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HF HAUFF Mobile Wind Turbine: Lateral Articulating Arm

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HF HAUFF Mobile Wind Turbine

Lateral Boom Extension and all accompanying hardware

Brett Ulrich

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Introduction

1a. Motivation

This project is motivated by special interests in agriculture; my mother's side of the family has farmed in the Pasco/tri-cities area for the last several decades for mainly apples, but also potatoes, asparagus, and cherries. Another large motivation is the opportunity to work with one other classmates and the manufacturing company HF HAUFF based out of Yakima who will be aiding us in part of the design process.

2a. Function Statements

A device is needed for a large-scale agricultural application-oscillating fan to horizontally extend the vertical stabilizing legs far enough away from the platform so to provide resistance to the thrust created by the fan.

3a. Requirements

The design requirements are as follows:

- The project part is must be dimensioned to fit in the trailer provided by HF HAUFF.
- The final product will be able to stabilize against the force and the moment created by the thrusting force of the wind turbine, 2000 pounds
- The system is to function is to be completed in 3 steps or less
- The system must be able to operate on a maximum of a 15% grade
- Minimize the use of hydraulics
- Cost upon completion will total less than $2,500
- Leveling task will be completed at any instance in less than 5 minutes
- The entire part will weigh less than 1,000 lbs
- The part will be designed so that is can be manufactured and reproduced easily

4a. Success criteria

The project success depends on the final performance of the device; this is based on both the satisfaction of the customer and the compliance with the primary requirements. In summary, the completed system will be mobile, and it will level up to a 15% grade.

5a. Scope of Effort

The majority of this project will be spent in the design phase. The production time will be split partially between the labs at CWU and the production facility for HAUFF in Yakima. The manufacturing company HAUFF will provide the trailer and wind machine. All structural steel will be ordered from Pacific Steel, and all other hardware items will be sourced externally.

6a. Benchmark

Two similar stabilization techniques are used for comparison; the motors that are used on recreational vehicles are similarly used so that the refrigerators may operate properly, and a modified design that mimics an extendable boom similar to a crane truck. One similar product made by Cascade Wind Machine Service with a local office in the area has a similar product used, pictured above. This product costs $35,200 and aside from the propane-powered propeller, all functions on this platform are human operated, meaning it does not utilize the use of hydraulics or electronics to aid the setup. This design uses a telescoping boom that consists of two concentric beams that slide out from the trailer and lock into place via pinned connection. The extending support is given by a hand-crank screw-type leg extension. The trailer is eight feet wide, weighs eleven thousand pounds, and revolves on a similar time interval.

7a. Success of the project

This project will be graded by its movement and performance abilities while complying with the primary requirements. The project will be considered successful if the project sponsor will use this design in future platforms.

B. Design and Analysis

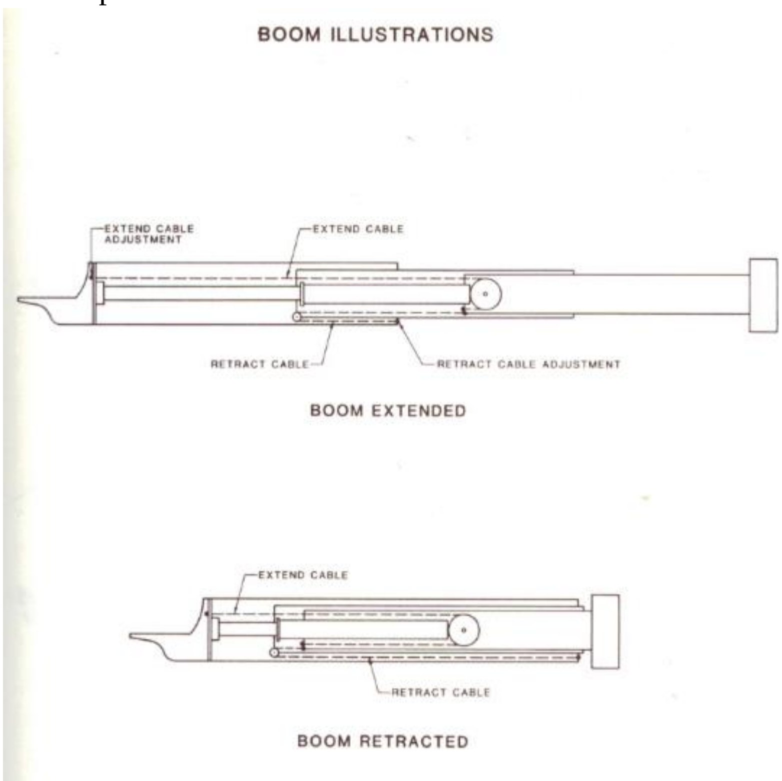
1b. Approach

The first priority of composing a solution will be to design something that will operate safely. This means that appropriate factors of safety will be applied will be applied properly to each component to ensure that during operation each piece of the design will be able to withstand many cycles of use.

The proposed approach to the problem at hand is to create a system that will extend two sets of telescoping boom arms horizontally outward from the trailer before any movement from the vertical booms.

Applications of engineering that will be used on this project will include geometry, static and dynamic analysis, strength of materials, and finite element analysis to calculate appropriate forces and stress throughout the platform. Examples of stress analysis will include shear, bending, and loads under tension and compression.

2b. Design description



Pictured above is a design based off of an extending multiplier similar to those used on crane trucks. The lateral booms for this platform will replicate this design in a simpler fashion using two telescoping beams instead of four. While the vertical arms will use circular tubing, concentric pieces of square steel tubing coupled with ultra-high molecular weight polyethylene rollers as guides will be used on the lateral booms to ensure there is no unwanted rotation. Each boom will be cable operated powered by individual electric motors, one each for the lateral and vertical extensions. One previously discarded design included the use of a centralized hydraulic reservoir and pump with oil lines running to a hydraulic cylinder inside of the lateral booms. This aspect of the project would compromise the primary requirements; an emphasis is placed on minimal hydraulic use for this application because if there happens to be any leaks ever in the system it could result in damage to the surrounding produce.

3b. performance predictions

The performance of this part is predicted to be able to laterally extend the vertical telescoping arms away from the trailer 4.5 feet on a 8.53° slope. The structure of the lateral arms will be strong enough to withstand the weight of the 5,000 lb. trailer, as well as the 2,000 lb. force created by thrust during operation. The set-up step of the procedure before the fan can be turned on will take less than 5 minutes, and can be accomplished in 3 steps or less. The parts will total a weight of no more than 450 lbs.

4b. description on analyses

With the consideration of the success of this project, all attributes will be tested in the most extreme cases. For example, the lateral arms of the trailer must extend a certain distance away from the trailer to ensure stability. This is done via a simple summation of moments. This is detailed in Appendix A, figure 2.

Two other critical assessment areas concern the strength of the cable needed to draw up the vertical mounting legs, as well as the surface mounting hardware. The strength of the cable need to keep the trailer level is derived from a static stress analysis, taking into account how much weight each of the leveling arms will carry. In this scenario, two lateral trailer arms on the same side of the platform are carrying half of the weight of the trailer, 2500 lbs. each. Using an outside reference, it is determined that if using a half inch diameter steel cable, a safe load of 4,280 lbs. and a minimum breaking force of 21,400 lbs. can be incorporated into the design. See Appendix A.

To determine the size of the bolts needed to hold down the pulley that re-directs the steel cable from a horizontal fashion into the vertical extending arms, a reference table in ‘Mechanical

Elements in Machine Design' is used. After determining that a grade 5 bolt is a suitable choice, a relation between the proof strength and tensile area is created to determine the diameter needed of a chosen number of bolts required to ensure that the pulley will remain stationary. See Appendix A.

Square tubing is chosen for the lateral arms so that there is no unwanted rotation. The beam geometry is decided by taking into account the length of the inside beam, outside beam, and how much each overlap when at full extension. A shear and moment diagram are drawn up when considering propeller thrust and trailer weight. Using a bending equation to find an 'S' value, a suitable beam can be chosen from 'Mechanical Elements in Machine Design', see Appendix A Figure.

5b. scope of testing and evaluation

Any evaluations of this project will be determined by the customer, HF HAUFF. The scope of testing will include an actual trial of use in a real-life scenario application to assess the strength of the design, all other criteria will be based on functionality and ease of use which is determined by the customer's ability to proficiently manage all device functions.

6b. analyses

The design analysis for the lateral arm is given below.

i. Design issue: 1, 2, 3

One of the primary requirements of the horizontal boom is to place the vertical leg 4.5 feet away from the trailer. The first method of placing this component is a swing out type of carrier that is already the specified length for extension and is saddled up to the side of the trailer during transportation. This design was discarded because it would apply too much stress to the pin that kept it stationary. Another similar design using a swing down extension was discarded because for the practical application in an orchard, the leg extension will need to happen straight outward from the trailer so to not interfere with any of the vegetation.

Another requirement is to minimalize the use of hydraulics, which if leaked could damage a substantial amount of plant life. The current design implements certain aspects of a boom used in a crane truck, using ultra high molecular weight polyethylene rolling guides and steel cable to extend itself, eliminating the use of hydraulics.

A device is needed for the vertical legs that will translate the horizontally oriented steel cable into the vertical legs. A previously discarded design employed the use of a stationary pulley that the steel cable would slide over. This design was discarded for a rotating pulley to cut down on undesirable friction and heat.

Another design criterion that was discarded is the automated portion of the leveling process. Initially, a request was made that as much of the process as possible be automatic from engaging the system one time. This part of the project proved to be too difficult, as there was a too great of need for an electronic engineer on this project.

The material used for the rolling guides must be a closed lubricating system that does not require lubrication after each use, and must also be able to withstand the force of the vertical components during operation.

ii. Calculated parameters

Appendix A states that one of the primary design requirements is that the trailer will be able to level itself on a grade of 15%. This figure shows the geometry of the trailer on an incline, the calculated angle downward if the grade is 15% and the similar triangles ratio to determine the height difference the vertical legs will need to extend to level itself.

Appendix A shows that there must be a certain amount of horizontal movement to place the vertical legs outwards. Taking into account the 2,000 lb thrust force created by the propeller and the 5,000 lb weight of the trailer, a 4.5-foot extension is needed for the horizontal boom is needed.

Appendix Ais a developed moment summation, taking into account several factors into a multiple part breakdown of each aspect. Variations of these summations are primary and secondary positions of the direction of the fan, and also one summation with and one without the weight of the trailer.

Appendix A shows that during operation at full horizontal extension on the 15% grade, there is not enough of a height difference for the vertical leg to fit in the space created by the trailer deck height. This means that on a 15% grade at the full horizontal extension length, all four of the extension legs must operate to level the platform.

Appendix A in an updated design replacing the stationary pulley that loops the steel cable wire from the top of the horizontal boom into the vertical legs. The stress in the cable is found by sigma=force/area given in pounds per square inch. Using The Engineering Toolbox, a half inch diameter cable is chosen, given a specification of 4,280 lb. safe load and 21,400 lb. minimum breaking force. Appendix A also shows the relation between tensile stress and shear stress, shear=tensile/2, and also that tensile stress is given by force/area. Using these relations, a tensile area of 0.504 square inches is found. Using table 19.4 for coarse threads UNC in Mott, one can conclude that either one bolt with a diameter of one inch can be used, or four bolts with a diameter of one half an inch each.

Appendix A is a picture of the telescoping arms from the side. Given the dimensions retracted and at full extension, there is an overlap of the inside and outside steel tubes. Using these dimensions and the forces from Appendix A, shear and moment diagrams can be derived. As per request of the customer, the design will be made around A-36 hot rolled steel. Using the given 36,000 psi yield strength, formulate a design stress using the appropriate safety factor. Using the equation sigma=Mc/I=M/S, an S value will give you enough information to reference table appendix 15 table 14 to determine a correct tube dimension.

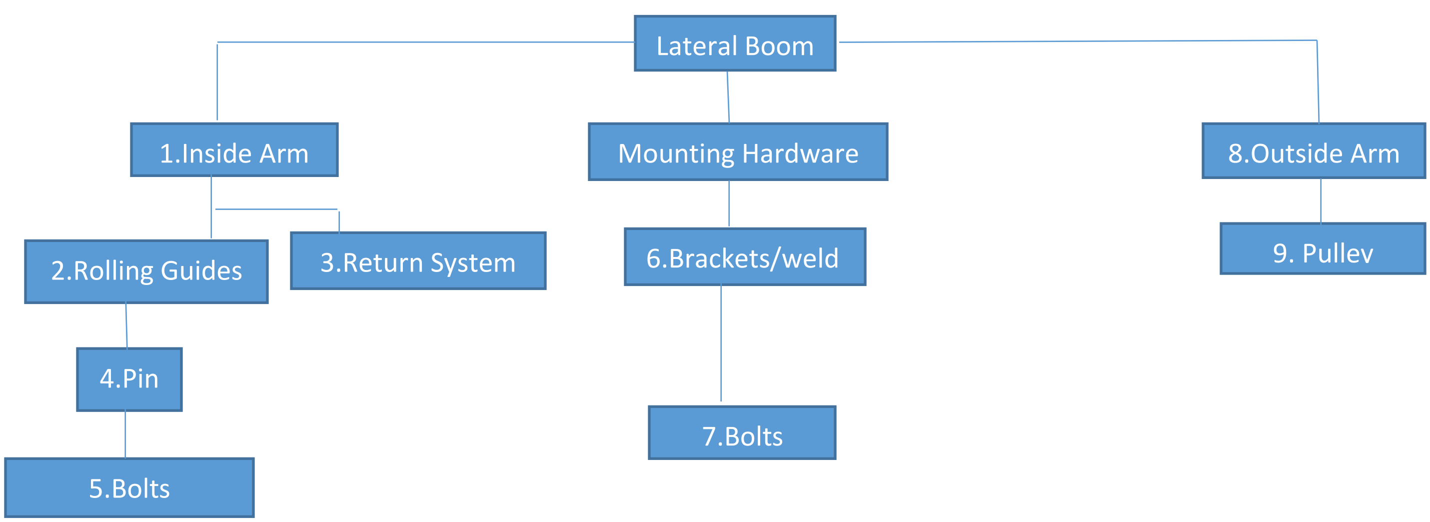
iii. Best practices

In Mott, a design factor of 2-2.5 is used to design a machine under dynamic loading with average confidence in all design data, a higher design factor of 2.5-4 can also be used when dealing with uncertainty about loads, material properties, stress analysis, or the environment. The purpose of this project will require a safety factor of 2.

7b. device: parts, shapes, and conformation

Rectangular steel tubing 6x6x0.5 will be enclosed by a concentric piece of steel tubing 8x8x0.25. Several guides will be used to ensure any unwanted friction or heat is created. These will be made of an ultra-high molecular weight polyethylene, and will be pinned into the inside of the tube at the critical points where the tubes will want to touch. All necessary hardware will be bolted down with correlating washers and nuts. To secure all hardware from sliding laterally, a fabricated bracket will be welded in place at the edge of the trailer and the end of the steel tube.

Drawing Tree/Drawing ID



8b. device assembly and attachments

All the involved electronic including an auxiliary power supply will be housed on the above picture as well as parts for the winch and level system. All hardware will be bolted down through the saddle and possible through the trailer with the included nuts and washers if the application calls for it. The heavier duty applications may also include a weld, which will be from the tungsten inert gas (TIG) welder. This device will be made of steel because of its strength, toughness, and hardness qualities.

9b. tolerances, kinematics, ergonomics, etc.

When comparing the lateral boom to the vertical extension, there is not nearly as much need to focus on the lateral fitment as the vertical fitment. The vertical fitment will have closely associated stress concentrations and tolerances down to 0.005 inches, and will need to be closely fitted and calculated in order to account for variances in any hillside impedance. The horizontal boom will have slightly larger known tolerances (0.1 inches), but also several rolling guides in order to assist with movement. These guides must be able to resist the same force that was calculated in order to specify a tube shape.

Kinematics can be evaluated in this project in the operation of the electric winches. At different points during the extension process one can measure the extended length and relate this figure to the size of the winch and rotational ability.

To make this project more user friendly, all of the motorized functions will be operated by a centralized control panel located at the rear of the trailer, powered by common source of the auxiliary battery.

10b. technical risk analysis, failure mode analysis, safety factors, operation limits

Some of the risks surrounding the project include problems concerning scheduling, project management, and requirements. When making a project schedule, it is nearly impossible to predict the exact length of different aspects of the project. A delay in one part can cause cascading delays in subsequent project parts. Project management conditions can be completely date driven, meaning that research could be weeks behind but a milestone is due even if the part is not finished being designed, even if the priorities change within the project. The most difficult hazard when overseeing the project is the requirement risks. This includes but is certainly not limited to; requirements being baselined but changing, changing definitions which in turn means expanding the scope of the project, some requirements of the project taking more time than others, or even some requirements are only partially known at the beginning of the project.

The horizontal booms will fail to operate if any of the calculated values are overloaded. For example, if a grade two bolt with a proof strength of 33 ksi is used to fasten a pulley where a grade 5 bolt with a proof strength of 85 ksi is called for, then the bolts will fail in shear. If the outside telescoping steel tube is chosen for building with an S value that does not meet the required value, these will also fail in shear. An overloaded trailer will cause the steel cable wire to fail in tension, if the steel cable is over dimensioned and the trailer is grossly overloaded this will most likely result in failure from bending fatigue stress.

All of the project parameters have been set accordingly. If this platform were to move to a different trailer with a different mass, or if during a routine upkeep components are swapped out so that the propeller exerts a larger force than 2,000 pounds (larger prop, different engine, different gearing), all project parameters must be reset. This design is made for this trailer geometry, weighing a certain amount, exerting a certain amount of thrust.

