Wave Powered Water Pump

ENGINEERING 340

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Team 6 – The Bobbers

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EXECUTIVE SUMMARY

Our studies at Calvin College have ingrained in us the need to draw on our abilities and proficiencies as engineers to positively impact our environment. Our senior design project was aimed at creating a water pump, powered by the continuous motion of waves. Wave energy is an overlooked renewable and alternative energy source. We believe that by harnessing wave energy to pump water, instead of an electric pump, we would be acting as good stewards of the environment as pollution will be reduced.

We were successful in designing and building this device and fulfilled each requirement that we set for our project. During the testing stage, our device was also successful in harnessing this wave energy to pump water.

ACKNOWLEDGEMENTS

We would like to express our appreciation to the following people who served as our professors during this capstone senior design course: Ned Nielsen, who was our team advisor and gave us critical reviews and guidance with the design, Leonard De Rooy, Aubrey Sykes, and Steve VanderLeest who offered very helpful suggestions and ideas throughout the project. We appreciate all the assistance they provided to us during the course.

We would like to thank Chuck Spoelhof and Greg Baak, who served Industrial Consultants. We are grateful for their input, critique, and encouragement during our review sessions with them. They motivated us to work together as a team and follow our schedule in order to complete our project.

We would also like to extend our appreciation to Dave Ryskamp in the machine shop for helping us during our construction phase and also to Jim Phillips who helped us with our pump test in De Vries hall.

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TABLE OF CONTENTS

SECTION **PAGE**

1 INTRODUCTION

1.1 Background Information

Dependence on coal, oil, and natural gas for energy is ever increasing. Coal, oil and natural gas are nonrenewable energy sources because they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve. In contrast, renewable energy resources - such as waves from large bodies of water - are constantly replenished and will never run out. There is a need to develop alternative energy sources along with the methods to harness these energy sources.

Renewable energy is important because of the benefits it provides. Two key benefits are:

<u>Environmental Impact</u>

Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies.

<u>Energy for the Future Generation</u>

Renewable energy will not run out. Other sources of energy are finite and will some day be depleted.

Waves are a form of this renewable energy. Winds across a body of water form waves, and these waves act as a giant capacitor for the wind energy. The waves are constantly undulating and are a virtually untapped energy source.

1.2 Problem Statement

The goal of this project was to design, build, and test a device that will harness wave energy, convert it into usable mechanical energy, and use this mechanical energy to actuate a piston style, water pump.

1.3 Design Description

The design of the system involves a buoy, “the bobber,” riding the surface of the water. A nylon cable connects the bobber to an ‘L’ shaped lever arm. The lever arm provides a mechanical advantage which actuates a piston style water pump. Figure 1.3.1 displays the final design diagram of our device. From this diagram, it can be seen that the opposite end of the lever arm is connected to the pump and the pump is constrained from any translational motion by the frame. The pump also has holes around it to facilitate water entry. The bobber’s buoyancy will provide the lift to pump the water out of the pump into a hose. As the waves cycle, the buoy will continually provide pumping power. Figure 1.3.2 displays the final prototype based on this design.

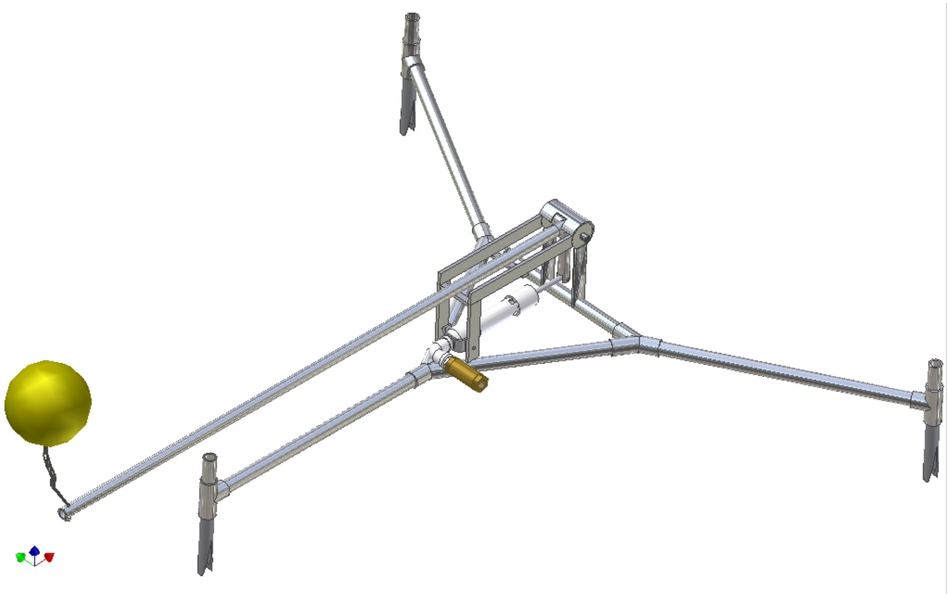


Figure 1.3.1 Design diagram

Figure 1.3.2 Bobber prototype

2 PROJECT OVERVIEW

The wave powered water pump uses the horizontal motion of waves to pump water. In order to accomplish this task, we established project objectives that would guide our design and fabrication processes. We also described the requirements with regards to the performance of our device.

2.1 Objectives

- To design and build the wave powered water pump
- To test the device and assess its performance
- To generate schematics of all the parts of design
- To provide documentation on how to build and assemble a prototype
- To present a final design that is complete with recommendations on future improvement

2.2 Requirements

- Generate pressure greater than 25 psi (to achieve 50 ft of head)
- The device should be portable with an overall weight that is less than 50 lb
- The pump should be capable of generating a volumetric flow rate of 300 gallons per day
- Budget not to exceed $500

3 LAKE MICHIGAN RESEARCH

3.1 Wave Research

In order to integrate the components of our system, including the pump, the frame, the bobber arm, and the bobber into a robust design, we needed to have accurate and reliable data regarding waves in Lake Michigan, our chosen testing ground. To obtain this data, we contacted and subscribed to online journals of the International Association of Great Lakes Research, or IAGLR (www.iaglr.org).

The IAGLR had access to two documents which we found relevant to the information we required. The first document was *Wind and Wave Measurements Taken from a Tower in Lake Michigan*, a comprehensive study of wind and wave behavior of Lake Michigan with over 1300 documented hours of measurement. The data that we found most important was the documented average wave size in Lake Michigan: 0.68 meters (2.23 ft) and average wave period: 3.6 seconds. Another important piece of information was the fluctuations of water levels: 2 meters (6.56 ft). The second document that we found relevant to our project was *A Generalized Parametric Wind Wave Model* that discussed how waves in Lake Michigan changed in shape, force, and velocity as they reached the shore. This was relevant because the measurements taken from the tower as presented in the first paper were taken 2 kilometers (1.2 miles) offshore, where the water is 16 meters (53 ft) deep. Our project is to be launched in about 0.9 meters to 1.5 meters (3 ft to 5 ft) of water. Using this model, we converted the tower's data into applicable data in order to create a theoretical model of waves for our proposed design site.

3.2 Legality of Project – Department of Natural Resources

We needed to learn about possible laws or permits that could hinder our ability to test the bobber and also if individuals could use this device without breaching any laws. With this in mind, we called the law enforcement office of the Department of Natural Resources (DNR 269.685.6851). We were contacted by Lieutenant James, who told us that we did not need a permit to operate our device in Lake Michigan if we would remove the device at the end of testing. He also told us that we could use our device in any state or local park, but we needed permission to use privately owned sections of the lake frontage. This information suggested to us that as long as our device is not a permanent fixture in the Lake, there should be no regulations that would make the use of this device illegal.

4 DESIGN NORMS

With the looming environmental concerns raised with current energy generation methods and the need to develop renewable and alternative sources, our team felt it prudent to design and build a device that would not be powered by conventional energy sources but rather a device that would be powered by an alternative and renewable energy source. By this undertaking, we are of the opinion that our project is influenced by two main design norms: stewardship and cultural appropriateness.

4.1 Stewardship

We are called to be good stewards, or caretakers, of our world. We are called to use our resources wisely and with the "big picture" in mind. The United States does not follow this ideology as we are using up almost every available resource at an alarming rate. To help combat the current "gas guzzling" culture, we designed a device that uses wave energy, a renewable and abundant energy source, to pump water. With concern for the environment in which we live and the environment in which our grandchildren will someday live, we designed a device that actually reduces pollution by replacing electric powered water pumps. Most electricity is generated by burning coal, an inefficient process, so by reducing the electrical load our device reduces inefficiency and pollution while utilizing a free, green, and renewable source of energy.

4.2 Cultural Appropriateness

A key design norm for this project was the cultural appropriateness of putting a device into a lake or ocean. Most people like to have unobstructed ocean or lake views and installing a large device that could be seen as an eyesore would be contrary to this desire. We designed our wave powered water pump to be submerged in a water body, with the exception of the buoy. The buoy, although highly visible to boat operators, does not qualify as an eyesore because buoys are commonly used in most water ways. The design is also culturally appropriate because it is portable such that an individual user can transport the device (two persons are recommended). Our device will not be a permanent fixture in the Lake and will therefore not breach any laws.

5 APPLICATIONS

5.1 Pump Storage Facilities

The wave powered water pump can be used to continuously pump water up to a storage tank. For example the Ludington Pump Storage facility in Ludington, Michigan generates electricity by pumping water up to a reservoir and then releasing this water through turbines when energy is needed. If a "farm" of wave powered water pumps were in front of the facility they would continuously pump water up to the facility by utilizing the free wave energy. The downsides to this application would be that the wave powered water pump farm would have to be removed for each winter season. The benefits to the farm would be the free energy harnessed and offsetting the previous costs to run the electrical pumps. More cost analysis and testing would be required before this application could be deemed viable.

5.2 Irrigation for Lawns

For the individual home owner, the wave powered water pump would be an ideal solution for maintaining the water supply for a lawn or garden if they lived near a large body of water. The wave powered water pump could be placed in the water body during the spring or summer, when lawns demand water, and removed during the winter seasons, when watering is no longer needed. The wave powered water pump could help supplement the homeowner's domestic water supply that is used in watering the lawn, in turn reducing their water bill. This is also an ideal solution because the water used on lawns and gardens does not need to be treated by a drinking water plant, so the wave powered water pump also helps reduce the demand on the city's domestic drinking water. For this type of application, the wave powered water pump would be outfitted with a valve to allow the user to determine the maximum flow rate.

5.3 Water Supply for Ponds and Water Gardens

The wave powered water pump would be an excellent way to provide fresh lake water to a pond or water garden. The fresh water supply would ensure that the pond had all the required oxygen to sustain aquatic life. This application would also keep the water level in the pond or water garden at a certain height by having a semi constant supply of lake water flowing into the pond. A runoff would be needed to ensure that excess water would drain back into the lake.

5.4 Remote Location Water Supply

For a remote location application the wave powered water pump would be well suited. Because the wave powered water pump requires no electricity, only wave action, it can be used anywhere there are waves. The continuous wave action is the source of power for the device and would pump water up to the needed location. A possible example would be remote desalination plants. The wave powered water pump could deliver the water to the plant with no use of electricity. This could be very beneficial in locations where electricity is scarce or unreliable. As many wave powered water pumps could be used as necessary to satisfy the water demand or a larger scale wave powered water pump could be manufactured.

6 DESIGN PROCESS

6.1 Pump

We began our design process by considering the integral component of our design; the pump. We set requirements for our pump, so that we could assess its performance upon completion of its design.

Vertical Pump

The first design that was investigated was a vertical pump which is shown in Figure 6.1.1. This was a simple yet compact design that would include a piston, a cable, two check valves, buoy, and a spring; essentially, our whole device in one package. We recognized this design would not be effective because it did not provide an effective means for anchorage. This design was not pursued further because of anchoring issues, spring corrosion, and a lack of mechanical advantage.

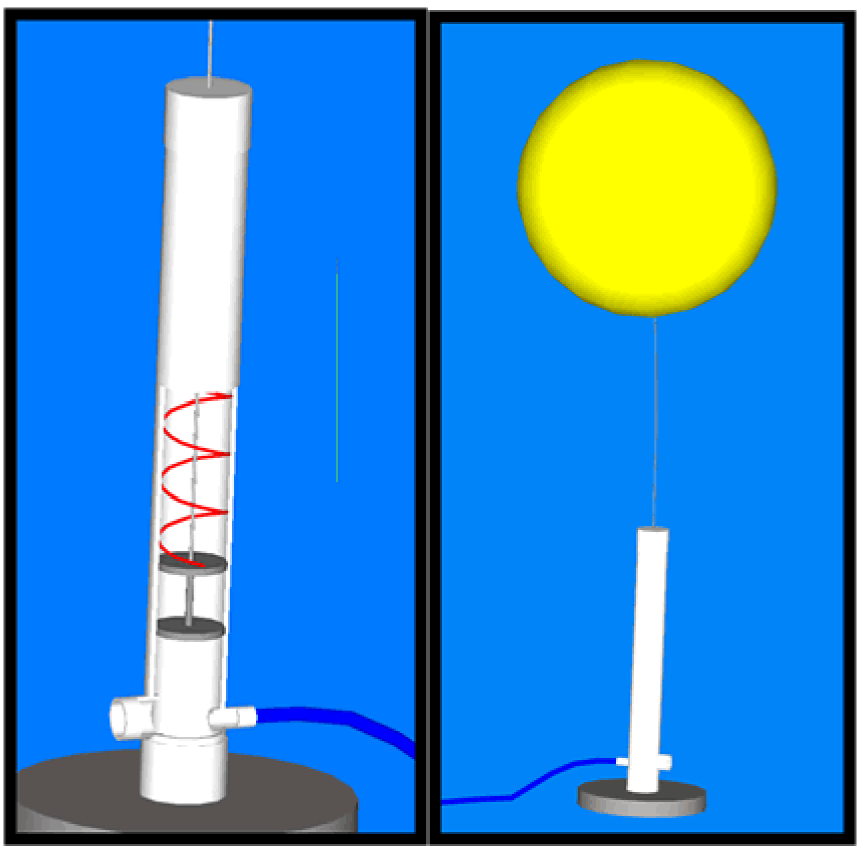


Figure 6.1.1 – The vertical pump

Commercial Pumps

After the vertical pump research, the team decided to research commercially made pumps with the hope that we would find one that could be used for our device. We investigated various pneumatic pumps and some commercial piston pumps. We decided not to use pneumatic pumps because they required oil lubrication, an unacceptable requirement for device which will be submerged in water. The commercial piston pumps that were investigated would not fit in our design because either they pumped in the wrong direction or their size was not suitable for our design; however, the basic design of one pump was used to fabricate our own pump.

Final Pump

The fabrication process began by purchasing a siphon pump that utilized a piston for its operation. We reverse engineered this siphon pump by taking it apart and studying its components and specifically how it was sealed when pushing fluids out. Based on this siphon pump, we designed our pump. We optimized our pump diameter such that we could generate the greatest amount of pumping pressure and satisfy our requirement of 300 gallons per day while considering the materials available to us. We determined that as the diameter of our pump increased, the pumping pressure decreased. Figure 6.1.2 shows this relationship and Appendix 12.3 shows the computations used. The schematics of the pump can be found in the Appendix 12.7.

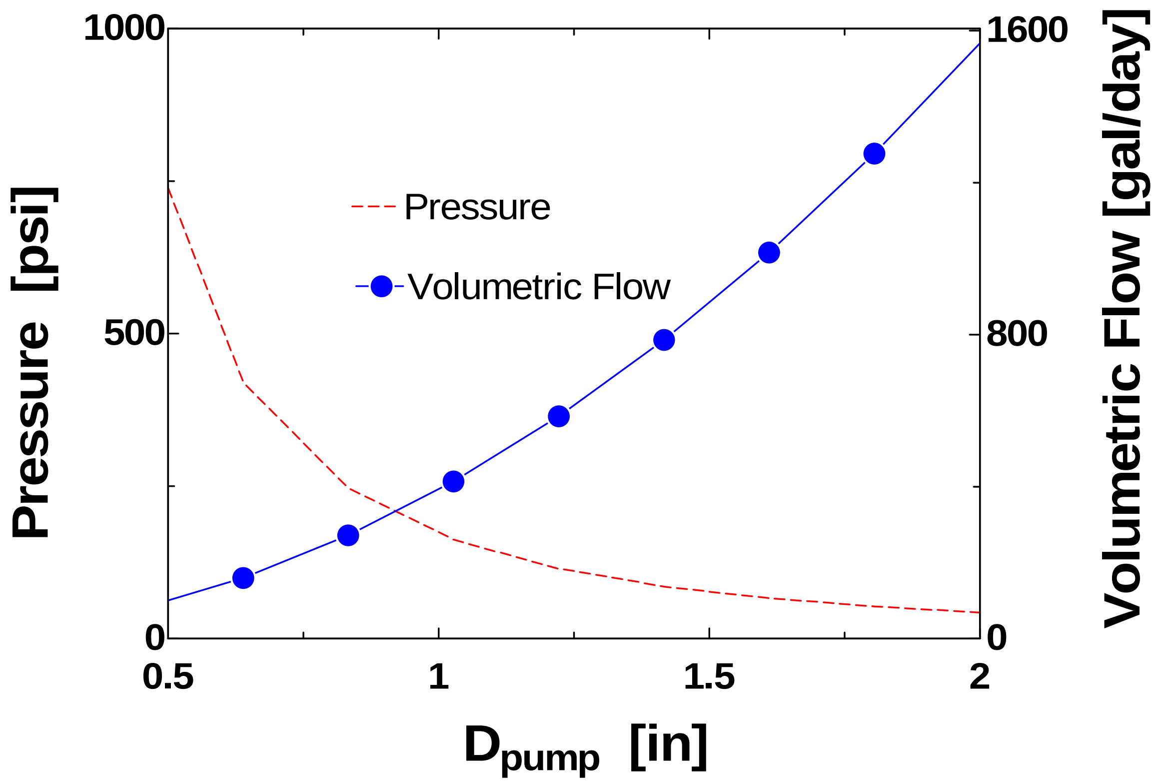


Figure 6.1.2 – Pump Diameter Optimization Diagram

6.2 Frame Designs

The orientation of the pump caused us to evaluate two frame designs. We considered a vertical orientation and a horizontal orientation within the frames. Each orientation additionally called for a new design of the bobber arm and how it was attached to the pump.

Vertical Orientation - Cam

The distinguishing feature in the vertical frame design is its utilization of a cam roller to contact the pump and actuate it. Figure 6.2.1 shows the wooden prototype built based on this design. The prototype was built so we could ensure that the arm action could push the piston down to pump the water out of the pump. The cam shape was also determined so that the contact point remained constant over the surface of the pump. This prototype was successful in pumping water, however; the base of the frame experienced stresses and cracked.

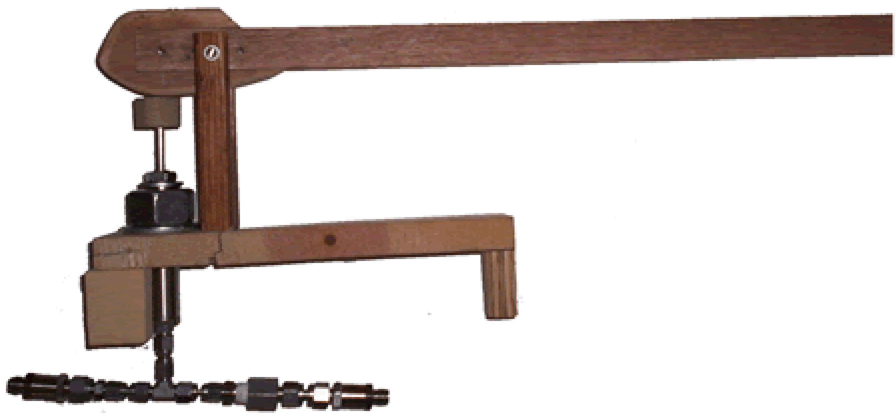


Figure 6.2.1 - Vertical Frame Design with Cam

Vertical Frame - Pivot

The vertical pump orientation was also investigated using a pivoting pump, vertically oriented. This design proved to be taller than desired and required more material for its construction in comparison to the horizontal design. Another downside to this design was that it had an increased surface area, perpendicular to water currents. This facilitated moving bodies of water to push against the frame and make it unsteady. Figure 6.2.2 shows a prototype built with this frame design.

Figure 6.2.2 - Vertical Frame Design with Pivoting Pump

Horizontal Frame Designs

The horizontal pump orientation features an 'L' shaped bobber arm in which the shorter length of the bobber arm is connected to the pump. The pump is oriented horizontally within the frame. The main attribute of the horizontal pump design is that it is low lying. This allows it to operate in lower wave conditions. Two variations of the horizontal pump design were considered. These designs are the flat base (Figure 6.2.3) and the steel pipe design (Figure 6.5.1).

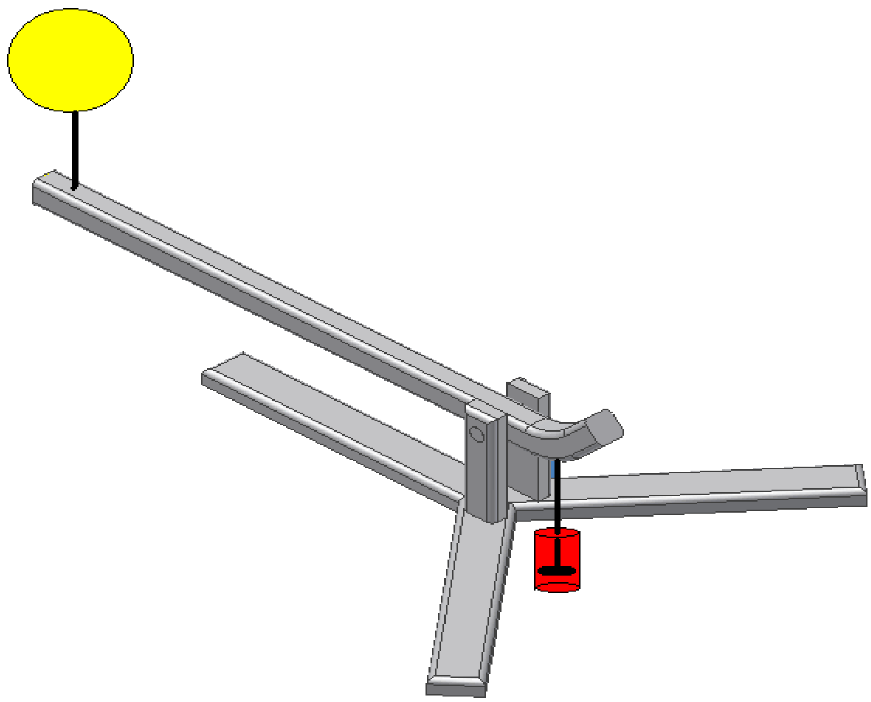


Figure 6.2.3 - Flat base frame design

The essential feature in the flat base frame is the large surface area of the base. This design was abandoned after testing in the Gulf of Mexico. The test showed us that a large base was not a wise choice because although it provided convenient locations on the device for easy anchoring, it made anchoring more difficult. Lateral forces from the water current imposed hydrodynamic forces that tended to lift the entire device. The frame design needed to have less surface area and also had to be streamlined in order to minimize the hydrodynamic forces.

The final design that was considered and chosen was the steel tube design. This design can be seen in Figure 6.5.1. The unique quality this design displays is a streamlined frame that minimizes the hydrodynamic forces due to the water current. This design also implemented optimal locations for weight addition and used stakes to firmly anchor the device in a sandy or muddy lake bed. The lever arm used a 10:1 ratio such that the buoyancy force increased tenfold when applied to the pump. Schematics for the final design of our frame can be found in Appendix 12.7

6.3 Floatation Devices

We made the following considerations when designing our flotation device or “bobber.” We had considered a Styrofoam ball as a lightweight and environment resistant option, however; finding a suitable ball proved more difficult and costly than we had assumed. A thirty inch diameter ball from Barnard Limited (http://www.barnardltd.com) costs $93.00. We contacted West Marine about our project, and they offered us a buoy for about a quarter the original price. This buoy can generate 14 pounds of buoyancy force and was made from a plastic material specifically designed for the harsh marine environment.

6.4 Accessories

In order for our device to function, critical decisions were made with regards to other accessories. These are outlined below;

***Cable* –** Attached the bobber to the lever arm. It was made out of nylon to take care of corrosion issues.

***Fittings* –** The frame was made of threaded tubes that could be screwed into fittings so the device can be easily disassembled.

***Brass Bushings* –** The brass bushings acted as bearings to reduce the friction during the movement of the bobber arm.

***Check Valve* –** This would allow the water to flow out of the pump with no back flow.

***Woven mesh* –** This would prevent sand and other debris from entering the pump and interfering with the pumping action.

6.5 Final Prototype

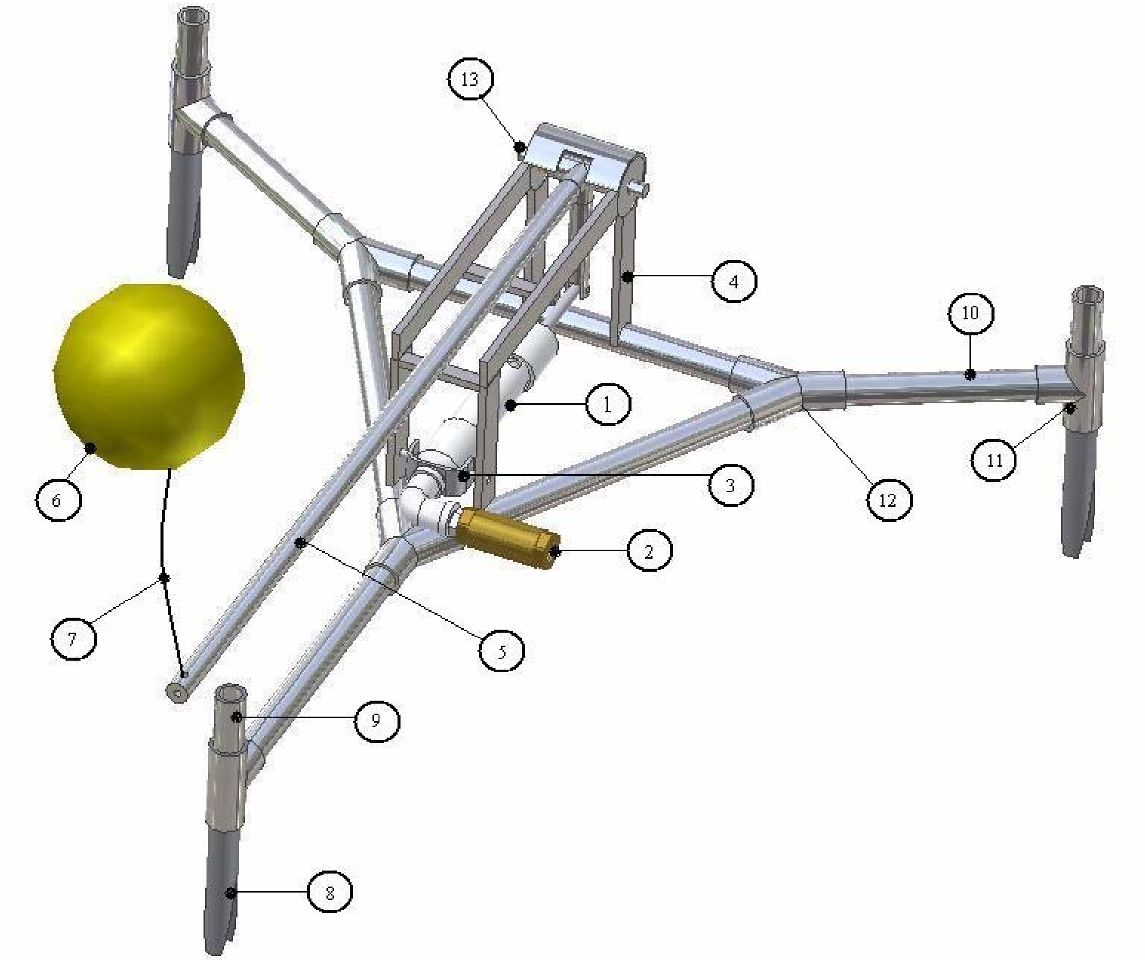


Figure 6.5.1 – Labeled Prototype

1) Piston Style Pump	8) Stake
2) Check Valve	9) Location of Weight Addition
3) Pump Pivot Bracket	10) Leg to Stake and Weight Addition
4) Lever Arm Side Support	11) Common T Fitting
5) Lever Arm	12) Custom T Fitting
6) Buoy	13) Bushing and Pin Assembly
7) Nylon Rope	

7 TESTING

7.1 Pump Pressure Test #1

One of the tradeoffs to building a pump is not knowing all the specifications of the pump. After building the pump, it was necessary to test the pumping capability. According to task specifications, water must be pumped to at least 50 vertical feet. This amounts to a pressure of about 25 psi. This pressure required the pump to be sealed with tight fittings. An area of concern in testing the pump was the two check valves in the pump assembly. If the check valve integrated into the piston was insufficient, water could not be pumped up to 50 feet but leak from within the pump. If the second check valve required a great deal of pressure to overcome the back pressure, the pump would also fail. These concerns were laid to rest after testing the pump.

A hose was laid out and marked at 10-foot increments. The hose was hung from the third floor of Calvin's DeVries Hall all the way to the basement. Altogether this was a distance of about 55 feet. A bucket filled with water was placed in the basement, and the pump was manually driven.

At first it did not seem like the pump would work. Minutes went by without any sign of the water reaching the top, however; after about three minutes water was observed flowing out of the end of the hose on the third floor. The only leakage that occurred was between the standard garden hose connection and a fitting attached to the pump. The pump itself remained completely sealed and intact.

It is estimated that at least 75 pounds of force was input into the pump. An important lesson gained from this experience however is that of watertight seals. The amount of pressure that can be developed in the pump (and in the system as a whole) depends heavily on the seals. It is possible that the pump could achieve heights greater than 55 feet; however, the force required to achieve this also increases.

7.2 Pump Pressure Test #2

In a second and more direct pressure test, the entire device was submerged in a 90 gallon tank where it could be manually operated to simulate the action of waves. A 500 psi range pressure gauge was attached. Initially, each stroke of the arm would cause the gage to display a reading of about 80 psi. This would rapidly drop down to zero. This was due to improper seals in the gauge. The fittings were reattached using Teflon tape. The device was placed back in the tank and a pressure of 350 psi was recorded. The check valve held, but the pressure gauge still had a few leaks so the gauge would drop steadily after the maximum was reached. In order to test to see that the gauge was indeed calibrated and working, it was also connected to a faucet in the building. A reading of about 35 psi was measured. This was a reasonable reading and verified the gauge was correctly calibrated.

Figure 7.2.1 – Picture taken moments after the pressure gauge peaked at 350 psi

It is estimated that the input force was about 45 pounds. The mechanical advantage did all the work. The maximum pressure obtained in the pump is higher than the recommended operating range of the pump. The pin between the bottom arm and the aluminum rod was bent during the test due to the 45 pound load (recommended load is 14 pounds). Furthermore, the test was destructive to the pump cylinder, therefore; it is not recommended that the pump function above 100 psi. Above this range, the pump may be damaged.

7.3 Pool Test

On March 14, 2005 a wooden frame prototype was tested in a pool in Dallas, Texas. The wooden frame was a mock up of the proposed metal frame. The frame was loaded with 32 pounds of weight and lowered into a 12 feet deep pool. The frame handled very well when entering and leaving the water after a few modifications were made to the lever arm support system and the weight distribution system. These modifications included adding a second support arm for the lever arm and a spreading the weight out in front of the device. With these slight modifications, the Bobber was able to be thrown horizontally into the pool and glide down to the bottom. The weights were sufficient in holding down the entire device.

The problems with this prototype included the lever arm not returning to the horizontal position, the lever arm rising to far causing the pump to over actuate and stick, and the pump not pivoting correctly. The first problem was solved by adding weight to the end of the lever arm causing it to fall back into position. The wooden lever arm will be replaced by metal in the next prototype. This material change will cause the lever arm to fall on its own accord because it will not have any buoyancy force. The second problem was solved by tying rope from the frame to the end of the lever arm, limiting the amount of travel. The last problem was solved by attaching the pump with a new set of zip ties which were not tied as tightly (about ½" of play). In the final design the pump will be mounted on an actual pivot, allowing the pump to move as needed.

The pool test showed that the design would actually glide to the bottom of a body of water and that the pump worked when the buoyancy device was driven by hand (repeated dunking of the buoy). The test was documented by use of video and still photography. Further testing in a large body of water is needed to determine the prototype's performance with actual waves.

7.4 Ocean Test

On March 15, 2005 the wooden frame prototype was tested in the Gulf of Mexico, off the shores of South Padre Island, Texas. The conditions were extremely windy and the seas were very rough. Despite the conditions, the Bobber was carried out do a depth of about 2-3 feet. This was right where the waves were starting to break, but because of the rough seas it was the furthest out the Bobber could be safely taken.

It was quite apparent from the very beginning that the device was not able to support itself. This was due to the strong currents of the water. The Bobber's wooden frame was built out of 4 inch wide side supports and a 6 inch wide base. This provided the currents a large surface area to act upon as it pushed the Bobber back and forth along the bottom. The flat bottom of the frame provided negligible resistance to the horizontal forces. Accepting defeat in effectively anchoring the Bobber, Andy Van Noord and Tunde Cole positioned themselves on top of the Bobber in an attempt to hold it down. This allowed the Bobber to stay somewhat stationary, and the waves were able to actuate the lever arm by means of the buoy, a milk jug. The Bobber was able to pump water once anchored by the team members.

The test showed that the entire framed must be redesigned to overcome the obstacles discovered. There must be a redesign that minimizes surface area of the frame in order to decrease the hydrodynamic drag. There must also be a means of digging into ocean or lake bed in order to prevent the device from sliding along the bottom. The test was documented by use of video and still photography. Once redesigned, the Bobber must be tested further to determine the performance capabilities.

