of BS2p24 module

Pins 1-4: used to link the module to a computer which is described in more detail below

Pins 5-20: I/O pins that can be used for a variety of applications

Pin 21: regulated voltage input

Pin 22: reset I/O, connected to a circuit used to reset the program

Pin 23: ground

Pin 24: unregulated voltage into the module

Carrier Board

Since we had decided to build our own carrier board, we would also need to include a connection on the board that would allow us to connect the BS2p24 to a computer to store our program on it. This is done by using pins 1 thru 4 and a female 9-pin serial port using the wiring diagram in Figure 3.1.3 available from Parallax Inc.

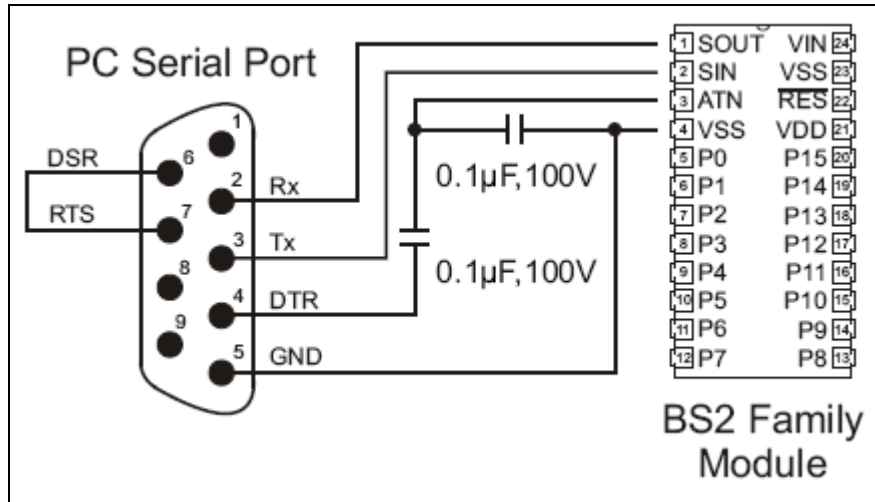


Figure 3.1.3 – Wiring diagram for serial port connection to BS2p24 module

Since the main objective of the carrier board is to translate user input to the linear actuator, it was paramount that these systems could communicate properly. Since we discovered that the linear actuators operate best at a voltage between 4.8 and 6.0 volts, and the BS2p24 module can accept and input between 5.5 and 15.0 volt, we would need to have a voltage regulator to allow us to use a single voltage source to power the devices. It was decided that the module would receive an input voltage of roughly 12 volts directly from the battery. A 9-18 to 5 VDC voltage regulator (by CINCON) was added to reduce the voltage for use by the servos. This would provide a very steady 5 volts to the servos making their performance smooth and predictable. Below in Figure 3.1.4 is a basic schematic of the finished carrier board.

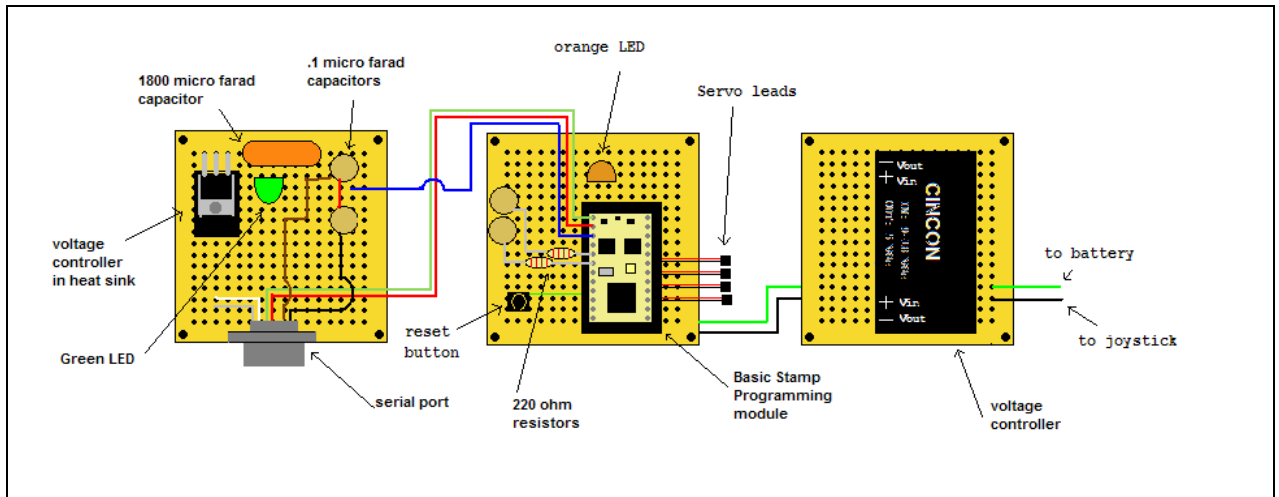


Figure 3.1.4 – Basic carrier board layout

Carrier Board Housing Box

Since the choice was made to build a custom carrier board, the box was designed to fit the carrier board and the wiring only. This provided an abundance of room in the back of the submarine compared to previous years. To fit the complete carrier board, the box was dimensioned to have inside measurements of $3\frac{3}{8}'' \times 2\frac{1}{2}'' \times 3''$. To make sure the box was strong enough yet not as heavy as previous models, it was created out of clear $\frac{1}{4}''$ hard plastic. Using plastic as opposed to metal also allowed the team to visually verify that the carrier board was receiving power through the use of an LED, as well as see if any leaks were occurring. Figure 3.1.5 shows the box fully assembled.



Figure 3.1.5 – Carrier board inside carrier board housing box

To make sure the box was completely waterproof, the edges were bonded together using Dichloromethane. To ensure there were no holes where the dichloromethane bonded, silicone sealant was later applied in a bead along the inside where each plastic panel was joined. In addition, a coat of Elmer's epoxy was used over the outside edges where the panels made contact to be certain that at a higher pressure there would be no leaks.

Since the servos, battery, and the joystick were all in separate locations from the carrier board box, the team needed to have several waterproof connections to the box to allow for these things to interact. Thus, holes were drilled and waterproof connectors were secured using Elmer's epoxy and Gorilla glue.

Joystick

The next phase in the Fly-by-Wire design was to create a well functioning joystick (Figure 3.1.6). To ensure that the joystick would be 100% waterproof, a plastic housing box was chosen. This box needed to be large enough to hold the PlayStation2 joystick and the required wiring for it. A waterproof connector was mounted on the side of the box that would later be used to connect to the carrier board box.



Figure 3.1.6 - Joystick

The circuitry inside the joystick was simply extensions back to the carrier board. At the board, the proper electrical components were attached to create a capacitor-resistor circuit as in Figure 3.1.7

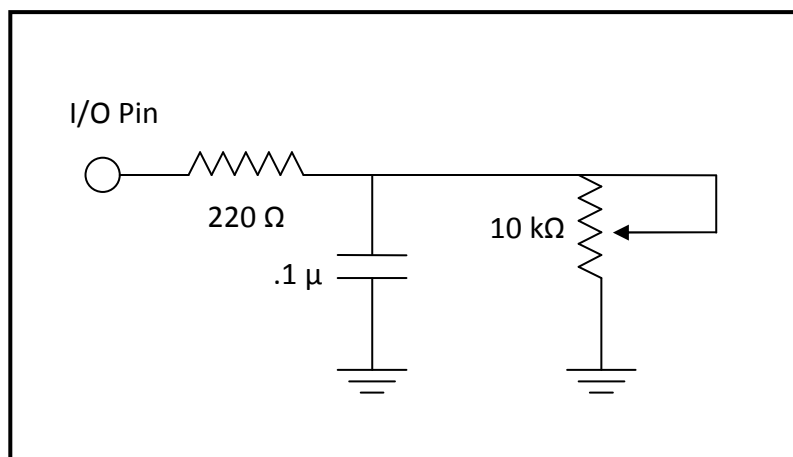


Figure 3.1.7 – Schematic for capacitor-resistor joystick circuit

The 10 kilo ohm potentiometer represents one joystick axis, so in reality there are two identical circuits, one for each axis. This simple circuit is needed because BASIC Stamp cannot directly read changes in resistance, which is how an analog controller works. To circumvent this, BASIC Stamp has a function that allows it to time the discharge of a capacitor. By varying the resistance with the potentiometer (joystick), the amount of time it takes for the capacitor to discharge is also varied using the following relation.

$$T = R \times C \quad (\text{Equation 3.1.1})$$

Where T is time, R is resistance, and C is capacitance. This returned a value proportional to the angle of the joystick, allowing us to scale the value as desired, and output to the linear actuators.

Since the PlayStation2 joystick was very small, an adapted larger joystick was needed to give better grip and performance. To do this a copper tube of ~4" was glued to the top of the PlayStation2 joystick. A hole was drilled in the top plate of the plastic housing box to allow for the joystick to be outside the box. To let the joystick be movable yet still waterproof a bellows was adapted from a shock boot of a bicycle. This was glued around the joystick and to the plastic housing box. To keep the copper pipe from corroding, surgical tubing was put around the piping and capped at the top. Since the on/off relay switch was not waterproof on its own, the top of an eye dropper was cut and glued around the switch. Again this allowed for the switch to move yet be waterproof. To make sure the entire housing box was waterproof, epoxy and gorilla glue was used to seal all cracks or openings.