C. methods and construction

1c. construction

i. Description

The Horizontal boom will consist of two concentric pieces of steel rectangular tubing, one large and one slightly smaller. These tubes will slide into each other, and the remaining tolerance area between the two will utilize several rolling guides composed of ultra-high molecular weight polyethylene. These tubes will be six and a half feet long, and at full extension will have two feet of overlap. Two extend horizontally; a pulley on the end of the smaller enclosed tube will utilize the pin of one of the guides as an anchor and will pull itself around, so when tension is placed on the operating cable, the beam will extend out. At the end of the smaller beam will be a pulley attached, feeding the steel cable through a hole that is drilled into it down to the vertical extension.

Part ID	Name, description/use	Source	Qty. x Cost
1.	Steel tube, 6x6x0.5 beam used for the enclosed telescoping arm	Pacific Steel	24 ft. x 33.00
2.	Rolling guide, UHMW PE bearing fastened to internal telescoping arm	Misumi.com	8 x 20.00
3.	Return spring/shock		4 x 20.00
4.	Pin/anchor	UScargocontrol	4 x 2.00

5.	Bolts	ASMCindustrial	16 x 2.00
	Sheet metal for custom mounting bracket fabrication	Pacific Steel	1 x 25.00
6.	Mounting bracket, fastener for outside lateral boom		4 x
	Mounting bracket, for internal lateral arm extension		4 x
	Mounting bracket, for vertical boom cable routing		
7.	Bolts, additional support for lateral boom bracket (part#6)	ASMCindustrial	16 x 2.00
8.	Steel tube, 8x8x0.25	Pacific Steel	24 ft. x33.00
9.	Pulley, for vertical boom cable route	http://www.directindustry.com/industrial-manufacturer/pulley-bearing-141428.html	4 x 3.00
	Washers		32 x 1.00
	Nuts		32 x 2.00
	Electric motors, lateral boom extension	Harbor Freight	4 x 80.00
	Electronic control module	Sparkfun	1 x 50.00
	All accommodating electric wiring and plastic tubing	digikey	1 x 25.00
	Welding gas/wire		1 x 10.00
	Materials for weatherproof control box		1 x 20.00

ii. Manufacturing issues

One task will be once the two concentric tubes are inserted into each other, the rolling guide that is attached to the inside via a bolt will double as an anchor for the extension pulley that redirects the steel cable in a 180 degree turn. The manufacturing issue will be to decide how to anchor this part to the outside beam. One might consider a design where there is an inlet and a fixture is attached to the outside (welding) so that this function of the platform could be easily adjusted and taken apart during any upkeep operation.

Another issue is the directive to keep the cost of the product as low as possible. As the project sits, two motors are needed for every boom. One motor will do the work to extend the boom outward, and another motor is needed to put tension on the vertical boom. One way to cut costs down will be to run another set of pulleys so that the lateral movement can be done with one motor for two sides, reducing the number of motors needed from eight to six.

The HF HAUFF company will use Pacific Steel to order the materials needed for this project. The company sells tubing in all shapes, and several simple measurements are need for the company to do all of the needed cutting. Several small adjustments will be added to the tubing, for example several holes will be needed for the function of the internal pulley, the anchor for the pulley, and also the rolling guides. These modifications will either be done by hand with power tools, or with a vertical mill.

D. testing methods

i. Introduction

The purpose of testing is to ensure that the device meets the design requirements and predictions. These tests will be conducted in a similar manner as the full scale project would be, testing the downriggers ability to withhold the force that will be created by the vertical member during the leveling process. Based on the calculations made during the fall quarter for the full scale project, certain equations made on the ‘green sheets’ will be reverse engineered, using the new dimensions for the proof of concept model to arrive at usable and testable numbers for the this section.

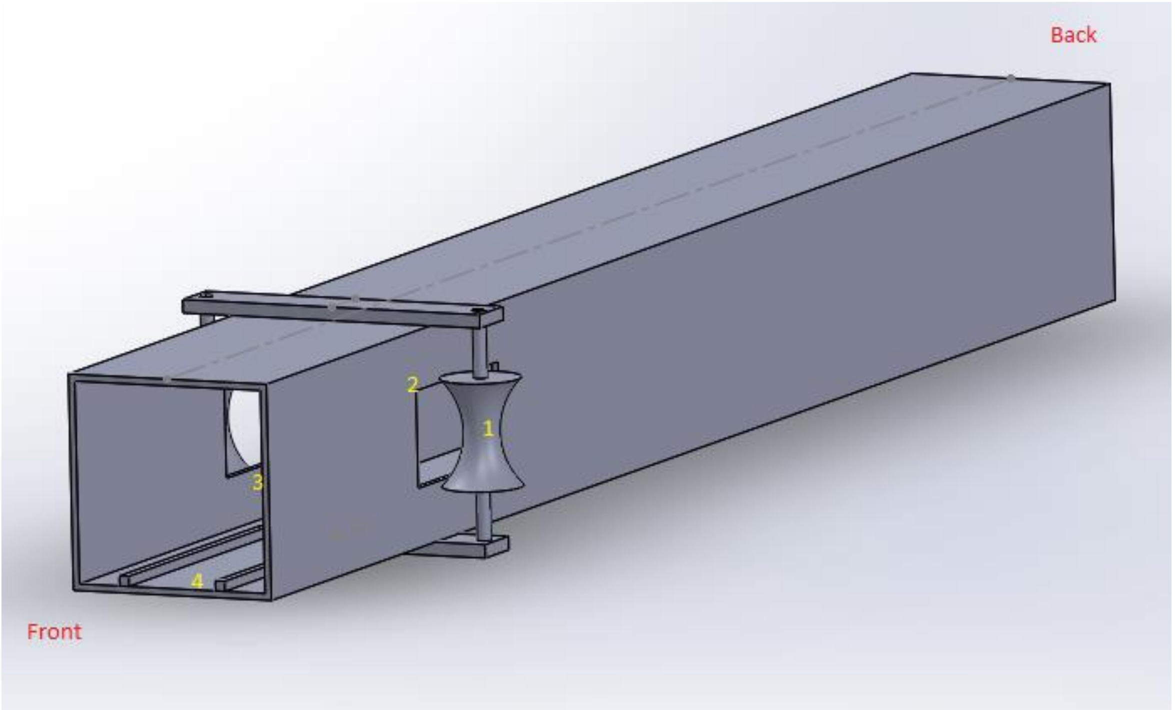
Method/Approach:

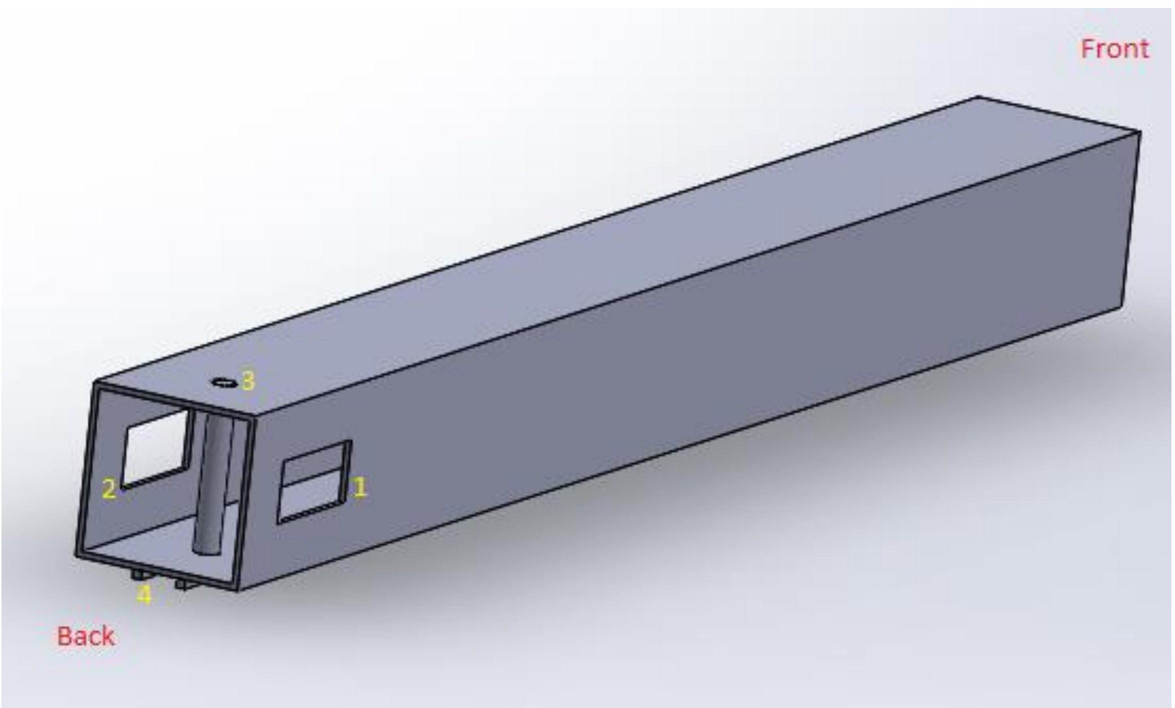
The first test applied to the part will be a fitment. This will account for any variances within the metal or the welded guides. This test will prove that both parts fit together and there is enough room for the inside beam to move freely without any major restrictions, but also to provide enough rigidity so that following tests can be accomplished.

The second test is a static analysis of weight on one end, and will provide a visual display that the beam is capable of holding the predicted load at the designated extension length. This test will incorporate a large C-clamp, along with two volunteers balanced the end of the inside beam whilst extended. The largest amount of force created when the beam is loaded with weight at the designated extension length is located at the opposite end of the inside beam from where the weight is positioned. This end of the beam will be weighed down with a combination of weights and people.

The third test will be an analysis of the spring used for the retraction process. This will test against how much force is needed to keep the articulating arm at its designated extension length, and also how much force is needed to fully extend the enclosed beam. After one round of testing the force needed to extend the device and keep it extended while it is dry, a round of testing will be conducted after a lubricated application is applied to the inside and outside beam parts.

For the load test weight will be added to the beam while at its extended length until the projected figure has been reached including a safety factor, which means that the final result will be under the max load so to avoid yielding or any other irreversible damage.





(Top figure: Large beam, Bottom figure: Small beam)

Test Procedure:

All tests will be conducted inside of the Washington Society for Safety Engineers classroom at the Central Washington University. All testing completed is non-destructive and no personal protective equipment is needed. All test data will be recorded onto green sheets and provided below.

Assembly/Fitment

This test will be performed to guarantee that all parts fit together. Test duration should last no longer than 5 minutes

Steps:

I. Gather all necessary project parts (small diameter beam, large diameter beam, steel braided cable)

II. Lay beam on flat table, so that the long edge is laying down

a) The welded guides in figure one labeled "4" should be closest to the table surface

III. Insert the back of the small beam concentrically into the front of the large steel beam.

a) Make sure that the welded guides on the larger steel beam as well as the small steel beam (labeled "4" in both figures) are oriented so that they are closest to the table surface. Simply slide one beam into the other so that the larger beam completely encloses the smaller beam

a) Make sure that when the beams are fully enclosed, the guides on the outside of the small steel beam are on the opposite end of the assembly as the guides on the inside of the large beam

IV. Thread the provided steel cable through the opening at the front of the large beam (label "2", large beam)

V. Route the steel through the inside of the space provided between the two beams toward the back of the small beam to the welded stock (label "3", small beam). Thread the cable through the opening at the back of the small beam (label "1/2", small beam)

VI. Wrap the steel cable around the welded stock located at the back of the small beam (Label "3", small beam) and return the cable through the openings at the back of the steel beam and return it to the front of the opening at the front of the large beam (label "3")

VII. Wrap the steel cable around the pinned rollers (large beam, label "1/3" and lay the cable pointing towards the back of the large beam

VIII. A successful test will result in being able to move the enclosed beam into the larger beam with little opposition from the metal to metal contact or the steel cable.

IX. Record time to complete test. Record a pass or fail.

Weight/Load test

This test will show that the beam assembly is capable of supporting the predicted amount of weight. Test duration should last no longer than 5 minutes.

Steps:

I. Gather all supplies necessary for testing (concentrically oriented steel beams, 450 pounds of weight in lead and human volunteers, ruler, marker)

II. Measure exactly where the middle length of the inside beam is. This point should be exactly 1.5 feet. Mark the small beam for future reference

III. Lay the beams down on a table in a similar manner to the fitment test, steps II and III.

IV. Using a large C-clamp, secure the outer beam to a flat table, making sure that the end of the outside beam is not protruding from the table.

V. Assemble the beams together in a similar concentric fashion as the assembly/fitment test steps II and III

VI. Using the mark from step II of this test, extend the front of the inner beam out of the front of the outer beam to the 1.5 foot mark. For this test the spring operated retraction device should not be attached.

VII. Because 450 pounds of weight proved to be too difficult to secure to the end of the beam, several volunteers are asked to balance themselves on the end of the beam.

a) The weight is to be added incrementally, meaning that the smallest person stands on the beam first, and additional weight is added until the calculated weight parameter is achieved. Record a pass or fail.

Friction test

This test will prove that the articulating parts will move back and forth with ease. Test duration should last no longer than 15 minutes.

Steps:

I. Gather all necessary supplies (concentrically loaded steel beams from the load and fitment test, steel cable, digital scale, oil, c-clamp)

II. Lay the concentric beam so that the long edge is sitting on the table, and the welded guides labeled "4" in each diagram are closest to the table surface.

III. Attach assembly to the table with c-clamp.

IV. Thread the steel cable into the front of the small beam

V. Loop the steel cable around the welded stock (label "3", small beam) located at the back of the inside beam. This is where the spring retraction device is normally located

VI. Thread the steel cable out of the far out through the front end of the inside beam.

VII. Tie a loop at the end of the steel cable that is now sticking out of the front of the small and larger beams

VIII. Power on the spring scale and pull loop from steel cable out away from the front of the beams with the scale.

IX. Take several readings from 3 different positions of extension; one position where the inside beam is not extended at all, one position where the beam starts at the 1.5 foot mark as described in the load test step II, and another position approximately half the distance from the end of the beam and the mark mentioned above

X. Record and report

XI. After the first trials of testing have been completed, add a light application of oil to the bottom inside of the larger beam

XII. Repeat all previous steps for this test series and record/report

Deliverables:

Below is a summarized table of all test results. For a majority of the test the primary calculation are accurate and precise, only one set of values from the dry friction tests were considered outliers and withheld from the finals report.

Test Procedure	**Performance Predictions**	**Test Results**
weigh device	55 lbs.	60.2 lbs.
assembly test	5 minutes	4 minutes
load test	450 lb.	pass
friction test, dry	8.999 lbf	11.2 lbf
friction test, wet	2.8801 lbf	3.3 lbf
budget	$200.00	$158.62
schedule	stay on schedule	over time

Conclusion

The success of the project is based off of whether or not the project meets the primary requirements and design predictions. The friction test is added to the original test itinerary because the initial design incorporated the use of several sheets of ultra high molecular weight plastic. When these plastic sheets became stuck in transit a re-design with welded metal pieces of stock are added to reduce the amount of metal to metal contact between the two moving beams. All other predictions are met, and overall this project is a success and a large learning experience.

E. budget, schedule, project management

For keeping within the projected time and budget, a combined schedule is submitted in appendix D. This Chart maps the estimated time allowance aspects of the project, as well as the time it actually took to complete.

1e. proposed budget

The proposed cost for this project is estimated at $2,454 not including the trailer or the wind machine. This is a significantly less amount in comparison to the benchmark mentioned above in section 6a, the proposed model even includes a handful of features that the benchmark does not, in contrast making it a superior machine. If not for the gracious sponsorship this project is receiving from the HF HAUFF company, several measures would be needed to gain funding from outside sources to complete this project.

2e. proposed schedule

The specific dates of individual part completion will be managed by a Gant chart as assigned in the senior project MET495 course. This chart will dictate this project's particular schedule, time management, and deliverables. This chart is categorized monthly starting in September and ending in June. Reference appendix E.

3e. project management

Human resources (departments, people)

Dr. Craig Johnson, Roger Beardsley, Charles Pringle, Casey Macfarlane, Dana Morgan and Scott Howard of Cascade Wind Machine Service

Physical resources (machines, etc)

Cold saw, ban saw, drill press, vertical mill, tig welder, grinding wheel

Soft resources (programs)

Solidworks,

Financial resources (sponsors, free stuff)

HF HAUFF,

Conclusion

In conclusion this project has been able to relay some very important realities about a future involving an engineering occupation. This specific senior project is one of few that was allowed to work with more than one person, and one of even fewer projects that was able to obtain sponsorship. If there is one thing that became very clear during this endeavor it is that the more intricate the project and the more divisions of labor, the amount of communication must rise exponentially. There are often times where one simple phrase or equation can be mis-translated and can send the whole project in a tangent direction. Communication seems to be most detrimental during the design phase rather than the construction phase, based on the fact that if there is a miscommunication somewhere during the early stages of the project, then the final design product may be somewhat distant from what the originator of the idea or the person in charge had in mind.

This project has laid some principal foundations down in the sense that one must not question the mandated milestone due dates of a project. Even if one's work is behind schedule, there are often other people waiting for the status of your input as it may be deemed valuable to them even if it seems like a minor portion of work to oneself. This includes any setbacks that may or may not be related to the speed, effort, or pride that one puts into their work. Any sort of change to the project after completion, or perhaps project requirements may result in a need for a substantial amount of work to be altered or changed completely. This is no reason to pout as engineers are strong minded and strong at heart, but this point prompt one last topic that has been successfully learned over the duration of this designing task. Time is the most valuable commodity by far over any other aspect. With enough time, any project can be as complex or detailed as any other. Planning is key.

