Tree Stand Redesign

A Major Qualifying Project completed in partial fulfillment of the Bachelor of Science degree at

WORCESTER POLYTECHNIC INSTITUTE

By

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Submitted to

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Acknowledgements

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Abstract

Nature photography is an ever-evolving field with a demand for innovative and creative shooting angles and locations. The team has identified a need for a device to help nature photographers climb trees and stay there for long periods of time to capture pictures of the fauna and flora around tree canopies. Several design concepts were considered before the team decided on a hang-on tree stand redesign. The new design emphasizes safety, portability and having a large angle of rotation, allowing photographers to access more vantage points than classic tree stands. Changing the design of the seat and integrating a swivel plate mechanism to the stand achieved the larger angle of rotation. A prototype was designed and built, weighing less than 25 lb. and supporting up to 350 lb.

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CHAPTER 1 – Introduction

The team is designing a tree stand for use primarily by nature photographers and enthusiasts. It would expand upon the utility of tree stands available on the market at this time. The tree stand would seek to provide a wider range of view, and be more portable while still meeting the manufacturing association’s safety standards.

This report presents some initial designs that were considered as well as a final design concept. It also includes all the necessary analyses and schematics showing all the parts of the tree stand as well as further recommendations for introduction to the market.

CHAPTER 2 – Background Information

- ## Identifying the need

There is a significant market of nature enthusiasts and explorers. The MQP team has identified a need for an assistive and safe means to climb trees for observing nature and photographing animals and birds whose habitat is in trees. The problem with current models of tree stands is lack of adaptability to the needs of nature photographers. The biggest concern was that tree stands allow the user to look only one way, away from the tree. Most photographers would need to also sit facing the tree and the canopy above them. The majority of tree stand models currently on the market only allow the use to stand with their back to the tree. One of the few types of tree stands that does not have that restriction, is the ladder tree stand, which is prohibitively large, heavy and takes a long time to set up. This is inherently a poor choice for photographers who need the ability to move and set up in different places.

The need for using a tree stand in taking pictures in nature is a result of several reasons. First, being on a higher elevation than the ground, allows for the scent of the photographer to go unnoticed by most wild animals. It also allows for a much better angle for photographing the fauna and flora in tree canopies. Photographing bird nests or woodpeckers and other animals that live in trees in their natural habitat is a very difficult task without the help of this sort of equipment. Finally, tree stands would allow photographers to take great aerial pictures.

- ## Why nature photography is important? Why is this device important?

Photography is a form of art as well a tool for historic documentation and a fundamental method for conveying information. Having a better tool to photograph nature could advance our understanding of certain species and further our appreciation of them. Many similar tools have been utilized by nature photographers and biologists exploring new species, and each tool has unlocked a lot of mysteries for us. If successfully and widely used, this tree stand has the capability of furthering the physical range that we could explore more closely.

2.1 Targeted Habitat

The team has researched and identified several habitats where the tree stand designed would be most appropriately used. Areas that had an abundance of tall trees with few low hanging branches as well as a vibrant wildlife and interesting birds were prioritized. Below are some of the trees that were identified and their locations:

- Ash Trees

Figure 1: White Ash Tree

White Ash Tree

Ash trees are very common in New England. Specifically white ash trees, scientifically known as *Fraxinus americana*. They are some of the most commonly grown and useful trees and are therefore lucrative to design the tree stand for. Currently, they mostly grow in forests, away from urban habitats.

-Pine Trees

Figure 2: Pine Tree

Pine trees, and specifically White pine trees are the tallest trees in New England, reaching 45 meters (148 ft.) in some locations. They would provide for great aerial views and at higher altitudes. The White Pine tree, scientifically known as *Pinus Strobus*, grow a diameter of 20-40 inches by the time they mature. Although White pine trees do grow low hanging branches, which would potentially hinder the setup of the tree stand, the older the tree is, the less low-hanging branches it has and the thinner its lower twigs are.

- American Beech Trees

Figure 3: American Beech Tree

https://seasonsflow.wordpress.com/2013/11/30/ohio-trees-american-beech/

Fagus Grandfolia, or American Beech is also a tall tree, native to the Northeast of the United States. It is a deciduous tree that mostly grows in forests, but is occasionally used in golf courses and urban settings for the beautiful wide canopy it provides. It spreads to about 40” at maturity, making it a reliable tree to hang from. The beech tree grows beechnuts, which are a primary food for chipmunks and squirrels. In hilly locations, it is also home to mountain pigeons.

http://www.nativetreesociety.org/fieldtrips/mass/big_trees_ma_1999.htm

http://www.theplantlist.org/tpl1.1/record/kew-369468

https://www.arborday.org/trees/treeguide/treedetail.cfm?itemID=903

2.2 Current Tree Stands on Sale

At the time of the report there multiple types of tree stands that are available on the market. The main three types of tree stands are climbing tree stands, hang-on tree stands, and ladder tree stands. To determine what is available on the market the team looked on Cabela's which is a company that sells hunting equipment. From the Cabela's website the team found all the data in Appendix 1: Data of Tree Stands on the Consumer Market. The team noted that not a single tree stand had the ability for the seat to rotate.

2.3 Goal Statement

To redesign a Tree Stand that has been optimized for nature photography.

2.4 Functional Requirements

1. Supported Weight of 300-350 lbs.
2. High stress components should have a safety factor of at least 4.
3. Weight of tree stand: Under 25 lbs.
4. Platform Area Size: Under 30" x 25"
5. Seating Area Size: Under 20" x 16"
6. Set Up Time (Time to attach the stand to the selected tree): Under 12 minutes
7. Cost of tree stand: Under $400
8. Material for the stand (Durable, light, corrosion resistant, can withstand extreme temperature)
9. Must meet ASTM standards (created by TMA) for stress load tests, etc.

    F2120-06 Standard Practice for Testing Tree Stand Load Capacity

    F2121-13 Standard Practice for Tree Stand Labels

    F2122-13 Standard Practice for Tree Stand Safety Devices

F2123-13 Standard Practice for Tree Stand Instructions

F2124-13 Standard Practice for Testing Tree Stand Ladder, Tripod Stands and Climbing Stick Load Capacity

F2125-09 Standard Test Method for Tree Stand Static Stability and Adherence

F2126-06 Standard Tree Stand Static Load Capacity

F2128-13 Standard Test Method for Tree Stand Repetitive Loading Capability

F2275-10 Standard Practice for Tree Stand Manufacturer Quality Assurance Program

F2337-11 Standard Test Method for Tree Stand Fall Arrest System

F2531-13 Standard Test Method for Load Capacity of Tree Stand Seats

10. Minimum tree diameter: 6”
11. Maximum tree diameter: 20”
12. Tree Stand should not left installed for more than two weeks.
13. Tree stand should be designed for use with Summit Tree Stands Seat-O-The-Pants STS Deluxe Harness.
14. The tree stand while fully loaded should have a maximum deflection 10° for the seating area.
15. The tree stand will be designed to give a 210° horizontal view and 110° vertical view.
16. Tree stand can be assembled with a multi-tool (Leatherman).
17. The seat platform must be able to carry up to 80% of the supported weight.
18. The tree stand will not be damaged from a drop of 5 ft.
19. The tree stand should last 10 years assuming that it is being used 30 times per year.

CHAPTER 3 – Design Process

The team started the design process with brainstorming ideas for tree stand styles and then constructing a first design matrix to pick the best one. Afterwards, the team produced a SolidWorks model of the device and made several iterations to it based on the results from the Free Body Diagrams and the static analyses.

The design matrix was based on the three categories: weight, set-up time and ease of assembly. The outcome of the design matrix favored a hang-on tree stand. The next step for the team was to construct a SolidWorks model to solidify the design idea that was discussed. Looking at the feasibility of this project, the team saw that the next step was to make a Free Body Diagram of the whole device, followed by Free Body Diagrams of the individual sections. The final step of the design process involved a full static analysis and singularity functions for the analyzed sections of the tree stand.

3.1 Design Matrix

The purpose of the team's design matrix was to guide the team on what style of tree stand should be the chosen tree stand style. In the design matrix the team ranked styles for meeting the criteria of weight, set-up time, and ease of assembly. To determine whether the style would receive a check mark or an X for the different criteria the team researched tree stand that are available on the consumer market. After compiling three tree stands for each of the styles the team placed the found in Appendix 1: Data of Tree Stands on the consumer market into *Table 1: Design Matrix* as found below. The data found from these tree stands found that the Ladder style of tree stands did not met any of the team's criteria while both the Hang-On and Climbing tree stands met all the criteria.

Table 1: Design Matrix

Style	Weight (Under 25 lbs.)	Set-Up time	Ease of Assembly
Hang-On	✓	✓	✓
Climbing	✓	✓	✓
Ladder	✗	✗	✗

3.2 Preliminary Design Concepts

Several preliminary designs were considered for the tree stand. The design process started with the assumption that there will be two platforms: one for the user's feet and the other would have the seat. This is shown in the Free Body Diagram in section 4. The first design challenge was to decide the shape of the foot platform. Below is one of the first designs that were made. The honeycomb pattern was chosen because it would distribute weight evenly on the platform.

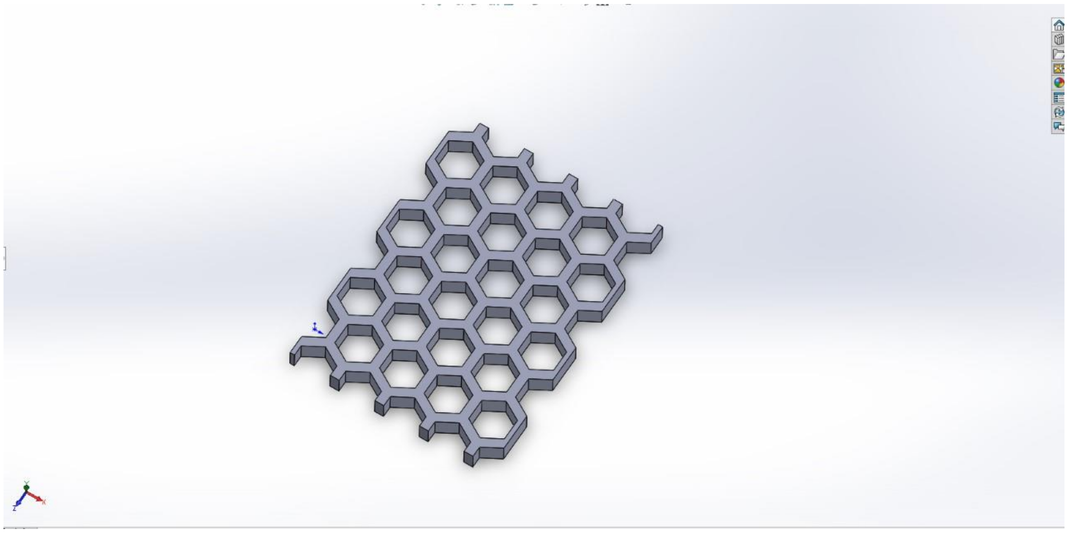


Figure 4: Preliminary Honeycomb Pattern

However, due to limitations on casting aluminum to this shape, given the available resources, the team moved away to this design and towards a design that would involve a frame made of aluminum tubing, welded onto a jaw part that would clamp the stand to a tree. Below are some of the earlier versions of that design.

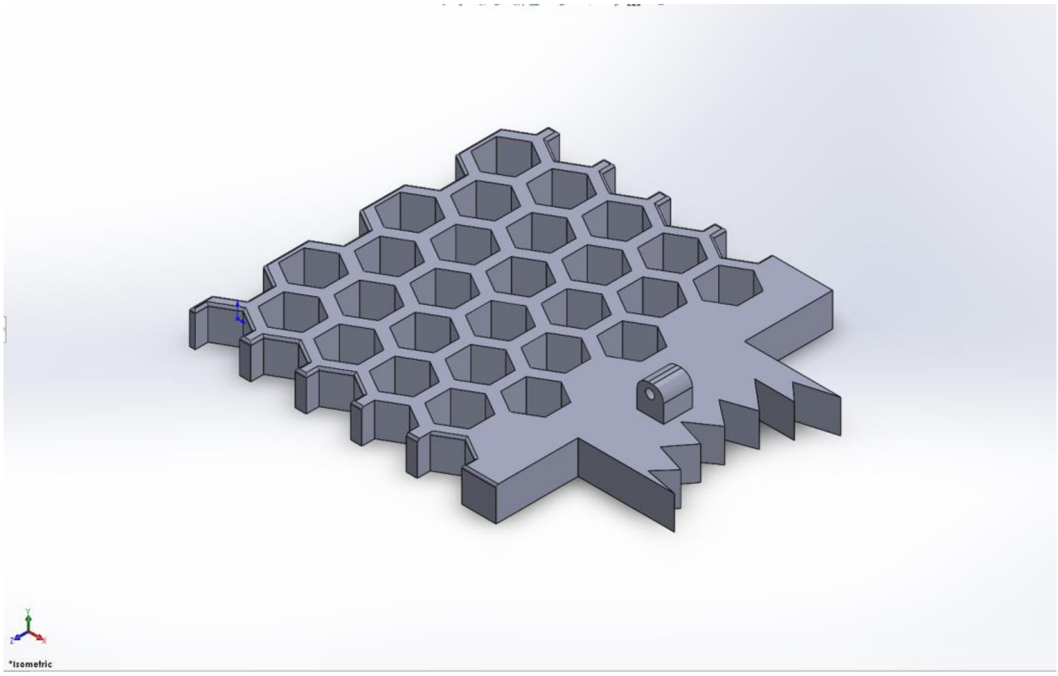


Figure 5: Preliminary SolidWorks Model of Base

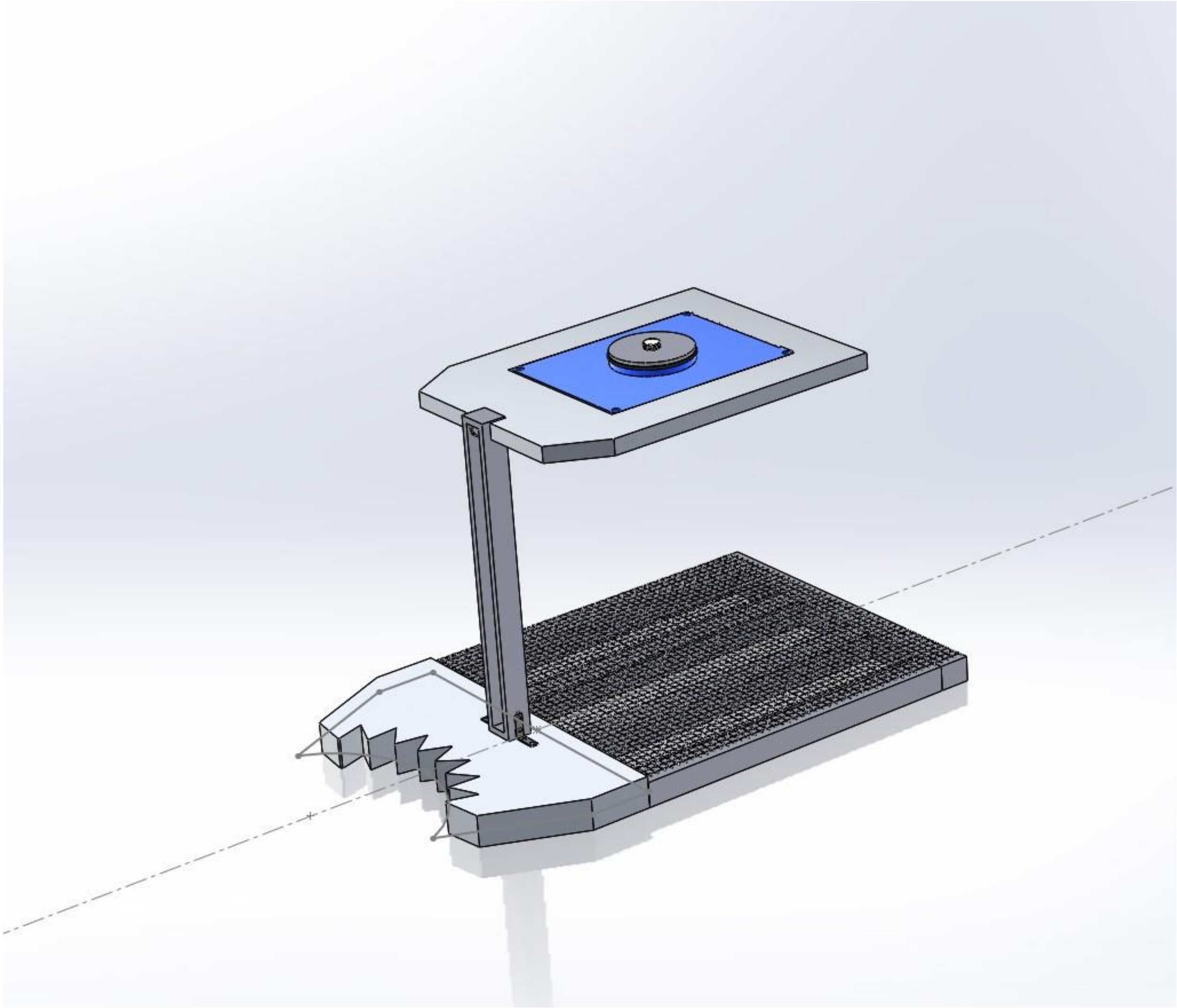


Figure 6: Preliminary SolidWorks Model

After several design iterations, consulting the Washburn machine shop workers and running a deflection analysis of different shapes and sizes of aluminum tubing, the design below was refined. It weighed much less than the previous iteration and it included some of the exact parts that the team has decided to purchase.

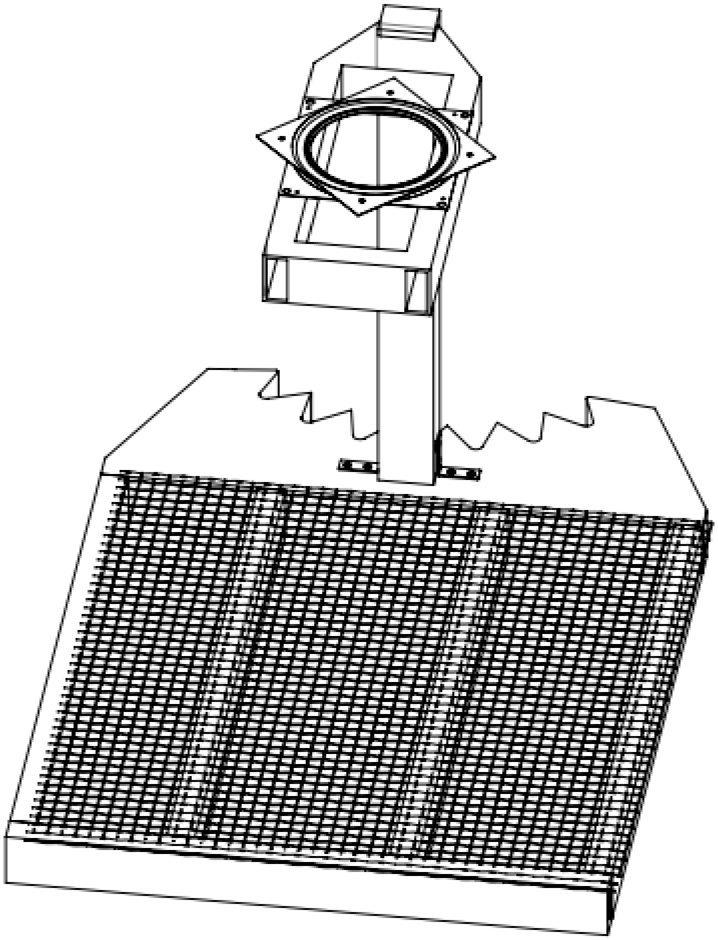


Figure 7: Wireframe of SolidWorks Model

When doing more analysis of the weight of the tree stand, the team decided that the heaviest part in the stand was the jaw. In order to decrease weight, pockets and slots were to be machined into it. To decide which parts had the least internal stress, the team ran a simple SolidWorks simulation with remote loads at the ends of each of the four base tubes. The results of that analysis are shown below.

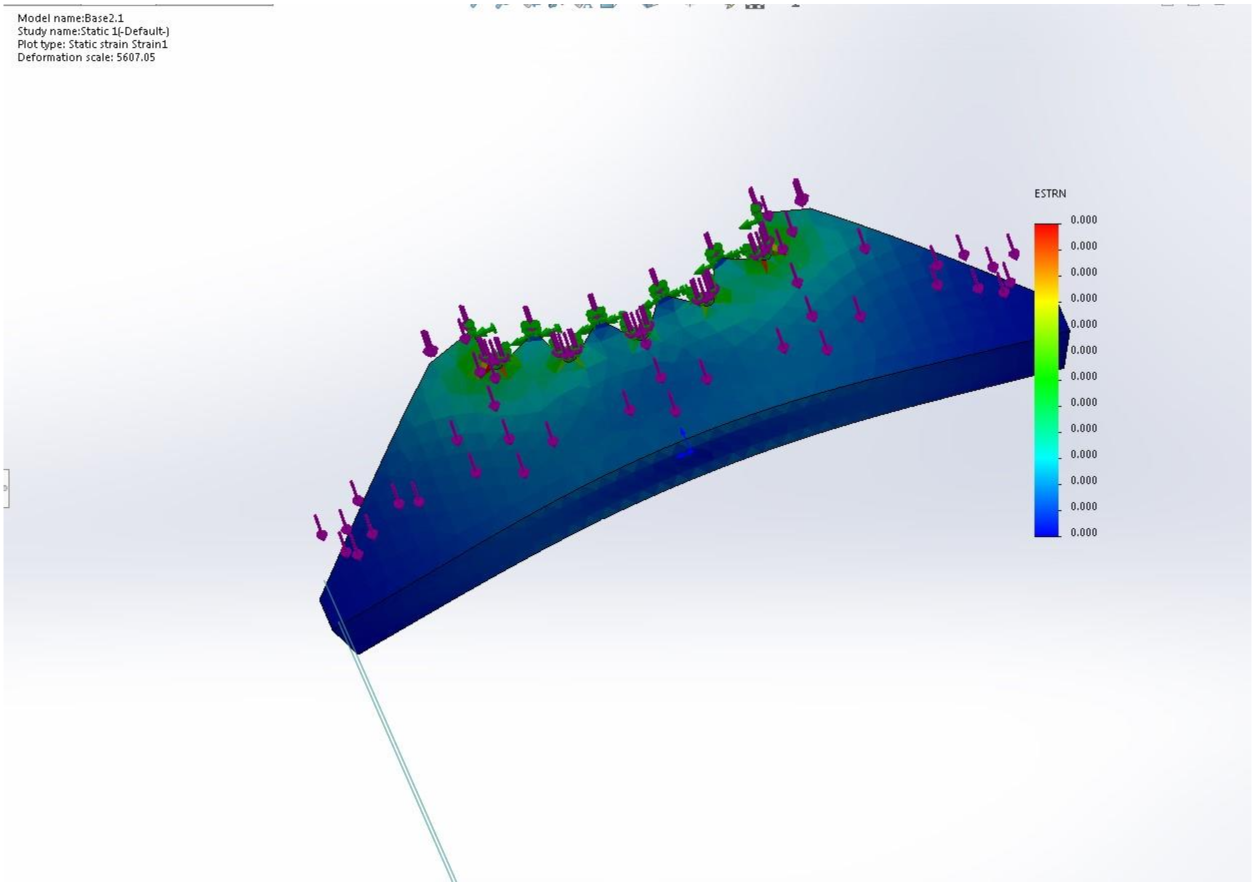


Figure 8: SolidWorks Analysis for Weight Reduction

The team then added two large slots on either side of the vertical beam, a slot in the center and a large pocket on the bottom. Another stress analysis was run on SolidWorks to test whether the part would fail, given its current geometry. The results are shown below.

