JCATI Base Plate

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By

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Abstract: Students of the Mechanical Engineering Technology (MET) program at Central Washington University have contributed to an ongoing Carbon Fiber Recycler project funded by the Joint Center for Aerospace Technology Innovation (JCATI). The goal of this project was to modify the existing recycling system to produce a higher success rate of recycled carbon composite material. This report focuses on increasing the rigidity of the crushing gears so that the deflection occurring among the components during operation was below 0.005 inches to ensure proper operating conditions. The operating speed of the crushing gears was 2.5 rpm with a crushing load of 10,500 pounds. A base plate design ensured the rigidity of all components operating on a singular plane. Flat plate analysis was conducted to determine the thickness of the plate required of ASTM A36 Steel to produce a deflection less than the required value. Plate models run in Autodesk Nastran provided stress and deflection results used to confirm green sheet calculations and assembly modifications. Testing consisted of using dial indicators to determine deflections at various locations of the base plate and confirmed the deflection of the plate to be 0.003 inches within the required maximum deflection of 0.005 inches. All testing, manufacturing, and analyses took place in the Hogue Technology Building at Central Washington University with the help of MET Faculty.

Contents

1. INTRODUCTION

a. Description

The process of constructing aircraft wings leaves excess scrap composite material that is left to be dumped in landfills. To reduce waste, a carbon fiber composite recycler would delaminate aircraft trimmings, shred them into fiber pieces, and pyrolyze said pieces to be recycled. With proper engineering techniques, the recycler can be revamped to recycle aircraft trimming efficiently.

b. Motivation

This project was motivated by a need for a device that would make the crushing gears more rigid. The previous project's system in place experienced a shift in the gears through the delamination process. With a rigid frame this problem would be solved.

c. Function Statement

The function of this project is to provide rigid mounting for the crushing wheels operating in the delamination process.

d. Requirements

A frame is required to withstand the loads of the crushing gears so that the shaft connected to the side housing will not displace more than 0.005 inches. The following factors need to be considered:

- Deflection of gears cannot exceed 0.005 inches
- Frame needs to hold gears revolving at 2.5 rpm
- Frame needs to withstand a radial crushing load of the gears at 10,500 lb.
- Feed rate of crushing wheels needs to stay at 1 foot per minute

e. Engineering Merit

The goal of this project was to design a recycling system based from principles of mechanical engineering. This project will show applications of mechanical engineering knowledge to solve a problem and present a solution. Going forth with this project will contribute to reducing the amount of waste produced by aircraft manufacturers not only in the United States but hopefully worldwide, effectively reducing the carbon footprint of manufacturers.

f. Scope of Effort

The scope for this project is to construct a rigid base or frame for the crushing housing. The current system allows for too much movement. Connecting all components of the system to the housing will provide greater system rigidity.

g. Success Criteria

Success depends on the final performance of the crushing wheels operating at 100% delamination not causing a deflection of more than 0.005 inches.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The dimensions of the current operating system needed to be considered to start the design process. The goal was to maximize the rigidity of the crushing gears through the contact of the shaft, flange bearings, and side plates, keeping the housing components that were currently in place. Connecting the base of the Crushing Housing, Gearbox #2, and the Shredder Housing was also an intent of design to increase the fluidity of the recycling process. This base design would decrease the deflection of spur gears that ultimately resulted in the displacement of the crushing gears during the delamination process.

b. Design Description

Figure 1 shows the original design intent for a base plate connecting the three recycling components mentioned in the approach. The rectangular notched edges of the plate are incorporated to attach the baseplate to the existing foundation. Design of the supports would be further analyzed.

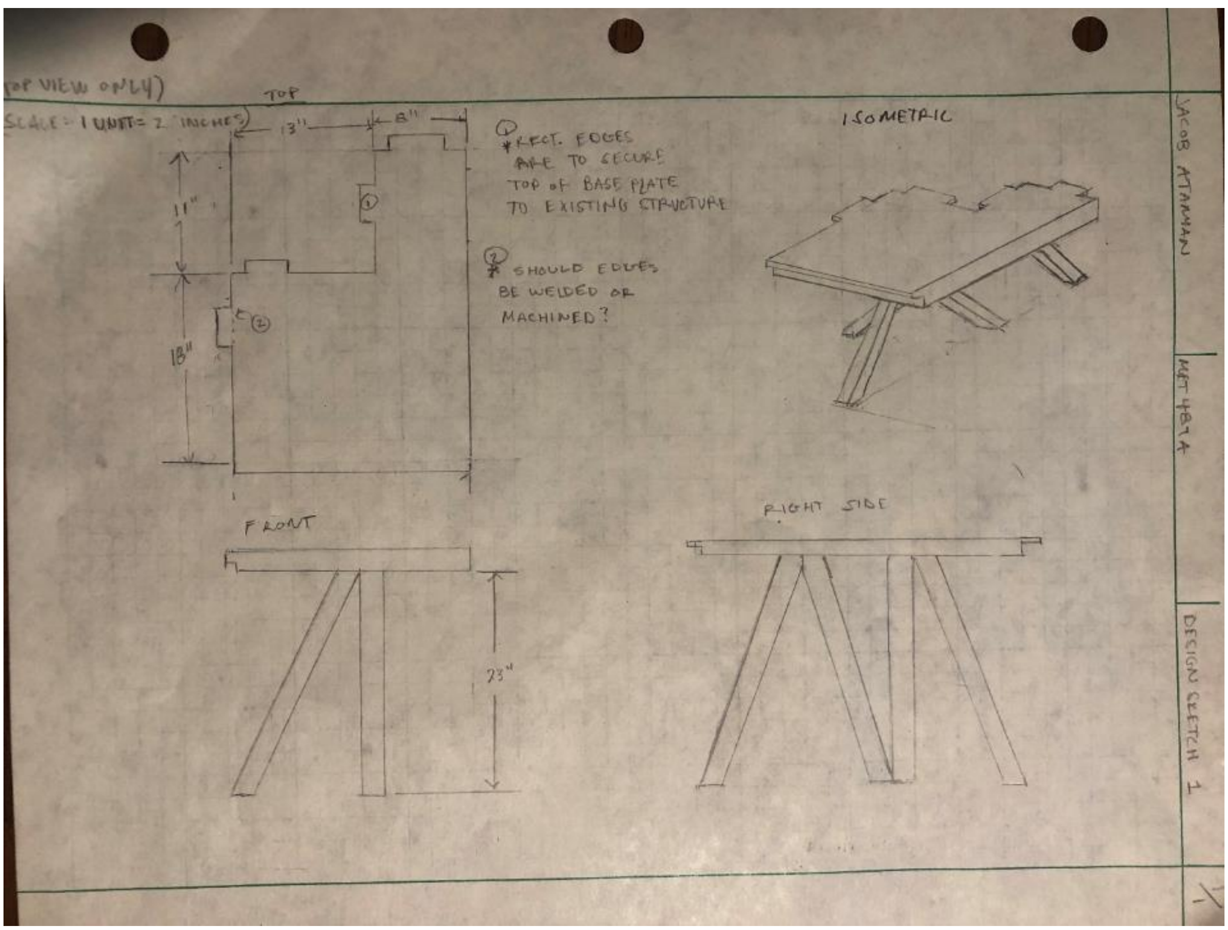

Figure 1: Base Plate Sketch

c. Benchmark

The benchmark of this project was to keep the delamination system up to par with the progress made by previous project members. The crushing gears should operate as well as they previously were after modifications were made to the supporting members.

d. Performance Predictions

The predicted performance of the device is that the frame will be able to hold the crushing gears with a displacement within less than 0.005 inches. The side plates and bearings will be able to stay rigid under the torsion 3100 lb-in of the shaft. The feed rate of the crushing gears will remain at 1 foot per minute.

e. Description of Analysis

Analysis of the existing components was necessary before any design could be approached. The first component on the recycling system analyzed was the crushing gear housing observing the motions in the x-y-z planes through the delamination process. Observing the movement of gearbox 2 led to the initial design of a connecting base.

f. Scope of Testing and Evaluation

The scope of testing and evaluation for this project is focused on the deflection of the entire crushing system. Two major areas of testing for deflection are underneath the plate area and the side walls of the crushing housing. If the deflections recorded are within the maximum deflection of 0.005 inches, the parts serve as functional.

g. Analysis

i. Analysis 1 (Housing Movements):

Magnet base dial indicators were used to observe the motion of the crushing gear housing and Gearbox #2 along the x-y-z planes. Dial indicators were placed on the front and back side of the crushing gear housing showing the motion of the housing to move away from the feeding entrance. Next, indicators were placed on the top and bottom of the housing. It was observed that the back side of the housing was moving downwards. For the final direction of motion, indicators were placed on both sides of the housing. Testing revealed the side plate closest to the spur gears to be moving out and away from the crushing gears. The final component analyzed was Gearbox #2. Testing indicated movement of the gearbox away from the crushing gear housing. This explains the initial binding of the spur gears. No values of displacement were able to be calculated due to the recurring binding of spur gears. A result of this analysis was the initial design of a base plate connecting the crushing gear housing and Gearbox #2. Notes for analysis are found in Appendix A1.

ii. Analysis 2 (Plate Dimensions):

Measurements of the existing frame and locations of components were recorded to determine the parameter of the base plate. Three components of focus are gearbox 2, the crushing gear housing, and the shredder housing. The goal was to connect all three to a single base. The dimensions of the rectangular base are 21 in x 29 in. The keep the existing welds for gearboxes 1 and 2, a chunk of area (13 in. x 11 in.) was taken from the top left corner. The location of tapped holes and frame thickness are shown in Appendix A2.1.

iii. Analysis 3 (Flat Plate Analysis 1)

The requirement of the crushing gears not exceeding the maximum deflection of 0.005 inches was considered in this analysis. A plate thickness was to be determined using the dimensions of the 21in. x 29in. plate and the maximum deflection of 0.005 inches. Analysis of a flat plate supported on all edges under a uniform distributed load was the assumed condition. Figure 3.2.70 and Table 3.2.20 were used to determine the k_1 factor used in the maximum deflection equation (1). The maximum deflection equation results in a load that deflects the plate at 0.005 inches. The material of the plate was AISI 1020 steel and the assumed weight of components on the plate was 375 lbs. With a thickness of 0.75 inches the plate would experience maximum deflection at a load of 863 lbs. This load is greater than the weight of the components meaning a thickness of 0.75 inches would be suitable for design. Calculations can be found in Appendices A3.1-3.3.

iv. Analysis 4 (Crushing Load Acting in Plate Area)

To increase the factor of safety, a truss was designed to support the load acting at the crushing gears. To determine the axial loads acting in the truss members, deflection of the current angle iron supporting the crushing housing needed to be analyzed. Testing showed at the intended location of support that the angle iron was deflecting approximately 0.025 inches before the spur gears driving the crushing mechanism begin to shift. Finding data from MOTT Table A15-1 and A14-1b, the moment of inertia and deflection equation for the angle iron was determined to find the load (P) causing a deflection of 0.025 inches [3]. Youngs Modulus was assumed to be 30 x 10^6 psi, and the moment of inertia (I) was determined to be 0.348 in^4. The vertical load causing deflection was found to be 467 pounds. Calculations can be found in Appendix A4.1-4.2.

v. Analysis 5 (Axial Load in Truss Members)(OBSOLETE)

The external load acting on the truss was found to be 467 lb. Now the axial loads acting in each truss member could be determined. The mount locations were restricted to the current dimensions of the support table. The angles of the truss members with respect to the horizontal were θ_{AB} = 81.6 degrees, θ_{AC} = 67.6 degrees. Using the method of joints the axial loads were found to be N_{AB} = 348lb (C), N_{AC} = 133 lb (C), and N_{BC} = 50.7 lb (T). The vertical reactions at B and C were found B_y = 344 lb and C_y = 123 lb. These reactions would be used in a future analysis to determine any deflection of the base supports for the truss members. Calculations found in Appendix A5.1-5.3.

vi. Analysis 6 (Flat Plate Analysis 2)

Due to the change in the design of the base plate to be mounted to the top of the existing table structure, a new plate analysis needed to be done. The new plate dimensions were 26in x 36in. The thickness was estimated at a standard plate thickness of 0.75 inches. The plate material was designated AISI 1020 steel. The max deflection was set at 0.005 inches. Using the same equations as referenced in Analysis 3, the thickness and deflection produced a critical load of 905.9 lbs. With the actual load of components operating on the plate estimated at 350lbs, the safety factor results in a desirable value of FS=2.6 (refer to Appendix A6.1). This analysis does not account for the load of the crushing gears calculated in Analysis 7. If this load is applied to the safety factor, a value results in FS=1.1. This validates the need for a truss to support the crushing load in the delamination process. Chain would need to be added to the motor connection to Gearbox #1 because all components were moved upwards ¾ of an inch.

vii. Analysis 7 (Buckling of Truss Members)(OBSOLETE)

This analysis designated the size square tubing needed for the truss at ½ in x ½ in x 0.049 in material ASTM A513. Yield strength and young's modulus were used to determine the critical buckling load of each truss member taking material properties from metalsdepot.com, the planned source of material [5]. The critical load (P_{cr}) was found using Euler's buckling equation assuming that each truss is pinned-fixed [3]. A critical bending stress was then found using P_{cr} leading to a desirable design factor of 2.6 for AB and 2.97 for AC. The critical load and design factor calculated for each truss was used to determine the allowable load using design equation $P_a = P_{cr}/N$ [3]. The allowable loads for each truss fall within the design parameters of 348 lbs for Truss AB and 133 lbs for Truss AC. Calculations can be found in Appendix A(7.1-7.3).

viii. Analysis 8 (Vertical Shear At Bolts) (OBSOLETE)

Shear stress needed to be calculated at the three hole-locations to ensure 1/4 inch bolts would be strong enough to hold the truss together. Values were found using the maximum shear stress equation for circular cross-sections in MARKS' Handbook [1]. Vertical loads were calculated at each location using standard trigonometry of a triangle. All of the design factors calculated were well above 2.0 meaning it was okay to go forth with 1/4 inch bolts at each mounting location. Calculations are found in Appendix A(8.1-8.2).

ix. Analysis 9 (Truss Geometry) (OBSOLETE)

To start drawing each truss, the cutting angles and hole positions needed to be calculated. These values were found using basic trigonometry rules. Each truss was cut in a way that allows for the truss members to be centered on their previously calculated axial loads. The bottom of Truss AB was cut at 81.6 degrees in reference to Datum A and the top was cut 30.8 degrees in reference to Datum A. The hole position at the bottom was placed 0.656 inches from the base of the bottom cut and through the tubing's central axis 0.25 inches from Datum A. The holes were placed in such a way to allow for the use of 1.5in. x 1.5in. x 0.25in. Angle Iron for the mounting brackets. Refer to drawing 20-004 in Appendix B8.

Truss AC was designated a base cutting angle of 67.6 degrees from Datum A and an angle of 67.6 degrees from Datum B. Hole placements are the same as described for Truss AB. Refer to drawing 20-005 in Appendix B8.

x. Analysis 10(Locating Pins)

The purpose of this analysis was to ensure that the locating pins for the components connected to the chain drive would not shear. Two different pin sizes were considered, 1/2 inch for Gearbox 2 and 3/8 inch for the Crushing Housing. The tension in the chain found from project member Tim Boswell was 7500 lbs. Material properties were assumed to be SAE 1144 OQT 1300 based from material specs on the part's website [5]. For the ½-inch pin, the load was divided amongst three pins resulting in a safety factor 5.3. The load for the 3/8-inch pin was divided amongst four pins resulting in a safety factor of 4. Both are desirable for design and were chosen to press fit the components. Calculations can be found in Appendix A10.1-10.2.

xi. Analysis 11 (Finite Element Analysis)

A model of part 20-002 was ran in Nastran to determine the maximum deflection as a result of a radial load acting in the plate area of 5253 lb. The deflection came to be 0.003335 inches with a linear mesh of 0.3 inches (refer to Figure 2). This value was checked using the deflection equation found in MARKS': $y_{max} = k_1 * PR^2/(Et^3)$ where P = 477.5 lbs [1]. Calculations found in Appendix A11.1. The value of P was found from the radial load distributed across the side length of the crushing housing per inch. This equation resulted in in a deflection of 0.00365 inches and error of 8.7% compared to the Nastran model. The new safety factor was F.S. = 1.4. Consulting the project mentors, a decision was made to discard the truss assembly. The plate alone would fulfill the requirement of staying under 0.005 inches of deflection.

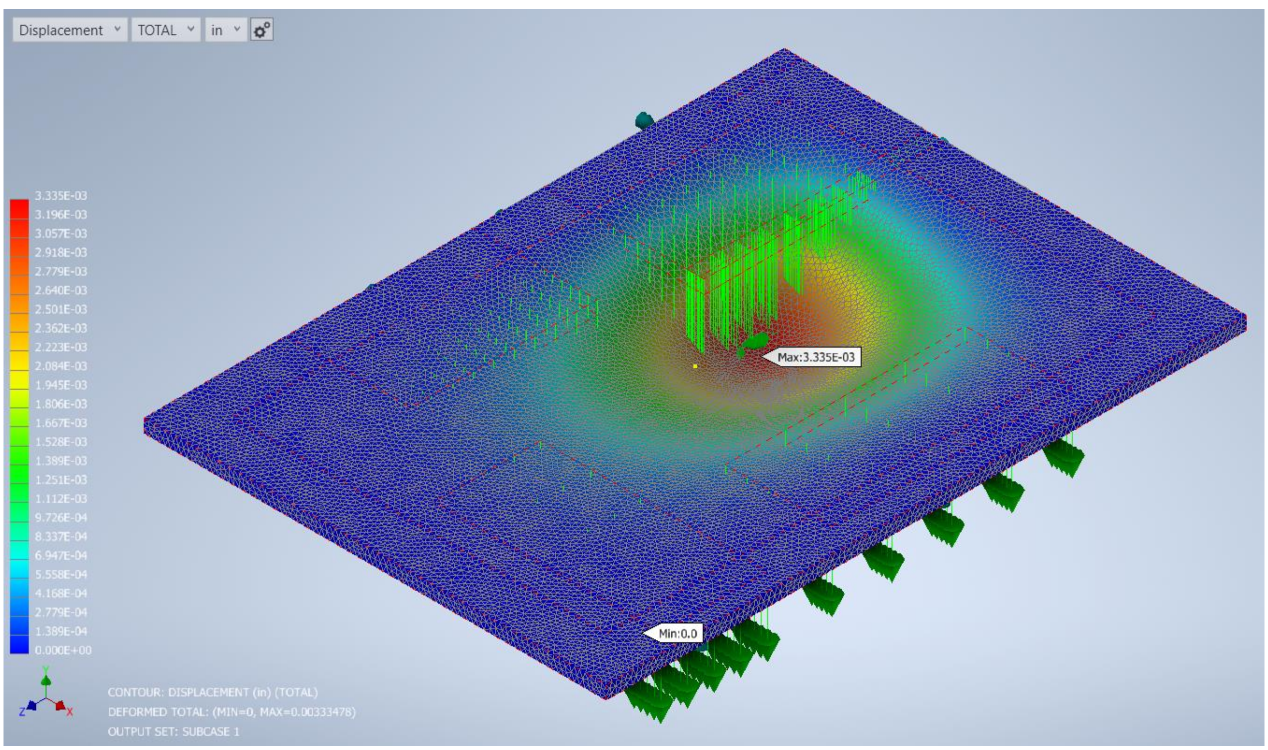

Figure 2: Nastran Model Showing Plate Deflection

xii. Analysis 12 (Measurements of Existing Parts)
More measurements needed to be taken to accurately locate holes on part 20-002. The hole locations originally drawn were based on part files provided by previous project members. The dimensions of these part files did not match the physical parts of the assembly. After taking accurate measurements, new hole locations were drawn. The truss holes were also discarded from the plate and a new drawing for 20-002 was made.

viii. Analysis 13 (Side Plate FEA)
A final finite element analysis was conducted to determine if any significant side plate deflection would occur in the existing crushing housing assembly. A Nastran model confirmed the side plate would absorb the load from the crushing gears. The stress of 5082 psi, shown in Figure 3, is well below the yield of ASTM A36 Steel. Green sheet calculations confirmed a stress of 5059 psi, 0.45% error to the Nastran model. Maximum deflection occurred was well below the requirement at 0.0004 inches, refer to Figure 4. This analysis confirmed the safety of the side plate and the reason for focus on parts external to the crushing housing causing displacements greater than 0.005 inches during operation.

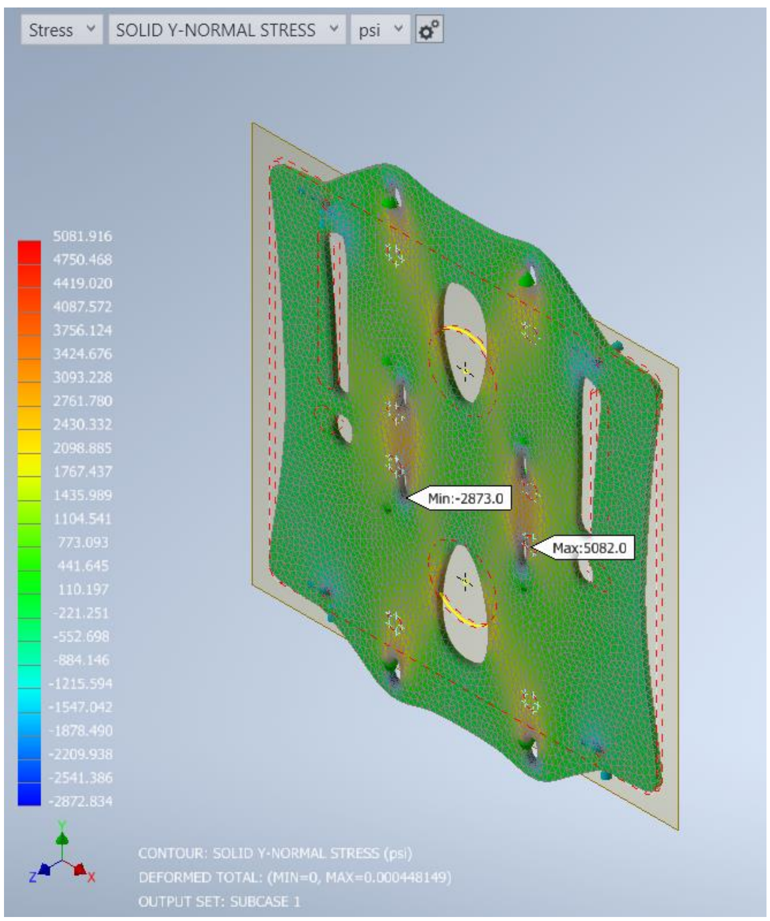

Figure 3: Side Plate Y-Normal Stress

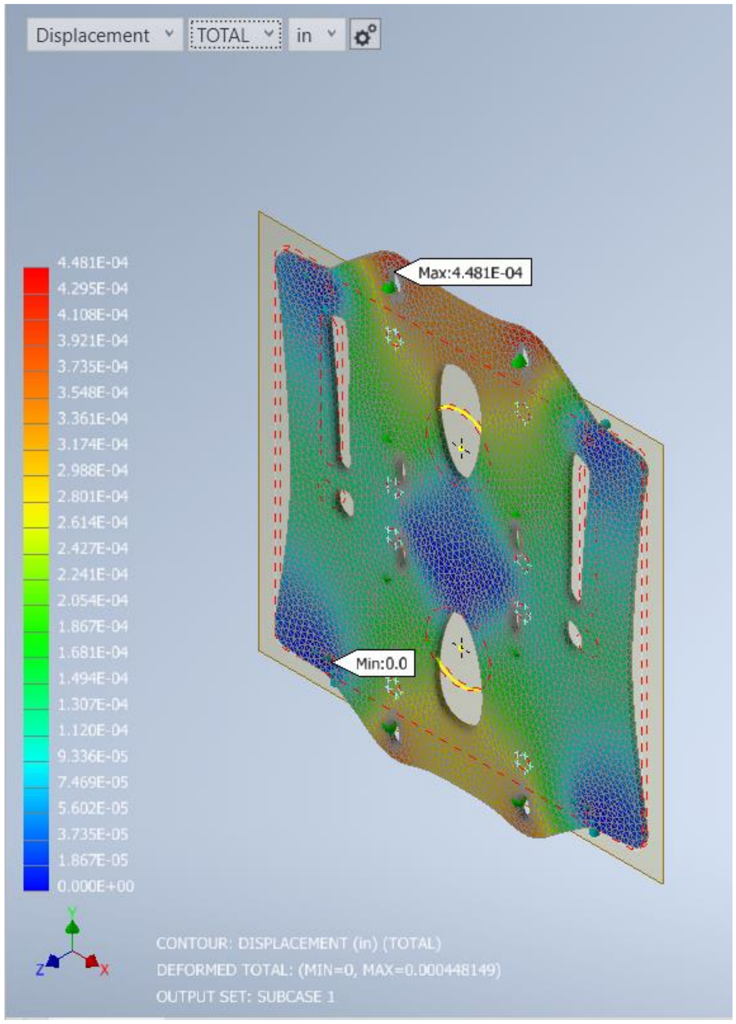

Figure 4: Maximum Side Plate Deflection

h. Device: Parts, Shapes, and Conformation

The geometry of the parts in this project were designed to be incorporated into the current crushing assembly. Several modifications of hole locations were done to fit components on the plate in a way that allowed them to function together. The safety factors calculated for all components in the assembly were above 2.0. Choosing this design parameter ensures that the components will not fail in the assembly. The tolerance of the plate dimensions were within 0.1 inches due to the larger perimeter. However, the hole locations for the plate were within a tolerance of 0.001 inches because the locations of each component on the plate was crucial to the function of the crushing assembly. Various bolts and fasteners were chosen to mount components to the existing supporting table.

i. Device Assembly

The assembly consisted of two main sub-assemblies. The first was a plate assembly with locating pins and spacer components. The second assembly was a table assembly to secure the plate assembly. This would prevent the plate from deflecting under the load produced by the crushing gears during the delamination process. Chain links were added to the motor connections to account for the rise in component placements.

j. Technical Risk Analysis

Some technical risks associated with this solution were incorrect locations of the parts on the base plate. If any hole were slightly out of alignment it would cause deflection in the connecting shafts and spur gears. It was crucial that each component was placed in the correct position.

k. Failure Mode Analysis

There were three failure mode analyses considered in the designing of parts. The first was the analysis of a flat plate with the maximum deflection. This produced the design parameter of the plate withstanding an assumed uniform maximum load. The second failure analysis focused on the buckling of columns using the Euler equation. A material and size for the Truss members were chosen after the axial loads were calculated. Truss geometry was determined from this analysis. To determine the need for a truss an analysis of beam deflection in the current assembly was conducted. The final failure mode analysis implored was shear in the bolts and locating pins. This was conducted to ensure that the parts would function using their assigned fasteners.

l. Operation Limits and Safety

The plate assembly was successful in preventing deflection of 0.005 inches. An increase in input rpm would cause higher deflection in the side plates and put the spur gears and crushing wheels at risk of failing. This would be dangerous for anyone operating the machine. To prevent this safety hazard, it was important to keep the nominal input speed at 189 rpm.

3. METHODS & CONSTRUCTION

a. Methods

This project was conceived, analyzed, and designed at Central Washington University. Working within the constraint of the university's resources, parts for the project were constructed in the Hogue Technology Building making use of the machining labs. Parts were also considered to be manufactured through Western Metal as an alternative. This was to plan for possible campus closures due to the COVID-19 pandemic.

i. Plate Design

A few designs were considered to construct a base plate that would connect all components of the crushing system together. The first design included only two components of the entire system with mount locations for gearbox 2 and the crushing housing. After considering the goal of the project was to provide a steady crushing and shredding process, a new design was drawn up to incorporate the shredder housing onto the plate area. Design 2 incorporated notches on the edge of the plate to attach it to the table structure. This design was also scrapped due to the difficulty in manufacturing such a plate without risk of the plate bending in the machining process. Finally Design 3 was drawn to incorporate all components driving the crushing gears to operate on the same plate. This would make the manufacturing process easier for securing a rectangular plate to the existing table.

Professor Charles Pringle suggested to scrap the welding plans and make a new design bolting the plate to the table. This required work to be done to the existing table structure. Holes needed to be drilled into the table at the mount locations for the base plate. Though there was added machining for the table, this method required less work in the construction process. Another design change was to do away with the access slots for the gears to dip below the surface and instead place half inch spacers underneath the shredder housing where the gears were interfering with plate surface. This eliminated the risk of plate deflection in the manufacturing process and reduced the time it would take to manufacture the plate.

Manufacturing of the plate was either to be done on a drill press or knee mill available in Hogue. The decision was made to drill holes on the mill for its secure support table. If manufacturing took place on the drill press, it would not have been as safe. Even with the large supporting table, the plate still needed a safety mechanism to machine certain hole locations. A hydraulic lift table and c-clamps were used to support the hanging end of the plate when these holes were being accessed.

ii. Truss Design

The original sketch for the truss design (refer to Figure 1) showed truss members placed along the length of the plate. This design was changed to have the members placed across the shorter width of the plate to mount the base of each member to the table structure. The tops of where the truss members meet included a few design changes. The designs needed to ensure that the load exerted on the members would act through the axes of each member for support. The final truss design includes a weld where the trusses meet and three holes for mounting. The design eventually was scrapped after Finite Element Analysis 11 confirmed the plate would not deflect more than 0.005 inches without the support of the truss. This cut the time of assembly and construction for the project. Assembly 10-001 and all associated part drawings and analyses were left in this report for reference.

b. Construction

i. Description

The supporting plate assembly was built using three main components: the base plate, modified components, and locating pins. There were five new and modified parts of the new final assembly and two subassemblies. The first was the plate assembly and the second a table assembly. Two parts were locating pins ordered from Carrlane and the rest was ordered material for parts machined in Hogue Technology Building at CWU.

ii. Drawing Tree, Drawing ID's

The Drawing Tree can be referenced in Appendix B. It includes the two sub-assemblies and the parts they are composed of.

iii. Parts

The only parts not modified were the purchased pins designated 55-000 and hardware fasteners designated 50-000. Parts 20-002 through 20-011 had material ordered and were machined in Hogue. A rectangular chain access hole for part 20-002 and holes for location pins and mounting locations were added. Half inch plate for part 20-011 was ordered to its dimensions and machined for holes on a knee mill. Parts 20-012, 20-013, and 20-014 were modified from previous project member's work.

iv. Manufacturing Issues

The beginning of the manufacturing process was very slow. Due to a two-week campus closure, there was no permitted access to Hogue's facilities. Another delay was due to the purchase list not being made in time to start ordering material through the CWU financial office. Plans were still being arranged in the third week to gain access to Hogue and meet up with a new lab tech for access.

v. Discussion of Assembly

After 20-002 was completed, assembly 10-002 was able to be started. A few issues arose in the pin locations for Gearbox #1. Part 20-014's pin hole needed to be modified to align with the through holes and pin hole drilled into the plate. After this problem was fixed assembly 10-003 was completed with further modifications made to part 20-012 mentioned in part modifications of this section. The final assembly 10-004 was postponed due to lack of chain needed to drive the crushing housing from Gearbox #2.

vi. Deconstruction

The first step made was disassembling all components to make room for incorporating the new parts. This process was done with project member Tim Boswell. Another reason components were removed from the table was to locate them on the base plate to ensure all hole locations were correct. The main reason for doing so was because the previous members Solidworks drawings were not exactly to the dimensions of the actual assembly. This extra step ensured that all parts would function correctly at their locations.

vii. Part Modifications

Because the base plate was to be mounted to the supporting table, holes needed to be drilled through the top of the structure. These holes were 17/32-inch in diameter to allow clearance for ½"-20, partially threaded hex bolt screws. The holes were drilled after the plate (20-002) had been manufactured for accurate location. A total of eight holes were drilled for mounting the plate. Holes that previously mounted the components needed to be modified for new locations. Holes for Gearbox #2 needed to be cut out through the edge of the table to allow for bolt clearance. The component was secured using washers of a large outer diameter to prevent the fastener from moving out of location.

Parts 20-013 and 20-014 were modified to locate Gearbox 1. Pin holes were drilled between the two through holes. Spacer 20-013 was shaved by 0.25 inches using a bandsaw and a ½-inch end mill to bring it to the same height as part 20-014. During assembly 10-004, an issue arose in the concentricity of the output and input shafts of the connected gearboxes. This required the housing spacers to be shaved by 0.18 inches. This made the output shaft of Gearbox 1 concentric with the input shaft of Gearbox 2.

viii. Base Plate 20-002

Manufacturing of the base plate took place on the knee mill. Through holes were the first to be drilled, then the bottomed pin holes, and finally the chain slot was milled using ½" end mill. This process took a while due to the weight of the A36 steel and difficult locations. Safety was a big factor in making manufacturing decisions.

Several modifications needed to be made after the plate had been manufactured. During assembly 10-003 it was found that the previous location of Gearbox #2 was incorrect. This was an obvious reason for the intent of a new plate design, to locate all components to a singular part. It shows why the previous design was not working properly. All holes for Gearbox #2 needed to be moved 0.40 inches to the right to align the shafts of Gearboxes #1 and #2 concentric. This resulted in the need to modify the holes in part 20-012 as previously mentioned.

iv. Crushing Housing Spacers 20-011

The crushing housing spacers did not take much time to manufacture. All they required were two through holes and a pin location to locate the crushing housing. Two quantities of this part were manufactured.

4. TESTING

a. Introduction

Testing was focused on the deflection of the base plate and crushing housing. All components needed to fall within the requirement of maximum deflection at 0.005 inches, with crushing gears operating at a feed rate of 1 foot per minute.

b. Method/Approach

The method of testing used was measuring displacement of the system with dial indicators around the area of the crushing housing. Three methods of testing were considered with two driving methods and two material methods. Tests were conducted driving the system manually and by the motor connection. By these two methods, partially delaminated carbon fiber strips and full composite carbon fiber strips were used. The crushing housing was the main area of focus because it was the area causing the most deflection. Data collected showed whether the design was successful.

Some issues arose in the initial motor testing. The rpm on the crushing wheels was too high reading at 7 rpm when they needed to be at 2.5 rpm. The rpm on the shredders needed to be decreased as well because as the composite is fed through the blades, it is being crushed by the wheels. If operating at a high rpm, the shredders would pull the composite from the crushing gears not achieving delamination. These issues were resolve by replacing the old power boxes with a new PowerFlex 523 power box with an adjustable ac power drive. Connecting both the motors to the box, the drive rpm of the motors was adjusted allowing the system to operate smoothly. If this issue were not resolved, the wear on the components would be significant enough to cause failure in the driving components during testing.

c. Test Procedure

Testing first started with observing any deflection in the side walls of the crushing housing. Dial indicators were placed on the front and back of the side wall crushing housing. Deflections were measured in relation to the top and bottom input shafts to the crusher. The next area of focus was underneath the plate. Various locations were considered. The first couple locations were mapped out where the predicted maximum deflection occurred, under the crushing gears. The first data collection did not require the system to be driven by the motor. Data was collected by manually driving the system of gears to test how all components meshed with one another. The second set of displacements were recorded with the driving horsepower applied to the system.

d. Deliverables

Deliverables for testing are recorded in data collection forms in Appendix G. This form includes the deflections measured from the plate, crushing housing, and driving components. Data was collected driving the gears both manually and by the motor. The motor drives the operating condition of the crushing wheels at 0.5 rpm under the crushing load of 10,500 lb. The predicted value for the deflection underneath the crushing housing was 0.0035 inches. The manual test produced a deflection of 0.002 inches with the partially delaminated carbon fiber. The predicted deflection on the side wall of the crushing housing was to be less than 0.001 inches. The actual deflection from manual testing ranged from 0.005 inches to 0.007 inches. With the full composite, the plate produced a maximum deflection of 0.004 inches downwards and 0.030 inches in the side walls. During motor testing, partially delaminated carbon fiber produced the same deflection recorded in the manual test. Unfortunately testing for the full composite wasn’t able to be conducted due to issues with the slack in the drive chain.

Some other issues found in testing were in the setup of the dial indicator. Finding an accurate zero was difficult, especially for the values underneath the crushing housing. Gravity kept pulling the tip of the indicator away from the plate while data was trying to be collected. As a result, deflection values would sometimes range back and forth about the zero or not record any value at all. This issue was resolved by tightening the components of the dial indicator and the magnetic base to increase the rigidity of the mechanism. Measurements were also recorded from the top of the plate. Another issue was finding a way to access the side wall of the crushing housing around the chainguard. The chainguard needed to be removed to produce results. For motor testing the chainguard was required. This relocated the dial indicator to test the deflection of the side wall from the op of the plate instead of the side.

5. BUDGET

The estimated budget for this project was $1,250. As the project specifications were more defined and parts were accumulated, material and hardware were assigned to fit within budget. A goal of this project was to not use more than 75% of the budget. Parts that effected most of the budget were the fasteners and the plates ordered.

All parts were ordered the second week of winter quarter with a few exceptions. Some fasteners were not ordered until the end of winter quarter due to some design changes made in the deconstruction and manufacturing processes. The material for parts, custom parts, and fasteners arrived in the fifth and sixth weeks of winter quarter. Arrival of material set the project back a little bit but allowed time for necessary design changes to be made. The remaining fasteners arrived in the last week of winter quarter.

a. Parts

All parts designated 20-XXX were planned to be machined at CWU in Hogue at zero labor cost. Material for part 20-002 was priced at $308. Material for parts 20-004 and 20-005 cost $6.40 each. Material for parts 20-006 through 20-010 cost a total of $6.16. These parts did not end up being used. All prices for these parts were from metalsdepot.com except for 20-002 which was purchased through Haskins Steel in Spokane, WA. Material for part 20-011 was ordered through metalsdepot.com at $74.30. Parts 50-001 through 50-017 were priced at a total cost of $146.19 with fasteners ordered from McMaster-Carr and Fastenal. Some money was saved using some fasteners previously apart of the assembly. Parts 55-001 and 50-003 were priced at $55.34 from carrlane.com. Refer to Appendix C for Parts and Cost List.

b. Outsourcing

Some parts for this project needed to have alternate considerations for manufacturing accounting for any closure of the CWU Hogue facilities due to COVID-19. Luckily no external manufacturers needed to be contacted.

c. Labor

The project had zero labor cost. All laborers on the project were paid employees of CWU and project members.

d. Estimated Total Project Cost

The estimated total cost of the project was $540.38. This did not account for fasteners needed for the final assembly considering material available for use in Hogue. The estimated cost put the project at 43.2% of the budget. The actual budget increased to $622.21. The cost could have been higher if the decision to buy the plate from Haskins had not been considered. The cost was roughly $200 less than the formerly planned source, metalsdepot.com. Along with the fasteners, this put the total consumed budget at 49.8%.

e. Funding Source

The funding source for this project was JCATI. The amount of funding received for the project was split up amongst the four members working on it. Each project member received $1250. If project costs exceeded this amount, funds would come out of pocket.

6. Schedule

a. Design

The design schedule was a longer process than intended. Figuring out where to start was a difficult process. After physically testing the previous system's movements, a base plate design was settled on. Once the design of a base plate was determined, the analyses for the project started to come faster. A few analyses determined methods that would not be successful in finding a solution and became irrelevant to the report. From there a new design was considered and further analyses determined geometry and material for the parts. It took 7 weeks to complete the first 10 analyses. Three more were conducted in winter quarter as modifications were made to the parts and assemblies. Most drawings were completed over 7 weeks. The final assembly and drawing changes were finished in winter quarter. The Budget for the project was completed over a 5-week period with some additional work done in winter quarter. The total time to complete the design process in fall quarter took 46.5 hours and an additional 19.25 hours in winter quarter.

b. Construction

The planned schedule for construction needed to be pushed back as a result of campus closers due to COVID-19. Deconstruction started in the third week of winter quarter. Once deconstruction had been completed, there were found more modifications that needed to be done to part drawings. Part files taken from previous project members were not to actual part dimensions. This required more time to be spent in Hogue measuring hole locations on parts and component locations on the supporting table. Once these were determined, a new plate drawing was drawn to locate each component in its correct location. Part modifications took a couple weeks. Part 20-002 needed to be modified several times as issues became evident in the assembly process. All parts were modified and assembled by the end of the winter quarter deadline.

The ordering of parts was also a factor in delay of the manufactured parts. Material was ordered in the second week of winter quarter. Material did not arrive until the end of week five. This allowed for necessary design changes to be made.

c. Testing

Hours for testing were scheduled every Monday, Wednesday, and Friday at 8:00 am. Tests were able to be completed over the course of a five-week period. Additional time was spent in Hogue 127 to make system modifications and re-test values where needed. For example, machining additional spacers for the shredder housing and feeler gauges for the crushing wheel keyways added time to the testing period. Time was also added when Test 1 needed to be redone to produce accurate results in the direction of side plate deflection. The total hours of performing evaluation, including additional manufacturing, was roughly 11 hours.

7. Project Management

This project would be successful given the available resources and expertise provided by CWU. A few risks were associated with this project. The project was planned to be manufactured and assembled in the Hogue building on campus. However, if COVID-19 forced multiple lockdowns, manufacturing of parts and testing would need to take place off campus. This would have increased the budget of the project and would have set the project behind schedule if alternatives were not arranged fast enough. Luckily, campus closures did not derail the project schedule.

a. Human Resources

Human resources, made accessible through the university, include Professor Charles Pringle, Dr. John Choi, and Student Lab Technician Muir Hamilton. The associated risk working with Hamilton was a conflict of time. To manage this risk a set schedule was arranged to manufacture all project parts in a timely manner.

b. Physical Resources

Physical resources needed to complete this project were access to the CWU Metal Working Shop and the Metallurgy Lab in Hogue. These shops included all equipment needed to manufacture and assemble parts.

c. Soft Resources

Software used to complete this project were CAD programs Solidworks and Inventor Nastran Pro. All project files were saved to a flash drive as a back-up in case of a computer crash. If Solidworks and Inventor Pro stopped running on the main project desktop, the software would be accessed through the school computer labs in Hogue.

d. Financial Resources

The primary financial resource for this project is the project sponsor JCATI. All project costs exceeding the budget would fall to the Principal Engineer, Jacob Atamian.

