DESIGN AND DEVELOPMENT OF A HANDCYCLE CAR RACK

Prepared By:

Arshdeep Singh Saran
Harjit Singh Grewal
Jaswinder Singh Johal
Santanjot Singh Dhaliwal

A report presented to the

British Columbia Institute of Technology

In partial fulfilment of the requirement for the degree of

Bachelor of Engineering (Mechanical)

Faculty Advisors:

Jamie Borisoff, Garrett Kryt

Program Head:

Mehrzad Tabatabaian

Burnaby, British Columbia, Canada, 2019

Author's Declaration Page

I/we hereby declare that I/we am/are the sole author(s) of this report.

Arshdeep Singh Saran
Harjit Singh Grewal
Jaswinder Singh Johal
Santanjot Singh Dhaliwal

Signature(s)*

I/we further authorize the British Columbia Institute of Technology to distribute digitally, or printed paper, copies of this report, in total or in part, at the request of other institutions or individuals for the purpose of scholarly activity.

Arshdeep Singh Saran
Harjit Singh Grewal
Jaswinder Singh Johal
Santanjot Singh Dhaliwal

Signature(s)*

- Please consider the typed names of the team members to be signatures

Abstract

Handcycling is a popular hobby carried out by many individuals. A few of these individuals are however in a wheelchair and transporting their personal hand-cycle can lead to astray of difficulties. Most of these difficulties involve the user in the wheelchair having no assistance to mount the hand-cycle to the car in an efficient, safe and effective way. This is where the introduction of a handcycle car rack takes place.

There are a variety of handcycle car racks on the market today however the reliability, durability and ease of use is always in question when it comes to the car racks currently used. The price of some of these is astronomical and just not affordable for the majority of wheelchair users. Also, with the use of electrical components raises the issue of reliability of the rack especially in the harsh climates that occur in the Vancouver area.

Throughout this project, the team and the client have been closely working together to come up with a handcycle car rack that can be easily used by the client while using no electrical components.

Acknowledgements

The team at Lakeside Engineering would love to give out our warmest thanks to our project sponsors, Jamie Borisoff and Garret Kryt who have trusted us with this project of theirs. They have been a great help through this whole process and have communicated extremely well whenever help was required.

We would also like to thank Johan Fourie who has managed our success and helped us along the way when the team needed.

Another thanks goes out to Greg King, who has helped the team with manufacturing and material selection in this project. Also, a huge thank you to Chris Townsend, of BCIT who has helped immensely in the manufacturing portion of this project.

Dedication

As a team we would like to dedicate this project to our client who will be in possession of the final prototype once completely finished.

Table of Contents

List of Tables

List of Figures

Introduction

This report outlines the details and methodology used for the **DESIGN AND DEVELOPMENT OF A HANDCYCLE CAR RACK.**

This report will include the initial designs of the rack and the iterations done up until the final design, detailed calculations and FEA simulation results assuring the design is safe for use and as well as outlining the teams progress throughout the project.

This report will be split up into five sections each containing distinctive methodology of the project. They will be divided in terms of: Background, Concept Generation, Results and Discussion, Project Management and Conclusion.

1.0 Background

Our client is a wheelchair user who requires a handcycle car rack to transport his handcycle efficiently and safely on the back of his vehicle. A design has been presented to the client which has met all the requirements pertaining to the design and is completely safe to use.

This design is based on the client's previous design which can be seen in the figure below. (Kryt, 2015)

Figure 1- previous design of clients handcycle car rack

1.1 Problem Statement

The concept of car racks is nothing new in the market, there are several bike racks out there that are designed for specific applications. Similarly, the handcycle car rack that we were proposed to design also had a very focused objective of being independently used by a wheel-chair user. This added to the technicality of this project since we have to consider various elements that might not be suitable to be used by a person on wheel chair.

The restriction to use any type of electrical component was another obstacle that we had in our project, which required us to use purely mechanical system to safely lift and secure the handcycle at the rear of the vehicle.

1.2 Objectives

The primary objective of this project is to design and develop a handcycle car rack for the independent use of a wheel chair user. The handcycle car rack is supposed to be a robust design which can effectively and safely transport the handcycle mounted on the back of the vehicle.

Some secondary objectives include:

- Using Finite element analysis on the critical components of the design to ensure the safety of the frame
- Hand calculations to determine the friction between surfaces, proper sizing of the tubes, bolts and pins used.
- Verifying the FEA weld analysis results with hand calculations to ensure the right size of welds are used at critical locations.
- Development of a second prototype with improvements to the initial design

The handcycle car rack is designed and built with certain material and design specifications in mind. Some of them are:

- Minimum safety factor n=2
- Structural frame made of Aluminum 6061 and hot rolled steel
- All welds are done using metal inert gas welding

1.3 Scope

The scope of this project requires the understanding and application of a variety of skills to carry out the objectives in a timely and efficient manner. The skills are critical in a developing a new model, making suitable recommendations and writing a successful report. Other skills required to meet project objectives required using the machine shop skills learned earlier in the course, machine design weld analysis and good techniques of project management.

Designing a frame such as a car rack from scratch, requires solid knowledge of SolidWorks, product development, design concepts and hands-on skills. Additionally, designing such systems requires a systematic and disciplined approach which comes with time.

The design of the frame and the size of the components used to build the car-rack was done keeping in mind the weight of the handcycle, the verification of these designs was done by means of FEA and hand calculations. Since, the application of a car rack is to transport the handcycle efficiently and safely on the back of the car, the results from FEA and hand calculations were verified using manual testing to ensure the proper decisions are made on the selection of material.

Lastly, completing a technical project of this scope cannot be completed without effective project management. Setting realistic timelines for completing tasks while documenting and ensuring all team members are on track will be vital to ensuring success. Poor management, lack of communication between members and poor consolidation of data will inevitably lead to unsatisfactory results.

1.4 Patents

Handcycle car rack is a unique project and does not have patents which directly resemble the design we are developing, but doing some research it was found out that there are various patents which relate to some of the components that were used in the project. Some of these are:

1.4.1 Bike rack attachment for a vehicle

Patent number: US9533625B2

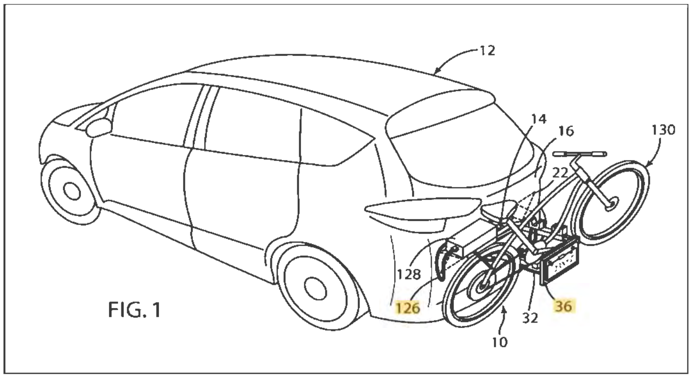


Figure 2- perspective view of showing a vehicle bike rack assembly according to the present invention supporting an electric bike on a vehicle

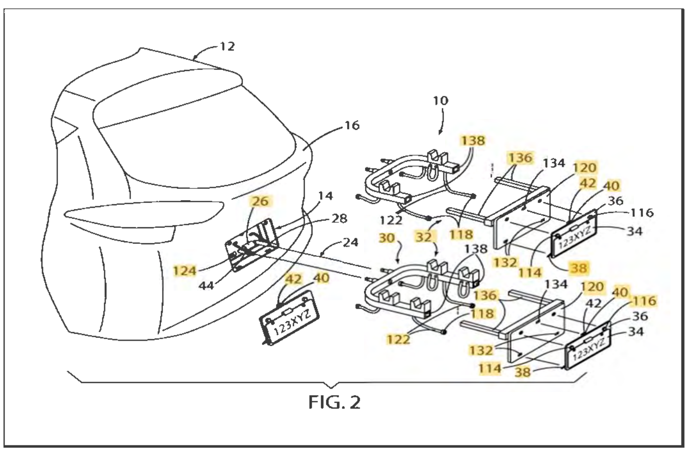


Figure 3- exploded perspective view of a vehicle bike rack according to the present invention

This mechanism shows the attachment of a bike rack to a vehicle including a support member located behind the exterior wall of a vehicle. This mechanism has a similar concept of attaching a bike to the rear of a vehicle but has a different type of mounting system which can be seen in FIG.2. This concept involves the use of mounting system which is connected to the license plate via a bracket. Even though this design has a similar type of mounting style as done in our project, but the components used and the bike that the rack is designed for makes our project entirely different from this patent. (USA Patent No. US9533625B2, 2014)

1.4.2 Rowing Bicycle

Patent Number: US7237786B2

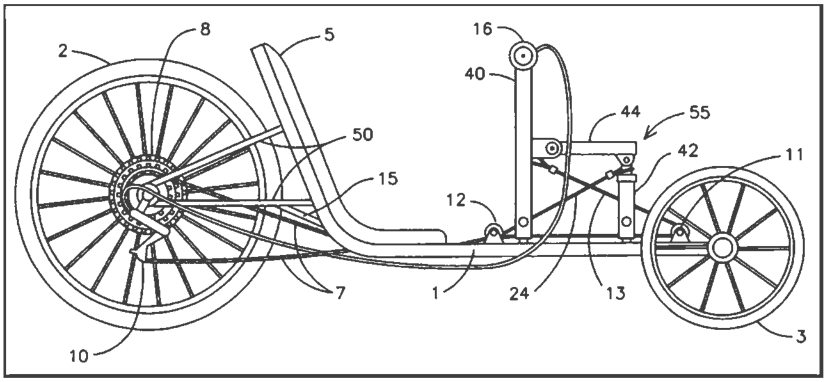


Figure 4-side view of the rowing bicycle of the present invention

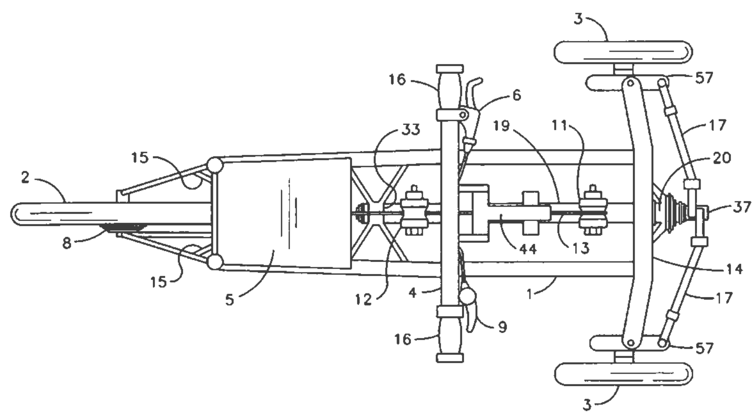


FIG. 2

Figure 5-top view of the embodiment

This patent provides a detailed description of the rowing bicycle and specifies each component used to build the tricycle shown in FIG.1. For our project the handcycle was provided to us for which we had to design the car rack, but this rowing bicycle has a similar type of tadpole design to our handcycle. (USA Patent No. US7237786B2, 2004)

1.5 Specifics

The technical requirement specifics for this project are as follows:

- Must be a rear mounted on a vehicle (cannot be mounted to the roof due to ferry restrictions)
- Be light enough to mount on a class 1 Hitch (can hold up to 200 lbs.)
- Should be a modular to the extent of allowing tadpole and delta designed handcycles to secure to the mount.
- Must be accessible for a person on a wheelchair to use comfortably by him/herself

Our final prototype was built taking into considerations all the technical requirements and we were able to achieve all these specifications successfully.

1.6. Deliverables

The deliverables for this project include:

- The prototype of the handcycle car rack
- FEA test on the final solid works model
- A Project presentation
- A technical report

Initially the deliverables also included ISO testing which was later omitted by the project sponsor due to the lack of time and the design was verified based on the FEA results and hand calculations.

The final technical report will include all the FEA results which were conducted to come up with a safe and effective design, fully assembled SolidWorks model of the handcycle car rack, weld calculations and friction calculations.

