Project Number: RDS MQP IM02

Design and Prototype of a Mobile File Transport System

A Major Qualifying Project Report
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of the
WORCESTER POLYTECHNIC INSTITUTE
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Degree of Bachelor of Science
by

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Abstract

The file transportation system currently in use by Iron Mountain has been thought to be insufficient. It was the goal of this MQP to work with Iron Mountain's Special Projects Team to design a more efficient, safe and secure system. Once the specific areas of interest were introduced, the investigation phase began. This included background, patent and benchmark examination as well as a survey of the current system to note specific defects and strengths. An investigation of alternatives proceeded, leading to the initial designs. A prototype was built and presented to Iron Mountain for their intermediary critique. The final design and prototype were tested, evaluated and analyzed. Our final solution was a side loading cart that Met Iron Mountain's as well as our performance specifications.

Acknowledgements

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1 Introduction

Information technology is facing one of its most difficult challenges today. The breach of information technology can lead to identity fraud. The protection of our information is of the utmost importance to our everyday lives, from swiping your credit card at the gas pump to paying bills online. That is why information protection during storage and transportation is vital to our way of life. The subject of this project is improving the physical transport of records for the project sponsor, Iron Mountain. These records contain sensitive data, such as social security numbers, credit card information, medical records, and addresses, which needs to be protected.

Iron Mountain was founded in 1951 in Livingston, NY and now has locations in North America, South America, Europe, Australia and Asia. The company specializes in records management and storage, among other document based services. This involves storing files and films in mass quantities in a warehouse facility. Transportation of these files and films is needed externally to and from the clients' locations as well as internally from different locations in the warehouse.

Iron Mountain is the "global leader in information protection and storage." The company specializes in records management and storage, and other document based services. This involves storing files and films in mass quantities in a warehouse facility. Transportation of these files and films is needed externally to and from the clients' locations as well as internally from different locations in the warehouse. Iron Mountain specializes in the following:

- Records Management
- Data Protection & Recovery
- Intellectual Property Management
- Digital Services & Software
- Film & Sound Archiving
- Comac Fulfillment Services

During the storage and retrieval processes stored files must be accessed and transported to their new destinations. Currently, a cart transportation system is employed. Iron Mountain states that these carts have proven to be dangerous and inefficient. The conditions which these carts are exposed to causes them to break apart easily, splinter, and tip over. They take up excessive space when not being used, and cannot be loaded or unloaded efficiently.

The goal of this project was to design a system that will optimize the transport of records stored by Iron Mountain in the areas of:

- Safety
- Reliability
- Efficiency in time & space
- Durability
- Value
- Mobility

After an investigation of the current system, available patents and benchmarks, and the design process, the concepts were presented physically to Iron Mountain for their use. The investigation of the problem with Iron Mountain leads to the development of a design process and a methodology to resolve the issues that were found in the original carts.

All parties involved the project team members, advisor and off-campus liaison, worked towards a consensus on solutions. The main deliverable was a prototype that was built for Iron Mountain representatives to visualize the design. The results should be used as recommended in this report in order to optimize the solution to the problem.

2 Background

Learning about the current situation and problem, processes to solve that problem, and ideas and products available that may already solve the problem provide the background information needed to successfully present a solution. Different versions of the design process were investigated. Investigation of Iron Mountain's history and information about their company provided insight on the problem. A series of interviews with Iron Mountain staff and tours of their facilities provided information specific to our goal. Patent and benchmark investigations provided a general knowledge of specific technologies and ideas already available in the industry. Expert interviews suggested advice and specific information pertinent to the project.

2.1 Design Process

There are many design processes; they range from few to over twenty steps based on the process in use. With respect to engineering, a design process is a set of steps used to maximize the efficiency of engineers when creating designs by providing guidance in identifying, investigating and solving a problem. The following sections will focus on two different types of engineering design processes, theoretical design and axiomatic design.

2.1.1 Theoretical Design

The theoretical design method that will be discussed can be found in Machine Design: An Integrated Approach by Worcester Polytechnic Institute Professor, Robert L. Norton. In this book the design process is reduced to ten steps:

- Identification of need – This is generally defined by what the customer wants and provides direction to the construction of the design.
- Background Investigation – The purpose of the background investigation is to increase the knowledge of the subject matter and to avoid possible mistakes.
- Goal statement – A goal statement provides a very concise description of all that needs to be accomplished.
- Task specification – Identifying and dividing the tasks creates a better understanding of all the steps that must be fulfilled for the design to be considered complete.
- Synthesis – Synthesis focuses on the creation and development of ideas and subsequently the creation of rough designs.

- Analysis – The analysis is done through numerous analytical tests to eliminate designs that do not meet defined specifications.
- Selection – Following the analysis, the designs that have the best results from the tests are chosen.
- Detailed design – A more comprehensive design is the created from the rough designs that were chosen in the selection process.
- Prototyping and testing – Each detailed design is then built into a physical prototype, which undergoes physical tests.
- Production – If a design completes all of the previous nine steps successfully then it is ready to be manufactured and put into production.

It must be noted that each step is interconnected and necessary for the final design to be complete. Norton cautions that, "The above description may give an erroneous impression that this process can be accomplished in a linear fashion as listed. On the contrary, iteration is required within the entire process, moving from any step back to any previous step, in all possible combinations, and doing this repeatedly." (Norton)

2.1.2 Axiomatic design

One of the newer forms of engineering design is axiomatic design. It is a design method that was created by Professor Nam Suh at Massachusetts Institute of Technology in the 1970's. In Nam Suh's book Complexity, Suh states that axiomatic design was created for the following purposes:

- To provide a systematic way of designing products and large systems.
- To make human designers more creative.
- To reduce the random search process.
- To minimize the iterative trial-and-error process.
- To determine the best designs among those proposed.
- To create systems architecture that completely captures the construction of the system functions and provides ready documentation.
- To endow the computer with creative power.

Axiomatic design is a straight forward process that does not rely on multiple iterations like the theoretical design process. The benefits of less iteration are fewer costs, reduction of development time, and higher reliability in the design process.

Axiomatic design states that a design process can be divided into four domains: the *customer domain*, the *functional domain*, the *physical domain*, and the *process domain*. A visual representation of this relationship can be seen in Figure 1.

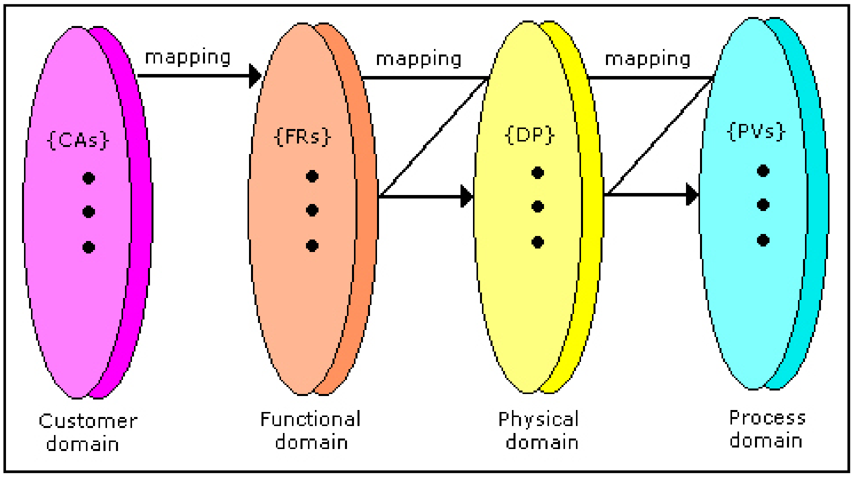

Figure 1 – Visual Representation of the domains (Axiomatic Design Solutions, Inc.)

As the Figure 1 shows, each domain is inter-related. Information flows from its entry at the customer domain to the final output at the process domain. For the sake of simplicity, only the functional and physical domains will be elaborated upon in this report.

Information that enters the functional domain is decomposed into functional requirements (FRs). Functional requirements are defined as, "a minimum set of independent requirements that completely characterize the functional needs of the design solution in the functional domain." (Axiomatic Design Solutions, Inc.). The functional requirements are identified based on the needs of the customer and they are listed numerically starting at FR0. The FRs are structured in a hierarchy with FR0 as the highest and broadest of the FRs. Each subsequent FR is based off of FR0 and it requires the most refining because of this fact. An example of an FR hierarchy can be seen in Appendix A.

The physical domain is characterized by design parameters (DPs) which are defined as, "the elements of the design solution in the physical domain that are chosen to satisfy the specified FRs." (Axiomatic Design Solutions, Inc.) The DPs follow a similar hierarchical structure with DP0 as the parent to all the following DPs. Each DP must match up with the FR of the same number and must state what the design element or process is required based on its FR counterpart.

The axiomatic design theory is based around two major axioms. Axioms are defined as, “truths that cannot be derived but for which there are no counter-examples or exceptions.” (Suh) The design axioms apply to the CN, FR, DP, PV framework and provide guidance in choosing and screening the variables entered in each section. The first of the two axioms is to maximize independence. This is done by minimizing the coupling of functional elements which assures that the design is adjustable without affecting the other parts of the design. This does not apply to physical coupling, but applies specifically to functional coupling. This axiom pertains almost exclusively to the FRs and their interaction with the DPs. The DPs must be chosen in a manner that satisfies the FRs but still preserves the independence of each FR.

The second Axiom is to minimize information. This axiom immediately follows the first axiom because it states that the best design contains the least information. Minimizing the information lowers the chances of errors by reducing the complexity of the design.

As axiomatic design grew in popularity, software companies took note and created software to streamline and document the process. A program that was made specifically for axiomatic design is Acclaro, which is created by Axiomatic Design Solutions, Inc. Acclaro allows the entry of all the parameters from each domain, and intuitively converts them into a design matrix. A design matrix is another tool that visually shows coupling by the use of X’s (coupled) and O’s (not coupled). Studying the design matrix aids in the de-coupling of coupled entities. An example of a design created by axiomatic design and a design matrix created by the Acclaro software can be seen in the Appendix A.

2.2 Iron Mountain

Iron Mountain is a company concerned with records management, data protection, and information destruction solutions. Founded in 1951, this company has grown from a depleted iron ore mine used to store the microfilm copies of deposit records into the first nationwide provider in the industry. As of 2005, Iron Mountain has 850+ facilities, 15,500+ employees, and “100,000 corporate clients throughout North America, Europe, Latin America and the Pacific Rim” in 26 countries (Iron Mountain). Iron Mountain’s records management has been adopted by over 98% of the Fortune 1000 companies (Iron Mountain). These companies store and retrieve files from Iron Mountain's facilities because of their records indexing and retrieval technology, and secure transportation and destruction services.

2.2.1 Visiting Iron Mountain

During the early investigation stages of this project, we paid a visit to one of the storage facilities of Iron Mountain. Throughout the visit we interviewed their employees that work with mobile transport system currently in place and looked at the physical layout of the facility that the carts are exposed to and identified areas of concern for us to address.

Safety

Safety is one of the standards that we set for the design intent of our final design. Some of the issues that Iron Mountain brought to our attention was that sometimes a cart may tip over going on an incline or declined surface. If for example there is a pot hole on the inclined or declined surface, the caster may fall into it and completely flip the cart over. Depending on the position of the employee, the cart may potentially tip over onto the person. Another safety issue was splinters from the wood. These carts are exposed to physically demanding environments which bring us to out next topic, reliability and durability.

Reliability* & *Durability

Iron Mountain wants a cart that is dependable and viable. The carts need to be corrosion resistant for use in moist environments, be able to handle exposure to high and low temperatures as the seasons change and handle vibration stresses during transported in moving trucks from location to location. Fatigue stresses due to constant on loading and offloading of files must also be taken into high consideration. In summary, the design objective for our cart is having the strength and reliability to endure the situations it may encounter.

Efficiency in Time and Space

Iron Mountain has large storage facilities, and as a result has lengthy hallways. When an employee, for example, is only able to bring 2 carts at a time from one end of the hallway to the next, it yields in a considerable amount of time consumption. Iron Mountain is in the business of storage, therefore space optimization is definitely a one thing that is considered to be a "must have". Seeking out a range of interlocking options and making the best use o space in each cart is one of the areas of concern we are keeping in mind for our final design.

Value

It is in our best interest for our customer, Iron Mountain, to provide them with an economical design that meets and/or exceeds all the requirements set by us and Iron Mountain.

Mobility

In addition to inclined/declined surfaces and potholes, the cart also needs to be mobile over different types of surfaces. For example, carpeting is harder to roll over while on the contrary linoleum floors are marked by the caster. Iron Mountain would like a caster that not only is durable, reliable and safe but also versatile enough to go over bumpy surfaces, dents in the transport path, carpeting and not mark the floors they are moved on.

2.3 Patent Investigation

As part of the background investigation, multiple patent databases were searched with key words to identify if our ideas already exist and to discover new ideas based on those already patented. A patent is "the exclusive right granted by a government to an inventor to manufacture, use, or sells an invention for a certain number of years." (Dictionary.com) This can extend to processes, machines, information, methods, and improvements to current ideas. When one is given the task to develop a new design, it is important not to violate any patents when creating and building prototypes.

The key search words were chosen to help look for a specific feature and to avoid possible patent infringement. Patents were searched for based on these key words because we thought that they would be similar to what we are creating. Within these patent designs we found a plethora of designs suitable for consideration. For example, the first key word was "book cart". Another key word that we focused on was "baby carriage." Our purpose for looking at baby carriage patents is to understand how secure wheel locks work. Wheel locks are one of the design specifications given to our group by the Iron Mountain staff, and understanding needs is important. Another key word was "shopping carts." The main feature that we were looking for in the shopping carts was found in the carts design for portability. These carts each featured a collapsible holding area in order to facilitate storage and transportation.

While some of the key words produced results, others did not. None of these designs were similar to what is currently being used at Iron Mountain. Key words such as "bread cart" and "file cart" were found to have useful elements, but were too different in design to be effectively used for our purpose. The majority of the designs found for a file cart were specifically for hanging files. Since hanging files are not used by Iron Mountain, these designs were not considered further. While searching through the patents using the "bread cart" key word we found many designs that were not of any use because they utilized stacking.

2.4 Benchmarks

A benchmark is considered to be "a standard or reference by which others can be measured or judged." (Dictionary.com) We considered benchmarks to be all carts and parts available on the market already. These benchmarks had many favorable features desired by Iron Mountain. Some qualities of the benchmarks seemed like a logical transition toward the final design while others were a step towards innovations. The current carts used by Iron Mountain are shelves made of wood with 4 metal casters. These have been bought from outside company and have also been made by Iron Mountain themselves. According to Iron Mountain, the quality seems to be similar whether purchased or built. Both seem very homemade and thrown together without much thought to the needs expressed. Logically, cost is greater when the project is outsourced. When built by the other company the cost of the carts are $200 to $250. When built by Iron Mountain the cost of the carts is roughly $150. This system has proven costly, ineffective, non-ergonomic, and at times is dangerous. Parts that fall off and need to be replaced increase the price. The carts become ineffective due to loss of time when carts cannot be completely filled or spill. The hand positioning is painful and can decrease stability. When up to 800 lbs can fall on workers, it poses a safety issue leading to injuries as well as a confidentiality issue if files spill. Iron Mountain is the "global leader in information protection and storage." The current means of transportation are two carts with the dimensions and characteristics found in Figure 2. This system has proven costly, ineffective, non-ergonomic and at times dangerous.

Figure 2 – Example of a Benchmark Cart

Many benchmark carts, those available on the market already, had many favorable features desired by Iron Mountain.

2.5 Expert Interviews

Sometimes the best way to find out information about something is to ask an expert in that field of interest. We conducted an interview with Professor Mustafa Fofana of Worcester Polytechnic Institute's Material Science Department. The goal of the interview with Professor Fofana was to find out what materials may be best suited for the design of our cart. During the interview he suggested that although the material we use is important, it is more important to be concerned with the rigidity of the cart. He recommended designing the cart with enough reinforcement to handle the stresses to be applied to the cart and take into account the weight when reinforcing. He suggested using trusses to strengthen the shelving and door of the cart. As for materials, Aluminum 6061 would be satisfactory for the use of our cart, since the drawback of reinforcing wood if that the cart will become heavy. We took into account his recommendation and applied them to our final design.

The next interview we conducted was with Professor Robert L. Norton of Worcester Polytechnic Institute's Mechanical Engineering Department. Professor Norton is known for machine design. We asked him what type of screws he suggested for the cart and what resources we could use as a reference to find fasteners, screws and brackets. Professor Norton suggested

Machinery’s handbook for standardized screws, fasteners and brackets. We mentioned that we are concerned about corrosion since the carts may be exposed to wet environments; he suggested using stainless steel or zinc-galvanized wood screws. Even though stainless steel screws are fairly expensive (about one dollar per screw) screws he said it may be our best viable option. He also said to avoid brass and copper wood screws because they are weak, corrosive and expensive. He said if the screws are not stainless or coated with something, they will rust. Based on our expert interviews, we were suggested to do the following:

- Used corrosive resistant wood screws
- Make sure that design of the cart of rigid enough to meet the stress requirements
- Design the cart to be strong yet lightweight

3 Methodology

This section details our methodology for completion of our project. We focused on furthering our understanding of the background, social and technical resources available, as well as investigation techniques. Through our investigation we identified applicable testing methods that were used throughout the project.

We utilized commonly used design processes to create and choose designs, and common manufacturing processes to create the prototypes. The steps for the process that best fits the scope of our project are the following:

1. Create a problem statement
2. Investigate the problem
3. Create Designs
4. Choose the strongest solutions
5. Manufacture a prototype
6. Test and Evaluate
7. Propose Possible Solutions
8. Redesign if necessary

The utilization of this tool provided structure for an approach to accomplish our objective which was to create a mobile file storage system in the areas of safety, reliability, efficiency in time and space, durability and value.

3.1 Problem Statement

The first step to figuring out any problem is to define what is being asked. This step is a two part process: (1) need is identified either by the customer or the consultant and then we (2) define the problem and write the statement that we must solve. Without a properly defined problem statement, it is possible to provide a solution to the customer is unsatisfied with. If the customer is unsatisfied everyone's efforts are wasted.

In this case, Iron Mountain identified a need for their current file transportation system. The problem was defined as redesigning their system to solve most of their current issues.

Finding more information on the issues at hand and possible solutions to the problem is the next step.

3.2 Investigate the Problem

The previous step, defining the problem statement provided a guideline to finding more information about the topic at hand. When investigating a problem the best way to go about doing so, at least initially, is to keep the range of sources wide as possible. This allows a large amount of potential solutions to be considered, which in turn will allow the engineers to filter out what will not meet the design intent. Eventually the investigation sources were narrowed and probed for more detail. The sources of problem investigations included, but were not limited to:

1. Information about our customer and their needs
   a. What is currently being done and what others may be doing that can solve the problem
2. Patent and Benchmarking Databases
   a. Benchmarks (what is currently in use) and patents (legally protected idea that may not be in physical existence yet) provide transferable solutions that may be applied to our problem
3. Expert Interview
   a. This is where experts in the field are interviewed on their recommendations or suggestions to the meet the design intent. The work site was also visited to identify any other challenges.

Having as much background knowledge on the challenge provided a strong foundation to move on to the next steps of the design process.

3.3 Create Designs

At this point, the problem is known and background information encourages ideas for creating solutions. Brainstorming is a group activity designed to encourage a large number of ideas that may be a potential solution to a problem. Another method is to apply investigation results and identify solutions to other challenges, whether they are similar challenges or not, that may be transferable solutions to our challenge.

Similarly to the problem statement and investigation, creating designs also happens in two phases. Initially, we want to use the brainstorming method to generate as many solutions as possible. During the early brainstorming sessions, the ideas that presented do not necessarily have to be considered as a final result, that's where the analysis come in later on throughout this process. The reason for this is to simply get as many ideas on the table and move into the second phase which is to then either modify or filter out the strongest potential solutions for our problem. The second phase in creating a design is to take realistic and feasible features from either existing features that we know through our investigation and apply them to our design or modify the ideas that came out of our brainstorming sessions.

3.4 Choose the Strongest Solution

When choosing the strongest solutions we designed a chart that compared and contrasted areas of concern for Iron Mountain as well as the feasibility of the project. The formal name of this method is called a design matrix, Multi-Attributed Decision Table, or a Scoring Chart. (Sullivan, Wicks and Luxhoj) These terms will be used interchangeably for the purpose of this report. The strategy of this method of solution selection is to compare the required/desired outcomes set by us and the company with the available design inputs that may meet that criterion. When considering parameters for the matrix, such as high strength, low cost and light weight, were defined. The requirements are usually measured quantitatively while on the contrary, parameters that are more subjective such as durability, manufacturability and aesthetics are more qualitative. An example of this method is shown below in Table 1.

	Variable 1	Variable 2	Variable 3
Parameter 1			
Parameter 2			
Parameter 3			
Parameter 3			

Table 1 – Sample Scoring Chart

Once the scoring chart was completed with the numbers that were found through investigation, non-dimensional scaling was applied. To apply the scaling, the first step was to identify if a higher number or a lower number was the best choice in each parameter. Once that was known then a formula was used to create the scale. For the case that the higher number was the best choice the formula was as follows:

$$\frac{Variable\ x\ Parameter\ Value - Best\ Value}{Best\ Value - Worst\ Value}$$

While in the case that a lower number was the best choice the formula was as follows:

$$\frac{Best\ Value\ -\ Variable\ x\ Parameter\ Value}{Worst\ Value -\ Best\ Value}$$

Once all the values are converted to a non-dimensional scale the best value for each parameter was assigned a value of “1” and the worst value was assigned a value of “0.” To obtain the variable that is the best choice, all of the scaled numbers for the variable from each parameter were summed and the variable with the highest number was the best choice.

This provided a visual aid and a formal analysis that assisted in which solution was best suited for the design intent.

3.5 Creating the Perfect Prototype

Prototyping is a small scale model used for the purposes of testing, demonstrating features and to gather early user feedback. Prototyping is necessary to confirm that one’s design is feasible. Although those are the reasons for prototyping, sometimes a prototype may be used only for modeling purposes or only for testing purposes. The intent of the prototype will determine the design, size and purpose of the prototype. For the scope of this project, the prototype cart was used for modeling and demonstration purposes.

3.6 Testing and Evaluation

The next step of the design process was to test and evaluate the potential solution. Sometimes physical testing is not always feasible depending on the constraints of the project. Usually, when testing is conducted situations are simulated or exaggerated to incorporate a safety factor into the final design solution to make sure that the theoretical calculations match the physical test. Evaluation is the analysis of the solution presented and procedures are used to determine if the test results are accurate. If the test failed, the simulation would be assessed to figure out more alternatives to the solution to the challenge. For this project, no physical testing was conducted but an evaluation procedure was used which is found in a later section.

3.7 Propose the Solutions

Once the previous steps of our outlined design process were completed, the solutions to Iron Mountain were proposed for feedback. Comments on practicality and questions on usage were considered. We provided Iron Mountain with our cost analysis, our scoring chart and provided visual aids such as a CAD model and detailed drawings along with manufacturing instructions.

3.8 Redesign if Necessary

The role of engineers is to constantly improve on a design, making it more efficient and easier to use. Once the solutions are presented to the customer, Iron Mountain, ideas are either completely abandoned or the existing design continues to be improved based on comments made. This is the stage where the cycle begins all over again (usually from steps 2-7), the difference is that it may only be one parameter that needs to be modified.

4 Results

In this chapter we will discuss results and analyze our investigation and the prototypes. The design process section will discuss the process we chose and why we chose it. The prototype section will discuss the prototype built and an analysis of it. The full scale model section will discuss the final details of the cart being presented and an analysis of it. The following sections discuss in detail the background research of the problem.

4.1 Problem Statement

Our objective was to provide Iron Mountain with a new mobile records transport system that will meet the expectations set by us and Iron Mountain and eventually replace their current system. The current records transport device in use, the standard cart and the “cubby” cart are shown below in Figure 3.

Figure 3 – Iron Mountain’s current carts “bookshelf” cart (left) “cubby” cart (right)

We identified issues in Iron Mountain’s current system that slowed productivity and created hazards. With the current system, Iron Mountain employees could not unload a cart that was parked in an aisle at their storage facility. The cart could only be unloaded when it was in the main aisle so employees would have to carry loose files 50 feet to shelf them. Durability was another major concern that Iron Mountain expressed. Their current carts have a typical lifespan of about two years before general wear and tear caused them to become unusable. In some instances fully loaded carts have collapsed causing casualties on the work site. This is not only extremely hazardous, but when a cart collapses it could ruin or expose the confidential files to passersby. Sometimes the casters breaking off of the cart will cause that cart to become immobile and or tip over. Iron Mountain sought a cart that could be maneuvered down a narrow aisle and unloaded next to the shelving, which was more durable, and had a better caster arrangement, along with the other performance specifications illustrated in section 4.3.

4.2 Created Designs

In the following sections we will detail some of our original attempts, the feedback that we received, and the redesigning that took place during these steps in our process. Overall we came up with a few final designs that included everything from skeletal structures to stackable models. The purpose of illustrating our original designs was to show some of its features that were transferable to our final cart design.

Initially, our group was given a vague idea of what Iron Mountain wanted. We received a tour of their facility where they gave our group the dimensions of the current carts and relayed some of the current problems they were having. This verbal statement of problems was the basis for all of our earliest models.

From each of the specifications Iron Mountain provided during the original meeting, our group created a table with all the features that we thought would be beneficial. We sorted each of these features into groups based on the categories provided in our goal statement. The categories are as follows, safety, reliability, efficiency, durability, and mobility.

Using the features that we found to be the strongest we began to create designs. We decided to divide our designs into two categories, incremental improvements and "out of the box" ideas. The incremental improvements were small improvements to the current standard cart idea while the "out of the box" ideas were more extravagant. For example, our folding collapsible cart is an "out of the box" idea, while the cart mentioned above is the incremental improvements made to the current system in place.

4.2.1 Original Design 1 – Incremental

After brainstorming many ideas, we narrowed them down to two main designs, one of them being a traditional cart with added features as shown below in Figure 4. This design had the same basic features of the carts that Iron Mountain currently uses.

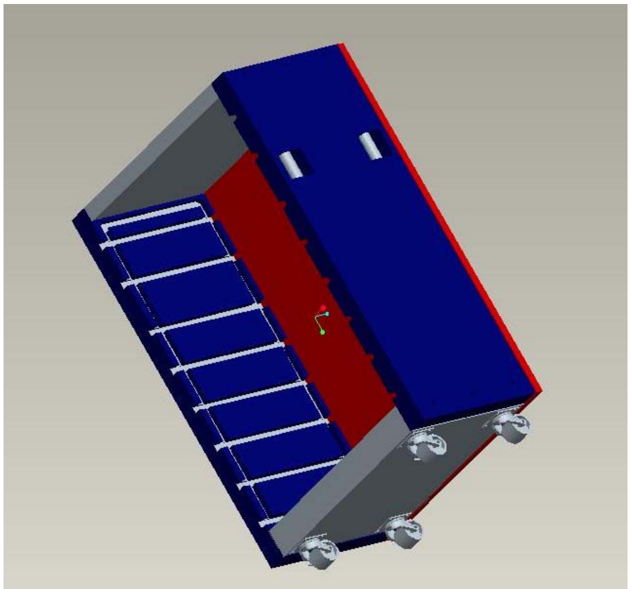

Figure 4 - Incremental Cart

This cart had embedded handle bars for easy handling. The shelves were customizable, meaning each one could be adjusted to their own height due to the slotted shelf grooves shown in Figure 5. For security, there was a roll over tarp and a cam lock attached to the bottom of it. The Velcro strips kept the tarp in place. The interlocking system utilized a rope and carabineer attached at the bottom of the cart as shown in Figure 6. The advantages of this cart over the current system were that it would have more durable design, adjustable shelving, connectivity, and most of the other features that Iron Mountain requested.

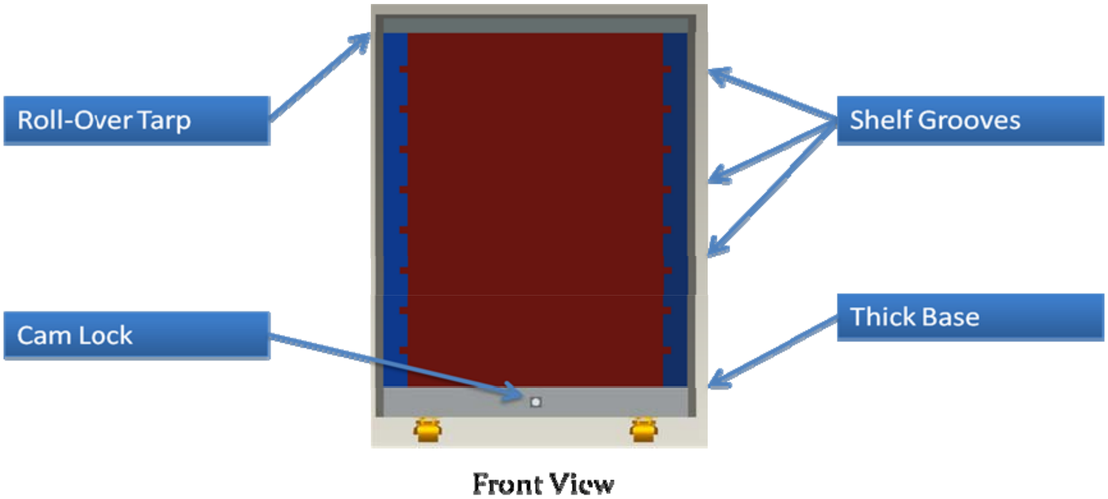

Figure 5 - Incremental Cart: Front View

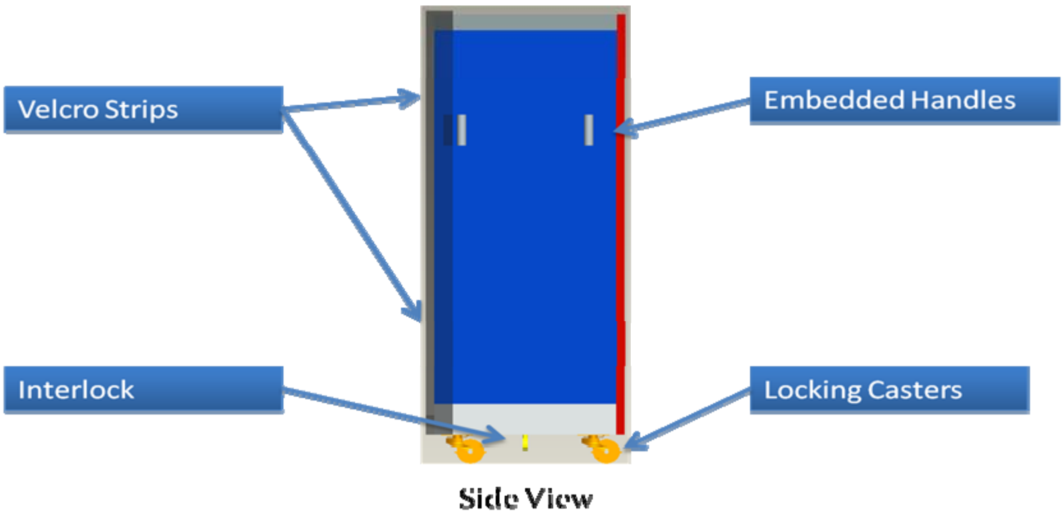

Figure 6 - Incremental Cart: Side View

This idea was not chosen partially because the course of the project changed. Once we presented this solution to Iron Mountain, they brought to our attention that they are purchasing new shelving units and they want a cart compatible with the new system. The new system has cubby inserts that go into large stackable grids, which then resulted in our group designing a new end loaded cart system with cubby boxes to be inserted into the new storage grids. We will discuss the final design later on this chapter.

