Design for Manufacturing, Reliability and Economics Report

Team 1

Sealing Ring Testing and Characterization

Members:

Tawakalt Akintola	
Richard Edgerton	Rme11c
Erin Flagler	Ef11d
Emilio Kenny	Eak12d
Kenneth McCloud	Ksm10h

Faculty Advisors:

Dr. William Oates

Dr. Farrukh Alvi

Sponsor:

Cummins, Inc.

Instructors:

Dr. Nikhil Gupta

Dr. Chiang Shih

April 3rd, 2015

Table of Contents

Table of Figures

Table of Tables

ABSTRACT

Designing a test fixture to be used in static face seal compression tests began with assessing the MTS machine available. An MTS machine model C45.105 with a 50 kN load cell was available, so measurements were taken of the mounting receivers. These measurements were used to design the mounting shafts of the test fixture. The next part of the test fixture is the groove plate which has a groove cut in it that is specific to each seal sample. The grooves were designed to Cummins standard 98010 Molded Elastomeric Gaskets for each sample to be tested. The base was designed to hold one groove plate. For even distribution of pressure the load piece was required to have a flat surface parallel to the top surface of the groove plate. Once the design was finalized and CAD models produced, finite element modelling was performed for the most extreme test parameters. Testing performance is measured by consistency and repeatability of the test and the condition of the equipment during the tests. When using the user interface, performance is measured by the estimated dimensions outputted by the program. Its reliability lies in instrumental error and possible problems that could arise while using it. Main reliability concerns are the data collection and reducing the amount of instrumental error, since this will affect the correlations and the performance accuracy of the user interface. This concern was addressed by doing three or more iterations of the same parameters in order to create more data points to increase the precision of our data. The project cost a total of $593.87. Of the $2000 given by Cummins, Inc., only 30% was spent.

ACKNOWLEDGMENTS

Senior Design Team 1 would like to acknowledge and thank Cummins, Inc. for making this project possible, particularly Terry Shaw and Parker Harwood for being our liaisons and providing guidance along the way. We would also like to thank Dr. Alvi and Dr. Oates for acting as faculty advisors and being available to meet and discuss the project whenever the need arose. We would like to thank Danny, a teaching assistant of Dr. Kalu, for volunteering his time to help the team access and use the facilities. Furthermore, the team thanks Dr. Kalu for letting the group use his lab and equipment. Team 1 would additionally like to acknowledge Dr. Gupta and his teaching assistants Sam Botero, Ricardo Aleman, and Yuze Liu (Liam) for all the time and effort put into the Senior Design class. Last but not least Team 1 thanks Dr. Shih, for without whom all this would not be possible.

1. Introduction

Each Cummins, Inc. (and non-Cummins) engine currently being produced contains a variety of elastomeric sealing rings. Each engine contains multiple types of rings that vary in cross sectional shape and thickness, as seen in Figure 1 and 2. They are implemented in order to create leak free joints between engine parts that may contain a range of fluids from coolant and lube oil to compressed air. Many of these fluids are subjected to high pressures with internal parts reaching relatively high temperatures during operation. These high temperature and high-pressure environments require the joint to be designed with the best quality elastomeric sealing rings

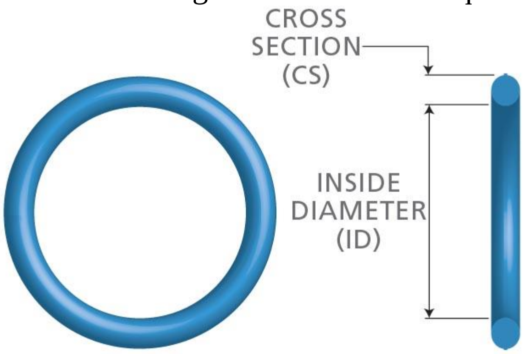


Figure 1: Typical Circular Sealing Ring Profile [3]

available. Depending on the working environment, the rings must also have the capability to function while exposed to the elements and harsh chemicals. In response to these conditions, sealing rings are made from a variety of materials; such as silicon rubber, which is resistant to weathering [1], and fluorocarbon, which can be used in the presence of petroleum based chemicals [2]. In order to produce longer lasting, low maintenance engines, the need for better-designed joints containing elastomeric sealing rings is increasing. Because of this and specifications determined

Figure 2: Sealing Rings with Irregular Cross Sections [5]

by the sponsor, the team tested sealing components of varying cross sections in order to understand the advantages of varying the cross sections on sealing rings.

A typical elastomeric sealing ring is circular in cross section and is referred to as an “O-ring”, as seen in Figure 1. Although these will work for most joints, Cummins, Inc. has found that using an elastomeric ring with a rectangular or irregular cross section, like the ones shown in Figure 2, can increase sealing pressure while using less material. However, the current procedure for determining the best type of seal ring for a specific joint requires multiple iterations of finite element analysis, which is costly both in time and money.

2. Background and Literature Review

Due to its simplistic shape, the circular seal ring can be quickly and cost effectively designed by varying the clearance gap between mating parts that would define a percent crush and result in a sealing pressure. Percent crush is defined as a ratio between the compressed height (or radial dimension) under loading and the original sealing component height (or radial dimension) times 100, as seen in Equation 1.

$$Percent\ Crush = \frac{Compressed\ height}{Initial\ Height} \times 100\% \tag{1}$$

Sealing pressure is defined as the pressure generated between the elastomeric sealing component and the mating parts due to the crush of the sealing component [6]. When the sealing is crushed, a force is being applied by the mating parts onto the seal, causing it to deform and create an equal and opposite force. Depending on the force applied by the mating parts, and the cross section of the sealing ring, the contact area where the force is being applied will grow to match the force, creating the sealing pressure. In Figure 3, one can see how sealing rings are used between mating parts and how their performance varies depending on the pressure applied. When a fluid is trying to escape, it applies pressure on the sealing ring and if the sealing pressure is not greater, then the sealing ring will fail and the fluid will escape.

