

# Group 24: Magnetically Coupled Pump System for Cryogenic Propellant Tank Destratification

FAMU/FSU College of Engineering  
Department of Mechanical Engineering

## Interim Design Report

Group 24:

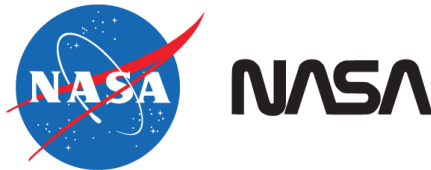
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## Team Member Biography's

**Matthew Boebinger (Team Leader):** Matthew is a senior mechanical engineering student that is specializing in mechanics and materials engineering at Florida State University. After graduating in Spring 2015 with his Bachelors of Science in Mechanical Engineering, he plans on pursuing a Master's degree and then a Doctoral degree in materials engineering.

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**Anthony Ciciarelli:** Anthony is a senior mechanical engineering student with a focus in thermal fluids at Florida State University. He will graduate in the spring 2015 with a Bachelor of Science in Mechanical Engineering. After graduation he plans on pursuing a full time job in the industry, obtaining his MBA, and obtaining a professional engineering license.

**Janet Massengale:** Janet is a senior mechanical engineering student specializing in thermal fluid sciences at Florida State University. This is her second year as the treasurer of ASME. She is also the webmaster for both the SWE and AIAA. Upon graduation she plans to work in the pulp and paper industry and obtain a professional engineering license.

## Acknowledgement

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## Abstract

National Aeronautical and Space Administration has proposed a project to mix cryogenic fluids by way of magnetic coupling to successfully aid in the destratification of propellants such as liquid hydrogen and liquid oxygen. This allows the placement of the motor that is currently submerged in the cryogen to be placed on the exterior to reduce the amount of heat being generated inside the tank. The selected design must be attached to a 6 inch flange and fit into a 3.75 inch port located on the top of the cryostat. The selected pump design consists of a three tooth inducer that is commonly used in pump design for liquid propellant rocket engines. To ensure the system will not fall inside the tank, calculations were done to select the appropriate ball bearings that can support the load of the system be force fitted onto the rotating and static shaft. With the progression of computational analysis, the motor for the system has been selected and will generated 1500 rpm with 0.5 hp. Also, magnets have been selected and can support a load up to 36lbs. In the upcoming spring semester, the team will begin testing the attractive forces of the magnets, procurement of raw materials for fabrication, as well as building and testing of the system.



# 1 Project Overview

NASA has given us the task to design, fabricate, and test an electric motor-pump unit that makes use of magnetic coupling technology to position the motor outside of the cryogenic tank, while still providing sufficient pumping pressure/flow in both water and liquid nitrogen, and incorporate insulation between the coupling and tank wall so as not to introduce additional heat leak. A simple block diagram of the system can be seen in Figure 1. The power supply runs the motor cause the coupled magnets to rotate. The rotation from the magnets allows the pump to effectively circulate the fluid.

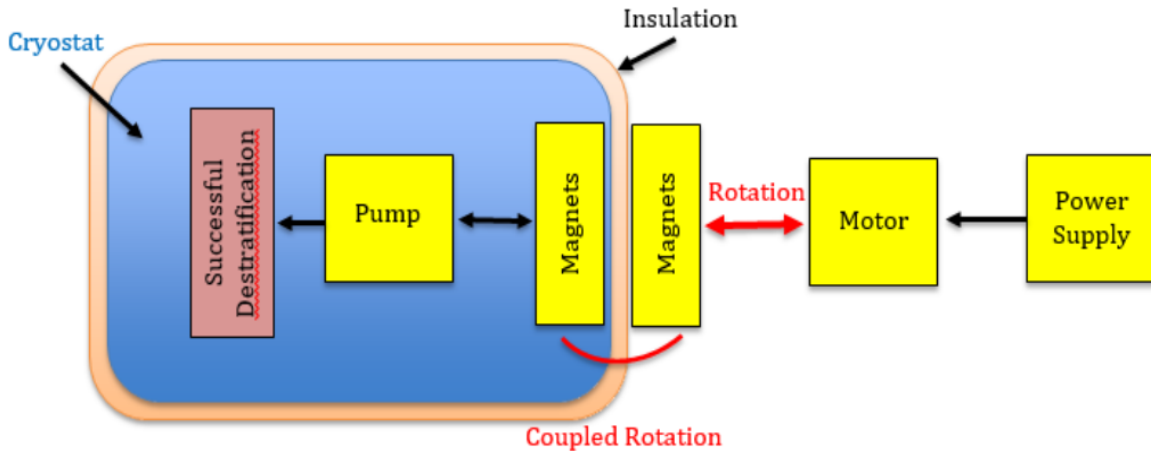


Figure 1: Block Diagram of system incorporating magnetic coupling technology

## 1.1 Background Research

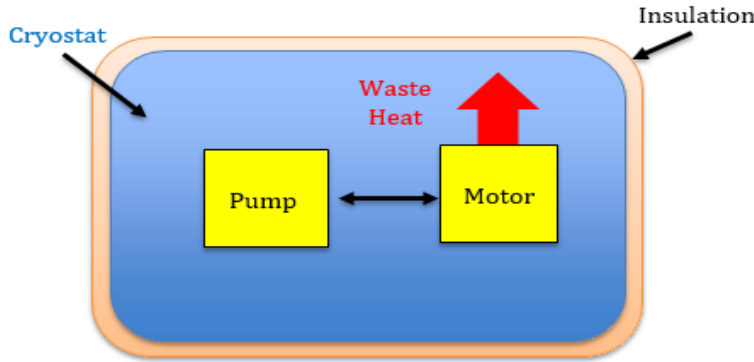
Pressure control and destratification, or the process achieving temperature equalization by mixing the internal air to eliminate stratified layers, presents issues with long term storage of cryogenic propellants. Heat leak from the surrounding environment causes these propellants to boil causing the pressure in the tanks to rise and there is an increase in the fluid saturation temperature if the tank is sealed off. In order to reduce the environmental; heat leak in conditions such as ground/atmosphere and space/vacuum, foam and insulation are used and can be seen in Figure 2. In order to decrease rapid increase in pressure, the propellants can be mixed to create a more uniform temperature condition within the vapor and fluid portion of the tank.



Figure 2: Layers of insulation currently in place surrounding a cryogenic tank

Currently, the mixing process consists of using AC single and 3-phase motor systems, which are directly coupled to a pump and placed within the tank itself or mounted to a flange with the motor operating in a submerged condition. A simple block diagram can be seen in Figure 3. By using this method, waste heat

from the motor is flowing into the tank and is generating a rapid pressure rise within the tank. Also, the feedthroughs or connectors may create leak paths for potential failure. Research and develop of motors suitable to handle low temperature conditions is highly expensive.



**Figure 3: Block Diagram of current system**

To decrease heat leak, high performance insulation systems are incorporated into the design of the tank, even with perfect vacuum [2], thermal radiation can still contribute significantly to the total heat leak. The radiation from room temperature is also one of the main heat loads in cryogenic systems, and

heat addition is what the team is trying to avoid throughout the entire project. Therefore the standard multi-layered insulation used at the NASA Marshall Space Flight Center will be used throughout the project.

Magnetic coupling was introduced that may allow the placement of the motor outside the cryogenic tank. [3] Magnetic couplings are generally used to transmit torque from one system to another where the magnetic transmission is required to maintain a hermetic seal to prevent leakage and contamination. The magnetic coupling is used in this project to transmit rotational motion from the motor across the tank wall to a mixer/pump located on the inside. The mixer/pump would be designed to operate in the cryogen receiving the magnetic rotational motion and imparting it to the fluid through impellers/etc. contained within a housing to produce flow up to 15gpm and pressure rise up to 5psid.

## 1.2 Scope

NASA Marshall Space Flight Center is in need of a way to mix cryogenics without adding heat to the system. Currently a motor is placed inside the cryogenic tank in order to operate the mixing pump. The motor not only inserts heat to the system but also causes a rise in pressure. Additionally many of the motors used inside the system are costly and impractical. The purpose of this project is to reduce the heat added to the cryogenic system while effectively mixing the cryogenics to uniform temperature.

**“Due to the motor used inside cryogenic tanks there is too much heat addition when mixing the fluids”**

## 1.3 Goal Statement & Objectives

**“Design a better way of mixing cryogenic fluids incorporating magnetic coupling technology”**

The objectives are as follows:

- Minimize heat addition to cryogenic system
- The pressure rise due to the pump must be 5psid
- Magnetically couple motor shaft to pump shaft
- The system must be installed through a 3.75 inch port on the top of the tank
- Contain a minimal parts and be compact
- The system has to be tested in both water and liquid nitrogen

## 1.4 Constraints

There are several categories for our constraints and are as follows:

- Budget: The overall budget of the project consists of \$500 from Space Florida for the purchasing of the motor, magnets, and fabrication costs. The materials will be provided by our sponsor as long as a prepared list is submitted prior to November. Therefore, a complete list of materials will be needed prior to this date.
- Ease of assembly: The design must be able to be fitted to the standard 6” ConFlat flange in order to be properly and easily installed into the Cryofab CF 1424-F cryostat.
- Size: The design must be compact and easily portable.
- Insulation and heat shielding: The design must not add heat to the system and therefore the motor must be insulated from the tank to prevent heat addition.
- Materials: The materials used in the design must be able to withstand such low temperatures without any structural damage. The materials of the tank must also be non-magnetic in order for the coupling to be successful.
- Magnets: There must be enough magnets used in the design to ensure that there is enough coupling strength to make any rotation motion one-to-one. The magnets chosen must be able to penetrate through the tank material as well as the insulation used around the tank.

### 1.4.1 Design specifications

The design specifications of the system are broken down as the tank specifications that must meet the requirements of the sponsor. The pump/mixer system must meet the constraint of the tank and be portable to similar cryostats.

The cryogenic tank that will be used in the project is the Cryofab CF 1424-F cryostat. And the design must be attached to a 6 inch ConFlat flange in order to be easily assembled. The design must be compact and portable. The design also needs to be attached to the top of the cryostat. The motor-pump unit must make use of magnetic

## Magnetically Coupled Pump System for Cryogenic Tank Destratification

coupling technology and an electronic motor. The unit must be tested with water and liquid nitrogen. Table 1 shows all design specifications for the project.

**Table 1: Design Specifications**

<b>Requirement</b>	<b>Specification</b>
<b>Tank Size</b>	<ul style="list-style-type: none"><li>• Height: 29 in</li><li>• Outer Diameter: 16 in</li><li>• Inner Diameter: 14 in</li><li>• Gross Capacity: 60 Liters</li></ul>
<b>Insulation</b>	<ul style="list-style-type: none"><li>• 0.5 in of foam</li><li>• &gt;20 layers of multi-layer insulation (MLI)</li></ul>
<b>Mounting</b>	<ul style="list-style-type: none"><li>• Mounted to 6 in flange</li><li>• Flange has 4 in port into tank</li></ul>
<b>Pump Motor</b>	<ul style="list-style-type: none"><li>• Variable Flow Rate : 5 - 15 gpm</li><li>• Generates 5 psid rise in pressure</li><li>• Mixer/Pump must reach 12 inches into tank</li></ul>
<b>Additional Requirements</b>	<ul style="list-style-type: none"><li>• Tank must be adiabatic to surroundings</li><li>• Pump shaft must be magnetically coupled to the motor shaft</li><li>• Friction must be held to a minimum</li><li>• System must be compact</li><li>• Materials used for the magnetic housing and flange must be non magnetic</li><li>• Materials must withstand extremely cold temperatures between 63K - 77.2K</li></ul>

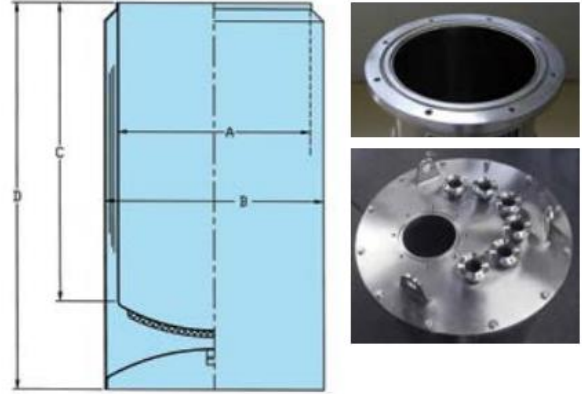
## 2 Design and Analysis:

In the following section, proposed designs components are discussed, computational analysis is conducted in order to select components of the design, and a final design is selected.

