adVise Final Report

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Executive Summary

Machinist vises are a necessary work holding accessory to manual and CNC mills. Parts must be secured in a vise for the duration of the milling operation. Common problems that arise when using a machinist vise include: a struggle to tighten the vise while holding the part, lack of certainty when attempting to hold a part at a desired force, and the inability to have multiple vises tighten to the same force for long parts on the same mill. We propose a system to counteract these problems that consists of a retrofit design that can be mounted to any standard machinist vise and automatically tighten the vise to a specified force. This automated vise tightener can be used for any standard milling operation.

To begin the design process, research into prior art found a few current products that were similar to the concepts for the automated vise tightener. Upon completing this research, market research from a survey distributed to Georgia Tech Invention Studio Prototype Instructors, Montgomery Machining Mall Workers, and Practical Machinist Online Forum validated the proposed ideas based on feedback from potential customers. About 65% of respondents reported having work holding failure in the last year. In addition, about 60% of respondents said they would use the automated vise tightener as proposed if it were an available product. It was also evident from surveying that a major factor in the usability of the device is the time it takes to operate. If the device cannot work the same speed or faster than the machinist would work themselves, they will not use it.

The design ideation process begins with a Morph Chart which identifies the controller, drivetrain, motor, and lead screw interfaces to be used. It is then necessary to fully model the different possibilities for mounting and housing. Three designs are thus proposed through design ideation. These three designs, named Adapt-A-Vise, Miami Vise, and adVise, are modeled in SolidWorks and evaluated using a design matrix. Using the design matrix, adVise is the selected design moving forward. This is due to its design efficiency, its high rigidity, and its low cost to implement. Moving forward, the design will incorporate a user interface to fully meet the remaining specifications of ease of use. Finally, a FMEA chart is made for both the design and the process of using the design. These charts allow for countermeasures to proactively eliminate design risks.

A prototype was fabricated to demonstrate the effectiveness of the device as well as validate the concept of the automated vise tightener. The major design goals for the device are to

apply a clamping force of 2,000 pounds within a five second time frame for success of the project. The design has been thoroughly tested to ensure the design goals are met. The tests are performed by first calibrating the force sensors using a torque wrench on the lead screw of a standard milling vise and the output reading on the LCD, then fitting the data to find the regression line. To test the product, the revolutions per minute were measured and determined to be $36\ RPMs$. This translates to a linear speed of 2.25 inches per minute. Since the closing time is largely based on the initial distance between the jaw face and the part, it is not possible to guarantee a set closing time. However, this closing time is slower than desired. With respect to the clamping force, a clamping force of 1,000 pounds was achieved. This shows the clamping force reaches the necessary amount to ensure a part is held in the vise.

Next steps for this project could entail obtaining a patent, as this is the only retrofit, electrically controlled vise available. Before applying for a patent, it would be important to perform an economic analysis on the product to make sure it was both marketable and profitable. To allow for a quicker closing time and more force, the device would need a more powerful motor and a more efficient gearbox. This project is limited in capacity by the budget constraints, but it would be well worth the extra expense to purchase a new motor for any sort of production level work. In addition, there are other areas to be improved, such as a more accurate force sensor, higher efficiency gearbox, and higher strength socket adapter.

Nomenclature

1. **Backlash:** Clearance or lost motion in a mechanism caused by gaps between the parts
2. **CNC**: Computer Numerical Control
3. **FMEA:** Failure Mode and Effects Analysis

1. Introduction

For milling operations, it is required to secure the material so that is remains in a fixed location throughout the milling procedure. Currently, a standard machinist vise is used to secure parts, and this method introduces several potential issues when tightening the vise. It is difficult for one person to hold the part still in the vise while tightening the vise at the same time. Second, it is also difficult for a person to evaluate the exact amount of applied force to a part, which is important for thin-walled parts or for high precision machining. Also, when long parts require multiple vises for holding, it is imperative that each vise apply the same force to the part. The goal of this project is to create an automated tightening device that aids machinists with exact securing of parts in a vise. This device is intended to be a retrofit design for an existing standard machinist vise. The device interfaces with the tightening hex shaft on all standard vise grips on milling machines. It uses a drive system with the interface to rotate the hex shaft until a desired clamping force is reached. The drive system has a feedback controller that uses a given user input to apply the desired amount of force. Additionally, the interfacing structure will be mounted to a central housing that contains a mounting structure for the milling machine.

The design constraints for this project include interface dimensions, necessary clamping force range, power requirements for clamping force, and user interface necessities. It is also important to evaluate the novelty and freedom to operate constraints associated with past and current patents.

Ultimately, it will be evaluated based on its ability to efficiently tighten parts in a milling vise to a specific force. The current market for this device ranges from large scale industrial companies to the individual hobbyist. Since this device can interface with any standard milling machining, it is thus applicable to any company or person milling products. The major issues with this project include device weight, ability to clamp the device to the machine table, the layout of the user interface, and instrumentation for sensing applied force.

2. Prior Art

Background research is conducted to determine existing solutions and other automatic vise tightening devices. Figure 1 shows one solution for setting a specified force. The EnerPac Hydraulic Torque Wrench uses a compressor with a two-button controller to determine the desired pressure. An analog readout displays force, and, when the desired pressure is reached, the compressor shuts off. This product allows users to control the pressure, but it does not interface with a machinist vise.

Another design with comparable features is the HILMA Machine Vise. This device, shown in Figure 2, is a vise with a built-in pressure readout. The HILMA Vise allows users to see the current pressure being applied to the part, which is an important aspect of the project. However, this device does not automatically tighten the vise. In addition, this is not a retrofit design, which is a desired characteristic of the design.

One option to assist in the tightening of a vise is the DIY Hydraulic Vise in Figure 3. This vise is tightened by a foot pedal hydraulically using a floor jack. A major issue with this design is the lack of a control system to reach a target pressure. There is no way to know how much pressure is being applied other than the user's intuition. The only real benefit this design provides is the ability to tighten the vise without the use of hands.

Figure 4 shows another notable option for accomplishing some of the tasks associated with automatically tightening a vise. The DIY Electric Vise allows users to control the motion of the vise with two-foot pedals. One pedal tightens the vise, and the other pedal loosens the vise, but lacks a controller with pressure feedback to stop when a certain specified force is reached.

The final product found is the Posi Lock Hydraulic Bench Vise. This device works by using a foot pedal to control hydraulic pressure and tighten the vise. It can be seen in Figure 5. This accurately controls pressure to the vise, while also allowing the user to have minimal exertion and force applied. It also shows the pressure using an analog readout. The only area lacking by this system is it is not a retrofit option for a current machinist vise.

3. Customer Requirements/Engineering Specifications

Before determining the engineering specifications associated with the project, it is important to first understand the customer requirements and user needs. A stakeholder matrix is shown in Table 1 to highlight the stakeholders and their relation to the overall project.

Table 1. Stakeholder Matrix for Automated Tightening Device.

Stakeholder	Interests	Impact	Importance	Influence
Professional Mill Operator	Consistent clamping force	High	High	Medium
Hobbyist Machinists	Peace of mind knowing an appropriate clamping force is being applied	High	High	Medium
Shop Supervisors	Confidence that parts are being properly manufactured	Low	Low	Low
Engineers Using Machinery	Satisfies precise demands for prototypes, as well as allows engineers to have known custom specifications	High	High	High

By identifying key customer requirements, which focuses on the groups identified in the stakeholder matrix, the number one user need was determined to be the ability to easily clamp the part in place. This desire in sensible considering the functionality of autonomous devices and their aim to assist users. The second most desired function is the ability to provide consistent, known force to the part. Specifically, machinists would like to be able to know how much force is being applied during operations with multiple vises to ensure consistency. The ability to provide a known force with ease for the user is the novelty of the device, so the market research immediately validates the need for the design.

Other customer requirements are work time and safety. These two are often associated together, as the need for a faster closing time poses a greater safety concern due to more power requirements and a faster tool response. While these are valid concerns, the safety concerns should properly be addressed by the design testing and specifications. The final few customer requirements relate to universal fitting of the retrofit, and an intuitive user interface so users can operate the device with little to no training.

Engineering constraints associated with the automated tightening device are important when considering the specifications for the design. A list of constraints is constructed, beginning with size and device geometry. It is imperative that the device be able to interface with the existing vise, which yields the need for geometric and weight constraints. Also, there are power requirements necessary to run the motor. Constraints involving power requirements will heavily factor in to both the feasibility of the project and the weight and size requirements for the project. Quality constraints deal with the strength of the selected material, the device to be sealed from the environment to protect from flying chips and coolant from the workpiece, and the life of the device to be appealing to potential customers. Ideally, the total cost will be reasonable so that customers will find the device to be a worthwhile purchase.

Through identifying engineering constraints for the automated vise tightener, a Specification Sheet is derived to establish hard specifications for the design of the device. Table 2 below shows the full Specification Sheet. As seen in Table 2, the Specification Sheet provides an extensive list of engineering specifications to be accomplished during the design of the automated vise tightener. The engineering specifications with the Operations category are most desirable to meet, as the Clamping Time and Assembly Time are major factors in the success and usefulness of the device. Other important specifications include the total clamping force and removing any loose wires from the device.

4. Market Research

Market research is necessary to evaluate the need and response from potential consumers when considering a new design. Market research was conducted for this project by a survey, which was sent to Georgia Tech Prototype Instructors and workers in the Montgomery Machining Mall, as well as posted to Practical Machinist Online Forum. In all, there are seventeen respondents to the survey. Around 90% of respondents are male, over half are over the age of forty-five, and sixteen of the seventeen are professional machinists.

About 65% of respondents say they have experienced a failure due to inadequate work holding in the past year. When told of the proposed automated vise tightener, 60% of respondents say they would use the device, assuming it worked.

Additionally, a small business was asked about the potential for an automated vise tightener and the feasibility of using the device. The main feedback received was the importance of a quick operating time for the device. If the machinist could perform the job faster than the device, which has a targeted clamping time of five seconds, then the machinist would not use the device no matter how consistently or accurately it performed. This feedback is used as an additional metric used to validate the usefulness and success of the automated vise tightener.

5. Design Concept Ideation

To begin the ideation process, the main functions of the design are determined to be the ability to provide a substantial clamping force, attach to and drive of the vise and lead screw, and include a user interface that can provide the option for user input as well as a readout. Upon considering these design functions, a morphological chart is created to show several different solutions to the tasks associated with completing the functions. Figure 6 shows the Morphological Chart in detail.

The device is broken down into seven main subsystems with three potential design solutions for each function. For the final design, a Raspberry Pi will be implemented due to its ability both to meet the fidelity specifications and minimize the overall cost of the system. A myRIO, however, is used in the initial prototype in order to verify the capabilities that a Raspberry Pi will offer. A DC motor with a planetary gearbox transmission, such as is found in a common power drill, is implemented to drive the system because of the available torque output and compactness of design. As a result of the standard lead screw sizes found on machining vises, a standard ½” drive, nineteen-millimeter socket is best suited for the lead screw interface of the system.

The mounting and housing subsystems introduce an extra level of complexity that must be addressed prior to function selection through realization in preliminary CAD models, which are demonstrated below. Additionally, the user interface subsystem must be explored later in order to be incorporated with the housing structure that will be chosen preceding the prototype assembly. To explore these potential subsystems further, layouts of each user interface will be developed and compared based on ease of use and ease of assembly.

The proposed ideas and selected functions in the morphological chart led to several common features among preliminary sketches and CAD designs, which are discussed further below. One common feature is the drive subsystem. A DC motor, accompanied with a planetary gearbox transmission, is used to deliver the required torque to the lead screw interface. A custom piece is then used to connect the motor shaft to a standard nineteen-millimeter socket, which interfaces to the lead screw on the vise. This custom piece is round, metal stock that is drilled and tapped on one end to secure to the threading on the motor shaft, and the other end is milled to a square for the interface with the socket. Since all these systems incorporate the same drive system, all systems are also capable of running on the same control system, which is selected to be a Raspberry Pi. Two of the remaining subsystems - mounting and housing - are differentiated in the CAD designs, and the user interface subsystem will be examined later.

Adapt-A-Vise

The Adapt-A-Vise design as shown in Figures 7 - 9 contains a main housing structure, a mounting subsystem, and several internals including a drive subsystem. The main functions addressed by the CAD design include vise mounting, lead screw interfacing, lead screw driving, drive system control, and component housing. The mounting subsystem (Figure 8) is self-contained within the housing lid and contains two clamp arms, a rack and pinion, a control knob, and a ratcheting gear mechanism. The user turns the control knob to tighten the clamp arms onto the surface. The ratcheting gear mechanism can then be disengaged to allow for removal of the Adapt-A-Vise. The ratcheting gear, the rack, the pinion, the knob, and the spring are standardized parts that are commercially available for purchase. The clamp arms, however, can be assembled via a joining operation, welding, with commercially available sheet metal. The only custom components include the lid and spring holder which could be 3D printed or machined out of stock material. Both would present their own unique challenges from a manufacturing standpoint. The entire mounting sub-system is press fit into a housing structure which contains the drive and control subsystems (Figure 9). The housing would be made from formed sheet metal or welded sheet metal that is readily available.

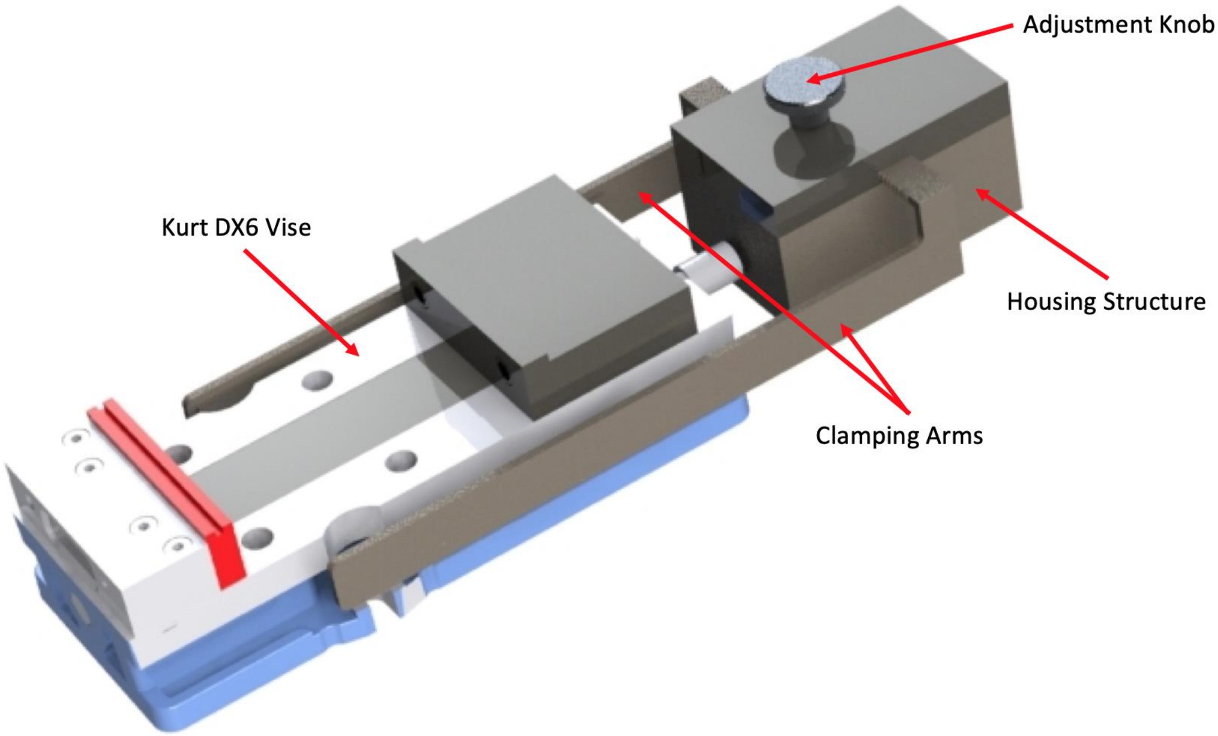

Figure 7. Adapt-A-Vise isometric view rendering showing the overall device.

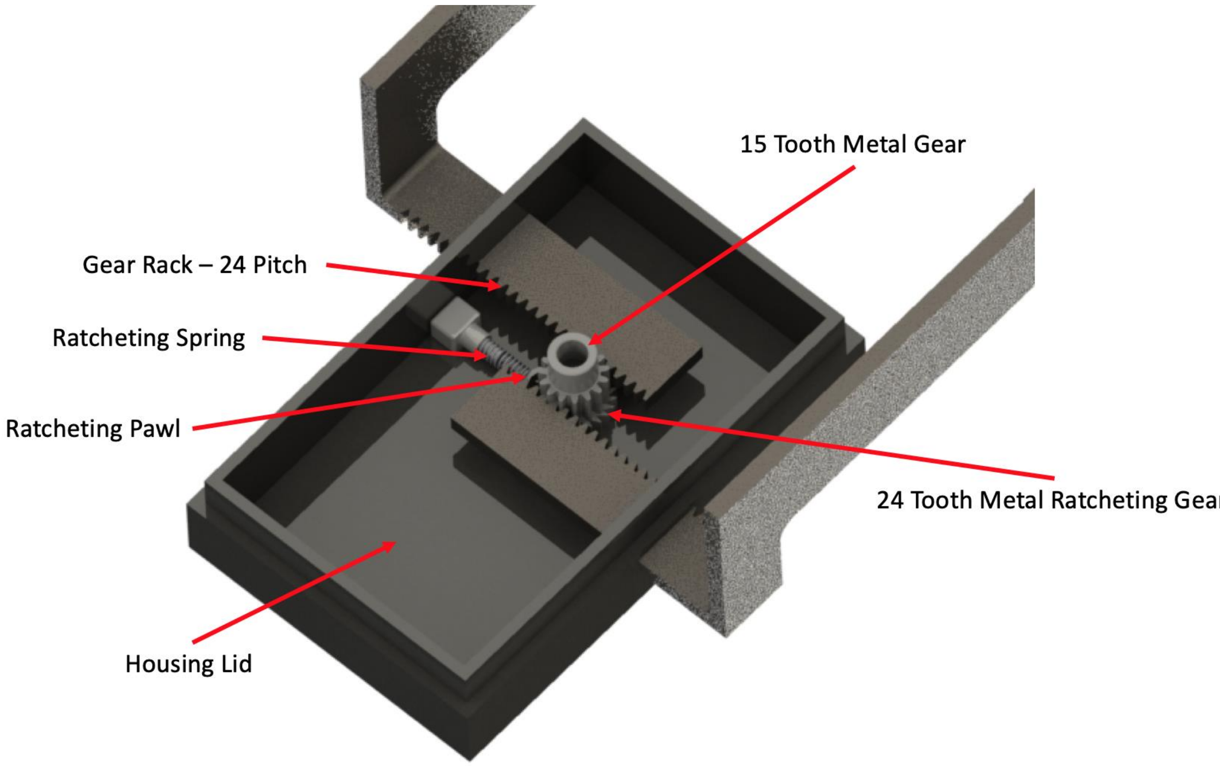

Figure 8. Adapt-A-Vise internals of ratcheting mounting sub-system.

