Course: ME 430 – Section 04

DESIGN OF AN AUTOMATIC WOOD TRIMMING MACHINE

A Final Design Report

Submitted to the Faculty of the

Department of Mechanical Engineering

by

Van Ho, Nicholas Maskal, and Andrew Rutland

Date: December 8, 2013

Project #31

Approved by

Advisor:

Dr. Mohammad Noori, ME

Sponsor:

Bruce Palmer, Electrical Engineer and Owner of Sunrise Arts

ABSTRACT

This final design report, prepared for Sunrise Arts by the Cal Poly design team Mahogany Automation, details the year-long process in which the team of three engineering students designed and built an automated wooden -plank edge trimming machine that incorporates anti-jamming and continuous loading features. The team has examined current woodworking machines and features available on the industrial and commercial market, and used these as guides along with device requirements set by the project sponsor, Bruce Palmer. The focus has been on designing the simplest and most cost effective device that allows operators to make production runs of wooden slats at an increased rate. The final result of this project is a functioning prototype to be used by Sunrise Arts in their production of Wind Spinners.

Contents

LIST OF TABLES AND FIGURES

1. INTRODUCTION

Sunrise Arts is a Central Coast local business owned and operated entirely by Bruce Palmer and his wife. One of their products, the Wind Spinner, is made from slats of wood cut, finished and assembled to form beautiful tapering helical shapes. Their business has recently taken an upturn and production has increased to the point where output cannot meet demand. Mahogany Automation's device allows Sunrise Arts to meet the increased demand for Wind Spinners. It allows Bruce Palmer to expand his business to the point where he can mass produce his product in quantities necessary to sell his product to retail stores. With Sunrise Arts being a relatively small business, Bruce will be the only operator of the machine. However, it has been designed in such a way that users with low woodworking skill can operate the device with minimal training. The troubleshooting guideline is included in this report, so there should be no need for him to contact the team for troubleshooting advice. The device's construction and testing is being completed by members of Mahogany Automation along with input from Bruce Palmer as needed.

Figure 1.1. Current router table setup at Sunrise Arts.

The original router table assembly used to trim wood is shown in Fig. 1.1. A plastic jug with an adapter to a vacuum hose is placed over the cutter head to suck dust away from the table. It uses a wooden, spring loaded guide system to keep the wooden slats against the fence as shown below in Fig. 1.2. There is a steel plate bolted over the cutter head to ensure no operator sets anything, including his or her hand, on the rotating bit. This can be seen in Fig. 1.3. Wooden slats are hand-fed through the router one at a time, a slow and tedious process that ultimately prevents the production rates necessary for wholesale quantities of wind spinners.

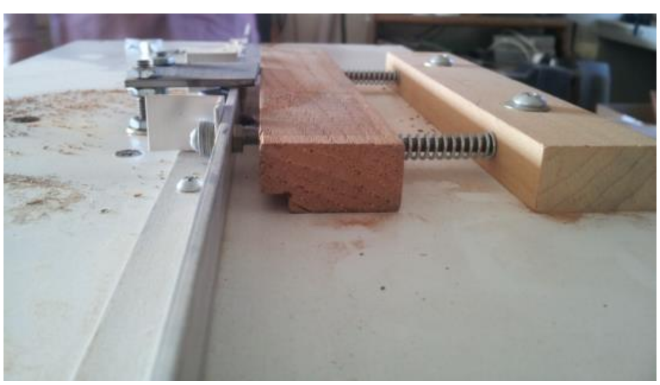


Figure 1.2. Steel plate used as current cutter head safety guard.

Mahogany Automation has designed and built an automated router table that shapes the edges of the wooden slats in large scale production batches. As stated before, Sunrise Arts is a very small business, so minimizing cost was a high priority. However, an absolute budget cap was $2000. The device incorporates an automated loading system that accepts a batch of approximately 100 unfinished slats and runs all of them through the machine at the flip of a switch. The magazine can be reloaded in less than five minutes. The automated loader has been designed to deal with the interference between the wooden slats; meaning that the loader is able to separate individual slats before they get into the cutter head no matter what their size or condition. The machine can accommodate slats up to 72 inches in length, up to ¼ inch thick, and up to .9 inch in width. The cutter head has a depth of cut adjustable from 0 to 0.1 inch and a variable cutting speed of 10,000 rpm to 25,000 rpm. The motor and driver allow adjustment of the feed rate. One of the features incorporated into the system is anti-jamming. The device is able to detect when a piece of wood has jammed either in the cutting bit, loading apparatus, or in the approach to the cutting tool. If such a jam is detected, all power will be cut to both the cutting tool and loading mechanism. The machine also incorporates an adapter that will accept a 4" vacuum hose from the customer's dust collection system. The electronic control system can detect an empty magazine and safely power down the machine. An emergency shutoff that cuts all power to the machine has been incorporated as well.

Figure 1.3. Steel plate used as current cutter head safety guard.

The design team has applied an engineering design process to solve the problem of automating a standard wood working process. Members have worked effectively as a team to completely design and prototype the wooden slat edge trimmer. In order to stay on track for completing the project, the team developed and maintained a project schedule. This has ultimately been accomplished using a Gantt chart and the appropriate software. Quality Function Deployment has been utilized to translate the customer's requirements into quantifiable engineering specifications in order to more fully define an engineering problem. This information was then used to create a more formal engineering specification document. After completely defining the capabilities and limitations of the machine, team members applied creative techniques to generate conceptual solutions to the various subsystems, such as ways to hold and feed the wooden slats.

After extensive concept generation, the design team followed structured decision schemes to select feasible solutions from these concepts. Selected concepts were then developed into systems and subsystems that meet the various constraints. Once multiple potential solutions had been designed, the team evaluated each solution through the use of engineering analysis and tools presented in Cal Poly's mechanical engineering curriculum. To achieve the highest possible level of success team members applied current industrial design practices, including Design for X and Failure Mode and Effects Analysis, throughout the engineering design process. Once the various potential solutions had been meticulously investigated and analyzed, a final design verification plan and report was developed and implemented. A prototype was built in the third and final quarter of the year-long project based on engineering specifications. Testing commenced after completion of prototype assembly. To complete the project successfully, the team considered alternative solutions, concurrent engineering design, economic factors, safety, reliability, manufacturability, maintainability, aesthetics, environmental effects, and societal impact. In addition to these criteria, engineering professionalism, engineering ethics, and product liability are very essential. This engineering project was communicated orally, graphically, and in writing in order to establish a full understanding of the project.

2. BACKGROUND

2.1 Previously Conducted Research

Power tools used in the cutting and shaping of wood have greatly increased human's ability to process timber. With the increase in power tool complexity and use, the more dangerous woodworking has become. Research has been conducted on operator injuries caused by woodworking machines. According OSHA, machines cause "57000 injuries per year" and "358 fatalities per year"[16]. The cause of these casualties is usually clothing, limbs, or loose stock getting caught in, on, or under these machines. As a result, OSHA publishes guidelines for operating woodworking machine to prevent injury. For example, when working with routers "use push sticks or push bar[s] to guide short or narrow pieces of stock through saws"[16]. This prevents workers from being directly exposed to the moving blades.

Push sticks or push bars are not the only tools that guide wood pieces through the moving parts. There are different techniques that can perform similar jobs. For example, US Patent # 2699804 describes an apparatus for guiding wood pieces through machines "wherein the apparatus has elongated support rail structure having attachment clamps for quickly and easily removing or affixing the apparatus to a wood cutting machine"[17]. The structure has vertical and lateral restraining bars with respect to a wood piece and fence to hold wood pieces in precise position and prevent them from flying away when operated.

In addition to these guarding methods, OSHA has a list of advantages and limitations for fixed, adjustable, self-adjusting, and automatic feeding guards. Automatic feeding has more advantages than other kinds of guards. Operators are not required to contact directly with machines which prevents getting caught into the moving blades.

2.2 Woodworking Machinery State of the Art

In response to the research done by OSHA, the modern woodworking industry employs extended use of automation to cut and shape wooden planks. Much of what is available to the public is on the industrial scale and is meant for large pieces of wood such as logs. The wood slat trimming machine being designed by Mahogany Automation will be a device very similar to a modern sawmill. However, all the components will be scaled down since the stock wood pieces to be worked on are only six feet by three-quarters of an inch maximum in size.

A piece of woodworking equipment is considered "state of the art" if it is automated, safe, and moves lots of material. A modern saw mill, for example, uses automated gates to allow logs to be fed into each mill process. A sled then recognizes it is carrying a log and feeds it through the saw blade. The sled makes multiple passes through the same saw, each time shaving off a plank of equal width. This whole process is under the supervision of a single human operator sitting in a raised, windowed operators nest. By working in this elevated and secure position, the operator can command the mill without ever touching the stock or being anywhere close to cutting tools. These sawmills move the wood stock in two ways: gravity or conveyor belts. Stock either rolls or slides down metal pathways to the next process. The coefficient of friction is low enough to allow bare planks of wood to slide on the polished steel. Where a drop in elevation is not feasible or the wood needs to be carried across a larger distance, sawmills use conveyor belts.

This allows for wood to be transported quickly, yet controlled. Two types of conveyor belts are used in the timber industry: 1) metal chain, and 2) rubber belt. A benefit of using metal chain conveyor belts is that the belt can be continuously moving. If a wood plank needs to be held (by a mechanical lever for example) to allow for the plank in front to finish a process, the wood can simply be held back while the belt moves beneath it. The coefficient of friction between the wood and metal belt is low enough that there is minimal resistance from the stationary wood plank.

In wood processing plants where the wood planks need to be shaped, one will find more complex machines with advanced sensors. Raimann makes a wood shaping machine that uses multiple lasers to measure the width, length, and shape of the plank so that it can make a cut that yields the biggest shaped plank possible. Other plants employ the use of motorized rollers on actuating levers to lift planks off conveyor belts and move them in another direction. Motorized rollers are common in wood processes where planks need to be precision shaped. Rollers can be self-contained pieces of equipment. These stationary units use electric motor powered rubber wheels on spring-loaded suspension to move planks of wood across a smooth surface. These rollers have enough power to push planks through a cutting tool even if there is a knot in the wood.

The pencil making industry uses a loading machine very similar in concept to load wood stock. A spring-loaded arm pulls stacks of wood planks into a loader. The loader holds one stack at a time. The stack sits on a continuously moving conveyor belt that takes one plank off the bottom of the stack at a time. It can take one plank at a time because the stack sits in a box with a slit at the bottom just tall enough for one plank at a time to be pulled out. The conveyor belt is moving fast enough to overcome any static friction between the wood slats. This type of loading mechanism is perfect for the pencil making machine since all the planks are exactly the same shape and size.

The state of the art of motion detection technology is far beyond the jamming detection needs of Mahogany Automation. Research is underway to develop a three-dimensional non-contacting angular motion sensor. This type of motion detection could track any rigid body rotation about a fixed point with an undefined axis of rotation. Also, it has been proven that rotational motion (say from a roller tracking the movement of a slat) could be measured with linear accelerometers. The state of the art of the technology Mahogany Automation would be using to create the wood trimming device can be described as too large in scale or far beyond the precision needed. The team's focus will be to take the technology proven in the field and scale it down.

2.3 Existing Solutions for Automating Woodworking Equipment

Western Pneumatics, Inc. and Corvallis Tool Company have developed systems that may be scaled to the requirements of our project. WPI makes an automated board stacker that stacks wooden slats in a catcher that keeps the stacks straight. Our machine could build on this concept by then developing a way for these stacks to be moved so the machine could effectively stack in two dimensions. The hybrid random stacker, produced by Corvallis Tool Company, stacks flat veneer sheets randomly within a confined volume. The veneer sheets are of varying widths, which could be applied to the varying lengths of the slats that we would like our edge trimmer to successfully trim and stack. Another lumber handling system, the veneer feeder, uses conveyor belts that swivel about an axis through one of the rollers. The conveyor belt swings down to make contact with a veneer sheet, which is then pulled/pushed along the manufacturing line. A movable conveyor belt could move wood slats out of a magazine or hopper to the cutter head(s), and then from the cutter head(s) to a final holder/container.

In addition to these commercial applications of lumber handling, many patents describe methods of moving wood that are directly applicable to an automated router/jointer setup. US 4330055 details a “board feeder for lumber handling systems” that loads boards one at a time from a feeder station to a delivery station. This process describes what may take place between a hopper/magazine and the cutter head(s), and between the cutter head(s) and the final position of the slat. The “wood handling machine” presented in US4324519 uses a pushing device at one side of a stack of boards or slats to push the top layer of slats across and off of the stack so as to expose the layer beneath. This method could be a starting point in the progress of the slats from some sort of holding cell or initial position to the cutter head(s). Our project will need to build on both of the systems described in these patents by successfully incorporating a mechanism to move the slats past and through the cutter head(s), as well as employing sensors to detect and possibly correct jamming.

3. DESIGN DEVELOPMENT

3.1 Definition of Tasks and Subtasks

In order to successfully complete the project from start to finish in less than 30 weeks, it is important to understand exactly how project completion will be approached. This is easily accomplished by dividing project phases into tasks and subtasks that describe the entire design process. The first and most important step in arriving at any solution is to completely define the problem to be solved. Problem definition for the wood trimming project has been accomplished through utilization of Quality Function Deployment. Since this particular system will be used by only one operator, the project's sponsor is the sole customer. The design team began developing a working relationship with the sponsor over Weeks 2 and 3 of the first quarter of the project, thus establishing open communication channels for accurate definition of the problem. Customer requirements were drafted from the original list of requirements provided by the sponsor, and also from the initial meeting between the sponsor (customer) and team members.

Interviews with the customer produced subsequent revisions of this list, clarifying requirements and differentiating between engineering specifications and actual requirements. The customer approved a finalized list of requirements, assigning each condition an importance weighting. The design team then translated this list into various engineering specifications. Investigating correlations between each customer requirement and each engineering specification allowed the team to refine the list, and ultimately resulted in further customer interviews for the last iterations of customer requirements. Once each list was finalized, target values were developed for each engineering specification, based on the customer requirements and importance weightings. By week 5, the problem definition was quantified and qualified in a House of Quality. This House of Quality chart can be found in Appendix A.

Once the team reached a better understanding of the problem and established the scope of the project, development of a solution began. The entire process was planned in advance to allow for efficient time management. The project schedule has been developed in the form of a Gantt chart using appropriate computer software. The chart will be maintained and updated as necessary so as to provide maximum transparency between the team and the project's sponsor.

With a project plan established, the team moved into the ideation phase of the design process. Brainstorming and morphological matrices have generated various concepts, which have been sorted using simple feasibility studies. Design matrices were then employed to narrow the list of feasible concepts into a single top concept. This top concept was then converted into a CAD model using SolidWorks. After this concept was approved by the sponsor, the team began to size each component to an exact dimension and assemble them together in SolidWorks. Next, the team moved on to the analysis phase of the design to investigate effects of things such as stress, fatigue, safety factor, and friction on the various subsystems and parts. The team will also perform analysis of electrical circuits in the next few days to provide information necessary for specification of any off-the-shelf items, including sensors and motors.

Once the design has been completely finalized in a solid model, the team will produce part drawings with dimensions and tolerances for every part in the system. The CAD model also included mass properties which were used to verify or iterate material selection and product cost. After the final design has been modeled and analyzed, prototype construction will follow.

The first step in prototype construction will be part acquisition and fabrication. For this process, each component necessary for construction of the individual subsystems (and eventually the complete system) must either be purchased from a current commercial manufacturer or fabricated specifically for the prototype. Once the parts have been acquired and/or fabricated, the design team will continue with careful assembly of the system. This process will include dry fitting all of the various components, initial assembly of the system, verification/measurement of clearances and interferences, replacement of parts not within specification, and final assembly. The prototype will then be tested and evaluated according to the engineering specifications, as detailed below. Once a working prototype is able to satisfy the specified requirements, the product will be presented to the project's sponsor and advisors, as well as to the general public, during the Senior Design Exposition at the end of Fall Quarter 2013.

3.2 Required Resources

Although the design team will perform the majority of the project's design and construction, the project will certainly require a variety of external resources as well. In order to ensure the design is working properly and safely before constructing the prototype, team members have carried out stress and fatigue analysis, statistical analysis, and any other engineering calculations personally, with guidance from university faculty. For the design of the circuit and electrical system, the project sponsor has offered his expertise as an electrical engineer up to and including complete design. The design team has been working closely with him to translate mechanical conditions and requirements into useful electrical designs and circuit diagrams. Appendix D is the updated circuit diagram provided by sponsor which will be constructed into the design in a few weeks. For part fabrication a variety of resources may be employed, including machining, welding, and rapid prototyping/part printing equipment, along with the corresponding qualified operators. The university provides means of performing these processes on campus, allowing team members to perform fabrication to the extents that they are capable.

3.3 Data Required Prior to Machine Design

While our project is the design of a simple woodworking device, there is much data that needs to be collected before component design can begin. First and foremost, we need to know what requirements the customer wants to include in our design as well as each requirement's relative importance to the customer. This information has already been collected using direct conversations with our sponsor, Bruce Palmer. Requirements set by Mr. Palmer as well as interview questions posed to him can be found in Appendix B and C, respectively. After compiling his requirements into an organized chart, we asked him via email to rate the importance of each requirement on a scale from 1 to 5, with 5 being most important.

With all features that are going into the device compiled and rated by importance, we sized the machine's components based on engineering specifications. For this, we collected data such as the forces required to push the wooden slats through the cutting tool at different feed rates. These forces have been determined using experimental methods including measuring the actual physical forces needed to overcome friction and measuring shear forces induced by the cutting tool on the wood. The results of which can be found in Appendix E. We have determined the correct combination of cutting tool speeds and feed rates to satisfy the requirements set by the customer. Such requirements include not having knots in the wood knocked out of the wood slats. The appropriate machine speeds can be determined by running knotted wooden slats through the machines at various speed combinations and observing which ones knock out knots and which ones do not. These results can be found in Appendix E.

Some of the more important pieces of data that needed to be collected before doing component design were the various coefficients of friction between the wood slats and whatever work surface they are sliding across. This data was collected by attaching a force gage to the slat and pulling it across a particular surface while different weights were placed on the slat. The coefficients of friction, both static and dynamic, included the following surface interactions:

- Redwood – Redwood
- Redwood – Aluminum
- Redwood – Polished Steel
- Redwood – Router Table Surface
- Redwood – Lexan Plastic

The results of the above tests can be found in Appendix E.

From a more top level perspective, we will need to collect data that ensures each feature of our device functions properly. Our system that guides the wood slats into the cutting tool needs to be set in such a way that the correct depth of cut is achieved. This data can be easily collected by running trials with different placements of the guide system and choosing the setting that results in a depth of cut desired. We will also need to know how quickly the machine can be loaded with slats. This rate can be determined by building prototypes of hoppers, magazines, or other loading mechanism and run timed trials of how long it takes one of our team members to load such mechanism. The effectiveness of our dust collection system will need to be quantified as well. We can measure the weight or mass of a slat of wood, run it through the machine, and measure the weight or mass of dust collected by the dust collection system. Any difference between the two will be quantified as a percentage of the material removed. This will determine exactly how much material our dust collection system is picking up. Data on the fatigue of the machine over the course of the duty cycle will also need to be collected. We can monitor the temperature of the cutting tool bit and router over time, measure the amount of dust that accumulates, and build prototype structures to be used to determine if the structural rigidity decreases over time. Two of the most important conditions that will need to be monitored over the course of the duty cycle will be any changes in cut depth or surface finish on the wood slats. This duty cycle data can be collect by running the machine for a set duty cycle time and measuring or monitoring the conditions described above.

3.4 Analysis Methods for Experimental Data

Our customer requirements data has already been analyzed using a QFD process. A technique known as a House of Quality was used to analyze the weighted customer requirements. The House of Quality used to analyze our requirements can be found in Appendix A. This method is used throughout the engineering industry with a most beneficial effect. Much of the data described in the paragraphs above has been tabulated for reference during design. For data such as the coefficients of friction, these values have been taken into account when sizing the motors that will drive our system. For data such as cutting depth, we will compare the results of the tests to target values and make adjustments as necessary. To analyze the duty cycle data, we will employ the use of plots, curve fitting, and statistical analysis to optimize our system. The ultimate verification for our data will be feedback from our sponsor and whether or not our customer requirements have been met. With our machine to be used by a single individual, we have the luxury of being able to tune its performance exactly how he desires.

3.5 Layout Drawings and Concept Descriptions

3.5.1. Concept A1

The "Ratcheting Shelf" concept, shown in Fig.3.1, focuses on eliminating any and all interference between slats in the holder. This concept utilizes physical separation between the slats via a shelving unit with at least fifty shelves, each one with enough room for a six-foot slat. The magazine is about six feet long, twenty inches tall, and about one inch thick. The pushing mechanism has the ability to coil up so as to not take up extra room off the end of the magazine.

To load the device, an operator must load one shelf at a time. While only one layer of slats can be placed on each shelf, multiple slats adding up to a total length of six feet can be placed on one shelf. Once the shelves are full, a clear door slides down, which keeps the slats in place on the shelves. The back end of each shelf is open so that the plunger can extract the slats. Slat

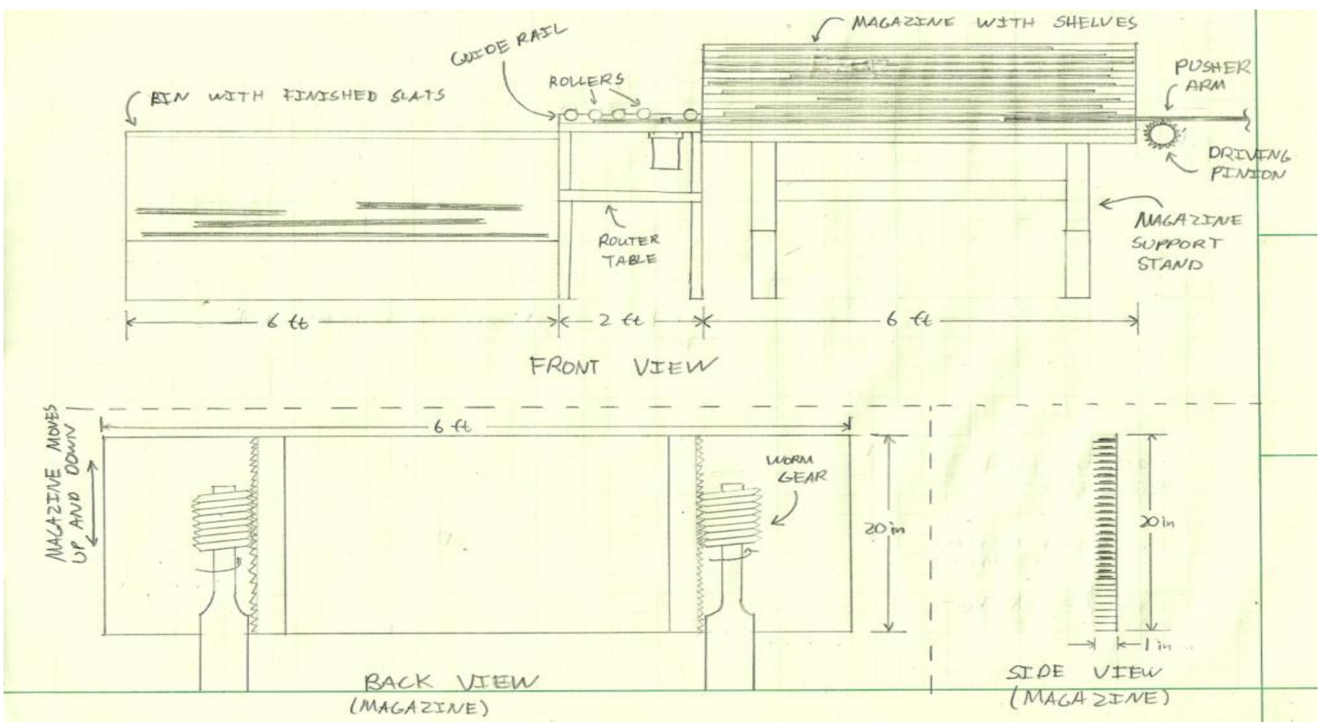


Figure 3.1. Concept sketch of design A1.

extraction occurs by worm gears lowering the shelving unit so that the lowest shelf containing a slat is level with the router table. The plunger then uses a normal force to push the slat out of the magazine and into the router bit. The plunger then retracts out of the back of the shelving unit and the worm gears slowly lower the magazine so that the next shelf lines up with the top of the router table.

While this is a fairly simple design, some drawbacks are immediately apparent. The first is that the rack and worm gears will have to be precision machined, costing a few hundred dollars. Also, each shelf would have to be welded into place, which would be an enormous manufacturing hurdle. Another issue is that the coiled plunger will have to be able to push a slat out from the bottom of a stack of 50+ slats. The high friction forces may be too much for the coil to handle. Finally, having to load each shelf one at a time is very time consuming. A better design would allow for bundles of slats to be loaded at one time.

3.5.2. Concept A2

The “L-Shape” design, shown in Fig. 3.2a and 3.2b, can be thought of as taking the magazine from the Ratcheting Shelf design and turning it on end. The L-Shape completely eliminates friction due to gravity and the weight of the stacked slats by holding all the slats on their ends. This would cause the magazine to have a length of about twenty inches, but a height of six feet. These six feet would not have to extend from the top of the top of the router table because of the pivoting lever described below. The characterizing feature of this design is the L-shaped piece of sheet metal that holds all the slats.

The slats are extracted from the magazine in the following way: a spring force, either from springs or elastic band, anchored in the lower twelve inches of the base of the L presses the stack of slats against a very wide conveyor belt. This belt is oriented in such a way that a brief rotation of the belt extracts one slat in a sideways direction. This slat is deposited in a pivoting laver arm that reorients the slat to a horizontal position. A roller then moves into position on top of the slat and feeds it into the cutter head.

This device does save much more space than the ratcheting shelf, but at the cost of adding many more parts. The springs would have to be set perfectly to provide an even normal force on the conveyor belt. Developing this device would also require much more research into how to dampen the velocity of the pivoting lever arm as it came down. The motor would have to be very large to prevent the arm from slamming down every time.

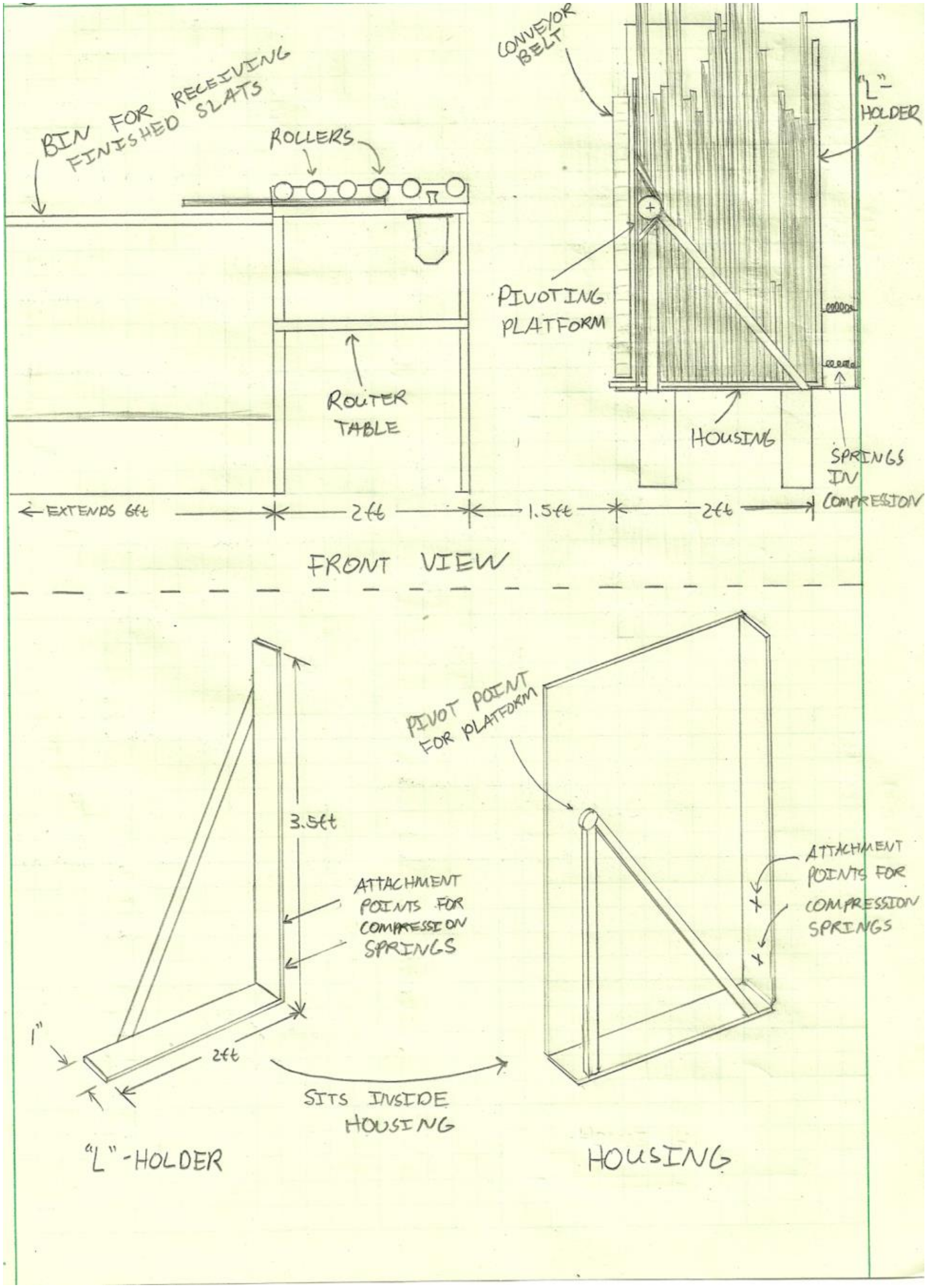


Figure 3.2. Concept sketches of whole assembly, "L"-holder, and housing components of design A2.

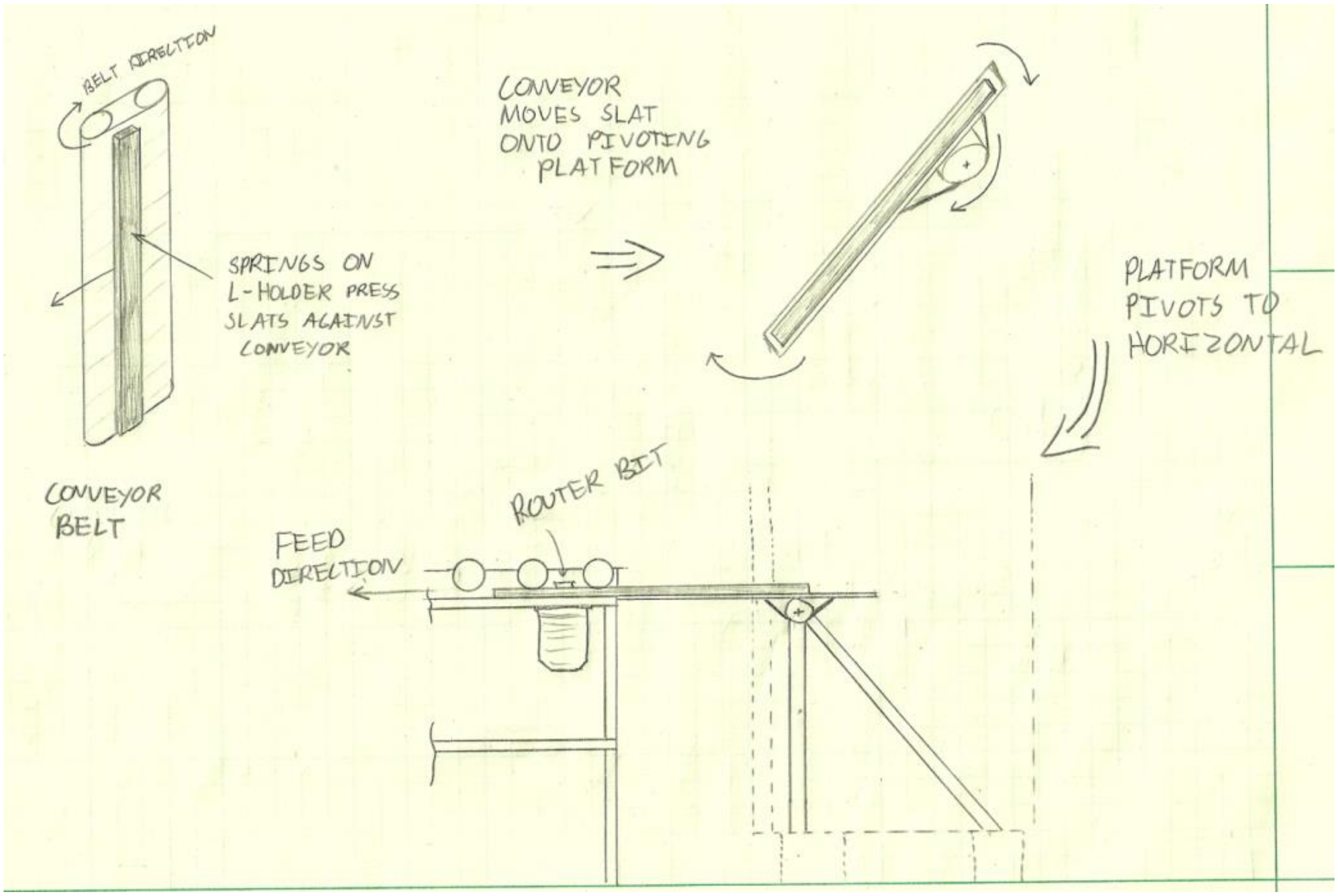


Figure 3.3. Concept sketches of how design A2 feeds the slats into the router bit.

3.5.3. Concept V1

Wood slats are stacked face to face at an angle against a magazine that is four feet above the ground. Each slat is then forced into a drum slot one at a time by a spinning brush. The drum rotates and drops each slat onto a conveyor belt moving horizontally. On this horizontal conveyor belt, slats will be oriented sideway. This mean the conveyor belts must be at least 6 foot wide to ensure that none of the slats will stick out their ends. This horizontal conveyor belt is also connected to a second conveyor belt at ninety degree angle. The purpose of this setup is to change the orientation of the slats and rotate them ninety degrees. Each slat is driven into the slot which has two fences on the side to keep a slat from flying away from the cutter. The cutter head is placed between the fences and used to cut slats when they pass through. After the slats are cut, they will be dropped into a bin that is placed next to the table. In addition, spinning bushes are installed around the cutter head to collect dust. This concept can be viewed below in Fig. 3.4.

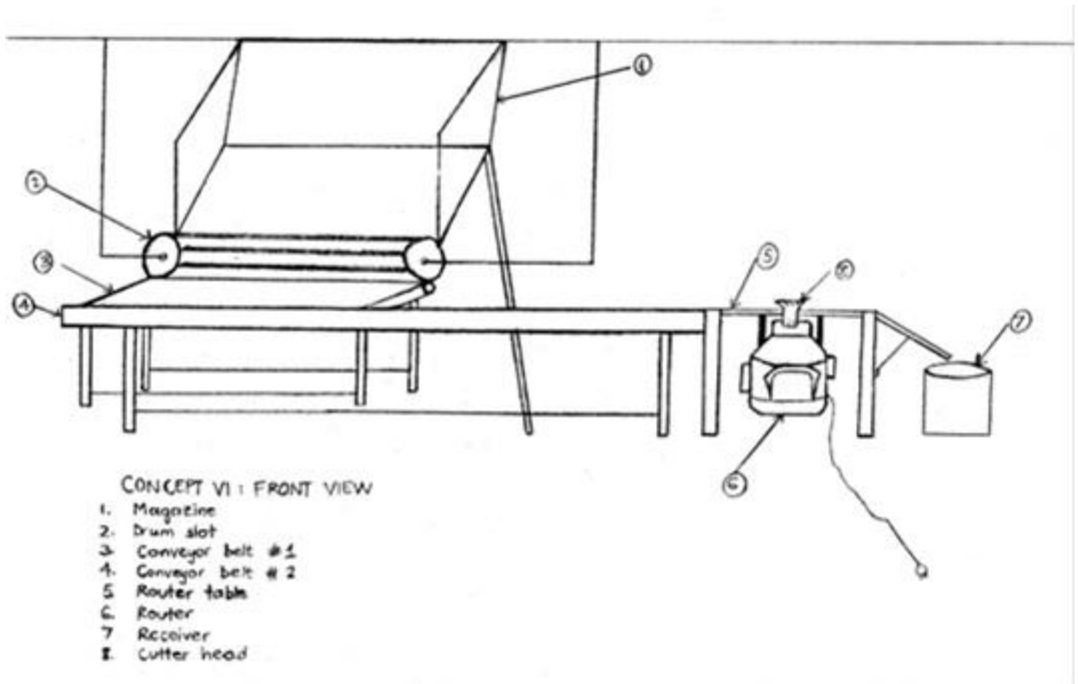


Figure 3.4. Concept sketches of whole assembly of design V1.

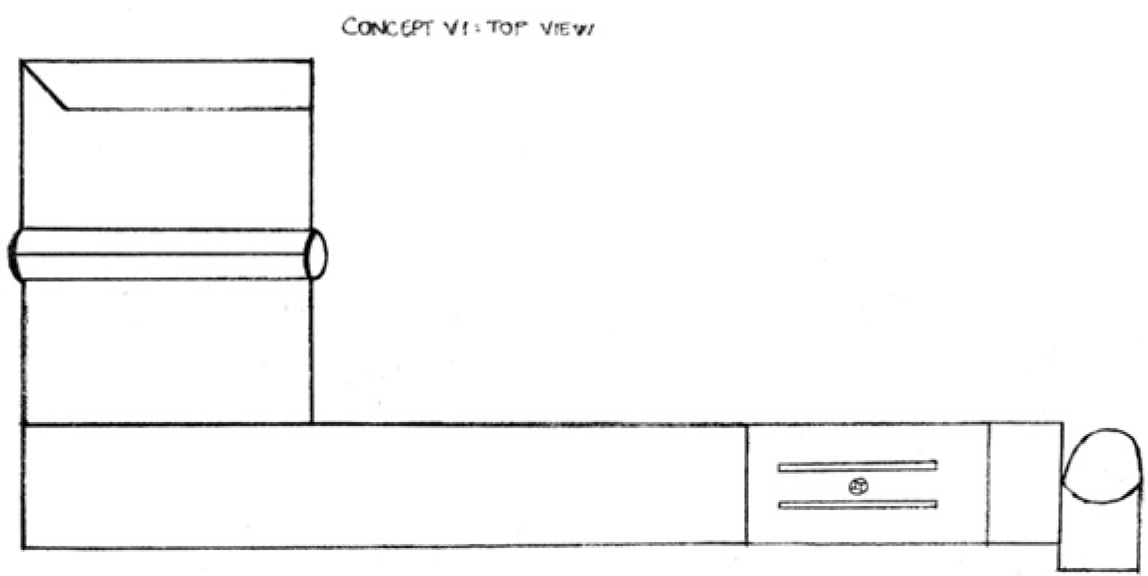


Figure 3.5. Concept sketches of top view of whole assembly of design VA11.

3.5.4. Concept V2

As shown in Fig. 3.4, slats are stacked atop one another inside a long thin magazine that is hanging above the router table. A drum slot is installed at the bottom of the magazine so when it rotates, each slat will come out at time and drop onto the table. There is a sensor connecting to drum to control when to drop a slat. A plunger is connected to piston-cylinder system that moves backs and forth on the table. When a slat is dropped onto the table, the plunger will push it through the cutter head of the router and then moves back to the original position. The next slat will be dropped onto the table, and again the plunger will push it through the cutter head of the router and then moves back to the original position. This process repeats until all the slats are cut. The cutter head is covered by transparent material to prevent slat flying out of the cutter head unexpectedly. Behind the router table there is a bin that receives finished cut slats. The router table is also connected to a vacuum chamber below the table to suck all the dust out.

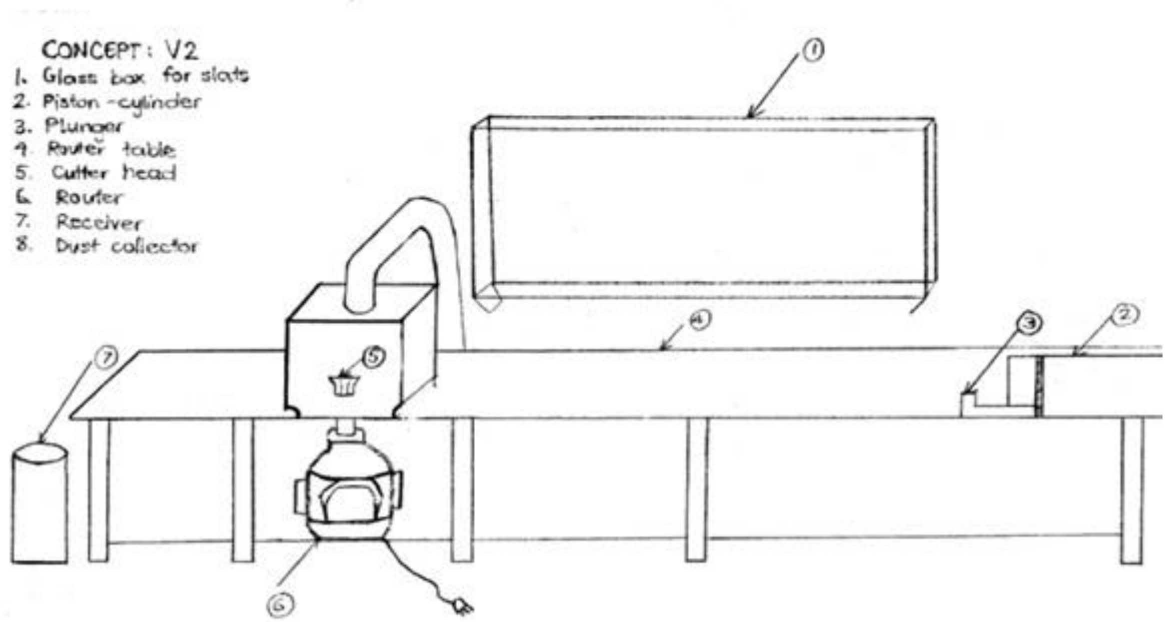


Figure 3.6. Concept sketch of whole assembly of design V2.