4.2.2 Original Design 2 – Collapsible

One of the designs that we pursued was a folding cart as shown in Figure 7. The advantages of this cart are that it would be able to be folded when it was not in use so that it takes up less room when being storage or transported. One of the disadvantages of this cart design is that it is less durable than a cart with a non-folding structure. All of the connecting hardware that allows the side wall sections to fold needed to be very strong. The wear on the hinges was the area of major concern. If a hinge failed on the cart, the cart would immediately collapse. Another disadvantage of this design is that it is complicated to build due to critical loading points where the sides are connected to the back of the cart. Forklift compatibility is also a major concern with this design, since there is no base structure the entire weight of the cart is was placed on the bottom shelf and the four rods connecting the shelf to the rest of the unit.

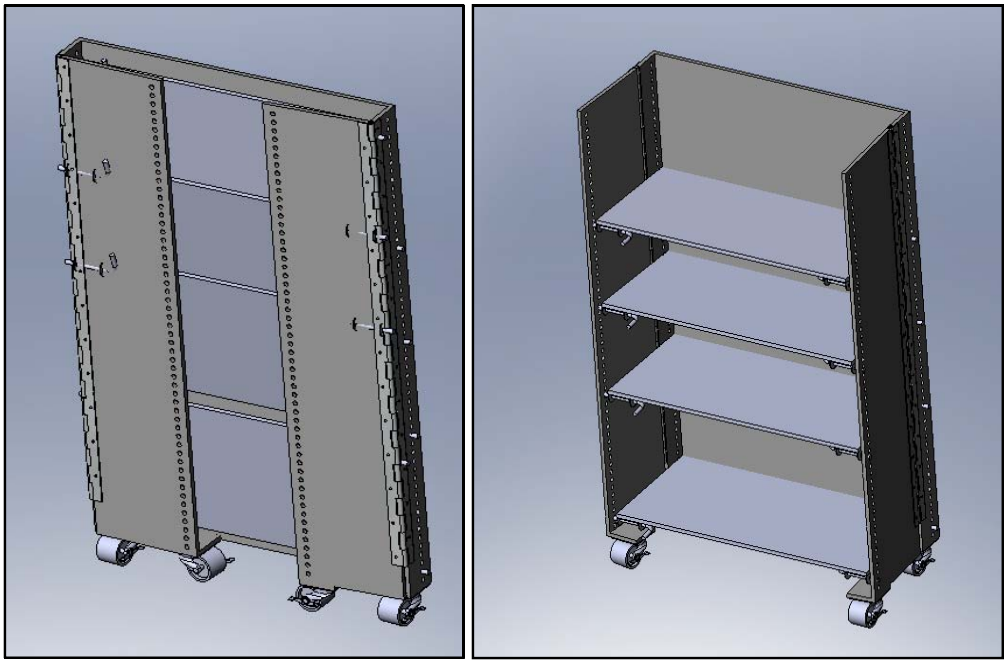

Figure 7 – Folding cart, closed view (left) and open view (right)

Following the creation of multiple designs we met with the Iron Mountain staff and received their feedback, which can be seen in the next section.

4.3 Choosing the Strongest Solution

During the first semester, several meetings took place between Iron Mountain and our group. After Iron Mountain reviewed all of the features that we wanted to put on the cart they created a list of the ones they found to be the most important. The performance specification desired by Iron Mountain assisted us with narrowing down design solutions. This list is shown in Table 2.

Performance Specifications

Wheels

Omni-directional – can spin and make tight turns
Six or more wheels depending on design
Large / Solid
Locking casters/wheels

Base Unit

Low center of gravity – avoid tipping
Sliding/adjustable shelves and cubby dividers on shelves
Stackable/modular design – adjust height, separate base with wheels
Fork lift compatible – multiple carts can be picked up by fork lift
Connect ability of carts – "train"
Side and corner protection / pads
Locking cover – reusable w/ Iron Mountain logo
Brake – dead man's brake system
Temperature neutral – doesn't get too hot or cold outside
Hand grips – built in and possibly fold out

Shelves

Removable bins
Slotted shelf – decreased cart weight

Tracking

Tracking device – RFID or GPS

Miscellaneous

Label Holder – on side to identify contents
Locking device to lock cart to fixed object or other carts
Additional work surface that folds out from side

Table 2- Iron Mountain Performance Specifications

On December 4th, 2007, Iron Mountain stated that they were changing the way in which they conducted their filing system. Up until this point we were designing a cart to move loose files. Now we were loading the cart with small boxes. Iron Mountain emphasized interest in efficiency in the loading and unloading aspects of the cart design. As stated before, the loading and unloading processes were very time consuming. The end loading cart, shown in Figure 10, was designed so that it could be moved down aisles and loaded or unloaded next to the shelving unit, shorting the loading time and strain on the operator. Following the receipt of this list we set about redesigning our cart. The section below details the changes that we made to the cart.

4.4 Redesigning

The specific goal of our redesign was to make sure that our final design contained as many of the performance specifications that the Iron Mountain staff suggested. We proceeded down the list and observed which of our designs contained the features that they requested, to determine which design features we should have transferred onto our new end loading cart.

All of the performance specifications under the wheels category were easily met, by using swivel casters that had the right load specifications. All of the casters on the cart are larger than 5" inches in diameter and have a wheel width larger than 1 inch so that the cart can be maneuvered over grating, carpeting and will not mark linoleum floors.

The performance specifications for the base unit were in general met except for the Modular design, dead man's brake and the Adjustable shelving. The modular shelving design was pursued by another Worcester Polytechnic Institute's Major Qualifying Project group working on the same project, authors Matthew Cook, Rory C Moulton, Matthew B Nichols, Joshua D Osgood, and Sean Waithe. Please reference their report for any questions about the stacking cart. We initially wanted to pursue the dead man's breaking system but we found that there were two major problems with it. First, since Iron Mountain required all of the casters to swivel it was very difficult to design any type of wheel braking system. To have a control bar or cable hooked up to a brake on the caster and still have the caster still be able to move freely required having the cable about the same axis of rotation as the caster. This would require the use of a customized kingpin-less caster. The other concept we tried to apply was a friction brake on the bottom of the cart. This idea would have worked well except that the brake needed to be applied without human interaction. If the cart operator were to let go of the handle then the brake needed to engage. For this to occur, the brake would have to be spring loaded with the ability to apply enough pressure to stop a loaded cart, and still be easily reset by the user. Both designs were rejected by the team because of the cost and complexity. The adjustable shelving was not incorporated into our design because instead of moving open files with different heights and widths we are now going to be moving small file boxes (Height 10" X Width 7.75" X Length 11.5".). Hence the advantages of adjustable shelving no longer out weighted the cost of producing it.

The other performance specifications for the base unit were all met. The low center of gravity was incorporated in to our design but without adding excessive weight the center of gravity depends largely on how the cart is loaded. To make the cart fork lift compatible we kept the under carriage uncluttered so that a fork lift can get under the cart and pick it up even when loaded. The interlocking of the carts was accomplished so the carts can be connected end to end or side by side as shown in Figure 8 - Interlocking.

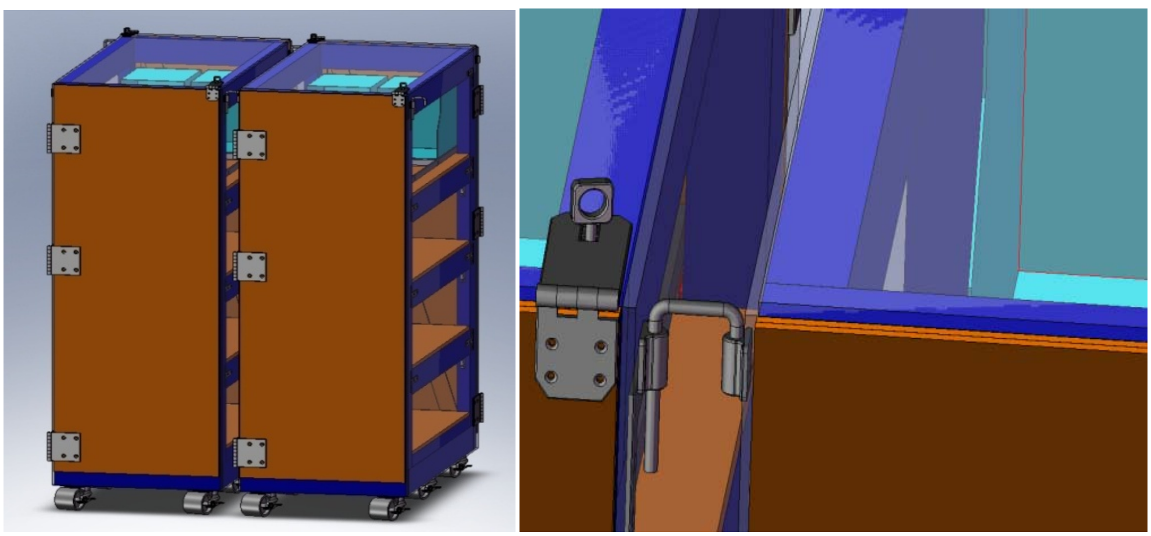

Figure 8 - Interlocking

Connecting points were attached near each corner of the cart. A sliding door latch is then used to connect these points together. For corner pads we used a stick on 1/8th inch thick neoprene cork strip that is applied as a bumper. The strip does not hinder the carts overall motion, and protects the cart from impacts. The issue of a locking cover was solved with a solid locking door. This cart is mainly constructed out of wood, which is a very temperature neutral substance.

We used removable bins for the main concept of our design as shown below in Figure 9

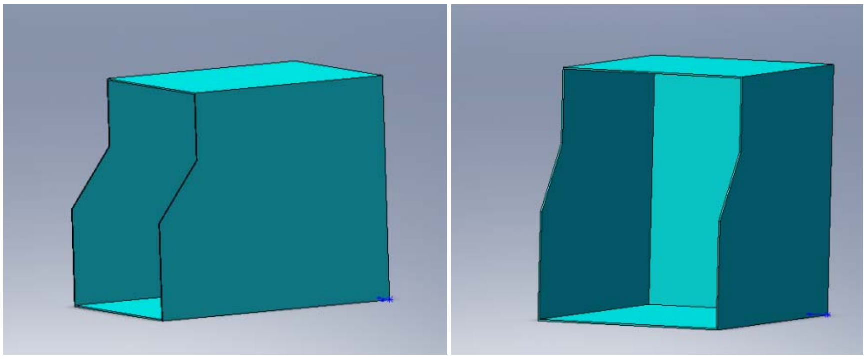

Figure 9 - File Boxes

Slotted shelving to reduce weight was not feasible because the conveyor, that needs to move easily inside the cart, would not work well on a rough surface. The RFID tracking was not added due to the fact that it lays out side our major area. The label holder was easily added to the side of the cart. The locking device and additional work surface were deemed unnecessary by Iron Mountain.

The end loaded cart design worked better. We found the features desired by Iron Mountain to be easier to apply to the new design compared to our original incremental and collapsible designs. The only challenge we had was being able to access all the files from one end while the cart is in between the narrow aisles.

4.5 The Final Result – End Loaded Cart

The final proposed design was a cart that is compatible with Iron Mountain's new shelving system. The new layout of their shelving system has created a challenge for us. Iron Mountain requested a new design that was end loaded and accessible from both ends of the cart. The reason for accessibility from both ends is because the layout of their new shelving system has narrow aisles and it may be difficult for the iron Mountain staff member to go around the cart to get from one end of the cart to the other. See Figure 10 for a visual on the end loading cart design.

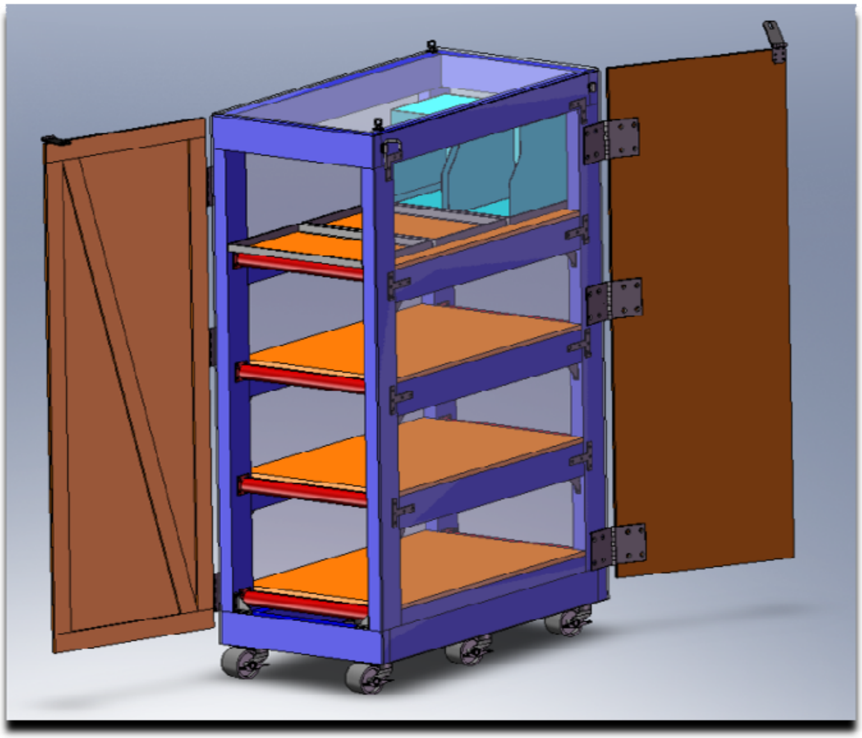

Figure 10 - End Loading Cart

Based on the performance specifications requested by Iron Mountain, please refer to the table below for a visual aid of what criteria our new cart design meets.

Desired Feature	Feature on Cart	Requirement Met/Not
6 Omni-Directional Wheels		Met
Low Center of Gravity	Heavier base (also depends on file placement)	Met
Cubby Dividers	Cubby File Boxes	Met
Fork Lift Compatible	Wide Base	Met
Interlocking	4 Corner Door Latches	Met
Side and Corner Protection	Bumper Pads (Not Shown)	Met
Locking Cover	2 doors on each end with Lock	Met
Brake	Foot Brake	Met
Tracking Device		Not Met – Can be met
Removable Bins	File Boxes	Met
Slotted Shelving	Fixed Shelving	Not Met
Hand Grips		Not Met
Temperature Neutral	Wooden Cart	Met
Label Holder	Label Holder	Met
Locking Device to other objects		Not Met
Additional Work Surface		Not Met

Table 3 - Met Desired Performance Specifications

4.5.1 Product Summary

The following table is a summary of the features that the cart posses:

Dimensions: 56” H X 39” L X 20” W
Material: Wood (Plywood)
Wheels: 6
Shelves: 4
Locking Doors: 2
File Movement Method: Conveyor Belt w/ Frame
Cost: Variable (See Cost Analysis Section 5.2)
Storage Capacity: 24 file boxes ~ 200 files*
Theoretically Analyzed Load Capacity: ~800 lbs

*Each file thickness is variable. The calculation above is under the assumption that each file is 1” inch thick.

Table 4 - Product Summary

4.6 Prototyping

Prototyping is an important step in the design process. Physical visualizations can help explain or bring up unforeseen issues before a design goes into final production. In this case, prototyping was used to help explain our ideas to Iron Mountain as well to visually test the feasibility of some of the features. To begin building our prototype, we decided that it would be made of wood because of its availability and ease of construction. At that time specific material properties of the wood were not taken into account as the main purpose of this prototype was for testing its feasibility and demonstrating of its features. Multiple versions of certain features, such as interlocking, were put on the prototype to demonstrate options available. It should be understood that in the case of the full scale model and product, custom or more realistic parts will be more carefully chosen. Please refer to Figure 11 below for a visual of our final small scale prototype.

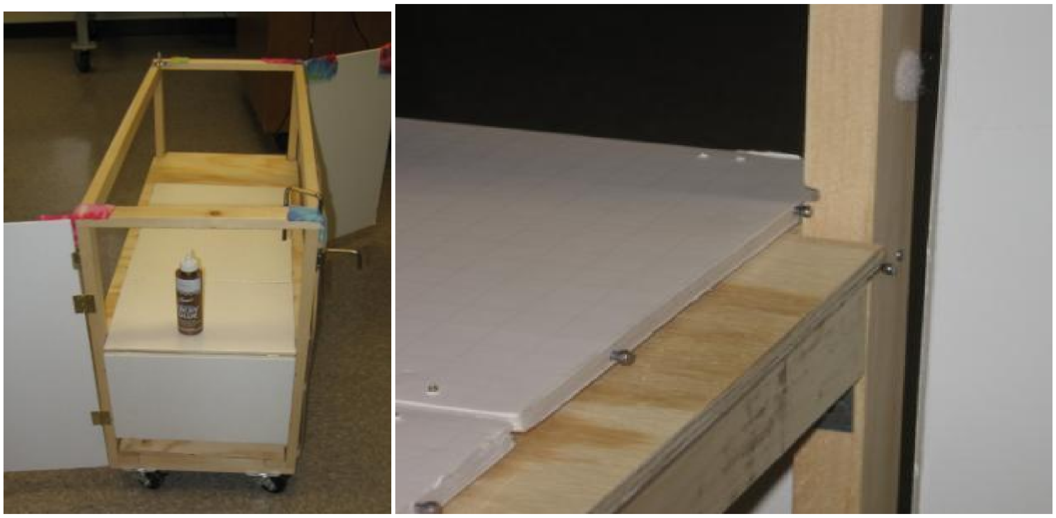

Figure 11 – Small scale prototype

4.7 Full Scale Model

For our full scale model we built a model with one shelving unit only due to the cost of each conveyer belt. We assembled the cart as it would be if Iron Mountain were to build the cart in their own facilities (Please refer to Appendix B for assembly instructions). We used all materials listed below, except for the casters and screws which we bought from Home Depot. As we mentioned earlier it was suggested to use stainless steel screws since they are the most corrosion resistant. For our full scale model, we used drywall screws which are about .03 cents per screw, the trade off being that they will eventually rust. We do suggest that Iron Mountain invest in quality wood screws to prolong the life of the cart.

Figure 12 – Full scale model

5 Analysis

5.1 Materials Selection

After doing some research on specific methods of material selection, we settled on creating a scoring chart to identify the best material for our cart. The materials that we selected for analysis were 319 Steel, 304 Steel, T6061 Aluminum, T2024 Aluminum, Polymethyl methacrylate (PMMA), and wood. For our chart, the categories that we choose to focus on and use to differentiate between the materials were: Strength to density, Strength to price, density, price, corrosive resistance, manufacturability, Yield strength, and tensile strength. The data for the scoring chart can be seen in Table 5.

Material	Steel 316	Steel 304	6061 Aluminum	2024 Aluminum	PMMA	Wood
Strength to density	38.75	25.63	102.23	124.55	54.17	110
Strength to price	5.22	4.38	22.12	15.11	15.48	55
Density g/cm^3	8	8	2.7	2.77	1.2	0.5
Price	59.36	46.82	12.48	22.84	4.2	1
Corrosive (resistance)	9	8	6	4	10	1
Manufacturability	5	5	7	7	3	10
Yield Strength Mpa	310	205	276	345	65	55
tensile strength Mpa	860	515	310	45	48.3-72.4	55

Table 5– Scoring Chart Rough Numbers

Once all the data was entered into the tables, we scaled all the values on a non-dimensional scale. Each of the values was scaled based on which material had the highest and the lowest values in each category. Once they were identified the lowest value was set at 0 while the highest value was set at 1. Once this was done for each category the material with the highest value is considered to be the best option. The values from the non-dimensional scaling can be seen in Table 6.

Material	Stainless Steel 316	Stainless Steel 304	Aluminum 6061	Aluminum 2024	PMMA	Wood
Strength to weight	0.13	0	0.77	1	0.29	0.85
Strength to price	0.017	0	0.35	0.21	0.22	1
Density	0	0	0.71	0.70	0.91	1
Price	0	0.22	0.80	0.63	0.95	1
Corrosive (resistance)	0.89	0.78	0.56	0.33	1	0
Manufacturability	0.29	0.29	0.57	0.57	0	1
Yield Strength	0.88	0.52	0.76	1	0.03	0
Tensile Strength	1	0.58	0.33	0	0.02	0.01
Total	**3.207**	**2.39**	**3.02**	**4.44**	**3.42**	**4.86**

Table 6 – Non-Dimensional Scaling Values

As shown in Table 6 above the material that had the highest rating was wood with a value of 4.86. Wood was the best option in four of the eight categories. It was the best option in, Strength to price, Density, Price, and Manufacturability. Due to this result we chose to make the prototype out of wood, and to propose that the production model be made out of wood.

5.2 Cost Analysis

The cost analysis was done following the identification of the best cart material. Once wood was chosen, we began to search locally for the cheapest high-quality wood available. We also searched for the other materials that we needed to build a prototype and eventually a full-scale cart. We created a parts list based on our design that states the sizes, number of parts required, cost and purchasing locations. This parts list can be found in Appendix C.

During the investigation and prototyping stages when searching for the lowest prices, our group aimed at ensuring all of the items were from as few sources as possible to keep potential shipping costs down. The problem with having as few sources as possible is that the prices that we found might not have been the cheapest possible, but by reducing the shipping cost, we hoped that it would nullify the slightly higher prices. Additionally, to avoid potential problems with shipping and to aid in the creation of future carts, we found most of our materials from suppliers that can be found near almost every Iron Mountain branch.

There were two major suppliers that had most of the materials that is needed to build a complete cart, McMaster-Carr and Home Depot. Each of these companies had their own strengths and weaknesses, but if used in tandem Iron Mountain could benefit from both suppliers. McMaster-Carr is a purely online database with a huge selection of materials for all purposes. The benefit to this being an online database is that all the materials can be shipped to each Iron Mountain facility, and no pick-up would be required. Home Depot conversely is chiefly a walk in store, which can be beneficial if a quick fix is needed. For our prototypes we relied heavily on Home Depot due to its proximity and selection of materials.

Following the completion of the investigation for stores, our group compiled all the data and priced out all of the components of the cart. The prices of each item with the total cost of the cart can be found in Appendix D. The total cost of the cart was found to be approximately $885.63. This was found by using the number of pieces used in the prototype with the overall cost of the stock and identifying how many pieces can be garnered from the amount of stock. We found that this cost was high, so we scanned through the parts list and found which items cost the most. The items that cost the most were the conveyor belt at $258.46 followed by the castors at $180.00. This cost caused our group to calculate the cost of the cart without the conveyor system. We found that the price of the conveyor system alone was $399.97. If this value is subtracted from the overall cost of the cart the cart would cost $478.66.

Our group added a 10% buffer to each final value in order to account for mistakes in assembly or manufacturing. This brings the final cost of the entire cart to $974.20 and the cart without the conveyor system to $534.23. These costs associated with the cart are very approximate, mainly because of the method of calculation.

5.3 Stress Analysis

All of the stress analysis was completed for the parts being used in the construction of the cart except for the casters, sliding door latches, hinges, and latches. We used the manufactures specifications for the caster of a maxim loading of 400lbs. The hinges, sliding door latch, and hasp latches are non critical parts that are not under any considerable stresses, therefore the calculations were not required. All of the critical construction parts were well within the requested and maxim amount of stress from the load that the cart will have to carry.

Component	Cross section	Load	Max allowable load	Calculated deflection
Shelf beam 2X4	5.25 in2	100 lbs/ft	1400lbs/ft	0.014 in
Main Column 2X4	5.25 in2	200lbs	700lbs	0.0001 in
End supporting beam 2X4	5.25 in2	2 X 200lbs	755lbs	700*10^-6 in
Loading of the base beam 2X4	5.25 in2	2 X 200lbs 30lbs/ft	387lbs	0.0023 in
Fixed roller OD 1” ID 0.87"	0.19092 in2	50 lbs/ft	501 Lbs/foot	0.00724 in
Moving roller OD 1.5” ID 1.25”	0.542in2	50lbs/ft	20,000 Lbs/foot	0.00124 in
Screws Dry Wall	0.236 in2	25lbs	600lbs	0.03 in
Angle bracket	0.177in2	50lbs	161Lbs	0.00145 in

Table 7 - Structural Stress Analysis

5.4 Testing and Evaluation

Iron Mountain was concerned about the cart’s response to several different situations regularly encountered at sites. Testing of the prototype consisted of qualitative testing rather than quantitative. Mainly, these tests were specific to individual features.

Testing of specific features is very important to a concept that may be used in the final full-scale model. The side loading ability, door latches, conveyor function and wheel placements were all specific features that needed to be tested. The side loading was a feature that was tested by conception. It was not a specific part but more of a concept to be integrated into the cart. Specifically concerning side loading led to consideration of door latches and conveyor functions. As stated before, there were two options for each feature and both were integrated into the prototype to be more efficient. Physical ease and ergonomic tests were done to assure the better of each option or the best changes would be made.

5.4.1 The Conveyor and H-Frame

The main feature of our cart was the conveyor system. Iron Mountain was concerned about the amount of friction that the file boxes would apply to the shelf if we were to use the H Frame as directed (See Figure 13).

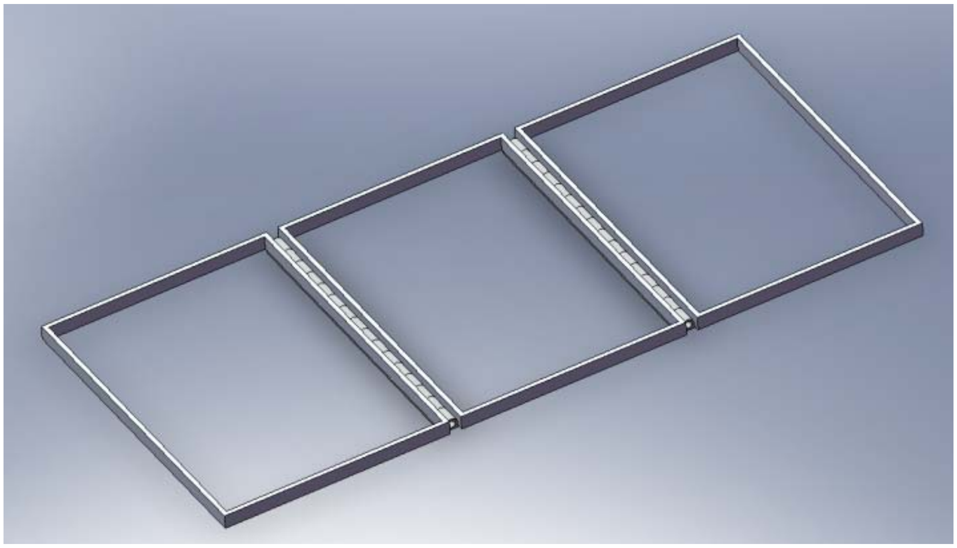

Figure 13 - H Frame

We designed a conveyor system (See Figure 14) with the design intent that had a high coefficient of friction between the file boxes and the top conveyor contact surface and a low coefficient of friction between the bottom of the conveyer belt and contact with the shelf.

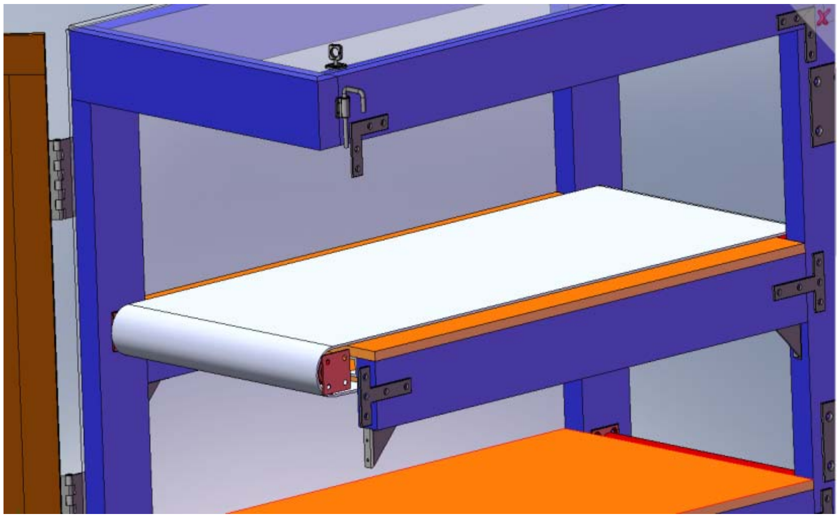

Figure 14 - Conveyor System

We found coefficient of friction cut offs and search for a belt that met that requirement. We used a cut off of .10 which requires about 20 pounds of human force to pull all six file boxes towards them if they were to have a total weight of 200 pounds. The conveyor we used from the Treadmill Doctor (Treadmilldottor.com) which ran us about 70 dollars. We contacted Sparks Belting Company and they sent us their economy pack samples that had a coefficient of friction of .25 – wood to steel, which is still too high for our purpose. The conveyor system alone cost about 400 dollars. Our cart system is best when used with two people and once we tested the conveyor belt, we deemed it to be unnecessary and we are suggesting other alternatives discussed in the next section.