### 2.1 Functional Analysis

The functional analysis can be broken down to the mechanical specifications that must be met with the design and then the requirements that must be met by the electrical motor system.

designs components are discussed,



**Figure 4: Cryostat Dimension Figure Guide provided by the sponsor**

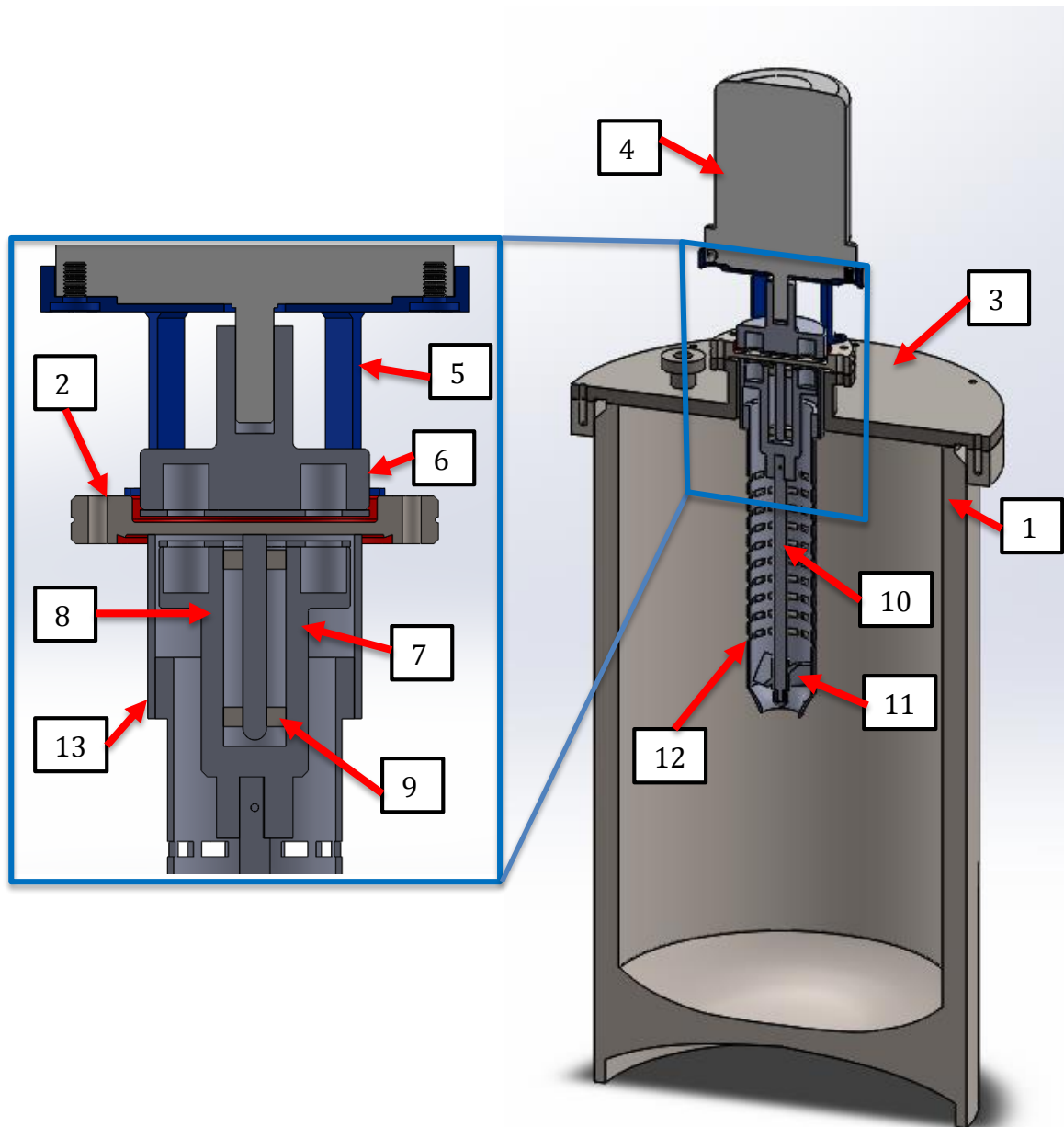
#### 2.1.1 Mechanical Specifications

The cryogenic tank that will be used in the project is the Cryofab CF 1424-F cryostat. The dimensions are as follows in Table 2 and referenced in Figure 4. The cryostat is also seen identified as item 1 in Figure 5.

**Table 2: Cryostat Dimensions**

Model	“A” Inside Diameter (Inches)	“B” Outside Diameter (Inches)	“C” Inner Depth (Inches)	“D” Overall Height (Inches)	Gross Capacity (Liters)	Loss Rate (Liters/Hr)	Liters/Inch
<b>CF 1424</b>	13.93	16.0	24.0	29.0	59.9	0.340	2.49

The motor-pump system must be fitted to a 6” ConFlat flange made of stainless steel, which can be seen as item 2 in Figure 5. This flange can be milled to 1/5 inch in thickness to guarantee that the magnets can sufficiently couple through the flange. The seal mechanism is a knife-edge that is machined below the flange’s flat surface. These knife-edges make grooves into a copper gasket as the flange-pair is tightened thus yielding a leak-tight seal. However, there has been a more inexpensive and just as effective cryogenic seal proposed. Indium wire can be used and placed between the flange and the cryostat lid. Through tightening the flange to the lid, the wire is compressed and flattens creating an effective seal.



**Design proposed by the group utilizing an axial pump. (1) Tank, (2) Flange, (3) Top of Cryostat, (4) Motor, (5) Motor Mount, (6) Outer Magnet Couple, (7) Inner Magnet Coupler, (8) Static Shaft, (9) Roller Bearings, (10) 12" Pump Shaft, (11) Pump Inducer, (12) Pump Housing, (13) Pump Housing Anchor**

The cryostat top, as seen in Figure 5 and is labeled as item 3, has a 3.75 inch port that leads into the tank; therefore, the section of the system that is inserted inside the tank must not exceed 3.75 inches in diameter.

Item 4 in Figure 5 is the motor that we have selected for our design using the computational analysis that is described in future sections.

The blue item in the Figure 5 (item 5) is the motor mount that has been designed by the group. The mount will be made of PVC which has a very low thermal conductivity so heat is not transferred conductively through the mount into the flange itself. Item 6 in

Figure 5 is the outer magnet coupler. This coupler will be physically attached to the motor shaft. The coupler holds 8 magnets in the spaces shown in the cross section. These magnets are .75” in diameter and are made of the rare earth metal neodymium. This coupler is magnetically coupled with the inner magnet coupler, item 7. Through the magnetic coupling the rotational motion of the outer coupler is transferred to the inner coupler, and therefor to the pump shaft and pump.

The static shaft is item 8 in Figure 5. The static shaft will be welded to the exact center of the inner side of the flange. The shaft acts as a support to the inner coupler and the pump through the stainless steel ball bearings (item 9), as well as aligns the pump to ensure that it remains level.

Item 10 in Figure 5 is the 12” pump shaft that holds the inducer (item 11) and guarantees that the inducer is located in the middle of the tank. The inducer is only 2.75” in diameter to ensure that the pump fits into the tank. The housing for the pump is shown as item 12 in Figure 5. This housing ensures that the flow is directionalized in order to sufficiently destratify the cryogenic fluids. The part that will attach the pump housing to the flange is the Pump Housing Anchors and is seen in Figure 5 as item 13.

### 2.1.2 Electrical specifications

The only electrical components in this design project are the motor, which will be powered by a simple AC plug in socket. This AC motor sacrifices the portability aspect of the design but does save on the overall cost. The type of motor will be discussed further in the procurement section of this report. Additionally the process on how the motor specifications were calculated is described in great detail in the computational analysis of this report.

### 2.1.3 Computational Analysis

The project requires extensive computational analysis in order to properly select various components for the design. The major calculations that are required for this project are the required power of a motor to produce the specified flow rate and pressure rise, the angular velocity of the pumps propeller to produce the indicated flow rate, the total tangential force necessary to produce this power, the maximum tangential force the magnet can withstand without slipping. All of these calculations are important to ensure the device works properly however some experimental observations will be made in order to further increase the success of the design.

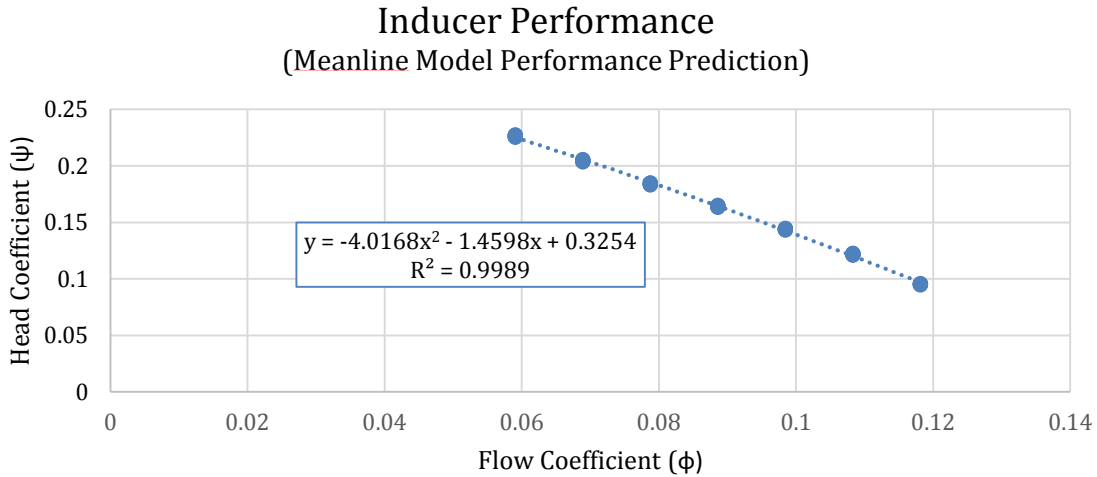
Calculations were done in order to select a motor that would be able to sufficiently supply the power needed to work the pump. Using the lowest requirement of 5 gpm and the inducer inlet cross-sectional area the meridional flow velocity can be found using the following (1):

$$C_m = \frac{\dot{V}}{A_{inlet}} = 0.265 \frac{ft}{sec} \quad (1)$$

In order to calculate the flow coefficient the tip speed is then needed. Picking an RPM of 1500 as suggested by our liaison engineer at NASA, the tip speed was found to be 18 ft/sec. Therefore using equation 2 the flow coefficient can be found,

$$\phi = \frac{C_m}{U_{tip}} = 0.015 \quad (2)$$

Using the flow coefficient,  $\phi$ , the head coefficient,  $\psi$ , is extrapolated from the following plot in Figure 6 provided to the group by our liaison engineer. It is found to be about 0.3.



**Figure 6: Inducer meanline performance plot relating the head and flow coefficients.**

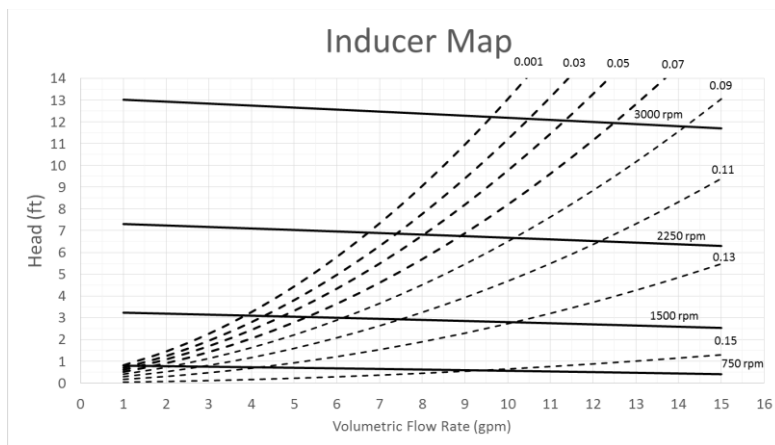
The head of the pump is then found ( 3),

$$Head = \frac{\psi \times U_{tip}^2}{g} = 3 \text{ ft} \quad (3)$$

Using the head of the pump mass flow rate of the fluid across the pump, which can easily be found using the density of the fluid and the required volumetric flow rate, the power requirement of the pump can be found (4). We assume that the overall efficiency with losses is 20%.

$$Power = \frac{(\dot{m} \times Head)}{(\eta \times 550)} = 0.02 \text{ hp} \quad (4)$$

Finally a motor with at least 5 to 10 times this calculated power is selected in order to be safe and allow for more functional flexibility. Therefore a motor that runs at 1500 RPM and supplies 0.5hp must be selected for this design. To confirm these values an inducer map was constructed showing various constant speed and constant flow lines. The inducer map can be seen in Figure 7.



**Figure 7: Inducer map used for provided inducer. Solid lines indicate constant speed lines and dashed represent constant flow coefficient lines.**



NASA has specified a desired flow rate and pressure rise that they believe will successfully destratify the cryogenic fluids. The tangential force is found (5).

$$F_{mag} = \frac{P}{\omega \cdot l} \quad (5)$$

In Equation 5, P is the required power,  $\omega$  is the calculated angular velocity, and l is the radius of the propeller shown in Figure 7. From Equation 5 the tangential force was found to be 83.1 N. Once this force is calculated,  $F_{mag}^*$ , the maximum tangential force the magnet can withstand must be calculated. This tangential force  $F_{mag}^*$  is a function of Z the vertical distance between the coupled magnets shown in Figure A-1 in Appendix A,  $B_0$  the magnetic induction exerted by the magnet, and  $\gamma$  the angle the coupled magnet is displaced from the vertical axis of the other magnet. When  $\gamma$  moves in the direction of angle  $\phi$  shown in Figure A-2, a maximum tangential force will be achieved before the magnet begins to slip shown in Figure 8. This force  $F_{mag}^*$  must be greater than the force calculated in Equation 5

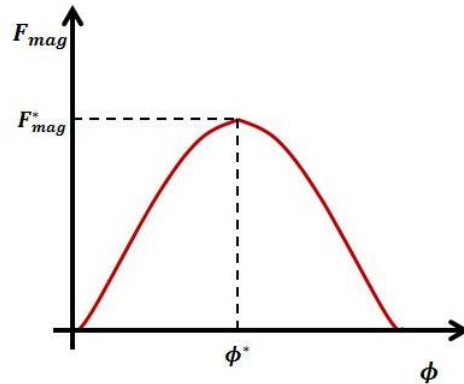


Figure 8: Graph of Force vs. angle  $\phi$

to ensure the magnetic couple is 1-1 and no slip occurs. This  $F_{mag}^*$  will be found experimentally by holding one end of the coupler shaft still while rotating the other. A force will be applied to the rotating coupler and a force meter will record this force. The applied force will increase until the magnetic coupling slips at which point the force will be noted and is equal to  $F_{mag}^*$ . Further analysis of the  $F_{mag}^*$  will be done by using the equations in “Magnetostatic interactions and forces between cylindrical permanent magnets” [7] provided by the team’s faculty advisor Dr. Guo. All the calculations for this report project are shown in Appendix A.

