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H.F. Hauff Portable Wind Fan Stabilizer

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Abstract

Agricultural areas with cold weather in winter and early spring face significant risk of damage to crops due to freezing. To combat this issue, several farms use fans to keep goods from freezing. For some orchards and vineyards, the use of large-scale fans is not cost effective nor pragmatic. H.F. Hauff, a farming equipment company based out of Yakima, Washington, has developed a mobile, self-contained fan that operates on a seven-by-twelve-foot trailer. As a function of environment, the trailer sometimes operates on uneven or unlevel terrain. There arises a need for an improved outrigger system to keep the trailer stabilized. To address this need, a design was conceived, analyzed, and tested as part of the CWU MET Senior Project class in conjunction with H.F. Hauff. The main design uses telescopic outrigger booms with stabilizing legs to keep the trailer stabilized. Once the design concept was conceived, engineering analyses were conducted. A one-fourth scale model was then constructed and tested to prove the design concept. This report details the design of the stabilizing leg portion of the project. The outrigger boom design is contained in the report by Jose Reyna. During the testing phase, it was determined that the device met the design requirements. The device maintained enough structural integrity to counteract the applied forces to the system. The booms and stabilizing legs were able to articulate from two to four feet. Finally, the outrigger system was able to keep the trailer level on a 15% grade.

Key Words: outrigger, stabilize, telescopic boom

Introduction

Description

Agricultural areas with cold weather in winter and early spring face significant risk of damage to crops due to freezing. To combat this issue, several farms use fans to keep goods from freezing. For some orchards and vineyards, the use of large-scale fans is not cost effective nor pragmatic. H.F. Hauff, a farming equipment company based out of Yakima, Washington, has developed a mobile, self-contained fan that operates on a 7’x12’ trailer. As a function of environment, sometimes the trailer must operate on uneven or unlevel terrain. There arises a need for a leveling system for the trailer. Outriggers with stabilizing legs must be extended horizontally to keep the trailer stabilized and level.

Motivation

The motivation for this project was the need for the trailer to be stabilized and level as it moves through the orchard without constant manual adjustments.

Function Statement

Vertical stabilizing legs at the end of outriggers were needed to stabilize the H.F. Hauff portable wind fan.

Requirements

The design requirements are as follows:

1. Must weigh no more than 800 pounds
2. Must be dimensioned to fit on a 7’x12’ trailer
3. Vertical leg/foot must be able to extend out horizontally and articulate down 90 degrees
4. All sections of the device must be able to retract inside the largest boom
5. Must be able to support a load of 5000 pounds
6. Must be able to counter a moment caused by a 20-foot tower with 2000 pounds of thrust
7. Must keep trailer level within ±5 degrees
8. Must allow the trailer to operate on a 15% grade

Engineering Merit

There are several points of engineering merit in this project. Among these were load and moment calculations, dynamic movements, kinematics, strength calculations, and several other mechanical design components.

Scope of Effort

The primary focus of the project is the design according to the requirements. A proper design and proof of concept were the top priorities.

Benchmarks

Certain pieces of heavy machinery such as excavators contain outriggers that can articulate on two axes. These are relatively compact and can support large amounts of weight.

Success Criteria

The leveling system will be mobile, fit on a 7’x12’ trailer, and will level the trailer up to a 15% grade.

Design and Analyses

The portion of the system that was focused on for design was the stabilizing leg and foot. The main design of the leg was to extend out and down with the hydraulic for the boom and retract inside the inner boom tube. Several analyses were conducted to aid in this design.

The initial analysis dealt with the general requirement that the outrigger system would adequately support the trailer. In Analysis #1, which is listed in Appendix A-1, the total length the boom needed to extend beyond the trailer in order to support the 2000-pound moment at the top of the wind tower was found. To complete this calculation, moments were summed about the end of one of the booms. It was found that the boom needed to extend a minimum of 4.5 feet beyond the trailer edge, creating a total boom extension length of 16 feet.

Once the total length was found, the next analysis, listed in Appendix A-2, dealt with the requirement of leveling the trailer for inclines with up to a 15% grade. Using trigonometry and the total length of the boom extension, the minimum height for the vertical leg at the bottom of the 15% grade was found to be 2.4 feet.

Analysis #3, listed in Appendix A-3, analyzed the external forces acting on the vertical legs when operating on flat ground. The maximum normal force acting on the vertical legs was found to be 2500 pounds acting on each of the vertical legs opposite the 2000 pound thrust force.

Analysis #4, listed in Appendix A-4, analyzed the external forces on the vertical legs when operating on a 15% incline. All normal forces calculated in this analysis were less than the 2500 pounds from Analysis #3, but a friction force of 1360 pounds was found to be a reaction to the incline.

Analysis #5, listed in Appendix A-5, calculated the minimum dimensions for the bottom of the foot to be 2.75 inches by 2.75 inches. As a measure of safety and uncertainty regarding the type of ground the device would operate on, an area of 7 inches by 7 inches was later decided on. Appendix B-1 contains the drawing for the foot.

Analysis #6, listed in Appendix A-6, performed a column analysis on the vertical leg in order to find the stress and potential deformation. A stress of 55,098 psi and a maximum deformation of 0.1056 in were found. The stress aided in the material designation of the vertical legs. The main choices for the square tubing material of the vertical leg (due to cost, availability, etc.) were

A500 Grade B steel and A513 steel. A500’s 46,000 psi yield stress was too low based on the Analysis #6 calculations, but A513’s 72,000 psi yield stress was acceptable.

Analysis #7, listed in Appendix A-7, dealt with the stress concentration in the vertical leg. The max stress due to the pin hole was found to be 28,000 psi. Because this value was below the stress due to column buckling and the yield strength of A513, this was acceptable.

Analysis #8, listed in Appendix A-8, dealt with the stress on the hole in the vertical leg caused by the pin. This stress was found to be 12,732 psi. Because this value was also below the stress due to column buckling and the yield strength of A513 steel, this was also acceptable.

Analysis #9, listed in Appendix A-9, dealt with the stress in the foot due to the pin hole. The assumption was made that the force from the trailer weight and thrust would be transferred through the booms and the pin connection to the foot. As such, the stress in the pin holes of the foot was calculated to be 1600 psi. This value was much lower than the other stresses acting on the system, so the design for the foot was acceptable.

Analysis #10, listed in Appendix A-10, dealt with the sizing of the vertical leg. Various wall thicknesses were compared, and it was determined that a wall thickness of 5/16” would be chosen for the vertical leg. In similar fashion to the stress analysis in Analysis #9, the normal stress acting on the vertical leg with 5/16” wall thickness due to the reaction load of 5000 pounds was calculated to be 1652 psi. As this value was well below the yield strength for the material, 5/16” wall thickness was determined to be acceptable. Only the vertical leg sizing was analyzed because it is the smallest boom and, therefore, contains the smallest cross-sectional area and highest amount of stress.

Analysis #11, listed in Appendix A-11, dealt with the forces acting on the chain. Due to the limited size within the booms, #25 chain was chosen, which has an average tensile strength of 925 pounds. An important distinction to make is that the chain is not used to lift anything or support the device from the reaction loads. The chain is only required to extend and retract the two smallest booms and the corresponding components of the end of the boom system. As such, the weight of the portion of the device that the chain pulls was calculated to be 87.08 pounds. Since this weight is much less than the 925-pound average tensile strength of #25 chain, the selection was determined to be acceptable.

The previous eleven analyses were conducted according to the design of the full-sized device that would operate on the 7’x12’ wind fan trailer. Due to the scope of the project and manufacturing resources, a ¼-sized scale model was constructed in lieu of the full-sized system. The required manufacturing modifications due to the change in the size of the device are detailed more in the following sections, but Analysis #12, listed in Appendix A-12, dealt with scaling the project parts down and selecting standard sizes that would allow for the scale model to operate.

Methods

The project solution was conceived, analyzed, and designed at CWU in conjunction with H.F. Hauff. The resources available to the project for the construction phase were those available at the machine shops at CWU and H.F. Hauff. Working within the constraints of CWU and H.F. Hauff, parts were ordered, machined, and assembled at CWU in Ellensburg, Washington and at H.F. Hauff in Yakima, Washington.

Primary engineering analyses were conducted in the design stage of the project. These included sketching free body diagrams, summating forces and moments about points and axes, trigonometry, shear and moment analyses, column buckling analyses, maximum stress due to a pin, and chain and sprocket design.

Construction

In accordance with the scope of the project resources, it was determined that a proof of concept scale model would be constructed in lieu of the full outrigger system. The model was determined to be 1/4 scale, which decreased the size and cost of the system significantly. While the full system would have totaled nearly 16 feet in overall length and would have been too costly and heavy to efficiently construct, the scale model was designed to be approximately 4 feet long, cost $118, and be much easier to construct.

The device was built in accordance to the parts listed in Appendix B. The drawing tree of these parts and corresponding assembly is captured in Figure B-1. The construction and assembly of all parts was completed in conjunction with the additional parts of the boom designed by Jose Reyna.

The design for the largest and second largest booms of the overall project are outlined in Jose Reyna's project report and listed in Appendix B-2 and B-3, respectively. The 3x2 inch boom (designed for an 8 inch full-sized square tube), listed in Appendix B-2, acts as the largest horizontal boom. The boom would normally be a 2-inch square tube, but additional room for the wire rope and pulley system was required for the scale model, so a 3x2 inch tube was chosen. The 1.75-inch boom (designed for a 7-inch full-sized square tube), listed in Appendix B-3, is the second largest horizontal boom.

The 1.5-inch boom (designed for a 6-inch full-sized square tube), listed in Appendix B-4, acts as the third largest horizontal boom. This boom was constructed by purchasing the square tubing, machining a cutout on the bottom of the tube so the vertical leg can articulate down, and machining a ¼ inch diameter hole (based on a 1-inch diameter for the full-sized boom) for the corresponding pin connection to the vertical leg.

The vertical leg, listed in Figure B-4, was constructed out of 1.25-inch square tubing (designed for a 5-inch full-sized boom). Two ¼ inch diameter holes were machined on each end. One hole is for the pin connection to the 1.5-inch horizontal boom, and the other hole is for a pin connection to the foot.

The foot, listed in Figure B-2, was constructed out of 1.75-inch square steel bar. The bar was machined down to have a $1/8^{th}$-inch thick base (designed for a 7-inch square, ½-inch plate) and two ¼-inch thick steel triangular vertical struts (designed for 1-inch thick struts).

The 1.5-inch boom and the vertical leg were designed to be constructed to work in cohesion with the hydraulic cylinder and chain and sprocket design present in the design completed by Jose Reyna. The sprockets were to be mounted to the booms by machining cutouts in the tubing and welding rods for the sprockets to rotate on. This chain design would allow for the 1.5-inch boom to extend horizontally, and the vertical leg to extend out horizontally and down. The foot was to be constructed to rotate on the pin connection to the vertical leg. This mechanism, along with the height of the vertical leg, would allow for the platform to operate on uneven terrain. Because of the limited size of the booms, however, wire rope and pulleys were required in lieu of the chain and sprocket system.

One major manufacturing issue that required working around was the fit of the wear pads and boom tubes. Because of the limited achievable accuracy of the available 3D printer when dealing with exceedingly small sizes, the wear pads did not all come out perfectly sized. Additionally, the largest boom tube came with slight ridges along the top and bottom of the inside. Both of these factors contributed to prevent the first batch of printed wear pads to fit well enough for the other boom tubes to function. One method that was implemented to solve the issue of the improper wear pad fit was to widen the holes in the booms and corresponding wear pad pegs from 1/8" diameter to 9/64" diameter. This allowed for slightly more material to be applied for the 3D printed wear pads, causing a sturdier fit. Additionally, the thickness of the top and bottom wear pads was reduced to allow for more clearance for the boom tubes. A file was used to wear down the ridges on the largest boom to help the wear pads sit flush with the tube. The final solution to the wear pad fit problem was to use epoxy as needed, ensuring the wear pads would not be jarred loose with the extension and retraction of the booms.

Another manufacturing issue that was discovered was the application of a chain and sprocket system to extend and retract the booms. Due to the project being scaled to ¼ the original size, there was no available chain that would be small enough to implement in the model. Instead of implementing chain and sprockets, it was determined that wire rope and pulleys would be sufficient for the scale model. To implement the wire rope and pulley system, wire rope that was sturdy enough to not immediately bend or buckle when pushed had to be used. 1/8" galvanized steel wire rope was purchased for this purpose. Additionally, pulleys small enough to fit inside the boom tubes were not available, so they had to be machined out of aluminum stock metal.

The assembly of the device is listed in Appendix B-9.

Testing Method

The full-sized device was intended to be tested in a number of ways. One such method included applying weight to the booms and the vertical leg sections. In this way, the structural integrity of the device would be evaluated.

Another intended method of testing was to simply extend and retract the boom multiple times to test whether or not the device met the requirement of extending and retracting with a single hydraulic. During this test, the design requirement of the device collapsing to a 7-foot wide window would also have been tested.

A third method of testing the full-sized system was to mount the boom assembly to a trailer and evaluate if the device could level the trailer on inclines of up to a 15% grade. This test would also measure the device's ability to keep the trailer level within five degrees.

Due to the project scope being modified from a full-sized system to a ¼ scale model, testing methods were slightly modified. Since the ¼ scale model did not require a hydraulic cylinder to prove the concept, the extension and retraction tests were no longer autonomous. Instead, the booms had to be extended and retracted using manual force. Because the reduced size of the scale model required the use of wire rope in place of the chain system designed for the full system, the retraction and extension of the boom involved pulling corresponding wire rope strands to test the system.

The Extension Test was designed to evaluate how well the horizontal booms could be extended using the wire rope system. The test revealed that the horizontal booms required some manual assistance to be fully extended. The wire rope system worked well for extending the second largest boom (the 1.75-inch boom), but the 1.5-inch boom and vertical leg and foot portion had to be pushed out by hand. The cause of this issue was hypothesized to be the switch from the chain design of the full-scale model to the wire rope system of the ¼ scale model. The wire rope did not have the strength to push all the booms out, although it was able to extend the 1.75-inch boom with the smaller booms still inside.

In addition to testing the wire rope extension system, the Extension Test was also used to test some geometrical measurements of the device. The overall length of the ¼ scale model when fully extended was 51.5 inches, which would equate to 17 feet-2 inches of total extension on the full-scale system. The 3x2-inch boom had a length of 24 inches, and there was 13.75 inches of extension on each side. 9.25 inches of that extension was from the 1.75-inch boom, and the remaining 4.5 inches resulted from the 1.5-inch boom.

The second major test conducted was the Retraction Test, which was designed to evaluate how well the horizontal booms, vertical legs, and feet could retract inside the largest boom tube. This test revealed that the booms could all easily be retracted by pulling the retraction strand of the wire rope. The wire rope system was more applicable to retraction because it simply involved pulling the booms in one direction. The Retraction Test also revealed that the booms could only be retracted inside the largest boom until the hydraulic mount came into contact with the largest boom. Upon measurement, it was found that there was 0.75 inches of overhang on each side of the largest boom from the smaller booms and feet. The overall retraction length of the device was found to be 25.5 inches, with the length of the largest boom being 24 inches. If multiplied by four, this length would not have met the 7-foot retraction design requirement that the full-scale system required. Since the ¼ scale model was designed to be a proof of concept model, the specific retraction length was not determined to be vital to the success of the model. Therefore, the design of the model involved using a 24-inch long tube to make construction more viable. On the full-scale system, measures would be taken to ensure that the device could collapse to the 7-foot requirement.

A third major test conducted was the Foot Rotation Test, which aimed to evaluate how well the device could operate on uneven ground. The design requirement for such was operation on slopes of up to 15% grade, or 8.53 degrees. The Foot Rotation Test revealed that the feet could rotate to maximum angles between 12 and 18 degrees. This test indicated that the device passed the evaluation, since the lowest measured maximum angle of 12 degrees was still above the 8.53-degree design requirement.

The complete test report is listed in Appendix G.

Budget

With the initial design for the full-scale model, the budget for the vertical leg and foot portion of the project was estimated to be $455.62, and the total budget for the project was projected to be approximately $2,500. After the decision was made to construct a ¼ scale model in lieu of the full system, the project budget was decreased drastically to an estimated $118 for the entire project. There were two main reasons for the budget reduction. First, much less material was required to be purchased because of the reduction in size. Second, it was determined that since the primary function of the ¼ scale model was to be a proof of concept model, the implementation of a hydraulic cylinder was not necessary. Instead, the motion of the booms would be simulated by pushing the appropriate booms out by hand.