Acknowledgements

Avery special thank you to all of the Central Washington University's Mechanical Engineering program, my gratitude goes out to the advisors who have mentored me from entry level classes through to my graduation this senior year; Doctor Craig Johnson of the materials sciences, Roger Beardsley of the thermodynamics discipline, and Charles Pringle professor of the machine design. My gratitude goes out to the teachers who have helped me succeed in previous years in

preparing me for these demanding classes, at and below the college level. My gratitude also goes out to every peer who strived with me through these years that are college. A special recognition to Mister Ted Bramble, one of the reasons that made staying in the engineering program so much easier, you are a remarkable individual and the interest you take in your classes seems to come effortlessly. Thank you to all.

Appendix A - Calculations

Figure A1

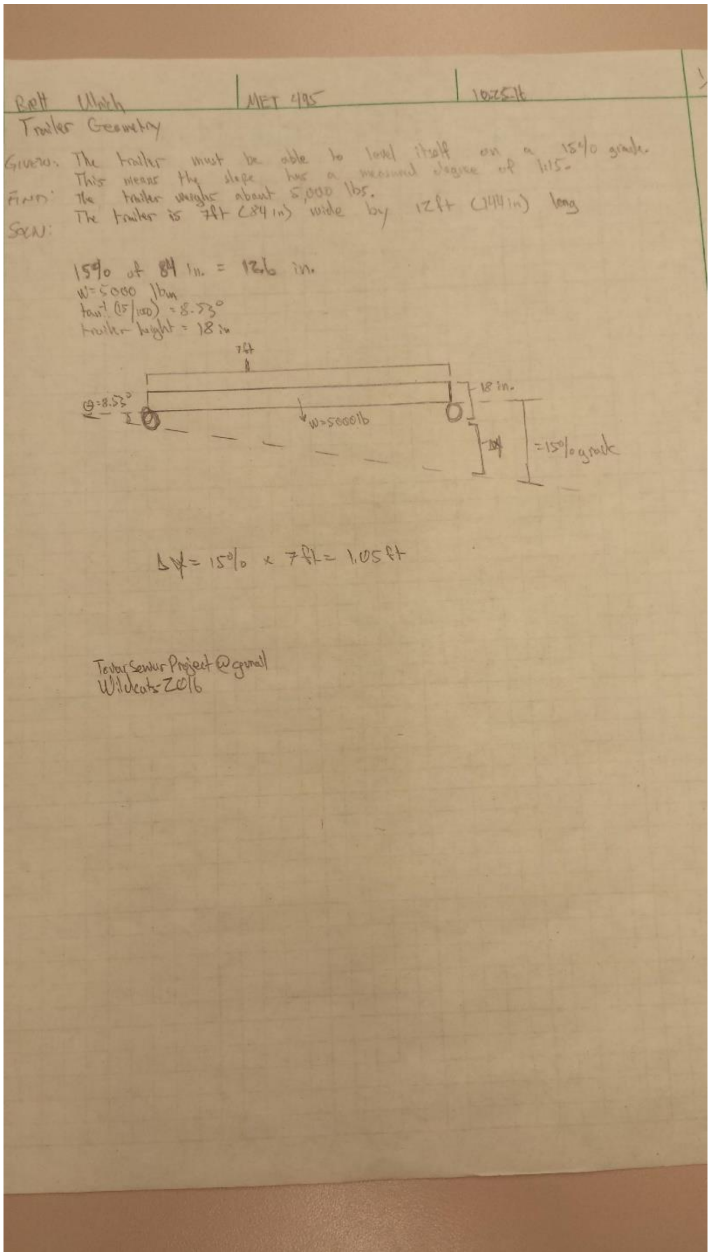
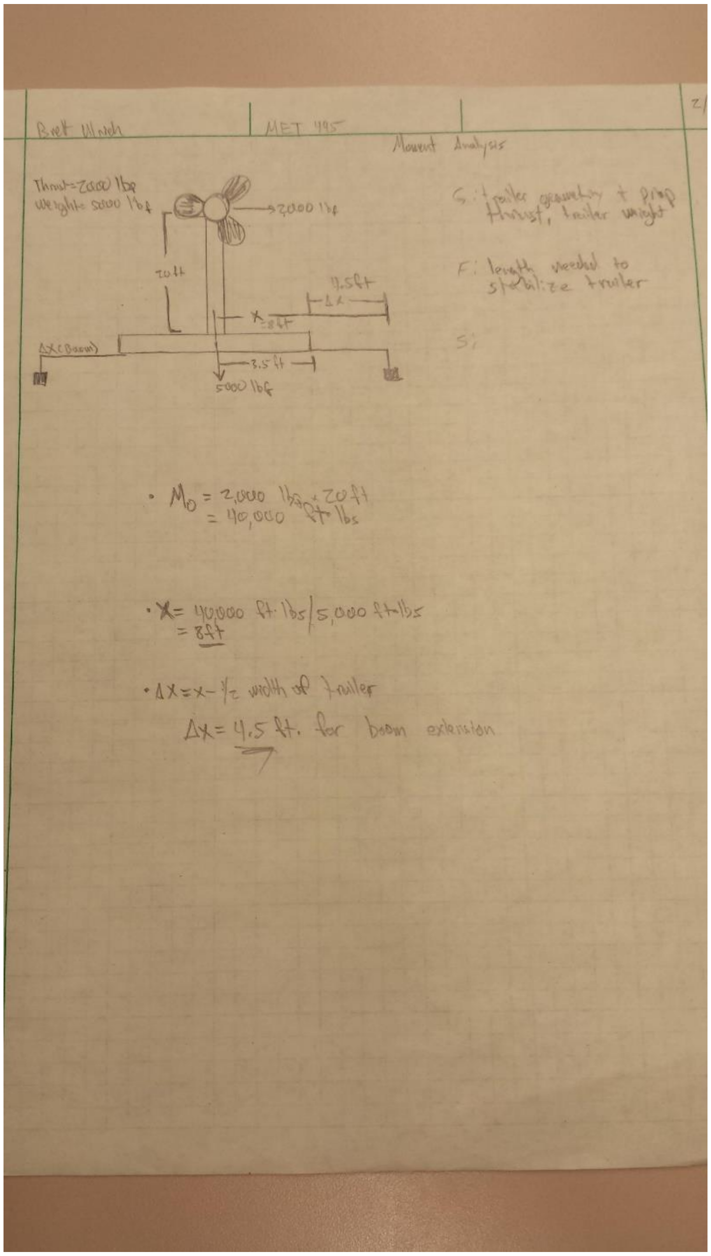
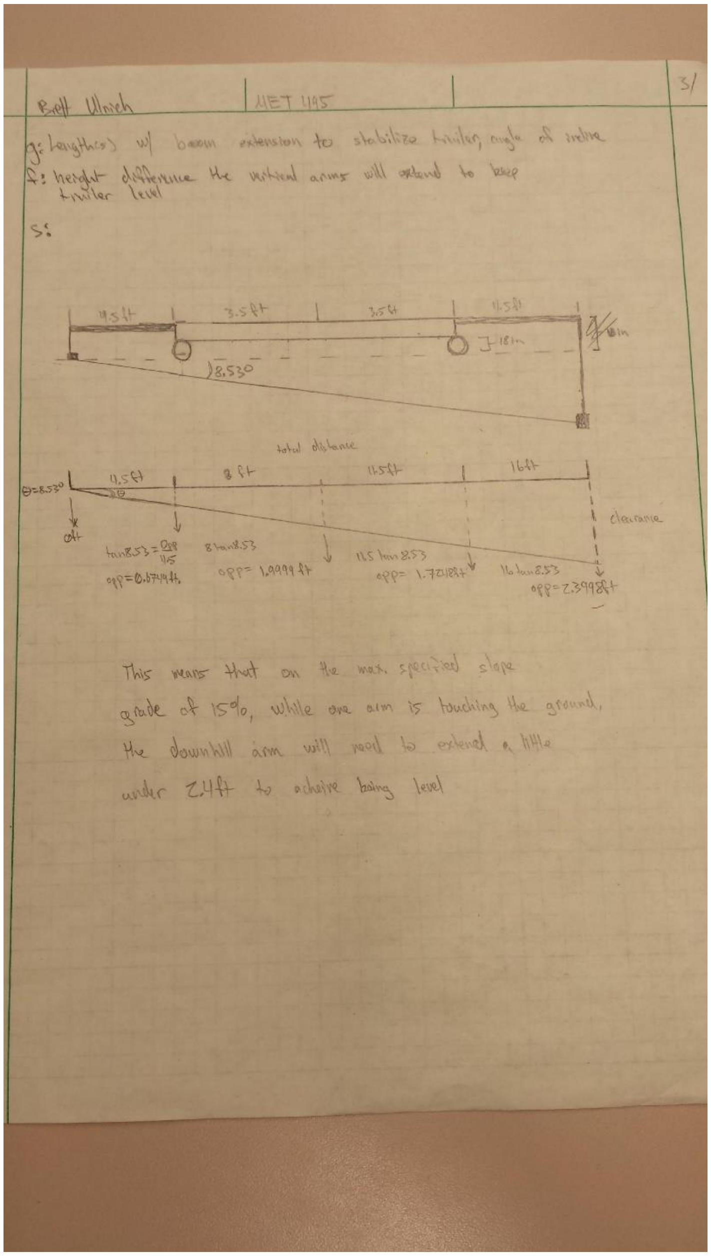


Figure A2



MET 495
Moment Analysis
Thrust=2000 lbf
Weight= 5000 lbf
2000 lbf
20 ft
4.5ft
Δx
x =8ft
3.5 ft
5000 lbf
G: trailer geometry + prop thrust, trailer weight
F: length needed to stabilize trailer
S:
• M0 = 2,000 lbs * 20 ft
= 40,000 ft lbs
• X= 40,000 ft·lbs/5,000 ft-lbs
= 8ft
• Δx=x− ½ width of trailer
Δx= 4.5 ft. for boom extension

Figure A3


Brett Ulrich | MET 495 | 3/

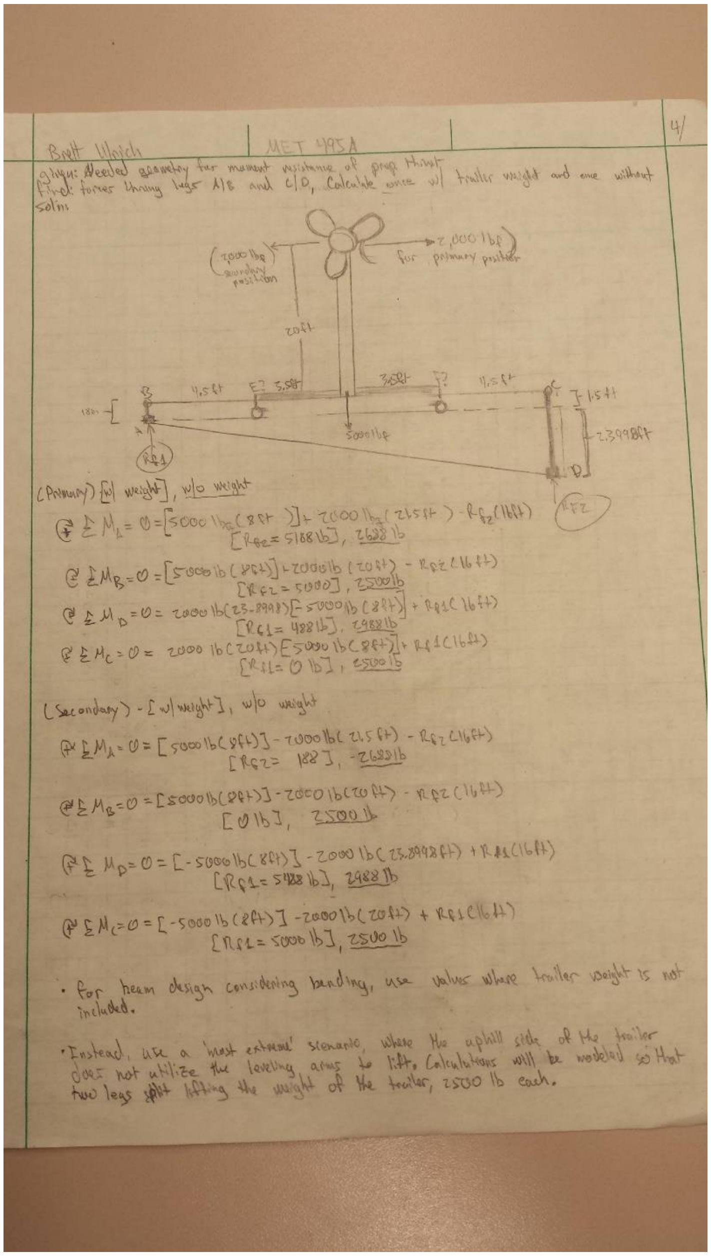
g: Lengths(s) w/ beam extension to stabilize trailer, angle of incline

f: height difference the vertical arms will extend to keep trailer level

S:

This means that on the max. specified slope grade of 15%, while one arm is touching the ground, the downhill arm will need to extend a little under 2.4 ft to acheive being level

Figure A4



Brett Ulrich | MET 495A | 4/

given: Needed geometry for moment resistance of prop thrust
find: forces through legs A/B and C/D, Calculate once w/ trailer weight and once without
soln:

(Primary) [w/ weight], w/o weight

$\circlearrowleft \Sigma M_A = 0 = [5000\,lb(8ft)] + 2000\,lb(21.5ft) - R_{f2}(16ft)$
$[R_{f2} = 5188\,lb]$, 2688 lb

$\circlearrowleft \Sigma M_B = 0 = [5000\,lb(8ft)] + 2000\,lb(20ft) - R_{f2}(16ft)$
$[R_{f2} = 5000]$, 2500 lb

$\circlearrowleft \Sigma M_D = 0 = 2000\,lb(23.8998)[-5000\,lb(8ft)] + R_{f1}(16ft)$
$[R_{f1} = 488\,lb]$, 2988 lb

$\circlearrowleft \Sigma M_C = 0 = 2000\,lb(20ft)[5000\,lb(8ft)] + R_{f1}(16ft)$
$[R_{f1} = 0\,lb]$, 2500 lb

(Secondary) - [w/ weight], w/o weight

$\circlearrowleft \Sigma M_A = 0 = [5000\,lb(8ft)] - 2000\,lb(21.5ft) - R_{f2}(16ft)$
$[R_{f2} = 188]$, -2688 lb

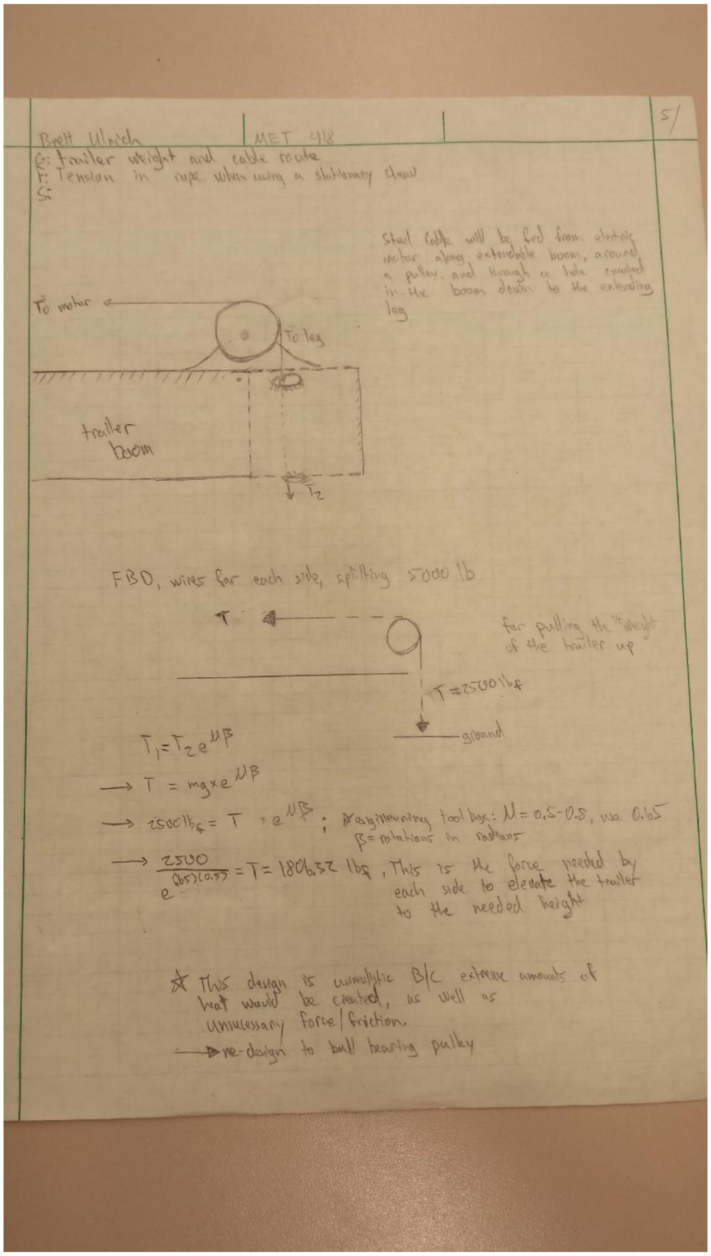
$\circlearrowleft \Sigma M_B = 0 = [5000\,lb(8ft)] - 2000\,lb(20ft) - R_{f2}(16ft)$
$[0\,lb]$, 2500 lb

$\circlearrowleft \Sigma M_D = 0 = [-5000\,lb(8ft)] - 2000\,lb(23.8998ft) + R_{f1}(16ft)$
$[R_{f1} = 5488\,lb]$, 2988 lb

$\circlearrowleft \Sigma M_C = 0 = [-5000\,lb(8ft)] - 2000\,lb(20ft) + R_{f1}(16ft)$
$[R_{f1} = 5000\,lb]$, 2500 lb

- for beam design considering bending, use values where trailer weight is not included.
- Instead, use a 'most extreme' scenario, where the uphill side of the trailer does not utilize the leveling arms to lift. Calculations will be modeled so that two legs split lifting the weight of the trailer, 2500 lb each.