3.5.5. Concept N1

In this concept, shown in Fig. 3.5a and 3.5b, slats are loaded into a funnel-like hopper from the top, allowing bundles of slats to be loaded all at once. A rotating drum underneath the exit of the hopper rotates 90° to pull a slat from the hopper exit and drop it onto a ramp adjacent to the drum. The slat slides down across the ramp in order to be able to clear the edge of the hopper, where it lands on a platform 6 feet long and wide enough to catch the slat. The platform travels vertically along a track, driven by a chain, belt, or linear actuators, until the top face of the slat comes into contact with an overhead conveyor belt. The conveyor slides the slat off of the platform, onto the router table, and past the cutter head. Once the slat has passed through the cutter head, gravity drops the slat into a six foot long receiving bin, stationed at the far end of the router table.

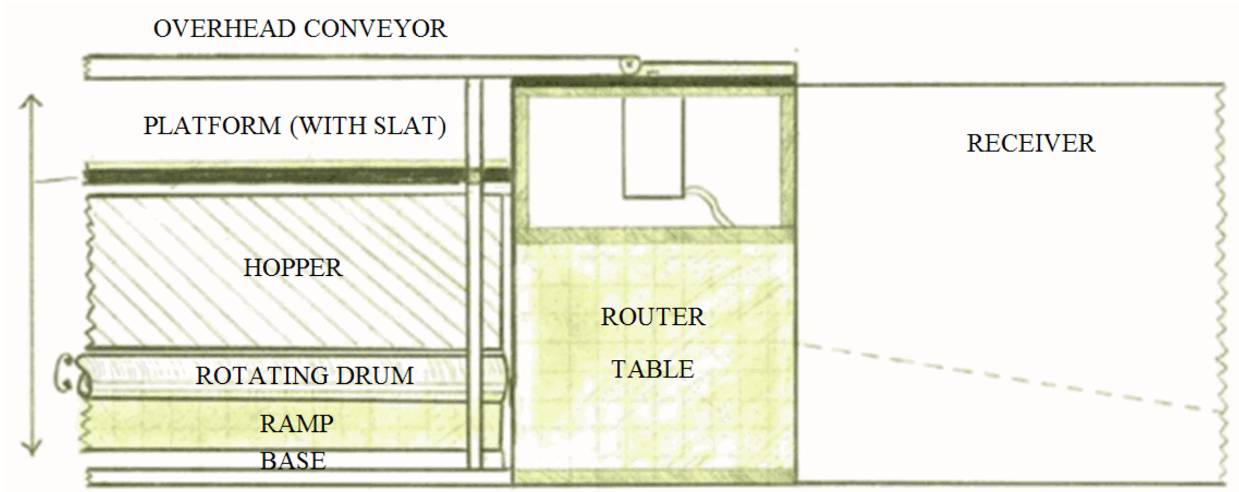


Figure 3.8. Schematic of front view of design concept N1.

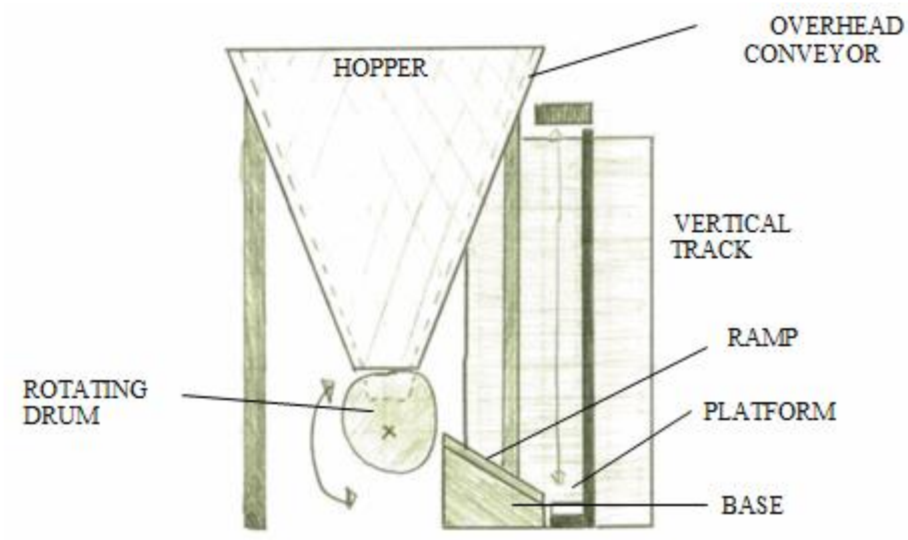


Figure 3.7. Schematic of side view of design concept N1.

3.6 Top Concept Selection

For the wood trimming project, the customer requirements developed by the design team and the project sponsor were independent enough that they could each easily be satisfied without sacrificing one requirement for another. That is to say, every concept fulfills every customer requirement, but to varying degrees of performance and reliability. To choose our top concept, it was necessary to combine the features from each concept that would satisfy the requirements better than the features of the other ideas. Due to the nature of the project, there is very little *quantitative* work capable of proving one design better than another, provided they both fulfill the requirements. Instead, the method each concept uses to fulfill the requirements was analyzed according to a set of *qualitative* standards that use logical reasoning to evaluate the design.

The first part of the wood trimming system is the material holder. To satisfy the customer requirements, this part of the system must hold slats of varying lengths, widths, and thicknesses and dispense them to the automated feeder without excessive interference between slats. One of the top concepts accomplished this using a hopper, maximizing the ease with which the holder could be loaded. Instead of stacking each individual slat into a magazine by hand, the intent was to allow the operator to release an armful of slats into the top of the hopper, and by means of a rotating drum on the hopper's underside, separate one slat from the bunch and drop it to the feeder below. Since the router only cuts one edge of the slat at a time, however, and the customer opted to keep his current router table setup, it was determined that the slats must be loaded into the holder in a fixed orientation, at least the second time through. This way, the system does not end up cutting the same edge twice if a slat ends up rotated the wrong way inside the hopper. This effectively ruled out all hopper-style holders and narrowed down the design team's choices to systems using a magazine-style holder.

Figure 3.9. Testing to determine coefficient of friction between redwood and the router table surface.

During preliminary testing, the static friction coefficient between two redwood slats was found to be approximately μ = 0.402 (see Appendix E for preliminary testing results), while the average weight density of redwood was found to be less than 0.017 lb/in^3. This means that the force required to move one slat from the bottom of a stack of 50 slats, where no separation between slats exists, is just over 5 pounds if the slat does not need to slide across the surface below it. Additionally, the maximum force required to feed a slat past the cutting head, at the standard depth of cut and the maximum feed rate, is less than 6 pounds. This means the total maximum force require to move a slat through the system, from the bottom of a group of slats stacked flat on top of one another, is approximately 11 pounds. It was also determined that for a maximum depth of cut, where the maximum amount of cutting surface is exposed on the bit, the maximum force required to push a slat through the router bit was still less than 7 pounds. So if maximum depth of cut was required, the force required to move a slat through the system, from the bottom of the stack, is only 12 pounds. This force could be reasonably provided by means of a conveyor belt, driven rollers, or a plunger mounted at the rear end of the slat to be fed. Since this force is small and easily achievable, the design team has ruled out physically separating the slats from one another within the magazine, as this method would unnecessarily complicate the design with negligible benefit. A design such as this would allow us to use smaller and less expensive motors to drive the slat through the cutter head; however, one has to take into account how to iterate through each shelf. We determined that it would take precision worm gears and/or rack and pinion setups welded to the back of the magazine. Manufacturing these precision components would most likely have to be done by an outside source, and thus very expensive. Also, manufacturing the shelves in the magazine would be a very time intensive process since each shelf would have to be welded in. The alternative design, which is used in our top concept, does not have any physical separation between the slats in the magazine. This also renders a separator at the bottom of the holder (such as a rotating drum) unnecessary, since the friction force is low enough to allow the feeder to move the slats against one another. Other design possibilities included stacking the slats vertically on end, as though a stack of slats had been rotated 90°about a horizontal axis perpendicular to the direction of feed. While this method could significantly reduce the standing footprint of the entire system, the slats would need to be rotated from a vertical to horizontal orientation to be fed through the machine, and the required working space of the system would remain essentially the same as for a flat stack. This, again, would cause unwarranted complications in the design of the system, such as a way to rotate slats of varying dimensions from vertical to horizontal one at a time.

Figure 3.10. Apparatus used to record force needed to push slats.

When choosing the driving mechanism for our top concept, we wanted a system that could transfer maximum force in the feed direction, guarantee no slippage when pushing slats through, and be as little prone to wear as possible. The three basic options for driving the slats through the cutter head are driven rollers, conveyor belts, and a plunger. The conveyor belts were one of the first systems to be ruled out because it requires a lot of room and when the slats are only .75 inches wide, the belts will just get in the way. Theses belts also have the highest potential of the three to wear out, adding to cost of operation. Another problem with conveyor belts is that they have the potential to slip since there is such a small normal force pressing on the face of the slat. Small wheels or rollers driven individually or in parallel would be a better alternative to a conveyor belt. They could be evenly placed to come into contact two at a time with even the shortest slat. These rollers would be loaded in the normal direction using either springs or weights so that there is a load keeping the slats on the table. Also, with the rollers there is no thick belt getting in the way of guides or dust control hoods. The only drawback to rollers is that they do have a potential to slip if the slat has a very hard area or knot. The normal force applied by the rollers can only be increased so far before the wood surface begins to deform, so it would be impossible to achieve complete confidence against slipping, especially if the cutter head kicks the slat back against the feed direction. A pusher or plunger mounted behind the slat is the best system for driving slats through a cutter head because it exerts a force entirely in the direction of feed. It is a near guarantee that there will be no slip when pushing a slat through. If the motor is powerful enough, the plunger can push a piece of wood through no matter what the condition of the slat or the condition of the sliding surface. However, with a pure plunger system, there is nothing keeping the slat from buckling. In our preliminary tests, it was determined that a 2.1 pound force normal to the end of a redwood slat will cause at least 6 inches of buckling deflection. Therefore, the best system employs the use of rollers and a plunger. Our top concept uses a plunger as the main driving mechanism, while rollers guide the slats straight through the cutter head and prevent deflection perpendicular to the feed direction.

The final component of the automated feeding system is the receiver past the cutter head, which accepts trimmed slats for temporary storage. Since this part of the system is so simple, relatively few different concepts were considered. The simplest of these, a box or bin at the end of the router table, would allow the slats to just fall in as they are pushed past the last set of guides on the router table. Since the slats are as small as 6’ long, however, slats falling into the bin could end up standing on end, interfering with the successive slats fed past the cutter head. In order to prevent this issue, and to keep the slats lined up with the most recently trimmed edge to the same side, a receiver was chosen that will support the slats until they leave the edge of the router table completely, sliding them down a ramp to prevent rotation.

3.7 Specification Satisfaction

Based on the morphological list, each team member came up with different ideas and concepts for the design of this project. All of the concepts were evaluated based on the house of quality. According to the customer requirements, each design has to meet four main categories which include holder, cutter head, electronics, and usability. Each main category was then broken down into many subsections with different target values and weighed from 1 to 5 (1 is the least important, and 5 is the most important).

In the holder category, it requires a holder to be capable of continuous loading and hold at least fifty slats which are pre-cut to approximate 0.22 - 0.24 inch high, 6 -72 inches long, and 0.6 - 0.8 inch wide. Since wood slats come in different sizes, the design must be able to deal with interference between slats and between slats and other materials while the system is running. The holder must be capable of separating each slat before it comes to the cutter head to prevent interference. The holder should be easily removed from cutting portion, and the loading time should take less than five minutes. The system feeds slats through the cutter head autonomously, and cuts one edge at a time. Slats should be able to move past the cutter head with a speed of at least 2 - 4 inches per second, and the cut depth needs to be adjustable from 0.0 inch to 0.1 inch. More importantly, the machine must detect jams and automatically shut off. There will be multiple switches displayed on the table to shut off the machine such as an emergency power cut-off switch, cutter head power switch, and a power switch for the other machine electronics. In addition, the design needs to connect to a 4 inch diameter vacuum hose to collect dust because trimming wood pieces generates a significant amount of waste. The machine will be run approximately one hour per day.

The concepts that team members came up with satisfied most of the customer requirements. The electronics portion of the machine was not considered in depth since this area will be addressed in detail by the project sponsor. The main focus was on loading slats into the holder, automatically transferring slats to the cutting head at a constant feed rate, detecting jams, and collecting dust. After discussing the concepts one by one, the strengths and weaknesses of each concept became clear. As a result, it was decided to take the best components of each idea and put them into one final design concept.

3.8 Top Concept Description

The top concept chosen by Mahogany Automation includes bits and pieces from all concepts developed by the team and is designated Concept T1. A SolidWorks CAD model of this concept was created and images of the model can be found in Appendices F-I. It employs the non-slip guarantee of a pusher, but uses a roller chain with clips to minimize the device's footprint. The magazine can be bulk loaded and holds approximately 100 slats up to six feet in length. A door swings down for magazine loading, but is transparent to allow for viewing of magazine fill level. A metal bar extends the length of the magazine and presses down on the slats to prevent internal buckling. This bar will slide down as the number of slats decreases and stop when the magazine is completely empty. An electric motor is required to drive one of the sprockets. On top of the chain, there are plastic attachments which are used to provide a smooth surface to prevent the slats from getting caught in the chain. A spring-loaded guide keeps the slat against the guide rail and rollers keep the slat flat on the table as the slat is fed through the cutter.

Our top concept rises about five feet from the ground at the magazine. The magazine is about six and a half feet long with a width of less than an inch and an internal height of about two feet. The magazine is mounted to three aluminum tube A-frame style legs. The router table top is three feet off the ground and has a one square-foot surface. The top surface of the chain has the same height with the router table so the slats can be transferred smoothly.

The following is one cycle of the machine needed to cut one slat and prepare for the next. It is assumed that the slats have already been loaded in the magazine and doors locked:

1. Pusher moves forward in a track below the magazine and comes into contact with the lowest slat in the magazine.
2. The pusher is just thick enough to contact only one slat, so it pushes just the lowest slat through an opening in the magazine exit just big enough for one slat.
3. The pusher continues to move forward until the slat is fed completely through the cutter head.
4. The set of rollers on the sides of the cutter head are used to keep the slats from buckling.
5. After the slat has been fed through, the pusher retracts slowly until the front face reaches the inside rear edge of the magazine.
6. The pusher stops moving backwards and the cycle repeats until the magazine is empty.

3.9 Top Concept Analysis and Material Selection

The power needed to drive the slats through the cutter head was calculated based on the maximum force and the maximum feed rate from the experimental data. The maximum power required for the driving mechanism was about 1/10 hp. The calculation is shown in Appendix H. With this basic requirement, team members and sponsor were looking to different DC motors and finally, the team decided to choose the Bison DC gear motor for several reasons. First, this motor is a 1/10 HP motor which exceeds the requirement and the price is reasonably cheap comparing to other DC motors. The rotational speed of the motor is about 152 RPM which is perfect for the chain. If the motor drives at a very high speed we would need to add more gears and shafts to reduce the chain speed. Since this motor shaft is attached directly to one of the sprockets, the speed of the chain was calculated to be about 21.1 in/s. Another advantage of selecting this motor is that the motor can generate up to 42 in-lb_f torque and the maximum torque needed to drive the chain is 34 in-lb_f.

A roller chain ANSI # 40 is used in this design because it is a standard size chain which makes it easier to find standard size sprockets and attachments that can fit the chain. In addition, this chain is inexpensive but its performance is excellent. The factor of safety was calculated in Appendix H in order to ensure that the chain will not fail due to stress or fatigue and the result came out to be greater than 7. This safety factor shows that the chain is not likely to fail if operate under normal conditions for 15000 hours. The sprocket was selected based on the Bruce's requirement and the shaft diameter of the motor. The outer diameter of the sprocket is approximately 3 inches and the bore diameter must be equal to the shaft diameter which is 0.5 inch. Based on these two parameters, a Steel Finished-Bore Roller Chain Sprocket for #40 Chain, 1/2" Pitch, 15 Teeth, 1/2" Bore was chosen for this design. The second sprocket is the roller chain idler sprocket steel with ball bearing, for #40 Chain, 18 Teeth, 1/2" Bore. This sprocket was selected because it has ball bearings and easy to mount to the aluminum plate.

In the selection of fasteners for the system, it is typically most convenient to use the smallest possible bolt for most of the fasteners. Calculations were performed to determine if this size bolt would be strong enough to support the loads exerted by the magazine and driving assembly while the bolt is under tension. The stress in the bold was found to be 170 psi which is higher than maximum stress required; therefore the bolt is safe to operate.

3.10 Current Design

The current design is a more detailed revision of the previous top concept. Rollers behind the plunger have been simplified to low-friction plastic clips that will attach to the roller chain without interference with the sprocket, while preventing the loaded slats from falling into the track behind the plunger. The frame supporting the magazine and driving mechanism will be a series of A-style braces that are rigidly attached to one another using a long aluminum plate. The motor is mounted to the back of this plate, while the sprockets, chain, and multiple spacers are mounted to the front side. A second aluminum plate is bolted on over the first plate and its attached hardware. With a sturdy frame and base assembled, the magazine is mounted to the first plate from the back. The magazine features a weighted aluminum bar running the length of the inside, guided by rods that fasten to the top of the bar and slide through bushings in the roof of the magazine. This bar serves to resist buckling inside the magazine from the last few slats as the system feeds them through. Mechanical limit switches at the tops of the guide rods alert the system to an empty magazine. An aluminum-framed clear plastic door is hinged to the front of the second aluminum plate, securing the slats during operation while allowing the operation of the machine to be observed externally. This door swings out and down away from the magazine for expedient loading.

Fixed below the magazine, the chain assembly is driven by a 24V DC motor of variable speed at the front. The rear of the chain is positioned using an idler sprocket with ball bearings which rotates around a pinned shaft between the two aluminum plates. The plunger is fastened to the roller chain using pressed pins, and features a mechanical limit switch in front of the pushing face. The plunger will stop its retreat and begin feeding once a slat drops into the feed plane and depresses this limit switch in front of the plunger. A rotary encoder mounted next to the motor is spun by a sprocket riding the chain. This encoder delivers position and velocity information to the control board, allowing the system to smoothly control the advancement of the plunger and aid in jam detection.

As the front edge of the slat is pushed out of the magazine assembly, it is received by the router table and guide assembly. This system features a curved chain guard at the leading edge of the table to prevent the slat from catching on the front lip of the table as it is fed. An adjustable fence determines the depth of cut, and remains stationary while the machine is running. Meanwhile, a live guide on the opposite side of the slat is spring loaded to keep slats of varying thicknesses pressed up against the fence as they are fed past the cutter head. A pair of rollers and torsion springs mounted to the depth fence apply a downward force to the slats, preventing lifting and vibration during the cut. The entire router table is clamped to the front of the magazine and driving mechanism frame with bolts, preventing the two from separating along the feed axis during operation. Once the slat is fed through the cutter head, the rotary encoder monitoring chain position alerts the control module to retract the plunger for the next slat. A second rotary encoder and an infrared optical sensor work together at the cutter head and in conjunction with the chain encoder to detect multiple jam scenarios. These sensors, as well as those on the magazine and driving mechanism, provide feedback to a control module housed in a panel on the front edge of the router table. As the system operates, each slat is pushed into a receiving box on the end of the router table by the slat being fed after it.

4. MANAGEMENT PLAN

4.1 Team Member Responsibilities

In order to accomplish this project, each team member was assigned specific roles which he/she will lead and guide the team through the process. Andrew will lead modeling and manufacturing process. He will be managing various tasks in these processes. Van is assigned to be a leader in engineering analysis. She will be responsible for all the calculations and make sure they are correct. Last but not least, Nick will be a testing leader who will handle all the testing including component tests and system test. Three team members will work through all tasks and subtasks together, but at each state of the process a different team member will be heavily responsible for his/her role.

4.2 Budget Analysis

Initial discussion of the budget with the sponsor has resulted in an absolute cap at $3000, with cost reduction being an important motivation in the design process. The costs of items such as the motor and control board are to be included in this overall budget. Items to be purchased will include raw material such as aluminum, steel, wood and plastic sheet, bar, plate and tubing, Commercials / Off The Shelf (COTS) components such as the roller chain, motor, and all sensors, and all associated hardware and fasteners. Upon initial review, the team decided upon a target cost of less than $2000 for all materials and associated paid fabrication. After detailed design of the system and a rough cost estimate of all the currently anticipated raw material and hardware, the cost of the system is estimated at $750. This ballpark estimate does not include tax, shipping or handling for all of the anticipated materials.

4.3 Gantt Chart

The Gantt chart for this project specifies completion dates all the way from the start date to the completion date of the project. This Gantt chart can be found in Appendix J. The first quarter of the project was dedicated to problem definition and concept generation and selection. After the team selected and presented a top concept to the sponsor, detailed design of the top system ensured. Over the second quarter, the various subsystems of the machine were designed and specified by all three team members, resulting in an accurately sized solid model using CAD from which to create individual part layout drawings. The third quarter was dedicated to fabrication, assembly of the system, testing, troubleshooting, and calibration.

4.4 Preliminary Construction and Testing Plans

With the automated edge trimming system fully designed and analyzed, construction of the prototype will follow. Due to the nature of the project, the prototype must become a working system that the customer will use and maintain either for the life of the prototype, or until his business expands to require higher capacity equipment. This means the construction and testing of the prototype is at least as important as the design of the system itself, and these steps will require extensive planning to produce a successful and reliable machine.

Construction of the prototype requires three major steps: acquisition of all COTS parts, fabrication of remaining custom parts, and assembly of the system. Each of these steps will be performed separately for each subsystem of the machine: the magazine, the slat feeder, and the receiver. The order in which each subsystem is assembled will be determined once the complexity of the entire machine is fully determined. However, it is certain that the construction of each subsystem will progress according to the following procedure. First, all COTS components will be purchased and obtained. To minimize complications due to unforeseen circumstances beyond the control of the design team, the COTS components will be acquired and tested for functionality before the fabrication of any custom components. This will allow the team to account for any unexpected dimensions or features of the components that may require alteration of other dependent parts. Testing each COTS for functionality before implementation in the system will reduce the amount of troubleshooting and calibration necessary to get the system functioning correctly and consistently.

Once all COTS components for a particular subsystem have been acquired and their functionality has been ascertained, the team will fabricate the custom components. This process will begin with parts that are the least dependent on the dimensions of other components for the same reasons as acquiring COTS parts first: to reduce unexpected complications that may affect other components. As parts are fabricated they will be dry-fit with all corresponding elements to ensure they have been designed and produced correctly. In this way the team will work through the parts with the fewest dependencies up to the components that are directly sized according to more functional parts. Weights and dimensions will be double checked as the process continues to make sure all stresses and system effects have been accurately accounted for.

With all COTS and custom components collected and constructed, assembly of the subsystem begins. All components must be dry fit and attached non-permanently at first, if possible, to check clearances, interferences and fits. Parts will be permanently attached only insofar as is necessary to test the system, allowing for part removal, replacement, or reworking. Once all subsystems have been assembled and checked for functionality, all remaining permanent mates/attachment processes will be performed to arrive at the first fully-assembled working prototype.

In order to ensure proper device operation, the design team will need to perform extensive testing on the system once it is completely assembled. This will include observation of any current or imminent weaknesses and failures, determination of all necessary maintenance and repair procedures, and investigation of all potential failure modes. The device will be run at every possible combination of operating speeds and conditions to confirm complete and proper functionality. After testing the system extensively, all joints, fasteners, and parts will be double checked for status and stability.

5. FINAL DESIGN AND PROTOTYPE

5.1 Cost Breakdown

The total cost for the project came in significantly under budget at $1265.00. Raw materials such as metals and plastics account for approximately half of the project costs. Commercial, Off-The-Shelf components account for another quarter, and the remaining costs are split between fasteners, tax and shipping. A detailed breakdown of the project cost can be found in Appendix L.

5.2 Material, Geometry and Component Selection

The team selected material, geometry, and components based on the house of quality and customer requirements. The router table and magazine were mostly made out of custom components because most of the components that go onto the magazine and router table were not available off the shelf and raw materials were not too expensive to purchase. In addition, aluminum is lightweight and portable which allows the user to carry the machine to different locations easily. With these concerns, the team purchased and machined standard sizes of aluminum bars, tubes, plates to correct dimensions to create a support structure for the magazine and router table. Aluminum sheet metal was welded together to create a back wall for the magazine where slats will be resting against.

Along with aluminum raw materials, the team also purchased standard size Delrin bars and rods to make spacers, the chain pusher, and guiderail. Delrin spacers separate aluminum plates and provide a smooth surface for the chain to slide on. Similarly, Delrin was chosen for the guiderail because it has low friction, allowing wood slats to move pass the router smoothly. The pusher was also made out of Delrin because it is flexible and slightly elastic, making it easier to snap onto the chain links.

There are several components off the shelf that were purchased for the driving mechanism such as the motor, roller chain, and sprockets. These items were selected based on customer requirement and system analysis. For instance, the power needed to drive slats through the cutter head was calculated based on the maximum force and the maximum feed rate from the experimental data. The maximum power required for the driving mechanism was less than 1/10 hp. The calculation is shown in Appendix H. With this basic requirement, team members and sponsor were looking into different DC motors and finally, the team decided to choose the Bison DC gear motor for several reasons. First, this motor is a 1/10 hp motor which exceeds the requirement and the price is reasonably cheap compared to other DC motors. The rotational speed of the motor is about 152 RPM which is perfect for the chain. With this motor, the shaft can be attached directly to a sprocket driving the chain at a speed of 21.1 in/s based on the calculation in Appendix H. Another advantage of selecting this motor is that the motor can generate up to 42 in-lb$_f$ toque and the maximum torque needed to drive the chain is 34 in-lb$_f$.

A roller chain ANSI # 40 is used in this design because it is a standard size chain allowing the team to easily find standard size sprockets and attachments for the chain. In addition, this chain is inexpensive but its performance is excellent. The factor of safety calculated in Appendix

H ensures that the chain will not fail due to stress or fatigue. The calculated safety factor shows that the chain is not likely to fail if operate under normal conditions for 15000 hours.

The sprocket was selected based on the Bruce's requirement and the shaft diameter of the motor. The outer diameter of the sprocket is approximately 3 inches and the bore diameter must be equal to the shaft diameter which is 0.5 inch. Based on these two parameters, a Steel Finished-Bore Roller Chain Sprocket for #40 Chain, 1/2" Pitch, 15 Teeth, 1/2" Bore was chosen for this design. The second sprocket is the roller chain idler sprocket steel with ball bearing, for #40 Chain, 18 Teeth, 1/2" Bore. This sprocket was selected because it has ball bearings and easy to mount to the aluminum plate.

The team also used fasteners to attach components together because of the assembly and disassembly process. Fasteners allows component to be attach, detach, and replace easily. In the selection of fasteners for the system, it is typically most convenient to use the smallest possible bolt for most of the fasteners. Calculations were performed to determine if this size bolt would be strong enough to support the loads exerted by the magazine and driving assembly while the bolt is under tension. The stress in the bold was found to be 170 psi which is higher than maximum stress required; therefore the bolt is safe to operate.

5.3 Post-Critical Design Revisions

As this is the first full-fledged engineering project this team has undertaken from start to finish, there are of course unforeseeable circumstances that demand revision of the planned design as manufacturing and assembly progress. Although the major functions, materials, and geometry of the design are still largely the same, many parts were reevaluated and updated as the project came to a close. Some changes were made on-the-fly during fabrication, as the team encountered issues and agreed on simple solutions. Other conflicts required more meetings, brainstorming and concept evaluation in order to find the most viable alternative. The changes made during fabrication and assembly will be presented here in the order in which the parts or assemblies are physically encountered, from left to right, on the prototype.

Originally, the team had decided upon a custom vacuum hood constructed from a thin, clear acrylic sheet. As it came time to fabricate this component, concerns were raised regarding the rigidity of the structure and its ability to support the weight of the 4" vacuum hose that would eventually hang from it. Joining the edges of the various sides of the hood was also an issue, as acrylic is relatively brittle and, like most plastics, does not behave reliably under adhesion. A design incorporating brackets on the various corners was first considered, but the team eventually decided upon a simpler design using an existing plastic container modified to cover the table assembly. This solution is far more reliable, since the entire component is cast from a single piece of plastic thicker than the original acrylic sheet, and eliminates the concern of failure at the hood's edges. This also allowed the acrylic sheet to be repurposed for an unanticipated component, which will be discussed later.

The planned magazine door design incorporated three clear polycarbonate (PC) sheets floating in slots milled out of a rectangular aluminum bar frame. The slots were to be 1/16 of an inch wide to accommodate the thickness of the PC sheet. When it came time to manufacture the door, the team learned the smallest available end-mill was twice the required width of the slot, preventing a rigid assembly. In addition to this complication, the team realized a sheet-in-slot design would leave lips on the inside face of the door that might interfere with movement of the slats within the magazine. A solution was then decided upon which would solve both issues. By switching from a mid-thickness slot to a recess on the inside edges of the frame, any size end-mill could be used to perform the cut, and the entire inside face of the door would be smooth and flush. To secure the PC sheets to the aluminum frame, a series of countersunk through-holes were drilled in the PC sheets, which corresponded to #4-40 tapped holes lying in the recesses of the frame. Thus the sheets were screwed to the frame, no welding of the frame corners was required (which may have ultimately melted or at least deformed the plastic), and the entire assembly was converted to a non-permanent solution, allowing replacement of any individual component that may wear or become damaged.

The next revised component in the prototype is the weighted bar within the magazine, intended to prevent upward buckling of the wooden slats as they are compressed from end to end between the pusher and the cutter head. The original concept utilized two rigid columns that would slide through holes in the magazine roof, keeping the weight bar horizontal and pressing downward on the slats under the acceleration of gravity. The main issue with this concept is one with which the team was not initially familiar during the design phase: binding at the metal-metal interface between the guide columns and the metal bar through which they passed. Also, were the machine operator to load shorter slats atop longer slats in the magazine, the weight bar would be inclined to settle in a non-horizontal position atop the stack, encouraging binding. To prevent this situation, the team decided to replace the rigid guides with rope that would slide through the same holes initially cut for the metal guides. The rope will not bind at the metal surface, and it will allow the bar to drop freely in the magazine at whatever angle is necessary to press down on the stack of slats. This design also solves the heretofore issues of how to conveniently lift and secure the weight bar for loading of the magazine. The ropes extending through the magazine roof will be pulled out to lift the bar, and wrapped around a cleat on the side of the magazine to secure the bar in the raised position. This process is similar to the raising of a set of mini blinds on a window.

As previously mentioned, changing the vacuum hood design resulted in leftover clear acrylic sheet, which would have gone to waste if not for the following design change. At the right-hand end of the machine, the driver plates extend approximately 18” past the end of the magazine in order to allow the pusher to fully retract past the ends of the slats. This results in a length of chain, wrapped around the idler sprocket, which is exposed from above. This portion of the machine could potentially result in complications or even damage to the machine if foreign matter were to settle into the chain and sprocket, not to mention the obvious safety concerns associated with exposed moving parts. To solve this issue, a strip was cut from the clear acrylic sheet and heat-formed around the back end of the driver plates, covering the top of the exposed area, while still allowing inspection of the covered components. This chain guard is secured to the driver plates with two #4-40 screws tapped into the plates near the right edge of the magazine, and secured to the right-hand edges of the plates beneath the foot of the chain tensioner. This custom component also gives the prototype a more professional and sophisticated look.

The final revision to the planned design is a rather simple one. The original chain tensioner incorporated a press clamp: a large threaded rod, similar to that found in a bench vise, with a crank handle at one end and a foot at the opposite end. The press clamp chosen for this part of the assembly was ordered, and was soon found to be on back-order not only with the retailer from which it was purchased, but also from the original supplier. The same general concept was conserved, but the top half of a pipe clamp was used in place of the original press clamp. This component was purchased from a hardware store and modified to fit the prototype.

5.4 Safety Considerations

The nature of this design is such that the majority of the moving components are guarded from physical contact by the structure of the prototype. Most of the chain is covered on either side by the driver plates, the cutter head is surrounded first by metal guides and second by the plastic vacuum hood which will be in place during operation, and the entire spinning shaft of the motor is contained within the magazine assembly. However, there are still a few points in the machine where care should be taken during operation so as to prevent injury to the operator or bystanders. At the mouth of the magazine between the frame and the table assembly is a gap through which wood will travel to reach the cutter head. This results in the potential for pinching or jamming if an operator’s hand or clothing were to come between the vacuum hood and a slat being fed towards the cutter. The second potential for harm occurs at the top of the magazine, where rope slides through two holes to allow the weight bar to be drawn upward before loading. Although the rope only drops approximately ¼ inch each time the pusher retracts, there is the small possibility that a finger could become pinched between the rope and the edge of the hole if it were near this interface when the weight lowers. The final and most obvious safety consideration is the potential for wood chips and fragments to be expelled from the cutter head during feeding or from a slat damaged/shattered by compression during the feeding process. Since the entire cutter assembly and feed path are covered first by thick metal and second by rigid plastic, there is virtually no danger to operators or bystanders from wooden debris. The remaining pinch points (magazine exit and guide holes) are left unguarded since the machine will only be operated by one person, who will never have the need to touch the prototype anywhere near these points during operation.

5.5 Maintenance and Repair Considerations

Since this prototype incorporates relatively few moving parts and extremely low stresses relative to the strength of the components, maintenance and repair considerations are few. There is of course the potential for wear in all moving metal parts, such as the sprockets, chain, and the guide rollers on the table assembly. The sprockets are both made of steel, however, and will likely long outlast the required life of the machine. Although the chain may wear and stretch over time, the built-in chain tensioner prevents this from becoming an issue, as the location of the rear idler shaft is arbitrary and pulling it back to tension the chain is more than acceptable. The main concern with wear is most likely the rope holding the weight bar inside of the magazine. The rope will be sliding past aluminum (although slowly) during normal operation, introducing the potential for chafing on the sides of the rope. Also, it is important that the length from the bottom knot to the top knot in the rope is accurate and consistent, since allowing the weight bar to drop into the feed plane could be catastrophic for the soft pusher.

When it comes to repair or replacement of the components in the prototype assembly, the machine was designed in such a way as to minimize the number of skilled manufacturing processes required for completion of the design. This means that if a part or component wears out or fails, it will be relatively simple to fabricate a replacement from the engineering drawings provided to the project sponsor. There are numerous local alternatives for skilled fabrication of any of the required custom components, and all COTS components were chosen from common, readily available retail options.

6. REFERENCES

[1] "Automated Rip Saw Infeed For Sale! Side Delivery." YouTube. YouTube, 16 Jan. 2009. Web. 22 Jan. 2013.

[2] "Choosing a Router Table." - Rockler Woodworking and Hardware. N.p., n.d. Web. 22 January.2013.

[3] "Guide for Protecting Workers from Woodworking Hazards." Guide for Protecting Workers from Woodworking Hazards. N.p., 1999. Web. 15 Jan. 2013. http://www.osha.gov/Publications/woodworking_hazards/osha3157.html

[4] "How It's Made PENCIL." YouTube. YouTube, 08 June 2010. Web. 22 January. 2013.

[5] "Introduction." Corvallis Tool Company. N.p., n.d. Web. 21 Jan. 2013. <http://www.corvallistool.com/>.

[6] Palmer, Bruce. Personal interview. 18 Jan. 2013.

[7] "Raimann KM310 2M with Valu-Rip 3 Plus Video." YouTube. YouTube, 18 Nov. 2011. Web. 22Jan. 2013.

[8] "Twin Double Arbor Sawmilling Machine FKD-500." YouTube. YouTube, 22 July 2010. Web. 22January. 2013.

[9] "Vision Senors Improve Pickup Truck Part Handling at DaimlerChysler." Proquest. Taylor &Francis Ltd, 2010. Web. 21 Jan. 2013. <http://search.proquest.com/abicomplete/docview/217024796/13C0717D616E19478D/1?accountid=10362>.

[10] "Western Pneumatics, Inc. - Home." Western Pneumatics, Inc. - Home. N.p., n.d. Web. 20 Jan. 2013. <http://westernp.com/>.

[11] "Wood Technology Show Digest." Proquest. Neilson Business Media, Nov.-Dec. 2000. Web. 20 Jan. 2013. <http://search.proquest.com/abicomplete/docview/216507249/13C070C799B4F30D5F8/1?accountid=10362>.

[12] "Wood-Mizer Twin Blade Edger." YouTube. YouTube, 25 Mar. 2011. Web. 22 Jan. 2013.

[13] Klinkhachorn, Powsiri, and Ravi Kothari. "Prototyping an Automated Lumber ProcessingSystem." Proquest. Forest Products Journal, Feb. 1993. Web. 20 Jan. 2013.

<http://search.proquest.com/abicomplete/docview/214634175/13C070E89BC4F5AE649/1?accountid=10362>.

[14] Lee, D.V.; Velinsky, S.A.; , "Analysis and Experimental Verification of a Three-DimensionalNoncontacting Angular Motion Sensor," Mechatronics, IEEE/ASME Transactions on , vol.12, no.6, pp.612-622, Dec. 2007

[15] Schuler, Alfred R.; Grammatikos, Anthony; Fegley, Kenneth A.; , "Measuring Rotational Motion with Linear Accelerometers," Aerospace and Electronic Systems, IEEE Transactions on , vol.AES-3, no.3, pp.465-472, May 1967

[16] United States. OSHA. By Craig Hameland. N.p., n.d. Web. 14 Jan. 2013. <http://www.cbs.state.or.us/osha/pdf/pubs/2980.pdf>.

[17] USPTO Patent. By Glen E. Hylton. N.p., 29 May 2001. Web. 14 Jan. 2013.<http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=7&f=G&l=50&co1=AND&d=PTXT&s1=%22wood+cutting+machine%22&OS=%22wood+cutting+machine%22&RS=%22wood+cutting+machine%22>.

[18] USPTO Patent. By Robert L. Moore. N.p 27 February. Web. 20 Jan. 2013http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4324519.PN.&OS=PN/4324519&RS=PN/4324519

[19] USPTO Patent. By Sydney L. Lunden. N.p, 18 May 1982. Web. 21 Jan. 2013<http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4330055.PN.&OS=PN/4330055&RS=PN/4330055>

[20] Budynas, Richard. *Shigley's Mechanical Engineering Design*. City of Publication: McGraw-Hill Science/Engineering/Math, 2010. Print.

APPENDICES

APPENDIX A: HOUSE OF QUALITY

Wooden Slat Edge Trimmer

■ = 9 (Strong correlation)
o = 3 (Medium correlation)
Δ = 1 (Weak correlation)
Blank = 0 (No correlation)

Engineering Requirements (HOWS)

Customer Requirements (Whats)			Weighting (Total 100)	Chuck inner diameter	Depth of cut	Rotational speed	Feed rate	Holder capacity	Autonomy	Holder loading rate	Deal with slat interfence	Type of loading	Holder cutter interface	Acceptable slat dimensions	Holder empty detection	Control module for system	Emergency Cutoff Switch	Adjustability of feed rate	Jam detection	Dust control	Duty cycle	Portability
Automatically Cuts Wood Slats	Cutterhead	Accepts 1/4" shaft router bits	2	■																		
		Cut depth adjustable from 0.0" to 0.10"	4		■	■	■		Δ					o						Δ	■	o
		Does not knock out knots or damage wood surface	4		■	■	■				Δ		Δ								■	
		Slats move past cutter between 2 and 4 in/s	3		■	■	■		Δ		o		Δ					o	o	Δ	■	
	Holder	Hold at least 50 slats	3					■	■	■	o	o	Δ	■	Δ							■
		Feed slats through the cutter autonomously	5				Δ	■	■		■	o	Δ		■	Δ	Δ	o	■	Δ	o	■
		Can be loaded in 5 minutes or less	3					■	o	■	o	■	Δ	■	Δ				Δ			■
		Deals with interference between slats	4					■	■	■	■	■	Δ	■				■	■			o
		Capable of continuous loading	1					■	■	■	■	■	Δ	o	■						■	■
		Easily removable from cutting portion	3					■	Δ			■	■			■	■		■	■		
		Must hold slats 0.22-0.24 H, 6-72 L, 0.6-0.8 W	5					■		■	■	Δ	■	■								■
	Electronics	System shuts off after last slat is out	3												■	■						
		Emergency cutoff switch for entire machine	4													■	■					
		Ability to turn each portion on/off separately	3													■	■					
		Variable feed through rate	2		■		■									■		■				
		Turn off power to cutterhead in case of jam	4													■			■			
	Usability	Connects to a 4" diameter vacuum hose	1																	■		
		Operates continuously for one hour per day	4					■	■		■	Δ			o	■			o	o	■	
		System is on wheels	1					Δ					Δ									■
		Units:		in	in	rpm	in/s	slat		#/min				in			#				hr/day	
		Target Values:		≥1/4	0-.1	10K-25K	2.0-4.0	50	yes	>10	yes	continuous	removable	.22-.24 H 6-72 L .6-.8W	yes	yes	1	yes	yes	yes	1	yes

Figure A.1. House of quality utilized to accomplish Quality Function Deployment (QFD).

APPENDIX B. PROJECT REQUIREMENTS SET BY SPONSOR

<u>Requirements for the Wood Slat Edge Trimming Machine</u> 16 January 2013

Principal requirements:

- Design and prototype a machine to cut a ¼ inch diameter rounded edge on a 0.23”x 0.75” wood slat.
- Design and prototype a mechanism, as part of the machine, to hold at least 50 slats and that will feed slats through the cutting portion of the machine autonomously.

Specific requirements:

- **Cutting head**
  - ➢ The cutting head should accept ¼ inch shaft router bits.
  - ➢ The cutting head’s cut depth should be adjustable from 0.0 inches to 0.10 inches.
- **Magazine requirements**
  - ➢ The magazine should hold at least 50 slats. Slats are 0.23 +/- 0.01 inch in height and from 6 to 72 inches long. The nominal width is 0.75 inches but can vary +/- 0.15 inches.
  - ➢ An operator should be able to load the magazine in 5 minutes or less.
  - ➢ The machine should detect when the magazine of slats is empty and turn power to the cutting head off.
- **Operator interface**
  - ➢ The cutting head should have a manual on/off switch so that the operator can turn off power for safety reasons. Other electronics on the machine should have a separate on/off switch.
- **Vacuum**
  - ➢ The machine should use a vacuum to remove wood cuttings. The vacuum hose diameter should be 4 inches
- **Operating speeds**
  - ➢ The cutting head speed should be variable from 10,000 to 25,000 rpm.
  - ➢ The slats should move past the cutting head at a rate of between 2 to 4 inches/second. Knots in the wood are a factor limiting this speed. A hard knot will shatter if fed through too fast. A variable feed through rate function would be useful, but not required
- **Jam detection**
  - ➢ A jam occurs when a slat is prevented from moving in the machine, either from obstruction or failure of a transport mechanism. The machine should detect non movement of slats and turn power to the cutting head off.