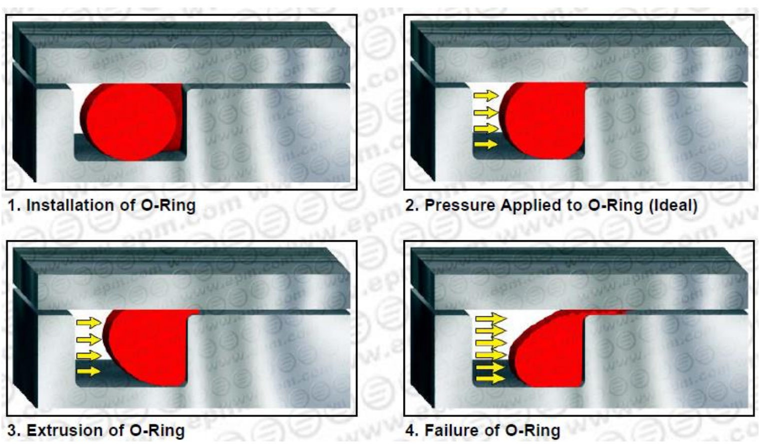


Figure 3: Application of Sealing Rings [8]

The goal of this project was to apply a similar method to measure sealing pressures and understand how varying the cross section affects their performance. This method would simplify the sealing ring selection process, allow research into the relationship between sealing ring geometry, percent crush, and sealing pressure, and ultimately reduce the time and cost of designing or selecting sealing rings. In order to apply the data to practical use, this method will involve parameters such as a shape factor, percent crush, and sealing pressure. This is a crucial step for the project sponsor, Cummins, Inc., such that costs will be reduced in the form of time saved during the design process and less material will be required.

Currently, there are some existing ASTM standards for testing elastomeric seal rings' performance capabilities. The ASTM D1414-19 - Standard Test Methods for Rubber O-Rings is conducted on rings with contrasting cyclic loads and working temperatures in order to give insight into how the different properties of an O-ring will be affected by age [4]. Although standards for testing sealing rings with a general cross section already exist, standards specific to non-circular cross sections do not exist. Therefore, testing beyond circular rings currently has no standrads. Also, the sponsor requested testing a percent crush of up to 40%, which is beyond the industry standard of 30%, since damage can occur to the seal beyond 30% crush due to the limitation of space in a mating groove. To be able to reach 40% crush, the depths of the grooves used in testing had to be decreased from the standard dimensions so that the load piece applying the load did not bottom out on the top of the groove plate before reaching 40% crush. The ASTM D395 - Standard Test Methods for Rubber Properties in Compression was also consulted but had to be adapted to testing seals in grooves whereas the standard calls for the test fixture being two parallel flat plates [7]. During testing, the team dealt with the differences in data with assistance from sponsor and faculty advisors to create the test method used.

3. Design for Manufacturing

The process for designing a test fixture to be used in the static face seal compression tests began with assessing the MTS machines available. In order to compress the samples to the required 40 percent crush, an MTS machine with adequate load capacity was located. For this purpose an MTS machine model C45.105 with a 50 kN load cell was to be used so measurements were taken of the mounting receivers. These measurements were used to design the mounting shafts of the test fixture. The next most crucial part of the test fixture is the groove plate which has a groove cut in it that is specific to each seal sample. The grooves were designed to Cummins standard 98010 Molded Elastomeric Gaskets for each sample to be tested. The base was designed to hold one groove plate at a time but be quickly interchangeable so multiple samples can be tested one after another efficiently. The load piece was required to have a flat contact surface that was parallel to the top surface of the groove plate to ensure even distribution of pressure. Once the design was finalized and CAD models produced, finite element modelling was performed for the most extreme test parameters, results of which are explained later in section 4.1 with details on why aluminum 6061 was chosen as the material for the test fixture. Allotted time for the machining of the test fixture was about one week as the machining processes used are relatively simple. Detailed drawings of all parts can be found in appendix A.

Assembly of the fixture into the MTS machine and set up of the test requires about 10 minutes. The load piece and the base are mounted to the upper and lower receivers of the MTS machine using a pin that is provided with the MTS machine hardware. The sample to be tested is loaded