1.7 Limits and Exclusions

The major limitation for this project was that the use of any type of electrical component for the mount was completely prohibited by the sponsor due to reliability issues. Some other limitations included the design to be light enough to be supported by class 1 hitch and the mounted bike to be close enough to the rear of the vehicle to prevent high bending moment.

2.0 Concept Generation

2.0 Initial Designs

The designs shown below are the initial concepts the team had come up. Below each figure is the reasoning behind why that design wasn't suitable and why it was unused into the final design.

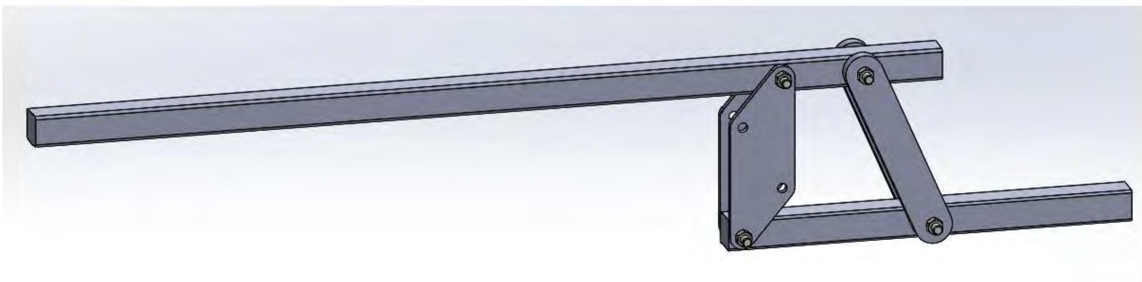


Figure 6- initial raising/lowering design

This was the initial design for the lifting mechanism to be used for the rack. It is far away from the rear of the vehicle which will maximize the force required to lift. Also, this mechanism did not allow the travel required for the lift.

Figure 7- initial mount design

This design above was deemed not suitable for a wheelchair user by the team and we decided it would be too difficult to use this mechanism to mount the handcycle on. To locate the three tires of the handcycle repeatedly would just be a nuisance for the user so this idea was let go.

Figure 8- initial full design

This was the initial full assembly of the car rack the team had come up with but it is clearly evident that this design will be extremely prone to bending and will be fairly difficult and costly to manufacture. From this design, the team marched forward and iterated it to a desirable design. These iterations are shown in the next section of this report.

2.1 Iterations

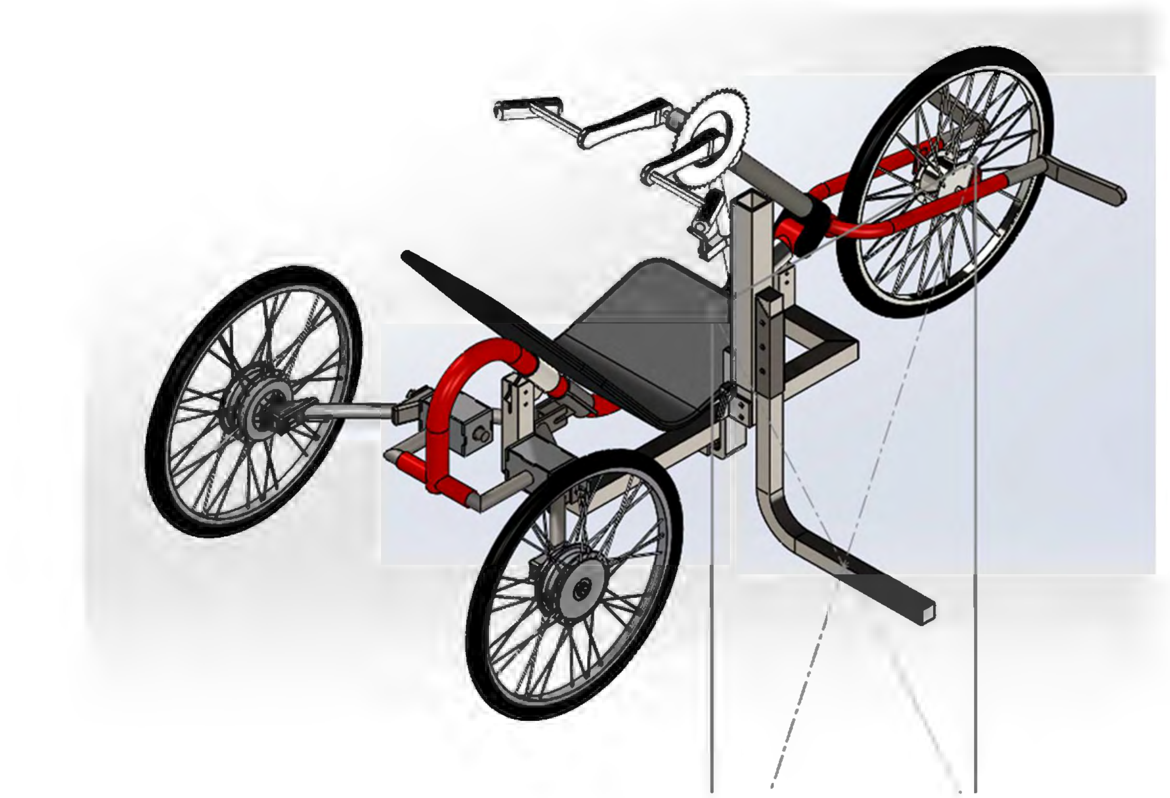


Figure 9- iterated design

This was the first iteration the team had designed. The handcycle was moved much closer to the rear of the vehicle and the concept was much simpler. However this design required components to be permanently attached to the handcycle itself which the client did not like.

This design had a spring system however this spring was deemed not necessary as the team decided to forgo a mechanical advantage to lift the handcycle. The lever system shown to the right was further iterated and enhanced for the handler to use.

The final design is shown in the next section.

Figure 10- iterated design without handcycle

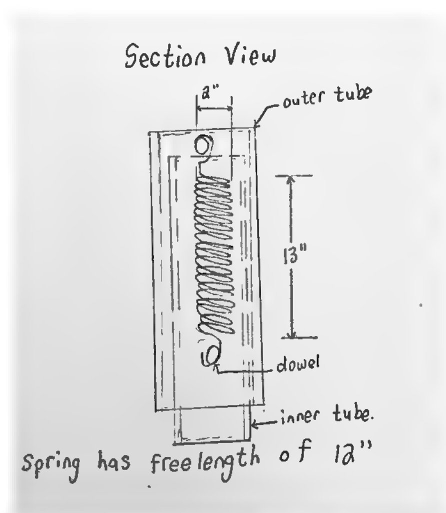


Figure 11- spring system

2.2 Final Design

Figure 13- final design in lowered position

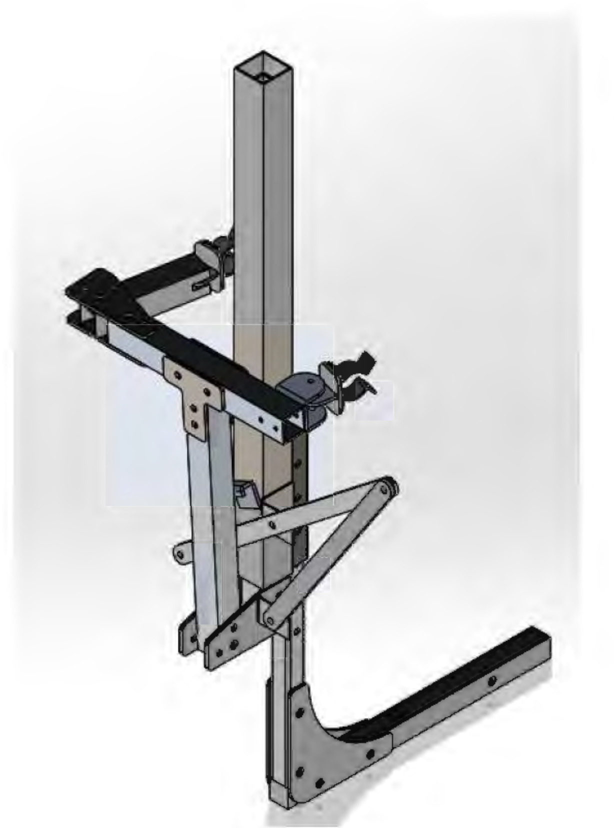


Figure 12- final design in raised position

This is what the final design of our rack looks like. The left shows the position at which the handcycle will be transported and the image on the left shows the position of the rack whilst out and about in the vehicle with the handcycle not mounted. The base is modular due to the component on the left which can be flattened for hand cycles that do not have an angle within them. The lever system will work by attaching a pipe which the user will do extending the torque arm making it easier for the user to raise and lower the rack. The implementation of 8 roller bearings seen in the figure on the next page are the mechanism behind the telescoping action of the inner tube. The total travel of the rack will be 12”.

2.2.1 Individual Parts

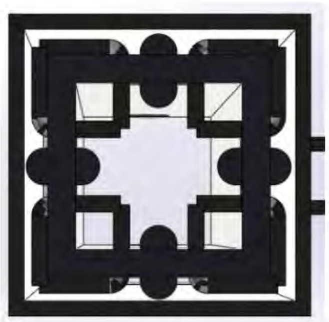


Figure 14- top view of bearings in the tube

This is the top view of the inner and outer tubes highlighting the bearings inside that will provide the rolling action.

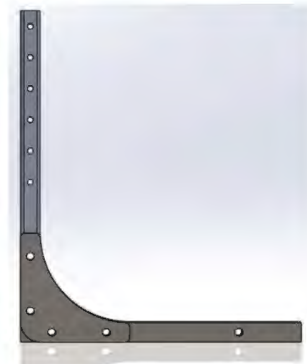


Figure 15- side view of hitch

This sub-assembly illustrates the hitch and vertical component that will be welded with the outer tubes. The holes on the vertical member are done to raise and lower the height of the rack depending on the height of the vehicle. For our clients vehicle the rack will be supported with the top three holes.

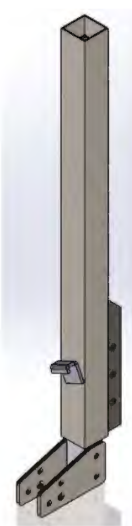


Figure 19- inner/outer tube assembly

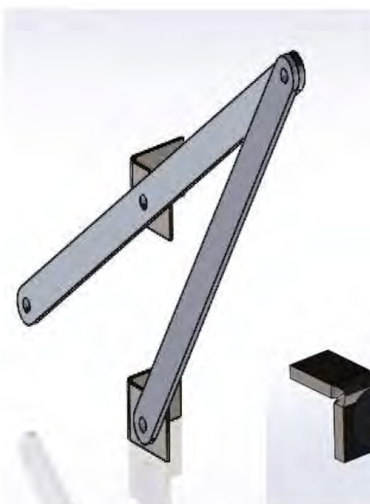


Figure 17- lever

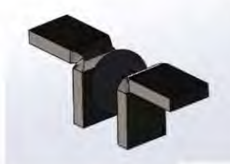


Figure 16- roller bearing

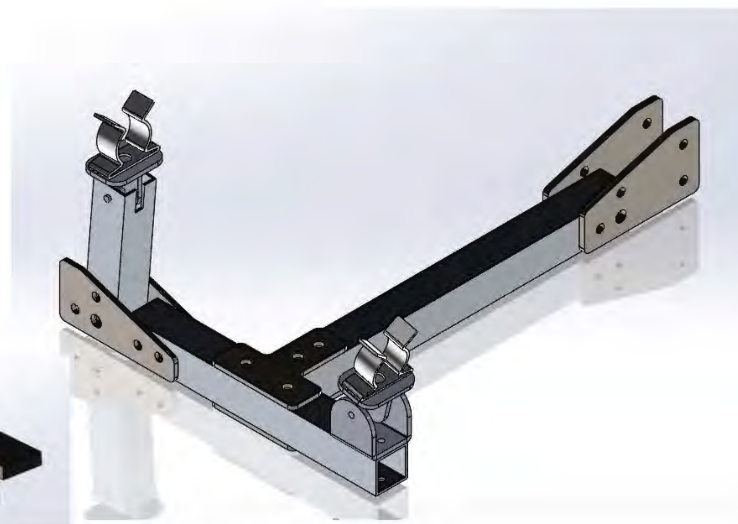


Figure 18- sub-assembly of the mounting system

The figures shown above are the individual components that make up the entirety of the rack. The assembly of the roller bearing is also shown which was assembled using two waterjet l-shapes.