Anticipated problems:

- Slats may interfere with each other in the magazine. The slats may have cracks, splits, broken ends or other defects that could interfere with sliding against each other in the magazine. Therefore, some way to prevent interference (perhaps by physical separation) between slats may be necessary.

Notes:

- An off the shelf, variable speed router will effectively meet the need for the powered cutter portion of the machine. I can provide a Porter Cable model # 690LRVS (1001-T2 base).

I can provide as much assistance as needed for the electronic portion of the machine, up to complete design and fabrication of electronic circuits and sensors.

APPENDIX C. CUSTOMER INTERVIEW QUESTIONS

- What sort of communication protocols would you like us to follow? (Includes weekly progress reports, questions and inquiries, etc.)
- Will a NDA or IPA be necessary for this project?
- What is our budget?
- Must the slats be fed from a magazine, or would some other form of hopper/holder be acceptable?
- Space limitations?
- Should we design an external power switch for the router?
- Would you prefer using your current router or designing the project to accept/adapt to multiple routers/router tables?
- Should noise suppression be considered/incorporated into the project?
- Will the weight/portability of the machine be a necessary consideration?
- Desired life expectancy of the system?
- What is your vision at this point of the type of system you would like us to design and build?
- Is the actual speed of the cutter head important, or are you looking for a range of speeds and feed rates that will successfully cut the wood without damaging it?
- Would you like the main power switch to actually turn the entire machine on and off, while having an emergency cutoff switch for the cutter head, or would you like to have 2 separate switches to shut down and start up the machine?
- Should the system attach to the current router table, or can we build one all-inclusive machine?
- Should the system be height adjustable to accept different tables?
- Should we try to incorporate the planning process as well, since it shouldn't be too difficult to complete the process in a similar manner?
- What are the current wood species used for manufacture of spinners, and what species may potentially be used in the future?
- What is the cost of the controller you have recommended?
- What is the anticipated use of the machine, with respect to period and frequency?
- What are your expectations/anticipations as far as a final deliverable?

APPENDIX D. ELECTRICAL CONTROL SYSTEM DIAGRAM

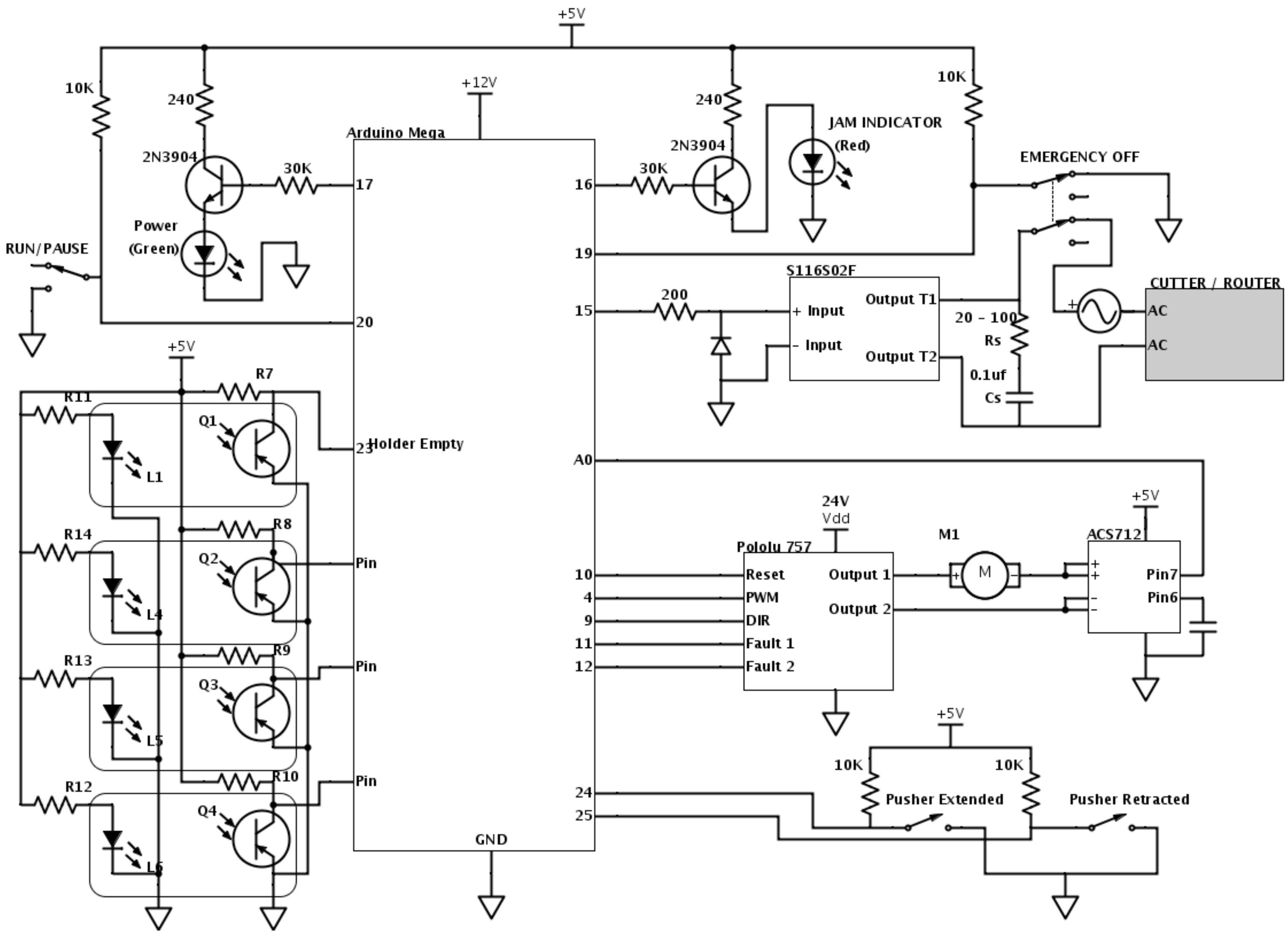


Figure D.1. Diagram of electrical control system provided by project sponsor, electrical engineer Bruce Palmer.

APPENDIX E. PRELIMINARY TESTING DATA AND RESULTS

Table E.1. Data and results for determination of friction coefficients between redwood slats and various materials.

Material:	F_N (N)	F_N (lb)	Trial	Max F_{FS} (N)	Max F_{FS} (lb)	Avg (lb)	Min F_{FD} (N)	Min F_{FD} (lb)	Avg (lb)
			1	9.0	2.02		4.0	0.90	
	22.5	5.06	2	10.0	2.25	2.25	4.4	0.99	0.97
			3	11.0	2.47		4.5	1.01	
			1	14.5	3.26		5.5	1.24	
REDWOOD	33.5	7.53	2	14.5	3.26	3.33	6.5	1.46	1.39
			3	15.5	3.48		6.5	1.46	
			1	25.5	5.73		15.0	3.37	
	70	15.74	2	30.0	6.74	6.11	13.5	3.03	3.07
			3	26.0	5.85		12.5	2.81	
			1	12.0	2.70		6.0	1.35	
	22.5	5.06	2	13.0	2.92	2.85	5.8	1.30	1.32
			3	13.0	2.92		5.8	1.30	
			1	15.0	3.37		8.0	1.80	
STEEL (POLISHED)	33.5	7.53	2	18.0	4.05	3.60	8.2	1.84	1.81
			3	15.0	3.37		7.9	1.78	
			1	33.0	7.42		16.0	3.60	
	70	15.74	2	36.0	8.09	7.72	15.5	3.48	3.56
			3	34.0	7.64		16.0	3.60	
			1	11.0	2.47		8.0	1.80	
	22.5	5.06	2	10.5	2.36	2.36	8.5	1.91	1.84
			3	10.0	2.25		8.0	1.80	
			1	17.0	3.82		13.0	2.92	
ALUMINUM (UNPOLISHED)	33.5	7.53	2	18.5	4.16	3.97	12.0	2.70	2.70
			3	17.5	3.93		11.0	2.47	
			1	38.0	8.54		22.0	4.95	
	70	15.74	2	36.0	8.09	8.09	23.0	5.17	5.02
			3	34.0	7.64		22.0	4.95	
			1	6.2	1.39		3.2	0.72	
	22.5	5.06	2	6.6	1.48	1.45	3.0	0.67	0.69
			3	6.6	1.48		3.0	0.67	
			1	12.0	2.70		5.0	1.12	
TABLE SURFACE	33.5	7.53	2	12.0	2.70	2.55	5.0	1.12	1.11
			3	10.0	2.25		4.8	1.08	
			1	18.5	4.16		10.0	2.25	
	70	15.74	2	18.5	4.16	4.27	10.0	2.25	2.25
			3	20.0	4.50		10.0	2.25	
			1	13.0	2.92		10.5	2.36	
	22.5	5.06	2	12.5	2.81	2.89	10.0	2.25	2.40
			3	13.0	2.92		11.5	2.59	
			1	17.0	3.82		14.0	3.15	
LEXAN	33.5	7.53	2	18.0	4.05	3.90	15.0	3.37	3.33
			3	17.0	3.82		15.5	3.48	
			1	40.0	8.99		26.0	5.85	
	70	15.74	2	40.0	8.99	8.95	26.0	5.85	5.70
			3	39.5	8.88		24.0	5.40	

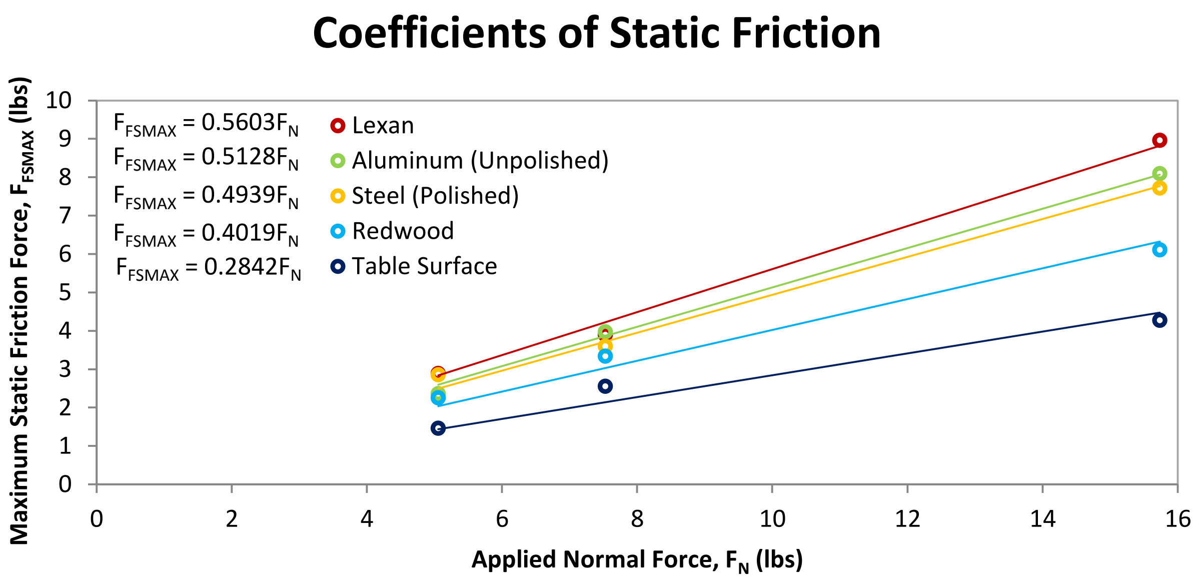


Figure E.1. Coefficients of static friction between redwood and various materials. Value of each coefficient is equal to slope of trend line next to chart legend.

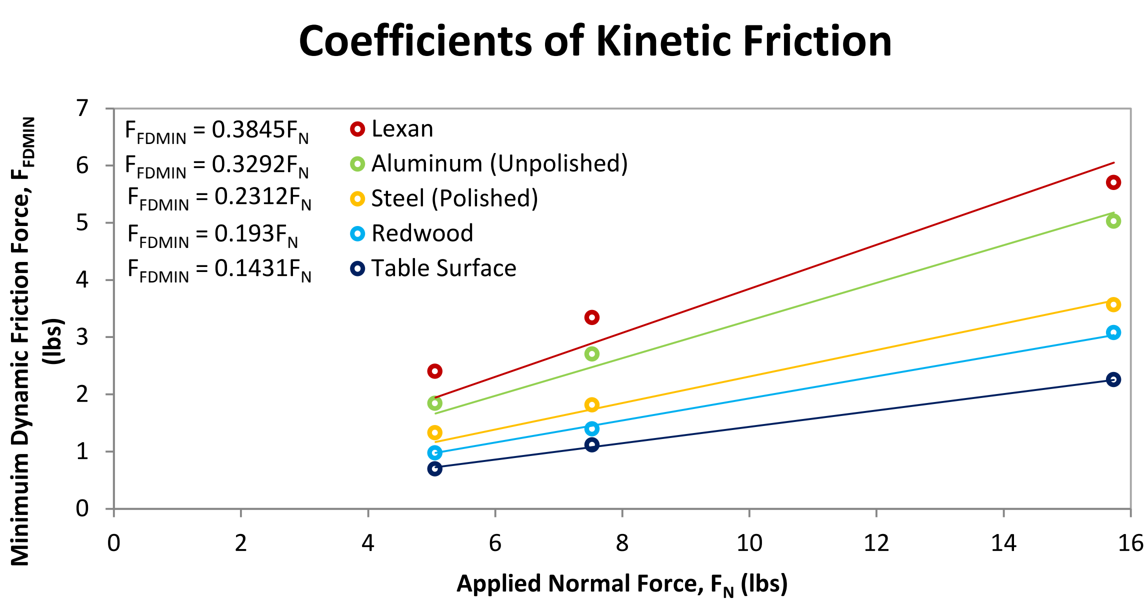


Figure E.2. Coefficients of kinetic friction between redwood and various materials. Value of each coefficient is equal to slope of trend line next to chart legend.

Table E.2. Data and results for testing of forces required to achieve different feed rates at standard depth of cut. Wood type used is redwood, router speed is varied from speed setting 1 to speed setting 4. "Maximum" feed rate is that achieved using an aggressive force, "standard" feed rate is that achieved using a moderate force.

		Maximum Feed Rate:				Standard Feed Rate:			
Router Speed Setting	Trial:	Time (s)	Feed Rate (in/s)	Maximum Observed Force (N)	Maximum Observed Force (lb)	Time (s)	Feed Rate (in/s)	Maximum Observed Force (N)	Maximum Observed Force (lb)
1	1	1.33	7.5	15	3.4	5.25	1.9	15	3.4
	2	1.61	6.2	15	3.4	4.92	2.0	16	3.6
	3	4.41	2.3	20	4.5	7.26	1.4	17	3.9
	4	1.22	8.2	18	4.1	5.93	1.7	14	3.2
	5	1.00	10.0	20	4.5	5.25	1.9	30	6.8
	6	-	-	17	3.9	5.00	2.0	16	3.6
	7	1.36	7.4	19	4.3	4.03	2.5	13	3.0
	8	1.30	7.7	20	4.5	4.63	2.2	14	3.2
	9	-	-	25	5.7	4.50	2.2	11	2.5
	10	0.86	11.6	15	3.4	5.16	1.9	15	3.4
	Avg:	1.64	6.1	18.4	4.2	5.19	1.9	14.6	3.3
2	1	0.86	11.6	20	4.5	1.46	6.8	15	3.4
	2	1.01	9.9	15	3.4	4.46	2.2	9	2.1
	3	1.01	9.9	18	4.1	3.79	2.6	13	3.0
	4	1.38	7.2	16	3.6	3.63	2.8	14	3.2
	5	0.85	11.8	18	4.1	3.95	2.5	14	3.2
	6	1.43	7.0	14	3.2				
	7	2.15	4.7	25	5.7				
	8	1.10	9.1	23	5.2				
	9	0.98	10.2	15	3.4				
	10	1.48	6.8	16	3.6				
	Avg:	1.23	8.2	18.0	4.1	3.46	2.9	13.0	3.0
3	1	0.88	11.4	15	3.4	3.35	3.0	10	2.3
	2	0.71	14.1	16	3.6	4.10	2.4	8	1.8
	3	-	-	16	3.6	2.92	3.4	11	2.5
	4	1.07	9.3	15	3.4	3.94	2.5	11	2.5
	5	0.89	11.2	16	3.6	3.50	2.9	9	2.1
	6	1.23	8.1	20	4.5				
	7	-	-	17	3.9				
	8	1.18	8.5	17	3.9				
	9	-	-	14	3.2				
	10	0.98	10.2	16	3.6				
	Avg:	0.99	10.1	16.2	3.7	3.56	2.8	9.8	2.3
4	1	1.06	9.4	11	2.5	3.23	3.1	9	2.1
	2	0.99	10.1	10	2.3	3.34	3.0	11	2.5
	3	0.70	14.3	10	2.3	3.25	3.1	11	2.5
	4	0.75	13.3	10	2.3	2.27	4.4	12	2.7
	5	0.75	13.3	11	2.5	2.02	5.0	11	2.5
	Avg:	0.85	11.8	13.2	3.0	2.82	3.5	10.8	2.5

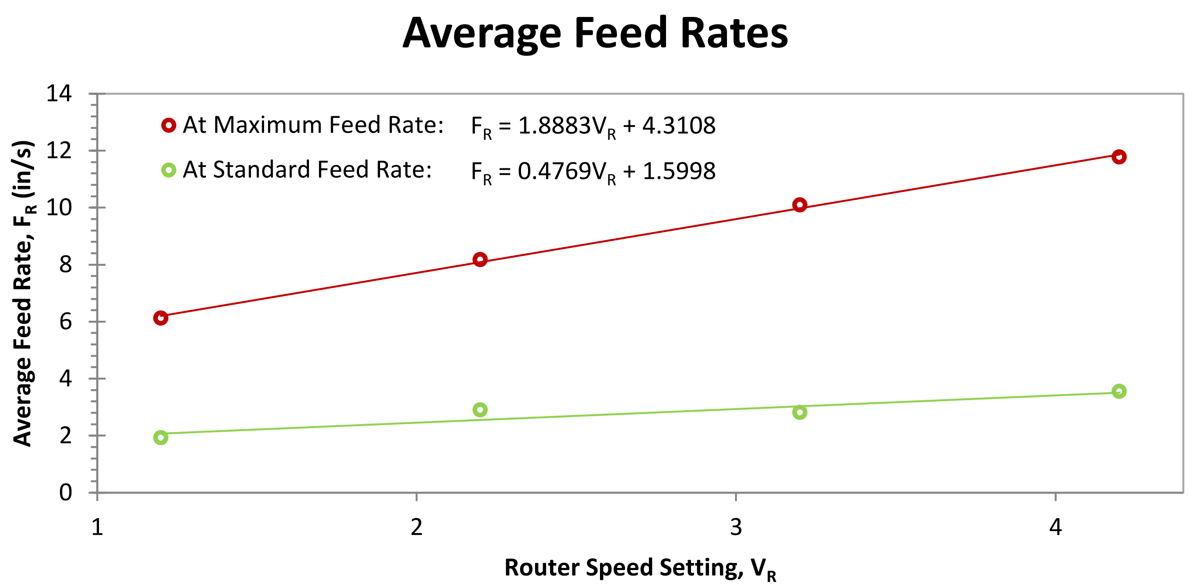


Figure E.3. Average maximum and standard feed rates versus router speed setting for redwood slat at standard depth of cut.

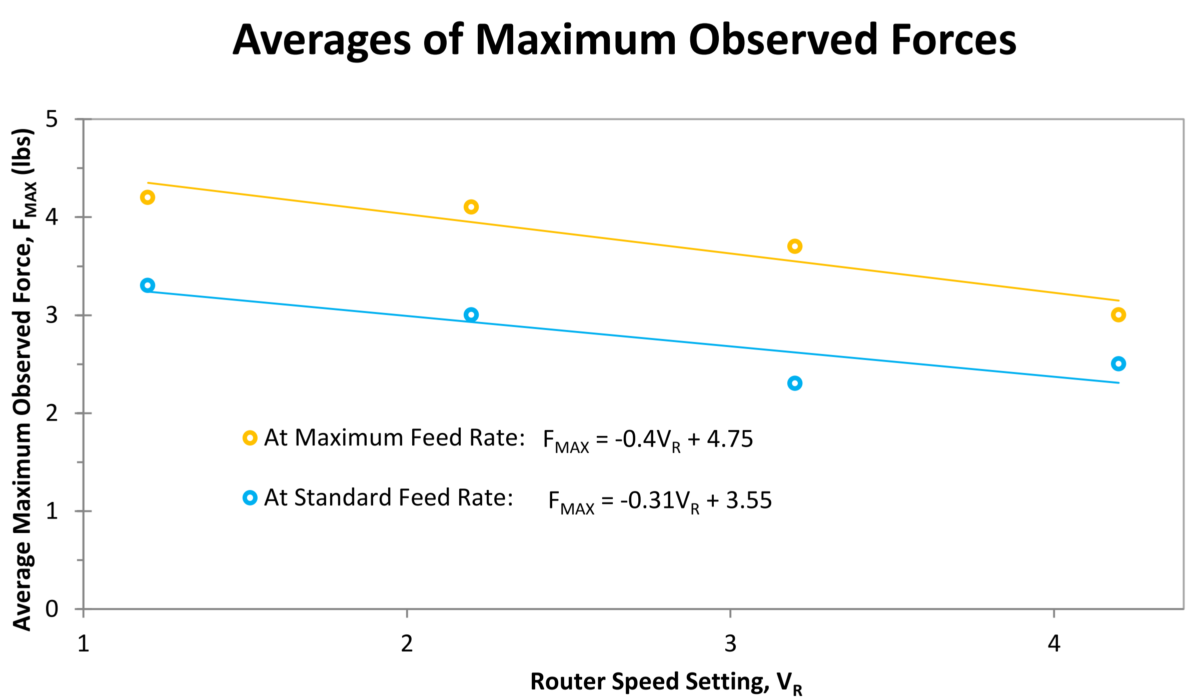


Figure E.4. Averages of the maximum force observed while feeding a redwood slat at maximum and standard feed rates for the standard depth of cut; plotted versus each router speed setting.

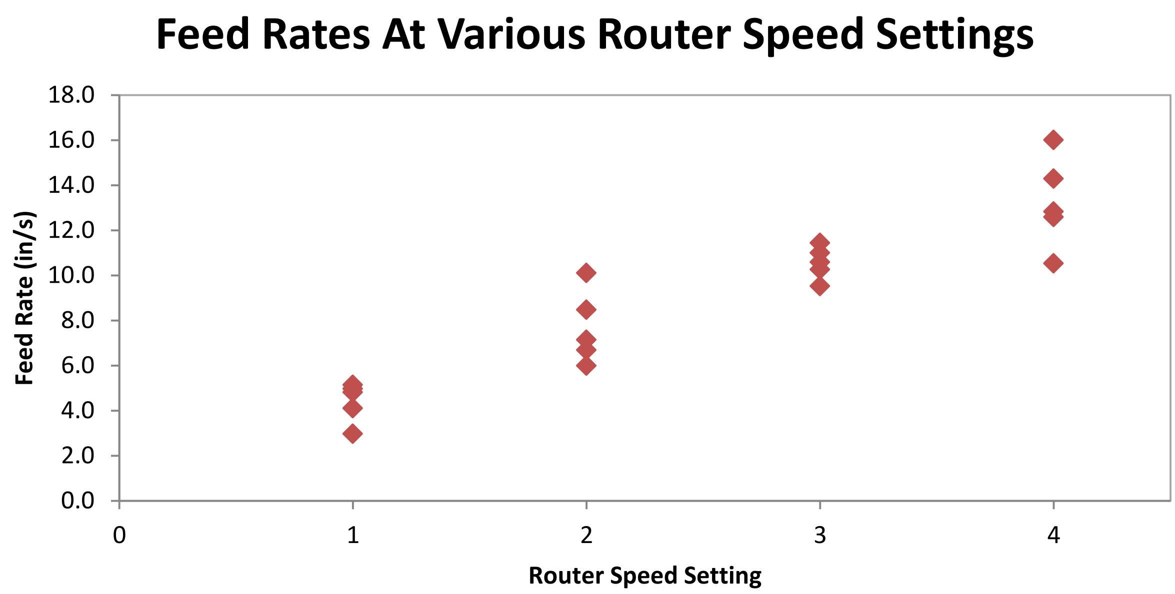


Figure E.5. Maximum feed rate versus router speed setting for redwood slat at maximum depth of cut, for a sample size of 5.

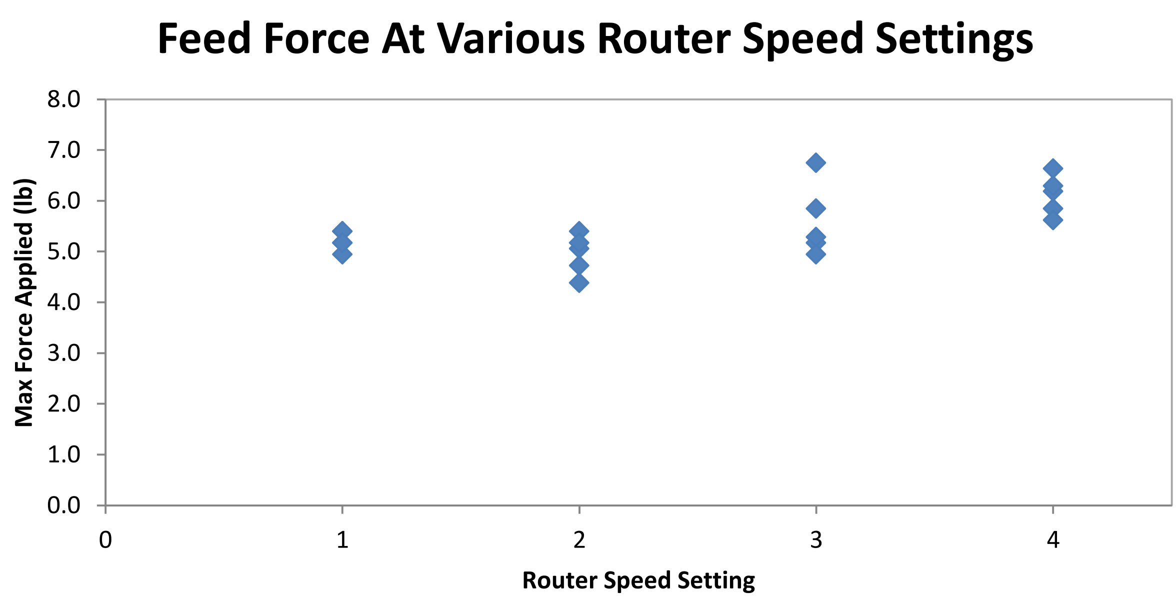


Figure E.6. Samples of the maximum force observed while feeding a redwood slat at maximum feed rate for the maximum depth of cut; plotted versus each router speed setting.

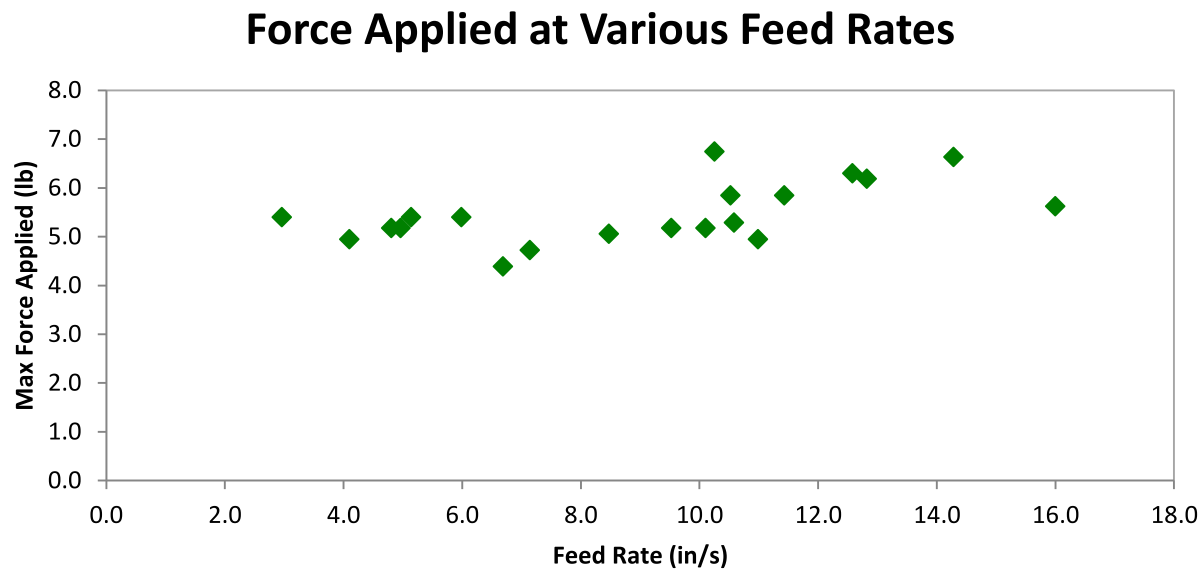


Figure E.7. Samples of the maximum force observed while feeding a redwood slat at maximum feed rate for the maximum depth of cut; plotted versus respective achieved feed rate for each run.

Table E.3. Data and results of redwood density test.

Single Test Slat:	Length (in)	Width (in)	Height (in)
	10	0.794	0.238
Volume (in^3)	1.88972		
Number of Slats:	Weight (N)	Weight (lb)	Density (lb/in^3)
10	1.50	0.34	0.0178
20	2.75	0.62	0.0164
30	4.00	0.90	0.0159
40	5.50	1.24	0.0164
50	6.75	1.52	0.0161
Average:			0.0165

Table E.4. Data and results of cedar density test.

Slat:	1	2	Average:
Length (in)	70	71	
Width (in)	0.763	0.763	
Height (in)	0.22	0.236	
Volume (in^3)	11.7502	12.784828	
Weight (N)	0.4	0.4	
Weight (lb)	0.09	0.09	
Weight Density (lb/in^3)	0.00765	0.00703	0.00734

Table E.5. Data and results of buckling deflection test. Both ends of test piece pinned, one end supported and force applied at opposite end using force scale.

Wood Type:	Deflection (in)	Applied Force (N)	Applied Force (lb)
Redwood (62 5/16" x .788" x .245")	3	9.5	2.14
	6	9.5	2.14
	9	9.5	2.14
	12	9.5	2.14
Cedar (71" x .763" x .236")	3	12.5	2.81
	6	13	2.92
	9	Beam Failure	-

Table E.6. Cantilever deflection test of 6' redwood slat (dimensions same as above table). Beam clamped at one end and deflection measured at opposite end.

	Deflection due to:	
	Gravity:	0.4 N Force:
Side 1:	3.25	15.25
Side 2:	1	11
Average:	2.125	13.125

APPENDIX F. FINAL DESIGN RENDERED CAD IMAGES

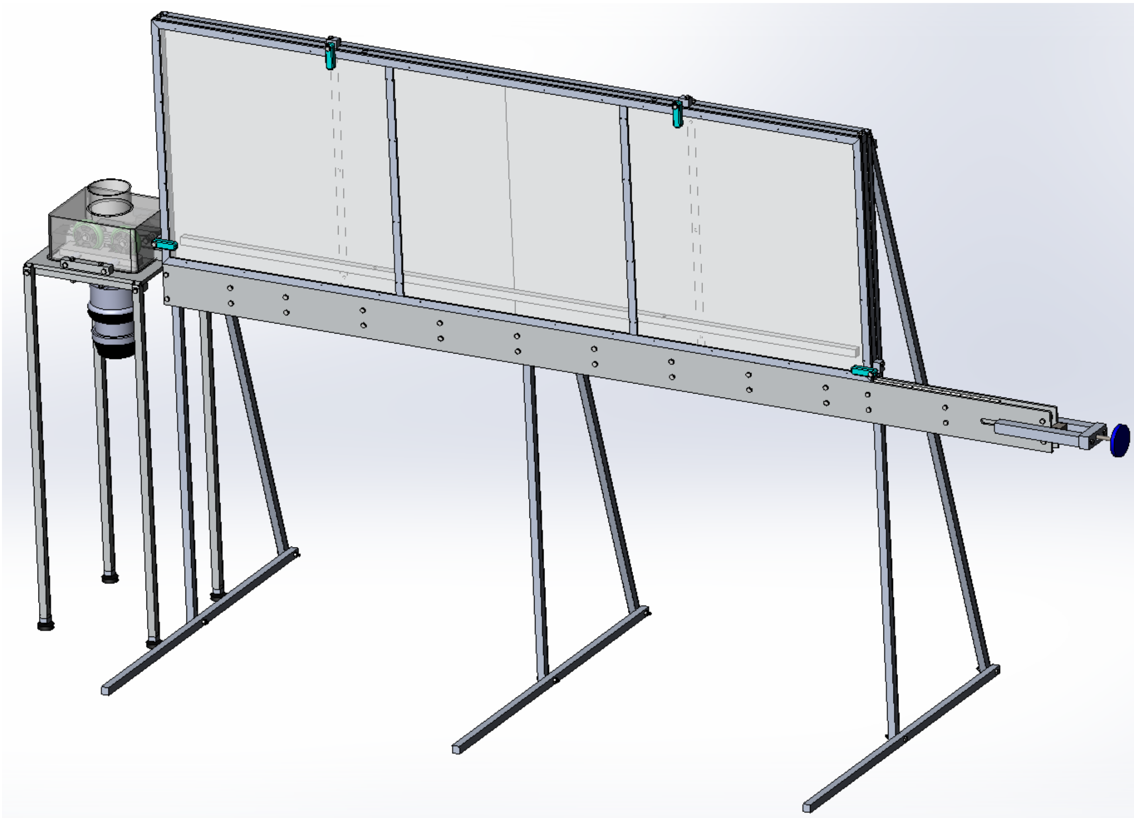


Figure F.1. Final prototype rendered in 3D as a solid model.

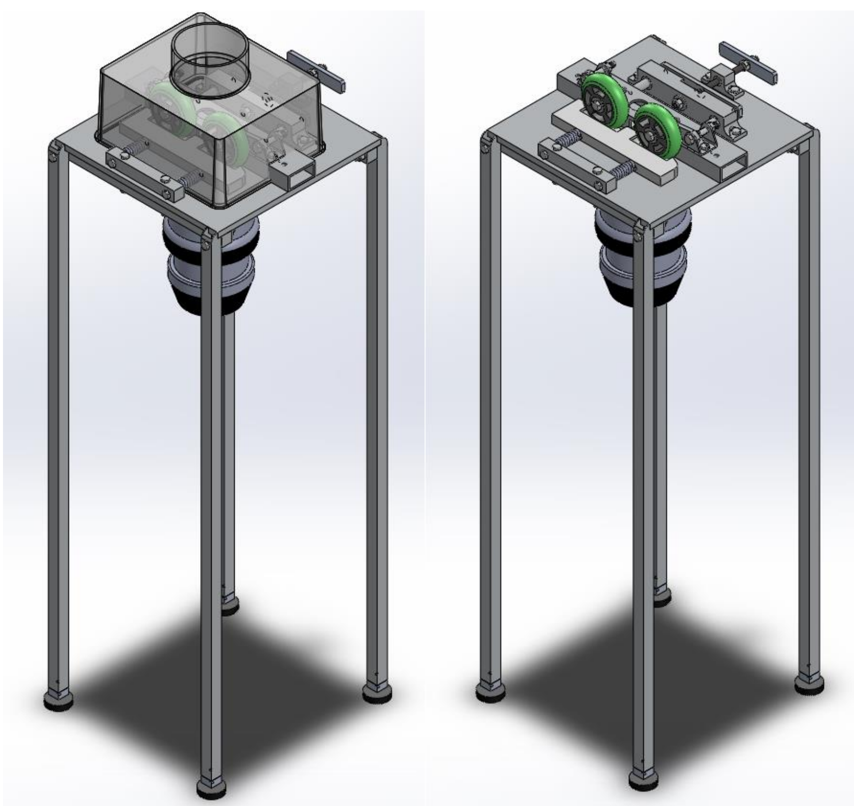


Figure F.2. 3D depiction of router table built in SolidWorks

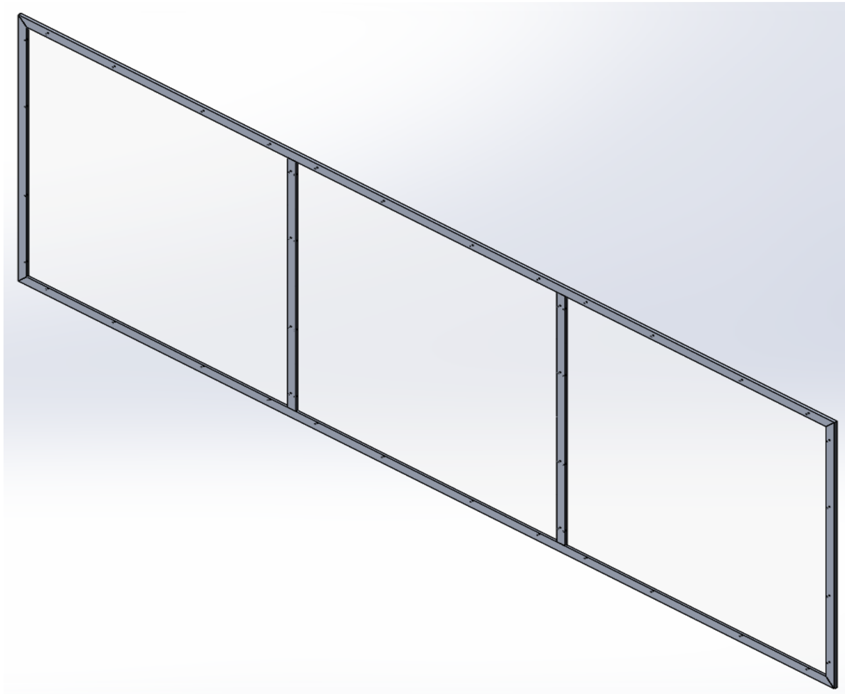


Figure F.3. Magazine door solid model rendered in SolidWorks.

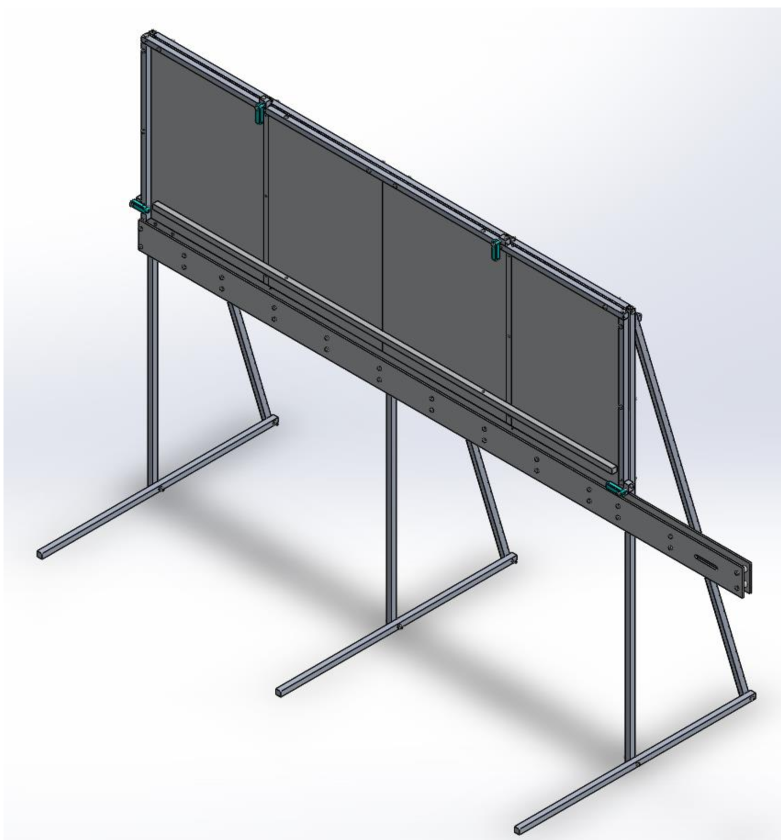


Figure F.4. 3D Solid model of magazine assembly, rendered in SolidWorks.

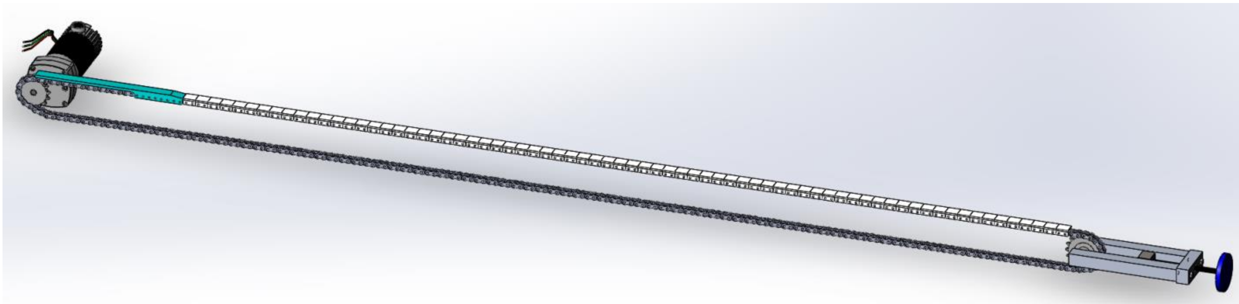


Figure F.5. 3D solid model of driving mechanism assembly, rendered in SolidWorks.