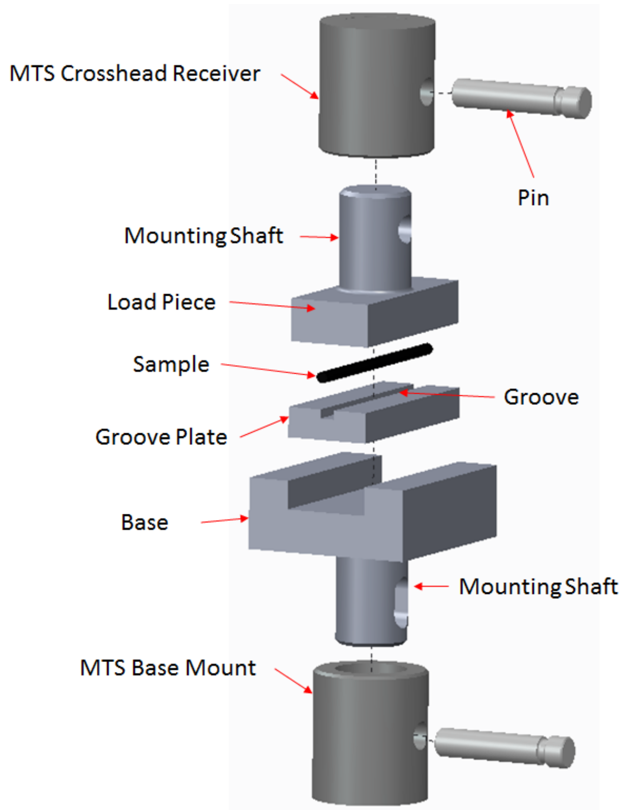


Figure 4: CAD Model of Test Fixture Design

into its corresponding groove plate and a slice of Fujifilm is placed on top of the sample making sure the rough sides of the 2 piece film are facing each other. Once the groove plate is seated in the base of the fixture the test can be performed. An assembly of the test fixture is shown in Figure 4.

4. Design for Reliability

During experiments, the main concern for reliability was the testing procedure consistency and the test fixture performance after repeated uses. During testing, main reliability concerns are the data collection and reducing the amount of instrumental error, since this will affect the correlations and the performance accuracy of the user interface. The main way in which addressed this concern was by doing three or more iterations of the same parameters in order to create more data points to increase the precision of our data.

In order to keep consistency in our experiments, multiple sealing rings of the same cross section were also tested throughout the experiments. Compression tests were done on the sealing rings in increments of 5 percent (starting at 5 percent) and the same sample was used until 20 percent. After this point, sealing rings change in density by almost 25 percent when compressed to this point and that will skew the percent crush value since the seal has decreased in dimension and material hardness [8].

Reliability of the test fixture could be compromised under the high amount of cyclic loads being applied. The test fixture cannot have any deflection, so plastic deformation is considered failure. Under normal circumstances, the amount of load needed to compress sealing rings does not exceed 6 MPa and the test fixture's tensile yield strength of 276 MPa, so it won't fail under these circumstances. Under a high amount of tests, the fixture could fatigue and fail under lower stresses than the yield tensile strength, but since we used Al6061 this is not a possibility. Al6061 has fatigue strength of 96.5 MPa after five hundred million cycles, so the fixture will not fatigue after multiple tests. If during testing, the input displacement is incorrect and the load piece and base make contact, problems could arise. FEM analysis was done on the fixture and the results can be seen in Figure 7. One can see that the stress on the fixture does not exceed 998 kPa, which is way below the fatigue stress and tensile strength. Lastly, consistency in the data could be skewed during testing due to the surface finish of the load piece. Scratches on the surface in which seals ae boing tested can result in a redistribution of stress across the contact area and stress concentrators. In order to limit any damage to the surface, when not in use, the load piece and groove plates would be wrapped in tin foil to maximize the reliability of the fixture.

