Determining the Effectiveness of Oleophobic Gaskets

Fall Final Report: Interim Design Review

Team Number: 1

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ABSTRACT

The goal of this Cummins Inc. sponsored project is to determine the effectiveness of oleophobic gaskets compared to standard nonoleophobic gaskets. This objective will be completed by utilizing on market oleophobic sealing solutions on current gasket materials, as well as non-traditional gasket materials and then testing these products in an experimental test rig, which will be designed and constructed by the team. The effectiveness of the oleophobic gaskets will be assessed by comparing the respective leak rates of each gasket type under several conditions, including two variable temperatures and variable clamping pressures, to that of baseline nonoleophobic gasket leak rates. The team has performed research on types of oleophobic solutions and have investigated which of these solutions are potential candidates to create an oleophobic gasket. The test rig must be designed and built by the team so that it can test gaskets with oil at room temperature and at an elevated engine-like temperature while under a constant low internal pressure of 2.5 psi with variable gasket clamping pressure. A House of Quality determined that the primary engineering characteristic tested is gasket leak rate. Using this, multiple concepts were generated and then evaluated using a Pugh Matrix. Once the final concept was chosen, in-depth analysis was performed on various components in hopes of reducing and mitigating any sort of failure. Additionally, the team has allotted its budget accordingly and begun purchasing materials. The team created a Gantt chart to create a time dependent project plan and identified critical tasks that the team must complete in order to finish this experiment on time and successfully.

1 Introduction

Cummins Inc. has proposed a project to determine the effectiveness of oleophobic gaskets to reduce the measured leak rate at low pressure, large joints on engines compared to the current gaskets used on engines. Oleophobic items are items which repel oil by having a lower surface energy than the oil. A gasket is an item which is placed between two flanges to form a seal, which is meant to prevent oils from leaking to the opposite side of the flange. The theory behind the project is that if the gasket can repel the oil, it is less likely that oil will be capable of leaking past the gasket.

In order to determine the effectiveness of oleophobic gaskets, the design team needs to determine what products on the market can be used to give a gasket oleophobic properties, create oleophobic gaskets using these products and nontraditional gasket materials, as well as design and build a test rig which measures the leak rate of a gasket at various temperatures and pressures. Once the design and construction of the project is complete, tests will be performed on oleophobic and standard gaskets using the test rig and results will be compared to determine the effectiveness. The test rig must be capable of testing oils that range from 22 to 120° Celsius and inducing a pressure on the oil ranging from 0 to 2.5 psi.

2 Project Definition

2.1 Background Research

Gaskets materials are used for different applications to prevent leakage of fluids at a joint, typically flanged bolted joints. These gaskets are usually metallic, polymeric, or paper materials, and they are expected to function effectively when subjected to various pressures and temperatures [1]. Gaskets are more likely to fail under adverse conditions, such as at higher pressures, higher temperatures, and poor flange surface conditions. The failure of gaskets can also be dependent on the size of the gasket, as larger gaskets have more potential leak paths. This project team is saddled with the task of determining if the use of an oleophobic gasket would prevent/reduce the effect of a gasket failure, while still having the reliability and durability of standard gaskets. The gasket performance will be tested with the use of a test rig, which is the second responsibility of the team.

Figure 1. Nonoleophobic (left) vs. oleophobic (right)

To have oleophobic properties means a material will have a tendency to repel oil from its surface which can be seen in Figure 1 [2]. Oleophobicity is reliant upon the concept of surface energy, which is the excess energy on the surface of a bulk material [3]. Therefore, oleophobic material must have a lower surface energy than oil.

This project is a first for FAMU/FSU senior design, meaning it is not a continuation of a previous project. Also, Cummins Inc. has not performed research or tests of their own, meaning that this senior design team is the first group to work on this project. Previous works related to this project involving oleophobic coatings are found on various items such as phones and clothing. Additionally, oleophobic impregnators are used as a tile and grout sealer. These sealants are not intended to prevent oil leakage. All of the aforementioned oleophobic solutions aim to simply repel oil from a surface, allowing the surface to maintain a clean finish. Currently, the design team has found no existing work involving the use of oleophobic sealing solutions on gaskets.

Lakshmi discusses how to lower the surface energy of a material through the application of a fluoropolymer [4]. This is relevant to the project as fluoropolymers are typically found in oleophobic sealing solutions, confirming the feasibility of on market sealing solutions.

There are four main types of gaskets used on engines to create seals: paper gaskets, FIPG gaskets, molded elastomer gaskets, and rubber coated metal gaskets. Paper gaskets are composed of 90% fibers and 10% elastomeric binder [1]. These gaskets are widely used because of how cost effective the production process is for them; however, they are subject to many failure modes such as weeping oil through the paper and bolt load relaxation. FIPG gaskets are gaskets that are applied to flanges in a liquid state and cure to create a seal. FIPG gaskets rely on adhesion to the flange surface to prevent leakage rather than pressure, as the other gaskets do. Rubber coated metal gaskets are composed of a metal core, which is coated with a thin layer of rubber, typically 25-75 μm thick [1]. Rubber coated gaskets are typically used in high temperature applications. The final type of gasket, molded elastomer gaskets, are gaskets which are composed of elastomers which were molded into a particular shape for usage. An example of a molded elastomer gasket is an o-ring. These gaskets typically display the best sealing characteristics of the four types of gaskets.

2.2 Need Statement

Cummins Inc., the largest diesel engine manufacturer in the world, would like to investigate if introducing an oleophobic substance to gaskets will decrease the amount of oil leakage experienced at various joints on their engines. Within the scope of the investigation is to research different types of oleophobic products, the different application procedures for these products, and which materials are compatible with these products. The contact joints that Cummins Inc. is most interested in are larger, low pressure flange joints. Examples of such a joint is the joint between the engine block and the oil pan. In such a joint, the oil is at a low pressure, but there is a large exposed gasket length for potential leaks to occur at. These leaks can lead to excessive engine wear and possible catastrophic failure. Currently gaskets prevent oil leakage solely through contact pressures between the gasket and the flange surfaces, which create a seal. The purpose of this project is to determine if using an oleophobic gasket would reduce the amount of oil leakage compared to current gaskets used by Cummins Inc.

Need Statement:

“Gaskets used at large joints where the oil is at low pressure leak more oil than desired.”

2.3 Goal Statement and Objectives

Goal Statement: “Determine the effectiveness of oleophobic gaskets through the use of a test rig designed by the team.”

Table 1. Project Objectives

Objective Number	**Objective**
1	Research what causes items to become oleophobic.
2	Create oleophobic gaskets using on market products.
3	Create oleophobic gaskets using non-conventional gasket materials
4	Design and build the test rig to be capable of varying clamping pressure and temperature
5	Test oleophobic gaskets and currently used gaskets for leak rate and compare results

3 Design and Analysis

3.1 Project Constraints

Multiple constraints associated with this project must be adhered to in order to determine the effectiveness of the gaskets. There are several categories for the constraints, and they are as follows:

Components/Gaskets

- An oleophobic gasket must be created using non-conventional gasket materials. This means that any form of rubber may not be used in the creation of this gasket.

Time Constraint

- The test rig construction must be completed within one month prior to the end of the semester, allowing time for gasket testing.
- The leak rate test results will be completed by the end of spring 2016 semester.

Testing Constraints

- Cummins Inc. requires that the design team use two types of standard gaskets as a baseline test to compare to the oleophobic gaskets. These two standard gasket types are paper gaskets and rubber coated metal gaskets.
- Cummins Inc. asks that the design team not test at internal pressures greater than 2.5 psi. The reasoning behind this is to accurately simulate the pressure present within an oil pan of an engine and to reduce the risk of injury during testing.

3.2 Design Specifications

Measurable design specifications important to this design include test rig dimensions, internal stress bearing capacity of the test rig, flange dimensions, clamping pressure needed for the bolts on the flanges, as well as flange surface roughness as shown in Table 2. Through preliminary research, some materials have been considered for the design. For example, the test rig can be made from an aluminum alloy or a steel alloy. The thickness of the test rig wall is not critical since the pressure difference between the inside and outside of the test rig is nearly negligible.

The minimum thickness of the bottom flange was determined to be 4.94 mm as calculated in Appendix A.

Table 2. Design Specifications

Design Specifications	Expected Value
Test Rig Dimensions	Inner Diameter (ID): < 55 mm
Test Rig Stress Capacity	Minimum thickness of bottom flange: 4.94 mm
Flange Dimensions	Inner Diameter (ID): < 55 mm Minimum Outer Diameter (OD): 140 mm
Clamping Pressure	Minimum of 0.5 MPa according to Cummins standards. Maximum of 10 MPa according to Cummins standards.
Flange Surface Roughness	Maximum 3.2 microns RA.

3.3 Performance Specifications

The gasket will sit between the flanges of the test rig, providing adequate sealing and minimal leak rate during testing, thus simulating an actual bolted joint on an engine. The operational temperature of the test rig will be between 22-120° C with ± 2° C accuracy, and the internal oil pressure will range from 0 to 2.5 psi with ± 0.01 psi accuracy. The pressure sensor must be very precise as it will be used to measure the leak rate, which is expected to be a relatively small value. A very precise pressure sensor, such as a pressure transducer, will provide the necessary resolution. The test rig will be heated through an external source such as an electric hot plate, which will display the external temperature on its digital display. This heating arrangement will induce elevated temperature within the oil, which can be directly measured via an RTD (Resistance Temperature Detector) sensor within the test rig.

3.4 Functional Analysis

To ensure the consistency and accuracy with which testing will be conducted, a functional analysis has been conducted.

3.4.1 Ideal Gas Law

In order to calculate the leak rate from the test rig, the Ideal Gas Law will be used. The Ideal Gas Law is shown in Equation 1.

$$PV = nRT \quad (1)$$

In Equation 1, P is the pressure of the gas which in this case is the air, V is the volume of the air, n is the number of moles of air, R is the universal gas constant, and T is the temperature of the air. During the testing of the gaskets within the test rig, the temperature (T) of the air within the test rig will be maintained constant. Also, the number of moles (n) of air within the test rig will remain constant since air will not leak out of the test rig. In addition, the value of the gas constant (R) remains constant since it is a constant value by definition. Therefore, the entire right side of the Ideal Gas Law in Equation 1 will remain constant throughout the test. As a result of this, the Ideal Gas Law can be reduced to enable the calculation of the final volume of air in the pressure vessel (V_2) since the values of the initial internal pressure of the air (P_1), the initial volume of air (V_1), and the final pressure (P_2) are known. The pressure values will be recorded using a pressure transducer, and the initial volume of air will be know based on the known volume of the test rig as well as the volume of oil which was inserted into the test rig. The reduced version of the Ideal Gas Law is shown in Equation 2.

$$P_1V_1 = P_2V_2 \quad (2)$$

Following the calculation of the volume of air in the test rig at the end of the test (V_2), the difference between the initial volume of the air and the final volume of air will equal the change in volume of oil within the test rig. This volume, when divided by the total time of the test, will give the oil leak rate. This oil leak rate is a result of the oil which leaked past the tested gasket, thus giving a quantifiable number to the effectiveness of the gasket.

3.4.2 Pressure and Bolt Torque Relationship

In order to introduce a performance variable to the testing, the clamp load on the gasket will be varied during testing. Clamping load has a significant impact on the sealing of gaskets, since it is the compression of the gasket which creates the seal. Therefore, by varying the clamp load, the ability of the gasket to prevent leakage in various conditions can be determined. Since the clamp load will be applied through the use of bolts, the relationship between the applied torque (T) (measured via a torque wrench) and clamping force (F) must be determined. Equation 3 shows the relationship between the applied torque to a bolt and the axial force it applies [5].

$$T = cdF \quad (3)$$

The nominal major bolt diameter is defined by *d*, and the coefficient of friction of the material is shown as the variable *c*. For testing, the induced clamping pressure over the gasket will be varied from 0.5 MPa – 10 MPa. The relationship between total bolt force (F), gasket area (A), and clamping pressure (P) is shown in Equation 4. Thus, the team will be able to relate the desired clamping pressure to an applied torque value on the bolts.

$$P = \frac{F}{A} \tag{4}$$

3.5 Concept Generation

In order to design and build the most efficient and accurate test rig, the design team generated a total of five concepts. Each concept contained the same base requirements, as explained in the product specifications. All five concepts would be a cylindrical shaped pressure vessel capable of withstanding the 2.5 psi internal pressure induced upon it, and each concept contained two flanges which would compress a flat gasket. In addition to the flanges, each test rig concept contained four bolts which are oriented 90 degrees apart from one another. These bolts could serve two purposes for the test rig concepts: create a clamping load on the flanges, or simply align the two test rig "halfs" if some other means of inducing a clamp load is used. If the bolts are used to create the clamping load, then they will also keep the test rig components aligned. Another feature of all five concepts is the elevation of the fasteners (nuts and/or bolts) from the bottom surface of the test rig. The design team had decided upon using a hot plate as the heat source for the test rig; therefore, it was necessary to elevate the fasteners off the bottom surface to prevent the heating of the fasteners directly. If the fasteners were heated directly, it is more likely that there could be a load relaxation in the bolted flange caused by thermal expansion of the bolts.

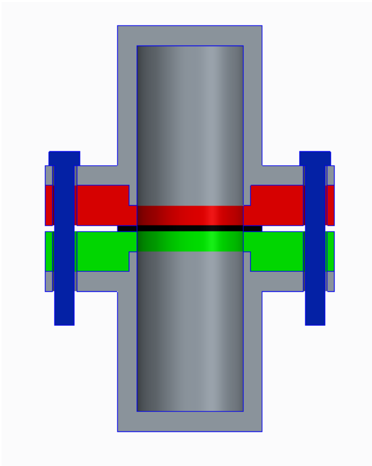


Figure 2. Concept #1 and Concept #2 cross section

3.5.1 Concept #1

With the goal in mind to create a test rig which can interchange at least one the flange that is in contact with the gasket, the team generated Concept #1, which is shown in Figure 2. Concept #1 utilizes removable flanges which slide onto and off of the upper and lower bodies of the test rig, thus allowing the flanges to be changed while maintaining the repeated use of the main components of the test rig, such as any sensors. The upper and lower flanges shown in Figure 2 are removable. The lower body of the test rig is identical to the upper body in terms of geometric measurements, and thus fasteners are elevated off the bottom surface of the test rig as desired.