8. DISCUSSION

a. Design

The initial design for this project was changed frequently in the first couple weeks. Several testing's took place to figure out what was going wrong with the previous project members' efforts to delaminate the aircraft trimmings. The initial design was to implement connecting arms to the crushing housing and gearboxes to prevent independent movement. Though more testing discovered the gearboxes not only to be moving away from the crushing housing, but also that the crushing housing was moving downwards due to weak support from beneath. This led to the design of a base plate to connect all components and put them on the same surface level.

There were two base plate designs ventured to determine what would be the easiest to manufacture. The first design (20-001) included notched edges to connect the plate to the supporting table in place. The reason this design was scrapped was due to the difficult manufacturing methods that would need to be explored. There would be risk of the plate bending during the manufacturing process for milling the notched edges. Taking this into consideration a new design (20-002) was drawn to have the plate mounted to the supporting table. This way the plate would be able to rest flush on the table. This design made for easier and less time-consuming manufacturing methods. The machining needed for the plate was drilling the holes for mounting components and milling a slot for the chain access.

A truss was initially designed to support the crushing load during the delamination process. This would provide extra support reducing the deflection of the plate. After Finite Element Analysis 1 was conducted in winter quarter, the truss design was scrapped. It was determined that a safety factor of 1.4 would be sufficient enough for the plate to act as the sole supporting member.

The last design component considered in the process were locating pins for the components connected on the plate. These pins would prevent each component from moving in independent directions on the plate. A round and diamond pin were found for each component. The size for each were assigned to match previous project members component drawings.

Some issues were found in putting together the assembly. The actual manufactured dimensions for the supporting table were different than the dimensions in the Solidworks part files. Some reconstruction of previous members part files took place to have the designed parts fit together in the assembly.

b. Construction

Deconstruction

The first part of the construction process was deconstruction. Issues associated with this part of the construction included modifications that needed to be made to existing parts. Firstly, the angle irons welded to the table needed to be cut out of the inner frame. This was to allow for the truss to be placed beneath the base plate and for all fasteners to reach the bottom of the plate to fasten components. It was determined after this step was done that the truss would be discarded from the design. A port-a-band saw was used to resolve this issue.

Part Construction

The main focus of manufacturing focused on part 20-002. This plate consists of an access slot for the motor connection, twenty through holes for fasteners, and six bottomed holes for pins. A knee mill was used to drill all the holes. This required two people to work the plate in a safe manner. Clamps were used to secure the plate to the table. Some holes were difficult to reach and required much of the plate area to be unsupported by the table. To ensure safe handling and accurate drilling, a hydraulic lift was used to support the hanging edge of the plate area when needed. A level was used to ensure the plate was level before drilling started. Some hole locations through the center of the plate required the use of spacers clamped through the top of the plate to the bottom of the mill table. Spacers were also used to mill out the access slot.

Part Modifications

Laying out the holes was important to locate each component on the plate correctly. Several hole locations had to be re-drilled due to incorrect placement. The pin location for part 20-014 was placed incorrectly on part 20-002. To fix this error, 20-014 was modified to extend the pin hole to a slot so that the pin inserted into the base plate would also fit into part 20-014 while aligning with the fastener holes. The holes to locate Gearbox #2 were placed incorrectly. They had to be moved 0.4 inches to the right so that the output shaft of Gearbox #1 would be concentric with the input shaft of Gearbox #2. All six holes, two bottomed and four through, were re-drilled with ease on a knee mill. Another issue arose when lining up the two gearboxes. The output shaft was placed too high on Gearbox #1 making it nonconcentric with Gearbox #2. This problem was resolved by shaving the housing spacers, 20-013 and 20-014, by 0.18 inches.

Table Modification 20-012

To secure part 20-002 to part 20-012, new holes needed to be drilled. This part was done after part 20-002 was finished to ensure proper alignment. Some existing holes needed to be modified to align with the new plate holes. Holes located around the crushing housing were easily drilled out to a larger diameter. The holes located around Gearbox #2 needed to be cut out entirely with an angle grinder to allow for bolt clearance.

c. Testing

During testing the dial indicator initially being used was not giving accurate results. Due to this issue a new indicator with a more stable magnetic base was used. Some data collected contradicted previous data collected. For example, in the first manual test with the partially delaminated carbon fiber, the deflection of the side plate on the front of the housing was indicated to be deflecting inwards towards the crushing wheels and the back was indicated to be deflecting out from the wheels. In the manual test with the full composite, the front and back of the side wall both deflected out from the crushing wheels. To ensure accurate results, re-testing of the partially delaminated composite needed to be conducted.

The motor test also ran into some issues. Because the components in the motor test were operating at higher speeds, the chainguard was needed to cover the input shafts to the crushing housing. This disabled the testing locations to the side wall of the housing, used in the manual tests. To work around this issue, a new testing location was chosen to observe vertical deflection on the top of the side wall. The indicator was clamped to the shredder housing and the tip was placed on the back end of the side wall. It also became evident that the crushing wheels could not handle delaminating full composite without binding the spur gears. Testing with the motor required partially delaminated carbon fiber composite at a quarter inch thickness. To resolve the issue to increase the amount of crushable composite thickness, the crushing wheels needed to be altered to fit securely on the driving shafts. This would reduce the binding of the gears for smooth operation. Deliverables indicated the base plate served its function in reducing system deflection downwards to under 0.005 inches. The input side plate was the component of the crushing housing that failed to meet this requirement.

9. CONCLUSION

The base plate design process went through several different designs until a final design was decided on. Analyses 4, 6, and 11 were the most important in determining geometry of the base plate. These analyses found the following design parameters:

- The maximum load the plate can support alone is 905 lb.
- The load acting in the plate area produced by the crushing gears is 467 lb.
- The maximum deflection the plate experiences during operation is 0.004 inches.

The predicted performance of the assembly was that the crushing gears would not deflect more than 0.005 inches during delamination as the parts were designed to parameters above. The assembly would be successful with the crushing gears operating around 2.49 rpm. Testing found that the plate was successful in preventing a downwards deflection greater than 0.005 inches. However, the side wall of the crushing housing deflected over the requirement at 0.030 inches with the full composite. The motor operated at a low-speed crushing partially delaminated composite, driving the wheels at 0.5 rpm. The drive chain and side walls need a redesign to operate the system at 2.5 rpm to delaminate the full ½-inch composite. This will be the focus of next year's project members.

10. ACKNOWLEDGEMENTS

Thanks to Prof. Charles Pringle and Dr. John Choi for mentoring and providing useful feedback in completing this project.

Thanks to Jim Helsius for help in running tests and providing insight on manufacturing techniques.

Thanks to Muir Hamilton for suggesting manufacturing techniques through the construction process.

Thanks to project members Tim Boswell and Ben Cooley for their hard work and coordination throughout this project.

Thanks to Join Center for Aerospace Technology and Innovation (JCATI) for funding the project.

Thanks to Central Washington University in providing access to necessary equipment for the project to reach completion.

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APPENDIX A - Analysis

Appendix A1 – Deflection Testing

JACOB ATAMIAN | DIAL INDICATOR ANALYSIS 1 | 10/6/20 | 1/1

- DIAL INDICATORS SHOW the base of the frame being pushed downwards
- The side plates are being pushed outwards

- It looks as if the Lower Spur gear is being displaced downwards resulting in gear tooth displacement.

#1.1 : MOVED DOWNWARDS

#1.2 : MOVED DOWNWARDS

#2.1 : FROM PLATE. MOVING OUTWARDS

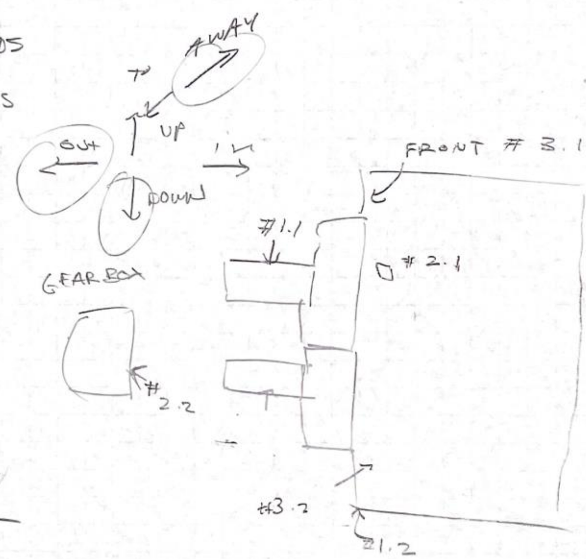
#2.2 : GEARBOX is ALSO MOVING OUTWARDS

#3.1

THE TOP IS MOVING AWAY FROM THE INDICATOR (FRONT)

#3.2

NO MOVEMENT

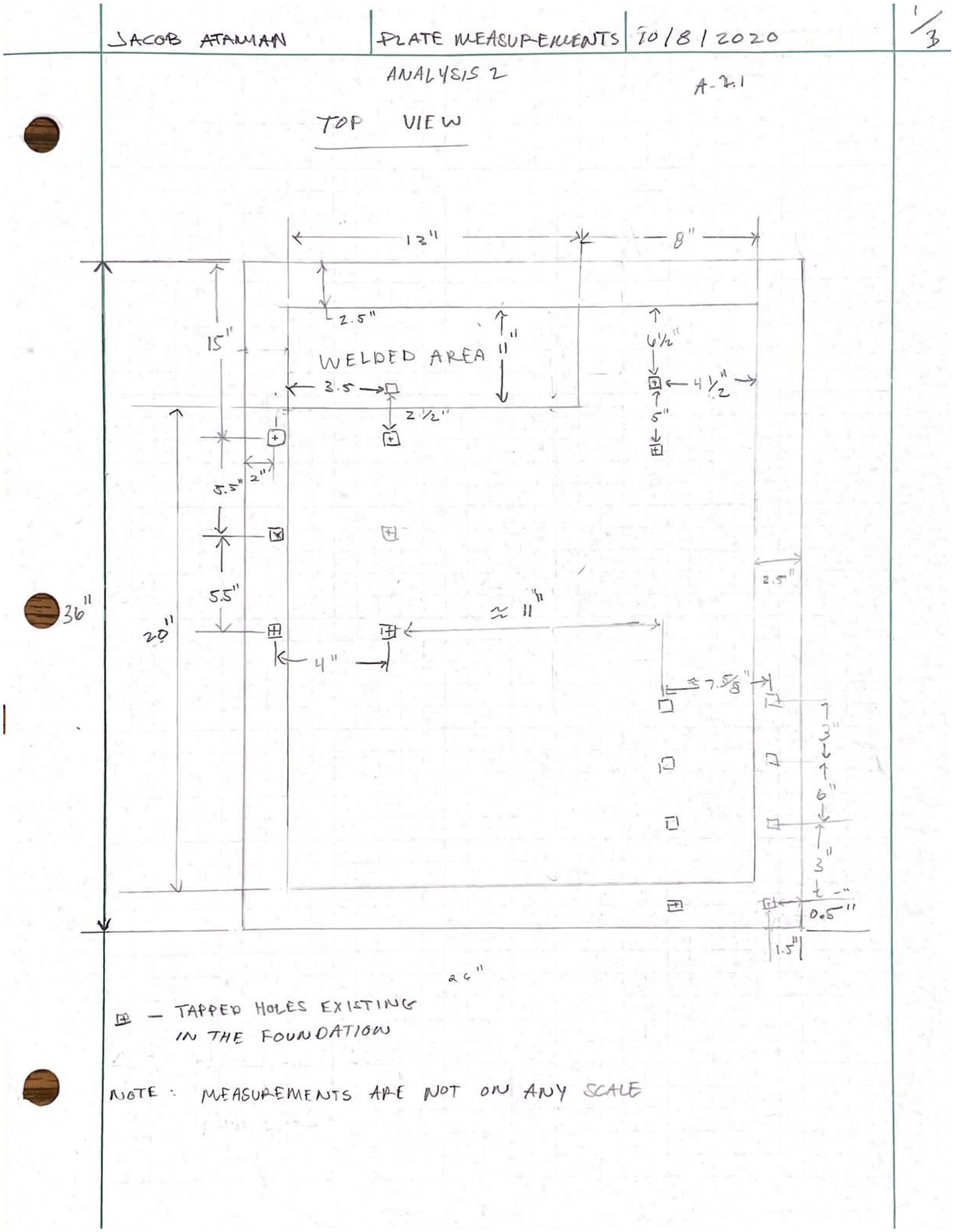


MEETING 1 (4:00 PM 10/7/20) : 30 minutes
HOURS SPENT : 4.5 hours

- GET ANALYSIS 1 LOCKED DOWN
- SHOULD I GO MEASURE DISTANCES BETWEEN EACH LOCATION?
- FBD - ANALYZING THE FORCES ACTING ON THE CRUSH HOUSING
- A SUPPORT BELOW THE SIDE WALL OF THE CRUSH HOUSING THAT IS EXPERIENCING THE LOAD
- COORDINATE WITH TIM
- AM I USING DYNAMIC LOAD OF BEARINGS FOR MY FBD OR THE SOLVED REACTIONS FROM D & B

A1.1

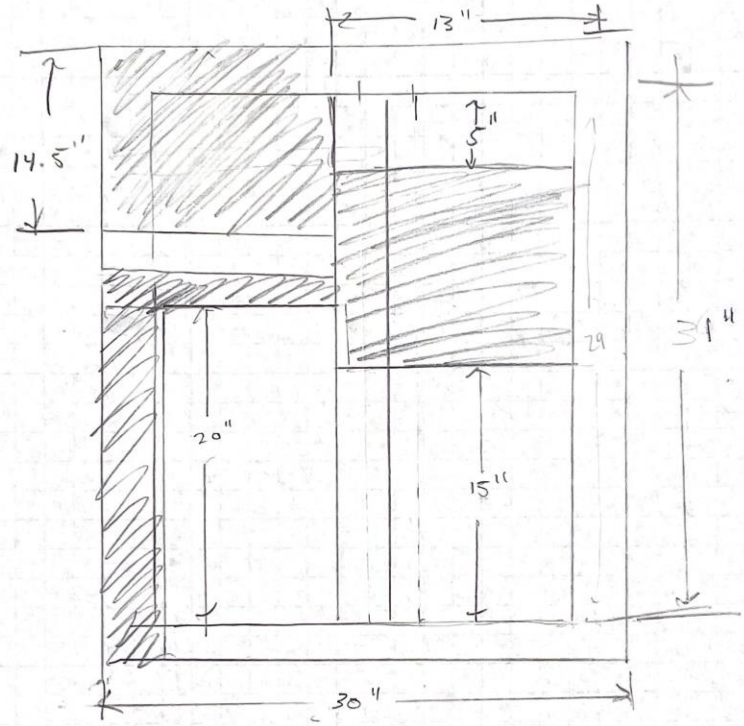
Appendix A-2 – Plate Dimensions



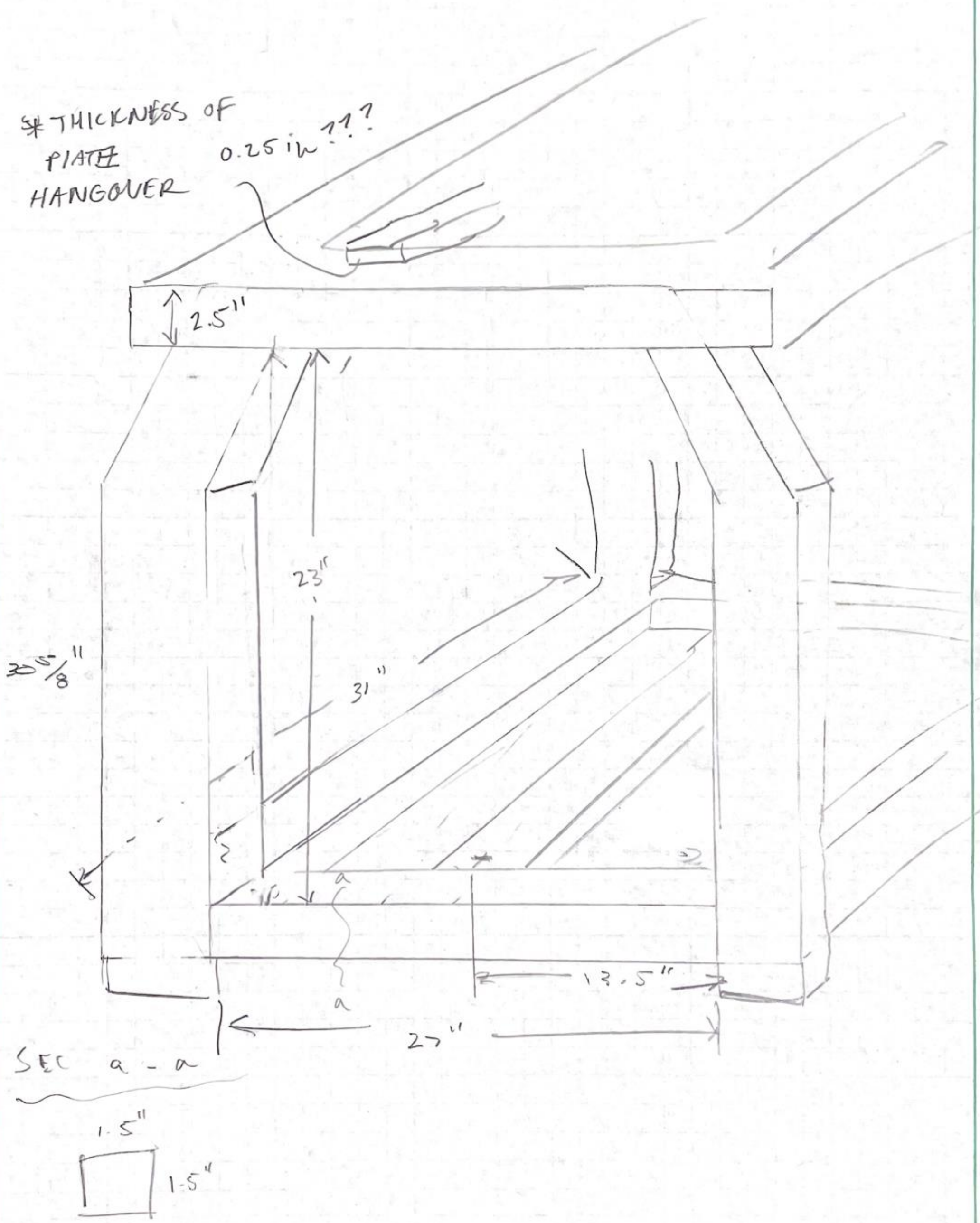
A2.1

JACOB ATAMIAN	ANALYSIS 2	LIMITATIONS OF LOCATION FOR BASE SUPPORTS	2/3

SPACE UNDERNEATH PLATE



A2.2


* THICKNESS OF PLATE HANGOVER
0.25 in ???
2.5"
23"
30 5/8"
31"
13.5"
27"
SEC a - a
1.5"
1.5"

A2.3

Appendix A-3 – Deflection Analysis

JACOB ATAMAN | DEFLECTION ANALYSIS #1 | 10/8/2020 | 1/3

ANALYSIS 3

A-3.1-3.3

GIVEN: - Y_m = 0.005 in (MAX DEFLECTION)

- CASE 16 (MARK'S P.249)

FIND: DESIGN PARAMETER - FORCE (P) THE PLATE CAN WITHSTAND WITHOUT DEFLECTING MORE THAN 0.005 inches.

ASSUME: - ASSIGNED MATERIAL: STRUCTURAL A992 (AISI 1020)
- DISTRIBUTED LOAD / SUPPORTED ON ALL EDGES (CASE 16)
- THICKNESS OF THE PLATE
- WEIGHT OF COMPONENTS

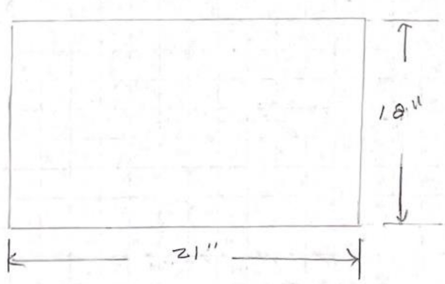
METHOD: (1) - ASSIGN PLATE DIMENSIONS
(2) - DETERMINE ASSUMED WEIGHT OF COMPONENTS
(3) K_1 (TABLE 3.2.20 MARKS)
(4) SOLVE FOR P

$$Y_m = K_1 \frac{PR^2}{Et^3} \Rightarrow P = Y_m \times \frac{Et^3}{K_1 R^2}$$

(5) P > WEIGHT OF COMPONENTS

SOLN:

① ESTIMATED PLATE DIMENSIONS



③

r = 18 in   R/r → K_1 (16)

R = 21 in

$\frac{21}{18} = 1.17 \approx 1.0$

$K_1 = 0.0443$

② GEARBOX 3 ≈ 100 lb

CRUSH GEAR HOUSING ≈ 200 lb

TOTAL WEIGT ≈ 300 lb

A3.1

④ ASSUME: $E = 29 \times 10^6$ psi
$t \approx 0.75$ in

$$P = y_m \times \frac{Et^3}{k_1 R^2} = \frac{(0.005\,in)(29 \times 10^6\,\frac{lb}{in^2})(0.75\,in)^3}{(0.0443)(21\,in)^2}$$

$P = 3131$ lb > 300 lb

* IT WORKS BUT CAN PROBABLY REDUCE PLATE THICKNESS

$t = 0.5$ in

$$P = \frac{(0.005\,in)(29 \times 10^6\,\frac{lb}{in^2})(0.5\,in)^3}{(0.0443)(21\,in)^2}$$

$P = 928$ lb > 300 lb ✓

* THICKNESS AT $t = 0.5$ in CAN HANDLE THE LOAD OF COMPONENTS

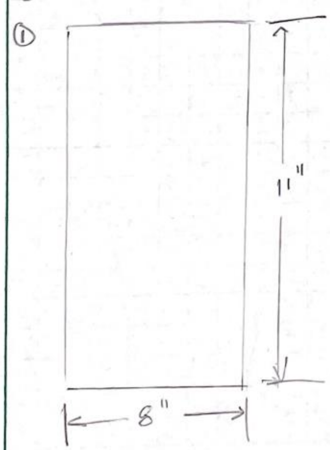
FIND: CONFIRM THE THICKNESS WILL WORK FOR THE LONGER SIDE OF PLATE. (REFER TO DESIGN SKETCH)

METHOD: ① FIND DIMENSIONS OF PLATE
② USE STEPS (2–5)

ASSUME: $t = 0.5$ in
$E = 29 \times 10^6$ psi
PLATE DIMENSIONS

SOLN:

①



$R = 11$
$r = 8$

$\frac{R}{r} = 1.375$

≈ 1.5

$k_1 = 0.0843$

② ASSUMED WEIGHT OF SHREDDER ≈ 75 lb

* THE SHREDDER BOX IS THE ONLY COMPONENT PRESENT ON THIS SECTION OF THE PLATE

A3.2

JACOB ATAMIAN	DEFLECTION ANALYSIS 3	10/8/2020	3/3

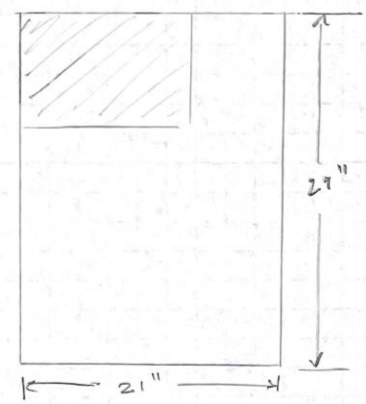
④

$$P = \frac{(0.005\,in)(29\times10^{6}\,\frac{lb}{in^2})(0.5\,in)^3}{(0.0843)(11\,in)^2}$$

$P = 1777\,lb > 75\,lb$ * WELL EXCEEDS THE LOAD

* CALCULATION CONSIDERING THE ENTIRE AREA

①



② WEIGHT OF COMPONENTS $\approx 375\,lb$

③ $R = 29$
$r = 21$

$\frac{R}{r} = \frac{29}{21} = 1.38 \approx 1.5$

$k_1 = 0.0843$

$t = 0.5\,in$

④ $$P = \frac{(0.005\,in)(29\times10^{6}\,\frac{lb}{in^2})(0.5\,in)^3}{(0.0843)(29\,in)^2}$$

$P = 255.65\,lb < 375\,lb$ ✗ * GO UP TO $t = 0.75\,in$

$t = 0.75\,in$

$$P = \frac{(0.005\,in)(29\times10^{6}\,\frac{lb}{in^2})(0.75\,in)^3}{(0.0843)(29\,in)^2}$$

$P = 863\,lb > 375\,lb$ ✓

* $t = 0.75\,in$ WORKS FOR AN APPROXIMATED AREA OF THE ENTIRE PLATE

$t = 0.75\,in$

A3.3

Appendix A4 (Crushing Load at Support Location)

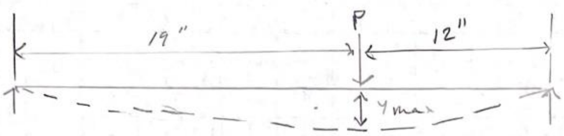
JACOB ATAMAN | RAW DATA A4 | 10/22/2020 | 1/2

GIVEN: ANGLE IRON SUPPORT

ASSUMED DIMENSIONS = 1.5" x 1.5" TO FIND I
MEASURED " " = 2.0" x 2.0"

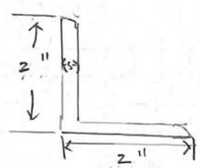
MATERIAL

ASSUME: $E = 30 \times 10^6$ psi



FIND: y_{max} = ? BASED ON MEASUREMENT
P = ?

ASSUME: $E = 30 \times 10^6$ psi
I = BASED FROM ANGLE IRON DIMENSIONS

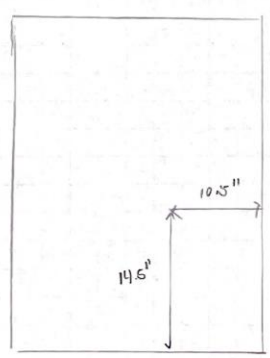


⇒ L2 × 2 × 1/4 : I_x = 0.348 in^4 * WESTERN METALS

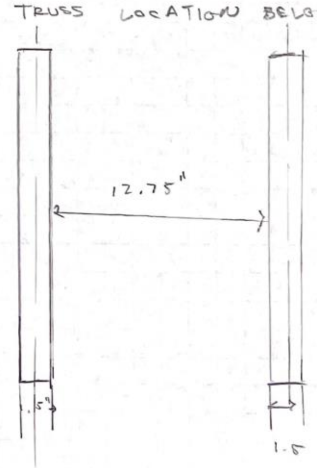
* TABLE A15-1

S = 0.25 in y_{max} = 0.025 in

POSITION (a)



(b) TRUSS LOCATION BELOW

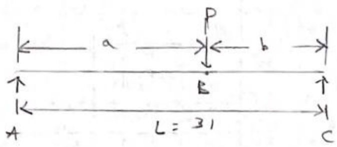


A4.1

JACOB ATAMIAN | ANALYSIS 4 | 10/22/2020 | 2/2

METHOD: - APP A14-1 (b)

$$Y_b = \frac{-Pa^2b^2}{3EIL}$$



SOLN:

$$-Pa^2b^2 = -Y_b\, 3EIL$$

$$P = \frac{Y_b\, 3EIL}{a^2b^2}$$

$a = 19$

$b = 12$

$Y_b = 0.025$ in

$L = 31$ in

$$P = (0.025\text{ in}) \times \frac{3(30\times10^6 \frac{lb}{in^2})(0.348\text{ in}^4)(31\text{ in})}{(19\text{ in})^2(12\text{ in})^2} = 466.93\text{ lb}$$

P = 467 lb

* 466 lb IS ACTING AT THE INTENDED POSITION FOR THE TRUSS

* 0.025 in IS THE MAX DEFLETION OF THIS POINT BEFORE SPUR GEARS BEGIN TO DISPLACE

A4.2

Appendix A5 – Axial Load in Truss Members (OBSOLETE)

JACOB ATAMIAN | ANALYSIS 5 | 10/22/2020 | 1/3

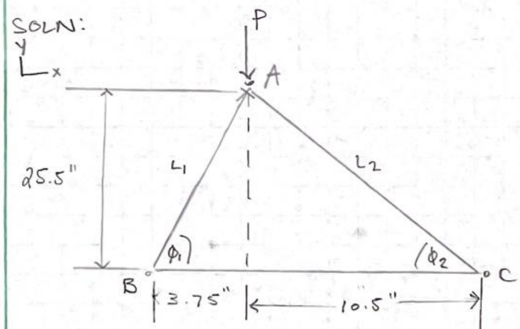
GIVEN: - EXTERNAL VERICAL LOAD : P = 467 lb
- LOCATION MEASUREMENTS

FIND: ① GEOMETRY OF TRUSS
② AXIAL LOADS IN TRUSS MEMBERS

ASSUME: - TRUSS IS FIXED AT THE BOTTOM / ACTS AT CENTER
- LOCATION

METHOD: - REFER TO DRAWING (b) OF ANALYSIS 7 IN THE ASSUME SECTION.
- DRAWING
- FBD
- METHOD OF JOINTS

SOLN:



$L_1 = ?$ $\phi_1 = ?$

$L_2 = ?$ $\phi_2 = ?$

$L_2 = \sqrt{10.5^2 + 25.5^2}$

$L_2 = 27.58\ in$

$\phi_2 = \tan^{-1}\left(\frac{25.5}{10.5}\right)$

$\phi_2 = 67.6°$

$L_1 = \sqrt{3.75^2 + 25.5^2} = 25.77\ in$

$\phi_1 = \tan^{-1}\left(\frac{25.5}{3.75}\right) = 81.6°$

$\phi_1' = 80° \Rightarrow \tan\phi_1 = \frac{25.5}{x_1}$

$x_1' = \frac{25.5}{\tan 80°} = 4.496\ in \approx 4.5\ in$ $L_1' = \sqrt{4.5\ in^2 + 25.5\ in^2}$

$L_1' = 25.89\ in$

$x_2' = 14.75 - 4.5 = 10.25\ in$

$L_2' = \sqrt{10.25^2 + 25.5^2} = 27.48\ in$

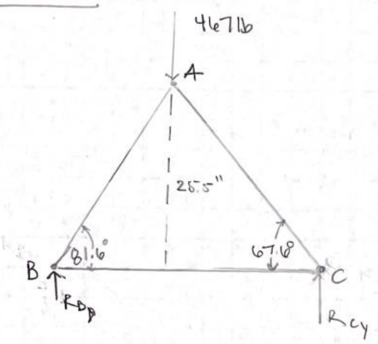
$\phi_2' = \tan^{-1} \frac{25.5}{10.25} = 68.1°$

MIGHT USE FOR A DIFFERENT ANALYSIS

* MOVING THE TOP LOCATION OF THE TRUSS 0.75 in TO THE RIGHT GIVES WHOLE # ANGLES WHICH MIGHT BE EASIER TO MANUFACTURE.
* ASSUME THE LOAD REMAINS THE SAME.

A5.1

REDRAWN

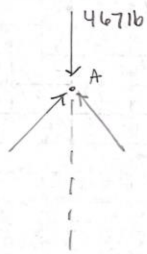


ASSUME: FIXED AT ENDS

(T) - MEMBERS IN TENSION

(C) - MEMBERS IN COMPRESSION

JOINT A



$+\uparrow \Sigma F_y: -467lb + N_{AB} \sin 81.6° + N_{AC} \sin 67.6° = 0$

$\overset{+}{\rightarrow} \Sigma F_x: N_{AB} \cos 81.6° - N_{AC} \cos 67.6° = 0$

$$N_{AB} = \frac{N_{AC} \cos 67.6°}{\cos 81.6°}$$

$$N_{AB} = 2.6086\, N_{AC}$$

$$-467lb + 2.6085\, N_{AC} \sin 81.6° + N_{AC} \sin 67.6° = 0$$

$$3.505\, N_{AC} = 467lb$$

$N_{AC} = 133.23\,lb$
or
133 lb (T)

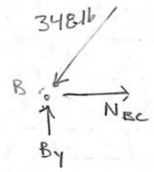
$N_{AB} = 2.6086\, N_{AC} = 2.6086(133lb)$

$N_{AB} = 347.54lb$
or
348 lb (C)

* AXIAL LOADS FOUND WILL BE USED TO DETERMINE BEAM DIMENSIONS IN ANALYSIS 9

A5.2

JOINT B



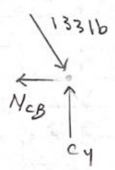
$+\uparrow \Sigma F_y = B_y - 348\text{lb} \sin 81.6^\circ = 0$

$B_y = 343.82$ lb
or
344 lb

$\overset{+}{\rightarrow} \Sigma F_x = N_{BC} - 348 \cos 81.6^\circ = 0$

$N_{BC} = 50.77$ lb
or
50.8 lb (T)

JOINT C



$N_{CB} = 50.8$ lb

CHECK

$\overset{+}{\rightarrow} \Sigma F_x = 133\text{lb} \cos(67.6^\circ) - N_{CB} = 0$

$N_{CB} = 50.68 \approx 50.7$ (T) ✓

$+\uparrow \Sigma F_y = C_y - 133\text{lb} \sin 67.6 = 0$

$C_y = 122.96$ lb
or
123 lb

* C_y & B_y WILL BE USED LATER TO DETERMINE THE DEFLECTION (IF ANY) OF THE LOWER SUPPORTS.

A5.3

Appendix A6 – Base Plate Redesign

JACOB ATAMIAN | ANALYSIS 6 | 10/19/2020 | 1/2

(ANALYSIS 3 REVAMPED)

GIVEN: PLATE DIMENSIONS: 36 × 26 inches

MAX DEFLECTION = 0.005 in

MATERIAL AISI 1020 CD = SAE 1020 CD

· S_y = 51 ksi $E = 30 \times 10^6$ psi

· S_u = 61 ksi

WEIGHT OF GEARBOXES = 28 lb × 3 = 84 lb

FIND: PLATE THICKNESS t

ASSUME: - WEIGHT OF GEARBOX = 200 lb $t = 0.5$ in

- WEIGHT OF SHREDDER = 50 lb $t = 0.75$ in

- $F.S \geq 2$ - CASE 16 P. 249 MARKS

METHOD: - DEFLECTION OF A FLAT PLATE

- FIG 3.2.70 P. 249 MARKS

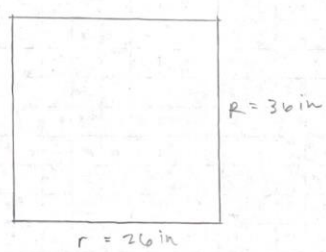
- TABLE 3.2.20 P. 250 MARKS

- $Y_m = k_1 \frac{P R^2}{E t^3} \Rightarrow P = Y_m \frac{E t^3}{k_1 R^2}$

- $FS = \frac{S_y}{\sigma_{cr}}$ $\sigma_{cr} = \frac{P_{cr}}{A_p}$

- P > WEIGHT OF COMPONENTS

SOLN:



$R/r = \frac{36}{26} = 1.38 \approx 1.5$

$k_1 = 0.0843$

WEIGHT OF COMPONENTS = 350 lb

INTERPOLATE

$k_1 = 0.0539$

$t = 0.5$ in

$$P = (0.005\text{ in}) \times \frac{(30 \times 10^6 \text{ psi})(0.5\text{ in})^3}{(0.0539)(36\text{ in})^2} = 268.4\text{ lb} < 350\text{ lb}$$

$t = 0.75$ in

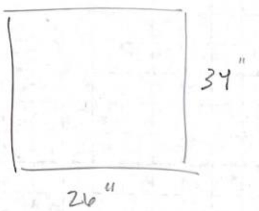
$$P = (0.005\text{ in}) \times \frac{(30 \times 10^6 \text{ psi})(0.75\text{ in})^3}{(0.0539)(36\text{ in})^2} = 905.7\text{ lb} > 350\text{ lb}$$ ✓

* WOULD WORK FOR PLATE IF 36 in = R

$$F.S = \frac{P_{FAIL}}{P_{ALLOW}} = \frac{905.7}{350} = 2.6 > 2$$ ✓

A6.1

USING PLATE DIMENSIONS : 34" × 26"



INTERPOLATE FOR k_1

$\frac{R}{r} = \frac{34}{26} = 1.3$

k_1	R/r
0.0443	1.0
k_1	1.3
0.0843	1.5

$$k_1 = 0.0443 + \frac{(0.0843 - 0.0443)}{(1.5 - 1.0)}(1.3 - 1.0)$$

$$k_1 = 0.0683$$

$$P = y_m \times \frac{Et^3}{R^2 k_1}$$

$t = 0.5\,in$

$$P = (0.005\,in)\frac{(30 \times 10^6\,psi)(0.5\,in)^3}{(0.0683)(34\,in)^2} = 237\,lb < 350\,lb$$

$t = 0.75\,in$

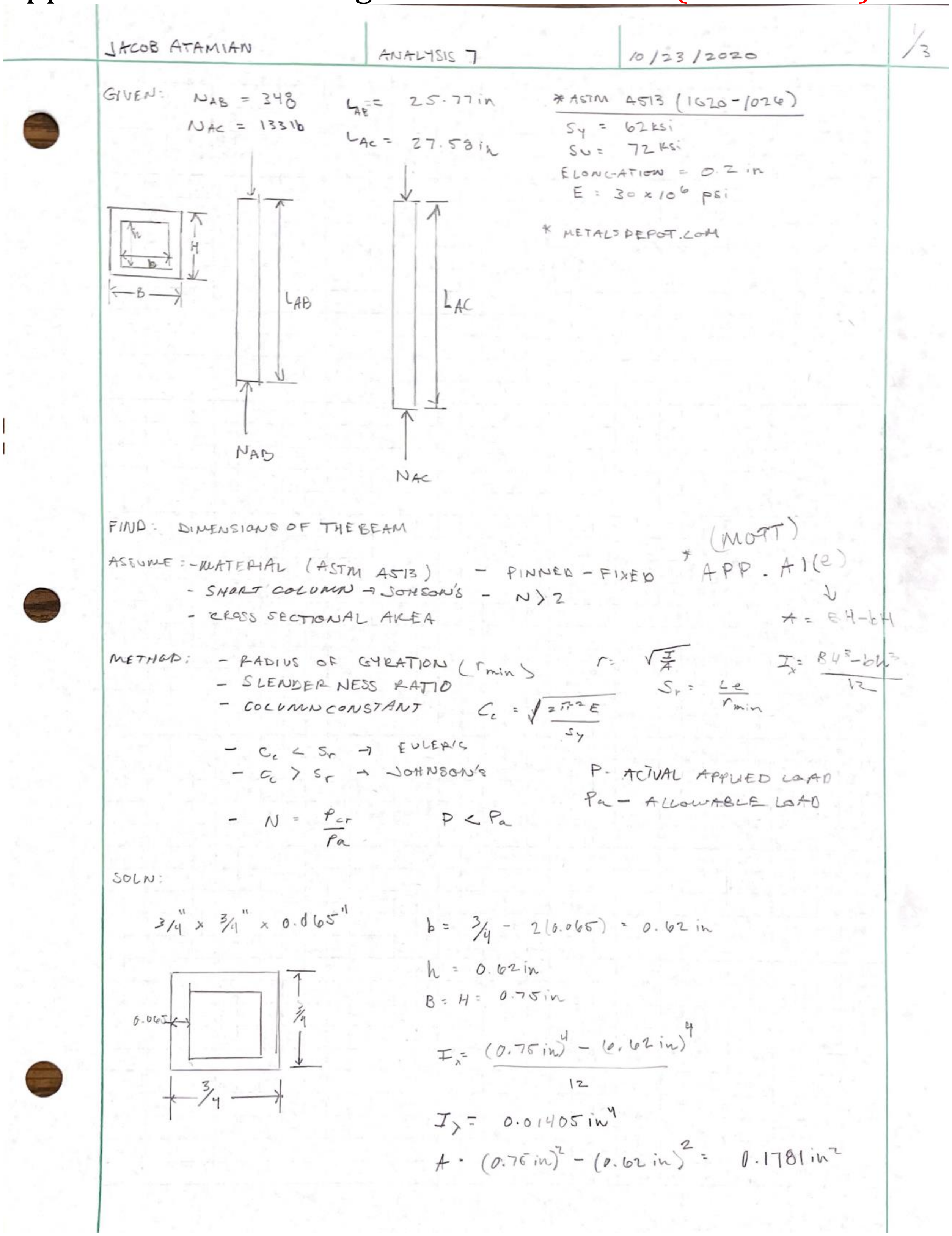
$$P = (0.005\,in)\frac{(30 \times 10^6\,psi)(0.75\,in)^3}{(0.0683)(34\,in)^2} = 801.49\,lb > 350\,lb$$

$$F.S. = \frac{P_{FAIL}}{P_{ALLOW}} = \frac{801\,lb}{350\,lb} = 2.29 \geq 2 \quad ✓$$

* CAN USE IF PLATE DIMENSIONS ARE 26" × 34"

A6.2

Appendix A7 – Buckling Of Truss Members (OBSOLETE)



JACOB ATAMIAN | ANALYSIS 7 | 10/23/2020 | 1/3

GIVEN: $N_{AB} = 348$, $N_{AC} = 133\,lb$, $L_{AB} = 25.77\,in$, $L_{AC} = 27.58\,in$

* ASTM A513 (1020-1026)
$S_y = 62\,ksi$
$S_u = 72\,ksi$
ELONGATION = 0.2 in
$E = 30 \times 10^6\,psi$

* METALSDEPOT.COM

FIND: DIMENSIONS OF THE BEAM

ASSUME: - MATERIAL (ASTM A513) - PINNED - FIXED * APP. A1(e) (MOTT)
- SHORT COLUMN → JOHNSON'S - N > 2
- CROSS SECTIONAL AREA $A = BH - bh$