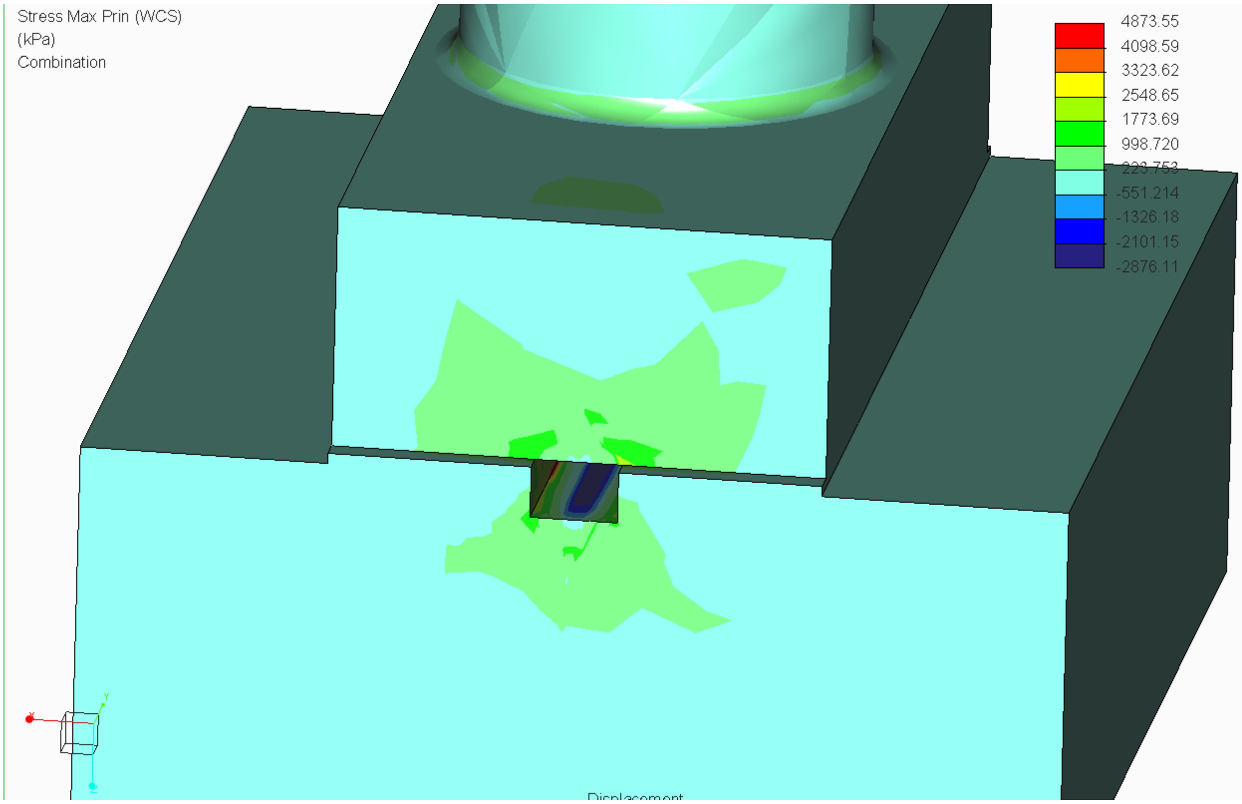


Figure 5: FEM zoomed image of principal stresses on testing fixture

Personal bias is also a key factor when reading the pressure readings of the Fujifilm, since it is a visual selection of what one thinks is the correct pressure. When the Fujifilm is scanned, the error was minimized by having multiple people read every Fujifilm separately and averaging out the values. Any further reliability controls can be seen in the FEMA located in Appendix B.

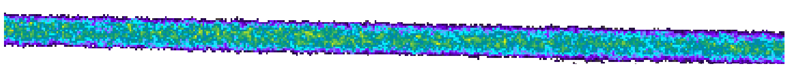


Figure 6: Fujifilm PreScale paper scan results

5. Design for Economics

The project cost a total of $593.87. Out of the $2000 budget given to us by Cummins, Inc., as you can see in Figure 5, we only spent 30%. The Fujifilm Prescale pressure sensitive paper cost

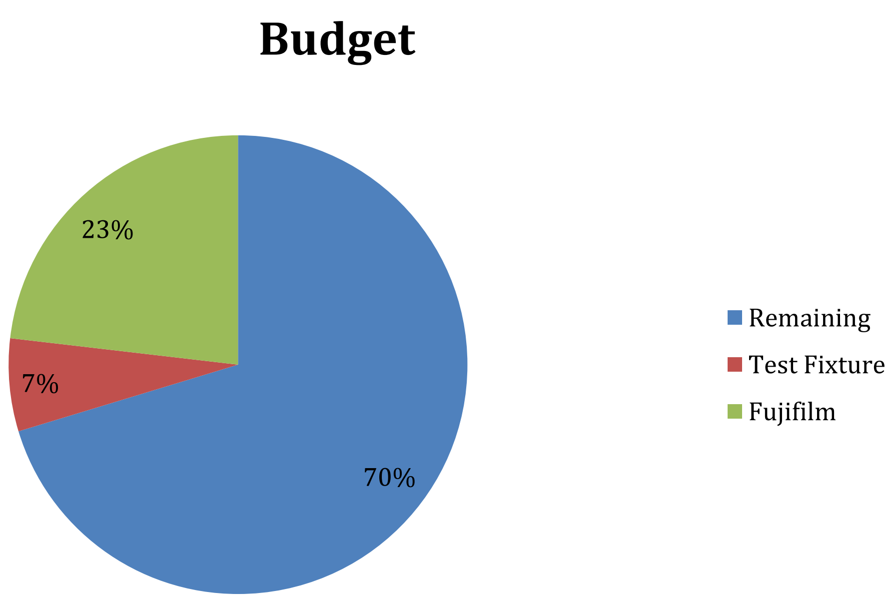


Figure 7: Budget diagram

$380.99, which was 27% of the budget. This paper comes in different pressure sensitivities that work in limited pressure ranges. Prior to the experiment, theoretical data was devised and it was concluded that for these tests three sensitivities needed to be purchased [Low (350-1400psi), Super Low (70-350psi), and Ultra Low (28-85psi)]. Each of them cost $123 and its shipment in a special container cost $59.99. The Al6061 used to build the testing fixture and its accompanying groove plates cost $130.7, which was 7% of the budget. The expenditures were kept low do to having zero machining costs, receiving the sealing rings from the sponsor, and having the Fujifilm analyzed by Cummins, Inc.

Since most testing prior to this project was only done on orings, the fixtures available in the market are limited to flat plates. One of these products can be seen in figure 6 from CCSi ULTRALIFE Test Fixtures. Although this could be used for testing orings and some rectangular rings, it is meant for testing standardized pucks of material and will not properly test irregular cross sections because they tend to buckle under compression when a groove is not used to sustain it. The cost of the CCSi test fixture is $2881.00 and is shown in figure 7.

Figure 8: CCSi ULTRALIFE test fixture

6. Conclusion

An MTS machine model C45.105 with a 50 kN load cell was used to perform the test needed in this project. The receivers of this machine were measured and the mounting shafts of the test fixture were designed accordingly. Individual groove plates were created for each sealing ring. The grooves were designed to Cummins standard 98010 Molded Elastomeric Gaskets. The base was designed to hold one groove plate. For even distribution of pressure the load piece was required to have a flat surface parallel to the top surface of the groove plate. Once the design was finalized and CAD models produced, finite element modelling was performed for the most extreme test parameters. Testing performance is measured by consistency and repeatability of the test and the condition of the equipment during the tests. The test fixture held up well, and there were no deformities measured upon completion of testing.

The user interface created is unique to this project. When using the user interface, performance is measured by the estimated dimensions outputted by the program. Its reliability stems from the reliability of the pressure values and the ability of the interface to accurately retrieve values from the data files. Multiple compression tests were performed on the sealing rings to increase the precision of our pressure values. The project cost a total of $593.87. Of the $2000 given by Cummins, Inc., only 30% was spent.

References

[1] *Silicone*. n.d. Webpage. 10 October 2014. <http://www.aceseal.com/ring-materials-silicone-c-17_20-l-en.html>.