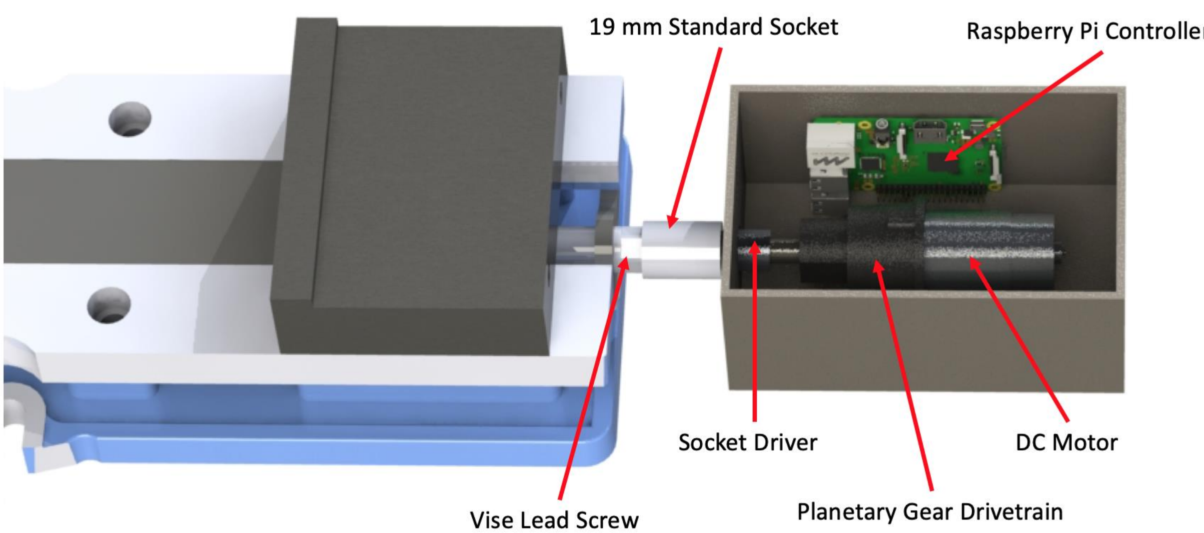

Figure 9. Adapt-A-Vise internals including controller and driver system

Miami Vise

The Miami Vise design was intended to be modular and inexpensive, combining simple, easily manufactured parts into a part-interchangeable design to accomplish the design goals. As seen in Figure 10, the main body of the part is a single bent sheet of aluminum, to which other supports are mounted. In order to retrofit to most vises, the sheet metal structure is designed to interface with the same milling table that vises are mounted on. The spacing between milling table T-slots is standardized, and the sheet metal plate's slots are designed to be bolted to these slots on the outside of the vise. Because the sheet metal is inexpensive to manufacture, many different iterations can be created for each of the standard vise width sizes (4, 6, 8, & 10 inches). Alternatively, the design can be manufactured to the maximum vise width size in order to fit all vises.

To secure the motor to the sheet metal plate and socket, a motor mount would be manufactured separately. This motor mount is secured to the sheet metal plate via screws and is shorter than the total height of the motor/drivetrain/socket assembly in order to keep the socket driver firmly attached to the vise. This motor mount also has an indentation to interface with the motor and prevent movement due to reactionary torque from the motor. The Raspberry Pi would be mounted directly to the plate with screws.

Feasibility concerns with this design concept include possible bending due to the weight of the motor subassembly, and difficulty in manufacturing the proposed motor mount in the current design iteration.

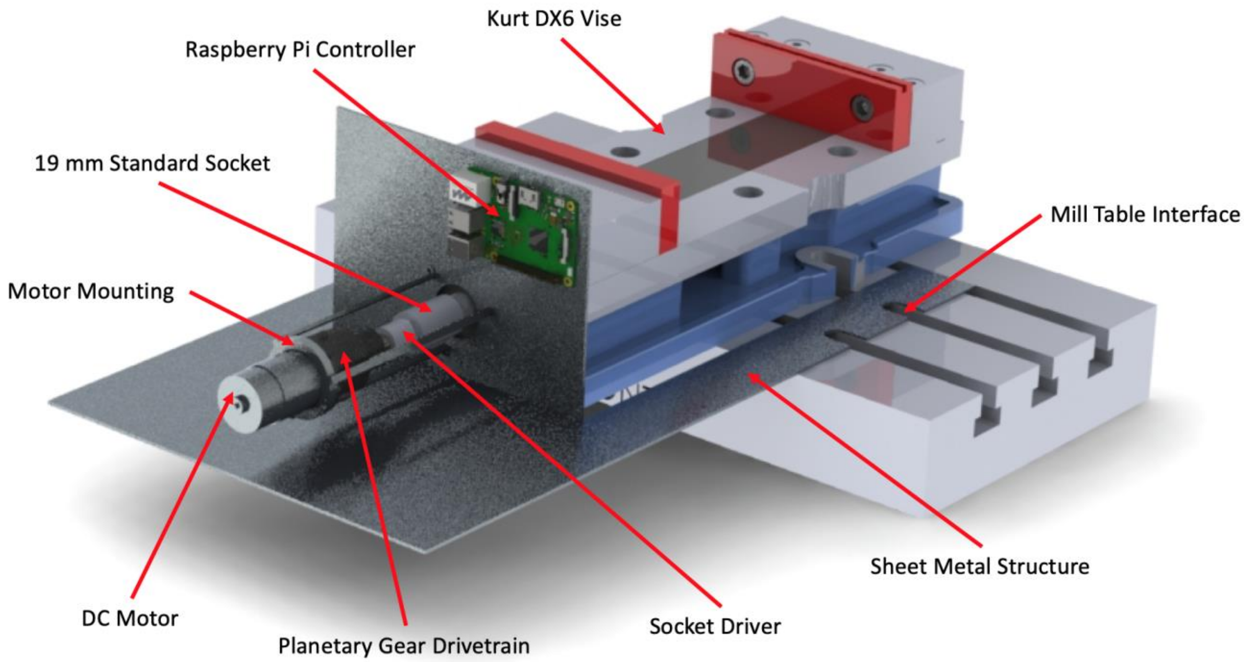

Figure 10. Miami Vise isometric view showing all relevant components and subsystems.

adVise

The adVise design, as illustrated in Figure 11, contains a front and back plate, two square tube steel arms, eleven standard bolts, and the same drive and control subsystem as used in the other two designs. This model benefits from the utilization of all standard components in the design. The parts to be machined are also designed to be 2D machined via abrasive waterjet manufacturing. The aforementioned allotments will allow for the device to be manufactured from square tube steel and a solid plate of material. The only part that is custom to this design is the socket driver which connects the power and torque output from the motor to the standard socket. Specifically, the mounting arms are designed to fit in the groove between the vise's interface plane with the table and the material clamping surface, allowing easy mounting to the vise. The arms are designed to withstand the rotational torque imparted by the mechanism's operation. This design feature allows the front and back plates to securely bolt together through the arms and hold the device in place. The entire design is sized to specifically fit the Kurt DX6 Crossover Vise but can be easily adapted to most other devices on the market with solely new front and back plates.

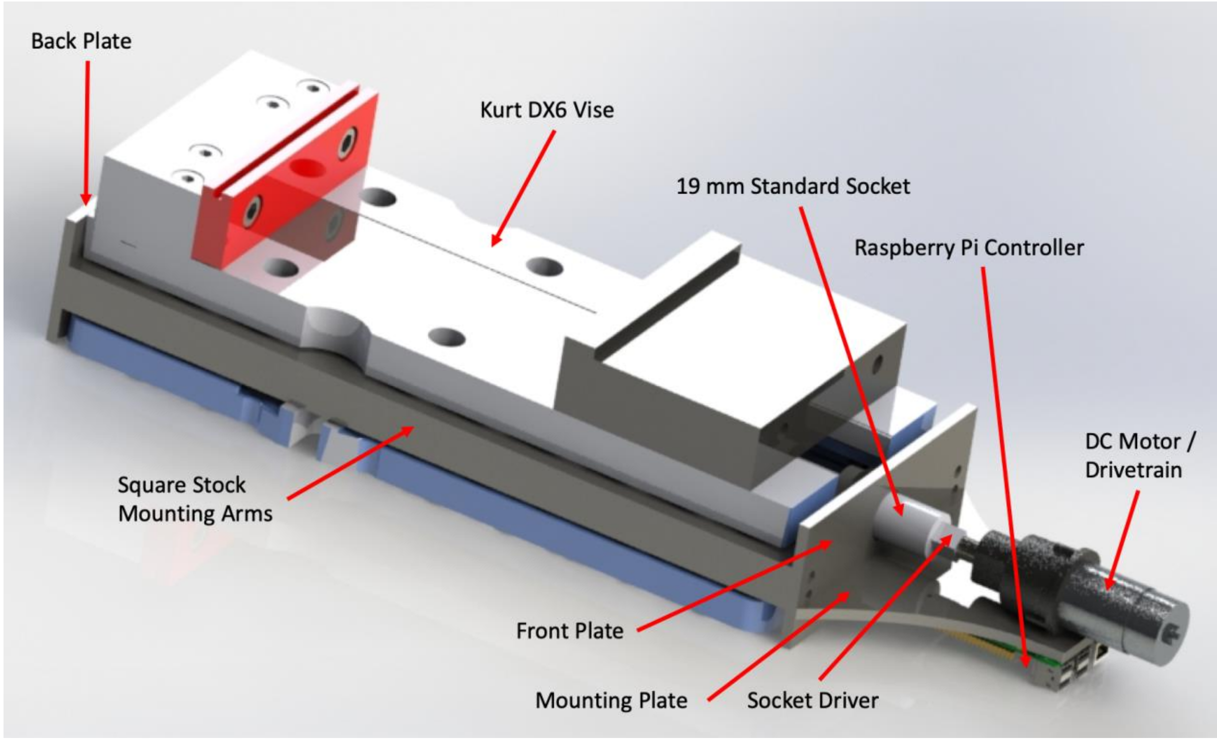

Figure 11. adVise design shown mounted to the demonstration vise

6. Preliminary Concept Selection and Justification

The adVise concept was selected due to its ability to meet important functionality requirements while also incorporating top selected concepts from the Morphological Chart (Figure 6)**.** The three design concepts were judged on their ability to meet functions that were not fulfilled in the Morphological Chart selection process. Specifically, the differences between the Adapt-A-Vise, Miami Vise, and adVise in terms of functionality were universality of application, torsional rigidity, bending rigidity, manufacturability, cost, and ease of install as seen in Table 3.

Although the adVise is not universally adaptable or the easiest to install, it exceeded expectations in the following categories: rigidity for mounting, manufacturability, and cost. The quantity of standardized versus custom parts in the design decreases costs and increases manufacturability compared to the other concepts. Additionally, standardized parts reduce the material costs. The simplicity of the small number of custom parts in the adVise design significantly reduces the labor associated with manufacturing, thus decreasing costs. The manufacturing of the Adapt-A-Vise, in contrast, would include a complicated lid structure that would require more time and capital create. Additionally, the design would require a multi-step assembly process. Both of these factors significantly decrease the design efficiency and make it less desirable compared to the adVise.

For actual application of the retrofit to the vise, the device would remain in place after the initial installation, since vises are seldom moved after installation. Therefore, a secure install with slightly longer installation time takes precedence over potential portability.

In terms of bending rigidity, the adVise has the smallest lever arm in the lead screw direction which concentrates the equivalent weight closer to the clamped end, thus deflecting less due to bending. With less deflection there is also a smaller maximum bending moment which reduces the likelihood of material yielding. Finally, the plate on which the motor and controls components are mounted is thicker than the sheet metal design Miami Vise utilizes. This fact further distinguishes the adVise in terms of bending rigidity, giving it a better score in this category. It is also better than the Adapt-A-Vise design, which utilizes a housing structure that is mounted further away from the interface point. This causes a larger moment and thus a higher potential for failure. Additionally, the adVise has no structural degrees of freedom and is mounted snugly to the vise with the wrap-around design. It was deduced that the torsional rigidity will be higher than the Miami Vise, which uses thin sheet metal drill mounting to prevent rotation. It is also better than the Adapt-A-Vise, which utilizes clamping arms that themselves are connected to a rack and pinion mounting system. This rack could potentially have backlash which would cause some undesirable rotation, and further reduce its torsional rigidity.

Table 3. Design selection and comparison matrix with various functionality considered.

	Function						
Concept	**Universal Application**	**Torsional Rigidity**	**Bending Rigidity**	**Manufacturability**	**Cost**	**Ease of Install**	**Total Design Performance**
Adapt-A-Vise	4	3	2	2	3	5	19
Miami Vise	2	3	4	2	4	3	18
adVise	2	4	5	4	3	3	21

Scale: 1-5 (5 = best)

With the adVise design selected, the required specs were then evaluated in comparison to the adVise's functionality to determine concept feasibility.

Because a retrofit requires sufficient clamping force to resist the reactionary torque from driving the vise power screw, clamping force and torsional rigidity were of utmost importance when selecting the final design. It was decided that the adVise provided the greatest stability in terms of interfacing with existing mill setups as previously discussed. As seen in the Specification Sheet in Table 2, the desired rotational stiffness of the mounting structure should be greater than 165 (lbf-in/deg), which physically means that the structure should not rotate more than five degrees under the maximum load. The adVise meets this requirement under the maximum 590 lbf-in reactionary torque because this torque generates a 44 PSI maximum shear stress in the front mounting plate based on a preliminary deformable bodies analysis. This is significantly lower than the yield stress of any metal considered for manufacturing and would thus be structurally sound with regards to the reactionary torque. Assuming typical aluminum for construction, the maximum rotation would be 0.273 degrees under the aforementioned torque values, which falls within the rotation requirements in the Specification Sheet.

In order to achieve the maximum clamping force of 2,000 pounds, the torque requirement of $250\ lbf - in$ was derived using an online ACME lead screw torque calculator. A motor to generate that level of torque was both too large and too expensive to consider; it was decided that a transmission system was needed. A planetary gearbox was selected, and a deconstructed drill was used to achieve the appropriate amount of torque.

Additionally, the adVise needs to meet the Specification Sheet consumer cost and prototyping cost. This requirement is reasonable because of the aforementioned low cost associated with simplistic custom parts and the prevalent use of standardized parts. Additionally, these standardized parts and different install configurations will easily allow the adVise to be mounted to the vise in under ten minutes - thus meeting the Assembly/Installation spec.

The User Interface, will consider the end user in guiding the design. Therefore, a simple and spatially ergonomic button interface is desired. The adVise takes up a relatively small amount of space, due to the mounting of the electronics underneath the motor mount. This allows for a large outside box surface area surrounding the mechatronics, giving the user interface designer plenty of room to make the buttons large and logically simple to use. It should be noted that the user interface has yet to be incorporated in a specific design and will be integrated into the next phase of prototyping and design.

The overall dimensions of the adVise must meet the geometry specifications set in Table 2. The front portion of the design, including the drivetrain system, the controller, and other control equipment is only three inches, and fits easily within the base height dimension. The front mounting plate is currently six inches wide, fulfilling the width requirement. It should be noted that the adVise width would be manufactured to a potential customer's vice width, meaning the possible range of widths are from four to ten inches to accommodate all standard vise sizes. All these widths are still within the maximum width of twelve inches. The width range of the front plate also accommodates the desired range of motion (six inches) that is set in the specifications.

When designing and operating a device, potential risks must be identified, and countermeasures must be taken to avoid failure. These risks can be broken down into two main categories: design and process failure modes. In order to design around foreseeable failures in the design process, a design FMEA, shown in Table 4, is built with potential countermeasures. The design FMEA is broken down into five failure modes - material properties, geometry, tolerances, interfaces with other components, and engineering noise - each with its own subcategories. A notable failure mode and countermeasure with this device in the design process is the incompatibility with the vise due to poor mechanical mating. This failure mode, examined earlier in the CAD models, can be counteracted by incorporating standard milling table slot locations or creating a universal connection to the vise. Another notable failure mode associated with the design phase is motor to lead screw interface, which also is a result of poor mechanical mating. This system is responsible for driving the entire device and must be compatible with the lead screw on the vise; otherwise, the device becomes inoperable. A corrective measure that must be considered is the use of a set screw to allow for reversible direction of the motor and a predetermined or adjustable height measure to allow for a proper interface with the lead screw.

The risks associated with the processing and use of the device are shown in a process FMEA, which is given in Table 5. The process FMEA is broken down into six failure modes: human factors, methods followed while processing, materials used, machines utilized, measurement systems impact on acceptance, and environmental factors. While these can oftentimes be more difficult to account for, there are multiple significant failure modes that must be addressed. One such failure mode is the user interface of the device being too difficult to operate. It is imperative to make the machinist's input minimal and the devices processing maximal in order to increase the ease of operation. Also, the force sensors are a crucial failure mode that must be addressed. Without these sensors, the device is incapable of reaching the desired final output. Therefore, careful calculations must be taken in order to guarantee the specifications of the device can be attained.

7. Industrial Design

In order to make the AdVise a viable market option, it was designed to be modular. The structural components of the overall design only involve two plates, two mounting bars, and an enclosure. The enclosure for the electronics is designed so that the pieces snap together and can be joined by either welding or glue. The final design only has screws to mount the plates to the square-stock mounting bars so there would be a limited number of screws. The device has high manufacturability and a low unit cost due to no complex shapes within the design.

Another important consideration when designing the adVise was ergonomics, and users being able to intuitively understand the operating system. In order to achieve an intuitive User Interface for the target customer, the buttons and dials were selected and laid out based on similarity to other machinist user interfaces. This would allow for a small learning curve and smooth transition in learning how to use the adVise.

Operation of the adVise requires no instructions, and has a simple, robust LCD screen to show tightening options and current force settings. It was decided that a dial and button setup was ideal, as the buttons would allow for a quick-clamp feature while the dial would allow a specific force to be set. The buttons are arrows in order to intuitively indicate the direction in which they work. Finally, the gear reduction box was chosen to be a right angle gearbox in order to minimize the amount of additional space taken up by the adVise. This is important in a machine shop with many people moving around.

