Montana State University

Department of Mechanical and Industrial Engineering

ETME 489R/ETME 499 CAPSTONE: MECHANICAL ENGINEERING TECHNOLOGY DESIGN 1 & 2 and

EMEC 489R/EMEC 499 CAPSTONE: MECHANICAL ENGINEERING DESIGN 1 & 2

ErGus Radiolucent Prototype

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For:

Prepared to Partially Fulfill the Requirements for EMEC 489R/ETME 489R

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Executive Summary

ErGus Surgical Innovations performs surgeries on patients in the prone and supine positions along the spinal column regularly. Commercially available medical table attachments are primarily composed of metal materials known to interfere with radiological x-ray imaging used alongside these procedures. Our goal is to develop a radiolucent, ergonomic, and structurally sound alternative using composite materials while maintaining patient safety and provider accessibility.

To achieve this goal, all metal components located within the head and spinal column field of view must be removed or replaced on the device with a radiolucent material. Positional adjustability must also be maintained to create an ergonomic device that puts medical professional's comfort into consideration.

Throughout the design process various methods were utilized to ensure a successful project and design. Project management via weekly meetings, and a Gantt chart ensured the group stayed on schedule with deadlines and set clear expectations. Background research and analysis provided the foundation in which innovative design ideas could be generated, as well as aided in the awareness of common issues that arise in products designed out of composite materials, and how to work around potential issues.

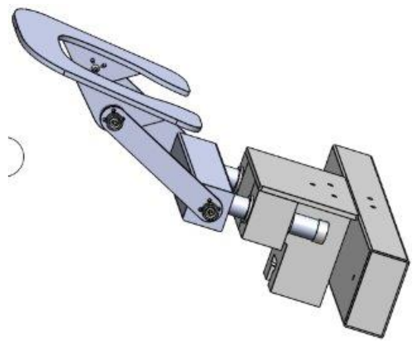
Most radiolucent tables on the market today achieve transparency by positioning structural components outside the imaging area and using thin radiolucent layers for the patient surface. However, this approach often results in larger-than-necessary tables and restricted access to critical operating areas. The ErGus radiolucent design offers a novel solution by placing the main structural components beneath the patient and fabricating them from radiolucent materials such as high-density polyethylene (HDPE) and carbon fiber. This innovative configuration allows for full imaging access while maintaining a compact, ergonomic profile—giving medical professionals better access to the patient and enhancing procedural efficiency.

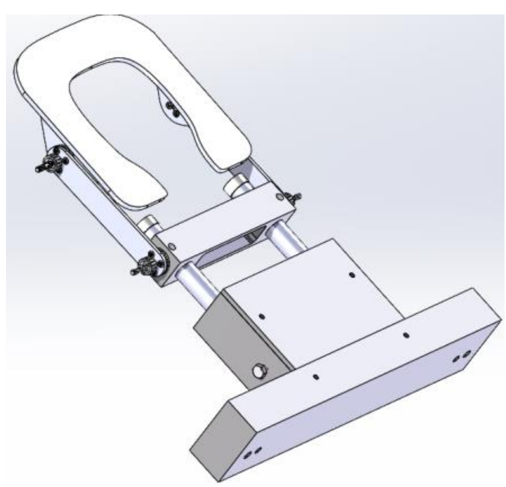
Head rest support brackets were widened lengthwise to maintain clear head and spinal column frame of interest, while simplified geometry with integrated material assembly of the chest support bracket allowed for adjustability and range of motion on the composite version prototype to remain the same. Design considerations of wall thickness and fiber orientation, along with where handmade layups were placed, allowed the final design to maintain a similar structural integrity to its metal counterpart.

Table of Contents

I. Introduction

The ErGus Radiolucent Prototype project addresses the critical need for a patient positioning device that is both radiolucent and ergonomically optimized for spinal surgeries. Conventional systems rely heavily on metal components, which interfere with X-ray imaging and hinder surgical efficiency. This capstone design project, sponsored by ErGus Surgical Innovations LLC, aimed to develop a radiolucent, structurally sound, and adjustable alternative using composite materials, ensuring both clear radiological imaging, and safe, accessible patient positioning.





II. Problem Statement/Intellectual Property Statement

ErGus is in the process of creating an Adaptive Ergonomic Positioning Device to bring to market. The current prototypes for the patient positioning device rely on aluminum and other metals, which interfere with radiology imaging. Our goal is to develop a radiolucent, ergonomic, and structurally sound alternative using composite materials while maintaining patient safety and provider accessibility.

This new design must be compatible with industry-standard medical tables, such as the Skytron 6500 Elite and Steris Cmax, by incorporating interchangeable mounting brackets. It should feature an improved head support system with widened brackets to enhance comfort and safety while eliminating metal components near the head and spinal column. All metal aspects of the device within the field of view of the head and spinal column must either be relocated or replaced with radiolucent material to allow for clear radiological imaging. The device must also meet hospital sterilization standards and maintain its positional adjustability.

Requirements:

- Radiolucent structural components to be used along the spinal column.
- Maintain the current metal prototype's adjustability and range of motion.
- Modified, radiolucent mounting bracket compatible with various medical tables.
- Widened headrest support bracket.
- Radiolucent adjustable mechanism for the chest support block.
- Load capacity of up to 350 lbs.
- Structural integrity (must endure ongoing use and repetitive stresses).
- Include the engraved or etched patent number.
- Meet hospital-acquired infection (HAI) cleaning procedures.

Deliverables Expectations:

- Provide two functional radiolucent patient positioning device prototypes. One with a Skytron table insert bracket and one with a Steris table insert bracket, using the metal insert rods provided by the sponsor.
- Complete drawing package.
- Radiolucent component construction manual.

Expectations:

- The sponsor expects the above standards to be met.

- The sponsor is expected to be available to contact for any required design or issue clarifications.

MEMORANDUM OF UNDERSTANDING REGARDING PROJECT INTELLECTUAL PROPERTY RIGHTS

The undersigned student(s) have been given the opportunity to work on the following project ("Project"):

ErGus Adaptive Ergonomic Positioning Device

The Project may be of a proprietary nature and/or funded by a Project Sponsor. The Project may or may not result in the development of patentable inventions and/or copyrightable work products in which the Project Sponsor may have a proprietary interest.

Therefore, it is important that the students working on the Project and the Project Sponsor have a full understanding of the students' respective rights and obligations regarding these proprietary interests, copyright, and patent rights. This memorandum sets forth the understanding of the parties.

1. The students have the right to submit any thesis, dissertation, or other academic product based upon or resulting from the Project work as part of the fulfillment of the requirements for obtaining an undergraduate, master's, or doctoral degree from Montana State University. The students understand that participation in any given project is voluntary and a student may request an alternative means to fulfill any applicable academic requirements.

2. The students understand that their work on the Project must be available to the Sponsor to meet grant or other contractual requirements. Therefore, in exchange for the valuable educational experience gained by participation in the Project, the undersigned students do hereby assign their respective rights, titles and interests in any research or other project outcome, including but not limited to copyright or patent rights if applicable, derived from their work on this Project to the Sponsor.

3. Except as otherwise provided herein, each student agrees that he/she will not disclose any confidential information, data, knowhow, or research results obtained from Sponsor in connection with this Project without the prior written permission of the Sponsor.

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Project Sponsor: Signed by: David R. Johnson 390A0D5427E84AA... Date: 2/3/2025

III. Background Research

Summary of problem statement

The goal of the ErGus design project is to is to develop an adaptive ergonomic positioning device to replace current metal-based prototypes that interfere with radiology imaging. The new design will use radiolucent materials/composites to ensure clear imaging while maintaining structural support, patient safety, and provider accessibility. Two prototypes will be made compatible with industry-standard medical tables; the Skytron 6500 Elite and Steris Cmax, featuring interchangeable mounting brackets and an improved head support system with widened brackets for enhanced comfort and safety. All metal components within the head and spinal column's field of view will be removed or replaced, and the device will meet hospital sterilization standards while maintaining its positional adjustability.

Project Requirements

- Provide two functional radiolucent patient positioning device prototypes. One with a Skytron table insert bracket and one with a Steris table insert bracket, using the metal insert rods provided by the sponsor.
- Radiolucent structural components to be used along the spinal column.
- Radiolucent adjustable mechanism for the chest support block.
- Load capacity of up to 350 lbs.
- Include the engraved or etched patent number.
- Radiolucent adjustable mechanism for the chest support block.
- Widened headrest support bracket.
- Modified, radiolucent mounting bracket compatible with various medical tables.

Primary, Difficult Technical Challenges

- **Structural support:** Current components made of metal will be replaced with weaker and more flexible radiolucent materials.

- **Component construction:** Any custom components will have to be constructed using unique techniques for that material.

- **Ergonomics:** The device as a whole must maintain its low profile and allow for ease of use for patient access.

- **Adjustability:** The device will have to be adjustable to comfortably fit any patient or position.

- **Fasteners:** Threaded components must have a way of being inserted and removed repeatedly from metal and nonmetal components.

- **Radiolucency:** Components in line with the head and spinal column must be radiolucent as not to obscure x-ray imaging. No metal fasteners can be located in this region of the device.

- **Multiaxial Stresses:** Composites commonly used for devices in the medical field are strong in one state of stress but weaker in others.

Past solutions, related technology, some patent searching

ErGus has not yet taken steps in past prototypes to make the design radiolucent. Given the widespread use of radiolucent devices in the medical industry, the next step in the design process is to incorporate x-ray-compatible materials. This can be achieved by selecting appropriate materials and utilizing mechanical solutions to position metal components outside the x-ray frame.

Common materials for this application include carbon fiber, phenolic board, and thermoplastics. Carbon fiber provides the highest strength but comes at a higher cost, while thermoplastics and phenolic board offer lower strength at a lower cost and are easier to machine and repurpose. Additionally, several existing patents outline variations of these techniques, which may offer useful insights for implementation.

Radiolucent Patient Table (US9282938B2):

This patent describes a patient tabletop comprising two face sheets and a honeycomb core. The first face sheet includes carbon fibers oriented in a specific direction to enhance radiolucency and structural integrity, making it suitable for imaging procedures.

Radiolucent Table Extension and Method (US6003174A):

This invention details an elongated patient support table with a horizontal surface, featuring a radiolucent extension connected in a cantilevered manner. This design allows for extended imaging capabilities without interference from non-radiolucent materials.

Patient Table with Cantilevered Radiolucent Pallet (US20040131159A1):

This patent presents a patient table featuring a generally C-shaped lower base with opposing end portions connected by a central section. A cantilevered radiolucent pallet is supported above this base, allowing for unobstructed imaging access.

Buy or build – information to decide on design directions

With a budget of $1,000–$3,000, purchasing high-precision custom composite parts would be prohibitively expensive. The low-volume nature of the project further increases the per-unit cost of purchased components. However, certain parts, such as the arm mount bracket, may require high-strength carbon fiber to withstand specific geometric and stress demands, making ordering select components necessary. For other structural elements, phenolic board offers a more practical alternative. It is easier to machine, requires less expertise, and is readily compatible with screws and bolts, simplifying assembly. Thermoplastics tend to be more cost-effective for low-quantity purchases. However, given access to a CNC machine, it is more economical to buy raw thermoplastic material and machine it to match custom CAD designs rather than ordering pre-made components.

Emerging technologies

The medical industry is constantly evolving, and surgical tables are no exception. The primary focus has always been patient support but recently these tables are growing to be integral parts of the surgical ecosystem enhancing both precision and imaging capabilities. Among the various materials in this industry, one that has gotten a lot of attention in regard to research and development is advancing carbon fiber composites due to their versatile properties, including high strength-to-weight ratios and radiolucency. These newer advanced materials still face many challenges such as high costs and manufacturing limitations related to complex geometries.

In addition to material advancements, automated smart tables with robotic integration are gaining momentum. These tables offer enhanced comfort for patients by incorporating features like automatic positioning tailored to specific surgeries, memory functions that allow tables to return to pre-set positions, and integration with hospital operating systems. This integration helps in real-time monitoring and management of patient status, improving workflow efficiency and surgical outcomes. However, the adoption of these technologies is slowed by factors like initial investment, training requirements for medical staff, and ensuring compatibility with the various settings within hospital infrastructure.

Relevant components, materials, suppliers, techniques

Relevant components of this prototype are the cushioning pads made of anti-bacterial/anti-fungal rated foam with anti-bacterial vinyl sewn cover as well as the mounting brackets to be compatible with some industry-standard medical tables such as the Skytron 6500 Elite and the Steris Cmax. The material already in use is mostly aluminum but with the requirement of radiolucency, plastic or composite materials such as carbon fiber, glass fiber reinforced polymers, Kevlar, thermosets, and polyetheretherketone (PEEK) could possibly be utilized depending on certain mechanical requirements. Nanocomposites and self-reinforced polymers are also interesting materials to look at but are still only just emerging in the market as there are a lot of questions around feasibility even though theoretically, they have many advantages.

There are a multitude of suppliers for materials in this industry but Toray industries for carbon fiber solutions and Solvay for high-performance polymers are popular options. Techniques when working with these materials are very diverse: composite layering, CNC machining of composite chunks is sometimes used, injection molding, and 3D printing are some of the most common and cost efficient. Some mechanically efficient techniques are surface treatments as well as producing a radiolucent thermoplastic resin with a suitable shape then covering it with carbon fiber and/or reinforced plastics to create a layered construction.

What can put me into trouble? Failures/failure modes, legal issues, health & safety

Primary functions of the prototype are to comfortably support a patient while also providing more access for doctors to the head and neck area of the patient. This means that patient and healthcare worker safety are the largest liability in case of a mechanical failure. Since this product is in the medical field, it will also likely have to meet regulatory compliance requirements for organizations like the FDA in the United States, which includes biocompatibility, mechanical strength, and safety standards. Failure to comply can result in product recalls, fines, or even bans from the market. Additionally, there is an active patent for this prototype, which means caution must be taken when making modifications. While patents can offer protection, changes to the prototype could fall outside the scope of the existing patent or infringe on other patents if not carefully managed. For instance, modifications that enhance or alter the original frame of the project significantly could expose the product to competition or require new patent filing. On the other hand, if the prototype changes are too similar to another product, there's a risk of patent infringement lawsuits.

Operating environment issues

The outstanding issues that will be encountered are the impact and fatigue resistance on the individual parts of the prototype with the stiff and durable metals being replaced by radiolucent materials that tend to have lower material properties. Other than mechanical durability the considerations of the sterilization and cleaning products used as well as the radiation exposure can cause unexpected degradation of certain composites. Although cushioning pads made of anti-bacterial/anti-fungal rated foam with anti-bacterial vinyl sewn cover are what encounters the patient directly, the rest of the assembly should be biocompatible ensuring that no leaching of harmful substances that could cause toxicity and allergic reactions.

Cost issues/solutions

The medical industry typically turns to carbon fiber reinforced composites in order to have a radiolucent material that still maintains the exceptional mechanical properties of using a traditional metal like aluminum or stainless steel, but this comes at a significant cost. Typically, if carbon is decided as the desired fiber to use, costs can be mitigated through the use of virgin carbon or even recycled carbon that show to still uphold exceptional performance standards.

Thermoset composites specifically with a glass epoxy fiber reinforcement is a potential option available on the market that significantly reduces cost without losing much of the desired mechanical properties and even offers added advantages like that of higher impact resistance and toughness prioritized over pure strength.

Durability/reliability issues/solutions

Realistically both carbon fiber and thermoset composites have their drawbacks for being a reliable material choice, but carbon fiber in particular due to its brittle nature is more of a concern because of its potential for a sudden and catastrophic failure. A glass epoxy thermoset tends to be more resistant to impact, so it comes down to designing various parts considering where heavier stress concentrations and tensile strength will matter, because ultimately lack of durability or reliability in the medical industry could have severe consequences. The main challenge with design development of composites will be along which axes their strength supports, and possible fiber and resin reinforcements along weaker axes could help aid in support where needed.

List of critical analyses required for project success

Due to fully reversing load over the products life, undergoing a fatigue analysis to predict life cycles will help better design varying components that undergo more stress with improved durability and reliability to resist fatigue failure and can help investigate where crack propagation could occur. Finite element analysis (FEA) could also be helpful in ideation for designs that allow weight reduction while retaining stiffness-to-weight ratio. Performing a typical load analysis with a FBD to assess structural integrity along varying axes will aid in material strength requirements alongside what material will be best for the different parts.

List/description of technologies, materials, processes, techniques, algorithms, etc., which offer potential solutions to technical challenges

- **Composite Materials:** Our project poses a unique challenge when it comes to material selection due to the technical challenges of the use of a composite pose. High production costs, unique adhesion methods, and difficulty to manufacture and produce with care to mechanical properties are amongst some of the significant factors to consider in the design stage.

High production costs can be mitigated by usage of deploying construction of the composites to varying companies that already have the specialized machinery used for composites in-use and professionals who will be equipped with the skill of how to manufacture a unique material like that of composites with attention to detail of how to retain its desired mechanical properties. The type of composites used in the final design will need to be considered at every step of the design and manufacturing process as some of the reinforcements used like carbon fiber exhibit anisotropic behavior where the fiber composites exhibit different mechanical properties depending on orientation and how they're laid making material selection a huge consideration from beginning to end.

Various construction methods for adhering composite materials can make production costs go down including 3D printing, CNC machining methods, and varying welding techniques. Adhesive bonding is a recommended way to bond composites as it leads to significantly lower stresses in the joint region. Fusion bonding processes for a bonding technique is also recommended since thermoplastics can easily be melted and consolidated making them favorable for this process without degrading in-plane mechanical properties like elastic modulus, strength, and fatigue performance.

- **Geometry Considerations:** The space provided to construct a new design that is more optimized and addresses the project requirements still within the original dimensions provided will come down to carefully considering geometry and therefore use of space. On top of optimization of the design, simplifying geometry will also aid in the manufacturing process where if less parts are constrained to be made out of composite materials, the better. The more complex geometry can be refined down to simple shapes, the easier and more cost effective it will be which can only be beneficial.
- **Environmental Impact:** Preserving resources as much as possible and reducing our carbon footprint are subjects that hold more weight in today's day and age than before. It's because of this that critical analyses should be done to evaluate how production of a new product can mitigate the harmful waste that is added to the environment.

One of the biggest drawbacks of turning to a common composite available on the market like carbon fiber is its limited to no recyclability and biodegradability. Thermoplastics in this regard tend to be favored as they offer the ability to be recycled and reused, but then the challenge turns to what material is used as a reinforcement within it that will retain its environmental impact and not destroy its mechanical properties. More in-depth research into our top materials once a load and stress analysis are performed will be necessary to determine viable options and the varying tradeoffs that must be made for each and every different material choice.

Summary of the team's findings in background research into each of the potential solutions to the project's primary challenges

All of the research performed thus far throughout the design process concludes that the main challenges will include (1) choice of a composite that offers all the desired mechanical properties without a tradeoff of an equally important design parameter, (2) how the redesigned aspects of the main design will include all the desired design parameters of adjustability, structural stability and ergonomic use with simplifier shapes that will make manufacturability of more ease, and (3) how all the various components will come together in construction overcoming a.) expertise of unique materials and machinery that must be used in manufacturing b.) retaining mechanical properties and minimizing multiaxial stresses through fiber orientation and c.) unique adhesion methods.

1. Several material types were explored for potential usage including

- Plastic or composite materials reinforced with carbon fiber, epoxy or glass fiber polymers.
- Kevlar
- Thermoset resins with reinforcements
- Polyetheretherketone (PEEK) or carbon polyphenylene sulfide (PPS)
- Lamitex XXRK-1 or Lamitex G-11

2. Designing with simpler shapes in mind can be done by looking for bad use of space and considering what aspects of the design help to optimize important design parameters like ergonomics, adjustability and structural stability.

- The consideration of weight of materials chosen helps ergonomic design when it comes down to how the medical device is used and ease of use for the medical professionals. Material chosen along with manufacturing process chosen will determine how adjustable the design is and how structural sound it can get since each material listed above to consider offer varying mechanical properties.

3. The final construction brings all aspects considered above into one. General assembly will consider how complex/simple our design geometry was made, what material is chosen will decide how easy/hard it is to manufacture and quality control during assembly while minimizing cost, time, and effort, and all of these factors together will determine the designs adjustability, structural stability and ergonomics. All the possible issues mentioned above will figure themselves out as the design process is worked through and more finalized decisions are made backed by engineering analysis.

IV. Design Alternatives Creation and Evaluation

System Functions

With the next adaptive ergonomic positioning device, subsystems and their functions are as follows:

1.) **Modular Attachment Bracket:**

This is the main load bearing component of the device. This bracket is a flat stock of material that must be detachable from the rest of the device as it has multiple different configurations of pins that are used to connect it to various types of surgical tables. A bracket must be made to attach to Skytron 6500 Elite and a Steris Cmax medical tables. The table pins must be permanently attached to each bracket to fit one of the table configurations stated above while also allowing them to be easily interchangeable with the rest of the device. This is also one of the largest pieces of the device so, other than the pins, it must be fully radiolucent.

2.) **Chest Support:**

The chest support plate takes most of the load of the patient once in position and is a flat plate that is the immediate attachment to the modular attachment bracket. Underneath and attached to the plate is the housing for the sliding chest rods as well as where the arm support bracket connects. This is geometrically the most complicated part of the device with many of the subsystems interacting with it. This system will have to contain a mounting bracket, hold the arm support bracket, and a mechanism for the sliding rods to operate through while maintaining radiolucency.

3.) **Arm Support bracket:**

As stated above the arm support bracket is attached below the chest support. This is a small bracket where the arm rests of the device, which does not need to be radiolucent but does need to be detachable, connects when a patient is needed in the prone position. Once the patient is rested these will only carry the load of the arms but as the patient is getting into position this will be the likely place where they will support their weight. This means that the arm support bracket will be the concentrated point of this load. With is being directly below the chest plate this system must also be fully radiolucent meaning geometry will have to be enhanced to ensure that this system stays attached to the chest support and is compatible with the arm brackets.

4.) **Sliding Chest Rods:**

The sliding chest rods allow for the inward and outward extension of the head support system. These rods require high precision fits so that the rods can freely slide in and out without there being any play in the headrest. These rods must be able to support the weight of the patient's neck and head while being radiolucent. The design must prevent any rotation while being moved or stationary.

5.) **Adjustable Headrest Fasteners:**

The adjustable head fasteners control the height and angle of the headrest. They attach to the sliding chest rod bodies. They consist of two arm brackets which can rotate about adjustable angle rosette knobs. These adjustable knobs will have to prevent the arms from rotating down when the weight of a patient’s head presses down on the headrest.

6.) **Head Support:**

The head support connects to the adjustable head fasteners and must be a radiolucent plate of horseshoe shape to allow the patient's face to fit in the hole. A cushion must also be attachable to the top of the plate for patient comfort and to keep the facial features protected.

Subsystems Alternatives Analysis

Modular Attachment Bracket-

Table 1: Pugh Chart for Modular Attachment Bracket

Modular Attachment Bracket							
		Threaded holes		Rod with Bushings		Fixed Rod	
Parameters	Relative importance	Reference	Total	Relative Weight	Total	Relative Weight	Total
Cost	0.2	1	0.2	1	0.2	1.2	0.24
Weight	0.1	1	0.1	0.9	0.09	1	0.1
Simplicity	0.1	1	0.1	0.8	0.08	1.3	0.13
Durability	0.35	1	0.35	1.75	0.6125	0.8	0.28
Strength	0.25	1	0.25	1.5	0.375	0.9	0.225
Total	**1**		**1**		**1.3575**		**0.975**

Parameters and Weighting-

Cost (0.2)- Cost is more of a factor here as two of these brackets must be made and they are the largest parts of the device.