7.5 Reed’s Lake Test

After a major redesign to the Bobber frame, the final prototype was tested in Reed's Lake on April 15, 2005. The frame was loaded with 32 lbs (four 8 lb weights). A rope was also tied to the frame in case the buoy became unattached, and the frame needed to be hauled out of the water. This rope was tied off to the bow of the boat with about 20 feet of line. The frame was then placed into the water. The water depth was about 6 feet. Then the hose was unreeled and allowed to fill with water. The wind picked up a little but not enough to create any significant wave motion; however, the boat was blown out of position. The boat in use was 16½ ft speed boat with a V-hull and loaded with 4 adult passengers. The wind was causing the boat to drift at a steady pace until the 20 ft rope had no more slack. All of the sudden the boat came to an abrupt stop and the bow swung around towards the direction of the Bobber. The Bobber frame was anchoring the entire boat. The lake bed of Reed's Lake is muddy and the metal spikes were able to penetrate this mud enough to hold the boat in position.

Finally the buoy was manually pushed and released under water for about a minute. This caused the pump to start pushing water through the hose. The next step was to put a nozzle on the end of the hose to test the pressure. After a few minutes of pumping, the nozzle was depressed and shot water about 10 feet. This was repeated but the nozzle was not depressed. After a few minutes it was evident that the water was not leaking out of the connections and the pressure was maintained.

The conclusions from this test are two fold. One, the Bobber frame is well built and anchors extremely well. Two, the Bobber pump works with the horizontal arrangement and maintains adequate pressure. The concern still remains that Lake Michigan testing conditions are different than Reed's Lake and the Bobber may function differently. Further testing is necessary to determine the functionality of the device in a large body of water with actual waves. This test was documented using still photography.

7.6 Lake Michigan Test #1

After seeing how the anchoring system worked in a lake environment in the previous Reed's lake test, we then proceeded to make plans on having an open water wave test in Lake Michigan at Holland Beach. The anchoring system was still a concern, though somewhat abated from the last test. We weren't exactly sure how it would behave in open water conditions with both vertical and lateral forces.

The test was planned for April 21, 2005. The wind was blowing around 10-15 miles per hour and at first in the wrong direction, parallel to the shore. The wind shifted and began to produce 1-2 foot waves that would be adequate for testing our device. The device was placed approximately twenty feet into the lake at a depth of 2-3 feet. The waves were adequate for pumping water, but no water came out of the hose. After examining the device, it was discovered that the hose fitting was loose, and we did not have the required tools to tighten it.

The day was not a loss, however, as we got to see the anchoring system in a fairly hostile environment. The device held, was easy to place in the water, and just as easy to remove. It did not require force to place it in the sand; its own weight was adequate. It stayed completely anchored even when the waves swept over the top of the buoy and went completely underwater. Further testing was still necessary to demonstrate the pump's performance under real world conditions.

7.7 Lake Michigan Test #2

Failing to demonstrate the pumping ability on the first Lake Michigan test, a second test was required. On May 1, 2005 the team returned to Holland State Park to test the Bobber. The Bobber was placed about 20 feet from shore and in 2-3 feet of water. The air temperature was about 45 F; the water temperature was about 40 F. The wind was blowing at about 5 mph, and the wave height was about 2 feet. The fittings held tight, the undulating waves lifted the buoy, and the Bobber pumped water. This test proved the complete success of the Bobber. Every requirement set for the wave power water pump had been achieved. The Bobber anchored itself in pounding waves. The water pressure had been tested to over 164 psi with the size buoy we were using. The volumetric flow rate of the pump was achieving the 300 gallons per day. This test was documented using still and video photography.

8 FINAL DESIGN

8.1 Materials

Due to monetary and time constraints, ideal materials were not always available during the construction of the final prototype. This section specifies the materials that should be used in the final design versus the materials actually used in the prototype.

The pump was the first part of the design that was considered. Metals were out of the question because corrosion on the inside of the pump would cause poor pump piston movement as well as loss of pressure due to pitting on the walls of the pump. Plastics were the obvious choice, but choosing a suitable plastic was the next hurdle.

Poly vinyl chloride, PVC, came out to be one of the leading contenders in the choice for plastic materials for the pump body because it has good ratings for cold-water use and is resistant to bacterial or fungal growth due to its extremely smooth surface finish. It is also stronger, lighter and cheaper than most other common plastics.

One consideration was whether thermal expansion and contraction would be an issue. If the pump contracted too much in cold weather, the plunger would be pressed harder against the sides of the pipe.

Plastic Type	Relative Thermal Movement
Engineered Plastics (ABS, Acrylic, Polycarbonate)	1.0
Polyvinyl Chloride (PVC)	1.5
Polyethylene	1.8

To find out how important this factor was, calculations were done to determine the change in wall thickness of PVC for a specified range of temperatures. Our calculations, shown in Appendix 12.3, revealed that the change in wall thickness that can be expected from the PVC is about 0.7 thousandths of an inch, a negligible number. The plunger for the pump was chosen to be nylon because of its extreme durability and self-lubricating properties. These material used for the pump in the prototype are recommended for as the materials to be used in the final pump design.

The materials for the pump had been chosen, but the issue still remained as to what could be some possible materials for the frame. Polyurethane was a plastic option for the frame because it has excellent abrasion, corrosion and impact resistance and is also affordable.

As for metals, steel and aluminum were both options. Steel is not corrosion resistant by itself. Aluminum will also corrode when exposed to oxygen, especially when surrounded by water, but will take more time to do so. It would seem that either metal would need corrosion protection in the form of a coating. The weight and the cost of aluminum were considered.

The weight was an issue because a lighter product would be more economical to ship, but would have to be weighted down more before implementation. The real deciding factor became price. The team had already decided to use tubing for the bobber frame, and the price of aluminum tubing is approximately 3 to 4 times as much as steel tubing, so coated steel was the metal option for the frame. The coating was chosen to be a layer of rubberized spray on top of a layer of primer, covered with a layer of paint. The rubberized spray would provide durability for the coating to ensure it did not chip or rub off easily. The specified material for the frame is aluminum to protect against corrosion due to the harsh environment of wind and water. Also instead of using bronze bushings that rub directly against the frame at the lever arm pivot point, two nylon bushings should be used at the frame and the lever arm pivot point locations such that their relative motion against each other will reduce wear.

8.2 Accessories

Due to the various applications of the 'Bobber,' a variety of accessories would accompany the product. A valve would be needed if the flow of the water needed to be controlled. This valve would be attached to the end of the hose that will be out of the water. A pressure relief valve should also be included in the final design. This pressure relief valve should be set to open at 100 psi. This is well under the maximum pressure the PVC pump is rated (testing has shown the pump can handle up to 350 psi). Another design accessory should be a plastic mesh around the side supports. By enclosing the pump, the chances of anyone pinching their fingers or toes if swimming near the Bobber will be reduced. We recommend a plastic mesh for this application because it is low cost and it will not corrode. Also, a mesh is specified to minimize hydrodynamic forces. See Figure 8.2.1 for Prototype design with mesh in place.

Figure 8.2.1 – Mesh for safety precautions

9 STRUCTURAL ANALYSIS

The loads subjected to the Bobber need to be determined in order to calculate the stresses in the device. For example, in a worst case scenario where the pump is stuck, possibly due to build of sediment in the pump, the stress must be determined in the lever arm. If these stresses exceed the yield strength of the material used, the device will fail. Three main areas of the device were studied for structural integrity. They are:

-Connection between the T-joint and lever arm

-Pin connection between arm and pump

-Pin connection between pump and frame

Connection between the T-joint and lever arm

For the hand calculations, the lever arms (parts 1 and 3 shown in Figure 9.1.1) were assumed to be rigidly attached to the fitting (part 2). An equation for beam bending and torsion was used for rough approximations for stresses in these members.

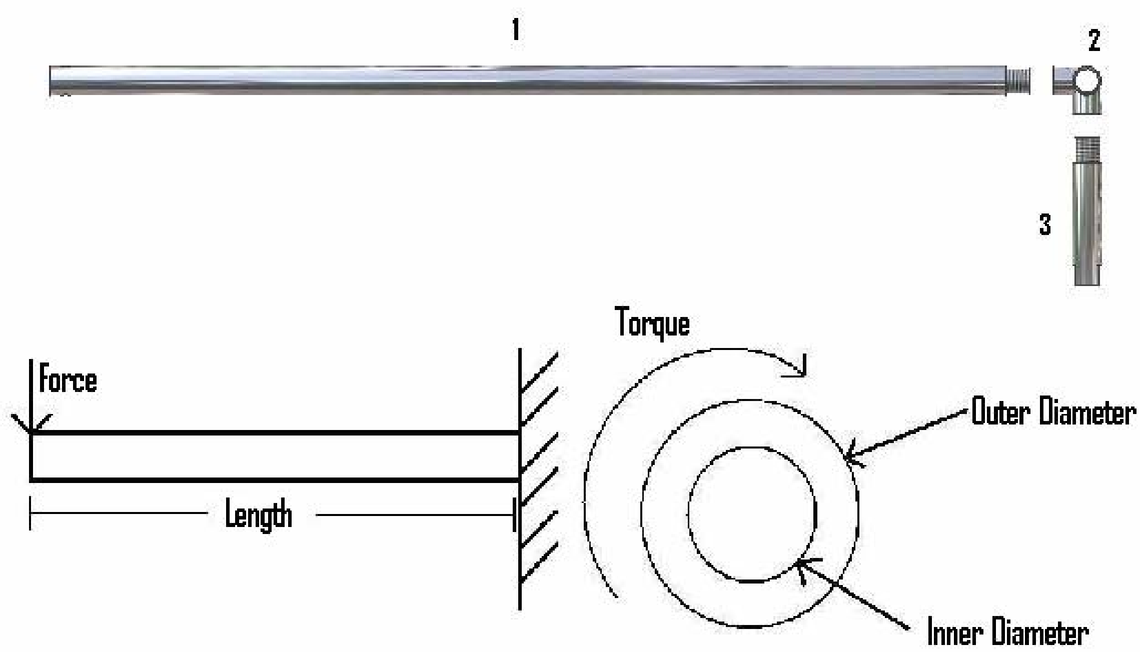


Figure 9.1.1 – Diagram of the three parts that the arm assembly was spilt into for analysis. Also shown are the models used to calculate stresses.

Parts one and three were modeled as cantilever beams in bending. The torsional forces were ignored since bending is the dominate force. Part two was modeled as a circular rod in torsion. The software EES was used to perform the necessary calculations. The force experienced by the end lever arm is known to be 14 pounds force due to the buoyancy force of the buoy. This translates to about 140 pounds force at the pivot due to the mechanical advantage of the lever arm. Properties such as the moments of the inertia (both I and J) were found. Bending stress and shear stress were found using the following equations:

$$\sigma = \frac{M \cdot c}{I} \qquad \tau = \frac{\mathrm{T} \cdot c}{J}$$

M is the moment about the beam, T is the torque and c is the distance from the centriod of the beam to the edge of which stress is being measured. Results are shown in Table 9.1.1.

Table 9.1.1

σ_{part1}	22 [ksi]
τ_{part2}	11 [ksi]
σ_{part3}	22 [ksi]

These are well below the yield strength of steel or aluminum that would be used for the device.

Pin Connections

A basic shearing analysis was performed on the pin connection between the arm and pump and the pin connection between the pump and frame. Using the force obtained by mechanical advantage and the cross-sectional areas of the respective pins, the following equation was used to find the shear stress in the pins. The results are shown in Table 9.1.2

$$\tau = \frac{Force}{Area}$$

Table 9.1.2

$\tau_{arm-pump}$	5.4 [ksi]
$\tau_{pump-frame}$	5.4 [ksi]

These stresses are well below the yield strength of steel or aluminum materials.

Finite Element Analysis

A finite element analysis was performed for comparison purposes using ALGOR software. An arm assembly was created in Autodesk Inventor and then transferred to ALGOR. The assembly consisted of the lever arm, bottom arm, T-joint, left and right bearings, T-joint pin, and the bottom arm pin. Both the T-joint pin and the bottom arm pin were fixed as boundaries conditions in the x-y-z directions. The end of the lever arm was loaded with 14 pounds of vertical force. Results of the FEA showed the highest stress to be 64 ksi. This much stress would cause failure in the part, however; the model is slightly inaccurate.

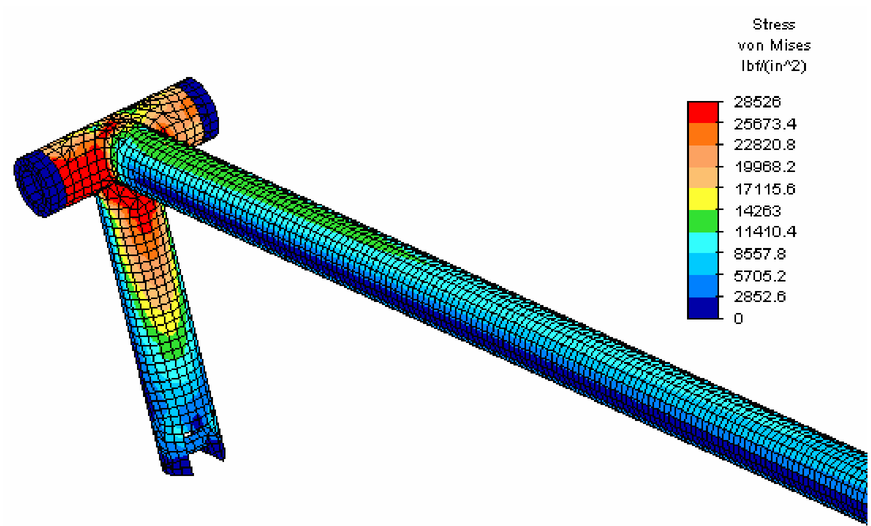


Figure 9.1.2 – FEA on arm component

In actuality, the T- joint is actually thicker than the model. It is also difficult to model the welds between the bottom arm and T-joint, so the welds were modeled as simple bonds, introducing errors. With this consideration, the stress was calculated to be about 16 ksi. The overall stress is higher because the FEA analysis takes stress concentration factors at the joints into account. Displacement was about 0.7 inches at the end of the arm.

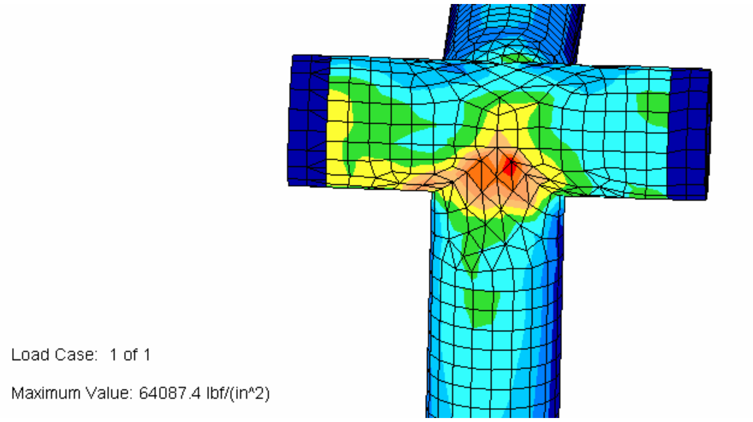


Figure 9.1.3 - Stress concentration in the Joints causes higher stresses

The pin connection between the arm and pump, the swivel bracket, the bracket pins, and the two front supports were put into an assembly in Inventor. This assembly was transferred to ALGOR. The bottom surfaces of the front supports were constrained in the x-y-z directions while the bracket was loaded with almost 170 pounds of force.

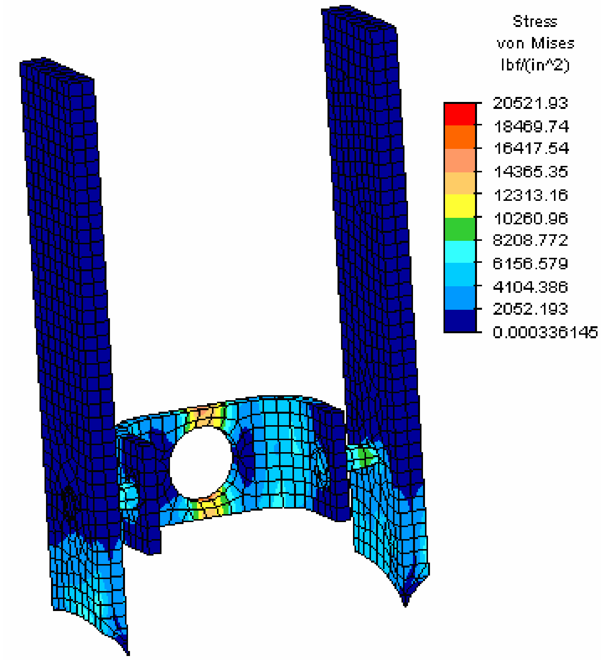


Figure 9.1.4 – Stress developed in the pump bracket

Under these conditions, shear stress developed in the pins was about 8.4 ksi. The higher stresses occurred in the bracket and were about 20 ksi. This indicates that the pins are not an area of major concern under nominal conditions. Maximum deflection found was four thousandths of an inch. Most of the stress developed in the pump is transferred to the front supports. Solid welds are needed at that point to ensure that failure does not occur. The pins showed deflections on order of thousandths of an inch. The deflection in the bracket was about 0.0025 inches.

10 COST ESTIMATE OF FINAL PRODUCT

10.1 Costs to Manufacture Final Product

The prototype for the wave powered water pump was constructed using iron and steel pipe, however; aluminum or polyurethane would not corrode as easily. If the wave powered water pump was put into production, there would need to be further testing on the plastic and aluminum to determine how durable they would be in the harsh marine environment. The following is a cost estimate for the frame construction if using aluminum or plastic. These costs are only for the frame.

Polyurethane plastic				
Part	Description	Price per unit	Quantity	Total
1	1" of schedule 40 1" poly plastic tube	0.26	178	46.28
2	Plastic 1" tee fitting	4.73	4	18.92
3	Plastic 1" pipe cap	0.48	3	1.44
4	1" of 2" x .5" plastic framing bar	0.54	25	13.5
			Total	80.14

Aluminum				
Part	Description	Price per unit	Quantity	Total
1	1" of schedule 40 1" aluminum tubing	0.69	178	122.82
2	Aluminum 1" tee fitting	7.69	4	30.76
3	Aluminum 1" pipe cap	3.47	3	10.41
4	1" of 1" x .5" aluminum framing bar	0.16	25	4
			Total	167.99

Besides the framing, all other costs such as floatation device, pump, etc. would be comparable between the three choices. See Appendix 12.1 for pump and miscellaneous costs. The following is a summary of total costs for the three material choices.

Steel	$160.28
Aluminum	$261.66
Polyurethane	$173.81

We recommend using aluminum even though it is the most expensive choice. Aluminum will stand up better in the marine environment and is strong enough to withstand the stresses applied to it. Using polyurethane would require a substantial redesign of the frame.

11 CONCLUSION

11.1 Assessment of Project Objectives and Requirements

Upon the conclusion of this project, the assessment has been made that the Bobber is a successful prototype. It met or exceeded all objectives and requirements set.

Objectives:

Set	Achieved
Design and Build Wave Powered Water Pump	Figure 1.3.2
Test the Device and Assess its Performance	Section 7
Generate Schematics of All the Parts of Design	Appendix 12.7
Provide Documentation on How to Build and Assemble a Prototype	Appendix 12.4, 12.5
Present a Final Design that is Complete with Recommendations on Future Improvement	Section 8

Requirements:

Set	Achieved
Pressure Greater than 25 psi	164 psi
Portable / Weight Limit of 50 lb	49 lb
Volumetric Flow rate of 300 gpd	391 gpd
Budget not to exceed $500	$129.09

We are deeply satisfied with the outcome of our project, from the design stage through the construction stage and finally testing. We effectively demonstrated and proved that the wave powered water pump can indeed harness wave energy and pump water. We created a device which can potentially save users money by pumping free water, free of charge. The cost savings of having a wave powered water pump were calculated. See Appendix 12.3. The electrical savings were only $2.49/year (versus having an electrical pump), but the water utility savings were $286/year based on average *external* water usage of people living outside of a city. This is a substantial monetary savings.

11.2 Future Recommendations

We have several recommendations for the further design and testing of the Bobber before it is put into production. Cycle testing needs to be performed on a complete prototype to ensure the device will continue to work as desired after years of use. The steel materials used for the prototype are not recommended for the final design unless they are tested in actual conditions for an extended period of time to determine the amount of damage rust would cause the device. It is possible with the right type of coating material that the current steel materials would hold up for several years before corroding to a point of disrepair. We recommend that aluminum be used as the material for the frame instead of steel or iron pipe. Using a polyurethane plastic for the frame would require more testing and design and is therefore not recommended with the current schematics and calculations. We also recommend securing a plastic mesh around the supports to keep the fingers and toes of curious swimmers out of the way of the pivot point. This small safety measure would ensure that no one could be accidentally injured by the motion of the lever arm. A pressure relief valve and a valve to limit the flow are also recommended in the final design. These two small parts would increase the functionality and act as precautionary measures to ensure a user could not accidentally misuse and damage the pump.

12 APPENDICES

12.1 Expense Report (Bill of Sale)

12.2 Project Timeline

12.3 Computations

12.4 Assembly per Component

12.5 User Manual

12.6 Customer Survey and Comments

12.7 Design Schematics

12.1 Expense Report (Bill of Sale)

The following is a list of the parts purchased.

Piston Pump	Grainger	$9.50
Pipe and Fittings	McMaster-Carr	$76.53
Split Ring Hanger	McMaster-Carr	$9.46
Bronze Bearings	McMaster-Carr	$11.58
Buoy	West Marine	$9.54
Pipe Fittings	Lowes	$4.55
Paint	Wal-Mart	$7.93
	Total	$129.09

Most of the materials used for the frame construction were scrap materials found in the metal shop at Calvin College. The following is a list of actual parts used in the Bobber prototype and their estimated cost.

Pipe/Fittings				
Component	Description	# of items	Price per item	Total price($)
1	Iron pipe, 1/2" schedule 40, 14" frame base	3	3.08	9.24
2	Iron pipe, 1/2" schedule 40, 21" arm	3	4.62	13.86
3	Iron pipe, 1/2" schedule 40, 46" bobber arm	1	10.12	10.12
4	Iron pipe, 1/2" schedule 40, 5.5" arm base	1	1.21	1.21
5	Iron pipe, 1/2" schedule 40, 4" weight holder	3	0.88	2.64
6	Iron pipe, 1/2" schedule 40, 7" spike	3	1.54	4.62
7	1/2" Black iron pipe caps	3	1.08	3.24
8	1/2" Black iron T Junctions	4	2.81	11.24
			Sub Total:	56.17

Pump Parts				
Component	Description	# of items	Price per item	Total price($)
1	Aluminum rod, 1/4" dia x 8" long anodized	1	2.04	2.04
2	Nylon 90 deg elbow 3/4" pipe	1	2.57	2.57
3	1" Pipe cap, PVC	1	0.31	0.31
4	3/4" x 1" male adaptor, PVC	1	0.44	0.44
5	Bronze check valve, 3/4" pipe fittings	1	16.04	16.04
6	PVC pipe, 1" std, 7 1/4" long, schedule 40	1	0.24	0.24
7	3/8" x 1" dia 6/6 Nylon disk	2	0.09	0.18
8	Polyurethane bumper, 1" dia disk	1	0.41	0.41
9	Screen Filter	1	0.47	0.47
			Sub Total:	22.23

Steel Bar				
Component	Description	# of items	Price per item	Total price($)
1	1/4" x 1" x 2.5" Cross-member	1	0.58	0.58
2	1/4" x 1" x 9" Cross-member	2	2.07	4.14
3	1/4" x 1" x 5" Cross-member	2	1.15	2.3
4	1/4" x 1" x 5.5" Cross-member	2	1.27	2.54
5	1/4" x 2" x 2" Cross-member	2	0.44	0.88

			Sub Total:	10.44

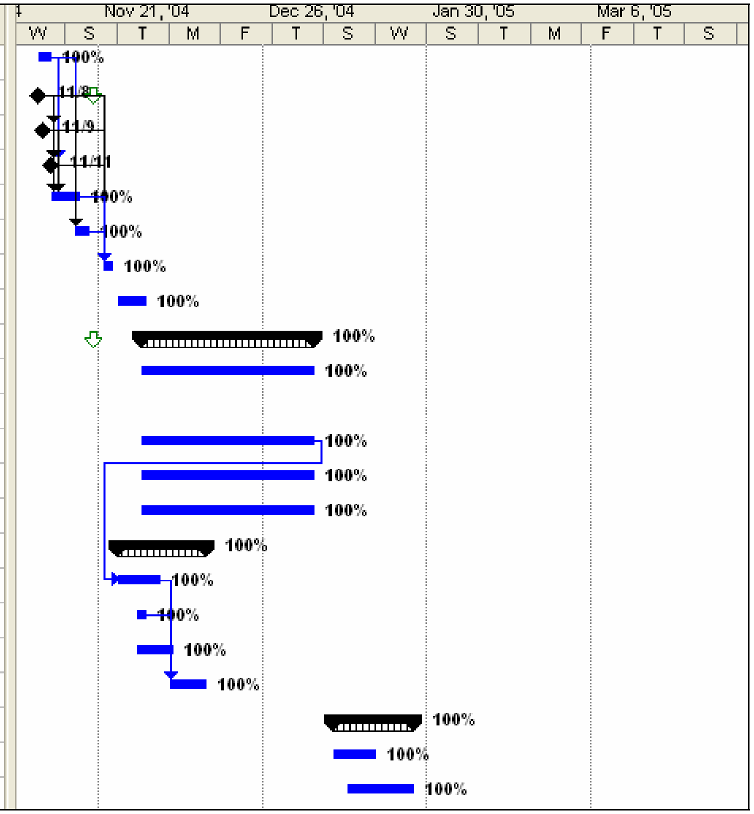
Miscellaneous				
Component	Description	# of items	Price per item	Total price ($)
1	Bronze bushings, 1/2" rod, 5/8" dia	2	3.97	7.94
2	Split ring hangers 1" pipe size	2	2.73	5.46
3	Nylon bushings, 1/4" rod, 3/8" dia	2	1.2	2.4
4	Dowel pin, 3/16" dia x 2" long	1	0.21	0.21
5	Dowel pin, 1/2" dia x 5" long	1	5.11	5.11
6	Hitchpin clip for 1/2" rod	2	0.1	0.2
7	Hitchpin clip for 3/4" rod	3	0.25	0.75
8	Vinyl coated steel wire rope, 1/8" dia, 2.5 ft	1	0.63	0.63
9	Nylon solid braided rope, 10 ft, 1/4" dia	1	1.264	1.264
10	Steel wire rope clip for 1/8" rope	2	1.87	3.74
11	Steel wire rope clip for 1/4" rope	2	2.77	5.54
12	Zinc plated oval compression sleeve for 1/8" rope	1	0.27	0.27
13	Zinc plated oval compression sleeve for 1/4" rope	1	0.94	0.94
14	Buoy	1	36.99	36.99
			Sub Total:	71.444

			Grand Total:	160.284

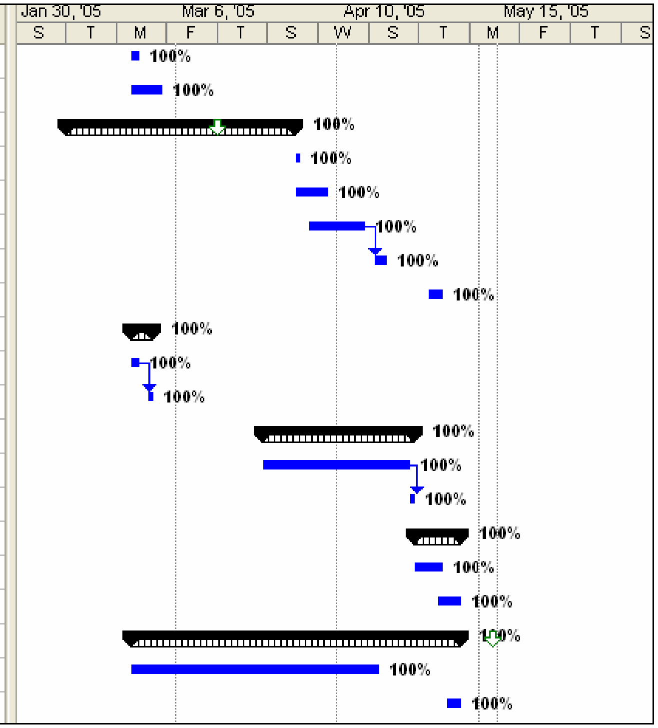
12.2 Project Timeline

In order for the project to be successful, the team followed a schedule. This schedule was created using Microsoft Project. The software enabled the team to proceed with the project in a stepwise approach while always completing the high priority tasks at the right time. It also allowed the team to plan and make sure that there were always tasks for each individual member to perform. Below we have the project file that the team followed during the course of the project. It shows also shows a Gantt chart together with the text.