8. Detailed Technical Analysis

Certain assumptions were made during the technical analysis. One assumption was that the mounting structure is rigid, allowing the torsion and bending analysis to only be performed on the base plate and front plate. This assumption is valid if the front and base plates are not subject to yielding, which is evaluated below, since they are the parts most likely to fail. Another assumption was that the bending load on the base plate could be modeled as a point load on a beam. This is valid because this assumption overestimates the actual bending stress on the part. It was also assumed that all bolts are rigid and not subject to shear forces. This is due to the bolts having a very high yield stress and engineering intuition that qualifies the bolts as not being the failure point.

To ensure the product meets the specifications, a detailed technical analysis was performed. The torsion and bending stresses were calculated using the final geometry of the product, and can be seen in Equations 1 and 2. The front and base plate torsions were calculated to be $115.9\ kPa$ and $151.7\ kPa$, respectively. By comparing these to the torsional yield stress of $217.5\ MPa$, these values can be considered negligible, since they are three orders of magnitude smaller. The calculations for these torsional stresses can be seen below.

$$\tau_{max} = \frac{T}{\kappa b h^2} = 115.9\ kPa$$

$$b = 7.5\text{"} = 0.1905\text{ m},\ \text{h} = 2.87\text{"} = 0.0729\ m, \kappa = 0.258$$

Equation 1. Torsion Equation of Front Plate.

$$\tau_{max} = \frac{T}{\kappa b h^2} = 151.7\ kPa$$

$$b = 7.5\text{"}=0.1905\ \text{m}, \text{h}=0.125\text{"} = 0.003175\ m, \kappa = 0.330$$

Equation 2. Torsion Equation of Base Plate.

By making the assumption of a cantilever beam for the base plate with an overhung load concentrated at the end of the beam, which makes for a worst-case-scenario, the bending stress can be calculated. The calculated stress was $18.1\ MPa$. This gives a factor of safety of 24, since the yield stress is $485\ MPa$. Each of these calculations, shown in Equation 3, prove that the product meets the specifications regarding torsion and bending requirements.

$$\sigma = \frac{Mc}{I} = 18.1\ MPa$$

$$M = W * l = 44.5\ N * 0.1905\ m = 8.48\ Nm$$
$$c = \frac{t}{2} = \frac{0.003175}{2} m = 0.0015875\ m$$
$$I = \frac{1}{12} bh^3 = \frac{1}{12} * 0.2794\ m * 0.003175^3\ m^3 = 7.453e - 10\ m^4$$

Equation 3. Bending Equation of Base Plate.

Calculations were performed to evaluate the amount of torque needed to be delivered to the lead screw from the stepper motor and gear reduction box. Equation 4 below shows the governing equations, and the torque needed to produce a force of $2000\ lbf$ was determined to be $250\ lbf - in$. The motor delivers a torque of $26.8\ lbf - in$, and this was selected based on the best price to torque ratio. This information on the required torque and motor was used to select gear reduction box, which has a gear ratio of $10:1$. Therefore, the motor and gear reduction box drivetrain should theoretically be able to provide a torque of $268\ lbf - in$, which would be able to meet the required specification.

$$\tau = \frac{Tr}{J} = \frac{F}{A}; T = 28.2\ Nm = 250\ lbf - in$$

$$F = 8896.4\ N, r = 0.00635\ m$$
$$A = \pi r^2 = 1.267e - 4\ m^2$$
$$J = \frac{\pi}{2} r^4 = 2.554e - 9\ m^4$$

Equation 4. Torque Equation for Lead Screw.

For the testing of the prototype, the pressure mounting plates were attached to a standard milling vise and a torque wrench used to apply a known torque to the lead screw. For each applied torque, the force reading on the LCD was recorded, and this data was used to calibrate the force sensors. Figure 12 shows the calibration fit, which allows the device to know the applied force based on the calibration.

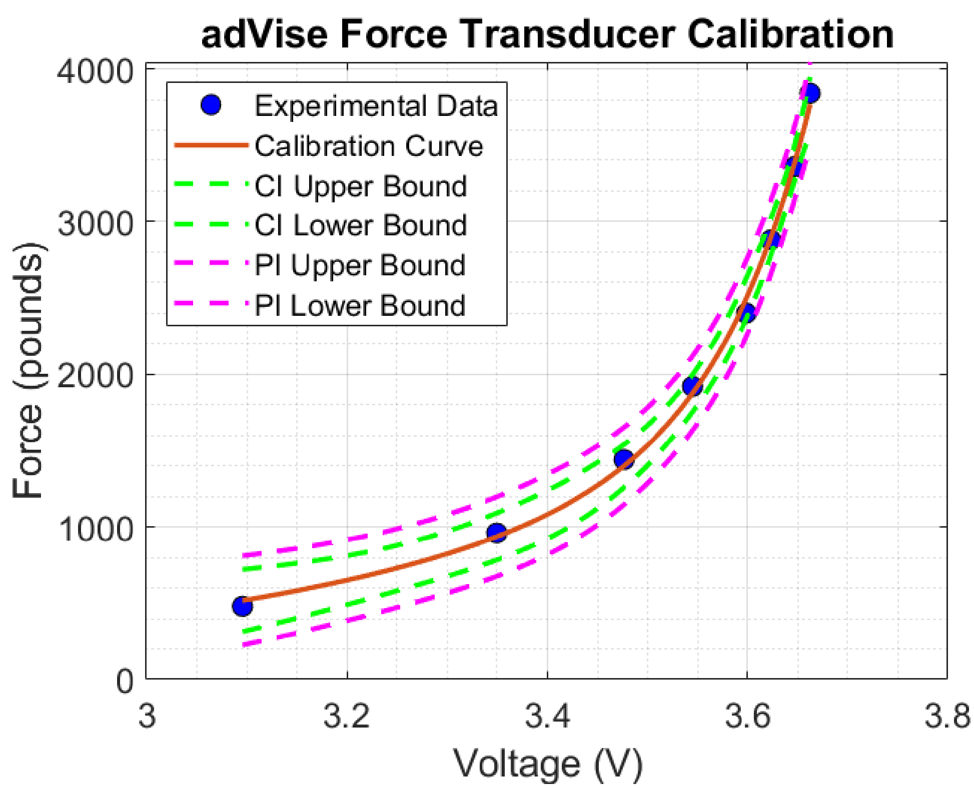

Figure 12. force Sensor Calibration Fit.

Once the force sensors were calibrated, the prototype was tested to determine the accuracy of the force that could be applied to the part within the vise to validate the calibration. The test setup for the force testing is shown in Figure 13 below.

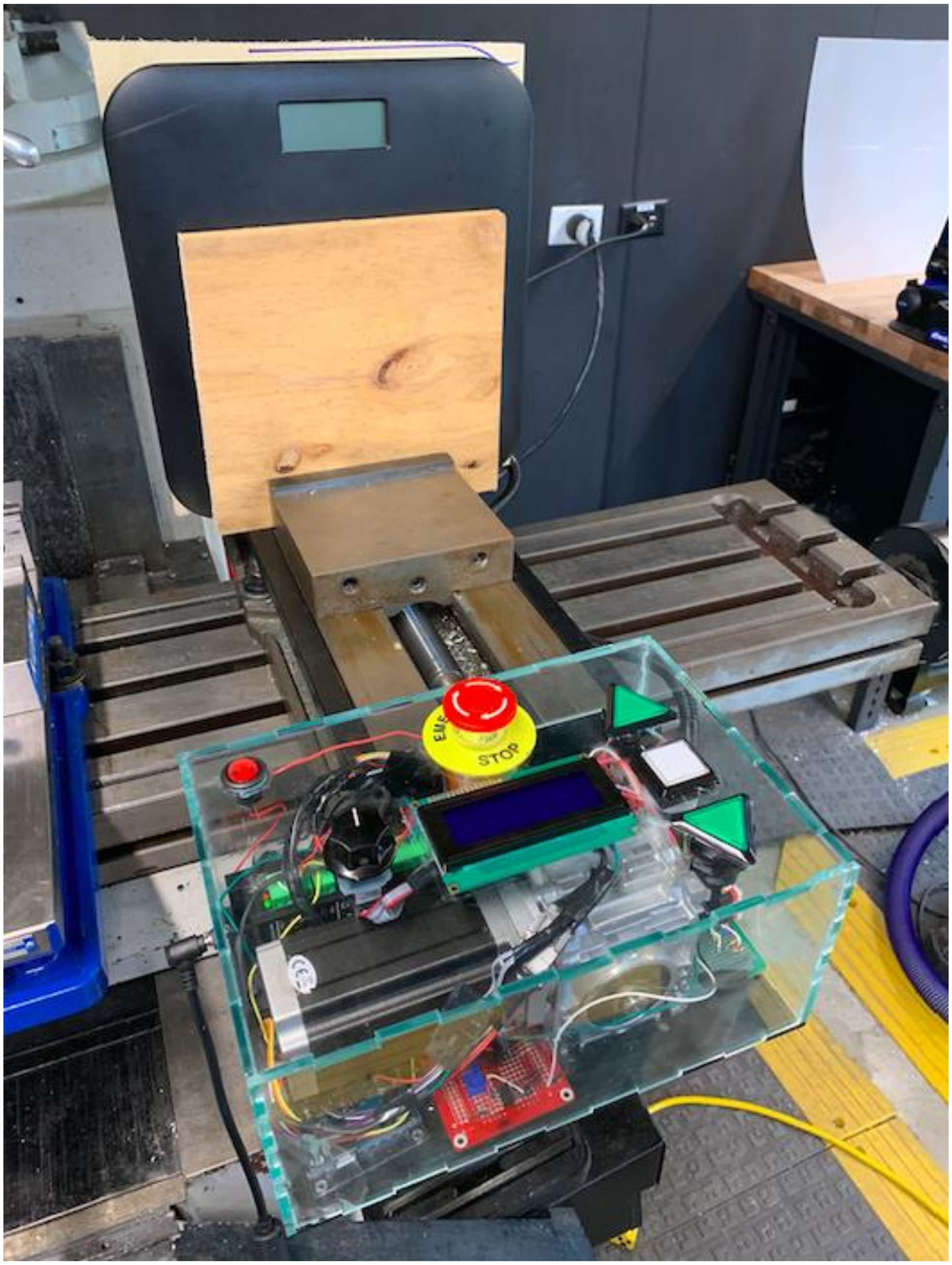

Figure 13. Force Testing and Calibration Verification.

The test was performed by placing a standard scale within the vise and adding a force from the vise. The wooden plates are placed around the scale to help distribute the weight evenly across the scale. The results of the force testing can be seen in Table 6 below.

Table 6. Force Testing Results.

Test Number	adVise Reading [lbf]	Scale Reading [lbf]	Percent Error [%]
1	13	13.6	4.411764706
2	27	27.6	2.173913043
3	56	54.4	2.941176471
4	104	108	3.703703704
5	136	139.2	2.298850575
6	163	165.2	1.331719128
7	210	202.8	3.550295858
8	224	217	3.225806452
9	259	255.4	1.409553641
10	322	318.6	1.067168864
		Standard Deviation	1.13323349
		95% Confidence Interval	± 2.26646698

The force tests demonstrate the ability of the prototype to reach forces with a decent amount of accuracy. Through ten trials, the 95% confidence interval for the forces were $\pm 2.3\%$ of the force reading. After completing these tests to determine accuracy of the force sensors, the prototype attempted to put the maximum force possible on a part. The device was able to put about 1000 pounds of force onto a block of wood. This verifies the ability of the design to tighten to a force capable of holding a part during the milling process. However, it does not reach the design goal of 2,000 pounds. Since the 1,000 pound mark was reached with this current setup, this gives reason to believe that much higher forces can be reached with a higher power motor and more efficient gearbox.

9. Final Design, Mockup, and Prototype

The final design builds off of the selected preliminary design and optimizes different critical areas to create the ideal product for our specifications. Figure 14 below shows the final design mounted to a mill.

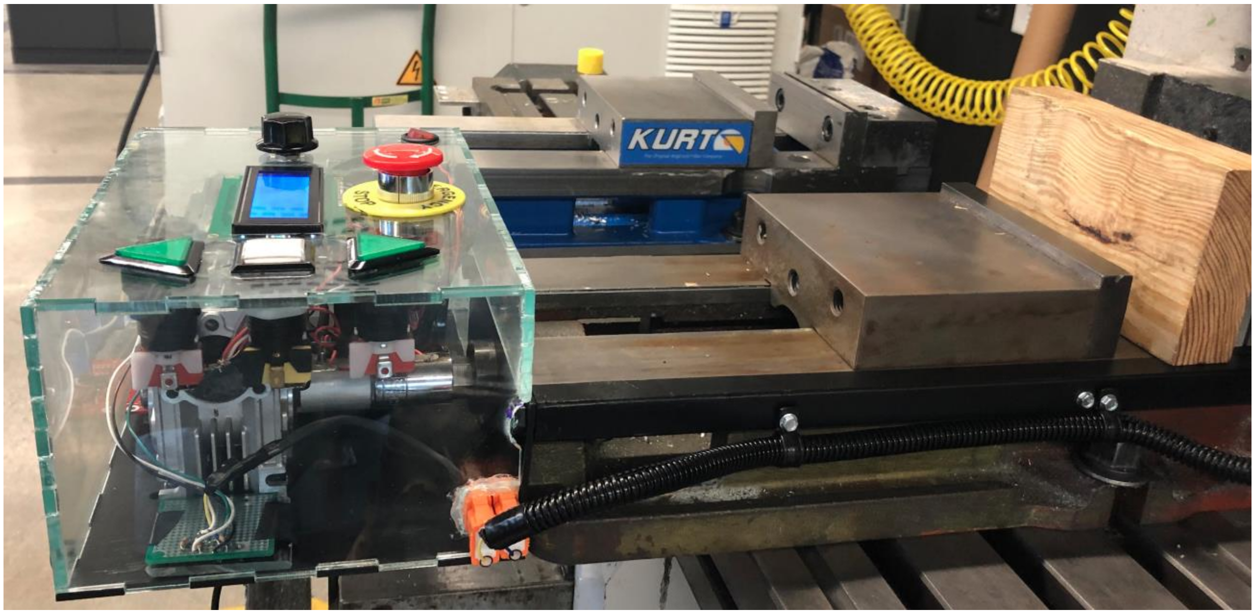

Figure 14. adVise Mounted to Mill.

The product is easily attached to the Kurt DX6 vise by tightening two bolts from the back plate, then attaching the pressure mounting plate to the back jaw of the vise. The pressure mounting plates are machined to attach to the back jaw of the vise and serve to hold the force sensors in place. This setup can be done in thirty seconds, and is the only prerequisite to using the device other than plugging the power in to the wall outlet. When attaching the vise, it is important to make sure the socket is placed around the lead screw of the vise. If the vise is not on the lead screw, no functions will occur.

The power transmission system for the prototype consists of a NEMA 23 motor, gear reduction box with a 10: 1 gear ratio, a nineteen millimeter socket, and a socket drive adapter between the gearbox and socket. As shown in Section 8, the power transmission should be able to provide a torque of $268\ lbf - in$ to the lead screw. Considerations for the selection of the power transmission system were primarily guided by costs and budget constraints. With a larger budget, an extremely powerful motor and extremely efficient gearbox can be purchased. However, we were challenged with trying to find the best transmission with the budget we had. This led to purchasing the NEMA 23 motor paired with a gear reduction box to supply the adequate amount of torque. Although increasing torque with the gear reduction box decreases the output speed of the system, it is most important to demonstrate the ability of the prototype to clamp the part with an adequate force for the proof of concept.

The user interface has been created in a simple, intuitive manner so users can quickly learn how to operate the device. The user interface can be seen in Figure 15 below.

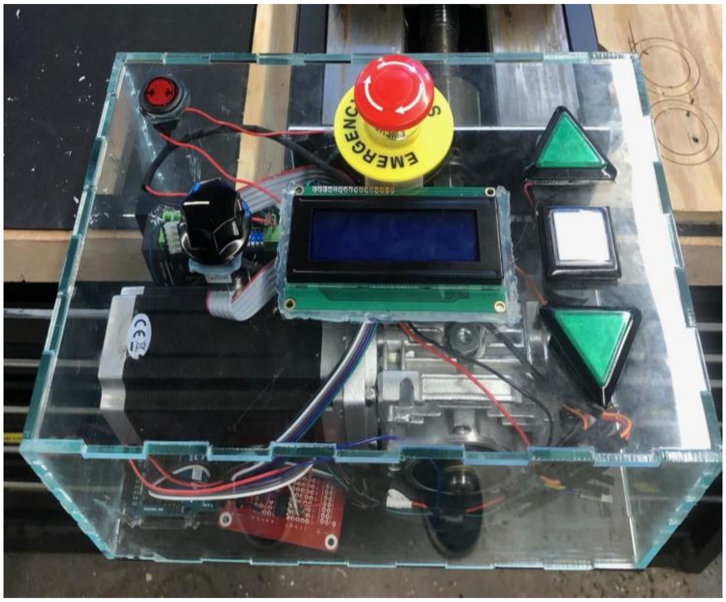

Figure 15. Top View of User Interface.

The rocker switch in the top left corner is the power switch to turn the device on. The two triangular buttons allow the user to manually control the vise, while the square button activates the automated system. Upon activation the LCD tells the user that the system is active, as well as the current force and target force. The target force is adjusted using the dial next to the LCD. The emergency stop is in series with the power being delivered to the system, and it has the ability to cut the power to the system when pressed, causing the vise to turn off. The user interface is modeled to replicate common features of other machine parts, such as the standard emergency stop and large, easy-to-see buttons. Also, the simple LCD screen is similar to that of an old manual mill or other metalworking tools. Figure 2 in the Fabrication Package Appendix shows the assembly for the housing, which details the location of each part and assembly procedure for each component. The assembly also provides vendor information for the parts that were purchased from outside sources.

The electronic components of this system can be divided into three main subsystems. The first subsystem involves the power supply, motor driver, and motor. This system is responsible for getting power to the motor. The next subsystem involves the user interface. This involves the protoboard circuit, dial, LCD screen, and buttons. The third subsystem is the force sensor system, which uses the force sensor with a low pass filter to eliminate noise for the microcontroller. Each of these systems are controlled by a single Arduino.

The prototype is able to meet all specified engineering requirements with respect to geometry, weight, power requirements, and material strength. These specifications were easily met since they were the basis for the design decisions. The customer requirements of a fast closing time, an adequate clamping force, and safe operation were more difficult. Through the implementation of an emergency stop, the prototype is safe to operate for users. The emergency stop is in series with the power circuit, so pressing it immediately shuts down the system. The vise face is able to close at a rate of 2.25 inches per minute, which is not extremely fast. However, this speed is as fast as possible with this gear reduction box and motor, which are necessary to obtain the required amount of torque. As discussed in Section 8, the prototype is only able to output a clamping force of 1,000 pounds. This falls short of the 2,000 pound goal in the specifications sheet. The failure to reach the target force can be attributed to inefficiencies in the gearbox. These inefficiencies are a result of the worm gears within the gearbox slipping. To reach higher clamping forces, a more efficient gearbox should be utilized. In addition, a more efficient gearbox would be able to provide higher output speeds, decreasing closing time. With the current gearbox, the output shaft should be rotating and ten times less revolutions per minute than the motor shaft. However, the motor shaft rotates at close to 2000 RPMs, while the gearbox output shaft only rotates at about 35 RPMs. This demonstrates the inefficiencies within the gearbox.