Weight (0.1)- Although the device should be as light as possible, these being the main load bearing components, more weight will be required.

Simplicity (0.1)- This is a simple geometry part as it is so the only concern here will be how to connect the pins.

Durability (0.35)- Again this system takes on the most load and will be constantly inserted and removed from the end of surgical tables.

Strength (0.25)- Need the system to hold metal pins as a composite and distribute forces adequately.

Comments on Alternative Designs-

- Threaded holes in the stock of material is easy to accomplish in metals for this application, but being that this must be made of a composite or polymer material this would introduce too many blemishes and stress concentrations in weaker materials
- Rods with bushings would be drilling holes in the material and adding hardware and fasteners in the system to hold it together and distribute some of the forces.
- Fixed table rods would keep this system in one piece but have a higher risk of failure in the part with keeping two different materials together can be challenging and introduce a lot of stress.

Optimal Solution-

Rod with bushings is the best solution from *Table 1* as it provides the best strength and durability by distributing the loads on the bolts/fasteners to the bushings and washers allowing for weaker fasteners to be used to maintain radiolucency in this area of the device. It adds more weight and complexity to this system, but the fasteners will be easy to acquire and provide the most structurally sound design.

Chest Support-

Table 2: Pugh Chart for Chest Support

		Chest Support					
		Welded		Single Mold		Attatchable Brackets	
Parameters	Relative importance	Reference	Total	Relative Weight	Total	Relative Weight	Total
Cost	0.15	1	0.15	1.1	0.165	0.9	0.135
Weight	0.1	1	0.1	0.8	0.08	1.2	0.12
Simplicity	0.1	1	0.1	0.75	0.075	1.3	0.13
Durability	0.35	1	0.35	1.3	0.455	0.4	0.14
Strength	0.3	1	0.3	1.3	0.39	0.5	0.15
Total	**1**		**1**		**1.165**		**0.675**

Parameters and Weighting-
Cost (0.15)- The chest support is the central aspect of the entire positioning device so more expenses can be put toward it to ensure proper functioning.
Weight (0.1)- The component is entirely structural so weight plays a minor role.
Simplicity (0.1)- The chest plate is going to be the most complex aspect of the whole system so simplicity has a low rating.
Durability (0.35)- Cyclical stresses from patient use will require high resistance to fatigue and wear.
Strength (0.3)- Supporting the weight of the patient's entire upper body will require high strength.

Comments on Alternative Designs-

- Attachable brackets allow for ease of construction but the addition of fasteners creates weaker components. The design also causes the joining of dissimilar materials which introduces manufacturing complications.

Optimal Solution- The single mold design, while more complex to construct, allows for one unanimous material to be used for construction which will increase the strength and endurance of the system. The use of fasteners will also be eliminated, decreasing the cost.

Arm Support Bracket-

Table 3: Pugh Chart for Arm Support Bracket

		Arm Support Bracket					
		Pinned T-bar		Slotted T-bar		Friction Fit	
Parameters	Relative importance	Reference	Total	Relative Weight	Total	Relative Weight	Total
Cost	0.1	1	0.1	1	0.1	1	0.1
Weight	0.05	1	0.05	1	0.05	1	0.05
Simplicity	0.2	1	0.2	1.3	0.26	0.8	0.16
Durability	0.35	1	0.35	1.2	0.42	0.8	0.28
Strength	0.3	1	0.3	1.2	0.36	1.1	0.33
Total	**1**		**1**		**1.19**		**0.92**

Parameters and Weighting-

Cost (0.1)- Lower mechanical complexity means lower spending
Weight (0.05)- Considering the relatively small size of the part weight will play a menial effect
Simplicity (0.2)- Since the part has no moving aspects, maintaining its simplicity will be important for construction
Durability (0.35)- The fluctuating stress of patients pushing off the arm supports will cause high fatigue that the bracket will need to endure as well as potential surface stresses from being in contact with the metal arm support bar.
Strength (0.3)- High amounts of force will be placed on the bracket as patients push up from the table.

Comments on Alternative Designs-

- The friction fit would require high precision and increase wear on the component
- The pinned T-bar would add stress concentrations at the pin holes.

Optimal Solution-

The Slotted T-bar will maintain the simplicity of the original design and eliminate stress concentrations caused by drilling holes for pins. It will also allow for easy attachment and detachment.

Adjustable Head Fasteners-

Table 4: Pugh Chart for Adjustable Head Fasteners

Adjustable Head Fasteners									
		Metal Rosette Washers		Nylon Fastners		Thermoset Fastners		Composite Fasteners (Glass-Fiber)	
Parameters	Relative importance	Reference	Total	Relative Weight	Total	Relative Weight	Total	Relative Weight	Total
Cost	0.2	1	0.2	0.8	0.16	0.7	0.14	0.5	0.1
Adjustability	0.2	1	0.2	0.8	0.16	0.7	0.14	0.9	0.18
Simplicity	0.2	1	0.2	1.2	0.24	0.8	0.16	0.3	0.06
Durability	0.2	1	0.2	1	0.2	0.9	0.18	0.6	0.12
Strength	0.2	1	0.2	0.9	0.18	0.8	0.16	1	0.2
Total	**1**		**1**		**0.94**		**0.78**		**0.66**

Parameters and Weighting-
Cost (0.2)- We have to buy multiple fasteners so being as cost-effective as possible is important.
Adjustability (0.2)- Equal weightings because the whole point of these fasteners is to be adjustable
Simplicity (0.2)- These are all bought parts that just have to be attached
Durability (0.2)- Must last a long time and be able to endure use without shearing
Strength (0.2)- No matter what fastener is used, each will need to withstand a good amount of force distribution amongst it.

Comments on Alternative Designs-

- Nylon fasteners: strong, lightweight, synthetic material that is extremely durable and has easy installation
- Thermoset fasteners: high strength and dimensional stability. Can be made from epoxy or phenolic resins
- Composite fasteners: designed to bond well with composite materials to avoid delamination and other structural issues that may wreck structural stability. Can be carbon fiber or glass fiber reinforced.

Optimal Solution-

As shown above in Table 4, nylon fasteners placed the highest by quite a bit because of their high durability and cost effectiveness since we will have to buy quite a bit, which lowers production costs. They also tend to be the easiest to install, which is preferred since our design requires areas fastened together to be easily taken apart.

Head Support-

Table 5: Pugh Chart for Head Support

Head Support							
		Welded Flange		Solid Mold		Glued Epoxy	
Parameters	Relative importance	Reference	Total	Relative Weight	Total	Relative Weight	Total
Cost	0.2	1	0.2	0.7	0.14	0.8	0.16
Weight	0.15	1	0.15	0.8	0.12	0.8	0.12
Simplicity	0.2	1	0.2	0.5	0.1	0.7	0.14
Durability	0.25	1	0.25	0.9	0.225	0.6	0.15
Strength	0.2	1	0.2	0.8	0.16	0.8	0.16
Total	**1**		**1**		**0.745**		**0.73**

Parameters and Weighting-

Cost (0.2)- Still to be considered but not terribly important as it's not the biggest piece to manufacture

Weight (0.15)- One of the components that gets moved the most while in-use, so a lightweight design is preferable.

Simplicity (0.2)- Due to composites being material of choice for this component, simpler shapes to optimize design and manufacturability are preferred over complex curved geometry

Durability (0.25)- This is a part of the device that will constantly be adjusted so must be able to withstand that.

Strength (0.2)- Must support a patient's head in varying angled positions, so must be strong enough to endure load at different angles.

Comments on Alternative Designs-

- Solid Mold would be a resin mold of a simpler shape like an upside-down U
- Glued Epoxy would simply be binding material components together with reinforced composite epoxy based on composite material chosen

Optimal Solution-

Based on Table 5, a solid mold scored higher over an epoxy glue as making one a mold that would encompass all the attachments including the flanges immensely simplifies the design by creating less pieces to keep track of, and overall would create less stress concentrations because using glue would make the piece less structurally sound and introduce less contact surface area for the two parts to adhere to one another.

Sliding Chest Rods-

Table 6: Pugh Chart for Sliding Chest Rods

Sliding Chest Rods										
		Circular		I Beam		Sliding Plate		T Bar		
Parameters	Relative importance	Reference	Total	Relative Weight	Total	Relative Weight	Total	Relative Weight	Total
Cost	0.15	1	0.15	0.5	0.075	1.5	0.225	0.8	0.12
Weight	0.1	1	0.1	0.8	0.08	0.6	0.06	0.9	0.09
Simplicity	0.15	1	0.15	0.75	0.1125	1	0.15	0.9	0.135
Durability	0.3	1	0.3	1.5	0.45	1.1	0.33	1.3	0.39
Strength	0.3	1	0.3	1.5	0.45	1.1	0.33	1.2	0.36
Total	1		1		**1.1675**		**1.095**		**1.095**

Parameters and Weighting-
Cost (0.15)- A heavily mechanical component of the device meaning more spending on this system to ensure it works properly.
Weight (0.1)- This is a vital part of the system meaning weight may be necessary to sustain a load.
Simplicity (0.15)- Working with composites limits the geometries that can be produced.
Durability (0.3)- This is a part of the device that will constantly be adjusted so must be able to withstand that.
Strength (0.3)- This will be a load bearing part with various loads and various moment arms as it is adjustable.

Comments on Alternative Designs-

- Circular rods are a simple geometry that is easy to design around, implement, and to obtain.
- I-beam rods would have tailored slots that allow them to slide easily through and provide the most structural stability but are very difficult to manufacture.
- The sliding plate is the simplest design, but it would likely have the play when adjusting the device
- T bar is the same premise as the I-beam but with a simpler geometry at the cost of some structural integrity, also difficult to manufacture.

Optimal Solution-

The circular rod may be the lowest Pugh Chart value, but it is by far the easiest to acquire and design around making it the most ideal solution even with lower structural stability. They are cheap to order by size while the other options would require a longer and more complex manufacturing process.

Full System Configuration

The optimal system configuration balances strength, durability, simplicity, and manufacturability. For the modular attachment bracket, a rod with bushings provides the strongest and most durable solution, effectively distributing loads while allowing the use of weaker fasteners to maintain radiolucency. Though it adds weight and complexity, the fasteners are readily available and enhance structural integrity. The chest support benefits from a single-mold design, which, despite its complexity, ensures uniform material construction, increases strength, and eliminates fasteners to reduce costs. A slotted T-bar optimizes the arm support bracket by minimizing stress concentrations from drilled holes while enabling easy attachment and detachment. For head support, a solid mold is preferred over epoxy glue, as it integrates all attachments and flanges, reducing stress concentrations and simplifying assembly. Lastly, circular rods are the most practical choice for the sliding chest rods. While they score lower in the Pugh Chart for structural stability, they are easy to source, cost-effective, and straightforward to integrate, making them the most viable option despite their lower strength.

V. Design Specifications

Functional specifications

- Head support lateral tilt up to 30°
    - Steris Cmax: 20°
    - Skytron Elite: ±30°
- Accommodate patients in both prone and supine positions

Performance specifications

- A dilution of 3oz of OxyCide per gallon of water requiring minimum contact time of 5 minutes to achieve effective sterilization of head and chest cushions

- Support max load capacity of 350lbs without compromising safety or stability
- Choose material with density of 1g/cm^3 or less to be considered radiolucent and provide clear imaging pictures

Reliability specifications

- Repeated cyclic use (10,000 cycles
- Must ensure several types of stresses (fatigue, axial, creep, shear, bending moments) in varying directions

User-Driven specifications

- Provide a structurally sound alternative to the devices metal counterpart that is also ergonomic, adjustable, and can adapt to varying patient anatomy

Interface specifications

- All mechanical system interface with medical professionals operating adjustability of moving components to fit patient needs
- Must withstand environment operating condition that undergo medical-grade cleaning on protective pads that overlay design body

Radiolucency specifications

- Must have at least an 80% transmissibility at an X-ray strength of 120 kVp

Cost specifications

- Total project budget $1,000
- $827.14: raw materials and fasteners
- $172.86: outsourcing manufacturing

VI. Description of Project/Design

The primary objective of this project was to eliminate all metal components from the head and spinal column field of view while maintaining structural integrity, ergonomic functionality, and medical compatibility. The final design incorporates radiolucent materials—specifically **carbon fiber**, **high-density polyethylene (HDPE)**, and **WEST System Epoxy** to deliver a fully functional patient positioning system compatible with **Skytron 6500 Elite** and **Steris Cmax** surgical tables. The device is organized into five key subsystems, each tailored to meet the unique structural and medical performance requirements.

- **Mounting Table Brackets**
- **Chest Support Assembly**
- **Headrest System**
- **Head Support Brackets**
- **Sliding Chest Rods**

Mounting Table Brackets

These brackets are the primary load-bearing connection between the device and the surgical table. Designed using a **rod-and-bushing** assembly, they ensure strength and repeatable engagement while eliminating internal threaded fasteners that compromise radiolucency. A simplified **block extension mechanism** allows for smooth integration into the chest support structure, with **alignment holes** enabling secure pin-locking without overcomplicating construction.

Chest Support Assembly

The chest support consists of **three main components** to minimize material waste and reduce construction costs. This modular design accommodates **sliding chest rods**, allowing clinicians to adjust patient positioning based on anatomy and procedure type. An integrated **arm support bracket** featuring a **slotted T-bar design** ensures both strength and easy disassembly. By minimizing frictional surfaces and threaded connections, the system reduces long-term wear and increases service life, while maintaining full patient access.

Headrest System

The headrest was constructed from **HDPE**, chosen for its **ease of machining**, **radiolucency**, and **patient comfort**. The design features an **open-face horseshoe shape** to cradle the head while allowing clear access to facial features for airway management and imaging. Its seamless integration with the adjustable head brackets ensures consistent support during repositioning.

Head Support Brackets

Made from **carbon fiber**, the adjustable head brackets offer both **lightweight strength** and **durability**. They utilize **angle rosette fasteners** strategically placed to maintain component alignment while shifting any metallic elements outside the radiological field. This allows for **undisturbed imaging** of the spinal column and head, a critical requirement for surgical precision.

Sliding Chest Rods

Fabricated from **circular carbon fiber stock**, these rods allow smooth, high-precision extension and retraction of the headrest system. The use of **stock composite material** helped reduce fabrication complexity, enabling high tolerances and cost efficiency without sacrificing structural reliability.

Material Selection

- **HDPE (High-Density Polyethylene)** was selected as the core structural material due to its **strength-to-weight ratio**, **biocompatibility**, and **compliance with FDA cleaning protocols**, such as those required by **Hospital-Acquired Infection (HAI)** sterilization standards. Its moisture resistance and low cost make it ideal for consistent clinical use.

- **Carbon Fiber** was used in areas subject to elevated mechanical stress. Its high tensile strength allows for thinner, more compact components that enhance radiolucency. Off-the-shelf carbon fiber stock components were sourced to ensure **tight manufacturing tolerances** while reducing labor and cost.

- **WEST System Epoxy** was chosen as the adhesive for high-load joints. Known for its **1:1 mix ratio**, **excellent tensile strength**, **moisture resistance**, and **maritime-grade durability**, it provides a clean and reliable bonding solution that withstands repetitive loading and harsh hospital sterilization conditions.

This combination of materials and design strategies results in a lightweight, durable, and fully radiolucent patient positioning system. The device prioritizes patient safety, provider usability, and radiological performance within the strict constraints of cost, sterilization standards, and mechanical demands of clinical environments.

Design Concerns

At present, there are no immediate concerns regarding the structural or functional integrity of the device. However, the team has limited hands-on experience with composite materials, particularly with respect to fiber orientation, bonding methods, and machining tolerances—all of which can significantly affect strength, durability, and manufacturing consistency.

Another ongoing consideration is radiolucency. While all materials selected (HDPE, carbon fiber, and WEST System Epoxy) are known to be radiolucent to varying degrees, precise X-ray transmissibility has not yet been quantified through imaging tests. Some adhesive joints and fiber-rich regions may produce minor imaging artifacts, especially near thicker cross-sections or overlapping layups. Additional testing under clinical imaging conditions will be required to validate full radiological transparency and ensure there is no obstruction to diagnostic or surgical imaging in critical areas, particularly near the head and spinal column.

VII. Conclusion

The ErGus Radiolucent Prototype project has made good progress this semester in designing a radiolucent, ergonomic patient positioning device for spinal surgeries. Using carbon fiber, HDPE, and WEST System Epoxy, the team developed a system with five subsystems: modular attachment brackets, chest support, headrest, adjustable head brackets, and sliding chest rods.

These meet key requirements like compatibility with Skytron and Steris tables, a 350-lb load capacity, and hospital sterilization standards.

Status and Plans: The design is complete, with drawings ready. Next semester, we'll build and test two prototypes—one for each table type—focusing on composite manufacturing, structural strength, and X-ray clarity.

Successes: We chose affordable, radiolucent materials that balance strength and cost. The bracket's rod-and-bushing design and single-mold chest support improve durability and imaging. The headrest's solid mold and off-the-shelf chest rods simplify construction while maintaining function.

Challenges: Some adhesive joints and thicker composite areas might affect X-ray images. Our limited experience with composites makes machining and bonding tricky, and early design ideas like threaded holes were dropped due to weakness.

Future Work: Next semester, the team will focus on prototyping and rigorous testing to validate radiolucency (≥80% at 100–120 keV), structural integrity, and ergonomic performance. Finite element analysis (FEA) and fatigue testing will guide design refinements, particularly for multiaxial stress resistance in composites.

Appraisal: The design is promising but untested. Composite fabrication and imaging clarity are concerns but testing and sponsor support should help. The project is on track, with prototyping and testing next to confirm performance.

We'll revisit these conclusions after testing to finalize the design.

Appendix A. Analysis

Moments & Stresses

Shear moments and stress can probably be consolidated into one large section as they are all very closely related as moments work together with stresses to analyze external components of a structure to get an in-depth idea of internal stresses that may occur. Moments deal more with the torque associated with a point and therefore the rotational effect of where forces are placed.

Assumptions:

In the stress analysis, distributed loads were conservatively approximated as point loads to reflect the inconsistent and localized nature of patient weight distribution. Segmental weight values were sourced from the NASA study "Weight, Volume, and Center of Mass of Segments of the Human Body" by Clauser et al. (1969), allowing for a simplified and structured approach to load estimation. Moments were then derived from these point loads and used to perform shear and normal stress analyses at critical regions of the device. A safety factor of 4 was applied to all calculated stresses to ensure structural integrity under unexpected or high-impulse loading resulting from patient motion. This factor of safety is consistent with established design standards for patient load-bearing medical equipment.

Equations:

HDPE:

$\tau = 4{,}350$ psi

$\sigma = 3{,}000$ psi

Carbon Fiber:

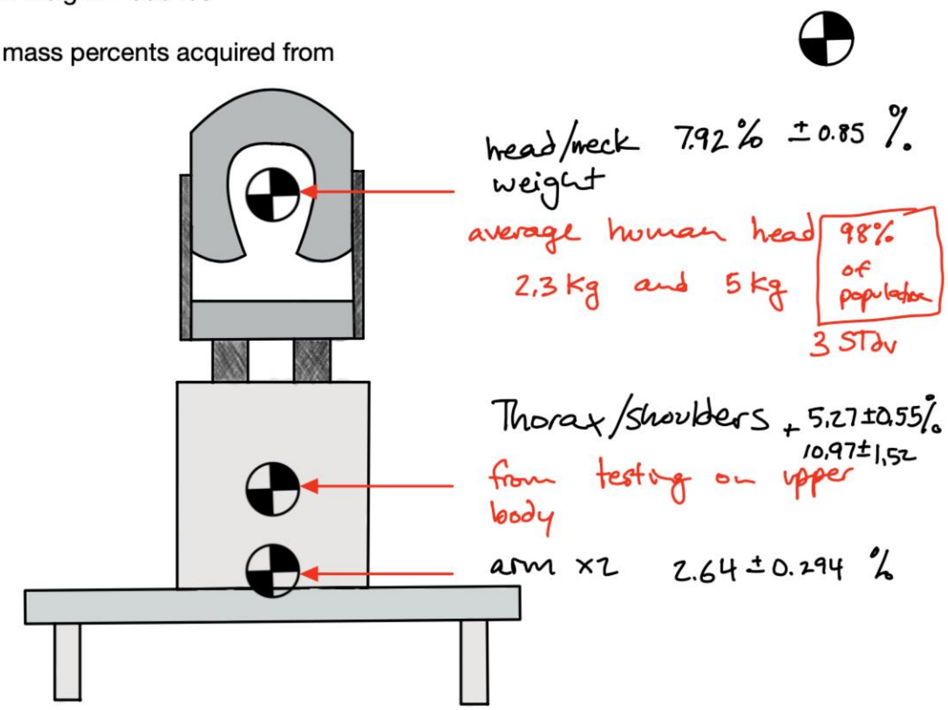
$\tau = 60{,}000$ psi

$\sigma = 8{,}000$ psi

Calculations:

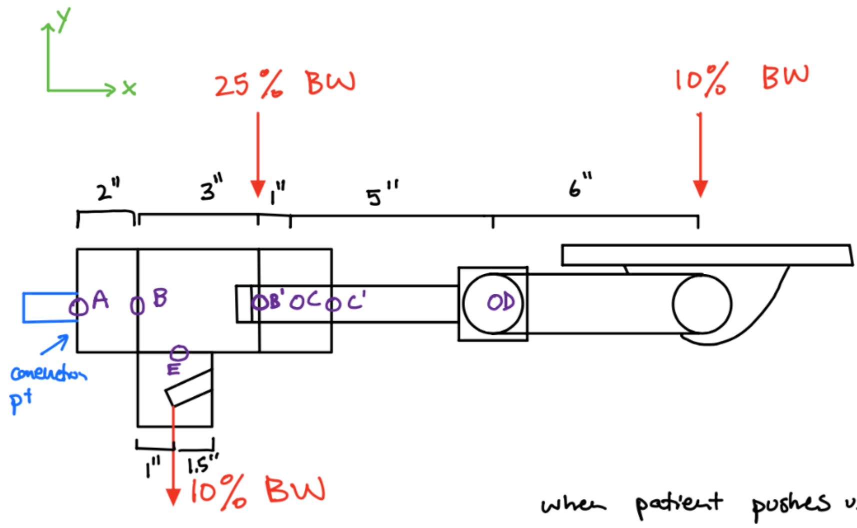
Assumptions:

- All consequential forces will be experienced normal to the top surface
- HDPE yield strength 3600psi
- Max patient weight = 350 lbs
- Body part mass percents acquired from



patient @ 350 lbs (max patient weight)

Moment Analysis



when patient pushes up all weight goes to arms

for 350 lbs patient

ΣM_A = 105 in lb + 437.5 in lb + 595 in lb = 962.5 in lb ≈ 80 ft lbs ×4

ΣM_B = 35 in lb + 262.5 in lb + 525 in lb = 822.5 in lb ≈ 68.5 ft lbs ×4

ΣM_C = 385 in lb ≈ 32 ft lbs ×4 ΣM_B

ΣM_D = 210 in lb ≈ 17.5 ft lbs ×4

Moment cabacity for tubes calculation

hollow carbon fiber $M_{Allow} = \frac{\sigma_{max} I}{y}$

σ = bending stress (~500 – 1500 MPa for carbon fiber)

