Determining the Effectiveness of Oleophobic Gaskets

Design for Manufacturing, Reliability, and Economics

Team Number: 1

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ABSTRACT

The goal of this Cummins Inc. sponsored project was to determine the effectiveness of oleophobic gaskets compared to standard nonoleophobic gaskets. This objective was completed by utilizing on market oleophobic solutions with current gasket materials, as well as non-traditional gasket materials and then testing these products in an experimental test rig, which was designed and constructed by the team. The effectiveness of the oleophobic gaskets was 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 test rig has been 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. The manufacturing steps required in the construction of the test rig and gaskets were documented by the team, as well as suggestions for how to improve the test rig. The test rig was also designed to be as reliable as possible through the use of FEA and other design tools. Finally, the economics of the project were analyzed and the team was able to complete the project under budget.

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 determined what products on the market could be used to give a gasket oleophobic properties, created oleophobic gaskets using these products and nontraditional gasket materials, as well as designed and built a test rig which measures the leak rate of a gasket at various temperatures and pressures. The test rig must be capable of testing oils that range from 22 to 120° C and inducing a pressure on the oil ranging from 0 to 2.5 psi. Once the design and construction of the project was completed, tests were performed on oleophobic and standard gaskets using the test rig and results will be compared to determine the effectiveness.

2 Design for Manufacturing

For the fabrication of the test rig, machining occurred in two locations. The machining and fabrication of the steel components, such as the flanges, was completed at the FAMU-FSU College of Engineering Machine Shop because the use of the water jet was needed. The only component not fabricated at the FAMU-FSU College of Engineering Machine Shop was the strain gauge bolts. These bolts were machined at a Cummins Inc. facility in Columbus, Indiana. Cummins Inc. had the experience and capabilities to modify a standard M10 bolt in order to incorporate strain gauges; therefore, it was decided it would be best to allow Cummins Inc. to prepare the bolts. Full CAD drawings are shown in Appendix A, where details such as dimensions, materials, and tap sizes can be found. The drawings in Appendix A also state all the part names, as well as the quantity in which they are needed in the test rig.

2.1 Sub-Assembly Fabrication

Before assembly of the test rig could occur, the Top Assembly sub-assembly needed to be fabricated. The Top Assembly consists of the following parts: Top Flange, Top Tube, and Top Cap. These parts were welded together using stainless steel weld, and the welds were done as full beads in order to create an air tight joint between the parts. In Figure 1, the Top Assembly is shown in its exploded view in order to show how the components mate together prior to welding. After the welding was completed, the Oil Inlet Valve, Pressure Relief Valve, Air Inlet Valve, and the RTD sensor with its compression fitting were assembled to the Top Assembly. Each of these parts had NPT threads in order to create an air tight seal; therefore, it was required to apply significant torque to each part while installing in order to distort the threads as desired. As an additional form of sealing, PTFE Teflon tape was wrapped around the threads of the parts before they were installed into the Top

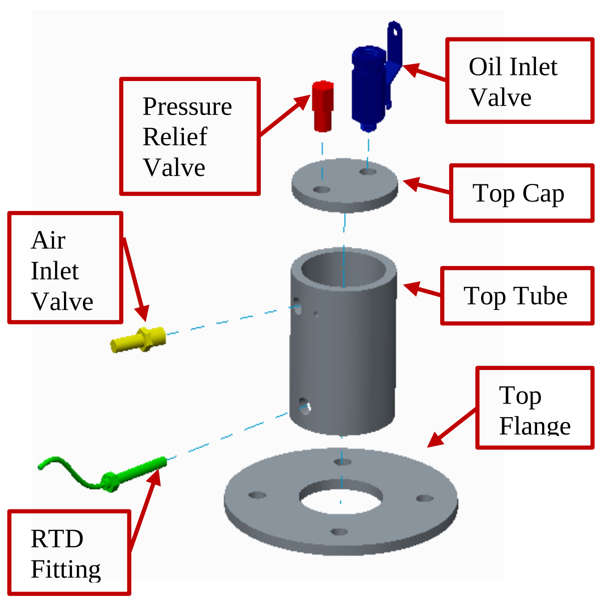


Figure 1. Exploded view of the Top Assembly

Assembly. This serves as an additional seal in order to ensure there is no gap between threads. The rest of the parts for the test rig do not require sub-assembly, and therefore are included in the final assembly stage.

2.2 Assembly of Test Rig

After completing the Top Assembly sub-assembly, the remaining components could be assembled to the test rig. This assembly process occurs before every use of the test rig, meaning that this assembly is done before every gasket test. Figure 2 shows the final assembly exploded view for the test rig.

The first step of the assembly is to place the Bottom Flange on top of the Spacer. If the test being performed is a high heat test, then the Spacer should be placed on top of the cool hot plate prior to placing the Bottom Flange onto it. Once the Bottom Flange is in position, the next step is to place the gasket onto the Bottom Flange. The tabs which were welded onto the Bottom Flange serve as a method of centering the gasket. So while assembling the gasket to the Bottom Flange, the tabs on the Bottom Flange were always placed within the inner diameter of the gasket.