[2] *Flourosilicone*. n.d. Webpage. 10 October 2014. <http://www.aceseal.com/ring-materials-flourosilicone-c-17_24-l-en.html>.

[3] *Typical O-Ring Model*. n.d. Webpage. 10 October 2014. <http://fs23.formsite.com/parcoinc/images/O-ring_Cross_Section_V2.jpg>.

[4] "ASTM Standard Test Methods for Rubber O-Rings." Technical Standard. n.d. Online. 10 October 2014. <http://www.astm.org/Standards/D1414.htm>.

[5] *Elastomeric Static Seal*. n.d. Webpage. 10 October 2014. <http://articles.sae.org/12886/>.

[6] Cummins, Inc. "Seals, Molded Elastomeric." Technical Standard. n.d. 10 October 2014.

[7] "ASTM Standard Test Methods for Rubber Properties." Technical Standard. n.d. Online. 10 October 2014. <http://www.astm.org/Standards/D395.htm>.

[8] Green, Itzhak, and Capel English. "STRESSES AND DEFORMATION OF COMPRESSED ELASTOMERIC." Georgia Institue of Technology, 8 Apr. 1994. Web. 2 Mar. 2015.

Biography

Richard Edgerton - Team Leader

Richard is a senior Mechanical Engineering student at Florida State University with a focus in Mechanical systems. He recently interned for Cummins, Inc. as a product validation engineer for the QSK 23L engine family in Seymour, IN but will be working as a Product Development Associate Engineer in the Engineering Rotational Development Program at Caterpillar in Peoria, IL after graduation.

Emilio Kenny - Project Analyst

Emilio is a senior Mechanical Engineering student at Florida State University with a focus in Thermal Fluids. Emilio recently interned for Eli Lilly and Company as an Automation/Process Engineer in the injectables sector in Indianapolis, IN. After graduation, he plans to get a Master's Degree in Thermal Fluids.

Kenneth McCloud - Financial Coordinator, Webmaster

Kenneth is a senior Mechanical Engineering student at Florida State University with a focus on Thermal Fluids. He is interested in working on the research and development of renewable energy sources.

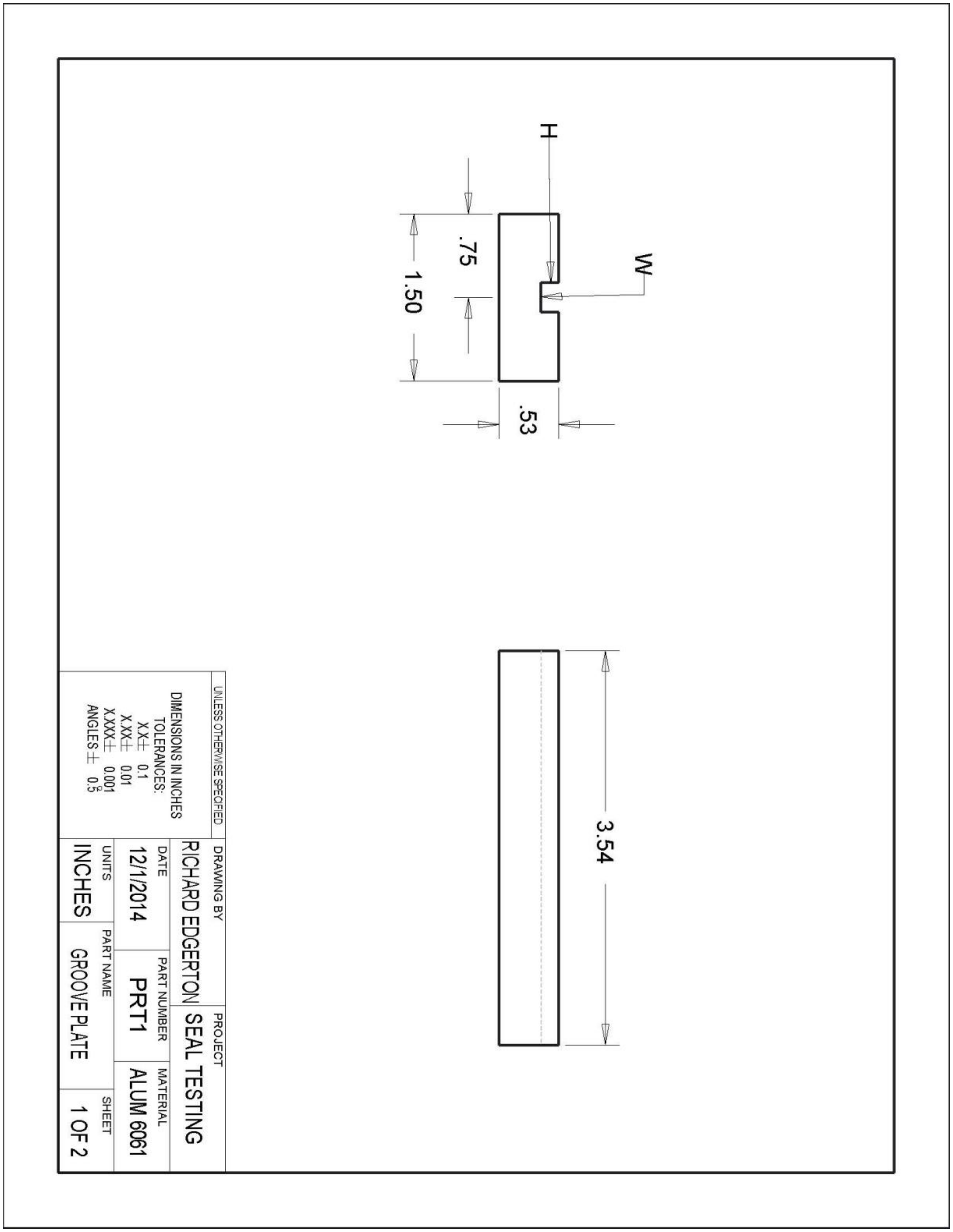
Tawakalt Akintola - Project Support

Tawakalt is an exchange student at Florida Agricultural and Mechanical University from Federal University of Technology Akure, Nigeria. Her main focus is in Materials Engineering. She obtained a Diploma in Metallurgical and Materials engineering and had an industrial training at Tower Aluminum Roofing Company, Nigeria. She plans to get a master's degree in Materials Engineering after graduating with a B.S. in Metallurgy and Materials.