Troubleshooting

Since the carrier board is an electrical device that is used to control the sub it had to operate consistently all of the time. Loose connections or badly soldered wires lead to weak or unusable signals. The voltage had to meet the requirement of each individual piece of the carrier board. To test the voltage at different locations along the carrier board a voltmeter was used.

Trouble shooting became a large issue with the carrier chip at one point in time. It was known that the linear actuators could only take positive voltage pulses. The servomotors inside the linear actuators operate by a coordinate system. A small voltage pulse will set them counter clockwise to a certain position and a larger voltage set them clockwise to another position. The mean of these voltage pulses places the position of the linear actuator to the center. Over and over again the linear actuator would only turn in the counter clockwise direction. The way the devices worked told us that it was only receiving a small pulse from the program even though in the programming language it was specified as a large pulse. To begin testing for the problem, a test program was run that would start at the smallest pulse possible and step up the pulse all the way to the largest pulse. As the program ran through, the linear actuator should have turned counter clockwise until the program reached a certain value and then rotated clockwise. Since this was not the case, we knew that the programming itself that was not the issue. Somewhere on the circuit there was some malfunction that led to the linear actuators only receiving small pulses. To check this, an oscilloscope was hooked up in parallel with the output wires to the linear actuators. The oscilloscope shows the signal that is being sent out of the carrier chip. The oscilloscope showed exactly what the program was sending out and it followed what we were trying to do. This made us focus directly on the carrier chip itself to look for short circuits or poorly soldered leads.

Upon using the oscilloscope, it was noted that a certain connection with the ground wire would cause the linear actuators to turn both directions. This was the first time the

linear actuators had gone both directions on command. This led to some experimentation of the carrier board. A new ground wire was connected between the linear actuator voltage reducer and the main ground of the carrier board. This finally solved the problem of the small pulses being sent out. The problem was that it was assumed upon connecting the voltage reducer that its own negative lead would be a sufficient ground connection. This was not the case, and needed to be hooked into the ground for the entire carrier board.

To make sure that the carrier board stayed dry while in operation there had to be no leaks at all when submerged in a bucket of water. Any small sign of water entering the box meant that at 15 ft underwater the problem would be much larger due to the increase in pressure. To make sure the box was waterproof it was done in steps and checked each time to find trouble spots. After each completion of water testing, the box was dried off and more water proof sealant was added. This was continued until no water would enter the box or accessories. Unfortunately, troubleshooting had put us a few weeks behind schedule so we did not have time to test how water resistant the box was at operation depth.

3.2 Linear Actuators

The waterproof servo cases were created by milling ABS plastic to fit the servomotor and attached arm. ABS plastic was chosen for its machining and waterproof properties. Metal would have been much more costly, harsher on lab equipment, and slightly more difficult to machine. The cover was chosen to be made from clear acrylic, held on with screws and sealed with RTV gasket maker. The clear cover allowed the team to view any leaks or other problems while the servo was being used. Gasket maker proved to be an exceptionally useful sealer at a very low cost.

A small threaded pushrod was attached to the servo arm, extending out through a small hole. In order to waterproof this, a flange was set around the hole, with latex tubing attached to the flange by means of a hose clamp. This tubing extends out over a portion of the pushrod, where it attaches to a threaded metal dowel used to increase the diameter at that point so another hose clamp could be used. The threads on the dowel were sealed with gasket maker. This was decided on over a direct connection between the latex/rubber piece and the box because nothing provided a good enough seal to that material. Although adding the flange and metal dowel increased the number of connections needing waterproofing (which is generally a poor idea), the connections were much easier to waterproof properly.

The linkages between the pushrod and control service were cut, hand filed, and drilled from aluminum. The concept was based on the very simple engineering premise that if you increase the distance that the force is applied at from the point of rotation you need less force. This eased the load on the servomotors. The size of the links was constrained by the area in which they needed to be able to turn. A small commercially available ball and socket set were used as the joints between the pushrod and arms at either end of it.

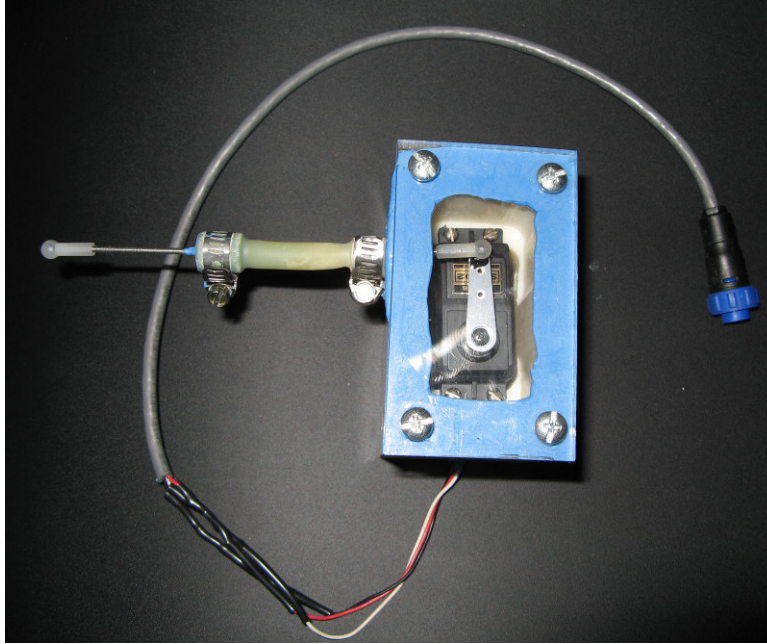


Figure 3.2.1 - Final waterproofed servomotor enclosure

The manual controls were set up differently than the fly-by-wire system since past competitions proved the pilot's ability to pedal and steer at the same time to be too complex. To this end, the manual controls needed to be easier to control and less sensitive. Our system addresses this concern by linking the control surfaces in a manner that leads to only two controls. One control modifies the pitch while the other modifies the roll. These allow full maneuverability while easing the mental complexity of steering.

The control over the roll is achieved by linking the opposing control surfaces with a 3-gear system. This causes the control surfaces to rotate in opposite directions of each other. The pitch is controlled by the two horizontal surfaces, which are linked by clamps to a metal bar, causing them both to rotate in unison. The linkages between the control cable and control surfaces were designed to optimize the user-friendliness. This was done by making them the perfect length to trim down sensitivity of the controls while not making them too difficult to turn.



Figure 3.2.2 - 3-gear system used for opposite control surface movement

In order to keep the gears properly meshed and in place for the vertical control surfaces, a brace system was developed. This system consisted of a bar extending vertically, mounted in the tail cone behind the shafts from the control systems. Each control surface had a gear mounted on its shaft, with a third gear to create the connection and opposing movement dropped into a bushing secured in the center of the bar. The bar had two braces, which were J-B welded into place. These had holes for the control surface shafts to go through, bracing the shaft on the outside of the gear. These allowed for rotation while eliminating side-to-side movement and greatly reducing backlash. Two other designs simply varied the method of securing the braces to the bar to increase strength. There was concern about the possible failure of the adhesive due to its limited shear strength, and relatively small application line. To greatly reduce the risk of failure, angle iron was welded into position and a new, stronger bracket was produced.

3.3 Manual Controls

The manual controls consist of throttle cables which will be controlled by twisting a handle which in turn twists the control surface. One of the key modifications made this

year was moving the control handles forward towards the front of the sub as well as manufacturing new handles which solve the previous problem of the pilot's gloves being caught on the handles. To move the handles forward, the mounting brackets were taken off and reattached further toward the front of the sub. This allowed for more room for the driver to control the submarine with more access and maneuverability.

Moving the position of the handles (Figure 3.3.1) caused an unforeseen problem of the throttle cables not reaching the back where they needed to be attached to the control planes. Finding throttle cables of the correct dimensions proved to be a bigger challenge than we thought, so the links on the handles were redesigned. Therefore the old short links, see Figure 3.3.2, were switched out to longer links (Figure 3.3.3). The new dimensions of the links were enough to make up the needed length in the throttle cables.



Figure 3.3.1 Newly mounted control mounting brackets



Figure 3.3.2 Picture of old short links



Figure 3.3.3 Picture of new links

The new attachments for the manual steering handles were made to be much thicker so that the screw attached to throttle cables could be countersunk (Figure 3.3.4). Countersinking the screws allows for smooth operation of the handles, without interference with the driver's hands. The new attachments also were designed with more precision as the old ones were not up to the standards required.



Figure 3.3.4 Image of control handle with throttle cable plate

The last step in finishing the manual controls was to attach them to the control surfaces. This is where there is some overlap between the control group and the linear actuator group. Because of this, a joint effort was made in determining the best way to combine each group's components. It has been decided that the manual controls will not be able to be engaged "on the fly" but instead will need to be engaged in the event of an electronic system failure by manually connecting the controls to the control planes.

The parts constructed for the manual controls system included plastic connectors to hold throttle cables in position, throttle cable plates and links for the handles. The methods used to accomplish the building of these materials were tapping and dyeing of link system (Figure 3.3.5 and Figure 3.3.6), polishing of exposed parts, and drilling.



Figure 3.3.5 After the ends of the throttle cable was dyed



Figure 3.3.6 Tapped Connector Link

The plastic connectors used to hold the throttle cables were glued to the side of the submarine, with the connectors close enough together to prevent slack in the cables.