3.5.2 Concept #2

The second concept the team generated is very similar to Concept #1 in appearance, thus Figure 2 is also a good representation of Concept #2. The feature which distinguishes Concept #2 from Concept #1 is the means of adding/removing the removable flanges. Instead of sliding on and off, as in Concept #1, the flanges in Concept #2 will have internal threading which will allow the flanges to screw onto the test rig body components. Obviously, this will also require that the test rig body components have external threading to create the interface with the flanges. In order to reduce the leak paths which are associated with straight threads, Concept #2 utilizes tapered threads which will create an air tight seal between the test rig and the flanges. Therefore, it is anticipated that Concept #2 would contain less unwanted leak paths, however lacks the easy of assembly and durability of Concept #1

3.5.3 Concept #3

Concept #3 takes a different approach to incorporating a means to interchange at least one flange which is in contact with the gasket. Instead of having removable flanges, Concept #3 would instead have several different lower test rig bodies which would be interchanged based on the experimental trial. The lower test rig body would contain the flange that is in contact with the gasket, thus reducing the leak path introduced by having a removable flange. The upper body of the test rig would also have the flange incorporated into it as a solid body, since only one flange needs to be interchangeable based on the sponsor requirements. In order to keep the fasteners elevated off the bottom surface of the test rig, the lower body pieces will have a bowl shape. Thus, the bottom of the lower body remains as the

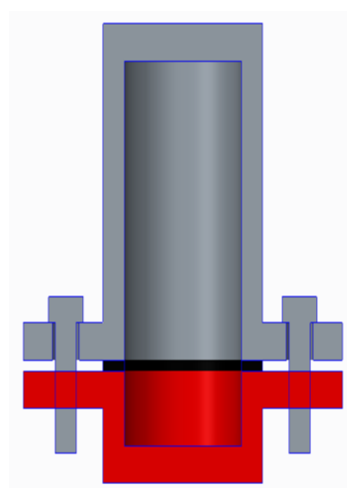


Figure 3. Concept #3 cross section

lowest surface of the test rig.

3.5.4 Concept #4

Concept #4 again utilized the idea of having several different test rig lower bodies rather than removable flanges. However, Concept #4 took a different approach to keeping the fasteners off the lowest surface of the test rig. The bowl-shaped test rig lower body in Concept #3 requires fabrication in order to create the bowl. As an attempt to reduce the amount of fabrication, the team set out on creating a concept which utilized a flat plate as the lower body/flange. Therefore, as shown in Figure 4, Concept #4 uses a flat plate instead of a bowl shaped lower body. In order to prevent the fasteners from being the lowest surface on the test rig, the bottom plate would be threaded for the bolts.

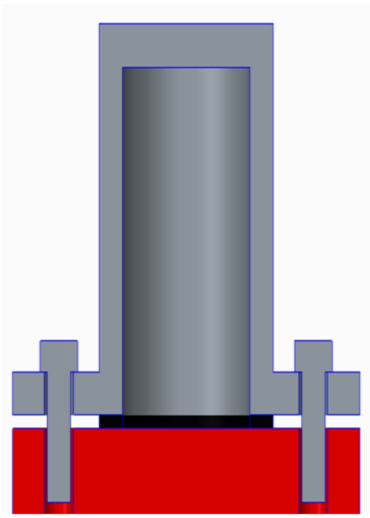


Figure 4. Concept #4 cross section

By threading the lower body directly, as long as the bolts used were not long enough to protrude from the lower body, the bolt would not contact the heat source. However, this will require that the lower body be thicker than otherwise necessary. Also, the possibility of thermal expansion of the bolt is still a risk since the bolt is in direct contact with the threaded component on the heat source (the lower body). Therefore, Concept #4 would be easier to manufacture, but may not offer the best performance in terms of functionality.

3.5.5 Concept #5

With Concept #5, the design team wanted to use a flat plate for the lower body/flange, but offer a different method to prevent the fasteners from being the lowest surface on the test rig. As it can be seen in Figure 5, Concept #5 uses a thinner flat plate for the lower body/flange. This plate would be changed and replaced with a different plate based on the experimental trial being performed. Nuts will be used to secure the bolts in Concept #5, therefore the lower body/flange will not be threaded as it is in Concept #4. In order to

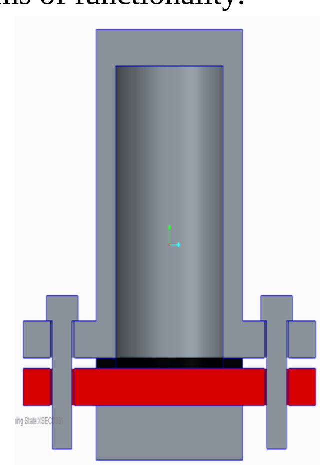


Figure 5. Concept #5 cross section

prevent the fasteners from being the lowest surface of the test rig, an additional spacer will be placed below the lower body/flange. This spacer will be of the same material as the rest of the test rig, therefore will have the same thermal conductivity as the lower body/flange. The spacer would not be permanently secured to the lower body/flange, therefore the same spacer could be used for every lower body/flange used in testing. This spacer would sit directly on the heat source, thus elevating the fasteners. Concept #5 allows for fast and simple fabrication, as well as preventing the thermal expansion of the fasteners.

3.6 Evaluation of Concepts

The technique chosen to evaluate these five concepts was in the form of a Pugh matrix (Figure 6). On the left hand side, there are different categories such as number of leak paths, ease of assembly, and machinability assigned to each concept. These categories are then assigned a weighting factor which are dependent upon their importance. The weighting factors of all of the categories sum up to one. Therefore, the categories of greater importance are assigned higher weighting values. For instance, number of leak paths is weighted the highest at 0.25 because this is the main method of determining the effectiveness of oleophobic gaskets, whereas cost is weighted the lowest at 0.05 since additional funding can be obtained if needed. This means the team is more concerned with a test rig that will not confound the results with potential leak paths than with the cost of manufacturing it.

This Pugh matrix allows for evaluation of different concepts in relation to a baseline concept. The first concept was set as the baseline with zeroes in all of the categories. All of the other concepts were evaluated in relation to whether it was an improvement or degradation of concept one. A score of one or two denotes improvement, while negative one or negative two denotes degradation. A score of zero means neither improvement nor degradation.

All team members participated by completing their own Pugh matrix and the results were averaged together as shown in Figure 6 below. The results of the Pugh matrix identified concept five as the winning one. This concept won due to the very high scores in categories: number of leak paths, machinability, and cost. Concept Five simplifies the bottom flange down to a single sheet of material that does not require embedded threading or extra material as a buffer for the bolt lengths.

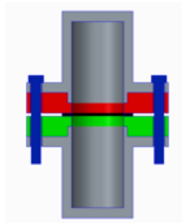
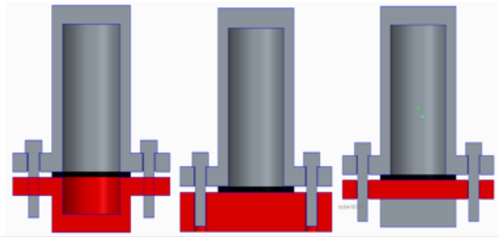
			NPT Threaded Removable Flanges			
	Weight	#1	#2	#3	#4	#5
Number of Leak Paths	0.25	0	0.3	1.3	2.0	2.0
Ease of Assembly	0.1	0	-0.3	1.0	1.3	1.0
Machinability	0.1	0	-0.7	1.3	1.7	1.7
Temperature Variation	0.2	0	0.0	0.3	0.7	1.0
Pressure Variation	0.2	0	0.0	0.0	0.3	0.7
Durability	0.1	0	-0.3	1.0	0.0	1.0
Cost	0.05	0	-0.3	1.0	1.3	1.7
Total	1	0	-0.1	0.8	1.1	1.3
Rank		4	5	3	2	1

Figure 6. Pugh decision matrix for test rig decision

3.7 Detailed Evaluation of Concept Five

After selecting Concept #5 as the winning concept for the test rig, the design team began to lay out where the hardware items would be located. Figure 7 shows a CAD model of the more

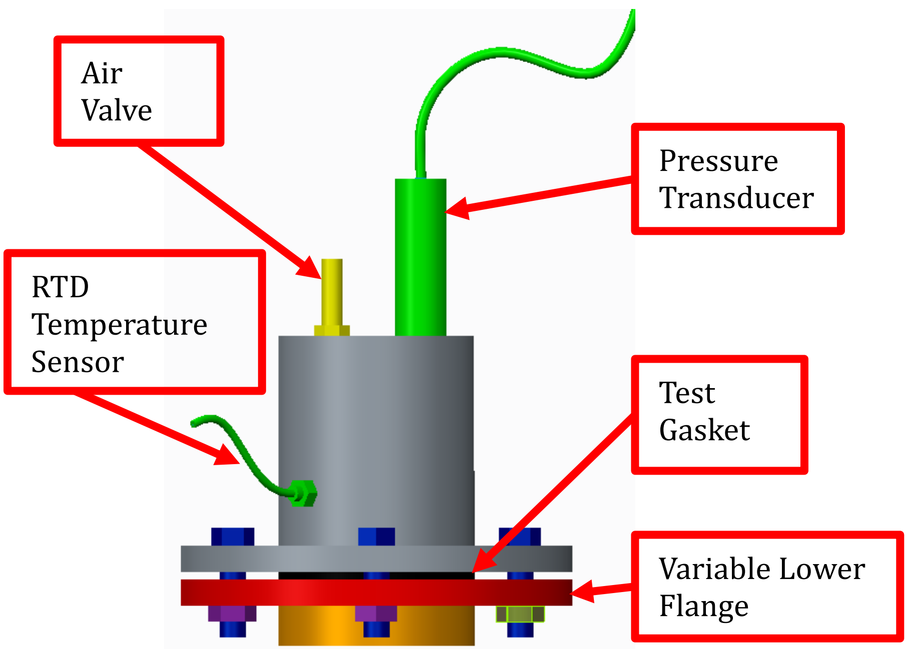


Figure 7. CAD model of test rig Concept #5 with the additional hardware components required for testing purposes

detailed layout of the test rig. The hardware includes items such as the pressure transducer, air inlet valve, etc. The layout of the hardware in Figure 7 is dependent on bolts being used to create a clamping pressure on the gasket. As shown in Figure 7, all of the hardware items are located on the upper body of the test rig. This allows for the hardware to only be required to be installed once. If the hardware were installed in the lower flange, then the hardware items would need to be removed and re-installed each time the lower flange was swapped for testing conditions. Not only does having all the hardware located on the upper body make the testing process more time efficient, but it also minimizes the likelihood of a leak occurring at one of the hardware interfaces. All of the hardware has NPT threading, and NPT threading creates a tight seal by causing yielding in the materials when tightened. Therefore, NPT threads are not durable to repeated installation and removal.

As shown in Figure 7, the pressure transducer and the air inlet valve are located on the top surface of the test rig. This allows both of these hardware components to be open to the air cavity which is present above the oil level. Figure 8 shows the approximate oil level location for the test rig. With both of these items being exposed to the air, it minimizes the likelihood of oil entering either of these components and fouling them. The pressure transducer needs to be exposed to the air in order to measure the air pressure, which is used in the Ideal Gas Law calculations. The RTD sensor is located below the oil level, as shown in Figure 8. This allows for the oil temperature to be measured rather than the air temperature.

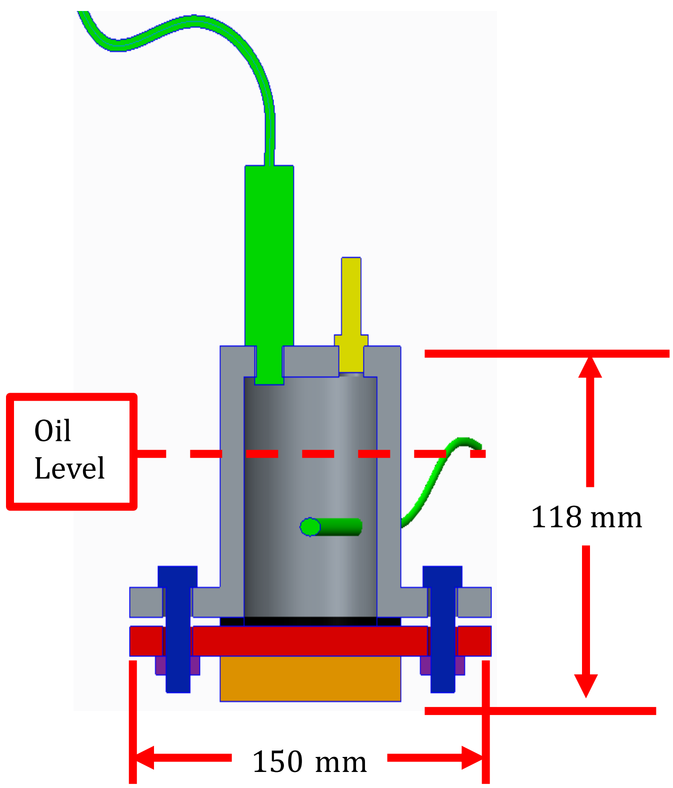


Figure 8. Cross sectional view of the test rig, which shows the oil level relative to the hardware components

The purpose of measuring the oil temperature is to know the state of the oil during the test. For example, the oil will become less viscous at elevated temperatures, and therefore more likely to leak.

3.8 Failure Modes and Effect Analysis

In order to minimize and prevent failures of the test rig, a Failure Modes and Effect Analysis (FMEA) was constructed, as shown in Table 3.

Table 3. Failure Modes and Effect Analysis

Component	Mode Of Failure	Cause	Probability	Effect	Severity	Suggested Action
Flanges	Bending	Over Loaded Bolts	4	Increase in leak rate	2	Monitor bolt load
	Surface Roughness	Machining Flaw	2			Follow machining standards
Gasket	Blowout	Material selection	1	Safety hazard	5	Material testing
	Oil leak	Improper materials	4	Increase in leak rate	4	Material testing
		Leak paths	6		2	Design selection
Pressure Vessel	Crack/ break	Material selection	1	Gasket blowout	6	Factor of Safety
		Tolerances	2			
Sensors	Overload	Improper selection	1	Inaccurate results	6	Consult sensor data sheet
	Accuracy					

Ranking Scale: 1-6; 1 = Low 6 = High

Each component in the test rig was evaluated in Table 3 to determine the methods in which the component could fail during testing. Each failure mode had its own cause and effect, along with their probability and severity, respectively. For example, a failure mode for the sensors is "inaccuracy", shown in the bottom row of Table 3. This failure mode had a cause of "improper selection" of the sensors and had a low probability of 1, since the team would be able to select a sensor based on the known test conditions. This was followed by the effect of "improper selection" which was "inaccurate results" with a high severity of 6, since the entire design project focuses on producing accurate results for analysis. In order to ensure the failure modes' probabilities of occurring are minimized, the FMEA table was iterated to ensure that the "suggested action" for each mode of failure of each component would decrease or eliminate the "cause" and therefore the "effect" of said failure. Analysis of the design was then performed to minimize several of these modes of failure.

3.9 Analysis of Design

3.9.1 Bolt Load Analysis

As previously stated, the test rig is currently designed to be clamped using four bolts. The reason that four bolts were chosen for the design is that using four bolts around the circular gasket is an accurate method to simulate an actual engine seal. If only two bolts were used, less of the bolt load would be transferred through the gasket interface, thus not sealing properly. When designing bolted joints on engines, it is typical to place the bolts along the gasket path. Therefore, using four bolts is a better solution than using two or three bolts, because the bolts follow the gasket path more closely.