The pressure mounting plates are designed such that they interface with the back jaw of a standard milling vise. The steel plate has cutouts for the force sensors, as well as relief areas for the wiring. The wiring is contained in a plastic sleeve that is secured to the holding arms of the mounting structure. This sleeve ensures that the wires will not be exposed and will remain next to the vise for both safe functionality and aesthetic improvement. The aluminum plate has two raised areas that fit into the steel cutouts and serve to completely compress the force sensors. These pressure mounting plates were designed to provide a secure method of holding the force sensors to the vise face. As seen in Figure 17 of the Fabrication Package Appendix, the holes in the pressure mounting plates allow for interfacing with the back jaw of the vise, and this installation procedure is something that every machinist is familiar and comfortable with performing.

Some major obstacles presented themselves throughout the design and build of the prototype. These obstacles were navigated by careful planning and research into existing solutions to these problems. The first major obstacle was during the concept validation stage. It became apparent that the DC motor initially being used would not immediately stop when the supply voltage was cut off from it. This was due to the inertia of the motor causing further rotation. To fix this, a stepper motor was used to prevent the extra rotation. The stepper motor allows for the motor to stop as soon as the current is cut off from it. Another issue faced was the location of the force sensors. It was not clear how to fix the force sensors so they would not simply be taped to the vise jaw or have wires all over the top of the vise. To combat this issue, the pressure mounting plates were fabricated to give the force sensors a fixed location. Also, the wiring sleeve was implemented to eliminate the loose wiring around the vise. The other main obstacle faced was the design of the circuit elements. During the assembly of the circuit elements, issues such as noise from the force sensor and noise from the stepper motor driver caused issues with the force readings and LCD display. These extraneous high frequencies corrupted the LCD signal and would result in illegible characters appearing on the screen. These electronic problems were solved by separating the power supply for the LCD from the remainder of the system. Now, the LCD is powered by a 9 volt battery within the housing. The issue with noise from the force sensors was solved by creating a low pass filter between the sensors and the Arduino. The low pass filter eliminated the high frequency noise from the force sensors, allowing for a clean, legible, alphanumeric LCD display.

The Fabrication Package Appendix is provided to detail the complete manufacturing process for the adVise system through assembly and part drawings. With these, and the instructions provided on them, any manufacturer can replicate the work done over the course of this project. The prototype's top level assembly can be seen in Figure 1 of the Fabrication Package Appendix, and the three subsystem assemblies follow suit. The subassemblies are divided into the Outside Mounting Assembly, Inside Mounting Assembly, and Housing Assembly. Each of these subassemblies call out the parts within the assembly. The parts fabricated by the design team also have part drawings to show the manufacturing instructions. In addition to dimensioning, these drawings include notes on material selection and manufacturing processes used to ensure the correct fabrication of each part.

The Bill of Materials shown in Table 1 of the Fabrication Package Appendix takes the Bill of Materials for each of the subassemblies and condenses them into one table. From the Specification Sheet, the target price for the device was set to be less than $350. This number was determined from taking the difference in price for an all-in-one vice, valued at about $1400, and a standard milling vise, valued at about $700, and giving a comfortable margin of half. This specification would give a viable economic justification for the device. As can be seen in Table 1 in the Fabrication Package Appendix, the total price of $253.42 falls well within the specification and gives proof that this retrofit device is viable on this market.

10. Manufacturing

The design is manufactured to be a working prototype made to validate the design concept. For the prototype, material selection was a primary concern. For the mounting structure, bottom of the housing, and square mounting interfaces, a 4310 steel plate was used. This material provides strength and stability against the torsional and bending loads seen by these first two parts and is easy to weld for the square mounting interfaces. In addition, steel can be welded easily, which aids with assembly. Because the back plate of the mounting structure is not subject to the same intensive load as the front plate, 6061 aluminum was selected to be more cost effective than the steel plate. The holding arms of the mounting structure were selected to be plain steel bars, which are inexpensive, off the shelf products, and can easily be cut to length. The housing was selected to be acrylic for the design expo so judges could see into the prototype. If this was not a consideration, the housing would be aluminum, since aluminum is cost effective and the housing is not a structural element.

To manufacture the prototype, multiple fabricating methods were used. For the steel bottom of the housing, square mounting interfaces, front mount plate, and back mount plate, a waterjet was used to cut the required shape. The waterjet was selected as the ideal way to precisely cut the 4130 steel plates and 6061 aluminum. The holding arms were cut to the specified length using a bandsaw, and the ends were sanded with a belt sander to ensure a smooth, flat end. The acrylic housing pieces were laser cut, as this method provided a quick, accurate way to cleanly fabricated the material, since acrylic can crack easily if cut with traditional metalworking methods. The final fabricating method used was CNC milling. The socket drive adapter and force sensor housing were both CNC milled since they were more complex parts with geometries best suited for a mill.

For assembly of the parts, the square mounting interfaces were welding on to the end of the holding arms. Also, the bottom of the housing was welded to the front plate at a right angle. The holding arms were connected to the front and back plates by bolts running through the plates and into the tapped ends of the square mounting interfaces. The acrylic housing was glued together, with the top piece just being snap-fit into place so it can be removed for the judges at the design expo.

The only stand-alone parts are the pressure mounting plates. One of the plates is low carbon steel, which is the strongest and most difficult to machine. It was machined using a CNC mill at a very slow speed, since low carbon steel has a strength and can be difficult to machine. The other plate is CNC milled out of 6061 aluminum. This part compresses the force sensors into the steel piece and ensures the force sensors are fully covered when being compressed.

11. Codes and Standards

The fact that there are no applicable patents for retrofit vise technology demonstrates the novelty of the device. Further, the lack of current patents for vise functions relieves the device of the freedom to operate constraint. There are, however, two notable code standards that the device must be in compliance with. The first, OSHA 1910.211(d)(44), deals with possible pinch points. Since the device presents a pinching hazard, safety labels and buttons must be included to minimize the possibility of pinching. The second, UL 50/50E, deals with enclosures of electrical equipment. The standard requires that all electrical equipment be properly insulated, and that the enclosure shall not be sufficiently sharp as to cause a risk for injury.

12. Societal, Environmental, and Sustainability Considerations

While the use of acrylic is not environmentally friendly, acrylic was selected for the capstone design presentation so that judges could see inside of the enclosure. For the manufactured design, steel will be used. While the production of steel does impact the environment by increasing emissions, an eco-friendly alternative would be to use recycled steel to produce our parts. This would be the long-term manufacturing goal, as recycled steel is generally cheaper than “new” steel.

A second environmental consideration is the use of power as opposed to a manual tightening of the vise grip. Because this is an automated device, using power is a necessary effect. However, the adVise uses much less power compared to the large machines often found in machine shops.

13. Risk Assessment, Safety, and Liability Considerations

The largest potential safety risk has to do with pinch points. A potential operator would see and feel when the vise was closing on their fingers and could stop closing the vise when operating manually. However, an additional safety feature had to be implemented with an automatic tightener. The emergency stop button sits in series with the power circuit, and completely shuts off power when activated. This prevents further tightening of the vise and allows the operator to turn on the vise and remove any pinched limbs. The emergency stop button is visually similar to other machine shop emergency stops and situated clearly in the center of the user interface for easy access.

In order to evaluate if any additional safety measures needed to be taken, a risk evaluation matrix was used. This evaluation matrix is shown in Figure 16. Because the adVise does not travel at an unreasonably fast speed, the frequency of a limb getting caught in the vise is very low. In addition, the worst-case scenario harm inflicted on a user would be serious if it was a broken finger. Thus, the risk evaluation matrix shows that the adVise belongs to class D. Class D is a low risk condition with additional mitigation contingency planning, which is simply advisory in nature. This means that additional safety features do not need to be implemented.

14. Patent Claims and Commercialization

In researching existing patents, no patent exists for a “retrofit, electrically powered vise grip tightener”. This means that a patent could potentially be filed for the adVise, and commercialized. The possibility for commercialization is contingent upon judge and Capstone Expo feedback on the device and would require further market research on economic analysis. The first step would be to secure a patent and consider lowering the cost by creating a custom planetary gearset instead of buying one fully manufactured. This would lower the cost to a reasonable price point.

In order to market the adVise, a grassroots marketing campaign would be needed. This would entail contacting engineering university machine shops across the country to gauge interest, as the device is relatively niche. Once a sufficient interest level has been reached, small-scale production could begin. Because the adVise was designed and prototyped with modularity in mind, implementation of production through small and large scale manufacturing would be a seamless transition.

15. Conclusions

In summary, this project has demonstrated the validity of an automated vise tightener. This product can take a user input, apply a controlled force, and sufficiently clamp the part within the vise. Additionally, the vise is retrofitted to a standard milling vise. The product can provide a clamping force of up to 1,000 pounds, as well as travel at a linear speed of 2.25 inches per minute.

For future work, it would be beneficial to buy a more powerful motor so the vise could close faster and apply more force. The improvements to closing time will increase effectiveness and user interest, while the added force will allow for a wider variety of parts to be placed in the vise. Because of budget constraints for this project, a more powerful motor was not able to be implemented. However, the current prototype serves as a sufficient proof of concept to validate this idea. Another feature to improve would be the force sensors. Better force sensors could withstand a higher load rating, allowing more force to be delivered to the vise face. It would be beneficial to use load cells as the force sensors to be able to withstand high loads over a long period of time with less susceptibility to fatigue failure. Also, a higher efficiency gearbox could be used to prevent losses in torque and speed through the power transmission. The current gearbox utilizes worm gears and is around 80% efficient, not considering slipping effects, while other types of gearboxes, such as helical gearboxes, can reach efficiencies greater than 95% and do not slip. A final adjustment to make to improve the product would be adding a low pass filter for the motor controller to eliminate noise coming from the motor controller. This would allow every component to be used on one power supply.

16. References

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[3] W. and Art, "How to Make an Automatic Vise [DIY]," *YouTube*, 16-Sep-2018. [Online]. Available: https://www.youtube.com/watch?v=O1WCL49Xj5w. [Accessed: 12-Jun-2019].

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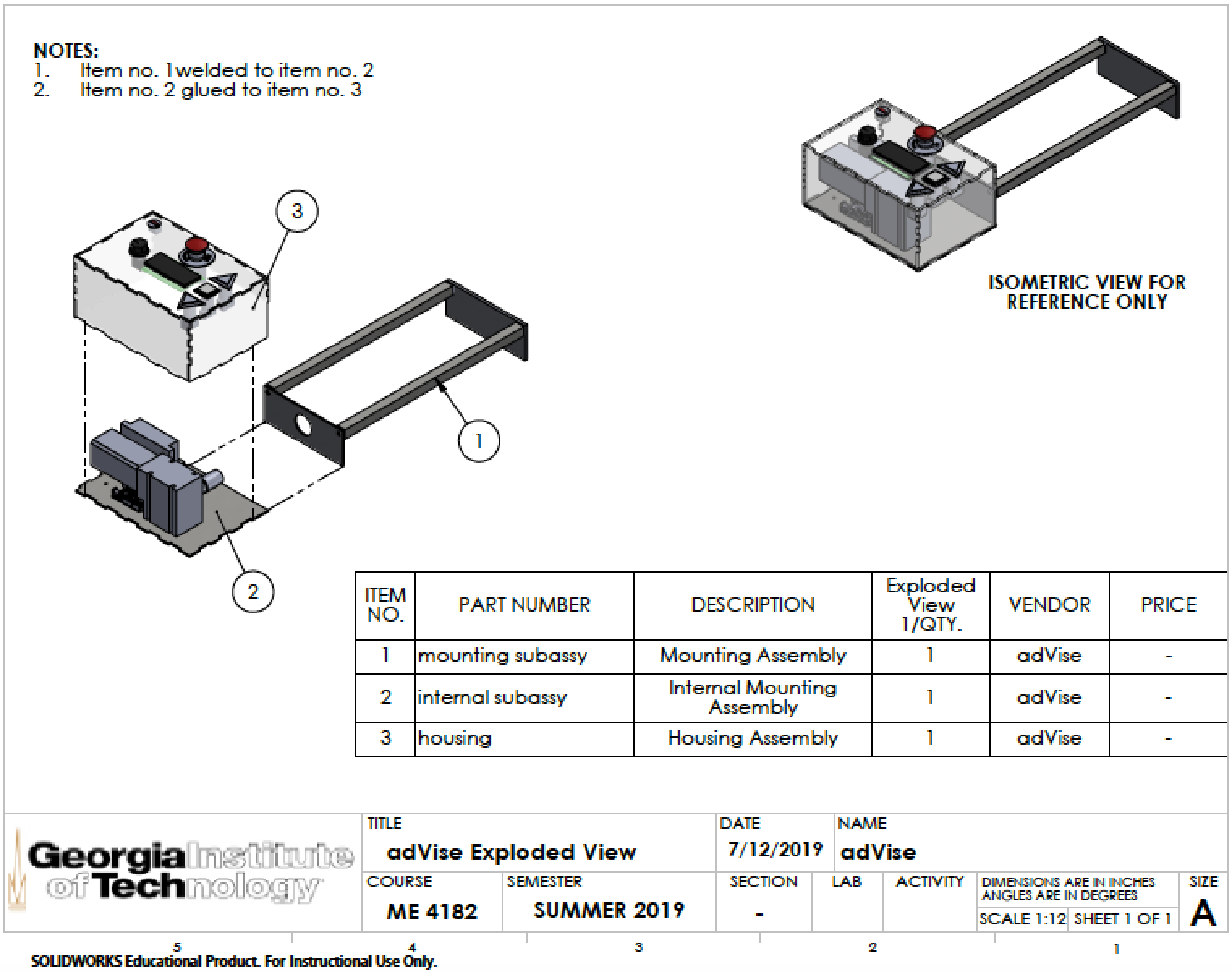
Budget Appendix

Description	Store / Website	Price	Buyer
Kuman Screw Shield Expansion Board	Amazon	$9.19	Clay Dodson
Maxmoral 1-Pack DC-DC 24V to 5v stepdown	Amazon	9.59	Clay Dodson
Load Cell	Amazon	8.75	Clay Dodson
Pressure Sensor	Tekscan	$100.20	Clay Dodson
motor controller + Capacitors	Amazon	$10.23	Clay Dodson
Worm Gear Speed Reducer	Amazon	$65.00	Clay Dodson
Stepper Motor Controller	Amazon	$39.95	Clay Dodson
Planetary Gearbox	Amazon	$55.55	Clay Dodson
Stepper Motor Controller, Stepper motor, Power Adapter	Amazon	$68.09	Clay Dodson
Logic Converters		$6.99	Clay Dodson
Dc Motor Controller High Amp		$13.59	Clay Dodson
velcro, zip ties, socket, screws, clamp	Home Depot	$14.44	Jason Vickers
Rod Stock	McMaster	$10.02	Jason Vickers
UI Buttons	Adafruit	$23.96	Jason Vickers
Emergency Stop Button	Amazon	$6.69	Jason Vickers
Black and Decker 18 V Drill	Target	$44.64	Nick Thalken
Bolts, nuts, duct tape, wire nuts	Home Depot	$14.00	Nick Thalken
Acrylic, bolts	Home Depot	$43.23	Nick Thalken
4130 Steel Plate	McMaster	$89.78	Nick Thalken
Poster board, adhesive, easel	Staples	$33.62	Andrew Belflower
Table cloth for expo	Target	$4.36	Andrew Belflower
	TOTAL:	$667.51	

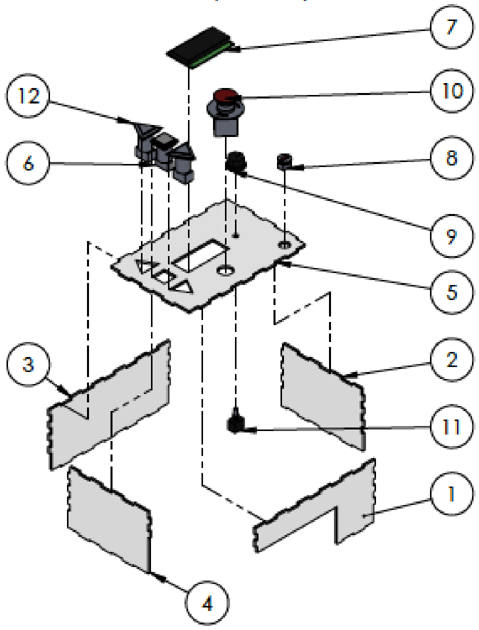
Fabrication Package Appendix

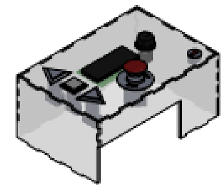


ITEM NO.	PART NUMBER	DESCRIPTION	Exploded View 1/QTY.	VENDOR	PRICE
1	mounting subassy	Mounting Assembly	1	adVise	-
2	internal subassy	Internal Mounting Assembly	1	adVise	-
3	housing	Housing Assembly	1	adVise	-

Figure 1. Top Level Exploded View of adVise.

