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Solar Water Heater: Mobile Stand

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Solar Water Heater: Mobile Stand

By

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ABSTRACT

During the course of this project, a solar thermal collector and supporting stand were designed and manufactured to be used during Mechanical Engineering Technology labs. Students will be able to use the collector to heat water, with the sun being the only heat source. The collector was designed by calculating surface area limitations, estimated solar input, and desired efficiency, to find the required water flow rate. From there, the necessary pipe lengths and diameters were determined, and the solar thermal collector was constructed. Two pipe paths were manufactured: a curved path, and a manifold path. Students will be able to test the difference in efficiency between the two paths, with the potential for other forms of manipulation and experimentation. Furthermore, the collector requires ease of transport from the classroom to outdoor areas for use, necessitating a mobile stand that people of different builds can operate. Considering this, size, portability, and ease of use were primary intents in the stand design. Statics, strengths of materials analyses, and mechanical design principles determined placement of features with minimized size and weight to support the loadings created by the solar heating system. The result was a stand with solid support for the solar collector and water tank with the balance to provide easy transport by an average person into and out of a building. This report will show the results of the heating capacity and efficiency of the collector at varying solar inputs, as well as the physics behind the stand design.

INTRODUCTION

Problem

The inefficient solar water heater housed in Hogue 205 currently consists of several disjointed parts: a water tank on a dolly, and a solar collector mounted to a barely mobile frame. To enable easy transportation for frequent use, it requires a mobile frame to mount the parts together into a single assembly that should be capable of being moved by one person. Due to the weight of the components, particularly the full water tank, if a tilting mechanism similar to a hand truck is employed, the system will be particularly hard to initially tip or be returned to horizontal.

Functions

The system as a whole is to do the following:

- Heat the water in the tank using solar radiation incident upon the collector.

The stand will perform the following functions:

- Support full water tank and solar collector while holding them securely in place.
- Provide ease of transport for assembly.

Requirements

The following are design requirements of the mobile stand:

- Support combined load of up to 255 lbs without buckling. Base of the stand must support the full water tank at 230 lbs over its horizontal surface and the back frame beams must support the solar collector and mounting hardware at 25 lbs.

- Mount 19.9 gal water tank (diameter 20 in, height 26 in) and 30 in width x 36 in tall x 3.75 in thick solar collector together while providing a minimum of 90° of rotation for the collector (from horizontal facing up to vertical facing forward.
- Fit through standard doorway (36 in x 80 in). Total width should not exceed 32”, and height should not exceed 70”.
- Weight of stand, including mounting hardware, must not exceed 50 lbs.
- The entire assembly must be transportable from Hogue 205, down through the elevator, out the doors to the patio outside the atrium, deployed for use, returned to transport position, and transported back without failure of any parts.
- Require no more than 20 lbs of force to hold up by the handles when it is tipped back between 30° and 40° for transport.
- Cost of materials must not exceed $200

Success Criteria

The primary function of this stand is support and transport the water tank and solar collector, a combined weight of 255 lbs, so it must do this without failure while being moved by a single person into and out of buildings.

Scope of this effort:

This includes the stand, mounting hardware, and mobility mechanism for the water tank and solar collector.

Hazel Tickner will be redesigning the solar collector to improve efficiency of the system at heating water.

Success of the project:

Success of this stand will be transport by one person of the water heater assembly from Hogue 205 to the patio outside Hogue Hall’s atrium, deployment of the system where the collector is moved through its full range of motion, and back to Hogue Hall 205 without failure of any parts.

DESIGN & ANALYSIS

Approach

Since the primary goal is to support the water heater assembly, a detailed analysis of equilibrium states will be required to balance the forces, determine stresses and how much each part will need to support. Once that is determined, materials can be selected to balance strength and cost.

A secondary goal is to provide ease of transport. One of the ways this can be accomplished is to have the center of gravity over the wheels when it is tipped for transport. This will require repeated center of gravity calculations and force analyses for the various positions it will be in.

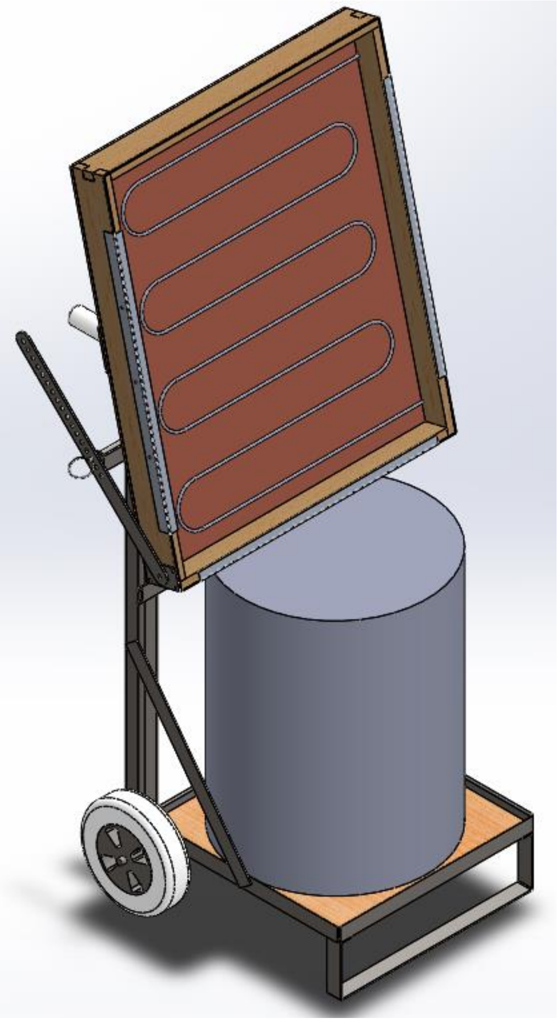
- Measure dimensions, weigh each component, and determine individual centers of gravity.
- Use force and moment analysis and calculate maximum stresses on individual components.

- Calculate maximum required force to be exerted by the person transporting the assembly.
- Measure distances of each individual component center of gravity and compute location of overall center of gravity when stand is sitting flat and when tipped for transport at 30° and 40°.

Design Description

Due to a possible need for ascending stairs, a hand truck like system will be preferable to a pulled cart. When the assembly is tipped for transport, the center of gravity will shift. To minimize this shift, the components should be placed as close together as possible. To facilitate ease of use when tipping the assembly, the axle can be placed under the center of gravity to within a few inches. This will ensure minimal force will be required to tip the assembly and maintain it when transporting at specified angles. This can be determined from a force and moment analysis. After determining stresses on each component, materials can be selected for the required strengths that balance out weight and cost.

- Position tank and collector as close as possible for compactness and to minimize shift in center of gravity within designated tipping angles of 30-40°.
- Position handles so that the least amount of force is required by the person transporting it to support it while falling within a reachable height by an average human. Provide other handholds for comfort of individual users.
- Materials used will provide balance of strength, lightness of weight, and cost.



The base frame will be made of L-bars welded together. A wood board will sit on top of this and support the water tank. The top of the L-bars will keep the water tank from sliding off. This will sit on connections supporting the axle near the rear, and a rest made from flat bar will support the front end. Square tube will comprise the upright frame beams, and support bars will help carry the load of the base when it is tipped for transport. Another horizontal support bar will provide stability for the square tube beams and provide a backing for the water tank to rest against when the assembly is tipped. The tank will be further secured with a belt that will be held in place with the flanges on the side of the horizontal support bar. Handles will be attached to the back of the upright beams. A bar across the top will provide a mounting point for the solar collector. Hinges will connect the top bar to an interface plate attached to the back of the collector. A locking bar attached to the side of the collector will be allowed to freely rotate and will hold the collector in the desired position with a pin connecting to an extension attached to the frame.

A-36 steel is cheap and available in the bar profiles that are used in the design. The analyses that follow will use A-36 unless otherwise stated. The handles can be constructed of aluminum bar to save weight and cost.

Performance Prediction

Axle placement to provide a balance of least force to hold the assembly tipped and least force required to tip it back is at 1 in forward from the back of the base frame. The force required to hold it up at 30° is 10.4 lb, 36.3 lb at 40°, and 47.1 lb required to tip it from horizontal (see appendix A, Figure A - 1 and Figure A - 2).

Description of Analysis

The water tank and solar collector will need to be placed as close together as possible to provide for ease of transport, so these positions are where analysis will begin. Force, moment, and stress analysis will determine center of gravity for positioning of the wheels and identify suitable materials and dimensions. Minimum standard dimensions will be used since weight is a consideration. Materials will be further narrowed by availability and cost. Optimization of weight and cost will almost always depend on choosing the lowest acceptable common dimensions as they fit into the design.

Most of the calculations will involve balancing forces so that the assembly is in static equilibrium and computing stresses to determine required dimensions. The following equations apply:

$$+\uparrow \Sigma F_y = 0 \qquad +\rightarrow \Sigma F_x = 0 \qquad \Sigma M = 0$$

$$Direct\ tensile\ or\ compressive\ stress\ \sigma = P/A$$

$$Direct\ shear\ stress\ \tau = \frac{V}{A}$$

$$Bending\ stress\ \sigma = \frac{Mc}{I}\ or\ M/S$$

Scope of Testing and Evaluation

Weight of stand will be evaluated. Load support will not be tested beyond that it will support the full water tank and solar collector assembly, including during transport at normal walking speed over paved surfaces. For practicality of analysis and standardization of testing, usage specifications will specify that the transport position for the collector is vertical relative to the base of the frame.

Analyses

Figure A - 1 shows weights and centers of gravity for each component. The axis centers the origin at the back of the base frame of the stand and coordinates are referenced from there. It also shows the center of gravity for the completed assembly at the max and min transport angles.

Figure A - 2 shows the forces required to hold the assembly at the max and min transport angles as well as the forces required to tip the assembly when it is horizontal for various axle locations. Based on the calculated values and the time spent holding the assembly at a transport angle versus tipping it, the decision was made to use the lower values for holding it up. The axle will be placed 1 in from the back of the base frame. The force required to tip it is 47.1 lbs, while 10.4 lbs will be required to hold it up when tipped back at 30° and 36.3 lbs at 40°.

Figure A - 3 is a stress analysis of the foot that the stand rests on when horizontal. The only stress here is direct tensile stress, calculated at 344 psi on each side when using a thickness of 1/8 in. After applying a safety factor of 3, this is still well under the yield stress of 36 ksi, so 1/8 in thickness will be used.

Figure A - 4a shows a stress analysis of the upright beams when it is horizontal, tipped back at 30° and 40°. The maximum stresses mostly occur at 30°, and the combined stress from bending and normal stresses is 1.41 ksi in compression and 941 psi in tension when using the thinnest wall thickness of 2 in x 2 in square tubing available at 1/16 in.

Figure A - 5 shows the required length of weld to resist the bending stress when tilted and the shear stress when horizontal, and it is much less than the length that will be welded.

Figure A - 6 shows stress on the top connector bar that the hinges are mounted to. The stress is higher than expected due to the stress concentrations from the holes, and a 3/16 in thickness had to be used to bring the actual stress under the yield strength with the required safety factor of 3.

Figure A - 7 shows the stress on the locking bar. The maximum will occur when it is holding the collector horizontal. 1/8 in thickness is more than adequate.

Figure A - 8 shows the stress on the support bars between the upright frame and the base frame. While these are statically indeterminate, they will still likely carry the entire load of the base frame and water tank when the assembly is just starting to tip. Again, 1/8 in thickness will support this load.

Figure A - 9 shows required length of the weld for the support bars, which is again well below the actual.

Figure A - 10 shows stress on the rear base frame L-bar. The rear beam will have the most stress since the axle is supported under it while the upright frame is welded to the back of it. 1/8 in thickness was found to be sufficient.

Figure A - 11 shows stress on the axle. Due to the availability of axle diameters for the size of wheels, and the length required, only one of suitable dimensions was found, and the specific type of steel was unknown. Assuming a low grade steel, the safety factor for this will only be around 2.

Figure A - 12 shows that the weld length for the axle connection is more than adequate.

Figure A - 13 shows the required diameter and tensile stress area for the fasteners connecting the handle to the upright frame bars as well as required thread length with a safety factor of 3. 1/4-20 with a thread length of .5 in suffices.

Tolerances, Kinematics, Ergonomics

Tolerances: Tolerances for the frame can be fairly low, as most of the connections will be welded and the rest will be secured with fasteners. For many of the larger beams, tolerances will fall within plus or minus .1 in. Drilled holes will require .05 in. The locking bar will require slightly more accuracy at plus or minus .01 in and will be created after the frame is assembled and collector attached.

Kinematics: This device is designed to be mobile, but all of the parts will remain stationary relative to the frame during transport. The collector will need to rotate (while the stand is stationary), and will require adequate clearance to do so. A locking bar with drilled holes and a pin will secure this when desired rotational angles are achieved.

Ergonomics: As discussed above, the force analysis of the assembly will provide an optimal placement for the axle so that it will be easier to tip for transport and require less force to hold at the desired transport angle.

Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits

Failure modes:

- Base bar fractures under load of assembly
- Base bar plastically deforms under load of assembly
- Base frame weld shears
- Axle fractures under load of assembly
- Axle plastically deforms under load of assembly
- Axle connector weld shears
- Mounting hardware for solar collector plastically deforms
- Mounting hardware for solar collector fractures
- Foot fractures under load of stand assembly
- Foot plastically deforms under load of stand assembly
- Locking bar assembly plastically deforms
- Locking bar assembly fractures
- Handle bar assembly fractures
- Handle bar assembly plastically deforms
- Handle bar fastener fractures
- Handle bar fastener plastically deforms
- Support bar fractures
- Support bar plastically deforms
- Support bar weld shears
- Upright frame square tube fractures
- Upright frame square tube plastically deforms
- Upright frame weld shears
- Top connector bar fractures
- Top connector bar plastically deforms

Analysis shows that all parts with the exception of the axle have a stress within the yield strength with a safety factor of 3. The axle due to availability of materials will only have a safety factor of 2, and thus is the most likely point of failure.

The assembly is not designed to operate when tipped back further than 40° or with loads greater than 230 lbs where the water tank sits and 25 lbs where the collector is attached.

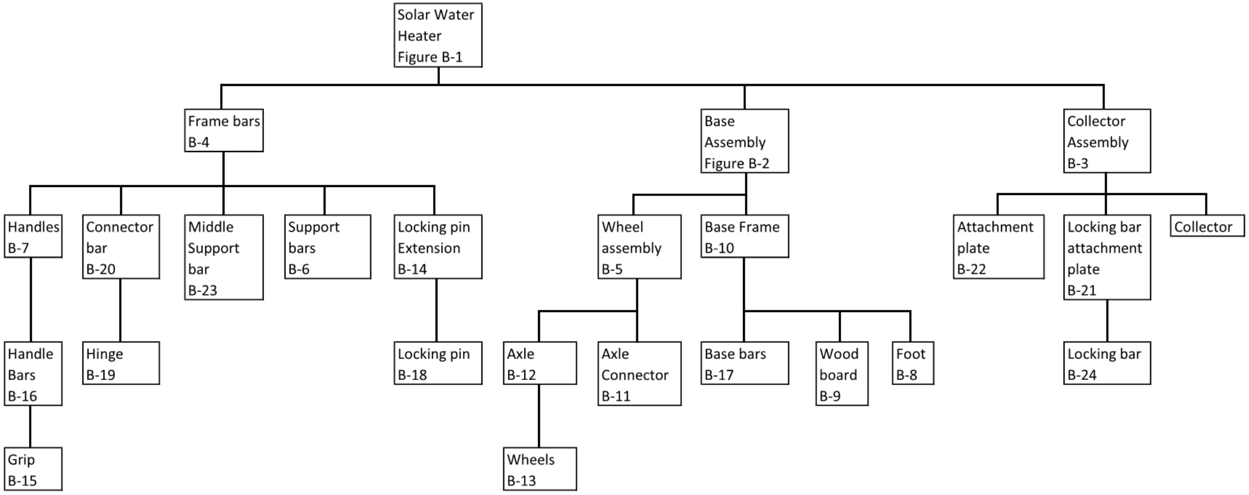
METHODS & CONSTRUCTION

The stand will be an assembly of many different parts. As such, all parts that can be purchased will be for practicality and timeliness of construction. These will include the wheels, fasteners, locking bar pin, and collector mounting hinges at a minimum. Other parts, will need to be constructed from purchased parts. The base frame will be constructed from L-bars, the upright frame from square tubing, support bars, locking bar, and connector plates from flat bar, and the handles and axle from round bar if a suitable length of axle cannot be found.

The main function of the stand is to support the water tank and solar collector. The tank will sit on the base and be secured to the upright portion via a belt. The wheels will be attached to the axle, which will be fastened to the base frame. The rest can be shaped and then welded to the base. The frame of the base can be constructed from L-bars welded or fastened together to support a wood board base. If fasteners are used, then holes will need to be drilled. The upright frame will be constructed of square tubing and holes will be drilled for the handles. Another square tube will span the top which the hinges for the collector will attach to in order to mount the collector. A plate interface between the back of the collector and the hinges will be necessary. Additional support will likely need to be added, such as a bar welded or fastened to the upright bars near the height of the top of the water tank. A straight bar can then be machined as well as an interface plate attaching to the collector for pinning it at desired angles, and an extension from the upright frame to reach the pin.

Drawing Tree

The drawing tree represents from the ground up that parts and assemblies that make up the device. Drawings can be found in Appendix B.



Parts List and Labels

The following parts will comprise the assembled stand:

Part	Designation	Quantity/length	Cost per part/length	Total Cost
L-bar	B-17	84” (4x 21”)	$14.72/8’	$14.72
Wood board	B-9	21” x 21” x .5”		
Square tube 2” x 1/16”	B-4	90” (2x 45”)	$28.39/96”	$28.39
Flat Bar 1.5” x 1/8”	B-6, 8, 23, 21, 24	124” (2x 21”, 1x 22.7”, 1x 33”, 1x 22.5”, 1x 3.5”)	$3.96/2’, $6.92/4’	$22.76
Flat Bar 2” x 3/16”	B-20	21.74”	$4.14/2’	$4.14
Flat Bar 2” x 1/4”	B-22	30”	$8.73/30”	$8.73
Wheel (10” dia)	B-13	2	$14.40	$28.80
Axle (5/8”)	B-12	1x 29”	$15.08	$15.08
Collar (5/8")		2	$0.89	$1.78
Square tube 1.5” x 1/4”	B-11	2x 3”	$6.95/3”	$13.90
Round bar 1.5” dia	B-16	1’ (2x 6”)	$12.48/1’	$12.48
Ball lock pin	B-18	1x 3/8” x 3”	$2.48	$2.48
Hinge	B-19	2	$5.48	$10.96
Fasteners (estimate)				$5
Total				$167.44

This is also shown in Appendix C Figure C – 1 with possible sources listed.

Manufacturing Issues

Manufacturing the stand should not present any particular issues. Various elements such as the handle bars and collector connections will require light machining in the form of drilled holes for fasteners. Most of the purchased materials will require cutting to length. Simple welding will be required for connecting the L-bars for the base, the support bars, and the bars for attaching the collector and handles. Some or all of these could be connected via drilled holes and fasteners if welding is not an option, however this would be much more time consuming.

Assembly, Sub-assembly, Parts, Drawings

The base will be the starting point, and thus the base frame will be the first thing constructed. It will consist of four L-bars welded together. These will need to be machined in preparation for welding. The foot will need to be constructed next and then welded to the base frame. A wooden board can be cut to size and placed on the base frame. The square tube for the axle connections will require drilled holes and then welding to the base frame. The axle and the wheels will be attached next. Then the square tubing for the upright part of the frame will need to be cut to size, have holes drilled for the handles, and then welded to the base frame. The support bars can be cut to size and then welded into place. The handles will be drilled and tapped before being attached. The top connector bar for the hinges will also need holes drilled before being welded in place. Once the complete frame is assembled, the mounting plates can be drilled and then attached to the solar collector. Hinges will be fastened to the frame and then the collector can be attached. The locking bar and attachments can then be machined and attached, and lastly, the water tank.

Manufacturing Discussion

As planned, manufacturing went mostly without issues, and was completed several days early. When designing the schedule, it was not taken into account that materials would be received as single pieces. It was more efficient to cut everything to length first rather than setup the same machine multiple times for each piece.

Several minor issues were encountered. The hinges that were purchased were not the same as the ones designed. This required a redesign of the 3d model and adjustment of the hole locations. It was also not taken into account that the fasteners would be larger, so the countersinks on the hinges needed to be enlarged. Also, a welding class was required and taken during the same quarter as manufacturing, however the gas metal arc welding method used was not a part of the class. A few extra hours of tutoring and practice were put in, however most of the welds did not turn out as high quality as they should have.

TESTING METHOD

Test Plan

Testing will consist of non-destructive methods. It is designed to function over paved surfaces at normal walking speeds of 3.1 mph, so those are the conditions which it will be tested on.

The main function of the stand is to support the expected load and transport it from Hogue 205 to the patio outside the atrium and back. While it is outside, it will be deployed for use. For the stand, this means it is standing upright, flat on the ground, and locking the collector in the desired position for use.

Ease of use is a primary consideration in the design. Primarily affecting this is the force required to hold it up during transport, and it is required to be less than 20 lbs at some angle within the specified transport angles of 30-40°. This is predicted with calculations in Figure A - 2 to be 10.4 lbs at 30° and 36.3 lbs at 40°.

The weight of the stand will also affect ease of use and thus be evaluated, not to exceed 50 lbs. This was difficult to predict with the 3d model, Solidworks not having all of the correct materials, and purchased parts such as the wheels not being modeled in exact detail, however the estimation by Solidworks was 82.3 lbs.

To further enable ease of transportation, the assembly must be able to fit through a standard doorway, which is 36 inches wide by 80 inches tall. The collector was the widest part of the assembly and is centered on the stand. The locking pin sticks out on one side of this slightly and the entire assembly is expected to be 30.6 inches wide and 69.4 inches tall when vertical (60.1 inches when tipped back 30°).

Method

Testing can all be completed inside and outside around Hogue. It will require a scale to measure the weight of the stand and the force required to hold it up, and is recommended to have one person assisting. There is a scale in the Hogue foundry that may be used for this.

The first test will determine the force necessary to hold the assembly up at the maximum and minimum transport angles. It will be tipped back 30° and rest on a scale sitting on a counter. The scale will then be placed on a lower surface and the process repeated at 40°. During the process of transporting the assembly, whether or not it will be able to fit through a standard doorway will be determined.

The next test is the weight of the stand by itself. The same scale may be used. A board large enough for the stand to be placed on may be used, or the stand turned on its side sitting fully on the scale. The collector, water tank, and pump will be removed before weighing it.

The last test is simply to transport it from Hogue 205 to the patio outside the atrium, deployed for use, and returned to 205. This is the minimum required travel distance, and a detour to the foundry for one of the other tests can be completed during this test.

This stand was built for one purpose, so it will not be further evaluated for different loadings. Further, it was only designed to be transported between 30 and 40°.

Procedure

The tests for force and weight are described in detail here. The other tests are minimal in procedure, and can each be completed in several minutes or less.

Test 1: Force to hold assembly at minimum and maximum transport angles
Duration: 20 minutes
Place: Hogue foundry
Steps:

1. Obtain protractor, small weight, and string. String must be long enough to clear angle markings on protractor with enough extra to fasten the weight to.
2. Fasten weight to one end of the string.

3. Fasten opposite end of the string to the origin of the protractor.
4. Ensure stand is sitting flat on floor, collector is locked in position for transport (top of collector tipped slightly forward so that pin locks in lowest position on locking bar), and water tank is filled to operational capacity (between 15 and 19.9 gal).
5. Fasten protractor to a free spot on a vertical beam of stand so that the 0° marking points straight down, the angle markings are pointed towards the rear (away from the water tank) and the string hanging still and on its own aligns with this 0° marking.
6. Place scale on table or counter top.
7. Power on and zero scale.
8. Tip assembly to 30° so that the handle is resting on scale (if necessary, use available Styrofoam to bridge gap between handle and scale so that assembly is still at 30° when resting) so that the assembly is supported solely by the handle on the scale and the wheels.
9. Record force.
10. Repeat step 8 and 9 at 40°. Place scale on lower surface if necessary.

Risk/Safety: Care must be taken when tipping the device so that it does not move. An assistant would be beneficial to assist in tipping and ensuring the wheels do not continue to move. The person(s) operating the device must have adequate muscular endurance to hold the stand up while adjustments are being made.

Discussion: Ease of use was a primary consideration in design, and the force necessary to hold the device up is perhaps the largest factor. The tank may be filled between 15 and 19.9 gallons. This test was conducted with the water tank capacity at approximately 15 gallons. The calculations for center of gravity and placement of the axle determined this, however actual weight of the collector varied significantly from expected, which also affected this measured force.

Test 2: Weight of stand alone
Duration: 20 minutes
Place: Hogue foundry
Steps:

1. Obtain assistance of one other person.
2. Bring stand to foundry or somewhere with a functional scale large enough to weigh stand.
3. Remove locking pin.
4. Remove collector by loosening fasteners attaching collector mounting bar to the hinges while assistant holds collector up.
5. Remove belt holding water tank in place.
6. Remove water tank. It is recommended to drain the water beforehand (close valve, unhook hoses, relocate so the valve is over a drain or outside (if necessary, use a hose to extend distance), open valve, wait until water has drained, close valve).
7. Remove pump by unfastening U bolt.
8. Locate a board large enough to place stand on.
9. Place scale on floor, place board on scale, zero scale, and place stand on board.

10. Record reading.
11. Remove stand from scale.
12. Replace pump, water tank, and collector on stand.

Risk/Safety: Care should be taken when removing the collector not to damage it. Assistant holding collector up while it is being removed must have adequate muscular endurance to support it. Collector weighs 34.6 lbs with mounting bar and locking bar attached. Person(s) removing water tank must have adequate muscular strength to remove water tank. Tank weighs 63.8 lbs when empty.

Discussion: Minimization of collector weight was limited by standard sizes of materials used. One of the things overlooked in weight estimation was weld electrode material and fasteners. Actual radius' of parts such as the angle bar and square tubing differed from default models.

Test Documentation and Deliverables

The following table shows the results of each test, calculated or expected outcomes, requirements for success, and whether or not it passed.

	Calculated/expected	Actual	Requirement	Success
Supports actual loads	Yes	Yes	Yes	Yes
Force to hold up 30 ° 40°	10.4 lbs 36.3 lbs	29.9 lbs 44.2 lbs	20 lbs	No
Weight	82.3 lbs[1]	53.5 lbs	50 lbs	No
Fits through door	Yes[2]	Yes	Yes	Yes
Transport route	Yes/Capable	Yes	Yes	Yes

[1] Unrealistic expected value given from Solidworks.

[2] Hoses must be removed from the side of the collector to be able to fit through a standard doorway.

Conclusion

While the stand did perform a core requirement of supporting and transporting the water heater assembly outside, it was harder to do so than expected. Minimum force necessary to hold the assembly up (at 30°) was 9.9 lbs over the requirement and 19.5 lbs over the calculated value. This was likely a due in part to the weight of the collector being significantly more than expected. The collector was supposed to weight no more than 25 lbs (all calculations used this maximum weight), and the actual weight was 32 lbs. The weight of the stand alone was not to exceed 50 lbs, and while this was hard to predict, it failed by 3.5 lbs.