2.2.2 Real World Use

Figure 20- side view of rack mounted on client's vehicle

Figure 21- view of handcycle mounted to frame on client's vehicle

The two images above demonstrate the car rack in use with the client's vehicle. It is important to note the client did not have access to his vehicle that had the class I hitch at this time so another one of his vehicles was used that had a class II hitch.

3.0 Results and Discussion

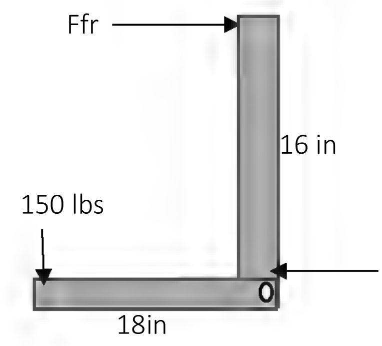
3.1 FEA Results

The FEA results for the main components of the frame including the lever, inner tube plate hitch plate. A weld analysis was also conducted to ensure the welds on the rack were safe.

Through the FEA simulation the rack was deemed to be completely safe however each component did not have a minimum safety factor of 2 when a force of 150 lbs was implemented. This force already has some sort of safety factor as the weight of the bike is only 100 lbs. So considering this fact, a safety factor of about 2 can be accepted for each individual component.

These results can be viewed in section B of the Appendix.

3.2 Hand Calculations



$$M\ @\ 0 = 0$$

$$F_{fr} = \frac{150 * 18}{16}$$

$$F_{fr} = 168 * 2 = 336\ lbs$$

This friction load was then multiplied by various friction coefficients to determine the best material to select to reduce friction.

$$Polyetheleyne\ \mu_{fr} = 0.2$$

$$F_{fr} = \ \mu_{fr} * F_{fr} = \ 0.2 * 336 = 67.2\ lbs$$

$$Steel\ \mu_{fr} = 0.8$$

$$F_{fr} = \ \mu_{fr} * F_{fr} = \ 0.8 * 336 = 268.8\ lbs$$

$$Teflon\ \mu_{fr} = 0.04$$

$$F_{fr} = \ \mu_{fr} * F_{fr} = \ 0.04 * 336 = 13.4\ lbs$$

Evident from the calculations completed above, the use of Teflon between the pipes will be adequate to reduce the friction present. However due to the expense of Teflon considering the amount required the team decided to use roller bearing in between the telescoping tubes to reduce the friction to virtually negligible.

3.3 Discussion of Final Design

In the final design of the handcycle car rack, the team was successfully able to fulfill all the technical specification provided earlier in the report and effectively build a fully working prototype. The prototype was tested on the user's vehicle and was safely and securely able to lift the bike and hold it in place.

The mechanism consisted of telescopic tube system, where the outer tube was welded on to the hitch and the inner tube was free to slide and connected to the rest of the mounting assembly. To reduce the friction between the tubes, rollers were attached on all four sides of the tube. The mounting assembly consists of a T-shaped structure, with terry clamps connected at the corners where the middle tube of the bike can rest and then lifted securely. To lift the bike above the ground, a lever mechanism was used. The lever was accessible from the side of the car rack and designed in a way so that the user can easily apply the force required to lift the handcycle. Once the bike is of the ground and the lever fully retracted, a safety pin will be used to secure the bike in place. To avoid lateral movement of the handcycle, a bungee cord or a strap will be fastened around the handcycle.

To enhance the modularity and ease of assembly, most of the components of the frame were connected via bolts and nuts, leaving the frame with one major weld connection between the hitch and the outer tube. To make the mounting assembly light and strong, Aluminum 6061 was used along with some components of the assembly that were made up of hot rolled steel.

3.4 Bill of Materials

Table 1- Bill of Materials

Part	Material	Size	Length
Inner Tube	Aluminum 6061-T6	1.5” X 1.5” X 0.188”	32”
Outer Tube	Structural Steel Hot Rolled	2” X 2” X 0.100”	30”
Frame Beam (1)	Aluminum 6061-T6	1.5” X 1.5” X 0.188”	16”
Frame Beam (2)	Aluminum 6061-T6	1.5” X 1.5” X 0.188”	12”
Frame Beam (3)	Aluminum 6061-T6	1.5” X 1.5” X 0.188”	6.5”
Hitch	Steel Hot or Cold Rolled	1.25” X 1.25” Solid	35”
Weld Bracket	Structural Steel Hot Rolled	1.5” X 1.5” X 0.125”	10”

*All materials not available in BCIT shop

These are the required materials that were required for the completion of the rack.

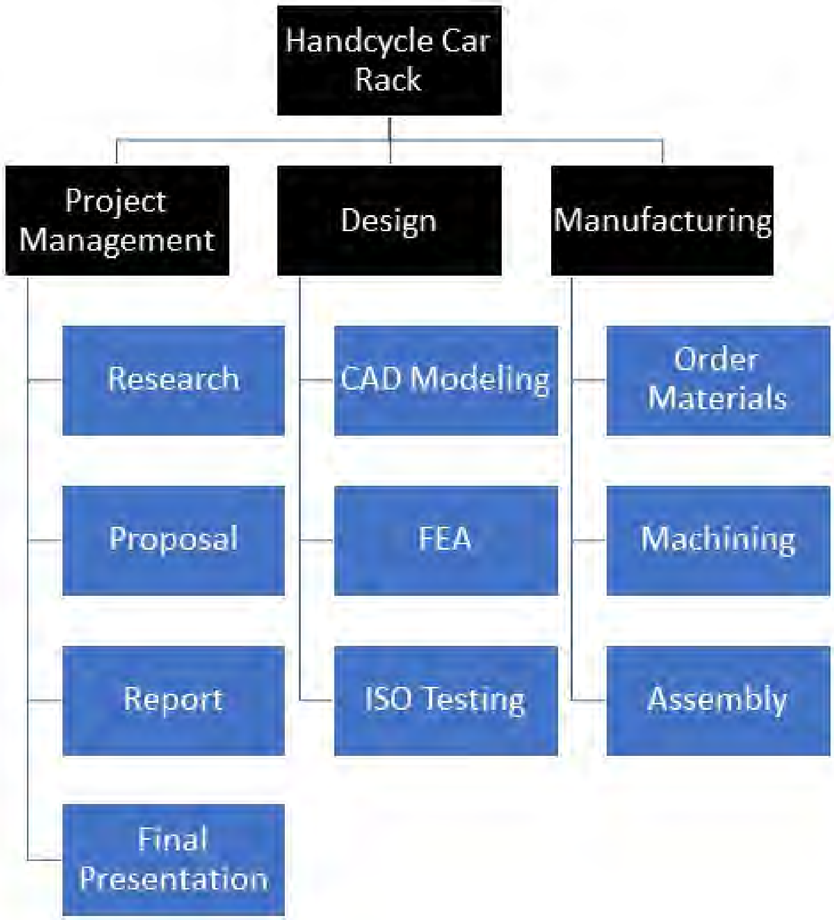
The items not listed that were used

- Black Nylon-Coated Steel Clip
- Cotter Pins
- Ball Bearings
- Compression Spring
- Bushings
- Quick Fist Clamp©

4.0 Project Management

4.1 Work Breakdown Structure

Table 2- Work Breakdown Structure



4.2 Responsibility Assignment Matrix

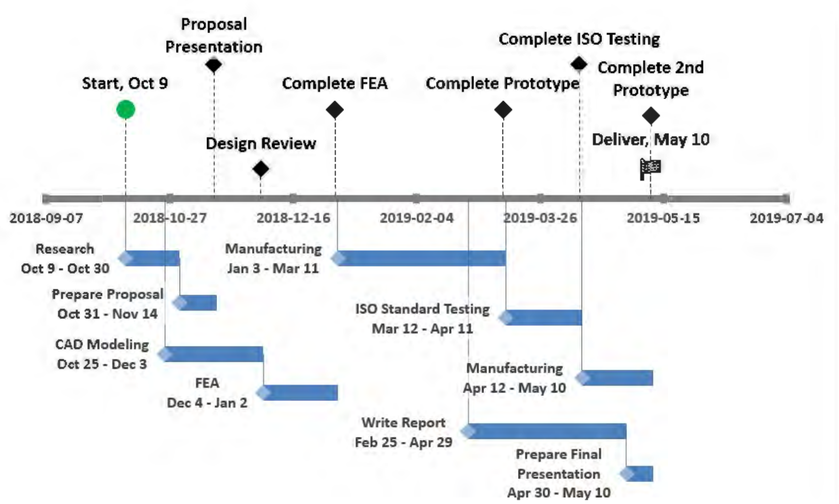
Table 3- Responsibility assignment Matrix

RACI Chart	Person				
Activity	Arshdeep Saran	Harjit Grewal	Jaswinder Johal	Santanjot Dhaliwal	Garett
Research	R	A	R	R	C
Proposal	R	A	R	R	I
Report	C	R	C	A	I
Final Presentation	R	R	A	R	I
CAD Modeling	A	C	R	C	I
FEA	I	C	A	R	I
ISO Testing	R	I	C	A	C
Order Material	A	I	C	R	C
Machining	C	I	R	A	I
Assembly	I	R	A	I	I
	R = Responsible	A = Accountable	C = Consult	I = Inform	

This table above shows who is either responsible or accountable for a given task as well as who will be consulting or the team member responsible for informing of the completed task.

4.3 GANNT Chart

Table 4- initial Schedule

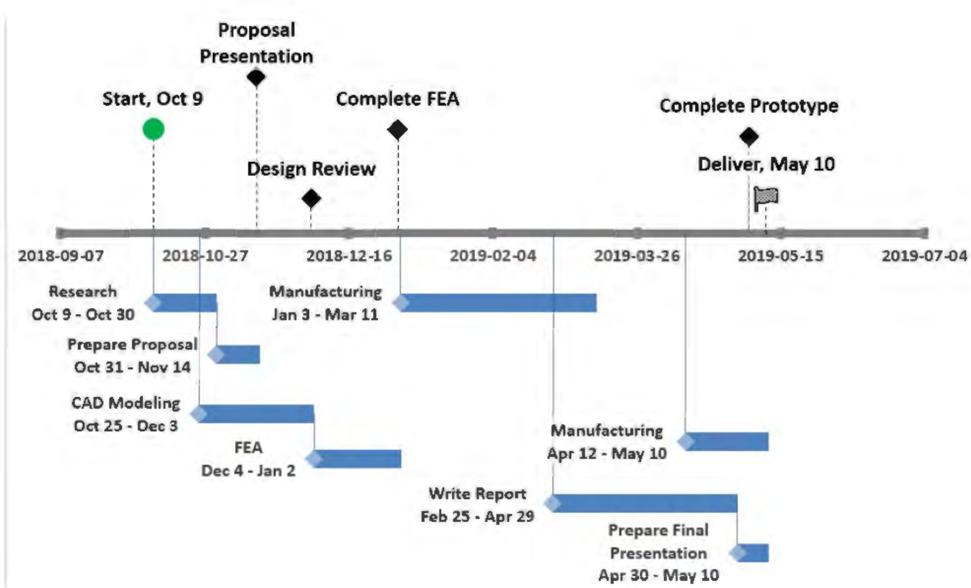


While the team worked extremely hard to ensure project milestones were met on time, a few objectives have been dropped or the time for the completion of the certain objective has extended.

With a conversation between the team and the client, it was agreed upon cancelling the ISO testing of the rack. It was deemed not necessary because the safety of the design can be assured with FEA results. Also, at the time of this report, a second prototype has still not been in the works. If the client deems it necessary the team will produce a second prototype subsequently this project completes.

The schedule in the figure above is what was planned by the team during the initiation phase of the project while, the figure below indicates the teams actual progress throughout the project.