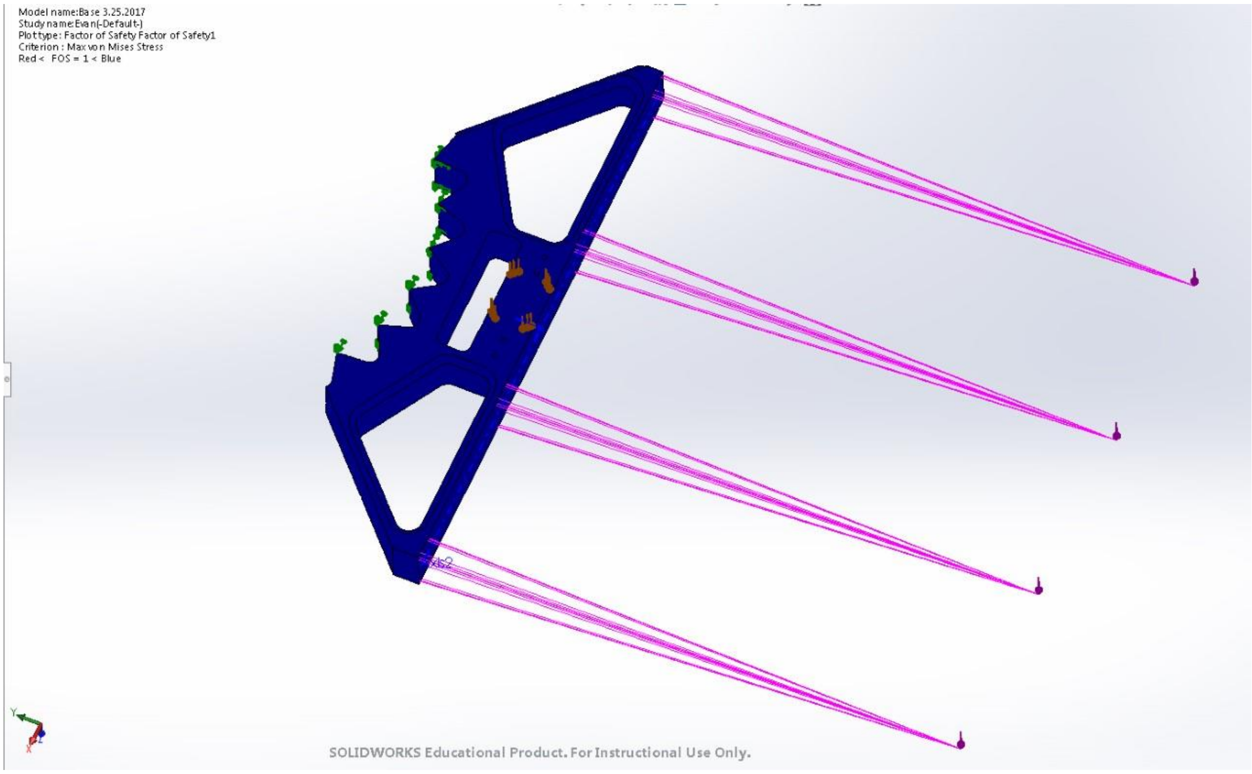
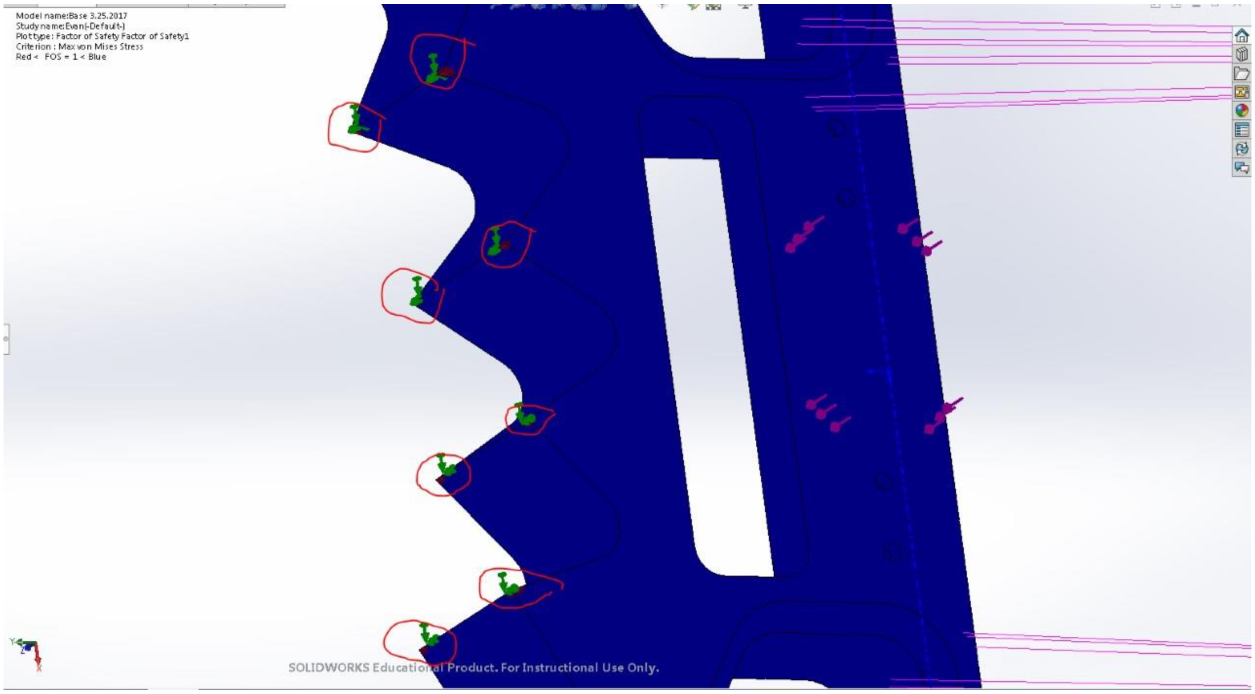

Model name:Base 3.25.2017
Study name:Evan(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Max von Mises Stress
Red < FOS = 1 < Blue

Figure 9: SolidWorks Static Analysis Isometric View

This stress analysis was run by adding remote loads at the points shown above, as well as adding a load from the vertical beam. The top and bottom points of each tooth were all constrained in XYZ and moment. The result of this simulation showed some deformation in the top and bottom ends of the teeth.



Model name:Base 3.25.2017
Study name:Evan(-Default-)
Plot type : Factor of Safety Factor of Safety1
Criterion : Max von Mises Stress
Red < FOS = 1 < Blue

Figure 10: SolidWorks Static Analysis close view

Due to the limited time available, the team was not able to set up a more accurate, detailed finite element analysis. Based on the recommendation by several faculty members, and the deformation area being contained to a very small locations, the team proceeded with machining and building the jaw.

3.3 Final SolidWorks Model

Looking at our functional requirements and the hang-on technology for tree stands, the team decided to make a design that allows for two contact points with the tree. On contact point is at the shaft and the other is at the pointed jaw. Several iterations of this design were made and the final design was taken to the Washburn machine shops for consultation with the machine shop monitors and Teaching Assistants.

The model is composed of ⅛ inch thick aluminum tubing that makes both platform frame as well as the seat base of the swivel mechanism. Below in *Figure 4: Isometric View of SolidWorks Model* and *Figure 5: Wireframe Isometric View of SolidWorks Model* the assembled model can be found. More detailed drawings as well as the drawings for each part are to be found in Appendix 13. The team has produced the following SolidWorks model as a reference for the tree stand design.

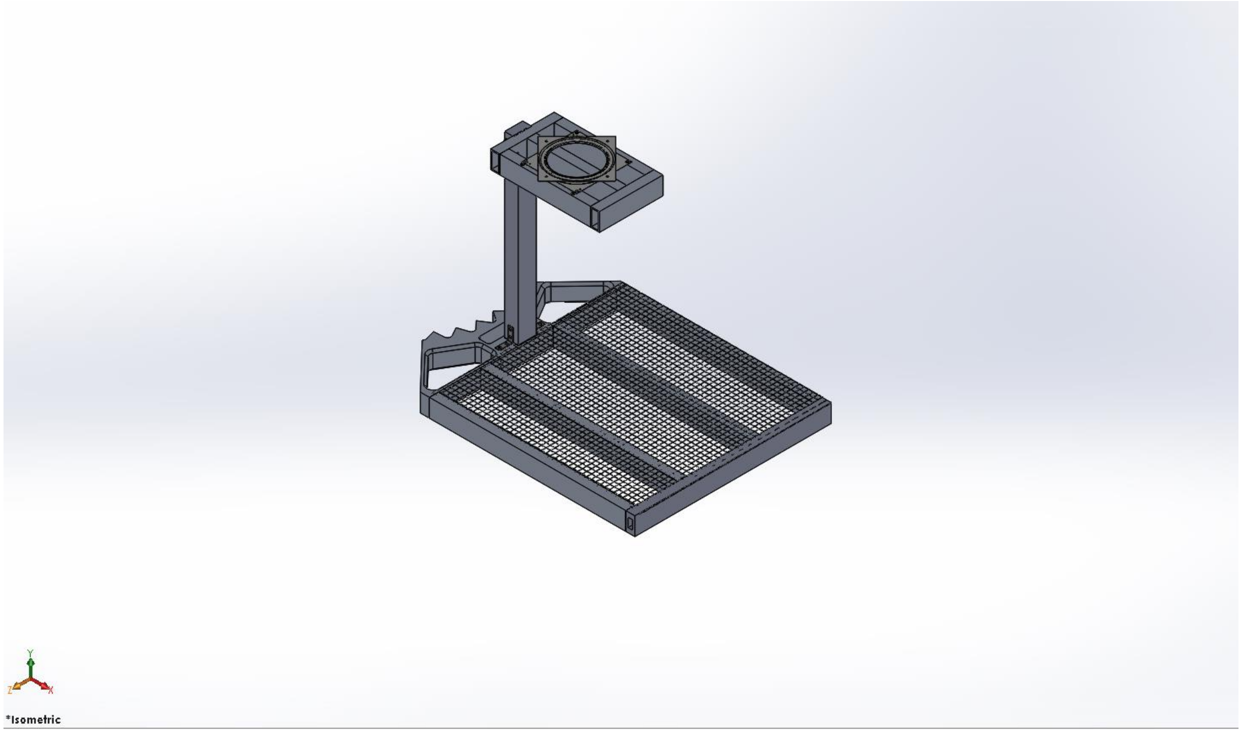


Figure 11: Isometric View of SolidWorks Model

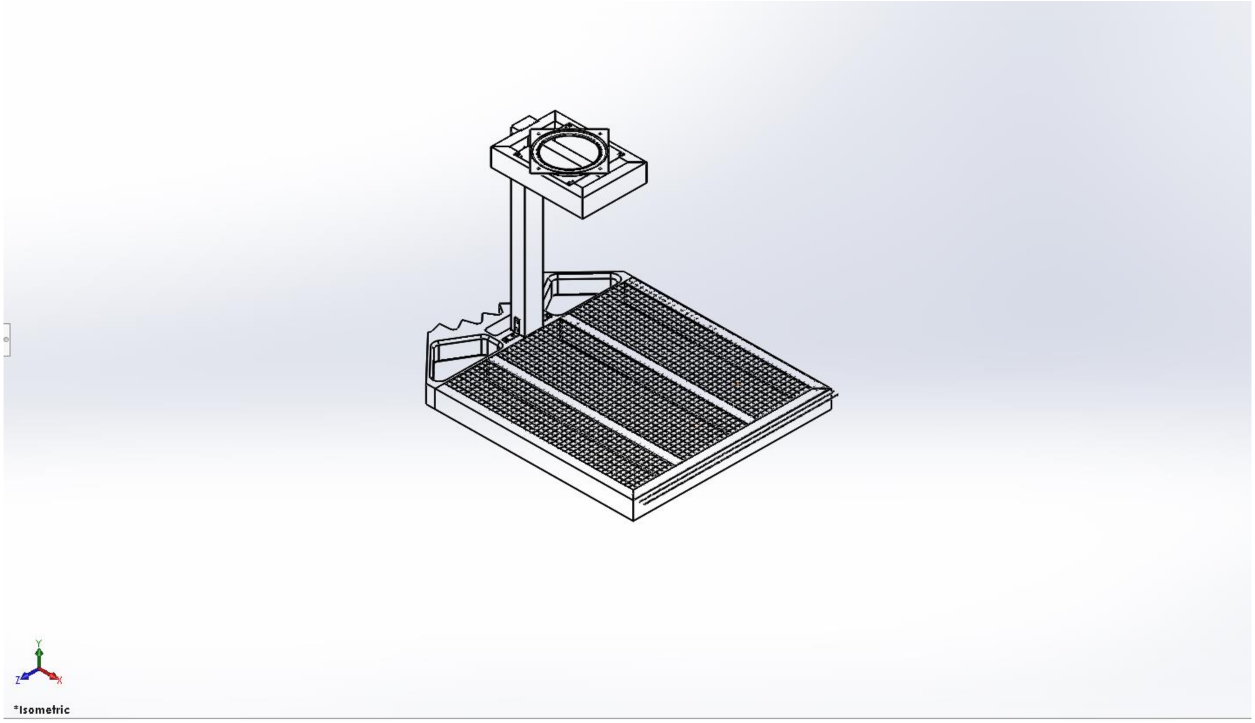


Figure 12: Wireframe Isometric View of SolidWorks Model

3.4 FBD of the Tree Stand

Below is the full Free Body Diagram of the tree stand.

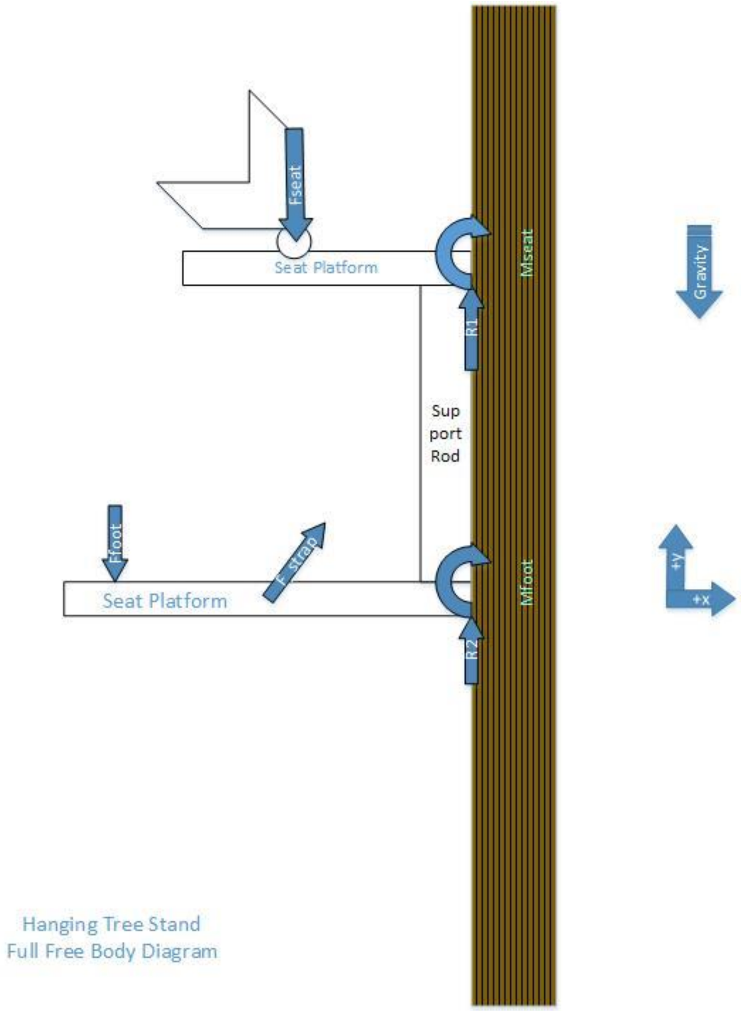


Figure 13: Free Body Diagram of the Tree Stand

3.5 FBD of the Seating Platform

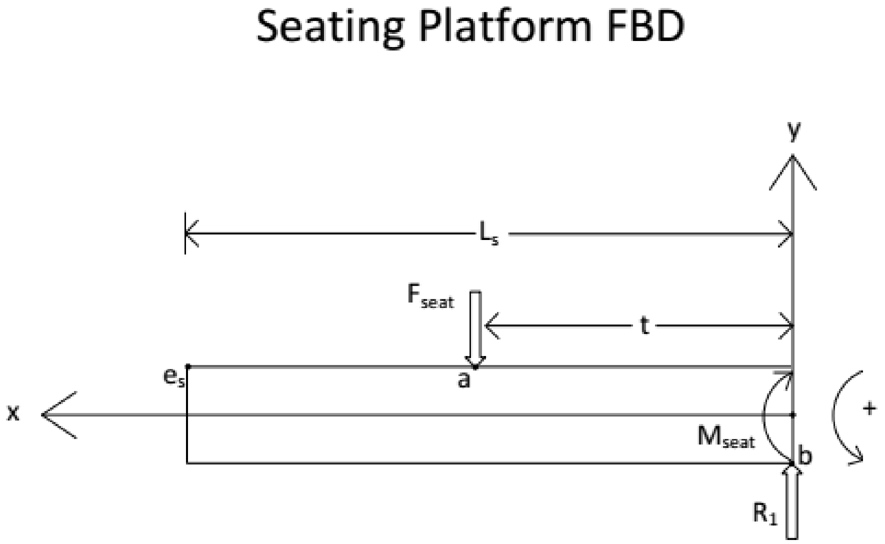


Figure 14: FBD of Seat Platform

In *Figure 6: FBD of Seat Platform* the team utilized multiple variables to show points, lengths, forces, and moments. The first point is “a” which shows the location where the applied force “F_{seat}” is located on the beam. Force “F_{seat}” is the force from the user sitting down on the seat therefore it is a percentage of their weight. Point “b” is the location of the reactionary force, “R_1”, on the beam. Point “e_s” is the location where the maximum deflection will occur. The variable “t” is the distance between the fixed end of the beam and y-axis, and point “a” where force “F_{seat}” is applied. The variable “L_s” is the total length of the team. The moment on the beam is defined as the variable “M_{seat}” as a result of force “F_{seat}”.

3.6 FBD of the Foot Platform

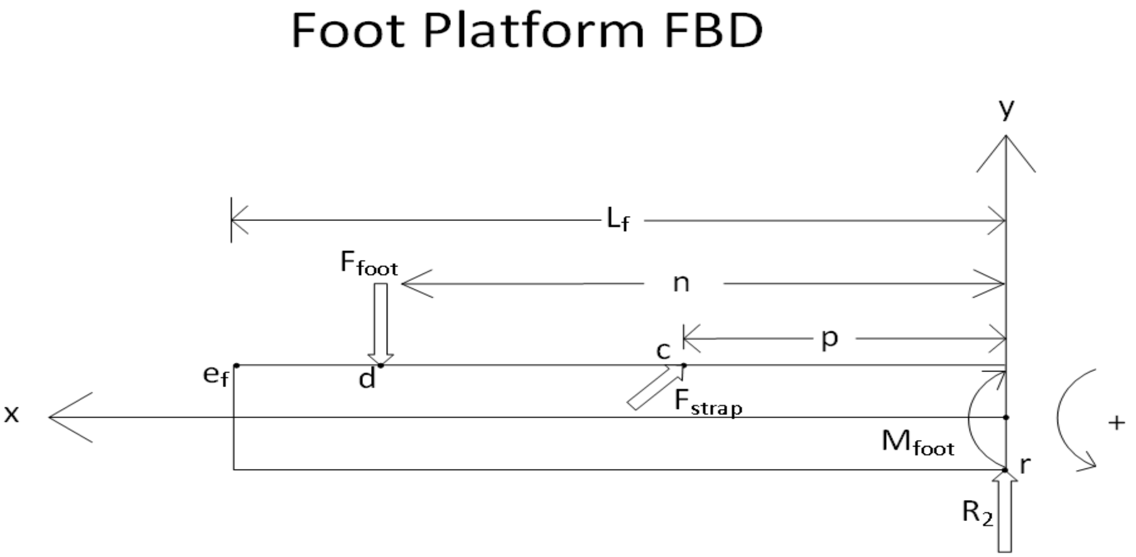


Figure 15: FBD of Foot Platform

In *Figure 7: FBD of Foot Platform* the team utilized multiple variables to show points, lengths, forces, and moments. The first point is "c" which shows the location where the applied force "F_{strap}" is located on the beam. Force "F_{strap}" is the force from the straps which are providing a force in the positive y direction and the negative x direction. Point "d" is the location of the force "F_{foot}" on the beam. The force "F_{foot}" is the applied force from the user's weight which is located at their feet. Point "e_f" is the location where the maximum deflection will occur. The variable "n" is the distance between the fixed end of the beam and y-axis, and point "d" where force "F_{foot}" is applied. The variable "n" is the distance between the fixed end of the beam and y-axis, and point "d" where force "F_{foot}" is applied. Variable "p" is the distance between the fixed end of the beam and y-axis, and point "c" where force "F_{strap}" is applied. The variable "L_f" is the total length of the beam. The moment on the beam is defined as the variable "M_{foot}" as the result of forces "F_{foot}" and "F_{strap}".

3.7 Static Analysis of the Individual Sections of the Tree Stand

The team upon making the free body diagrams determined that a static analysis was needed. It is required to determine that the forces on the beams equal zero and what the moment is equal to. For the seat platform the two forces were found to be equal and the moment of the seat was “M_{seat}” equals “$R_S*L_S-F_{S*}(L_S-t)$”. The foot platform also required a static analysis where it was found that “R_f” was equal to “F_{strap}” and those forces equal “F_{foot}”. It was found that the moment on the foot platform was $[R_f*L_f – F_{foot}*(L_f – p) + 2*F_{strap.y}*(L_f – n)]$.

3.8 Singularity Functions

The team utilized singularity functions to represent the loads applied on the beam. The function are easier to integrate and allowed for the team to use a MathCad program to solve them. In setting up the equations the team decided that the beams should be modeled as a cantilever beam with one end fixed. The equations where found from the Norton Machine Design textbook. Once the equations where found the team created the MathCad files in Appendix 7: MathCad of Deflection and Stress – Seat Platform and Appendix 8: MathCad of Deflection and Stress – Foot Platform for each of the platforms which were used to determine the maximum deflection. In the singularity functions below q is the loading function. Each of the following functions below is an integral of the previous equation. The singularity function V is the shear function which is found by taking the integral of q. After the shear function is M the moment function and from the integral of the moment function the slope function can be found. Finally after the integrating the slope function the deflection function has been found. The deflection function is the function that the team was solving for using the singularity functions.

3.8.1 Singularity Function for Seat Area

$q = -M_{seat} < x-0 >^{-2} + R < x-0 >^{-1} - F_{seat} < x-t >^{-1}$

$V = \int q\, dx = -M_{seat} < x-0 >^{-1} + R < x-0 >^{0} - F_{seat} < x-t >^{0} + C_1$

$M = \int V\, dx = -M_{seat} < x-0 >^{0} + R < x-0 >^{1} - F_{seat} < x-t >^{1} + C_1 x + C_2$

$\theta = \int \frac{M}{EI}\, dx = \frac{1}{EI}\left(-M_{seat} < x-0 >^{1} + \frac{R}{2} < x-0 >^{2} - \frac{F_{seat}}{2} < x-t >^{2} + \frac{C_1}{2} x^2 + C_2 x + C_3\right)$

$y = \int \theta\, dx = \frac{1}{EI}\left(\frac{-M_{seat}}{2} < x-0 >^{2} + \frac{R}{6} < x-0 >^{3} - \frac{F_{seat}}{6} < x-t >^{3} + \frac{C_1}{6} x^3 + \frac{C_2}{2} x^2 + C_3 x + C_4\right)$

$V(L_s) = 0 = R < s-0 >^{0} - F_{seat} < s-t >^{0} = R - F_{seat} \therefore R = F_{seat}$

$M(L_s) = 0 = -M_{seat} < L_s - 0 >^{0} + R < L_s - 0 >^{1} - F_{seat} < L_s - t >^{1} = -M_{seat} + R(L_s) -$

$F_{seat}(L_s - t) \therefore\ M_{seat} = R * L_s - F_{seat}(L_s - a)$

$\theta(0) = 0 = \frac{1}{EI}\left(-M_{seat} < 0-0 >^{1} + \frac{R}{2} < 0-0 >^{2} - \frac{F_{seat}}{2} < 0-t >^{2} + \frac{C_1}{2} * 0^2 + C_2 * 0 + C_3\right)$

$C_3 = M_{seat} < 0-0 >^{1} - \frac{R}{2} < 0-0 >^{2} + \frac{F_{seat}}{2} < 0-t >^{2} = 0$

$y(0) = 0 = \frac{1}{EI}\left(\frac{-M_{seat}}{2} < 0-0 >^{2} + \frac{R}{6} < 0-0 >^{3} - \frac{F_{seat}}{6} < 0-t >^{3} + \frac{C_1}{6} * 0^3 + \frac{C_2}{2} * 0^2 + C_3 * 0 + C_4\right)$

$C_4 = \frac{M_{seat}}{2} < 0-0 >^{2} - \frac{R}{6} < 0-0 >^{3} + \frac{F_{seat}}{6} < 0-t >^{3} = 0$

$y_{max} = \frac{F_{seat}}{6EI}\left({L_s}^3 - 3 * t{L_s}^2 - (L_s - t)^3\right) = \frac{F_{seat} t^2}{6(EI)}(t - 3L_s)$

3.8.2 Singularity Function for Foot Area

$$q = -M_{foot} < x - 0 >^{-2} + R < x - 0 >^{-1} - F_{foot} < x - n >^{-1} + 2F_{strap,y} < x - p >^{-1}$$

$$V = \int q \, dx = - M_{foot} < x - 0 >^{-1} + R < x - 0 >^{0} - F_{foot} < x - n >^{0} + 2F_{strap,y} < x - p >^{0} + C_1$$

$$M = \int V \, dx = - M_{foot} < x - 0 >^{0} + R < x - 0 >^{1} - F_{foot} < x - n >^{1} + 2F_{strap,y} < x - p >^{1} +$$

$$C_1 x + C_2$$

$$\theta = \int \frac{M}{EI} \, dx = \frac{1}{EI}\Big(-M_{foot} < x - 0 >^{1} + \frac{R}{2} < x - 0 >^{2} - \frac{F_{foot}}{2} < x - n >^{2} + F_{strap,y} < x - p >^{2} +$$

$$\frac{C_1}{2} x^2 + C_2 x + C_3 \Big)$$

$$y = \int \theta \, dx = \frac{1}{EI}\Big(\frac{-M_{foot}}{2} < x - 0 >^{2} + \frac{R}{6} < x - 0 >^{3} - \frac{F_{foot}}{6} < x - n >^{3} + \frac{F_{strap,y}}{3} < x - p >^{3} + \frac{C_1}{6} x^3 +$$

$$\frac{C_2}{2} x^2 + C_3 x + C_4 \Big)$$

$$V(L_f) = 0 = R < L_f - 0 >^{0} - F_{foot} < L_f - n >^{0} + 2F_{strap,y} < L_f - p >^{0} = R - F_{foot} + 2F_{strap,y}$$

$$\therefore F_{foot} = R + 2F_{strap,y}$$

$$M(L_f) = 0 = -M_{foot} < L_f - 0 >^{0} + R < L_f - 0 >^{1} - F_{foot} < L_f - n >^{1} + 2F_{strap,y} < L_f - p >^{1} =$$

$$-M_{foot} + R(L_f) - F_{foot}(L_f - n) + 2F_{strap,y} < L_f - p >^{1}$$

$$\therefore \; M_{foot} = R * L_f - F_{foot}(L_f - p) + 2F_{strap,y}(L_f - n)$$

$$\theta(0) = 0 = \frac{1}{EI}\Big(-M_{foot} < 0 - 0 >^{1} + \frac{R}{2} < 0 - 0 >^{2} - \frac{F_{foot}}{2} < 0 - n >^{2} + F_{strap,y} < 0 - p >^{2} +$$

$$\frac{C_1}{2} * 0^2 + C_2 * 0 + C_3 \Big)$$

$$C_3 = M_{foot} < 0 - 0 >^{1} - \frac{R}{2} < 0 - 0 >^{2} + \frac{F_{foot}}{2} < 0 - n >^{2} - F_{strap,y} < 0 - p >^{2} = 0$$

$$y(0) = 0 = \frac{1}{EI}\Big(\frac{-M_{foot}}{2} < 0 - 0 >^{2} + \frac{R}{6} < 0 - 0 >^{3} - \frac{F_{foot}}{6} < 0 - n >^{3} + \frac{F_{strap,y}}{3} < 0 - p >^{3} + \frac{C_1}{6} * 0^3 +$$

$$\frac{C_2}{2} * 0^2 + C_3 * 0 + C_4 \Big)$$

$$C_4 = \frac{M_{foot}}{2} < 0 - 0 >^{2} - \frac{R}{6} < 0 - 0 >^{3} + \frac{F_{foot}}{6} < 0 - n >^{3} - \frac{F_{strap,y}}{3} < 0 - p >^{3} = 0$$

$$y_{max} = \frac{R}{2} n {L_f}^2 + \frac{R}{2} n^2 L_f - \frac{R}{6} n^3 - 2F_{strap,y} p {L_f}^2 - F_{strap,y} n^2 L_f + F_{strap,y} p^2 L_f + \frac{F_{strap,y}}{3} n^3 - \frac{F_{strap,y}}{3} p^3$$

3.9 The Area Moment of Inertia

The area moment of inertia is an important calculated value for analyzing the seat and foot platforms when a load is applied. It is used to calculate the maximum deflection at points e_s and e_f, and the maximum stress on the cantilever beam. The team looked into five different cross sectional shapes for constructing the platforms. Each of the cross sectional shapes that were examined for constructing the frames required a different equation which are found in Appendix 2: Area Moment of Inertia along with an image showing the cross sectional shape. To solve for the area moment of inertia for each of the examined cross sectional shapes and cross sectional area dimensions, the team utilized a MathCad program which was later used to determine the deflection and stress. The area moment of inertia were calculated in the MathCad programs found in Appendix 7: MathCad of Deflection and Stress – Seat Platform and Appendix 8: MathCad of Deflection and Stress – Foot Platform. All the data was inputted into the tables found in Appendix 9: Prediction of Seat Platform Weight and Appendix 8: MathCad of Deflection and Stress – Foot Platform.