NOTES:
1. Item no. 7 and 8 glued to item no. 5
2. Item no. 1, 2, 3, 4, 5 glued together
3. All other items captured by nut onto item no. 5





ISOMETRIC VIEW FOR REFERENCE ONLY

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	VENDOR	PRICE
1	Housing Front Plate	Front Housing Face	1	adVise	$1.34
2	Housing Side Plate Left	Left Side Housing Face	1	adVise	$1.57
3	Housing Back Plate	Back Housing Face	1	adVise	$2.30
4	Housing Side Plate Right	Right Side Housing Face	1	adVise	$1.56
5	Housing Top Plate_UICut	Top Housing Face	1	adVise	$2.99
6	Square Button	Start/Stop Button	1	Adafruit	$3.95
7	LCD Screen	User Display Screen	1	Adafruit	$17.95
8	OnOffButton	On/Off Rocker Switch	1	Amazon	$5.95
9	Dial	Set Pressure Dial	1	Bourns	$2.81
10	Emergency Stop	Standard Emergency Stop	1	Amazon	$9.69
11	Encoder	Dial Encoder	1	Bourns	$3.25
12	Triangle Button	Manual Control Buttons	2	Adafruit	$3.95

Georgia Institute of Technology

TITLE		DATE	NAME			
HOUSING EXPLODED VIEW		7/12/2019	adVise			
COURSE	SEMESTER	SECTION	LAB	ACTIVITY	DIMENSIONS ARE IN INCHES ANGLES ARE IN DEGREES	SIZE
ME 4182	SUMMER 2019	-			SCALE 1:12 SHEET 1 OF 1	A

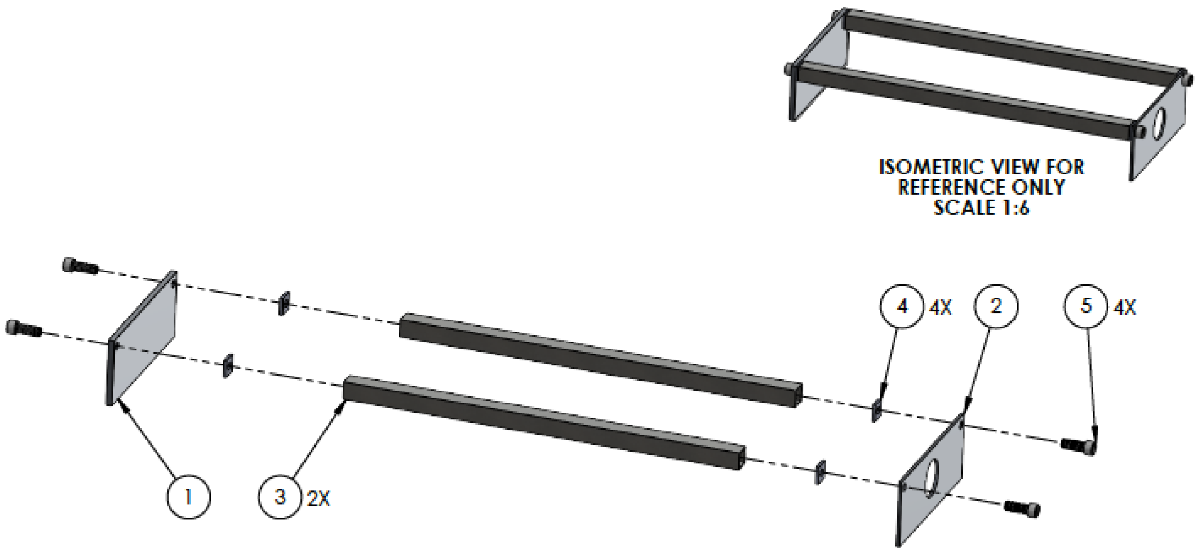
5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

Figure 2. Housing Subassembly.

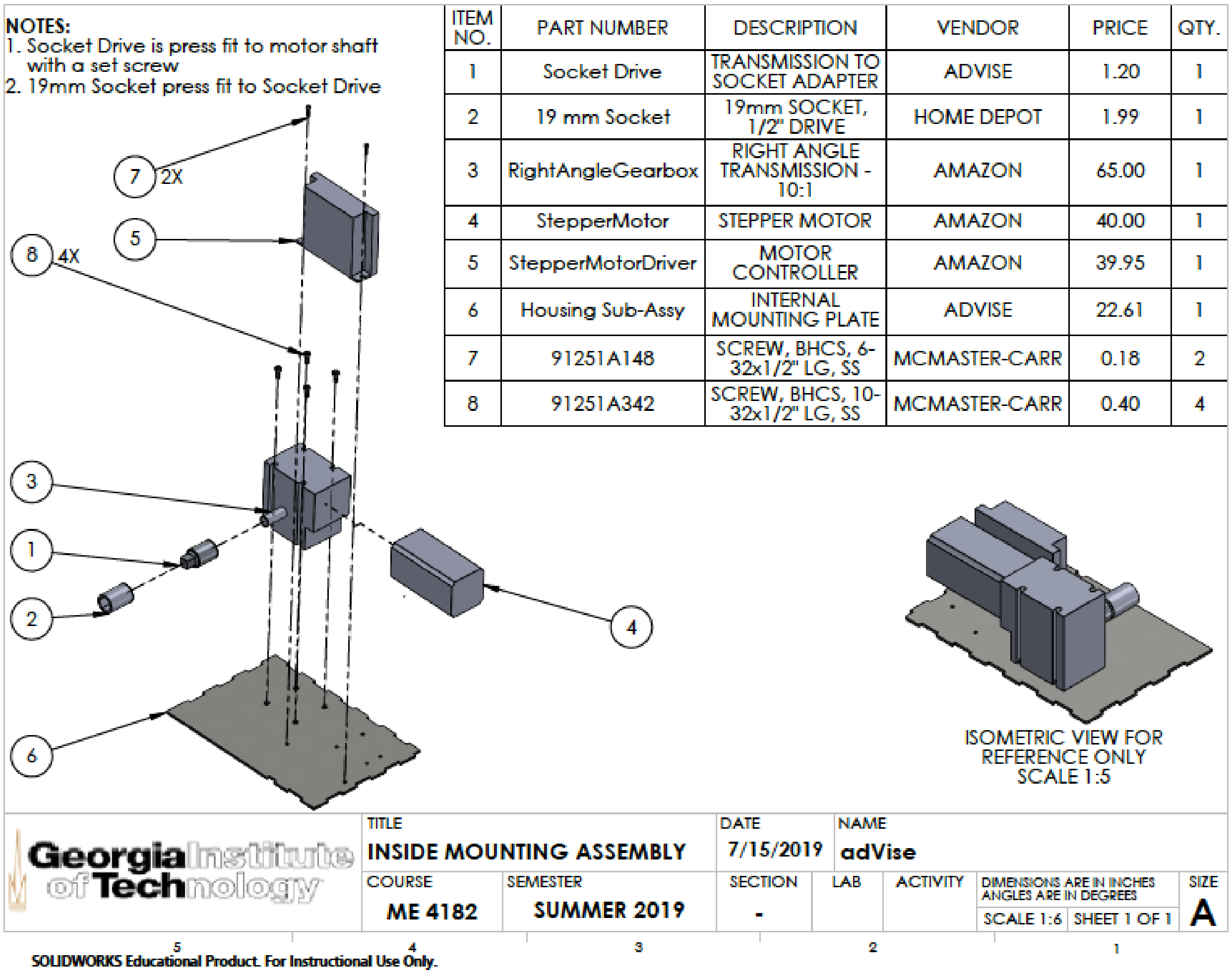
NOTES:
1. Square Stock Interface is 3/8-24 threaded and welded to the Square Stock Holding Arm

ITEM NO.	PART NUMBER	DESCRIPTION	VENDOR	PRICE	QTY.
1	Back Plate	REAR CONNECTING PLATE	adVise	2.81	1
2	Front Plate	FRONT CONNECTING PLATE	adVise	8.22	1
3	Square Stock Holding Arm	VISE MOUNTING ARMS	HOME DEPOT	5.01	2
4	Square Stock Interface	THREADED ARM TO PLATE ATTACHMENTS	adVise	0.28	4
5	91251A424	SCREW, BHCS, 3/8-24x1" LG, SS	MCMASTER-CARR	0.36	4



Georgia Institute of Technology	TITLE: MOUNTING ASSEMBLY		DATE: 7/15/2019	NAME: adVise		
	COURSE: ME 4182	SEMESTER: SUMMER 2019	SECTION: -	LAB	ACTIVITY	DIMENSIONS ARE IN INCHES ANGLES ARE IN DEGREES; SCALE 1:5; SHEET 1 OF 1; SIZE A

Figure 3. External Mounting Subassembly.



ITEM NO.	PART NUMBER	DESCRIPTION	VENDOR	PRICE	QTY.
1	Socket Drive	TRANSMISSION TO SOCKET ADAPTER	ADVISE	1.20	1
2	19 mm Socket	19mm SOCKET, 1/2" DRIVE	HOME DEPOT	1.99	1
3	RightAngleGearbox	RIGHT ANGLE TRANSMISSION - 10:1	AMAZON	65.00	1
4	StepperMotor	STEPPER MOTOR	AMAZON	40.00	1
5	StepperMotorDriver	MOTOR CONTROLLER	AMAZON	39.95	1
6	Housing Sub-Assy	INTERNAL MOUNTING PLATE	ADVISE	22.61	1
7	91251A148	SCREW, BHCS, 6-32x1/2" LG, SS	MCMASTER-CARR	0.18	2
8	91251A342	SCREW, BHCS, 10-32x1/2" LG, SS	MCMASTER-CARR	0.40	4

Figure 4. Internal Mounting Subassembly.

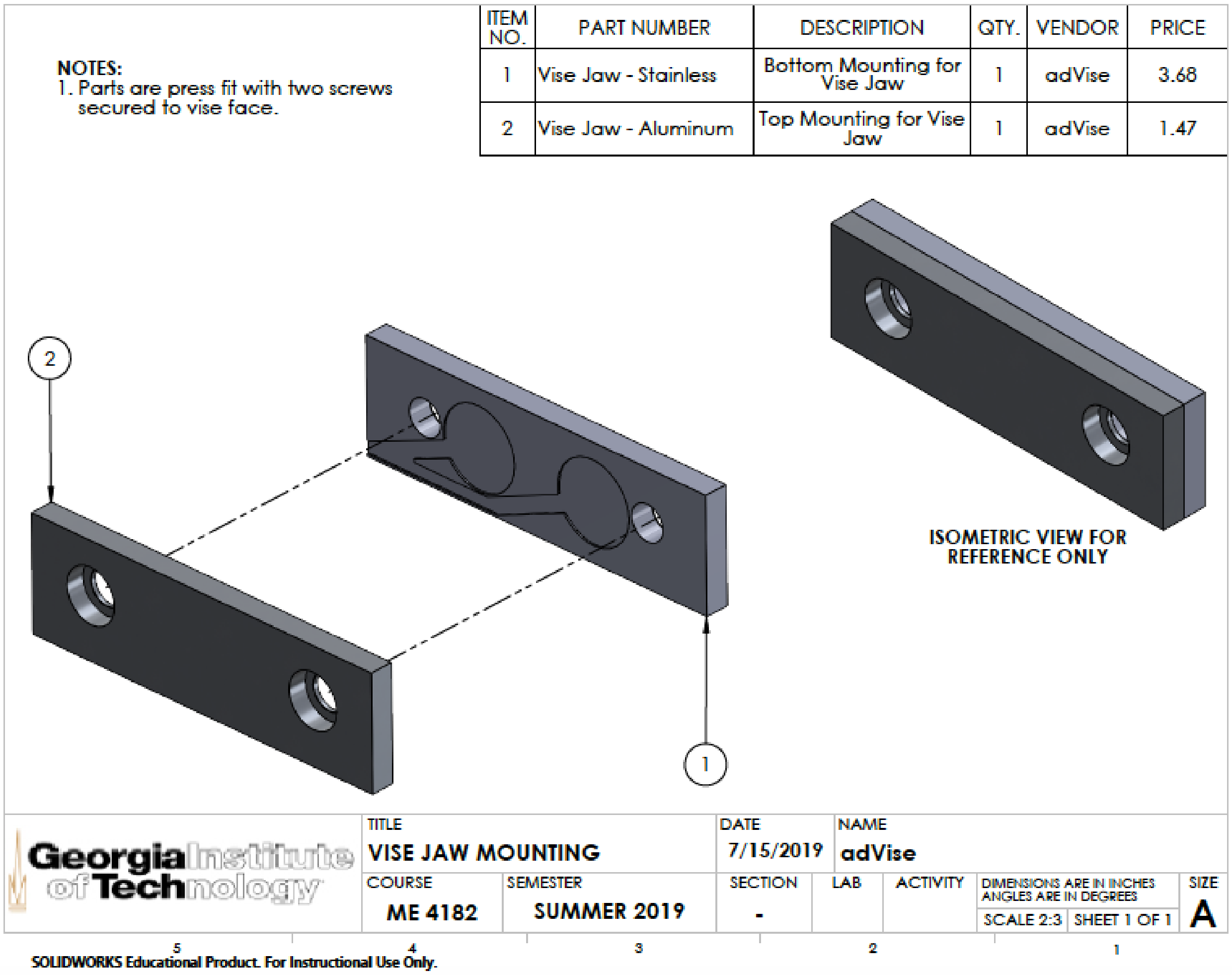


Figure 5. Vise Jaw Subassembly.

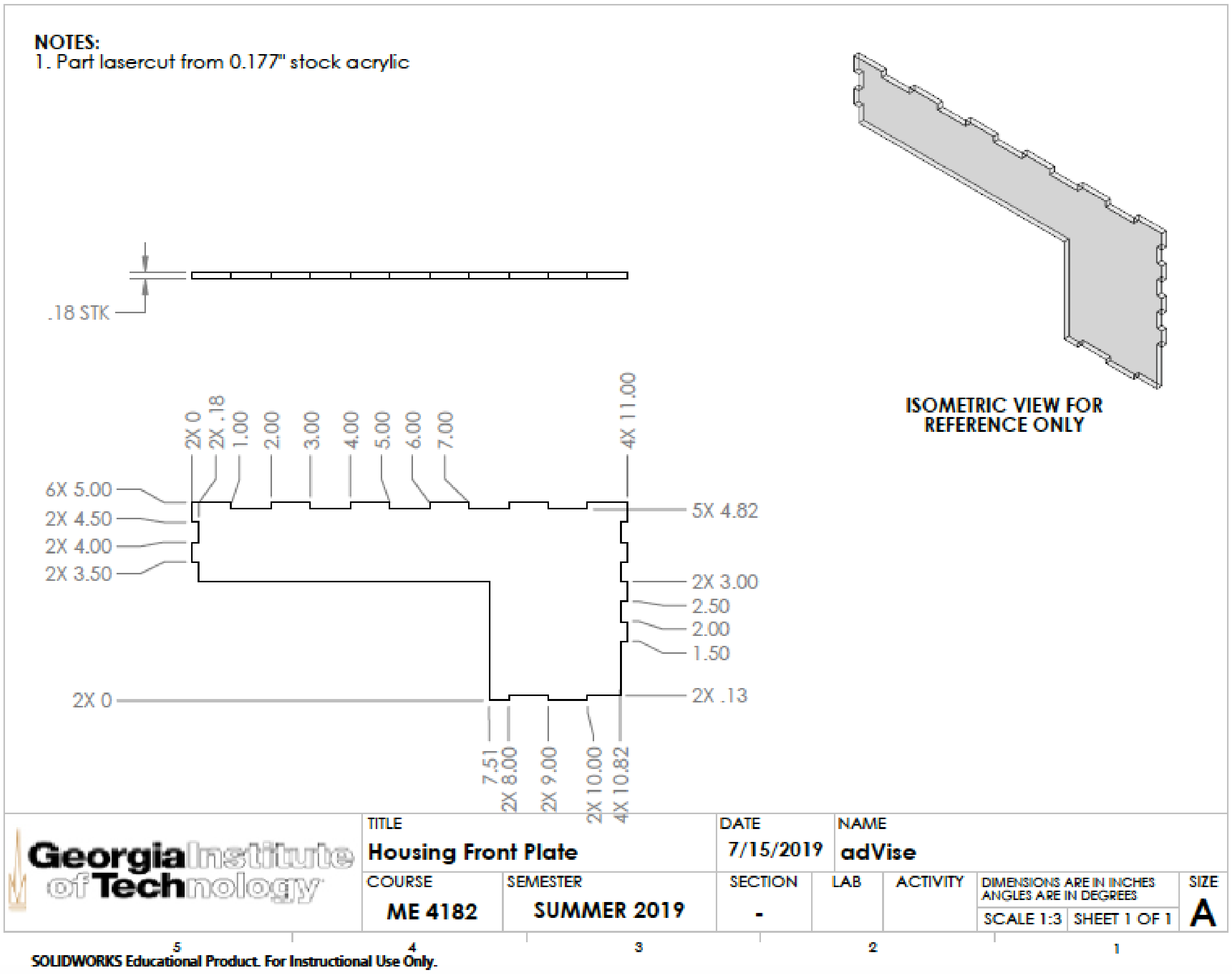


Figure 6. Front Plate for Housing Assembly.

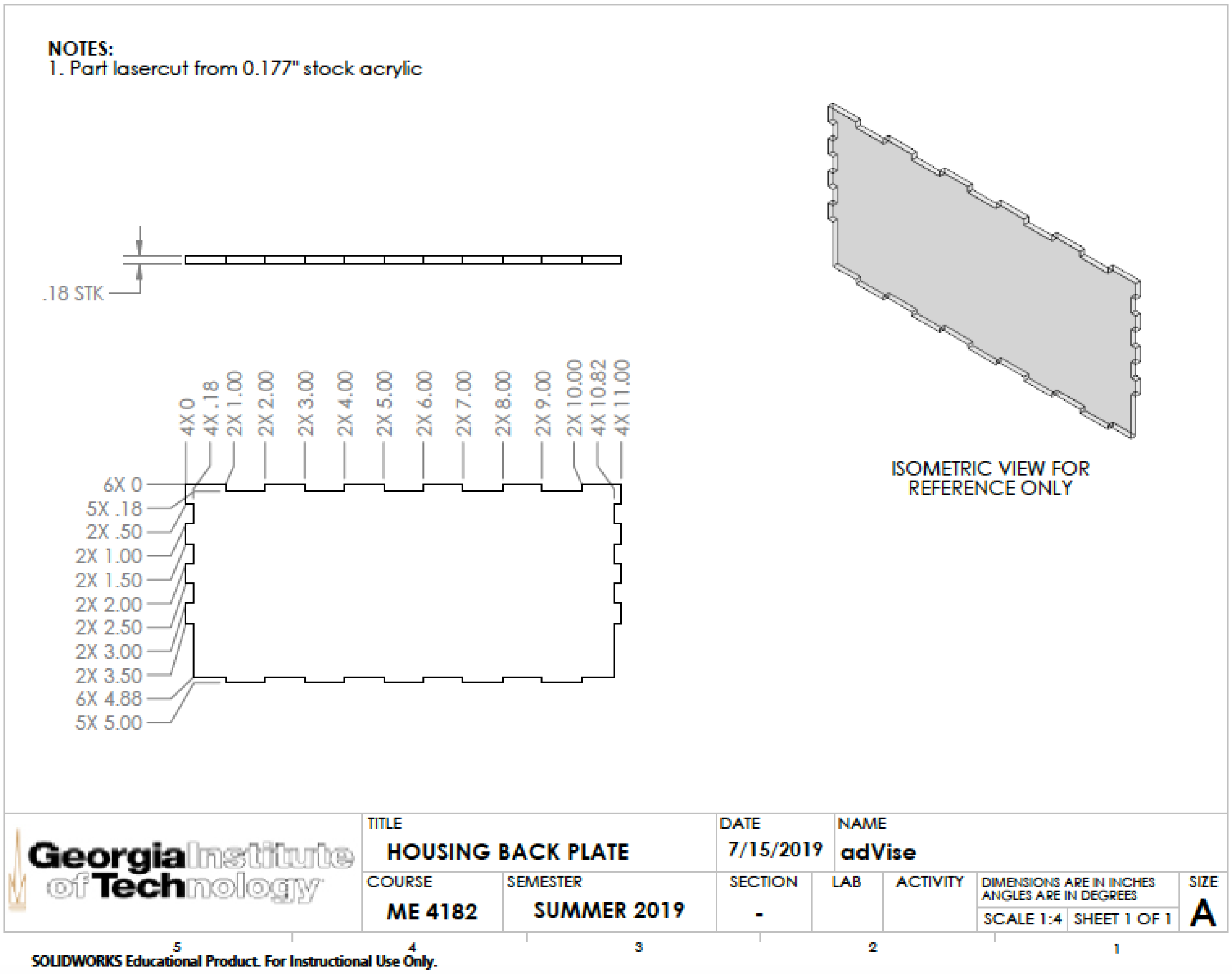


Figure 7. Back Plate for Housing Assembly.