Table 5- followed schedule



5.0 Conclusion

5.1 Lessons Learned

A leason learned earlier in the project was the need for effective communication between team members. With a heavy workload and other extra-curricular activities encompassing the lives of the team members, it was tough to coordinate meeting times. The busy lives and the inconveniences that came along with them entailed that communication was key when arranging meeting times. Being prompt to respond back and to reply effectively via email or instant messaging was crucial in terms of saving time and energy. The team pledged to respond back as soon as possible. Additionally, each team member was encouraged to give simple and straightforward responses as to when they could or could not meet when project work was being completed on almost a daily basis.

When it came to the heart of the project (manufacturing of the rack), the team came across many issues. These issues ranged from lining up holes and mating them to other parts which came to be more difficult than anticipated. Also, assembly methods which were not always known to the team such as welding, the team always consulted knowledgeable faculty in these areas.

5.2 Future Work

This project being a fairly large and complicated one, additional work will be needed to introduce a design such as the one presented by the team to be fully presented into the marketplace. Work that can be done includes:

- The use of more cost-efficient materials to reduce the cost of the rack
- Assemble the rack in a more professional manner, i.e. better welding
- Making further design improvements to both the rack and other components

The team believes with the appropriate improvements and effective marketing, the design of this rack can sell extremely well to the right market.

Bibliography

Kryt, G. (2015). *A Handcycle Car Rack for Independent Use by People with Disabilities.* Burnaby : BCIT Rehabilitation Engineering Lab.

Montez, D. (2004). *USA Patent No. US7237786B2.*

Venkatesh, K., & al, e. (2014). *USA Patent No. US9533625B2.*

Appendix A. Project Meetings

Weekly Progress Report 1

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: January 10, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

- Developed multiple designs over winter break which were shared
- Design concept accepted and will be continued to be iterated
- Multiple lifting mechanisms discussed
- Decision on lifting mechanism to be used going forward will be based upon a leadscrew, winch system or Jack

To be done before next meeting:

- Determine if there is a Jack on the market that is capable of required travel

Weekly Progress Report 2

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: January 17, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

- Broke project into 3 components
    - Robust transportation (completed)
    - Design movement method (completed)
    - Design lifting method (completed)
- Found spring and material prices online
- Did calculations to determine spring constants and forces

To be done before next meeting:

- Begin working on detailed design of handcycle rack

Weekly Progress Report 3

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: February 14, 2019 @ 12:30pm **Location:** CARI Building

Members Present: Arshdeep Saran, Jaswinder Johal, Santanjot Dhaliwal
Faculty Advisors: Jamie Borisoff, Garrett Kryt

- With design in mind, start detailed design aspect of the frame
- Implement a clamping system in the under-carriage portion; determine how to engage this clamp
- Research and have a look into foams that will help with the clamping
- Look into Gas springs that are used in hatchbacks

To be done before next meeting:

- Finish the clamping system
- Friction calculations

Weekly Progress Report 4

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: February 21, 2019 @ 12:30pm **Location:** CARI Building

Members Present: Arshdeep Saran, Harjit Grewal, Santanjot Dhaliwal, Jaswinder Johal
Faculty Advisors: Jamie Borisoff, Garrett Kryt

Completed this week:

- Friction Calculations Complete
    - Determined forces of friction between various combinations of materials
- Multiple clamping systems developed
    - Trying to receive go-ahead on one of the developed designs

To be done before next meeting:

- Begin detailed design
- Begin making shop drawings
- Start ordering material

Weekly Progress Report 5

Development of a Handcycle Car Rack **MECH 8190 –** Capstone Project
Meeting Minutes: February 28, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

Completed this week:

- Frame Design Complete
    - Previous design unusable due to low ground clearance so a new design was developed to work through this issue
- Work safe lifting limit found to be 35 lbs
    - We are going to limit our lifting to 30 lbs or less to ensure safety and ease of use for wheelchair user

To be done before next meeting:

- Complete lifting mechanism
- Order materials

Weekly Progress Report 6

Development of a Handcycle Car Rack **MECH 8190 –** Capstone Project
Meeting Minutes: March 7, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

Completed this week:

- Lifting mechanism complete
- Begin detailed design

To be done before next meeting:

- Complete detailed design
- Order materials
- Begin manufacturing

Weekly Progress Report 7

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: March 28, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

Completed this week:
- Metal has been bought
- Group has started prototyping

To be done before next meeting:
- Order materials
- Talk to shop advisor about welding and milling
- Talk to Garrett about bending

Weekly Progress Report 8

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: April 4, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

Completed this week:
- Milling complete (drilled instead)
- Materials to be ordered (Garrett)

To be done before next meeting:
- Order materials
- Talk to shop advisor about welding and complete by next week
- Talk to Garrett about bending

Weekly Progress Report 9

Development of a Handcycle Car Rack **MECH 8190** – Capstone Project
Meeting Minutes: April 11, 2019 @ 12:30pm **Location:** CARI Building

Members Present:	Arshdeep Saran	Faculty Advisors:	Jamie Borisoff
	Harjit Grewal		Garrett Kryt
	Santanjot Dhaliwal		
	Jaswinder Johal		

Completed this week:
- Parts to be ordered (Jaime)
- Redesign of the hitch

To be done before next meeting:
- Assemble sliding mechanism
- Talk to shop advisor and get ready for welding

Appendix B1. Simulation Results (von misses stress)

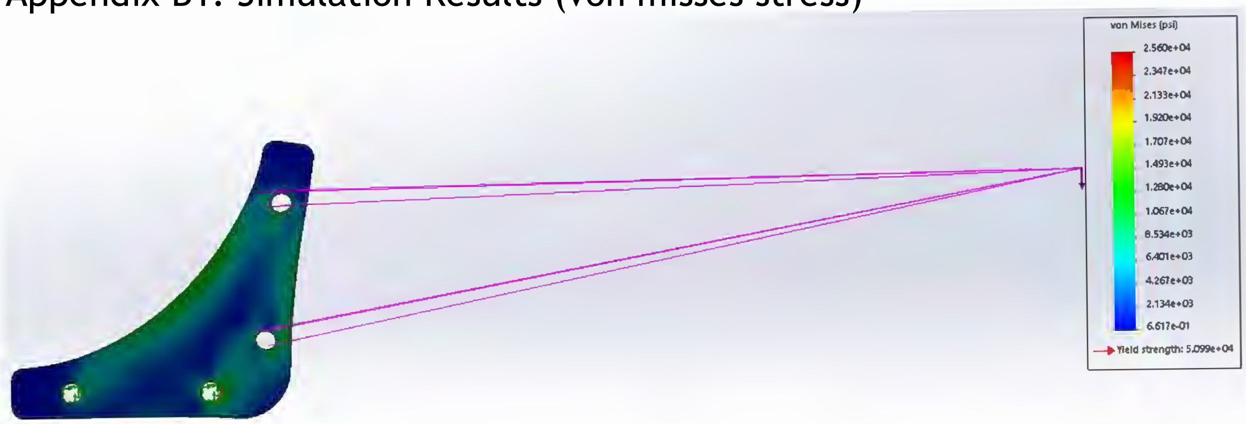


Figure 22- stress on hitch plate

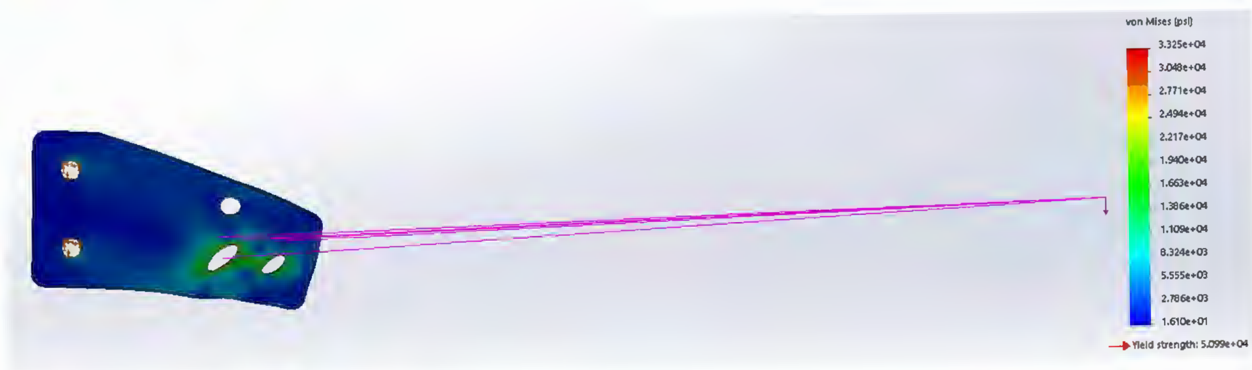


Figure 23- stress on inner tube plate

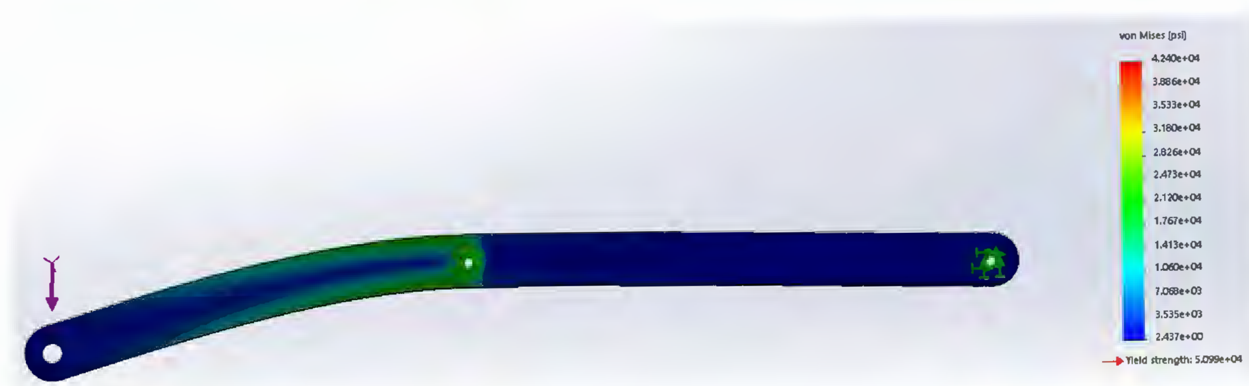


Figure 24- stress on lever

Appendix B2. Simulation Results (displacement)