METHOD: - RADIUS OF GYRATION (r_{min}) $r = \sqrt{\frac{I}{A}}$ $I_x = \frac{BH^3 - bh^3}{12}$
- SLENDERNESS RATIO $S_r = \frac{L_e}{r_{min}}$
- COLUMN CONSTANT $C_c = \sqrt{\frac{2\pi^2 E}{S_y}}$
- $C_c < S_r$ → EULER'S
- $C_c > S_r$ → JOHNSON'S
P - ACTUAL APPLIED LOAD
P_a - ALLOWABLE LOAD
- $N = \frac{P_{cr}}{P_a}$ $P < P_a$

SOLN:

3/4" × 3/4" × 0.065"

$b = 3/4 - 2(0.065) = 0.62\,in$
$h = 0.62\,in$
$B = H = 0.75\,in$

$$I_x = \frac{(0.75\,in)^4 - (0.62\,in)^4}{12}$$

$I_x = 0.01405\,in^4$

$A = (0.75\,in)^2 - (0.62\,in)^2 = 0.1781\,in^2$

A7.1

$r_{min} = \sqrt{\dfrac{0.01405\ in^4}{0.1781\ in^2}} = 0.281 in$

K = 0.8
PRACTICAL VALUE K
FIXED - PINNED

AB

$S_r = \dfrac{L_e}{r_{min}} = \dfrac{0.8\,(25.77\ in)}{0.28\ in} = 73.39$

$C_c = \sqrt{\dfrac{2\pi^2 (30\times10^6\ psi)}{62\ ksi}} = 97.73 > 73.39$ ← JOHNSON'S

$P_{cr} = A\, S_y \left[1 - \dfrac{S_y\, S_r^{\,2}}{4\pi^2 E}\right]$

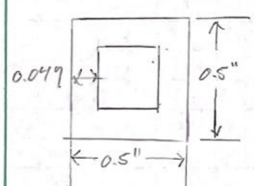
$= (0.1781\ in^2)(62\ \frac{kip}{in^2})\left[1 - \dfrac{(62\ ksi)(73.4)^2}{4\pi^2 (30\times10^3\ ksi)}\right]$

$P_{cr} = 7.929\ kip = 7929\ lb$

$P_a = \dfrac{P_{cr}}{N} = \dfrac{7929\ lb}{2} = 3964.5\ lb > P = 348\ lb$ ✓

* TRY TO USE SMALLER TRUSS BEAM

$\frac{1}{2} \times \frac{1}{2} \times (0.049\ WALL)$



$b = h = 0.5'' - (2\times0.049)'' = 0.402$

$B = H = 0.5 in$

$I_x = \dfrac{(0.5\ in)^4 - (0.402\ in)^4}{12} = 0.00303\ in^4$

$A = (0.5\ in)^2 - (0.402\ in)^2 = 0.088\ in^2$

$r_{min} = \sqrt{\dfrac{0.00303\ in^4}{0.088\ in^2}} = 0.1852 in$

$S_r = \dfrac{(0.8)(25.77\ in)}{0.1852\ in} = 111.31 > C_c = 97.73$ ← EULER'S

~~$P_{cr} = \dfrac{\pi^2 E I}{L_e^{\,2}} = \dfrac{\pi^2 (30\times10^6\ psi)(0.00303\ in^4)}{(0.8\times 25.77\ in)^2}$~~

~~$P_{cr} = 2112.2\ lb$ $\quad P_a = 1056.11 > P$~~ ✓

A 7.2

JACOB ATAMIAN | ANALYSIS 7 | 10/23/2020 3/3

USING DESIREABLE EULER'S

$P_{cr} = \frac{\pi^2 E A}{S_r^2} = \frac{\pi^2 (30\times10^6 psi)(0.088 in^2)}{(111.31)^2} = 2102.98\ lb$

$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{2102.98\ lb}{0.088\ in^2} = 23.79\ ksi$

$N = \frac{S_y}{\sigma_{cr}} = \frac{62\ ksi}{23.79\ ksi} = 2.6 > 2$ ✓

$P_a = \frac{P_{cr}}{N} = \frac{2102.98\ lb}{2.6} = 806.93\ lb > P = 348\ lb$ ✓

| 1/2" x 1/2" x 0.049" ASTM A513 (1020-1026) WORKS FOR TRUSS AB | ✓

AC

* USE SAME SIZE TUBE

$S_r = \frac{(0.8)(27.58 in)}{0.1852 in} = 119.13 > C_c$

$P_{cr} = \frac{\pi^2 E A}{(S_r)^2} = \frac{\pi^2 (30\times10^6 psi)(0.088 in^2)}{(119.13)^2}$

$P_{cr} = 1844.1\ lb$

$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{1844}{0.088} = 20.86\ ksi$

$N = \frac{S_y}{\sigma_{cr}} = \frac{62\ ksi}{20.86\ ksi} = 2.97 > 2$ ✓

$P_a = \frac{P_{cr}}{N} = \frac{1844}{2.97} = 620.5\ lb > 133\ lb$ ✓

| 1/2" x 1/2" x 0.049" ASTM A513 (1020-1026) WORKS FOR AC | ✓

A 7.3

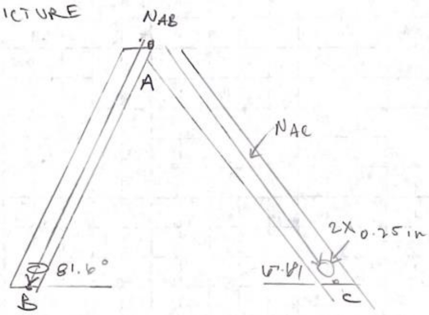
Appendix A8 – Vertical Shear In Bolts (OBSOLETE)

JACOB ATAMIAN | ANALYSIS 8 | 10/28/2020 | 1/2

GIVEN: AXIAL LOADS: $N_{AB} = 348$ lb $N_{AC} = 133$ lb $P_A = 467$ lb

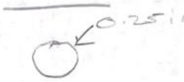
BOLT DIA = 0.25 in

PICTURE



$S_y = 150{,}000$ psi

CIRCULAR C–S



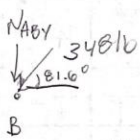
FIND: SHEAR STRESS IN 0.25 ϕ BOLTS

ASSUME: SHEAR IS ACTING VERTICALLY, PURE SHEAR,

METHOD:
- F_y
- FBD
- $S_v(max) = \frac{4}{3}\frac{V}{\pi r^2}$ (MOTT FIG 3.2.10b P.216)
- $N = \frac{S_v}{S_{v\,max}} \Rightarrow N > 2$

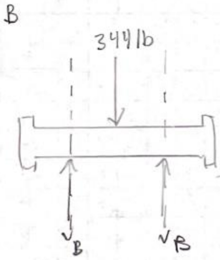
SOLN:

PIN B



$N_{ABy} = \sin 81.6° \times 348$ lb

$= 344$ lb

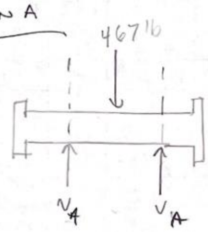


$V = \frac{N_{ABy}}{2} = \frac{344}{2} = 172$ lb

$S_{v\,max_B} = \frac{4}{3} \times \frac{172\text{ lb}}{\pi(\frac{0.25}{2}\text{ in})^2} = 4671.94$ psi

$N = \frac{150{,}000}{4671.94} = 32.1$ ✓

PIN A



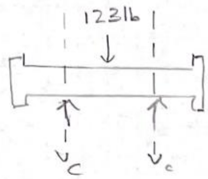
$V = \frac{467}{2} = 233.5$ lb

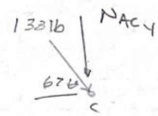
$S_{v\,max_A} = \frac{4}{3} \cdot \frac{233.5\text{ lb}}{\pi(0.125\text{ in})^2} = 6342.43$ psi

$N = \frac{S_u}{S_{vA}} = \frac{150{,}000}{6342.43} = 23.65$ ✓

A 8.1

PIN C





$N_{ACy} = \sin 67.6° \times 133\text{lb}$

$= 123 \text{ lb}$

$V_c = \frac{123\text{lb}}{2} = 61.5 \text{ lb}$

$S_{v_{max_c}} = \frac{4}{3} \frac{61.5 \text{ lb}}{\pi (0.125 \text{ in})^2}$

$= 1670.49 \text{ psi}$

$N = \frac{150{,}000}{1670.49} = 89.8$ ✓

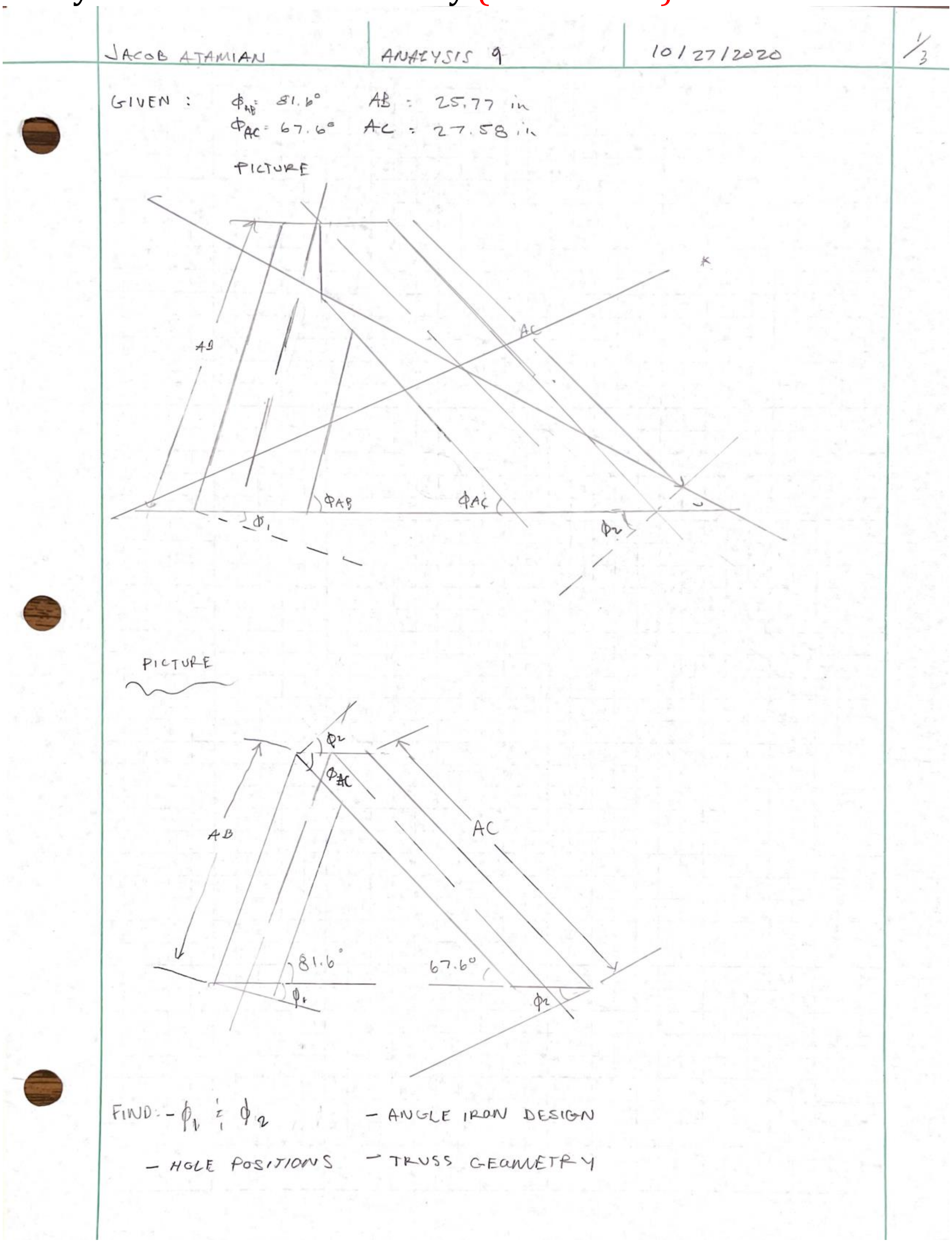
* ALL BOLTS SHOULD BE FINE AT 1/4"-20 UNC

18-8 STAINLESS STEEL HEX HEAD SCREWS

$S_y = 70{,}000$ psi ✓

A 8.2

Analysis A9 – Truss Geometry (OBSOLETE)



JACOB ATAMIAN | ANALYSIS 9 | 10/27/2020 | 1/3

GIVEN: $\phi_{AB} = 81.6°$ AB: 25.77 in
$\phi_{AC} = 67.6°$ AC: 27.58 in

PICTURE

PICTURE

FIND: – ϕ_1 & ϕ_2 – ANGLE IRON DESIGN
– HOLE POSITIONS – TRUSS GEOMETRY

A 9.1

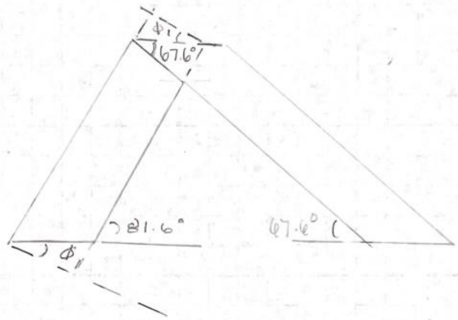
ASSUME: SQR TUBING BEING CUT AT EACH END AT 90°

METHOD: $\phi_n = 90° - \phi_{AN}$

SOLN:

$\phi_1 = 90° - 81.6° = 8.4°$

$\phi_2 = 90° - 67.6° = 22.4°$



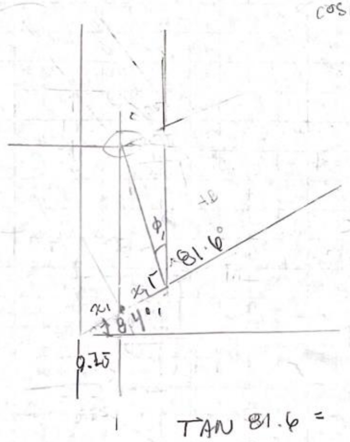
* TO MAKE TRUSS AB, TWO EXTRUDE CUTS WILL BE MADE IN SOLID WORKS. ONE AT ϕ_1 & ONE AT ϕ_{AC}

HOLE POSITION

TRUSS AB

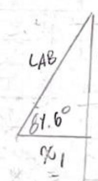
BOTTOM

$\cos 81.6 = \frac{0.25}{y_1}$



$\cos 8.4° = \frac{0.25}{x_1}$

$x_1 = 0.25271$ in



$\tan 81.6 = \frac{y_1}{x_1}$

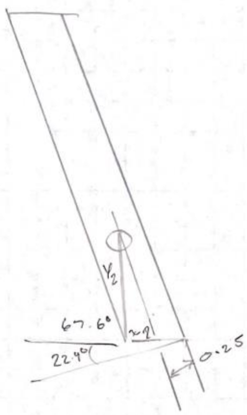
$y_1 = 1.71$ in

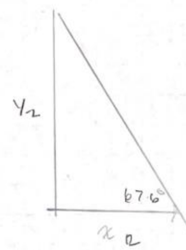
A 9.1

JACOB ATAMAN	ANALYSIS 9	10/29/2020	5/3

TRUSS AT BOTTOM:

* TOP IS THE SAME AS BOTTOM MOUNT

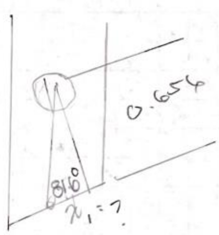




$$\cos 22.4^\circ = \frac{0.25}{x_2} \Rightarrow x_2 \approx 0.27 \text{ in}$$

$$\tan 67.6^\circ = \frac{Y_2}{X_2} \Rightarrow Y_2 = 0.656 \text{ in}$$

* TO MAKE THE BASE ANGLE IRONS BOTH 1.5" x 1.5" x 1/4" CHANGE TRUSS ANGLE



$$\tan 81.6^\circ = \frac{0.456}{x_1}$$

$x_1 = 0.0968$

$x_1 \approx 0.10$ in

$Y_1 = 0.656$

A 9.3

Appendix A10 – Location Pins

JACOB ATAMIAN | ANALYSIS 10 | 11/5/2020 | 1/2

GIVEN: PIN SPECS

$T = 7500$ lb

$\phi = 0.5$ in   A & B

ROUND & DIAMOND PRESS FIT PINS

MATERIAL: 1144 STEEL HEAT TREATED

* CARRLANE.COM

FIND: WILL THE LOCATING PINS BE ABLE TO WITHSTAND THE TENSION OF THE CHAIN AT 7500 lb?

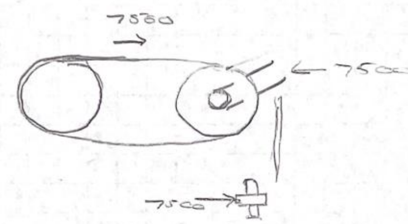
ASSUME: MATERIAL IS 1144 OQT 1300 $S_y = 68$ ksi {MOTT APP 3 P. 787}

METHOD:

$$\sigma_{cr} = \frac{P}{A}$$

$$N = \frac{S_y}{\sigma_{cr}}$$

$$N > 2$$

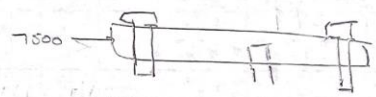


SOLN:

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4}(0.5\text{ in})^2 = 0.1963\text{ in}^2$$

$$\sigma_{cr} = \frac{7500/3\text{ lb}}{0.1963\text{ in}^2} = 12.7\text{ ksi}$$

$$N = \frac{68\text{ ksi}}{12.7\text{ ksi}} = 5.3 > 2 \checkmark$$



* THE FORCE IS DISTRIBUTED AMONGST 3 "PINS"

$\therefore \frac{7500}{3}$ lb

A10.1

JACOB ATAMAN | ANALYSIS 10 | 11/5/2020 | 2/2

GIVEN: CRUSHER LOCATING PINS ARE AT 3/8"

FIND: SAFETY FACTOR N

ASSUME/METHOD: SAME AS PREVIOUS

SOLN:

$$A = \frac{\pi}{4}(0.375 in^2) = 0.1104 in^2$$

$$P = \frac{7500}{4} = 1875 lb$$

$$\sigma_{cr} = \frac{1875 lb}{0.1104 in^2} = 16,976 psi$$

$$N = \frac{68 ksi}{16.98 ksi} = 4 > 2 \checkmark$$

A10.2

Appendix A11 – Finite Element Analysis (Base Plate)

JACOB ATAMIAN	ANALYSIS 11	2/19/21	1/1

GIVEN: RADIAL LOAD FROM CRUSHING GEARS IS 5253 lb-in

ASTM A36, E = 30 E6 psi t = 3/4 in.

DIMENSIONS R = 36 r = 26

FIND: MAX DEFLECTION

ASSUME: CASE 16: supported on ALL edges (MARK'S P. 249)

METHOD: $y_{max} = K_1 \frac{P R^2}{E t^3}$

TABLE 3.2.20 MARK'S → K_1

SOLN:

$R/r = \frac{36}{26} = 1.38$

INTERPOLATE K_1

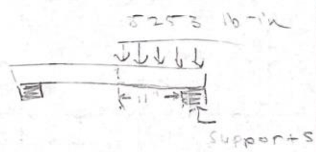
1.6	0.0443
1.38	K_1
1.5	0.0843

$K_1 = 0.0443 + \frac{(0.0843 - 0.0443)}{1.5 - 1}(1.38 - 1)$

$K_1 = 0.0747$

LOAD P

$P = \frac{w}{L} = \frac{5253 \text{ lb-in}}{11 \text{ in}} = 477.5 \text{ lb}$



MAX DEFLECTION

$y_{max} = 0.0747 \frac{(477.5 \text{ lb})(36 \text{ in})^2}{(30E6 \frac{lb}{in^2})(0.75 \text{ in})^3} = 0.00365 \text{ in} < 0.005$

% ERROR w/ NASTRAN MODEL : MESH : 0.3 in LINEAR

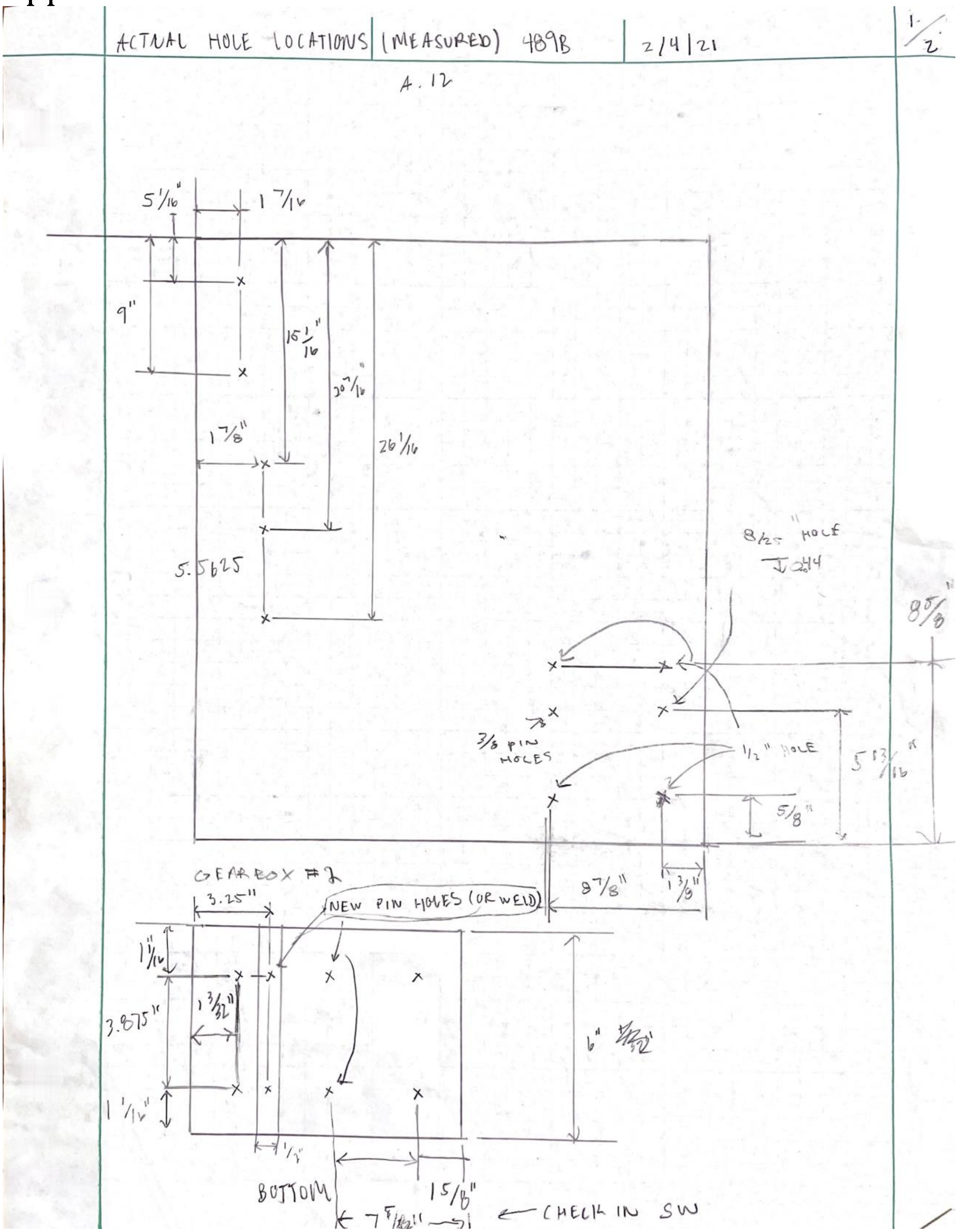
$\% \text{ ERROR} = \frac{0.00365 \text{ in} - 0.00335 \text{ in}}{0.00365 \text{ in}} \times 100\% = 8.7\% < 10\%$

$N = \frac{0.005 \text{ in}}{0.00365 \text{ in}} = 1.4 < 1$

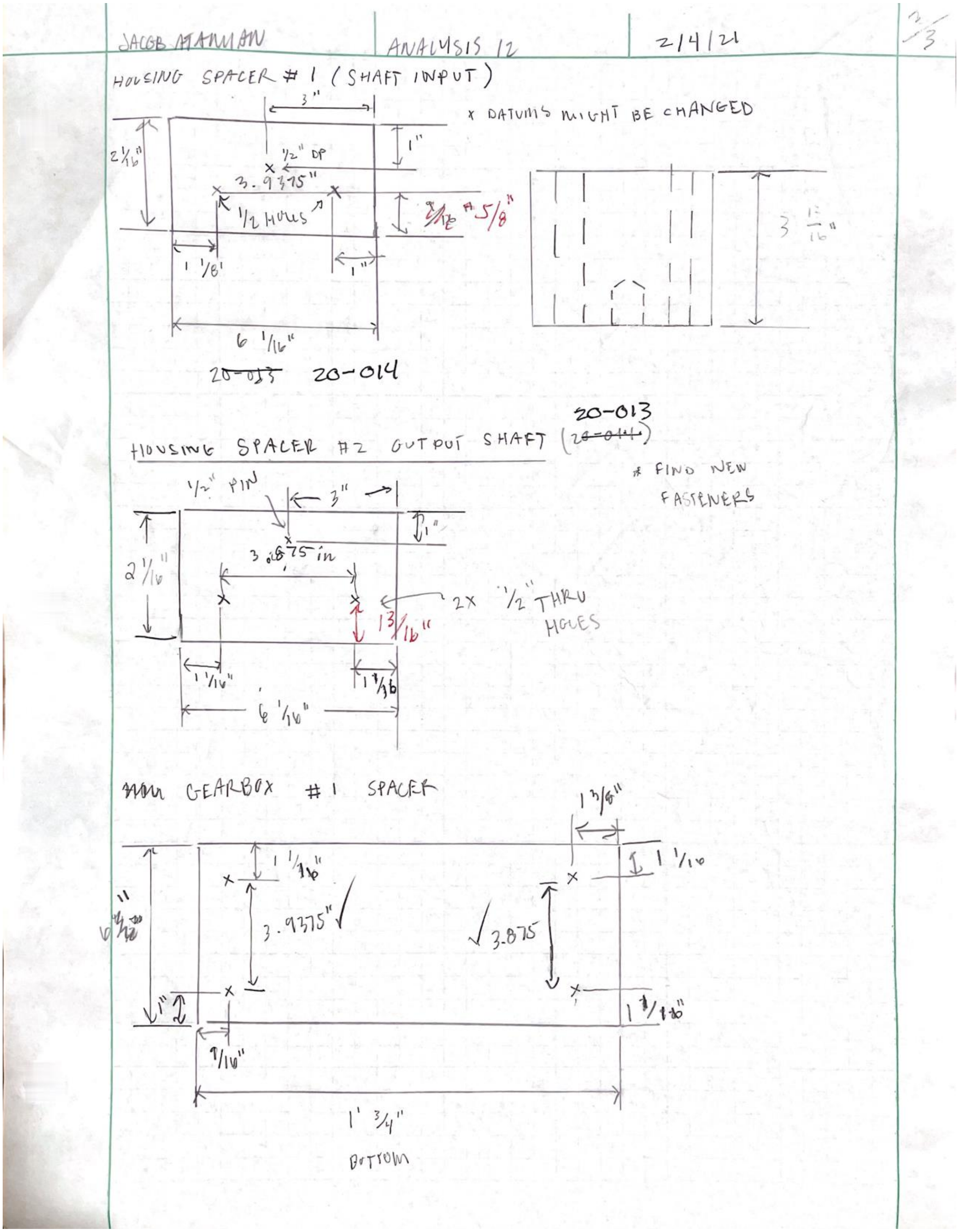
* F.S. IS ABOVE 1
TRUSS CAN BE DISCARDED

A11.1

Appendix A12 – Part Measurements



A12.1


JACOB
ANALYSIS 12
2/4/21
HOUSING SPACER #1 (SHAFT INPUT)
3"
* DATUMS MIGHT BE CHANGED
1"
2 1/16"
1/2" DP
3.9375"
1/2 HOLES
5/8"
1 1/8"
1"
3 15/16"
6 1/16"
20-014
20-013
HOUSING SPACER #2 OUTPUT SHAFT
* FIND NEW FASTENERS
1/2" PIN
3"
1"
3.875 in
2 1/16"
2X 1/2" THRU HOLES
13/16"
1 1/16"
6 1/16"
GEARBOX #1 SPACER
1 3/8"
1 1/16"
3.9375"
3.875
1"
9/16"
1' 3/4"
BOTTOM

A12.2

Appendix A13 – Finite Element Analysis (Side Plate)

JACOB ATAMIAN | SP2 – MET420 | 3/8/2021 | 1/2

GIVEN: SIDE PLATE OF CRUSHING HOUSING
RADIAL LOAD FROM CRUSHING GEARS = 10,506 lb
TWO HOLE CONCENTRATIONS
HOLE DIA = 3 in   PLATE THICKNESS = 0.25 in
MATERIAL = A36 STEEL   16 X 17 in PLATE

FIND: DEFLECTION / STRESS IN PLATE (MAX CONDITIONS)

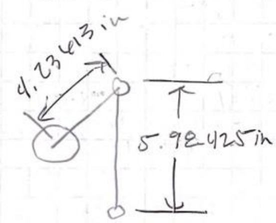
ASSUME: BOTTOM OF PLATE IS FIXED
FORCE TRANSFERED THROUGH BOLTS (8)
+ APPROX CENTR HOLE

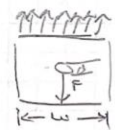
METHOD: FBD
APPENDIX 18-4 CURVE B

$\sigma_{nom} = \frac{F}{(w-d)t}$

$\sigma_{MAX} = K_t \sigma_{nom}$

CNT DIST →





W = 17 in
d =

$\phi \sim 5/8"$ ← HOLE

SOLN:

LOAD PER HOLE

MESH = 0.3 in
CONTROL MESH = 0.1

$P = \frac{10,506 / 2}{8} = 656.625$ lb

$\sigma_{nom} = \frac{656.625 \text{ lb}}{(17 - 0.625)(0.25) \text{ in}^2} = 160$ psi

$K_t \rightarrow$ FIG A18-4 p. 831 CURVE B

$d/w = \frac{0.625}{17} \approx 0.04$

ASSUME: $8 \times 0.625 = 5$ in $= d$

$d/w = \frac{5}{17} = 0.29$

$K_t = 3.7$

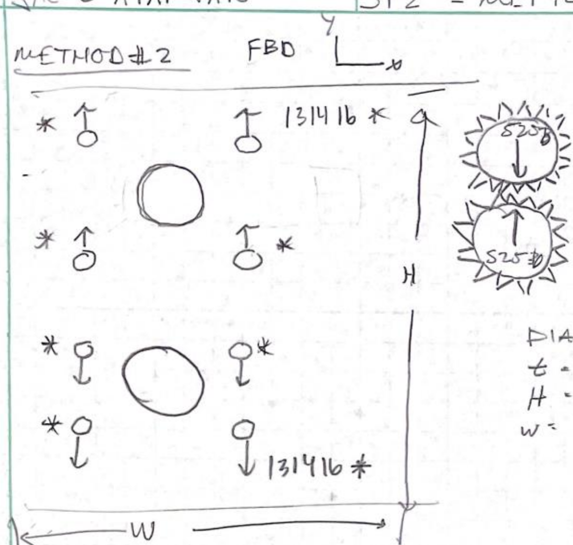
$\sigma_{nom} = 8 \times 160$ psi $= 1280$

$\sigma_{max} = 1280(3.7)$ psi $= 4,736$ psi $S_y = 36000$ psi

$N = \frac{36000 \text{ psi}}{4,736 \text{ psi}} = 7.6$

A13.1

METHOD #2 FBD



DIA: 0.625 in
t = 0.25 in
H = 16 in
w = 17 in

$$\sigma_{nom} = \frac{1314 \text{ lb}}{(16 - 0.625)(0.25) \text{ in}^2} = 341.85 \text{ psi}$$

$$= 4 \text{ holes} \times 341.85 \text{ psi} = 1367 \text{ psi}$$

k_t

$$d/w = \frac{0.625(8)}{17} = 0.29$$

$k_t = 3.7$

$$\sigma_{max} = 1367 \text{psi} (3.7) = 5059 \text{ psi}$$

% ERROR OF NASTRAN MODEL

$$\% \text{ ERROR} = \frac{5082 - 5059}{5059} \times 100\% = 0.45\% \text{ error}$$

$$n = \frac{30{,}000}{5082} = 7$$

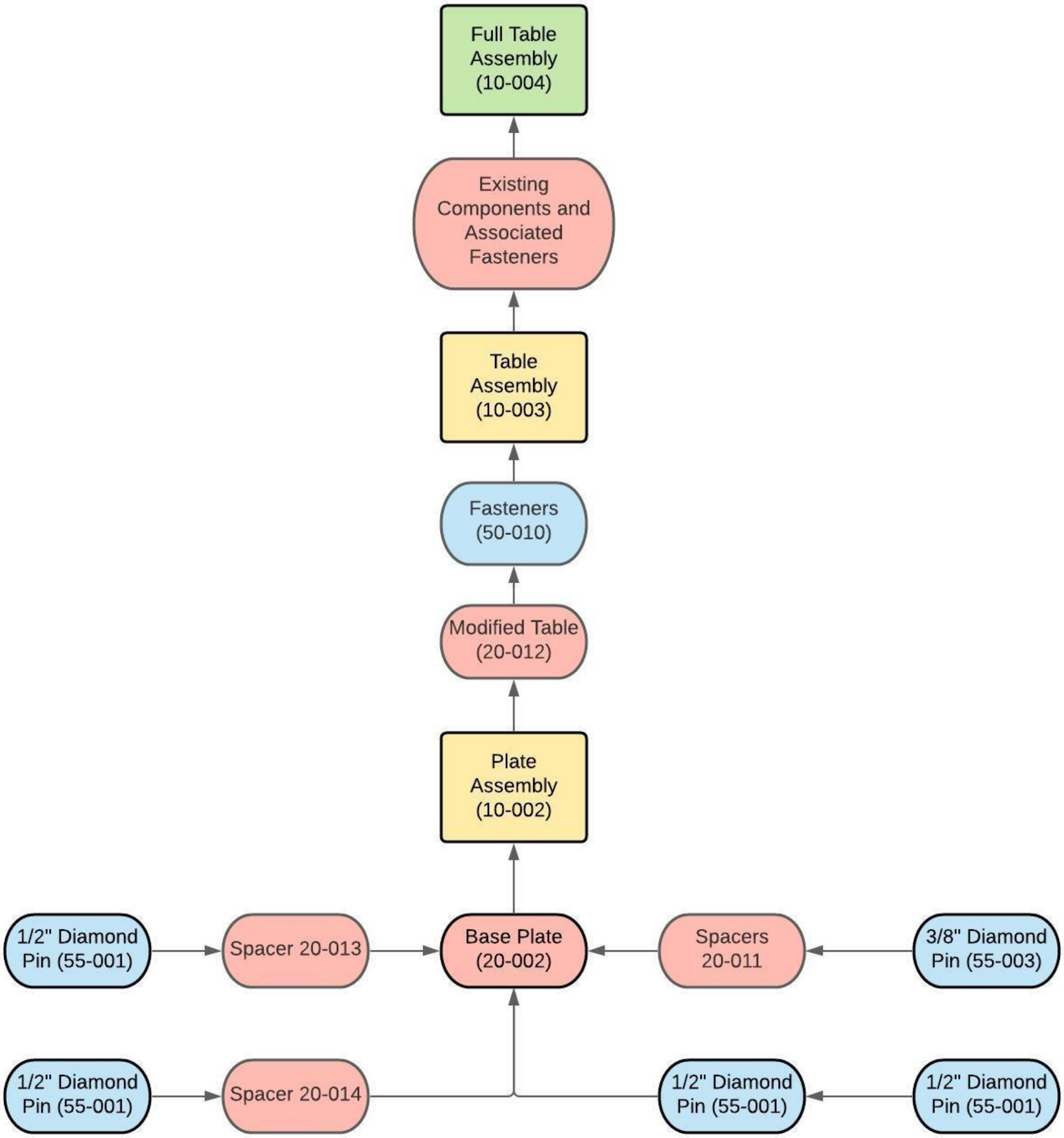
Z-DISPLACEMENT = 9.822E-06

* THE PLATE WILL BE OKAY

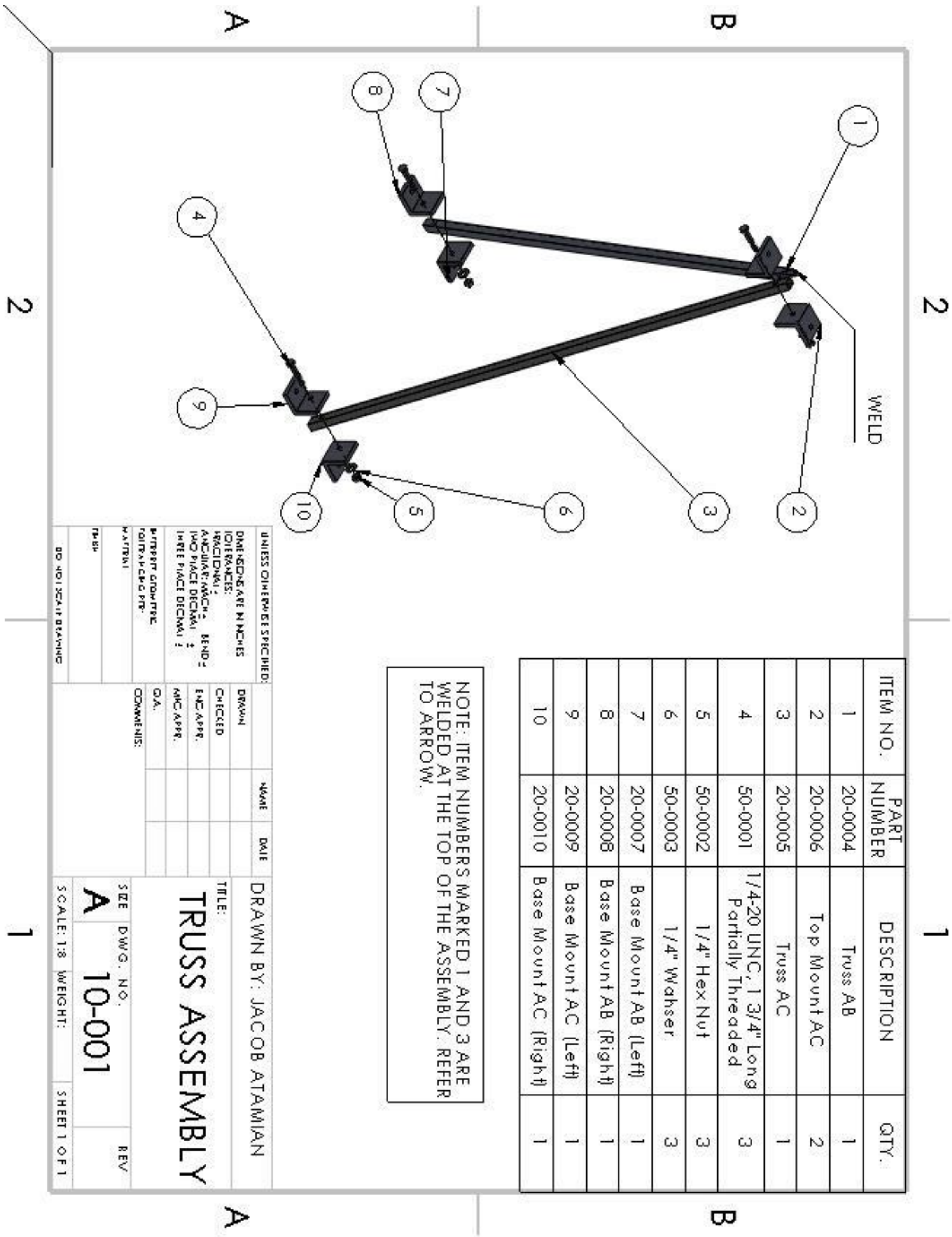
A13.2

APPENDIX B - Drawings

Appendix B – Drawing Tree



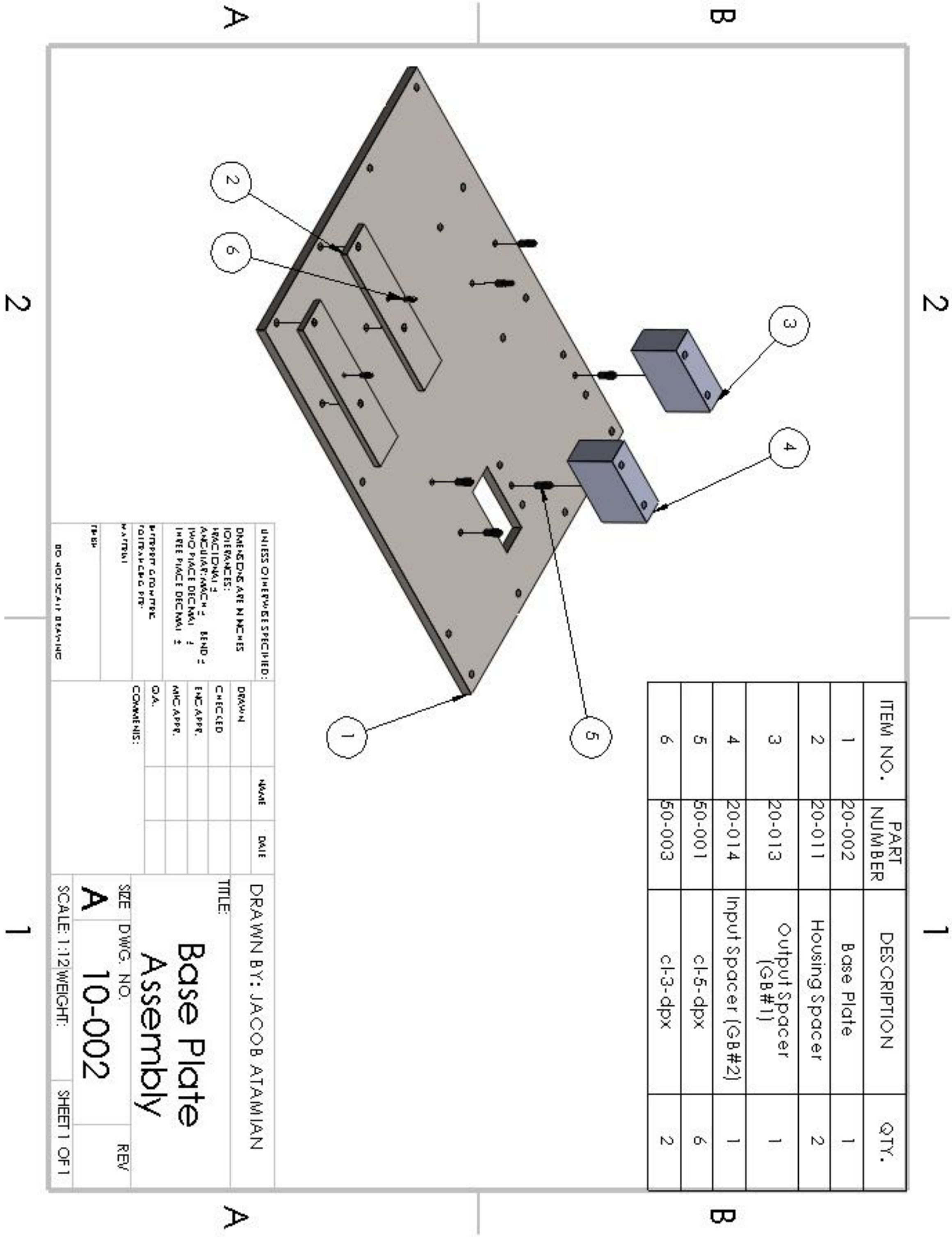
Appendix B1 – Assembly 10-001(OBSOLETE)



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-0004	Truss AB	1
2	20-0006	Top Mount AC	2
3	20-0005	Truss AC	1
4	50-0001	1/4-20 UNC, 1 3/4" Long Partially Threaded	3
5	50-0002	1/4" Hex Nut	3
6	50-0003	1/4" Wahser	3
7	20-0007	Base Mount AB (Left)	1
8	20-0008	Base Mount AB (Right)	1
9	20-0009	Base Mount AC (Left)	1
10	20-0010	Base Mount AC (Right)	1

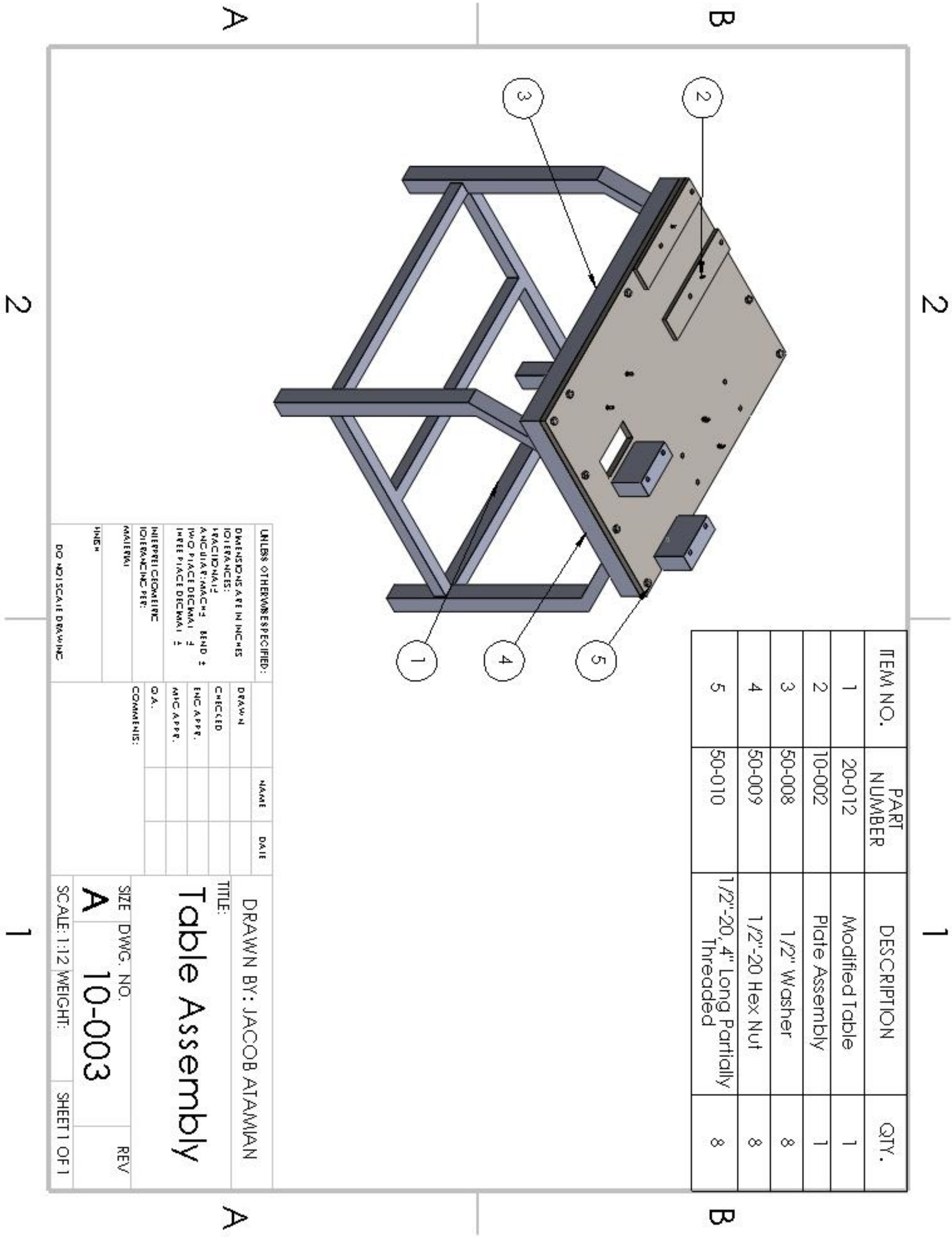
NOTE: ITEM NUMBERS MARKED 1 AND 3 ARE WELDED AT THE TOP OF THE ASSEMBLY. REFER TO ARROW.