	Task Name	Duration	Start	Finish
1	Group Poster	3 days	Mon 11/8/04	Wed 11/10/04
2	Call DNR	1 day	Mon 11/8/04	Fri 11/19/04
3	Determine Regulations	2 days	Tue 11/9/04	Wed 11/10/04
4	Subscribe to IAGLR.org	3 days	Thu 11/11/04	Mon 11/15/04
5	Yearly Wave Info Database	4 days	Thu 11/11/04	Tue 11/16/04
6	Determine Testing Feasibility	3 days	Tue 11/16/04	Thu 11/18/04
7	Meeting with Ind. Consultant	2 days	Mon 11/22/04	Tue 11/23/04
8	Monthly budget Report	4 days	Thu 11/25/04	Tue 11/30/04
9	**Analyze System Components**	**27 days**	**Tue 11/30/04**	**Wed 1/5/05**
10	Pump Research	27 days	Tue 11/30/04	Wed 1/5/05
11	Valve Research	27 days	Tue 11/30/04	Wed 1/5/05
12	Bobber Research	27 days	Tue 11/30/04	Wed 1/5/05
13	Cable Research	27 days	Tue 11/30/04	Wed 1/5/05
14	Anchoring Alteranatives	27 days	Tue 11/30/04	Wed 1/5/05
15	**Class Requirements**	**13 days**	**Thu 11/25/04**	**Mon 12/13/04**
16	PPFS Draft	7 days	Thu 11/25/04	Fri 12/3/04
17	Oral Presentation PPT	2 days	Mon 11/29/04	Tue 11/30/04
18	Website Design	6 days	Mon 11/29/04	Mon 12/6/04
19	PPFS	6 days	Mon 12/6/04	Mon 12/13/04
20	**Component Analysis**	**13 days**	**Mon 1/10/05**	**Wed 1/26/05**
21	AutoDESK Design	7 days	Mon 1/10/05	Tue 1/18/05
22	ALGOR Analysis	10 days	Thu 1/13/05	Wed 1/26/05



		Task Name	Duration	Start	Finish
31	✓	Testing of new pump	2 days	Thu 2/24/05	Fri 2/25/05
32	✓	Anchoring	5 days	Thu 2/24/05	Wed 3/2/05
33	✓	**Industrial Consultant Preparation**	**37 days**	**Thu 2/10/05**	**Thu 3/31/05**
37	✓	Complete Design	1 day	Fri 4/1/05	Fri 4/1/05
38	✓	Detailed Drawing	5 days	Fri 4/1/05	Thu 4/7/05
39	✓	Material Acquisition	10 days	Mon 4/4/05	Fri 4/15/05
40	✓	Construction	3 days	Mon 4/18/05	Wed 4/20/05
41	✓	Lake Test	2 days	Sat 4/30/05	Mon 5/2/05
42	✓	**Presentation**	**3 days**	**Thu 2/24/05**	**Mon 2/28/05**
43	✓	Powerpoint preparation	2 days	Thu 2/24/05	Fri 2/25/05
44	✓	Presentation	1 day	Mon 2/28/05	Mon 2/28/05
45	✓	**Final Presentation**	**23 days**	**Fri 3/25/05**	**Tue 4/26/05**
46	✓	Powerpoint presentation	22 days	Fri 3/25/05	Mon 4/25/05
47	✓	Presentation	1 day	Tue 4/26/05	Tue 4/26/05
48	✓	**Design Banquet Preparation**	**9 days**	**Wed 4/27/05**	**Fri 5/6/05**
49	✓	Brainstorm Ideas on presentation	5 days	Wed 4/27/05	Mon 5/2/05
50	✓	Construction	5 days	Mon 5/2/05	Fri 5/6/05
51	✓	**Class Submittals and Presentations**	**53 days**	**Thu 2/24/05**	**Fri 5/6/05**
52	✓	Final Report	38 days	Thu 2/24/05	Mon 4/18/05
53	✓	Banquet Presentation	3 days	Wed 5/4/05	Fri 5/6/05



12.3 Computations

Pump Sizing Worksheet

Constants

$v1 = 0.0000166$ [ft^2/s]

$v2 = 0.00000989$ [(ft^2)/s]

$T1 = 40$ [F]

$T2 = 75$ [F]

$g = 32.2$ [ft/s^2]

Pump Variables

$D_{pump} = 1$ [in]

$Stroke = 4$ [in]

Hose Variables

$D_{hose} = 5 / 8$

$L_{hose} = 100$ [ft]

$$A_{hose} = \pi \cdot \left[\frac{D_{hose}}{2}\right]^2$$

Bobber Variables

$F_{Bobber} = 14$ [lbf]

Mech Advantage

$$Mech_{advan} = \frac{48}{5}$$

Force on Piston

$F_{piston} = F_{Bobber} \cdot Mech_{advan}$

Wave Constants

$Period = 3$ [sec]

Pump Dimensions

$$A_{pump} = \pi \cdot \left[\frac{D_{pump}}{2}\right]^2$$

Pressure

$$P = \frac{F_{piston}}{A_{pump}}$$

Head

$Head = Z$

$$P \cdot \left| 144 \cdot \frac{lbf/ft^2}{psi} \right| = \rho_{H2O} \cdot g \cdot \left| 0.031081 \cdot \frac{lb_f}{lb_m\text{–}ft/s^2} \right| \cdot Z$$

$$\rho_{H2O} = \rho(\text{'Water'}, T = T2, P = 14.7)$$

Volumetric Flow Rate

$$Vol_{pump} = A_{pump} \cdot Stroke$$

$$\dot{V}_{pump} = \frac{Vol_{pump}}{Period} \cdot \left| 0.25974 \cdot \frac{gpm}{in^3/s} \right|$$

$$\dot{V}_{day} = \dot{V}_{pump} \cdot \left| 1440 \cdot \frac{gal/day}{gpm} \right|$$

$$\dot{V}_{year} = \dot{V}_{pump} \cdot \left| 525600 \cdot \frac{gal/year}{gpm} \right|$$

Reynolds #s

$$v = 2 \cdot \dot{V}_{pump} \cdot \frac{\left| 0.002228 \cdot \frac{ft^3/s}{gpm} \right|}{A_{hose} \cdot \left| 0.006944 \cdot \frac{ft^2}{in^2} \right|}$$

$$Re1 = \frac{v \cdot D_{hose} \cdot \left| 0.083333 \cdot \frac{ft}{in} \right|}{v1}$$

$$Re2 = \frac{v \cdot D_{hose} \cdot \left| 0.083333 \cdot \frac{ft}{in} \right|}{v2}$$

Friction Factors/ Head Loss

$$f1 = \frac{64}{Re1}$$

$$f2 = \frac{64}{Re2}$$

$$hd_{loss1} = f1 \cdot \frac{L_{hose}}{D_{hose} \cdot \left| 0.083333 \cdot \frac{ft}{in} \right|} \cdot \frac{v^2}{2 \cdot g}$$

$$hd_{loss2} = f2 \cdot \frac{L_{hose}}{D_{hose} \cdot \left| 0.083333 \cdot \frac{ft}{in} \right|} \cdot \frac{v^2}{2 \cdot g}$$

Average Reverse Osmosis Pressure Requirements

$$P_{brackishosmosis} = 22 \; [bar] \cdot \left| 14.5038 \cdot \frac{psi}{bar} \right|$$

$$P_{seawaterosmosis} = 67 \; [bar] \cdot \left| 14.5038 \cdot \frac{psi}{bar} \right|$$

Structural Analysis Hand Calculations

Structural Analysis

Three main areas are studied

- T-Joint and Arm
- Pin connection between arm and pump
- Pin connection between pump and frame

Settings

Arm Dimensions

$length_{arm} := 48in$

$diameter_{armouter} := .875in$

$diameter_{arminner} := .75in$

$$I_{arm} := \pi\frac{(diameter_{armouter})^4}{64} - \pi\frac{(diameter_{arminner})^4}{64}$$

T-Joint Dimensions

$length_{tjoint} := 2.75in$

$diameter_{tjointouter} := .875in$

$diameter_{tjointinner} := .75in$

$$J_{tjoint} := \frac{\pi}{2}\left(\frac{diameter_{tjointouter}}{2}\right)^4 - \frac{\pi}{2}\left(\frac{diameter_{tjointinner}}{2}\right)^4$$

Bottom Arm Dimensions

$length_{bottomarm} := 5in$

$diameter_{bottomarmouter} := .875in$

$diameter_{bottomarminner} := .75in$

$$I_{bottomarm} := \pi\frac{(diameter_{bottomarmouter})^4}{64} - \pi\frac{(diameter_{bottomarminner})^4}{64}$$

Forces and Moments

$Force_{input} := 14lbf$

$$Force_{output} := \frac{(Force_{input} \cdot length_{arm})}{length_{bottomarm}}$$

$Force_{output} = 134.4lbf$

$$Mechanical_{advantage} := \frac{Force_{output}}{Force_{input}}$$

$Moment_{arm} := Force_{input} \cdot length_{arm}$

$Torque_{arm} := Moment_{arm}$

Stresses

Arm Stress

Arm Stress

$$\sigma_{arm} := \frac{Moment_{arm} \cdot \frac{diameter_{armouter}}{2}}{I_{arm}}$$

$\sigma_{arm} = 2.22 \times 10^4 \, psi$

T-joint Stress

$$\tau_{tjoint} := \frac{Torque_{arm} \cdot \frac{diameter_{tjointouter}}{2}}{J_{tjoint}}$$

$\tau_{tjoint} = 1.11 \times 10^4 \, psi$

Bottom Arm Stress

$$\sigma_{bottomarm} := \frac{Moment_{arm} \cdot \frac{diameter_{bottomarmouter}}{2}}{I_{bottomarm}}$$

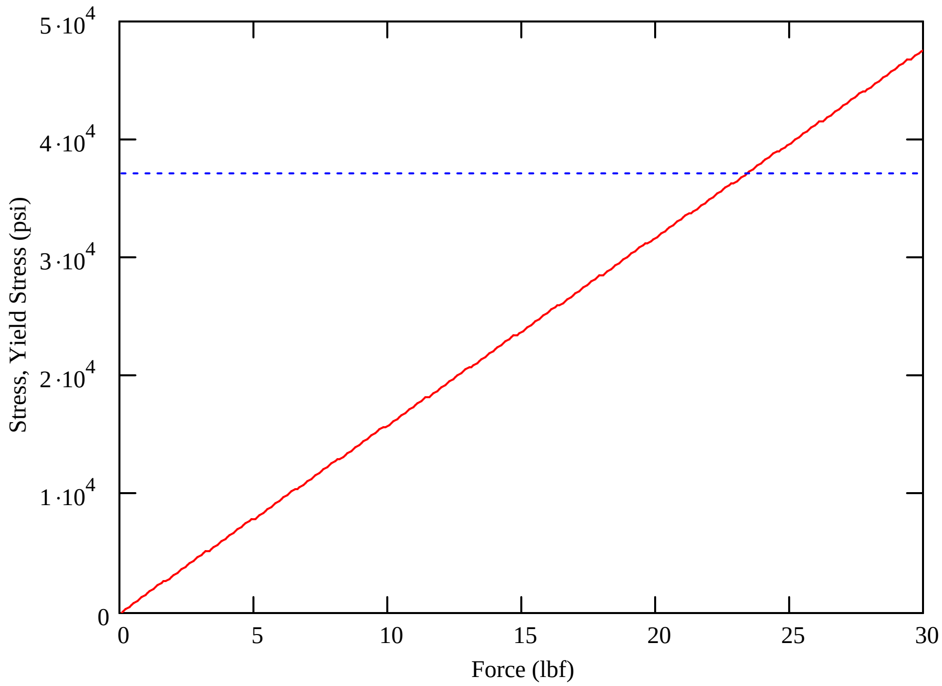
$\sigma_{bottomarm} = 2.22 \times 10^4 \, psi$

$force := 0, .1 .. 30$

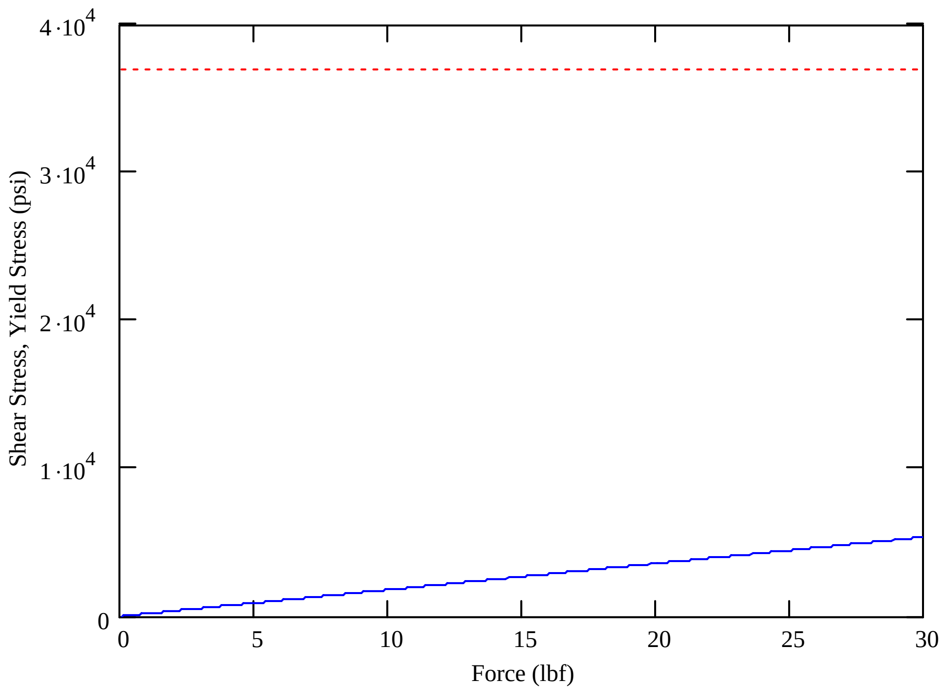
$$\sigma(x) := \frac{(x \cdot length_{arm}) \cdot \frac{diameter_{armouter}}{2}}{I_{arm}} in^2 \qquad \tau(x) := \frac{x \cdot length_{arm} \cdot \frac{diameter_{tjointouter}}{2}}{J_{tjoint}}$$

$\sigma_{yield}(x) := 37000 psi$

force =	σ(force) =	τ(force) = $\frac{1}{m^2}$
0	0	0
0.1	158.58	$1.229 \cdot 10^5$
0.2	317.159	$2.458 \cdot 10^5$
0.3	475.739	$3.687 \cdot 10^5$
0.4	634.318	$4.916 \cdot 10^5$
0.5	792.898	$6.145 \cdot 10^5$
0.6	951.477	$7.374 \cdot 10^5$
0.7	$1.11 \cdot 10^3$	$8.603 \cdot 10^5$
0.8	$1.269 \cdot 10^3$	$9.832 \cdot 10^5$
0.9	$1.427 \cdot 10^3$	$1.106 \cdot 10^6$
1	$1.586 \cdot 10^3$	$1.229 \cdot 10^6$
1.1	$1.744 \cdot 10^3$	$1.352 \cdot 10^6$
1.2	$1.903 \cdot 10^3$	$1.475 \cdot 10^6$
1.3	$2.062 \cdot 10^3$	$1.598 \cdot 10^6$
1.4	$2.22 \cdot 10^3$	$1.721 \cdot 10^6$
1.5	$2.379 \cdot 10^3$	$1.843 \cdot 10^6$



Stress, Yield Stress (psi)
$5 \cdot 10^4$
$4 \cdot 10^4$
$3 \cdot 10^4$
$2 \cdot 10^4$
$1 \cdot 10^4$
0
0
5
10
15
20
25
30
Force (lbf)



Shear Stress, Yield Stress (psi)
$4 \cdot 10^4$
$3 \cdot 10^4$
$2 \cdot 10^4$
$1 \cdot 10^4$
0
0
5
10
15
20
25
30
Force (lbf)

Pin Connection Between the Pump and Frame

Dimensions

$length_{pinframeump} := .75in$

$diameter_{pinframepump} := .125in$

$$I_{pinframepump} := \pi \frac{(diameter_{pinframepump})^4}{64}$$

Arm and Pump Pin Shear Stress

$$\tau_{pinframepump} := \frac{\frac{Force_{output}}{2}}{\left[\pi \cdot \left(\frac{diameter_{pinframepump}}{2}\right)^2\right]}$$

$\tau_{pinframepump} = 5.476 \times 10^3 psi$ {*Per Pin*}

Well below yield strength

Pin Connection Between the Arm and Pump

Dimensions

$length_{pinarmpump} := 2in$

$diameter_{pinarmpump} := .125in$

$$I_{pinarmpump} := \pi \frac{(diameter_{pinarmpump})^4}{64}$$

Arm and Pump Pin Shear Stress

$$\tau_{pinarmpump} := \frac{\frac{Force_{output}}{2}}{\pi \cdot \left(\frac{diameter_{pinarmpump}}{2}\right)^2}$$

{*Two shear surface contacts thus half the force is used*}

$\tau_{pinarmpump} = 5.476 \times 10^3 psi$

Well below yield strength

Power Savings Worksheet

Power Savings

$year = 1$ [yr]

$\dot{V}_{year} = 140000$ [gal/year]

$\dot{V}_{pump} = 42$ [gpm] 42 gpm @50 ft head

$Cost_{pump} = 745$ [\$]

$$Run_{time} = \frac{\dot{V}_{year}}{\dot{V}_{pump}} \cdot \left| 0.016667 \cdot \frac{hr}{min} \right|$$

$hp_{pump} = 0.75$ [hp]

$$Power_{usage} = hp_{pump} \cdot \left| 0.7457 \cdot \frac{kW}{hp} \right| \cdot Run_{time}$$

$Cost_{electric} = 0.08$ [\$/kW-hr]

$$Electric_{Bill} = Cost_{electric} \cdot Power_{usage}$$

$$Total_{Cost} = Electric_{Bill} \cdot year + Cost_{pump}$$

Solution

Main

Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]

$Cost_{electric} = 0.08$ [\$/kW-hr]	$Cost_{pump} = 745$ [\$]
$Electric_{Bill} = 2.486$ [\$/yr]	$hp_{pump} = 0.75$ [hp]
$Power_{usage} = 31.07$ [kW-hr/yr]	$Run_{time} = 55.56$ [hr/year]
$Total_{Cost} = 747.5$ [\$]	$\dot{V}_{pump} = 42$ [gpm]
$\dot{V}_{year} = 140000$ [gal/year]	$year = 1$ [yr]

Water Savings Worksheet

Water Savings Study

Water Use Information

$$Annual_{usage} = \frac{146000 \quad [gal]}{1 \quad [yr]}$$

$$Monthly_{usage} = \frac{Annual_{usage}}{12 \quad [1/yr]}$$

$$Daily_{use} = Annual_{usage} \cdot \left| 0.00274 \cdot \frac{gal/day}{gal/yr} \right|$$

$$Externaluse = 58 \quad [\%]$$

$$Internaluse = 42 \quad [\%]$$

$$Annual_{externaluse} = Annual_{usage} \cdot \frac{Externaluse}{100 \quad [\%]}$$

Some Outdoor Usage

$$Sprinkler_{useage} = 1000 \quad [L/hr] \cdot \left| 0.264172 \cdot \frac{gal/hr}{L/hr} \right|$$

$$Carwash_{useage} = 200 \quad [L] \cdot \left| 0.264172 \cdot \frac{gal}{L} \right|$$

$$Hosingdriveway_{useage} = 75 \quad [L] \cdot \left| 0.264172 \cdot \frac{gal}{L} \right|$$

Source: http://www.awwa.org/Advocacy/pressroom/STUDY.cfm

Useage Costs Inside of the City

$$ccf = 748.05 \quad [1/gal]$$

$$Cost_{tier,in,0} = \frac{1.04 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,in,1} = \frac{1.2 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,in,2} = \frac{2.02 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,in,3} = \frac{2.7 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,in,4} = \frac{3.9 \quad [\$]}{748.05 \quad [gal]}$$

Useage Costs Outside of the City/Remote Areas

$$Cost_{tier,out,0} = \frac{1.3 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,out,1} = \frac{1.5 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,out,2} = \frac{2.53 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,out,3} = \frac{3.38 \quad [\$]}{748.05 \quad [gal]}$$

$$Cost_{tier,out,4} = \frac{3.9 \quad [\$]}{748.05 \quad [gal]}$$

Source - http://www.tampagov.net/dept$_{water}$/RatesAndFees/Water$_{usage,rates.asp}$

Annual Usage by Tier

$$Usage_{tier,0} = \left[\frac{3750 - 0}{2}\right] \cdot 12 \quad [gal/yr]$$

$$Usage_{tier,1} = \left[\frac{9725 - 4490}{2}\right] \cdot 12 \quad [gal/yr]$$

$$Usage_{tier,2} = \left[\frac{19450 - 10475}{2}\right] \cdot 12 \quad [gal/yr]$$

$$Usage_{tier,3} = \left[\frac{33675 - 20200}{2}\right] \cdot 12 \quad [gal/yr]$$

$$Usage_{tier,4} = 34410 \cdot 12 \quad [gal/yr]$$

Annual Savings - Average use is Tier 2

$$Annual_{savings,in} = Cost_{tier,in,2} \cdot Annual_{externaluse}$$

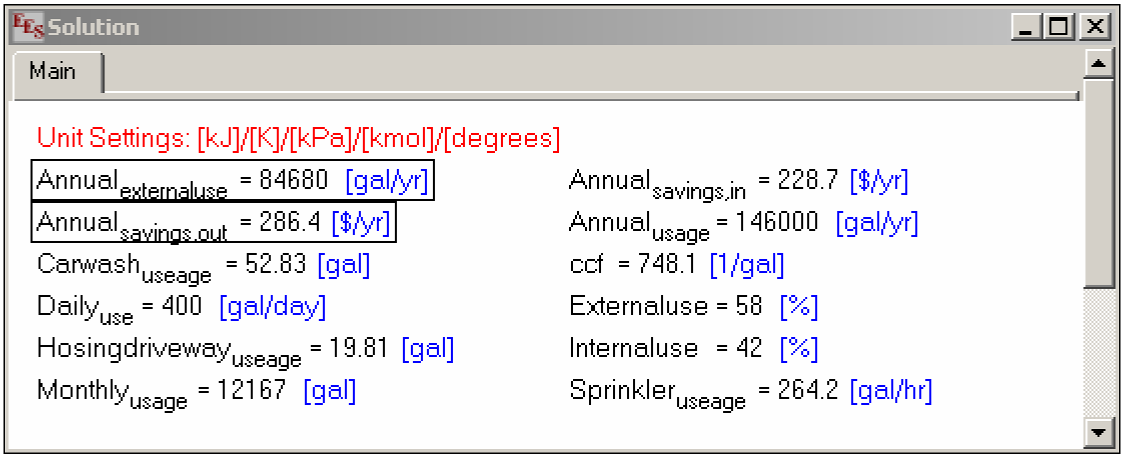
$$Annual_{savings,out} = Cost_{tier,out,2} \cdot Annual_{externaluse}$$

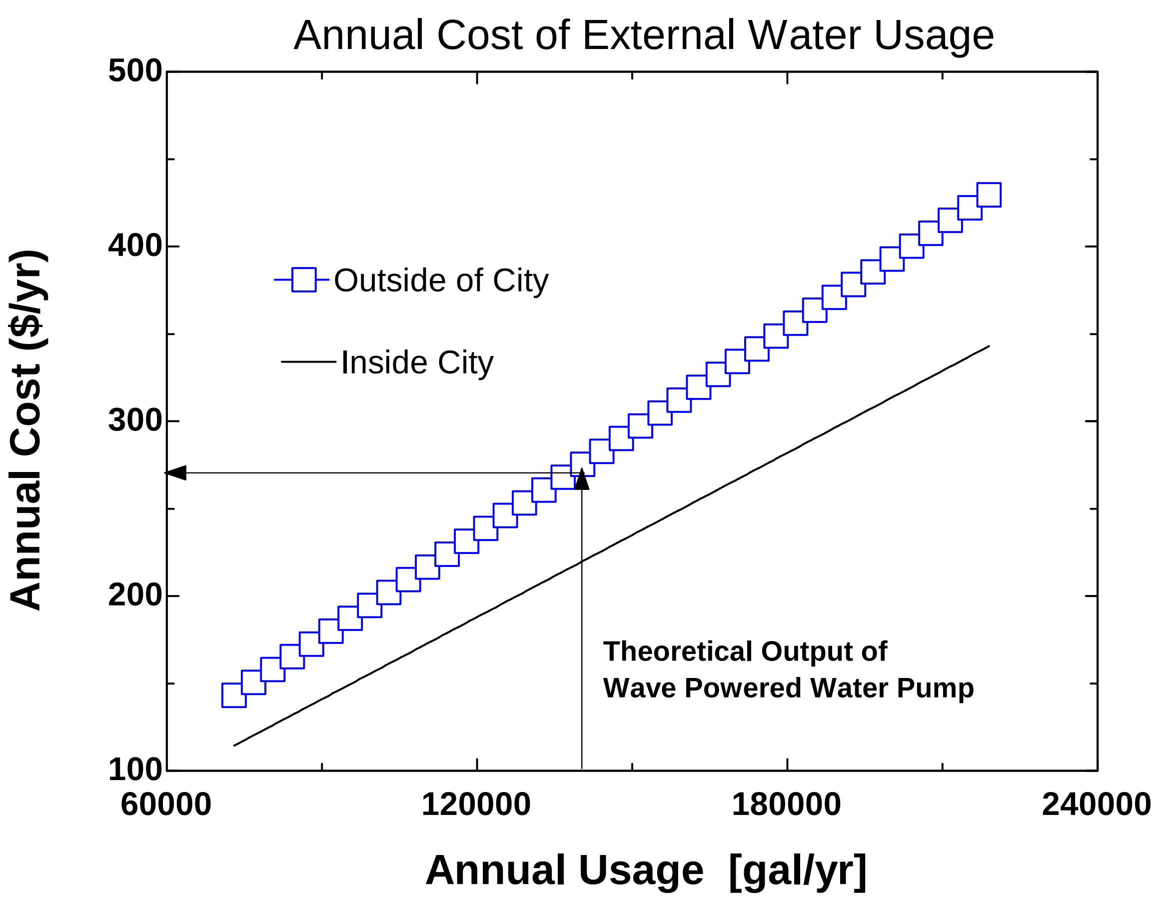
Inside City Savings

$$Savings_{tier,in,i} = \frac{Externaluse \cdot Cost_{tier,in,i} \cdot Usage_{tier,i}}{100 \quad [\%]} \qquad \text{for } i = 0 \text{ to } 4$$

Remote Location City Savings

$$Savings_{tier,out,i} = \frac{Externaluse \cdot Cost_{tier,out,i} \cdot Usage_{tier,i}}{100 \quad [\%]} \qquad \text{for } i = 0 \text{ to } 4$$


Solution
Main
Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]
Annual_externaluse = 84680 [gal/yr]
Annual_savings,out = 286.4 [$/yr]
Carwash_useage = 52.83 [gal]
Daily_use = 400 [gal/day]
Hosingdriveway_useage = 19.81 [gal]
Monthly_usage = 12167 [gal]
Annual_savings,in = 228.7 [$/yr]
Annual_usage = 146000 [gal/yr]
ccf = 748.1 [1/gal]
Externaluse = 58 [%]
Internaluse = 42 [%]
Sprinkler_useage = 264.2 [gal/hr]


Annual Cost of External Water Usage
Annual Cost ($/yr)
500
400
300
200
100
60000
120000
180000
240000
Annual Usage [gal/yr]
Outside of City
Inside City
Theoretical Output of
Wave Powered Water Pump

PVC – Shrinkage Estimation

shrinkage of pvc plastic pipe

coefficient of thermal expansion

$T_c = 0.000006$ [in/in/F]

wall thickness

$t_{wall} = 0.266$ [in]

$T_{base} = 60$ [F]

$T_1 = 80$ [F]

$T_2 = 32$ [F]

wall thickness change, taking 60 degrees
to be average lake temperature when pump is installed

$$thickness_{32} = t_{wall} - T_c \cdot (T_{base} - T_2)$$

$$thickness_{80} = t_{wall} + T_c \cdot (T_1 - T_{base})$$

12.4 Assembly per Component

Figure 12.4.1 shows all the components of the pump. This includes two check valves, the piston rod, and the piston pump cavity.

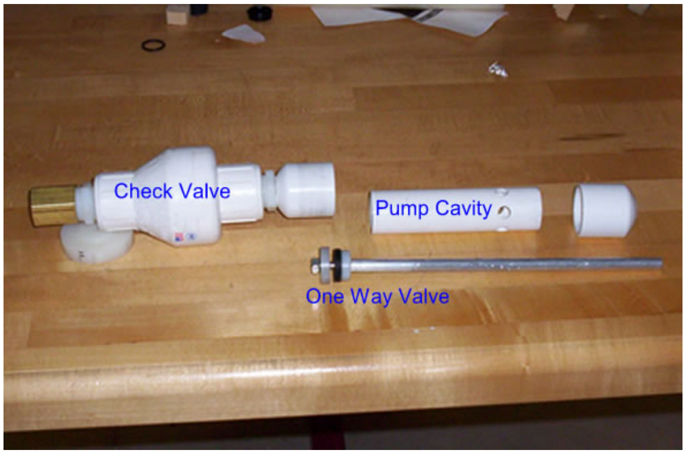


Figure 12.4.1 Pump components

The piston rod also includes a check valve built into the piston. Figure 12.4.2 shows the rod components.

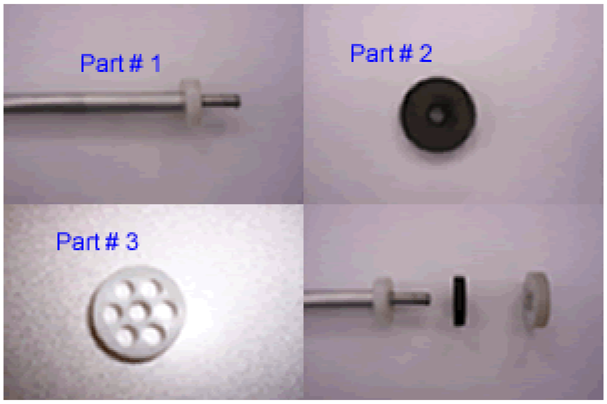


Figure 12.4.2 Rod components.

Figure 12.4.3 shows the check valve assembly with the black rubber acting as a seal between the two plastic pistons.

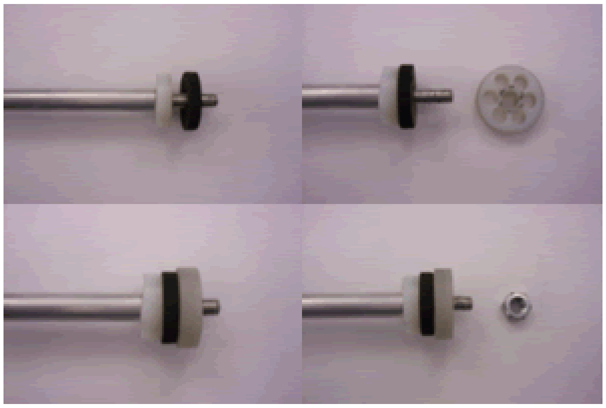


Figure 12.4.3 Check valve assembly

Figure 12.4.4 shows the components pieced together. Note the nut should not be tightened completely to allow water to flow past during the down stroke of the piston.

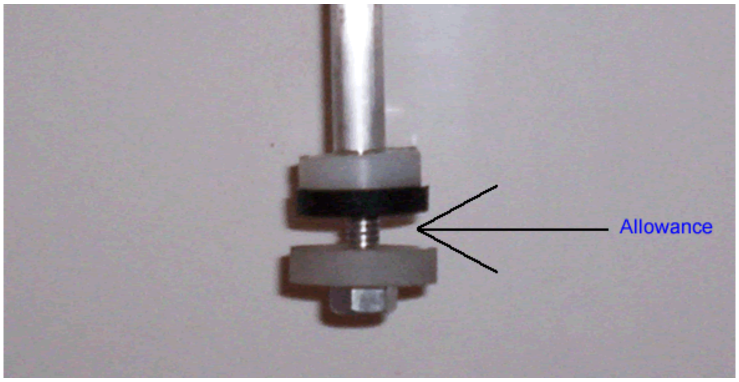


Figure 12.4.4 Allowance in check valve

The pump components are shown in Figure 12.4.5. These components include the piston (1), the pump housing (2), the inlet cap (3), and the outlet cap (4).

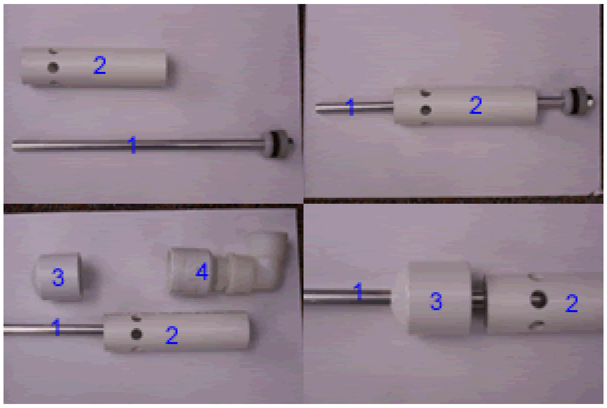


Figure 12.4.5 Pump components

The final pump assembly is shown in Figure 12.4.6.

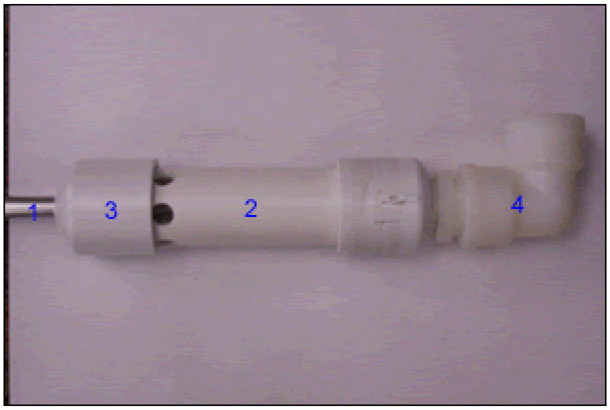


Figure 12.4.6 Pump assembly

12.5 User Manual

Assembly of the Bobber

Step (1)

Verify that all parts are present

Figure 12.5.1 - Bobber Parts

1 – buoy	
1 – length of rope	
1 – triangular pump housing	
3 – T shaped legs	
3 – 10 lb weights	
3 – hairpins	
1 – standard hose	

Step (2)

Screw T shaped legs into the triangular frame. The pointed end of the T should be facing down as seen in Figure 2.

Figure 12.5.2 - Legs assembled

Step (3)

Screw lever arm into the T fitting.

Figure 12.5.3 - Lever arm assembled

Step (4)

Place the 3 weights on the uprights at the end of the legs. Clip the hairpins to the holes above the weights to keep the weights in place.

Figure 12.5.4 - Weights and pins in place

Step (5)

Attach the hose to the fitting on the pump. This connection must be very tight.

Figure 12.5.5 - Hose connected to the pump

Step (6)

Attach the buoy to the end of the lever arm. The length of this rope is dependant on the depth of water in which the Bobber will be placed.

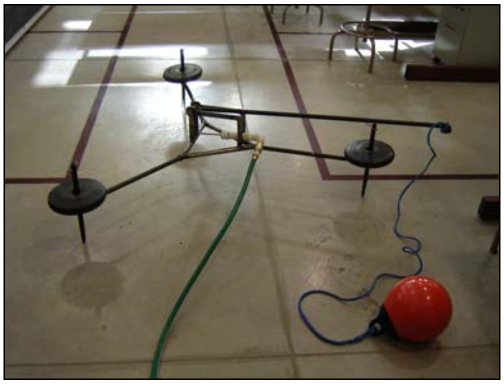


Figure 12.5.6 - Buoy attached to the lever arm

Installation

The Bobber may be installed using a few different methods. The Bobber performs at optimum when placed past the breaking waves but can be installed anywhere the lake bed is relatively flat. The typical installations are described here.

Walk-In Method

After assembly the Bobber can be carried by one person to the depth desired for maximum wave action. Having two people to carry the Bobber is easier and also recommended. The Bobber is then placed with the spikes pointing down towards the lake bed. The length of the rope should be adjusted at this time to have the rope barely slack at the valley of the wave action. The hose should be laid out to the desired location of water pumping.

Dock Launch

This method can be done quite easily by one person. The Bobber can be carried onto the dock after assembly and dropped into the water off the side of a dock. The bottom of the lake bed should be fairly flat at this location (no large rocks or boulders). The length of the rope should be adjusted at this time to have the rope barely slack at the valley of the wave action. The hose should be laid out to the desired location of water pumping.

Boat Launch

This method is the most effective for getting the Bobber into the optimum location. After assembly the Bobber should be loaded into a boat and driven into location. The Bobber can be dropped into the water off the side of the boat. The length of the rope should be adjusted at this time to have the rope barely slack at the valley of the wave action. The hose should be laid out to the desired location of water pumping.

12.6 Customer Survey and Comments

A customer survey was conducted to attain possible customer interest in the device. Although the survey sample was small, it yielded the following results:

- Of the people surveyed 76% expressed interest in using the device
- The average price listed for the device was $137
- Garden and water supply were the top two uses for the device

Other suggested uses for the device were to generate electricity and plumbing. It is not immediately evident from this survey whether there would be a market for this device as most of the people surveyed were only hypothetical customers. The best way to determine the possibility of selling the Bobber would be to introduce a few Bobbers to the market and allow word of mouth to promote the device. If this device works well, the market would grow. As it stands now, it is difficult to obtain reliable information because people are not familiar with the product. People may not immediately see the usefulness until the product receives more exposure.

The construction of this device cost $160 in parts. These were made from stock components bought from suppliers who make their own profit on the sale of their parts. With mass production and less expensive suppliers, the cost to manufacture could possibly be cut in half. Also, the prototype was built simply for demonstration purposes. If customizable systems were built for different applications, then customer satisfaction would be even higher. For example, many people wanted more volume out of the pump. Units could be fitted with various pump sizes. Also, the device can easily be repaired, if needs be, with parts available from a local hardware store. Already the design is so simplistic and easy to use that customers do not feel intimidated by the device. In fact most people who learned about the project were able to understand how the device worked with a brief explanation.

This device is the equivalent of a manual pump. There exists on the market, a manual hand pump which pump 25 gallons per minute. The product sells for $40. (http://www.harborfreight.com/cpi/ctaf/Displayitem.taf?itemnumber=47664). Also there are manual pumps for wells which work in much the same way this device does. These can sell for as much as $1000. However the functions of these devices do not exactly correlate to the wave powered water pump. A pump that harnesses wave energy takes manual pumps one step further. Green energy is becoming increasingly popular. People are realizing that more efficient energy use is not an option but must. Environmental issues are progressively becoming a concern, and people living by lakes are not exempt from these concerns and might be interested in using a wave powered water pump.