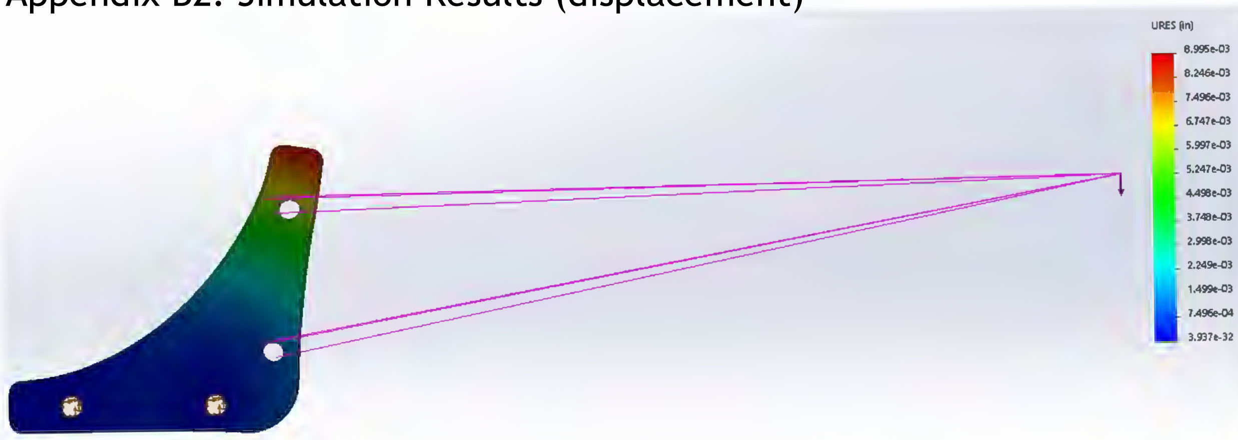


Figure 25- displacement of hitch plate

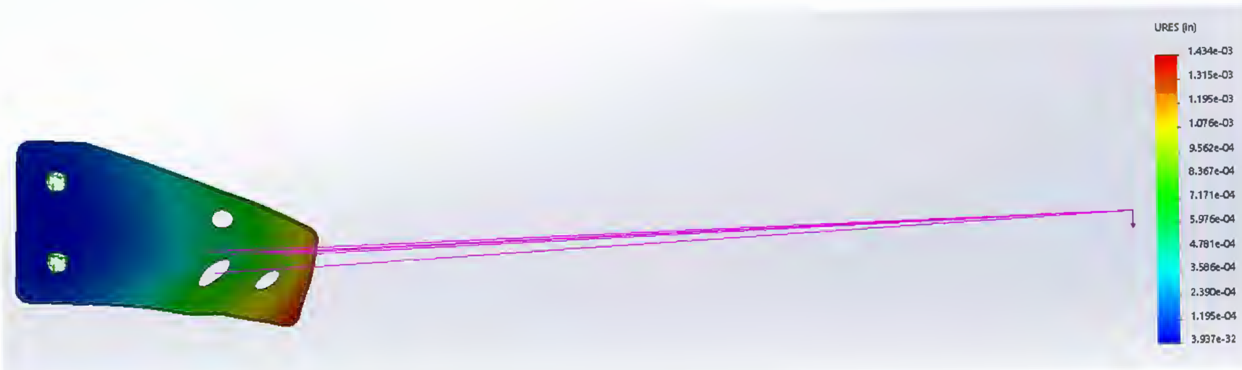


Figure 26- displacement of inner tube plate

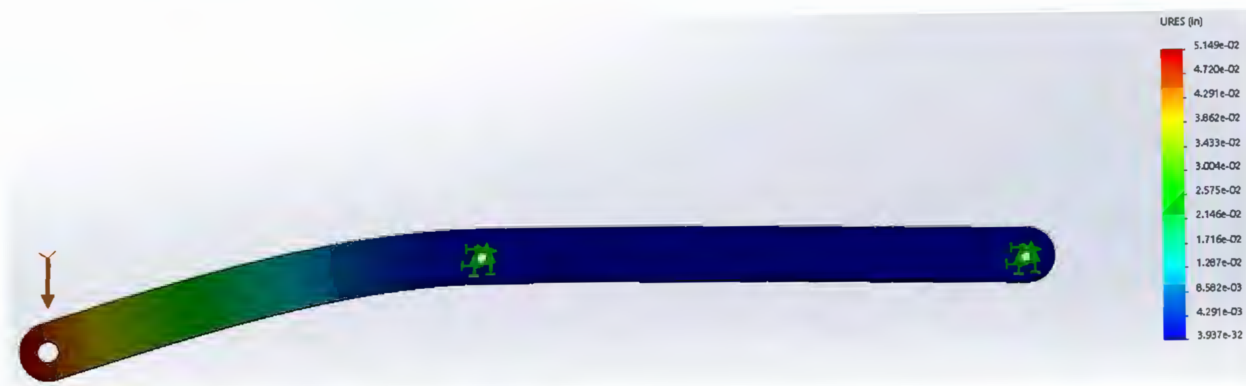


Figure 27- displacement of lever

Appendix B3. Simulation Results (factor of safety)

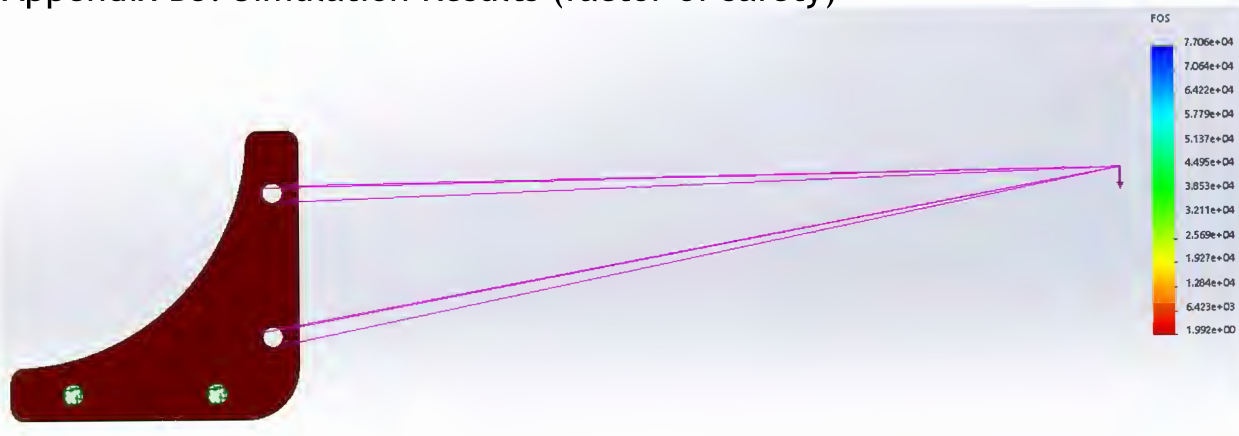


Figure 28- FOS of hitch plate

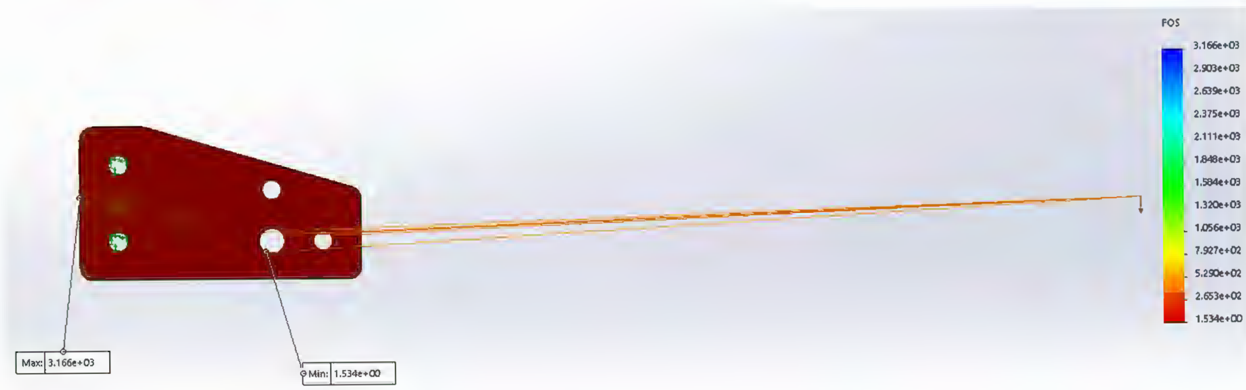


Figure 29- FOS of inner tube plate

Figure 30- FOS of lever

Appendix B4. Simulation Results (weld analysis)