The throttle cable plates were initially hand constructed using the machining tools in the lab but in the end the circular shape was too difficult to produce a smooth product. In the end, the plates were made up at the AMC based on the Solid Works Drawing shown in Figure 3.3.7. The next item built was the links for the handles. The first set that was created was too short for the final design but the ones used followed approximately the same design procedure.

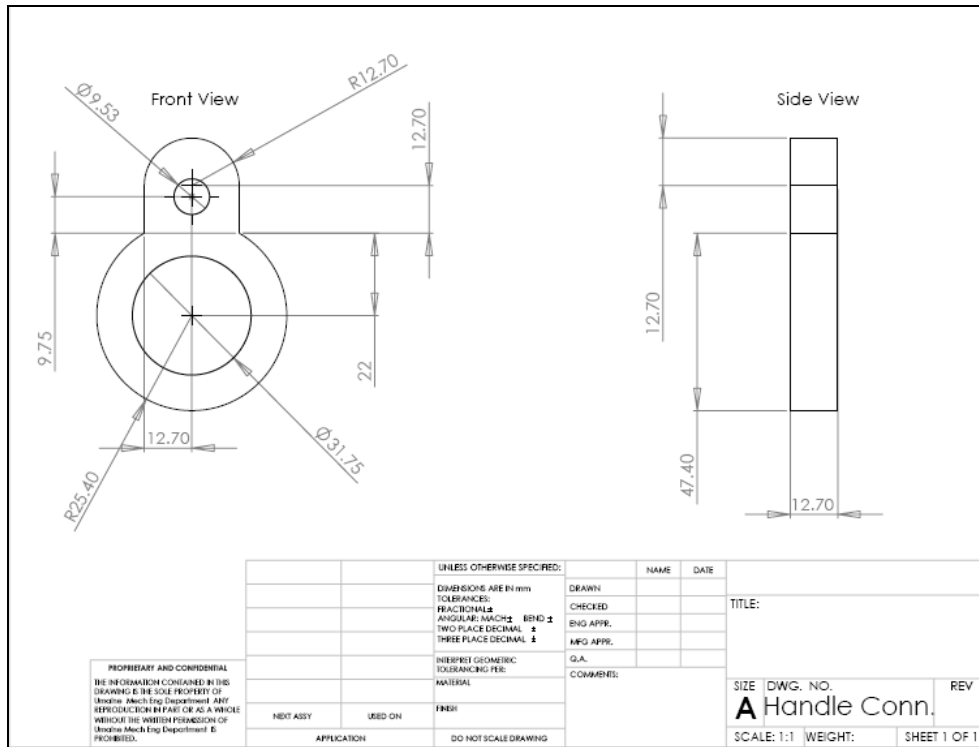


Figure 3.3.7 Solid Works Drawing showing the dimensions of the throttle cable plates

As seen in Figure 3.3.6 the Connector link was made by using a lay to round it off then was polished using a belt sander. All materials that were used for the construction of the manual controls needed to be able to withstand salty underwater conditions. The throttle connectors are just made of plastic and the rest was constructed using stainless steel.

3.4 Bow Planes

The main design of the bow plane components (Figure 3.4.1) was in the mounting system. A mounting system was needed that would be able to hold the bow plane statically in position, but would also have a small amount of damping to adjust for various speeds of the sub. Since the bow planes were already manufactured, there was not much work in designing the way that the sub would hook on to them. The bow planes had a rod built into them that the fin would rotate around. In order to attach the fin to the sub, the rod would have to be mounted.

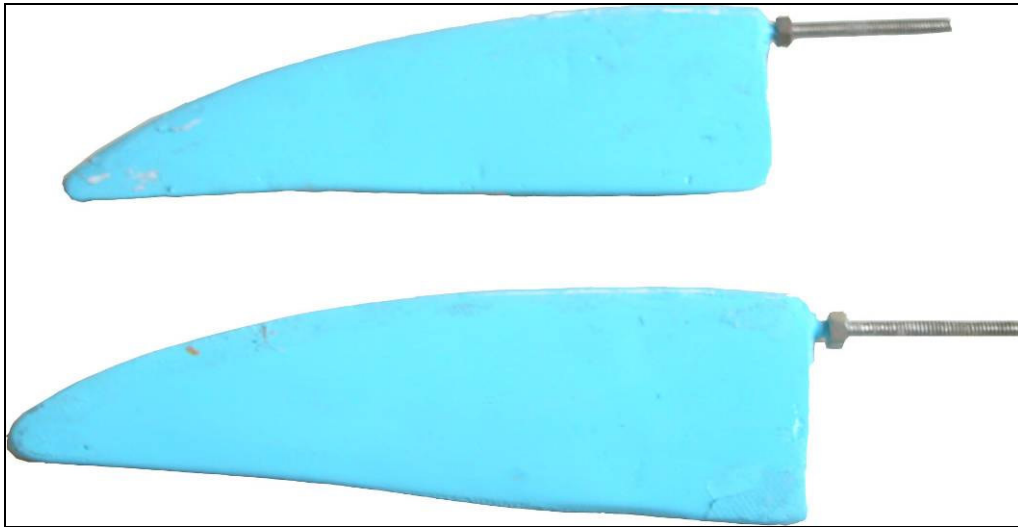


Figure 3.4.1 – Bow planes

Since the walls of the submarine are not very strong, there would need to be a large mounting plate that the whole assembly would fit on. This plate would have to be light in weight and rust resistant, because of its underwater working condition. The final design involved using surgical tubing for the damping material. For this, a hose barb was to be threaded into the mounting plate. This hose barb would have to be large enough for the rod to pass through. The surgical tubing was placed on the hose barb and clamped tight. A nut assembly was then placed at the end of the rod. With this configuration, the spring constant of the tubing can be adjusted by the position of the nut on the rod.

3.5 Tow Cone

To make the nose cone a negative mold of the inside nose of the sub had to be made. To make the negative a large amount of insulation foam was used. The insulation foam was then filed down so that it would fit into the nose of the sub. Once the foam was made fit with the nose, a positive of the nose was made. The material used to make the positive was a Silicone rubber by Smooth-On. The final product was a negative cast of

the nose. A ¼” metal plate was attached to the back for reinforcement and the nose was drilled so it could be held in place with an I-bolt (Figure 3.5.1).



Figure 3.5.1 – Finished tow cone

The nose cone is made from a liquid polyurethane plastic, Smooth-Cast 300. The plastic is mixed with a hardener in a 1:1 ratio by volume. The completed tow cone has a specific gravity of 1.05 g/cm³. This means that the nose cone is negatively buoyant and will help with the problem of having the nose pointing up while it is moving underwater. A finite element analysis was done on the nose cone to see if the material was strong enough to handle the weight of the sub under water (which is 1050 lbs). The FEA analysis determined that the cone should be strong enough to hold the tow cable while the sub is being pulled.

3.6 Window

A piece of 1/16” plexi-glass was cut into a rough oval shape. The plexi-glass was then placed in position around the hole of the previous window. A heat gun was used to heat and shape the glass to form. Epoxy and silicon were used to finish the window by filling in any gaps around the reshaped plexi-glass, completing the task of a new front bottom window.

3.7 Safety Buoy

The original buoy was salvaged, but the mechanism used to deploy it was altered. A pull lever was placed near the driver for easy release in case of an emergency. The lever works via a throttle cable mounted along the edge of the submarine and is integrated into the release mechanism (Figure 3.7.1). The string was replaced with highly visible fluorescent yellow string as required by sub competition rules (Figure 3.7.2).

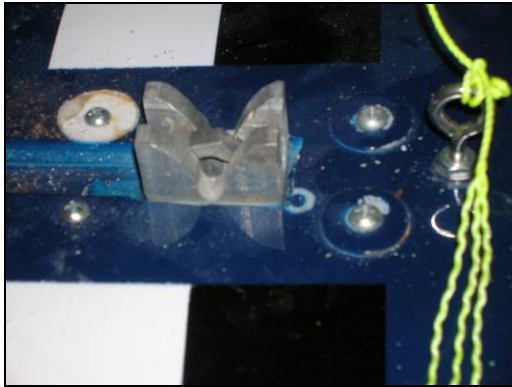


Figure 3.7.1 – Safety buoy release mechanism



Figure 3.7.2 – High visibility string on buoy

4.0 Design Evaluation

4.1 Overview

Once the major components of the sub were constructed, they were in need of thorough testing. Since each of the three main systems were interlinked, it was important that all were fully functional. This was also a cause for delay as a major setback in integrating the servos with the Fly-by-Wire system postponed testing on both components for nearly three weeks.

4.2 Fly-by-Wire

The test of the Fly-by-Wire system had two main objectives. Objective one was to test the impermeability of the box, since it contained almost all of the electrical components

of the sub. The second objective was to verify the response of the control surfaces. When the driver tells the sub to surface or dive, it is important that both the left and right elevator move the same amount to avoid unintentional rolling.

Apparatus & Setup

Please see Figure 4.2.1 for a picture of the setup of this experiment. The test was set up by placing the tail piece of the submarine in a mounting fixture constructed from OSB and 2x4's. The fixture also has a place for a rod that goes through the hole in the bottom of the tail piece where the lower control surface would mount. The rod is used to secure the tail piece while the test is performed. The left and right control surfaces are installed with linear actuators attached. The linear actuators are then connected to the housing box which is then connected to the joystick. Next the battery pack is attached to the housing box as well (not pictured).