5.4.2 Alternative 1 – Two Person Operation

The biggest challenge with the new shelving systems is that the aisles are narrow. The cart needs to be accessible from both sides without the employee having to go around the cart. Here are the benefits of a having tow people operate instead of one:

- Eliminates the H-Frame and the conveyor belt system all together
- Saves time in stoning file boxes
- Resolves ergonomic concern of having an employee reach into the very bottom shelf of the cart and potential injury their shoulder.

5.4.3 Alternative 2 – Low Friction Coating

The other option is to simply coat the surface with a slick substance. For example Teflon or wax solid materials in that category would be good for this purpose. The H Frame may or may not be necessary, but either way it is definitely an economic alternative to the conveyor belt system. Another option would be to simply cover the shelf with another layer or sheet of low frication, non-stick material.

6 Conclusion

Our goal was to redesign this current cart system to be safer and more efficient in compliance with Iron Mountain's customer demands. The design intent was to optimize the transport of records stored by Iron Mountain in the areas of:

- Safety
- Reliability
- Efficiency in time & space
- Durability
- Value
- Mobility

Our final design resulted in a wooden end loading cart that is accessible from both sides. The benefits of having an unloaded cart are:

- **Bi-Loaded**
  - Files may be accesses from both ends of the cart making it ideal for narrow aisles in case an employee cannot get from one end of the cart to the other side
- **One or Two Member Outfitted**
  - Although we highly suggest two members operating the cart, it may also be operated by one member if needed.
- **Structural benefits**
  - The cart is structurally strong by nature simply because the shelving is supported on both lengths of the cart, which also reduces deflection in the final design
- **Security**
  - Both doors are lockable providing security for Iron Mountain's

The final design was completed through the application of suggestions, design processes, and investigation to find a solution to the problem. The prototype and full scale model have proven to be successful. We followed an eight step process to meet the customer's needs. Fist we investigated and defined the problem; which was that Iron Mountain had an area of concern in their file transport system. We visited the company's facility to get an idea of the challenges that the employees may face while handling the carts for record transport. We then brainstormed designs, proposed them and identified the strongest solution for our design intent. One of our deliverables was the prototype version of our final design with the main purpose being a visual representation of the design concept. Throughout the process of creating a full scale model of the shelving unit for the cart, we conducted stress analysis, material selection and put innovation to work to satisfy the needs of Iron Mountain.

7 Future Recommendations

The following section highlights future suggestions for Iron Mountain to look into that are beyond the time constraints of this project.

7.1 Radio Frequency Identification Tags

Radio Frequency Identification Tags were not discussed as a feature because they were not a feature to be analyzed. We do recommend they be added to the cart even though they will be an extra cost. This extra cost will be offset in the carts not left behind at client locations simply because RFID will provide an electronic record of what and where files are located.

7.2 Conveyor Belt Alternatives

There are other economic alternatives to the entire conveyor belt system, seeing that our cost analysis shows that it is fairly expensive. The two options can, but do not necessarily have to, include the H-frame. We recommend the H-frame is included to help prevent tipping of the file boxes during transportation, but because the files are already in the file boxes this may not necessary.

The first option is to utilize a low friction coating instead of a full conveyor belt or to make sure two operators are always available to unload or load carts in narrow aisles. A coating such as Teflon can be used to reduce friction so that less moving parts are necessary for the entire system. This will make the system a lot simpler to manufacture and fix. Cost and manufacturing time will also be reduced.

By making sure two operators are on the carts when they are being loaded or unloaded it is no longer necessary to have the conveyor system. Files are reachable from both sides when two people use the cart. It also alleviates ergonomic concerns such as over extending ones arm to reach a file box at the other end of the cart when one person is using it. This also saves time because two people unloading and loading the cart will be more time efficient, which will end up saving the company money in the long run.

7.3 Plastic File Boxes

Customized file boxes can be easily integrated into the new file system. They can easily be transported between the storage units and the carts. The each can also have a barcode placed on each box so that they may be scanned to help keep them organize. We suggest making them out of plastic via injection molding them because they will be a part needed to be mass produced. Injection molding these parts will increase productivity and decrease the cost of production.

7.4 Custom Belt for Conveyor

As stated in the Cost Analysis section above, the majority of the cost of the new cart is from the belt for the conveyor system. This is most likely due to the popular use of treadmills and their need for replacement belts. To deal with this issue we recommend Iron Mountain contact Sparks Belting Company directly to customize a specific belt for the purpose of this cart. Instead of buying each belt separately of such a high grade, mass quantities of belts with a friction coefficient of .1 or better can be ordered in time and at a lower cost for production.

7.5 Teledynamics

A future recommendation is to utilize automated or partially automated systems. These systems can be used to at Iron Mountain's facilities to reduce the amount of labor at the facility and reduce the use of the cart. This will increase productivity of staff and the life of the carts. Because these systems are automated, they cannot be brought to the client sights and cannot fully replace the current cart system.

One specific company that we find can integrate their product into Iron Mountains filing system is Teledynamics, L.L.C. File boxes, compatible with Iron Mountain's current system as well as the recommended carts, can be placed into the custom built telecars which run on an installed monorail system. The monorail system can direct the telecars to move horizontally or vertically and between buildings. Different stations can be set up throughout the facilities. Each station can send or receive telecars. The proposed set up includes one station at each truck dock, each floor in long term storage, as well as receiving, and multiple locations in short term storage including one near the work stations and the rest to be placed strategically close to the aisles.

When files are being received they would be taken off the carts then placed in the telecars and sent to receiving to be scanned into the system box by box. From receiving the file boxes would be sent to either the long or short term stations which could then send it to the next substation closer to where it will be filed or stored. From there manual carts, like the ones used now, could be utilized to bring the file boxes directly to their new locations. To be sent out, the closest station would be utilized to send the file boxes to the truck station. Once the file boxes are in the docking location they can be placed onto carts and placed onto the trucks and delivered to the clients. The carts will continue to be used at remote locations.

This system will promote savings, through less wear and tear on the carts and less man power needed throughout the facility, and the level of confidentiality of files will increase through less human interaction.

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9 APPENDIXES

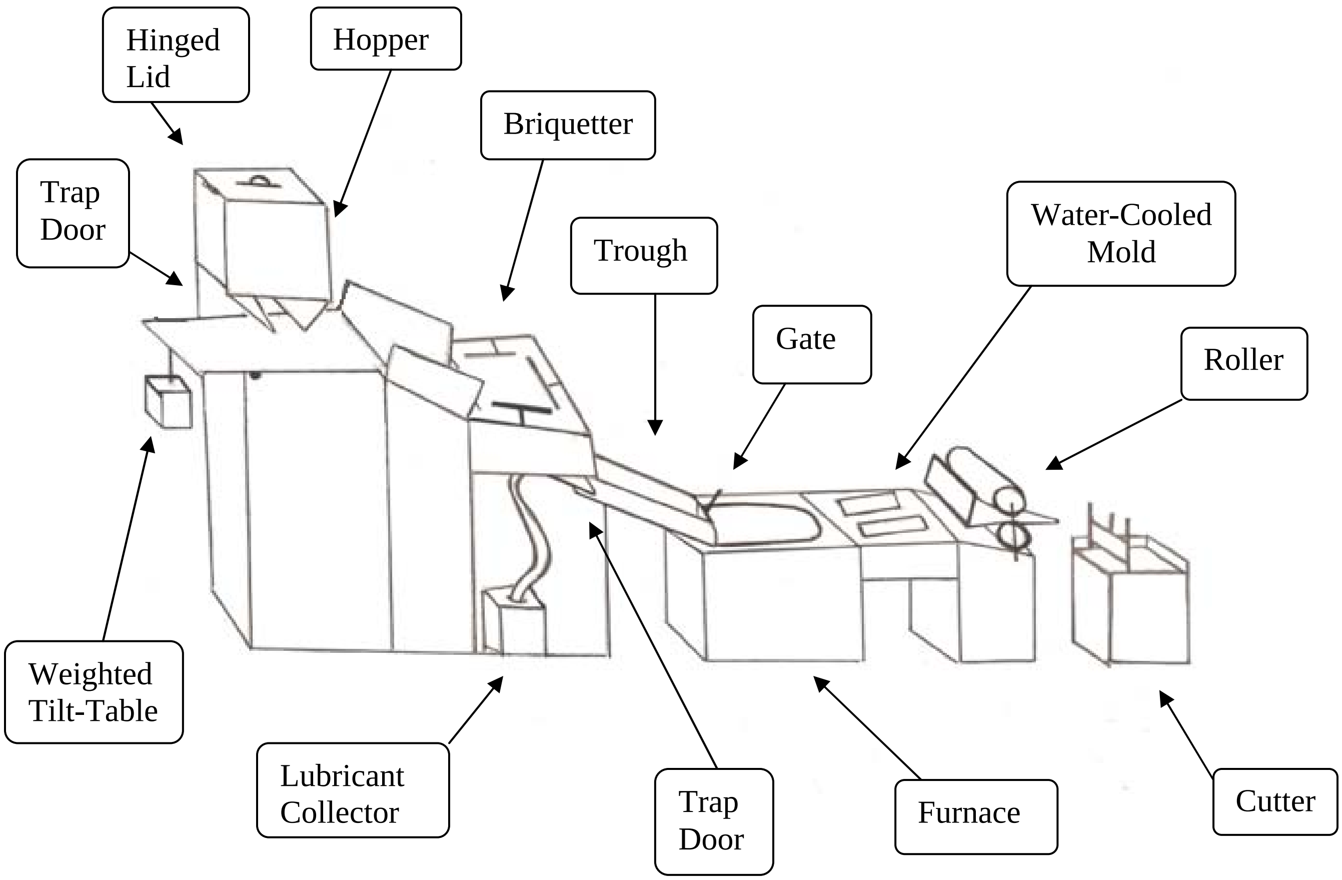
9.1 Appendix A – Axiomatic Design Sample

No.		Functional Requirement		Design Parameter
0	FR	Recycle one type of aluminum alloy chips on a small scale	DP	Self Contained Chip Recycling system
1	FR	Get desirable Mechanical Properties	DP	System for producing mechancial properties
1.1	FR	Ready Chips	DP	System for readying chips
1.1.1	FR	Hold chips	DP	Covered Hopper
1.1.2	FR	Sense collected chip weight	DP	Sensor system
1.1.2.1	FR	Input desired weight	DP	User interface
1.1.2.2	FR	Collect weight data	DP	Weight sensor
1.1.2.3	FR	Interprete chip weight data	DP	Computer
1.1.3	FR	Release chips to briquetter	DP	Chip release system
1.1.3.1	FR	Allow chip movement	DP	Door
1.1.3.2	FR	Control chip movement	DP	Trough
1.1.4	FR	Create preferable material melting conditions	DP	Chip briquetting system
1.2	FR	Remove material impurities	DP	System for removing impurities
1.2.1	FR	Collect briquettes	DP	Vat
1.2.2	FR	Heat briquettes	DP	Furnace
1.2.3	FR	Remove slag	DP	Mechanical scraper
1.2.4	FR	Pour melt	DP	Mechanical pouring system
1.2.5	FR	Clean vat	DP	Cleaning system
1.3	FR	Produce desirable microstructure	DP	System for producing the desired microstructure
1.3.1	FR	Control cooling rate	DP	Cooling system
1.3.2	FR	Restrict exposure to impurities	DP	Enclosed unit
2	FR	Create the right shape	DP	Mechanism for forming
2.1	FR	Flatten ingots	DP	Rolling mill
2.2	FR	Size ingots	DP	Cutter system

Note: This picture is taken from an acclaro file that one of the students in this group created for a project. The purpose of this project was to create a small scale recycling plant for developing nations. As is shown in the figure above, FR0 and DP0 are the highest level available, and are the broadest. They then flow down to FR1 and FR2 which are children of FR0. From there more children are devolved and the DP's are created to match them.

	DP0: Self Contained Chip Recycling system	DP1: System for producing mechancial properties	DP1.1: System for readying chips	DP1.1.1: Covered Hopper	DP1.1.2: Sensor system	DP1.1.2.1: User interface	DP1.1.2.2: Weight sensor	DP1.1.2.3: Computer	DP1.1.3: Chip release system	DP1.1.3.1: Door	DP1.1.3.2: Trough	DP1.1.4: Chip briquetting system	DP1.2: System for removing impurities	DP1.2.1: Vat	DP1.2.2: Furnace	DP1.2.3: Mechanical scraper	DP1.2.4: Mechanical pouring system	DP1.2.5: Cleaning system	DP1.3: System for producing the desired microstru	DP1.3.1: Cooling system	DP1.3.2: Enclosed unit	DP2: Mechanism for forming	DP2.1: Rolling mill	DP2.2: Cutter system
FR0: Recycle one type of aluminum alloy chips on a small scale	X																							
FR1: Get desirable Mechanical Properties		X																				O	O	O
FR1.1: Ready Chips			X										O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.1: Hold chips				X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.2: Sense collected chip weight				O	X				O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.2.1: Input desired weight				O		X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.2.2: Collect weight data				O		O	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.2.3: Interprete chip weight data				O		X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.3: Release chips to briquetter				O	X	O	O	O	X			O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.3.1: Allow chip movement				O	O	O	O	O		X	O	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.3.2: Control chip movement				O	O	O	O	O		X	X	O	O	O	O	O	O	O	O	O	O	O	O	O
FR1.1.4: Create preferable material melting conditions				O	O	O	O	O	O	O	O	X	O	O	O	O	O	O	O	O	O	O	O	O
FR1.2: Remove material impurities			O	O	O	O	O	O	O	O	O	O	X						O	O	O	O	O	O
FR1.2.1: Collect briquettes			O	O	O	O	O	O	O	O	O	O		X	O	O	O	O	O	O	O	O	O	O
FR1.2.2: Heat briquettes			O	O	O	O	O	O	O	O	O	O		O	X	O	O	O	O	O	O	O	O	O
FR1.2.3: Remove slag			O	O	O	O	O	O	O	O	O	O		O	X	X	O	O	O	O	O	O	O	O
FR1.2.4: Pour melt			O	O	O	O	O	O	O	O	O	O		O	O	O	X	O	O	O	O	O	O	O
FR1.2.5: Clean vat			O	O	O	O	O	O	O	O	O	O		X	O	O	O	X	O	O	O	O	O	O
FR1.3: Produce desirable microstructure			O	O	O	O	O	O	O	O	O	O	X	O	O	O	O	O	X			O	O	O
FR1.3.1: Control cooling rate			O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		X	O	O	O	O
FR1.3.2: Restrict exposure to impurities			O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		O	X	O	O	O
FR2: Create the right shape		X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X		
FR2.1: Flatten ingots		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		X	O
FR2.2: Size ingots		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		X	X

The above image shows the design matrix the coupled items with an X and the un-coupled items with a 0. If all of the coupled items are below the line of X's across then the coupling in those certain items is okay. There is no perfect system that eliminates all coupling so even in the most detailed of systems; there is still some level of coupling.



The above image was the final result of our axiomatic design project, it feature all of the DP's and performs all of the functions required with very minimum coupling.

9.2 Appendix B – Assembly Instructions

Tools needed:

Screw gun
Table saw
Circular saw
Level
Welder
Metal saw

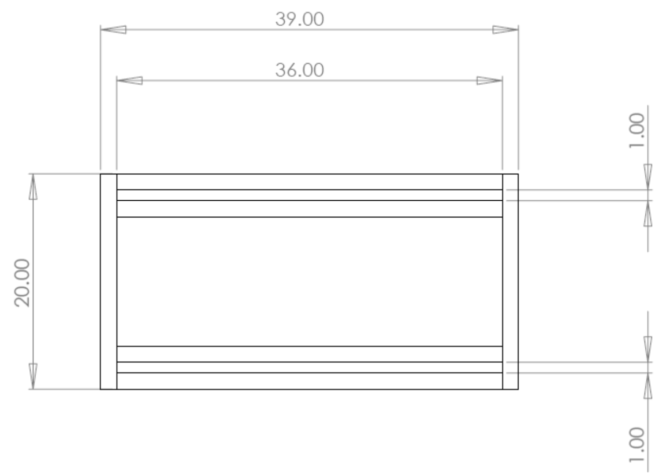
Building the frame

Base

1. First assemble and cut the number and lengths of 2"x4" wooden pieces shown in the table below.

# of pieces	Length in inches
6	36
4	48
4	20
6	32

2. Also cut one 2"x4" down the middle to make it a 2"x2" and cut to 32" in length
3. For every following instruction use pilot holes at your discretion
4. Using 3" dry wall screws to build the base of the cart as shown below.

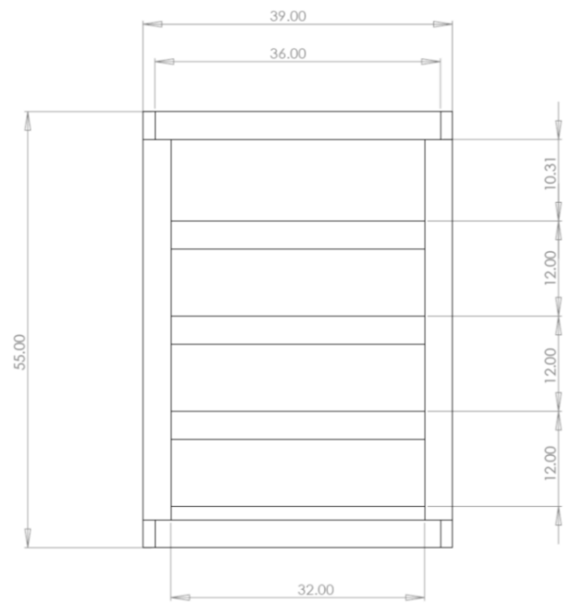


5. The screws should be driven perpendicular though the 20" pieces in to the 36" pieces to hold the bottom frame together. The best way to do this is to build it laying flat on a level surface.
6. Use the four remaining 20" and 36" pieces to build the top. The top is constructed exactly the same as the bottom but without the 2 interior 2"x2"x36"pieces.
7. Now attach the two 2"x2" to the interior of the base as the supporting braces. 3.5 inches in on each side. It may useful to lay a 2X4 along the 20" pieces to get the positioning exact.

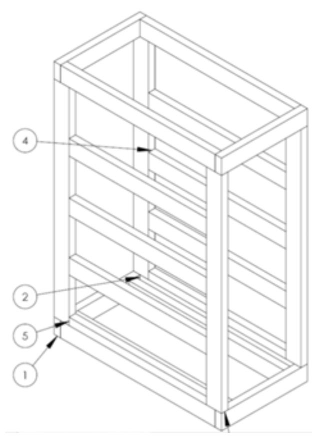
8. Next use the 1-1/4” dry wall screws along with the angle brackets to install the 4 vertical columns in each corner making sure that it is flush with the outer geometry.

Columns

1. First attach each column in turn to the base of using angle brackets to hold it upright. **Do not fully tighten the screws for the brackets** tighten each screw down just enough to hold each column upright.
2. Now attach the top frame that was built earlier to the tops of the columns using the L brackets.
3. Make sure that the frame is squared up and tighten the screws on each bracket.
4. Now use the T and angle brackets to install the six 32” boards at their appropriate heights. As shown below.



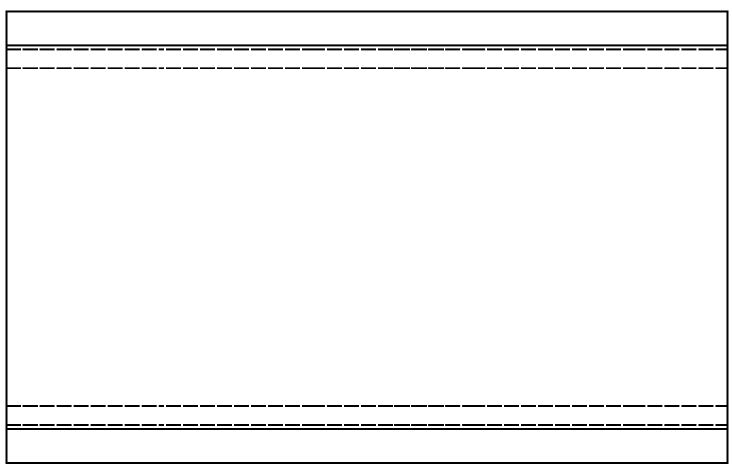
5. The final frame should look like the image below:

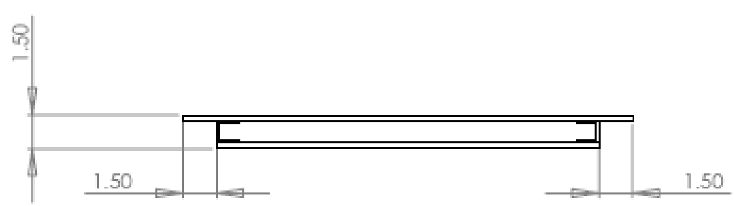


Shelf assembly

Material	# of pieces	Dimensions in inches
½ inch plywood	4	32X20X1/2
¼ inch plywood	3	32X20X1/4
1 inch base AL channel stock	6	32X1X1

1. Drill four 1/8" equally spaced holes in each channel starting on the bottom shelf
2. Attach the ½" plywood to the interior 2"x2" boards using 6 dry wall screws. One screw in each corner and two in the middle.
3. On the second shelf attach the U channel stock to the inside of the 32"x2"x4" and 3.5" in boards, and flush with the top.
4. Now clamp the ¼" plywood to the bottom and drill 4 holes smaller then the threads on the screw but larger then base diameter of the screw, down through the U channel and plywood. Using ½" screws from the bottom attach bottom shelf though the holes you just drilled.
5. Attach the ½ inch plywood to the top in same way as the first shelf.
6. Repeat for the third and fourth shelf
7. The 2,3,4 shelf should look like this but assembled to the 32" 2X4s

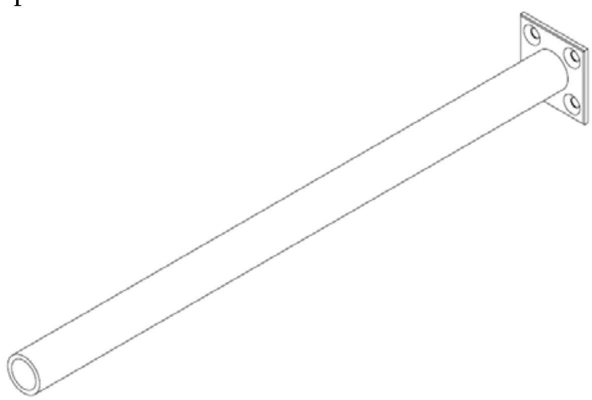




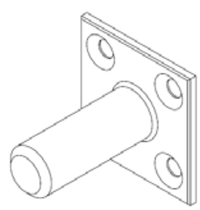
Roller assembly

Material	# of pieces	Dimensions in inches
Sleeve bearings	16	1.25 OD, 1 ID 1 in length
Steel pipe	8	1.5 OD, 1.25 ID 16 in length
Steel pipe	8	1 OD, .87 ID 16.5 in length
Steel bar stock	16	2X2X 1/8
Steel rod	8	.75” Diameter 2” in length

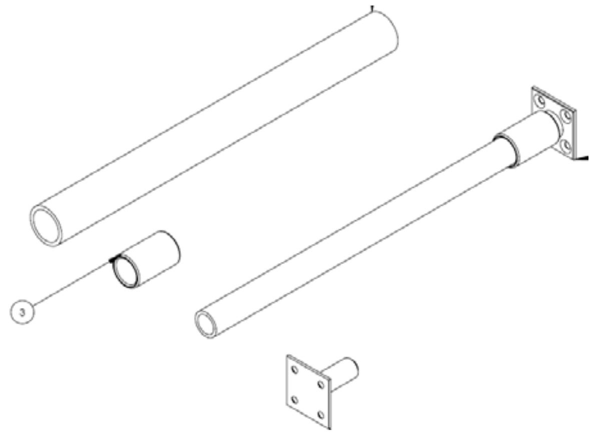
1. Weld the inner pipe to the bar as shown below.
2. The center of the pipe should be in the center of the bar stock.



3. Weld the rod to the bar as shown below.
4. The center of the rod should be in the center of the bar stock.

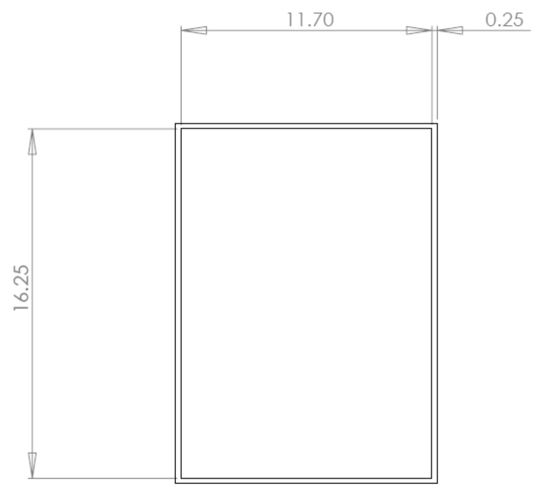


5. Now assemble this assembly as shown below.
6. The sleeve bearing fits on the inner pipe
7. The outer pipe over the sleeve bearings
8. Rod into the inner pipe

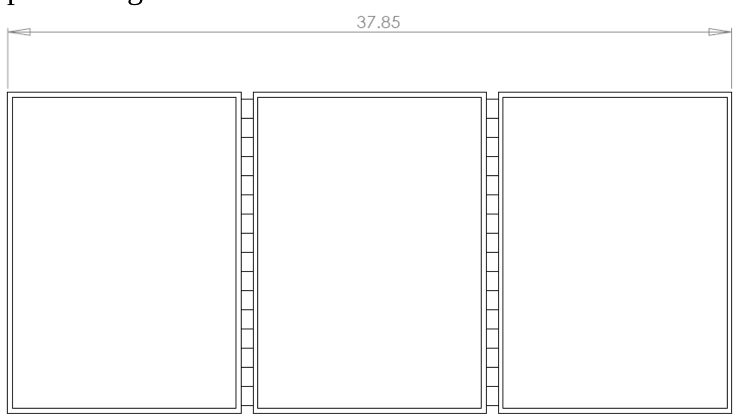


Box holder

1. Either cut and weld the ¼” X ¾” stock into the frames below or use a bending machine and weld the loose end.
2. You will need 3 sections similar to the one shown below.



3. Now cut the piano hinge in to two 16” sections and weld it to the frames as shown below.

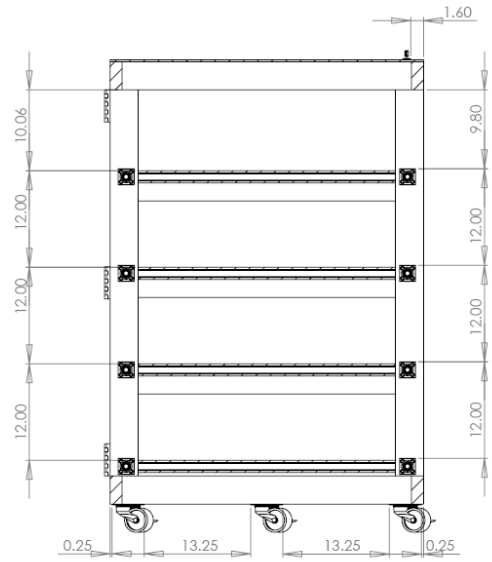


4. You will need 4 of these assembles per cart.

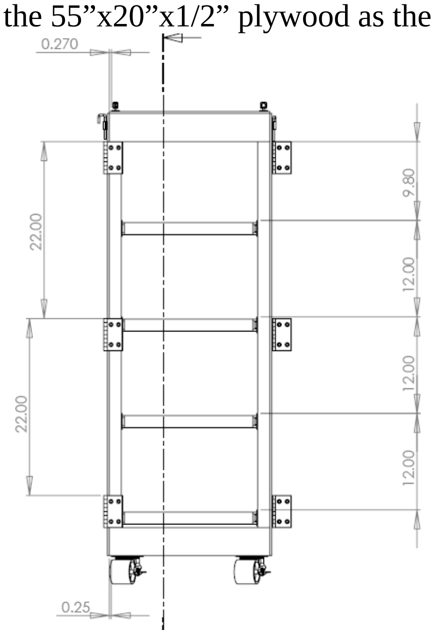
Final assembly

Material	# of pieces	Dimensions in inches
½ inch plywood	4	55X20X1/2
¼ inch plywood	1	39X20X1/4
¼ inch plywood	2	55X39X1/4

1. Now install the roller assemblies as shown below.



2. Now attach the 55”x39” pieces to the sides of the cart to act as the walls.
3. Use 1 ¼ inch dry wall screws around the perimeter and to the shelf beams.
4. Attach the 39”x20x1/4” plywood to the top of cart to act as the roof.
5. Use the hinges to attach the 55”x20”x1/2” plywood as the doors to the cart.



6. Attach the hasp latches to the tops of the doors and the roofs in the opposite corners as the hinges

7. Attach the 4 sliding door latch to the side near each corner of the cart one inch below the top and ½" from the side.
8. Lay the cart down on its side and attach the casters as shown in the figures above.