3.10 Material Determination

In the course of designing the tree stand for the project it was necessary for the team to determine what material or materials would be used for construction. The team broke down the requirements for the materials to be that it meets deflection, stress, and weight requirements, and commercially available. Before determining whether the materials would met the requirements for deflection, stress, and weight the team began finding what would be available for purchase. After finding what is available for purchase the team utilized the singularity functions found above and the MathCad files found in Appendix 7: MathCad of Deflection and Stress – Seat

Platform and Appendix 8: MathCad of Deflection and Stress – Foot Platform to determine the maximum deflection for what’s available.

CHAPTER 4 – Testing

Upon completing the construction of the team's tree stand it was time to test the device and determine whether the Functional Requirements were met. The very first step to testing the newly built tree stand was to determine whether or not the tree stand would truly attach at a tree. To confirm that it would attach the tree stand was brought to Institute Park in Worcester, Massachusetts and attached to a tree as seen in *Figure 9: Tree Stand*.

Figure 16: Tree Stand

Once the team determined that the tree stand can attach to a tree it was time to determine the amount of time it takes to assemble the tree stand before testing the weight capacity. To determine the assembly time each of the team members assembled the tree stand while being timed. After each team member finished assembling the tree stand it was found that the average time for assembly was 4 minutes. The third test was to load the tree stand incrementally until either the tree stand had a failure or the tree stand was supporting the 350 lbs. the team had designed for. To load the tree stand the team utilized weight plates which were borrowed from the Worcester Polytechnic Institute Recreational Center. In the testing 45 lbs. plates, a 10 lbs. plate, and a 25 lbs. plate were used to test at approximately 100 lbs., 200 lbs., 300 lbs., and 350 lbs. It was found that the tree stand did in fact hold 350 lbs. as seen in *Figure 9: Tree Stand supporting 350 lbs.*

Figure 17: Tree Stand supporting 350 lbs.

CHAPTER 5 – Final Design and Validation

The final design for a tree stand can be found in Appendix 13. This chapter describes the impact the tree stand will have on the economy and environment. It also discusses the influence on society, health and safety issues, and ethical concerns. Lastly the chapter discusses the manufacturability, sustainability, and the results on the functional requirements.

5.1 Economics

The design of the tree stand utilized fairly low cost materials for fabrication although there could be a reduction in cost when produced in large scale. It is meant to be produced on a large scale as the product could be sold to both hunters and nature photographers. The team would want to see the tree stand carve out a small portion of the market.

5.2 Environmental Impact

The tree stand mainly uses 6061-T6 aluminum and a small amount of steel, both of which are designed to be long lasting parts. These materials can be recycled which greatly reduces the impact to the environment. All waste material from manufacturing the tree stand were properly recycled.

5.3 Societal Influence

This project was designed for nature photographers so the team has determined that the photographs and videos obtained from using the stand could inspire wonder in viewers. If the stand is utilized by hunters it could be seen that anger and excitement could stem from its use. Anger would come from people who are against hunting because the stand would be used for hunting. Excitement would come from hunters who successfully used the tree stand to kill their target and from the ability to feed their family or members of the community.

5.4 Political Ramifications

This project should not have any major influence on the global market, and the target market of nature photographers is significantly smaller than the number of hunters that buy tree stands.

5.5 Ethical Concerns

The tree stand is meant to make photographers lives easier when they need specific pictures that they can't take get without a tree stand. Our team believes that the only ethical concern could come when hunters utilize the tree stand and members of the public who think it is ethically wrong to be hunting.

5.6 Health and Safety Issues

This project was designed to make it easier for nature photographers to utilize tree stands. An in-depth failure analysis utilizing real world testing would be useful before a final product would be produced. If the tree stand was to fail while in use, it could put the user in the way for serious bodily harm if the user isn't utilizing the proper safety harness.

5.7 Manufacturability

The product in its current form is not easy to manufacture on a small scale, but on a large scale it could become easier. The tree stand consists mainly of aluminum rectangular tubing and a machined block of aluminum. To create more tree stands the machining of the block of aluminum would require making custom fixtures to decrease the time required to re-fixture between machining operations.

5.8 Sustainability

The tree stand utilizes material which are durable and should withstand high impacts. In designing the tree stand all materials were chosen to ensure that the life time would be approximately 300 uses. All materials that were used can be recycled. The tree stand does not require any external forms of energy.

5.9 Results of Functional Requirements after Testing

After testing of the team's tree stand it time to determine whether the functional requirements set out in the beginning of the project were met. Not all the functional requirements set out by the team were able to be tested. The team during testing was able to determine that the tree stand was able to satisfy functional requirements 1, 3, 4, 5, 6, 7, 8, 10, 11, 13, 14, and 15. During testing two functional requirements were determined to have not been met. Functional requirement number two was found to not be met during the design phase because it was a decision that the weight of the tree stand was more important while keeping a safety factor at least of two. The team also found that functional requirement 16 was not met as assembly of tree stand currently requires more tools than the tools found in a standard multi-tool.

1. Supported Weight of 300-350 lbs. ✓
2. High stress components should have a safety factor of at least 4. ✗
3. Weight of tree stand: Under 25 lbs. ✓
4. Platform Area Size: Under 30" x 25" ✓
5. Seating Area Size: Under 20" x 16" ✓
6. Set Up Time (Time to attach the stand to the selected tree): Under 12 minutes ✓
7. Cost of tree stand: Under $400 ✓

8. Material for the stand (Durable, light, corrosion resistant, can withstand extreme temperature) ✓
9. Must meet ASTM standards (created by TMA) for stress load tests, etc.
    - F2120-06 Standard Practice for Testing Tree Stand Load Capacity
    - F2121-13 Standard Practice for Tree Stand Labels
    - F2122-13 Standard Practice for Tree Stand Safety Devices
    - F2123-13 Standard Practice for Tree Stand Instructions
    - F2124-13 Standard Practice for Testing Tree Stand Ladder, Tripod Stands and Climbing Stick Load Capacity
    - F2125-09 Standard Test Method for Tree Stand Static Stability and Adherence
    - F2126-06 Standard Tree Stand Static Load Capacity
    - F2128-13 Standard Test Method for Tree Stand Repetitive Loading Capability
    - F2275-10 Standard Practice for Tree Stand Manufacturer Quality Assurance Program
    - F2337-11 Standard Test Method for Tree Stand Fall Arrest System
    - F2531-13 Standard Test Method for Load Capacity of Tree Stand Seats
10. Minimum tree diameter: 6” ✓
11. Maximum tree diameter: 20” ✓
12. Tree stand should not left installed for more than two weeks.
13. Tree stand should be designed for use with Summit Tree stands Seat-O-The-Pants STS Deluxe Harness. ✓
14. The tree stand while fully loaded should have a maximum deflection 10° for the seating area. ✓

15. The tree stand will be designed to give a 210° horizontal view and 110° vertical view. ✓

16. Tree stand can be assembled with a multi-tool (Leatherman). ✗

17. The seat platform must be able to carry up to 80% of the supported weight.

18. The tree stand will not be damaged from a drop of 5 ft.

19. The tree stand should last 10 years assuming that it is being used 30 times per year.

CHAPTER 6 – Conclusions

This report was a summary of the design and build process of the prototype of a hang-on tree stand. The design process started with researching a gap in the market and learning about the targeted audience. Research then continued for the current models on the market and brainstorming for ways to improve them. Afterwards, a static analysis and CAD models were generated to guide the design. Finally, a prototype was built to test the validity and practicality of the design concept. Testing was successful, and the prototype met the majority of functional requirements that the team has set beforehand, but came short in some areas. The tree stand weighed under the goal weight of 25lb, and was able to support the goal weight of 350lb. This model is comparable to other ones in the market, currently aimed at deer hunting, in terms of size, weight and price. Some design and manufacturing recommendations were finally made for anyone who would pursue this project further.

CHAPTER 7 – Recommendations

The goal of the project was to design and produce a tree stand that could help nature photographers take pictures of the animal and plant life found in the trees. Our design could be utilized as a baseline for future projects as it was validated through testing in nature. Analysis in a more controlled environment for real world testing, dynamic loading and finite element analysis should provide better results allowing for intelligent changes to the current design.

In the future, based on the experience of manufacturing the tree stand there should be a few changes made to the design for ease of manufacturability. It was found that machining the base piece was more difficult and longer than expected. One difficulty with the base was how to safely hold the stock in the Haas VM-2 (Vertical Mold Making Machine) from Washburn Building room 108. The machining of the part required the team to fixture the stock three different times which took up a lot of time. It would be recommended that any future teams work closely with manufacturing engineers to redesign this part for easier manufacturing. The team found that welding the rectangular tubing to the base forming the foot platform was not an easy process and it couldn’t be guaranteed that the welds would be structurally supportive. After welding was completed and discussing the welds with manufacturing engineers they gave a recommendation that in the future gusset plates be used to reduce the needs for welding. Utilizing gusset plates for assembling the foot platform would reduce the time required for assembly and the number of welds.

Lastly, the team would want to see a future group do mechanical testing to determine the fatigue of the tree stand. The durability of the tree stand could analyzed by determining how many loading and unloading cycle can occur before failure. It would be helpful in deciding on the recommended lifetime of the tree stand and predicting when the tree stand would break.

Hand calculations and stress analysis were conducted to validate the safety of the device, but testing would be useful to determine if a different material or stock should be used.

APPENDICES

APPENDIX A: Authorship Page

	Huda	Evan
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CHAPTER 2 – Literary Review	X	X
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2.2 Current Tree Stands on Sale		X
2.3 Goal Statement	X	X
2.4 Functional Requirements		X
CHAPTER 3 – Design Process	X	X
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3.2 Preliminary Design Concepts	X	
3.3 SolidWorks Model	X	
3.4 FBD of the Tree Stand	X	
3.5 FBD of the Seating Platform		X
3.6 FBD of the Foot Platform		X
3.7 Static Analysis of the individual sections of the tree stand		X
3.8 Singularity Functions		X
3.8.1 Singularity Function for Seat Area		X
3.8.2 Singularity Function for Foot Area		X
3.9 The Area Moment of Inertia		X
3.10 Material Determination		X
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CHAPTER 5 –Final Design and Verification		X
5.1 Economics		X
5.2 Environmental Impact		X
5.3 Societal Influence		X
5.4 Political Ramifications		X
5.5 Ethical Concerns		X
5.6 Health and Safety Issues		X
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5.8 Sustainability		X
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CHAPTER 6 – Conclusions	X	
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APPENDIX C: Area Moment of Inertia		X
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APPENDIX E: Simplified Deformation and Weight Charts		X
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APPENDIX H: MathCad of Deflection and Stress – Seat Platform		X
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APPENDIX B: Data of Tree Stands on the Consumer Market

Table 2: Tree Stands currently available for sale

Style	Manufacturer	Model	Cost	Weight	Platform Size	Seat Size
Hang-On	Lone Wolf	Alpha II	$249.99	14 lbs.	30” x 19-1/2”	14” x 12”
	Lone Wolf	Assault II	$239.99	11 lbs.	26” x 19-1/2”	14” x 12”
	Hawk	Mega Combat	$99.99	17 lbs.	30” x 24”	10” x 16”
Climbing	Lone Wolf	Hand Climber Combo II	$379.99	17-1/2 lbs.	30” x 19-1/2”	15” x 9”
	Summit Tree stands	Goliath SD	$319.99	21 lbs.	28-3/4” x 20”	N/A
	Summit Tree stands	Viper SD	$299.99	20 lbs.	28-3/4” x 20”	18” x 12”
Ladder	Big Game Tree stands	NextGen Stealth Deluxe Ladder Stand	$159.99	55 lbs.	19” x 26”	20” x 15”
	Big Game Tree stands	Warrior Deluxe 17’ Ladder Stand	$129.99	50 lbs.	19” x 10”	20” x 15”
	Hawk	21-ft. Destination Ladder Stand	$229.99	92 lbs.	19” x 26”	20.5” x 16”

APPENDIX C: Area Moment of Inertia

Square Bar

$$I = \frac{b^4}{12}$$

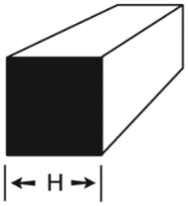


Figure 18: Area Moment of Inertia - Square Bar

Rectangle Bar

$$I = \frac{bh^3}{12}$$

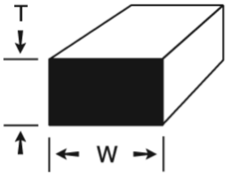


Figure 19: Area Moment of Inertia - Rectangle Bar

Rectangular Tubing

$$I = \frac{bd^3 - hk^3}{12}$$

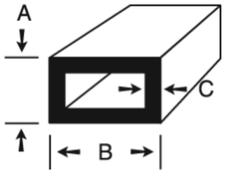


Figure 20: Area Moment of Inertia - Rectangular Tubing

Round Bar

$$I = \frac{\pi r^4}{4}$$

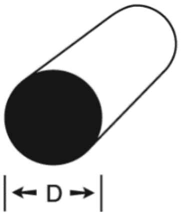


Figure 21: Area Moment of Inertia - Round Bar

Round Tubing

$$I = \frac{\pi(d_o^4 - d_i^4)}{64}$$

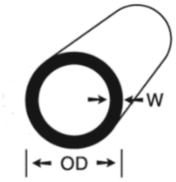
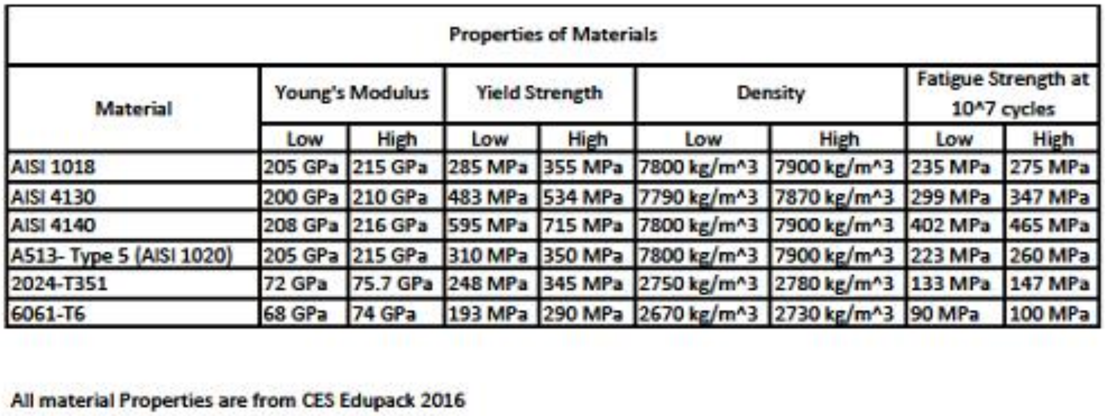


Figure 22: Area Moment of Inertia - Round Tubing

APPENDIX D: Properties of Materials for Constructing Platforms

Table 3: Properties of Materials



Properties of Materials

Material	Young's Modulus		Yield Strength		Density		Fatigue Strength at 10^7 cycles	
	Low	High	Low	High	Low	High	Low	High
AISI 1018	205 GPa	215 GPa	285 MPa	355 MPa	7800 kg/m^3	7900 kg/m^3	235 MPa	275 MPa
AISI 4130	200 GPa	210 GPa	483 MPa	534 MPa	7790 kg/m^3	7870 kg/m^3	299 MPa	347 MPa
AISI 4140	208 GPa	216 GPa	595 MPa	715 MPa	7800 kg/m^3	7900 kg/m^3	402 MPa	465 MPa
A513- Type 5 (AISI 1020)	205 GPa	215 GPa	310 MPa	350 MPa	7800 kg/m^3	7900 kg/m^3	223 MPa	260 MPa
2024-T351	72 GPa	75.7 GPa	248 MPa	345 MPa	2750 kg/m^3	2780 kg/m^3	133 MPa	147 MPa
6061-T6	68 GPa	74 GPa	193 MPa	290 MPa	2670 kg/m^3	2730 kg/m^3	90 MPa	100 MPa

All material Properties are from CES Edupack 2016

APPENDIX E: Simplified Deformation and Weight Charts

Table 4: Simplified Deformation and Weight Chart – Seat Platform

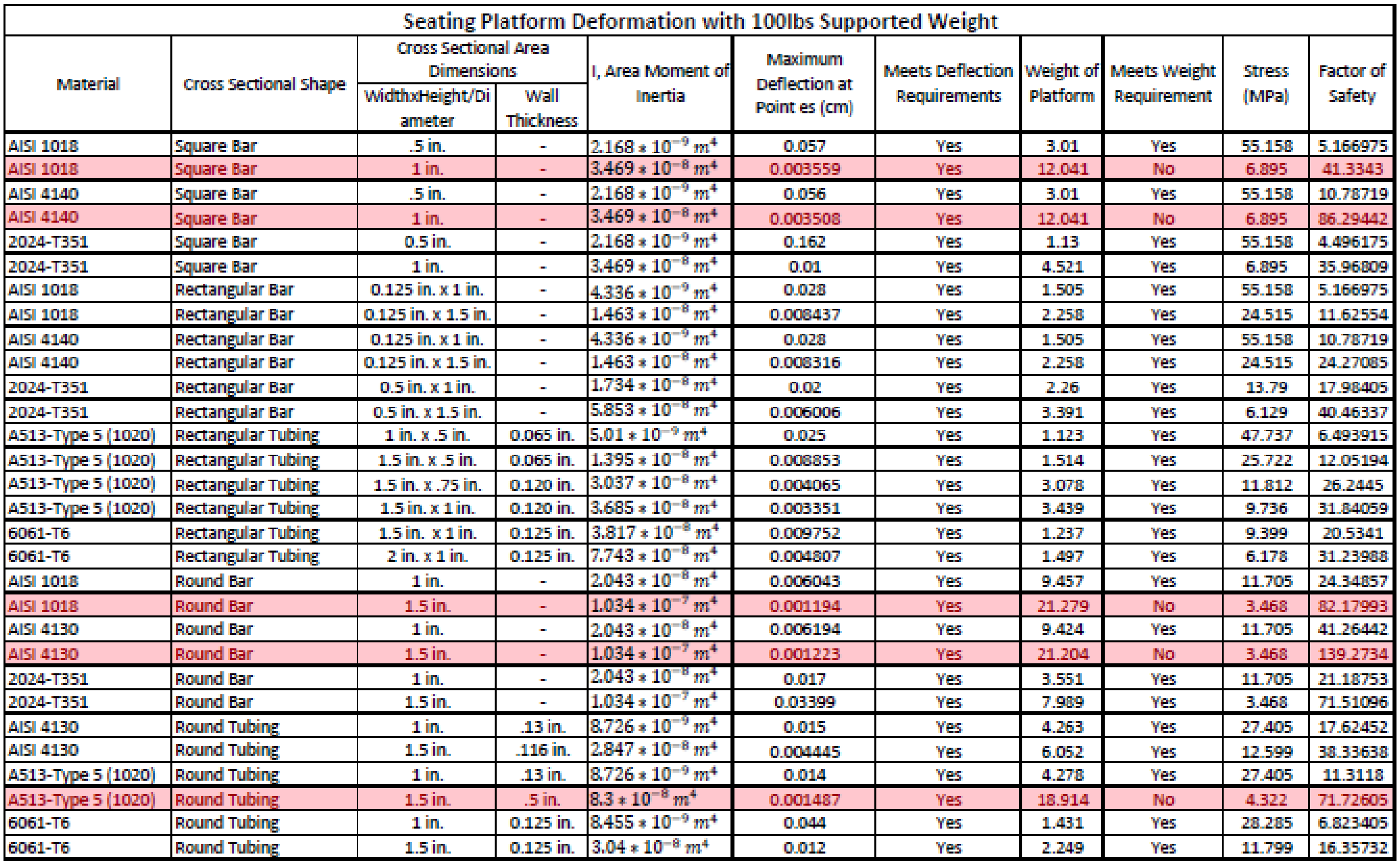
Seat Platform				
Material		Cross Sectional Shape	Deformation (Yes/No)	Weight (Yes/No)
Steel	AISI 1018	Square Bar	Yes	Yes
		Rectangular Bar	Yes	Yes
		Round Bar	Yes	No
	AISI 4130	Round Bar	Yes	No
		Round Tubing	Yes	Yes
	AISI 4140	Square Bar	Yes	Yes
		Rectangular Bar	Yes	Yes
	A513-Type 5 (AISI 1020)	Rectangular Tubing	Yes	Yes
		Round Tubing	Yes	Yes
Aluminum	2024-T351	Square Bar	Yes	Yes
		Rectangular Bar	Yes	Yes
		Round Bar	Yes	Yes
	6061-T6	Rectangular Tubing	Yes	Yes
		Round Tubing	Yes	Yes

Table 5: Simplified Deformation and Weight Chart – Foot Platform

Foot Platform				
Material		Cross Sectional Shape	Deformation (Yes/No)	Weight (Yes/No)
Steel	AISI 1018	Square Bar	No	No
		Rectangular Bar	Yes	Yes
		Round Bar	Yes	No
	AISI 4130	Round Bar	Yes	No
		Round Tubing	Yes	No
	AISI 4140	Square Bar	No	No
		Rectangular Bar	Yes	Yes
	A513-Type 5 (AISI 1020)	Rectangular Tubing	Yes	Yes
		Round Tubing	Yes	No
Aluminum	2024-T351	Square Bar	No	No
		Rectangular Bar	Yes	Yes
		Round Bar	No	No
	6061-T6	Rectangular Tubing	Yes	Yes
		Round Tubing	No	Yes

APPENDIX F: Deformation for the Seat Platform

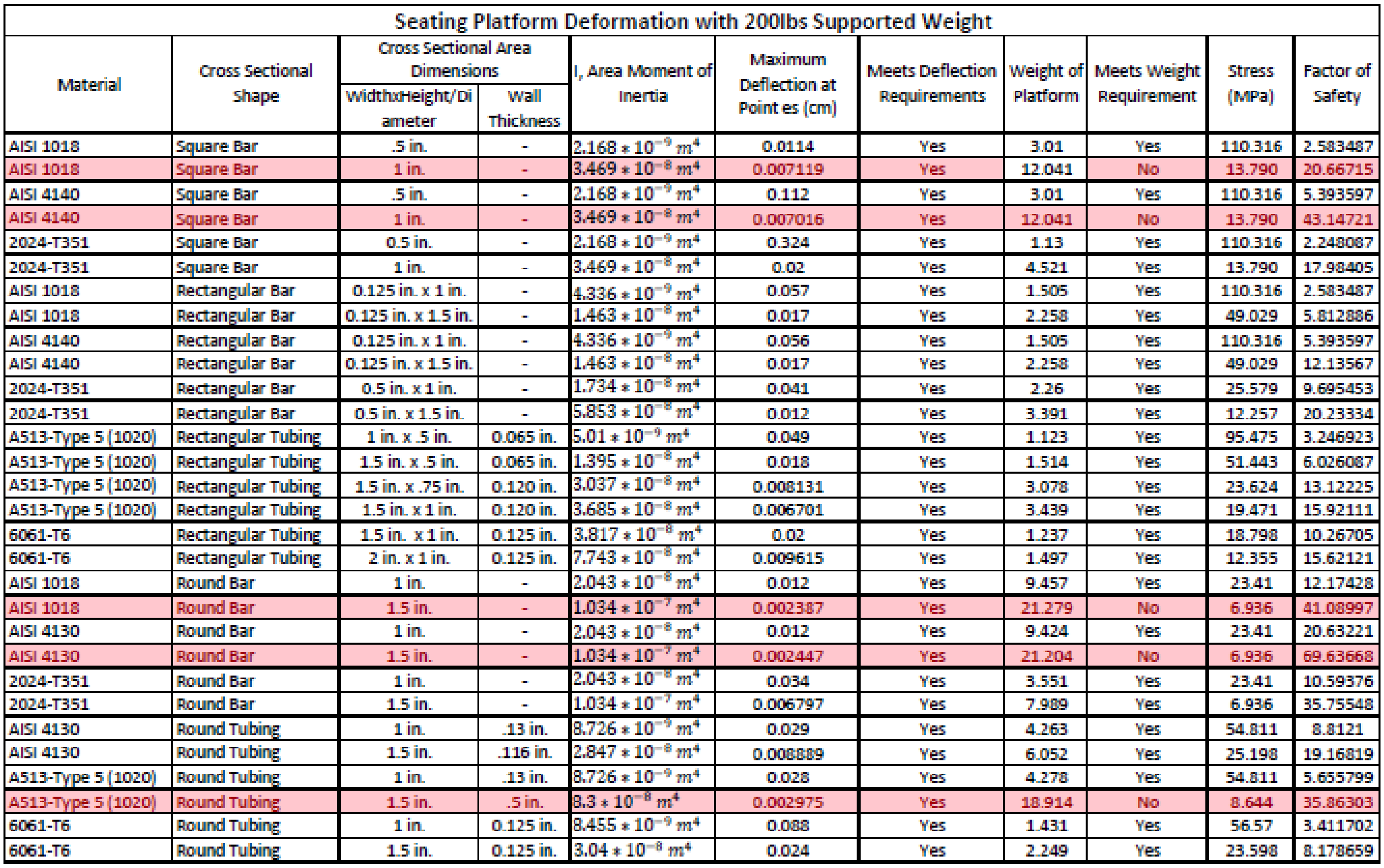
Table 6: Seat Platform Deformation Chart - 100 lbs.