Projected costs for parts were calculated using reference data from online parts suppliers metalsdepot.com and McMaster-Carr (mcmaster.com), and Amazon (amazon.com). The actual costs for the steel tubing for the booms and the steel bar for the foot coincided with the projected costs, since they were ordered from H.F. Hauff. The actual cost of the wire rope, pulleys, and 3D printed parts are not yet known, as they have yet to be constructed and assembled. Finally, an estimate for general machining and construction costs was also made.

Upon completion of the manufacturing and testing phases of the project, the total cost of the project was $81.04. The actual cost of $81.04 was lower than the expected cost of $118 by $36.96. The cause of this difference was the fact that materials expenses ended up being lower than projected and that testing costs were negligible. One such material expense that was eliminated was the estimated cost of pulleys, as these were constructed out of the leftover steel dowel stock used to construct the pins. All necessary testing resources were already readily available to the project engineers, so there were no additional expenses during the Testing Phase of the project.

For the detailed budget of the project, refer to Appendix D.

Schedule

The full schedule for the H.F. Hauff Portable Wind Fan Stabilizer project is listed in Appendix E. The majority of fall 2019 was spent working on the general design, analyses, and drawings.

Winter 2020 was spent on the manufacturing phase of the project, and spring 2020 was spent on the testing phase of the project. The total estimated timeframe of the project was calculated to be 123.5 hours. At the end of fall quarter, an estimated 56.5 hours had been spent on the project.

Manufacturing was originally intended to begin at the beginning of winter quarter. Due to complications in the design process, however, the design phase continued through December 2019 and January 2020. During this time, it was determined that a ¼ scale model would be constructed in lieu of the full-sized system. A redesign process was conducted in December and January, resulting in new analyses and drawings being completed.

At the end of January 2020, parts and materials for the scale model were ordered through H.F. Hauff and the manufacturing process began. Because of the redesign process, the schedule for the remaining portions of the manufacturing process was accelerated to meet the goal of having a working device by March 11th. Parts were scheduled to be made and machined through the first part of February, and assembly was scheduled for the latter part of the month and into March until the deadline on the 11th. In actuality, parts were continued to be made and modified through the end of February and into the first week of March. The assembly process was begun in the latter half of February and finished in the final week before the March 11th deadline.

The project report was updated continually throughout winter quarter up to the project report deadline of March 16th. These updates were weekly in nature and conducted on schedule as outlined in the Gantt chart in Appendix E.

At the end of winter quarter, the total amount of time spent on the project was 123 hours. For the ‘Proposal’ and ‘Analyses’ sections, which were completed in fall quarter, more time was allotted than was needed. The ‘Documentation,’ ‘Proposal Modifications,’ and ‘Device Assembly’ sections of the project, however, all took significantly longer than projected, and the ‘Part Construction’ section took slightly longer than expected.

The remaining sections of ‘Device Evaluation’ and ‘489 Deliverables’ were scheduled to require an additional 32.5 hours. These sections, as well as any necessary modifications to previous sections, were scheduled to be conducted in spring 2020.

The testing phase of the project took place during April and early May 2020. Plans for testing were made in the latter portions of winter quarter and early April. The tests themselves were conducted in the third week of April, and the project test report was finalized by the first week of May. The project SOURCE presentation was prepared through April and May in preparation for the event taking place May 18th-24th. Through the completion of the project SOURCE presentation, a total of 22.5 hours were spent on the project during spring quarter. The remainder of the quarter was spent updating the project report, editing the project website, and compiling the project deliverables.

One issue that required scheduling accommodations was the isolated operation of the project during spring quarter due to the COVID-19 pandemic. Scheduling arrangements for the testing of the device, complete with special social distancing accommodations, were made by the two principal engineers. Ultimately, the project remained on or ahead of schedule during the testing phase in spring 2020.

The project was officially finished in June 2020. A total of 155 hours were spent on the project over the course of the 2019-20 school year. The project took 31.5 hours more than the projected time of 123.5 hours.

The complete Gantt chart schedule for the project is listed in Appendix E.

Discussion

The method for coming up with the proposed solution involved a substantial amount of researching potential solutions. This started with the objective of the project: to design a better version of the wind fan outriggers that were already in place. The current models manufactured by H.F. Hauff utilize booms that extend in just one direction at a time, with manual, crankshaft-operated vertical legs at the ends. The objective of the project involved designing a boom that could extend in both directions simultaneously and include a vertical leg that could extend horizontally and articulate down to support the trailer.

One concept that was important in the design phase was having a product that required as little machining as possible. One initial design involved multiple tubes of the boom requiring significant slots to be cut from the sides so that the vertical leg could articulate down. This design was discouraged for two main reasons: 1) because the required machining would add additional costs onto the manufacturing phase, and 2) removing material from the sides would make the booms weaker.

Another important design point of the project was meeting the requirement that the boom could collapse down to 7 feet, the width of the trailer. In an initial design, the vertical leg had two sections. These sections would be extended and retracted using a chain and sprocket system similar to the system on current models that operate the horizontal booms.

A third concept regarding the methods followed was the objective of meeting the design requirement for the trailer to be able to operate on an incline of up to a 15% grade. Multiple design iterations were considered to meet this requirement. One such iteration was having one vertical leg that would have a catch. As the booms were pushed out, the vertical leg would start in a collapsed horizontal position and get pushed out via a hydraulic cylinder and chain operation. As the vertical leg was pushed out, it would eventually catch on the smallest boom tube and rotate down. There would be a ratchet and pawl mechanism in place to ensure that once the vertical leg rotated down and hit the ground, it would not collapse back. Ultimately, this overall design was determined to be unfeasible because there would not be enough room in the inner most boom for the vertical leg to either collapse in or rotate down without removing material from the inner most horizontal boom.

The solution that was settled on involves the horizontal booms extending out via a hydraulic cylinder coupled with chain and sprockets. A similar chain and sprocket system was to be used to extend and retract the inside vertical leg along with the horizontal booms.

Several aspects of the project were redesigned and optimized as part of the design and early manufacturing processes. The first of these involved eliminating one section from the vertical leg. The original reasoning for having two sections for the vertical leg was a lack of space inside the larger booms to allow for the vertical leg to be tall enough. After some optimization, however, it was discovered that more space could be utilized inside the booms by having the tubes retract completely inside the largest boom so that each set of smaller booms met in the center inside the largest boom. This optimization allowed for a single, two-foot-long square tube to be used for the vertical leg instead of two shorter sections, which would have increased the complexity of the chain and sprocket extension and retraction method dramatically.

The second aspect of the assembly that was redesigned was the method by which the vertical leg would articulate down. In the initial design, the vertical leg was designed to go over the smallest horizontal boom and be connected by a pin along the neutral axis of both tubes. The vertical leg was designed to articulate down due to gravity as the booms were extended and retract with the chain and sprocket system. This design was determined to have issues with the articulation process, particularly with regards to the retraction of the vertical leg. To solve these issues, a new design, shown in Figures B-4, B-5, and B-9, was implemented. In the new design, an off-centered pin connection allowed for the vertical leg to operate inside of the smallest horizontal boom instead of outside it. When the booms are extended, the vertical leg still articulates down due to gravity, but the redesign helped to fix the issues with the retraction due to the chain and sprocket system.

A third aspect of the assembly that was optimized involved the sizing and spacing of the boom tubes. Initially, the largest horizontal boom was an 8-inch square tube, the second boom was a 6-inch square tube, the third horizontal boom was a 3.75-inch square tube, and the larger vertical leg section was a 4-inch square tube. It was determined that there was too much space between the tubes, as there would be too much pressure applied to the wear pads with their initially large size. Upon redesigning the system, the 8-inch tube remained the same, but the smaller tubes stepped down an inch in size each, from 8-inch to 7-inch to 6-inch to 5-inch for the vertical tube. As expected, on the ¼ scale model, the boom sizes are 2-inch, 1.75-inch, 1.5-inch, and 1.25-inch for the vertical tube. Limiting the size between the tubes allowed for both less friction due to smaller wear pads and more room allowed for the vertical leg and foot.

With the model being scaled to ¼ size for construction, some tweaks were necessary. Because of the limited size of the ¼ scale model and the cost associated with the project, it was determined that the model wear pads would be 3D printed using ABS plastic instead of UHMW strips. As the primary function of the wear pads on the full-scale system would be to minimize metal-on-metal wear to the steel tubes, adjusting the material and thickness of the wear pads on the scale model was determined to be acceptable. The model was designed to be a proof of concept and not for repeated use in industry, so the wear pads were not required to last as long.

The initial design of the 3D printed wear pads included pegs that would be mated to corresponding holes in the boom tubes via force fits. Once the wear pads were 3D printed and assembly began, it was soon discovered that the size and strength of the wear pad pegs did not allow for reliable mating with the boom tube holes. As the pegs would break off easily during assembly, it was determined that attaching the wear pads to the boom tubes with epoxy would be a stronger and more effective mating mechanism.

Another modification that was made on account of the device being scaled to ¼ size involved the extension and retraction of the booms. Due to the optimized space inside the boom tubes and the small size of the model, an appropriately sized chain and sprocket system for the model was not available. To be able to operate inside of the boom tubes, an extension and retraction system based on wire rope and pulleys was required. On the full-scale device, a chain and sprocket system would need to be implemented as it would be stronger and more reliable, but for the scale model the wire rope and pulley system was determined to be adequate. To construct the system, wire rope was purchased, and the pulleys were manufactured out of steel dowel stock. The wire rope was threaded through the system and attached to the boom tubes by soldering.

An additional modification due to the device being scaled to ¼ size was the removal of a hydraulic cylinder. In the full-scale model, a hydraulic cylinder would be required to extend and retract the middle boom tube, which would in turn cause the other booms to extend and retract with the chain and sprocket mechanism. For the ¼ scale model, it was determined that a hydraulic would not be required for proof of concept. Instead, the middle boom tube could be pushed in and out by hand, which would still allow for the other tubes to extend and retract with the wire rope and pulley system.

Once the proof of concept model was constructed, the testing phase of the project began. As the constructed device was a ¼ scale model of the full-sized system, the design requirements regarding size were scaled down, as necessary. For example, the requirement of the full-sized device to fit on a 7-foot trailer became a 1.75-foot requirement for the ¼ scale model. In general, the focus of the testing phase was to evaluate the design of the full-scale system itself by performing tests on the proof of concept model.

The main functions of the device that were tested during this phase was the extension, retraction, foot rotation, and weight. The extension and retraction tests evaluated both the geometry and functionality of the extension and retraction of the boom tubes and vertical leg and foot system. The Extension Test revealed that the overall length of the ¼ scale model was 51.5 inches, translating to 17 feet-2 inches of total extension on the full-sized device. This value met the minimum length requirement of 16 feet, as calculated in Analysis #1, listed in Appendix A-1. During the Extension Test, the limitations of the wire rope and pulley system were also revealed. The wire rope was able to extend the 1.75-inch boom with the smaller sections still inside, but it was not able to extend the remaining sections. Instead, these had to be pushed out by hand. It was determined that the chain and sprocket design for the full-scale model should theoretically work better for this application, but there was not enough room to implement chain and sprockets in the scale model.

The Retraction Test revealed that the collapsed length of the scale model was 25.5 inches. There was 0.75 inches of overhang outside of the largest boom tube on either side, as the smaller booms could only retract until the hydraulic mount came into contact with the largest boom. The retraction length did not proportionally pass the 7-foot design requirement, as the prorated retraction length would have been 8.5 feet. The reason for this was the use of a 2-foot long steel tube for the largest boom on the scale model. As the scale model's main purpose was to prove the design concept, the use of this 2-foot long tube for improved construction was determined to be acceptable. For the full-scale system, measures would be taken to ensure the device would fit inside the 7-foot window. The Retraction Test also revealed that the wire rope system was appropriate for complete retraction of the booms and vertical leg and foot system. Although a hydraulic was still not used for the scale model, the booms were able to be fully retracted by simply pulling one end of the wire rope.

The Foot Rotation Test revealed that the lowest angle of rotation for either foot in either direction was 12 degrees. This value met the design requirement of the device functioning on slopes of up to a 15% grade (or 8.53 degrees), because the 12-degree value was still above the minimum 8.53-degree requirement. The results of the Foot Rotation Test indicate that the device can operate on grades of up to 21% (equivalent to 12 degrees).

The Weight Test revealed that the complete scale model weighed 10.6 pounds, well below the 200-pound prorated weight design requirement. The scale model was much lighter than the requirement because it did not utilize a hydraulic and portions of the device would not scale linearly from ¼-size to full-scale in terms of weight, such as the boom tubes and wear pads.

The Structural Support Test revealed that the device could support loads of up to 150 pounds, but the device failed at 170 pounds. In doing so, the device did not meet design requirements #5 and #6, because it could not support up to 625 pounds. The cause of the device failure was the 3D-printed wear pads, which gave out once 170 pounds was loaded. The steel tubes of the device appeared to be able to withstand much more than 170 pounds, but because the device failed at 170 pounds this was not able to be measured. On the full-sized system, the wear pads would not be 3D-printed and glued on, so they would be much stronger and better able to transfer the forces to the booms themselves. Resources were also a limiting factor in the Structural Support Test, as the COVID-19 pandemic limited the use of strength-evaluating laboratory equipment.

In general, the nature of the device being a scale model rather than full size was the greatest source of limitation in the testing phase. The required size limitations of the device being 1/4th-scale necessitated the switch from the original chain and sprocket extension/retraction design to a wire rope and pulley system. This change hindered the model's ability to fully extend the booms, vertical legs, and feet, thus limiting the evaluation of the extension/retraction design. Similarly, the use of a standard-sized steel tube for the largest boom of the scale model limited the Retraction Length Test. The switch to a scale model also eliminated any ability to test the design of the hydraulic, intended to power the extension and retraction system on the full-sized device. Finally, the Structural Support Test was hindered by the scope of the project being reduced to constructing and testing a scale model. In the testing phase, it was determined that certain components of the device, such as the wear pads, were not manufactured to structural capacity, thus limiting the evaluation of the structural integrity of the device as a whole.

Conclusion

This H.F. Hauff Portable Wind Fan Stabilizer has been conceived, analyzed, and designed to meet the function requirements presented. Parts were designed, sourced, and budgeted for the manufacturing phase. The boom and stabilizing leg system was designed to be able to extend horizontally, articulate down, support the weight and thrust of the wind fan and trailer, collapse back into the seven-foot-wide frame, and level the wind fan trailer on inclines with up to 15% grades. The cost of the project was estimated and accounted for.

With these prerequisites having been met, the H.F. Hauff Portable Wind Fan Stabilizer proof of concept ¼ scale model was constructed. During the manufacturing phase, parts for the model were constructed and assembled such that the device would perform according to the design requirements. Necessary accommodations were made such that the model could operate at ¼ scale and, most importantly, prove the concept of the design.

During the testing phase of the project, the constructed device was evaluated according to the design requirements. The design concept was determined to be successful, and areas of potential improvement were addressed.

This project met the requirements for a successful senior project, including:

1. Having substantive engineering merit
2. Size and cost within the parameters of CWU and H.F. Hauff resources
3. Being of great interest to the principal investigator

Acknowledgments

H.F. Hauff Company, for the idea and sponsorship of the project

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Appendix A – Analyses

Figure A-1B: Moment Analysis of Fan and Boom Including Weight of Boom

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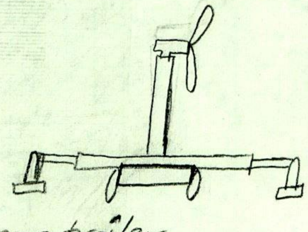
Analysis #1: Moment Analysis of Fan and Boom (revised 12/4/19)

Given: • 2000lbf of thrust at top of 20' tall wind tower
• 7' wide trailer
• Design weight of tower/trailer is 4500lbf

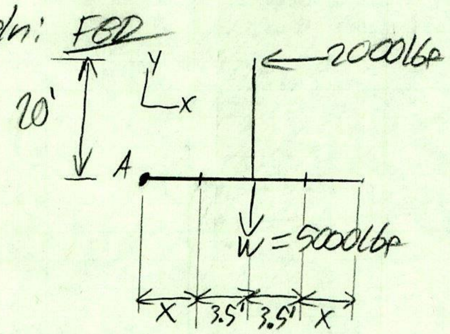


Find: • min. length boom obtrudes from trailer
• total length of boom

Assume: • Weight of boom system is 500lbf (5000lbf total)
• planar forces
• weight is symmetric about both sides of the trailer

Methods: 1) FBD 2) Equilibrium Equations

Soln: FBD



$\circlearrowleft \Sigma M_A = 0 = 2000lbf(20ft) - 5000lbf(3.5ft + x)$

$40000lb\cdot ft - 17500lb\cdot ft - 5000lb(x) = 0$

$\Rightarrow \boxed{x = 4.5ft}$

(min) Total Length of boom $L = 2x + 7ft$

$= 2(4.5ft) + 7ft$

$\boxed{\text{(min) Total Length of boom} = 16ft}$

Tolerance: ±.25ft based on low-tolerance weight and thrust estimates

Figure A-2: Vertical Leg Maximum Required Height Analysis

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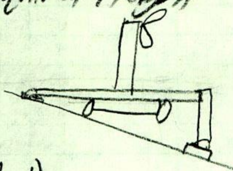
Analysis #2: Vertical Leg Maximum Required Height
(revised 12/4/19)

Given: • Vertical leg operating at end of boom
• 15% grade design requirement
• Total boom length 16ft (App. A-1)

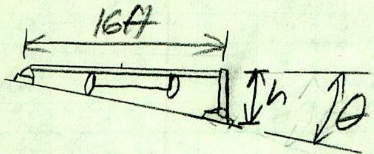


Find: Max. required height for vertical leg

Assume: • vert. leg operates at end of boom
• boom fully extended

Method: 1) FBD 2) Convert 15% to degrees 3) solve for max height using trig.