This said there are concerns of over use of this device. Overuse of this product by multiple users could have negative environmental impacts. Lakes could be drained or ruined if too much is drawn from them. Hopefully the volume per person drawn would remain small so that this is not a problem. Another possible problem is safety. The device has sharp edges that could lead to injury to users. If used in highly volatile wave conditions, chances of injury increase. Cycle tests were not performed. However, in the three months of use and testing the pump and structure are yet to fail. With more time and development, this wave powered water pump can developed to last for years. As it stands now, this device would have to be replaced frequently due to corrosion, which is the main concern. Furthermore, from a customer standpoint, not being able to use this device as a hose is a bit problematic. A separate tank would be required to store the water in order to make effective use of the device. This must be factored in as an additional cost. Finally, although the device is relatively simple to install and remove, it may be view as cumbersome to have to move the device around.

The conclusion of these studies is that there is indeed an undeveloped market for this product, and furthermore; the product is simplistic enough that almost anyone who is interested could use the device. In production, the device would probably sell from $100 - $200, depending on features. There are a certain tradeoffs that must be considered when using this device. Overall however, there is a high-level of interest and the wave powered water pump is feasible for production.

12.7 Design Schematics

The dimensions of all the components of the bobber are listed below. The quantities needed to build the device are also listed.

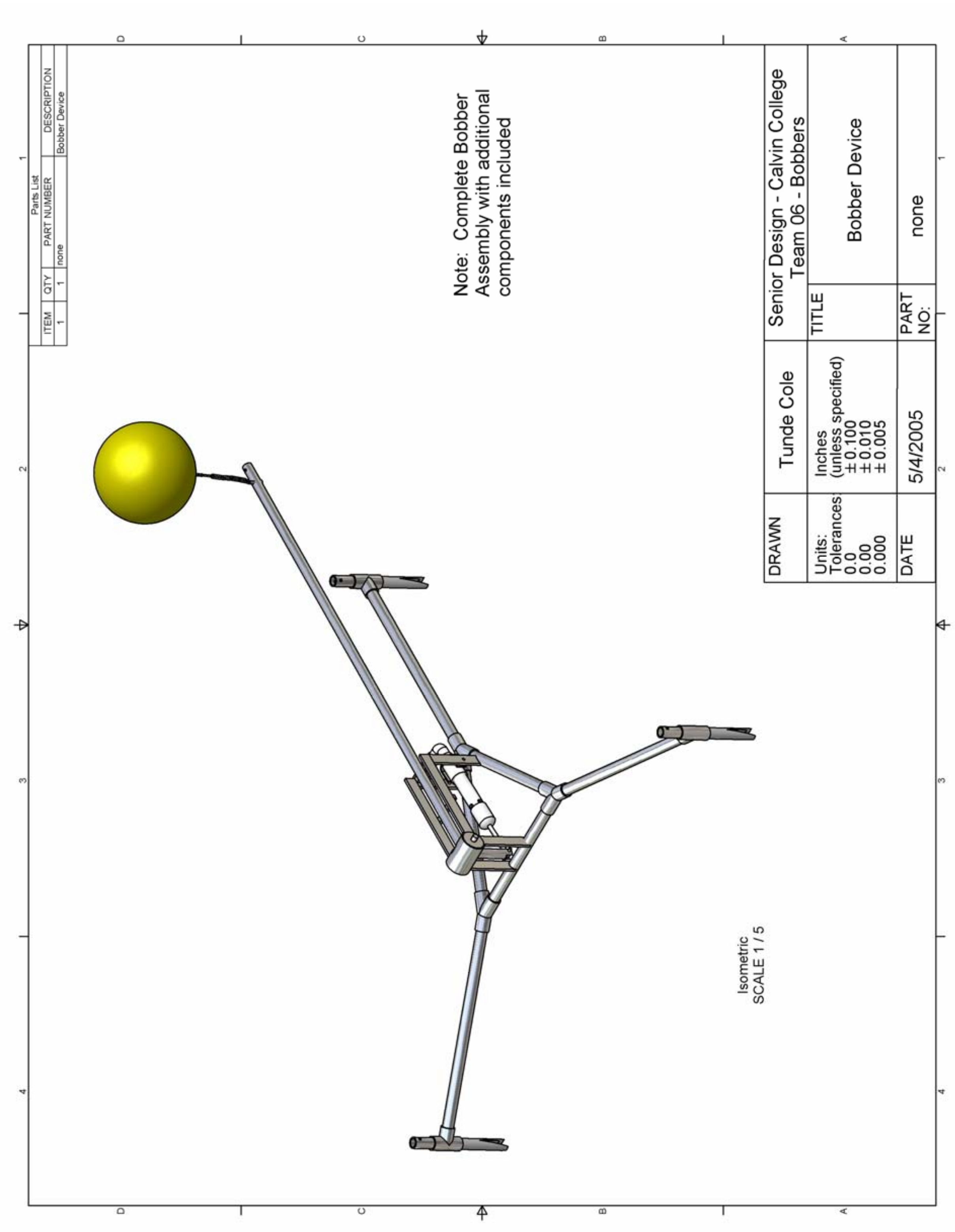
Bobber Device Components List

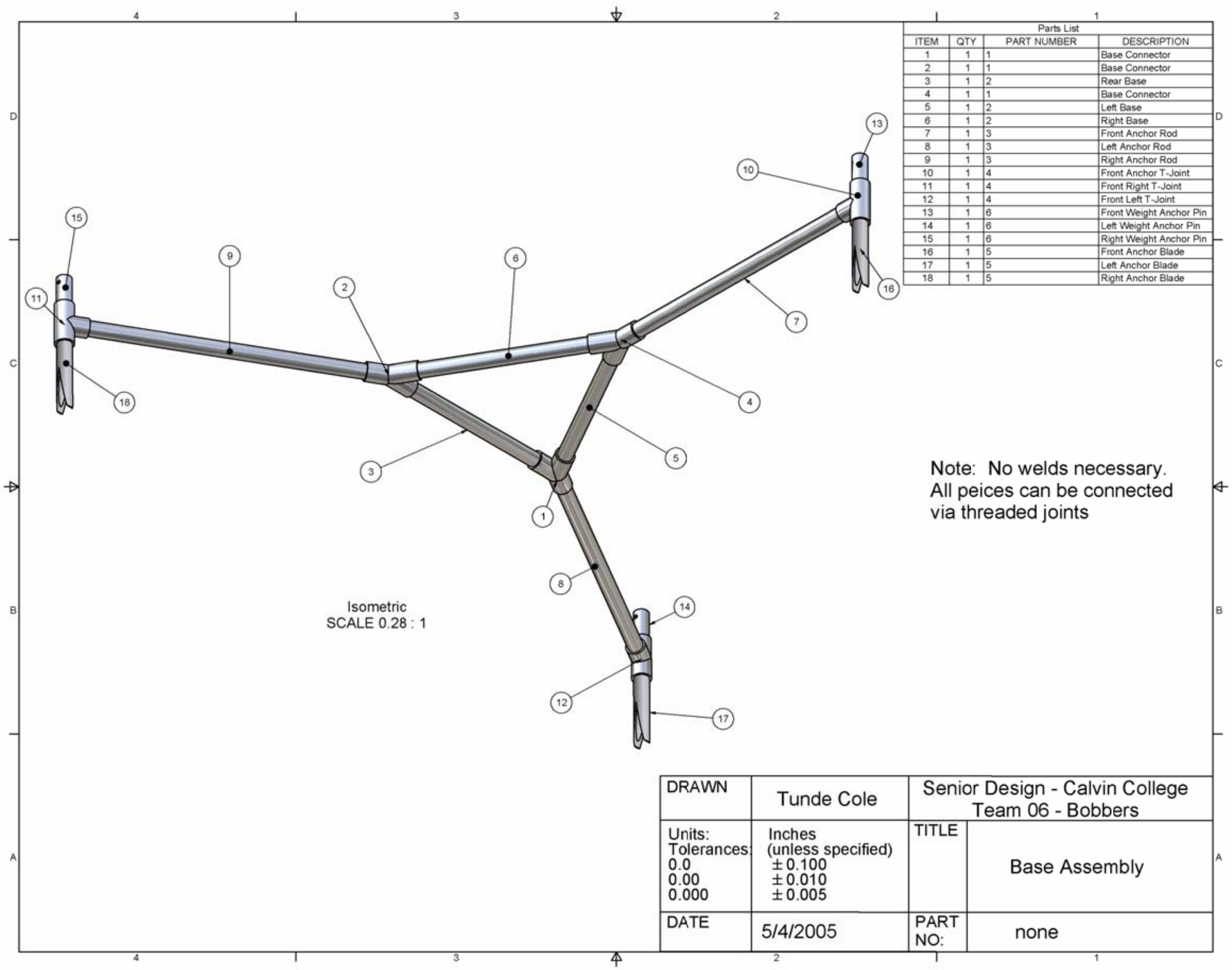
Notes:

- All dimensions are in inches
- Tolerances- (unless otherwise specified)
  0.0 - ±0.100
  0.00 - ±0.010
  0.000 - ±0.005
- Recommended materials are specified in the Parts Overview section below
- Actual part quantities per kit are specified in the Parts Overview section below
- Parts that are not threaded should be welded for assembly (see assemblies)
- Not included are the following necessary but standard components
  - Rope or chain
  - Cotter Pins
  - Weights
  - Hose

Parts Overview				
Part Name	Part #	Quantity	Material	Comments
Base Connector	1	3	Steel or Aluminum	
Base	2	3	Steel or Aluminum	
Anchor Rod	3	3	Steel or Aluminum	
Anchor T-Joint	4	3	Steel or Aluminum	
Anchor Blade	5	3	Steel or Aluminum	
Weight Anchor Rod	6	3	Steel or Aluminum	
Rear Support	7	2	Steel or Aluminum	
Front Support	8	2	Steel or Aluminum	
Top Support	9	2	Steel or Aluminum	
Side Housing	10	2	Steel or Aluminum	
Top Housing	11	1	Steel or Aluminum	(optional, recommended)
Front Top Support	12	2	Steel or Aluminum	
Arm Bearing	13	2	Brass	(softer metal)
Arm T-Joint	14	1	Steel or Aluminum	
Arm	15	1	Steel or Aluminum	
Bottom Arm	16	1	Steel or Aluminum	
T-Joint Pin	17	1	Steel or Aluminum	
Bottom Arm Pin	18	1	Steel or Aluminum	
Bobber	19	1	Plastic	(size may vary with pump)
Aluminum Rod	20	1	Aluminum	

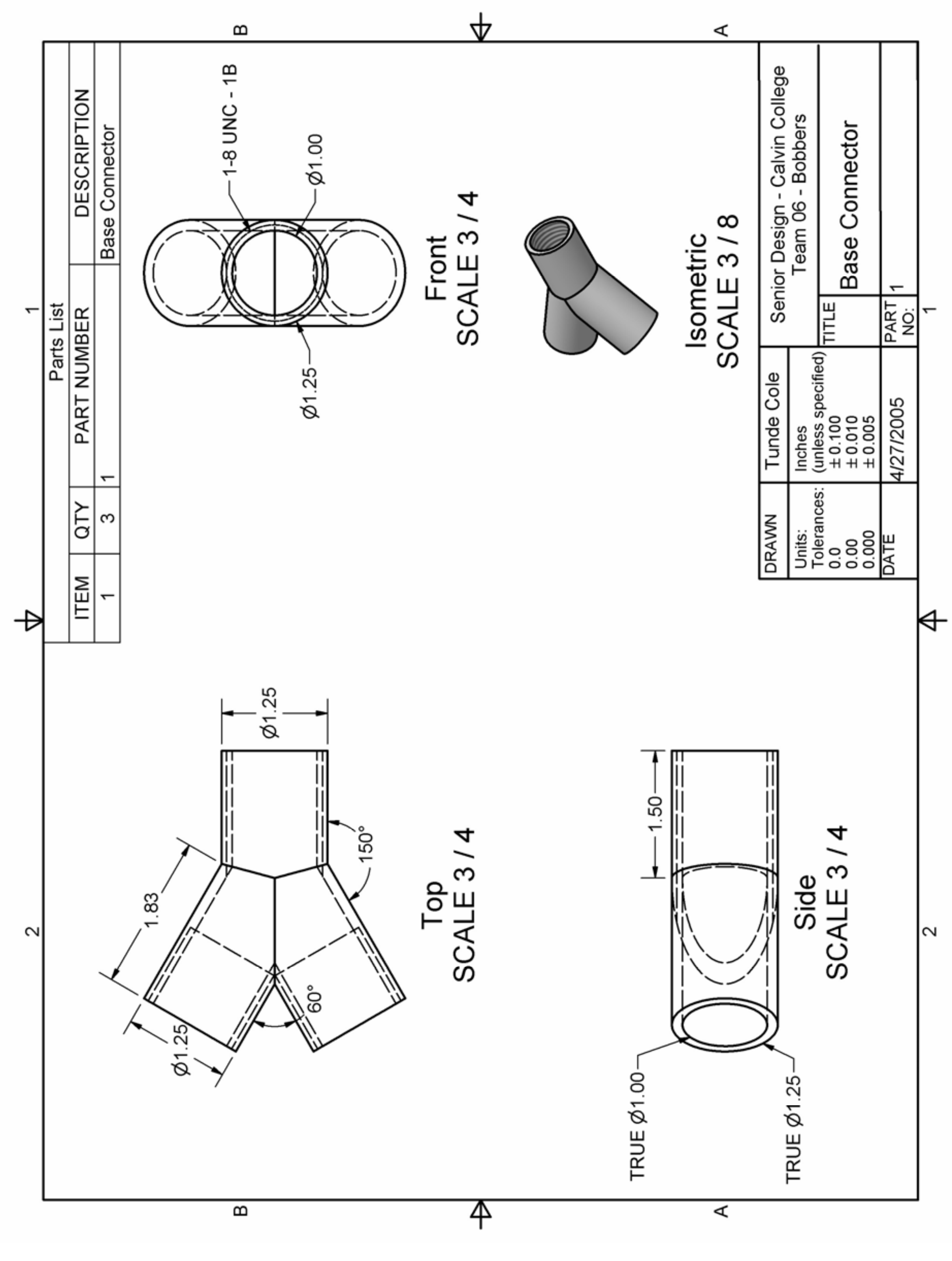
Nylon Check Valve	21	1	Nylon	
Rubber Check Valve	22	1	Rubber	
Inner Nylon Check Valve	23	1	Nylon	
Piston Nut	24	1	Steel	(size is variable)
Main Pump Body	25	1	PVC	
Top Pump Cap	26	1	PVC	
Bottom Pump Cap	27	1	PVC	
Pump Hose Connector	28	1	Plastic	
Pump Angle Joint	29	1	Plastic	
Pump Valve Connector	30	1	Plastic	
Outer Check Valve	31	1	Steel	
Outer Rubber Check Valve	32	1	Rubber	
Pump Swivel Bracket	33	1	Steel or Aluminum	
Pump Bracket Pin	34	2	Steel or Aluminum	
Center Top Support	35	1	Steel or Aluminum	(optional)

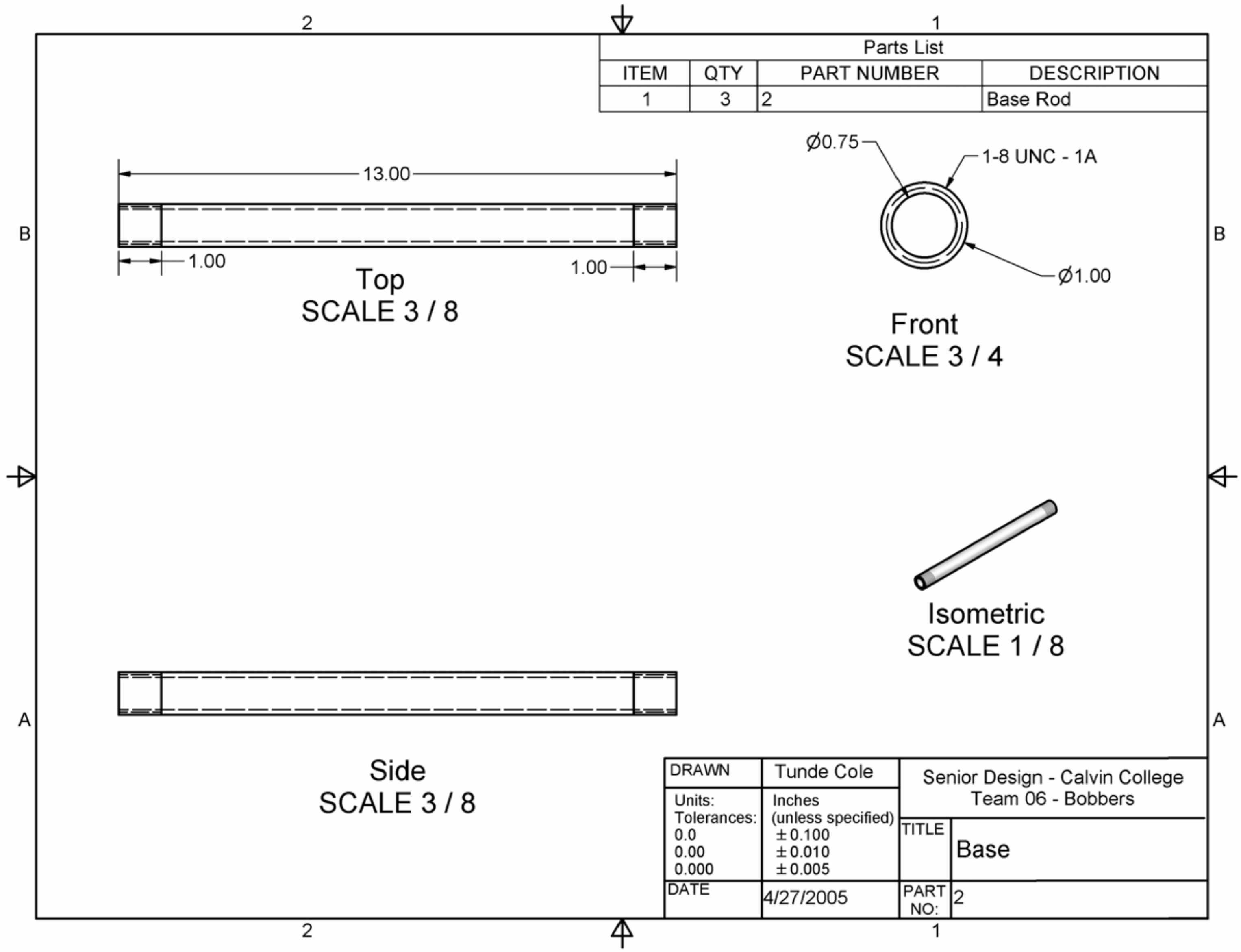

Parts List
ITEM QTY PART NUMBER DESCRIPTION
1 1 none Bobber Device
Note: Complete Bobber
Assembly with additional
components included
Isometric
SCALE 1 / 5
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Tolerances:
0.0
0.00
0.000
Inches
(unless specified)
± 0.100
± 0.010
± 0.005
TITLE
Bobber Device
DATE
5/4/2005
PART
NO:
none

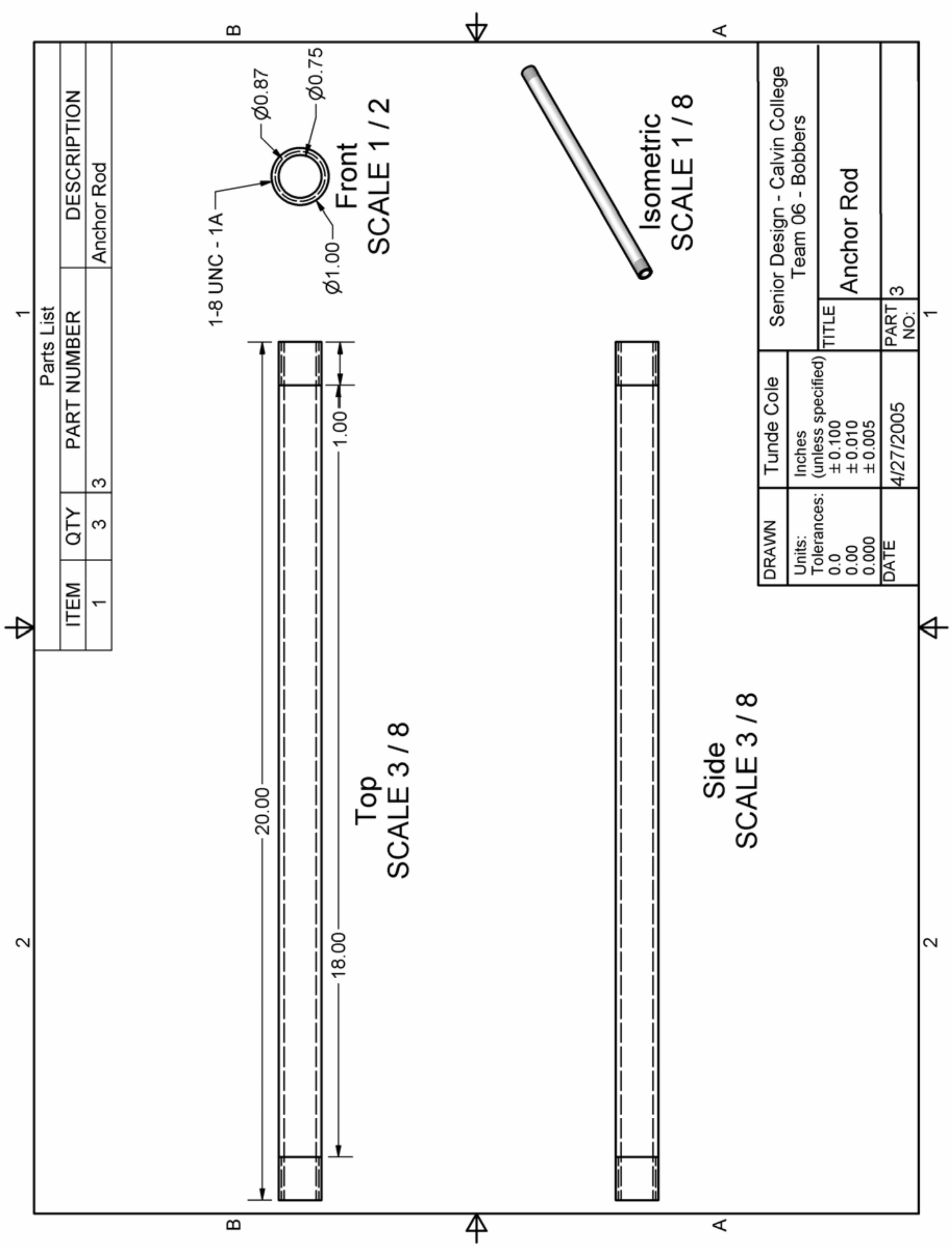


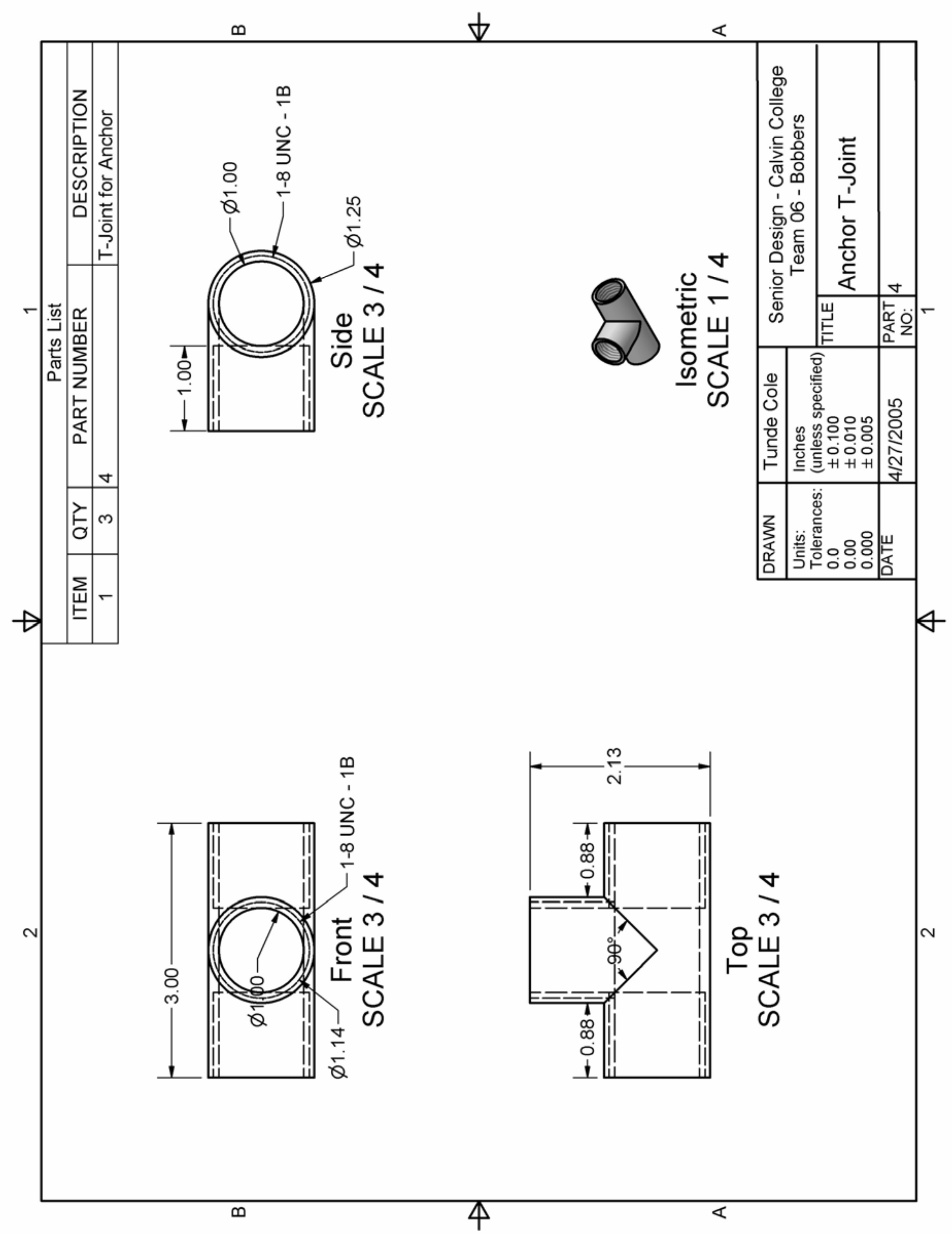
Parts List

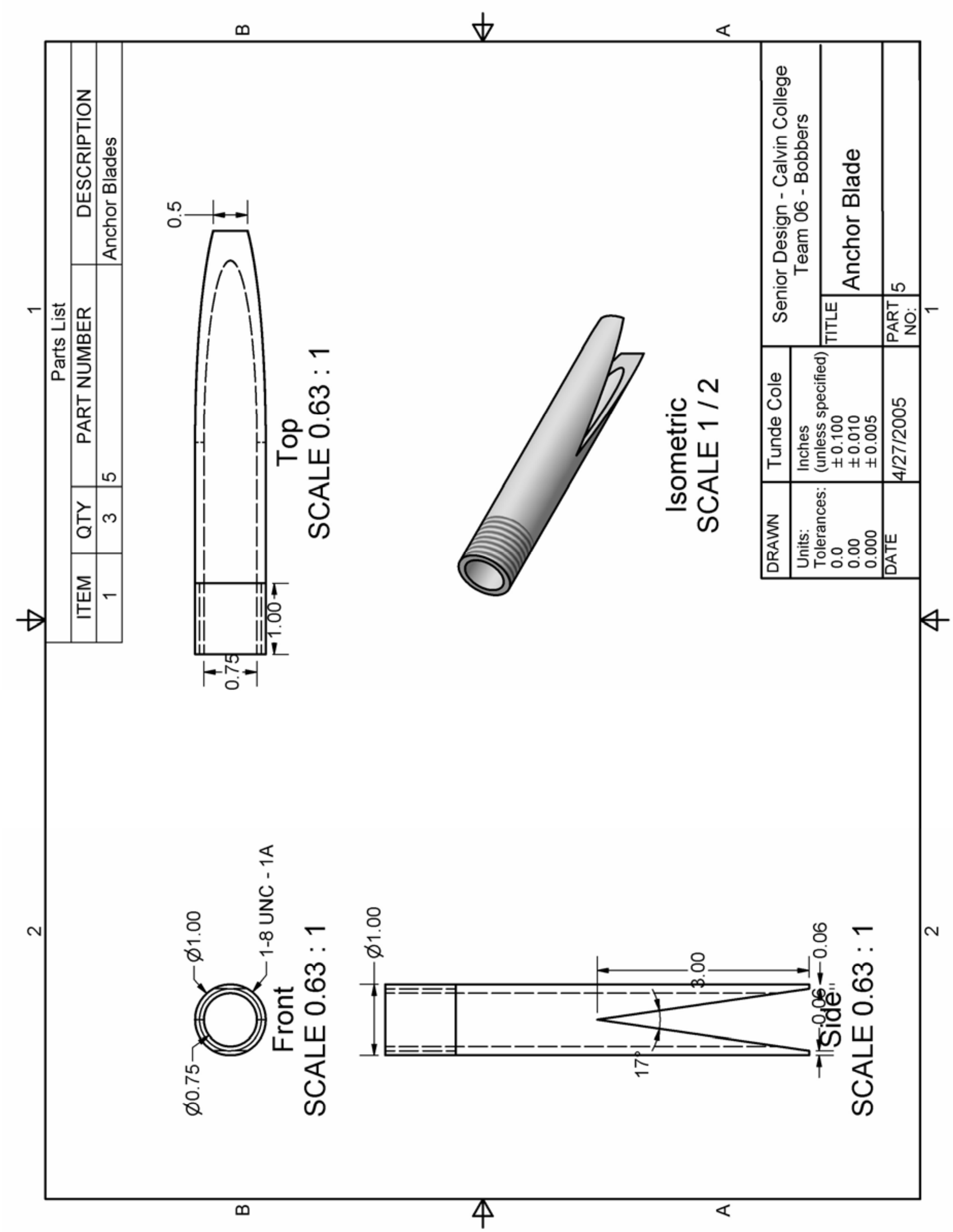
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	1	Base Connector
2	1	1	Base Connector
3	1	2	Rear Base
4	1	1	Base Connector
5	1	2	Left Base
6	1	2	Right Base
7	1	3	Front Anchor Rod
8	1	3	Left Anchor Rod
9	1	3	Right Anchor Rod
10	1	4	Front Anchor T-Joint
11	1	4	Front Right T-Joint
12	1	4	Front Left T-Joint
13	1	6	Front Weight Anchor Pin
14	1	6	Left Weight Anchor Pin
15	1	6	Right Weight Anchor Pin
16	1	5	Front Anchor Blade
17	1	5	Left Anchor Blade
18	1	5	Right Anchor Blade

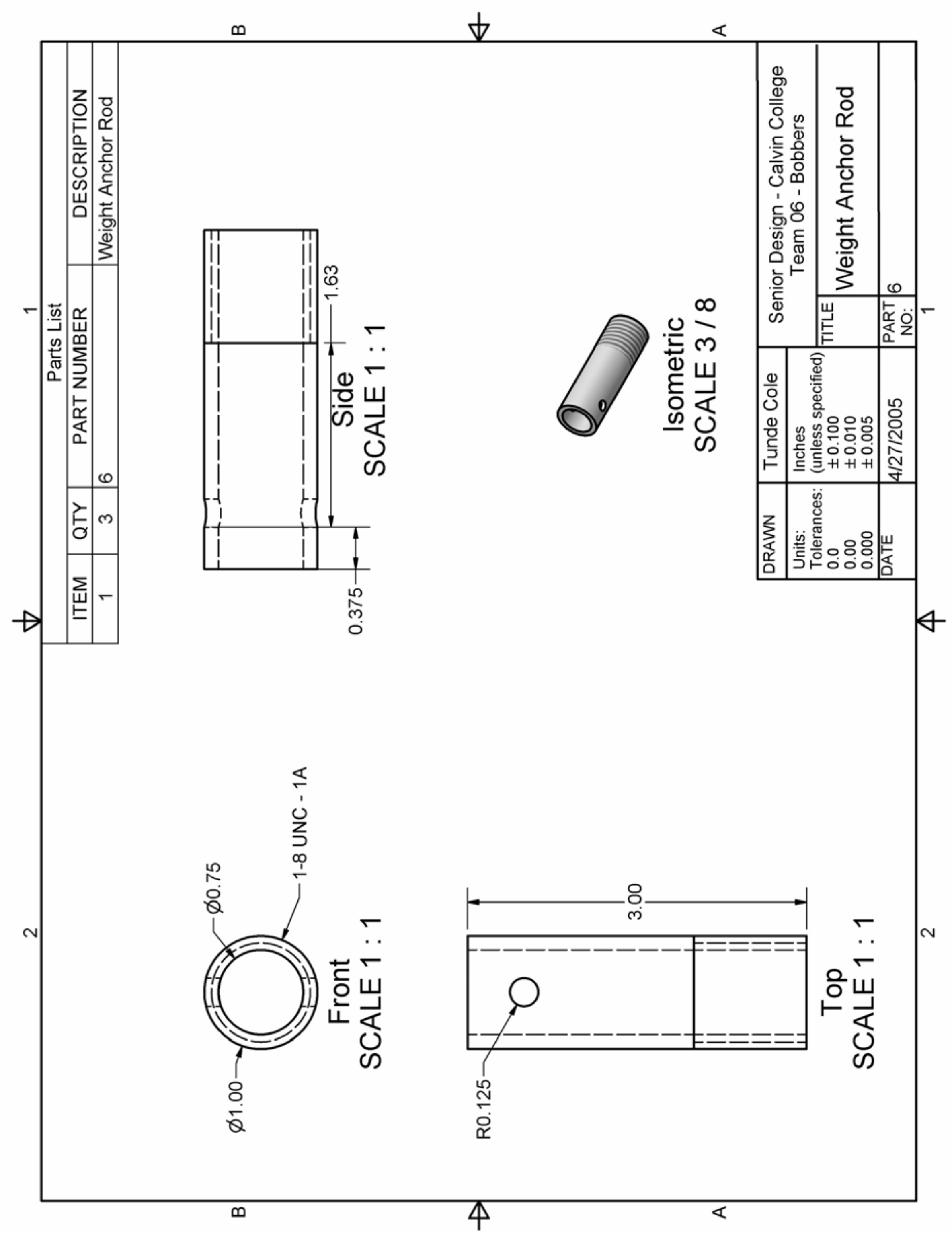

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
3
1
Base Connector
1-8 UNC - 1B
Ø1.00
Ø1.25
Front
SCALE 3 / 4
Isometric
SCALE 3 / 8
Ø1.25
1.83
150°
60°
Ø1.25
Top
SCALE 3 / 4
1.50
TRUE Ø1.00
TRUE Ø1.25
Side
SCALE 3 / 4
DRAWN
Tunde Cole
Units: Inches
Tolerances: (unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
DATE
4/27/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Base Connector
PART NO:
1
A
B
1
2