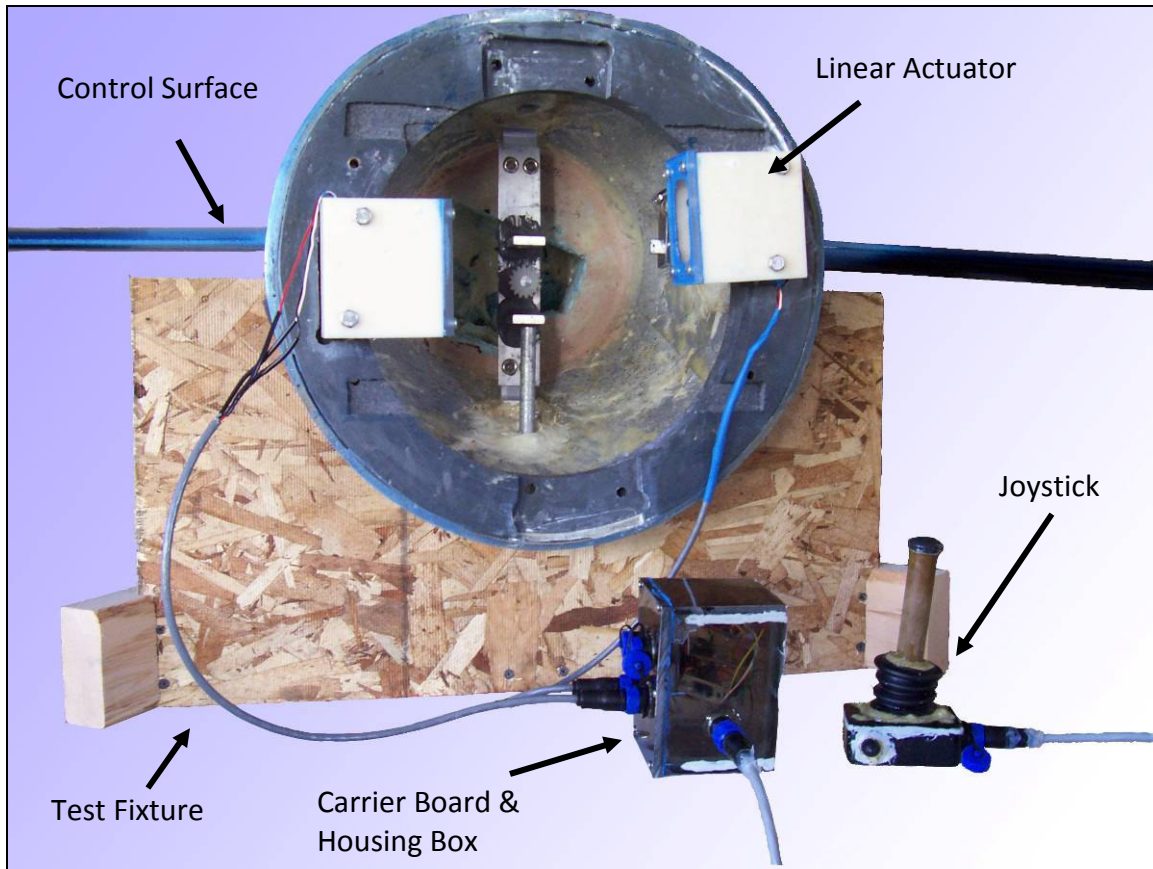


Figure 4.2.1 – Apparatus setup

Instrumentation

The only instrumentation required for this experiment was a dial indicator, which had readability of ~ 2.5 thousandths of an inch. See Figure 4.2.2.



Figure 4.2.2 – Dial indicator used in testing

Experiment Procedure

To ensure that the test would be repeatable, a simple program was written to move the control surfaces in small increments every few seconds. With each movement of the control surface, it would ideally move 1/10 of its maximum displacement. The increments were chosen such that the control surface should stop in the same position on the way up as it does on the way down. Any discrepancies here would point to hardware issues.

To begin the experiment the housing box and battery pack were submerged in a tub of water. The apparatus was left alone for a few minutes to make sure no leaks are present. We carefully monitored the box for escaping air bubbles that would alert us to water entering the box.

After the box was determined to be water tight, the power was applied to the carrier board. This act automatically initiates the program which rotates the control surfaces to their fullest extent downward where their position is recorded using the dial indicator. Approximately every 8 seconds the program sends a signal to both surfaces that rotates them at which time their position is recorded again. This is repeated until the surfaces reach their fullest extent upward, at which time the program reverses their direction. Data points are then collected in the same fashion as before. The entire test is then repeated by switching the power off then on again.

Waterproof Test Results

Although we were able to finish all of the testing without any electronic failure, when the housing box was removed from the tub of water it was clear that there had been severe leakage. The box was nearly $\frac{1}{2}$ full of water that was covering a significant amount of circuitry. We immediately disconnected the power and all other components and attempted to drain the box. At this time it was not clear where exactly the water was entering the box. Upon further inspection, it was discovered that there was a seal

missing underneath one of the caps used to cover unused watertight connectors. After replacing this seal, the box appeared to perform much better.

An unintended result of waterproof testing was discovered when it came time to reprogram the module for normal operations. Since the only way to alter the program stored on the module was to connect directly to the serial port on the carrier board, any program modifications require destruction of the watertight gasket beneath the box face. This presents two major issues. First, it was time consuming as the gasket is required to dry for roughly 24 hours before it can be submerged. Second, each new gasket runs the risk of not forming a fully water tight seal.

Control Surface Response Test Results

It was noted that when the carrier board was turned off between tests that the linear actuators would relax somewhat, offsetting the dial indicator reading. To account for this, the dial indicator was zeroed while the carrier board was on. After collecting the control surface data, the response was plotted. Figure 4.2.3 is the plot of the response of both the left and right control surfaces for both repetitions of the test.

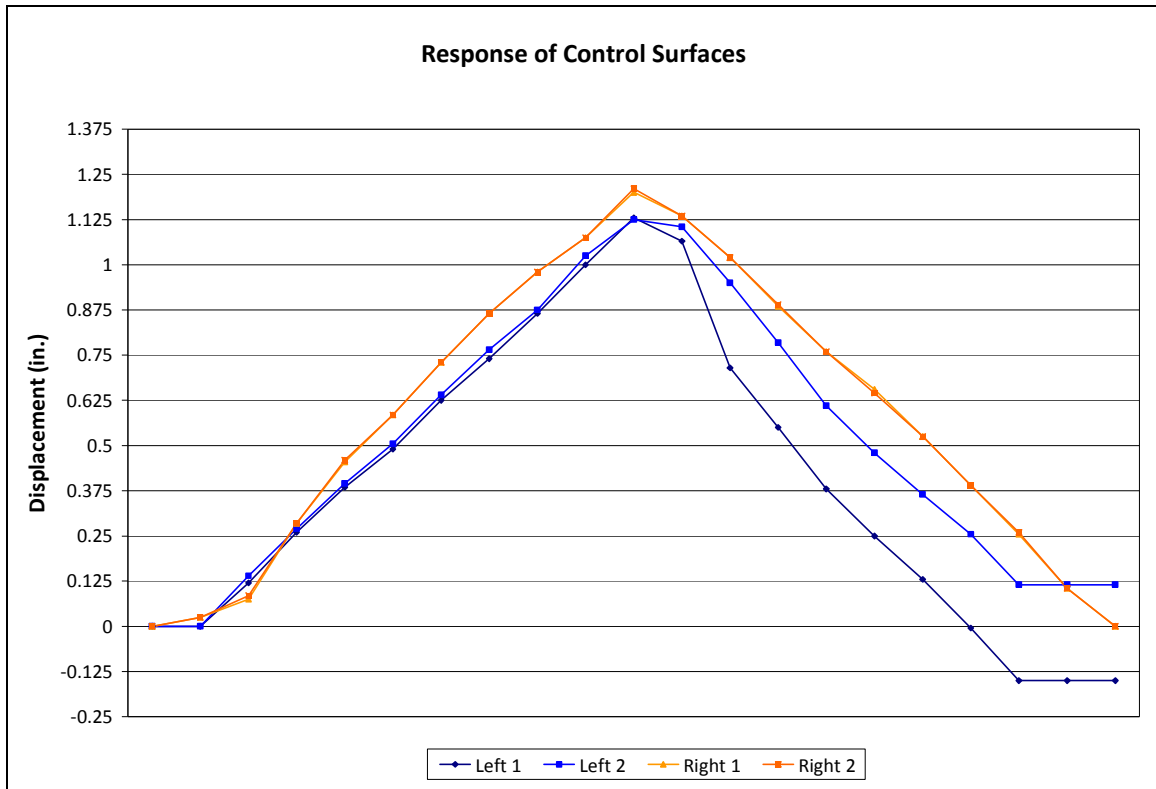


Figure 4.2.3 – Graph of response of control surfaces

One will notice that the right control surface performed almost identically in both tests. During testing we were actually able to predict the readings on the dial indicator for the right surface. The left surface however did not respond as well. When the program signaled the left surface to move for the first few iterations, its response was sluggish. This seemed to correct itself after a few signals had been sent however. One will see from the graph that once the left surface began to respond correctly it was moving at magnitudes very close to those of the right surface. This is a promising result as it means that the slow response of the left control surface is most likely due to friction and not a software or linear actuator issue.