I = moment inertia

$\left(\frac{\pi}{4}\left(r_0^4 - r_1^4\right)\right)$	hollow	circular
$I = \frac{\pi d^4}{64}$	solid	
$\frac{bh^3}{12}$	hollow	rectangular
$\frac{b_o h_o^3}{12} - \frac{b_i h_i^3}{12}$	solid	

y = distance from neutral axis

1" diameter rods should be above and beyond

Shear forces are neglecting part weight as <u>negligeable</u>

V @ $A = B$ = 350 lbs × 0.45 = 157.5 lbs

V @ C' = 350 lbs × 0.1 = 35 lbs

$$\tau = \frac{F}{A}$$

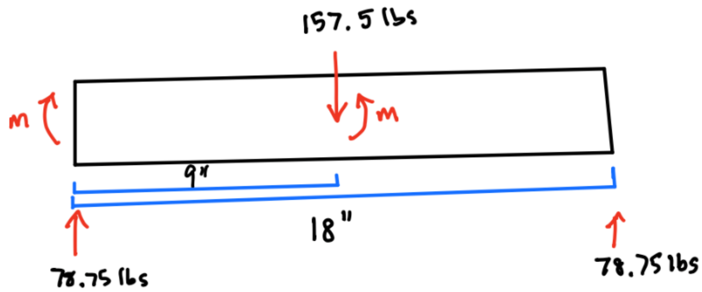
$$\sigma = \frac{F}{A}$$

(A) Mounting Bracket

- metal pins already tested and applied to new prototype

$M = 962$ inlbs

- Carbon fiber tube to endure moment

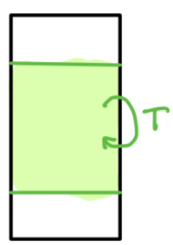


$I = \frac{2 \cdot 4^3 - (2-0.17)(4-0.17)^3 - 0.17 \cdot 2^3}{12}$

$= 1.985\ in^4$

$M = 157.5\ lbs \cdot 9" = 1417.5$ inlbs

$\sigma = \frac{1417.5\ \text{inlbs} \cdot 2"}{1.9856\ in^4} = \boxed{1427.78\ psi}$ ✓ ≪ σ_{max} CF



epoxy handled τ

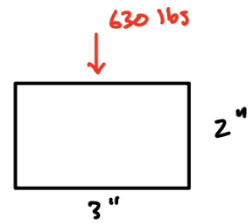
- delrin insert to handle torque

$\tau = \frac{Tr}{J}$

$J = \frac{bh^3}{3} = \frac{2 \cdot 3^3}{3} = 18\ in^4$

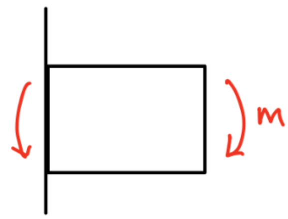
$\tau = \frac{962\ \text{inlbs} \cdot 1.5"}{18\ in^4} = \boxed{80.2\ psi}$ ✓ ≪ τ_{yield} HDPE and τ epoxy

(B) mounting bracket sleeve insert



$V = 630\text{lbs}$

$$\tau = \frac{630\text{ lbs}}{(3\cdot 2)} = \boxed{105\text{ psi}}\ \checkmark \ll \sigma_{yield}$$



$$\sigma = \frac{(68.5\text{ ft lbs})(12\text{ in})\ 1''}{\frac{2\cdot 3^3}{12}} = \boxed{182.7\text{ psi}}\ \checkmark$$

(B') Chest Support Sleeve

most weight transfered as normal force to insert block

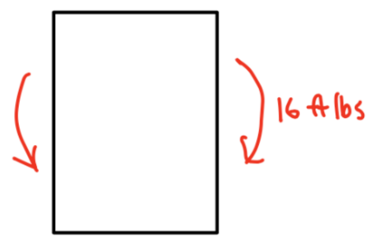
$$\sigma = \frac{(35\text{ ft lbs})(12\text{ in})(1.25'')}{\frac{1}{12}(3.5\cdot 2.5^3 - 3\cdot 2^3)}$$

$$\sigma = \boxed{205.3\text{ psi}}\ \checkmark \ll \sigma_{yield}$$

$k_t = 3$ for pin holes $402 \times 3 = \boxed{616\text{ psi}}$ $\times\ 4 = \boxed{2463.5\text{ psi} < \sigma_{yield}}\ \checkmark$

$$\tau = \frac{157.5\text{ lbs}}{(3\cdot 0.5\cdot 2)} = \boxed{52.5\text{ psi}}\ \checkmark$$

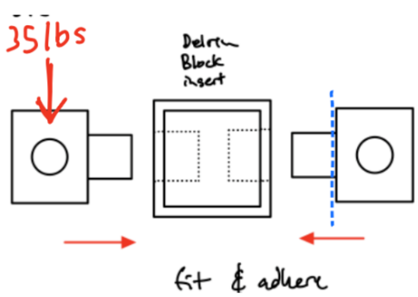
HDPE Rod Insert Blocks



(c)

$$\tau = \frac{\left(\frac{32}{2}\ \text{ft lbs}\right) 12\text{in} \sqrt{1.5^2+1.5^2}}{\frac{1.5^4}{3}} = \boxed{120.7\ \text{psi}}$$

$$\sigma = \frac{\frac{35\ \text{lbs}}{2} \cdot 1'' \ (.75)''}{\frac{1.5^4}{12}} = \boxed{31.11\ \text{psi}}$$



Carbon Fiber Rods

(c)

$$\sigma = \frac{(32\ \text{ft lbs})(12)(.5)}{\frac{\pi}{64}\left(1^4 - 0.875^4\right)} = \boxed{3911.62\ \text{psi}}$$

for carbon fiber

(c')

$$\tau = \frac{140\ \text{lbs}}{\frac{1^2 - 0.875^2}{4}} = \boxed{2389.33\ \text{psi}}$$

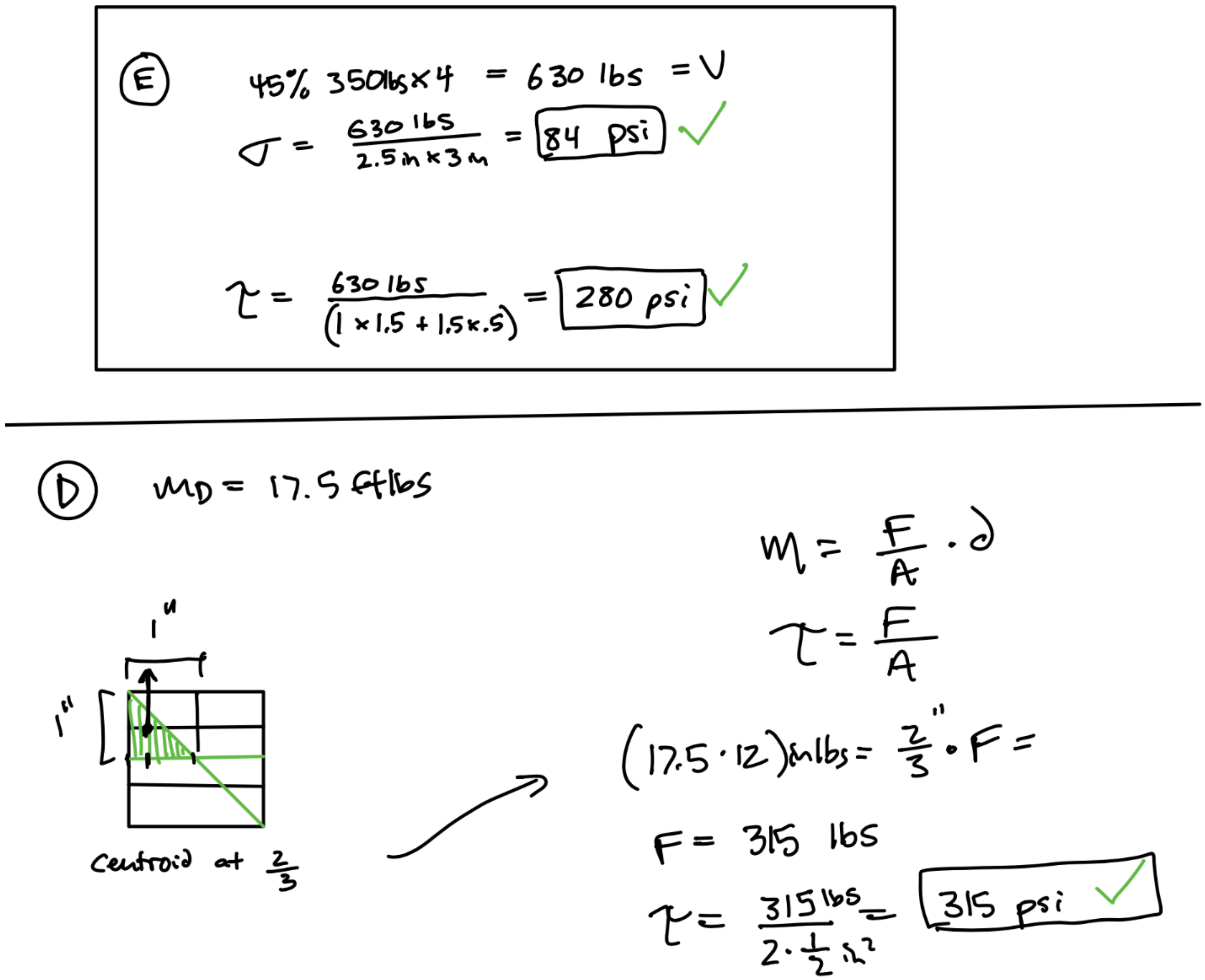


Figure A1: Stress, Shear, and Moment Analysis Hand Calculations

Conclusion:

The calculated shear and normal stress values were used to verify the structural adequacy of the patient positioning device, ensuring that stresses remain below the ultimate strength of the corresponding materials. The analysis confirmed that the device dimensions meet or exceed the required factor of safety at all high-stress locations, validating the design's ability to withstand expected and unexpected loading conditions.

FEA: Fatigue and Stress/Shear

A fatigue analysis using Finite Element Analysis (FEA) was considered for the chest support and head support since these components would encompass the majority of repeated cyclic loading, and therefore having an estimate of lifetime cycles could be helpful, but deeper research shows using a tool like SolidWorks to run an FEA model for multi-layered materials like carbon fibers alongside HDPE can be extremely difficult to accurately depict due to composites anisotropic fiber nature. Figure A.1 below shows an SN curve derived from a research paper that predicts HDPE's behavior under cyclic loading. Further hand calculations can be used in addition to the data available in similar online research papers if fatigue is an avenue worth exploring for the future of this project. However, as mentioned earlier in moment analysis, a high factor of safety was already applied in the calculations done by-hand which should deplete the need for an in-depth fatigue analysis.

FEA was used to run a static study that assesses where stress concentrations may accumulate, along with if material yielding would be an issue focusing solely on the HDPE block to get an estimated number of the stress and shear values the block would be able to withstand, knowing that in actual use our design will have a higher value that what is found since it will have a carbon fiber wrap around where the HDPE block insert rests.

Assumptions:

- Heterogenous makeup; behavior varies based on direction of loading
- Material properties for HDPE such as Young Modulus, Elastic Modulus, and Yield Strength were derived from a variety of material databases, research papers, and ASTM standards
- Stress and shear values were recorded using model type of linear elastic orthotropic and max normal stress since Von Mises particularly doesn't account for fiber orientation

Calculations:

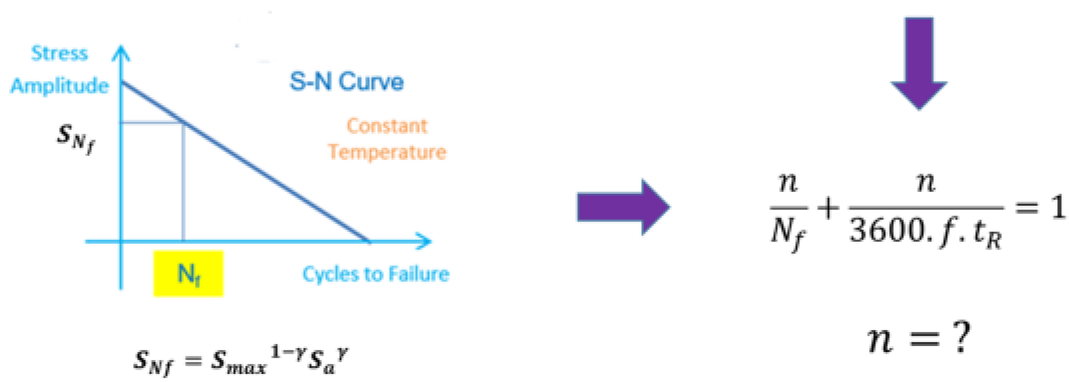


Figure A2: SN Curve for HDPE material to estimate fatigue life cycles

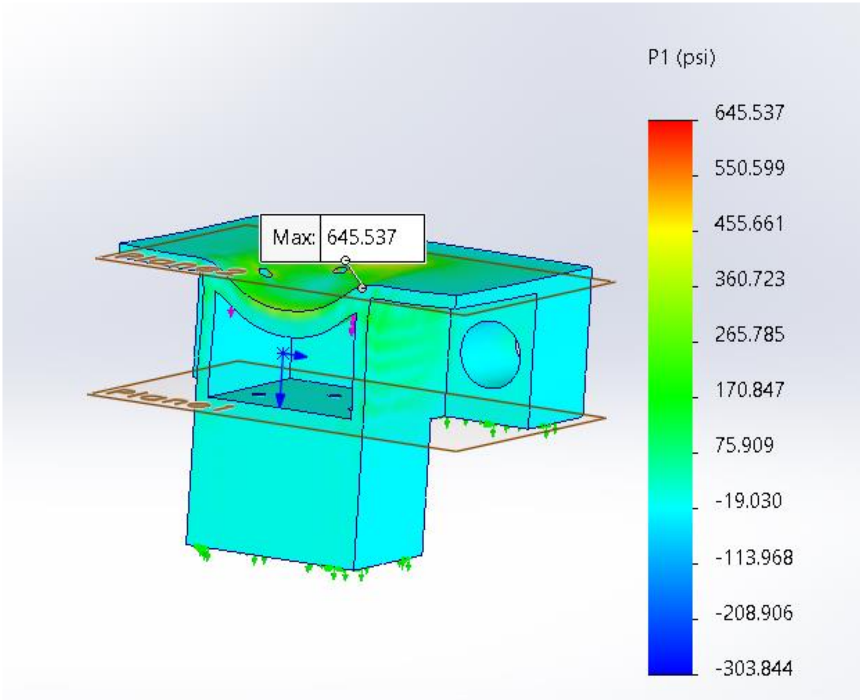


Figure A3: Stress FEA results depicting the chest support (points B and C on FBD). Combined principal stress calculated shows the HDPE block insert will withstand the force

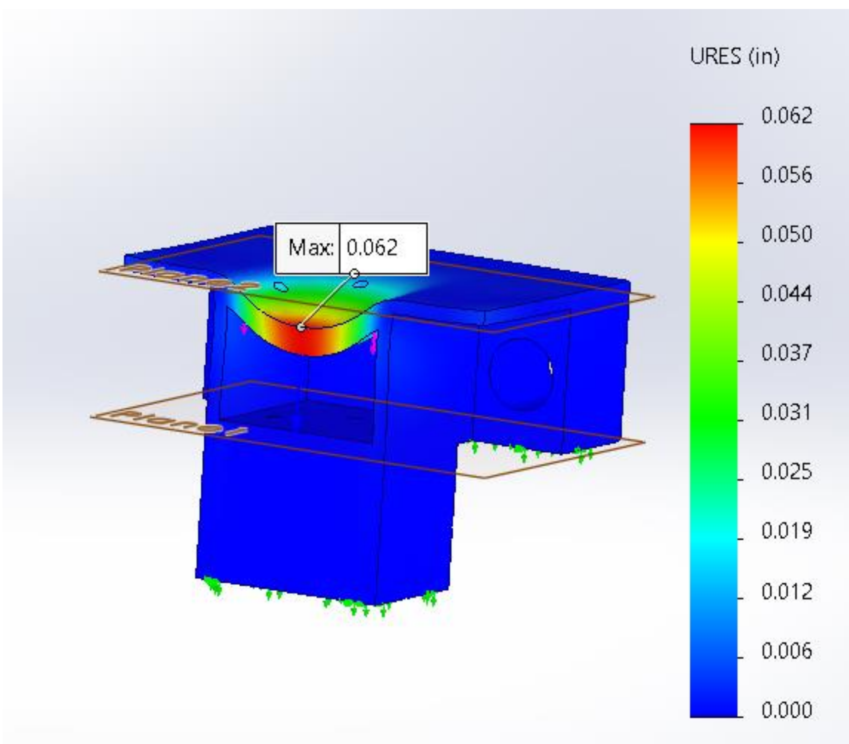


Figure A4: Depicts resultant displacement of chest support HDPE block insert showing less than an inch, while piece is over 2 inches, so the block shall not deform

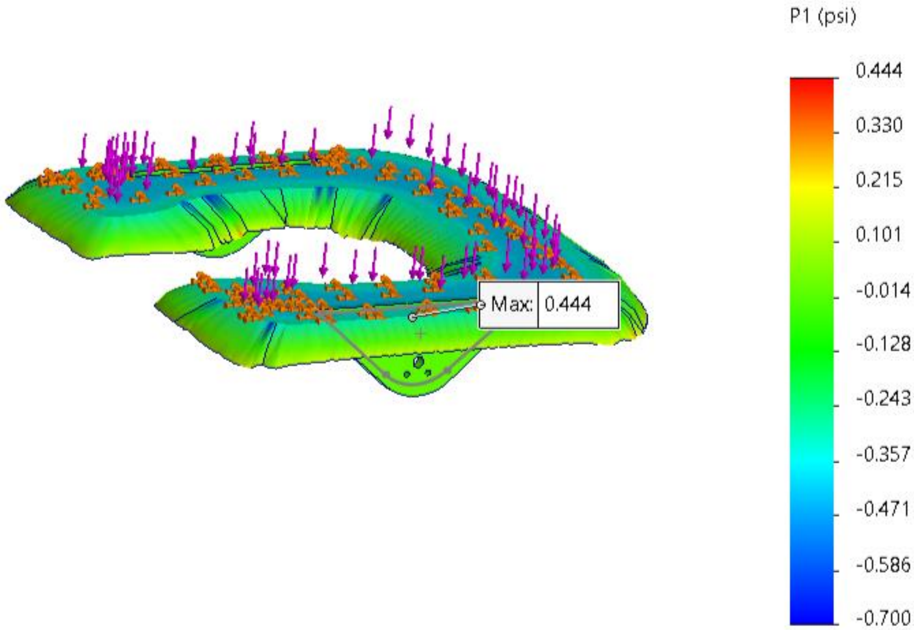


Figure A5: Results of 1st Principal Stress for Head Support in psi, but converted to psf 0.444=63.936 lbs which is below the threshold of 35 lbs (10% of the 350 lb body weight that will reside on this component)

Conclusion:

Overall, using SolidWorks to perform FEA models for stress and strain is just a method to further back up the numbers composed from hand calculations and allows us an engineer to have an additional form of validity to know that the numbers in which we are designing our project on will actually work and not fail in real-life use.

Radiolucency

The device must allow X-rays to pass through with minimal attenuation for clear imaging in the area of interest. The challenge lies in ensuring radiolucency across the imaging zone with multiple different cross sections, angles of the material with the adjustability of the table, and the different materials used.

Assumptions:

- The imagine zone of interest is along the spine and head of the patient.

- Radiolucency Target: X-ray transmission > 80% at 100 keV through imaging zone.
- Rectangular cross sections at a tilt of 0° for calculations.
- Material Properties of interest:
  - Carbon fiber: X-ray attenuation coefficient μ = 0.15 cm-1, density = 1.8 g/cm³.
  - HDPE: μ = 0.05 cm-1, density = 0.95 g/cm³

<u>Radiolucency</u>

$I = I_0 \cdot e^{\mu t}$

I = intensity of X-rays after passing through material (eV)

I_0 = initial X-ray intensity (eV)

μ = linear attenuation coefficient (cm^{-1})

t = thickness of material (cm)

If I/I_0 is close to 1, material is completely radiolucent

If I/I_0 is close to 0, material is completely radiopaque

Want $I/I_0 \geq 0.8$ Mid strength X-ray → I_0 = 100eV

Carbon fiber	$\mu = 0.18$	$t = \frac{-\ln(I/I_0)}{\mu} = 1.2$ cm
Fiber glass	$\mu = 0.27$	$t = \frac{-\ln(I/I_0)}{\mu} = 0.8$ cm
Delrin	$\mu = 0.18$	$t = \frac{-\ln(I/I_0)}{\mu} = 1.2$ cm
HDPE	$\mu = 0.15$	$t = \frac{-\ln(I/I_0)}{\mu} = 1.5$ cm
Aluminum	$\mu = 0.4$	$t = \frac{-\ln(I/I_0)}{\mu} = 0.55$ cm

Calculations depend on X-ray strength and desired radiolucency

μ is dependent on material density and <u>Z composition</u>

↳ (atomic packing + structure)

Figure A6: Radiolucency Hand Calculations

Conclusion:

The radiolucency calculations are very limited by geometry and angle of the device. It should also be noted that radiolucency acts in an exponential manner, meaning that the materials with a better linear attenuation coefficient will lose radiolucency at a slower rate as thickness is added. Most medical tables leave all the structural components on the edges, out of the imaging view and this is a limiting factor in the design as the structural components must be in the desired imaging zone to maintain the ergonomics and adjustability of the device. Because of this, there are various cross sections of different geometries making it difficult for these calculations to predict the full radiolucency of the device. Further testing will need to be done with an actual X-ray, if possible, of differing cross sections of each of the materials being used to see the true radiolucency of the device.