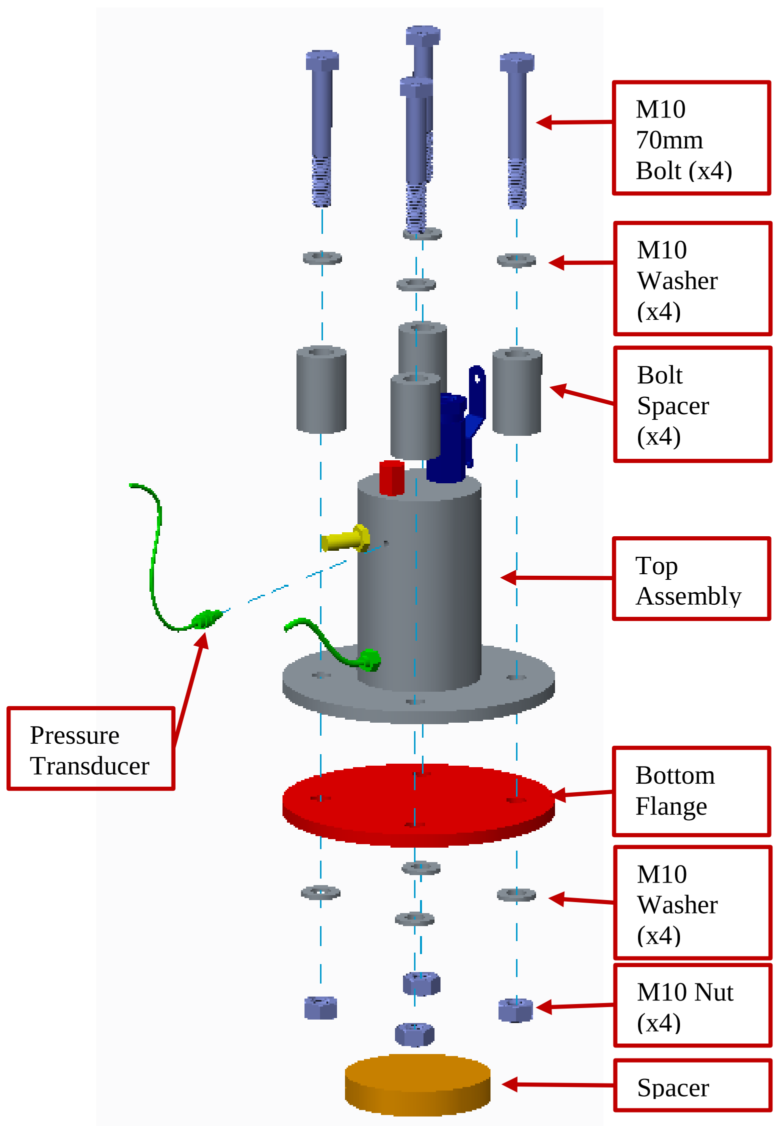


Figure 2. Exploded view of the final assembly for the test rig.

With the gasket in position, the Top Assembly was then lowered onto the gasket. While lowering the Top Assembly, care was taken to ensure the bolt thru holes from the Top Assembly and the Bottom Flange were aligned along their respective center axes. This removes the need to adjust the alignment after the Top Assembly is fully lowered, since adjustments after that point can cause damage to the gasket.

The next step in the assembly was to install the Bolt Spacers, Bolts, Washers, and Nuts. The arrangement of these parts can be found in Figure 2. For the purpose of conducting an experiment/test on a gasket, the nuts are not torqued down immediately. Since the bolts are strain gauged, it is important to collect the unstrained microstrain value. This is used to calibrate each bolt prior to applying a load. After the unstrained microstrain value was recorded, the bolts were tightened to the desired bolt load value. During the tightening process, the bolts were gradually loaded while alternating between sides of the test rig in order to ensure even loading on the gasket.

With the Bolts installed, the final step in the assembly of the Test Rig was to install the Pressure Transducer. This is done after oil is added to the test rig. That process is part of the testing procedure, and not the assembly of the test rig. The Pressure Transducer is installed into the Top Assembly section of the test rig using an 8 mm wrench.

2.3 Manufacturing of Oleophobic Gaskets

Oleophobic gaskets were also manufactured by the team. There were two different solutions chosen to make gaskets oleophobic; Staingaurd WB Impregnator and Ultra-EverDry Spray. For the Impregnator, the manufacturing process consists of dipping the gaskets into a bath of the solution and then allowing it to dry for 24 hours. For the Spray, the manufacturing process consists of applying two different coats via an aerosol spray. The first coat is an adhesive layer, which must be allowed to dry for 1 hour before application of the second coat. The second coat is the oleophobic solution, and it must be allowed to dry for 2 hours after application.

The gaskets which were manufactured were impregnated paper gaskets, sprayed Rubber Coated Metal (RCM) gaskets, and impregnated and sprayed combination felt gaskets. The oleophobic paper and RCM gaskets were made by applying the solutions to standard paper and RCM gaskets which were provided by Cummins Inc. The felt gasket was first cut to size from a sheet of high density felt and then had the oleophobic solutions applied. The total time to create the gaskets, including the 24 hour dry time, was 25 hours.

2.4 Assembly Time

The assembly of our test rig occurred over a period of about 2 months. However, this is not reflective of how long the actual assembly time is. The reason that the assembly process took a month to complete was because the strain gauged bolts provided by Cummins Inc. arrived much later than scheduled. Table 1 shows the timeline of the assembly process of the test rig in both the actual dates, as well as the physical number of hours to perform the task. The majority of the assembly time was from the fabrication process in the COE Machine Shop, where the cutting and welding of the Top Assembly was done. The rest of the assembly process was just installing threaded components, so the assembly time in terms of hours was relatively short.

Table 1. Assembly Time for Test Rig

Assembly Task	Time Span to complete	Duration (hours)
Fabrication in COE Machine Shop	1/11/2016 - 1/20/2016	5
Installation of Oil Inlet Valve, Air Inlet Valve, and Pressure Relief Valve	1/21/2016	1
Installation of RTD sensor	3/1/2015	0.25
Final Mock Up Assembly	3/1/2015	0.5
Total Assembly Time	1/11/2016 - 3/1/2016	6.75

2.5 Design Optimization

During the design process of the test rig, the team made a strong effort to keep the design as simple as possible. Therefore, it would be very difficult to reduce the number of components of the system. Every component on the system serves an important role. For example, all items on the Top Assembly, such as the Oil Inlet Valve, Air Valve, etc. were needed for the functionality of the test rig. Even items such as the Bolt Spacer were required for functional usage, since Cummins, Inc. required that the strain gauged bolts have at least two inches of length between the bolt head and the first engaged thread.

However, there could be an added component to the test rig which the team did not anticipate needing. This component is an additional RTD sensor in the air cavity. During testing, it was discovered that the air temperature does not reach equilibrium as quickly as the oil, and thus the air temperature continued to increase even after the RTD sensor in the oil displayed a stabilized condition. With the addition of an RTD sensor in the air cavity, the air temperature could be measured as well to ensure that there isn't a temperature fluctuation in the air. The team discovered this air temperature fluctuation during testing, because a pressure increase was recorded instead of a pressure decrease. The only source of a pressure increase would be the air temperature changed.

3 Design for Reliability

In order to ensure consistent results when testing gaskets, various methods of design analysis were completed before the final prototype was constructed, including a Failure Modes and Effects Analysis (FMEA), a Finite Element Analysis (FEA) of the contact pressure, a surface roughness measurement, and a minimum material thickness analysis.

The first analysis conducted was FMEA on the test rig (Table 2). Each part of the test rig was analyzed to determine the most likely methods of failure. In order to reduce or eliminate the possibility of these failure modes, the last column of the table recommends an action.

Table 2. FMEA Table

Component	Mode Of Failure	Cause	Probability	Effect	Severity	Recommended Action
Flanges	Bending	Torque	4	Increase in leak rate	2	Monitor torque wrench
	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	Blowout	6	Factor of Safety
		Tolerances	2			
Sensors	Overload	Improper selection	1	Inaccurate results	6	Consult sensor data sheet
	Inaccuracy					

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

The second analysis conducted on the prototype was FEA on the gasket pressure, shown in Figure 3. This shows the pressure distribution along the gasket face due to a 10MPa clamping pressure. The FEA results proved that the use of four bolts was sufficient because the gasket face had the desired clamping load and showed no leak paths as a result of the design.

