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Articulating Balsa Wood Bridge

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By

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ABSTRACT

Bridges have been used worldwide to allow passage between untraversable terrain. These bridges are built according to their terrain and environment, while also withstanding the forces of objects going across them. This project explores building a bridge under specific design restrictions to be able to simulate objects traversing across and under it.
The device consists of a bridge, utilizing a Pratt truss design, and an articulation tower which are mechanically linked using a hinge. The articulation tower allows the bridge to be raised and lowered, simulating an object to be passed under. Raising and lowering the bridge consists of using a motor controlled by an Arduino. Both the bridge and articulation tower are designed and built using balsa wood, making the device very lightweight.
The device is tested through several methods. A tape measure and an applied load is used to test the performance. The results found that the bridge withstood a center load of 19 kg. The center of the bridge also deflected less than 25 mm when the load was applied. Other tests that meet specification requirements were completed, such as making sure the device was under the required mass of 85 kg and measuring the middle of the bridge when it's raised to be at least 140 mm.

Keywords: balsa wood, bridge, articulation, design

Contents

1. INTRODUCTION

a. Description

Engineering is used to design and construct a balsa wood bridge spanning over a body of water that also articulates to clear an object going through. Design on the bridge includes predicting stresses and analyzing how an articulating component affects the system.

b. Motivation

This project was motivated by a need for a device that would be able to withstand a certain amount of weight and articulate to let objects underneath through. Every bridge in the world is specifically designed to accommodate its environment to cross bodies of water. With it being an invaluable tool to many today, it's important to realize the processes of planning, designing and building a bridge, that not only connects two lands, but to show further utility in being able to lift from its horizontal position to allow passage underneath it.

c. Function Statement

The bridge allows objects to pass over terrain that was previously impassable.

d. Requirements

1) When a 20 kg load is applied the bridge must not deflect more than 25 mm.
2) Articulation element must support the bridge using 2 strings
3) The road deck of the bridge must be more than 38 mm.
4) The height clearance within the road deck must be more than 25 mm.
5) The midpoint of the bridge must be 140 mm above its original position.
6) The bridge must open, stay open for 10 seconds, and close within 60 seconds.
7) The total weight of the bridge without an articulation component must not exceed 85g.
8) An 8 mm diameter hole must be in the center of the bridge for testing.
9) The bridge must be longer than 400 mm long.
10) The bridge must support 20 kg without collapsing.

e. Engineering Merit

Using statics, calculations are needed to analyze the bridge where it will experience higher or lower points of stress. Deflection in the bridge will also need to be considered in calculations. Mechanics of materials will be used to analyze the properties of the balsa wood and the various parts of the articulating component. Dynamics will be used in the lifting component of the bridge. Calculations include finding the work needed to lift the bridge from a horizontal to vertical position.

f. Scope of Effort

The project will include designing and building the bridge and its articulating component. The bridge will be built only from balsa wood and glue, while the articulating component can include hardware such as gears, shaft, bearings, cable, circuit. Any other components such as the steel abutments that the bridge will sit on are not included in the build process.

g. Success Criteria

The project will be successful by designing and building an articulating balsa wood bridge that allows an object to cross the bridge and an object to cross underneath in addition to the specified testing criteria.

h. Stakeholders

The stakeholders are the Industrial Advisory Board that will review the project after designing, manufacturing, testing, and a written report is completed and submitted. CWU MET instructors; Professor Pringle and Professor Choi provide further guidance throughout the process. Combined feedback from both faculty and students shares ideas and provide information to complete the project.

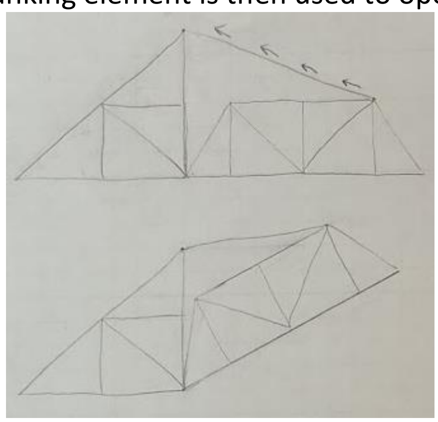
2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The bridge needs to support a load and be able to raise to let access for objects of a certain height to be able to pass under. Several designs of this kind of bridge were considered. The first design included the bridge and an additional structure on one end that will be the articulating element. Strings are placed from the top edges of the structure and connected to the farthest point of the bridge, much like a drawbridge. The second design was like the first, but two parts of the bridge would rise in the middle instead of one end. The third design would be similar to a lift bridge, where the middle section would raise vertically. Using a decision matrix (see Figure 1 in Appendix F), the drawbridge would be the best design.

b. Design Description

The current design includes a bridge with a structure on one end that connects two ropes to some point on the bridge. A cranking element is then used to open and close the bridge.



c. Benchmark

An already completed bridge can support a load without collapsing. The bridge can also rise a certain height to allow access under.

d. Performance Predictions

The bridge is predicted to support 20 kg across any point. While this load is applied, the vertical deflection of the bridge will not be more than 18 mm. The articulation of the bridge will be able to open and close within 30 seconds. As the bridge opens, its position will be held for at least 10 seconds. The articulation element will be able to last at least 50 cycles.

e. Description of Analysis

Statics will be used to analyze forces that the bridge will experience. Using accurate FBD’s will show correct equilibrium equations of the beams in the bridge. It can also be used to find the most effective angle to hold the most weight. The angle of the rope connected to a certain point on the bridge will also have an impact on the amount of force needed to lift the bridge the required height. Mechanics of materials will be used to find stresses in the bridge and component sizes so the bridge will not fail when the required load is applied.

f. Scope of Testing and Evaluation

The bridge must meet all clearance and weight requirements. The articulation element will be designed to allow for multiple cycles.

g. Analysis

i. Analysis 1 – Bridge minimum angle when open

The bridge must be able to rise to let access through for objects under. The midpoint of the bridge must be 140 mm above its original height. (See 1d5) The bridge must also be longer than 400 mm. (See 1d9) Assuming the bridge length to be 450 mm, the minimum angle for the bridge is calculated to be 38.48 °. (See Appendix A01)

ii. Analysis 2 – Minimum area of balsa wood

The engineering analysis uses the Modulus of Rupture formula. The bridge must be able to withstand a load of 20 kg. The Modules of Rupture of balsa wood is used to calculate this. With a length of 450 mm (see 1d5) and a center force of 196.2 N, the area is calculated to 18.3 mm. This number is rounded up to the next balsa wood size of 20 mm. (See Appendix A02)

iii. Analysis 3 – Total Weight of Bridge

The bridge must weigh less than 85 g. (See 1d7) Using standard balsa wood sizes, they can be calculated and used to find the total weight based on the current bridge design. After predicting the sizes, using the density of balsa wood from matweb.com, dynamics can be used to calculate the mass of all the members. The truss members, road deck, and cross members are all included to be 78.206 g, leaving 6.79393 g before the 85 g restriction. (See Appendix A03)

iv. Analysis 4 – Force in member to find area

The bridge must support 20 kg. (See 1d10) By using statics, the compression and tension values can be calculated for a bridge that supports 20 kg. The scope of calculations only goes up to the halfway point on the bridge because the values from one half would be the exact mirror on the other half. This makes doing the full bridge redundant. After analyzing the forces, the area of all members is calculated through the stress equation and rounded to be .5 x .5 in. (See Appendix A04)

v. Analysis 5 – Deflection Analysis

The bridge must support 19.4 kg (See 1d10) and must deflect less than 25 mm. (See 1d1). By analyzing the bridge to as a single truss and applying a virtual load, the deflection can be found. The truss is calculated by applying a 190 N load on the center and 1 N virtual load. Then by using the sum of the load from the theoretical and virtual and dividing by the area and modulus of elasticity, the deflection is calculated, being 5.84 mm. This verifies the use of a 3/8 x 3/8 in cross section for the bridge. (See Appendix A05)

vi. Analysis 6 – Shear-Moment Analysis
The bridge must support 20 kg (See 1d10). By applying a shear-moment diagram to the bridge, the max shear and moment can be calculated which can then be used to find max stress. Since the diagram only accounts for one side of the bridge, the stresses and moment would need to be halved for each side. After creating the diagram, the max shear across both sides of the bridge that it will experience is 98.1 N. The max moment is 27.07 Nm. From the moment, the stress can be calculated using Mc/I, resulting in a stress of 140 MPa. (See Appendix A06)

vii. Analysis 7 – Minimum String Length
The bridge must be longer than 400 mm (See 1d9). Using a bridge length of 450 mm, geometric relations of a triangle are used to find the length of the string. Sectioning the bridge into 2 triangles; the articulation element and the bridge, where the hypotenuse of the triangle is the string length is used. After defining all the needed sides, the hypotenuse is found, and the total length is 719.46 mm. Since the articulation element will have 2 strings connecting to the bridge, the minimum length needed is 1438.92 mm (See Appendix A07).

viii. Analysis 8 – Force to Lift Bridge
The bridge must be longer than 400 mm (See 1d9) and must weigh less than 85 g (see 1d7). Using these conditions, and assuming the load from the bridge is a distributed load, the force to lift the bridge can be calculated. By using statics, the sum of moments can be used from the force of the distributed load and the location of the upward that the string will pull the bridge from to find the force. The force calculates to .5559 N (See Appendix A08).

ix. Analysis 9 – Angle of Inner Diagonal Truss
The bridge must be longer than 400 mm (See 1d9). After defining the length of the bridge as 450 mm, the bridge can be sectioned into 4 parts. The dimensions of one section can be seen in the analysis. By accounting for the width of each surrounding beam, a free body diagram can be created using the adjusted lengths of the surrounding beams. The total length of the inner truss beam can be found using Pythagorean theorem. The law of sines can then be used to find the angles of the inner truss beams, being 43.12° and 46.88°. (See Appendix A09).

x. Analysis 10 – Force in String
The bridge must weigh less than 85 g (See 1d7). After defining the force to lift the bridge, the force the string will experience can be found. By using trig identities, the angle of the string when the bridge is closed can be found at 23.38°. Using this angle, a force vector can be created, as shown in the analysis. Since the force in the y-axis is known, trig identities can be used to find the force in the x-axis. Pythagorean theorem can then be used to find the resultant force on the string, being 1.40 N. Since there will be 2 strings, the force in each string is .70 N (See Appendix A10).

xi. Analysis 11 – Area of Articulation Beams
The articulation element must support the bridge using 2 strings (See 1d2). After defining the resultant forces of the string, a statics diagram can be created. By using the method of joints, the compression and tension values in the articulation element can be found. The method of joints is also used to find the reactions at the contact points. To find the area, the stress equation is used. Choosing the lowest force that the bridge will experience results in the smallest cross-sectional area. This will be used in deciding the size of the beams. The lowest area is calculated at 2 mm x 2 mm. Since there is no weight requirement for the articulation element, any size of balsa wood can be used. ¼" x ¼" balsa wood will be used in the beams (See Appendix A11).

xii. Analysis 12 – Deflection of String Guide Rod
The articulation element must support the bridge using 2 strings (See 1d2). The top of the articulation element will have a string guide that will keep the strings in place when lifting and lowering the bridge. By assuming a design parameter of .2 in diameter of the rod, a 4-point deflection load can be simulated. After defining Young's Modulus, moment of inertia, and load, the max deflection can be found, resulting in $6.25(10)^{-3}$ in. Using this value verifies the assumption in the .2 in diameter rod and can be used to support the strings. (See Appendix A12).

xiii. Analysis 13 – Midpoint Height
The height of the bridge's midpoint must be over 140 mm (See 1d5). After defining the speed of the motor at 30 RPM, a reference height can be found by programming the motor to spin for 1000 ms. The reference height is measured at 29 mm. This can be applied to the desired height of 141 mm to find the amount of time the motor must spin to reach this which comes out to 4400 ms (See Appendix A13).

xiv. Analysis 14 – Cycle Time
The bridge must open, stay open for 10 seconds, and close within 60 seconds (See 1d6). After defining the minimum height that is considered open, the cycle time can be calculated. The angle of the bridge when it is open is found and converted to radians. The speed of the motor is then converted to radians per second. The time to open is found by dividing radians by radians per second resulting in a time of 5.83 seconds. This verifies the use of a 425 mm long piece for the bottom horizontal member (See Appendix A14).

h. Device: Parts, Shapes, and Conformation
The bridge will be made of many pieces of balsa wood connected by glue, using a simple truss as its design. The bridge needs to be under 85 g so having a safety factor that accommodates this would be the best option. Tolerance for the bridge members will be .5 mm to also make sure the weight restriction is met. The bridge needs to articulate a certain height. Designing the articulation element to raise the bridge to a certain angle is needed as well as the rope length to make it as ergonomic as possible.

i. Device Assembly

The bridge needs to be able to span 2 abutments, 400 mm apart, allowing a 100 mm long object and a 32 mm x 25 mm object to pass through. The bridge design uses a Pratt truss It also needs to articulate such that the midpoint of the bridge is 140 mm above its horizontal position to allow passage underneath.

j. Technical Risk Analysis

Since the bridge is restricted to being under 85 g, the size of the components and how they are oriented on the bridge is important to ensure it can support the required load. The amount of glue is also included in the weight so making sure to use the right amount to ensure the build is stable is important. The articulating element will need to activate through a button press. Using an Arduino will be required. Learning how to use it and how to correctly build its circuit is important to be able to articulate.

k. Failure Mode Analysis

The bridge will experience a static load through the middle, eventually failing past a certain load. Maximum shear stress theory will be here used in designing the bridge to support the minimum load and predict when it will fail.

l. Operation Limits and Safety

The bridge will only be designed to support 20 kg. Anything after that will risk failure in the bridge. Objects that follow the height and width dimensions will only be used when passing objects through the bridge. Opening and closing the bridge will need to be monitored closely to prevent possible premature failures.

3. METHODS & CONSTRUCTION

a. Methods

Manufacturing of the bridge will be done within the home of the student and at CWU. 3D printed components of the bridge will be made at CWU. Cutting the balsa wood to length will also be done at CWU or in-house. Assembling of the bridge will be done in-house. This will include gluing together the truss members for the bridge and the articulation element. Assembling of the electronic components for articulation will be done in-house.

i. Process Decisions

The main decisions for the bridge included choosing the size of balsa wood, how to cut the wood, and the type of glue to use in assembling the bridge. These decisions can be seen in Appendix F. Since the material for this project must be balsa wood, the size of the wood was used in the decision matrix. When choosing the size, analyses were made to ensure that the bridge will not weigh more than 85 g. These can be seen in Appendix A03 and A04 and in section $2g_{iii}$ and $2g_{iv}$. The analyses find the best size of the bridge members while also following the weight condition, being ½" x ½". The decision matrix further explores how efficient the weight is with an 85 g restriction, the strength, and cost. This verifies the use of ½" x ½" balsa wood.

Cutting the wood will be a major process in manufacturing the pieces. The main decisions included cutting with tools, by hand, or having them commissioned. The criterion considers the time spent, finish quality, ease of use, and availability. Time spent and finish quality was the most important among the criteria. Following the decision matrix, Figure 3 in Appendix F, using tools to cut the wood is the best approach. The time invested in cutting the wood using tools is much faster than getting the pieces made by an outside manufacturer. The finish quality can also be just as good as a commissioned piece. The ease of use and availability does not score the highest but is not the lowest among the criteria, making this method the best.

Gluing the wood together is the main process in building the bridge and the articulation element. The main decisions included using wood glue, hot glue, or epoxy. The criterion included curing time, strength, ease of use, availability, and cost. After following the decision matrix, Figure 4 in Appendix F, using wood glue would be the best to use. It did not score the best in curing time as hot glue cures much faster, while epoxy cures the slowest. Wood glue has exceptional strength, much greater than hot glue and like epoxy. Wood glue is much easier to use and acquire than hot glue and epoxy. Compared to wood glue, hot glue and epoxy require more equipment to use, such as a hot glue gun or creating jigs to shape the epoxy. Wood glue is relatively low cost compared to hot glue and epoxy.

During the manufacturing process in Winter, cutting the wood included using a hack saw. An issue from doing this is the cuts may not come out completely straight. The process was modified by adding a sanding step. The wood sticks were sanded down until straight using a belt sander or sandpaper. Another issue was that when cutting the wood, there was always some amount of material taken off, so marking the wood to the exact lengths specified in part drawings was not feasible. Measurements were modified by adding 2-3 mm when marking to cut. This allowed parts to be manufactured closer to the desired length instead of possibly being cut shorter.

Another manufacturing method used specifically for the vertical articulation member (KCB-20-009) and the road deck (KCB-20-003) was using the drill press to make a through-hole. For the vertical articulation member, the piece was cut to the designed length first. This made drilling the hole challenging as there was no easy way to clamp the piece to the table. This was not a problem with the road deck as it was long and could easily be braced against the center column. Regarding different methods of manufacturing the hole, using a drill press, hand tools, and power drill were considered. The best decision was using the drill press because it would be the most accurate and quickest way to manufacture this piece. A decision matrix for this method can be found in Appendix F.

An additional manufacturing method that had to be implemented later was to sand down the pieces used for the bridge to a new height and width while the length would stay the same. This is different than previous sanding steps because it only affected length. This was needed because a mistake in the mass calculations for the bridge was made that turned out to be over the required mass after recalculating. The modification implemented was to sand all pieces to 1/2" x 3/8" instead of the ½" x ½". From choosing among sanding them down, buying new pieces, or doing nothing, the best solution was to sand down all pieces for the bridge. This could be done relatively quickly and would still be within the budget. The decision matrix for this can be seen in Appendix F.

b. Construction

i. Description

The device will be built in 2 sections: the bridge and articulation element. Most parts will be bought and manufactured to the designed dimensions. All truss members will be the same size of ½" x ½" so cutting them to designed size includes only length and whether they have chamfers. The bridge and articulation sub-assemblies are made of 7 parts. Some parts in the articulation element will be 3D printed or manufactured at CWU. Connecting the bridge assembly to the articulation assembly will use a hinge which will also be 3D printed at CWU. All parts will be obtained from two online suppliers: Amazon and specializedbalsa.com. This includes the balsa wood, which will be bought in bulk, and the electronic elements of the articulator. The assembly order consists of building the bridge and articulation element first, then attaching them, completing the device.

ii. Drawing Tree, Drawing ID's
The bridge and articulation sub-assemblies will be created at the same time. This will avoid situations of downtime while waiting for one assembly to cure thoroughly before building the whole assembly. Once all parts are obtained and cut at CWU, they will be glued together as trusses in-house. After curing, the trusses will be attached with cross members by gluing. The bridge and articulation element will be attached by hinges, acting as a guide to allow for the bridge to articulate. The drawing tree can be seen in Appendix B01.

iii. Parts
All parts will be bought from an online supplier. Most parts will require the balsa wood to be cut to the designed dimensions. Since the bridge and articulation element is required to have all pieces be the same cross section, the cutting will be limited to length and/or creating chamfers. The road deck will be bought and cut to designed dimensions. There are some parts that will be 3D printed at CWU such as the String Guide Rod (KCB-20-007). Some parts will be bought as is, such as the Arduino Uno Rev3 (KCB-55-001), which will act as the brain for the electronics and controls the articulation of the bridge. These parts will not be modified. The parts lists can be seen in Table C1 – Parts Lists of Appendix C.

In Winter, changes have been made to the parts list. Some additional parts have been added that are needed to complete the articulation element. This includes the Arduino Motor Shield (KCB-55-003) which is needed to control the dc motor. Some parts have been taken off the parts list such as several 3D printed parts that were not essential to the completion of the device. The updated parts lists can be seen in Table C1 – Parts Lists of Appendix C.

iv. Manufacturing Issues
The main manufacturing process is cutting balsa wood. All cutting will be done at CWU. The risks associated with this are that the tools may not be available when needed. Another risk to cutting is the lab that has the tools may not be accessible when needed. When gluing the bridge together, sufficient time must be allocated waiting for the glue to cure. If the bridge is handled while the glue has not cured, the glue joints could become weaker and possibly detach, resulting in a waste of time.

Addressing the manufacturing risks made in Fall included whether the tools in the Woods lab would be available or not. This would not be as much of an issue as whether the lab itself was open or not and having a lab partner be present. Another risk is giving enough time to let the glue cure. The glue used does require a curing time of 24 hours so planning for that time has been accounted for with no issues.

A manufacturing issue that wasn't considered in Fall was realizing a design specification when doing calculations was incorrect. The calculations for mass were done incorrectly and when recalculated, the mass was over the requirement. Solving this problem included sanding down all parts for the bridge to have a cross sectional area of 1/2" x 3/8" from ½" x ½". Length would stay the same. Another issue was the road deck (KCB-20-003) had shipping problems. It arrived later than expected and was an essential part in assembling the bridge. Assembly could not be completed until this part arrived. The part was eventually delivered but assembly was delayed.

v. Discussion of Assembly

The bridge and articulation element were glued simultaneously. The order of gluing for the bridge consisted of the top and middle truss members first, then side diagonals, then the road deck and bottom truss member last. This order was realized when the road deck would go in between the bottom truss member and the upper truss section. This would be done a second time for another truss and then glued together to complete the bridge assembly. The articulation element was much simpler. The whole truss could be glued at once and then glued to another truss. The circuitry for the articulator would be attached to the top. The sub-assemblies: bridge and articulator are completed and can be attached to complete the top assembly. A drawing tree can be seen in Appendix B01. The bridge assembly and articulator are lined up and attached with a wire where it can open and close to create the full assembly. The assembly is operated by a push button located on top of the articulation element. When this is pushed, the bridge will open and close. Compared to the benchmark, the cost was slightly more, as it did not account for some circuitry components. The manufacturability of the device is similar to the benchmark as it requires the same operations of manufacturing.

4. TESTING

a. Introduction

To meet the test criteria for the bridge, several measurements will need to be taken. The mass and length of the bridge will be needed. This will be measured using a scale and measuring tape. The bridge's strength will be tested by adding weights to its center. A testing hole through the center of the bridge will allow weights to be added. These measurements will verify correct analysis of the bridge and fulfill the test criteria. Any situations where the test criteria aren't met, corrections on the analysis will need to be made.

b. Method/Approach

There are several measurement tools that will be acquired to allow for proper testing. A tape measure, scale, a 20 kg mass, a stopwatch and resting planes will be needed. The tape measure will measure the bridge's length, verifying it is longer than 400 mm. Deflection will be measured when a 20 kg mass is applied through the bridge's center. The max deflection must not be more than 25 mm. Clearance through the bridge will be measured, ensuring a block that is 32 mm wide and 25 mm high can cross through the bridge. When the bridge is open, the height of the midpoint will be measured, making sure the minimum height is 140 mm. A scale will weigh the bridge, fulfilling the 85 g limit. A 20 kg mass will be needed to test if the bridge can hold 20 kg. Using the middle hole that will be in the center of the bridge. Masses will be slowly applied to the bridge until 20 kg and/or failure is met. The stopwatch will verify if the bridge can stay open for 10 seconds. It will also be used to measure if the bridge can open within 60 seconds. The resting planes will act as the bridge's abutments where the deflection and mass testing will take place.

To further elaborate on how the 20 kg load will be applied to the bridge, a jig will be machined to utilize the 8mm hole in the middle of the road deck. The jig will consist of a hook that will be fastened onto a flat plate. A bucket will hang from the hook, allowing 20 kg to be slowly applied.

Performing test 1 where a stopwatch is used to verify if the bridge can open and stay open for 10 seconds, then close all within 60 seconds is evaluated. The method to this stayed the same as written earlier in section 4b.

Test 2 looked at the height of the midpoint of the bridge when it is open. The method for the test requiring the midpoint to be greater than 140 mm, was done similarly to the method that was created earlier. When establishing constants within the device, such as motor speed and the minimum height of the midpoint of the bridge, being 141 mm, the test could be done. Addressing the main issues for testing was making sure the bridge was set up the exact same when doing multiple trials. This required marking the bridge along reference points to ensure the bridge is in the same position for each trial. This is written in more detail in section 4d.

c. Test Process

Testing the bridge will require a flat space where it can lie between 2 abutments. This will be done using tables that will be spaced 400 mm apart. The tables will also be used to check the performance for the bridge's articulation. Weights will be used to apply a load of 20 kg to the bridge. These will be placed in the bucket that will hang under the bridge. To ensure the load will be applied consistently, flat blocks will be used. This will prevent any unnecessary movement in the bucket as weights are placed inside. A scale will be used to measure the weight of the bridge, making sure it is less than 85 g.

d. Deliverables

To show the bridge's performance, a checklist of the requirements for a successful device will be used as shown below in Table 4-1. This will be used when testing the bridge in Spring quarter. The scope of the checklist consists of whether the bridge met the requirement or not with an applicable numerical value that may further show the performance of the bridge. In addition to the checklist, videos and photos will also be taken to document the testing.

Table 4-1: Test Deliverables

Requirement	Pass/Fail	Magnitude
Vertical deflection less than 25 mm		
"Vehicle" traversing bridge		
Bridge resting on abutments		
Support between 18.9 to 20 kg load		
Weight of bridge less than 85 g		
10 grams allowing gap for 20 lb. paper		
Raising the bridge takes less than 60 seconds.		
Bridge midpoint is above 140 mm when fully opened		

For Test 1, the speed at which the bridge is raised is tested. The requirement is it must take less than 60 seconds from the bridge being closed to fully open. This test also checks that the midpoint of the bridge is above 140 mm when fully open. This check verifies that the bridge is opened to the required height every time the test is performed.

To calculate a prediction for the time the bridge takes to open, the angle from the resting plane to when the bridge is fully open is found and then converted to radians. Then using the RPM the motor spins at, it is converted to radians per second. Using the radians calculated from the bridge, it is divided by the speed of the motor and the time it takes to open is found. The predicted value was calculated at 5.8376 seconds. The actual results measured an average of 6.96 seconds. The possible reason for the difference in time is the calculations consider the resistance of the bridge on the motor.

An issue that was encountered while doing the tests was making sure the device was set up in the exact same position for each trial. After each test, the string that connects to the bridge had a different amount of slack. This was solved by marking the string along a reference point when the string is tensioned properly. This ensures that all tests were the same each time.

5. BUDGET

a. Parts

Larger cost items such as balsa wood sticks and sheets and Arduino boards can be expected to be bought online. Items such as balsa wood sticks will be bought in bulk to ensure enough material is present when assembly begins. Amazon will be used for purchasing most of the items so planning toward shipping times of at least 2 days will be expected. Other items will also be purchased from specializedblasa.com and planning for greater shipping times will also be accommodated. Any items that will be 3D printed will be done at CWU. How much parts will cost and where they will be purchased from can be seen in Appendix C.

b. Outsourcing

No processes for outsourcing will be needed for Winter. The extent adjusting the balsa wood is by cutting. All items will be manufactured by the student.

c. Labor

This project will span 30 work weeks at 10 hours per week. At $20/hour, the projected labor costs for this project would be $6,000. These labor costs will be neglected as the student will be investing voluntary hours toward this project.

d. Estimated Total Project Cost

As of Fall quarter, around $6080.70 is the estimated project cost. This includes parts and labor. However, this will be expected to increase as more items are listed. The itemized costs can be found in Appendix D.

e. Funding Source

The cost of this project is expected to be supported by Kyle Barayuga and CWU. Expenses of parts are relatively low and can be covered by the student, while 3D printed parts will be covered by CWU.

f. Winter Updates

5a: The total budget for the parts was adjusted to $150 with the current costs totaling to $119.03. This gives some room for any extra expenses to be made. Most parts that were planned to purchase in Fall, have been unchanged in Winter. Almost all the parts were ordered from Amazon, some were donated, and some were ordered from specializedbalsa.com. The parts from specializedbalsa.com include longer length parts that were not sold from Amazon such as the road deck (KCB20-003) or the bottom horizontal member (KCB-20-001). These items came out to be $3 each. Some additions to the parts lists have been made. Most of these additional items are for the articulation element. Items like the Arduino Motor Shield were added which increased the total by $29.00. Some items were taken out because they became redundant and other items could be used to replace them. This included 3D printed parts which decreased the total by an estimated $1-$2. Other changes include updating costs for each specific item. All changes can be seen in Appendix C.

5b: No parts needed to be outsourced for Winter.

5c: Labor costs are associated with the Gantt Chart in Appendix E. Total cost is shown in Appendix D. Rates are estimated at industry standards.

5d: Since some items in Appendix C were added and some updated to reflect their cost more accurately at the time of purchase, the estimated total cost has been adjusted. The total cost is $6150.00. This includes parts and labor with an additional section that acts as a buffer in case additional purchases apart from the planned items need to be made. This can be seen in Appendix D.

5e: The funding source has not changed in Winter.

g. Spring Updates

5a: In Spring, the bridge had to be redesigned and rebuilt to meet a requirement that was not accounted for during Winter. The device at the end of Winter had a mass that went over the maximum of 85 g. This redesign required a different size of balsa wood for the device. The cross-sectional area was lowered from ½" x ½" to 3/8" x 3/8". The road deck was also smaller, going from 3" x 1/16" to 1 ½" x 1/16". These extra expenses totaled around $17. After these expenses, the project came out to be $136 which was still within the budget of $150. When considering shipping and tax, balsa wood from specializedbalsa.com had a minimum shipping cost of $20 per order. This was the highest and only shipping cost across the whole project as the rest of the items were ordered in person or through Amazon. 2 orders were made from this vendor so shipping cost totaled $40. When including tax, an extra $10 can be added. Adding shipping and tax, the total cost of this project does go above the planned budget of $186.22. Ordering from this storefront was important as it provided balsa wood over 12" in length and in many cross sections.

5c: Labor costs can be calculated by looking at the Gantt Chart in Appendix E. With a general rate of $25 per hour and a total of 96.3 hours spent on the project, the cost for labor is $2407.50.

5d: During testing, the bridge was evaluated on its midpoint height, cycle time, and deflection. The first two tests did not create any risk for the bridge that would require additional cost. The last test, however, which applied a load on the bridge to test its deflection did create a possibility that the bridge may break and would be unable to test further. This test was done as the last test and has no direct effect on the budget as a result.

6. SCHEDULE

a. Design

Fall: The schedule during Fall required analyzing a bridge design, creating component drawings and writing an accommodating report. The scheduling of this process can be seen in the Gantt Chart of Appendix E. Some risks were realized when doing analyses as some drawings became dependent on completing an analysis. For example, task 2c from the Gantt Chart is an analysis of the cross-sectional area of all the truss members. That would need to have been completed first to be able to complete a component drawing. Regarding the estimated time to complete tasks, by closely following the Gantt Chart, tasks should be started on time. Tasks are generally completed within the estimated time. Completing tasks longer than estimated would require reevaluation of the Gantt Chart to accommodate for the extra time spent.

Winter: This quarter mainly consists of building the bridge. Any design decisions will be thought of and finalized during the Fall quarter. Some design changes have occurred during Winter. The road deck was redesigned and may be used if the manufacturing of the original design cannot be done. This is discussed more in 6b. This design change has affected the schedule slightly, but tasks can be rearranged while the part is waiting to be manufactured.

b. Construction

Fall: Regarding the schedule before building the bridge, knowing exactly what components to make the bridge before Winter will be known. This will be through drawings of major components such as truss members and articulation hard components. The building of the bridge will include buying the correct components and assembling them. To accommodate shipping times, the estimated time to buy the components is 5 days. The estimated time given to assemble the bridge is 9 hours. The predicted schedule can be found in Section 4 and 5 in the Gantt Chart of Appendix E.