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 3 | 2 | Base Rod
13.00
1.00
1.00
Top
SCALE 3 / 8
Ø0.75
1-8 UNC - 1A
Ø1.00
Front
SCALE 3 / 4
Isometric
SCALE 1 / 8
Side
SCALE 3 / 8
DRAWN
Tunde Cole
Units:
Tolerances:
0.0
0.00
0.000
Inches
(unless specified)
± 0.100
± 0.010
± 0.005
DATE
4/27/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Base
PART NO:
2


Parts List
ITEM QTY PART NUMBER DESCRIPTION
1 3 3 Anchor Rod
1-8 UNC - 1A
Ø0.87
Ø0.75
Ø1.00
Front
SCALE 1 / 2
Isometric
SCALE 1 / 8
20.00
18.00
1.00
Top
SCALE 3 / 8
Side
SCALE 3 / 8
DRAWN Tunde Cole
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
DATE 4/27/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE Anchor Rod
PART NO: 3

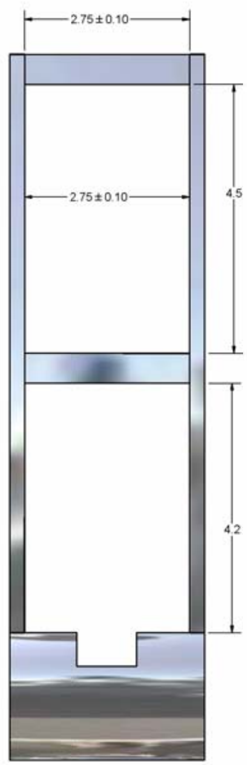

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
3
4
T-Joint for Anchor
Ø1.00
1-8 UNC - 1B
Ø1.25
1.00
Side
SCALE 3 / 4
Isometric
SCALE 1 / 4
3.00
Ø1.00
Ø1.14
1-8 UNC - 1B
Front
SCALE 3 / 4
2.13
0.88
0.88
90°
Top
SCALE 3 / 4
DRAWN
Tunde Cole
Units:
Inches
Tolerances:
(unless specifed)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
DATE
4/27/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Anchor T-Joint
PART NO:
4
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
3
5
Anchor Blades
Top
SCALE 0.63 : 1
Isometric
SCALE 1 / 2
Front
SCALE 0.63 : 1
Side
SCALE 0.63 : 1
1-8 UNC - 1A
Ø1.00
Ø0.75
3.00
0.06
17°
0.5
0.75
1.00
DRAWN
Tunde Cole
Units:
Inches
Tolerances:
(unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
DATE
4/27/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Anchor Blade
PART NO:
5

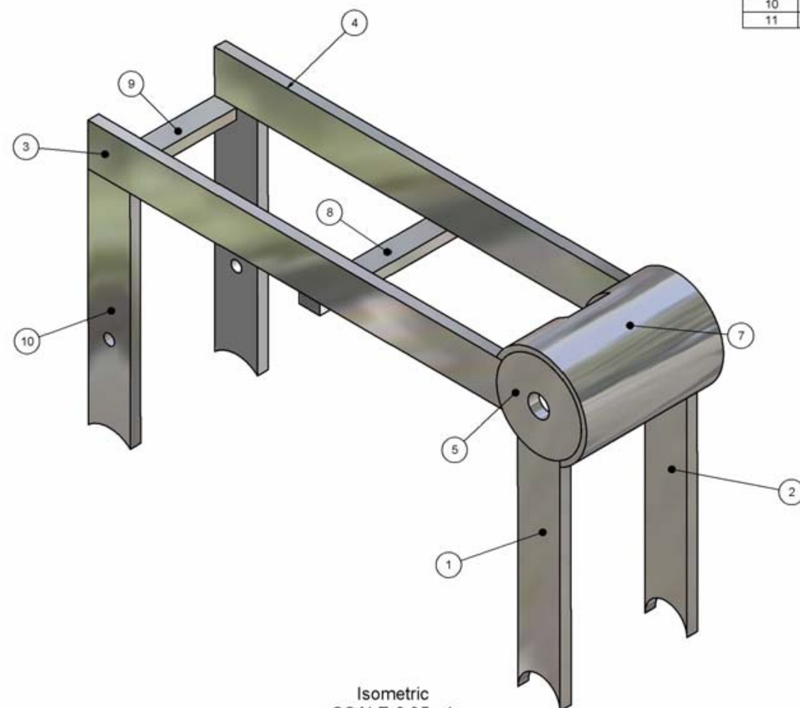

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
3
6
Weight Anchor Rod
Side
SCALE 1 : 1
1.63
0.375
Isometric
SCALE 3 / 8
Front
SCALE 1 : 1
Ø0.75
1-8 UNC - 1A
Ø1.00
Top
SCALE 1 : 1
3.00
R0.125
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Weight Anchor Rod
DATE
4/27/2005
PART NO:
6

Parts List

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	7	Rear Support (L)
2	1	7	Rear Support (R)
3	1	9	Top Support (L)
4	1	9	Top Support (R)
5	1	10	Side Housing (L)
6	1	10	Side Housing (R)
7	1	11	Top Housing
8	1	35	Top Center Support
9	1	12	Top Front Support
10	1	8	Front Support (L)
11	1	8	Front Support (R)



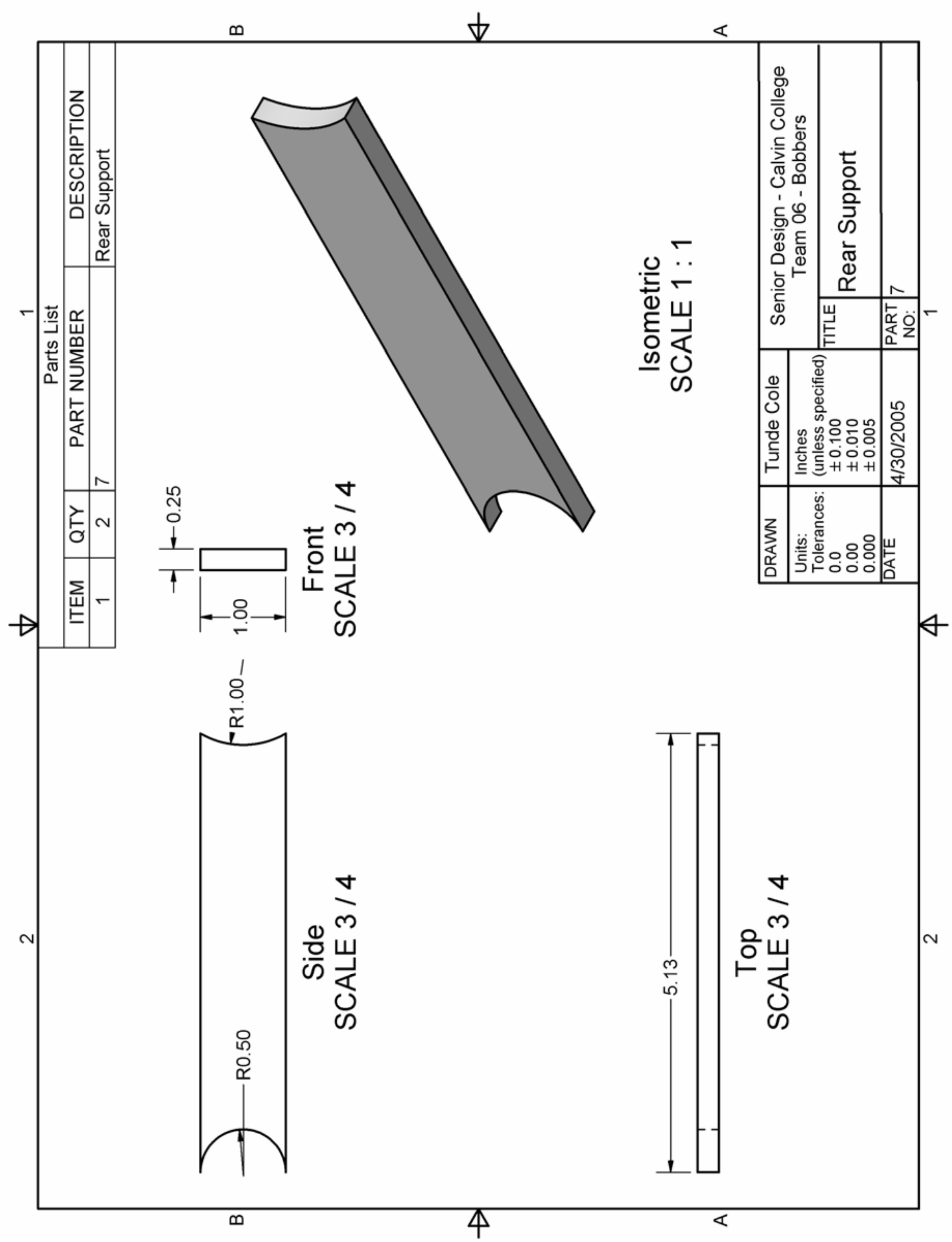
Top
SCALE 0.85 : 1

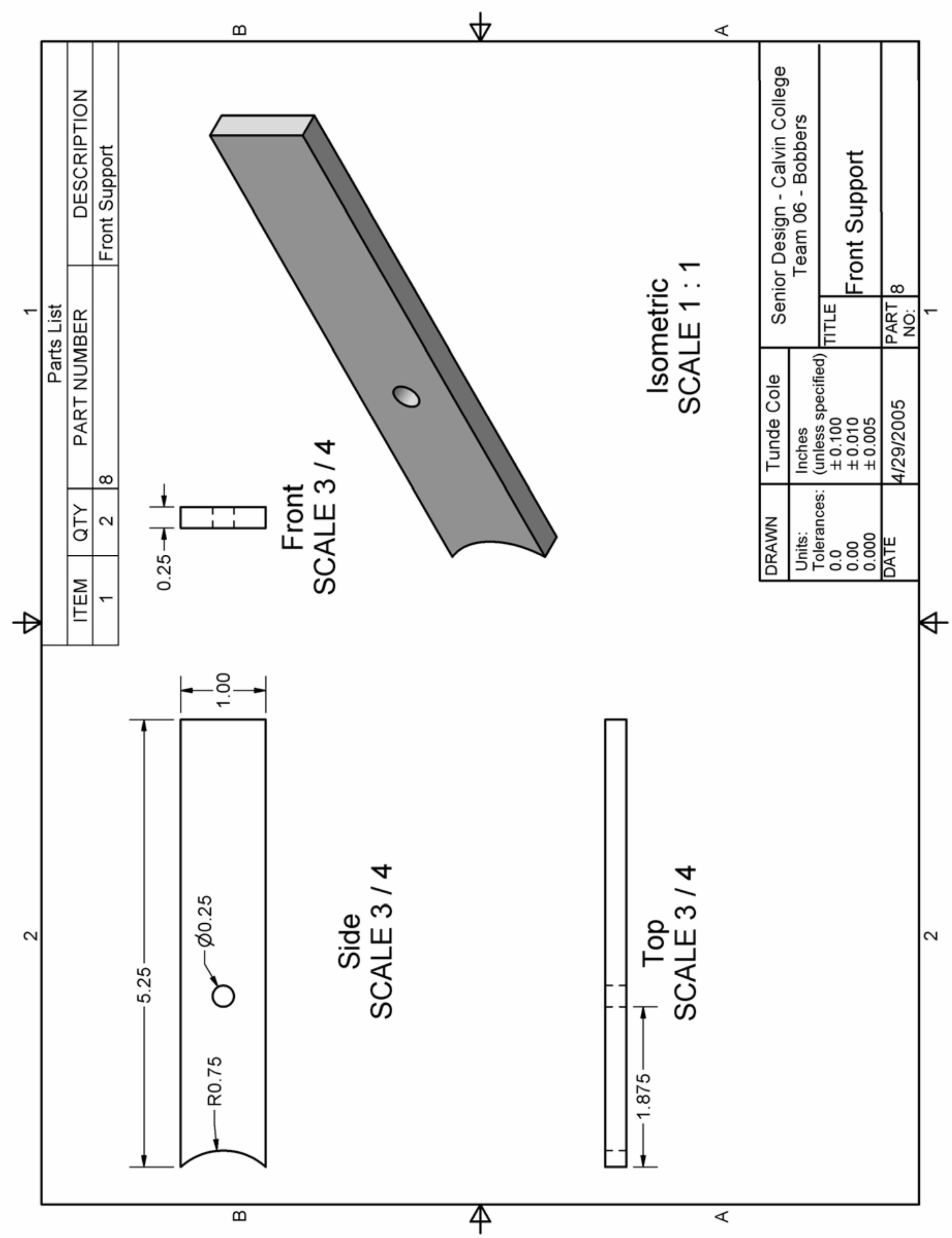


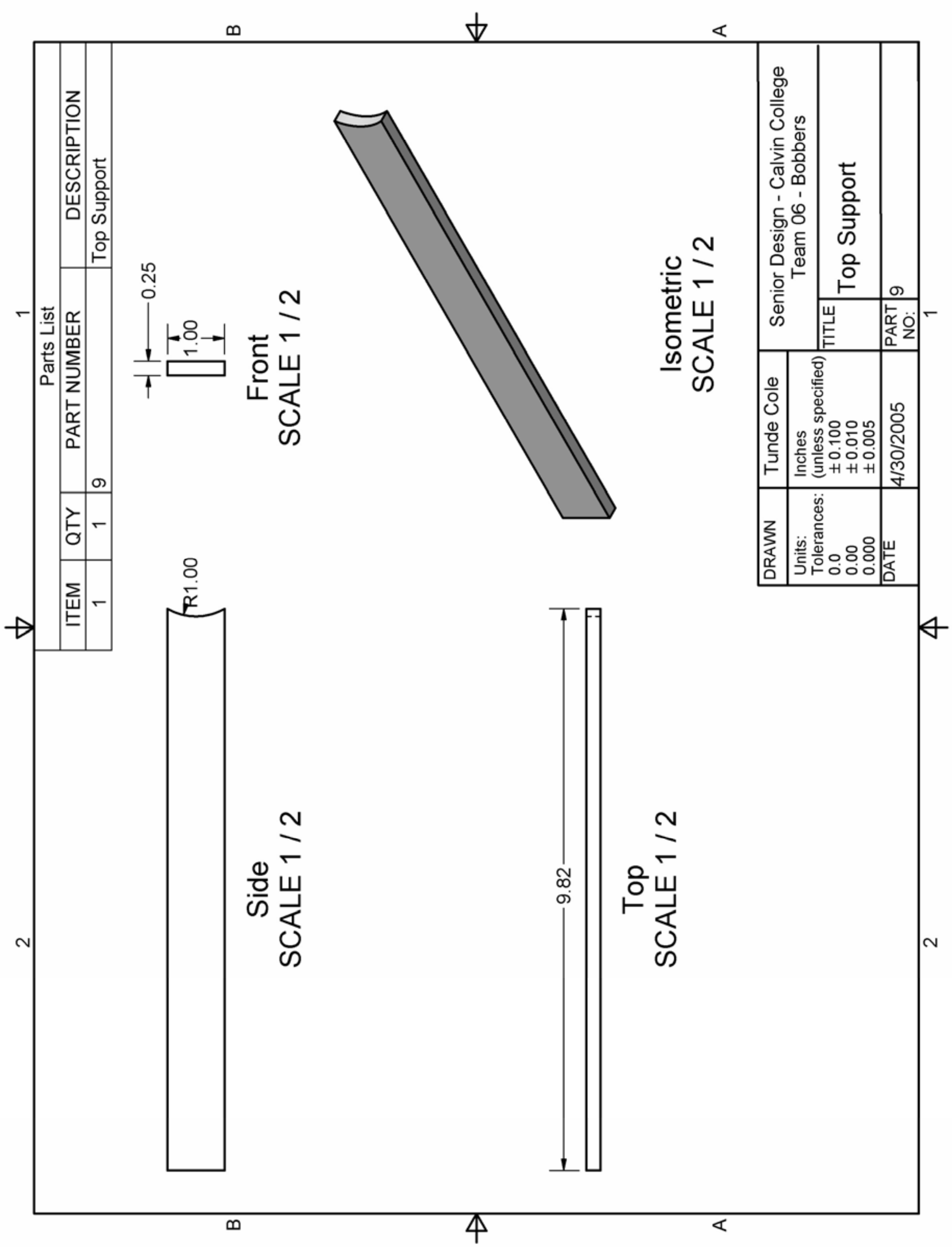
Isometric
SCALE 0.85 : 1

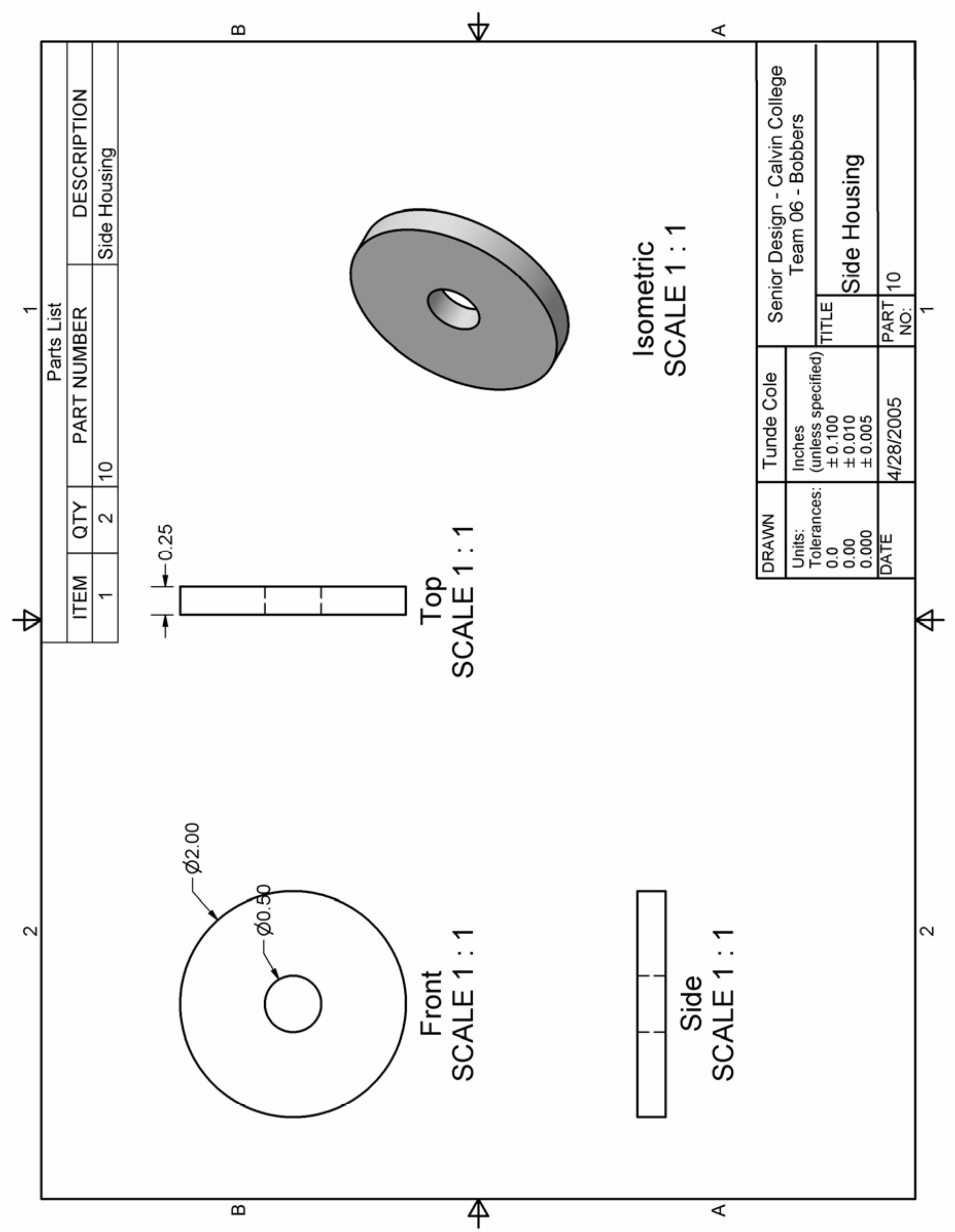
Notes:
-All components in this assembly should bonded by welding
-Side Housing (R) is not shown in current view

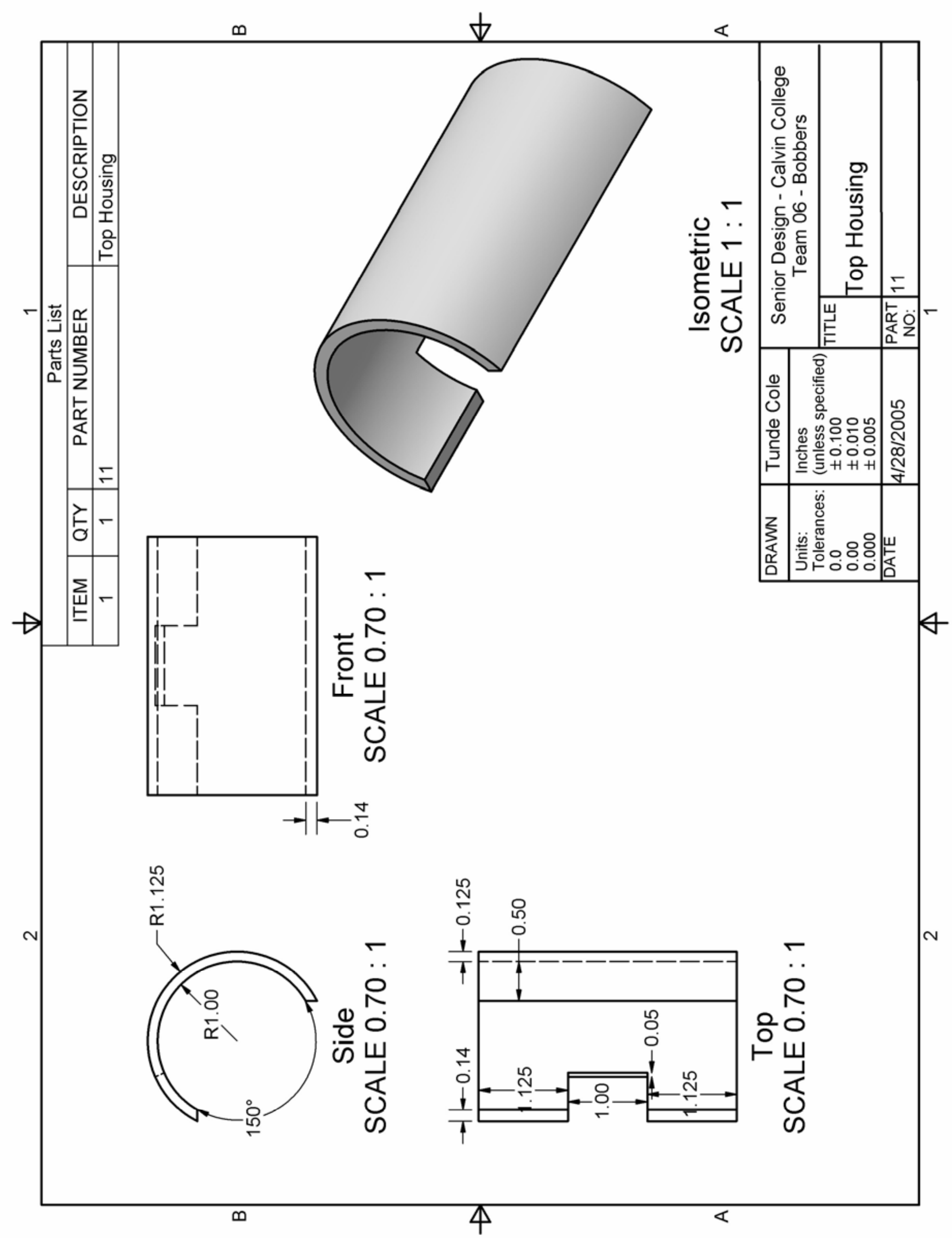
DRAWN	Tunde Cole	Senior Design - Calvin College Team 06 - Bobbers	
Units: Tolerances: 0.0 0.00 0.000	Inches (unless specified) ± 0.100 ± 0.010 ± 0.005	TITLE	Support Assembly
DATE	5/4/2005	PART NO:	none

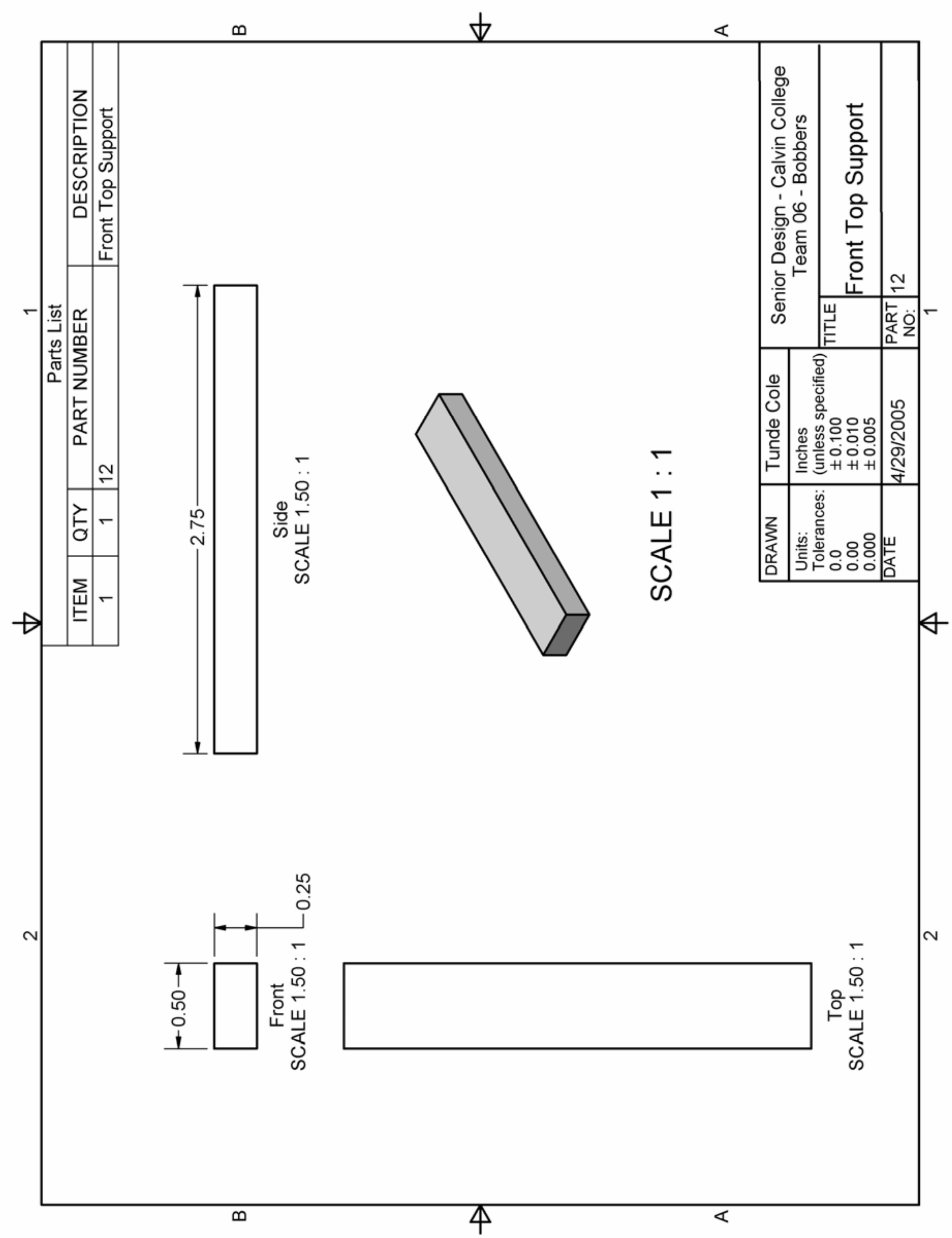

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
2
7
Rear Support
0.25
1.00
Front
SCALE 3 / 4
R1.00
R0.50
Side
SCALE 3 / 4
5.13
Top
SCALE 3 / 4
Isometric
SCALE 1 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Rear Support
DATE
4/30/2005
PART NO:
7
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
2
8
Front Support
0.25
Front
SCALE 3 / 4
Isometric
SCALE 1 : 1
1.00
5.25
Ø0.25
R0.75
Side
SCALE 3 / 4
1.875
Top
SCALE 3 / 4
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Front Support
DATE
4/29/2005
PART NO:
8
A
B
1
2

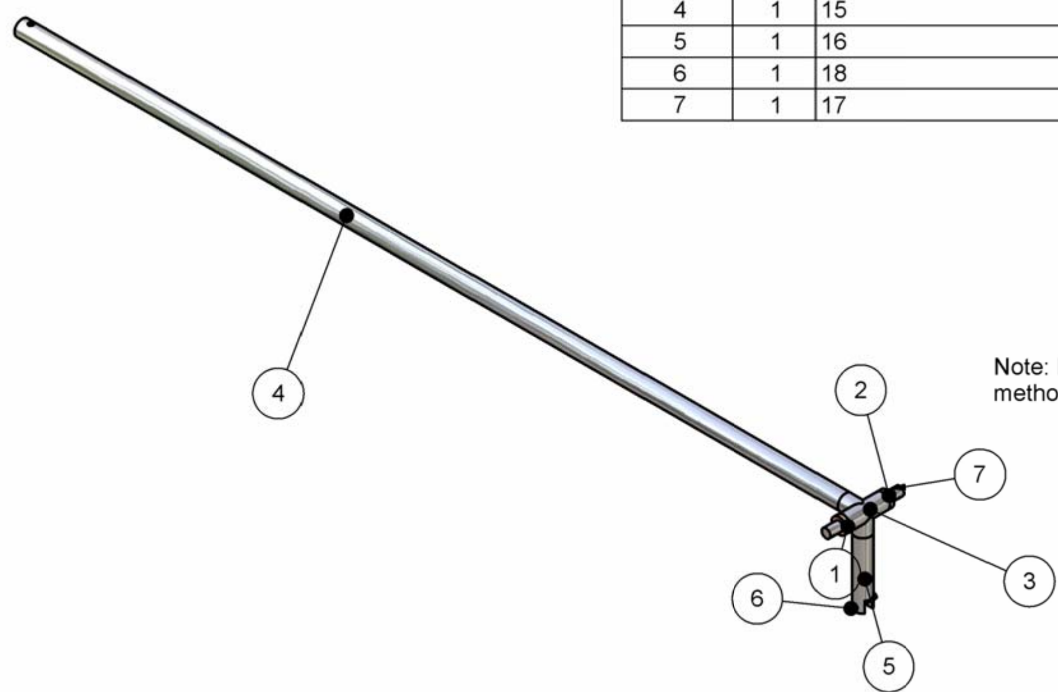

Parts List
ITEM QTY PART NUMBER DESCRIPTION
1 1 9 Top Support
0.25
1.00
Front
SCALE 1 / 2
R1.00
Isometric
SCALE 1 / 2
Side
SCALE 1 / 2
9.82
Top
SCALE 1 / 2
DRAWN Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE Top Support
DATE 4/30/2005
PART NO: 9
A
B
1
2


Parts List
ITEM QTY PART NUMBER DESCRIPTION
1 2 10 Side Housing
0.25
Top
SCALE 1 : 1
Ø2.00
Ø0.50
Front
SCALE 1 : 1
Side
SCALE 1 : 1
Isometric
SCALE 1 : 1
DRAWN Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE Side Housing
DATE 4/28/2005
PART NO: 10


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
11
Top Housing
R1.125
R1.00
150°
Side
SCALE 0.70 : 1
0.14
Front
SCALE 0.70 : 1
0.125
0.50
0.14
.125
1.00
0.05
1.125
Top
SCALE 0.70 : 1
Isometric
SCALE 1 : 1
DRAWN
Tunde Cole
Units:
Inches
Tolerances:
(unless specifed)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
DATE
4/28/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Top Housing
PART NO:
11
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
12
Front Top Support
2.75
Side
SCALE 1.50 : 1
0.50
0.25
Front
SCALE 1.50 : 1
Top
SCALE 1.50 : 1
SCALE 1 : 1
DRAWN
Tunde Cole
Units:
Inches
Tolerances:
(unless specifed)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
DATE
4/29/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Front Top Support
PART NO:
12
A
B
1
2