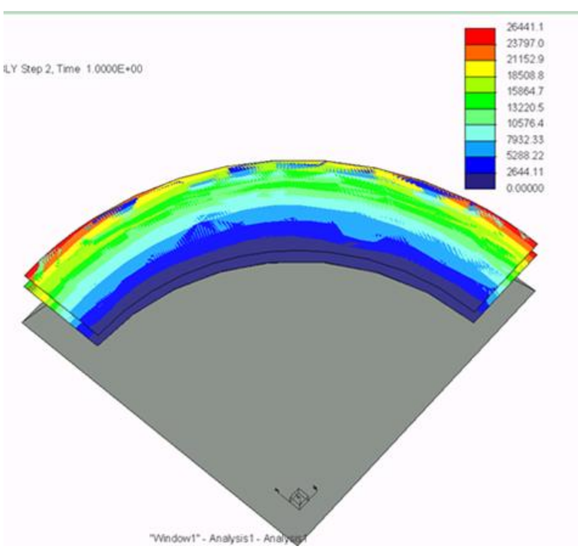


Figure 3. FEA of the Pressure Distribution (10 MPa)

Another analysis completed was the measurement of the flange surface roughness using a Coherix ShaPix S150 sensor. Initially, the average surface roughness values found were higher than the 3.2 micron RA maximum Cummins Inc. had set for the test rig; however, this was mitigated by sending the flanges back to the machine shop in order to decrease the surface roughness.

The final analysis conducted was to verify that the thickness of the material being used for the test rig was thick enough to prevent any yielding or failure under pressurized and loaded conditions. This analysis considered the maximum internal stress of the test rig of 2.5 psig and the maximum clamping bolt pressure of 10 MPa. The result of the analysis was that the minimum thickness of the test rig was 4.94 mm, and therefore the team selected 6.35 mm material to provide a factor of safety.

In addition to the above analyses, the reliability of the test rig could be improved with some additional long-term design problem mitigations. The provided raw strain gauge wires protruding from the bolts machined by Cummins Inc. would not be sustainable long-term because of their susceptibility to breakage with a small application of force to the connection. This weakness could be corrected through the use of a protective casing to ensure the protection of the connections.

This design could be reliable for hundreds of tests because of the careful analyses conducted on each aspect of the test rig, as well as the simplicity of the design. One source of reliability concern would be damage to the flange surfaces after repeated use, such as scratches. This damage could be easily remedied with a simple finishing pass or some other method of machining the flange to produce a surface roughness within the defined machining standards.

4 Design for Economics

The budget given for this project was $2,000 through the Aero Propulsion, Mechatronics and Energy Center. This budget was used to acquire all of the materials that were needed for application and testing for determining the effectiveness of oleophobic gaskets. Even after calculating for the maximum prices, the total estimated cost only came out to $1,850, which left a remainder of $150 in case of an emergency.

In Appendix B, 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. The test rig sensors cost $704.00 and the test rig materials cost $218.41. The oleophobic solution cost $70.00, whereas the teflon gaskets cost $170.00. The rest of the money spent was used for anything needed for the testing process which totaled $73.42. The pie chart in Figure 4 shows the percentage breakdown of the different budget categories.

After extensive research, a similar test rig made by the German company Amtec was found; however, this test rig is not for sale [1]. It measures bolt load and leak rate but does not measure temperature. Also, for the leak rate to be calculated correctly, the test rig must be placed in a vacuum chamber and the leak is measured using a helium mass spectrometer, which would be much more expensive than our test rig design.

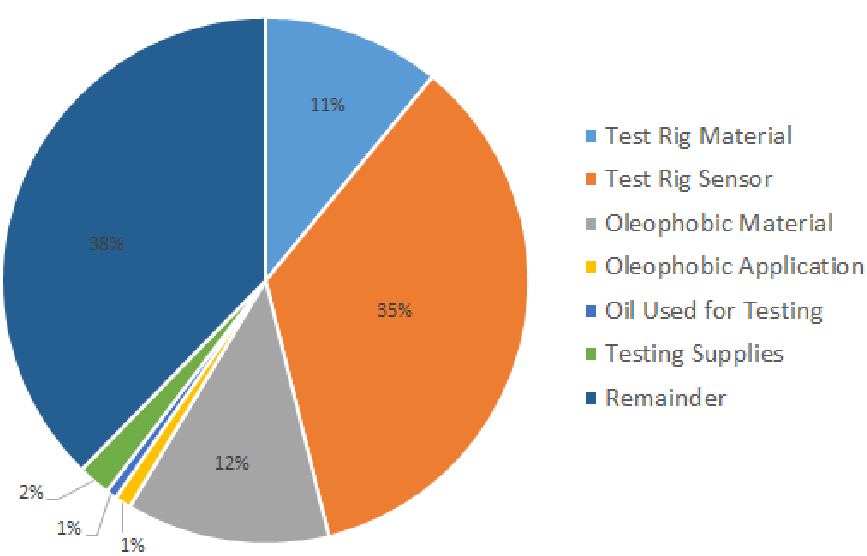


Figure 4. Pie chart showing distribution of funds

5 Conclusion

The team was tasked with designing and building a test rig which could test standard and non-standard gaskets, with and without oleophobic solutions. The test rig was also designed to handle an internal pressure of 2.5 psi, a temperature range between 22°C and 120°C, and variable clamping loads between 0.5 MPa and 10 MPa.

The estimated assembly time for the machine shop was listed at about 5 hours total to completely manufacture the test rig. The rest of the components assembly took about 2 hours to have a full functioning test rig that could provide adequate results. FMEA, minimum thickness analysis, and FEA were done to ensure the safety of the test rig and that the test rig would satisfy all required constraints. For example, the FEA confirmed that there were no significant leak paths as a result of the test rig design, and therefore any leak would be a result of the gaskets. Also, a Coherix ShaPix S150 sensor was used to ensure an acceptable surface roughness for the top and both interchangeable bottom flanges.