Winter: Since this quarter is mostly building the bridge, making sure that all components to build it are ordered. There was a risk that affected the schedule during construction, however. Looking at the Gantt Chart of Appendix E, task 4x required manufacturing the road deck (KCB-20-003). This part is very important for construction as it is required to start the assembly. Since this part was longer than what most sellers had on Amazon, it was ordered from specializedbalsa.com. This part did not ship at the expected time. To stay on track with the schedule, assembling the articulation element and its programming will be worked on earlier. If the piece cannot be shipped on time, an alternate design has also been created and can be used. Regarding the estimated times for each task, most tasks can be done in an hour. Estimated times were close to the actual time.

c. Testing

Fall: To make sure the bridge is ready for testing in the Spring, the testing criteria will be followed such as ensuring a hole is in the middle of the bridge. This will be used to test the deflection of the bridge. Tasks like creating and performing a practice test for the bridge will be

held in Spring quarter. The estimated time to complete this task will take more than a day, making sure to obtain all the resources to perform the practice test.
Spring: This quarter tested the bridge and completed deliverables, seen in Section 6 and 7 in the Gantt Chart of Appendix E. Evaluating the performance of the bridge included testing the bridge's deflection, the height of the bridge's midpoint and the articulation cycle time. From the Gantt Chart, the estimated times did fall within the actual time invested for each task. Initially, the location of the tests was planned to be held in Hogue Hall's room 205 but it was realized the room does not have to be restricted to a specific room as the first two tests only require a flat surface. The first two tests being the height of the bridge's midpoint and the cycle time did not take long to test. There were no schedule issues with those tests. However, the third test evaluating the device's deflection and weight required more planned scheduling. It needed to be in room 127 as it required the use of the Instron to perform the deflection test. This test was done as a group with other students who also built the bridge. The scheduling for this test was set on a planned day, so it was ensured that the bridge and articulation tower was ready to be tested on.

7. PROJECT MANAGEMENT

There will be several risks with this project. This includes acquiring the balsa wood. Since these will be ordered from online stores, there may be delays in shipping resulting in not being able to start building the bridge. Not ordering enough balsa wood is also a risk which can then lead to not having enough time to build the bridge since a lot of it may be spent on waiting for replacement pieces. The availability of CWU labs may be a risk as they may not be open when it is needed. Controlling these risks requires effective time management and being proactive with each task. Having a schedule and closely following it is very important in staying on track to successfully complete this project. Also having to do weekly progress reports will encourage effective use of time.

a. Human Resources

The principal engineer of this project invests time to analyze and design a solution to the problem. The experience and expertise of the engineer to be used to complete this project can be seen in Appendix H. Other sources that contributed greatly to the project were the CWU staff and students. These resources, however, come with some risk. There can be times when a CWU staff member is not present when something is needed. These situations can further be limited to e-mail, where a response back can lead into the next day. Managing these risks includes allowing for adequate time to work on tasks.

b. Physical Resources

Various parts of the MET labs at CWU will be used to complete the project. Tools such as saws to cut the components to the correct size will be needed. 3D printers at CWU will also be used. The associated risks with these resources include whether the student will have access to the labs. Also, if the student will be able to invest enough time within the week to complete the project. These risks can push back the time it takes to complete the project. To prevent this, being proactive in these situations is important.

c. Soft Resources

The CWU computer labs will be used to complete SolidWorks drawings and create any 3D printed components. The risks that come with this resource are access to the labs are only available within the work week. When using SolidWorks, crashes in the program may happen. These risks may prolong the time it takes to complete project tasks. To prevent these risks, enough time being in the computer labs should be invested to complete any SolidWorks drawings or assemblies. When working in SolidWorks, make sure to save often so not to lose any drawings.

d. Financial Resources

All financial resources are covered by the principal engineer. All expenses are referenced in Appendix D. Going over budget will be at the expense of the principal engineer. Keeping close to the plan of this project will prevent any unnecessary expenses.

8. DISCUSSION

a. Design

Initially, the design of the bridge revolved around how it would articulate. The main designs considered were a draw bridge, vertical bridge, and double draw bridge. After evaluating design factors through a decision matrix, the drawbridge would be the best design for the project. It was the simplest to manufacture while still being able to provide the support needed for the load requirements. The vertical bridge would be the most complex of the three where it needed a way to lift the bridge from both sides. The double drawbridge would be similar in complexity in that the bridge would need to be lifted from both sides, requiring double the articulation hard components than the draw bridge.

A minor design change and failure was in the bridge length and height that affected the design of the inner diagonal members. After defining the overall length, height and width of the bridge beams, the inner diagonal members could not be manufactured at a 45° angle as designed. The angles had to be adjusted to accommodate the inner lengths and heights of the truss. This situation could have been avoided if the height and length of each beam was accounted for to allow for 45° angles across the whole bridge. This would include making sure the length of one section of the truss was equal to its height while also accounting for the beam widths.

A success but also turned out to be a risk was making sure to do the right analyses that would be used for drawings. Specifically, this analysis included finding the area of the truss members. Finding this area would allow for several drawings to be made from this one analysis, saving time, resulting in a success. However, this would inadvertently introduce time management risks as not doing these analyses would result in falling behind in drawings.

A design success that was utilized early on was by creating conditions for the bridge that would save time during analyses while still falling within the project requirements. These conditions included restricting the cross section of the truss members to only be a square. This would simplify calculations as finding the values such as the moment of inertia could be easily found. Using a moment of inertia of a rectangle would introduce having to account for the x or y-axis during calculations. Another condition included restricting the truss members to being the same cross section across the whole bridge and articulation element. Following this would simplify the calculations for the weight requirement and overall dimensions of the bridge. Several analyses that would have been done without this condition would be more complicated and difficult to keep track of. Calculations such as stress concentration would be introduced which would otherwise be irrelevant to the current design of the bridge.

b. Construction

While manufacturing parts, there were some changes in how the parts were manufactured that sped up the process. Originally, the process of manufacturing the balsa wood sticks was to measure and cut to length. Then if a part was too long, it would be sanded down using sandpaper. Instead of using sandpaper, it was changed to using a belt sander. This made creating the part much faster with greater accuracy to the desired length. However, the belt sander is only accessible through the wood lab in CWU, so if any sanding should be done elsewhere, sandpaper would need to be used.

A risk during manufacturing was after the bridge's schedule was made, the shipping times of parts would affect whether the bridge can be assembled properly and on time. This specific piece was the road deck (KCB-20-003). In the current design, the road deck would be placed in between the bottom horizontal truss member and the rest of the bridge above it. The assembly of a truss would need to include this part as it can't be added after. Since this part needed to be thin and long enough to span the whole bridge, online vendors like Amazon did not sell this stock. Using Amazon was preferred as the shipping times are usually much faster than any other vendor and contacting sellers is much easier. This part also needed to be ordered to Ellensburg during winter so shipping times would increase if the weather was not ideal. This resulted in a design change to the road deck to make it shorter and use multiple pieces instead of one. To ensure the road deck is stable, cross members (KCB-20-004) will be placed below where two road deck pieces meet. This change allowed stock to be ordered from Amazon and continue with the current schedule for assembly.

Some parts needed to have chamfers such as the inner diagonal member for the articulation element (KCB-20-012). This part needed two 45° chamfers on one side creating a v shape. To do this, marking to cut/sand the area was done. This method was not successful as after the part was made, the chamfers were not equal when the exact markings were followed. To fix this, a guide was made by printing out the v shape and attaching it to the part. This made manufacturing the part much easier and more consistent since more than one part needed to be made.

A success in the manufacturing process was realizing how easily balsa wood sticks could be cut. Originally, most manufacturing would be done at CWU using the wood lab. If some manufacturing can't be done such as cutting parts to length, then plans were made to cut them using other methods. It was thought that to cut the balsa wood sticks, a tool had to be bought, but any blade with a mild density of serration can be used to cut easily. This alternative method would be used to cut the sticks to length if the wood lab is inaccessible.

A major flaw in the design of the device was realized late in Winter quarter when the engineering specifications required the bridge and articulation element to be under 85 g. Initially, it was thought that only the bridge had to be under 85 g, not including the articulation element. With the current design, the bridge has a mass of 83 g which cannot be used to test as any articulation element design would most likely go over this requirement. To fix this, a redesign of both the bridge and articulation element will be made in the Spring. While redesigning the device, more optimizations with the bridge and articulation element will be considered to ensure its performance can be successful in testing.

Regarding risks that occurred during construction and assembly was making sure the articulation tower doesn't tip over when trying to open the bridge. This made the placement of the circuitry on the articulation element very important. These components consisted of a 9V battery, a breadboard, and the Arduino modules. The placement of these components would assist in keeping the articulation tower stable when it articulates the bridge. Originally, they were designed to lay on the diagonal members of the articulation tower but were changed to sit on the horizontal articulation members further away from the bridge. This ensured that the components would create a larger moment from the point where the force from the bridge is acting on the articulation tower. The circuitry's placement also had to accommodate where the motor will be placed on the tower. Since there was a limited amount of jumper wires, the motor had to be relatively close to the rest of the articulation components.

A success from the device was building the code to be used for the articulation of the bridge. An Arduino is used to communicate to the motor that would articulate the bridge. A breadboard is connected to the Arduino and consists of button switches that controls whether the motor spins clockwise or counterclockwise. There were many resources from Arduino's website that documented how to program components using their boards. This made it much easier to control the motor.

c. Testing

Test 1 measures the time it takes for the bridge to fully open and close. When creating the documents for Test 1, there were several considerations to be made. The test procedure had to be created in a very specific process. This included establishing the time and location of the test, where the equipment will be in that room, and a step-by-step process of the test itself. The step-by-step process required being specific enough to have anyone be able to follow the test and get similar results.

When performing test 1, there was an issue with ensuring that each trial was starting at the same position. After each trial, the motor would be in a position where the nylon wire, that connects to the bridge, has a lot of slack. To get the most consistent data, the wire would need to be tightened the same. This was solved by setting up the wire to the desired tension and marking the wire along a reference point. This change ensured that the wire would be at the same tightness for the rest of the trials.

Addressing the risk for this test was making sure to press the correct switch to open and close the bridge. The device is not equipped with an emergency stop, so when one of the switches is pressed, the motor will spin for its programmed duration. The battery is also clipped onto its connector and cannot be quickly disconnected. Making sure to know what direction the buttons will spin is important because if the bridge is fully opened, and the button to raise the bridge is pressed again, the bridge will rise and eventually stop from the hinge that connects to the articulation tower. This would cause an increase in tension in the wire as the motor is still spinning and cause damage to the bridge. This risk was solved by establishing in the step-by-step procedure that the yellow button opens the bridge, and red closes it.

After considering all the changes and risks, performing test 1 was a success as all trials were done without issue. The data overall was consistent and was within the requirement.

Like test 1, some of the issues with test 2 were making sure each trial was performed the exact same. Since this test involved the articulation of the bridge, keeping the wire that connects the bridge to the motor tensioned the same way was needed. Another issue during testing was after each test, the battery would be drained slightly. The battery powers the motor and the Arduino. During testing, the measurements started to become inconsistent compared to previous trials. The motor would spin at a slower speed than before. It was later learned that the battery was drained completely, affecting the motor performance. After replacing the battery, the trials were more consistent and closer to the expected calculations.

Tests 1 and 3 were able to meet the requirements they were testing for. Test 1 was the articulation cycle test where the bridge must perform a full articulation cycle within 60 seconds. A full articulation cycle includes opening, staying open for 10 seconds, and closing. Performing calculations to find a prediction comes out to 5.83 seconds. This value is doubled to account for closing the bridge and 10 seconds is added as required for the requirement. The total comes out to 21.67 seconds. After performing the test, the total was 23.28 seconds, which met the requirement of an articulation cycle under 60 seconds. Test 3 required the bridge to deflect less than 25 mm when a load of 190 N is applied to the center. After performing calculations, the predicted value resulted in a deflection of 5.84 mm. After doing the test, the deflection came out to 3.55 mm which did meet the requirement of deflecting less than 25 mm. Test 2 was not able to meet the requirement of having to raise the bridge so the height of its midpoint is 140 mm above its resting plane. Defining the height the bridge raises is dependent on programming the motor to spin in some amount of milliseconds. Performing calculations to find a prediction comes out to 4400 ms. Then doing the test with this value raises the bridge to a height of 121 mm which did not meet the requirement of at least being above 140 mm.

9. CONCLUSION

a. Design

The design of this articulating balsa wood bridge allows an object passage across and underneath. The analyses that contributed to this design the most included finding the areas of the beams. This would be the building block of the bridge design as most of the analyses after would be based off these design parameters. These parameters all meet the requirements regarding weight, length, and strength of the bridge. These requirements include having the engineering merit in statics and mechanics of materials that all contribute to the success of the bridge. All drawings have been created to show the components that will make up the bridge. Manufacturing of the bridge includes cutting the balsa wood pieces to designed specifications or 3D printing the pieces that would be used to complete the device. Acquisition of the parts include the cost and source or the parts. The estimated budget, including the parts and labor to show the time investment of the project, is planned in this proposal. This project has sufficient evaluation of design factors of a balsa wood bridge to be built.

b. Construction

The construction of the bridge and articulation tower requires closely manufacturing each part to its designed drawings. Stock and associated parts were purchased following the planned parts lists. Manufacturing of all parts included cutting balsa wood stock to length, sanding extra material or creating chamfers and drilling through-holes. The assembly of the bridge and articulation tower consisted of gluing all completed parts together. The assembly of the device which consists of the bridge, articulation tower and its circuitry will allow for the device to fulfill the established requirements to perform as expected. The bridge can open and close with a button push within the required 60 seconds. The device can hold the bridge in the open position for at least 10 seconds to allow for an object to pass under. The bridge can span the minimum length for testing. With these requirements fulfilled, the project was constructed successfully and is ready to be tested.

c. Testing

Prior to testing, the bridge was rebuilt as the current design was over the weight requirement of 85 g. New analyses and part drawings were created and used to manufacture and assemble the bridge using the revised design. There were a few issues and risks with testing the bridge. When testing for articulation, the circuitry only allows for raising and lowering the bridge. There was no emergency stop button. It was ensured that the correct button was pressed when lowering the bridge as to not raise it even more and cause damage to the bridge and articulation tower. This risk was accompanied by clearly documenting the correct outcomes for each button when following the step-by-step procedures. After testing, the bridge was able to meet all the requirements stated in the engineering specifications.

10. ACKNOWLEDGEMENTS

All MET classmates that contributed greatly towards the advancement of this project, providing invaluable information towards further completing this project, regardless of doing a balsa wood bridge or not. CWU and Hogue Hall for providing the various shops and equipment used to create and test the device. Professor Pringle and Professor Choi for providing guidance throughout the whole process and sharing advice on the steps that should be taken to effectively work on the project.

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APPENDIX A - Analysis

Appendix A01 – Bridge minimum angle when open

Kyle Berayuge	MET 486	10/04/23	1/1

Given: Bridge midpoint must be 140mm above its original position when opened (1d5)
Bridge length must be longer than 400mm (1d9)

Find: minimum θ

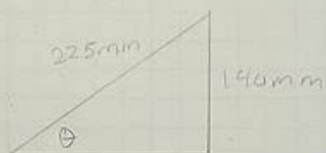
Assume: Bridge length = 450mm

Method: trigonometric ratios

Soln

trig ratios

$$\text{Midpoint} = \frac{450\,mm}{2} = 225\,mm$$

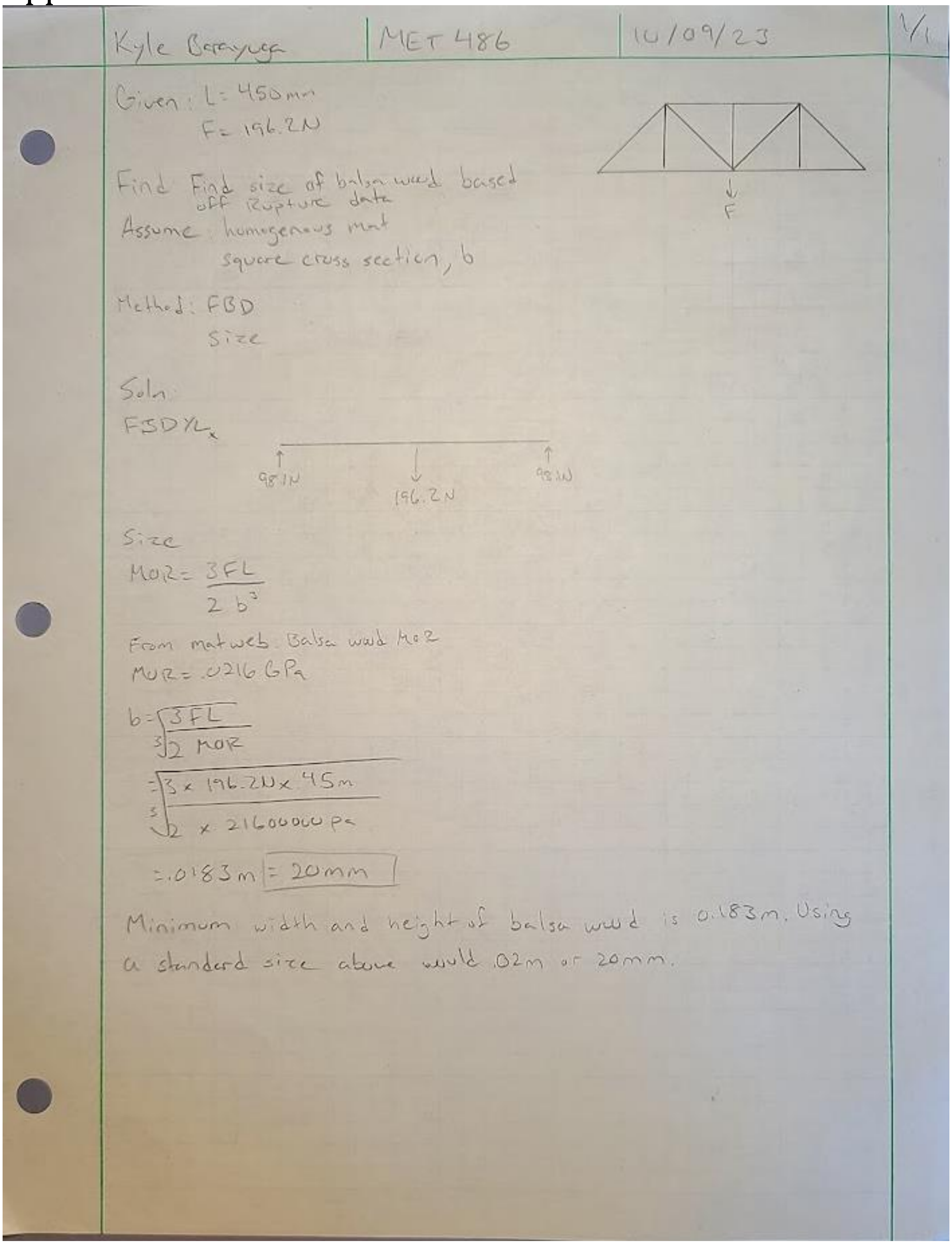


$$\sin\theta = \frac{opp}{hyp}$$

$$\theta = \sin^{-1}\left(\frac{140}{225}\right)$$

$$\boxed{\theta = 38.48^\circ}$$

Appendix A02 – Minimum Area of Balsa Wood



Kyle Barayuga | MET 486 | 10/09/23 | 1/1

Given: L = 450mm
F = 196.2N

Find: Find size of balsa wood based off Rupture data

Assume: homogenous mat
square cross section, b

Method: FBD
Size

Soln:
FBD/Lx

98.1N ↑ — ↓ 196.2N — ↑ 98.1N

Size

$$MOR = \frac{3FL}{2b^3}$$

From matweb Balsa wood MoR
MOR = .0216 GPa

$$b = \sqrt[3]{\frac{3FL}{2\,MOR}}$$

$$= \sqrt[3]{\frac{3 \times 196.2N \times .45m}{2 \times 21600000\,Pa}}$$

$$= .0183m \approx 20mm$$

Minimum width and height of balsa wood is 0.183m. Using a standard size above would .02m or 20mm.

Appendix A03 – Total Weight of Bridge

Kyle Barayuga | MET 489 | 05/01/24 | 1/2

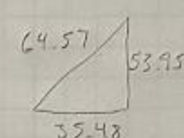
Given: Bridge must be less than 85g

Find: Total weight of Bridge

Assume: Square cross section

Method: Density

Soln:



① $3/8" \times 3/8" \times 16.76" \times 2 = 4.71375 \text{ in}^3$

② $3/8" \times 3/8" \times 2.54" \times 4 = 1.42875 \text{ in}^3$

③ $3/8" \times 3/8" \times 2.124" \times 22 = 6.5711 \text{ in}^3$

④ $3/8" \times 3/8" \times 1.700" \times 20 = 4.78125 \text{ in}^3$

⑤ $3/8" \times 3/8" \times 13.967" \times 2 = 3.928 \text{ in}^3$

Road Deck: $1/16" \times 1\,1/2" \times 16.76" = 1.57125 \text{ in}^3$

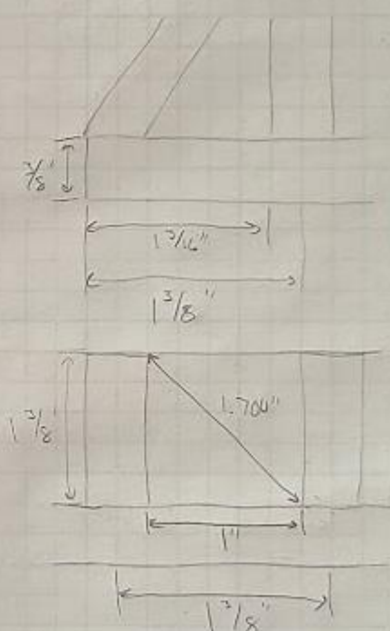
Total Volume $= 22.99411 \text{ in}^3$

$= 376.8058 \text{ cm}^3$

Density of Balsa Wood: 0.00578 lb/in^3

0.160 g/cc

Mass: 0.1329 lb, 60.289 g

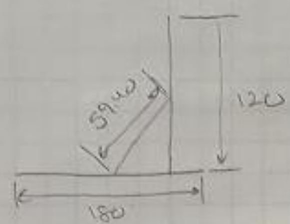


Appendix A03 – Total Weight of Bridge Cont.

Kyle Berayuga	MET489	05/01/24	2/2

Cont

Balsa Wood Density: 0.00578 lb/in³
0.160 g/cc



$3/8" \times 3/8" \times 7.09" \times 2 = 1.994 \text{ in}^3$

$3/8" \times 3/8" \times 4.724" \times 2 = 1.3286 \text{ in}^3$

$3/8" \times 3/8" \times 2.339" \times 2 = 0.6578 \text{ in}^3$

$3/8" \times 3/8" \times 2.25" \times 3 = 0.9492 \text{ in}^3$

Total Vol = 4.9296 in^3
80.78167 cm^3

Mass: 0.02849 lb
12.92507 g

Total Mass = 0.172371 b
78.206 g

6.79393 g could be used before the weight restriction is reached

Appendix A04 – Force in Members to Find Area

Kyle Barayuga | MET 486 | 10/16/23 | 1/2

Given: shown

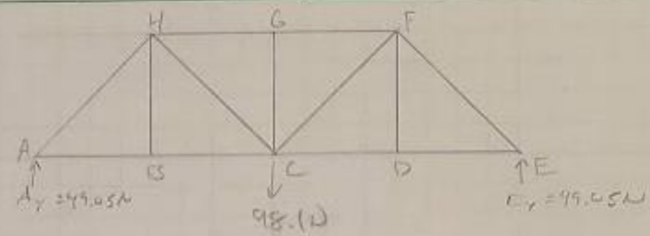
Find: Compression/Tension at points A, B, H

Areas of members

Assume: homogenous material

Method: Method of joints

Area



$\circlearrowright \Sigma M_A = 0 = 98.1N \times .225m + E_y \times .450m$

$E_y = 49.05N$

$+\uparrow \Sigma F_y = 0 = A_y - 98.1N + 49.05N$

$A_y = 49.05N$

Solve:

At A

$+\uparrow \Sigma F_y = 0 = 98.1N - AH \sin 45$

AH = 69.367N (C)

$\xrightarrow{+} \Sigma F_x = 0 = -69.367N \sin 45 + AB$

AB = 49.05 N (T)

At B

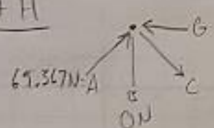
$\xrightarrow{+} \Sigma F_x = 0 = -49.05N + BC$

BC = 49.05N (T)

$+\uparrow \Sigma F_y = 0 = BH$

BH = 0

At H



$+\uparrow \Sigma F_y = 0 = 69.367N \sin 45 - HC \sin 45$

HC = 69.367N (T)

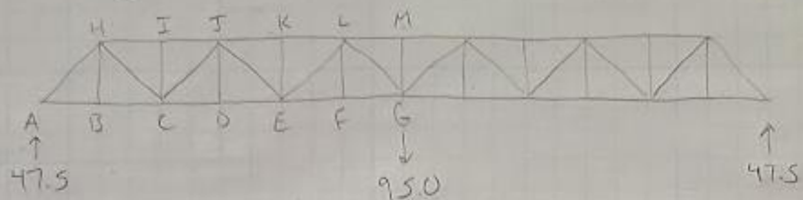
$\xrightarrow{+} \Sigma F_x = 0 = 69.367N \cos 45 - HG + 69.367N \cos 45$

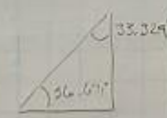
HG = 98.1 N (T)

Appendix A04 – Force in Members to Find Area

Kyle Barayuga | MET 489 | 05/01/24 | 1/2

Given: Image Shown





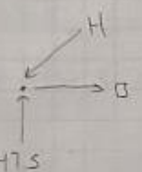
Find: Minimum Cross Sectional Area

Assume: static loading

Method: Method of Joints

Soln:

At A



$+\uparrow \Sigma F_y = 0 = 47.5 - AH \sin 56.671$

$AH = 56.85\,N$ (C)

$\underset{\rightarrow}{+} \Sigma F_x = 0 = -56.85 \cos 56.671 + AB$

$AB = 31.236\,N$ (T)

At B

$+\uparrow \Sigma F_y = 0 = BH$

$BH = 0$

$\underset{\rightarrow}{+} \Sigma F_x = 0 = -31.236 + BC$

$BC = 31.236\,N$ (T)

At H

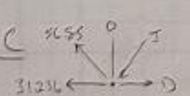
$+\uparrow \Sigma F_y = 0 = 56.85 \sin 33.329 - HC \sin 33.329$

$HC = 56.85\,N$ (T)

$\underset{\rightarrow}{+} \Sigma F_x = 0 = 56.85 \sin 33.329 + 56.85 \sin 33.329 - HI$

$HI = 62.471$ (C)

At C



$+\uparrow \Sigma F_y = 0 = 56.85 \sin 56.671 - CJ \sin 56.671$

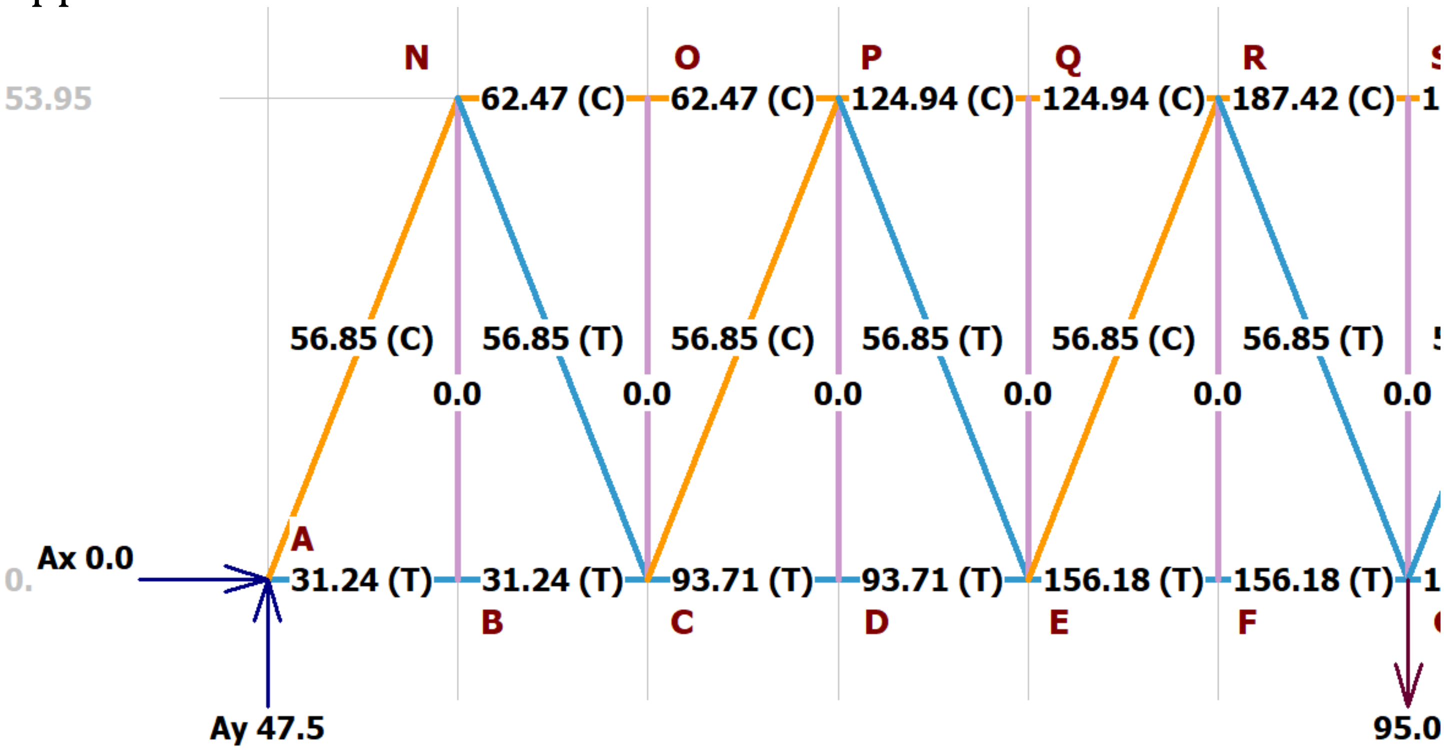
$HJ = 56.85$ (C)

$\underset{\rightarrow}{+} \Sigma F_x = 0 = -31.236 - 56.85 \cos 56.671 - 56.85 \cos 56.671 + CD$

$CD = 93.7523\,N$ (T)

Remaining Joints computed using MD Solids

Appendix A04 – Force in Members to Find Area Cont.



Appendix A04 – Force in Members to Find Area Cont.

Kyle Boravyuga | MET489 | 05/01/24 | 2/2

Cont. Lowest strength of Balsa Wood: Compressive Strength (matweb.com)

$\sigma = 6.90 \times 10^{6}\,Pa$

Minimum Cross Section

At LM

$$A = \frac{F}{\sigma} = \frac{187.42\,N}{6.90 \times 10^{6}\,Pa}$$ ← Highest Compression Force from Static Analysis

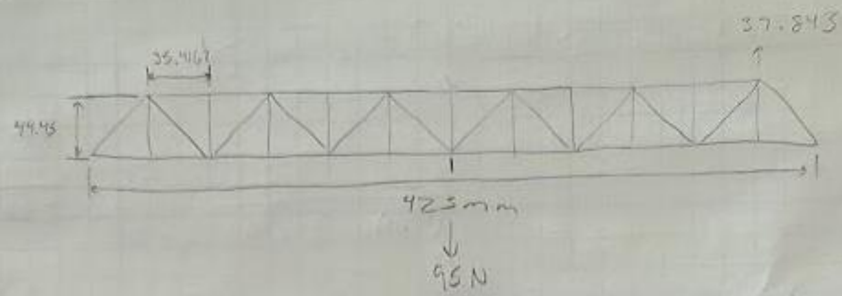
$= 2.7162 \times 10^{-5}\,m^2 = .0421\,in^2 = 0.20518\,in \approx 1/4''$

The minimum cross section is 1/4". This value is calculated from using the member that experiences the highest force and Compressive Strength of Balsa Wood. One size higher at 3/8" x 3/8" will be used for each member.