Appendix A1. Analysis Revision

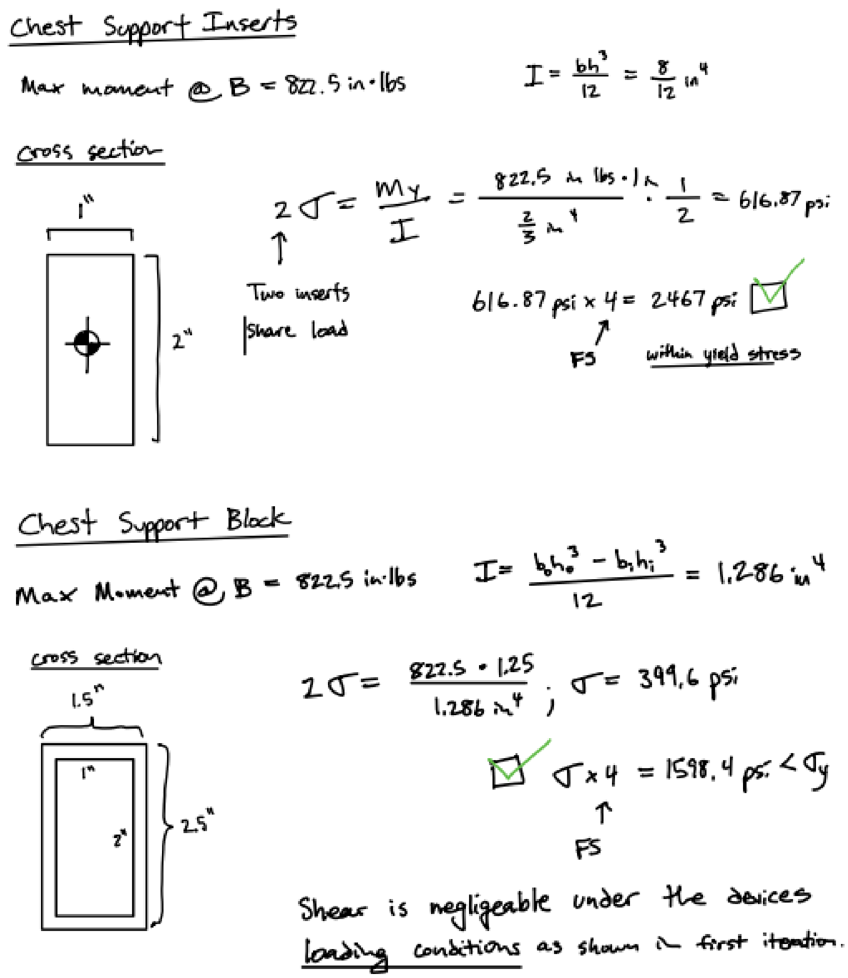


Figure A1.1: Revised Chest Support Insert and Support Block Analysis of Moment and Shear

Sliding Rod Block $\tau_y = 3600$ psi

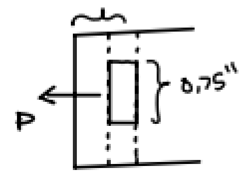
—Threaded Dowel Inserts (Shear) ⇒ Threaded rod is inserted and nylon ribbed nob is screw down and fasten angle rossets in place. This will place normal load on Dowel inserts.

$$\frac{\tau_y}{4} = \frac{P}{A}$$

↗ FS

$$A = 2 \cdot 0.32 \cdot 0.75$$

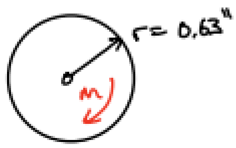
$$A = 0.48\ in^2$$



$$3600 = \frac{P_{allow}}{0.48} \cdot 4 \Rightarrow P_{allow} = \underline{432\ \text{lbs}}$$

to find P allow we analyze torque on angle rosets

Angle rosets experience moment @ D = 210 in-lbs



$$F = \frac{M}{r} = \frac{210}{0.63} = 333.3\ \text{lbs}$$

equal @ 45° contact angle $P_e = F = 333.3$ lbs

$P_{ex} < P_{allow}$ ☑

Neglecting friction adds to FS

A2.2: Revised Sliding Rod Block Analysis

Appendix B. Manufacturing Plan

Table B1: Assembly Instructions

Steps	Parts Involved	Instruction
1	Block Inserts / Carbon fiber tube	Sand and epoxy contact surfaces and insert HDPE blocks into the carbon fiber tube
2	Metal Table Inserts	Insert the metal table attatchments to the mounting bracket and fasten with bolts
3	Mounting Bracket / Pins	Add pins into mounting bracket to hold block insert in place
4	Mounting Bracket	Insert Mounting bracket (Skytron or Steris) into corresponding medical table
5	Chest Support Inserts	Sand and apply epoxy to the surface of HDPE block to insert into the chest support (make sure tube orientation is horizontal)
6	Chest Support Plate	Sand and apply epoxy to contact surface, align pin holes and adhere to chest support block
7	Chest Support Block / Pins	Fit the chest support block over the mounting bracket block insert, and place pins
8	Bushing Inserts	Feed each bushing through the two chest rod holes
9	Chest Rods / Chest Rod Mount/ angle rosettes	Sand and Epoxy contact surfaces between parts Insert the two carbon fiber rods into the HDPE mount, align angle rosettes w/ corresponding pin holes and adhere
10	Adjustable Chest Rods Piece / Chest Support Bushings	Insert carbon fiber chest rods into corresponding chest support bushings
11	Head Support Brackets / Angle Rosettes	Sand and epoxy contact surfaces, align angle rosettes with pin holes and adhere
12	Head Spport Bracket / Chest Support	Align the coresponding angle rosettes on each component and fasten down with wing nuts
13	Head Support Plate / Head Support Flanges	Sand and Epoxy contact surfaces, align machined flange inserts with coresponding head plate grooves and adhere
14	Head Spport Bracket / Head Support Flanges	Align the coresponding angle rosettes on each component and fasten down with wing nuts

Table B2: Operations Sheet for Table Mounting Bracket 1

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
1001	Table Mounting Bracket #1	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Skytron Medical Table Bracket			
Carbon Fiber Tubing	2"x4"x48"				
Operation	Op. Description	Machine	Tooling	Time	
10	cut 2"X 4" stock to 19" length	bandsaw	bandsaw blade + wood	5 mins	
20	drill 2 7/16" diameter holes	end mill	center drill, 7/16" drill	1 min	
20.1	mill out 2.5" X 2.5" hole through	end mill	end mill cutter 1/2"	5-10 mins	
30	drill 2x 1/4" hole through all	end mill	1/4" drill bit, center drill	2 mins	

Table B3: Operations Sheet for Table Mounting Bracket 2

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
1002	Table Mounting Bracket #2	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Steris Cmax Medical Table Bracket			
Carbon Fiber Rectangular Tubing	2"x4"x48"				
Operation	Op. Description	Machine	Tooling	Time	
10	cut 2"X 4" stock to 19" length	bandsaw	bandsaw blade + wood block to push through	5 mins	
20	drill 2 1/4" diameter holes through all at 15 3/8" on center (front face)	end mill	center drill, 1/4" drill bit	1 min	
20.1	mill out 2.5" X 2.5" hole through on center	end mill	end mill cutter 1/2"	5-10 mins	
30	drill 2x 1/4" hole through all (top face)	end mill	1/4" drill bit, center drill	2 mins	

Table B4: Operations Sheet for Head Support Flanges

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
3001	Head Support Flanges	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Outsourcing to sendcutsend.com			
Carbon Fiber	N/A				
Operation	Op. Description	Machine	Tooling	Time	
10	upload CAD files to sendcutsend website	N/A	laptop	2 mins	
20	Receive back final piece from company	N/A	N/A	N/A	
30	Attach rosettes with epoxy resin and pins	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	

Table B5: Operations Sheet for Head Support Bracket

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
3002	Head Support Bracket	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Outsourcing to sendcutsend.com			
Carbon Fiber	N/A				
Operation	Op. Description	Machine	Tooling	Time	
10	upload CAD files to sendcutsend website	N/A	laptop	2 mins	
20	Receive back final piece from company	N/A	N/A	N/A	
30	Attach rosettes with epoxy resin and pins	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	

Table B6: Operations Sheet for Block Inserts

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
1003	Block Inserts	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
HDPE	2"x3"x6"				
Operation	Op. Description	Machine	Tooling	Time	
10	Mill to Carbon Fiber tube inner diameter	end mill	end mill cutter	30-60 min	
20	drill 2 1/4" diameter holes	end mill	center drill, 1/4" drill bit	1 min	
20.1	mill shape of 2.5" X 2.5" extrude	end mill	end mill cutter 1/2"	5-10 mins	
30	drill 2x 1/4" hole through all	end mill	1/4" drill bit, center drill	2 mins	
40	Sand and adhere extrude with west epoxy	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	

Table B7: Operations Sheet for Chest Support

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
2001	Chest Support	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Milling in three parts and two smaller parts attached on the sides			
HDPE	5"x5"x4"				
Operation	Op. Description	Machine	Tooling	Time	
10	Mill HDPE block to general shape	end mill	end mill cutter	30 mins	
20	Mill arm support bracket cutout	end mill	end mill cutter and 10 degree mount	10 mins	
30	Mill out 3"x3" block insert location	end mill	end mill cutter	10 mins	
40	Mill 2 2"x3.5" HDPE blocks with rod holes	end mill	end mill cutter	10 mins	
50	Adhere rod hole blocks with pins and west epoxy	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	
60	drill three 1/4" holes at specified locations on top for insert block	end mill	center drill, 1/4" drill bit	10 mins	

Table B8: Operations Sheet for Adjustable Chest Rod Pieces

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
2501	Adjustable Chest Rods Piece	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Rods are bought and inserted into HDPE stock piece			
HDPE + Carbon Fiber Tubing	2"x2"x9"				
Operation	Op. Description	Machine	Tooling	Time	
10	Mill HDPE stock to size	end mill	end mill cutter	20 mins	
20	Drill 2 1" holes into HDPE block	end mill	center drill, 1" drill bit	5 mins	
30	Drill 1/4" hole in center of either end of HDPE block	end mill	center drill, 1/4" drill bit	5 mins	
30.1	Drill 4 1/8" holes on either end around operation 30 drill holes	end mill	center drill, 1/8" drill bit	5 mins	
40	Insert Carbon fiber tubes and	hand labor	sandpaper, mixing	application: 10 mins	
50	Attach rosettes with epoxy resin	hand labor	sandpaper, mixing	application: 10 mins	

Table B9: Operations Sheet for Head Support Plate

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
3003	Head Support Plate	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Stock material used for two parts (chest and head plates)			
HDPE Sheet	24"x48"x2/4"				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut sheet to shape	Band saw	Band saw blade	20 mins	
20	Sand edges	hand labor	sandpaper	30 mins	
30	Apply velcro strips for cushions	hand labor	N/A	5 mins	

Table B10: Operations Sheet for Chest Support Plate

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
2002	Chest Support Plate	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Stock material used for two parts (chest and head plates)			
HDPE Sheet	24"x48"x2/4"				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut sheet to shape	Band saw	Band saw blade	20 mins	
20	Sand edges	hand labor	sandpaper	30 mins	
30	Apply velcro strips for cushions	hand labor	N/A	5 mins	
40	Etch patent number and sponsor company name	laser cutter	N/A	2-3 hours	

Table B11: Operations Sheet for Rod Caps

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
2502	Rod Caps	T11P52 Group		4/9/2025	1 of 1
Material	Stock Size	Comments: These are the removable caps that are there to prevent head support from unwanted disconnection			
ABS	N/A				
Operation	Op. Description	Machine	Tooling	Time	
10	Upload CAD design to printer	N/A	N/A	2 mins	
20	3D Print two of the caps	3D Printer	N/A	60 mins	

Table B12: Operations Sheet for Head Support Adjustable Rods

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
2503	Head Support Adjustable Rods	T11P52 Group		4/9/2025	1 of 1
Material	Stock Size	Comments: Stock material will be cut in half and grooves cut into it for the end cap rods			
Carbon Fiber	0.875 x 1.000 x 12				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut stock tube in half	Band saw	Band saw blade	2 mins	
20	3D Print two of the caps	Lathe	Groove chisel	10 mins	

Table B13: Operations Sheet for Chest Piece Bushing Inserts

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
03_03	Chest Piece Bushing Inserts 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
HDPE block	2"x3"x6"				
Operation	Op. Description	Machine	Tooling	Time	
10	turn down to size	lathe	turning tool	30 mins	
20	add lip to outer dia	lathe	turning tool	15 mins	
30	debur inside and edges	hand labor	debur tool	10 mins	
40	press fit into chest support block	hand labor	N/A	2 mins	

Table B14: Team Manufacturing Breakouts

Team Member Name	Part Name	Quantity	Due Date	Estimated hours to manufacture
Brianna	Table Mounting Bracket #1	1	10/1/2025	20 minutes
Anders	Table Mounting Bracket #2	1	10/1/2025	20 minutes
Ethan	Head Support Flanges	2	10/1/2025	2-4 business days
Ethan	Head Support Bracket	2	10/1/2025	2-4 business days
Brianna	Block Inserts	2	10/1/2025	73 hours, 23 minutes
Brianna	Chest Support	1	10/1/2025	73 hours, 20 minutes
Anders	Adjustable Chest Rod Pieces	2	10/1/2025	45 minutes
Ethan	Head Support Plate	1	10/1/2025	55 minutes
Anders	Chest Support Plate	1	10/1/2025	4 hours

Appendix B1. Manufacturing Plan Revision

Table B1.1: Revised Assembly Instructions

Steps	Parts Involved	Drawing No.'s	Instructions	Assembly No.
1	Table Attachment Bracket/Chest Support	02_01 02_02 02_03	Sand and epoxy contact surfaces and insert chest support inserts into attachment bracket with pin supports	1
2	Chest support Block/Chest support Plate/Hollow Rods/CF pins/ Rod caps	03_01 03_02 03_04 03_05 03_06	Sand and epoxy contact surfaces. Place hollow rods into chest support blocks. Place rod caps on end of hollow rods. Align chest support plate pin holes with chest support block pin holes an epoxy pins in	2
3	Sliding Rod Block/Threaded Dowel/Angle Rosette/screws/ Heat-sets/ Threaded Rod	04_01 04_03 04_02 91500A126 93365A230 98827A422	Insert threaded dowl into slot and screw in threaded rod. align rosette with holes and screw in with screws. Do this for both sides	3
4	ErGus Head rest/ Head Flanges/Anlge Rosette/Washer /Nuts/Screws	05_01 05_02 04_02 92141A005 90760A005 91500A126	Sand and epoxy contact surfaces and inset flanges into the ErGus head rest. Once dried, align rosettes on outside of flanges and screw in with nuts and washers on inside side of head rest.	4
5	ErGus Head Brackets/Angle Rosettes/Washe r/Nuts/Screws	05_03 04_02 92141A005 90760A005 91500A126	ALign two rosettes on each head bracket on the same sides and screw in with washers and nuts	5
6	Assembly 2/ Assembly 3	03 04	Remove rod caps of assembly 2 and slide hollow rods into holes of sliding rod block assembly (assembly 3)	
7	Assembly 2/ Assembly 5	04 05	Put a spring over threaded rods of Sliding Rod BLock (assembly 2) then slide ErGus head Brackets assembly (assembly 5) over the threaded rods and tighten with a fly nut	
8	Assembly 4/ Assembly 5	05 0	Put threaded bolt through ErGus Head Rest assembly (assembly 4) from the inside with spring on it on outside side of head rest. Slide head brackets (assembly 5) over bolt as well and tighten with fly nut	
9	Assembly 1/ Assembly 2	02 04	Slide chest support insets from assembly 1 into chest support blocks from assembly 2 and fasten with bolts into the side holes	

Table B2.2: Revised Operations Sheet for Table Mounting Bracket 1

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
02_01	Table Mounting Bracket #1	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Skytron Medical Table Bracket			
Carbon Fiber Tubing	2"x4"x48"				
Operation	Op. Description	Machine	Tooling	Time	
10	cut 2"X 4" stock to 19" length	bandsaw	bandsaw blade + wood block to push	5 mins	
20	drill 2 7/16" diameter holes through all at 1.5"	end mill	center drill, 7/16" drill bit	1 min	
20.1	mill out 2.5" X 2.5" hole through on center	end mill	end mill cutter 1/2"	5-10 mins	
30	drill 2x 1/4" hole through all (top face)	end mill	1/4" drill bit, center drill	2 mins	

Table B3.1: Revised Operations Sheet for Table Mounting Bracket 2

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
02_01	Table Mounting Bracket #2	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Steris Cmax Medical Table Bracket			
Carbon Fiber Rectangular Tubing	2"x4"x48"				
Operation	Op. Description	Machine	Tooling	Time	
10	cut 2"X 4" stock to 19" length	bandsaw	bandsaw blade + wood block to push through	5 mins	
20	drill 2 1/4" diameter holes through all at 15 3/8" on center (front face)	end mill	center drill, 1/4" drill bit	1 min	
20.1	mill out 2.5" X 2.5" hole through on center	end mill	end mill cutter 1/2"	5-10 mins	
30	drill 2x 1/4" hole through all (top face)	end mill	1/4" drill bit, center drill	2 mins	

Table B4.1: Revised Operations Sheet for Head Flanges

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
05_02	Head Flanges 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Outsourcing to sendcutsend.com			
Carbon Fiber	N/A				
Operation	Op. Description	Machine	Tooling	Time	
10	upload CAD files to sendcutsend website	N/A	laptop	2 mins	
20	Receive back final piece from company	N/A	N/A	N/A	
30	Attach rosettes with epoxy resin and pins	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	

Table B5.1: Revised Operations Sheet for Head Brackets

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
05_03	Head Brackets 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Outsourcing to sendcutsend.com			
Carbon Fiber	N/A				
Operation	Op. Description	Machine	Tooling	Time	
10	upload CAD files to sendcutsend website	N/A	laptop	2 mins	
20	Receive back final piece from company	N/A	N/A	N/A	
30	Attach rosettes with epoxy resin and pins	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	

Table B6.1: Revised Operations Sheet for Chest Support Inserts

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
02_02	Chest Support Inserts 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
HDPE block	2"x3"x6"				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut to size from stock	end mill	end mill cutter	30-60 min	
20	drill 2 1/4" dia holes on top face	end mill	center drill, 1/4" drill bit	1 min	
20.1	mill shape of 2.5" X 2.5" extrude from	end mill	end mill cutter 1/2"	5-10 mins	
30	drill 2x 3/8" hole and tap on right face	end mill, power tap	center drill, 3/8" drill, 3/8" tap	30 mins	
40	Sand down and epoxy onto mounting bracket	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing:	

Table B7.1: Revised Operations Sheet for Chest Support Block

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
03_01	Chest Support Block 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
HDPE block	5"x5"x4"				
Operation	Op. Description	Machine	Tooling	Time	
10	Mill HDPE block to general shape	end mill	end mill cutter	30 mins	
20	Mill out 3"x3" block insert location	end mill	end mill cutter	10 mins	
30	Mill 2 2"x3.5" HDPE blocks with rod holes	end mill	end mill cutter	10 mins	
40	Adhere rod hole blocks with pins and west epoxy	hand labor	sandpaper, mixing buckets/sticks	application: 10 mins curing: 72 hrs	
50	drill 3/8" hole on right face and tap	end mill, power tap	center drill, 3/8" drill bit, 3/8" tap	30 mins	
60	drill 1/4" hole on top	end mill	center drill, 1/4" drill bit	15 mins	
70	pins	hand labor	screwdriver	5 mins	

Table B8.1: Revised Operations Sheet for Sliding Rod Block

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
04_01	Sliding Rod Block	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
HDPE block	5"x5"x4"				
Operation	Op. Description	Machine	Tooling	Time	
10	mill down stock to size	end mill	end mill cutter	30 mins	
20	mill out 5" middle section	end mill	end mill cutter	15 mins	
30	drill 2x 1" holes	end mill	center drill, 1" drill bit	10 mins	
30.1	drill out head bracket pattern on sides	end mill	center drill, 1/4" and .16 drill bit	20 mins	
30.2	drill 2x .38 dia holes on top	end mill	center drill, .38" drill bit	10 mins	
40	epoxy top screws into hole	hand labor	mixing buckets, sticks	plication: 10 mins curing: 72 h	

Table B9.1: Revised Operations Sheet for Headrest

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
05_01	HeadRest	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Stock material used for two parts (chest and head plates)			
HDPE Sheet	24"x48"x2/4"				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut sheet to size	Band saw	Band saw blade	20 mins	
20	Sand edges/debur	hand labor	sandpaper	10 mins	
30	get to correct shape	CNC	N/A	1-2 hours	
40	Apply Velcro strips for cushions	hand labor	N/A	5 mins	

Table B10.1: Revised Operations Sheet for Chest Support Plate

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
03_02	Chest Support Plate	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Stock material used for two parts (chest and head plates)			
HDPE Sheet	24"x48"x2/4"				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut sheet to shape	Band saw	Band saw blade	10 mins	
20	Sand edges/debur	hand labor	sandpaper + debur tool	10 mins	
30	drill 2x 1/4" holes on top	end mill	center drill, 1/4" drill bit	30 mins	
40	name	CNC	N/A	2-3 hours	
50	Apply Velcro strips for cushions	hand labor	N/A	5 mins	

Table B11.1: Revised Operations Sheet for Rod Caps

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
03_06	Rod Caps 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
ABS					
Operation	Op. Description	Machine	Tooling	Time	
10	export CAD file to correct format	computer	N/A	5 mins	
20	Send CAD file to makerspace for printing	computer	N/A	5 mins	
30	Pickup finished piece once create	3d printer	N/A	1 hr	
40	press fit onto hollow rods	hand labor	N/A	5 mins	

Table B12.1: Revised Operations Sheet for ErGus Hollow Rods

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
03_04	ErGus Hollow Rods 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments: Rods are bought and inserted into HDPE stock piece			
Carbon Fiber Tubing	2"x2"x9"				
Operation	Op. Description	Machine	Tooling	Time	
10	Cut carbon fiber tubes to size	circular saw	N/A	10 mins	
20	debur inside of tubing	hand labor	debur tool	5 mins	

Table B13: Revised Operations Sheet for Chest Piece Bushing Inserts

Route Sheet: Innovation Alley					
Part Number	Part Name	Developed By:	Checked By:	Date	Page
03_03	Chest Piece Bushing Inserts 2x	T11P52 Group		3/30/2025	1 of 1
Material	Stock Size	Comments:			
HDPE block	2"x3"x6"				
Operation	Op. Description	Machine	Tooling	Time	
10	turn down to size	lathe	turning tool	30 mins	
20	add lip to outer dia	lathe	turning tool	15 mins	
30	debur inside and edges	hand labor	debur tool	10 mins	
40	press fit into chest support block	hand labor	N/A	2 mins	

Table B14.1: Revised Team Manufacturing Breakouts

Team Manufacturing Breakout				
Team Member Name	Part Name	Quantity	Due Date	Estimated hours to manufacture
Anders	Table Attachment Bracket	1		4 hours
Brianna	ErGus Headrest	1		4 hours
SendCutSend	Head Brackets	2		2-3 business days
SendCutSend	Head Flanges	2		2-3 business days
Anders	Chest Support Block	2		4 hours
Anders	Chest Support Inserts	2		4 hours
Brianna	Chest Support Plate	1		2 hours
Brianna	Chest Piece Bushing Insert	2		2 hours
Brianna	ErGus Hollow Rods	2		1 hour
Anders	Rod Caps	2		2 hours
Anders	Sliding Rod Block	1		1 week

Appendix C. Project Management Plan and Schedule

1. Scheduled Meetings

- T11P52 Peer Group: meets every Wednesday at 9:00am or 10:00am depending on workload in Norm Asbjornson Hall

-Faculty Advisor, Lewis Cox: Convene every Friday at 10:00am in his office Roberts 201F

-Sponsor, ErGus Surgical Innovations: Will meet up whenever questions, comments, or concerns arise either over Zoom/Teams or scheduled in-person in reserved library room

- Attendance Requirement: Members agree to attend all meetings unless prior notice is given.
- Meeting Etiquette: Come prepared, be punctual, and actively participate.

2. Leadership Schedule & Responsibilities

Each team member agrees to fulfill their leadership role and contribute to the team's success.

Group leader role and responsibilities will rotate every 2 weeks.