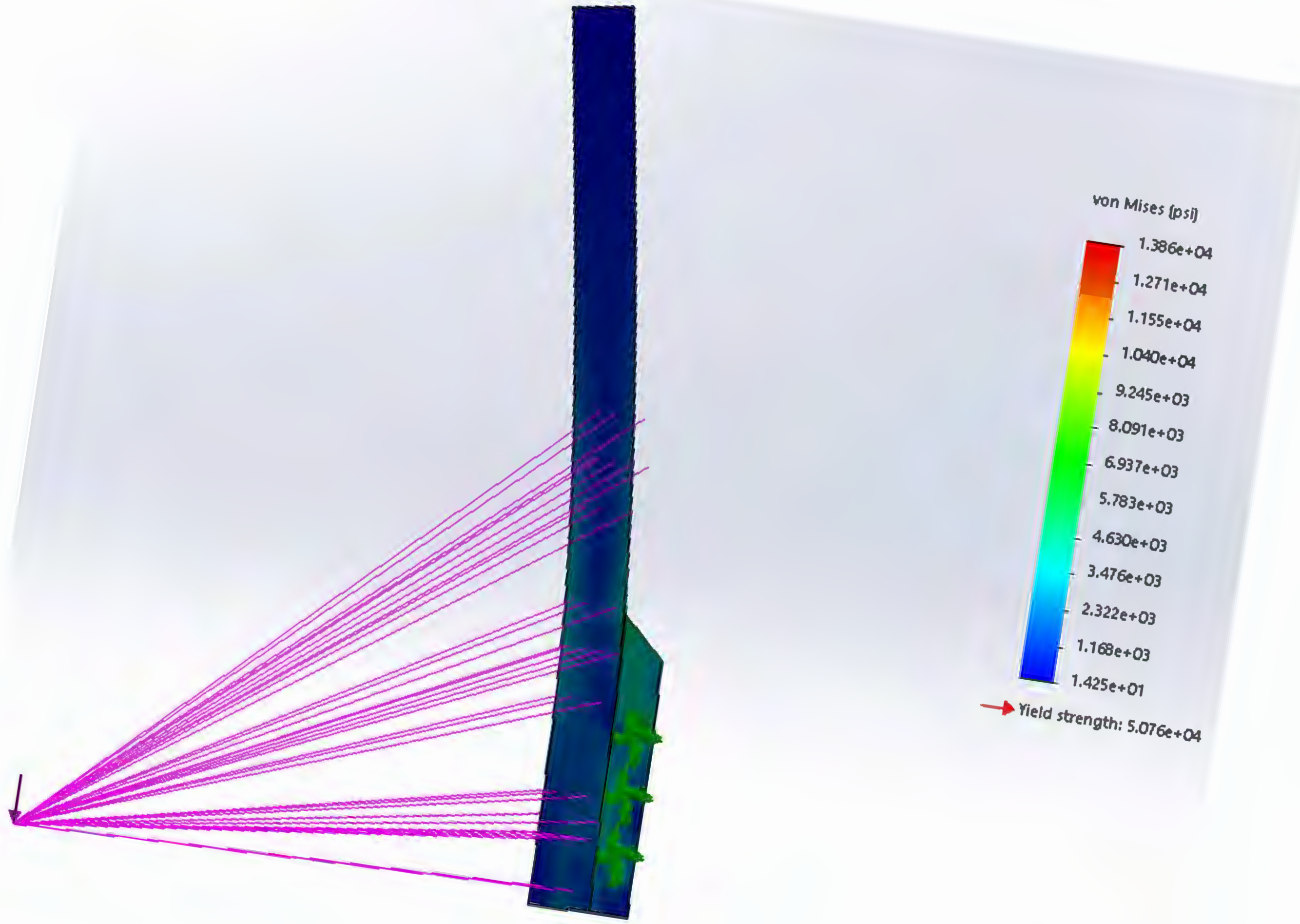


Figure 31- Stress on weld

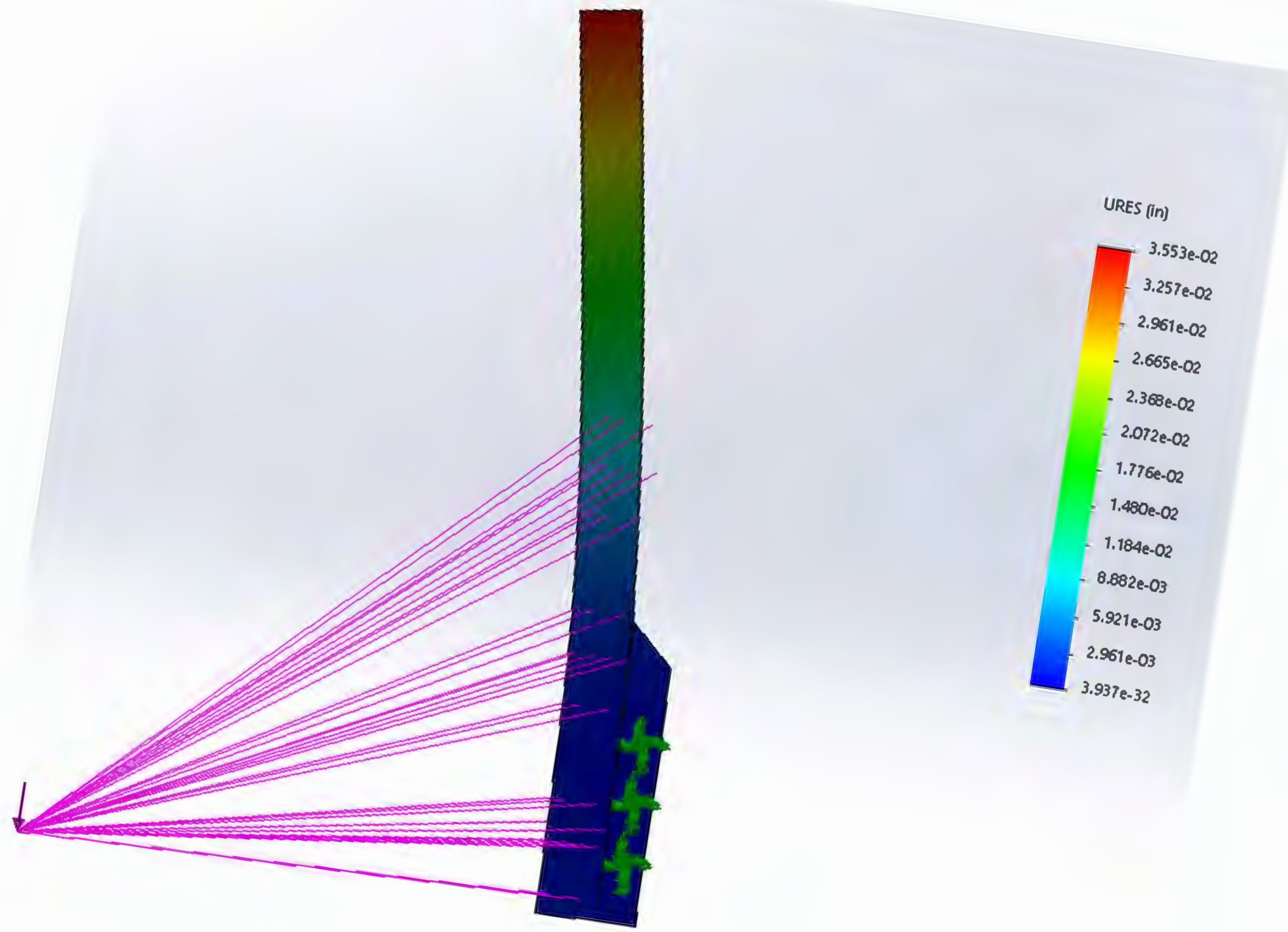


Figure 32- displacement of weld

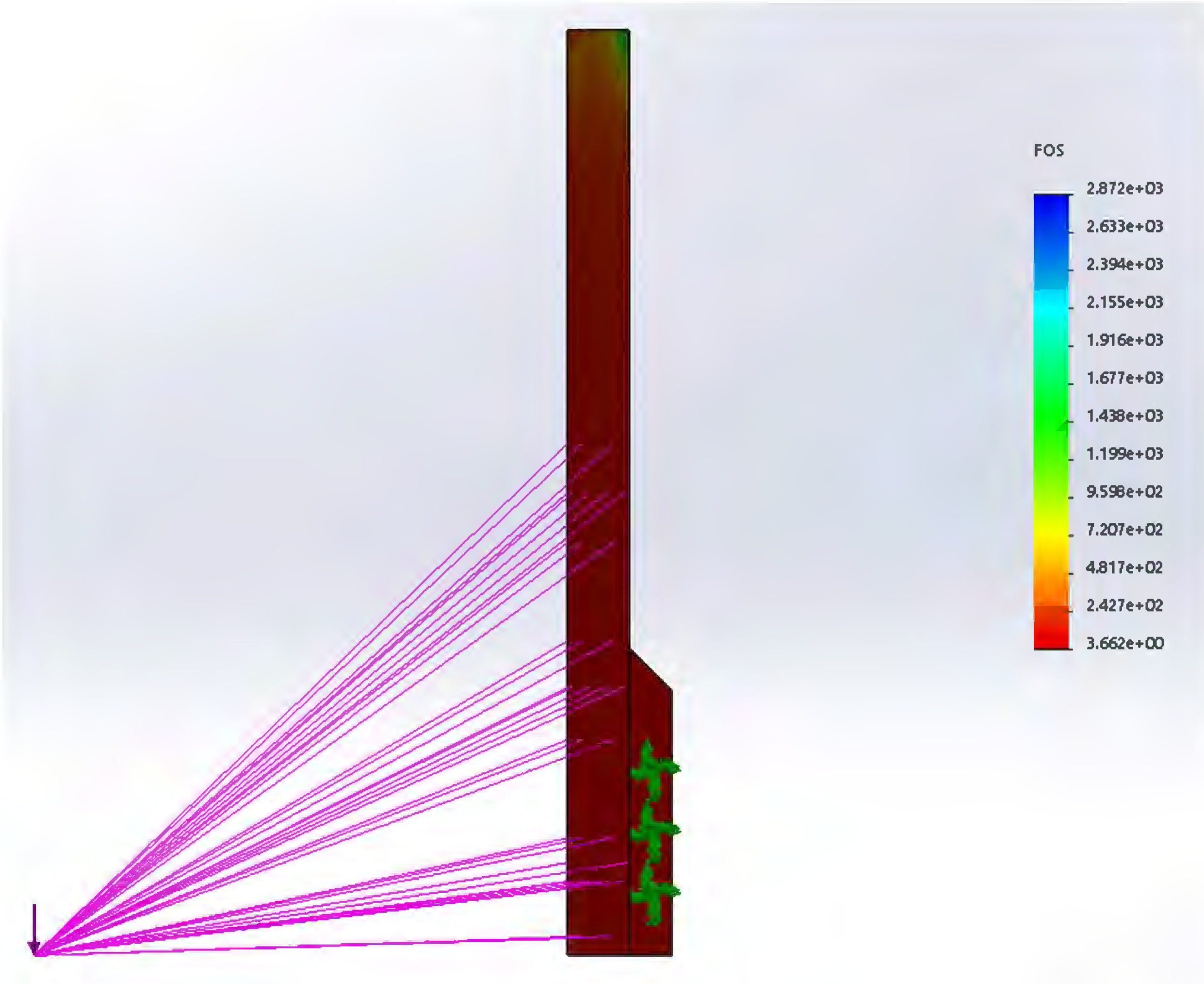


Figure 33- FOS of weld

Appendix C. Shop Drawings

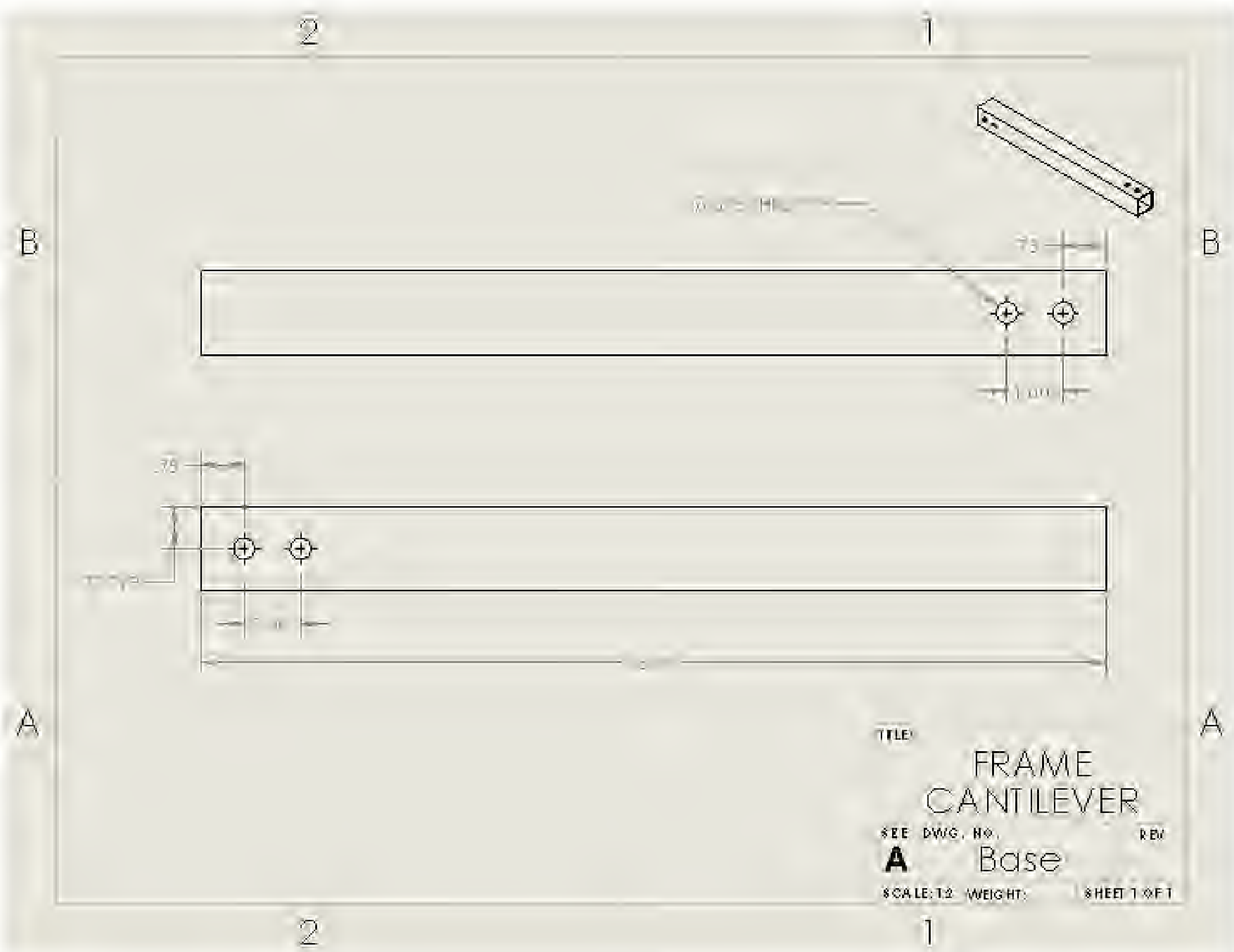