Appendix A05 – Deflection Analysis

Kyle Barayuga | MET420 | 05/10/24 | 1/2

Given: Image Shown



Find: Max Deflection

Assume: Center load
Static Load

Method: Virtual Load

Soln:

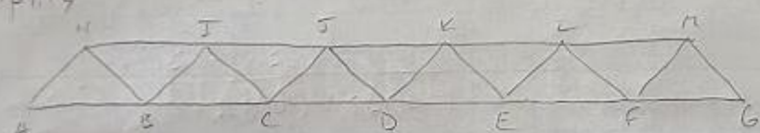
$E = 3.4 \times 10^9 \, Pa$

$A = (.009525\,m)^2 = 9.07 \times 10^{-5}\,m^2$

$I = \frac{(.009525)^4}{12}$

$= 6.86 \times 10^{-10}\,m^4$

Simplify

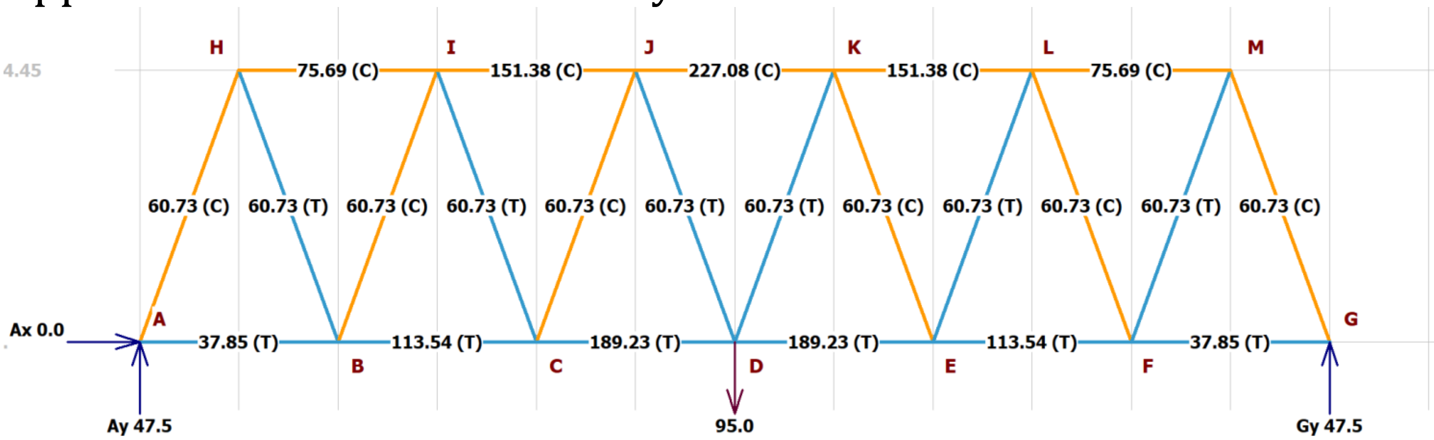


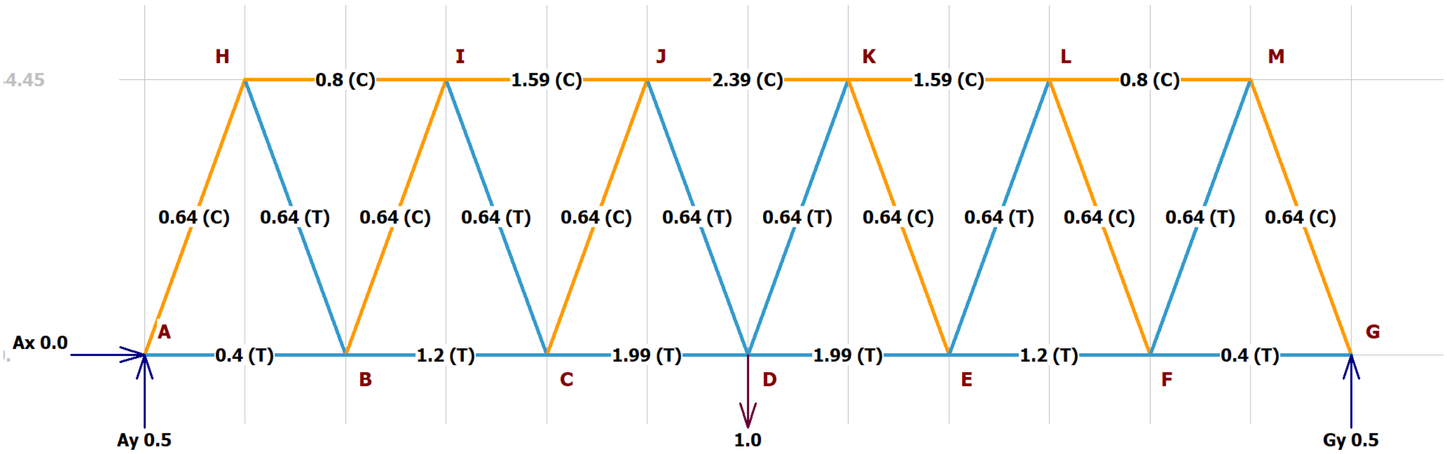
Deflection

$\delta = \frac{180.211}{9.07(10^{-5}) \times 3.4(10^9)}$ – sum of member

$= 5.84\,mm$

Appendix A05 – Deflection Analysis Cont.

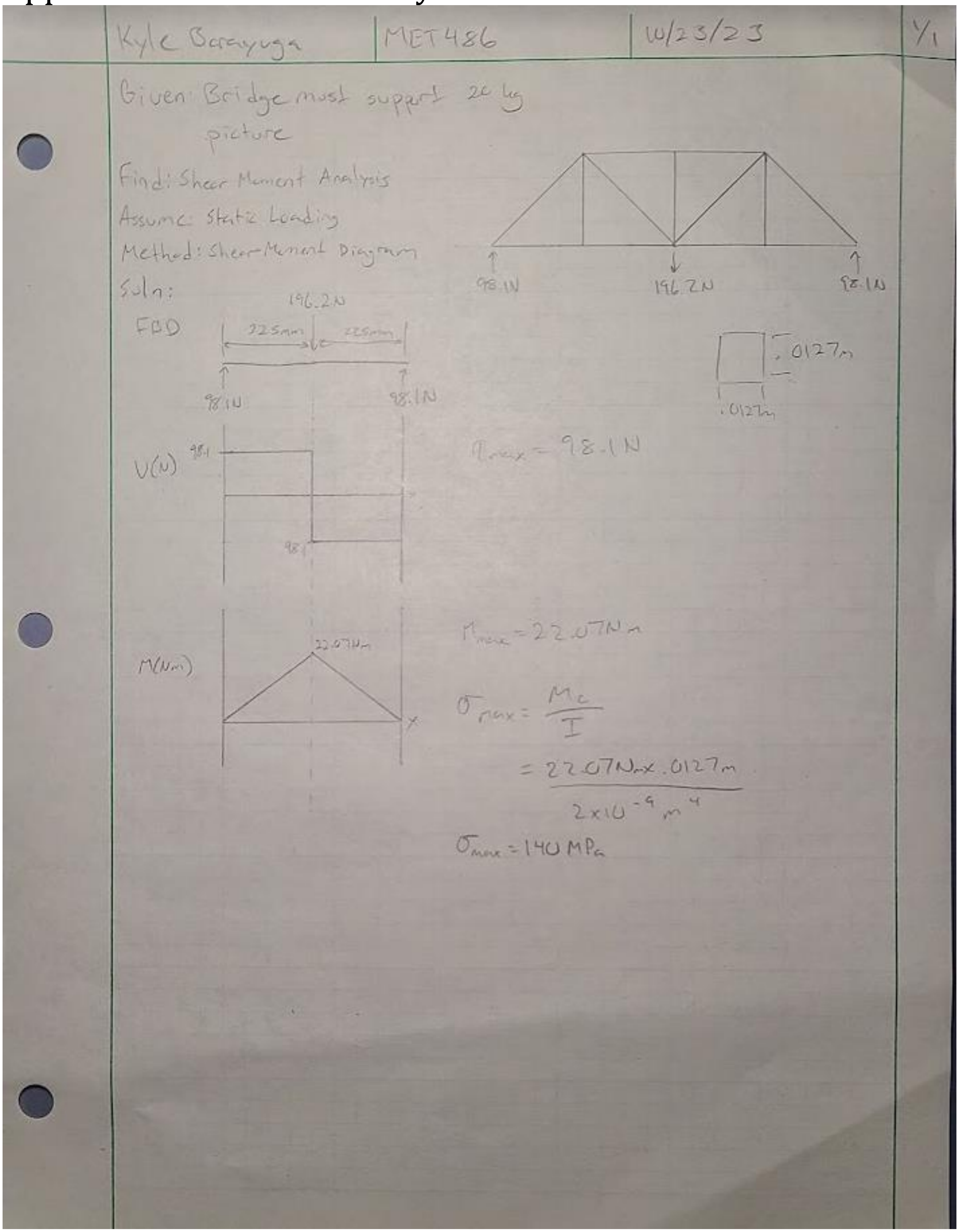




Appendix A05 – Deflection Analysis Cont.

Member	N (N)	n (N)	L (m)	NnL (N2m)
AB	37.85	0.4	0.070833	1.07241162
AH	60.73	0.64	0.056834	2.20897844
BH	60.73	0.64	0.056834	2.20897844
BI	60.73	0.64	0.056834	2.20897844
BC	113.54	1.2	0.070833	9.65085458
CI	60.73	0.64	0.056834	2.20897844
CJ	60.73	0.64	0.056834	2.20897844
CD	189.23	1.99	0.070833	26.6734199
DJ	60.73	0.64	0.056834	2.20897844
DK	60.73	0.64	0.056834	2.20897844
DE	189.23	1.99	0.070833	26.6734199
EK	60.73	0.64	0.056834	2.20897844
EL	60.73	0.64	0.056834	2.20897844
EF	113.54	1.2	0.070833	9.65085458
FL	60.73	0.64	0.056834	2.20897844
FM	60.73	0.64	0.056834	2.20897844
FG	37.85	0.4	0.070833	1.07241162
HI	75.69	0.8	0.070833	4.28907982
IJ	151.38	1.59	0.070833	17.0490923
JK	227.08	2.39	0.070833	38.4425708
KL	151.38	1.59	0.070833	17.0490923
LM	75.69	0.8	0.070833	4.28907982
				180.21105

Appendix A06 – Stress Analysis



Kyle Barayuga | MET486 | 10/23/23 | 1/1

Given: Bridge must support 20 kg picture

Find: Shear Moment Analysis

Assume: Static Loading

Method: Shear-Moment Diagram

Soln:

$V_{max} = 98.1\,N$

$M_{max} = 22.07\,Nm$

$$\sigma_{max} = \frac{Mc}{I}$$

$$= \frac{22.07\,Nm \times .0127\,m}{2 \times 10^{-9}\,m^4}$$

$\sigma_{max} = 140\,MPa$

Appendix A07 – Minimum Length String

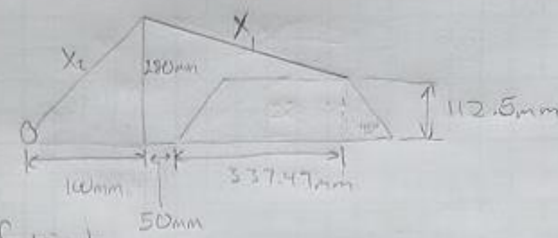
Kyle Bereyuga | MET 486 | 10/30/23 | 1/1

Given: Image shown

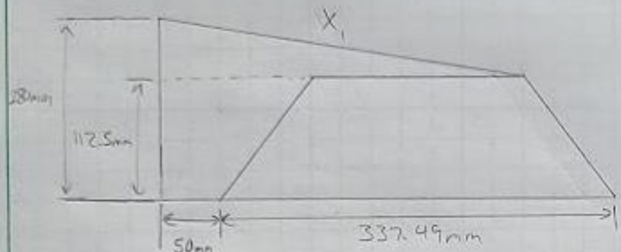
Find: Min length string

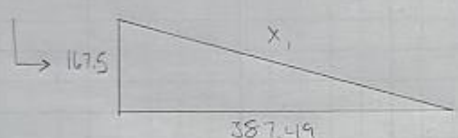
Assume: No slack in string

Method: geometric relations of triangle



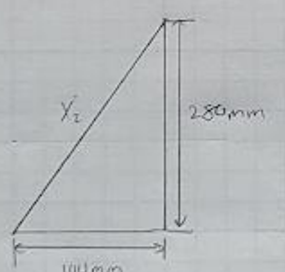
Soln:





$X_1 = \sqrt{387.49^2 + 167.5^2}$

$= 422.14 mm$



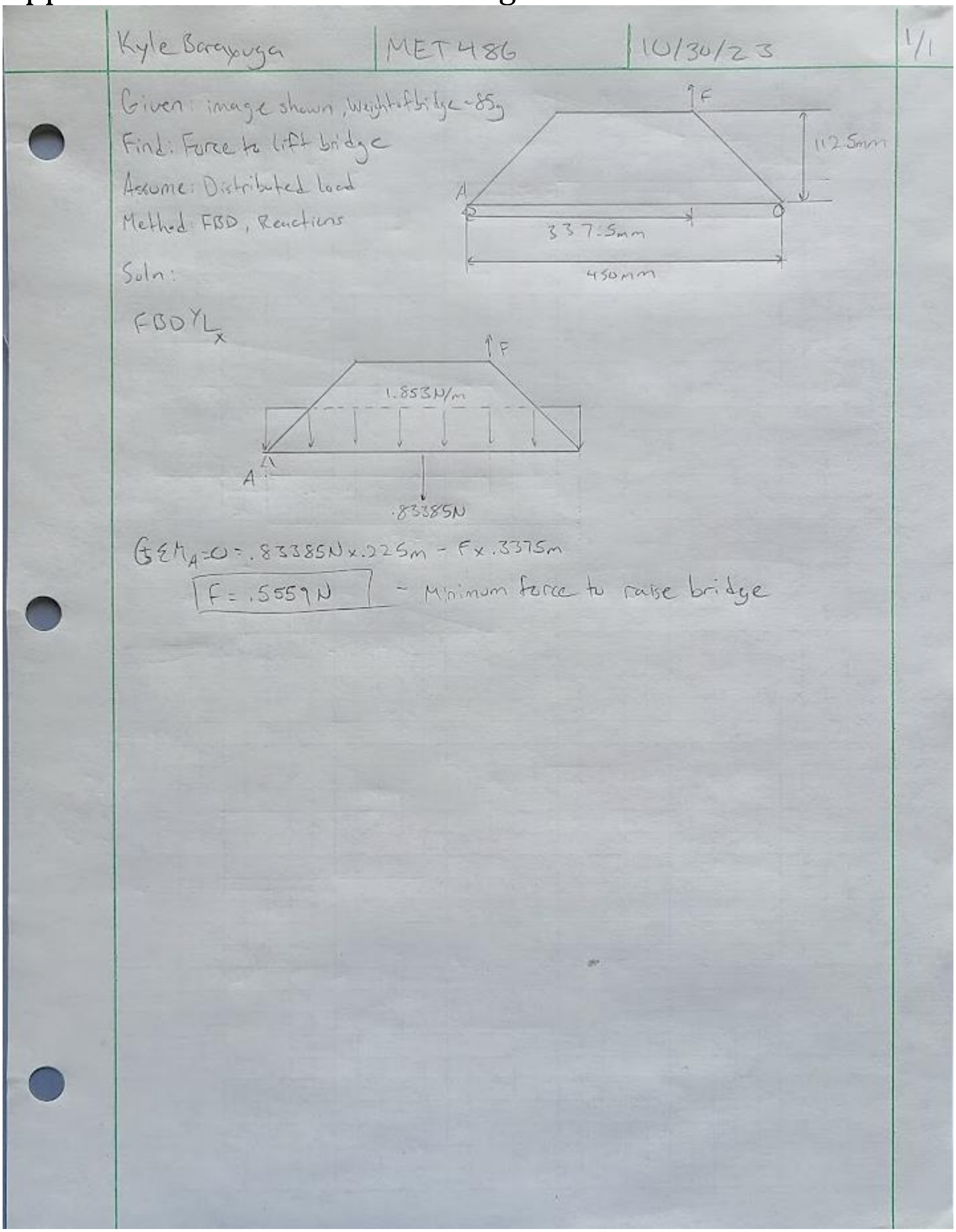
$X_2 = \sqrt{280^2 + 100^2}$

$= 297.32 mm$

Min. Length string = 719.46mm x 2 sides

= 1438.92mm

Appendix A08 – Force to lift bridge



Kyle Barayuga | MET 486 | 10/30/23 | 1/1

Given: image shown, weight of bridge ~85g

Find: Force to lift bridge

Assume: Distributed load

Method: FBD, Reactions

Soln:

FBD $Y L_x$

$\circlearrowleft \Sigma M_A = 0 = .83385N \times .225m - F \times .3375m$

$F = .5559N$ – Minimum force to raise bridge

Appendix A09 – Angle of Inner Diagonal Truss

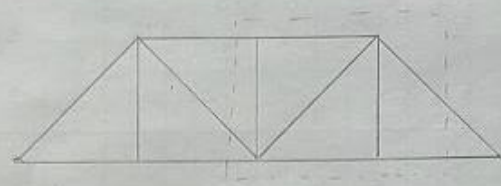
Kyle Barayuga | MET 489 | 11/03/23 | 1/1

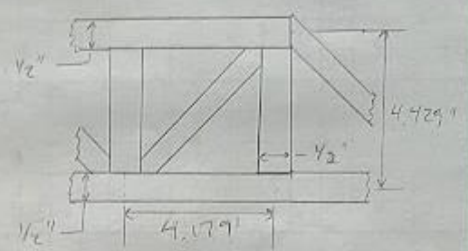
Given: Image shown

Find: angle of inner diag. truss

Assume: Account for thickness of beams

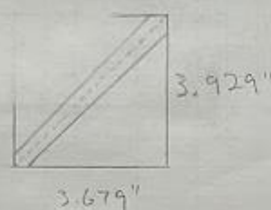
Method: FBD, total length of inner truss, angle





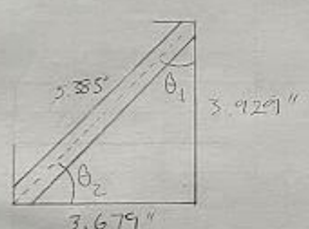
Soln:

FBD



total length $= \sqrt{3.679^2 + 3.929^2} = 5.383''$

Angle



$\theta_1 = \tan^{-1}\left(\frac{3.679}{3.929}\right) = 43.12°$

$\theta_2 = \tan^{-1}\left(\frac{3.929}{3.679}\right) = 46.88°$

Appendix A10 – Tensile Force of String

Kyle Berayuga | MET 489 | 11/06/23 | 1/1

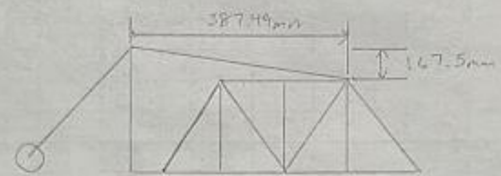
Given: Image shown

Find: Force in string

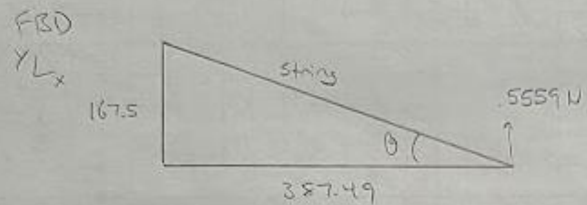
Assume: Force to lift brigde = .5559N

Method: FBD, θ, trig identities

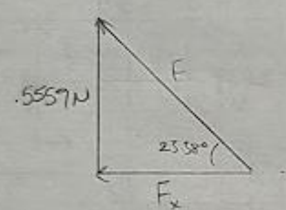
Soln:



FBD



$$\theta = \tan^{-1}\left(\frac{167.5}{387.49}\right) = 23.38°$$



$$F_x = \frac{.5559N}{\tan(23.38)} = 1.29N$$

$$F = \sqrt{1.29^2 + .5559^2}$$

$$\boxed{F = 1.40N}$$

Force acting on string is 1.40 N

Appendix A11 – Area of Articulation Beams

Kyle Barayuga | MET 489 | 11/13/23 | 1/1

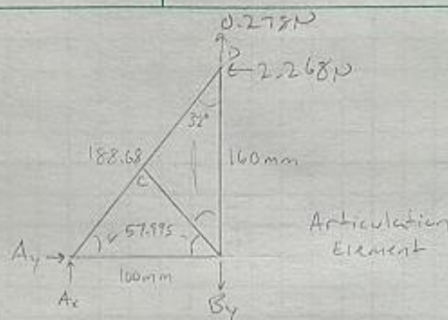
Given: Image Shown

Find: Cross Sectional Area of Weakest Beam

Assume: Static Load

Method: Statics, Area

Soln:



A+ D

$\xrightarrow{+} \Sigma F_x = 0 = -2.268N - DC \sin 32$

$DC = 4.28N$ (C)

$+\uparrow \Sigma F_y = 0 = -4.28 \cos 32 - DB + 0.278N$

$DB = 3.91$ (T)

A+ A

$+\uparrow \Sigma F_y = 0 = -4.28 \cos 32 + A_y$

$A_y = 3.63 N$

$\xrightarrow{+} \Sigma F_x = 0 = A_x - 4.28 \sin 32$

$A_x = 2.27N$

A+ B

$+\uparrow \Sigma F_y = 0 = -3.91 + B_y$

$B_y = 3.91 N$

$\xrightarrow{+} \Sigma F_x = 0$

Area

$\sigma = \frac{P}{A} \rightarrow A = \frac{P}{\sigma}$

$= \frac{3.91N}{1 \times 10^6 Pa}$ ← Tropical Balsa Wood stress (matweb.com)

$= 3.91 \times 10^{-6} m^2 = 2mm \times 2mm$

Beams must be larger than 2mm x 2mm ∴ standard size of 1/4" x 1/4" will be used

Appendix A12 – Deflection of String Guide Rod

Kyle Barayuga | MET 489 | 11/13/23 | 1/1

Given: Image Shown

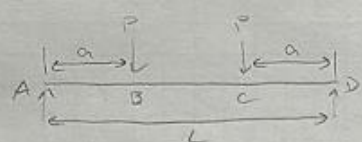
Find: Deflection of String Guide Rod

Assume: 4-Point Load

Method: Deflection

Soln:

FBD



$$Y_{max} = \frac{-Pa}{24EI}(3L^2 - 4a^2)$$

↳ $E = 377\,ksi$

$I = \frac{\pi}{64} \times (.2\,in)^4 = 7.85 \times 10^{-5}\,in^4$

$P = .0625\,lb$

$$Y_{max} = -\frac{.0625\,lb \times 1\,in}{24 \times 377\,ksi \times 7.85 \times 10^{-5}\,in^4} \times (3 \times (5\,in)^2 - 4 \times (1\,in)^2)$$

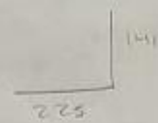
$Y_{max} = 6.25 \times 10^{-3}\,in$

Appendix A13 – Midpoint Height

Kyle Borayuga	MET420	04/23/24	1/1

Given: Length = 225mm

height = 141mm



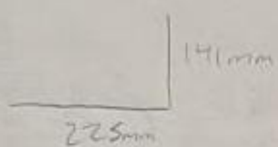
Find: Ratio of radians

Assume: Motor up time: 1000ms = 29mm

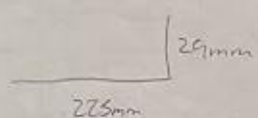
Method: Trig Relations

Soln:

Req. angle



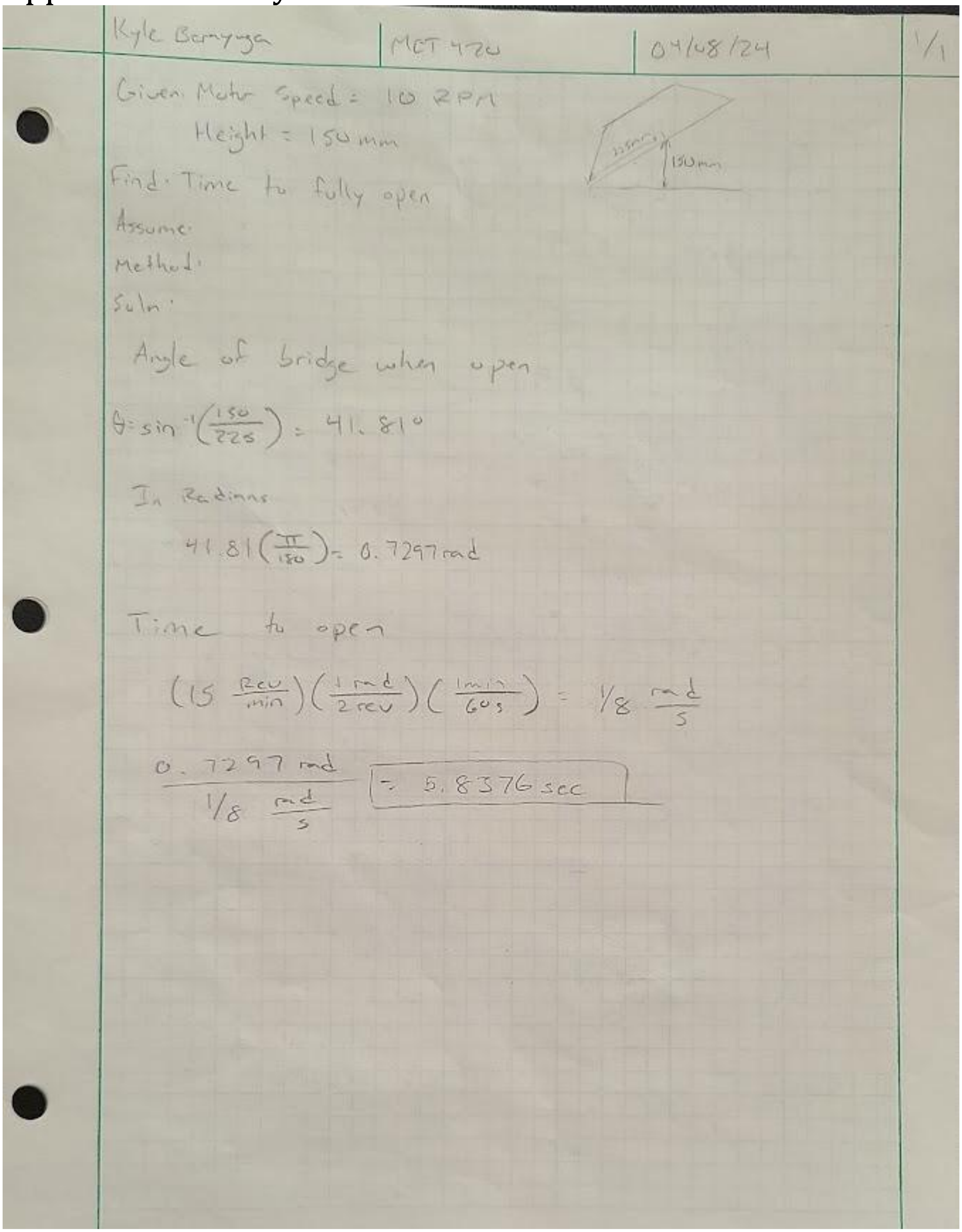
$\tan^{-1}\left(\frac{141}{225}\right) = 32.074° = 0.5598\text{rad}$



$\tan^{-1}\left(\frac{29}{225}\right) = 7.3445° = 0.1282\text{rad}$

$\frac{0.5598}{0.1282} = 4.3666 \times 1000\text{ms} = 4367\text{ms}$: motor up time to raise bridge 141mm

Appendix A14 – Cycle Time



Kyle Bernyga | MET 420 | 04/08/24 | 1/1

Given: Motor Speed = 10 RPM

Height = 150 mm

Find: Time to fully open

Assume:

Method:

Soln:

Angle of bridge when open

$$\theta = \sin^{-1}\left(\frac{150}{225}\right) = 41.81^\circ$$

In Radians

$$41.81\left(\frac{\pi}{180}\right) = 0.7297\ \text{rad}$$

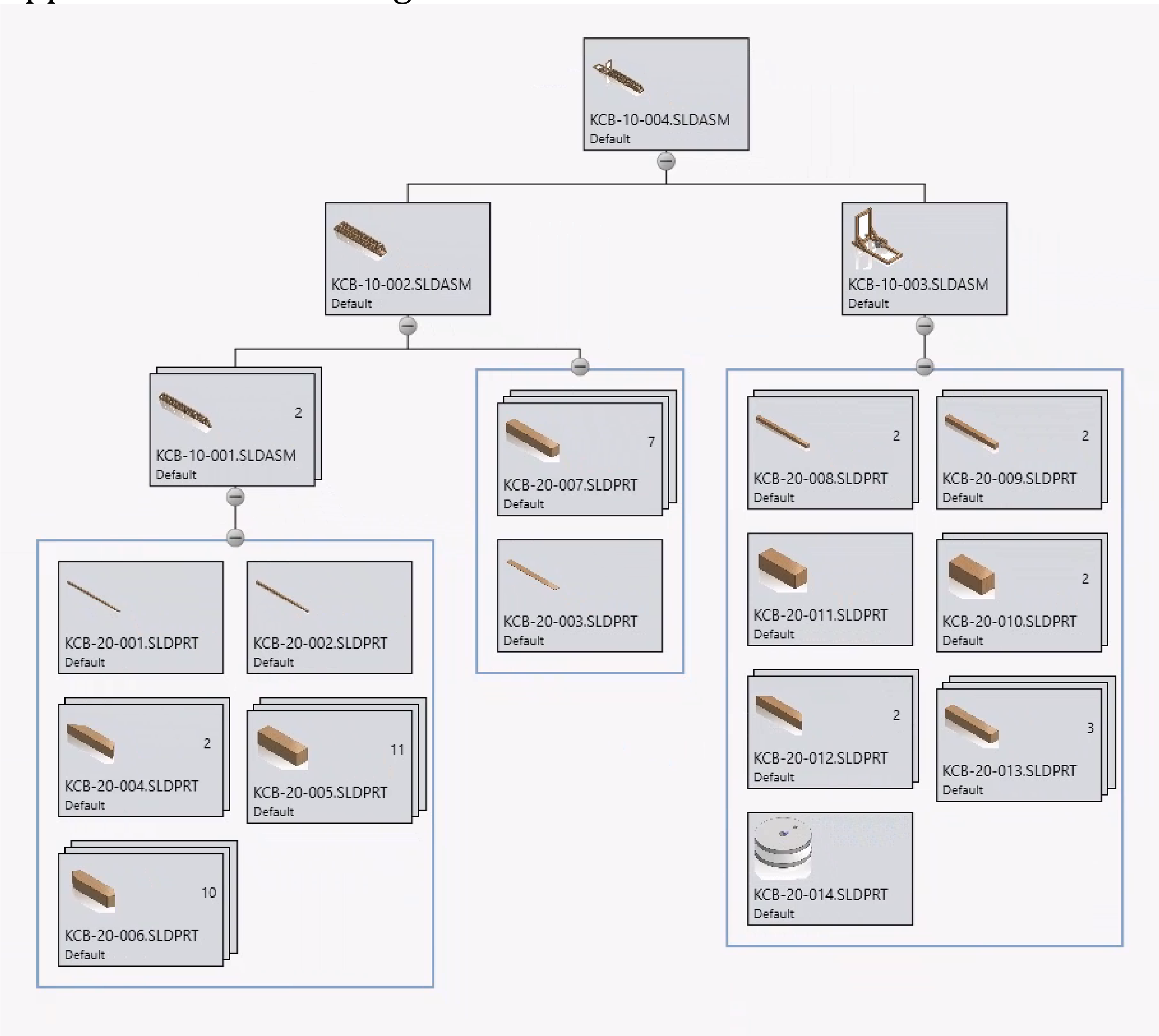
Time to open

$$\left(15\ \frac{\text{Rev}}{\text{min}}\right)\left(\frac{1\ \text{rad}}{2\ \text{rev}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = \frac{1}{8}\ \frac{\text{rad}}{\text{s}}$$

$$\frac{0.7297\ \text{rad}}{\frac{1}{8}\ \frac{\text{rad}}{\text{s}}} = 5.8376\ \text{sec}$$

APPENDIX B - Drawings

Appendix B01 – Drawing Tree



Appendix B02 – Drawing Index

Table B1 - Drawing Index

Drawing Assignment Num.	Drawing #(s)	Date submitted
Upload: DWG 1	KCB-20-001	10/11/23
Upload: DWG 2	KCB-20-002	10/18/23
Upload: DWG 3	KCB-20-003	10/25/23
Upload: DWG 4	KCB-20-004	10/25/23
Upload: DWG 5	KCB-20-005	11/01/23
Upload: DWG 6	KCB-20-006	11/01/23
Upload: DWG 7	KCB-20-007	11/08/23
Upload: DWG 8	KCB-20-008	11/08/23
Upload: DWG 9	KCB-20-009	11/15/23
Upload: DWG 10	KCB-20-010	11/15/23
Upload: DWG 11	KCB-20-011	11/27/23
Upload: DWG 12	KCB-20-012	11/27/23
Upload: DWG 13	KCB-20-013	11/27/23
Upload: DWG 14	KCB-20-014	11/15/23
Upload: Assy DWG	KCB-10-003	12/05/23