Seating Platform Deformation with 100lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point es (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9} m^4$	0.057	Yes	3.01	Yes	55.158	5.166975
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8} m^4$	0.003559	Yes	12.041	No	6.895	41.3343
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9} m^4$	0.056	Yes	3.01	Yes	55.158	10.78719
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8} m^4$	0.003508	Yes	12.041	No	6.895	86.29442
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9} m^4$	0.162	Yes	1.13	Yes	55.158	4.496175
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8} m^4$	0.01	Yes	4.521	Yes	6.895	35.96809
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9} m^4$	0.028	Yes	1.505	Yes	55.158	5.166975
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8} m^4$	0.008437	Yes	2.258	Yes	24.515	11.62554
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9} m^4$	0.028	Yes	1.505	Yes	55.158	10.78719
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8} m^4$	0.008316	Yes	2.258	Yes	24.515	24.27085
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8} m^4$	0.02	Yes	2.26	Yes	13.79	17.98405
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8} m^4$	0.006006	Yes	3.391	Yes	6.129	40.46337
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9} m^4$	0.025	Yes	1.123	Yes	47.737	6.493915
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8} m^4$	0.008853	Yes	1.514	Yes	25.722	12.05194
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8} m^4$	0.004065	Yes	3.078	Yes	11.812	26.2445
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8} m^4$	0.003351	Yes	3.439	Yes	9.736	31.84059
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8} m^4$	0.009752	Yes	1.237	Yes	9.399	20.5341
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8} m^4$	0.004807	Yes	1.497	Yes	6.178	31.23988
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8} m^4$	0.006043	Yes	9.457	Yes	11.705	24.34857
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7} m^4$	0.001194	Yes	21.279	No	3.468	82.17993
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8} m^4$	0.006194	Yes	9.424	Yes	11.705	41.26442
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7} m^4$	0.001223	Yes	21.204	No	3.468	139.2734
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8} m^4$	0.017	Yes	3.551	Yes	11.705	21.18753
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7} m^4$	0.03399	Yes	7.989	Yes	3.468	71.51096
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9} m^4$	0.015	Yes	4.263	Yes	27.405	17.62452
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8} m^4$	0.004445	Yes	6.052	Yes	12.599	38.33638
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9} m^4$	0.014	Yes	4.278	Yes	27.405	11.3118
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8} m^4$	0.001487	Yes	18.914	No	4.322	71.72605
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9} m^4$	0.044	Yes	1.431	Yes	28.285	6.823405
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8} m^4$	0.012	Yes	2.249	Yes	11.799	16.35732

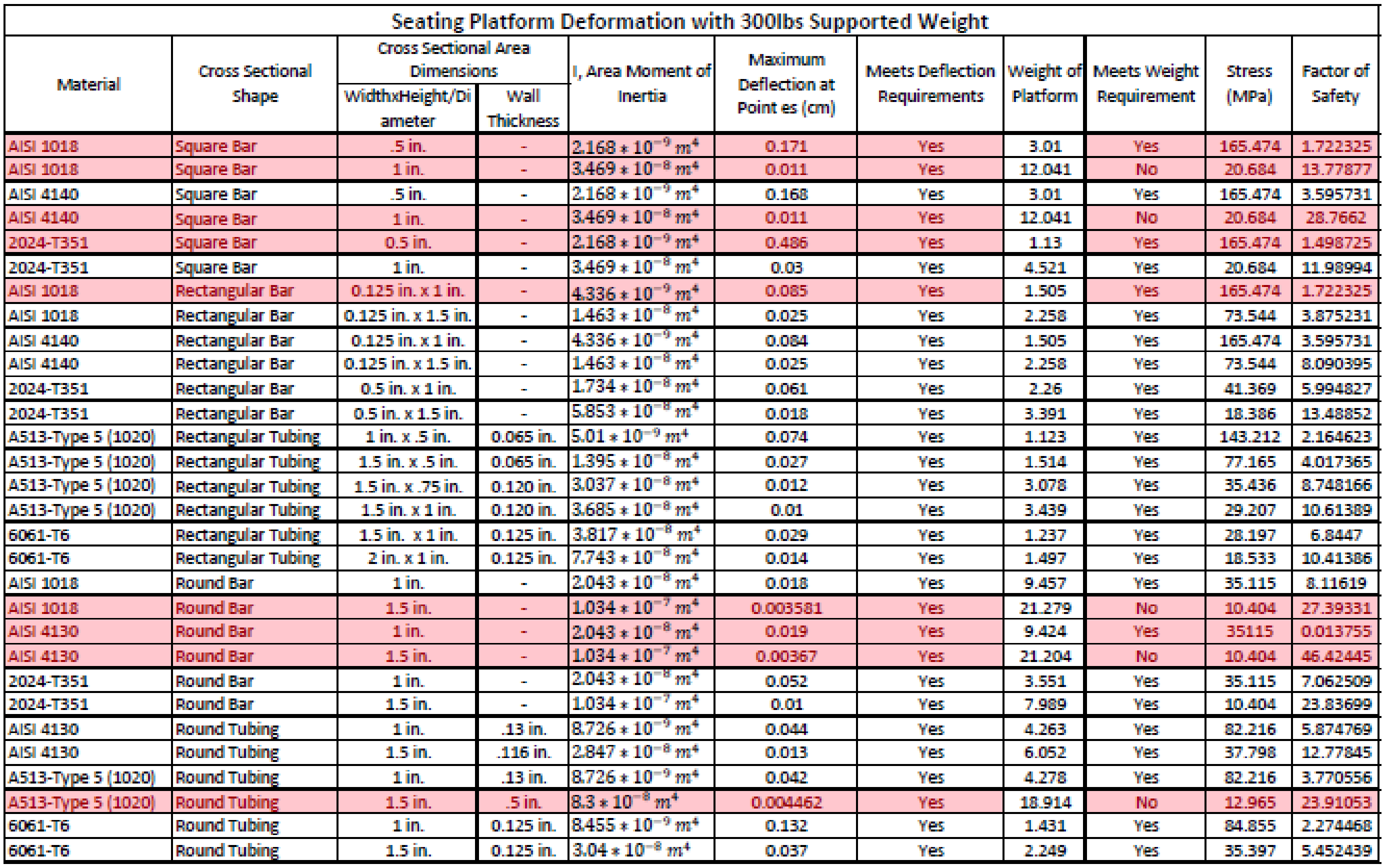
Table 7: Seat Platform Deformation Chart - 200 lbs.



Seating Platform Deformation with 200lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point es (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.0114	Yes	3.01	Yes	110.316	2.583487
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.007119	Yes	12.041	No	13.790	20.66715
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.112	Yes	3.01	Yes	110.316	5.393597
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.007016	Yes	12.041	No	13.790	43.14721
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.324	Yes	1.13	Yes	110.316	2.248087
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.02	Yes	4.521	Yes	13.790	17.98405
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	0.057	Yes	1.505	Yes	110.316	2.583487
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.017	Yes	2.258	Yes	49.029	5.812886
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	0.056	Yes	1.505	Yes	110.316	5.393597
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.017	Yes	2.258	Yes	49.029	12.13567
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	0.041	Yes	2.26	Yes	25.579	9.695453
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.012	Yes	3.391	Yes	12.257	20.23334
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	0.049	Yes	1.123	Yes	95.475	3.246923
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	0.018	Yes	1.514	Yes	51.443	6.026087
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.008131	Yes	3.078	Yes	23.624	13.12225
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.006701	Yes	3.439	Yes	19.471	15.92111
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	0.02	Yes	1.237	Yes	18.798	10.26705
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	0.009615	Yes	1.497	Yes	12.355	15.62121
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.012	Yes	9.457	Yes	23.41	12.17428
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.002387	Yes	21.279	No	6.936	41.08997
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.012	Yes	9.424	Yes	23.41	20.63221
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.002447	Yes	21.204	No	6.936	69.63668
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.034	Yes	3.551	Yes	23.41	10.59376
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.006797	Yes	7.989	Yes	6.936	35.75548
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.029	Yes	4.263	Yes	54.811	8.8121
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.008889	Yes	6.052	Yes	25.198	19.16819
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.028	Yes	4.278	Yes	54.811	5.655799
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.002975	Yes	18.914	No	8.644	35.86303
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	0.088	Yes	1.431	Yes	56.57	3.411702
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	0.024	Yes	2.249	Yes	23.598	8.178659

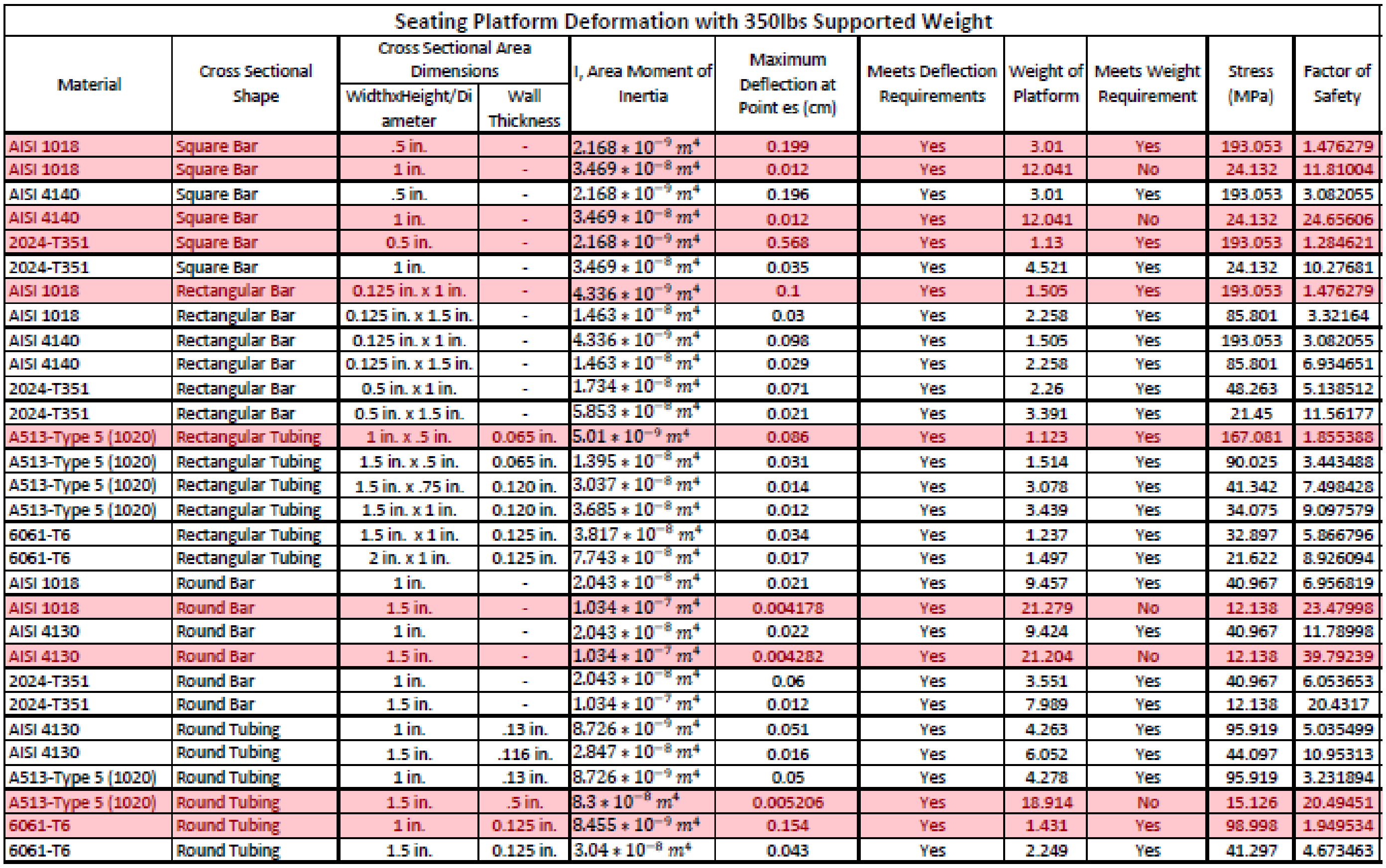
Table 8: Seat Platform Deformation Chart - 300 lbs.



Seating Platform Deformation with 300lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point es (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.171	Yes	3.01	Yes	165.474	1.722325
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.011	Yes	12.041	No	20.684	13.77877
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.168	Yes	3.01	Yes	165.474	3.595731
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.011	Yes	12.041	No	20.684	28.7662
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.486	Yes	1.13	Yes	165.474	1.498725
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.03	Yes	4.521	Yes	20.684	11.98994
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	0.085	Yes	1.505	Yes	165.474	1.722325
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.025	Yes	2.258	Yes	73.544	3.875231
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	0.084	Yes	1.505	Yes	165.474	3.595731
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.025	Yes	2.258	Yes	73.544	8.090395
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	0.061	Yes	2.26	Yes	41.369	5.994827
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.018	Yes	3.391	Yes	18.386	13.48852
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	0.074	Yes	1.123	Yes	143.212	2.164623
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	0.027	Yes	1.514	Yes	77.165	4.017365
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.012	Yes	3.078	Yes	35.436	8.748166
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.01	Yes	3.439	Yes	29.207	10.61389
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	0.029	Yes	1.237	Yes	28.197	6.8447
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	0.014	Yes	1.497	Yes	18.533	10.41386
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.018	Yes	9.457	Yes	35.115	8.11619
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.003581	Yes	21.279	No	10.404	27.39331
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.019	Yes	9.424	Yes	35115	0.013755
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.00367	Yes	21.204	No	10.404	46.42445
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.052	Yes	3.551	Yes	35.115	7.062509
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.01	Yes	7.989	Yes	10.404	23.83699
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.044	Yes	4.263	Yes	82.216	5.874769
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.013	Yes	6.052	Yes	37.798	12.77845
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.042	Yes	4.278	Yes	82.216	3.770556
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.004462	Yes	18.914	No	12.965	23.91053
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	0.132	Yes	1.431	Yes	84.855	2.274468
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	0.037	Yes	2.249	Yes	35.397	5.452439

Table 9: Seat Platform Deformation Chart - 350 lbs.

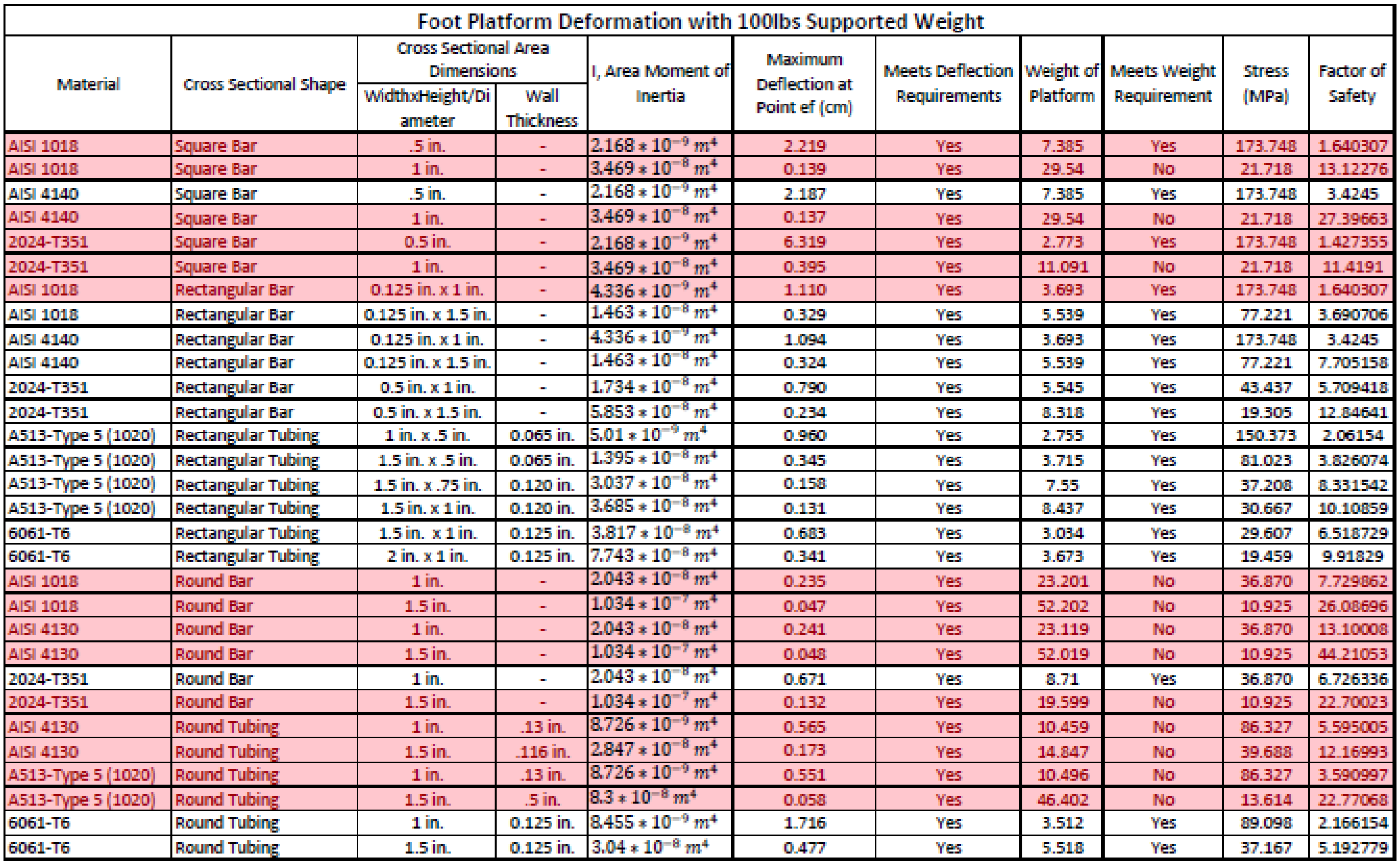


Seating Platform Deformation with 350lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point es (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.199	Yes	3.01	Yes	193.053	1.476279
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.012	Yes	12.041	No	24.132	11.81004
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.196	Yes	3.01	Yes	193.053	3.082055
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.012	Yes	12.041	No	24.132	24.65606
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	0.568	Yes	1.13	Yes	193.053	1.284621
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.035	Yes	4.521	Yes	24.132	10.27681
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	0.1	Yes	1.505	Yes	193.053	1.476279
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.03	Yes	2.258	Yes	85.801	3.32164
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	0.098	Yes	1.505	Yes	193.053	3.082055
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.029	Yes	2.258	Yes	85.801	6.934651
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	0.071	Yes	2.26	Yes	48.263	5.138512
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.021	Yes	3.391	Yes	21.45	11.56177
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	0.086	Yes	1.123	Yes	167.081	1.855388
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	0.031	Yes	1.514	Yes	90.025	3.443488
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.014	Yes	3.078	Yes	41.342	7.498428
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.012	Yes	3.439	Yes	34.075	9.097579
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	0.034	Yes	1.237	Yes	32.897	5.866796
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	0.017	Yes	1.497	Yes	21.622	8.926094
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.021	Yes	9.457	Yes	40.967	6.956819
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.004178	Yes	21.279	No	12.138	23.47998
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.022	Yes	9.424	Yes	40.967	11.78998
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.004282	Yes	21.204	No	12.138	39.79239
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.06	Yes	3.551	Yes	40.967	6.053653
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.012	Yes	7.989	Yes	12.138	20.4317
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.051	Yes	4.263	Yes	95.919	5.035499
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.016	Yes	6.052	Yes	44.097	10.95313
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.05	Yes	4.278	Yes	95.919	3.231894
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.005206	Yes	18.914	No	15.126	20.49451
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	0.154	Yes	1.431	Yes	98.998	1.949534
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	0.043	Yes	2.249	Yes	41.297	4.673463

APPENDIX G: Deformation for the Foot Platform

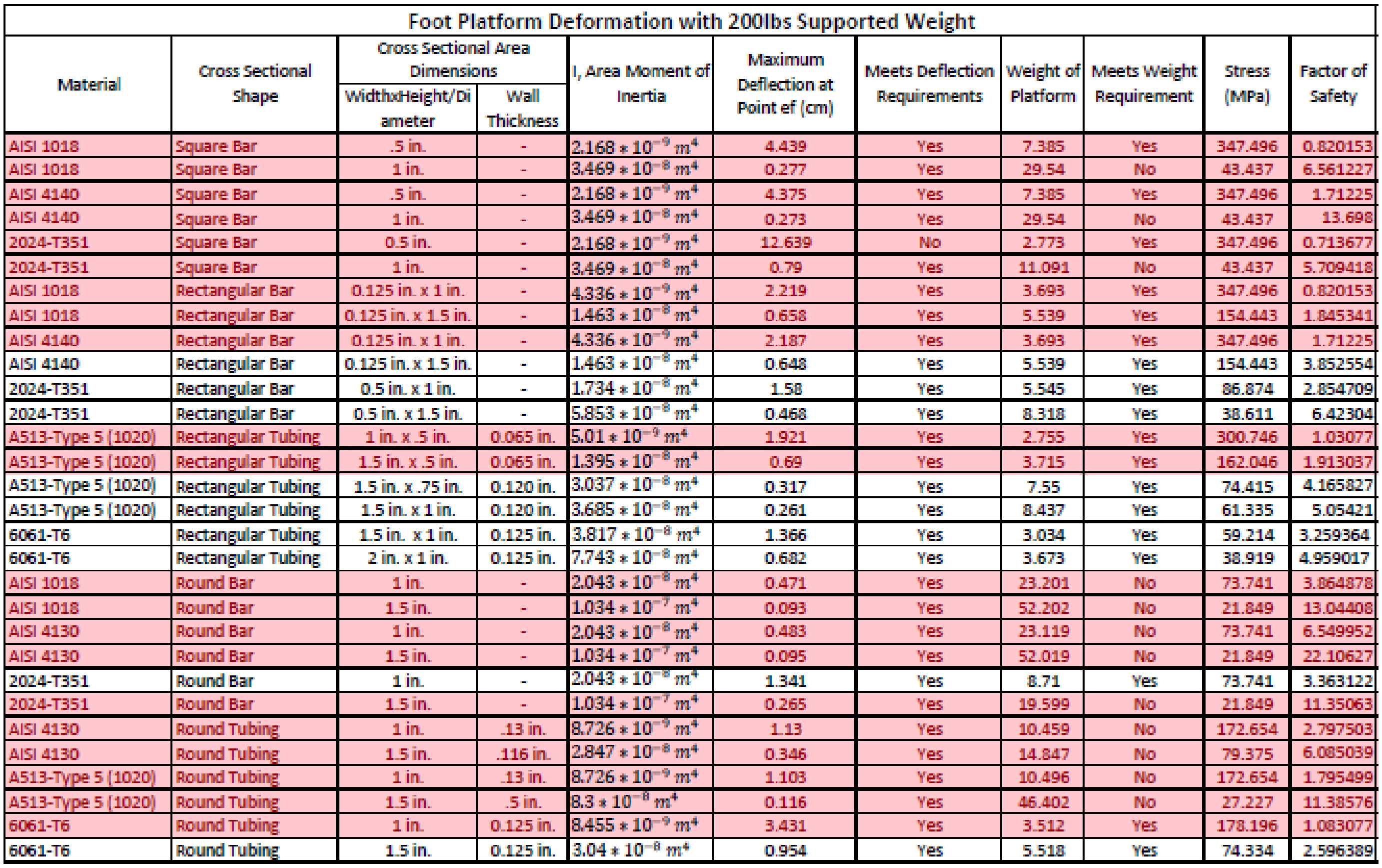
Table 10: Foot Platform Deformation Chart - 100 lbs.



Foot Platform Deformation with 100lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point ef (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	2.219	Yes	7.385	Yes	173.748	1.640307
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.139	Yes	29.54	No	21.718	13.12276
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	2.187	Yes	7.385	Yes	173.748	3.4245
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.137	Yes	29.54	No	21.718	27.39663
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	6.319	Yes	2.773	Yes	173.748	1.427355
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.395	Yes	11.091	No	21.718	11.4191
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	1.110	Yes	3.693	Yes	173.748	1.640307
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.329	Yes	5.539	Yes	77.221	3.690706
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	1.094	Yes	3.693	Yes	173.748	3.4245
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.324	Yes	5.539	Yes	77.221	7.705158
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	0.790	Yes	5.545	Yes	43.437	5.709418
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.234	Yes	8.318	Yes	19.305	12.84641
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	0.960	Yes	2.755	Yes	150.373	2.06154
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	0.345	Yes	3.715	Yes	81.023	3.826074
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.158	Yes	7.55	Yes	37.208	8.331542
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.131	Yes	8.437	Yes	30.667	10.10859
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	0.683	Yes	3.034	Yes	29.607	6.518729
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	0.341	Yes	3.673	Yes	19.459	9.91829
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.235	Yes	23.201	No	36.870	7.729862
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.047	Yes	52.202	No	10.925	26.08696
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.241	Yes	23.119	No	36.870	13.10008
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.048	Yes	52.019	No	10.925	44.21053
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.671	Yes	8.71	Yes	36.870	6.726336
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.132	Yes	19.599	No	10.925	22.70023
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.565	Yes	10.459	No	86.327	5.595005
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.173	Yes	14.847	No	39.688	12.16993
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	0.551	Yes	10.496	No	86.327	3.590997
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.058	Yes	46.402	No	13.614	22.77068
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	1.716	Yes	3.512	Yes	89.098	2.166154
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	0.477	Yes	5.518	Yes	37.167	5.192779

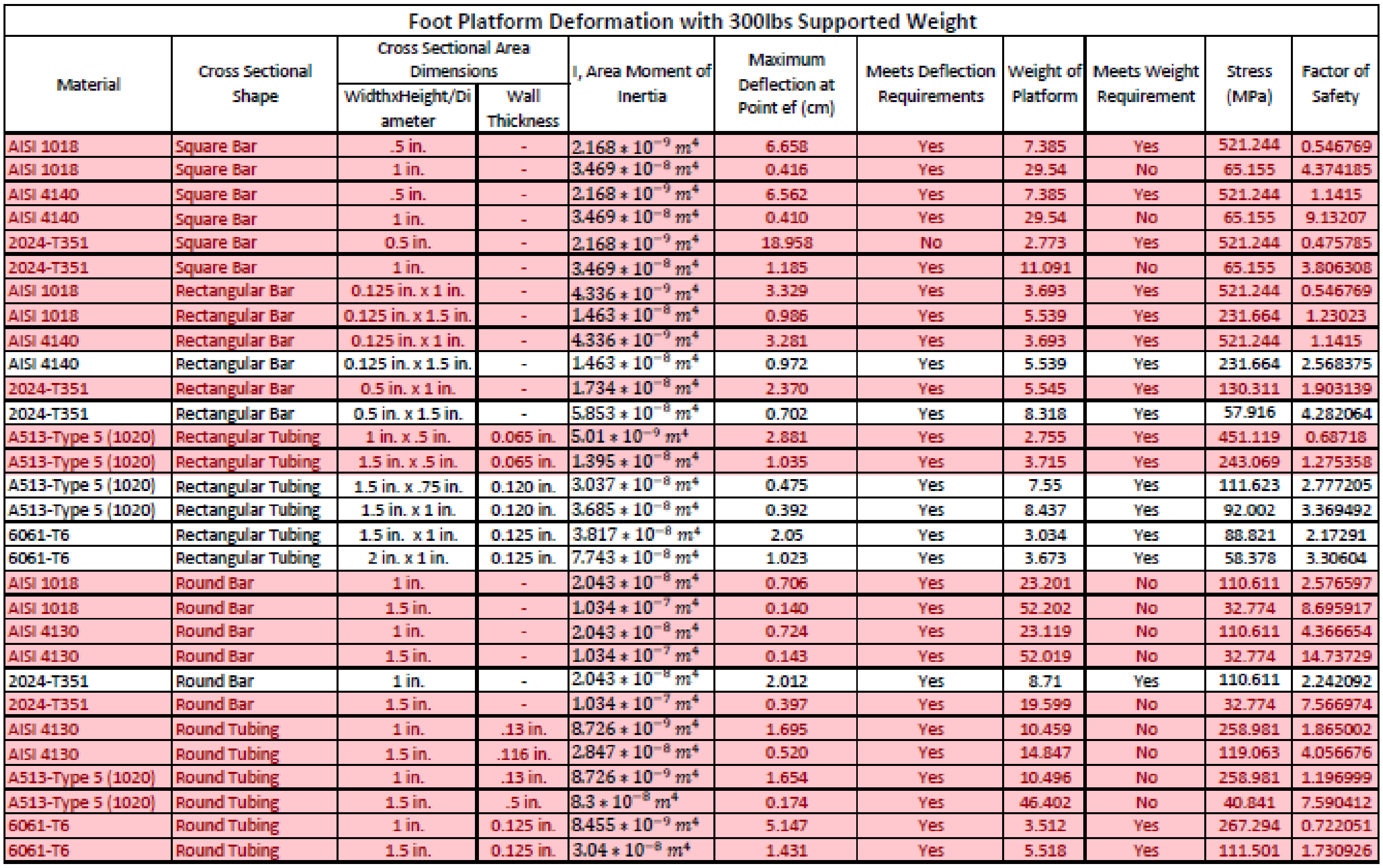
Table 11: Foot Platform Deformation Chart - 200 lbs.