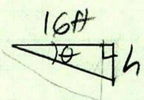
Soln: FBD



$\theta = \tan^{-1}(\text{slope}\%/100)$

$= \tan^{-1}(15/100)$

$= \underline{8.53^\circ}$



$\tan\theta = \frac{h}{16'}$

$h = 16' \tan 8.53^\circ$

$\underline{h = 2.4ft}$

Use $\boxed{h = 2.5ft}$

Tolerance: ±.1ft based on ±.5ft tolerance of boom length

Figure A-3: Vertical Leg Force Analysis (Flat Ground)

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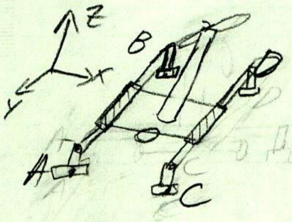
Analysis #3: Vertical Leg Force Analysis (Flat Ground)
(Revised 12/4/19)

Given:
- 2000 lbf thrust at top of 20' tower
- 7' wide tower
- 4.5' distance from trailer to end of boom
- two sets of booms
- weight of system is 5000 lbf

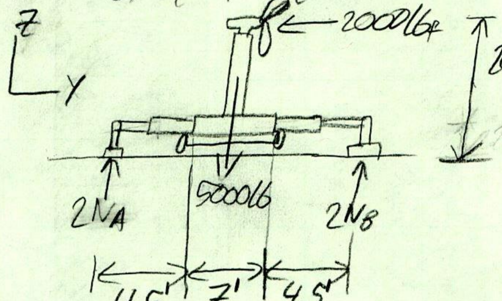


Find: External forces acting on foot

Assume:
- planar forces
- weight acts through center of trailer
- thrust acts in y direction (see diagram ↑)
- no forces acting in x direction
- Normal forces at A/C, and B/D are equal
- wheels have no contact forces with ground

Method: 1) FBD 2) Equil. Equations

Soln: 1) FBD



2) Equil. Eq.

$$\circlearrowleft \Sigma M_B = 0 = 2000\,lbf(20\,ft) + 5000\,lbf(4.5\,ft + 3.5\,ft) - 2N_A(16\,ft)$$

$$\Rightarrow 2N_A = 5000\,lb$$

$$\boxed{N_A = 2{,}500\,lbf \uparrow}$$

$$+\uparrow \Sigma F_z = 0 = 2(2500\,lbf) - 5000\,lbf + 2N_B$$

$$\Rightarrow \boxed{N_B = 0\,lbf}$$

Tolerance: ±10 lb, based on estimated values for weight and thrust

Figure A-4: Vertical Leg Force Analysis: 15% Incline

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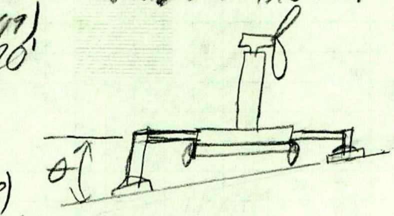
Analysis # 4: Vertical Leg Force Analysis: 15% incline
(revised 12/4/19)

Given:
- 2000lb thrust at top of 20' wind tower
- 7' wide trailer
- Overall length of boom = 16ft
- acting on 15% grade (8.53°)
- weight of system is 5000lb

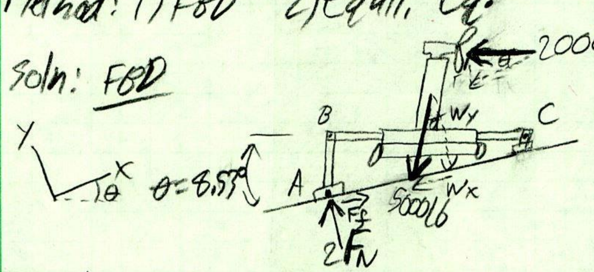


Find: forces acting on lower vertical leg/foot

Assume:
- planar forces
- upper leg is "resting" on ground (no reaction forces)

Method: 1) FBD 2) Equil. Eq.

Soln: FBD



Equil. Eq.

$+\uparrow \Sigma F_y = 0 = 2F_N - 5000lb(\cos 8.53°) + 2000lb(\sin 8.53°)$

$\Rightarrow 2F_N = 4648\ lbf$

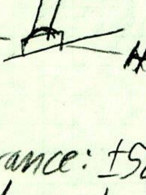
Since there are two booms equidistant from the weight force, $F_N = 4648lbf/2 \Rightarrow \boxed{F_N = 2324lbf}$

$+\rightarrow \Sigma F_x = 0: 2F_f - 5000lb \sin 8.53° - 2000lb \cos 8.53° = 0$

$\Rightarrow 2F_f = 2719.57$

$\Rightarrow \boxed{F_f = 1360lbf}$

Normal Force acting along vertical leg axis



$(F_N)_V = 2324 \cos 8.53°$

$\boxed{(F_N)_V = 2298lbf}$

Normal Force acting along horizontal axis

$(F_N)_H = 2324 \sin 8.53° \Rightarrow \boxed{(F_N)_H = 345lbf}$

Tolerance: ±5% based on estimated values for weight and thrust

Figure A-5: Minimum Area for Bottom of Foot

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Analysis #5: Min. Area for Bottom of Foot
(revised 12/4/19)

Given: • From Analysis #3/4, max normal force in foot = 2500 lbf
• operating ground rated for 1000–1500 psi
• Use safety factor of N=3

Find: • Min. area of foot to overcome normal force and prevent from sinking into ground
• dimensions of min. foot area

Assume: • bottom of foot is square and evenly distributes normal force
• analyze for ground rated for 1000 psi

Method: Use max. normal force and 1000 psi rated to solve for foot area dimensions

Soln: $(F_N)_{max,actual} = 2500 lb \times 3 = 7500 lb$

$$\frac{1 in^2}{1000 lbf} = \frac{A(foot)}{7500 lbf}$$

$$\Rightarrow A(foot) = 7.5 in^2$$

Dimensions: $A = s^2$

$$s = \sqrt{A} = \sqrt{7.5 in^2} = 2.739 in$$

$$\boxed{\text{Use (min) } 2.75 in \times 2.75 in}$$

$$\text{Actual area} = (2.75 in)^2 = 7.5625 in^2$$

$$\boxed{\text{Actual min area} = 7.563 in^2}$$

Tolerance: ±.5 in based on estimated values for weight/thrust

Figure A-6: Column Analysis for Vertical Leg

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Analysis #6: Column Analysis for Vertical Leg

Given: • Eccentrically loaded by weight with $e = 8ft$ and $P = 5000lb$
• Column length of 2.5ft
• Use design factor of $N = 3$
• Dimensions of boom leave room for 4in square cross section

Find: Max stress, max deflection, allowable yield stress, material designation

Assume: • homogenous material
• column perfectly vertical and boom completely extended
• use square tube for cross section and neglect inside fillets.

Method: 1) First iteration: assume .25in wall thickness and steel $E = 2.9\times10^7 psi$, calc $\sigma_{L/2}$
2) calc. y_{max}
3) calc S'_y
4) perform additional iterations if need be using Excel spreadsheet

Soln: $\sigma_{L/2} = \frac{P}{A}\left[1 + \frac{ec}{r^2}\sec\left(\frac{KL}{2r}\sqrt{\frac{P}{AE}}\right)\right]$

$A = (4in)^2 - (3.5in)^2 = \underline{3.75in^2}$

$I = \frac{1}{12}(H^4 - h^4) = \frac{1}{12}\left((4in)^4 - (3.5in)^4\right) = \underline{8.828in^4}$

$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{8.828in^4}{3.75in^2}} = \underline{1.534in}$

$c = 2in$ / $P = 2500lb$ / $K = 1.0$ / $E = 2.9\times10^7 psi$

$e = 8ft \times 12in = \underline{96in}$ / $L = 2.5ft \times 12in = \underline{30in}$

$\sigma_{L/2} = \frac{2500lb}{3.75in^2}\left[1 + \frac{(96in)(2in)}{(1.534in)^2}\sec\left(\frac{(1.0)(30in)}{2(1.534in)}\sqrt{\frac{2500}{(3.75)(2.9\times10^7)}}\right)\right] = \boxed{55{,}098psi}$

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Analysis #6 (cont.)

2) $Y_{max} = e\left[\sec\left(\frac{KL}{2r}\sqrt{\frac{P}{AE}}\right) - 1\right]$

$$= 96in\left[\sec\left(\frac{(1.0)(30in)}{2(1.534in)}\sqrt{\frac{25001b}{(3.75in^2)(2.9\times10^7 psi)}}\right) - 1\right]$$

$$\boxed{Y_{max} = .1056 in}$$

required $S_y = \frac{NP_a}{A}\left[1 + \frac{ec}{r^2}\sec\left(\frac{KL}{2r}\sqrt{\frac{NP_a}{AE}}\right)\right]$

$$P_a = \frac{P_y}{N} = \frac{25001b}{3} = 833.33 1b+$$

$$S'_y = \frac{3(833)}{A}\left[1 + \frac{(96)(2)}{(1.534)^2}\sec\left(\frac{(1.0)(30)}{2(1.534)}\sqrt{\frac{3(833)}{(3.75)(2.9\times10^7)}}\right)\right]$$

$$= \boxed{55,098 psi}$$

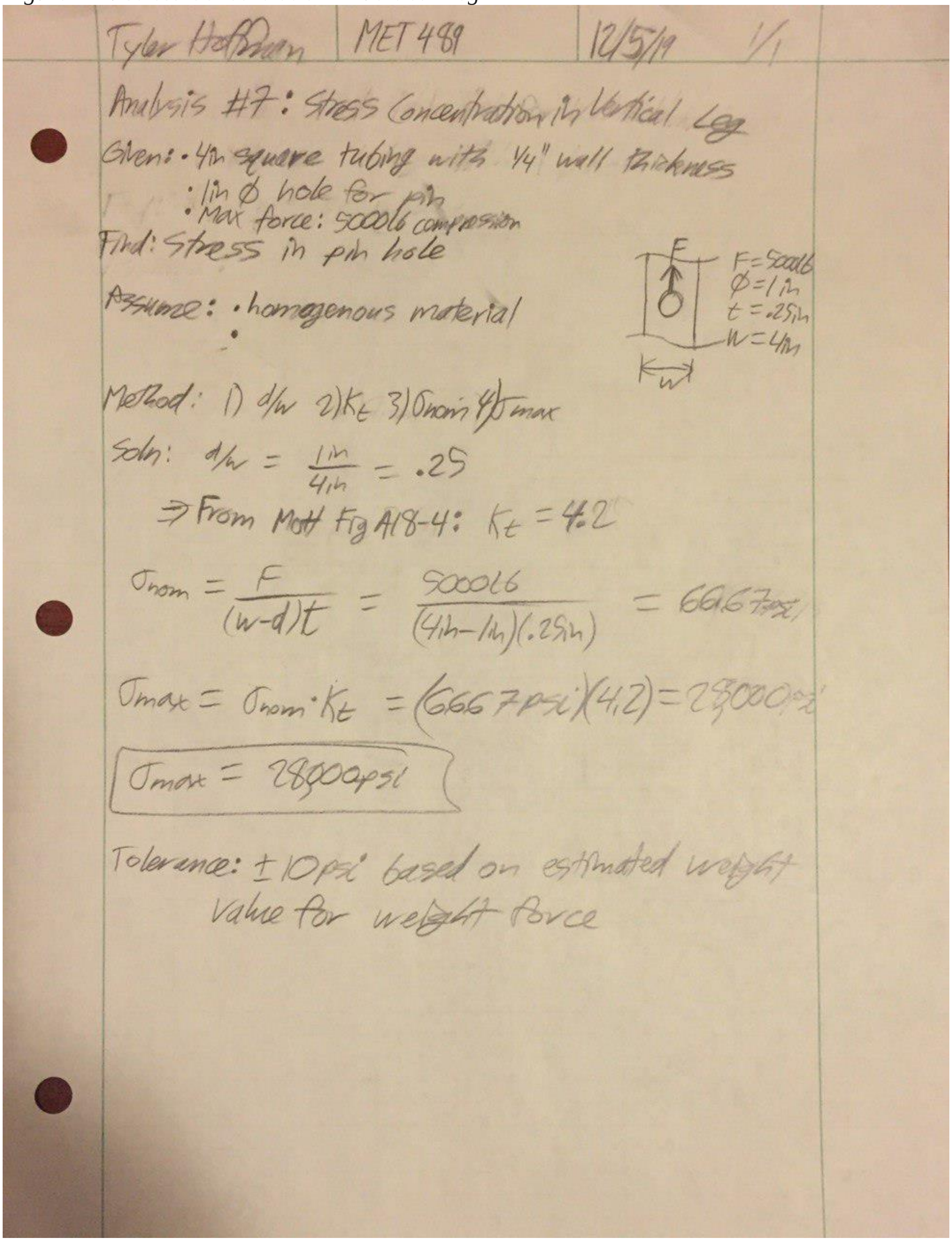
Material Designation

$S'_y = 55,098 psi > A500$ Grade B yield $= 46000 psi$

$55098 psi < A513$ yield $= 72,000 psi$

⇒ Use ASTM A513 square tubing
Dimensions: 4in x 4in, .25in wall thickness
2.5ft long

Figure A-7: Stress Concentration in Vertical Leg



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Analysis #7: Stress Concentration in Vertical Leg

Given: • 4in square tubing with 1/4" wall thickness
: 1in ∅ hole for pin
• Max force: 5000lb compression

Find: Stress in pin hole

F = 5000lb
∅ = 1in
t = .25in
W = 4in

Assume: • homogenous material
•

Method: 1) d/w 2) K_t 3) σ_{nom} 4) σ_{max}

Soln: $d/w = \frac{1in}{4in} = .25$

⇒ From Mott Fig A18-4: $K_t = 4.2$

$$\sigma_{nom} = \frac{F}{(w-d)t} = \frac{5000lb}{(4in-1in)(.25in)} = 6667psi$$

$$\sigma_{max} = \sigma_{nom} \cdot K_t = (6667psi)(4.2) = 28000psi$$

$$\boxed{\sigma_{max} = 28000psi}$$

Tolerance: ± 10psi based on estimated weight value for weight force

Figure A-8: Stress on Hole in Vertical Leg Caused by Pin

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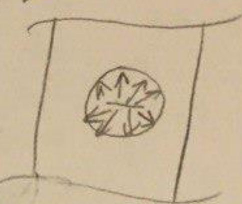
Analysis #8: Stress on Hole in Vertical Leg caused by Pin

Given: • 5000lb load
• 4in square tubing with .25" wall thickness
• 1in Ø hole

Find: Stress on hole wall caused by pin

Assume: • homogenous material
• planar forces
• even stress distribution



Method: 1) Area of pin hole 2) $\sigma = F/A$

Soln: $A = \pi d t = \pi (1in)(.25in) = .785 in^2$

$$\sigma = \frac{5000lb}{(.785in^2)} = 6366 psi$$

If safety factor $N=2$ is used,

$$\sigma = (6366psi)(2)$$

$$= \boxed{12732 psi}$$

Tolerance: ±50psi based on estimated weight value.