In order to determine how much torque needs to be applied to the bolts to achieve the desired clamping pressure, the team performed calculations utilizing Equations 3 and 4. Appendix B shows the calculations performed for a clamping pressure of 10 MPa. For the analysis, M8 bolts were chosen for the design. M8 class 5.8 bolts can provide a maximum axial force of 10.4 kN when torqued to a maximum torque of 16.7 N*m [6]. As shown in Appendix B, in order to achieve a clamping load of 10 MPa, each bolt will need to provide an axial force of 5.1 kN, which is associated with a tightening torque of 8.168 N*m. Therefore, the required force and torque required to achieve the 10 MPa clamping pressure are well within the maximum values for the selected bolt type. Using this same calculation method, the team is able to calculate the required tightening torque for the bolts for any desired clamping pressure. This will provide the team with a method of ensuring that the bolts are not overloaded, which could result in the bending of the flanges.

3.9.2 Pressure Distribution Analysis

In order to test that the use of four bolts would cause the clamping pressure on the gasket to not dip below the desired pressure, a simulation was created within Creo Parametric 2.0 to analyze the contact pressure on the gasket face. In order to improve the "run time" of the analysis, the test rig was divided into four pieces. Analysis was done for one-quarter of the test rig, with the bolts being located at the cut interfaces. Figure 9 displays the CAD model used in the analysis. During the simulations, the bolt load which was applied was equal to the axial force found during the torque calculations for desired pressures. For example, for the desired clamping pressure of 10 MPa, the applied axial forces in the analysis was 5.1 kN. Figure 10 displays the results of the analysis for a desired clamping load of 10 MPa. The results of the analysis shows that between the bolts, there is no portion of the gasket which will experience less than 10 MPa of pressure all the way across the gasket face. Based on this result, the use of four bolts was confirmed to be a suitable amount of bolts for the design.

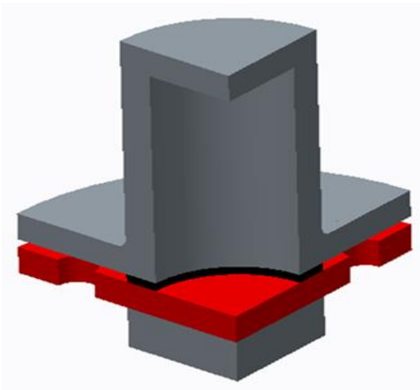


Figure 9. One quarter of the test rig, which was used for analysis

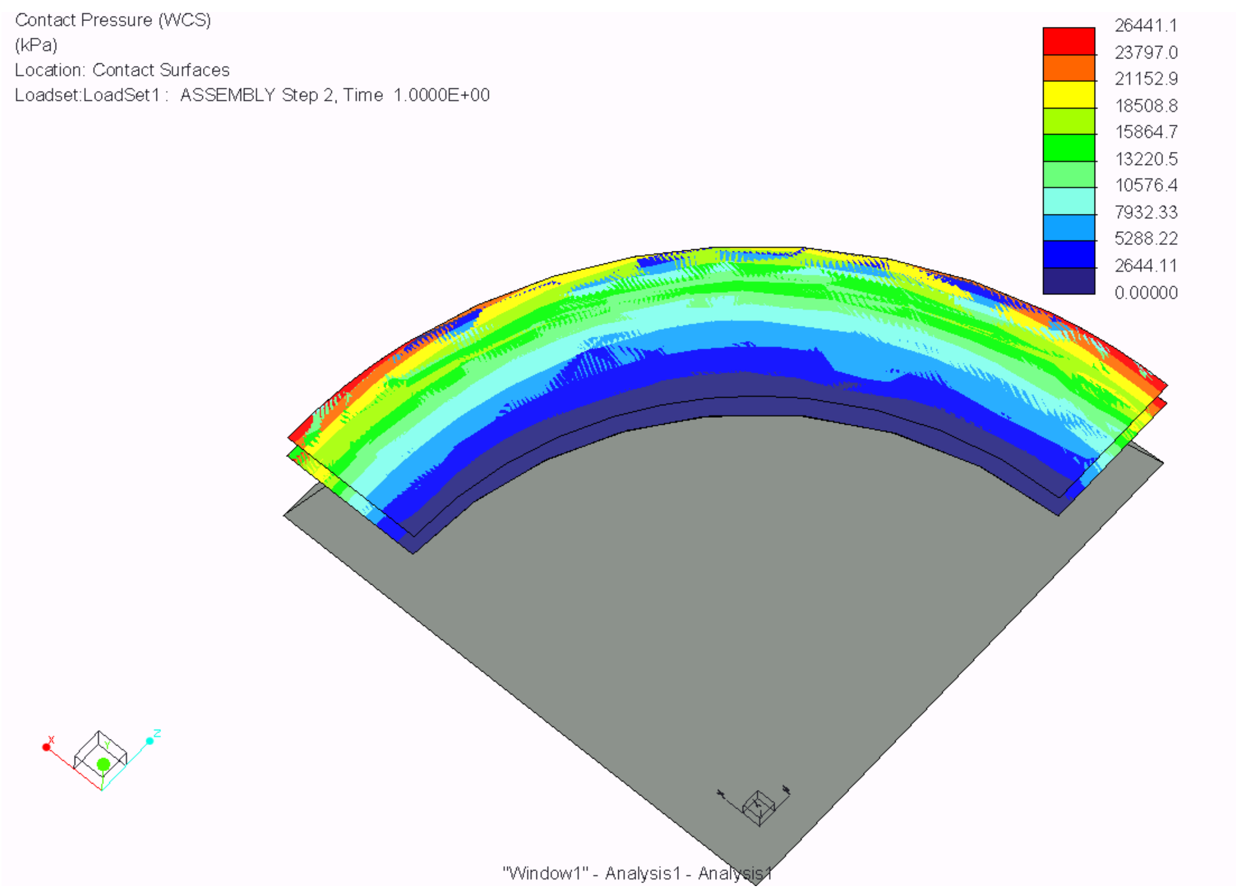


Figure 10. Gasket clamping pressure distribution based on analysis results

3.9.3 Flange Thickness Calculations

To ensure that the bottom removable flange would pose no threat of suddenly failing under the various pressures present during experimentation, a minimum thickness analysis was performed. Both A36 Steel and Aluminum 6061 were analyzed; however, A36 Steel was chosen as it was determined to be the more inexpensive of the two minimum thicknesses calculated. This analysis was broken up into two different regions. The bottom flange is subject to the internal pressure of the vessel as well as the clamping pressure from the bolts. The internal pressure is felt on a center circular portion of the flange. The maximum internal pressure that will be felt is 2.5 psi. This center disc extends out to the inner radius of the vessel (50 mm). A visual of this can be viewed below in Figure 11.

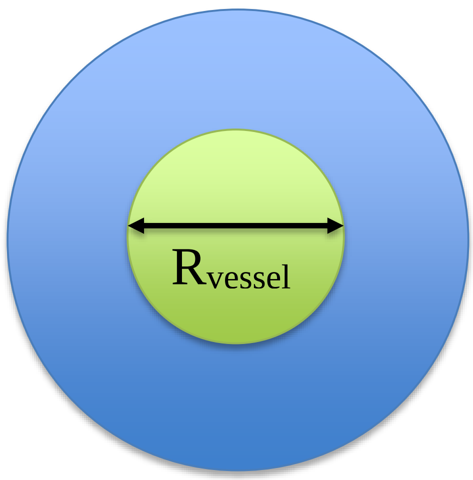


Figure 11. Top view of removable bottom flange

The second region is the outer ring of the bottom flange that is affected solely by the clamping pressure of the four bolts, which is a maximum of 10 MPa. The final and simplified equation that was used to calculate the minimum thickness of these two portions is dependent upon a pressure differential (ΔP), Poisson's ratio (υ), failure strength (σ_f), radius (R), density (ρ), area (A), and a constant (C) which is determined based upon whether the region is clamped (C=1) or simply supported (C=3). The equation is as follows

$$t_{min} = \frac{\sqrt{\frac{3\pi^2 R^6 \Delta P (C+\upsilon)}{8}}\left(\frac{\rho}{\sqrt{\sigma_f}}\right)}{\rho * A} \tag{5}$$

Using Eq. 5, the A36 Steel minimum thickness required for the middle circular portion was calculated to be 0.31 mm, while the outer ring minimum thickness was calculated to be 4.94 mm. These calculations can be found in Appendix A. The large difference in thicknesses is due to the significant difference in the pressure differential term. To make the machining process easier, the minimum bottom flange thickness was decided to be the larger of the two thicknesses as this accounts for both thickness requirements. Following this logic, the bottom flange's overall minimum thickness was determined to be 4.94 mm.

3.10 Final Design

After completing the FMEA and the appropriate analysis, the team was able to revise the selected design concept to create the final design for the test rig. Figure 12 shows the CAD model for the final design. In this final design, the team has selected the optimum location for all

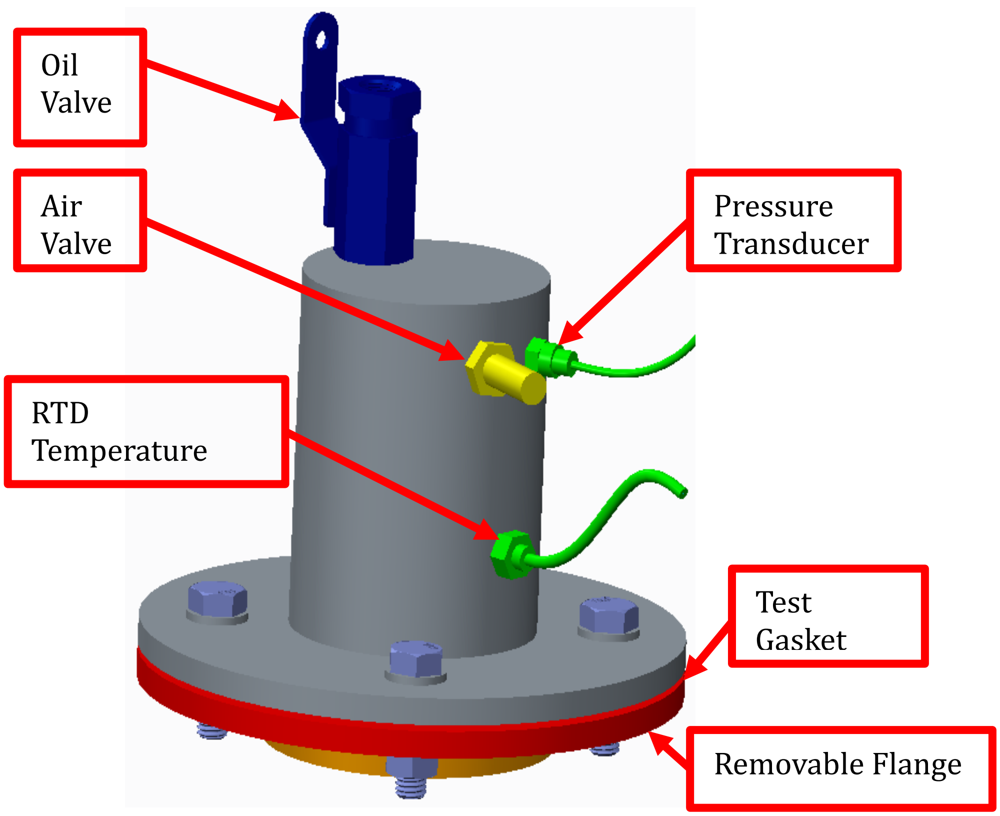


Figure 12. CAD model of the final design for the test rig.

of the hardware components. The oil valve, which will be used to add and remove the oil, is located at the top face of the test rig. It is also offset from the center of the top face, which will allow for easier removal of the oil. The pressure transducer and air valve are both on the cylindrical wall towards the top of the test rig. This location exposes those items to the air cavity above the oil, but also places them far from the oil valve. This will minimize the likelihood of oil getting inside of these hardware items during the process of adding or removing oil. The RTD sensor is still on the cylindrical wall of the test rig, but is located below the oil level. It is also below the pressure transducer and the air valve, as this puts all of the wires for the test rig in the same approximate location. This was done to create a cleaner design, as well as make it easier to set up the electrical connections on the test rig during testing. A removable flange is still incorporated in the final design because the team wants to test a scenario in which no gasket is used, but an oleophobic solution is applied directly to the lower flange face. Thus, two lower flanges are still required. The CAD drawing for the final design can be found in Appendix C. These are the drawings that will be used by the machine shop to fabricate the test rig.

3.10.1 Design Optimization

The final design of the test rig took into account all of the analysis results to create the optimum design. For example, the calculated required flange thickness was found to be 4.94 mm. However, the thread engagement length for many of the hardware components were recommended to be approximately 0.25 inches. Therefore, the team decided to purchase A36 steel with a 0.25 inch thickness for the test rig. This thickness is uniform throughout the test rig, meaning that both the flanges as well as the cylindrical walls are composed of steel at this thickness. This not only provided a margin of safety in our design, with our selected thickness being 31% thicker than required, but also reduces the machining time required to fabricate the test rig. So not only is the material thickness chosen as the optimum thickness based on analysis requirements, but also in terms of being the optimum thickness to reduce the fabrication time in the machine shop. If the team had chosen a thinner thickness for the cylindrical walls, then additional items would have been required to be welded onto the test rig to provide adequate thread engagement for the hardware.

Another item of the test rig that was optimized was the selection of four bolts. For sealing the test rig, any number of bolts could have been selected. However, the team wanted the design to simulate an actual seal on an engine in the most realistic way possible. To simulate an actual seal, the pattern formed by connecting the bolts should follow the path of the gasket. With a circular design having been specified by the sponsor, the test rig would only create a circular bolt pattern if many bolts were used. However, the use of many bolts would no longer allow for a realistic pressure drop on the gasket faces between bolts, since the bolts would be placed too closely together. The design team determined that the use of four bolts provided an adequate compromise to meet both of these requirements. Four bolts is better at following the gasket path than the use of two or three bolts, but still provides adequate bolt spacing to allow for a realistic pressure prop on the gasket face. Thus, a four bolt pattern was chosen as the optimum design. Also, M8 bolts were specified as the bolt to use because they can easily handle the required load for proper sealing and are similar to the bolt sizes used on an engine.

3.10.2 Bolt Load Measurement

One of the test parameters that the team must be capable of varying is the clamping pressure on the gasket. In order to vary this pressure, the team must have a method of controlling the bolt load applied by the bolts used to clamp the two flanges together. One method to control the bolt load is to use a torque wrench with a predefined torque setting. Based on the coefficient of friction for the bolt, a theoretical torque value can be calculated to provide the desired bolt load. However, it is not possible to measure the exact coefficient of friction for each bolt. The standard friction coefficient for a steel bolt is 0.2, but this can vary by as much as 30% from bolt to bolt. Therefore, this method of controlling the bolt load would put the clamping pressure on the gasket in the approximate range desired, but it would not be a precise value. Because of this potential error, the team has decided to use an alternative method for controlling the bolt loads.