Appendix B2 – Assembly 10-002



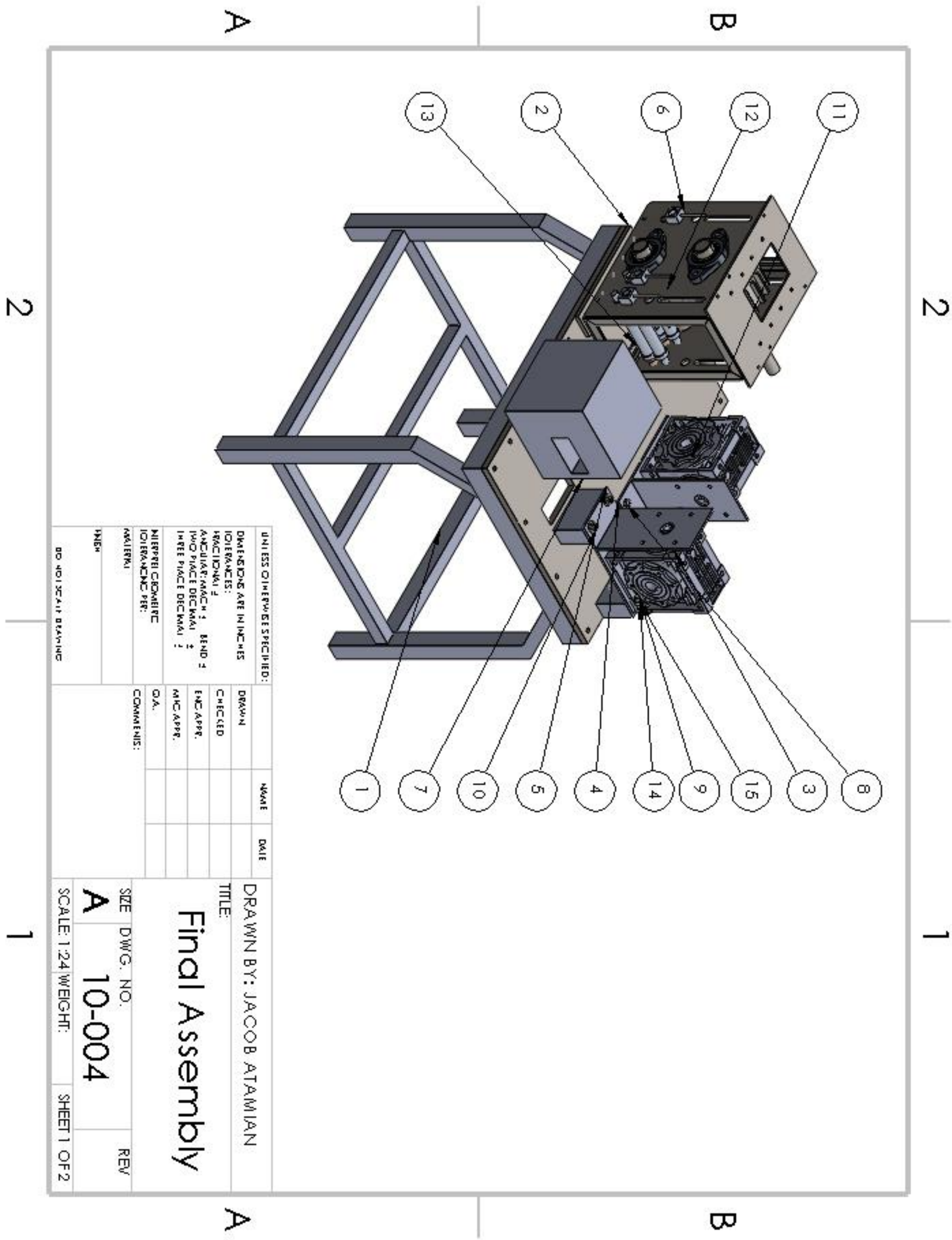
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-002	Base Plate	1
2	20-011	Housing Spacer	2
3	20-013	Output Spacer (GB#1)	1
4	20-014	Input Spacer (GB#2)	1
5	50-001	cl-5-dpx	6
6	50-003	cl-3-dpx	2

Appendix B3 – Assembly 10-003



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-012	Modified Table	1
2	10-002	Plate Assembly	1
3	50-008	1/2" Washer	8
4	50-009	1/2"-20 Hex Nut	8
5	50-010	1/2"-20, 4" Long Partially Threaded	8

Appendix B4.1 – Assembly 10-004



Appendix B4.2 – Assembly 10-004

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-012	Modified Table	1
2	10-002	Plate Assembly	1
3	CALM90-56C	Gear Reducer	2
4	20-0006 (housing2edit)	Gearbox #2 Housing	1
5	20-0005 (housing1edit)	Gearbox #1 Housing	1
6	10-0001_Chassis	Crusher Housing	1
7	Shredder Housing	Shredder Housing	1
8	50-014	1/2"-20, 2 1/4" Long	2
9	50-012	1/2"-20, 9" Long Partially Threaded	2
10	50-011	1/2"-20, 5 1/2" Long, Partially Threaded	2
11	50-013	1/2"-20, 4 3/4" Long Partially Threaded	2
12	50-016	1/2"-20, 4 3/4"	3
13	50-017	1/2"-20, 2/14" Long Partially Threaded	1
14	50-008	1/2" Washer	8
15	50-009	1/2"-20 Hex Nut	8

DRAWN BY: JACOB ATAMIAN

TITLE: Bill Of Materials

SIZE A | DWG. NO. 10-004 | REV

SCALE: 1:24 | WEIGHT: | SHEET 2 OF 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

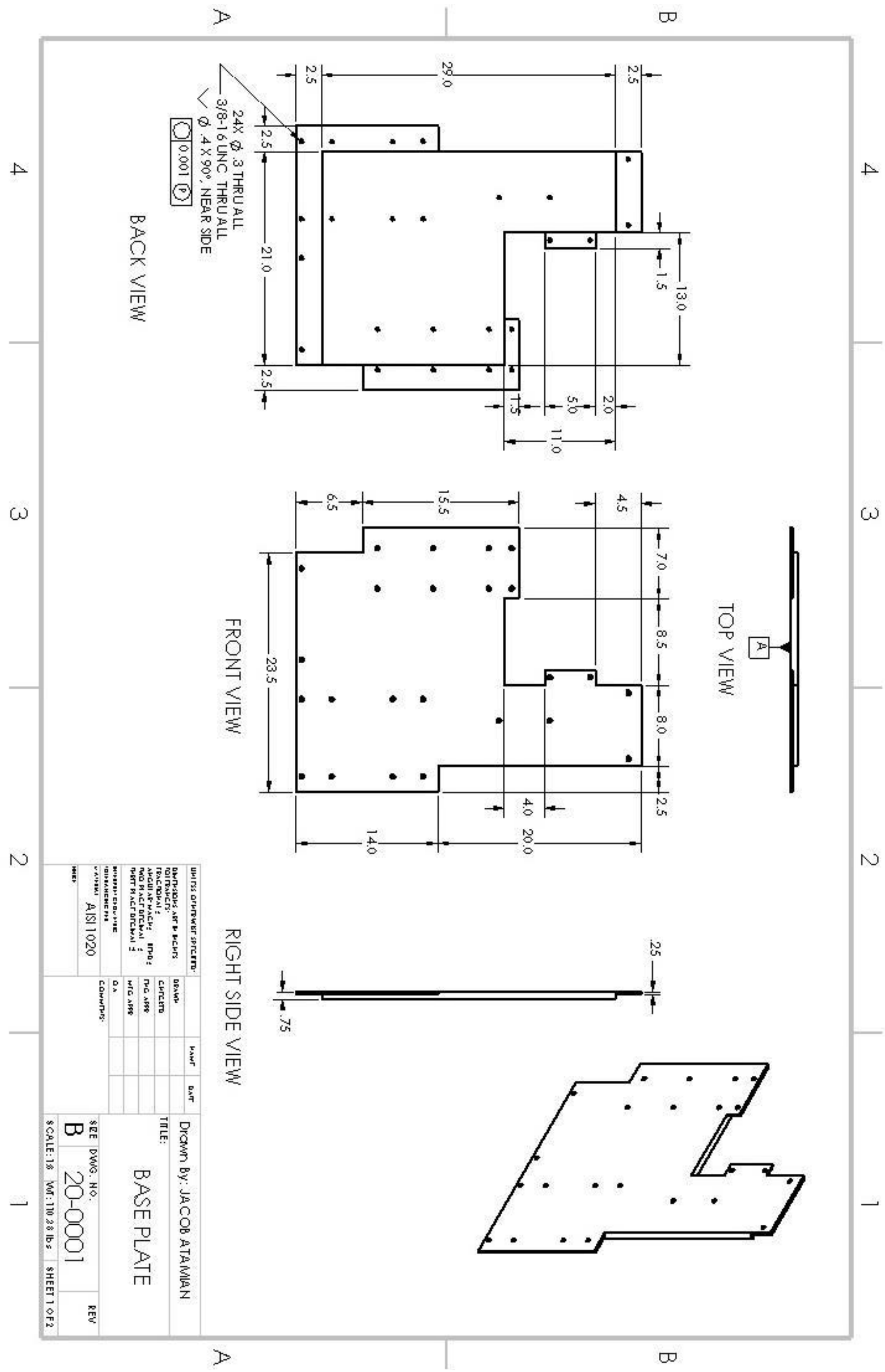
COMMENTS:

NEXT ASSY | USED ON

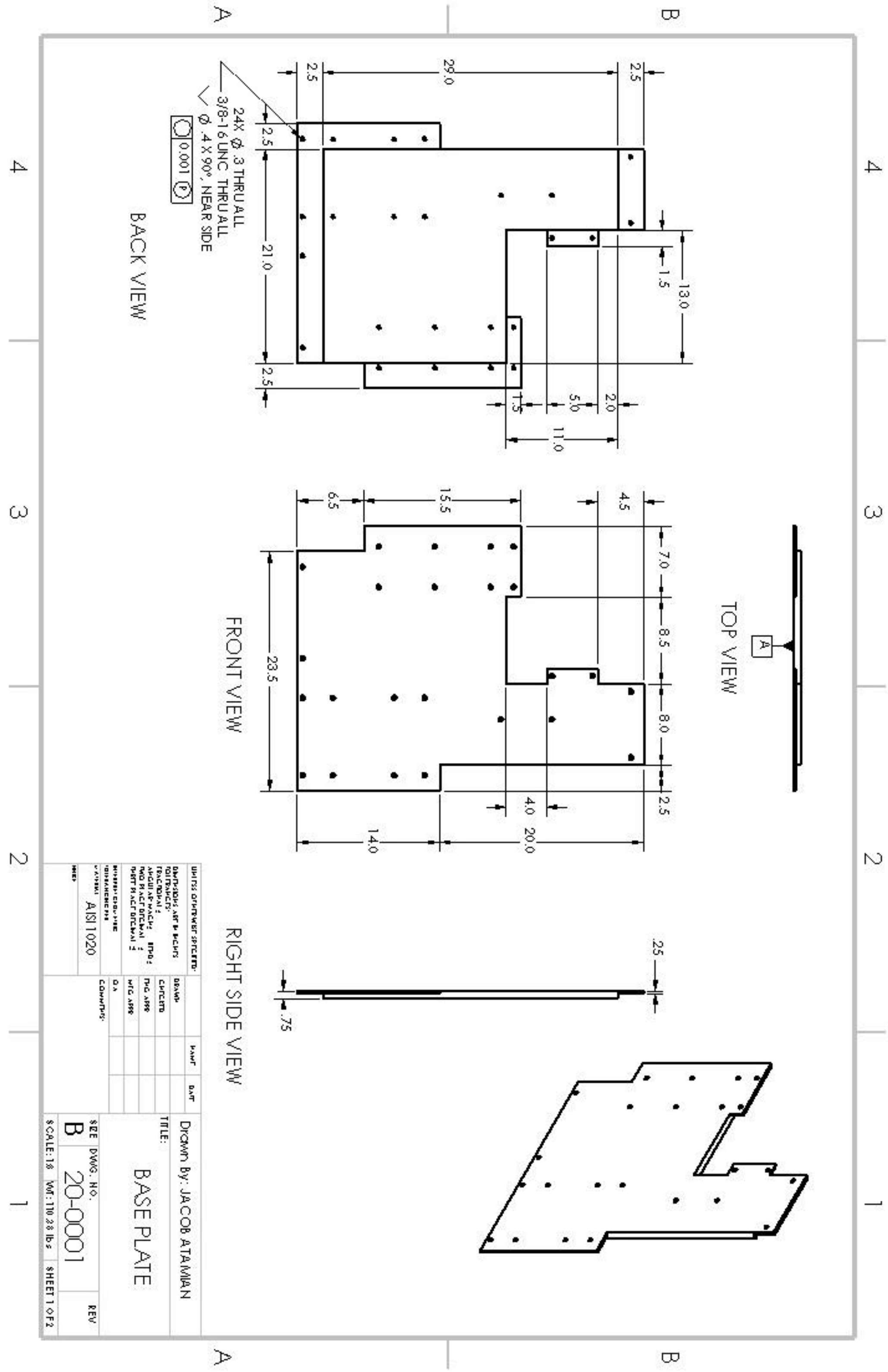
APPLICATION

PROPRIETARY AND CONFIDENTIAL

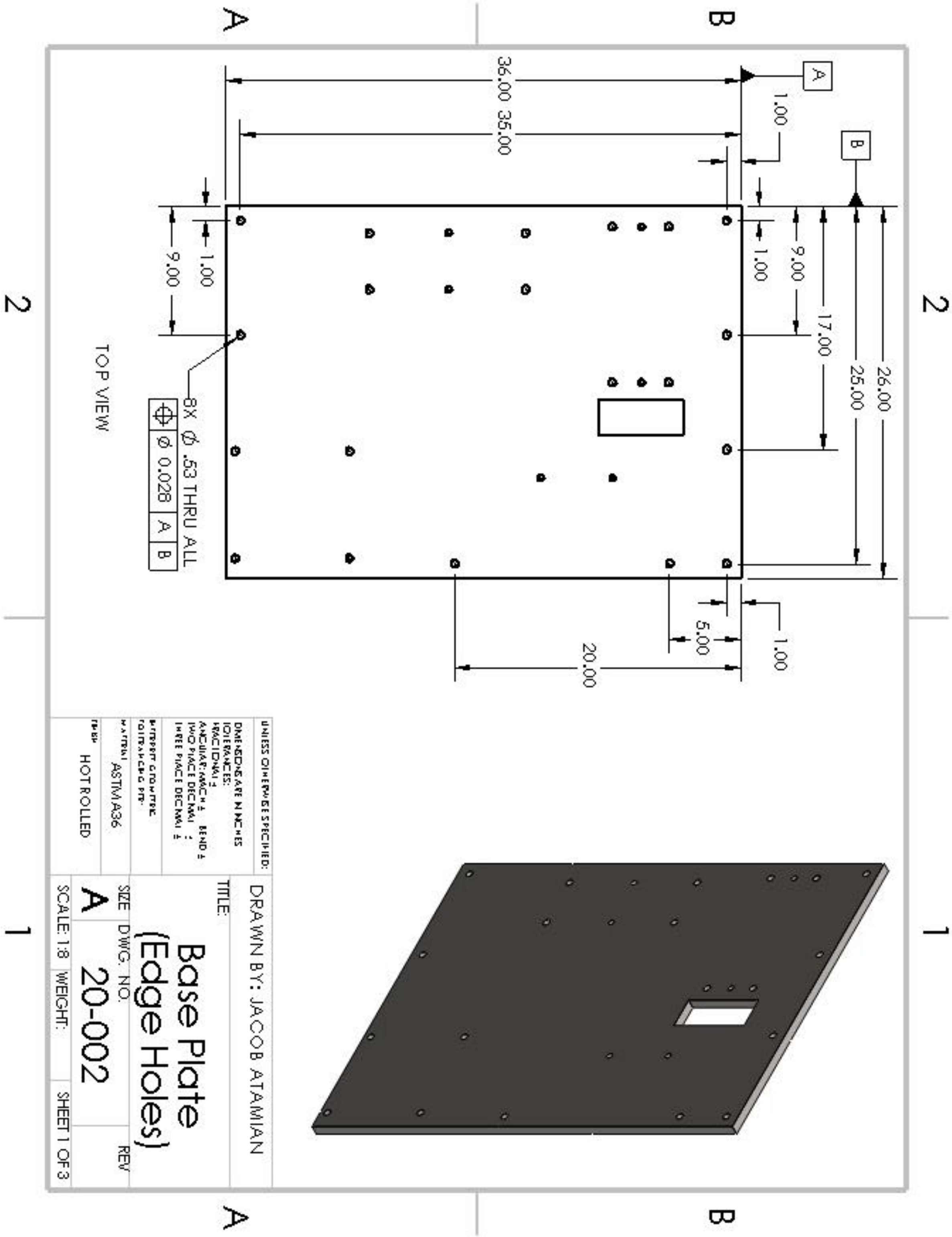
Appendix B5.1 – 20-001(OBSOLETE)



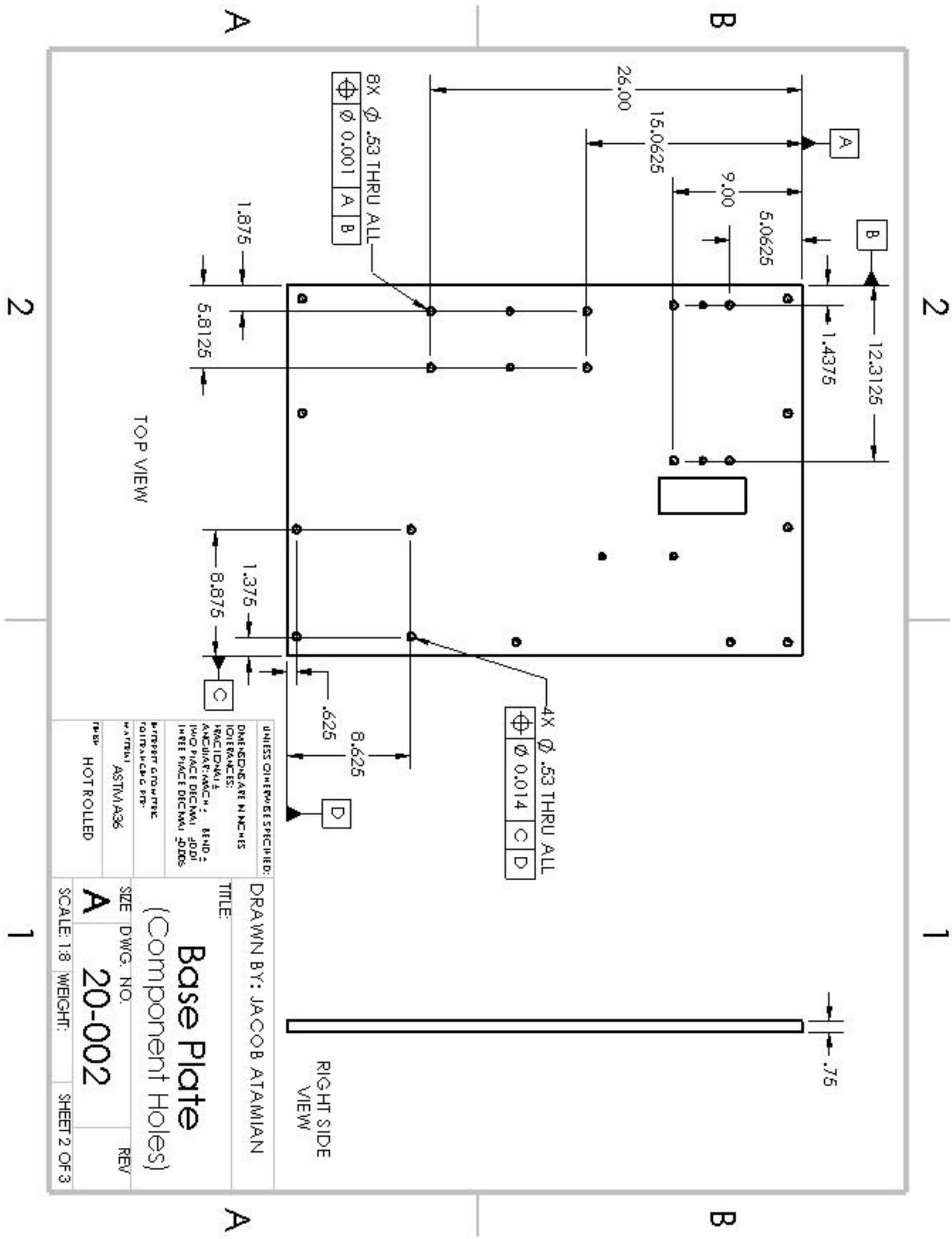
Appendix B5.2 – 20-001(OBSOLETE)



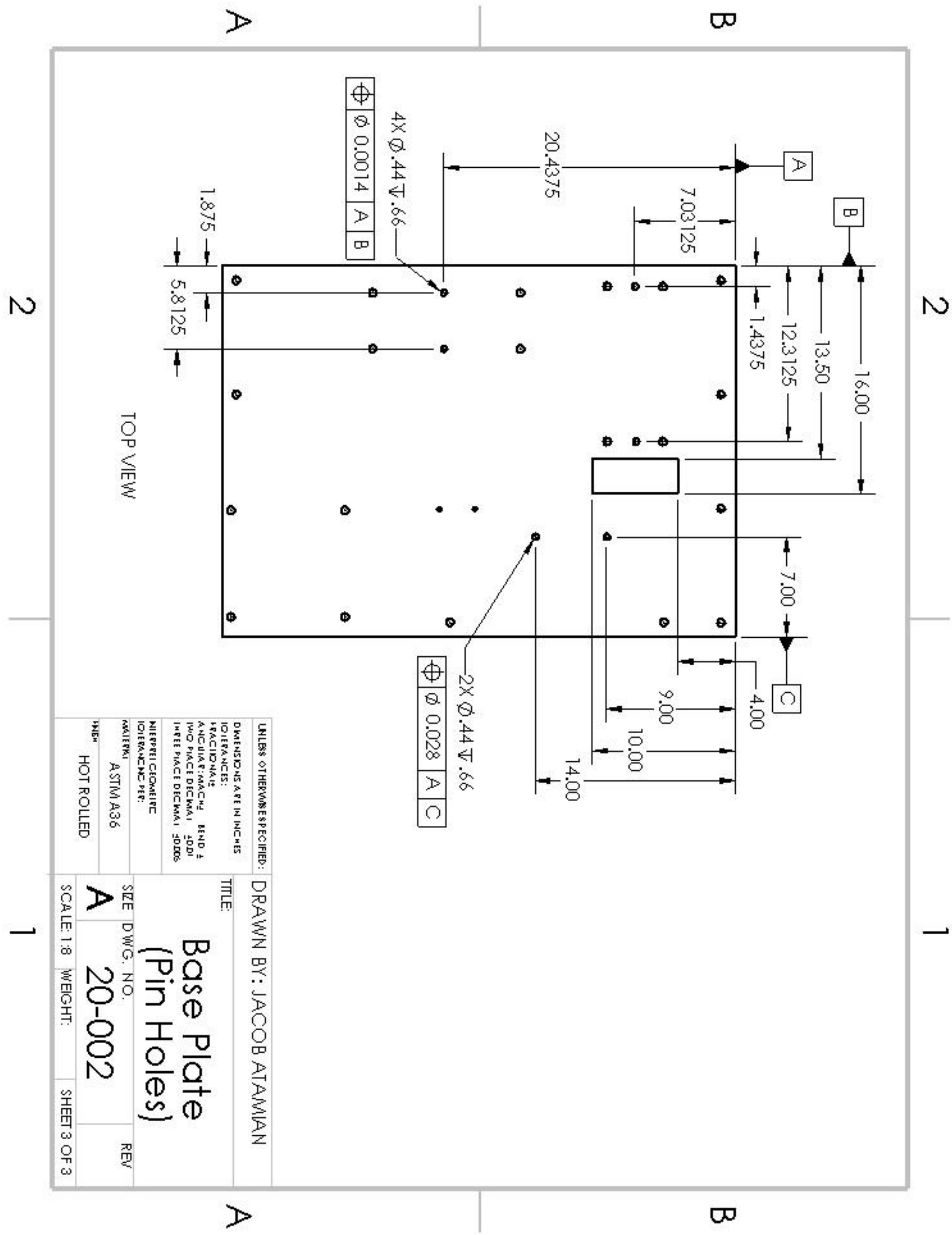
Appendix B6.1 – 20-002 (Mount Holes)



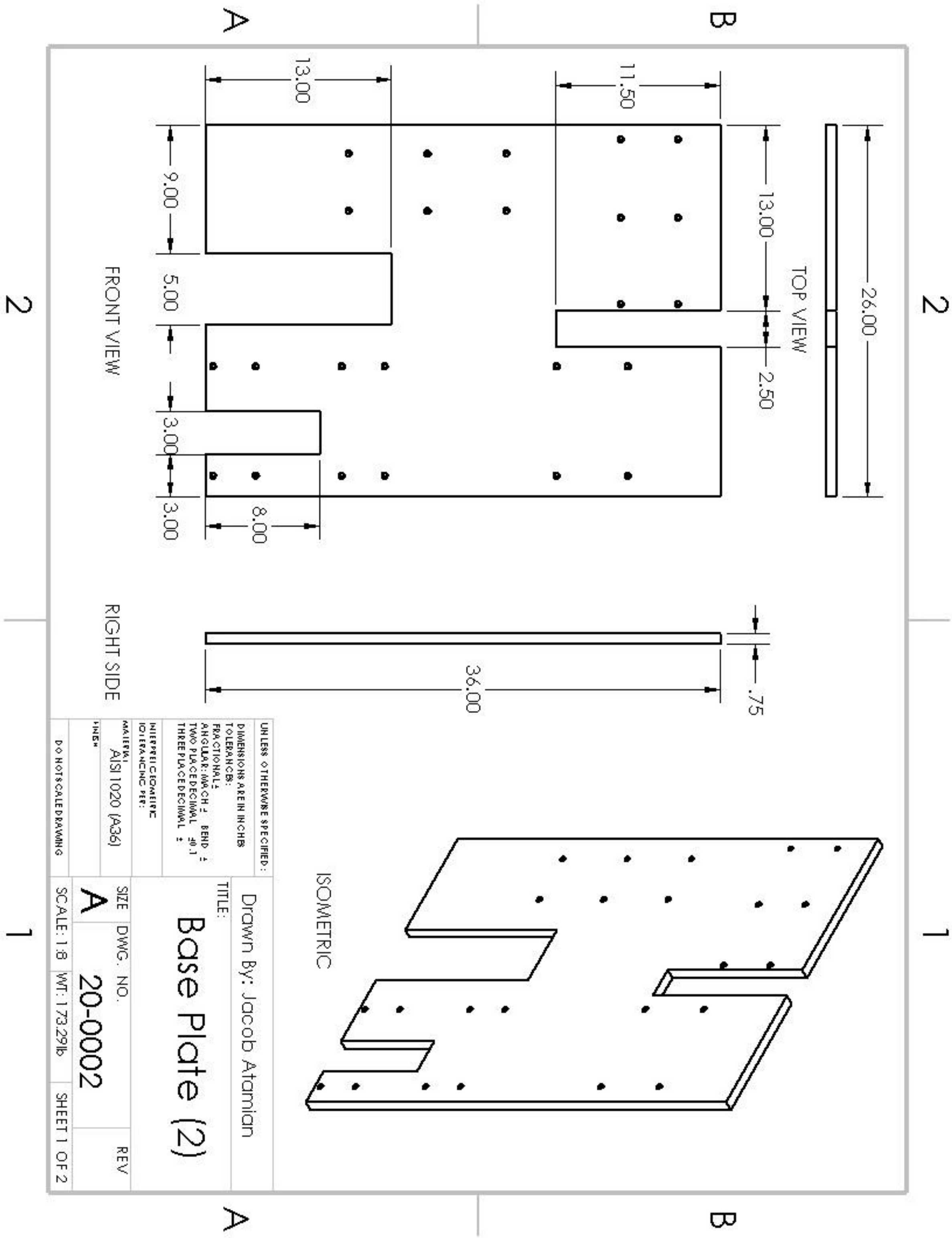
Appendix B6.2 – 20-002 (Component Holes)



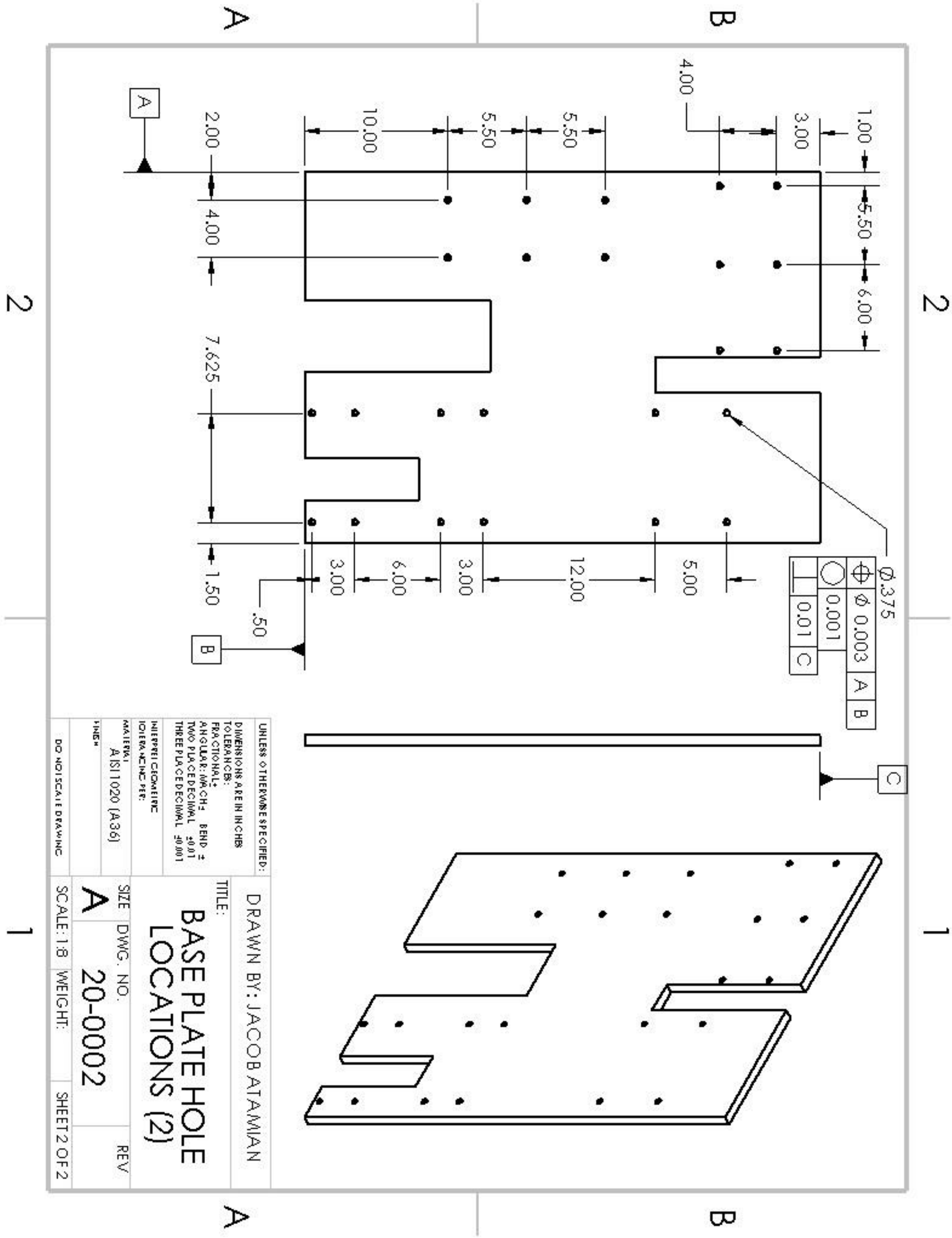
Appendix B6.3 – 20-002 (Pin Holes)



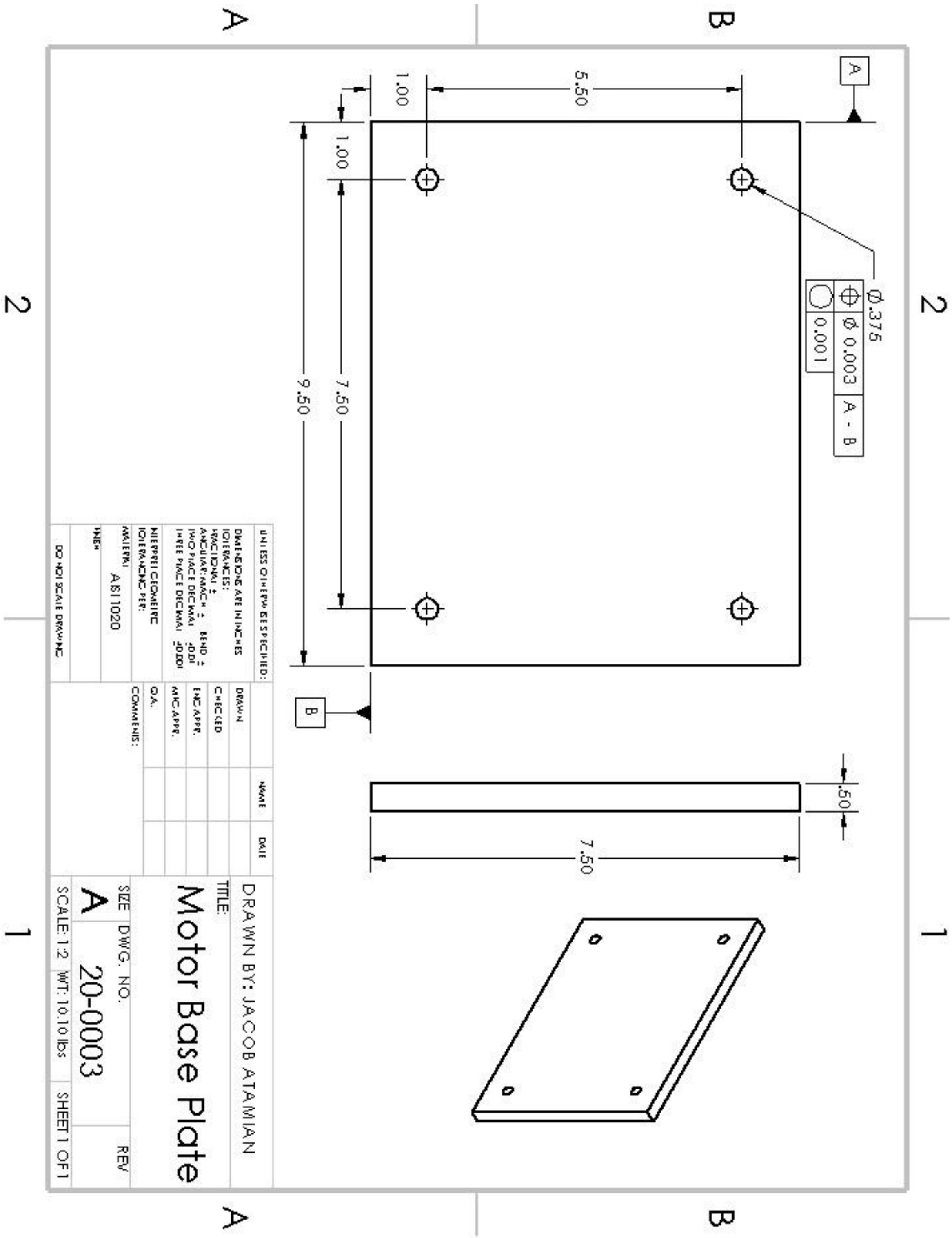
Appendix B6.4 – 20-002 (OBSOLETE)