Once the necessary rpm, power, and tangential forces were calculated bearing computations were performed. The first step to in bearing calculations is to first find the life of the bearings in millions of revolutions. Using factory defaults for bearing life in hours the bearing life in millions of revolutions was found (6).

$$L_{10} = L_h * \omega * 60 \times 10^{-6} \quad (6)$$

$L_h$  is the life in hours  $\omega$  is the angular velocity of the system in rpm and  $60 \times 10^{-6}$  is a conversion factor. The life  $L_{10}$  was found to be 720Mrev. Once the life  $L_{10}$  was found the dynamic load of the bearing was calculated using equation 7.

$$C = F_e L_{10}^{\frac{1}{3}} \quad (7)$$

$F_e$  is the equivalent force applied to the bearing which is a combination of radial force and thrust. The equivalent force  $F_e$  was first estimated using a RMS method shown in equation 8.

$$F_e = \sqrt{F_a^2 + F_r^2} \quad (8)$$

In the above equation  $F_a$  is the axial force or thrust and  $F_r$  is the radial force. These forces were doubled in order to guarantee a factor of safety of 2. Using the equivalent force  $F_e$  the dynamic load was found to be 108.45lbf. Next the static load  $C_0$  was found using the SKF bearing catalog for stainless steel bearings. Once the static load was found equation 9 was used to find a ratio between the static load and axial force.

$$\frac{F_a}{C_0} \tag{9}$$

After finding this ratio linear interpolation was performed to find a factor  $e$  using Figure 11-24 in the “Machine Design an Integrated Approach”. This factor  $e$  was then compared to another ratio (10).

$$\frac{F_a}{VF_r} \tag{10}$$

Where  $V$  is a rotation factor that is based on whether the inner or outer ring of the bearing is rotating. For a bearing with a rotating outer ring  $V$  is determined to be 1.2. Using this ratio the radial factor  $X$  and thrust factor  $Y$  were determined by performing linear interpolation in Figure 11-24 in the “Machine Design an Integrated Approach”[2]. A new equivalent force  $F_e$  was found (11).

$$F_e = XVF_r + YF_a \tag{11}$$

Using this new equivalent a new dynamic load can be calculated using. This process is then repeated until the dynamic load does not change when the process is performed. Sample calculations for the bearings can be viewed in Appendix A

## 2.2 Design Concepts

The design concept process was unique for our project. When the project was originally selected by the group members, two key magnetic coupler designs were proposed. A pancake magnet coupler and a concentric magnet cylinder design. The concentric cylinder design, although it would yield a very strong magnetic coupling, would require a large protrusion attached to the flange. This protrusion was deemed unsuitable to the design by the sponsors. The sponsors then sent us a basic design that they had drawn up; this design can be seen in Figure 9. The design makes use of a Tesla pump with a pancake shaped magnetic coupler.

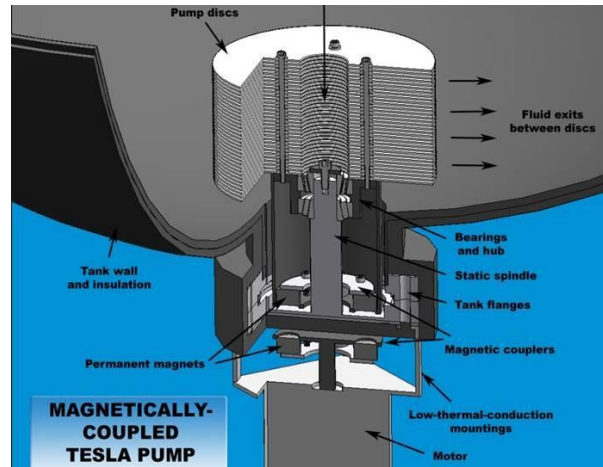
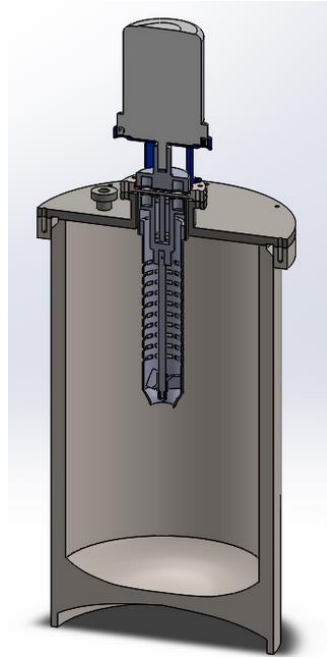


Figure 9: Design for magnetically couple Tesla pump provided by the sponsor

The proposed design can be seen in Figure 10, and is shown again below. While the pancake magnet coupler and the static shaft with the inner magnetic coupler design remains the same between the designs, there are several key differences between the designs. First and for-most is the difference between the axial and Tesla pump used in these designs. This selection was based on the amount of power it was able to deliver to the system given the size restraint. The pump selection will be discussed in length in a later section. Second, the new design will be installed through the top of the tank rather than the bottom, thus allowing it to be used on current pump models. In order for this to be accomplished, the pump shaft will be extended 12 inches into the tank; therefore, the pump will be located in the center of the tank. Lastly, the new design can be inserted through the four inch port in the cryostat lid. This means that the entire cryostat does not have to be disassembled in order for the pump to be fitted to the system. This also played a factor into the pump selection.

The new design was deemed more efficient than the design concept sent to us by the sponsor. Therefore the new design will be further pursued.



**Figure 10: Design proposed by the group utilizing an impeller.**

## 2.3 Evaluation of designs

Each pump/mixer design has performance advantages and disadvantages for the system. The tesla pump would seem to be the best fit for the design due to the ease of manufacturing or fabrication the pump; it can be used for a variety of fluids without any damage. The efficiency of the tesla pump has been questioned with past research and the pump produces a low rotor torque. Also, in order to produce to required flow rate, the disks of the tesla pump will have to be larger than the 4” constraint of the system.

The centrifugal pump has its own set of advantages and disadvantages making it yet another good selection for the magnetically coupled pump system. The centrifugal pump is small in size, requires easy maintenance, and can also be used for a variety of fluids. The centrifugal pump however cannot produce a high viscous flow, and is subjected to cavitation. The pump can also over heat due to low flow production.

Instead of using the axial pump, the design will only use the propeller connected to the static shaft with a housing. The axial pump is great for high flow rates and low pressures making it suitable for the system. The axial pump can be adjusted for producing the best efficiency at varying conditions. This type of pump however is not suitable for suction lift.

Upon receiving materials from NASA, a three toothed inducer was among these supplies. The inducer usually acts as the inlet portion of a centrifugal pump, however the

teams design is different than that of a centrifugal pump so it will be acting as the impeller. It is used in applications in which the inlet pressure of a pump is close to the vapor portion of the pumped liquid and are frequently used in design of pumps for liquid propellant rocket engines.

In Table 3 a decision matrix was made to decide to use a tesla pump, a centrifugal pump, the provided inducer to act as an impeller, or an axial pump based on a set of criteria. The scale for the decision matrix is 1-10, 10 being the best and 1 the worst. Since the budget for the project is \$500, the weighting factor for the cost of the pump is one of the largest weight factors. Power efficiency is also largely weighted since the pump has to produce a flow rate between 5-15 gpm. Fabrication is the second largest weight factor in the decision matrix. Depending on the style of pump, the propeller, impeller, or disk will have to be fabricated and can cause the team to deviate away from the budget. Pressure conditions and cavitation are rated the lowest since the pressure isn't significantly high and a system of this size cavitation isn't a huge factor.

The team decided the ratings for each pump criteria and the provided inducer is the optimum choice. Since decision matrices are used to choose the most efficient selection for a project, it is still up to the team to pick the best for the requirements of the system. The team decided to continue with the provided inducer that will act as an impeller for the pump.

**Table 3: Decision Matrix**

	Cost	Fabrication Ease	Power Efficiency	Cavitation	Pressure Conditions	Total
Weight	0.3	0.2	0.3	0.1	0.1	1
Axial	9	6	9	4	8	7.8
Centrifugal	7	7	7	2	4	6.2
Tesla	5	8	5	9	8	6.3
Inducer	10	10	8	6	6	8.6

## 2 Risk and Reliability Assessment

### **Liquid Nitrogen:**

There are extreme safety measures that need to be taken into account especially during testing. Handling liquid nitrogen is one of the most vital risks of the project. The project requires testing with water and liquid nitrogen which temperatures range from 63K to 77K. Due to the extremely low temperature of this cryogen, safety precautions have to be taken in order to ensure no member of the team comes in contact with the substance. Also, due to the density of nitrogen gas, if a substantial amount of the cryogen were to boil off, the gas would sink to the floor causing an increase in nitrogen gas. Oxygen meters are used at the National High Magnetic Field Laboratory to detect a sudden decrease in oxygen in the cryogenics lab where testing of the system will take place. To ensure the dewar does not become over pressurized, which could cause a catastrophic failure of the tank, a pressure relief valve was installed for venting the ullage out of the tank. The reliability of the valve is essential since over time the liquid nitrogen will eventually boil off and become vapor. If this valve were to fail (not vent the vapor), the tank would become over pressurized and overstressed which could potentially cause the tank to break. Heat leak from an improperly sealed tank is also a reliability factor. The tank has to be properly sealed with either copper gaskets or indium wire to ensure proper sealing so no additional heat from the surrounding environment gets into the tank and causes the liquid nitrogen to boil.

### **Electrical Components:**

This project will also incorporate electrical wiring from the motor, to the toggle switch, and then to the power source that will run the system. In order to operate the motor, and AC power source that will plug into a socket will be used and will be constructed as a team. It is important that the wiring from the power source, to the toggle switch is correct to ensure no complications with the circuit. This project also requires the use of a hand truck to transport the dewar and its components. The vessel weighs between 50-60 lbs and if improperly handled, the amount of weight subjected will cause injury.

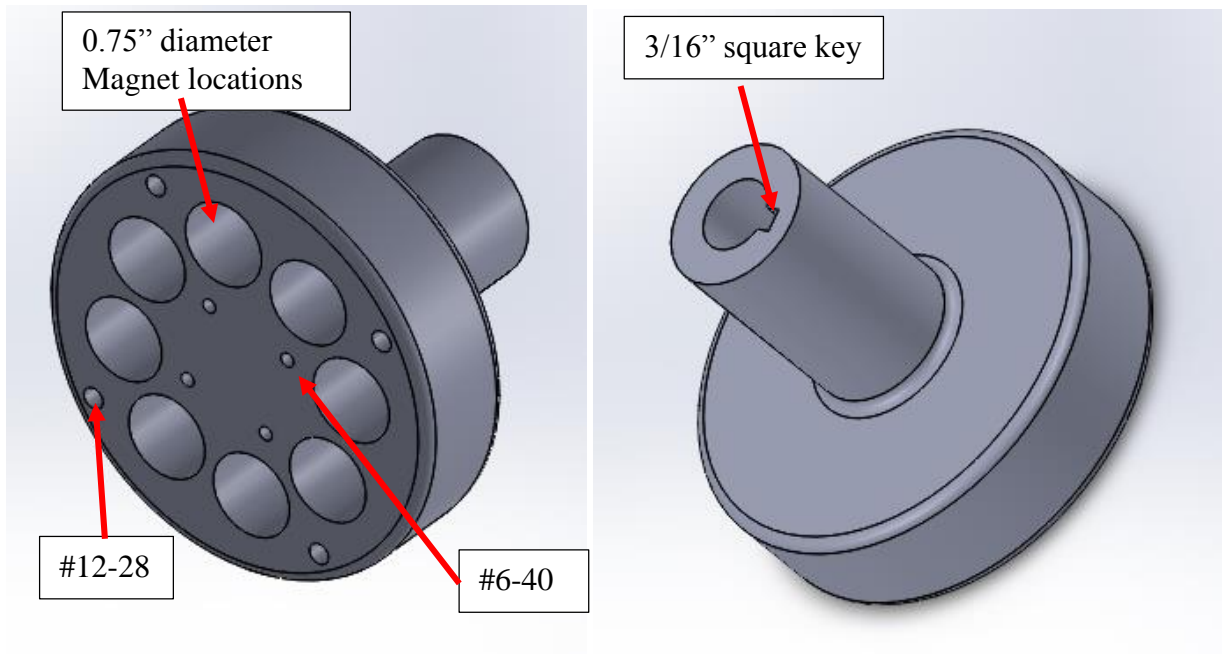
### **Magnets and Bearings:**

Since the system is being installed onto the tank lid, the reliability of the magnetic attractive force and the amount of load the ball bearings can hold come into play. In order to support the system, ball bearing are going to be force fitted onto the static and rotating shaft in order to support the load of the pump system. If these bearings cannot support the system, the bearing would break.

