

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

FAMU/FSU College of Engineering  
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## Midterm I Report

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## Abstract

As an updated version of the Project Plan and Product Specification report, this report is a continuation of the magnetically coupled cryogenic pump system. The distinct sections have been improved by visual aids and a new section titled design and analysis captures a progression in the development of the project. The new design and analysis section encompasses information used to determine the components within the system. By evaluation methods from engineering principles (mechanical, electrical, and industrial), the final design selection, component selection, material selection, and much more was determined. The evaluation methods include computational analysis, a decision matrix including advantage and disadvantage comparisons, and CAD drawings.

In addition to the design and analysis portion of the report, the project definition and methodology encompasses past information with a block diagram of the system. An evaluation method, such as the work breakdown structure, is utilized in the methodology section. The appendix has been expanded to include computation analysis and computer aided drawings. Furthermore, our future involvement in the project includes deeper computational analysis, motor and magnet selection, material selection, and fabrication and testing.

# 1 Introduction

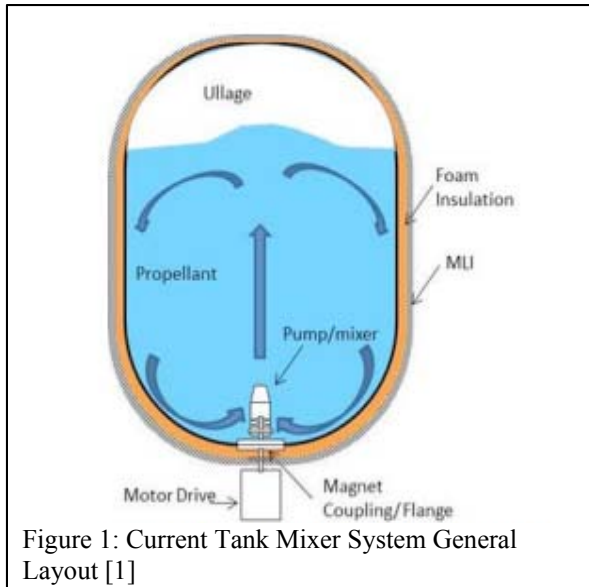
NASA Marshall Space Flight Center has proposed a project to mix cryogenic fluids by way of magnetic coupling to successfully aid in the destratification of propellants. The magnetic coupling will remove the motor from the cryogenic system, thus reducing the heat addition to the system. The entire design must fit inside a four inch port that will be attached using a six inch flange. The system will only have to be operated on the top of the tank, which simplifies some of the design process.

Three designs have been proposed to magnetically couple the motor shaft to the pump shaft in order to reduce the heat addition to the cryogenic system. Although all of the proposed designs will reduce the heat addition in the system, some important parameters will way in our design selection. These parameters include ease of assembly, strength of magnetic coupling, and cost of overall design. All of the proposed designs will be put in a decision matrix and the design with the best overall score will be selected. Another important aspect of the design will be choosing an appropriate pump. Currently a tesla pump, an axial propeller, and centrifugal pump are being considered. These pumps will also be put into a decision matrix and the design with the best overall score will be selected. All aspects of the design will be discussed in great detail in the remainder of this report.

## 2 Project Definition

### 2.1 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. 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.



Currently and previously, 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 (Figure 1). By using this method, heat will be generated within the tank causing the pressure to rise rapidly and, the feedthroughs or connectors will create leak paths for potential failure. Research and develop of motors suitable to handle low temperature conditions is highly expensive.

To decrease heat leak, high performance insulation systems are incorporated into the design of the tank, even with perfect vacuum,<sup>2</sup> 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 (Figure 2) 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. 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



Figure 2: Layers of insulation currently in place on cryogenic tank

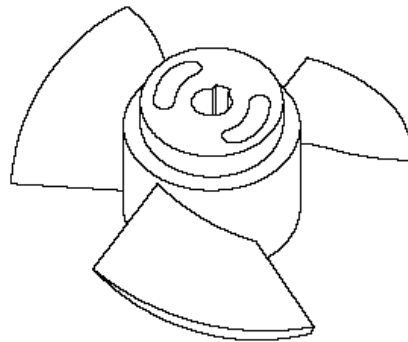
contamination.<sup>3</sup> The magnetic coupling is used in this project to transmit rotational motion from the motor across the tank wall to a mixer/pump located on the inside. The mixer/pump would be designed to operate in the cryogen receiving the magnetic rotational motion and imparting it to the fluid through impellers/etc. contained within a housing to produce flow up to 15gpm and pressure rise up to 5psid.

Even though there are different types of pumps that can be used for this application, three are being considered; a tesla pump, a centrifugal pump with a three tooth inducer, and an axial pump.<sup>4</sup> Created by Nikola Tesla, the tesla pump uses a series of disks that can vary based on certain factors. Each disk is made with opening surrounding the shaft that acts as ports through which the fluid will exit and to make sure the fluid is passing freely, metal washers are used as dividers. The tesla pump is an ideal option for this type of application due to its simplicity and it can be built with readily available materials.



**Figure 3: Three tooth inducer with diameter of 2.5in provided by the sponsor**

<sup>5</sup>Inducers are used when low suction pressure is expected. Inducer blades are tapered, with a thicker blade width at the root to provide strength and can be seen in Figure 3. It also provides a stable Net Positive Suction Head (NPSH) over a wide flow range. An inducer works as the impeller for a centrifugal pump, the second pump being considered for this project.<sup>6</sup> A centrifugal pump converts input power to kinetic energy by accelerating liquid in a revolving device such as an impeller. Fluid enters the pump through the eye of the impeller and radially, the fluid accelerates outward from the pump creating a vacuum at the impellers eye which will continuously draw more fluid into the pump.



**Figure 4: Axial pump impeller**

The axial flow pumps utilize fluid momentum and velocity to generate pump pressure<sup>7</sup>. Axial pumps are one of the three subtypes of centrifugal pumps and are characterized by the highest flow rates and lowest discharge pressures. The impeller of the axial pump operates similar to that of a boat propeller and can be seen in Figure 4. These pumps provide high flow rate and can be adjusted to run efficiently depending on its use.

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 and incorporating insulation between the coupling and tank wall so as not to introduce additional heat leak.

## 2.2 Need Statement

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”**

## 2.3 Goal Statement & Objectives

**“Design a better way of mixing cryogenic fluids”**

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
- Contain a minimum number of parts and be compact in arrangement

## 2.4 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.



## 2.4.1 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.

## 2.4.2 Performance specifications

The design should be compact and easily installed into an existing cryogenic tank. It should also not introduce any additional heat into the cryogenic system. The cryogenic tank will be vacuum-sealed and there must be minimal heat leak from the environment. The cryogenic propellants will be stored at a low pressure of 15 to 25 psia. In order to prevent the pressure from rising, the mixer must make the temperature homogenous to prevent the cryogen from boiling. The heat will also be limited through the use of 0.5 in of insulation foam and 20-30 layers of MLI (Multi-Layer Insulation) where necessary. The pump will have a variable volumetric flow rate of no less than 3gpm and up to 15 gpm in order to satisfy the requirements. The mixer should also facilitate a pressure rise of up to 5 psid in the cryogenic fluid. Additionally, the device will be able to successfully perform destratification of the cryogenic fluids with ease. The motor-pump unit must make use of magnetic coupling technology and an electronic motor. The unit must be tested with water and liquid nitrogen.

### 3 Design and Analysis:

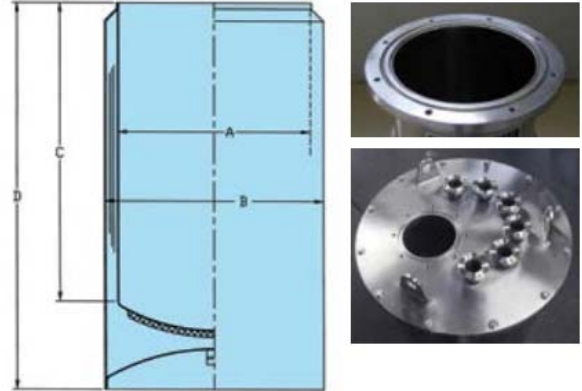
In the following section, proposed designs components are discussed, computational analysis is conducted in order to select components of the design, and a final design is selected.