BUDGET/SCHEDULE/PROJECT MANAGEMENT

Cost and Budget:

One of the requirements is a reasonable materials cost of less than $200. Appendix C contains a parts list (Figure C - 1) with associate costs from possible suppliers. Figure C - 2 contains actual costs.

The cost of this project is supported by the CWU Mechanical Engineering department since this device will be used by the thermodynamics lab.

Schedule:

The schedule is depicted in a Gantt chart (see Appendix E Figure E - 1). It is broken down by tasks for each quarter with planned and actual time spent. There are several milestones, such as integration of the three dimensional models, completion of the proposal, completion of sub-assembly and complete assembly builds, as well as interfacing the collector with the stand and completion of the project.

Figure E - 2 shows a detailed build schedule, breaking down each of the parts builds to specific tasks. Depending on the details of how the parts are ordered and received, some of these may not be necessary.

DISCUSSION

Design Evolution / Performance Creep

Much of the time for this project was devoted to the design and rendering a three dimensional model. The older solar thermal collector that prompted this project had a frame that was barely mobile. The initial design incorporated use of that frame so that less work would be required in the build phase, however, due to the dimensions not working with the water tank and extra weight from redundancies that couldn't be eliminated, the decision was made to forego use of it.

The next iteration is the basic design that was chosen. Most of the parts then went through small design changes to be easier to build or based on the analysis. Simplification and reducing the number of parts was a concern due to the number of parts that would need to be prepared and attached for the build.

In order to simplify it greatly from using the original frame, the collector was attached to the top of the upright frame. This also assisted in having the larger, heavier components closer together and minimizing the center of gravity shift as it's tilted. The rest was initially two pieces, but combining it into one assisted in simplifying it. The mechanism to lock the collector in position was initially going to be locking hinges, however due to the poor service life of many locking hinges, the design evolved to use freely rotating hinges with a locking bar. This complicated the design and will increase build time, however it is necessary for the functionality of the device.

Project Risk analysis

Time taken to design this stand was largest risk. The design was constantly being optimized and revised, leading to much wasted time in revising and redoing many sections of the proposal. The analysis was constantly put off due to this, and it contained some complexity of its own that manifested in another large time sink.

The build phase will also pose some time risks, as there are many parts to build. Basic machining skills have already been acquired, however the welding skills will be acquired during the build phase.

Successful

The plans for this device have met the specific requirements outlined in the introduction. These specified the size the entire assembly not exceed 32 in width and 70 in height, and it fits within those dimensions, though both the height and width are within an inch of those maximums, however minimizing this was not a goal as the size is limited by the collector. The actual size of the assembly was within specifications, however when the hoses are attached to the collector, it exceeds the width requirement and will not fit through a single door. Concerns were raised about the height of the assembly, however it is designed to be transported at an angle, and when tipped to the minimum specified angle, the vertical height will not exceed 5 feet. The weight limit for the stand itself was 50 lbs. The weight estimate from the three dimensional model is 45 lbs, but the actual ended up being 53.5 lbs. The analysis showed that for many of the parts, the minimum available thicknesses are more than sufficient for the stresses involved, allowing for optimized weight while supporting more than the required 255 lb load. To ensure ease of transport at the minimum transport angle of 30°, the force required to hold the assembly up is 10.4 lbs, or 5.2 lbs per handle. The actual was 29.9 lbs due to the increased weight of the stand and the collector. Cost was not to exceed $200, and the estimate for parts was $168 and the actual was $189.

This project has been successful in being a learning opportunity and providing a significant creative challenge. The requirements for supporting the loads, being within budget, and mobility were also a success. The weight of the stand and the force required to hold it up during transport both failed, however the stand is still quite functional.

CONCLUSION

The disassociated and inefficient solar water heater in the thermodynamics lab has now been redesigned. The goal was to create a solar collector with improved efficiency and an easy to transport stand on which to mount it and the water tank. The scope of this part of the project was to create the stand. After completion, it was able to mount the solar water heater assembly in a single package, albeit it was harder to transport than expected.

Based on the analysis and predictions, this project was functionally a success. The actual constructed device did not meet all the requirements, however safety considerations engineered into the device prevented failure. The time and effort spent acquiring the skills to design and build this, along with the department funding and mentorship has also contributed to the success of this project.

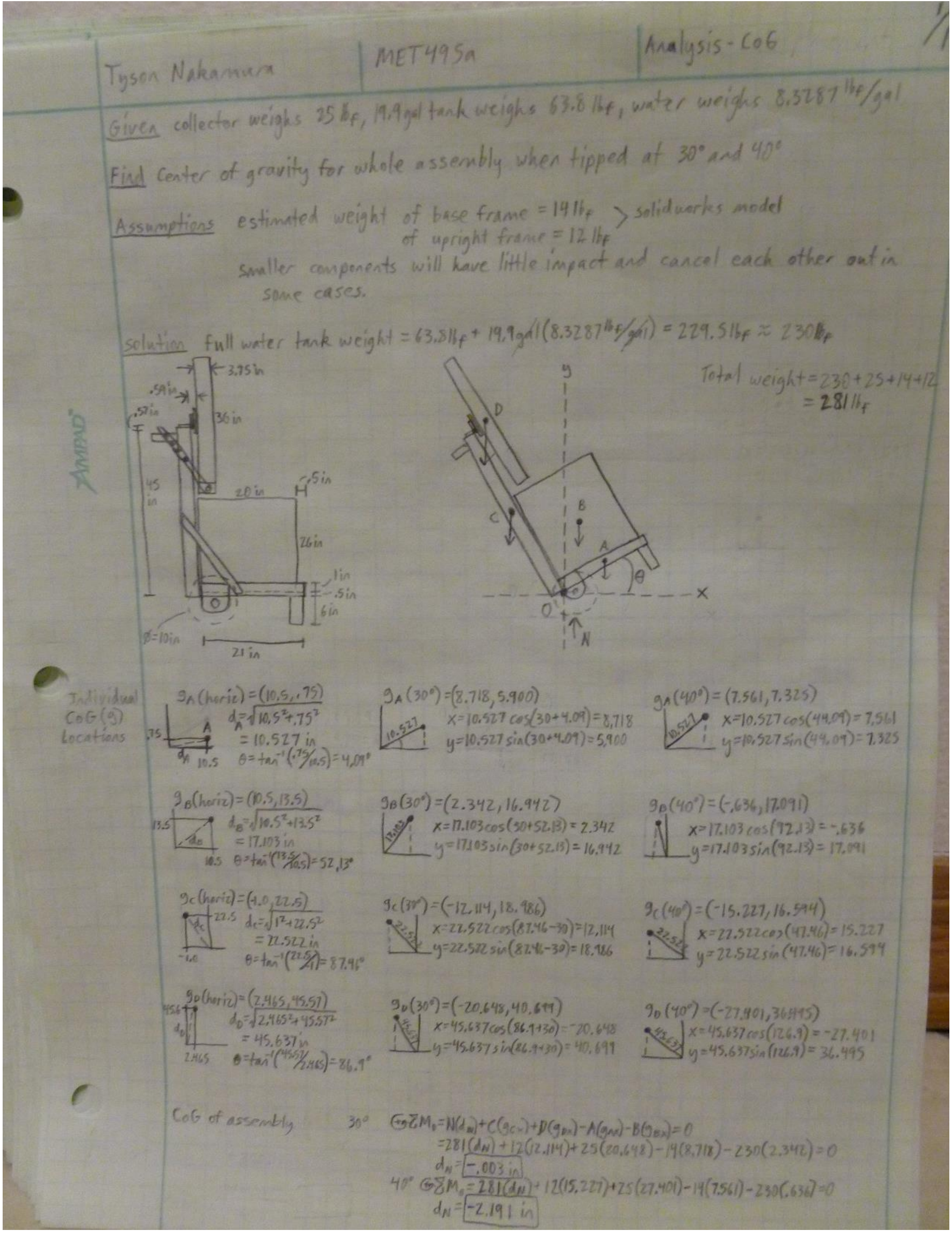
ACKNOWLEDGEMENTS

Thanks to:

- Central Washington University Mechanical Engineering Technology department for the machine and welding shops as well as funding for the project.
- Professor Roger Beardsley for the mentorship and design suggestions.
- Matt Burvee, Ted Bramble, Jose Behar, and Trevor Reher for the manufacturing advice and assistance.
- Hazel Tickner for being a competent and supportive teammate.

This project would not have been possible without their support.

APPENDIX A – Analyses



Tyson Nakamura | MET495a | Analysis - CoG

Given collector weighs 25 lbf, 19.9 gal tank weighs 63.8 lbf, water weighs 8.3287 lbf/gal

Find Center of gravity for whole assembly when tipped at 30° and 40°

Assumptions estimated weight of base frame = 14 lbf, of upright frame = 12 lbf > solidworks model

smaller components will have little impact and cancel each other out in some cases.

solution full water tank weight = 63.8 lbf + 19.9 gal (8.3287 lbf/gal) = 229.5 lbf ≈ 230 lbf

Total weight = 230 + 25 + 14 + 12 = 281 lbf

Individual CoG (g) locations

$g_A(\text{horiz}) = (10.5, .75)$
$d_A = \sqrt{10.5^2 + .75^2} = 10.527\text{ in}$
$\theta = \tan^{-1}(.75/10.5) = 4.09°$

$g_A(30°) = (8.718, 5.900)$
$x = 10.527\cos(30+4.09) = 8.718$
$y = 10.527\sin(30+4.09) = 5.900$

$g_A(40°) = (7.561, 7.325)$
$x = 10.527\cos(44.09) = 7.561$
$y = 10.527\sin(44.09) = 7.325$

$g_B(\text{horiz}) = (10.5, 13.5)$
$d_B = \sqrt{10.5^2 + 13.5^2} = 17.103\text{ in}$
$\theta = \tan^{-1}(13.5/10.5) = 52.13°$

$g_B(30°) = (2.342, 16.942)$
$x = 17.103\cos(30+52.13) = 2.342$
$y = 17.103\sin(30+52.13) = 16.942$

$g_B(40°) = (-.636, 17.091)$
$x = 17.103\cos(92.13) = -.636$
$y = 17.103\sin(92.13) = 17.091$

$g_C(\text{horiz}) = (-1.0, 22.5)$
$d_C = \sqrt{1^2 + 22.5^2} = 22.522\text{ in}$
$\theta = \tan^{-1}(22.5/1) = 87.46°$

$g_C(30°) = (-12.114, 18.986)$
$x = 22.522\cos(87.46-30) = 12.114$
$y = 22.522\sin(87.46-30) = 18.986$

$g_C(40°) = (-15.227, 16.594)$
$x = 22.522\cos(47.46) = 15.227$
$y = 22.522\sin(47.46) = 16.594$

$g_D(\text{horiz}) = (2.465, 45.57)$
$d_D = \sqrt{2.465^2 + 45.57^2} = 45.637\text{ in}$
$\theta = \tan^{-1}(45.57/2.465) = 86.9°$

$g_D(30°) = (-20.648, 40.699)$
$x = 45.637\cos(86.9+30) = -20.648$
$y = 45.637\sin(86.9+30) = 40.699$

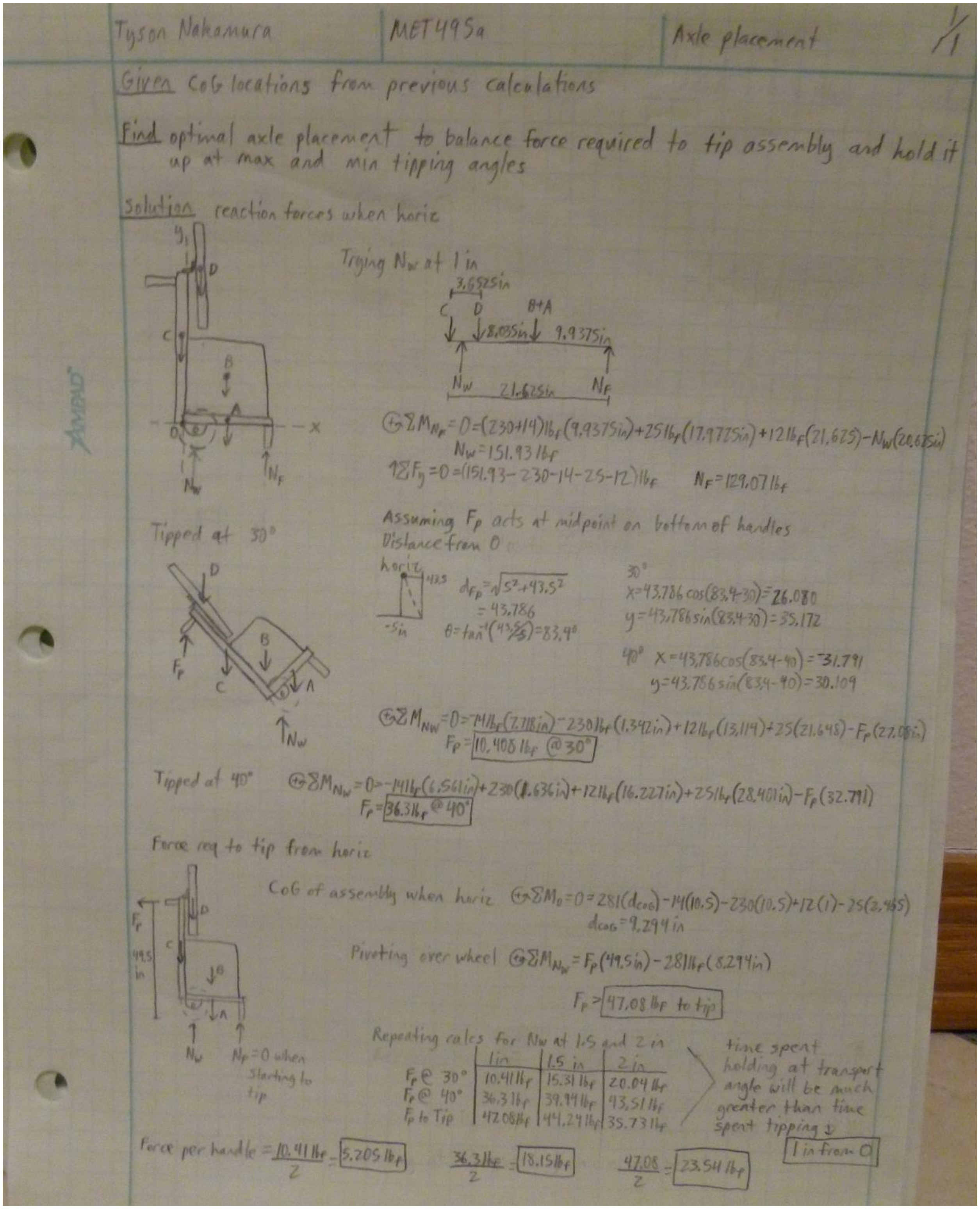
$g_D(40°) = (-27.401, 36.495)$
$x = 45.637\cos(126.9) = -27.401$
$y = 45.637\sin(126.9) = 36.495$

CoG of assembly

30° $\sum M_o = N(d_N) + C(g_{Cx}) + D(g_{Dx}) - A(g_{Ax}) - B(g_{Bx}) = 0$
$= 281(d_N) + 12(12.114) + 25(20.648) - 14(8.718) - 230(2.342) = 0$
$d_N = \boxed{-.003\text{ in}}$

40° $\sum M_o = 281(d_N) + 12(15.227) + 25(27.401) - 14(7.561) - 230(.636) = 0$
$d_N = \boxed{-2.191\text{ in}}$

Figure A - 1



Tyson Nakamura | MET495a | Axle placement | 1/1

Given CoG locations from previous calculations

Find optimal axle placement to balance force required to tip assembly and hold it up at max and min tipping angles

Solution reaction forces when horiz

Trying N_w at 1 in

3.6525in; 8.035in; 9.9375in; 21.625in

C, D, B+A, N_W, N_F

$\circlearrowleft+ \Sigma M_{N_F} = 0 = (230+14)lb_f(9.9375in) + 25lb_f(17.9725in) + 12lb_f(21.625) - N_W(20.625in)$

$N_W = 151.93 lb_f$

$\uparrow \Sigma F_y = 0 = (151.93 - 230 - 14 - 25 - 12)lb_f \qquad N_F = 129.07 lb_f$

Tipped at 30°

Assuming F_P acts at midpoint on bottom of handles

Distance from O

horiz

43.5; -5in

$d_{F_P} = \sqrt{5^2 + 43.5^2}$
$= 43.786$
$\theta = \tan^{-1}(43.5/5) = 83.4°$

30°
$x = 43.786\cos(83.4-30) = 26.080$
$y = 43.786\sin(83.4-30) = 35.172$

40° $x = 43.786\cos(83.4-40) = 31.791$
$y = 43.786\sin(83.4-40) = 30.109$

$\circlearrowleft+ \Sigma M_{N_W} = 0 = 14lb_f(7.718in) - 230lb_f(1.342in) + 12lb_f(13.114) + 25(21.648) - F_P(27.08in)$

$F_P = \boxed{10.408 lb_f \ @30°}$

Tipped at 40° $\circlearrowleft+ \Sigma M_{N_W} = 0 = -14lb_f(6.561in) + 230(1.636in) + 12lb_f(16.227in) + 25lb_f(28.401in) - F_P(32.791)$

$F_P = \boxed{36.3lb_f \ @40°}$

Force req to tip from horiz

$N_F = 0$ when starting to tip

CoG of assembly when horiz $\circlearrowleft+ \Sigma M_O = 0 = 281(d_{CoG}) - 14(10.5) - 230(10.5) + 12(1) - 25(2.485)$

$d_{CoG} = 9.294 in$

Pivoting over wheel $\circlearrowleft+ \Sigma M_{N_W} = F_P(49.5in) - 281lb_f(8.294in)$

$F_P > \boxed{47.08 lb_F \text{ to tip}}$

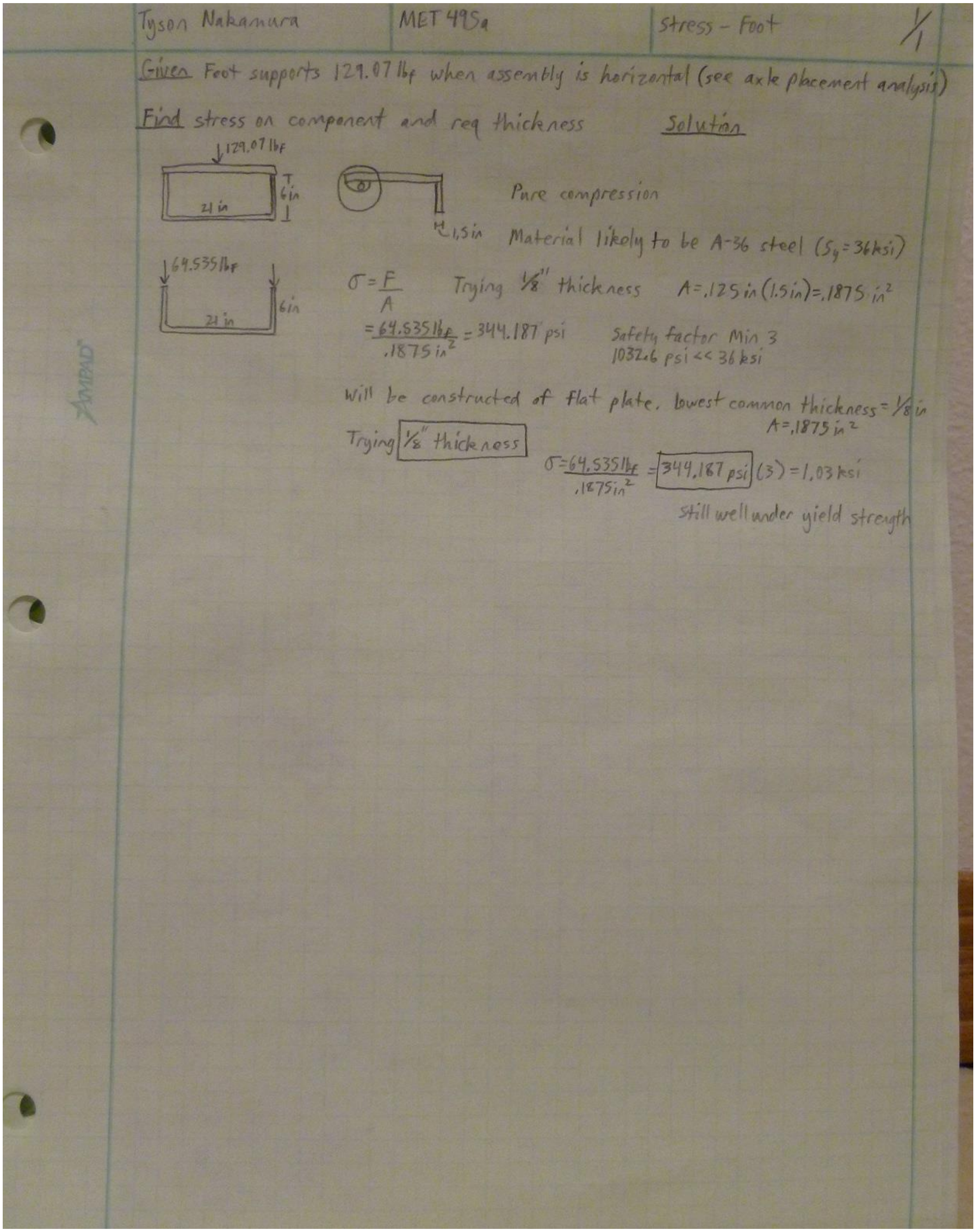
Repeating calcs for Nw at 1.5 and 2 in

	1in	1.5 in	2 in
F_P @ 30°	10.41 lb_f	15.31 lb_f	20.04 lb_f
F_P @ 40°	36.3 lb_f	39.94 lb_f	43.51 lb_f
F_P to Tip	47.08 lb_f	44.24 lb_f	35.73 lb_f

time spent holding at transport angle will be much greater than time spent tipping ∴ $\boxed{\text{1 in from O}}$

Force per handle $= \frac{10.41 lb_f}{2} = \boxed{5.205 lb_f}$ $\quad \frac{36.3 lb_f}{2} = \boxed{18.15 lb_f}$ $\quad \frac{47.08}{2} = \boxed{23.54 lb_f}$

Figure A - 2



Tyson Nakamura | MET 495a | Stress - Foot | 1/1

Given Foot supports 129.07 lbf when assembly is horizontal (see axle placement analysis)

Find stress on component and req thickness

Solution

129.07 lbf
6 in
21 in
1.5 in

Pure compression

Material likely to be A-36 steel (S_y = 36 ksi)

64.535 lbf
6 in
21 in

$\sigma = \frac{F}{A}$ Trying 1/8" thickness $A = .125\,in\,(1.5\,in) = .1875\,in^2$

$= \frac{64.535\,lbf}{.1875\,in^2} = 344.187\,psi$

Safety factor Min 3
1032.6 psi << 36 ksi

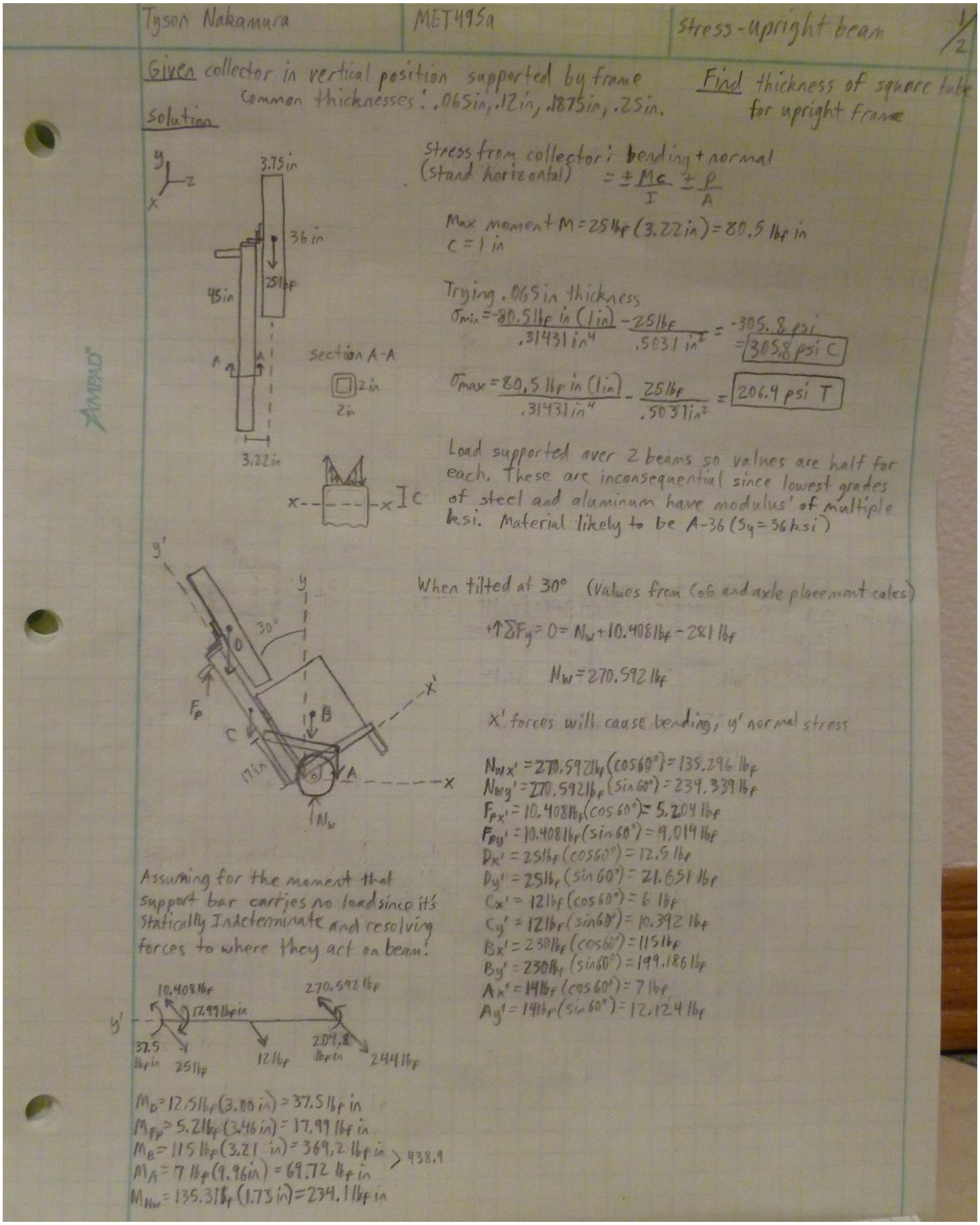
Will be constructed of flat plate. lowest common thickness = 1/8 in
A = .1875 in²

Trying $\boxed{\text{1/8" thickness}}$

$\sigma = \frac{64.535\,lbf}{.1875\,in^2} = \boxed{344.187\,psi}\,(3) = 1.03\,ksi$

Still well under yield strength

Figure A - 3



Tyson Nakamura | MET495a | Stress - upright beam 1/2

Given collector in vertical position supported by frame

Common thicknesses: .065in, .12in, .1875in, .25in.

Find thickness of square tube for upright frame

Solution

Stress from collector: bending + normal

(stand horizontal) $= \pm \frac{Mc}{I} \pm \frac{P}{A}$

Max moment $M = 25\,lb_f (3.22\,in) = 80.5\,lb_f\,in$

$c = 1\,in$

Trying .065in thickness

$\sigma_{min} = \frac{-80.5\,lb_f\,in\,(1\,in)}{.31431\,in^4} - \frac{25\,lb_f}{.5031\,in^2} = -305.8\,psi = \boxed{305.8\,psi\ C}$

$\sigma_{max} = \frac{80.5\,lb_f\,in\,(1\,in)}{.31431\,in^4} - \frac{25\,lb_f}{.5031\,in^2} = \boxed{206.4\,psi\ T}$

Load supported over 2 beams so values are half for each. These are inconsequential since lowest grades of steel and aluminum have modulus' of multiple ksi. Material likely to be A-36 ($S_y = 36\,ksi$)

When tilted at 30° (Values from CoG and axle placement calcs)

$+\uparrow \Sigma F_y = 0 = N_w + 10.408\,lb_f - 281\,lb_f$

$N_w = 270.592\,lb_f$

x' forces will cause bending, y' normal stress

$N_{wx'} = 270.592\,lb_f (\cos 60°) = 135.296\,lb_f$

$N_{wy'} = 270.592\,lb_f (\sin 60°) = 234.339\,lb_f$

$F_{px'} = 10.408\,lb_f (\cos 60°) = 5.204\,lb_f$

$F_{py'} = 10.408\,lb_f (\sin 60°) = 9.014\,lb_f$

$D_{x'} = 25\,lb_f (\cos 60°) = 12.5\,lb_f$

$D_{y'} = 25\,lb_f (\sin 60°) = 21.651\,lb_f$

$C_{x'} = 12\,lb_f (\cos 60°) = 6\,lb_f$

$C_{y'} = 12\,lb_f (\sin 60°) = 10.392\,lb_f$

$B_{x'} = 230\,lb_f (\cos 60°) = 115\,lb_f$

$B_{y'} = 230\,lb_f (\sin 60°) = 199.186\,lb_f$

$A_{x'} = 14\,lb_f (\cos 60°) = 7\,lb_f$

$A_{y'} = 14\,lb_f (\sin 60°) = 12.124\,lb_f$

Assuming for the moment that support bar carries no load since it's Statically Indeterminate and resolving forces to where they act on beam:

$M_D = 12.5\,lb_f (3.00\,in) = 37.5\,lb_f\,in$

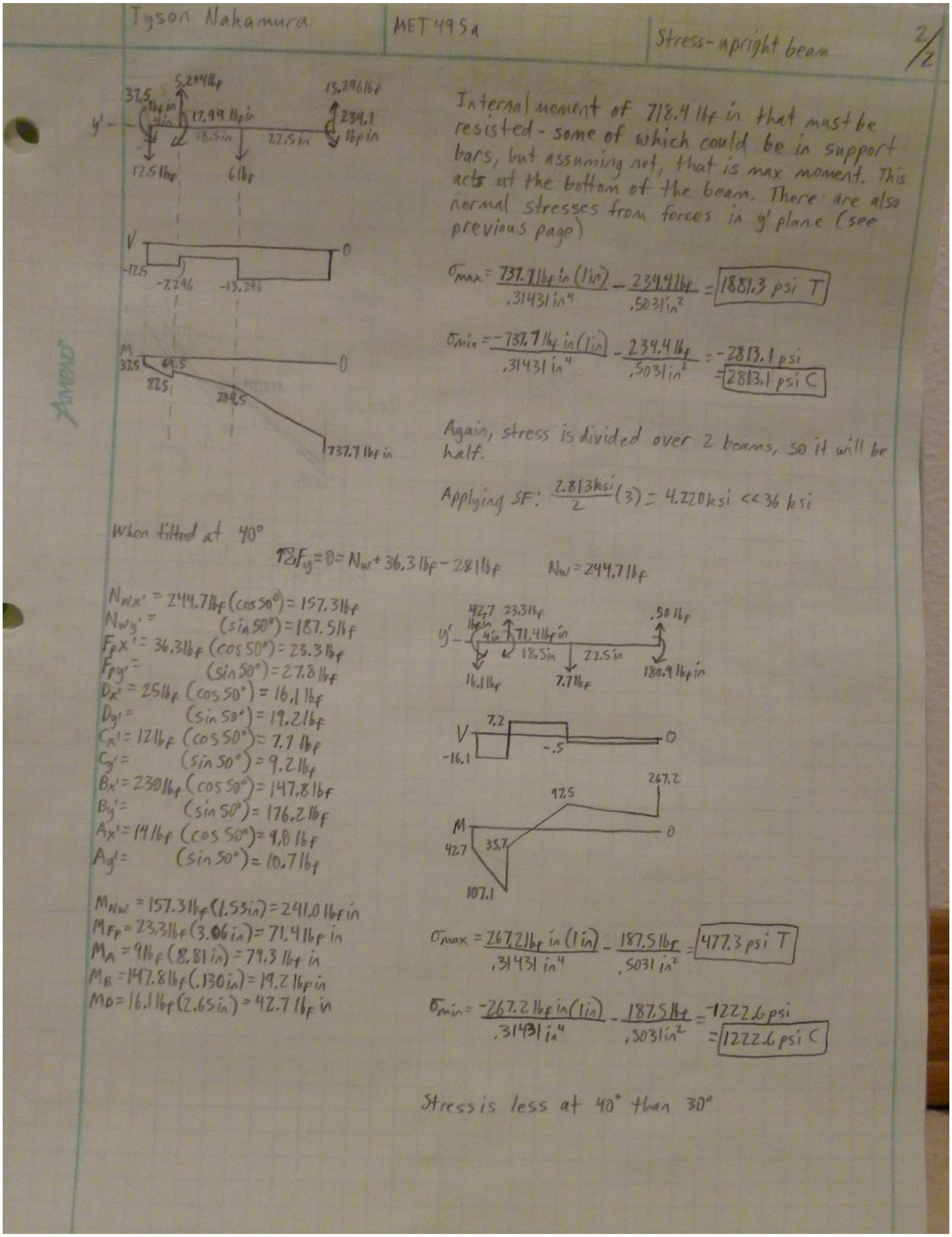
$M_{Fp} = 5.2\,lb_f (3.46\,in) = 17.99\,lb_f\,in$

$M_B = 115\,lb_f (3.21\,in) = 369.2\,lb_f\,in$ } 438.9

$M_A = 7\,lb_f (9.96\,in) = 69.72\,lb_f\,in$

$M_{Nw} = 135.3\,lb_f (1.73\,in) = 234.1\,lb_f\,in$

Figure A - 4a



Tyson Nakamura | MET 495a | Stress- upright beam | 2/2

Internal moment of 718.4 lbf in that must be resisted - some of which could be in support bars, but assuming not, that is max moment. This acts at the bottom of the beam. There are also normal stresses from forces in y' plane (see previous page)

$$\sigma_{max} = \frac{737.7\,lbf\,in\,(1in)}{.31431\,in^4} - \frac{234.4\,lbf}{.5031\,in^2} = \boxed{1881.3\ psi\ T}$$

$$\sigma_{min} = \frac{-737.7\,lbf\,in\,(1in)}{.31431\,in^4} - \frac{234.4\,lbf}{.5031\,in^2} = -2813.1\ psi = \boxed{2813.1\ psi\ C}$$

Again, stress is divided over 2 beams, so it will be half.

Applying SF: $\frac{2.813ksi}{2}(3) = 4.220ksi << 36\ ksi$

When tilted at 40°

$$\uparrow\Sigma F_y = 0 = N_w + 36.3\,lbf - 281\,lbf \qquad N_w = 244.7\,lbf$$

$N_{wx'} = 244.7\,lbf(\cos 50^0) = 157.3\,lbf$
$N_{wy'} = (\sin 50°) = 187.5\,lbf$
$F_{px'} = 36.3\,lbf\,(\cos 50°) = 23.3\,lbf$
$F_{py'} = (\sin 50°) = 27.8\,lbf$
$D_{x'} = 25\,lbf\,(\cos 50°) = 16.1\,lbf$
$D_{y'} = (\sin 50°) = 19.2\,lbf$
$C_{x'} = 12\,lbf\,(\cos 50°) = 7.7\,lbf$
$C_{y'} = (\sin 50°) = 9.2\,lbf$
$B_{x'} = 230\,lbf\,(\cos 50°) = 147.8\,lbf$
$B_{y'} = (\sin 50°) = 176.2\,lbf$
$A_{x'} = 14\,lbf\,(\cos 50°) = 9.0\,lbf$
$A_{y'} = (\sin 50°) = 10.7\,lbf$

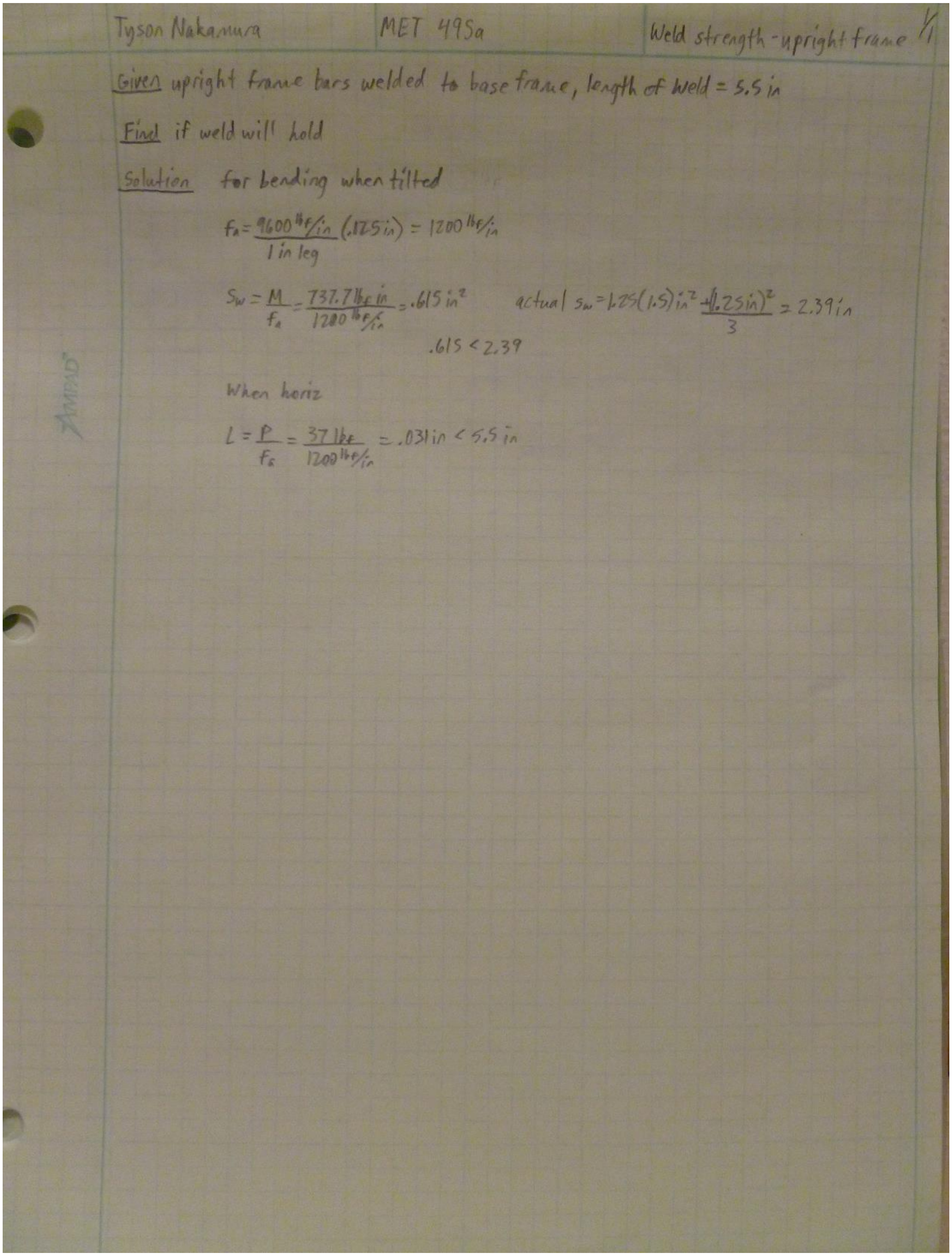
$M_{Nw} = 157.3\,lbf(1.53in) = 241.0\,lbf\,in$
$M_{Fp} = 23.3\,lbf(3.06in) = 71.4\,lbf\,in$
$M_A = 9\,lbf(8.81\,in) = 79.3\,lbf\,in$
$M_B = 147.8\,lbf(.130in) = 19.2\,lbf\,in$
$M_D = 16.1\,lbf(2.65in) = 42.7\,lbf\,in$

$$\sigma_{max} = \frac{267.2\,lbf\,in\,(1\,in)}{.31431\,in^4} - \frac{187.5\,lbf}{.5031\,in^2} = \boxed{477.3\ psi\ T}$$

$$\sigma_{min} = \frac{-267.2\,lbf\,in(1in)}{.31431\,in^4} - \frac{187.5\,lbf}{.5031\,in^2} = -1222.6\,psi = \boxed{1222.6\ psi\ C}$$

Stress is less at 40° than 30°

Figure A - 4b



Tyson Nakamura
MET 495a
Weld strength - upright frame 1/1

Given upright frame bars welded to base frame, length of weld = 5.5 in

Find if weld will hold

Solution for bending when tilted

$$f_a = \frac{9600\ lb_f/in}{1\ in\ leg}(.125\ in) = 1200\ lb_f/in$$

$$S_w = \frac{M}{f_a} = \frac{737.7\ lb_f\ in}{1200\ lb_f/in} = .615\ in^2$$

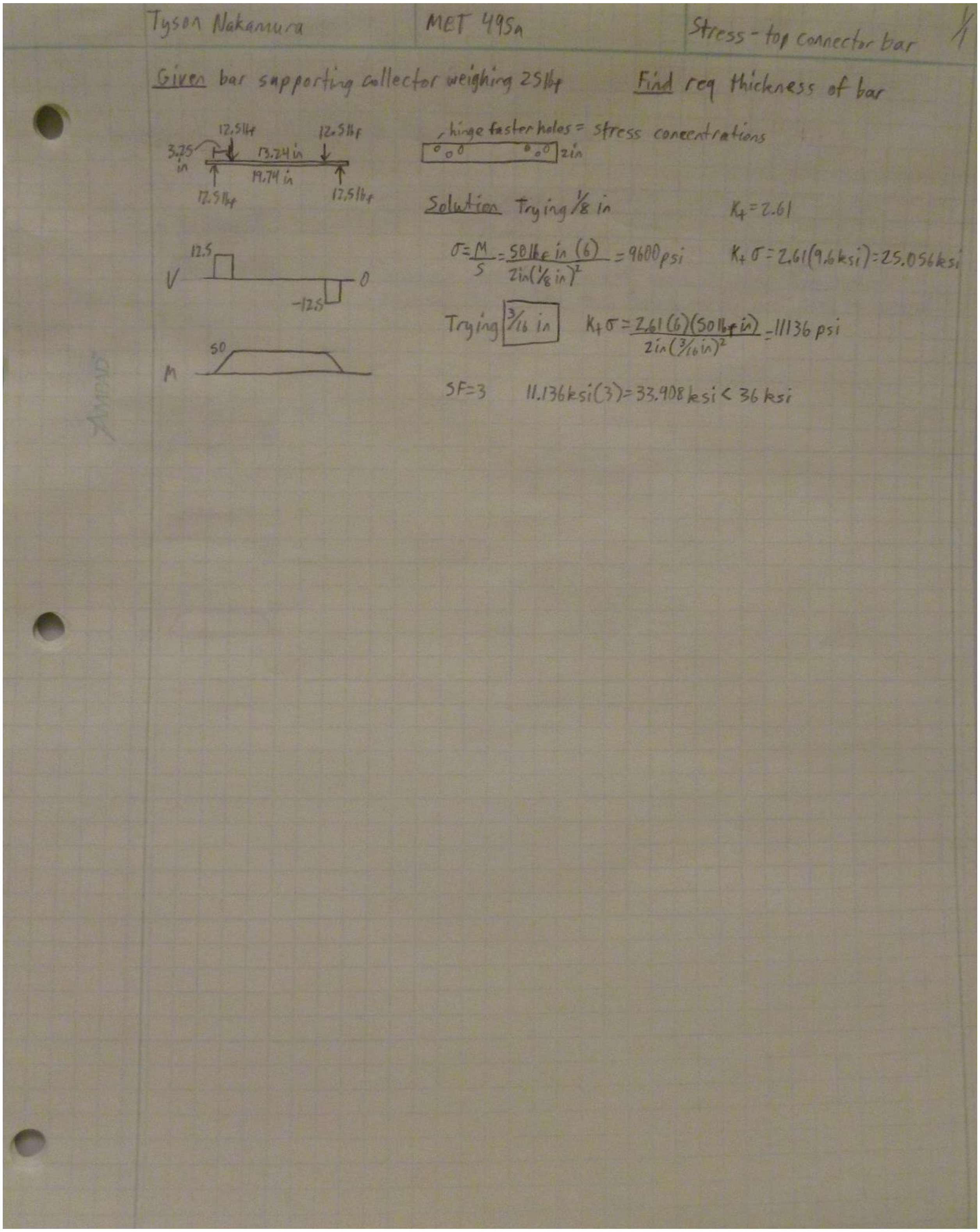
$$\text{actual } s_w = 1.25(1.5)\ in^2 \frac{+(1.25\ in)^2}{3} = 2.39\ in$$

$$.615 < 2.39$$

When horiz

$$L = \frac{P}{f_a} = \frac{37\ lb_f}{1200\ lb_f/in} = .031\ in < 5.5\ in$$

Figure A - 5



Tyson Nakamura | MET 495a | Stress - top connector bar | 1/1

Given bar supporting collector weighing 25lbf

Find req thickness of bar

Solution Trying $\frac{1}{8}$ in

$K_t = 2.61$

$$\sigma = \frac{M}{S} = \frac{50\,lb_f\,in\,(6)}{2in(\frac{1}{8}in)^2} = 9600\,psi$$

$$K_t\sigma = 2.61(9.6ksi) = 25.056ksi$$

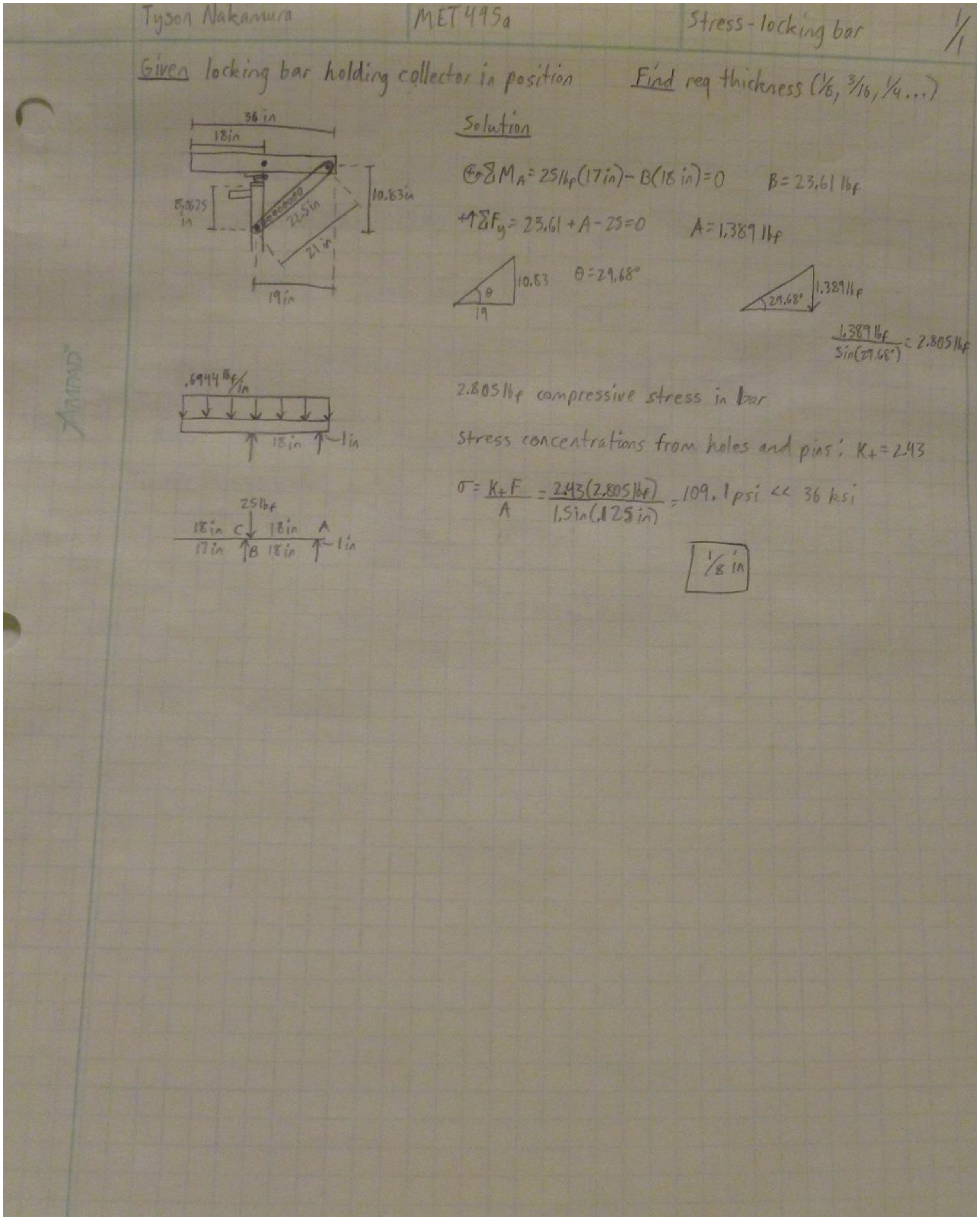
Trying $\boxed{\frac{3}{16}\,in}$

$$K_t\sigma = \frac{2.61(6)(50\,lb_f\,in)}{2in(\frac{3}{16}in)^2} = 11136\,psi$$

SF=3

$11.136ksi(3) = 33.908\,ksi < 36\,ksi$

Figure A - 6



Tyson Nakamura | MET 495a | Stress - locking bar | 1/1

Given locking bar holding collector in position

Find req thickness (1/8, 3/16, 1/4...)

Solution

$\circlearrowleft + \sum M_A = 25\,lb_f(17\,in) - B(18\,in) = 0 \qquad B = 23.61\,lb_f$

$+\uparrow \sum F_y = 23.61 + A - 25 = 0 \qquad A = 1.389\,lb_f$

$\theta = 29.68°$

$\frac{1.389\,lb_f}{\sin(29.68°)} = 2.805\,lb_f$

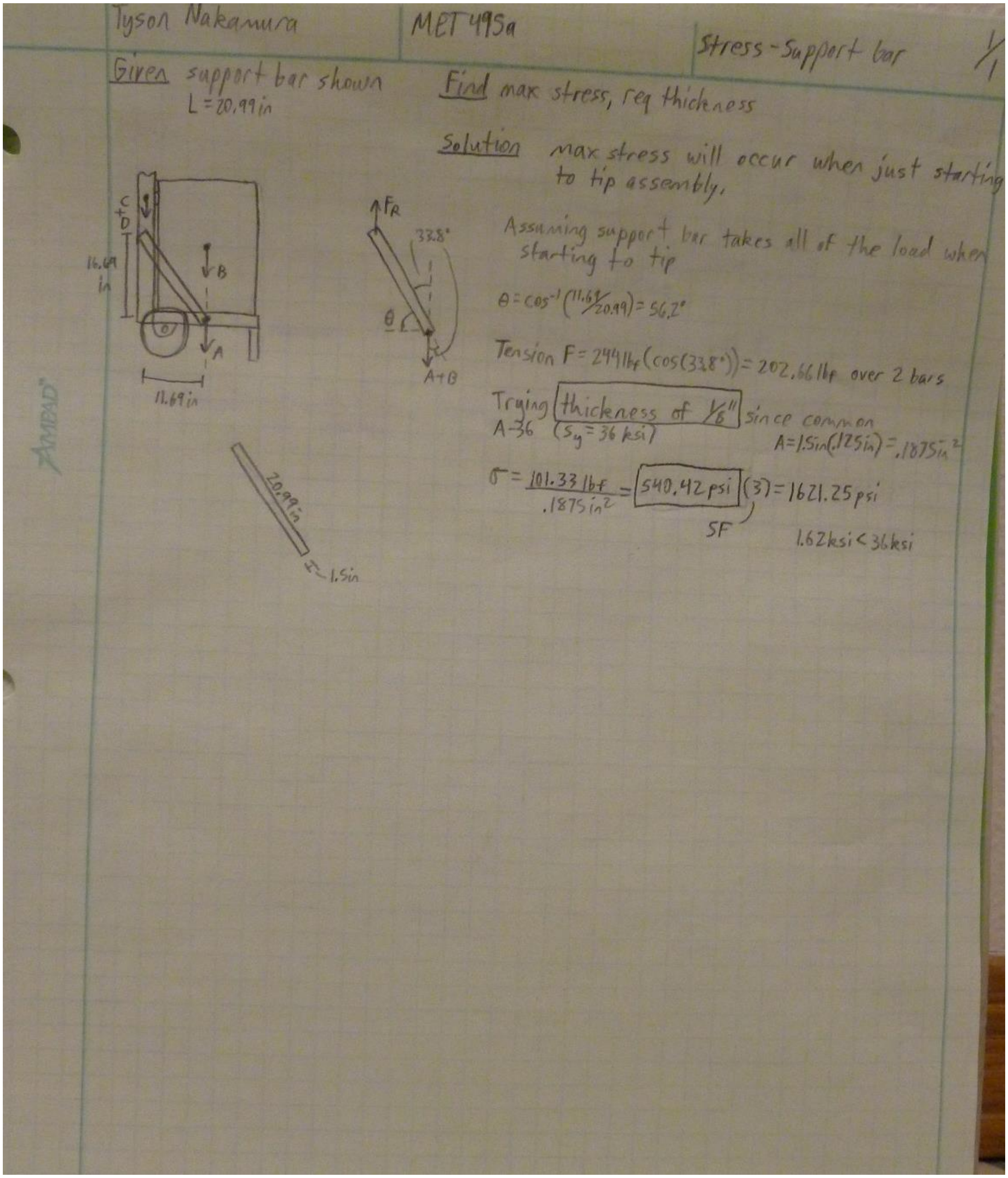
2.805 lbf compressive stress in bar

stress concentrations from holes and pins: $K_t = 2.43$

$\sigma = \frac{K_t F}{A} = \frac{2.43(2.805\,lb_f)}{1.5in(.125\,in)} = 109.1\,psi << 36\,ksi$

$\boxed{1/8\,in}$

Figure A - 7



Tyson Nakamura | MET 495a | Stress - Support bar | 1/1

Given support bar shown

$L = 20.99 \text{ in}$

Find max stress, req thickness

Solution max stress will occur when just starting to tip assembly.

Assuming support bar takes all of the load when starting to tip

$\theta = \cos^{-1}(11.69/20.99) = 56.2°$

Tension $F = 244 \text{ lbf} (\cos(33.8°)) = 202.66 \text{ lbf}$ over 2 bars

Trying $\boxed{\text{thickness of } 1/8''}$ since common

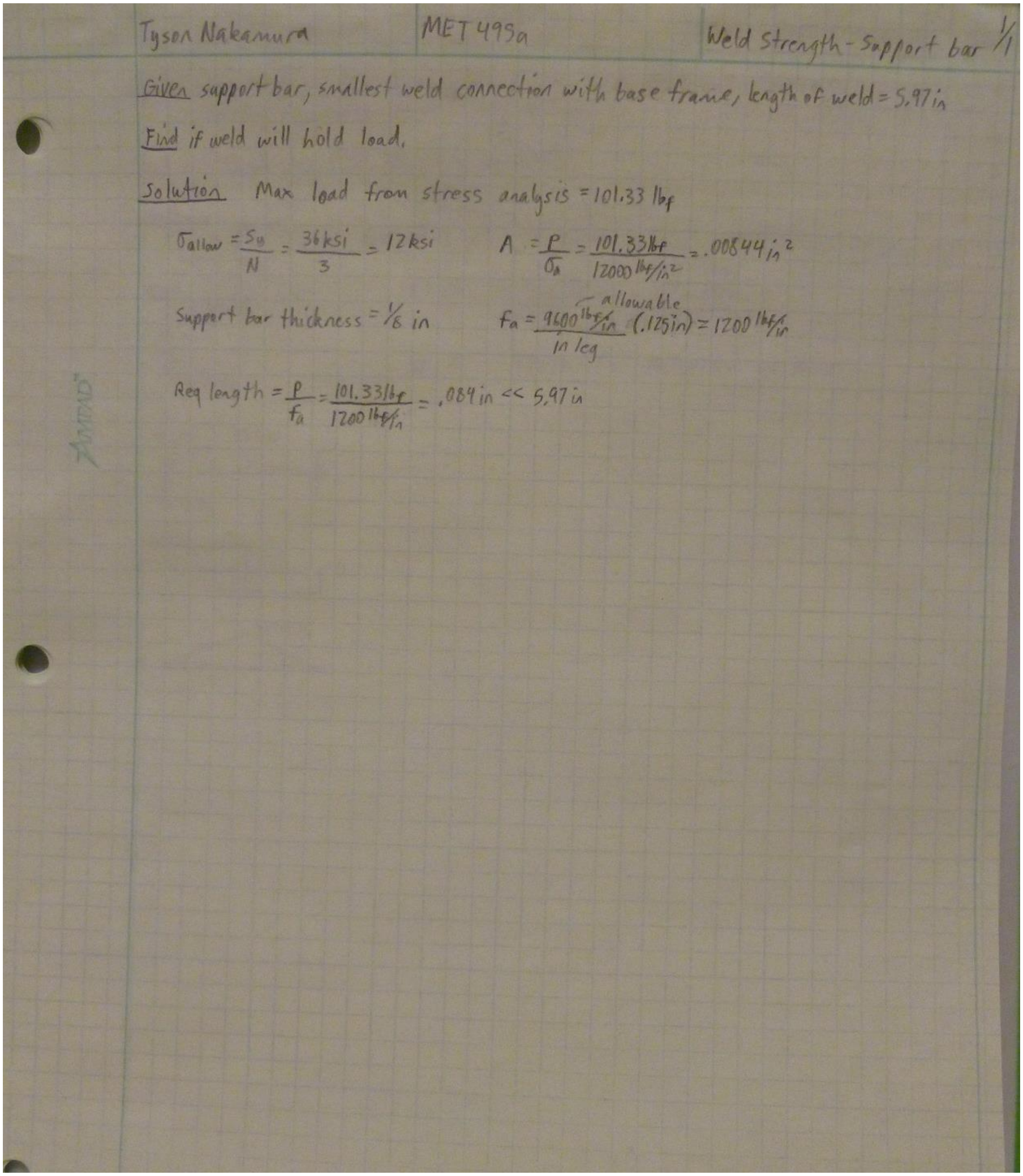
A-36 $(S_y = 36 \text{ ksi})$

$A = 1.5 \text{in}(.125 \text{in}) = .1875 \text{in}^2$

$\sigma = \frac{101.33 \text{ lbf}}{.1875 \text{ in}^2} = \boxed{540.42 \text{ psi}} \underbrace{(3)}_{SF} = 1621.25 \text{ psi}$

$1.62 \text{ ksi} < 36 \text{ ksi}$

Figure A - 8



Tyson Nakamura | MET 495a | Weld Strength - Support bar 1/1

Given support bar, smallest weld connection with base frame, length of weld = 5.97 in

Find if weld will hold load.

Solution Max load from stress analysis = 101.33 lb_f

$\sigma_{allow} = \frac{S_y}{N} = \frac{36 ksi}{3} = 12 ksi$

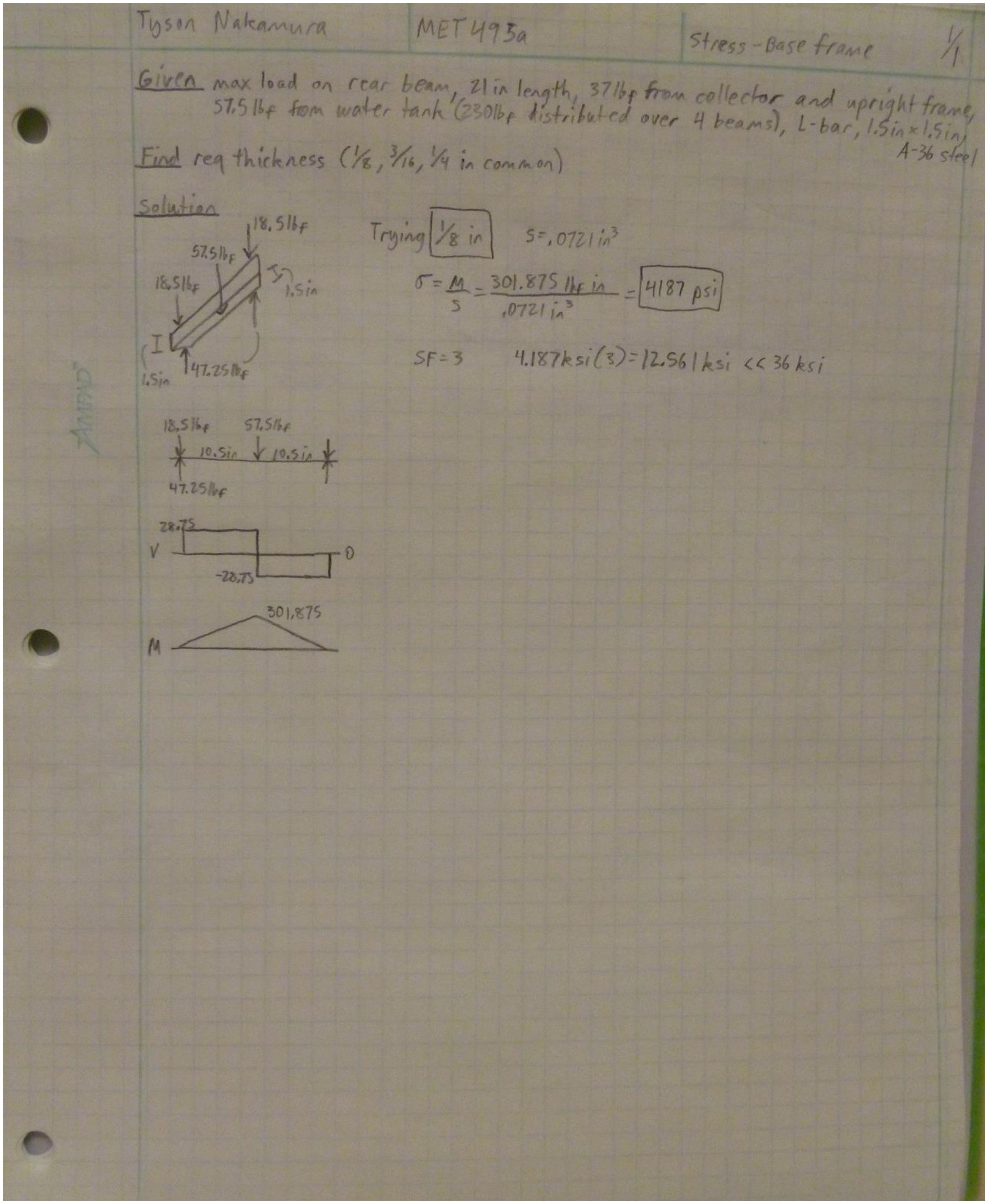
$A = \frac{P}{\sigma_a} = \frac{101.33 lbf}{12000 lbf/in^2} = .00844 in^2$

Support bar thickness = $\frac{1}{8}$ in

$f_a = \frac{\overset{\text{allowable}}{9600\ lbf/in}}{\text{in leg}}(.125 in) = 1200\ lbf/in$

Req length $= \frac{P}{f_a} = \frac{101.33 lbf}{1200 lbf/in} = .084 in << 5.97 in$

Figure A - 9



Tyson Nakamura | MET 493a | Stress - Base frame | 1/1

Given max load on rear beam, 21 in length, 37 lbf from collector and upright frame, 57.5 lbf from water tank (230 lbf distributed over 4 beams), L-bar, 1.5 in × 1.5 in, A-36 steel

Find req thickness (1/8, 3/16, 1/4 in common)

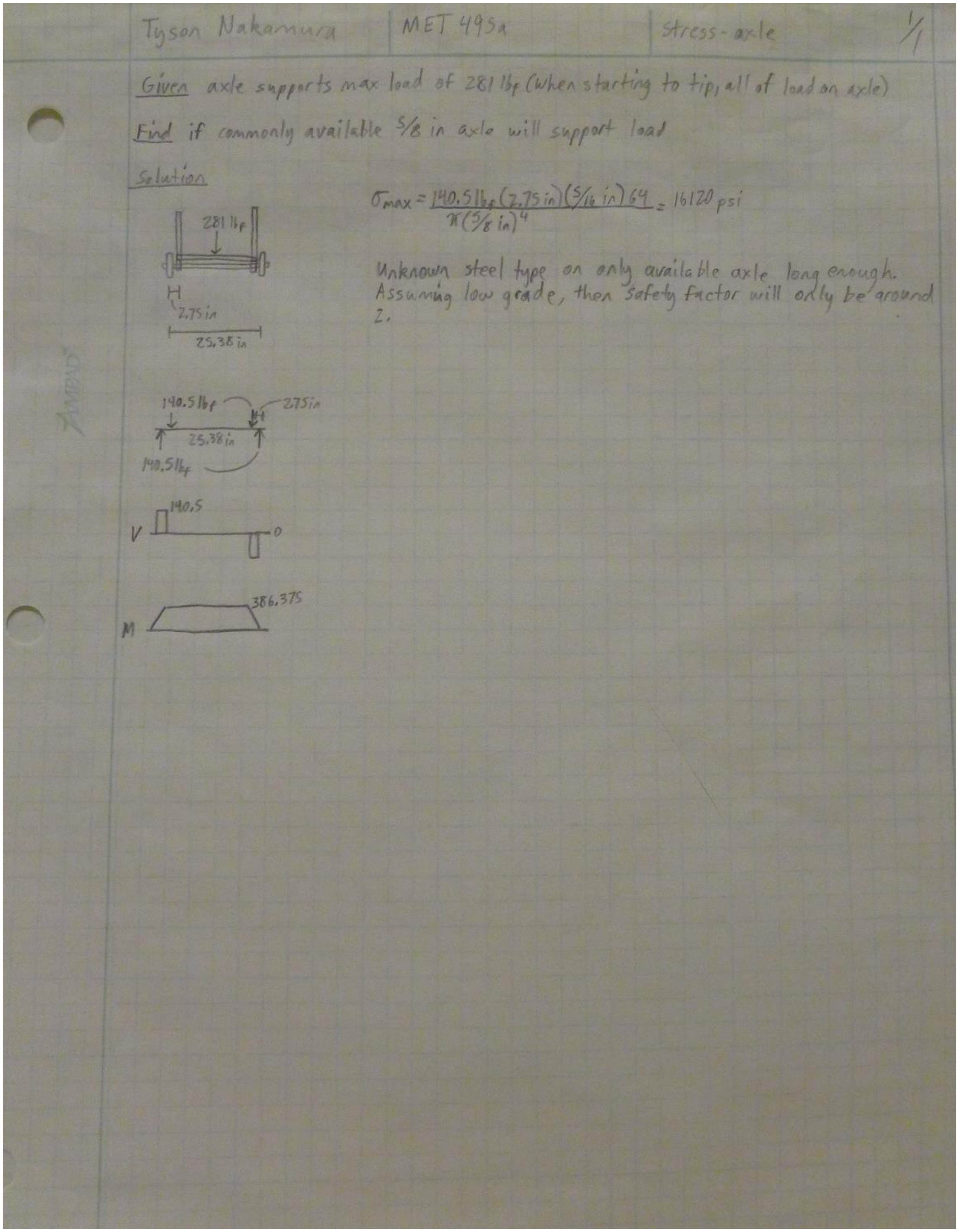
Solution

Trying $\boxed{1/8 \text{ in}}$ $S = .0721 \text{ in}^3$

$$\sigma = \frac{M}{S} = \frac{301.875 \text{ lbf in}}{.0721 \text{ in}^3} = \boxed{4187 \text{ psi}}$$

SF = 3 $4.187 \text{ ksi}(3) = 12.561 \text{ ksi} << 36 \text{ ksi}$

Figure A - 10



Tyson Nakamura | MET 495a | Stress- axle | 1/1

<u>Given</u> axle supports max load of 281 lbf (when starting to tip, all of load on axle)

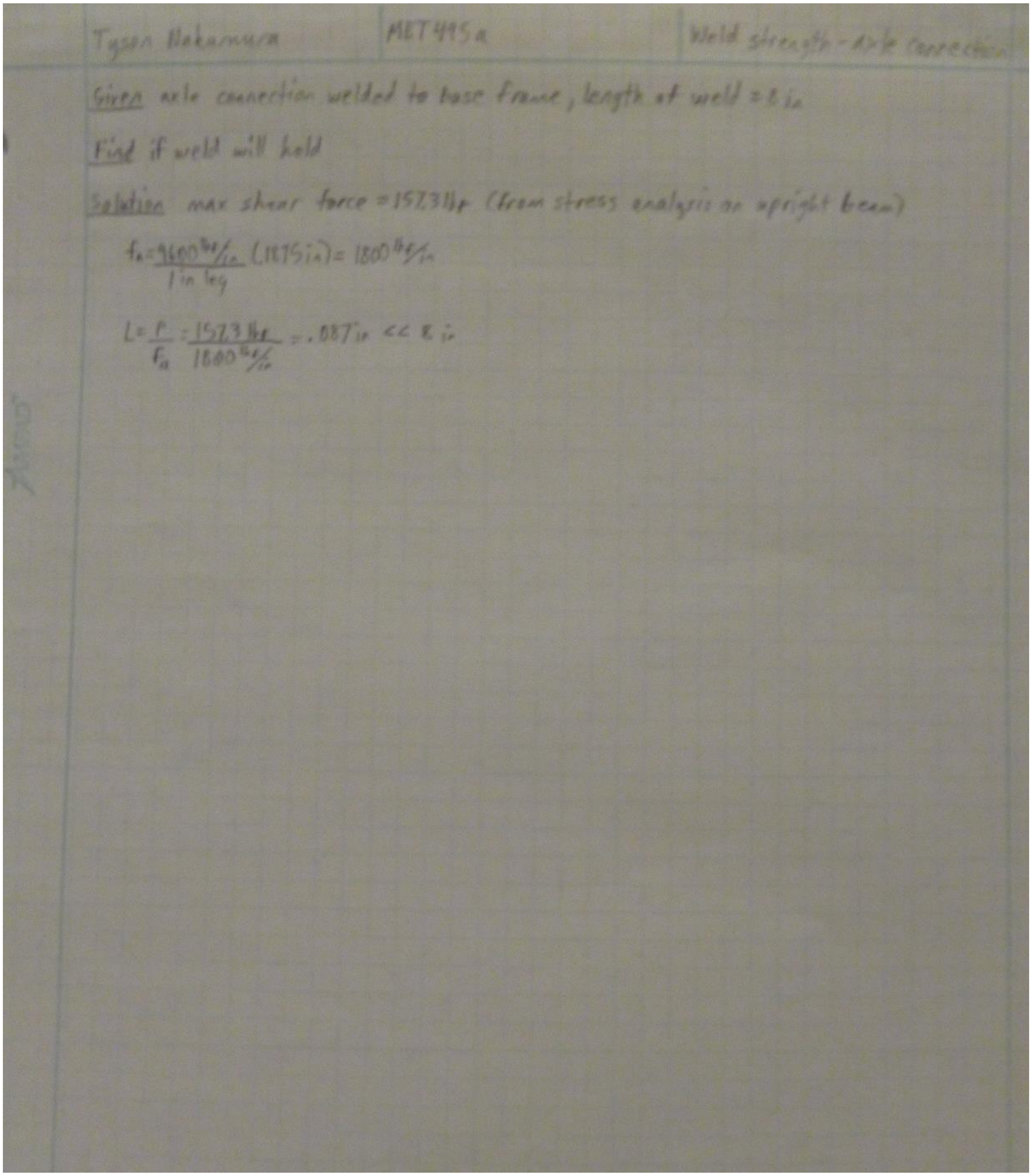
<u>Find</u> if commonly available 5/8 in axle will support load

<u>Solution</u>

$$\sigma_{max} = \frac{140.5\,lb_f\,(2.75\,in)(5/16\,in)\,64}{\pi(5/8\,in)^4} = 16120\,psi$$

Unknown steel type on only available axle long enough. Assuming low grade, then safety factor will only be around 2.

Figure A - 11



Tyson Nakamura | MET 495 a | Weld strength - Axle connection

Given axle connection welded to base frame, length of weld = 8 in

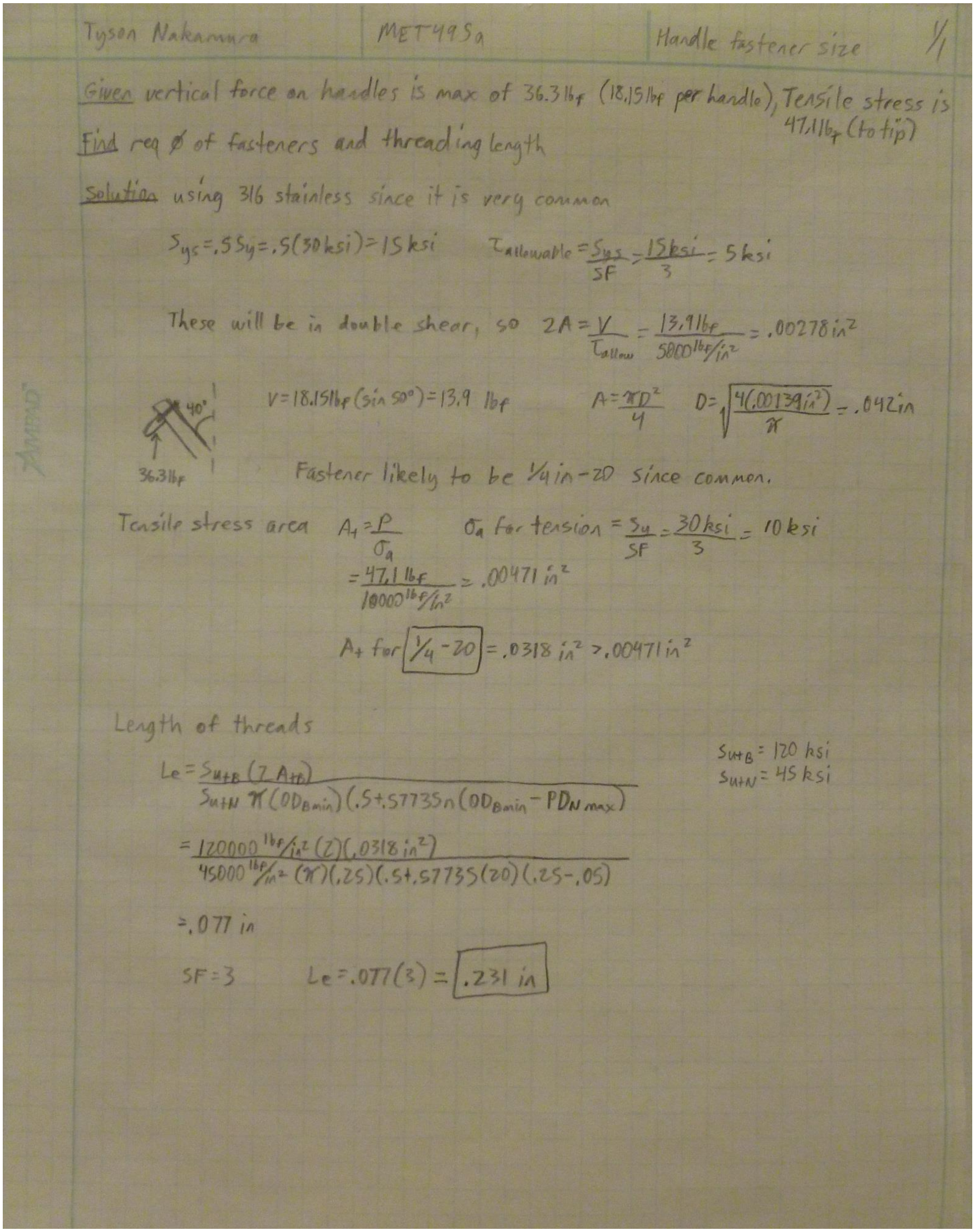
Find if weld will hold

Solution max shear force = 157.3 lbf (from stress analysis on upright beam)

$$f_a = \frac{9600 \, ^{lbs}/_{in}}{1 \text{ in leg}} (.1875 \text{ in}) = 1800 \, ^{lbs}/_{in}$$

$$L = \frac{P}{f_a} = \frac{157.3 \text{ lbs}}{1800 \, ^{lbs}/_{in}} = .087 \text{ in} << 8 \text{ in}$$

Figure A - 12



Tyson Nakamura MET495a Handle fastener size 1/1

<u>Given</u> vertical force on handles is max of 36.3 lb_f (18.15 lb_f per handle), Tensile stress is 47.1 lb_f (to tip)

<u>Find</u> req ∅ of fasteners and threading length

<u>Solution</u> using 316 stainless since it is very common

$S_{ys} = .5 S_y = .5(30 ksi) = 15 ksi \quad \tau_{allowable} = \frac{S_{ys}}{SF} = \frac{15 ksi}{3} = 5 ksi$

These will be in double shear, so $2A = \frac{V}{\tau_{allow}} = \frac{13.9 lb_f}{5000 lb_f/in^2} = .00278 in^2$

40°

36.3 lb_f

$V = 18.15 lb_f (\sin 50°) = 13.9\ lb_f \quad A = \frac{\pi D^2}{4} \quad D = \sqrt{\frac{4(.00139 in^2)}{\pi}} = .042 in$

Fastener likely to be 1/4 in-20 since common.