Figure A5


Brett Ulrich | MET 418 | 5/

G: trailer weight and cable route
F: Tension in rope when using a stationary sheave
S:

Steel cable will be fed from electric motor along extendable boom, around a pulley, and through a hole created in the boom down to the extending leg

FBD, wires for each side, splitting 5000 lb

$T_1 = T_2 e^{\mu\beta}$

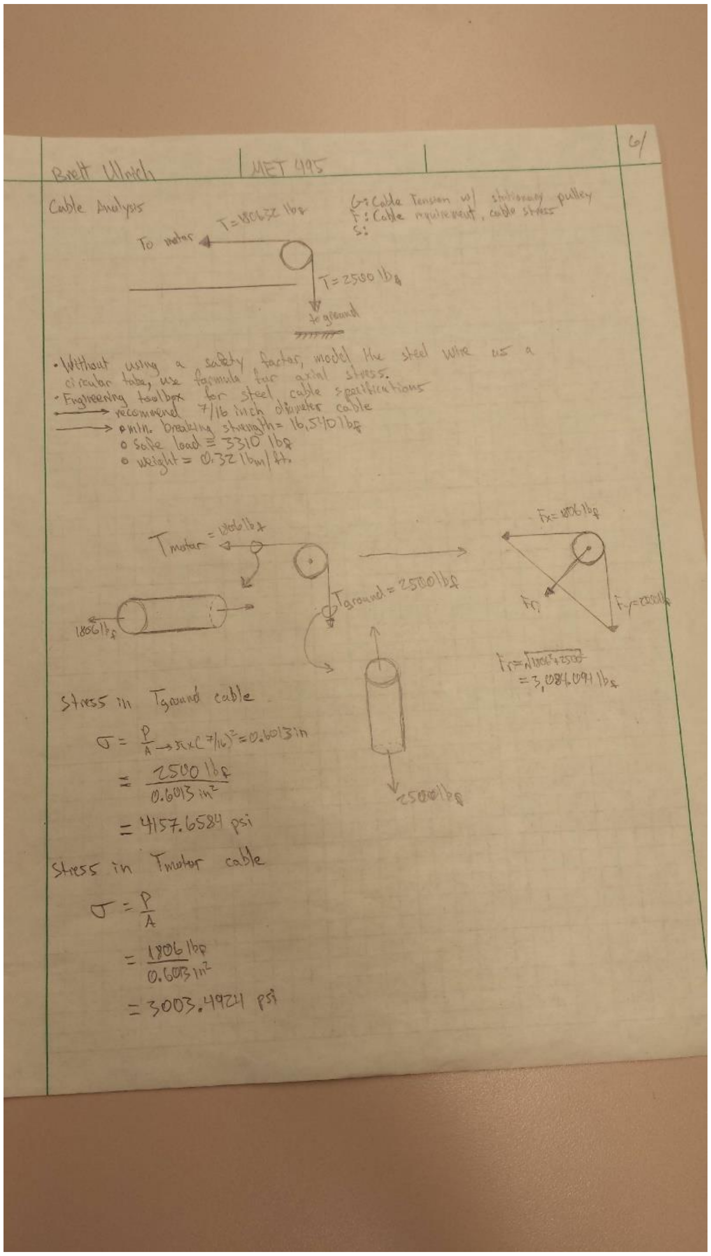
$\longrightarrow T = mg \times e^{\mu\beta}$

$\longrightarrow 2500\,lb_f = T \times e^{\mu\beta}$; engineering tool box: $\mu = 0.5 - 0.8$, use 0.65
β = rotations in radians

$\longrightarrow \frac{2500}{e^{(.65)(0.5)}} = T = 1806.52\ lb_f$, This is the force needed by each side to elevate the trailer to the needed height

☆ This design is unrealistic B/C extreme amounts of heat would be created, as well as unnecessary force/friction.
⟶ re-design to ball bearing pulley

Figure A6


Brett Ulrich | MET 495 | 6/

Cable Analysis

G: Cable Tension w/ stationary pulley
F: Cable requirement, cable stress
S:

- Without using a safety factor, model the steel wire as a circular tube, use formula for axial stress.
- Engineering toolbox for steel cable specifications
  → recommend 7/16 inch diameter cable
  → min. breaking strength = 16,540 lbf
    - safe load ≅ 3310 lbf
    - weight = 0.32 lbm/ft.

Stress in Tground cable

$\sigma = \frac{P}{A} \rightarrow \pi \times (7/16)^2 = 0.6013 \text{ in}$

$= \frac{2500 \text{ lbf}}{0.6013 \text{ in}^2}$

$= 4157.6584 \text{ psi}$

Stress in Tmotor cable

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

$= \frac{1806 \text{ lbf}}{0.6013 \text{ in}^2}$

$= 3003.4924 \text{ psi}$

Figure A7

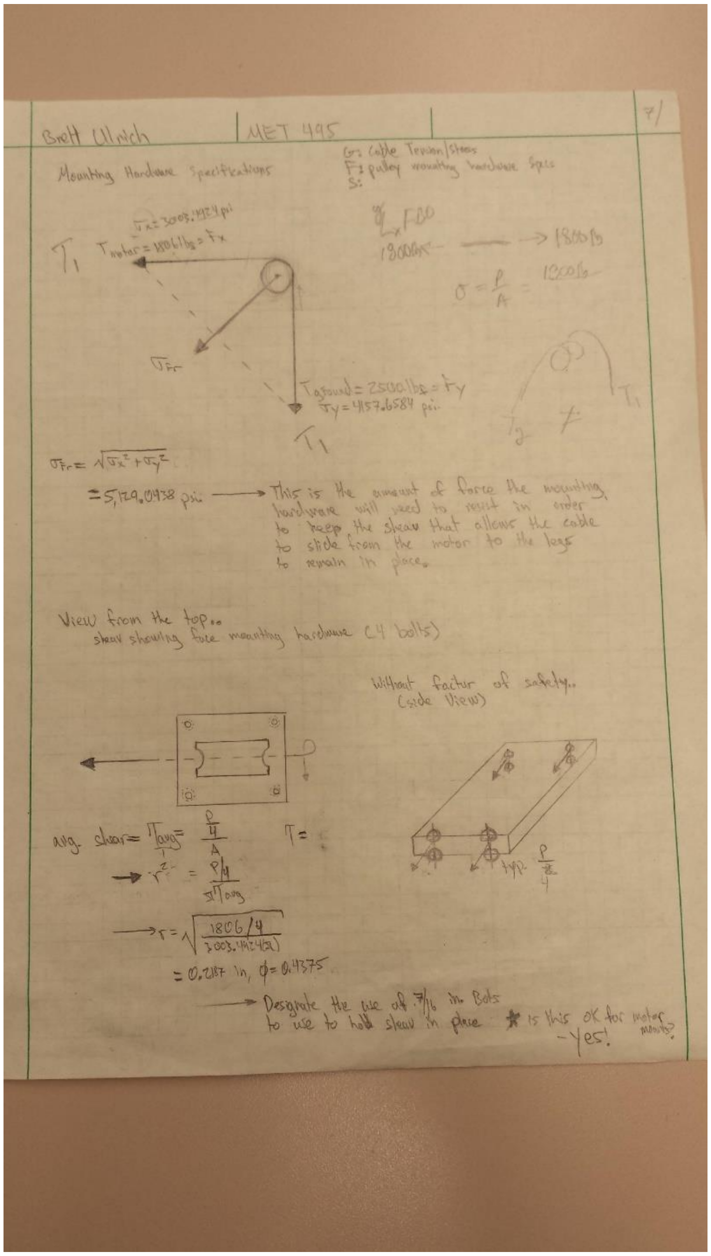

Brett Ulrich
MET 495
Mounting Hardware Specifications
This is the amount of force the mounting hardware will need to resist in order to keep the sheave that allows the cable to slide from the motor to the legs to remain in place.
View from the top..
sheave showing force mounting hardware (4 bolts)
Without factor of safety..
(side View)
Designate the use of 7/16 in Bolts to use to hold sheave in place
* is this OK for motor mounts?
- Yes!

Figure A8

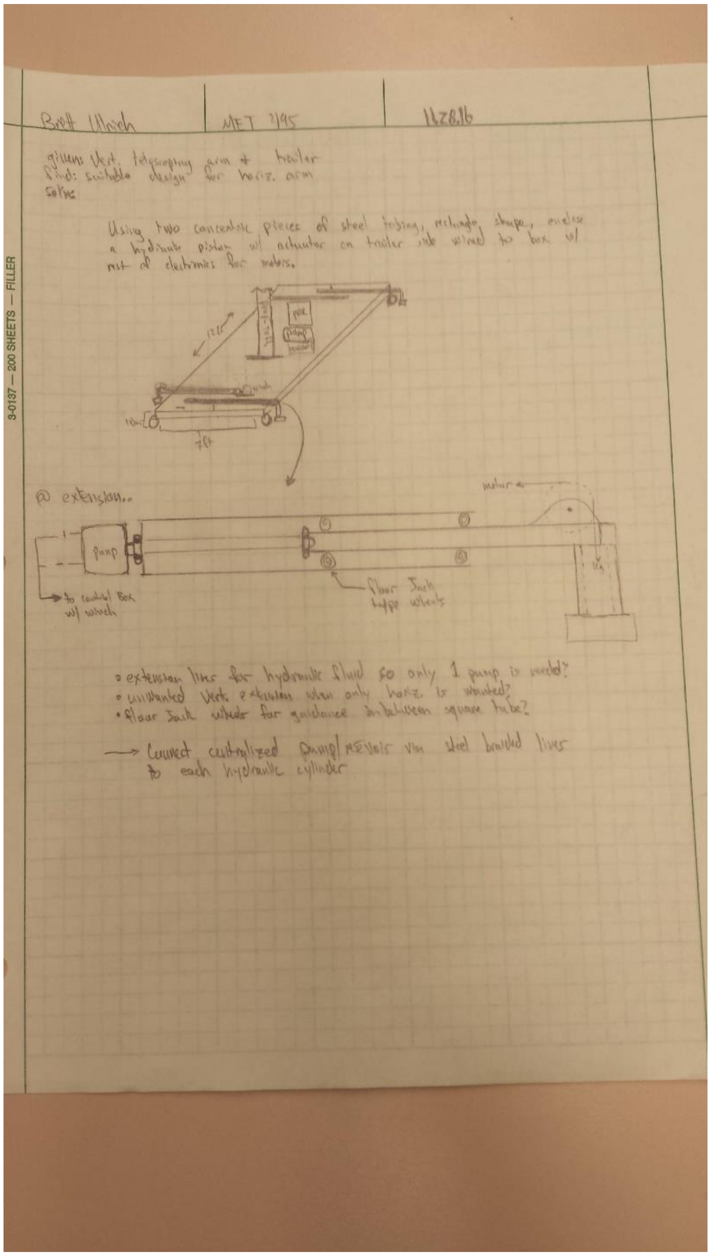
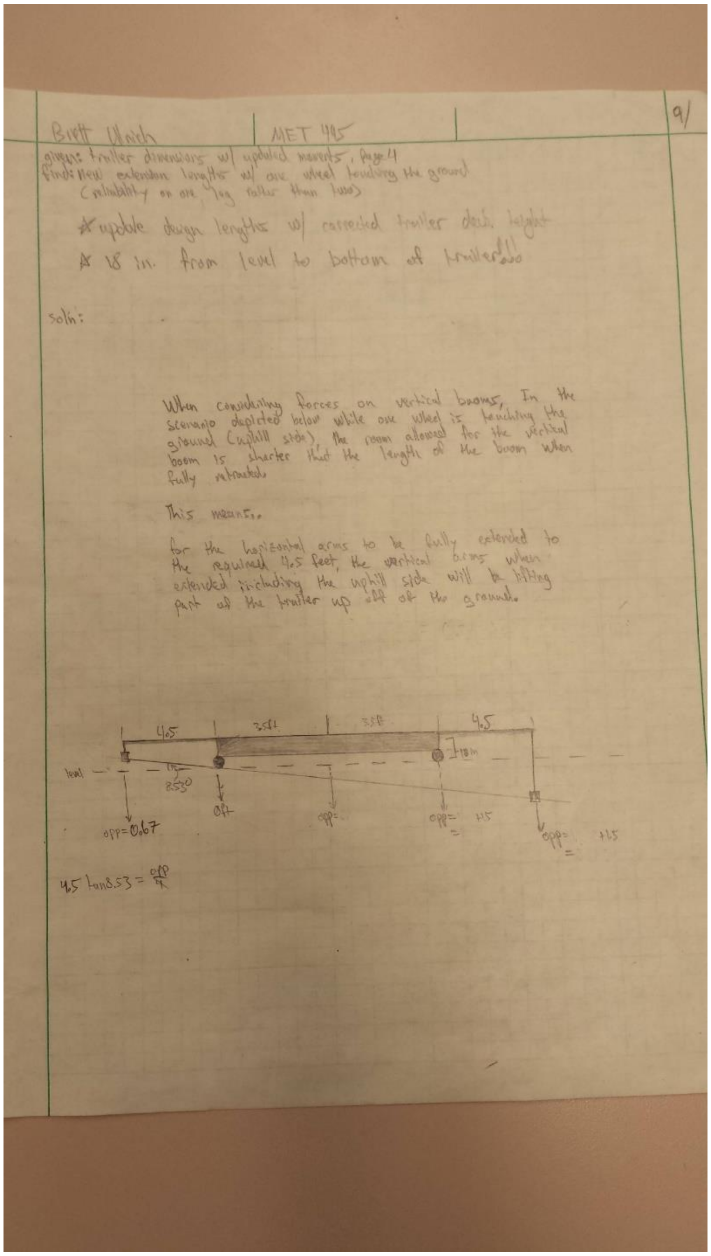


Figure A9



Brett Ulrich | MET 495 | 9/

given: trailer dimensions w/ updated moments, Page 4
find: new extension lengths w/ one wheel touching the ground
(reliability on one leg rather than two)

★ update design lengths w/ corrected trailer deck height

★ 18 in. from level to bottom of trailer!!!

soln:

When considering forces on vertical booms, In the scenario depicted below while one wheel is touching the ground (uphill side), the room allowed for the vertical boom is shorter that the length of the boom when fully retracted.

This means..

for the horizontal arms to be fully extended to the required 4.5 feet, the vertical arms when extended including the uphill side will be lifting part of the trailer up off of the ground.

$4.5 \tan 8.53 = \frac{opp}{4}$

Figure A10

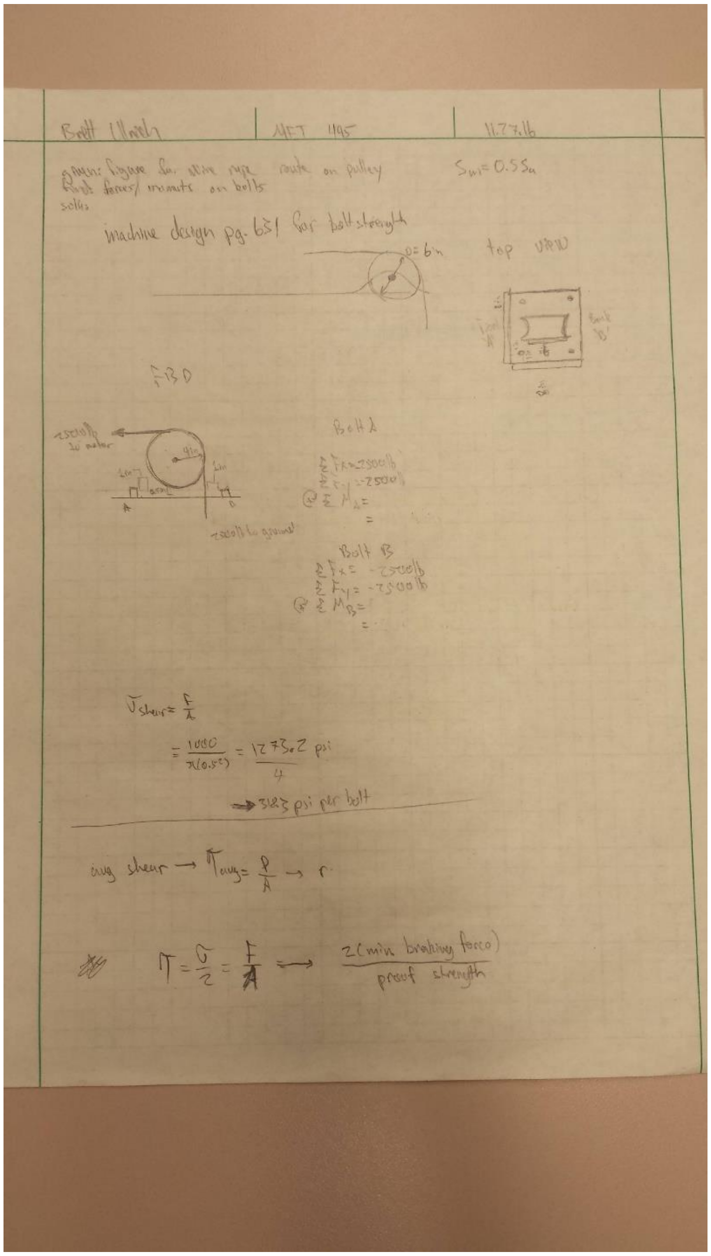
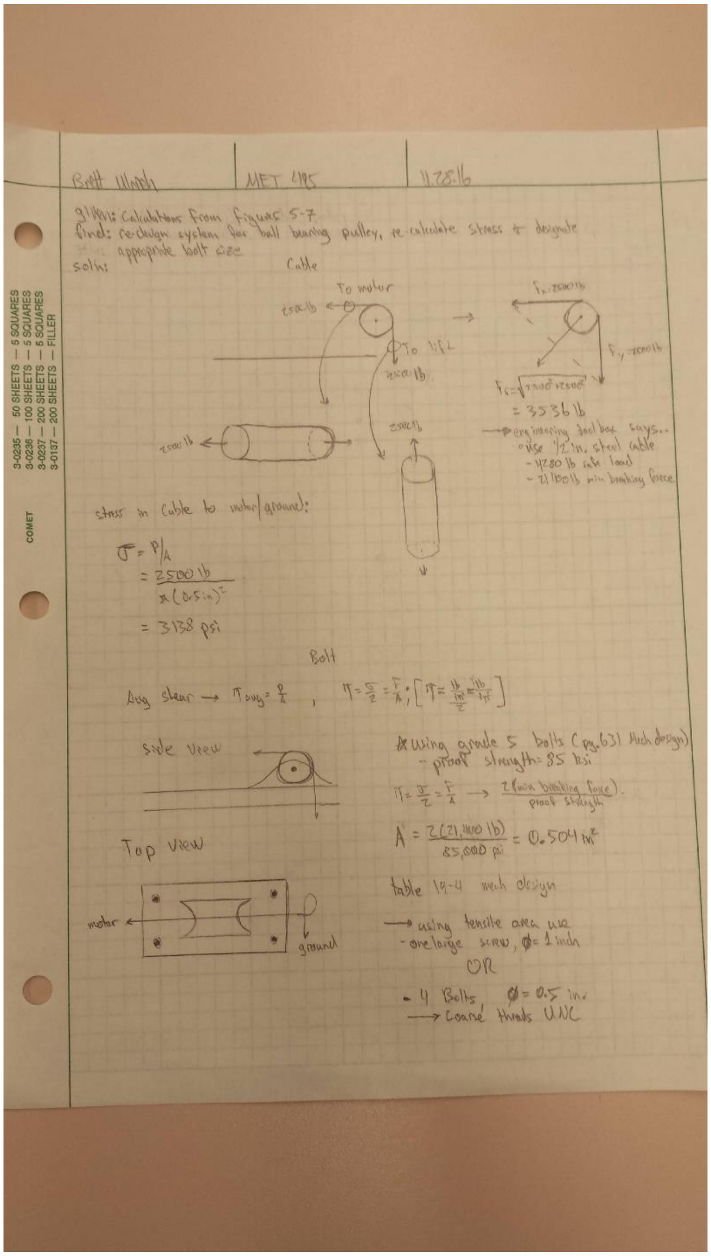