Foot Platform Deformation with 200lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point ef (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	4.439	Yes	7.385	Yes	347.496	0.820153
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.277	Yes	29.54	No	43.437	6.561227
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	4.375	Yes	7.385	Yes	347.496	1.71225
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.273	Yes	29.54	No	43.437	13.698
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	12.639	No	2.773	Yes	347.496	0.713677
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.79	Yes	11.091	No	43.437	5.709418
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	2.219	Yes	3.693	Yes	347.496	0.820153
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.658	Yes	5.539	Yes	154.443	1.845341
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	2.187	Yes	3.693	Yes	347.496	1.71225
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.648	Yes	5.539	Yes	154.443	3.852554
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	1.58	Yes	5.545	Yes	86.874	2.854709
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.468	Yes	8.318	Yes	38.611	6.42304
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	1.921	Yes	2.755	Yes	300.746	1.03077
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	0.69	Yes	3.715	Yes	162.046	1.913037
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.317	Yes	7.55	Yes	74.415	4.165827
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.261	Yes	8.437	Yes	61.335	5.05421
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	1.366	Yes	3.034	Yes	59.214	3.259364
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	0.682	Yes	3.673	Yes	38.919	4.959017
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.471	Yes	23.201	No	73.741	3.864878
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.093	Yes	52.202	No	21.849	13.04408
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.483	Yes	23.119	No	73.741	6.549952
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.095	Yes	52.019	No	21.849	22.10627
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	1.341	Yes	8.71	Yes	73.741	3.363122
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.265	Yes	19.599	No	21.849	11.35063
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	1.13	Yes	10.459	No	172.654	2.797503
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.346	Yes	14.847	No	79.375	6.085039
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	1.103	Yes	10.496	No	172.654	1.795499
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.116	Yes	46.402	No	27.227	11.38576
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	3.431	Yes	3.512	Yes	178.196	1.083077
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	0.954	Yes	5.518	Yes	74.334	2.596389

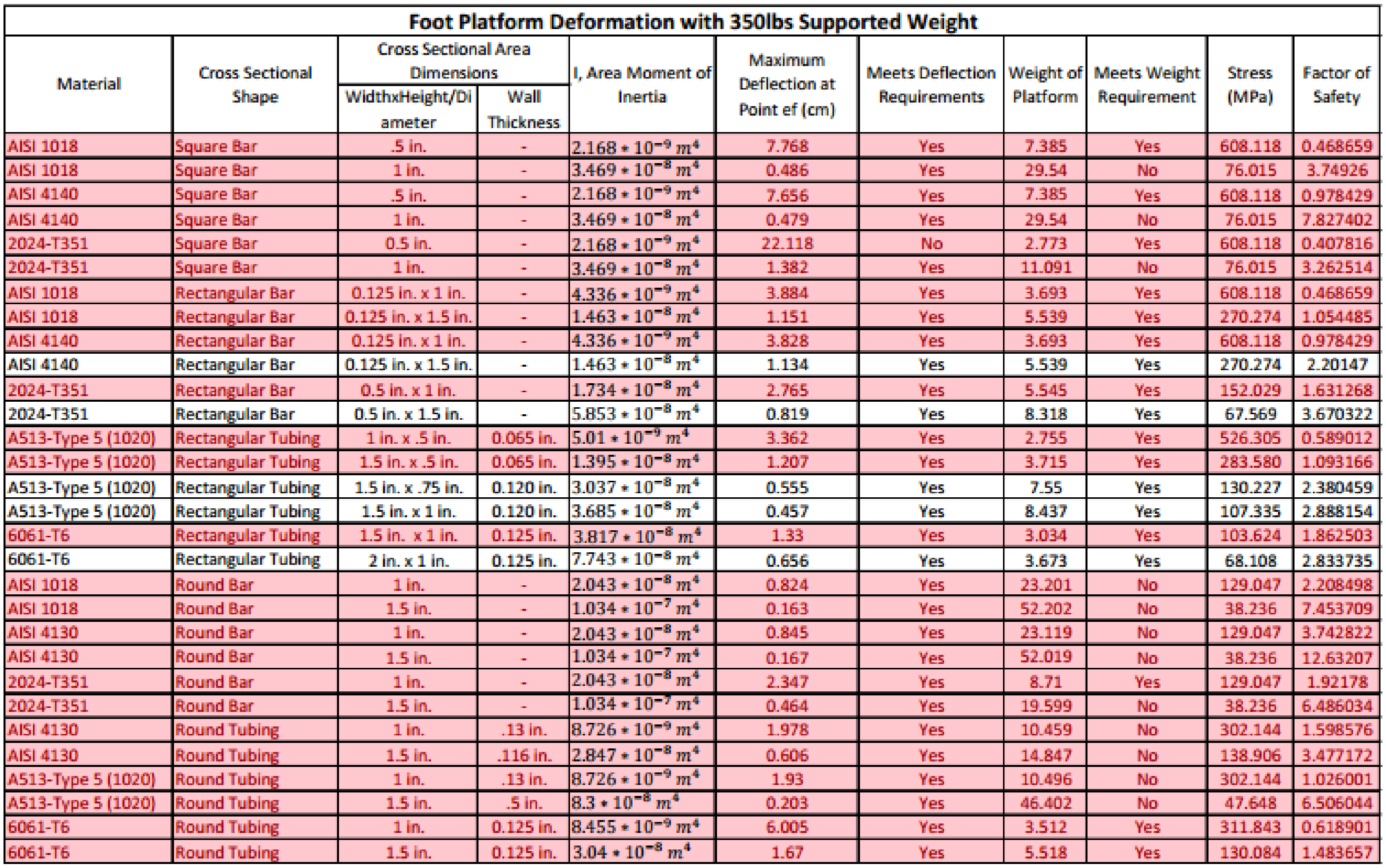
Table 12: Foot Platform Deformation Chart - 300 lbs.



Foot Platform Deformation with 300lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point ef (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	6.658	Yes	7.385	Yes	521.244	0.546769
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.416	Yes	29.54	No	65.155	4.374185
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	6.562	Yes	7.385	Yes	521.244	1.1415
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.410	Yes	29.54	No	65.155	9.13207
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	18.958	No	2.773	Yes	521.244	0.475785
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	1.185	Yes	11.091	No	65.155	3.806308
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	3.329	Yes	3.693	Yes	521.244	0.546769
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.986	Yes	5.539	Yes	231.664	1.23023
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	3.281	Yes	3.693	Yes	521.244	1.1415
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	0.972	Yes	5.539	Yes	231.664	2.568375
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	2.370	Yes	5.545	Yes	130.311	1.903139
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.702	Yes	8.318	Yes	57.916	4.282064
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	2.881	Yes	2.755	Yes	451.119	0.68718
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	1.035	Yes	3.715	Yes	243.069	1.275358
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.475	Yes	7.55	Yes	111.623	2.777205
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.392	Yes	8.437	Yes	92.002	3.369492
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	2.05	Yes	3.034	Yes	88.821	2.17291
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	1.023	Yes	3.673	Yes	58.378	3.30604
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.706	Yes	23.201	No	110.611	2.576597
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.140	Yes	52.202	No	32.774	8.695917
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.724	Yes	23.119	No	110.611	4.366654
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.143	Yes	52.019	No	32.774	14.73729
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	2.012	Yes	8.71	Yes	110.611	2.242092
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.397	Yes	19.599	No	32.774	7.566974
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	1.695	Yes	10.459	No	258.981	1.865002
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.520	Yes	14.847	No	119.063	4.056676
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	1.654	Yes	10.496	No	258.981	1.196999
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.174	Yes	46.402	No	40.841	7.590412
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	5.147	Yes	3.512	Yes	267.294	0.722051
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	1.431	Yes	5.518	Yes	111.501	1.730926

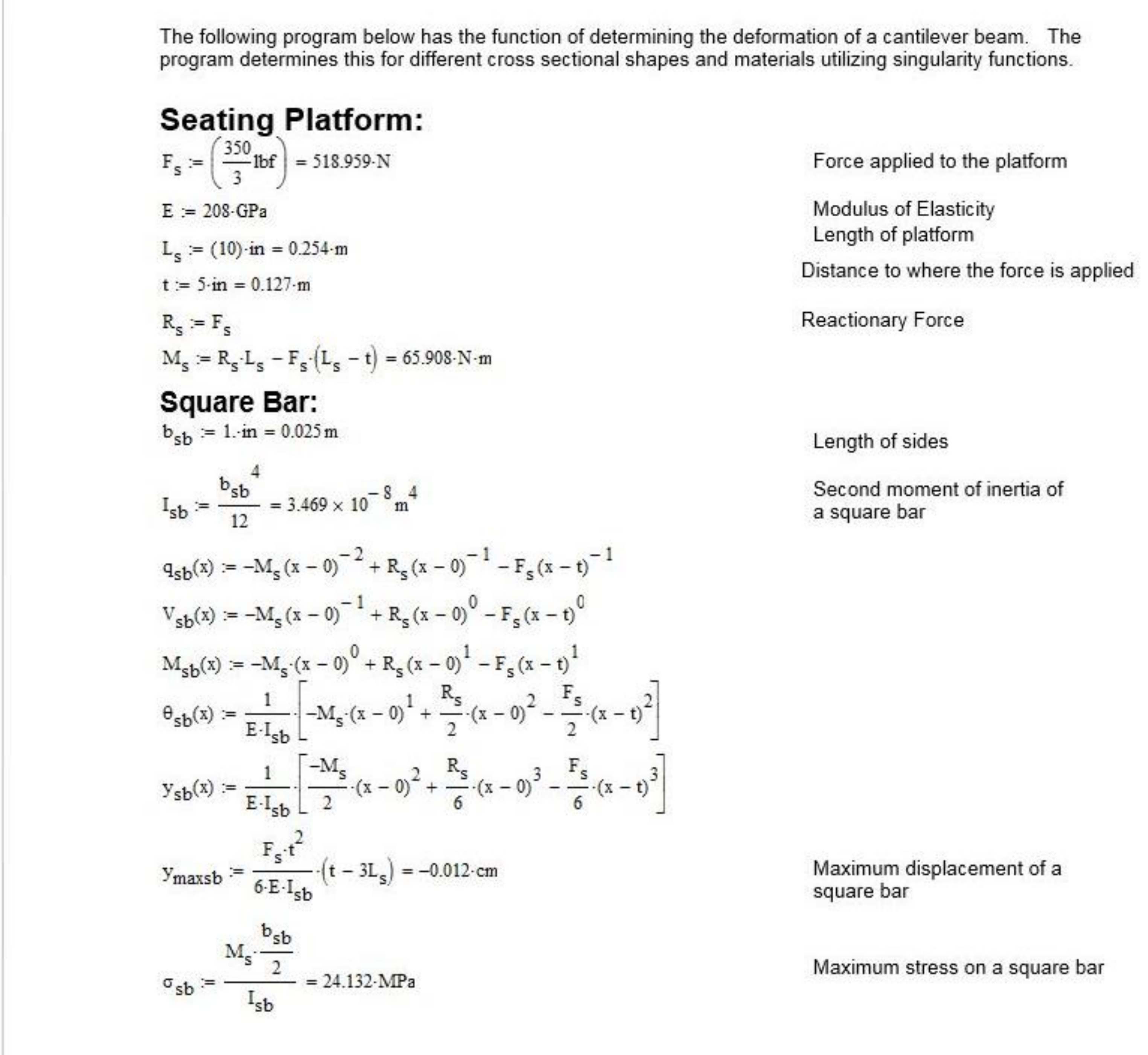
Table 13: Foot Platform Deformation Chart - 350 lbs.



Foot Platform Deformation with 350lbs Supported Weight

Material	Cross Sectional Shape	Cross Sectional Area Dimensions		I, Area Moment of Inertia	Maximum Deflection at Point ef (cm)	Meets Deflection Requirements	Weight of Platform	Meets Weight Requirement	Stress (MPa)	Factor of Safety
		WidthxHeight/Diameter	Wall Thickness							
AISI 1018	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	7.768	Yes	7.385	Yes	608.118	0.468659
AISI 1018	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.486	Yes	29.54	No	76.015	3.74926
AISI 4140	Square Bar	.5 in.	-	$2.168 * 10^{-9}\ m^4$	7.656	Yes	7.385	Yes	608.118	0.978429
AISI 4140	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	0.479	Yes	29.54	No	76.015	7.827402
2024-T351	Square Bar	0.5 in.	-	$2.168 * 10^{-9}\ m^4$	22.118	No	2.773	Yes	608.118	0.407816
2024-T351	Square Bar	1 in.	-	$3.469 * 10^{-8}\ m^4$	1.382	Yes	11.091	No	76.015	3.262514
AISI 1018	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	3.884	Yes	3.693	Yes	608.118	0.468659
AISI 1018	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	1.151	Yes	5.539	Yes	270.274	1.054485
AISI 4140	Rectangular Bar	0.125 in. x 1 in.	-	$4.336 * 10^{-9}\ m^4$	3.828	Yes	3.693	Yes	608.118	0.978429
AISI 4140	Rectangular Bar	0.125 in. x 1.5 in.	-	$1.463 * 10^{-8}\ m^4$	1.134	Yes	5.539	Yes	270.274	2.20147
2024-T351	Rectangular Bar	0.5 in. x 1 in.	-	$1.734 * 10^{-8}\ m^4$	2.765	Yes	5.545	Yes	152.029	1.631268
2024-T351	Rectangular Bar	0.5 in. x 1.5 in.	-	$5.853 * 10^{-8}\ m^4$	0.819	Yes	8.318	Yes	67.569	3.670322
A513-Type 5 (1020)	Rectangular Tubing	1 in. x .5 in.	0.065 in.	$5.01 * 10^{-9}\ m^4$	3.362	Yes	2.755	Yes	526.305	0.589012
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .5 in.	0.065 in.	$1.395 * 10^{-8}\ m^4$	1.207	Yes	3.715	Yes	283.580	1.093166
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x .75 in.	0.120 in.	$3.037 * 10^{-8}\ m^4$	0.555	Yes	7.55	Yes	130.227	2.380459
A513-Type 5 (1020)	Rectangular Tubing	1.5 in. x 1 in.	0.120 in.	$3.685 * 10^{-8}\ m^4$	0.457	Yes	8.437	Yes	107.335	2.888154
6061-T6	Rectangular Tubing	1.5 in. x 1 in.	0.125 in.	$3.817 * 10^{-8}\ m^4$	1.33	Yes	3.034	Yes	103.624	1.862503
6061-T6	Rectangular Tubing	2 in. x 1 in.	0.125 in.	$7.743 * 10^{-8}\ m^4$	0.656	Yes	3.673	Yes	68.108	2.833735
AISI 1018	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.824	Yes	23.201	No	129.047	2.208498
AISI 1018	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.163	Yes	52.202	No	38.236	7.453709
AISI 4130	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	0.845	Yes	23.119	No	129.047	3.742822
AISI 4130	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.167	Yes	52.019	No	38.236	12.63207
2024-T351	Round Bar	1 in.	-	$2.043 * 10^{-8}\ m^4$	2.347	Yes	8.71	Yes	129.047	1.92178
2024-T351	Round Bar	1.5 in.	-	$1.034 * 10^{-7}\ m^4$	0.464	Yes	19.599	No	38.236	6.486034
AISI 4130	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	1.978	Yes	10.459	No	302.144	1.598576
AISI 4130	Round Tubing	1.5 in.	.116 in.	$2.847 * 10^{-8}\ m^4$	0.606	Yes	14.847	No	138.906	3.477172
A513-Type 5 (1020)	Round Tubing	1 in.	.13 in.	$8.726 * 10^{-9}\ m^4$	1.93	Yes	10.496	No	302.144	1.026001
A513-Type 5 (1020)	Round Tubing	1.5 in.	.5 in.	$8.3 * 10^{-8}\ m^4$	0.203	Yes	46.402	No	47.648	6.506044
6061-T6	Round Tubing	1 in.	0.125 in.	$8.455 * 10^{-9}\ m^4$	6.005	Yes	3.512	Yes	311.843	0.618901
6061-T6	Round Tubing	1.5 in.	0.125 in.	$3.04 * 10^{-8}\ m^4$	1.67	Yes	5.518	Yes	130.084	1.483657

APPENDIX H: MathCad of Deflection and Stress – Seat Platform



The following program below has the function of determining the deformation of a cantilever beam. The program determines this for different cross sectional shapes and materials utilizing singularity functions.

Seating Platform:

$F_s := \left(\frac{350}{3}\text{lbf}\right) = 518.959 \cdot \text{N}$ Force applied to the platform

$E := 208 \cdot \text{GPa}$ Modulus of Elasticity

$L_s := (10) \cdot \text{in} = 0.254 \cdot \text{m}$ Length of platform

$t := 5 \cdot \text{in} = 0.127 \cdot \text{m}$ Distance to where the force is applied

$R_s := F_s$ Reactionary Force

$M_s := R_s \cdot L_s - F_s \cdot (L_s - t) = 65.908 \cdot \text{N} \cdot \text{m}$

Square Bar:

$b_{sb} := 1. \cdot \text{in} = 0.025\,\text{m}$ Length of sides

$I_{sb} := \frac{{b_{sb}}^4}{12} = 3.469 \times 10^{-8}\,\text{m}^4$ Second moment of inertia of a square bar

$q_{sb}(x) := -M_s\,(x-0)^{-2} + R_s\,(x-0)^{-1} - F_s\,(x-t)^{-1}$

$V_{sb}(x) := -M_s\,(x-0)^{-1} + R_s\,(x-0)^{0} - F_s\,(x-t)^{0}$

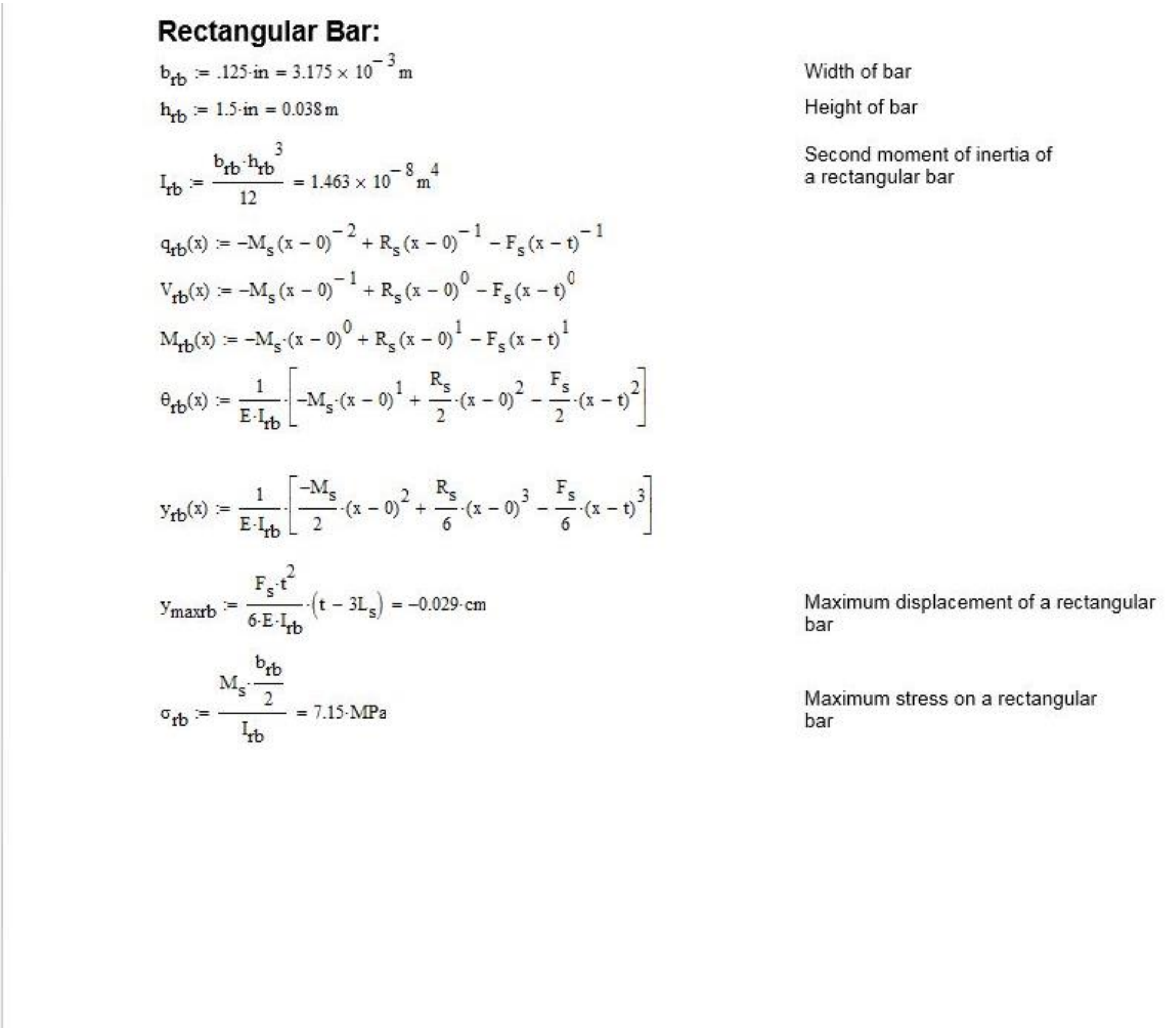
$M_{sb}(x) := -M_s \cdot (x-0)^{0} + R_s\,(x-0)^{1} - F_s\,(x-t)^{1}$

$\theta_{sb}(x) := \frac{1}{E \cdot I_{sb}} \cdot \left[-M_s \cdot (x-0)^1 + \frac{R_s}{2} \cdot (x-0)^2 - \frac{F_s}{2} \cdot (x-t)^2\right]$

$y_{sb}(x) := \frac{1}{E \cdot I_{sb}} \cdot \left[\frac{-M_s}{2} \cdot (x-0)^2 + \frac{R_s}{6} \cdot (x-0)^3 - \frac{F_s}{6} \cdot (x-t)^3\right]$

$y_{maxsb} := \frac{F_s \cdot t^2}{6 \cdot E \cdot I_{sb}} \cdot (t - 3L_s) = -0.012 \cdot \text{cm}$ Maximum displacement of a square bar

$\sigma_{sb} := \frac{M_s \cdot \frac{b_{sb}}{2}}{I_{sb}} = 24.132 \cdot \text{MPa}$ Maximum stress on a square bar



Rectangular Bar:

$b_{rb} := .125 \cdot in = 3.175 \times 10^{-3} m$ Width of bar

$h_{rb} := 1.5 \cdot in = 0.038 m$ Height of bar

$$I_{rb} := \frac{b_{rb} \cdot h_{rb}^{3}}{12} = 1.463 \times 10^{-8} m^{4}$$

Second moment of inertia of a rectangular bar

$$q_{rb}(x) := -M_s (x-0)^{-2} + R_s (x-0)^{-1} - F_s (x-t)^{-1}$$

$$V_{rb}(x) := -M_s (x-0)^{-1} + R_s (x-0)^{0} - F_s (x-t)^{0}$$

$$M_{rb}(x) := -M_s \cdot (x-0)^{0} + R_s (x-0)^{1} - F_s (x-t)^{1}$$

$$\theta_{rb}(x) := \frac{1}{E \cdot I_{rb}} \cdot \left[-M_s \cdot (x-0)^{1} + \frac{R_s}{2} \cdot (x-0)^{2} - \frac{F_s}{2} \cdot (x-t)^{2} \right]$$

$$y_{rb}(x) := \frac{1}{E \cdot I_{rb}} \cdot \left[\frac{-M_s}{2} \cdot (x-0)^{2} + \frac{R_s}{6} \cdot (x-0)^{3} - \frac{F_s}{6} \cdot (x-t)^{3} \right]$$

$$y_{maxrb} := \frac{F_s \cdot t^{2}}{6 \cdot E \cdot I_{rb}} \cdot \left(t - 3L_s \right) = -0.029 \cdot cm$$

Maximum displacement of a rectangular bar

$$\sigma_{rb} := \frac{M_s \cdot \frac{b_{rb}}{2}}{I_{rb}} = 7.15 \cdot MPa$$

Maximum stress on a rectangular bar

Rectangular Tubing:

$b_{rt} := (.5in) = 0.013\,m$

Width of bar

$$d_{rt} := \left(1.5in \cdot 0.0254\,\frac{m}{in}\right) = 0.038\,m$$

Height of bar

$thickness_{rt} := (.065in) = 1.651 \times 10^{-3}\,m$

Wall thickness

$h_{rt} := \left(b_{rt} - thickness_{rt}\right) = 0.011\,m$

Inner width of bar

$k_{rt} := \left(d_{rt} - thickness_{rt}\right) = 0.036\,m$

Inner height of bar

$$I_{rt} := \frac{b_{rt} \cdot d_{rt}^{\,3} - h_{rt} \cdot k_{rt}^{\,3}}{12} = 1.395 \times 10^{-8}\,m^4$$

Second moment of inertia of
a rectangular tube

$$q_{rt}(x) := -M_s\,(x-0)^{-2} + R_s\,(x-0)^{-1} - F_s\,(x-t)^{-1}$$

$$V_{rt}(x) := -M_s\,(x-0)^{-1} + R_s\,(x-0)^{0} - F_s\,(x-t)^{0}$$

$$M_{rt}(x) := -M_s \cdot (x-0)^{0} + R_s\,(x-0)^{1} - F_s\,(x-t)^{1}$$

$$\theta_{rt}(x) := \frac{1}{E \cdot I_{rt}} \cdot \left[-M_s \cdot (x-0)^1 + \frac{R_s}{2} \cdot (x-0)^2 - \frac{F_s}{2} \cdot (x-t)^2\right]$$