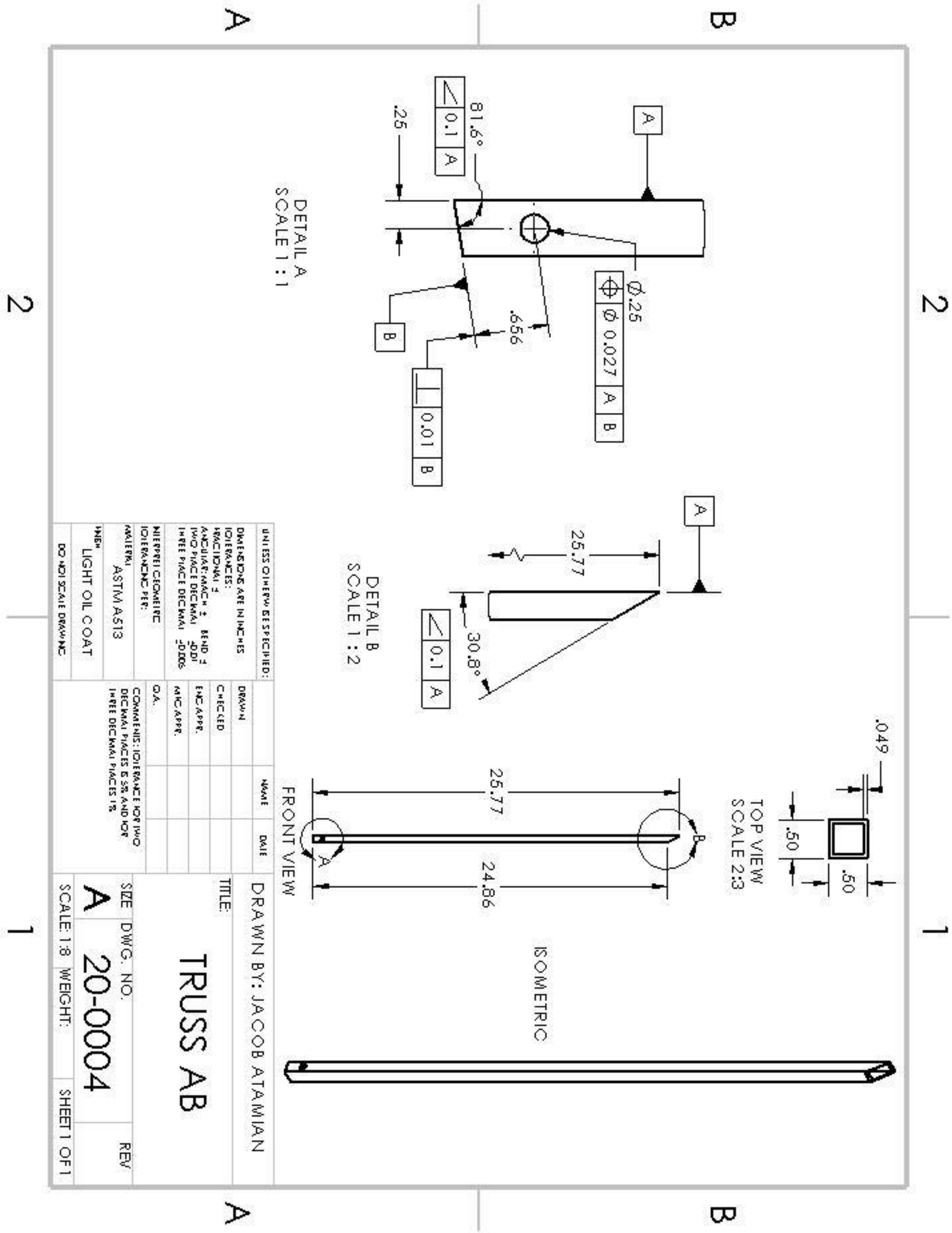
Appendix B6.5 – 20-002 (OBSOLETE)



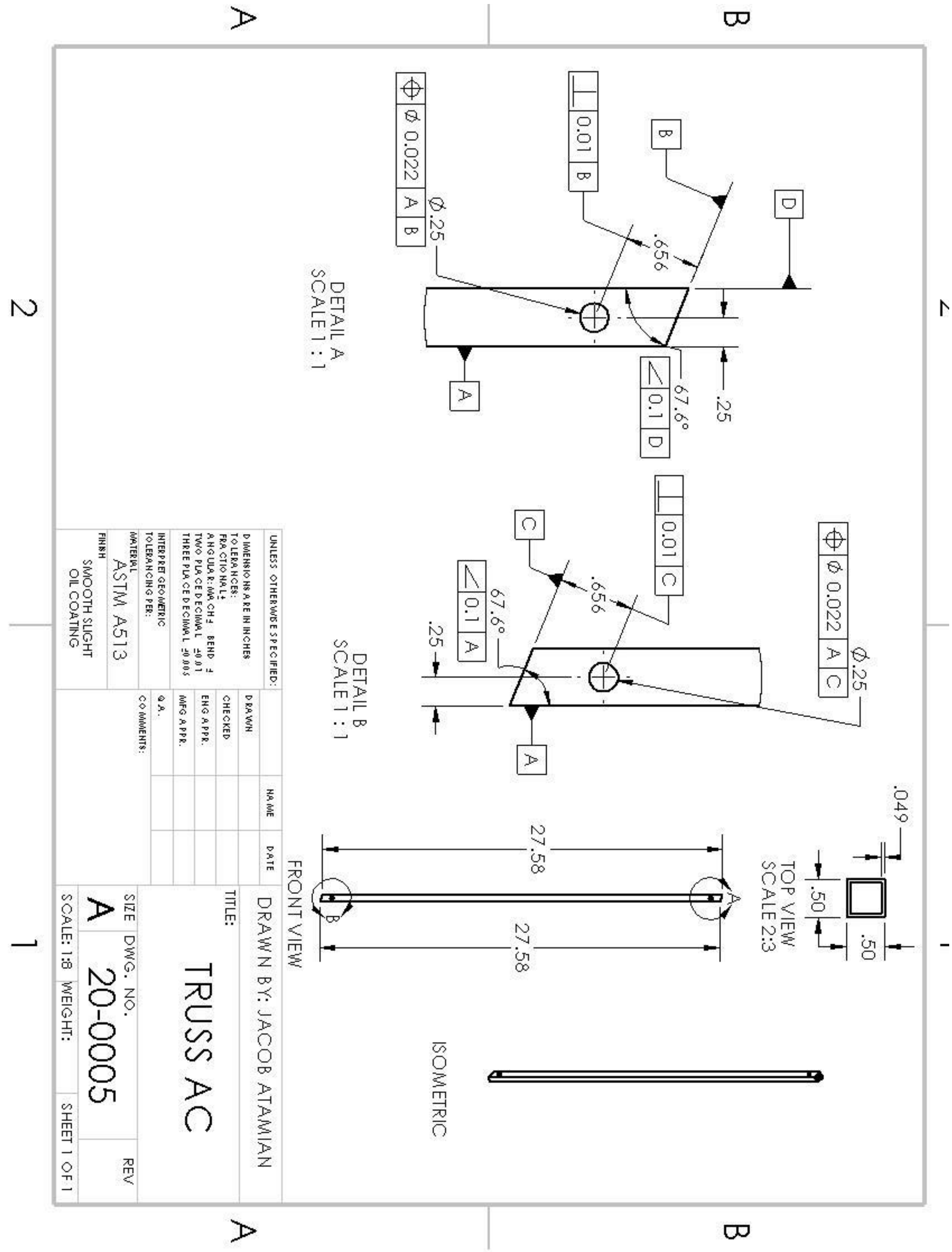
Appendix B7 – 20-003 (OBSOLETE)



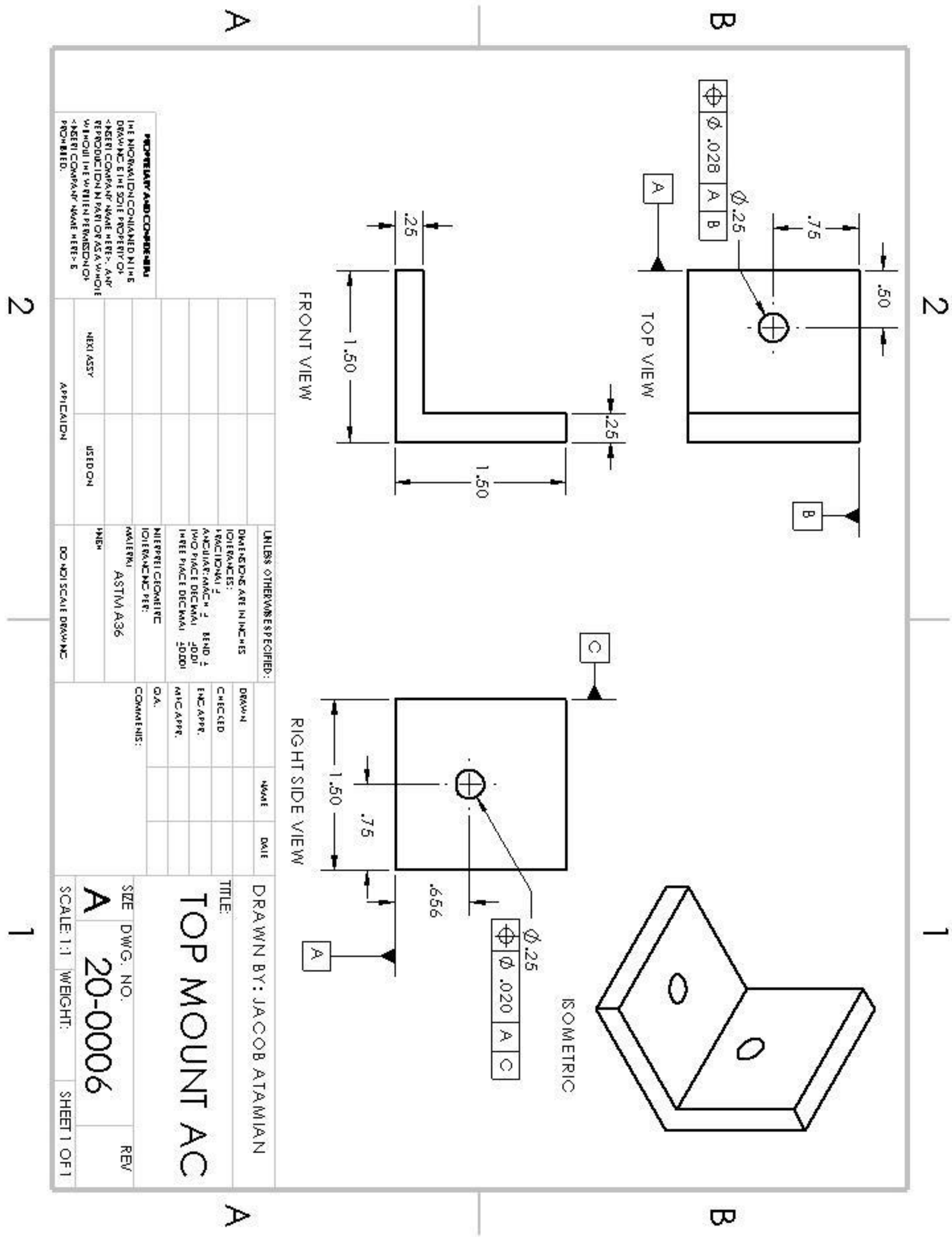
Appendix B8 – 20-004 Truss AB (OBSOLETE)



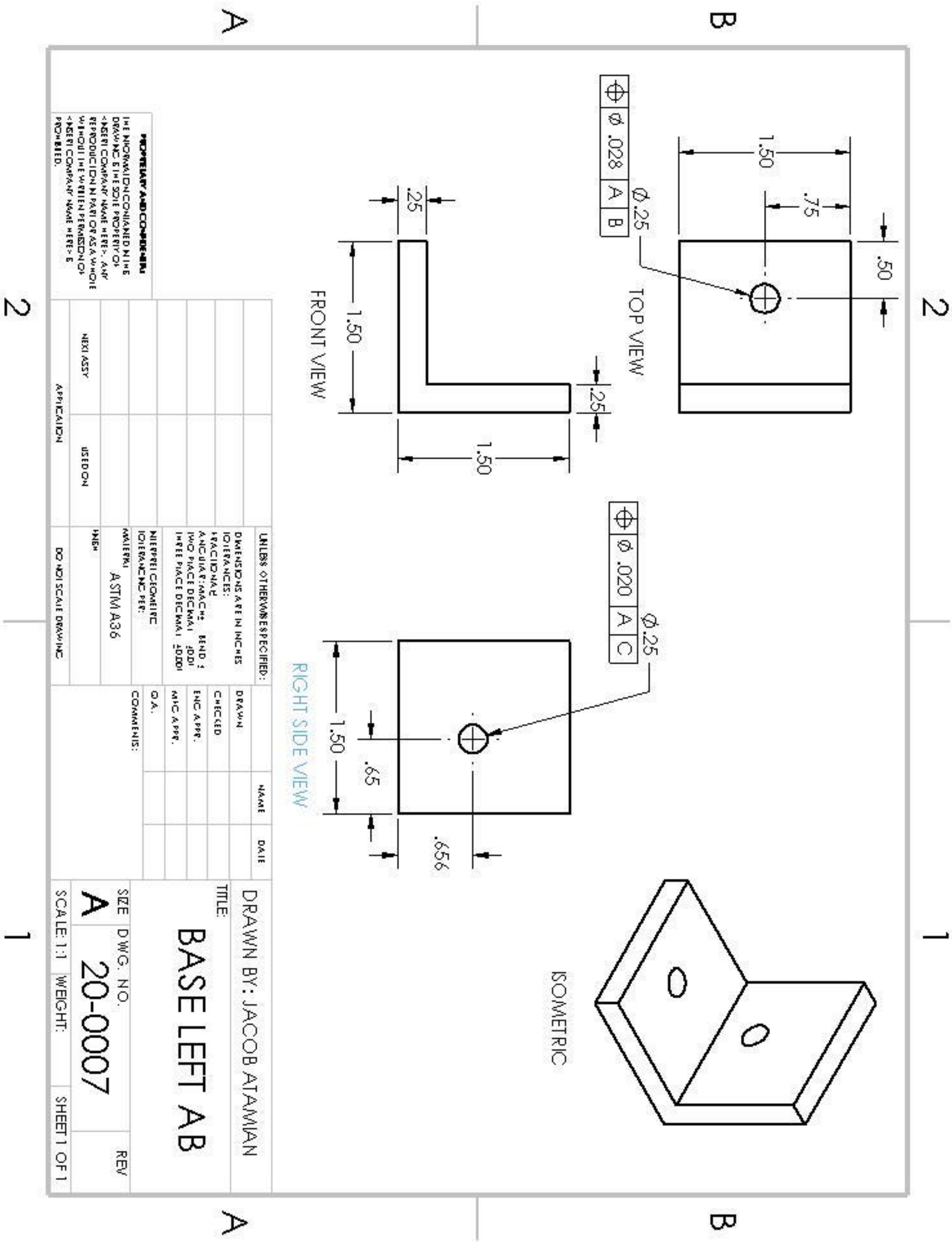
Appendix B9 – 20-005 Truss AC (OBSOLETE)



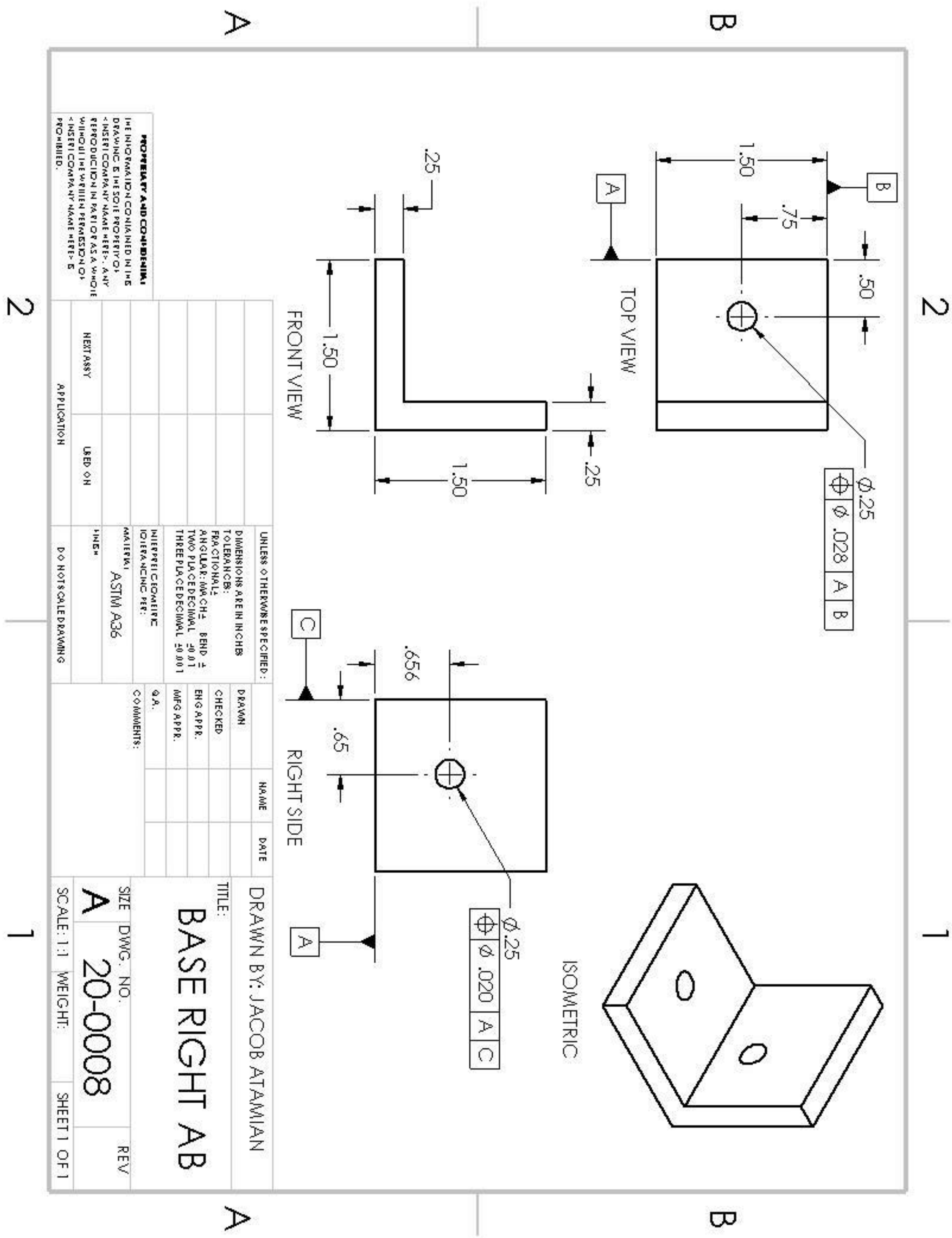
Appendix B10 – 20-006 Top Mount AC (OBSOLETE)



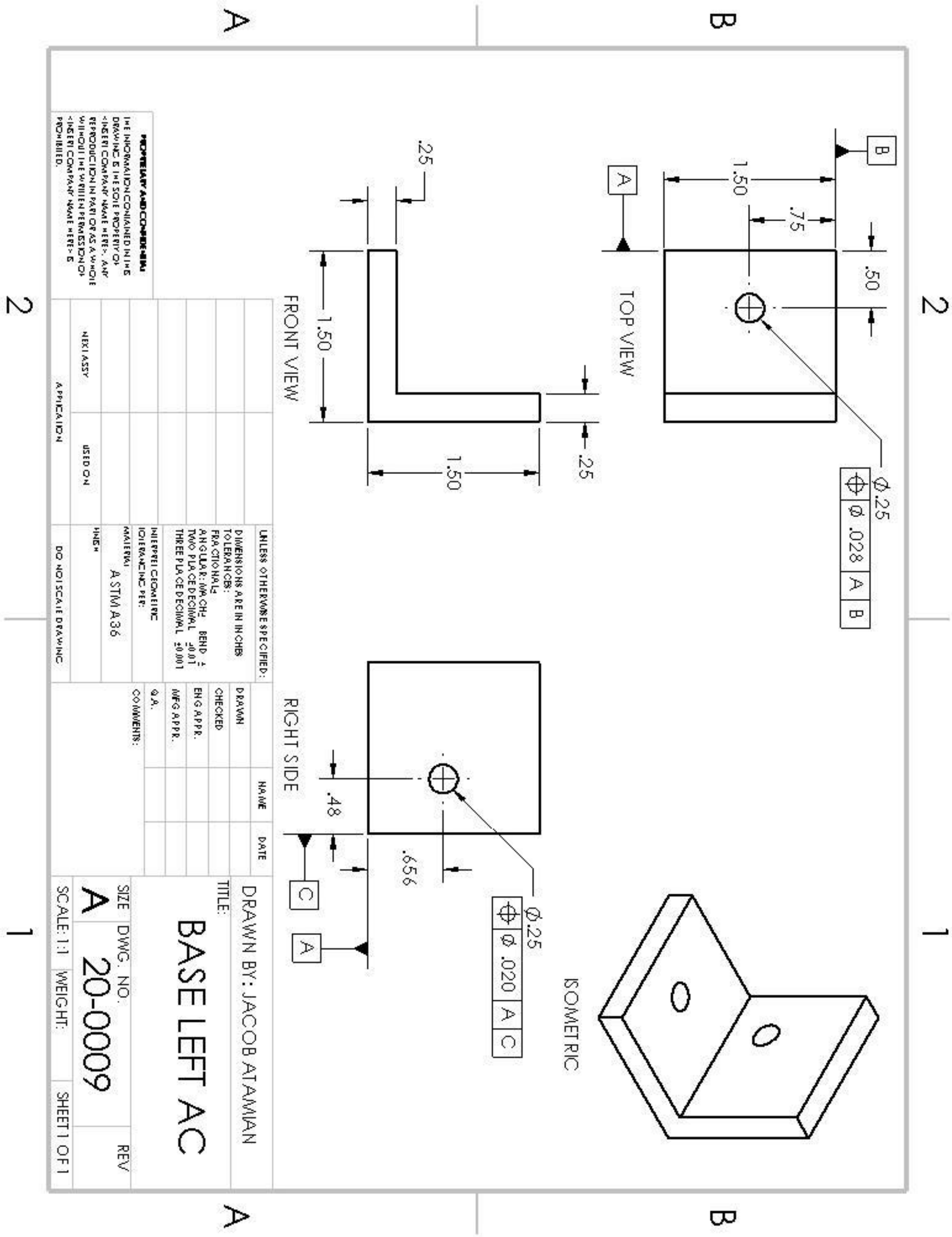
Appendix B11 – 20-007 Base Left AB (OBSOLETE)



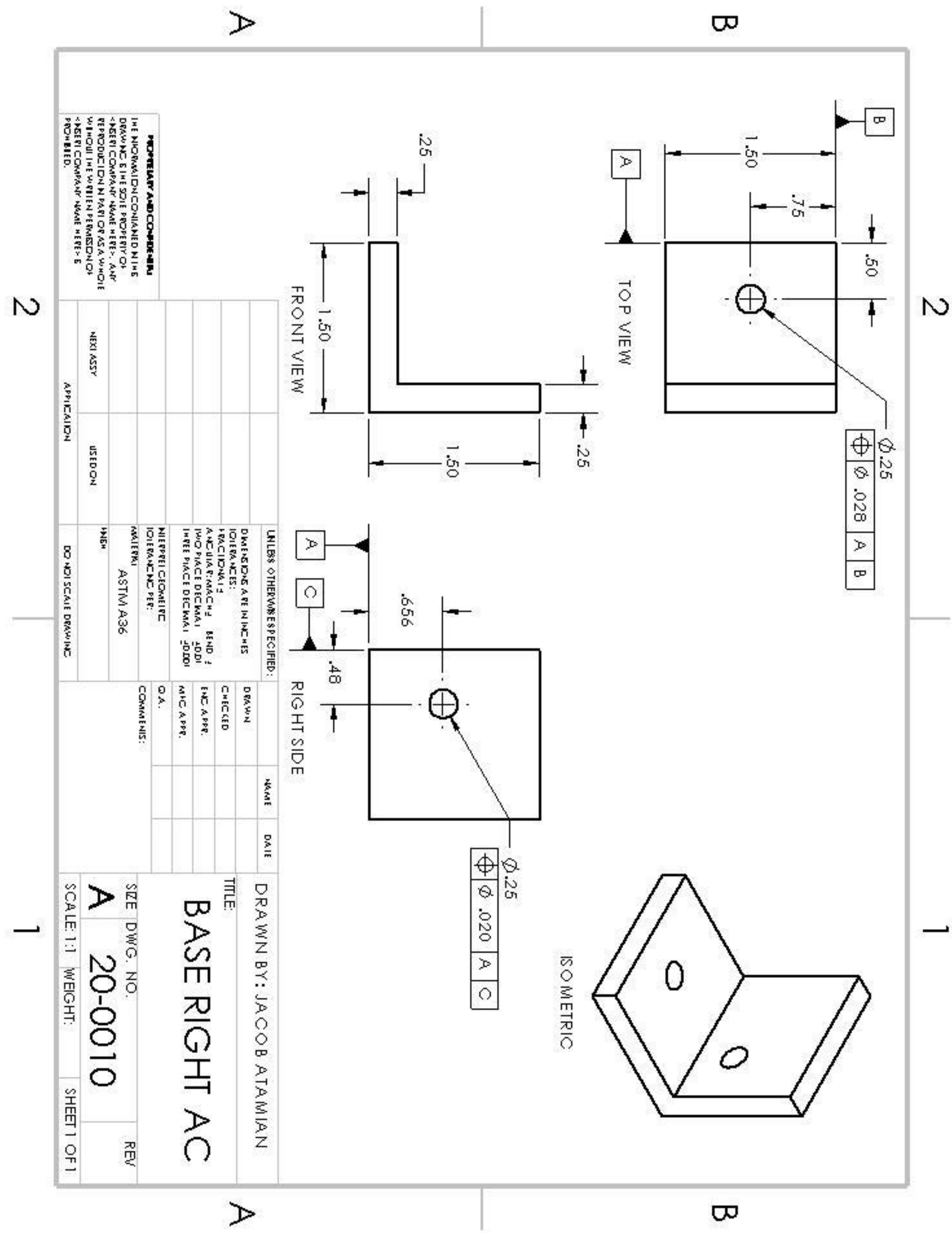
Appendix B12 – 20-008 Base Right AB (OBSOLETE)



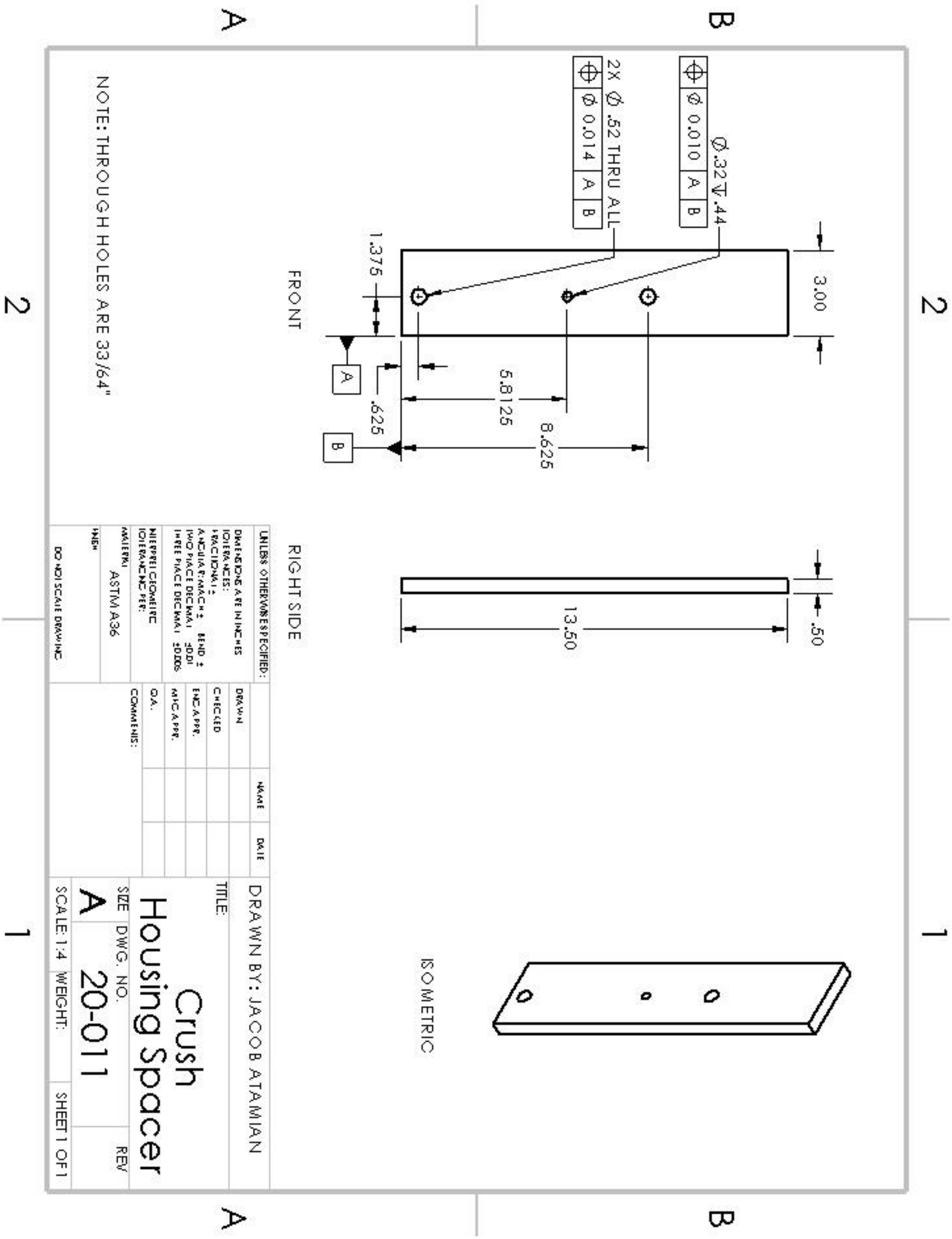
Appendix B13 – 20-009 Base Left AC (OBSOLETE)



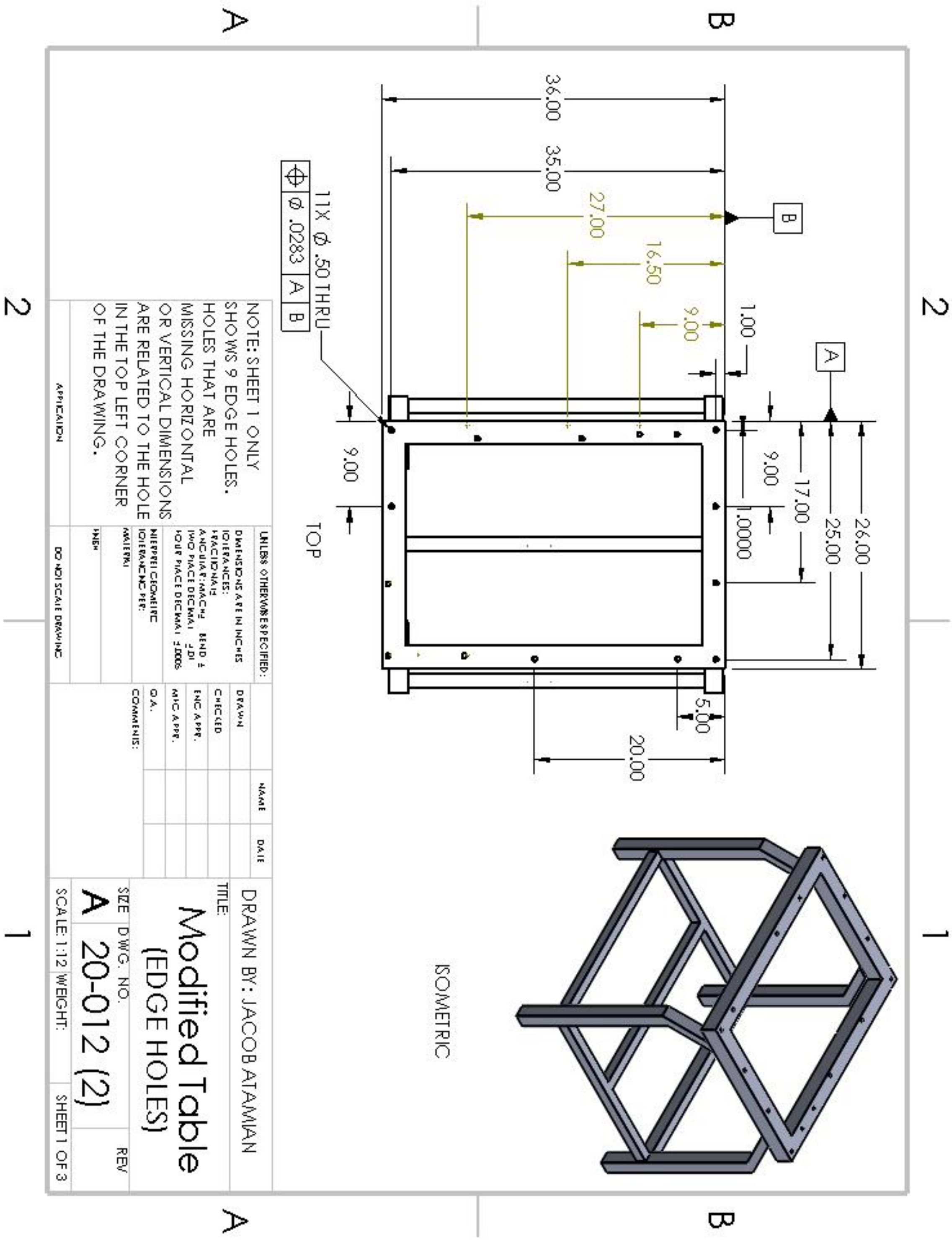
Appendix B14 – 20-010 Base Right AC (OBSOLETE)



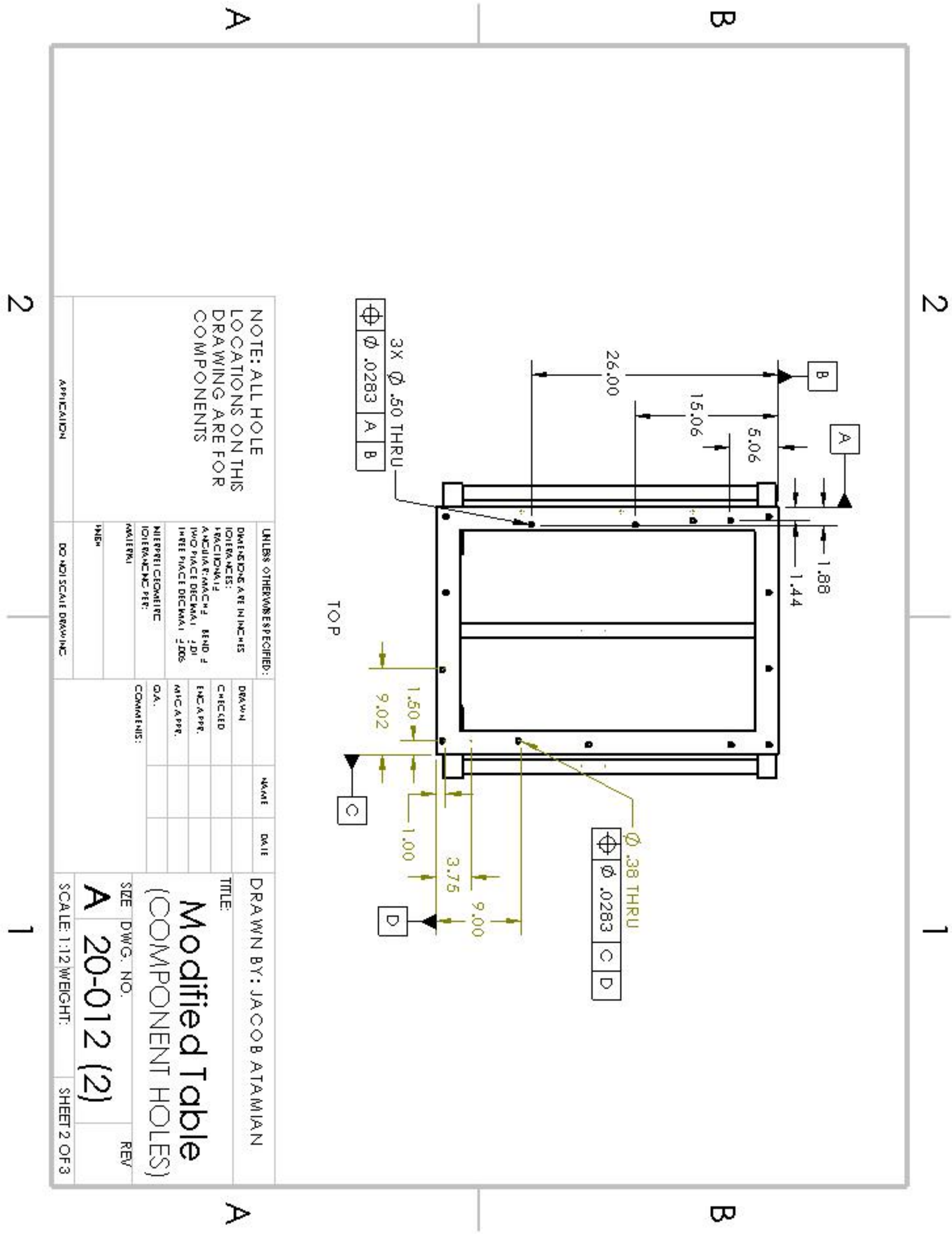
Appendix B15 – 20-011 Housing Spacer



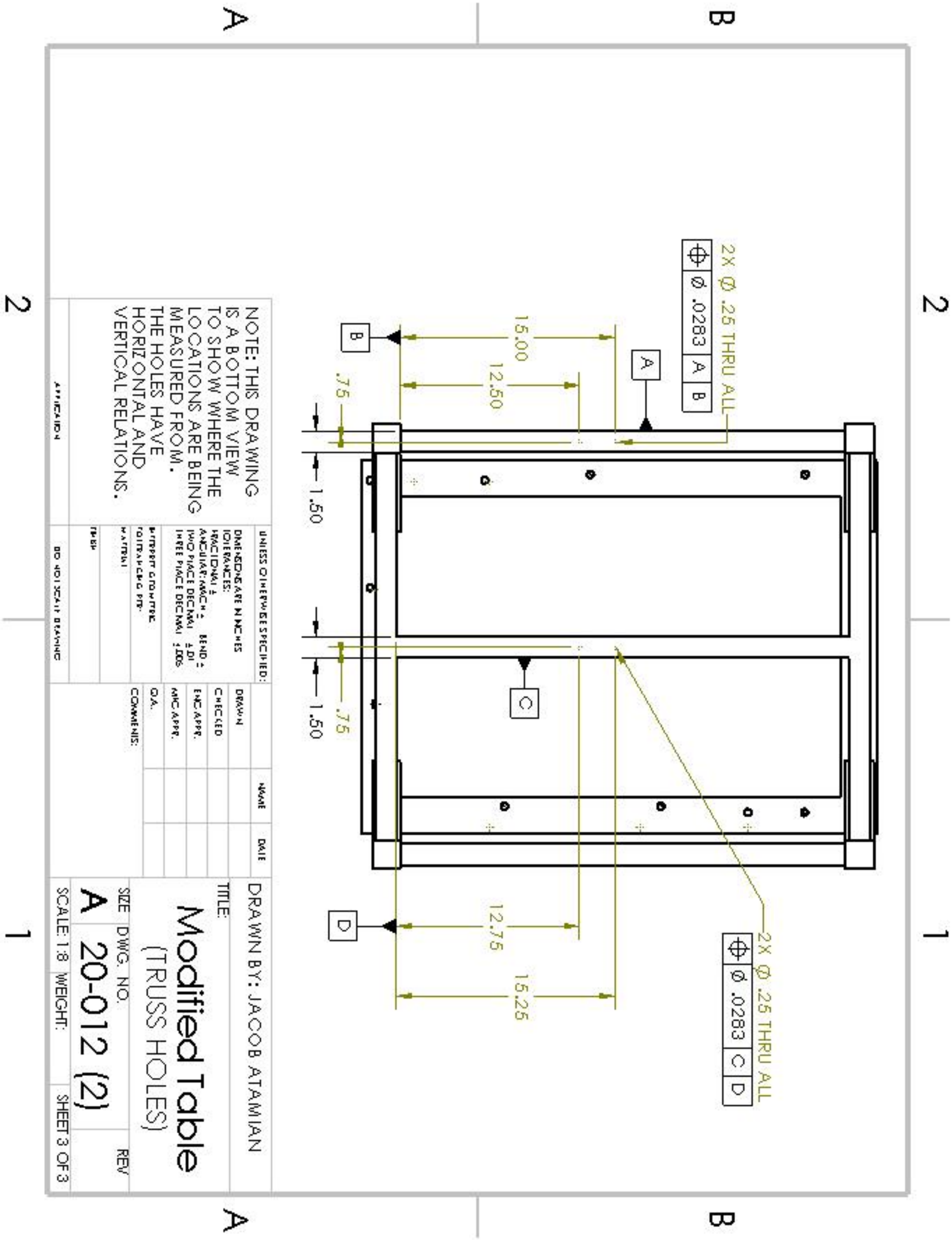
Appendix B16.1 – 20-012 Modified Table (Edge Holes)