Figure A11



Brett Ulmch | MET 495 | 11.28.16

given: Calculations from figures 5-7
find: re-design system for ball bearing pulley, re-calculate stress & designate appropriate bolt size
soln:

Cable

$F_R = \sqrt{2500^2 + 2500^2}$
$= 3536$ lb

→ engineering tool box says..
- use 1/2 in. steel cable
- 4280 lb safe load
- 21,400 lb min breaking force

stress in Cable to motor/ground:

$\sigma = P/A$
$= \frac{2500 \text{ lb}}{\pi (0.5 \text{ in})^2}$
$= 3138$ psi

Bolt

Avg shear → $\tau_{avg} = \frac{P}{A}$, $\tau = \frac{\sigma}{2} = \frac{F}{A}$; $\left[\tau = \frac{\text{lb}/\text{in}^2}{2} = \frac{\text{lb}}{\text{in}^2} \right]$

side view

Top view

* using grade 5 bolts (pg. 631 Mech design)
- proof strength = 85 ksi

$\tau = \frac{\sigma}{2} = \frac{F}{A} \rightarrow \frac{2(\text{min breaking force})}{\text{proof strength}}$

$A = \frac{2(21,400 \text{ lb})}{85,000 \text{ psi}} = 0.504 \text{ in}^2$

table 19-4 mech design

→ using tensile area use
- one large screw, $\phi = 1$ inch

OR

- 4 Bolts, $\phi = 0.5$ in.
→ Coarse threads UNC

Figure A12

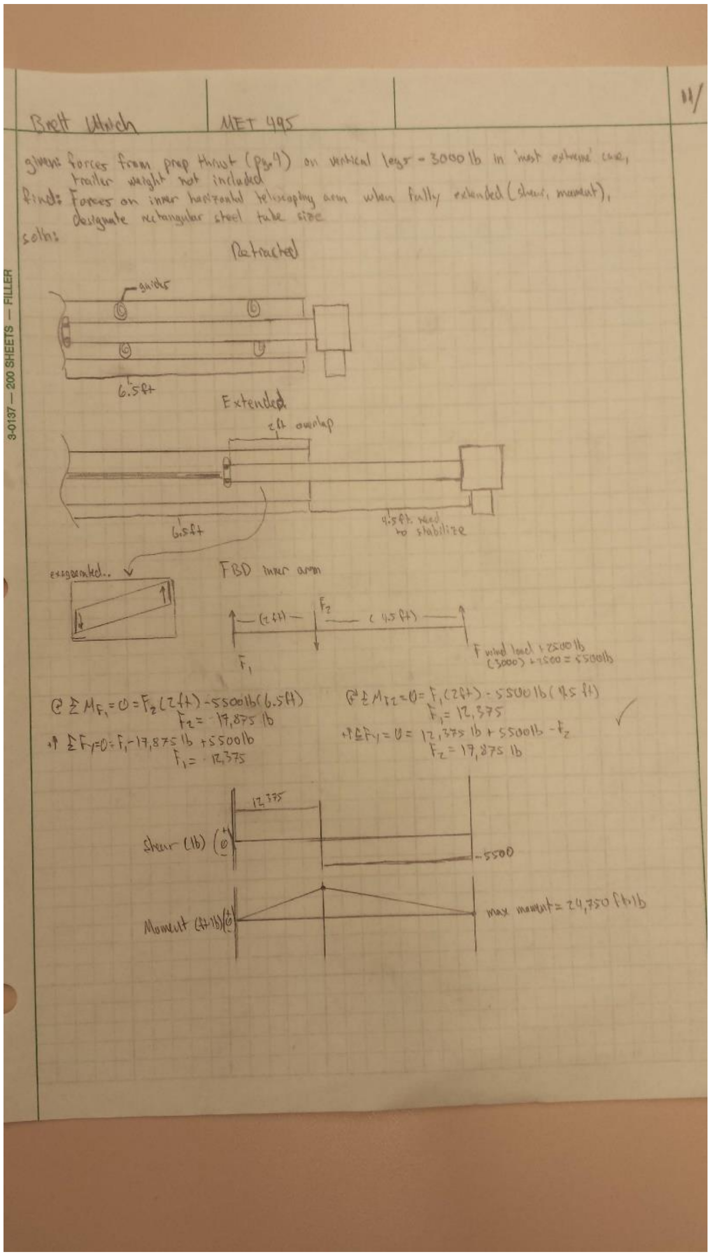


Figure A13

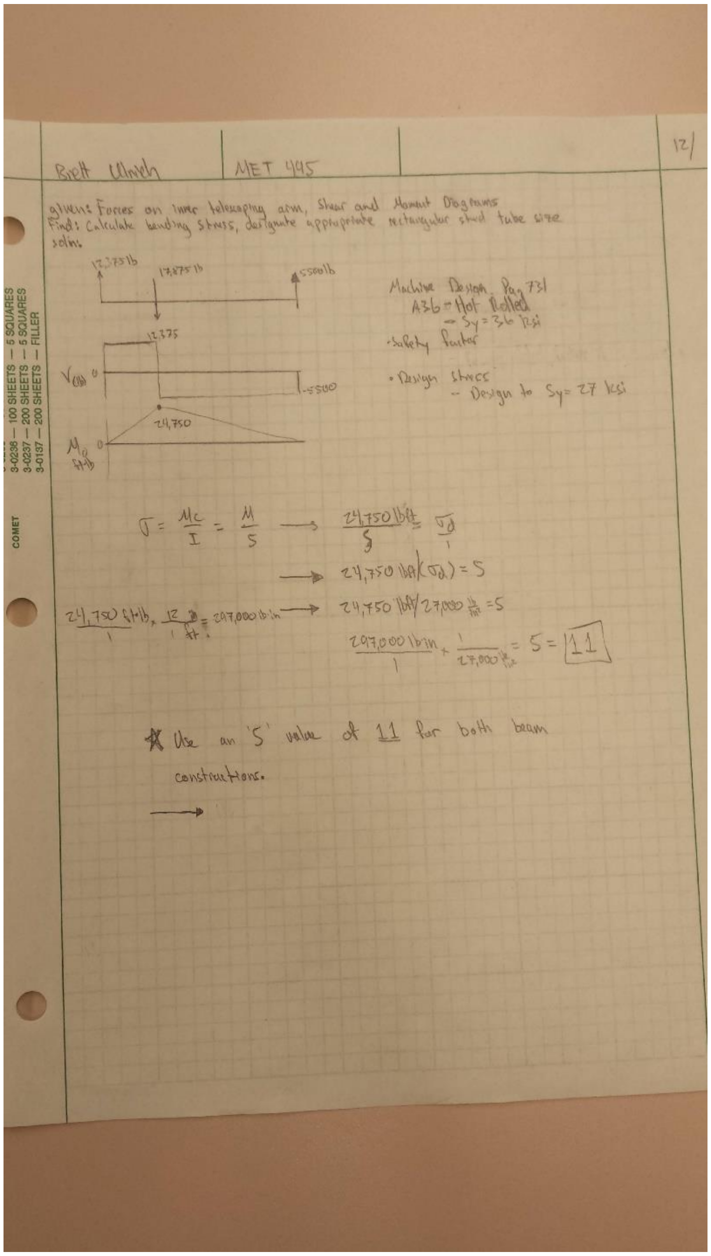
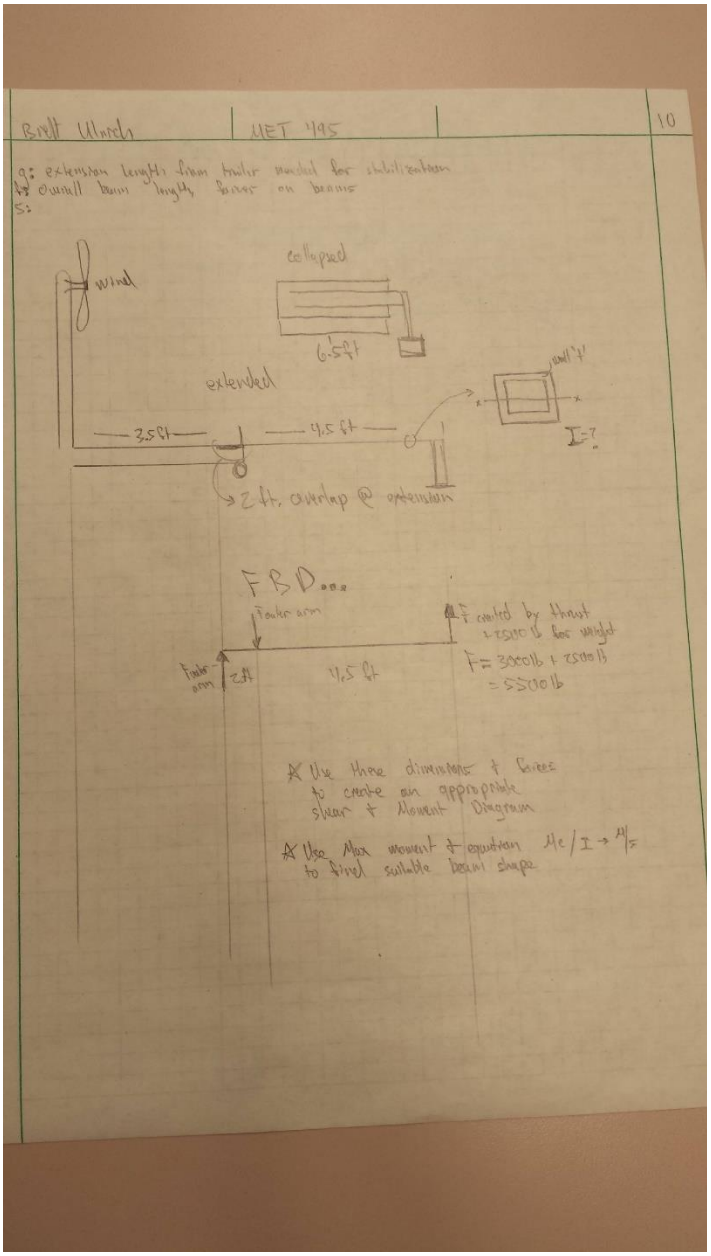
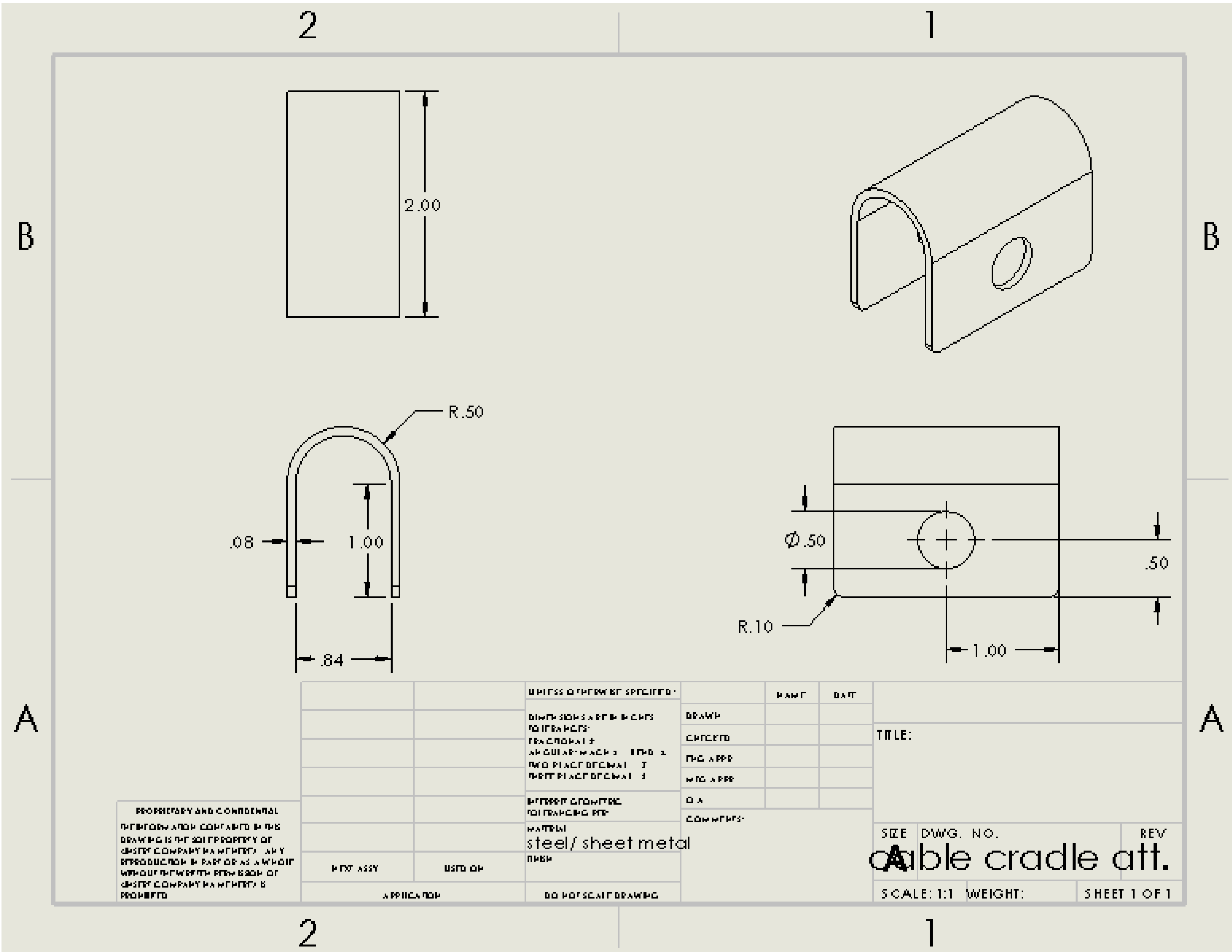

Brett Ulrich
MET 445
given: Forces on inner telescoping arm, Shear and Moment Diagrams
Find: Calculate bending stress, designate appropriate rectangular steel tube size
Machine Design Pag 731
A36 = Hot Rolled
→ Sy = 36 ksi
• Safety Factor
• Design stress
→ Design to Sy = 27 ksi
24,750
-5500
Use an 'S' value of 11 for both beam constructions.