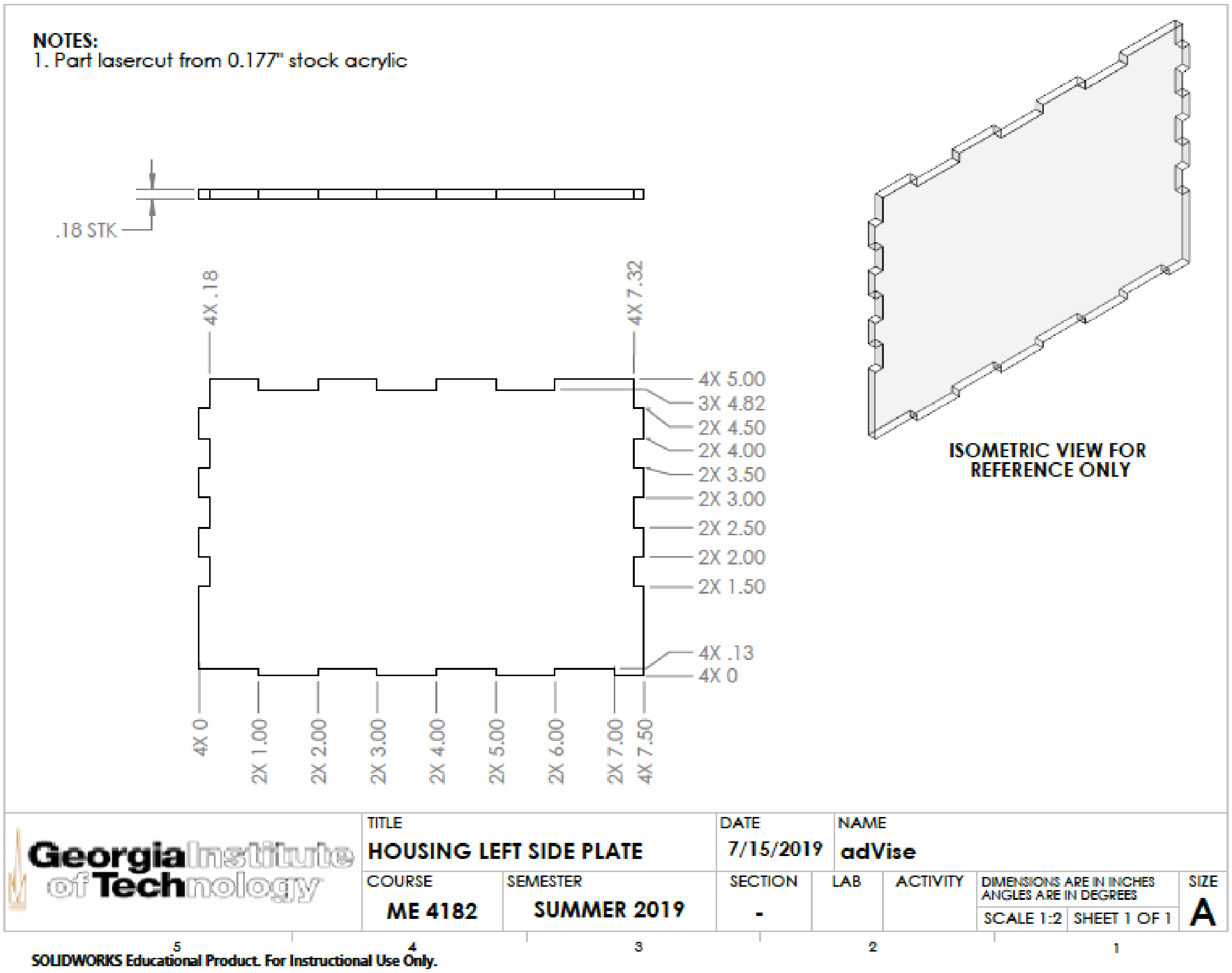


Figure 8. Left Side Plate for Housing Assembly.

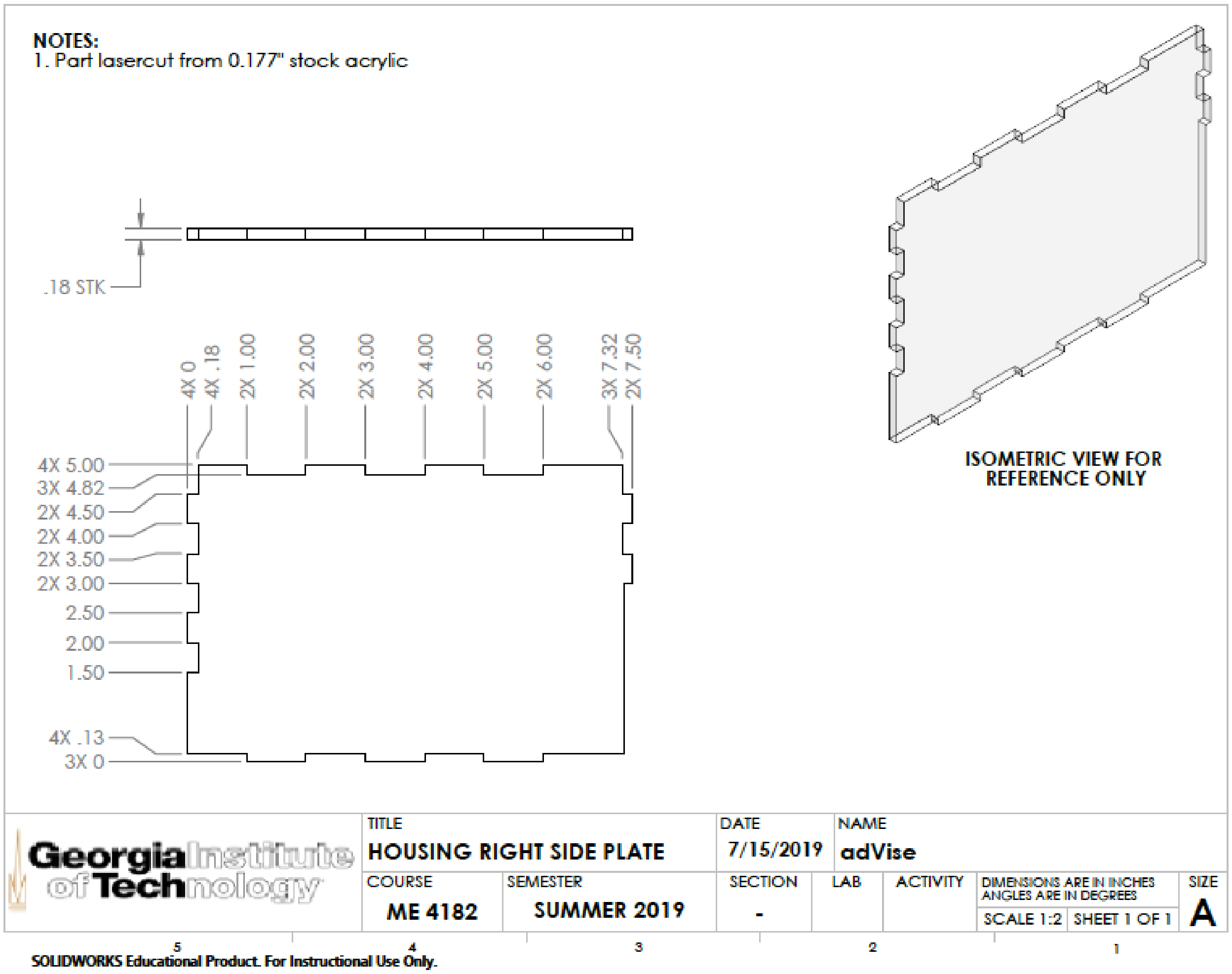


Figure 9. Right Side Plate for Housing Assembly.

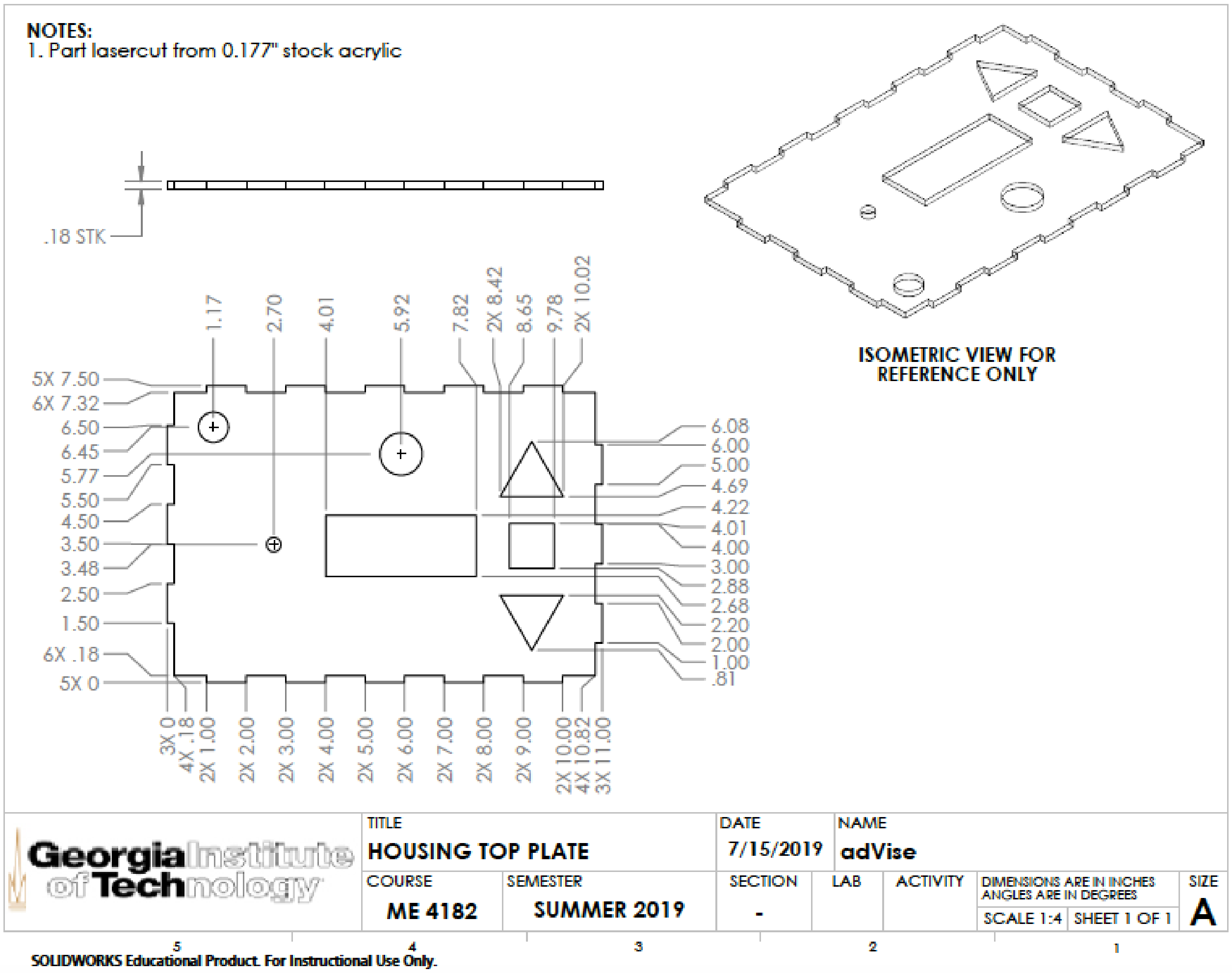


Figure 10. Top Plate for Housing Assembly.

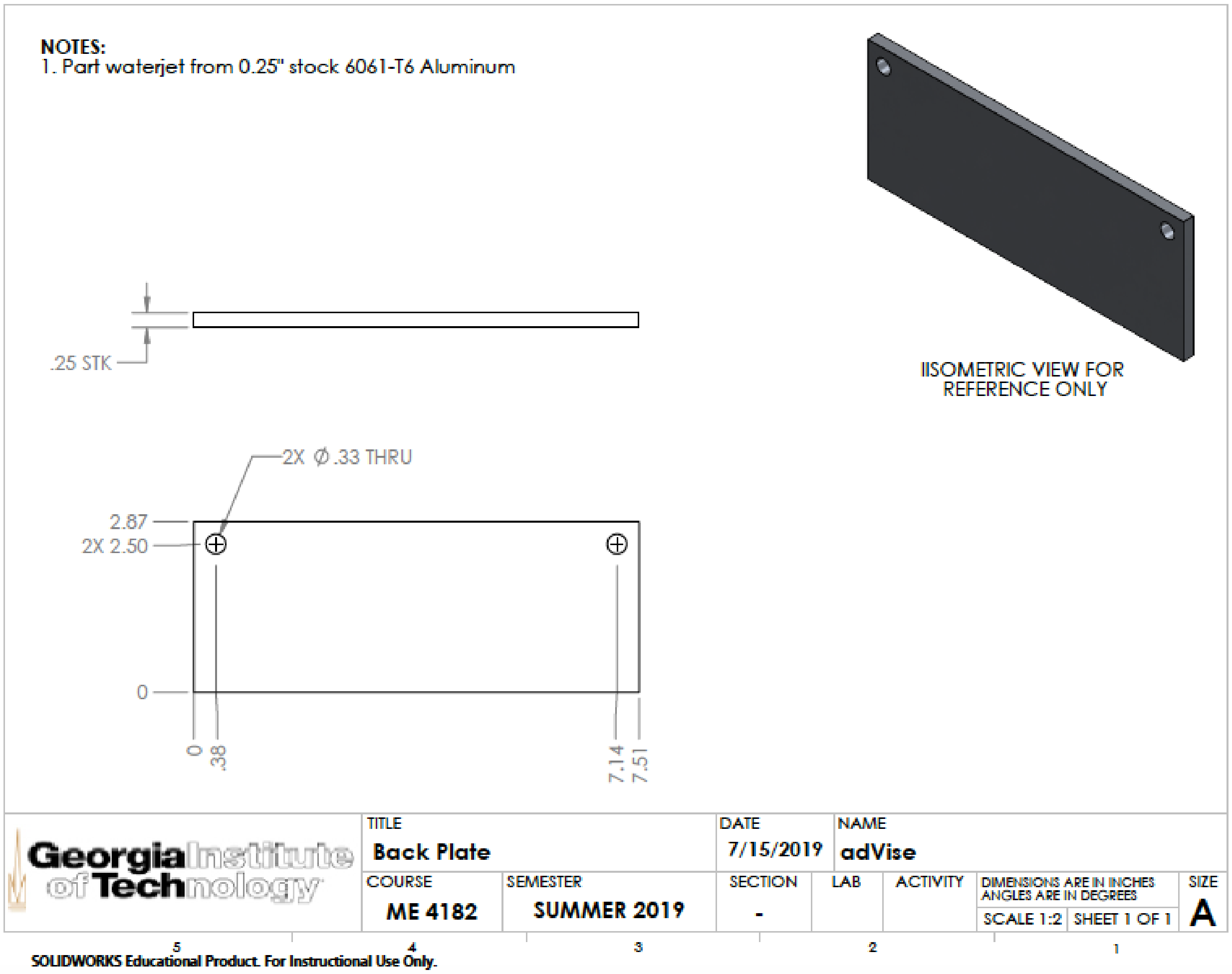


Figure 11. Back Plate for External Mounting Assembly.

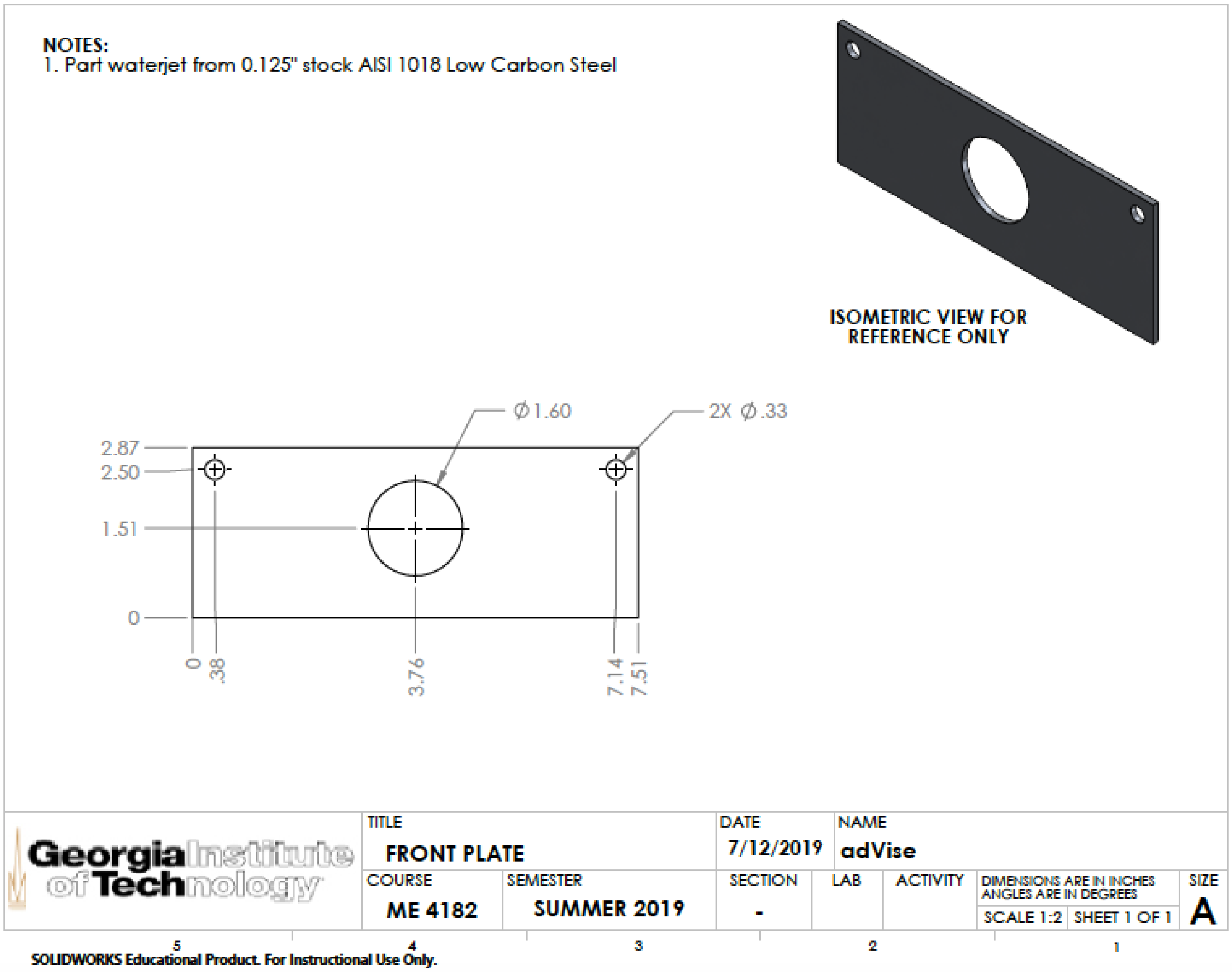


Figure 12. Front Plate for External Mounting Assembly.

