Team 512 Operation Manual

In-Space Cryogenic Propellant Storage

Anna Gilliard, Liam McConnell, Samantha Myers, Brandon Young

FAMU-FSU College of Engineering

Overview

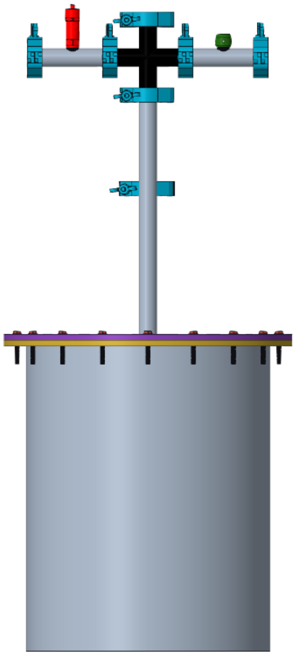

Figure 1: Prototype Front View

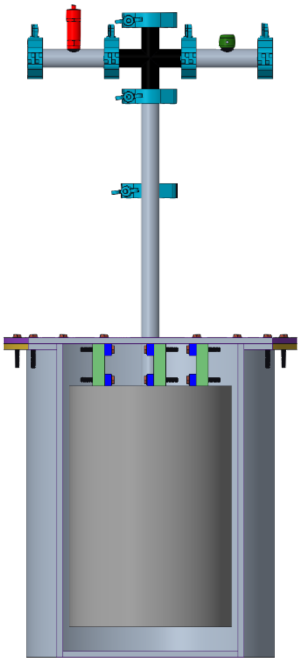

Figure 2: Prototype Section View

Figure 3: Full-Scale Front View

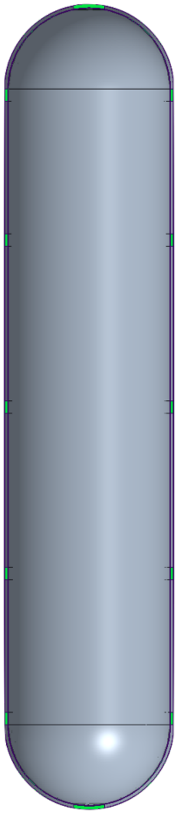

Figure 4: Full-Scale Section View

Table 1: Tank Dimensions

	Prototype (in)	Full-Scale (ft)
Outer Tank Diameter	10.125	27.450
Outer Tank Height	13.000	130.410
Outer Tank Thickness	0.375	0.105
Inner Tank Diameter	6.625	26.240
Inner Tank Height	10.000	129.200
Inner Tank Thickness	0.438	0.105

Note the prototype dimensions are in inches and the full-scale tank dimensions are in feet.

Acronyms

CAD – Computer Aided Design

MLI – Multilayer Insulation

NASA – National Aeronautics and Space Administration

Project Description

Currently, NASA is performing research to design the most efficient cryogenic storage system to allow for longer space missions. To do this, they must design a tank that reduces heat transfer into the fluid and extends the amount of time the fluid is in a usable, liquid state. Our project aims to design and prototype a storage container to hold cryogenic propellants in space that maintains the fluid at the proper temperature and pressure by reducing heat loss into the system. We have designed a full-scale tank to be recommended for use by NASA, as well as a simplified prototype that can be tested in a lab to validate our design choices.

Project Objective

The objective of this project is to design a storage tank for cryogenic propellant that increases storage time, reduces fuel loss, and reduces heat transfer.

Key Goals

There are five main key goals to achieve for this project to be successful. They are maintaining temperature, maintaining pressure, reducing heat transfer, reducing fuel loss, and developing a prototype. Heat transfer into the tank causes the temperature of the fluid inside to rise. As the temperature exceeds the boiling point of the fluid, it will go through a phase change from a liquid to a gas. This gas causes the internal pressure of the tank to rise. To prevent the pressure from exceeding the limit of the tank, there must be a pressure relief valve. The gas that is released from the system is fuel that is no longer usable. A prototype must be developed to properly test our design and validate each design choice.

Assumptions

Three assumptions were made to narrow the scope of the project. First, we are assuming that liquid nitrogen will be used for testing, rather than liquid hydrogen or oxygen that would be used in a full-scale tank. Liquid hydrogen and oxygen are much more dangerous to test with, due to their flammability, and liquid nitrogen is readily available for use in the lab. Next, we are assuming the tank can withstand Earth, space, and lift-off conditions. The tank will be filled with fuel on Earth, loaded into the spacecraft, launched into space, undergo various temperatures and pressures based on positions in space, as well as reenter Earth's atmosphere. It should maintain structural integrity through each of these stages. Finally, we are assuming that we are designing for a lunar mission lasting two weeks, therefore the tank should maintain the fuel at the appropriate temperature and pressure for at least that amount of time.

Integration

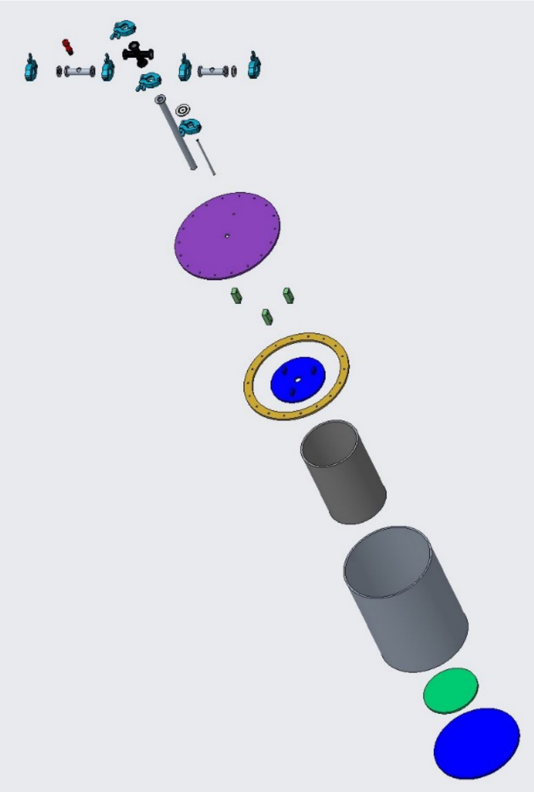

Figure 5: Full Exploded View

The outer tank is a cylinder that was cut to the correct height by the machine shop with one circular endcap welded inside the bottom end and a flange welded to the upper perimeter of the outer surface. It is its own separate part, so that the tanks can be taken apart during testing if there are any issues.

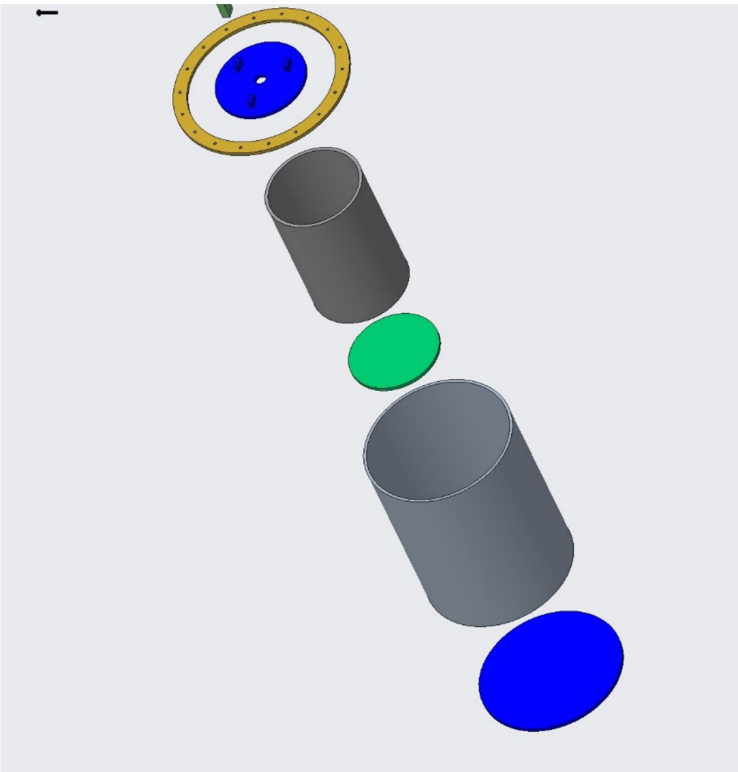

Figure 6: Exploded view, Zoomed in on Tank Assembly

The inner tank was also cut to the correct height by the machine shop with circular endcaps welded inside the top and bottom edges. The top endcap has a hole that the fill pipe is welded to. There is a flange that will serve as the top of the outer tank that will have a hole in the middle that the fill pipe goes through. Each endcap for the tanks and both flanges were waterjet from a 2’x2’ plate of Stainless Steel 304 by the machine shop, as well as the metal plates that are used to secure the G10 supports to the tank. Bolt holes were also cut during this process and threaded. When sealing the tank, liquid flange sealant is spread between the top and bottom flange before they are bolted together. It is important to note how long the sealant takes to dry to ensure we are pulling the most effective vacuum between the tanks as possible.