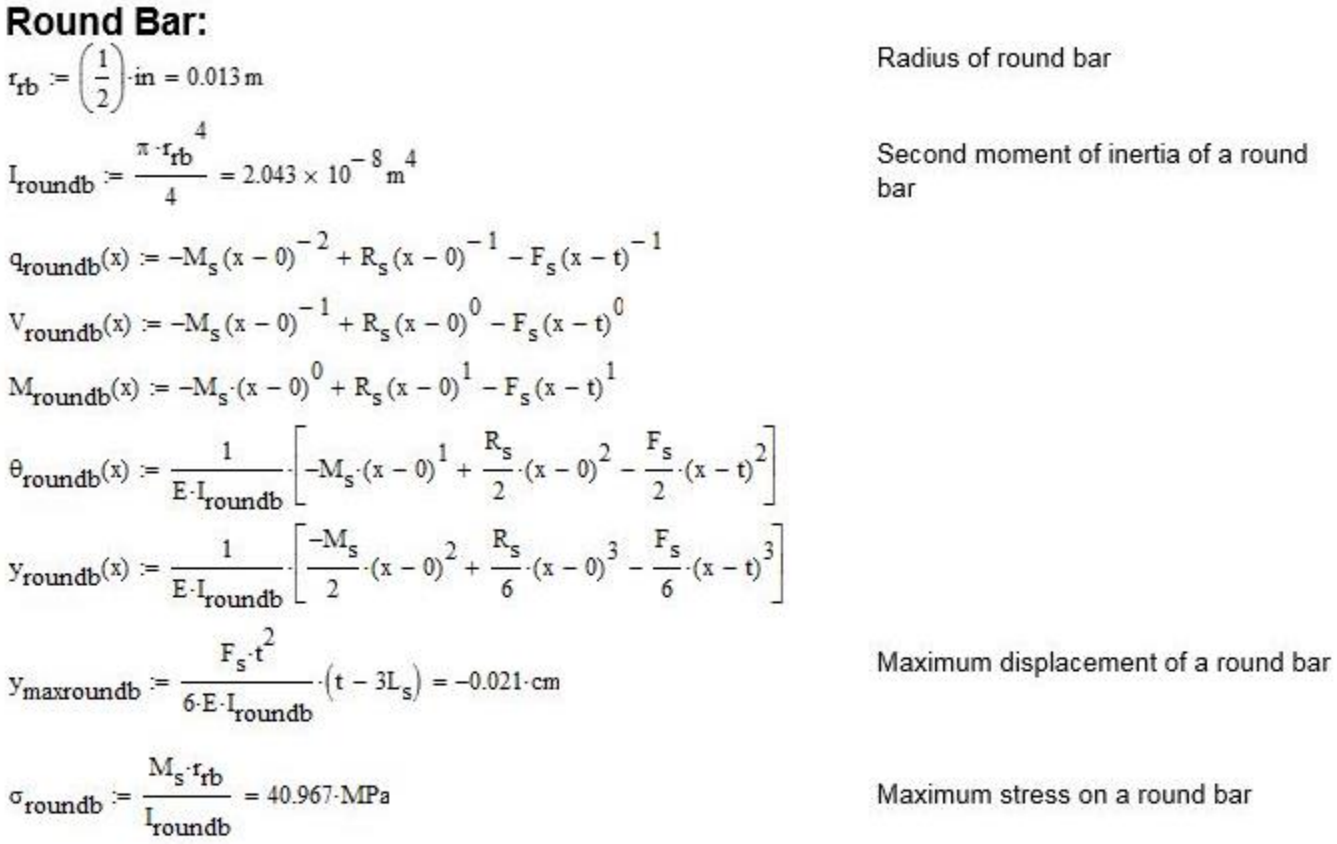
$$y_{rt}(x) := \frac{1}{E \cdot I_{rt}} \cdot \left[\frac{-M_s}{2} \cdot (x-0)^2 + \frac{R_s}{6} \cdot (x-0)^3 - \frac{F_s}{6} \cdot (x-t)^3\right]$$

$$y_{maxrt} := \frac{F_s \cdot t^2}{6 \cdot E \cdot I_{rt}} \cdot \left(t - 3L_s\right) = -0.031 \cdot cm$$

Maximum displacement of a rectangular
tube

$$\sigma_{rt} := \frac{M_s \cdot \frac{b_{rt}}{2}}{I_{rt}} = 30.008 \cdot MPa$$

Maximum stress on a rectangular tube



Round Bar:

$$r_{rb} := \left(\frac{1}{2}\right) \cdot in = 0.013\,m$$

Radius of round bar

$$I_{roundb} := \frac{\pi \cdot r_{rb}^{\,4}}{4} = 2.043 \times 10^{-8}\,m^4$$

Second moment of inertia of a round bar

$$q_{roundb}(x) := -M_s\,(x-0)^{-2} + R_s\,(x-0)^{-1} - F_s\,(x-t)^{-1}$$

$$V_{roundb}(x) := -M_s\,(x-0)^{-1} + R_s\,(x-0)^{0} - F_s\,(x-t)^{0}$$

$$M_{roundb}(x) := -M_s \cdot (x-0)^{0} + R_s\,(x-0)^{1} - F_s\,(x-t)^{1}$$

$$\theta_{roundb}(x) := \frac{1}{E \cdot I_{roundb}} \cdot \left[-M_s \cdot (x-0)^1 + \frac{R_s}{2} \cdot (x-0)^2 - \frac{F_s}{2} \cdot (x-t)^2 \right]$$

$$y_{roundb}(x) := \frac{1}{E \cdot I_{roundb}} \cdot \left[\frac{-M_s}{2} \cdot (x-0)^2 + \frac{R_s}{6} \cdot (x-0)^3 - \frac{F_s}{6} \cdot (x-t)^3 \right]$$

$$y_{maxroundb} := \frac{F_s \cdot t^2}{6 \cdot E \cdot I_{roundb}} \cdot \left(t - 3L_s\right) = -0.021 \cdot cm$$

Maximum displacement of a round bar

$$\sigma_{roundb} := \frac{M_s \cdot r_{rb}}{I_{roundb}} = 40.967 \cdot MPa$$

Maximum stress on a round bar

Round Tube:

$d_o := 1 \cdot in = 0.025\,m$

Outer diameter of round tube

$thickness := (.13in) = 3.302 \times 10^{-3}\,m$

Wall thickness

$d_i := d_o - thickness = 0.022\,m$

Inner Diameter of round tube

$$I_{roundt} := \frac{\pi \cdot \left(d_o^{\,4} - d_i^{\,4}\right)}{64} = 8.726 \times 10^{-9}\,m^4$$

Second moment of inertia of a round tube

$$q_{roundtube}(x) := -M_s\,(x-0)^{-2} + R_s\,(x-0)^{-1} - F_s\,(x-t)^{-1}$$

$$V_{roundtube}(x) := -M_s\,(x-0)^{-1} + R_s\,(x-0)^{0} - F_s\,(x-t)^{0}$$

$$M_{roundtube}(x) := -M_s \cdot (x-0)^{0} + R_s\,(x-0)^{1} - F_s\,(x-t)^{1}$$

$$\theta_{roundtube}(x) := \frac{1}{E \cdot I_{roundt}} \cdot \left[-M_s \cdot (x-0)^{1} + \frac{R_s}{2} \cdot (x-0)^{2} - \frac{F_s}{2} \cdot (x-t)^{2}\right]$$

$$y_{roundtube}(x) := \frac{1}{E \cdot I_{roundt}} \cdot \left[\frac{-M_s}{2} \cdot (x-0)^{2} + \frac{R_s}{6} \cdot (x-0)^{3} - \frac{F_s}{6} \cdot (x-t)^{3}\right]$$

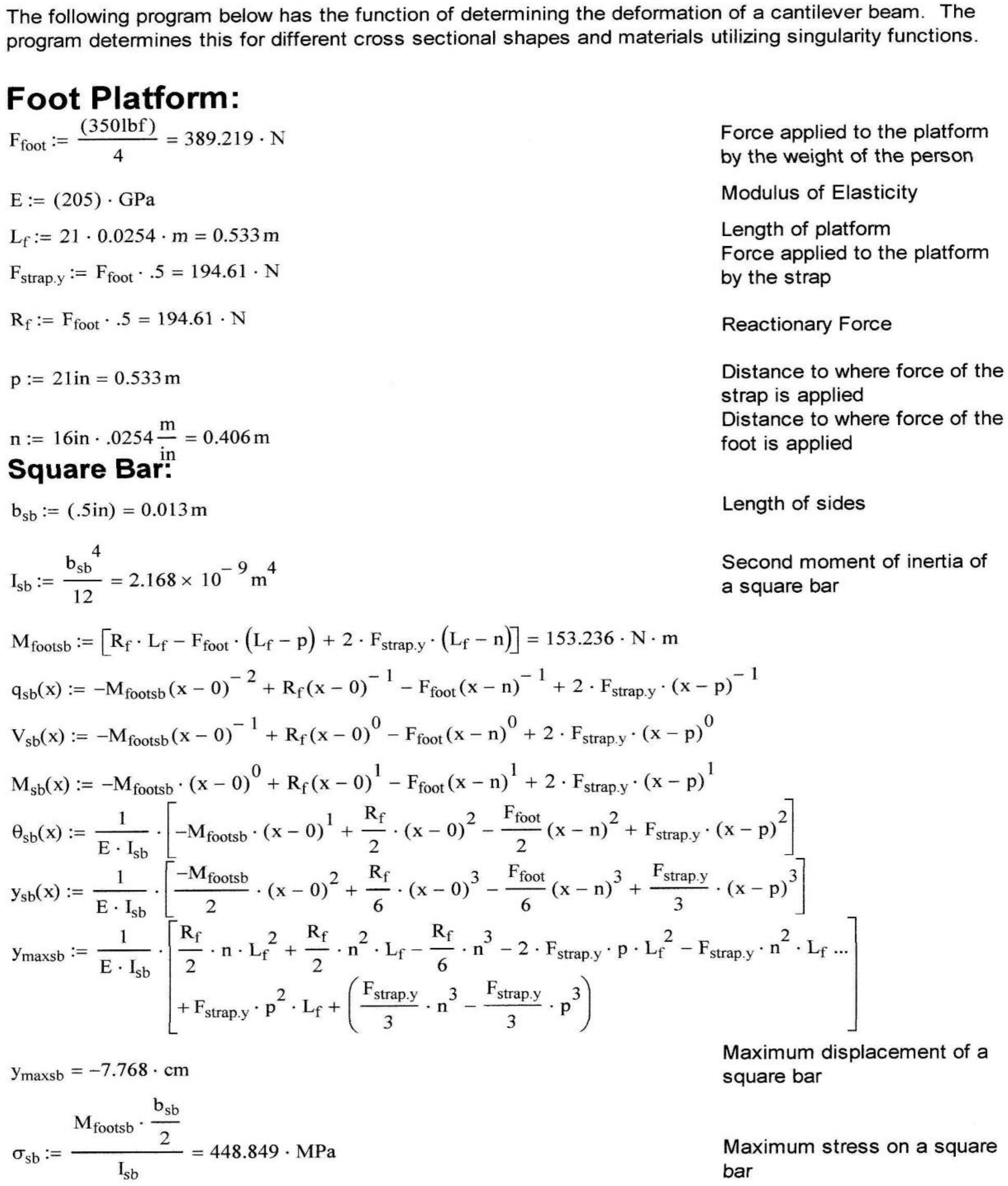
$$y_{maxroundt} := \frac{F_s \cdot t^2}{6 \cdot E \cdot I_{roundt}} \cdot \left(t - 3L_s\right) = -0.049 \cdot cm$$

Maximum displacemet of a round tube

$$\sigma_{roundt} := \frac{M_s \cdot \frac{d_o}{2}}{I_{roundt}} = 95.919 \cdot MPa$$

Maximum stress on a round tube

APPENDIX I: MathCad of Deflection and Stress – Foot Platform



The following program below has the function of determining the deformation of a cantilever beam. The program determines this for different cross sectional shapes and materials utilizing singularity functions.

Foot Platform:

$$F_{foot} := \frac{(350lbf)}{4} = 389.219 \cdot N$$

Force applied to the platform by the weight of the person

$$E := (205) \cdot GPa$$

Modulus of Elasticity

$$L_f := 21 \cdot 0.0254 \cdot m = 0.533\,m$$

Length of platform

$$F_{strap.y} := F_{foot} \cdot .5 = 194.61 \cdot N$$

Force applied to the platform by the strap

$$R_f := F_{foot} \cdot .5 = 194.61 \cdot N$$

Reactionary Force

$$p := 21in = 0.533\,m$$

Distance to where force of the strap is applied

$$n := 16in \cdot .0254 \frac{m}{in} = 0.406\,m$$

Distance to where force of the foot is applied

Square Bar:

$$b_{sb} := (.5in) = 0.013\,m$$

Length of sides

$$I_{sb} := \frac{b_{sb}^{\;4}}{12} = 2.168 \times 10^{-9}\,m^4$$

Second moment of inertia of a square bar

$$M_{footsb} := \left[R_f \cdot L_f - F_{foot} \cdot \left(L_f - p\right) + 2 \cdot F_{strap.y} \cdot \left(L_f - n\right)\right] = 153.236 \cdot N \cdot m$$

$$q_{sb}(x) := -M_{footsb}(x-0)^{-2} + R_f(x-0)^{-1} - F_{foot}(x-n)^{-1} + 2 \cdot F_{strap.y} \cdot (x-p)^{-1}$$

$$V_{sb}(x) := -M_{footsb}(x-0)^{-1} + R_f(x-0)^{0} - F_{foot}(x-n)^{0} + 2 \cdot F_{strap.y} \cdot (x-p)^{0}$$

$$M_{sb}(x) := -M_{footsb} \cdot (x-0)^{0} + R_f(x-0)^{1} - F_{foot}(x-n)^{1} + 2 \cdot F_{strap.y} \cdot (x-p)^{1}$$

$$\theta_{sb}(x) := \frac{1}{E \cdot I_{sb}} \cdot \left[-M_{footsb} \cdot (x-0)^{1} + \frac{R_f}{2} \cdot (x-0)^{2} - \frac{F_{foot}}{2}(x-n)^{2} + F_{strap.y} \cdot (x-p)^{2}\right]$$

$$y_{sb}(x) := \frac{1}{E \cdot I_{sb}} \cdot \left[\frac{-M_{footsb}}{2} \cdot (x-0)^{2} + \frac{R_f}{6} \cdot (x-0)^{3} - \frac{F_{foot}}{6}(x-n)^{3} + \frac{F_{strap.y}}{3} \cdot (x-p)^{3}\right]$$

$$y_{maxsb} := \frac{1}{E \cdot I_{sb}} \cdot \left[\begin{array}{l}\frac{R_f}{2} \cdot n \cdot L_f^{\;2} + \frac{R_f}{2} \cdot n^2 \cdot L_f - \frac{R_f}{6} \cdot n^3 - 2 \cdot F_{strap.y} \cdot p \cdot L_f^{\;2} - F_{strap.y} \cdot n^2 \cdot L_f \ldots \\ + F_{strap.y} \cdot p^2 \cdot L_f + \left(\frac{F_{strap.y}}{3} \cdot n^3 - \frac{F_{strap.y}}{3} \cdot p^3\right)\end{array}\right]$$

$$y_{maxsb} = -7.768 \cdot cm$$

Maximum displacement of a square bar

$$\sigma_{sb} := \frac{M_{footsb} \cdot \frac{b_{sb}}{2}}{I_{sb}} = 448.849 \cdot MPa$$

Maximum stress on a square bar

Rectangular Bar:

$b_{rb} := (.5in) = 0.013\,m$

Width of bar

$h_{rb} := (1.in) = 0.025\,m$

Height of bar

$$I_{rb} := \frac{b_{rb} \cdot h_{rb}^{3}}{12} = 1.734 \times 10^{-8}\,m^{4}$$

Second moment of inertia of a rectangular bar

$$M_{footrb} := \left[R_f \cdot L_f - F_{foot} \cdot \left(L_f - p\right) + 2 \cdot F_{strap.y} \cdot \left(L_f - n\right)\right] = 153.236 \cdot N \cdot m$$

$$q_{rb}(x) := -M_{footrb}(x-0)^{-2} + R_f(x-0)^{-1} - F_{foot}(x-n)^{-1} + 2 \cdot F_{strap.y} \cdot (x-p)^{-1}$$

$$V_{rb}(x) := -M_{footrb}(x-0)^{-1} + R_f(x-0)^{0} - F_{foot}(x-n)^{0} + 2 \cdot F_{strap.y} \cdot (x-p)^{0}$$

$$M_{rb}(x) := -M_{footrb} \cdot (x-0)^{0} + R_f(x-0)^{1} - F_{foot}(x-n)^{1} + 2 \cdot F_{strap.y} \cdot (x-p)^{1}$$

$$\theta_{rb}(x) := \frac{1}{E \cdot I_{rb}} \cdot \left[-M_{footrb} \cdot (x-0)^{1} + \frac{R_f}{2} \cdot (x-0)^{2} - \frac{F_{foot}}{2}(x-n)^{2} + F_{strap.y} \cdot (x-p)^{2}\right]$$

$$y_{rb}(x) := \frac{1}{E \cdot I_{rb}} \cdot \left[\frac{-M_{footrb}}{2} \cdot (x-0)^{2} + \frac{R_f}{6} \cdot (x-0)^{3} - \frac{F_{foot}}{6}(x-n)^{3} + \frac{F_{strap.y}}{3} \cdot (x-p)^{3}\right]$$

$$y_{maxrb} := \frac{1}{E \cdot I_{rb}} \cdot \left[\begin{matrix}\frac{R_f}{2} \cdot n \cdot L_f^{2} + \frac{R_f}{2} \cdot n^{2} \cdot L_f - \frac{R_f}{6} \cdot n^{3} - 2 \cdot F_{strap.y} \cdot p \cdot L_f^{2} - F_{strap.y} \cdot n^{2} \cdot L_f \ldots \\ + F_{strap.y} \cdot p^{2} \cdot L_f + \left(\frac{F_{strap.y}}{3} \cdot n^{3} - \frac{F_{strap.y}}{3} \cdot p^{3}\right)\end{matrix}\right]$$

$y_{maxrb} = -0.971 \cdot cm$

Maximum displacement of a rectangular bar

$$\sigma_{rb} := \frac{M_{footrb} \cdot \frac{h_{rb}}{2}}{I_{rb}} = 112.212 \cdot MPa$$

Maximum stress on a rectangular bar

Rectangular Tubing:

$$b_{rt} := (1.in) = 0.025\,m$$

Width of bar

$$d_{rt} := (2.in) = 0.051\,m$$

Height of bar

$$thickness_{rt} := (0.125in) = 3.175 \times 10^{-3}\,m$$

Wall thickness

$$h_{rt} := \left(b_{rt} - thickness_{rt}\right) = 0.022\,m$$

Inner width of bar

$$k_{rt} := \left(d_{rt} - thickness_{rt}\right) = 0.048\,m$$

Inner height of bar

$$I_{rt} := \frac{b_{rt} \cdot d_{rt}^{\;3} - h_{rt} \cdot k_{rt}^{\;3}}{12}$$

Second moment of inertia of a rectangular tube

$$M_{footrt} := \left\lceil R_f \cdot L_f - \frac{F_{foot}}{4} \cdot \left(L_f - p\right) + 2 \cdot F_{strap.y} \cdot \left(L_f - n\right) \right\rceil = 153.236 \cdot N \cdot m$$

$$q_{rt}(x) := -M_{footrt}(x-0)^{-2} + R_f(x-0)^{-1} - F_{foot}(x-n)^{-1} + 2 \cdot F_{strap.y} \cdot (x-p)^{-1}$$

$$V_{rt}(x) := -M_{footrt}(x-0)^{-1} + R_f(x-0)^{0} - F_{foot}(x-n)^{0} + 2 \cdot F_{strap.y} \cdot (x-p)^{0}$$

$$M_{rt}(x) := -M_{footrt} \cdot (x-0)^{0} + R_f(x-0)^{1} - F_{foot}(x-n)^{1} + 2 \cdot F_{strap.y} \cdot (x-p)^{1}$$

$$\theta_{rt}(x) := \frac{1}{E \cdot I_{rt}} \cdot \left[-M_{footrt} \cdot (x-0)^{1} + \frac{R_f}{2} \cdot (x-0)^{2} - \frac{F_{foot}}{2}(x-n)^{2} + F_{strap.y} \cdot (x-p)^{2}\right]$$

$$y_{rt}(x) := \frac{1}{E \cdot I_{rt}} \cdot \left[\frac{-M_{footrt}}{2} \cdot (x-0)^{2} + \frac{R_f}{6} \cdot (x-0)^{3} - \frac{F_{foot}}{6}(x-n)^{3} + \frac{F_{strap.y}}{3} \cdot (x-p)^{3}\right]$$

$$y_{maxrt} := \frac{1}{E \cdot I_{rt}} \cdot \left[\begin{array}{l} \frac{R_f}{2} \cdot n \cdot L_f^{\;2} + \frac{R_f}{2} \cdot n^{2} \cdot L_f - \frac{R_f}{6} \cdot n^{3} - 2 \cdot F_{strap.y} \cdot p \cdot L_f^{\;2} - F_{strap.y} \cdot n^{2} \cdot L_f \ldots \\ + F_{strap.y} \cdot p^{2} \cdot L_f + \left(\frac{F_{strap.y}}{3} \cdot n^{3} - \frac{F_{strap.y}}{3} \cdot p^{3}\right) \end{array}\right]$$

$$y_{maxrt} = -0.218 \cdot cm$$

Maximum displacement of a rectangular tube

$$\sigma_{rt} := \frac{M_{footrt} \cdot \frac{d_{rt}}{2}}{I_{rt}} = 50.27 \cdot MPa$$

Maximum stress on a rectangular tube

Round Bar:

$$r_{rb} := \left(\frac{1.5\text{in}}{2}\right) = 0.019\,\text{m}$$

Radius of round bar

$$I_{roundb} := \frac{\pi \cdot {r_{rb}}^{4}}{4} = 1.034 \times 10^{-7}\,\text{m}^{4}$$

Second moment of inertia of a round bar

$$M_{footroundb} := \left[R_f \cdot L_f - F_{foot} \cdot \left(L_f - p\right) + 2 \cdot F_{strap.y} \cdot \left(L_f - n\right)\right] = 153.236 \cdot \text{N} \cdot \text{m}$$

$$q_{roundb}(x) := -M_{footroundb}\,(x-0)^{-2} + R_f\,(x-0)^{-1} - F_{foot}\,(x-n)^{-1} + 2 \cdot F_{strap.y} \cdot (x-p)^{-1}$$

$$V_{roundb}(x) := -M_{footroundb}\,(x-0)^{-1} + R_f\,(x-0)^{0} - F_{foot}\,(x-n)^{0} + 2 \cdot F_{strap.y} \cdot (x-p)^{0}$$

$$M_{roundb}(x) := -M_{footroundb} \cdot (x-0)^{0} + R_f\,(x-0)^{1} - F_{foot}\,(x-n)^{1} + 2 \cdot F_{strap.y} \cdot (x-p)^{1}$$

$$\theta_{roundb}(x) := \frac{1}{E \cdot I_{rb}} \cdot \left[-M_{footroundb} \cdot (x-0)^{1} + \frac{R_f}{2} \cdot (x-0)^{2} - \frac{F_{foot}}{2}\,(x-n)^{2} + F_{strap.y} \cdot (x-p)^{2}\right]$$

$$y_{roundb}(x) := \frac{1}{E \cdot I_{rb}} \cdot \left[\frac{-M_{footroundb}}{2} \cdot (x-0)^{2} + \frac{R_f}{6} \cdot (x-0)^{3} - \frac{F_{foot}}{6}\,(x-n)^{3} + \frac{F_{strap.y}}{3} \cdot (x-p)^{3}\right]$$

$$y_{max.rb} := \frac{1}{E \cdot I_{rb}} \cdot \left[\begin{array}{l}\frac{R_f}{2} \cdot n \cdot {L_f}^{2} + \frac{R_f}{2} \cdot n^{2} \cdot L_f - \frac{R_f}{6} \cdot n^{3} - 2 \cdot F_{strap.y} \cdot p \cdot {L_f}^{2} - F_{strap.y} \cdot n^{2} \cdot L_f \ldots \\ + F_{strap.y} \cdot p^{2} \cdot L_f + \left(\frac{F_{strap.y}}{3} \cdot n^{3} - \frac{F_{strap.y}}{3} \cdot p^{3}\right)\end{array}\right]$$

$$y_{max.rb} = -0.971 \cdot \text{cm}$$

Maximum displacement of a round bar

$$\sigma_{roundb} := \frac{M_{footroundb} \cdot r_{rb}}{I_{roundb}} = 28.222 \cdot \text{MPa}$$

Maximum stress on a round bar

Round Tube:

Outer diameter of round tube

$$d_o := (1.\text{in}) = 0.025\,\text{m}$$

Wall thickness

$$\text{thickness}_{\text{roundt}} := (0.125\text{in}) = 3.175 \times 10^{-3}\,\text{m}$$