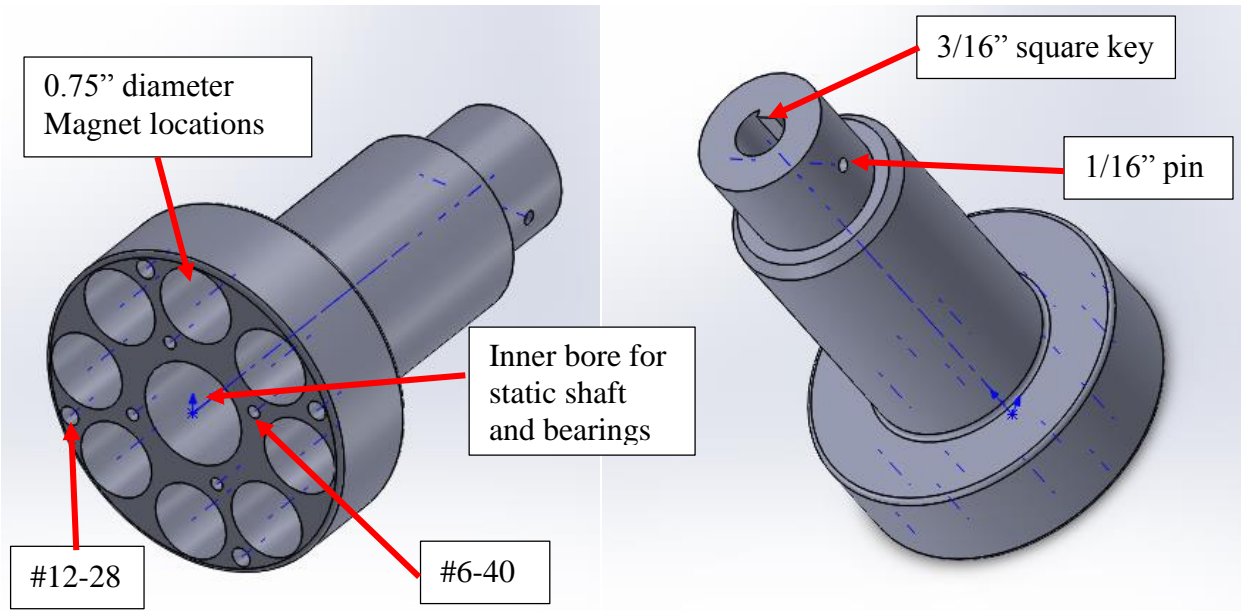
## 4 Detailed Design and Manufacturing

The detailed design of each individual component of the system can be seen in the engineering drawings produced by Solid Works and are seen in Appendix B. The parts were constructed in such a way as to be easily machined. The two main components that manufacturing was more complex were the two magnet couplers. These are looked at in the following section.

The outer magnet coupler will be made of nonmagnetic 304L stainless steel and can be seen in Figure 11.



**Figure 11: Outer magnet coupler component, engineering drawing in Appendix B**



**Figure 12: Inner magnet coupler component, engineering drawing in Appendix B**

The eight  $\frac{3}{4}$ " diameter neodymium magnets will be located in the holes as seen and will be force fitted. In addition to being force fitted into the coupler a stainless steel faceplate will be constructed to hold the magnets in place. The faceplate will have four #6-40 and four #12-28 screw holes to be secured in place. The outer coupler will be attached to the selected motor via a  $\frac{3}{16}$ " square key. The inner magnet coupler will also be made of 304L stainless steel and is seen in Figure 12.

The corresponding  $\frac{3}{4}$ " diameter neodymium magnets will be inserted into the coupler in the same way as in the outer magnetic coupler. A similar faceplate will also be constructed using the same screw types as before, however there will be a hole in the center of the faceplate for the static shaft to be located. The bearings that have been found will be attached to the inside of this coupler and the static shaft. The bearings selected are the SS600 stainless steel ball bearings from National Precision Bearing ®. The inner coupler will be attached to the pump shaft using a  $\frac{3}{16}$ " square key as before. In order to ensure that shaft does not fall into the tank and does not move will the pump is operating a  $\frac{1}{16}$ " pin will be used.

## 5 Procurement

Currently the senior design team is working on ordering all the parts necessary to fabricate the final design. NASA has agreed to provide the team with some very important components of final design. These Components include the CF-1424F Cryofab Dewar where the final design will be tested, two 6” ConFlat flanges, four copper gaskets for sealing, and a three tooth inducer for pumping the cryogenics. All of these components have been received by NASA and will be used to construct the design as soon as the rest of the components arrive. Additionally NASA is working with the team to procure the raw aluminum and stainless steel for the project. The price of these raw materials has been calculated and is represented in the bill of materials displayed in the Appendix C. Due to the small budget it is vital that NASA procures these materials and sends them to the COE ASAP. The bearings for the rotating shaft have been ordered from National Precision Bearing (NPB). NPB usually deals with very large orders and because of this they have agreed to provide two bearings free of charge. These bearings will be arriving to the COE before the beginning of next semester.

The rest of the components of the design will have to be purchased with the \$500 budget provided by the Florida Space Grant. These components include the Motor, Magnets, PVC for the motor mount, and small electrical components. The design team is working on finalizing these components and the materials will be ordered during the winter break. A detailed breakdown of these components can be seen in the Bill of Materials shown in the Appendix D.



## 6 Project Management

This design project has been carefully planned in order to ensure the design is completed in a timely cost effective manner. The budget was managed in order to keep track of all the costs the design will incur. Also specific task were set forth for each member of the group to ensure each aspect of the design was completed in a timely manner. Lastly a Gantt chart was constructed to set deadlines that were necessary to meet for the project to be successful and can be found in Appendix B.

### 6.1 Budget

The Budget for this design project is \$500 and is provided by the Space Florida Grant. The budget will be allocated in order to purchase magnets, a motor, PVC for the motor mount, and small electrical components. Additionally, NASA will provide a cryostat, ConFlat flanges, and copper gaskets. Moreover NASA plans on helping the design team procure the raw stainless steel and Aluminum. It is absolutely imperative that NASA provides these materials as our budget is extremely limited. Currently the budget totals \$420.13 not including the raw materials. A breakdown of the prices each component will require from the budget is provided in Table 4. From this table it can be easily seen that with the purchasing of raw materials the budget is exceed by nearly \$300. These raw materials are absolutely vital to the success of the project and cheaper materials cannot be purchased due to the nature of the project.

**Table 4: Allocated budget**

Item	Price
Motor	\$233.68
PVC	\$29.86
Magnets	\$137.76
Electrical	\$18.83
Raw Materials	\$364.28
Total	\$784.41

## 6.2 Resource Allocation

Table 5 shows a detailed breakdown of the tasks each group member is expected to complete in the time allotted for each task. Each group member is expected to complete the tasks assigned to them in a timely manner as to not delay the project.

<b>Task</b>	<b>Owner/Owners</b>	<b>Status</b>
Research	All	Completed
Design Concept Generation	All	Completed
Choosing final design	All	Completed
CAD Drawings	Matthew Boebinger & Kahasim Brown	Completed
Computational Analysis	Anthony Ciciarelli & Janet Massengale	Completed
Initial Web Page design	Janet Massengale	Completed
CAD Analysis/Working Model	Anthony Ciciarelli & Janet Massengale	Completed
Motor Selection	All	Completed
Material Selection	All	Completed
Pump Selection	All	Completed
Order Parts	Matthew Boebinger	In Process
Fabricate Coupling Shaft	All	10 days
Final Web Page design	Janet Massengale	Completed

## 6 Communications

The successful progression of the project for the fall semester has been due to the affective communication between the sponsor, faculty advisor, and the team members. The team meets with their faculty advisor every week to ensure progression of the project as well as bi-weekly meetings with the sponsor liaison. Also, staff meetings with the course instructors have allowed for positive and guiding feedback that helped in the advancement of group dynamics as well as working as a team.

Communications have also been made with outside resources to aid in the process for calculations and material selection. The team wishes to keep up this strong communication between faculty members and sponsors to aid in the full success of the project at the end of spring semester.

## 7 Future Plans

The future of this project leading into the spring semester will consist of procurement of materials, experimentation, fabrication, and testing of the final system.

Instead of calculating the attractive forces between the alternating poles of the magnets, the team is going to use experimentation. With the assistance of the team's faculty advisor, using a force meter, the forces of the magnets can be determined and will conclude if they are able to run the pump to produce a flow rate of 5-15gpm.

When testing the system, it is required to be tested in both water and liquid nitrogen. To show the system will work in water, the team is going to fabricate a square aluminum tank. Since the dewar is a completely closed system, it is difficult to tell if the system will work. Sight glasses on cryostats are not often common and are very expensive to install due to the material of the sight glass has to withstand extremely cold temperatures. In order to show this system works in liquid nitrogen, the team along with the team's faculty advisor and sponsor have pitched ideas on how to demonstrate the system's performance. The first idea is to have two separate cryostats, connected by a hose and to pump the liquid nitrogen from one tank to the other. This will only be possible with the assistance of another tank provided by the National High Magnetic Field Laboratory. The other solution makes use of a camera and a simple light emitting diode (LED). The camera will be mounted to the top of the cryostat lid and will record if the system is working.

## 8 Conclusion

In summary, the progression of magnetically coupled cryogenic pump has evolved into a compilation of hardware and supporting documentation. The improvements in the supporting documentation include new innovative drawings, environmental and safety issues, publisher information, and much more. This includes a detailed analysis of the cryogenic pump and the necessary power requirements for the pump. It was found the in order to achieve the parameters set forth by NASA a 1500rpm 0.5hp motor was needed. Additionally Bearing calculations were performed and it was determined that the bearings must withstand a dynamic load of no less than 739N. These improvements provide conceptual description of the physical hardware plus risk analysis to govern the scholastic purpose of the project. Additionally the design was finalized and the process of procuring parts has begun. These parts will be ordered over the break and should arrive before the start of the new year.

## 10 References

- [1] Senior Design Project Definition Group 24. PDF.
- [2] W., Van Sciver Steven. Helium Cryogenics. New York: Plenum, 1986. Print.
- [3] "Magnetic Couplings | Technology | Magnomatics." Magnetic Couplings | Technology | Magnomatics. N.p., n.d. Web. 25 Sept. 2014.
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- [5] "Axial Flow Pumps Information." *On GlobalSpec*. N.p., n.d. Web. 25 Oct. 2014.
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# Appendix A

## Bearing Calculations

$$F_r := 61\text{bf}$$

$$F_a := 10.5\text{bf}$$

$$L_h := 8000\text{hr}$$

$$\omega := 1500\text{rpm}$$

$$F_e := \left( F_r^2 + F_a^2 \right)^{\frac{1}{2}} = 53.794\text{ N}$$

$$C_{-} := F_e \cdot L_{10}^{\frac{1}{3}} = 482.146\text{ N}$$

From SKF bearing catalog

$$C_0 := 193\text{N} = 43.388\text{ lbf}$$

From Table 11-24

$$\frac{F_a}{C_0} = 0.242$$

+

Linear Interpolation

$$e_{\omega} := .34 + (.38 - .34) \cdot \frac{.242 - .17}{.28 - .17} = 0.366$$

$$V := 1.2$$

$$\frac{F_a}{V \cdot F_r} = 1.458$$

$$Y := 1.15 + (1.31 - 1.15) \cdot \frac{.242 - .17}{.28 - .17} = 1.255$$

$$X := .36$$

$$F_e := X \cdot V \cdot F_r + Y \cdot F_a = 76.539\text{ N}$$

$$C_{-} := F_e \cdot L_{10}^{\frac{1}{3}} = 686.004\text{ N}$$

Repeat process Until C does not change

**Power Calculations**

Pumping Requirement Calculations

Given - Volumetric Flow Rate  $\left( V = 15 \frac{\text{gal}}{\text{min}} \right)$