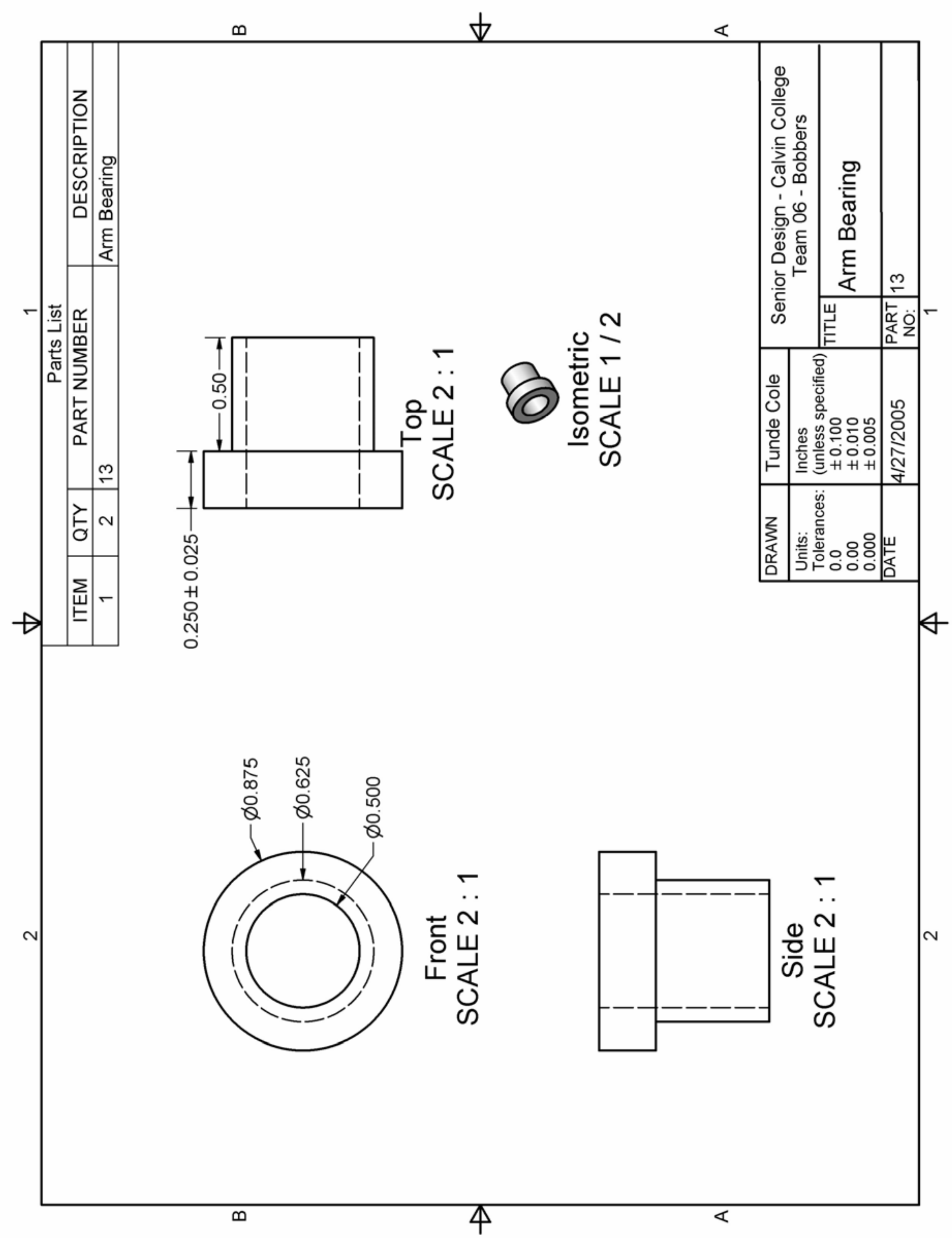
Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	13	Arm Bearing (L)
2	1	13	Arm Bearing (R)
3	1	14	Arm T-Joint
4	1	15	Arm
5	1	16	Bottom Arm
6	1	18	Bottom Arm Pin
7	1	17	T-Joint Pin

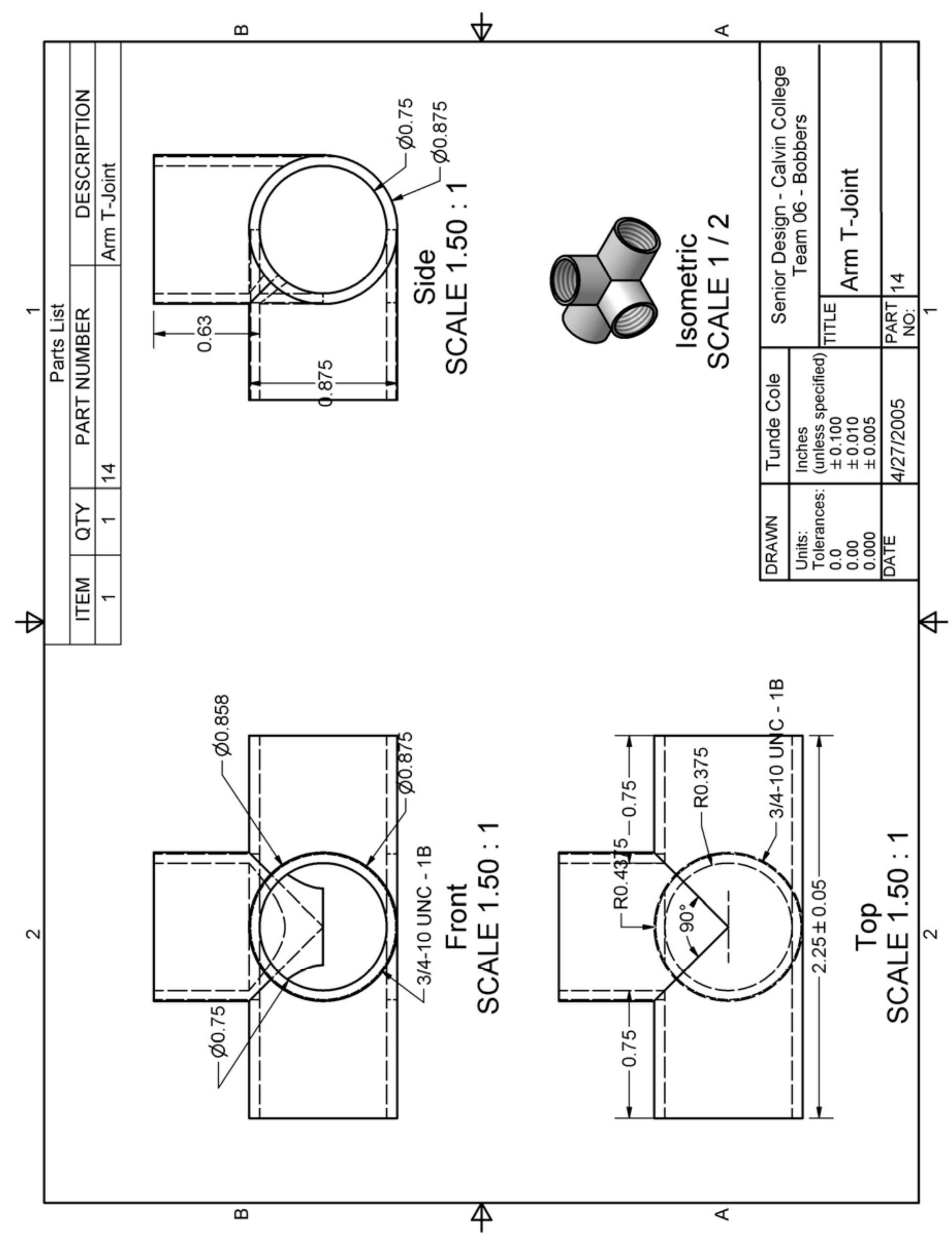


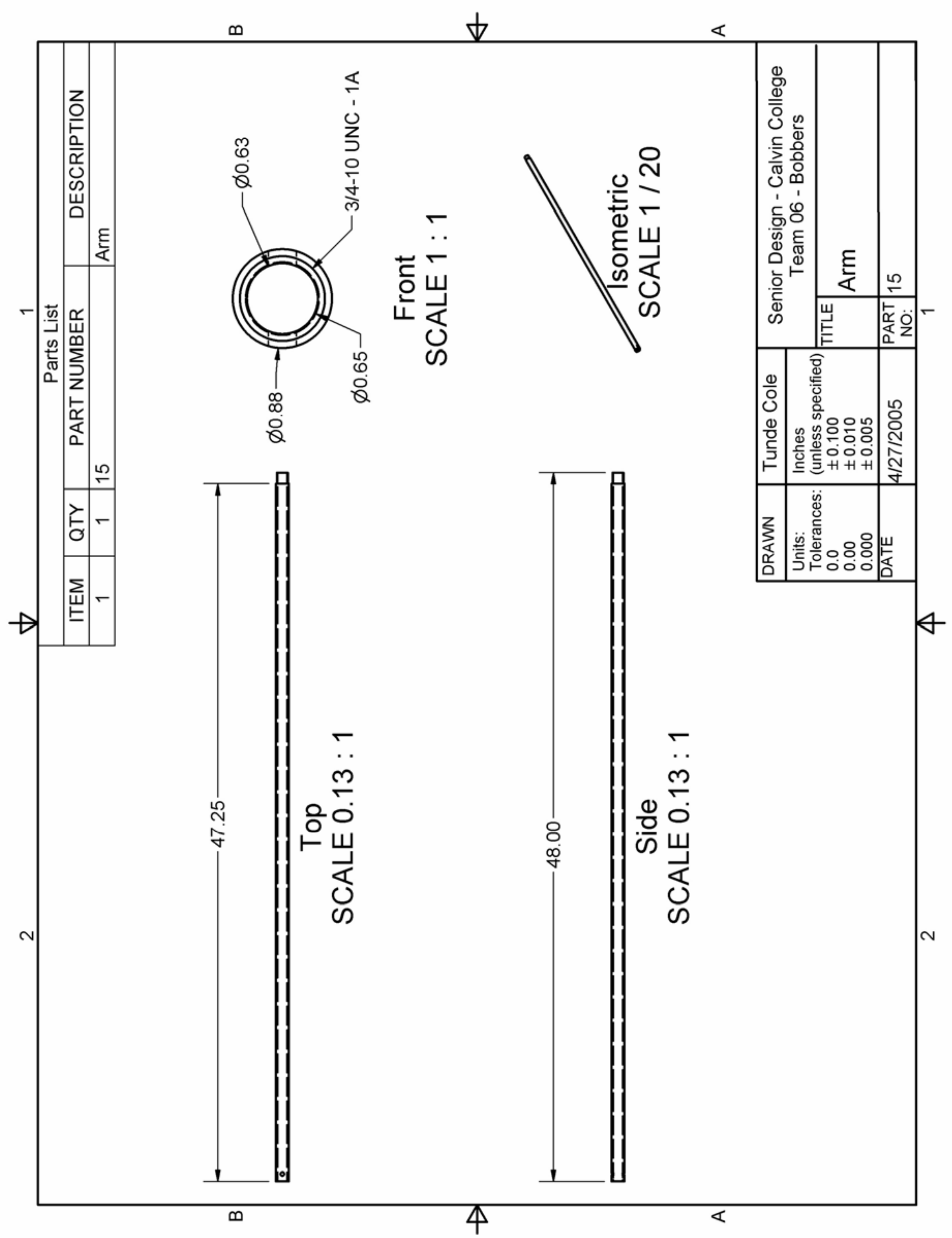
Note: No particular bonding method needed for this assembly

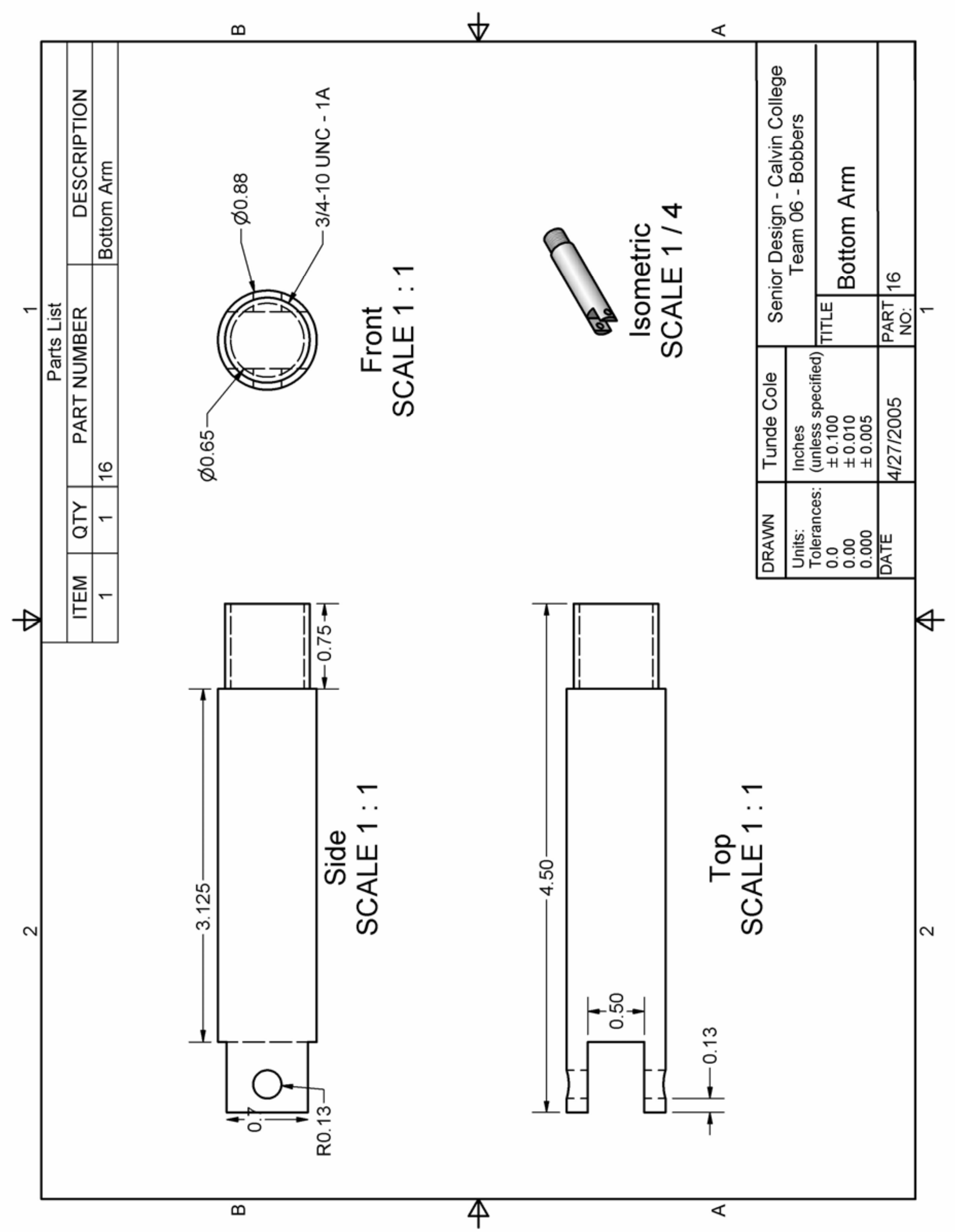
Isometric
SCALE 0.17 : 1

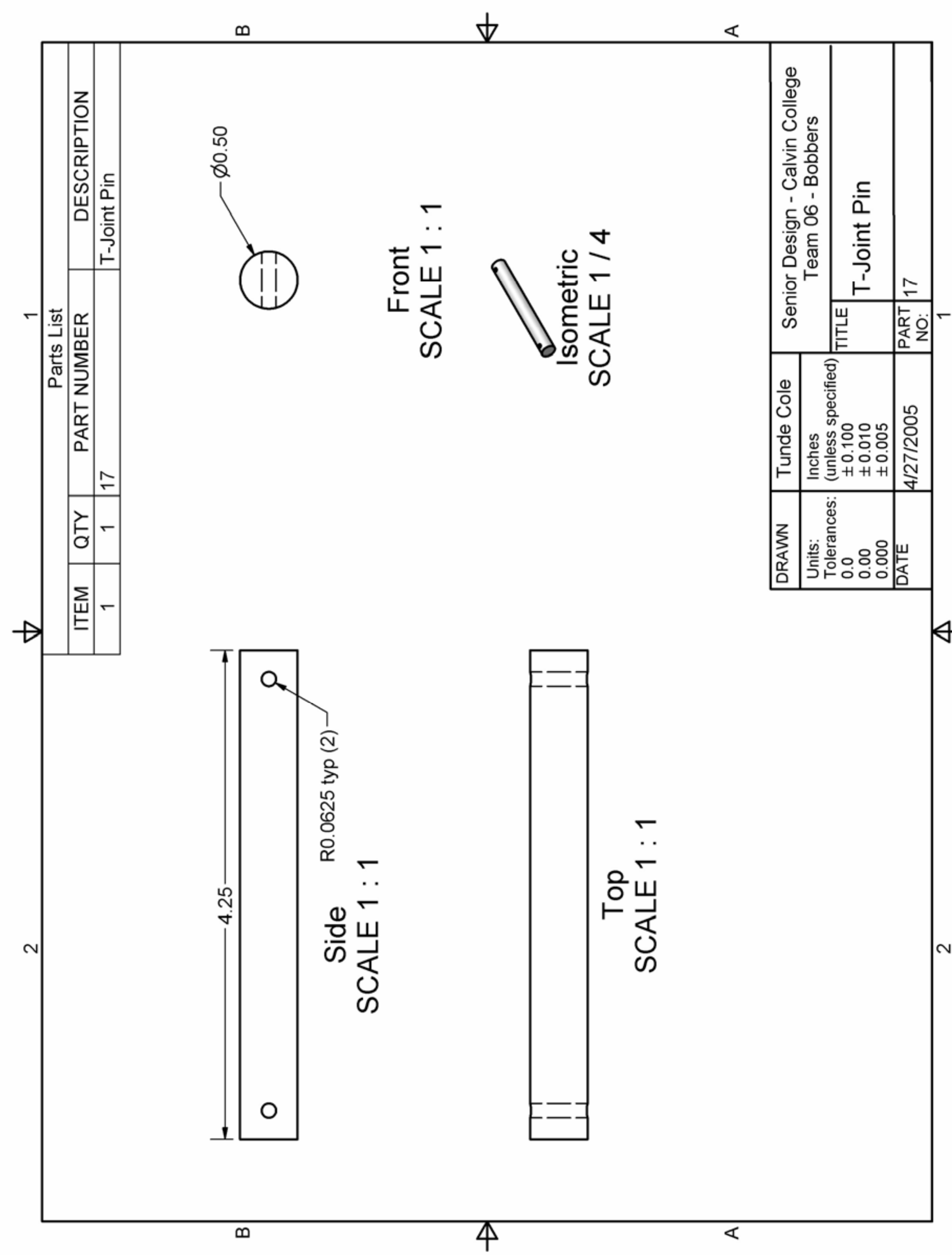
DRAWN	Tunde Cole	Senior Design - Calvin College Team 06 - Bobbers	
Units: Tolerances: 0.0 0.00 0.000	Inches (unless specifed) ± 0.100 ± 0.010 ± 0.005	TITLE	Arm Assembly
DATE	5/4/2005	PART NO:	none

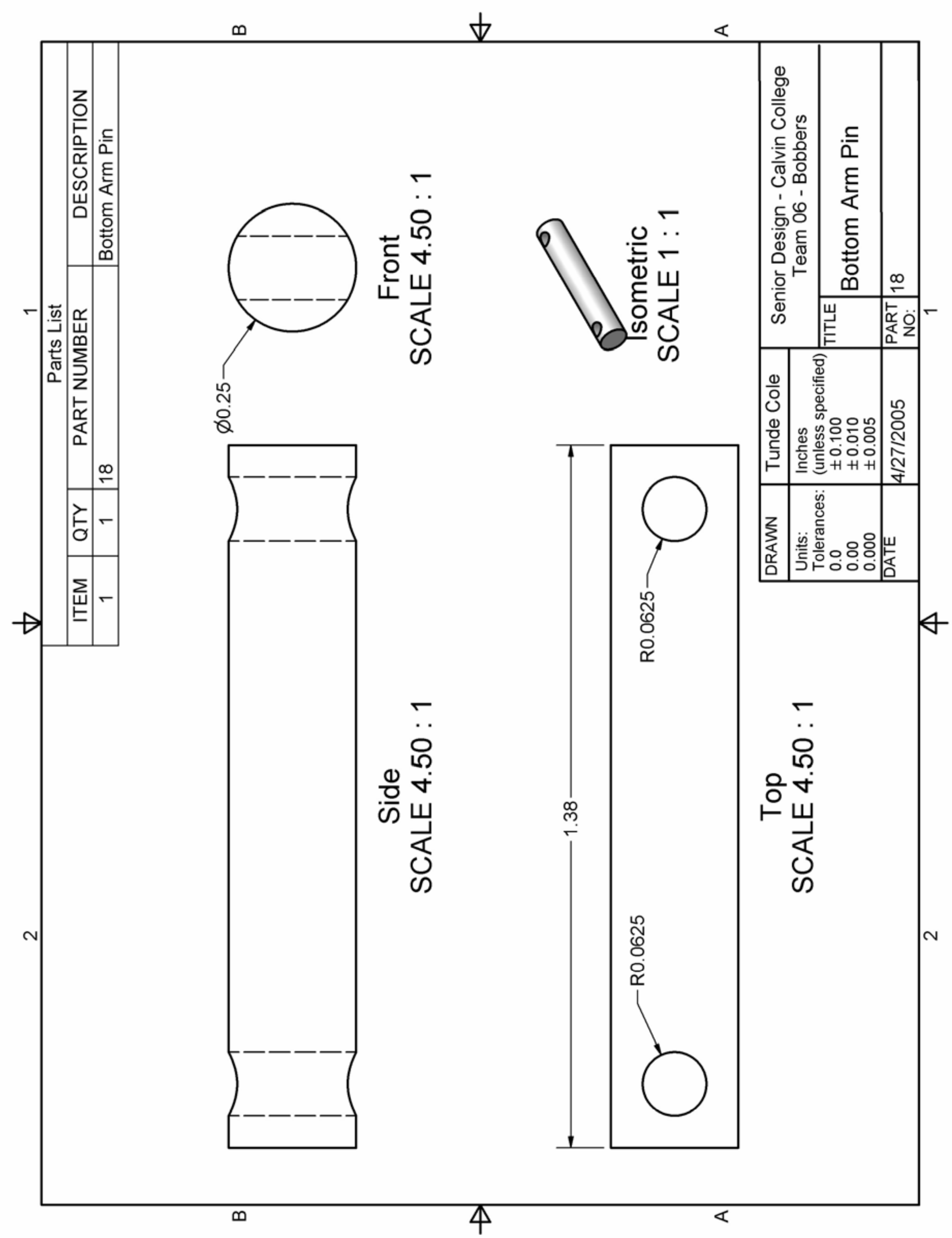

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
2
13
Arm Bearing
0.250 ± 0.025
0.50
Top
SCALE 2 : 1
Isometric
SCALE 1 / 2
Ø0.875
Ø0.625
Ø0.500
Front
SCALE 2 : 1
Side
SCALE 2 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specified)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Arm Bearing
DATE
4/27/2005
PART NO:
13
A
B
1
2

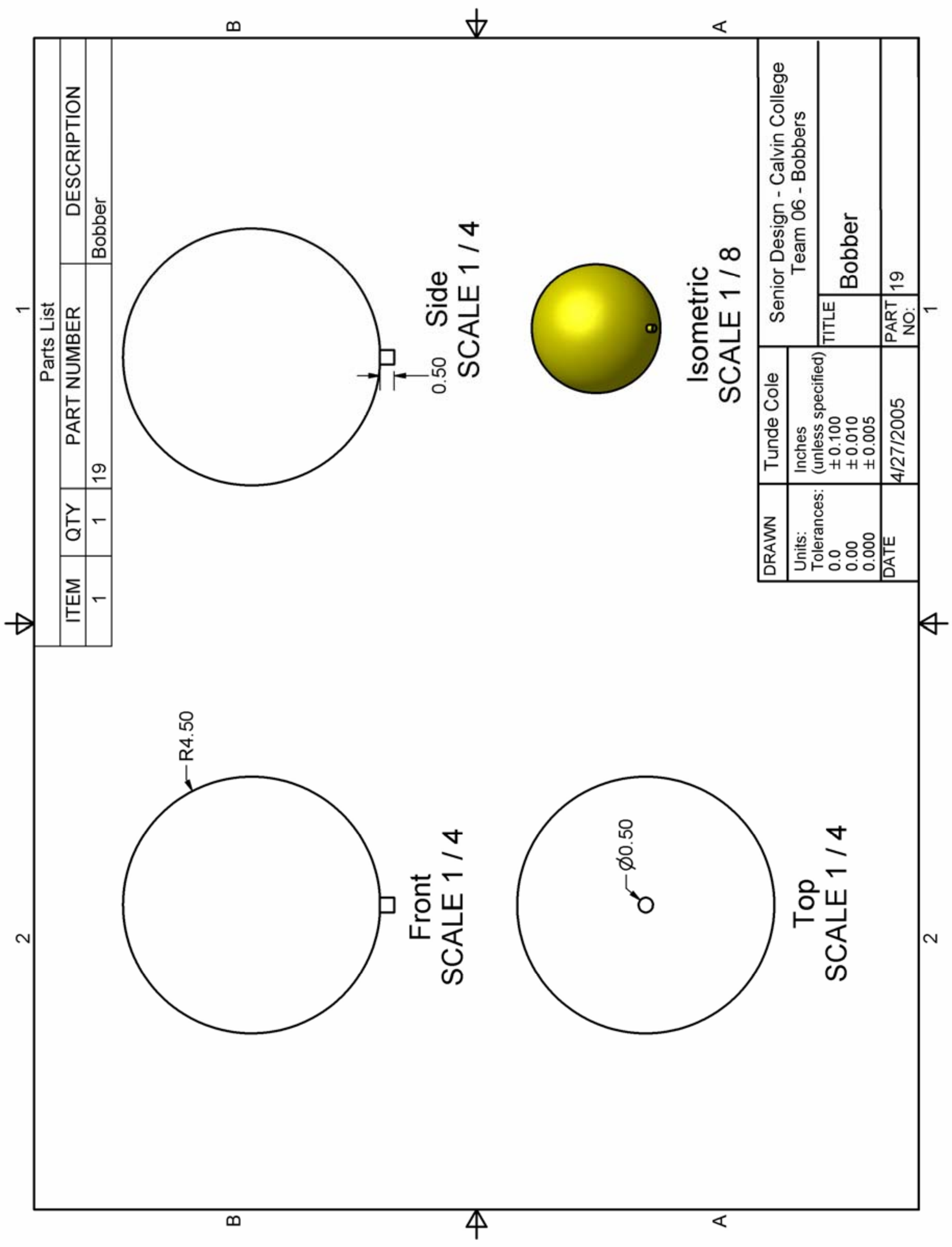

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
14
Arm T-Joint
Ø0.75
Ø0.875
0.63
0.875
Side
SCALE 1.50 : 1
Isometric
SCALE 1 / 2
Ø0.858
Ø0.875
Ø0.75
3/4-10 UNC - 1B
Front
SCALE 1.50 : 1
0.75
R0.4375
R0.375
90°
2.25 ± 0.05
Top
SCALE 1.50 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Arm T-Joint
DATE
4/27/2005
PART NO:
14


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
15
Arm
Ø0.63
3/4-10 UNC - 1A
Ø0.88
Ø0.65
Front
SCALE 1 : 1
Isometric
SCALE 1 / 20
47.25
Top
SCALE 0.13 : 1
48.00
Side
SCALE 0.13 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Arm
DATE
4/27/2005
PART NO:
15

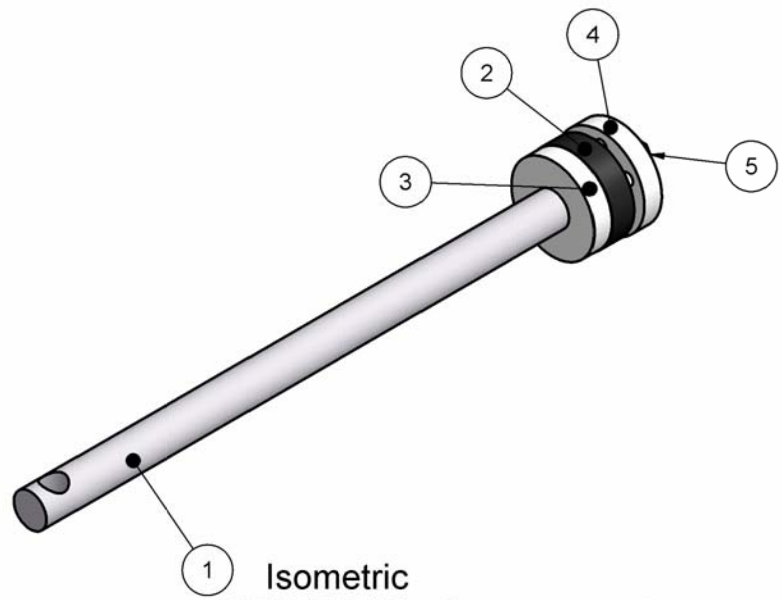

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
16
Bottom Arm
Ø0.88
3/4-10 UNC - 1A
Ø0.65
Front
SCALE 1 : 1
Isometric
SCALE 1 / 4
3.125
0.75
0.7
R0.13
Side
SCALE 1 : 1
4.50
0.50
0.13
Top
SCALE 1 : 1
DRAWN
Tunde Cole
Units:
Inches
Tolerances:
(unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
DATE
4/27/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Bottom Arm
PART NO:
16


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
17
T-Joint Pin
Ø0.50
Front
SCALE 1 : 1
Isometric
SCALE 1 / 4
4.25
R0.0625 typ (2)
Side
SCALE 1 : 1
Top
SCALE 1 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
T-Joint Pin
DATE
4/27/2005
PART NO:
17


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | 18 | Bottom Arm Pin
Ø0.25
Front
SCALE 4.50 : 1
Isometric
SCALE 1 : 1
Side
SCALE 4.50 : 1
1.38
R0.0625
R0.0625
Top
SCALE 4.50 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Bottom Arm Pin
DATE
4/27/2005
PART NO:
18
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
19
Bobber
R4.50
Front
SCALE 1 / 4
Ø0.50
Top
SCALE 1 / 4
0.50
Side
SCALE 1 / 4
Isometric
SCALE 1 / 8
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Tolerances:
0.0
0.00
0.000
Inches
(unless specifed)
± 0.100
± 0.010
± 0.005
TITLE
Bobber
DATE
4/27/2005
PART NO:
19
1
2
A
B

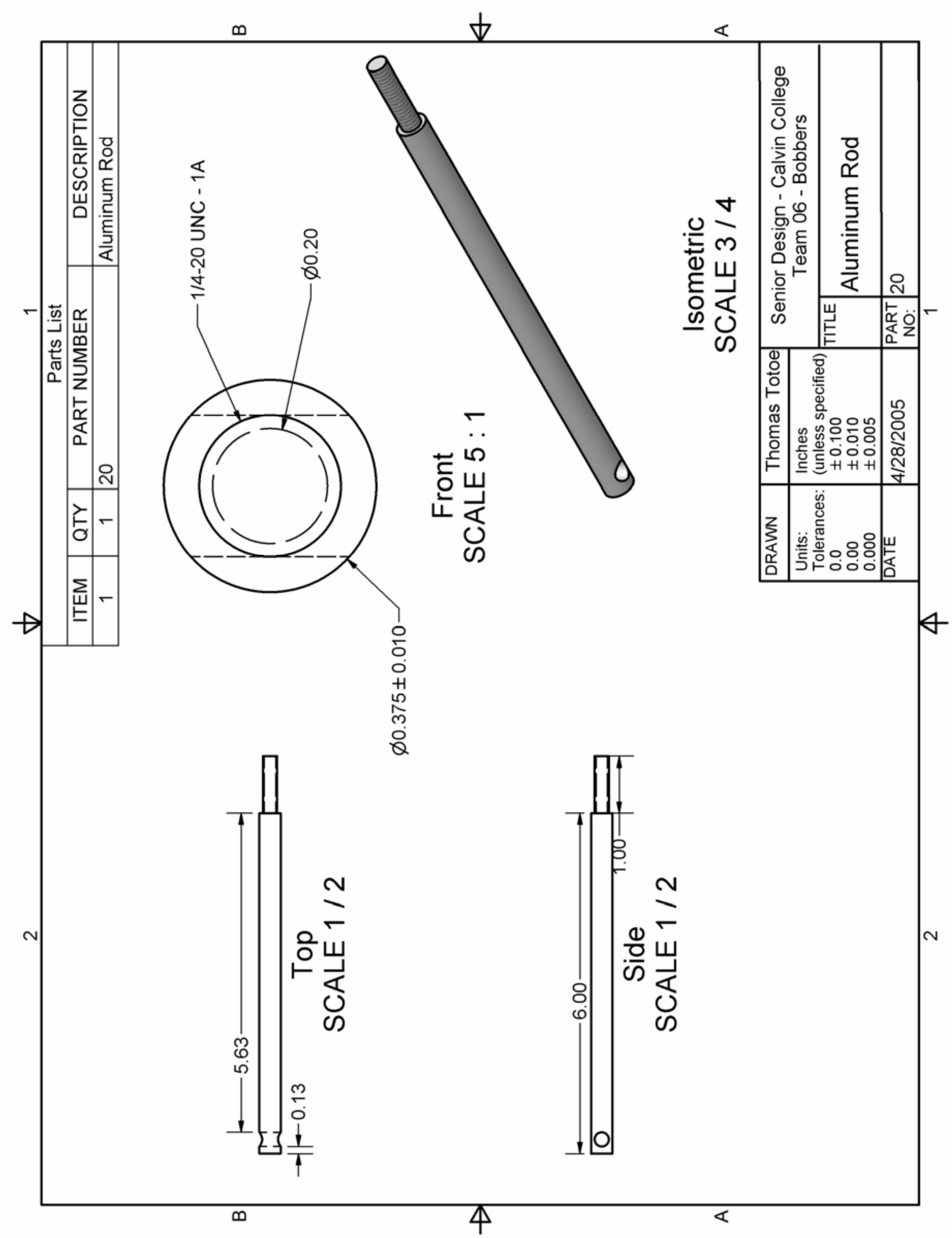
Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	20	Aluminum Rod
2	1	22	Rubber Check Valve
3	1	21	Nylon CheckValve
4	1	23	Inner Nylon Check Valve
5	1	24	Piston Nut