Inner Diameter of round tube

$$d_i := \left(d_o - \text{thickness}_{\text{roundt}}\right) = 0.022\,\text{m}$$

Second moment of inertia of a round tube

$$I_{\text{roundt}} := \frac{\pi \cdot \left(d_o{}^{4} - d_i{}^{4}\right)}{64} = 8.455 \times 10^{-9}\,m^{4}$$

$$M_{\text{footroundt}} := \left[R_f \cdot L_f - F_{\text{foot}} \cdot \left(L_f - p\right) + 2 \cdot F_{\text{strap.y}} \cdot \left(L_f - n\right)\right] = 153.236 \cdot \text{N} \cdot \text{m}$$

$$q_{\text{roundt}}(x) := -M_{\text{footroundt}}\,(x-0)^{-2} + R_f\,(x-0)^{-1} - F_{\text{foot}}\,(x-n)^{-1} + 2 \cdot F_{\text{strap.y}} \cdot (x-p)^{-1}$$

$$V_{\text{roundt}}(x) := -M_{\text{footroundt}}\,(x-0)^{-1} + R_f\,(x-0)^{0} - F_{\text{foot}}\,(x-n)^{0} + 2 \cdot F_{\text{strap.y}} \cdot (x-p)^{0}$$

$$M_{\text{roundt}}(x) := -M_{\text{footroundt}} \cdot (x-0)^{0} + R_f\,(x-0)^{1} - F_{\text{foot}}\,(x-n)^{1} + 2 \cdot F_{\text{strap.y}} \cdot (x-p)^{1}$$

$$\theta_{\text{roundt}}(x) := \frac{1}{E \cdot I_{\text{roundt}}} \cdot \left[-M_{\text{footroundt}} \cdot (x-0)^{1} + \frac{R_f}{2} \cdot (x-0)^{2} - \frac{F_{\text{foot}}}{2}\,(x-n)^{2} + F_{\text{strap.y}} \cdot (x-p)^{2}\right]$$

$$y_{\text{roundt}}(x) := \frac{1}{E \cdot I_{\text{roundt}}} \cdot \left[\frac{-M_{\text{footroundt}}}{2} \cdot (x-0)^{2} + \frac{R_f}{6} \cdot (x-0)^{3} - \frac{F_{\text{foot}}}{6}\,(x-n)^{3} + \frac{F_{\text{strap.y}}}{3} \cdot (x-p)^{3}\right]$$

$$y_{\text{maxroundt}} := \frac{1}{E \cdot I_{\text{roundt}}} \cdot \left[\begin{array}{l} \frac{R_f}{2} \cdot n \cdot L_f{}^{2} + \frac{R_f}{2} \cdot n^{2} \cdot L_f - \frac{R_f}{6} \cdot n^{3} - 2 \cdot F_{\text{strap.y}} \cdot p \cdot L_f{}^{2} - F_{\text{strap.y}} \cdot n^{2} \cdot L_f \ldots \\ + F_{\text{strap.y}} \cdot p^{2} \cdot L_f + \left(\frac{F_{\text{strap.y}}}{3} \cdot n^{3} - \frac{F_{\text{strap.y}}}{3} \cdot p^{3}\right) \end{array}\right]$$

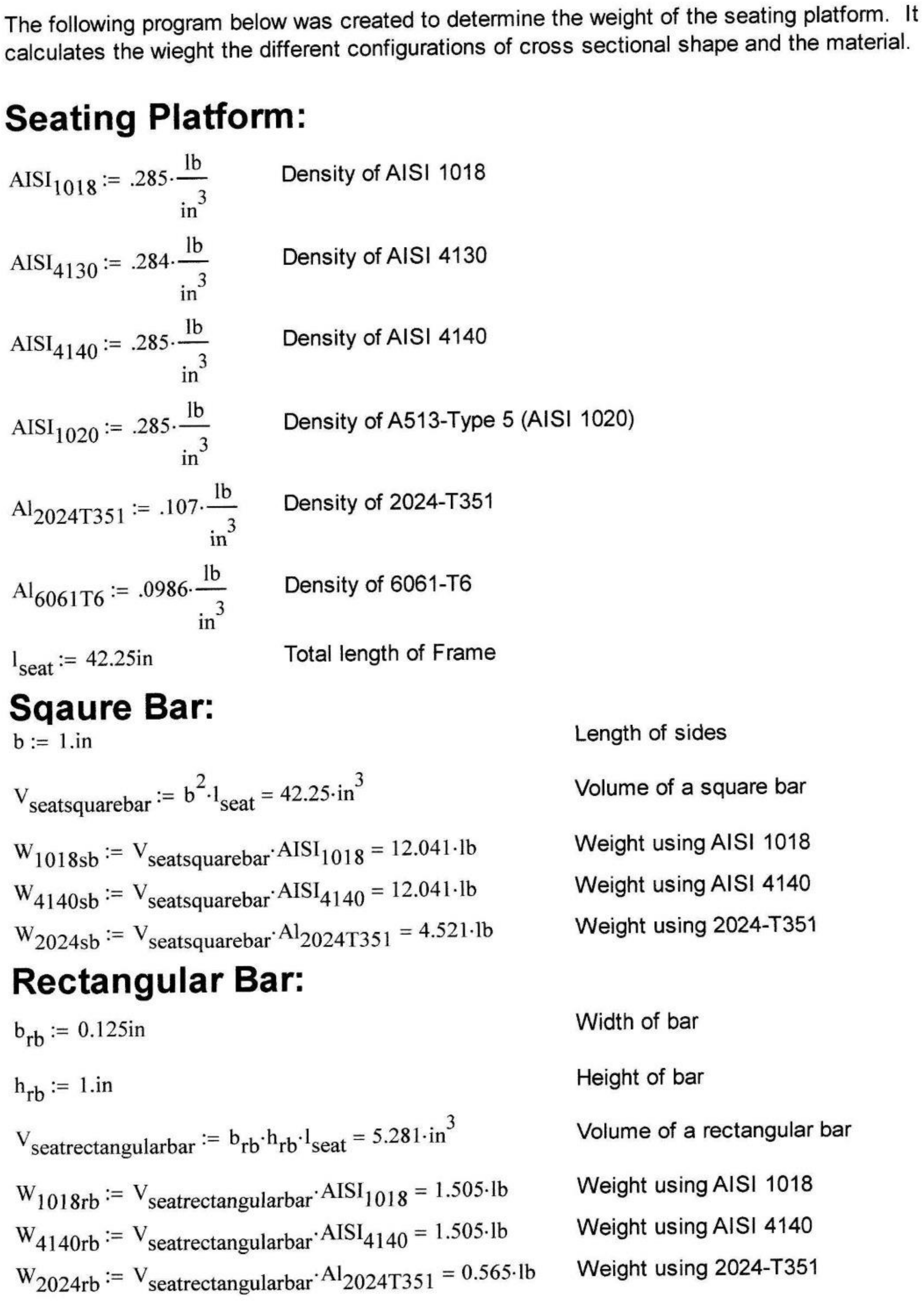
$$y_{\text{maxroundt}} = -1.992 \cdot \text{cm}$$

Maximum displacemet of a round tube

$$\sigma_{\text{roundt}} := \frac{M_{\text{footroundt}} \cdot \frac{d_o}{2}}{I_{\text{roundt}}} = 230.17 \cdot \text{MPa}$$

Maximum stress on a round tube

APPENDIX J: Prediction of Seat Platform Weight



The following program below was created to determine the weight of the seating platform. It calculates the wieght the different configurations of cross sectional shape and the material.

Seating Platform:

$AISI_{1018} := .285 \cdot \frac{lb}{in^3}$	Density of AISI 1018
$AISI_{4130} := .284 \cdot \frac{lb}{in^3}$	Density of AISI 4130
$AISI_{4140} := .285 \cdot \frac{lb}{in^3}$	Density of AISI 4140
$AISI_{1020} := .285 \cdot \frac{lb}{in^3}$	Density of A513-Type 5 (AISI 1020)
$Al_{2024T351} := .107 \cdot \frac{lb}{in^3}$	Density of 2024-T351
$Al_{6061T6} := .0986 \cdot \frac{lb}{in^3}$	Density of 6061-T6
$l_{seat} := 42.25in$	Total length of Frame

Sqaure Bar:

$b := 1.in$	Length of sides
$V_{seatsquarebar} := b^2 \cdot l_{seat} = 42.25 \cdot in^3$	Volume of a square bar
$W_{1018sb} := V_{seatsquarebar} \cdot AISI_{1018} = 12.041 \cdot lb$	Weight using AISI 1018
$W_{4140sb} := V_{seatsquarebar} \cdot AISI_{4140} = 12.041 \cdot lb$	Weight using AISI 4140
$W_{2024sb} := V_{seatsquarebar} \cdot Al_{2024T351} = 4.521 \cdot lb$	Weight using 2024-T351

Rectangular Bar:

$b_{rb} := 0.125in$	Width of bar
$h_{rb} := 1.in$	Height of bar
$V_{seatrectangularbar} := b_{rb} \cdot h_{rb} \cdot l_{seat} = 5.281 \cdot in^3$	Volume of a rectangular bar
$W_{1018rb} := V_{seatrectangularbar} \cdot AISI_{1018} = 1.505 \cdot lb$	Weight using AISI 1018
$W_{4140rb} := V_{seatrectangularbar} \cdot AISI_{4140} = 1.505 \cdot lb$	Weight using AISI 4140
$W_{2024rb} := V_{seatrectangularbar} \cdot Al_{2024T351} = 0.565 \cdot lb$	Weight using 2024-T351

Rectangular Tubing:

$b_{rt} := .5in$ Width of bar

$d_{rt} := 1.in$ Height of bar

$thickness := 0.065in$ Wall thickness

$V_{seatingrectangulartubing} := \left[b_{rt} \cdot d_{rt} - \left(b_{rt} - thickness\right)\left(d_{rt} - thickness\right)\right] \cdot l_{seat}$ Volume of a rectangular tube

$W_{1020rt} := V_{seatingrectangulartubing} \cdot AISI_{1020} = 1.123 \cdot lb$ Weight using AISI 1020

$W_{6061rt} := V_{seatingrectangulartubing} \cdot Al_{6061T6} = 0.389 \cdot lb$ Weight using 6061T6

Round Bar:

$r_{rb} := \frac{1.5}{2} in$ Radius of round bar

$V_{seatroundbar} := \pi \cdot {r_{rb}}^2 l_{seat} = 74.662 \cdot in^3$ Volume of Round Bar

$W_{1018} := V_{seatroundbar} \cdot AISI_{1018} = 21.279 \cdot lb$ Weight using AISI 1018

$W_{4130} := V_{seatroundbar} \cdot AISI_{4130} = 21.204 \cdot lb$ Weight using AISI 4130

$W_{2024} := V_{seatroundbar} \cdot Al_{2024T351} = 7.989 \cdot lb$ Weight using 2024-T351

Round Tubing:

$r_{rt} := \frac{1.5}{2} in$ Raduis of Round Tubing

$thickness := .116in$ Wall thickness

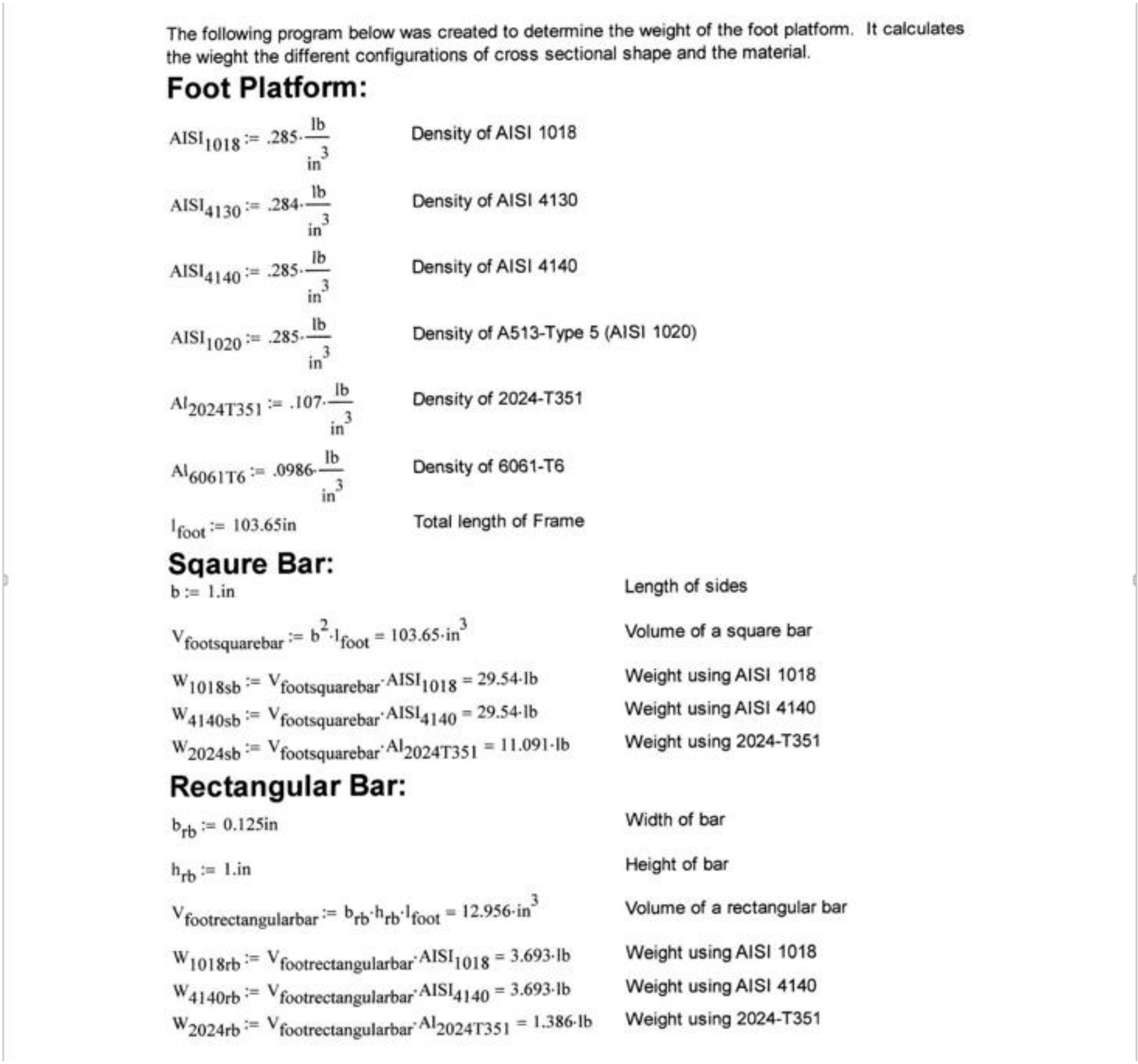
$V_{seatroundtube} := \left[{r_{rt}}^2 - \left(r_{rt} - thickness\right)^2\right] \cdot \pi \cdot l_{seat} = 21.309 \cdot in^3$ Volume of Round Tubing

$W_{4130roundtubing} := V_{seatroundtube} \cdot AISI_{4130} = 6.052 \cdot lb$ Weight using AISI 4130

$W_{1020roundtubing} := V_{seatroundtube} \cdot AISI_{1020} = 6.073 \cdot lb$ Weight using AISI 1020

$W_{6061roundtubing} := V_{seatroundtube} \cdot Al_{6061T6} = 2.101 \cdot lb$ Weight using 6061-T6

APPENDIX K: Prediction of Foot Platform Weight



The following program below was created to determine the weight of the foot platform. It calculates the wieght the different configurations of cross sectional shape and the material.

Foot Platform:

$AISI_{1018} := .285 \cdot \frac{lb}{in^3}$ Density of AISI 1018

$AISI_{4130} := .284 \cdot \frac{lb}{in^3}$ Density of AISI 4130

$AISI_{4140} := .285 \cdot \frac{lb}{in^3}$ Density of AISI 4140

$AISI_{1020} := .285 \cdot \frac{lb}{in^3}$ Density of A513-Type 5 (AISI 1020)

$Al_{2024T351} := .107 \cdot \frac{lb}{in^3}$ Density of 2024-T351

$Al_{6061T6} := .0986 \cdot \frac{lb}{in^3}$ Density of 6061-T6

$l_{foot} := 103.65in$ Total length of Frame

Sqaure Bar:

$b := 1.in$ Length of sides

$V_{footsquarebar} := b^2 \cdot l_{foot} = 103.65 \cdot in^3$ Volume of a square bar

$W_{1018sb} := V_{footsquarebar} \cdot AISI_{1018} = 29.54 \cdot lb$ Weight using AISI 1018

$W_{4140sb} := V_{footsquarebar} \cdot AISI_{4140} = 29.54 \cdot lb$ Weight using AISI 4140

$W_{2024sb} := V_{footsquarebar} \cdot Al_{2024T351} = 11.091 \cdot lb$ Weight using 2024-T351

Rectangular Bar:

$b_{rb} := 0.125in$ Width of bar

$h_{rb} := 1.in$ Height of bar

$V_{footrectangularbar} := b_{rb} \cdot h_{rb} \cdot l_{foot} = 12.956 \cdot in^3$ Volume of a rectangular bar

$W_{1018rb} := V_{footrectangularbar} \cdot AISI_{1018} = 3.693 \cdot lb$ Weight using AISI 1018

$W_{4140rb} := V_{footrectangularbar} \cdot AISI_{4140} = 3.693 \cdot lb$ Weight using AISI 4140

$W_{2024rb} := V_{footrectangularbar} \cdot Al_{2024T351} = 1.386 \cdot lb$ Weight using 2024-T351

Rectangular Tubing:

$b_{rt} := 1.\text{in}$ Width of bar

$d_{rt} := 2.\text{in}$ Height of bar

$\text{thickness} := 0.125\text{in}$ Wall thickness

$V_{\text{footrectangulartubing}} := \left[b_{rt} \cdot d_{rt} - \left(b_{rt} - \text{thickness}\right)\left(d_{rt} - \text{thickness}\right)\right] \cdot l_{\text{foot}} = 37.249 \cdot \text{in}^3$ Volume of a rectangular tube

$W_{1020rt} := V_{\text{footrectangulartubing}} \cdot AISI_{1020} = 10.616 \cdot \text{lb}$ Weight using AISI 1020

$W_{6061rt} := V_{\text{footrectangulartubing}} \cdot Al_{6061T6} = 3.673 \cdot \text{lb}$ Weight using 6061T6

Round Bar:

$r_{rb} := \frac{1.5}{2}\text{in}$ Radius of round bar

$V_{\text{footroundbar}} := \pi \cdot r_{rb}^{\ 2} l_{\text{foot}} = 183.165 \cdot \text{in}^3$ Volume of Round Bar

$W_{1018} := V_{\text{footroundbar}} \cdot AISI_{1018} = 52.202 \cdot \text{lb}$ Weight using AISI 1018

$W_{4130} := V_{\text{footroundbar}} \cdot AISI_{4130} = 52.019 \cdot \text{lb}$ Weight using AISI 4130

$W_{2024} := V_{\text{footroundbar}} \cdot Al_{2024T351} = 19.599 \cdot \text{lb}$ Weight using 2024-T351

Round Tubing:

$r_{rt} := \frac{1.}{2}\text{in}$ Raduis of Round Tubing

$\text{thickness}_{rt} := .125\text{in}$ Wall thickness

$V_{\text{footroundtube}} := \left[r_{rt}^{\ 2} - \left(r_{rt} - \text{thickness}_{rt}\right)^2\right] \cdot \pi \cdot l_{\text{foot}} = 35.615 \cdot \text{in}^3$ Volume of Round Tubing

$W_{4130\text{roundtubing}} := V_{\text{footroundtube}} \cdot AISI_{4130} = 10.115 \cdot \text{lb}$ Weight using AISI 4130

$W_{1020\text{roundtubing}} := V_{\text{footroundtube}} \cdot AISI_{1020} = 10.15 \cdot \text{lb}$ Weight using AISI 1020

$W_{6061\text{roundtubing}} := V_{\text{footroundtube}} \cdot Al_{6061T6} = 3.512 \cdot \text{lb}$ Weight using 6061-T6

APPENDIX L: Analysis of Pins

Pin in Double Shear Stress

$F_{seat} := 350\text{lbf} = 1.557 \times 10^{3}\,\text{N}$ Force applied to Seating Platform

$d := \frac{5}{16}\text{in} = 0.794\cdot\text{cm}$ Diameter of pin

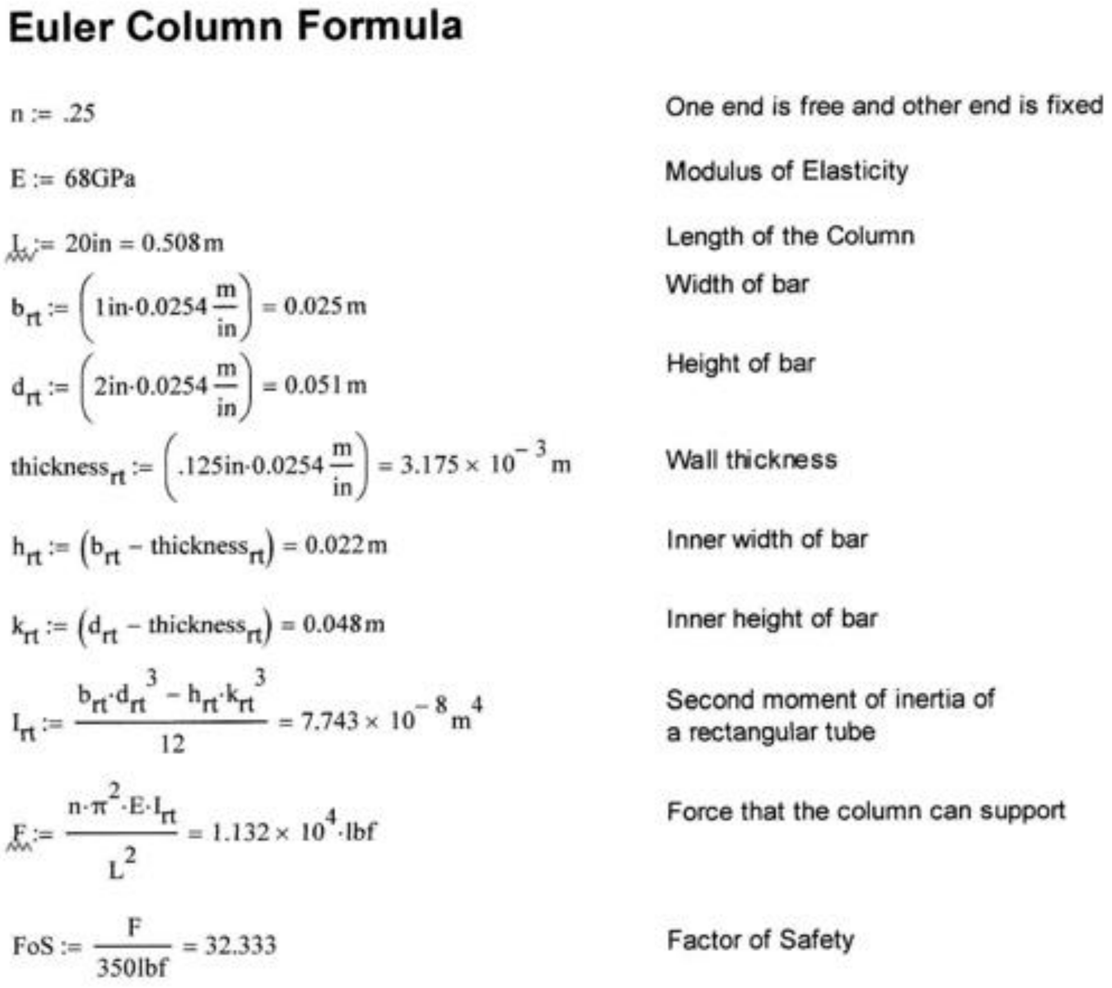
$r := \frac{d}{2} = 0.397\cdot\text{cm}$ Radius of pin

$\tau := \frac{F_{seat}}{\left(2\cdot\pi\cdot r^{2}\right)} = 15.731\cdot\text{MPa}$ Shear Stress

$FoS := 4$ Factor of Safety

$D_{SS} := \tau\cdot FoS = 62.926\cdot\text{MPa}$ Desired Shear Strength

APPENDIX M: Analysis of Vertical Beam



Euler Column Formula

$n := .25$	One end is free and other end is fixed
$E := 68\text{GPa}$	Modulus of Elasticity
$L := 20\text{in} = 0.508\,\text{m}$	Length of the Column
$b_{rt} := \left(1\text{in}\cdot 0.0254\frac{\text{m}}{\text{in}}\right) = 0.025\,\text{m}$	Width of bar
$d_{rt} := \left(2\text{in}\cdot 0.0254\frac{\text{m}}{\text{in}}\right) = 0.051\,\text{m}$	Height of bar
$\text{thickness}_{rt} := \left(.125\text{in}\cdot 0.0254\frac{\text{m}}{\text{in}}\right) = 3.175\times 10^{-3}\,\text{m}$	Wall thickness
$h_{rt} := \left(b_{rt} - \text{thickness}_{rt}\right) = 0.022\,\text{m}$	Inner width of bar
$k_{rt} := \left(d_{rt} - \text{thickness}_{rt}\right) = 0.048\,\text{m}$	Inner height of bar
$I_{rt} := \frac{b_{rt}\cdot d_{rt}^{3} - h_{rt}\cdot k_{rt}^{3}}{12} = 7.743\times 10^{-8}\,\text{m}^4$	Second moment of inertia of a rectangular tube
$F := \frac{n\cdot\pi^{2}\cdot E\cdot I_{rt}}{L^{2}} = 1.132\times 10^{4}\cdot\text{lbf}$	Force that the column can support
$\text{FoS} := \frac{F}{350\text{lbf}} = 32.333$	Factor of Safety