Tensile stress area $A_t = \frac{P}{\sigma_a} \quad \sigma_a$ for tension $= \frac{S_y}{SF} = \frac{30 ksi}{3} = 10 ksi$

$= \frac{47.1 lb_f}{10000 lb_f/in^2} = .00471 in^2$

A_t for $\boxed{1/4 - 20} = .0318 in^2 > .00471 in^2$

Length of threads

$S_{utB} = 120 ksi$
$S_{utN} = 45 ksi$

$$Le = \frac{S_{utB}(2 A_{tB})}{S_{utN}\pi(OD_{Bmin})(.5 + .57735n(OD_{Bmin} - PD_{Nmax})}$$

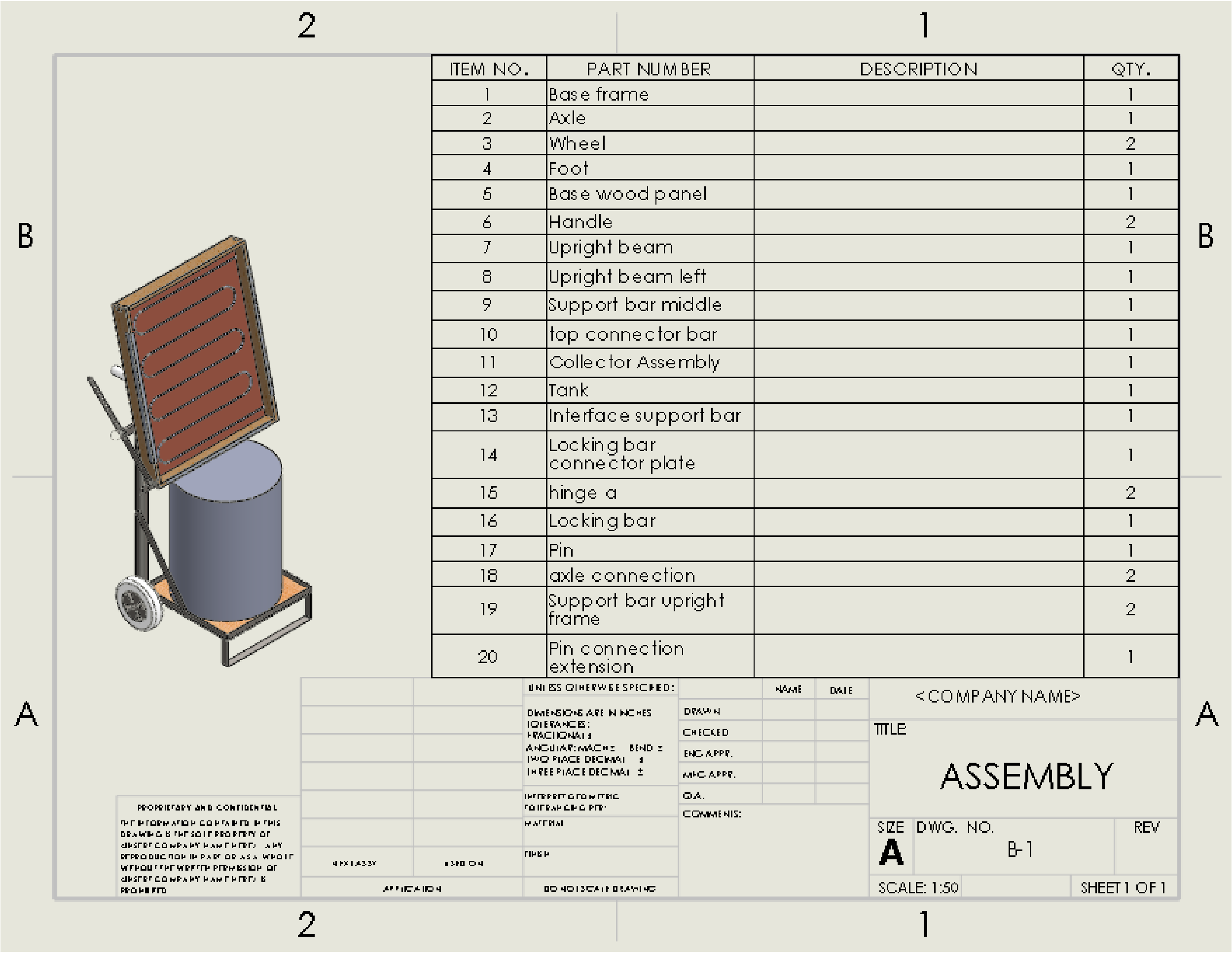
$$= \frac{120000 lb_f/in^2 (2)(.0318 in^2)}{45000 lb_f/in^2 (\pi)(.25)(.5 + .57735(20)(.25 - .05)}$$

$= .077 in$

$SF = 3 \quad Le = .077(3) = \boxed{.231 in}$

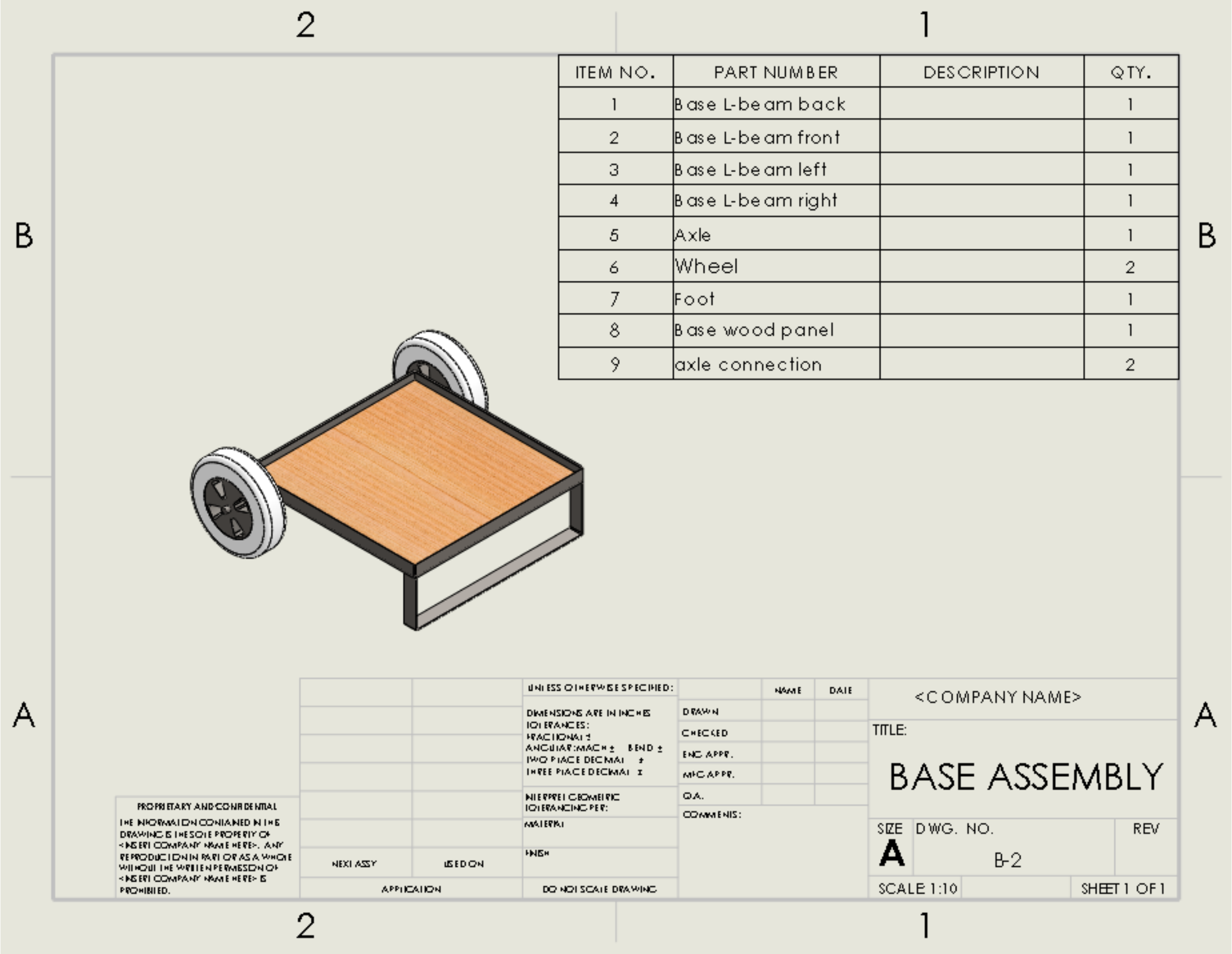
Figure A - 13

APPENDIX B – Sketches, Assembly drawings, Sub-assembly drawings, Part drawings



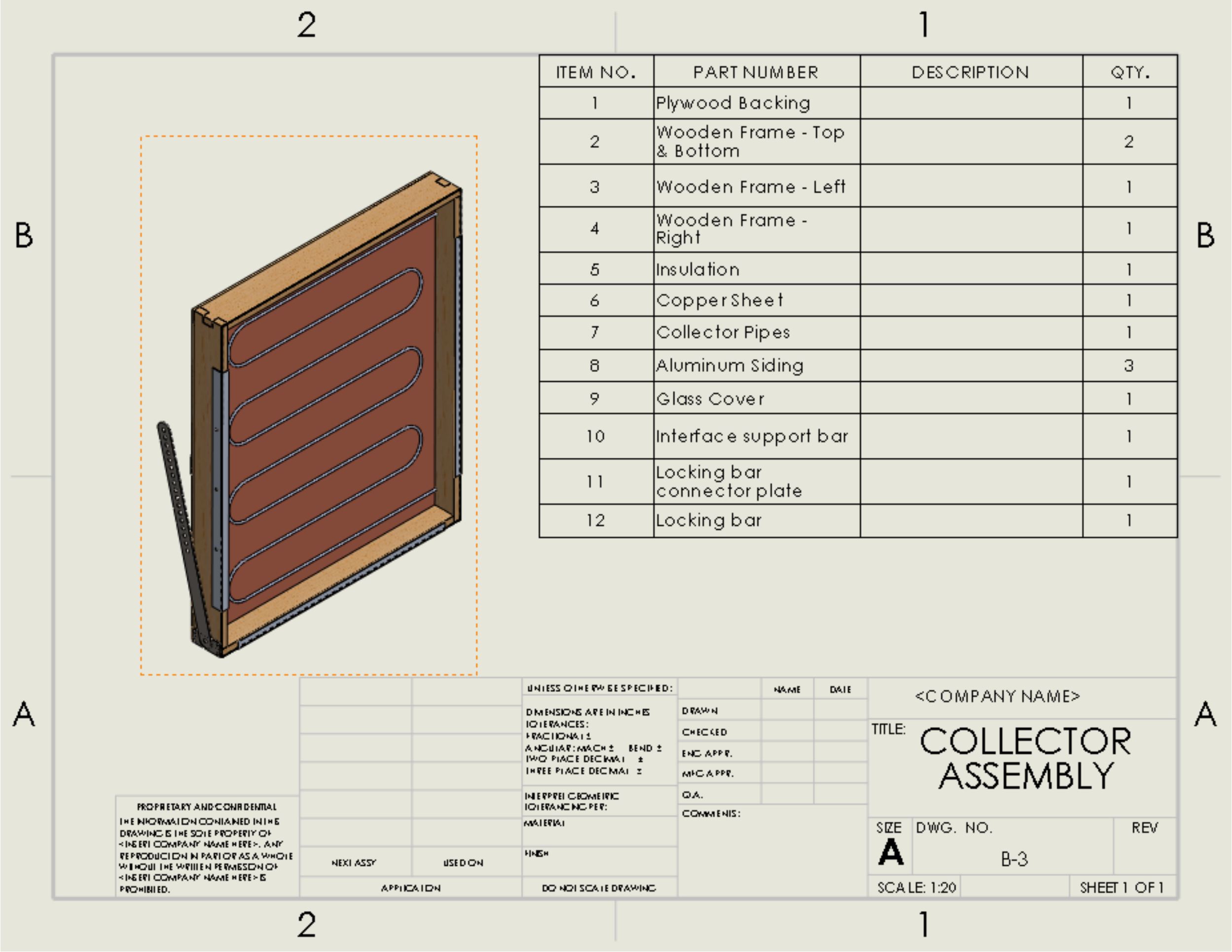
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base frame		1
2	Axle		1
3	Wheel		2
4	Foot		1
5	Base wood panel		1
6	Handle		2
7	Upright beam		1
8	Upright beam left		1
9	Support bar middle		1
10	top connector bar		1
11	Collector Assembly		1
12	Tank		1
13	Interface support bar		1
14	Locking bar connector plate		1
15	hinge a		2
16	Locking bar		1
17	Pin		1
18	axle connection		2
19	Support bar upright frame		2
20	Pin connection extension		1

Figure B-1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base L-beam back		1
2	Base L-beam front		1
3	Base L-beam left		1
4	Base L-beam right		1
5	Axle		1
6	Wheel		2
7	Foot		1
8	Base wood panel		1
9	axle connection		2

Figure B-2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Plywood Backing		1
2	Wooden Frame - Top & Bottom		2
3	Wooden Frame - Left		1
4	Wooden Frame - Right		1
5	Insulation		1
6	Copper Sheet		1
7	Collector Pipes		1
8	Aluminum Siding		3
9	Glass Cover		1
10	Interface support bar		1
11	Locking bar connector plate		1
12	Locking bar		1

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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.		

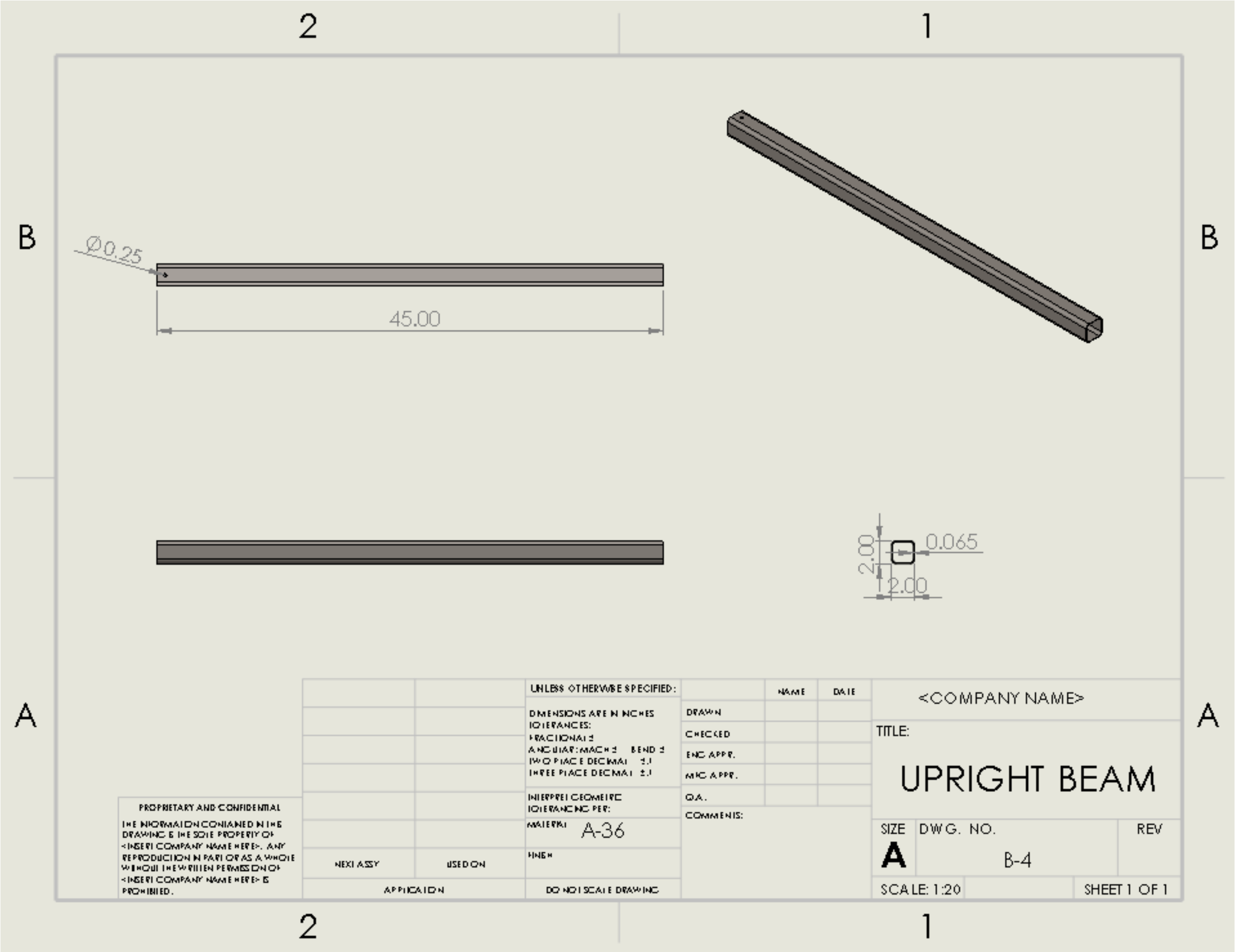
COMMENTS:

<COMPANY NAME>

TITLE: COLLECTOR ASSEMBLY

SIZE A
DWG. NO. B-3
REV
SCALE: 1:20
SHEET 1 OF 1

Figure B-3


2
1
B
B
Ø0.25
45.00
2.00
0.065
2.00
A
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.1
THREE PLACE DECIMAL ±.1
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL A-36
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
UPRIGHT BEAM
SIZE
A
DWG. NO.
B-4
REV
SCALE: 1:20
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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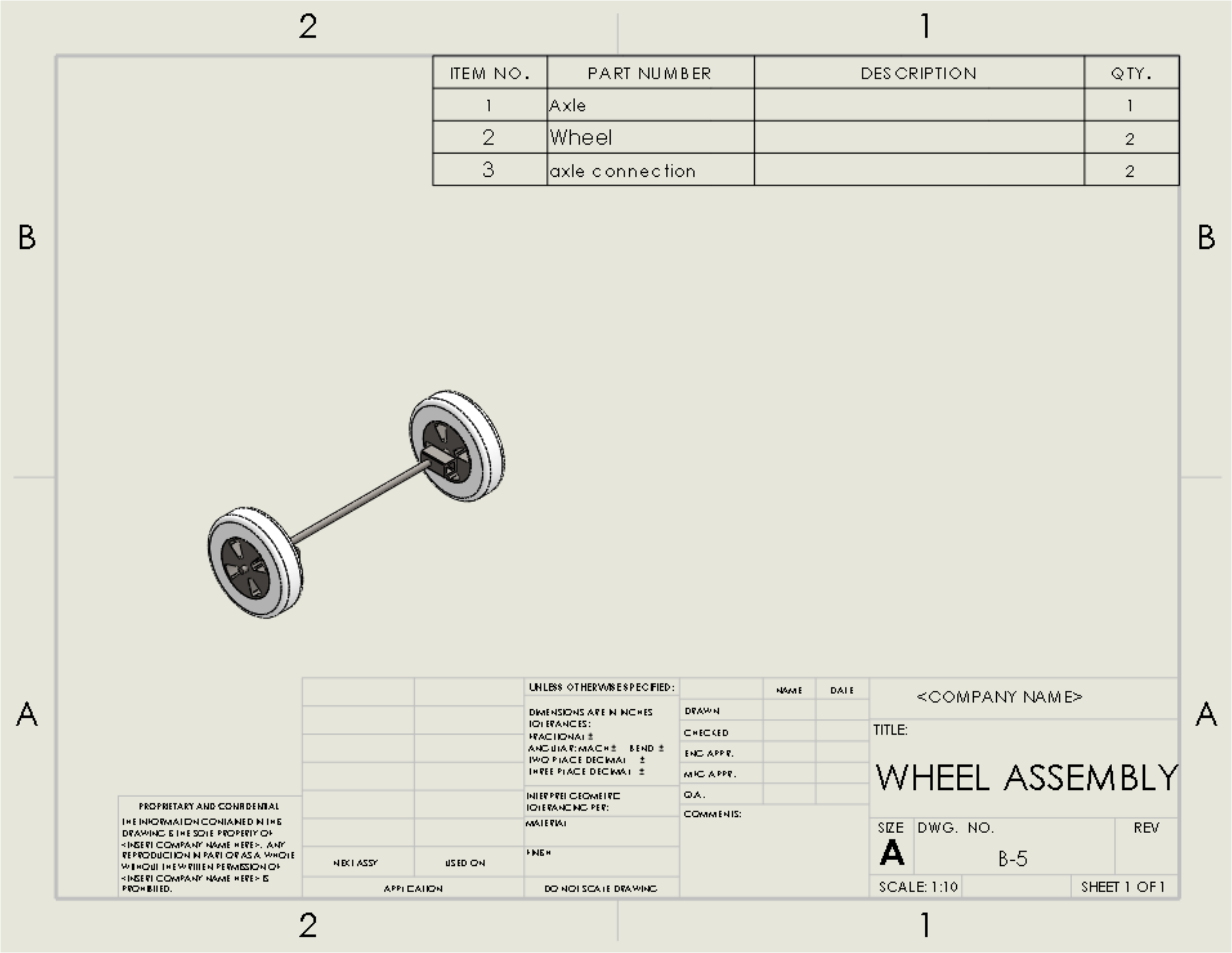
2
1

Figure B-4



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Axle		1
2	Wheel		2
3	axle connection		2

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

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

PROPRIETARY AND CONFIDENTIAL

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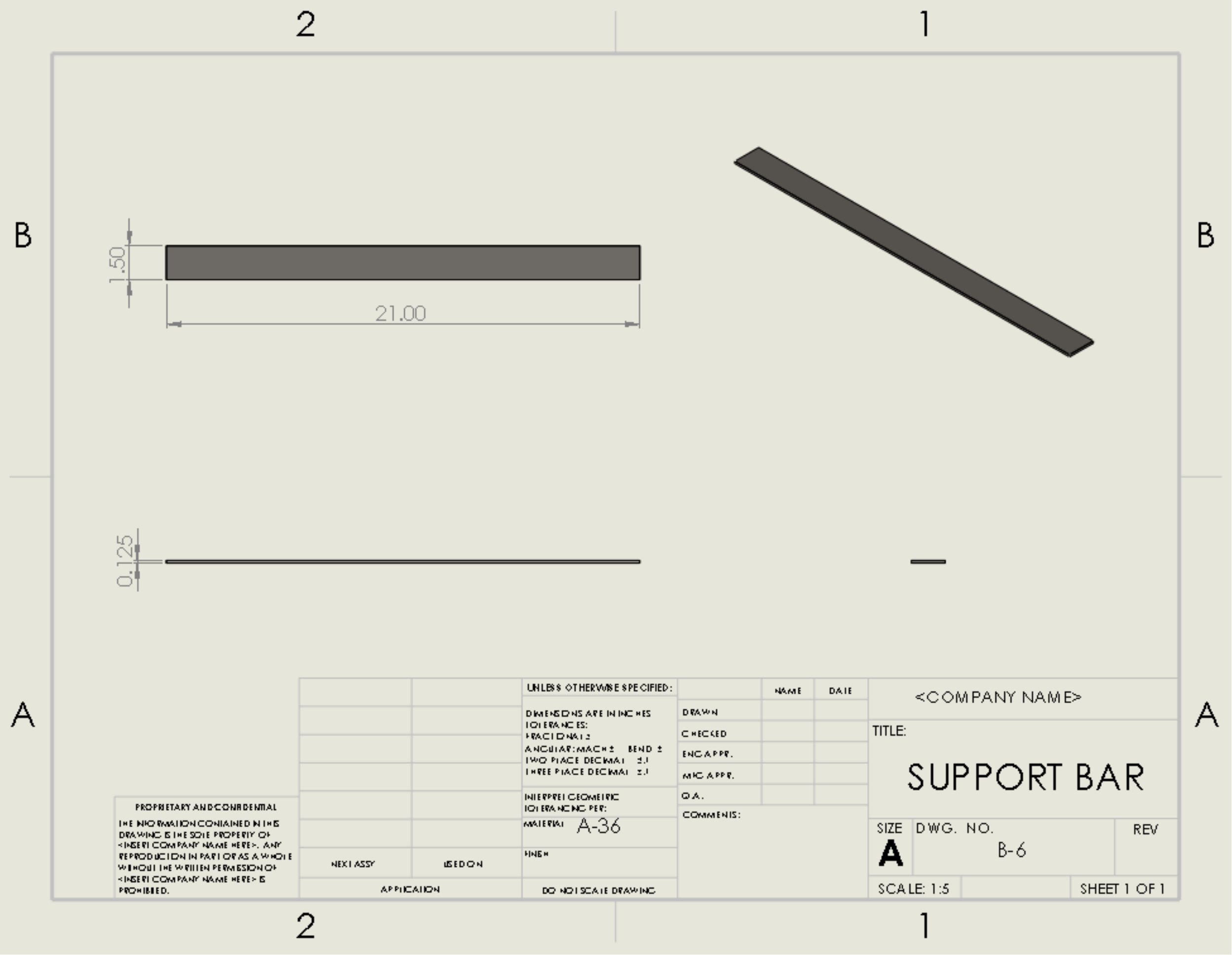
TITLE: WHEEL ASSEMBLY
SIZE A
DWG. NO. B-5
SCALE: 1:10
SHEET 1 OF 1

Figure B-5


2
1
B
B
A
A
1.50
21.00
0.125
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.1
THREE PLACE DECIMAL ±.1
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL A-36
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
SUPPORT BAR
SIZE
A
DWG. NO.
B-6
REV
SCALE: 1:5
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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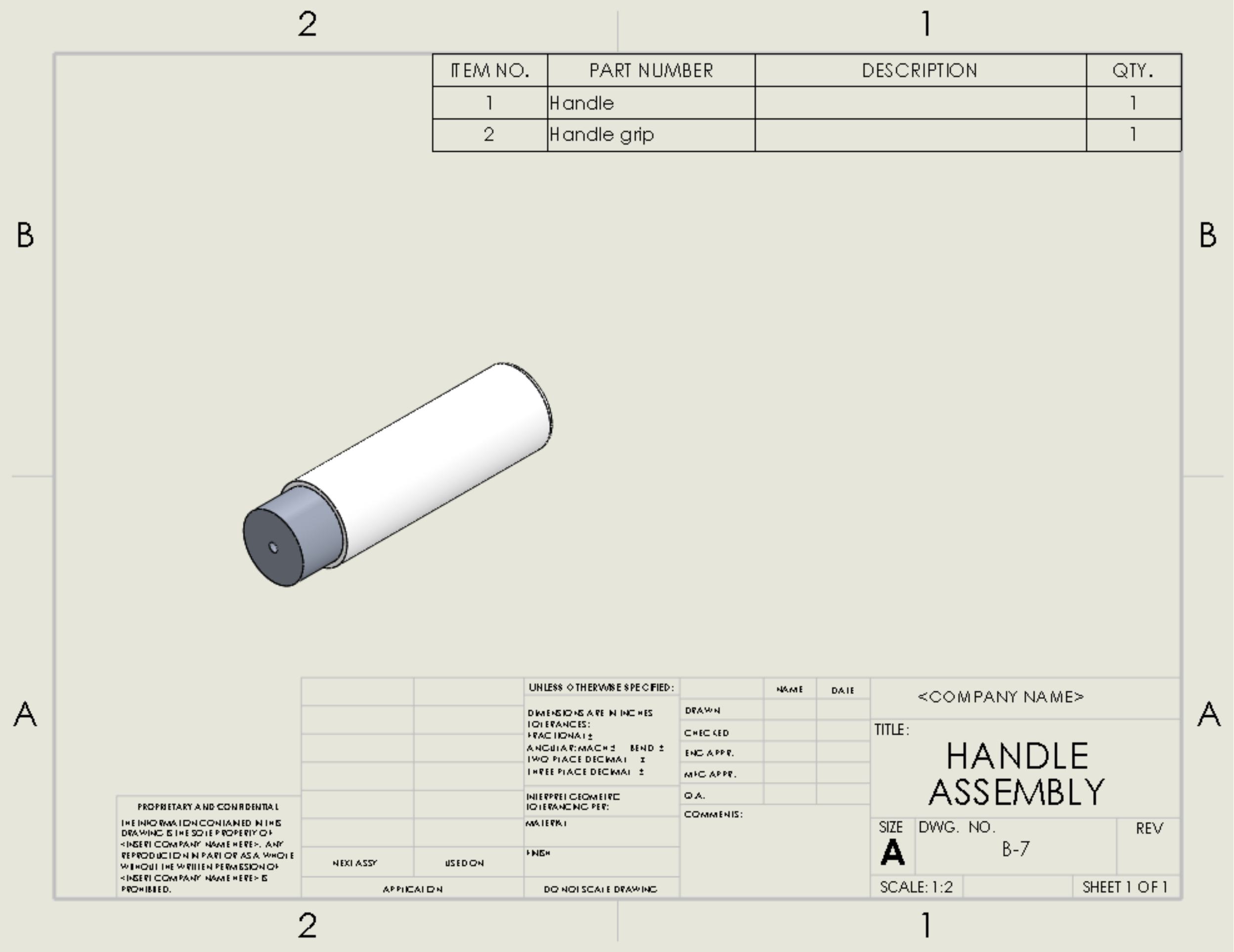
2
1

Figure B-6



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Handle		1
2	Handle grip		1

Figure B-7

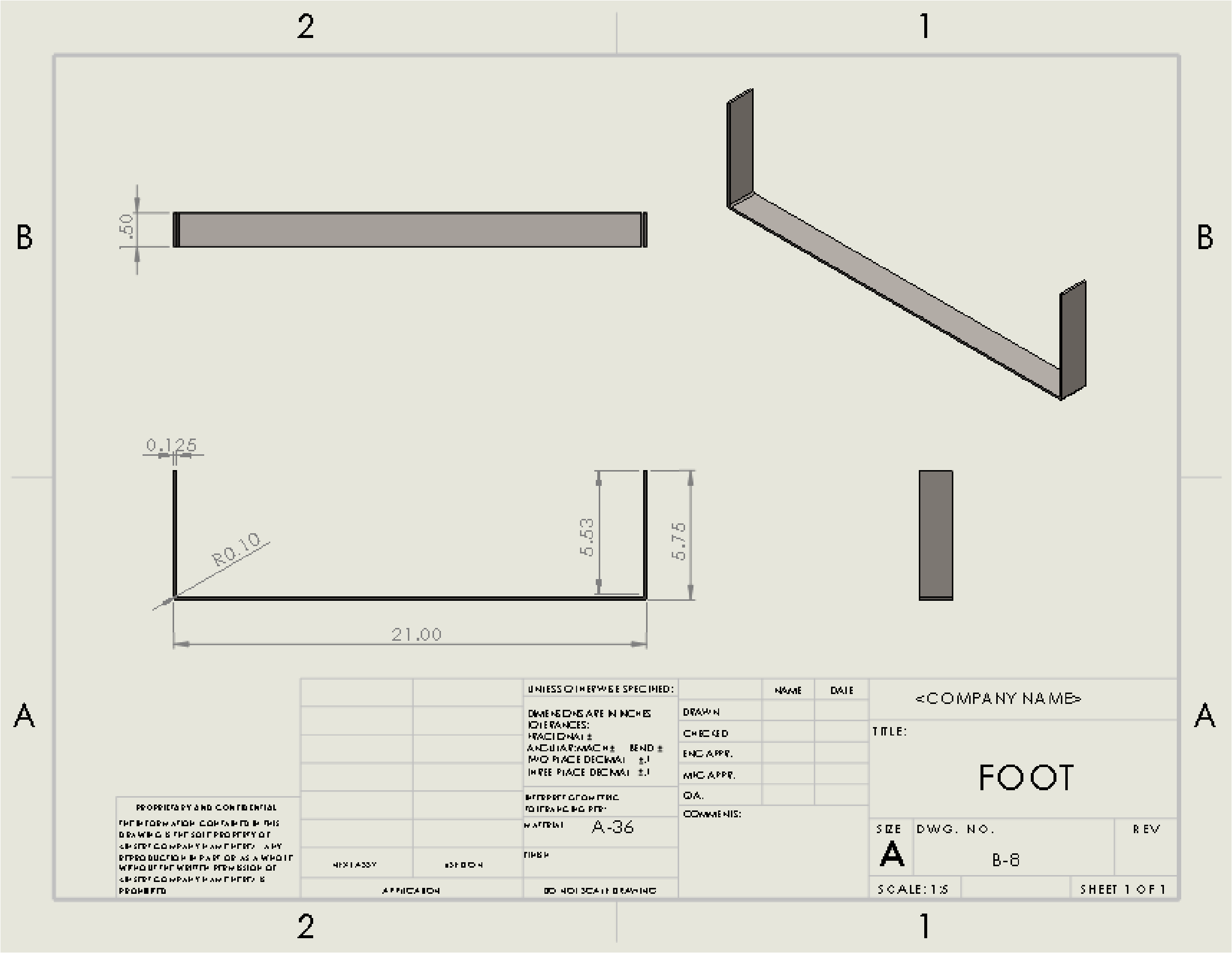

2
1
B
A
1.50
0.125
R0.10
5.53
5.75
21.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.1
THREE PLACE DECIMAL ±.1
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL A-36
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
FOOT
SIZE
A
DWG. NO.
B-8
REV
SCALE: 1:5
SHEET 1 OF 1
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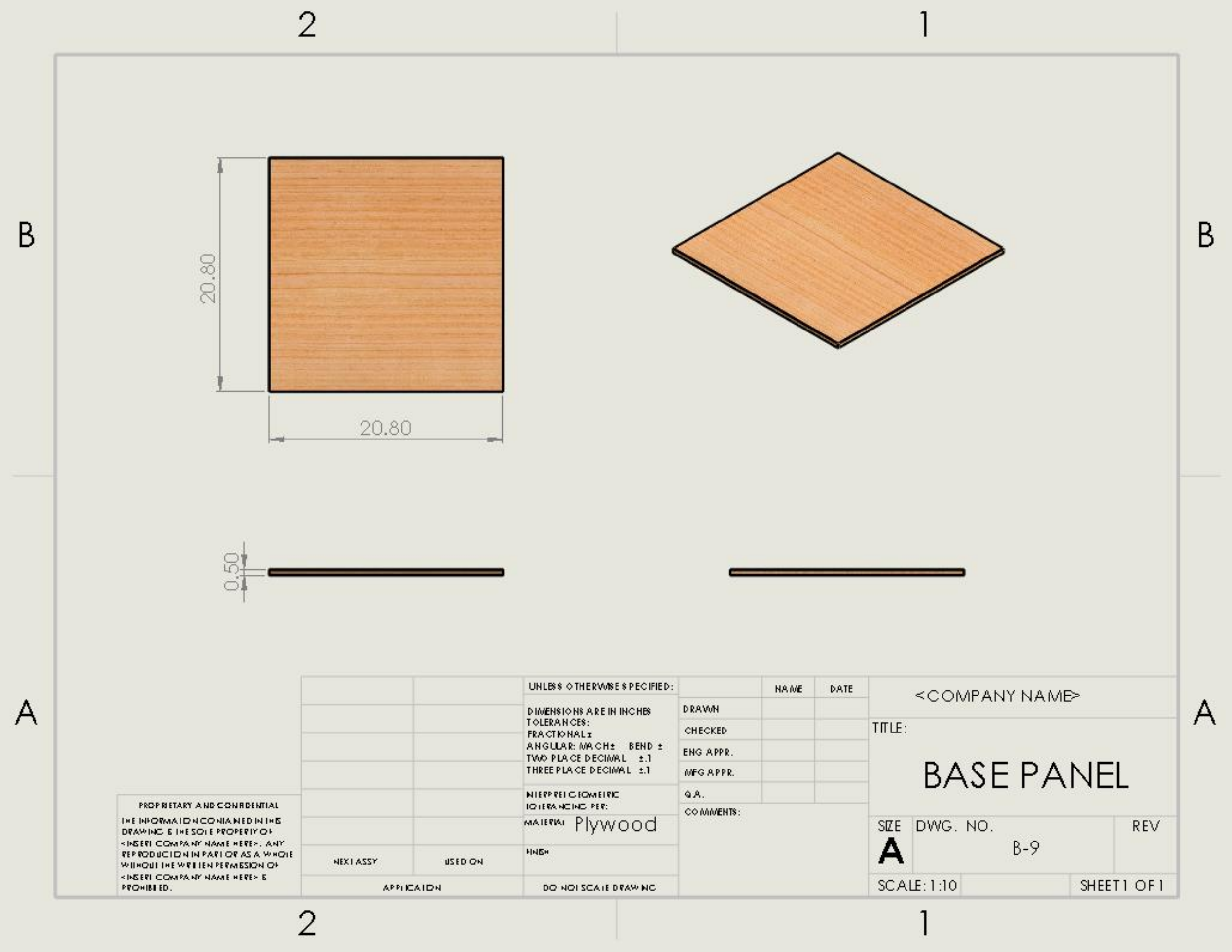
Figure B-8


2
1
B
B
A
A
20.80
20.80
0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.1
THREE PLACE DECIMAL ±.1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Plywood
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
BASE PANEL
SIZE
A
DWG. NO.
B-9
REV
SCALE: 1:10
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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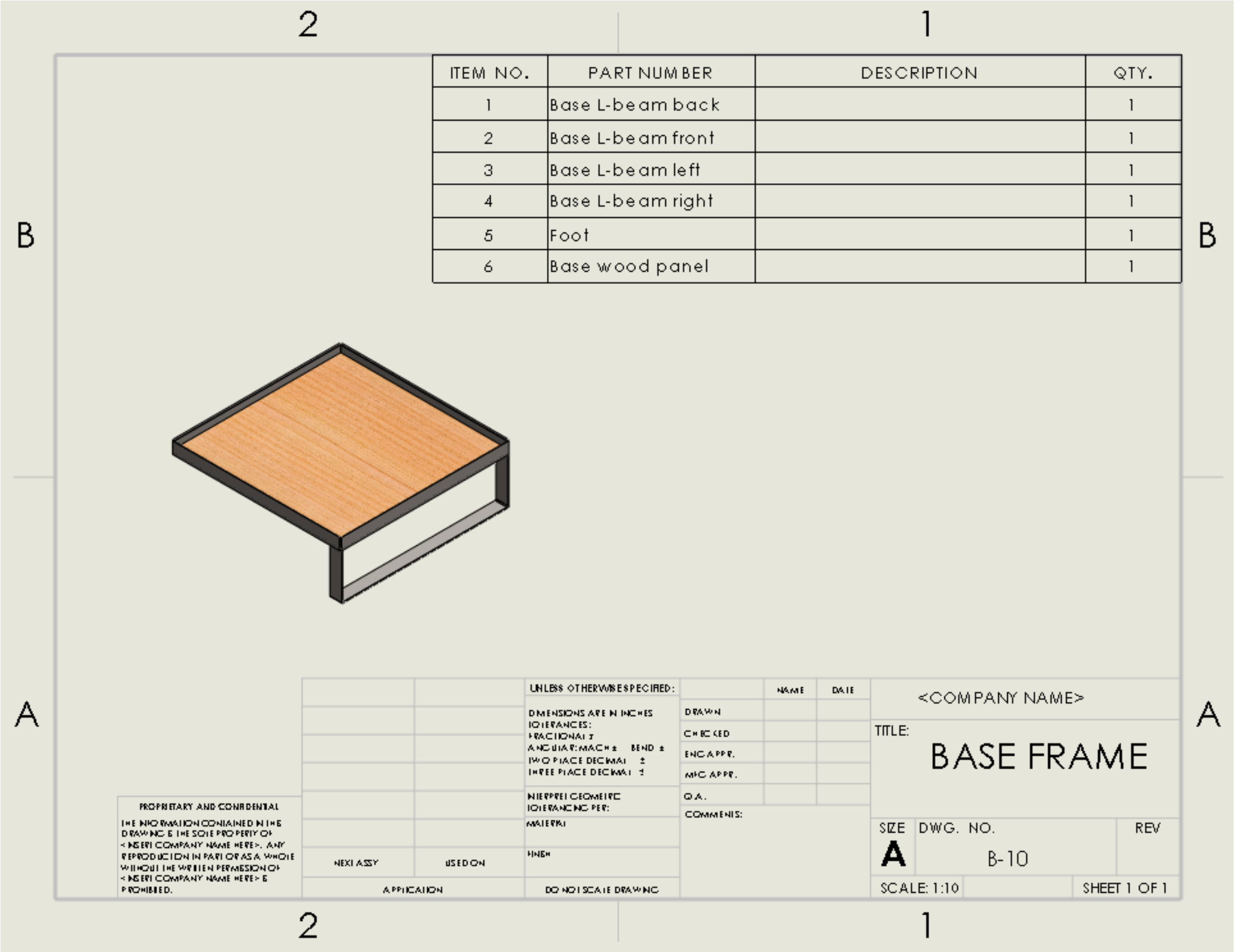
2
1

Figure B-9



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base L-beam back		1
2	Base L-beam front		1
3	Base L-beam left		1
4	Base L-beam right		1
5	Foot		1
6	Base wood panel		1

Figure B-10

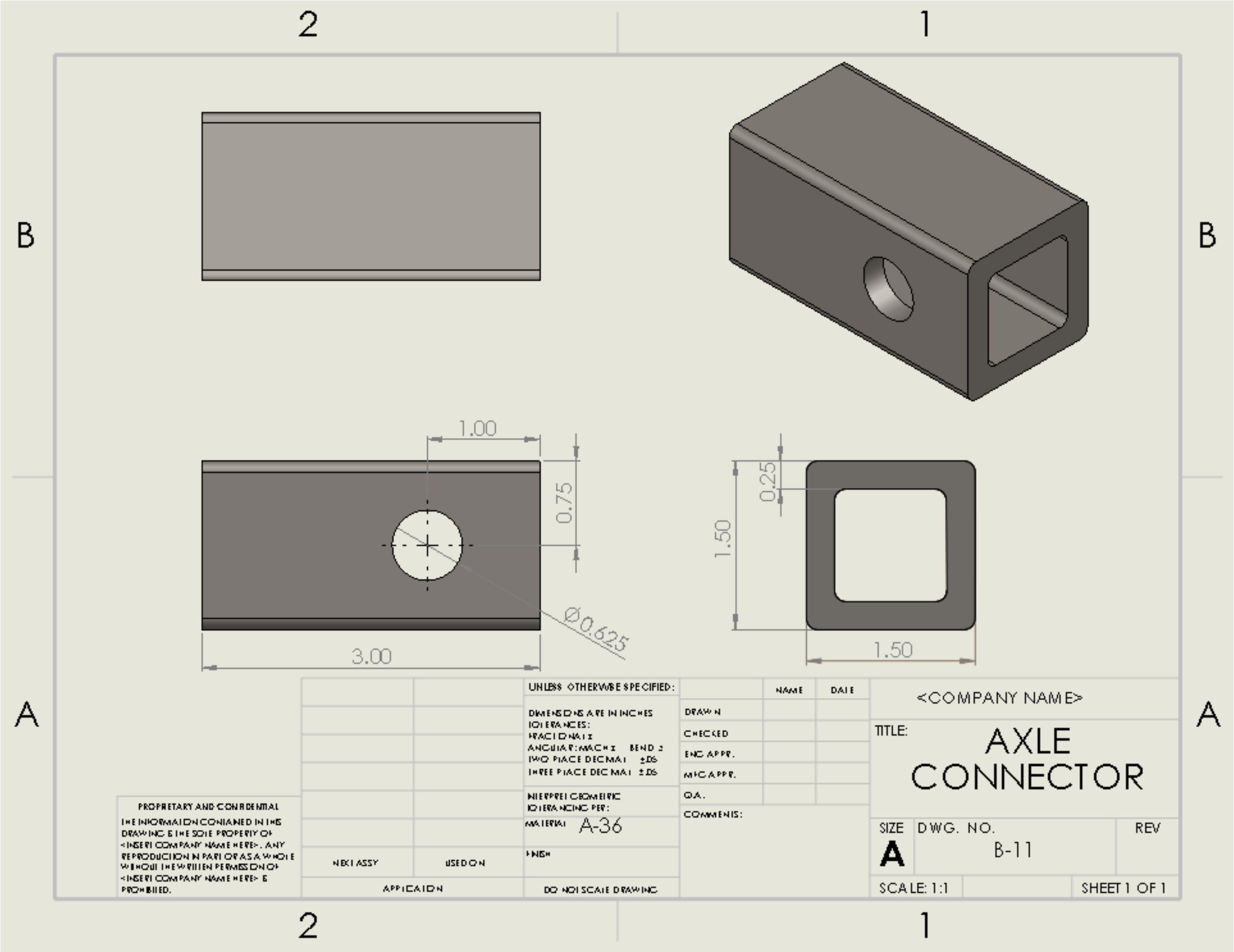

2
1
B
A
1.00
0.75
Ø0.625
3.00
0.25
1.50
1.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL A-36
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
AXLE CONNECTOR
SIZE A
DWG. NO. B-11
REV
SCALE: 1:1
SHEET 1 OF 1

Figure B-11

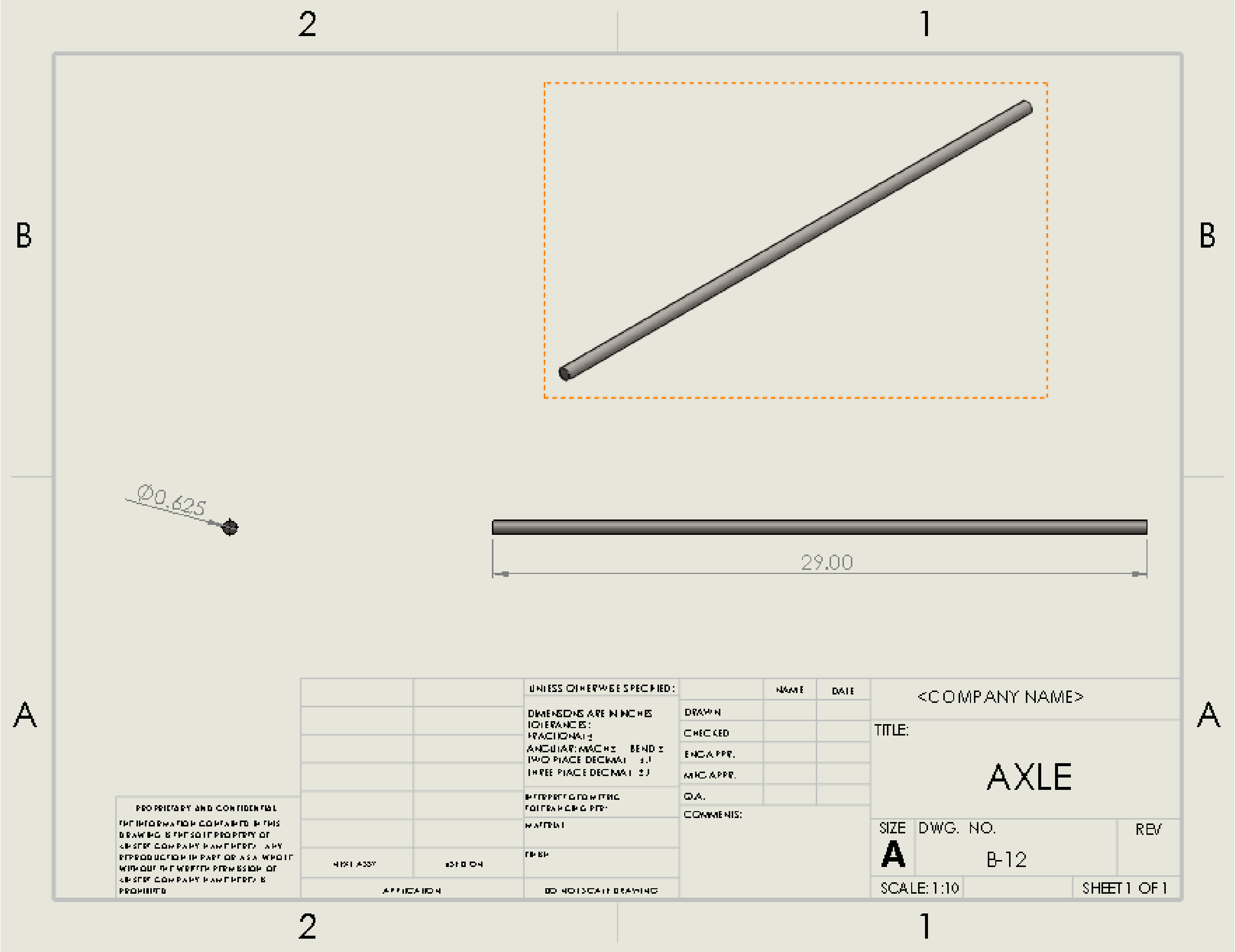
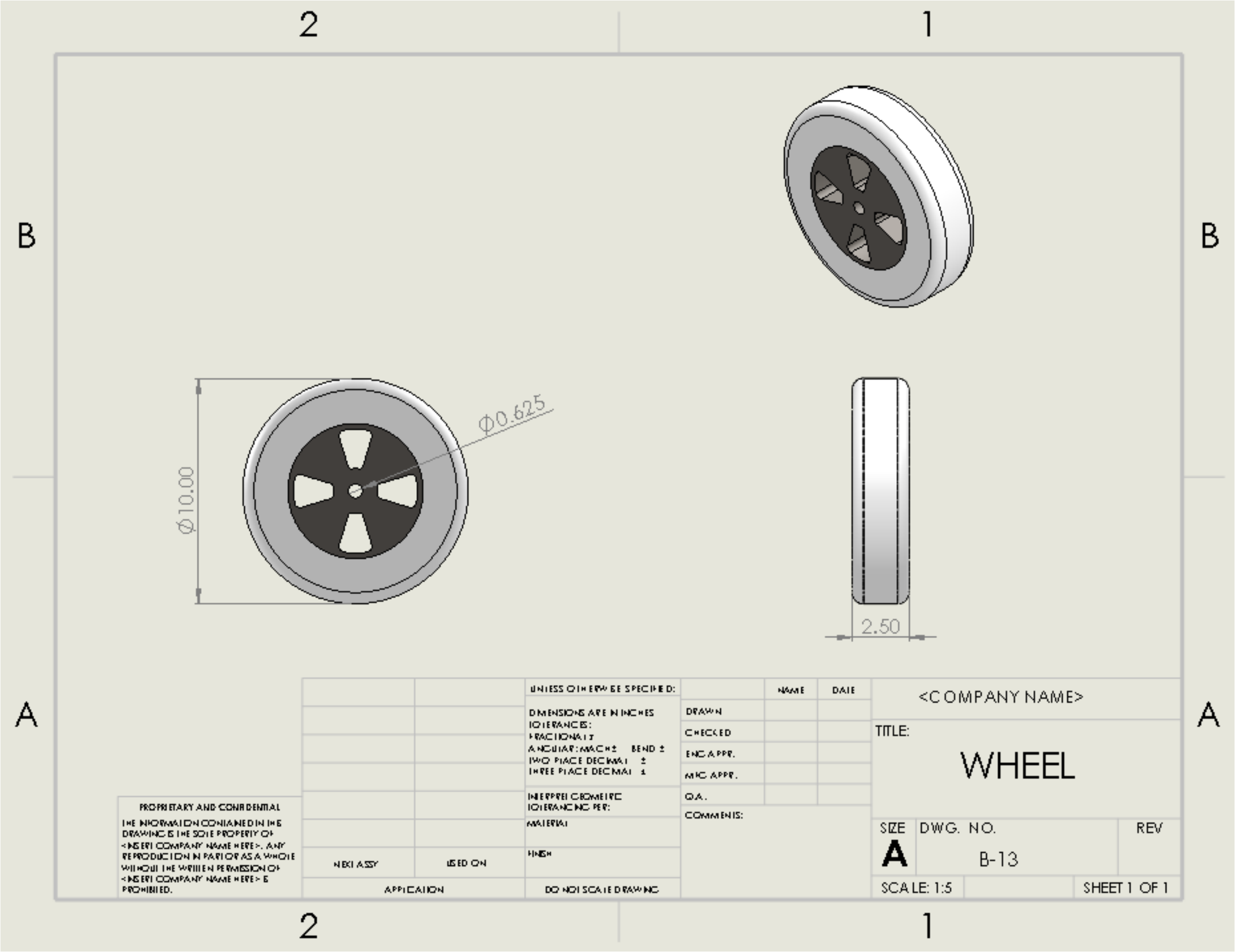

2
1
B
A
Ø0.625
29.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
<COMPANY NAME>
TITLE:
AXLE
SIZE
A
DWG. NO.
B-12
REV
SCALE: 1:10
SHEET 1 OF 1

Figure B-12


2
1
B
A
Ø10.00
Ø0.625
2.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
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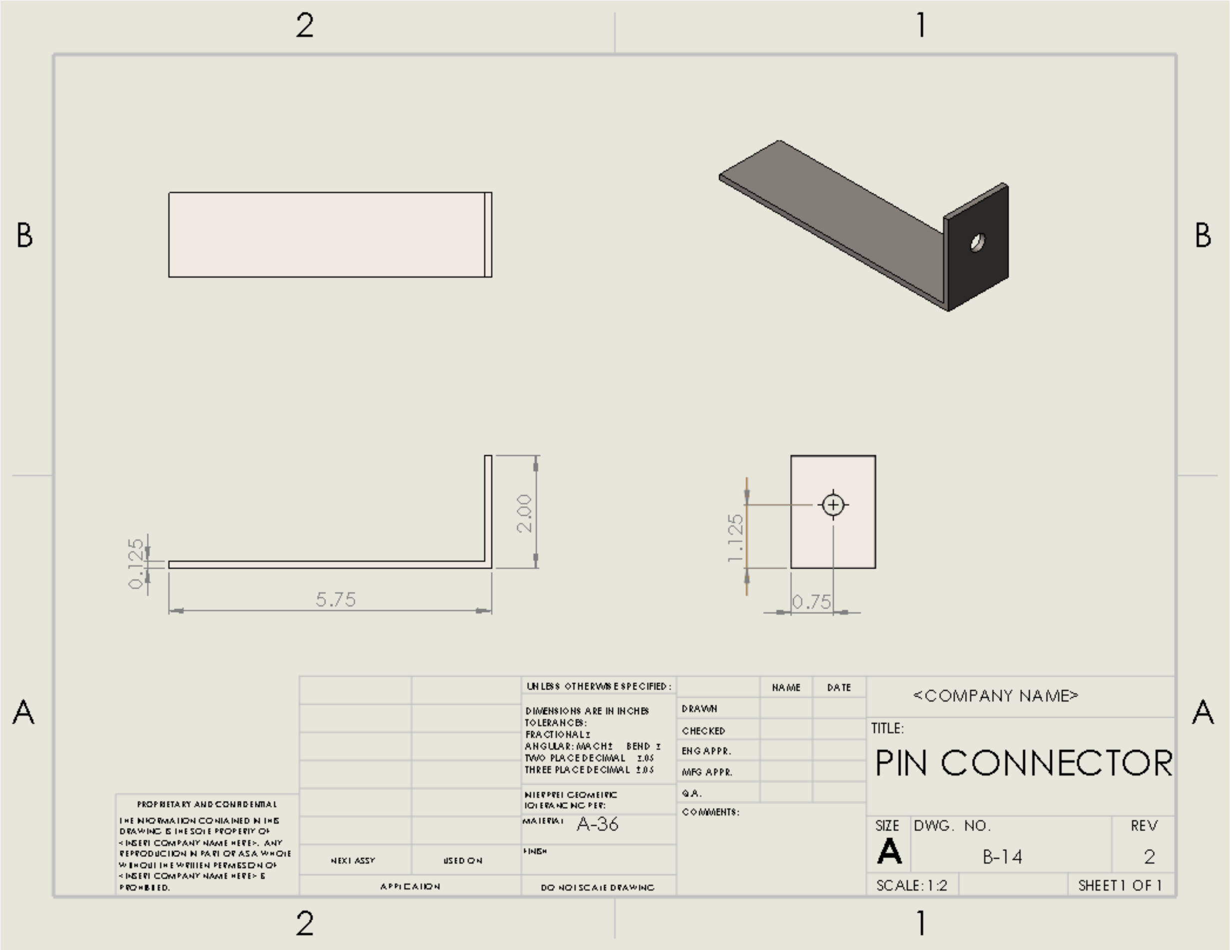
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
WHEEL
SIZE
A
DWG. NO.
B-13
REV
SCALE: 1:5
SHEET 1 OF 1

Figure B-13


2
1
B
B
A
A
0.125
5.75
2.00
1.125
0.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL A-36
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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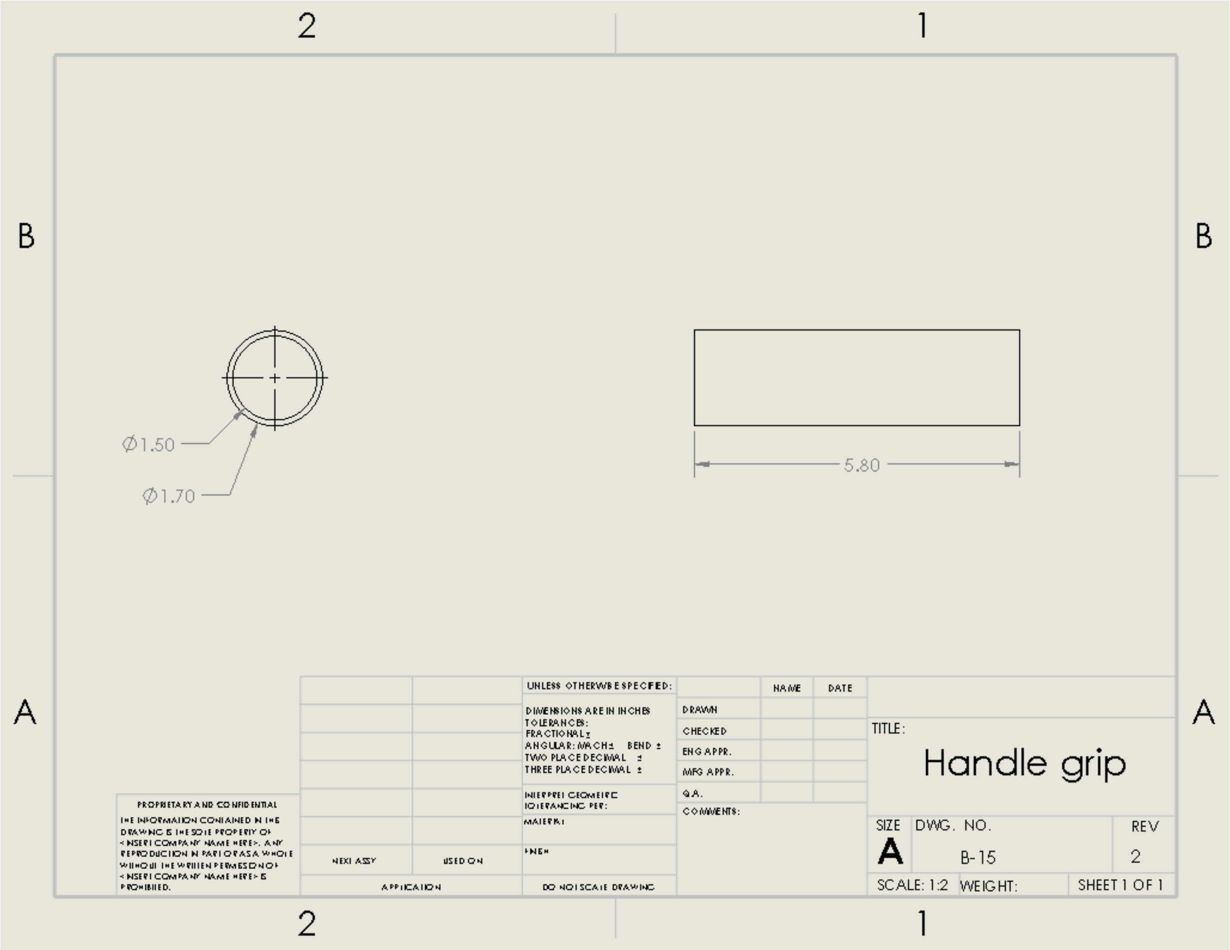
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
PIN CONNECTOR
SIZE
A
DWG. NO.
B-14
REV
2
SCALE: 1:2
SHEET 1 OF 1

Figure B-14


Ø1.50
Ø1.70
5.80
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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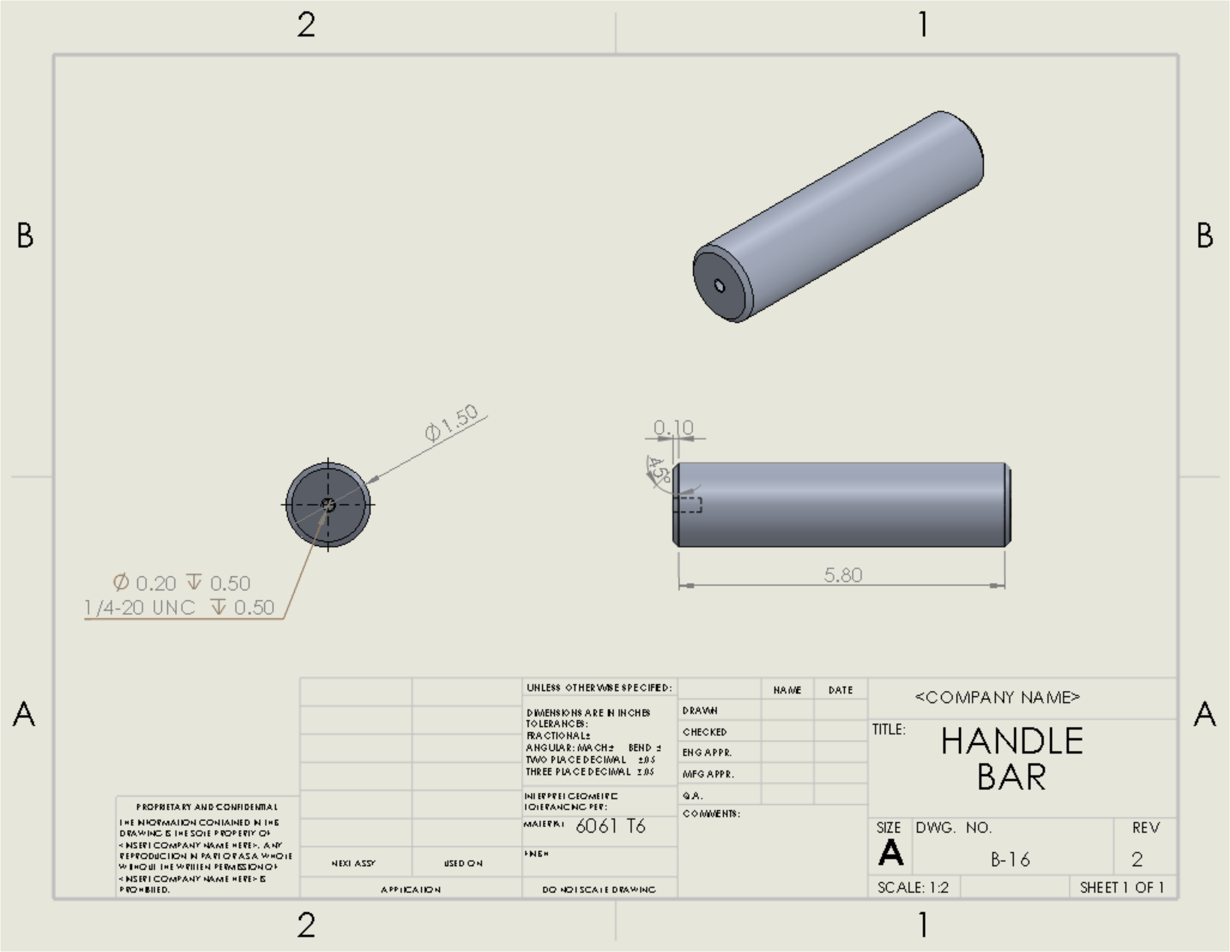
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Handle grip
SIZE
A
DWG. NO.
B-15
REV
2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Figure B-15


2
1
B
A
ϕ1.50
ϕ 0.20 ↧ 0.50
1/4-20 UNC ↧ 0.50
0.10
45°
5.80
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 6061 T6
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
HANDLE BAR
SIZE
A
DWG. NO.
B-16
REV
2
SCALE: 1:2
SHEET 1 OF 1

Figure B-16

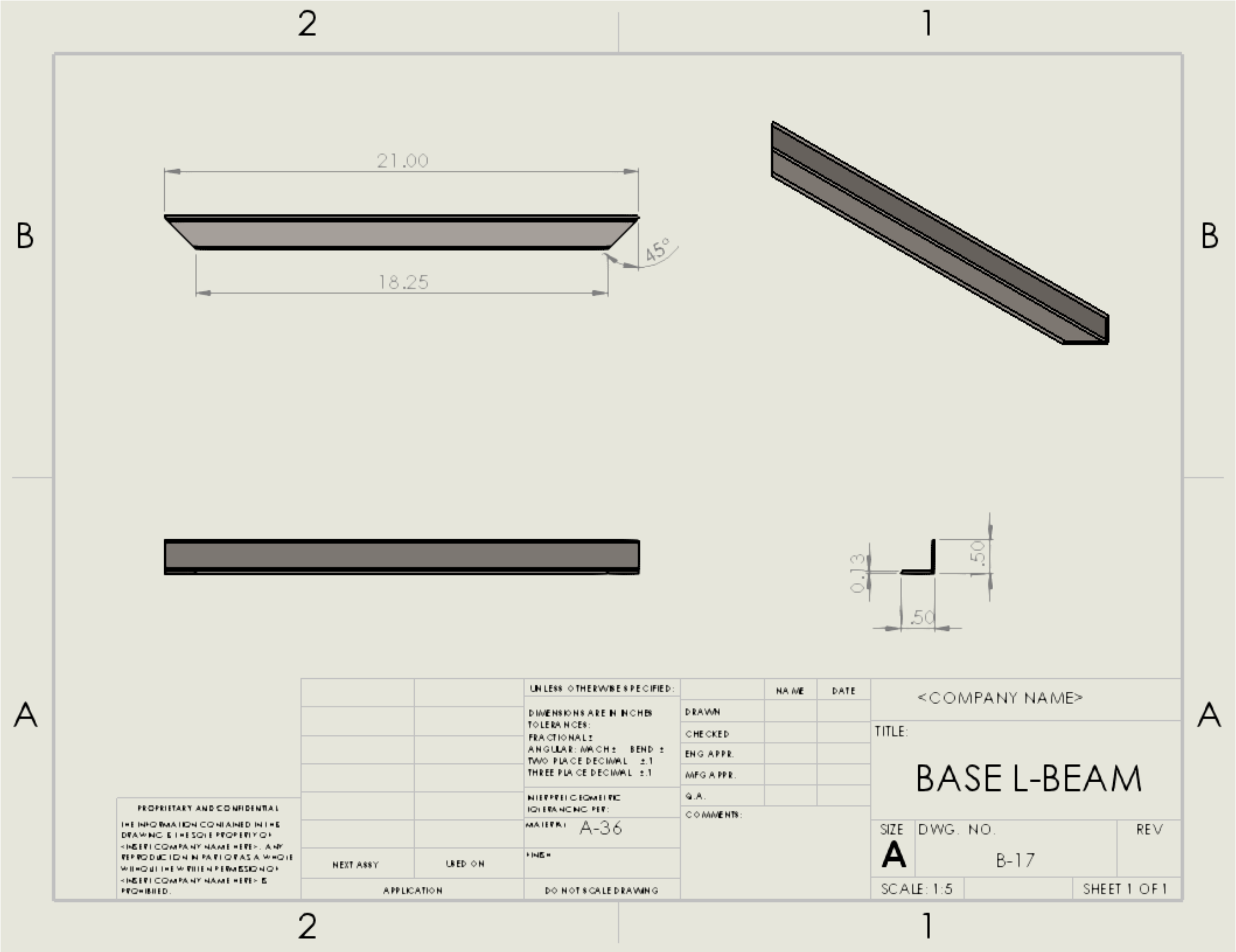
2
1
B
A
21.00
18.25
45°
0.13
.50
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.1
THREE PLACE DECIMAL ±.1
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL A-36
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
BASE L-BEAM
SIZE
A
DWG. NO.
B-17
REV
SCALE: 1:5
SHEET 1 OF 1
NEXT ASSY
USED ON
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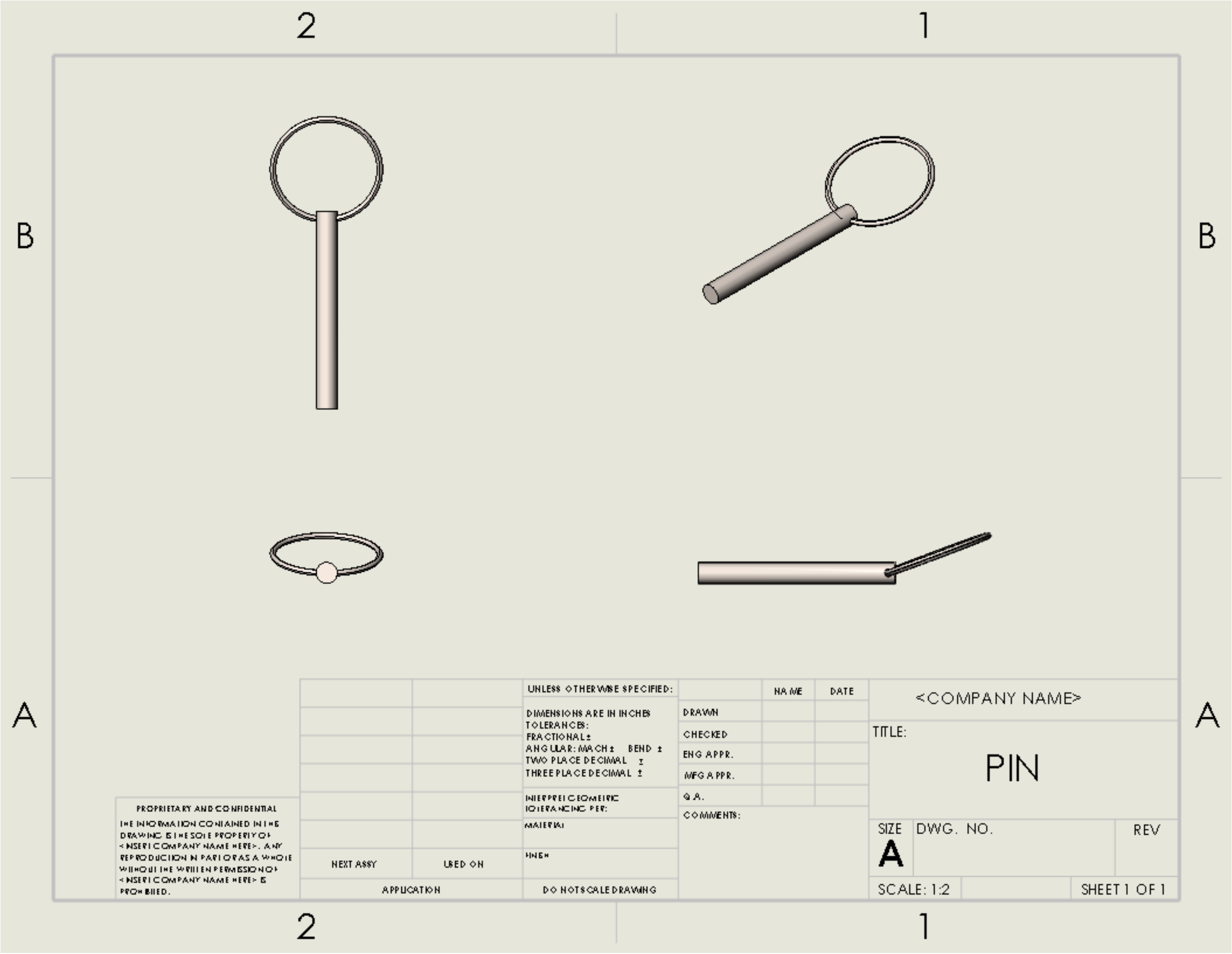
Figure B-17


2
1
B
B
A
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
PIN
SIZE
A
DWG. NO.
REV
SCALE: 1:2
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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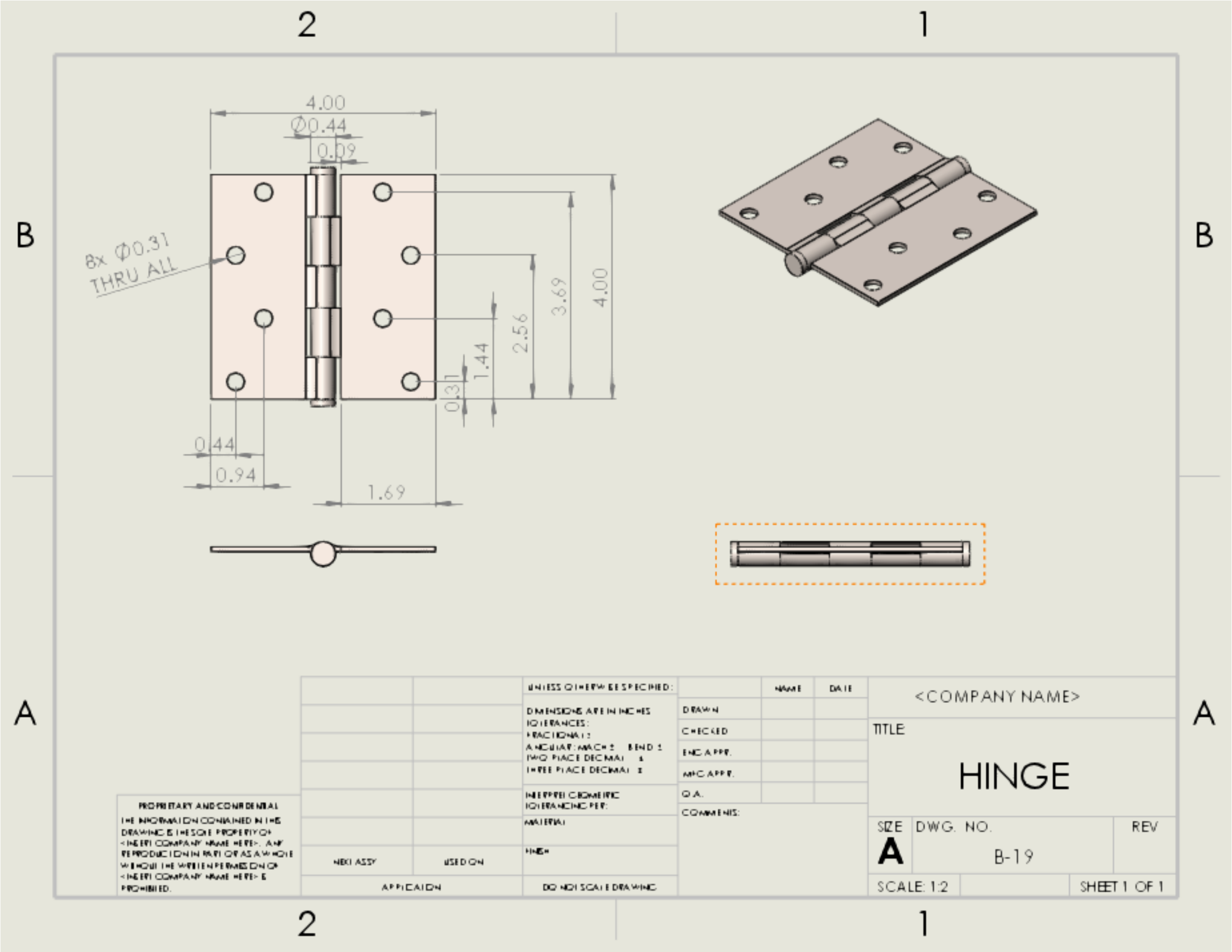
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
2
1

Figure B-18


2
1
B
A
4.00
Ø0.44
0.09
8x Ø0.31
THRU ALL
4.00
3.69
2.56
1.44
0.31
0.44
0.94
1.69
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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<COMPANY NAME>
TITLE:
HINGE
SIZE
A
DWG. NO.
B-19
REV
SCALE: 1:2
SHEET 1 OF 1

Figure B-19

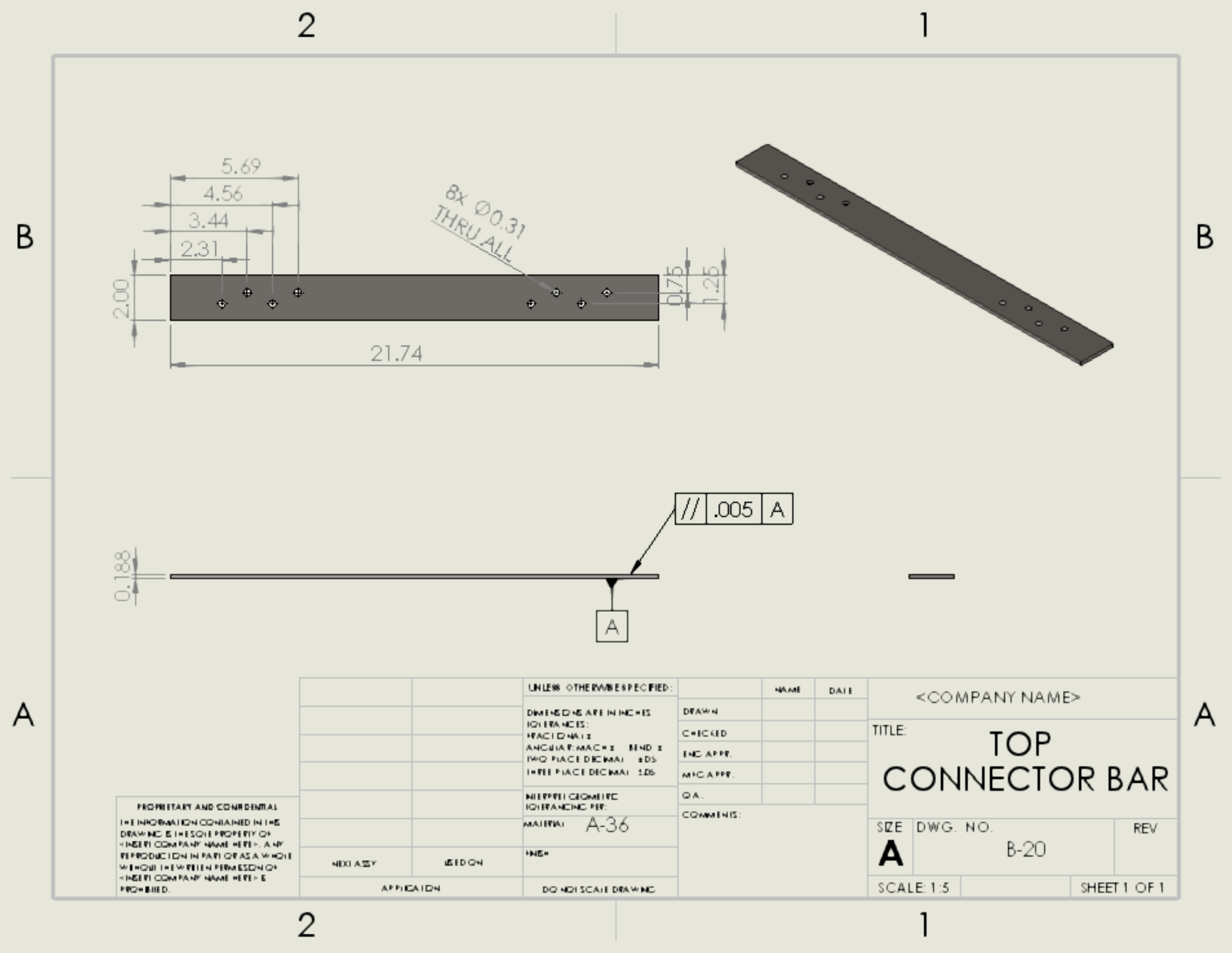
2
1
B
A
5.69
4.56
3.44
2.31
2.00
8x Ø0.31
THRU ALL
0.75
1.25
21.74
// .005 A
0.188
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL A-36
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
<COMPANY NAME>
TITLE:
TOP CONNECTOR BAR
SIZE
A
DWG. NO.
B-20
REV
SCALE: 1:5
SHEET 1 OF 1

Figure B-20

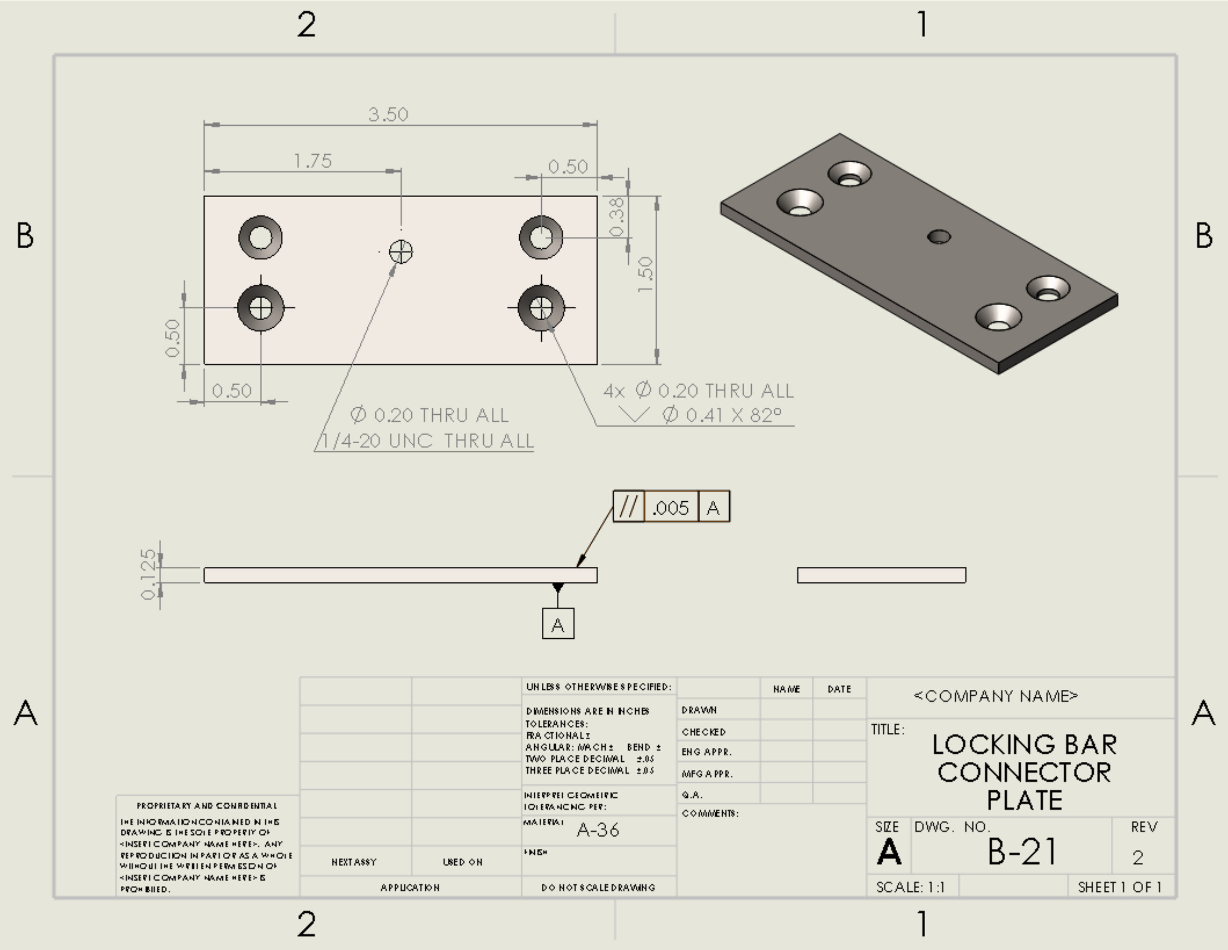
2
1
B
A
3.50
1.75
0.50
0.38
1.50
0.50
0.50
Ø 0.20 THRU ALL
1/4-20 UNC THRU ALL
4x Ø 0.20 THRU ALL
⌵ Ø 0.41 X 82°
// .005 A
0.125
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL A-36
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:
<COMPANY NAME>
TITLE:
LOCKING BAR CONNECTOR PLATE
SIZE
A
DWG. NO.
B-21
REV
2
SCALE: 1:1
SHEET 1 OF 1

Figure B-21

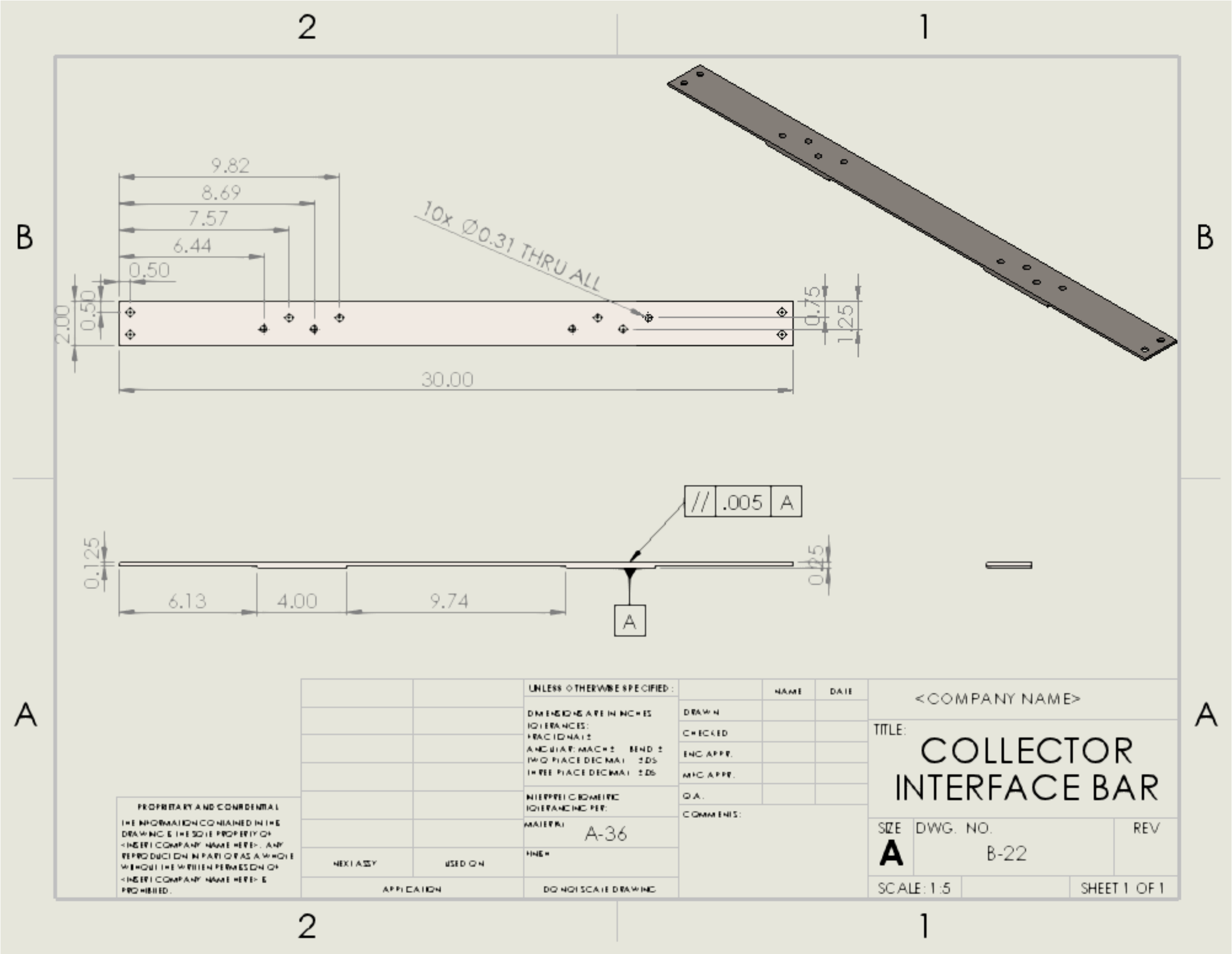
2
1
B
A
9.82
8.69
7.57
6.44
0.50
2.00
0.50
10x Ø0.31 THRU ALL
0.75
1.25
30.00
// .005 A
0.125
6.13
4.00
9.74
0.25
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL A-36
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
COLLECTOR INTERFACE BAR
SIZE A
DWG. NO. B-22
REV
SCALE: 1:5
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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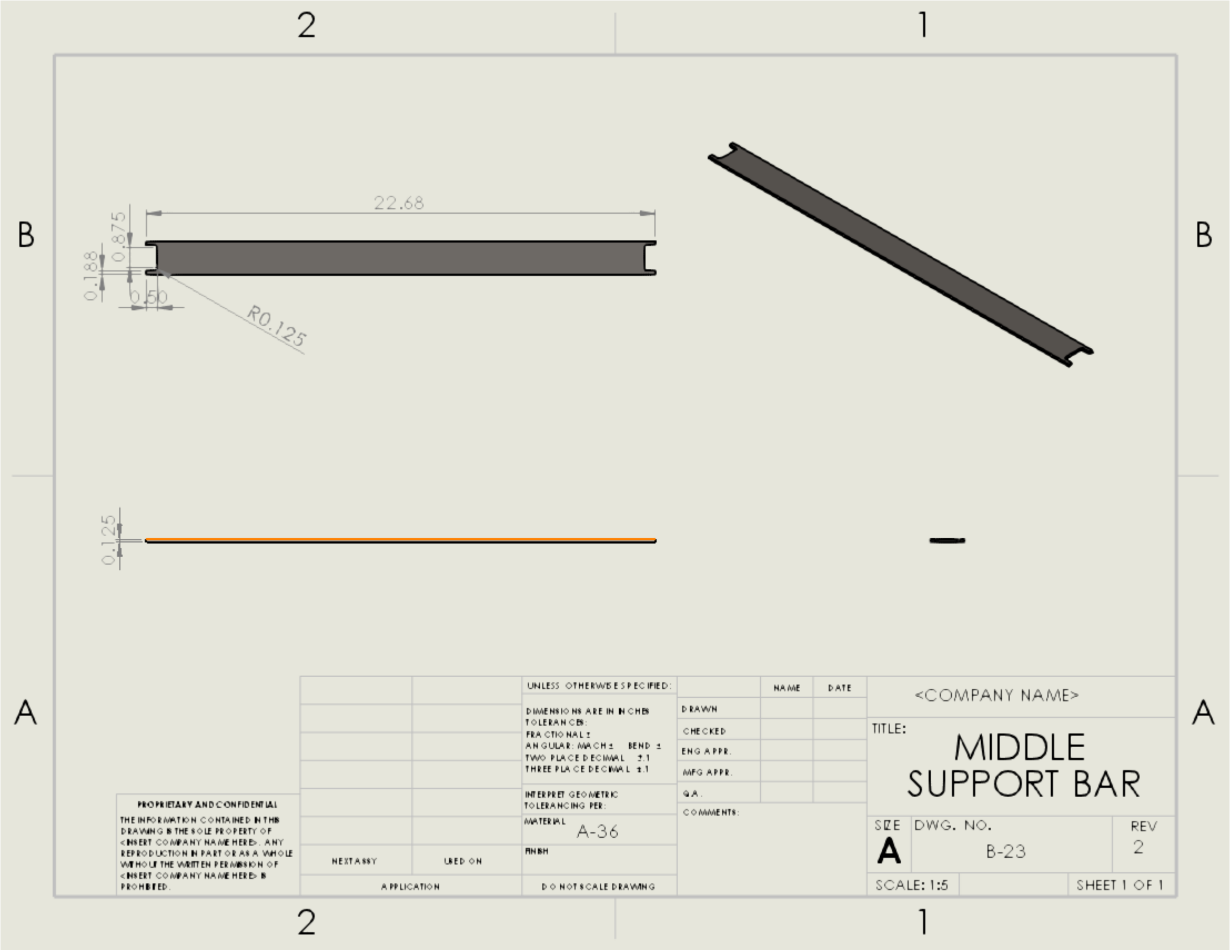
Figure B-22


2
1
B
B
A
A
22.68
0.875
0.188
0.50
R0.125
0.125
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.1
THREE PLACE DECIMAL ±.1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL A-36
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
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<COMPANY NAME>
TITLE:
MIDDLE SUPPORT BAR
SIZE A
DWG. NO. B-23
REV 2
SCALE: 1:5
SHEET 1 OF 1
2
1

Figure B-23

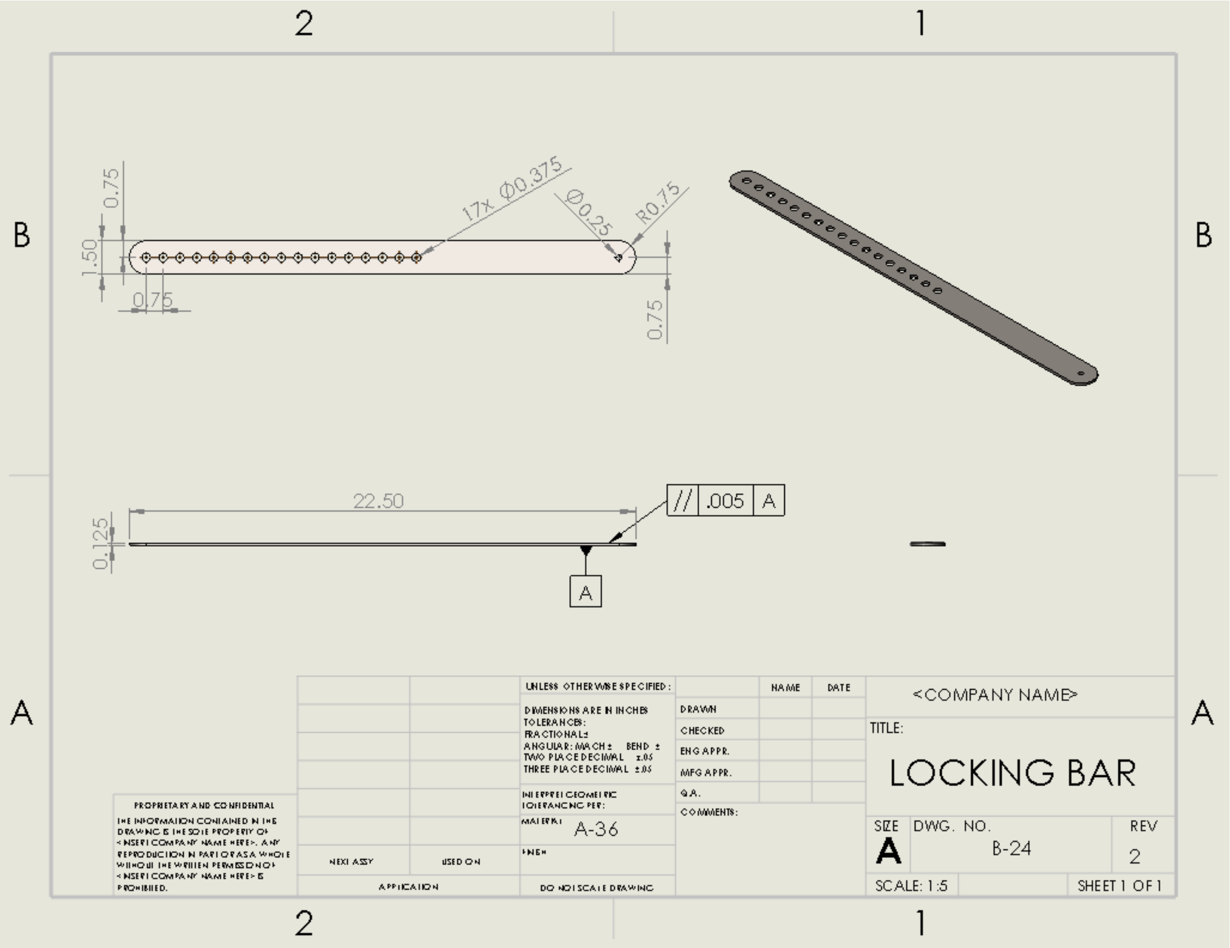
2
1
B
A
0.75
1.50
0.75
17x Ø0.375
Ø0.25
R0.75
0.75
22.50
0.125
// .005 A
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL A-36
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
<COMPANY NAME>
TITLE:
LOCKING BAR
SIZE A
DWG. NO. B-24
REV 2
SCALE: 1:5
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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Figure B-24

APPENDIX C and D – Parts List and Costs/Budget

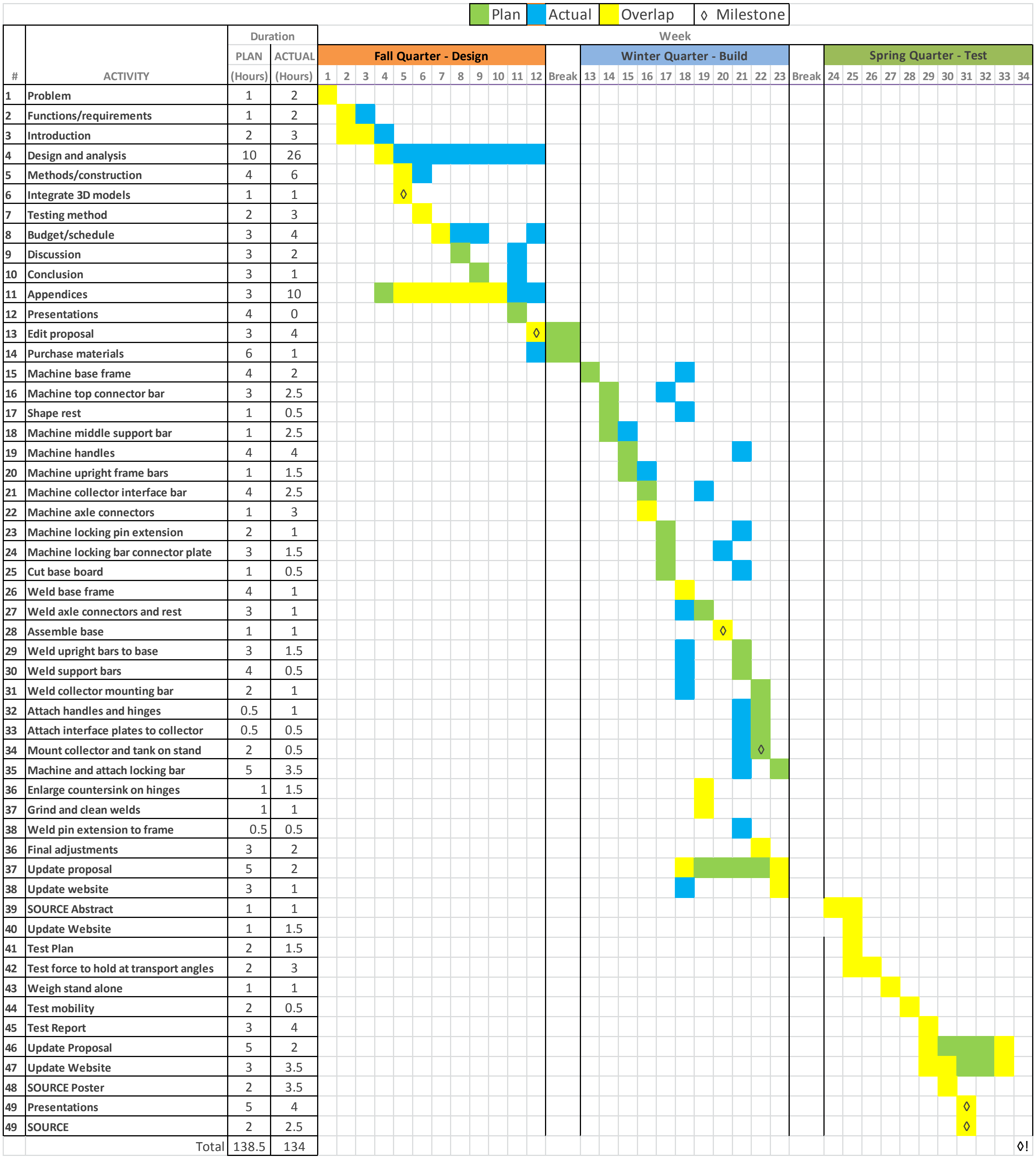
Part	**Quantity/length**	**Cost per part/length**	**Total Cost**
L-bar	84” (4x 21”)	$14.72/8’	$14.72
http://www.metalsdepot.com/products/hrsteel2.phtml?page=angle			
Wood board	21” x 21” x .5”		
Square tube 2” x 1/16”	90” (2x 45”)	$28.39/96”	$28.39
http://www.amazon.com/Carbon-Steel-Hollow-Rectangular-Rolled/dp/B0068UDRZ6			
Flat Bar 1.5” x 1/8”	124” (2x 21”, 1x 22.7”, 1x 33”, 1x 22.5”, 1x 3.5”)	$3.96/2’, $6.92/4’	$22.76
http://www.metalsdepot.com/products/hrsteel2.phtml?page=flat&LimAcc=%20&aident=			
Flat Bar 2” x 3/16”	21.74”	$4.14/2’	$4.14
http://www.metalsdepot.com/products/hrsteel2.phtml?page=flat&LimAcc=%20&aident=			
Flat Bar 2” x 1/4”	30”	$8.73/30”	$8.73
http://www.metalsdepot.com/products/hrsteel2.phtml?page=flat&LimAcc=%20&aident=			
Wheel (10” dia)	2	$14.40	$28.80
http://www.amazon.com/Hand-Truck-Tire-Solid-10x2-1/dp/B003Z9ZFLC			
Axle (5/8”)	1x 29”	$15.08	$15.08
http://www.amazon.com/Stanley-National-Hardware-4005BC-Plated/dp/B0029T9ALA			
Collar (5/8")	2	$0.89	$1.78
http://www.amazon.com/Climax-Metal-LC-062-Lightweight-Plating/dp/B003E7EBMY			
Square tube 1.5” x 1/4”	2x 3”	$6.95/3”	$13.90
http://www.metalsdepot.com/products/hrsteel2.phtml?page=sqtube&LimAcc=%20&aident=			
Round bar 1.5” dia	1’ (2x 6”)	$12.48/1’	$12.48
Ball lock pin	1x 3/8” x 3”	$10.09	$10.09
http://www.mscdirect.com/product/details/65069510			
Hinge	2	$5.48	$10.96
http://www.homesteadhardware.com/door-accessories/door-hinges/steel/emtek-steel-heavyduty14rad-hinges.html			
Fasteners (estimate)			$5
Total			$175.05

Figure C - 1

Part	**Total Cost**
L-bar	$9.91
Wood board	$0
Square tube 2” x 1/16”	$14.31
Flat Bar 1.5” x 1/8”	$10.61
Flat Bar 2” x 3/16”	$6.17
Flat Bar 2” x 1/4”	$8.26
Wheel (10” dia)	$28.80
Axle (5/8”)	$15.08
Collar (5/8")	$1.78
Square tube 1.5” x 1/4”	$18.07
Round bar 1.5” dia	$28.07
Ball lock pin	$1.98
Hinge	$10.96
Fasteners	$10
Shipping (total)	$12.84
Tax (total)	$12.36
Total	189.20

Figure C - 2

APPENDIX E – Schedule



#	ACTIVITY	Duration PLAN (Hours)	ACTUAL (Hours)
1	Problem	1	2
2	Functions/requirements	1	2
3	Introduction	2	3
4	Design and analysis	10	26
5	Methods/construction	4	6
6	Integrate 3D models	1	1
7	Testing method	2	3
8	Budget/schedule	3	4
9	Discussion	3	2
10	Conclusion	3	1
11	Appendices	3	10
12	Presentations	4	0
13	Edit proposal	3	4
14	Purchase materials	6	1
15	Machine base frame	4	2
16	Machine top connector bar	3	2.5
17	Shape rest	1	0.5
18	Machine middle support bar	1	2.5
19	Machine handles	4	4
20	Machine upright frame bars	1	1.5
21	Machine collector interface bar	4	2.5
22	Machine axle connectors	1	3
23	Machine locking pin extension	2	1
24	Machine locking bar connector plate	3	1.5
25	Cut base board	1	0.5
26	Weld base frame	4	1
27	Weld axle connectors and rest	3	1
28	Assemble base	1	1
29	Weld upright bars to base	3	1.5
30	Weld support bars	4	0.5
31	Weld collector mounting bar	2	1
32	Attach handles and hinges	0.5	1
33	Attach interface plates to collector	0.5	0.5
34	Mount collector and tank on stand	2	0.5
35	Machine and attach locking bar	5	3.5
36	Enlarge countersink on hinges	1	1.5
37	Grind and clean welds	1	1
38	Weld pin extension to frame	0.5	0.5
36	Final adjustments	3	2
37	Update proposal	5	2
38	Update website	3	1
39	SOURCE Abstract	1	1
40	Update Website	1	1.5
41	Test Plan	2	1.5
42	Test force to hold at transport angles	2	3
43	Weigh stand alone	1	1
44	Test mobility	2	0.5
45	Test Report	3	4
46	Update Proposal	5	2
47	Update Website	3	3.5
48	SOURCE Poster	2	3.5
49	Presentations	5	4
49	SOURCE	2	2.5
	Total	138.5	134

Figure E - 1

			Duration		Winter Quarter - Build										
		START	PLAN	ACTUAL	Week										
#	ACTIVITY	Week	(Hours)	(Hours)	13	14	15	16	17	18	19	20	21	22	23
15	Machine base frame bars	13	4	2	🟩										
a	Cut to length		0.5	0.5	🟩	🟦									
b	Cut corners		2	0.5	🟩	🟦									
c	Prep weld faces		1.5	1	🟩					🟦					
16	Machine top connection bar	14	3	2.5		🟩									
a	Cut to length		0.5	0.5		🟨									
b	Drill hinge connection holes		2.5	2		🟩			🟦						
17	Shape rest	14	1	0.5		🟩				🟦					
18	Machine middle support bar	14	1	2.5		🟩									
a	Cut to length		0.5	0.5		🟨									
b	Mill end slots		0.5	2		🟩	🟦								
19	Machine handles	15	4	4			🟩								
a	Cut to length		0.5	0.5			🟨								
b	Face ends		0.5	0.5			🟩						🟦		
c	Drill fastener holes		1	1			🟩						🟦		
d	Tap fastener holes		1	1			🟩						🟦		
e	Bore ends		1	1			🟩						🟦		
20	Machine upright frame bars	15	1	1.5			🟩								
a	Cut to length		0.5	0.5		🟦	🟩								
b	Drill handle fastner holes		0.5	1			🟩	🟦							
21	Machine collector interface bar	16	4	2.5				🟩							
a	Drill fastener holes		2	1				🟩		🟦					
b	Tap fastener holes		1.5	1.5				🟩			🟦				
22	Machine axle connectors	16	1	3				🟩							
a	Cut to length		0.5	0.5			🟦	🟩							
b	Drill axle holes		0.5	2.5				🟨							
23	Machine locking pin extension	17	2	1					🟩						
a	Cut to length		0.5	0					🟩				🟦		
b	Shape		1	0.5					🟩				🟦		
c	Drill hole		0.5	0.5					🟩				🟦		
24	Machine locking bar connector plate	17	3	1.5					🟩						
a	Cut to length		0.5	0.5		🟦			🟩						
b	Drill and countersink holes		2	0.5					🟩			🟦			
c	Tap main fastener hole		0.5	0.5					🟩			🟦			
25	Cut base board	17	1	0.5					🟩				🟦		
26	Weld base frame	18	4	1						🟨					
27	Weld axle connectors and rest	19	3	1						🟦	🟩				
28	Assemble base	19	1	1								🟨 ◊			
29	Weld upright bars to base	20	3	1.5						🟦			🟩		
30	Weld support bars to upright bars	20	4	0.5						🟦			🟩		
31	Weld top connector bar to upright bars	21	2	1						🟦				🟩	
32	Attach handles and hinges	21	0.5	1									🟦	🟩	
33	Attach interface plates to collector	21	0.5	0.5									🟦	🟩	
34	Mount collector and tank on stand	21	2	0.5									🟦	🟩 ◊	
35	Machine and attach locking bar	22	5	3.5											🟩
a	Cut to length		0.5	0.5		🟦							🟦		🟩
b	Fillet corners		1	0.5									🟦		🟩
c	Drill holes		3	2									🟦		🟩
d	Attach to collector		0.5	0.5									🟦		🟩
36	Enlarge countersink on hinges	19	1	1.5							🟨				
37	Grind and clean welds	19	1	1							🟨				
38	Weld pin extension to frame	21	0.5	0.5									🟦		
		Total	54	60									◊!!		

🟩	Plan
🟦	Actual
🟨	Overlap
◊	Milestone

Figure E - 2

APPENDIX F – Resume

Tyson Nakamura

2102 N Walnut St #262
Ellensburg, WA 98926
402-215-2716
tyson.nakamura@gmail.com

Objective

Seeking a full time position that will utilize my engineering skills and challenge my problem solving abilities.

Education

Central Washington University, Ellensburg, WA. 1/14 – 6/16
B.S. in Mechanical Engineering

Western Washington University, Bellingham, WA. 9/02 - 3/08
B.A. in Business Administration - Management Information Systems
B.A. in Music

Certifications

SolidWorks CSWA

Technical Skills

- Efficient in 2d and 3d design/modeling with AutoCAD 2015 and SolidWorks 2015.
- Solid understanding of physics, statics, dynamics, strength of materials, metallurgy, thermodynamics, fluid dynamics, heat transfer, statistical process and quality control, mechanical system design, welding, and basic electrical systems.
- Analysis of energy systems: Measuring, calculating, and evaluating results to determine efficiencies, analyze and optimize systems. Made use of technology such as spreadsheets to simplify calculations and chart data.
- Familiar with wiring and programming of PLC systems for integration of mechanical and electronic systems.

Work History

Cyberspace Systems Operator, United States Air Force. 9/09 - 9/13

- Provided consolidated call center support to over 400,000 Air Force, joint service members, and government civilians through tier 1 remote maintenance of a multi-billion dollar enterprise network. Performed remote administration, quality checked trouble tickets, rendered outstanding and knowledgeable customer service.
- Took on leadership role training airmen. Created consolidated knowledge documents and SOPs to improve efficiency and ensure consistent operation.
- Provided on-site support in a deployed location resolving network connectivity issues, installing new infrastructure, and replacing defective computer hardware, ethernet and telephone phone cabling.
- Maintained network infrastructure for the headquarters Air Force Weather Agency. Troubleshot router, firewall and WAN data flow issues, installed security/load balancing hardware, and maintained DNS.

Network Technician, Valley Computer Services, Bellingham, WA. 8/07 - 9/07

- Assisted with and worked alone on a variety of projects for clients from upgrading software and backing up data to maintaining active directory and installing new network hardware while providing technical support.

IT Intern, McEvoy Oil, Bellingham, WA. 6/07 - 8/07

- Documented the current network infrastructure and domain. Drafted and implemented redesign of Active Directory and file system structures to boost efficiency and security.
- Developed manuals and documentation to assist non-technical administrators in further maintenance.
- Maintained and improved physical network while providing technical support to users.

Affiliations

American Society of Mechanical Engineers
Washington FIRST Robotics