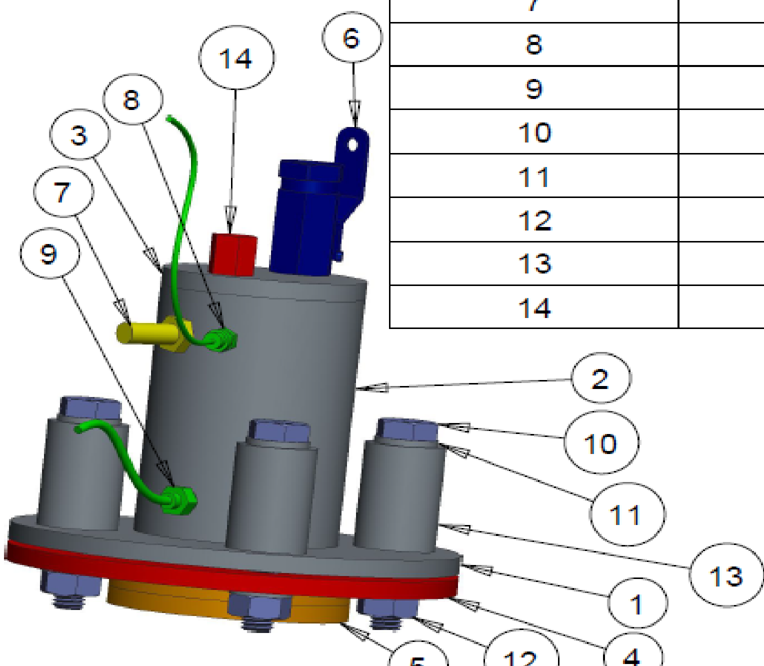
Lastly, the majority of the budget Cummins Inc. provided went to test rig sensor acquisition which amounted to 35% of the overall $2,000 budget. The second and third largest went to purchasing the oleophobic material (12%) and purchasing the test rig A36 steel (11%). The rest of the items in the budget were a small percentage of the budget. At the end of item purchasing, the team ended up only spending 62% of the overall $2,000 budget allocated for this project. Also, a leak rate testing device could not be found on the market which was capable of testing as many conditions as the test rig built by the team, so a price comparison could not be computed.

References

[1] "Leakage Test Rig." Gasket Test Rig for Leakage Testing. Web. 01 Apr. 2016. <http://www.amtec-services.com/leakage-test-rig-TA-Luft.html>.

Appendix A

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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Drawn By	Part Number
Erik Spilling	NA

Date	Revision	Sheet Number
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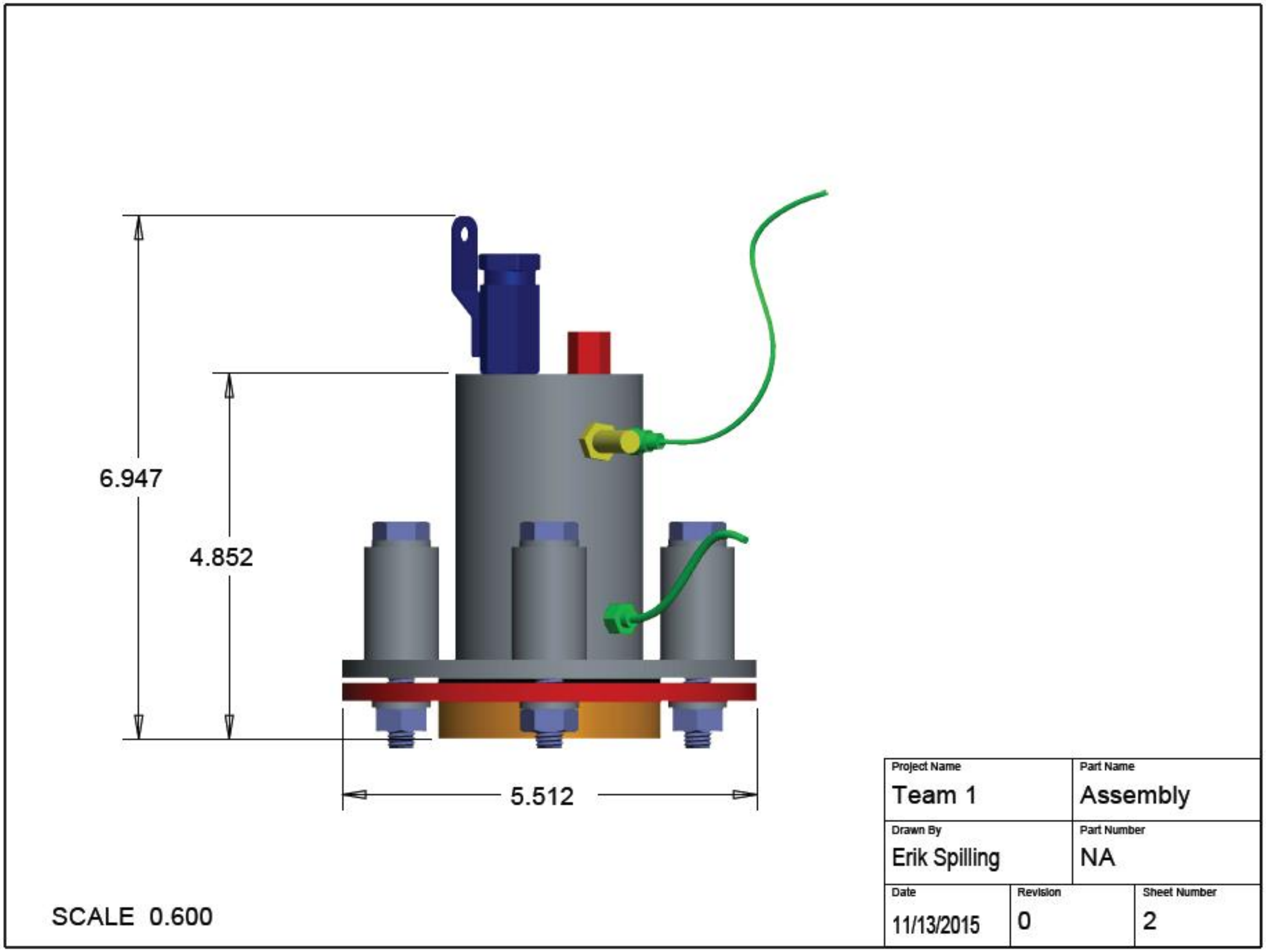
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Part Name
Assembly
Drawn By
Erik Spilling
Part Number
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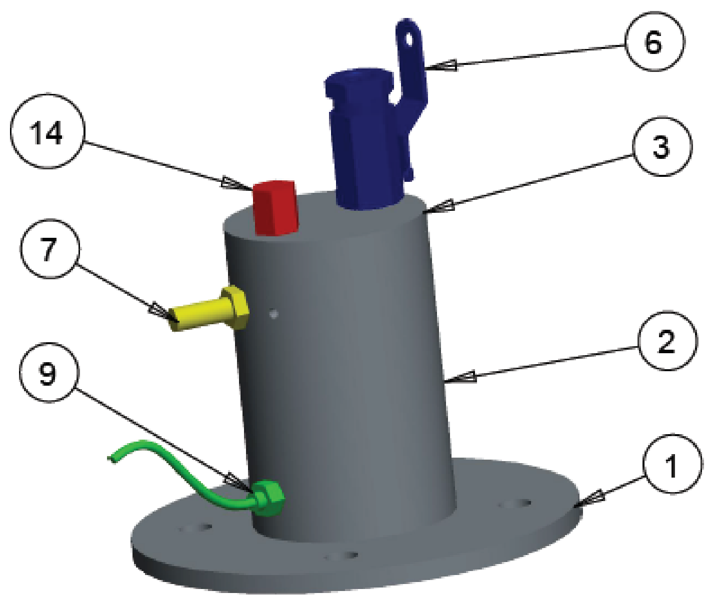
Date
11/13/2015
Revision
0
Sheet Number
2