Figure 34- Cantilever Shop Drawing

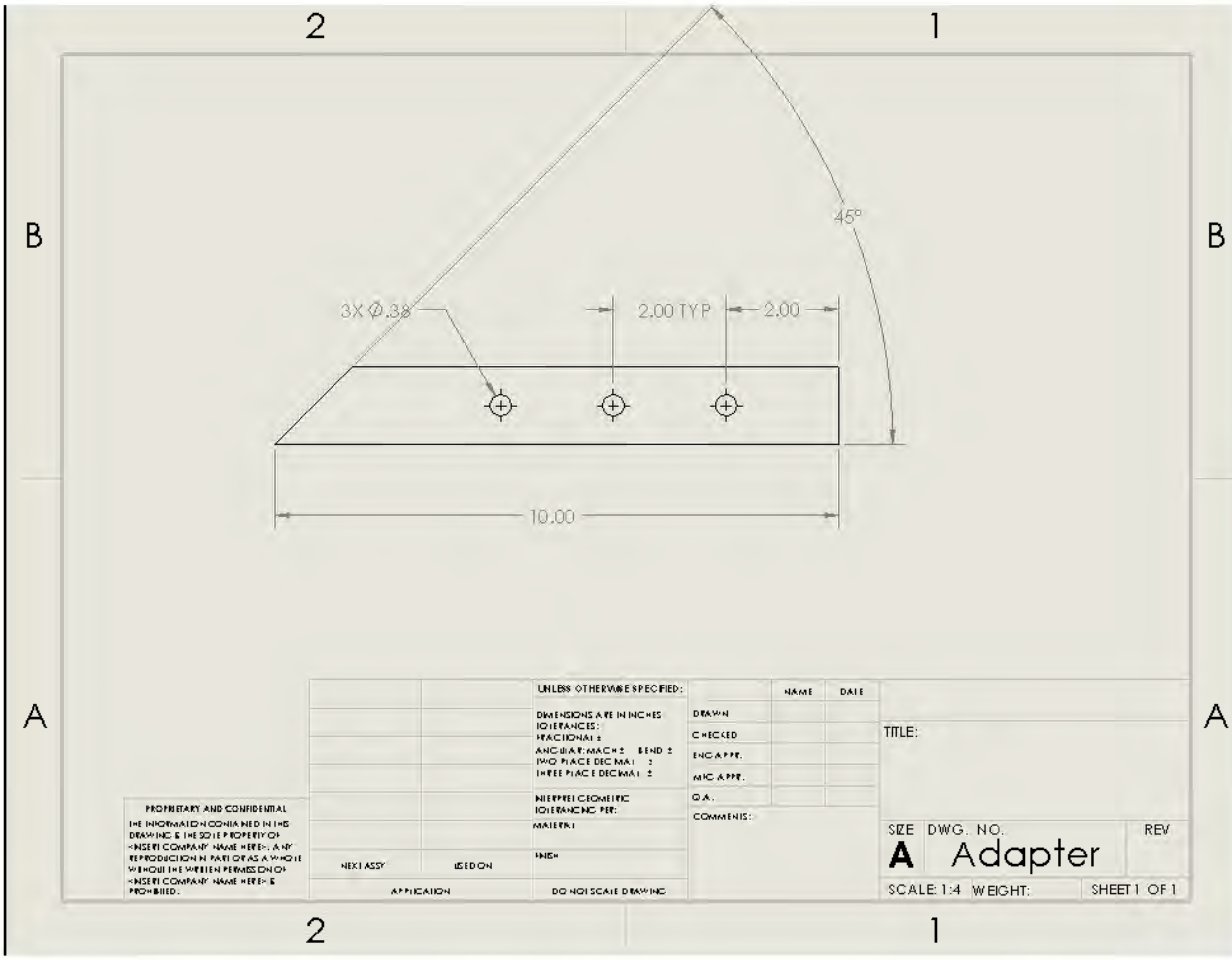


Figure 35- Adaptor shop drawing

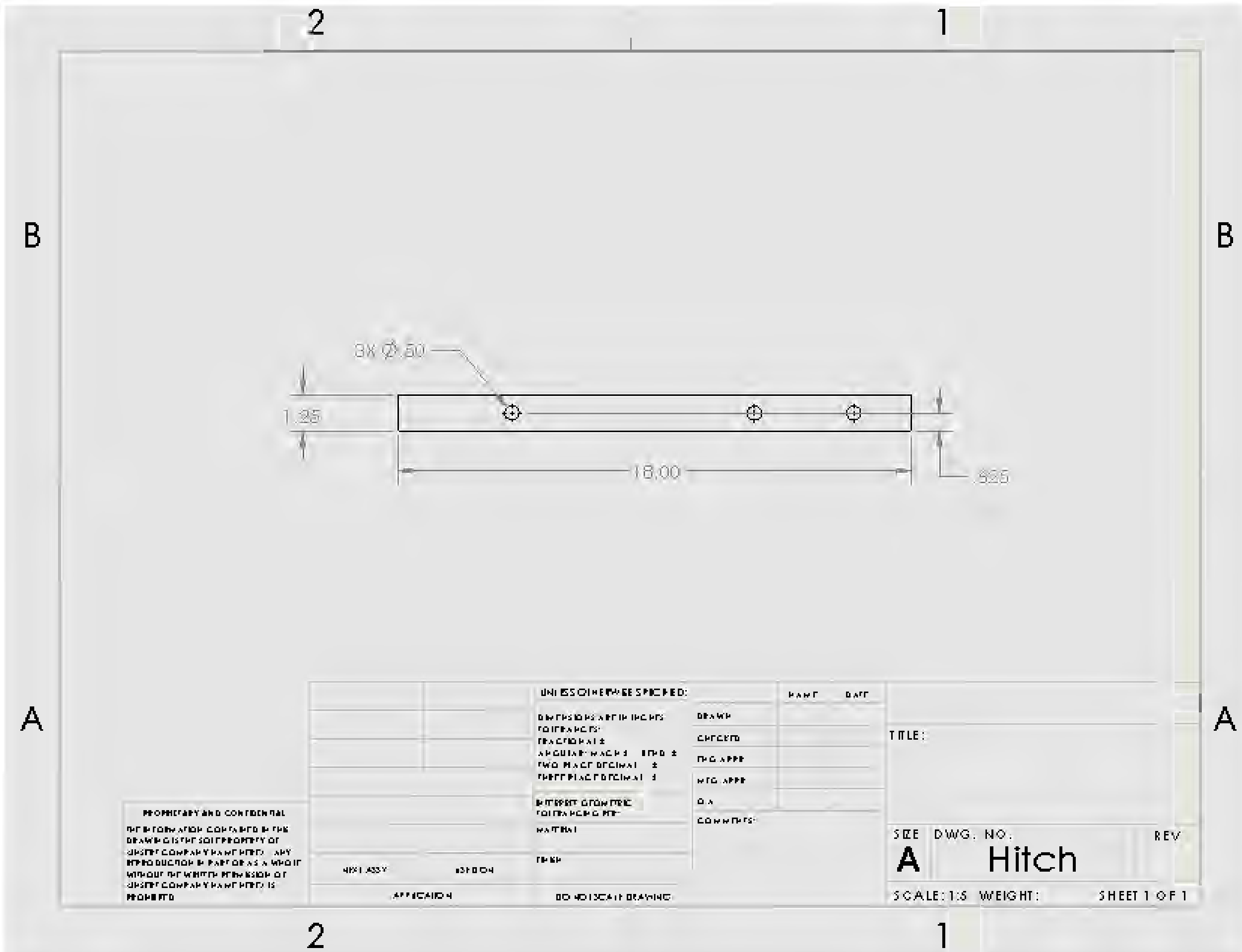


Figure 36- Hitch shop drawing

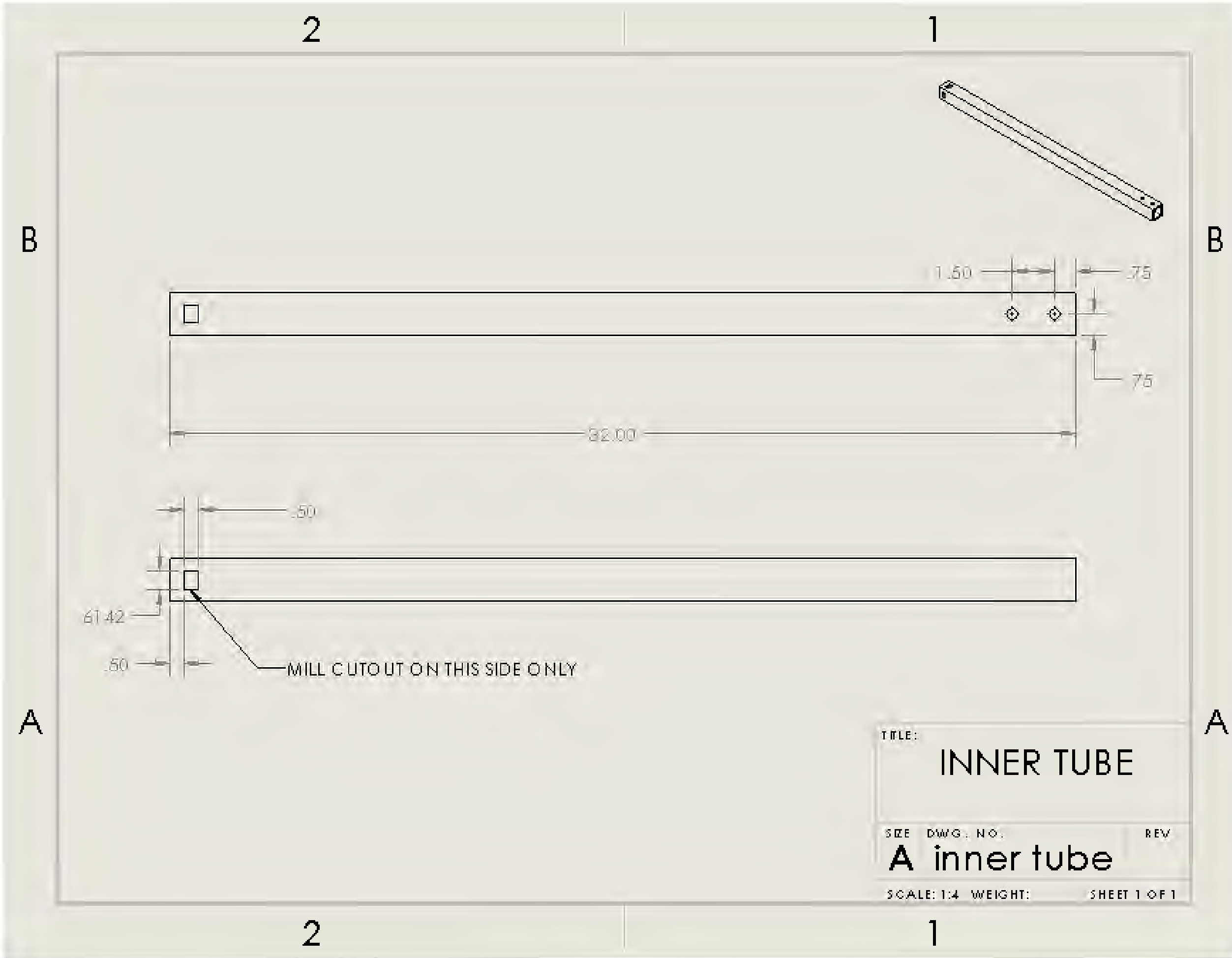


Figure 37- Inner tube shop drawing

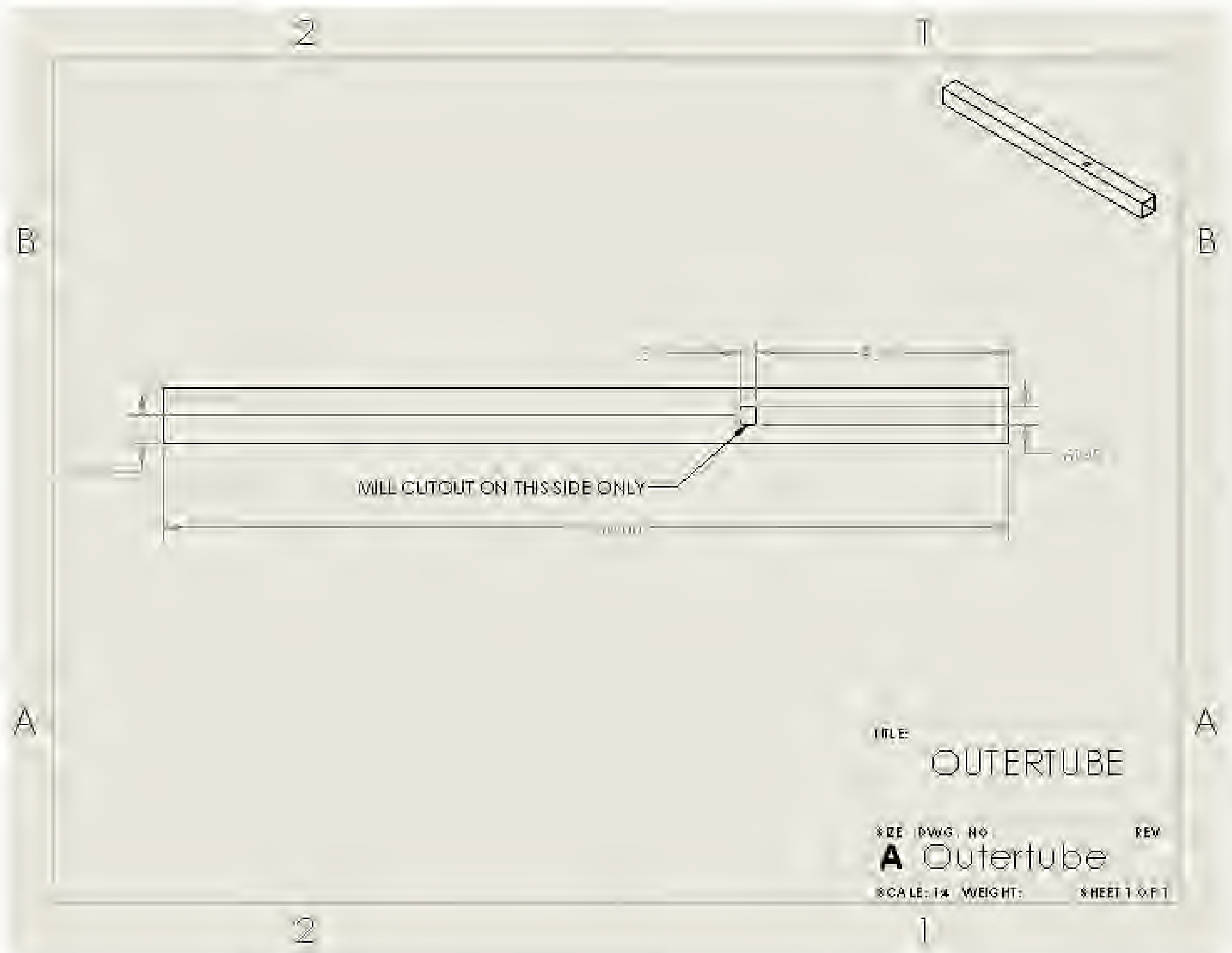