APPENDIX N: SolidWorks Drawings

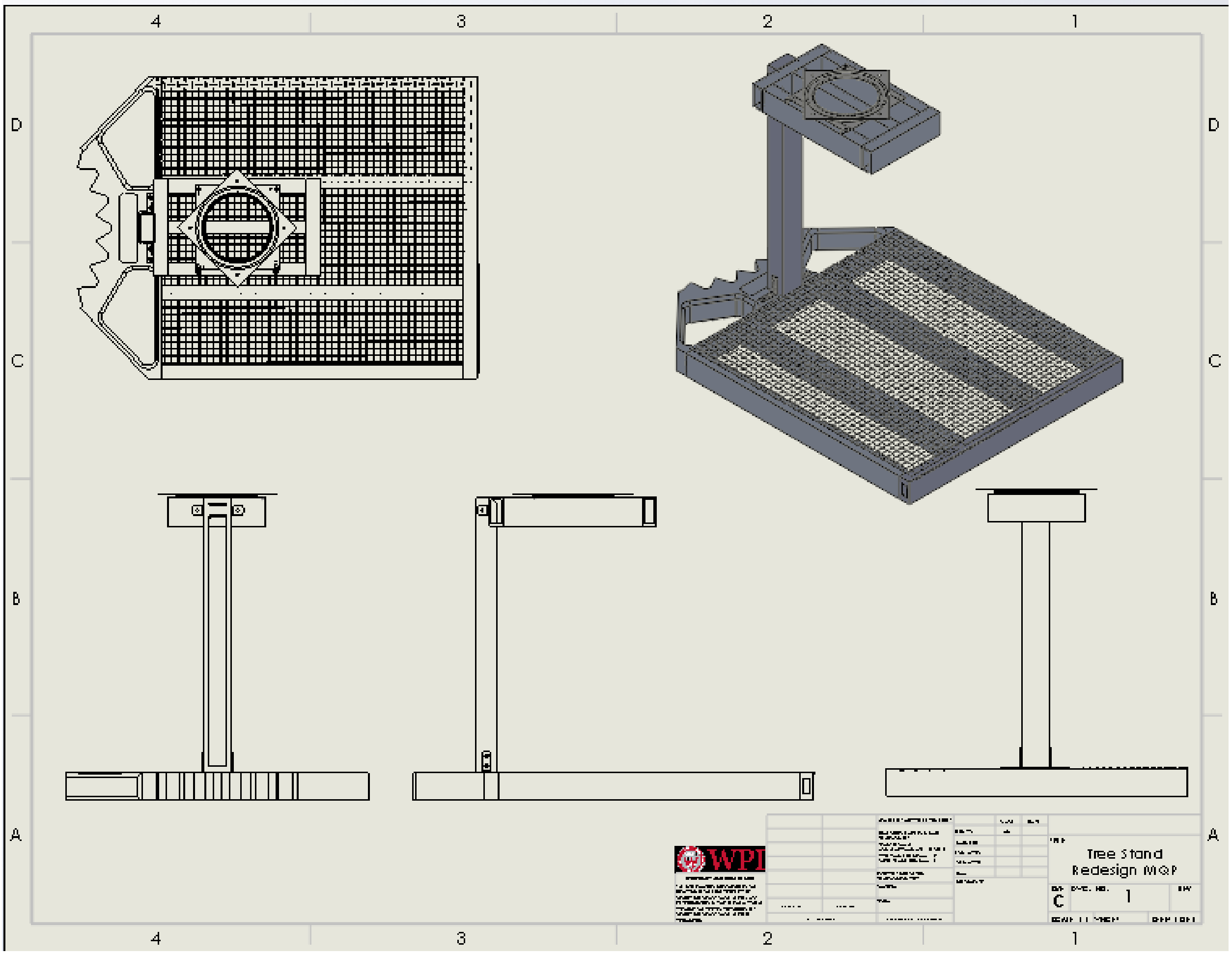
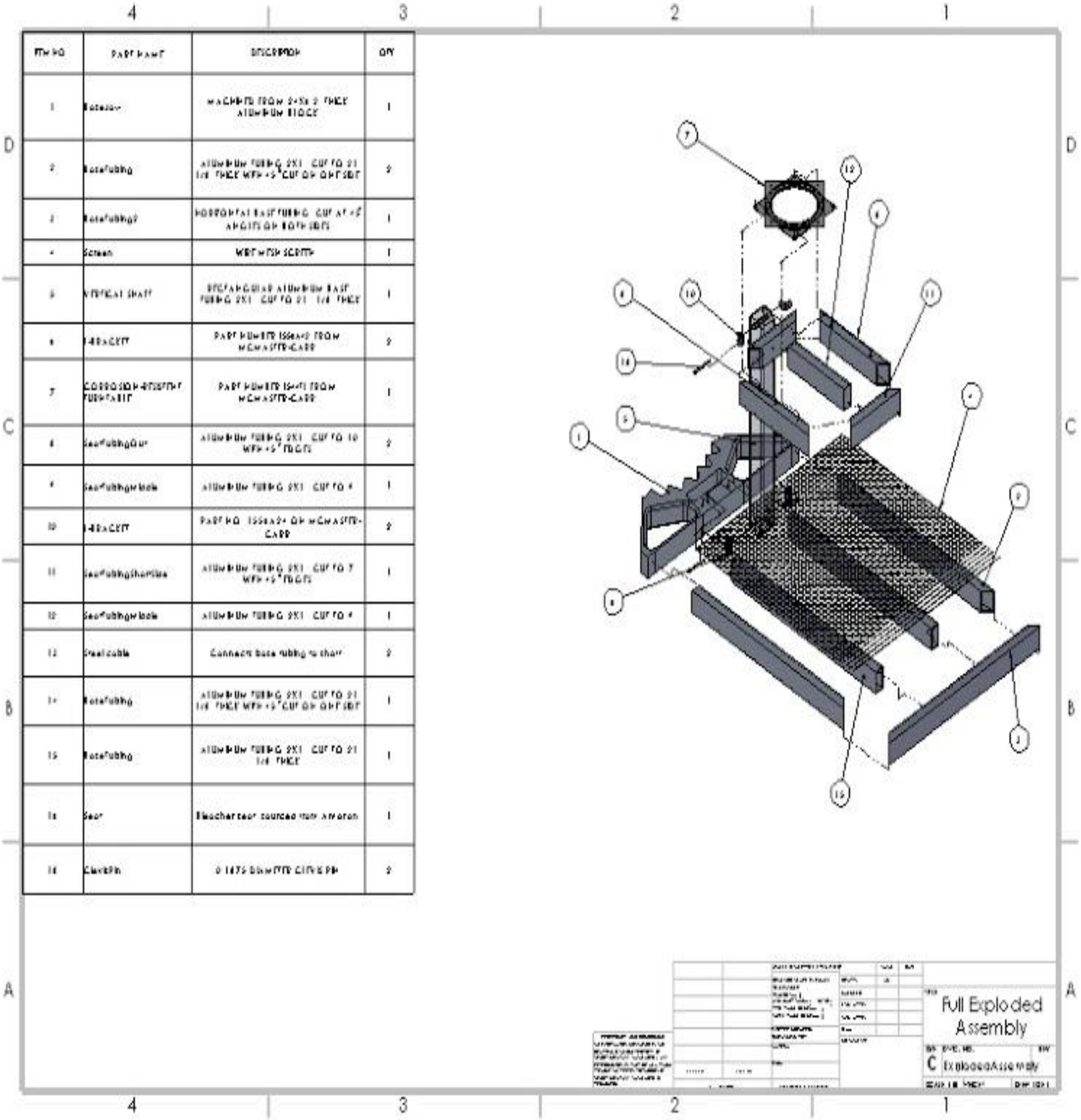


Figure 23: Drawing of Tree Stand



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	BaseJaw	MACHINED FROM [illegible] THICK ALUMINUM BLOCK	1
2	BaseTubing	ALUMINUM TUBING 2X1 CUT TO 21 1/4 THICK WITH 45° CUT ON ONE SIDE	2
3	BaseTubing2	HORIZONTAL BASE TUBING CUT AT 45° ANGLES ON BOTH SIDES	1
4	Screen	WIRE MESH SCREEN	1
5	VERTICAL SHAFT	RECTANGULAR ALUMINUM BASE TUBING 2X1 CUT TO 21 1/4 THICK	1
6	L-BRACKET	PART NUMBER [illegible] FROM MCMASTER-CARR	2
7	CORROSION-RESISTANT TURNTABLE	PART NUMBER [illegible] FROM MCMASTER-CARR	1
8	SeatTubingOut	ALUMINUM TUBING 2X1 CUT TO 10 WITH 45° EDGES	2
9	SeatTubingMiddle	ALUMINUM TUBING 2X1 CUT TO 9	1
10	L-BRACKET	PART NO. [illegible] ON MCMASTER-CARR	2
11	SeatTubingShortSide	ALUMINUM TUBING 2X1 CUT TO 7 WITH 45° EDGES	1
12	SeatTubingMiddle	ALUMINUM TUBING 2X1 CUT TO 9	1
13	Steel cable	Connects base tubing to chair	2
14	BaseTubing	ALUMINUM TUBING 2X1 CUT TO 21 1/4 THICK WITH 45° CUT ON ONE SIDE	1
15	BaseTubing	ALUMINUM TUBING 2X1 CUT TO 21 1/4 THICK	1
16	Seat	Bleacher seat sourced from Amazon	1
17	ClevisPin	0.1875 DIAMETER CLEVIS PIN	2

Figure 24: Exploded View and Bill of Materials of Tree Stand

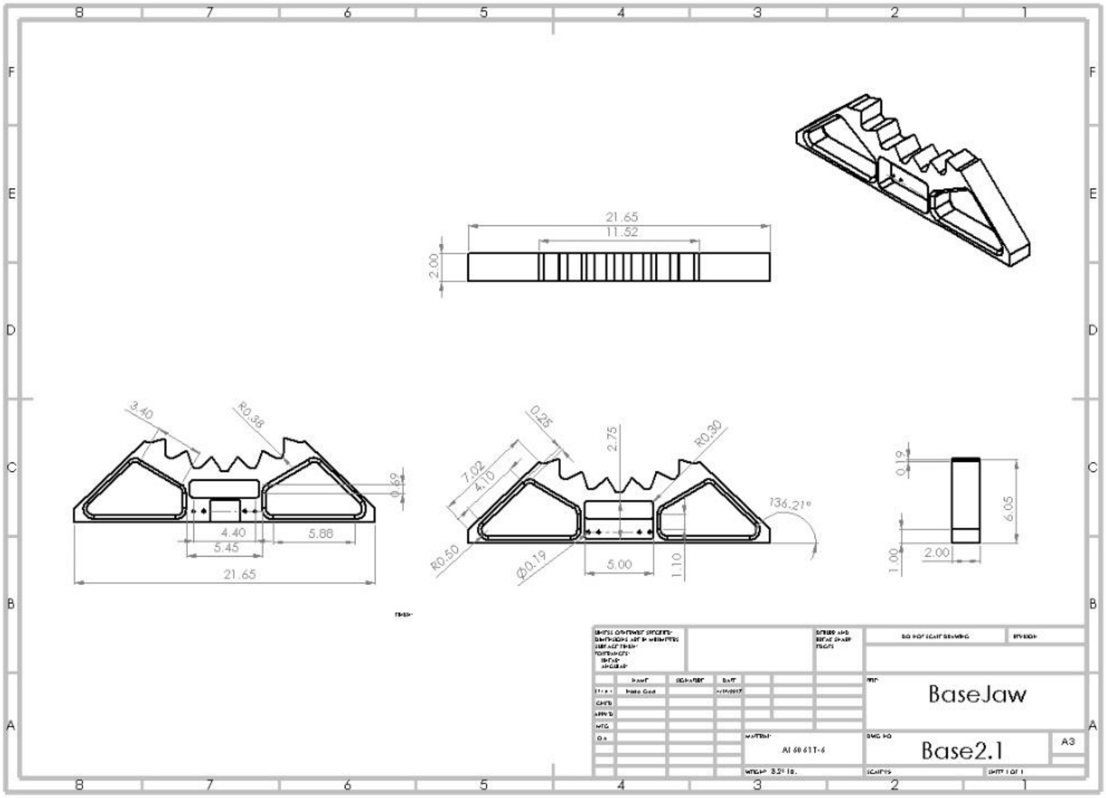


Figure 25: Drawing of Base

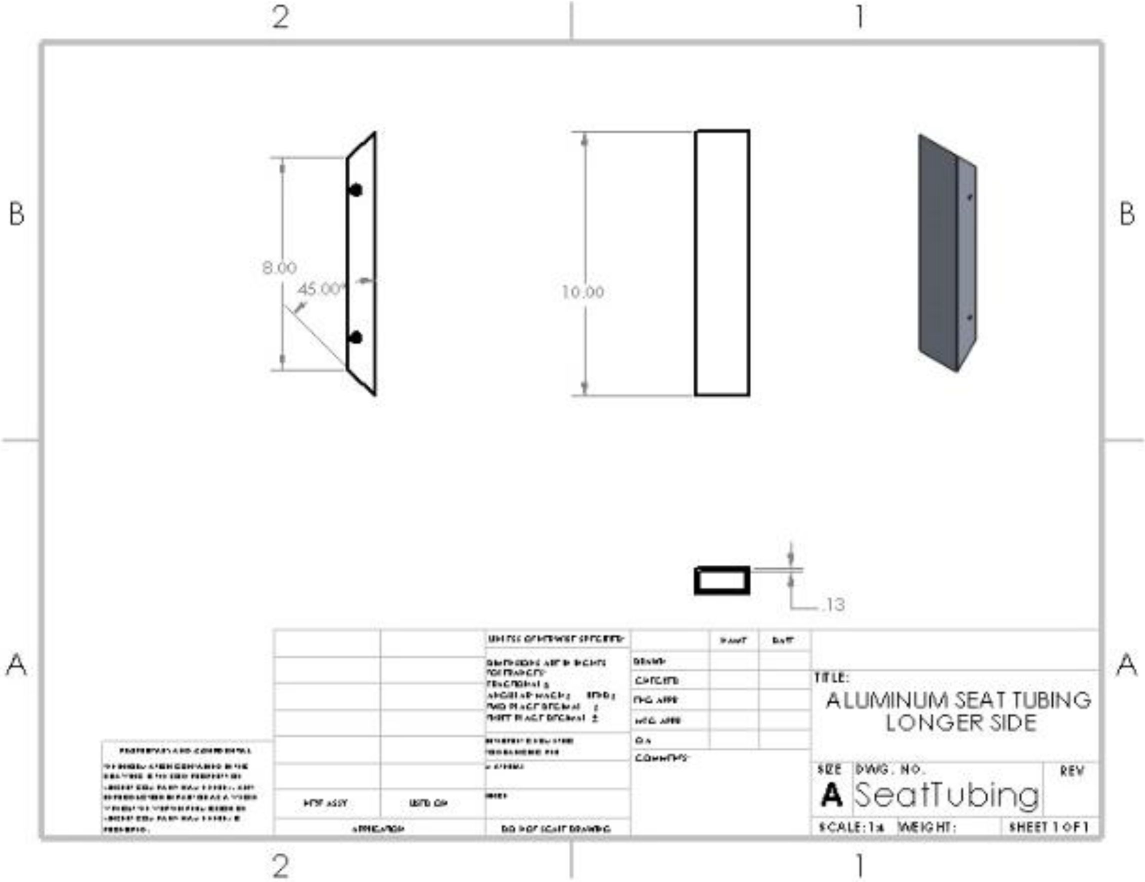


Figure 26: Drawing for Seat Tubing Longer Side

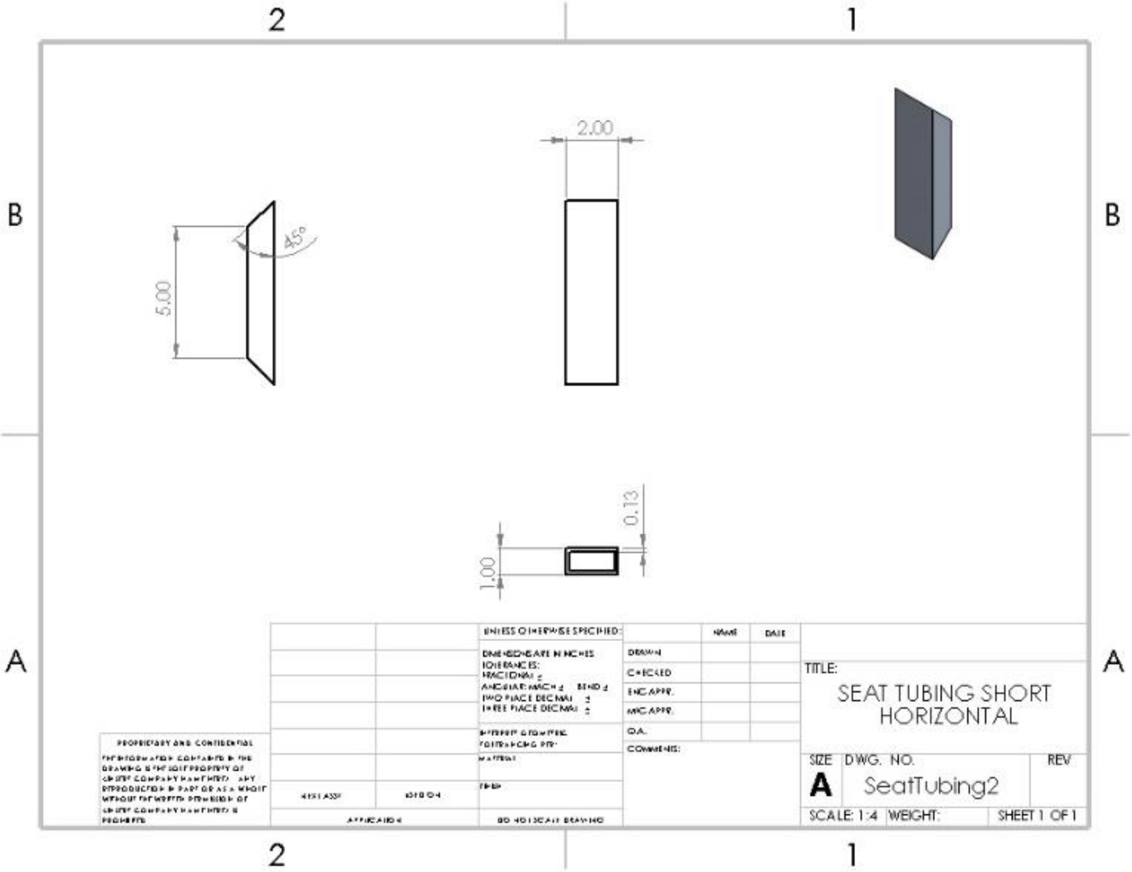


Figure 27: Drawing for Short Horizontal Seat Tubing

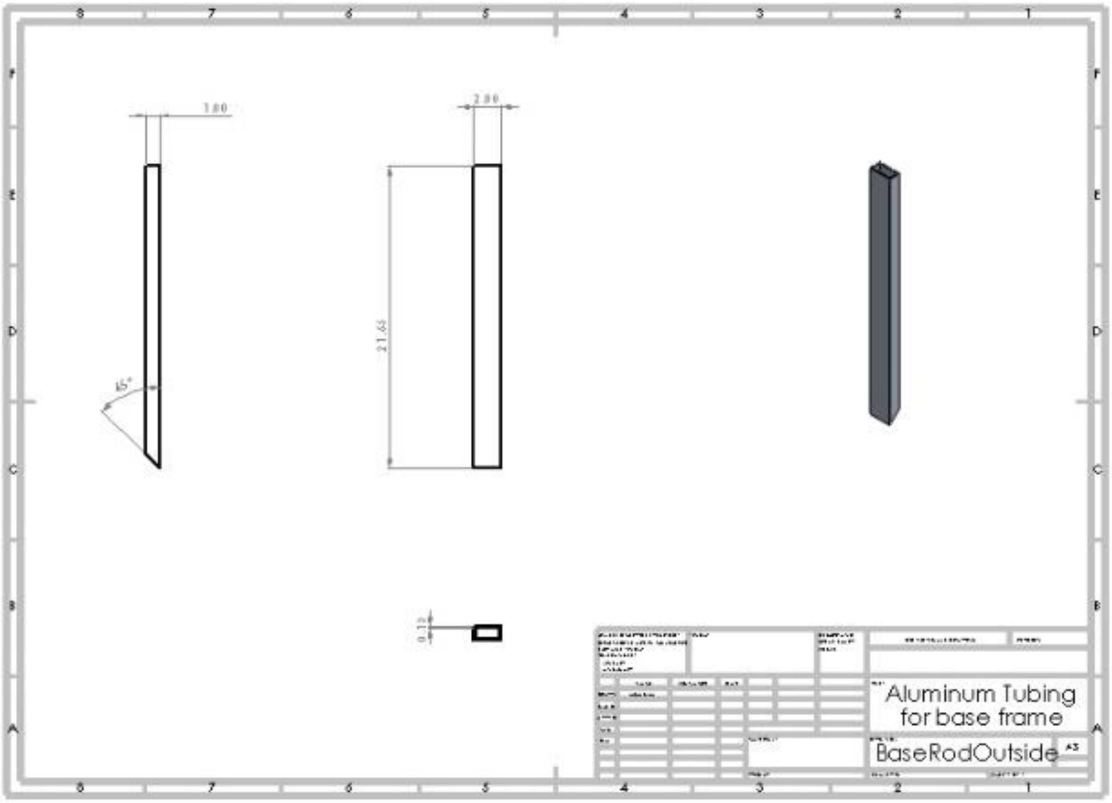


Figure 28: Drawing for Center Beams of Foot Platform

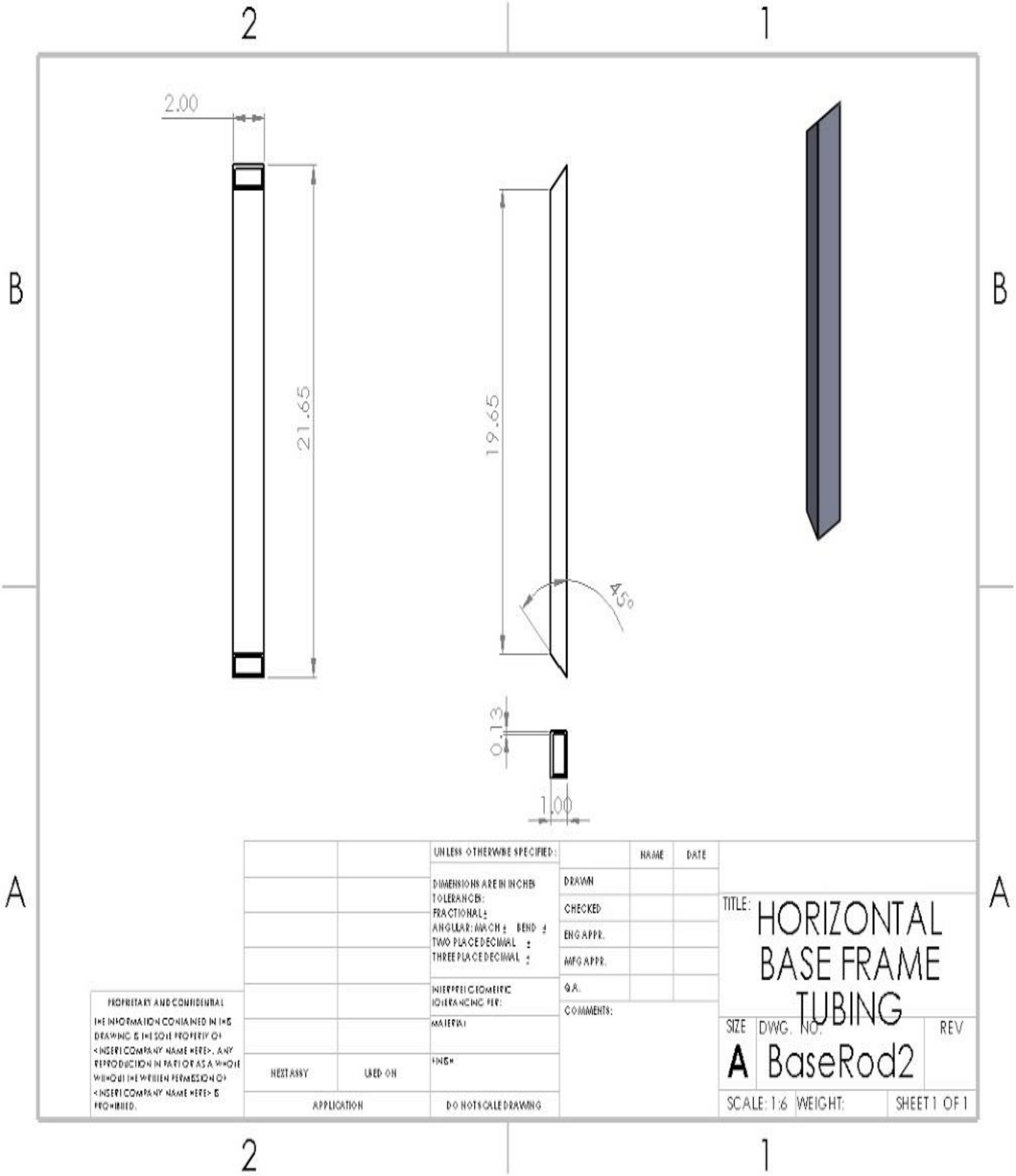


Figure 29: Drawing for Horizontal Beam of Foot Platform

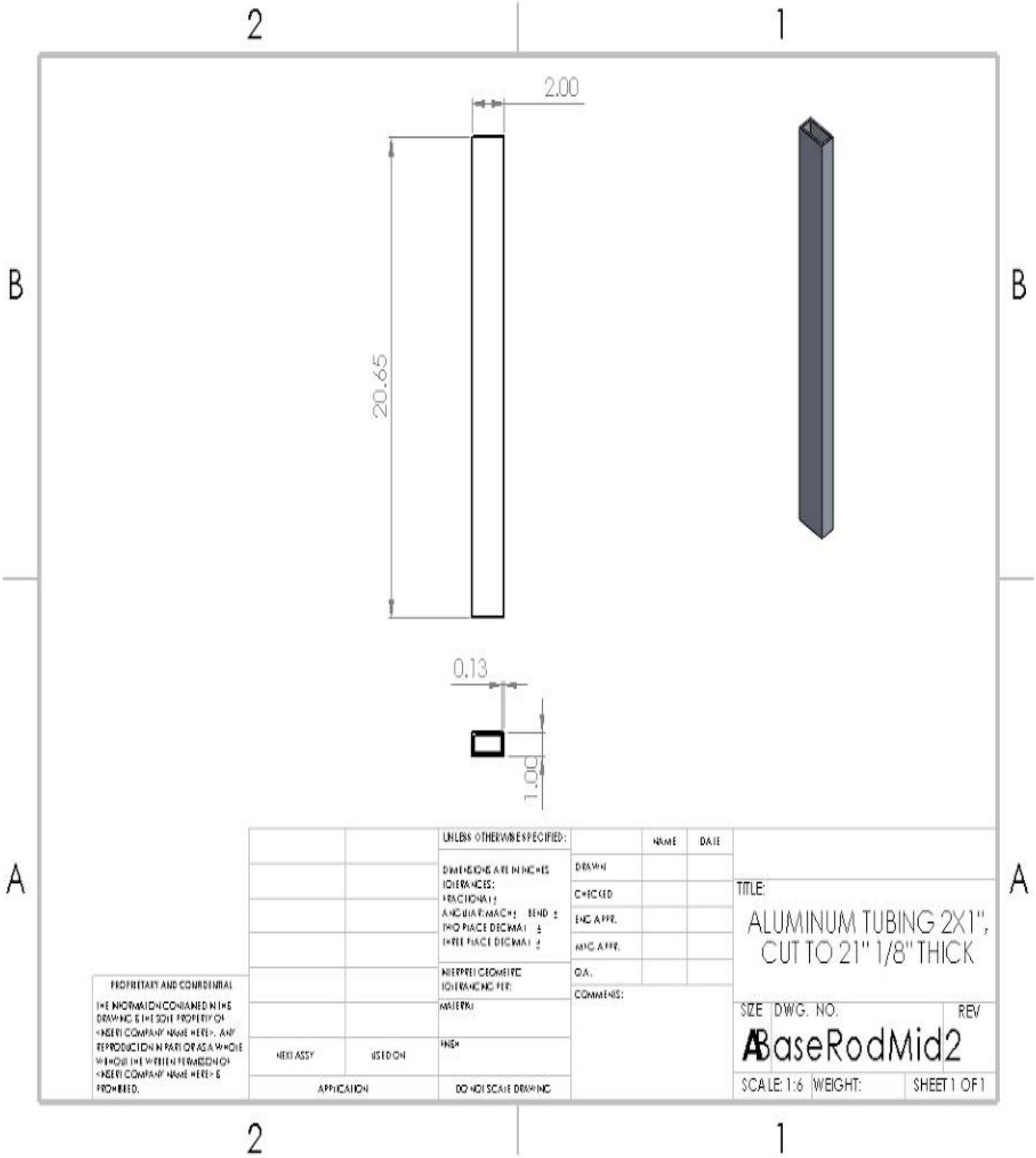


Figure 30: Drawing for Vertical Beam