APPENDIX G. SUB-ASSEMBLY DRAWINGS

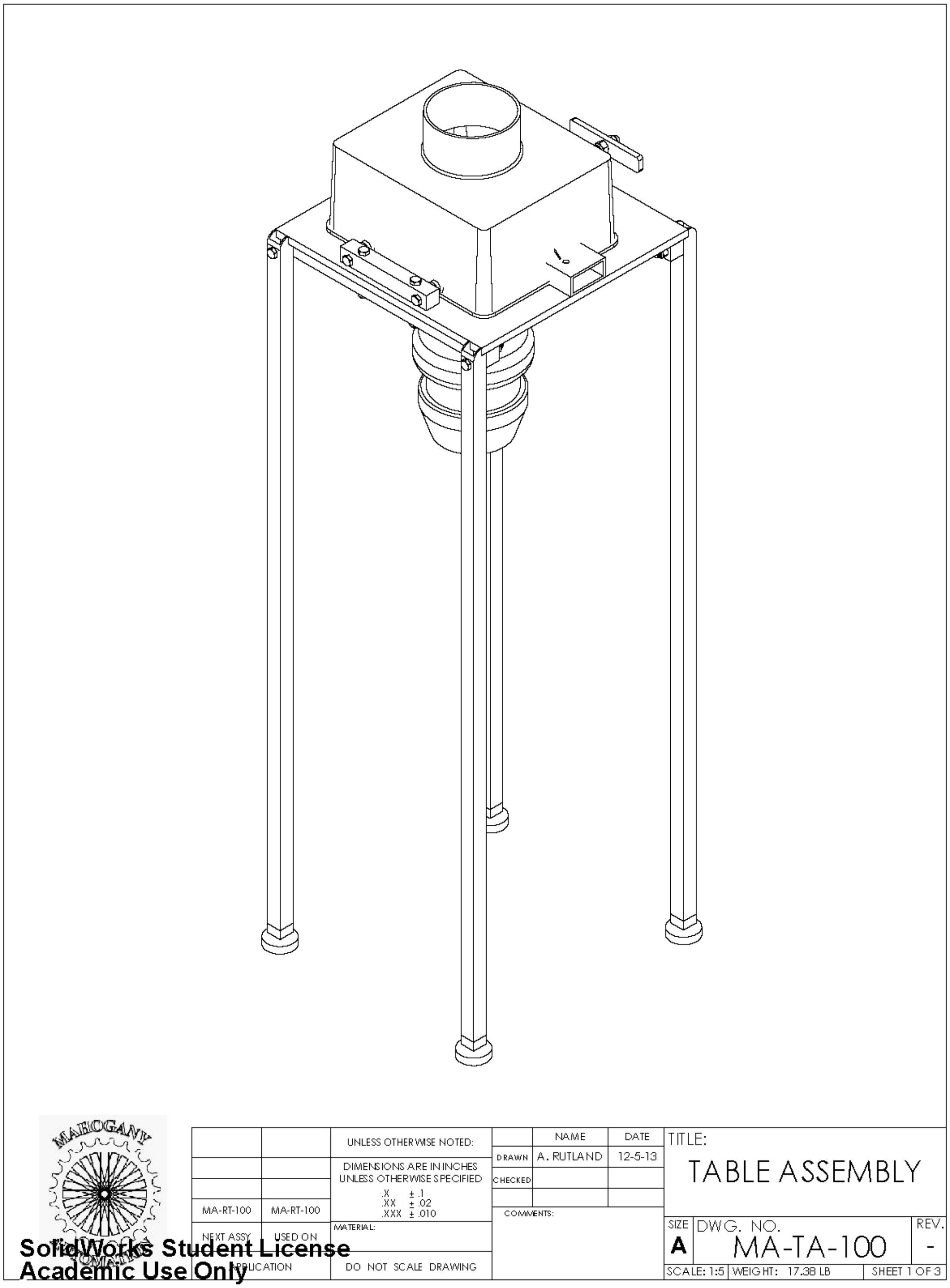


Figure G.1. Router table sub-assembly drawing.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MA-TAP001	TABLE TOP	1
2	MA-GR0100	GUIDE RAIL SUB-ASSEMBLY	1
3	MA-TAR008	3/4 DELRIN SPACER	2
4	MA-TAQ007	KNOB SHAFT MOUNT	1
5	MA-FAR596	5/16-18 ADJUSTMENT STUD	1
6	MA-TAR009	9/16 DELRIN SPACER	2
7	MA-TAP010	ATTACHMENT PLATE	1
8	690LRVS	PORTER CABLE ROUTER	1
9	MA-TAQ011	ACTIVE GUIDE ANCHOR	1
10	MA-TAQ012	ACTIVE GUIDE	1
11	MA-FAH416	1/4-20 1.00L HEX HEAD BOLT	2
12	MA-NUL004	1/4-20 NYLON LOCKNUT	10
13	MA-TAQ006	POSITIONER MOUNT	1
14	MA-FAH412	1/4-20 .75L HEX HEAD BOLT	2
15	MA-FAH448	1/4-20 3.00L HEX HEAD BOLT	2
16	MA-SPC28	COMPRESSION SPRING	2
17	MA-TAQ002	LEG ATTACHMENT - 2"	1
18	MA-TAQ003	LEG ATTACHMENT - 3"	1
19	MA-TAC004	TABLE LEG	4
20	MA-FAH0436	1/4-20 2.25 L HEX HEAD BOLT	2
21	MA-FAH428	1/4-20 1.75L HEX HEAD BOLT	2
22	MA-FAH0432	1/4-20 2.00L HEX HEAD BOLT	4
23	MA-TAQ005	THREADED LEG INSERT	4
24	MA-TAX014	LEVELING MOUNT	4
25	MA-TAP013	ADJUSTMENT HANDLE	1
26	MA-WA1405	5/16 WASHER	2
27	MA-NUL005	5/16-18 NYLON LOCKNUT	4
28	MA-TAX015	VACUUM HOOD	1
29	MA-FAK312	10-32 SOCKET HEAD CAP SCREW	3

UNLESS OTHERWISE NOTED:
DIMENSIONS ARE IN INCHES
UNLESS OTHERWISE SPECIFIED
.X ± .1
.XX ± .02
.XXX ± .010
MATERIAL:
DO NOT SCALE DRAWING

MA-RT-100 | MA-RT-100
NEXT ASSY | USED ON
APPLICATION

	NAME	DATE
DRAWN	A. RUTLAND	12-5-13
CHECKED		

COMMENTS:

TITLE:
TABLE ASSEMBLY

SIZE A | DWG. NO. MA-TA-100 | REV. -
SCALE: 1:1 | WEIGHT: 17.38 LB | SHEET 2 OF 3

Figure G.2. Router table sub-assembly BOM.

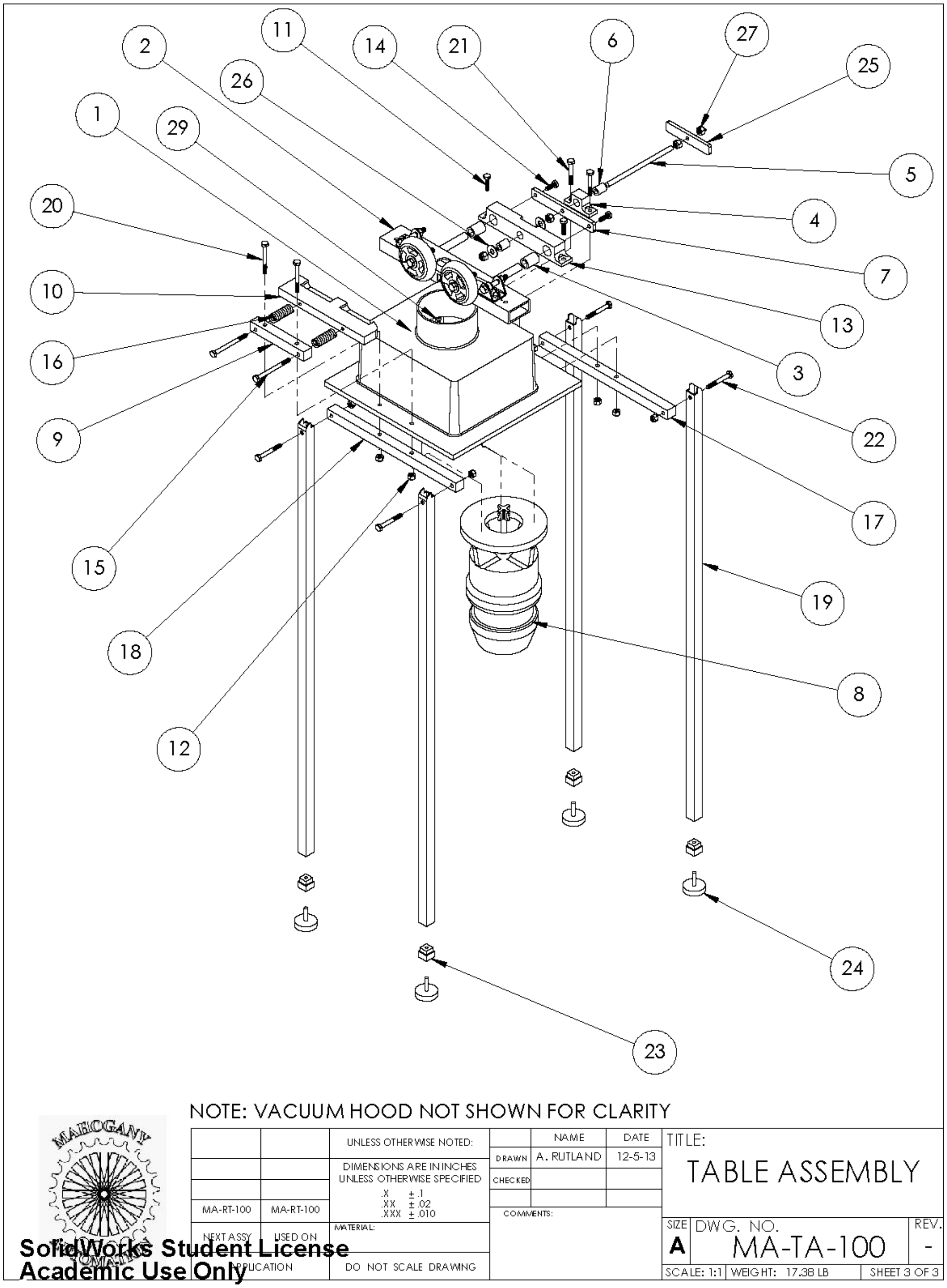


Figure G.3. Router table sub-assembly exploded-view drawing.

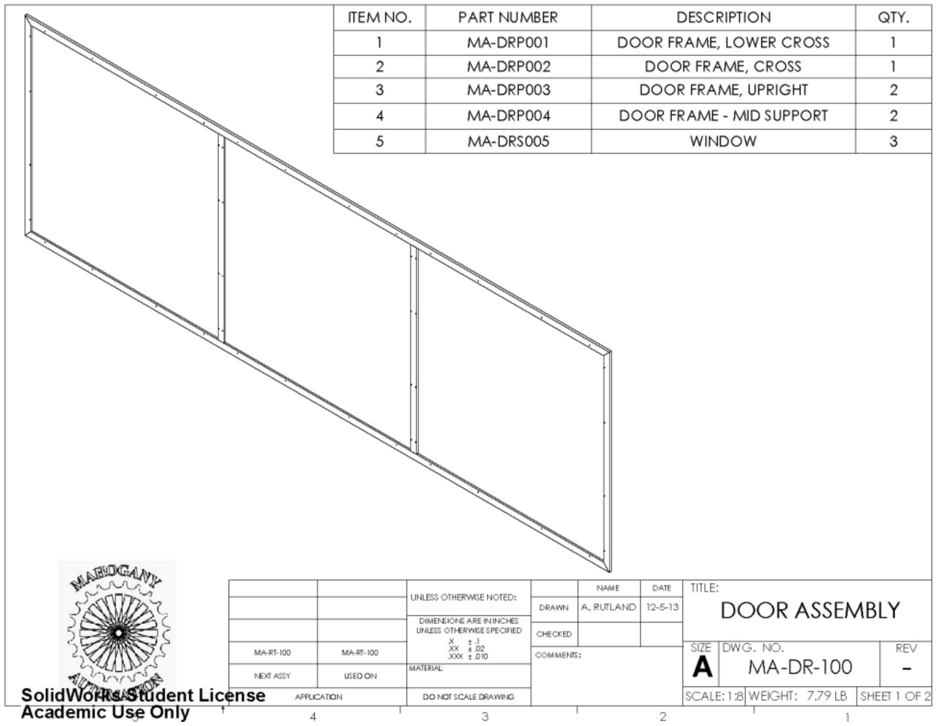


Figure G.4. Magazine door sub-assembly drawing with BOM.

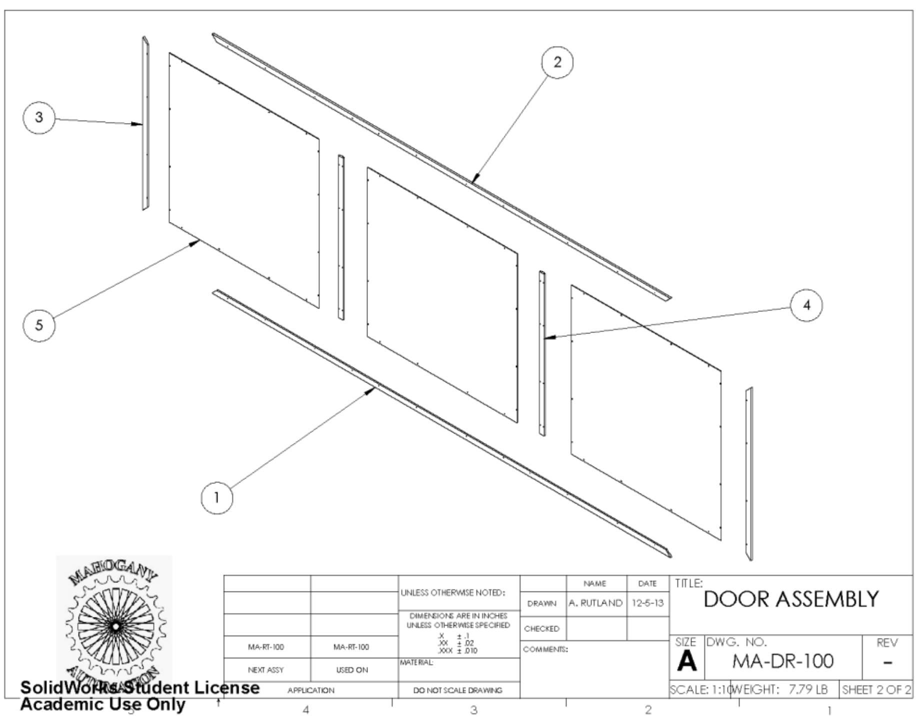


Figure G.5. Magazine door sub-assembly exploded-view drawing.

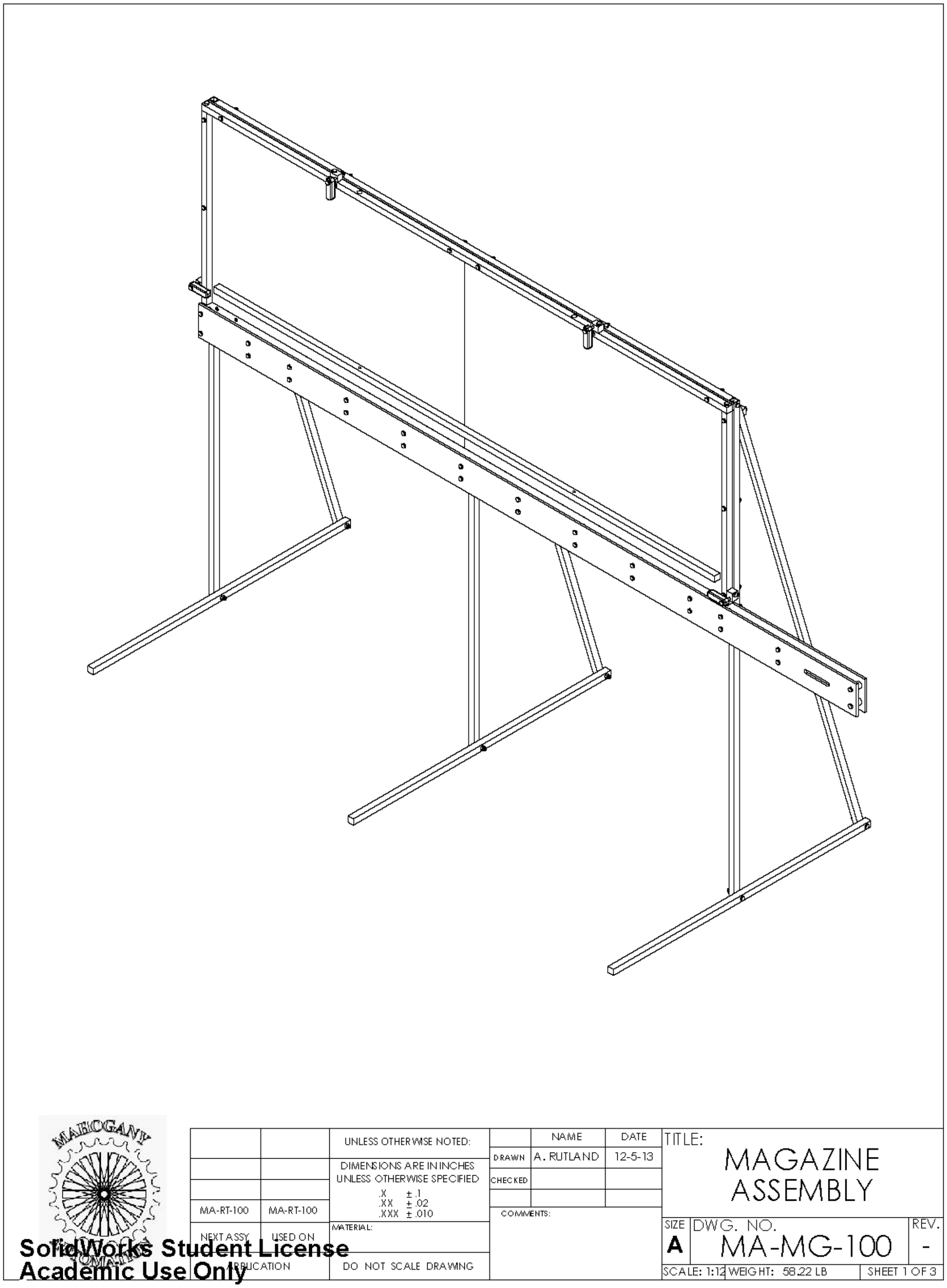


Figure G.6. Magazine sub-assembly drawing.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MA-MGR003	PLATE SPACER	25
2	MA-MGP001	DRIVER PLATE, FRONT	1
3	MA-MGS017	MAGAZINE SHEET, RIGHT	1
4	MA-MGS018	MAGAZINE SHEET, LEFT	1
5	MA-MGQ016	WEIGHT BAR	1
6	MA-MGP019	SHEET SPACER, TOP	1
7	MA-MGQ010	FRAME, REAR CROSS	1
8	MA-MGC007	LEG, MIDDLE	1
9	MA-MGC006	LEG, LEFT	1
10	MA-MGQ013	FRAME, REAR COLUMN	2
11	MA-MGP020	SHEET SPACER, SIDE	4
12	MA-MGC009	LEG, FOOT	3
13	MA-MGQ021	FRAME, FRONT COLUMN	2
14	MA-MGQ011	FRAME, FRONT CROSS	1
15	MA-MGC008	LEG, HYPOTENUSE	3
16	MA-MGQ012	FRAME, REAR COLUMN ANCHOR	2
17	MA-MGP002	DRIVER PLATE, BACK	1
18	MA-MGC005	LEG, RIGHT	1
19	MA-MGR004	PLATE SPACER, SMALL	1
20	MA-NUL004	1/4-20 NYLON LOCKNUT	49
21	MA-MGC022	HYPOTNUSE BOLT SPACER	3
22	MA-FAH0420	1/4-20 1.25L HEX HEAD BOLT	8
23	MA-FAH0432	1/4-20 2.00L HEX HEAD BOLT	22
24	MA-FAH0444	1/4-20 2.75L HEX HEAD BOLT	10
25	MA-FAK0424	1/4-20 1.50L SOCKET HEAD CAP SCREW	1
26	MA-MGQ014	CLIP ANCHOR	4
27	MA-MGQ015	DOOR CLIP	4
28	MA-FAH0436	1/4-20 2.25 L HEX HEAD BOLT	14
29	MA-FAH0448	1/4-20 3.00L HEX HEAD BOLT	2
30	MA-FAH0424	1/4-20 1.50L HEX HEAD BOLT	4

MA-RT-100 | MA-RT-100
NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE NOTED:
DIMENSIONS ARE IN INCHES
UNLESS OTHERWISE SPECIFIED
.X ± .1
.XX ± .02
.XXX ± .010
MATERIAL:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. RUTLAND	12-5-13
CHECKED		

COMMENTS:

TITLE:
MAGAZINE ASSEMBLY

SIZE A | DWG. NO. MA-MG-100 | REV. -
SCALE: 1:1 | WEIGHT: 58.22 LB | SHEET 2 OF 3

Figure G.7. Magazine sub-assembly BOM.

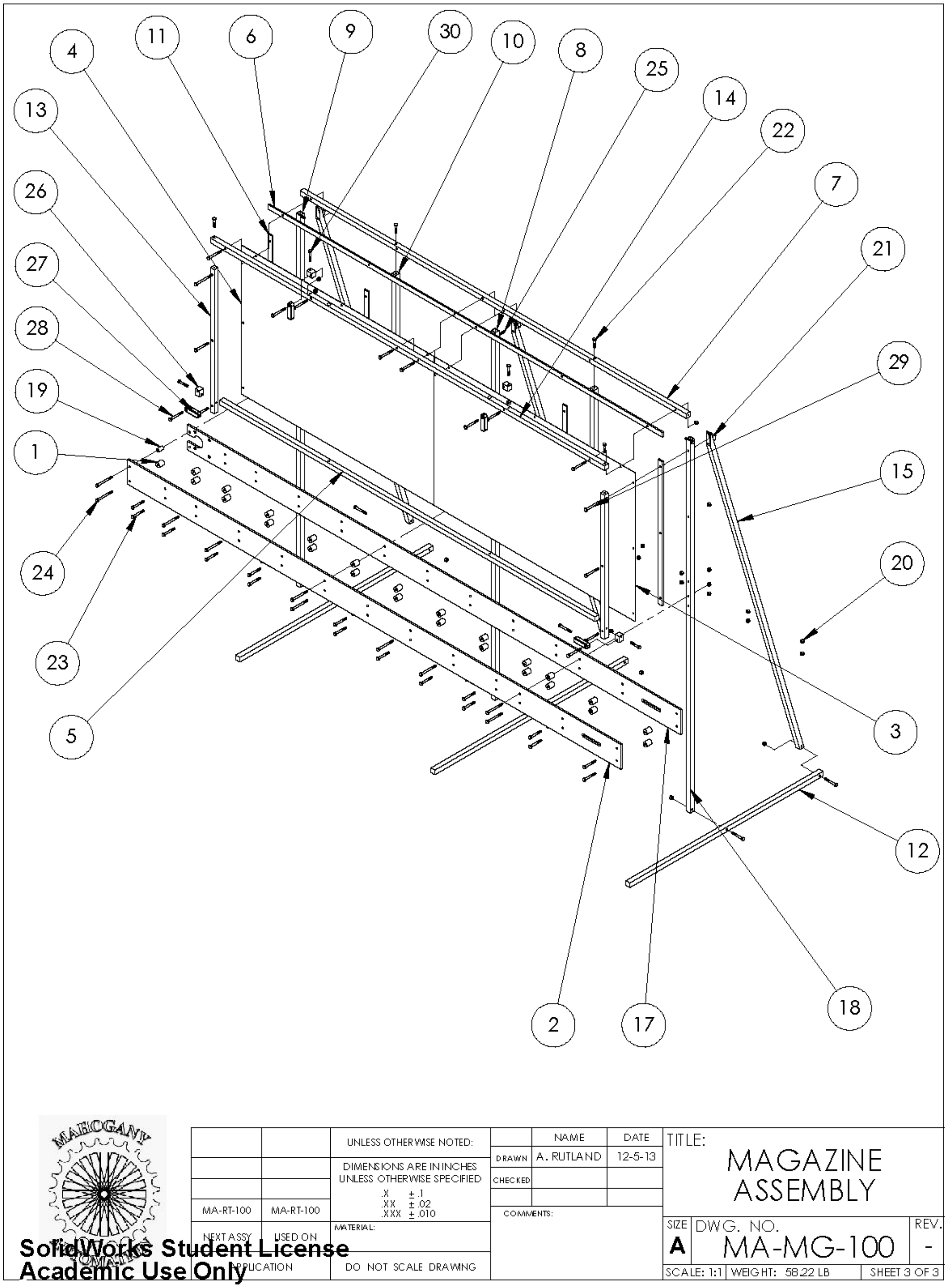


Figure G.8. Magazine sub-assembly exploded-view drawing.

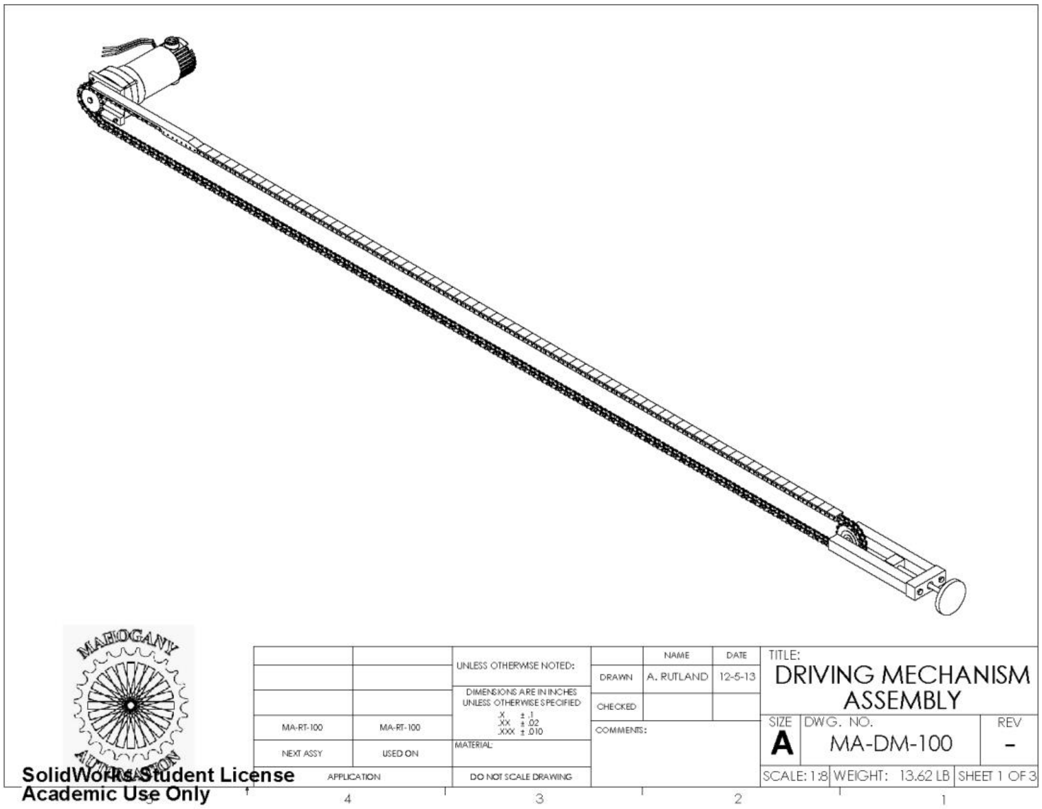


Figure G.9. Driving mechanism sub-assembly drawing.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MA-SK1508	DRIVING SPROCKET, 15 TOOTH	1
2	MA-DMC001	STANDARD .5 IN. PITCH CHAIN	1
3	MA-DMC002	6 FT CHAIN WITH FLAT TOP INSERTS	1
4	-	-	-
5	-	-	-
6	MA-SK1808	IDLER SPROCKET	1
7	MA-DMR003	IDLER SPROCKET SHAFT	1
8	MA-DMQ004	TENSIONER ARM	2
9	MA-DMQ005	TENSIONER BRACE	1
10	MA-FAH424	1/4-20 1.50L HEX HEAD BOLT	2
11	MA-DMX006	CHAIN TENSIONER ADJUSTER	1
12	MA-DMQ001	PUSHER	1
13	011-175-0025	BISON MOTOR	1
14	MA-DMQ002	MOTOR SPACER	2
15	MA-FAT316	10-32 1.00L BUTTON HEAD CAP SCREW	4

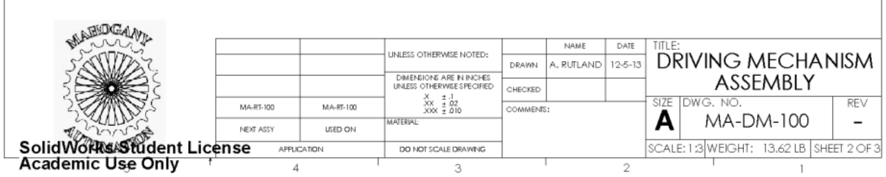


Figure G.10. Driving mechanism sub-assembly BOM.

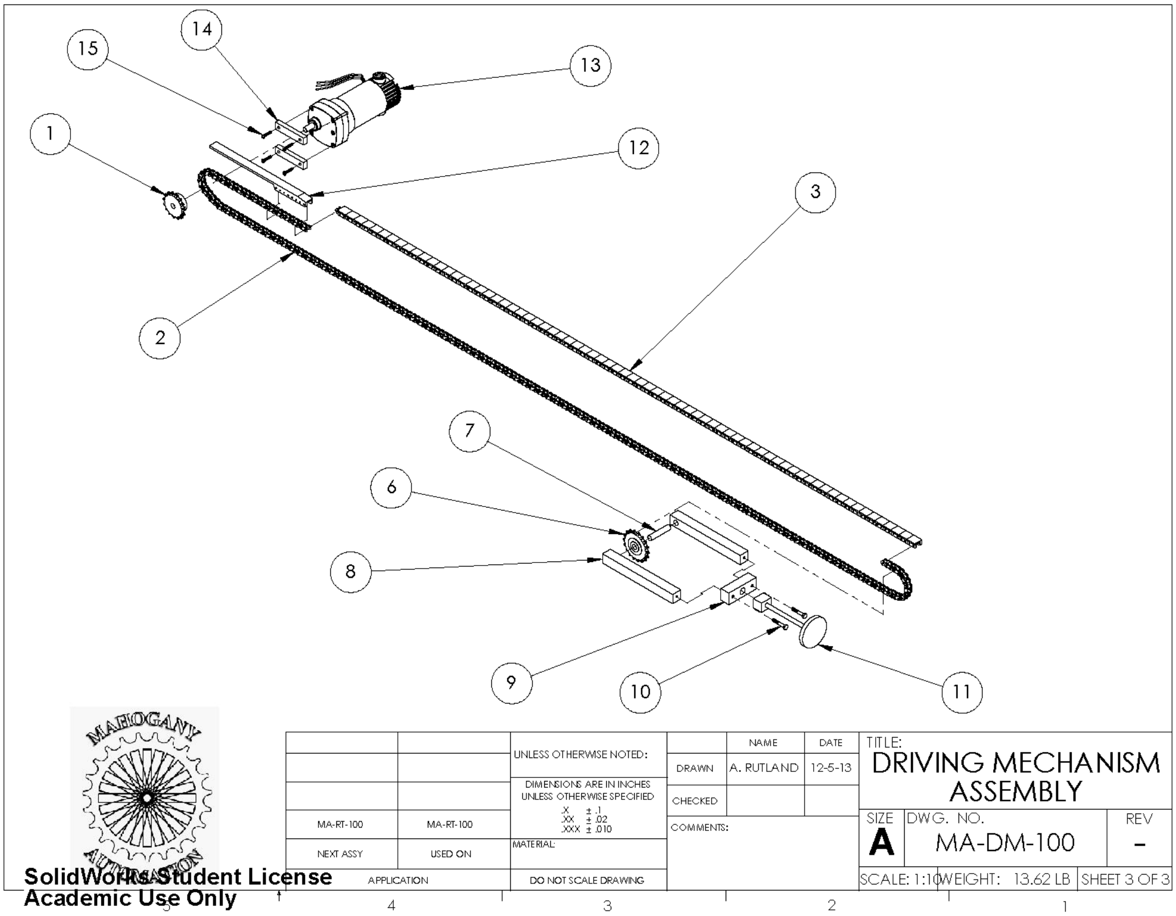


Figure G.11. Driving mechanism sub-assembly exploded-view drawing.