Fly-by-Wire Testing Conclusion

In conclusion to our testing the waterproofing of the housing box and all other accessories turned out to be done well enough to hold out any water at small depths.

Whether or not the housing box is susceptible to water intrusion at greater depths is still undetermined.

It was also noticed that both control surfaces did not turn at exactly the same intervals. This was most likely due to mechanical issues. Since the control surfaces will be more buoyant in the water, they will create less friction at their rotational points. This will let them turn more freely. The water will also act as a lubricant and assist in their rotation.

4.3 Linear Actuators

The manual and electronic controls were initially tested individually in the sub out of the water to ensure proper functioning. First, one servo was attached to the joystick, microprocessor and battery. Movement and range of motion were tested out of water and out of the submarine. All servos and electronics were then installed in the rear of the submarine and the interaction with the control surfaces was tested out of the water. The electronics were removed again and one servo was attached to the joystick, microprocessor and battery and submerged to the bottom of the pool, a depth of 13 feet. The full range of motion of the joystick was tested underwater and the response of the servos was observed. All servos and electronics were installed in the submarine, submerged to a depth of 13 feet and the joystick movement/control surface response was tested again.

After electronic control movement tests were completed, the submarine was left submerged for fifteen minutes at full depth. All components were then removed and thoroughly inspected for any leakage.

With the electronics removed, the manual controls were installed in the submarine. The full range of the throttle grips were tested and the corresponding motion of the control surfaces was observed out of the water. Then, the sub was submerged to full depth and

the throttle grips were tested again. Any changes to the performance of the manual control system functioning were recorded.

The entire procedure was performed twice. During the first dry electronics test, the right and left control servos performed as expected, but the top servo did not move at all and the bottom servo moved very slowly. We speculated that the top servo failure was due to a miswiring of the servo plug and the bottom servo moved slowly because the bottom control surface required more force to move than the others due to more friction in the bushing.

Since it performed the best, the right servo was used for the initial underwater test out of the submarine. Joystick interaction with the servo performed as expected at full depth. However, when the electronics were removed from the water, severe leakage was observed in the microprocessor box and all electronics had to be shut off until the circuits dried. After submerging all of the servo boxes for fifteen minutes, leakage was observed in only one of the enclosures. The right enclosure had a couple small drops of water that appeared to have leaked in from the push rod sleeve area.

The components were dried and a new method of waterproofing was used for the microprocessor box. The electronics were tested again a week after the initial test. The wiring on the top servo was double-checked and it had been miswired as speculated. The existing wire harness was taken off and rewired correctly. The latex tube around the pushrod on the right servo was replaced and new sealant was applied at the clamped ends. All components were dry tested, and although all of the servos worked and turned the control surfaces, the response was slower than desired. During the second underwater electronics test, all components functioned the same as on land; full movement but slow response.

One of the most difficult tasks when designing the new control system was working our design into the structure of the submarine as it was presented to us. To adapt the submarine to our needs, we had to take such measures as replacing and aligning the control surface bushings, extending the shafts, redesigning the rear mounting mechanism, and finding mounting locations for all the various components. In hindsight, it would have been easier to have first created the new design from scratch, and then refabricated the entire rear of the submarine to our exact specifications.

4.4 Buoyancy

Overview

One of the major issues needed to be resolved with this year's human powered submarine is that of neutral buoyancy. With neutral buoyancy, the righting moment is a crucial property that needs to be calculated in order to maintain the submarine's traveling integrity. The righting moment is a motion caused by an eccentricity between the center of gravity and the center of buoyancy in the hull of a submarine (Figure 4.4.1). The weight of the submarine pushes down at the center of gravity and the water pushes back at the point of center of buoyancy. When these two points on the hull of the boat are not equal, this is what causes the righting moment. If the center of buoyancy is able to return the submarine to an upright position then it is said to have a positive righting moment. However, if the center of buoyancy is, for any reason, unable to return the submarine to an upright position, then it is said to have a negative righting moment and will nose dive or tail dive to the bottom of the tank.

This moment was the basis of our laboratory study and is crucial to the design of this year's human powered submarine.

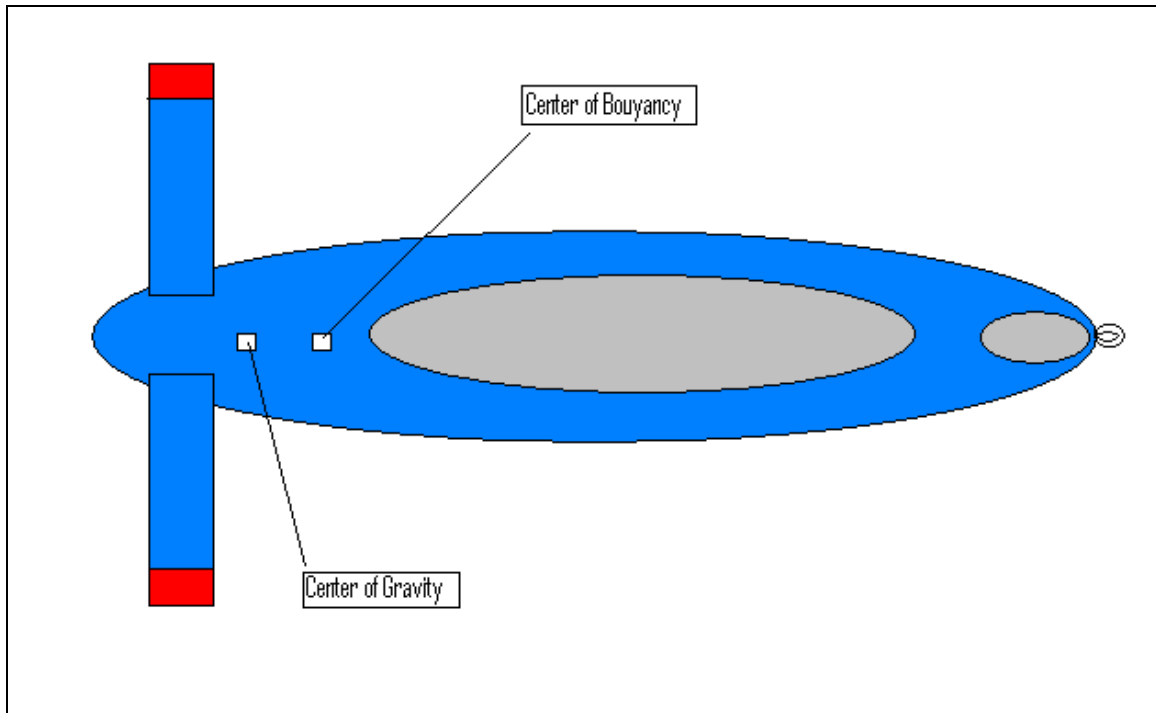


Figure 4.4.1 – Top view of sub showing center of gravity and center of buoyancy

The objective of our testing was calculated the righting moment of the submarine so we are able to later determine steps needed to create a neutrally buoyant sub.

Experiment Procedure

The righting moment of the submarine was determined by using the equation (eq.4.4.1):

$$W_{Sub} * d_{CG \rightarrow CB} \quad (\text{eq.4.4.1})$$

This equation states that the righting moment is the multiple of the weight of the submarine times the distance between the center of gravity and the center of buoyancy. To determine the center of gravity, we went to scales that you would typically use on humans and placed them facing each other, one submarine length apart. We then had one sub team member stand on one scale and another member on the other. Their weights were then taken in order to later determine the actual weight of the sub and in

turn its center of gravity. Both members each held one end of the sub out of its cradle so it was suspended by nothing more than its very tips of both ends by the hands of two team members. Two other team members then took the weight measurements of the team members and the suspended submarine combined. These weight measurements were used in accordance with the length of the sub to finally calculate the center of gravity of the submarine as shown below in Figure 4.4.2.

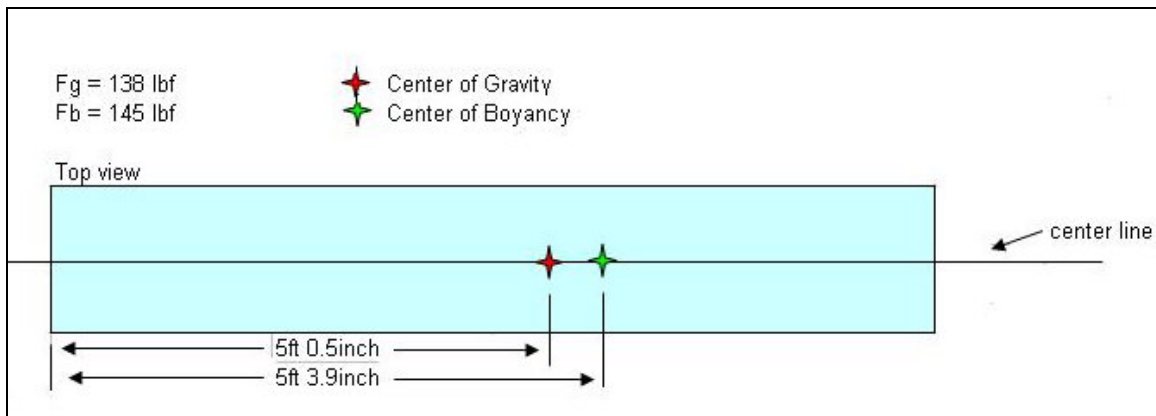


Figure 4.4.2 Righting Moment Diagram

The center of buoyancy was determined by a somewhat crude yet effective method. With the sub loaded with strategically placed weights to make it sit level in the water, it was completely submerged under water, with the control surfaces and the tail cone attached. A submarine team member then began pushing on the back end of the sub (Figure 4.4.3). This caused the sub's stern to dive and the nose to trim up in the water. This let us know that the center of buoyancy was closer to the bow of the submarine, so we leveled the submarine again and pushed on a spot a few inches further from the stern of the sub and again the stern dove and the bow trimmed toward the surface. We continued this process until we found the point at which the entire submarine was being pushed uniformly towards the bottom of the pool, not just the bow or stern individually.