9.3 Appendix C – Parts List and Associated Costs

	Location	Part	# of pieces	Dimensions in inches	Cost	Location
1	Top and Base	2"x4" Wood	6	36	$1.97 (8ft section)	Home Depot
2	Columns	2"x4" Wood	4	48	$1.97 (8ft section)	Home Depot
3	Top and Base	2"x4" Wood	4	20	$1.97 (8ft section)	Home Depot
4	Shelves Supports	2"x4" Wood	6	32	$1.97 (8ft section)	Home Depot
5	Offset shelves	2"x2" Wood	2	32	$1.97 (16ft section)	Home Depot
6	Top of shelf	½ inch plywood	4	32x20x1/2	$20 (8'x4')	Home Depot
7	Bottom of shelf	¼ inch plywood	3	32x20x1/4	$17.44 (8'x4')	Home Depot
8	Shelf spacing	1 inch base AL channel stock	6	32x1x1	$10.48 (96")	Home Depot
9	Roller assembly	Nylon Sleeve bearings	16	1.25 OD, 1 ID 1 in length	$11.46 (5 pack)	McMaster part # 6389k229
10	Roller assembly	Steel pipe	8	1.5 OD, 1.25 ID 16 in length	$29.10 (6')	McMaster part # 7767T43
11	Roller assembly	Steel pipe	8	1 OD, .87 ID 16.5 in length	$19.47 (6')	McMaster part # 7767T37
12	Roller assembly	Steel rod	8	.75" Diameter 2" in length	$20 (6')	Metal Supermarket
13	Doors	½ inch plywood	2	55x20x1/2	$20 (8'x4')	Home Depot
14	Top	¼ inch plywood	1	39x20x1/4	$17.44 (8'x4')	Home Depot
15	Side Panels	¼ inch plywood	2	55x39x1/4	$17.44 (8'x4')	Home Depot
16	Castors	400lb locking castors	6	5x1.25	$30	McMaster Part # 9949t16
17	H-Frame	Unfinished Piano Hinge	4	16"x1-1/2x0.75	$5.55 (3'x1-1/2x0.75)	McMaster Part # 15665A57
18	H-frame	Steel bar stock	16	2x2x 1/8	$6.97 (6')	McMaster part # 8910K136
19	Lock	Hasps with rotating Padlock Eye	2	2-7/16" 15/16"	$9.02	McMaster Part # 1912A17
20	Bumpers	Neoprene Corner Pads	8	3x2x1/8	$22.67 (50'x2x1/8)	McMaster Part # 94545k61
21	Label Holders	Avery Business Card Holder	1	2x3-1/2	$3.99 (10 pack)	Office Max Item # 04039873
22	Conveyor	Treadmill Material	4	84x16	$80.00 (104x16)	TreadmillDoctor.com
23	Interlocking	Sliding Door Latch	4		$6.99	Fdsons.com
24	Structural Support	Angle brackets	12	2"x2"	$2.98 (4pack)	Home Depot
25	Structural Support	T brackets	12	2.5"x4"	$1.25	Home Depot
26	Structural Support	Angle bracket (with wall)	16	3"x3"	$3.89 (2 pack)	Home Depot
27	Hinges	Door Hinges	6		$2.19	Home Depot
28	File Containers	Cardboard Box holders	24			
29	Structural Support	Drywall Screws	125	1-1/4	$4 (250 count)	Home Depot
30	Structural Support	Drywall Screws	20	3	$6 (83 count)	Home Depot
31	Structural Support	Lag bolts	24	1-1/4-5/16 diameter	$0.35	Home Depot
32	Coating	Waterproof Exterior Paint	1	¼ gallon	27.98 (1 gallon)	Home Depot

9.4 Appendix D – Detailed Cost Analysis

Cost of Frame and Amenities without Conveyor system

	Location	Part	Cost/Cart	Location
1	Entire Wood Frame	2”x4” Wood	$14.61	Home Depot
2	Top of shelf	½ inch plywood	$26.67	Home Depot
3	Bottom of shelf	¼ inch plywood	$21.80	Home Depot
4	Shelf spacing	1 inch base AL channel stock	$20.96	Home Depot
5	Doors	½ inch plywood	$22.92	Home Depot
6	Side And Top	¼ inch plywood	$63.94	Home Depot
7	Castors	400lb locking castors	$180	McMaster Part # 9949t16
8	Lock	Hasps with rotating Padlock Eye	$18.04	McMaster Part # 1912A17
9	Bumpers	Neoprene Corner Pads	$0.91	McMaster Part # 94545k61
10	Label Holders	Avery Business Card Holder	$0.80	OfficeMax Item # 04039873
11	Interlocking	Sliding Door Latch	$27.96	Fdsons.com
12	Structural Support	Angle brackets	$8.94	Home Depot
13	Structural Support	T brackets	$15.00	Home Depot
14	Structural Support	Angle bracket (with wall)	$31.12	Home Depot
15	Hinges	Door Hinges	$13.14	Home Depot
16	Structural Support	Drywall Screws	$2	Home Depot
17	Structural Support	Drywall Screws	$1.45	Home Depot
18	Structural Support	Lag bolts	$8.40	Home Depot
19	Coating	Waterproof Exterior Paint	$7	Home Depot
SUBTOTAL			**$485.66**	
TOTAL	**+%10 Buffer**		**$534.23**	

Cost of Conveyor System

	Location	Part	Cost/Cart	Location
1	Roller assembly	Nylon Sleeve bearings	$36.67	McMaster part # 6389k229
2	Roller assembly	Steel pipe	$51.73	McMaster part # 7767T43
3	Roller assembly	Steel pipe	$35.70	McMaster part # 7767T37
4	Roller assembly	Steel rod	$4.44	Metal Supermarket
5	H-Frame	Unfinished Piano Hinge	$9.87	McMaster Part # 15665A57
6	H-frame	Steel bar stock	$3.10	McMaster part # 8910K136
7	Conveyor	Treadmill Material	258.46	TreadmillDoctor.com
SUBTOTAL			**$399.97**	
TOTAL	**+%10 Buffer**		**$439.97**	

Total Cost of Cart

SUBTOTAL			**885.63**	
Total	**+10% Buffer**		**974.20**	

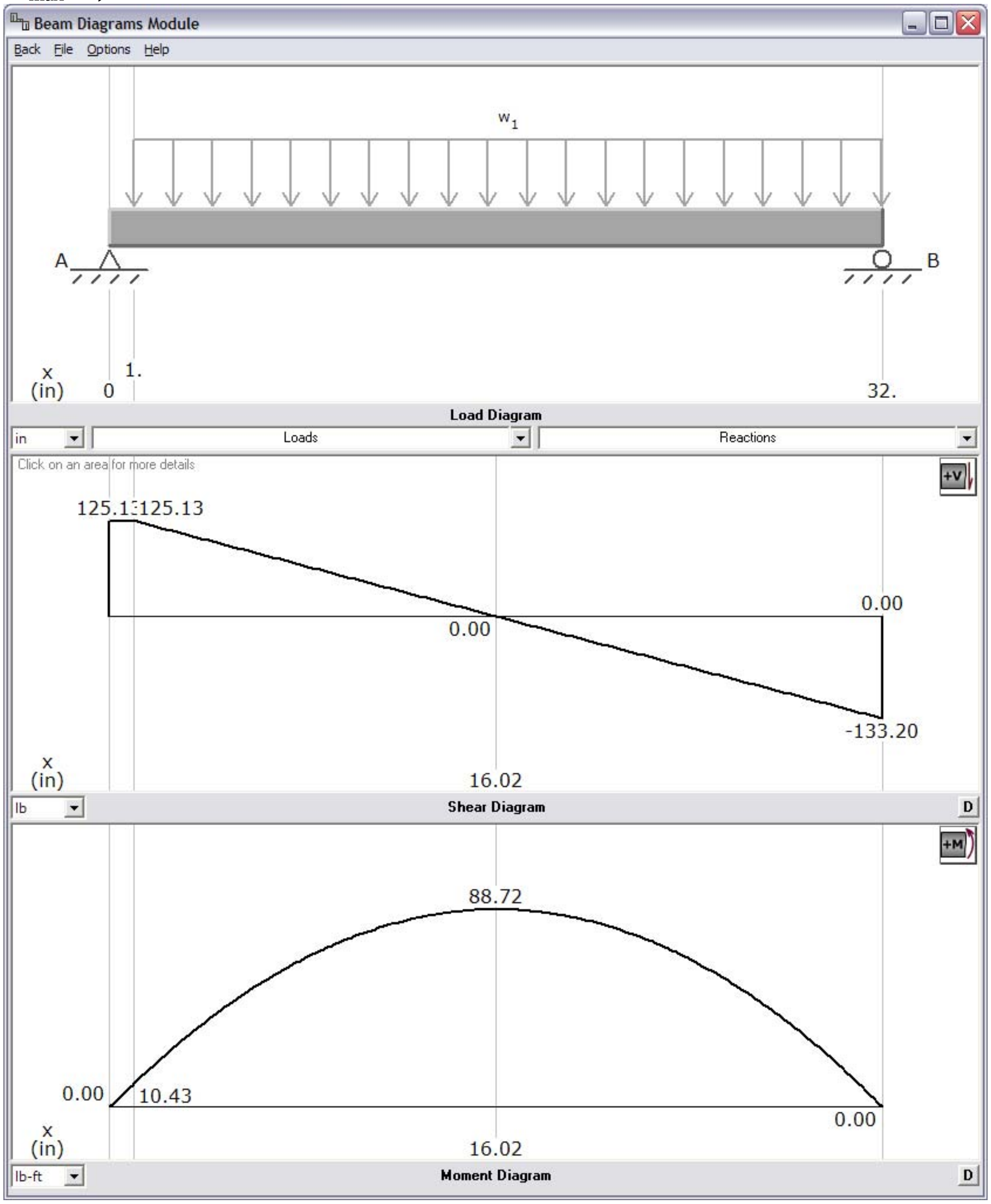
9.5 Appendix E – Stress Analysis for Columns and Supports

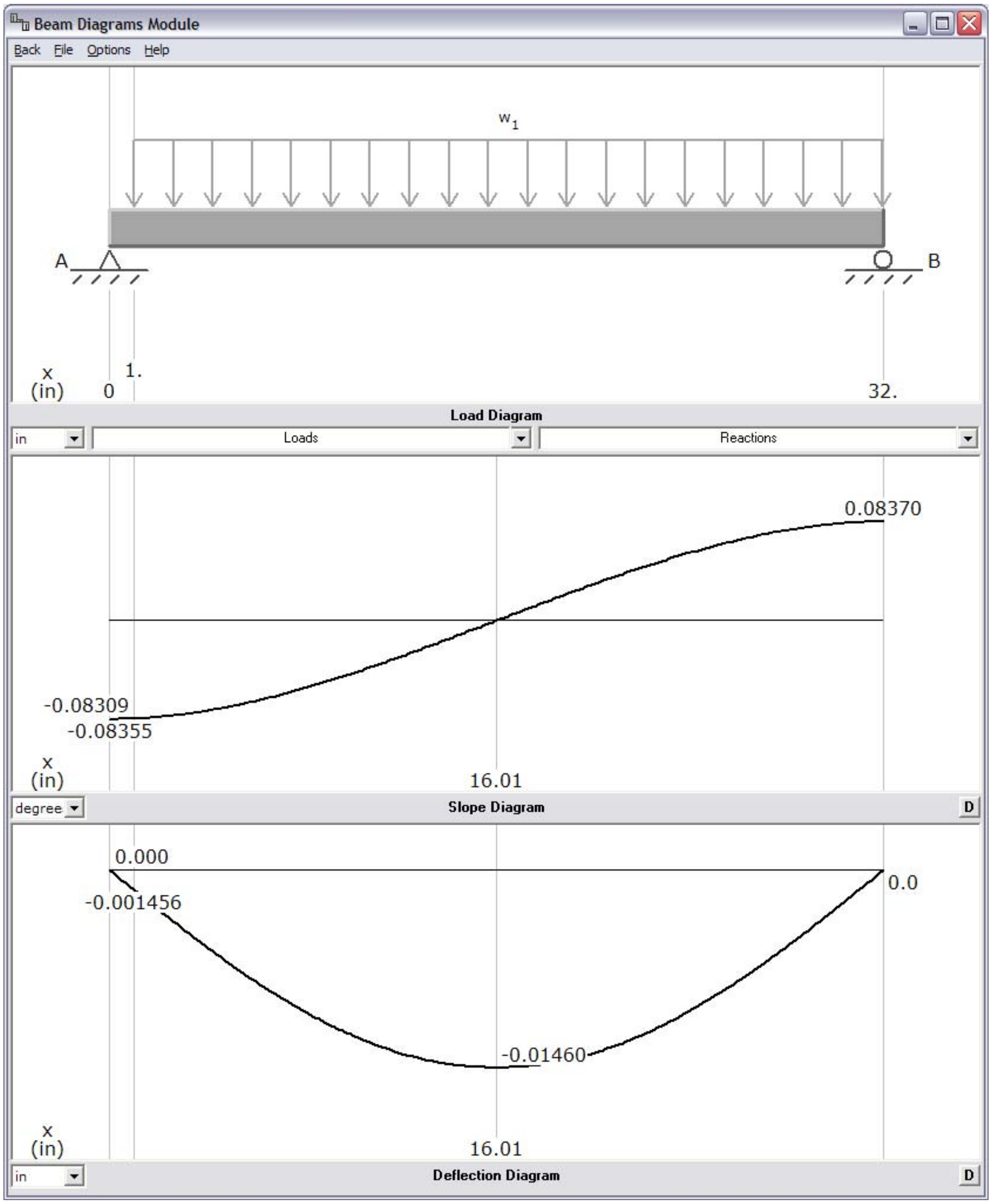
Stress Calculations on major components

Wood Properties

Strength	Ksi	Mpa
Ultimate Tensile Strength	8.4	55
Ultimate Compression Strength	5.0	34
Ultimate Shear Strength	1.0	7
Young's modules	1,300	10

Shelf beam
2” X 4” X 32” actual dimensions of 1.5” X 3.5” X 32”
Area = 3.5”x1.5”= 5.25^2 “
The W_1= 100lbs per foot
W_{max}=1,400 lb/foot




Beam Diagrams Module
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Slope Diagram
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-0.01460
x
(in)
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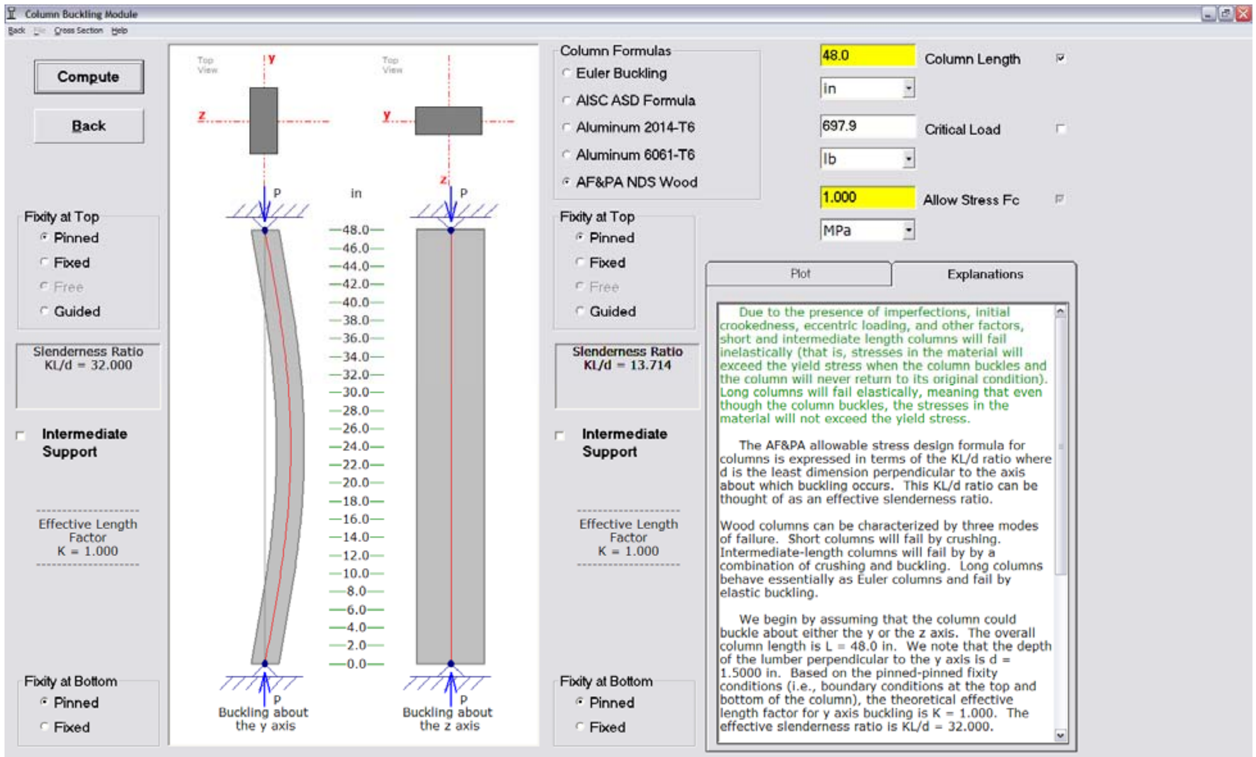
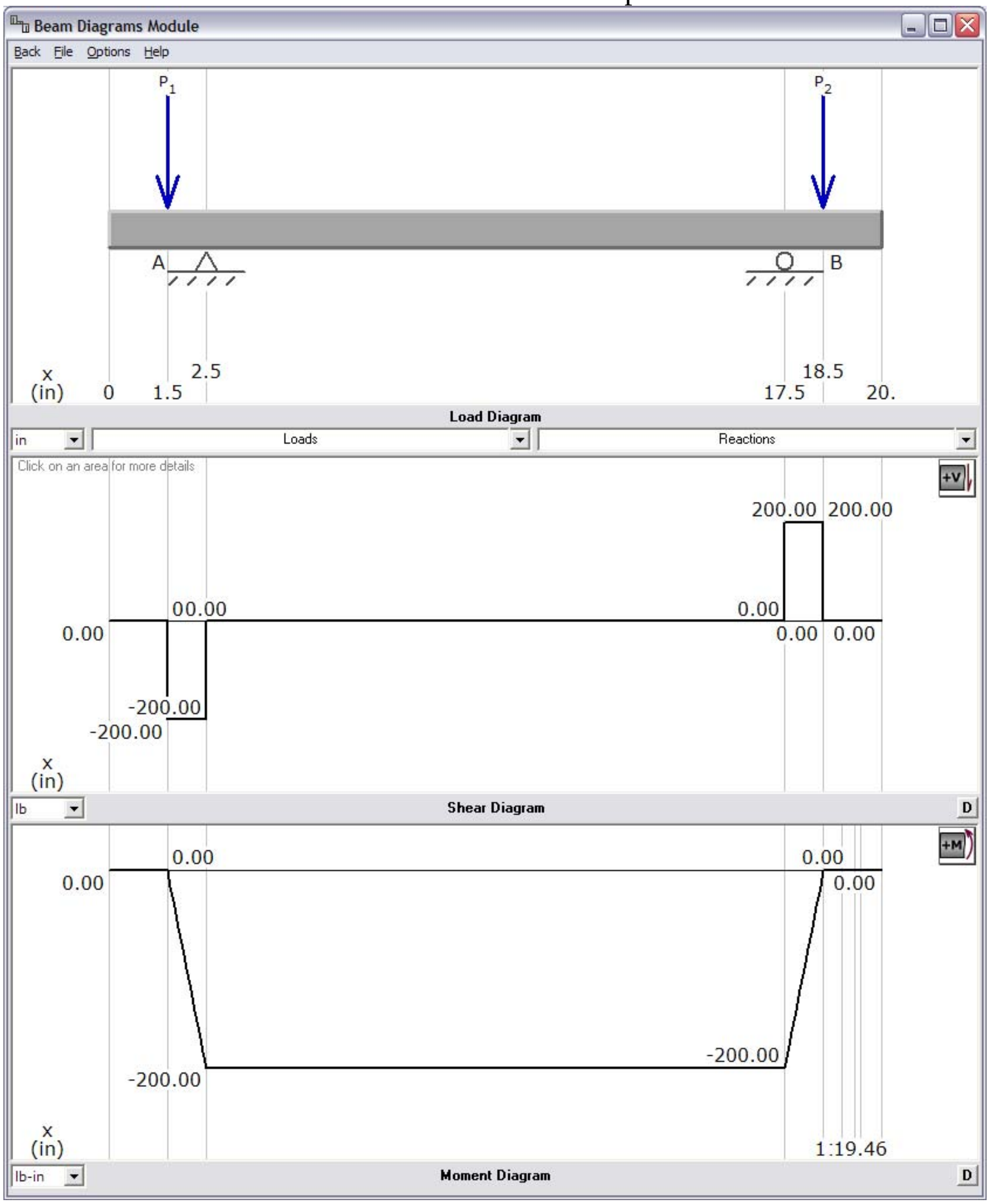
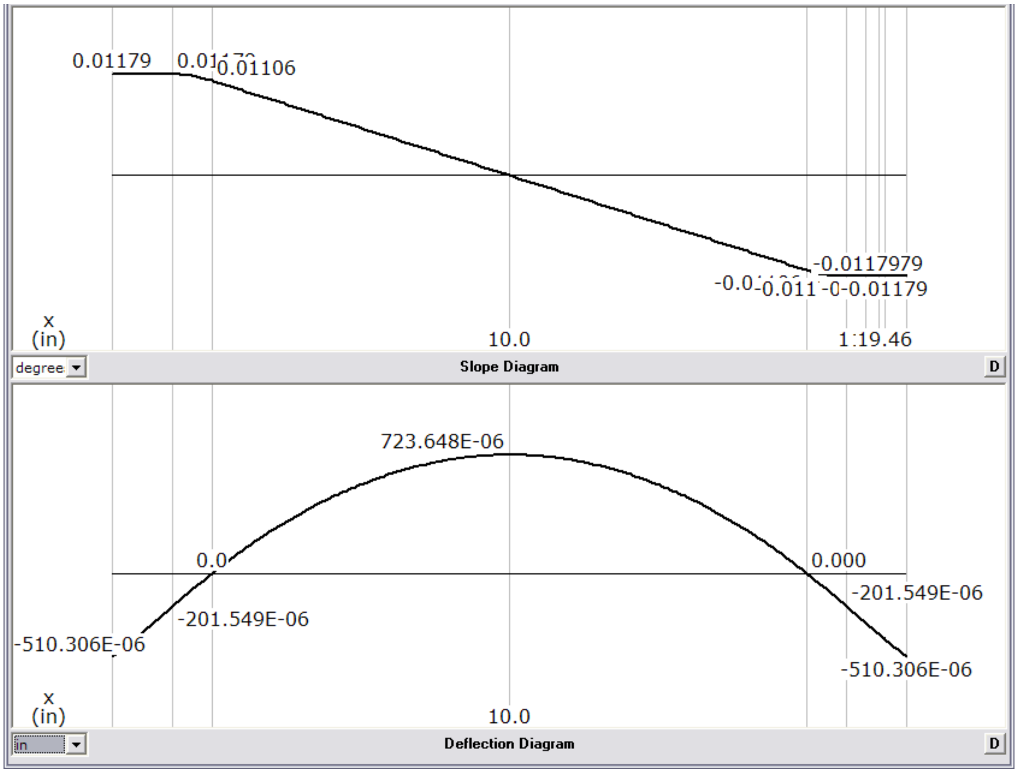
in
Deflection Diagram
D

Main Column
2” X 4” X 48” actual dimensions of 1.5” X 3.5” X 48”
Area = 3.5”x1.5”= $5.25^{2”}$
Critical load is 697.9 lbs with allowable stress at 1000PSI



End supporting beam under the door
2” X 4” X 20” actual dimensions of 1.5” X 3.5” X 20”
Area = 3.5”x1.5”= 5.25$^{2”}$
P1 and P2 are point loads = 200lbs




0.01179
0.01106
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-0.01179
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0.000
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-510.306E-06
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(in)
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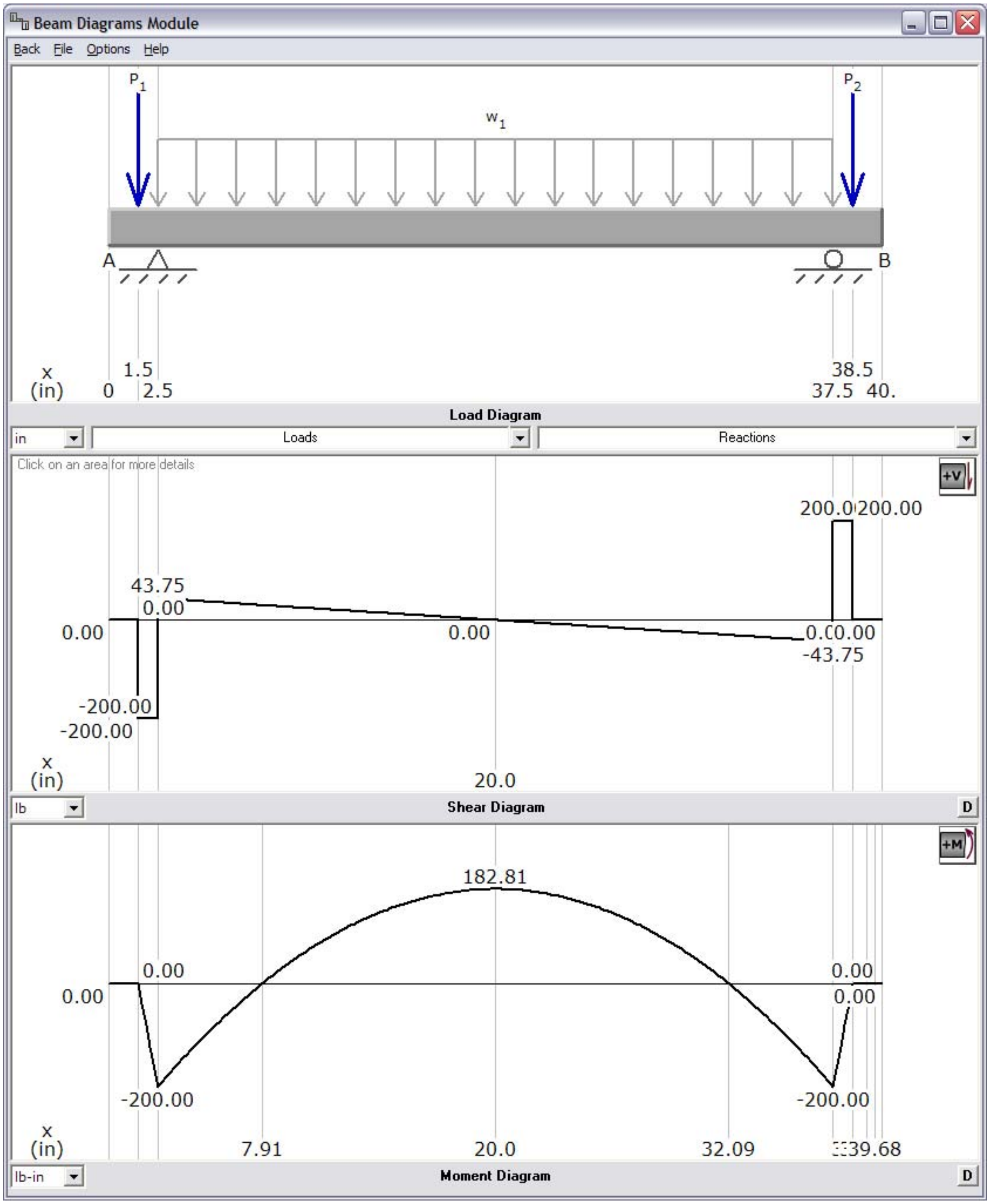
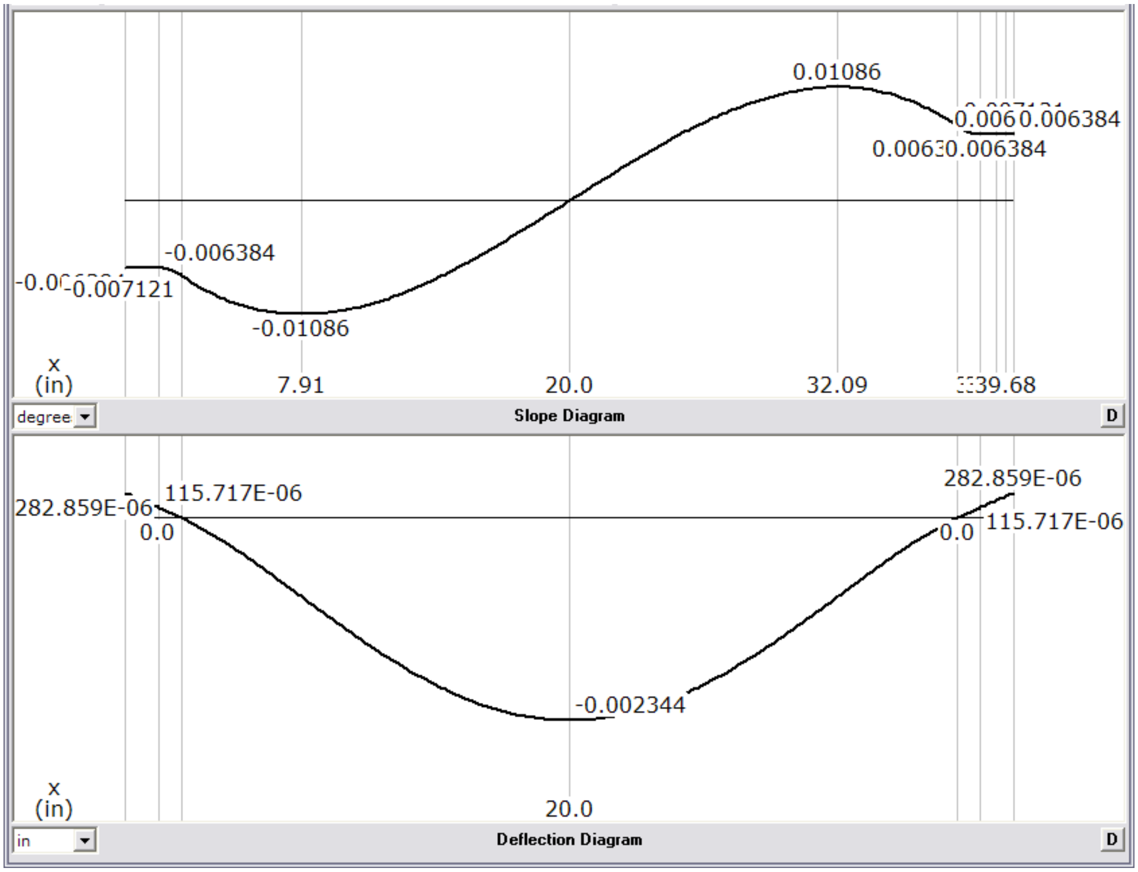
Deflection Diagram
D