Erin Flagler - Project Planner

Erin is a senior Mechanical Engineering student at the Florida State University with a mixed focus in Energy Systems and Materials. Erin interned for Black and Veatch this past summer as a Mechanical Engineer in the Energy Division in Overland Park, KS. After graduation, Erin plans to pursue an engineering career in the energy sector.

Appendix A: Test Fixture Part Drawings

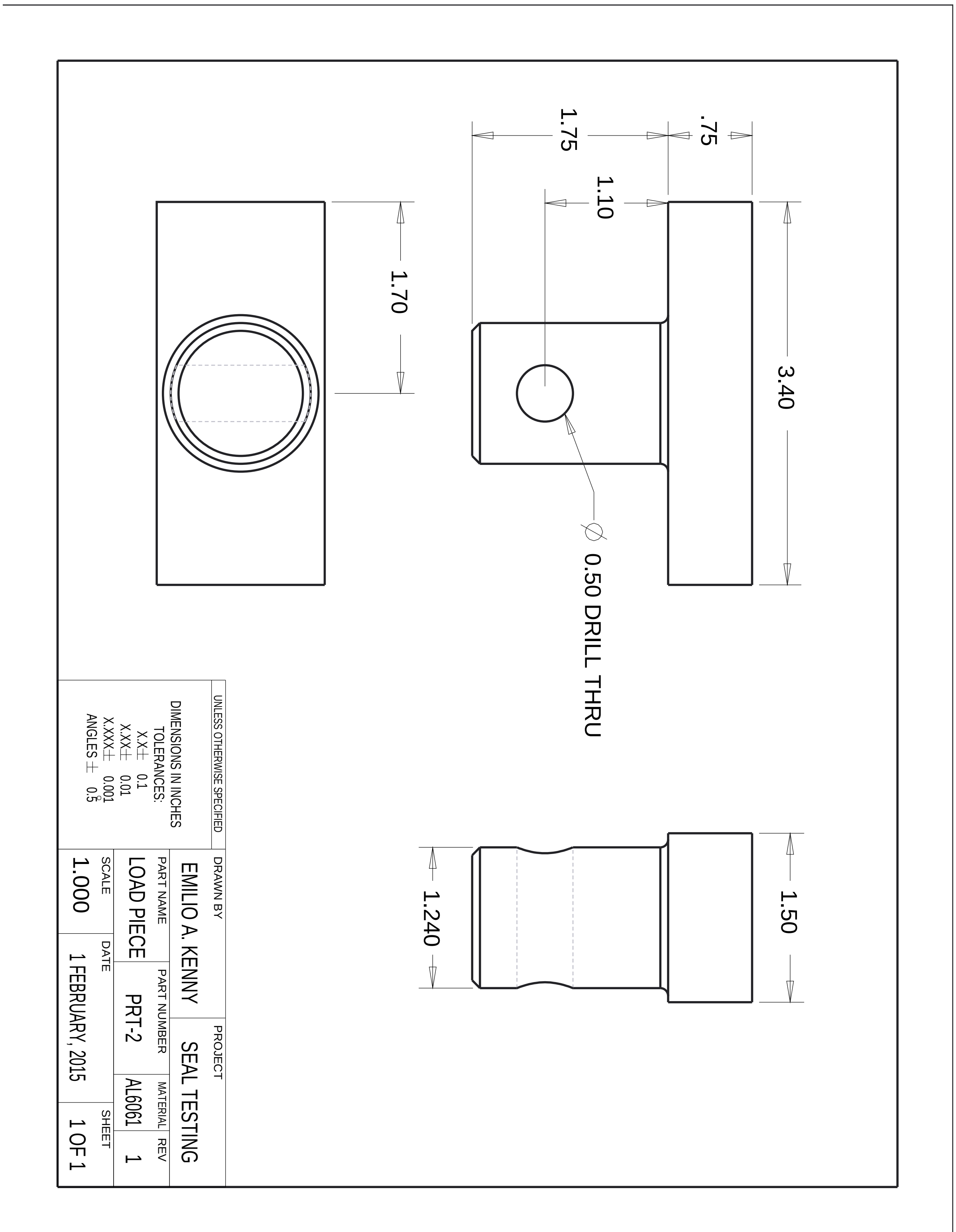


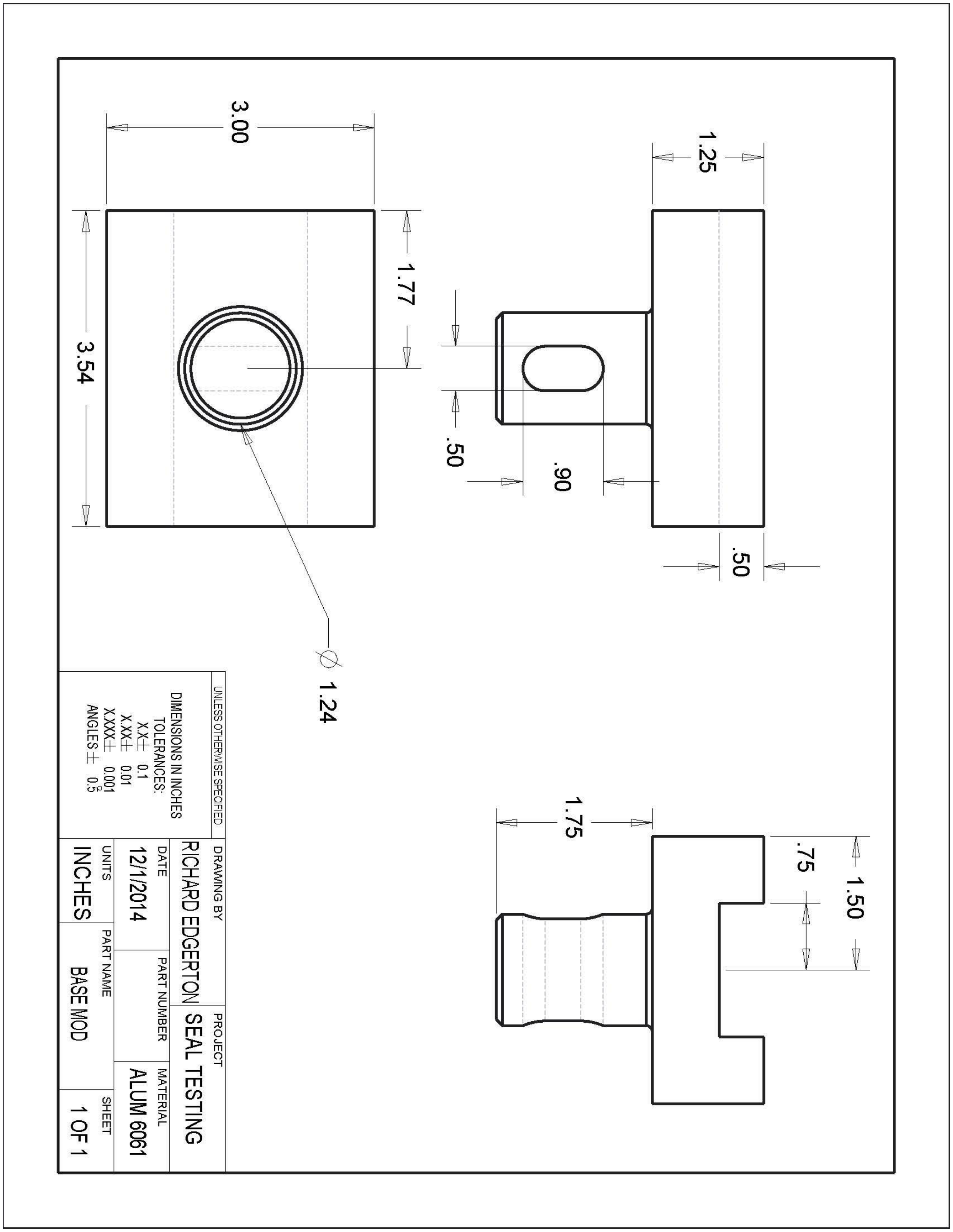
P/N	HEIGHT H	WIDTH W	NOTES
2863702	0.077	0.139	
3082358	0.168	0.291	
3348617	0.100	0.104	
3348618	0.122	0.077	
3638326	0.104	0.182	
3651213			
3683495			
3683495	0.118	0.197	
3685556	0.144	0.098	
3867646	0.052	0.101	
3914095	0.088	0.154	
3915772	0.049	0.096	
3919953	0.207	0.165	
4010636			
4323688	0.206	0.354	
4323985	0.104	0.186	
4325753	0.118	0.079	
4325829	0.169	0.118	
4910519	0.150	0.400	
4962609	0.265	0.265	
4985661			
4995185			
5253501	0.100	0.180	
5267506	0.117	0.119	