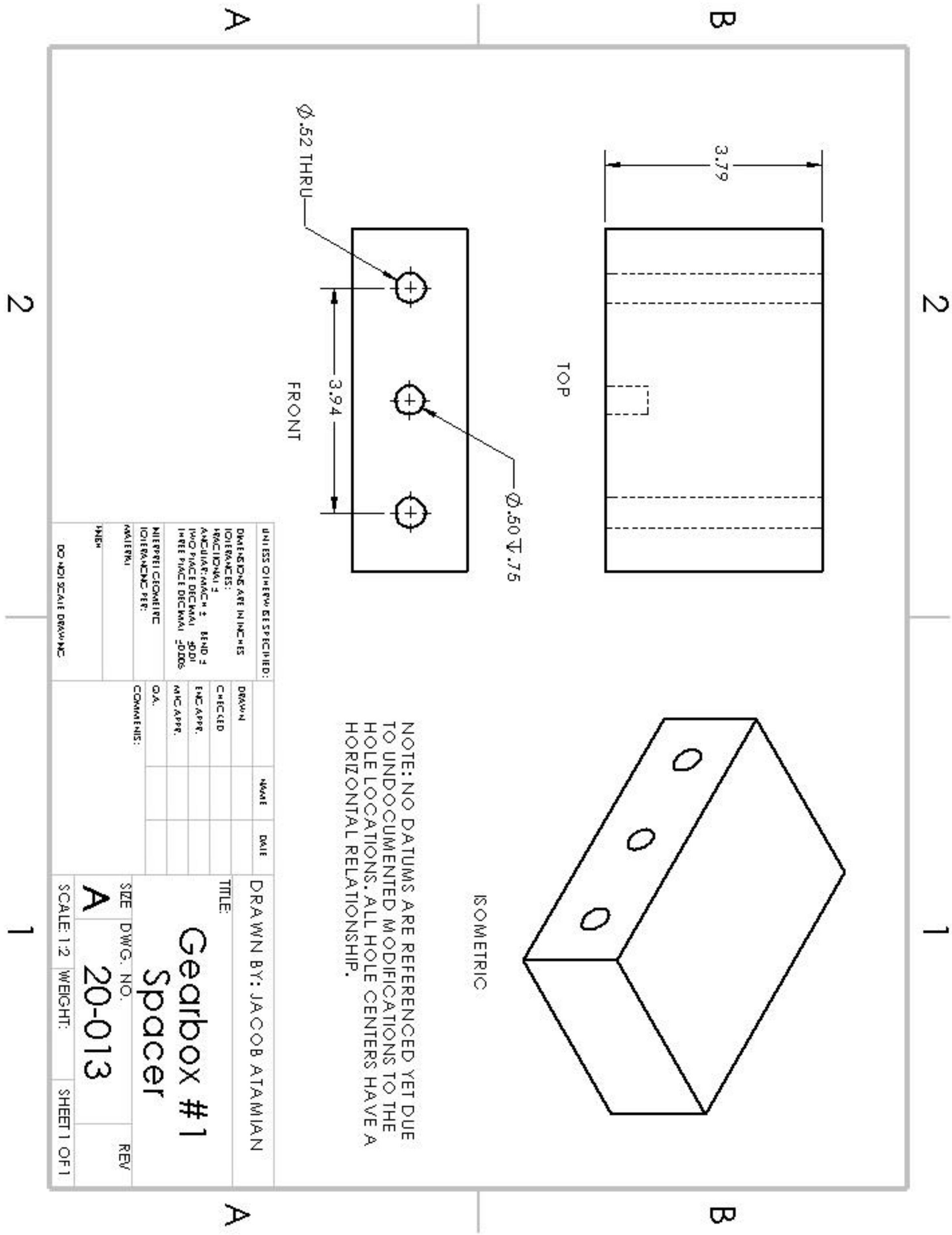
Appendix 16.2 – 20-012 (Component Holes)



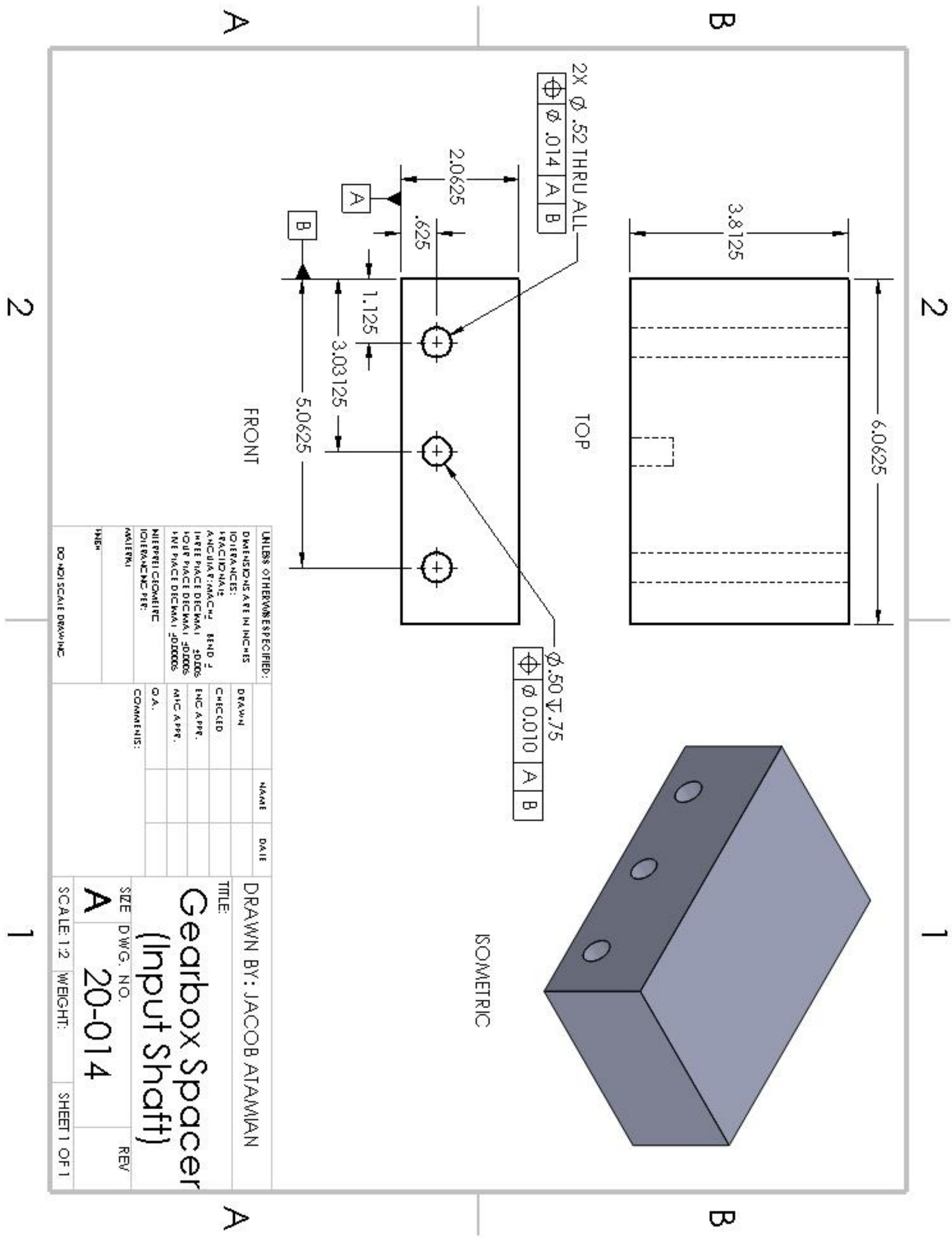
Appendix B16.3 – 20-012 (Truss Holes)