Loading of the base shelf beam
2” X 4” X 40” actual dimensions of 1.5” X 3.5” X 40”
Area = 3.5”x1.5”= 5.25$^{2”}$
P1 and P2 are point loads = 200lbs
W1 is uniform load of 30lbs/ foot





0.01086
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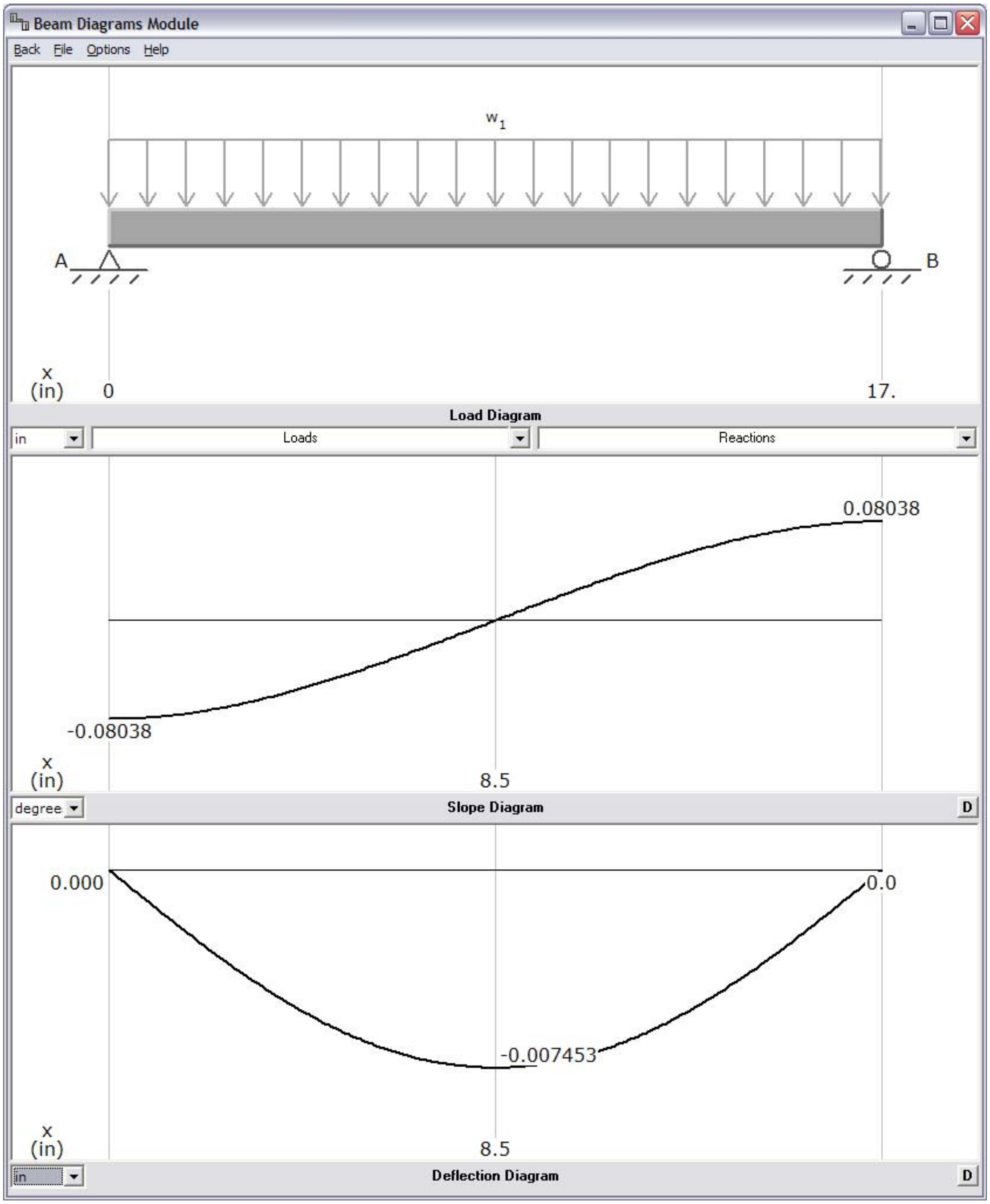
7.91
20.0
32.09
39.68
degree
Slope Diagram
D
282.859E-06
115.717E-06
0.0
282.859E-06
0.0
115.717E-06
-0.002344
x
(in)
20.0
in
Deflection Diagram
D

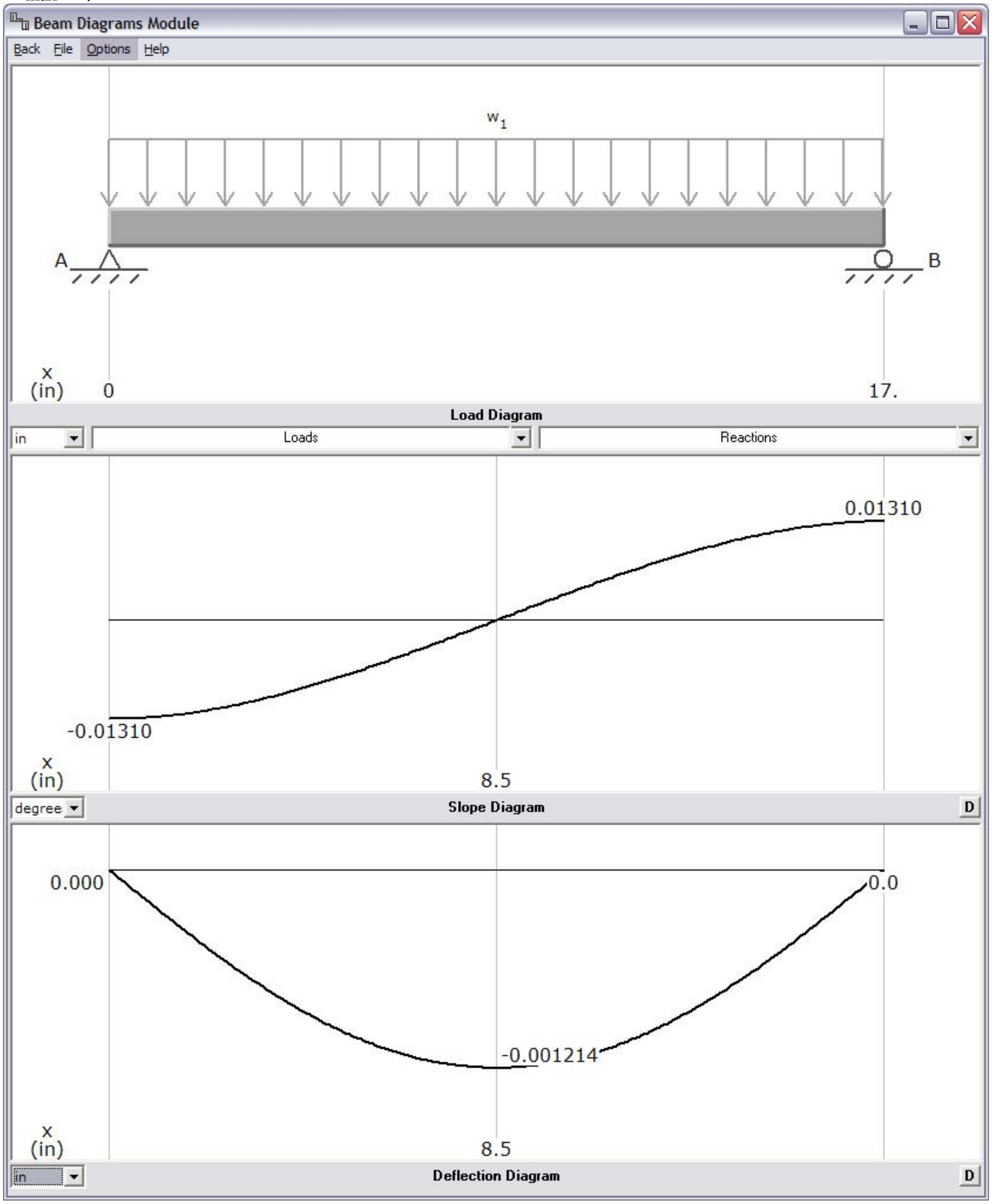
Properties of steel
Structural, ASTM-A36

Strength	Ksi	Mpa
Yield Tensile Strength	36	248
Yield Compression Strength	36	248
Yield Shear Strength	21	145
Young’s modules	29,000	200,000

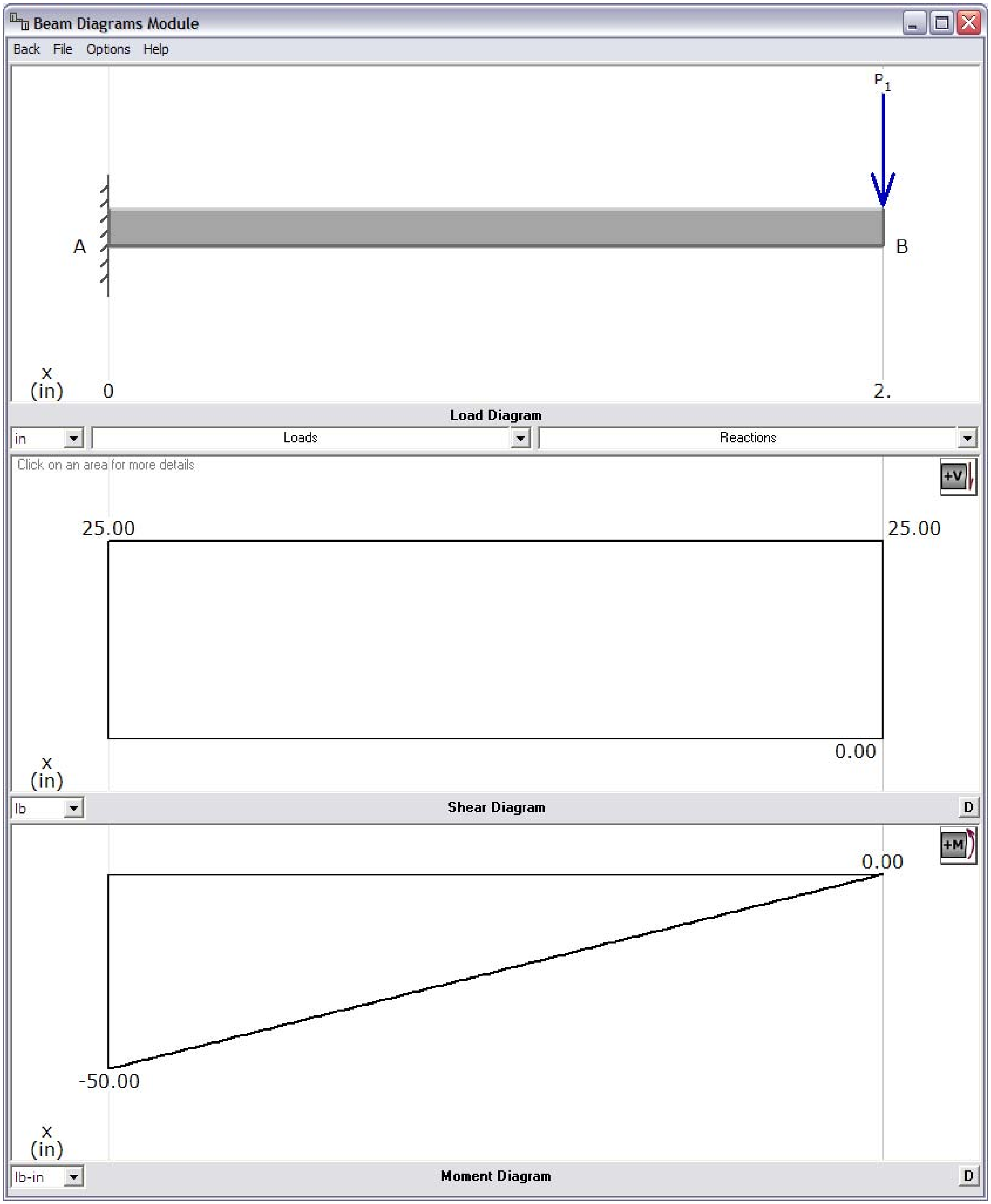
Fixed roller (inner pipe)
OD 1” ID 0.87” A^2=0.1909^2 “
With a load of 50 lbs/foot
$M_{max} = wL^2/8$
W_{max}=501.43 lb/ft.

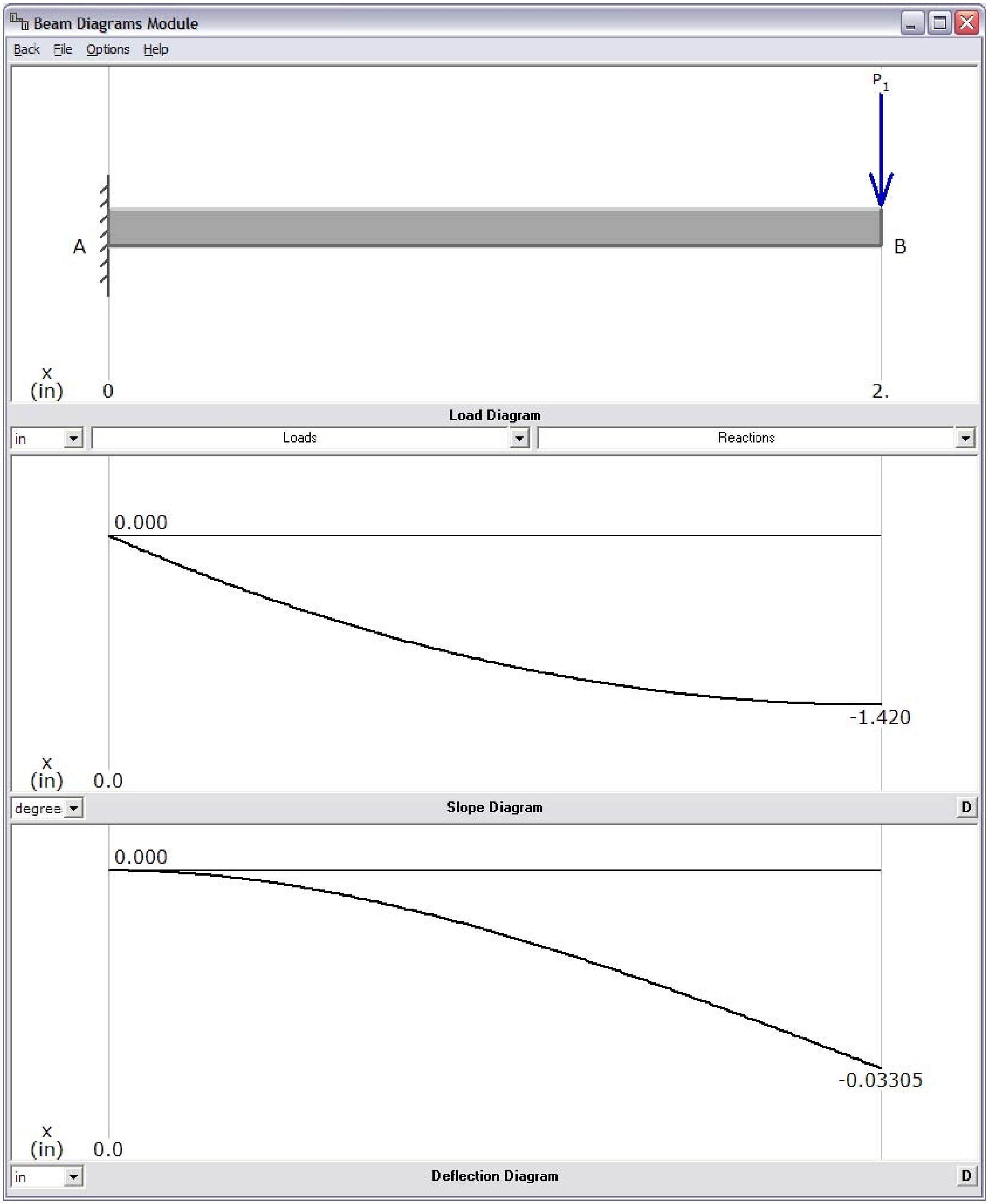


Moving roller (Outer pipe)
OD 1.5" ID 1.25" A^2=0.54^2 "
Load of 50 lbs/foot
$M_{max} = wL^2/8$
W_{max}=2,051.48 lb/ft



Nails (general construction)
Size # 10d length 3 inches Diameter of 0.194”
P1 = 25lbs force

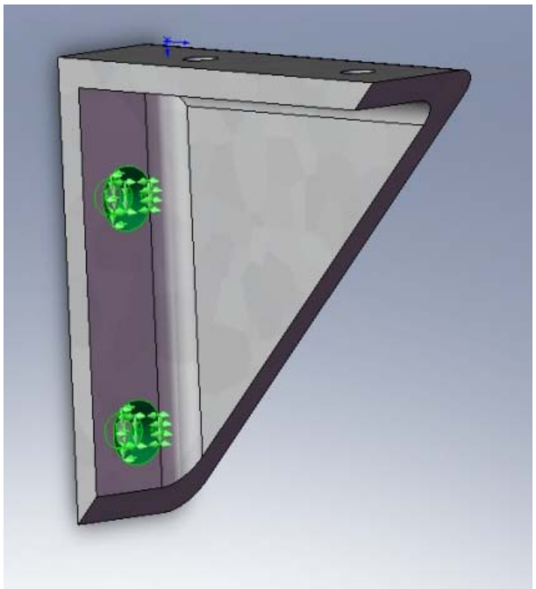



Beam Diagrams Module
Back File Options Help
P1
A
B
x (in)
0
2.
Load Diagram
in
Loads
Reactions
0.000
-1.420
x (in)
0.0
degree
Slope Diagram
D
0.000
-0.03305
x (in)
0.0
in
Deflection Diagram
D

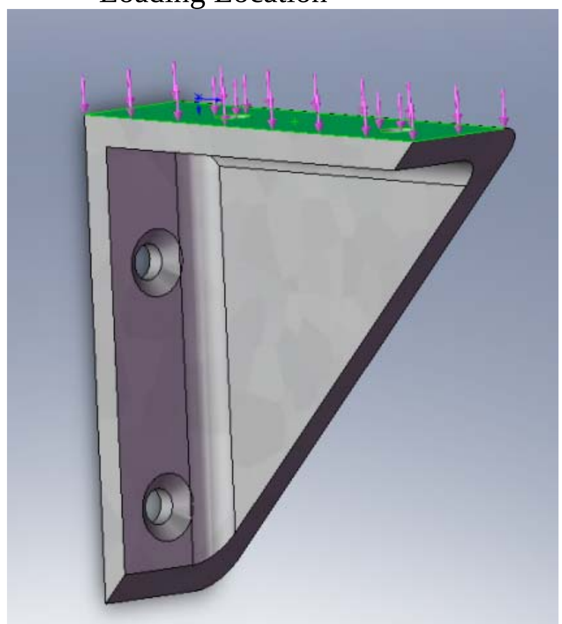
9.6 Appendix F – Stress Analysis for Brackets

Ribbed Angle Bracket
50lb load
.125” Thickness

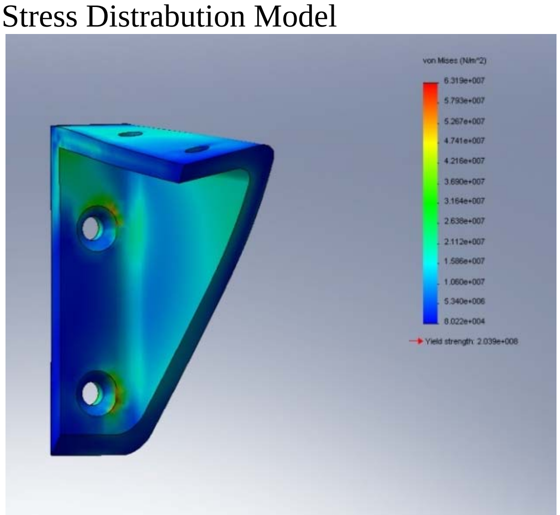
Restraint Locations



Loading Location

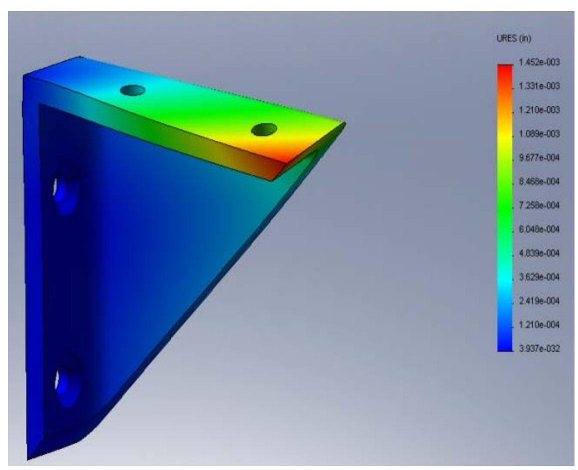


Stress Distrabution Model



Yield Strength = $0.2039\text{x}10^{9}$ (Nm^{2})
Max Stress = $0.0631\text{x}10^{9}$ (Nm^{2})

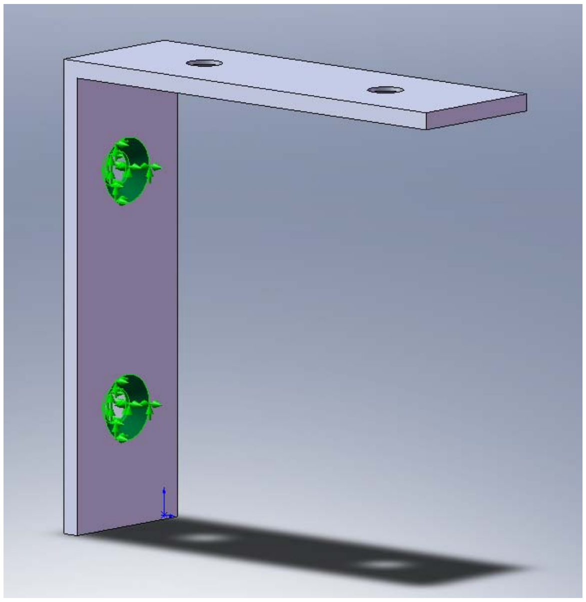
Deflection Distrabution Model



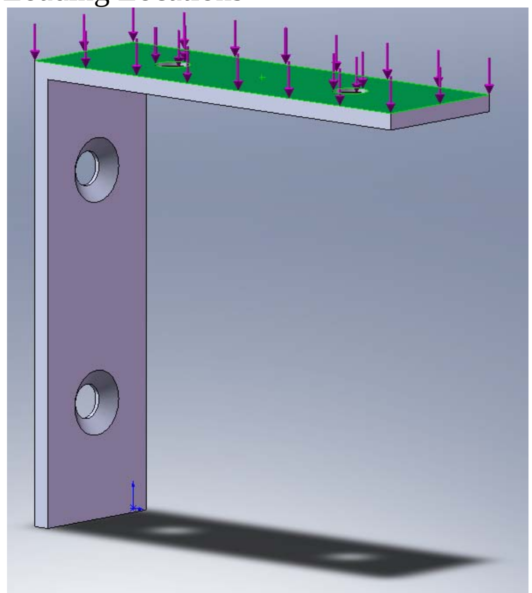
Max Deflection = .0014in

Angle Bracket
50lb Load
.125” Thickness

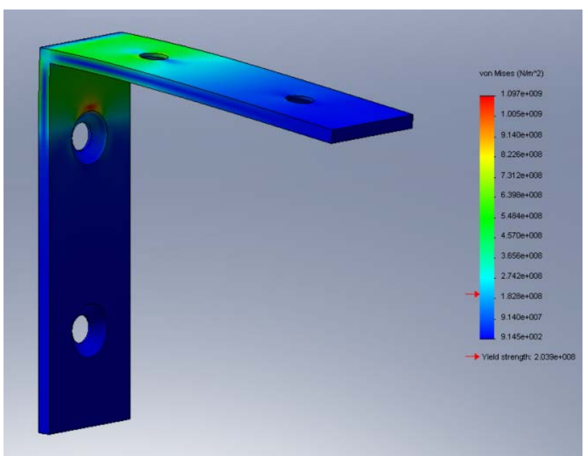
Restraint Locations



Loading Locations

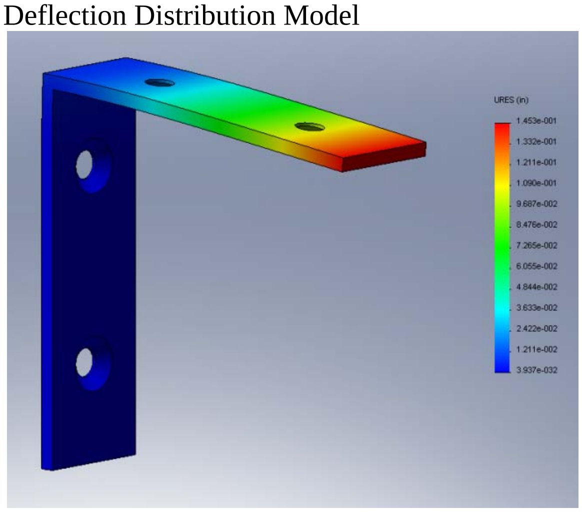


Stress Distribution Model



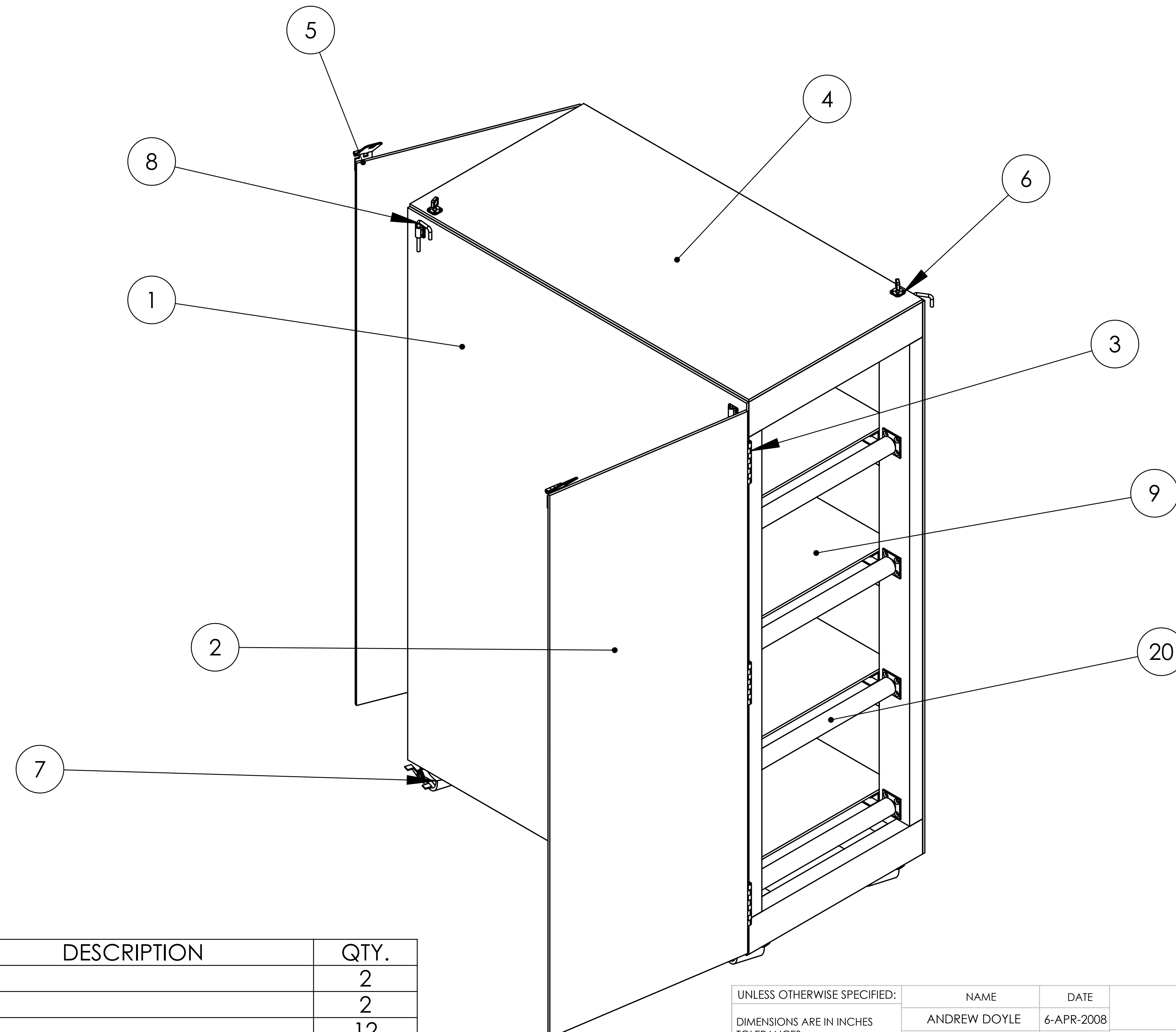
Yield Strength = 0.203×10^{9} (Nm^2)
Max Stress = 1.097×10^{9} (Nm^2)