- Roles and responsibilities include:

- Taking charge in weekly meetings to ensure all necessary information is collected to set team up for success
- Manage and lead team documentation and communication such as advisor meeting minutes, weekly memos, and draft chapters, along with collecting signatures where necessary
- Provide project timeline oversight to ensure all weekly assignments are completed, and submitted on-time

3. Task List

→ Sponsor Meeting
→ Memorandum of Understanding (MOU)
→ Problem Statement/Level 1 Requirements
→ Background Research Draft Chapter
→ Project Management Plan
→ Preliminary Design Review (PDR)
→ Preliminary Design/Drawings
→ Specification Draft Chapter
→ Alternatives Draft Chapter

→ Project Management Plan Updates
→ Preliminary Design Analysis
→ Failure Mode & Effects Analysis (FEMA)
→ Drawing Package
→ Executive Summary Draft Chapter
→ Design for Manufacturing Plans (DFMA)
→ Analysis Draft Chapter
→ Critical Design Review (CDR) Slideshow
→ Production Readiness Review (PRR)
→ CDR video
→ Final Report
→ Purchased Parts List
→ Component Construction Manual

4. Leadership Schedule

Week 1 & 2: 1/20/2025-2/2/2025 Anders Nelson

- Weekly Memo 1 & 2
- Schedule Advisor and Sponsor Meeting
- Problem Statement/Level 1 Requirements/MOU
- Background Research Chapter Draft
- Project Management Plan Initial
- Team Touchpoint Meeting
- Advisor Meeting Minutes

Week 3 & 4: 2/3/2025-2/16/2025 Brianna Chase

- - Weekly Memo 3 & 4
- -Alternatives Draft Chapter
- -Specifications Draft Chapter
- -Preliminary Analysis and Design Work
- -Complete IDR (Initial Design Review) w/ Glenn Foster
- -Advisor Meeting Minutes

Week 5 & 6: 2/17/2025-3/2/2025 Ethan Morse

- Weekly Memo 5 & 6
- Team Touchpoint Meeting
- Initial Design Review Form
- PDR Presentation
- Advisor Meeting Minutes
- Mid-Term Peer Evaluations
- Project Management Plan Update 1
- Upload PDR Slides to D2L
- Preliminary Analysis
- Preliminary Drawings (CAD or hand drawn)

Week 7 & 8: 3/3/2025-3/16/2025 Anders Nelson

- Weekly Memo 7 & 8
- Preliminary Design Update (CAD required)
- Complete Design for Manufacturing (DFMA) w/ Glenn Foster
- Preliminary Analysis Update
- Advisor Meeting Minutes
- Project Management Plan Update 2
- Prepare for CDR
- Work on Drawing Package & Manufacturing Plans

Week 9 & 10: 3/17/2025-3/30/2025 Brianna Chase

- Team Touchpoint Meeting
- Weekly Memo 10
- FEMA Assignment
- Proof of DFMA completion, submit form to D2L
- Executive Summary Draft Chapter
- Prepare for CDR

- Work on Drawing Package & Manufacturing Plans
- Advisor Meeting Minutes

Week 11 & 12: 3/31/2025-4/13/2025 Ethan Morse

- Weekly Memo 11 & 12
- Advisor Meeting Minutes
- Analysis Draft Chapter
- Schedule CDRs
- Continue to work on Drawing Package & Manufacturing Plans
- CDR throughout week; 2 viewing/grading required
- Project Management Plan Update 3
- CDR Slides submitted to D2L
- Finish all Design, Manufacturing, & Analysis for CDR

Week 13 & 14: 4/14/2025-4/27/2025 Anders Nelson

- Weekly Memo 13 & 14
- Schedule Production Readiness Review (PRR)
- Advisor Meeting Minutes
- Complete/Refine Drawing Package & Manufacturing Plans
- Plan for PRR based on CDR feedback
- Complete Shop Quiz via D2L
- Schedule and Complete PRR
- Submit Drawing Package, Manufacturing Plan, and PRR checklists

Week 15 & 16: 4/28/2025-5/9/2025 Brianna Chase

- Weekly Memo 15 & 16
- Advisor Meeting Minutes
- Submit Final Report
- Final Project Management Plan
- Project Video

- Peer/Course/Advisor Reviews via D2L
- Provide Advisor Raw Materials & Purchased Parts List
- Order Parts & Materials for Cap 2

4. Conflict Resolution

If conflicts arise, we agree to:

1. Address the issue directly with the parties involved.
2. Seek mediation within the team before escalating further.
3. Maintain professionalism and respect throughout the resolution process.
4. Ask for help with those higher up if the issue isn't resolved.

5. Communication & Documentation

- Each member agrees to meet deadlines and inform the team if obstacles arise.
- If a member cannot complete a task, they will proactively seek help or propose an alternative solution.
- All files will be stored in the files tab of shared Teams page
- Communication with professors, sponsor, and advisor will be done through Outlook
- Daily communications may be done through text

4. Preliminary Network Diagram

Shows the interdependencies between subsystems – fasteners, seals, actuators, data passed, connectors, wire function (power, data...)

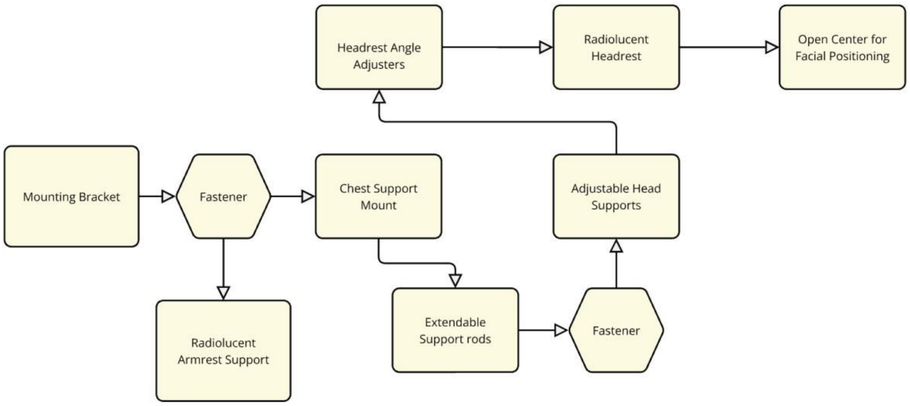


Figure C1: Preliminary Network Diagram

See Attached File: “Cap1_S25_T11P52_Gantt_2March2025” for Gantt Chart

Cap1_S25_T11P52_Gantt_2March2025.xlsx

Appendix C1. Project Management Plan & Schedule Revised

1. Scheduled Meetings

- T11P52 Peer Group: meets every Tuesday/Thursday during lecture period or on need basis

-Faculty Advisor, Lewis Cox: Convene every Monday 3-4pm in his office in Roberts 201F; but will occasionally come scope out workspace in Norm

-Sponsor, ErGus Surgical Innovations: Will meet up whenever questions, comments, or concerns arise either over Zoom/Teams or scheduled in-person in reserved library room

- Attendance Requirement: Members agree to attend all meetings unless prior notice is given.
- Meeting Etiquette: Come prepared, be punctual, and actively participate.

2. Leadership Schedule & Responsibilities

Each team member agrees to fulfill their leadership role and contribute to the team's success.

Group leader role and responsibilities will rotate every 2 weeks.

- Roles and responsibilities include:

1.) Taking charge in weekly meetings to ensure all necessary information is collected to set team up for success

2.) Manage and lead team documentation and communication such as advisor meeting minutes, weekly memos, and draft chapters, along with collecting signatures where necessary

3.) Provide project timeline oversight to ensure all weekly assignments are completed, and submitted on-time

Week 1 & 2: 8/26/25-09/07/25 Brianna Chase

- Weekly Memo 1 & 2
- Schedule Initial Advisor Meeting Time
- Project Management Update 1
- Team Touchpoint Meeting
- Project Update Meeting 1

Week 3 & 4: 09/09/2025-09/21/2025 Ethan Morse

- Weekly Memo 3 & 4
- Mandatory Class Lecture

Week 5 & 6: 09/23/2025-10/05/2025 Anders Nelson

- Weekly Memo 5 & 6
- Team Touchpoint Meeting
- Project Update Meeting 2
- Attend Cap 1 PDR Presentations
- Mid-Term Peer Survey

Week 7 & 8: 10/07/2025-10/19/2025 Brianna Chase

- Weekly Memo 7 & 8
- Mandatory Class Lecture
- Project Management Update 2
- Wrap up prototype fabrication

Week 9 & 10: 10/21/2025-11/02/2025 Ethan Morse

- Weekly Memo 10
- Begin testing
- Prototype Rollout
- Document Final Test Plans
- Prototype Rollout Pictures Assignment

Week 11 & 12: 11/04/2025-11/16/2025 Anders Nelson

- Weekly Memo 11 & 12
- Project Management Update 3
- Preliminary Test Results
- Prototype Test & Documentation

Week 13 & 14: 11/18/2025-11/30/2025 Brianna Chase

- Weekly Memo 13 & 14
- Final Test Results
- Final Specifications
- Create Poster for Design Fair
- Technical Addendum

- Prep for Design Fair
- Mandatory Class Lecture

Week 15 & 16: 12/02/2025-12/12/2025 Ethan Morse

- Weekly Memo 15 & 16
- Design Fair
- Sponsor Delivery Form
- Peer/Course/Advisor Feedback Surveys
- Commencement !!

3. Task List & Gantt Chart

→ Final Report
→ Project Management Plan Updates
→ Final Revised Drawing Package
→ Preliminary Test Results
→ Parts List
→ Component Construction Manual
→ Design Fair Poster
→ Technical Addendum
→ Final Test Results

4. Conflict Resolution

If conflicts arise, we agree to:

1. Address the issue directly with the involved parties.
2. Seek mediation within the team before escalating further.
3. Maintain professionalism and respect throughout the resolution process.
4. Ask for help with those higher up if the issue isn't resolved.

5. Communication & Documentation

- Each member agrees to meet deadlines and inform the team if obstacles arise.
- If a member cannot complete a task, they will proactively seek help or propose an alternative solution.
- All files will be stored in the files tab of shared Teams page
- Communication with professors, sponsor, and advisor will be done through Outlook
- Daily communications may be done through text

6. Preliminary Network Diagram

Shows the interdependencies between subsystems – fasteners, seals, actuators, data passed, connectors, wire function (power, data...)

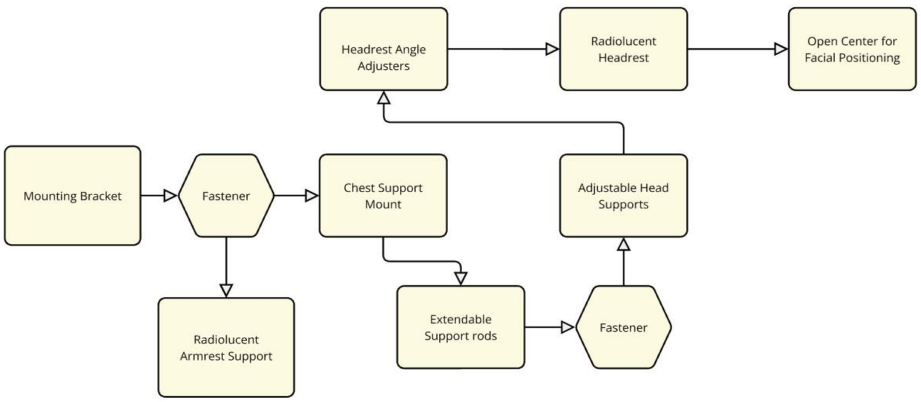


Figure C1.1: Preliminary Network Diagram Revised

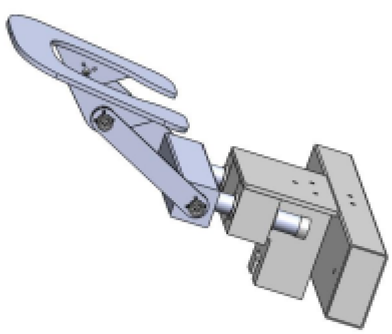
See Attached File: "Cap2_F25_FinalGanttVisual_3Dec2025 for Gantt Chart

Cap2_F25_FinalGanttVisual_T11P52_3Dec2025.pdf

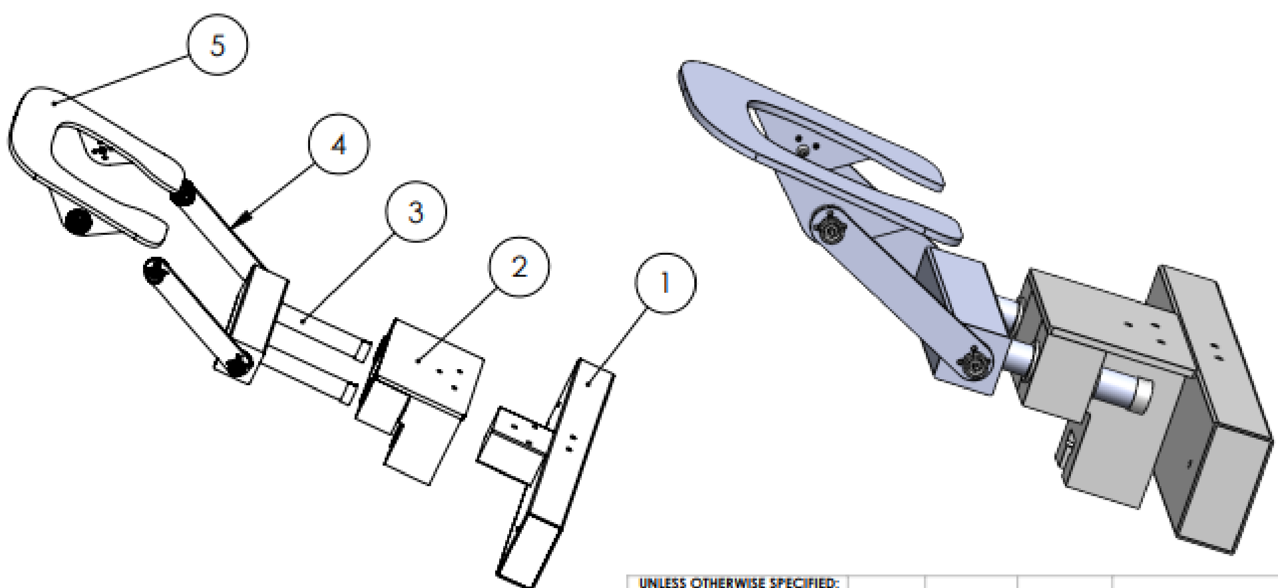
Appendix D. Engineering Drawings

ETME 489/EMEC 489 ErGus Radiolucent Prototype
Component/Assembly List

Designed Component	**Assy Used On**	**Qty**	**Description**
01	-	1	ErGus Prototype Assembly
02	-	1	Mounting Bracket Assembly
03	-	1	Chest Support Assembly
04	05	1	Sliding Rod Assembly
05	06	1	Head Rest Assembly
06	05	1	Head Bracket Assembly
02_01	02	1	SkyTron 6500 Elite HDPE Insert
02_02	02	1	SkyTron 6500 Elite CF Shell
02_03	02	1	Steris Cmax CF Shell
02_04	02	1	Steris Cmax HDPE Insert
02_05	02	1	Chest Support Insert Block
03_01	03	1	Chest Support Main Block
03_02	03	2	Chest Support Side Inserts
03_03	03	1	Chest Support Top Plate
03_04	03	2	Chest Piece Bushing Insert
04_01	04	2	ErGus Hollow Rods
04_02	04	1	Rod Bracket Support
04_03	04	2	Rod Caps
05_01	05	1	ErGus Head Rest
05_02	05	2	Head Flanges
05_04	05,06,04	8	Heat Set Inserts Plastic
05_05	01	4	Nylon Ribbed Knob
06_01	06	2	Head Brackets
Purchased Parts	**Assy Used on**	**Qty**	**Description**
02_06	02	2	CF ¼ "pins
05_03	05,06,04	2	Angle Rosette
92095A220	05,04	2	Button head hex drive screw



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02	Mounting Bracket Assembly	1
2	03	Chest Support Assembly	1
3	04	Sliding Rod Assembly	1
4	06	Head Bracket Assembly	2
5	05	Head Rest Assembly	1
6	62935K16	Nylon Ribbed Knob	4



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TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Brianna Chase	4/11/2025
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: ErGus Prototype Assembly

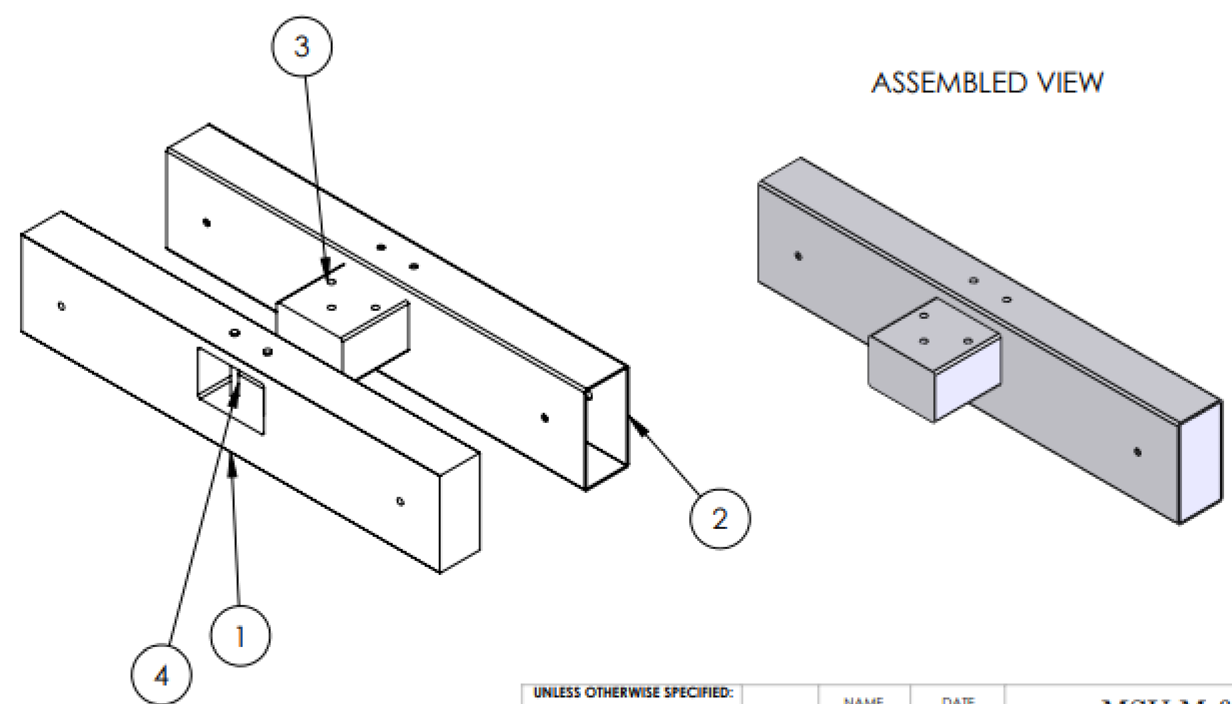
SIZE: A | DWG. NO.: 01 | REV: 0

SCALE: 1:8 | WEIGHT: | SHEET 2 OF 27

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02_01	SkyTron 6500 Elite HDPE insert	1
2	02_02	SkyTron 6500 Elite CF Shell	1
3	03_05	Chest Support Insert Block	1
4	02_03	CF 1/4" pins	2



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TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Brianna Chase	4/11/2025
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: Mounting Bracket Assembly

SIZE A | DWG. NO. 02 | REV 0

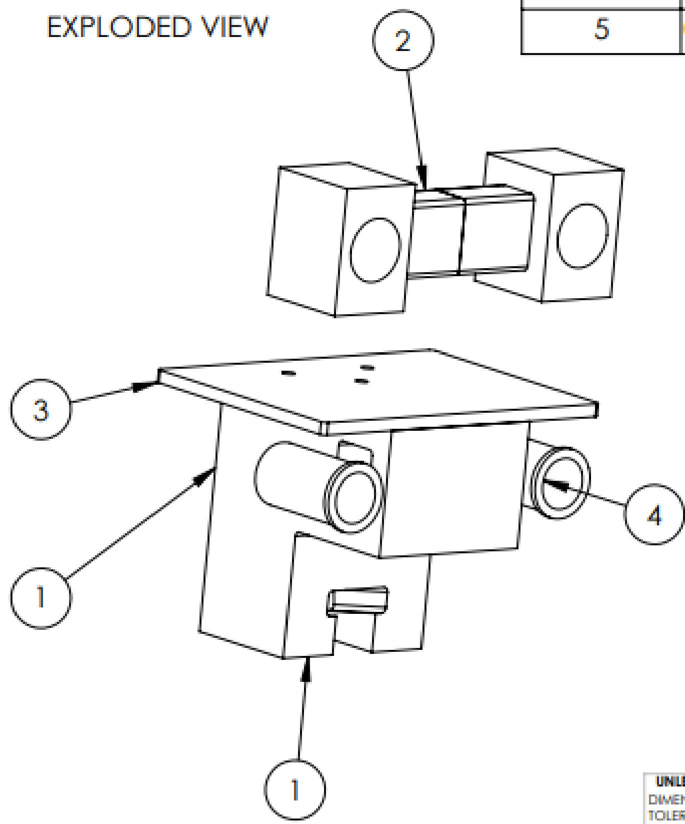
SCALE: 1:8 | WEIGHT: | SHEET 3 OF 27

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	03_01	Chest Support Main Plate	1
2	03_02	Chest Support Side Insert	2
3	03_03	Chest Support Top Plate	1
4	03_04	Chest Support Bushing Insert	2
5	03_05	Chest Support Insert Block	1

EXPLODED VIEW



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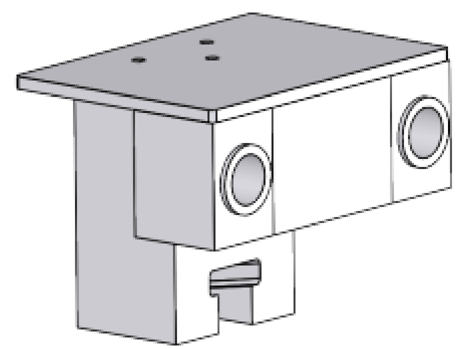

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ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Brianna Chase	4/11/2025
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: 03 Chest Support Assembly

SIZE A | DWG. NO. 03 | REV 0

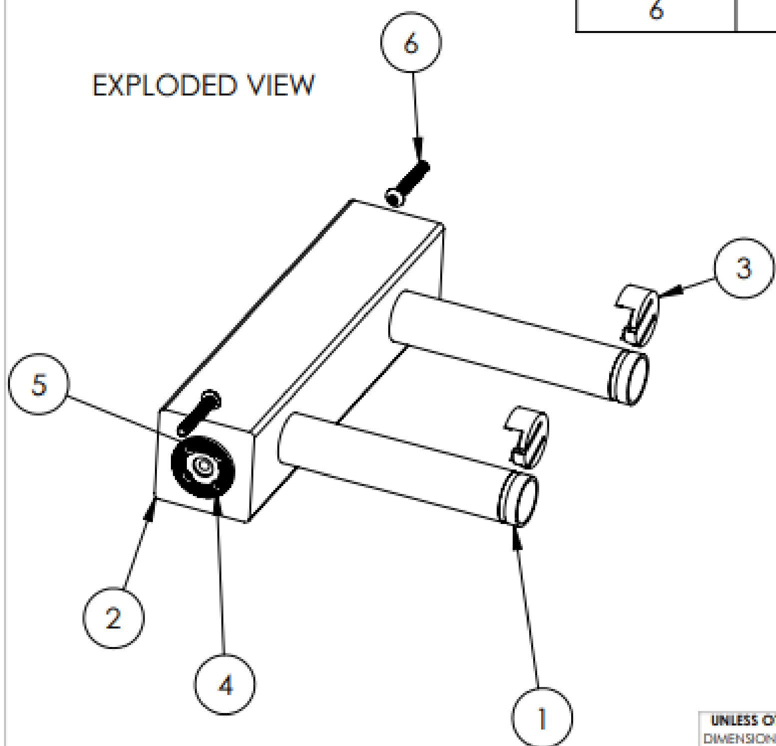
SCALE: 1:4 | WEIGHT: | SHEET 4 OF 27

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	04_01	Hollow Rods	2
2	04_02	Rod Bracket Support	1
3	04_03	Rod Caps	2
4	05_03	Angle Rosette	2
5	05_04	Heat-Set Inserts for Plastic	8
6	92095A220	Button Head Hex Drive Screw	2