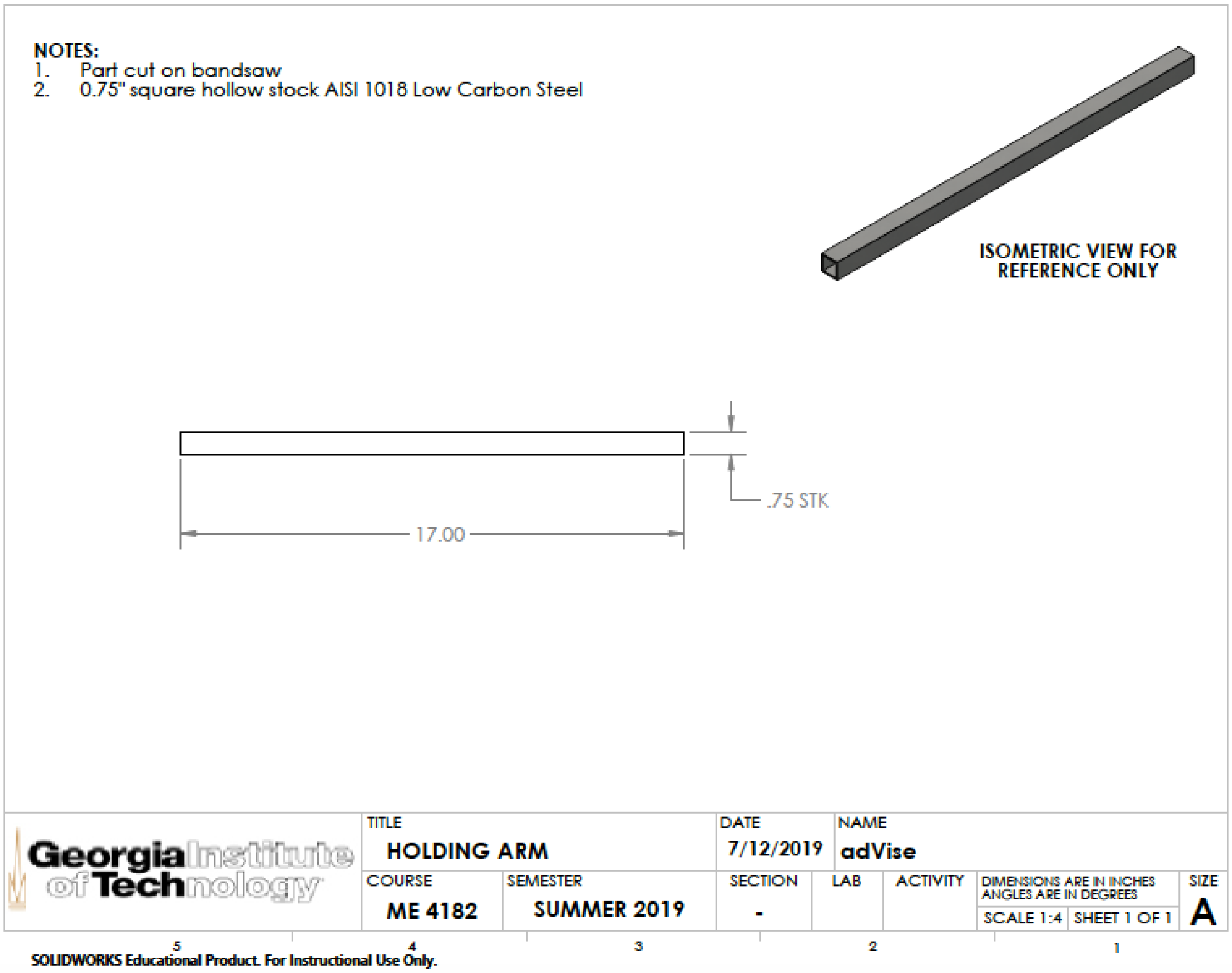


Figure 13. Holding Arm for External Mounting Assembly.

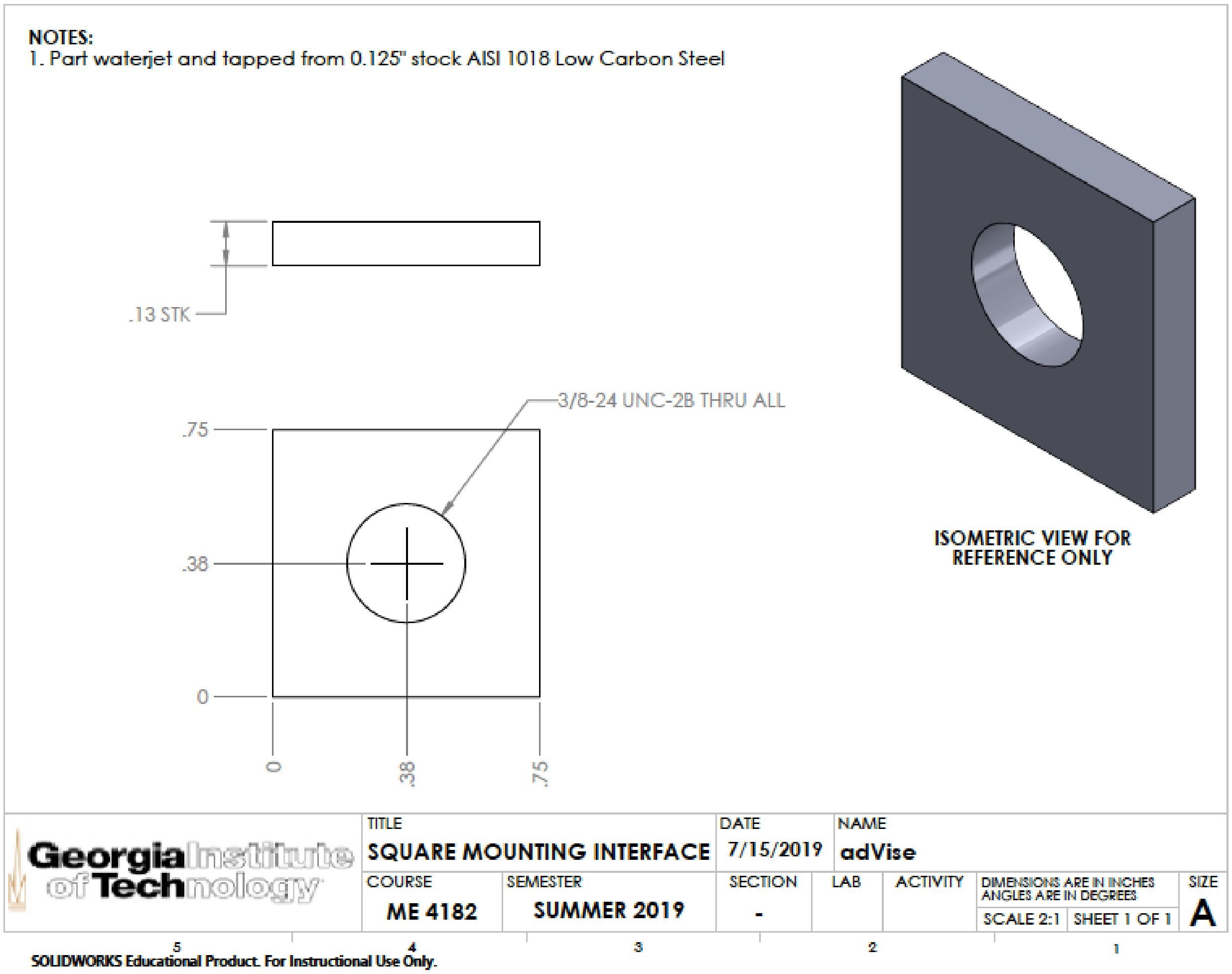


Figure 14. Square Mounting Interface for External Mounting Assembly.

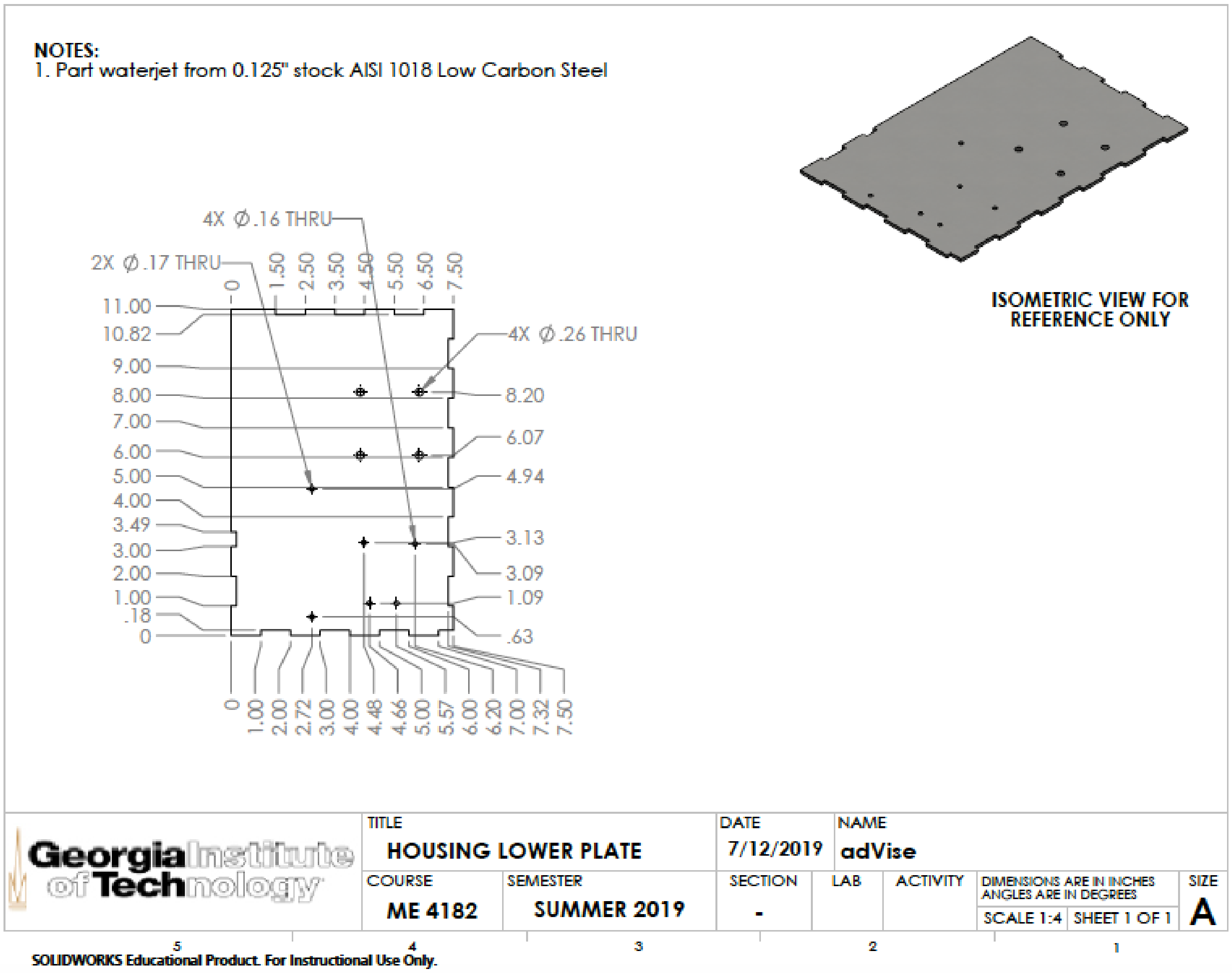


Figure 15. Bottom Mounting Plate for Internal Mounting Assembly.

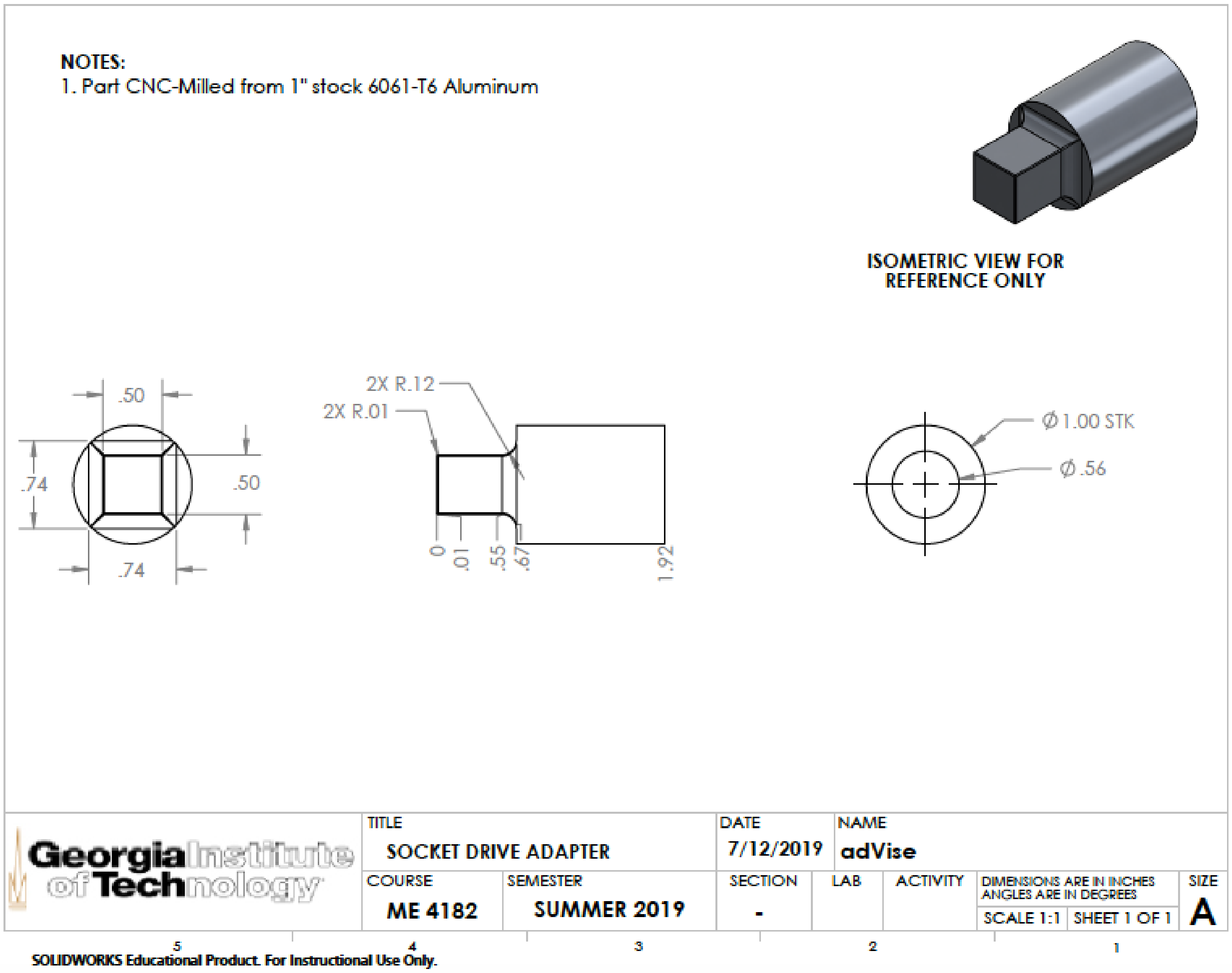


Figure 16. Socket Drive Adapter for Internal Mounting Assembly.