Figure 13. Modified bolt with strain gauge.

Load cells are devices that are capable of measuring the force being applied to them through the use of strain gauges within them. The team investigated purchasing load cells, however the cost of just the load cells would equal the budget for the entire project. Cummins Inc. has offered to provide the team with strain gauges that can be placed on the bolts themselves. Cummins Inc. has the capabilities at their facilities to machine bolts and apply sheet resistive type strain gauges to the modified bolts. Figure 13 shows what the modified bolts look like with a strain gauges applied to them. Therefore, the senior design team will provide bolts to Cummins Inc., and Cummins Inc. will make the necessary modifications to the bolts and send them back to the senior design team. With strain gauges applied to the bolts, Cummins Inc. will create a calibration curve for each bolt. Using an MTS machine to apply a tensile load to each bolt, the output voltage of the strain gauges can be calibrated to the known applied load. Using this calibration, the team will be able to tighten these modified bolts on the test rig and be able to know the exact bolt load value based on the voltage output of the strain gauges. This method of measuring the bolt load is very precise as well as a cost effective solution to measuring the bolt load. Using these bolts, the clamping pressure on the gasket will be known and can be easily repeatable from test to test.

3.10.3 Hardware Selection

As shown in Figure 12, there are multiple pieces of hardware being utilized in this test rig. In order to select the hardware with a correct resolution, a range of detection and an accuracy must be targeted. As stated previously, the temperature sensor will be reading the oil temperature and is not used in later calculations; therefore, its accuracy is not as important as the accuracy of the pressure which is used in future calculations. The temperature sensor must be able to read the range between 22-120˚C with ± 2˚C accuracy. This accuracy was selected by the team as appropriate for the variable. Using this information, an RTD (Omega PR-20 series), seen in Figure 14, was chosen as the best fit and most inexpensive sensor that meets the requirements. This RTD is smaller than a typical laboratory RTD as it must fit inside of the test rig fully submerged in the oil. It will be fitted into the side of the test rig using a compression fitting.

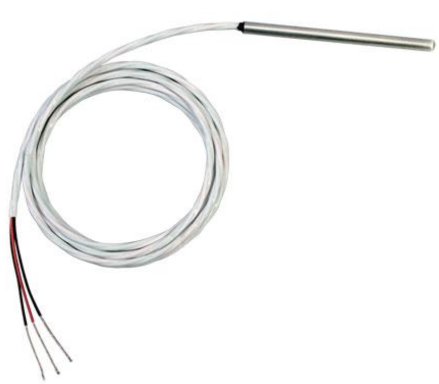


Figure 14. Short RTD probe [7]

The pressure sensor is much more important to the experiment and is required to read a range between 0-2.5 psi with a minimum of ± 0.01 psi accuracy. Additionally, it must function at the elevated temperatures mentioned above. Given these requirements, a pressure transducer (Kulite XT-123B-190-G) was chosen as the best fit, which can be seen in Figure 15. This pressure transducer is a gage sensor which will require an amplifier to read its 100 mV output range. This will then be read to the DAQ (Data Acquisition) system set up in the laboratory. It can measure up to 5 psi with an accuracy of ± 0.005 psi, which is better than the minimum accuracy required.

Figure 15. Pressure transducer [8]

The other two pieces of hardware on the test rig include the air inlet valve and the oil inlet valve. The air inlet valve will be a very basic stem (Figure 16) that can be fitted with a tap connected to compressed air which will pressurize the air cavity above the oil. This valve stem can be imagined as the air valve stem on a traditional bicycle tire. The air will be pumped in and can be released by pressing on the center of the valve stem. The oil inlet valve will be a ball valve, as shown in Figure 17, which creates an air-tight seal. To fill the test rig with oil, the ball valve will be opened by turning the valve handle, and a funnel will be used to pass the oil through it. During testing, the valve will be sealed shut which will eliminate the possibility of oil and air leaking past the valve. After testing, the valve can be opened and the test rig can be drained. The team has selected an appropriate ball valve to use for the test rig. It will use a compact high pressure ball valve, which has a total length of 1.875 inches, and a male thread of 1/8” NPT. This small size allows for the ball valve to claim minimal space on the test rig, thus leaving room for the other hardware.

Figure 16. Air valve stem [9]

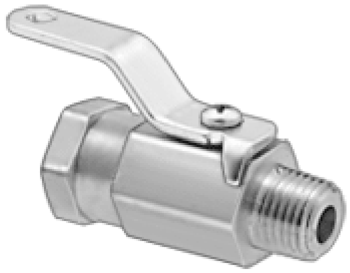


Figure 17. Ball Valve [10]

4 Results

4.1 Conventional Gasket Testing

Cummins Inc. has provided the team with two types of their standard gaskets commonly used on regions of their engines that experience low pressure failure. The gaskets provided were rubber coated metal gaskets and paper gaskets. The spray-on oleophobic solution that the team obtained is Ultra-Ever Dry and is applied using Ever Dry Sprayers provided from UltraTech International. First, each of the paper and rubber coated metal gaskets were tested by dropping an oil droplet onto the gasket before any oleophobic solution was applied. Seen in Figures 18 and 19, these results are provided, as well as the results after they had the Ultra-Ever Dry solution applied to them. The Ultra-Ever Dry must be applied in two stages. The first stage is an adhesive layer and must cure for an hour after being applied. After that hour has passed, the top layer which contains the oleophobic properties is applied and must dry overnight.

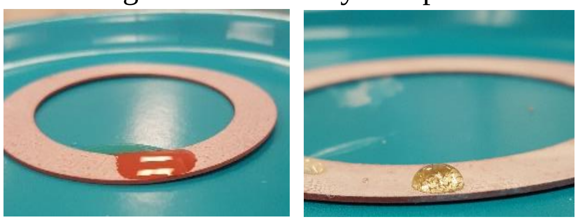


Figure 18. Paper gaskets before and after application of oleophobic solution.

In the before photos, the oil droplets on the paper gasket and rubber coated metal gasket are flat and spread out across their respective surfaces. Once applied with the oleophobic solution, the paper and rubber coated metal gaskets' contact angles increased significantly, which formed an oil bead in one concise location. This result demonstrated that the spray-on oleophobic solution was successful at transforming the standard gasket materials into an oleophobic gasket.

Figure 19. Rubber coated metal gaskets before and after application of oleophobic solution.

4.2 Non-Conventional Gasket Testing

The team obtained non-conventional gasket material samples from McMaster-Carr. These samples included a high density felt (Figures 20, 21 and 22), and a woven fabric as seen in

Figure 23. The team also received samples of an impregnator solution, Stainguard WB-50. The application procedure of the impregnator solution is to coat the material's surface using a brush, or allow the material to soak in the impregnator solution and then dry overnight. First, the felt and woven fabric were tested using no solution. As seen in Figures 20 and 23, the oil soaked completely through both materials and no oil beaded up on the surface. Two samples of the high density fabric were then applied with the impregnator and spray.

Figure 20. High density felt after oil has been poured onto it.

The two images in Figure 21 show the high density fabric applied with an oleophobic impregnator. A high contact angle has been generated as no solution penetrated the material. There is a small film of excess oil that can still be seen on the surface after the oil was attempted to be removed by tilting the felt at an inclined angle. This is a drastic improvement from having the oil soak completely through the material. The two images in Figure 22 show the high density felt applied with the oleophobic spray. The spray created a contact angle even larger than the contact angle generated by the impregnator solution. When the felt sample that had the spray-on solution was inclined to remove the oil, only a few small droplets remained on the surface. The team believes they can reduce the amount of oil left on top of both the impregnator and spray solution by testing and finding the best methods of application for both solutions. These results suggested that the oleophobic solutions are capable of making non-conventional gasket materials oleophobic. Therefore, the team is going to create gaskets out of the high density felt material and use them in the test rig during gasket testing.

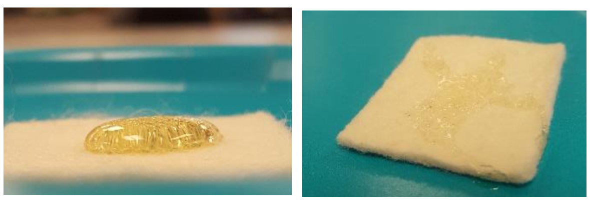


Figure 21. High density felt impregnated with oleophobic solution before and after oil has been poured off of it.

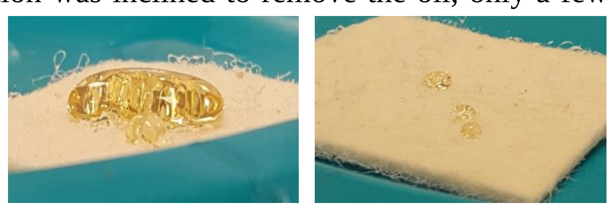


Figure 22. High density felt coated with oleophobic spray before and after oil has been poured off of it.

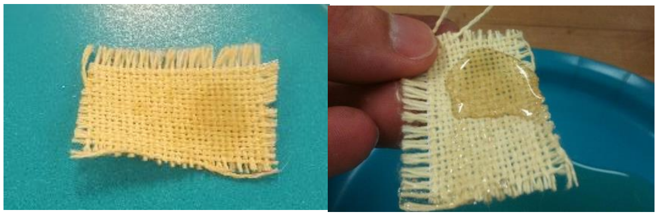


Figure 23. Woven fabric before and after application of impregnator solution.

The before and after photos of the woven fabric can be seen in Figure 23. Similar to the high density felt, oil soaked directly through the woven fabric. The photo on the right in Figure 23 shows oil beaded up on the surface. This might be the most impressive result from our initial testing because there are holes in the fabric where the oil could not pass through due to the impregnator solution. The impregnator soaked into the material and created a barrier in which the oil could not pass through. This is a good sign for the actual testing in the spring semester because it showed that materials with no oil repellent properties could be effective sealing solutions when applied with the correct chemical substance.

5 Project Management

The first major objective of the project that was completed was to determine what options are currently on market to make gaskets oleophobic. In order to determine which options are available, the team researched the market using the internet, and by contacting suppliers to get professional feedback. Once current market items are determined, they will be evaluated by the team for practicality, performance, and environmental applications. The team will then select the suitable method(s) to make an oleophobic gasket and procure these "on market" products. Using these products, the team will create the oleophobic gaskets, which will be leak rate tested.

The other major objective of the project is to design and build a test rig which will be capable of measuring the leak rate of gaskets. The team has held discussions with the sponsor to determine if there are any company standards for test purposes, such as leak path length, standard diameters, pressure ranges, and availability of current gaskets used by the sponsor. Using this information, the required size of the system was determined and designing began on the test rig. The physical designing of the testing rig utilized CAD software for visual purposes as well as part drawings, and any mathematical calculations were done using Mathcad in order to ensure accuracy.

Testing will be performed on the oleophobic gaskets using the test rig built by the team. The leak rate test results for the oleophobic gaskets will be compared to standard gaskets, which will allow the team to draw conclusions on the effectiveness of an oleophobic gasket. The tests will be performed using different oil pressures and temperatures within the test rig, which will provide more data to compare with standard gaskets.

In order to prevent exceeding the $2,000 budget, price will be weighed in every decision to make sure the team makes the best decision between performance and costs. Items which will be used in the building of the test rig will be quoted to ensure the lowest possible price was obtained, thus using the team's budget efficiently. In order to keep the project on schedule, a Gantt chart was created (Appendix D). The Gantt chart will continuously be updated by the team as the project advances, allowing for proper planning if the project deviates from the original schedule.

5.1 Resource Allocation

The background research phase was completed as an entire team, where individual team members were assigned small topics to research and share with the team. Heather Davidson and Norris McMahon researched the science behind oleophobicity, while Daniel Elliott researched common causes for gasket failures. Erik Spilling researched into what types of oleophobic spray coatings are currently available on market, and David Dawson researched if a product could be used to impregnate a material to create oleophobic characteristics for the material. Further research is being performed by the team, including researching temperature and pressure measurement devices, machining practices, pressure vessel minimum thickness criteria, bolt load and its effect on clamping force, and continued research into oleophobic solutions. The entire team contributed to the background research phase of the project.

The senior design team decided to divide into sub-teams so that the necessary effort could be applied to both the oleophobic gasket aspect of the project, as well as the design and fabrication of the test rig, simultaneously.

- Gasket Team:
  - This sub team consists of Norris McMahon, David Dawson, and Aruoture Egoh. The gasket team was responsible for continued research into what process and products can be used to create an oleophobic gasket. Once the gasket team identified the available oleophobic solutions on market, they were responsible for selecting the solutions for the team to purchase and test. The gasket team will also be responsible for creating the oleophobic gaskets. The gasket team is also responsible for providing the gasket needs to Cummins Inc., so that Cummins Inc. can provide the necessary gaskets for testing.
- Test Rig Design Team:
  - The test rig design team consists of Erik Spilling, Heather Davidson, and Daniel Elliott. The test rig team was responsible for generating concepts for the test rig, performing the calculations to determine the design details for the test rig (such as wall thickness, bolt loads, etc.), creating the CAD models and drawings, material selection, and creating a list of raw material quantities which will need to be purchased. The test rig design team worked as a group to complete all of the

aforementioned tasks, since the team believes a group effort yields the best design.

Fabrication will be performed by the entire team. The raw materials for the test rig will be machined by the COE machine shop in January, but the assembly of the test rig will be done by the entire team.

The testing process will be performed by the entire team as well. Since a large number of tests are expected to be performed, the team plans to do one set of tests as a group. These initial tests will be done together to create a step by step testing process that the entire group understands. Then, testing will be broken into smaller groups so that the entire team does not need to be present for every single test run. The smaller groups will be groups of two or three.

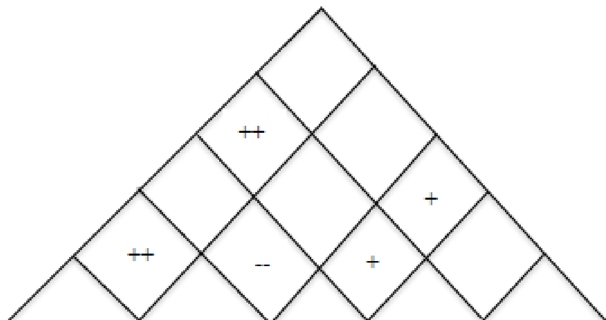
The team web page was designed by Heather Davidson. The team utilized the advice and resources provided by Ryan Kopinsky in order to best design the team web page.