Deflection Distribution Model



Max Deflection = .1453”

9.7 Appendix G – Drawings



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2	DOOR		2
3	HINGE		12
4	TOP		1
5	HASPLATCH		2
6	LOCK		2
7	CASTER		6
8	SLIDING DOOR LATCH		4
9	SHELF		4
20	RollerEXPLODE		8

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

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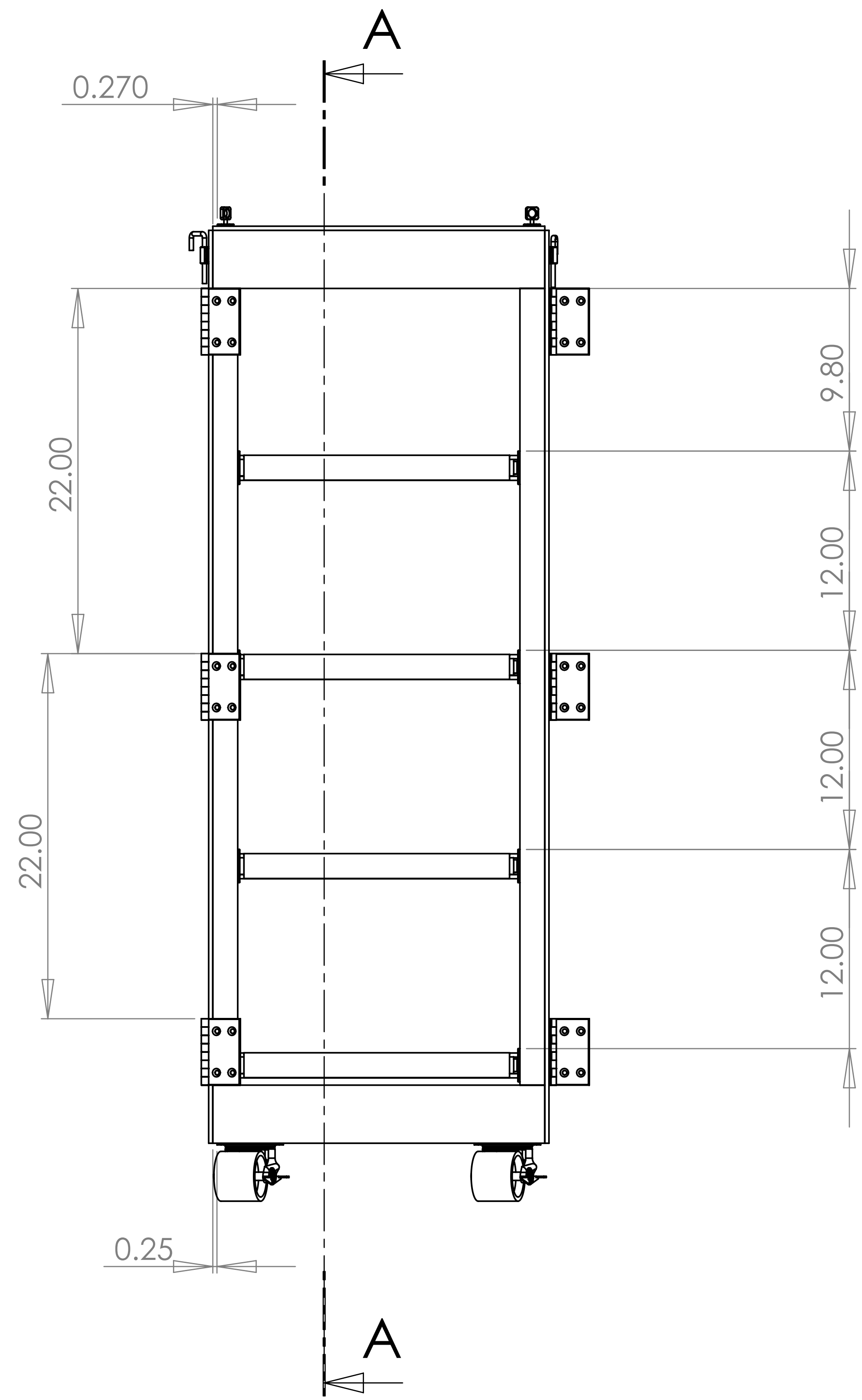
SCALE: 1:20 WEIGHT: SHEET 1 OF 5



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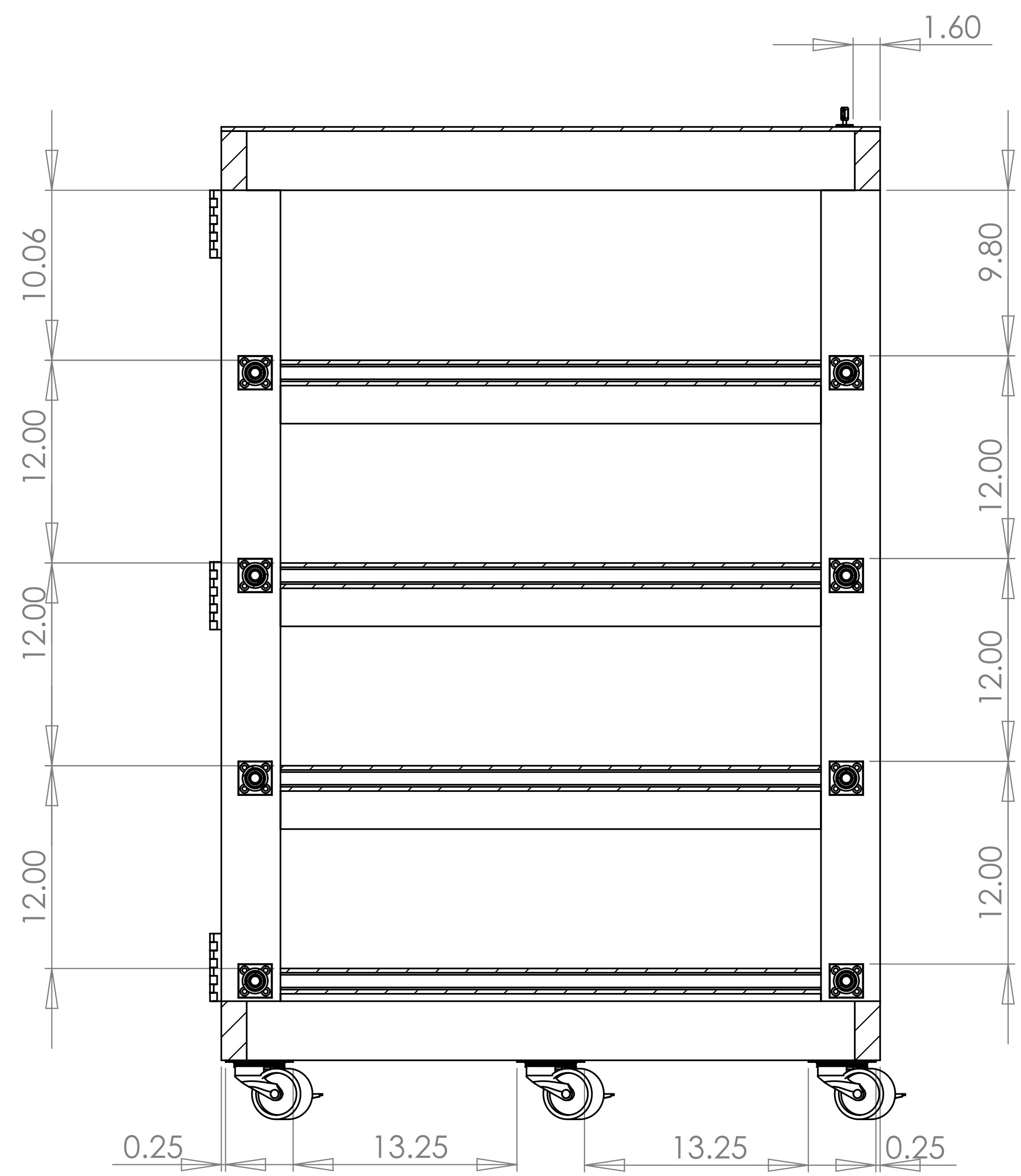

SECTION A-A
SCALE 1 : 10

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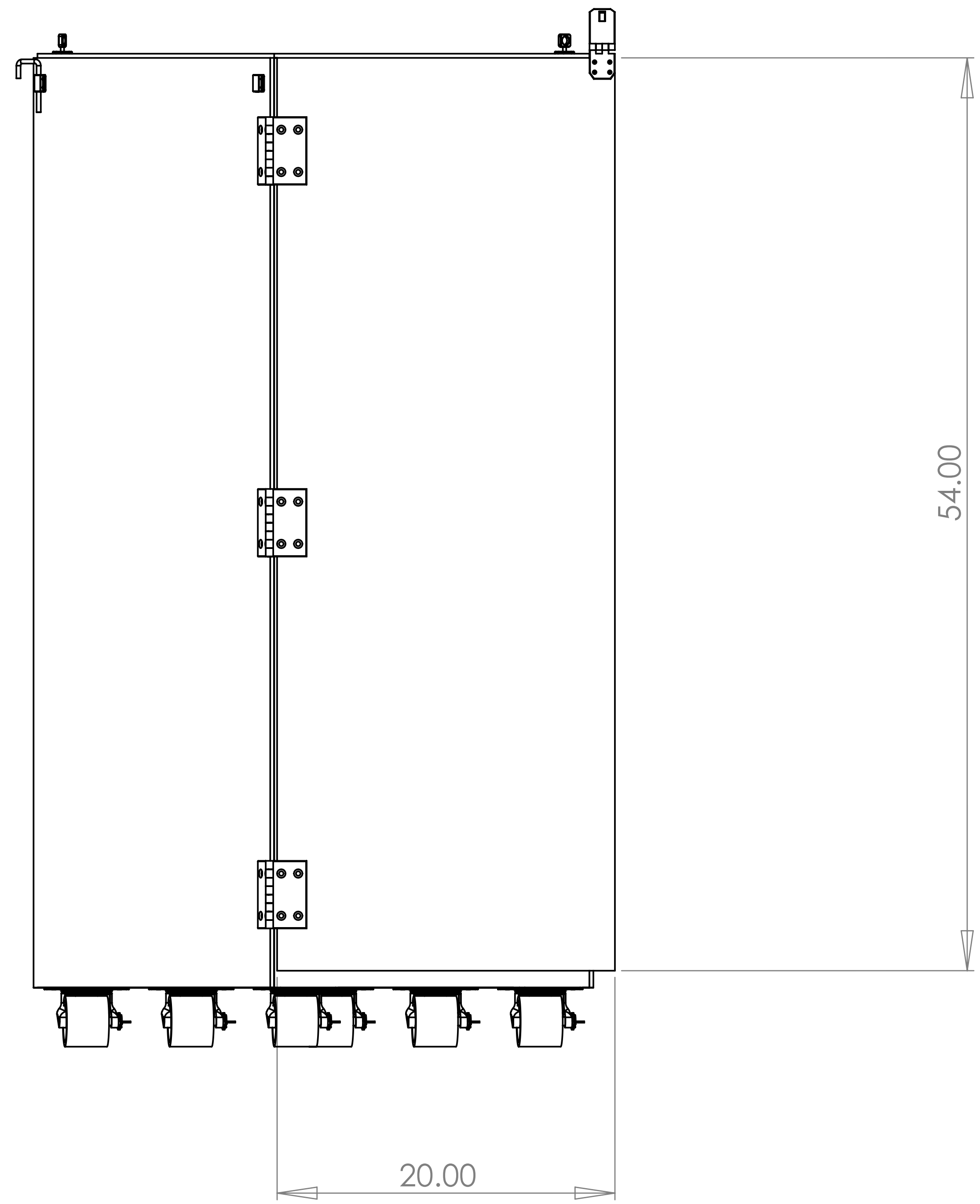

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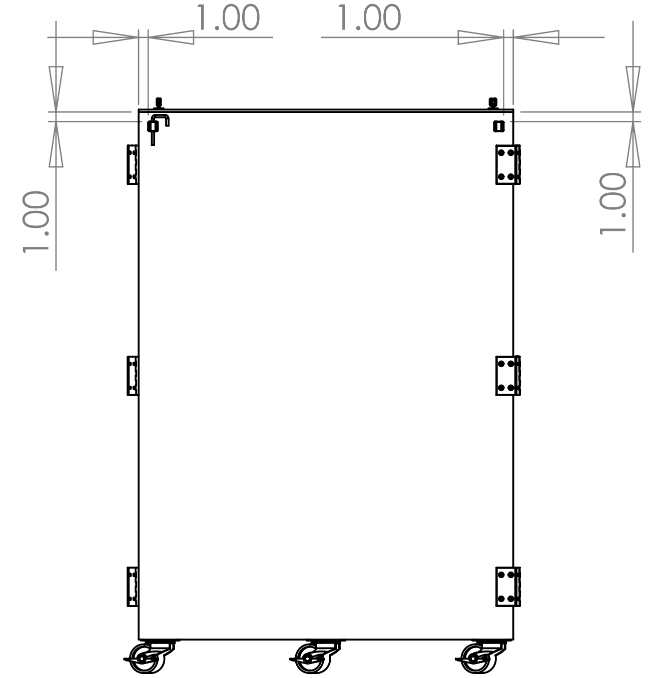

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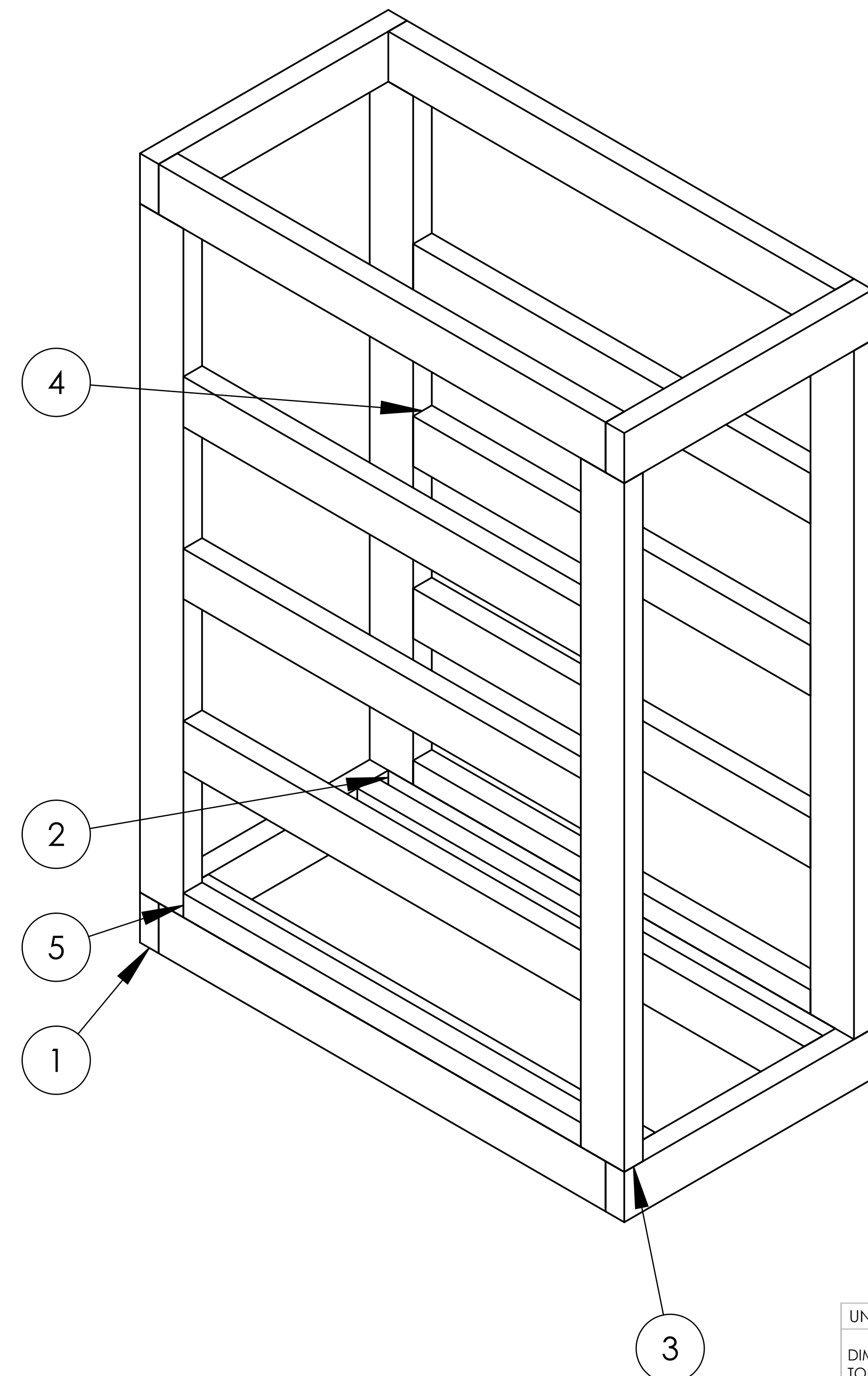

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2	48		6
3	45		4
4	41		6
5	Half2x4	2X4 RIPED IN HALF	2

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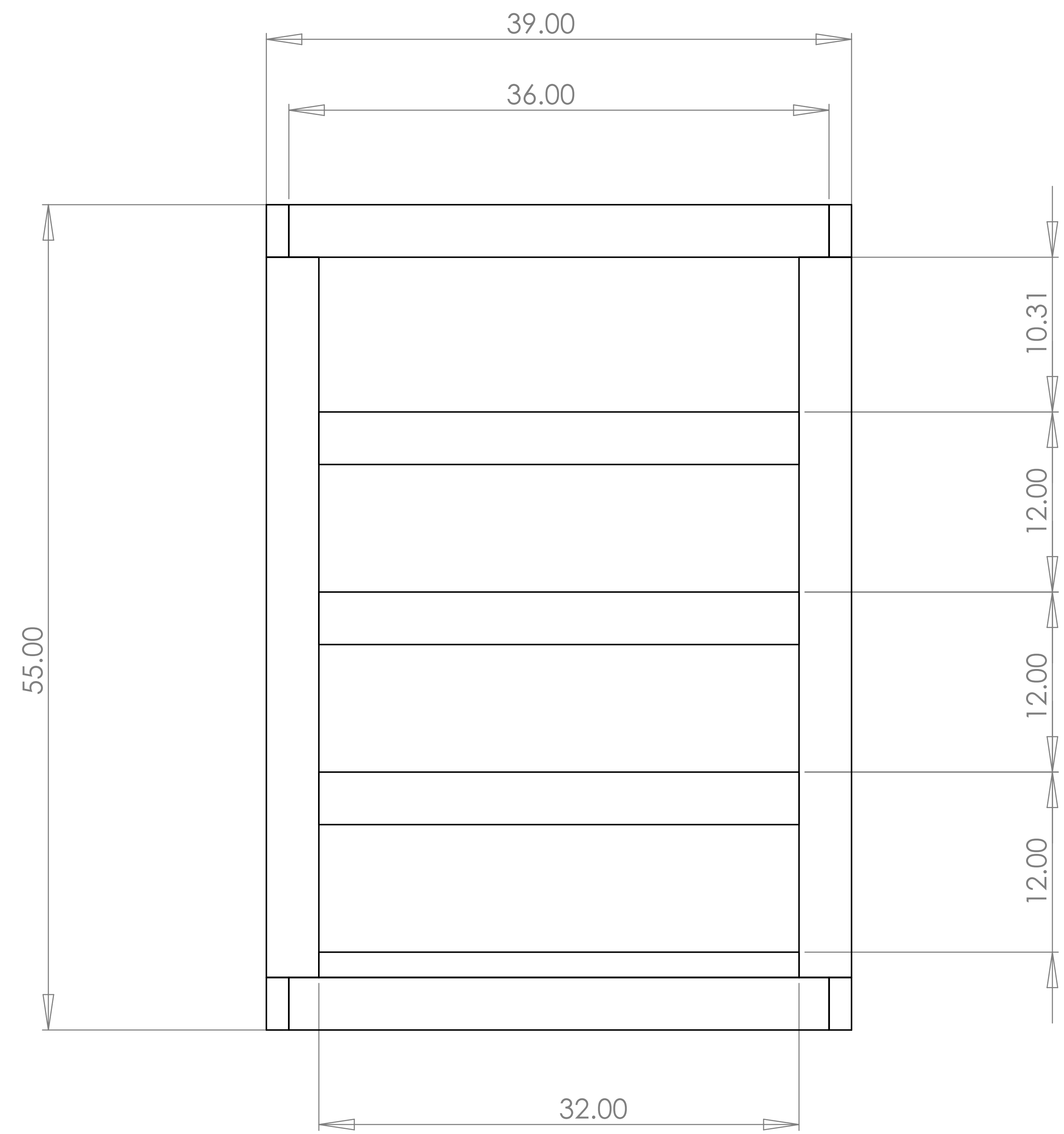

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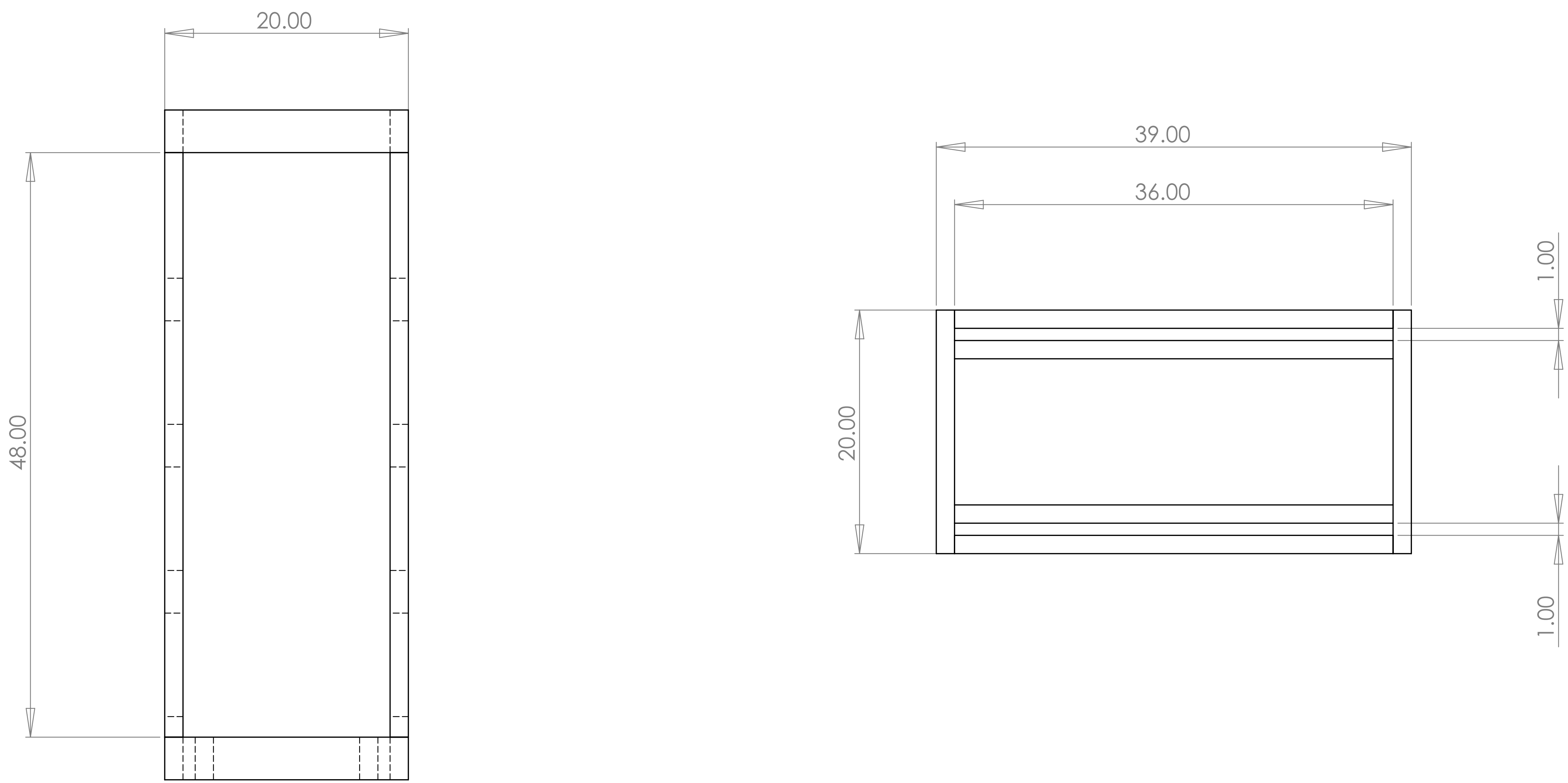

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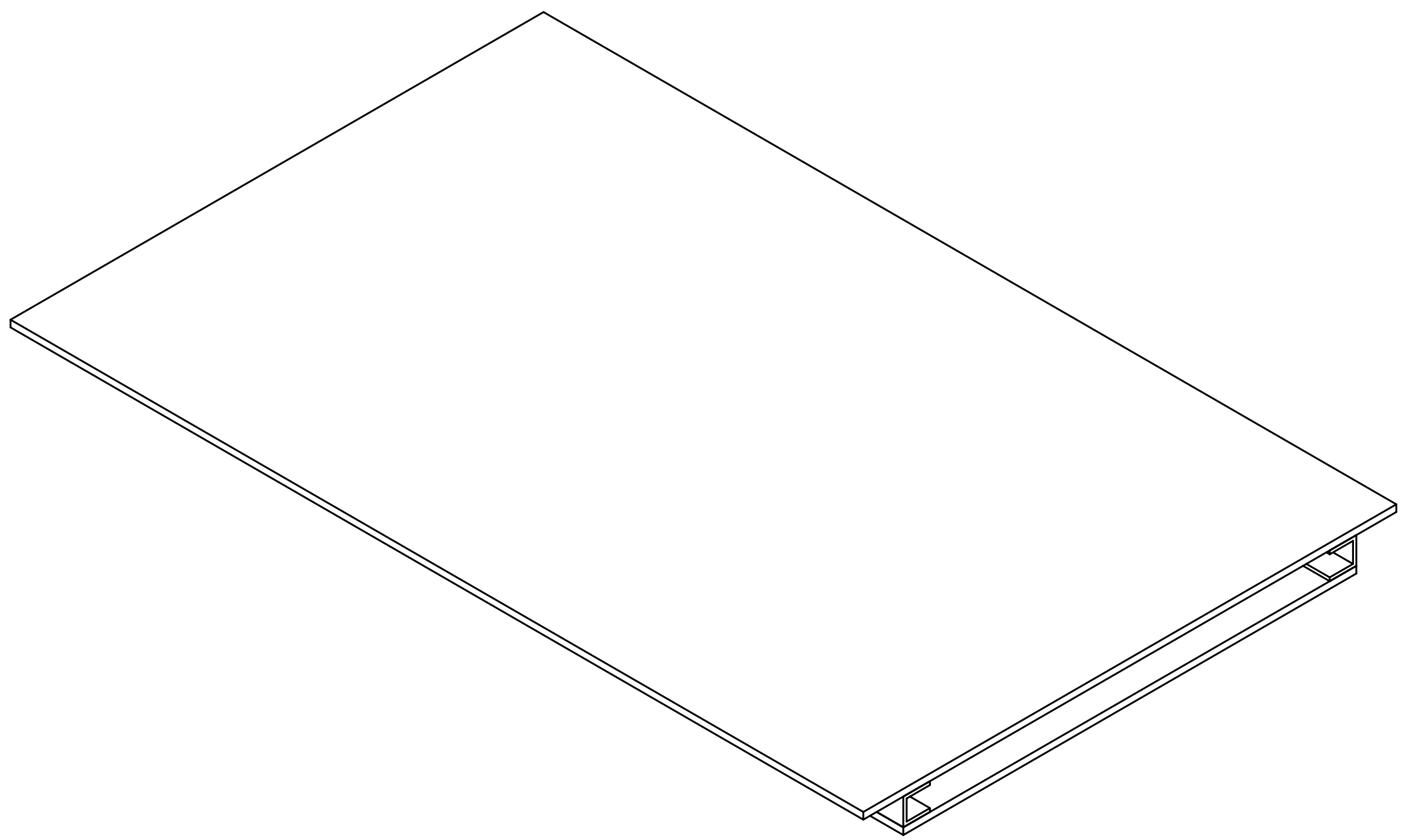
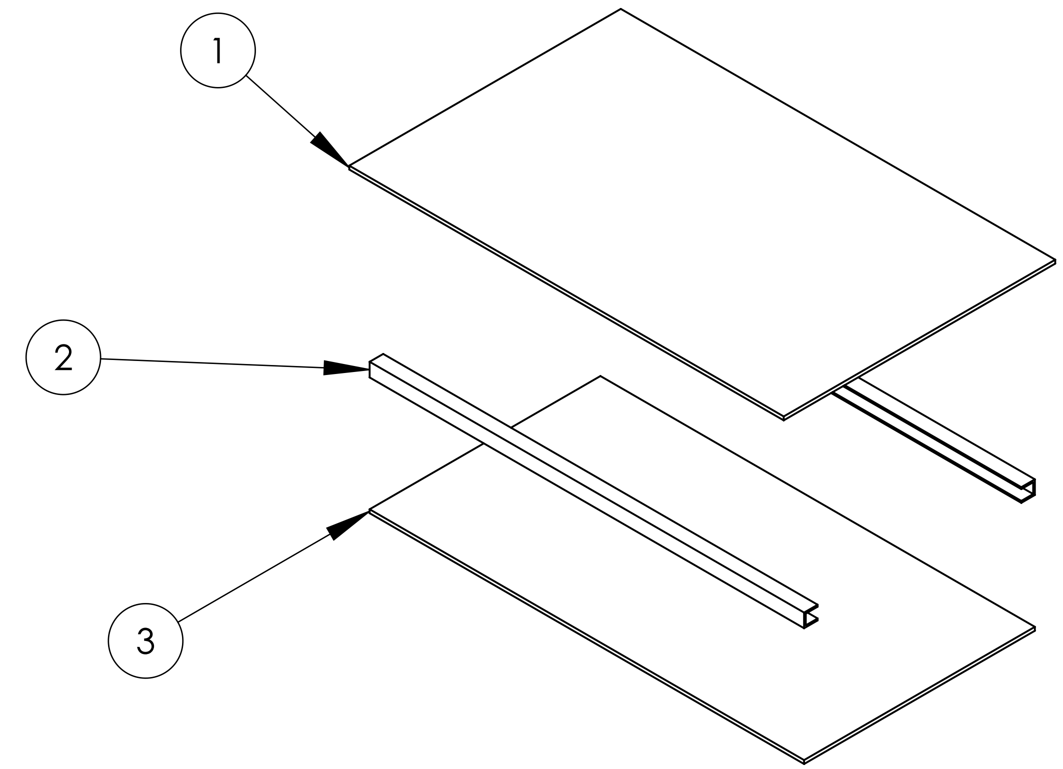
SIZE		REV
B	Frame	A