$$\text{RPM} = 1500 \frac{\text{rev}}{\text{min}}$$

Inducer  $d = 2.75 \text{ in}$

Convert vol flow rate to  $\text{ft}^3/\text{sec}$

$$V = 0.0334 \frac{\text{ft}^3}{\text{sec}}$$

Find inducer inlet cross-sectional area

$$A = \pi \left( \frac{d}{2} \right)^2$$

$$A = 0.0412 \text{ ft}^2$$

The meridional flow velocity

$$C = \frac{V}{A}$$

$$C = 0.8102 \frac{\text{ft}}{\text{sec}}$$

The tip speed is then found

$$U = \frac{\text{RPM} \cdot d}{2}$$

$$U = 17.9987 \frac{\text{ft}}{\text{s}}$$

The flow coefficient is found

$$\phi = \frac{C}{U}$$

$$\phi = 0.045$$

From the given plot, the head coefficient is found

$$\psi = \left( -4.0168 \cdot \phi^2 \right) - (1.4598 \cdot \phi) + 0.3254$$

$$\psi = 0.2515$$



## Magnetically Coupled Pump System for Cryogenic Tank Destratification

The head of the pump is then found

$$\text{Head} = \frac{\psi \cdot U^2}{32.174 \frac{\text{ft}}{\text{sec}^2}}$$

$$\text{Head} = 2.5328 \text{ ft}$$

Convert the volumetric flow rate converted into mass flow rate

$$m = V \cdot 62.3 \frac{\text{lb}}{\text{ft}^3}$$

$$m = 2.0821 \frac{\text{lb}}{\text{s}}$$

Power requirement assuming 20% efficiency

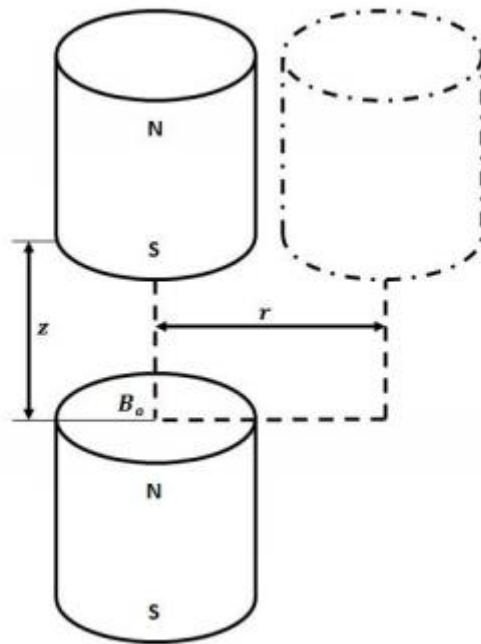