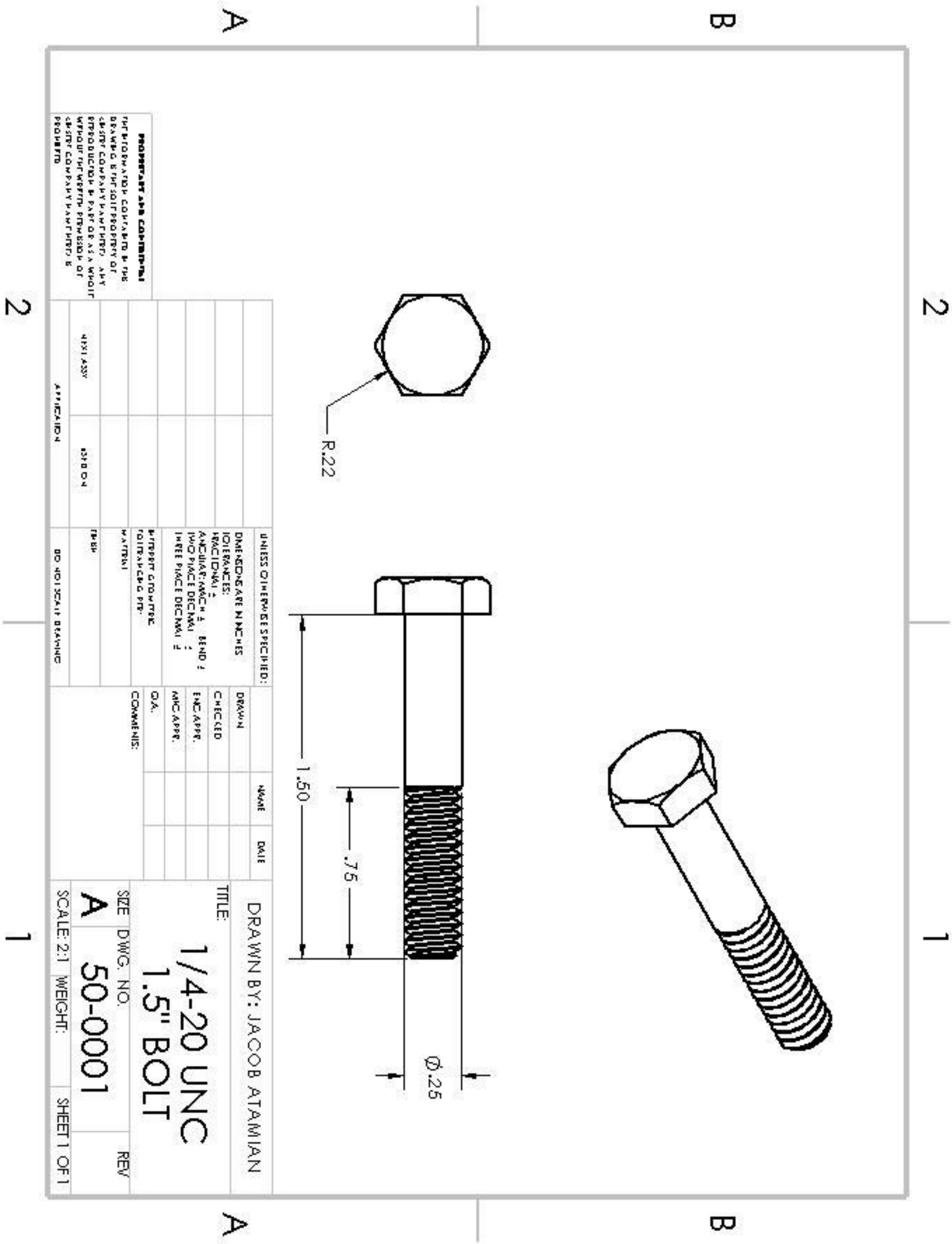
Appendix B17 – 20-013



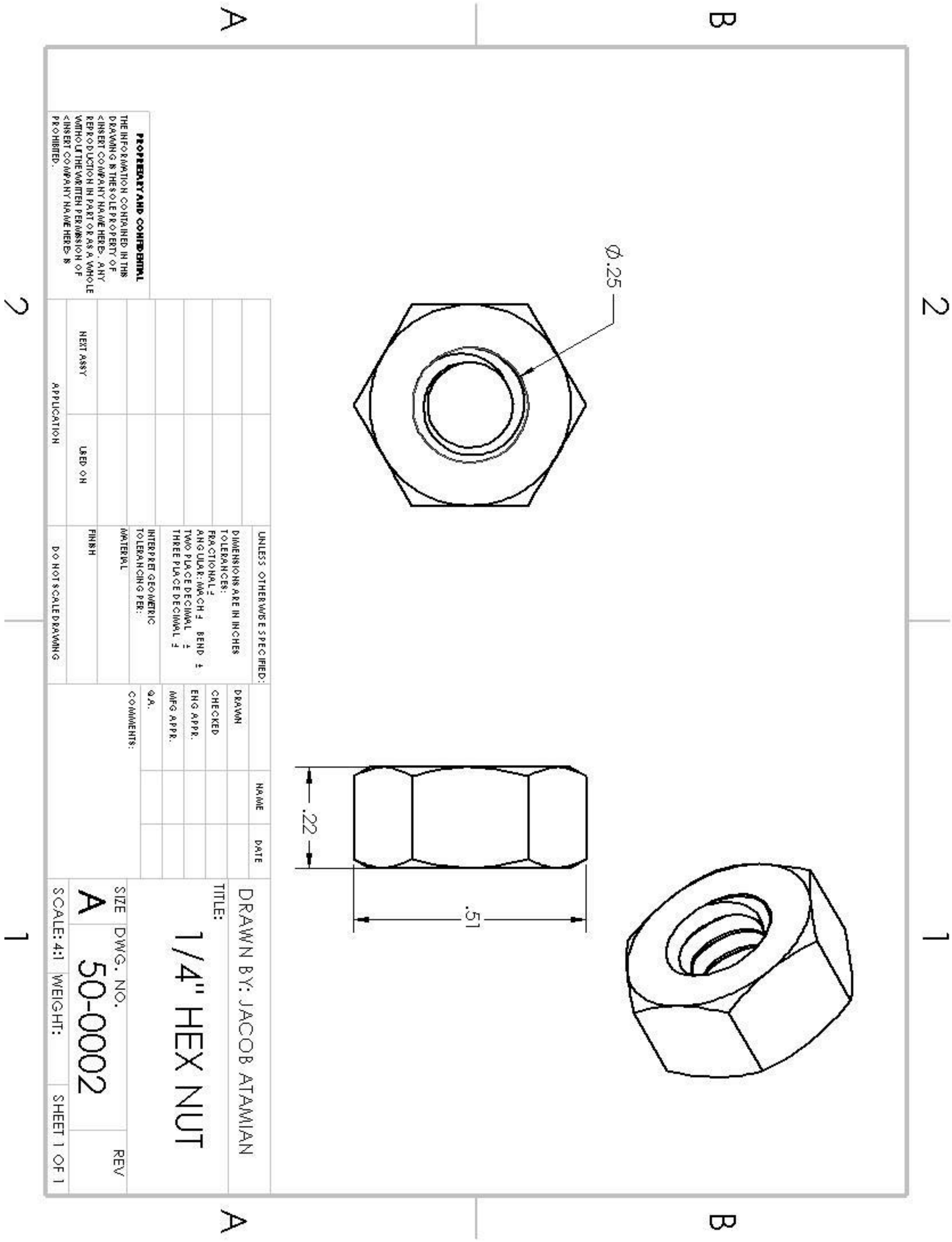
Appendix B18 – 20-014



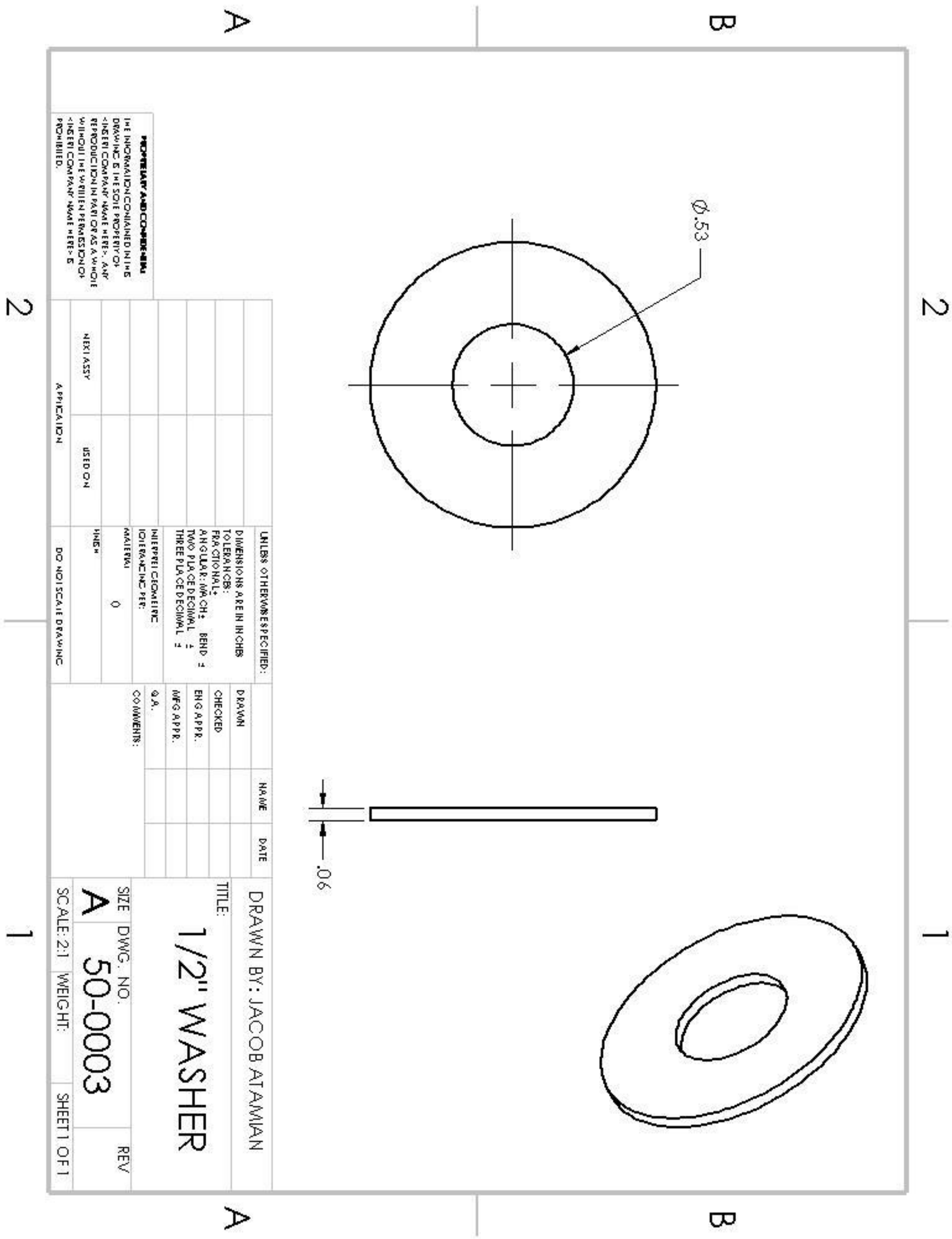
Appendix B19 – 50-001



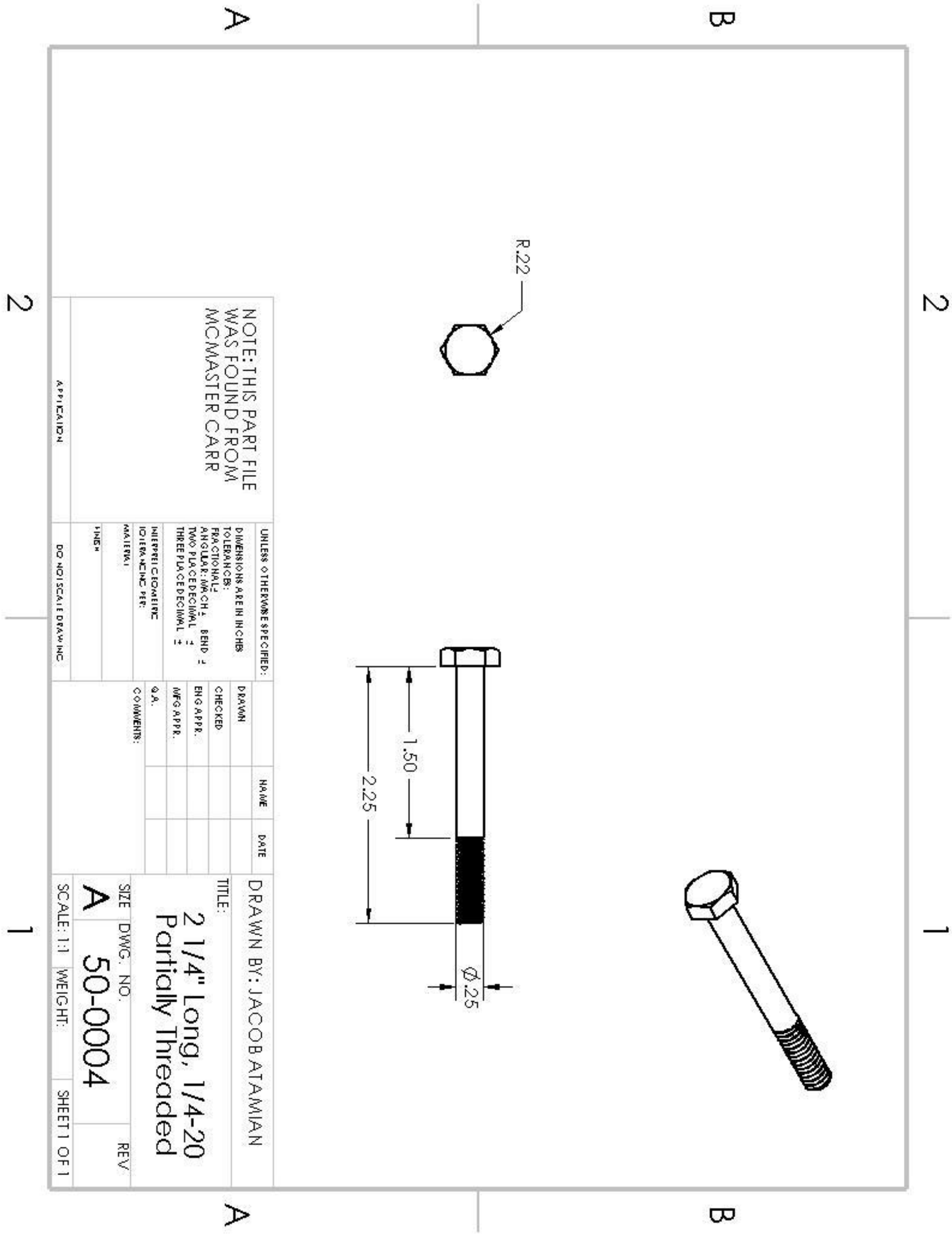
Appendix B20 – 50-002



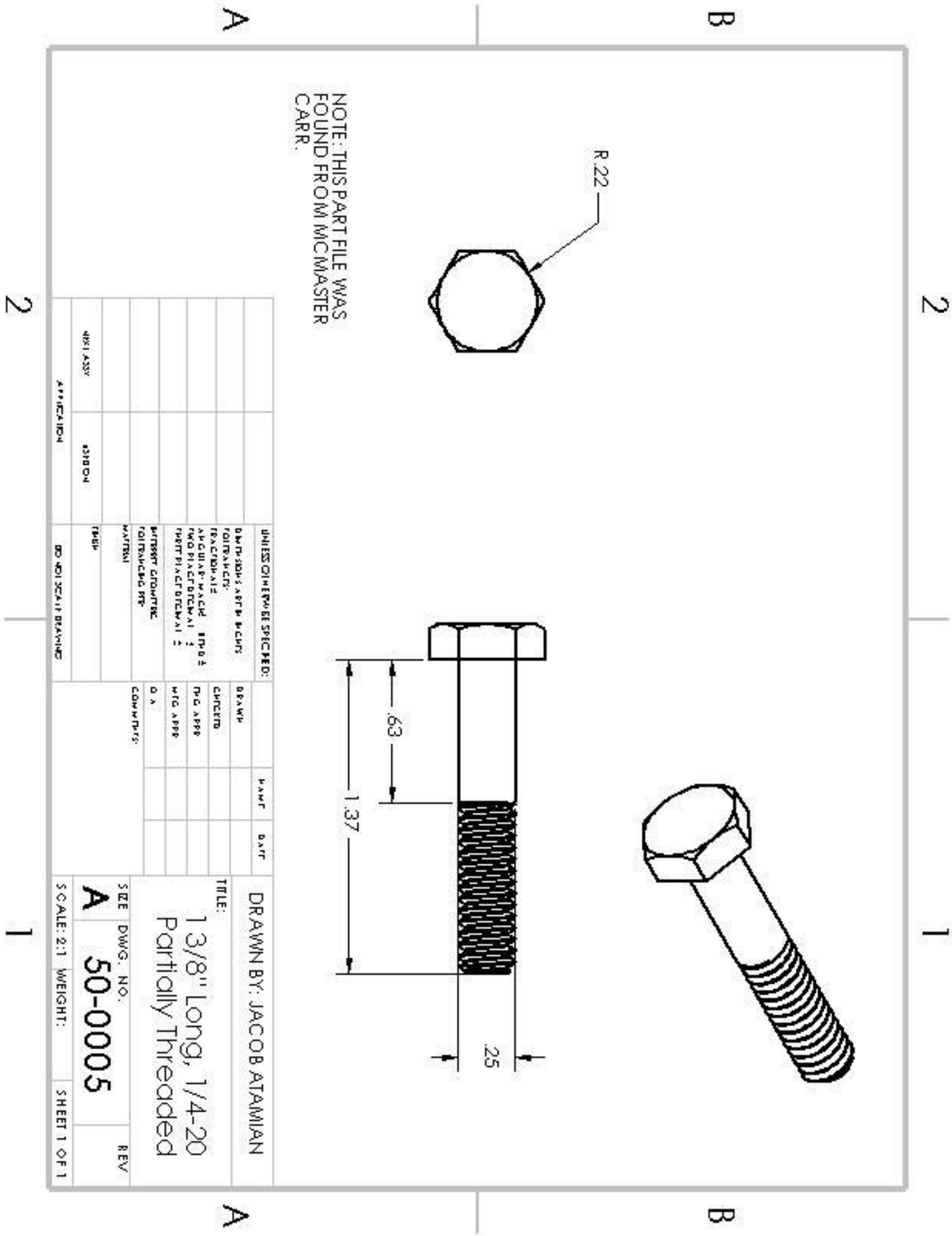
Appendix B21 – 50-003



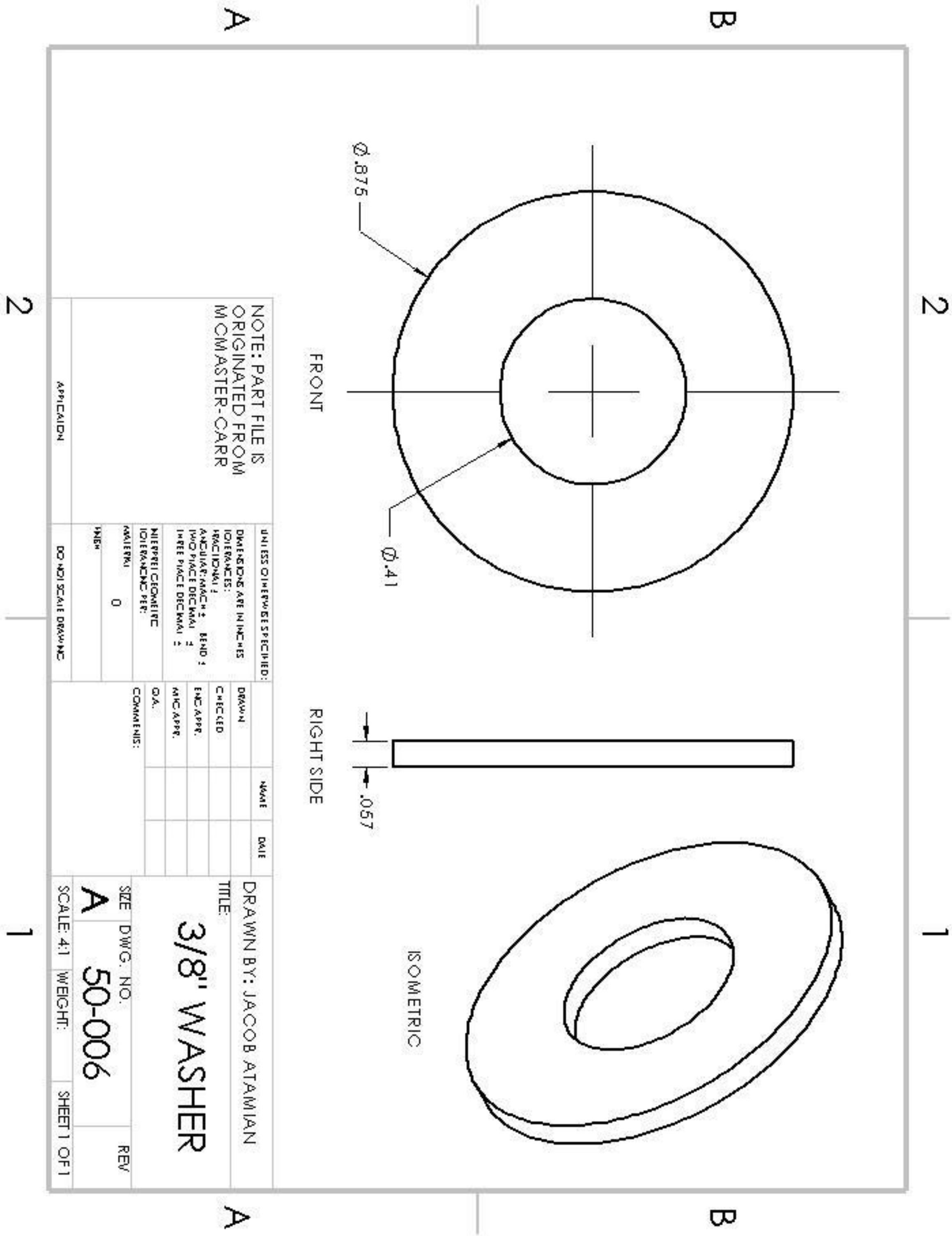
Appendix B22 – 50-004



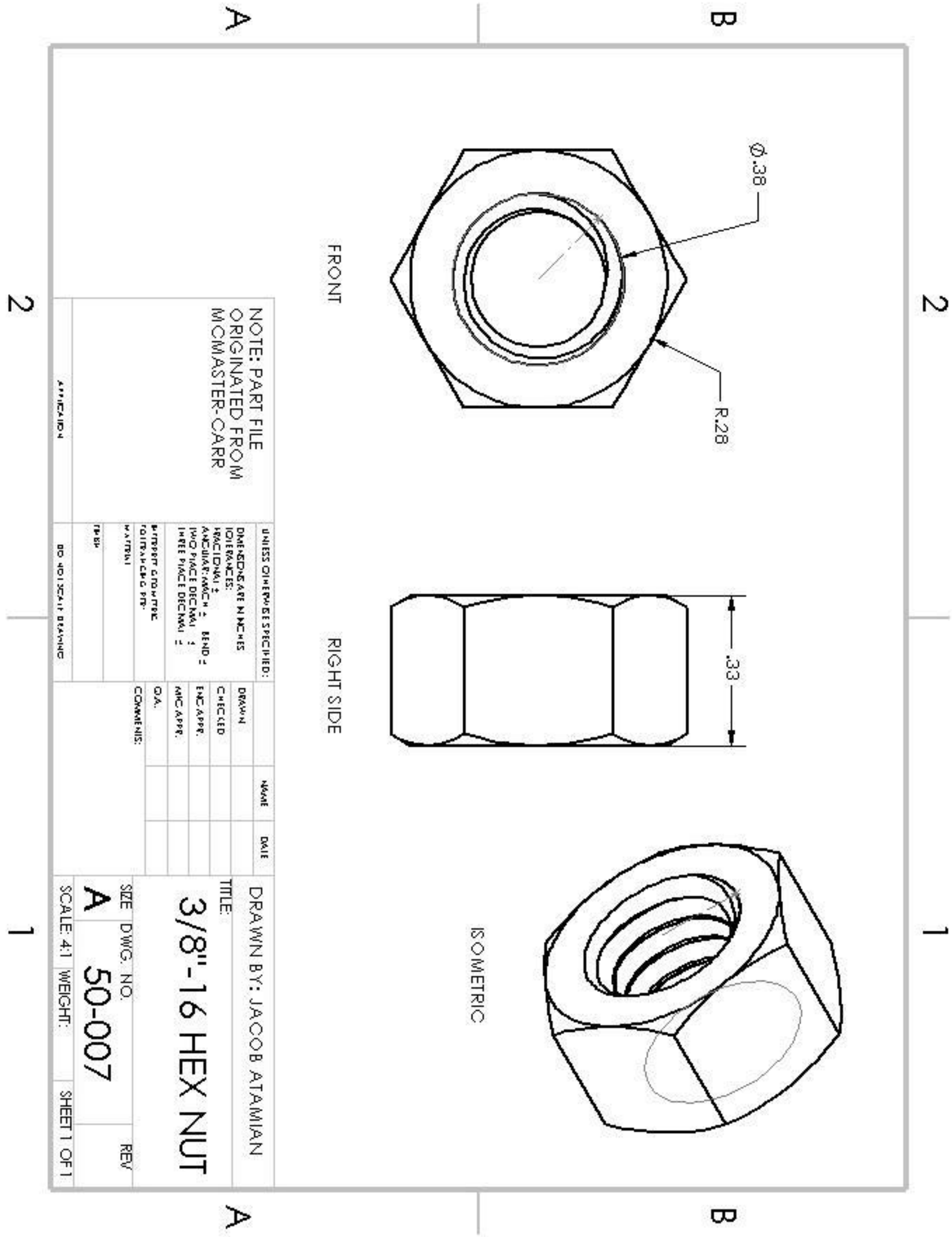
Appendix B23 – 50-005



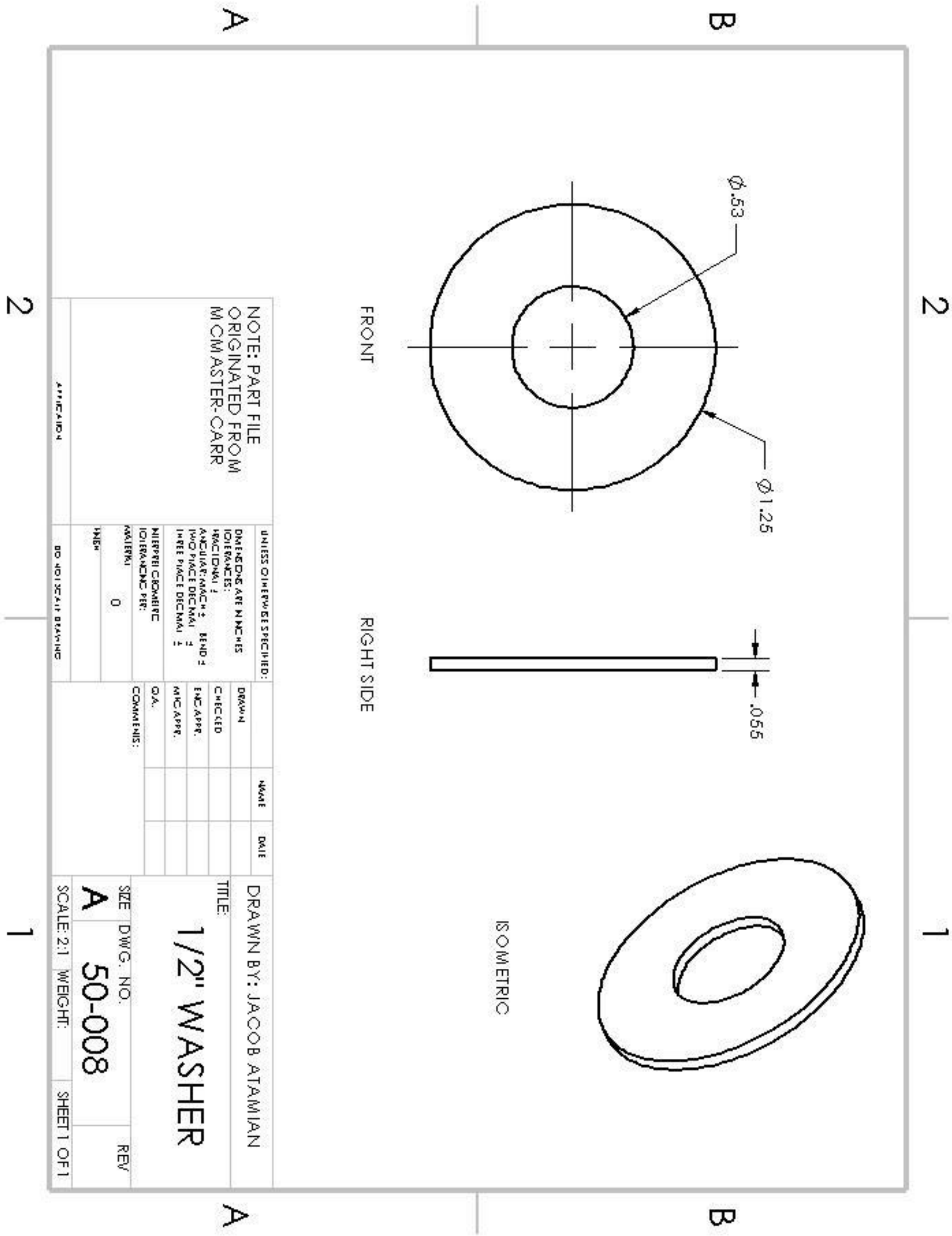
Appendix B24 – 50-006



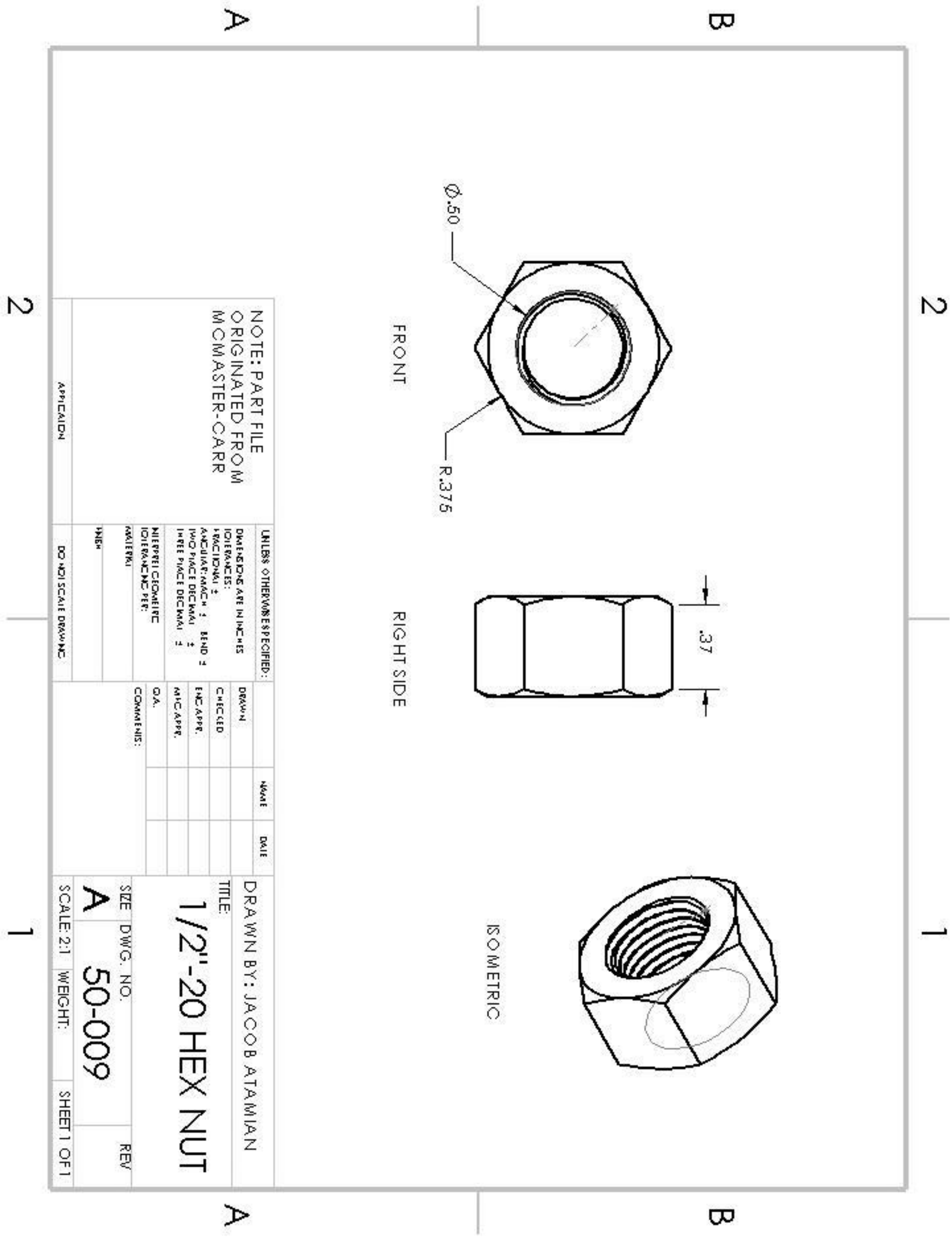
Appendix B25 – 50-007



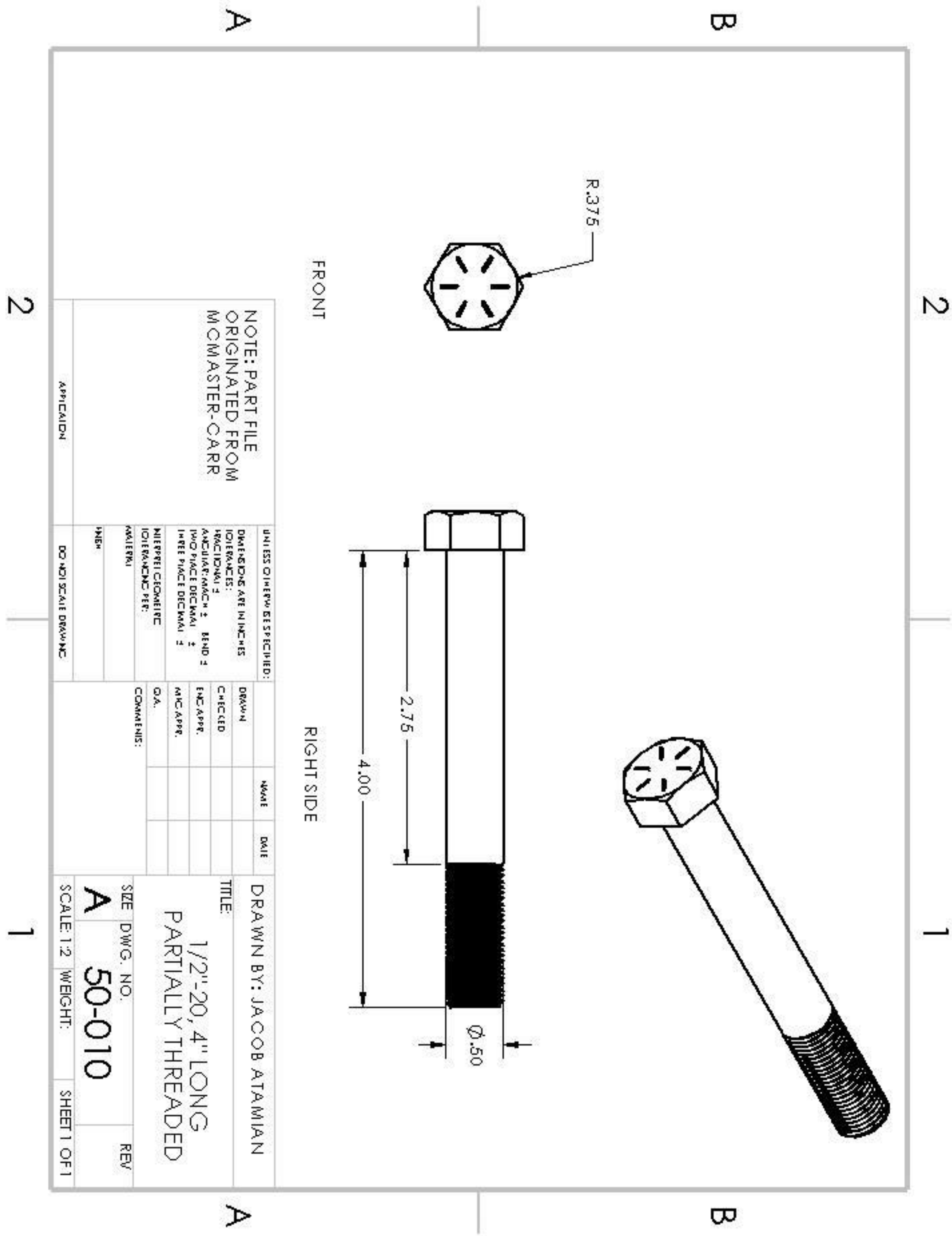
Appendix B26 – 50-008



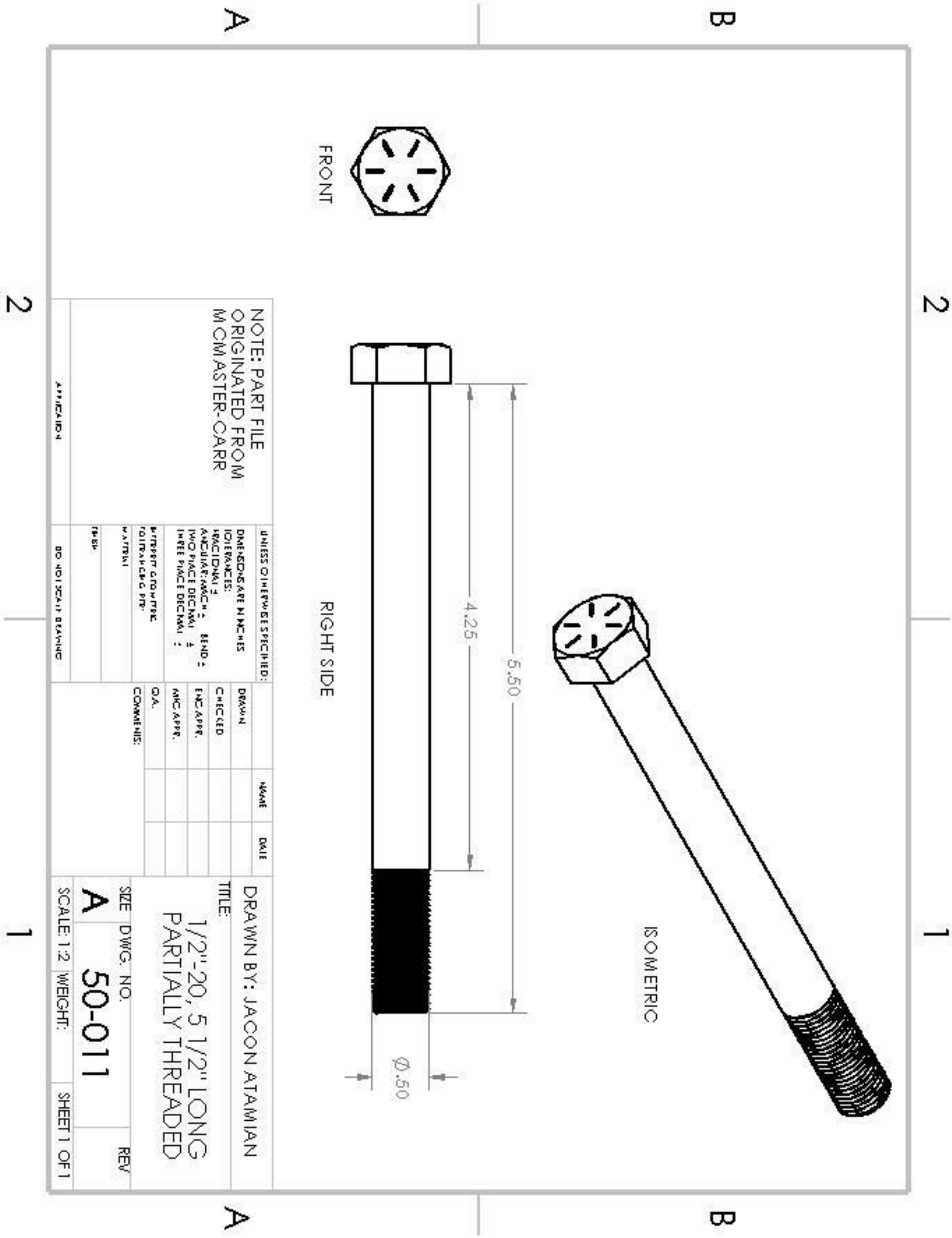
Appendix B27 – 50-009



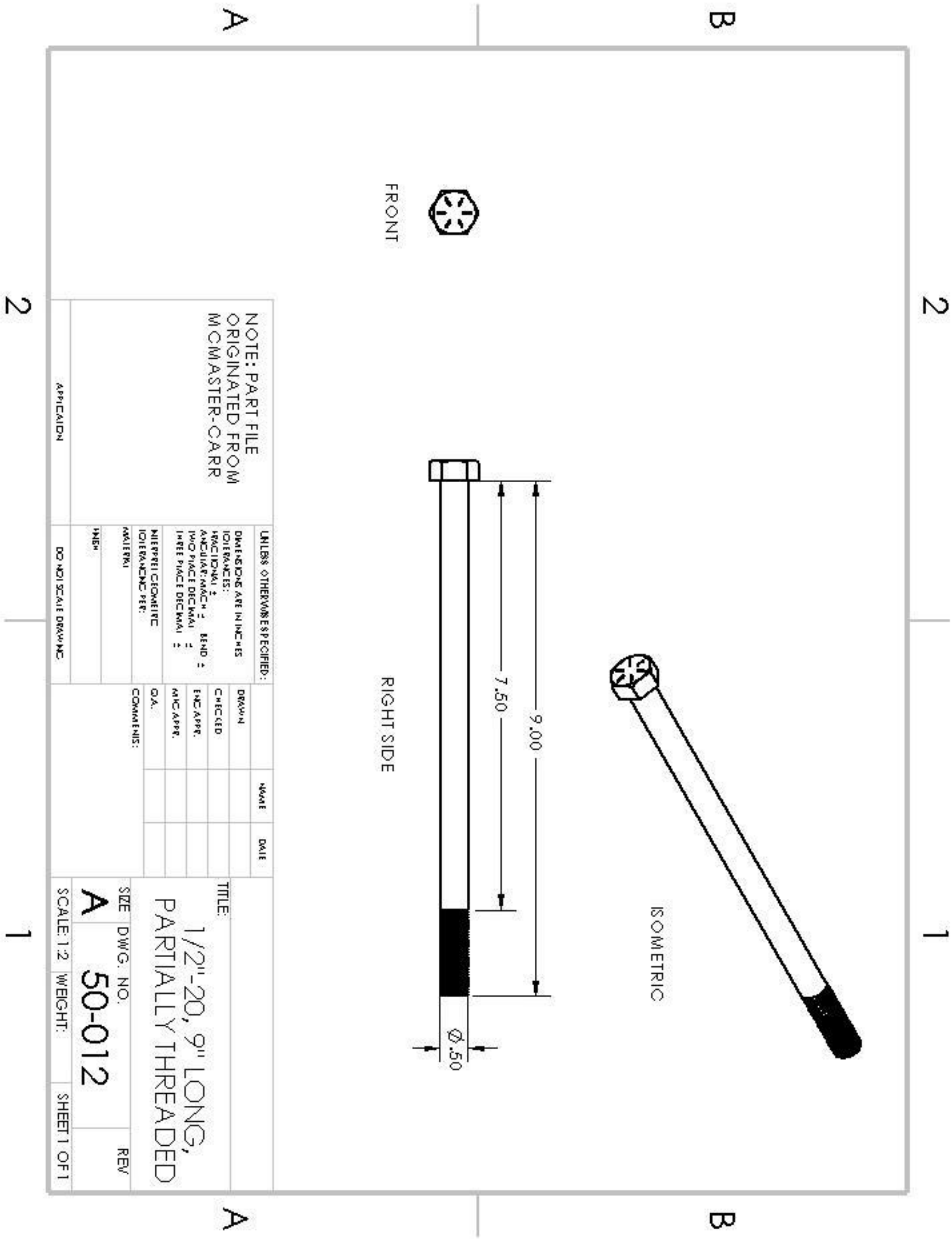
Appendix B28 – 50-010



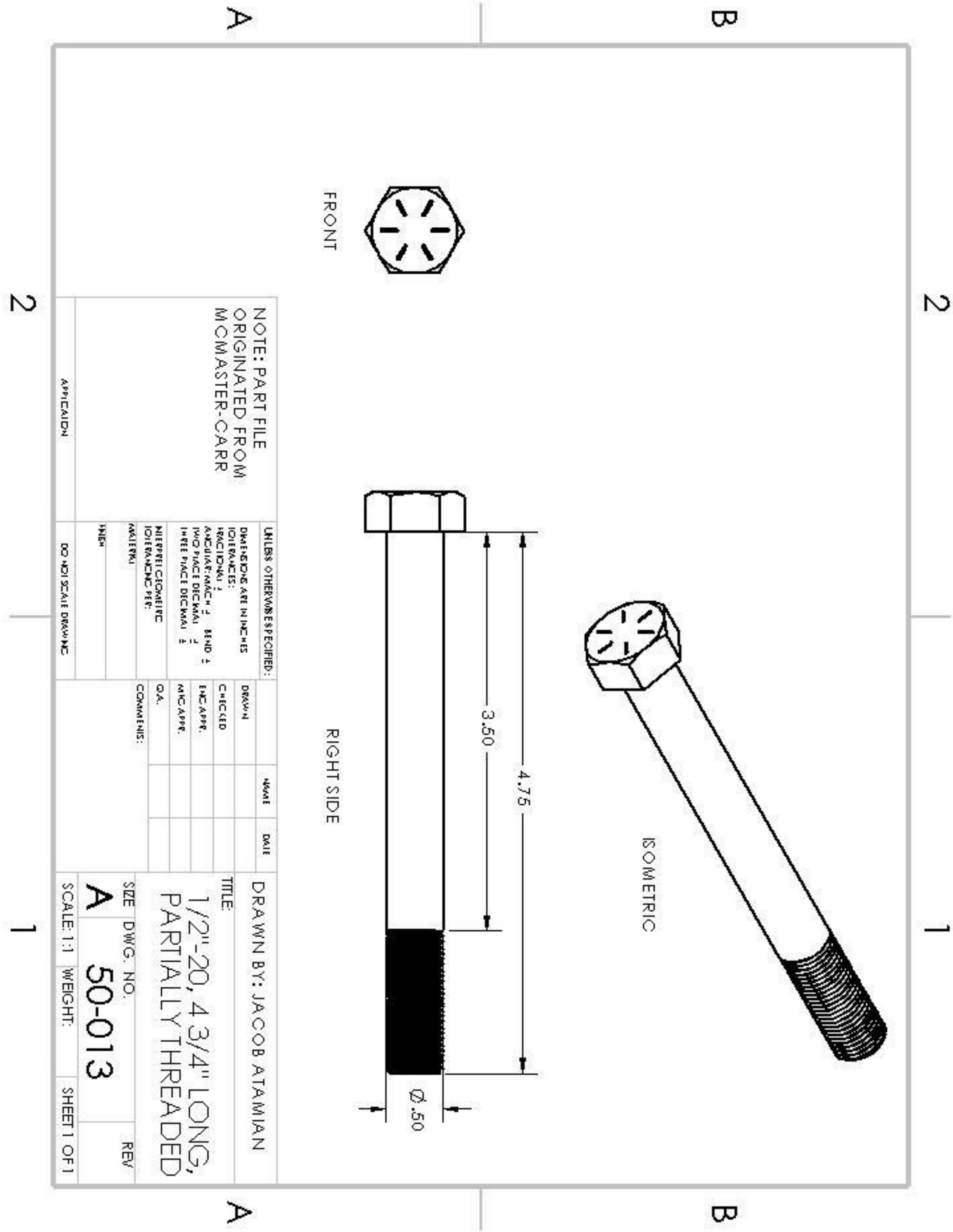
Appendix B29 – 50-011



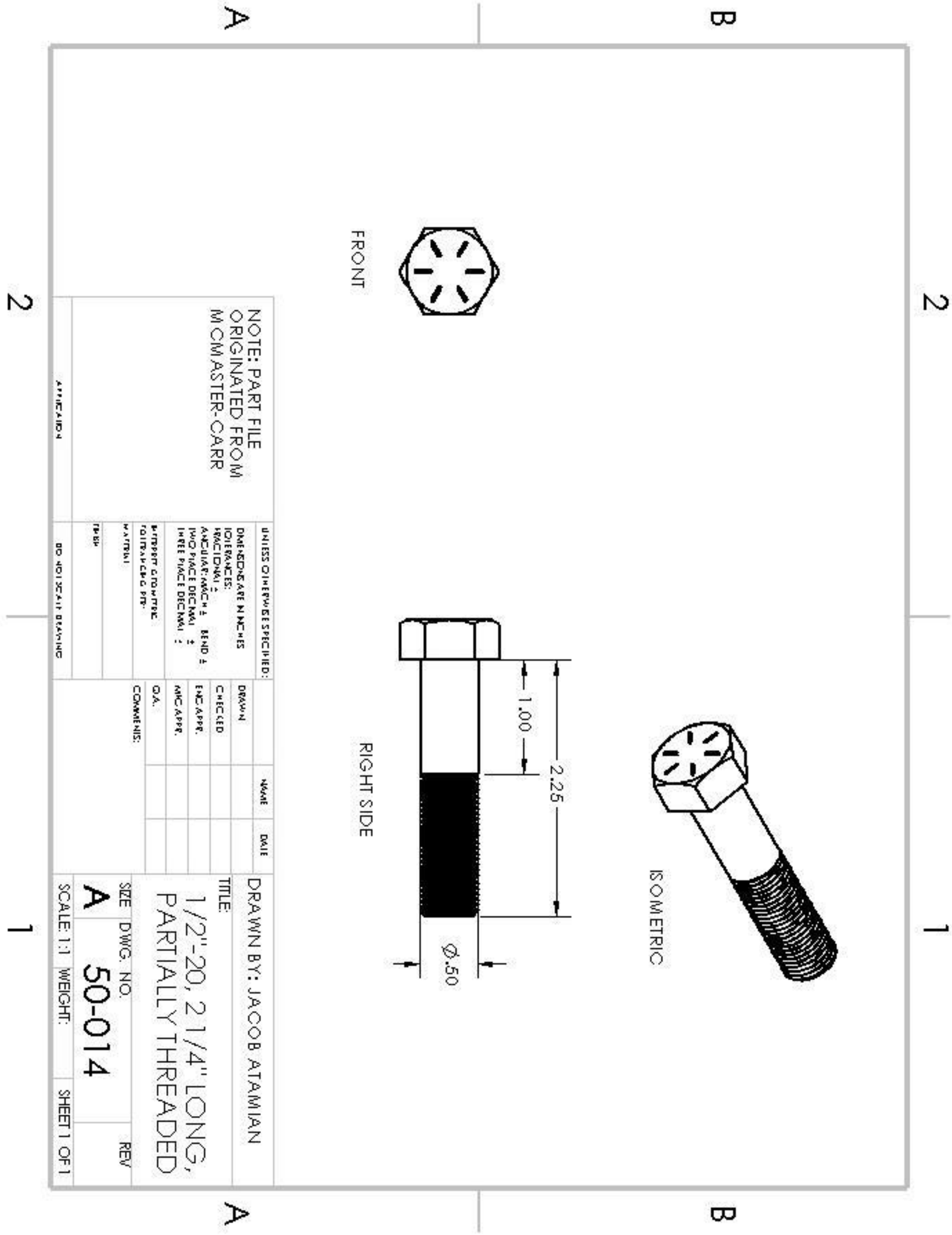
Appendix B30 – 50-012



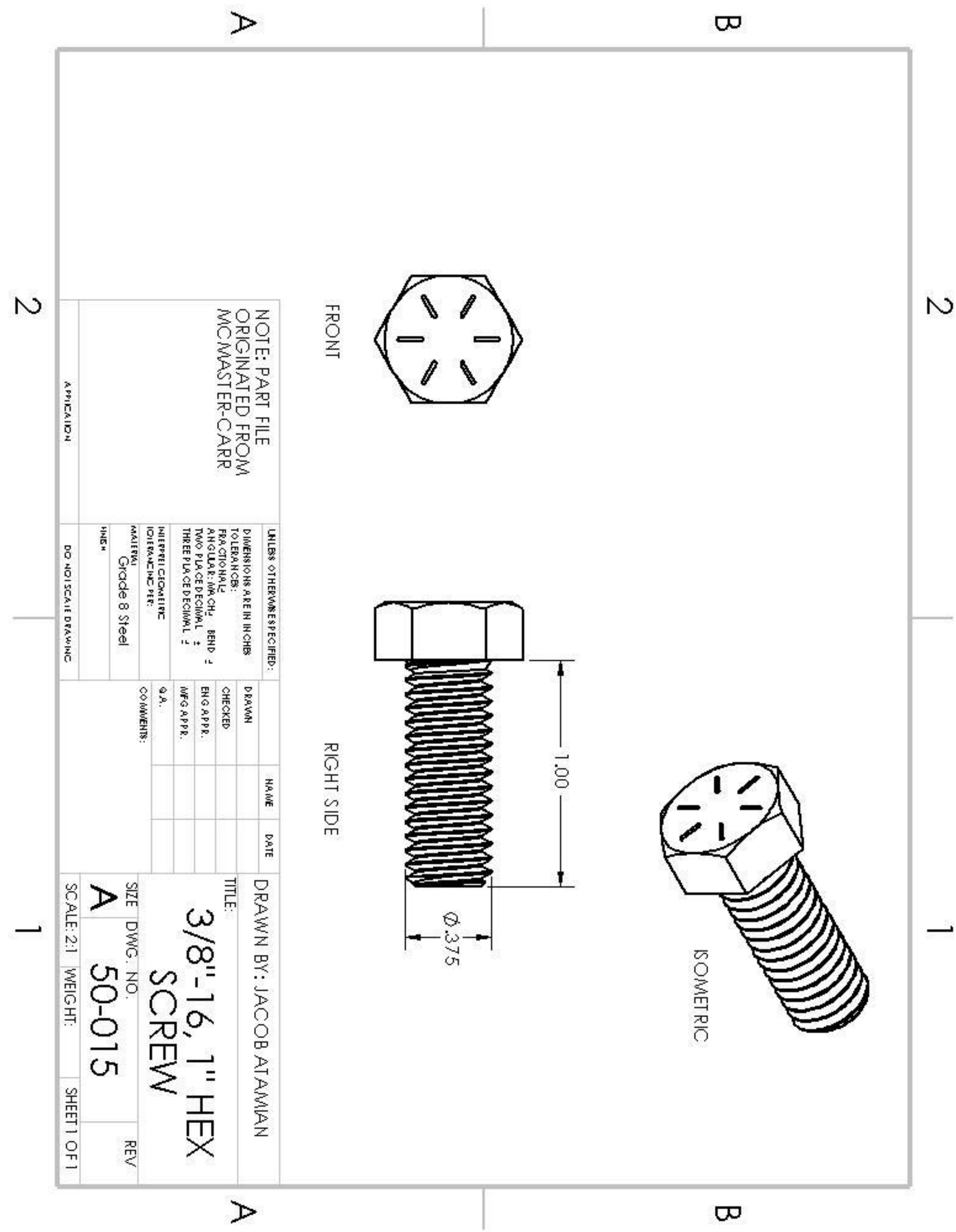
Appendix B31 – 50-013



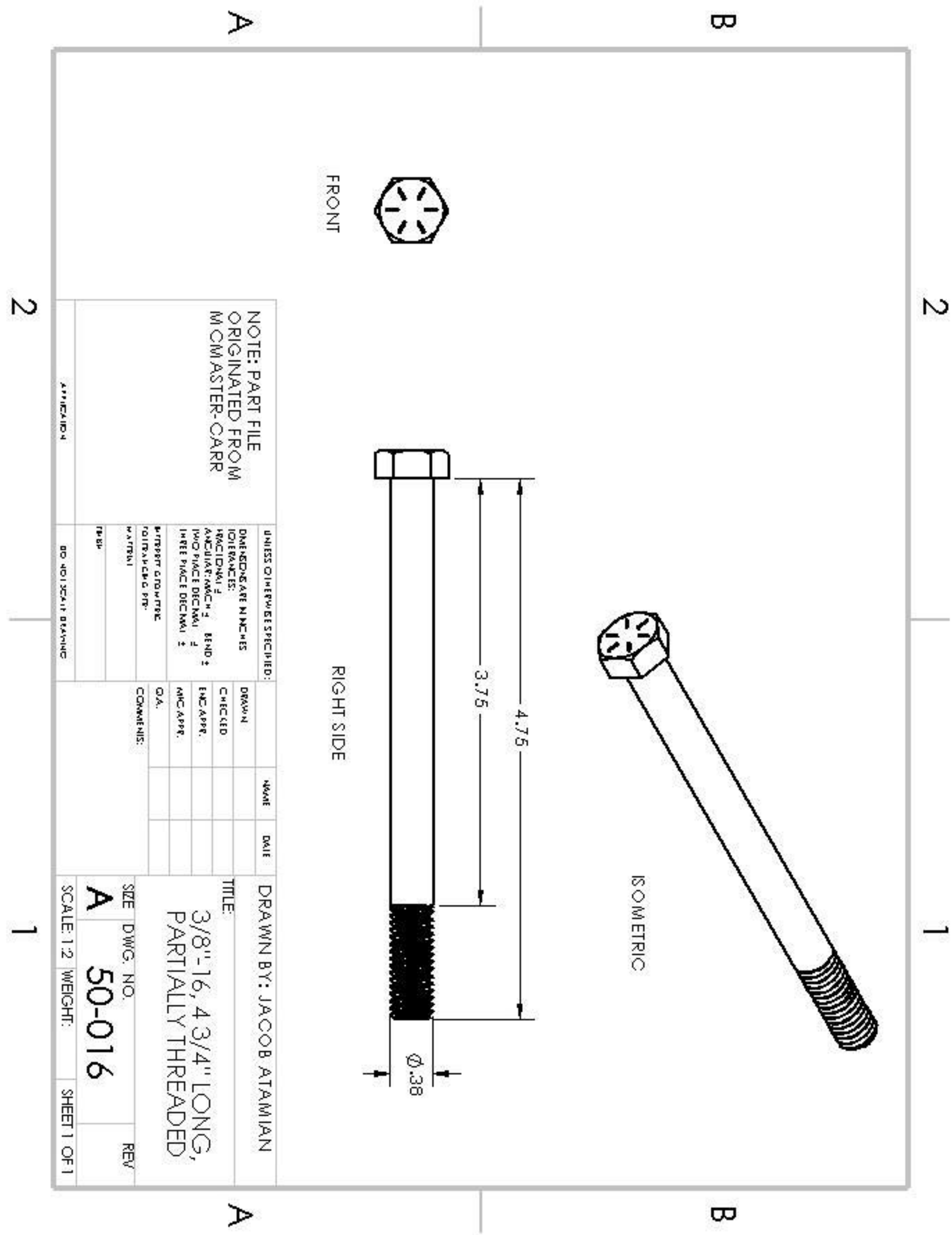
Appendix B32 – 50-014



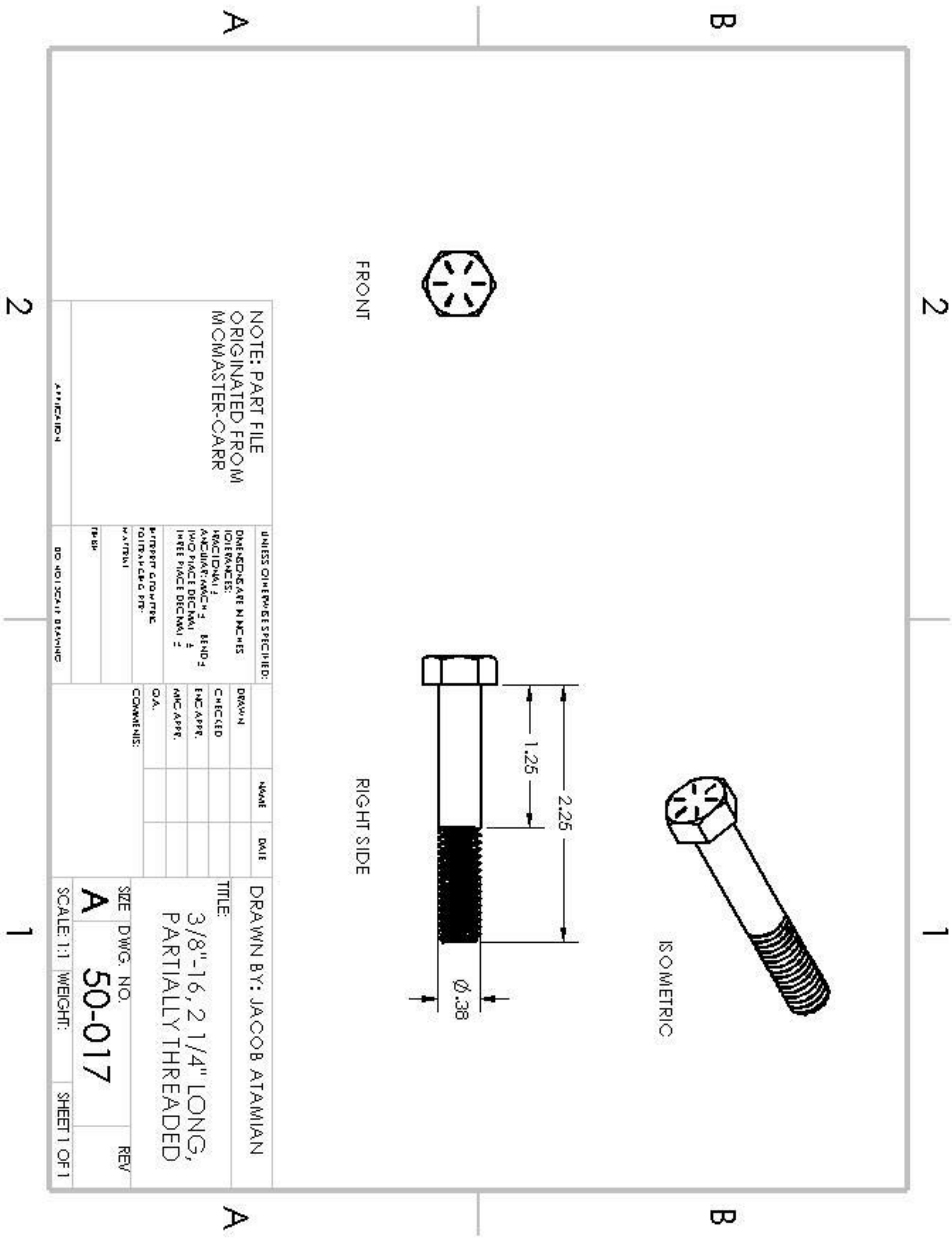
Appendix B33 – 50-015



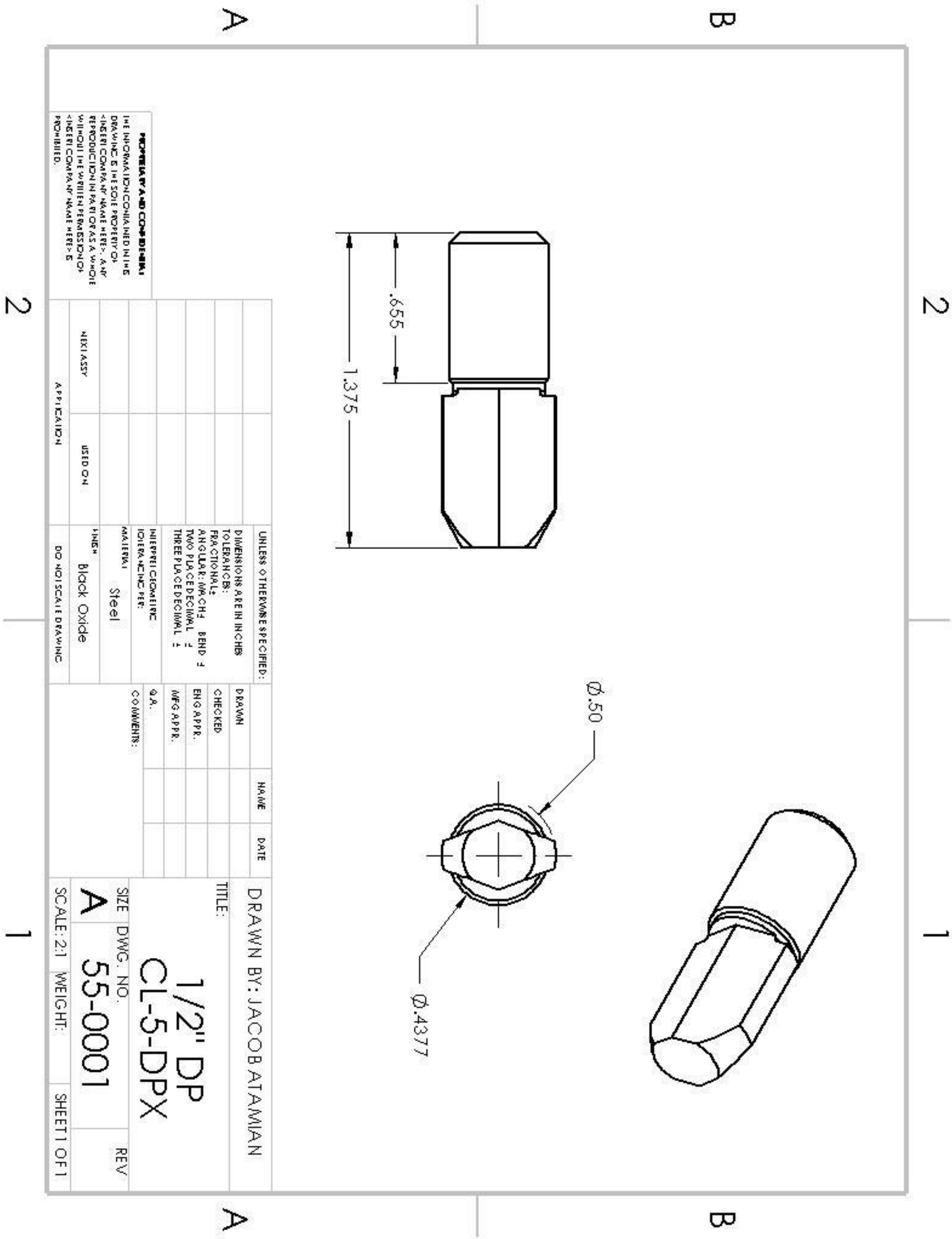
Appendix B34 – 50-016



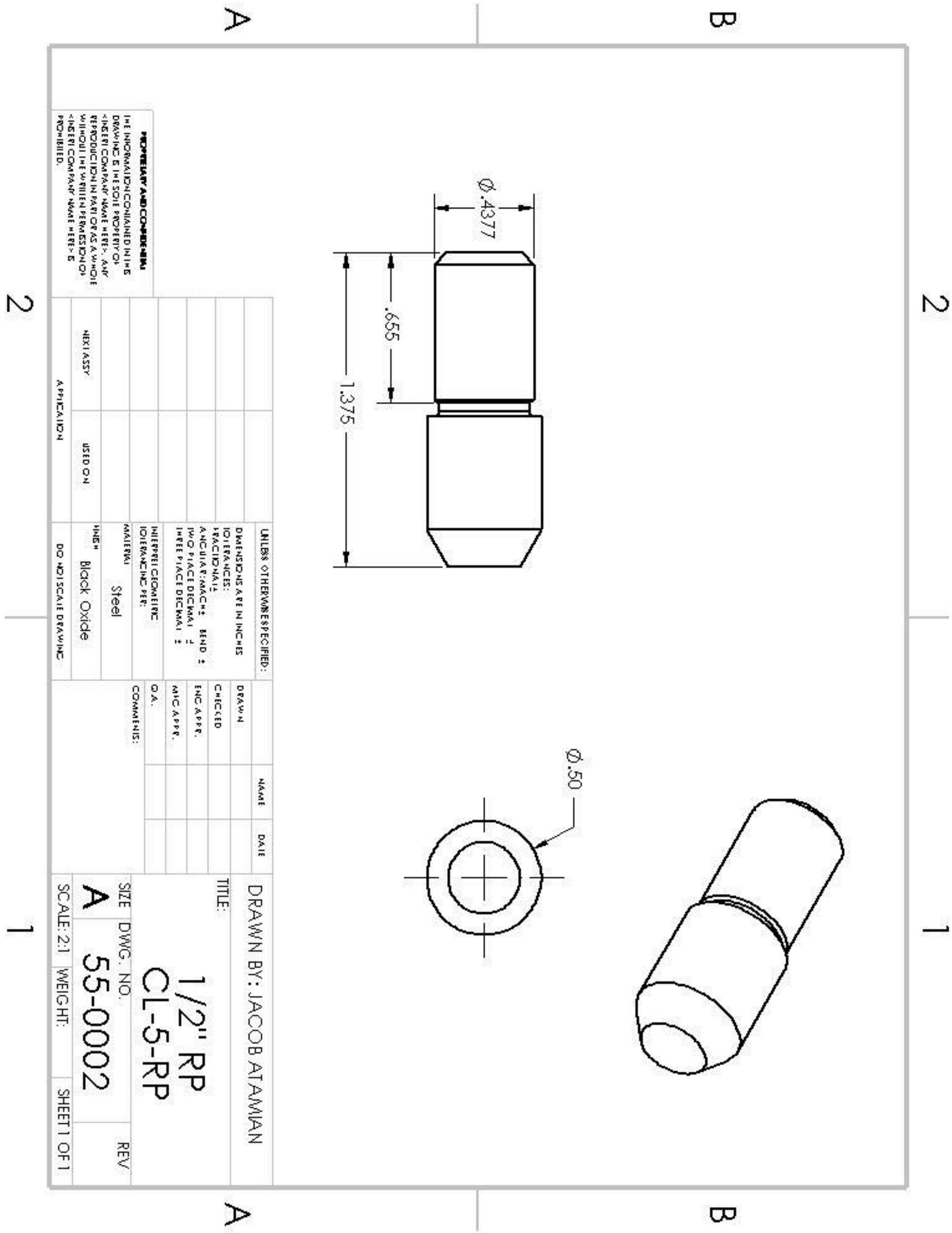
Appendix B35 – 50-017



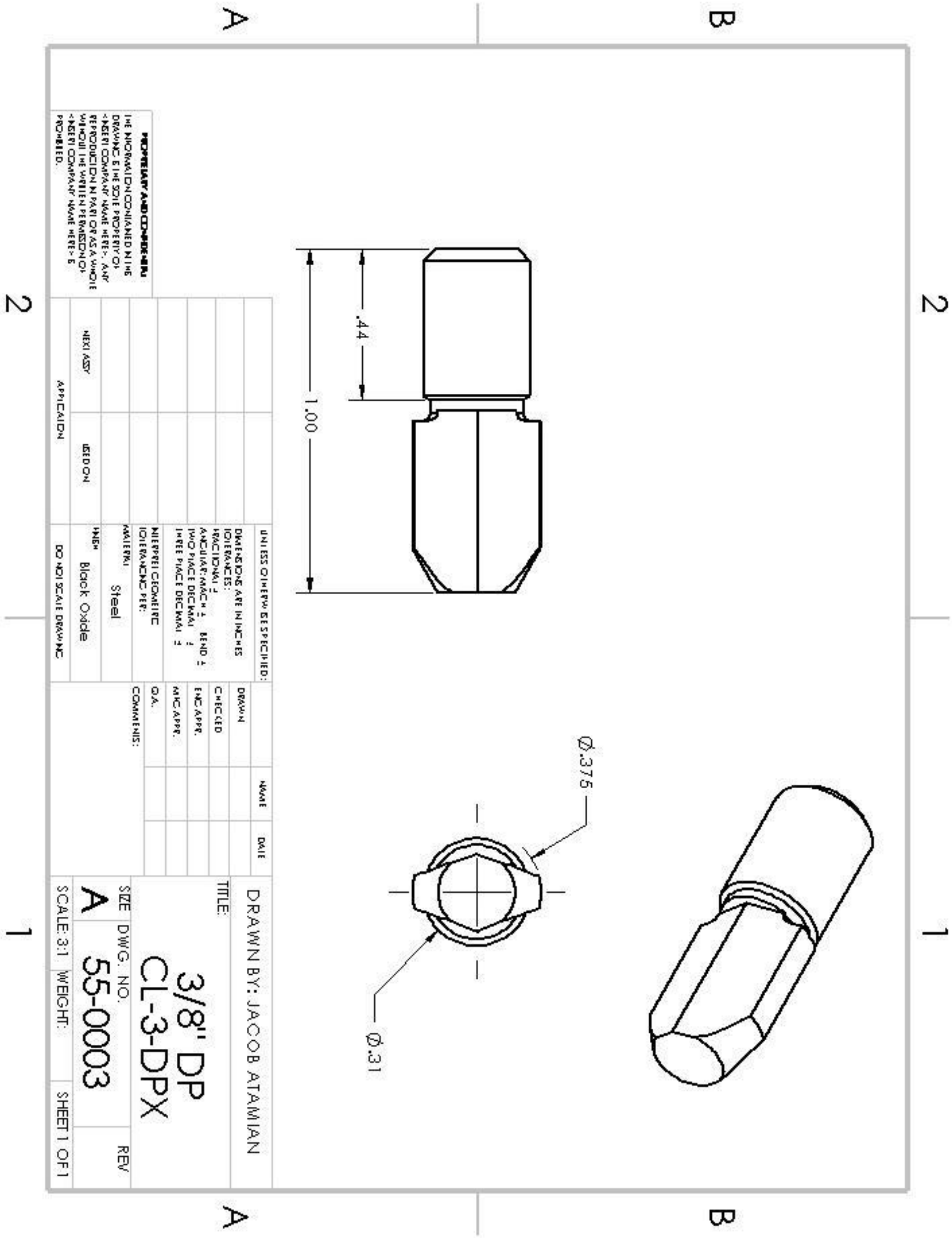
Appendix B36 – 55-001



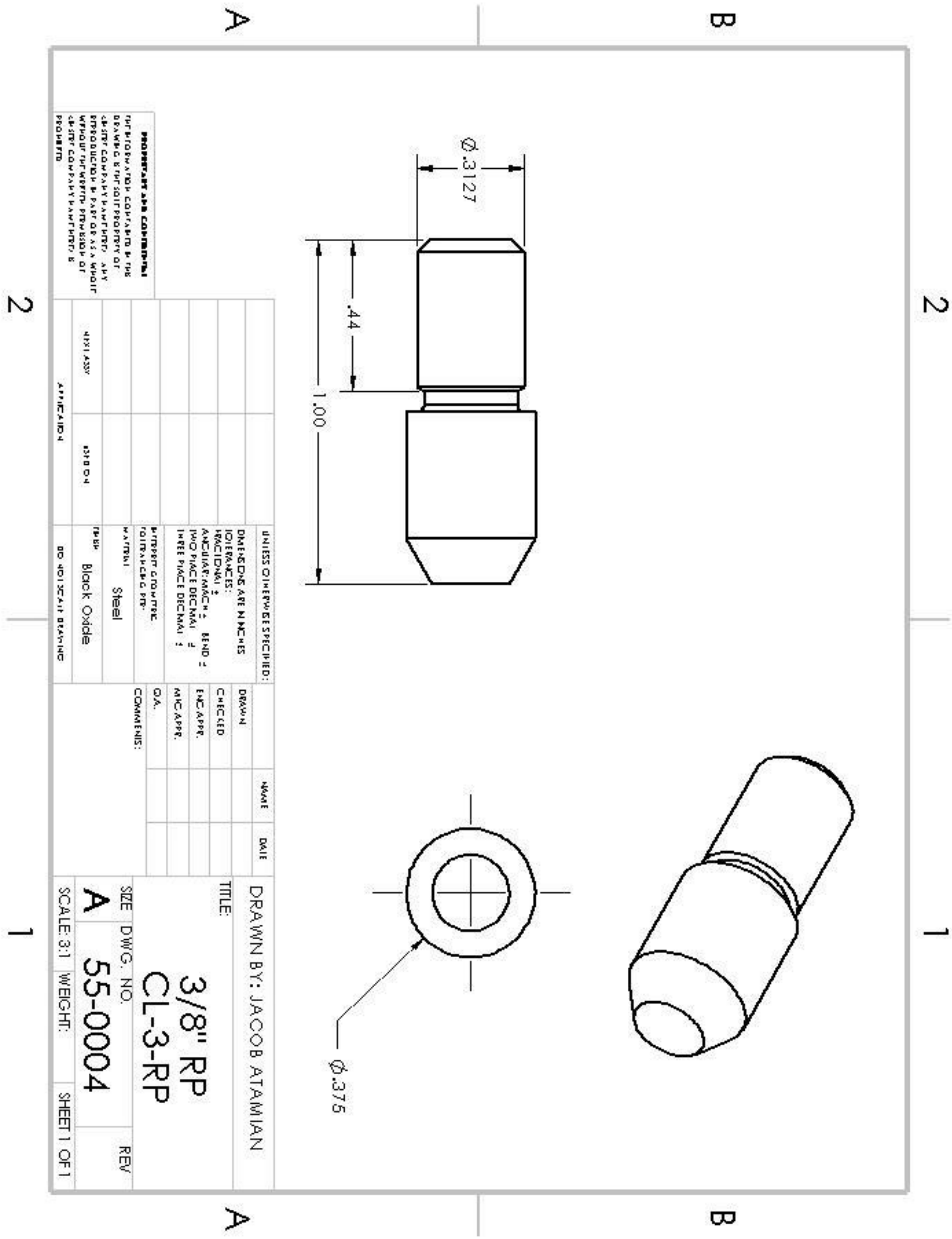
Appendix B37 – 55-002 (OBSOLETE)