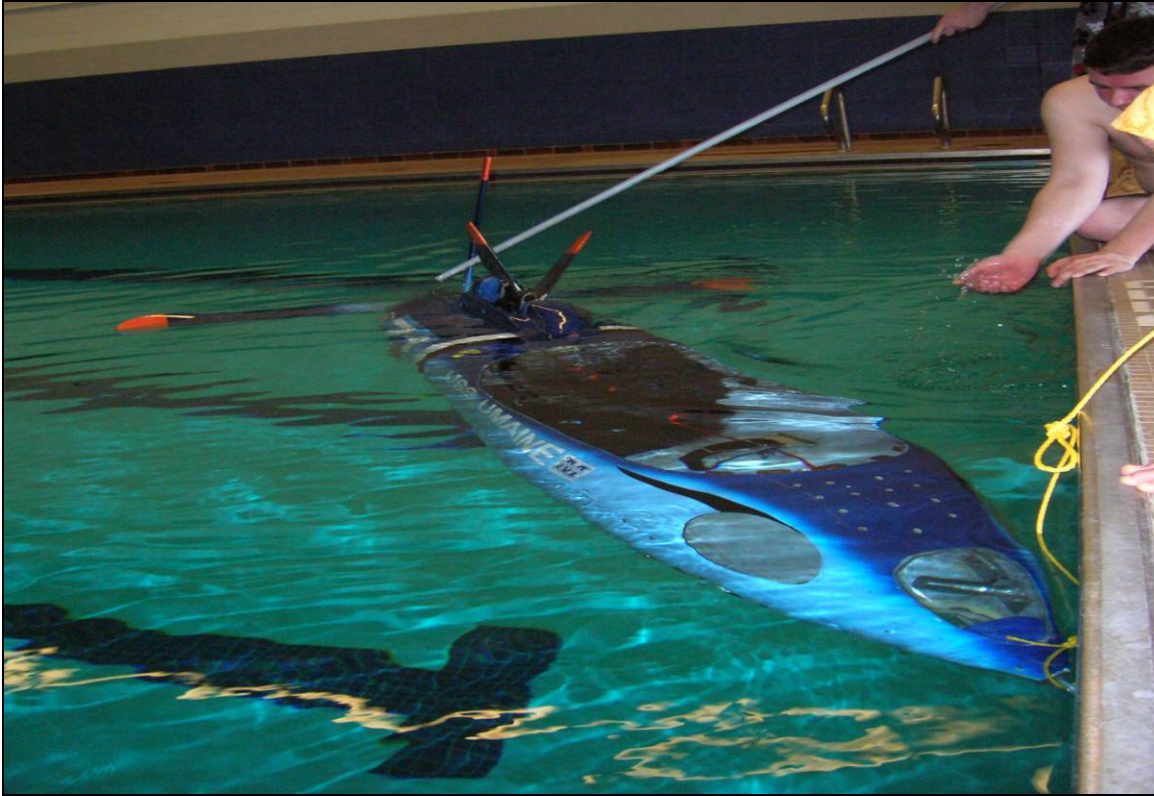


Figure 4.4.3 – Testing to find the center of buoyancy

All of this testing was done at Maine Maritime Academy's swimming pool. Testing was done by Jesse Ashmore, Matt Ledoux, Amy Wing, Dan Getchell, and Chris Briggeman.

Buoyancy Test Results

In the tests to determine the center of gravity, we used scales to determine the weight and weight distribution of the submarine. Matt Ledoux stood on one of the scales and weighed in at 183.5 pounds. Dan Getchell stood on the other scale and weighed in at 176 pounds. Matt and Dan then lifted the submarine out of the cradle and kept it completely suspended while Amy Wing and Chris Briggeman reweighed the two. Matt's new weight was 224 pounds while Dan weighed in at 250.5 pounds. This shows the substantial weight imbalance due to a much heavier stern of the submarine. A measurement of the length of the submarine was taken to be 9' 6" long. The net weight of the submarine was calculated to be 115 pounds.

These numbers state that the center of gravity is 5.5 feet from the bow of the submarine. This number makes sense because the sub has a tendency to surface at the nose due to the heavy rear cone and driving system.

With the crude procedure used to find the center of buoyancy, it was found that the center of buoyancy was 5 feet 3.9 inches. This measurement was taken with the submarine completely submerged. With this measurement we can now determine the righting moment of the submarine. The distance, $d_{CG \rightarrow CB}$, has been calculated to be 1.9 inches as shown below in Figure 4.4.4.

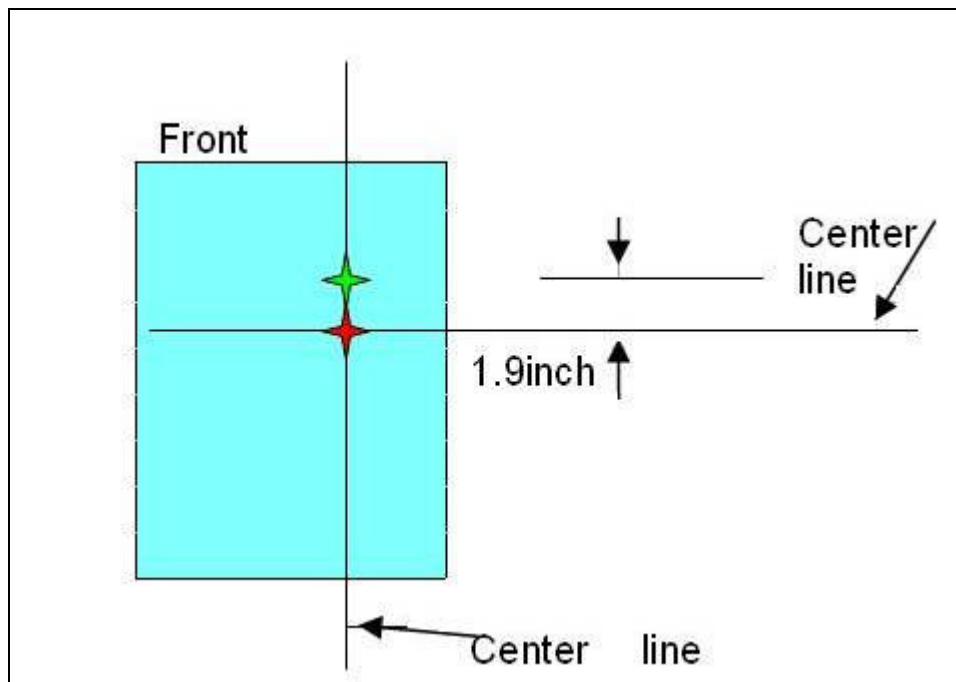


Figure 4.4.4 Distance needed to find the Righting Moment

With the weight of the submarine being 115 pounds:

$$115 \text{ lbs} * 1.9 \text{ ft} = 218.5 \text{ lbs} * \text{ft} \quad (\text{Equation 4.4.2})$$

Buoyancy Test Conclusion

The introduction of this righting moment shows that the submarine will have a tendency to not sit completely level in the water. From numerous water tests, however, it seems that the submarine, when weighted properly, has a positive righting moment. The tow cone created for testing will be left in the sub to act as a weight because it makes a contribution to the counteraction of the massive weight difference between the bow and stern of the submarine. The sub does have a tendency to trim slightly, but with proper bow plane angle placement, this should correct those eccentricities and allow for a stable and fluid ride through the water.

5.0 Conclusions and Recommendations

5.1 Overview

In conclusion, the 2007-2008 human powered submarine team would like to leave what we have learned through our experience and to give some guidance to any future human powered submarine team at the University of Maine.

Prior to this experience, the team knew little about the real life challenges that accompany actual work on such a project. Most of undergraduate student time is spent using equations that sometimes seem as if they are rarely used other than in the classroom. This project however, required both hands-on fabrication and modeling systems using theoretical equations, and through it, we have gained experience that will be very useful in our careers further down the road. Having the ability not only to create, but also to create as predicted, is a skill that not many can say they possess.

5.2 Fly-by-Wire

Advice that the 2007-2008 Fly-by-Wire team would like to leave to future teams includes the following:

- Program as quick as possible because deadlines will sneak up on you and testing can not be fully accomplished without the programming done.
- Waterproofing is key, just because something is waterproof in a bucket of 6 inches of water does not mean it will hold up at 10- 15 feet of water, the pressures are significantly different.
- Start by examining the programming of this and previous years to get a basis of where to start.
- Any accumulated knowledge can only help the team to progress further and come closer to getting to competition and winning.
- Create checklists of what needs to be done and stick to them.
- Don't put off milestones until they are right in your face and due. It is much easier to get things done before hand in case there is any troubleshooting, which there will be.
- Last but not least, research before doing, it may be faster to just build it without knowledge, but the next two times you rebuild it will cost you any time you may have gained in rushing.