$$P = \frac{m \cdot \text{Head}}{0.2}$$

$$P = 0.0479 \text{ hp}$$

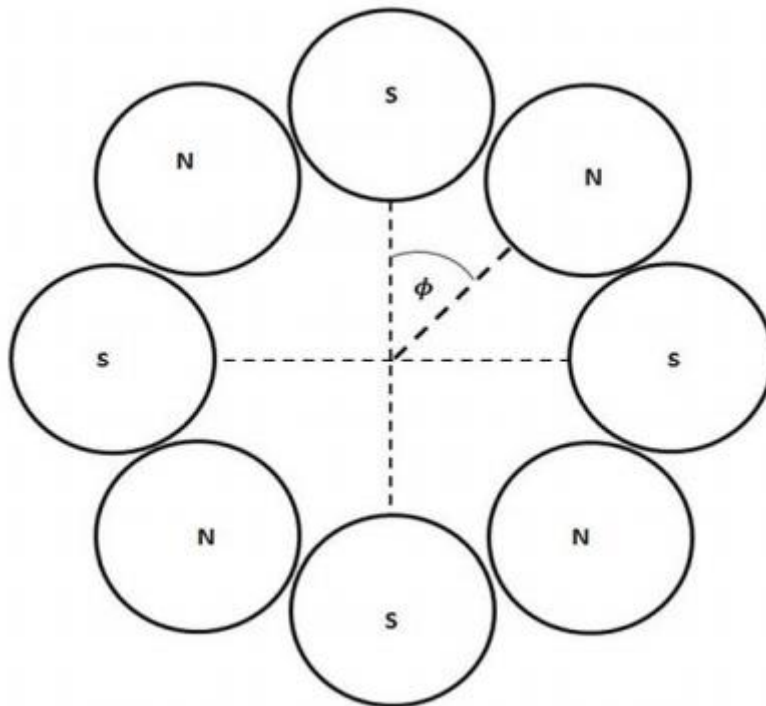
With a factor of safety of x5 to x10

$$\text{Power} = 10 \cdot P$$

$$\text{Power} = 0.4794 \text{ hp}$$

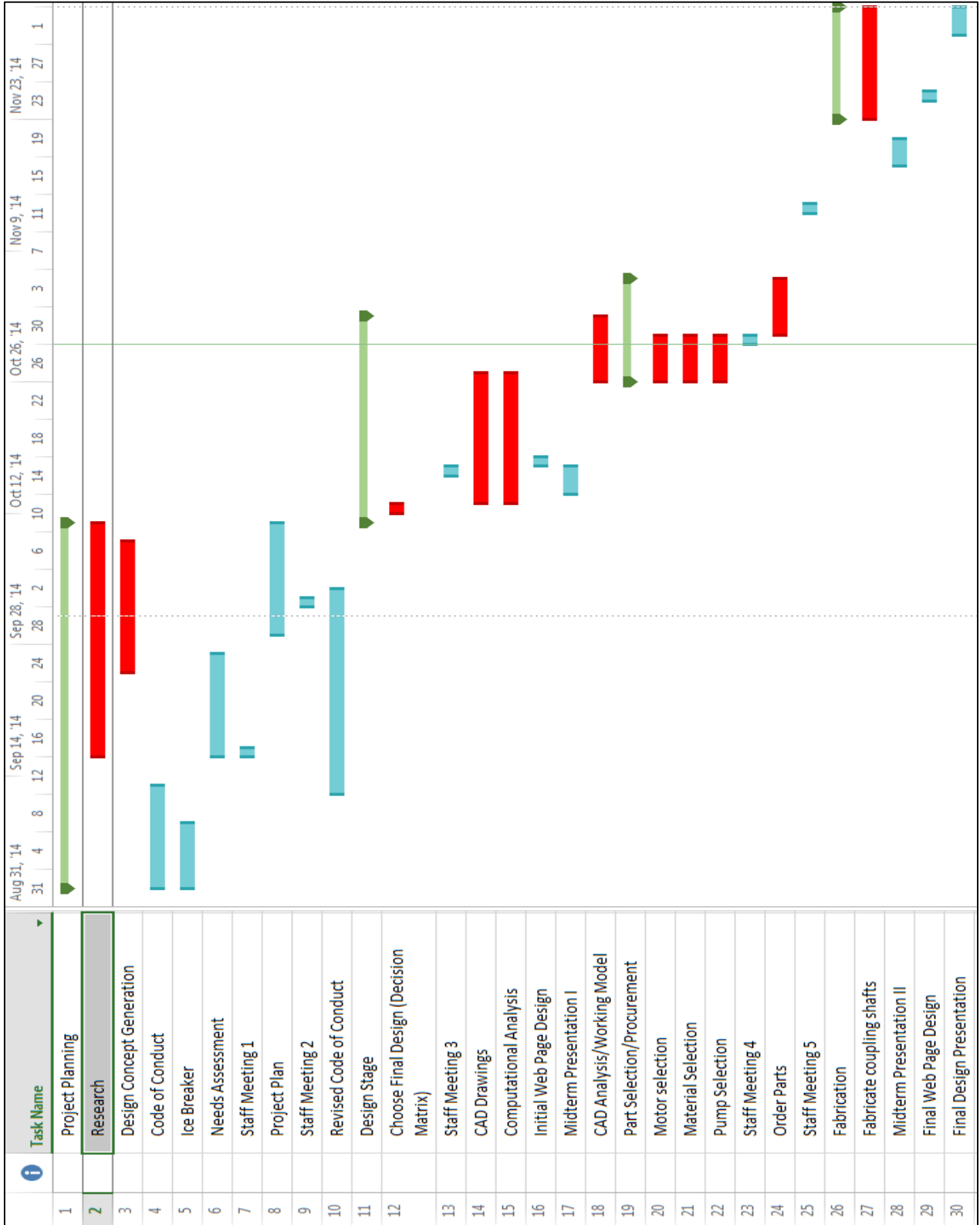


**Figure A-1:** Magnetic coupling geometry

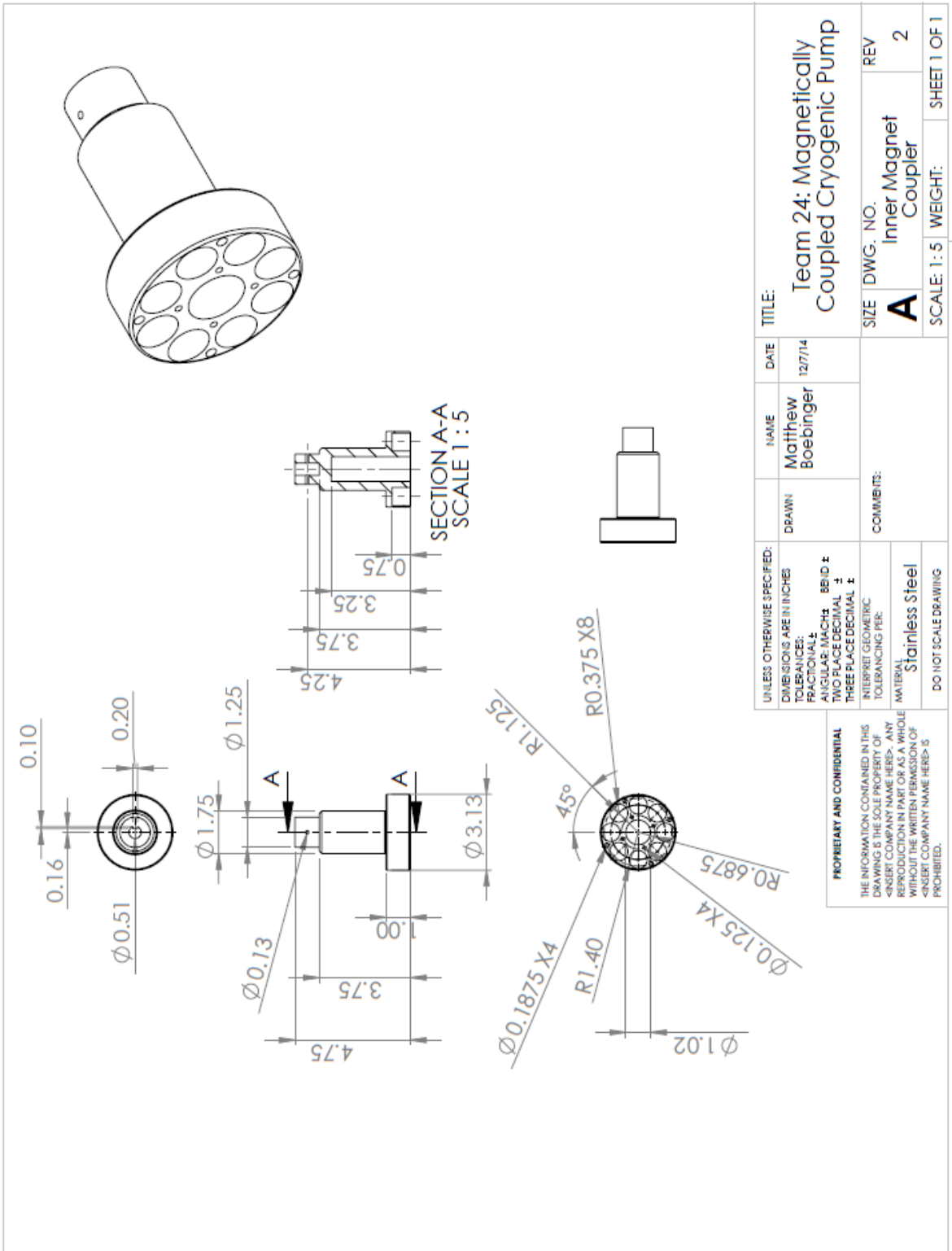


**Figure A-2:** Magnetic housing geometry (top view)

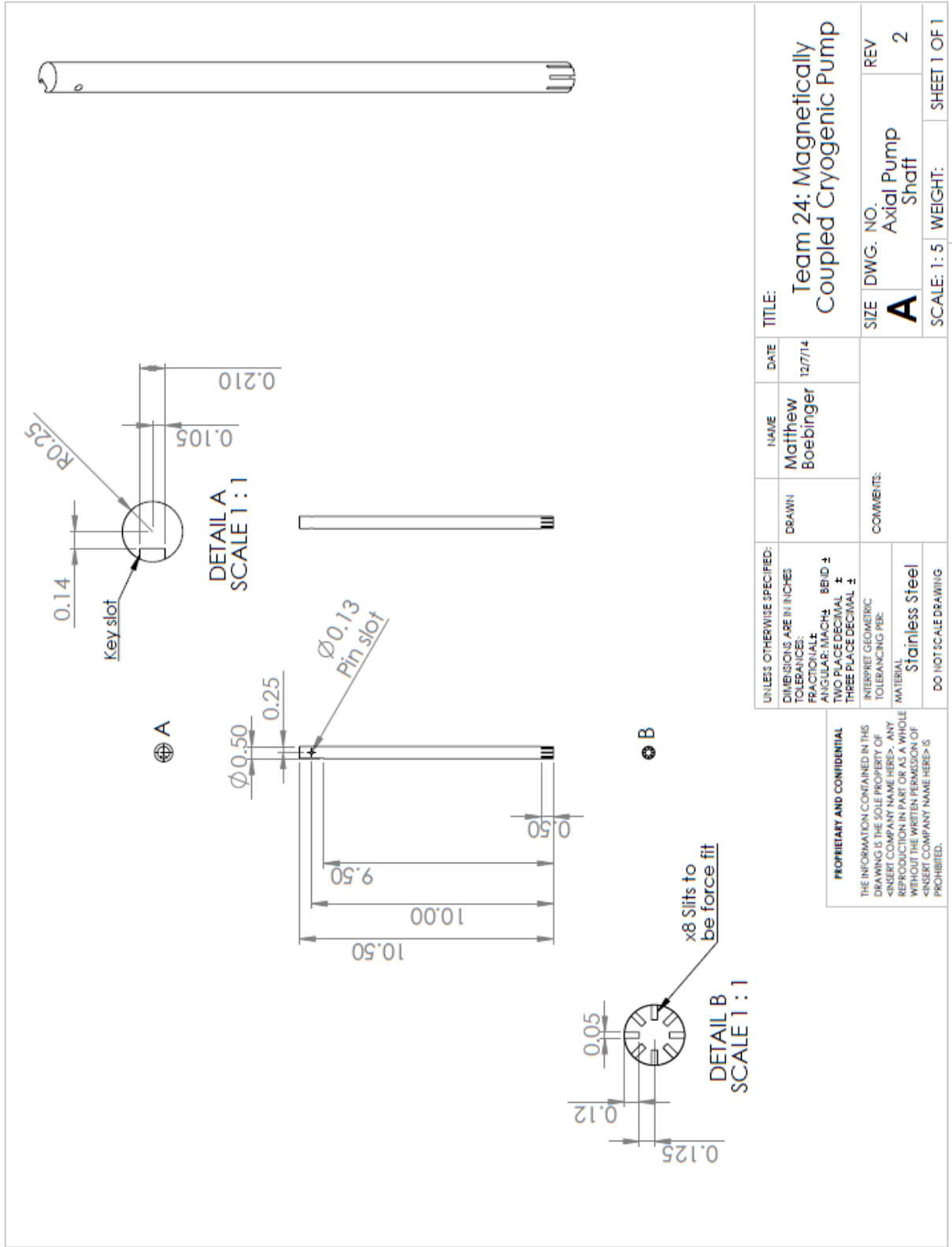
# Appendix B



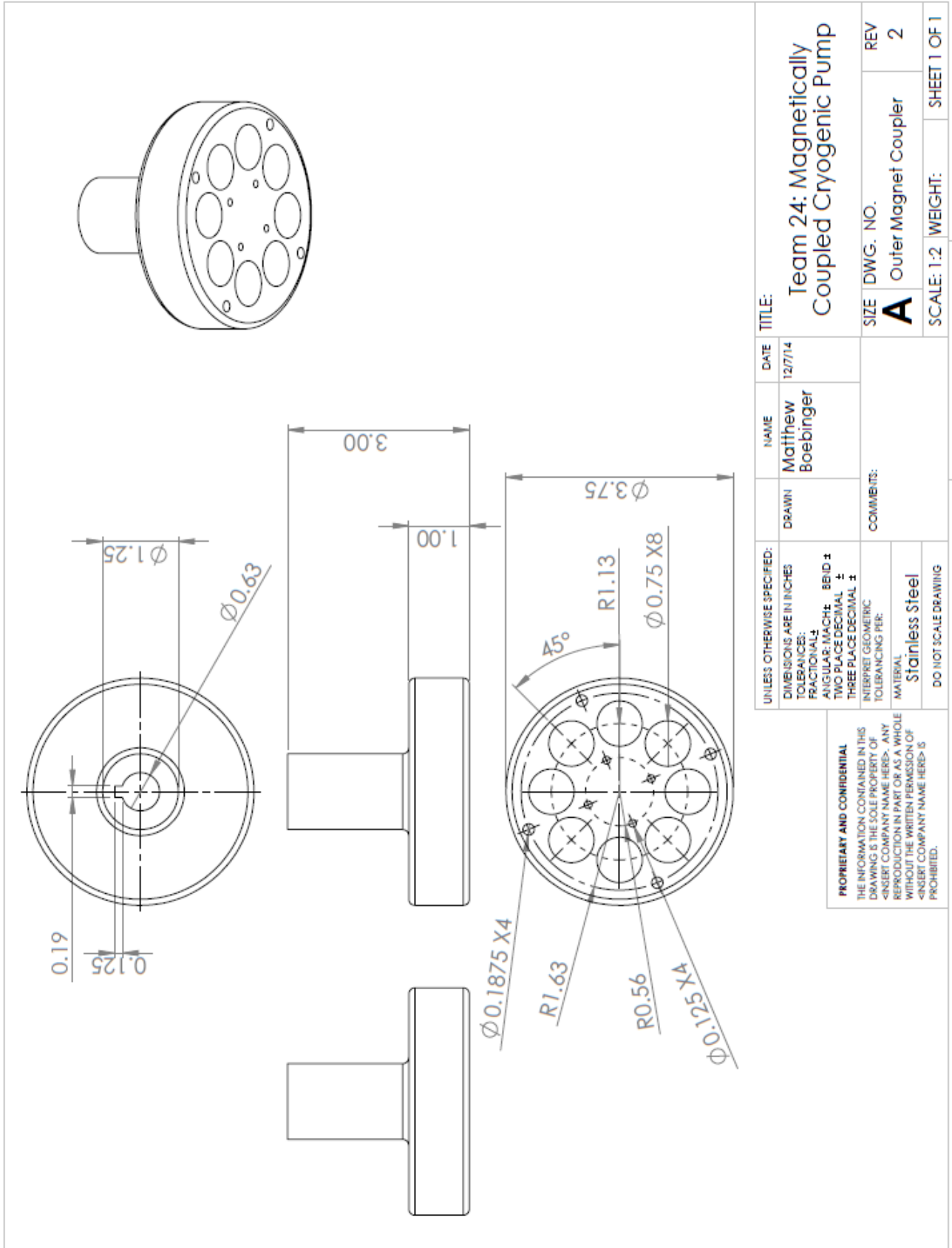
# Appendix C



Magnetically Coupled Pump System for Cryogenic Tank Destratification



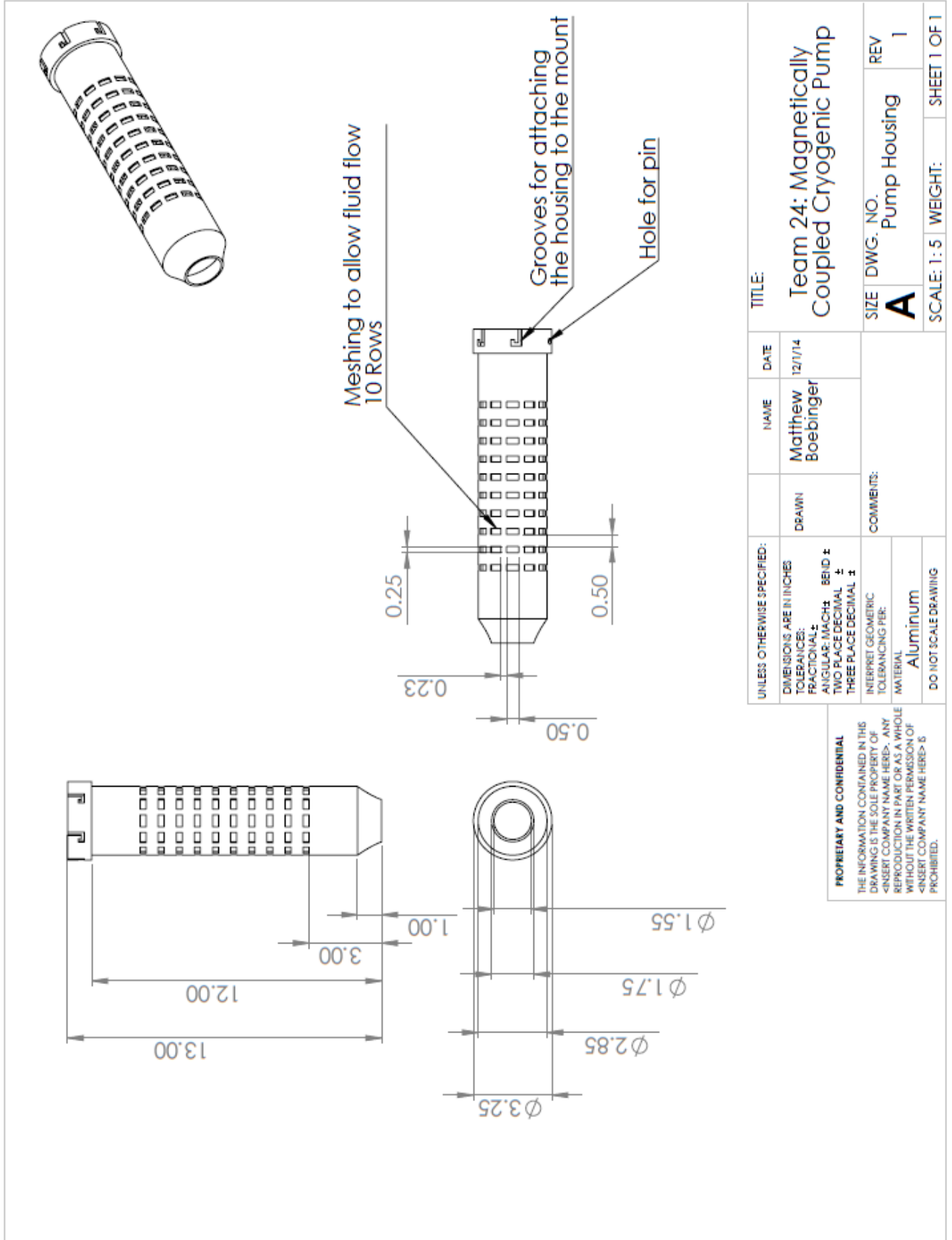
Magnetically Coupled Pump System for Cryogenic Tank Destratification



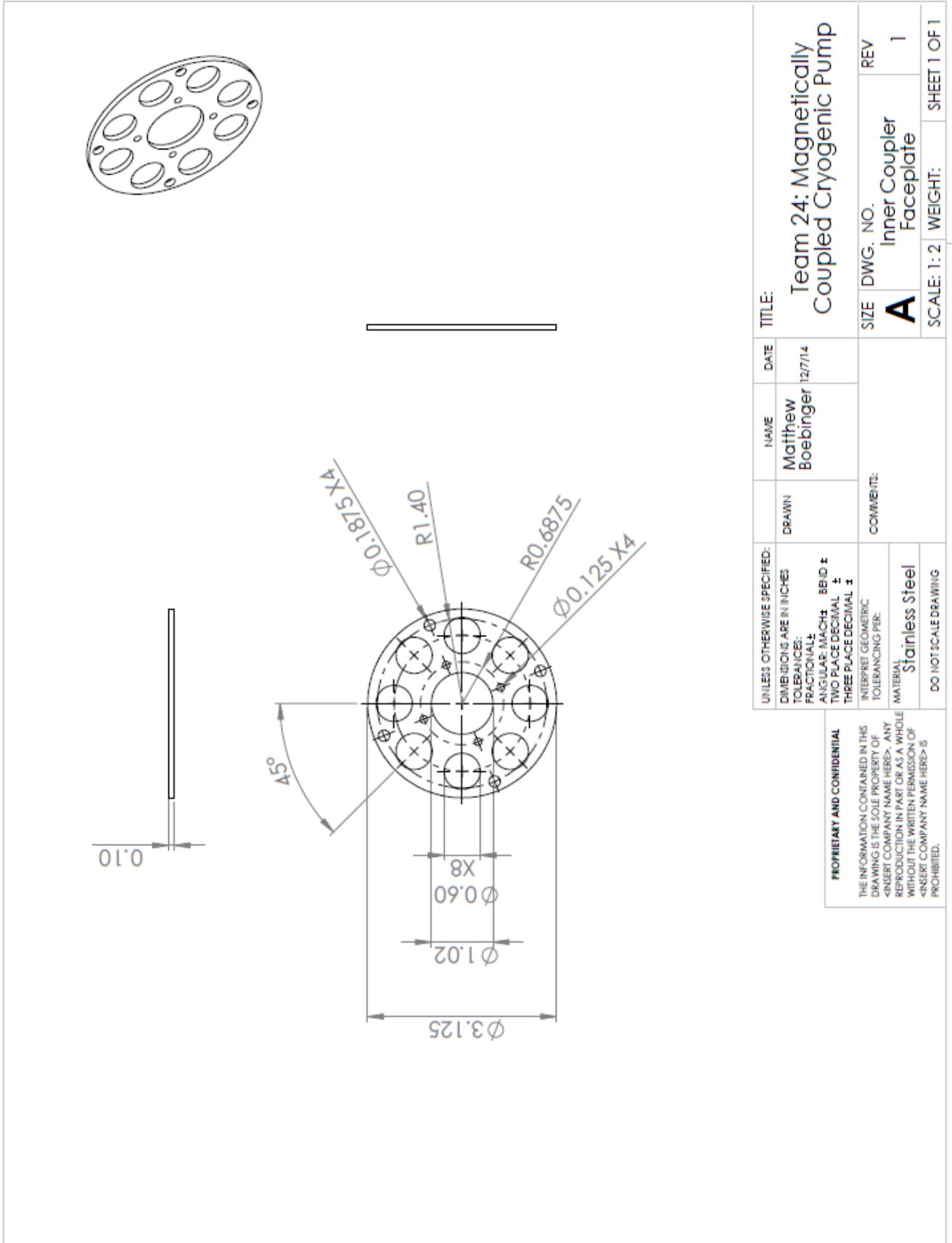
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UNLESS OTHERWISE SPECIFIED:	NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES	Matthew Boebinger	12/7/14	Team 24: Magnetically Coupled Cryogenic Pump
TOLERANCES:			
FRACTIONAL: ±			SIZE DWG. NO.
ANGULAR: MACH: BEND ±			<b>A</b> Outer Magnet Coupler
TWO PLACE DECIMAL ±			REV
THREE PLACE DECIMAL ±			2
INTERPRET GEOMETRIC TOLERANCING PER:			SCALE: 1:2 WEIGHT: SHEET 1 OF 1
MATERIAL			
Stainless Steel			
DO NOT SCALE DRAWING			