Figure A-9: Stress in Foot Pin Hole

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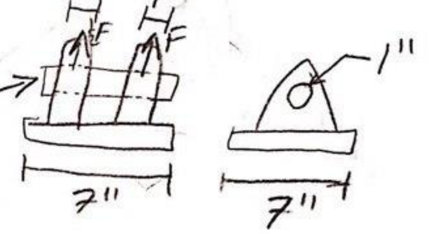
Analysis #9: Stress in Foot Pin Hole

Given: • Foot with dimensions shown below
• 5000lb force acting down and transferred through pin

Find: Stress in Pin Holes



Assume: • homogenous material
• even force distribution

Method: 1) $\sigma = F/A$, 2) safety factor 3) 15% incline

Soln:

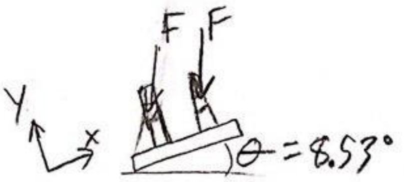
$$A = 2\left[\tfrac{1}{2}(\pi)(1in)(1in)\right] = 3.14in^2$$

$$\sigma = \frac{F}{A} = \frac{5000lb}{3.14in^2} = 1592.36psi$$

$$\boxed{\sigma = 1600psi}$$

$$\text{Safety Factor} = \frac{\sigma_y}{\sigma} = \frac{46000psi}{1600psi} = \boxed{28.9}$$

On 15% incline,



$F = 5000lb$

$F_x = 5000lb(\sin 8.53°) = \underline{741.6lb}$

$F_y = 5000lb \cos 8.53° = \underline{4944.7lb}$

Figure A-10: Vertical Leg Sizing Analysis

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Analysis #10: Size of Vertical Leg

Given: Vertical leg with 5"x5" square tubing (steel)

Find: Length and wall thickness, cost

Assume:
- Homogenous material
- minimal machining desired
- cost from midweststeelsupply.com

Method: compare weight/cost for different wall thickness and lengths (standard sizes)

Soln:

Wall	wt (lb)/ft	wt for 2 feet (lb)	cost for 2 feet ($)	wt for 2.5ft (lb)	cost for 2.5ft ($)	wt for 3ft (lb)	cost for 3ft ($)
5/16"	19.080	38.16	\$50.81	47.70	\$59.87	57.24	\$70.09
3/8"	22.370	44.74	\$97.16	55.93	\$69.13	67.11	\$79.08
1/2"	28.430	56.86	\$223.86?	71.08		85.29	\$332.86

⇒ Use 5/16" wall thickness because of lower cost and weight. The structural integrity remains intact with the smaller wall thickness.

For 5/16" wall thickness $A = (5in)^2 - (5in - 5/16")^2 = 3.027 in^2$

$$\sigma = \frac{F}{A} = \frac{5000 lb}{3.027 in^2} = \boxed{1652 psi}$$

Since 1652psi is well below the yield for steel, 5/16" wall thickness is adequate.

Figure A-11: Chain Analysis

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Analysis #11: Chain Analysis

Given: Because of size restraints, 25 chain required

Find: Forces acting on chain

Assume: · Friction is negligible
· planar forces
· low speed operation

Method: Estimate weight of what the chain pulls
compare to tensile strength of 25 chain

Soln: #25 chain: 1/4" Pitch, Max Roller Diameter = 0.130in
Average Tensile Strength = 925lb

Weight Estimate (metalsdepot.com)

6" boom: 23.25lb/ft × 2ft = 46.5 lb

5" vertical leg: 19.37lb/ft × 2ft = 38.74 lb

Foot (solidworks estimate) = .84 lb

Wear Pad Estimate = 1lb

Total Estimated weight of the portion of the device the chain pulls = 87.08 lb

Since 87.08lb << 925lb (the avg tensile strength of #25 chain), #25 chain is appropriate.

Figure A-12: Standard Sizing for ¼ Scale Model Parts

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Analysis #12: Standard Sizes for 1/4 Scale Model Parts

Given: Design for device must be scaled down to 1/4 size.

Find: Standard sizes for model parts

Assume: • proof of concept is most important objective for scale model

Method: Divide each part's dimensions by 4, select standard size

Soln:

Part	Key Dimensions	1/4 Scale	Standard Size
8" boom	8x8" tube, 5/16" wall	2"x2" .078" wall	use 3"x2" to be able to fit wire rope .065" wall
7" boom	7x7" tube 5/16" wall	1.75"x1.75" .078" wall	1.75"x1.75" .065" wall
6" boom	6x6" tube 5/16" wall	1.5x1.5" .078" wall	1.5"x1.5" .065" wall
5" vertical leg	5"x5" tube 5/16" wall	1.25"x1.25" .078" wall	1.25"x1.25" .065" wall
Foot	7"x7" base 1" dia hole	1.75x1.75 .25" dia hole	1.75"x1.75" base .25" dia hole
5" Pin	1" Ø 5" long	.25" Ø 1.25" long	.25" Ø 1.25" long
6" Pin	1" Ø 6" long	.25" Ø 1.5" long	.25" Ø 1.5" long
Wear Pads	1/8" thick	1/32" thick	side: 1/64" to allow for enough clearance for model booms to slide Top/Bottom: 1/2" thick since a 3"x2" boom was used