SCALE: 1:20 WEIGHT: SHEET 3 OF 3





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1	3	WoodShelf for roller		1
2	4	Channel Stock		2
3	5	UnderShelf		1

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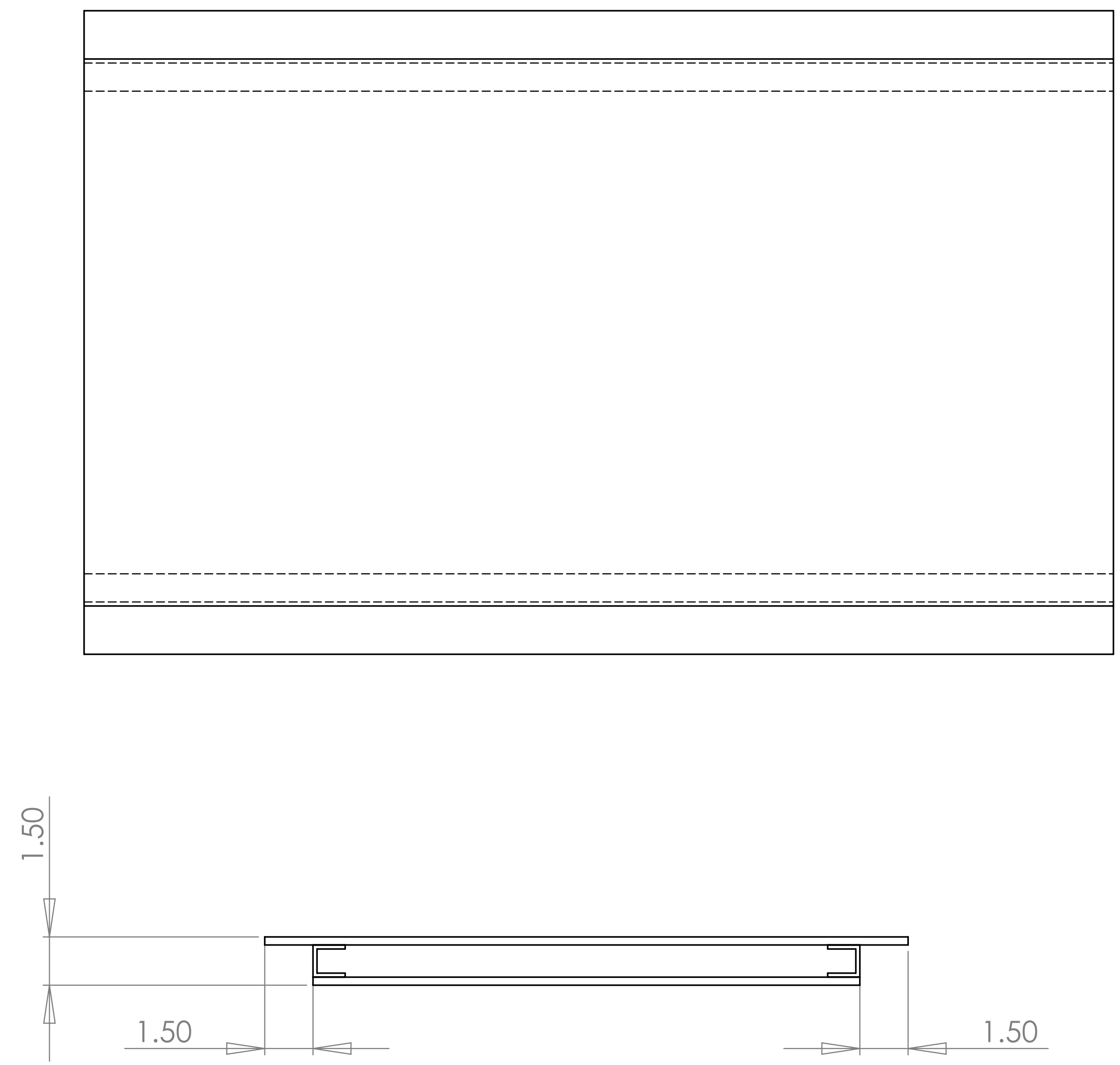
SIZE **B** Shelf REV A

SCALE: 1:10 WEIGHT: SHEET 1 OF 5



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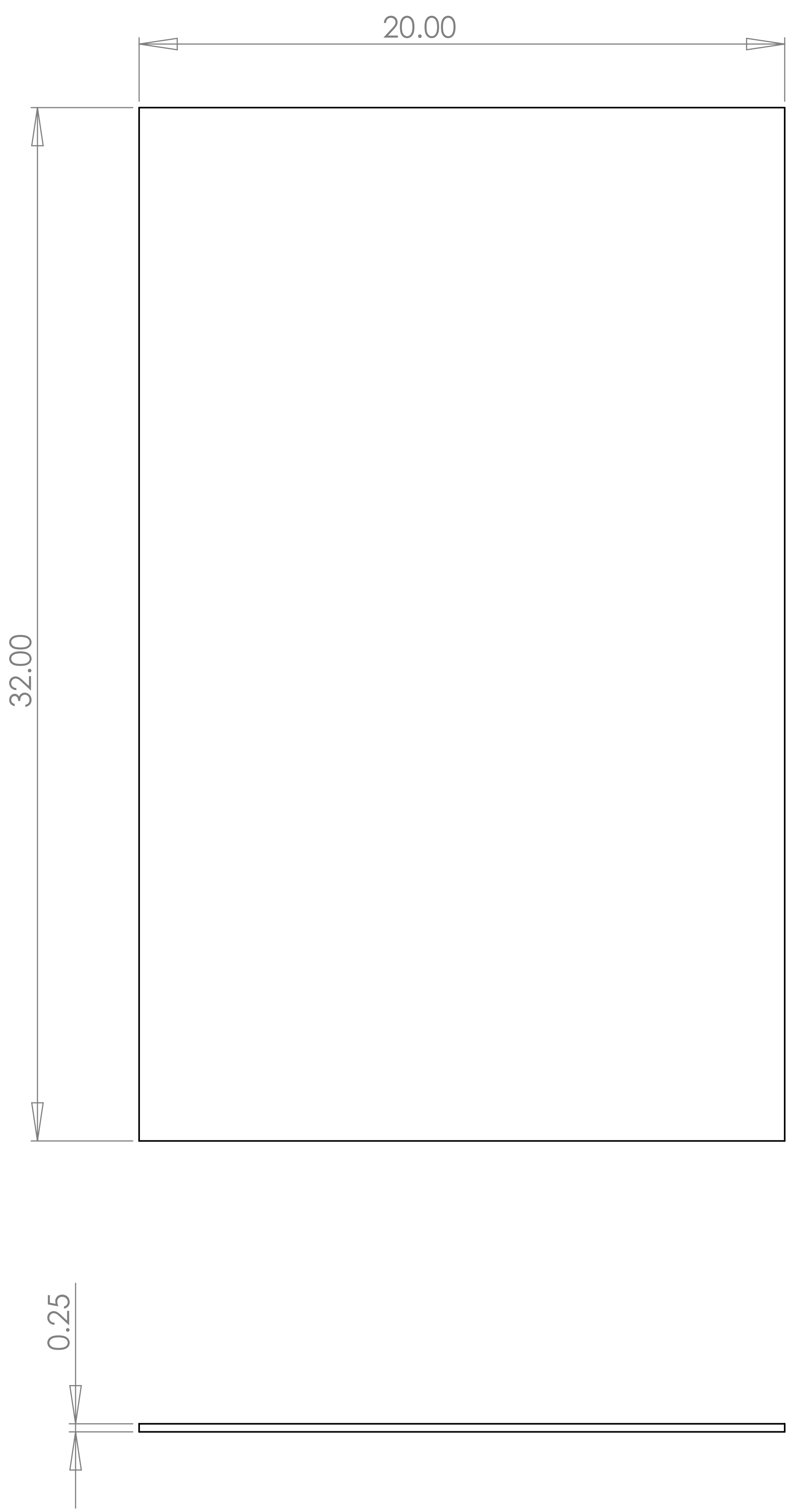
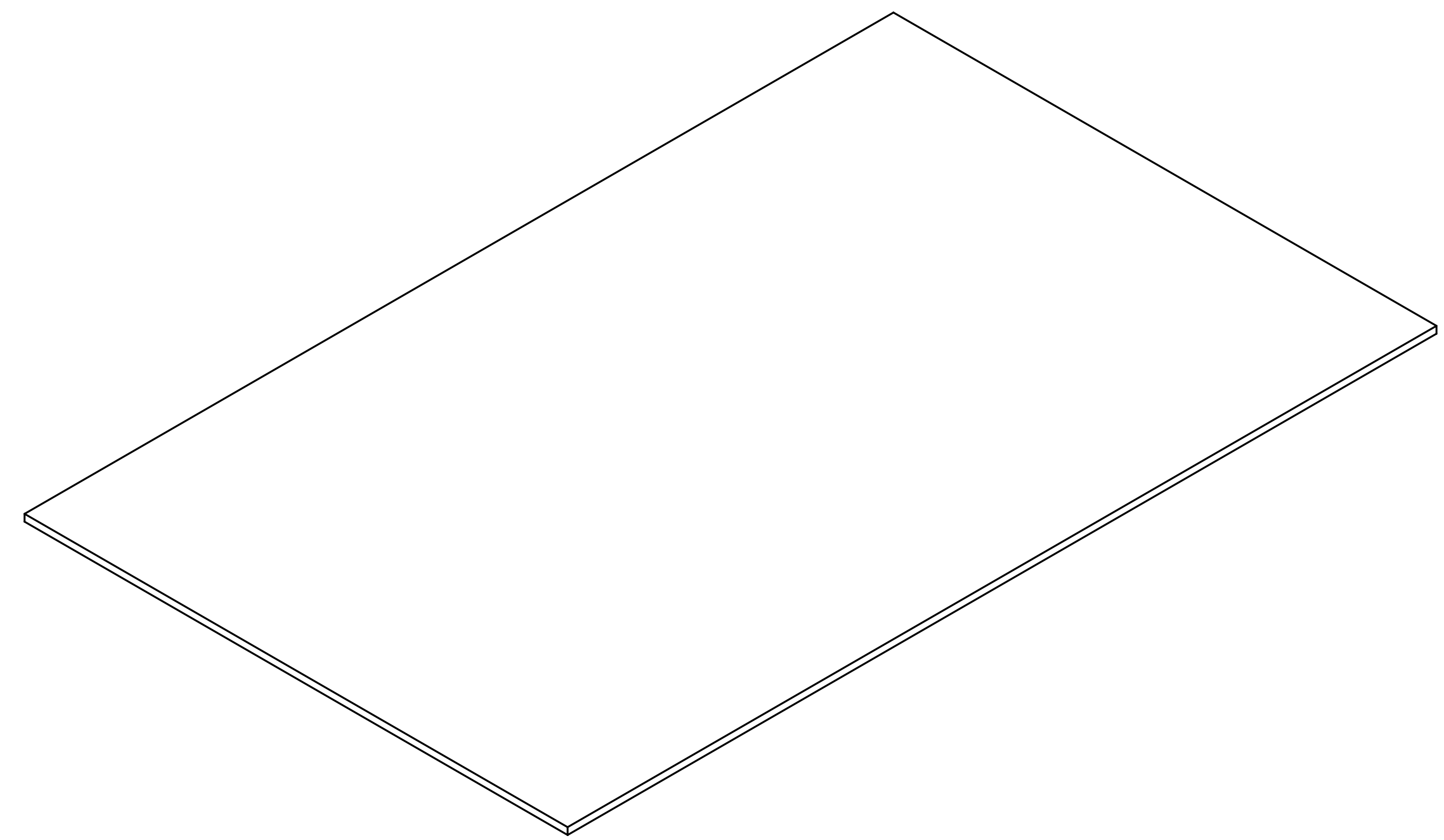
SIZE **B** | Shelf | REV A

SCALE: 1:10 WEIGHT: SHEET 2 OF 5





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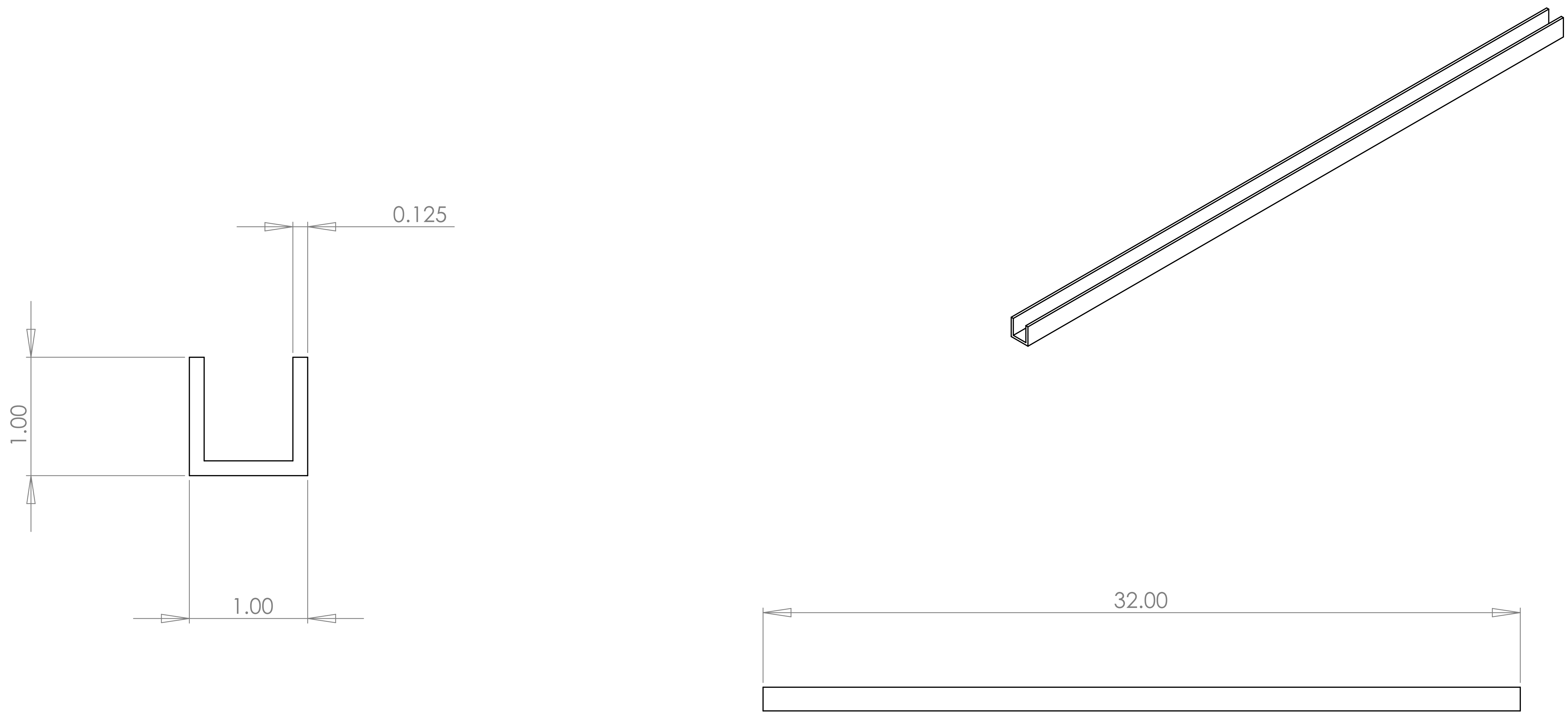
SIZE		REV
B	Shelf	A
SCALE: 1:10	WEIGHT:	SHEET 3 OF 5



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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

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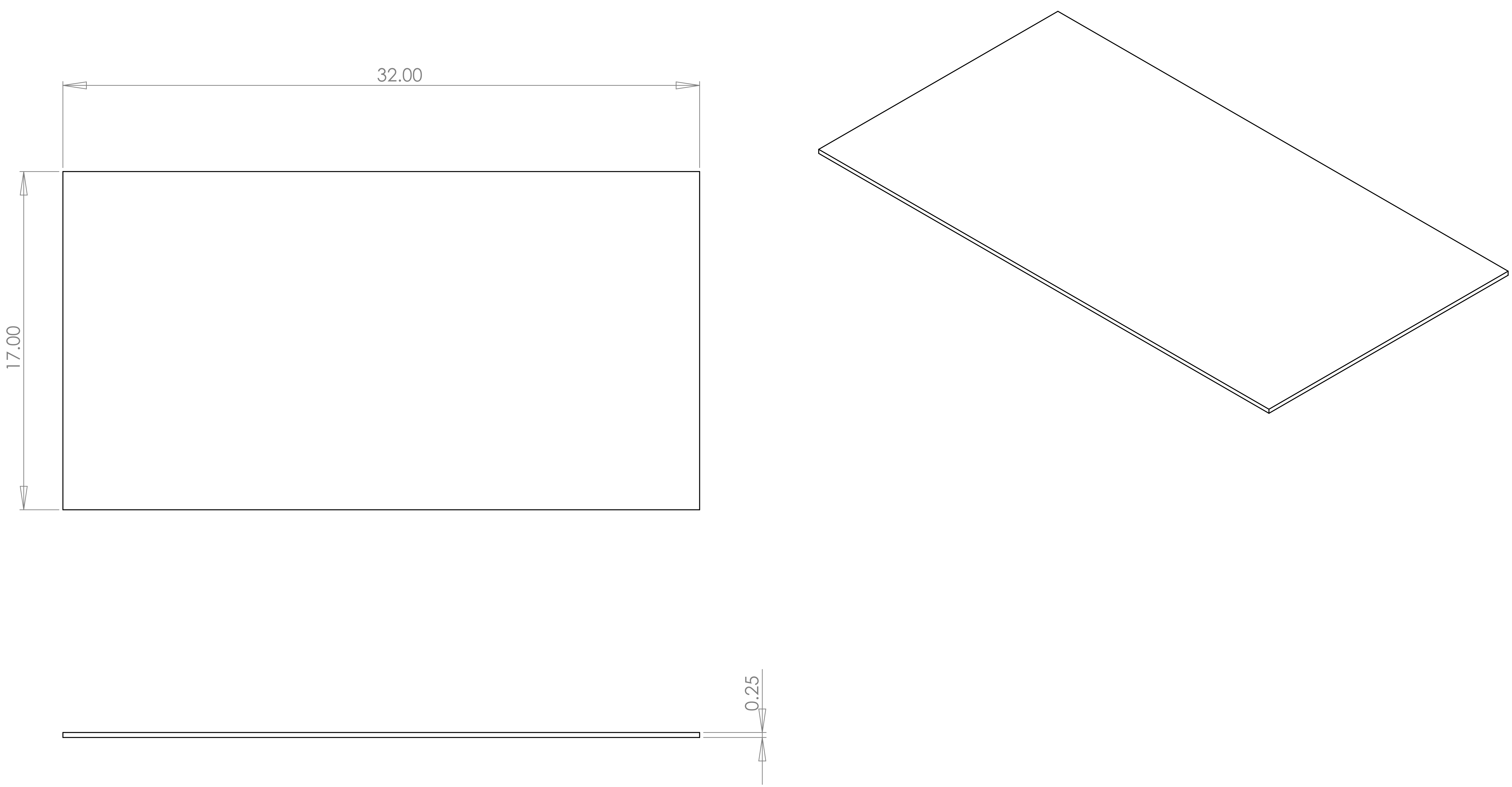
SIZE **B** | Shelf | REV A

SCALE: 1:10 WEIGHT: SHEET 4 OF 5



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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

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TITLE:
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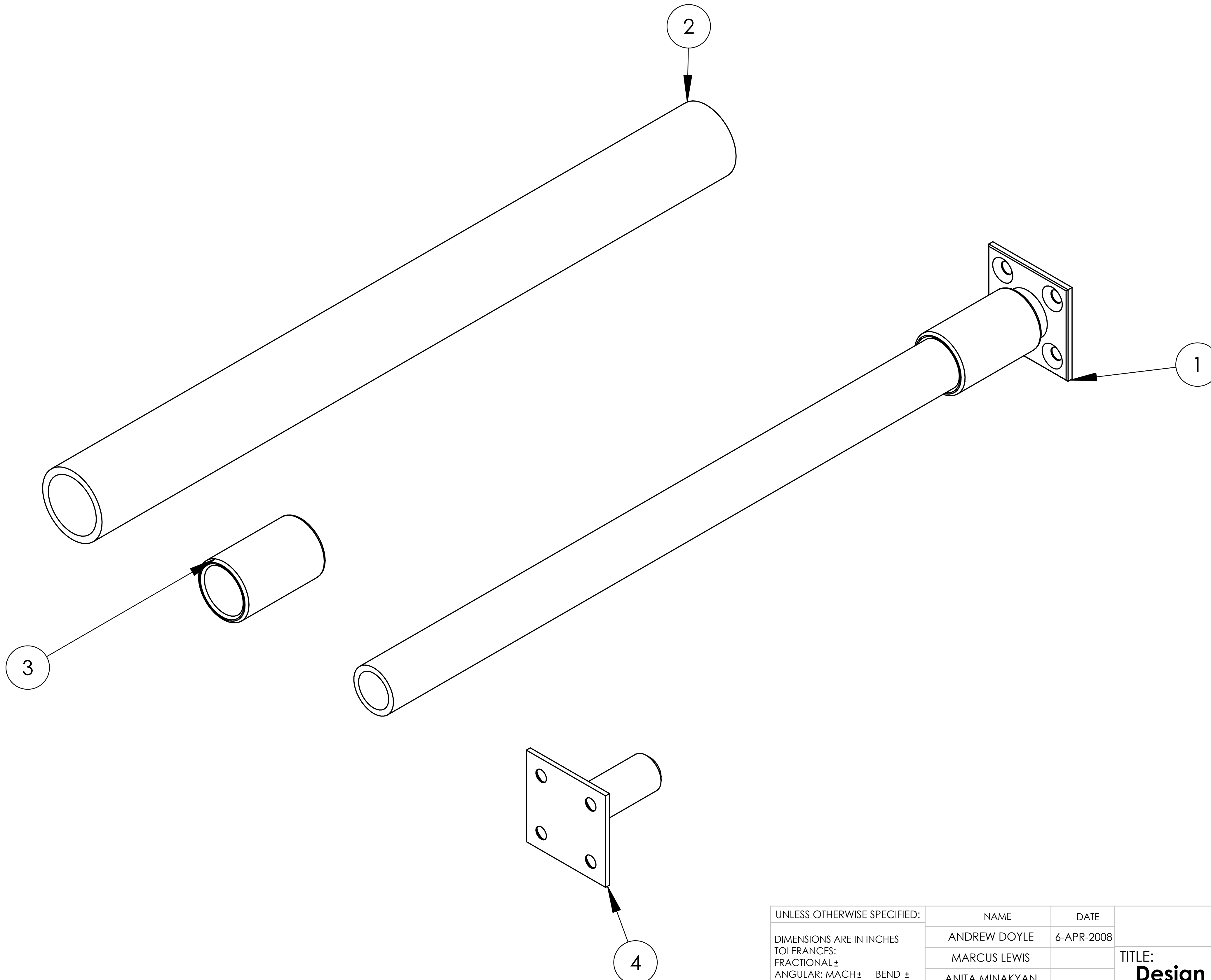
SIZE		REV
B	Shelf	A

SCALE: 1:10 WEIGHT: SHEET 5 OF 5



ITEM NO.	PAGE	PART NUMBER	DESCRIPTION	QTY.
1	2	Rollerinside		1
2	3	outsideroller		1
3	4	NylonBearing		2
4	5	EndCap		1

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TOLERANCES:
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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

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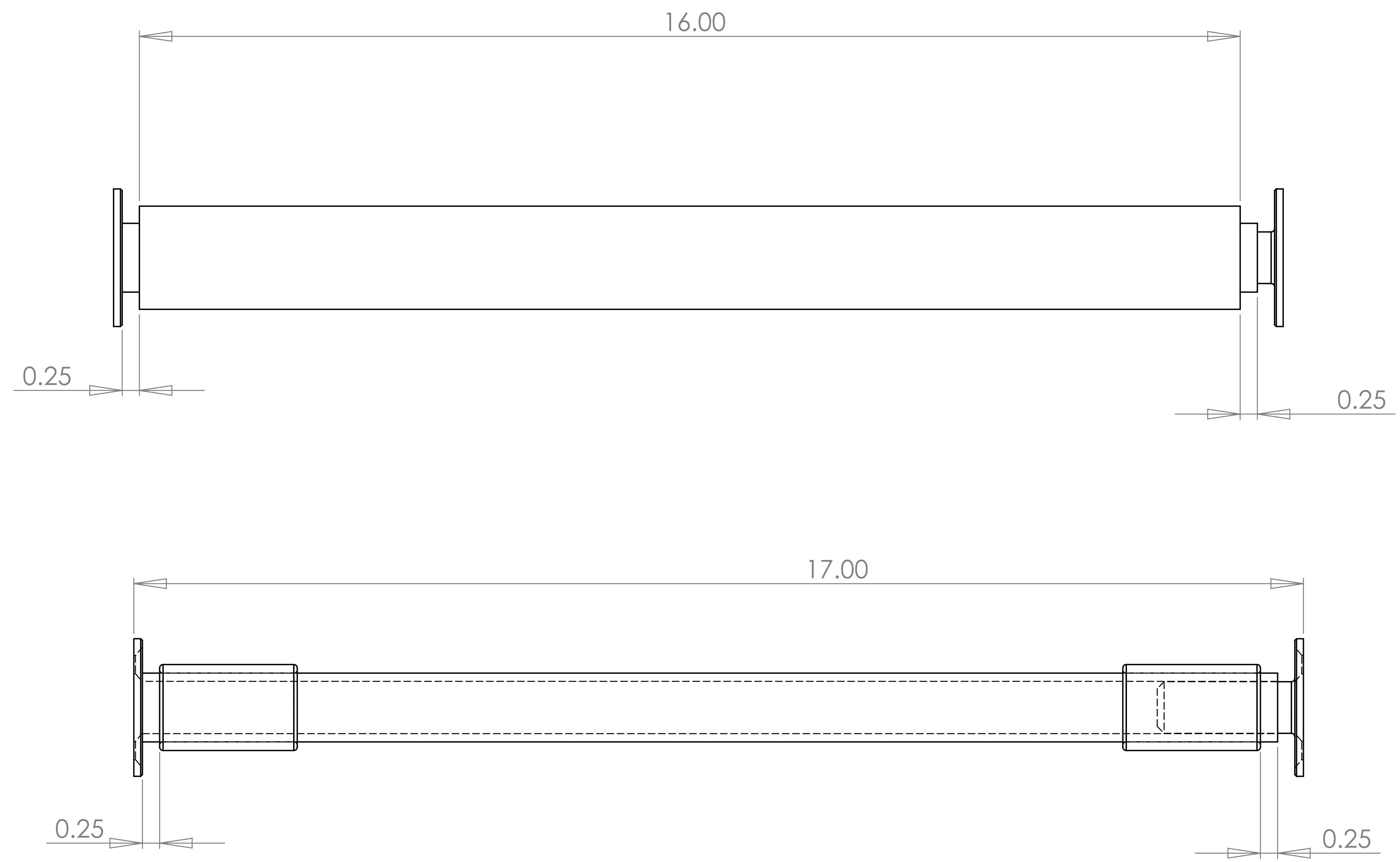
SIZE **B** RollerAssembly REV **A**