DWG Number and filename	Description	DateCreated	ByWhom
KCB-10-001	Bridge	11/15/23	Kyle Barayuga
KCB-10-002	Articulation Element	11/15/23	Kyle Barayuga
KCB-10-003	Articulating Bridge	11/15/23	Kyle Barayuga

Figure B1 – Drawing Log: Assemblies

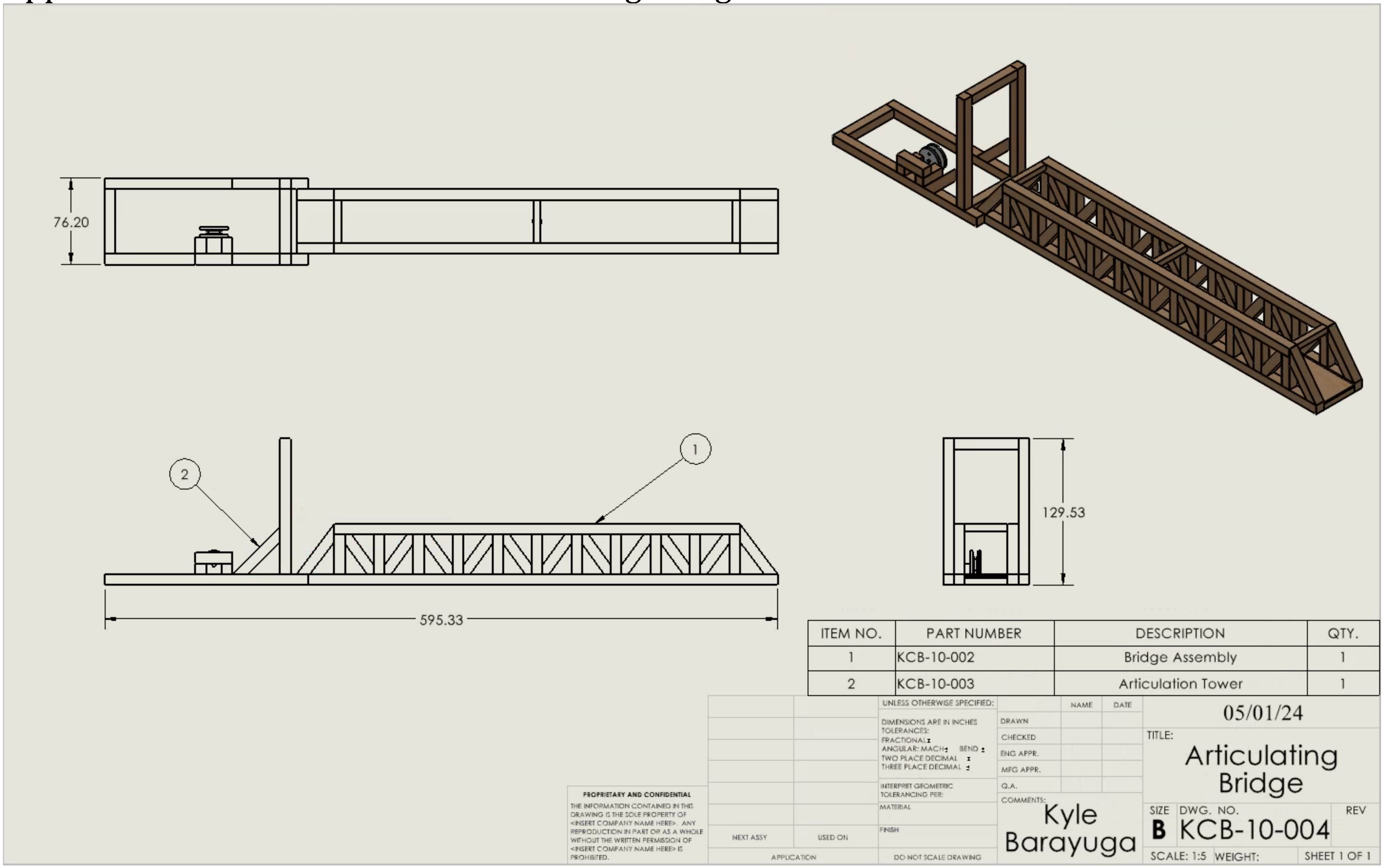
DWG Number and filename	Description	DateCreated	ByWhom
KCB-20-001	Bottom Horizontal Tress Member	10/11/23	Kyle Barayuga
KCB-20-002	Vertical Truss Member	10/18/23	Kyle Barayuga
KCB-20-003	Road Deck	10/23/23	Kyle Barayuga
KCB-20-004	Cross Member	10/23/23	Kyle Barayuga
KCB-20-005	Outre Diagonal Member	10/30/23	Kyle Barayuga
KCB-20-006	Inner Diag Member	10/30/23	Kyle Barayuga
KCB-20-007	Articulation Deck	11/06/23	Kyle Barayuga
KCB-20-008	Articulation Base Member	11/06/23	Kyle Barayuga
KCB-20-009	Articulation Vertical Member	11/13/23	Kyle Barayuga
KCB-20-010	Articulation Outer Diagonal Member	11/13/23	Kyle Barayuga
KCB-20-011	Top Horizontal Member	11/27/23	Kyle Barayuga
KCB-20-012	Articulation Inner Diag. Member	11/27/23	Kyle Barayuga
KCB-20-013	Connecting Bar	11/27/23	Kyle Barayuga
KCB-20-014	Spool	11/27/23	Kyle Barayuga
KCB-20-015	Upper Crossbar	11/27/23	Kyle Barayuga

Figure B2 – Drawing Log: Detail Drawings

DWG Number and filename	Description	DateCreated	ByWhom	Vendor	Link (If applicable)	Mfg.	Mfg. Part#	Vendor Part#
KCB-55-001	Arduino Uno REV3	12/13/23		Amazon	https://a.co/d/gLju6lV			
KCB-55-002	Battery Clip Connector	01/08/24		Amazon	https://a.co/d/huc3Mw2			
KCB-55-003	Arduino Motor Shield Rev3	01/19/24		Amazon	https://a.co/d/iNLrEYC			
KCB-55-004	9V Battery	01/08/24		Amazon	https://a.co/d/fSZGyPi			
KCB-55-005	DC Motor	01/08/24		Amazon	https://a.co/d/4zsdgyj			
KCB-55-006	Wood Glue	01/08/24		Amazon	https://a.co/d/d7KKTMp			
KCB-55-007	Nylon Wire	01/08/24		Amazon	https://a.co/d/1zyHSBf			
KCB-55-008	Push Button	01/19/24		Amazon	https://a.co/d/0UBbVDV			
KCB-55-009	Breadboard	02/02/24		Donated				
KCB-55-010	10K Resistor	02/02/24		Donated				

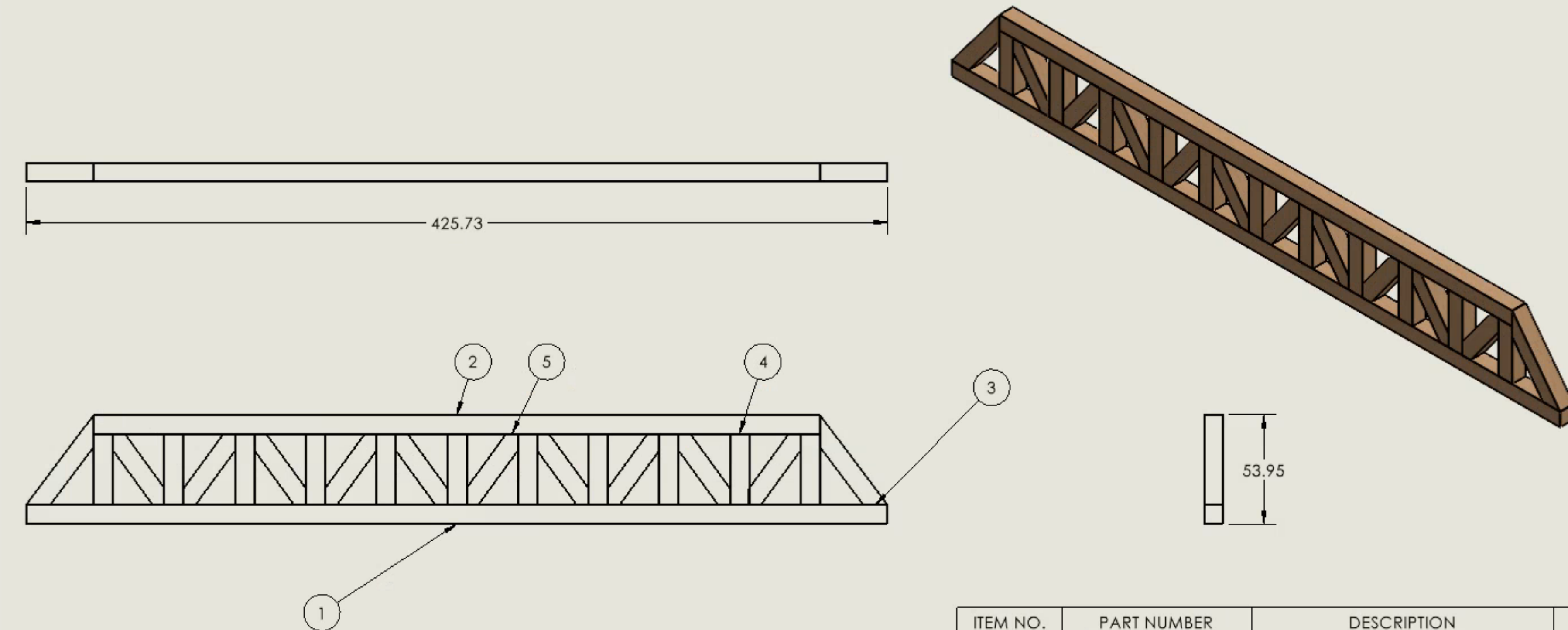
Figure B3 – Drawing Log: Purchased Parts

Appendix B03 – KCB-10-004 – Articulating Bridge Rev.1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	KCB-10-002	Bridge Assembly	1
2	KCB-10-003	Articulation Tower	1

Appendix B04 – KCB-10-001 – Truss Assembly Rev.1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	KCB-20-001	Bottom Hoizontal	1
2	KCB-20-002	Top Horizontal	1
3	KCB-20-004	Outer Diagonal	2
4	KCB-20-005	Vertical Member	11
5	KCB-20-006	Inner Diagonal	10

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

NEXT ASSY | USED ON
APPLICATION

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

COMMENTS: Kyle Barayuga

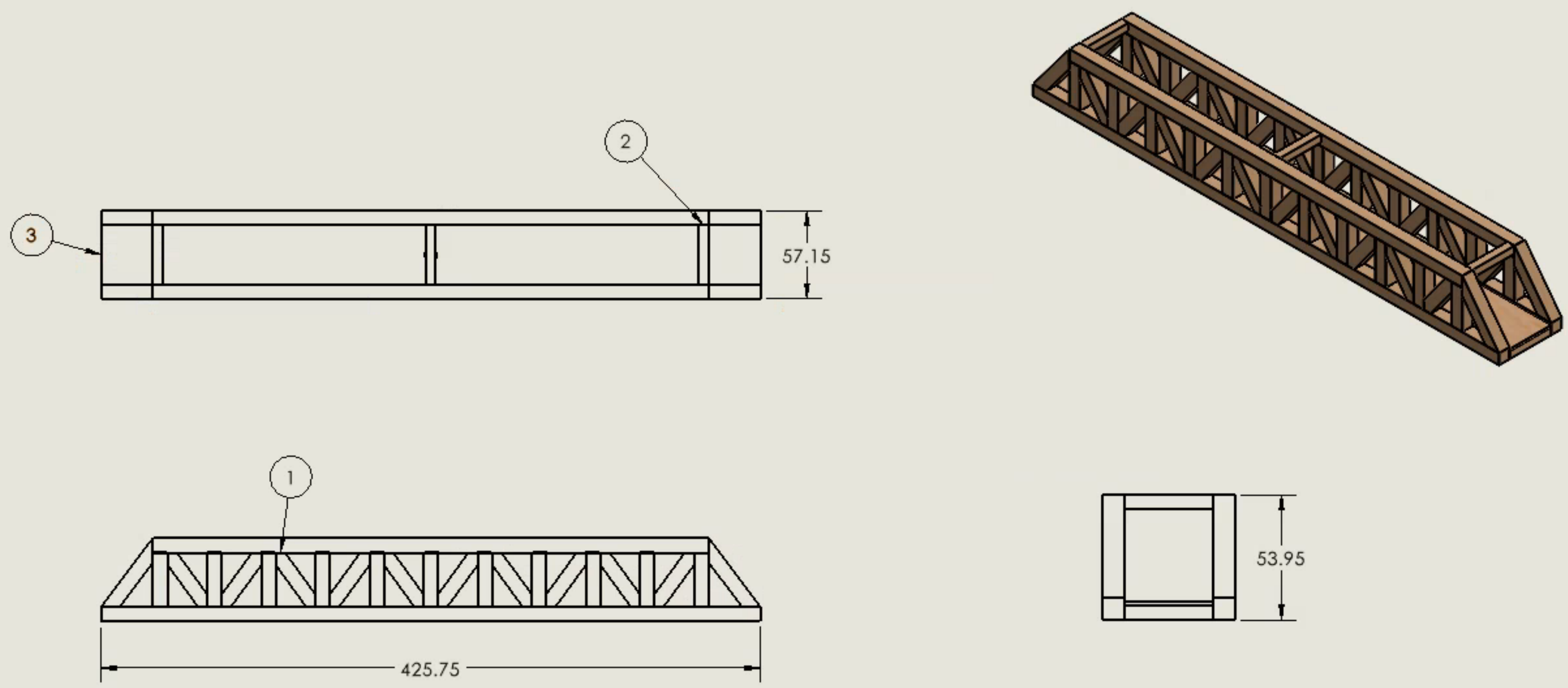
05/01/24

TITLE: Truss

SIZE B DWG. NO. KCB-10-001 REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

Appendix B05 – KCB-10-002 – Bridge Assembly Rev.1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	KCB-10-001	Truss	2
2	KCB-20-007	Cross Member	7
3	KCB-20-003	Road Deck	1

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NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

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

COMMENTS: Kyle Barayuga

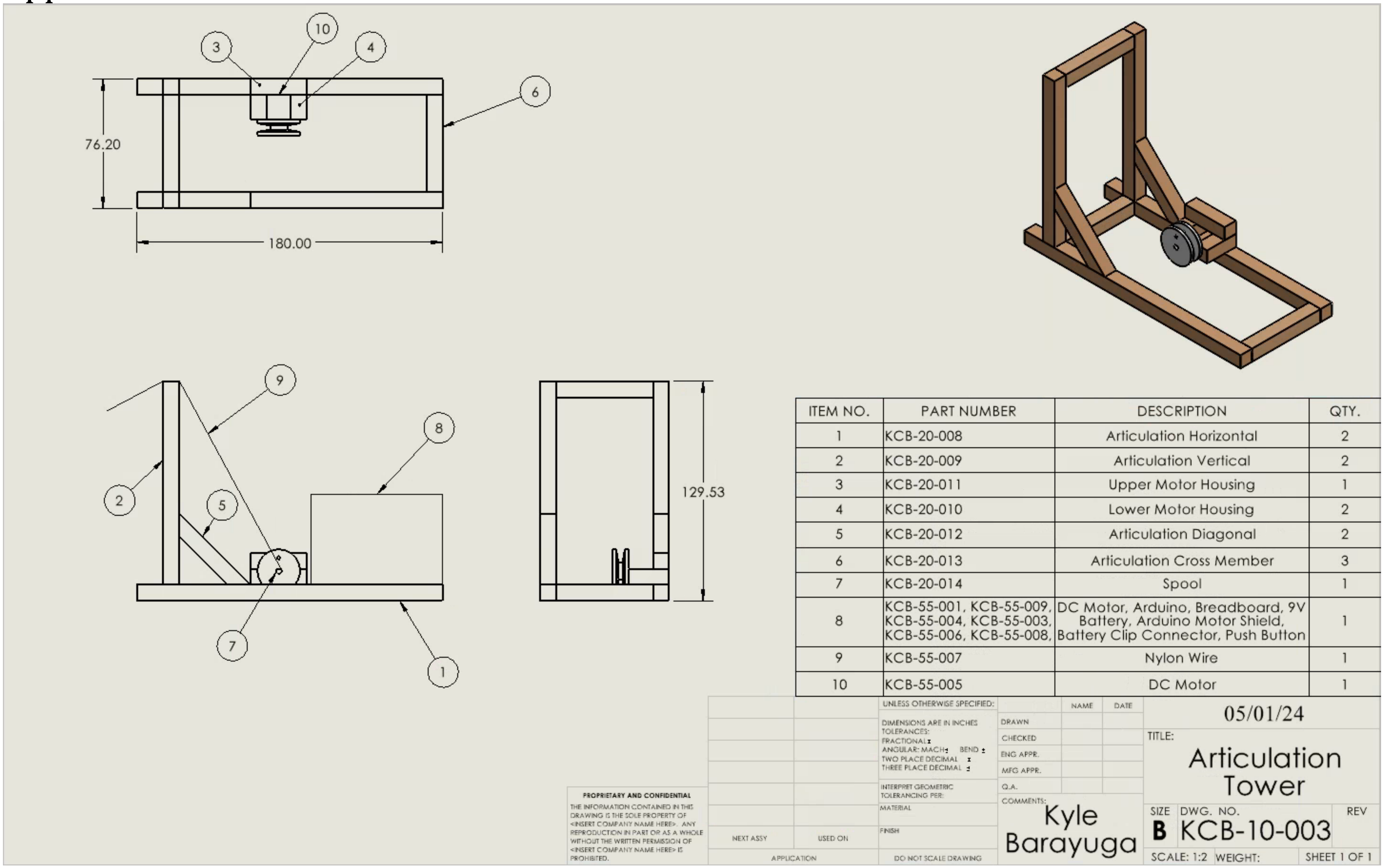
05/01/24

TITLE: Bridge Assembly

SIZE: B | DWG. NO. KCB-10-002 | REV

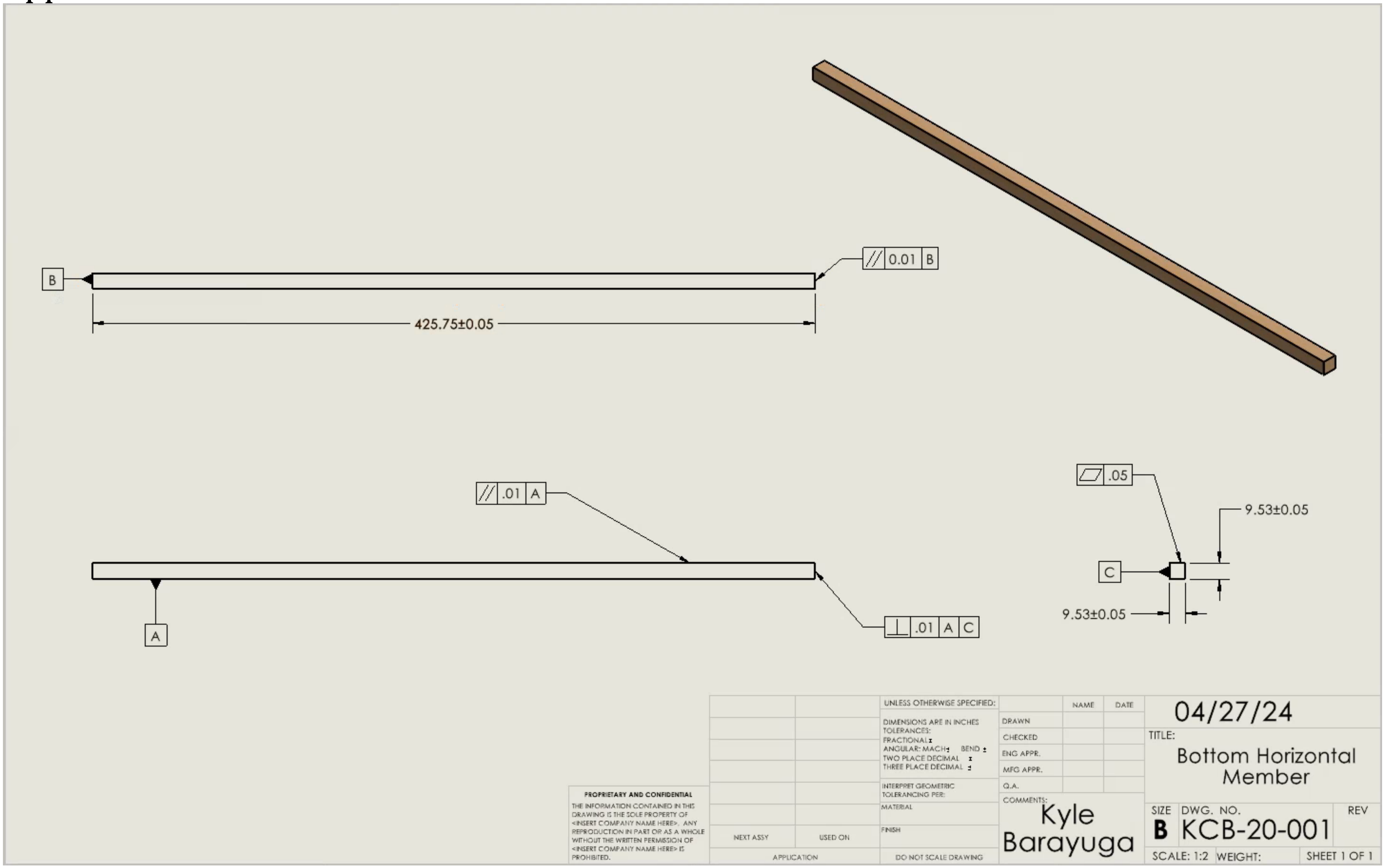
SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

Appendix B06 – KCB-10-003 – Articulation Tower Rev.1

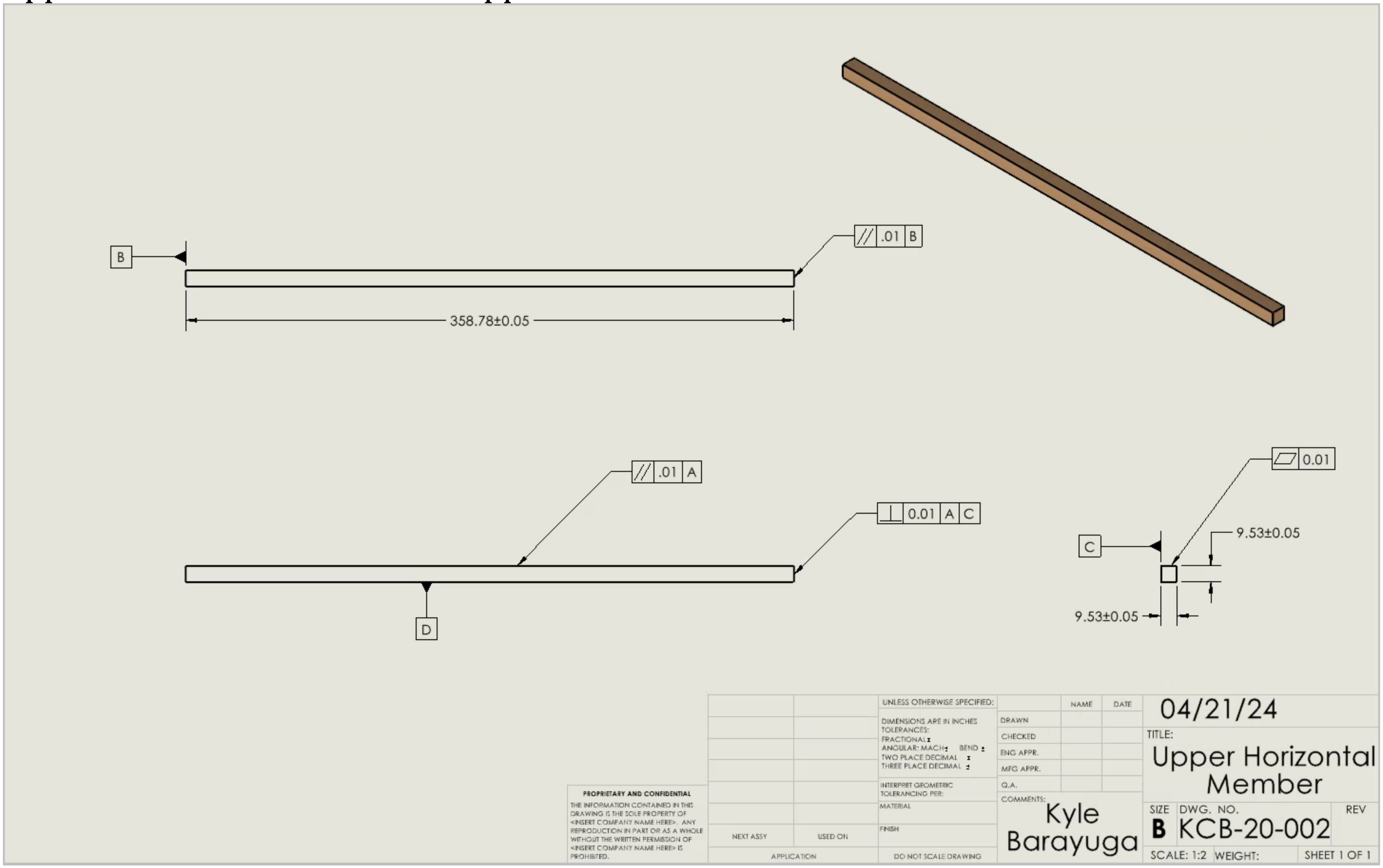


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	KCB-20-008	Articulation Horizontal	2
2	KCB-20-009	Articulation Vertical	2
3	KCB-20-011	Upper Motor Housing	1
4	KCB-20-010	Lower Motor Housing	2
5	KCB-20-012	Articulation Diagonal	2
6	KCB-20-013	Articulation Cross Member	3
7	KCB-20-014	Spool	1
8	KCB-55-001, KCB-55-009, KCB-55-004, KCB-55-003, KCB-55-006, KCB-55-008,	DC Motor, Arduino, Breadboard, 9V Battery, Arduino Motor Shield, Battery Clip Connector, Push Button	1
9	KCB-55-007	Nylon Wire	1
10	KCB-55-005	DC Motor	1

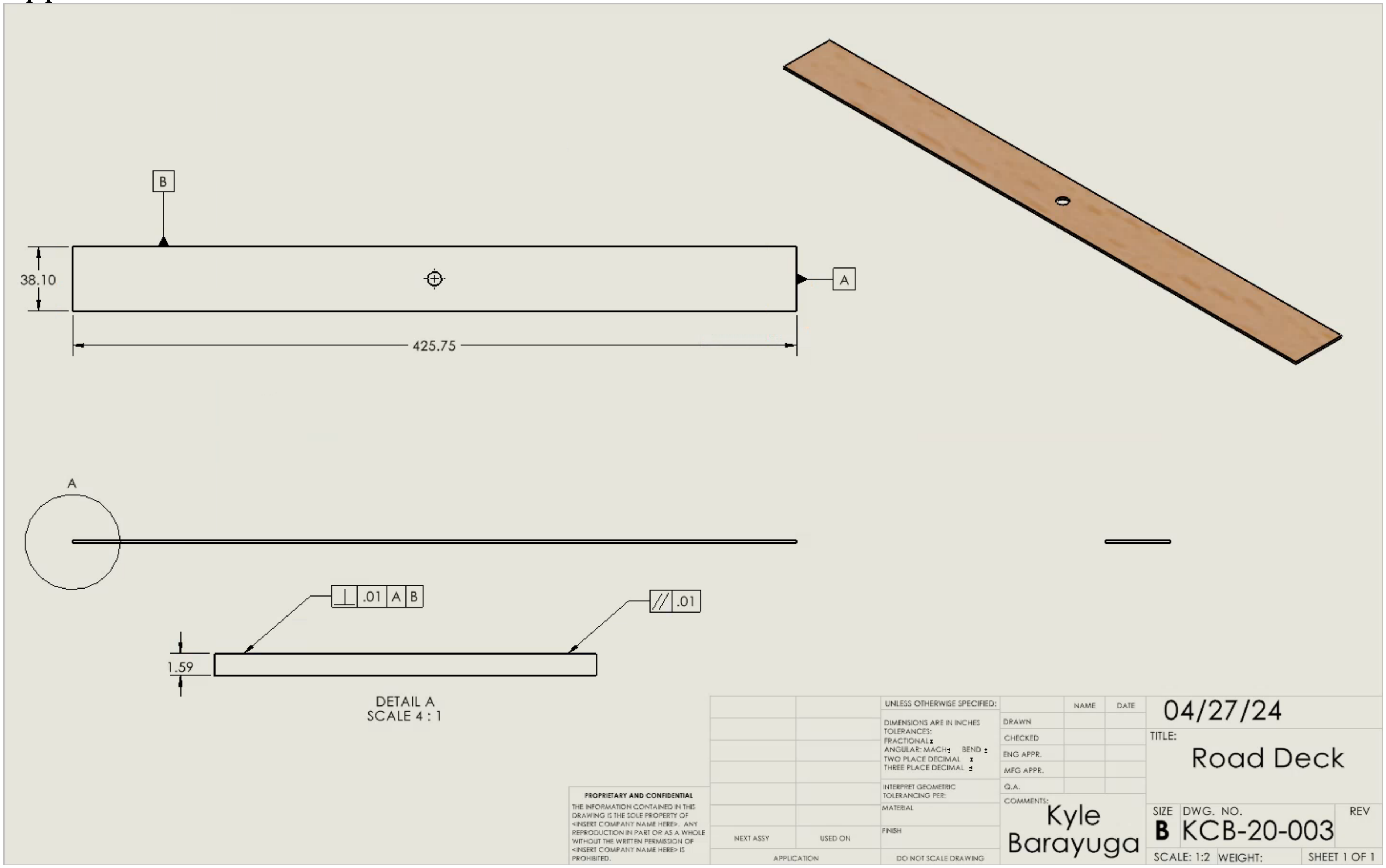
Appendix B07 – KCB-20-001 - Bottom Horizontal Member Rev.1