Appendix B – Drawings

Figure B-1: Drawing Tree

Figure B-2: 20_0001 3x2 in Boom

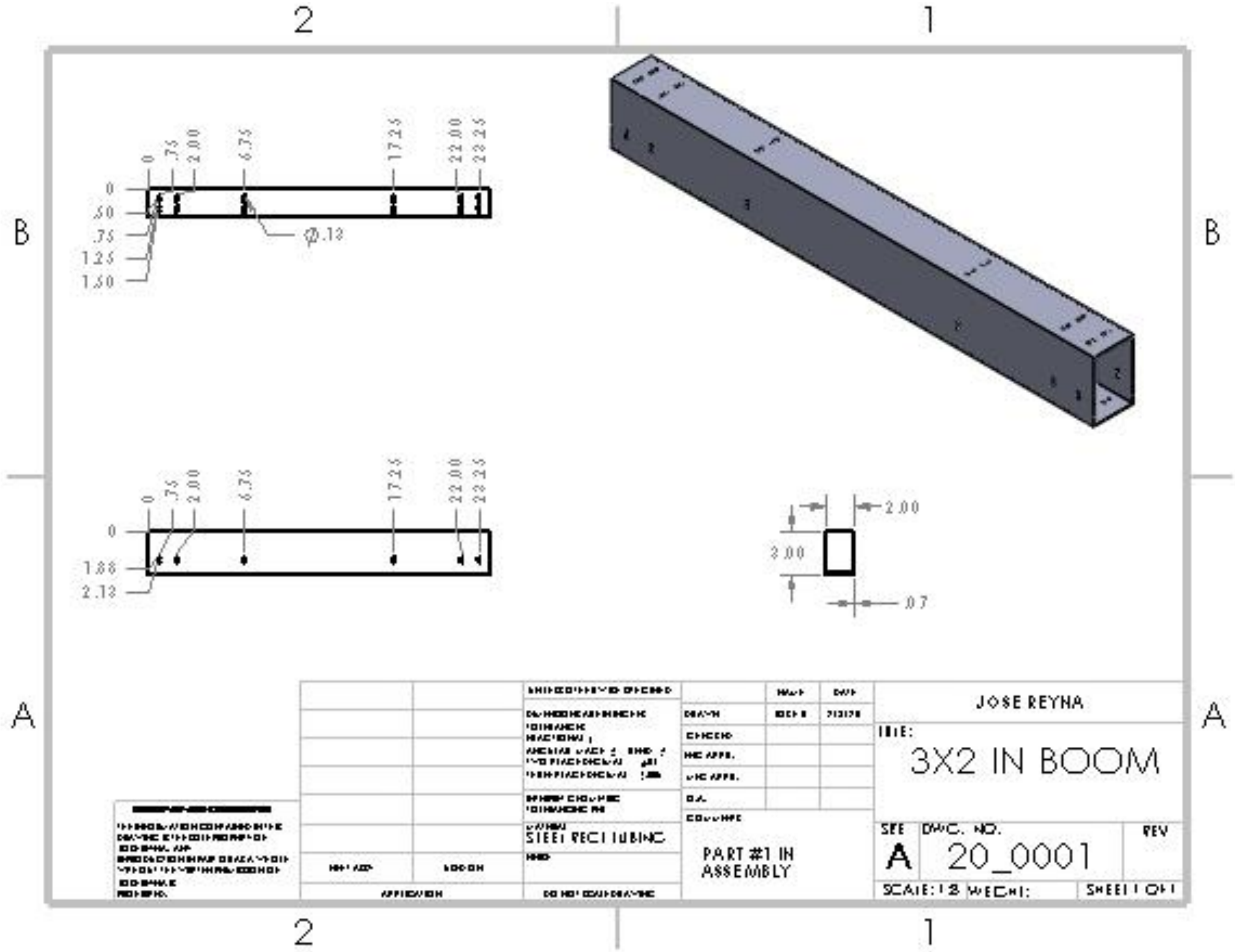


Figure B-3: 20_0002 1.75 in Boom

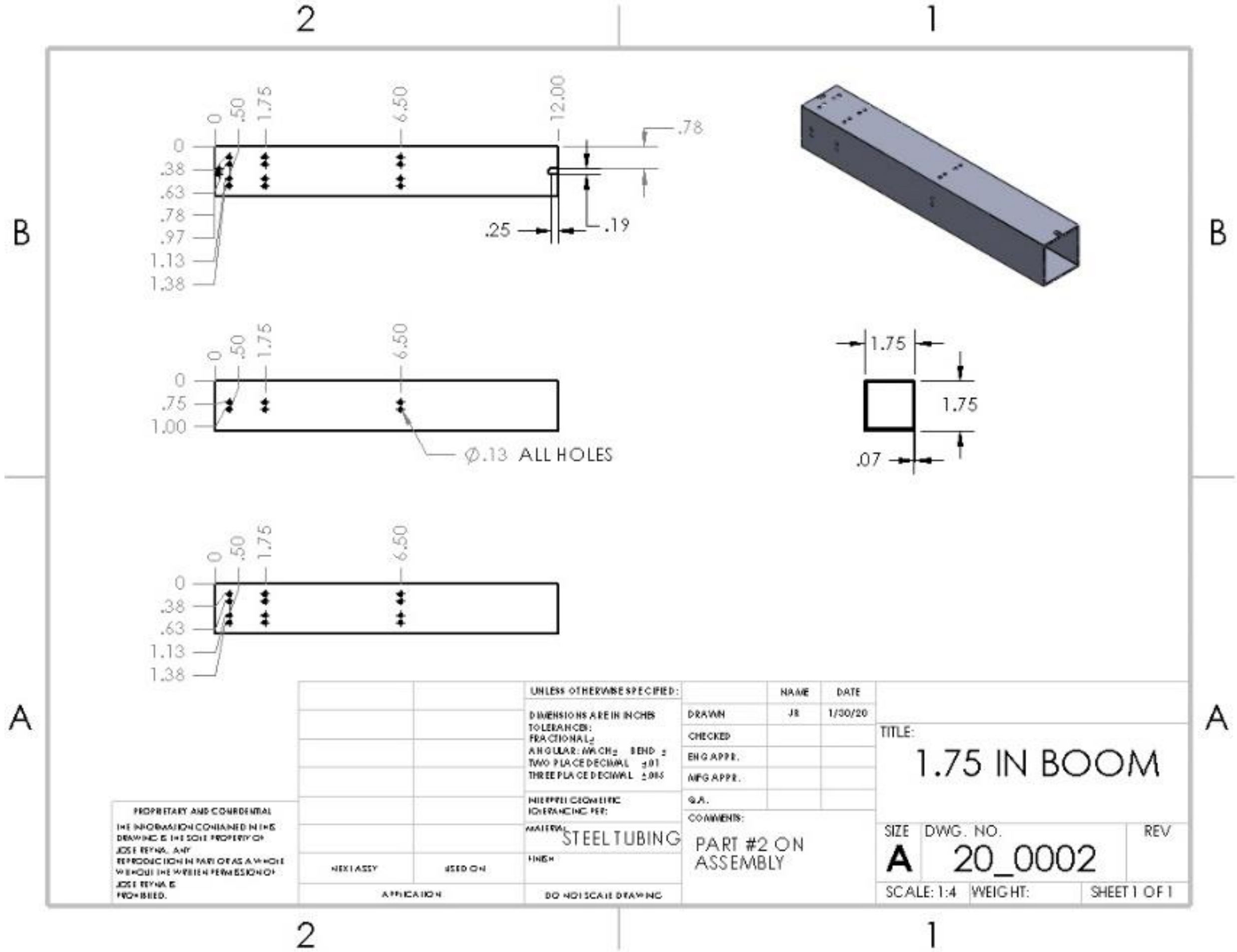


Figure B-4: 20_0003 1.5 in Boom

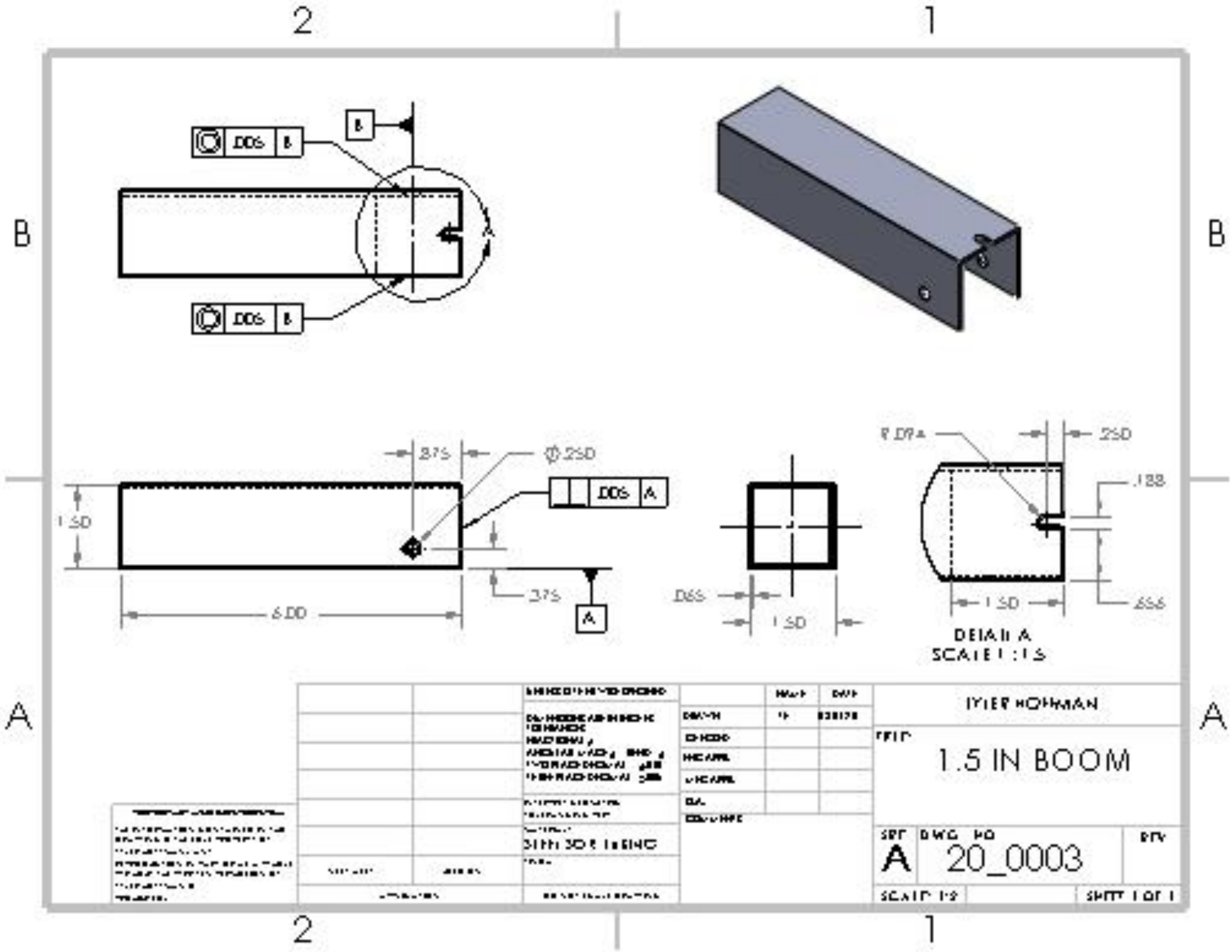


Figure B-5: 20_0004 1.25 in Vertical Leg

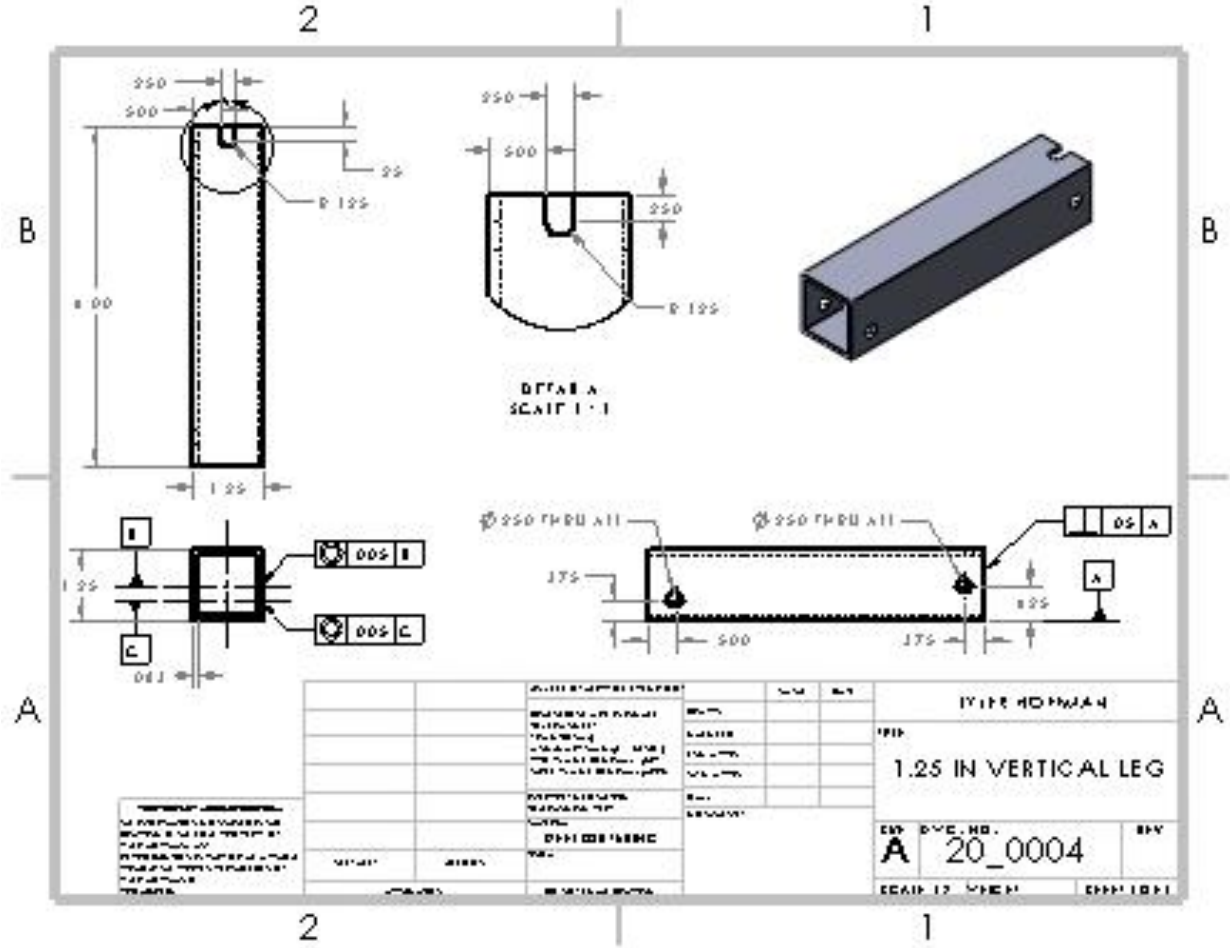


Figure B-6: 20_0005 Foot

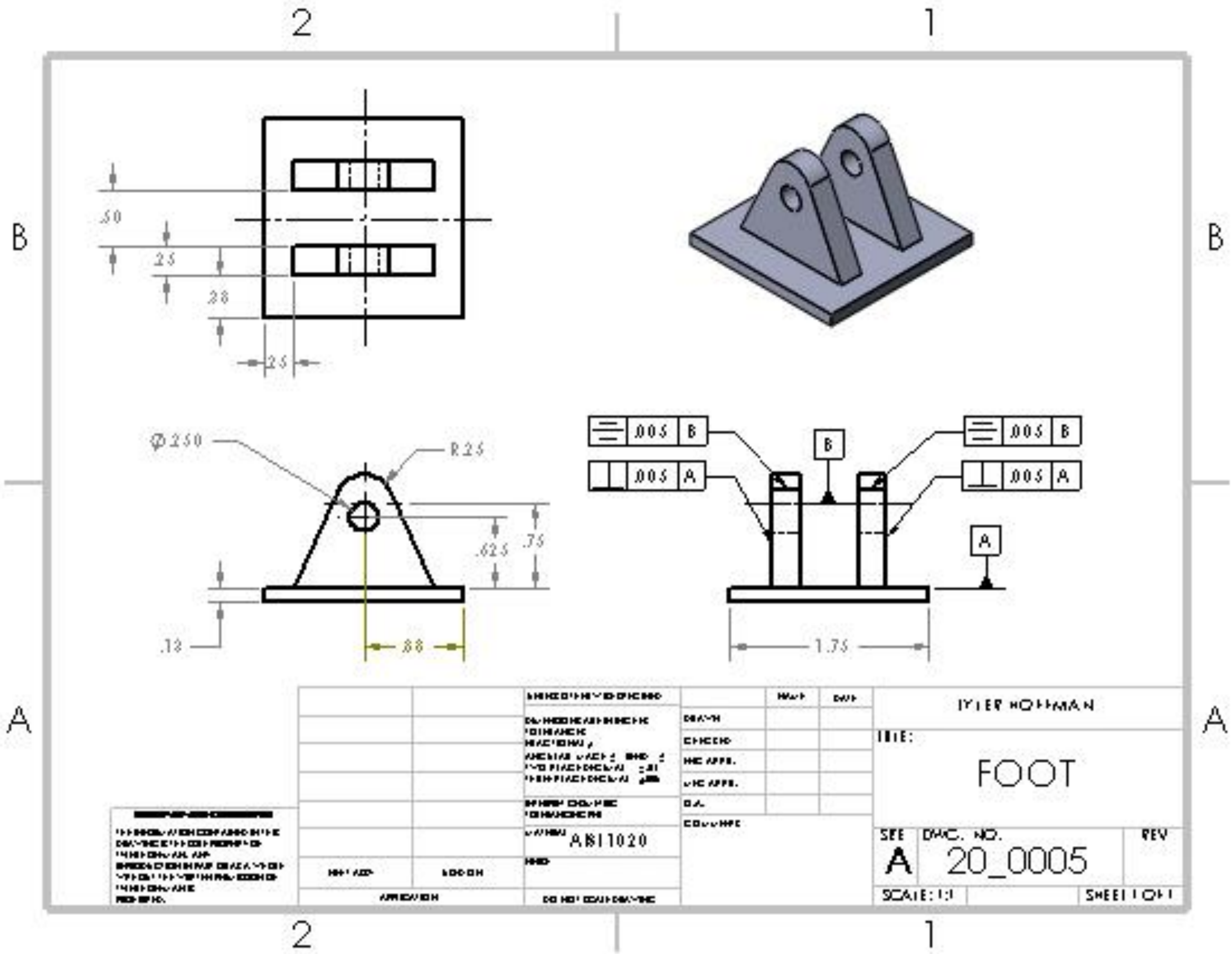


Figure B-7: 20_0006 1.25 in Pin

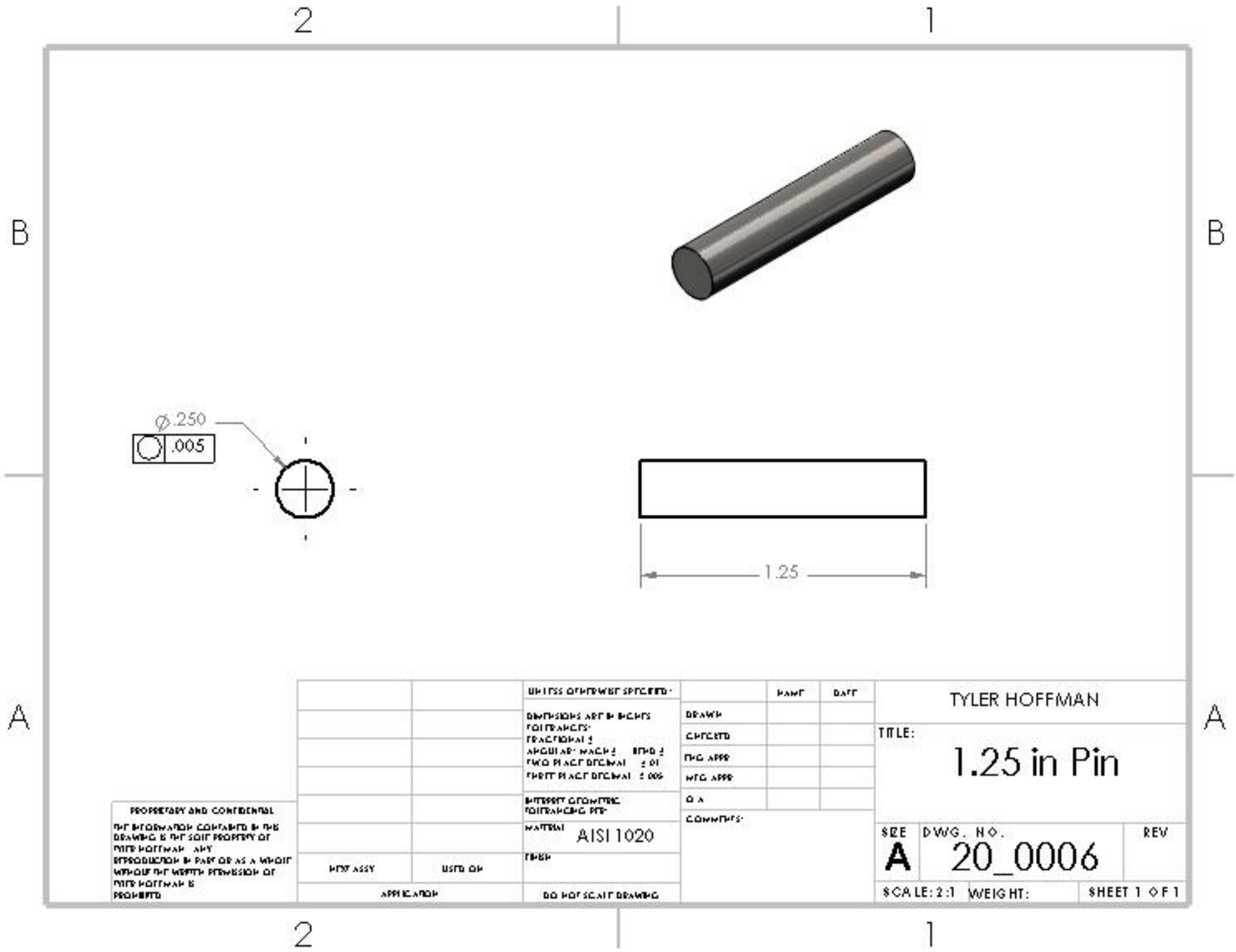


Figure B-8: 20_0007 1.5 in Pin

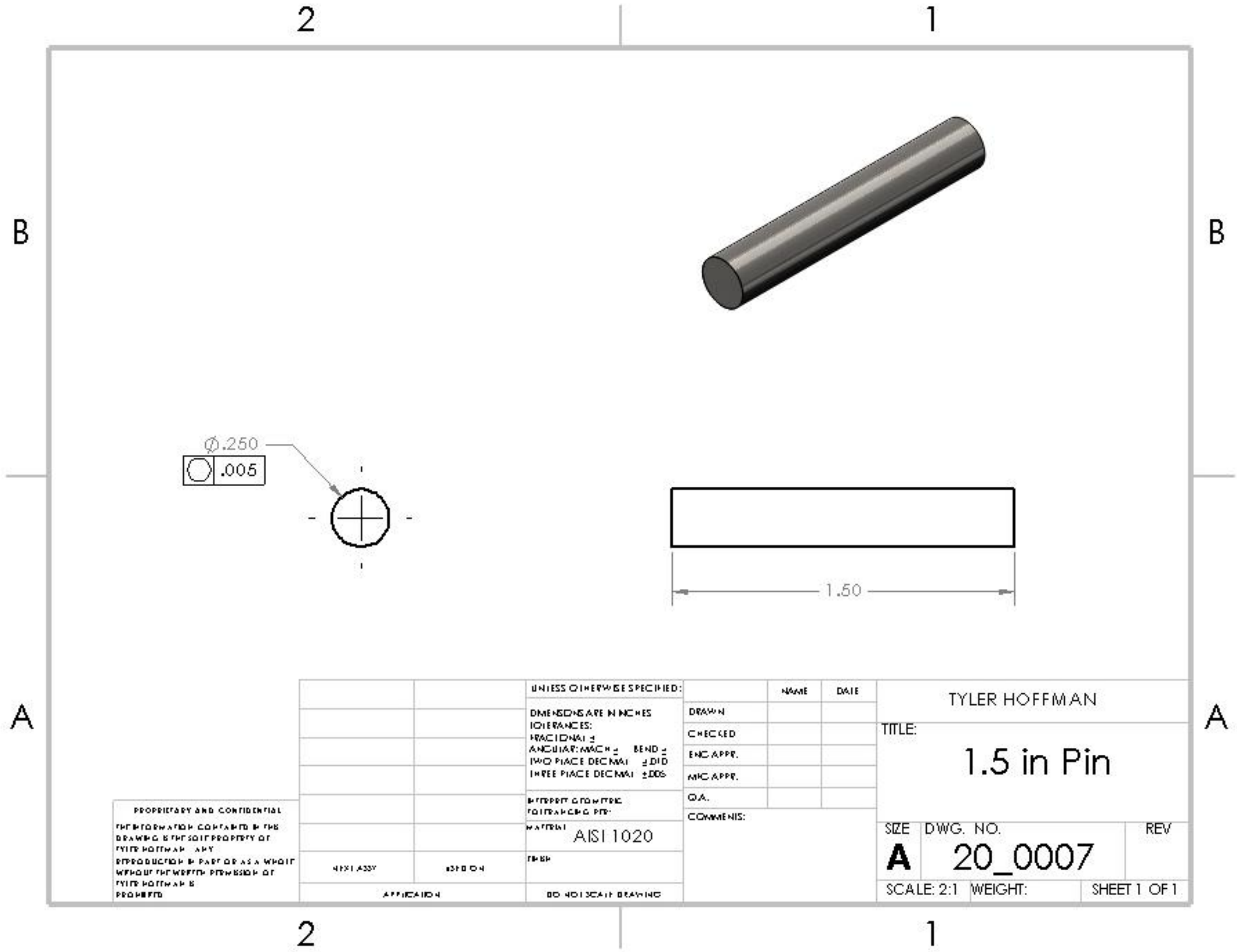
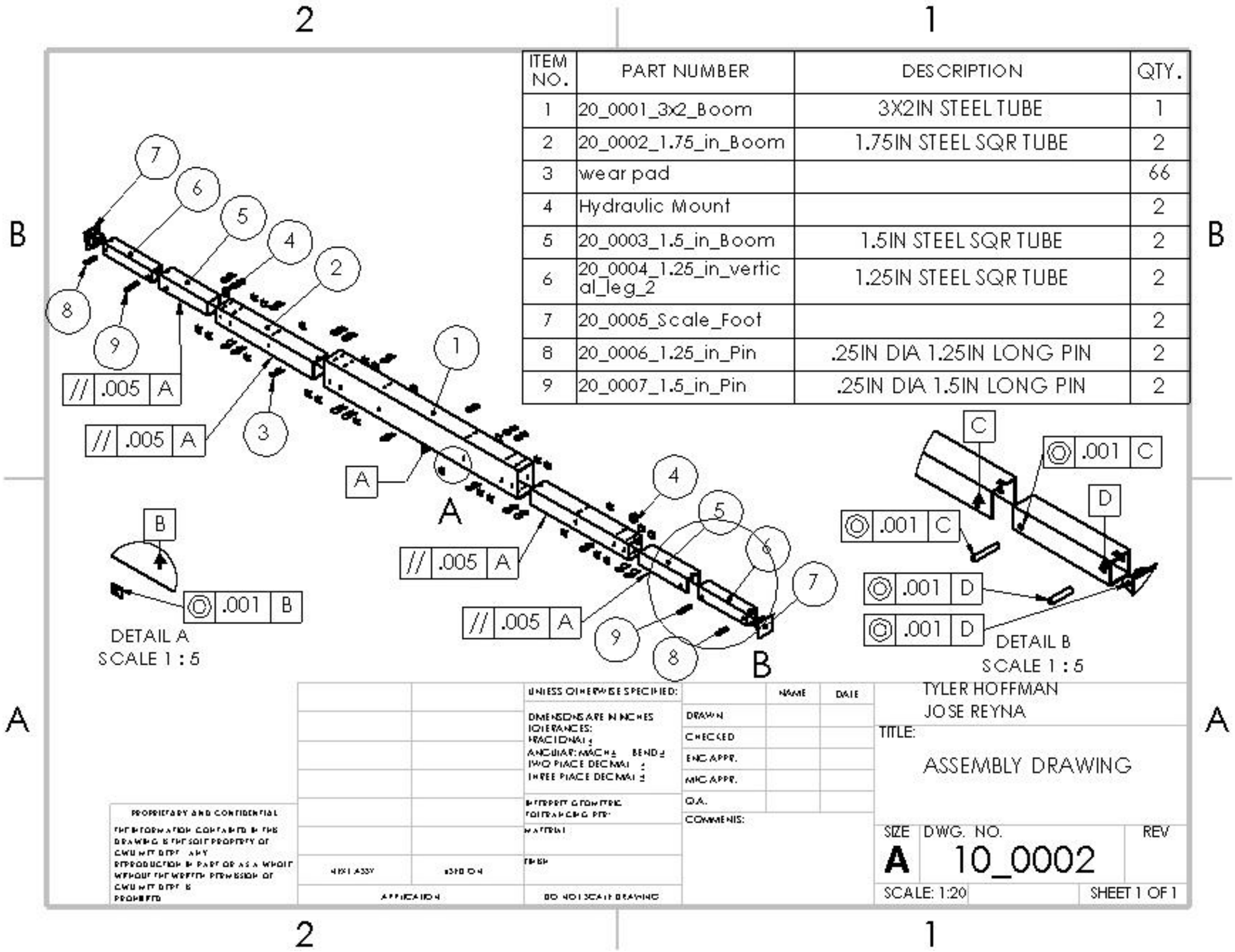