5.2 Schedule/Deliverables

A schedule of the team's project plan for the rest of the fall semester can be found in a Gantt chart (Appendix D). This Gantt chart encompasses a work breakdown structure (WBS) which details who is responsible for each task. The arrows in the Gantt chart show the prerequisite relationship between two tasks. Additionally, critical tasks can be identified by their duration in the time schedule. For example, part acquisition is a very critical task as it is expected to take the longest, and the project cannot precede without the completion of it.

5.3 House of Quality

After first speaking with the sponsor and defining their requirements, a diagram known as a House of Quality (HOQ) was constructed (Figure 24). This diagram relates the sponsor's requirements with various engineering characteristics. For instance, there is a strong correlation between the requirement of comparable performance and the characteristic gasket leak rate. Additionally, the diagram also depicts the relationship between any two engineering characteristics. This is illustrated in the top triangle of the "house." There is a strong positive correlation between the cost and the test rig pressure. To simulate higher pressures in the test rig a more complex design is required, and this will require money thus increasing the cost. Through this diagram, the number one engineering characteristic identified was the gasket leak rate. The HOQ was used by the team to divide tasks to ensure that the team's tasks were focused on meeting the customer requirements through prioritizing the corresponding engineering characteristics.



Direction of Improvement		Down	N/A	Down	N/A	Up
		Engineering Characteristics				
Customer Requirements	**Customer Importance**	Gasket Leak Rate (sccm)	Flange Surface Roughness (μm)	Cost ($)	Test Rig Pressure (psi)	Oil Temperature (°C)
Test various pressures	7	o		o	•	
Test various roughnesses	6	o	•	o		
Comparable performance	9	•	Δ		o	o
Test various oil temp.	7	o		o		•
Absolute Importance		201	81	120	117	117
Relative Importance		0.32	0.13	0.19	0.18	0.18
Rank Order of ECs		1	4	2	3	3

++	Strong positive
+	Positive
-	Weak
--	Strong weak

•	Strong (9)
o	Medium (6)
Δ	Weak (3)

Figure 24. Constructed HOQ using sponsor information

5.4 Risk Assessment and Reliability

After analyzing the risks that could occur during this project, a new set of testing procedures was created focusing on safety. When creating oleophobic gaskets, the team will wear gloves, longsleeved shirts, long pants, closed toe shoes, eye protection, and masks at all times. The test rig will be built by the FAMU/FSU machine shop safely and efficiently. When conducting the leak tests, the test rig will be placed into a plastic container. Anyone handling or monitoring a short distance away from the test rig will have to wearing heavy clothing which doesn't reveal skin, closed toe shoes, a mask with eye and face protection, and heavy gloves.

When examining the possible reliability issues for this project, it was found that there are two potential areas of concern: data collection and the test rig structure. Both of these issues have been noted, and the correct procedures have been created to make sure that neither will be a problem during testing. To make sure the data is collected correctly and identically each time, the team will use strain gauges to record the load on the bolts. The team also consulted Dr. Kumar on which pressure transducer and RTD probe to fit the constraints given to us by our sponsor.

The other goal was to create a test rig which would be able to handle the temperature, pressure, and bolt load. To make sure that there would be no problem with failures in the test rig, the minimum thickness for the metal was calculated, and A36 steel was chosen. This material with a thickness of 0.25 inch will allow us to operate the test rig with no concern of failure.

5.5 Procurement

Parts ordering has begun as the sub teams reached their final designs. David Dawson has been responsible for maintaining the team budget, and thus has also be responsible for the parts ordering. The sub teams have been providing David with a list of the desired raw materials, and David checks to make sure that the parts or materials can be purchased within the team's budget, and makes the purchases.

The budget given for this project was $2,000 through the Aero Propulsion, Mechatronics and Energy Center. This budget will be used to acquire all of the materials that will be needed for application and testing for determining the effectiveness of oleophobic gaskets. The values shown in Table 4 are the maximum estimated values for each item needed and were calculated by researching into potential products. Even after calculating for the maximum prices, the total cost only comes out to $1,850, which leaves a remainder of $150 in case of an emergency.

Table 4. Budget

Item	Maximum Estimated Amount
Test Rig Raw Materials	$150.00
Test Rig Sensors	$1,000.00
Gasket Materials	$150.00
Oleophobic Solutions	$300.00
Oleophobic Material	$200.00
Oils Used for Testing	$50.00
Total	**$1,850.00**

In Table 5, all of the purchased items are shown with quantity and price. It is also organized by which category that item fits into within the budget. As it can be seen, the team is under the estimated cost for each of the budget sub groups. It should be noted that the team has received samples of gasket materials and oleophobic solutions, and are finishing up initial testing to decide which materials and solutions will be used for the final experiments.

Table 5. Purchased Items

Budget Category	Item	Quantity	Cost
Test Rig Material	M8Class 10.9 Cap Screw	1(Pack of 25)	$7.91
Test Rig Material	M8General Purpose Steel Washer	1 (Pack of 100)	$6.09
Test Rig Material	M8 Class 10 Steel Nut	1 (Pack of 100)	$10.48
Test Rig Material	Compact High-Pressure Brass Ball Valve	1	$11.34
Test Rig Material	Brass Air Fill ValveStraight	1	$4.40
Test Rig Material	1ft x 1ft x ¼ in Thick A36 Steel Plate	1	$15.41
Test Rig Material	1ftLong 2-1/2 ODx 2 ID Round Steel Tube	1	$36.04
Test Rig Material	**Total**		**$91.67**
Test Rig Sensors	Short RTD Probe	1	$66.00
Test Rig Sensors	Compression Fitting	1	$20.00
Test Rig Sensor	Pressure Transducer	1	$618.00
Test Rig Sensor	**Total**		**$704.00**
Oleophobic Material	Teflon Gaskets	20	$170.00
Oils Used for Testing	T Triple Protection CJ-4 15W-40 Motor Oil	1 (Gallon)	$13.44
Purchased	**Total**		**$979.11**

6 Environmental, Safety, and Ethics

The assigned project was more of research oriented and not actually building a mass production item. Thus, environmental consideration was not focused on the production process, but rather the environmental impacts of our testing process. For example, the testing of the gasket will be completed using oil. To ensure that the used oil does not harm the environment, it will be recycled at a recycling center once testing is complete. Also, any leftover chemical solutions will be disposed at a proper disposal site.

Safety will be an influential factor during the design of the test rig and the testing of the gaskets. When designing the test rig, the stability and rigidity of the fixture will be taken into consideration, not only for performance reasons, but also for the safety of the team. The test rig will be built using A36 steel with uniform thickness of 0.25 inch to provide a safety factor in the design. This is to prevent any form of sudden failure during testing. When creating the various oleophobic gaskets, team members will wear personal protective equipment (gloves, shoes, eye goggles, and masks) at all times. When conducting the leak tests, the test rig will be placed in a plastic container. In addition, FMEA was carried out on the selected design concept of the test rig (components of the test rig) in order to locate possible failures modes in the final design, and how to best prevent the failure.

Ethics was also considered when designing the test rig. The team will be building the test rig based on an original design and the analysis done by the team. The design was developed solely by the team, thus using only the team’s intellectual property. The team followed engineering ethics during the project, ensuring that safety was a major focus, and that all designs generated were the intellectual property of the team.

7 Conclusion

The purpose of this project is to determine if the development and implementation of oleophobic gaskets would be useful in practical applications. This will be achieved by researching modern oleophobic gasket solutions and selecting the best solutions to test in an oil leak rate test rig, which will be constructed by the team. These oleophobic gaskets will be compared to baseline model tests using engine oil at a constant pressure of 2.5 psi. The goal of the test rig is to be capable of operating with oil temperatures of 22 to 120 °C. Tests will be performed with a gasket at variable clamping pressure to change the compression on the gasket. The results from this experiment will provide a better understanding if oleophobic gasket solutions are effective in terms of practicality, performance, and applicability.

The team is currently working on procuring the materials for the test rig as well the oleophobic solutions and non-traditional oleophobic gasket materials. In tandem with this, the team is compiling all necessary drawings to send to the machine shop once the machining process is ready to be initiated. In addition, preliminary testing of the trial oleophobic solutions are being conducted. The team will continue to hold informal and formal bi-weekly meetings to provide regular updates on the progress of the project. A schedule in the form of a Gantt chart has been put in place to allow the team to have a visualized timeline of major and minor tasks throughout the completion of this project. The team is on schedule and has met all of the goals set for this semester.

The goal for the next deliverable is to have all materials ordered and shipped to the team. The team also hopes to have the test rig machined and completed by the beginning of the next semester. All oleophobic solutions and non-traditional oleophobic gasket materials should be on site and ready to use. Finally using all these resources, the team will be applying the oleophobic solutions to the traditional and non-traditional gaskets in preparation for the testing portion of this project. For future work, the team expects for the test rig to be fabricated in the machine shop by the end of January. Thus, the team can begin the testing process in February. Once the testing process has begun, the design aspects of the project are completed. The project scope will shift to focusing on obtaining data which either supports or rejects the theory that oleophobicity is a desirable property for a gasket to contain.

References

[1] "Gasket Materials and Selection." Gasket Materials and Selection. Web. 25 Sept. 2015.

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[3] "Surface Energy and Wetting." Surface Energy and Wetting. Web. 25 Sept. 2015.

[4] "Fabrication of Superhydrophobic and Oleophobic Sol–gel Nanocomposite Coating." Fabrication of Superhydrophobic and Oleophobic Sol–gel Nanocomposite Coating. Web. 25 Sept. 2015.

[5] “Torque.” Engineers Edge. Web. 28 Oct. 2015

[6] "Tightening Torque." *Field Guide to Optomechanical Design and Analysis* (2012): Web.

[7] "Short RTD Probe." *Short RTD Probe*. Web. 30 Oct. 2015.

[8] "PX409 Series High Accuracy Pressure Transducers Now with 0.05% Accuracy and 0.03% Linearity Options." *High Accuracy Pressure Transducers*. Web. 30 Oct. 2015.

[9] "Valve, Air Tank Filler." *Cdi Control Devices TV12*. Web. 30 Oct. 2015.

[10] "McMaster-Carr." *McMaster-Carr*. Web. 30 Oct. 2015.

Appendix A

$\sigma_{clamping} := 10MPa$

$\sigma_{vessel} := 2.5psi = 0.017 \cdot MPa$

$ID := 50mm$

$OD := 150mm$

$D_{gasket} := 75mm$

$A_{vessel} := \pi \cdot \left(\frac{ID}{2}\right)^2 = 2.376 \times 10^{-3} \cdot m^2$

A36 Steel

$nu_{steel} := 0.26$

$A_{flange} := \pi \cdot \left[\left(\frac{OD}{2}\right)^2 - \left(\frac{ID}{2}\right)^2\right] = 0.015\,m^2$

$\sigma_{failuresteel} := 322.5MPa$

$density_{steel} := 7.85 \cdot 10^6 \frac{gm}{m^3}$

$P_{atm} := 14.696psi = 0.101 \cdot MPa$

$\Delta P_{vessel} := P_{atm} - \sigma_{vessel} = 0.084 \cdot MPa$

$\Delta P_{flange} := \sigma_{clamping} - (P_{atm}) = 9.899 \cdot MPa$

A36 Steel

$$m_{vesselsteel} := \left[\frac{3\cdot(1+nu_{steel})\cdot\Delta P_{vessel}\cdot\left(\frac{ID}{2}\right)^{6}\cdot\pi^{2}}{8}\right]^{\frac{1}{2}}\cdot\left(\frac{density_{steel}}{\sigma_{failuresteel}^{\frac{1}{2}}}\right) = 5.693\times10^{-3}\,kg$$

$$m_{vesselsteel} = 5.693\times10^{-3}\,kg$$

$$t_{vesselsteel} := \frac{m_{vesselsteel}}{density_{steel}\cdot A_{vessel}}$$

$$\boxed{t_{vesselsteel} = 0.305\cdot mm}$$

$$\sigma_{failuresteel} = \frac{3\cdot(3+nu_{steel})\cdot\Delta P_{flange}}{8\cdot t_{flange}^{2}}$$

$$m_{flangesteel} = density_{steel}\cdot A_{flange}\cdot t_{flangesteel}$$

$$m_{flangesteel} := \left[\frac{3\cdot(3+nu_{steel})\cdot\Delta P_{flange}\cdot\left[\left(\frac{D_{gasket}}{2}\right)^{2}-\left(\frac{ID}{2}\right)^{2}\right]\cdot\pi^{2}}{8}\right]^{\frac{1}{2}}\cdot\left[\frac{density_{steel}}{(\sigma_{failuresteel})^{\frac{1}{2}}}\right]\cdot\left[\left(\frac{OD}{2}\right)^{2}-\left(\frac{ID}{2}\right)^{2}\right] = 0.593\,kg$$

$$m_{flangesteel} = 0.593\,kg$$

$$t_{flangesteel} := \frac{m_{flangesteel}}{density_{steel}\cdot A_{flange}}$$

$$\boxed{t_{flangesteel} = 4.939\cdot mm}$$

Appendix B

Bolt Torque Calculations

The nominal diameter of the bolt

$D_{nom} := 8mm$

Number of Bolts

$NB := 4$

Input Gasket Parameters:

$D_{inner} := 55mm$

$D_{outer} := 75mm$

Sealing pressure on Gasket:

$P_{max} := 10MPa$

Determine gasket area:

$$A_{outer} := \frac{\pi \cdot D_{outer}^{2}}{4} = 4.418 \times 10^{-3} m^{2}$$

$$A_{inner} := \frac{\pi \cdot D_{inner}^{2}}{4} = 2.376 \times 10^{-3} m^{2}$$

$$A_{gasket} := A_{outer} - A_{inner} = 2.042 \times 10^{-3} m^{2}$$

The total force required to induce the desired pressure;

$$F_{tot} := P_{max} \cdot A_{gasket}$$

$$F_{tot} = 20.42 \cdot kN$$

Force required by each bolt for 4 bolt design

$$F_{ind} := \frac{F_{tot}}{NB}$$

$F_{ind} = 5.105 \cdot kN$ force per bolt

The torque coefficient K

$K := 0.2$ http://euler9.tripod.com/fasteners/preload.html

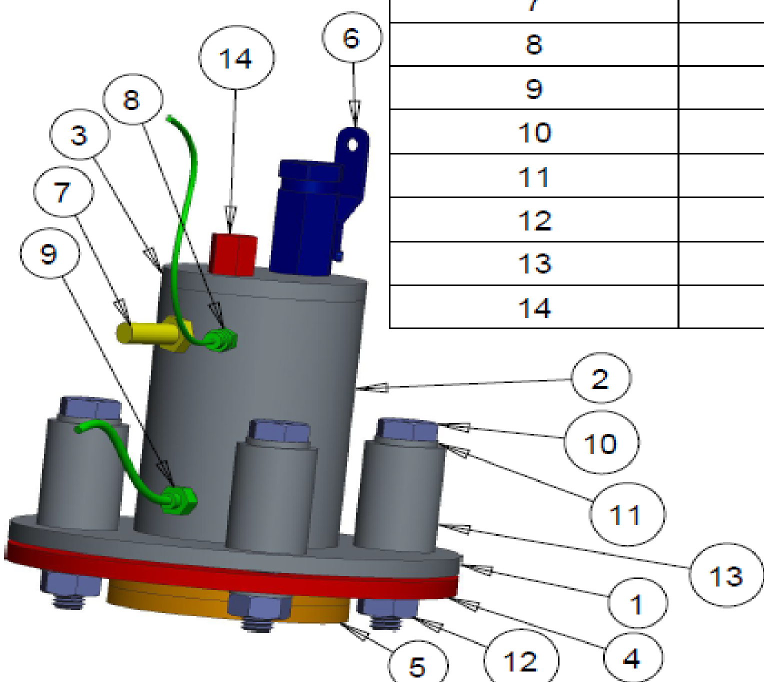
Finding the required torque

$$T_{needed} := F_{ind} \cdot K \cdot D_{nom}$$

$$\boxed{T_{needed} = 8.168 \cdot N \cdot m}$$

Appendix C

Part Number	Part Name	Quantity	Material
1	Top Flange	1	A36 Steel
2	Top Tube	1	A36 Steel
3	Top Cap	1	A36 Steel
4	Bottom Flange	1	A36 Steel
5	Spacer	2	A36 Steel
6	Oil Valve	1	Bronze
7	Air Valve	1	Bronze
8	Pressure Transducer	1	Steel
9	RTD Sensor	1	Steel
10	M10x1.5 70mm Bolt	4	Steel
11	M10 Washer	8	Steel
12	M10x1.5 Nut	4	Steel
13	Bolt Spacer	4	Steel
14	Pressure Relief Valve	1	Brass



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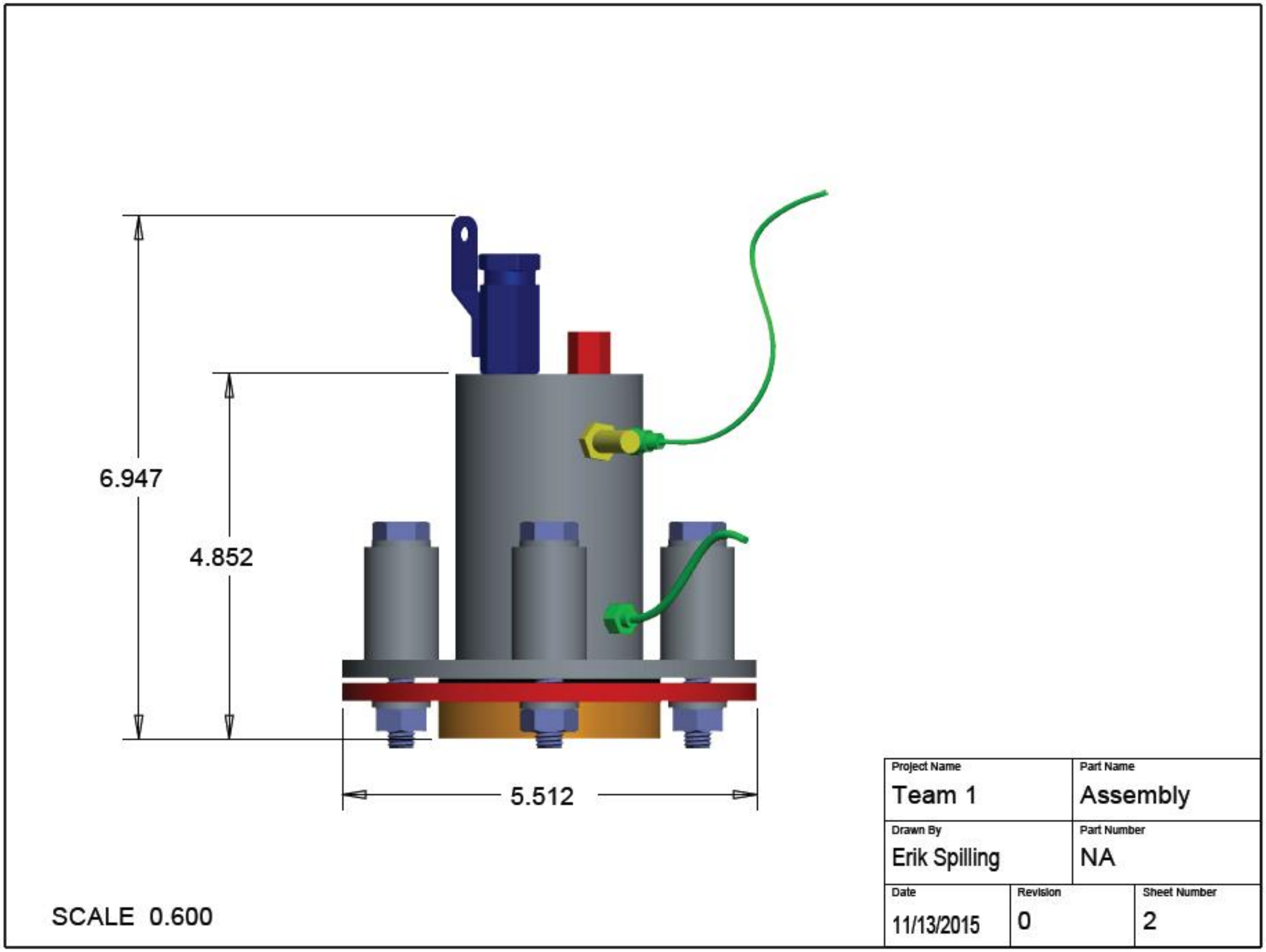
Project Name Team 1	Part Name BOM	
Drawn By Erik Spilling	Part Number NA	
Date 11/13/2015	Revision 0	Sheet Number 1


6.947
4.852
5.512
Project Name
Team 1
Part Name
Assembly
Drawn By
Erik Spilling
Part Number
NA
Date
11/13/2015
Revision
0
Sheet Number
2
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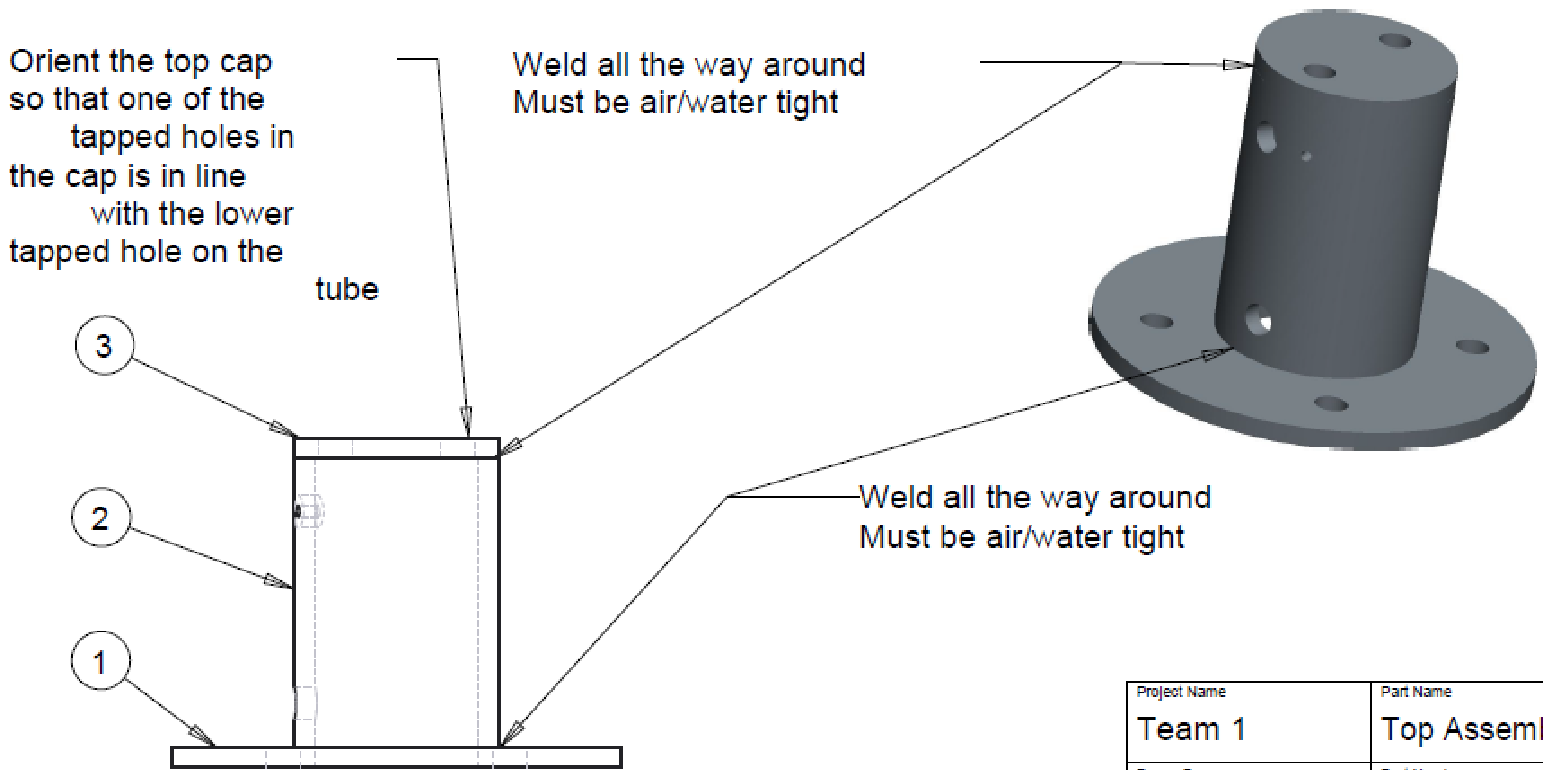
Part Number	Part Name	Quantity	Material
1	Top Flange	1	A36 Steel
2	Top Tube	1	A36 Steel
3	Top Cap	1	A36 Steel



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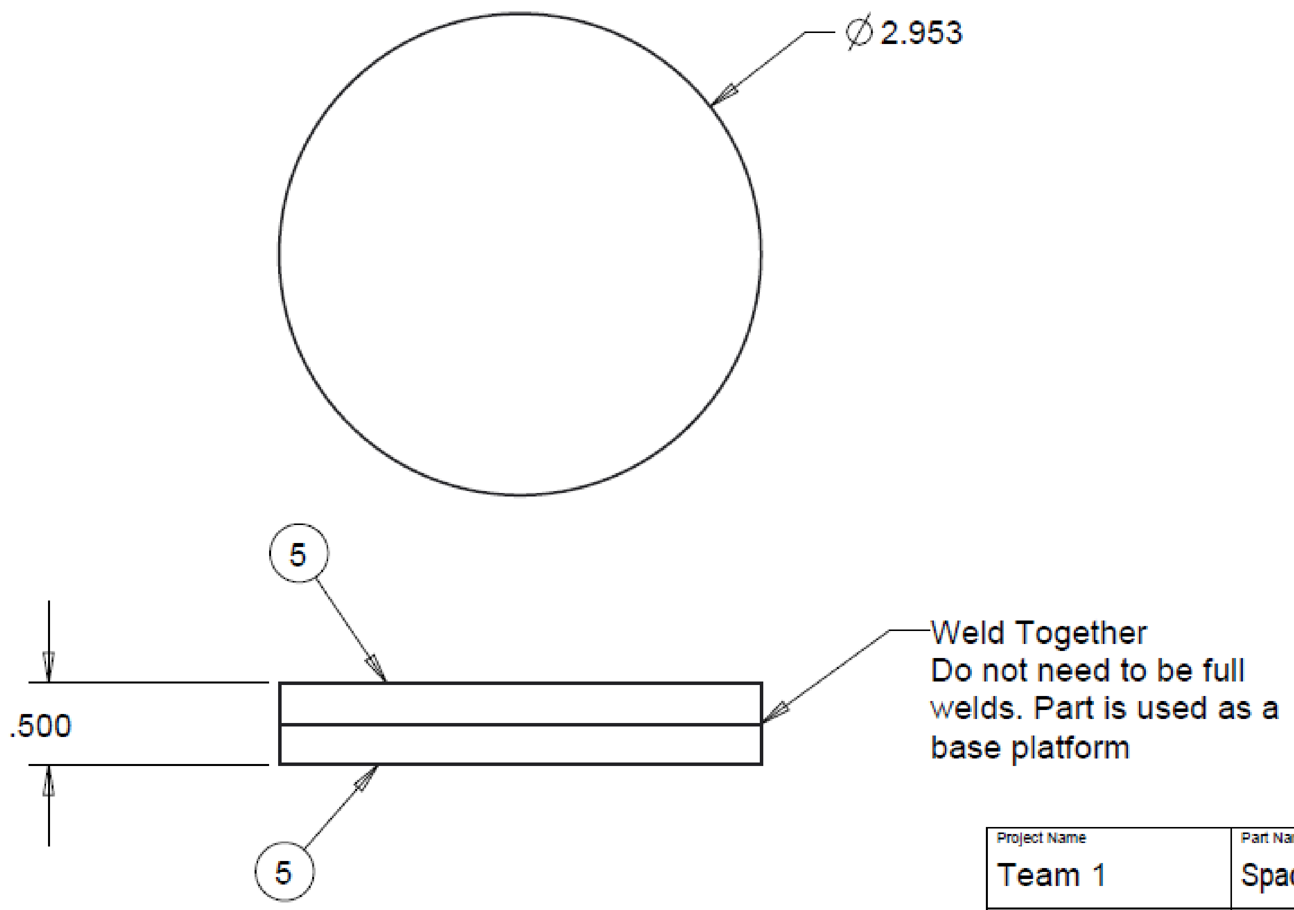
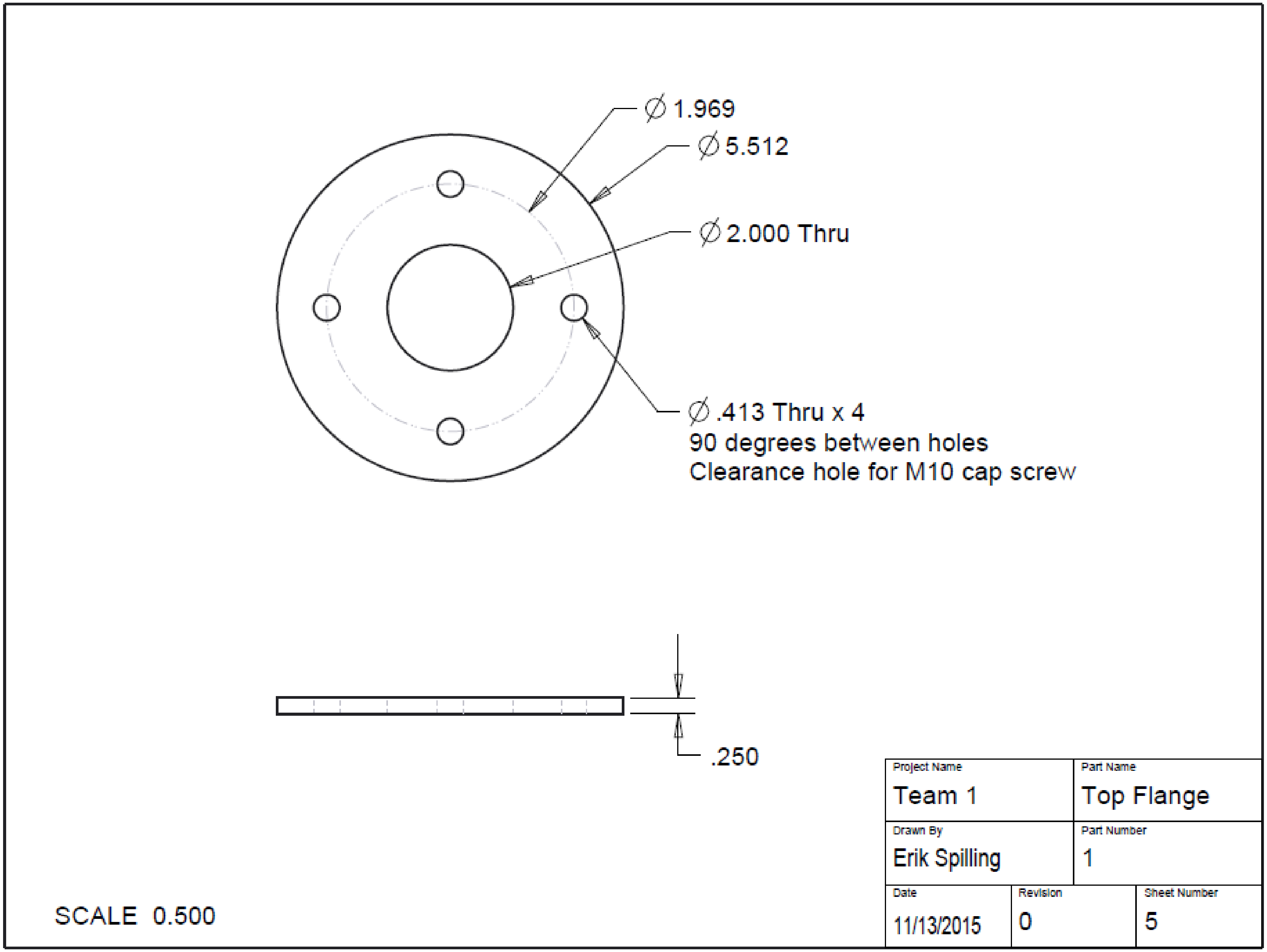
Project Name	Part Name
Team 1	Top Assembly
Drawn By	**Part Number**
Erik Spilling	NA

Date	Revision	Sheet Number
11/13/2015	0	3

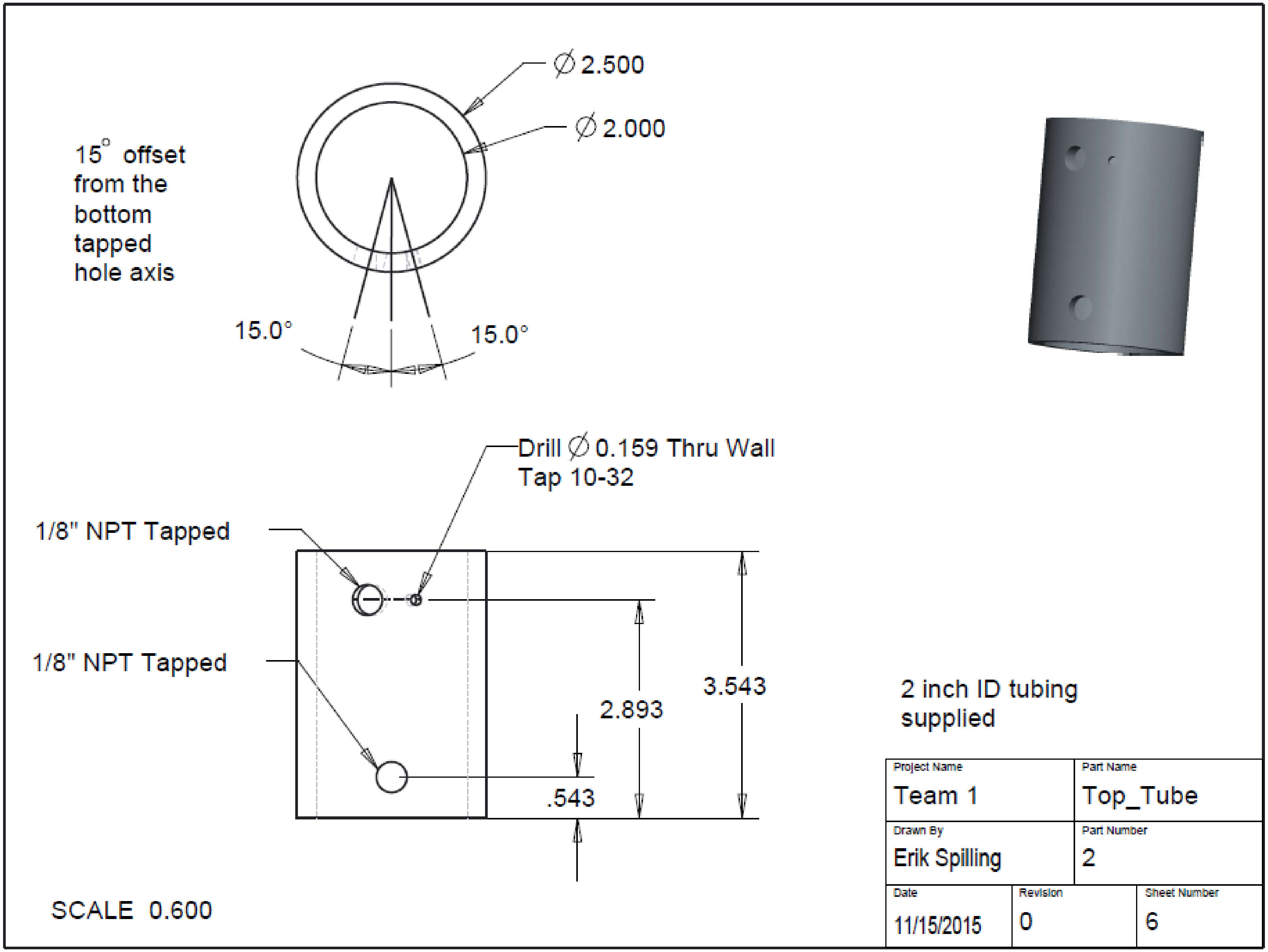
Part Number	Part Name	Quantity	Material
5	Spacer	2	A36 Steel

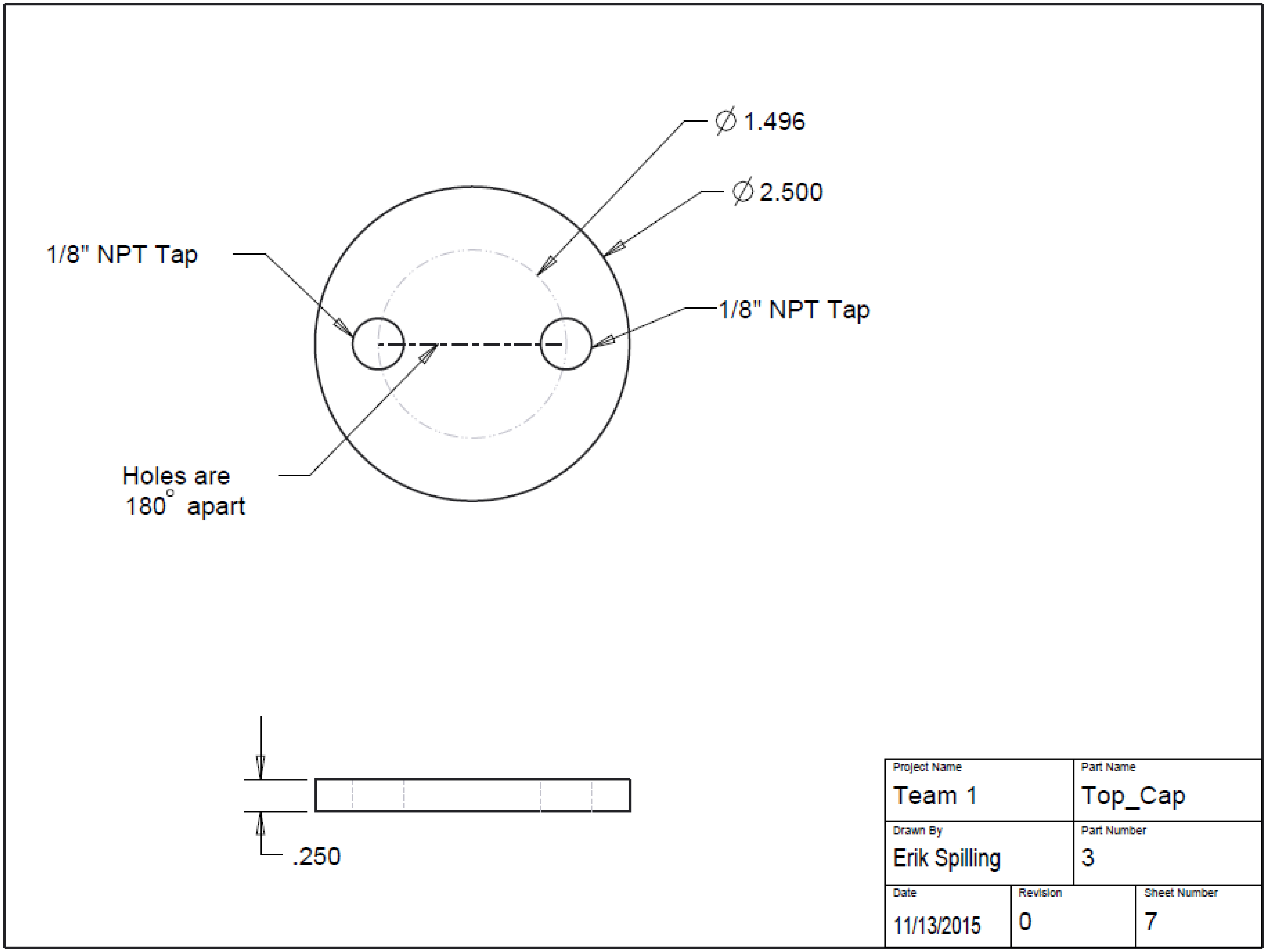


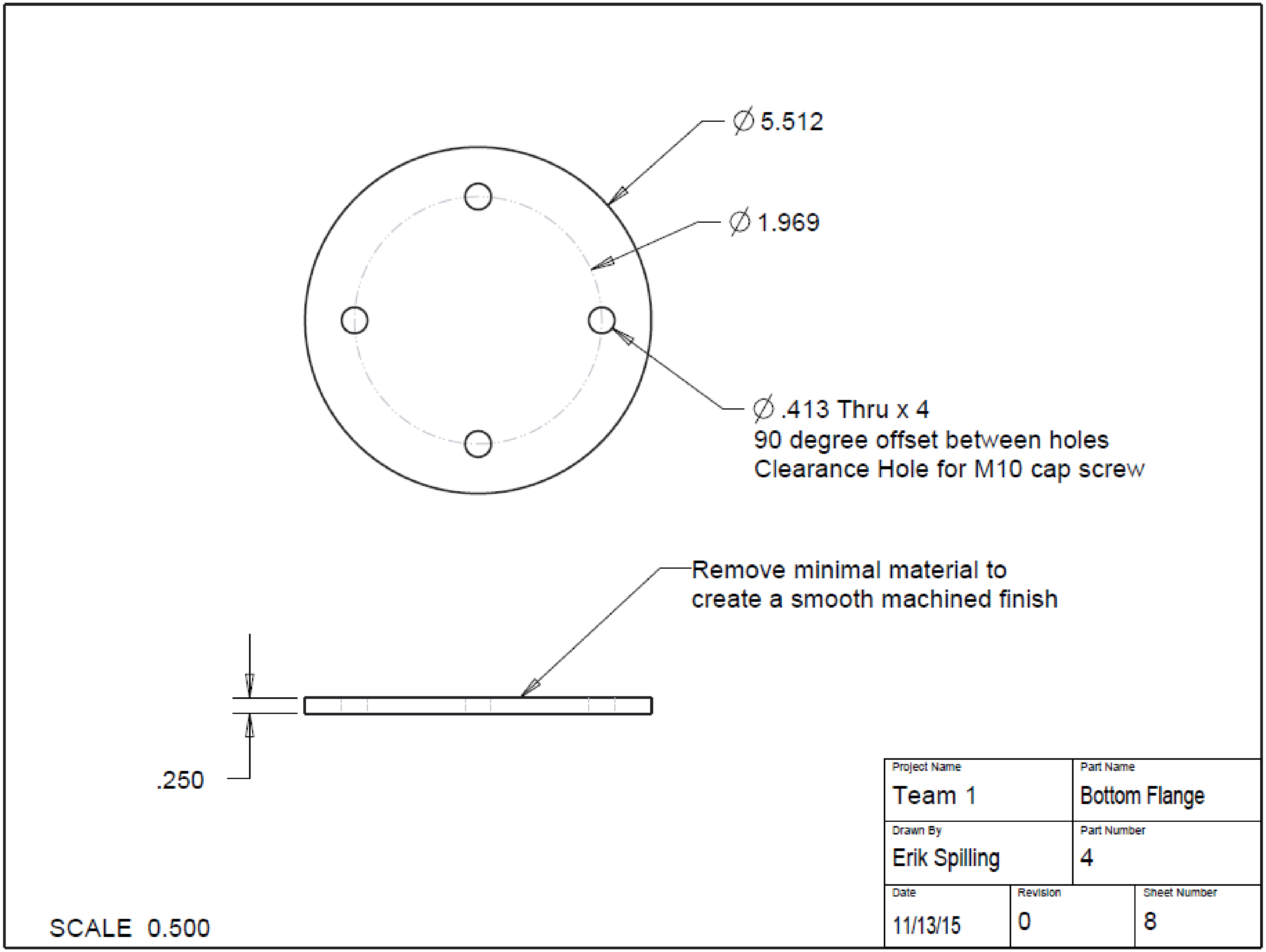
Project Name	Part Name	
Team 1	Spacer Welded	
Drawn By	**Part Number**	
Erik Spilling	NA	
Date	**Revision**	**Sheet Number**
11/13/2015	0	4

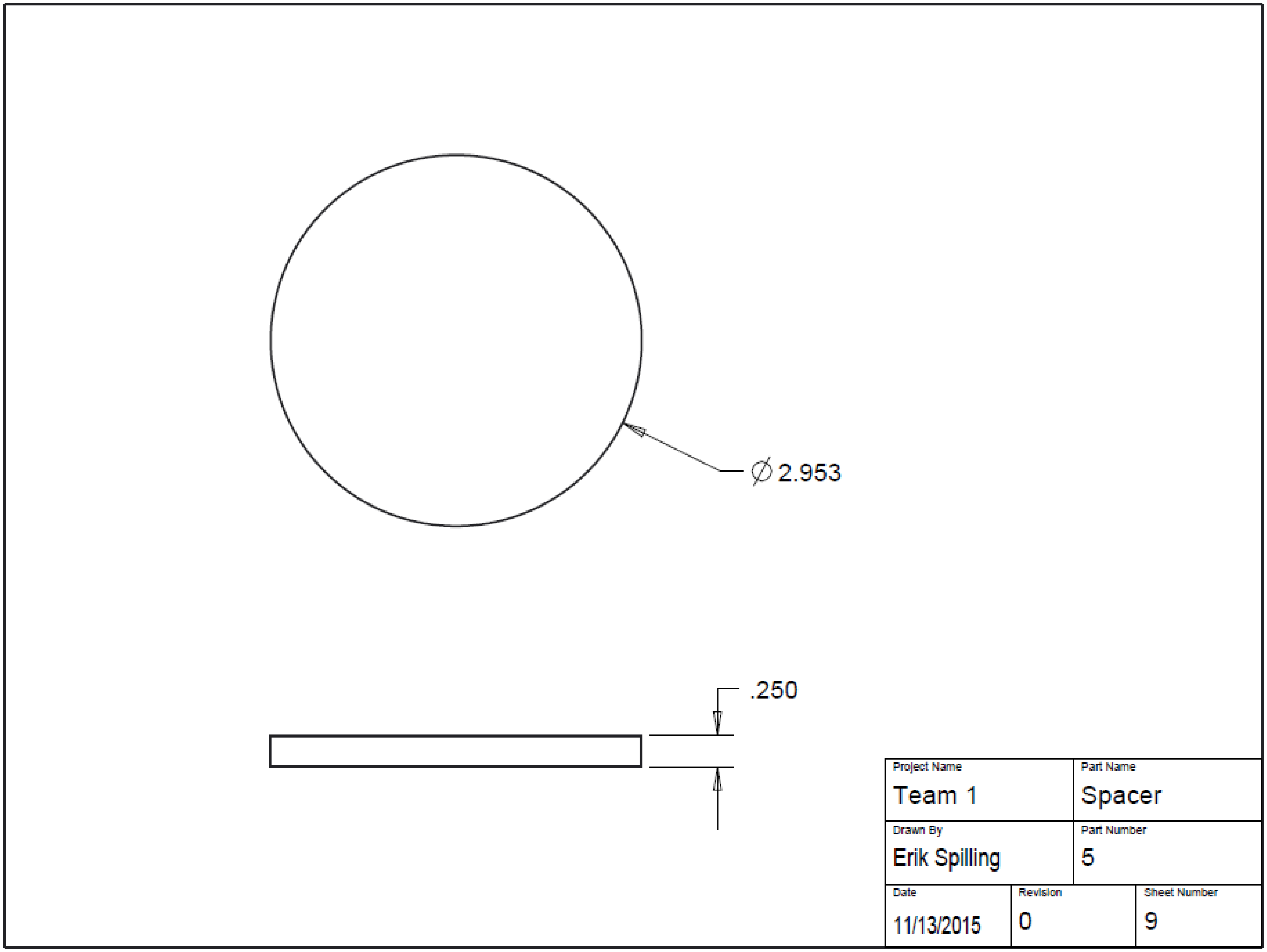


∅ 1.969
∅ 5.512
∅ 2.000 Thru
∅ .413 Thru x 4
90 degrees between holes
Clearance hole for M10 cap screw
.250
SCALE 0.500
Project Name
Team 1
Part Name
Top Flange
Drawn By
Erik Spilling
Part Number
1
Date
11/13/2015
Revision
0
Sheet Number
5


∅ 2.500
∅ 2.000
15° offset from the bottom tapped hole axis
15.0°
15.0°
Drill ∅ 0.159 Thru Wall
Tap 10-32
1/8" NPT Tapped
1/8" NPT Tapped
2.893
3.543
.543
2 inch ID tubing supplied
SCALE 0.600
Project Name
Team 1
Part Name
Top_Tube
Drawn By
Erik Spilling
Part Number
2
Date
11/15/2015
Revision
0
Sheet Number
6

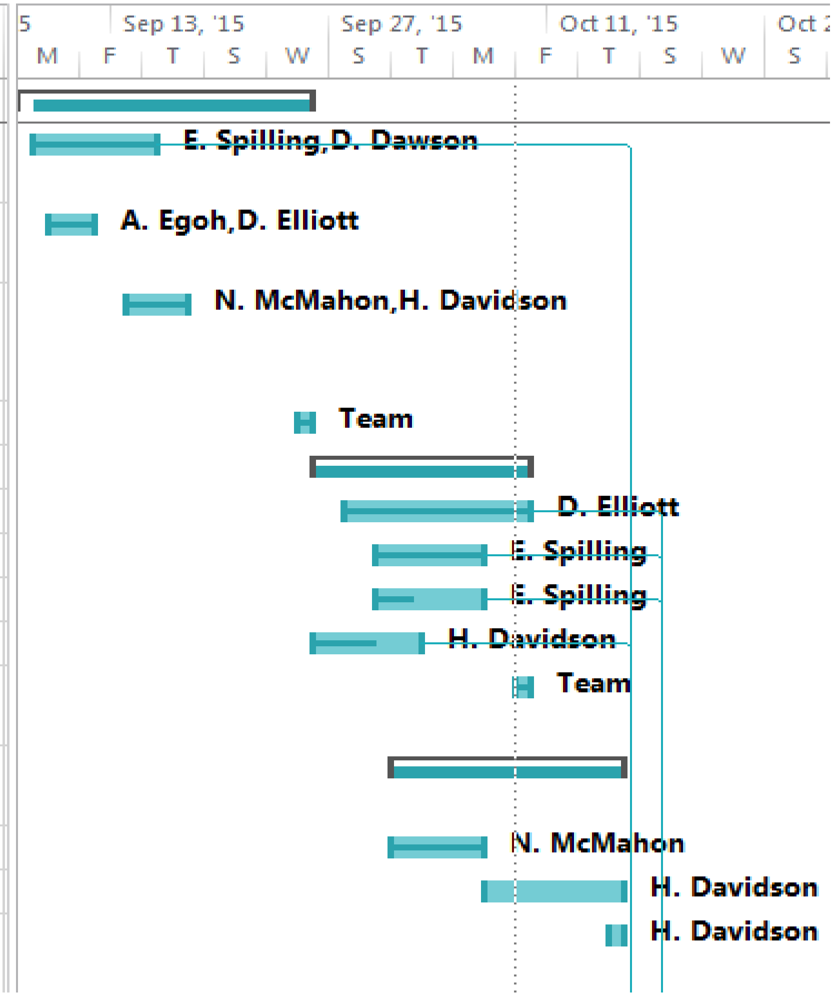

∅ 1.496
∅ 2.500
1/8" NPT Tap
1/8" NPT Tap
Holes are 180° apart
.250
Project Name
Team 1
Part Name
Top_Cap
Drawn By
Erik Spilling
Part Number
3
Date
11/13/2015
Revision
0
Sheet Number
7


∅ 5.512
∅ 1.969
∅ .413 Thru x 4
90 degree offset between holes
Clearance Hole for M10 cap screw
Remove minimal material to
create a smooth machined finish
.250
SCALE 0.500
Project Name
Team 1
Part Name
Bottom Flange
Drawn By
Erik Spilling
Part Number
4
Date
11/13/15
Revision
0
Sheet Number
8


∅2.953
.250
Project Name
Team 1
Part Name
Spacer
Drawn By
Erik Spilling
Part Number
5
Date
11/13/2015
Revision
0
Sheet Number
9

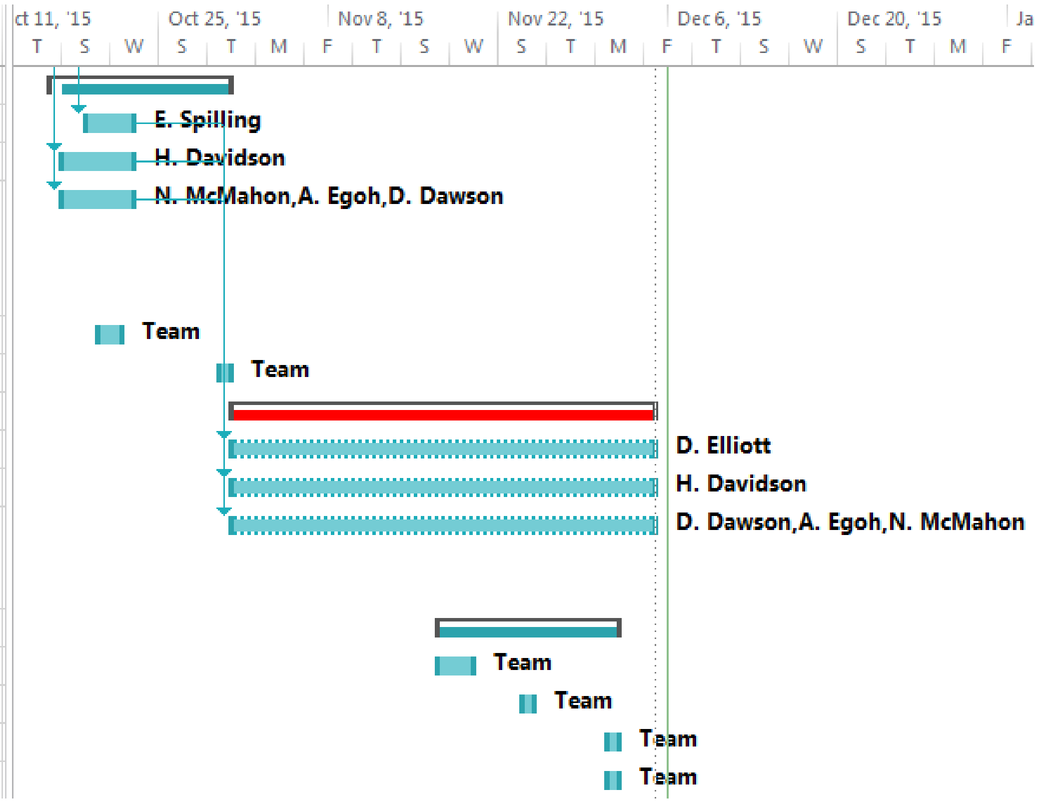
Appendix D

	Task Name	Start	Finish
1	◢ **Background Research**	**Mon 9/7/15**	**Fri 9/25/15**
2	Oleophobic Solutions	Tue 9/8/15	Tue 9/15/15
3	Gasket Materials	Wed 9/9/15	Fri 9/11/15
4	Science of Oleophobicity	Mon 9/14/15	Thu 9/17/15
5	Needs Assessment	Fri 9/25/15	Fri 9/25/15
6	◢ **Concept Generation**	**Sat 9/26/15**	**Fri 10/9/15**
7	Material Calculations	Mon 9/28/15	Fri 10/9/15
8	Mathcad Bolt Calculation	Wed 9/30/15	Tue 10/6/15
9	CAD Drawings	Wed 9/30/15	Tue 10/6/15
10	Hardware Research	Sat 9/26/15	Fri 10/2/15
11	Project Plans and Product Specifications	Fri 10/9/15	Fri 10/9/15
12	◢ **Web Design**	**Thu 10/1/15**	**Thu 10/15/15**
13	Template Selection	Thu 10/1/15	Tue 10/6/15
14	Populate Web Page	Wed 10/7/15	Thu 10/15/15
15	Initial Web Page Design	Thu 10/15/15	Thu 10/15/15



Gantt chart displaying the projected schedule for the first half of the semester

	Task Name	Start	Finish
16	**Concept Selection**	**Fri 10/16/15**	**Fri 10/30/15**
17	Final Test Rig Design	Mon 10/19/15	Thu 10/22/15
18	Hardware Selection	Sat 10/17/15	Thu 10/22/15
19	Sealing Solution Selection	Sat 10/17/15	Thu 10/22/15
20	Midterm Presentation I	Tue 10/20/15	Wed 10/21/15
21	Midterm Report I	Fri 10/30/15	Fri 10/30/15
22	**Part Acquisition**	**Sat 10/31/15**	**Fri 12/4/15**
23	Test Rig Material	Sat 10/31/15	Fri 12/4/15
24	Hardware	Sat 10/31/15	Fri 12/4/15
25	Sealing Solutions	Sat 10/31/15	Fri 12/4/15
26	**Final Design Requirements**	**Tue 11/17/15**	**Tue 12/1/15**
27	Midterm Presentation II	Tue 11/17/15	Thu 11/19/15
28	Final Web Page Design	Tue 11/24/15	Tue 11/24/15
29	Final Design Poster	Tue 12/1/15	Tue 12/1/15
30	Final Report	Tue 12/1/15	Tue 12/1/15



Gantt chart displaying the projected schedule for the second half of the semester

Biography

Erik Spilling: Project Leader

Erik is a Florida State University Mechanical Engineering student from Saint Augustine, Florida. Erik has completed three internships at Cummins Inc., with two of those internships having been spent in High Horse Power Design Engineering. After graduation, Erik will join Cummins Inc. full time as a High Horse Power Design Engineer.

Heather Davidson: Lead ME and Web Designer

Heather is a Florida State University Mechanical Engineering student graduating in May of 2016. Heather was born in Deland, Florida. She has completed two summer internships with ExxonMobil at an oil refinery in Torrance, California. After graduation, she will be working at Southern Company in Birmingham, Alabama.

David Dawson: Financial Advisor

David is a Florida State University mechanical engineering student with a focus on Thermal Fluids and Energy. David was born in South Africa and raised in Jacksonville, Florida. Following graduation, David plans to pursue a job in either energy satiability or work for the armed forces as a mechanical engineering officer.

Aruoture Egoh: Lead Materials Engineer

Aruoture is an exchange student of Florida Agricultural and Mechanical University from Federal University of Technology, Akure, Ondo state, Nigeria. He plans to complete his bachelor's degree in Materials Engineering, attend graduate school to pursue a master's degree and PhD in materials engineering focusing on Polymeric Materials.

Daniel Elliott: Research Coordinator

Daniel is a Senior Mechanical Engineering student with a minor in Psychology and a mixed focus in Materials and Energy Systems. After graduation, he plans to move to Austin, Texas as his first step in his professional career and in order to be closer to his family.

Norris McMahon: Chronicler

Norris is a student at Florida State University originally from Pensacola, Florida. His area of focus is Mechanics and Materials. He has experienced an internship with Blattner Energy Inc. Following graduation, Norris plans to pursue a Masters in Sports Engineering and would like to end up in the Research and Development of sports products field.