Figure A14



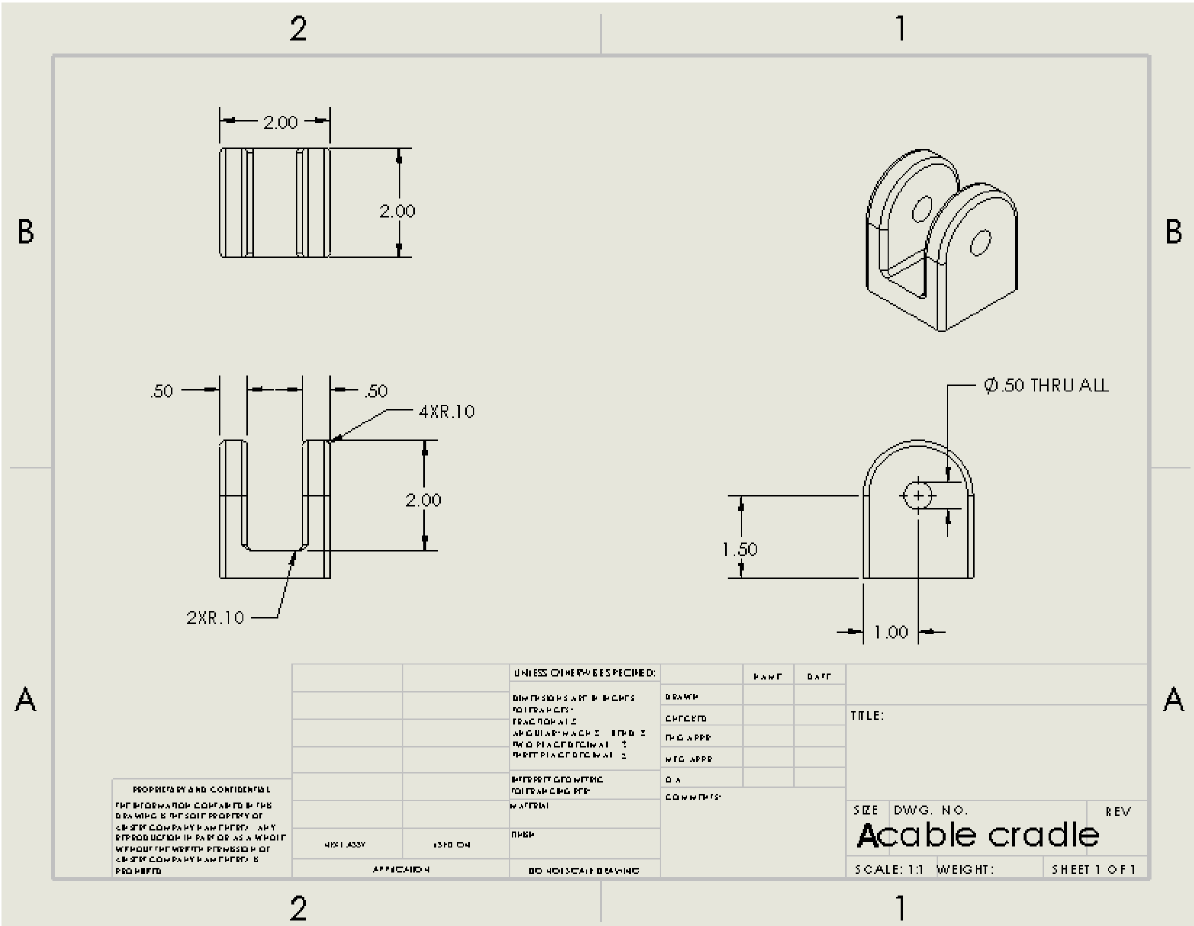
Appendix B – Solidworks Drawings

Figure B1



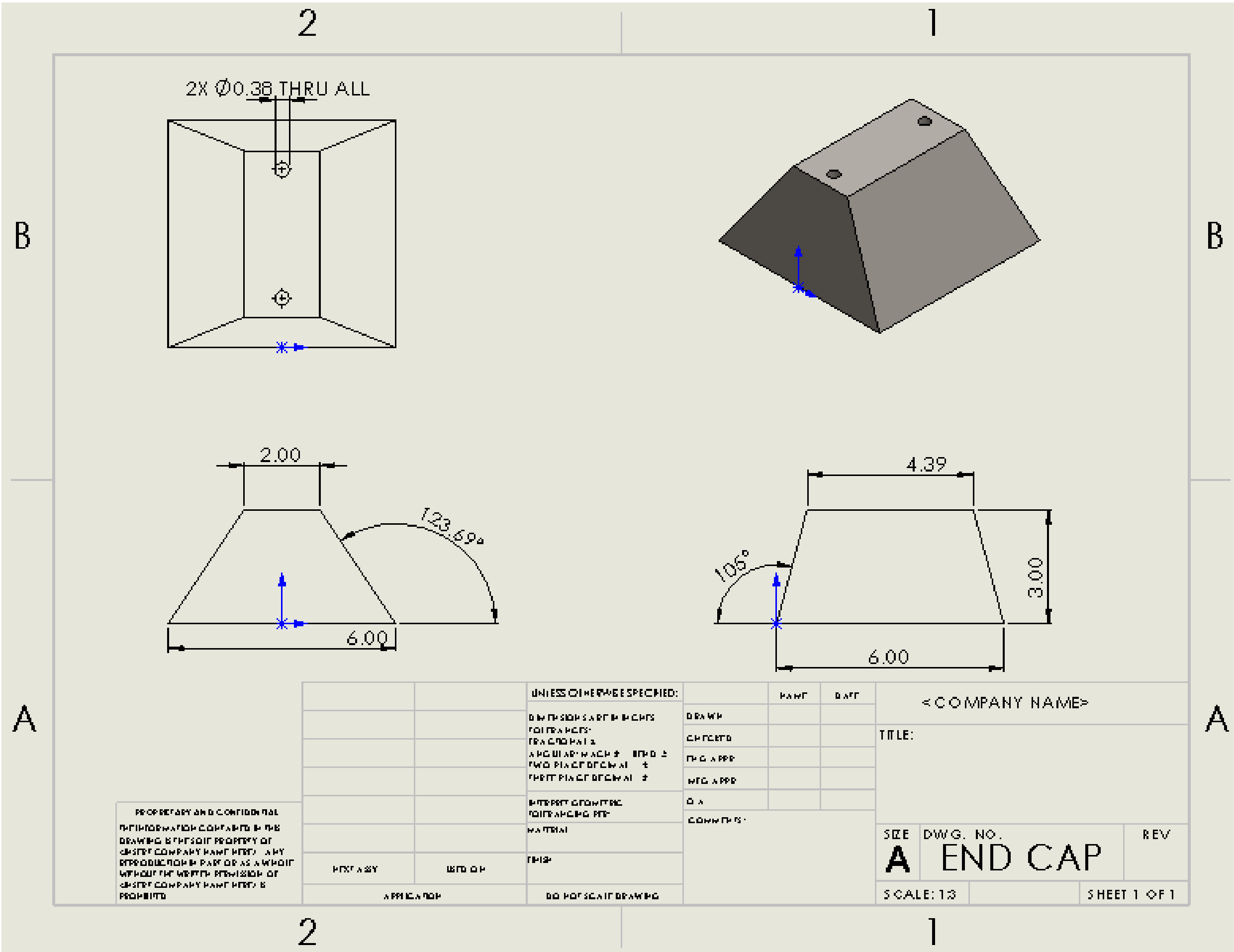
2.00
R.50
.08
1.00
.84
Ø.50
.50
R.10
1.00
TITLE:
steel/ sheet metal
SIZE DWG. NO.
REV
A
cable cradle att.
SCALE: 1:1 WEIGHT:
SHEET 1 OF 1

Figure B2



2.00
2.00
.50
.50
4XR.10
2.00
2XR.10
Ø.50 THRU ALL
1.50
1.00
TITLE:
SIZE DWG. NO. REV
A cable cradle
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Figure B3



2X Ø0.38 THRU ALL
2.00
123.69°
6.00
4.39
105°
3.00
6.00
UNLESS OTHERWISE SPECIFIED:
<COMPANY NAME>
TITLE:
SIZE
A
DWG. NO.
END CAP
REV
SCALE: 1:3
SHEET 1 OF 1

Figure B4

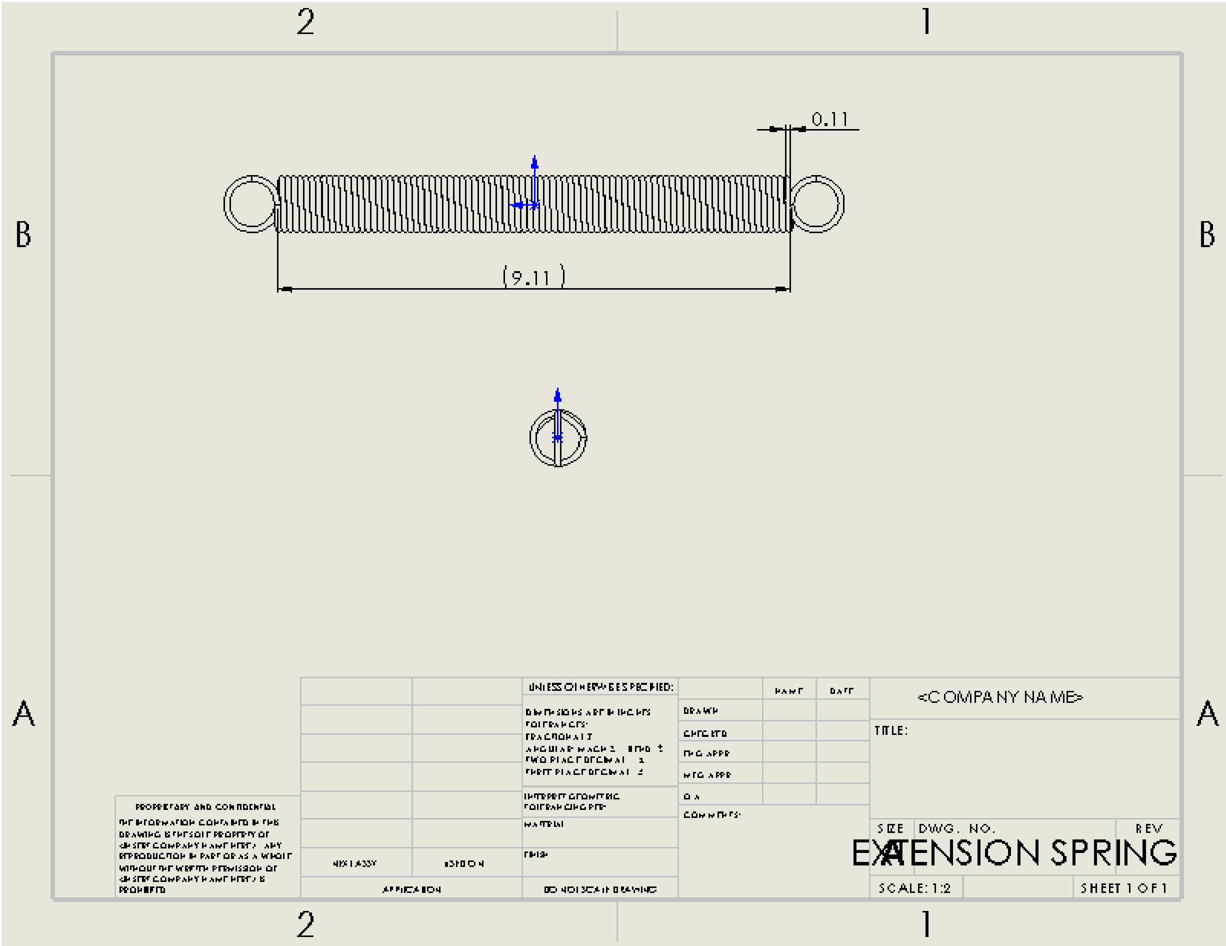

0.11
(9.11)
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
<COMPANY NAME>
TITLE:
SIZE
DWG. NO.
REV
EXTENSION SPRING
SCALE: 1:2
SHEET 1 OF 1
DO NOT SCALE DRAWING

Figure B5

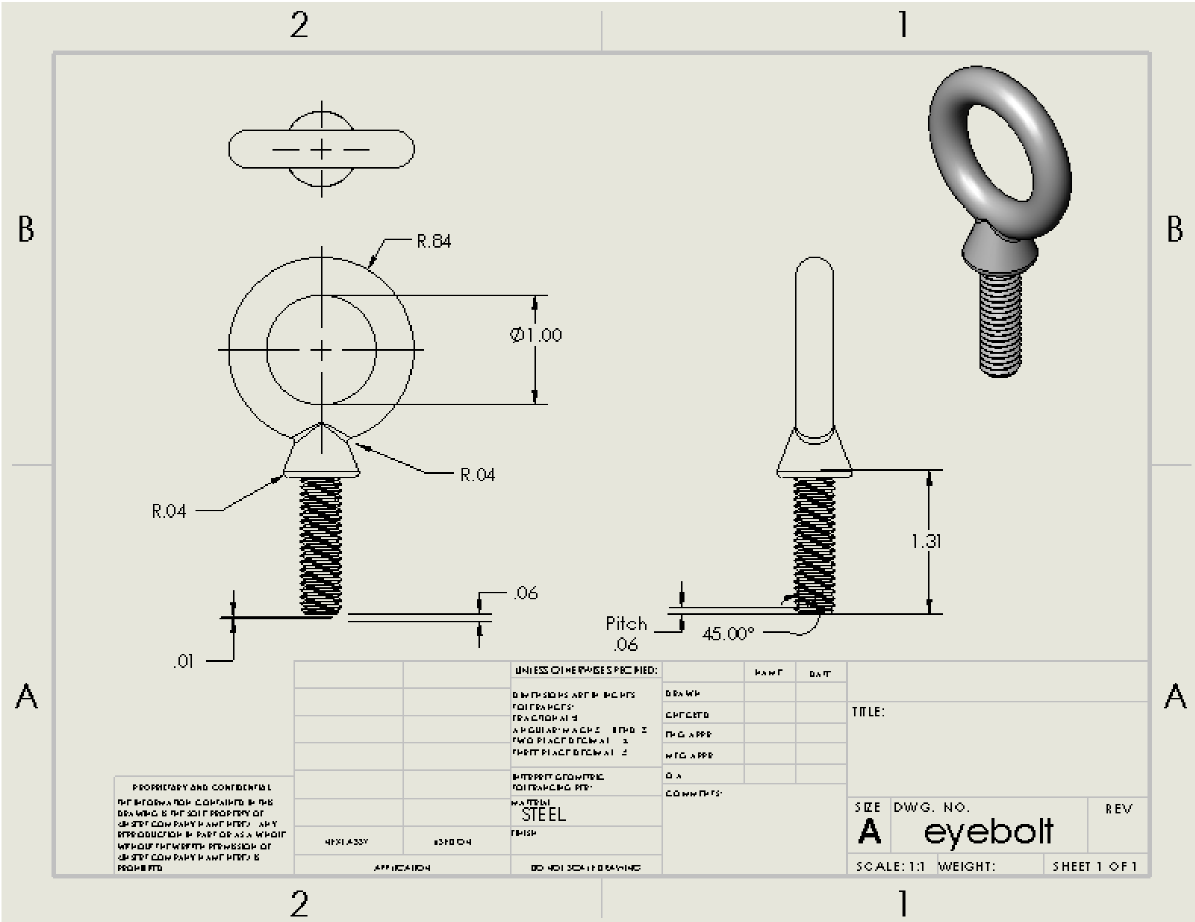

2
1
B
A
R.84
Ø1.00
R.04
R.04
.06
.01
Pitch
.06
45.00°
1.31
STEEL
TITLE:
SIZE
A
DWG. NO.
eyebolt
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