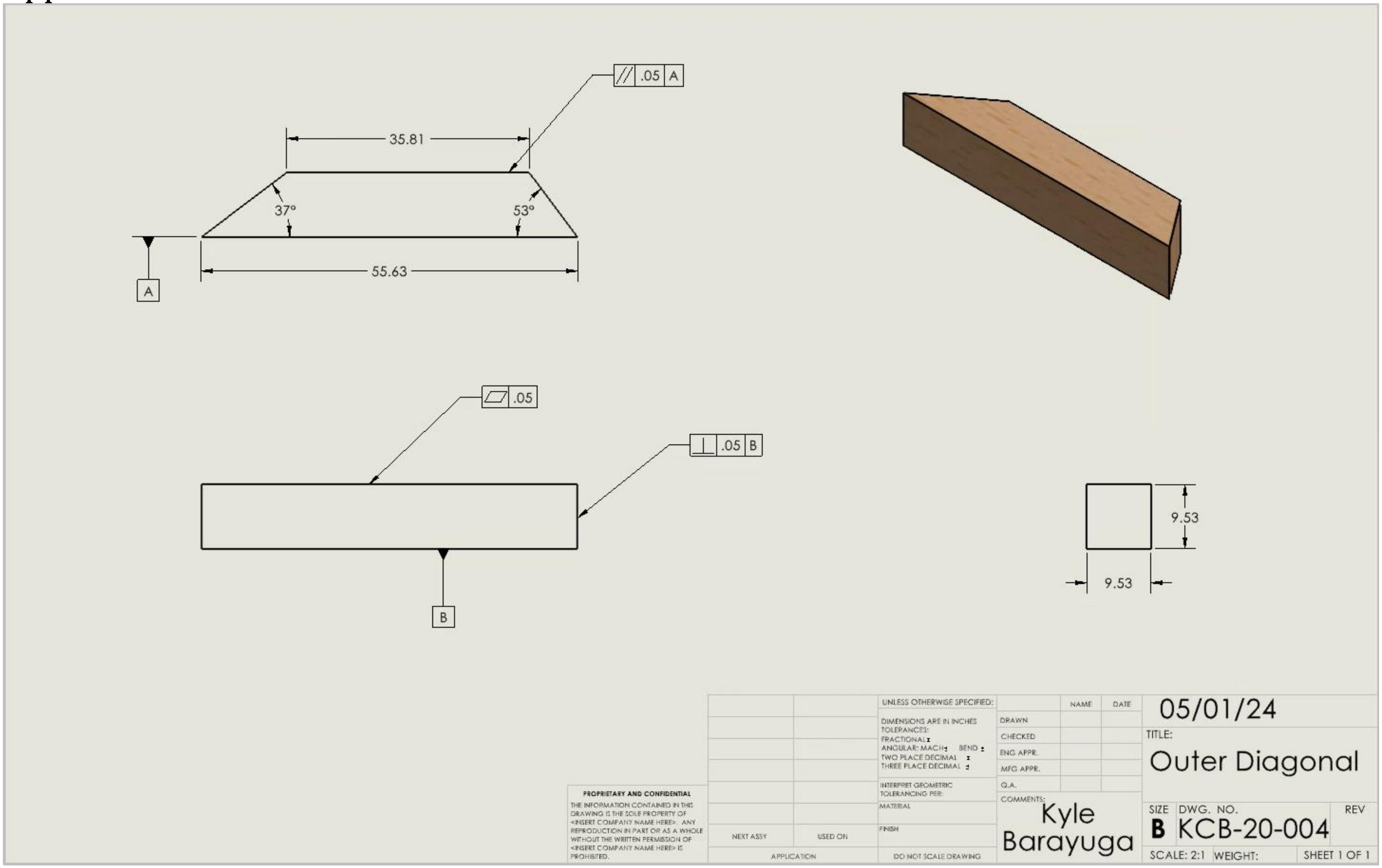
Appendix B08 – KCB-20-002 – Upper Horizontal Member Rev.1



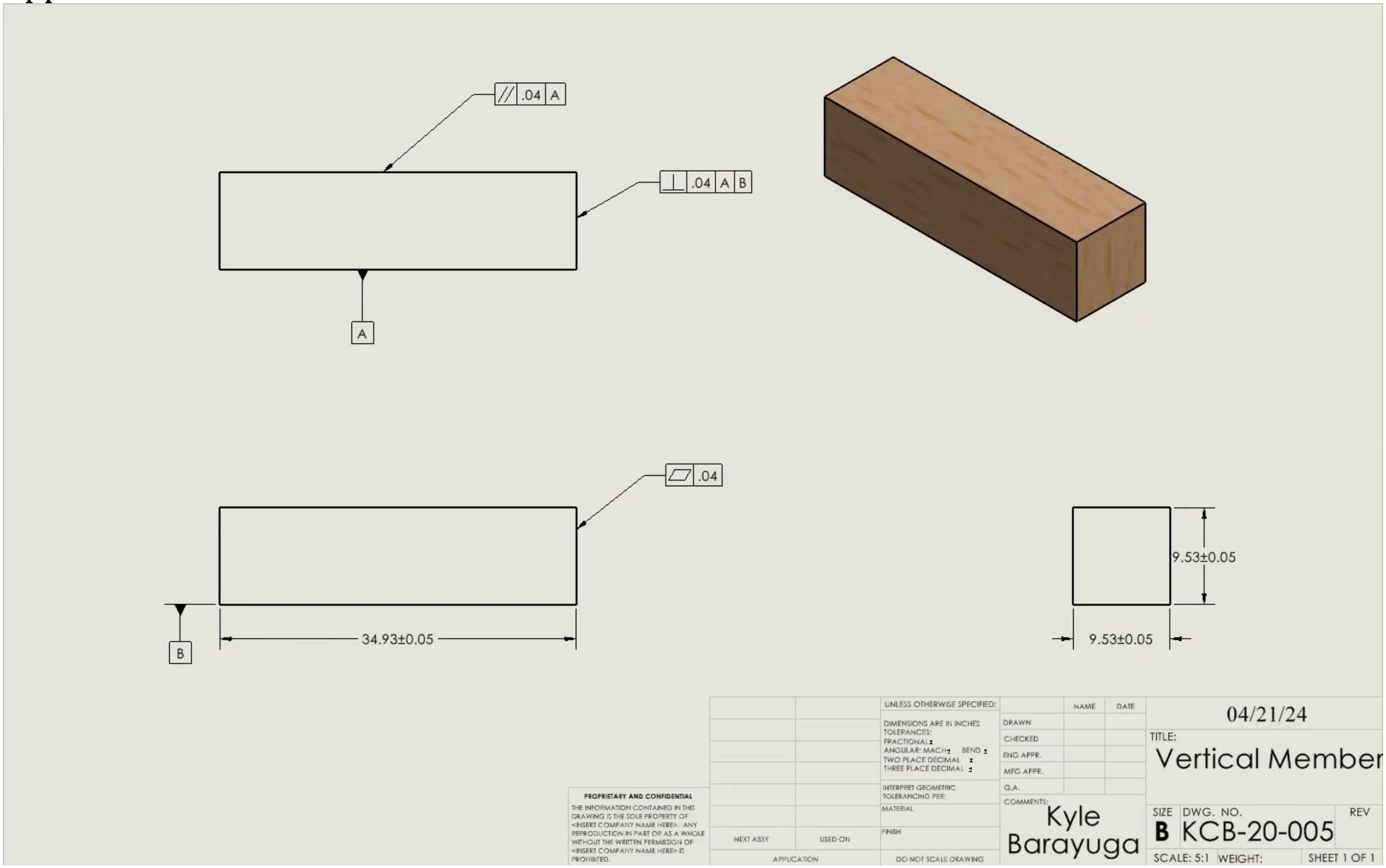
Appendix B09 – KCB-20-003 - Road Deck Rev.1



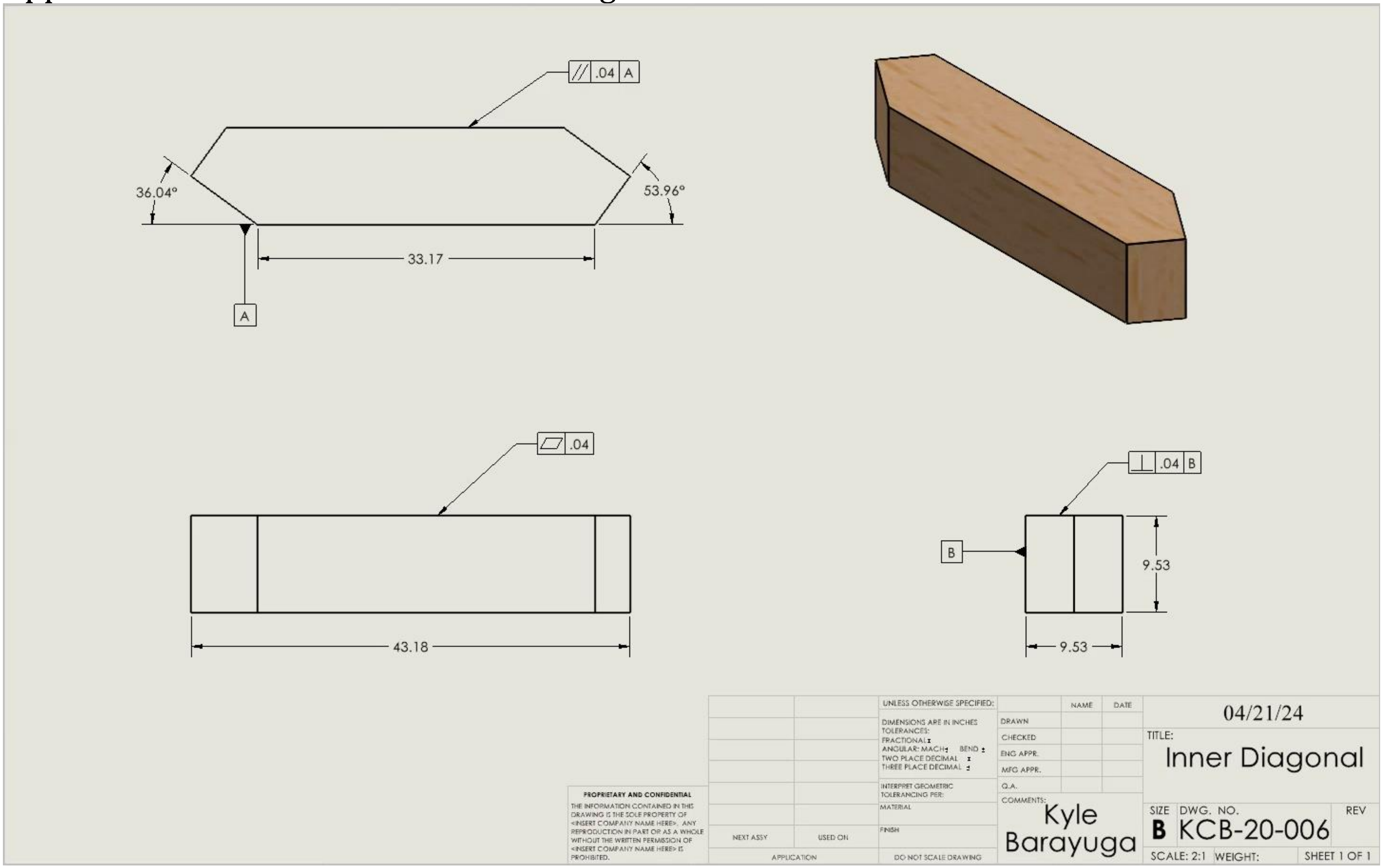
Appendix B10 – KCB-20-004 - Cross Member Rev.1



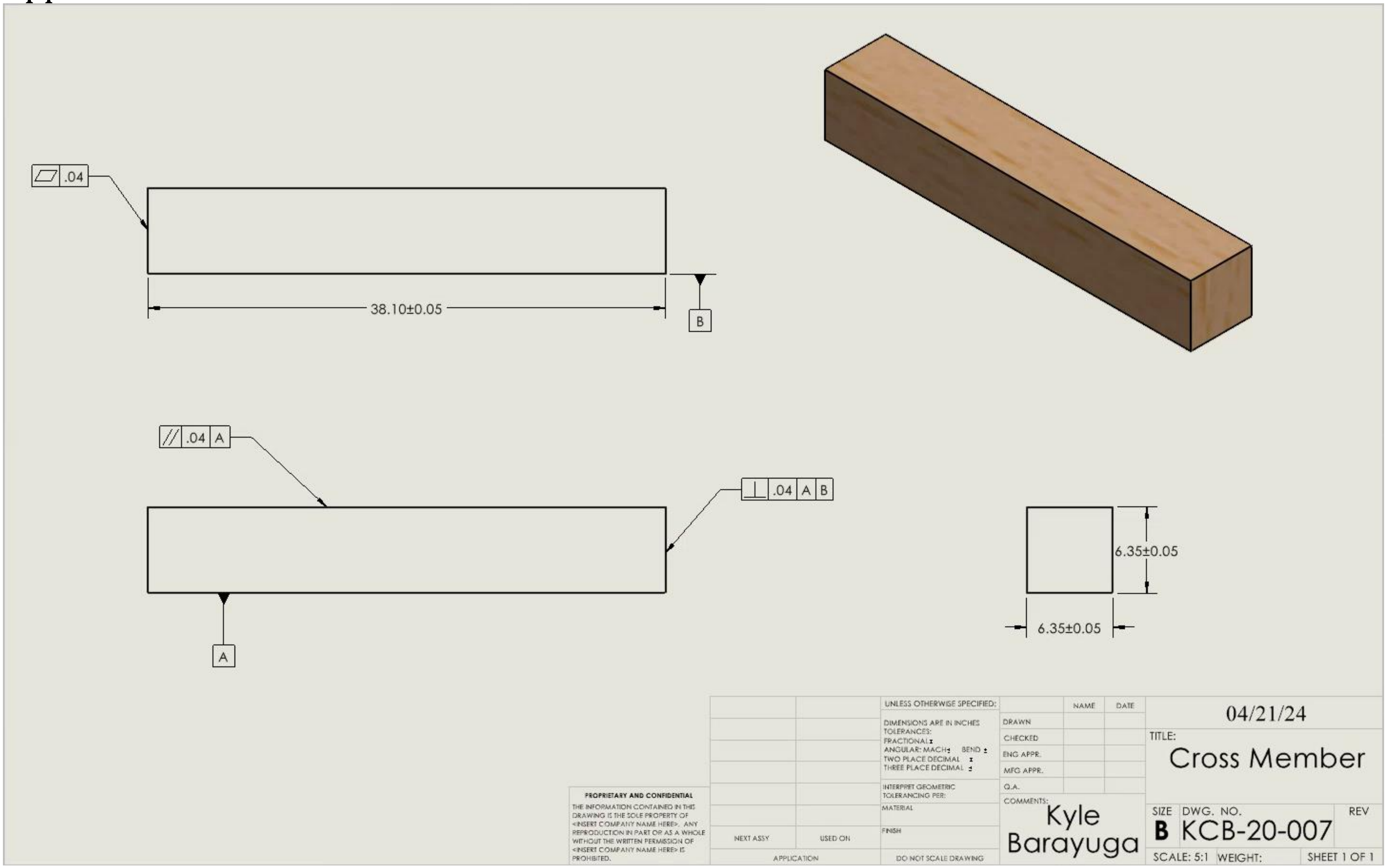
Appendix B11 – KCB-20-005 – Vertical Member Rev.1



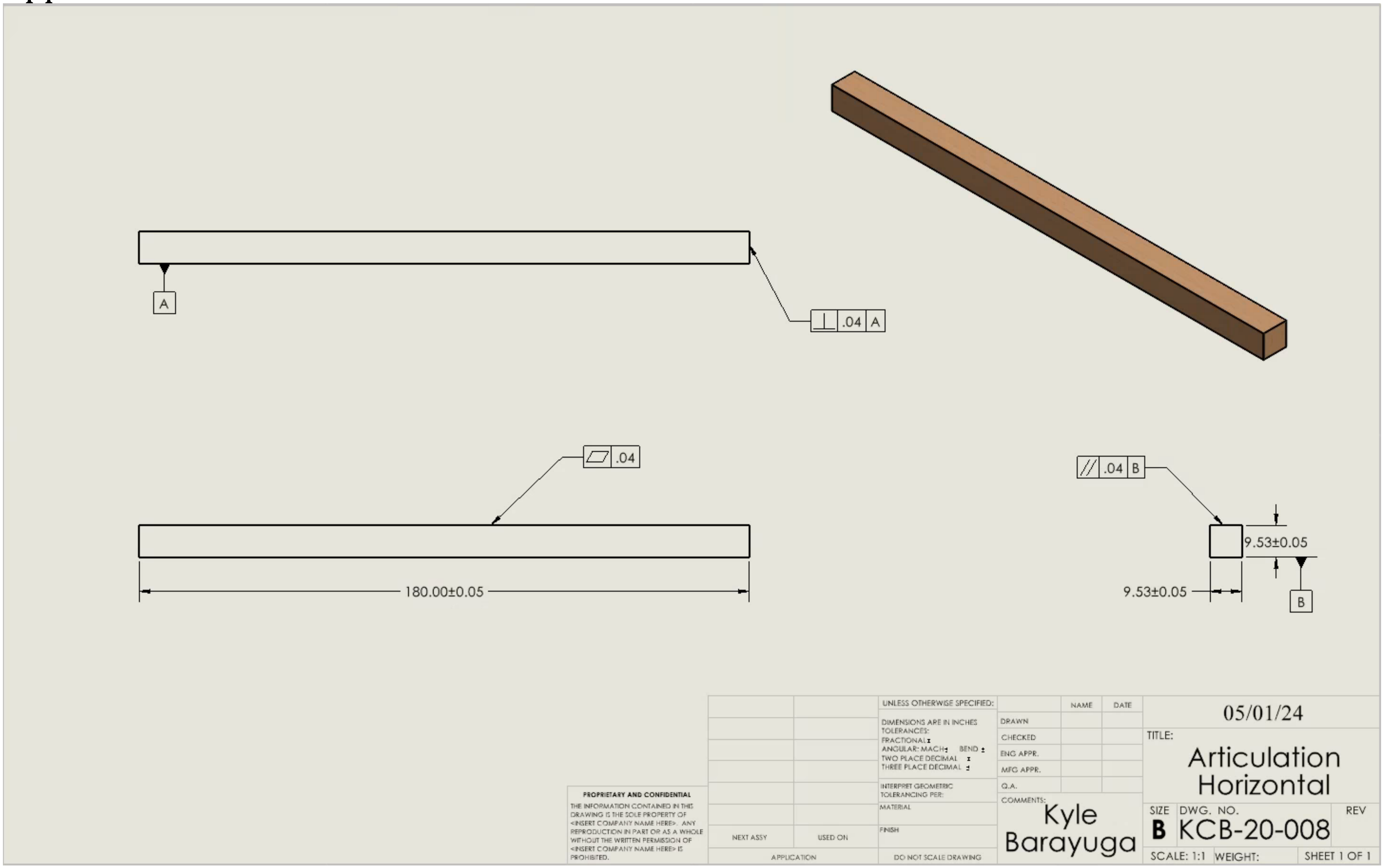
Appendix B12 – KCB-20-006 – Inner Diagonal Rev.1



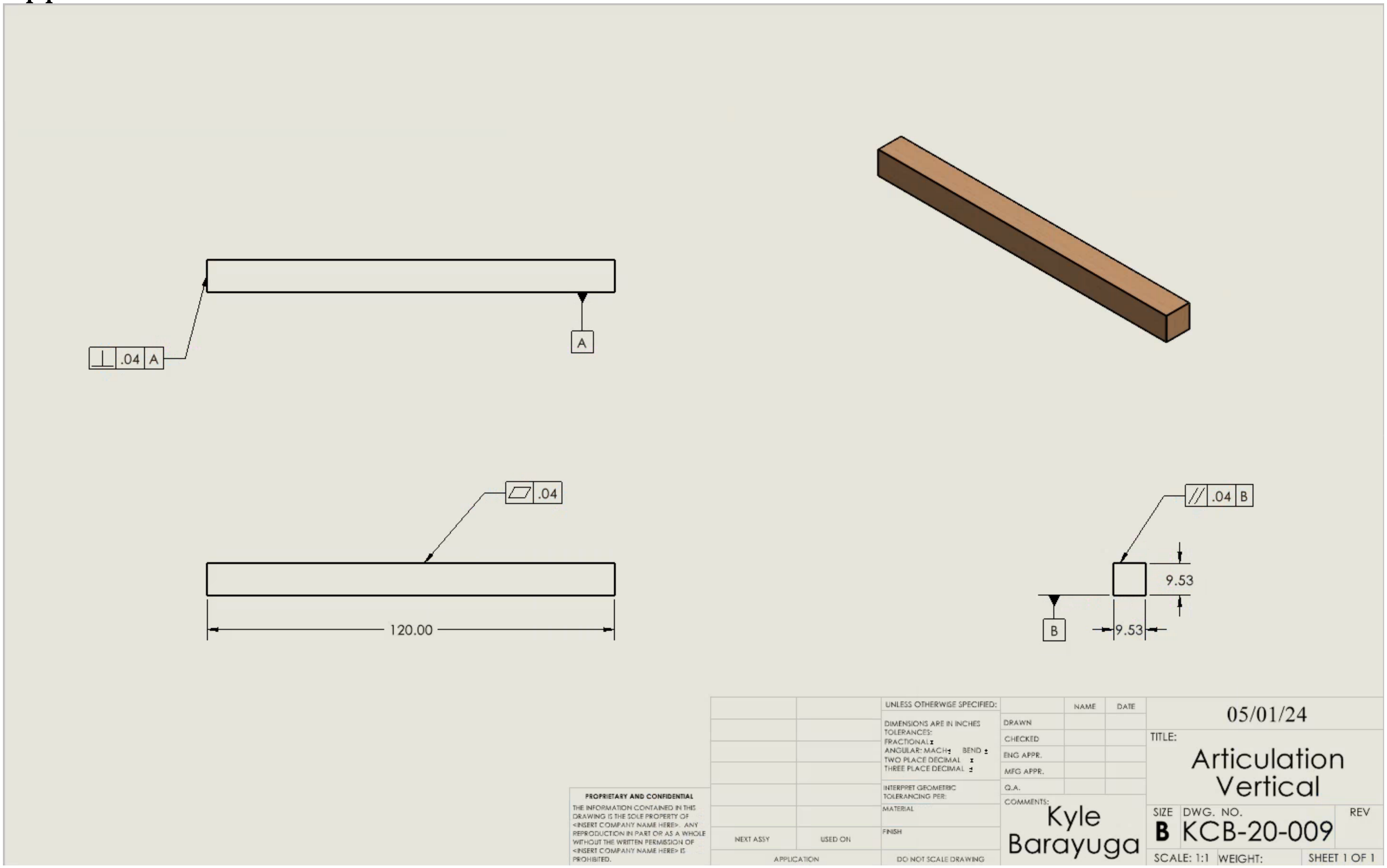
Appendix B13 – KCB-20-007 – Cross Member Rev.1



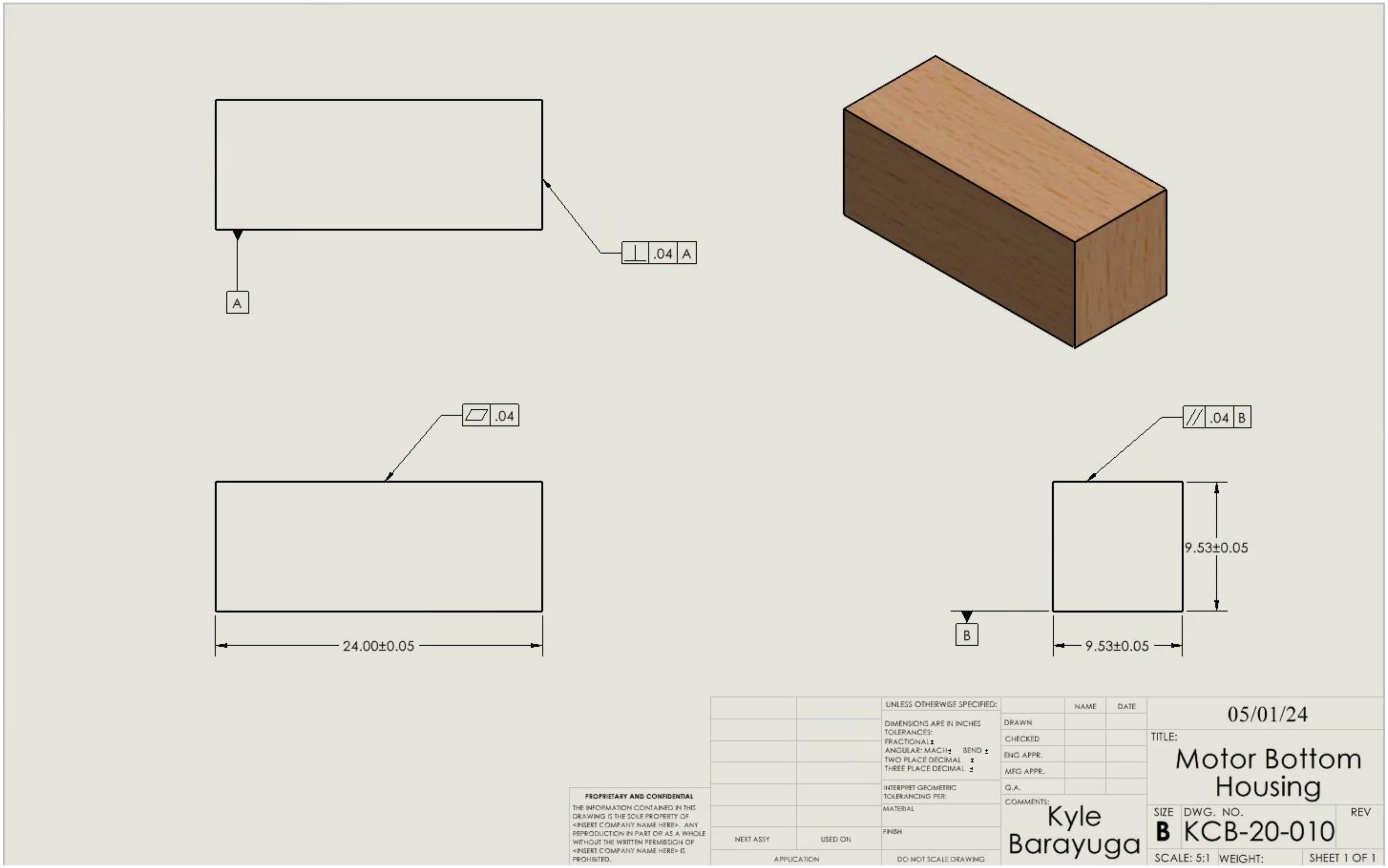
Appendix B14 – KCB-20-008 – Articulation Horizontal Rev.1



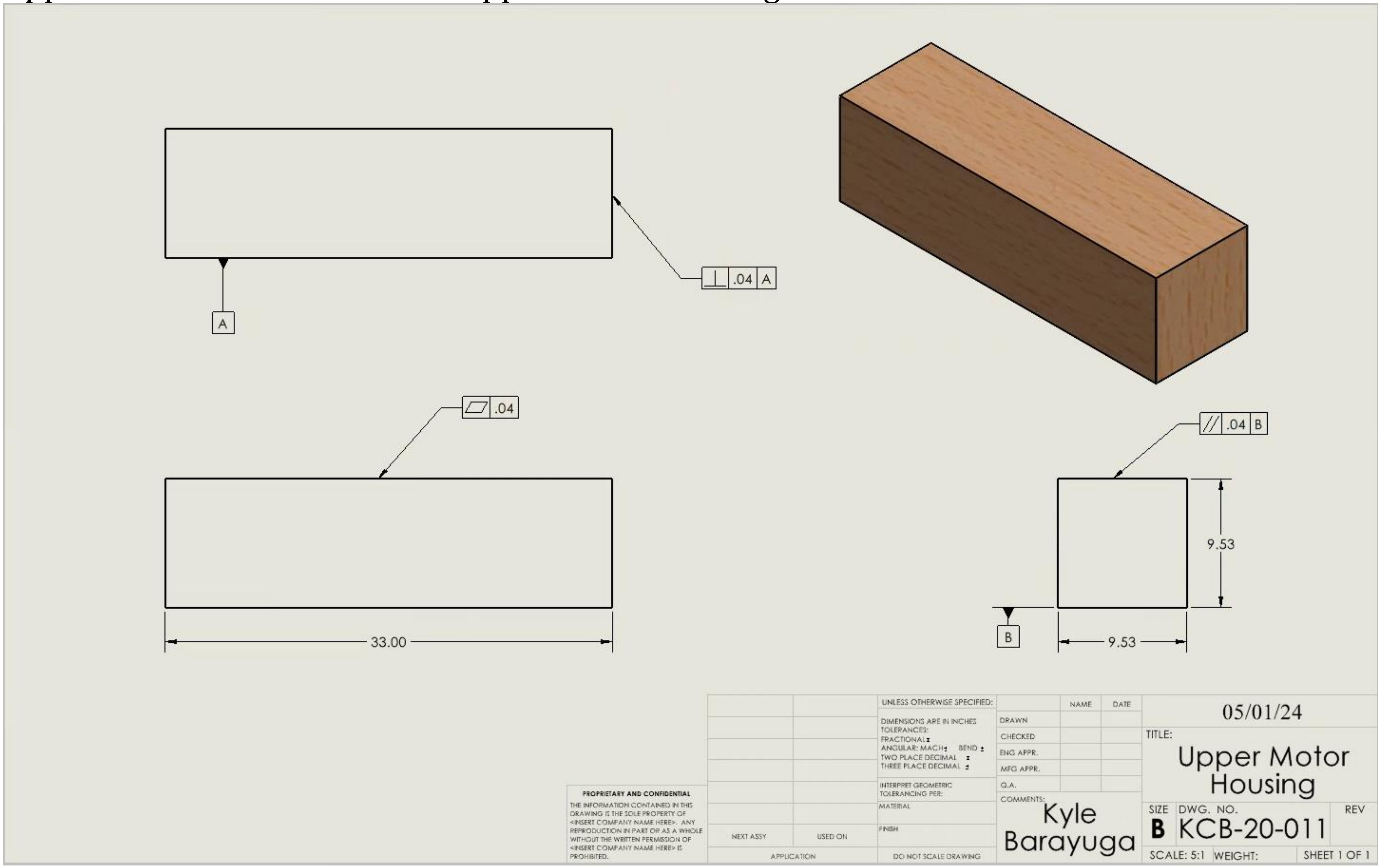
Appendix B15 – KCB-20-009 – Articulation Vertical Rev.1



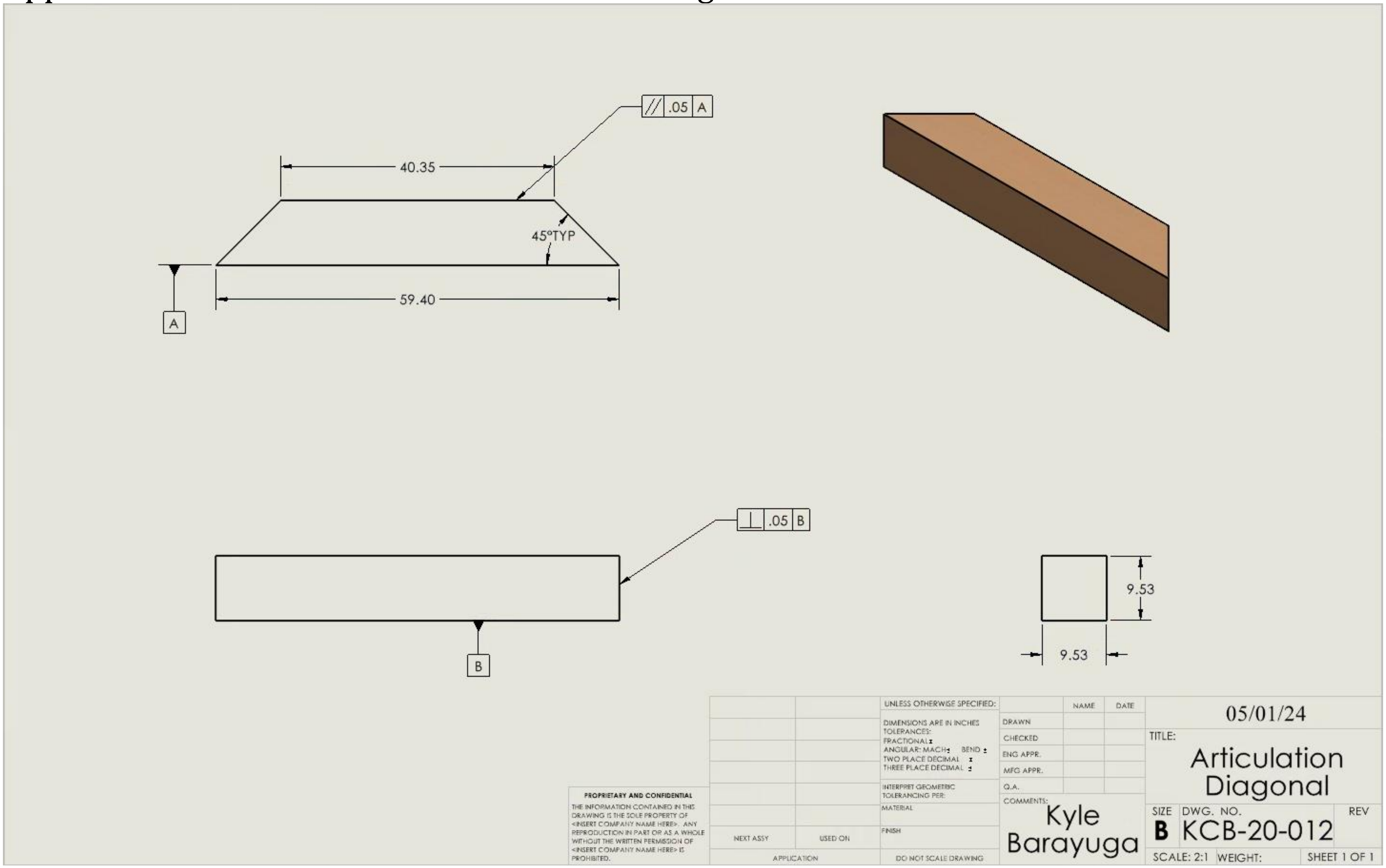
Appendix B16 – KCB-20-010 – Motor Bottom Housing