SCALE: 1:5 WEIGHT: SHEET 1 OF 6



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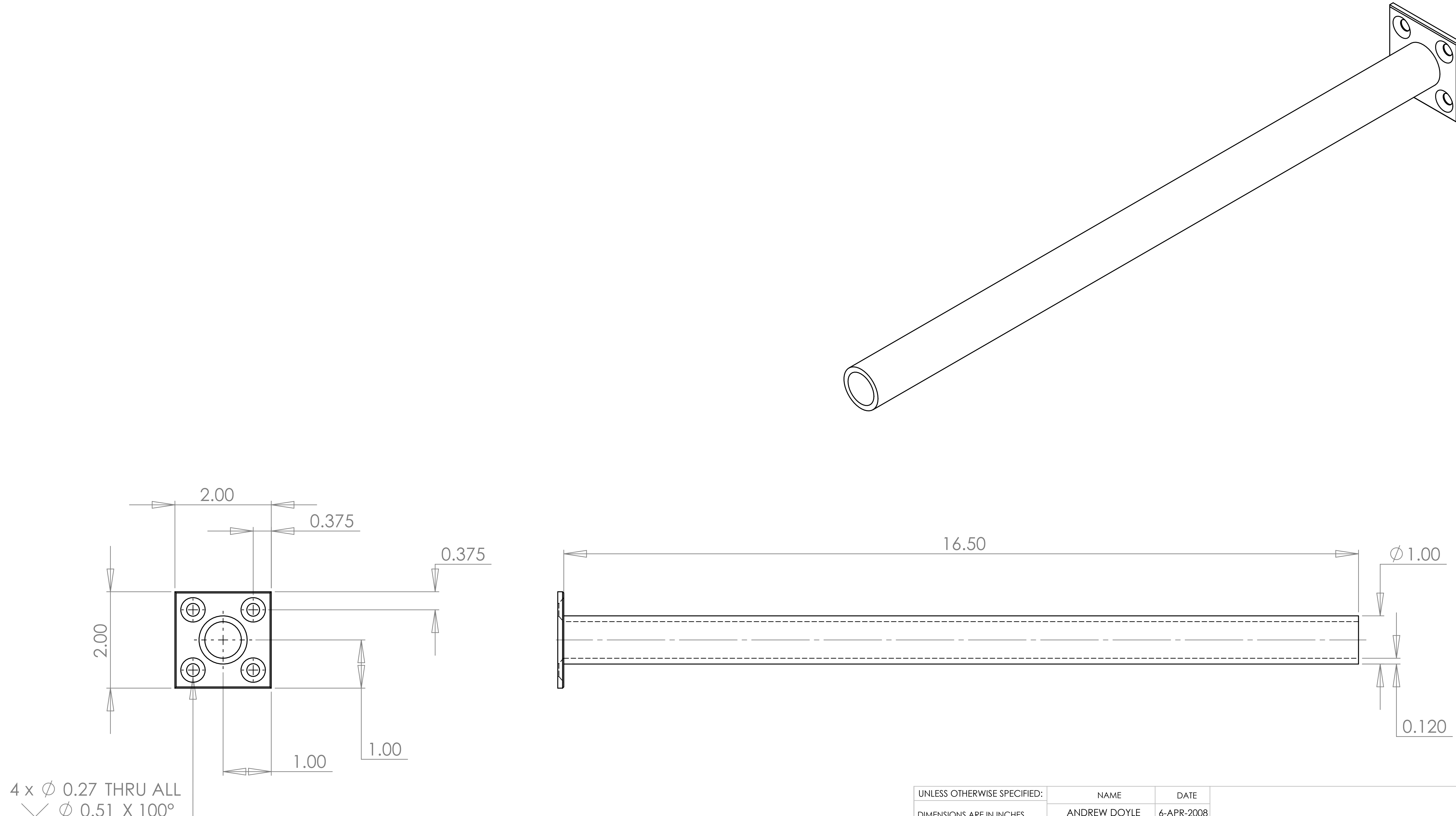
SIZE B | RollerAssembly | REV A

SCALE: 1:5 | WEIGHT: | SHEET 2 OF 6



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SIZE **B** RollerAssembly REV A

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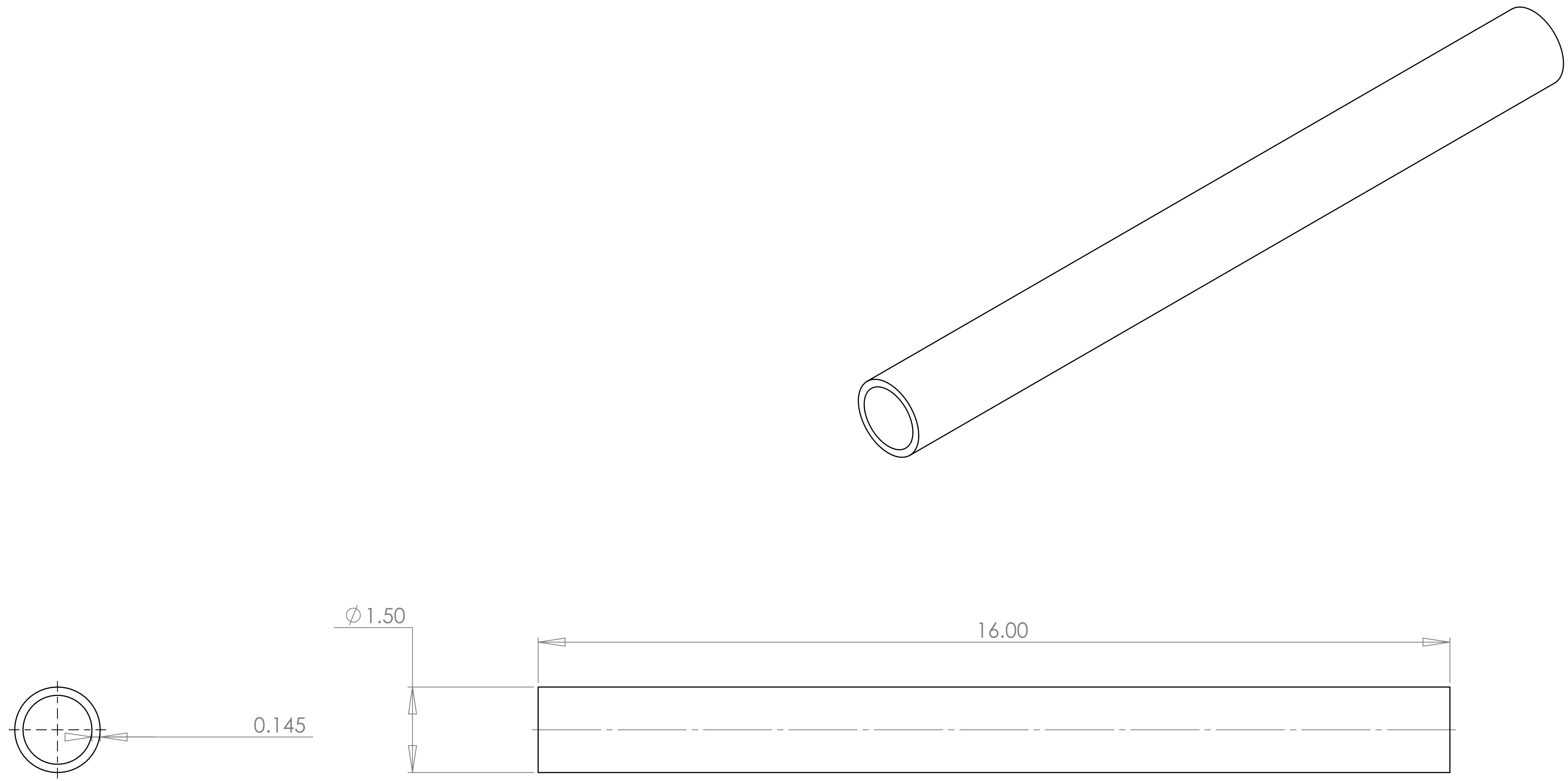

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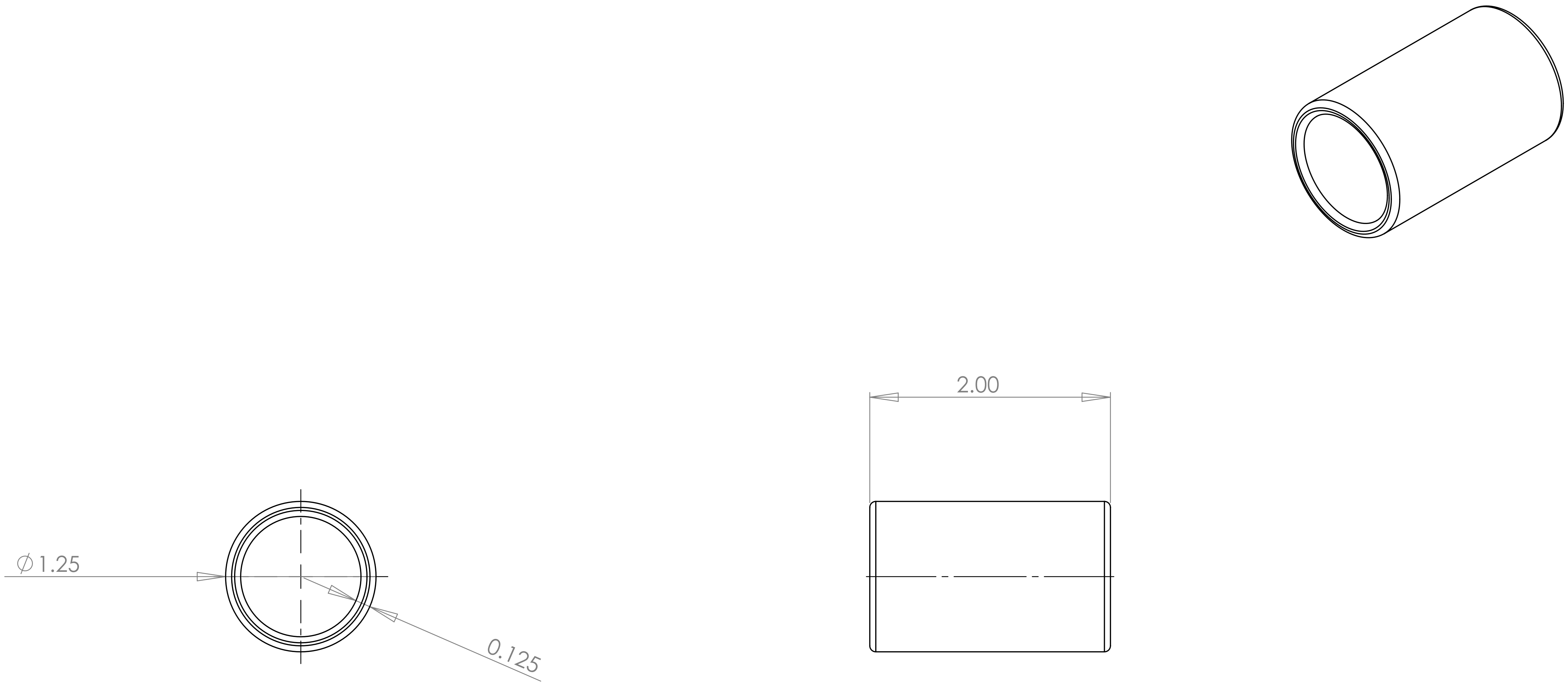
NAME	DATE
ANDREW DOYLE	6-APR-2008
MARCUS LEWIS	
ANITA MINAKYAN	
SHAUN PRICE	
DAVID WEISER	

COMMENTS:

TITLE:
Design and Prototype of a Mobile File Transport System WPI MQP

SIZE **B** RollerAssembly REV A

SCALE: 1:5 WEIGHT: SHEET 4 OF 6



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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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MARCUS LEWIS	
ANITA MINAKYAN	
SHAUN PRICE	
DAVID WEISER	

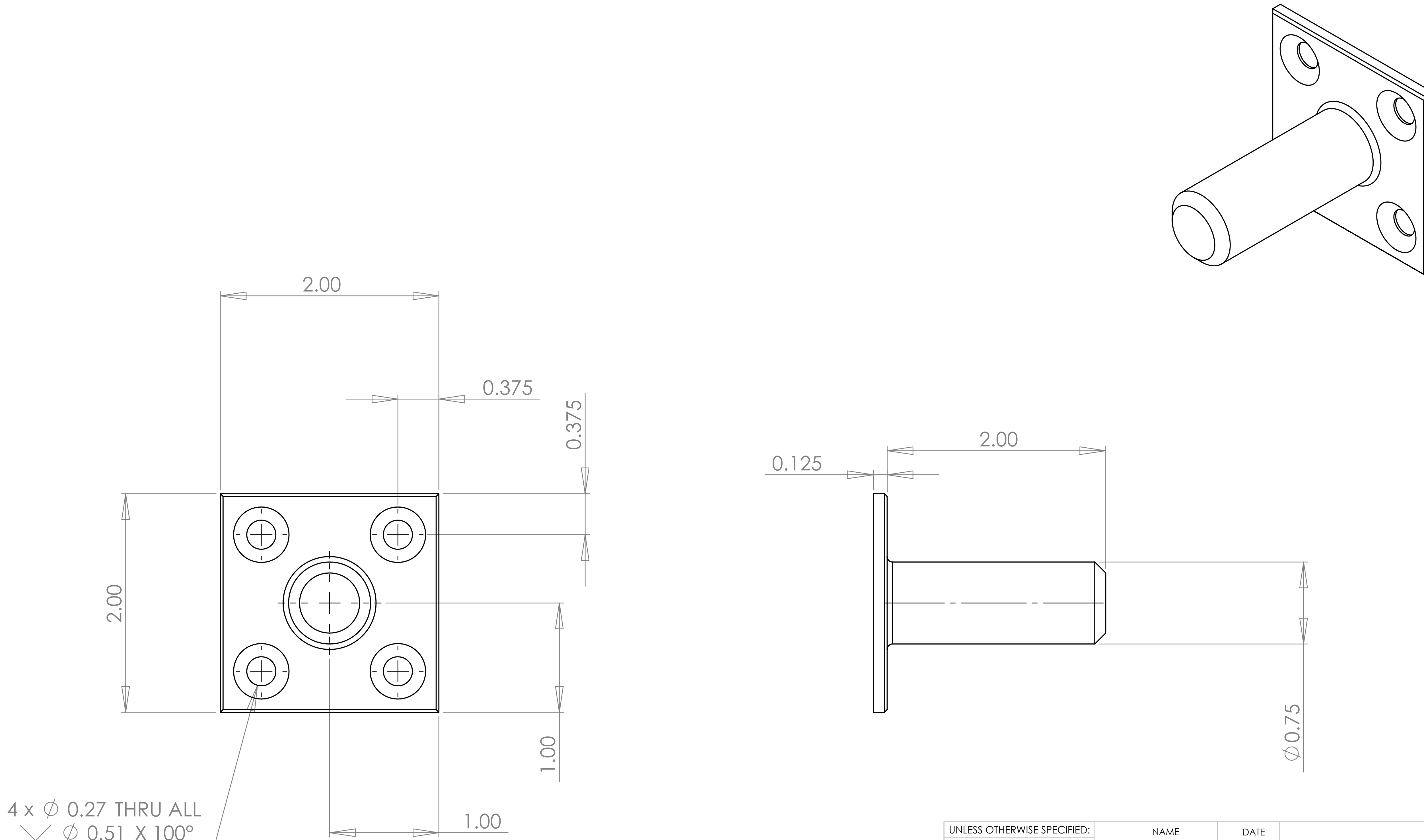
COMMENTS:

TITLE:

Design and Prototype of a Mobile File Transport System WPI MQP

SIZE **B** RollerAssembly REV A

SCALE: 1:1 WEIGHT: SHEET 5 OF 6



UNLESS OTHERWISE SPECIFIED:	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	
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TITLE:
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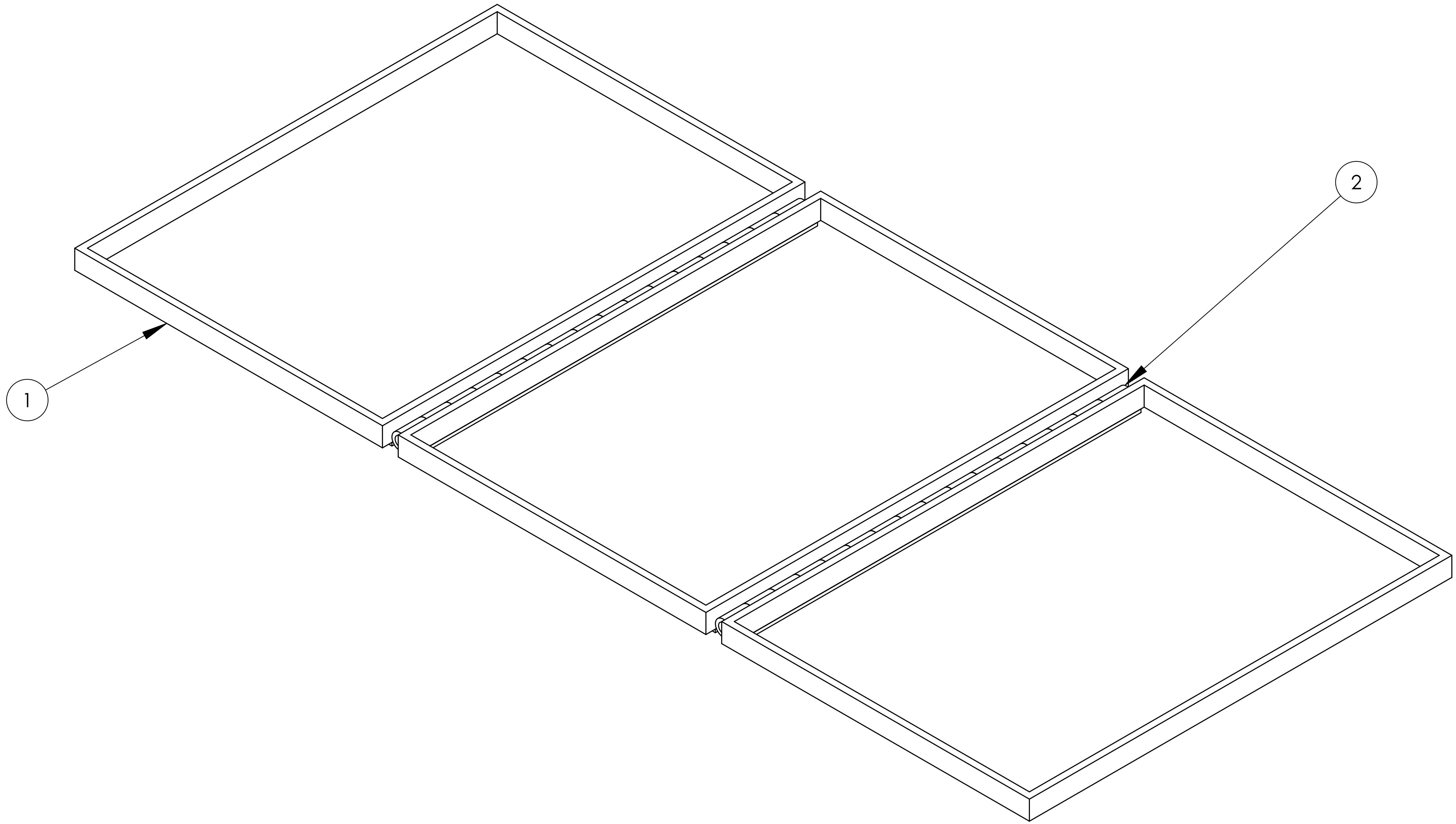
SIZE: **B** RollerAssembly REV: A

SCALE: 1:1 WEIGHT: SHEET 6 OF 6



ITEM NO.	PAGE NO.	PART NUMBER	DESCRIPTION	QTY.
1		Frame		3
2		PianoHinge		4

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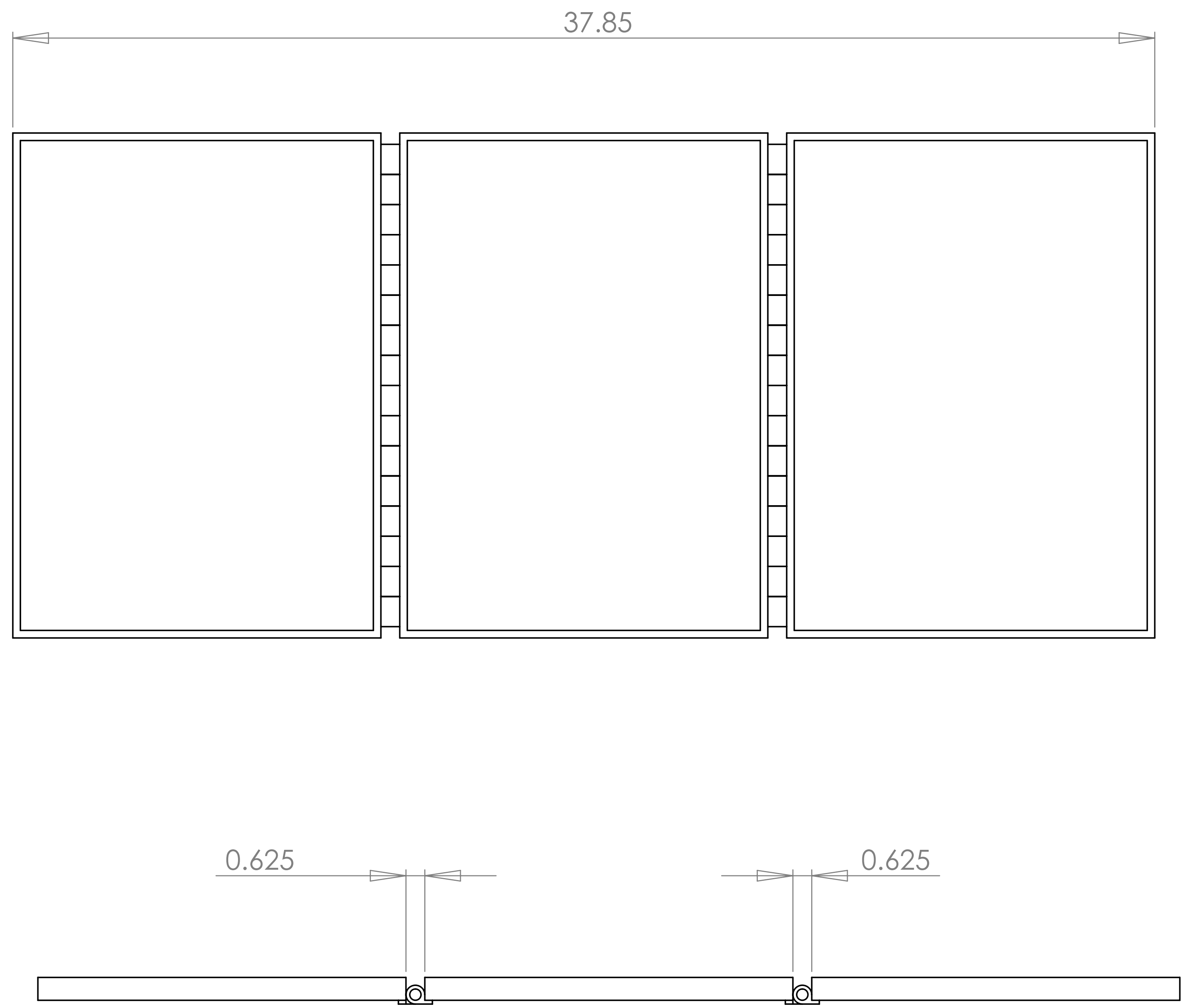
TITLE:

Design and Prototype of a Mobile File Transport System WPI MQP

SIZE **B** BoxHolder REV A

SCALE: 1:10 WEIGHT: SHEET 1 OF 4



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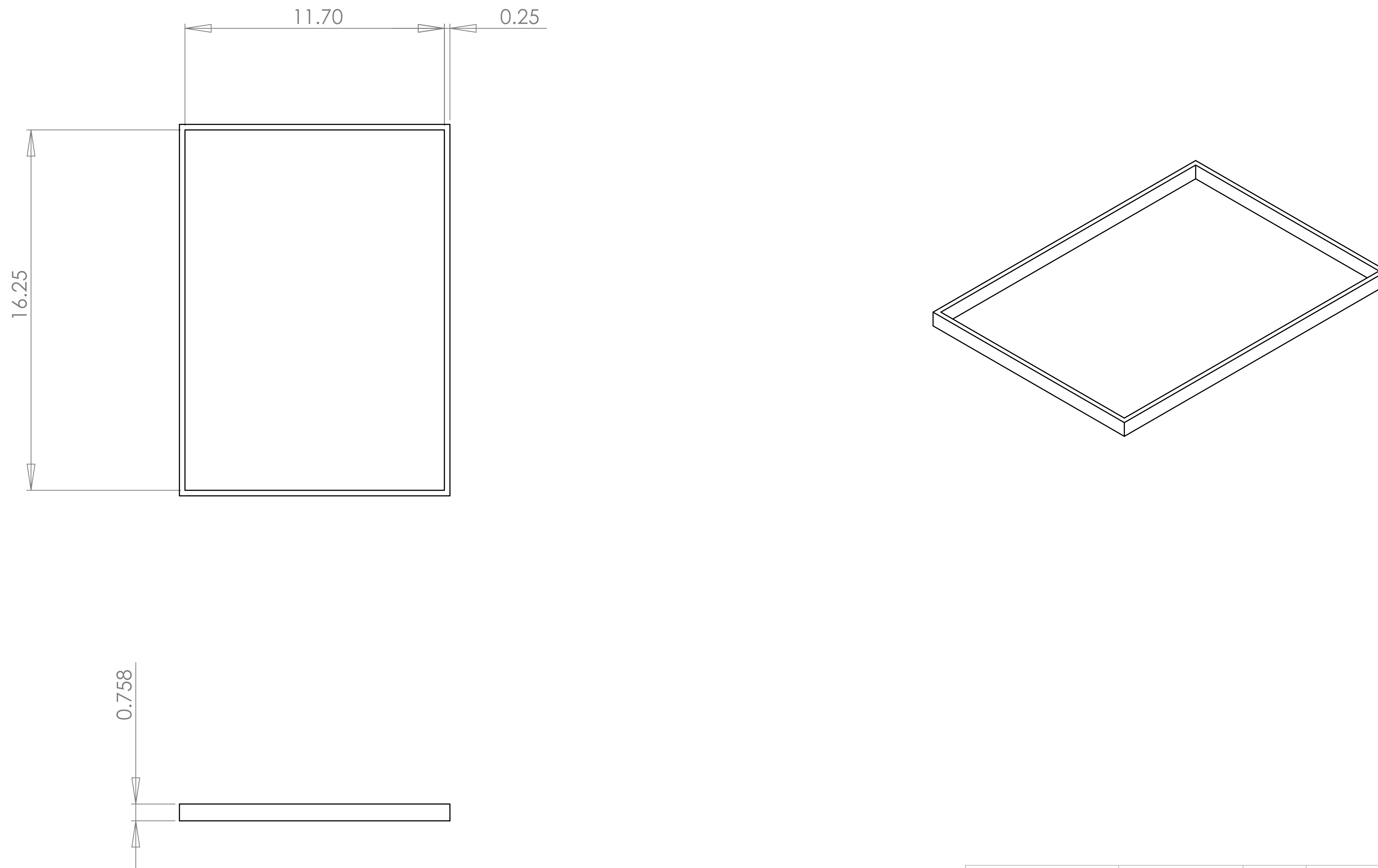
COMMENTS:

TITLE:
Design and Prototype of a Mobile File Transport System WPI MQP

SIZE		REV
B	BoxHolder	A

SCALE: 1:10 WEIGHT: SHEET 2 OF 4



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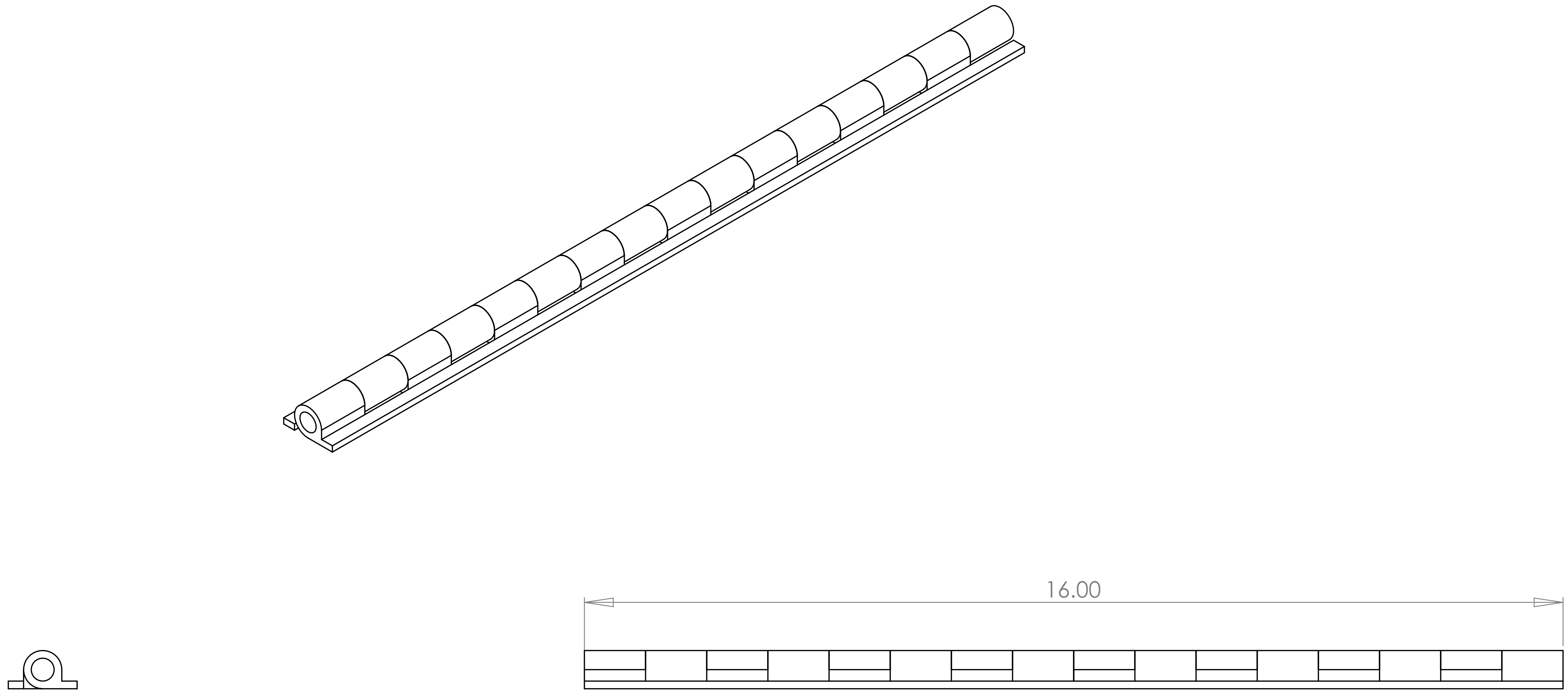
COMMENTS:

TITLE:
Design and Prototype of a Mobile File Transport System WPI MQP

SIZE **B** BoxHolder REV A

SCALE: 1:10 WEIGHT: SHEET 3 OF 4



NOTES:
1) PART IS READILY AVAILABLE FROM SUPPLIERS, PURCHASE IN 16" LENGTH

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SIZE **B** BoxHolder REV A

SCALE: 1:10 WEIGHT: