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Articulated Balsa Wood Bridge

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ARTICULATED BALSA WOOD BRIDGE

By

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Abstract

The project chosen was the challenge of designing and constructing an articulating Balsa Wood Bridge that would withstand a minimum load of 18.9 kg. The first step was to find which design will best work for the requirements; a decision matrix has been used in this decision. Analyses were completed to find the geometry of each part that will support the load. The project construction was in sequences: the first sequence was the construction of each component, then the construction of 3 subassemblies, and finally was the construction of the entire project. The last part of the project was programming the Arduino nano, which controls the stepper motor to raise and lower the bridge at will. The testing phase was to test if the project meets the requirements or fails. The finished device has demonstrated that it can span a clear opening of 400 mm. A vehicle can pass over the bridge. The articulation mechanism opens the bridge and maintains the opening for a minimum of 10 seconds.

Contents

1. INTRODUCTION

a. Description

The student needs to design and construct an articulating wooded bridge with knowledge about static and mechanical, to show what was learned on the courses of the Mechanical Engineering Technology program. Including a system of raising the bridge to let past objects under the bridge and need to have a span of 400mm, the system of raising the bridge will be manual or automated; it will be the student's choice to decide.

b. Motivation

The motivation for choosing this project is because due to COVID, there are new restrictions. One of those is to practice social distance, and in a classroom, it will be hard to maintain social distance. In addition, Face-covering is another rule that must obey. However, the primary motivation for choosing this project was to show that the student who took courses on the MET program can and do project with the knowledge collected during taking MET classes.

c. Function Statement

1. The bridge must span a divide while supporting a load.
2. The bridge must allow passage to moving structures moving perpendicular to the bridge span that have a height greater than bridge clearance.

d. Requirements

Requirements for this project are details to make this project successful and no waste time, and money, the requirements of this project are listed below:

- This bridge has not to exceed 85 grams in weight.
- The material will be only consisting of balsa wood and any type of glue.
- Must have a span clear opening of 400 mm.
- Road deck must be within 12 mm of the abutment level at the outside edge.
- A 38 mm wide solid balsa wood road deck.
- 8 mm diameter hole in the center of the deck for testing.
- The deck must be bigger than 32 mm X 25 mm.
- The lifting can be done by manual or automated.
- The bridge should be fully support by both abutments.
- Withstand 18.9 kg of load.

e. Engineering Merit

This bridge will be design with statics and mechanical principles that have been learned during the courses of the Mechanical Engineering Technology career, to find all the important characteristics of a bridge that need to be well defined by an engineer. For this project, the student needs to know more static to design this project to improve or create this project from scratch.

f. Scope of Effort

The bridge will be only constructed with balsa wood that will be purchase, however all the design and analysis will be made by the student. All the requirements need to be done by the student alone with the help of statics and mechanical principles. The parts that will be using on this device will be designed and manufactured by the student, except the parts that will need precise measurements or tolerances that need a machine to create it, these parts will be purchased.

g. Success Criteria

Bridge supports load and allows the passage of structures of above heights. The success of this project will depend on the final test, however with all the analysis that will be done it will performer good. The bridge will support the load that will be placed on top and it will lift the high that is required.

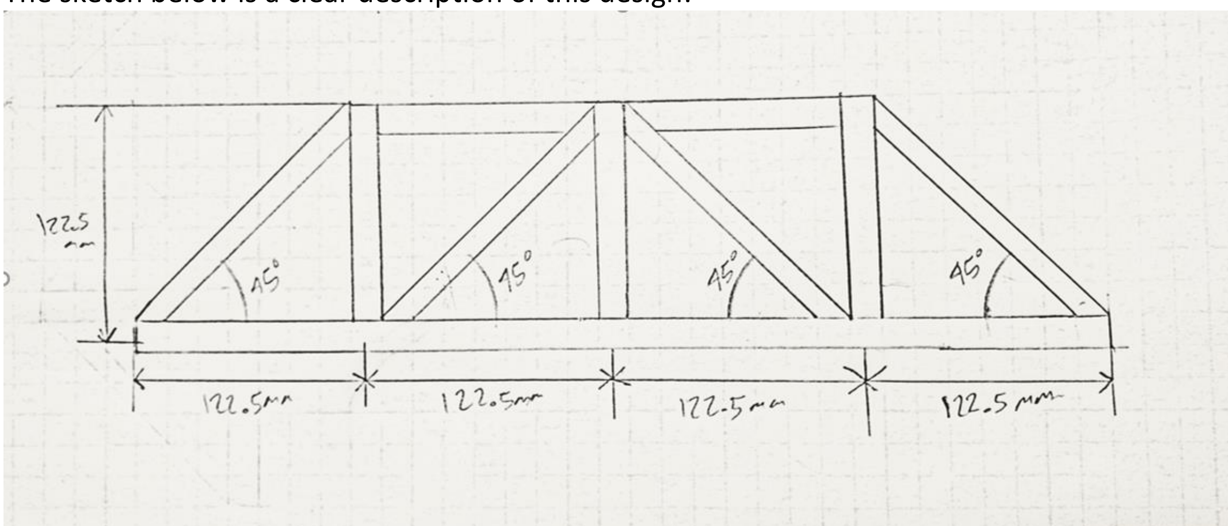
2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The design for this bridge was based on an actual bridge that was designed with 45 degrees angles, mostly this type of bridge is for trains. Therefore, the lift mechanism will be more efficient in this type of bridge.

b. Design Description

The design of this bridge is based mainly on 45 and 90-degree angles. With some static analysis, the idea behind this is that this method will have a most distributed load over the entire bridge. The sketch below is a clear description of this design.



c. Benchmark

Many students in different schools have been doing balsa wood bridges, there are different designs. However, the design concept is mostly the same, make the bridge with 45-degree angles. Mostly the designs of the other students weight more that was is required for this project, so this is taking in consideration in the construction of this bridge.

d. Performance Predictions

This bridge will hold more than 20kg.
It will rise enough to let slip a piece of 20lb paper.

e. Description of Analysis

To design the bridge, statics and mechanics were considered to make this bridge rigid and that this bridge will handle the 20kg. One of the main reasons is finding the internal stresses located in the bottom beam; the maximum shear and bending moments are in Appendix A-2. The distributed load of the 38mm X 38mm plate that will be placed at the time of the test is in Appendix A-3. For the lift mechanism, statics were also considered because this bridge will be like a bascule bridge, where “is a moveable bridge with a counterweight that continuously balances a span” (Wikipedia.com).

f. Scope of Testing and Evaluation

The bridge will be tested how much weight can support, if the bridge will span the required length, if the bridge will lift enough to let a 20 lb standard paper stack slip under one abutment, also with the help of a scale how much the bridge weight.

g. Analysis

One of the requirements is that the bridge will must have a span clear opening of 400 mm, another requirement is that the deck must be bigger that 32 mm X 25 mm. The dimensions that are for this bridge are length is of 490 mm and the height is of 122.5 mm. These measurements are taken in considerations because the bridge will be made of right isosceles triangles, the angles will be same, the calculations will be in appendix A-1. Also, in appendix A-1 and including appendix A-2 there are calculations for the internals stresses for the bottom beam.

i. Analysis 1

In the first analysis to the bridge was found and the maximum internal stresses of the bottom beam and the lengths for the beams that will be used in the bridge are in Appendix A-1a and A-1b. The maximum internal analysis is in Appendix A-2a, the shear and bending moment for the bottom beam in a not distribute load. Also, the stresses for each beam were calculated, appendix A-2b have the calculations on the beams, assuming the cross sectional are of the beam is 40.32 mm^2. Many dimensions were used to find which cross sectional are was the best to not over stress the beams and be under the required weight. The first cross sectional is that were used was of 20.97 mm^2, this was used in the first calculations these calculations are on Appendix A-2, after these other calculations were made for different areas, however this were done on the following analysis.

ii. Analysis 2

In this analysis the maximum stress of a distributed load where calculated and are shown in a shear and bending moment on see Appendix A-3. The maximum shear stress is of 1.86 MPa and the maximum bending stress is of 275 MPa, assuming that the cross-sectional area is of 40.32 mm^2 not the same as the one from Appendix A-3. Then many other calculations were done for different cross-sectional areas, the others cross-sectional area are 80.65 mm^2 and 40.32 mm^2 for each deferent cross-sectional area stress analysis were done, the calculations are as follows on appendix A-3b and A-3c.

iii. Analysis 3

The third analysis is for the lifting mechanism. Based on the first analysis the dimensions for the lifting section of the bridge were found for the outside beams. The tolerances of the dimensions are +3.17mm because of the thickness of the material where not taken in consideration. On Appendix A-4 are the calculations and details of the dimensions.

iv. Analysis 4

This analysis is for the trusses for the lifting mechanism. This analysis was done if the bridge is at its resting position, the trusses were calculated with the method of joints and with the assumed dimensions from Appendix A-4. The max force that will be applied will be 0.366 N at location of the fixture where the bridge will lift. On Appendix A-5a and A-5b will be the trusses at each location of each joint.

v. Analysis 5

Analysis five was for the pin diameter for the fixed part of the lifting section. On Appendix A-5 the trusses were found in each joint of the lifting section including where the pin will be located. Using the max shear strength of the balsa wood, find it on MatWeb.com, the shear force, and the equation to find Area of a circle, the minimum diameter of the pin is .65 mm. Appendix A-6 have the detail of the calculations.

vi. Analysis 6

This analysis is for the dimension for the base of the lifting mechanism, using the Analysis 3, the best dimensions were found, however the tolerance until its 3D modeling were made are of +- 6.33 mm for the thickness each member. Appendix A-7a, A-7b, and A-7c are the calculations for each member of the base for the lifting mechanism.

vii. Analysis 7

This analysis was for the dimensions of the opening of the bridge. The requirement for the opening of the bridge is that it will be free from any obstruction of 32mm by 25mm, and the road deck must be at least 38mm in wide. The previous analysis was taken in consideration for the dimensions of the opening, in the lifting section where supports will be for the z direction it was the lower part, so this will be the high of the opening and the wide is 40mm. The final dimensions for the opening are 40mm by 82mm the calculation for the high is on Appendix A-8

viii. Analysis 8

This analysis was for the floor section of the bridge. For this analysis, the number of main beams and dimensions of the beams are specified. From analysis 7 the length of the beams is 40mm, for the high, and thickness are the same from the raw material that are 6.33mm by 3.302mm. The number of beams were based on how many joints are in the bottom side of the bridge and how the opening for the 8mm hole will be located, the total beams for the floor section are 7. The Appendix A-9 shows how the beams will be located.

ix. Analysis 9

In this analysis the secondary beams are to be specified on the floor of the bridge. Using the analysis 8 this analysis was completed; this analysis was to find the dimensions, the number, and the locations of the secondary beams that will be perpendicular to the main beams. There will be 8 different secondary beams and the dimensions each beam is located on Appendix A-10.

x. Analysis 10

In this analysis the top section of the bridge was analyzed. This analysis was for the main beams that will be on top of each joint, the dimensions, the locations, and the total numbers of beams were found, also this analysis was for the lateral bracing too for this section of the bridge. The total number of main beams that will be using the top section are 6, the dimensions will be same 40mm X 6.3mm X 3.3mm, the locations of each beam are located on Appendix A-11a. For the lateral bracing will be round balsa wood, the total bracings will be 10 but with different length, the calculations of the lengths are on Appendix A-11b, also the locations are in the same appendix.

xi. Analysis 11

This analysis the gear and gear rack were specified, using McMaster the measurements are defined. The measurements for the gear rack are as follow; Face width 5 mm and the pitch height is 6.4 mm. For the gear, Face width 3 mm, Pitch Diameter 8 mm, and for the number of teeth 16, the gear and the gear rack are made of plastic and are 20-degree pressure angle, on appendix A-12 are notes about the gear and the rack. The pin or shaft that will be to connect the gear will have an outer diameter of 3mm.

xii. Analysis 12

This analysis was for the support or the links that will hold the counterweight for the lifting mechanism. Appendix A-13 shows how will be locate and dimensions of each link to support the counterweight. From previous analysis the dimensions of each link where found, there will be 4 total beams and it will be joining with 4 pins that will pass through the whole bridge. The links will be moving while the bridge will be lifting.

xiii. Analysis 13

In this analysis some gears were analyzed to find which gear ratio work best with the stepper motor and gear rack. The stepper motor spec sheet is on Appendix B-Drawing 55-001, the gears ratios and the gear-rack ration are on Appendix A-14. The purpose of this analysis was to find if the gears will be able to lift the bridge fast or slow. The findings show that this gear has the best fit of lift the bridge without going over the maximum RPM of motor.

h. Device: Parts, Shapes, and Conformation

Base on the analysis that has been done previously, the parts will be mostly beaming with one or both sides cut in 45 degrees of angle for the sides of the bridge. The first analysis is for how long each beam will be, not for the thickness or the width, for the thickness and width based on what was available on the market. Each shape of each part was based on how each part will mate together. Also, this made to decide at what degree the beam will be cut. The design factor of safety for the individual components that were chosen is 3, based on Mott for a factor of safety between 2.5 and 4 said: “ design of static strictures or machine elements under dynamic loading with uncertainty about loads, material properties, stress analysis, or the environment” (Mott, p. 189). This safety factor was chosen because, like what was said before, this device will be somehow in static load, so the factor of safety that will be best will be 3. The tolerances for the dimensions for all the beams are ±0.25 mm as similar for the degrees of angle of each cut and for the pin is -0.05 mm. The tolerances for the pin are from the distributor, the tolerances for the beams were chosen because it will be hard to make the part more precise.

i. Device Assembly

A balsa wood bridge will be constructed to span 400mm in the distance, thus connecting the two abutments. The bridge design consists of 52 different parts, including the purchased parts, the purchase part, and without modifications are7, for a total of parts. This design consists mainly of 45-degree cuts that will be assembled for the section of the bridge. The lifting base consists of 9 different parts; the total number of parts for the lifting base will be 18 parts. This design is made up of just using balsa wood, and there will be nine total metal parts.

The bridge also must articulate to allow tall objects to pass that would not otherwise be able to when the bridge is in its horizontal position. The articulation was incorporated in the assembly by designing a base where the lifting will occur; the base will consist of a counterweight to not put too much stress on the system that will drive the gear. The articulation will be connected to the bridge by a shaft that will move the bridge in a vertical position. The drawing assembly is located on Appendix B- Assembly drawing.

j. Technical Risk Analysis

This bridge needs to weigh less than 85 grams to satisfied one of the requirements for this project. This project started with a small dimension for the beams that will be used in constructing this bridge and small dimensions for sheets of balsa wood that were available in the market. Based on SolidWorks analysis for the mass properties, the bridge will weigh less than the requirement; however, it can weigh more for some other circumstances. Also, based on the analysis of the stresses that the bridge will experience in the beams, it will be more than the ultimate tensile stress. However, in this section, where there will be much stress, it will be others beams to help reduce the stress and support the load, so it will be strong enough to support the load. Based on a simulation on SolidWorks, the articulation will work. Based on multiples analysis for the stresses, the best dimensions available on the market the mass of the bridge were found to no overpass the requirement, so it will be good to reinforce the joints with any adhesive amount. For the raising mechanism, an Arduino will be used to control the lowering and rise of the bridge with an IR remote, it will be a challenger to learn Arduino; however, there is much information on how to program an Arduino on the internet. It will be a challenge, but it will be done on time.

k. Failure Mode Analysis

This bridge will experience a ductile failure because balsa wood it is more ductile than brittle, a brittle material is a material that will shatter, wood is more like a ductile material. It will experience a dynamic loading because it will be experiencing an increase of weight up to the 20kg, however it can be in static loading because if the total load is applied at same time, it will be in static load. It can experience a fatigue failure if the load stays for longer period. Mostly the analysis that were done was for the maximum shear and bending stress, for a beam, the maximum shear stress that was calculated was 1.86MPa and the shear stress that is for the balsa wood base on MatWeb is of 1.10MPa, if the bridge was constructed with just one beam it will fail before it reaches to 20kg. This bridge will be constructed of multiple beams to support the load applied and reach the desired load, analyzing each beam, the stress will be same or a little be higher for each one, so it will reach the 20kg load.

l. Operation Limits and Safety

This bridge is designed to not support more than 20kg, a car or truck that weight more than 20kg cannot cross the bridge. Cars on top of the bridge while is raising it is prohibited. Beams need to be inspected regularly.

3. METHODS & CONSTRUCTION

a. Methods

This project was created, analyzed, and Designed at the student's house. Working within the constrain of resources that the student has, the analysis, design, and the creation of each part was done. Mostly all the parts using in this project are made by the student using raw material and tools that the student has. Some parts were purchased, these parts required to be machined because it need to be more precise, and the student do not have the adequate tools to do it, these parts are for the lifting mechanism. Most of material used for this project is consisted of only balsa wood, some metal parts, and plastic that were used on the lifting section.

i. Process Decisions

Designing the appropriate design for the bridge, many options were taken in consideration, like what is the better way to raise the bridge, the lifting system will meet the requirements, and things like that. Also, a decision matrix was used to select which design was the best to continue doing or improving, it is on Appendix F.

One of the requirements of making the bridge was that the bridge need to have a mass less than 85 grams, analysis of the stresses (on analysis 2) and SolidWorks help to choose a design that weight 55 grams without the articulation for the lifting system. On the decision matrix for the weight, the first design was too light, second design was too heavy, and the last design was the one, this method was used for the other requirements to choose which was the best, also which lifting system will work best too.

One of the decisions to manufacture the parts was to buy a large piece of raw material and machine it into the parts that will be needed. However, because the student does not have access to the machines of the university, this decision was discarded. The best decision for the student was to buy a long balsa wood sticks or a flat bar that have already cut to the width and height that is needed on the parts, also based on what was available on the market the basic dimensions of the parts were taken in consideration. Analysis 1 was consisted of to find which balsa wood, that are available on the market, will work on the bridge to support the stresses that will have during the test.

The other decision of manufacturing the parts was to better purchase the part instead of making it because as mentioned before, the student do not have access to the machines of the university. The parts that need to be of metal, like the gears, gear rack, pin, or the ball bearings that the lifting mechanism need are more difficult to manufacture without proper machinery, so some of these parts were purchase. However, because the shaft dimeter change some of these parts change too, like the gears, so a 3d printer were used to make these parts.

The chosen method to manufacture the parts for the project, especially the parts that were made of balsa wood, is to use a X-ACTO knife and cut the parts to the required dimensions that are shown in each drawing. Some of the parts need an angle, the method used to make the angle in the part was to use a jig for sharpening chisel, sandpaper, and an angle gauge.

The first drilling method to make the holes on the parts did not work well, the method that best work was to take a drill bit and drill into the material by hand, however, this method took more time that the previous method. The previous method for drilling did not work because with the

drill driver must fast to make a straight hole, also the balsa wood acted very brittle, so doing by hand it have more control to do a straight hole and control over the speed.
The method of lifting the bridge will be using an Arduino module and an IR remote to raise and lowered the bridge. The software used in the programing of the module is the same as Arduino provided. For the construction of the circuit is from systems gathered while learning the program.

b. Construction

i. Description

The bridge was constructed in sections and mostly all the parts were manufactured from balsa wood, the parts that were obtained for the supplier are the gear, gear rack, pin, and all parts that are made of metal, and glue used to join all parts. The construction of the bridge were in sequence, the first section was the deck of the bridge, then the sides of the bridge, and last were the lifting mechanism. The parts were manufacture as the drawings number goes, then the assemblies were assembled.

ii. Drawing Tree, Drawing ID's

The drawing tree is located on Appendix B-Drawing tree and each of the subassemblies to construct the bridge has listed the number of parts that need to be complete it. On the following Appendixes B after the Drawing tree follows the drawings for the subassemblies, then the drawing for each independent part that meet the standard dimensions of ASME Y14.5.

iii. Parts

The parts that were manufacture, all the balsa wood parts, are made from raw material that have the dimensions of 6.43mm by 6.43mm with a tolerance of ±0.15mm. The length and the degree that need each part will be made with the dimensions from each drawing. The drawings for each part are located on Appendix B after the drawings of the subassemblies, the method for manufacturing these parts will be similar for all the parts made of balsa wood. The parts purchased are from different suppliers, the suppliers are ACE hardware, Amazon Market Place, and McMaster-Carr. The shaft used was cut from a 200mm shaft brought from Amazon, the pins used are from McMaster-Carr and Amazon. All this part were manufactured however because all the materials are precut to some dimension, these parts were modified to meet the require dimensions. Also, two gears were modified to meet the shaft diameter, the inner diameter was too big, the 3d model of each part were modified and 3d printed later, the original models are from 3d models that the supplier supplied. The parts that were not modified are one gear that meet the gear of the stepper motor, the ball bearings, and washers, and the gear rack, for the total part list go to Appendix C.
The Methods to manufacture each part will be as follow; for the parts that will be made of Balsa Wood, a caliper or a ruler will be use on measure the part length, a X-Acto knife will be used to cut the wood, after the length of the wood is cut, it will be placed on a chisel sharpening jig to sanded down to the desired angle if the part need it. For metal parts, the part will be measure then later will be placed on a clamp to hold the part in place and cut with a small handsaw.

iv. Manufacturing Issues

Issue in the manufacturing process of the parts will be is the messing up the measurement, movements on the parts while cutting it, the solutions will be to measure twice and cut once and put the part in a tight clamp. The finals subassembly can have some sort of distortion because in some parts the glue dries more faster than other parts. Another issue that will be when constructing the subassemblies is that there will be multiples parts that will be joining together, so the issue will be that while these parts are drying some parts will be moving and the results will be no good, and the subassembly will be needed to do it again. Some of the solutions will be to use pressure on top of each join to maintain it flat and let it dry until all the glue is dry.

v. Discussion of Assembly

The complete bridge will be composed of 4 main sub-assemblies and joined with horizontal and vertical supports from one side of the bridge to the other side. The first subassembly will be the deck or floor of the bridge, that is made up of 8 different parts with a total of 22 parts. Then the following subassembly is both sides of the bridge that is made up of 17 different parts with a total of 55 parts. The last subassembly is the base for the lifting mechanism that have 21 different parts including the gears, and gear rack, the total part for this subassembly is of 34. These subassemblies will be mated together to make a final assembly that is the 10-001. An Arduino module will be used to control the stepper motor that will lift the bridge. Each of the assemblies are locate on Appendix B-Drawing 10-001, Appendix B-Drawing 10-002, Appendix B-Drawing 10-003, and Appendix B-Drawing 10-004.

4. TESTING

a. Introduction

The methods that were used to test this bridge are mentioned below in Method/Approach. The items that were tested are the requirements that were stated on 1b, which are as follows:

- This bridge has not to exceed 85 grams in weight.
- The material will be only consisting of balsa wood and any glue.
- Must have a clear span opening of 400 mm.
- The road deck must be within 12 mm of the abutment level at the outside edge.
- A 38 mm wide solid balsa wood road deck.
- 8 mm diameter hole in the center of the deck for testing.
- The deck must be bigger than 32 mm X 25 mm.
- The lifting can be done manually or automated.
- Both abutments should fully support the bridge.

b. Method/Approach

The method used for measuring the bridge's weight was to place the bridge on top of a small scale. A measuring tape was used for measuring large dimensions of the device, like the span opening and how high the lifting mechanism can go. A caliper was used for small sizes, such as the diameter hole, and to measure the 32mm X 25mm block used for the vehicle simulation. The method used in the test of the lifting mechanism was to visually check if everything from the lifting system was working correctly; a timer was used for the 10 seconds requirement. The optical test was if everything in the lifting system works as expected. The method of testing the load of the bridge change, the first method was to use the 5 kg of weight, no sand, then added to the bucket five consecutive times up to 15 kg and then add 1 kg up to the minimum required load. However, the weights that were available to the student were not enough to achieve the required load. The new method of achieving the needed load was sand; water was also taken into consideration, but the sand was used on this test. The method of adding 5kg each time up to 15 kg change; instead of adding 5 kg, 2 kg of weight was added, up to 16 kg. Then 1 kg of sand was added every time up to 20 kg or before failing. The method of measuring the weight before adding it into the bucket was with the help of a small scale. The 2 kg weight change because the small scale could not reach 5 kg.

b. Tests Procedures

The bridge was placed on top of two books that were 400 mm apart; the books were representing the abutments. The lifting mechanism system was tested visually, with a timer, and with a tape measure. The bridge's midpoint needs to be at least 140 mm above the resting horizon position and then start the timer up to the 10 seconds requirement. The test for the bridge's opening, a 32mm by 25mm block was placed along the bridge; the block represents a vehicle passing through the bridge, the block was 3d printed. The procedure of measuring the bridge's weight was to place on top of a scale; however, because the scale design has a border around the area of measurement, a small box was placed first to raise the area of measurement, then zero the scale. For the test of how much load the bridge handles, two different methods of adding the sand into the bucket were used. First, the 2 kg of sand was used up to 16 kg or eight times 2 kg. Then after the 16 kg, the 1 kg of sand was added up to the 20 kg, or after the bridge fail. One issue in the load test, the bucket's handle broke before finishing the test; the solution was to make a handle out of a 50kg string to handle the load and redo the test. For more detailed test procedures of how those tests were complete, see appendix G for each performed test.

d. Deliverables

All the values that were collected from each of the tests are listed in Table 4-1, it is collected to show that the bridge passes or fail the requirements of each of its test. The devices that were used to complete those testing are in Appendix G, also raw data collected.

Table 4-1 Testing requirements

What was tested	Required values	Estimated values	Actual values	Pass /fail
Span opening	400 mm	412 mm	415 mm	pass
Lifting mechanism	Articulation	Visual	Visual	pass
Time in the up position	10 sec.	>10 sec.	15 Seconds	pass
Vehicle passing over the bridge	visual	Visual	Visual	pass
Bridge opening	32 X 25 mm	40 X 100 mm	40 mm X 114 mm	pass
Hole diameter	8.00 mm	8.00 mm	8.03 mm	pass
Weight of the bridge	85 grams	80 grams	83 grams	Pass
Load	18.9 kg	18.9 kg	20.66 kg	Pass

5. BUDGET

a. Parts

Mostly all the parts that will be used in the construction of the bridge will be made from balsa wood, the cost of balsa wood is approximately $5.63 per square foot, however for the lifting mechanisms like the gear, gear rack, pin, or any other metal part will be purchase. The approximate cost and the sources for each part are shown in Appendix C. There was no additional cost related to the testing of the bridge. The bridge's components did not receive any damage from each of the tests, so there was not needed to redo parts.

b. Outsourcing

Mostly all parts will be made in-house, the outside parts will be purchased. The students already owned all the equipment used in the testing of the bridge; no equipment was rented or bought.

c. Labor

The labor cost for creating the 3d modeling is $18.00/hr, analysis is $20.00 per hour, for manufacturing of each individual part is $14.00/hr, and for assembly is $15.00/hr. No labor cost for remanufacturing parts or subassemblies after each test.

d. Estimated Total Project Cost

The total estimated cost for labor is $3,163.00, for raw material is $56.22, and for outside part and software $21.00, making a total estimated cost of $2112.89. All the sub costs are listed on Appendix D.

e. Funding Source

The cost of this project is supported by the student and family. The parts that will be purchase and the material for the construction of this project will be paid by the student, including the labor cost.

f. Manufacturing

The total cost for the balsa wood was $71.21, including tax and shipping; this is the raw material, the estimated cost for the raw material was $16.89. However, because there was not enough material in the first order, it needs to be ordered twice to meet the necessary material needed in the manufacturing of these parts. Also, because the road deck was redesigned to put more rigidity at the time of the test, that is why the total cost for the raw material is more than what was estimated, and taxes were not included, and shipping too, same for the others purchased materials. The total cost for the parts that were purchased was $63.75, including tax and shipping, the estimated total cost for the purchased part was $21.00. However, in the estimated cost, one part was not considered, that was the Arduino system. The total cost for manufacturing the parts up to now is $558.32, and the estimated cost is $710.50. The total labor cost is $2037.32; the estimated cost was $3,163.00, so this project is still under the budget.

The major part that primarily affects the budget was introducing the Arduino system; this part will help in the lifting of the bridge; this was the only major part that affected the budget. At first, the lifting mechanism will be manual, but because of interest in adding an electronic system, this part was included in the project, and it cost more.

On November 21 of 2020, the Arduino system was ordered, and it arrived on November 23, 2020. This part was brought in advance because it will need to be studied to know how to program it. The next item's order date was on January 6 of 2021 and was delivered on January 9 of 2021, and these parts were the gears, gear rack, and shaft. The ball bearings were ordered on January 16, 2021 and were delivered on January 20, 2021. For the balsa wood stick to be ordered twice, the first order was made on January 4, 2021, and it was running late and delivered on January 20, 2021. The second time, the balsa wood was ordered on February 1, 2021, and it was delivered on time, on February 6, 2021. The last item purchased is the balsa wood sheets for the road deck; it was ordered on February 1, 2021 and delivered on February 4, 2021.

All the parts used on the bridge's construction are already purchased, including the adhesive; there were no complications for completing the project.

6. Schedule

a. Design

For the design phase, the first assumption for the time to complete this phase was 10 hours, however as for right now is 19.5 hours have been put in the design, so the assumption was wrong. Now the estimated hours to complete this phase is 46, it can change if there are other analysis added to the section. The estimated weeks to complete this phase is between 7 to 8 weeks starting for the 3rd week up to the 11th week. On the Appendix E is a picture of this schedule, the green boxes represent when the task is started and when is expected to end. Now that the Design phase is completed it took 40.5 hours, and the estimated time was 63 hours, so 22.5 hours was saved.

b. Construction

The construction of this project was on winter quarter of 2021. It will begin at the beginning of the quarter and end at the end of the quarter. On Appendix E shows every task about the construction of the bridge and where it needs to begin and end. Some issues regarding in the manufacturing schedule at the beginning of the construction of the parts were that the material was not on time, it was late than what was anticipated. The balsa wood took one week more than anticipated to arrive to solve this issue without affecting too much on the schedule, other parts were manufacture instead to not lose time in waiting for the balsa wood material. This issue did not cause too much problem in the schedule of completion of the project, there are no other issue/change on the schedule up to now. The expected time to complete the manufacturing of the parts was of 50.75 hours, the total time that took to complete this phase was of 14.13 hours, so 9.62 hours was saved.

For the assembly of the project the expected time was of 16.5 hours, but it took 15.5 hours to completed 1 hour was saved, in this phase 2 tasks too more time than what was estimated, tasks 9b and 9d. It took more time because it need more time to make the subassemblies mate almost perfect and modified some parts to reduce weight of parts that will be needed to support the project. Mostly all the tasks were started and finish on time, however the project was completed on time.

c. Testing

The testing phase was on Spring quarter of 2021. Each of the requirements for the project was tested on this quarter. The first test of the bridge was done on the last week of March and the last test was done on the third week of April, all this test was done on time to ensure the completion of the bridge before the SOURCE poster and have a complete project. Each of the task were done on time without delay. The schedule for the tests were well done that there were not majors issues/changes done to it. The actual time that took to complete the bridge evaluating including the testing of each requirement was 31.3 hours and the estimated time was of 36 hours, 4.7 hours was saved.

7. Project Management

Risk to completing the project; no having the require machines to complete this project and use a not adequate machine to complete the task or the task is completed late. Do not know how to program an Arduino control and burn the control. To control these risks, need to have resources and/or technical support from senior engineers. The risks will make to complete this project late or to be suspended. The risks that required addition attention will be risks that will cause that the project stop or cause budget shortage.

a. Human Resources

The human resource for this project is mostly the student, the resume is on the appendix H, however mentors will be available. The risks associated with a mentor will be that sometimes will need to wait, and the task will be no complete on time. If something like this happened the risk will be managed by finding another mentor or arranging an appointment on time or do a frequently report to the mentor.

b. Physical Resources

saw, table, glue, solder iron, drill, computer, and clamps. Risks associated with the physical resources it can be hard to access to a flat table making some joint to no glue property flat, saw can be worn out and do not make straight cuts making that the project's beams to not glue straight and having not crooked joints. To address these risks will be to find at least a small flat plate, and to buy new saw.

c. Soft Resources

Software used for the completion of this project will be SolidWorks, and a software to program the Arduino control. Risks associated with these resources are not available internet to access to the program, the software crashes, and the software freeze, this will cause that the task will be late to complete it. It something like this happen find a place where internet connection are, go to the software forum and ask for help or talk with customer service for the company of the software.

d. Financial Resources

The project sponsor is committed to providing monetary support for the completion of this project, including work hours and parts. It also provides equipment for the construction of each part that need to be manufacture.

8. DISCUSSION

a. Design

The lifting mechanism change: the first design was to have a hydraulic system, however, while surfing the web for some ideas, a bascule bridge comes up, and it was a good idea to do it. The hydraulic system idea was discarded because the hydraulic cylinder will be in the middle of the bridge. One of the requirements that this project has is to let an opening in the middle of the bridge, so this idea was no good. The bascule bridge lifts the bridge from one side to be free from any obstruction for the middle part of the bridge.

Another design that changed was the total length for the bridge; it was supposed 490 mm, but because the bridge design changed to a bascule bridge, the overall length of the bridge changed. The new length of the bridge now is 712 mm, making it longer than expected. The length of the bridge increase because it needs some additional parts to connect the lifting mechanism and the bridge.

Another change in the first design of this bridge was the first design of the lifting mechanisms, the pin that will connect both sides of the bridge and the base for the lifting it was in the wrong location. The location of the first pin was too low, so the bottom of the bridge will hit and not let the bridge rise. The new location let the bridge rise to the desired height and now has a good clearance at the bottom of the bridge and the floor; now, the lifting mechanism will work without a problem.

Another thing that changed was the part 20-019 because of some miss calculations the length of the previous part was wrong. This problem was found while the parts were mating on the subassemblies; this part did not match any other part, so a new analysis was made to find the correct length.

The things that went well were the hole's location where the shaft will be located, the stress analysis, and designing the parts on SolidWorks. To decided what kind of bridge will be constructed was a little be hard. However, there are some bridges around Ellensburg; take a trip and get some ideas of how each bridgework and help to understand how each beam help to support the load. This was how the bridge's design was chosen, and the design of the lifting mechanism was from a bascule bridge found on the internet.

b. Construction

i. Manufacturing issues

Issues in the manufacturing process for each of the parts included in the making of some assemblies. While doing the assemblies on SolidWorks, some issues show up, some parts did not mate together well, and some parts were a little too long; both issues were fixed in SolidWorks by how each part mate together better and finding the right length of each part. Manufacturing the shaft and metal pins where a little be challenging; the material was stainless steel; it was hard to cut with the tool that the student has. To fix this problem, a drill driver was used as a lathe; the driver was clamped into a table to be more fixable; using this method and with the help of a hand saw, it was able to make the cut. Also, this method was less time-consuming than the old method.

While manufacturing the first part, one side of this part needs to have an angle, and it was hard to make a 45°-degree angle with just the hand. The method was using a chisel sharpening jig with sandpaper and a protractor to measure the angle when the material was taken down with the sandpaper. This chisel jig helps to maintain a certain angle, not always 45 or any other angle, so for having a 45-degree angle, every time the part was sanded down, it needs to be measured to have the appropriate angle. This method helps to make the manufacturing of these parts go faster; however, by doing it one by one, it also takes time; this was another issue because the bridge needs about 108 manufactured parts; some of these parts are repetitive. So, to increase the manufacturing speed, 3 parts at a time are attached to the jig, and now multiples parts were done at the same time.

Another issue in the manufacturing of the parts was that the first method of cutting the balsa wood did not work at all. The tool that will be cutting the material did not work as support to do, and the primary tool was a handsaw. While cutting the first part with the handsaw, it took too much material out, and because the thickness of the material was small, also the material was too brittle, so the tool required to cut this material need to go faster or have a sharp edge. The solution to fix this issue was to use a different tool to make the parts, this new tool was an X-ACTO knife, and it works great more than anticipated.

Tolerances were another big issue in the manufacturing process of the parts, the first tolerances before the change were ±0.05 mm. In the making of the first part, it did not meet the required tolerance, the second and third try also did not meet the required tolerance, so it was time to decide if lowered the tolerances or find another method of cutting the wood. The best solution to fix this issue was to lower the tolerances because it will be easier, and it will cost less to be using the same tools than go and buy new tools to meet the higher tolerances. When doing the first tries of the parts, it was noticed that the tolerances always were between ±0.26 mm for the original measure, so it was decided that the new tolerances will be ±0.25 mm, these tolerances will be lower than before, but it will be less difficult to meet.

Another issue was an encounter at the assembly; one of the parts was cut wrong, the dimensions on the drawing were right. However, instead of using the right dimension, it was used another small dimension, and the parts did not mate on the assembly; to fix this problem; it looked twice the dimension and redone the parts again.

The initial motor that was to be used on the lifting system change to a stepper motor, the spacer change to a bracket for the stepper motor; this bracket was 3d printer.

An issue was encounter when the diameter shaft of the stepper motor was too big, and the diameter of the gear was small; to fix this problem, a new gear was 3d modeled with the help of the 3d models of the supplier and printed on the house to no order one and be on time for the completion of the project.

Another issue was that the bridge was overweight; to fix this problem, some parts were modified to reduce the weight, and some were taken out; the parts that were modified are the road deck, and one part from the lifting base, the parts that were taken out were the lateral bracings (parts 20-028 & 20-029). However, the base needs two more other parts to keep it in place, so the weight still over the requirements by between 8 to 10 grams.

c. Testing

The test for the span opening and hole opening for the load test was easy to complete a tape measure was used for the span opening. A caliper was used to measure the hole diameter. For the support on both ends of the bridge was a visual inspection.

The test for the lifting system shows that the system works as expected. Minor issues were encounter while doing this test. One issue was that the bracket holding the gear rack to the shaft on one side of the bracket was too loose; this cause that the gear to skip tooths from the gear rack. The solution for this issue was to print another bracket; this solution works well, no issues now. The other issue was that the bracket holding the stepper motor was too loose; the solution for this issue was to tighten more than the screws holding the bracket up to having an excellent tight without damaging the balsa wood. Just these two issues only were encounter in this test and were easy to fix them.

The test for the bridge's opening shows that it is wide enough that the vehicle passes without any problem; the object used as a vehicle was 3d-printed to the required dimension. The actual measurement of the opening is 115 mm X 40mm.

There were no issues in the test of the weight of the bridge; the required weight needs to be less than 85 grams. The estimated value was approximately 75 grams without the lifting system; the actual value, including the lifting system and the counterweight, is 230 grams. The weight without the lifting system and counterweight is 83 grams. The values gathered from each test show that 230 grams do not meet the required value; however, the 83 grams meet the requirement. So, 83 grams passed this requirement without counting the lifting system and counterweight. This test was done twice, one with the lifting system and the other without the lifting system.

There was just a small issue in the load test of the bridge, but the procedures were all good. The issue was that the bucket handle broke at 16 kg, the test must be redone, the new bucket handle was made of string that can handle more than 50 kg. After the new handle was made, the test was completed without any issues with the same procedures.

9. CONCLUSION

To design and construct an articulating wooded bridge with knowledge about static, mechanical and electrical. Including a system of raising the bridge to let past objects under the bridge and need to have a span of 400mm at least, the system will be programmed in an Arduino nano to control the raising of the bridge.

The analysis done and designs prove that this device can meet the requirements that were stated at the beginning of this report. The requirements parts will be manufacturing on time for the completion of this device, also the purchase parts will be arriving on time. For the budget will be managed wisely for the completion of the device without spending too much and doing quality parts.

The parts are ready to be manufacturing on house and the parts that will be purchased are ready to ship, this device is ready to be create. The parts that will be manufacturing on house are listed on Appendix C and each part's dimensions are on Appendix B.

10. ACKNOWLEDGEMENTS

Charles Pringle mentored the principal engineer by advising on the analysis, report, and for keeping the principal engineer on track.
John Choi mentored the principal Engineer by advising on the analysis and report for this project.
Family members as sponsored for this project by helping with budget and tools that were needed for this project.

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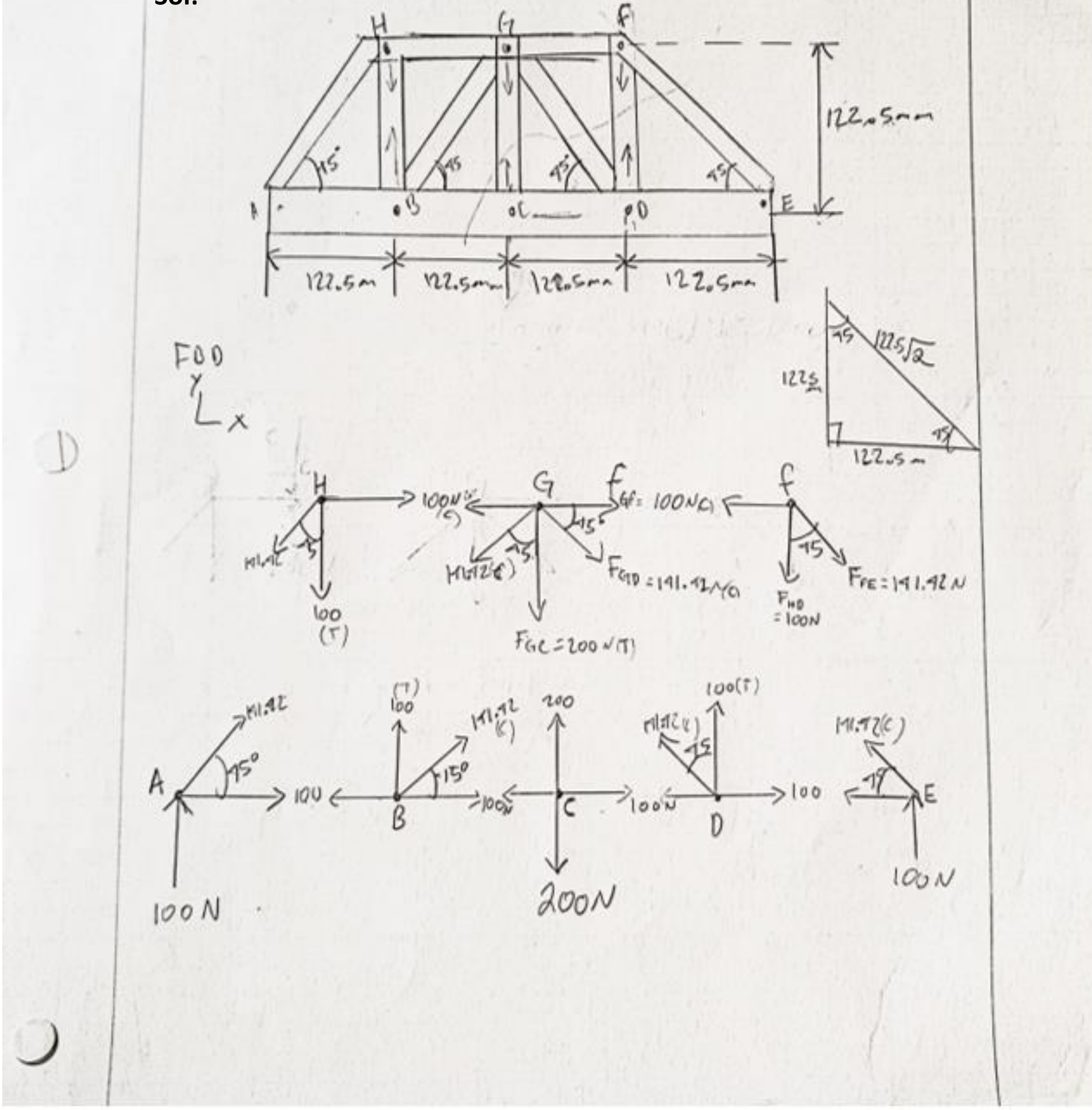
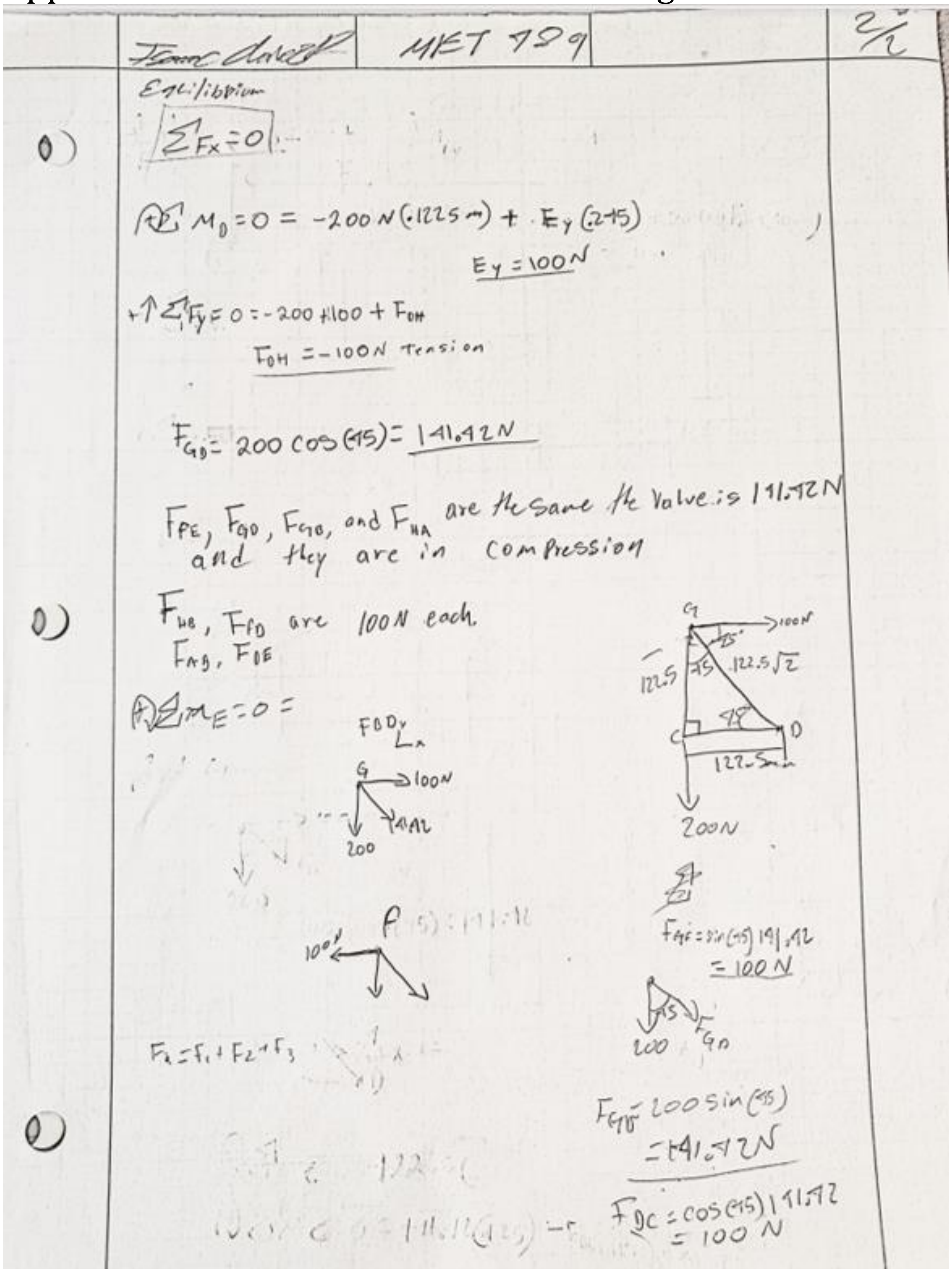
APPENDIX A - Analysis

Appendix A-1a – Measurements of the bridge

Given: requirements for the bridge
Find: the forces acting on the bridge
Assume: Static load is applied
Method: Simple trusses
Sol:



Appendix A-1b Measurements of the bridge



MET 429

Equilibrium

$\Sigma F_x = 0$

$\Sigma M_D = 0 = -200\,N(.1225\,m) + E_y(.245)$

$E_y = 100\,N$

$+\uparrow \Sigma F_y = 0 = -200 + 100 + F_{DH}$

$F_{DH} = -100\,N$ Tension

$F_{GD} = 200\cos(45) = 141.42\,N$

F_{FE}, F_{GD}, F_{GB}, and F_{HA} are the same the value is 141.42 N and they are in compression

F_{HB}, F_{FD} are 100 N each

F_{AB}, F_{DE}

$\Sigma M_E = 0 =$

FBD

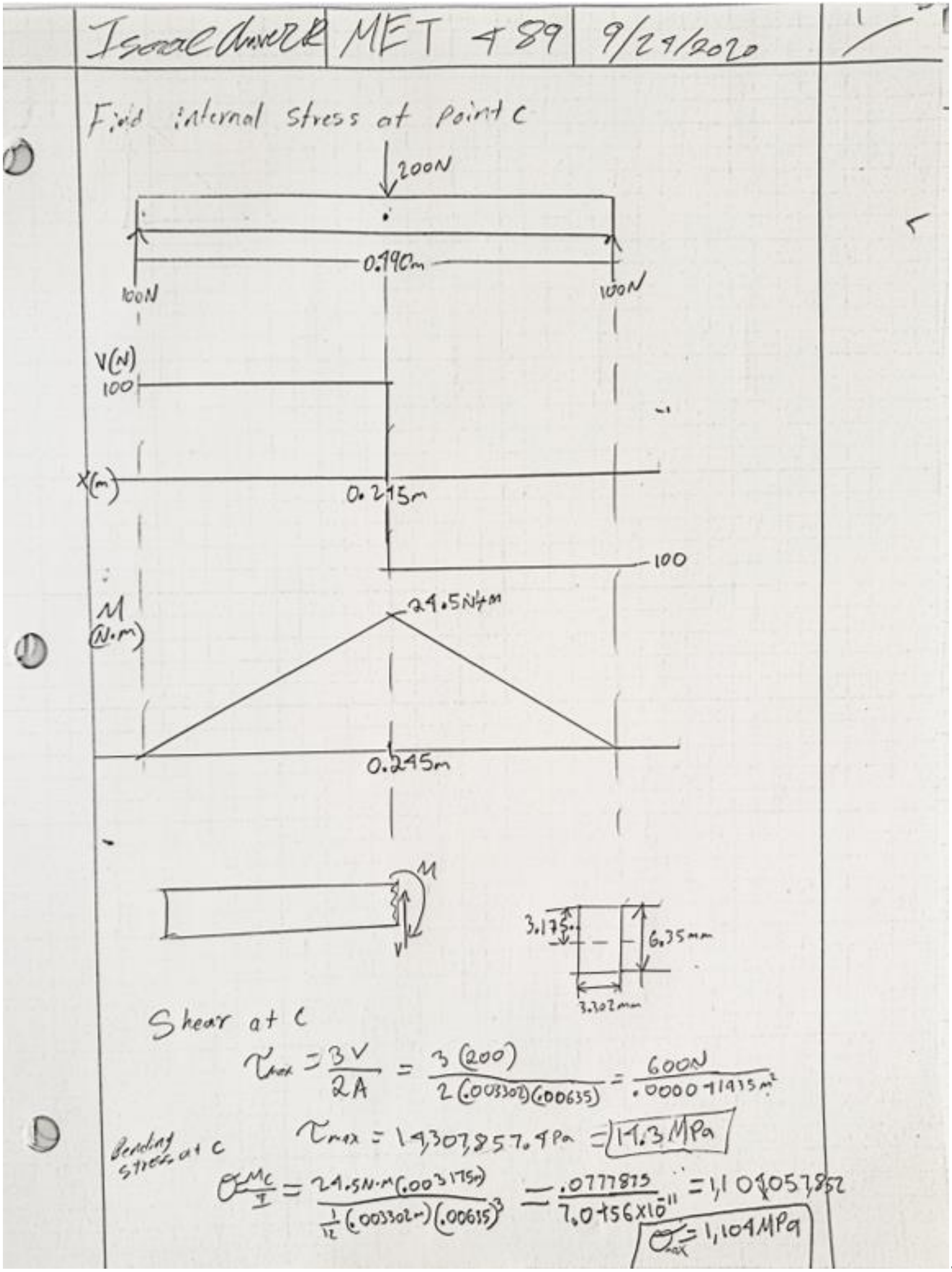
$F_{AF} = \sin(45)\,141.42 = 100\,N$

$F_x = F_1 + F_2 + F_3$

$F_{GB} = 200\sin(45) = 141.42\,N$

$F_{DC} = \cos(45)\,141.42 = 100\,N$

Appendix A-2a – shear and bending diagram for not distributed load.



Appendix A-2b Stresses on the beams with 40.32mm^2 area

Baal Clovel R	MET 489	Stress Analysis	1/1

Given: Analysis 1

Find: σ at Beams

Assume: static load

Method: Direct stress

Soln:

$A = .00635m(.00635m) = 4.03225 \times 10^{-5}$

$\sigma = \frac{F}{A}$ $\quad \sigma_{20-001} = \frac{70.71}{4.03225 \times 10^{-5}} = 1{,}753{,}633 = \boxed{1.7\ MPa}$

$\sigma_{20-002} = \frac{50}{4.03225 \times 10^{-5}} = 1{,}240{,}002 = \boxed{1.24\ MPa}$

$\sigma_{20-006} = \frac{100}{4.03225 \times 10^{-5}} = 2{,}480{,}007 = \boxed{2.48\ MPa}$

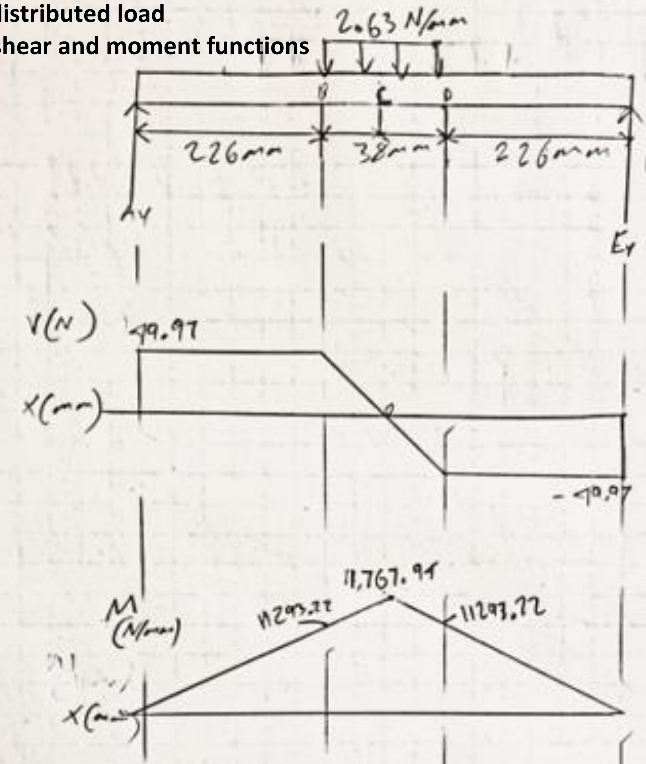
$\sigma_{20-001} = \sigma_{20-004}$

$\sigma_{20-002} = \sigma_{20-003} = \sigma_{20-005}$

Appendix A-3a Stress analysis for distributed load for 20.97 mm^2

[illegible] | MET 489

Given: first analysis
Find: shear and moment diagram
Assume: distributed load
Method: shear and moment functions
Soln:



$\circlearrowleft + \sum M_A = 0 = 2.63(38)(245) - 490E_y$

$E_y = 49.97\,N$

$\uparrow + \sum F_y = 0 = A_y + 49.97 - 2.63(38)$

$A_y = 49.97$

$\sum M_1 = 0 = M_B - 49.97(226)$

$M_B = 49.97(226)$

$M_B = 11293.22$

$\sum M_2 = 0 = M_C - 49.97(226) - 2.63(19)(\frac{19}{2})$

$M_C = 11767.99$

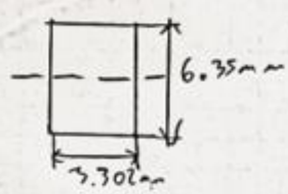
$\sum M_3 = M_B - 49.97(226) - 2.63(19)(\frac{19}{2}) + 2.63(19)(\frac{19}{2})$

$M_B = 11293.22$

$\tau_{max} = \frac{3V}{2A} = \frac{3(49.97)}{2(.003302)(.00635)}$

$\tau_{max} = 3{,}574{,}787\ Pa$

$\tau_{max} = 3.6\ MPa$



$\sigma_{max} = \frac{M_c}{I} = \frac{11.77(.003175\,m)}{\frac{1}{12}(.003302)(.00635)^3}$

$\sigma_{max} = 530{,}394{,}606.9$

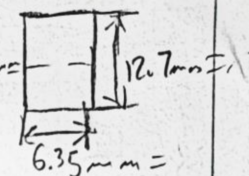
$\sigma_{max} = 530\ MPa$

Appendix A-3b Stress analysis for distributed load for 80.65 mm^2

Boaac Chanel | MET 489 | Stress Analysis | 4/1

Given: $M_{max} = 11.77\ N/m = 11{,}767.94\ N/mm$

$V = 49.97\ N$



Find: τ_{max} & σ_{max}

Assume: static load.

Method: Shear stress Due to Bending.

- Flexure Formula for Maximum Bending stress

Soln:

$$\tau_{max} = \frac{3V}{2A} \qquad \sigma_{max} = \frac{Mc}{I}$$

$$\tau_{max} = \frac{3(49.97\ N)}{(2)(.00635\ m)(.0127\ m)} = 929{,}473.8\ N/m^2$$

$= 929\ KPa$

$\approx 0.93\ MPa$

$$\sigma_{max} = \frac{11.77\ N/m\ (.00635\ m)}{\frac{1}{12}(.00635\ m)(.0127\ m)^3} = \frac{.06985\ N/m^2}{1.08394\times10^{-9}\ m^4}$$

$= 64{,}440{,}836$

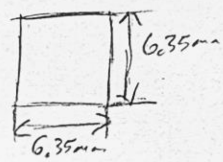
$= 64.4\ MPa$

Appendix A-3c Stress analysis for distributed load for 40.32 mm^2

Bacal Chavez	MFT 489A	Stress Analysis	1/1

Given: $w_{max} = 11.77\ N/m$

$V = 49.97\ N$



Find: τ_{max} & σ_{max}

Assume: Static load

Method: Shear stress due to bending

Flexure formula for maximum bending stress

Soln:

$$\tau_{max} = \frac{3(49.97N)}{2(.00635m)(.00635m)} = 1{,}858{,}887 = \boxed{1.86\ MPa}$$

$$\sigma_{max} = \frac{11.77\ N/m\ (.00635/2\ m)}{\frac{1}{12}(.00635)(.00635)^3} = \frac{0.03736975\ N/m^2}{1.35492\times10^{-10}\ m^4}$$

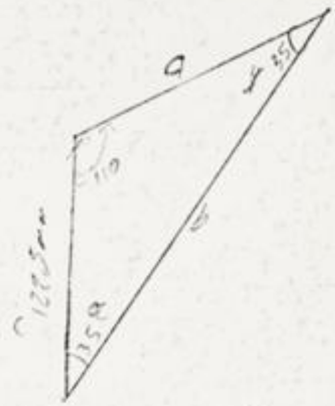
$$= 275{,}807{,}297$$

$$\boxed{275\ MPa}$$

Appendix A-4 Dimensions analysis for the lifting mechanism

Isaac Alvarez R	MET 489A	10/14/2020	1/1

Given: Picture shown



Find:
The dimension of c & b

Assume: No moving parts,
Method: Law of Sines & Law of cosine.

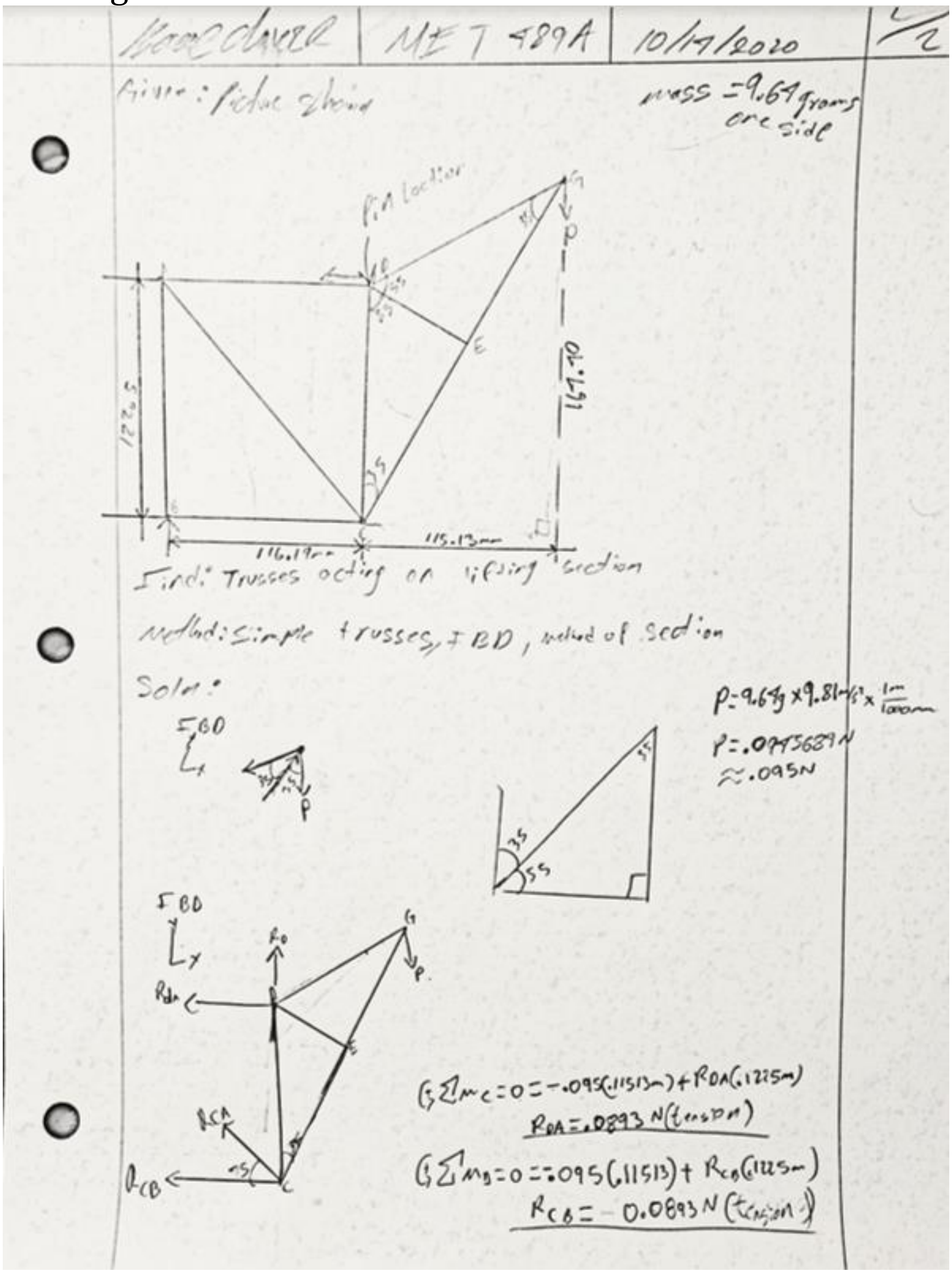
Soln:

$$\frac{\sin \alpha}{a} = \frac{\sin \beta}{b} = \frac{\sin \gamma}{c}$$

$$\frac{\sin(35)}{122.5\text{mm}} = \frac{\sin(35)}{a} \qquad a = 122.5\text{mm}$$

$$\frac{\sin(110)}{b} = \frac{\sin(35)}{122.5\text{mm}} \qquad b = 200.69\text{mm}$$

Appendix A-5a Analysis of the trusses on the lifting section of bridge



Appendix A-5b Analysis of the trusses on the lifting section of bridge

[illegible] | MET 489A | 10/17/2020 | 2/2

$+\uparrow \sum F_y = 0 = R_D - .095N + R_{CA}\sin(45)$

$+\rightarrow \sum F_x = 0 = -R_{CB} - R_{CA}\cos(45) - R_{BA}$

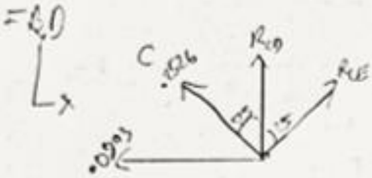
$\therefore -.0893 - R_{CA}\cos(45) - .0893$

$R_{CA} = -.2526N$ (comp)

$\therefore R_D = .095 - .2526\sin(45)$

$R_D = -.0836\ N$ (comp)

FBD



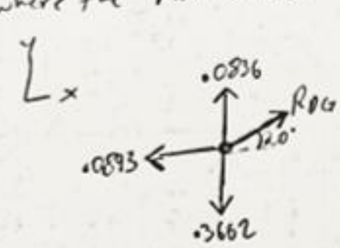
$+\rightarrow \sum F_x = 0 = -(.0893) - (-.2526\cos(45)) + \cos(35)R_{CE}$

$R_{CE} = -.327\ N$ (comp)

$+\uparrow \sum F_y = 0 = (-.2526\sin(45)) + (-.327\sin(35)) + R_{CD}$

$R_{CD} = -.3662\ N$ (comp)

FBD for D where the pin will be



$+\rightarrow \sum F_x = 0 = -.0893 + R_{DG}\cos(20)$

$R_{DG} = .095\ N$

Appendix A-6 Minimum Pin Diameter

[illegible]	MET 489A	10/15/2020	1/1

Given: V = .3662 N

Shear strength for Balsa wood (Tropical) according to Matweb is 1.10 MPa

Find: minimum Diameter of the Pin

Assume: Uniform material,

Method: Shear stress Eq

Soln:

$$\tau = \frac{V}{A}$$

$$1.10 \times 10^{6}\ Pa = \frac{.3662\ N}{\frac{1}{4}\pi d^2}$$

$$d = \sqrt{\frac{.3662\ N}{\frac{1}{4}\pi(1.10 \times 10^{6})}} =$$

$$d = .0006511 m$$

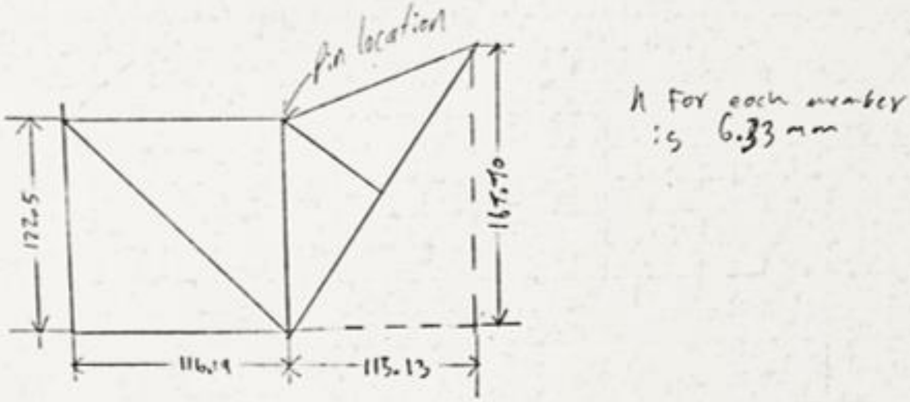
$$\boxed{d = .6511 mm}$$

Minimum Diameter

Appendix A-7a Base for the lifting mechanism

Marc Chizell	MET 489A	10/11/2020	1/3

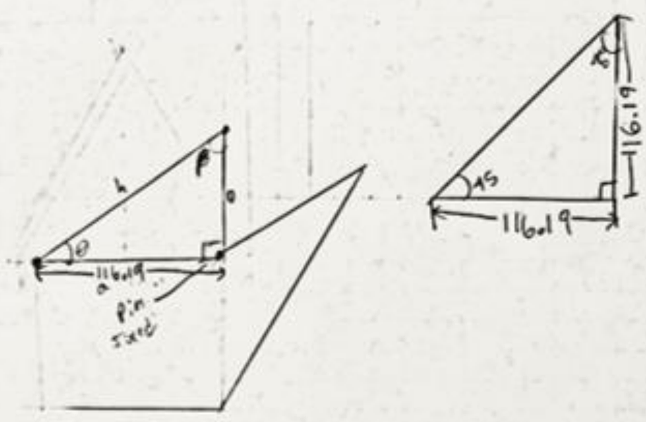
Given: Picture shown



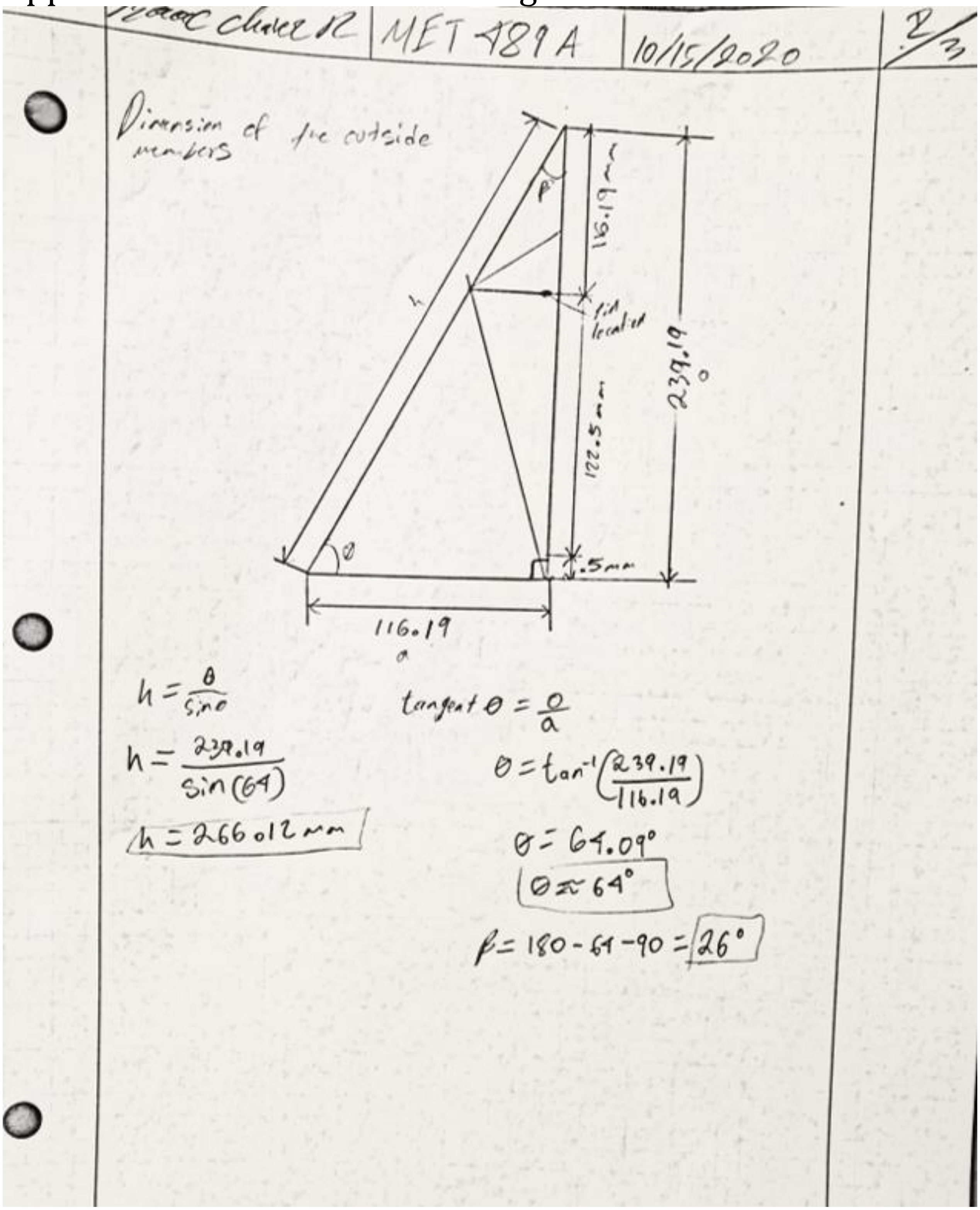
Find: Base for the lifting mechanism dimensions
First, location for the lifting mechanisms, supports, the best height, then the whole base

Assume: it is at resting position,

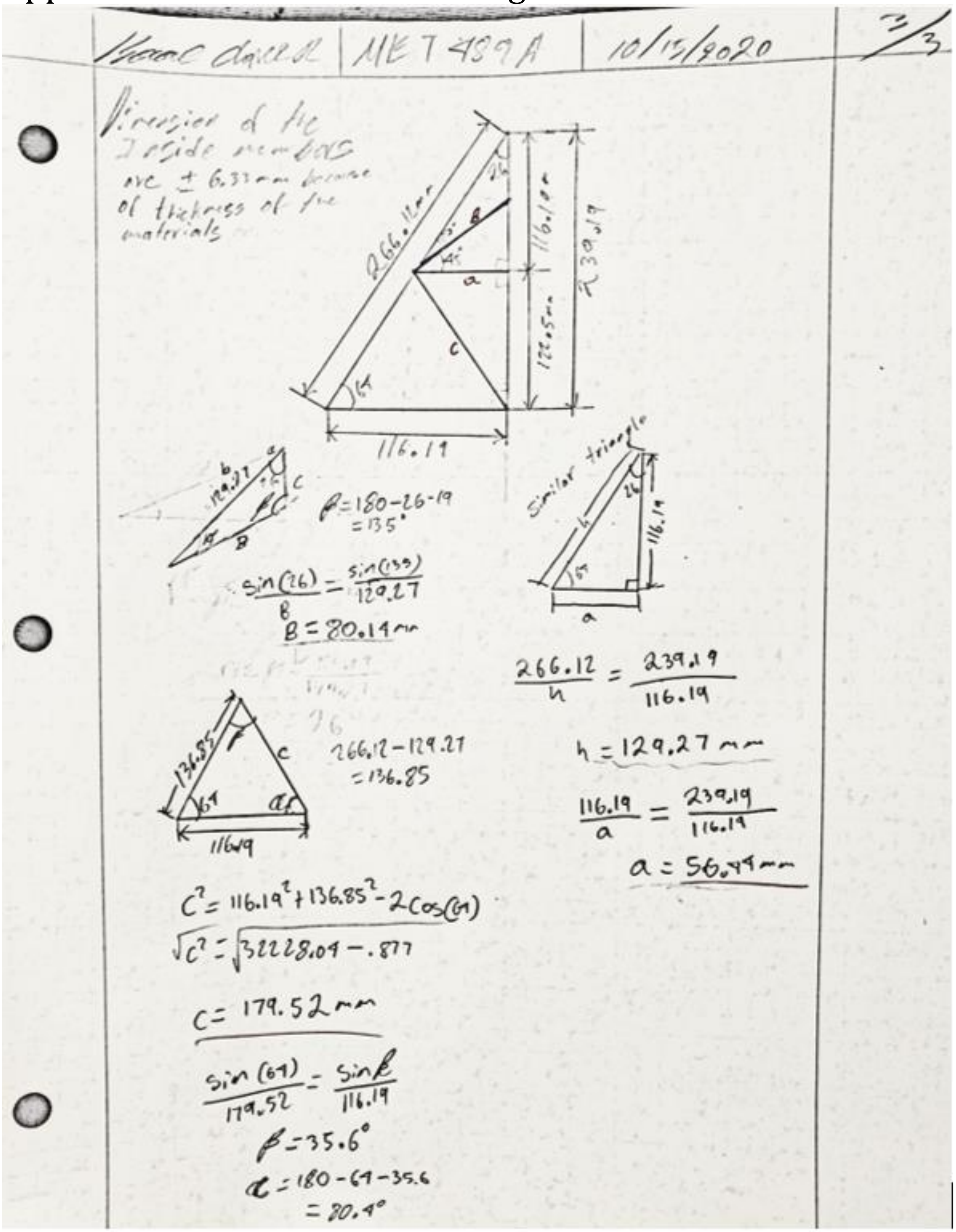
Method: Trigonometry functions



Appendix A-7b Base for the lifting mechanism



Appendix A-7c Base for the lifting mechanism



Kareem [illegible] | MET 489A | 10/15/2020 | 3/3

Direnzion of the Inside members are ± 6.3? mm because of thickness of the materials

266.12 mm, 116.19 mm, 122.5 mm, 239.19, 26, 64, a, b, c, B, 116.19

$\beta = 180 - 26 - 19 = 135°$

$\frac{\sin(26)}{B} = \frac{\sin(135)}{129.27}$

$B = 80.14$ mm

Similar triangle

$\frac{266.12}{h} = \frac{239.19}{116.19}$

$h = 129.27$ mm

$\frac{116.19}{a} = \frac{239.19}{116.19}$

$a = 56.44$ mm

$266.12 - 129.27 = 136.85$

$C^2 = 116.19^2 + 136.85^2 - 2\cos(64)$

$\sqrt{c^2} = \sqrt{32228.04 - .877}$

$c = 179.52$ mm

$\frac{\sin(64)}{179.52} = \frac{\sin\beta}{116.19}$

$\beta = 35.6°$

$\alpha = 180 - 64 - 35.6 = 80.4°$

Appendix A-8

[illegible]	MET 484	10/20/2020	1/1

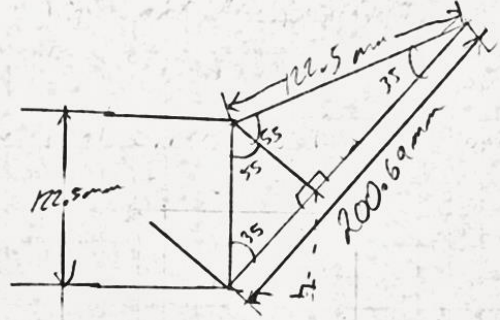
Given: Previous Analysis, the Bridge opening must be at least 38 mm wide by at least 25 mm high.

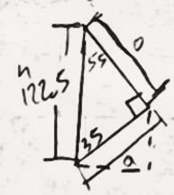
Find: The right dimensions of the Opening

Assume: Rectangular shape.

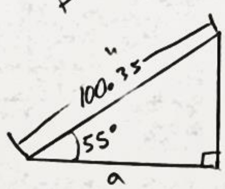
Method: Depends on the Find.

Soln: from Analysis 3





$\cos(35) = \frac{a}{122.5}$ $a = 100.35$ mm



$\sin(55) = \frac{o}{100.35}$ $o = \underline{82.20\text{ mm}}$

Road Deck is 40 mm X 82.20 mm

Appendix A-9

[illegible]	MET 489	10/20/2020

Given: Analysis 7, Hole Diameter = 8mm & Analysis 1

Find: Road deck beams Dimensions, floor & location of the hole.

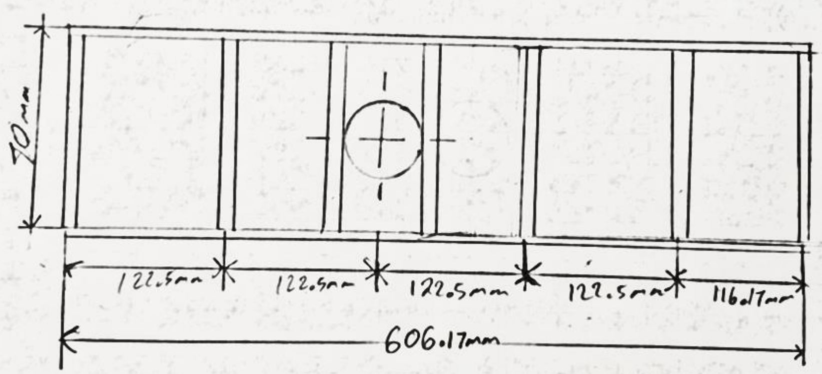
Assume: the beams will be rectangular shape

Method: Depends on find.

Soln: Analysis 7 dimensions 40 mm deck

floor: Length of the beams will be 40 mm

the width and thickness will be the same as the other beams components for the bridge 6.33mm X 3.302mm



Total Numbers of Beams

7 Beams Dimensions: 40mm X 6.33mm X 3.302mm

Appendix A-10

Isaac Chavez | MET 489 | 10/27/2020 | 1/1

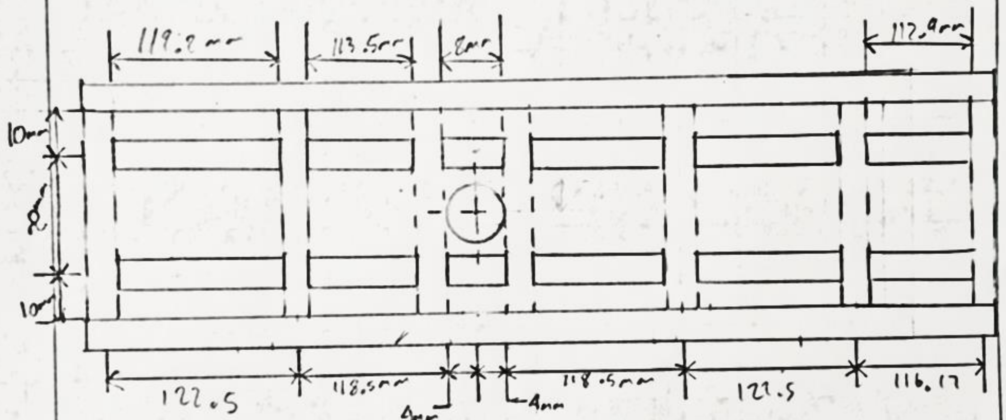
Analysis 9

Given: Analysis 8

Find: Bottom Secondary Beam dimensions, Numbers of beams & locations

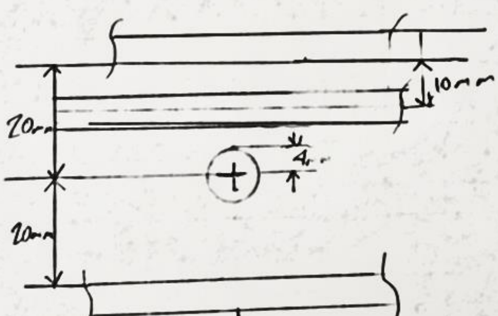
Assume: this are perpendicular to the main bottom beam

Soln:



40/2 = 20

20/2 = 10



118.5mm − 3.302mm − $\frac{3.302}{2}$
= 113.5mm
± .05mm

122.5 − 3.302mm
= 119.198mm
= 119.2mm
−.01

116.17 − 3.302
= 112.868
= 112.9mm
−.03

4 Beams of 119.2mm X 3.302mm X 6.33mm
4 Beams of 113.5mm X 3.3mm X 6.3mm
2 Beams of 8mm X 3.3m X 6.3mm
2 Beams of 112.9mm X 3.3mm X 6.3mm.

Appendix A-11a

[illegible] Chavez | MET 489 | 10/28/2020 | 1/2

Given: Analysis 1, 3, & 7

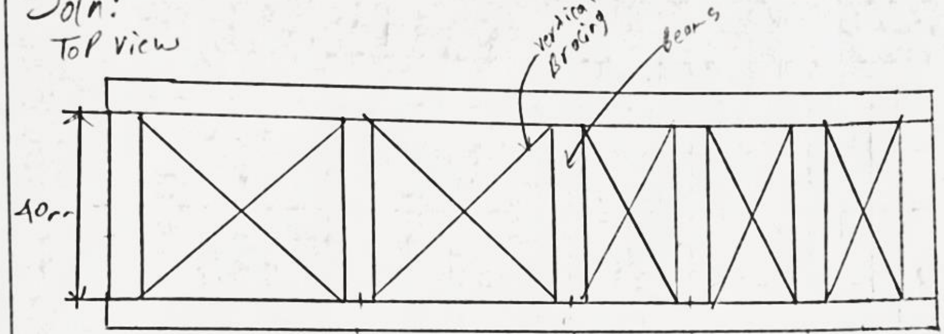
Find: the Dimensions of the Beams and location of each on the top section of the Bridge & lateral Bracing

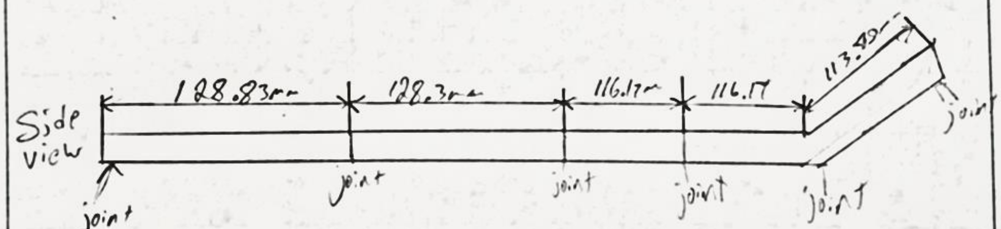
Assume: at each joint will be a support

Method: depend on find

Soln:

Top view





the width & high of each beam will be the same as previous Beams

> Total Beams Dimensions
> 6 Beams of 40mm X 6.33mm X 3.3mm

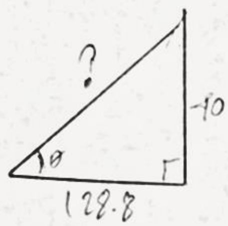
Lateral Bracing

Next Page

Appendix A-11b

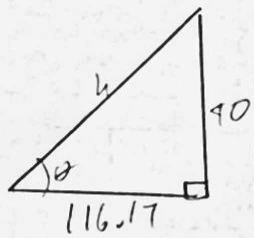
Omar R | ME T 489 | 10/29/2020 | 1/2

Lateral Bracing will be of round Balsa wood



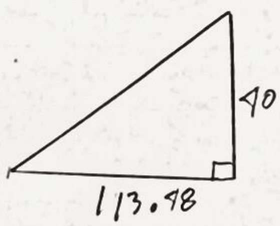
$\tan\theta = \frac{o}{a}$ $\theta = \tan^{-1}\left(\frac{40}{128.8}\right) = 17.25^\circ$
$= 17^\circ$

$\cos(17^\circ) = \frac{128.8}{?}$ $? = 134.68\,mm$



$\theta = \tan^{-1}\left(\frac{40}{116.17}\right) = 18.99^\circ$
$= 19^\circ$

$\cos(19) = \frac{116.17}{h}$ $h = 122.86\,mm$



$\theta = \tan^{-1}\left(\frac{40}{113.48}\right) = 19.416$
$= 19^\circ$

$\cos(19) = \frac{113.48}{h}$ $h = 120.02\,mm$

Total Lateral Bracing

4 Bracings of 134.68 mm long
4 Bracings of 122.86 mm long
2 Bracings of 120.02 mm long

Appendix A-12

[illegible signature]	MET 489A	11/3/2020	1

Analysis II

Given: Previous Analysis

Find: Mechanism of how the bridge will lift

Assume: Constant speed, constant load

method: Depends on find

Solution:

The Mechanism will be manual by gear and a gear rack

The gear rack dimensions will be like as follow

Face wd = 5mm

Pitch Height = 6.4mm

For the Gear

Face wd = 3mm

Pitch Dia = 8mm

N pinion = 16

Appendix A-13

Isaac daveR	MET 489	11/4/2020

Analysis 12

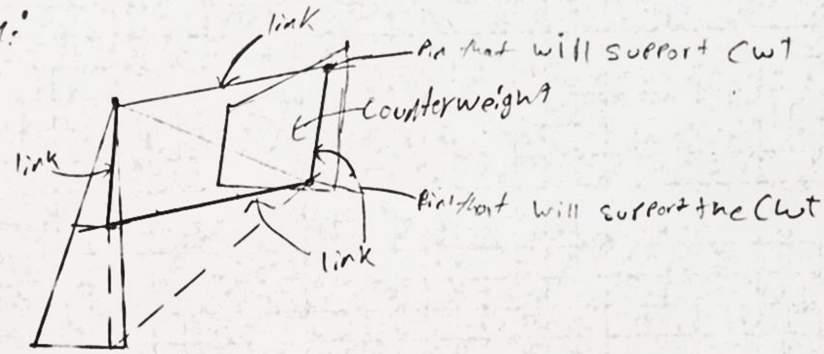
Given: Previous Analysis

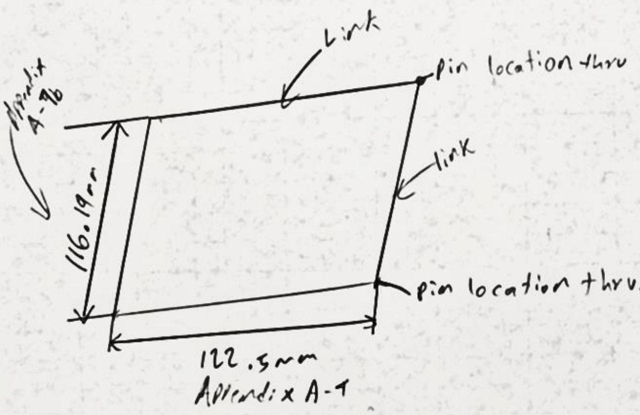
Find: Counterweight supports & link

Assumes the counterweight moves while the bridge moves

Method: Depend on find.

Soln:





the links will move while the bridge is lifting

Dimensions of the links

2 Beams of 116.19mm × 6.33mm × 3.3mm

2 Beams of 122.5mm × 6.33mm × 3.3mm

Appendix A-14

Israel Olavezzi | MET 489 | 1/1

Given: Gears teeths

Stepper Motor N=24

Shaft closes to stepper motor N=13

gear to rack = N=16

Find: Gear Ratios

Assume: Constant load

Method: Ratio

Soln:

Gear mating Gear from stepper motor

13:24 = .5

≈

1:2

Gear on the shaft

16:13

≈

1 ≈ .8

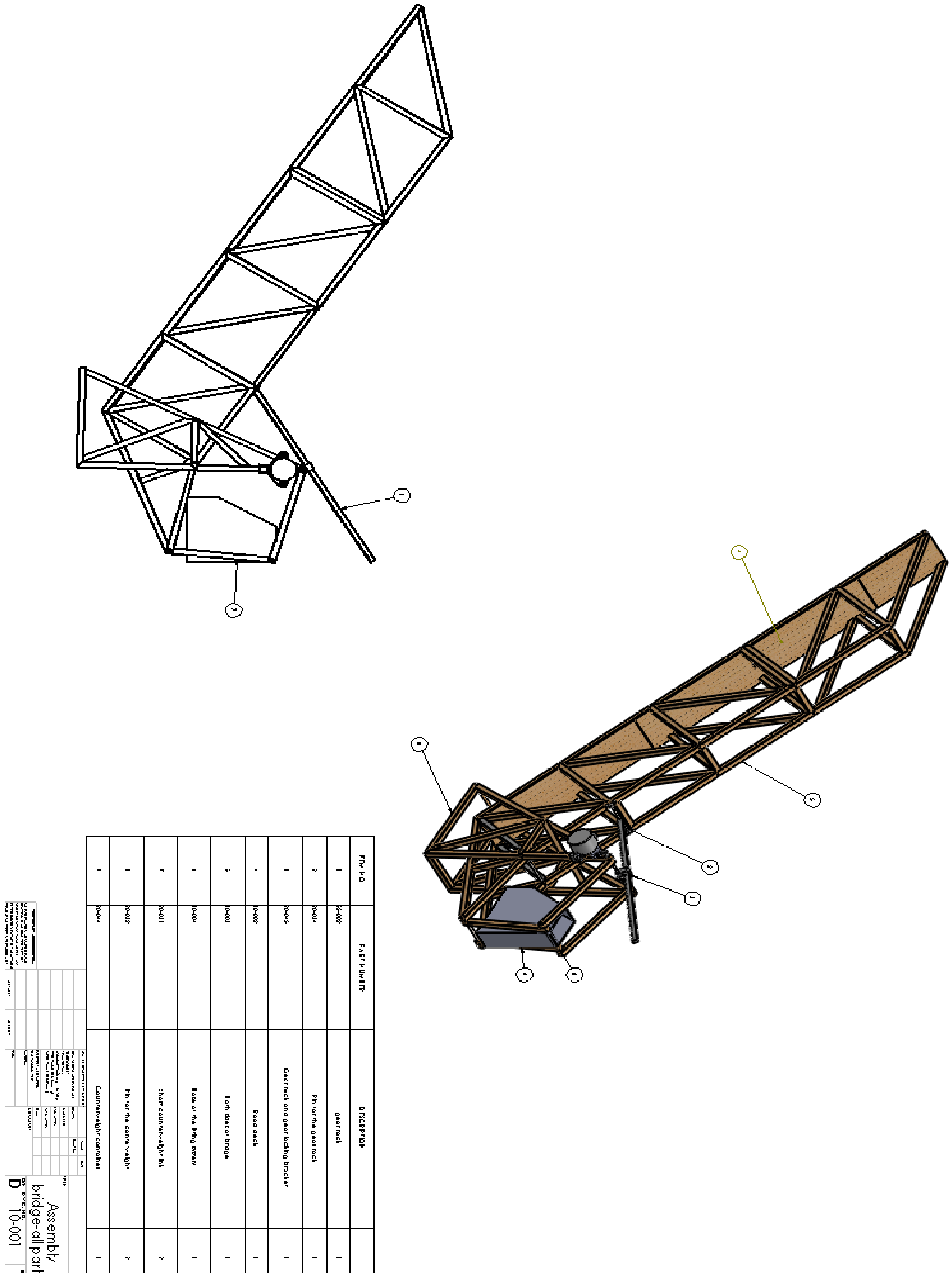
Rack & Gear.

25mm: 1 rev

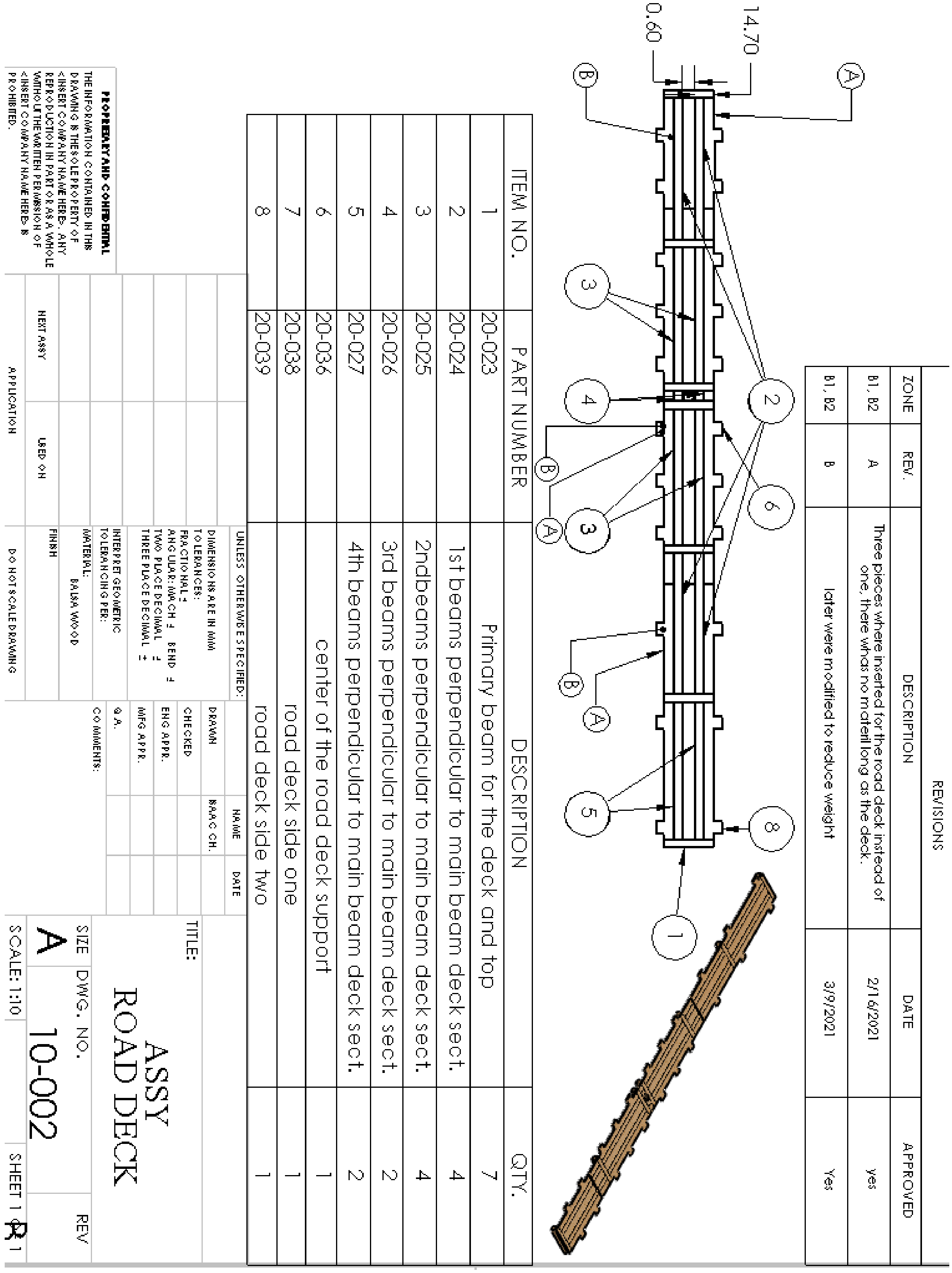
APPENDIX B – Drawings

Appendix B – Drawing Tree

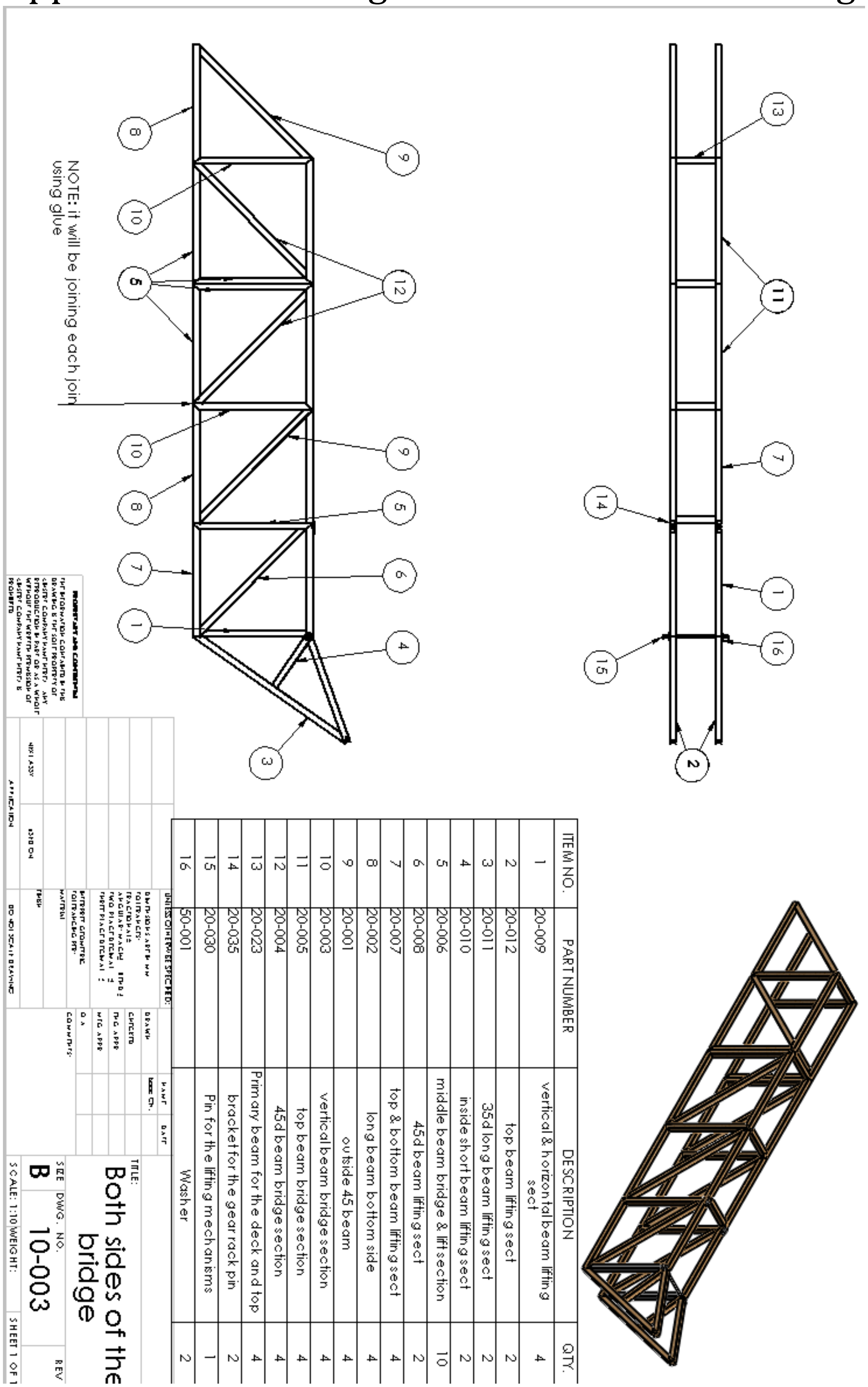
Appendix B-Drawing 10-001-Assy bridge



Appendix B – Drawing 10-002 Road deck Ass.

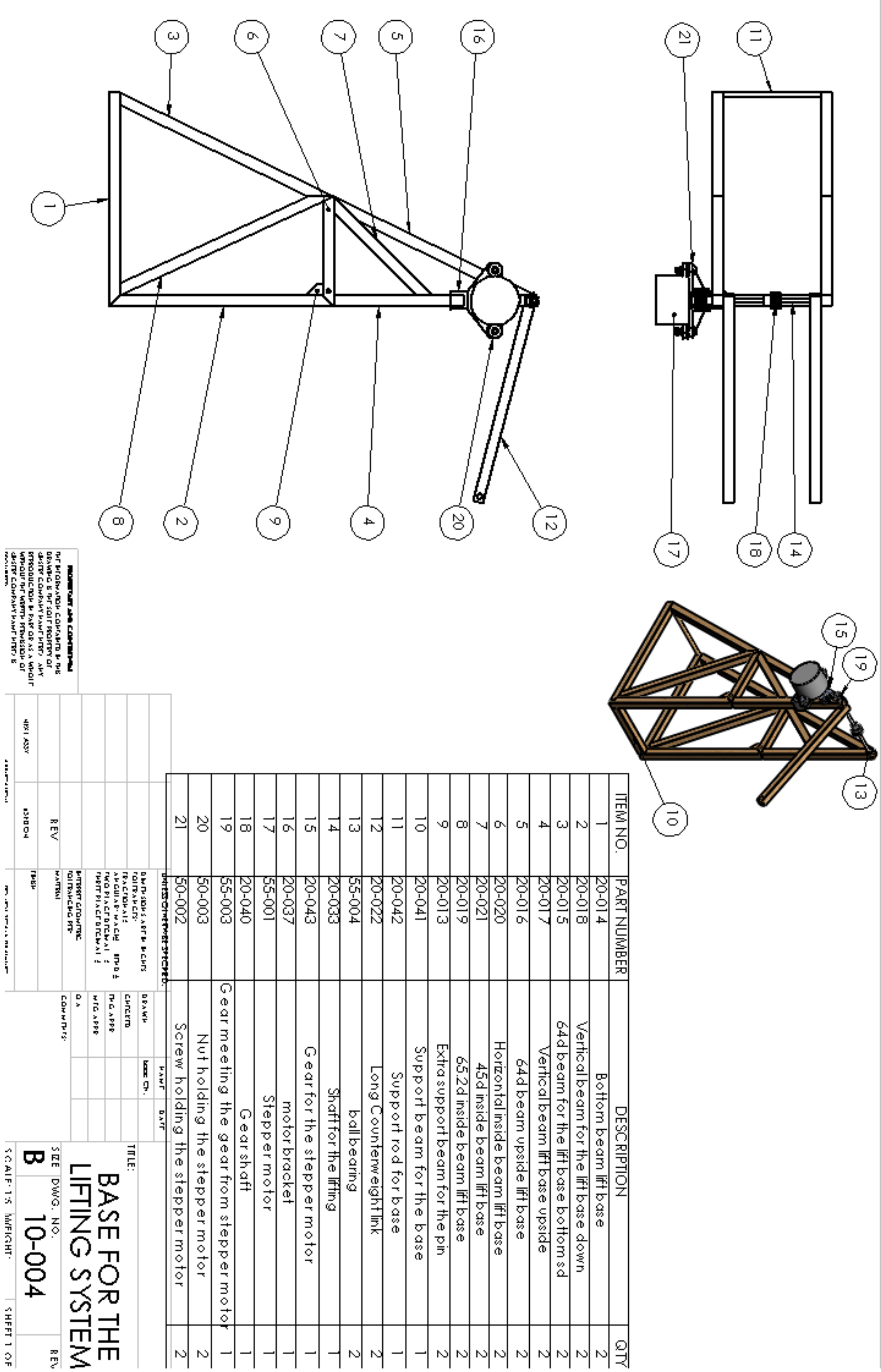


Appendix B – Drawing 10-003 Both sides of Bridge Ass.



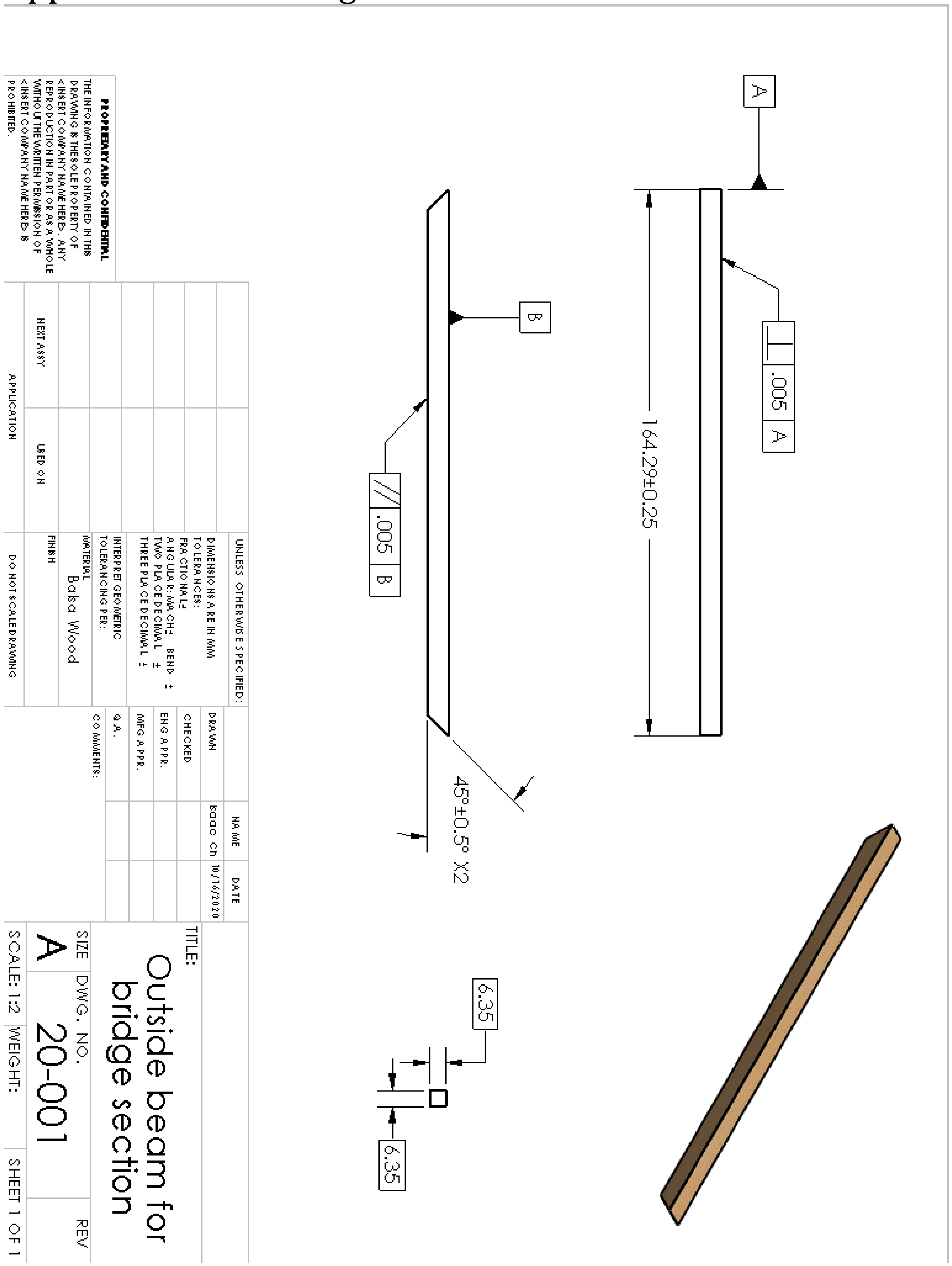
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-009	vertical & horizontal beam lifting sect	4
2	20-012	top beam lifting sect	2
3	20-011	35d long beam lifting sect	2
4	20-010	inside short beam lifting sect	2
5	20-006	middle beam bridge & lift section	10
6	20-008	45d beam lifting sect	2
7	20-007	top & bottom beam lifting sect	4
8	20-002	long beam bottom side	4
9	20-001	outside 45 beam	4
10	20-003	vertical beam bridge section	4
11	20-005	top beam bridge section	4
12	20-004	45d beam bridge section	4
13	20-023	Primary beam for the deck and top	4
14	20-035	bracket for the gear rack pin	2
15	20-030	Pin for the lifting mechanisms	1
16	50-001	Washer	2

Appendix B – Drawing 10-004 Base of Lifting System Ass.

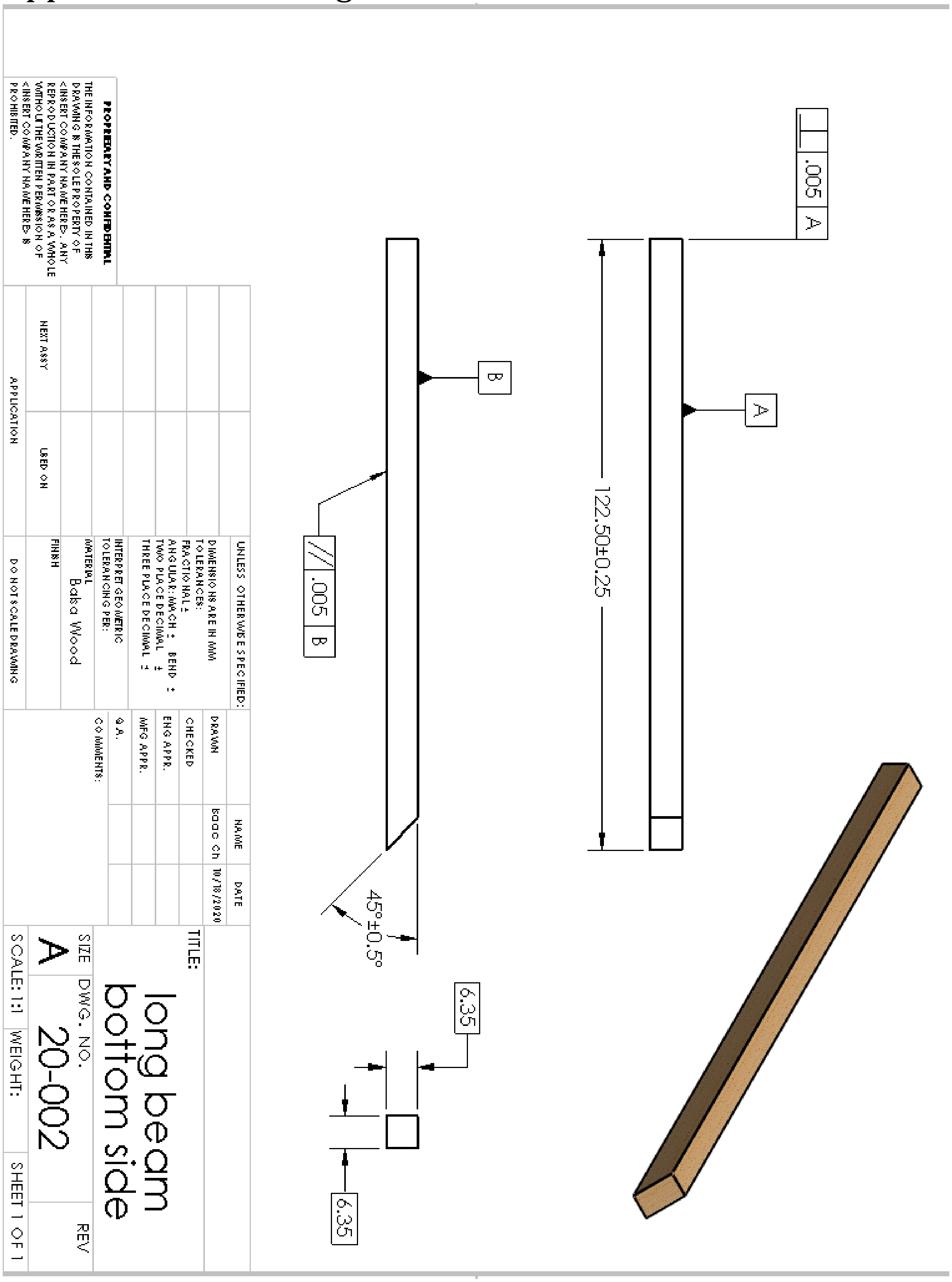


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-014	Bottom beam lift base	2
2	20-018	Vertical beam for the lift base down	2
3	20-015	64d beam for the lift base bottom sd	2
4	20-017	Vertical beam lift base upside	2
5	20-016	64d beam upside lift base	2
6	20-020	Horizontal inside beam lift base	2
7	20-021	45d inside beam lift base	2
8	20-019	65.2d inside beam lift base	2
9	20-013	Extra support beam for the pin	2
10	20-041	Support beam for the base	1
11	20-042	Support rod for base	1
12	20-022	Long Counterweight link	2
13	55-004	ball bearing	2
14	20-033	Shaft for the lifting	1
15	20-043	Gear for the stepper motor	1
16	20-037	motor bracket	1
17	55-001	Stepper motor	1
18	20-040	Gear shaft	1
19	55-003	Gear meeting the gear from stepper motor	1
20	50-003	Nut holding the stepper motor	2
21	50-002	Screw holding the stepper motor	2

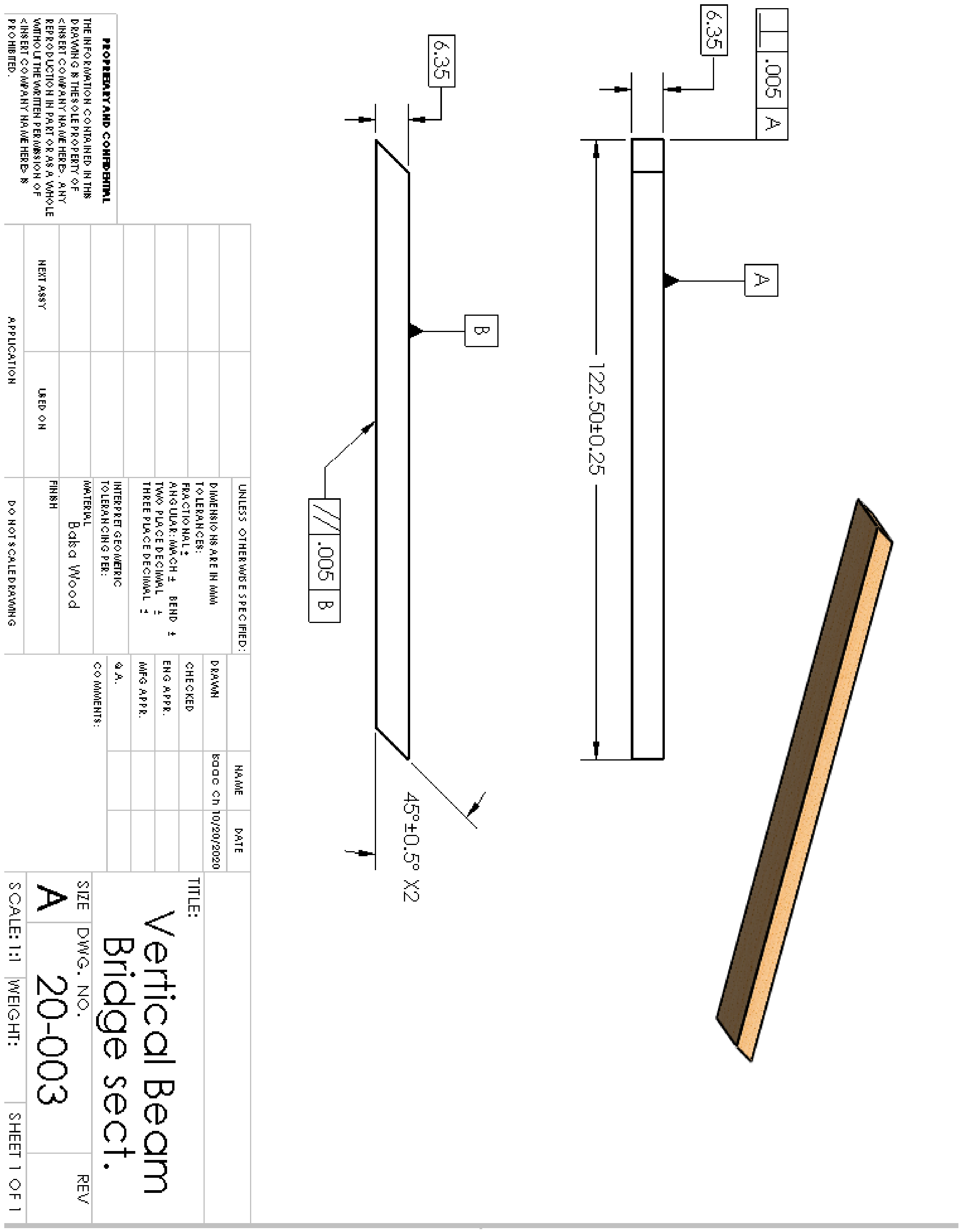
Appendix B – Drawing 20-001



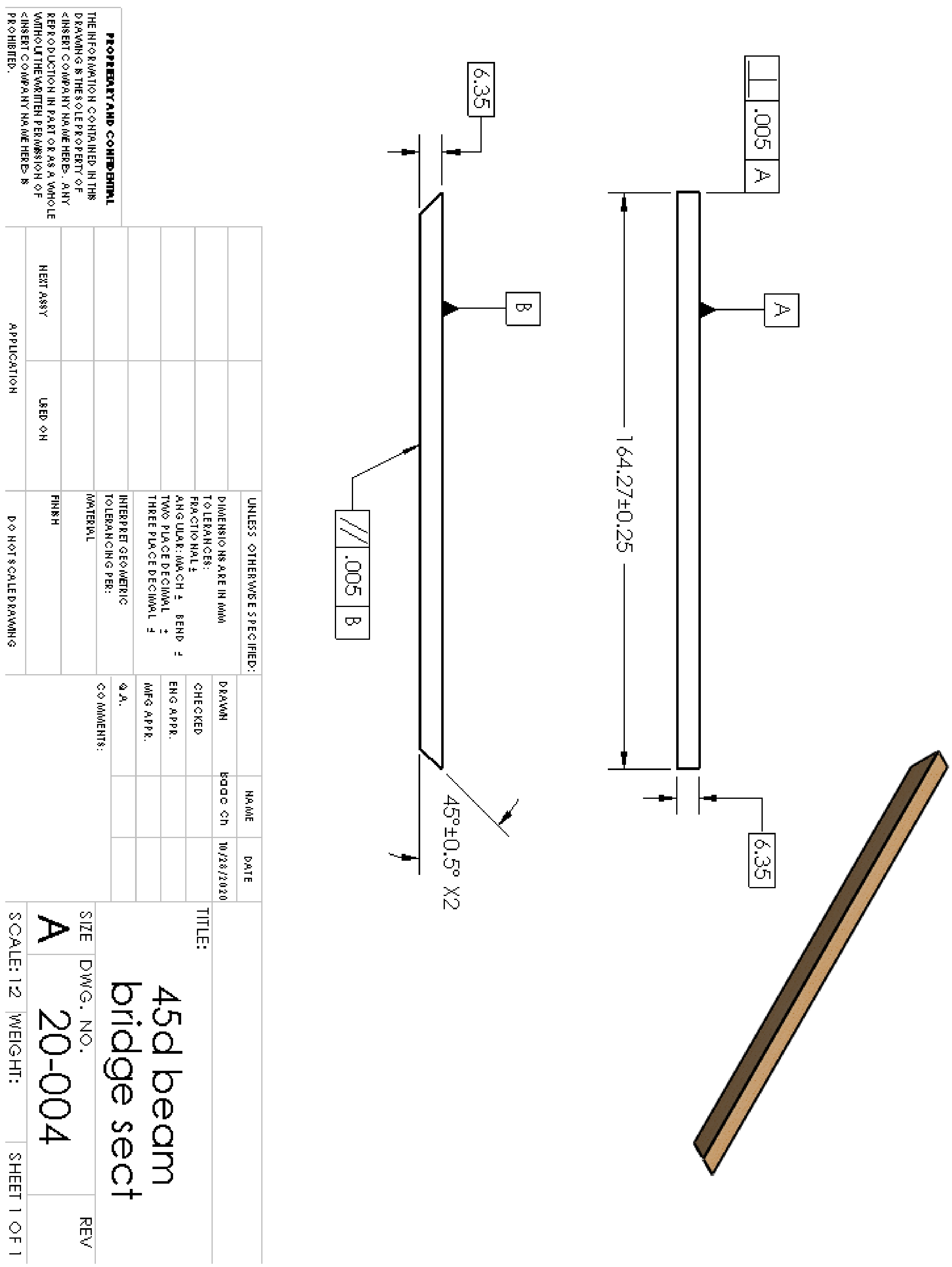
Appendix B – Drawing 20-002



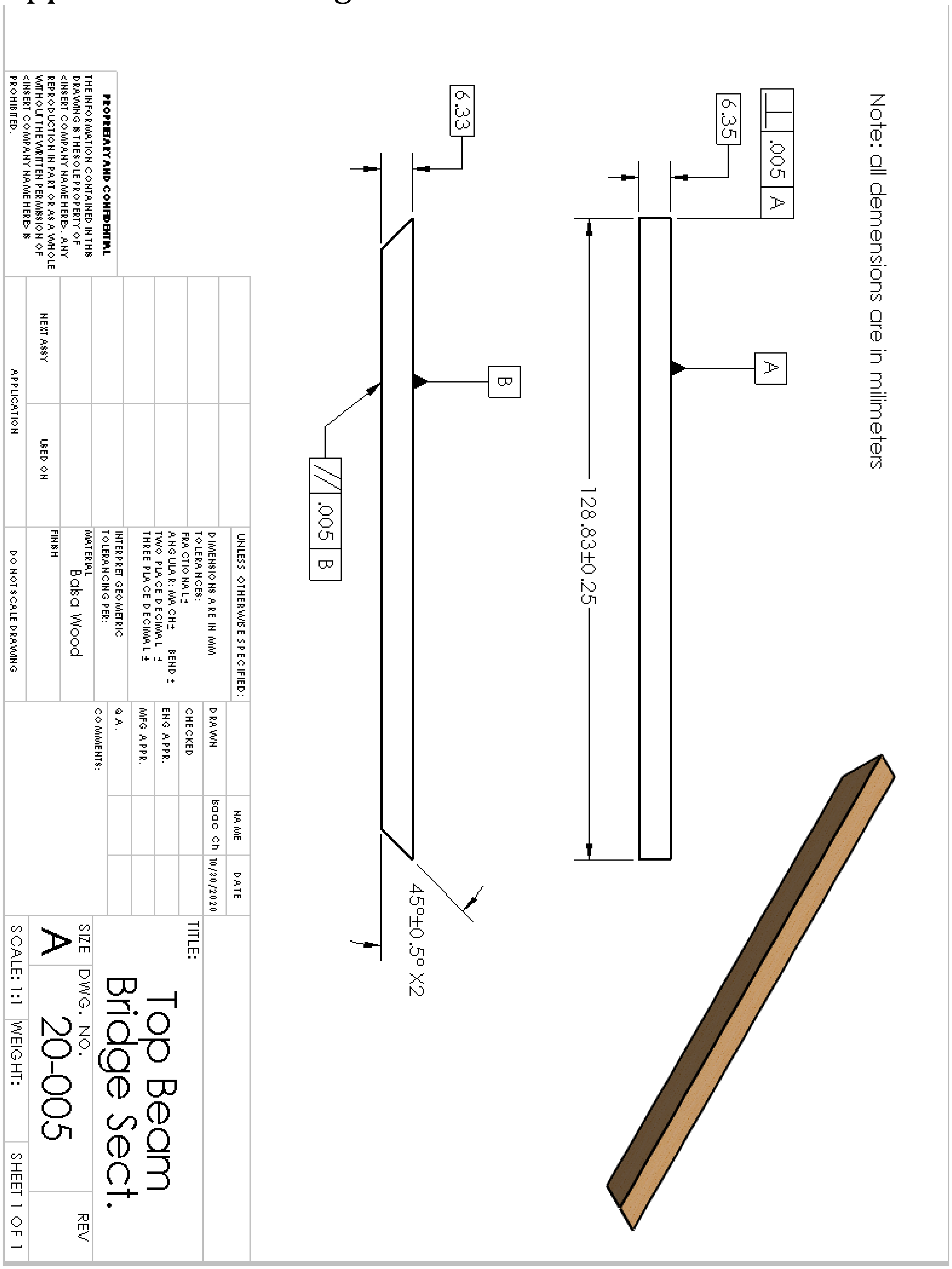
Appendix B – Drawing 20-003



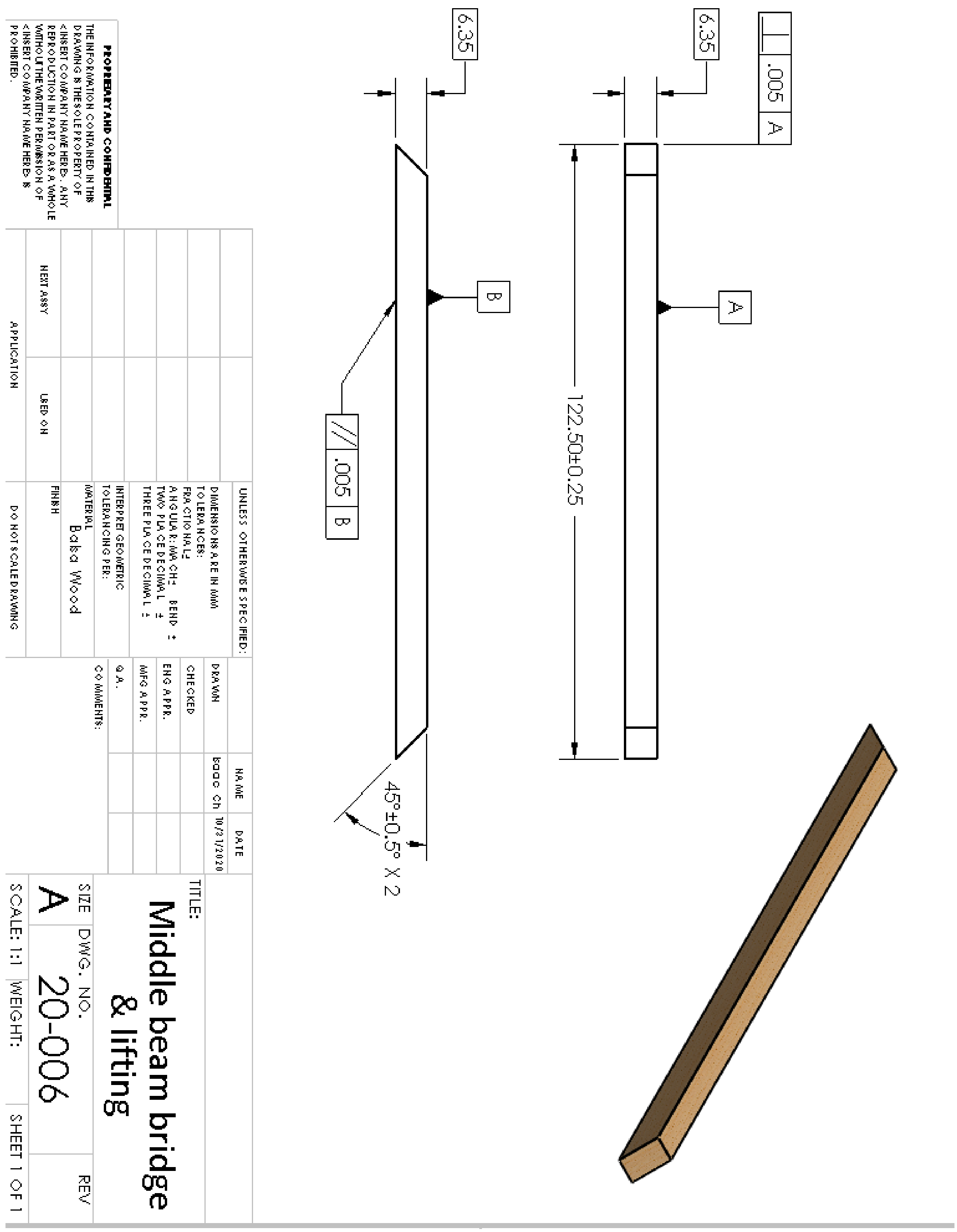
Appendix B – Drawing 20-004



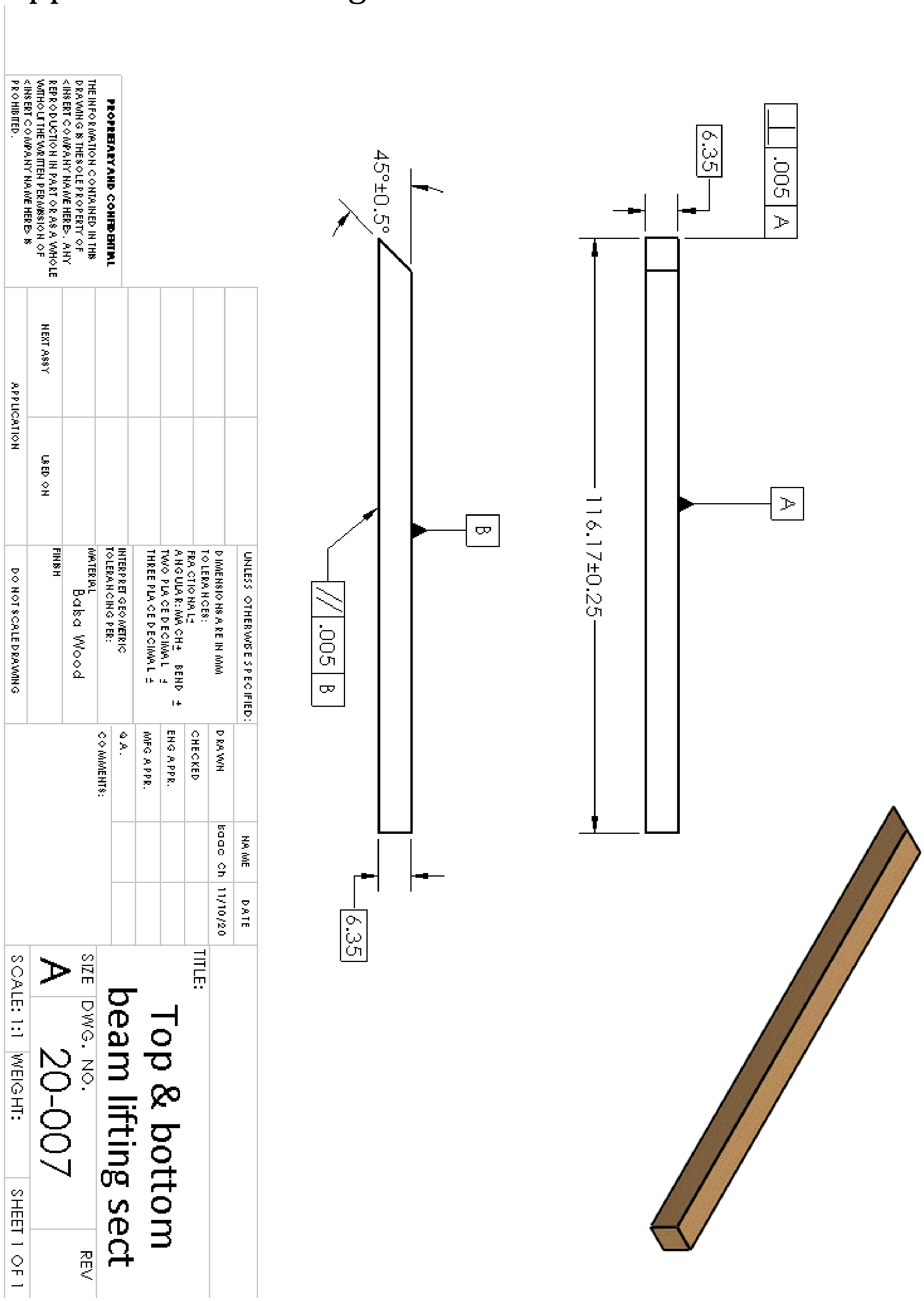
Appendix B – Drawing 20-005



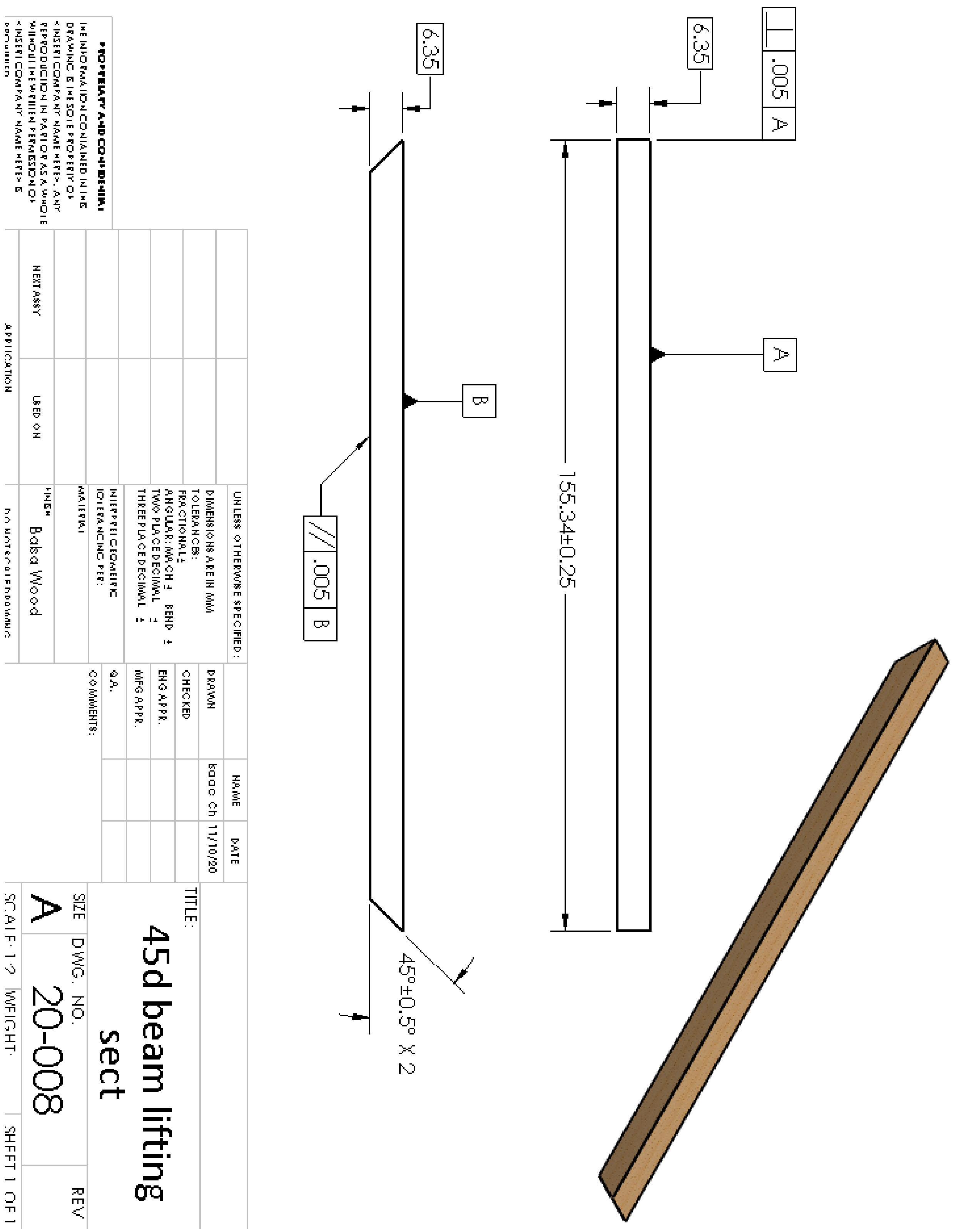
Appendix B – Drawing 20-006



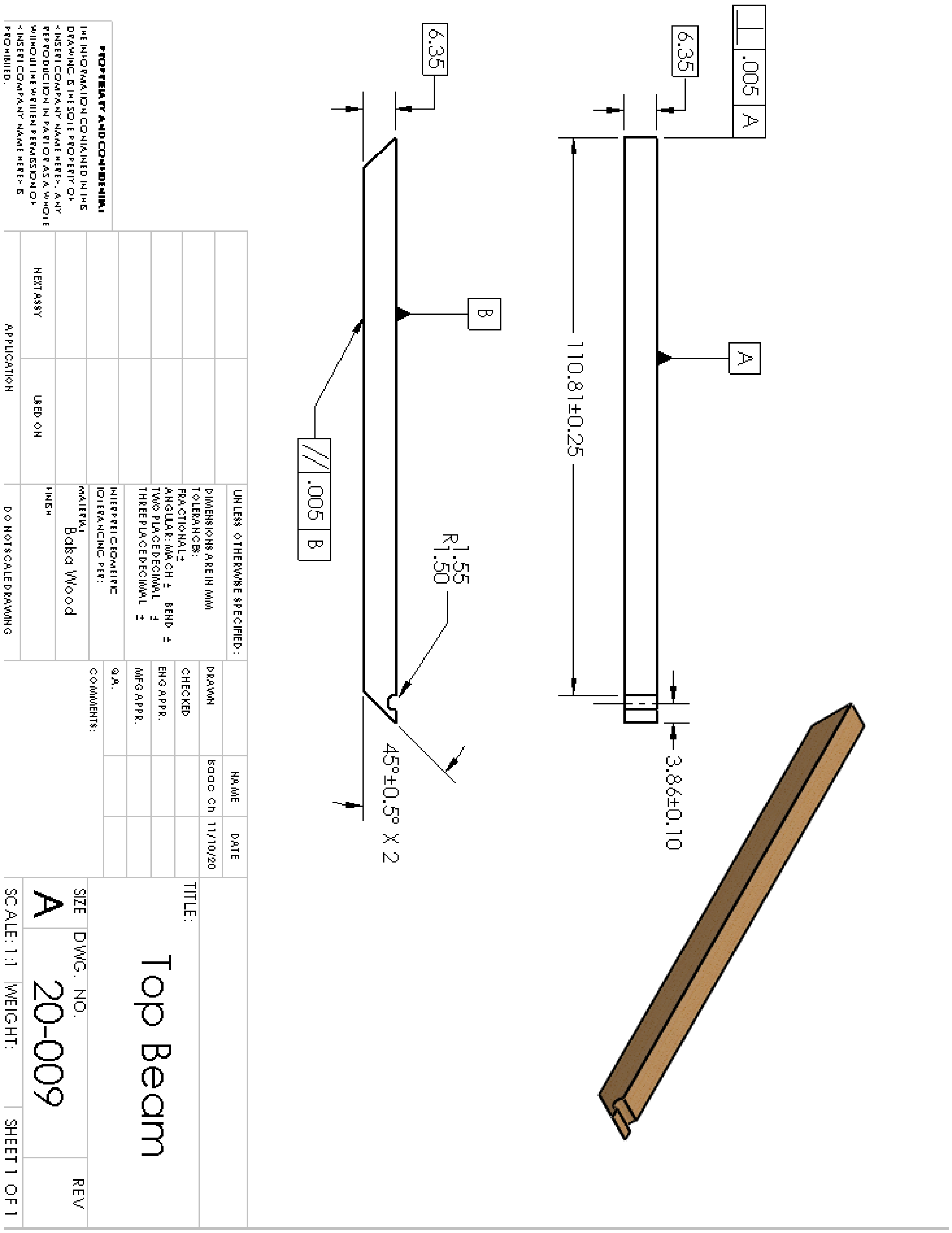
Appendix B – Drawing 20-007



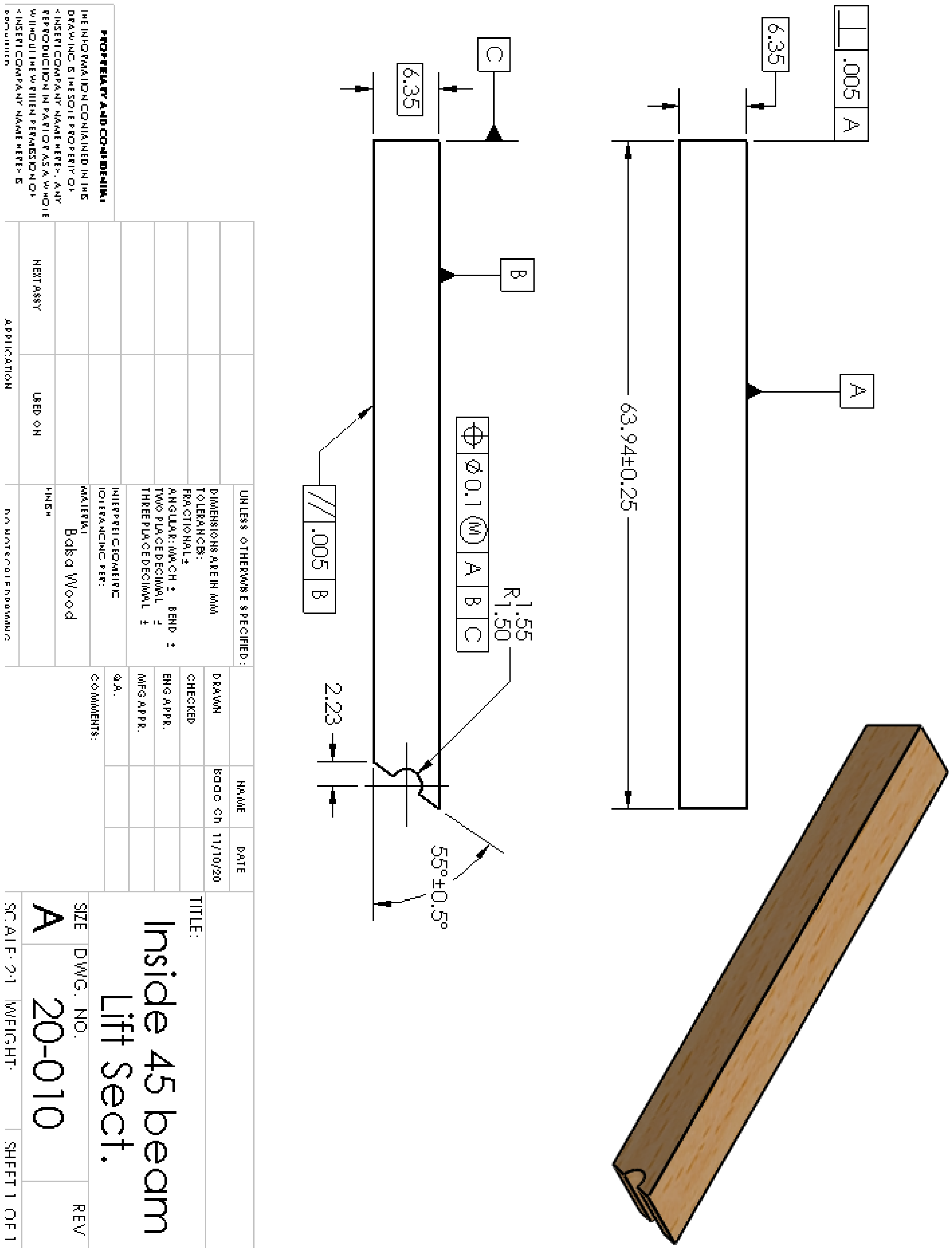
Appendix B – Drawing 20-008



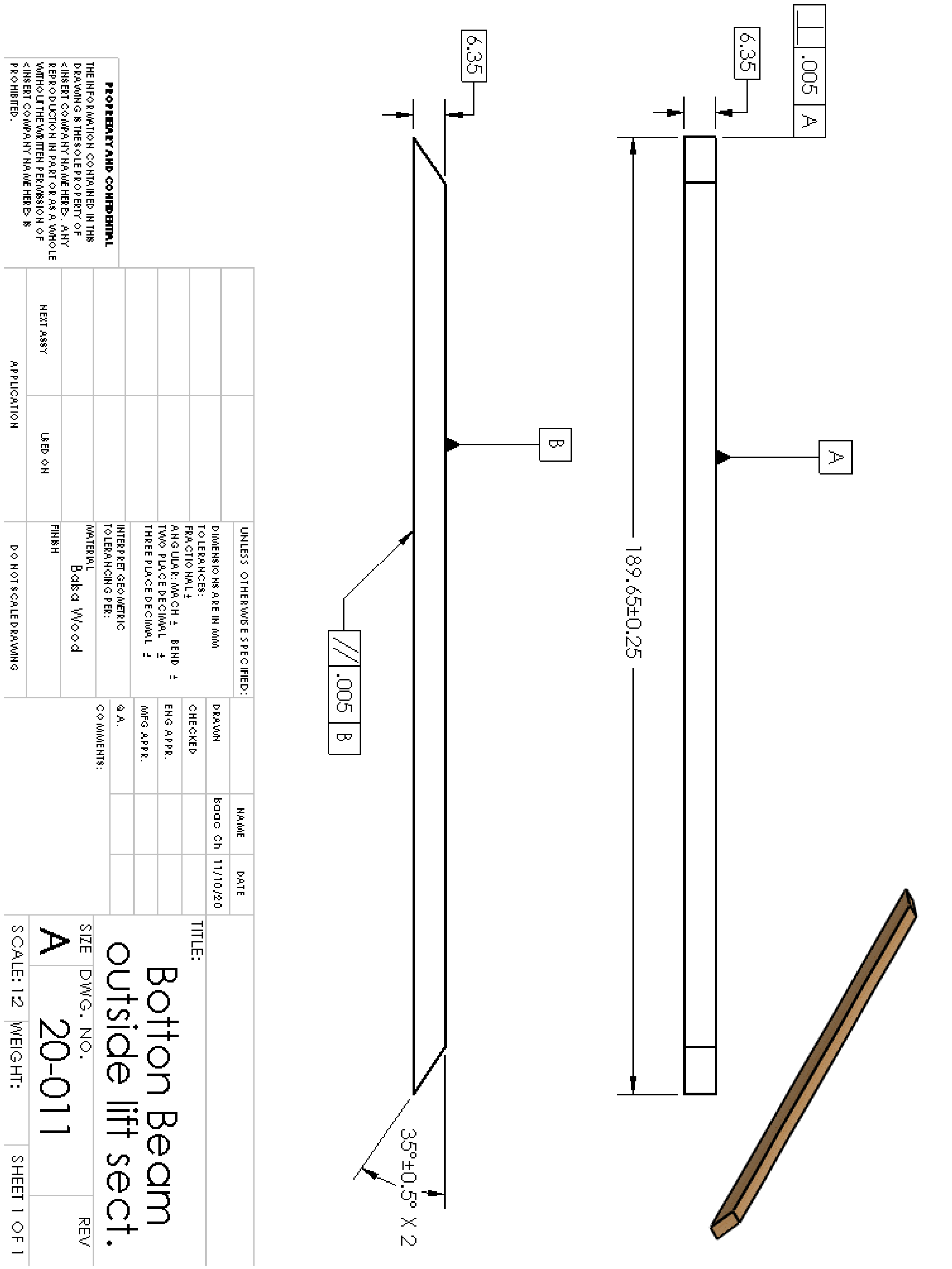
Appendix B – Drawing 20-009



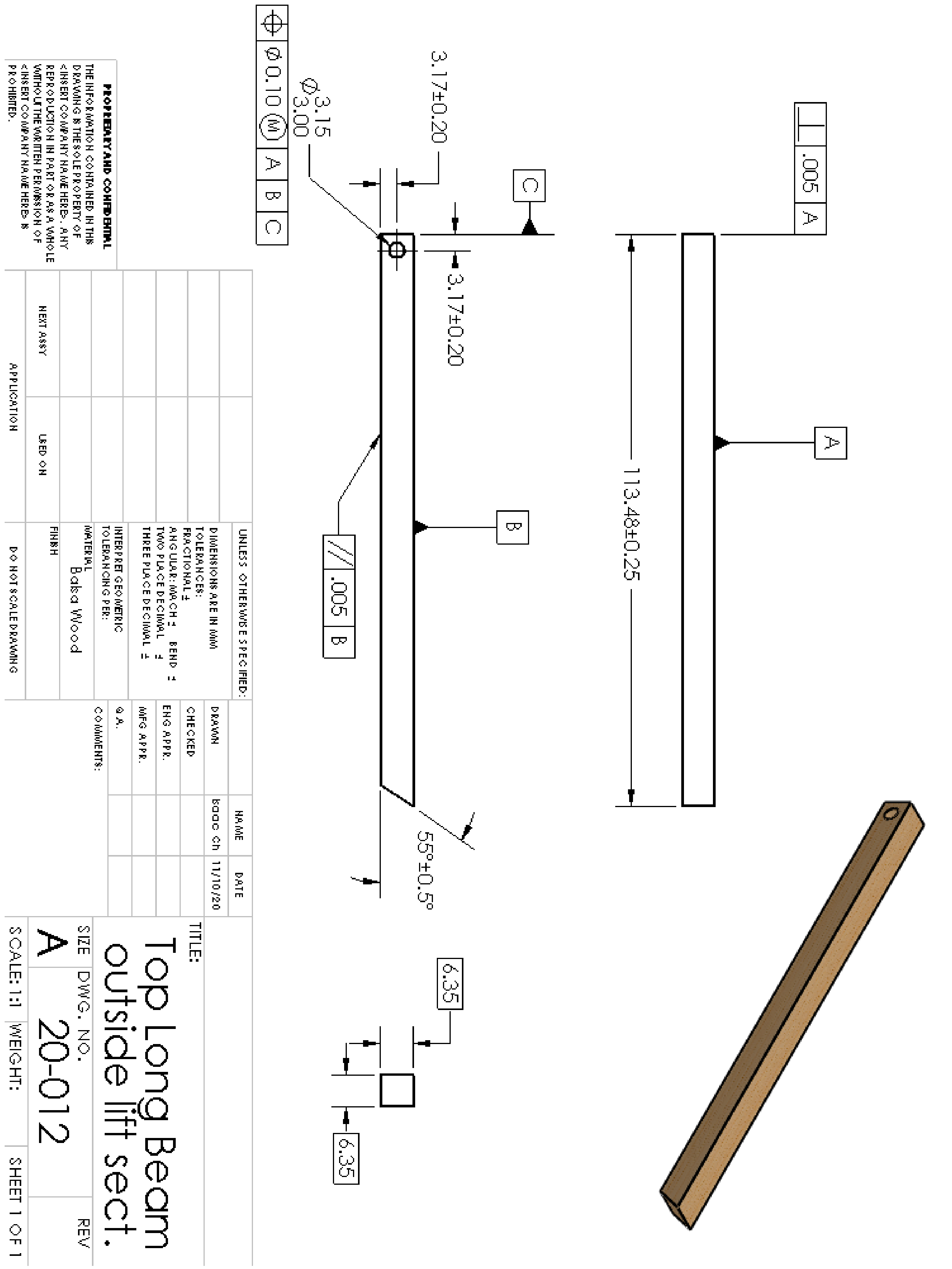
Appendix B – Drawing 20-010



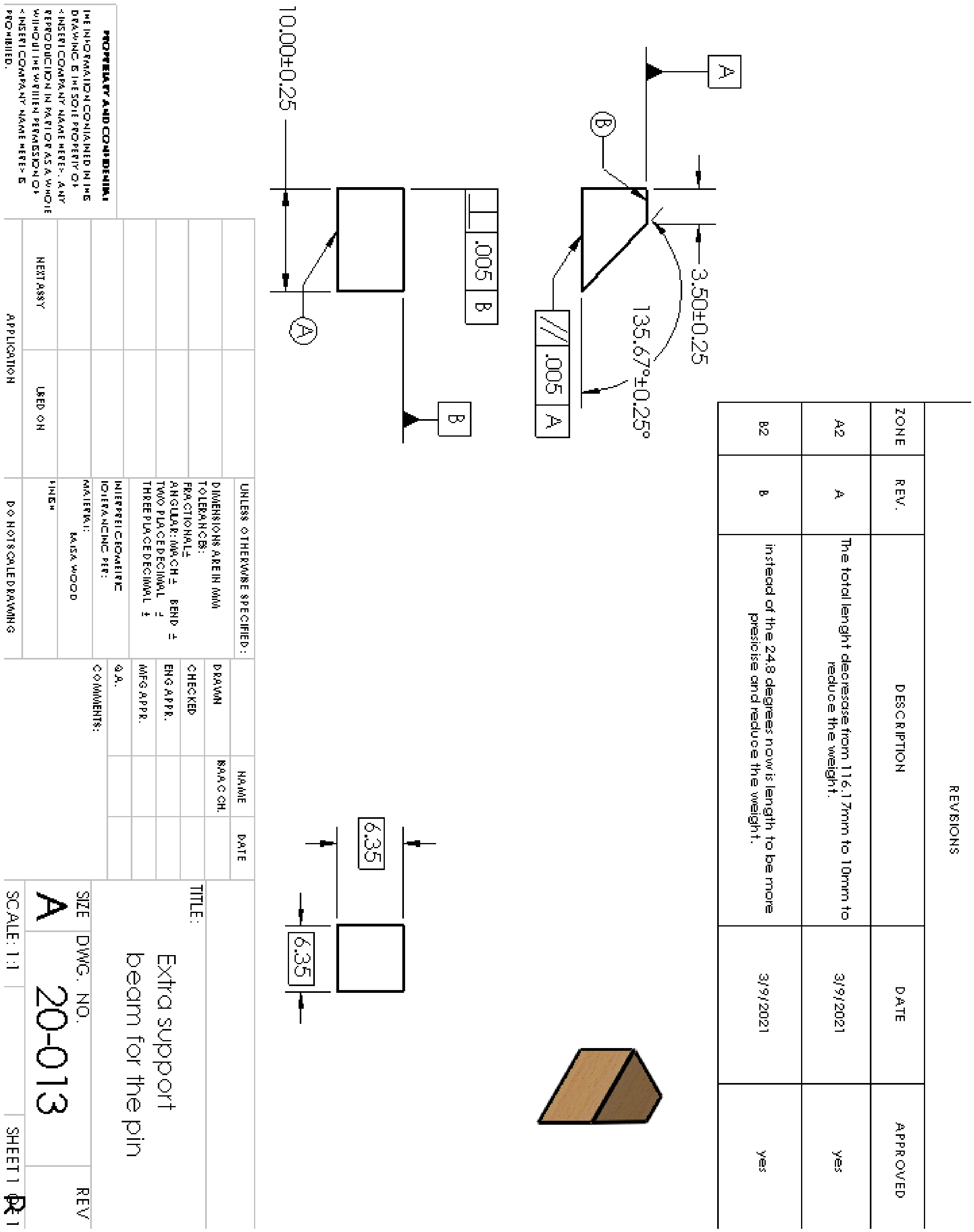
Appendix B – Drawing 20-011



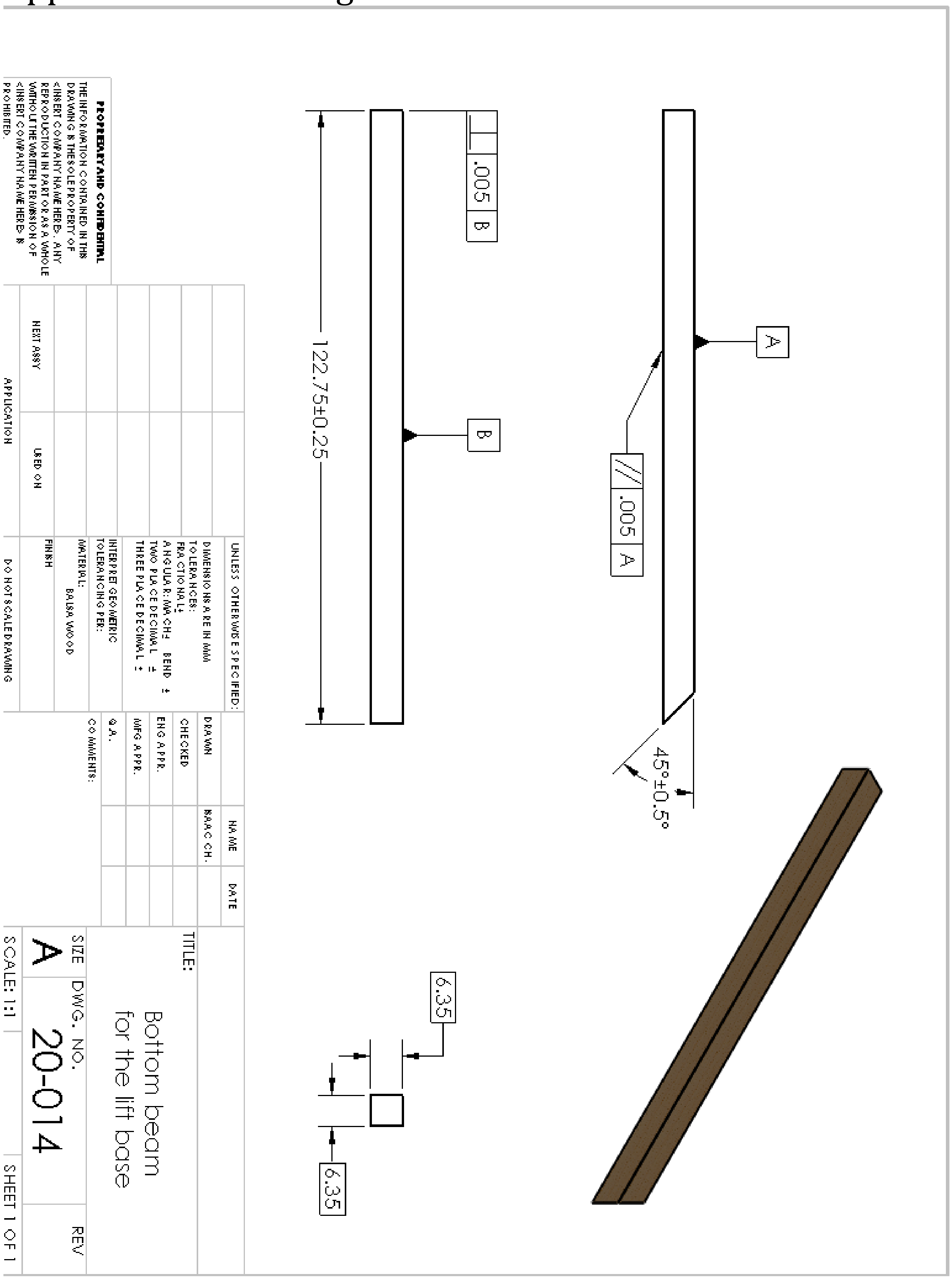
Appendix B – Drawing 20-012



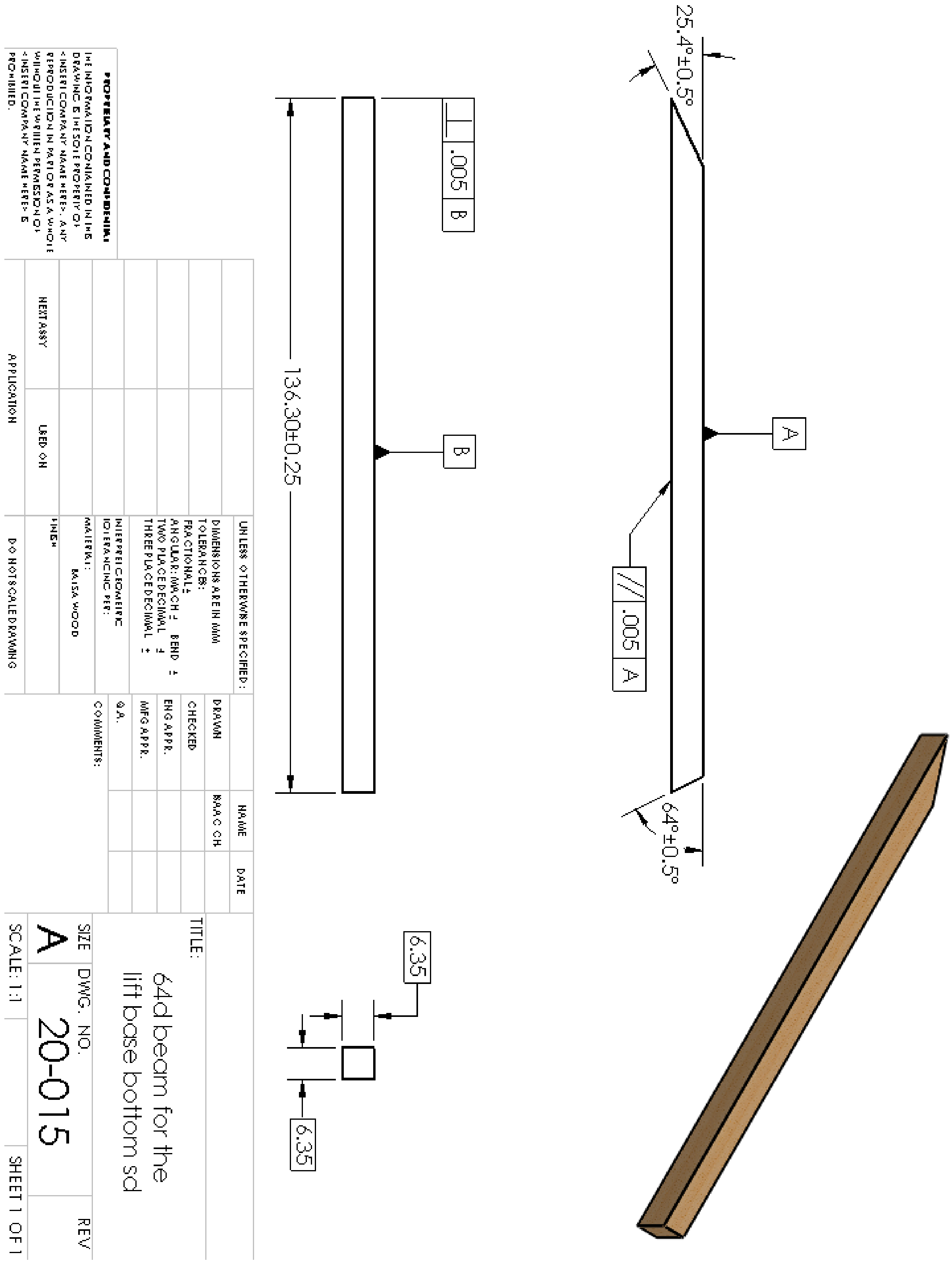
Appendix B – Drawing 20-013



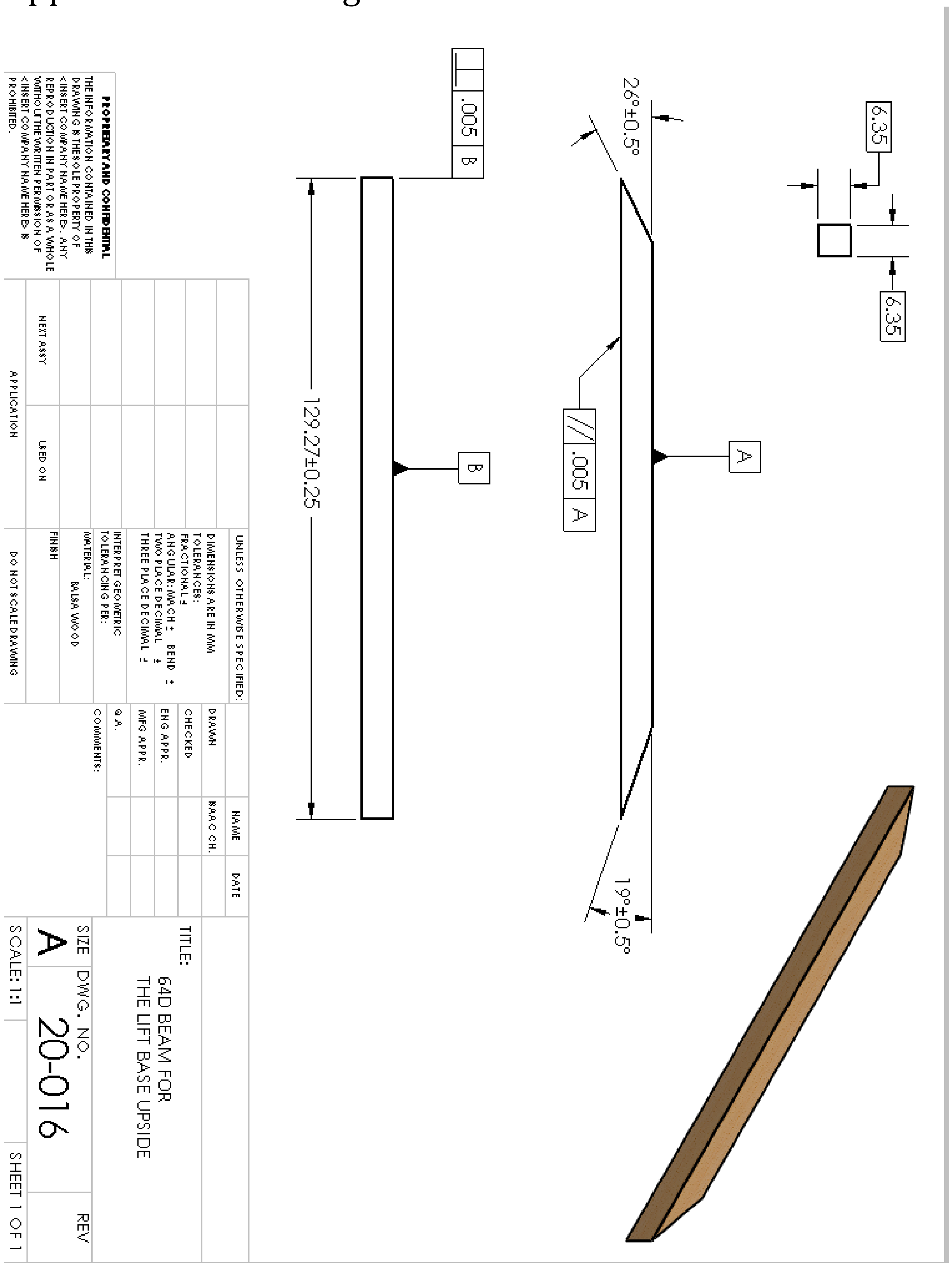
Appendix B – Drawing 20-014



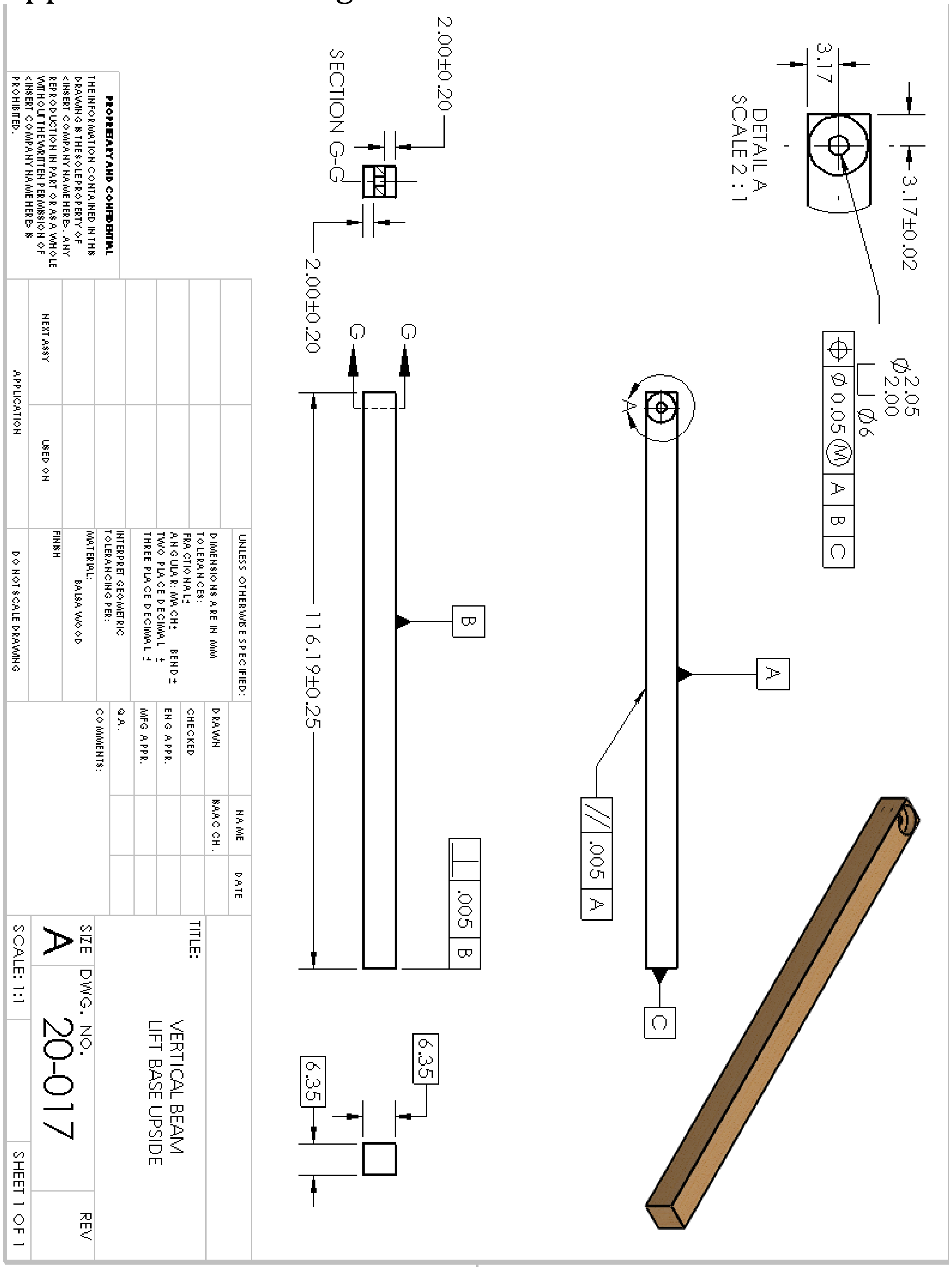
Appendix B – Drawing 20-015



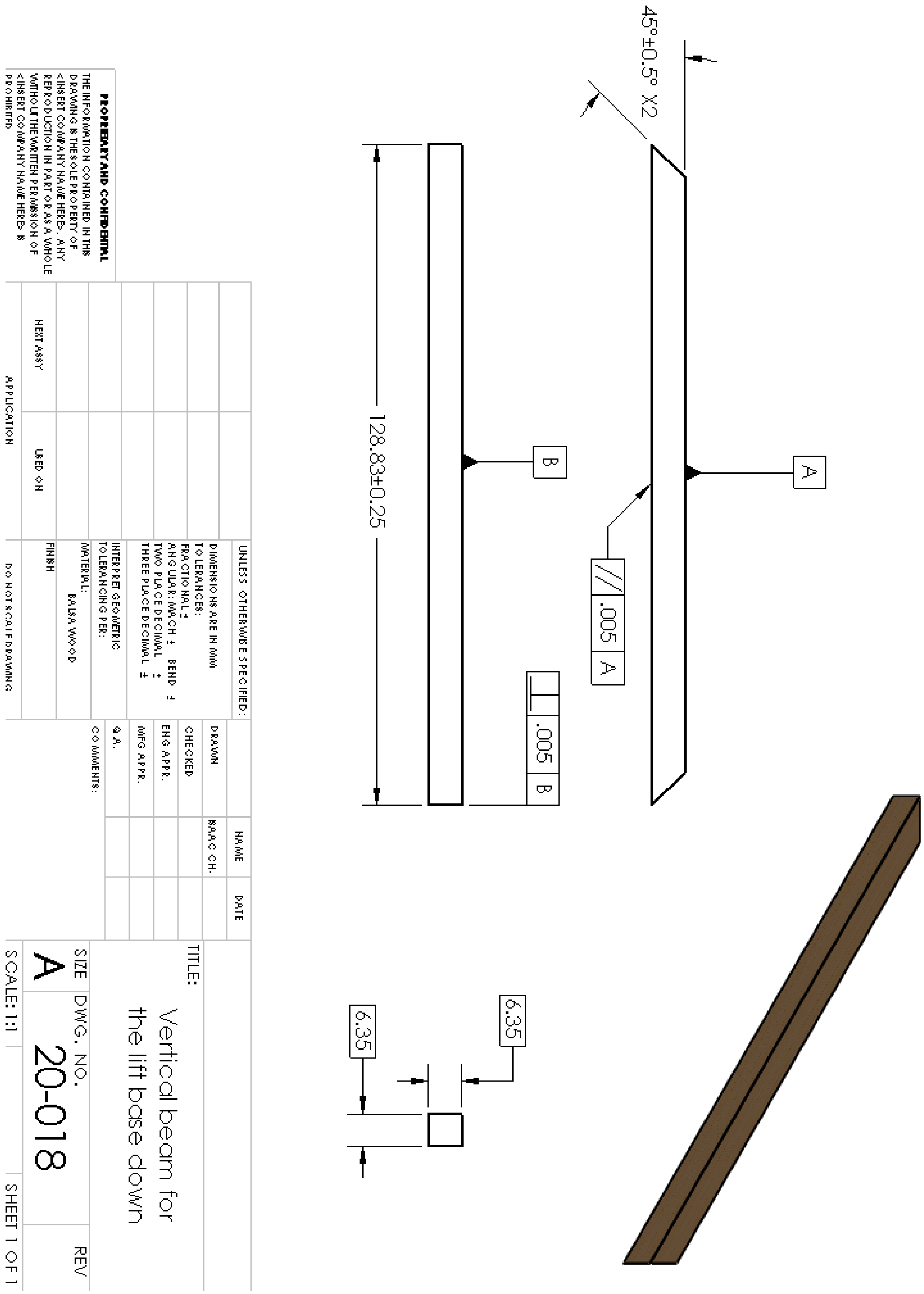
Appendix B – Drawing 20-016



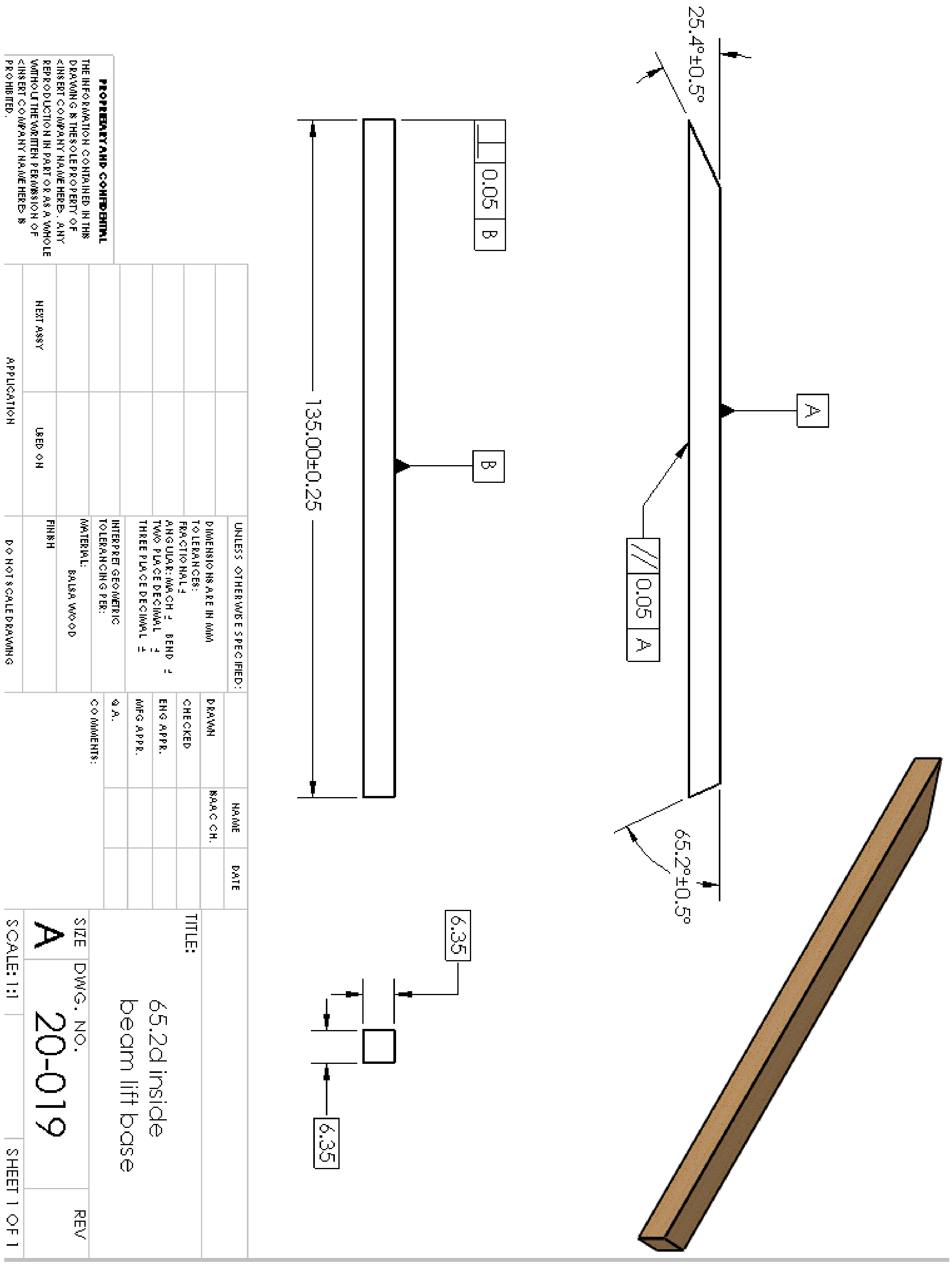
Appendix B – Drawing 20-017



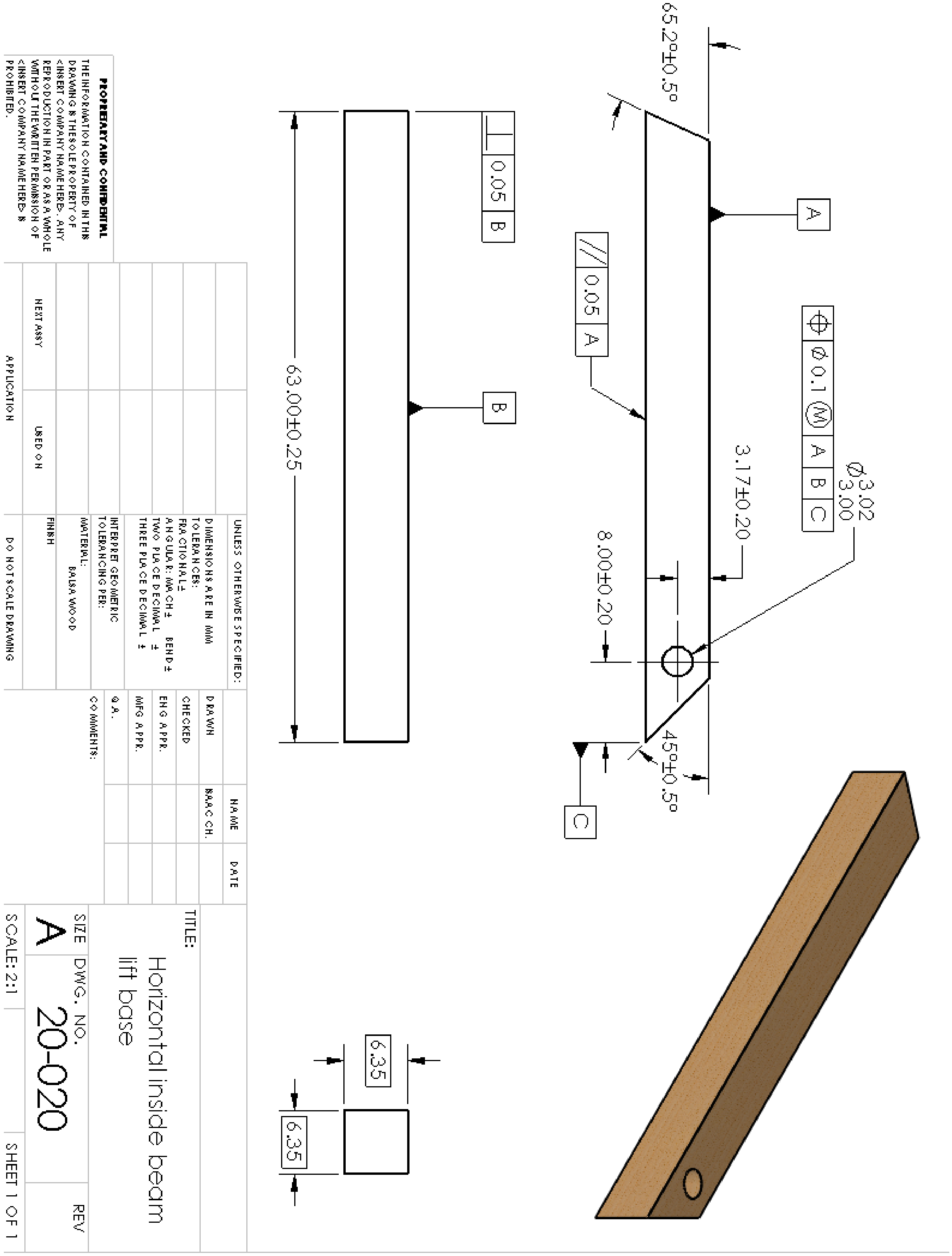
Appendix B – Drawing 20-018



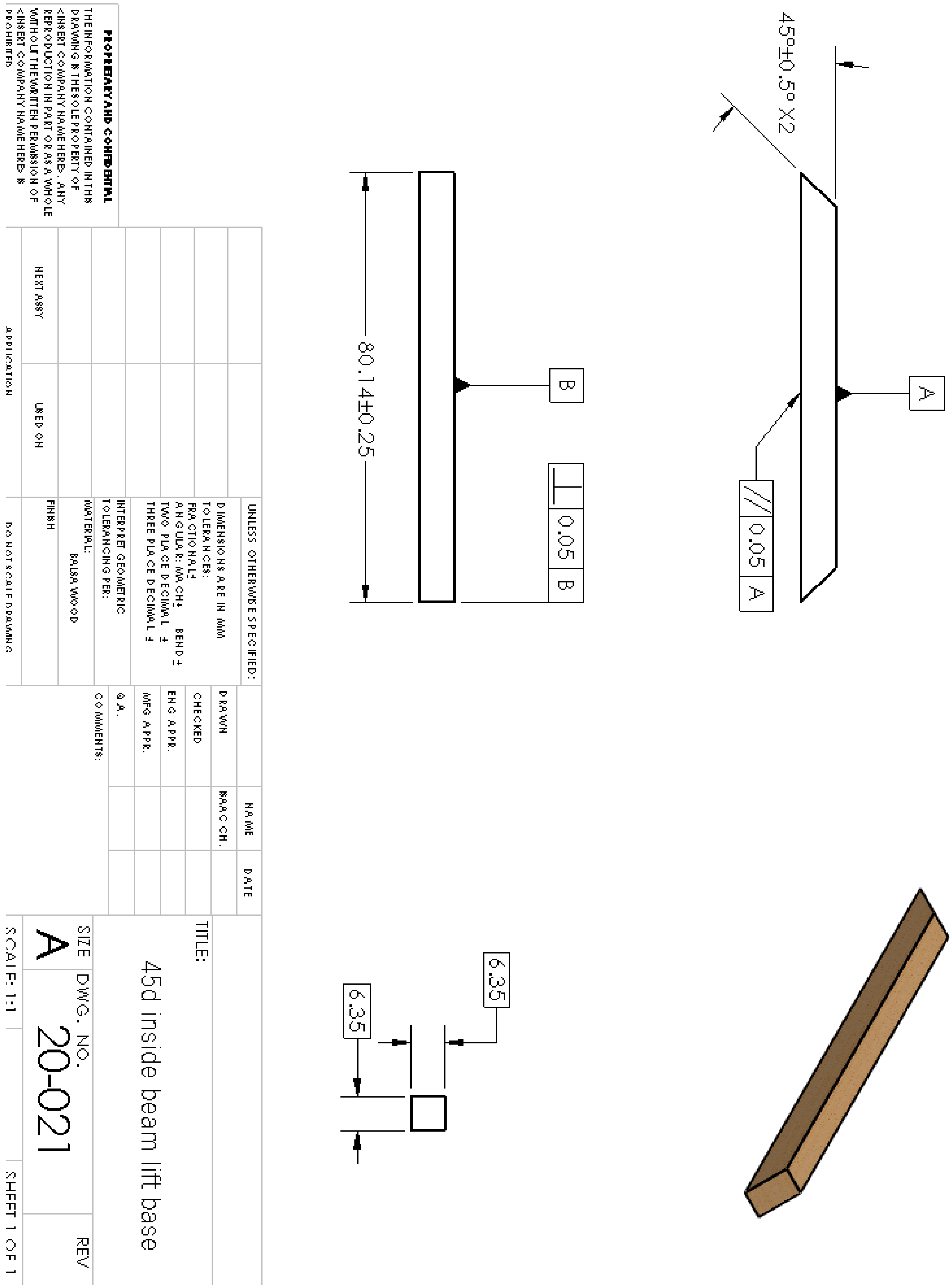
Appendix B – Drawing 20-019



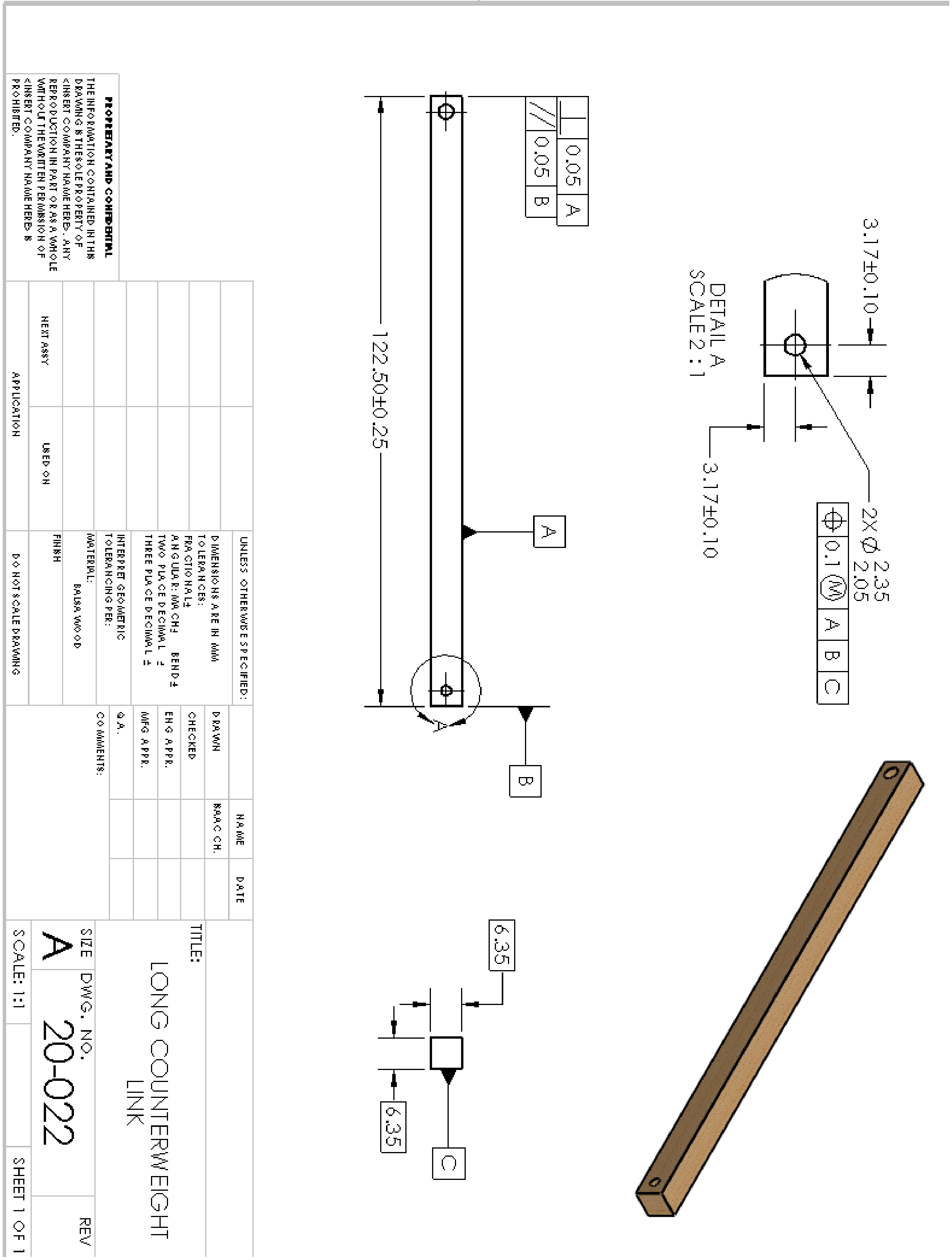
Appendix B – Drawing 20-020



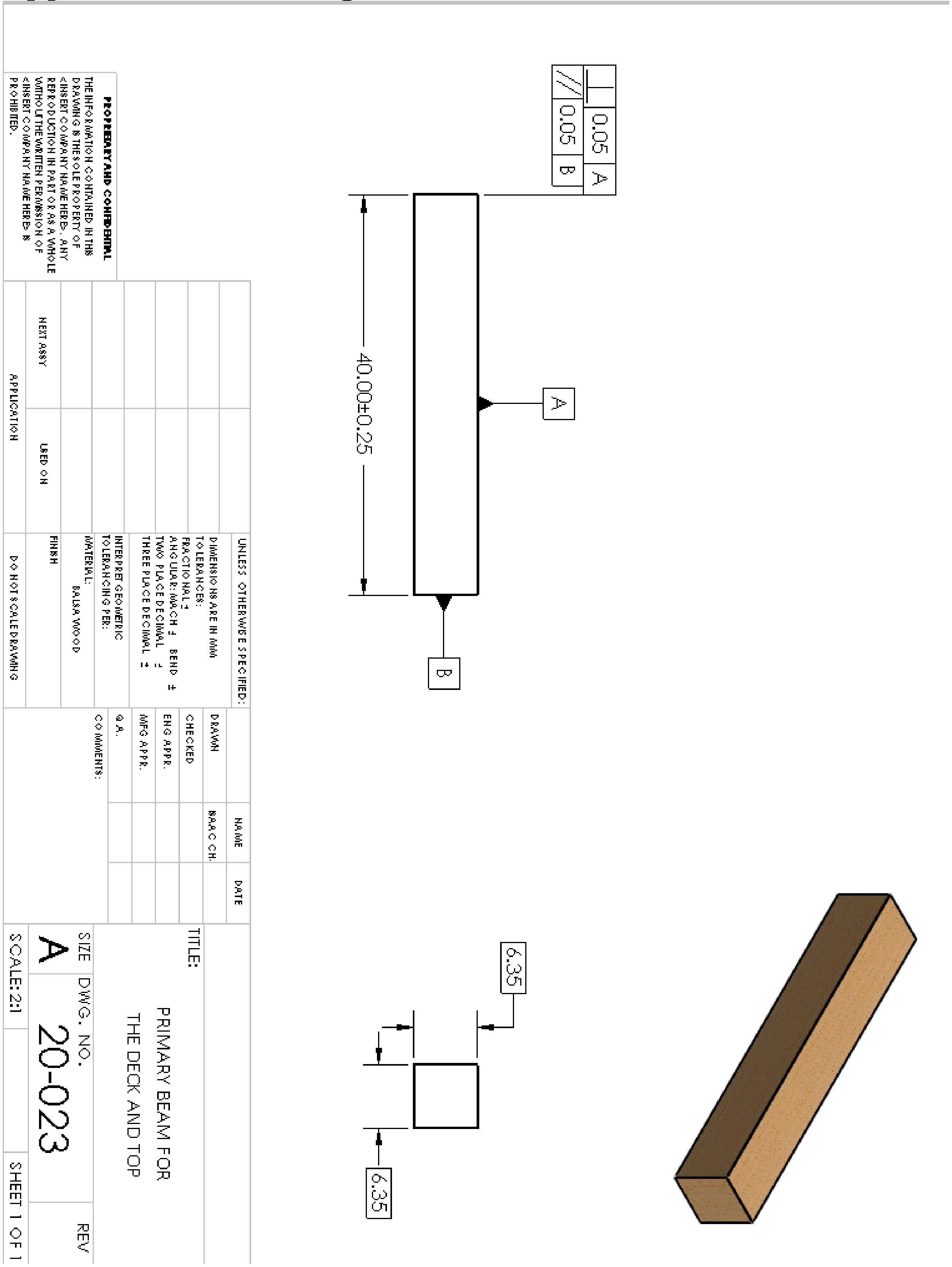
Appendix B – Drawing 20-021



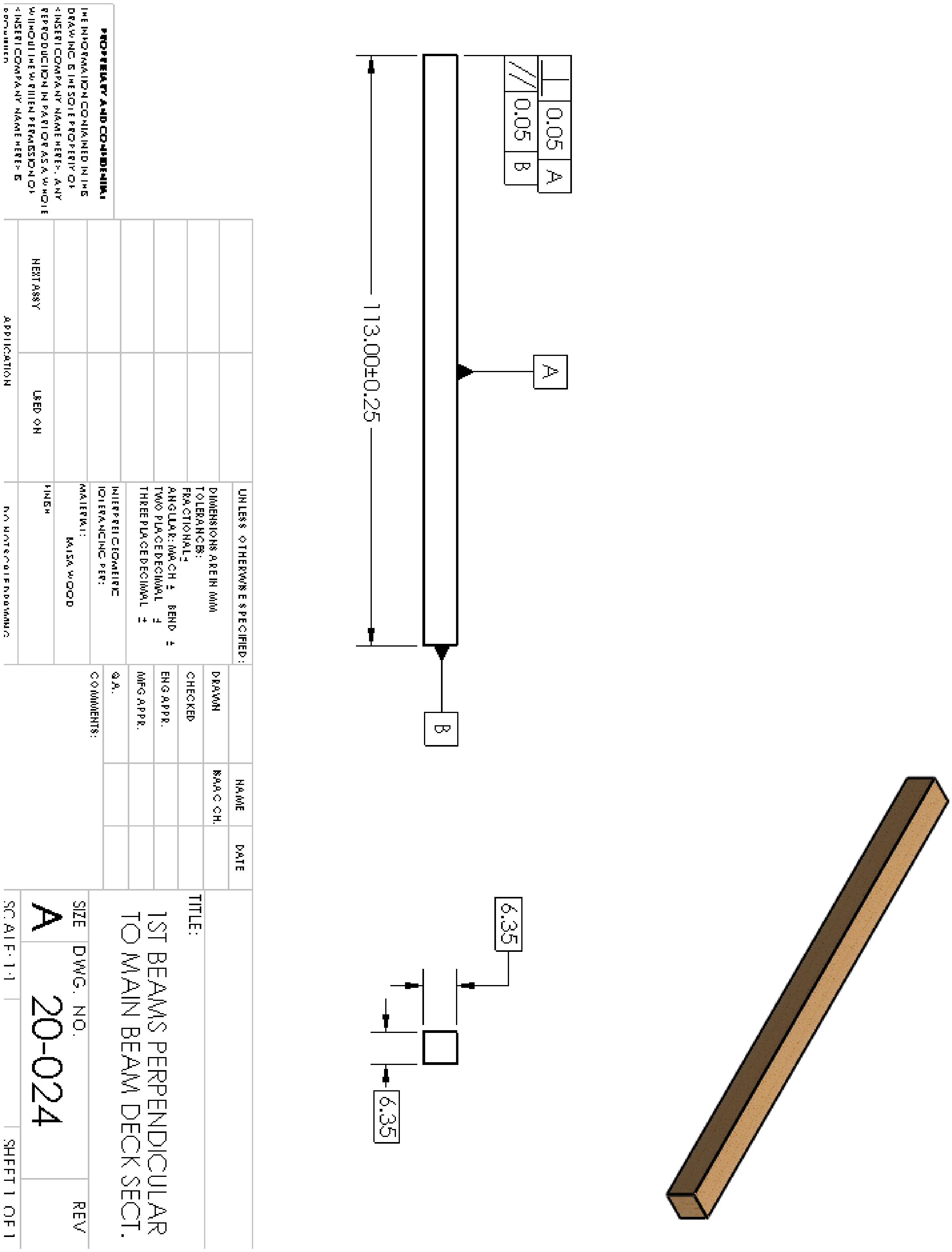
Appendix B – Drawing 20-022



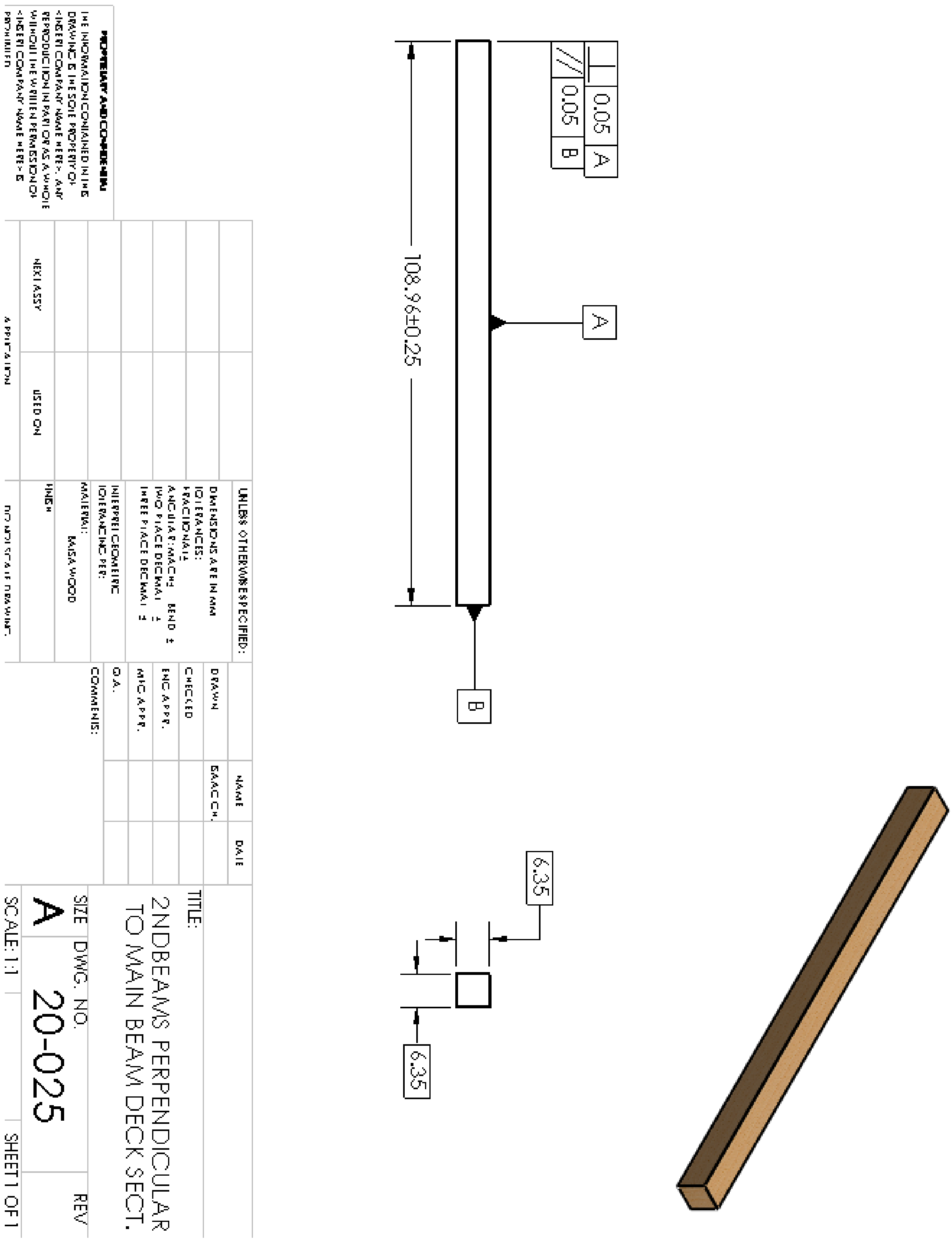
Appendix B – Drawing 20-023



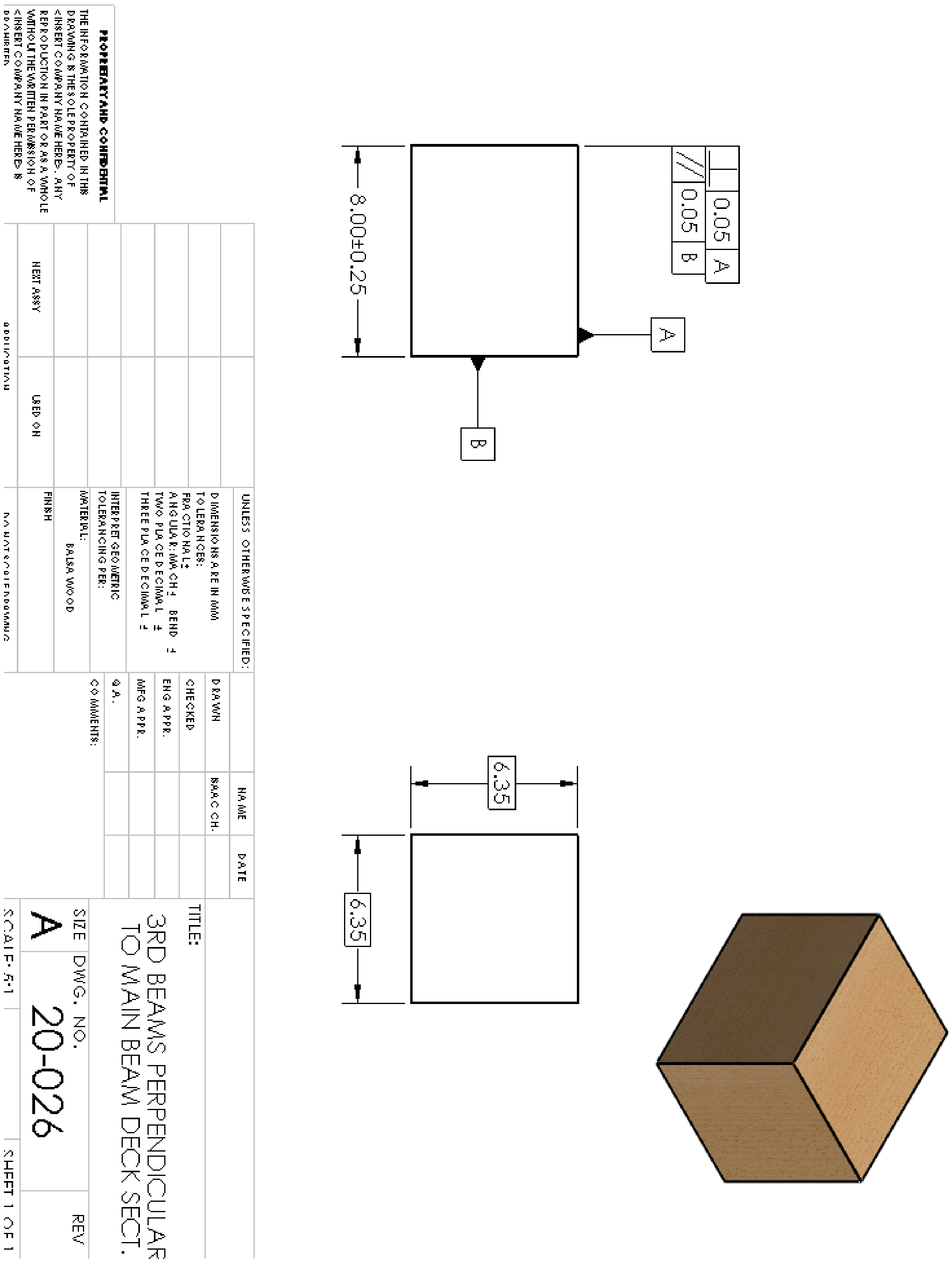
Appendix B – Drawing 20-024



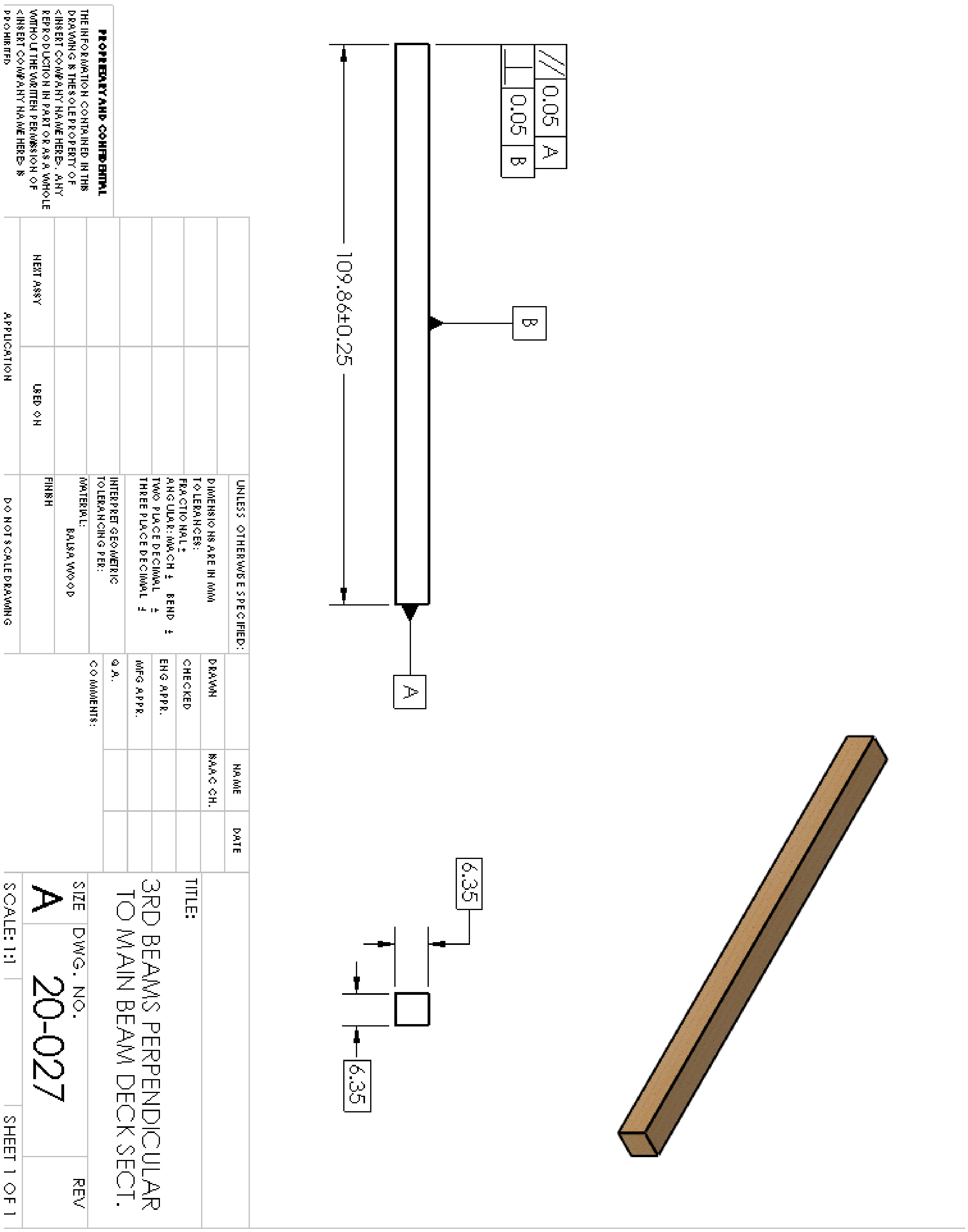
Appendix B – Drawing 20-025



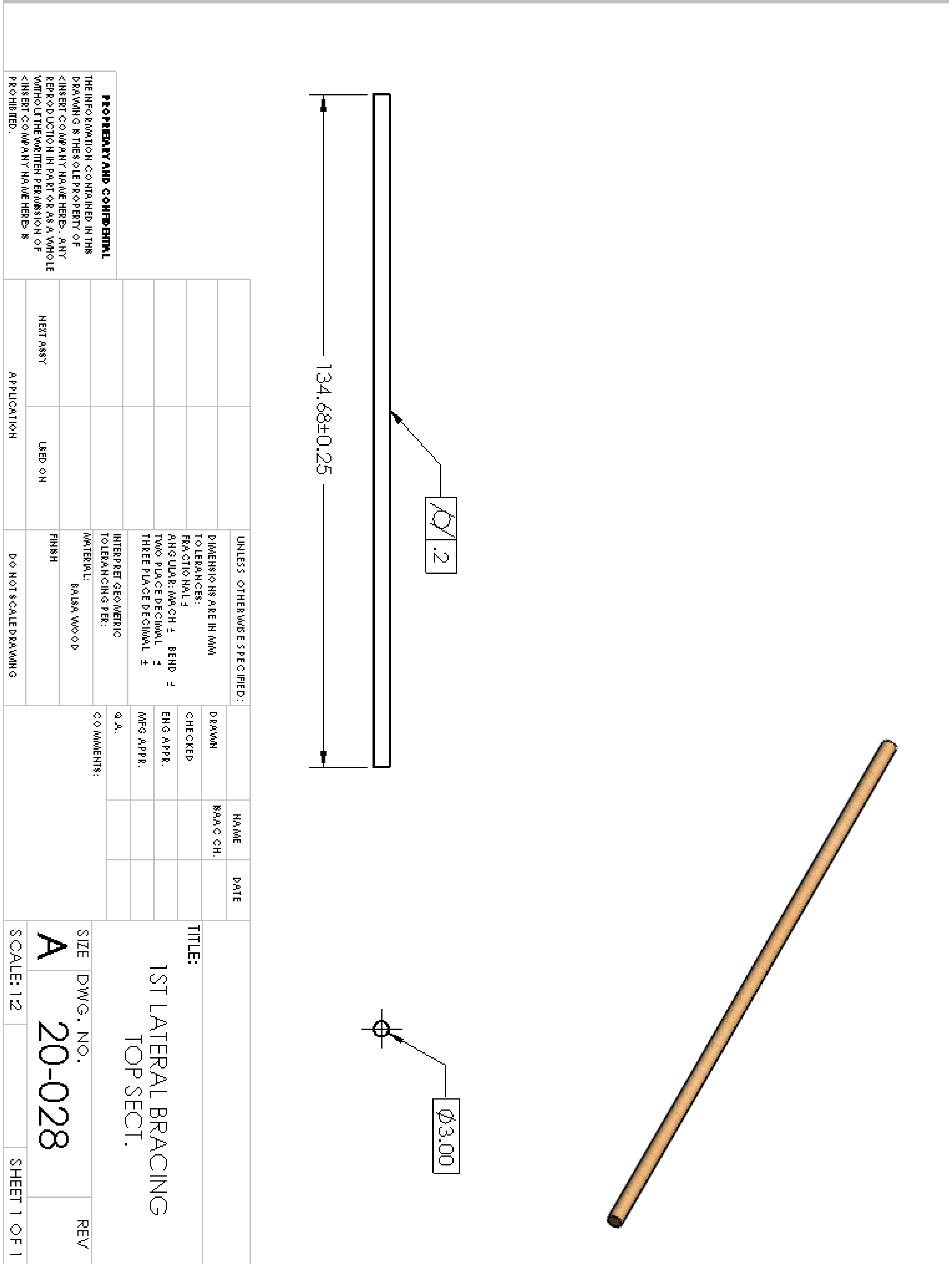
Appendix B – Drawing 20-026



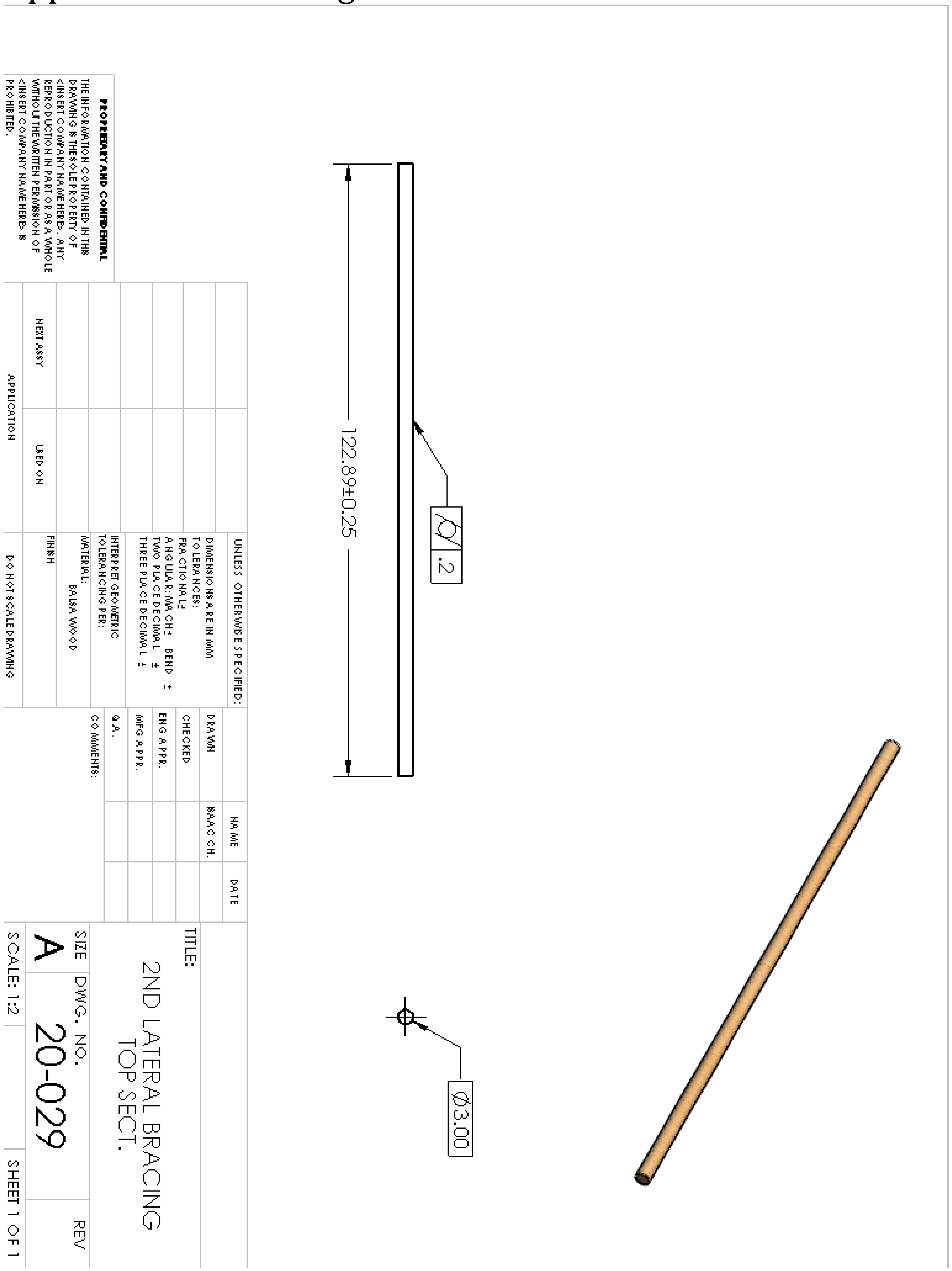
Appendix B – Drawing 20-027



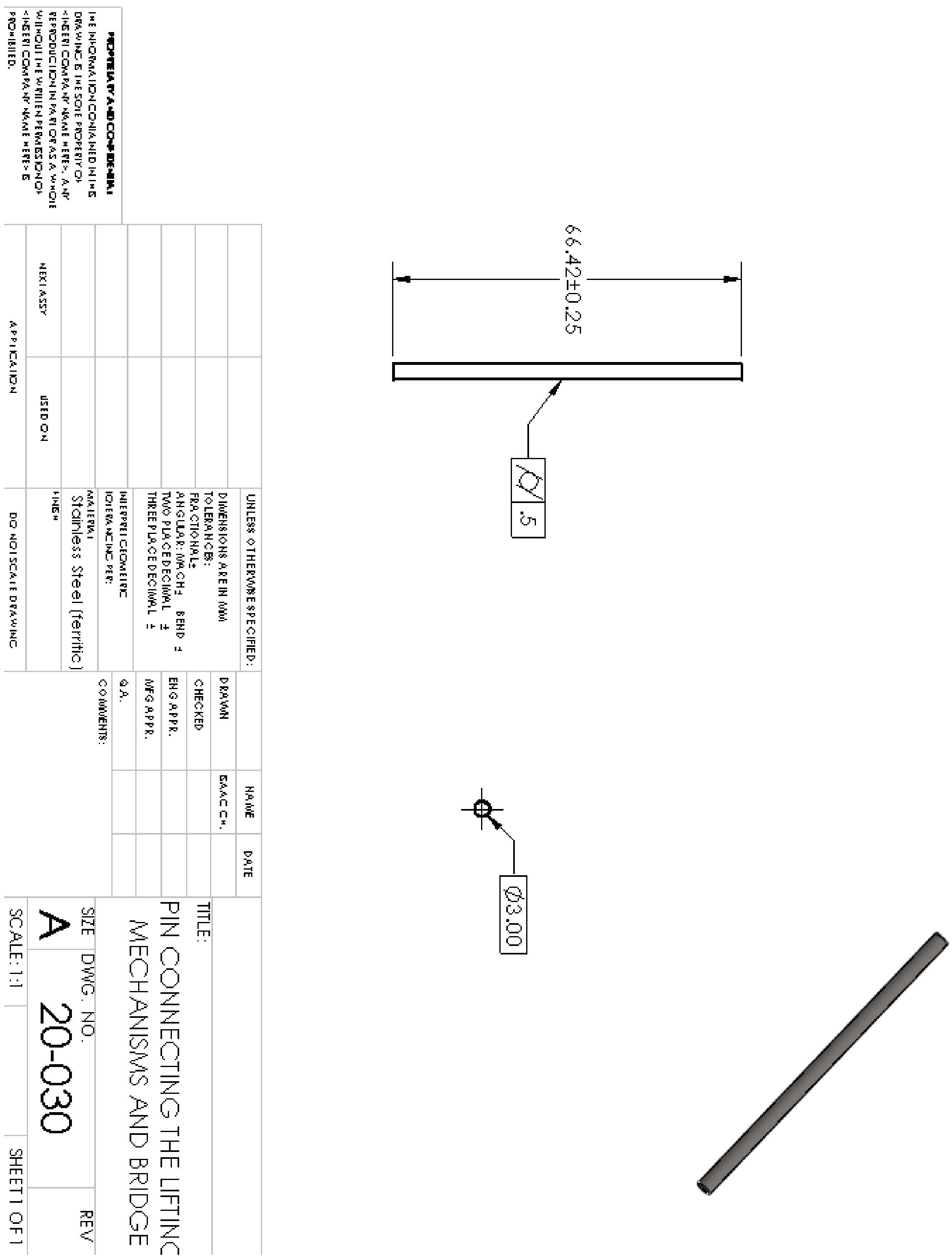
Appendix B – Drawing 20-028



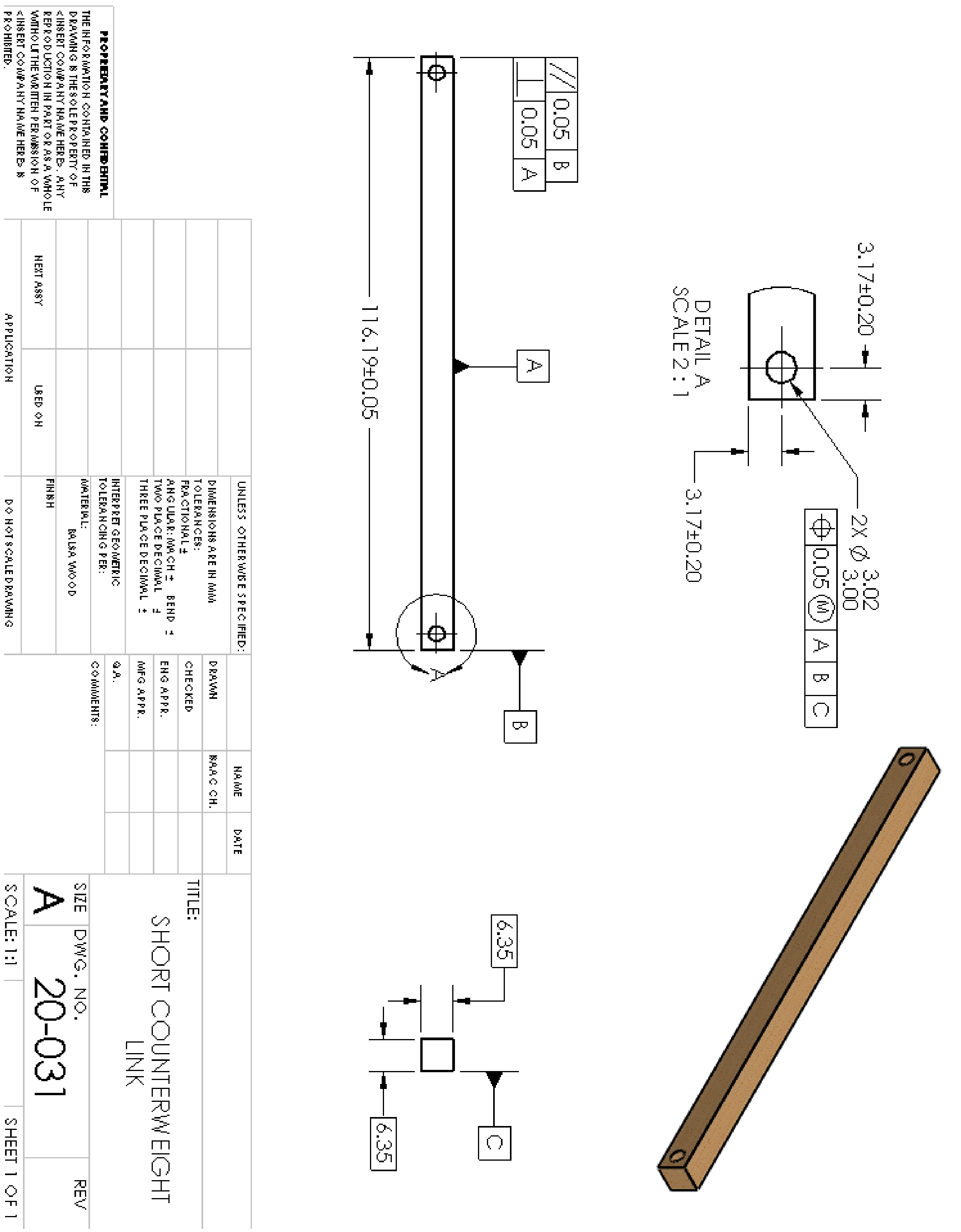
Appendix B – Drawing 20-029



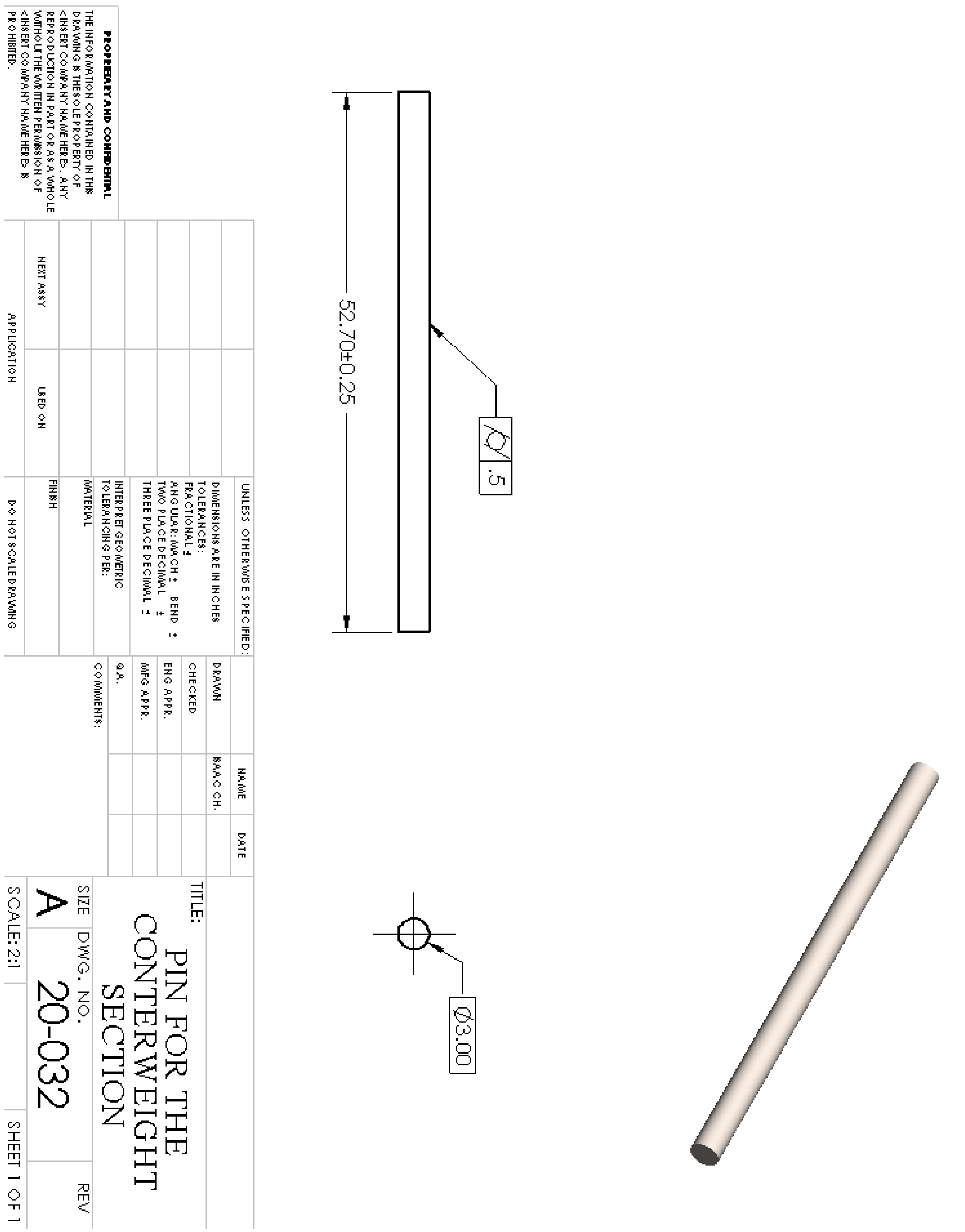
Appendix B – Drawing 20-030



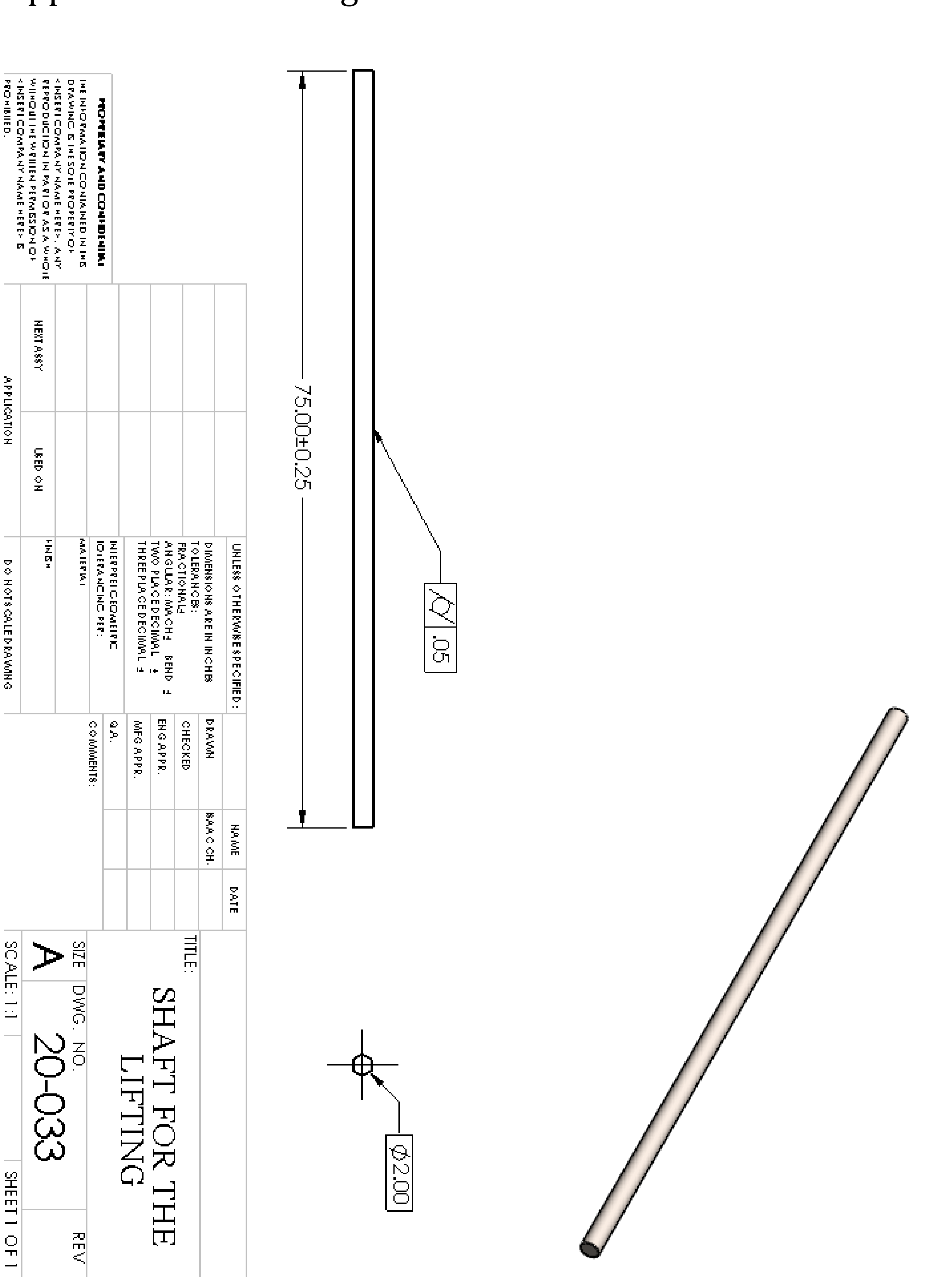
Appendix B – Drawing 20-031



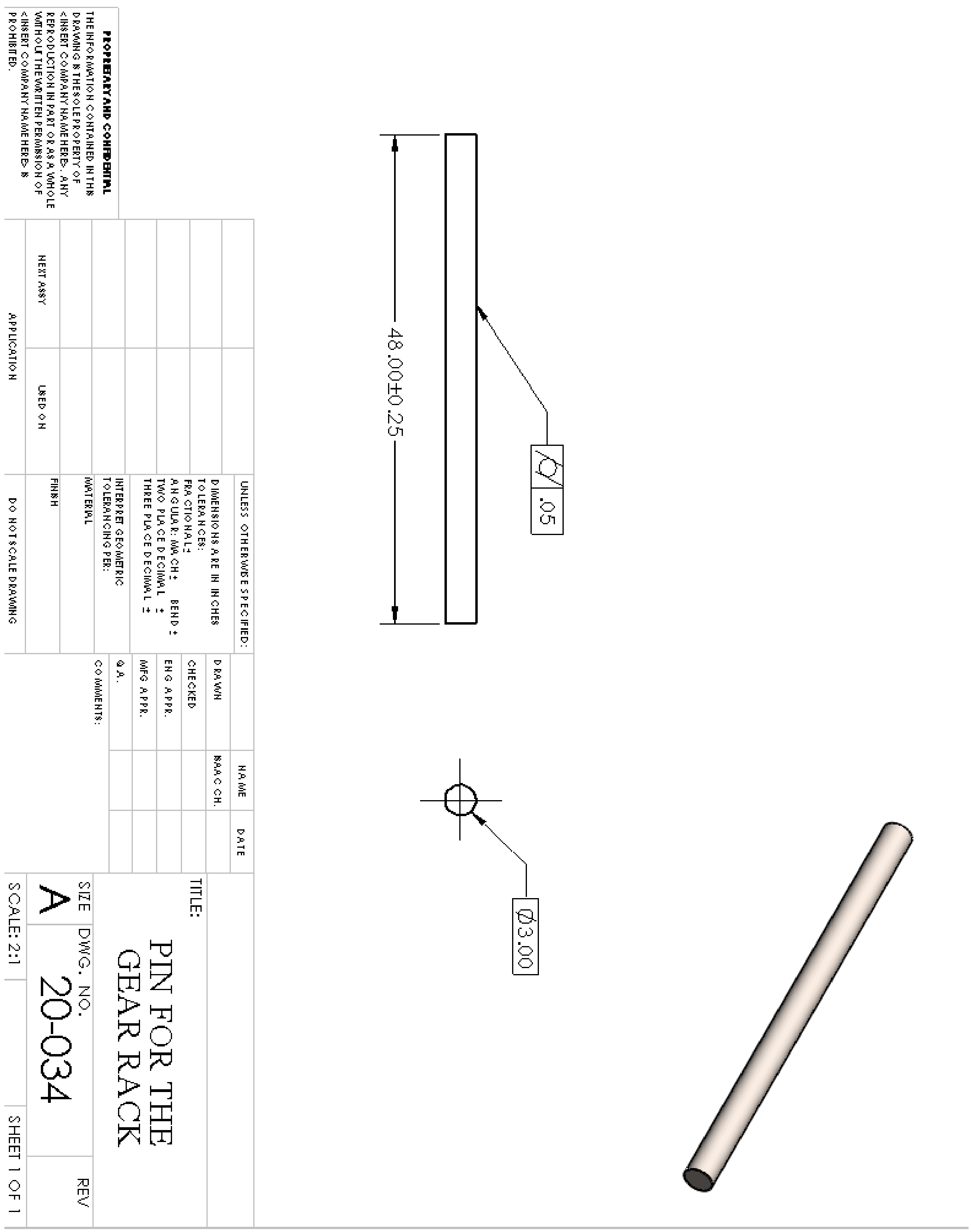
Appendix B – Drawing 20-032



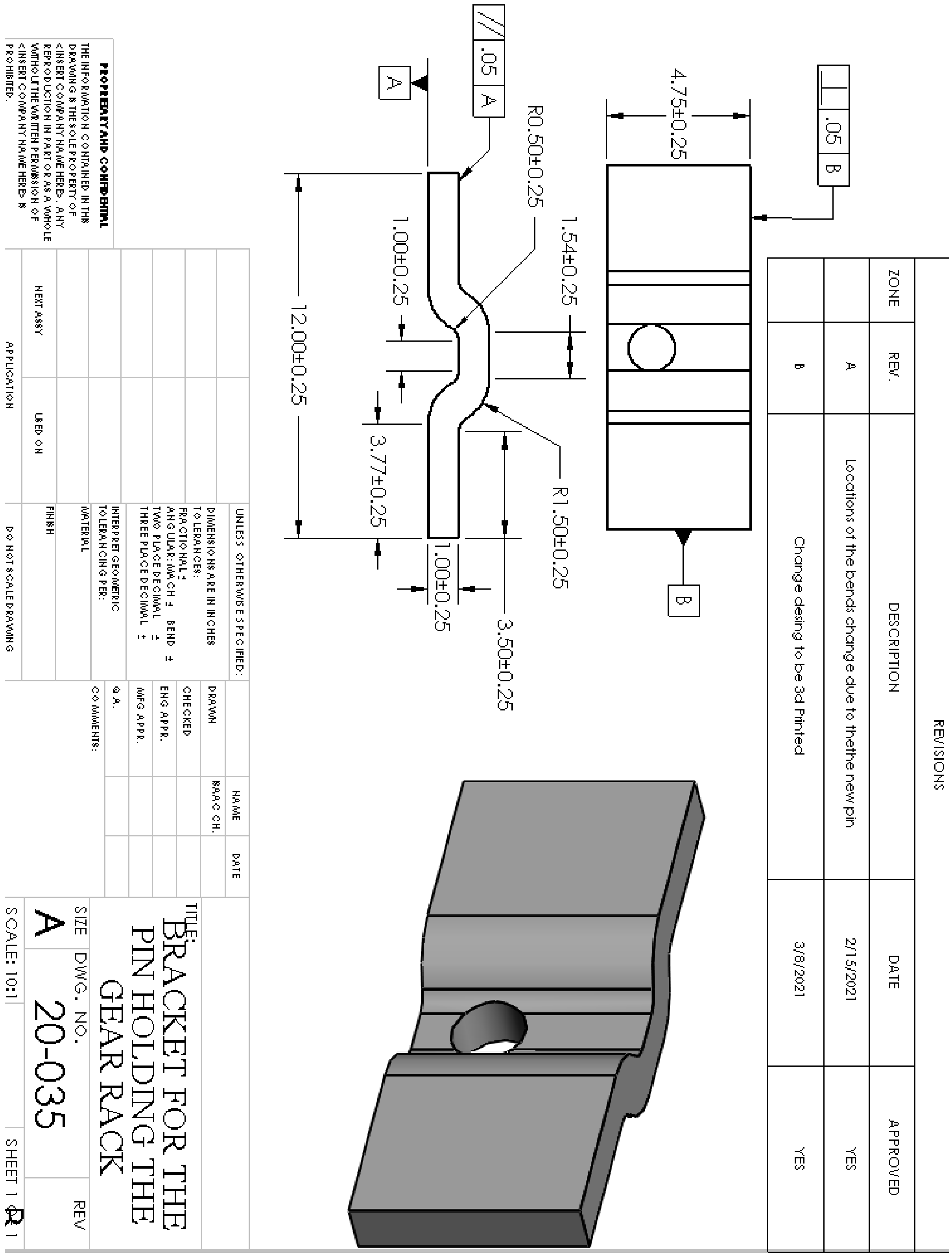
Appendix B – Drawing 20-033



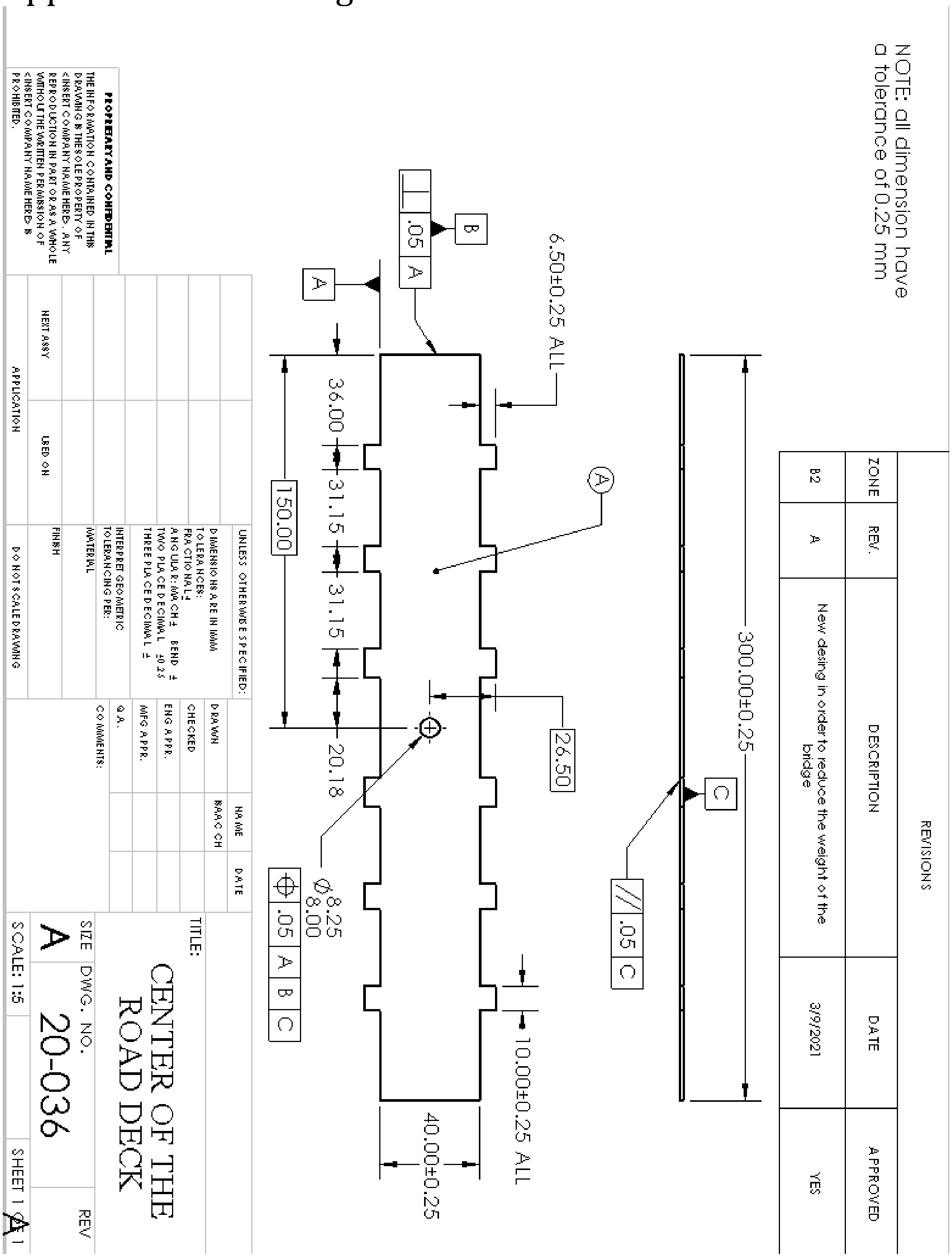
Appendix B – Drawing 20-034



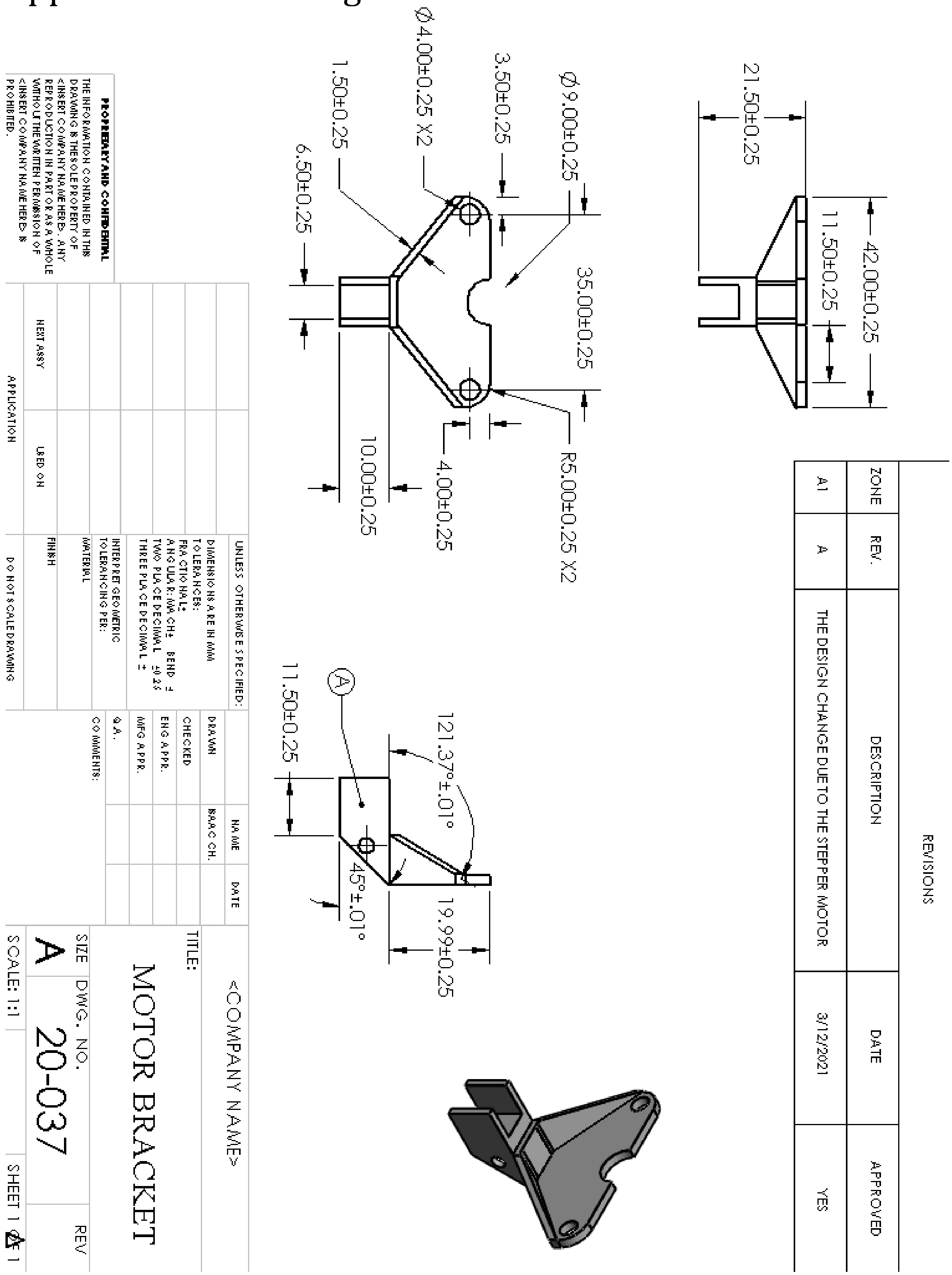
Appendix B – Drawing 20-035



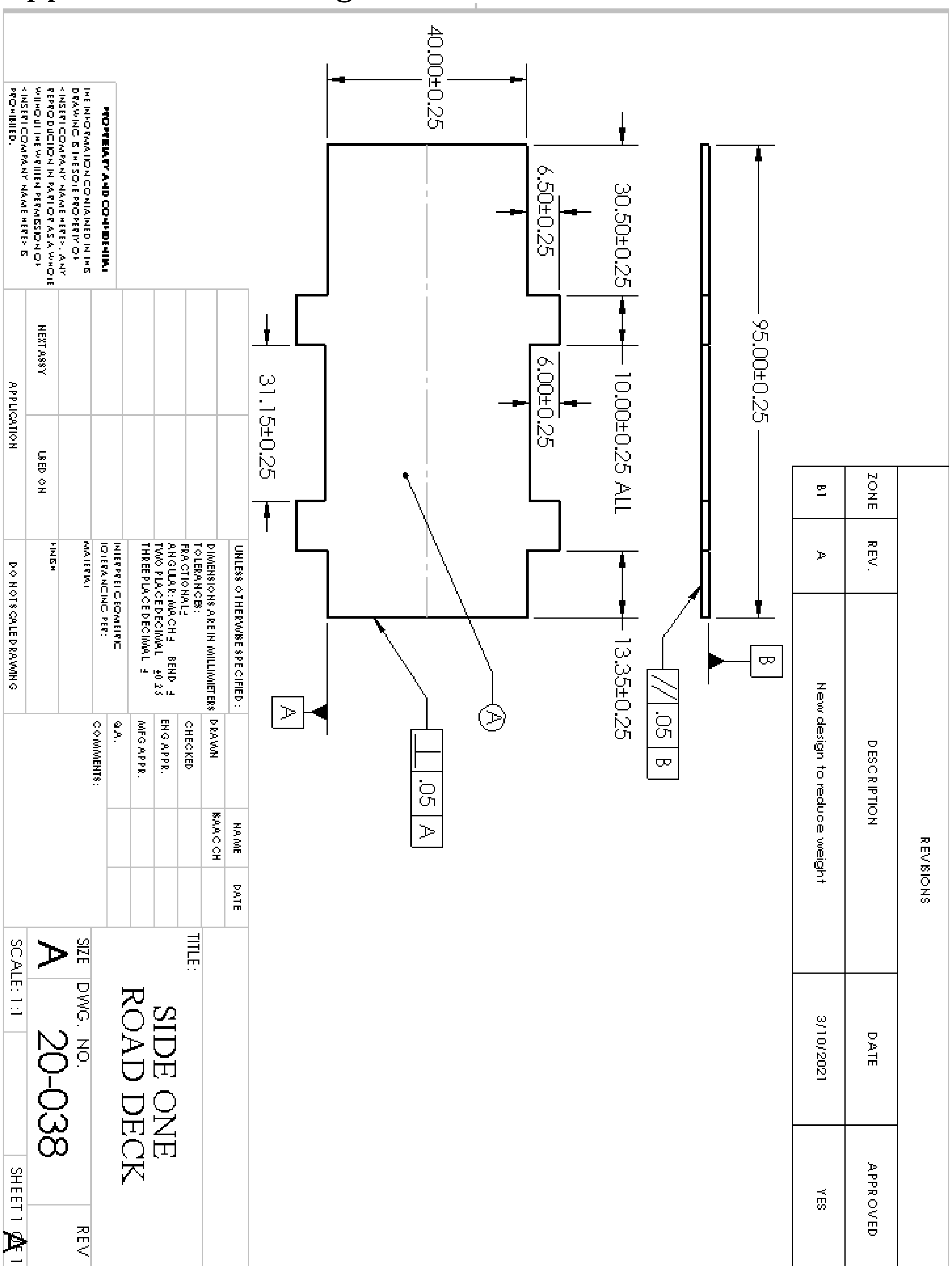
Appendix B – Drawing 20-036



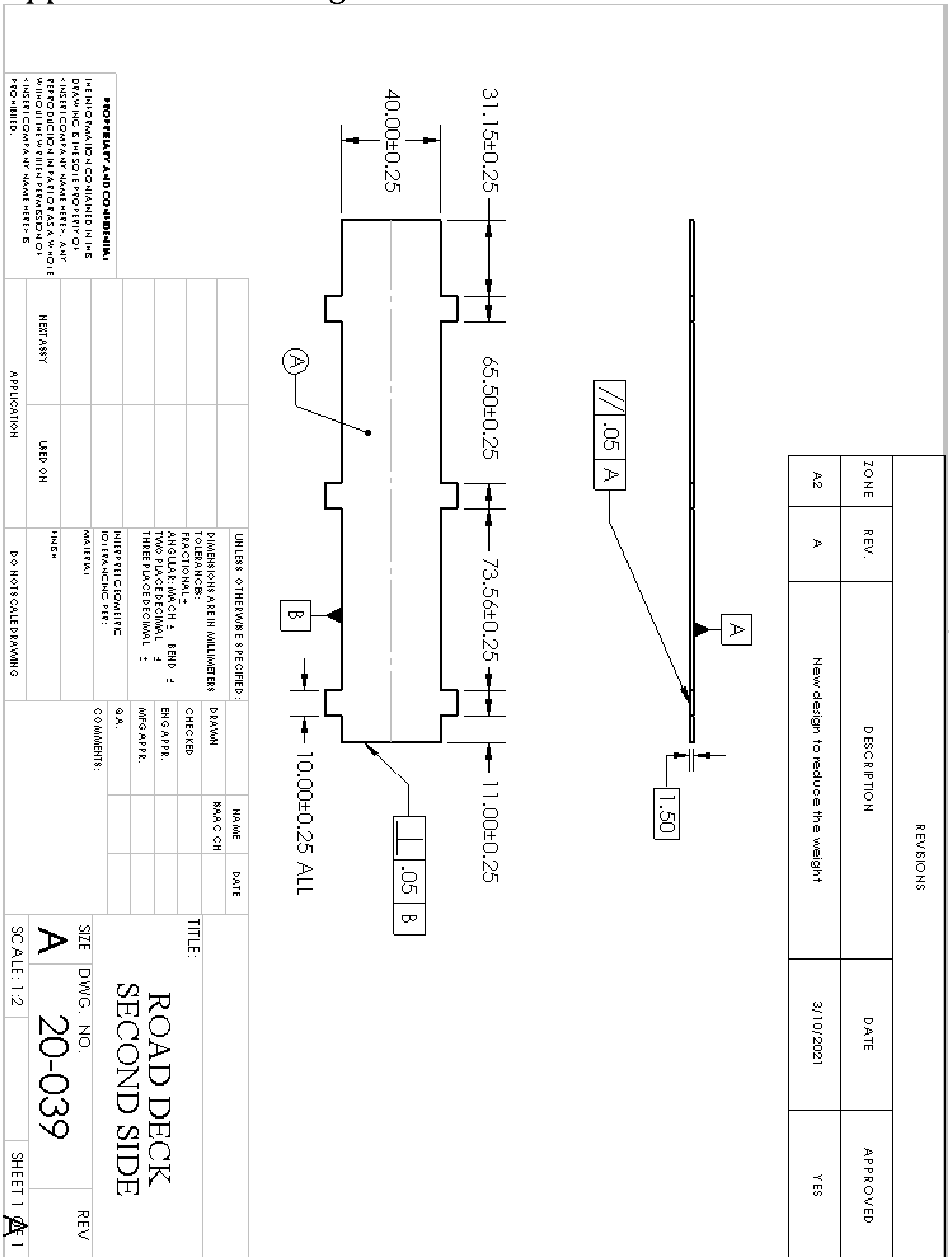
Appendix B – Drawing 20-037



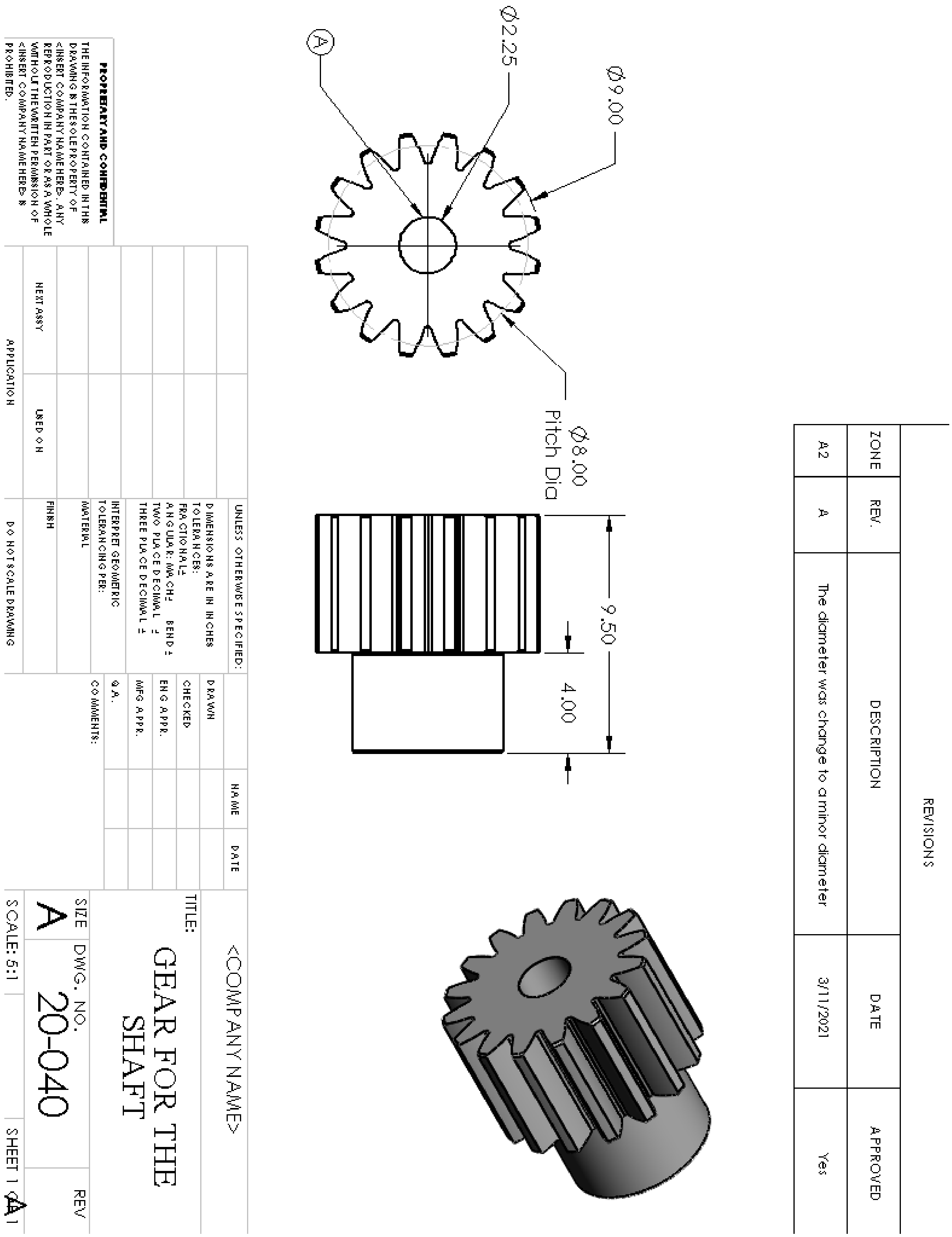
Appendix B – Drawing 20-038



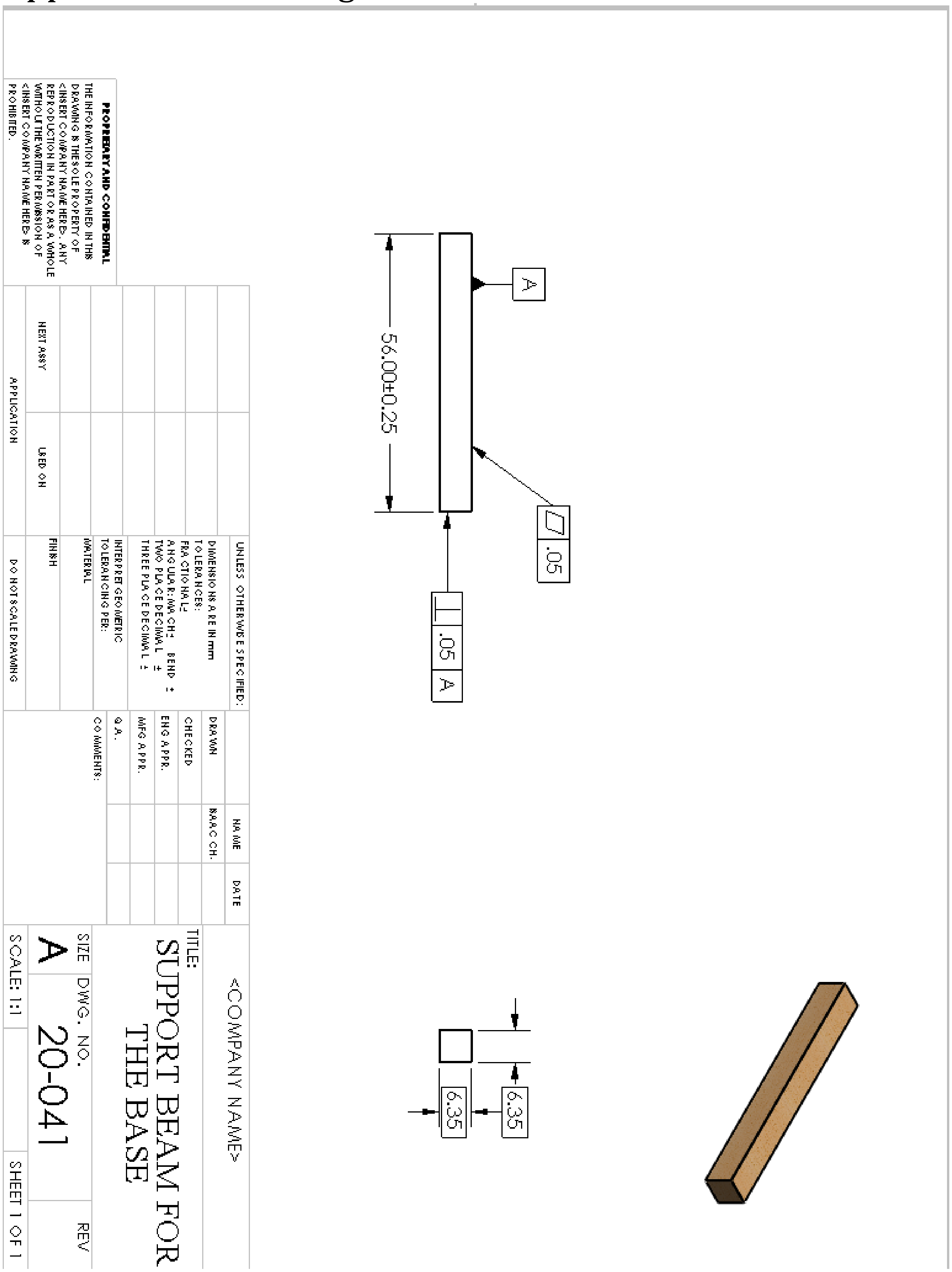
Appendix B – Drawing 20-039



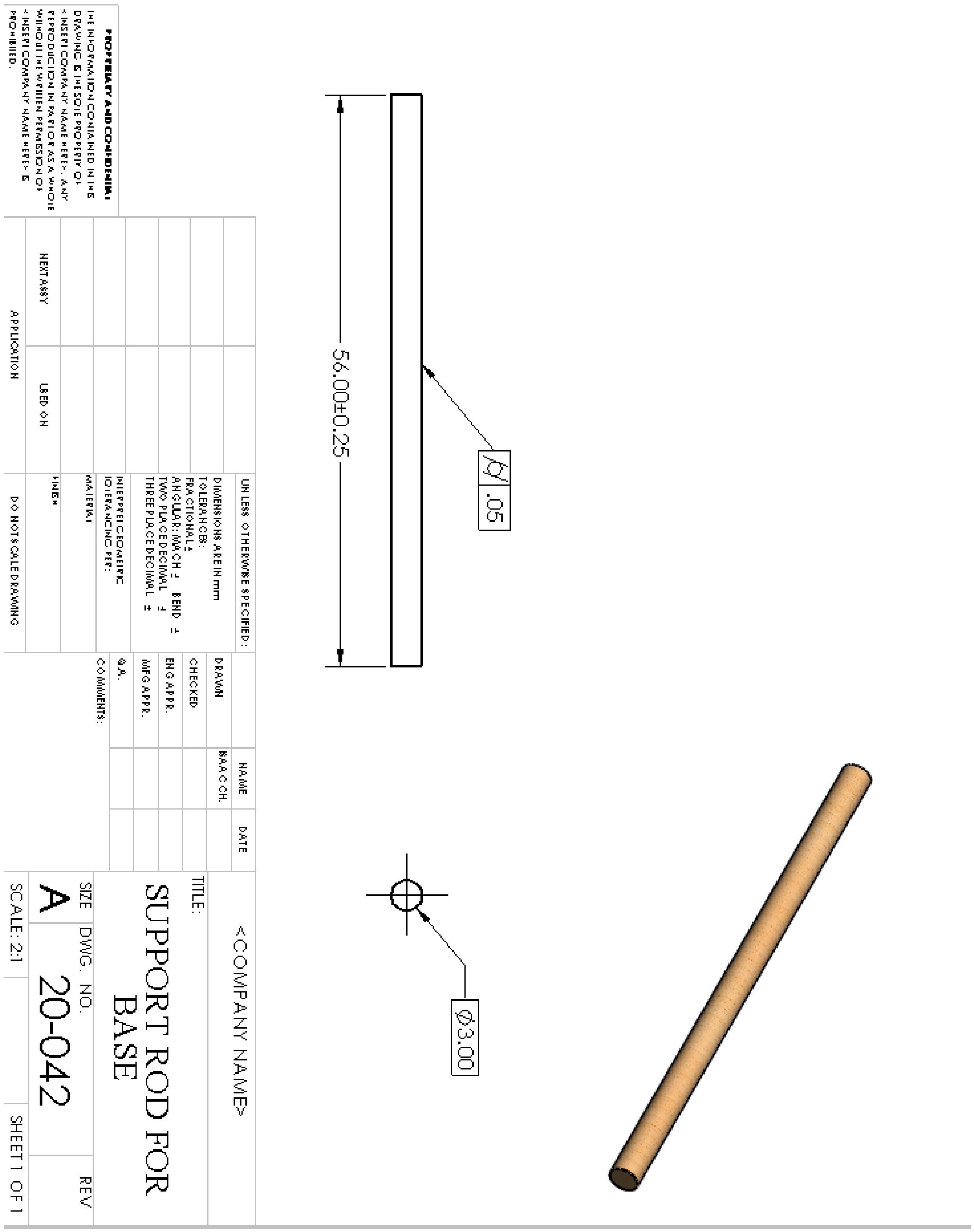
Appendix B – Drawing 20-040



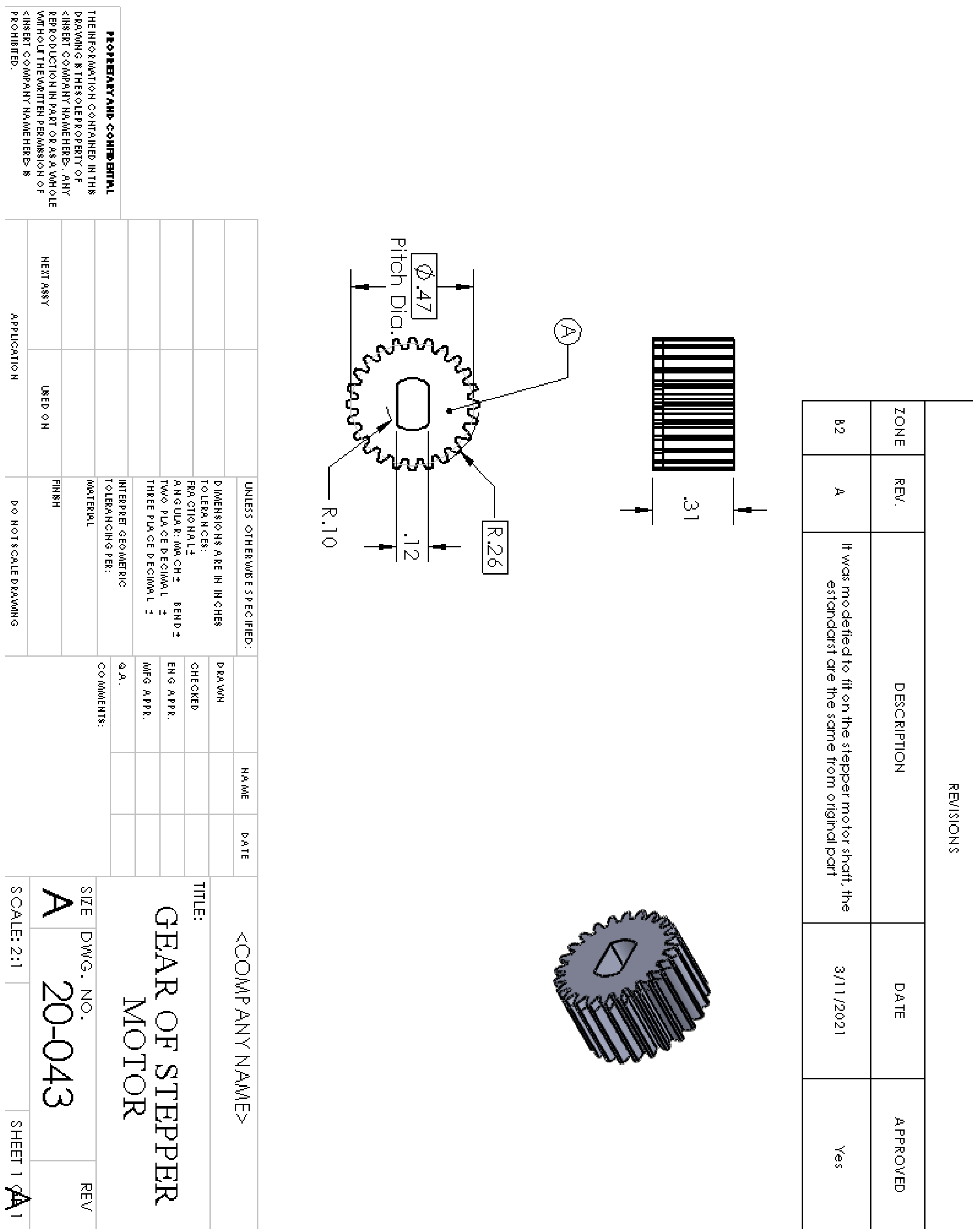
Appendix B – Drawing 20-041



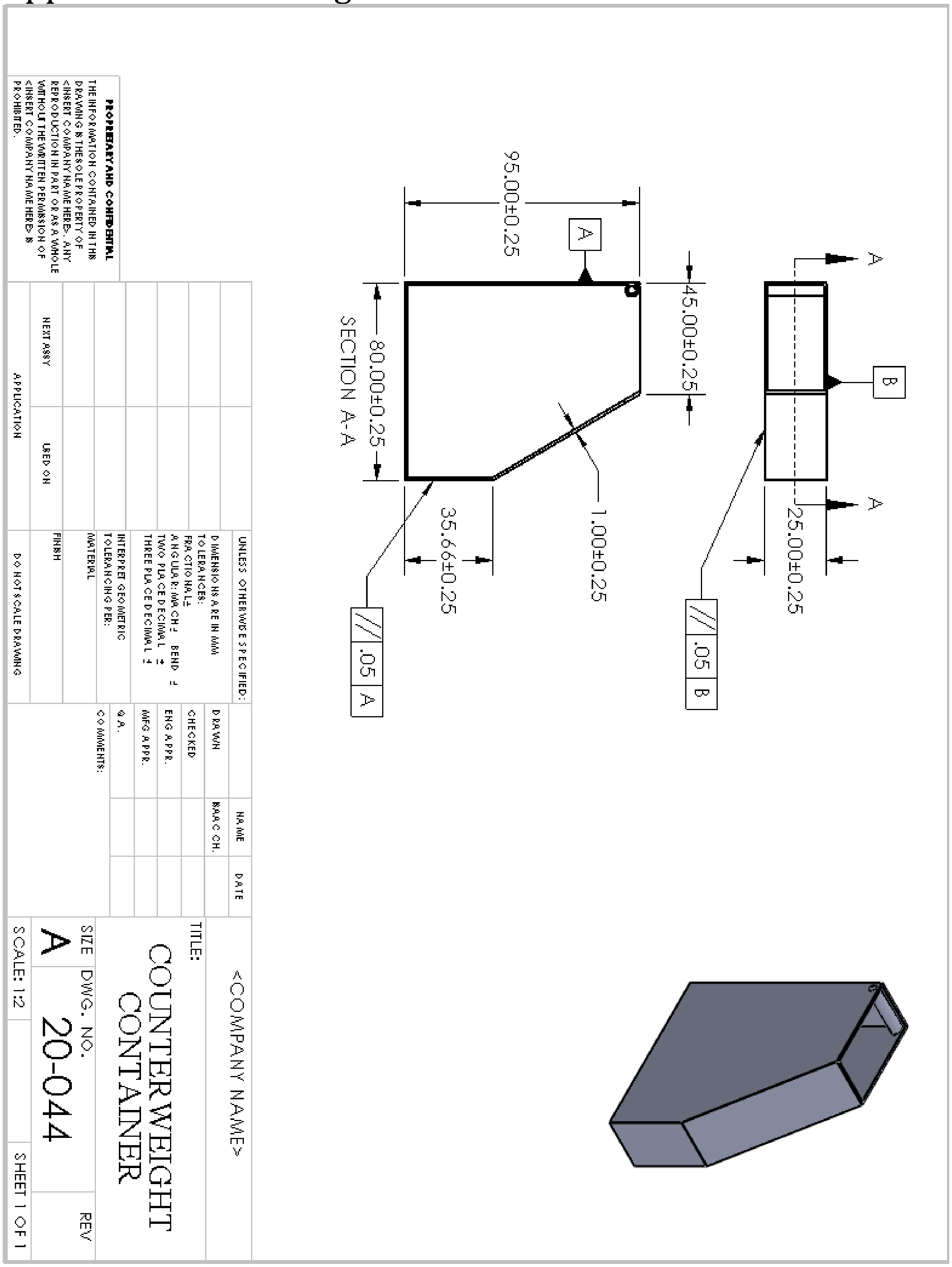
Appendix B – Drawing 20-042



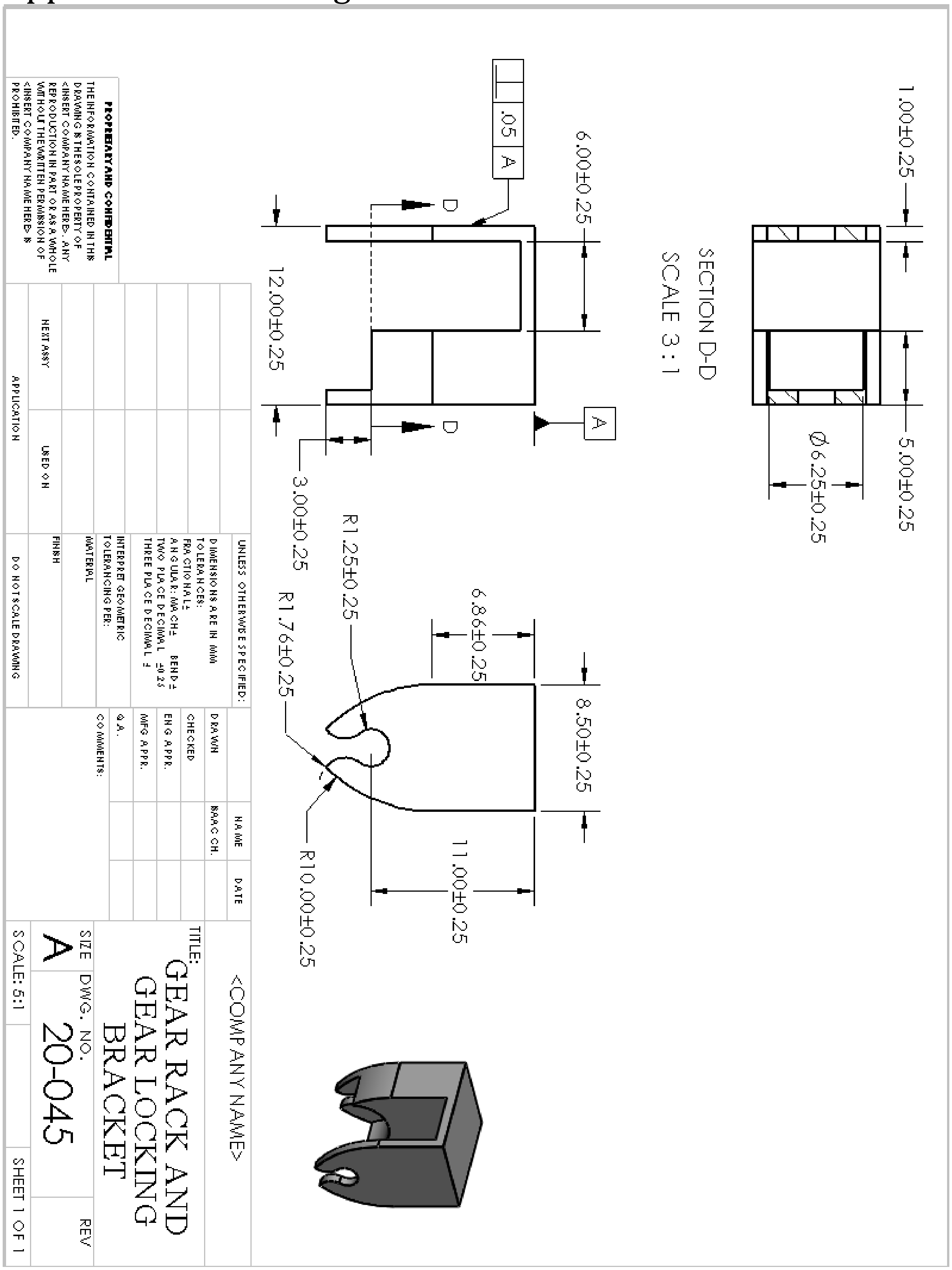
Appendix B – Drawing 20-043



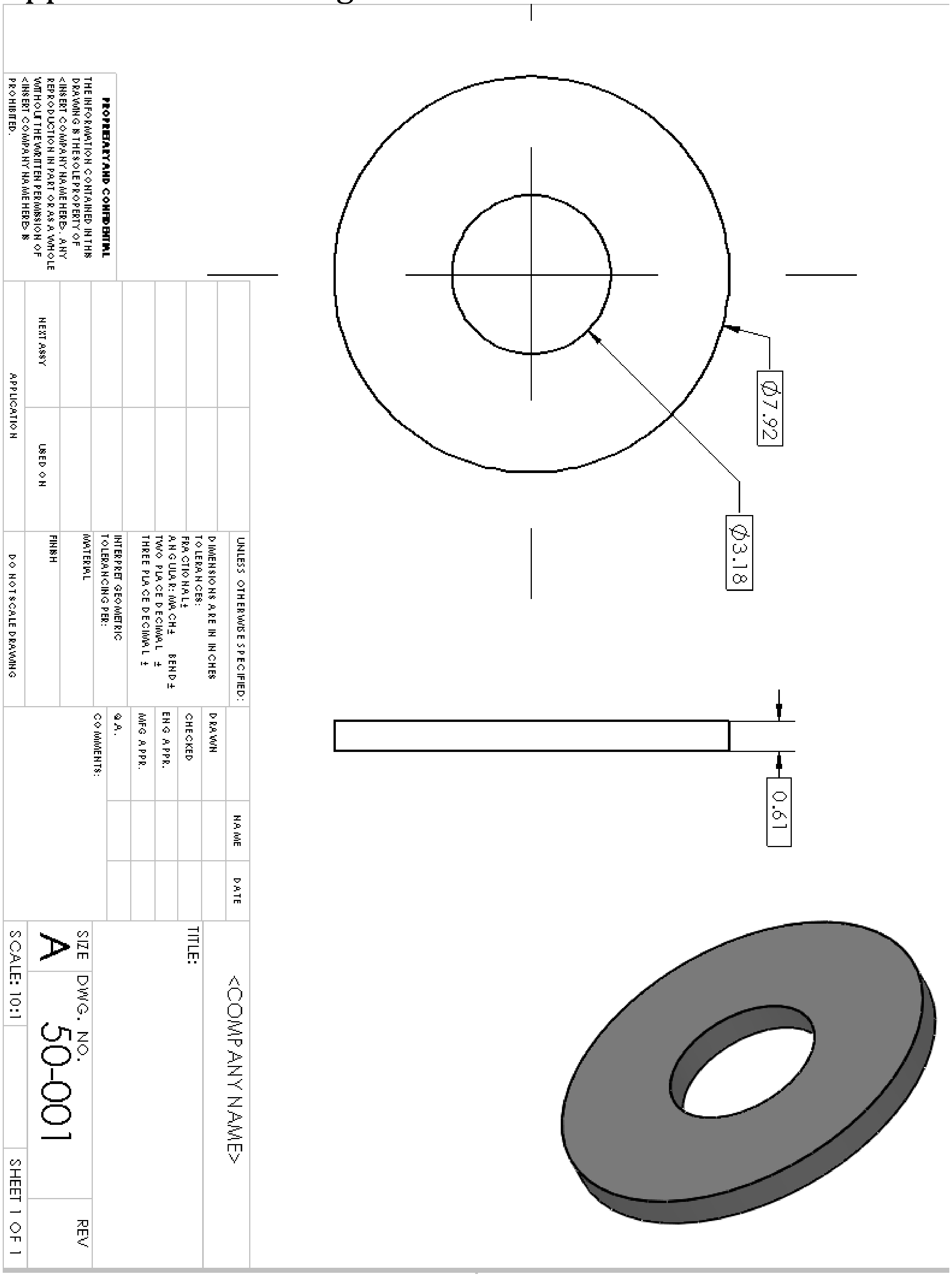
Appendix B – Drawing 20-044



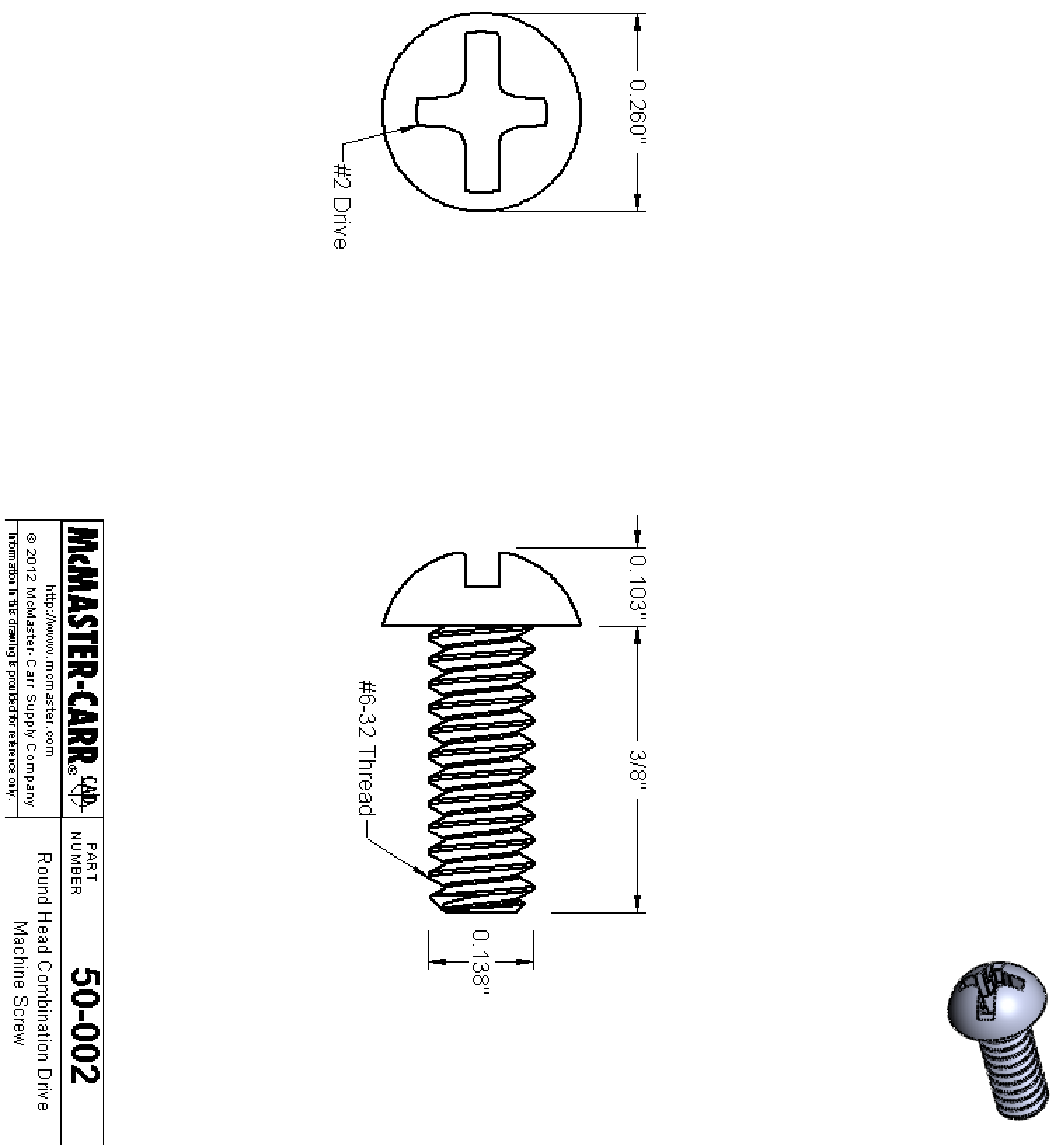
Appendix B – Drawing 20-045



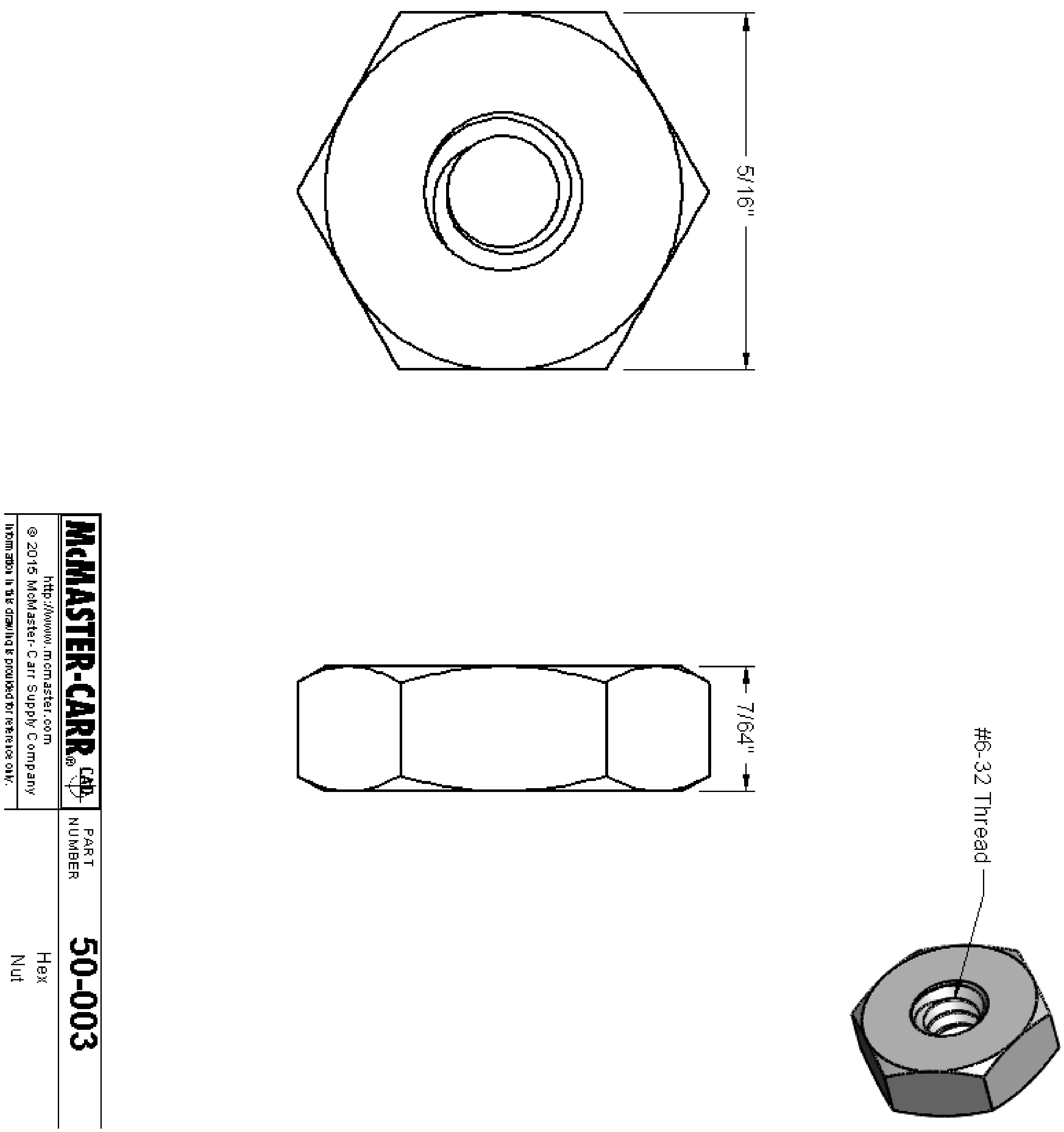
Appendix B – Drawing 50-001



Appendix B – Drawing 50-002



Appendix B – Drawing 50-003



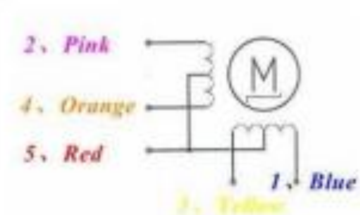
Appendix B – Drawing 55-001

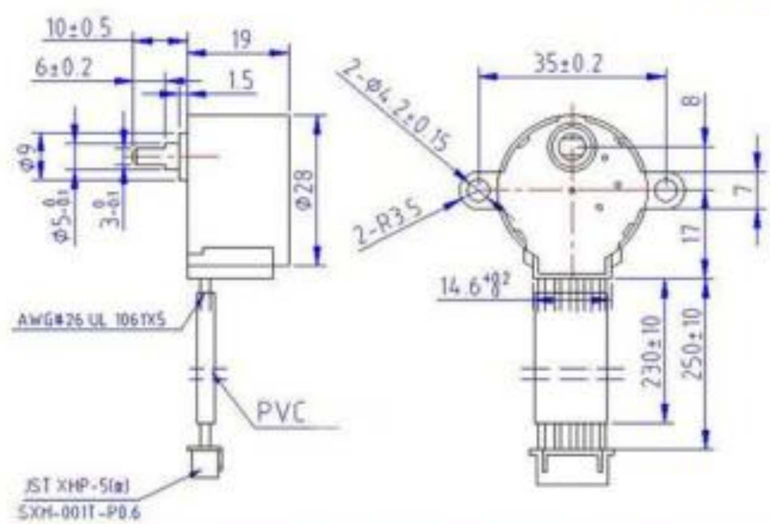
Kiatronics
electronic design and manufacture

28BYJ-48 – 5V Stepper Motor

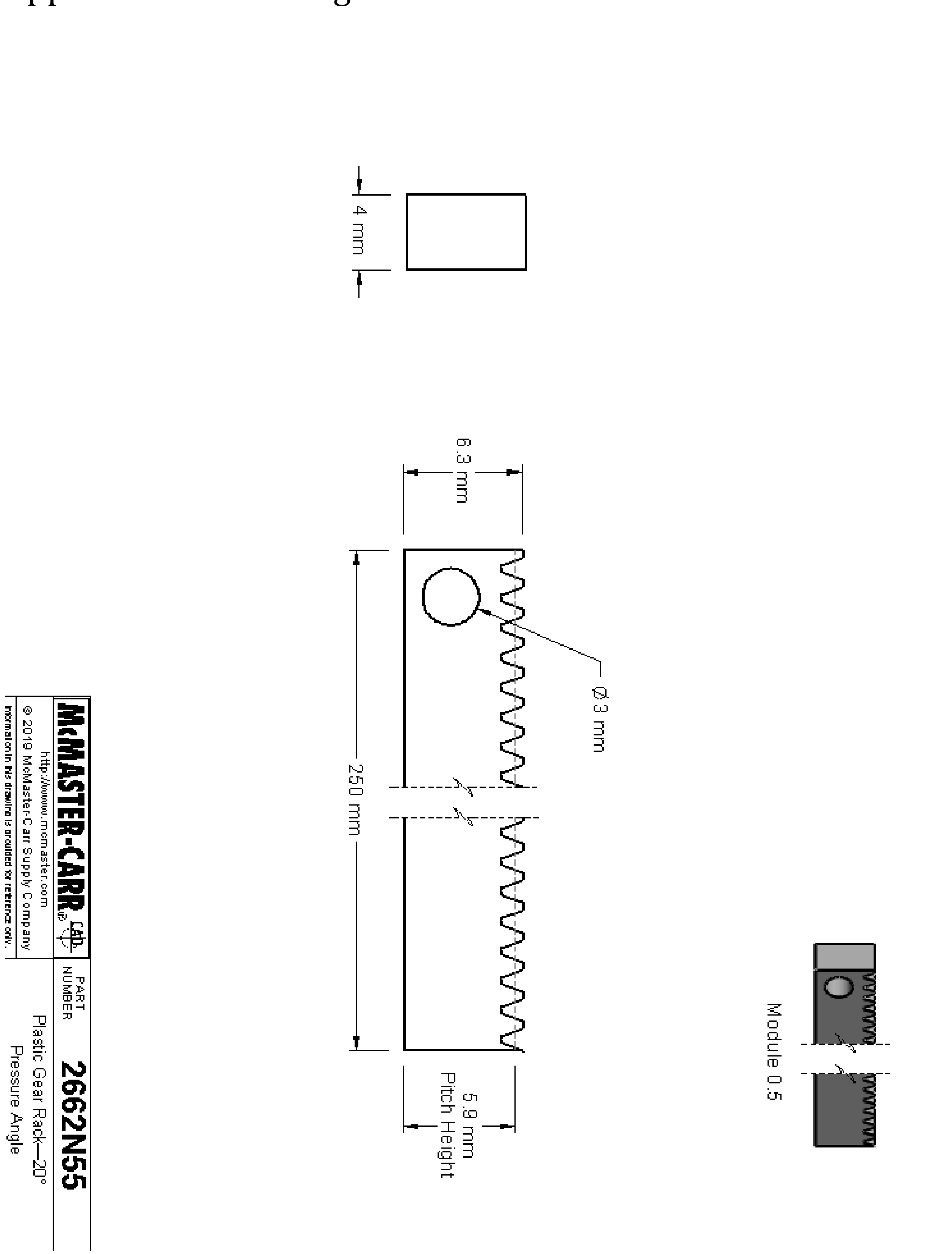
The 28BYJ-48 is a small stepper motor suitable for a large range of applications.

Rated voltage :	5VDC
Number of Phase	4
Speed Variation Ratio	1/64
Stride Angle	5.625°/64
Frequency	100Hz
DC resistance	50Ω±7%(25℃)
Idle In-traction Frequency	> 600Hz
Idle Out-traction Frequency	> 1000Hz
In-traction Torque	>34.3mN.m(120Hz)
Self-positioning Torque	>34.3mN.m
Friction torque	600-1200 gf.cm
Pull in torque	300 gf.cm
Insulated resistance	>10MΩ(500V)
Insulated electricity power	600VAC/1mA/1s
Insulation grade	A
Rise in Temperature	<40K(120Hz)
Noise	<35dB(120Hz,No load,10cm)
Model	28BYJ-48 – 5V

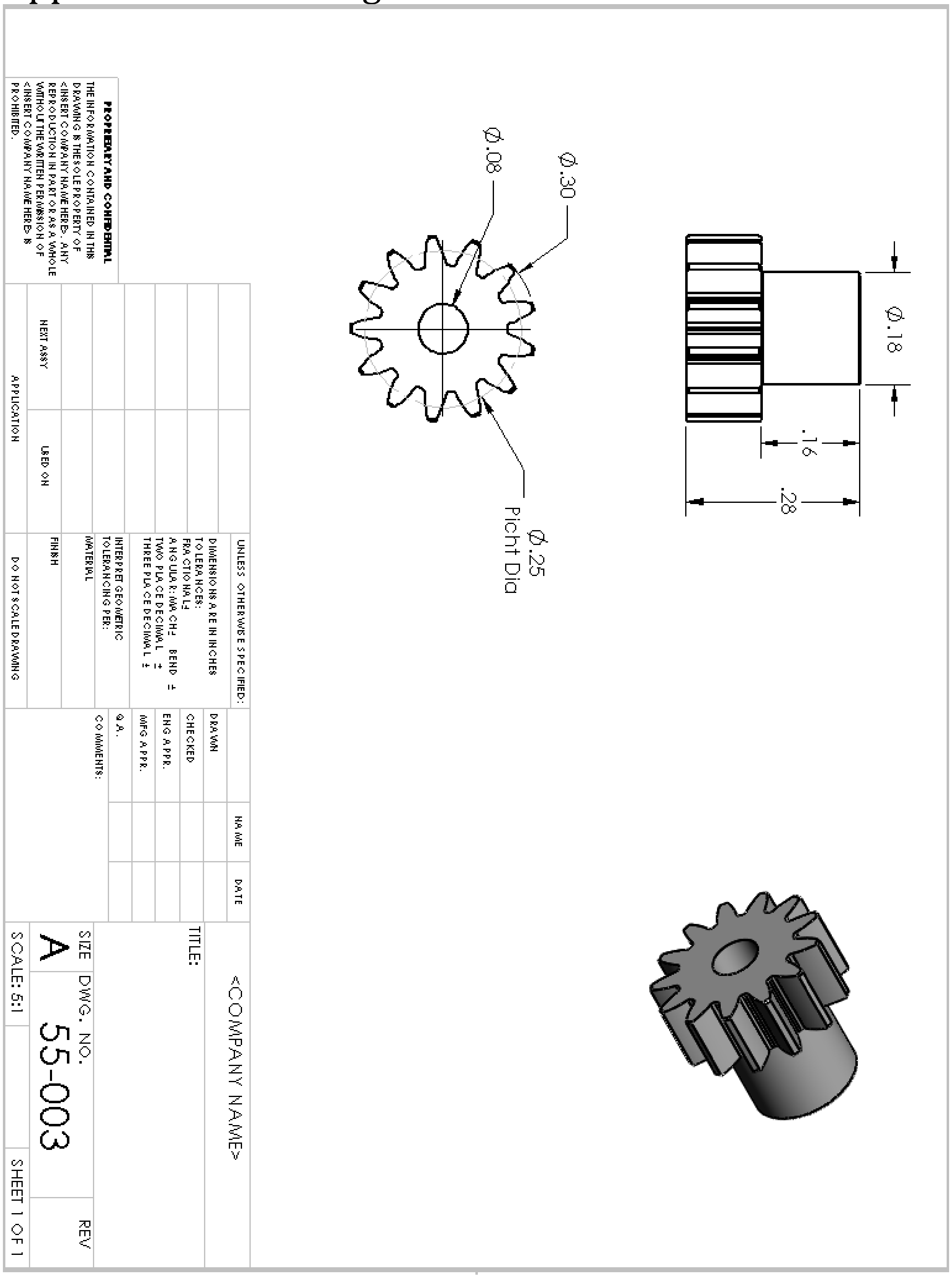




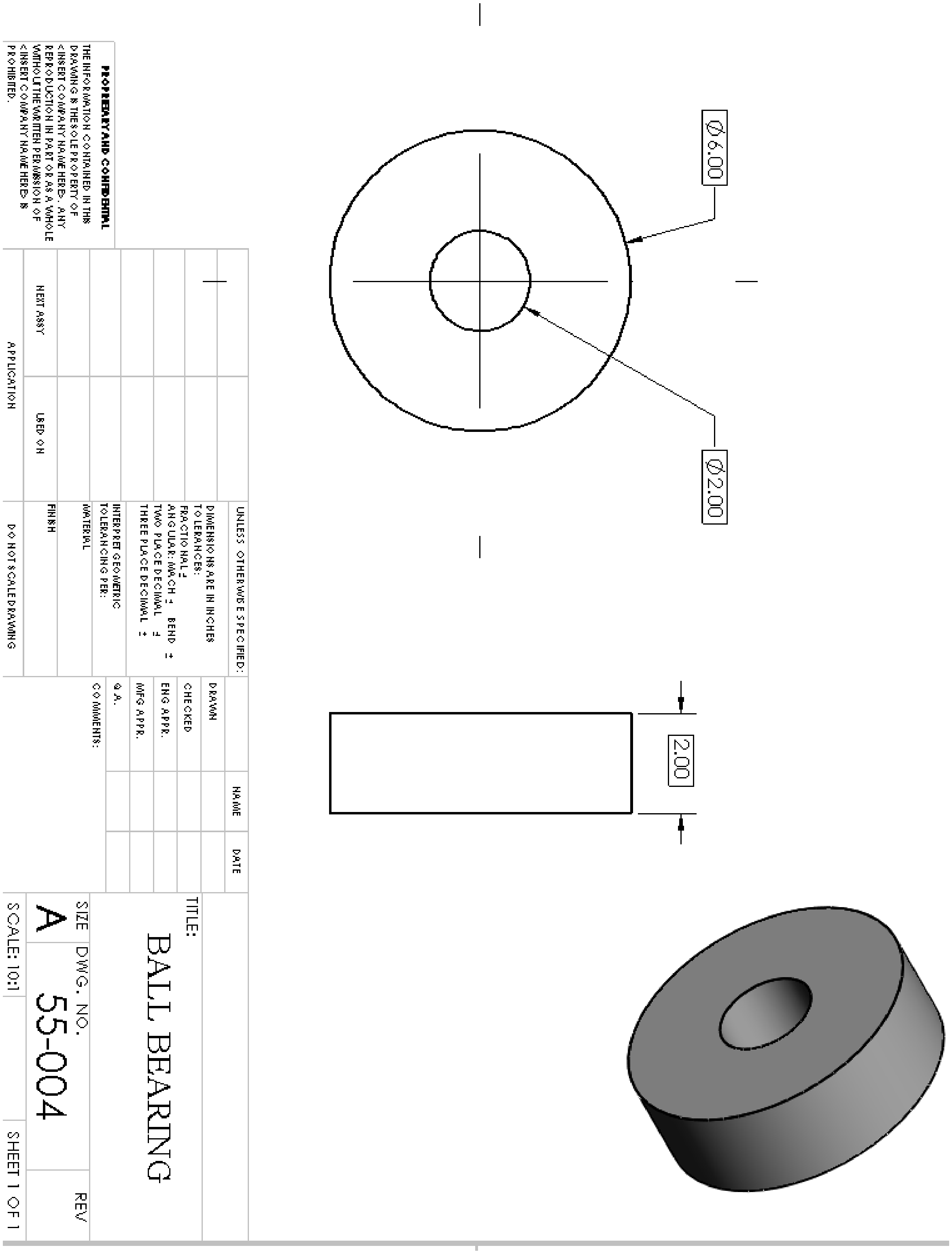
Appendix B – Drawing 55-002



Appendix B – Drawing 55-003



Appendix B – Drawing 55-004



APPENDIX C – Parts List and Costs

Average estimated cost for parts made in house are $25/part including assembly.

Part Number	Qty	Part Description	Source	Cost	Disposition
20-001	4	outside 45 beam	Made in house.	$33.5/hr	1/16
20-002	4	long beam bottom side	Made in house	$33.5/hr	1/23
20-003	4	vertical beam bridge section	Made in house	$33.5/hr	1/23
20-004	4	45d beam bridge section	Made in house	$33.5/hr	1/30
20-005	4	top beam bridge section	Made in house	$33.5/hr	1/30
20-006	10	middle beam bridge & lift section	Made in house	$33.5/hr	1/30
20-007	4	top & bottom beam lifting sect	Made in house	$33.5/hr	2/6
20-008	2	45d beam lifting sect	Made in house	$33.5/hr	2/6
20-009	4	vertical & horizontal beam lifting sect	Made in house	$33.5/hr	2/6
20-010	2	inside short beam lifting sect	Made in house	$33.5/hr	2/6
20-011	2	35d long beam lifting sect	Made in house	$33.5/hr	2/6
20-012	2	top beam lifting sect	Made in house	$33.5/hr	2/6
20-013	2	Extra support beam for the pin	Made in house	$33.5/hr	2/13
20-014	2	Bottom beam lift base	Made in house	$33.5/hr	2/13
20-015	2	64d beam for the lift base bottom sd	Made in house	$33.5/hr	2/13
20-016	2	64d beam upside lift base	Made in house	$33.5/hr	2/13
20-017	2	Vertical beam lift base upside	Made in house	$33.5/hr	2/13
20-018	2	Vertical beam for the lift base down	Made in house	$33.5/hr	2/13
20-019	2	65.2d inside beam lift base	Made in house	$33.5/hr	2/13
20-020	2	Horizontal inside beam lift base	Made in house	$33.5/hr	2/13
20-021	2	45d inside beam lift base	Made in house	$33.5/hr	2/13
20-022	2	Long Counterweight link	Made in house	$33.5/hr	2/13
20-023	11	Primary beam for the deck and top	Made in house	$33.5/hr	2/13

20-024	4	1st beams perpendicular to main beam deck sect.	Made in house	$33.5/hr	2/13
20-025	4	2ndbeams perpendicular to main beam deck sect.	Made in house	$33.5/hr	2/13
20-026	2	3rd beams perpendicular to main beam deck sect.	Made in house	$33.5/hr	2/13
20-027	2	4th beams perpendicular to main beam deck sect.	Made in house	$33.5/hr	2/13
20-028	0	1st lateral bracing top sect.	Made in house	$33.5/hr	2/20
20-029	0	2nd lateral bracing top sect.	Made in house	$33.5/hr	2/20
20-030	1	Pin for the lifting mechanisms	Modified part from McMaster carr	$10.50	2/20
20-031	2	Short counterweight link	Made in house.	$33.50/hr	2/13
20-032	2	Pin for the counterweight	Modified part from McMaster carr	$5.50	2/27
20-033	1	Shaft for the lifting	Modified part from Amazon	$5.50	2/27
20-034	1	Pin for the gear rack	Modified part from Amazon	$5.50	2/20
20-035	2	bracket for the gear rack pin	Made in house.	$33.50/hr	2/27
20-036	1	center of the road deck support	Made in house.	$33.50/hr	2/27
20-037	1	motor bracket	Made in house.	$33.50/hr	2/27
20-038	1	road deck side one	Made in house.	$33.50/hr	2/27
20-039	1	road deck side two	Made in house.	$33.50/hr	2/27
20-040	1	Gear shaft	Modified part from McMaster carr	$10.50	2/27
20-041	1	Support beam for the base	Made in house.	$33.50/hr	2/27
20-042	1	Support rod for base	Made in house.	$33.50/hr	2/27
20-043	1	Gear for the stepper motor	Modified part from McMaster carr	$10.50	2/27
20-044	1	Counterweight container	Made in house.	$33.50/hr	2/27
20-045	1	Gear rack and gear locking bracket	Made in house.	$33.50/hr	2/27

50-001	2	Washer	Mc Master Carr	$3.23	Order 1/20
50-002	2	Screw	ACE hardware (drawings are from McMaster)	$0.14	3/8
50-003	2	Nut	ACE hardware (drawings are from McMaster)	$0.14	3/8
55-001	1	Stepper motor	McMaster Carr	$5.50	Order 1/20
55-002	1	gear rack	McMaster Carr	$5.00	Order 1/20
55-003	1	Gear meeting the gear from stepper motor	Amazon Market place	$10.82	Order 1/20
55-004	2	ball bearing	Amazon Market place	$15.50	Order 1/20

APPENDIX D – Budget

Item	Qty	Description	Cost	%
20/hr	46	Analysis	$1,260.00	39%
18/hr	20	3d Modeling	$945.00	29%
15/hr	25	Assembly	$247.50	8%
14/hr	30	Manufacturing	$710.50	22%
Raw material	2	Balsa wood	$16.86	.5%
Outside parts	12	Purchased parts	$40.05	1.5%
		Total	$3,219.91	100%

APPENDIX E - Schedule

Fall quarter

ID	Description	Est.	Actual	%Comp.	September	October	November	Dec	January	February	March	April	May	June
	SCHEDULE FOR SENIOR PROJECT:													
	PROJECT TITLE: Balsa wood bridge													
	Principal Investigator.: Isaac Chavez Ramirez													
		Duration												
ID		(hrs)	(hrs)											
1	Proposal*													
1a	Outline	0	0											
1b	Intro	2	3.33		X X									
1c	Design & Analysis	63	43.5		X X	X X X X	X X X							
1d	Methods & Construction	6	6				X X							
1e	Discussion	3	2.5				X X X							
1f	Parts and Budget	3	1.5			X X								
1g	Drawings	20	35.5			X X X X	X X X		X					
1h	Schedule	5				X X	X X X							
1i	Summary & Appx	5												
	subtotal:	107	92.3											
2	Design & Analysis				X X	X X X X	X X X							
2a	Design & Analysis (a-q)				X									
2b	Scope of testing &evaluation	3	3		X									
2c	Failure Mode Analysis	5	5				X							
2e	Operation Limits & Safety	2	2.5				X							
2f	Analysis 1	1	1				X							
2g	Analysis 2	4	3		X									
2h	Analysis 3	4	5			X								
2i	Analysis 4	4	4			X								
2j	Analysis 5	5	1			X								
2k	Analysis 6	5	5			X								
2l	Analysis 7	5	1.5			X								
2m	Analysis 8	5	2			X								
2n	Analysis 9	5	3			X								
2o	Analysis 10	5	3			X								
2p	Analysis 11	5	2				X							
2q	Analysis 12	5	2.5				X							
	subtotal:	63.00	43.5											
3	Documentation					X X X X	X X X		◇					
3a	Part 1 drawing 20-001	1	0.5			X								
3b	Part 2 drawing 20-002	1	0.5			X								
3c	Part 3 drawing 20-003	1	0.5			X								
3d	Part 4 drawing 20-004	1	0.5			X								
3e	Part 5 drawing 20-005	1	0.5			X								
3f	Part 6 drawing 20-006	1	0.5				X							
3g	Part 7 drawing 20-007	1	0.5				X							
3h	Part 8 drawing 20-008	1	0.5				X							
3i	Part 9 drawing 20-009	1	0.5				X							
3j	Part 10 drawing 20-010	1	0.5				X							
3k	Part 11 drawing 20-011	1	0.5				X							
3l	Part 12 drawing 20-012	1	0.5				X							
3m	Part 13 drawing 20-013	1	0.5				X							
3n	Part 14 drawing 20-014	1	0.5				X							
3o	Part 15 drawing 20-015	1	0.5				X							
3p	Part 16 drawing 20-016	1	0.5				X							
3q	Part 17 drawing 20-017	1	0.5				X							
3r	Part 18 drawing 20-018	1	0.5				X							
3s	Part 19 drawing 20-019	1	0.5				X							
3t	Part 20 drawing 20-020	1	0.5				X							
3u	Part 21 drawing 20-021	1	0.5				X							
3v	Part 22 drawing 20-022	1	0.5				X							
3w	Part 23 drawing 20-023	1	0.5				X							
3x	Part 24 drawing 20-024	1	0.5				X							
3y	Part 25 drawing 20-025	1	0.5				X							
3z	Part 26 drawing 20-026	1	0.5				X							
3aa	Part 27 drawing 20-027	1	0.5					X						
3ab	Part 28 drawing 20-028	1	0.5					X						
3ac	Part 29 drawing 20-029	1	0.5					X						
3ad	Part 30 drawing 20-030	1	0.5					X						
3ae	Part 31 drawing 20-031	1	0.5					X						
3af	Part 32 drawing 20-032	1	0.5					X						
3ag	Part 33 drawing 20-033	1	0.5					X						
3ah	Part 34 drawing 20-034	1	0.5					X						
3ai	Part 35 drawing 20-035	1	1.5					X						
3aj	Part 36 drawing 20-036	1	0.5					X						
3ak	Part 37 drawing 20-037	1	0.5					X						
3al	Part 38 drawing 50-001	0.5	0.5					X						
3am	Part 39 drawing 55-001	0.5	0.5					X						
3an	Part 40 drawing 55-002	0.5	0.5					X						
3ao	Part 41 drawing 55-003	0.5	0.5					X						
3ap	Part 42 drawing 55-004	0.5	0.5						X					
3aq	Subassembly bridge portion w/o lifting drawing	2	2			X								
3ar	Subassembly lifting mechinism section drawing	2.5	2.5			X								
3as	Subassembly support for the lifting mechanism	2.5	2.5				X							
3at	Device bridge drawing	5	4.5				X							
3au	ANSY14.5 Compl	1	2			X X X X	X X X X	X X	X					
	subtotal:	52.5	35.5											

Winter Quarter

	Description	Est.	Actual	%Comp.	Septembe	October	November	Dec	January	February	March	April	May	June
4	Proposal Mods													
4a	Project Balsa Wood Bridge Schedule	5	0		X	X	X	X	X	X	X	X	X	
4b	Project Balsa Wood Bridge Part Inv.	2	2							X				
4c	Crit Des Review*	3	0											
	subtotal:	10	2											
7	Part Construction													
7a	Buy shaft material & gears	1	1.5						X					
7b	Buy balsa wood material	1	0.5						X					
7c	20-001	1	1.25						X					
7d	20-002	1	1						X					
7e	20-003	1	1						X					
7f	20-004	1	1.5						X					
7g	20-005	1	1.5						X					
7h	20-006	1	2						X					
7i	20-007	1	0.75							X				
7j	20-008	1	0.25							X				
7k	20-009	1	1							X				
7l	20-010	1	0.75							X				
7m	20-011	1	0.75							X				
7n	20-012	1	1							X				
7o	20-013	1	0.75							X				
7p	20-014	1	0.5							X				
7q	20-015	1	0.50							X				
7r	20-016	1	0.50							X				
7s	20-017	1	1.00							X				
7t	20-018	1	0.50							X				
7u	20-019	1	0.50							X				
7v	20-020	1	0.75							X				
7w	20-021	1	0.50							X				
7x	20-022	1	1.25							X				
7y	20-023	1	1.25							X				
7z	20-024	1	0.50							X				
7aa	20-025	1	0.50							X				
7ab	20-026	1	0.25							X				
7ac	20-027	1	0.25							X				
7ad	20-028	1	0.25							X				
7ae	20-029	1	0.25							X				
7af	20-030	1	0.75							X				
7ag	20-031	1	0.25							X				
7ah	20-032	1	1.00							X				
7ai	20-033	0.75	0.75						X					
7aj	20-034	1	0.25							X				
7ak	20-035	1	1.25							X				
7al	20-036	1	1.00							X				
7am	20-037	1	0.133							X				
7an	20-038	1	0.50							X				
7ao	20-039	1	0.25	4.25						X				
7ap	50-001	1	1						X					
7aq	55-001	1	1						X					
7ar	55-002	1	1						X					
7as	55-003	1	1						X					
7at	55-004	1	1						X					
7au	Take Part Pictures	1	1.25							X				
7av	Update Website prt1	1	1						X					
7aw	Manufacture Plan*	2	1.5						X					
7ax	Update Website prt2	1	1.5											
	subtotal:	50.75	41.13											
9	Device Construct													
9a	Assemble Sub road deck	3	2.75							X				
9b	Assemble Sub both Side bridge	3	3.25								X			
9c	Assemble Sub lifting base	3	3								X			
9d	Assemble all Subassemblies	4	4.5								X			
9e	Take Dev Pictures	2	1								X			
9f	Update Website	1.5	1.5								X			
	subtotal:	16.5	16											

Spring Quarter

APPENDIX F – Expertise and Resources

Criterion	Weight 1 to 3	Best Possible 3	Design # 1	1 Score x Wt	Design # 2	2 Score x Wt	Design # 2	3 Score x Wt	
Cost	1	3	1	1	1	1	1	1	
Weight	3	9	2	6	1	3	3	9	
Prediction precision	2	6	2	4	2	4	2	4	
Confidence in failure location	2	6	1	2	1	2	2	4	
Prismatic vs non prismatic	3	9	2	6	2	6	2	6	
Manufacturability	2	6	2	4	1	2	2	4	
Span	2	6	3	6	3	6	3	6	
Lifting system	3	9	1	3	2	6	3	9	
Total	18	54		32		30		43	
NORMALIZE THE DATA (muliply by fraction, N)		1.85		59.26		55.56		79.63	Percent
								64.81	Average
								12.96	Std Dev.

Decide if Bias is Good or Bad

Good Bias: Standard Deviation is two or more digits — Good? Then you're done.

Poor Bias: Standard Deviation is one or less digits — Poor? Then change something!!!

You can change the criteria, weighting, or the projects themselves…

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	
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
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

Each design was score like this because of the requirments, whichone of the desing will best work for the requirents

APPENDIX G – Testing Report

Test Report 01

Introduction:

This test requires that the bridge have a clear span opening of 400 mm and have an 8 mm diameter hole where a bolt will be placed to do the bridge's load test. The predicted value for the span opening was 412 mm; the bridge was designed to have at least 6 mm of support on each side. The predicted diameter for the hole was 8 mm; the hole was made with an 8 mm drill bit. The data from this test will be collected by using the datasheet from appendix G2.a. The test is scheduled for April 8, 2021.

Method/Approach:

The test will be done by the student alone with the help of a camera to record the test; there will be no cost to doing this test. The results of the test will be recorded on the datasheet. The bridge will be placed on top of two books representing the abutments that are 400 mm apart; the hole opening will be measured with a caliper. The precision of the caliper is ±0.01 mm, and its accuracy is ±0.02 mm. The Tape measurement precision and accuracy is within ± 1/32 inch.

Test Procedure: span opening & hole diameter.

This procedure documents the process of recording and measuring the span opening of the bridge. The bridge is designed to have a span opening of 400 mm and must rest on two abutments that are 400 mm apart. It also must have an 8 mm hole in the center of the road deck for the weight test. The bridge was designed and built by the student for the MET Senior project. The following is the test information and procedure for this test.

Time: This test was conducted on April 8, 2021 from 5:00PM to 7:00PM, the first half hour was used for gathering all equipment and setting up the test.

Place: Student’s apartment, Ellensburg, WA

Required equipment:

- Bridge.
- Camera.
- Tripod for the camera.
- Laptop or something to write the data that will be collected.
- Pen or pencil.
- Measuring tape.
- Caliper.
- Datasheet.

Risk: All equipment must be collected on time. Risk in the completion of the test would be a broken or bad measuring tape.

The test procedure is as follows:

1. Gather all the equipment:
    a) Bridge.
    b) Camera and a tripod.
    c) Measurement device (measure tape) and caliper.
    d) Laptop or something to write the data collected.
2. Place all the equipment and bridge on a table.
3. Connect the camera and tripod.
4. Place and adjust the tripod near the table pointing at the testing area of the bridge.

5. Start the recording.
6. Start measuring the span opening and abutment length from where the bridge will be on the abutments. See figure 1 for the setup.

Figure 1 setup test.

7. Measure the hole opening of the center of the bridge, see figure 2 hole opening for reference.

Figure 2 hole opening.

8. On a table, using the table datasheet from Appendix G2.01 record the span opening, hole opening, and if it is fully supported on both ends of the span. See table 1 for the datasheet.

Span measurement and abutment clearance			
Parameters to be tested	**Required values**	**Estimated Values**	**Actual values**
Span Opening			
Hole diameter			
Abutment's support			

Table 1 datasheet for the span and road deck.

9. Stop the recording.
10. Gather and store all the equipment.

Discussion: The test for the span opening and hole opening for the load test was easy to complete a tape measure was used for the span opening and a caliper was used for the hole opening. For the support on both ends of the bridge was a visual inspection. No issues with the completion of this test.

Deliverables:

Span measurement and abutment clearance

Parameters to be tested	Required values	Estimated Values	Actual values	Pass/Fail
Span Opening	400 mm	412 mm	415 mm	Pass
Hole diameter	8.00 mm	8.00 mm	8.03 mm	Pass
Abutment's support	fully	yes	Yes	Pass

Test Report 02

Introduction:

The project required that the bridge has an articulation to permit the bridge to raise the midpoint of the road deck 140 mm above its original horizontal resting position. The bridge must maintain the lifting position for at least 10 seconds to let the traffic traverse under the bridge. The lifting system can be manual or automated. The predicted height that the bridge will be in the lifting position is 400 mm, and it will maintain the position for more than 10 seconds. The data will be collected using the datasheet form from appendix G2.02. The test is scheduled for April 9, 2021.

Method/Approach:

The test will be completed by the student alone with the help of a camera to record or take pictures of the test, and there will be no cost in the completion of this test. The data will be collected by taking pictures or in the datasheet. The test will be visual that the lifting system is working correctly. A timer will be used to measure the time that the bridge is in the lifted position, and a tape measure to measure the bridge's height from the horizontal resting position. There are no operational limitations on the bridge that will limit this test. The precision and accuracy of the tape measure are ±1/32 in. The data will be presented in a table.

Test Procedure: Lifting mechanism

This procedure documents the process of recording and lifts the bridge to a position that can let the traffic traverse under the bridge, also look if the lifting mechanism work without any problem. The bridge is designed to raise the midpoint of the road deck at least 140 mm above the original horizontal resting position and maintain the lifted position for at least 10 seconds. The following is the test information and procedures.

Time: This test was conducted on April 9, 2021 from 5:00PM to 7:00PM the first half hour was used for gathering all equipment and setting up the testing are.

Place: Student's apartment, Ellensburg WA.

Required Equipment:

- Bridge.
- Arduino Nano.
- IR controller.
- Stepper Motor.
- Camera.
- Tripod for the camera.
- Laptop or something to write the data that will be collected.
- Pen or pencil.
- Measuring tape.
- A 20lb std. printer paper or an object of .
- Datasheet.

- ➢ Timer.

Risk: All equipment must be collected on time. Risk in the completion of the test would be broken or missing equipment.

The test procedures is as follows:

1. Gather all the equipment:
    a. Bridge, Arduino, IR controller, and Stepper Motor.
    b. Camera and tripod.
    c. Measuring tape.
    d. Laptop, datasheet, and plain paper, pen, or pencil.
    e. 20lb std. printer paper or object
    f. Timer.
2. Place all the equipment on a near table.
3. Connect camera and tripod.
4. Place and adjust the tripod near the table pointing at the testing are of the bridge.
5. Start recording.
6. Use the IR controller to raise the bridge, see figure 3 IR controller layout. Positioned the bridge up to an almost vertical position, see figure 4 Bridge on the lifting position for reference on how must look like.

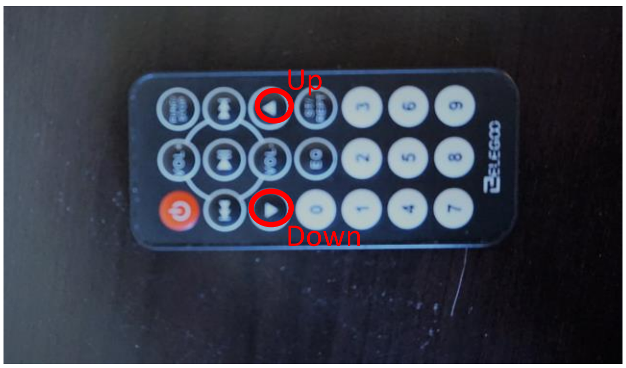


Figure 3 IR Controller setup.

7. Start the timer.
8. Stop the timer if it pass the 10 second's mark.
9. On the datasheet using the table from Appendix G2.02 record the time and if it pass or fail the test, see table 2 Lifting bridge.

Lifting Bridge			
Parameters to be test	**Required Values**	**Estimated value**	**Actual value**
Time			
Slide			
Height			

Table 2 Lifting bridge.

10. Slide the 20lb std. printer paper under the bridge in the raise position or use measuring tape to measure the height of the bridge for the midpoint of the road deck to the horizontal resting position, see figure 4 Bridge on the up position.

Figure 4 Bridge on the up position.

11. On the datasheet using the table from Appendix G2.d record the height and if it pass or fail, see table 2 Lifting bridge.
12. Lower the bridge to the resting position using the IR controller pushbutton down, see figure 3 IR Controller layout.
13. Stop the recording.
14. Gather and store all the equipment.

Discussion: The test was well done, the system work as what was expected, just some minor issues were encounter while doing this test. One issue was that the bracket holding the gear rack and gear was that one side of the bracket holding the shaft was broken and sometimes the gear skip tooths from the gear rack, the solution for this issue was to print another bracket, this solution work up to now. The other issue was that the bracket holding the stepper motor was loose, so when the stepper motor was working the gears was no making good contact with each other, the solution for the issue was too tight more the screws holding the bracket up to having a good tight without damaging the balsa wood. Just these two issues only were encounter in this test and were easy to fix them.

Deliverables:

Lifting Bridge				
Parameters to be test	**Required values**	**Estimated values**	**Actual values**	**Pass/fail**
Time	10 seconds	>10 sec.	15 seconds	Pass
Slide	20lb std. printer paper box	Pass	It pass	Pass
Height	140 mm	400 mm	450 mm	Pass

Test Report 03

Introduction:

The bridge must have a road deck big enough to let a 32 mm wide by 25 mm high block pass through the bridge without obstruction; the block will be representing a vehicle. The predicted performance is that the bridge is wide and high enough to let this block pass without any issue; this data will be collected by recording a video showing the test. The test is scheduled to take place on April 15, 2021.

Method/Approach:

The test will be conducted by the student alone with the help of a camera to record the test from start to finish, then later analyzing the recording to see if the test passes the requirement's criteria. The bridge will be placed on top of a table; then, the block will be placed on one side of the bridge with a string attached to the block and be on the other side of the bridge. The string will be pulled from the other side up to the block pass over the bridge completely. The limitations will be to find the right block with the right dimensions. For this, the block will be 3d printer on time; other than that, there are no other limitations of this test. The precision and accuracy for the caliper are ±0.02 mm, and the precision and accuracy of the 3d printer is ± 0.05 mm. A camera will record the data, and it will be presented on a table.

Test Procedure: Vehicle passing over the bridge.

This procedure documents the process of recording and simulates a vehicle passing over the bridge without any problem or obstruction. The bridge is designed to have an opening of 32 mm X 25 mm that will represent a vehicle passing over the bridge. The following is the test information and procedure for this test.

Time: This test was conducted on April 15, 2021 from 12:00PM to 2:00PM the first half hour was used for gathering all equipment and setting up the test area.

Place: Student's apartment, Ellensburg WA.

Required equipment:

- Bridge.
- Camera.
- Tripod for the camera.
- Laptop or something to write the data that will be collected.
- Pen or pencil.
- Measuring tape or caliper.
- Object representing a vehicle or a car toy (32mm X 25mm block).
- Datasheet.

Risk: All equipment must be collected on time. Risk in the completion of the test would be broken or missing equipment.

The test procedures is as follows.

1. Gather all the equipment:
    a. Bridge.
    b. Camera and tripod.
    c. Measuring tape (caliper).
    d. Laptop or something to write the data collected (datasheet).
    e. Object representing a vehicle.
2. Place all the equipment and bridge on a near table.
3. Connect the camera and tripod.
4. Place and adjust the tripod near the table pointing at the testing area of the bridge.
5. Start recording.
6. Use the caliper to measure the object or toy to be in the require dimensions that is needed for this test, see figure 5 for the setup measurements of the vehicle.

Figure 5 vehicle dimensions.

7. Attach a cord on the vehicle and place it on the road deck, the cord must be place on top of the road deck all the way to the other side of the bridge. See figure 6 for the setup of the vehicle on top of the bridge.

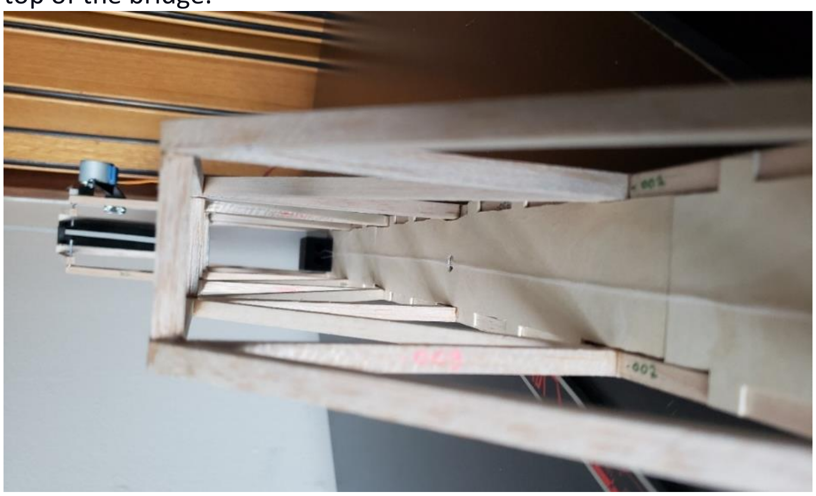


Figure 6 vehicle on top of the bridge

8. Pull the vehicle with the cord across the bridge.
9. On the datasheet, using the table from Appendix G2.03 record if the opening pass or fail the test. See table 3 vehicle passing over the bridge.

Vehicle passing over the bridge.			
Parameters to be test	**Required values**	**Predicted values**	**Actual values**
Vehicle passing over the bridge.			
Road deck dimensions.			

Table 3 Vehicle passing over the Bridge.

10. Stop the recording.
11. Gather and store all the equipment.

Discussion: This test was well done without issues. The open of the bridge was wide enough that the vehicle passes without any problem, the object was 3d-printed to the required dimension that this test needed. The actual road deck dimensions are 40mm wide by 115 mm high.

Deliverables:

Vehicle passing over the bridge.				
Parameters to be test	**Required values**	**Predicted values**	**Actual values**	**Pass/Fail**
Vehicle passing over the bridge.	N/A	It will pass	N/A	Pass
Road deck dimensions.	32 mm x 25mm	40 mm x 90 mm	40mm x 115 mm	Pass

Test Report 04

Introduction:

The project required that the bridge must weigh less than 85 grams without the articulation components of the lifting mechanism. The parameters of interest is that the bridge need to weigh less than 85 grams. The predicted performance of this test is that this bridge will weigh less than 85 grams base on the design of the bridge. The data will be collected by using a camera pointing at a scale measurement. The test is schedule to take place on April 18, 2021.

Method/Approach:

The test will be performed by the student alone with the help of a camera to record the test. The test will be done by putting the bridge on top of a small scale to measure its weight. It will be limitations on the test if the scale was no working property. The precision and accuracy of the scale is of ±0.5 grams. The data collected will be recorded on the datasheet provided to this test and it will be presented on a table.

Test Procedure: Weight of the bridge.

This procedure documents the process of recording and weighting the bridge. The bridge was designed to weight at least 85 grams. The following is the test information and procedures.
Time: This test was conducted on April 18, 2021 from 5:00PM to 7:00PM. The first half hour was used to gather all equipment and setting up the testing area.
Place: Student's apartment, Ellensburg WA.
Required Equipment:

- Bridge.
- Scale.
- Camera.
- Tripod.
- Laptop or something to write.
- Pen, pencil.
- Datasheet.

Risk: All equipment must be collected on time. Risk in the completion of the test would be a broken or missing equipment.
The test procedures is as follows:

1. Gather all equipment:
    a. Bridge and scale.

    b. Camera and tripod.
    c. Laptop, datasheet, and engineering paper, pen, or pencil.
2. Place all the equipment on a near table.
3. Connect camera and tripod.
4. Place and adjust the tripod near the table pointing at the testing area of the bridge.
5. Start recoding.
6. Check if the scale is on zero, if not zero it.
7. Place the bridge on top of the scale, see figure 7 for the setup of the bridge on top of the scale.

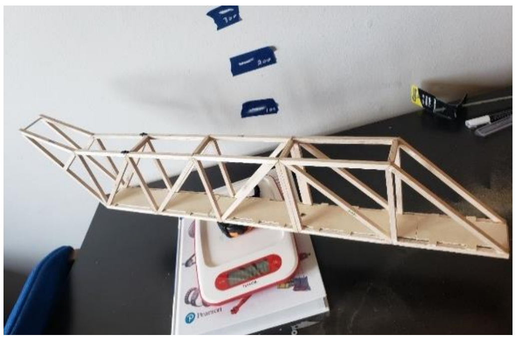


Figure 7 Bridge on top of scale setup

8. Take a picture of the scale reading.
9. On the datasheet using table from Appendix G2.04 record the value and if the test pass. See table 1 for details.

Weight of the bridge			
Parameter to be test	**Required value**	**Estimated value**	**Actual value**
Weight			

Table 4 Weight of the bridge.

10. Remove the bridge from the scale.
11. Stop recording.
12. Gather and store all the equipment.

Discussion: This test was well done, no issues on the completion of this test. However, the results were not what was expected the estimated value was approximately 75 grams without the lifting system, the actual value including lifting system and the counterweight is of 230 grams, this test proves that this bridge did not meet the required value, so this test fail.

Deliverables:

Weight of the bridge				
Parameter to be test	**Required value**	**Estimated value**	**Actual value**	**Pass/fail**
Weight	85 grams	80 grams	83 grams	Pass

Test Report 05

Introduction:

The bridge must support a minimum of 18.9 to 20 kg load. The parameter of interest is that the bridge must support at least 18.9 kg without breaking the bridge. The predicted performance is that the bridge will support 20 kg of load without breaking any part of the bridge. The data will be collected by recording the weight that is applied on the bridge on a datasheet made for this test. The test is schedule to take place on April 22, 2021.

Method/Approach:

The test will be performed by the student with the help of a camera to record the entire test. The bridge will be place on top of two tables that will be 400 mm apart, the bridge will be attached to a bucket with an eye bolt and a string. Then sand will be place into the bucket up to the 20 kg. The precision and accuracy for the scale used to measure 2 kg is of ±0.05 grams, so the result will be close to the required value of the test. The data will be recorded on a table with the estimated values and the required values, also the table will be used for the data presentation.

Test Procedure: Bridge's load

This procedure document the process of recording and testing the how much load can the bridge handle. The bridge was designed to withstand a load of 18.9 kg on the center of the road deck. The following is the test information and procedures.

Time: this test was conducted April 22, 2021 from 6:00PM to

Place: Student's apartment, Ellensburg WA.

Required Equipment:

- Bridge.
- Scale.
- Bucket.
- Small container.
- Sand.
- Eye bolt of 6 inches of length.
- One 1/4 -20 hex nut.
- One 3/8 X 1- ½ washer.
- Rope strong enough to hold at least 20 kg.
- Camera.
- Tripod.
- Laptop or something to write on.
- Pen or pencil.
- Datasheet.

Risk: All equipment must be collected on time. Risk in the completion of the test would be a broken or missing equipment.

The test procedures is as follows:

1. Gather all equipment:
    a. Bridge.
    b. Scale, bucket, and sand.
    c. Eye bolt, hex nut, and washer.
    d. Camera and tripod.

e. Laptop, datasheet, engineering paper, and pen or pencil.

2. Place all the equipment on a near table.
3. Connect the eye bolt, hex nut, and the washer on the bridge, attached with the rope and bucket, see figure 8 load bridge setup to know how it should look like. Put the bridge on a 400 mm span with space under it for the load.

Figure 8: load bridge setup

4. Connect camera and tripod.
5. Place and adjust the tripod near the table pointing at the testing area of the bridge.
6. Start recording.
7. In the scale with the help of the small container measure 2 kg of sand.
8. Place the 2 kg on the bucket under the bridge.
9. Repeat the process of measuring the 2 kg and putting the sand on the bucket for 3 more times, up to making 16 kg in total.
10. Now measure 1 kg of sand on the scale.
11. Place the 1kg on the bucket.
12. Repeat step 10 and 11 up to the 18.9 kg or up to the bridge fail.
13. Take picture of the bridge with the load on.
14. On the datasheet using the table form Appendix G2.05a record each value of the weight that is been putting on the bridge. See table 5 for details.

Load on the bridge	
	Weight
Initial weight	
2 kg increments	
1st increment	
2nd	
3rd	
4th	
5th	
6th	
7th	
8th	
1 kg increments	

1st	
2nd	
3rd	
4th	
Total	

Table 5 Weight on the bridge

15. Stop the recording.
16. Remove the load off the bridge.
17. Remove the eye nut, hex nut, washer, and everything from the bridge.
18. Record the total value on the datasheet from appendix G2.05b. see table 6 bridge's load.

Bridge's load			
	Required values	Estimated values	Actual value
Load			

Figure 6 bridge's load

19. Gather and store all the equipment.

Discussion: The procedures of the test help to achieve the value that the required value need, so there were not issues on the procedures. However, one issue was that the bucket handle broke at 16 kg, so the test must be redone. The solution for this issue was made a handle out of string that can handle more than 50 kg. After the new handle was made, the test was completed without any issues with the same procedures.

Deliverables:

Bridge's load				
	Required values	Predicted values	Actual value	Pass/Fail
Load	18.9 to 20 kg	20 kg	21.3 kg	Pass

Appendix G1

Appendix G1.01 Procedure checklist test 01.

X	Gather all equipment.
X	Get the datasheet.
X	Setup testing area.
X	Record the test.
X	Record the data collected.

Appendix G1.02 Procedure checklist test 02.

X	Gather all equipment.
X	Get the datasheet.
X	Setup testing area.
X	Record the test.
X	Record the data collected.

Appendix G1.03 Procedure checklist test 03.

X	Gather all equipment.
X	Get the datasheet.
X	Setup testing area.
X	Record the test.
X	Record the data collected.

Appendix G1.04 Procedure checklist test 04.

X	Gather all equipment.
X	Get the datasheet.
X	Setup testing area.
X	Record the test.
X	Record the data collected.

Appendix G1.05 Procedure checklist test 05.

X	Gather all equipment.
X	Get the datasheet.
X	Setup testing area.
X	Record the test.
X	Record the data collected.

Appendix G2

Appendix G2.01 Data forms test 01.

Span measurement and abutment clearance			
Parameters to be tested	**Required values**	**Estimated Values**	**Actual values**
Span Opening			
Hole diameter			
Abutment's support			

Appendix G2.02 Data forms test 02.

Lifting Bridge			
Parameters to be test	**Required values**	**Estimated values**	**Actual values**
Time			
Slide			
Height			

Appendix G2.03 Data forms test 03.

Vehicle passing over the bridge.			
Parameters to be test	**Required values**	**Predicted values**	**Actual values**
Vehicle passing over the bridge.			
Road deck dimensions.			

Appendix G2.04 Data forms test 04.

Weight of the bridge			
Parameter to be test	**Required value**	**Estimated value**	**Actual value**
Weight			

Appendix G2.05a Data form test 05.

Load on the bridge	
	Weight
Initial weight	
2 kg increments	
1st increment	
2nd	

3rd	
4th	
5th	
6th	
7th	
8th	
1 kg increments	
1st	
2nd	
3rd	
4th	
Total	

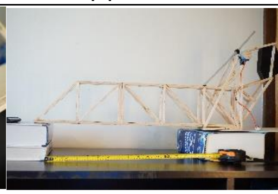
Appendix G2.05b Data form test 05.

Bridge's load			
	Required values	Estimated values	Actual value
Load			

Appendix G3

Appendix G3.01 Raw data test 01.

Span measurement and abutment clearance			
Parameters to be tested	**Required values**	**Estimated Values**	**Actual values**
Span Opening	400 mm	412 mm	415 mm
Hole diameter	8.00 mm	8.00 mm	8.03 mm
Abutment's support	fully	yes	Yes

Appendix G3.02 Raw data test 02.

Lifting Bridge			
Parameters to be test	**Required values**	**Estimated values**	**Actual values**
Time	10 seconds	>10 sec.	15 seconds
Slide	20lb std. printer paper box	Pass	It pass
Height	140 mm	400 mm	450 mm

Appendix G3.03 Raw data test 03.

Vehicle passing over the bridge.			
Parameters to be test	**Required values**	**Predicted values**	**Actual values**
Vehicle passing over the bridge.	N/A	It will pass	N/A
Road deck dimensions.	32 mm x 25mm	40 mm x 90 mm	40mm x 115 mm

Appendix G3.04 Raw data test 04.

Weight of the bridge			
Parameter to be test	**Required value**	**Estimated value**	**Actual value**
Weight	85 grams	80 grams	83 grams

Appendix G3.04 Raw data test 05

Bridge's load			
	Required values	Predicted values	Actual value
Load	18.9 to 20 kg	20 kg	21.3 kg

Appendix G4

Appendix G4.01 Evaluation Sheet test 01.

Span measurement and abutment clearance				
Parameters to be tested	**Required values**	**Estimated Values**	**Actual values**	**Pass/Fail**
Span Opening	400 mm	412 mm	415 mm	Pass
Hole	8.00 mm	8.00 mm	8.03 mm	Pass
Abutment's support	fully	yes	Yes	Pass

Appendix G4.02 Evaluation Sheet test 02.

Lifting Bridge				
Parameters to be test	**Required values**	**Estimated values**	**Actual values**	**Pass/fail**
Time	10 seconds	>10 sec.	15 seconds	Pass
Slide	20lb std. printer paper box	Pass	It pass	Pass
Height	140 mm	400 mm	450 mm	Pass

Appendix G4.03 Evaluation Sheet test 03.

Vehicle passing over the bridge.				
Parameters to be test	**Required values**	**Predicted values**	**Actual values**	**Pass/Fail**
Vehicle passing over the bridge.	N/A	It will pass	N/A	Pass
Road deck dimensions.	32 mm x 25mm	40 mm x 90 mm	40mm x 115 mm	Pass

Appendix G4.04 Evaluation Sheet test 04.

Weight of the bridge				
Parameter to be test	**Required value**	**Estimated value**	**Actual value**	**Pass/fail**
Weight	85 grams	80 grams	83 grams	Pass

Appendix G4.05 Evaluation Sheet test 05

Bridge's load				
	Required values	Predicted values	Actual value	Pass/Fail
Load	18.9 to 20 kg	20 kg	21.3 kg	Pass

Appendix G5

	Description	Est.	Actual	%Comp.	September	October	November	Dec	January	February	March	April				May	June
10	Device Evaluation												◇				
10a	List Parameters	1.5	0.5								X						
10b	Design Test&Scope	3	4								X	X	X	X			
10c	Obtain resources	1.5	2								X	X					
10d	Make test sheets	2.5	2								X	X	X	X			
10e	Test Plan 1 (span opening and dimensions)	2	1.5								X						
10f	Perform Test 1	2	2									X					
10g	Test Plan 2 (Vehicle passing over bridge)	2	1.5									X					
10h	Perform Test 2	3	2										X				
10i	Test Plan 3 (Lifting Mechanims)	2	1.5									X					
10j	Perform Test 3	3	2									X					
10k	Test plan 4 (Weight of the bridge)	2	1.75										X				
10l	Perform Test 4	3	2											X			
10m	Test plan 5 (strength of the bridge)	2	1.5											X			
10n	Perform Test 5	3	3											X			
10o	Take Testing Pics	1.5	2									X	X	X			
10p	Update Website	2	2										X	X	X		
	subtotal:	36	31.3														

APPENDIX H – Resume

ISAAC CHAVEZ RAMIREZ

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First-generation Mechanical Engineering Technology student seeking an opportunity to expand and apply the growth, knowledge, and experience in the Mechanical Engineering Technology field.

EXPERIENCE

MANAGER, FUENTE DE AGUAS, LLC

SEPTEMBER 2017 – PRESENT

- Employed 30+ staff to work as seasonal farmworkers.
- Negotiated Contracts/ Salaries with companies
- Budget Management

SEASONAL FARMWORKER, VARIOUS COMPANIES

2011 – PRESENT

- Picking & Thinning apples
- Maintenance various vegetable / fruit plants
- Detasseling corn
- Pruning fruit trees

CENTRAL WASHINGTON UNIVERSITY

SEPTEMBER 2015- PRESENT

BACHELORS IN MECHANICAL ENGINEERING TECHNOLOGY

COUSEWORK

- CNC Programmer (three axis)
- Thermodynamic
- Fluid mechanic
- Introduction to Metallurgy

EDUCATION

SKILLS

Reliable, Adaptable, and Self-motivated
Professional
Leadership
Bilingual (Spanish & English)
Excel, Word, SolidWorks