5.3 Linear Actuators

One major strength of the new control system design is the implementation of four individual waterproof servo housings instead of one giant box. This greatly reduced the chance of entire system failure and lowered the overall buoyancy of the submarine rear. Also, the innovative pushrod sleeve design and the nylon bushing replacements together limited unnecessary load on the servos through reduced friction. Furthermore, the acrylic covers allowed for hassle-free testing and troubleshooting.

The new clamping system for attaching the submarine rear was a great improvement and immensely reduced the time and effort previously required to put the sub together. The existence of manual controls as a backup was also an important addition to the control system.

The biggest weakness of the electronic control system was the servos that were selected for use. Although they were strong enough to move the control surfaces and passed all basic functional testing, the torque was too low to be ideally suited for race use. The only weakness observed in the manual control system was the minute lag between the differential control surfaces during operation. This was due to low tolerance machining of the control surface shafts, which in turn left the shafts too loosely held in the bushings, and negatively affected the operation of the nylon miter gears.

One recommendation for improvement is to re-fabricate all of the control surfaces. The size of the surfaces could be reduced with negligible loss of performance. Also, the biggest benefit of re-fabrication would be that the shafts could be machined to the proper length and diameter using only one piece of metal, eliminating the extensions currently in use, which are a likely failure point of the design.

Overall, we learned through our experience designing the submarine that the design process is dynamic and that to truly succeed you need to learn to effectively handle setbacks and be open to implementing new ideas.

5.4 General Maintenance

There are many lessons that have been learned by doing this project. Some of them have come about during the design phase of the project, while others were revealed during testing. Although temporary patches were devised, more permanent solutions

will be needed. In order to prevent such needs for quick solutions, an emphasis should be placed on testing. With much fabrication needed this year, especially with the control box, there were few times when the entire control assembly could be tested together. This combined testing was essential toward the overall functioning of the sub. The majority of our project revolved around the electronic control box. Since there was a large amount of programming to be done with this box, there was not much leftover time for testing.

Waterproofing was by far the largest problem that was dealt with on this project. Water and electronics do not mix. Therefore, every box and wire that had electrical current in it had to be water proofed. This problem was further complicated by the fact that the submarine will be operating at a depth of 15 ft, where the pressure of the water makes it more likely that water will get through cracks and spaces that were previously unnoticed. This was shown in great detail during the testing stages, where the control box and the joystick box developed leaks that were not visible in shallow water. Having these leaks caused another delay in testing, as the parts had to be removed from the pool, and sealed. During this drying time, they could not be touched as not to disrupt the epoxy.

The addition of the bow planes did help keep the sub in level operation. Because of their addition, the control surfaces can focus on steering the sub, rather than correcting the upward lift and positive buoyancy. In addition, the manual controls have been reformatted to allow greater ease for the user, by eliminating snag areas and using clamps to hold down the control cables.

This year's incarnation of the sub program was a stunning success. There is a compacted control box, easier to use joystick, and bow planes for added control. That being said, there are recommendations for future incarnations of this project. Better waterproofing techniques should be developed in advance, as it will occupy less time

than continually trying to find leaks. Also, the addition of an autopilot in the control program would help the pilot during any straight line testing. Finally, the air supply provided by the two pony tanks does not deliver much operational time at depth.

Therefore, a larger single tank would be recommended. With these added revisions, the submarine would be unstoppable.

6.0 Contributions

	Problem Definition								Concept Design								Design Description & Construction							Design Evaluation				Conclusions & Recommendations				Formatting	Compiling	Proofreading/Editing	
Section Number	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	1	2	3	4	1	2	3	4				
Corie Drake	•	•							•	•							•								•	•							•	•	•
Jeffery Poirier		•															•									•			•	•					•
Parker Eason			•								•							•									•				•				•
James Connolly			•								•							•									•				•				•
Jeffery Magoon			•								•							•									•				•				•
Amy Wing				•								•							•									•			•				•
Matthew Ledoux							•	•							•	•						•	•				•			•				•	
Daniel Getchell					•								•										•								•			•	
Chris Briggeman						•								•														•			•				•