Figure B6

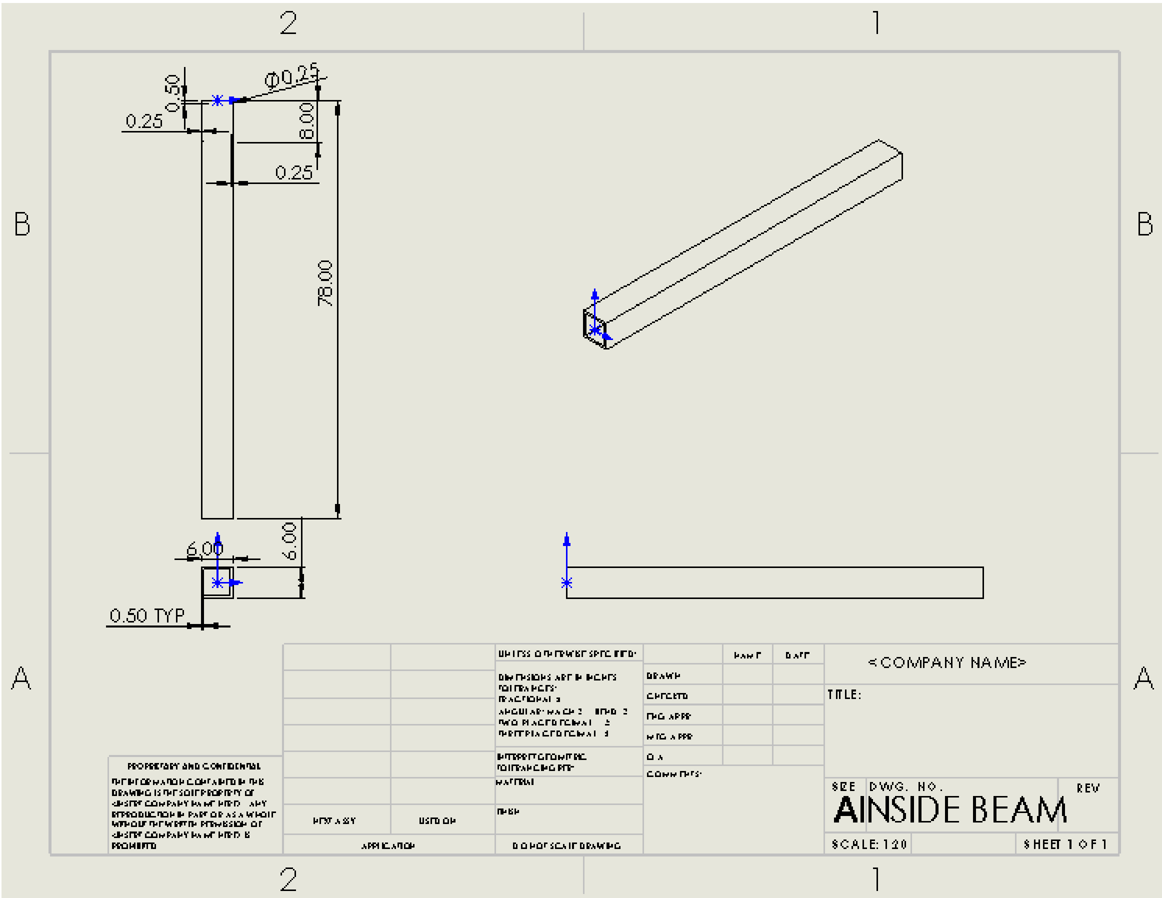
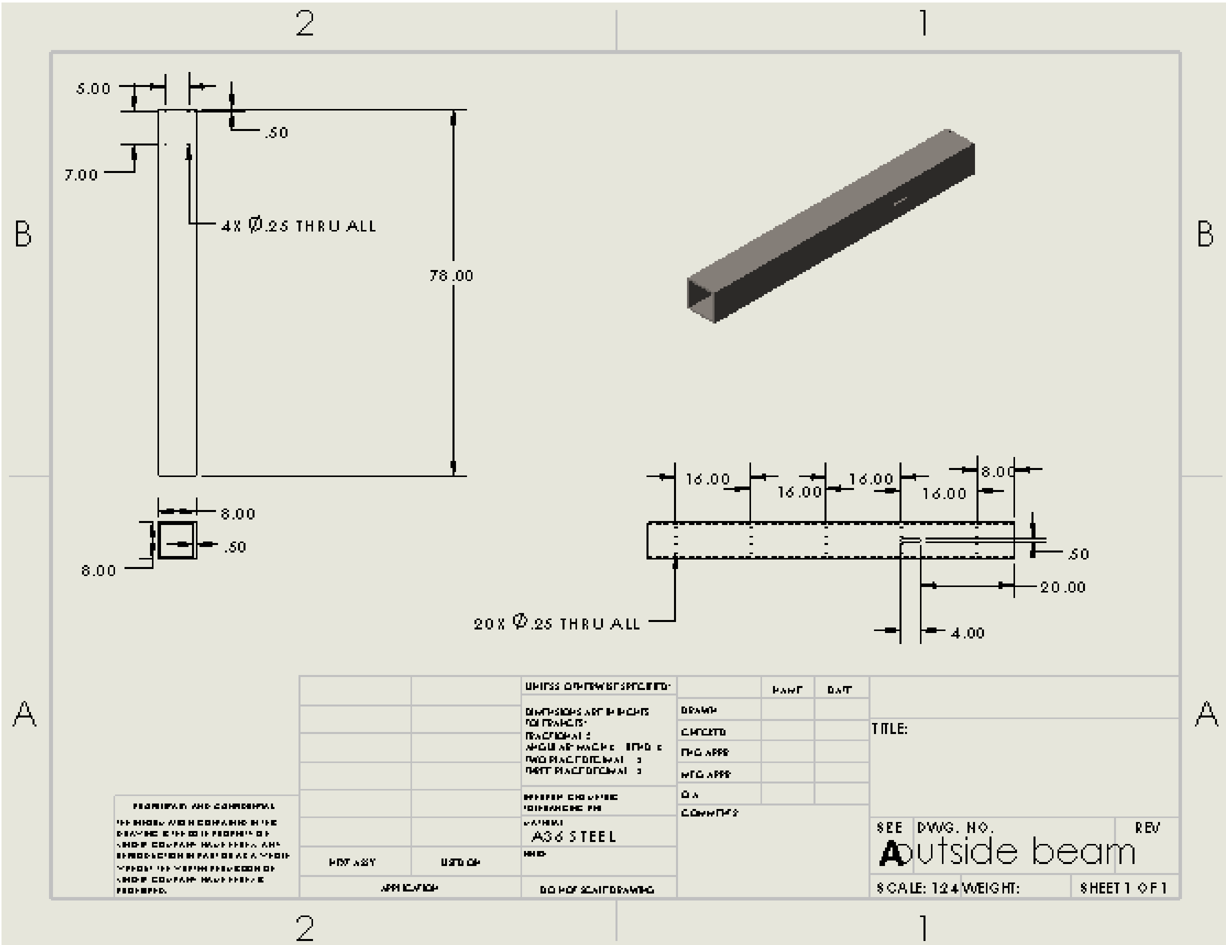
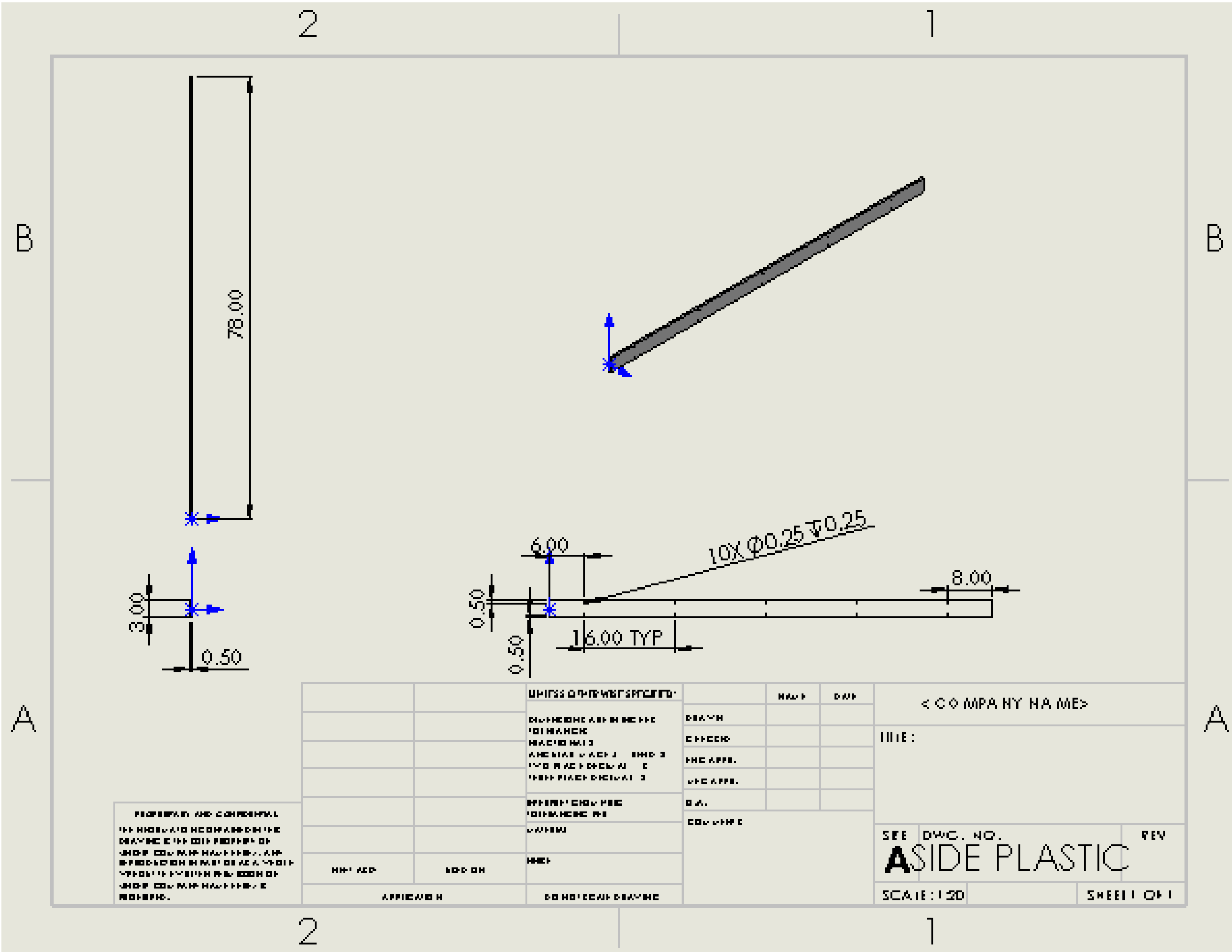

2
1
B
A
Ø0.25
0.50
0.25
8.00
0.25
78.00
6.00
6.00
0.50 TYP
<COMPANY NAME>
TITLE:
SIZE
DWG. NO.
REV
A
INSIDE BEAM
SCALE: 1:20
SHEET 1 OF 1

Figure B7



5.00
7.00
.50
4X Ø.25 THRU ALL
78.00
8.00
.50
8.00
16.00
16.00
16.00
16.00
8.00
.50
20.00
4.00
20X Ø.25 THRU ALL
A36 STEEL
TITLE:
SIZE DWG. NO. REV
A outside beam
SCALE: 1:24 WEIGHT: SHEET 1 OF 1

Figure B8



78.00
3.00
0.50
6.00
10X ⌀0.25 ↧0.25
8.00
0.50
0.50
16.00 TYP
<COMPANY NAME>
TITLE:
SIZE
DWG. NO.
REV
A
SIDE PLASTIC
SCALE:1:20
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
APPLICATION
DO NOT SCALE DRAWING
2
1
B
A

Figure B9

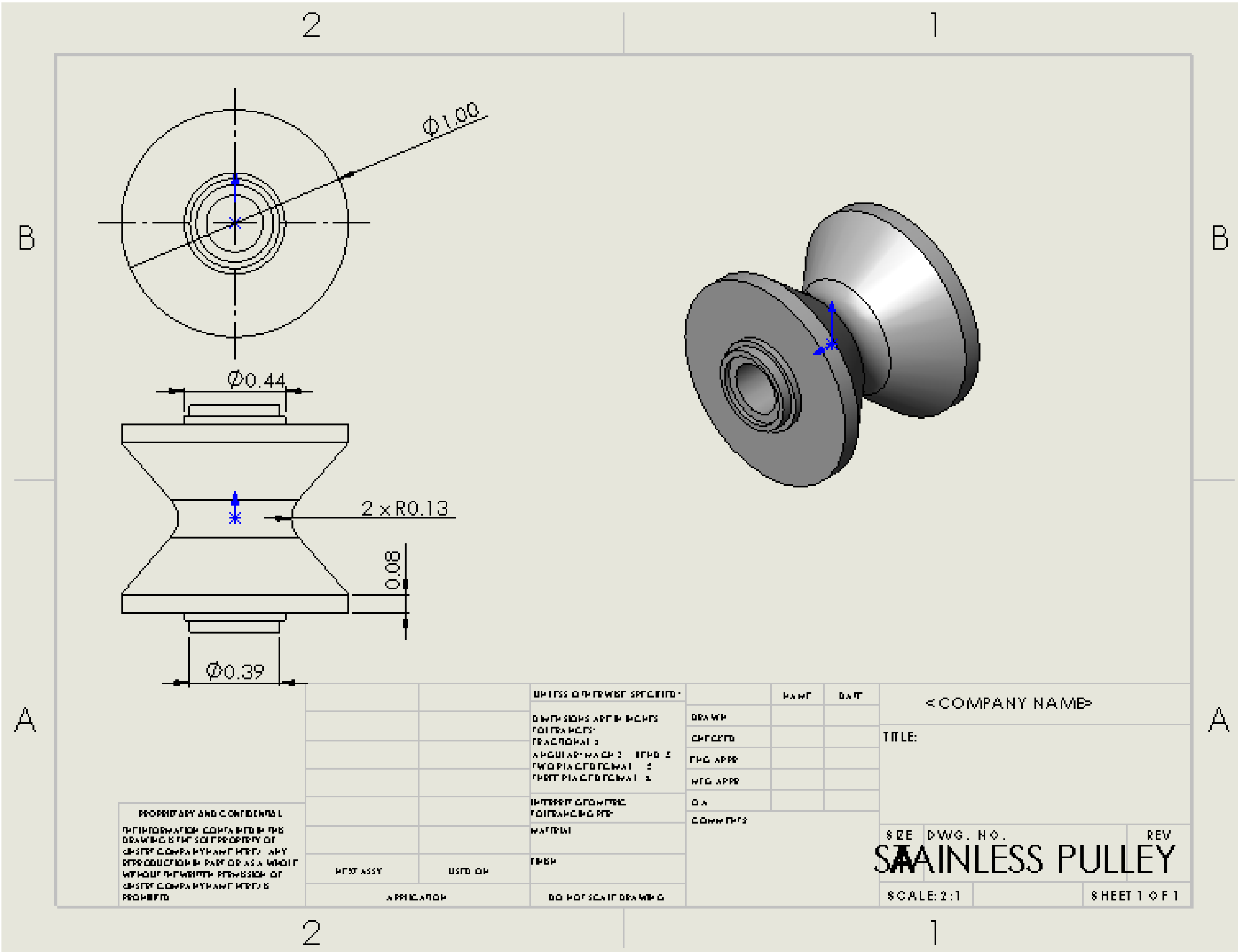


Figure B10

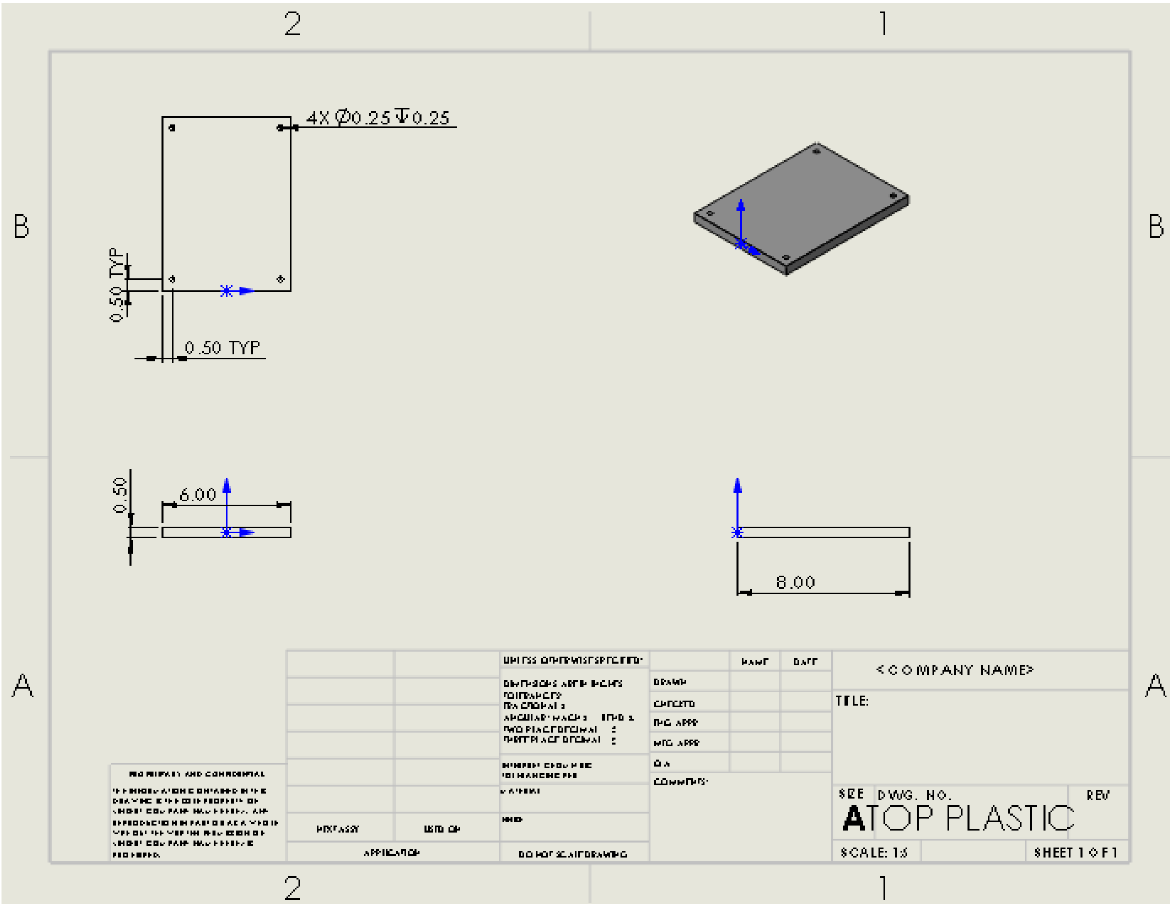
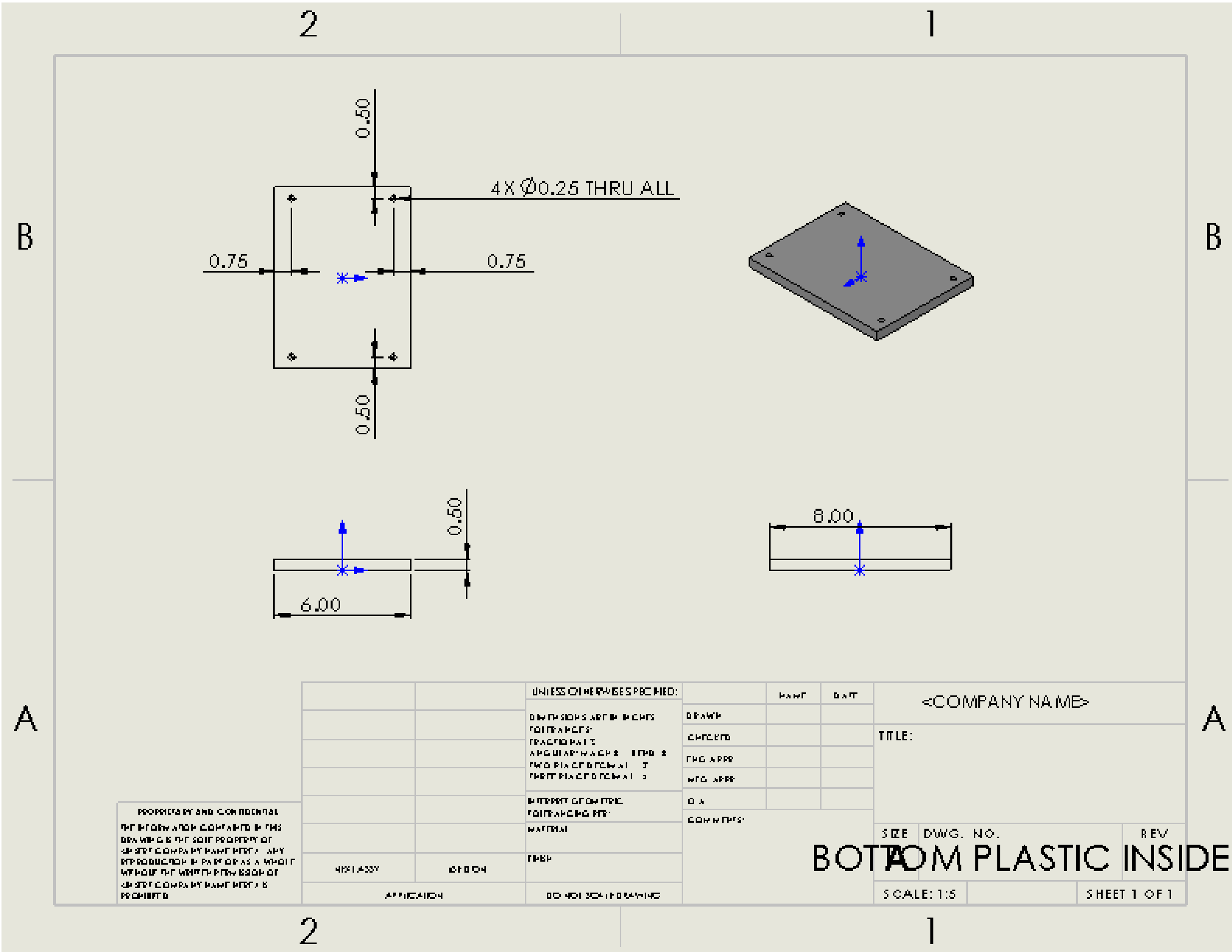
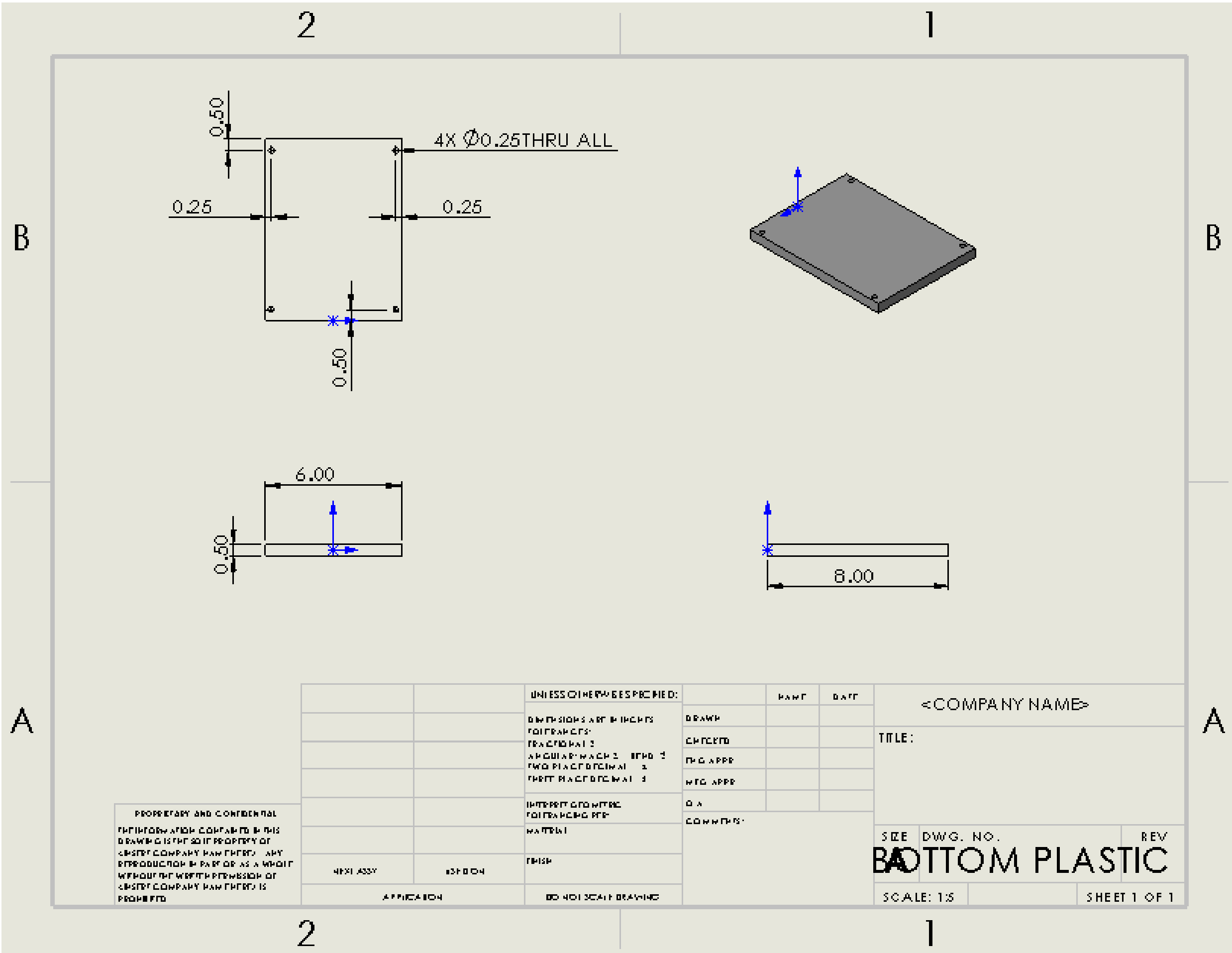