APPENDIX H. COMPONENT DRAWINGS – ROUTER TABLE

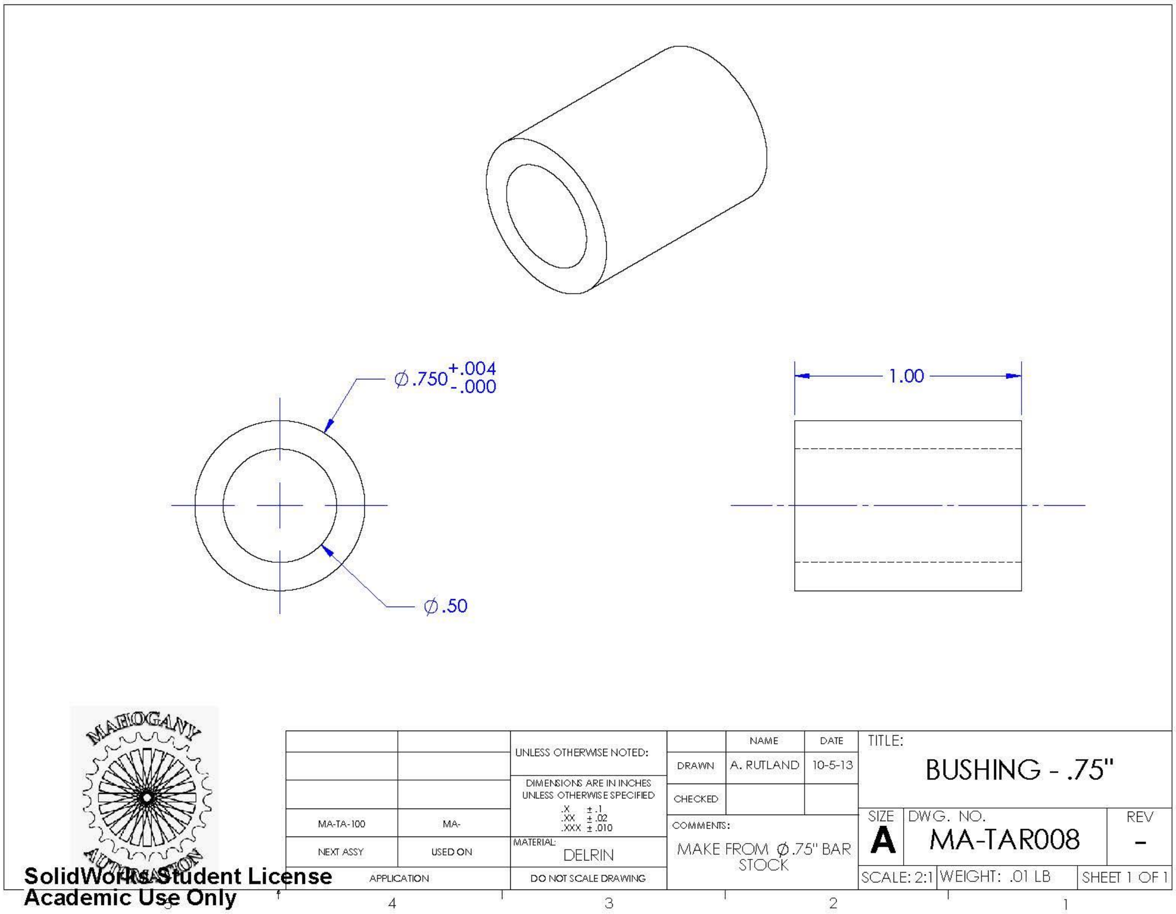


Figure H.1. Delrin bushing drawing

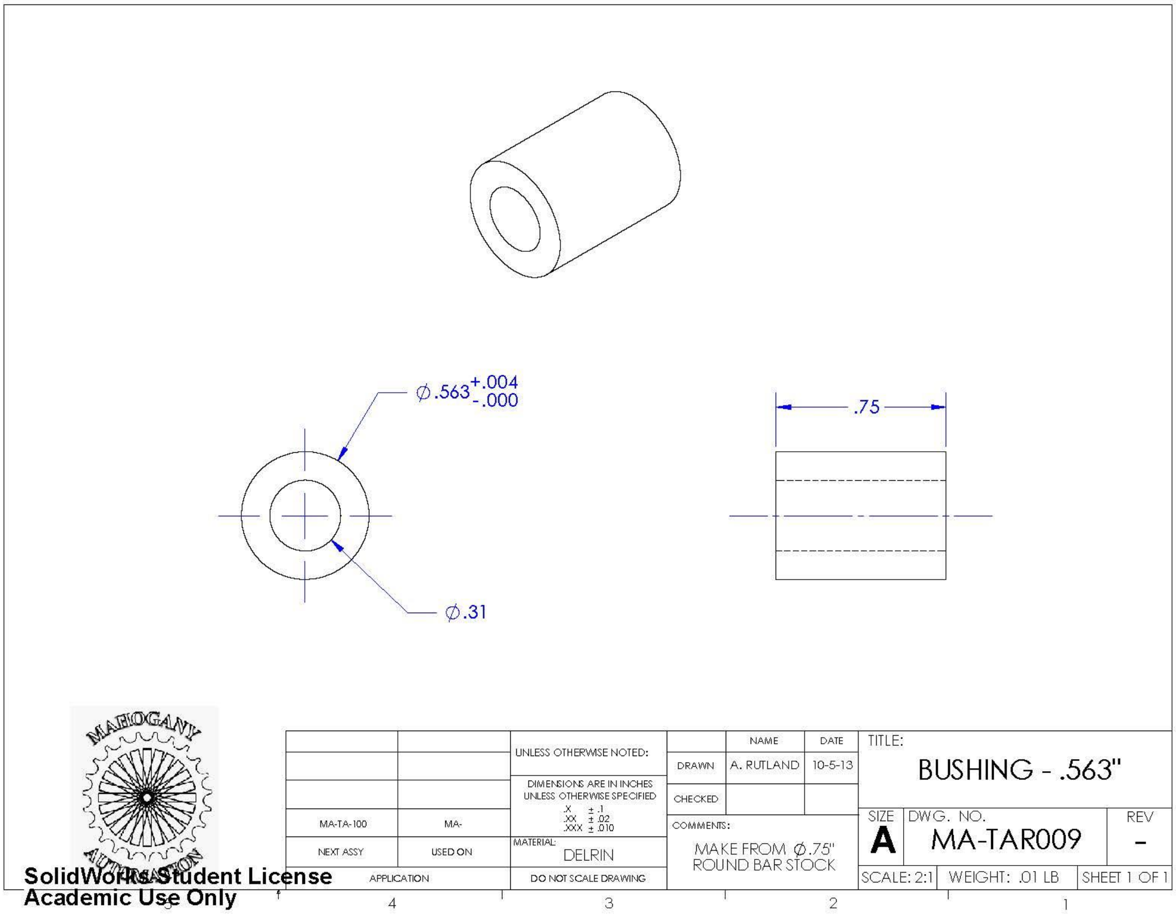


Figure H.2. Delrin bushing drawing

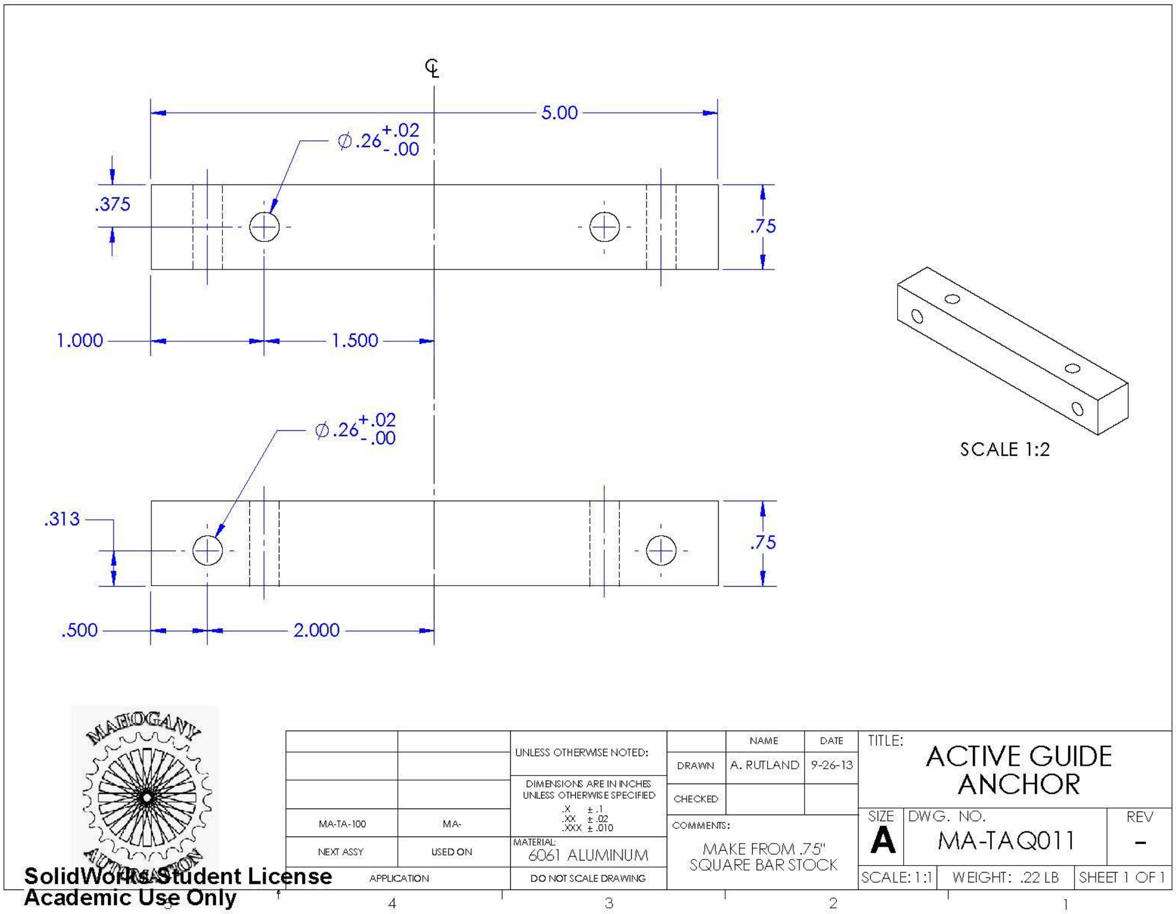


Figure H.3. Aluminum active guide anchor drawing

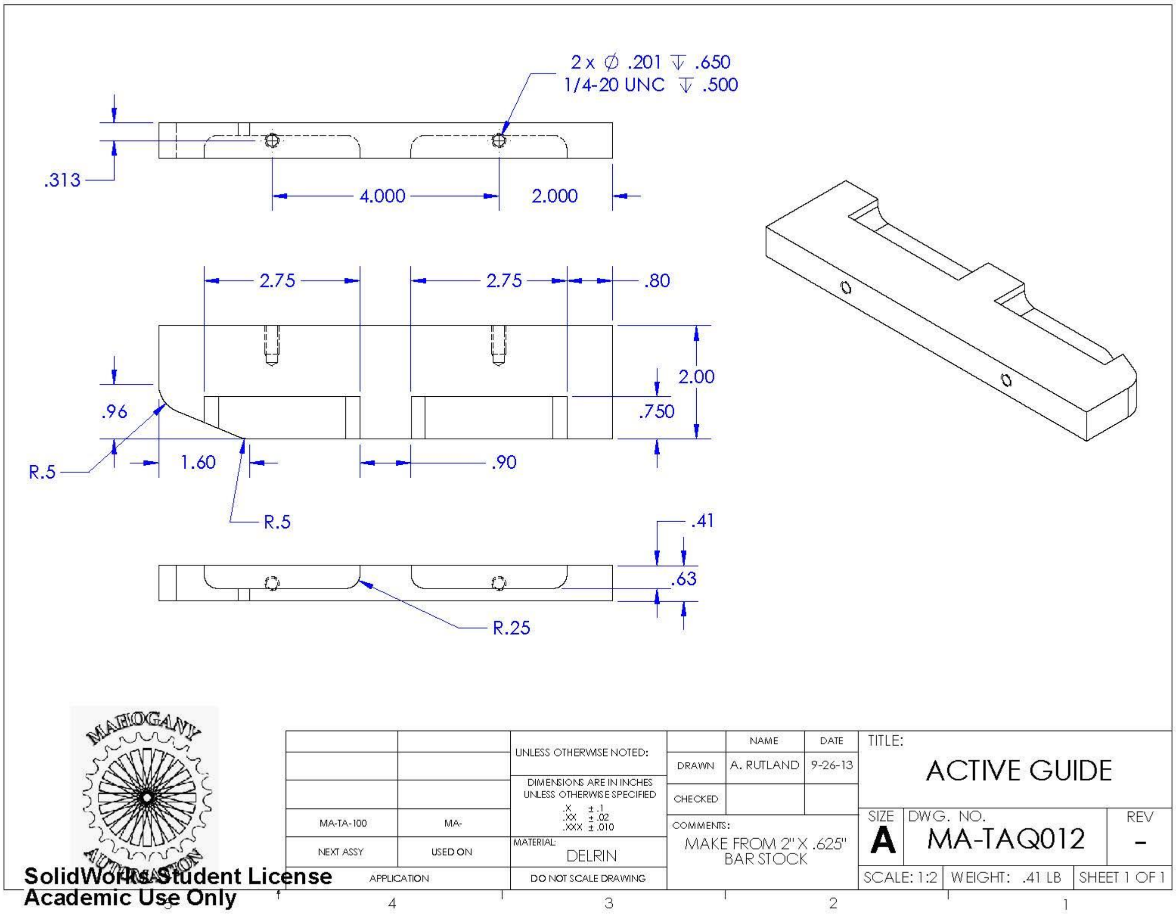


Figure H.4. Delrin active guide drawing

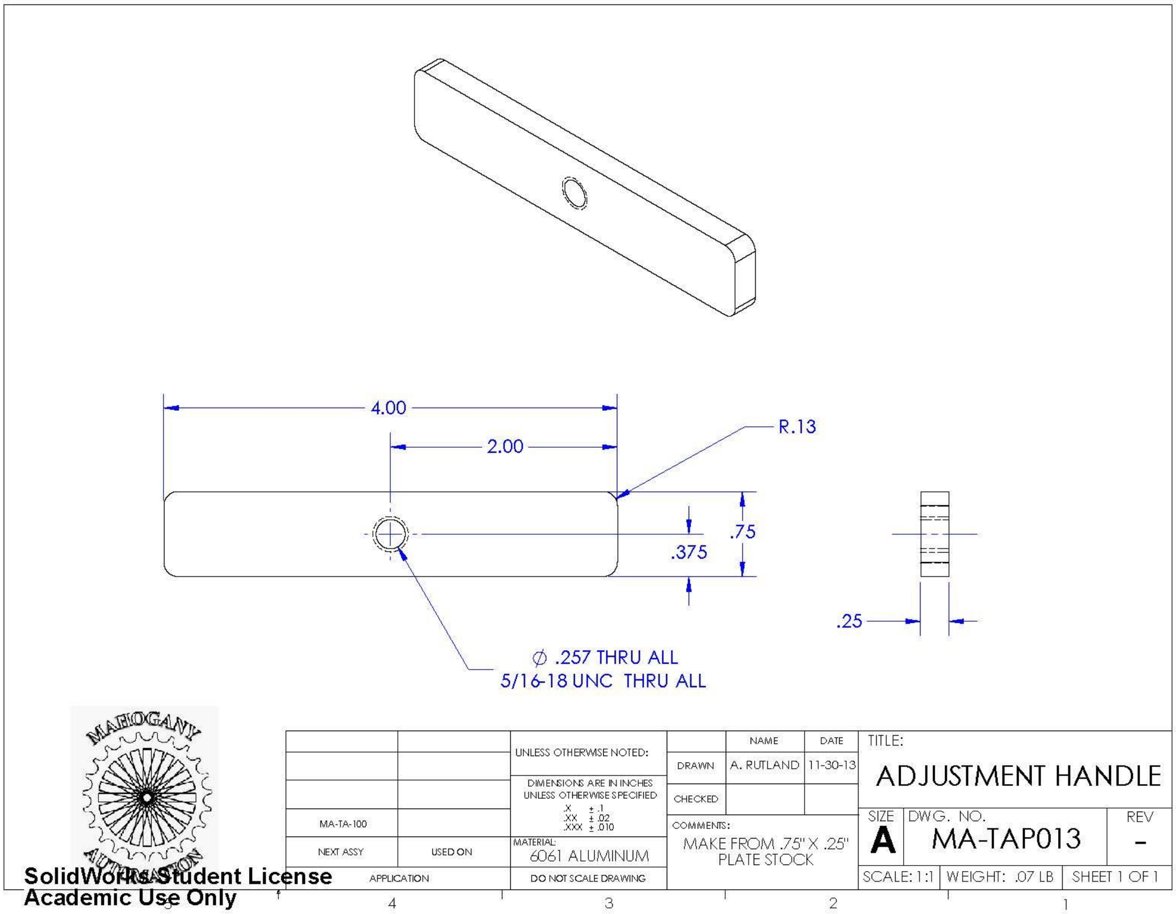


Figure H.5. Aluminum adjustment handle drawing

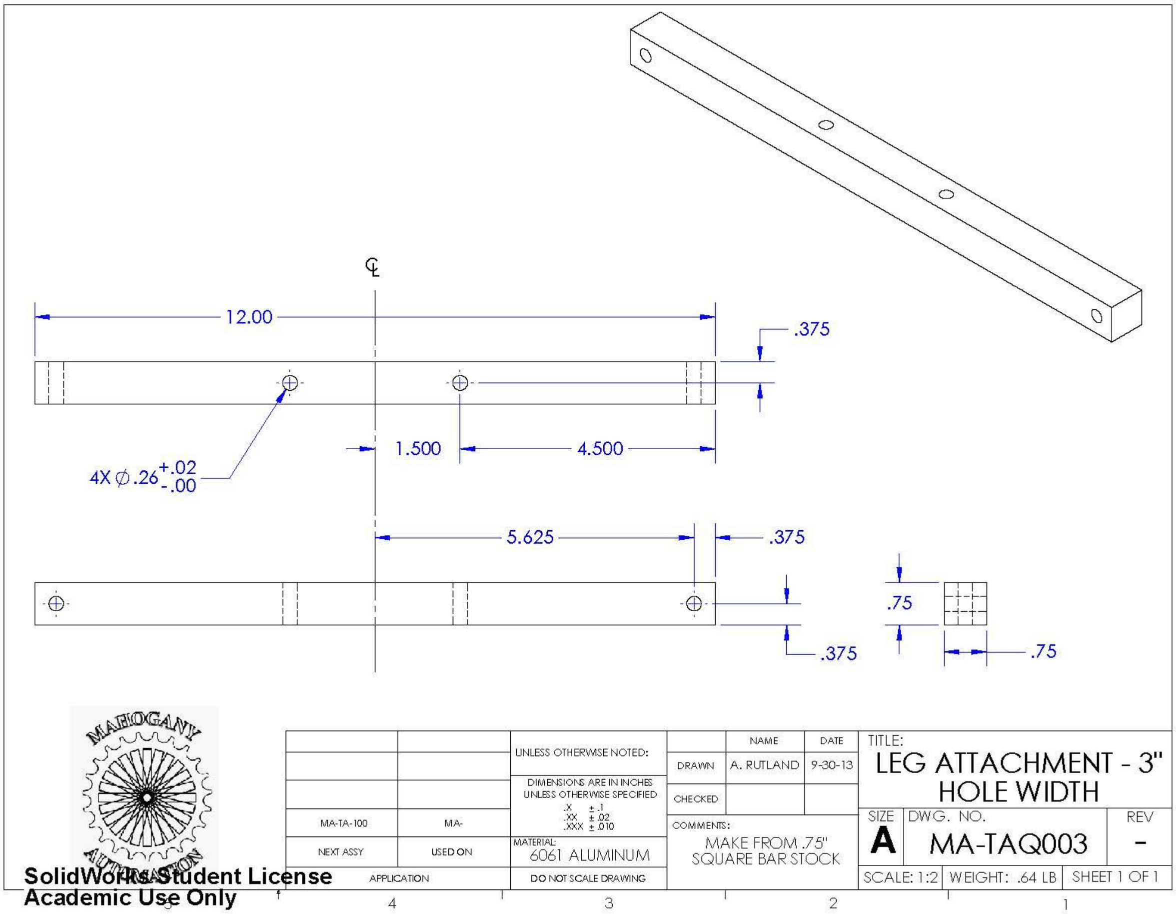


Figure H.6. Aluminum leg attachment – 3” hole width

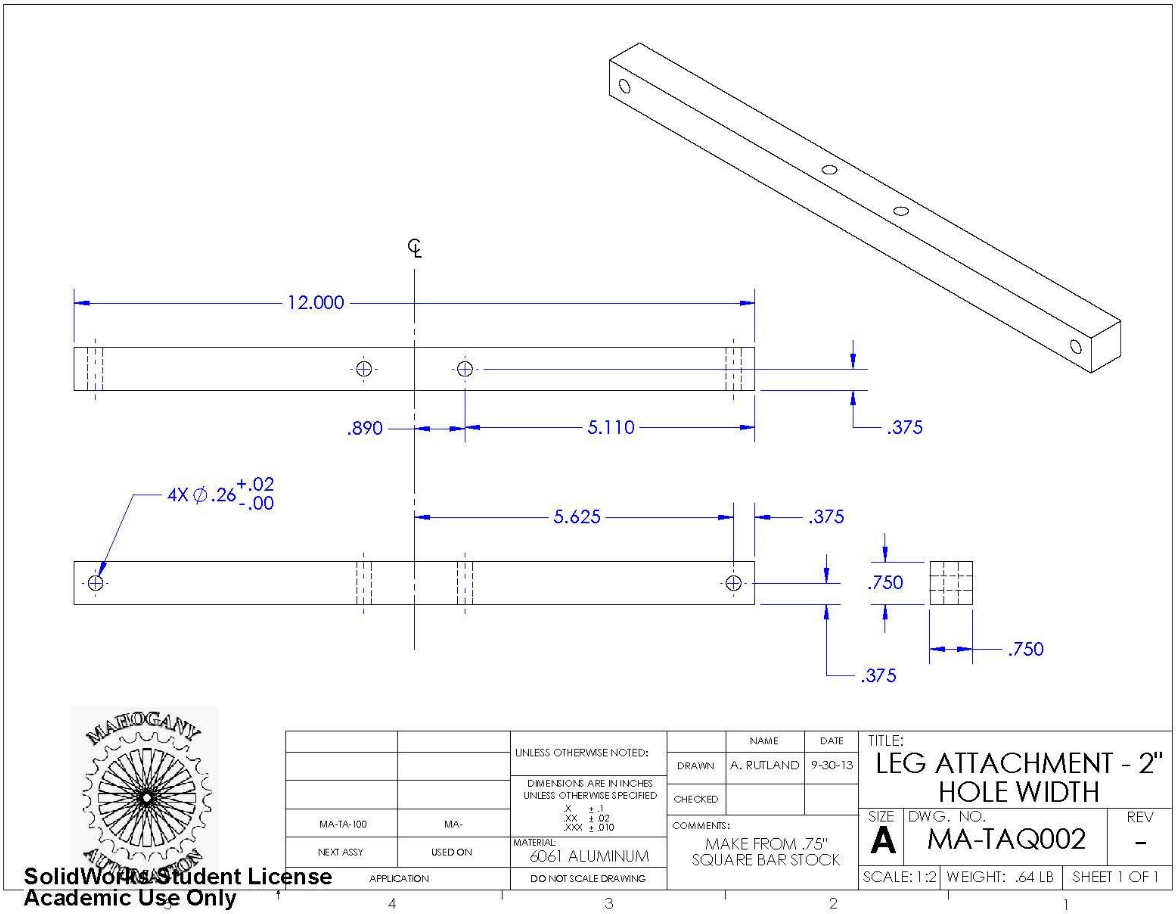


Figure H.7. Aluminum leg attachment – 2” hole width

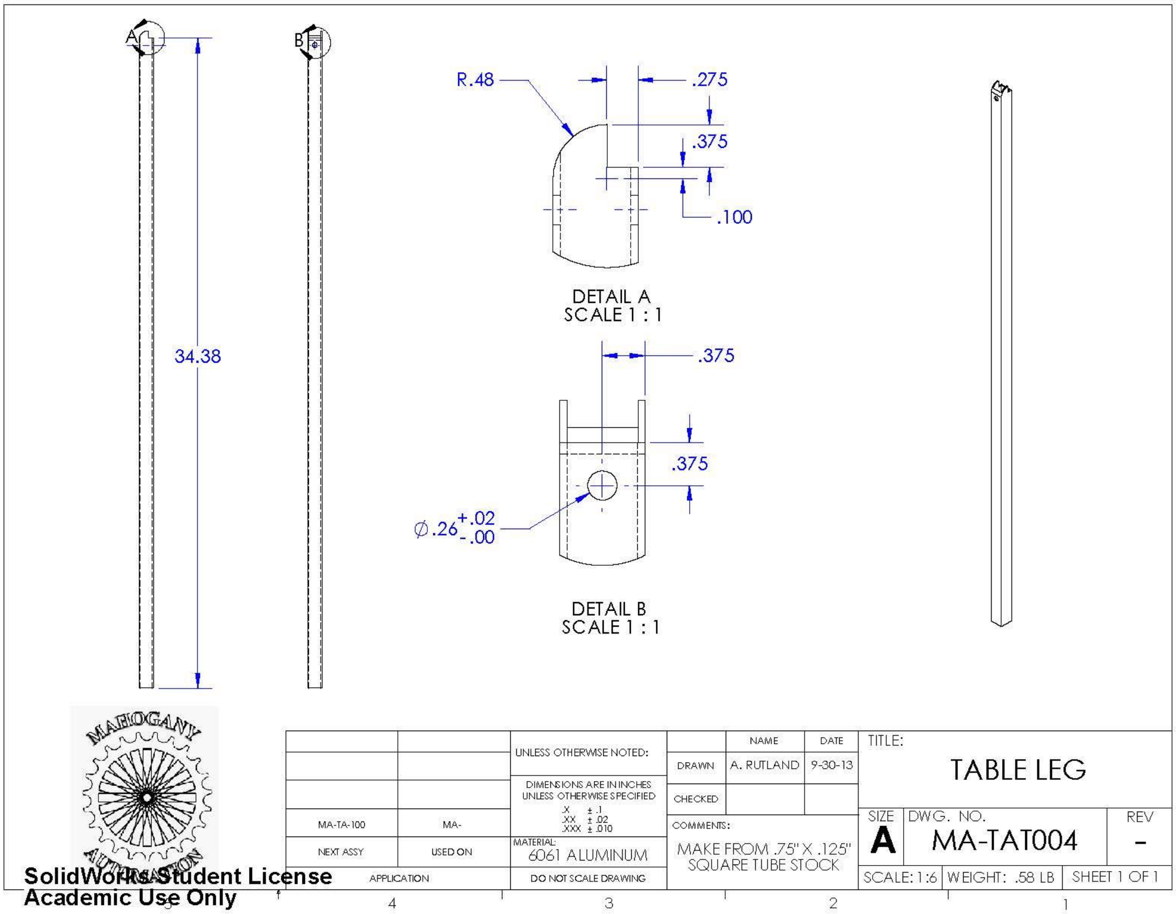


Figure H.8. Aluminum table leg drawing

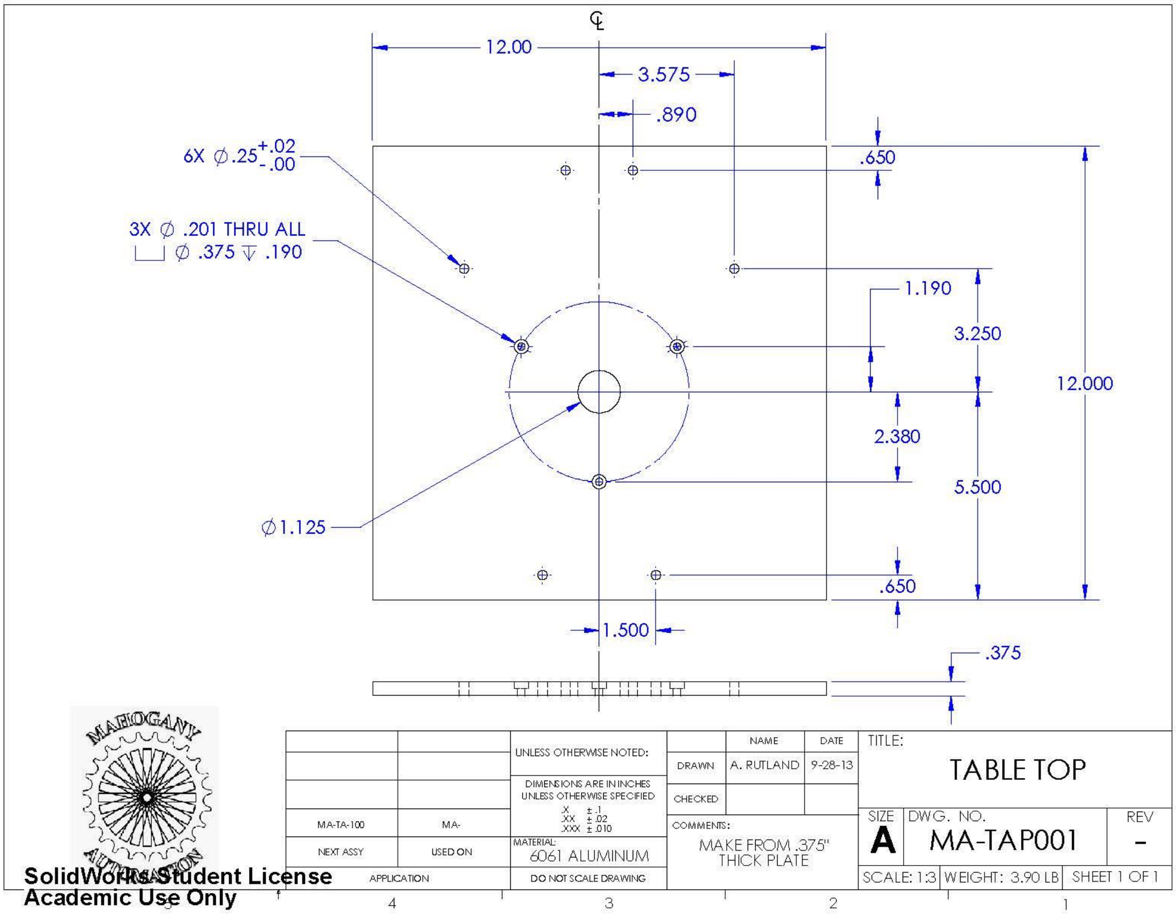


Figure H.9. Aluminum table top drawing

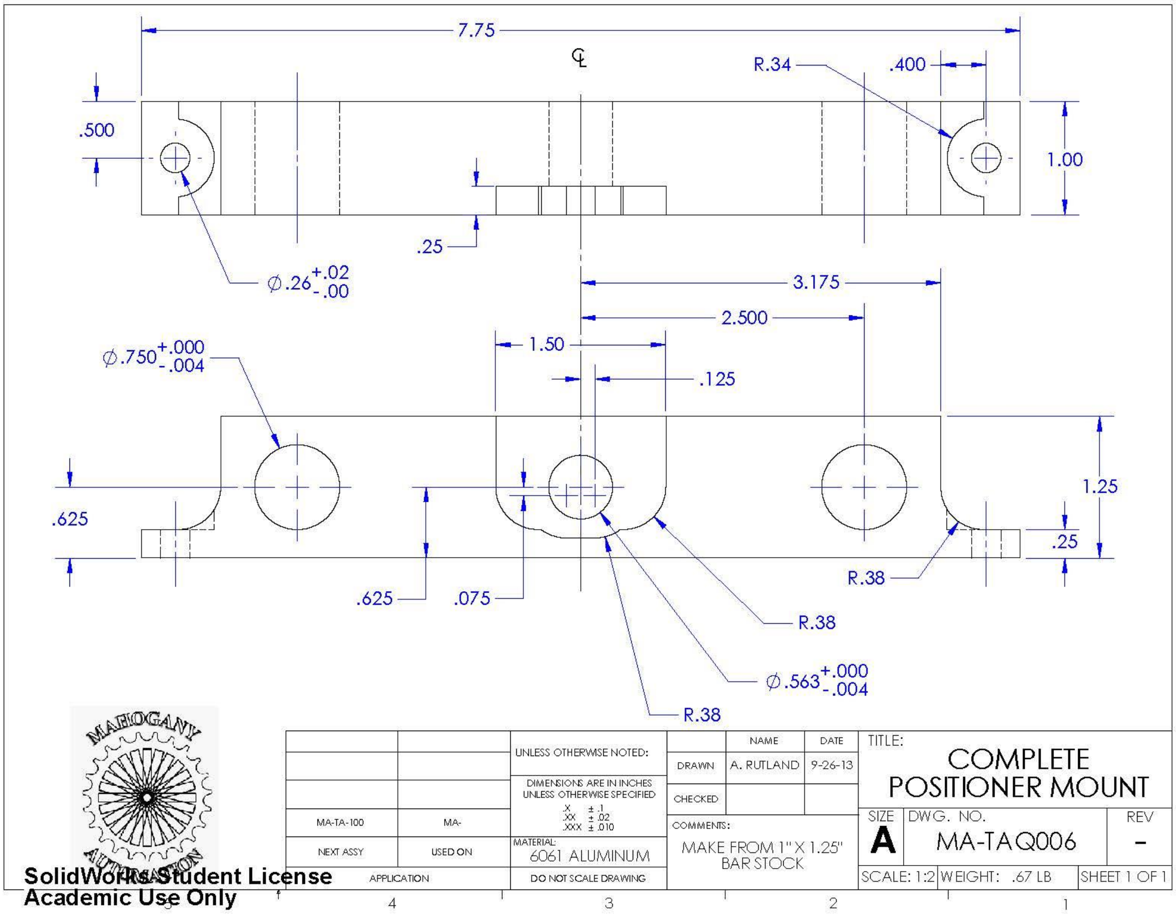


Figure H.10. Aluminum positioner mount drawing

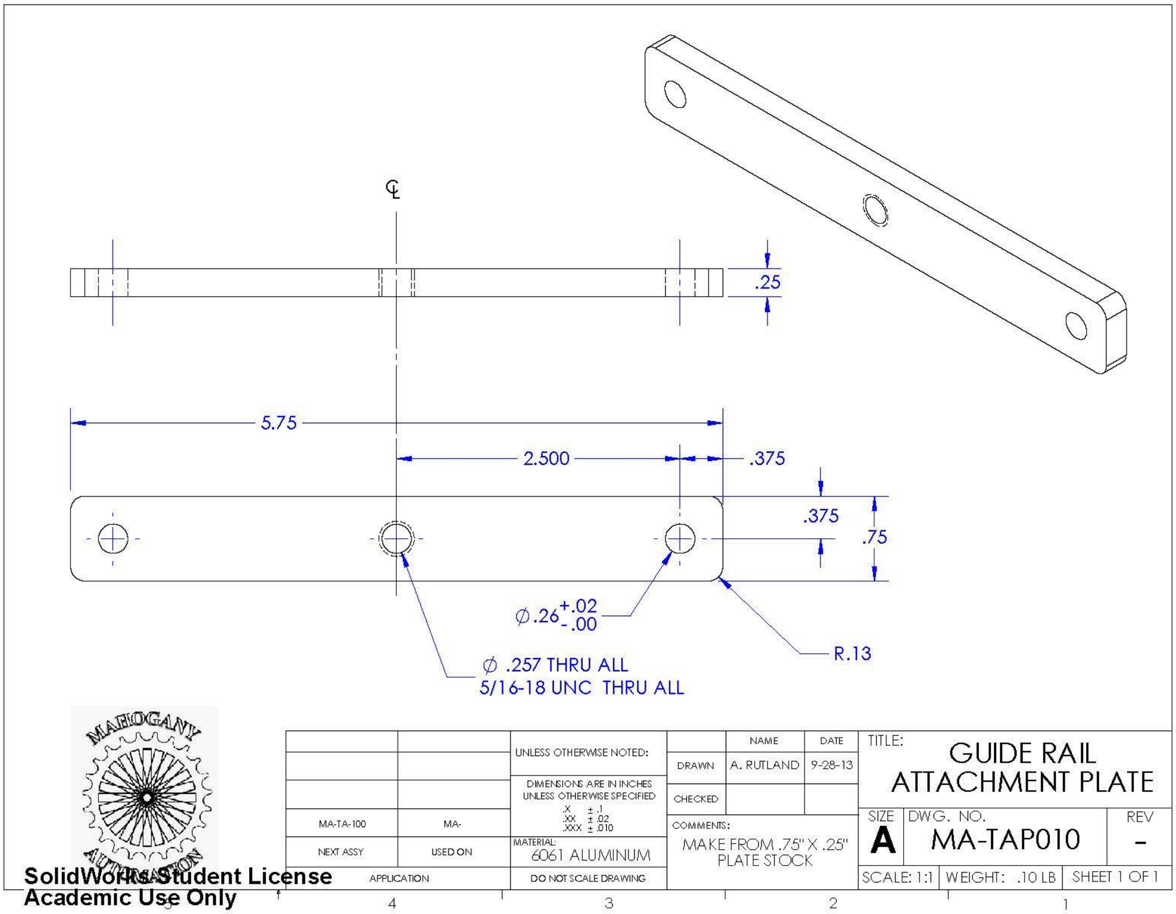


Figure H.11. Aluminum guide rail attachment plate drawing

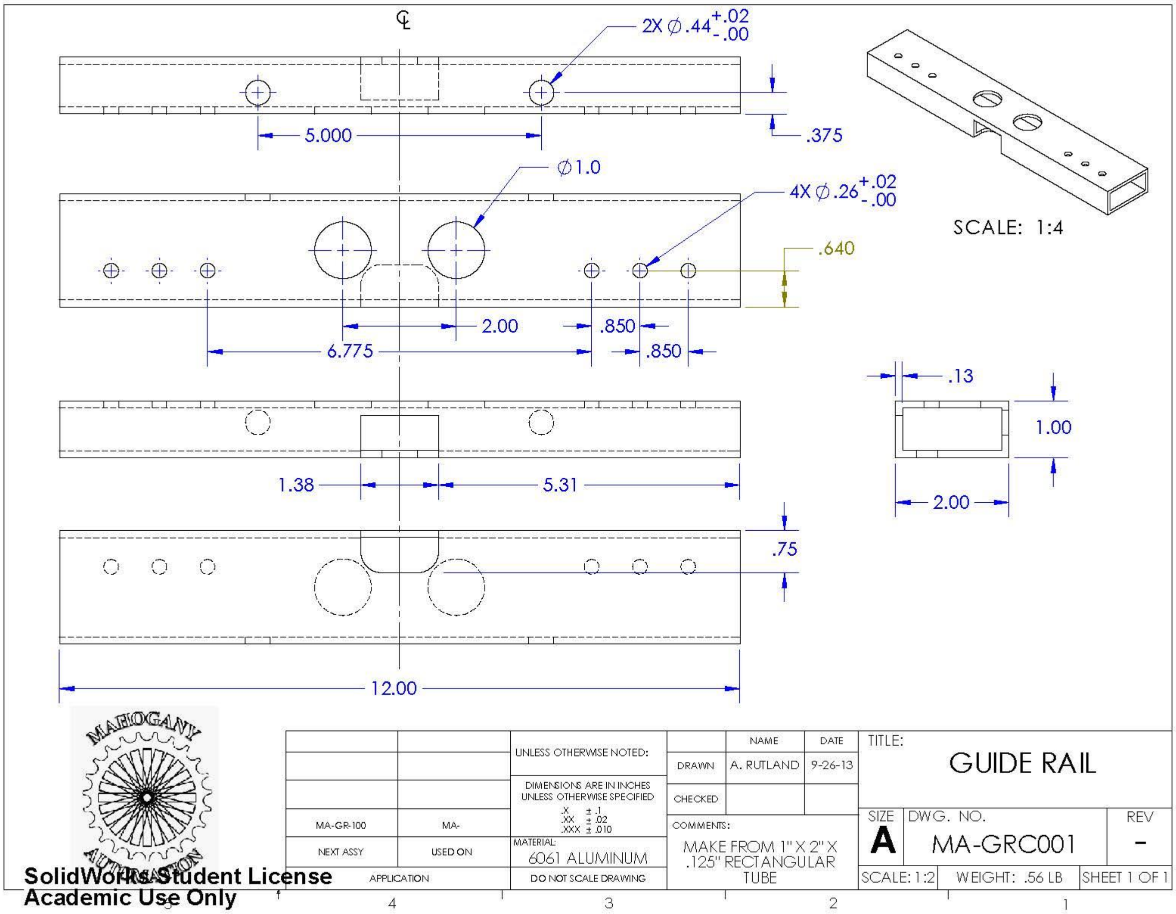


Figure H.12. Aluminum guide rail drawing

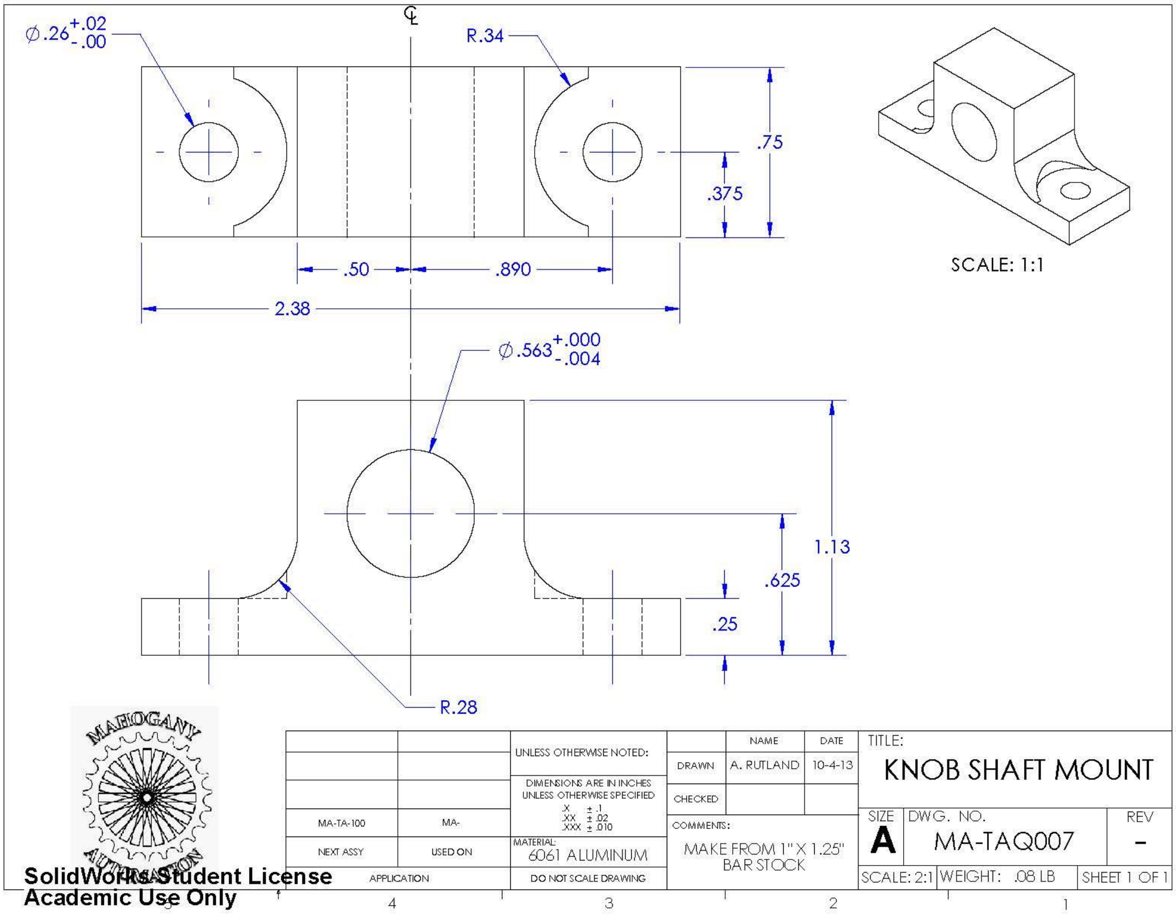


Figure H.13. Aluminum knob shaft mount drawing

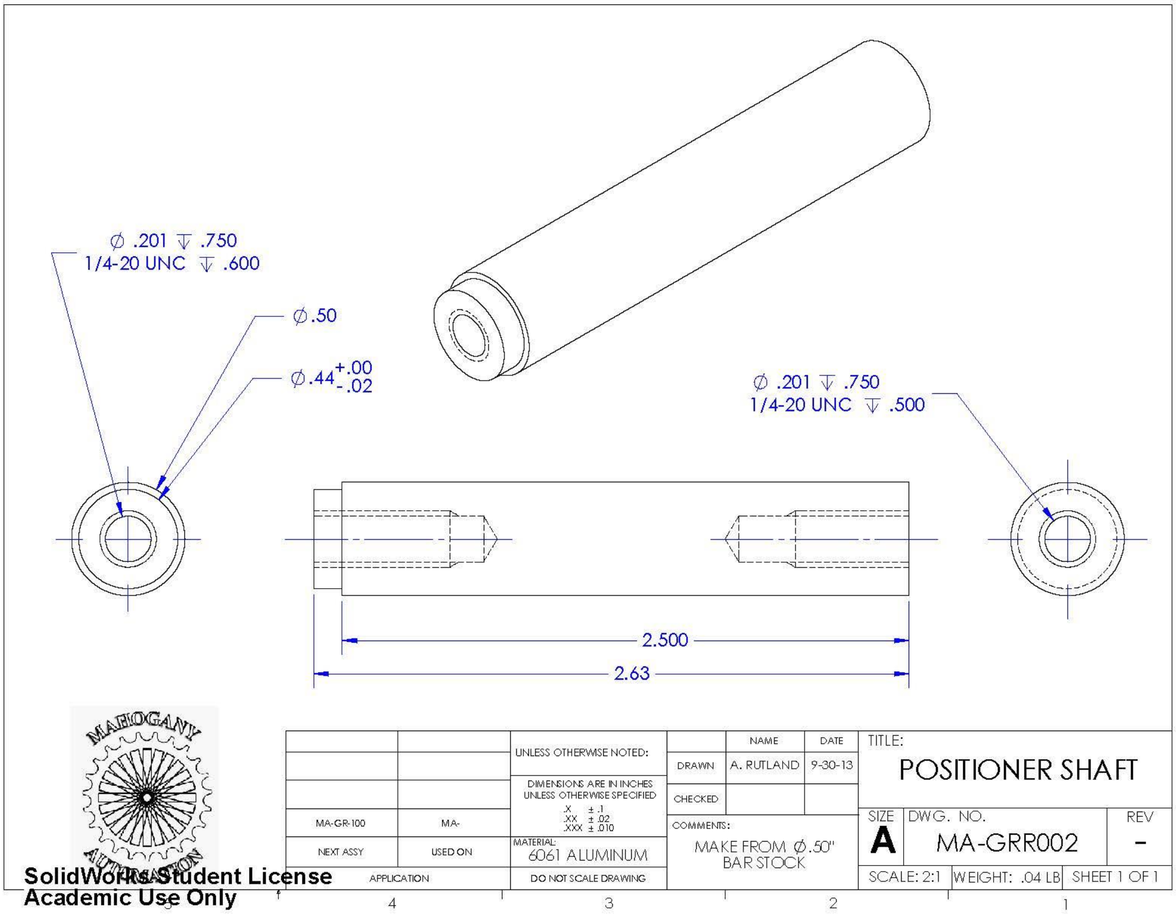


Figure H.14. Aluminum positioner shaft drawing

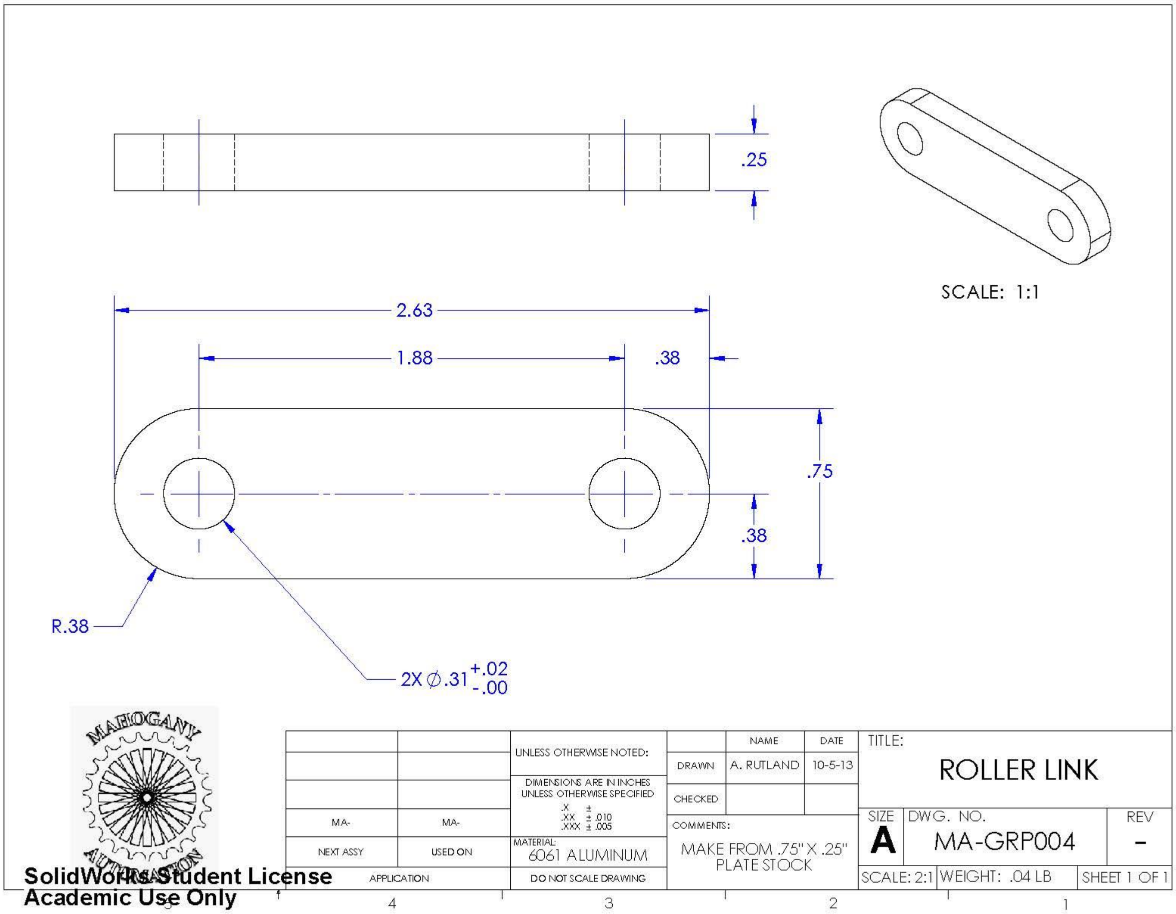


Figure H.15. Aluminum roller link drawing

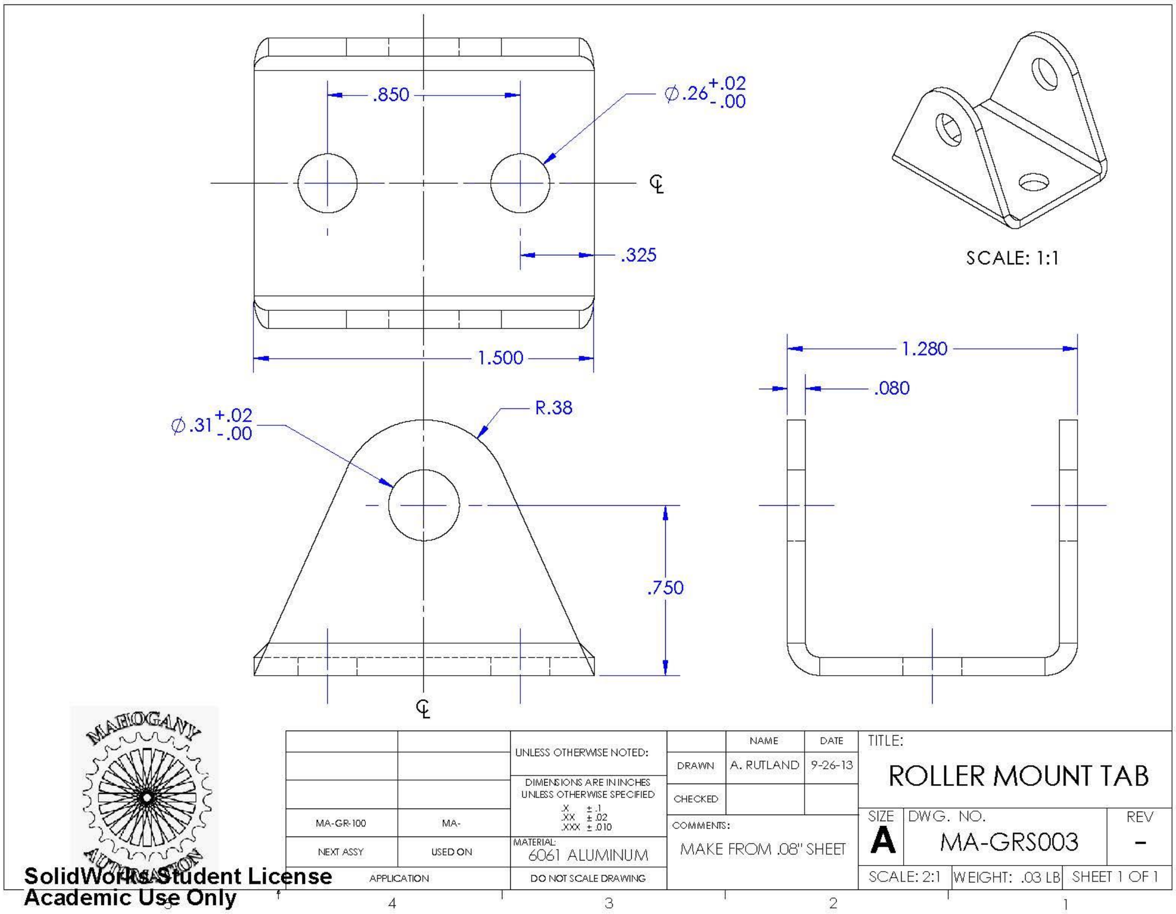


Figure H.16. Aluminum roller mount tab drawing

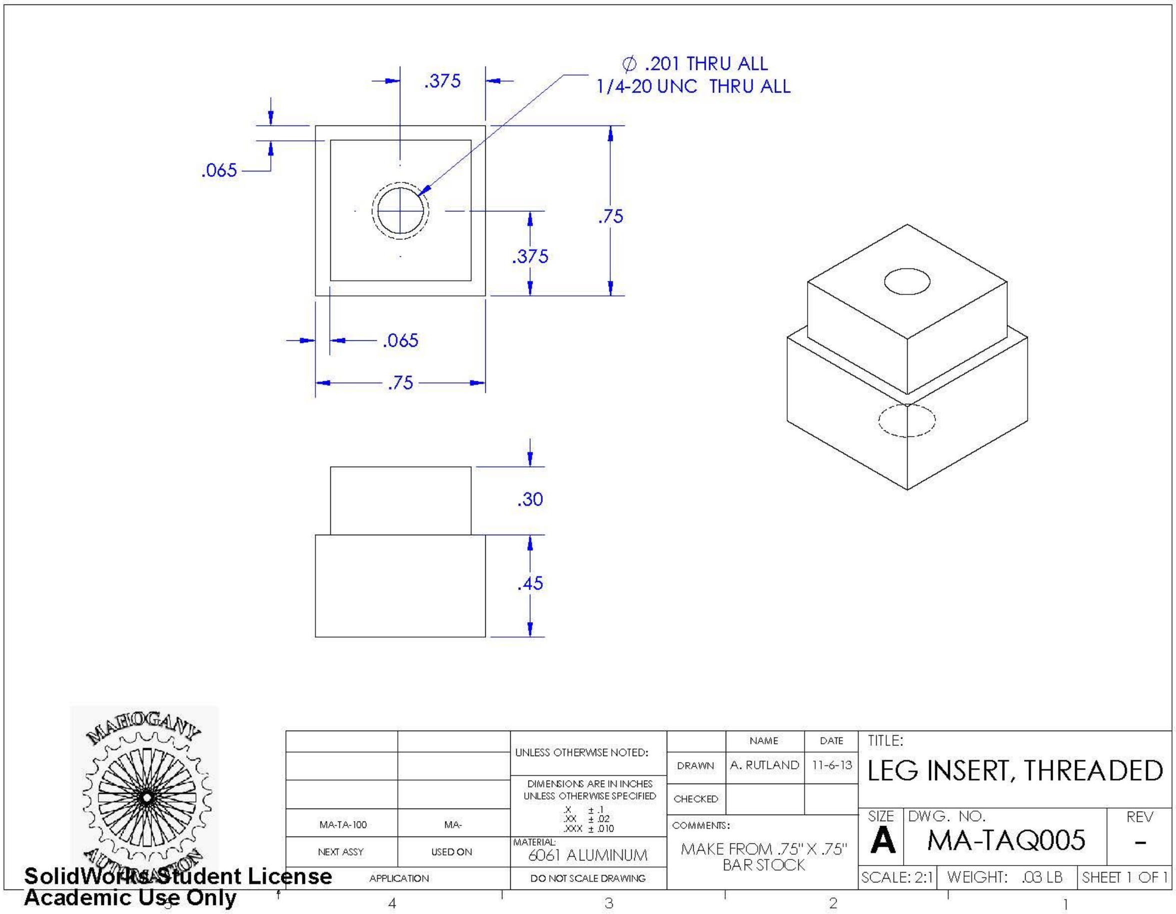


Figure H.17. Aluminum threaded leg insert drawing

APPENDIX I. COMPONENT DRAWINGS - MAGAZINE

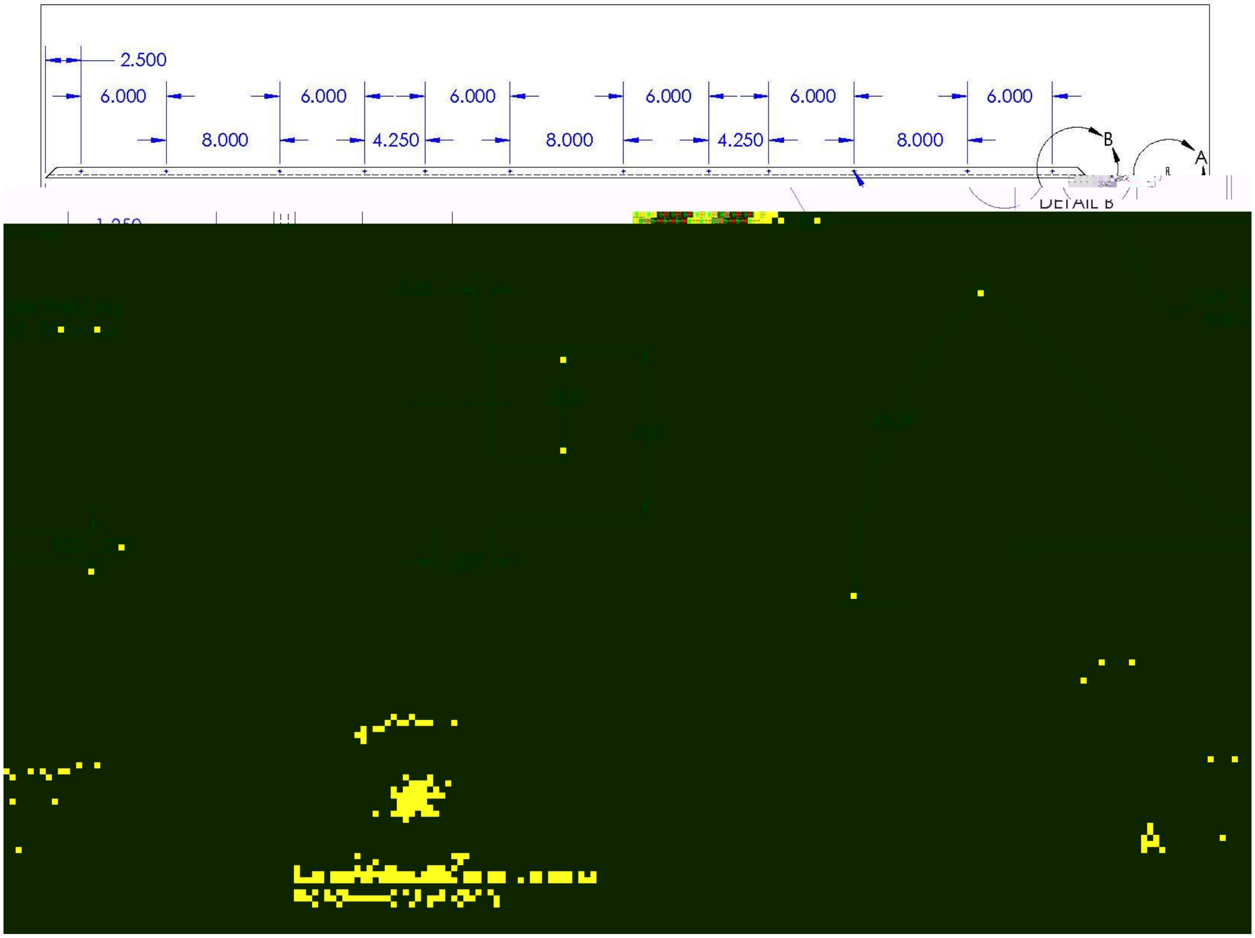


Figure I.1. Aluminum cross door frame drawing

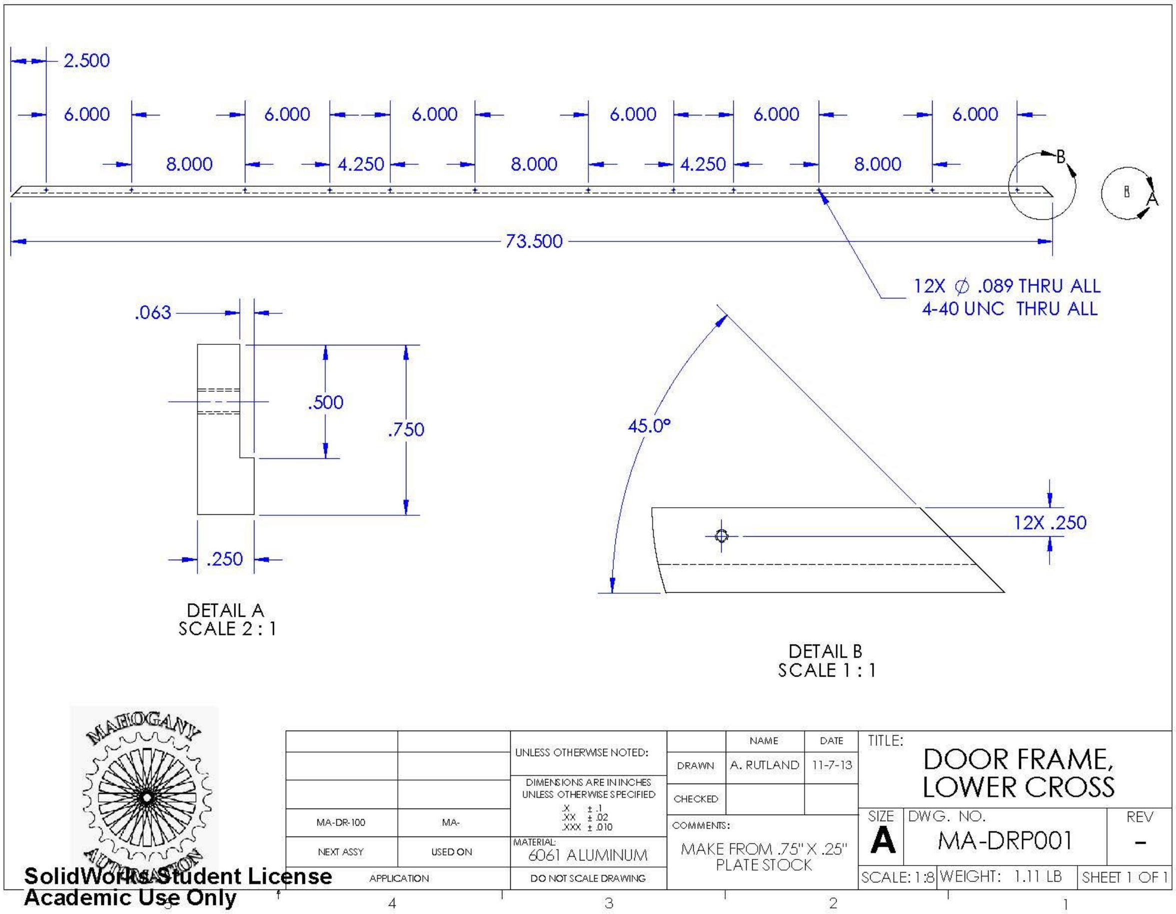


Figure I.2. Aluminum lower cross door frame drawing

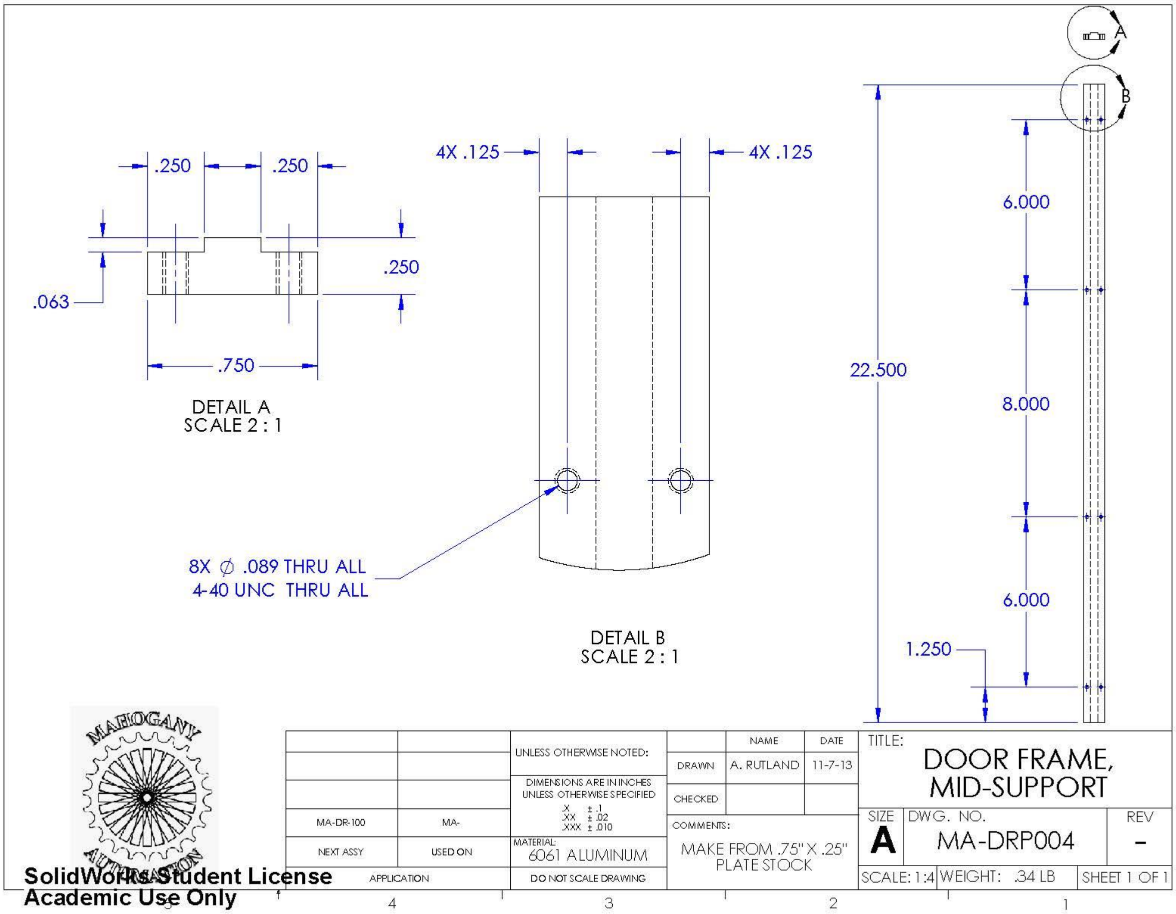


Figure I.3. Aluminum mid-support door frame drawing

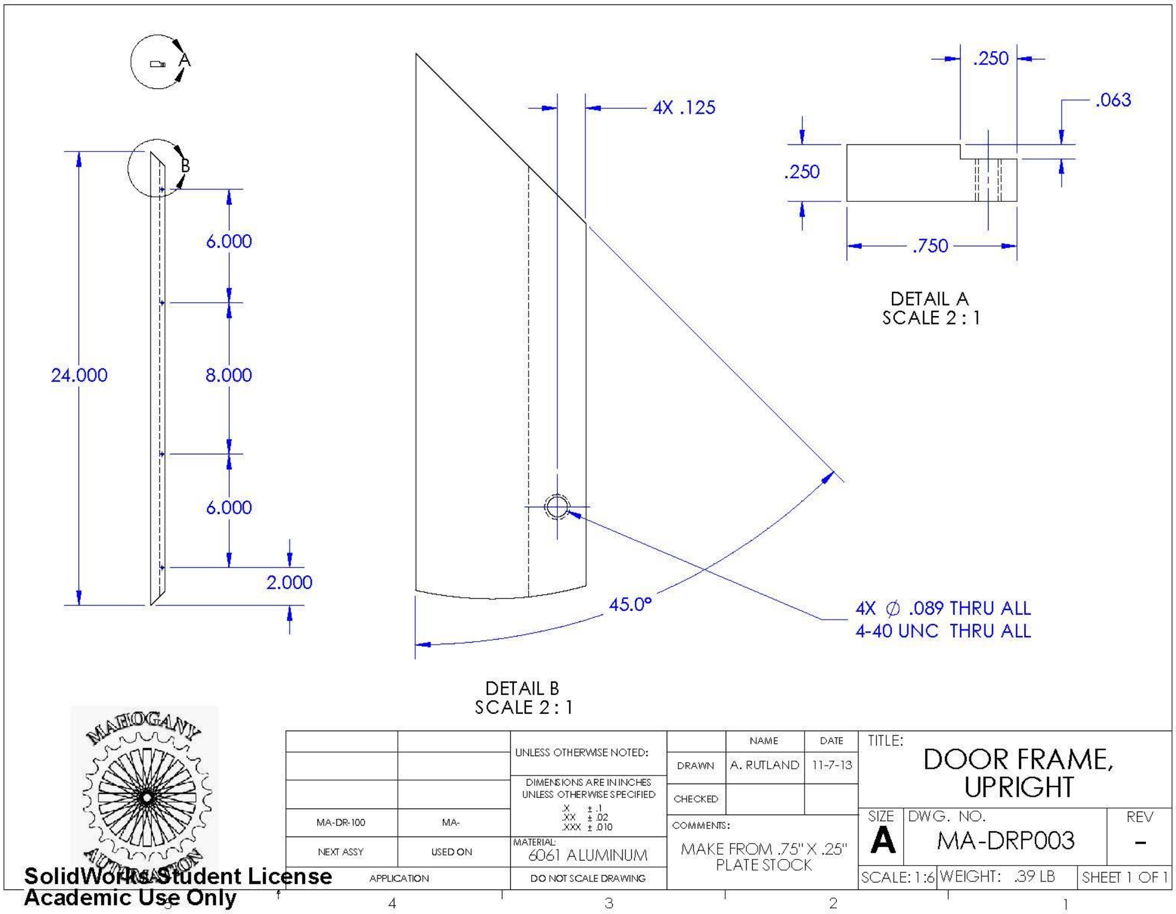


Figure I.4. Aluminum upright door frame drawing

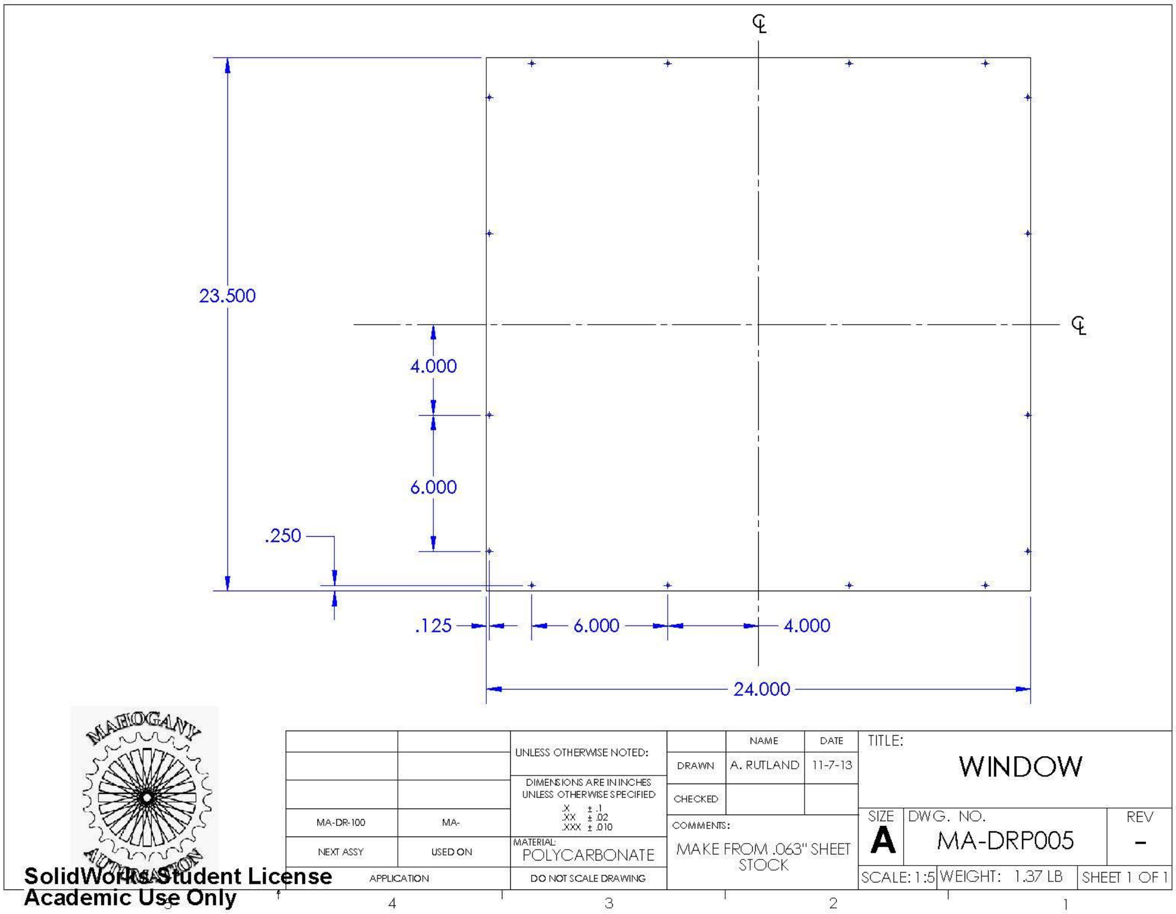


Figure I.5. Acrylic window drawing

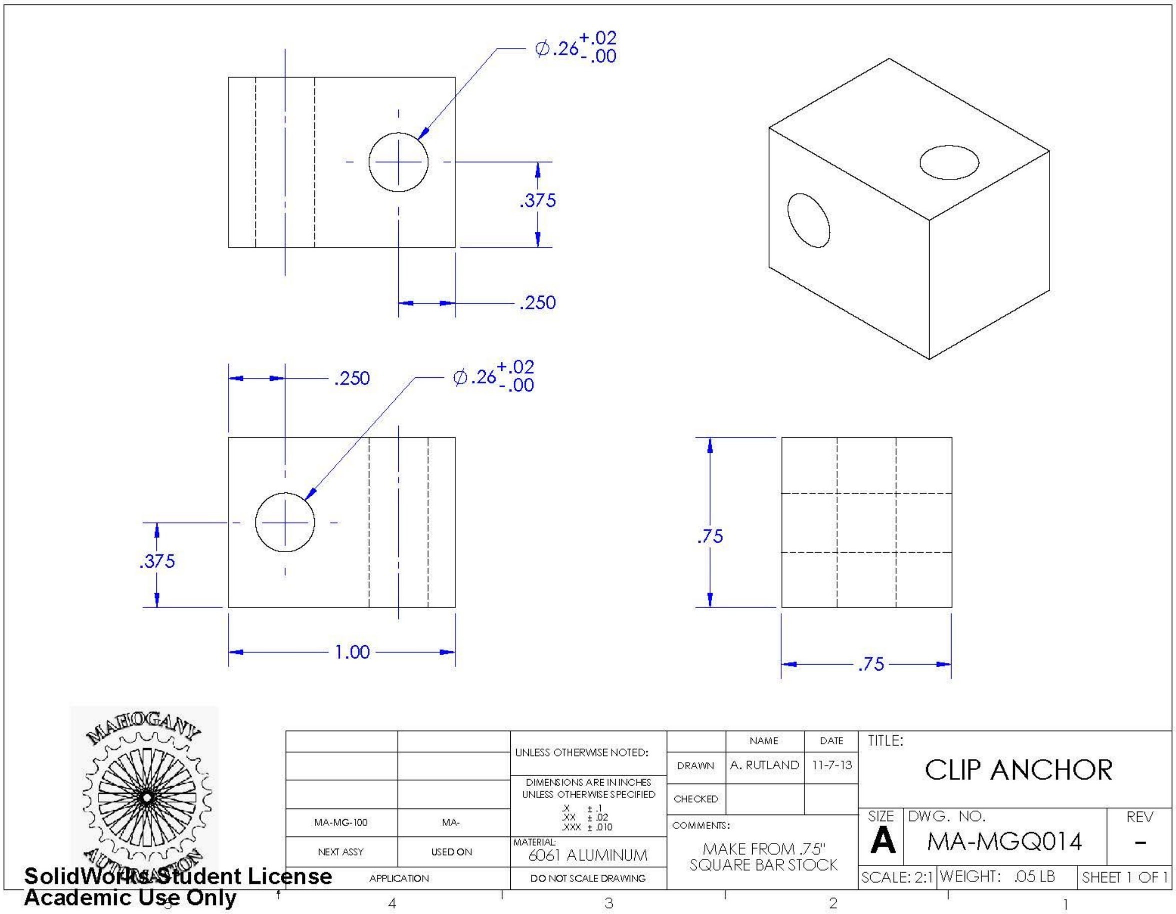


Figure I.6. Aluminum clip anchor drawing

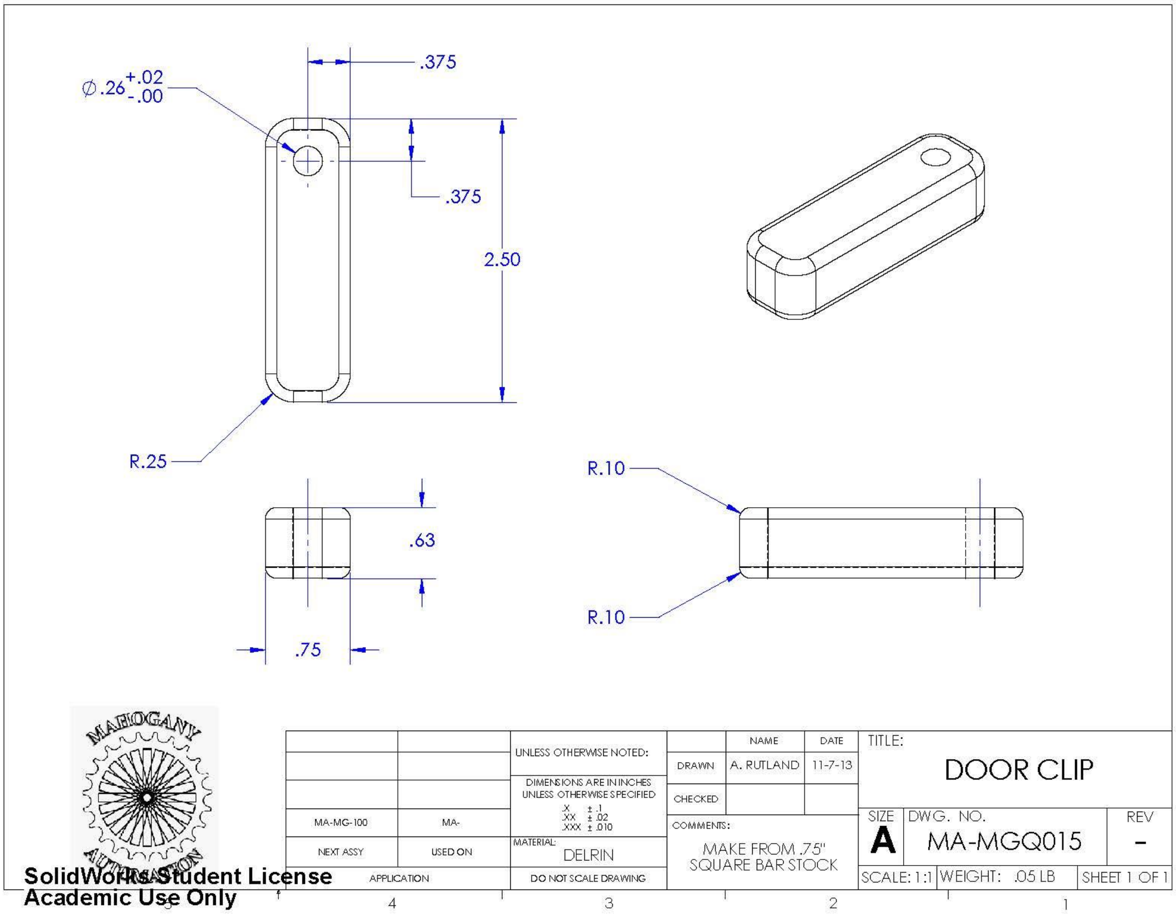


Figure I.7. Aluminum door clip drawing

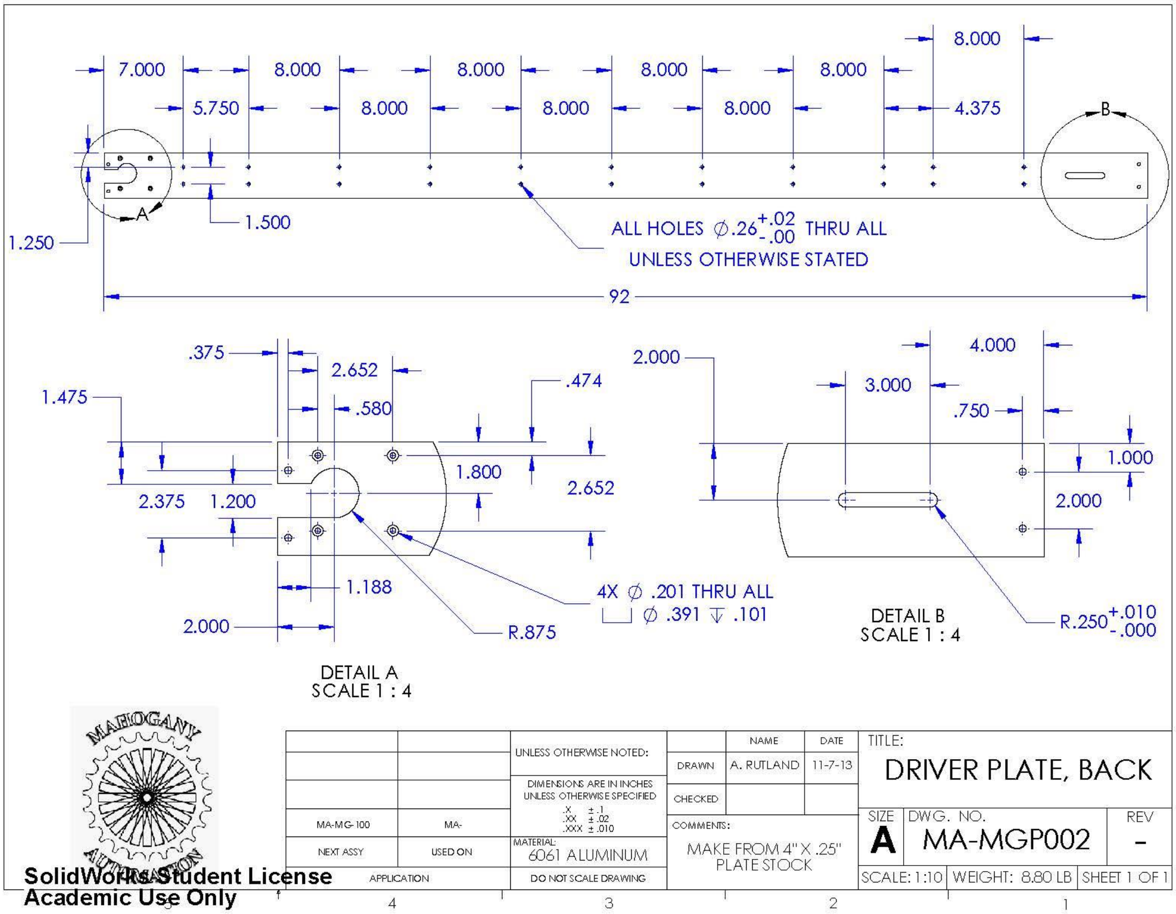


Figure I.8. Aluminum back driver plate drawing

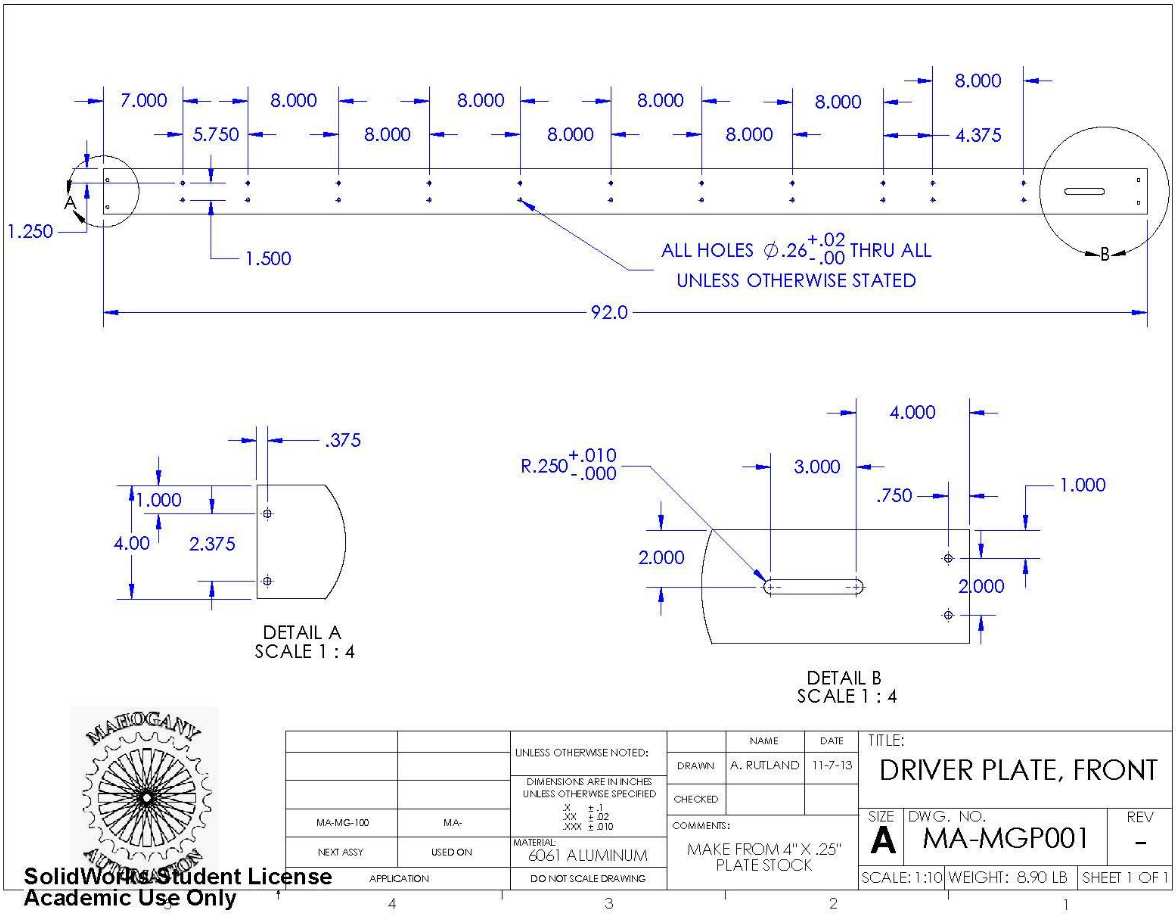


Figure I.9. Aluminum front driver plate

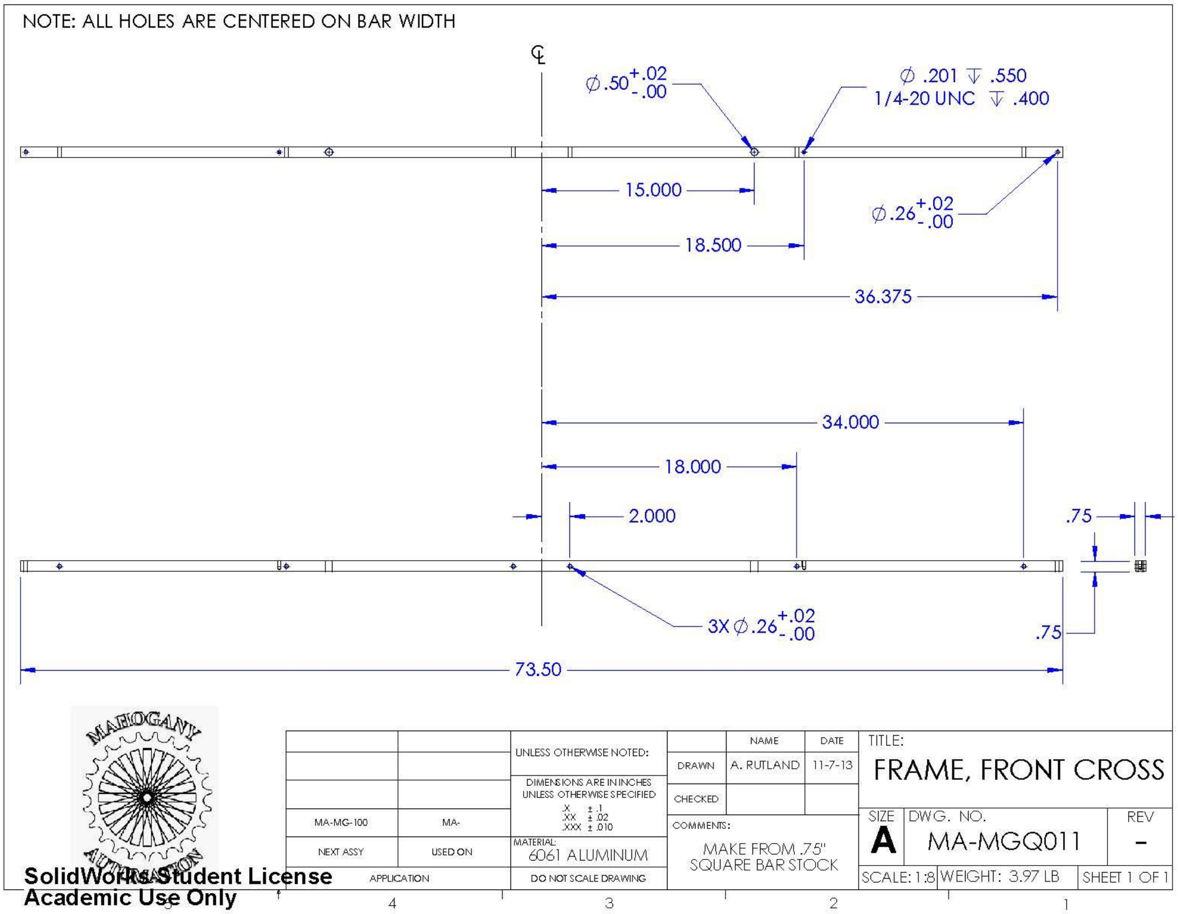


Figure I.10. Aluminum front cross frame drawing

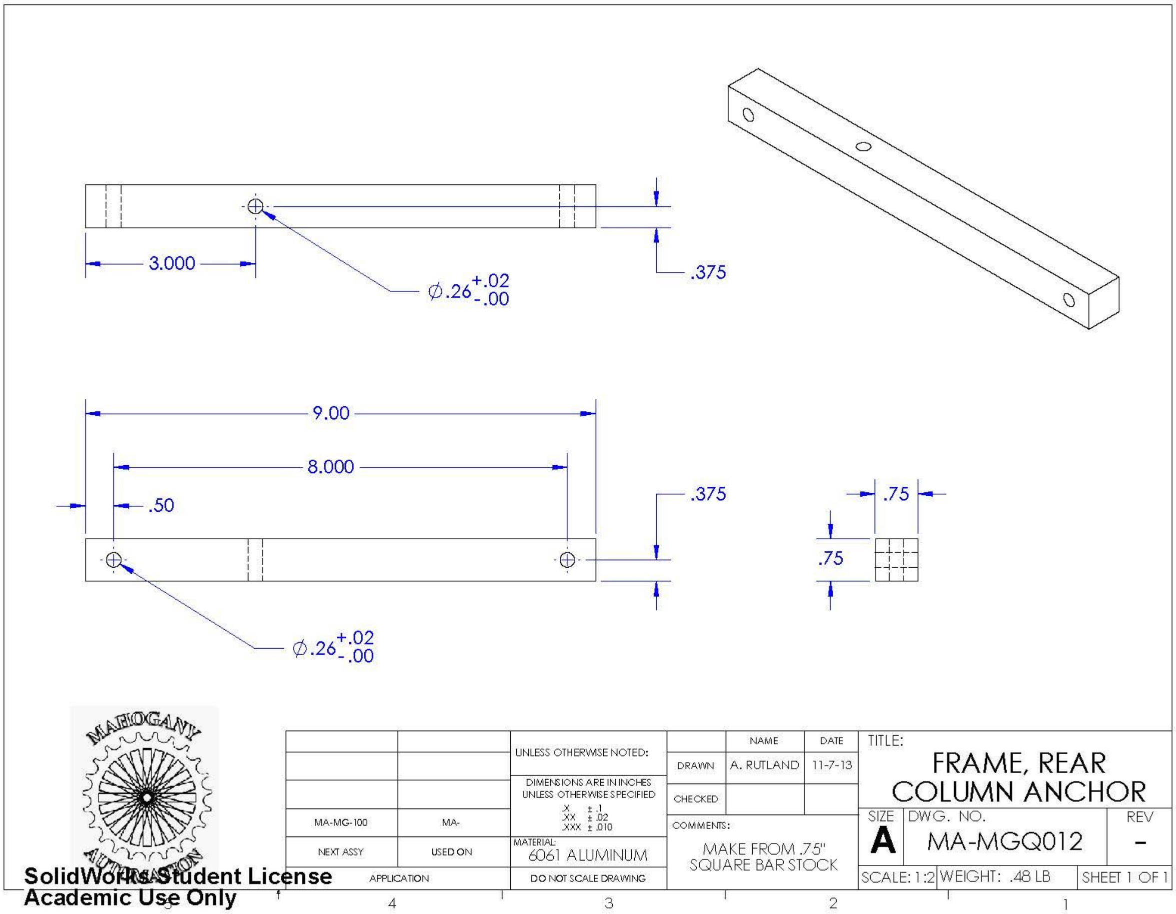


Figure I.11. Aluminum rear column anchor frame drawing

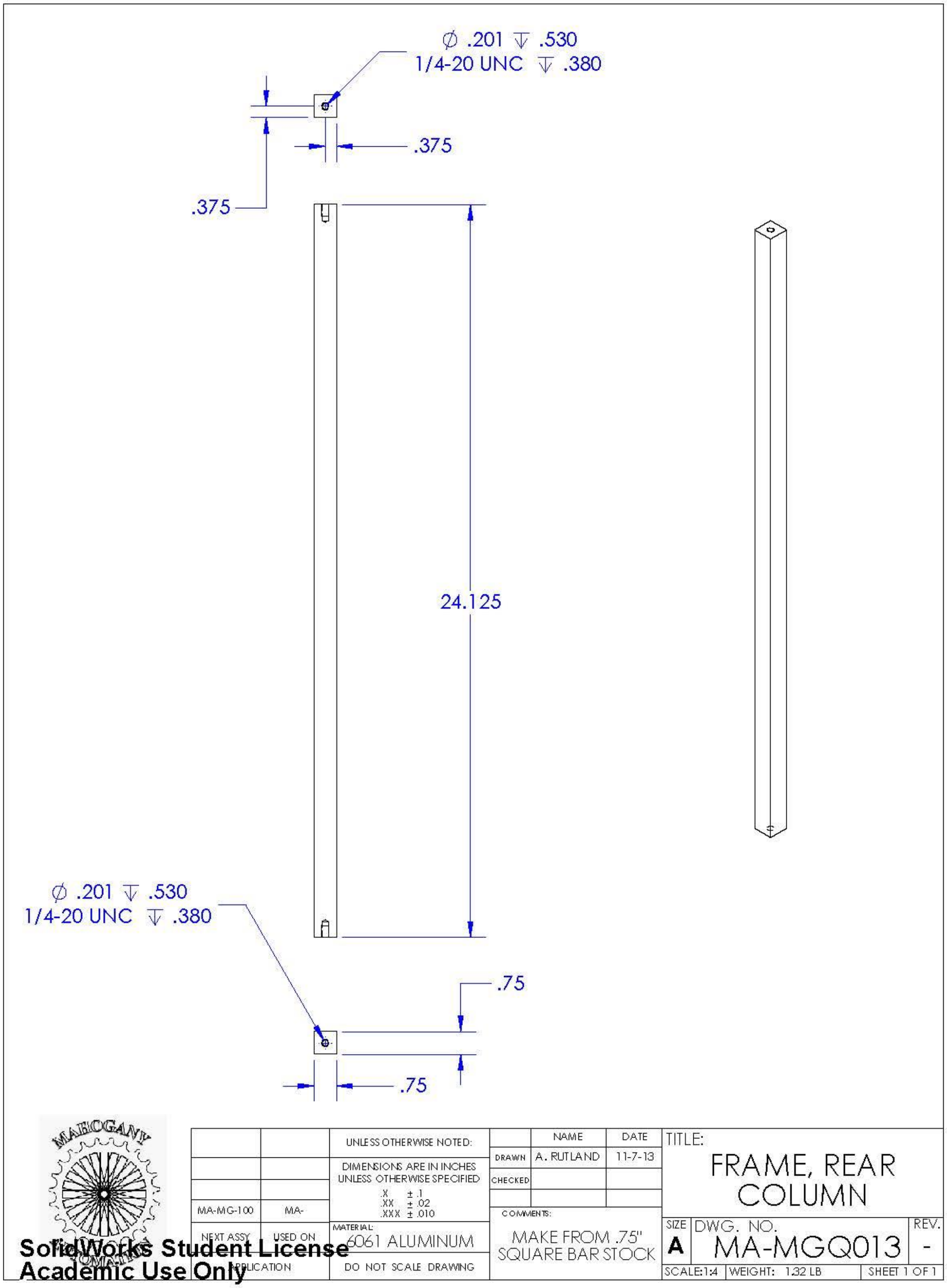


Figure I.12. Aluminum rear column frame drawing

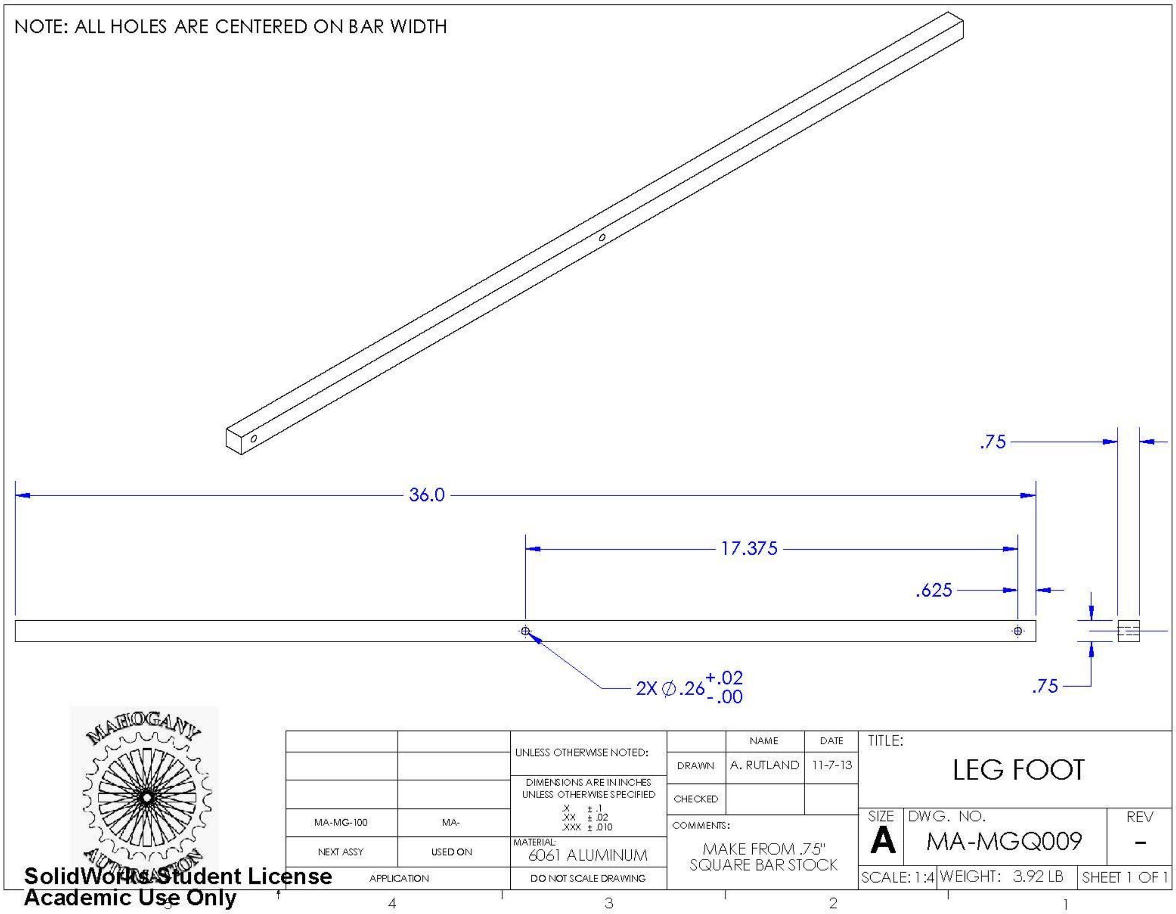


Figure I.13. Aluminum leg foot drawing

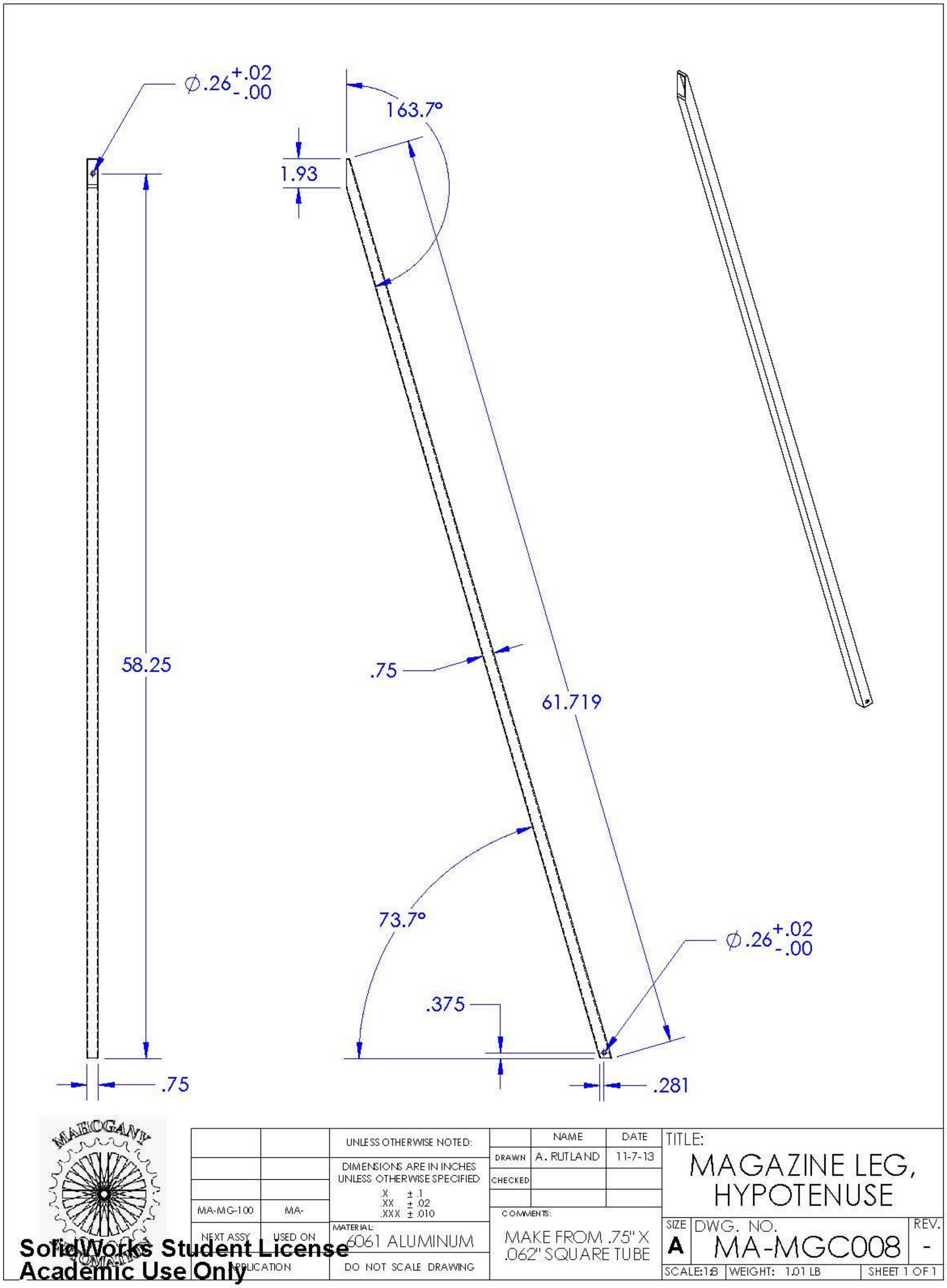


Figure I.14. Aluminum hypotenuse leg drawing

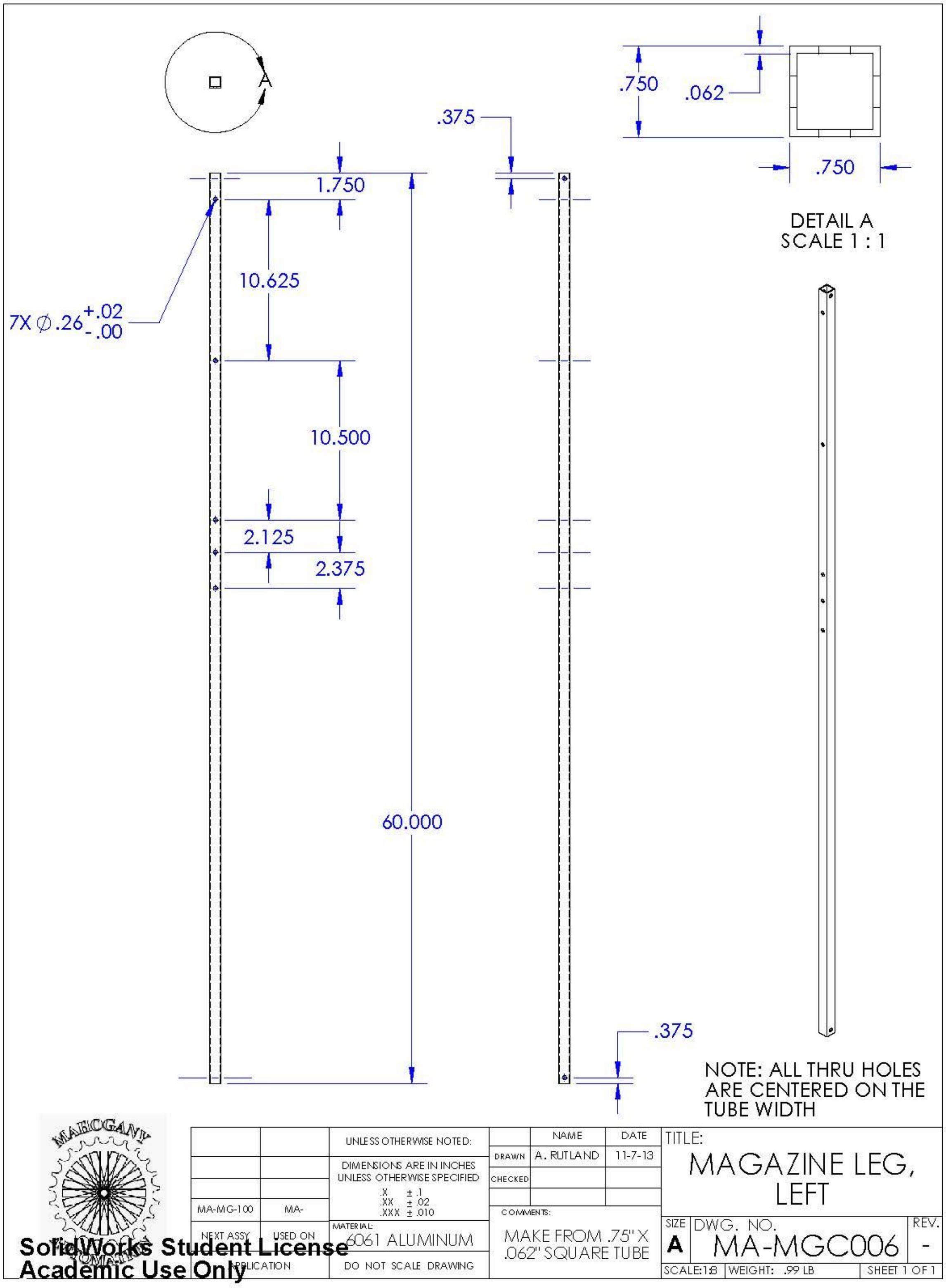


Figure I.15. Aluminum left leg drawing

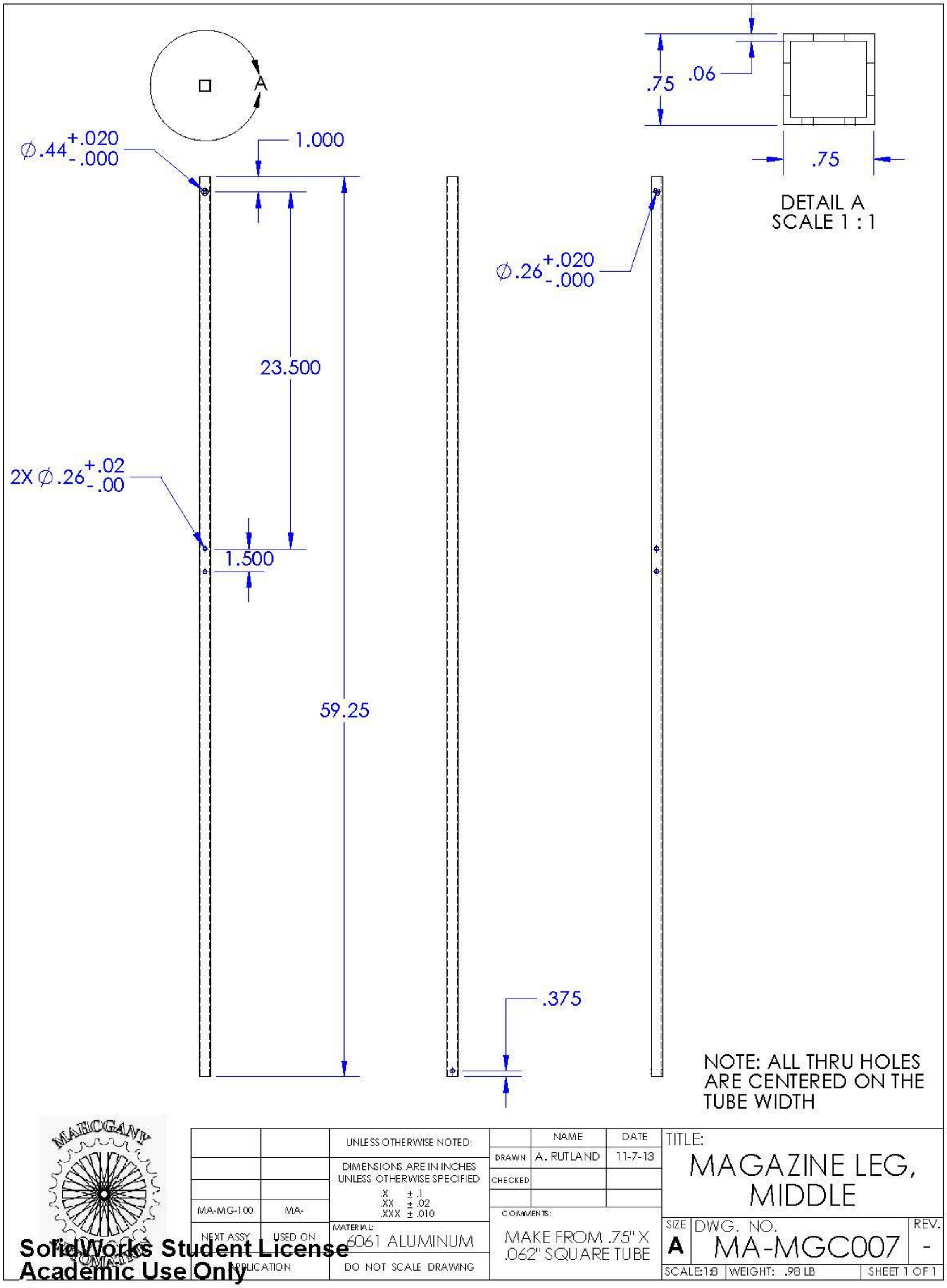


Figure I.16. Aluminum middle leg drawing

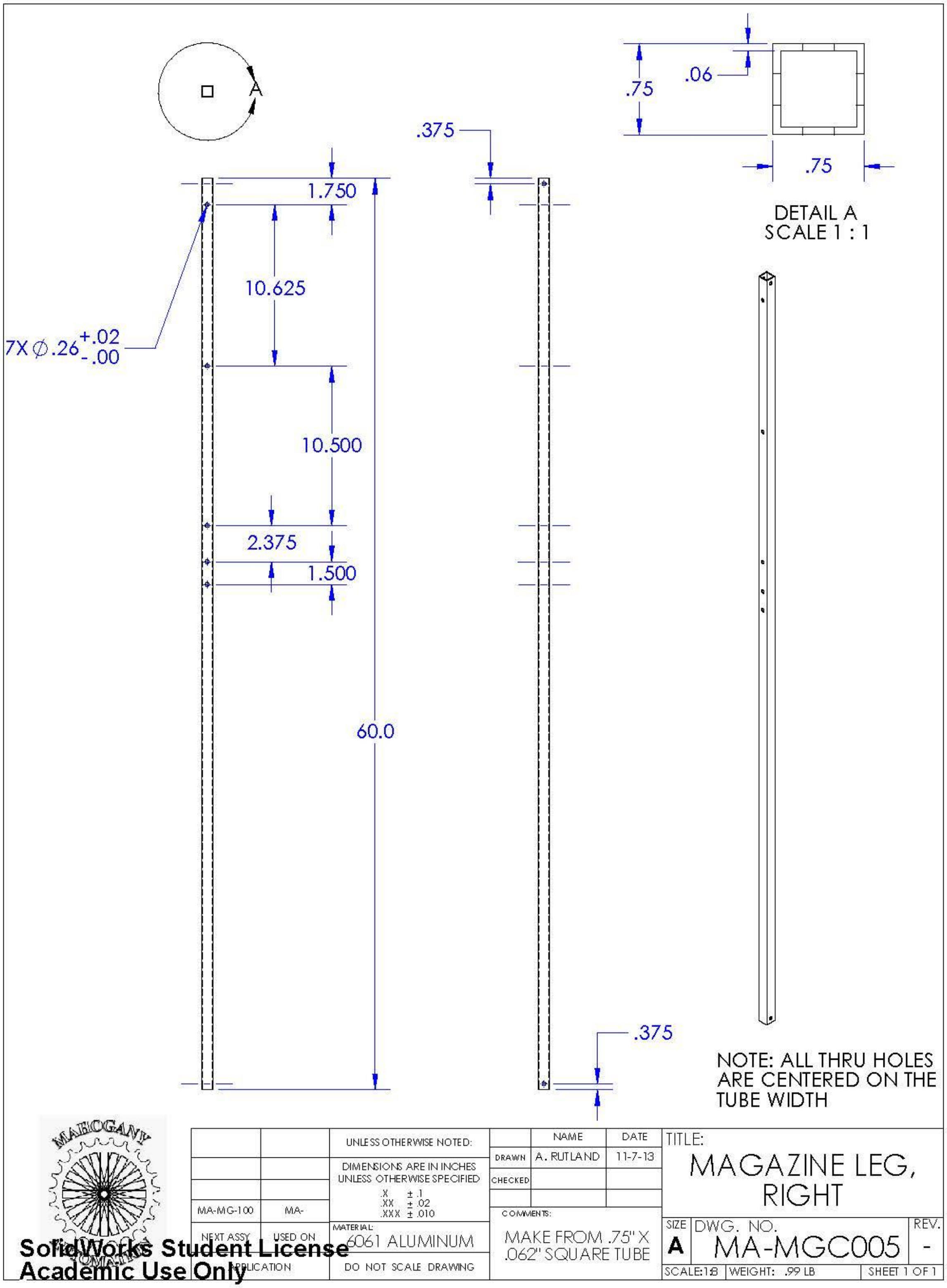


Figure I.17. Aluminum right leg drawing

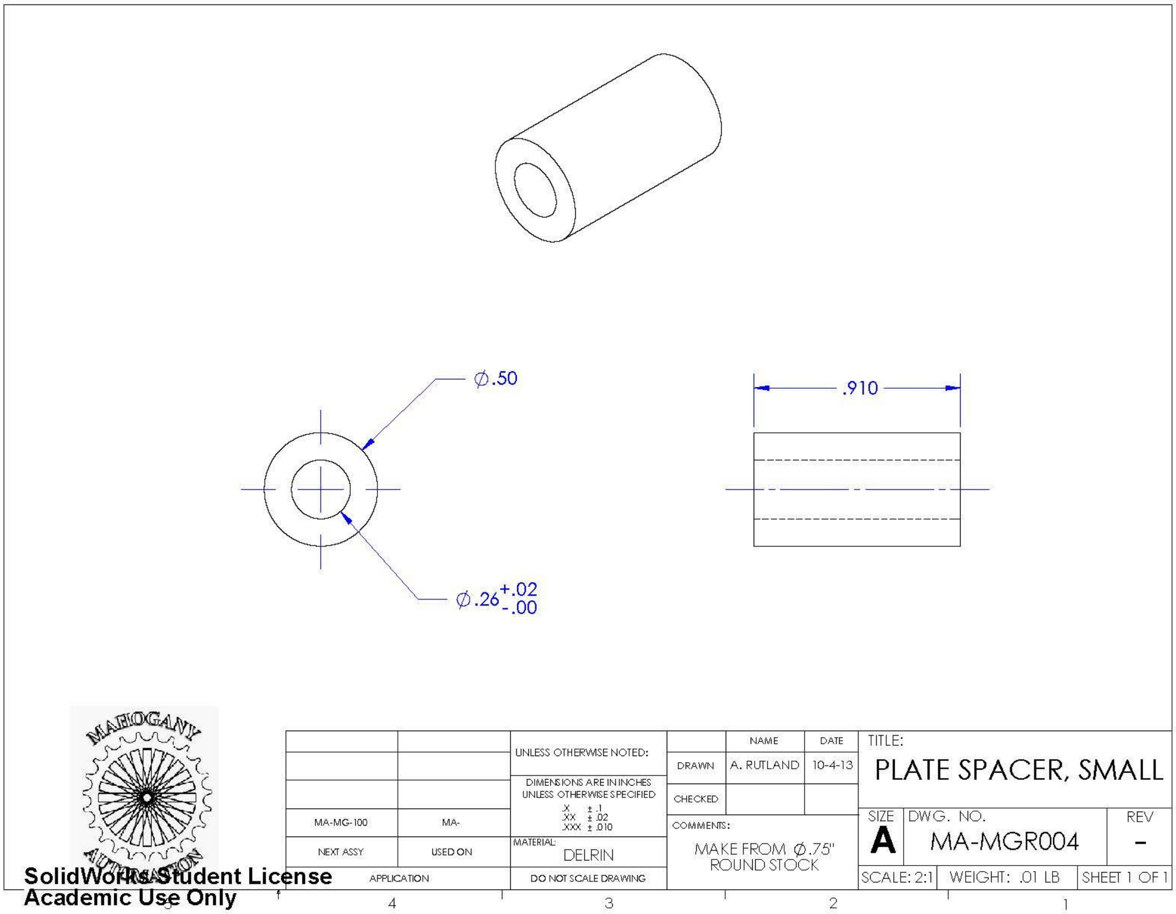


Figure I.18. Small Delrin plate spacer drawing

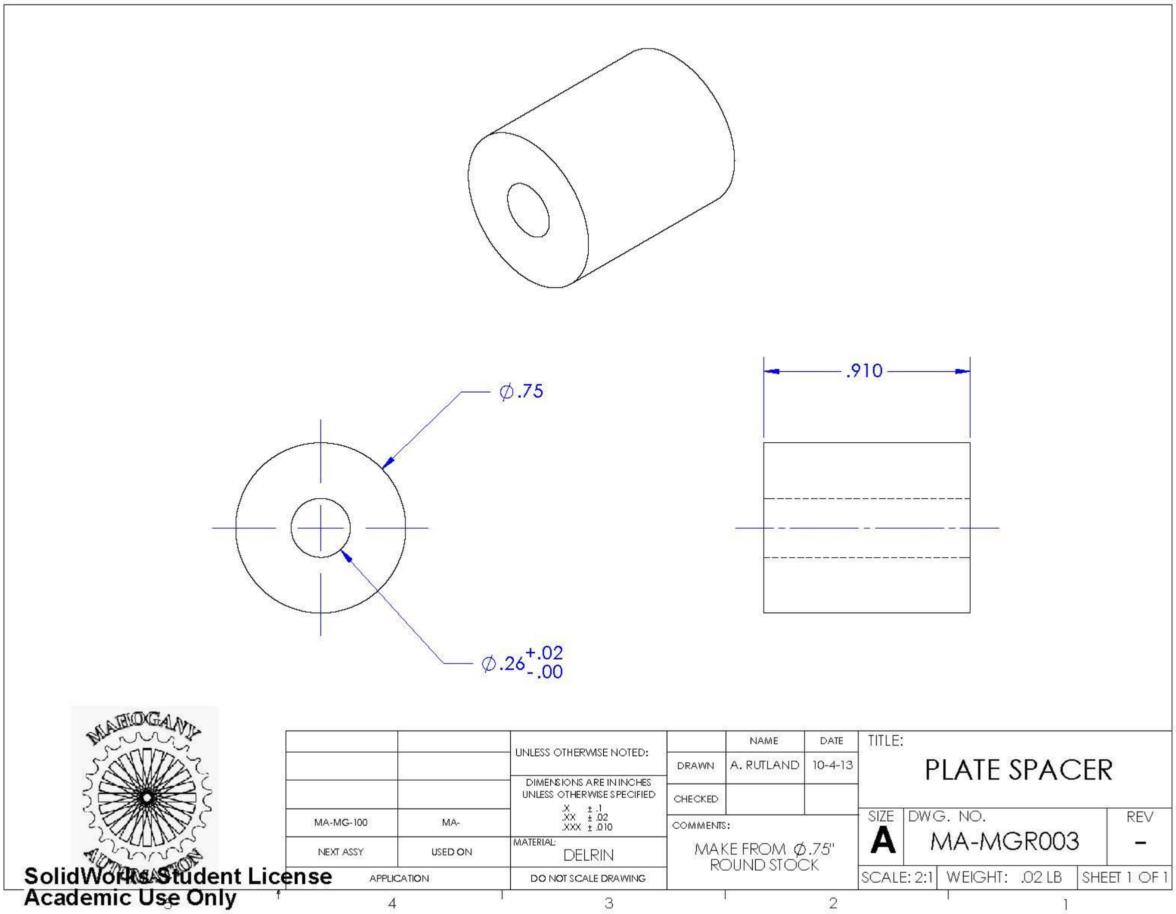


Figure I.19. Delrin plate spacer

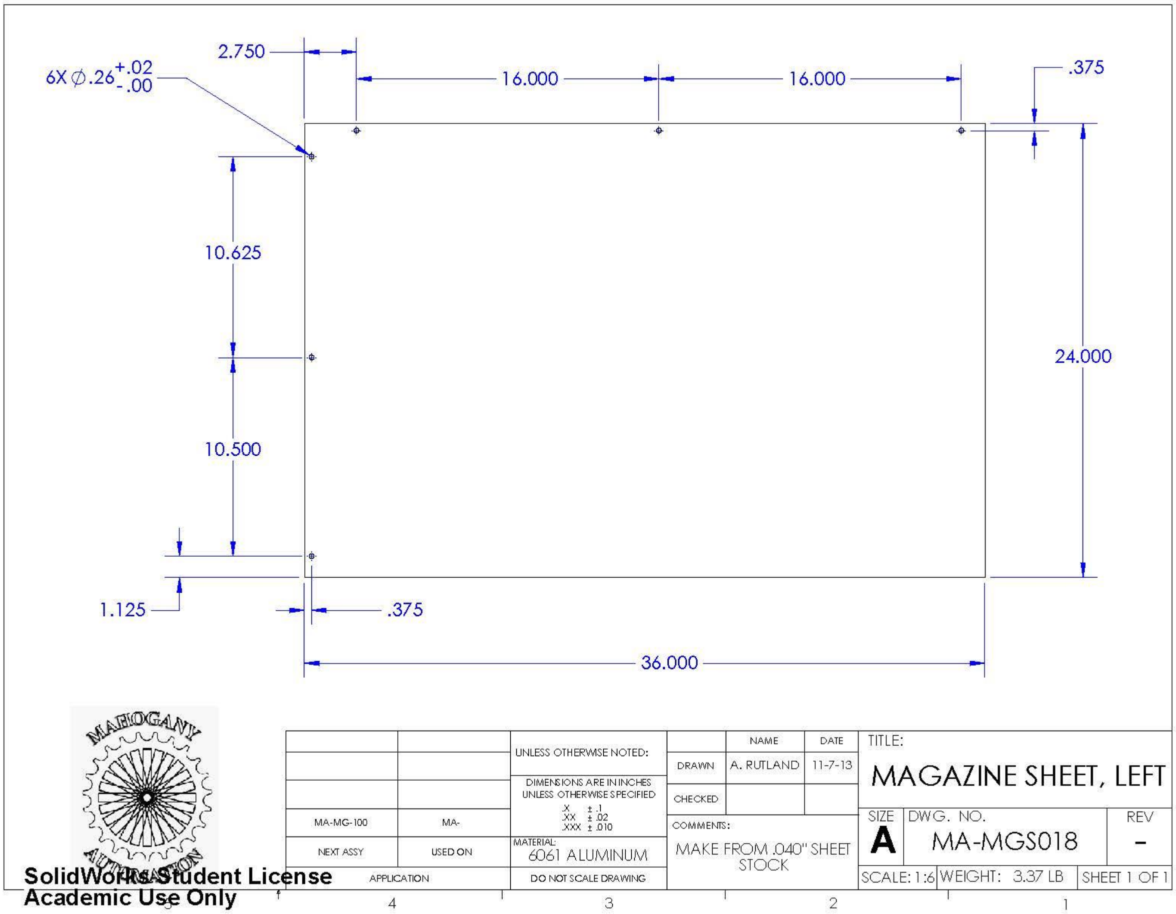


Figure I.20. Aluminum left sheet drawing

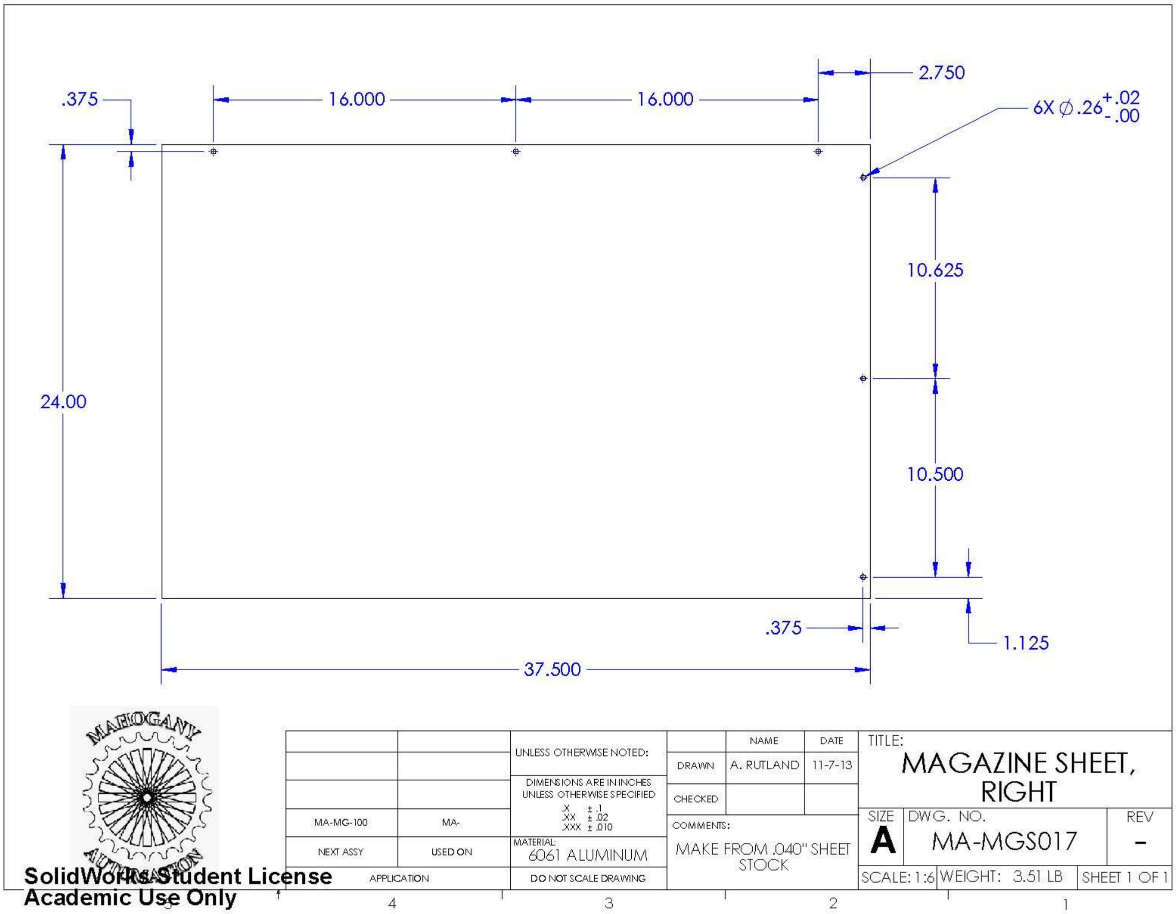


Figure I.21. Aluminum right sheet drawing

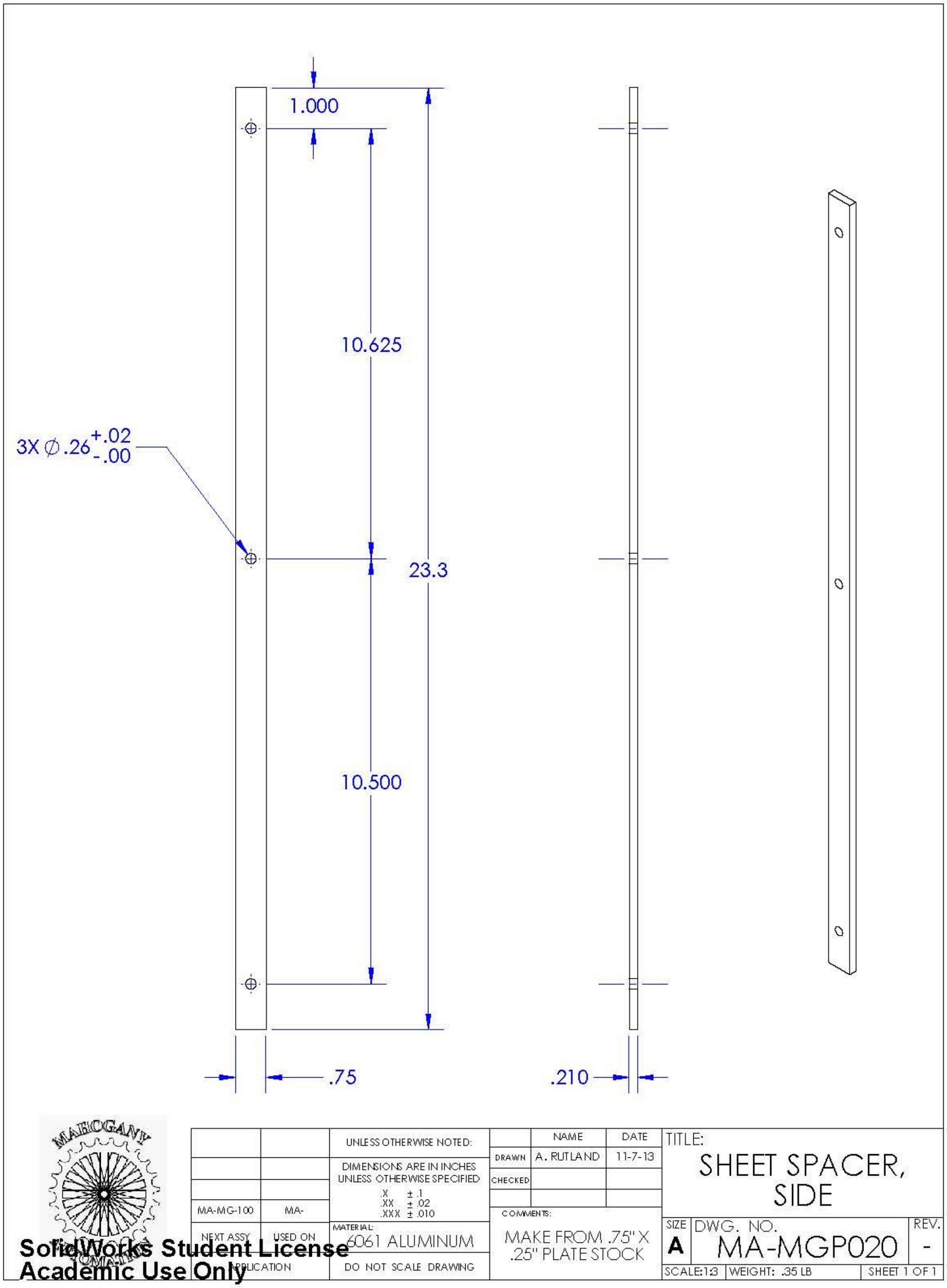


Figure I.22. Aluminum side sheet spacer drawing

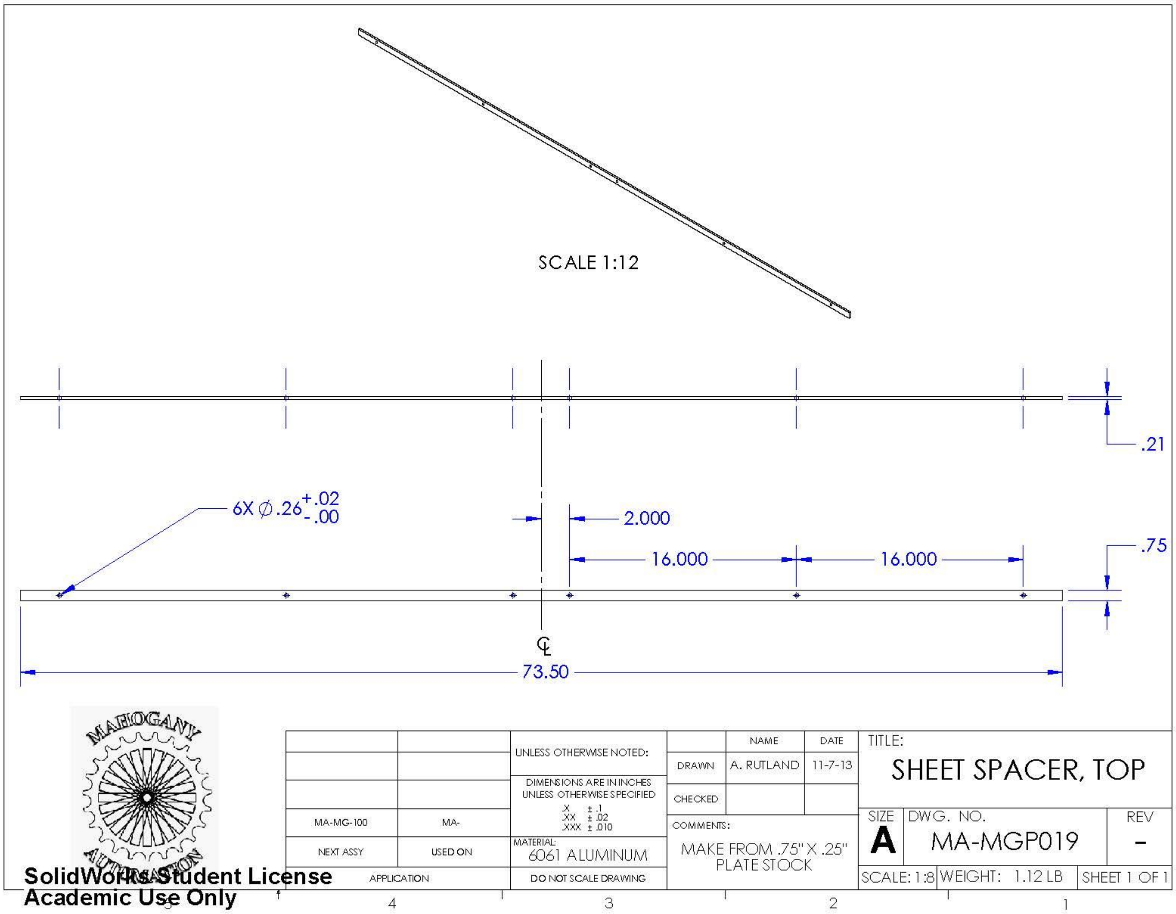


Figure I.23. Aluminum top sheet spacer drawing

APPENDIX J. COMPONENT DRAWINGS - DRIVING MECHANISM

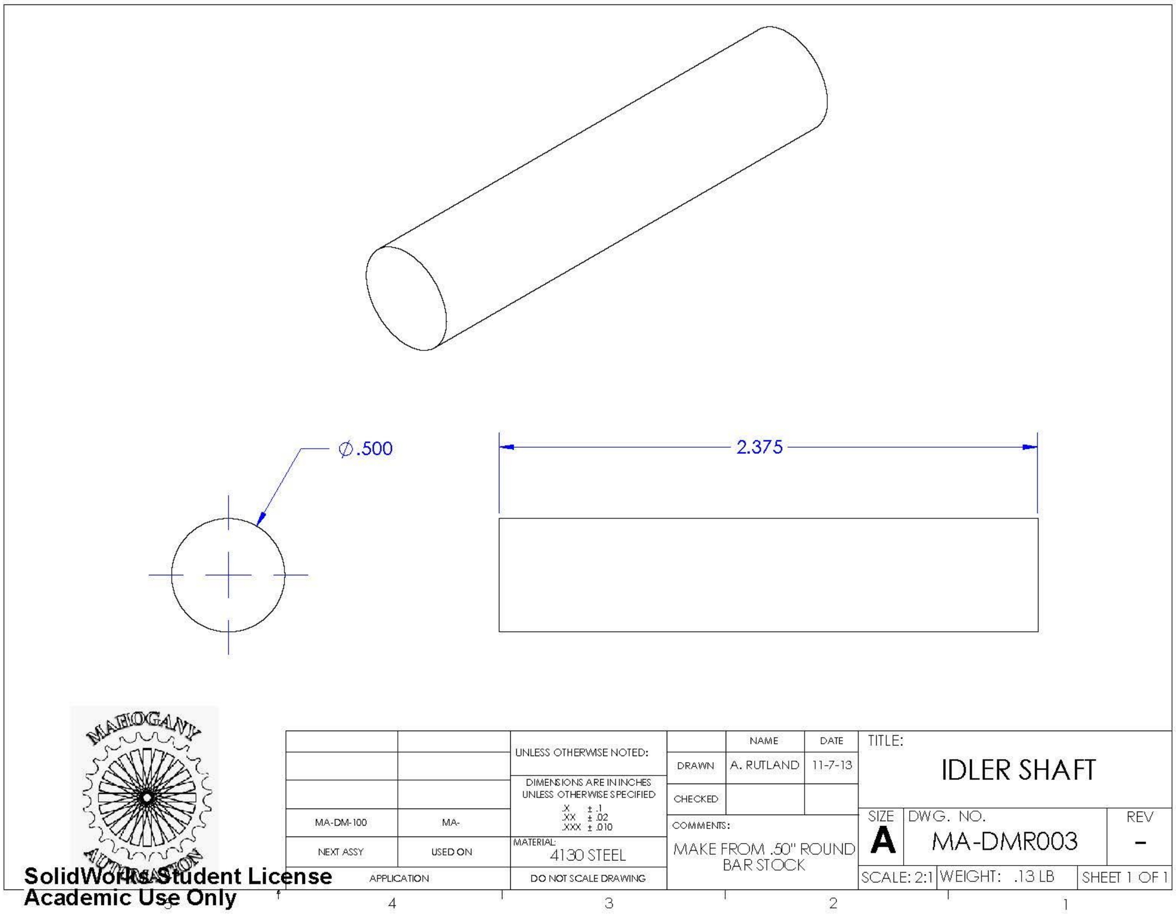


Figure J.1. Idler shaft drawing

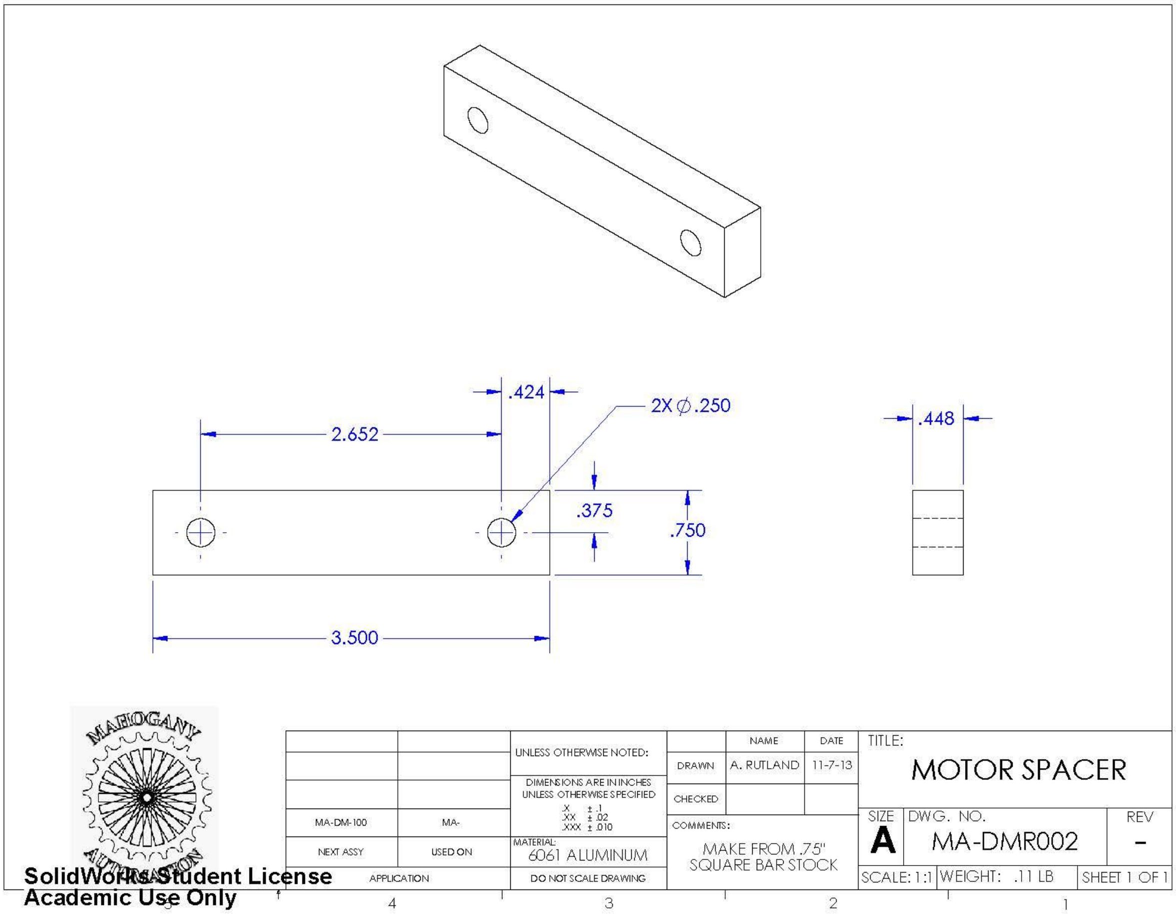


Figure J.2. Motor spacer drawing

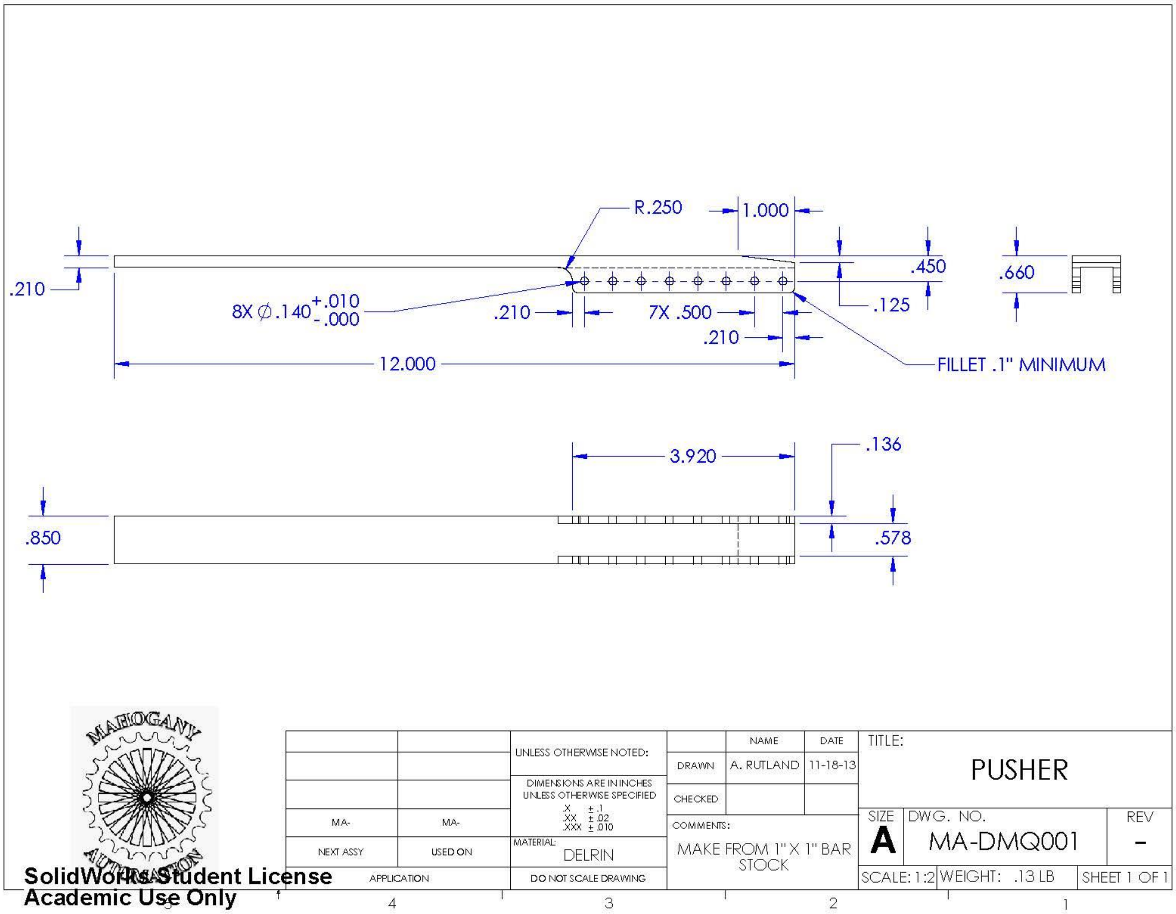


Figure J.3. Pusher drawing

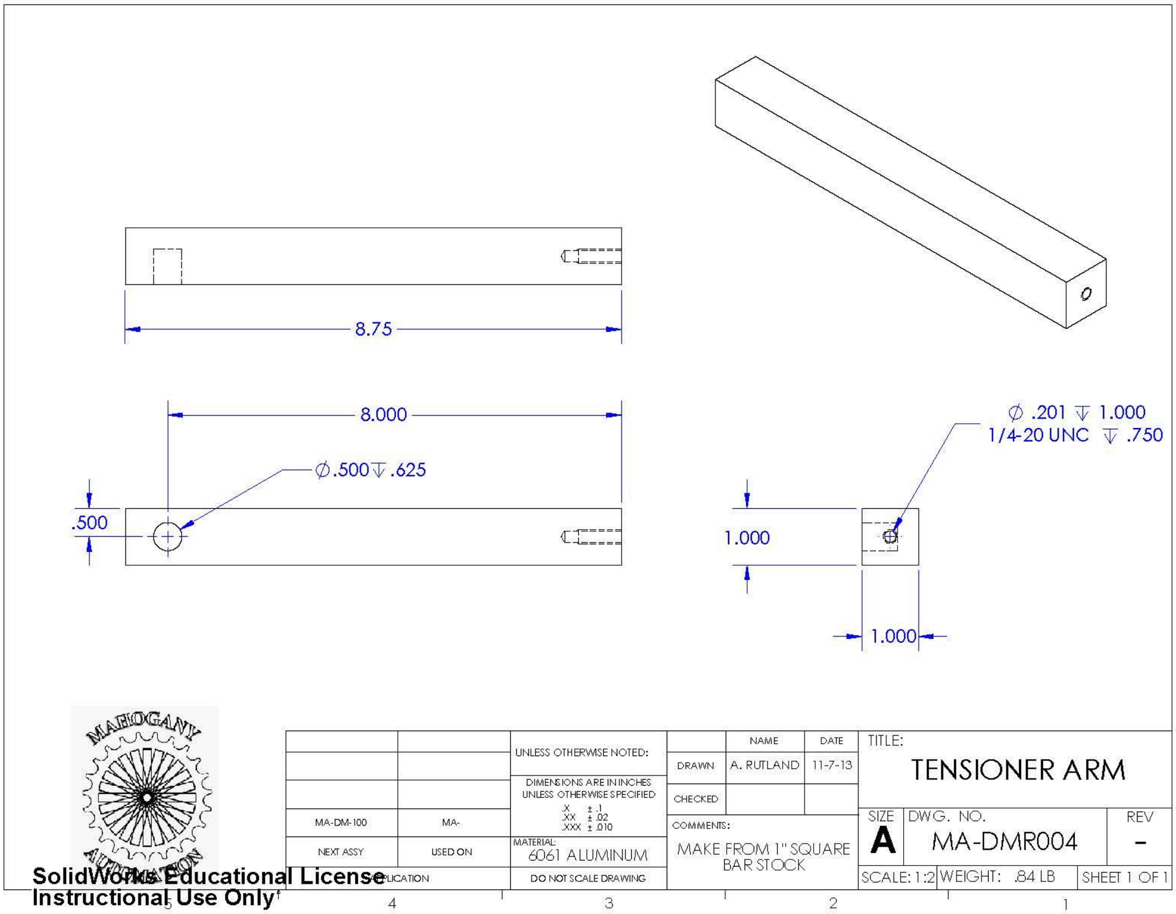


Figure J.4. Tensioner arm drawing

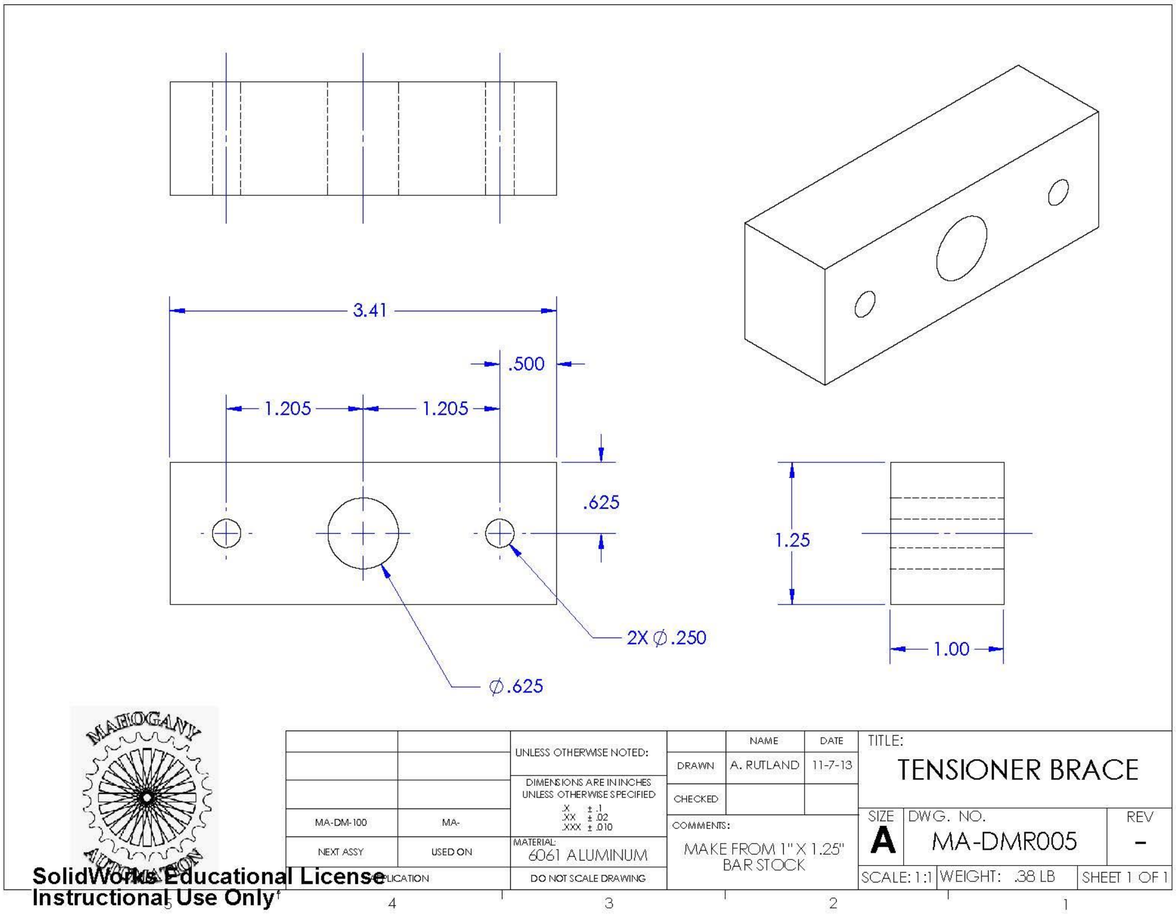


Figure J.5. Tensioner brace drawing

APPENDIX K. DETAILED SUPPORTING ANALYSIS

Motor Power