Appendix A: Drawings

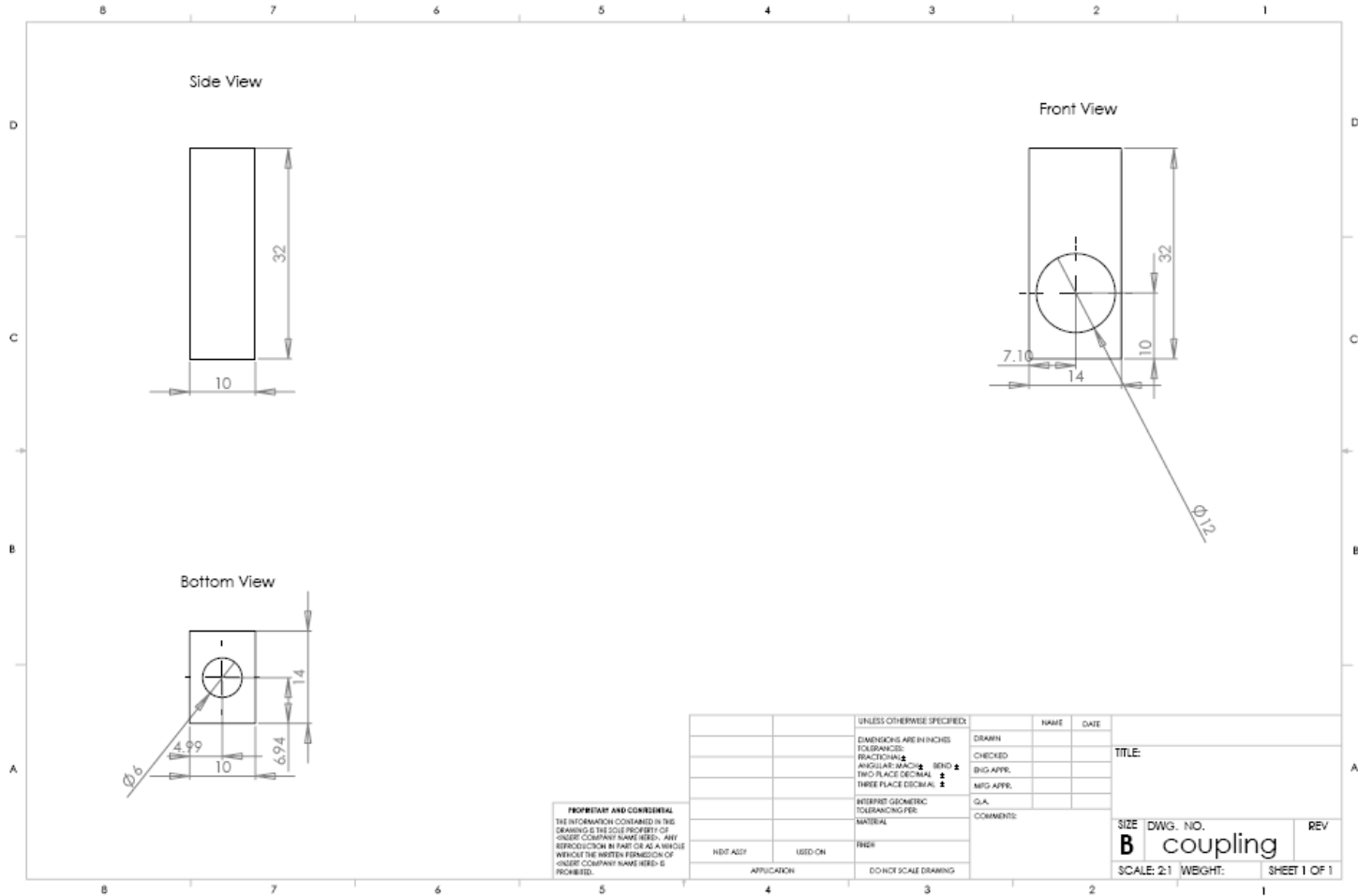


Figure A.1 – Drawing of coupling

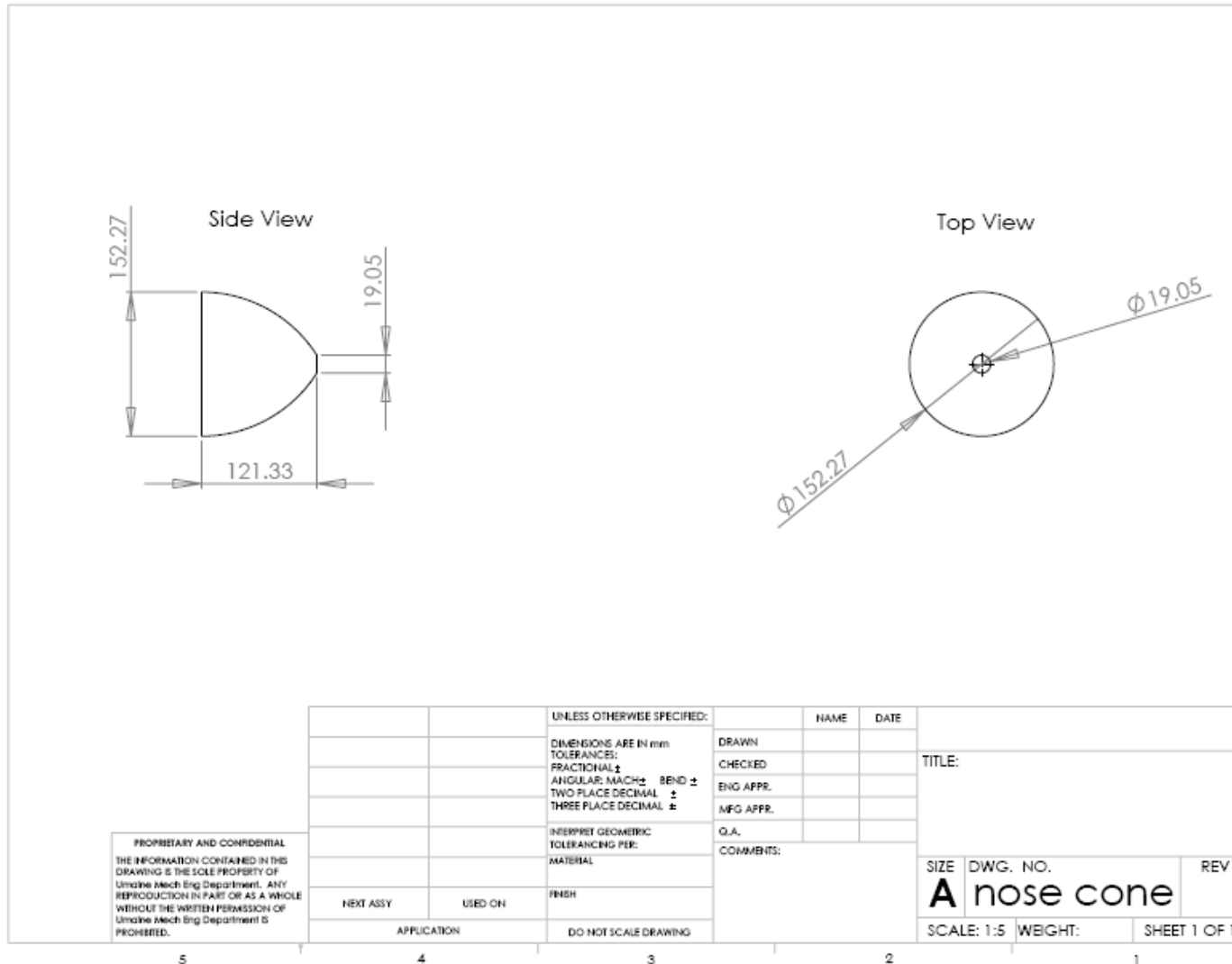


Figure A.2 – Drawing of the nose cone

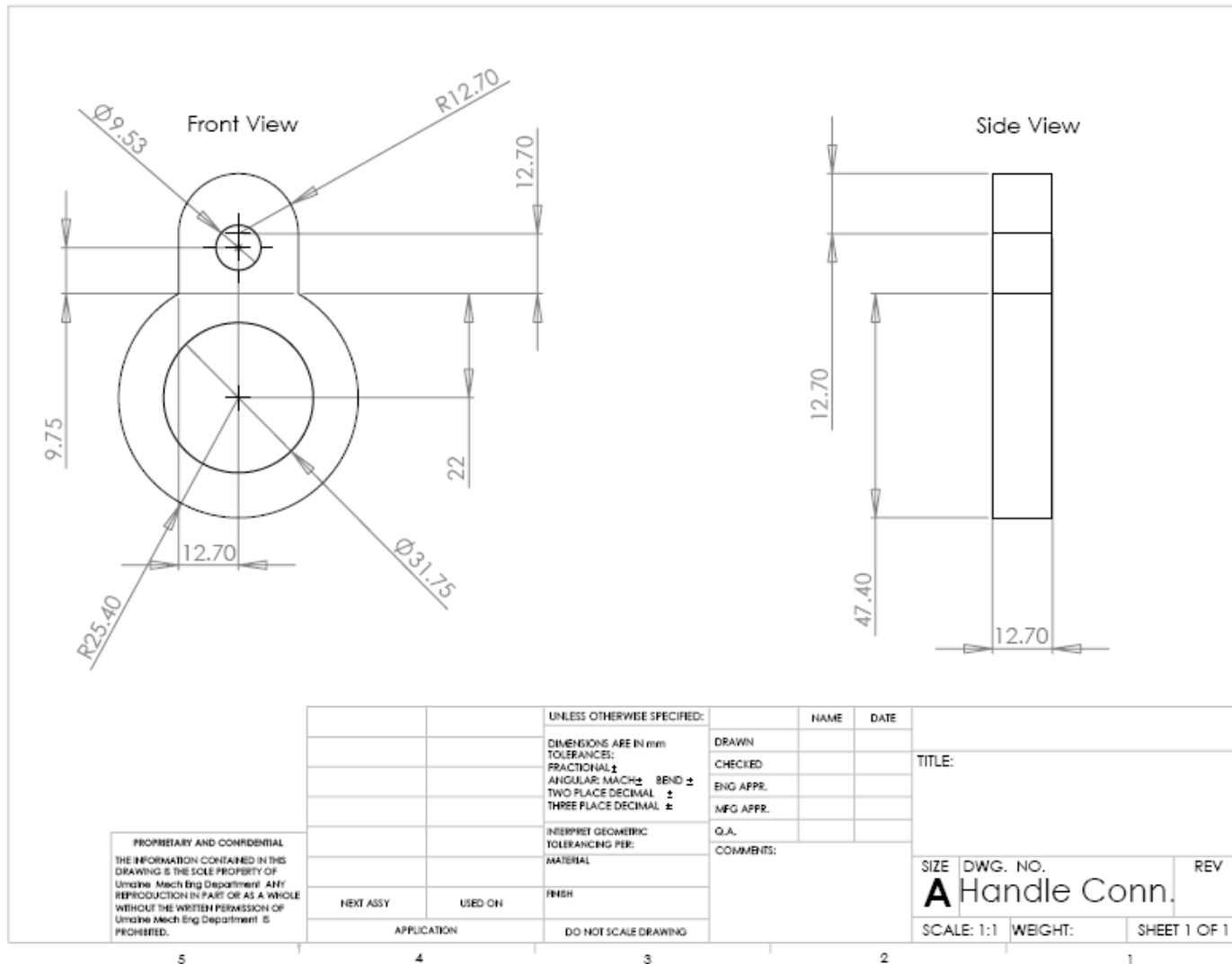


Figure A.3 – Drawing of handle connector

Appendix B: Program

```
' controls.bs2

' {$STAMP BS2p}
' {$PBASIC 2.5}

StickX      VAR    Word    ' Monitors joystick movement in x direction
StickZ      VAR    Word    ' Monitors joystick movement in z direction
BaseX       VAR    Word    ' Initial value of stick in x direction
BaseZ       VAR    Word    ' Initial value of stick in z direction
DurX        VAR    Word    ' X servo position WRT center
DurZ        VAR    Word    ' Z servo position WRT center
PNX         VAR    Bit     ' Adds/Subtracts DurX
PNZ         VAR    Bit     ' Adds/Subtracts DurZ
RCX         PIN    0       ' Reads joystick position in x direction
RCZ         PIN    1       ' Reads joystick position in z direction
ServoX1     PIN    15
ServoX2     PIN    14
ServoZ1     PIN    13
ServoZ2     PIN    12

'Sets the center position of the joystick

HIGH RCX
PAUSE 10
RCTYPE RCX, 1, BaseX

HIGH RCZ
PAUSE 10
RCTYPE RCZ, 1, BaseZ

'Sets default values

DurX=0
DurZ=0

Main:

'Reads Joystick

HIGH RCX
PAUSE 10
RCTYPE RCX, 1, StickX
```

```
HIGH RCZ
PAUSE 10
RCTIME RCZ, 1, StickZ

PAUSE 20

'Sets duration of pulse (position of servo)

IF (StickX <= BaseX-100) THEN
  DurX=(BaseX-StickX-100) MAX 300
  PNZ=0
ENDIF

IF (StickX >= BaseX+100) THEN
  DurX=(StickX-BaseX-100) MAX 300
  PNZ=1
ENDIF

IF (StickZ <= BaseZ-100) THEN
  DurZ=(BaseZ-StickZ-100) MAX 300
  PNZ=0
ENDIF

IF (StickZ >= BaseZ+100) THEN
  DurZ=(StickZ-BaseZ-100) MAX 300
  PNZ=1
ENDIF

IF (StickX > BaseX-100) AND (StickX < BaseX+100) THEN
  DurX=0
ENDIF

IF (StickZ > BaseZ-100) AND (StickZ < BaseZ+100) THEN
  DurZ=0
ENDIF

'Sends signal to servos

Pulses:

IF PNZ=0 THEN
  PULSOUT ServoX1, (2000+DurX)
  PULSOUT ServoX2, (2000+DurX)
ELSE
  PULSOUT ServoX1, (2000-DurX)
  PULSOUT ServoX2, (2000-DurX)
ENDIF
```

```
IF PNZ=0 THEN
  PULSOUT ServoZ1, (2000+DurZ)
  PULSOUT ServoZ2, (2000-DurZ)
ELSE
  PULSOUT ServoZ1, (2000-DurZ)
  PULSOUT ServoZ2, (2000+DurZ)
ENDIF

GOTO Main

END
```