EXPLODED VIEW



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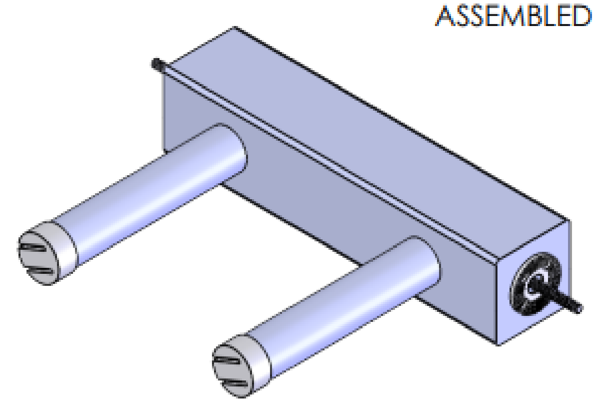

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ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Brianna Chase	4/11/2025
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	-	

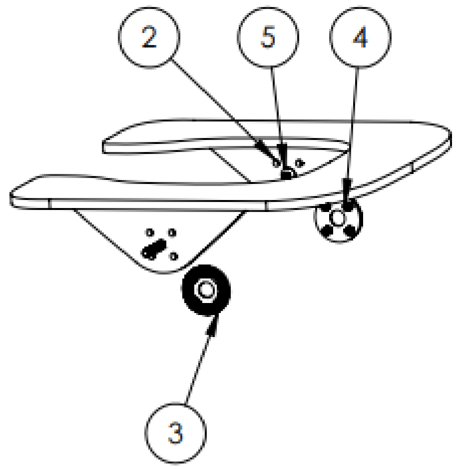
MSU M.& I.E. DEPT.
TITLE: Sliding Rod Assembly
SIZE A | DWG. NO. 04 | REV 0
SCALE: 1:4 | WEIGHT: | SHEET 5 OF 27

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	05_01	Head Rest	1
2	05_02	Head Flanges	2
3	05_03	Angle Rosette	2
4	05_04	Head-Set Inserts for Plastic	8
5	92095A220	Button Head Hex Drive Screw	2
6	05_05	Nylon Ribbed Knob(not shown)	2

EXPLODED VIEW



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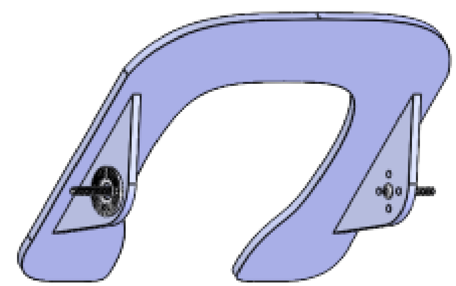

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TOLERANCES:
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ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
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COMMENTS:
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	NAME	DATE
DRAWN	Brianna Chase	4/11/2025
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	-	

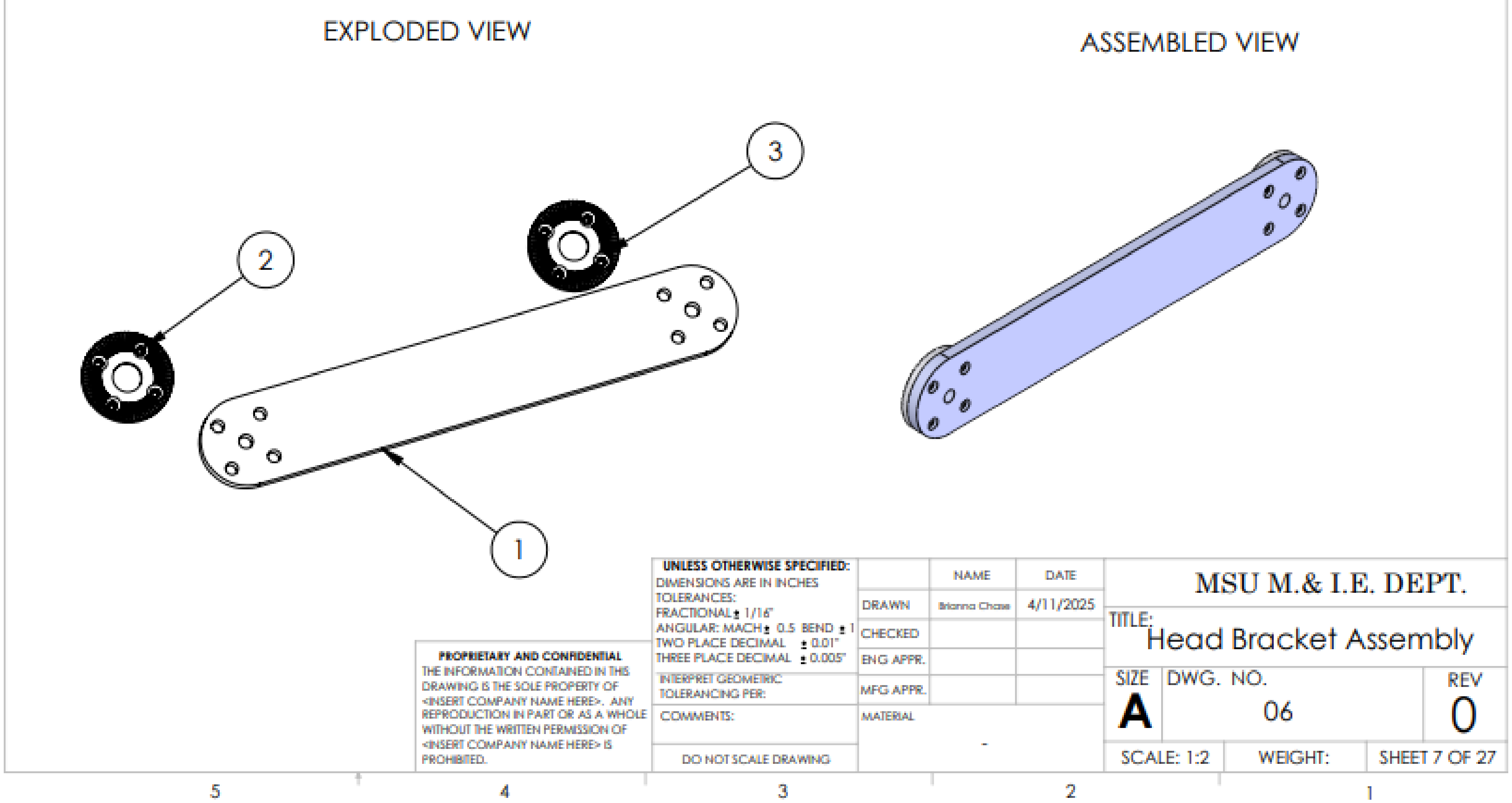
MSU M.& I.E. DEPT.

TITLE: ErGus Head Rest Assemby

SIZE	DWG. NO.	REV
A	05	0
SCALE: 1:4	WEIGHT:	SHEET 6 OF 27

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	06_01	Head Bracket	1
2	05_04	Heat-Set Inserts for Plastic	8
3	05_03	Angle Rosette	2



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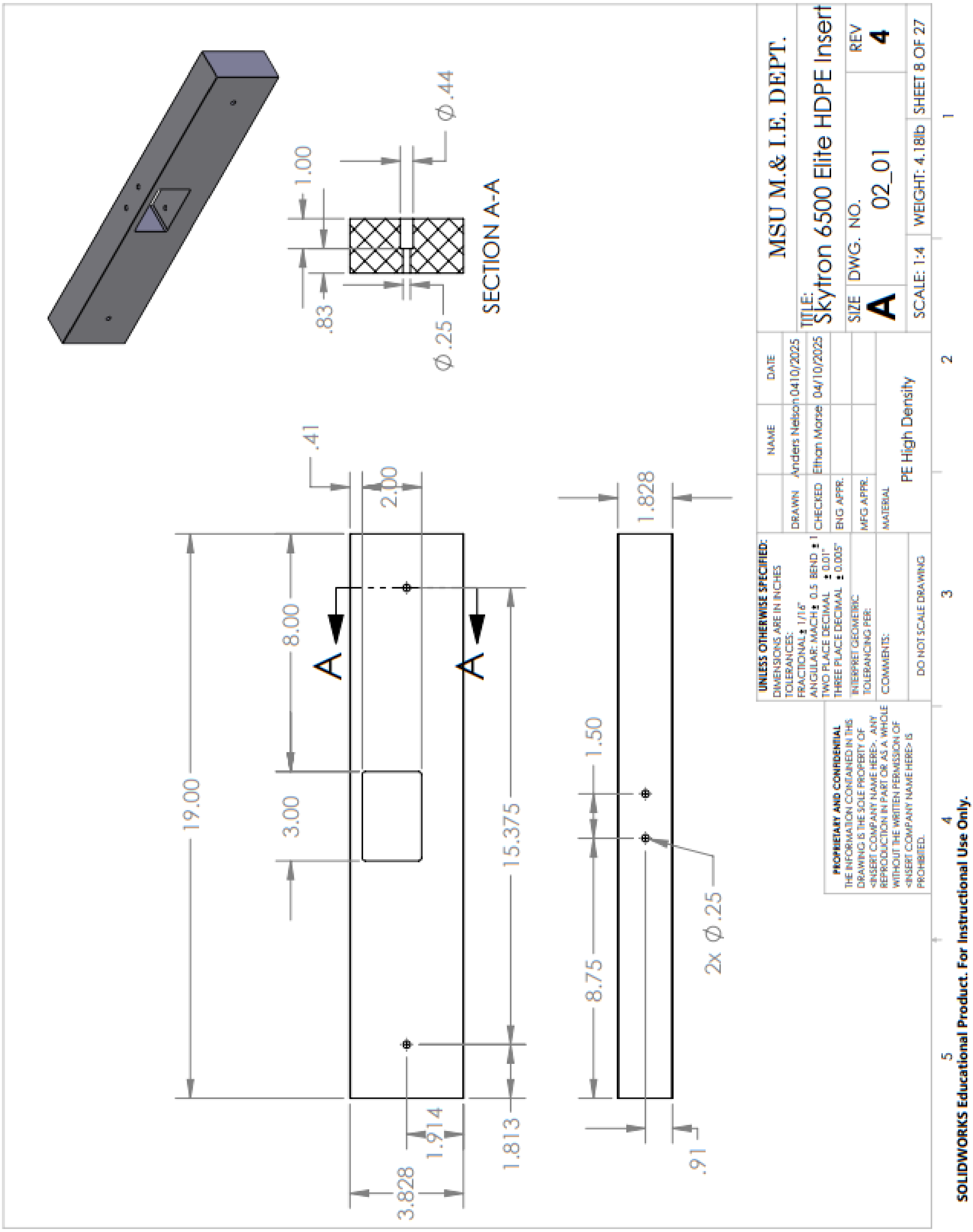
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TITLE: Skytron 6500 Elite HDPE Insert
SIZE A
DWG. NO. 02_01
REV 4
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WEIGHT: 4.18lb
SHEET 8 OF 27
NAME
DATE
DRAWN Anders Nelson 0410/2025
CHECKED Ethan Morse 04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
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COMMENTS:
DO NOT SCALE DRAWING
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Ø.25
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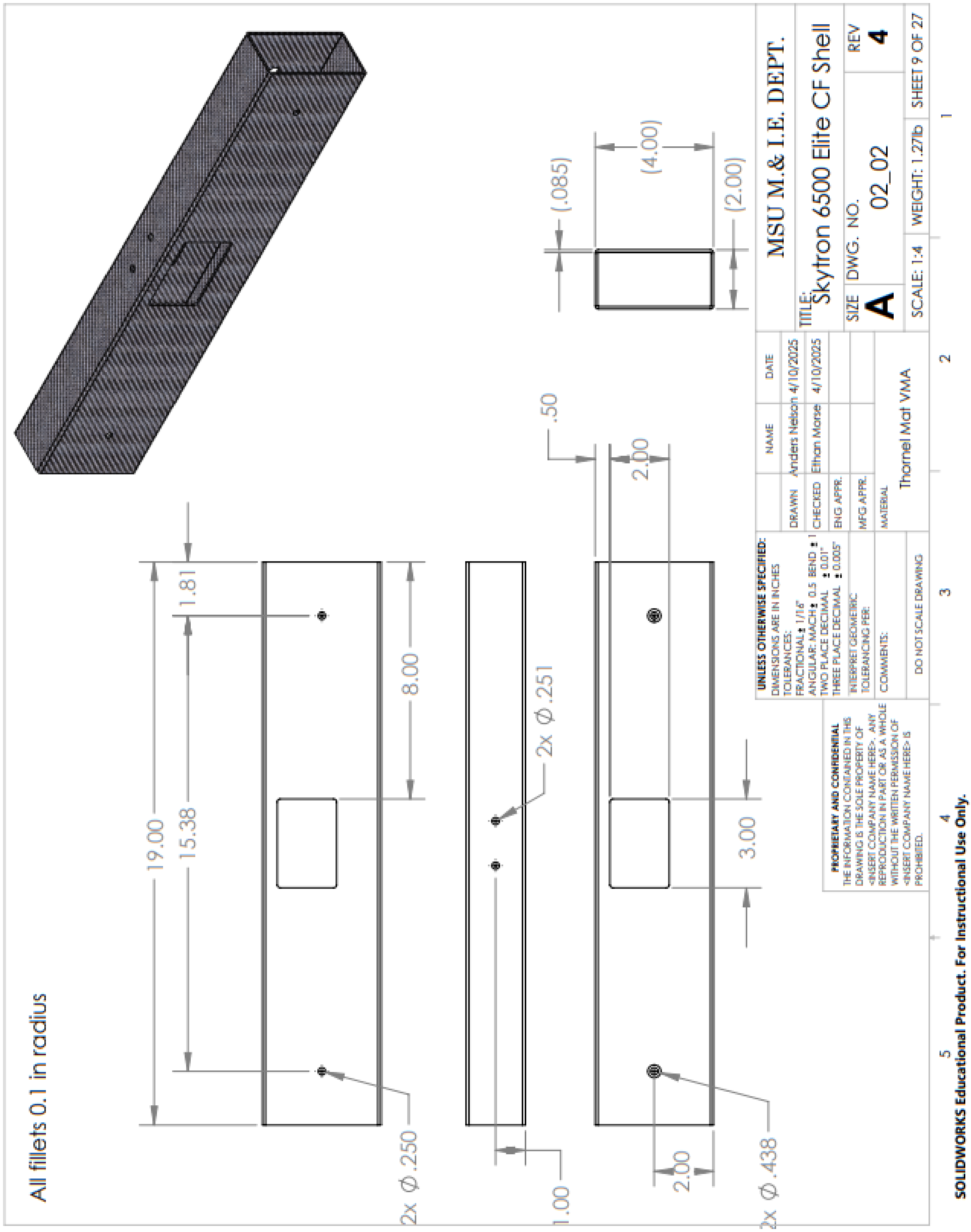
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TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
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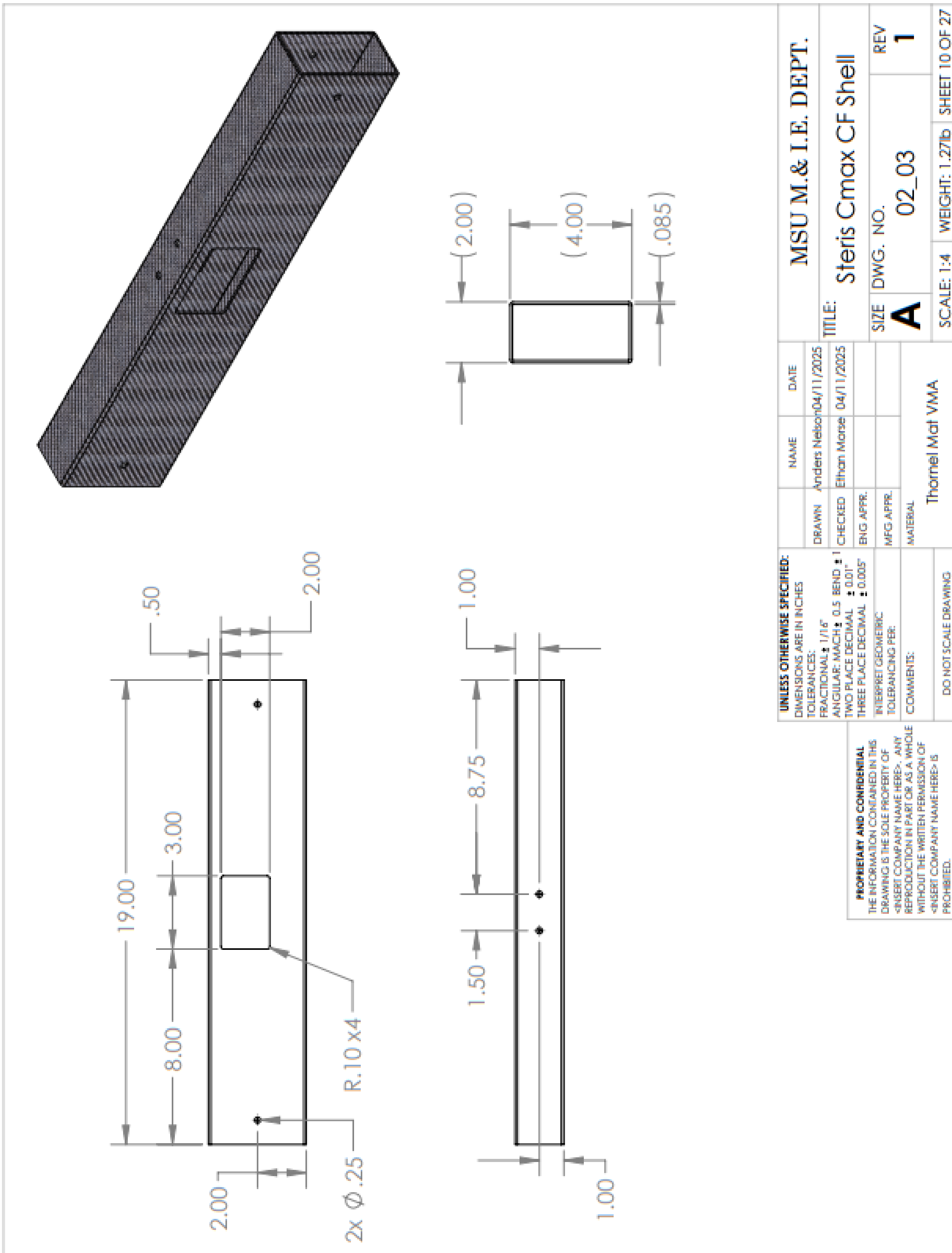
NAME
DATE
DRAWN Anders Nelson 4/10/2025
CHECKED Ethan Morse 4/10/2025
ENG APPR.
MFG APPR.
MATERIAL
Thornel Mat VMA
MSU M.& I.E. DEPT.
TITLE:
Skytron 6500 Elite CF Shell
SIZE A
DWG. NO. 02_02
REV 4
SCALE: 1:4
WEIGHT: 1.27lb
SHEET 9 OF 27
SOLIDWORKS Educational Product. For Instructional Use Only.


MSU M.& I.E. DEPT.
TITLE:
Steris Cmax CF Shell
SIZE
A
DWG. NO.
02_03
REV
1
SCALE: 1:4
WEIGHT: 1.27lb
SHEET 10 OF 27
NAME
DATE
DRAWN
Anders Nelson
04/11/2025
CHECKED
Ethan Morse
04/11/2025
ENG APPR.
MFG APPR.
MATERIAL
Thornel Mat VMA
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
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ANGULAR: MACH ± 0.5 BEND ± 1
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INTERPRET GEOMETRIC TOLERANCING PER:
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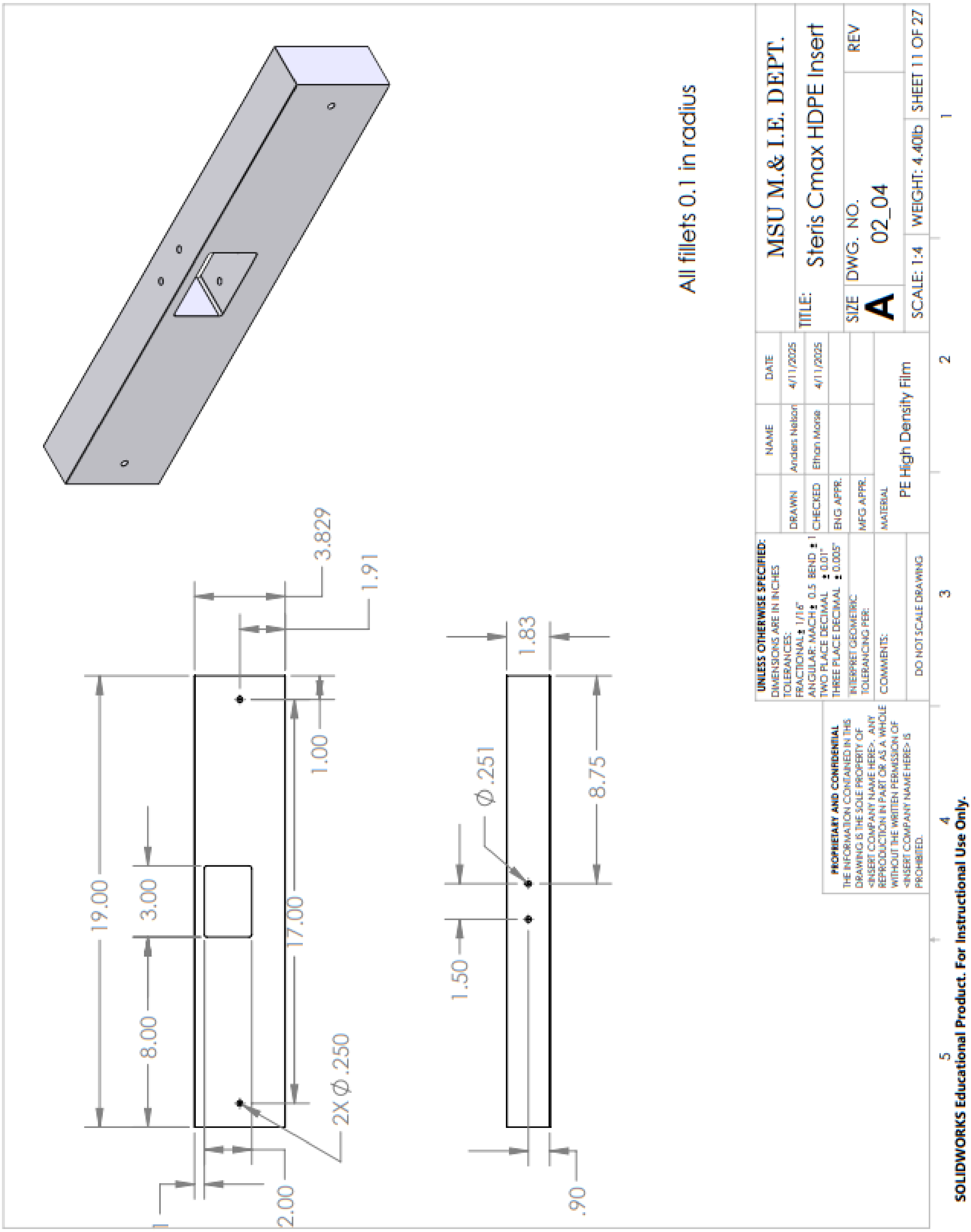

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8.00
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17.00
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1.50
Ø.251
1.83
8.75
.90
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
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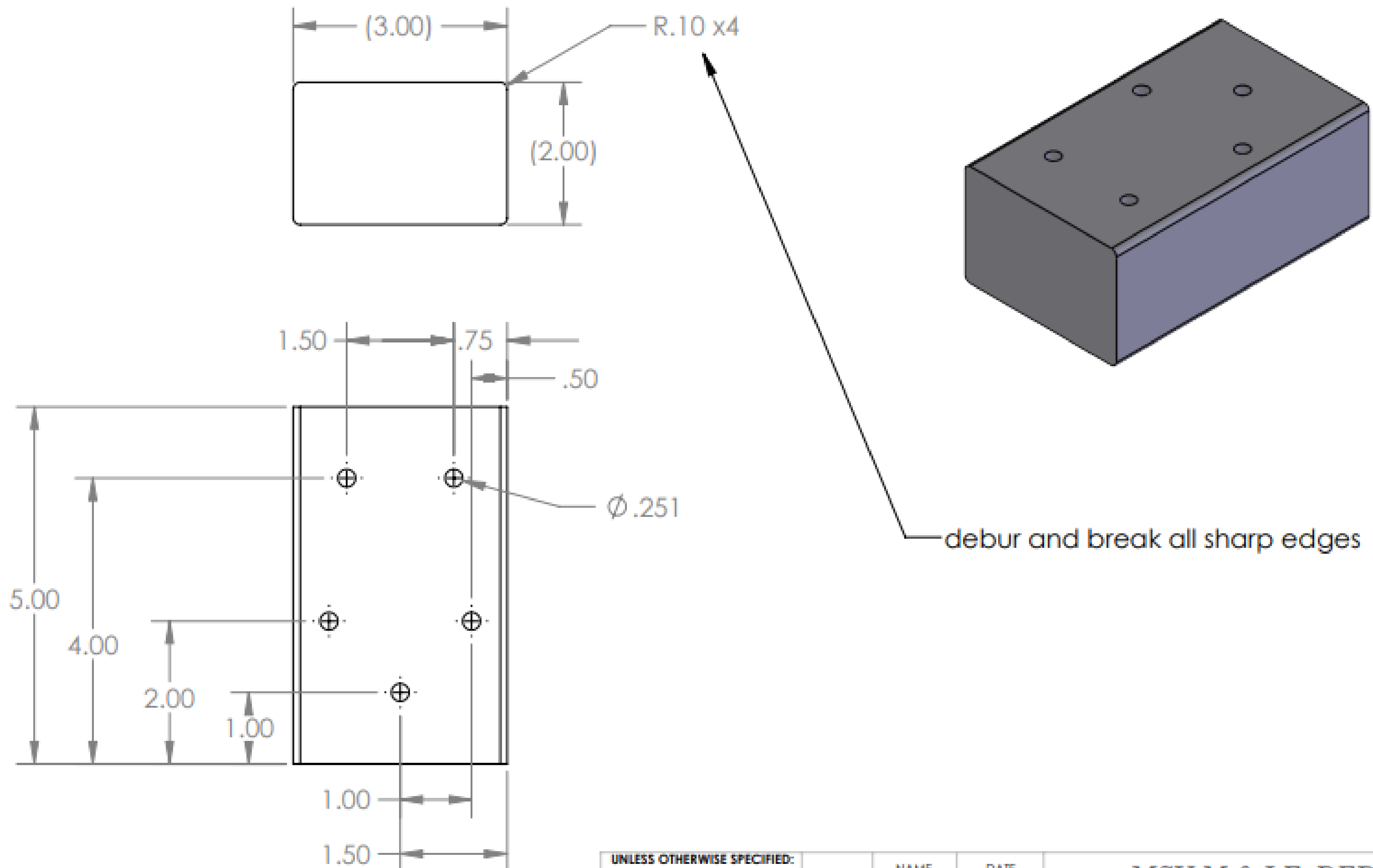
NAME
DATE
DRAWN Anders Nelson 4/11/2025
CHECKED Ethan Morse 4/11/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density Film
MSU M.& I.E. DEPT.
TITLE: Steris Cmax HDPE Insert
SIZE A
DWG. NO. 02_04
REV
SCALE: 1:4
WEIGHT: 4.40lb
SHEET 11 OF 27
SOLIDWORKS Educational Product. For Instructional Use Only.



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TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Anders Nelson	4/10/2025
CHECKED	Ethan Morse	4/10/2025
ENG APPR.		
MFG APPR.		

MATERIAL
PE High Density

MSU M.& I.E. DEPT.

TITLE: Chest Support Insert Block

SIZE	DWG. NO.	REV
A	02_05	4

SCALE: 1:2 | WEIGHT: 1.01lb | SHEET 12 OF 27

5 4 3 2 1

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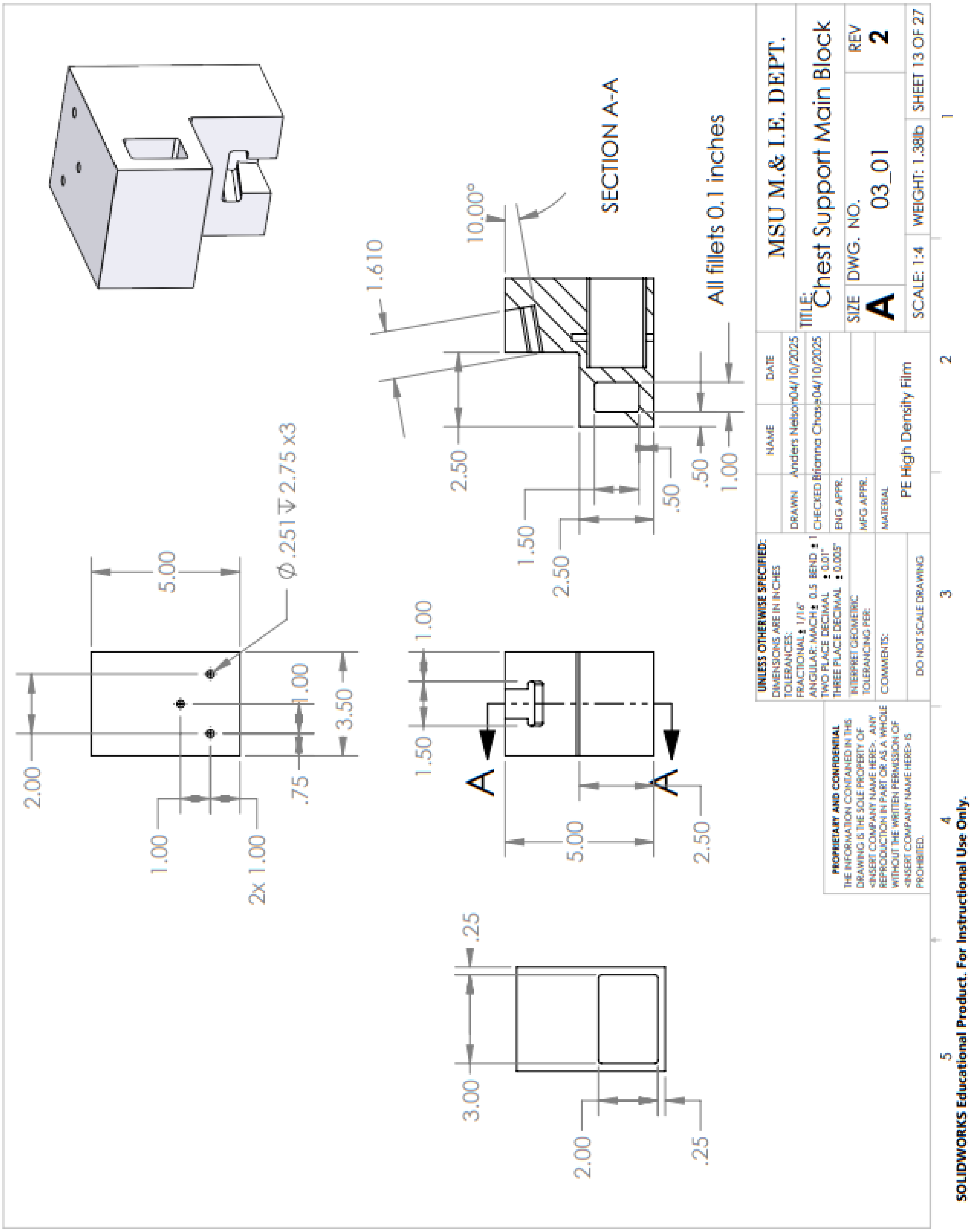
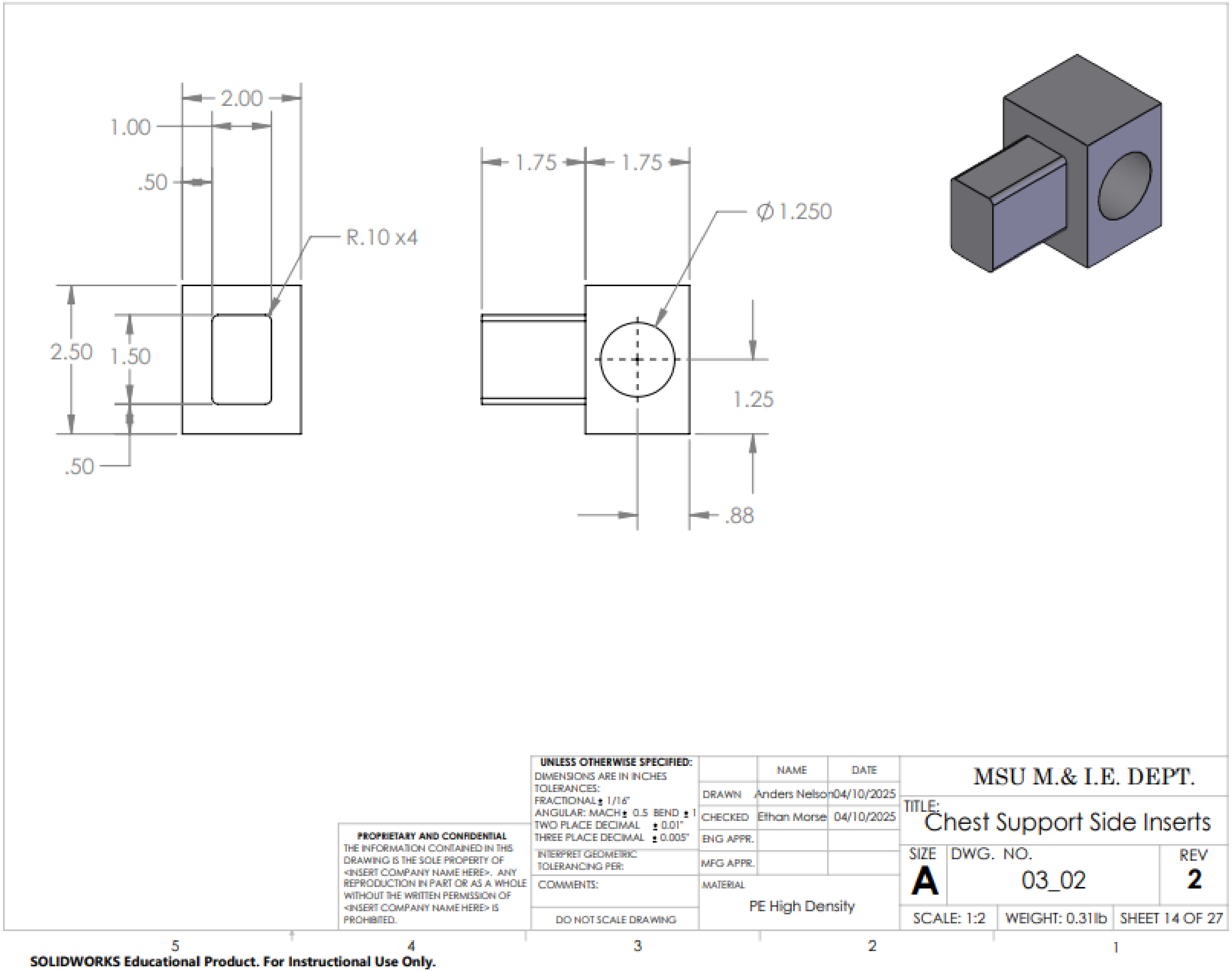

MSU M.& I.E. DEPT.
TITLE: Chest Support Main Block
SIZE A
DWG. NO. 03_01
REV 2
SCALE: 1:4
WEIGHT: 1.38lb
SHEET 13 OF 27
NAME
DATE
DRAWN Anders Nelson 04/10/2025
CHECKED Brianna Chase 04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density Film
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SECTION A-A
All fillets 0.1 inches
Ø.251 ⊽ 2.75 x3
10.00°
1.610
5.00
3.50
2.00
2x 1.00
1.00
.75
1.50
2.50
.50
3.00
.25
SOLIDWORKS Educational Product. For Instructional Use Only.


2.00
1.00
.50
R.10 x4
2.50
1.50
.50
1.75
1.75
∅1.250
1.25
.88
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
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NAME
DATE
DRAWN Anders Nelson 04/10/2025
CHECKED Ethan Morse 04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
MSU M.& I.E. DEPT.
TITLE: Chest Support Side Inserts
SIZE A
DWG. NO. 03_02
REV 2
SCALE: 1:2
WEIGHT: 0.31lb
SHEET 14 OF 27
5
4
3
2
1
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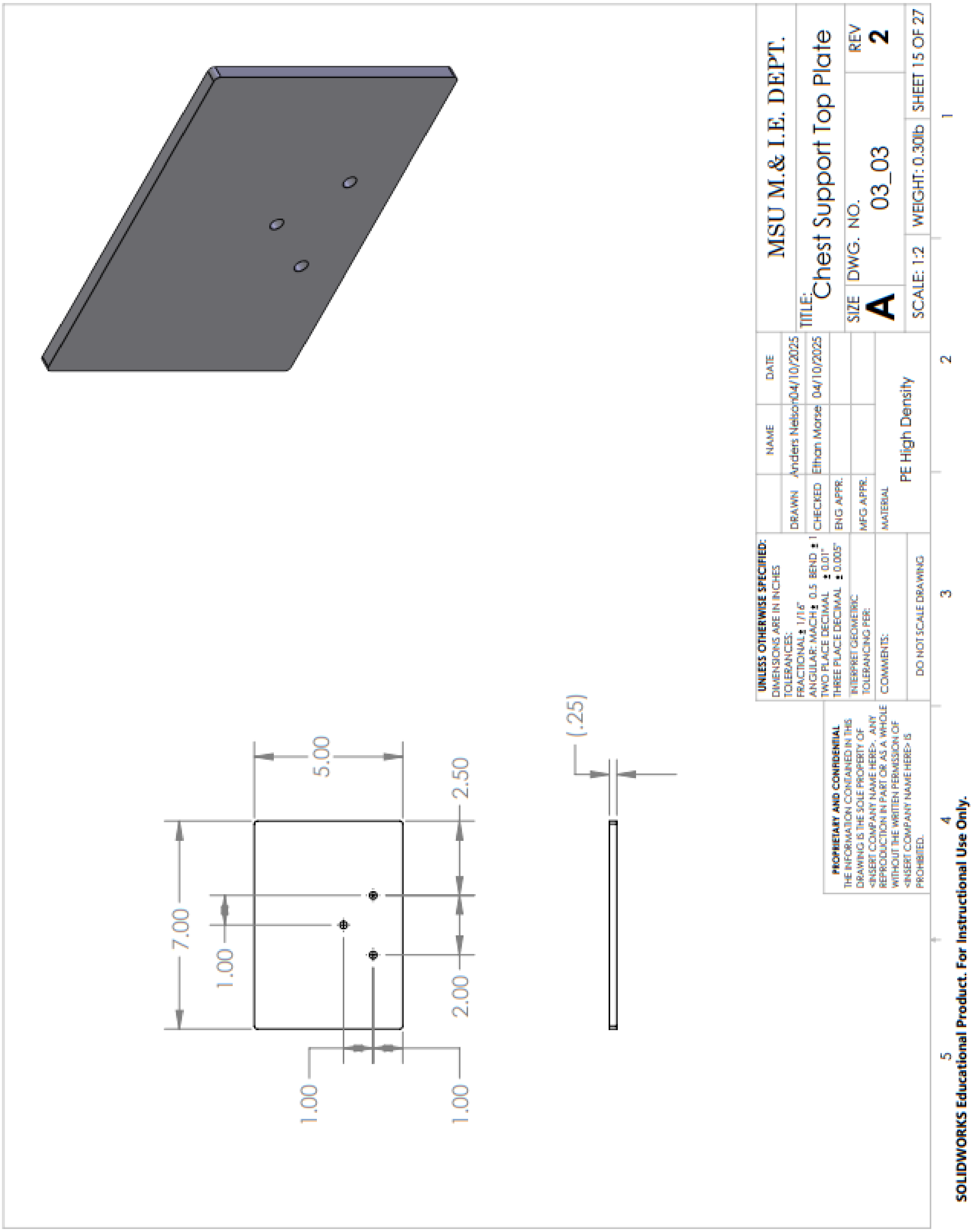
5.00
7.00
2.50
1.00
2.00
1.00
1.00
(.25)
PROPRIETARY AND CONFIDENTIAL
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN Anders Nelson 04/10/2025
CHECKED Ethan Morse 04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
MSU M.& I.E. DEPT.
TITLE:
Chest Support Top Plate
SIZE
A
DWG. NO.
03_03
REV
2
SCALE: 1:2
WEIGHT: 0.30lb
SHEET 15 OF 27
1
2
3
4
5
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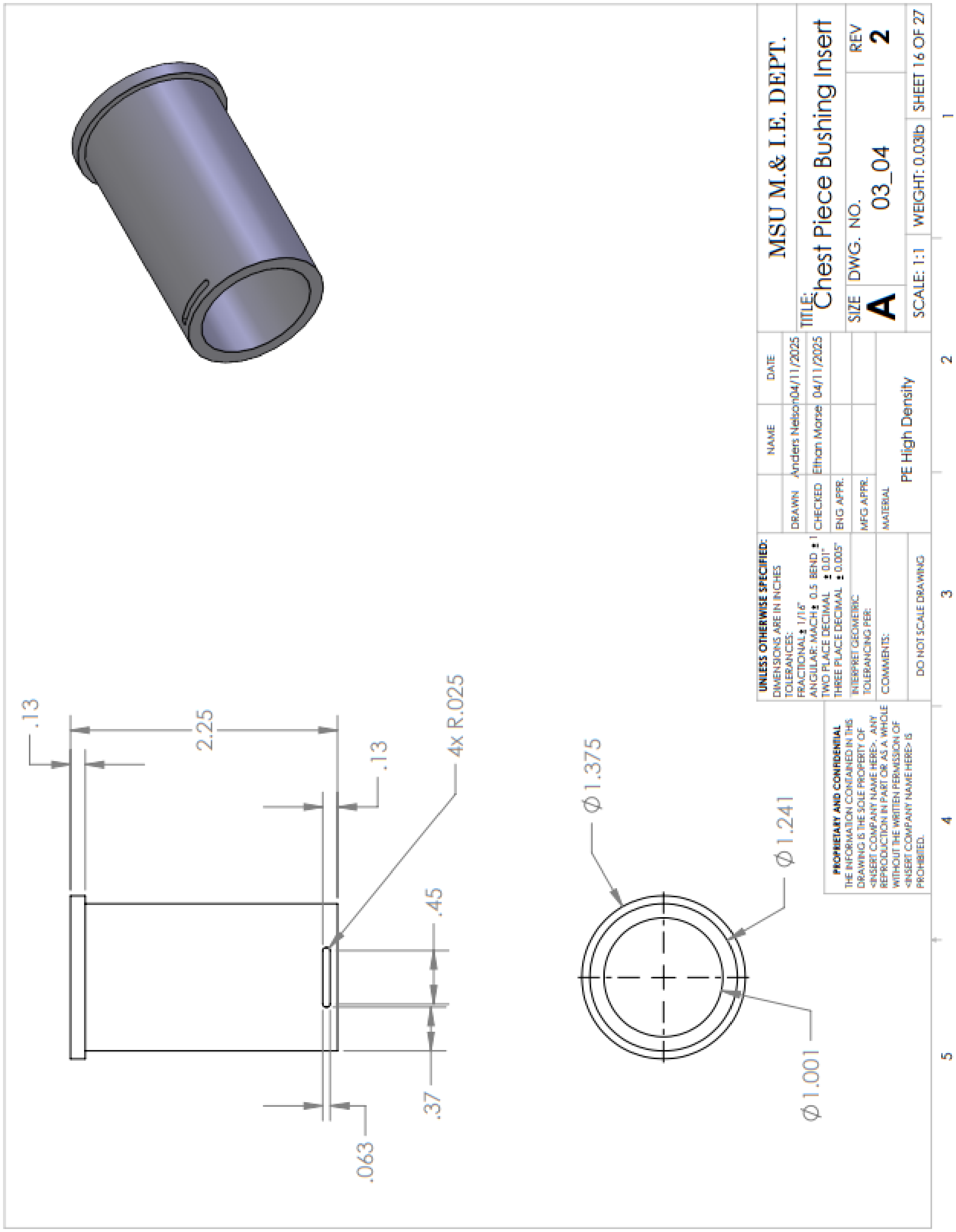
MSU M.& I.E. DEPT.
TITLE:
Chest Piece Bushing Insert
SIZE
A
DWG. NO.
03_04
REV
2
SCALE: 1:1
WEIGHT: 0.03lb
SHEET 16 OF 27
NAME
DATE
DRAWN
Anders Nelson
04/11/2025
CHECKED
Ethan Morse
04/11/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
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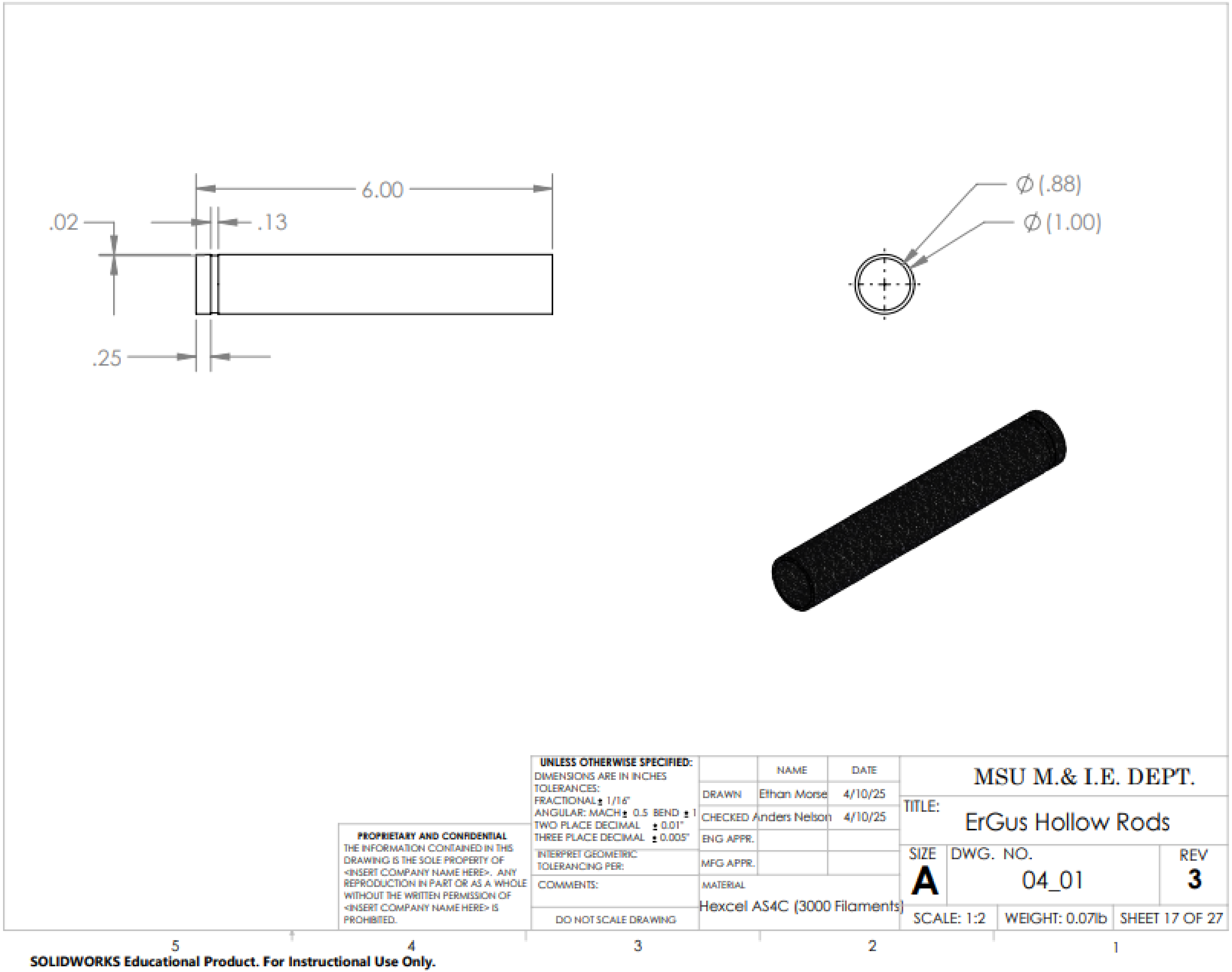
.13
2.25
.13
4x R.025
.45
.37
.063
Ø1.375
Ø1.241
Ø1.001
1
2
3
4
5
SOLIDWORKS Educational Product. For Instructional Use Only.