#### 3.1 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.

##### 3.1.1 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 1 and referenced in Figure 5. The cryostat is also seen identified as item 1 in Figure 7.



**Figure 5: Cryostat Dimension Figure Guide provided by the sponsor**

**Table 1: 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
CF 1424	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 in Figure 6 and as item 2 in Figure 7. 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 in the opposite side of the gasket as the flange-pair is tightened thus



**Figure 6: Picture of Flanges used provided by the sponsor**

yielding a leak-tight seal. However, there has been a more inexpensive and just as effective cryogenic seal proposed. Using indium wire can be 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.

The cryostat top, as seen in Figure 7 and is labeled as item 3, has a 4 inch port that leads into the tank; therefore, the section of the system that is inserted inside the tank must not exceed 4 inches in diameter.

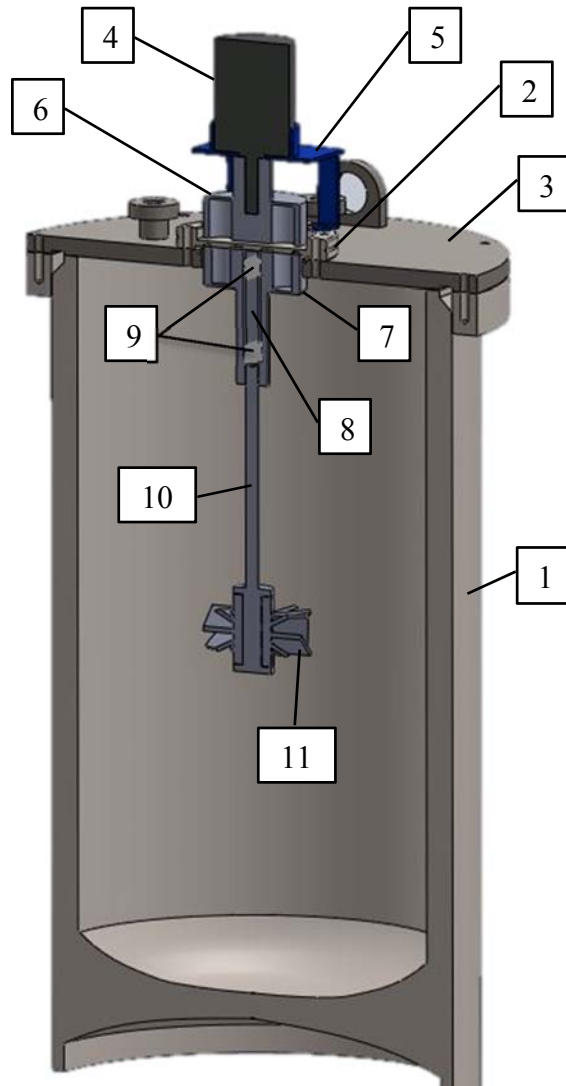
Item 4 in Figure 7 is the sample motor. This part in the design is a placeholder, and will be replaced once a motor has been selected.

The blue item in the Figure 7 (item 5) is the motor mount that has been designed by the group. The mount will be made of a material with a very low thermal conductivity so heat is not transferred conductively through the mount into the flange itself.

Item 6 in Figure 7 is the outer magnet coupler. This coupler will be physically attached to the motor shaft. The coupler hold 8 magnets in the spaces shown in the cross section.

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 7. 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 roller bearings (item 9), as well as aligns the pump to ensure that it remains level.



**Figure 7: Design proposed by the group utilizing an axial pump. (1) Tank, (2) Flange, (3) Top of Cryostat, (4) Sample Motor, (5) Top of Cryostat, (6) Outer Magnet Coupler, (7) Inner Magnet Coupler, (8) Static Shaft, (9) Roller Bearings, (10) 12” Pump Shaft, (11) Pump Propeller**

Item 10 in Figure 7 is the 12” pump shaft that holds the axial pump propeller (item 11) and guarantees that the propeller is located in the middle of the tank. The propeller blades are only 3.9” in diameter to ensure that the propeller fits into the pump.

### 3.1.2 Electrical specifications

The only electrical components in this design project are the motor which will be powered by a battery, thus satisfying the portable component required by the design constraints. The type of motor is unknown at this point, and will be selected according to the required torque that will be calculated using the formulas in the following section. A battery that can provide the required power necessary to run this motor will then be purchased.

### 3.1.3 Computational Analysis

This report 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 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, and 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 mad in order to further increase the success of the design.

NASA has specified a desired flow rate and pressure rise that they believe will successfully destratify the cryogenic fluids. The power necessary to produce these variables can be calculated using Equation 1.

$$P = \Delta p \cdot \dot{V} \quad (1)$$

Where  $\Delta p$  is the required amount of pressure rise in the system and  $\dot{V}$  is the specified volumetric flow rate. Using Equation 1 the power required to produce the necessary flow rate and pressure rise was found to be 32.62 W. This power represents the power that must be supplied from the motor to control the pump. A motor can now be selected using the calculated value for power. Once the required power is found the angular velocity of the pumps propeller must be found. In order to find the angular velocity of the pump the mean velocity of the fluid must be calculated using Equation 2.

$$\bar{V} = \frac{\dot{V}}{A} \quad (2)$$

In Equation 2, A is the cross-sectional area of the cryostat. Once the mean velocity is calculated, integration can be performed to relate the angular velocity of the propeller to the mean velocity of the fluid using Equation 3.

$$\bar{V} = \frac{1}{R} \int_0^R \omega \cdot x \cdot \sin \theta \cos \theta dx \quad (3)$$

In the above equation,  $\omega$  is the angular velocity of the propeller, x is

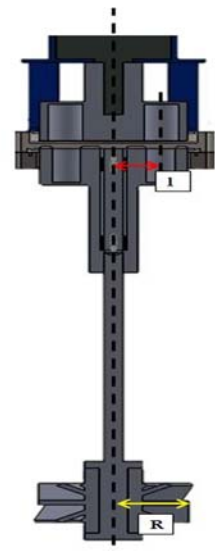


Figure 8: Cross-section of pump design

the horizontal distance from the center of the pump shaft,  $R$  is the radius of the pump, and  $\theta$  is the angle of the propeller with respect to the horizontal axis. Integrating Equation 3 and substituting Equation 2 leads to the angular velocity (Equation 4).

$$\omega = \frac{4\dot{V}}{A \cdot \sin^2 \theta \cdot R} \quad (4)$$

The required angular velocity of the propeller was calculated to be 0.433 1/s using Equation 4. The next step in the computational analysis process is to find the tangential force necessary to produce the calculated power. The tangential force is found using Equation 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 8. From Equation 5 the tangential force was found to be 2373 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 B-1 in Appendix B,  $B_0$  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 B-2, a maximum tangential force will be achieved before the magnet begins to slip shown in Figure 9. This force  $F_{mag}^*$  must be greater than the force calculated in Equation 5 to ensure the magnetic couple is 1-1 and no slip occurs. This  $F_{mag}^*$  will be calculated using the equations in “Magnetostatic interactions and forces between cylindrical permanent magnets”<sup>7</sup> provided by the team’s faculty advisor Dr. Guo. All the calculations for this report project are shown in Appendix B.

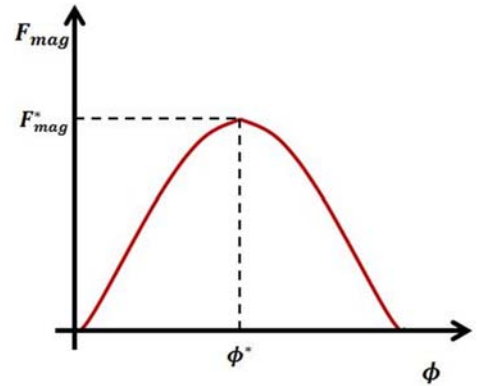
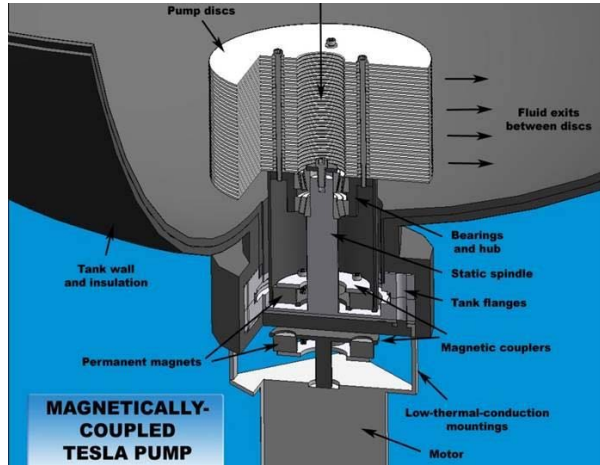


Figure 9: Graph of Force vs. angle  $\phi$

### 3.2 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 10. The design makes use of a Tesla pump with a pancake magnetic coupler.