Maximum recorded feed force plus maximum static friction force between redwood and redwood for about 100 full size slats:

$$10.3 + 6.7 = 17\ lbs$$

Multiply maximum force by 2 to account for friction, inefficiencies, etc:

$$17 * 2 = 34\ lbs$$

Multiply maximum force by maximum desired feed rate to find power. Convert to horsepower.

$$34 * \frac{20in}{s} = 680lb * \frac{in}{s} = 0.103\ HP$$

Translational Speed of the Chain

The translational speed of the chain is calculated based on the diameter of the Steel Finished-Bore, 1/2" Pitch, 15 Teeth, 1/2" Bore Roller Chain Sprocket for #40 Chain, and the rotational speed of the motor.

$d = 2.65$ [in]

$w = 152$ [rpm]

Conversion = 2*pi/60 [(rad/sec)/rpm]

$$v = d \cdot w \cdot \frac{conversion}{2}$$

Solutions:

v=21.09 in/sec

Factor of Safety of the Chain

$N_1 = 15$ [teeth]

$N_2 = 15$ [teeth]

$n = 152$ [rpm]

$H_{tab} = 1.002$ [hp]

$K_1 = 0.87$

$K_2 = 1$

$H_{nom} = 0.1$ [hp]

$n_d = 1.3$

$t = 15000$ [hr]

$K_s = 1.2$

$Ha = K_1 \cdot K_2 \cdot H_{tab}$

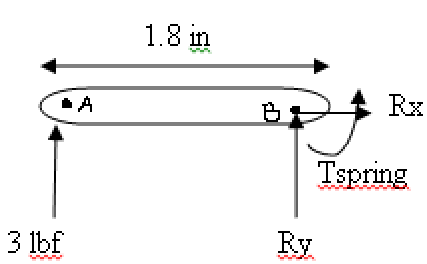
$$n_{fs} = K_1 \cdot K_2 \cdot \frac{H_{tab}}{K_s \cdot H_{nom}}$$

Solutions:

H_a=0.8717 hp

n_{fs}=7.265

Required Torsion Spring



$\Sigma M_B = T_{spring} - (3\ lb_f)(1.8in) = 0$

$T_{spring} = 5.4$ in-lb_f

Bolt Stress

The stress in the bolt is calculated based on the weight of the slats, design factor, and the diameter of the bolt. The stress result is then compared with the maximum stress required and it is safe to operate because the calculated stress is greater than the maximum stress.

W_{load} = 50 lb

Bold grade: 5

$\sigma_{manufacture}$ = 65 ksi

n = 1.5

d = 0.25 in

$\boldsymbol{\tau}_{bolt} = \frac{n*Wload}{Abolt}$

$\boldsymbol{\tau}_{bolt} = \frac{1.5*50\ lbf}{(pi/4)(0.25in)}$

τ_{bolt} = 170 psi

$\tau_{bolt} >> \sigma_{manufactur}$

APPENDIX L. SYSTEM COST

Table L.1. Detailed prototype cost analysis.

	QTY	UNIT PRICE	ITEM	TOTAL PRICE	VENDOR	ORDER
RAW MATERIALS	1	3.27	White Delrin Acetal Resin Bar 1/2" Thick X 1/2" Width, Square, 1' Length	3.27	McMaster-Carr	1608049
	1	8.71	1045 Medium Carbon Steel High-Strength Rod, 1/2" Diameter, 1' Length	8.71	McMaster-Carr	3525544
	3	6.30	Aluminum 6061-T6 Extruded Square Tube 0.75" x 0.062" Cut to: 96"	18.90	Online Metals	763530
	3	4.28	Aluminum 6061-T6 Extruded Square Tube 0.75" x 0.062" Cut to: 60"	12.84	Online Metals	763530
	3	14.99	Aluminum 6061-T6511 Bare Extruded Square 0.75" Cut to: 84"	44.97	Online Metals	763530
	2	16.67	Aluminum 6061-T6511 Bare Extruded Square 0.75" Cut to: 96"	33.34	Online Metals	763530
	2	29.63	Aluminum 6061-T6511 Bare Extruded Rectangle 0.25" x 4" Cut to: 96"	59.26	Online Metals	763530
	1	4.38	Aluminum 6061-T6511 Bare Extruded Round 0.5" Cut to: 72"	4.38	Online Metals	763530
	1	41.44	Aluminum 6061-T651 Bare Plate 0.375" Cut to: 12" x 12"	41.44	Online Metals	763530
	1	24.36	Aluminum 6061-T6 Bare Sheet PVC 1 Side 0.04" Cut to: 24" x 48"	24.36	Online Metals	763530
	3	7.64	Plastic Polycarbonate Clear Sheet 0.06" Cut to: 24" x 24"	22.92	Online Metals	763530
	1	18.70	Aluminum 6061-T6 Bare Sheet PVC 1 Side 0.04" Cut to: 24" x 36"	18.70	Online Metals	763530
	1	13.21	Aluminum 6061-T6511 Bare Extruded Square 0.75" Cut to: 72"	13.21	Online Metals	763530
	1	8.63	Aluminum 6061-T6 Bare Sheet PVC 1 Side 0.08" Cut to: 12" x 12"	8.63	Online Metals	763530
	2	5.00	Aluminum 6061-T6511 Bare Extruded Rectangle 0.25" x 0.75" Cut to: 84"	10.00	Online Metals	763530
	1	5.55	Aluminum 6061-T6511 Bare Extruded Rectangle 0.25" x 0.75" Cut to: 96"	5.55	Online Metals	763530
	1	4.09	Aluminum 6061-T6 Extruded Rectangle Tube 1" x 2" x 0.125" Cut to: 12"	4.09	Online Metals	763530
	1	3.63	Plastic Acrylic Clear Extruded Sheet 0.06" Cut to: 12" x 24"	3.63	Online Metals	763530
	1	12.70	Aluminum 6061-T6511 Bare Extruded Rectangle 1" x 1.25" Cut to: 24"	12.70	Online Metals	763530
	1	4.50	Cut Fee	4.50	Online Metals	763530
	1	2.33	Polypropylene Rectangular Bar 1" Thick, 1"	2.33	McMaster	1634108

			Width, 1 ft. Length		-Carr	
	1	12.27	White Delrin Acetal Resin Rectangular Bar 5/8" Thick X 2" Width, 1 ft. Length	12.27	McMaster -Carr	1634108
	2	6.17	Aluminum 6061-T6511 Bare Extruded Rectangle 0.25" x 0.75" Cut to: 96"	12.34	Online Metals	825625