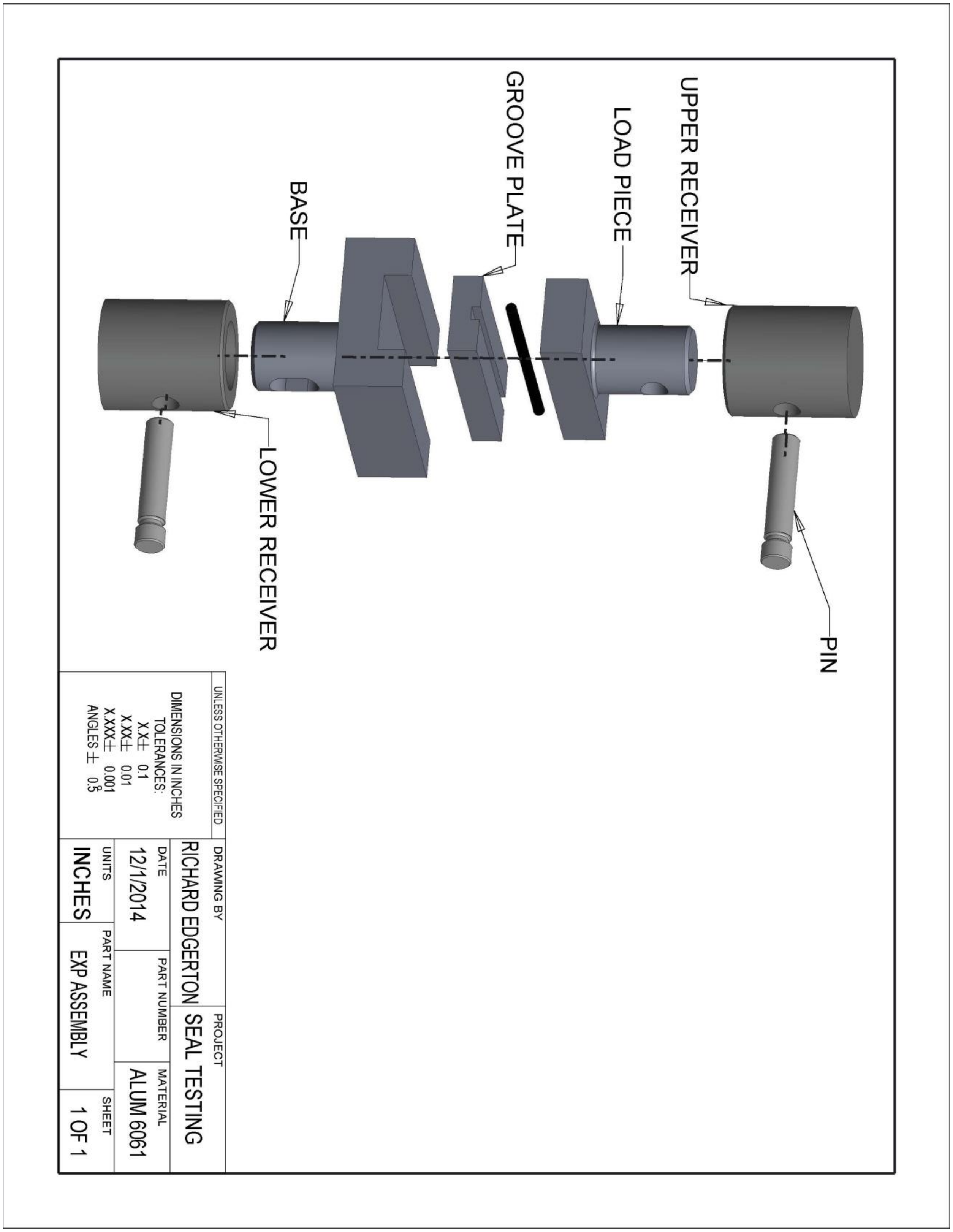
UNLESS OTHERWISE SPECIFIED

DIMENSIONS IN INCHES
TOLERANCES:
X.X± 0.1
X.XX± 0.01
X.XXX± 0.001
ANGLES ± 0.5°

DRAWING BY	PROJECT	
RICHARD EDGERTON	SEAL TESTING	
DATE	PART NUMBER	MATERIAL
12/1/2014	PRT2	ALUM 6061
UNITS	PART NAME	SHEET
INCHES	GROOVE PLATE	2 OF 2


1.75
.75
1.10
1.70
3.40
⌀ 0.50 DRILL THRU
1.240
1.50
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X± 0.1
X.XX± 0.01
X.XXX± 0.001
ANGLES ± 0.5
DRAWN BY
EMILIO A. KENNY
PROJECT
SEAL TESTING
PART NAME
LOAD PIECE
PART NUMBER
PRT-2
MATERIAL
AL6061
REV
1
SCALE
1.000
DATE
1 FEBRUARY, 2015
SHEET
1 OF 1


3.00
3.54
1.77
1.25
.50
.90
.50
Ø 1.24
1.75
.75
1.50
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X± 0.1
X.XX± 0.01
X.XXX± 0.001
ANGLES ± 0.5
DRAWING BY
RICHARD EDGERTON
PROJECT
SEAL TESTING
DATE
12/1/2014
PART NUMBER
MATERIAL
ALUM 6061
UNITS
INCHES
PART NAME
BASE MOD
SHEET
1 OF 1


UPPER RECEIVER
LOAD PIECE
GROOVE PLATE
BASE
LOWER RECEIVER
PIN
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X± 0.1
X.XX± 0.01
X.XXX± 0.001
ANGLES ± 0.5°
DRAWING BY
RICHARD EDGERTON
PROJECT
SEAL TESTING
DATE
12/1/2014
PART NUMBER
MATERIAL
ALUM 6061
UNITS
INCHES
PART NAME
EXP ASSEMBLY
SHEET
1 OF 1

Appendix B: FEMA

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.
Fujifilm Prescale Paper	Appers too dark	Unreadable Data	10	Not increasing the Fujifilm sensitivity	6	Increased number of iterations	10	600	Notice previous Fujifilm color	User/Tech Exper	Change Fujifilm and test again
	Appers too light	Unreadable Data	10	Increased the Fujifilm sensitivity too early	6	Increased number of iterations	10	600	Notice previous Fujifilm color	User/Tech Exper	Change Fujifilm and test again
	No imprint on film	No Data derived	10	Fujifilm not oriented correctly	6	Inspect Fujifilm before test	10	600	Make sure rough surfaces are in contact	User/Tech Exper	Change Fujifilm and test again
MTS Machine	Not recognized by computer	Can't run tests	10	Turned on software before test is ran	2	MTS mahine is off before programmed is started	10	200	Exit from pgram and restart MTS machine	User/Tech Exper	Made sure MTS machine is off before starting program
Test Fixture	Scratch on testing surface	Stress concentrators found on Fujifilm	8	Improper storage of test fixture components	6	Wrap components in aluminum foil when not in use	6	288	When not in use, wrap in foil and keep them in a container	User/Tech Exper	Wrapped in foil and kept components in safe storage