Magnetically Coupled Pump System for Cryogenic Tank Destratification

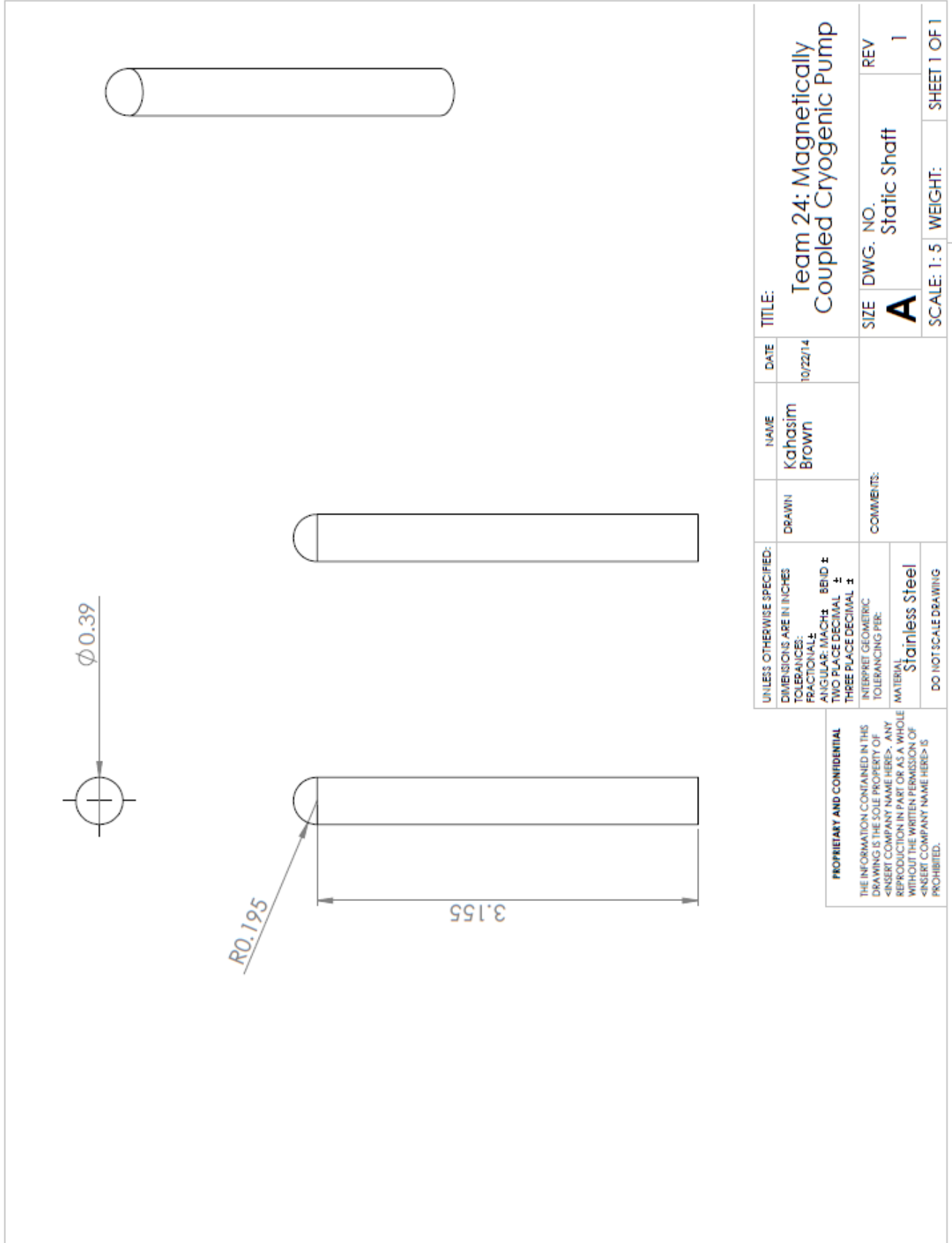


Magnetically Coupled Pump System for Cryogenic Tank Destratification

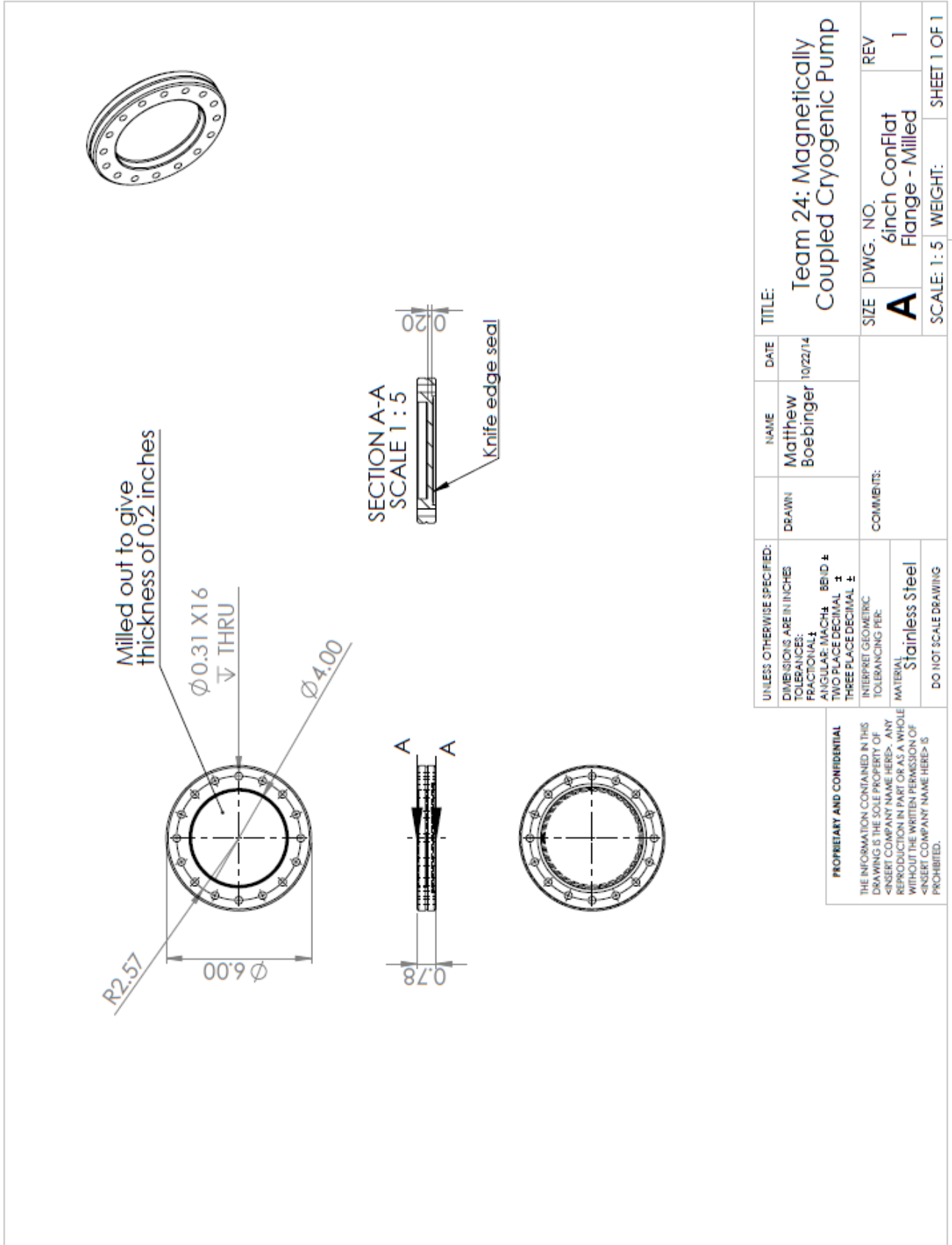




# Magnetically Coupled Pump System for Cryogenic Tank Destratification



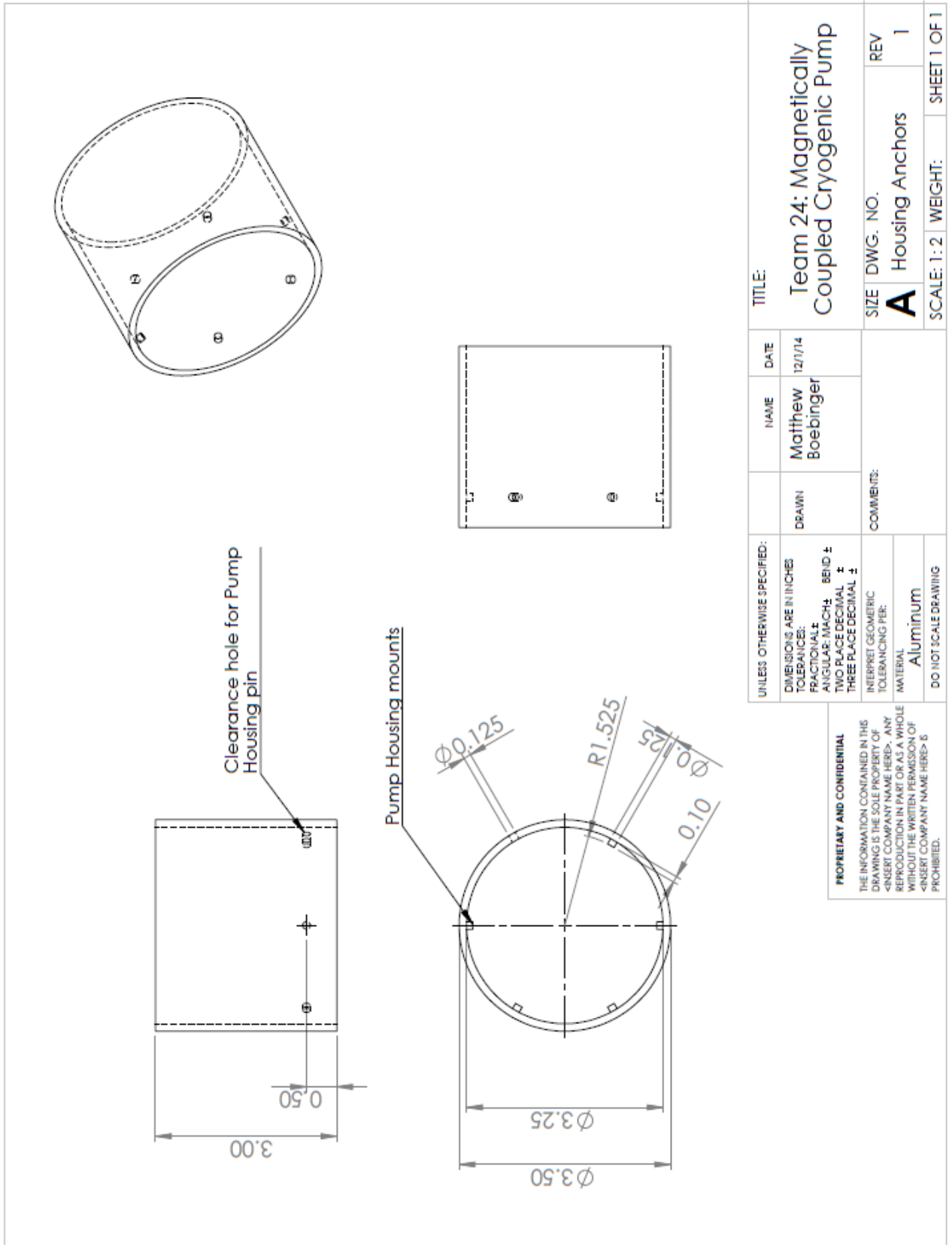
Magnetically Coupled Pump System for Cryogenic Tank Destratification



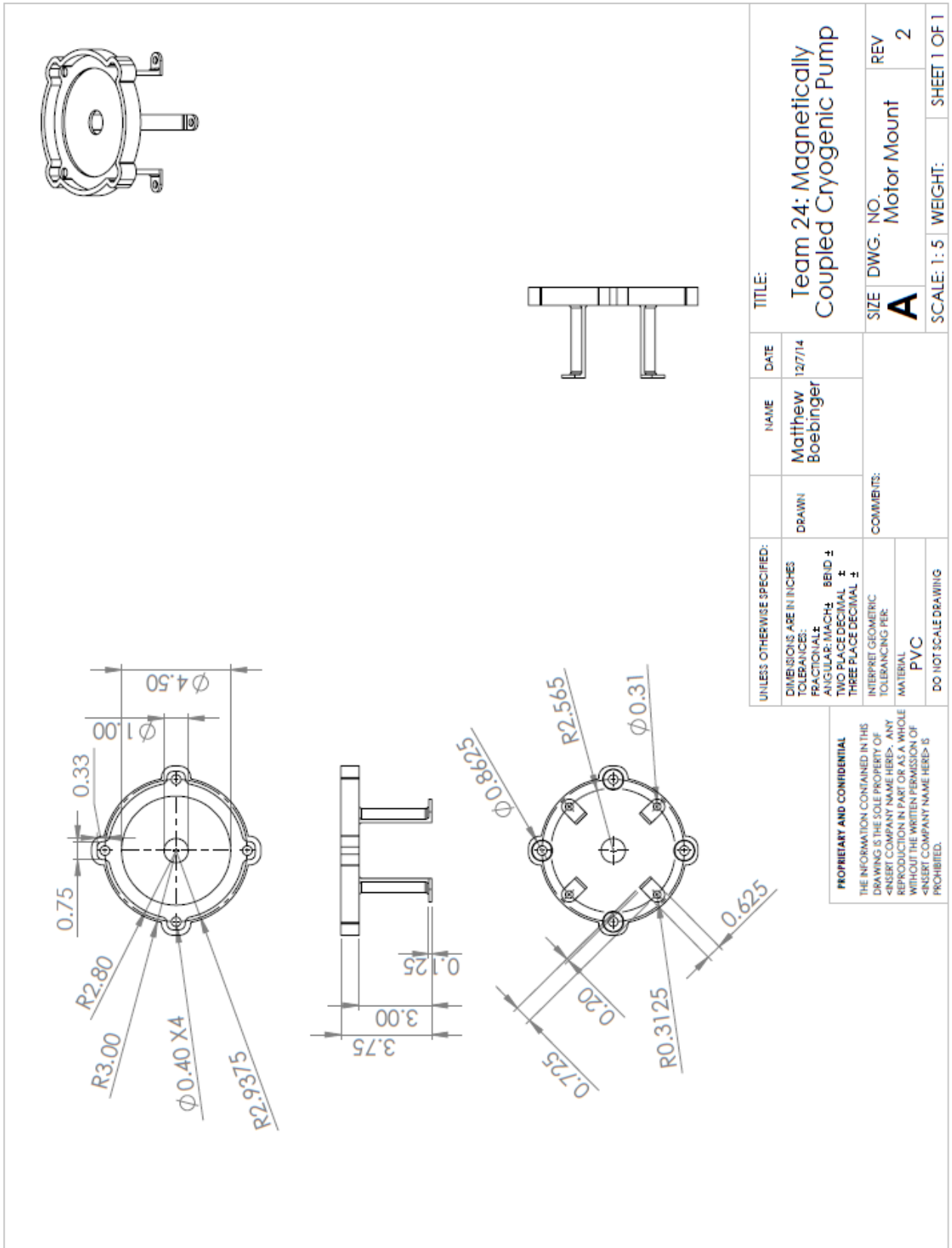
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INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL Stainless Steel	COMMENTS:			SIZE DWG. NO. <b>A</b> 6inch ConFlat Flange - Milled
DO NOT SCALE DRAWING				REV 1
				SCALE: 1:5 WEIGHT: SHEET 1 OF 1