4X Ø0.25 ↧0.25
0.50 TYP
0.50 TYP
6.00
0.50
8.00
<COMPANY NAME>
TITLE:
SIZE
DWG. NO.
REV
A
TOP PLASTIC
SCALE: 1:5
SHEET 1 OF 1

Figure B11



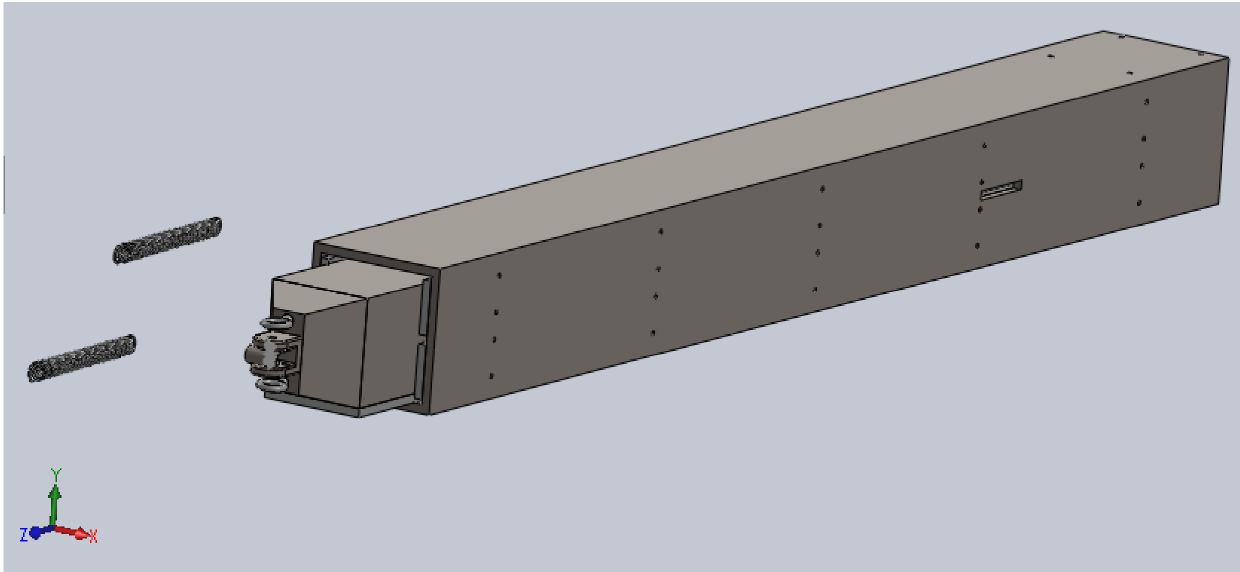
2
1
B
A
0.50
4X ∅0.25 THRU ALL
0.75
0.75
0.50
0.50
6.00
8.00
UNLESS OTHERWISE SPECIFIED:
<COMPANY NAME>
TITLE:
SIZE
DWG. NO.
REV
A
BOTTOM PLASTIC INSIDE
SCALE: 1:5
SHEET 1 OF 1

Figure B12

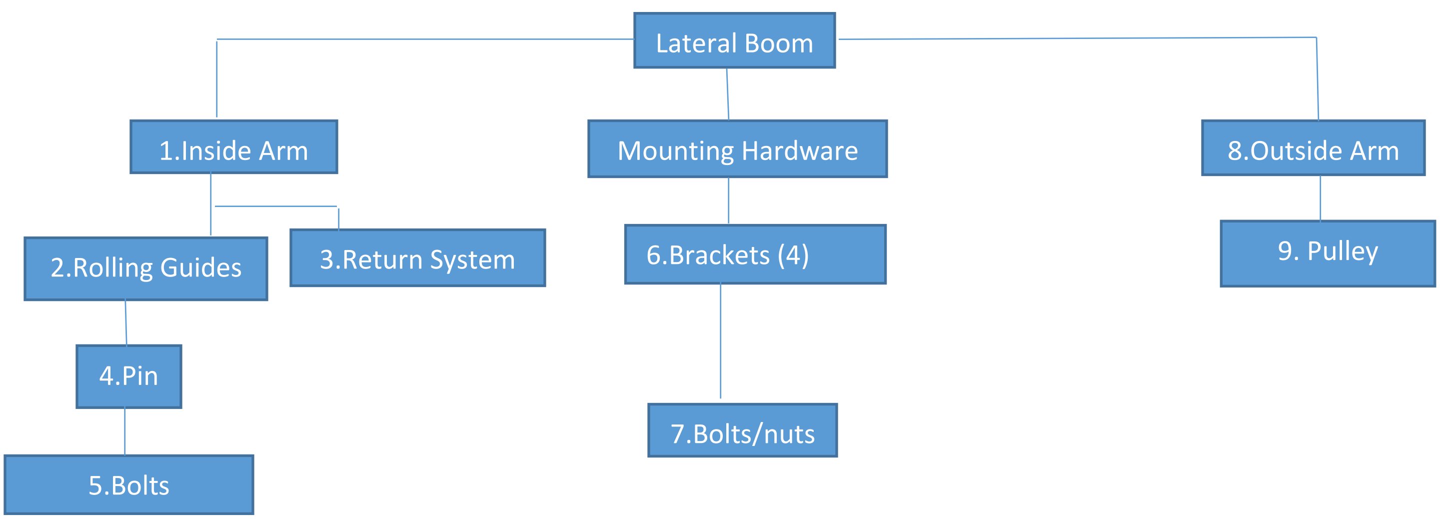


2
1
B
A
0.50
4X ∅0.25THRU ALL
0.25
0.25
0.50
6.00
0.50
8.00
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
<COMPANY NAME>
TITLE:
SIZE
DWG. NO.
REV
A
BOTTOM PLASTIC
SCALE: 1:5
SHEET 1 OF 1

Figure B12 - Assembly



Appendix C – Drawing Tree/Drawing ID



Appendix D

(Full scale model)

Part ID	Name, description/use	Source	Qty. x Cost
1.	Steel tube, 6x6x0.5 beam used for the enclosed telescoping arm	Pacific Steel	24 ft. x 33.00
2.	Rolling guide, UHMW PE bearing fastened to internal telescoping arm	Misumi.com	8 x 20.00
3.	Return spring/shock		4 x 20.00
4.	Pin/anchor	UScargocontrol	4 x 2.00
5.	Bolts	ASMCindustrial	16 x 2.00
	Sheet metal for custom mounting bracket fabrication	Pacific Steel	1 x 25.00
6.	Mounting bracket, fastener for outside lateral boom		4 x
	Mounting bracket, for internal lateral arm extension		4 x
	Mounting bracket, for vertical boom cable routing		
7.	Bolts, additional support for lateral boom bracket (part#6)	ASMCindustrial	16 x 2.00
8.	Steel tube, 8x8x0.25	Pacific Steel	24 ft. x33.00
9.	Pulley, for vertical boom cable route	http://www.directindustry.com/industrial-manufacturer/pulley-bearing-141428.html	4 x 3.00
	Washers		32 x 1.00
	Nuts		32 x 2.00
	Electric motors, lateral boom extension	Harbor Freight	4 x 80.00
	Electronic control module	Sparkfun	1 x 50.00
	All accommodating electric wiring and plastic tubing	digikey	1 x 25.00
	Welding gas/wire		1 x 10.00
	Materials for weatherproof control box		1 x 20.00

(Proof of concept model)

Part	Source	QTY x Cost
3 foot section square tube steel, 4x4x1/8	Western Metals, Ellensburg	1x24.99
3 foot section square tube beam, 3.5x3.5x1/8	Western Metals, Ellensburg	1x24.99
4.5 inch screws	Ace Hardware	4x
Bolts	Ace Hardware	4x
Pulley	Ace Hardware	4x
Extension spring	Ace Hardware	1x
3/16 square stock		
1/2 inch round stock		
Welding wire		

Appendix E

Brett Ulrich

HF HAUFF wind turbine

Fall Quarter

				Sep	October					November				December				January					February				March				April				May					June	
Task Number	Task	Estimated Time (hr)	Actual Time (hr)	9/26/2016	10/3/2016	10/10/2016	10/17/2016	10/24/2016	10/31/2016	11/7/2016	11/14/2016	11/21/2016	11/28/2016	12/5/2016	12/12/2016	12/19/2016	12/26/2016	1/2/2017	1/9/2017	1/16/2017	1/23/2017	1/30/2017	2/6/2017	2/13/2017	2/20/2017	2/27/2017	3/6/2017	3/13/2017	3/20/2017	3/27/2017	4/3/2017	4/10/2017	4/17/2017	4/24/2017	5/1/2017	5/8/2017	5/15/2017	5/22/2017	5/29/2017	6/5/2017	6/12/2017
1	Introduction																																								
A	Project Idea	1	7																																						
B	Introduction	1	2.5																																						
C	Design & Analysis	4	16																																						
D	Methods & Contstruction	2	2.5																																						
E	Testing Methods	1	1.5																																						
F	Budget & Schedule	1	2																																						
I	Drawing & Documentation	8.5																																							
J	Appendix	2	5																																						
K	Editing	0	5																																						
	Subtotal	20.5	41.5																																						
2	Analysis																																								
A	Geometry	1	2.5																																						
B	Weight & Thrust	0.5	3																																						
C	Tension & Friction	1.5	2.5																																						
D	Stress	1	3.5																																						
E	Shear	1.5	6																																						
F	Bending	1.5	3.5																																						
	Subtotal	7	21																																						
3	Drawing/documentation																																								
A	Inside steel tube	0.5																																							
B	rolling guides	0.5																																							
C	return system	0.5																																							
D	pins/anchor	0.25																																							
E	fasteners/bolts	0.25																																							
F	mounting bracket A	0.75																																							
G	mounting bracket B	0.75																																							
H	mounting bracket C	0.75																																							
I	outside steel tube	0.5																																							
J	Cable route pulley	0.25																																							
K	Wiring Diagram	1.5																																							
L	Assembly Drawing	2																																							
	Subtotal	8.5	0																																						

Brett Ulrich

HF HAUFF wind turbine

Winter Quarter

				Sep	October					November				December				January					February				March				April				May					June	
Task Number	**Task**	**Estimated Time (hr)**	**Actual Time (hr)**	9/26/2016	10/3/2016	10/10/2016	10/17/2016	10/24/2016	10/31/2016	11/7/2016	11/14/2016	11/21/2016	11/28/2016	12/5/2016	12/12/2016	12/19/2016	12/26/2016	1/2/2017	1/9/2017	1/16/2017	1/23/2017	1/30/2017	2/6/2017	2/13/2017	2/20/2017	2/27/2017	3/6/2017	3/13/2017	3/20/2017	3/27/2017	4/3/2017	4/10/2017	4/17/2017	4/24/2017	5/1/2017	5/8/2017	5/15/2017	5/22/2017	5/29/2017	6/5/2017	6/12/2017
4	Construction																																								
A	Material ordering/collection	5																																							
B	sheet metal setup/cutting	5																																							
C	internal arm hole drilling	2																																							
D	external arm hole drilling	2																																							
E	bracket prep	2																																							
F	bracket welding	4																																							
I	fitment test	6																																							
J	steel cable intallation	2.5																																							
K	Final assembly	5																																							
	Subtotal	33.5	0																																						

Brett Ulrich

HF HAUFF wind turbine

Spring Quarter

Task Number	Task	Estimated Time (hr)	Actual Time (hr)	9/26/2016	10/3/2016	10/10/2016	10/17/2016	10/24/2016	10/31/2016	11/7/2016	11/14/2016	11/21/2016	11/28/2016	12/5/2016	12/12/2016	12/19/2016	12/26/2016	1/2/2017	1/9/2017	1/16/2017	1/23/2017	1/30/2017	2/6/2017	2/13/2017	2/20/2017	2/27/2017	3/6/2017	3/13/2017	3/20/2017	3/27/2017	4/3/2017	4/10/2017	4/17/2017	4/24/2017	5/1/2017	5/8/2017	5/15/2017	5/22/2017	5/29/2017	6/5/2017	6/12/2017
				Sep	October					November				December				January					February				March				April				May					June	
5	Testing																																								
A	electronic controls test	2.5																																							
B	flat ground leveling test	2.5																																							
C	flat ground bracing test	2.5																																							
D	inclined leveling test	2.5																																							
E	full operation test	2.5																																							
I	project completion																																								
	Subtotal	12.5	0																																						
6	Final Report																																								
A	present to source	4																																							
	Subtotal	4	0																																						