	1	3.38	Aluminum 6061-T6 Extruded Square Tube 0.75" x 0.062" Cut to: 36"	3.38	Online Metals	825625
	1	11.28	Aluminum 6061-T6511 Bare Extruded Square 1" Cut to: 24"	11.28	Online Metals	825625
	1	5.80	Plastic Acetal (CoPolymer) Natural Round 0.75" Cut to: 36:	5.80	Online Metals	825625
	1	14.99	Aluminum Flat Bar 1/8" x 3/4" x 96"	14.99	Orchard Supply	2252815
	TOTAL			417.79		
FASTENERS	1	6.99	Stop Nuts USS 1/4-20 100 ct.	6.99	Ace Hardware	J24776
	5	0.17	5/16-18 Lock Nuts	0.85	Ace Hardware	J24776
	2	0.11	5/16-18 Jam Nuts	0.22	Ace Hardware	J24776
	8	0.10	5/16" Cut Washers	0.80	Ace Hardware	J24776
	2	0.09	1/4" Lock Washers	0.18	Ace Hardware	J24776
	12	0.33	Flat Head Socket Head Cap Screw #8-32 x 3/8"	3.96	Ace Hardware	J24776
	3	0.37	Socket Head Cap Screw #10-24 x 5/8"	1.11	Ace Hardware	J24776
	1	0.60	Socket Head Cap Screw 1/4-20 x 1-1/2"	0.60	Ace Hardware	J24776
	6	0.14	Hex Head Cap Screw 1/4-20 x 3/4"	0.84	Ace Hardware	J24776
	2	0.15	Hex Head Cap Screw 1/4-20 x 1"	0.30	Ace Hardware	J24776
	8	0.17	Hex Head Cap Screw 1/4-20 x 1-1/4"	1.36	Ace Hardware	J24776
	10	0.23	Hex Head Cap Screw 1/4-20 x 2"	2.30	Ace Hardware	J24776
	2	0.27	Hex Head Cap Screw 1/4-20 x 2-1/4"	0.54	Ace Hardware	J24776
	2	0.35	Hex Head Cap Screw 1/4-20 x 3"	0.70	Ace Hardware	J24776
	1	1.33	5/16-18 Threaded Rod, 6" long	1.33	Ace Hardware	J27174
	2	1.19	Compression Spring 2"	2.38	Ace Hardware	J27174

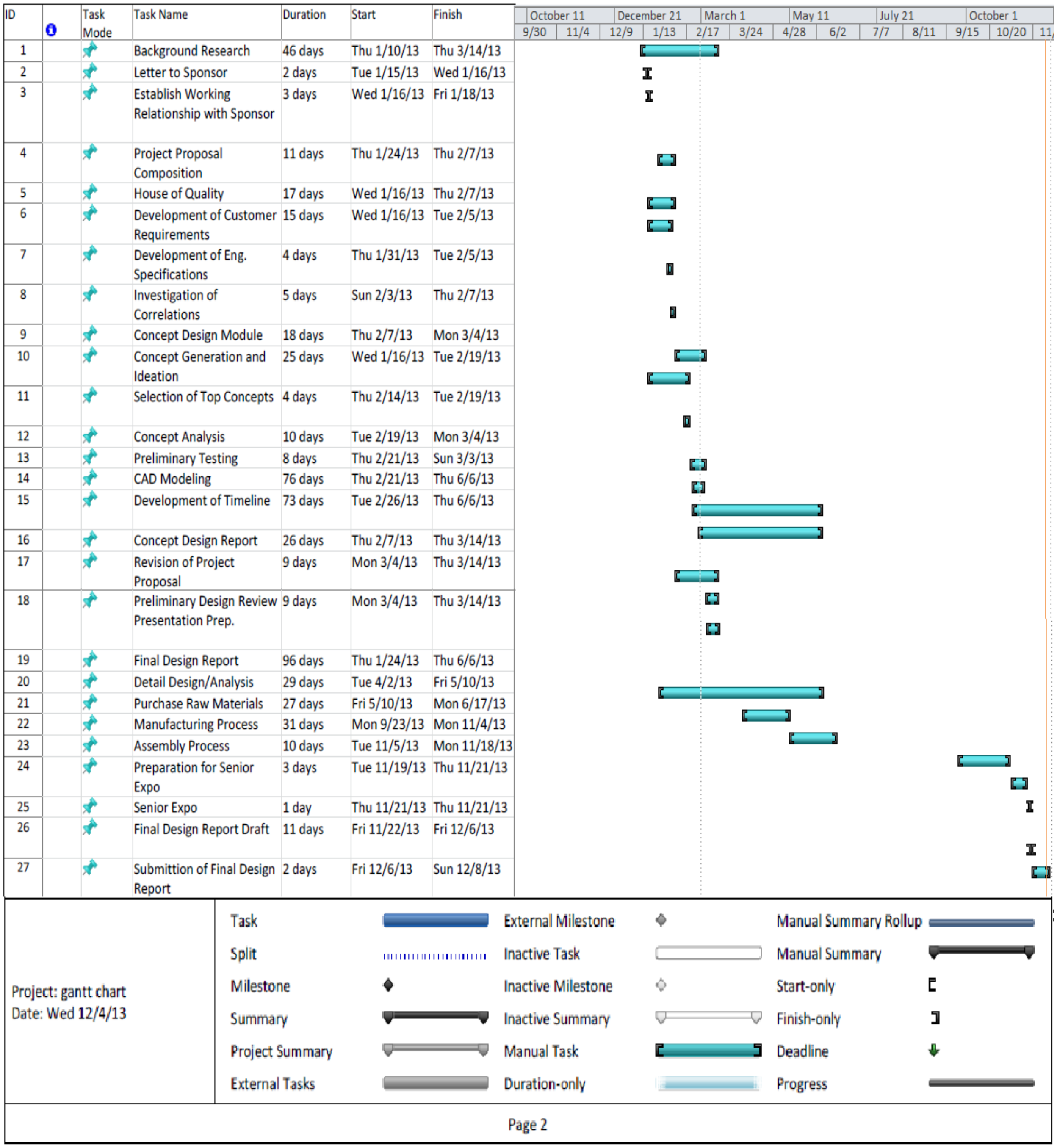
	2	1.19	Compression Spring 1.75"	2.38	Ace Hardware	J27174
	5	0.40	Hex Head Cap Screw 5/16-18 x 1-3/4"	2.00	Ace Hardware	J27940
	1	0.33	Flat Head Socket Head Cap Screw #8-32 x 3/8"	0.33	Ace Hardware	J27940
	4	0.41	Button Head Socket Head Cap Screw #10-32 x 7/8"	1.64	Ace Hardware	J27940
	10	0.27	Hex Head Cap Screw 1/4-20 x 2-1/2"	2.70	Ace Hardware	J27940
	19	0.25	Hex Head Cap Screw 1/4-20 x 1-3/4"	4.75	Ace Hardware	J27940
	2	0.38	Spacers Nylon 1" x 1/2"	0.76	The Home Depot	5938998
	1	1.64	Socket Cap Screw Button Head 1/4-20 x 1/2" Stainless Steel	1.64	The Home Depot	5938998
	1	0.75	Metric Flat Washer 10.9 M8 Zinc	0.75	The Home Depot	5938998
	2	0.85	Torsion Springs	1.70	Ace Hardware	J29107
	2	0.69	Torsion Springs	1.38	Ace Hardware	J29107
	2	0.59	Metric Socket Cap Screw	1.18	Orchard Supply	2252815
	4	0.20	1/4-20 x 2-1/2" Hex Bolt	0.80	The Home Depot	5808795
	4	0.17	1/4-20 x 1-1/2" Hex Bolt	0.68	The Home Depot	5808795
	2	0.11	Cut Washer 1/4"	0.22	The Home Depot	5808795
	6	0.12	Cut Washer 5/16"	0.72	The Home Depot	5808795
	1	5.97	Nylon Lock Nut Coarse USS 1/4" Zinc	5.97	The Home Depot	5808795
	12	0.34	Hex Head Cap Screw Full Thread 1/4-20 x 2-1/2"	4.08	Ace Hardware	J38293
	4	0.17	Hex Head Cap Screw 1/4-20 x 1-1/4"	0.68	Ace Hardware	J38293
	10	0.09	#4-40 x 1/4" Flat Head Screw Zinc	0.90	Ace Hardware	J38293
	28	0.09	1/4" Cut Washers	2.52	Ace Hardware	J38293
	2	0.40	Spacers Nylon 1" x 1/2"	0.80	The Home Depot	5828496
	3	0.42	4" x 4" Lateral Tie Plate	1.26	The Home Depot	5828496
	1	0.69	Bolt Eye w/Nut 3/16" x 1.5"	0.69	Ace	J40190

					Hardware	
	58	0.09	#4-40 x 1/4" Flat Head Screw Zinc	5.22	Ace Hardware	J40190
	TOTAL			70.21		
COTS	6	16.5	Snap-on Chain 1843 Tab, carbon steel base chain LF1843Tab-K125-CS	99.00	Midwest Chain	532
	1	129.00	Bison DC Gear Motor 1/10 HP 24V 152 RPM 25:1 Ratio 42 in-lb	129.00	Happiness Tech	38763207
	1	27.67	Idler Sprocket Steel w/Ball Bearing #40 Chain 18 Teeth 1/2" Bore	27.67	McMaster-Carr	3525544
	1	14.58	Steel Finished-Bore sprocket #40 Chain 1/2" Pitch 15 Teeth 1/2" Bore	14.58	McMaster-Carr	3525544
	1	35.30	Standard ANSI Roller Chain #40 Single Strand 1/2" Pitch .312" Diameter 10' L	35.30	McMaster-Carr	3525544
	1	11.99	Hinge Extrude Butt 2" x 3" 2 Pack 8091787	11.99	Ace Hardware	J27174
	1	13.97	Irwin 3/4" Pipe Clamp	13.97	The Home Depot	5937891
	1	2.48	Everbilt 1-1/16" Threaded Glide, 4-pack	2.48	The Home Depot	5938998
	1	5.99	SnapWare A/T Rectangle 18.5 Cup Container	5.99	Rite Aid	993577
	1	2.99	Cleat 4.5" Nickel 4015	2.99	Ace Hardware	J38293
	1	50.00	Arduino Mega Microcontroller	50.00	Mouser	N/A
	1	13.00	Housing Box	13.00	Mouser	N/A
	1	23.00	Switch - Emergency Off	23.00	Mouser	N/A
	1	3.00	Switch - Run/Pause	3.00	Mouser	N/A
	1	6.00	Cutter Motor Power Relay	6.00	Mouser	N/A