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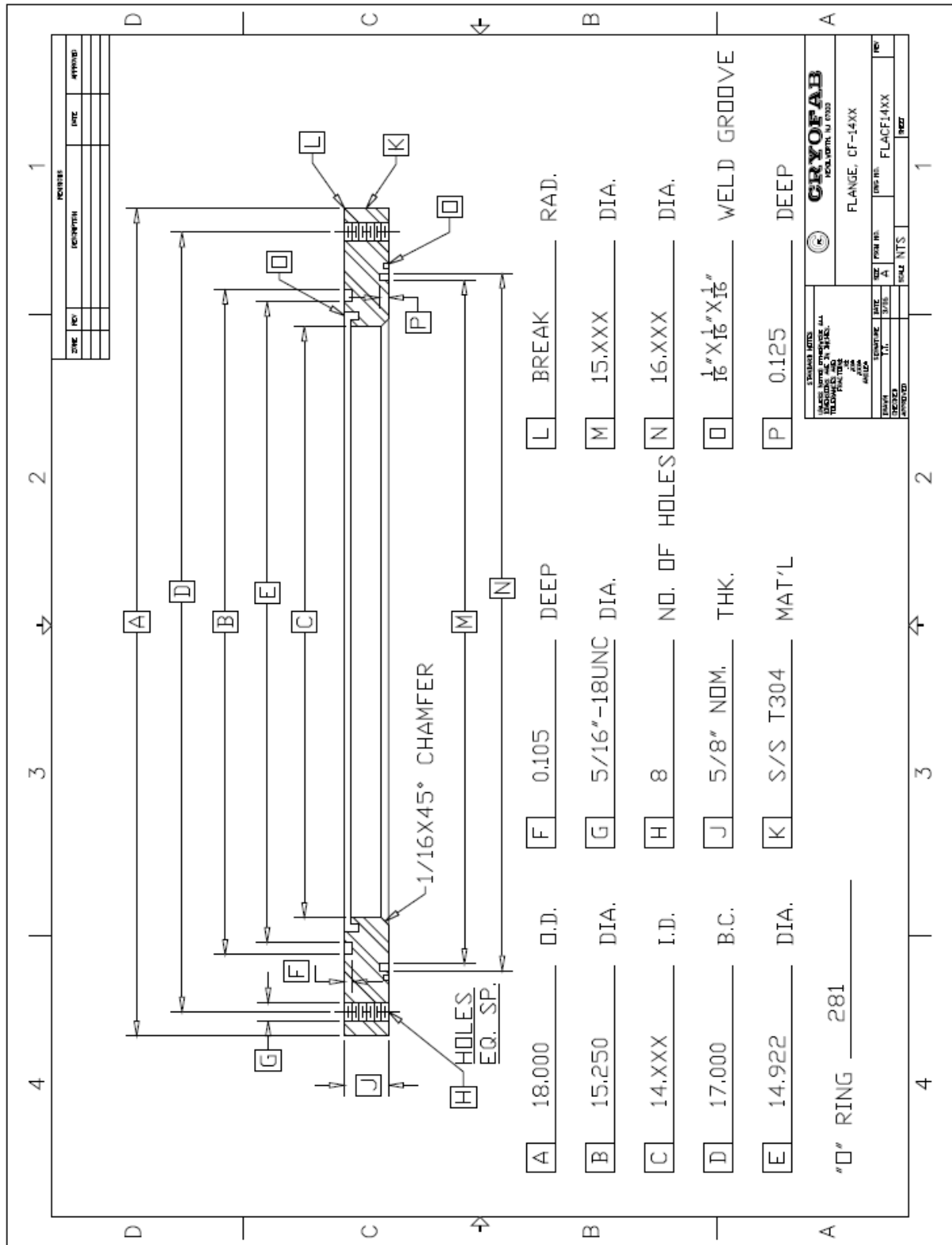
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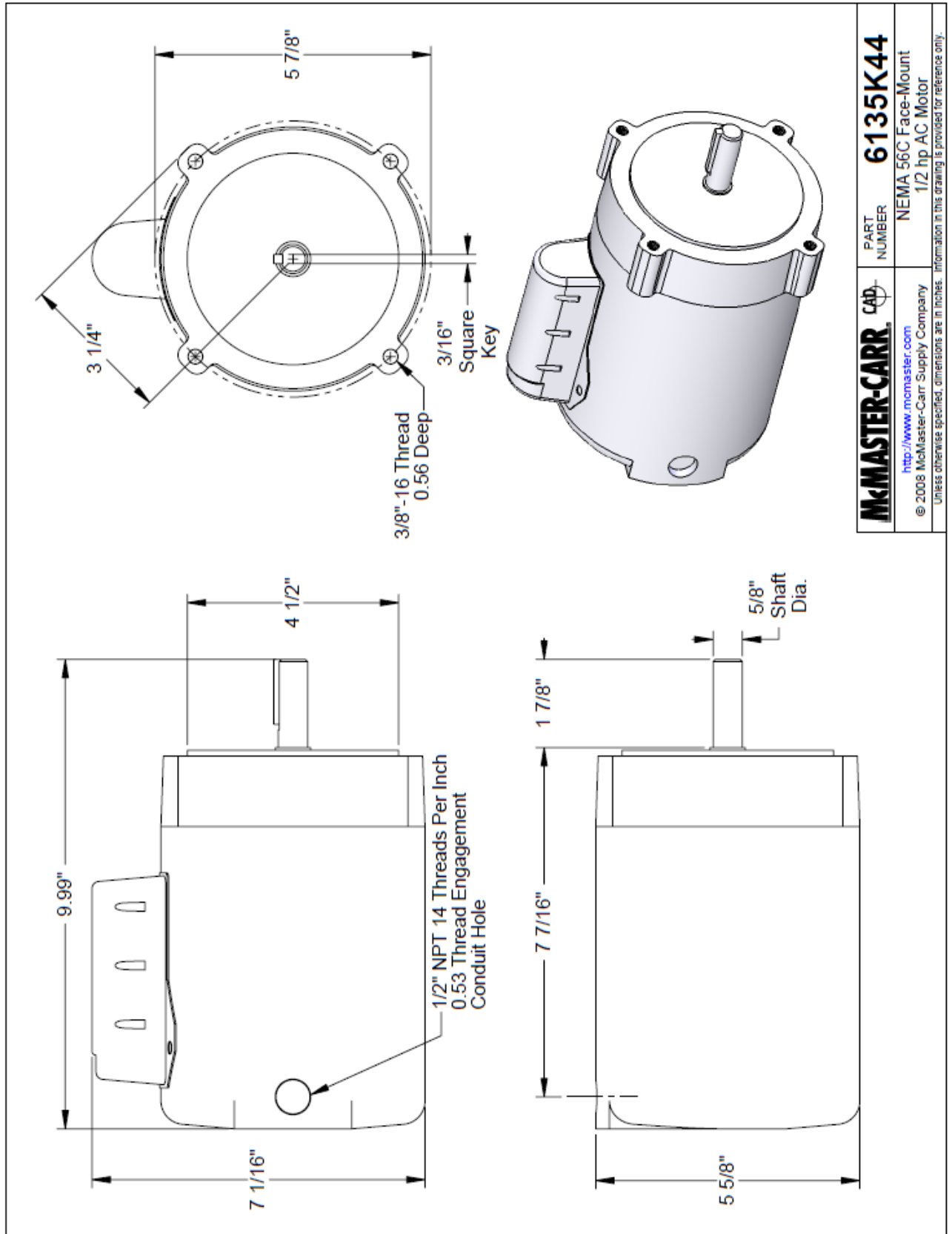
Magnetically Coupled Pump System for Cryogenic Tank Destratification



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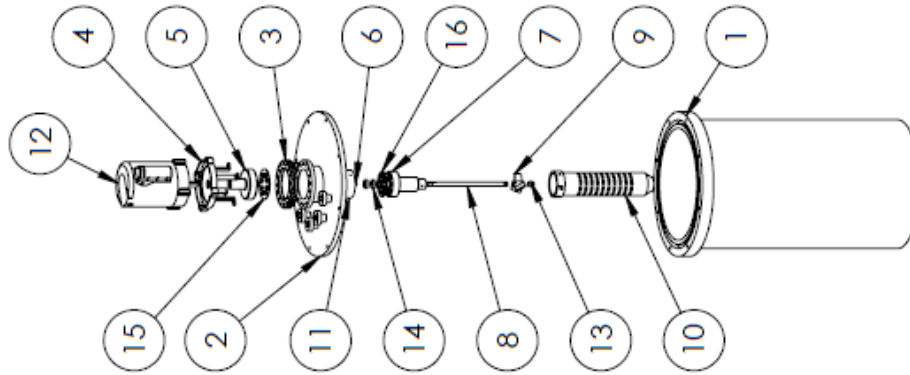


Magnetically Coupled Pump System for Cryogenic Tank Destratification



# Magnetically Coupled Pump System for Cryogenic Tank Destratification

ITEM NO.	PART NUMBER	QTY.
1	CF-1424 Cryostat	1
2	Cryostat Lid	1
3	6inch ConFlat Flange - Milled	1
4	Sample Motor Mount	1
5	Outer Magnet Coupler	1
6	Static Shaft	1
7	Inner Magnet Coupler	1
8	Axial Pump Shaft	1
9	Sample Propeller	1
10	Pump Housing	1
11	Housing Anchors	1
12	Motor	1
13	Shaft Cap	1
14	Bearings	2
15	Outer Magnet Coupler Faceplate	1
16	Inner Magnet Coupler Faceplate	1



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		Matthew Boebinger	12/7/14	Team 24: Magnetically Coupled Cryogenic Pump
COMMENTS:				SIZE
				DWG. NO.
				System Design Assembly
				REV
				1
DO NOT SCALE DRAWING				SCALE: 1: 20 WEIGHT:
				SHEET 1 OF 1

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## Appendix D

Part #	Component	Product Description	Quantity	Vendor	List Price	Status
1	Motor Mount	12"x 12" x 3/4" Sheet of PVC	1	Amazon	\$29.86	Not Purchased
2	Motor	Face Mount AC Motor	1	McMASTER-CARR	\$233.68	Not Purchased
3	Bearings	Stainless Steel Roller Bearings	2	National Precision Bearings	\$0.00	Ordered
4	Couplers	4" Diameter Stainless Steel Rod	1	Metals Depot	\$267.06	Not Purchased
5	Coupler Face Plate	Coupler Face Plate/Bearing Holder	2	Metals Depot		
6	Static shaft	10 mm Stainless Steel Shaft	1	Metals Depot	\$12.02	Not Purchased
7	Pump Shaft	.5" Aluminum Shaft	1	Metals Depot	\$2.76	Not Purchased
8	Pump Housing Anchor	1'x1' x .12" Stainless Steel Sheet	1	Metals Depot	\$30.24	Not Purchased
9	Pump Housing	Aluminum Sheet 1'x4'x.100"	1	Metals Depot	\$52.20	Not Purchased
10	Magnets	Neodymium Cylinder Magnets	16	K&J Magnets	\$8.61	Not Purchased
11	Power Cord	8' Power Supply Cord	1	Grainger	\$9.85	Not Purchased
12	Power Switch	10 Amp on of Switch	1	Radio Shack	\$3.99	Not Purchased
13	Electrical Enclosure	6"x3"x2" Project Box	1	Radio Shack	\$4.99	Not Purchased
14	Cryostat	Cryofab CF-1424F	1	NASA	\$0.00	Received
15	Flange	6" Conflat Flange	2	NASA	\$0.00	Received
16	Gaskets	Copper Gaskets	4	NASA	\$0.00	Received