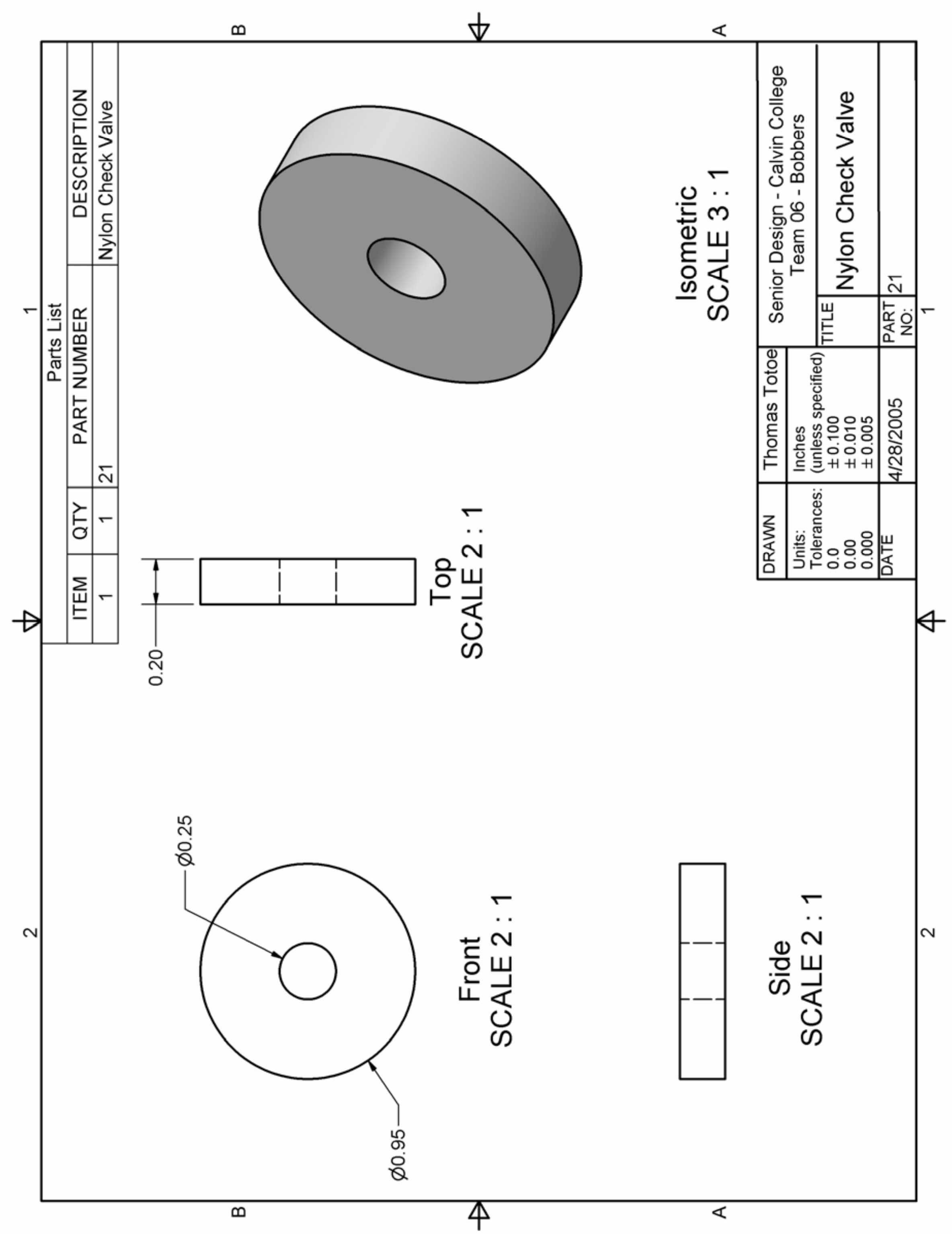


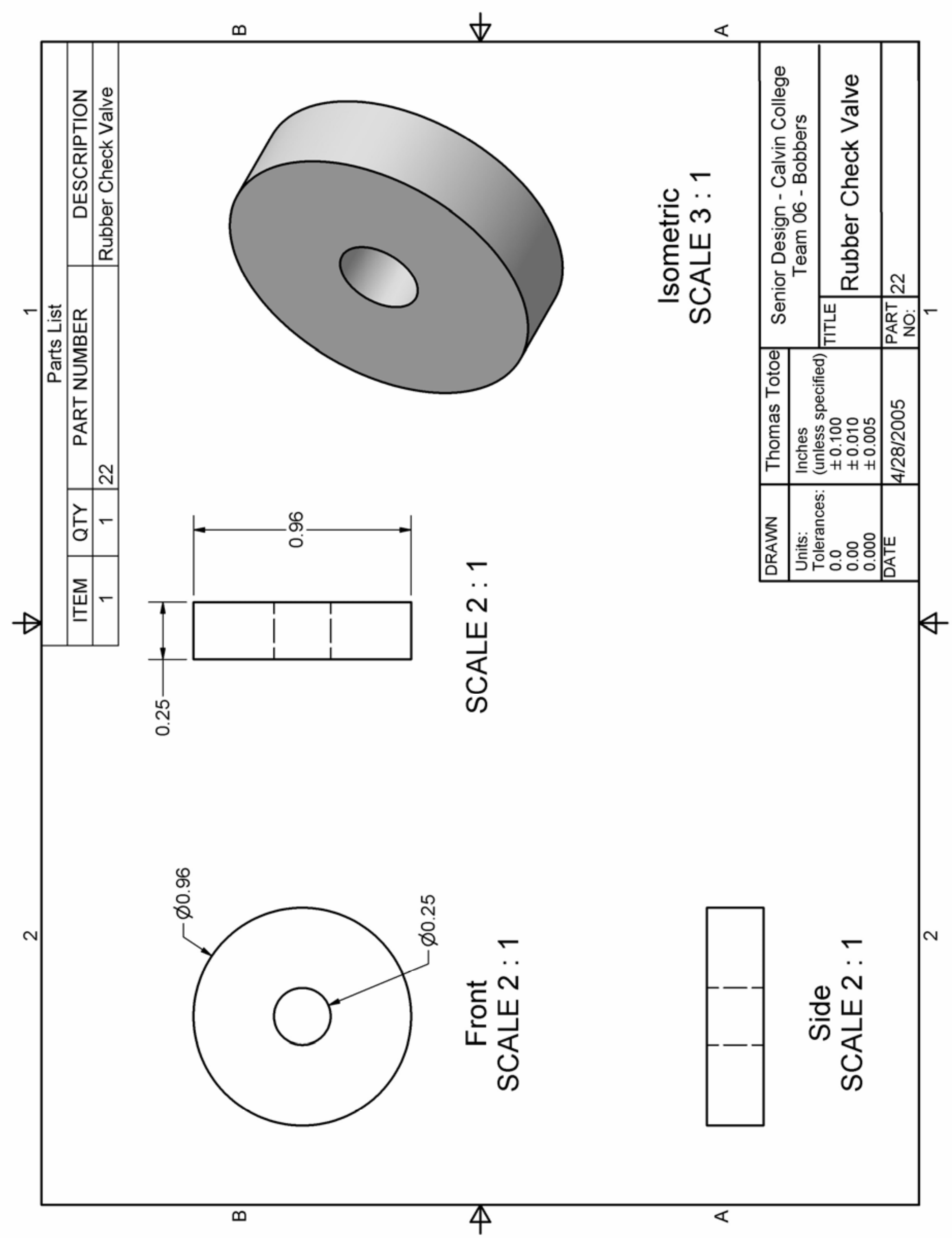
Isometric
SCALE 0.88 : 1

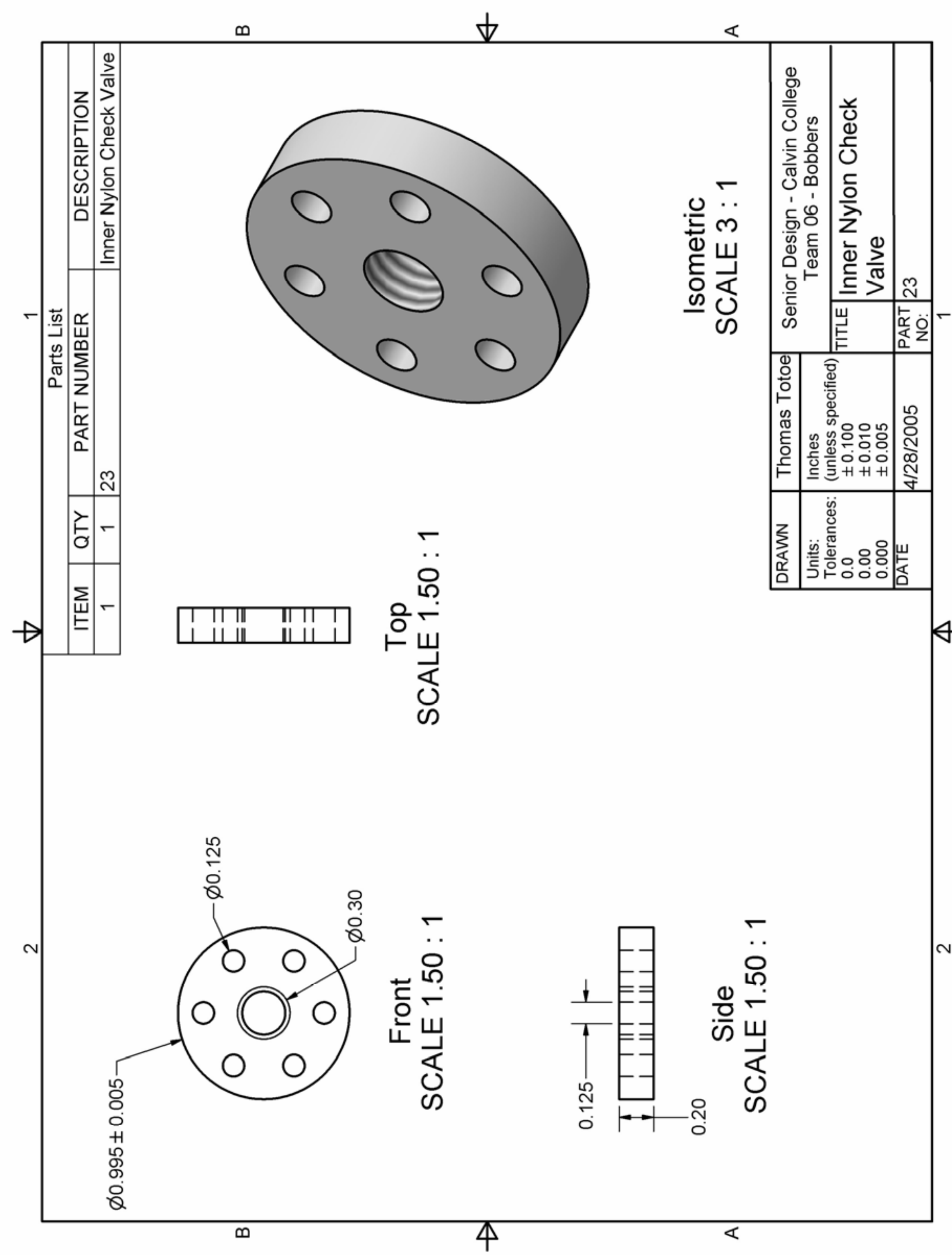
Note: No particular bonding method needed for this component

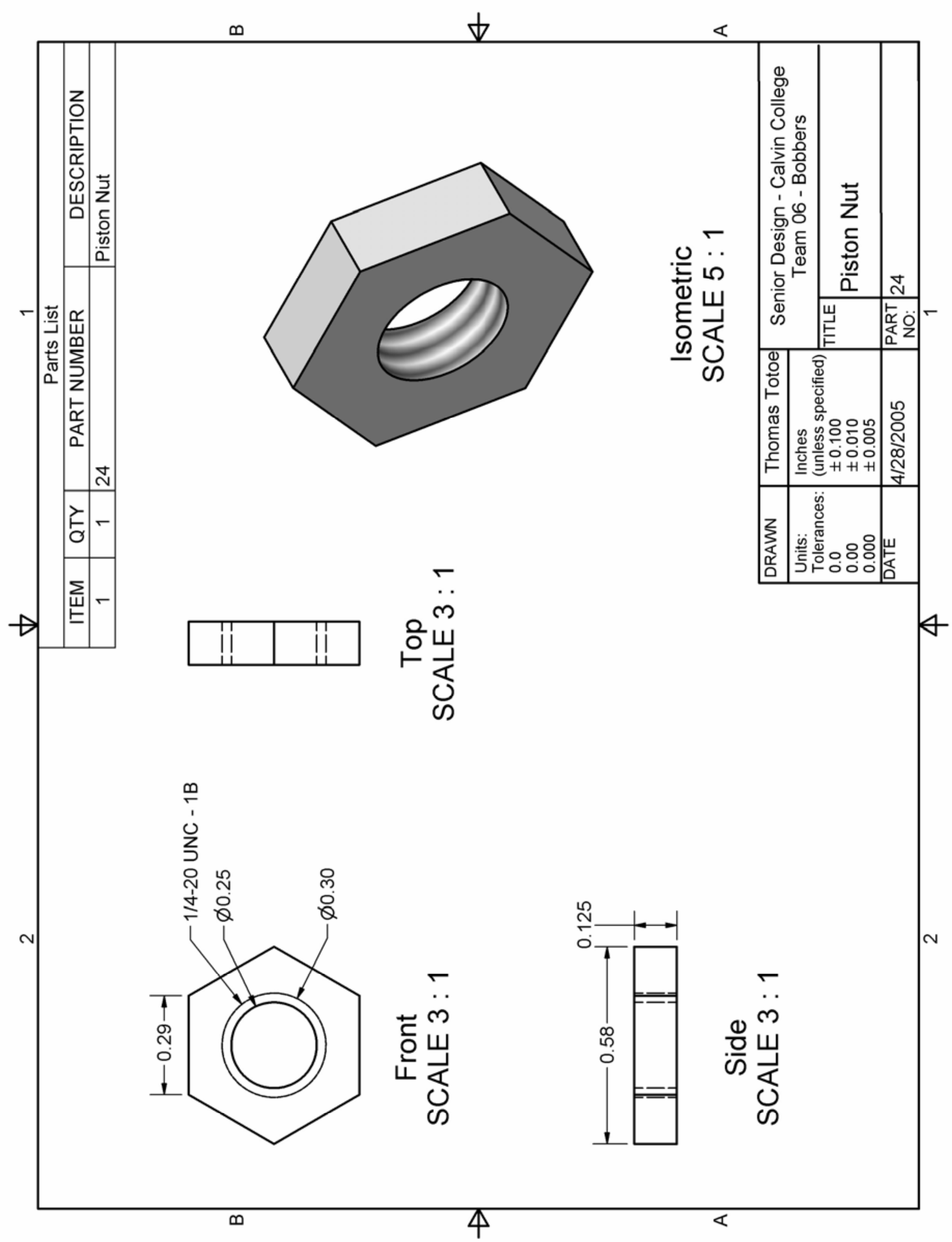
DRAWN	Thomas Totoe	Senior Design - Calvin College Team 06 - Bobbers	
Units: Tolerances: 0.0 0.00 0.000	Inches (unless specified) ± 0.100 ± 0.010 ± 0.005	TITLE	Piston Assembly
DATE	5/4/2005	PART NO:	none


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
20
Aluminum Rod
1/4-20 UNC - 1A
Ø0.20
Ø0.375±0.010
Front
SCALE 5 : 1
Isometric
SCALE 3 / 4
5.63
0.13
Top
SCALE 1 / 2
6.00
1.00
Side
SCALE 1 / 2
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specified)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Aluminum Rod
DATE
4/28/2005
PART NO:
20


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | 21 | Nylon Check Valve
0.20
Top
SCALE 2 : 1
Ø0.25
Ø0.95
Front
SCALE 2 : 1
Side
SCALE 2 : 1
Isometric
SCALE 3 : 1
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Tolerances:
0.0
0.00
0.000
Inches
(unless specified)
± 0.100
± 0.010
± 0.005
TITLE
Nylon Check Valve
DATE
4/28/2005
PART NO:
21
A
B
1
2

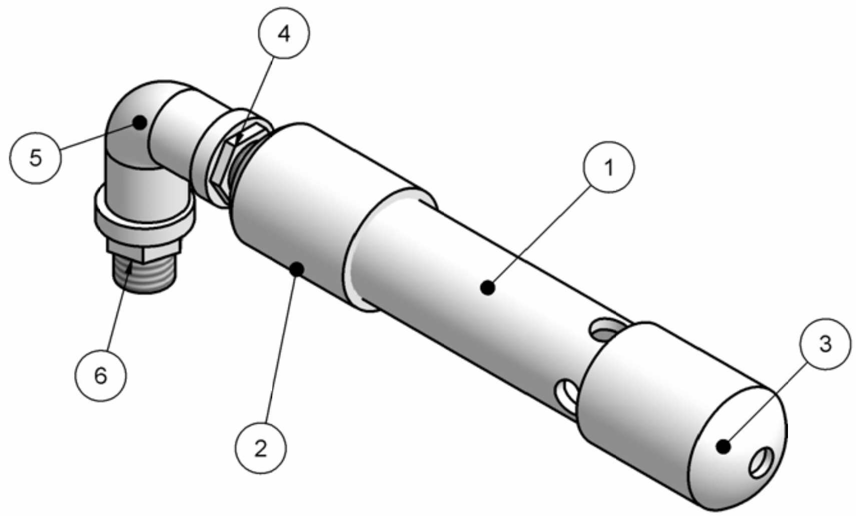

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
22
Rubber Check Valve
0.96
0.25
SCALE 2 : 1
Isometric
SCALE 3 : 1
Ø0.96
Ø0.25
Front
SCALE 2 : 1
Side
SCALE 2 : 1
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specified)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Rubber Check Valve
DATE
4/28/2005
PART NO:
22
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
23
Inner Nylon Check Valve
Ø0.995 ± 0.005
Ø0.125
Ø0.30
Front
SCALE 1.50 : 1
0.125
0.20
Side
SCALE 1.50 : 1
Top
SCALE 1.50 : 1
Isometric
SCALE 3 : 1
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Inner Nylon Check Valve
DATE
4/28/2005
PART NO:
23
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
24
Piston Nut
1/4-20 UNC - 1B
Ø0.25
Ø0.30
0.29
Front
SCALE 3 : 1
0.125
0.58
Side
SCALE 3 : 1
Top
SCALE 3 : 1
Isometric
SCALE 5 : 1
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Piston Nut
DATE
4/28/2005
PART NO:
24
A
B
1
2

Parts List

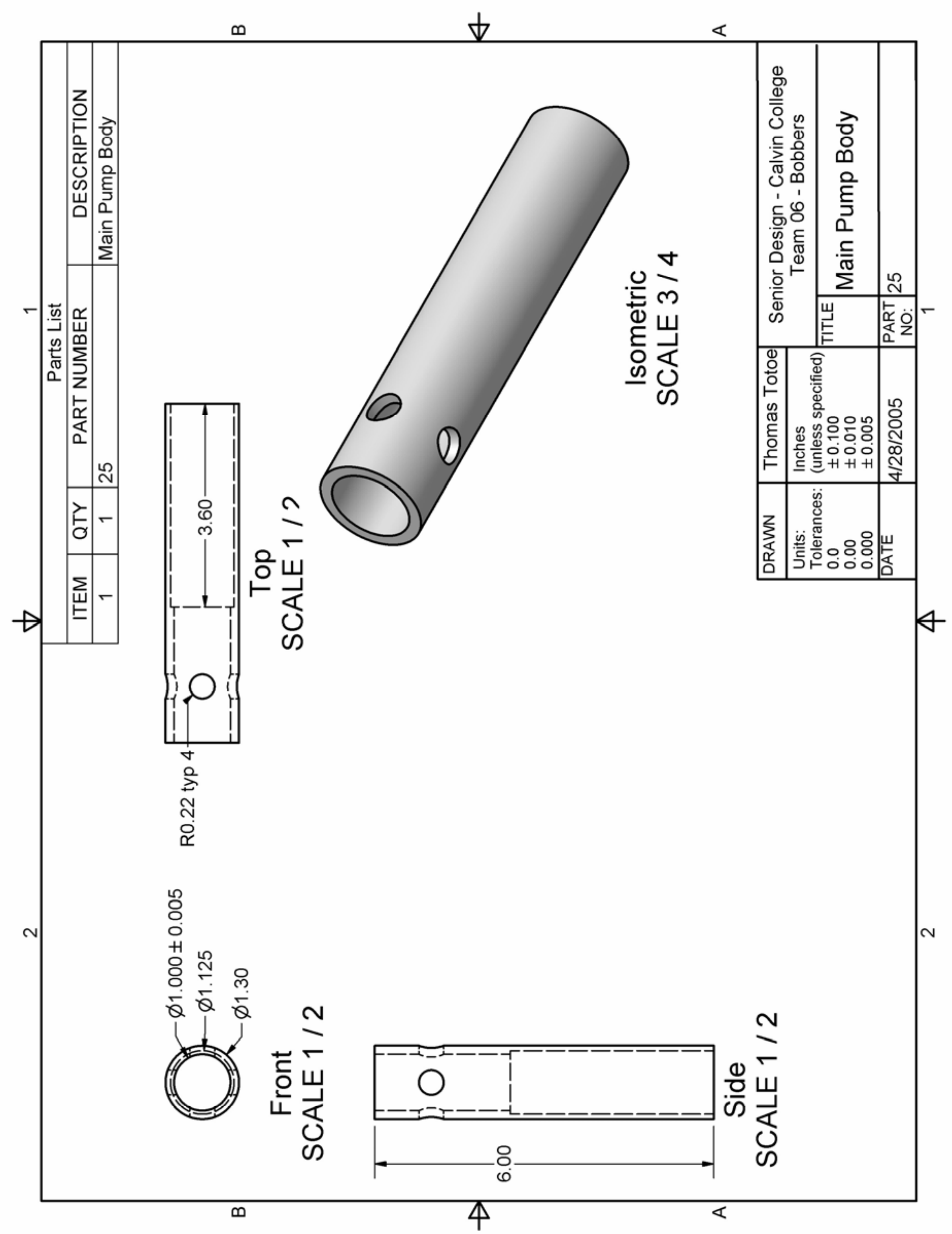
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	25	Main Pump Body
2	1	27	Bottom Pump Cap
3	1	26	Top Pump Cap
4	1	28	Pump Hose Connector
5	1	29	Pump Angle Joint
6	1	30	Pump Valve Connector

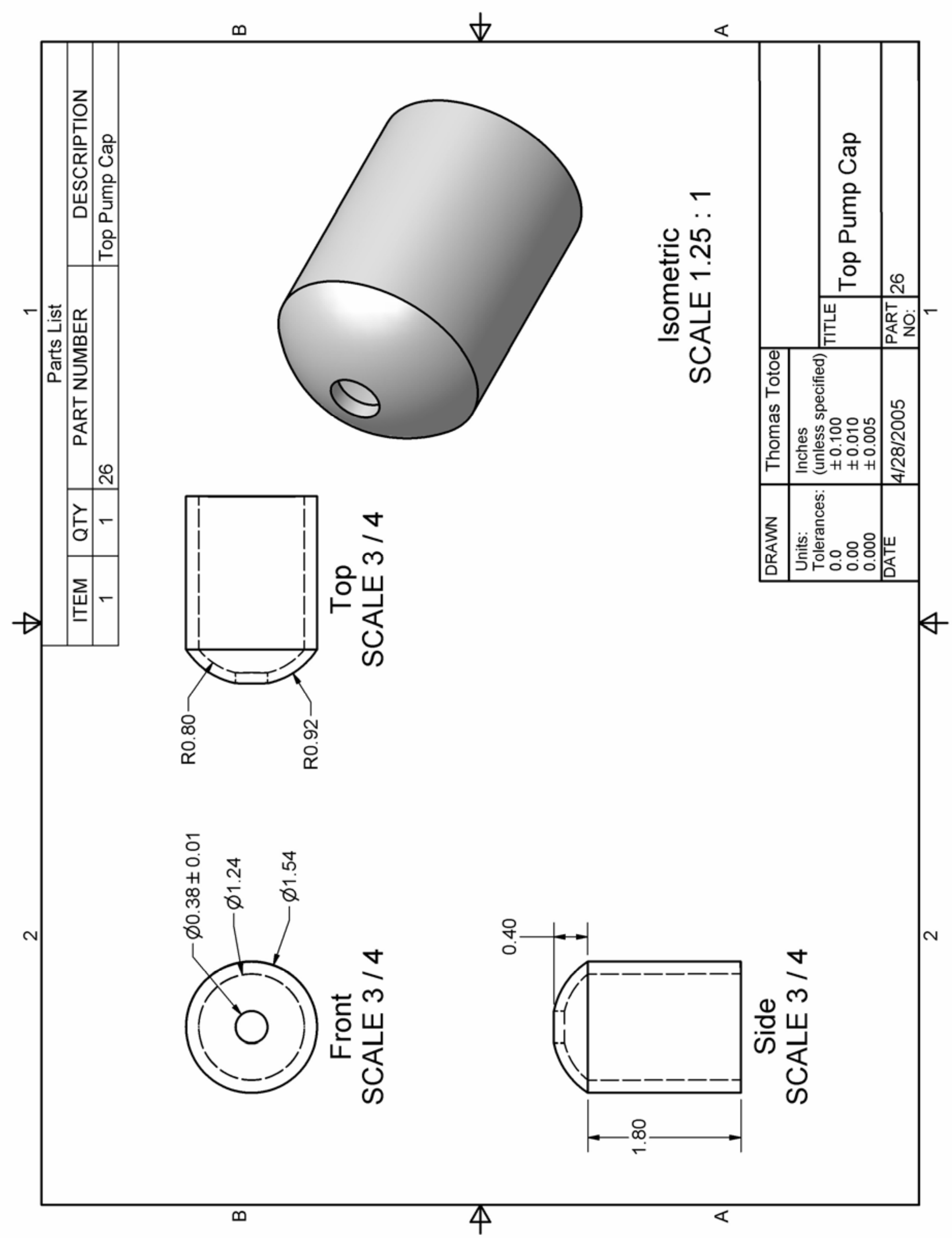


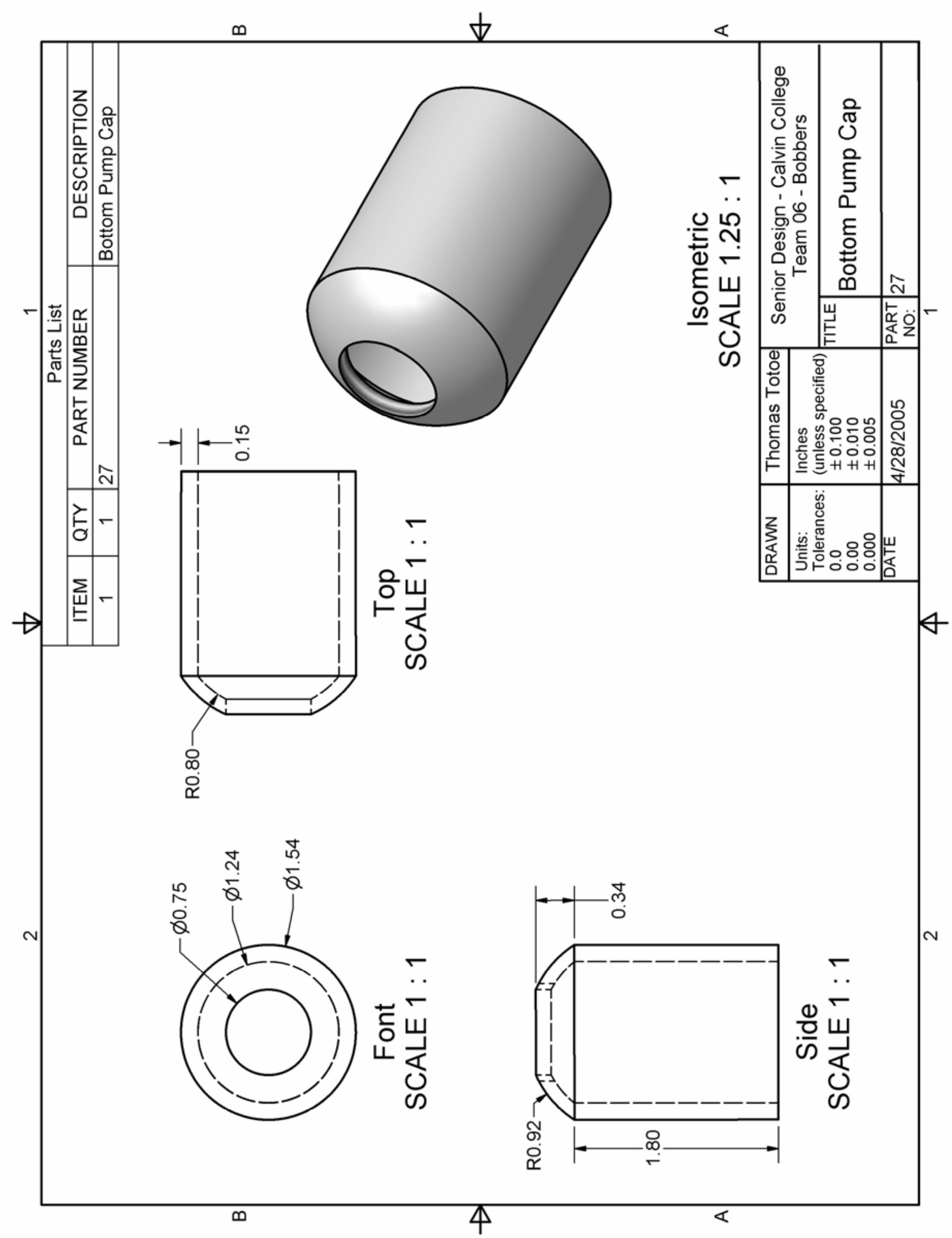
Isometric
SCALE 0.63 : 1

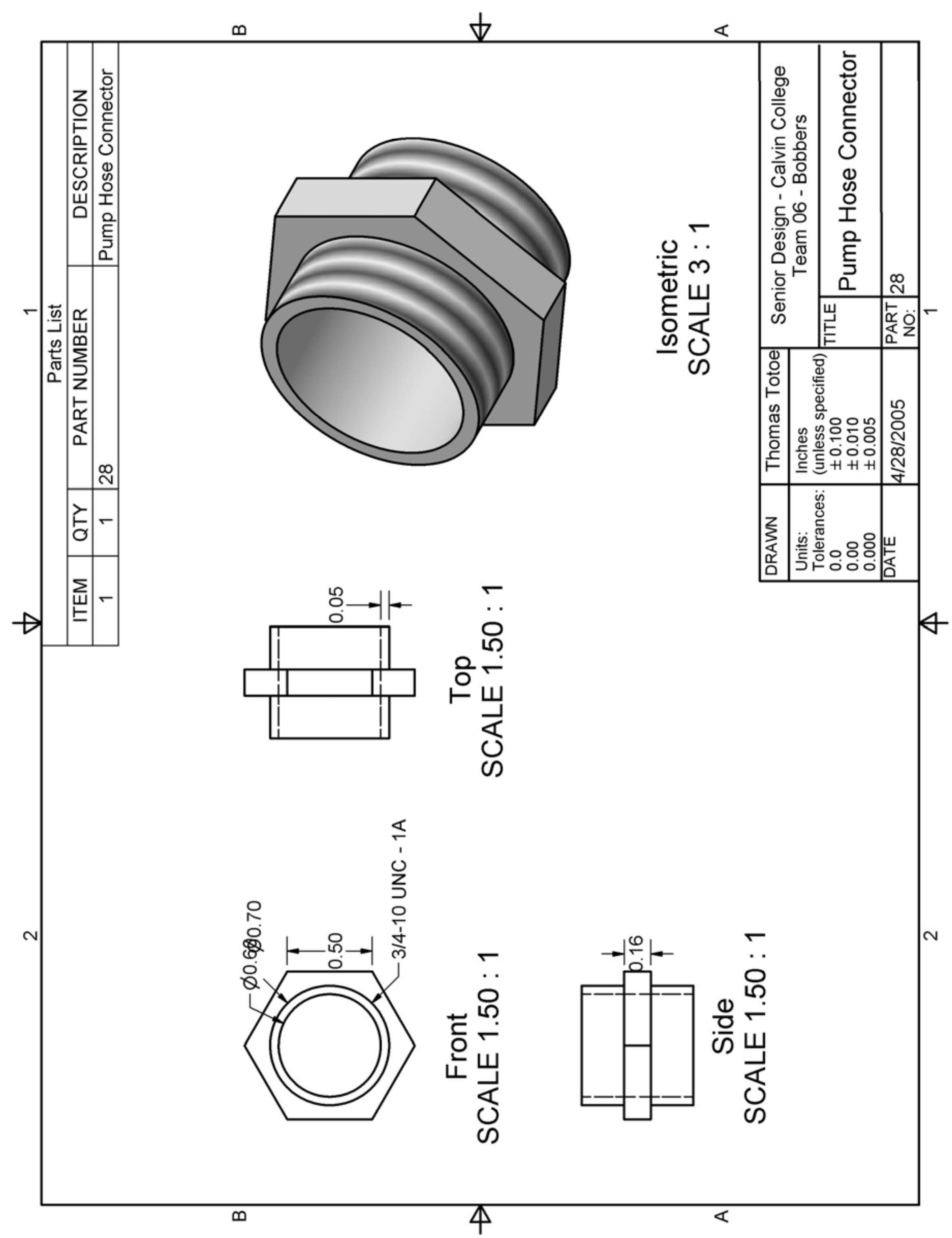
Note: Endcaps should be bonded to the main body with PVC cement.