.04 A
A
.04
//.04 B
9.53±0.05
24.00±0.05
B
9.53±0.05
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Kyle Barayuga
05/01/24
TITLE:
Motor Bottom Housing
SIZE
DWG. NO.
REV
B
KCB-20-010
SCALE: 5:1
WEIGHT:
SHEET 1 OF 1

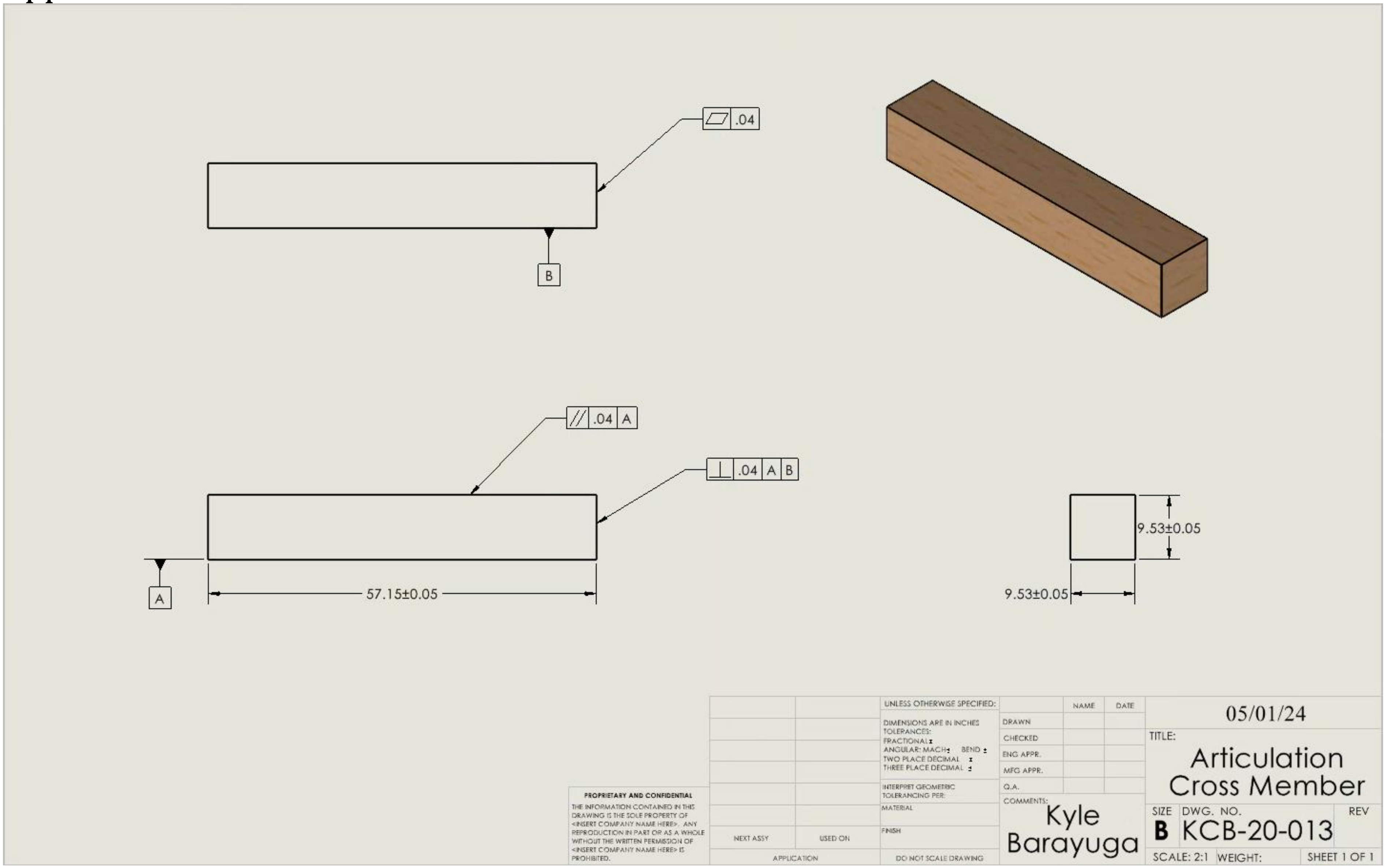
Appendix B17 – KCB-20-011 – Upper Motor Housing



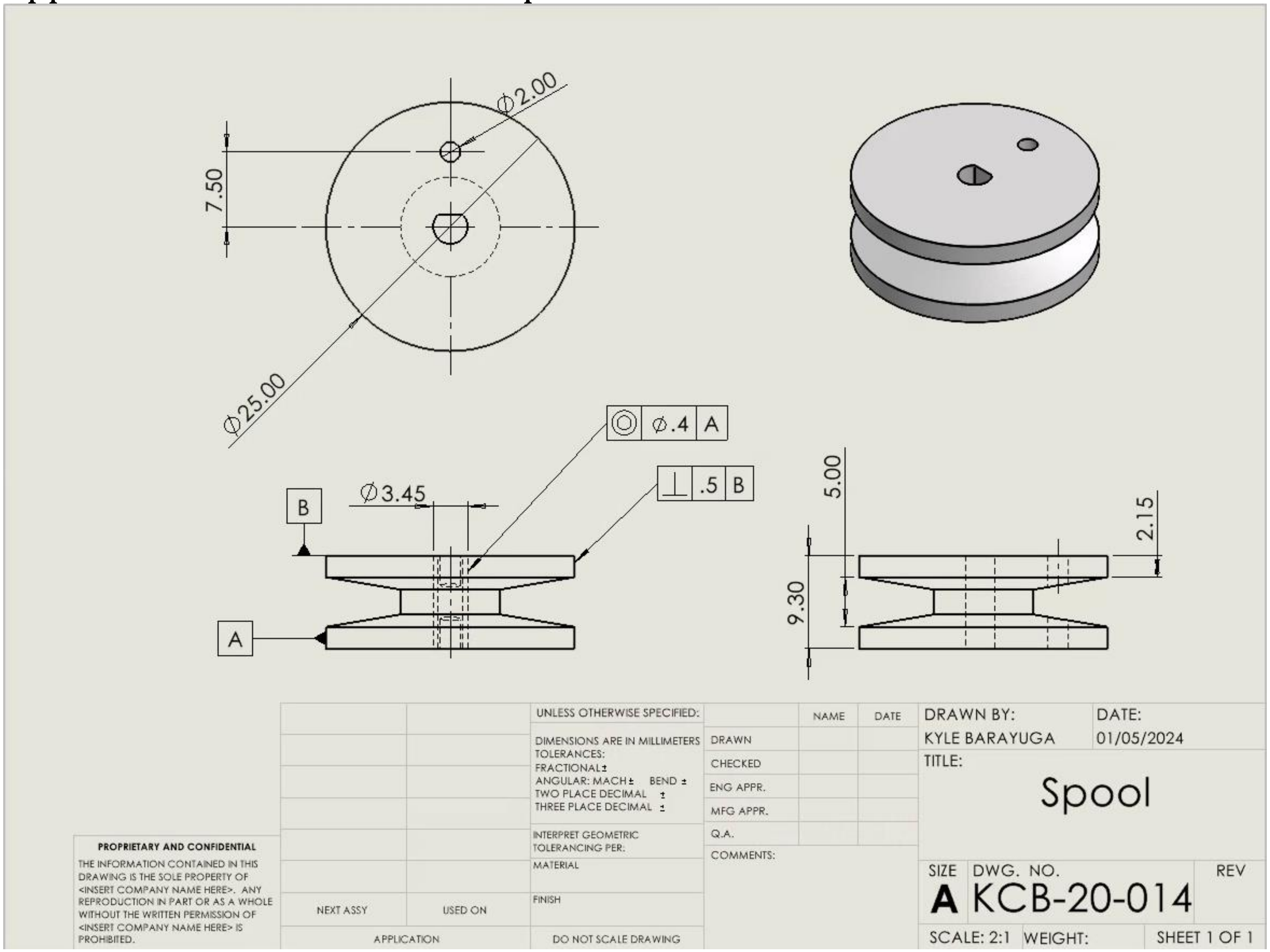
Appendix B18 – KCB-20-012 – Articulation Diagonal Rev.1



Appendix B19 – KCB-20-013 – Articulation Cross Member Rev.1



Appendix B20 – KCB-20-014 – Spool



APPENDIX C – Parts List and Costs

Table C1. Parts List

Part Number	Qty	Part Description	Source	Cost	Date Received
KCB-20-001, KCB-20-004, KCB-20-005, KCB-20-006, KCB-20-008, KCB-20-009, KCB-20-010, KCB-20-012, KCB-20-013	1	½" x ½" x 12” balsa wood sticks 3/8” x 3/8” x 12” balsa wood sticks	Amazon	$15.95 $12.99	01/03/2024 04/14/2024
KCB-20-002, KCB-20-011	1	½" x ½" x 36” balsa wood stick 3/8” x 3/8” x 36” balsa wood stick	Specializedbalsa.com	$2.10 $2.10	01/08/2024 04/19/2024
KCB-20-003 KCB-20-007	1	3” x 1/16” x 36” balsa wood sheet 2” x 1/16” x 36” balsa wood sheet	Specializedbalsa.com	$2.10 $2.10	01/03/2024 04/19/2024
KCB-20-014	1	Spool	CWU 3D Printer	$2.00	01/08/2024
KCB-55-001	1	Arduino Uno REV3	Amazon	$16.99	12/13/2023
KCB-55-002	1	Battery Clip Connector	Amazon	$4.99	01/08/2024
KCB-55-003	1	Arduino Motor Shield Rev3	Amazon	$29.00	01/19/2024
KCB-55-004	1	9V Battery	Amazon	$7.29	01/08/2024
KCB-55-005	1	DC Motor	Amazon	$8.60	01/08/2024
KCB-55-006	1	Wood Glue	Amazon	$7.99	01/08/2024
KCB-55-007	1	Nylon Wire	Amazon	$5.99	01/08/2024
KCB-55-008	1	Push Button Switch	Amazon	$8.68	01/19/2024
KCB-55-009	1	Breadboard	Donated	$6.75	02/02/2024
KCB-55-010	1	10K Resistor	Donated	$0.60	02/02/2024
Total				$136.22	

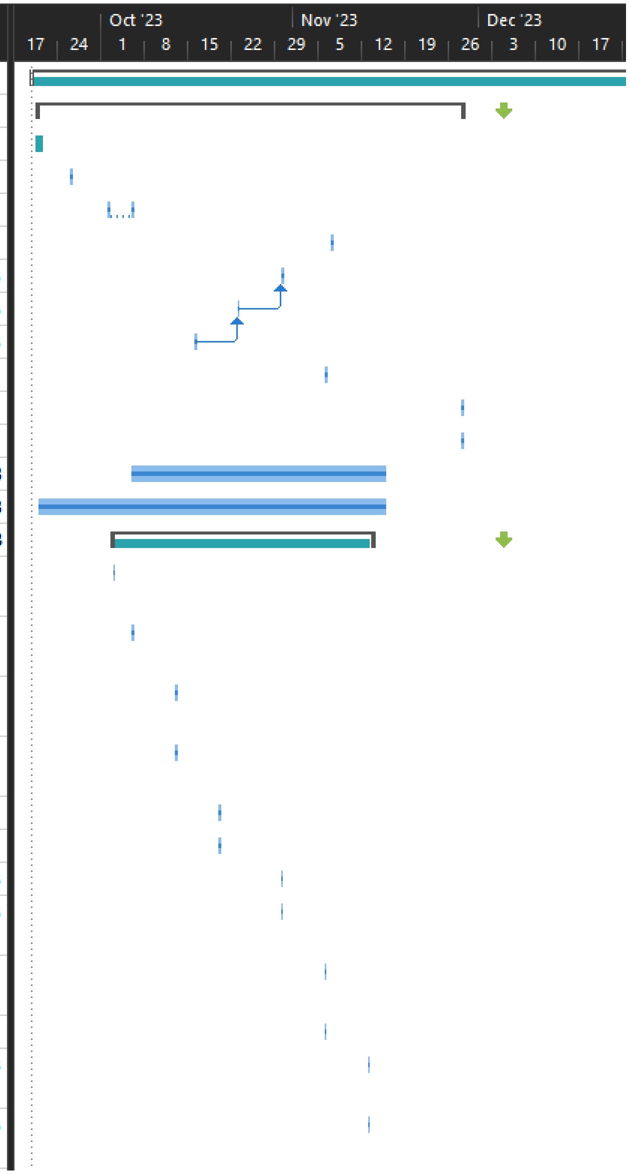
APPENDIX D – Budget

Table D1. Project Budget.

Item	Qty	Description	Cost
Parts (Appendix C)	14	All Parts listed in Appendix C	$136.22
Extended Expenses	1	Buffer for additional parts	$13.78
Labor	1	Estimated labor costs	$2407.50
Total			$2543.72

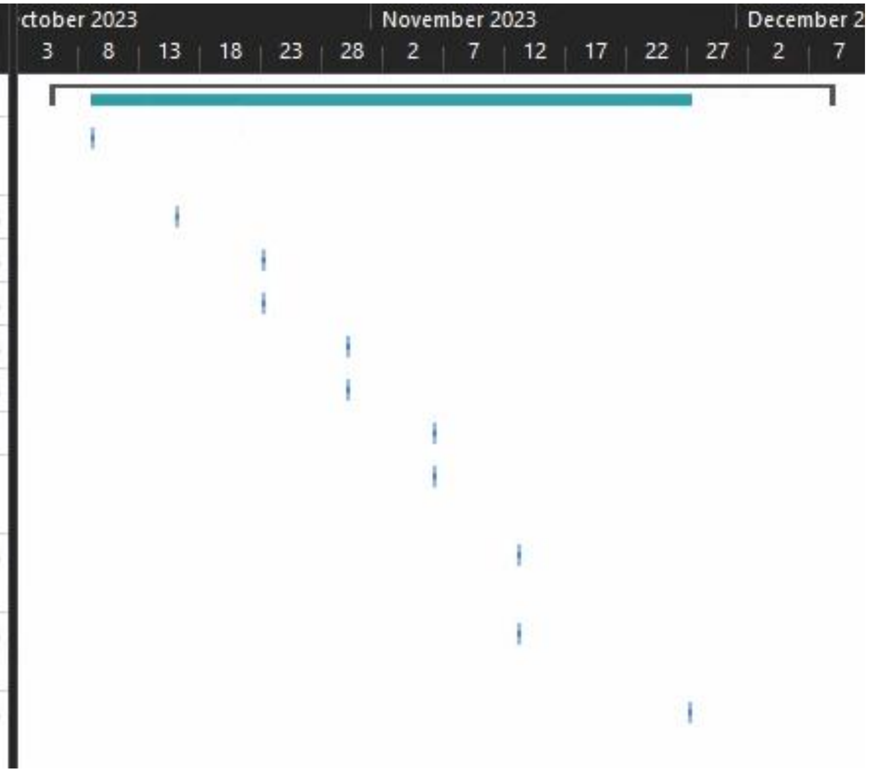
APPENDIX E – Schedule

	Task Name	Duration	Start	Finish
	Senior Project	**185 days?**	**Wed 9/20/23**	**Mon 6/3/24**
1	**PROPOSAL/REPORT WRITING**	**48.25 days**	**Thu 9/21/23**	**Tue 11/28/23**
1a	Appendix H	1 hr	Thu 9/21/23	Thu 9/21/23
1b	Intro	2.5 hrs	Tue 9/26/23	Tue 9/26/23
1c	Analysis	2 hrs	Mon 10/2/23	Fri 10/6/23
1d	Methods & Construction	3 hrs	Tue 11/7/23	Tue 11/7/23
1e	Testing	2 hrs	Mon 10/30/23	Mon 10/30/23
1f	Budget	1.5 hrs	Mon 10/23/23	Mon 10/23/23
1g	Schedule	2 hrs	Mon 10/16/23	Mon 10/16/23
1h	Project Management	2 hrs	Mon 11/6/23	Mon 11/6/23
1i	Discussion	2 hrs	Tue 11/28/23	Tue 11/28/23
1j	Conclusion	1.5 hrs	Tue 11/28/23	Tue 11/28/23
1k	Drawings	232 hrs	Fri 10/6/23	Wed 11/15/23
1l	Appendix	320 hrs	Thu 9/21/23	Wed 11/15/23
2	**ANALYSIS**	**30 days**	**Tue 10/3/23**	**Mon 11/13/23**
2a	Analysis 1 - Bridge min. angle when open	1 hr	Tue 10/3/23	Tue 10/3/23
2b	Analysis 2 - Min. area of balsa wood	1 hr	Fri 10/6/23	Fri 10/6/23
2c	Analysis 3 - Total weight of bridge	1 hr	Fri 10/13/23	Fri 10/13/23
2d	Analysis 4 - Force analysis and area	1 hr	Fri 10/13/23	Fri 10/13/23
2e	Analysis 5 - stress analysis	1 hr	Fri 10/20/23	Fri 10/20/23
2f	Analysis 6 - bridge deflection	1 hr	Fri 10/20/23	Fri 10/20/23
2g	Analysis 7 - Min. string length	1 hr	Mon 10/30/23	Mon 10/30/23
2h	Analysis 8 - Force to raise bridge	1 hr	Mon 10/30/23	Mon 10/30/23
2i	Analysis 9 - Angle of inner diag. mem	1 hr	Mon 11/6/23	Mon 11/6/23
2j	Analysis 10 - force on string	1 hr	Mon 11/6/23	Mon 11/6/23
2k	Analysis 11 - Area of beams of articulation components	1 hr	Mon 11/13/23	Mon 11/13/23
2l	Analysis 12 - deflection of string guide rod	1 hr	Mon 11/13/23	Mon 11/13/23



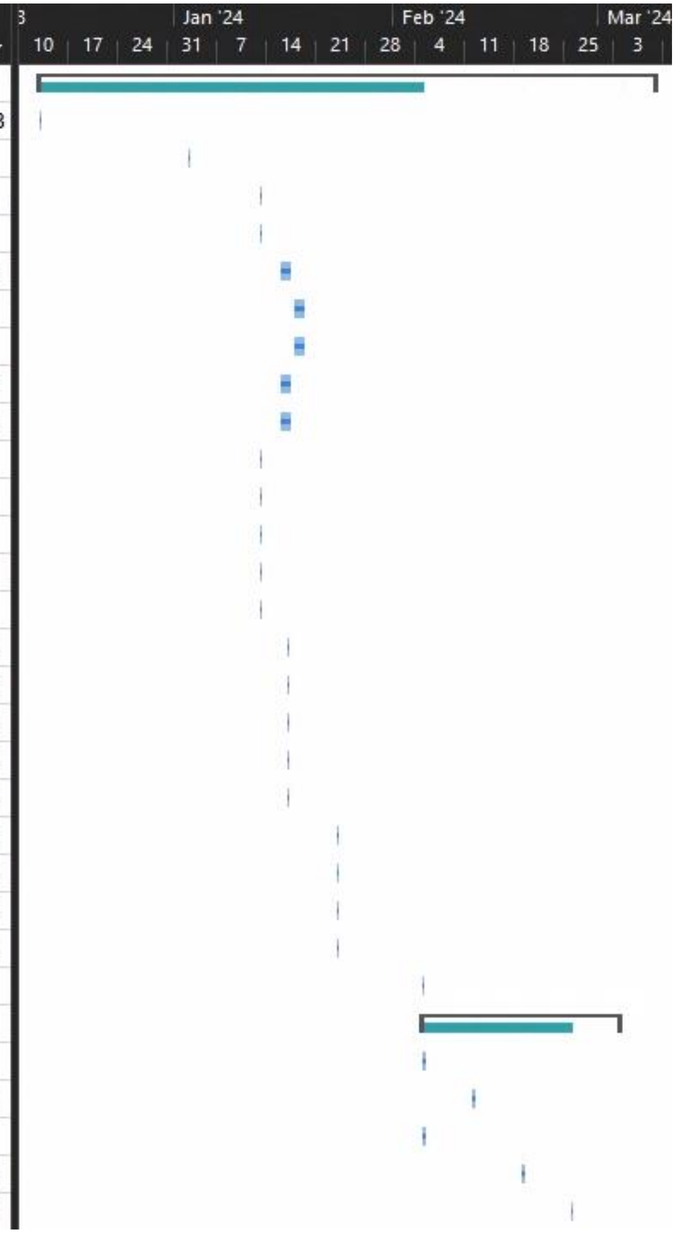
APPENDIX E – Schedule Cont.

ID	Task Name	Duration	Start	Finish
3	**DOCUMENTATION**	**46 days**	**Fri 10/6/23**	**Fri 12/8/23**
3a	Drawing 1 - Bottom Horiz. Mem.	0.5 hrs	Mon 10/9/23	Mon 10/9/23
3b	Drawing 2 - vertical truss mem.	0.5 hrs	Mon 10/16/23	Mon 10/16/23
3c	Drawing 3 - Cross mem.	0.5 hrs	Mon 10/23/23	Mon 10/23/23
3d	Drawing 4 - road deck	0.5 hrs	Mon 10/23/23	Mon 10/23/23
3e	Drawing 5 - Outer diag. mem.	0.5 hrs	Mon 10/30/23	Mon 10/30/23
3f	Drawing 6 - Inner diag mem.	0.5 hrs	Mon 10/30/23	Mon 10/30/23
3g	Drawing 7 - String Guide Rod	0.5 hrs	Mon 11/6/23	Mon 11/6/23
3h	Drawing 8 - Articulation Base Mem.	0.5 hrs	Mon 11/6/23	Mon 11/6/23
3i	Drawing 9 - Articulation Vertical Mem.	0.5 hrs	Mon 11/13/23	Mon 11/13/23
3j	Drawing 10 - Articulation Outer Dia. Mem.	0.5 hrs	Mon 11/13/23	Mon 11/13/23
3k	Drawing 11 - Top Horizontal Member	0.5 hrs	Mon 11/27/23	Mon 11/27/23



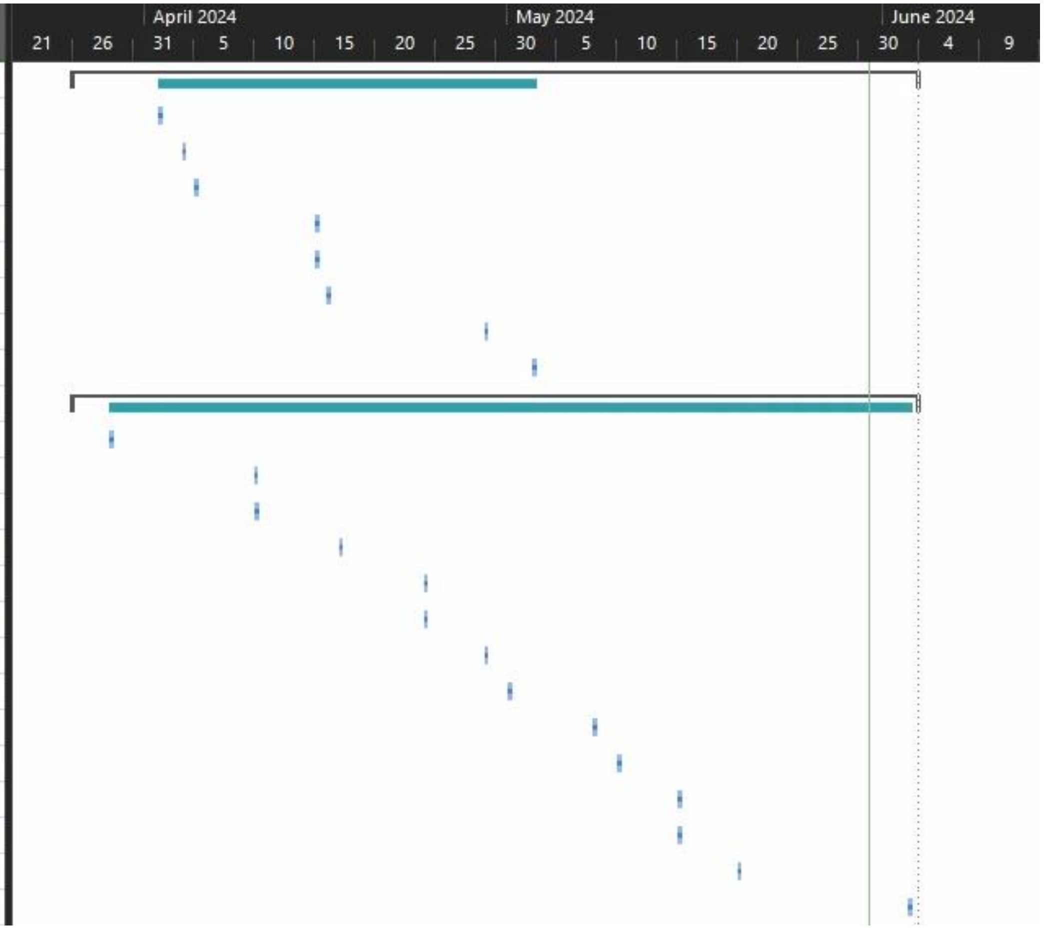
APPENDIX E – Schedule Cont.

ID	Task Name	Duration	Start	Finish
4	**PART MANUFACTURING**	**64 days**	**Wed 12/13/23**	**Fri 3/8/24**
4a	Buy Arduino	0.15 hrs	Wed 12/13/23	Wed 12/13/23
4b	Buy blasa wood sticks 12"	0.15 hrs	Wed 1/3/24	Wed 1/3/24
4c	buy balsa wood sheet	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4d	Buy balsa wood stick 36"	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4e	Print string rod	1.5 days	Tue 1/16/24	Wed 1/17/24
4f	Print Hinge plate	1.5 days	Thu 1/18/24	Fri 1/19/24
4g	Print hinge pin	1.5 days	Thu 1/18/24	Fri 1/19/24
4h	Print spool	1.5 days	Tue 1/16/24	Wed 1/17/24
4i	Print Motor Drive	1.5 days	Tue 1/16/24	Wed 1/17/24
4j	Buy 9V Battery	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4k	Buy Battery clip connector	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4l	Buy DC motor	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4m	Buy wood glue	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4n	Buy nylon wire	0.15 hrs	Sat 1/13/24	Sat 1/13/24
4o	Manufacture KCB-20-002	0.15 hrs	Wed 1/17/24	Wed 1/17/24
4p	Manufacture KCB-20-004	0.15 hrs	Wed 1/17/24	Wed 1/17/24
4q	Manufacture KCB-20-008	0.25 hrs	Wed 1/17/24	Wed 1/17/24
4r	Manufacture KCB-20-011	0.15 hrs	Wed 1/17/24	Wed 1/17/24
4s	Manufacture KCB-20-012	0.15 hrs	Wed 1/17/24	Wed 1/17/24
4t	Manufacture KCB-20-005	0.25 hrs	Wed 1/24/24	Wed 1/24/24
4u	Manufacture KCB-20-006	0.25 hrs	Wed 1/24/24	Wed 1/24/24
4v	Manufacture KCB-20-009	0.25 hrs	Wed 1/24/24	Wed 1/24/24
4w	Manufacture KCB-20-010	0.25 hrs	Wed 1/24/24	Wed 1/24/24
4x	Manufacture KCB-20-003	0.25 hrs	Mon 2/5/24	Mon 2/5/24
5	**DEVICE MANUFACTURING**	**21 days**	**Mon 2/5/24**	**Sun 3/3/24**
5a	Assemble Bridge trusses	4 hrs	Mon 2/5/24	Mon 2/5/24
5b	Assemble bridge	4 hrs	Mon 2/12/24	Mon 2/12/24
5c	Assemble articulation trusses	4 hrs	Mon 2/5/24	Mon 2/5/24
5d	Assemble Articulation Element	4 hrs	Mon 2/19/24	Mon 2/19/24
5e	Assemble Device	1 hr	Mon 2/26/24	Mon 2/26/24



APPENDIX E – Schedule Cont.

	Task Name	Duration	Start	Finish
6	**DEVICE EVALUATION**	**50 days?**	**Tue 3/26/24**	**Mon 6/3/24**
6a	Create Test Procedure 1	2 hrs	Tue 4/2/24	Tue 4/2/24
6b	Test 1: Obtain resources	1 hr	Thu 4/4/24	Thu 4/4/24
6c	Test 1: Perform Test	1 hr	Fri 4/5/24	Fri 4/5/24
6d	Create Test Procedure 2	1 hr	Mon 4/15/24	Mon 4/15/24
6e	Test 2: Obtain resoureces	0.5 hrs	Mon 4/15/24	Mon 4/15/24
6f	Test 2: Perform Test	0.5 hrs	Tue 4/16/24	Tue 4/16/24
6g	Create Test 3	1 hr	Mon 4/29/24	Mon 4/29/24
6h	Perform Test 3	0.5 hrs	Fri 5/3/24	Fri 5/3/24
7	**DELIVERABLES**	**50 days?**	**Tue 3/26/24**	**Mon 6/3/24**
7a	Abstract	1 hr	Fri 3/29/24	Fri 3/29/24
7b	Demo Test 1	0.05 hrs	Wed 4/10/24	Wed 4/10/24
7c	Testing 01	1 hr	Wed 4/10/24	Wed 4/10/24
7d	Discussion 01	1 hr	Wed 4/17/24	Wed 4/17/24
7e	Testing 02	1 hr	Wed 4/24/24	Wed 4/24/24
7f	Demo Test 2	0.05 hrs	Wed 4/24/24	Wed 4/24/24
7g	Poster Draft	1 hr	Mon 4/29/24	Mon 4/29/24
7h	Discussion 02	1 hr	Wed 5/1/24	Wed 5/1/24
7i	Schedule	1 hr	Wed 5/8/24	Wed 5/8/24
7j	Web 02	1.5 hrs	Fri 5/10/24	Fri 5/10/24
7k	Test Report	3 hrs	Wed 5/15/24	Wed 5/15/24
7l	Budget	1 hr	Wed 5/15/24	Wed 5/15/24
7m	Presentation: Final	0.16 hrs	Mon 5/20/24	Mon 5/20/24
7n	Final Report	3 hrs	Mon 6/3/24	Mon 6/3/24



APPENDIX F – Expertise and Resources

Criterion	Weight	Best Possible							
	1 to 3	3	Drawbridge	Score x Wt	Double	Score x Wt	Lift	Score x Wt	
manufacturability	2	6	2	4	2	4	1	2	
dimensions requirement	3	9	2	6	2	6	2	6	
weight	3	9	2	6	2	6	1	3	
cost	1	3	3	3	1	1	1	1	
Total	9	27		19		17		12	
NORMALIZE THE DATA (muliply by fraction, N)		3.70		70.4		63.0		44.4	Percent

Figure F1 – Decision Matrix: Bridge design

Criterion	Weight	Best Possible							
	1 to 3	3	1/2" x 1/2"	Score x Wt	1/2" x 3/8	Score x Wt	1/4" x 1/4"	Score x Wt	
Weight Efficient	3	9	3	9	2	6	1	3	
Strength	2	6	3	6	2	4	1	2	
Cost	1	3	1	1	2	2	3	3	
Total	6	18		16		12		8	
NORMALIZE THE DATA (muliply by fraction, N)		5.56		88.9		66.7		44.4	Percent

Figure F2 – Decision Matrix: Balsa Wood Size

Criterion	Weight	Best Possible							
	1 to 3	3	Tools	Score x Wt	Hand	Score x Wt	Comissioned	Score x Wt	
Time Spent	3	9	3	9	2	6	1	3	
Finish Quality	3	9	3	9	1	3	3	9	
Ease of Use	2	6	2	4	2	4	3	6	
Availability	2	6	2	4	3	6	2	4	
Total	10	30		26		19		22	
NORMALIZE THE DATA (muliply by fraction, N)		3.33		86.7		63.3		73.3	Percent

Figure F3 – Decision Matrix: Glue

Criterion	Weight	Best Possible							
	1 to 3	3	Wood glue	Score x Wt	hot glue	Score x Wt	epoxy	Score x Wt	
Curing Time	1	3	2	2	3	3	1	1	
Strength	3	9	3	9	2	6	3	9	
Ease of Use	2	6	3	6	1	2	1	2	
Availability	2	6	3	6	2	4	2	4	
Cost	3	9	3	9	2	6	2	6	
Total	11	33		32		21		22	
NORMALIZE THE DATA (muliply by fraction, N)		3.03		97.0		63.6		66.7	Percent

Figure F4 – Decision Matrix: Cutting Method

APPENDIX F – Expertise and Resources Cont.

Criterion	Weight	Best Possible							
	1 to 3	3	Sanding	Score x Wt	Buy New	Score x Wt	Do nothing	Score x Wt	
time	3	9	2	6	1	3	3	9	
difficulty	1	3	2	2	3	3	3	3	
cost	2	6	3	6	1	2	3	6	
weight	3	9	3	9	3	9	1	3	
Total	9	27		23		17		21	
NORMALIZE THE DATA (muliply by fraction, N)		3.70		85.2		63.0		77.8	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits				Good? Then done.		75.3	Average
	Poor Bias:	Standard Deviation is one or less digits				Poor? Change something!		11	Std Dev.

Figure F5 – Decision Matrix: New Area for Bridge Pieces

Criterion	Weight	Best Possible							
	1 to 3	3	drill press	Score x Wt	hand made	Score x Wt	power drill	Score x Wt	
time	3	9	3	9	1	3	2	6	
difficulty	2	6	2	4	1	2	2	4	
cost	2	6	3	6	2	4	2	4	
accuracy	3	9	3	9	1	3	2	6	
Total	10	30		28		12		20	
NORMALIZE THE DATA (muliply by fraction, N)		3.33		93.3		40.0		66.7	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits				Good? Then done.		66.7	Average
	Poor Bias:	Standard Deviation is one or less digits				Poor? Change something!		27	Std Dev.

Figure F6 – Decision Matrix: Through Hole

APPENDIX F – Expertise and Resources Cont.

```
int directionPin = 12;
int pwmPin = 3;
int brakePin = 9;

const int yellow = 6;
const int red = 7; // buttons

void setup() {

  pinMode(pwmPin, OUTPUT);
  pinMode(brakePin, OUTPUT);
  pinMode(directionPin, OUTPUT); // outputs

  pinMode(yellow, INPUT_PULLUP);
  pinMode(red, INPUT_PULLUP); // inputs w internal pullup resistors

}

void loop() {

  int leftPinState = digitalRead(yellow);
  int rightPinState = digitalRead(red); // set value names for read data

  if (leftPinState == LOW) { // if left button is pressed ...

    analogWrite(pwmPin, 100); // make motor go one way
    digitalWrite(directionPin, LOW);
    digitalWrite(brakePin, LOW);
    delay(6500);
    digitalWrite(brakePin, HIGH);
    analogWrite(pwmPin, 0);
  }

  else if (rightPinState == LOW) { // if right button is pressed ...

    analogWrite(pwmPin, 100);
    digitalWrite(directionPin, HIGH); // make motor go other way
    digitalWrite(brakePin, LOW);
    delay(5500);
    digitalWrite(brakePin, HIGH);
    analogWrite(pwmPin, 0);

  }

  else { // if neither button is pressed ...

    digitalWrite(pwmPin, LOW); // nothing happens
    digitalWrite(directionPin, LOW);

  }

}
```

Figure F7 – Arduino Code

APPENDIX G – Testing Report

Appendix G1 - Midpoint Height

Introduction

This test is based off the requirements that the bridge's midpoint height must be at least 140 mm when fully open. The parameter of interest is the run time of the motor and the height of the bridge after the motor spins for a set amount of time. Programming the motor uses milliseconds to decide its runtime. Creating a reference from the motor when it spins for 1 second, the height of the bridge can be applied to the minimum height from the requirement of 140 mm. The calculated value comes out to be 4400 milliseconds. These calculations can be seen in Appendix A13. The data will be collected by using a ruler to measure the height of the bridge's midpoint when it is fully open. A schedule of this test can be seen in the Gantt Chart of Appendix E.

Method/Approach

The hardware resources needed for this test include a flat surface, a ruler, and a video recorder. This test does not require more people than the individual performing it, and no financial resources are needed. The test will gather data using a ruler while also video recording the process all together. The data will then be written on a data sheet. Performing the test includes programming the motor to the calculated time. The bridge is set up to rest on a flat surface. The button used to raise the bridge is pressed. When the bridge stops, the height is measured. This process is repeated for three trials. When operating the motor, there are two buttons, one that raises and one that lowers the bridge. Once either button is pressed, the motor cannot be stopped until its programmed runtime is completed. Making sure to press the correct button is important in saving time in having to reset the bridge. The test uses a human operated stopwatch which comes with precision inconsistencies. Multiple trials are done, and the average is calculated to lessen this factor. The data is taken by writing the measurements onto a data sheet. The data is presented with a table, showing three trials and an average.

Test Procedure

Summary: This procedure documents the process of gathering data on the performance of the bridge's articulation. The height of the bridge's midpoint must be over 140 mm. The following is the test information and procedure.

Time: The test was conducted on 04/16/24 from 12:30 pm to 1:00 pm in Hogue 205. 20 minutes prior, the required equipment is gathered in the room. Data is gathered right as the test is conducted.

Place: Room 205, Hogue Hall, Central Washington University campus in Ellensburg, WA. All equipment will be placed in this room, Room 205.
Required equipment:

- Video camera
- Tripod
- Data sheet
- Writing implement
- Articulating balsa wood bridge
- Flat Surface
- Ruler
- 2 mm flathead screwdriver

Risk: The device performs at the push of a button and is not equipped with an emergency stop. Once a button is pushed it will spin as programmed unless the battery is disconnected. Safety glasses were required while conducting the test. Additional personnel were not required.

Procedure:

1. Go to room 205
2. Gather required equipment (except table) located on the counter farthest from entrance as listed and place on table.
3. Set up articulating balsa wood bridge on table as shown:

Figure G1 – Articulating Balsa Wood Bridge

   a. The articulating balsa wood bridge consists of the bridge, articulation tower, motor, spool, nylon wire, and foam circuitry box.
      i. The foam circuitry box consists of an Arduino, breadboard, battery, battery clip connector, and jumper wires.
   b. Place device so there is full contact with the table
   c. Ensure nylon wire is fed through both the white and black spools and is tied on the upper cross member on the opposite end of the bridge.
   d. Ensure nylon wire connecting the white spool to the bridge has little slack
      i. May need to manually spin motor to roll up spool.
   e. Place foam circuitry box on the articulation tower as shown

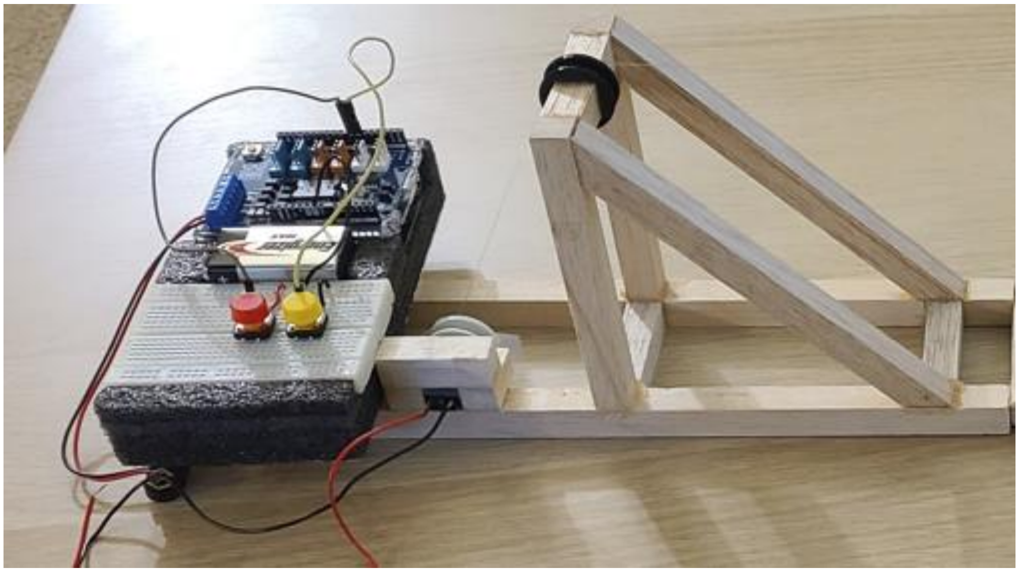


Figure G2 – Articulation Tower

f. Connect motor jumper wires to Arduino using the 2 mm flathead screwdriver. (If jumper wires are already set, skip to step 3h).
    i. Red wire connects to the negative port while black connects to the positive port.

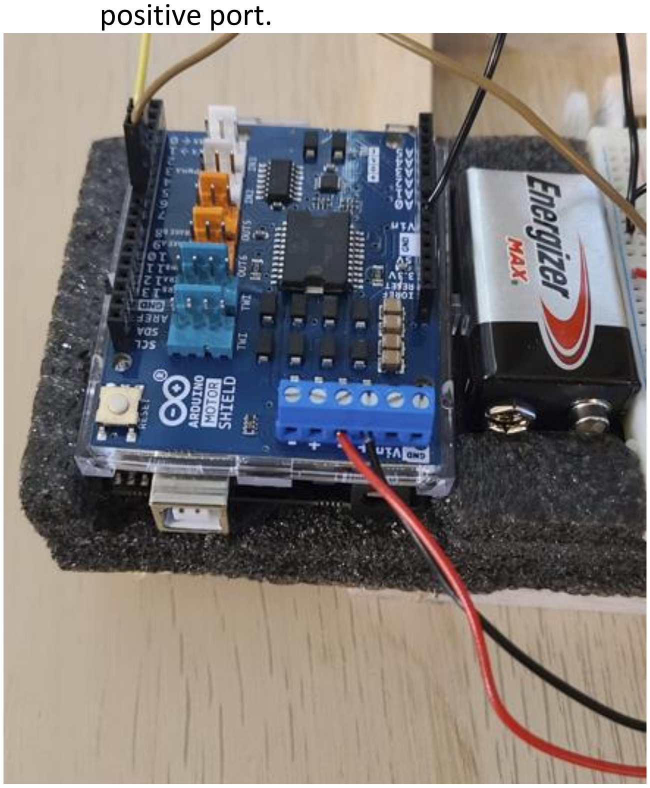


Figure G3 – Motor jumper wires into Arduino

g. Connect 9V battery to battery clip connector.

h. Use 2 mm Flat head screwdriver to connect battery clip connector jumper wires to Arduino (If jumper wires are already set, skip to step 4).

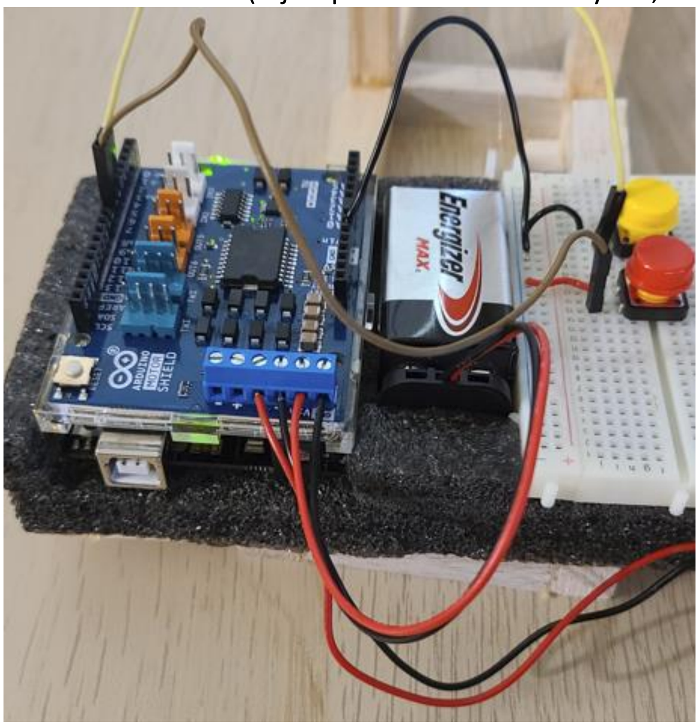


Figure G4 – Battery Clip Connector into Arduino

4. Set up tripod and video camera so it is pointing towards device.
5. Start recording.
6. Raise the bridge by pressing the yellow button on the breadboard.
7. Once the bridge stops, measure the height of the bridge at its midpoint

Figure G5 – Midpoint Height

8. Record the height on the data sheet.
9. Press the red button on the breadboard to lower the bridge to its closed position.
10. Repeat step 3d.
11. Repeat steps 6 – 11 for 2 more trials.
12. Disconnect battery clip from battery and motor wires from Arduino.

Discussion

The testing progressed with little problems. However, inconsistencies with the performance of the articulation needed addressing. It was realized that the bridge needed to be re-set which included lowering the bridge flat and tightening the wire again. To save time in this process, the wire was marked along a reference point on the bridge. Setting the wire to this point would set the wire to the desired tightness. Doing this would solve the inconsistencies when doing trials.

Deliverables

The parameters were established by setting the reference height of when the motor spins for 1000 milliseconds which was 29 mm. This was applied to a value above 140 mm to find the number of milliseconds to program the motor. The calculated values were 4400 milliseconds and after performing the test, the height came out to be 121 mm. This did not meet the requirement of the bridge's midpoint being at over 140 mm. This is a large variation between the calculated and measured values. This is most likely due to the calculations not considering the varying forces acting on the motor from the bridge as it is raised. Recalculations were done, and the motor was programmed to 6600 milliseconds, resulting in a midpoint height of 143 mm.

Appendix G1.1 – Procedure Checklist

- Flat surface (table)
- Device on table set up for testing
- Video camera set up to record test process
- Data sheet
- ruler

Appendix G1.2 – Data Forms

Table G1 – Height of Midpoint

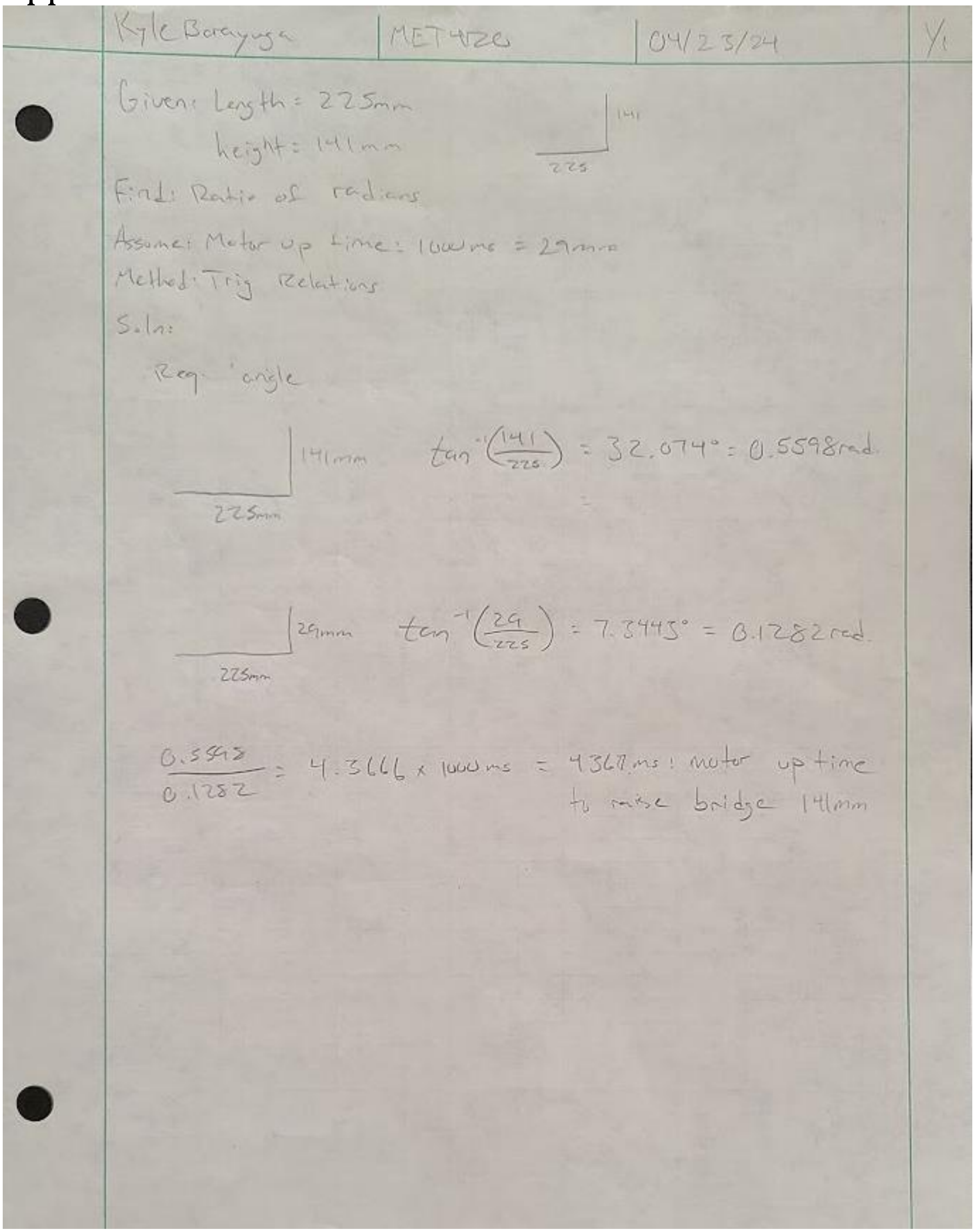
	Height at 4400 ms (mm)
Trial 1	
Trial 2	
Trial 3	
Average	

Appendix G1.3 – Raw Data

Table G2 – Height of Midpoint Raw Data

	Height at 4400 ms (mm)
Trial 1	121
Trial 2	120
Trial 3	121
Average	120.67

Appendix G1.4 – Evaluation Sheet



Kyle Borayuga | MET 420 | 04/23/24 | 1/1

Given: Length = 225mm

height = 141mm

Find: Ratio of radians

Assume: Motor up time: 1000ms = 29mm

Method: Trig Relations

Soln:

Req. angle

141mm, 225mm: $\tan^{-1}\left(\frac{141}{225}\right) = 32.074° = 0.5598\text{rad}$

29mm, 225mm: $\tan^{-1}\left(\frac{29}{225}\right) = 7.3445° = 0.1282\text{rad}$

$\frac{0.5598}{0.1282} = 4.3666 \times 1000\text{ms} = 4367\text{ms}$: motor up time to raise bridge 141mm

Figure G6– Midpoint Height Calculations

Appendix G1.5 – Schedule (Testing)

ID	Task Name	Duration	Start	Finish
6	**DEVICE EVALUATION**	**50 days?**	**Tue 3/26/24**	**Mon 6/3/24**
6a	Create Test Procedure 1	2 hrs	Tue 4/2/24	Tue 4/2/24
6b	Test 1: Obtain resources	1 hr	Thu 4/4/24	Thu 4/4/24
6c	Test 1: Perform Test	1 hr	Fri 4/5/24	Fri 4/5/24

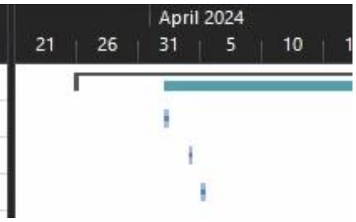


Figure G7 – Test 1 Gantt Chart

Appendix G2 - Cycle Time

Introduction

This test is based off the requirements that the bridge must be able to fully open, stay open for at least 10 seconds, and then close all within 60 seconds. The parameter of interest is the speed of the motor and the minimum height of the bridge when it is fully opened. After establishing that the motor will spin at a constant speed of 30 RPM and the bridge will only raise to a midpoint height 143 mm, the predicted time can be calculated to be 21.4 seconds. These calculations can be seen in Appendix A14. The data will be collected by using a stopwatch to measure the time it takes to complete a cycle. A schedule of this test can be seen in the Gantt Chart of Appendix E.

Method/Approach

The hardware resources needed for this test include a flat surface, a stopwatch, and a video recorder. This test does not require more people than the individual performing it, and no financial resources are needed. The test will gather data using a stopwatch while also video recording the process all together. The data will then be written on a data sheet. Performing the test includes setting up the bridge to rest on a flat surface. The wire must be tensioned so the bridge raises slightly when applying a downward force on it. The button used to raise the bridge is pressed and a stopwatch is started at the same time. The stopwatch is paused when the bridge stops raising. This process is repeated for three trials. When operating the motor, there are two buttons, one that raises and one that lowers the bridge. Once either button is pressed, the motor cannot be stopped until its programmed runtime is completed. Making sure to press the correct button is important in saving time. The test uses a human operated stopwatch which comes with precision inconsistencies. Multiple trials are done, and the average is calculated to lessen this factor. The data is taken by writing the measurements onto a data sheet. The values are then multiplied by 2 to account for opening and closing the bridge. 10 seconds are also added to fulfill secondary requirement that simulates an object traversing under the bridge. The data is presented with a table, showing three trials and an average.

Test Procedure

Summary: This procedure documents the process of gathering data on the performance of the bridge's articulation. The time it takes to raise the bridge from fully close to fully open cannot exceed 60 seconds. The following is the test information and procedure.

Time: The test was conducted on 04/05/24 from 12:30 pm to 1:00 pm in Hogue 205. 20 minutes prior, the required equipment is gathered in the room. Data is gathered right as the test is conducted.

Place: Room 205, Hogue Hall, Central Washington University campus in Ellensburg, WA. All equipment will be placed in this room, Room 205.
Required equipment:

- Video camera
- Tripod
- Data sheet
- Writing implement
- Articulating balsa wood bridge
- Table
- Stopwatch
- 2 mm flathead screwdriver

Risk: The device performs at the push of a button and is not equipped with an emergency stop. Once a button is pushed it will spin as programmed unless the battery is disconnected. Safety glasses were required while conducting the test. Additional personnel were not required.

Procedure:

1. Go to room 205
2. Gather required equipment (except table) located on the counter farthest from entrance as listed and place on table.
3. Set up articulating balsa wood bridge on table as shown:

Figure G8 – Articulating Balsa Wood Bridge

   a. The articulating balsa wood bridge consists of the bridge, articulation tower, motor, spool, nylon wire, and foam circuitry box.
      i. The foam circuitry box consists of an Arduino, breadboard, battery, battery clip connector, and jumper wires.
   b. Place device so there is full contact with the table
   c. Ensure nylon wire is fed through both the white and black spools and is tied on the upper cross member on the opposite end of the bridge.

d. Ensure nylon wire connecting the white spool to the bridge has little slack
    i. May need to manually spin motor to roll up spool.
e. Place foam circuitry box on the articulation tower as shown

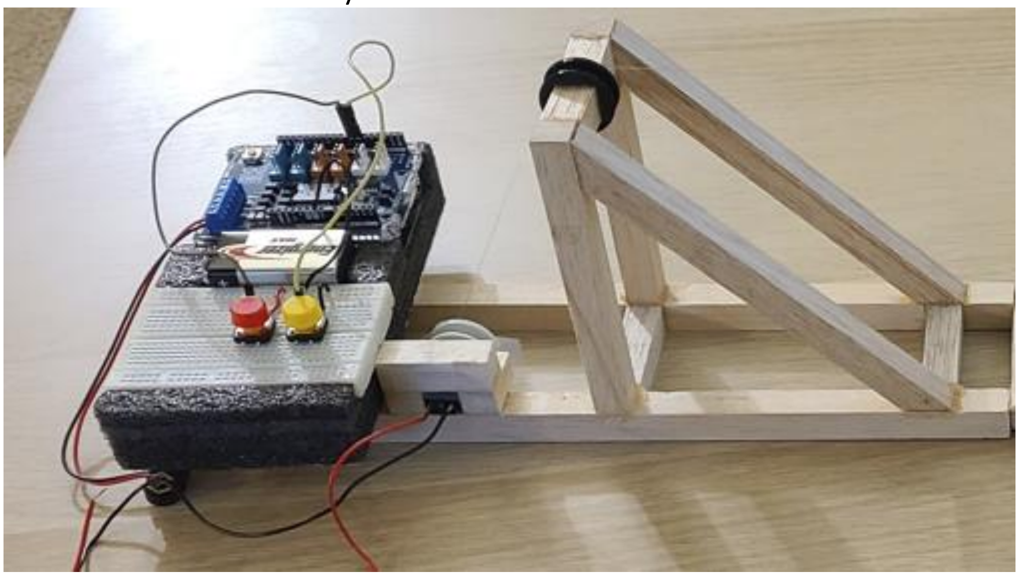


Figure G9 – Articulation Tower

f. Connect motor jumper wires to Arduino using the 2 mm flathead screwdriver.
    i. Red wire connects to the negative port while black connects to the positive port.

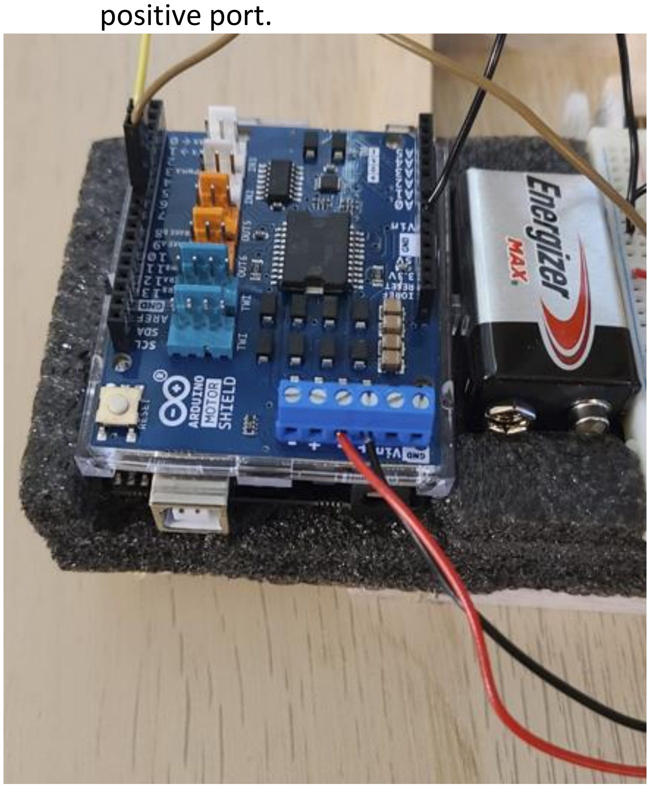


Figure G10 – Motor jumper wires into Arduino

g. Connect 9V battery to battery clip connector.
h. Use 2 mm Flat head screwdriver to connect battery clip connector jumper wires to Arduino

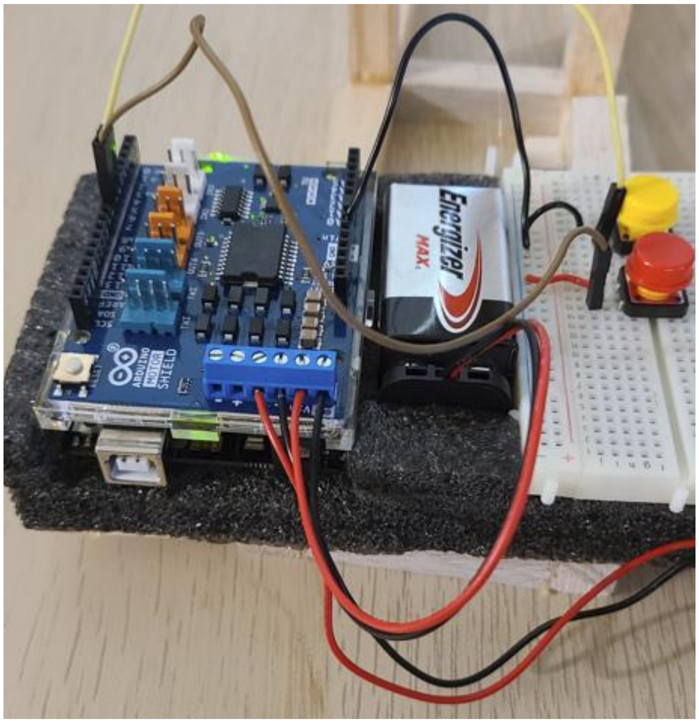


Figure G11 – Battery Clip Connector into Arduino

4. Set up tripod and video camera so it is pointing towards device.
5. Start recording.
6. Ready data sheet, writing implement and stopwatch next to device.
7. With the stopwatch on hand, simultaneously press the yellow button on the breadboard and start the stopwatch.
8. Measure the time it takes for the bridge to rise to its fully open position.
9. Record the time on the data sheet.
10. Press the red button on the breadboard to lower the bridge to its closed position.
11. Repeat step 3d.
12. Repeat steps 7 – 12 for 2 more trials.
13. Disconnect battery clip from battery and motor wires from Arduino.
14. Return all equipment to its original location. See step 2.

Discussion

The testing progressed with little problems. However, inconsistencies with the performance of the articulation needed addressing. It was realized that the battery used to power the Arduino and the motor needed to be charged sufficiently for the device to work properly. The battery would affect the speed of the motor and produce very inconsistent results. Replacing the battery solved this problem.

Deliverables

The parameters were established by setting the motor speed to 30 RPM and the midpoint height that would be considered fully open is set to a height above 140 mm. The calculated values came out to be 21.4 seconds with the measured values coming out to 23.91 seconds. This is a success as the requirement was to complete a full cycle within 60 seconds. There is little variation between the calculated and measured values. This is most likely due to the calculations not considering the resistances of the bridge on the motor itself.