	1	3.00	Power Indicator Lamp	3.00	Mouser	N/A
	1	3.00	Jam Indicator Lamp	3.00	Mouser	N/A
	1	50.00	Motor Driver	50.00	Pololu	N/A
	6	0.50	IR-LED Everlight IR908-7C-F	3.00	Digikey	N/A
	6	0.45	IR-Detector Everlight PT908-7C-F	2.70	Digikey	N/A
	1	4.50	Integrated Circuit, current sensor Allegro Microsystems ACS712ELCTR-20A-T	4.50	Digikey	N/A
	1	0.05	Resistor, 100 ohm, 1/4 W	0.05	Digikey	N/A
	1	0.05	Resistor, 200 ohm, 1/4 W	0.05	Digikey	N/A
	6	0.05	Resistor, 240 ohm, 1/4 W	0.30	Digikey	N/A
	6	0.05	Resistor, 30K ohm, 1/4 W	0.30	Digikey	N/A
	4	0.05	Resistor, 10K ohm, 1/4 W	0.20	Digikey	N/A
	1	0.05	Capacitor, 0.1 uf	0.05	Digikey	N/A
	6	0.20	Transistor 2N3904	1.20	Digikey	N/A
	1	65.00	Power Supply 24V, 6A Mean Well NES-350-24	65.00	Parts Express	N/A

	1	6.00	Power Supply, 5V, 1.5A Triad Magnetics WSU050-1500	6.00	N/A	N/A
	1	2.00	Power Supply, 12V, 1A PA1A1D	2.00	Scii USA	N/A
	TOTAL			579.32		
SALES TAX				0.25	McMaster-Carr	1608049
				6.47	McMaster-Carr	3525544
				25.75	Online Metals	763530
				2.46	Online Metals	825625
				1.09	McMaster-Carr	1634108
				1.65	Ace Hardware	J24776
				1.45	Ace Hardware	J27174
				0.92	Ace Hardware	J27940
				1.12	The Home Depot	5937891
				0.45	The Home Depot	5938998
				0.25	Ace Hardware	J29107
				1.33	Orchard Supply	2252815
				0.48	Rite Aid	993577
				0.67	The Home Depot	5808795
				0.89	Ace Hardware	J38293
				0.17	The Home Depot	5828496
				0.47	Ace Hardware	J40190
	TOTAL			45.87		
SHIPPING				18.10	Midwest Chain	532
				4.83	McMaster-Carr	1608049
				19.97	Happiness Tech	38763207
				6.00	McMaster-Carr	3525544

		71.26	Online Metals	763530
		26.44	Online Metals	825625
		5.21	McMaster -Carr	1634108
	TOTAL	151.81		
GRAND TOTAL				1265.00

APPENDIX M. GANTT CHART



ID		Task Mode	Task Name	Duration	Start	Finish
1			Background Research	46 days	Thu 1/10/13	Thu 3/14/13
2			Letter to Sponsor	2 days	Tue 1/15/13	Wed 1/16/13
3			Establish Working Relationship with Sponsor	3 days	Wed 1/16/13	Fri 1/18/13
4			Project Proposal Composition	11 days	Thu 1/24/13	Thu 2/7/13
5			House of Quality	17 days	Wed 1/16/13	Thu 2/7/13
6			Development of Customer Requirements	15 days	Wed 1/16/13	Tue 2/5/13
7			Development of Eng. Specifications	4 days	Thu 1/31/13	Tue 2/5/13
8			Investigation of Correlations	5 days	Sun 2/3/13	Thu 2/7/13
9			Concept Design Module	18 days	Thu 2/7/13	Mon 3/4/13
10			Concept Generation and Ideation	25 days	Wed 1/16/13	Tue 2/19/13
11			Selection of Top Concepts	4 days	Thu 2/14/13	Tue 2/19/13
12			Concept Analysis	10 days	Tue 2/19/13	Mon 3/4/13
13			Preliminary Testing	8 days	Thu 2/21/13	Sun 3/3/13
14			CAD Modeling	76 days	Thu 2/21/13	Thu 6/6/13
15			Development of Timeline	73 days	Tue 2/26/13	Thu 6/6/13
16			Concept Design Report	26 days	Thu 2/7/13	Thu 3/14/13
17			Revision of Project Proposal	9 days	Mon 3/4/13	Thu 3/14/13
18			Preliminary Design Review Presentation Prep.	9 days	Mon 3/4/13	Thu 3/14/13
19			Final Design Report	96 days	Thu 1/24/13	Thu 6/6/13
20			Detail Design/Analysis	29 days	Tue 4/2/13	Fri 5/10/13
21			Purchase Raw Materials	27 days	Fri 5/10/13	Mon 6/17/13
22			Manufacturing Process	31 days	Mon 9/23/13	Mon 11/4/13
23			Assembly Process	10 days	Tue 11/5/13	Mon 11/18/13
24			Preparation for Senior Expo	3 days	Tue 11/19/13	Thu 11/21/13
25			Senior Expo	1 day	Thu 11/21/13	Thu 11/21/13
26			Final Design Report Draft	11 days	Fri 11/22/13	Fri 12/6/13
27			Submittion of Final Design Report	2 days	Fri 12/6/13	Sun 12/8/13

Figure M.1. Project schedule, produced in the form of a Gantt Chart using Microsoft Project.

APPENDIX N. PHOTOS OF PROTOTYPE

Figure N.1. Prototype in progress at Fall 2013 Senior Project Expo.

Figure N.2. Photo of final prototype complete with magazine door and electrical components.

ACKNOWLEDGEMENTS

Mahogany Automation would like to thank California Polytechnic State University and mechanical engineering professors Dr. Mohammad Noori and Dr. Peter Schuster for their guidance and support in the completion of this project. We would like to give a special thanks to electrical engineer Bruce Palmer for sponsoring our senior project and giving us the opportunity to develop and produce a functioning prototype.