Part Number	Part Name	Quantity	Material
1	Top Flange	1	A36 Steel
2	Top Tube	1	A36 Steel
3	Top Cap	1	A36 Steel
6	Oil Valve	1	Bronze
7	Air Valve	1	Bronze
9	RTD Sensor	1	Steel
14	Pressure Relief Valve	1	Bronze



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Date	Revision	Sheet Number
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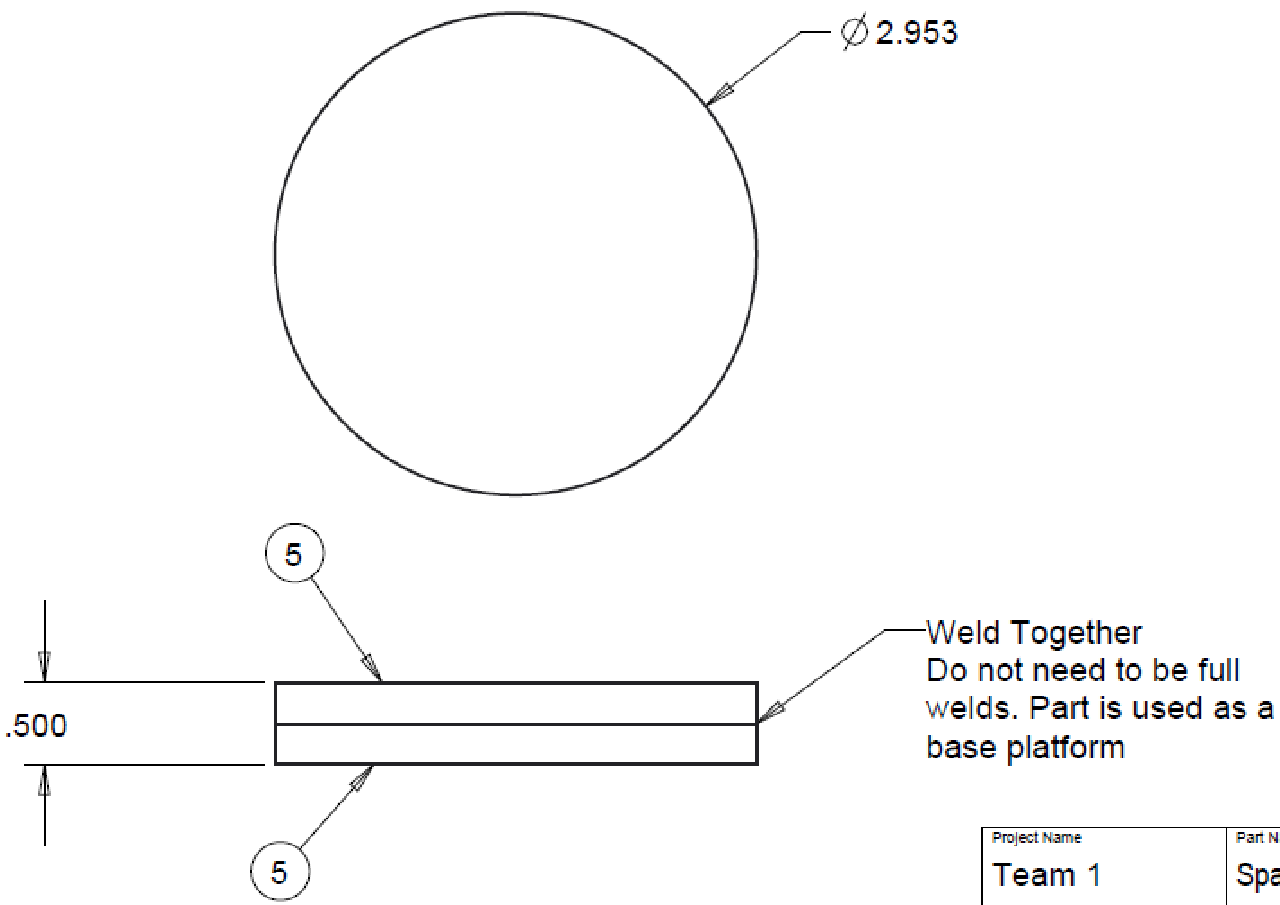
Part Number	Part Name	Quantity	Material
5	Spacer	2	A36 Steel



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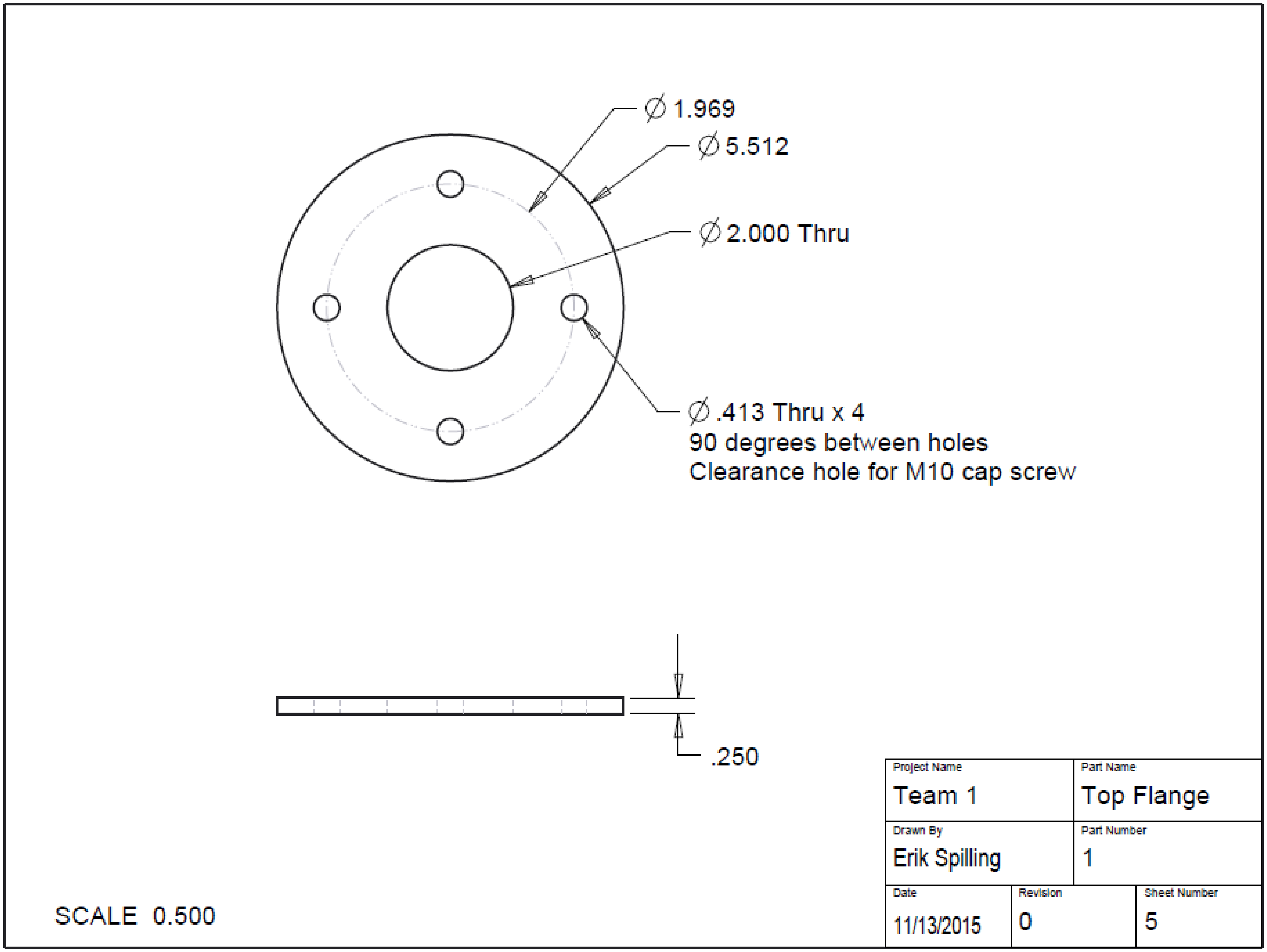
Ø 1.969
Ø 5.512
Ø 2.000 Thru
Ø .413 Thru x 4
90 degrees between holes
Clearance hole for M10 cap screw
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Part Name
Top Flange
Drawn By
Erik Spilling
Part Number
1
Date
11/13/2015
Revision
0
Sheet Number
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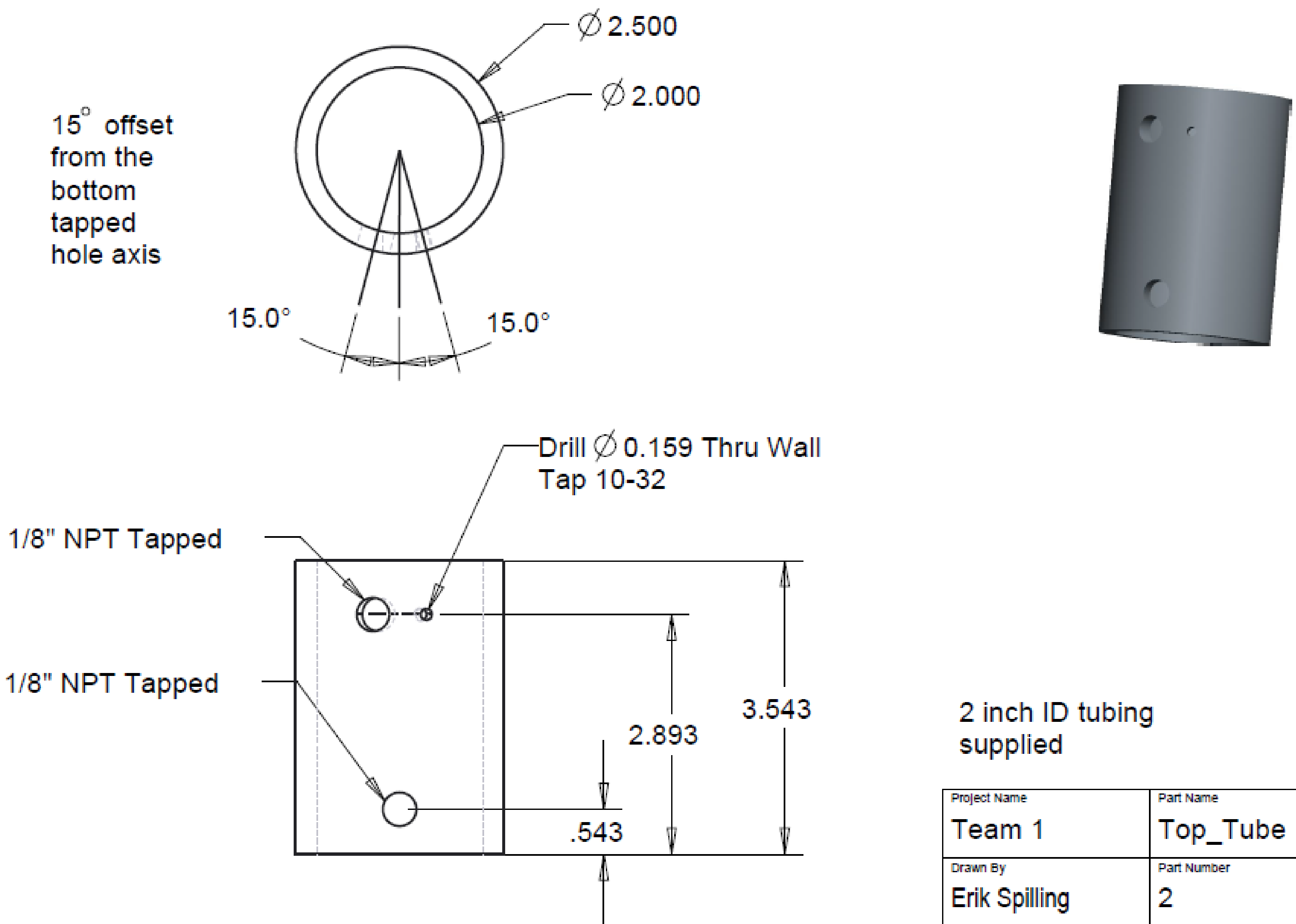

2 inch ID tubing supplied

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Drawn By: Erik Spilling		Part Number: 2
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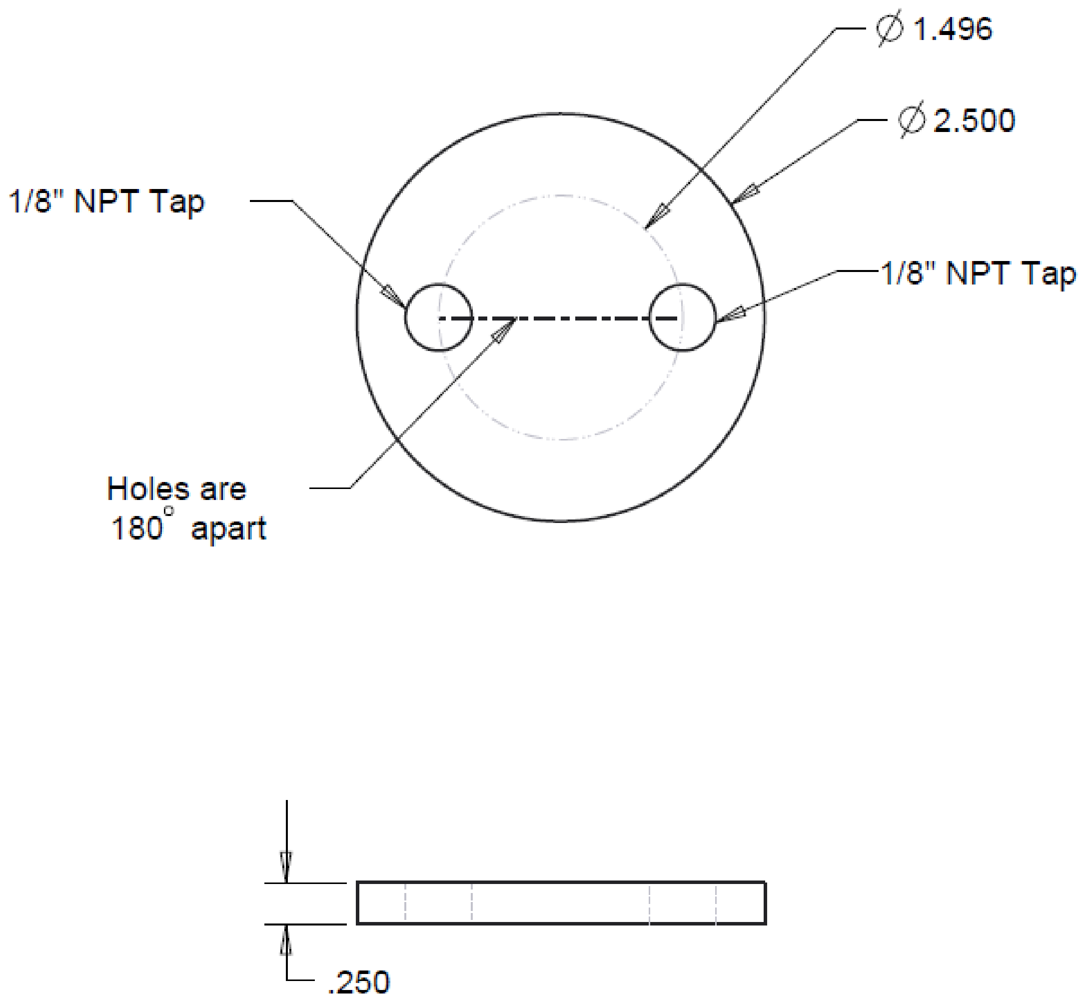

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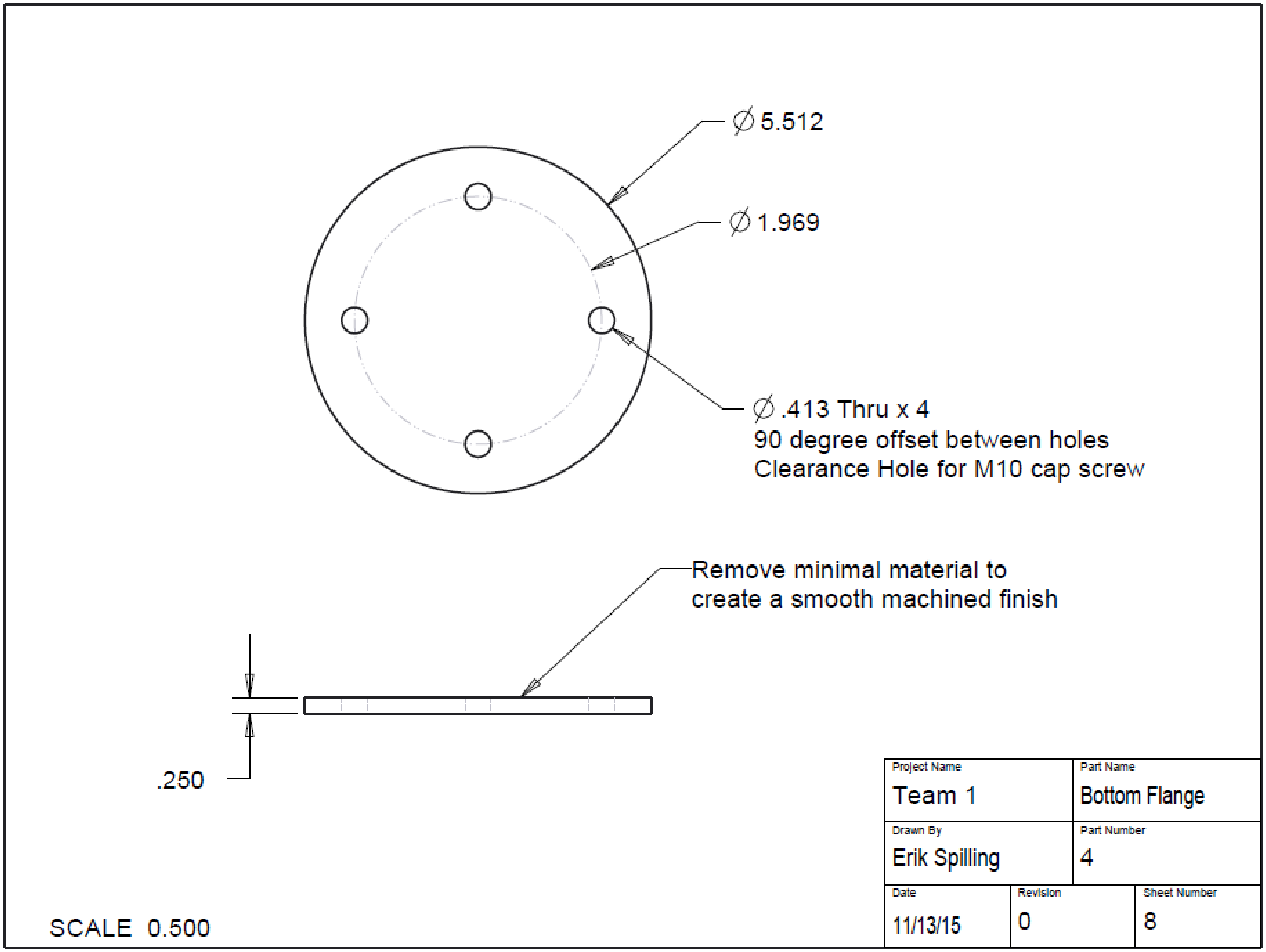
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Clearance Hole for M10 cap screw
Remove minimal material to
create a smooth machined finish
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Bottom Flange
Drawn By
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Date
11/13/15
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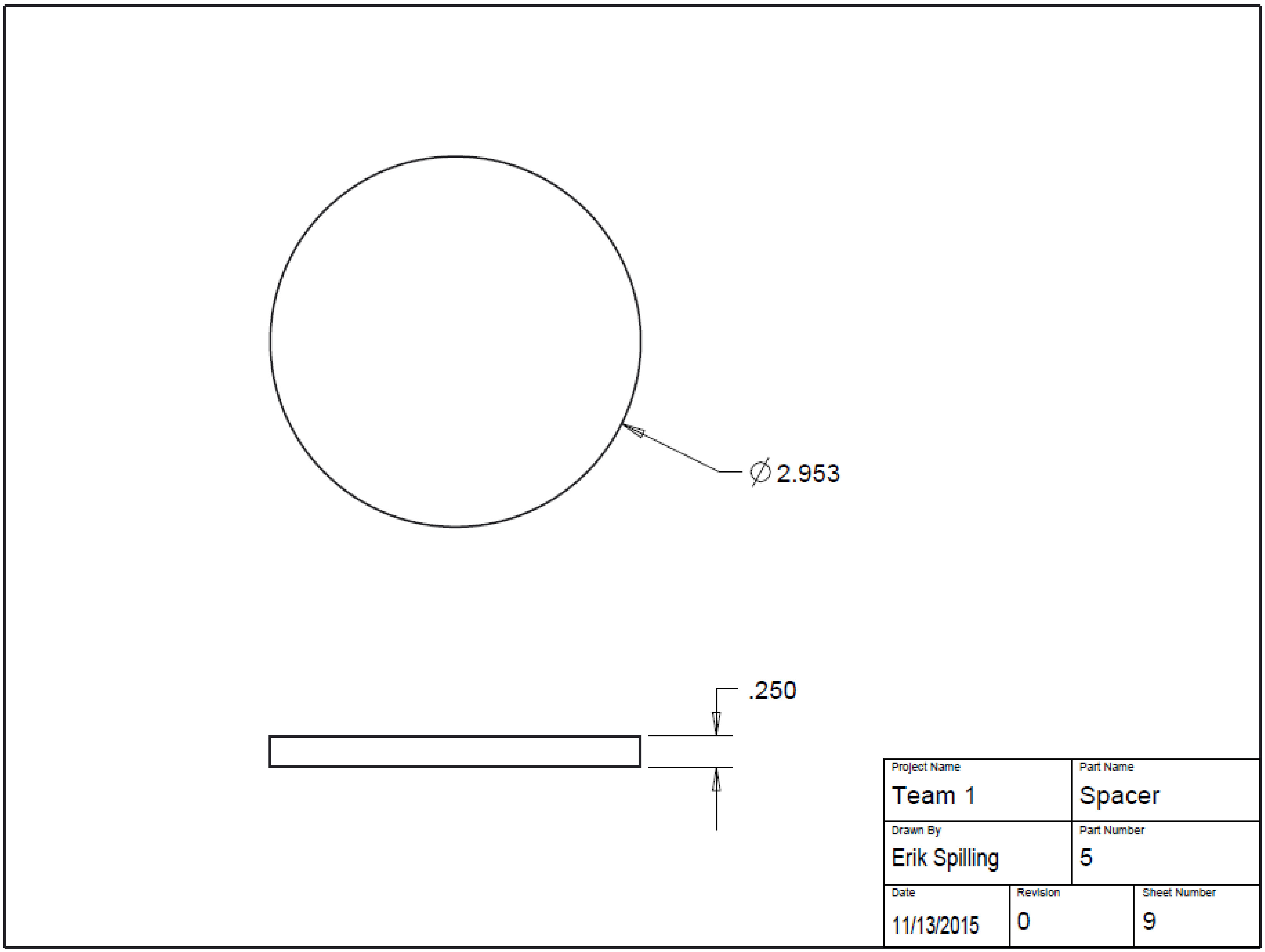
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Team 1
Part Name
Spacer
Drawn By
Erik Spilling
Part Number
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Date
11/13/2015
Revision
0
Sheet Number
9

Appendix B

Total Cost Breakdown

Budget Category	Item	Quantity	Cost
Test Rig Material	M8 Class 10.9 Cap Screw	1(Pack of 25)	$7.91
Test Rig Material	M8 General 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	M10 General Purpose zinc plated steel washer	1 (Pack of 100)	$4.36
Test Rig Material	M10 Class 8 Zinc Plated Steel Hex Nut	1 (Pack of 100)	$10.48
Test Rig Material	Zinc-Plated Steel Unthreaded Spacer	4	$55.32
Test Rig Material	M10x1.5 70mm long class 8.8 cap screw	1 (Pack of 10)	$8.58
Test Rig Material	Pressure Relief Valve	1	$48.00
Test Rig Material	Compact High-Pressure Brass Ball Valve	1	$11.34
Test Rig Material	Brass Air Fill Valve Straight	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 OD x 2 ID Round Steel Tube	1	$36.04
Test Rig Material	**Total**		**$218.41**
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
Oleophobic Material	Oleophobic Impregnator	1(Gallon)	$80.00
Oleophobic Material	**Total**		$250.00
Oleophobic Application	Spray Gun	1	$19.99
Oil Used for Testing	T Triple Protection CJ-4 15W-40 Motor Oil	1 (Gallon)	$13.44
Testing Supplies	Torque Wrench	1	$39.99
Purchased	**Total**		**$1,245.83**

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.