**Figure 10: Design for magnetically couple Tesla pump provided by the sponsor**

The proposed design can be seen in Figure 11, 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.



**Figure 11: Design proposed by the group utilizing an axial pump.**

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.

### 3.3 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 question 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 that axial pump, the design will only use the propeller connected to the static shaft. 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.

In Table 2 a decision matrix was made to decide to use a tesla pump, a centrifugal pump, 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 3-15 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.

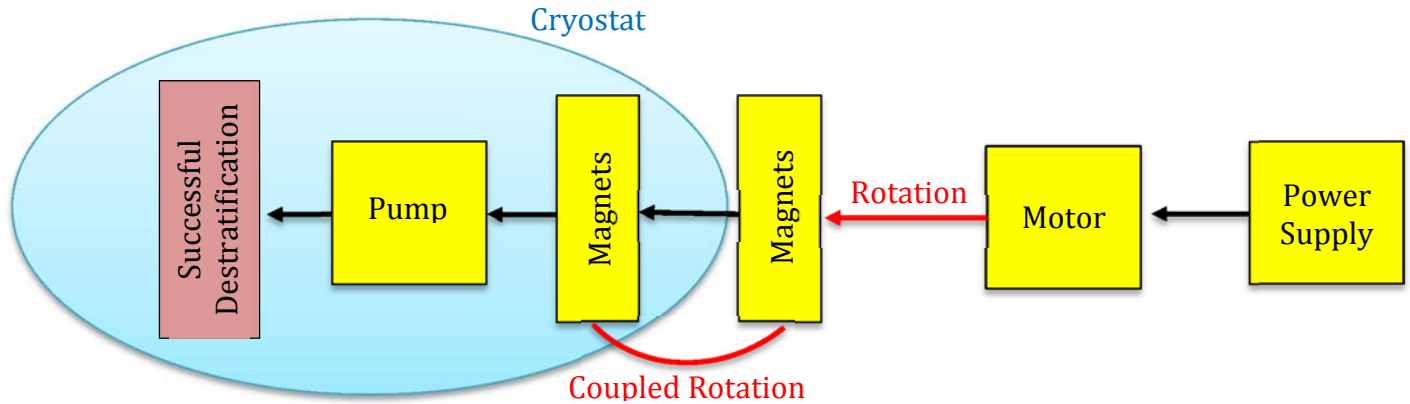
The team decided the ratings for each pump criteria and the axial pump is the optimum choice. Since decision matrices are used to choose the most efficient selection for a project, it is still up to the team to pick the best for the requirements of the system. The team decided to continue with the axial pump design for the project.

**Table 2: 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

## 4 Overall plan/Methodology/Approach

A block diagram of the magnetically coupled pump system can be seen in Figure 12. This diagram is a simple schematic of how the system will operate. The power supply powers the motor which cause the set of magnets outside the tank to rotate. This rotation causes the coupled magnets on the inside of the tank to rotate which will drive the pump resulting in successful destratification of the cryogen.



**Figure 12: Block Diagram of pump/mixer system**

The best methods to construct the magnetic coupled mixer/pump system require iterations, mathematical analysis, and much more for optimal design. These iterations consist of preparatory design methods to finalize the design selected. These preparatory design methods are taken from several fields of study in the engineering field. These actions emphasize the overall direction of constructing the magnetic couple mixer/pump system:

- Formulate a reasonable size of the system through theoretical estimation
- Determine the best cryogenic material and thermal fluid system design by researching the specific fields in engineering
- Choose a multi-layered insulation suitable for cryogenics
- Broaden research to obtain a suitable motor and impellor to create an appreciable fluid flow rate
- Establish a financial plan and spend based on the budget
- Utilize engineering computer software such as CAD Drawing
- Create Gantt charts, blueprints, virtual systems or theoretical calculations sheets. These theoretical calculations were derived from magnet lab testing.
- Search the market for useful materials/products with great quality and price.
- Present the details of the project to evaluators, sponsors, and the general public
- Finalize the decision and construct the project satisfying the objectives

Based on these actions, the system will be a successful sponsored project with the capabilities of being introduced to the market.



## 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, and fabricating materials. Additionally, NASA will provide materials, a cryostat, ConFlat flanges, some fabrications, and possibly a motor. A breakdown of estimated percentages each component will require from the budget is provided in Table 2. Later in the project, once computational analysis has been completed, materials will be selected and a formal budget will be constructed.

These costs are based on some rough estimates found researching the Internet. Additionally these percentages are subject to change based on how much aid is provided from NASA. The group will do its best to keep the cost of the project as minimal as possible while still providing a quality product.

<b>Item</b>	<b>Percentage of Budget</b>
<b>Fabrication</b>	45%
<b>Magnets</b>	15%
<b>Sealing</b>	20
<b>Motor</b>	20%
<b>Total</b>	100%

## 4.1 Schedule

### Gantt Chart

Appendix A-1 shows the Gantt chart for this design project although it is important to stay on schedule the chart does provide some leniency. The leniency is to account for unexpected issues with the project plan and ensures we will not be delayed in the design of the project.

### 4.1.1 Work Breakdown Structure

#### Project Planning

##### Background Research

The background research is an integral part of this and any design project. In order for all group members to have a good understanding of the scope of the design project everyone will participate in the research stage. Basic understanding of cryogenics, thermal fluids, and magnetic coupling is required to make this design project successful.

#### Design Stage

##### Design Concept Generation

Once all group members have done their part in researching the required fields a design concept will be generated. This stage of the project is sometimes called the brainstorming stage. All members of the group will input their knowledge to the design and help to come up with a viable concept.

## CAD Drawings

CAD drawings will begin after the design concept generation process. The CAD drawings require specific dimensions of the design concept and solidify the original design. It will introduce a 3D diagram of the concept and make it a more tangible design.

## Computational Analysis

At the same time the CAD drawings are being done the majority of the computational analysis will be done. The computational analysis is important because it will allow for material, motor, and pump selection. Additionally it will provide limits on the geometry of the design making changes where needed. The computational analysis will be broken into several sections, the motor calculations dealing with the determination of the power needed to run the system and what motor will be needed to provide this power. The next section deals with the calculation to determine what types of magnets will be needed to provide sufficient coupling. Another section will deal with the calculation of what bearing will be needed to support the whole system.

## CAD Analysis/Working Model

Once the CAD drawings and computational analysis have been completed the governing equations, materials, pump, and motor selection will be applied to the CAD drawings. CAD analysis will provide detailed breakdown of how the system operates as well as point out areas of concern.

## Part Selection/Procurement

### Motor Selection

Once the Computational Analysis is completed a motor will be selected that can sufficiently power the system.

### Material Selection

Once the Computational Analysis is completed materials for the couplers and flange will be selected that will allow the maximum magnetic coupling

### Parts Order

Parts will be ordered once the CAD analysis is completed and all issues are resolved. The order form will be turned in no later than November 23 2014 in order to be compliant with NASA regulations.

## Fabrication

Fabrication and assembly will begin as soon as the necessary parts arrive. This process will begin next semester and will include prototyping and testing the system.