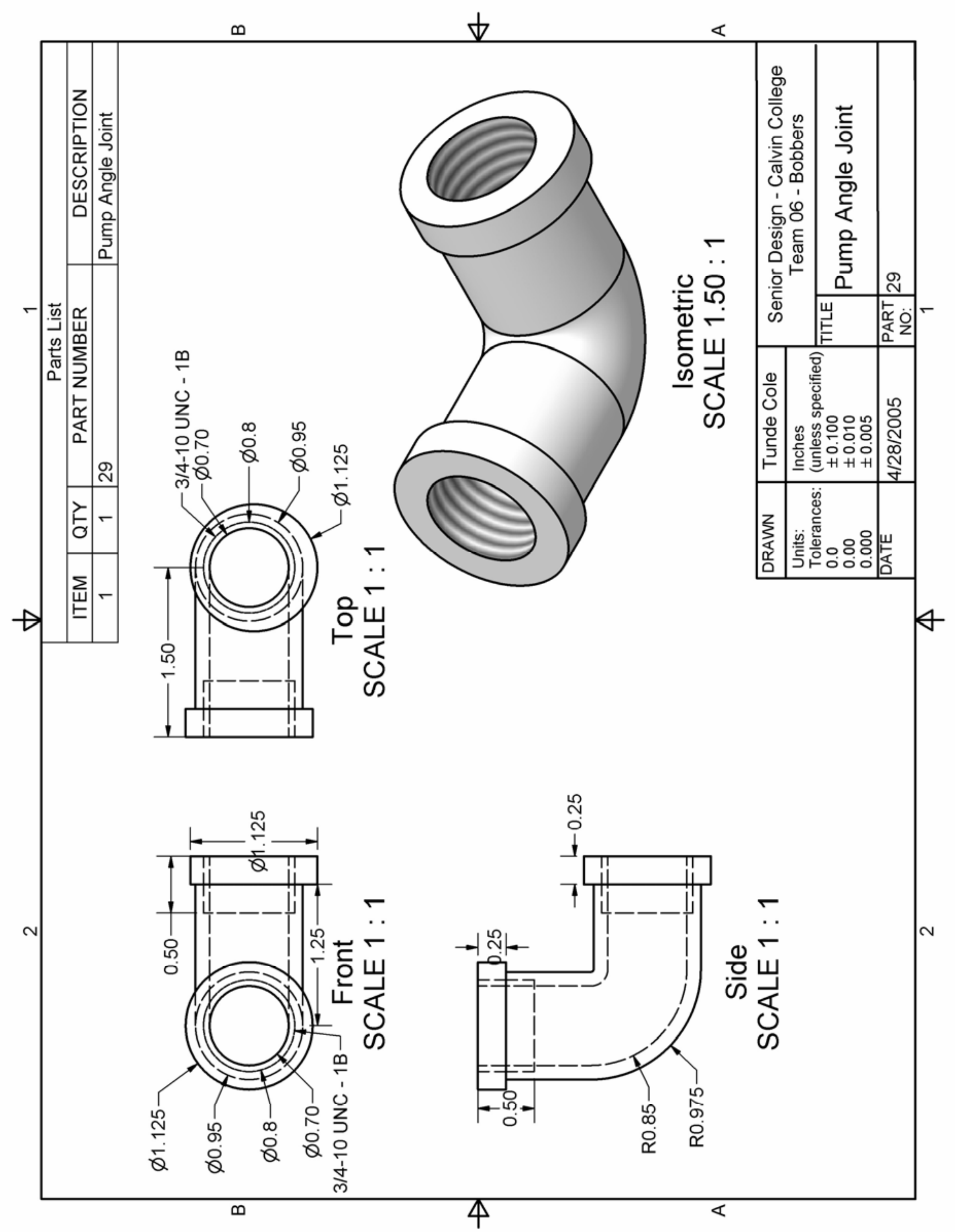
DRAWN	Thomas Totoe	Senior Design - Calvin College Team 06 - Bobbers	
Units: Tolerances: 0.0 0.00 0.000	Inches (unless specified) ± 0.100 ± 0.010 ± 0.005	TITLE	Pump Body Assembly
DATE	5/4/2005	PART NO:	none

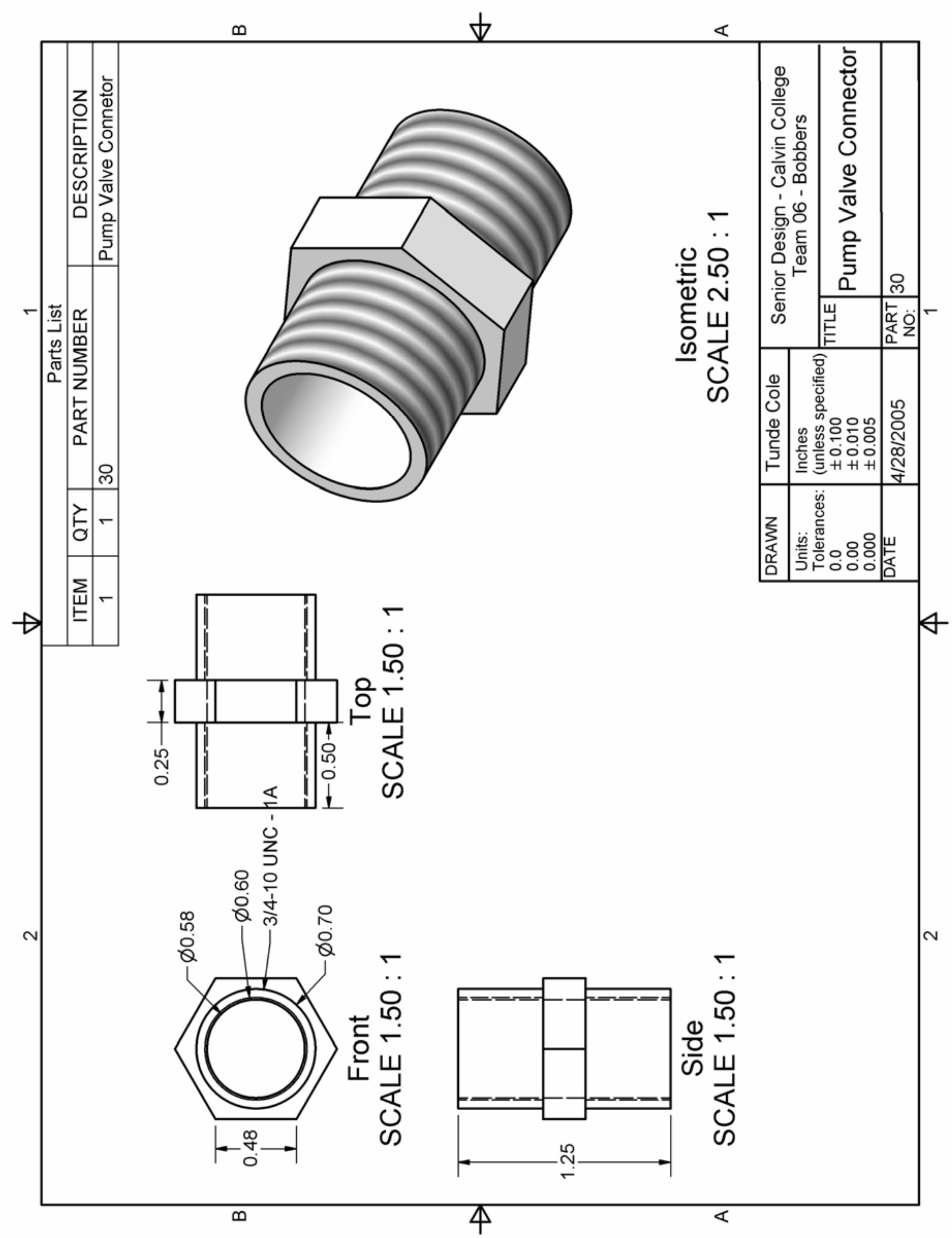

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
25
Main Pump Body
Ø1.000 ± 0.005
Ø1.125
Ø1.30
Front
SCALE 1 / 2
6.00
Side
SCALE 1 / 2
R0.22 typ 4
3.60
Top
SCALE 1 / 2
Isometric
SCALE 3 / 4
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Main Pump Body
DATE
4/28/2005
PART NO:
25


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
26
Top Pump Cap
Front
SCALE 3 / 4
Ø0.38 ± 0.01
Ø1.24
Ø1.54
Top
SCALE 3 / 4
R0.80
R0.92
Side
SCALE 3 / 4
0.40
1.80
Isometric
SCALE 1.25 : 1
DRAWN
Thomas Totoe
Units:
Inches
Tolerances:
(unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
DATE
4/28/2005
TITLE
Top Pump Cap
PART NO:
26
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
27
Bottom Pump Cap
Ø0.75
Ø1.24
Ø1.54
Font
SCALE 1 : 1
R0.80
0.15
Top
SCALE 1 : 1
Isometric
SCALE 1.25 : 1
0.34
R0.92
1.80
Side
SCALE 1 : 1
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Bottom Pump Cap
DATE
4/28/2005
PART NO:
27
A
B
1
2

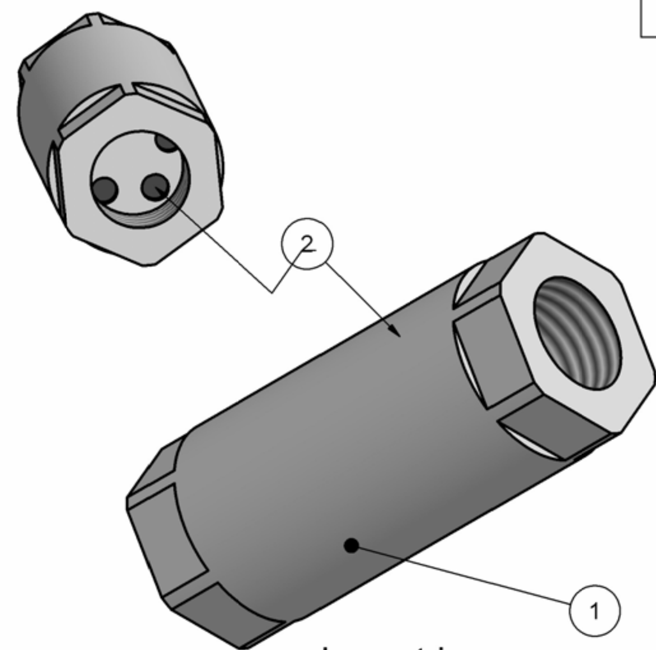

Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
28
Pump Hose Connector
Isometric
SCALE 3 : 1
Top
SCALE 1.50 : 1
0.05
Front
SCALE 1.50 : 1
Ø0.68
Ø0.70
0.50
3/4-10 UNC - 1A
Side
SCALE 1.50 : 1
0.16
DRAWN
Thomas Totoe
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specified)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Pump Hose Connector
DATE
4/28/2005
PART NO:
28


Parts List
ITEM QTY PART NUMBER DESCRIPTION
1 1 29 Pump Angle Joint
Ø1.125
Ø0.95
Ø0.8
Ø0.70
3/4-10 UNC - 1B
0.50
1.25
Front
SCALE 1 : 1
1.50
Top
SCALE 1 : 1
0.25
0.50
R0.85
R0.975
Side
SCALE 1 : 1
Isometric
SCALE 1.50 : 1
DRAWN Tunde Cole
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
DATE 4/28/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE Pump Angle Joint
PART NO: 29
A
B
1
2


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
30
Pump Valve Connetor
Ø0.58
Ø0.60
3/4-10 UNC - 1A
Ø0.70
0.48
Front
SCALE 1.50 : 1
0.25
0.50
Top
SCALE 1.50 : 1
1.25
Side
SCALE 1.50 : 1
Isometric
SCALE 2.50 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0
± 0.100
0.00
± 0.010
0.000
± 0.005
TITLE
Pump Valve Connector
DATE
4/28/2005
PART NO:
30
A
B
1
2

Parts List

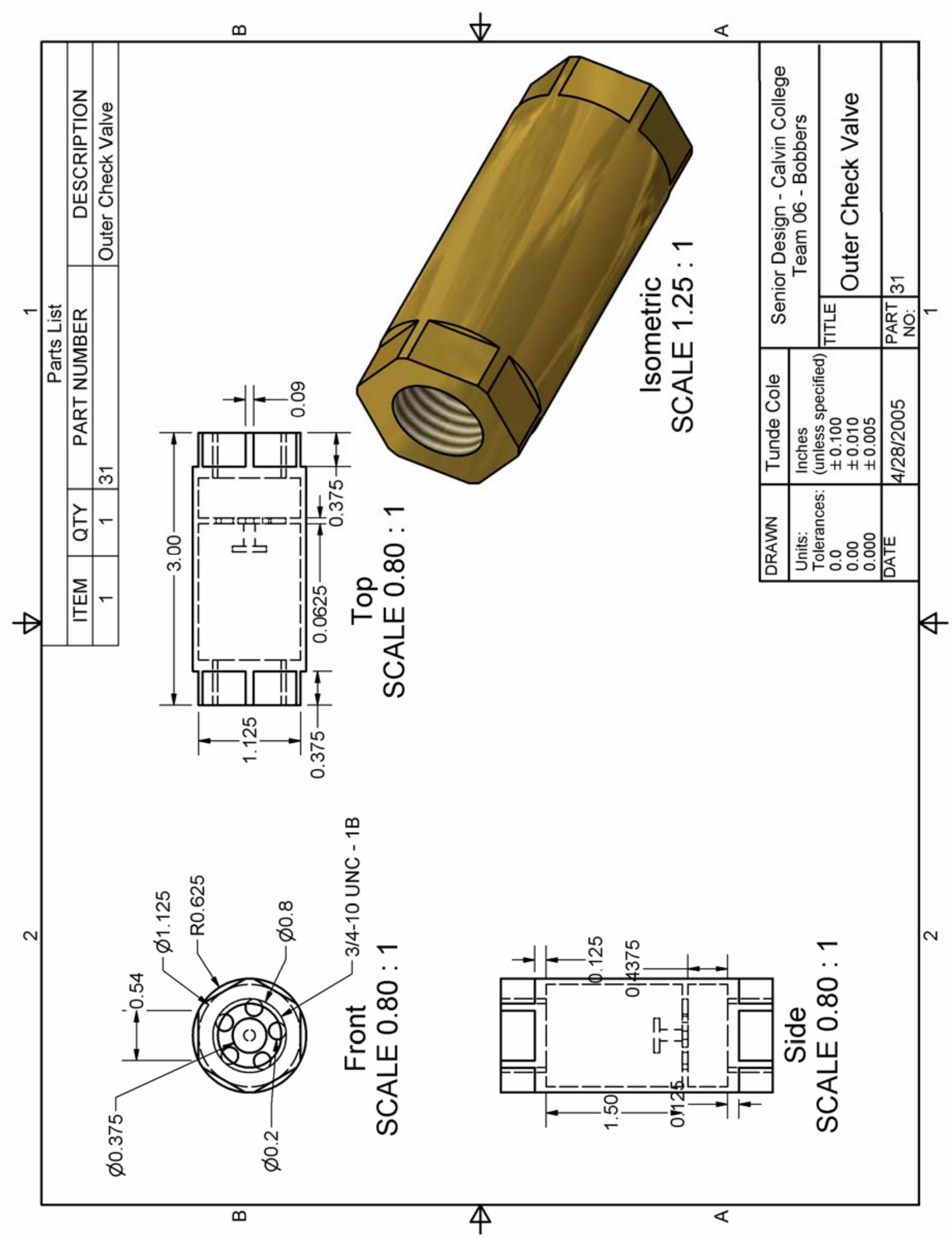
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	31	Outer Check Valve
2	1	32	Outer Rubber Check Valve

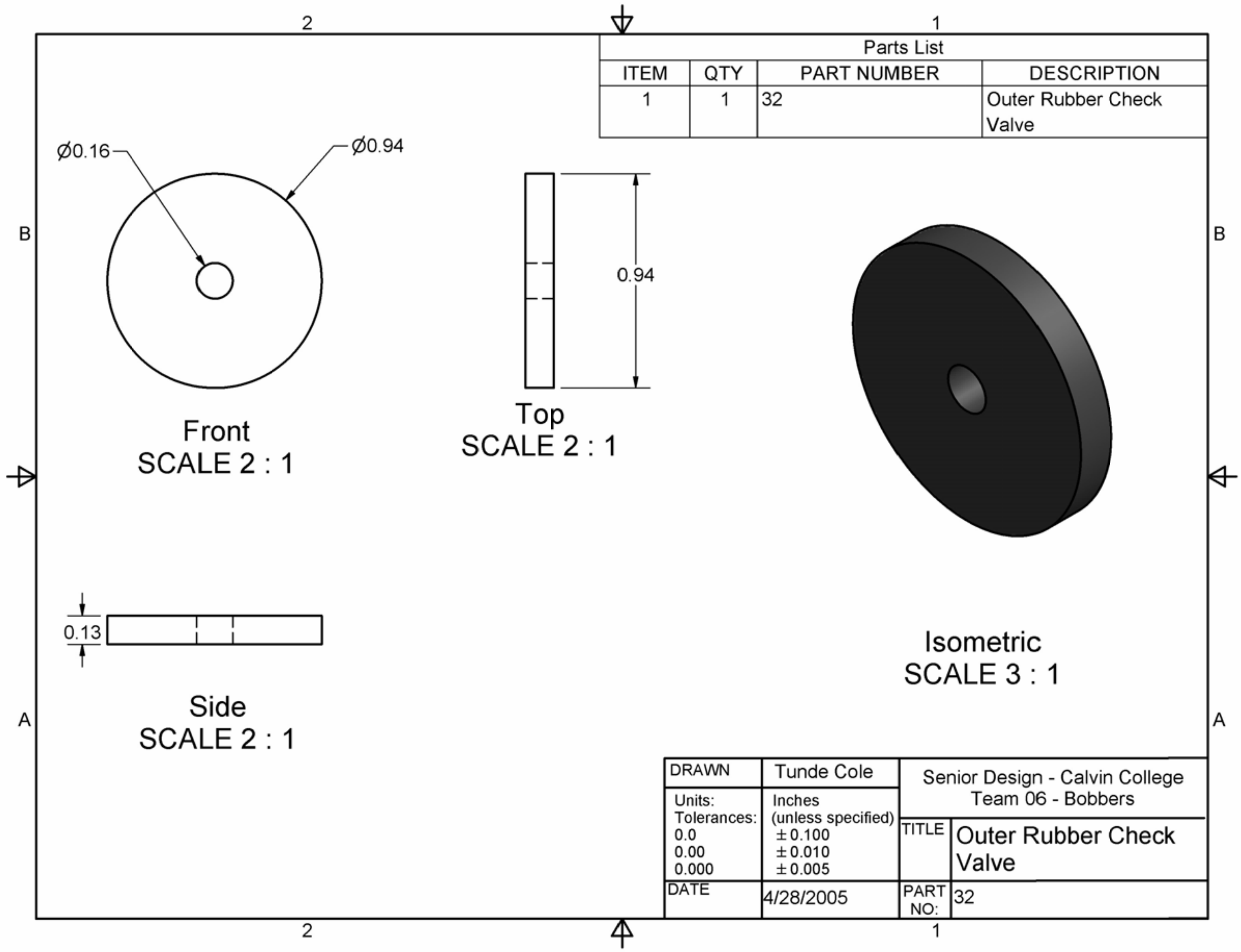


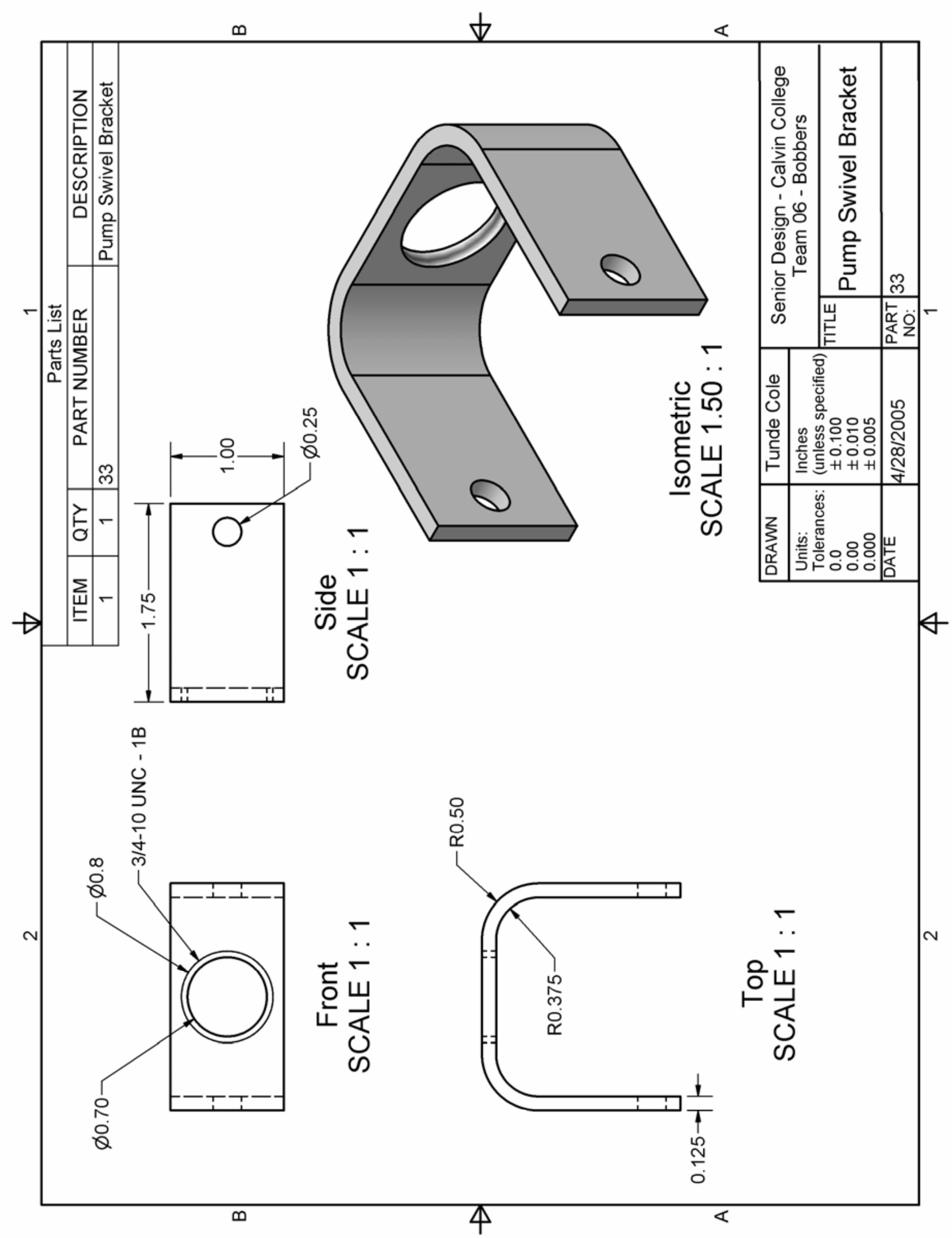
Isometric
SCALE 1.25 : 1

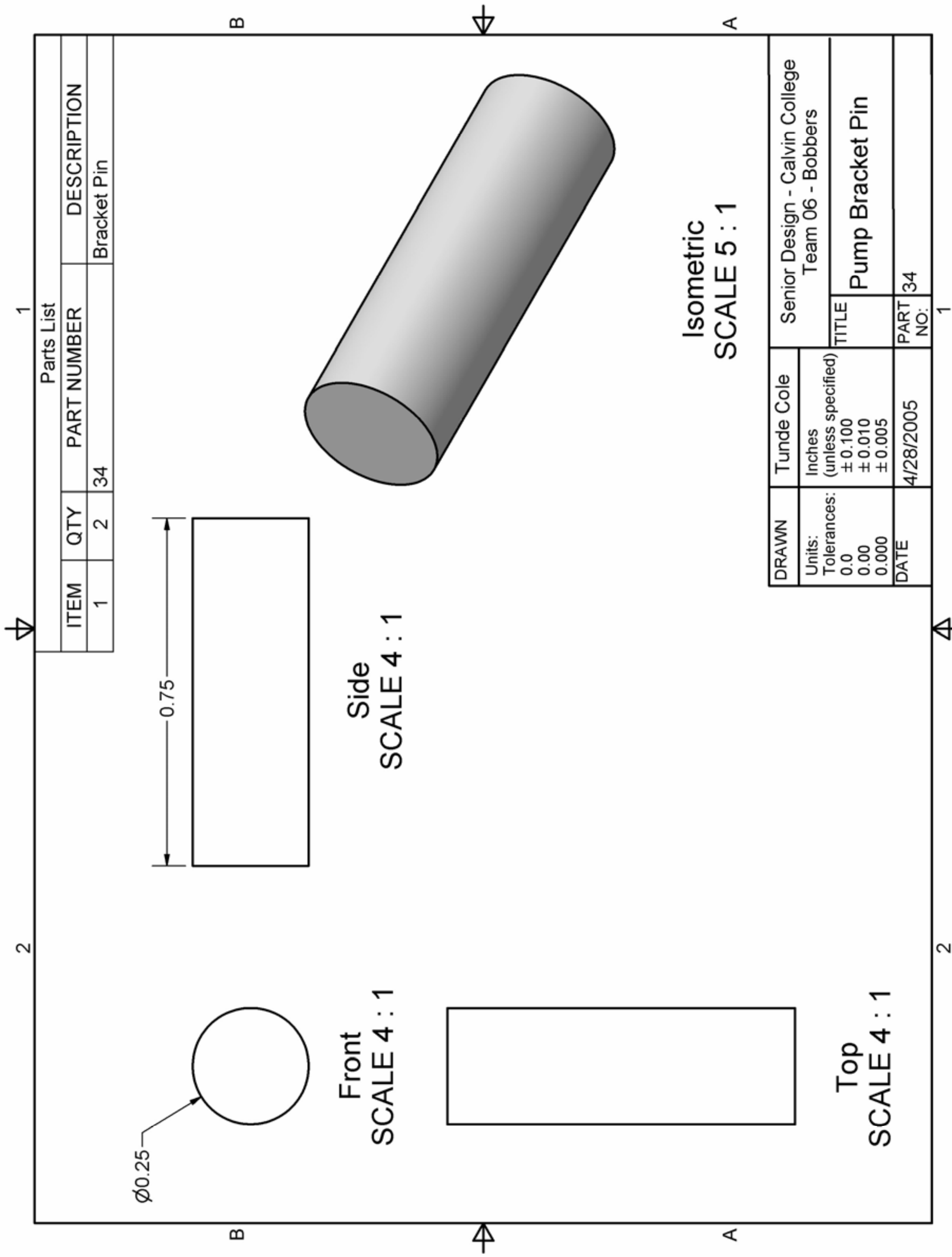
Note: No particular bonding method needed for this component

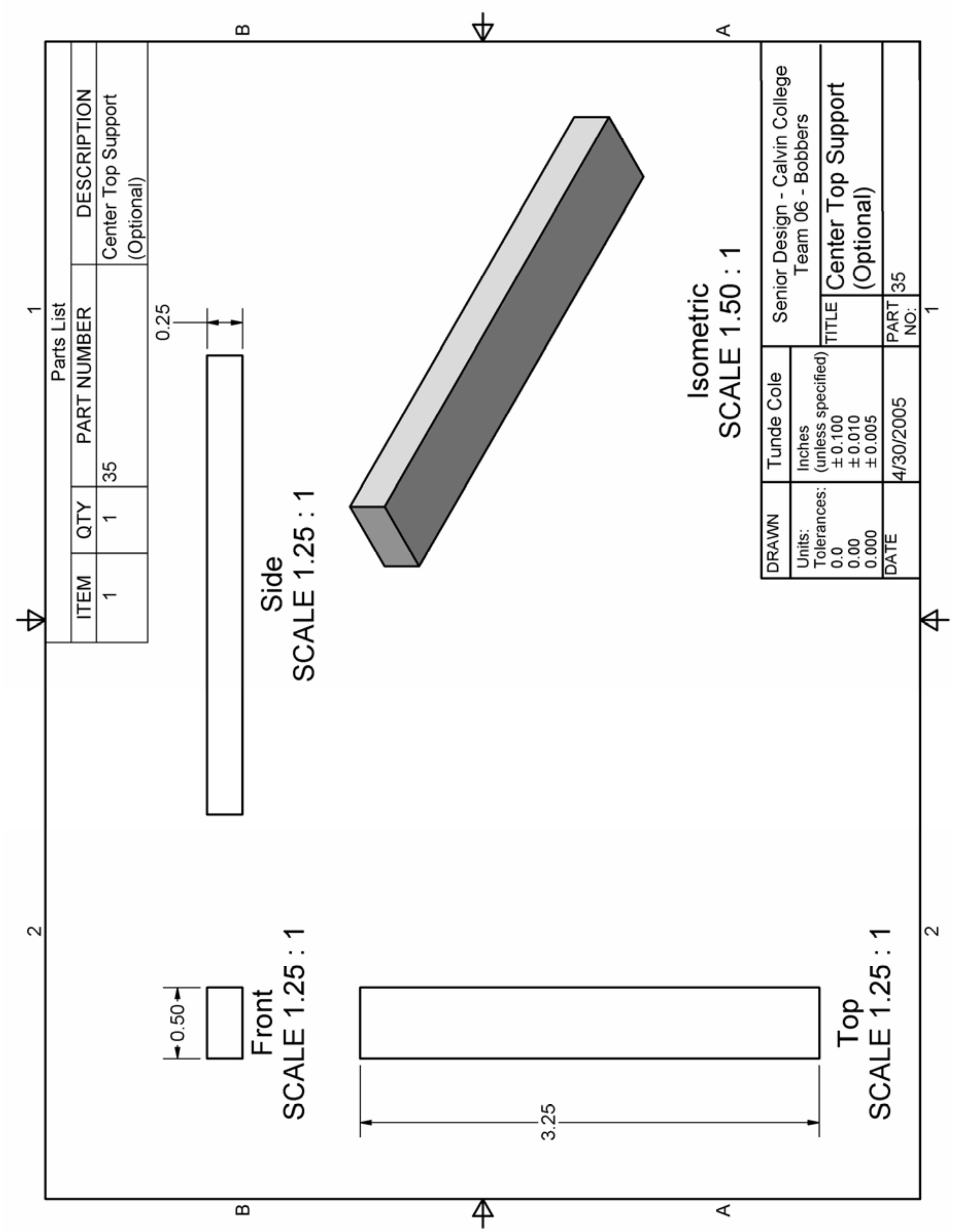
DRAWN	Tunde Cole	Senior Design - Calvin College Team 06 - Bobbers	
Units: Tolerances: 0.0 0.00 0.000	Inches (unless specified) ± 0.100 ± 0.010 ± 0.005	TITLE	Check Valve Assembly
DATE	5/4/2005	PART NO:	none


Parts List
ITEM
QTY
PART NUMBER
DESCRIPTION
1
1
31
Outer Check Valve
Ø0.375
Ø0.2
0.54
Ø1.125
R0.625
Ø0.8
3/4-10 UNC - 1B
Front
SCALE 0.80 : 1
1.125
0.375
3.00
0.0625
0.375
0.09
Top
SCALE 0.80 : 1
0.125
0.4375
1.50
0.125
Side
SCALE 0.80 : 1
Isometric
SCALE 1.25 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units:
Inches
Tolerances:
(unless specifed)
0.0 ±0.100
0.00 ±0.010
0.000 ±0.005
TITLE
Outer Check Valve
DATE
4/28/2005
PART NO:
31


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | 32 | Outer Rubber Check Valve
Ø0.16
Ø0.94
Front
SCALE 2 : 1
0.94
Top
SCALE 2 : 1
0.13
Side
SCALE 2 : 1
Isometric
SCALE 3 : 1
DRAWN
Tunde Cole
Units: Inches
Tolerances: (unless specified)
0.0 ±0.100
0.00 ±0.010
0.000 ±0.005
DATE
4/28/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Outer Rubber Check Valve
PART NO:
32


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | 33 | Pump Swivel Bracket
Ø0.8
3/4-10 UNC - 1B
Ø0.70
Front
SCALE 1 : 1
R0.50
R0.375
0.125
Top
SCALE 1 : 1
1.75
1.00
Ø0.25
Side
SCALE 1 : 1
Isometric
SCALE 1.50 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specified)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Pump Swivel Bracket
DATE
4/28/2005
PART NO:
33
A
B
1
2


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 2 | 34 | Bracket Pin
Ø0.25
0.75
Front
SCALE 4 : 1
Side
SCALE 4 : 1
Top
SCALE 4 : 1
Isometric
SCALE 5 : 1
DRAWN
Tunde Cole
Units:
Tolerances:
0.0
0.00
0.000
Inches
(unless specified)
± 0.100
± 0.010
± 0.005
DATE
4/28/2005
Senior Design - Calvin College
Team 06 - Bobbers
TITLE
Pump Bracket Pin
PART NO:
34
2
1
B
A


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | 35 | Center Top Support (Optional)
0.25
Side
SCALE 1.25 : 1
Isometric
SCALE 1.50 : 1
0.50
Front
SCALE 1.25 : 1
3.25
Top
SCALE 1.25 : 1
DRAWN
Tunde Cole
Senior Design - Calvin College
Team 06 - Bobbers
Units: Inches
Tolerances: (unless specifed)
0.0 ± 0.100
0.00 ± 0.010
0.000 ± 0.005
TITLE
Center Top Support (Optional)
DATE
4/30/2005
PART NO:
35