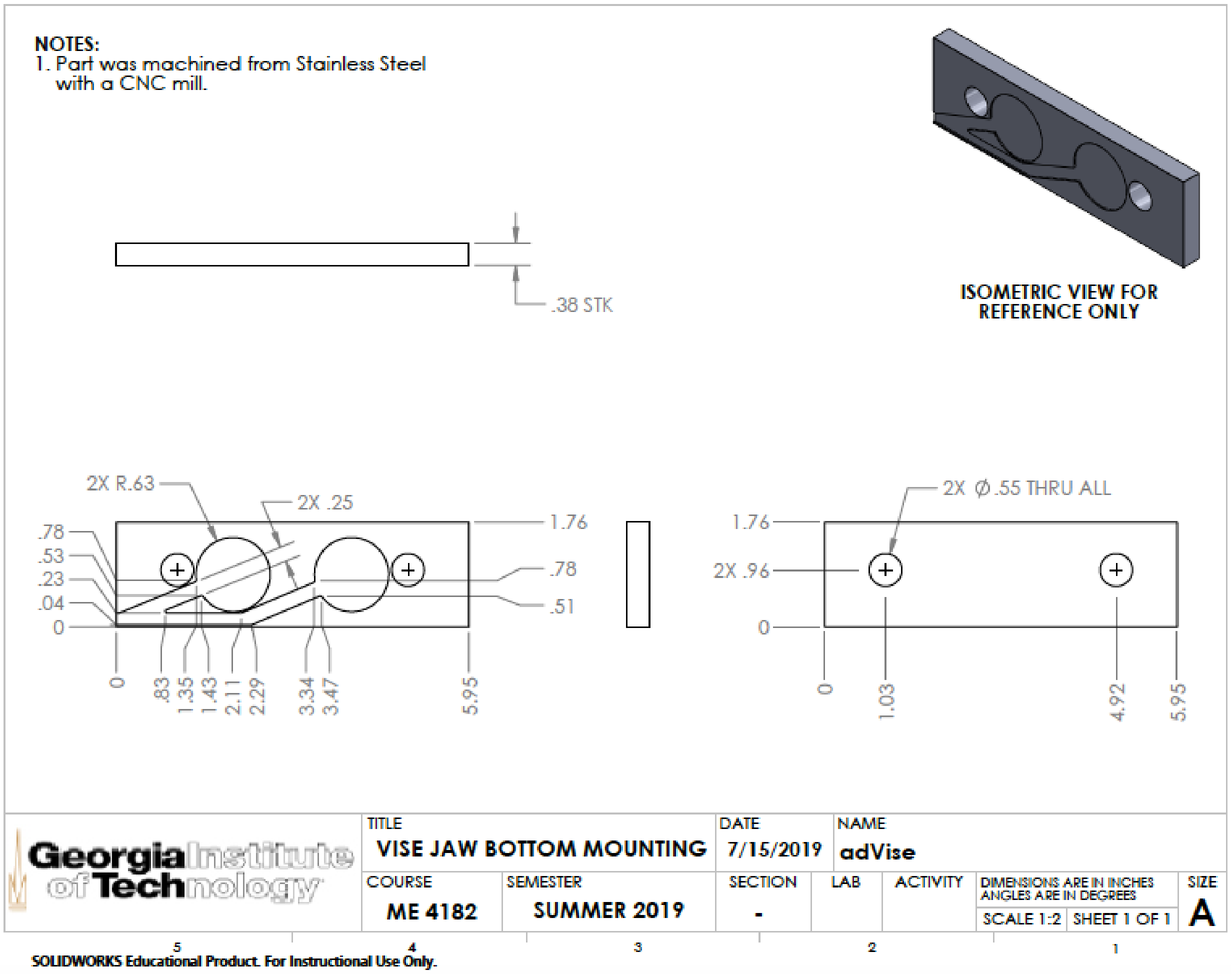


Figure 17. Bottom Mounting Plate for Vise Jaw Assembly.

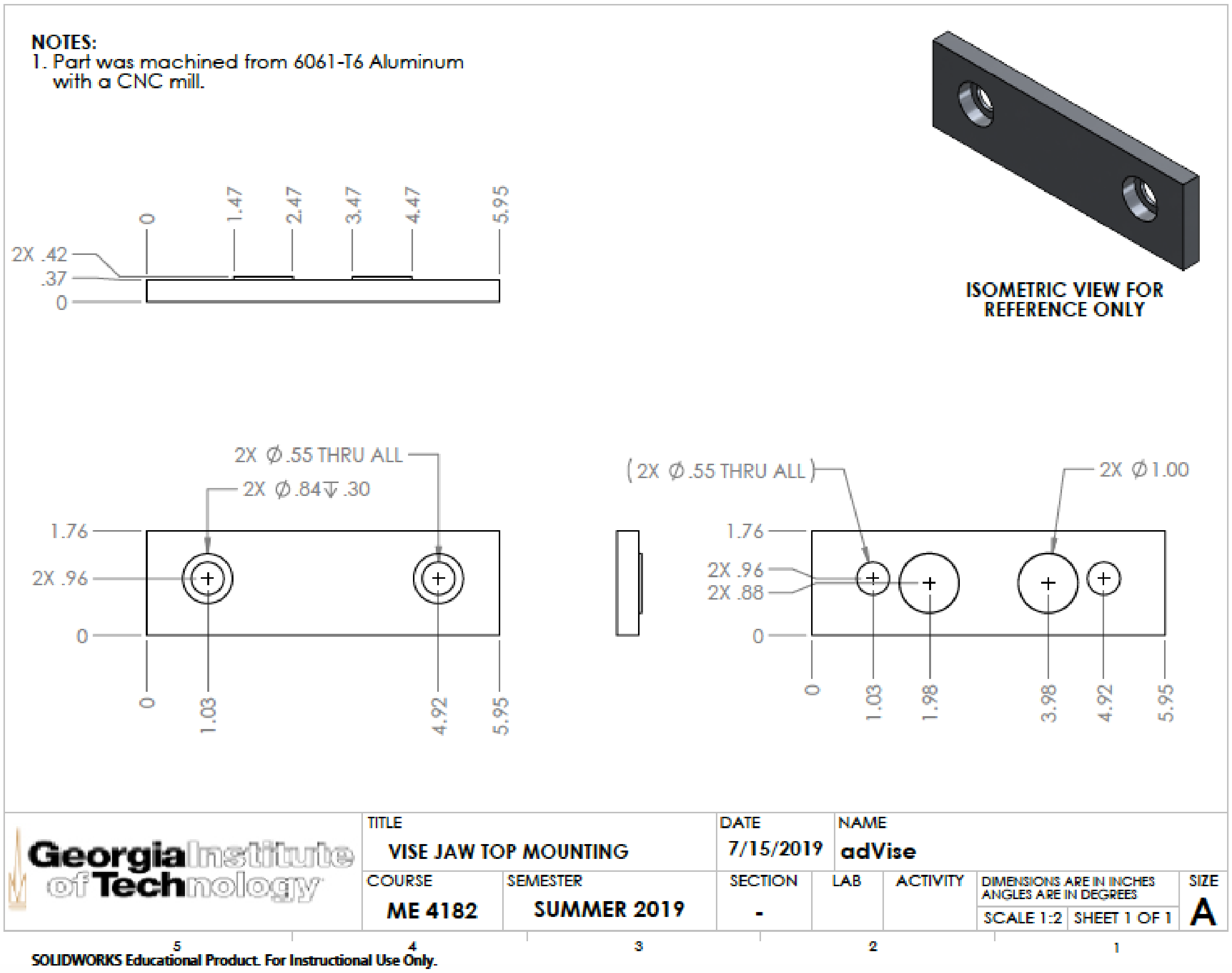


Figure 18. Top Mounting Plate for Vise Jaw Assembly.

Table 1. Bill of Materials.

Part Number	Description	Quantity	Vendor	Price
19mm Socket	19mm Socket 1/2" Drive	1	Home Depot	$ 1.99
91251A148	SCREW, BHCS, 6-32x1/2" LG, SS	2	Mcmaster-Carr	$ 0.18
91251A342	SCREW, BHCS, 10-32x1/2" LG, SS	4	Mcmaster-Carr	$ 0.40
91251A424	SCREW, BHCS, 3/8x1" LG, SS	4	Mcmaster-Carr	$ 0.36
Back Plate	Rear Connecting Plate	1	adVise	$ 2.81
Dial	Set Pressure Dial	1	Bourns	$ 2.81
Emergency Stop Button	Standard Emergency Stop	1	Amazon	$ 9.69
Encoder	Dial Encoder	1	Bourns	$ 3.25
Front Plate	Front Connecting Plate	1	adVise	$ 8.22
Housing Back Plate	Back Housing Face	1	adVise	$ 2.30
Housing Front Plate	Front Housing Face	1	adVise	$ 1.34
Housing Side Plate Left	Left Side Housing Face	1	adVise	$ 1.57
Housing Side Plate Right	Right Side Housing Face	1	adVise	$ 1.56
Housing Sub-Assy	Internal Mounting Plate	1	adVise	$ 22.61
Housing Top Plate	Top Housing Face	1	adVise	$ 2.99
LCD Screen	User Display Screen	1	Adafruit	$ 17.95
OnOffButton	On/Off Rocker Switch	1	Amazon	$ 5.95
Right Angle Gearbox	Right Angle Transmission 10:1	1	Amazon	$ 65.00
Socket Drive	Transmission to Socket Adapter	1	adVise	$ 1.20
Square Button	Start/Stop Button	1	Adafruit	$ 3.95
Square Stock Holding Arm	Vise Mounting Arms	2	Home Depot	$ 5.01
Square Stock Interface	Threaded Arm to Plate Attachments	4	adVise	$ 0.28
Stepper Motor	Stepper Motor	1	Amazon	$ 40.00
Stepper Motor Driver	Motor Controller	1	Amazon	$ 39.95
Triangle Button	Manual Control Buttons	2	Adafruit	$ 7.90
Vise Jaw - Aluminum	Top Mounting for Vise Jaw	1	adVise	$ 1.47
Vise Jaw - Stainless	Bottom Mounting for Vise Jaw	1	adVise	$ 2.68
			TOTAL	$ 253.42

Appendix

Figure 1. EnerPac Hydraulic Torque Wrench. [1]

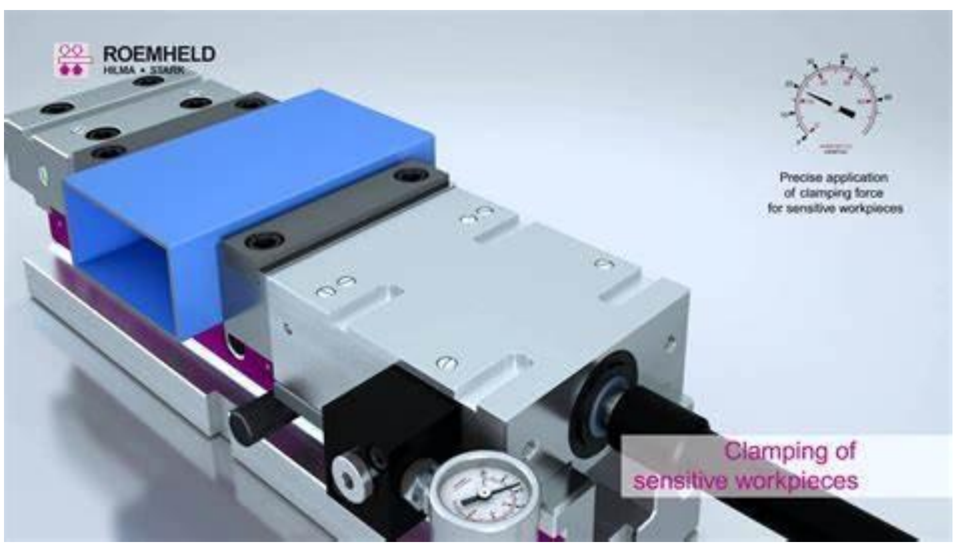


Figure 2. HILMA Machine Vise. [2]

Figure 3. DIY Hydraulic Vise. [3]

Figure 4. DIY Electric Vise. [4]

Figure 5. Posi Lock Hydraulic Bench Vise. [5]

Table 2. Specification Sheet.

Changes	D/W	Requirements	Target	Responsibility
		Geometry:		
	D	Base Height	< 6 in.	Thalken/Lopez
	D	Base Width	< 12 in.	Thalken/Lopez
	D	Arm (Wingspan) Length	< 24 in.	Thalken/Lopez
		Kinematics:		
	W	Range of Motion	6 inches	Thalken/Lopez
	D	Type of Motion	Linear (Rotational)	Kentez
		Forces:		
	D	Clamping Force	Max 2000 lbs.	Kentez
	D	Motor Torque	250 lbf-in	Kentez
		Energy:		
06/03/2019	D	Power Supply Voltage	18 V	Clay/Jason
06/03/2019	D	Motor Current	10 A	Clay/Jason
		Material:		
	D	High Rotational Stiffness	>=165.4 (lbf-in/deg) (<= 5 deg)	Thalken/Lopez
	W	Corrosion Resistance	Able to last 5 years	Thalken/Lopez
	D	Sealed from Coolant Incursion	IP66 Standard	Thalken/Lopez
		Signals:		
	D	Controller	My RIO / Arduino / Raspberry Pi	Clay/Jason
06/03/2019	D	Force Sensor	FlexiForce A401-25 Sensor	Clay/Jason
	D	Input Buttons	Start Button, E-Stop Button	Clay/Jason
	W	Sensor Readout / Gauges	Pressure Gauge, Torque Readout	Clay/Jason
		Safety:		
	D	Emergency Stop & Open Capability	< 1 Second Stop Time	Andrew
	D	No Cords Outside Machine	0 Visible Wires/Cords	Andrew
		User Interface:		
	W	Button Layout	Intuitive Design	Clay/Jason
	D	User Inputs / Readouts	Easy display / control for user	Clay/Jason
	W	Pedal Control	Easy use for hand-less control	Clay/Jason

		Operation:		
	D	Clamping Time	< 5 seconds	Kentez
	D	Assembly/Installation	< 10 minutes	All
		Aesthetic		
	W	Visually Appealing	Surface Finish	All
		Cost:		
	W	Consumer Cost	< $350	All
	D	Prototyping Budget	< $1,000	All

Subsystem/Component	I	II	III
Microcontroller	 Arduino	 MyRio	 Raspberry Pi
Motor	 DC Motor	 Stepper Motor	 Pneumatic Motor
Drive/Transmission	 Direct	 Belt	 GearBox (Drill)
Hex/Lead Screw Interface	 Socket Drive	 Oil Filter Wrench	 Spur Gears
UI	 Dial Readout	 Pedal	 Num Pad
Mounting	 Mill Table Slots	 C-clamps	 Vise-Wrap Around
Housing	 Sheet Metal Box	 3D printed	 Milled structure

Figure 6. Morphological Chart.

Table 4. Design FMEA

Failure Mode	Category	Effect	Countermeasure
Material Properties	Motor to Hex Rod	System Failure - No Drive from Motor to Vise	Structural Analysis for Material Selection
	Arms to Connect to Table	Inoperable - Attachment Failure	Torsional Analysis for Material Selection
Geometry	Noncompatible with Table	Inoperable - Mounting Failure	Standard Sizes / Universal Attachment
	Overall Dimensions	Ease of Use Concern	Sizing Dimensions through CAD
Tolerances	Square Stock to Socket	Replacement Issue in Case of Failure	Standard Tolerances for Application
	Socket to Hex	Inoperable - Nonstandard Sizes	Standard 19mm Attachment

Interfaces with Other Components and/or Systems	Motor to Hex	Inoperable - No Drive from Motor if Nonstandard Size	Set Screw / Adjustable Height
	Switch with Environment	Ease of Use Concern / Tripping Hazard	Cable Management / Adjustable Positioning
Engineering Noise: environments, user profile, degradation, systems interactions	Vibrations of Mill	Operation Malfunction - Dimension Inaccuracy	Compliant / Spacer Padding
	Cable Management	Ease of Use Concern / Tripping Hazard	Hole Locations / Set Locations for Cables

Table 5. Process FMEA

Failure Mode	Subcategory	Effect	Countermeasure
Human Factors	Device Attachment	System Malfunction from Improper Attachment	Universal Attachment
	Manual Clamping	Dimensional Inaccuracies - Inaccurate Clamping	Opening / Closing Hands-Free
	Damage to Sensors	System Malfunction / Inoperable - Inaccurate Readings	Warning Labels / Covering
Methods followed while processing	Starting Switch	Ease of Operation Concern	Switch Placement for Ease of Use
	User Interface	Ease of Operation Concern	Minimal User Input / Processing
Materials used	Milling Material	Dimensional Inaccuracies - Nonuniform Operation across Different Materials	Incorporated through User Specification
Machines utilized	Manual	Safety Concern - User Involvement after Clamping	Compact Design for Non-Interference
	CNC	Damage to Machine from Improper Mounting / Attachment	Geometry Design to Allow Room for Machine to Operate
Measurement systems impact on	Force Sensors	Reduced Reliability - Inaccurate Tolerancing	Buying Sensors with Desired

acceptance			Specifications
Environment Factors on process performance	Temperature	Clamping Inaccuracies - Thermal Expansion	Thermal Management System
	Moisture	Safety - Vise Slipping	Gaskets / IP-66 Requirements for Waterproofing

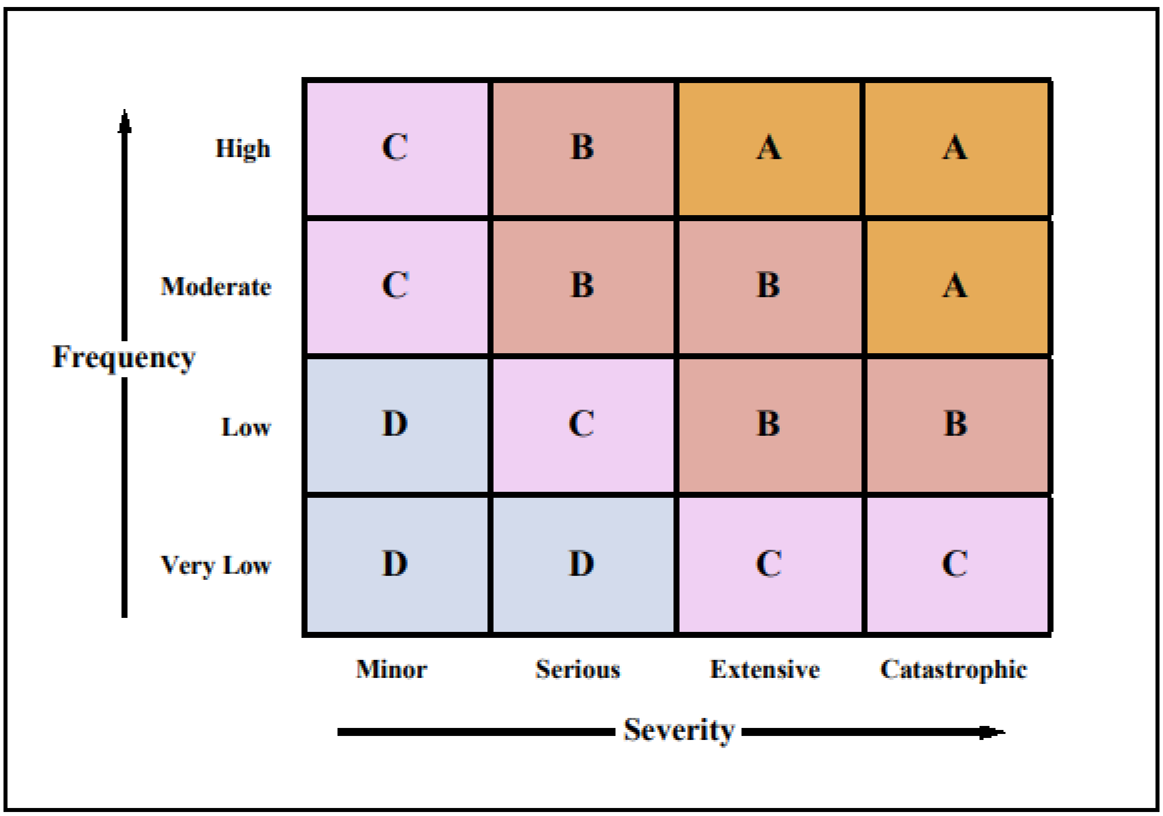


Figure 16: Risk Evaluation Matrix