## 4.2 Assign resources

Table 4 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>Table 4: Resource Allocations Table</b>		
<b>Task</b>	<b>Owner/Owners</b>	<b>Time</b>
Research	All	19 days
Design Concept Generation	All	10 days
Choosing final design	All	1 day
CAD Drawings	Matthew Boebinger & Kahasim Brown	7 days
Computational Analysis	Anthony Ciciarelli & Janet Massengale	11 days
Initial Web Page design	Janet Massengale	1 day
CAD Analysis/Working Model	Anthony Ciciarelli & Janet Massengale	7 days
Motor Selection	All	5 days
Material Selection	All	5 days
Pump Selection	All	5 days
Order Parts	Matthew Boebinger	4 days
Fabricate Coupling Shaft	All	10 days
Final Web Page design	Janet Massengale	1 day

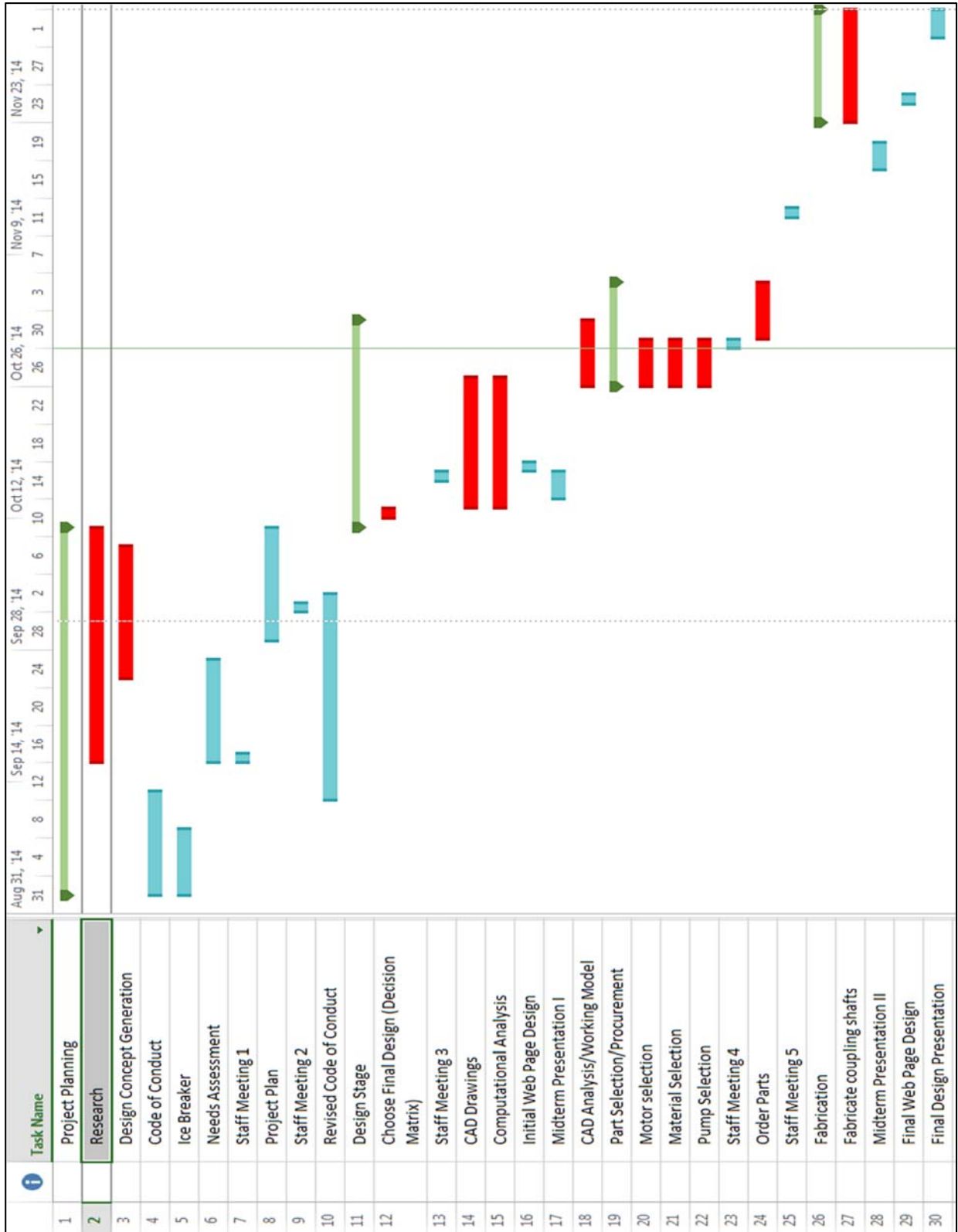
## 5 Conclusion

There are many constraints when dealing with cryogenics, such as eliminating heat addition which can cause pressure rise, as well as positioning of the system onto the top flange of the tank. Three design concepts were created by the team followed by a decision matrix to calculate the best design for the project. According to the decision matrix, the best design choice is the system with the axial pump. Although the team does not have to choose the design that the decision matrix deems fit, it was decided to continue with the axial pump. Since the CAD drawings have been completed, further computational analysis must be done for in order to make sure the system will work. Tasks will still be allocated to group members to continue to make the group's dynamics more efficient. Following computational analysis, the team can order parts and start fabrications for testing the device to produce the required flow rate and pressure rise.

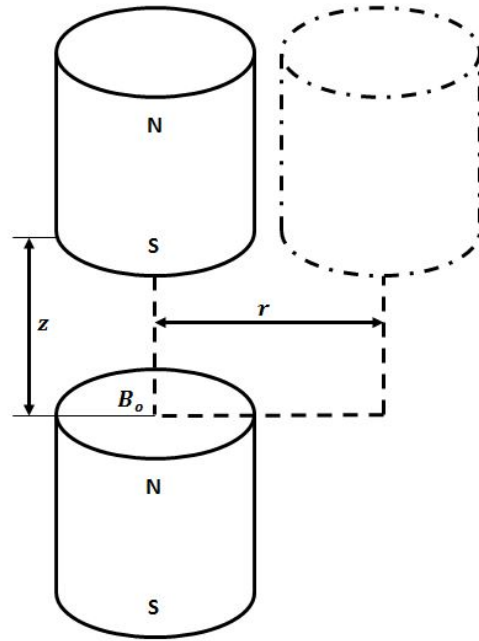
## 6 References

- [1] Senior Design Project Definition Group 24. N.p.: n.p., n.d. 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.
- [4] "HowStuffWorks "Parts of the Tesla Turbine"" *HowStuffWorks*. N.p., n.d. Web. 09 Oct. 2014.
- [5] "Axial Flow Pumps Information." *On GlobalSpec*. N.p., n.d. Web. 25 Oct. 2014.
- [6] Pump, Nikkiso Cryogenic. *NIKKISO CRYOGENIC PUMP* (n.d.): n. pag. Web.
- [7] Vokoun, David, Marco Beleggia, Luděk Heller, and Petr Šittner. "Magnetostatic Interactions and Forces between Cylindrical Permanent Magnets." *Journal of Magnetism and Magnetic Materials* 321.22 (2009): 3758-763. Web.

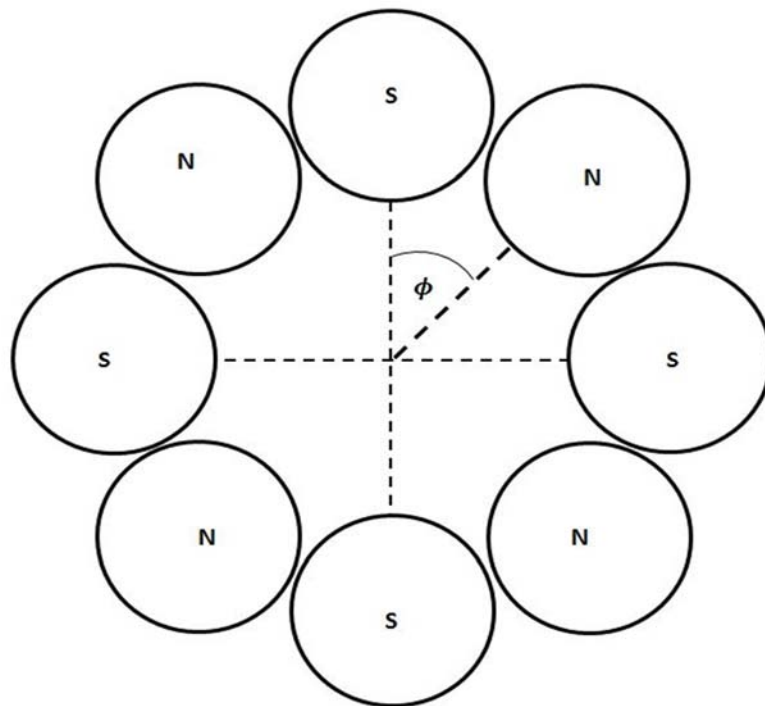
# Appendix-A



## Appendix-B



**Figure B-1** Magnetic coupling geometry (side view)



**Figure B-2** Magnetic housing geometry (top view)

$$\Delta p := 5.6895 \cdot \text{Pa}$$

$$\theta := 45 \cdot \text{deg}$$

$$V_{\text{dot}} := 15 \cdot \text{gpm}$$

$$R := 3.5 \cdot \text{in}$$

$$l := 1.25 \cdot \text{in}$$

$$d := 13.93 \text{in}$$

$$A := \pi \frac{d^2}{4} = 0.098 \text{m}^2$$

$$P := (\Delta p \cdot V_{\text{dot}}) = 32.626 \text{W}$$

$$V_{\text{avg}} := \frac{V_{\text{dot}}}{A} = 9.625 \times 10^{-3} \frac{\text{m}}{\text{s}}$$

$$V := \int_0^R \omega \cdot x \cdot \sin(\theta) \cos(\theta) dx$$

$$V := \frac{\sin(2\theta)}{2R} \cdot \frac{\omega \cdot R^2}{2}$$

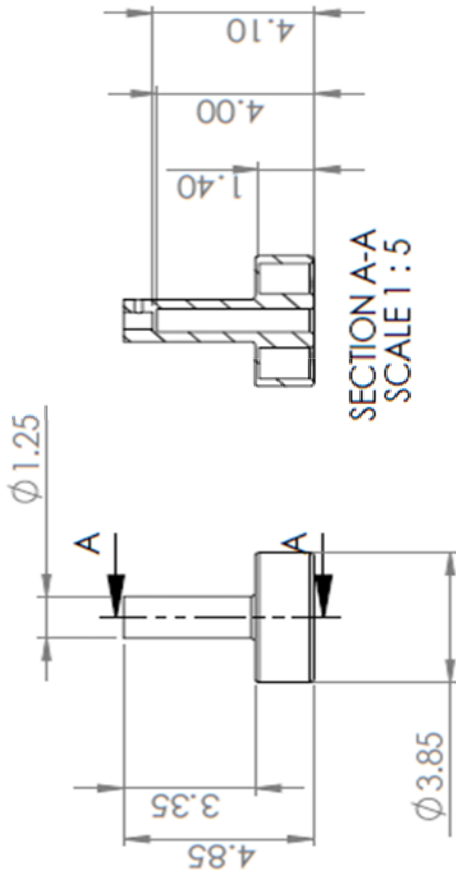
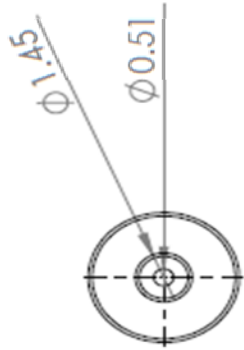
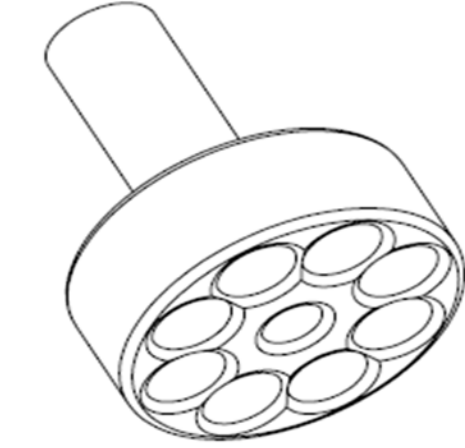
$$\omega := 4 \frac{V_{\text{dot}}}{A \cdot \sin(2 \cdot \theta) \cdot R} = 0.433 \frac{1}{\text{s}}$$

$$F := \frac{P}{\omega \cdot l} = 2.373 \times 10^3 \text{N}$$

+



# Appendix-C



SECTION A-A  
SCALE 1 : 5

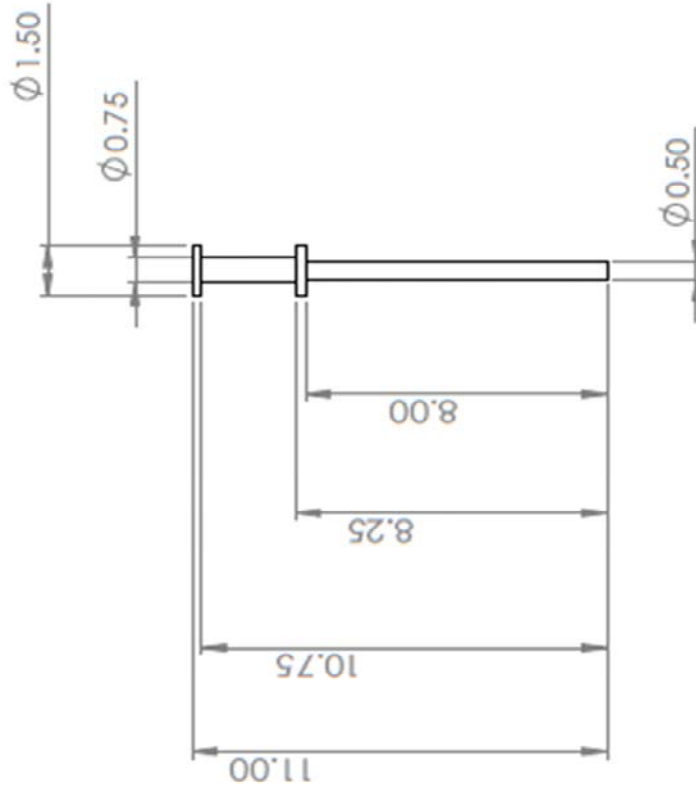
$\phi 0.90 \times 8$   
Magnet Holes



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ANGULAR: MACH: 8B/D ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ± INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL Stainless Steel DO NOT SCALE DRAWING	DRAWN	NAME Kahasim Brown	DATE 10/22/14	TITLE Team 24: Magnetically Coupled Cryogenic Pump	SIZE A	DWG. NO. Inner Coupler	REV 1
COMMENTS:				SCALE: 1: 5 WEIGHT: SHEET 1 OF 1			

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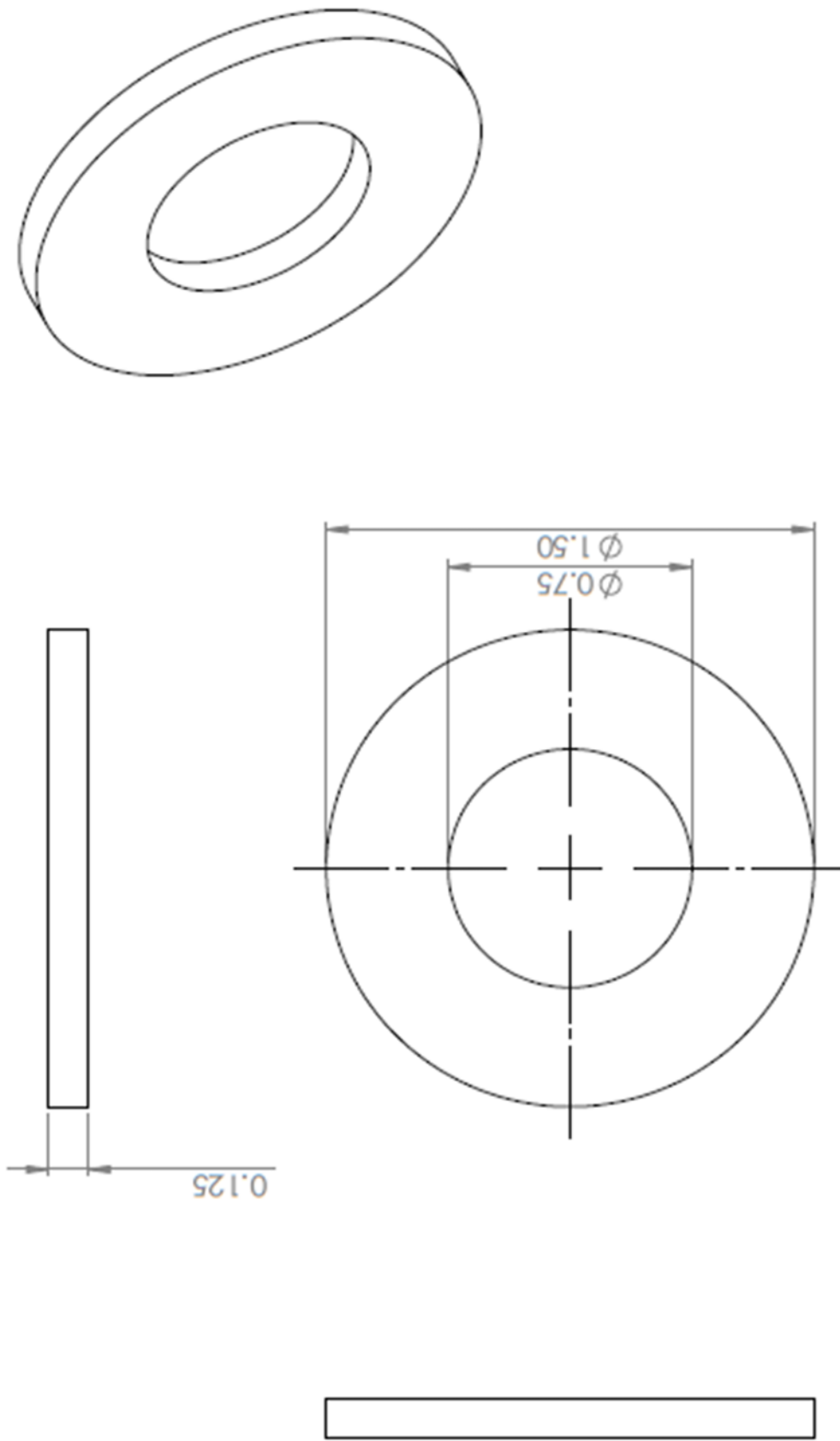
Magnetically Coupled Pump System for Cryogenic Tank Destratification



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	NAME <b>Matthew Boebinger</b>	DATE 10/22/14	TITLE: <b>Team 24: Magnetically Coupled Cryogenic Pump</b>
INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL <b>Stainless Steel</b>	COMMENTS:	SIZE <b>A</b>	DWG. NO. <b>Axial Pump Shaft</b>	REV <b>1</b>
DO NOT SCALE DRAWING		SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

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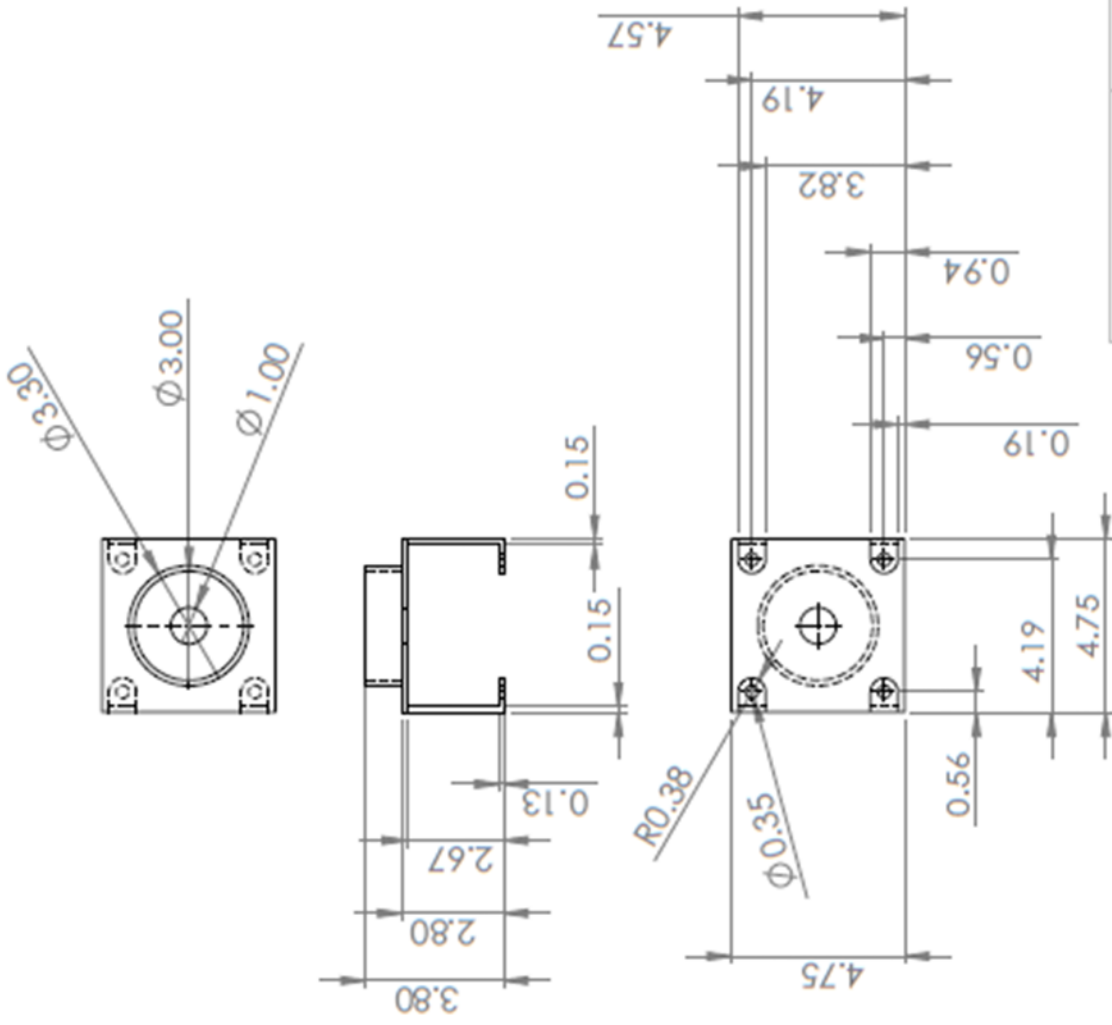
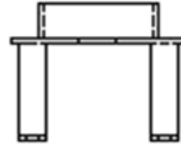
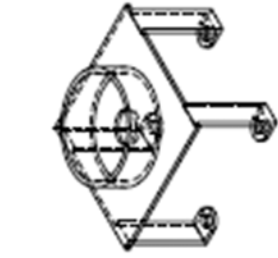
Magnetically Coupled Pump System for Cryogenic Tank Destratification