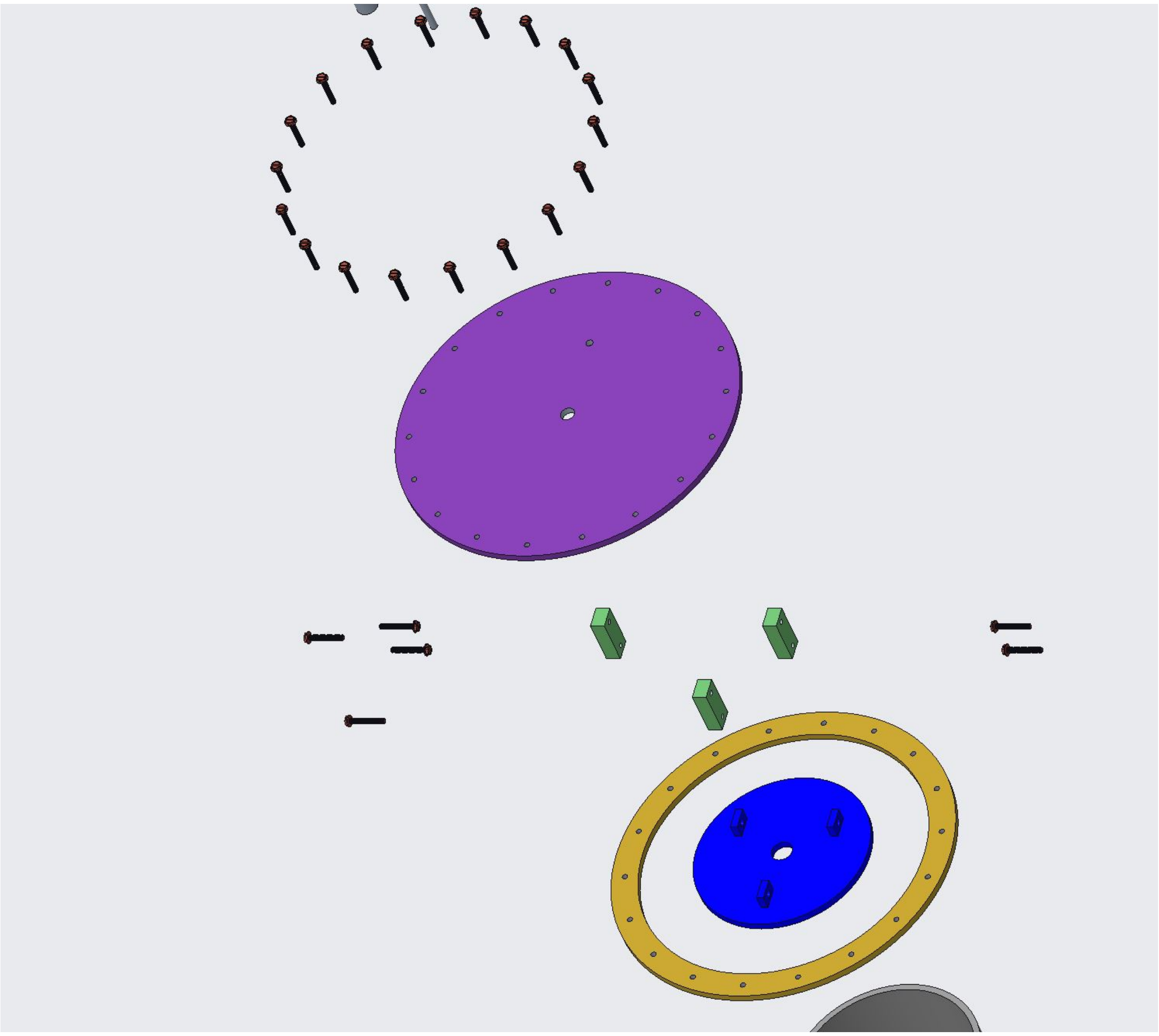

Figure 7: Exploded view, Zoom of G10 and Lid Assembly

Three of those metal plates were welded to the inside of the top flange, and three were welded to the top of the inner tank. The G10 was cut and is secured with bolts to the metal plates. The vacuum port is welded to the outer surface of the top flange corresponding to a hole that was cut in the flange. The final thing done by the machine shop was cutting holes in the two side pipes and threading them for our pressure release valve and vent.

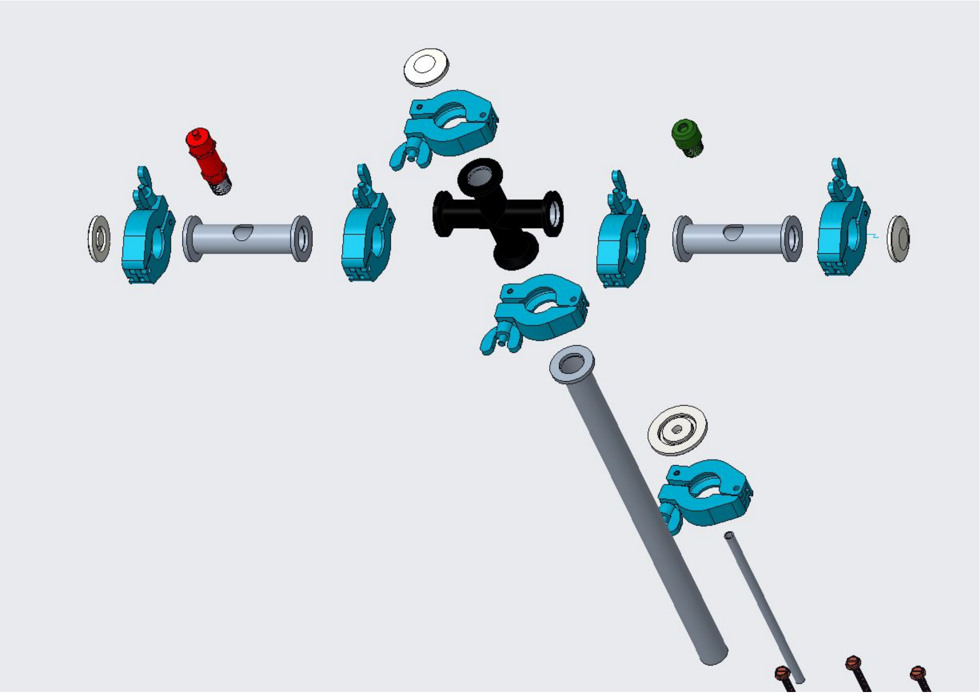

Figure 8: Exploded view, Zoom of Upper Pipe Assembly

The top piping portion of the tank was assembled by hand. The fill pipe coming out from the inner tank is connected to a cross-valve using a clamp and O-ring. Three more clamps and O-rings are connected to each of the other ends of the cross-valve. The top end will be sealed off with an endcap that will also be connected on with a clamp and O-ring. That endcap will only be removed while filling the tank. The left and right clamps and O-rings will connect the short pipes with threaded holes. The opposite ends of both short pipes will also have endcaps clamped on that will only be removed during the filling of the tank. The pressure release valve and vent are screwed in to the threaded holes in the short pipes. Finally, a clamp will attach a vacuum port fitting to the vacuum port.

Operation

Before filling the tank with cryogen, the system should be pressurized to ensure the pressure relief valve is operating correctly and will release gas from the tank at the appropriate pressure. The error for the relief valve should be found and results should be recorded accordingly. The final mass flow rate exiting the system should account for this error. Also, before filling the tank, proof is necessary that the vacuum is effective in reducing the heat transfer due to convection through the space between the inner and outer tank walls. We did this using a thermal camera to take pictures of the system with the vacuum on and off. The active vacuum pump should be connected to the vacuum port using a clamp. The empty tank should also be weighed using a kitchen scale, so that we know the weight without fluid.

All three endcaps for the cross-valve on the top of the tank should be removed by unscrewing the clamps on each end and removing the caps. A fill line connected to the liquid nitrogen storage tank in the lab will be inserted into the top hole of the cross-valve and pushed in until the end of the line reaches the bottom of the inner tank. The fill line is also connected to a pump that can now be used to fill the tank with the cryogen. Safety precautions must be taken and are stated in our risk assessment. As the tank is filled, there will be some gas vented off. When the tank is full, the fill-line should be removed, and endcaps should be clamped back on.

Once the system is sealed, it should be weighed again, so that the tank of the full system is known. The tank should be weighed every 8 hours until the tank is empty. The time and weight should be recorded each time. This is when the tank weighs the same as the original weight taken with the tank empty. The time it takes for the tank to release all of the gas can be used to find the mass flow rate. That can be compared to values found through calculations for the system to validate our testing.

Troubleshooting

If an issue is detected with the tank while there is fluid in the system, the fluid must first be drained or allowed to boil off and vent out using the ventilation valve on the top of the tank. This must be done before any checks can be completed. Conduct a visual test on the system after it is empty to identify any obvious integrity flaws. To check for small gaps or leaks in the system, the tank should be filled with air and submerged under water and checked for air bubbles as well as filled with water to ensure that there are no gaps in the welds.

Appendix A- CAD Part Drawings

These are the drawings presented to the machine shop.