Figure 38- Outer tube shop drawing

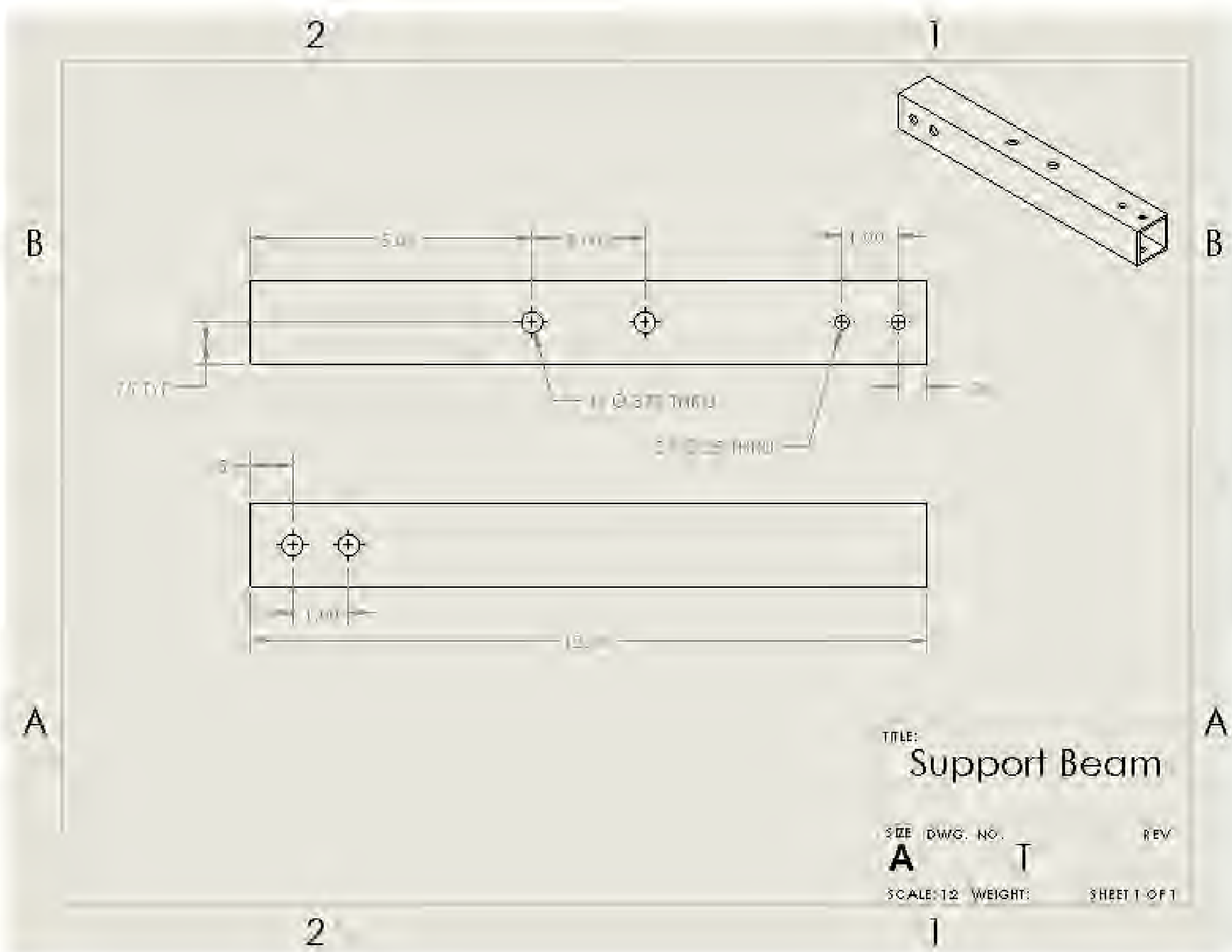


Figure 39- Support beam shop drawing

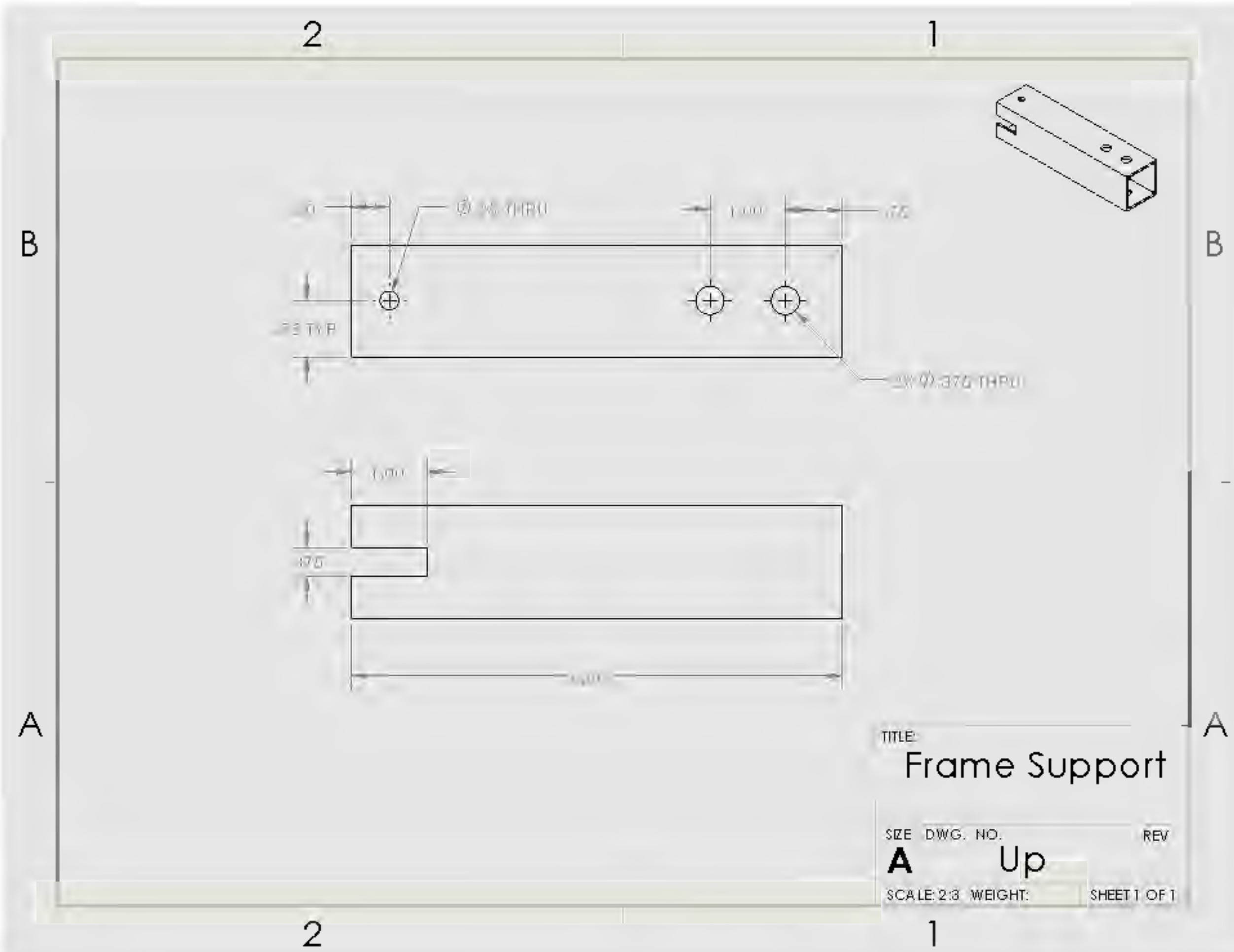


Figure 40- Frame support shop drawing

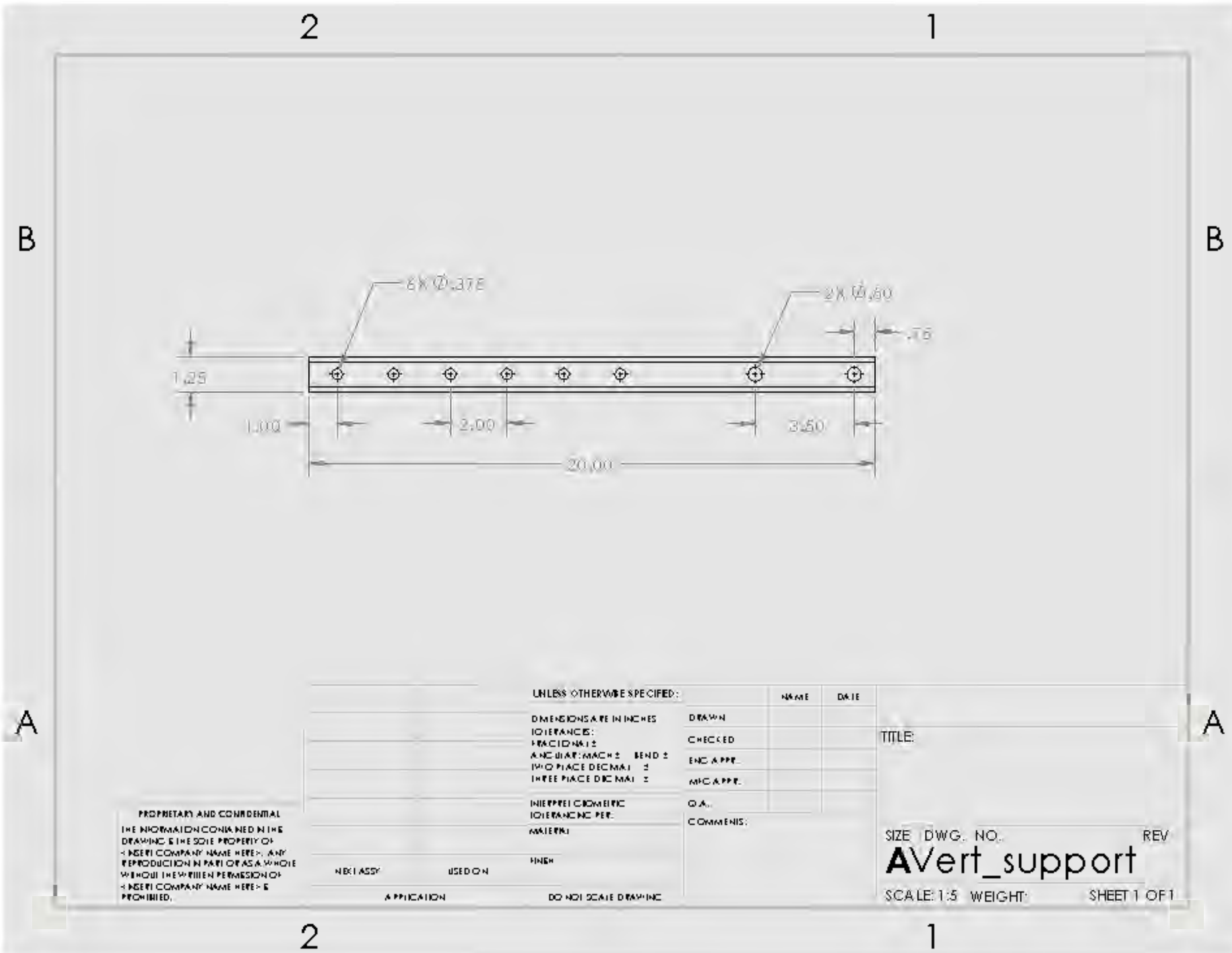


Figure 41- Vertical support shop drawing