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INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL <b>Plexiglass</b>	COMMENTS:	SIZE <b>A</b>	DWG. NO. <b>Tesla Pump Spacer</b>	REV <b>1</b>
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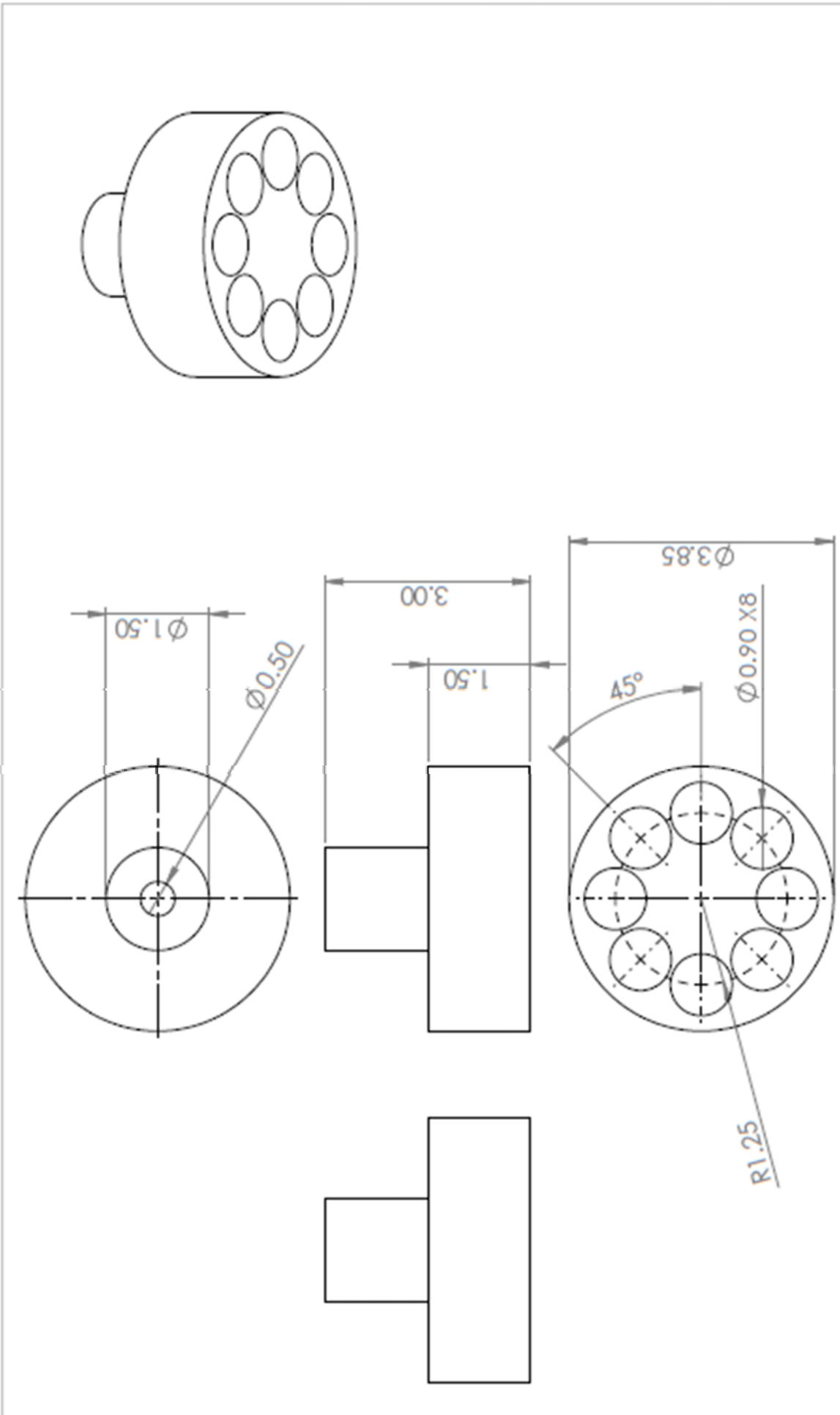
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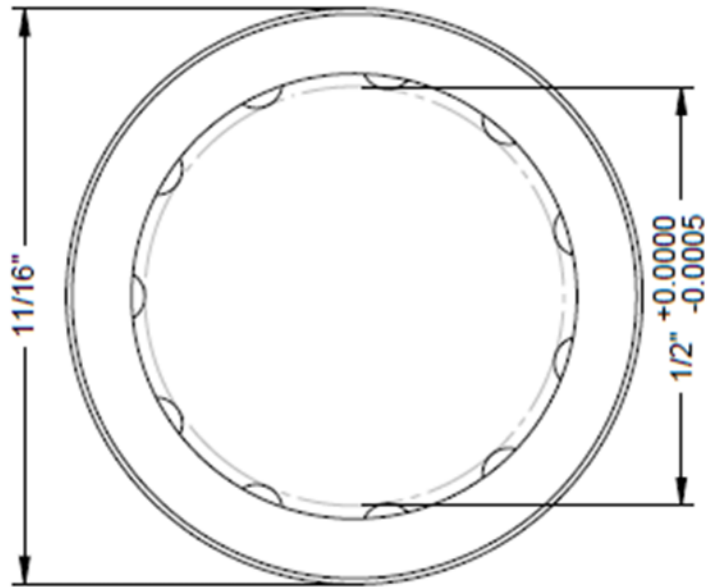
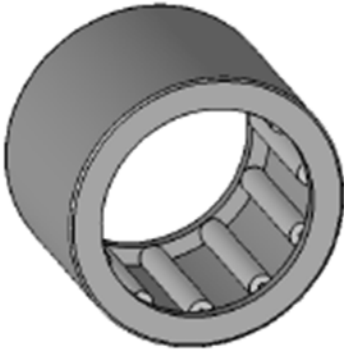
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INTERPRET DIMETRIC TOLERANCING PER: <b>Stainless Steel</b>		DRAWN		REV <b>1</b>	REV
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DO NOT SCALE DRAWING				SCALE: 1:5	WEIGHT: SHEET 1 OF 1

Magnetically Coupled Pump System for Cryogenic Tank Destratification



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DIMENSIONS ARE IN INCHES	DRAWN	Matthew Boebinger	10/22/14	Team 24: Magnetically Coupled Cryogenic Pump	
TOLERANCES:				SIZE	DWG. NO.
FRACTIONAL: ±				A	Outer Magnet Coupler
ANGULAR: MACH ± BEND ±				REV	1
TWO PLACE DECIMAL ±				COMMENTS:	
THREE PLACE DECIMAL ±				SCALE: 1:2 WEIGHT: SHEET 1 OF 1	
INTERPRET GEOMETRIC TOLERANCING PER:					
MATERIAL					
Stainless Steel					
DO NOT SCALE DRAWING					
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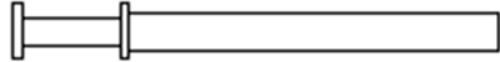
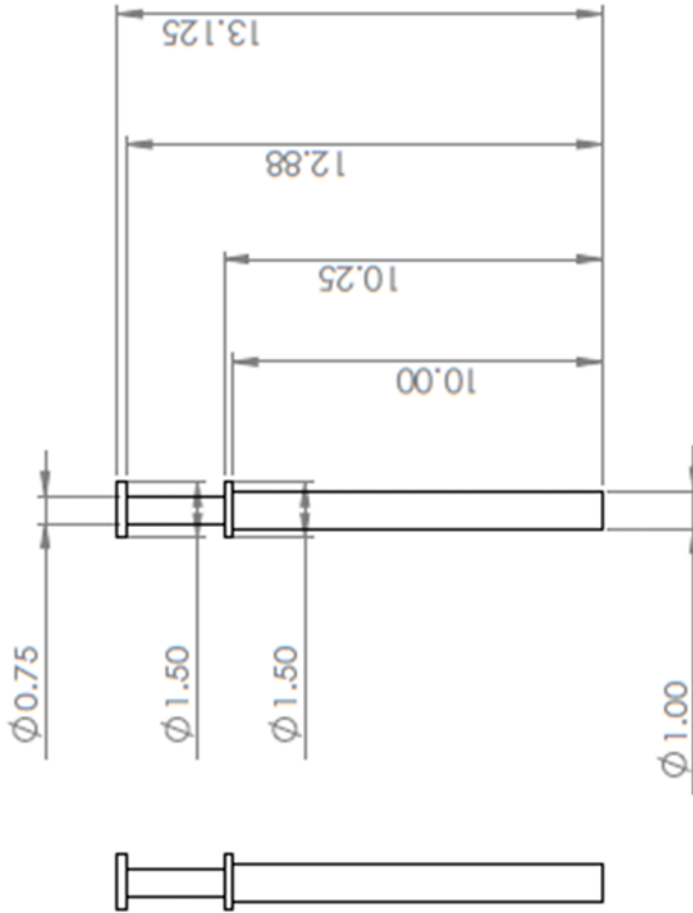
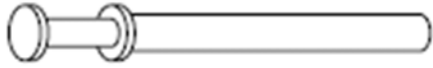
Magnetically Coupled Pump System for Cryogenic Tank Destratification



Housing Bore Tolerance:  
 Steel and Cast Iron Housing:  $+0.0005$  to  $-0.0005$   
 Powder Metal Housing:  $+0.0003$  to  $-0.0007$   
 Aluminum and Plastic Housing:  $+0.0001$  to  $-0.0009$