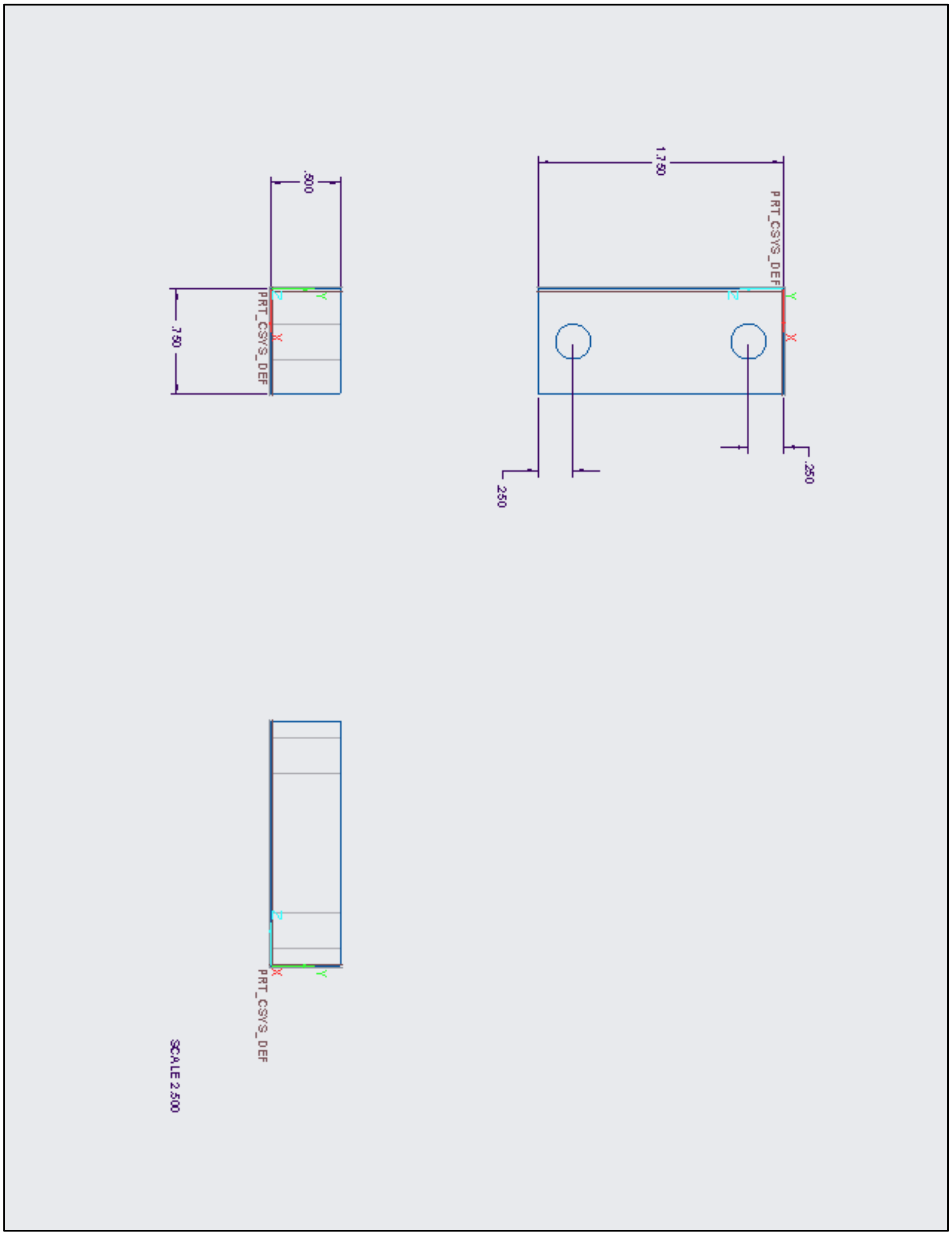

Figure 9: G10 Metal Support Dimensions

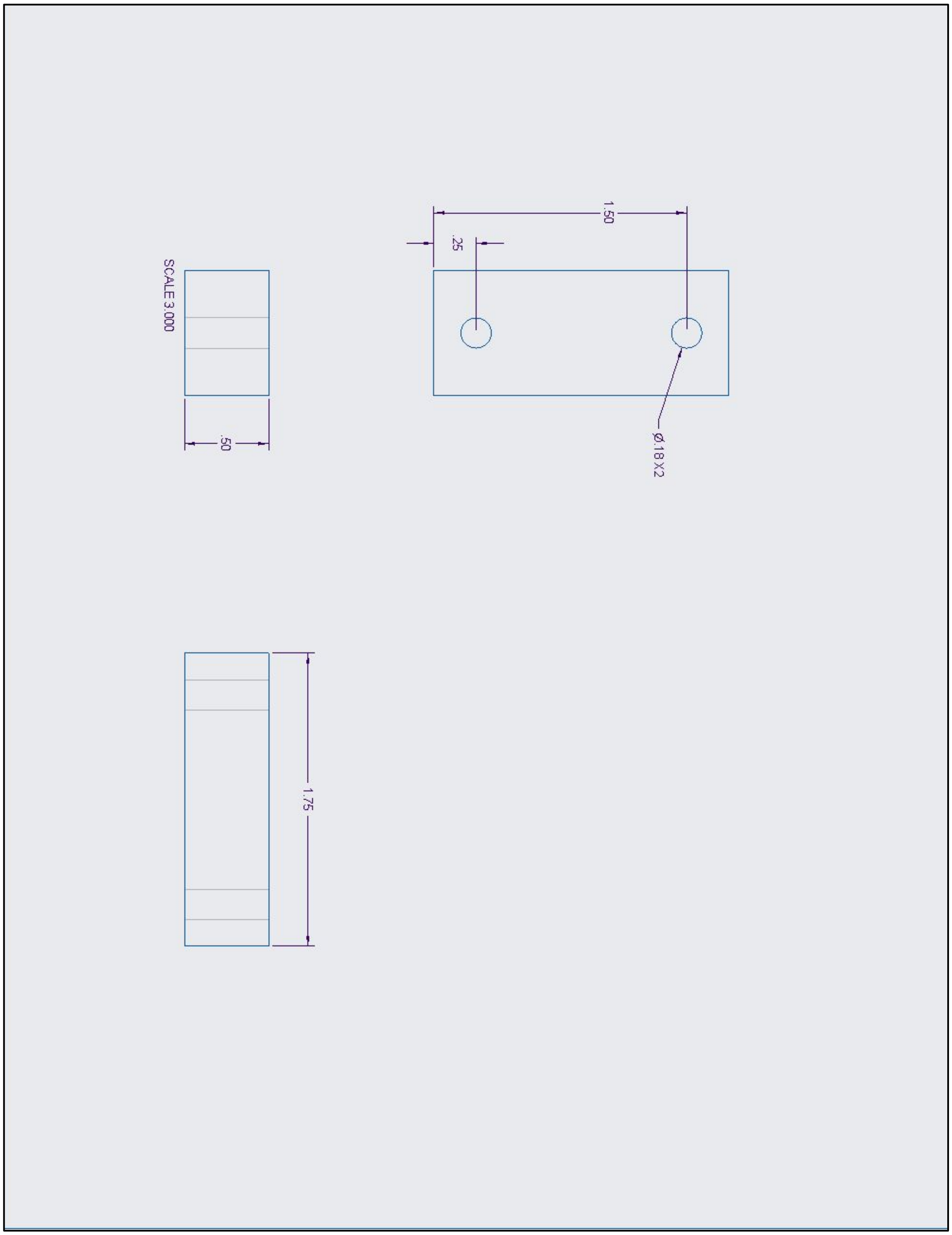

Figure 10: G10 Dimensions

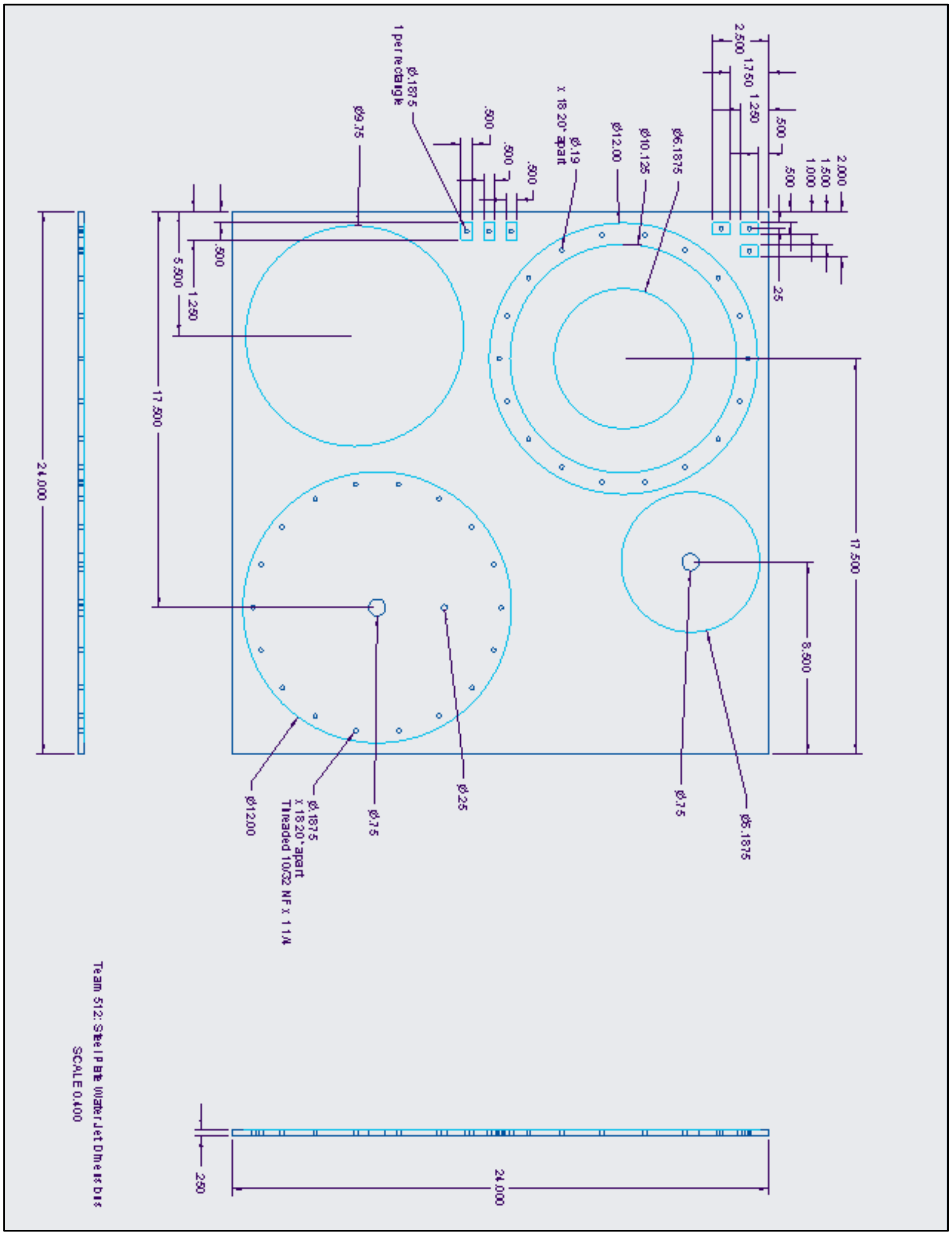

Figure 11: Steel Plate Dimensions

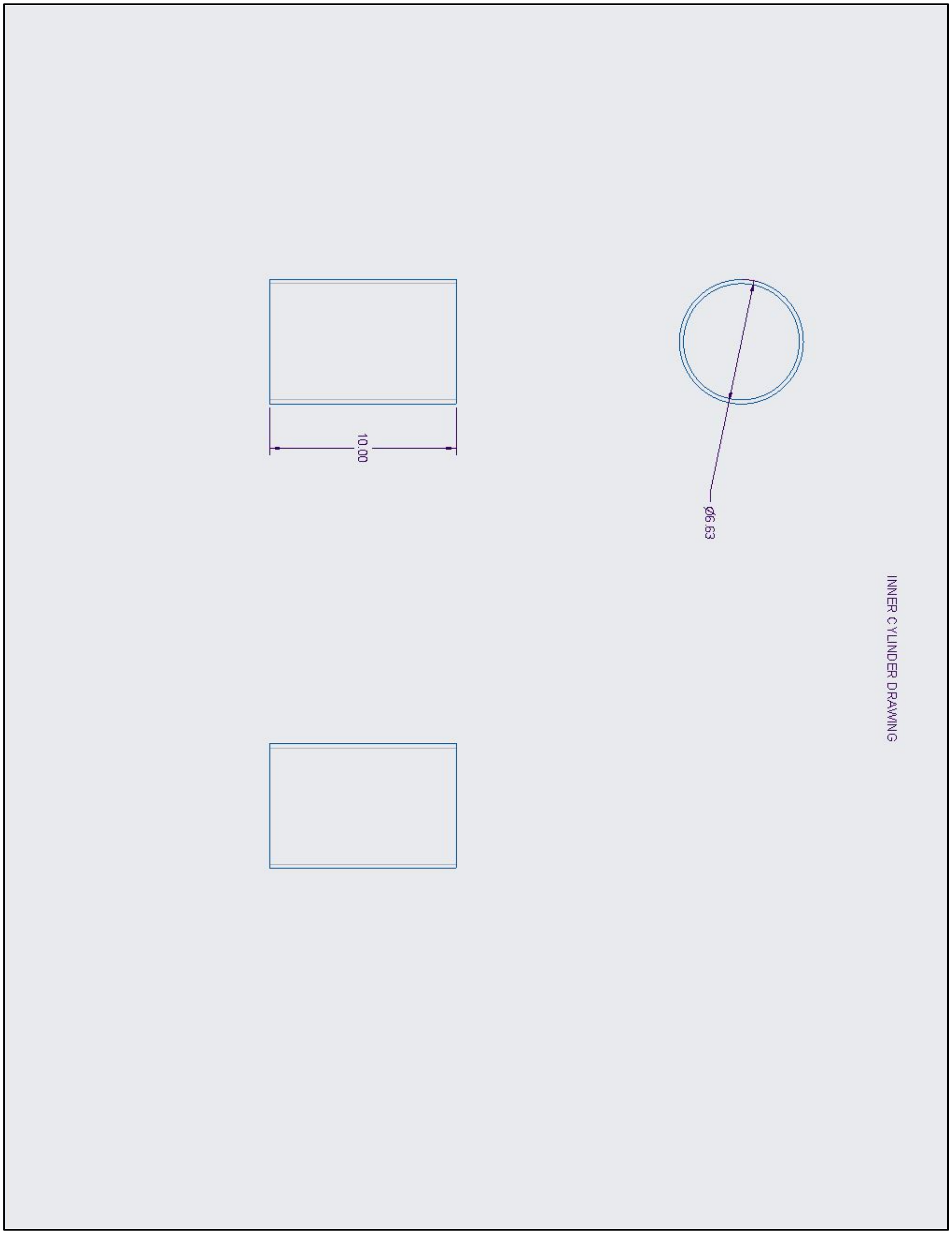

Figure 12: Inner Tank Dimensions

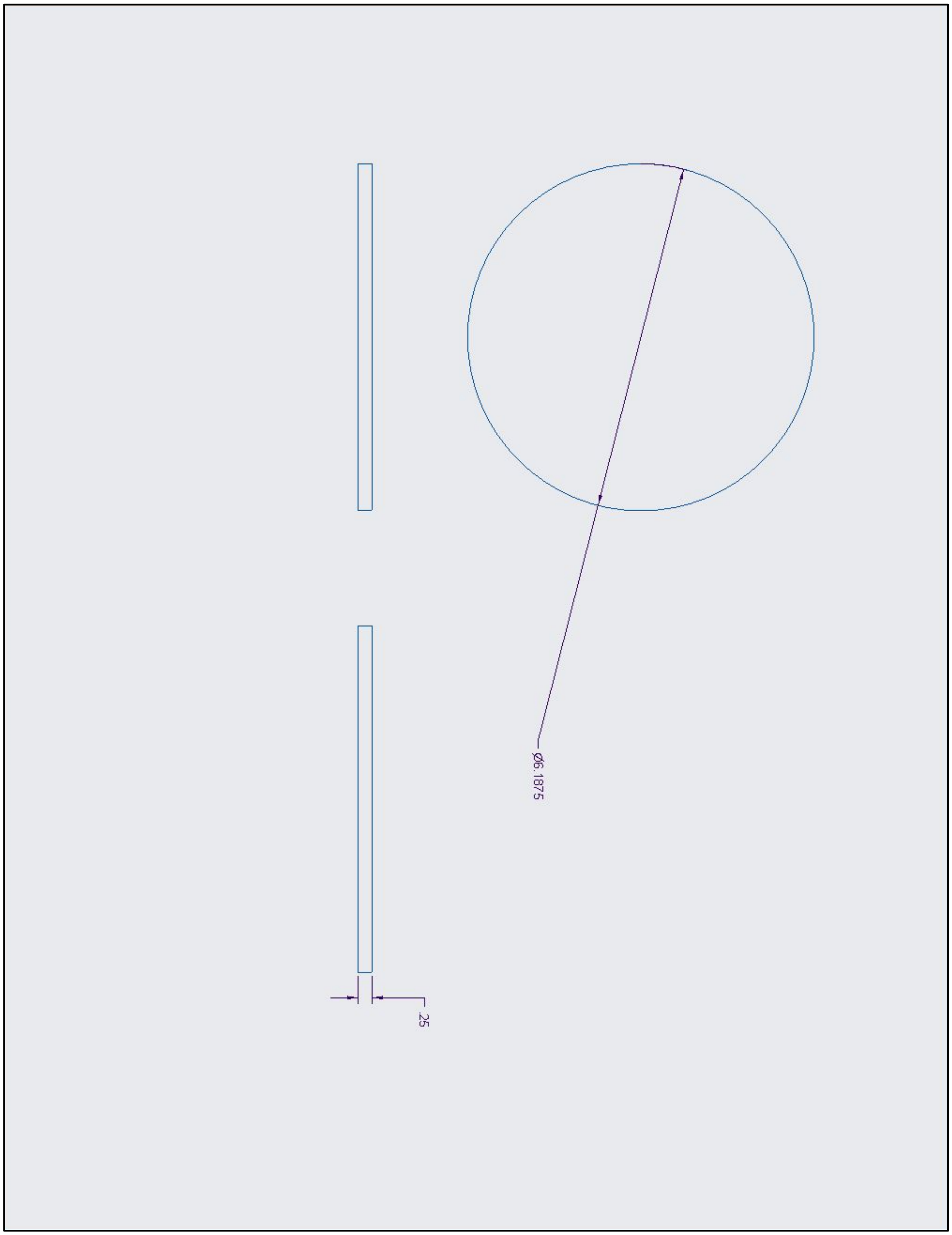

Figure 13: Inner Tank Bottom Endcap Dimensions

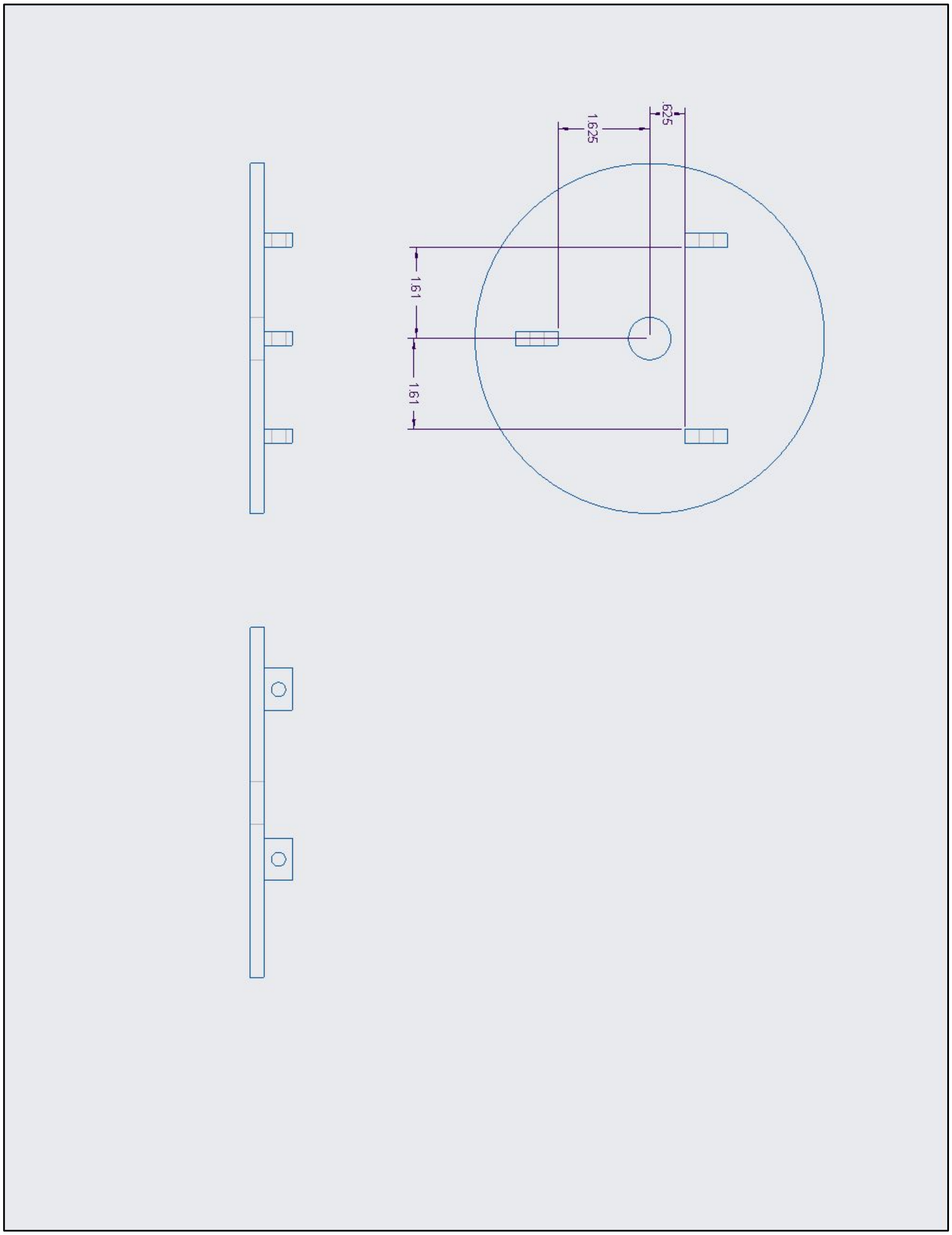

Figure 14: Inner Tank Top Endcap Dimensions

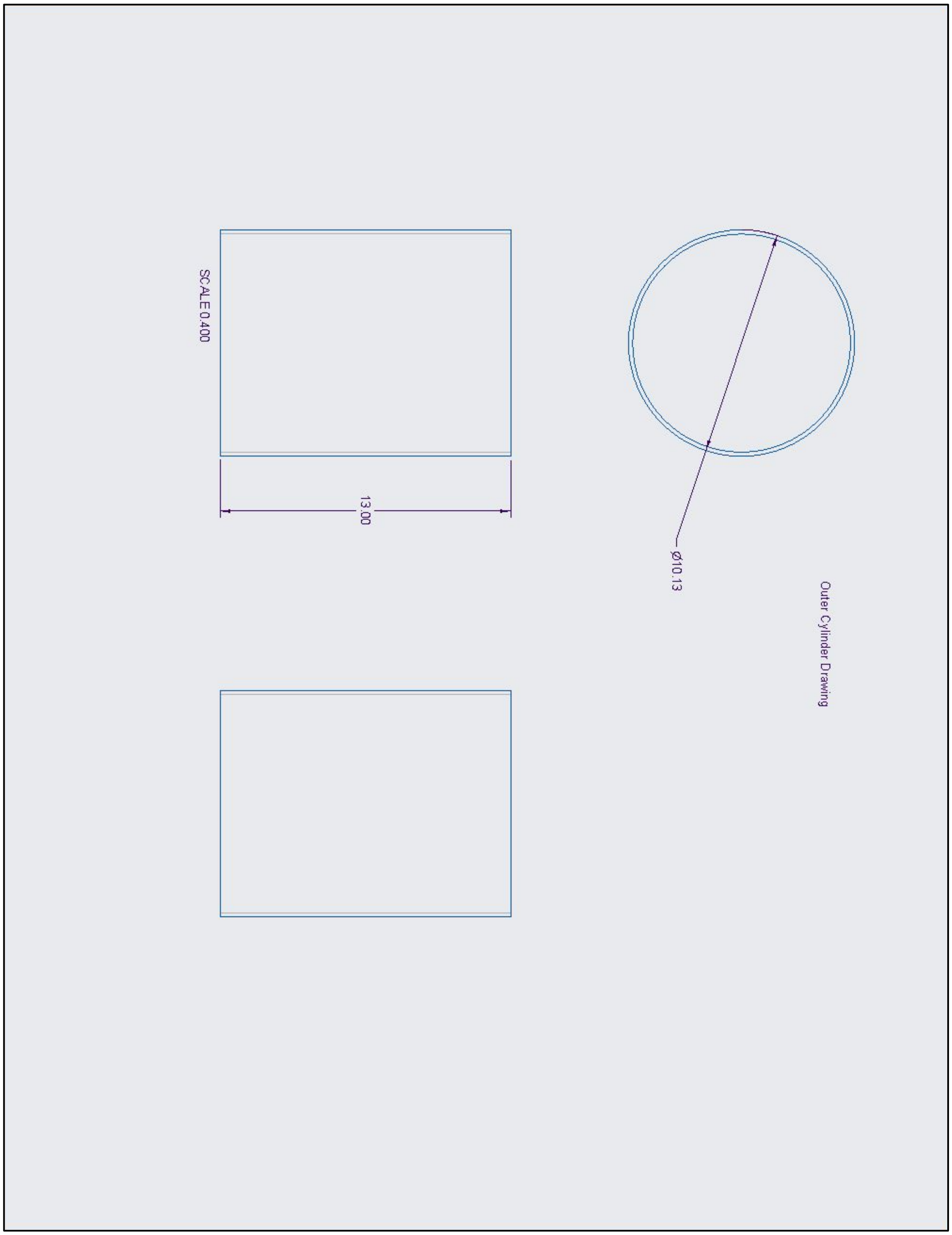

Figure 15: Outer Tank Dimensions

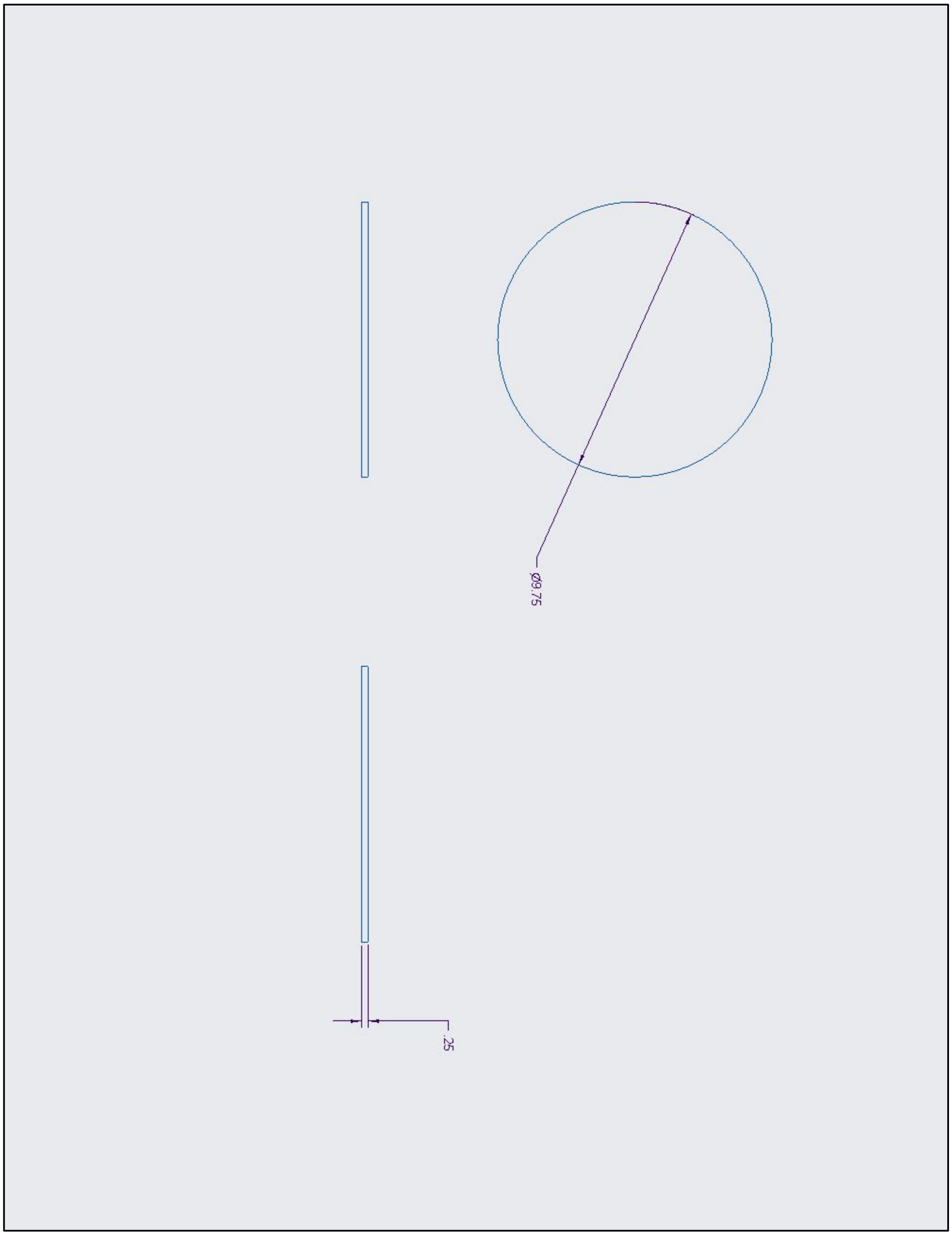

Figure 16: Outer Tank Bottom Endcap Dimensions

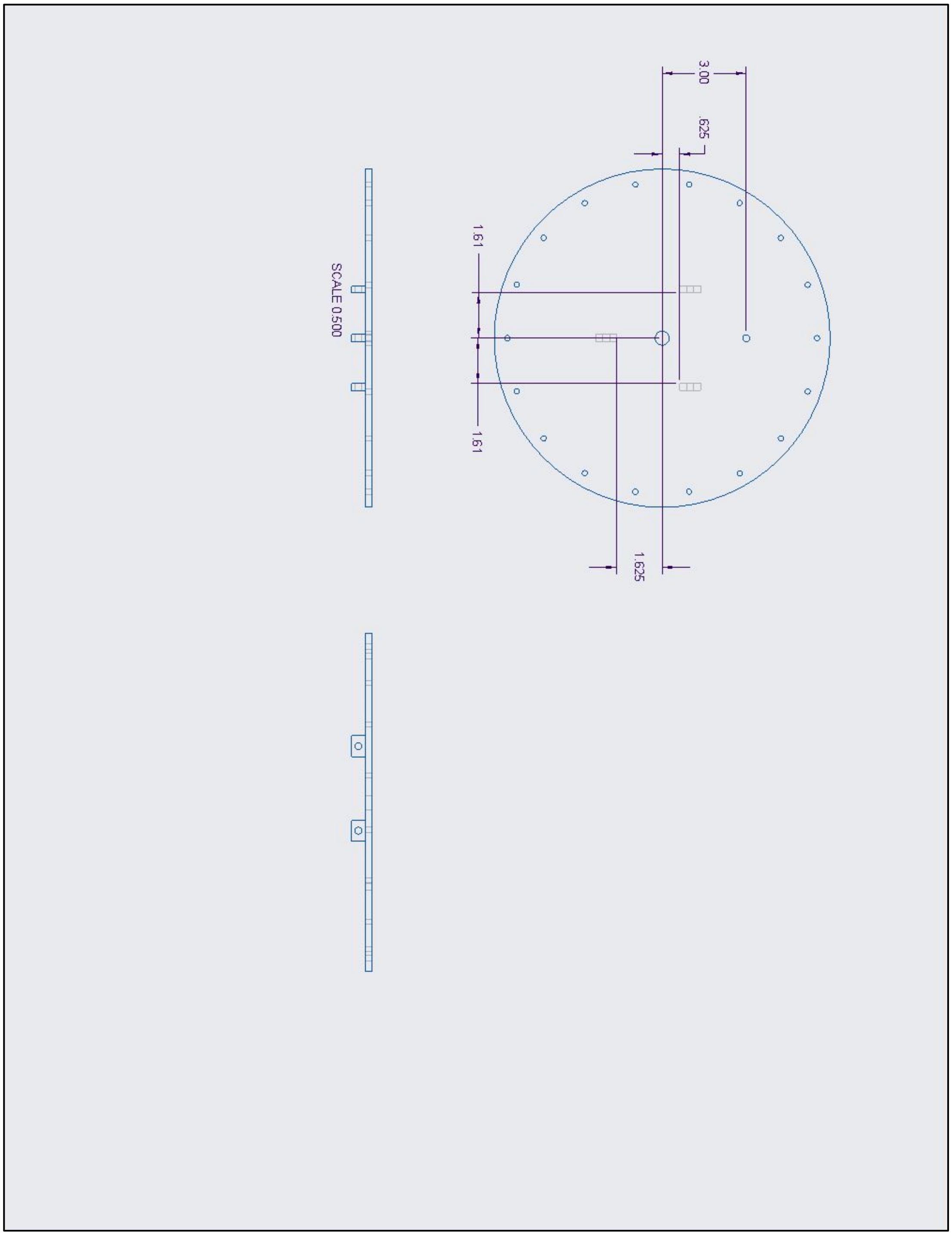

Figure 17: Outer Tank Top Flange Dimensions

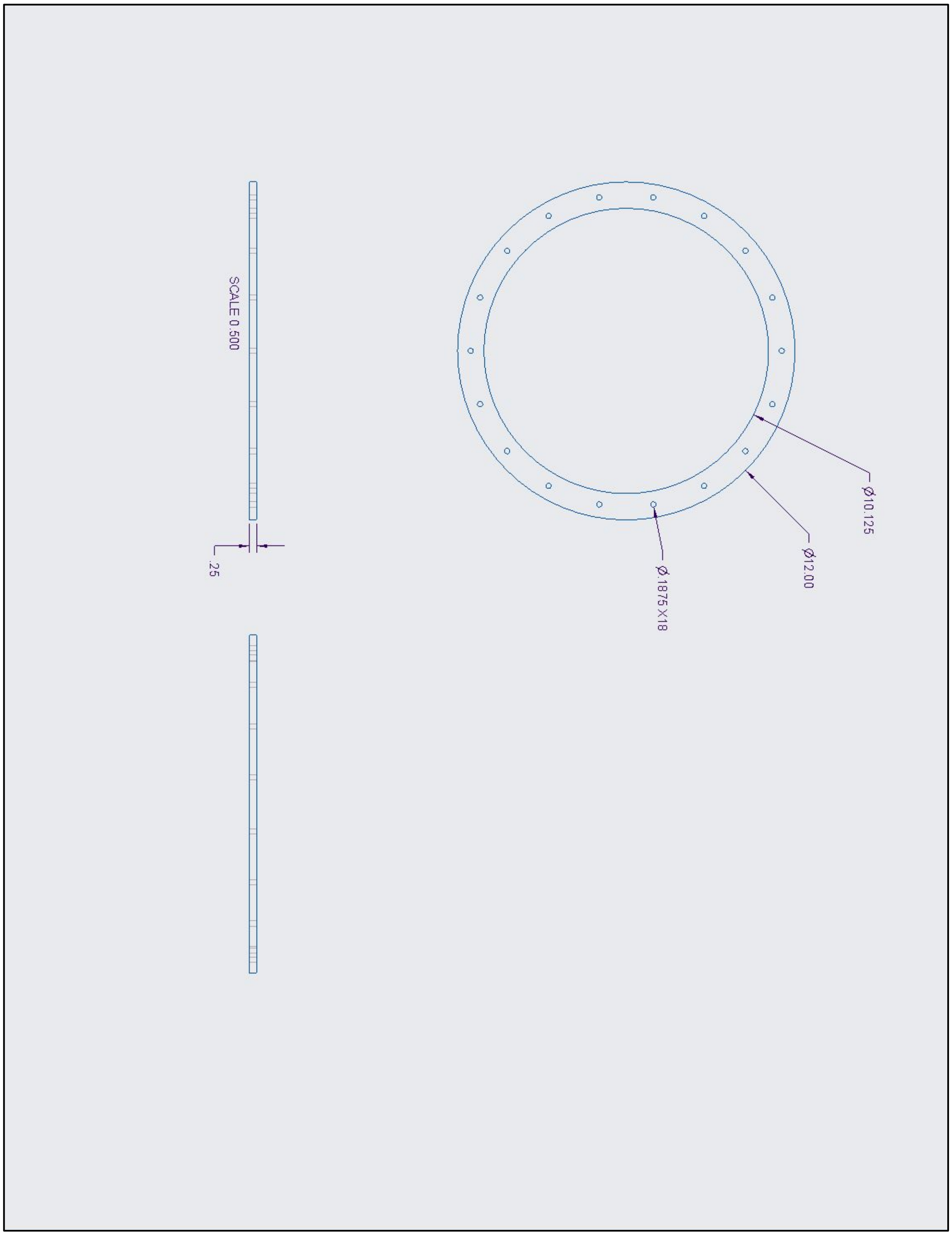

Figure 18: Outer Tank Bottom Flange Dimensions

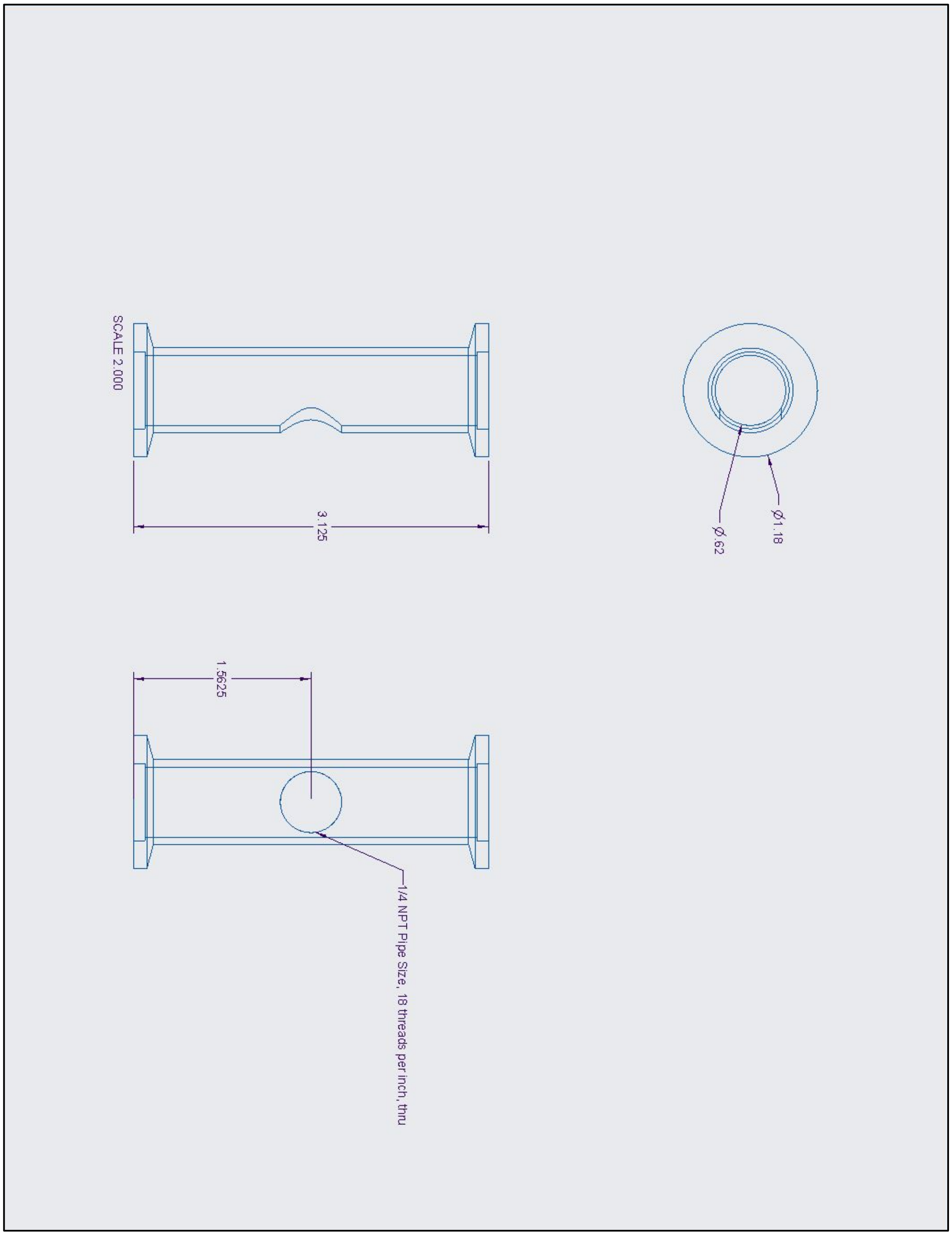

Figure 19: Connecting Pipe Dimensions

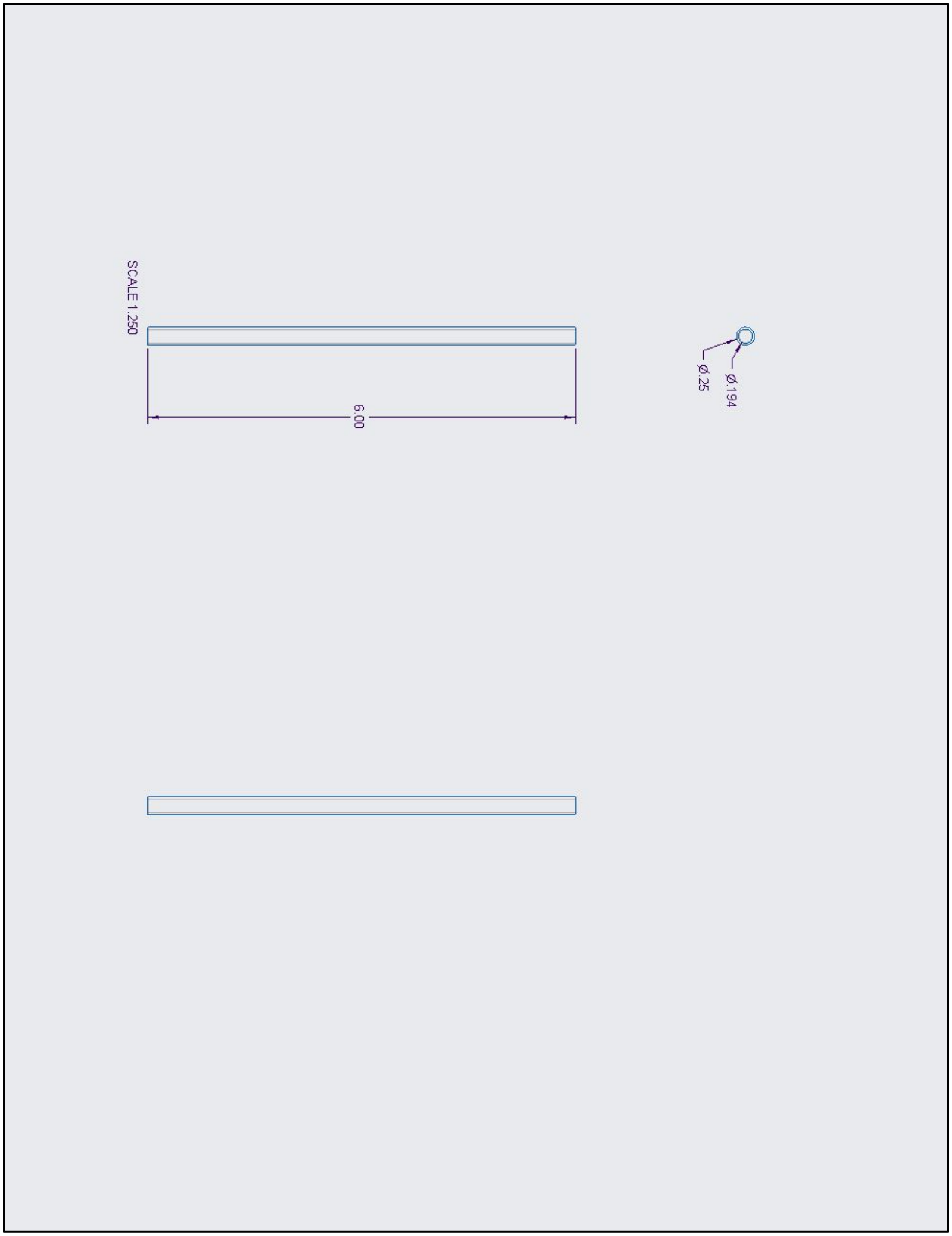

Figure 20: Vacuum Port Dimensions

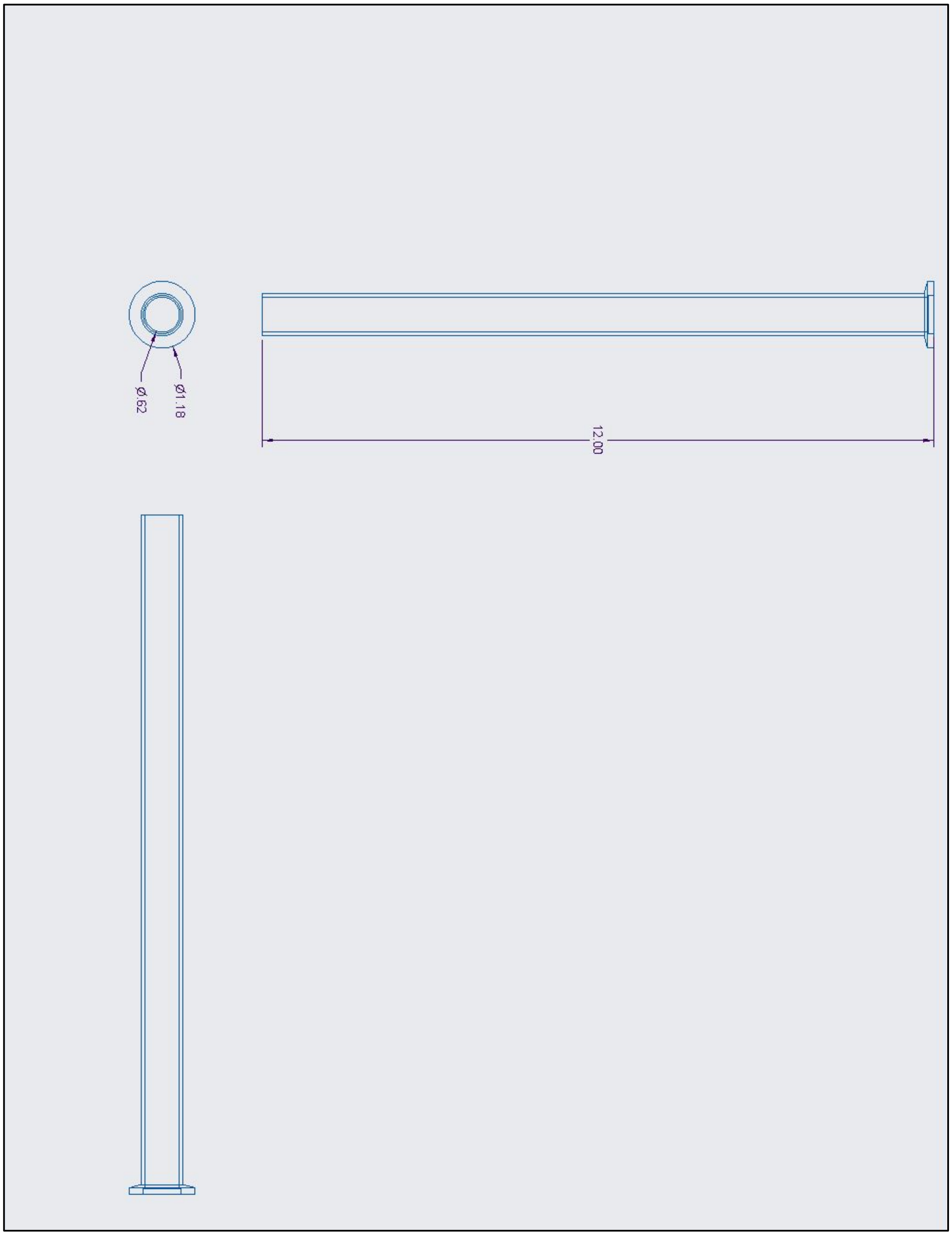

Figure 21: Fill Pipe Dimensions

Appendix B- Heat Transfer Calculations

Prototype Calculations

Table 2: Prototype Calculations without Insulation

Radiation to Inner Tank	3.06587 [W]
Conduction through Steel Walls	91.472 [W]
Conduction through G-10 Plate Supports	0.46477 [W]
Conduction through Fill Pipe	8.29964 [W]
Total Rate of Heat Transfer	103.302 [W]
Mass Flow Rate	1.8594 [kg/hr]
Total Time Duration	2.35 [hours] (0.0979 days)

Table 3: Prototype Calculations with Foam Insulation and Vacuum

Radiation to Inner Tank	3.0659 [W]
Radiation through Foam Insulation	50.856 [W]
Conduction through G-10 Plate Supports	0.46477 [W]
Conduction through Fill Pipe	8.2996 [W]
Total Rate of Heat Transfer	62.688 [W]
Mass Flow Rate	1.128 [kg/hour]
Total Time Duration	3.873 [hours] (0.1614 days)

Table 4: Prototype Calculations with MLI and Vacuum

Radiation through Reflective MLI	1.2515 [W]
Conduction through G-10 Plate Supports	0.46477 [W]
Conduction through Fill Pipe	8.2996 [W]
Total Rate of Heat Transfer	10.016 [W]
Mass Flow Rate	0.18029 [kg/hr]
Total Time Duration	24.244 [hours] (1.010 days)

Full-Scale Calculations

Table 5: Full-Scale Calculations without Insulation

Radiation to Inner Tank	11215.8 [W]
Conduction through Steel Walls	212348.8 [W]
Conduction through G-10 Plate Supports	1059.3 [W]
Conduction through Fill Pipe	3.922 [W]
Total Rate of Heat Transfer	224627.9 [W]
Mass Flow Rate	1754.14 [kg/hr]
Total Time Duration	63.67 [hours] (2.653 days)

Table 6: Full-Scale Calculations with Foam Insulation and Vacuum

Radiation to Inner Tank	11215.8 [W]
Radiation through Foam Insulation	140788.2 [W]
Conduction through G-10 Plate Supports	1059.3 [W]
Conduction through Fill Pipe	3.922 [W]
Total Rate of Heat Transfer	153067.3 [W]
Mass Flow Rate	1195.32 [kg/hr]
Total Time Duration	93.440 [hours] (3.893 days)

Table 7: Full-Scale Calculations with MLI and Vacuum

Radiation through Reflective MLI	6024.28 [W]
Conduction through G-10 Plate Supports	1059.3 [W]
Conduction through Fill Pipe	3.922 [W]
Total Rate of Heat Transfer	7087.53 [W]
Mass Flow Rate	55.347 [kg/hr]
Total Time Duration	2018 [hours] (84.08 days)

Appendix C – Ordered Part List

This table has each pre-made part that was ordered for the project.

Table 8: Ordered Part List

Vendor	Model Number	Item Description	Item Name	Quantity
McMaster-Carr	4518K711	Quick Clamp High-Vacuum Fitting Wing Nut Clamp for 1/2" and 3/4" Tube	Clamp	7
McMaster-Carr	4518K621	Ring for 3/4" Tube OD Quick-Clamp High-Vacuum Fitting	O-ring	7
McMaster-Carr	4518K571	Cap for 3/4" Stainless Steel Tube OD Quick-Clamp High-Vacuum Fitting	Endcap	3
McMaster-Carr	8602T31	Self-Draining Breather Vent 316 Stainless Steel, 1/4 NPT Male	Vent	1
McMaster-Carr	90316A841	Flanged Hex Head Screws w/ Slotted Drive 18-8 Stainless Steel, 10-32 Thread Size, 1-1/4" Long, Pack of 25	Screw	1
McMaster-Carr	89495K775	304/304L Stainless Steel Tube 0.028" Thick, 1/4" OD, 0.194" ID	Vacuum Port	1
McMaster-Carr	9137K11	Fast-Acting Pressure-Relief Valves for Cryogenic Liquids ¼ NPT Male, 30 psi	Pressure Relief Valve	1
McMaster-Carr	4518K241	Quick-Clamp High-Vacuum Fitting Cross Connector for 3/4" Tube OD	Cross-Valve	1
McMaster-Carr	4518K872	Quick-Clamp High-Vacuum Fitting for Stainless Steel Tubing, Connector for 3/4" Tube OD, 12-1/2" Long	Fill Tube	1
McMaster-Carr	4518K871	Quick-Clamp High-Vacuum Fitting for Stainless Steel Tubing, Connector for 3/4" Tube OD, 3-1/8" Long	Short Pipe	2
McMaster-Carr	4934A14	Thread Sealant Tape High-Density, 3M PTFE 48 0.003" Thick, 1/2" Wide, 7 Yard Long	Sealant Tape	1

McMaster-Carr	44745K23	Flexible Rubber Foam Pipe Insulation Tube Slit, 1/2" Thick Wall, 3/4" ID, 6 Feet Long	Solid Foam Pipe	1
McMaster-Carr	4507N57	Ultra-Low Temperature Garolite G-10 CR Sheets, 12”x12”, ½” Thick	G10	1
Loctite	483630	592 Thread Sealant and Vacuum Equipment Gasket Maker with PTFE	Liquid Sealant	1