Appendix B38 – 55-003



Appendix B39 – 55-004 (OBSOLETE)



APPENDIX C – Parts List and Costs

Appendix C - Parts List

Part Number	Qty	Part Description	Source	Cost	Disposition
20-001	1	Base Plate	OBSOLETE	OBSOLETE	OBSOLETE
20-002	1	Base Plate (Redesign)	Haskins Steel	$308	2/15/21
20-003	2	Motor Base Plate	Metalsdepot.com	OBSOLETE	OBSOLETE
20-004	1	Truss AB	Metalsdepot.com	$7.53	2/8/21
20-005	1	Truss AC	Metalsdepot.com	$7.53	2/8/21
20-006	2	Top Mount AC	Metalsdepot.com		2/8/21
20-007	1	Base Left AB	Metalsdepot.com		2/8/21
20-008	1	Base Right AB	Metalsdepot.com		2/8/21
20-009	1	Base Left AC	Metalsdepot.com		2/8/21
20-010	1	Base Right AC	Metalsdepot.com	$6.86	2/8/21
20-011	2	Housing Spacer	Metalsdepot.com	$74.30	2/8/21
20-012	1	Modified Table	N/A	N/A	N/A
20-013	1	Gearbox Spacer (Output)	N/A	N/A	N/A
20-014	1	Gearbox Spacer (Input)	N/A	N/A	N/A
50-001	3	¼-20 UNC 1.5” Bolt	McMaster-Carr	$1.17	2/6/21
50-002	9	¼” Hex Nut			2/6/21
50-003	9	¼” Washer			2/6/21
50-004	4	¼-20, 2 ¼ long, Partially Threaded	Fastenal	$2.28	2/6/21
50-005	2	¼-20, 1 3/8 Long, Partially Threaded	Fastenal	$1.16	2/6/21
50-006	14	3/8” Washer	Fastenal	$7.56	2/6/21
50-007	14	3/8”-16 Hex Nut	Fastenal	$4.76	2/6/21
50-008	15	½” Washer	Fastenal	$4.65	2/6/21
50-009	15	½”-20 Hex Nut	Fastenal	$13.20	2/6/21
50-010	9	1/2"-20, 4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$60.21	2/6/21
50-011	1	1/2"-20, 5 1/2" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$4.58	3/12/21
50-012	1	1/2"-20, 9" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$21.24	3/12/21
50-013	2	1/2"-20, 4 3/4" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$7.78	2/6/21

50-014	1	1/2"-20, 2 1/4" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$8.40	2/6/21
50-015	8	3/8"-16, 1" Long, Hex Bolt Screw	Fastenal	$5.28	2/6/21
50-016	3	½”-20, 4 3/4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$17.52	3/12/21
50-017	2	½”-20, 2 1/4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$3.84	3/12/21
55-001	6	½” Diamond Pin	Carrlane.com	$44.58	2/8/21
55-002	3	½” Round Pin	Carrlane.com	VOID	VOID
55-003	2	3/8” Diamond Pin	Carrlane.com	$10.76	2/8/21
55-004	1	3/8” Round Pin	Carrlane.com	VOID	VOID

APPENDIX D – Budget

Appendix D - Project Budget

Item	Qty	Description	Source	Cost
1	1	¾” THICK A36 HR Steel Plate – 26”x 36”	Haskins Steel	$308
2	2	½” THICK A36 Steel Plate – 3”x 13 1/2”	Metalsdepot.com	$74.30
3	2	1/2 X 1/2 X 18 GA (.049 wall) A513 Square Steel Tube (Length 2’6”)	Metalsdepot.com	$15.06
4	1	1 ½” x 1 ½” x ¼” Angle Iron	Metalsdepot.com	$6.86
5	6	½” Diamond Pin	Carrlane.com	$44.58
6	3	½” Round Pin	Carrlane.com	VOID
7	2	3/8” Diamond Pin	Carrlane.com	$10.76
8	1	3/8” Round Pin	Carrlane.com	VOID
9	3	¼”-20, 1 ½” Long, Partially Threaded Bolt	Fastenal	$1.17
10	4	¼”-20, 2 ¼” Long, Partially Threaded Bolt	Fastenal	$2.28
11	2	¼”-20, 1 3/8” Long, Partially Threaded Bolt	Fastenal	$1.16
12	14	3/8” Washer	Fastenal	$7.56
13	14	3/8”-16 Hex Nut	Fastenal	$4.76
14	15	½” Washer	Fastenal	$4.65
15	15	½”-20 Hex Nut	Fastenal	$13.20
16	9	1/2"-20, 4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$60.21
17	1	1/2"-20, 5 1/2" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$4.58
18	1	1/2"-20, 9" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$21.24
19	2	1/2"-20, 4 3/4" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$7.78
20	1	1/2"-20, 2 1/4" Long, Partially Threaded Hex Bolt Screw	McMaster-Carr	$8.40
21	8	3/8"-16, 1" Long, Hex Bolt Screw	Fastenal	$5.24
22	4	3/8"-16, 4 3/4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$13.44
23	2	3/8"-16, 2 1/4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$2.72
24	3	1/2"-20, 4 3/4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$4.08
25	1	1/2"-20, 2 1/4" Long, Partially Threaded Hex Bolt Screw	Fastenal	$1.12
		Budget: $1250	Total	$622.21

Appendix E: Schedule

Schedule for Senior Project:

PROJECT TITLE: JCATI Gearbox Frame
Principal Investigator.: Jacob Atamian

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)
1	Proposal*		
1a	Outline	1	1
1b	Intro	1	2
1c	Methods	2	5.5
1d	Analysis	10	5
1e	Discussion	1	0.5
1f	Parts and Budget	5	3.5
1g	Drawings	8	17.25
1h	Testing	3	1.25
1i	Schedule	2	2.75
1j	Summary & Appx	2	3
	subtotal:	35	41.75
2	Analyses		
2a	Housing Movements	2	1.5
2b	Plate Dimensions	2	1
2c	Flat Plate Analysis 1	2	5.5
2d	Crushing Load in Plate Area	2	2
2e	Axial Load in Truss Members	2	3
2f	Flat Plate Analysis 2	2	5
2g	Buckling of Truss Members	2	2
2h	Vertical Shear at Bolts	2	1
2i	Truss Geometry	2	1.5
2j	Locating Pins	2	0.75
2k	FEA: Base Plate	4	4.5
2l	Measurements of Existing Parts	2	2
2m	FEA: Side Plate	4	4
	subtotal:	30	33.75
3	Documentation		
3a	Modified Parts	2	2
3b	Base Plate	3	4
3c	Subassembly 10-002	1	1
3d	Subassembly 10-003	1	2
3e	Final Assembly 10-004	2	1
3f	Kinematic Check	1	0.5
3g	ANSIY14.5 Compl	20	19
	subtotal:	30	29.5
7	Part Construction		
7a	Buy Part Fasteners/Pins	0.5	0.75
7b	Buy Part Material	0.5	0.25
7c	Make Part 20-002	8	15
7d	Make Part 20-011	1	1.5
7e	Make Part 20-012	6	4
7f	Make Part 20-013	2	5.5
7g	Make Part 20-014	2	5.5
7h	Take Part Pictures	1	1
7i	Update Website	4	2.5
7j	Manufacture Plan*	1	1
	subtotal:	26	37
9	Device Construct		
9a	Assemble 10-002	2	4
9b	Assemble 10-003	2	1.5
9c	Assemble 10-004	6	5.5
9d	Take Dev Pictures	0.5	0.5
9e	Update Website	2	1.5
	subtotal:	12.5	13
10	Device Evaluation		
10a	List Parameters	0.5	0.5
10b	Test Report	7	10
10c	Obtain resources	0.25	0.25
10d	Make test sheets	0.5	0.75
10e	Plan analyses	0.25	0.25
10f	Update Test Section	2	1.5
10g	Test Plan*	1	0.5
10h	Perform Evaluation	6	14.25
10i	Take Testing Pics	1	1.25
10j	Update Website	6	5.75
	subtotal:	24.5	35
11	489 Deliverables		
11a	Final Proposal	2	0
11b	Make Slide Outline	2	1
11c	Create Presentation	6	3
11d	Make Drive Deli. List	0	0
11e	Write 495 Drive parts	6	4.5
11f	Project Drive	1	0
	subtotal:	17	8.5
	Total Est. Hours=	175	198.5
Labor$	100	17500	
Note:	Deliverables*		
	Draft Proposal		
	Analyses Mod		
	Document Mods		
	Part Construction		
	Device Construct		
	Device Evaluation		
	495 Deliverables / Final Proposal		

APPENDIX F – Expertise and Resources

Appendix F1 – Decision Matrix

Criterion	Weight 1 to 3	Best Possible 3	Design #1 G3 & Crushing Housing	Score x Wt	Design #2 G3, Crushing, Shredder	Score x Wt	Design #3 All Components	Score x Wt	
Cost	1	3	1	1	2	2	2	2	
Weight	1	3	1	1	3	3	2	2	
Prediction precision	3	9	1	3	2	6	3	9	
Confidence -failure loc	2	6	1	2	2	4	3	6	
Prismatic vs non prismatic	3	9	1	3	3	9	3	9	
Manufacture Methods	3	9	1	3	1	3	3	9	
Total	13	39		13		27		37	
NORMALIZE THE DATA (muliply by fraction, N)		2.56		33.33		69.23		94.87	Percent
								65.81	Average
							GOOD BIAS	30.91	Std Dev.

Weighting/Scoring Scale

1 Worst (too costly, low confidence, too big, etc.)
2 Median Values, or Unsure of actual value
3 Best (Low Cost, high confidence, etc.)

Criterion

Criterion	Description
Cost	More mass is more cost
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacture Methods	Is the design easily able to be manfucatured or is the design too complex

Comments:

Design #1 never got anywhere with analysis therefore it was scored all at 1. It helped lead to ideas for Designs 2 and 3.
Design #2 scored 2 in the failure location and calculations portion because the design did not get as far as Design 3.
The low score of 1 for manufacturing methods is the main reason why Design 3 was necessary.
Design #3 scored high due to a high confidence in the function and calculations. The manufacturing methods have been sorted to be the most efficient way to complete this project.

APPENDIX G – Testing Report

Testing Report 01

Introduction

The parameter of interest for this test was the plate deflection produced by the crushing force of 10,500 lbs. This test used partially delaminated carbon fiber composite of a 0.25-inch thickness. Testing the deflection of the crushing housing side wall and base plate during delamination indicated passing of the following requirements:

- Maximum deflection of the crushing wheels and components was 0.005 inches.
- Plates need to withstand a crushing force of 10,500 lbs.
- Plates need to hold crushing wheels operating at 2.5 rpm.
- Feed rate of carbon fiber operating at 1 foot per minute.

The areas of interest were underneath the crushing housing, the front and back of the input crushing housing side wall, and the top and bottom shafts the crushing wheels rotate on. It was predicted that the base plate would deflect 0.004 inches and the side wall would deflect less than 0.001 inches. Deflection data was collected using dial indicators. The Gannt Chart for the testing schedule can be referred to in Appendix G4.

Method/Approach

Data for the test was collected and organized into an excel spreadsheet that would later be transferred to a table in the Project Report Word document. Each test required the dial indicator to be placed at a specific location. Deflections were recorded manually driving the gears and running partially delaminated carbon fiber through the wheels. The table organized data at each testing location by actual deflection, predicted deflection, and the direction of deflection in relation to the crushing wheels. Operational limitations included the amount of driving force that could be produced by the operator. Before each test, the dial indicators were set to a zero for accurate reading of deflection and indicated direction. As deflection occurred, the indicator moved to a maximum value before losing initial zero. That maximum value was recorded and logged into the data table. Project partners were required to help with operation of the recycling system and recording of deflection data. The tools required for testing are referred to in the testing procedure.

Testing Procedure

Summary

This procedure documents the process of measuring plate deflections caused by the crushing force produced from running partially delaminated carbon fiber composite strips through the crushing wheels. The plate was designed to increase the rigidity of the crushing wheels so that deflections greater than 0.005 inches would not occur during operation. The carbon fiber material used to conduct testing originates from excess Boeing 737 aircraft wing trimmings. The following is the test information and procedure.

Time: The tests were conducted April 7th through 9th ,2021 from 8:00 am to 10:00 am in Hogue 127. The first half hour of testing included collection of test materials and set up. Each of the test locations took

45 minutes to complete. After each test, the recorded deflection measurements were documented. Clean up was estimated at 20 minutes.

Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required Equipment:

- Magnetic/Non-Magnetic Base
- Dial Indicator
- C-Clamp
- Data Sheet
- Crushing Mechanism
- Carbon Fiber Composite Strips

Risk: The chain guard from Gearbox 2 to the Crushing Housing was removed for accurate testing locations. Because the system was not operating at high speed, it was determined to be safe enough of an operation. Risk of injury to testing participants would occur if unguarded chains were to break during operation. Safety glasses were required for the testing operation.

Procedure

1) Collect Recording Equipment:
    a) C-Clamp
    b) Magnet Base
    c) Dial Indicator

Figure 5: Measurement Devices

2) Go to Hogue 127 where the Recycler is in the back left corner of the room.
3) Fasten the dial indicator to the arm of magnetic base. Refer to Figure 2.

Figure 6: Device Construction

4) Set up the magnetic base to the bottom of the table arm. 13 inches up and 10 inches to the left from the bottom left corner of the table. Figures 3 and 4 represent the location.

Figure 7: Distance From Long Edge

Figure 8: Distance From Corner

5) Adjust the position of the arm so that the tip of the dial indicator will be pressed against the base of the plate. The dial should be pressured a full revolution from its initial position at 0.0 inches. Data recorded from this position will tell the magnitude and direction of plate deflection. Refer to Figure 5.

Figure 9: Zero Indicator

6) Clamp the base of the indicator to the table to ensure a secure location as shown in Figure 6.

Figure 10: Clamp From Underneath

7) Get a good view of the dial indicator.
8) Have another person manually operate the recycling system with the driving wheel turning counterclockwise, as in Figure 7, while watching the deflection indicator.

Figure 11: Manual Driver

9) Feed the partially delaminated carbon composite through the front of the crushing housing as is shown in Figure 8.

Figure 12: Patrially Delaminated Input

10) Document deflection results on test sheet. Turn the driving wheel clockwise to feed the carbon fiber out of the crushing wheels and set up the next test location.
11) Change the location of the dial indicator to the front of the side wall housing. Set the magnetic base to the side of the supporting table as shown in Figure 9.

Figure 13: Magnet Position

12) Set the indicator tip in line with the central axis of the bottom shaft. Figure 10.

Figure 14: SW Bottom Front

13) Repeat Steps 5-10.
14) Reset the dial indicator as in Step 12, but in line with the top shaft as in Figure 11.

Figure 15: SW Top Front

15) Repeat Steps 5-10.
16) Change the location of the magnetic base to the back (exit) of the crusher side wall.
17) Set the indicator to the same location as in Steps 12, instead this time on the back of the housing as in Figure 12.

Figure 16: SW Bottom Back

18) Run Steps 5-10.
19) Set the indicator to the top shaft as in Step 14, instead this time on the back of the housing. Refer to Figure 13.

Figure 17: SW Top Back

20) Run steps 5-10. Record the data in the table and clean up.

Discussion

Deflection from the base plate produced a predictable value under 0.004 inches. This was because the calculations for the analysis were based on the crushing force of the full carbon fiber composite at a thickness of 0.5 inches, not partially delaminated at 0.25 inches. The side plate produced deflections higher than predicted. There were some challenges in setting the dial indicator to maintain its zero for accurate deflection readings. The testing device needed to have all components fastened tightly to operate successfully.

Deliverables

The calculated parameters for the test were that the base plate would not deflect more than 0.004 inches and the side plate no more than 0.001 inches. Feeding partially delaminated composite through the wheels produced a deflection of 0.002 inches downwards from the base plate, and an average deflection of 0.006 inches. The system meets the criteria of crushing 0.25-inch-thick carbon fiber composite through manual operation. The system failed to reduce deflection in the side plates to less than 0.001 inches and succeeded in reducing the deflection downwards to below 0.005 inches.

Testing Report 02

Introduction

The parameter of interest for this test was the plate deflection produced by the crushing force of 10,500 lbs. This test used a full carbon fiber composite strip at a 0.5-inch thickness. Testing the deflection of the crushing housing side wall and base plate during delamination indicated pass or fail of the following requirements:

- Maximum deflection of the crushing wheels and components is 0.005 inches.
- Plates need to withstand a crushing force of 10,500 lbs.
- Plates need to hold crushing wheels operating at 2.5 rpm.
- Feed rate of carbon fiber operating at 1 foot per minute.

The areas of interest were underneath the crushing housing, the front and back of the drive input crushing housing side wall, and the top and bottom shafts the crushing wheels rotate on. It was predicted that the base plate would deflect 0.004 inches and the side wall would deflect less than 0.001 inches. Deflection data was collected using dial indicators. The Gannt Chart for the testing schedule can be referred to in Appendix G4.

Method/Approach

Data for the test was collected and organized into an excel spreadsheet that would later be transferred to a table in the Project Report Word document. Each test required the dial indicator to be placed at a specific location. Deflections were recorded manually driving the gears and running full composite carbon fiber through the wheels. The table organized data at each testing location by actual deflection, predicted deflection, and the direction of deflection in relation to the crushing wheels. Operational limitations included the amount of driving force that could be produced by the operator. Before each test, the dial indicators were set to a zero for accurate reading of deflection and indicated direction. As deflection occurred, the indicator moved to a maximum value before losing initial zero. That maximum value was recorded and logged into the data table. Project partners were required to help with operation of the recycling system and recording of deflection data. The tools required for testing are referred to in the testing procedure.

Testing Procedure

Summary

This procedure documents the process of measuring plate deflections caused by the crushing force produced from running carbon fiber composite strips through the crushing wheels. The plate was designed to increase the rigidity of the crushing wheels so that deflections greater than 0.005 inches would not occur during operation. The carbon fiber material used to conduct testing originates from excess Boeing 737 aircraft wing trimmings. The following is the test information and procedure.

Time: The tests were conducted April 12th through 15th ,2021 from 8:00 am to 10:00 am in Hogue 127. The first half hour of testing included collection of test materials and set up. Each of the testing locations took an hour to record data. After each test, the recorded deflection measurements were documented. Clean up was estimated at 20 minutes.

Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required Equipment:

- Magnetic/Non-Magnetic Base
- Dial Indicator
- C-Clamp
- Data Sheet
- Crushing Mechanism
- 1/2” Carbon Fiber Composite Strips

Risk: The chain guard from Gearbox 2 to the Crushing Housing was removed for accurate testing locations. Because the system was not operating at high speed, it was determined to be safe enough of an operation. Risk of injury to testing participants would occur if unguarded chains were to break during operation. Safety glasses were required for the testing operation.

Procedure

1) Collect Recording Equipment:
   a) C-Clamp
   b) Magnet Base
   c) Dial Indicator

Figure 18: Required Equipment

2) Go to Hogue 127 where the Recycler is in the back left corner of the room.

3) Fasten the dial indicator to the arm of magnetic base. Refer to Figure 15.

Figure 19: Clamp Device

4) Set up the magnetic base to the bottom of the table arm. 13 inches up and 10 inches to the left from the bottom left corner of the table. Figures 16 and 17 represent the location.

Figure 20: Distance From Long Edge

Figure 21: Distance From Corner

5) Adjust the position of the arm so that the tip of the dial indicator will be pressed against the base of the plate. The dial should be pressured a full revolution from its initial position at 0.0 inches. Data recorded from this position will tell the magnitude and direction of plate deflection. Refer to Figure 18.

Figure 22: Zero Indicator

6) Clamp the base of the indicator to the table to ensure a secure location as shown in Figure 19.

Figure 23: Clamp From Underneath

7) Get a good view of the dial indicator.
8) Have another person manually operate the recycling system with the driving wheel turning counterclockwise, as in Figure 20, while watching the deflection indicator.

Figure 24: Manual Driver

9) Feed the full composite carbon composite through the front of the crushing housing as is shown in Figure 21.

Figure 25: Carbon Input

10) Document deflection results on test sheet. Turn the driving wheel clockwise to feed the carbon fiber out of the crushing wheels and set up the next test location.
11) Change the location of the dial indicator to the front of the side wall housing. Set the magnetic base to the side of the supporting table as shown in Figure 22.

Figure 26: Magnet Position

12) Set the indicator tip in line with the central axis of the bottom shaft. Figure 23.

Figure 27: SW Bottom Front

13) Repeat Steps 5-10.
14) Reset the dial indicator as in Step 12, but in line with the top shaft as in Figure 24.

Figure 28: SW Top Front

15) Repeat Steps 5-10.
16) Change the location of the magnetic base to the back (exit) of the crusher side wall.
17) Set the indicator to the same location as in Steps 12, instead this time on the back of the housing as in Figure 25.

Figure 29: SW Bottom Back

18) Run Steps 5-10.
19) Set the indicator to the top shaft as in Step 14, instead this time on the back of the housing. Refer to Figure 26.

Figure 30: SW Top Back

20) Run steps 5-10. Record the data in the table and clean up.

Discussion

Testing the recycling system with full carbon fiber composite was a half success. The base plate produced the predicted deflection of 0.004 inches. However, the side plate produced a large amount of deflection significantly over the requirement for maximum deflection. During testing, the crushing force was noticed to be significantly higher than that of the first test. The manual operator driving the system could feel the resistance of the gears. This was noted for the motor test to not operate at high speeds, otherwise this would cause components in the system to break.

Deliverables

The calculated parameters for the test were that the base plate would not deflect more than 0.004 inches and the side plate no more than 0.001 inches. Feeding full composite carbon fiber through the wheels produced a deflection of 0.004 inches downwards from the base plate, and an average deflection of 0.025 inches. The system meets the criteria of crushing 0.5-inch-thick carbon fiber composite through manual operation. The system failed to reduce deflection in the side plates to less than 0.001 inches. It was predicted that this portion of the test would fail based on the results from Test 1. The base plate was successful producing a predicted deflection of 0.004 inches within the requirement of maximum deflection at 0.005 inches.

Testing Report 03

Introduction

The parameter of interest for this test was the plate deflection produced by the crushing force of 10,500 lbs. This test used a partially delaminated carbon fiber composite strip at a 0.25-inch thickness. Testing the deflection of the crushing housing side wall and base plate during delamination indicated pass or fail of the following requirements:

- Maximum deflection of the crushing wheels and components is 0.005 inches.
- Plates need to withstand a crushing force of 10,500 lbs.
- Plates need to hold crushing wheels operating at 2.5 rpm.
- Feed rate of carbon fiber operating at 1 foot per minute.

The areas of interest were underneath the crushing housing, the front and back of the drive input crushing housing side wall, and the top and bottom shafts the crushing wheels rotate on. It was predicted that the base plate would deflect 0.004 inches and the side wall would deflect less than 0.001 inches. Another area of interest was at what speed the crushing wheels could operate. Deflection data was collected using dial indicators. The Gannt Chart for the testing schedule can be referred to in Appendix G4.

Methods/Approach

Three people were needed to conduct the motor test. One person was needed to monitor deflection, one to feed composite, and the other to standby the emergency stop. The motor input rpm needed to be adjusted to a desired crushing wheel speed of 2 rpm. This was achieved using a PowerFlex 523 VFD. Operation was limited to a maximum output speed of 2 rpm. Testing was also limited to crushing partially delaminated carbon fiber composite. Deflection testing was limited to underneath the crushing housing and to the top of the crushing side wall. This was due to the interference of the chainguard required for motor operation. Dial indicators were used to measure deflection to every 0.0005 inches and a tachometer to measure the output rpm of the crushing wheels. Data was collected and stored into a table in the report document.

Testing Procedure

Summary

This procedure documents the process of measuring plate deflections caused by the crushing force produced from running carbon fiber composite strips through the crushing wheels. It also documents the speed of the crushing wheels and the thickness of the composite strip allowed for recycle. The plate was designed to increase the rigidity of the crushing wheels so that deflections greater than 0.005 inches would not occur during operation. The carbon fiber material used to conduct testing originates from excess Boeing 737 aircraft wing trimmings. The following is the test information and procedure.

Time: The tests were conducted April 30th, 2021 from 8:00 am to 11:00 am in Hogue 127. The first half hour of testing included collection of test materials and set up. Each of the testing locations took an hour to record data. After each test, the recorded deflection measurements were documented. Clean up was estimated at 20 minutes.

Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required Equipment:

- Magnetic/Non-Magnetic Base
- Dial Indicator
- C-Clamp
- Data Sheet
- Crushing Mechanism
- 1/4” Carbon Fiber Composite Strips
- Motor connected to VFD
- Digital Tachometer

Risk: The motor was operating at a higher speed than the manual test. Risk of injury to testing participants would occur if unguarded chains were to break during operation. Incase components were to break; an operator was stationed at the breaker to emergency stop the system. Safety glasses were required for the testing operation.

Procedure

1) Collect Recording Equipment:
   a) C-Clamp
   b) Magnet Base
   c) Dial Indicator

Figure 27: Required Equipment

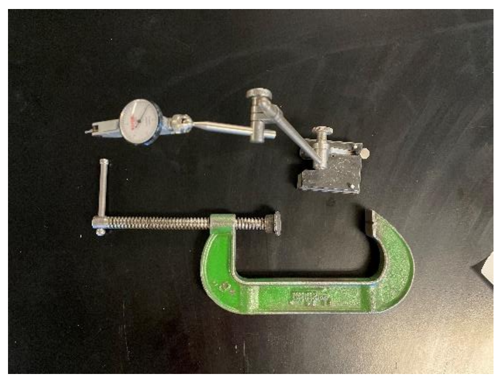


Figure 28: Required Equipment

2) Go to Hogue 127 where the Recycler is in the back left corner of the room.

3) Fasten the dial indicator to the arm of magnetic base. Refer to Figure 29.

Figure 31: Clamp Device

4) Set up the magnetic base to the bottom of the table arm. 13 inches up and 10 inches to the left from the bottom left corner of the table. Figures 30 and 31 represent the location.

Figure 32: Location From Long Edge

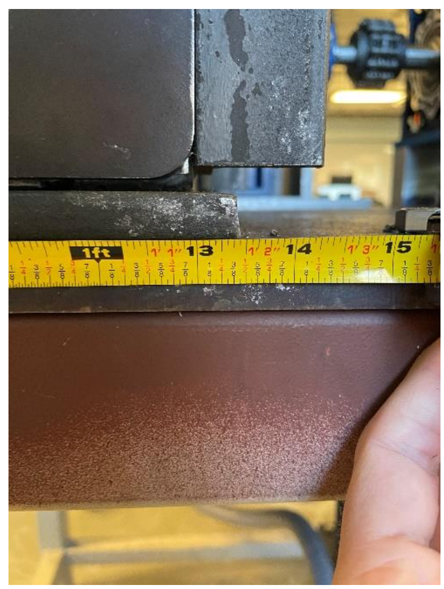


Figure 33: Location From Corner Edge

5) Adjust the position of the arm so that the tip of the dial indicator will be pressed against the base of the plate. The dial should be pressured a full revolution from its initial position at 0.0 inches. Data recorded from this position will tell the magnitude and direction of plate deflection. Refer to Figure 32.

Figure 34: Zero Indicator

6) Clamp the base of the indicator to the table to ensure a secure location as shown in Figure 33.

Figure 35: Clamp From Underneath

7) Set the second dial indicator base to the top of the shredder housing as in Figure 34. Use a c-clamp to secure the base as in Figure 35.

Figure 34: Location For Top Side Wall

Figure 35: Clamp to Shredder

8) Adjust the arm so that the tip of the indicator is touching the top of the side wall. Adjust the arm angle using the drive screw at the base of the indicator until the indicator is at zero. Refer to Figures 36 and 37.

Figure 36: Adjustable Arm Screw

Figure 37: Zero Indicator

9) Supply power to the VFD through the breaker.

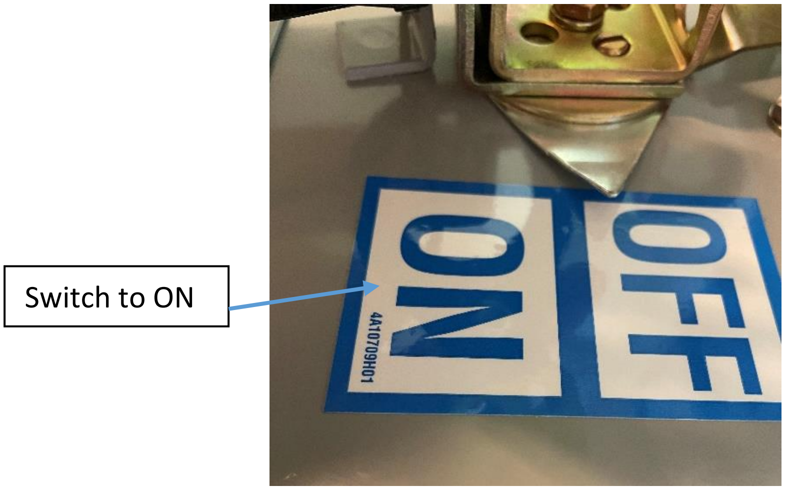


Figure 38: Power Switch

10) Turn on the VFD pressing the green button. Make sure the potentiometer is set to zero. Refer to Figure 39.

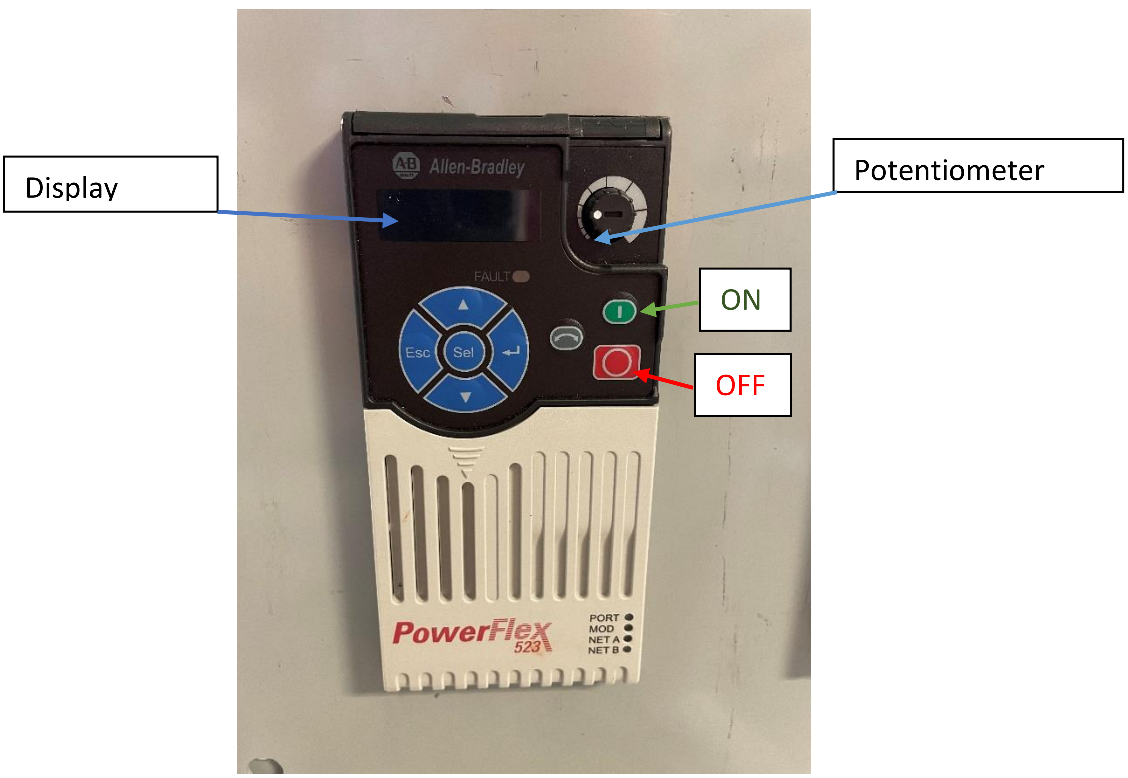


Figure 39: VFD Display

11) Adjust the potentiometer to a desired rpm read from the display screen. Refer to Figure 39.

12) Read the rpm using the digital tachometer. Turn the device on and place the tip on the top crushing wheel shaft as in Figure 40. Read the rpm. If the speed is not to a desired value, adjust the potentiometer and take another reading until the output reads 2 rpm.

Figure 40: Potentiometer

13) Make sure someone is standing by the emergency stop, Figure 41, incase the system needs to be stopped.

Figure 41: Emergency Stop

14) Run partially delaminated carbon fiber composite through the crushing wheels. Have observers at the two deflection locations. Record data.

15) Once process is complete, turn the VFD off pressing the red button, refer to Figure 39, and clean up testing materials.

Discussion

There were several issues with this test. Setting the rpm was the first issue. According to former project members, the input rpm should have been 1750. Setting the potentiometer to this input was driving the crushing wheels around 7 rpm which was too fast. The potentiometer was set to 189 rpm for a crushing speed of 0.5 rpm (feed rate 1 foot per minute). The next issue was that the composite thickness of the full composite was too thick. Running the composite through the wheels at this speed caused major flexing in the components and would have led to breaking the spur gears. This was a result from the crushing wheels not sitting tightly on the drive shafts and the slack in the drive chain causing a jolt in the wheels. To work around this issue, a quarter inch partially delaminated composite was used for testing.

Deliverables

The table includes the rpm setting of the potentiometer, the amount of deflection, and the direction of deflection for the two testing points. Testing produced the same base plate deflection of 0.002 inches, found in the manual test. The indicator on the top of the side wall deflected 0.003 inches upwards compared to its predicted deflection less than 0.001 inches. The system was not successful in crushing 0.5-inch-thick full composite carbon fiber at a crushing wheel speed of 2.5 rpm.

Appendix G1 - Testing Report 01

Appendix G1.1 – Procedure Checklist

Procedure Checklist 1	
Full Assembly	x
Testing Device Ready	x
Partially Delaminated Carbon Fiber Strip	x
Two Operators	x

Appendix G1.2 – Data Form

Manually Driven Test			
Partially Delaminated			
Location	Actual (in)	Predicted (in)	Direction
Underneath Housing			
SW (Top Shaft Back)			
SW (Top Shaft Front)			
SW (Bottom Shaft Back)			
SW (Bottom Front)			
*Directions of deflection are in relation to the location of the crushing wheels			

Appendix G1.3 – Raw Data

Manually Driven Test			
Partially Delaminated			
Location	Actual (in)	Predicted (in)	Direction
Underneath Housing	0.002	0.004	Downwards
SW (Top Shaft Back)	0.005	< 0.001	Out
SW (Top Shaft Front)	0.005	< 0.001	Out
SW (Bottom Shaft Back)	0.007	< 0.001	Out
SW (Bottom Shaft Front)	0.005	< 0.001	Out
*Directions of deflection are in relation to the location of the crushing wheels			

Appendix G2 – Testing Report 02

Appendix G2.1 – Procedure Checklist

Procedure Checklist 1	
Full Assembly	x
Testing Device Ready	x
Full Carbon Fiber Composite Strip	x
Two Operators	x

Appendix G2.2 – Data Form

Manually Driven Test			
Full Composite			
Location	**Actual (in)**	**Predicted (in)**	**Direction**
Underneath Housing			
SW (Upper Back)			
SW (Upper Front			
SW (Lower Back)			
SW (Lower Front)			
***Directions of deflection are in relation to the location of the crushing wheels**			

Appendix G2.3 – Raw Data

Manually Driven Test			
Full Composite			
Location	**Actual (in)**	**Predicted (in)**	**Direction**
Underneath Housing	0.004	0.004	Downwards
SW (Upper Back)	0.019	< 0.001	Out
SW (Upper Front	0.030	< 0.001	Out
SW (Lower Back)	0.019	< 0.001	Out
SW (Lower Front)	0.030	< 0.001	Out
***Directions of deflection are in relation to the location of the crushing wheels**			

Appendix G3 – Testing Report 03

Appendix G3.1 – Procedure Checklist

Procedure Checklist	
Full Assembly	x
Motor (connected to power source)	x
Programmed Variable Frequency Drive (PowerFlex 523)	x
Partially Delaminated Carbon Fiber Composite	x
Two Dial Indicators	x
Tachometer	x
Three Operators	x

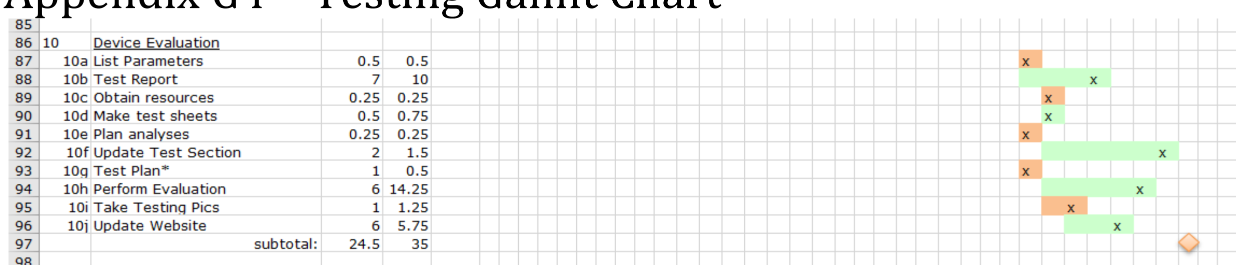
Appendix G3.2 – Data Form

Motor Driven Test					
Location	Composite Thickness (in)	Motor RPM	Actual (in)	Predicted (in)	Direction
Underneath Housing					
SW (Top Back)					
***Directions of deflection are in relation to the location of the crushing wheels**					

Appendix G3.3 – Raw Data

Motor Driven Test					
Location	Composite Thickness (in)	Motor RPM	Actual (in)	Predicted (in)	Direction
Underneath Housing	0.25	189	0.002	0.004	Downwards
SW (Top Back)	0.25	189	0.003	<0.001	Upwards
***Directions of deflection are in relation to the location of the crushing wheels**					

Appendix G4 – Testing Gannt Chart



85				
86	10	Device Evaluation		
87	10a	List Parameters	0.5	0.5
88	10b	Test Report	7	10
89	10c	Obtain resources	0.25	0.25
90	10d	Make test sheets	0.5	0.75
91	10e	Plan analyses	0.25	0.25
92	10f	Update Test Section	2	1.5
93	10g	Test Plan*	1	0.5
94	10h	Perform Evaluation	6	14.25
95	10i	Take Testing Pics	1	1.25
96	10j	Update Website	6	5.75
97		subtotal:	24.5	35
98				

APPENDIX H – Resume

Jacob Atamian

Mechanical Engineer

Relevant Experience

Fall 2020 – Spring 2021
Capstone Project *Central Washington University*

- Use of SOLIDWORKS and Autodesk Inventor Pro
- Demonstrated project management skills
- Implemented mechanical design and manufacturing
- Conducted finite element analysis

Additional Experience

Nov 2018 – Aug 2020
Line Cook, *Wing Central*
1801 N Walnut St, Ellensburg, WA

- Worked in a fast-paced team environment

Oct 2017 – Aug 2018
Delivery Driver, *Round Table Pizza*
15002 Summit Ave, Fontana, CA

- Demonstrated communication skills and customer service
- Time management skills maintaining steady delivery times

Jun 2017 – Oct 2017
Warehouse Packer, *Vida Divina*
1700 S Milliken Ave, Ontario, CA

- Packed inventory to fill order forms
- Documented inventory
- Demonstrated use of the 5S

Aug 2014 – Jun 2017
Manager, *Pizza 101*
14584 Baseline Ave, Fontana, CA

- Rose to position of manager within a year of employment
- Leadership skills managing 9 to 11 workers per 8-hour shifts
- Learned customer service skills
- Counted daily sales and profit

Contact / Links

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school email:
atamianj@cwu.edu
phone: (909) 441-1666
LinkedIn:
https://www.linkedin.com/in/jacob-atamian-90948a209/

Education

2018 - 2021
BS in Mechanical Engineering Technology
Central Washington University
Cumulative GPA: 3.65

Courses:

- Lean Manufacturing
- Mechanical Design
- Wood Machining
- Finite Element Analysis

Skills

- AutoCAD
- SOLIDWORKS
- Autodesk Inventor Nastran
- Project Management
- Technical Writing
- Microsoft Office (Excel/Word/etc)