<b>McMASTER-CARR</b> <small>CAD</small>	<b>PART NUMBER</b>	<b>5905K23</b>
<a href="http://www.mcmaster.com">http://www.mcmaster.com</a>		Steel Open
© 2010 McMaster-Carr Supply Company Information in this drawing is provided for reference only.		Needle-Roller Bearing

Magnetically Coupled Pump System for Cryogenic Tank Destratification



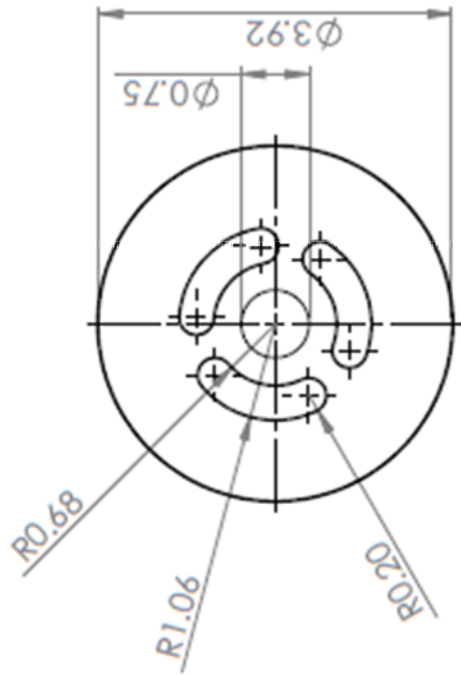
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DRAWN	NAME	10/20/14	Team 24: Magnetically Coupled Cryogenic Pump	
COMMENTS:		SIZE	DWG. NO.	REV
		A	Pump Shaft	1
MATERIAL Stainless Steel		SCALE: 1: 5		WEIGHT: SHEET 1 OF 1
DO NOT SCALE DRAWING				

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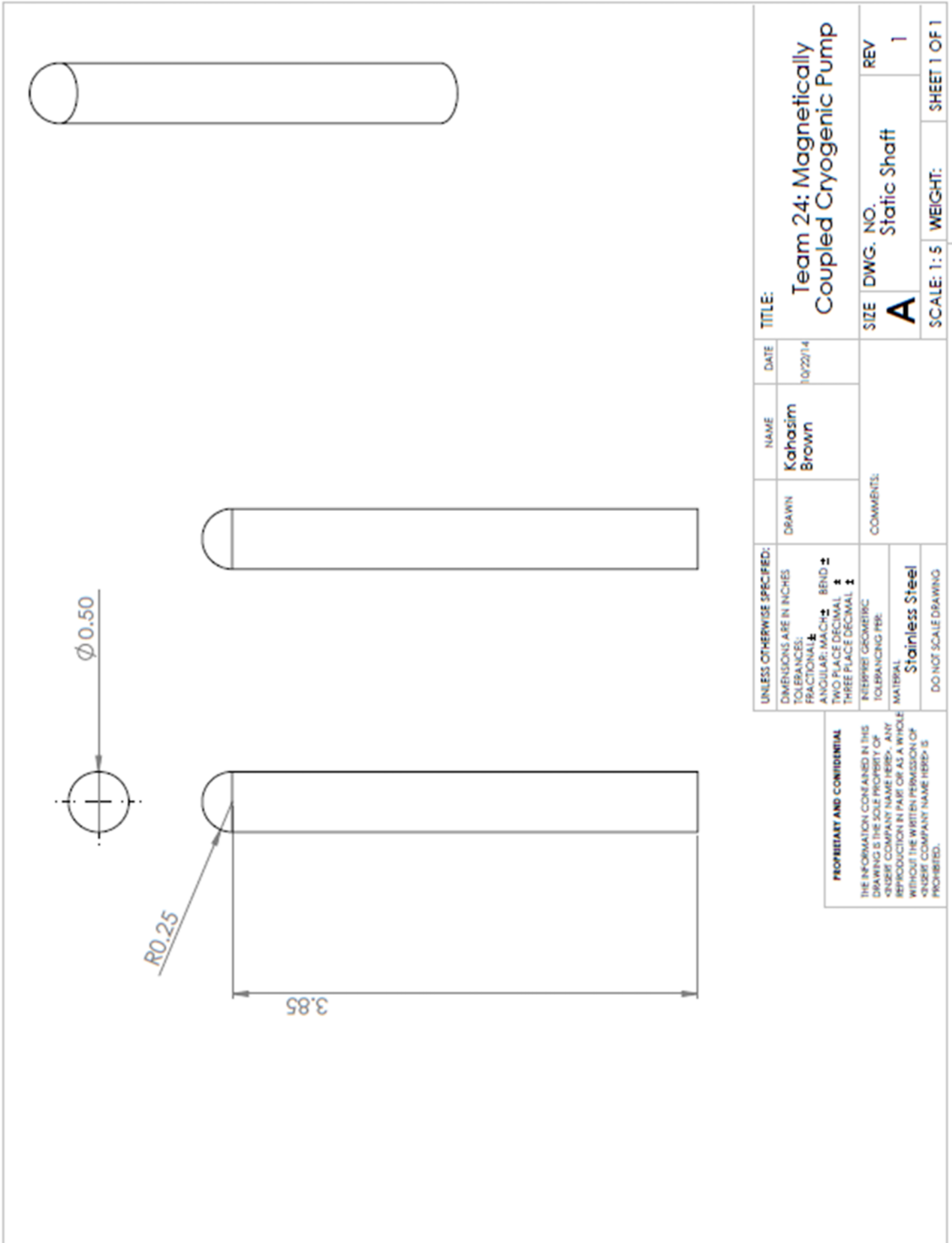
There will 10 discs  
used for the Tesla  
Pump

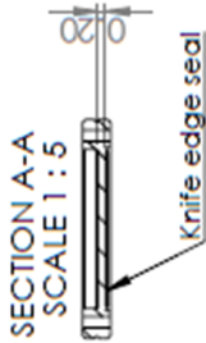
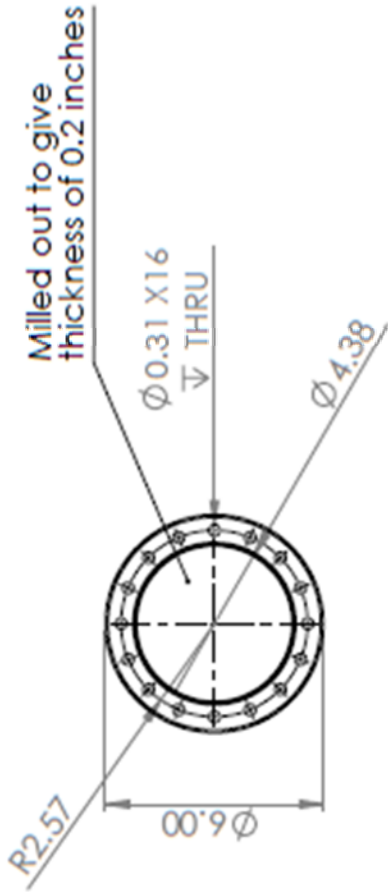


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INSUREPT GEOMETRIC TOLERANCING PER: MATERIAL <b>Stainless Steel</b> DO NOT SCALE DRAWING		COMMENTS:		SIZE <b>A</b>	DWG. NO. <b>Tesla Pump Disc</b>
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				SHEET 1 OF 1	REV <b>1</b>



Magnetically Coupled Pump System for Cryogenic Tank Destratification





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DIMENSIONS ARE IN INCHES	Matthew Boebinger	10/22/14	Team 24: Magnetically Coupled Cryogenic Pump
TOLERANCES:			
FRACTIONAL: ±			
ANGULAR: MATCH ±			
BEND: ±			
TWO PLACE DECIMAL: ±			
THREE PLACE DECIMAL: ±			
INTERFERE GEOMETRIC TOLERANCING/FDE			
MATERIAL			
Stainless Steel			
DO NOT SCALE DRAWING			
COMMENTS:			
SIZE	DWG. NO.	REV	
A	6inch ConFlat Flange - Milled	1	
SCALE: 1:5	WEIGHT:		SHEET 1 OF 1

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