Figure B-9: 10_0002 Assembly Drawing Revision 2



Appendix C - Parts List

ITEM ID	ITEM Description	Item Source	Brand Info	Model/SN	Price/Cost (US Dollars) ($ / hour)	Quantity (or hrs)	Cost: Subtotals	Actual $
1	ASTM A513 1.25", .065" thick square tubing, 6in	Metalsdepot.com		T111416	3.87	2	7.74	7.74
2	ASTM A513 1.5", .065" thick square tubing, 6in	Metalsdepot.com		T111216	4.09	2	8.18	8.18
3	ASTM A513 ", 1.75", .065 thick square tubing, 2ft	Metalsdepot.com		T113414	10.46	1	10.46	10.46
4	ASTM A513 3"x2", .083" thick rect. tubing, 2ft	Metalsdepot.com		T132083	12.82	1	12.82	12.82
5	A-36 Square Bar, 1.25", 2" long	Metalsdepot.com		SQ1114	6.44	1	6.44	6.44
6	.25" dia steel dowel for pins	McMaster-Carr		98912A540	12.36	1	12.36	5.4
7	1/16" Wire Rope	Amazon			10	1	10	5
8	Pulleys for Wire Rope	Amazon			10	1	10	0
9	3D printed parts	CWU			10	1	10	10
10	Machining/construction costs						30	15
				Tot Est.$	118		Tot Act. $	81.04

Appendix D - Budget

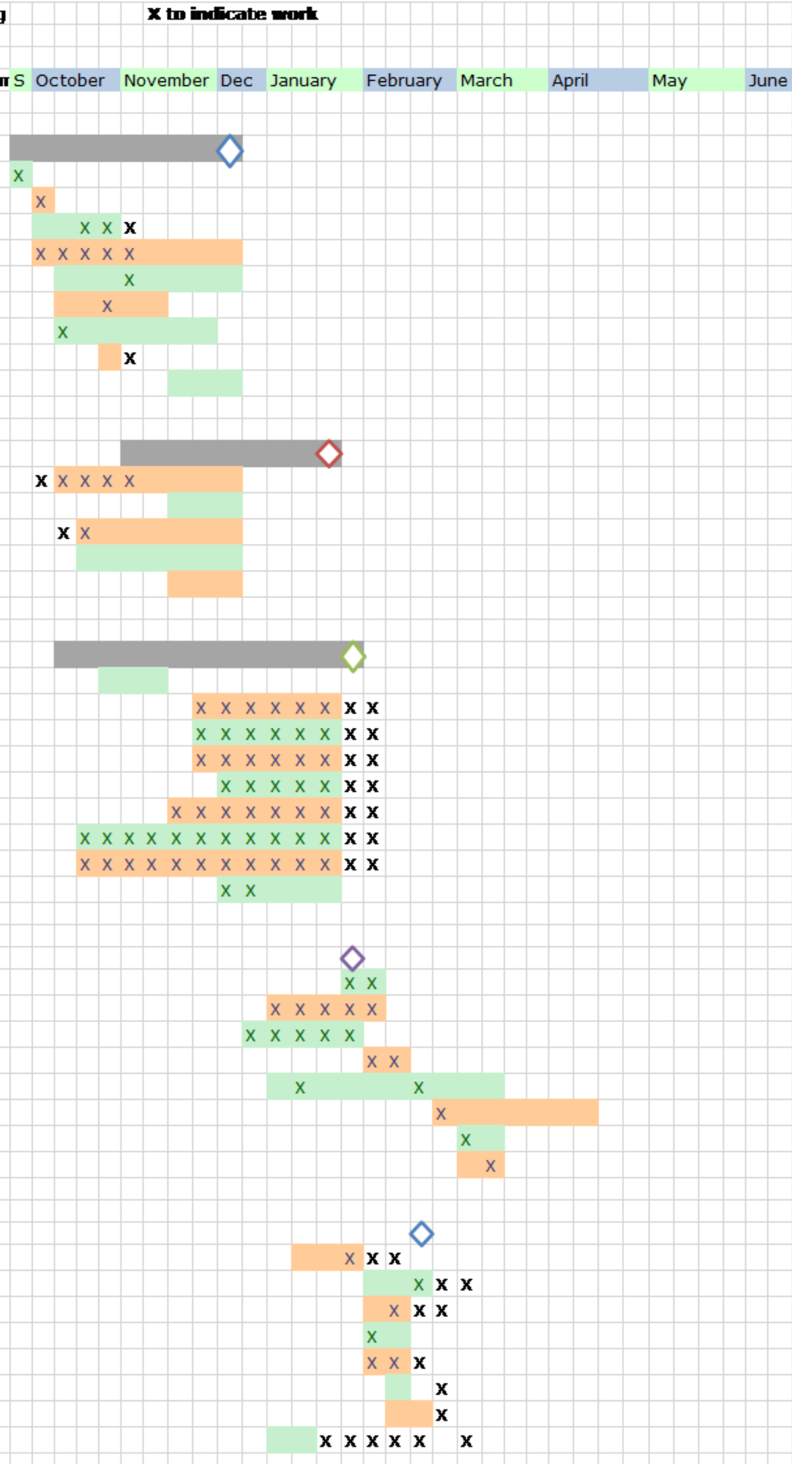
ITEM ID	ITEM Description	Item Source	Brand Info	Model/SN	Price/Cost (US Dollars) ($ / hour)	Quantity (or hrs)	Cost: Subtotals	Actual $
1	ASTM A513 1.25", .065" thick square tubing, 6in	Metalsdepot.com		T111416	3.87	2	7.74	7.74
2	ASTM A513 1.5", .065" thick square tubing, 6in	Metalsdepot.com		T111216	4.09	2	8.18	8.18
3	ASTM A513 ", 1.75", .065 thick square tubing, 2ft	Metalsdepot.com		T113414	10.46	1	10.46	10.46
4	ASTM A513 3"x2", .083" thick rect. tubing, 2ft	Metalsdepot.com		T132083	12.82	1	12.82	12.82
5	A-36 Square Bar, 1.25", 2" long	Metalsdepot.com		SQ1114	6.44	1	6.44	6.44
6	.25" dia steel dowel for pins	McMaster-Carr		98912A540	12.36	1	12.36	5.4
7	1/16" Wire Rope	Amazon			10	1	10	5
8	Pulleys for Wire Rope	Amazon			10	1	10	0
9	3D printed parts	CWU			10	1	10	10
10	Machining/construction costs						30	15
				Tot Est.$	118		Tot Act. $	81.04

Appendix E - Schedule

Link to schedule Excel file

PROJECT TITLE: H.F. Hauff Outrigger Stabilizing Leg
Principal Investigator.: Tyler Hoffman

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Com
1	Proposal*			
1a	Outline	0.5	0.5	
1b	Intro	2	2	
1c	Methods	1	1	
1d	Analysis	14	10	
1e	Discussion	5	2	
1f	Parts and Budget	4	1	
1g	Drawings	8	8	
1h	Schedule	2	1	
1i	Summary & Appx	4	1.5	
	subtotal:	40.5	27	
2	Analyses			
2a	Stress Anal=>Geo	5	2	
2b	Power Anal=>Geo	0.5	2	
2c	Kinematic => Geo	4	2	
2d	Tolerance => Geo	2.5	1	
2e	Material Anal=> Geo	2	2	
	subtotal:	14	9	
3	Documentation			
3a	Part 1 foot	2	2.5	
3b	Part 2 1.5 in boom	1.5	2.5	
3c	Part 3 1.25 vertical tube	2	2.5	
3d	Part 4 1.25 in Pin	2	1	
3e	Part 5 1.5 in Pin	1	1	
3f	Compliance with partner	2	3	
3g	Assembly	5	20	
3h	ANSIY14.5 Compl	1	2	
3i	Make Object Files	0.5	1	
	subtotal:	17	35.5	
4	Proposal Mods			
4a	Project Schedule	1	1.5	
4b	Project Part Inv.	1	1	
4c	Crit Des Review*	1.5	16	
4d	Project Budget	1	1	
4e	Methods/Construction	1	1	
4f	Testing	0.5	0.5	
4g	Discussion	1	1	
4h	Final Revisions	2	3	
	subtotal:	9	25	
7	Part Construction			
7a	Order Parts	1	4	
7b	Boom Modifications	3	2.5	
7c	Make 1.25/1.5 in pins	1	2.5	
7d	Purchase Wire Rope	0.5	0.5	
7e	Purchase/Make Pulleys	3	1.5	
7f	Take Part Pictures	0.5	0.5	
7g	Update Website	1.5	1	
7h	Manufacture Plan*	2.5	4	
	subtotal:	13	16.5	



9	Device Assembly		
9a	Assemble booms and pins	1	2
9b	Assemble booms/wear pad	2	5.5
9c	Assemble rope/pulleys	1	2
	subtotal:	4	9.5
10	Device Evaluation		
10a	Test Plan	2	1.5
10b	Obtain resources	2	0
10c	Test Extension	0.5	0.5
10d	Test Retraction	0.5	0.5
10e	Test Foot Rotation	1	1
10f	Test Structural Support	0.5	0.5
10g	Weight/Additional Tests	2	0.5
10h	Create Test Report	3	8.5
10i	Update Project Report	3	6.5
10j	Take Testing Pics	0.5	1.5
10k	Update Website	2	4
	subtotal:	17	25
11	489 Deliverables		
11a	Create Presentation	4	6
11b	Participate in SOURCE	2	0.5
11c	Make CD Deliv. List	1	0
11d	Write 489 CD parts	1	1
11e	Project CD*	1	0
	subtotal:	9	7.5
	Total Est. Hours=	123.5	155 =Total Actual Hrs
Labor$	25	3088	
Note:	Deliverables*		
	Draft Proposal		
	Analyses Mod		
	Document Mods		
	Final Proposal		
	Part Construction		
	Device Construct		
	Device Evaluation		
	489 Deliverables		

Appendix G - Testing Report

H.F. Hauff Portable Wind Fan Stabilizer Test Report
Tyler Hoffman

Introduction

Weight Test
The Weight Test will evaluate design requirement #1, which states that the full-sized device "must weigh no more than 800 pounds." For the ¼ scale model, the weight requirement prorates to 200 pounds. The parameter of interest is the weight, in pounds, of the entire device. The predicted weight of the device was 15 pounds, as calculated on the SolidWorks model. The data will be collected using a scale. For the timeline of the Weight Test in the project schedule, see task #10f on the project Gantt chart, listed in Appendix G5.

Extension Functionality Test
The Extension Functionality Test will evaluate design requirement #3, which states that the "vertical leg/foot must be able to extend out horizontally and articulate down 90 degrees." To do so, the smaller booms and vertical legs/feet will be extended repeatedly. The main parameter of interest for the Extension Functionality Test is the functionality of the extension of the device by the wire rope and pulley system. The prediction for the functionality of extension is that the device will consistently be able to extend the 1.75-inch boom but not the smaller booms and vertical legs/feet. The data will be collected using a visual pass/fail system. For the timeline of the Extension Functionality Test in the project schedule, see task #10c on the project Gantt chart, listed in Appendix G5.

Extension Length Test
The Extension Length Test will evaluate design requirement #6, which states that the device "must be able to counter a moment caused by a 20-foot tower with 2000 pounds of thrust." To counter the moment, the overall length of the full-sized device must be 16 feet, as calculated in Analysis #1, listed in Appendix A-1 in the project report. For the ¼ scale model, this value prorates to 48 inches of total extension. To evaluate design requirement #6, the overall length of the device when extended will be measured. The main parameter of interest is the overall length, in inches, of the device when extended. The predicted length of the extended device is 48 inches. The data will be collected using a tape measure. For the timeline of the Extension Length Test in the project schedule, see task #10c on the project Gantt chart, listed in Appendix G5.

Retraction Functionality Test
The Retraction Functionality Test will evaluate design requirement #4, which states that "all sections of the device must be able to retract inside the largest boom." To do so, the smaller booms and vertical legs/feet will be retracted inside the largest boom repeatedly using the wire rope and pulley system. The main parameter of interest for the Retraction Functionality is the functionality of the retraction of the device by the wire rope and pulley system. The prediction for the functionality of retraction is that the device will consistently be able to retract all sections inside the largest boom. The data will be collected using a visual pass/fail system. For the

timeline of the Retraction Functionality Test in the project schedule, see task #10d on the project Gantt chart, listed in Appendix G5.

Retraction Length Test

The Retraction Length Test will evaluate design requirement #2, which states that the device "must be dimensioned to fit on a 7'x12' trailer." For the ¼ scale model, the 7-foot width requirement prorates to 1.75 feet, or 21 inches. The main parameter of interest for the Retraction Length Test is the overall length, in inches, of the device when retracted. The prediction for the retraction length of the device is 21 inches. The data will be collected using a tape measure. For the timeline of the Retraction Length Test in the project schedule, see task #10d on the project Gantt chart, listed in Appendix G5.

Foot Rotation Test

The Foot Rotation Test will evaluate design requirements #7 and #8, which state that the device "must keep trailer level within ±5 degrees," and "must allow the trailer to operate on a 15% grade." The main parameter of interest for the Foot Rotation Test is the angle of rotation, in degrees, of both directions of each foot. The data will be collected using paper and a protractor. For the timeline of the Foot Rotation Test in the project schedule, see task #10e on the project Gantt chart, listed in Appendix G5.

Structural Support Test

The Structural Support Test will evaluate design requirements #5 and #6, which state that the device "must be able to support a load of 5000 pounds," and "must be able to counter a moment caused by a 20-foot tower with 2000 pounds of thrust." In Analysis #3, listed in Appendix A-3 in the project report, the force acting on the vertical legs with two legs on the ground was found to be 2,500 pounds. The engineering 'worst case scenario,' where only one vertical leg supports the system, would result in a 5,000-pound maximum load on the device. For the ¼ scale model, this value prorates to 1,250 pounds, and with two legs on the ground the reaction prorates to 625 pounds. To evaluate design requirements #5 and #6, the device will be incrementally loaded with a pass/fail designation. The main parameter of interest for the Structural Support Test will be that pass/fail designation given loads of varying weight, in pounds. The data will be collected using a scale and visual examination. For the timeline of the Structural Support Test in the project schedule, see task #10f on the project Gantt chart, listed in Appendix G5

Method/Approach

Weight Test
The Weight Test will be performed by a single person, the principal engineer, using a scale. The device will be weighed using this scale, and the data will be captured and recorded in the project testing Excel spreadsheet. Five trials will be recorded. There are no operational limits to the test procedure aside from level ground to place the scale on. The scale being used is a common house scale with a precision of ±0.05 pounds. The only data processing required will be averaging the five trials into one value.

Extension Functionality Test
The Extension Functionality Test will be performed by a single person, the principal engineer, using no resources aside from the device itself. The ability of the device to extend the vertical legs and feet will be evaluated, and the data will be captured visually and recorded as pass/fail in the project test Excel spreadsheet. There are no operational limits to the test procedure. As the test is a pass/fail one, there is no device precision to consider. The only data processing required will be providing a pass confidence percentage based on ten trials.

Extension Length Test
The Extension Length Test will be performed by a single person, the principal engineer, using a tape measure. The overall length of the device when extended will be measured, and the data will be captured and recorded in the project test Excel spreadsheet. There will be five trials. There are no operational limits to the test procedure aside from a level table to place the device on. The tape measure being used has a precision of ±1/32”. The only data processing will be averaging the five trials into one value. The data will be presented in a table.