Appendix G2.1 – Procedure Checklist

- Flat surface (table)
- Device on table set up for testing
- Video camera set up to record test process
- Data sheet
- Stopwatch

Appendix G2.2 – Data Forms

Table G3 – Cycle Time

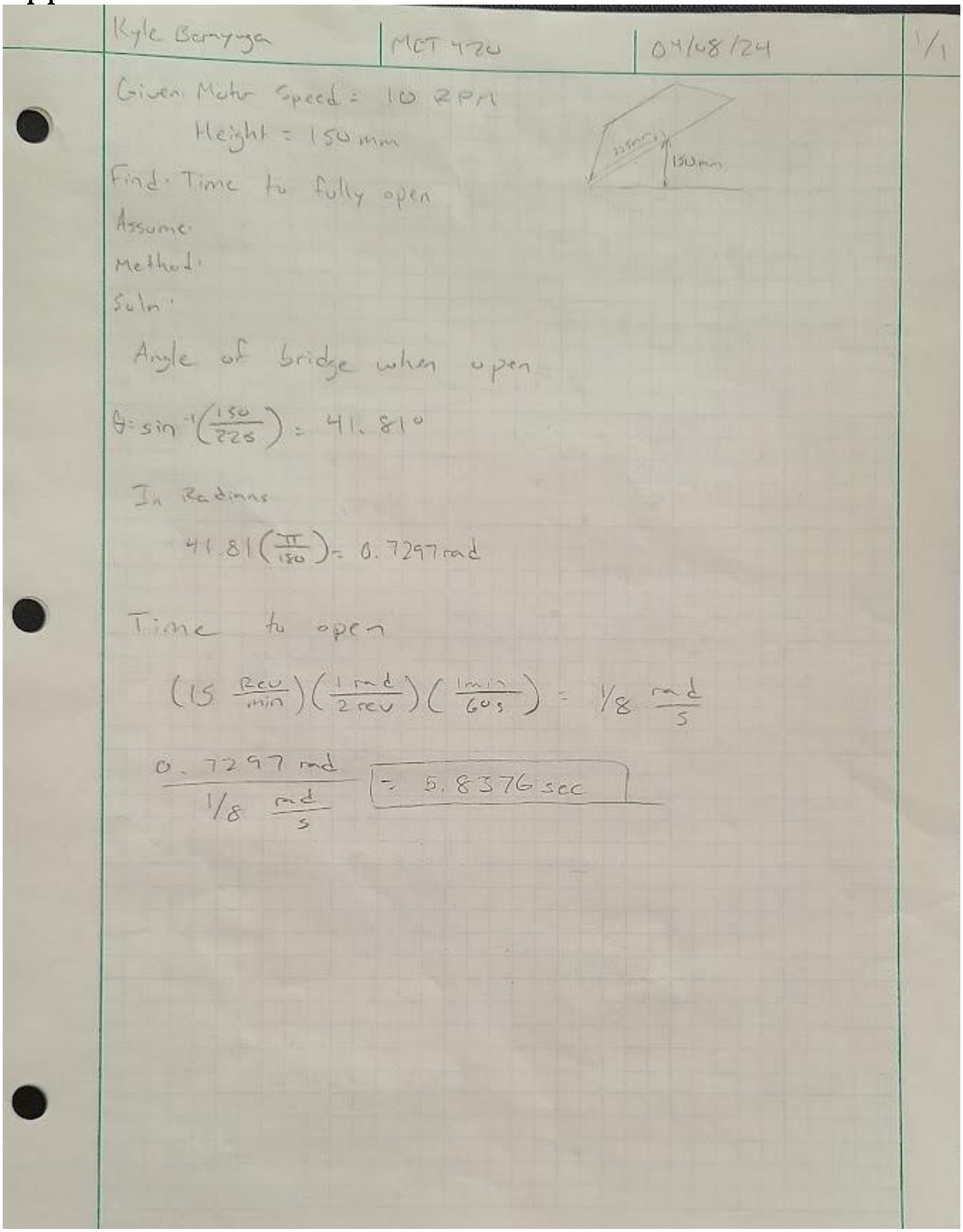
	Time (s)	Midpoint height (> 140 mm)	Total Cycle Time (s)
Trial 1			
Trial 2			
Trial 3			
Average			

Appendix G2.3 – Raw Data

Table G4 – Cycle Time Raw Data

	Time (s)	Midpoint height (> 140 mm)	Total Cycle Time (s)
Trial 1	6.90	143	23.8
Trial 2	6.89	143	23.78
Trial 3	7.08	142	24.16
Average	6.96	142.67	23.91

Appendix G2.4 – Evaluation Sheet


Kyle Bernyuga | MET 420 | 04/08/24 | 1/1

Given: Motor Speed = 10 RPM

Height = 150 mm

Find: Time to fully open

Assume:

Method:

Soln:

Angle of bridge when open

$\theta = \sin^{-1}\left(\frac{150}{225}\right) = 41.81°$

In Radians

$41.81\left(\frac{\pi}{180}\right) = 0.7297 \text{ rad}$

Time to open

$\left(15 \frac{Rev}{min}\right)\left(\frac{1 \text{ rad}}{2 \text{ rev}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 1/8 \frac{\text{rad}}{\text{s}}$

$\frac{0.7297 \text{ rad}}{1/8 \frac{\text{rad}}{\text{s}}} = 5.8376 \text{ sec}$

Figure G12 – Cycle Time Calculations

Appendix G2.5 – Schedule (Testing)

	Task Name	Duration	Start	Finish
6	**DEVICE EVALUATION**	**50 days?**	**Tue 3/26/24**	**Mon 6/3/24**
6a	Create Test Procedure 1	2 hrs	Tue 4/2/24	Tue 4/2/24
6b	Test 1: Obtain resources	1 hr	Thu 4/4/24	Thu 4/4/24
6c	Test 1: Perform Test	1 hr	Fri 4/5/24	Fri 4/5/24
6d	Create Test Procedure 2	1 hr	Mon 4/15/24	Mon 4/15/24
6e	Test 2: Obtain resoureces	0.5 hrs	Mon 4/15/24	Mon 4/15/24
6f	Test 2: Perform Test	0.5 hrs	Tue 4/16/24	Tue 4/16/24

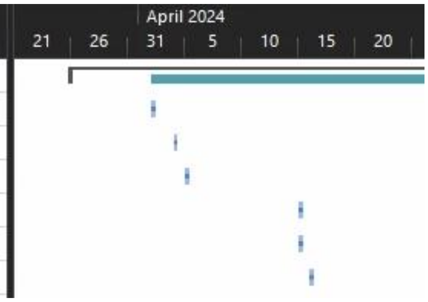


Figure G13 – Test 2 Gantt Chart

Appendix G3 - Deflection

Introduction

This test is based off the requirements that the bridge must be able to support 190 N and have a deflection of less than 25 mm. The parameter of interest is the deflection at the point where the load is applied. After establishing that the bridge will deflect less than 25 mm, the predicted value can be calculated to be 5.84. These calculations can be seen in Appendix A05. The data will be collected by using the Instron which logs the data onto an Excel spreadsheet. A schedule of this test can be seen in the Gantt Chart of Appendix E.

Method/Approach

The hardware resources needed for this test using the Instron. This instrument is used to finely evaluate the deflection over an applied load. This test requires an operator of the program. The Instron logs data onto an Excel spreadsheet. Performing the test includes fastening the bridge to the jig that is then fastened to the Instron. The Instron will pull on the bridge, displaying the amount of load being applied and its displacement. The program will stop applying a load once it reaches 190 N. The data measuring regarding the load and displacement is very precise as it measures time every 50 ms. Displacement and force are measured to the ten-thousandths. Multiple trials are done, and the average is calculated to lessen this factor. The data is taken by logging the data onto a data sheet, which can be viewed on Excel. The data can then be visualized by converting it into a graph that shows the displacement over the 190 N load.

Test Procedure

Summary: This procedure documents the process of gathering data on the performance of the bridge. When a load of 190 N is applied on the center of the bridge, the deflection must be less than 25 mm. The following is the test information and procedure.

Time: The test was conducted on 05/03/24 from 8:00 pm to 8:30 pm in Hogue 205. Data is gathered during the test.

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

- Go to room 127 at 8:00 AM

- Go to Instron
- Video camera
- Articulating balsa wood bridge
- Frame
- Washer
- Nut
- Flat plate

Risk: The Instron applies an upward load from the bottom of the bridge creating tension in the bridge. This requires the use of safety glasses for this test. An additional person assists in operating the Instron.

Procedure: (SOP for Instron used for deflection test was not provided)

1. Go to room 127
2. Set up Instron as shown in Figure 3.1
   a. Orient the bridge upside down
   b. Slot the threaded rod through the 8mm hold on the bridge
   c. In the order stated, Insert the flat plate, washer, and two nuts to fasten the bridge to the rod

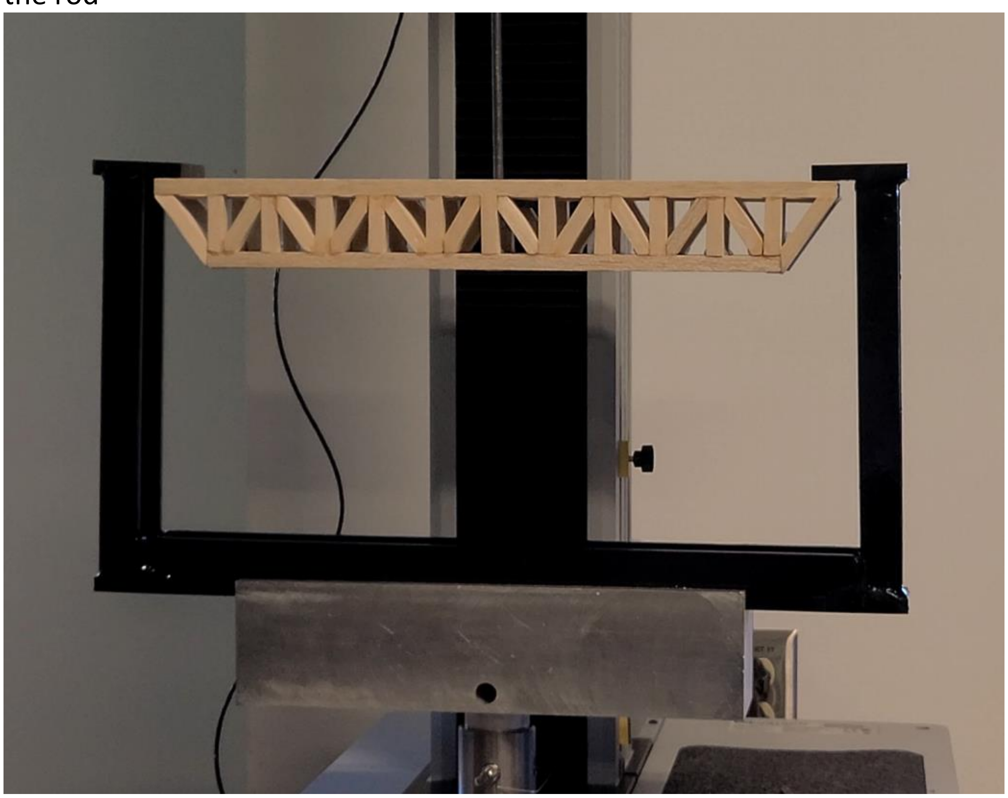


Figure G14 – Bridge in Instron

3. Set up software for deflection
   a. The Instron should steadily apply a load until 190 N is reached

4. Adjust the height of the Instron until the bridge is fully in contact with the two ends of the frame.
5. Start the deflection test
6. Once the test is finished, save data onto an excel file.

Discussion

When first performing the test, the Instron would stop applying a load right after starting the program. This was caused by the lower section of the Instron not being pinned to hold the aluminum block. This being pinned holds the frame in place allowing for the bridge to have a load applied instead of raising the whole piece from the slot.

Deliverables

The parameters were established by setting the Instron to apply a load until 190 N. Using this constant, the deflection of the bridge can be predicted. The calculated values came out to be 5.84 mm with the tested values coming out to 3.56 mm. This is a success as the requirement was to have a displacement of less than 25 mm when a load of 190 N is applied to the midpoint. There is little variation between the calculated and measured values. This is most likely due to the calculations not considering the position of the cross members under the road deck. Performing the calculations with this consideration will result in a closer value to the tested.

Appendix G3.1 – Procedure Checklist

- Instron
- Bridge fastened onto Instron
- Software ready to log data
- Video camera ready to record

Appendix G3.2 – Data Forms

Time	Displacem	Force
(s)	(mm)	(kN)

Figure G15 – Deflection Data Form

Appendix G3.3 – Raw Data

Time	Displacem	Force	Time	Displacem	Force	Time	Displacem	Force
(s)	(mm)	(kN)	(s)	(mm)	(kN)	(s)	(mm)	(kN)
0	0	0.0001	2.25	0.436	0.0258	4.5	0.8854	0.0585
0.05	0.0006	0.0001	2.3	0.4462	0.0266	4.55	0.8951	0.0592
0.1	0.0064	0.0003	2.35	0.4574	0.0275	4.6	0.9061	0.0601
0.15	0.0175	0.001	2.4	0.4654	0.0282	4.65	0.9172	0.0611
0.2	0.027	0.0017	2.45	0.4747	0.0289	4.7	0.9278	0.0621
0.25	0.0388	0.0025	2.5	0.4858	0.0298	4.75	0.9356	0.0627
0.3	0.047	0.0032	2.55	0.4967	0.0307	4.8	0.9445	0.0634
0.35	0.0553	0.0038	2.6	0.5082	0.0317	4.85	0.955	0.0642
0.4	0.0651	0.0044	2.65	0.5162	0.0325	4.9	0.9653	0.0652
0.45	0.0755	0.0051	2.7	0.5248	0.0331	4.95	0.9773	0.0661
0.5	0.0871	0.0058	2.75	0.5353	0.0339	5	0.9861	0.067
0.55	0.0969	0.0065	2.8	0.5456	0.0349	5.05	0.9952	0.0677
0.6	0.1052	0.0071	2.85	0.5572	0.0358	5.1	1.0059	0.0685
0.65	0.1152	0.0077	2.9	0.566	0.0367	5.15	1.0162	0.0695
0.7	0.1259	0.0084	2.95	0.5747	0.0372	5.2	1.0276	0.0704
0.75	0.1369	0.0091	3	0.5852	0.038	5.25	1.036	0.0712
0.8	0.1472	0.0099	3.05	0.5965	0.0387	5.3	1.0449	0.0718
0.85	0.1551	0.0104	3.1	0.608	0.0392	5.35	1.0553	0.0726
0.9	0.1643	0.011	3.15	0.6173	0.0398	5.4	1.0653	0.0734
0.95	0.1755	0.0118	3.2	0.6255	0.0399	5.45	1.077	0.0741
1	0.1867	0.0125	3.25	0.6352	0.0401	5.5	1.087	0.0748
1.05	0.1981	0.0133	3.3	0.6454	0.0401	5.55	1.0957	0.0752
1.1	0.2063	0.0139	3.35	0.656	0.0401	5.6	1.1055	0.0756
1.15	0.2153	0.0145	3.4	0.6674	0.0407	5.65	1.1162	0.0761
1.2	0.2257	0.0151	3.45	0.6761	0.0415	5.7	1.1273	0.076
1.25	0.2355	0.0154	3.5	0.6853	0.0422	5.75	1.1372	0.0761
1.3	0.247	0.0159	3.55	0.6958	0.043	5.8	1.1452	0.0761
1.35	0.2557	0.0166	3.6	0.7059	0.0435	5.85	1.1542	0.0761
1.4	0.2649	0.0171	3.65	0.7176	0.0443	5.9	1.1653	0.0762
1.45	0.2754	0.0172	3.7	0.7258	0.0451	5.95	1.1765	0.0764
1.5	0.2861	0.0173	3.75	0.7347	0.0458	6	1.1878	0.077
1.55	0.2984	0.0175	3.8	0.7454	0.0466	6.05	1.196	0.0775
1.6	0.3068	0.0177	3.85	0.7558	0.0475	6.1	1.2055	0.078
1.65	0.315	0.0178	3.9	0.7678	0.0485	6.15	1.2164	0.0788
1.7	0.3249	0.0183	3.95	0.7763	0.0493	6.2	1.2263	0.0795
1.75	0.3353	0.0189	4	0.785	0.05	6.25	1.2372	0.08
1.8	0.3468	0.0191	4.05	0.7957	0.0508	6.3	1.2455	0.0803
1.85	0.3566	0.0196	4.1	0.8065	0.0518	6.35	1.2546	0.0805
1.9	0.3651	0.0203	4.15	0.818	0.0527	6.4	1.2654	0.0809
1.95	0.3749	0.021	4.2	0.8267	0.0536	6.45	1.2755	0.0814
2	0.3858	0.0218	4.25	0.8349	0.0542	6.5	1.2877	0.0819
2.05	0.3966	0.0226	4.3	0.8448	0.055	6.55	1.2967	0.0821
2.1	0.4073	0.0235	4.35	0.8554	0.0559	6.6	1.3053	0.0819
2.15	0.4157	0.0242	4.4	0.8666	0.0568	6.65	1.3156	0.0818
2.2	0.4254	0.0249	4.45	0.8769	0.0578	6.7	1.3262	0.0819

Figure G16– Deflection/Load Raw Data

Appendix G3.3 – Raw Data Cont

Time (s)	Displacem (mm)	Force (kN)	Time (s)	Displacem (mm)	Force (kN)	Time (s)	Displacem (mm)	Force (kN)
6.75	1.3376	0.0821	9	1.7859	0.1012	11.25	2.236	0.1389
6.8	1.3465	0.0826	9.05	1.7966	0.1022	11.3	2.2447	0.1395
6.85	1.3546	0.0828	9.1	1.808	0.1032	11.35	2.2555	0.1403
6.9	1.3643	0.0833	9.15	1.8165	0.104	11.4	2.2656	0.1413
6.95	1.3752	0.0841	9.2	1.8253	0.1046	11.45	2.2772	0.1422
7	1.3871	0.0847	9.25	1.8356	0.1054	11.5	2.2859	0.1431
7.05	1.3979	0.0853	9.3	1.8459	0.1063	11.55	2.2952	0.1437
7.1	1.4061	0.0852	9.35	1.8566	0.1072	11.6	2.3059	0.1446
7.15	1.4154	0.085	9.4	1.8667	0.1081	11.65	2.3158	0.1454
7.2	1.4263	0.0851	9.45	1.8751	0.1087	11.7	2.3275	0.1462
7.25	1.4365	0.0852	9.5	1.8852	0.1095	11.75	2.3372	0.1472
7.3	1.4473	0.0855	9.55	1.8956	0.1104	11.8	2.3456	0.1477
7.35	1.4555	0.0857	9.6	1.9063	0.1113	11.85	2.3551	0.1483
7.4	1.465	0.0861	9.65	1.9178	0.1123	11.9	2.3656	0.1491
7.45	1.4756	0.0866	9.7	1.9263	0.113	11.95	2.3772	0.15
7.5	1.4858	0.0872	9.75	1.9351	0.1137	12	2.3875	0.1509
7.55	1.4979	0.0879	9.8	1.9453	0.1145	12.05	2.3955	0.1512
7.6	1.5068	0.0883	9.85	1.9557	0.1154	12.1	2.4049	0.1509
7.65	1.5156	0.0884	9.9	1.9674	0.1164	12.15	2.416	0.1485
7.7	1.5257	0.0887	9.95	1.9753	0.1171	12.2	2.4272	0.1436
7.75	1.536	0.0891	10	1.9844	0.1177	12.25	2.4376	0.1401
7.8	1.5476	0.0895	10.05	1.9958	0.1185	12.3	2.4454	0.1361
7.85	1.556	0.0901	10.1	2.0069	0.1195	12.35	2.4546	0.1352
7.9	1.5643	0.0903	10.15	2.0187	0.1205	12.4	2.466	0.1357
7.95	1.5746	0.0908	10.2	2.0265	0.1212	12.45	2.4765	0.1363
8	1.5857	0.0915	10.25	2.035	0.1216	12.5	2.4877	0.1369
8.05	1.5977	0.0921	10.3	2.0453	0.1224	12.55	2.4959	0.137
8.1	1.6071	0.0926	10.35	2.0554	0.1232	12.6	2.5053	0.1372
8.15	1.6155	0.0926	10.4	2.0665	0.124	12.65	2.5161	0.1378
8.2	1.6254	0.0928	10.45	2.0763	0.125	12.7	2.526	0.1385
8.25	1.636	0.0932	10.5	2.0853	0.1256	12.75	2.5378	0.1394
8.3	1.6463	0.0935	10.55	2.0958	0.1264	12.8	2.5464	0.1403
8.35	1.6566	0.094	10.6	2.106	0.1274	12.85	2.5548	0.1408
8.4	1.665	0.0942	10.65	2.117	0.1282	12.9	2.5648	0.1415
8.45	1.675	0.0945	10.7	2.1273	0.1293	12.95	2.5756	0.1424
8.5	1.6858	0.0949	10.75	2.1355	0.13	13	2.5873	0.1431
8.55	1.697	0.0953	10.8	2.1448	0.1307	13.05	2.5968	0.1438
8.6	1.7084	0.0959	10.85	2.1554	0.1316	13.1	2.6052	0.1438
8.65	1.7162	0.096	10.9	2.1664	0.1326	13.15	2.6155	0.1439
8.7	1.7246	0.0962	10.95	2.1776	0.1337	13.2	2.6263	0.1441
8.75	1.7351	0.0967	11	2.1856	0.1344	13.25	2.6376	0.1442
8.8	1.7459	0.0977	11.05	2.1946	0.1351	13.3	2.6472	0.1446
8.85	1.7577	0.0988	11.1	2.2055	0.136	13.35	2.6552	0.1448
8.9	1.7658	0.0997	11.15	2.2162	0.137	13.4	2.6648	0.1454
8.95	1.7746	0.1004	11.2	2.2279	0.1381	13.45	2.676	0.1465

Figure G16– Deflection/Load Raw Data cont

Appendix G3.3 – Raw Data Cont

Time (s)	Displacem (mm)	Force (kN)		Time (s)	Displacem (mm)	Force (kN)
13.5	2.6867	0.1475		15.75	3.135	0.1519
13.55	2.6978	0.1485		15.8	3.1453	0.153
13.6	2.7063	0.1491		15.85	3.1559	0.1541
13.65	2.7158	0.1495		15.9	3.1674	0.1553
13.7	2.7259	0.15		15.95	3.1759	0.1562
13.75	2.7355	0.1502		16	3.1852	0.157
13.8	2.747	0.1502		16.05	3.1958	0.1581
13.85	2.7561	0.1496		16.1	3.2065	0.1591
13.9	2.7651	0.1482		16.15	3.218	0.1603
13.95	2.7755	0.1468		16.2	3.2255	0.1611
14	2.7863	0.1447		16.25	3.2345	0.1618
14.05	2.7986	0.1409		16.3	3.2453	0.1628
14.1	2.8068	0.1365		16.35	3.2558	0.1639
14.15	2.8151	0.1317		16.4	3.2678	0.1651
14.2	2.8254	0.1268		16.45	3.2762	0.1661
14.25	2.8361	0.1225		16.5	3.2852	0.1667
14.3	2.8476	0.1205		16.55	3.2957	0.1677
14.35	2.857	0.1198		16.6	3.3061	0.1687
14.4	2.8651	0.1197		16.65	3.3177	0.1698
14.45	2.8747	0.121		16.7	3.3268	0.1708
14.5	2.8855	0.1225		16.75	3.3353	0.1714
14.55	2.8962	0.124		16.8	3.3452	0.1722
14.6	2.9072	0.1255		16.85	3.3553	0.1731
14.65	2.9157	0.1267		16.9	3.3663	0.1741
14.7	2.9256	0.1278		16.95	3.3773	0.1752
14.75	2.9361	0.1292		17	3.3857	0.176
14.8	2.9465	0.1305		17.05	3.3955	0.1767
14.85	2.9577	0.1319		17.1	3.4063	0.1776
14.9	2.9659	0.133		17.15	3.417	0.1785
14.95	2.9747	0.134		17.2	3.4277	0.1795
15	2.9854	0.1352		17.25	3.4354	0.1801
15.05	2.9962	0.1365		17.3	3.4443	0.1807
15.1	3.0083	0.138		17.35	3.455	0.1815
15.15	3.0164	0.1391		17.4	3.4657	0.1825
15.2	3.025	0.14		17.45	3.4778	0.1835
15.25	3.0352	0.1411		17.5	3.4861	0.1842
15.3	3.0453	0.1423		17.55	3.4954	0.1848
15.35	3.057	0.1435		17.6	3.5059	0.1856
15.4	3.0664	0.1448		17.65	3.5162	0.1865
15.45	3.0752	0.1457		17.7	3.5277	0.1875
15.5	3.0855	0.1467		17.75	3.5363	0.1883
15.55	3.0962	0.1479		17.8	3.5449	0.1889
15.6	3.1076	0.1491		17.85	3.5551	0.1896
15.65	3.117	0.1503		17.87	3.5593	0.19
15.7	3.1254	0.1511				

Figure G16 – Deflection/Load Raw Data cont

Appendix G3.3 – Raw Data Cont

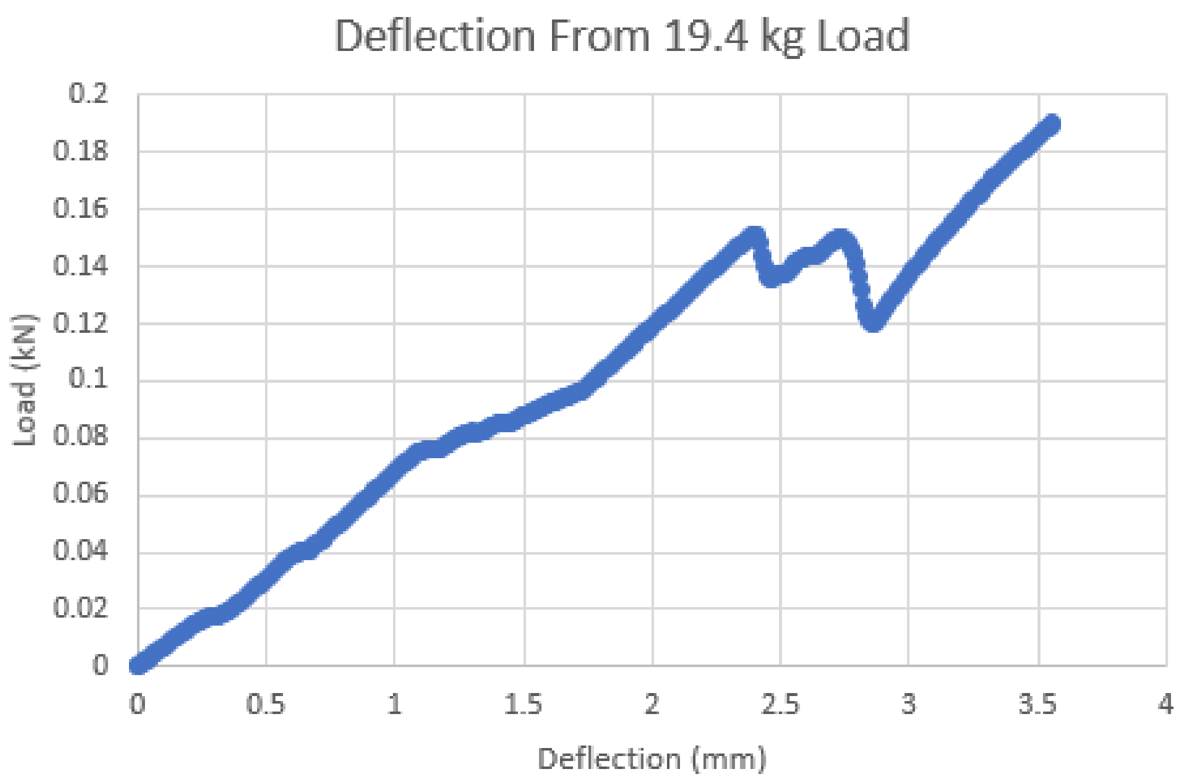


Figure G17 – Deflection/Load graph

Appendix G3.4 – Evaluation Sheet

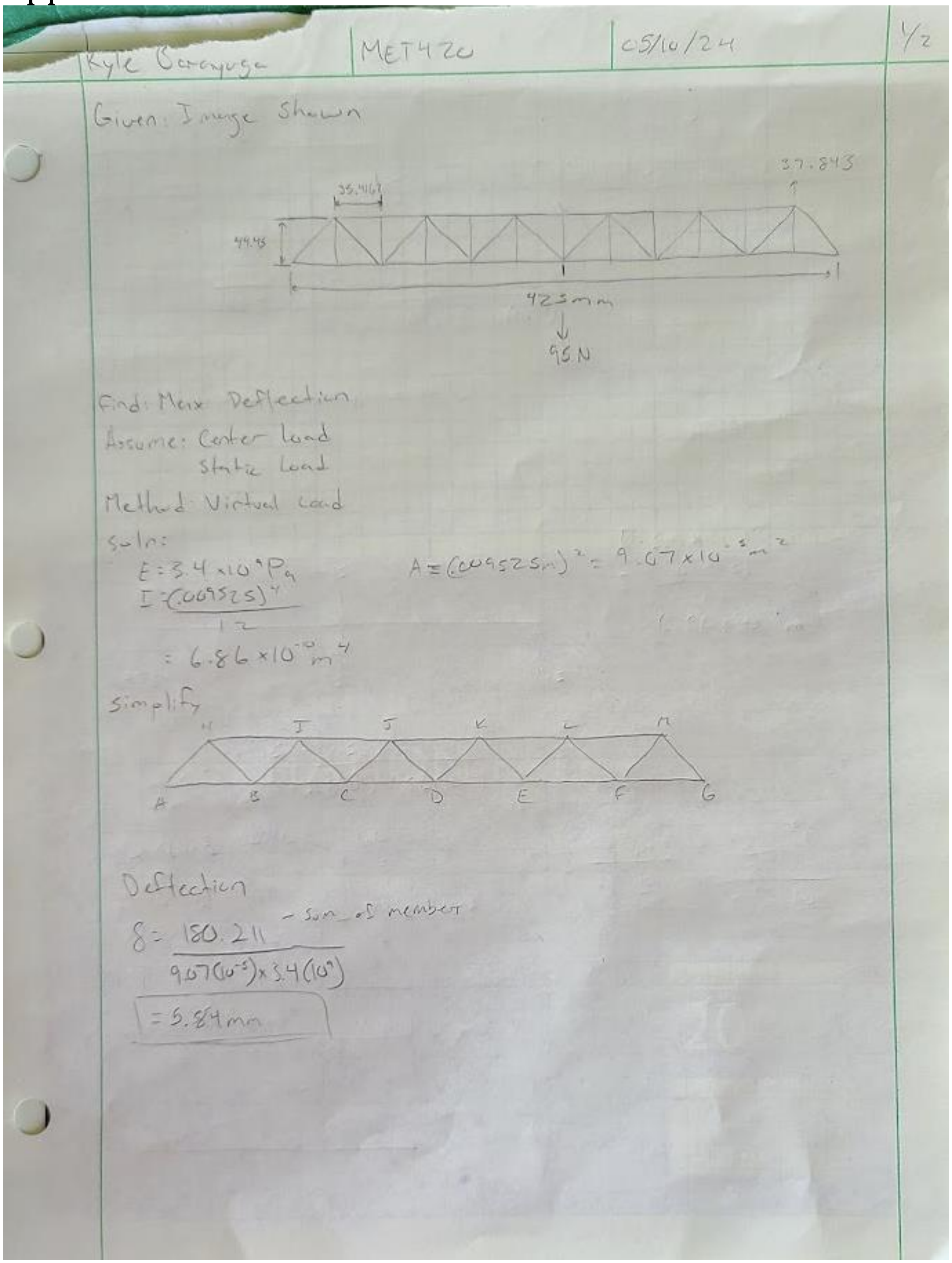


Figure G18– Deflection Calculations

Appendix G3.5 – Schedule (Testing)

ID	Task Name	Duration	Start	Finish
6	**DEVICE EVALUATION**	**50 days?**	**Tue 3/26/24**	**Mon 6/3/24**
6a	Create Test Procedure 1	2 hrs	Tue 4/2/24	Tue 4/2/24
6b	Test 1: Obtain resources	1 hr	Thu 4/4/24	Thu 4/4/24
6c	Test 1: Perform Test	1 hr	Fri 4/5/24	Fri 4/5/24
6d	Create Test Procedure 2	1 hr	Mon 4/15/24	Mon 4/15/24
6e	Test 2: Obtain resoureces	0.5 hrs	Mon 4/15/24	Mon 4/15/24
6f	Test 2: Perform Test	0.5 hrs	Tue 4/16/24	Tue 4/16/24
6g	Create Test 3	1 hr	Mon 4/29/24	Mon 4/29/24
6h	Perform Test 3	0.5 hrs	Fri 5/3/24	Fri 5/3/24

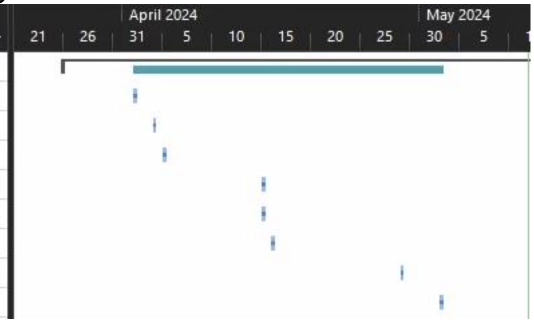


Figure G19 – Test 3 Gantt Chart

APPENDIX H – Resume

Kyle Barayuga

kyle.barayuga@cwu.edu

Objective

Starting a career in engineering & related systems in a challenging environment would give me the opportunity to bring out the best in me and for continuous improvement that leads to the growth of others around me.

Skills & Abilities

Diagnose and solve complex problems

Adaptable work ethic

Constant improvement to team effectiveness

Experience

Amazon Sortation Officer — Amazon

June 2020 — Sept 2020

Overlook and ensure packages are correctly transported to their correct destination while enforcing a strong work ethic to other associates.

Education

Central Washington University — BS Mechanical Engineering Technology

Jan 2018 — Present

Leadership & Communication

Kappa Sigma (Rho Mu) — Grand Scribe

Feb 2019 — Feb 2020

1 of 5 leadership positions in CWU's Greek Life. Managed 20+ brothers in community service, academic stability, campus events/activities. Note keeper of chapter meetings and new initiates. Constant interaction with executive officers improved leadership capabilities and mindset.