Retraction Functionality Test
The Retraction Functionality Test will be performed by a single person, the principal engineer, using no resources aside from the device itself. The ability of the device to retract the vertical legs and feet inside the largest boom will be evaluated. The data will be captured visually and recorded as pass/fail in the project test Excel spreadsheet. There will be ten trials. There are no operational limits to the test procedure. As the test is a pass/fail one, there is no device precision to consider. The only data processing required will be providing a pass confidence percentage based on ten trials. The data will be presented in a table.

Retraction Length Test
The Retraction Length Test will be performed by a single person, the principal engineer, using a tape measure. The overall length of the device when retracted will be measured, and the data will be captured and recorded in the project test Excel spreadsheet. There will be five trials. There are no operational limits to the test procedure aside from a level table to place the device on. The tape measure being used has a precision of ±1/32”. The only data processing required will be averaging the five trials into one value. The data will be presented in a table.

Foot Rotation Test
The Foot Rotation Test will be performed by a single person, the principal engineer, using a piece of paper and a protractor. The angle of rotation for both directions of each foot will be

measured, and the data will be captured and recorded in the project test Excel spreadsheet. There are no operational limits to test the procedure aside from a table to place the device on. The protractor being used has a precision of ±0.5 degrees. The only data processing required will be finding the minimum data point. The data will be presented in a chart.

Structural Support Test

The Structural Support Test will be performed with varying sources of weights, including textbooks and human volunteers, using a scale for reference. The amount of weight the device can support will be evaluated by incrementally loading textbooks and human volunteers of varying weights. The results will be of the pass/fail form, and the data will be captured and recorded in the project test Excel spreadsheet. The scale being used has a precision of ±0.05 pounds. The data will be processed using Excel and presented in a chart.

Test Procedure

Weight Test
The Weight Test evaluates the weight of the device, in pounds, using a scale. The test is expected to take approximately 1 minute and will be completed in the principal engineer's home. The only resources needed are the device, a scale, and the test performer.

Procedure Steps:

1. Place the scale on a rigid, level surface.
2. Test the scale using a known weight (such as the test performer's own weight).
3. Place the device, in its retracted state, on the scale and record the weight.
4. Repeat steps 2 and 3 for a total of five trials

Due to the simplicity of the weight test, there were no challenges presented, and the test went smoothly.

Extension Functionality Test

Figure 1: Extension Functionality and Length Testing Setup

The Extension Functionality Test evaluates the device's ability to extend the vertical legs/feet out and down to 90 degrees. The test is expected to take approximately 5 minutes and will be completed in the principal engineer's home. The only resources needed are the device and the test performer. For the testing setup, see Figure 1 above.

Procedure Steps:

1. Place the device, in its retracted state, on a raised, level surface. The surface should be raised enough so that the vertical legs can articulate down to 90 degrees and not touch any other surface. If needed, push the booms in by hand to start from a retracted state.
2. Pull the extension strand of the wire rope on one side of the device to extend the smaller booms and vertical legs/feet as far as they can simply by pulling the extension strand. The

extension strand is easily identifiable from the retraction strand because pulling the retraction strand when the device is already retracted will do nothing.

3. After the smaller booms have gone as far as they can with just pulling the extension strand of the wire rope, push the smaller booms out by hand to test if they can do so.
4. Record a pass/fail of the device's ability to extend the booms and vertical legs/feet with just pulling the wire rope and with pushing assistance, including comments.
5. Repeat steps 2-4 for the other side of the device.
6. Repeat steps 2-5 for a total of ten trials, retracting the booms in between each trial, either by hand or by pulling the retraction strand of the wire rope.

The Extension Functionality Test went smoothly, and the device performed consistently for every test. Pulling the extension strand of the device resulted in the 1.75-inch booms (the second largest booms) completely extending, but none of the 1.5-inch booms, vertical legs, nor feet were able to extend with just pulling the wire rope. These smaller sections were still able to fully extend by manual assistance, however.

Extension Length Test

The Extension Length Test evaluates the ability of the device to extend far enough to counteract the wind thrust generated at the top of the wind fan tower. To do so, the overall length of the device when fully extended. The test is expected to take approximately 2 minutes and will be completed in the principal engineer's home. The resources needed are a tape measure, the device, and the test performer. For the testing setup, see Figure 1 above.

Procedure Steps:

1. Place the device on a raised, level surface. The surface should be raised enough so that the vertical legs can articulate down to 90 degrees and not touch any other surface.
2. Extend the smaller booms and vertical legs/feet until the 3rd set of top holes from the edge of each boom are just visible and both sets of vertical legs and feet have articulated down to 90 degrees.
3. Using the tape measure, evaluate the overall length of the extended device from the far edge of one vertical leg to the far edge of the other vertical leg. Record this measurement once read.
4. Repeat steps 2 and 3 for a total of five trials

The Extension Length Test went smoothly with nothing unexpected occurring.

Retraction Functionality Test

Figure 2: Retraction Functionality and Length Testing Setup

The Retraction Functionality Test evaluates the device's ability to retract the 1.75-inch boom, 1.5-inch boom, vertical legs, and feet inside the largest boom. The retraction strand of the wire rope is used to complete the test. The test is expected to take approximately 5 minutes and will be completed in the principal engineer's home. The resources needed for this test are the device and the test performer. For the testing setup, see Figure 2 above.

Procedure Steps:

1. Place the device, in its extended state, on a raised, level surface. The surface should be raised enough so that the vertical legs do not touch any other surface when rotated down 90 degrees. The booms can be extended using the extension strand of the wire rope and manual assistance.
2. Pull the retraction strand of the wire rope for one side until the smaller sections have retracted as far as they can into the largest boom and the hydraulic mount touches the largest boom. The retraction strand is easily identifiable because pulling the extension strand while the device is fully extended will do nothing.
3. Record a pass/fail of the device's ability to retract its smaller sections by simply pulling the retraction strand of the wire rope.
4. Repeat steps 2 and 3 for the other side of the device.
5. Repeat steps 2-4 for a total of ten trials, extending the booms in between each trial either by hand or with the extension strand of the wire rope.

The Retraction Functionality Test went smoothly with nothing unexpected occurring.

Retraction Length Test

The Retraction Length Test evaluates the ability of the device to fit within the design requirement window of 21 inches for the scale model. To do so, the overall length of the device when fully retracted is measured. The test is expected to take approximately 2 minutes and will be performed in the principal engineer's home. The resources needed are measuring tape, the device, and the test performer. For the testing setup, see Figure 2 above.

Procedure Steps:

1. Place the device on any level surface.
2. If needed, fully retract the booms either by hand or by using the retraction strand of the wire rope.
3. Using the tape measure, evaluate the overall length of the retracted device from the far edge of one foot to the far edge of the other foot. Record this measurement.
4. Repeat steps 2 and 3 for a total of 5 trials.

Foot Rotation Test

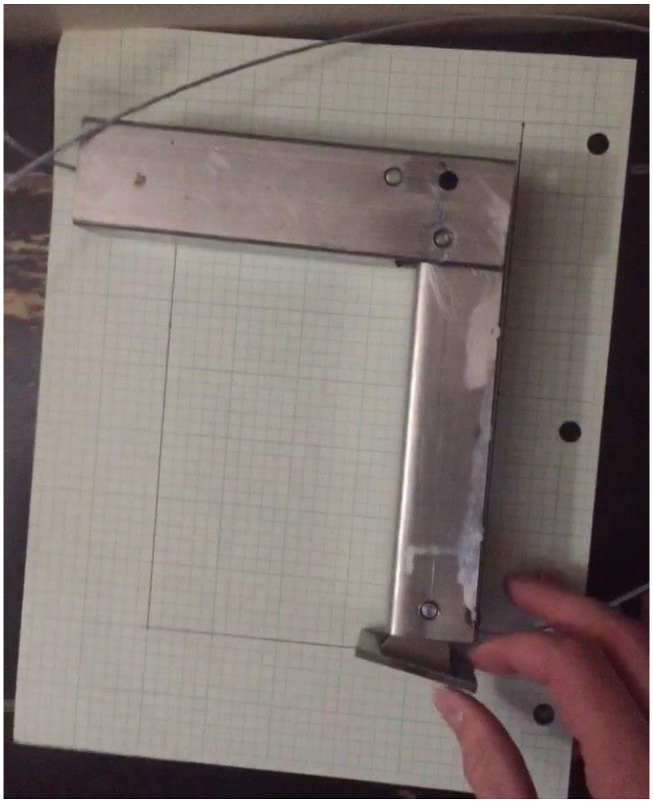


Figure 3: Foot Rotation Testing Setup

The Foot Rotation Test evaluates the ability of the device to keep the trailer level and operational on uneven terrain. To do so, the angle of rotation for both directions of each foot are measured. The test is expected to take approximately ten minutes and will be completed in the principal engineer's home. The resources needed for the test are a piece of paper, a protractor, the device, and the test performer. For the testing setup, see Figure 3 above.

Procedure Steps:

1. Draw three straight edges on the piece of paper such that they form a U-shape with each angle at 90 degrees. These will serve as a baseline for lining the device up.
2. Remove the right side of the device's inner section, containing the 1.5-inch boom, vertical leg, and foot, from the larger booms and line the vertical leg and foot up with the right and bottom edges. The foot should be tilted up to the left to its maximum, the bottom right edge of the foot should line up with the bottom right intersection on the paper, and the vertical leg should line up with the right edge on the paper.
3. Once everything is lined up, draw a line along the bottom edge of the foot.
4. Remove the device from the page and extend this line using the straight edge of the protractor.
5. Place the center mark of the protractor on the bottom right intersection on the paper and measure the angle created from the foot edge line. Record this value.
6. Repeat steps 2-5 for the case of the foot tilting up to the right, using the bottom left intersection on the paper as the focal point.
7. Repeat steps 2-6 for the left side of the device's inner section.

Initial trials of the Foot Rotation Test involved simply holding up a protractor to the device. These trials resulted in a great deal of unwanted variability in the angle measurements recorded, so additional steps were added to improve the process. Removing the inner sections of the device and using a piece of paper to aid in the protractor measurements improved the test by a good margin and resulted in more consistent data.

Structural Support Test

The Structural Support Test evaluates the ability of the device to support the assumed load from the weight of the trailer and the wind thrust. To do so, weight is added incrementally to the device, and pass/fail designations are assigned. The test is expected to take approximately 10 minutes and will be completed in the principal engineer's home. The resources needed for the test are objects or people of varying weights that can be balanced on the device, a scale, the device, and the test performer.

Procedure Steps:

1. Fully extend the device and place on rigid, level ground, making sure that the vertical legs are both operating 90 degrees to the ground and the feet are the only portions of the device in contact with the ground.
2. Weigh the lightest object assembled using the scale.
3. Place the lightest object on the largest boom of the device and visually determine if the device supports the weight.
4. Repeat steps 2 and 3 with the remaining assembled objects and human volunteers in increasing fashion until 625-pound predicted value is reached or some portion of the device fails. Instruct the human volunteers to simply stand on top of the largest boom in the middle. Make sure to reset the vertical legs after each trial. It is recommended to attempt at least 3 trials under 200 pounds before adding additional weight.
5. Record pass/fail tests for each trial weight. Once some portion of the device fails, record the breaking weight and the point of failure.

The Structural Support Test went smoothly, but the device was able to support less weight than expected due to the 3D-printed wear pads failing. This failure occurring sooner than expected prevented the ability to collect several "pass" data points, but the failure point was found.

Deliverables

Weight Test

The Weight Test revealed that the complete scale model weighed 10.6 pounds, meeting design requirement #1 as it was well below the prorated 200 pounds. The scale model was much lighter than the requirement because it did not utilize a hydraulic and portions of the device would not scale linearly from ¼-size to full-scale in terms of weight, such as the boom tubes (with smaller thicknesses) and wear pads (with slightly different material).

Extension Functionality Test

The Extension Functionality Test revealed that, in all 10 trials, the extension strand of the wire rope was able to extend the 1.75-inch boom with the smaller sections still inside, but it was not able to extend the remaining sections. Instead, these had to be pushed out by hand, and thus the device partially failed design requirement #3. It was determined that the chain and sprocket design for the full-scale model should theoretically work better for this application, but there was not enough room to implement chain and sprockets in the scale model.

Extension Length Test
The Extension Length Test revealed that the overall length of the ¼ scale model was 51.5 inches, translating to 17 feet-2 inches of total extension on the full-sized device. This value met the minimum length requirement of 16 feet (or 48 inches on the scale model), as calculated in Analysis #1, listed in Appendix A-1 in the project report.

Retraction Functionality Test
The Retraction Functionality Test revealed that, in all 10 trials, simply pulling the retraction strand of the wire rope resulted in the smaller sections of the device being fully retracted inside the largest boom. Thus, the device met design requirement #4.

Retraction Length Test
The Retraction Length Test revealed that the overall length of the retracted device was 25.5 inches. This value exceeded the maximum 21-inch length value, so the device failed design requirement #2. This failure was due to the scale model using a 24-inch steel tube for the largest boom for construction viability. On the full-sized model, measures would be taken to ensure the device remained in the 7-foot design window.

Foot Rotation Test
The Foot Rotation Test revealed that the lowest angle of rotation for either foot in either direction was 12 degrees, and all other angles were between 12 and 18 degrees. This value met design requirements #5 and #6, because the 12-degree value was greater than the minimum 8.53-degree requirement of the device operating on a 15% grade. The results of the Foot Rotation Test indicate that the device can operate on grades of up to 21% (equivalent to 12 degrees).

Structural Support Test
The Structural Support Test revealed that the device could support loads of up to 150 pounds, but the device failed at 170 pounds. In doing so, the device did not meet design requirements #5 and #6, because it could not support up to 625 pounds. The cause of the device failure was the 3D-printed wear pads, which gave out once 170 pounds was loaded. The steel tubes of the device appeared to be able to withstand much more than 170 pounds, but because the device failed at 170 pounds this was not able to be measured. On the full-sized system, the wear pads would not be 3D-printed and glued on, so they would be much stronger and better able to transfer the forces to the booms themselves.

Appendix G-1: Procedure Checklists

Weight Test
- Device
- Scale

Extension Functionality Test
- Device
- Prepare raised, level surface such that the vertical legs and feet can articulate out and down 90 degrees with no contact with any surface
- Fully retract smaller booms inside larger boom, either by hand or with the retraction strand of the wire rope

Extension Length Test
- Device
- Tape Measure
- Prepare raised, level surface such that the vertical legs and feet can articulate out and down 90 degrees with no contact with any surface
- Fully retract smaller booms inside larger boom, either by hand or with the retraction strand of the wire rope

Retraction Functionality Test
- Device
- Prepare raised, level surface such that the vertical legs and feet can articulate out and down 90 degrees with no contact with any surface
- Fully extend smaller booms, either by hand or with the extension strand of the wire rope

Retraction Length Test
- Device
- Tape Measure
- Prepare raised, level surface such that the vertical legs and feet can articulate out and down 90 degrees with no contact with any surface
- Fully retract smaller booms inside larger boom, either by hand or with the retraction strand of the wire rope

Foot Rotation Test
- Device
- Piece of paper and pen
- Protractor

Structural Support Test
- Device
- Scale
- Weighted objects and human volunteers

- Prepare an area with hard, level ground

Appendix G-2: Data Forms

Weight Test

Trial	Weight (lb)
1	
2	
3	
4	
5	

Extension Functionality Test

Trial	Pass/Fail	Comments
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Extension Length Test

Trial	Length (in)
1	
2	
3	
4	
5	

Retraction Functionality Test

Trial	Pass/Fail	Comments
1	Pass	
2	Pass	
3	Pass	
4	Pass	
5	Pass	
6	Pass	
7	Pass	
8	Pass	
9	Pass	
10	Pass	

Retraction Length Test

Trial	Length (in)
1	
2	
3	
4	
5	

Foot Rotation Test

Test #	Descriptor	Measurement
1	Leg 1, Right	
2	Leg 1, Left	
3	Leg 2, Right	
4	Leg 2, Left	

Structural Support Test

Weight (lbs)	Pass/Fail	Comments

Appendix G-3: Raw Data

Weight Test

Trial	Weight (lb)
1	10.6
2	10.6
3	10.6
4	10.6
5	10.6

Extension Functionality Test

Trial	Pass/Fail	Comments
1	Fail	1.75" boom extended, but smaller booms required manual assistance
2	Fail	1.75" boom extended, but smaller booms required manual assistance
3	Fail	1.75" boom extended, but smaller booms required manual assistance
4	Fail	1.75" boom extended, but smaller booms required manual assistance
5	Fail	1.75" boom extended, but smaller booms required manual assistance
6	Fail	1.75" boom extended, but smaller booms required manual assistance
7	Fail	1.75" boom extended, but smaller booms required manual assistance
8	Fail	1.75" boom extended, but smaller booms required manual assistance
9	Fail	1.75" boom extended, but smaller booms required manual assistance
10	Fail	1.75" boom extended, but smaller booms required manual assistance

Extension Length Test

Trial	Length (in)
1	51.5
2	51.5
3	51.5
4	51.5
5	51.5

Retraction Functionality Test

Trial	Pass/Fail	Comments
1	Pass	
2	Pass	
3	Pass	
4	Pass	
5	Pass	
6	Pass	
7	Pass	
8	Pass	
9	Pass	
10	Pass	
Confidence %		100% Pass

Retraction Length Test

Trial	Length (in)
1	25.5
2	25.5
3	25.5
4	25.5
5	25.5

Foot Rotation Test

Test #	Descriptor	Measurement
1	Leg 1, Right	12 degrees
2	Leg 1, Left	18 degrees
3	Leg 2, Right	14 degrees
4	Leg 2, Left	17 degrees

Structural Support Test

Weight (lbs)	Pass/Fail	Comments
18.8	Pass	No signs of failure
60	Pass	No signs of failure
150	Pass	Some signs of strain

170	Fail	Wear pad failure

Appendix G-4: Evaluation Sheets

Weight Test

Trial	Weight (lb)
1	10.6
2	10.6
3	10.6
4	10.6
5	10.6
Avg	10.6

Extension Functionality Test

Trial	Pass/Fail	Comments
1	Fail	1.75" boom extended, but smaller booms required manual assistance
2	Fail	1.75" boom extended, but smaller booms required manual assistance
3	Fail	1.75" boom extended, but smaller booms required manual assistance
4	Fail	1.75" boom extended, but smaller booms required manual assistance
5	Fail	1.75" boom extended, but smaller booms required manual assistance
6	Fail	1.75" boom extended, but smaller booms required manual assistance
7	Fail	1.75" boom extended, but smaller booms required manual assistance
8	Fail	1.75" boom extended, but smaller booms required manual assistance
9	Fail	1.75" boom extended, but smaller booms required manual assistance
10	Fail	1.75" boom extended, but smaller booms required manual assistance
Confidence %		100% for 1.75" boom, 0% for smaller booms

Extension Length Test

Trial	Length (in)
1	51.5
2	51.5
3	51.5
4	51.5
5	51.5
Avg	51.5

Retraction Functionality Test

Trial	Pass/Fail	Comments
1	Pass	
2	Pass	
3	Pass	
4	Pass	
5	Pass	
6	Pass	
7	Pass	
8	Pass	
9	Pass	
10	Pass	
Confidence %		100% Pass

Retraction Length Test

Trial	Length (in)
1	25.5
2	25.5
3	25.5
4	25.5
5	25.5
Avg	25.5

Foot Rotation Test

Test #	Descriptor	Measurement
1	Leg 1, Right	12 degrees
2	Leg 1, Left	18 degrees
3	Leg 2, Right	14 degrees
4	Leg 2, Left	17 degrees
Minimum Angle		12 degrees

Structural Support Test

Weight (lbs)	Pass/Fail	Comments
18.8	Pass	No signs of failure
60	Pass	No signs of failure
150	Pass	Some signs of strain
170	Fail	Wear pad failure

Appendix H - Resume/Vita

Link

Tyler Hoffman

Mechanical Engineering

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(509) 654-2418

2605 Macias Lane
Yakima, WA, 98901

EDUCATION

CENTRAL WASHINGTON UNIVERSITY

GPA: 3.7/4.0

Ellensburg, WA

B.S. Mechanical Engineering Technology Candidate

(Expected graduation June 13, 2020)

Minor in Mathematics

Relevant Coursework

- AutoCAD
- SolidWorks
- Mechanical Design
- Statics
- Dynamics
- Thermodynamics
- Fluid Dynamics
- Heat Transfer
- Finite Element Analysis
- Machining
- Upper-level Mathematics
- Instrumentation
- Technical Writing

Awards & Honors

- Washington State Opportunity Scholarship
- CWU Dean's List

Extracurricular Activities

- American Society of Mechanical Engineers Club

EXPERIENCE

TRANSPORTATION INTERN

Jacobs Engineering/WSDOT, Yakima, WA / Jun 2017–Jul 2019 (summer employment)

- Worked with the WSDOT South Central Region survey crew and construction offices
- Operated electronic distance-measuring equipment,
- Recorded survey measurements and data using notes and CAD software
- Set out and recovered stakes, marks, and monumentation

MATHEMATICS TUTOR

Central Washington University, Ellensburg, WA
Sep 2017 – Present

- Assisting students in understanding mathematics-based subjects
- Teaching students study skills, note-taking skills, and test-taking strategies.

SENIOR DESIGN PROJECT

Central Washington University, Ellensburg, WA
Sep 2019—May 2020

- Applied engineering fundamentals to design an improved outrigger support system for a wind fan trailer
- Modeled the design in SolidWorks and drafted ASME Y14.5-compliant parts and assembly drawings
- Manufactured and tested a ¼ scale model of the device
- Documented the project in an extensive engineering report

Project website: https://tylerhoffman555.wixsite.com/website

SKILLS

- Microsoft Office Suite
- GD&T experience
- Critical thinking
- Strong team collaboration
- Analytical approach to problem-solving
- Project management
- Self-motivated
- Detail-oriented
- Excellent communication skills, including technical writing

LICENSES AND CERTIFICATIONS

- Certified SolidWorks Associate
- CRLA Level II Tutor

REFERENCES

References available upon request

Appendix J – Safety

JOB HAZARD ANALYSIS
Device Construction: OPERATING A 12-INCH BAND SAW

Prepared by: Tyler Hoffman	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Safety Glasses or Face Shield, Proper Operation of Band Saw
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☒	☐	☐	☐	☐

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	1. Check condition of blade.	**Cutting fingers and hands**	**Avoid contact with blade teeth.**
	2. Align materials flat on table.	**Pinching fingers or hands**	**Keep fingers and hands away from pinch points.**
	3. Adjust guard to no more than ¼ inch above top of material.	**Pinching fingers or hands**	**Avoid pinch points between guard and housing and between guard and material.**
	4. Start blower and saw.	**Cutting fingers and hands** **Injuries from flying sawdust**	**Keep fingers and hands away from blade.** **Use push bar for smaller materials.** **Wear safety glasses or face**

			shield.

JOB HAZARD ANALYSIS
Device Construction: OPERATING A DRILL PRESS

Prepared by: Tyler Hoffman	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Gloves, Eye Protection, Operation of the Drill Press, First Aid
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☐	☒	☐	☒
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	1. Clean the table.	**Eye injury from metal debris**	**Wear eye protection. Do not use compressed air.**
	2. Load the vise.	**Foot injury if the vise falls**	**Secure the vise on the table with T-pins.**
		Finger pinching while sliding the vise	**Don't let your fingers get under the vise unless you are lifting it from the table. Keep your eyes on the task.**
	3. Lock the table in place.	**Back strain**	**Don't lean over the table to twist the lock handle.**

	4. Load the bit.	Hand injury from the bit	Wear gloves. Don't hold on the end of the bit.
	5. Start the drill.	None foreseen	
	6. Feed the drill feed	Injury caused by breaking the bit	Feed with the appropriate pressure. Use the appropriate bit for the type of metal. Wear eye protection.
		Eye or skin damage from cutting oil	Use the lowest RPM. Wear eye protection. Wear a long-sleeved shirt.
		Hand injury from the exposed pulley near the feed handle	Make sure a pulley guard is in place. Don't push the feed handle toward the pulley.
	7. Unload the vise.	Foot injury if the vise falls	Leave the vise secure on the table with T-pins until it is unloaded.
		Finger pinching while sliding the vise	Don't let your fingers get under the vise unless you're lifting it from the table. Keep your eyes on the task
	8. Clean the table.	Eye injury from metal debris	Wear eye protection. Do not use compressed air.

JOB HAZARD ANALYSIS
Device Construction: USING HAND-OPERATED POWER TOOLS

Prepared by: Tyler Hoffman	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Gloves, Eye Protection, and Mask When Necessary Operation of the Tool
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☐	☒	☐	☒
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	1. Check condition of the blade, if applicable.	**Lacerations.**	**Avoid contact with blade teeth.** **Be sure the tool is unplugged.**
	2. Check that the guard is in working condition and in the proper position, if applicable.	**Lacerations.**	**Avoid contact with blade teeth.** **Be sure the tool is unplugged.**
	3. Plug in power tool.	**Injuries from starting tool when in the "on" position.**	**Ensure tool is in the "off" position before plugging in.**
		Potential electrocution from cord in poor condition.	**Inspect condition of cord before plugging in.** **If cord is in poor condition,**

			do not use the tool until the cord has been repaired.
	4. Operating power tool.	Lacerations and other injuries.	Always wear safety goggles. Evaluate surroundings before turning on power tool and be aware of others. Make sure that cutting will not come into contact with any utilities. Don't wear loose clothing. Make sure the blade or bit is not binding as it goes into the work. If blade or bit is binding, cease operation of the tool and evaluate reasons for binding. Ensure that material being operated on is secured.
	5. Unplugging power tool.	Lacerations.	Ensure tool is in the "off" position before unplugging.
	6. Changing blade/bit/other tool parts.	Lacerations.	Ensure tool is unplugged before changing any part of the tool.

JOB HAZARD ANALYSIS
Device Construction: OPERATING A MILLING MACHINE

Prepared by:	Reviewed by:
Tyler Hoffman	Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Safety Glasses, Ear Plugs Milling Machine Operations
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☒	☐	☐	☒	☐

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Milling text blocks	**Injury to hands from milling blades**	**Never disconnect safety shields from milling blades.**
		Hearing damage from noise of machine operation	**Wear hearing protection, such as ear plugs, if operating machine for periods extending more than 10 minutes.**
		Possible eye injury from wire stitches thrown out by milling blade	**Wear safety glasses during operation.**
		Crushing finger hazard from book clamp	**Do not hold book at spine when activating book clamp. Hold book at the face.**

JOB HAZARD ANALYSIS
Device Construction: USING HAND TOOLS

Prepared by: Tyler Hoffman	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	None foreseen
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☐	☐	☐	☐	☐
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	1. Check condition of blade, if applicable.	**Lacerations**	**Avoid contact with blade or teeth of a tool.**
	2. Using hand tool.	**Lacerations, pinching or impact and other injuries**	**Assess surrounding environment and be aware of others.** **Check to see that replaceable parts such as blades are secured.** **Be aware of what may happen if the tool slips or is misdirected.** **Use caution when using tool.**
	3. Transporting hand tool.	**Injuries to self and others**	**Ensure that the blade is not exposed when transporting.** **Do not throw the tool.** **Assess surrounding environment and be aware**

			of others.

JOB HAZARD ANALYSIS
Device Construction: USING AN ARC WELDER

Prepared by: Tyler Hoffman	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Welding hood, Welding jacket and apron, Gloves, Safety glasses, work shoes Operation of arc welder, Operation of a fire extinguisher, Location and use of the fire alarm
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☒	☒	☐	☒
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	**TASK DESCRIPTION**	**HAZARDS**	**CONTROLS**
	1. Close off welding area.	**Flashing**	**Close welding curtain to shield outsiders from flashing.**
	2. Prepare for arc welding.	**Inhalation of fumes**	**Turn on exhaust fan and timer.**
		Flashing	**Wear welding hood.**
		Sparks	**Wear welding jacket, apron, gloves, work shoes.**
		Slag splatter	**Wear welding jacket, apron, gloves, work shoes.**
	3. Turn on power and	**Tripping**	**Take care to keep wire**

	unwrap wire.		untangled and free from under feet.
	4. Insert arc welding rod in handle.	**Pinch to fingers**	**Keep fingers away from pinch points.**
	5. Strike arc.	**Flashing, sparks, slag splatter**	**Wear welding hood, welding jacket, apron, gloves, work shoes.**
	6. Allow material to cool on workbench.	**Burn to hands or fingers**	**Wear glove. Chalk mark welded area "Hot"**
	7. Remove remainder of arc welding rod (if any) from handle, set aside on workbench to cool.	**Burn to hands or fingers**	**Chalk mark welded area "Hot"**
	8. Wrap wire.	**Tripping**	**Take care to keep wire untangled and free from under feet.**
	9. Use chipping hammer to remove excess slag.	**Eye damage by flying debris from hammer strikes**	**Wear safety glasses.**
		Injuring fingers with hammer	**Use caution to avoid striking fingers or hands with hammer.**

JOB HAZARD ANALYSIS
Moving/Lifting Heavy Objects

Prepared by: Tyler Hoffman	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Back Brace, Steel-toed Shoes (if necessary),
Reference Materials as appropriate:	UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☐	☐	☒	☐	☒
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	1. Lifting heavy object.	**Back injury**	**Bend knees to lessen pressure on the lower back.** **Use legs as the source of power to lift object.** **Solicit the help of others or employ tools if object is too heavy to be lifted by one person.**
		Foot injury from dropping heavy object	**Get a secure hold on object.** **Wear gloves to aid in a secure grip.** **Wear steel-toed shoes, or similar.**
	2. Transporting heavy object.	**Back injury**	**See above for more information.**

		Slipping on wet or slick floor	**Evaluate condition of floor along path from origin to destination.** **Do not move heavy loads until floor is dry.**
	3. Setting heavy object down.	**Foot injury from dropping heavy object**	**Do not drop object.** **See above for more information.**
		Back injury	**See above for more information.**

JOB HAZARD ANALYSIS
Device Construction: 3D PRINTING

Prepared by:	Reviewed by:
Tyler Hoffman	Approved by:

Location of Task:	Hogue Technology Building, CWU, Ellensburg, WA
Required Equipment / Training for Task:	Heavy Duty Neoprene Gloves (gauntlet style), Safety Glasses, Full Face Splash Shield, Liquid resistant lab coat Read and understand SDS on Stratasys P400SC Sodium Hydroxide Read and understand how to operate the Fendall Porta Stream II Emergency Eyewash Station Read and understand operation manual for proper and safe use of dissolve tank.
Reference Materials as appropriate:	Stratasys P400SC Sodium Hydroxide SDS, Fendall Porta Stream II Emergency Eyewash Station, dissolve tank operation manual UC Berkeley JHA; https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☒	☐	☐	☒

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	1. Assess work area; is it clear of obstructions and slip/trip hazards?	**Slip, Trip or Fall**	**Remove any obstructions or trip hazards. Maintain a dry floor.**
	2. Assess path to emergency eye wash station; is the path clear and free of obstructions?	**Not immediately able to access emergency eyewash station if needed**	**Remove any obstructions and maintain clear pathway**
	3. Select and don personal protective equipment	**Exposure of corrosive solution to eyes or skin.**	**Use of PPE is required and mandatory**
	4. Select items/parts needing dissolve support removed and place in appropriate soak basket	**Loss of parts within solution tank**	**Use appropriate basket**

	5. Slowly raise lid of solution tank and allow condensate to drain back into the solution tank	**Possible corrosive solution spilled outside of solution tank.**	**Place lid in secondary containment container**
	6. Slowly lower soak basket into solution tank making sure not to splash solution	**Exposure of corrosive solution to eyes or skin.**	**Work in a slow and deliberate manner**
	7. Make sure basket is submerged and sitting level on the bottom of tank	**Possible corrosive solution from being splashed on operator**	**Work in a slow and deliberate manner**
	8. Replace solution tank lid	**Possible accidental exposure of corrosive solution**	**No not operate without lid in place**
	9. Set timer on solution tank control	**Solution tank not dissolving support material properly**	**Verify timer is set and operating**
	10. Do not allow observers within splash area during time while parts are put into or being removed from dissolve tank	**Possible exposure of corrosive solution to eyes or skin.**	**Maintain a three foot perimeter anytime the tank lid is removed**
	11. Maintain tank water levels within the manufacturers specifications	**Possible exposure of corrosive solution to eyes or skin.**	**Don personal protective equipment, remove solution tank lid, and replace/remove water as necessary.**
	12. Draining solution from tanks as necessary	**Possible corrosive solution spilled outside of solution tank or exposure of corrosive solution to eyes or skin.**	**Don personal protective equipment, remove drain plug from tank, attach hose to drain, and drain liquid into designated 5 gallon containers. Constantly monitor disposal container, DO NOT overfill (more than 4 gallons)**
	13. Mixing and adding new solution to tanks	**Possible corrosive solution spilled outside of solution tank or exposure of corrosive solution to eyes or skin.**	**Don personal protective equipment** **Never add concentrate (P400-SC) to water, NEVER add water to concentrate!**