6.00
.02
.13
.25
Ø (.88)
Ø (1.00)
PROPRIETARY AND CONFIDENTIAL
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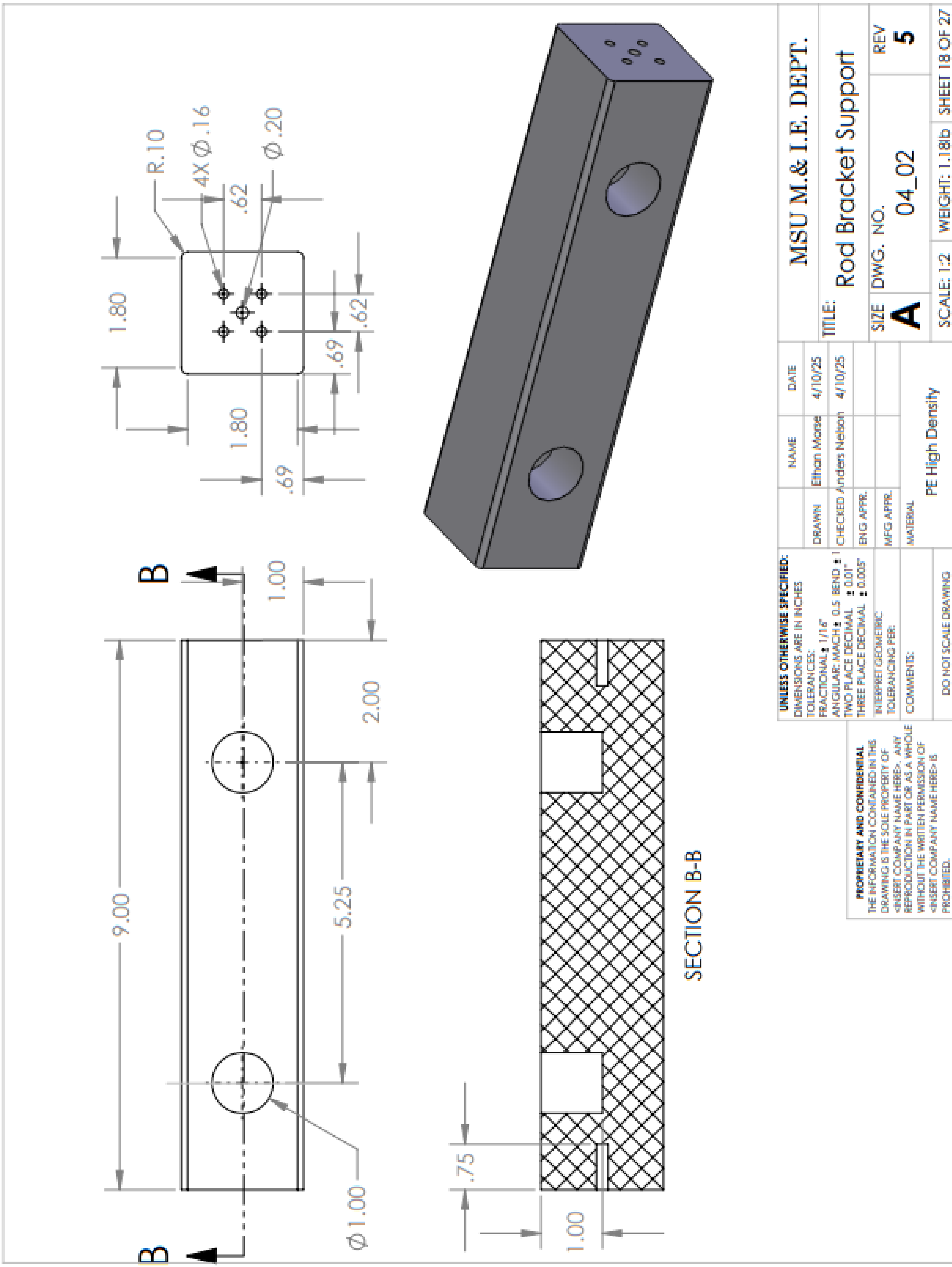
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN Ethan Morse 4/10/25
CHECKED Anders Nelson 4/10/25
ENG APPR.
MFG APPR.
MATERIAL
Hexcel AS4C (3000 Filaments)
MSU M.& I.E. DEPT.
TITLE:
ErGus Hollow Rods
SIZE A
DWG. NO. 04_01
REV 3
SCALE: 1:2
WEIGHT: 0.07lb
SHEET 17 OF 27
5
4
3
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.



B
B
9.00
5.25
2.00
1.00
Ø1.00
.75
1.00
SECTION B-B
R.10
4X Ø.16
Ø.20
.62
1.80
1.80
.69
.69
.62
MSU M.& I.E. DEPT.
TITLE:
Rod Bracket Support
SIZE A
DWG. NO. 04_02
REV 5
SCALE: 1:2
WEIGHT: 1.18lb
SHEET 18 OF 27
NAME
DATE
DRAWN Ethan Morse 4/10/25
CHECKED Anders Nelson 4/10/25
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
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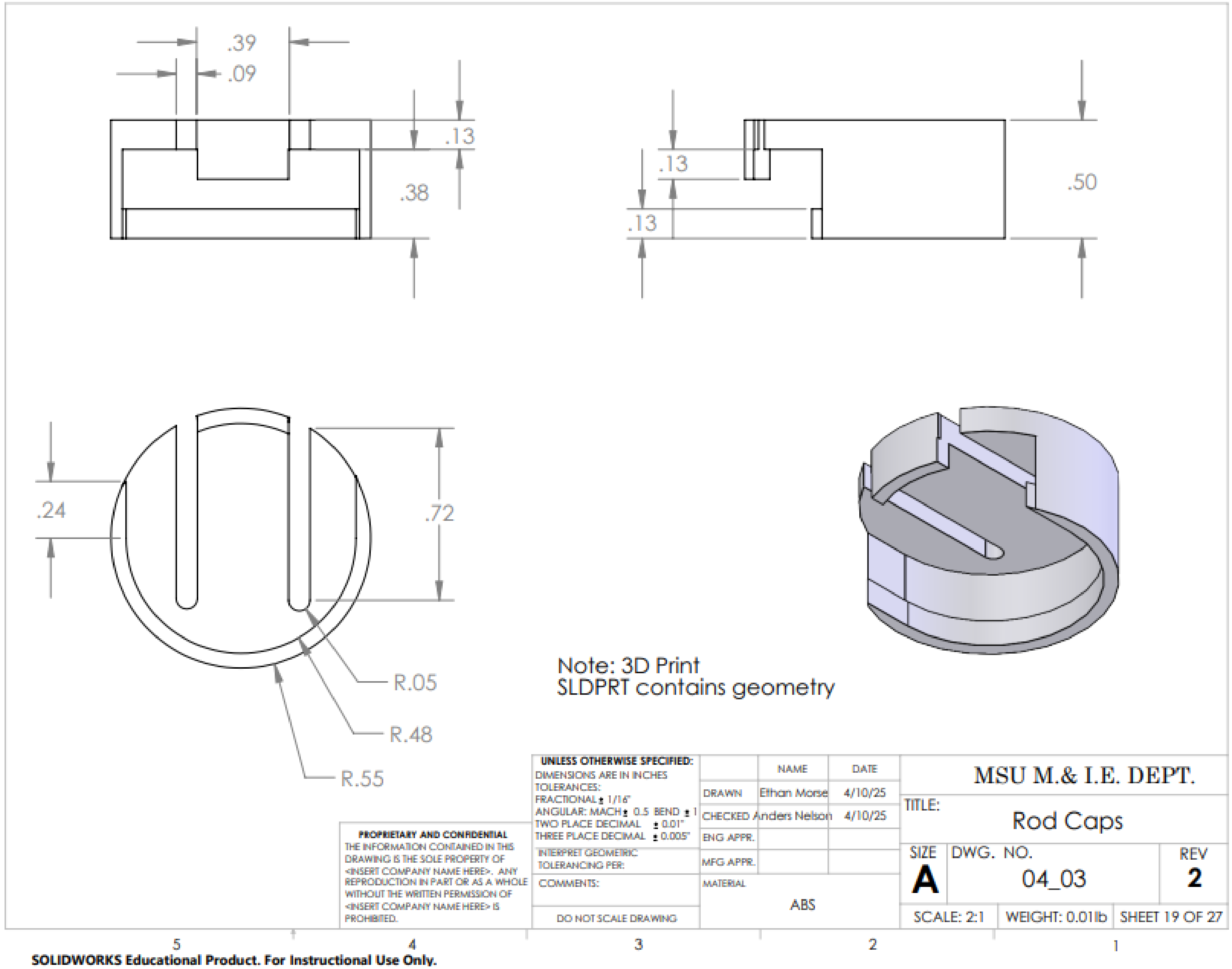
1
2
3
4
5
SOLIDWORKS Educational Product. For Instructional Use Only.



.39
.09
.13
.38
.13
.13
.50
.24
.72
R.05
R.48
R.55
Note: 3D Print
SLDPRT contains geometry
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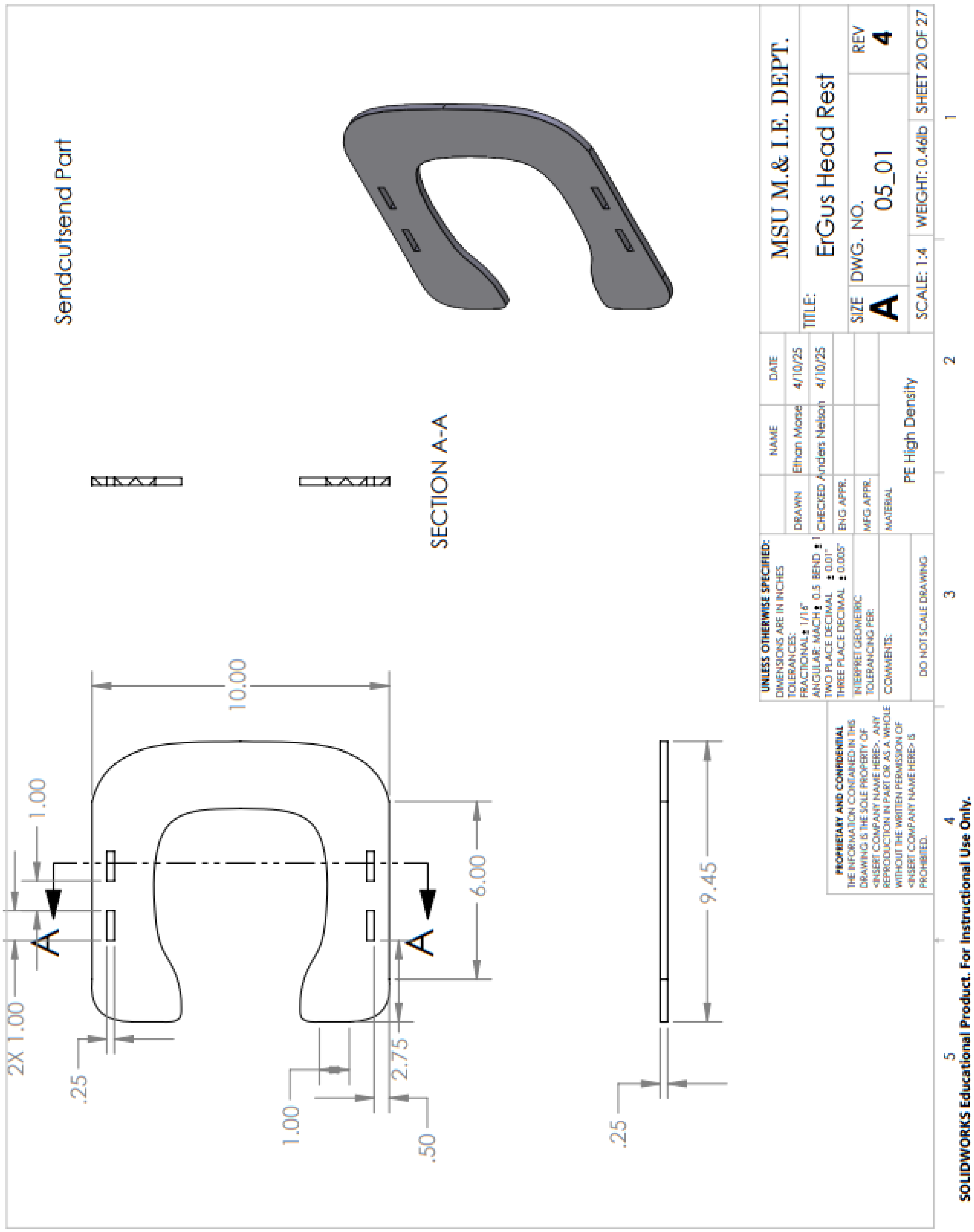
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN Ethan Morse 4/10/25
CHECKED Anders Nelson 4/10/25
ENG APPR.
MFG APPR.
MATERIAL
ABS
MSU M.& I.E. DEPT.
TITLE:
Rod Caps
SIZE
A
DWG. NO.
04_03
REV
2
SCALE: 2:1
WEIGHT: 0.01lb
SHEET 19 OF 27
5
4
3
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.


Sendcutsend Part
SECTION A-A
10.00
1.00
2X 1.00
.25
1.00
2.75
.50
6.00
9.45
.25
A
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN Ethan Morse 4/10/25
CHECKED Anders Nelson 4/10/25
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
MSU M.& I.E. DEPT.
TITLE:
ErGus Head Rest
SIZE A
DWG. NO. 05_01
REV 4
SCALE: 1:4
WEIGHT: 0.46lb
SHEET 20 OF 27
PROPRIETARY AND CONFIDENTIAL
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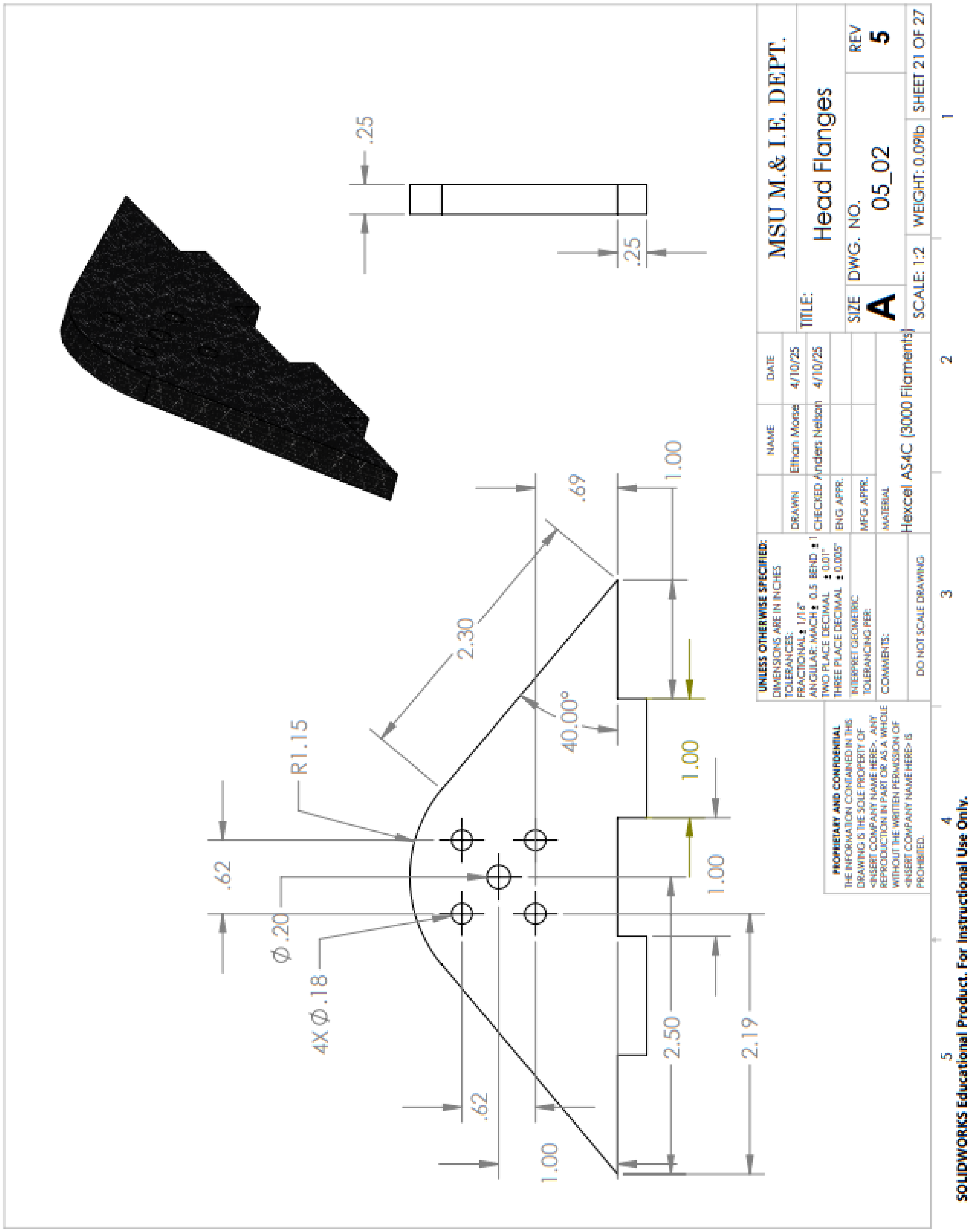
MSU M.& I.E. DEPT.
TITLE:
Head Flanges
SIZE
A
DWG. NO.
05_02
REV
5
SCALE: 1:2
WEIGHT: 0.09lb
SHEET 21 OF 27
NAME
DATE
DRAWN
Ethan Morse
4/10/25
CHECKED
Anders Nelson
4/10/25
ENG APPR.
MFG APPR.
MATERIAL
Hexcel AS4C (3000 Filaments)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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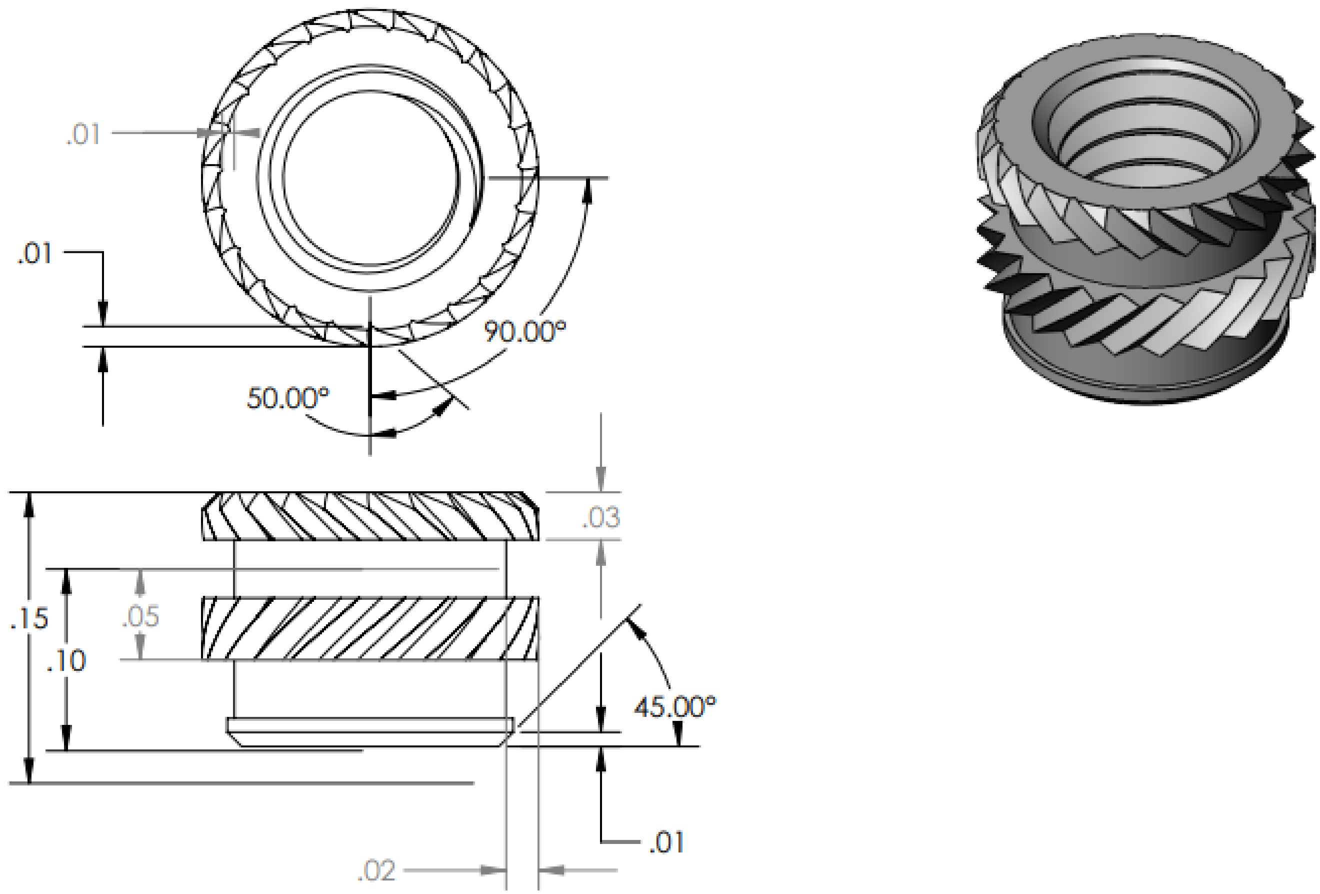
R1.15
4X Ø.18
Ø.20
.62
2.30
40.00°
.69
1.00
2.50
2.19
.25
SOLIDWORKS Educational Product. For Instructional Use Only.



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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Anders Nelson	4/11/2025
CHECKED	Brianna Chase	4/11/2025
ENG APPR.		
MFG APPR.		

MATERIAL
Aluminum

MSU M.& I.E. DEPT.
TITLE: Heat- Set Inserts Plastic
SIZE A | DWG. NO. 05_04 | REV 0
SCALE: 12:1 | WEIGHT: | SHEET 22 OF 27

5 4 3 2 1

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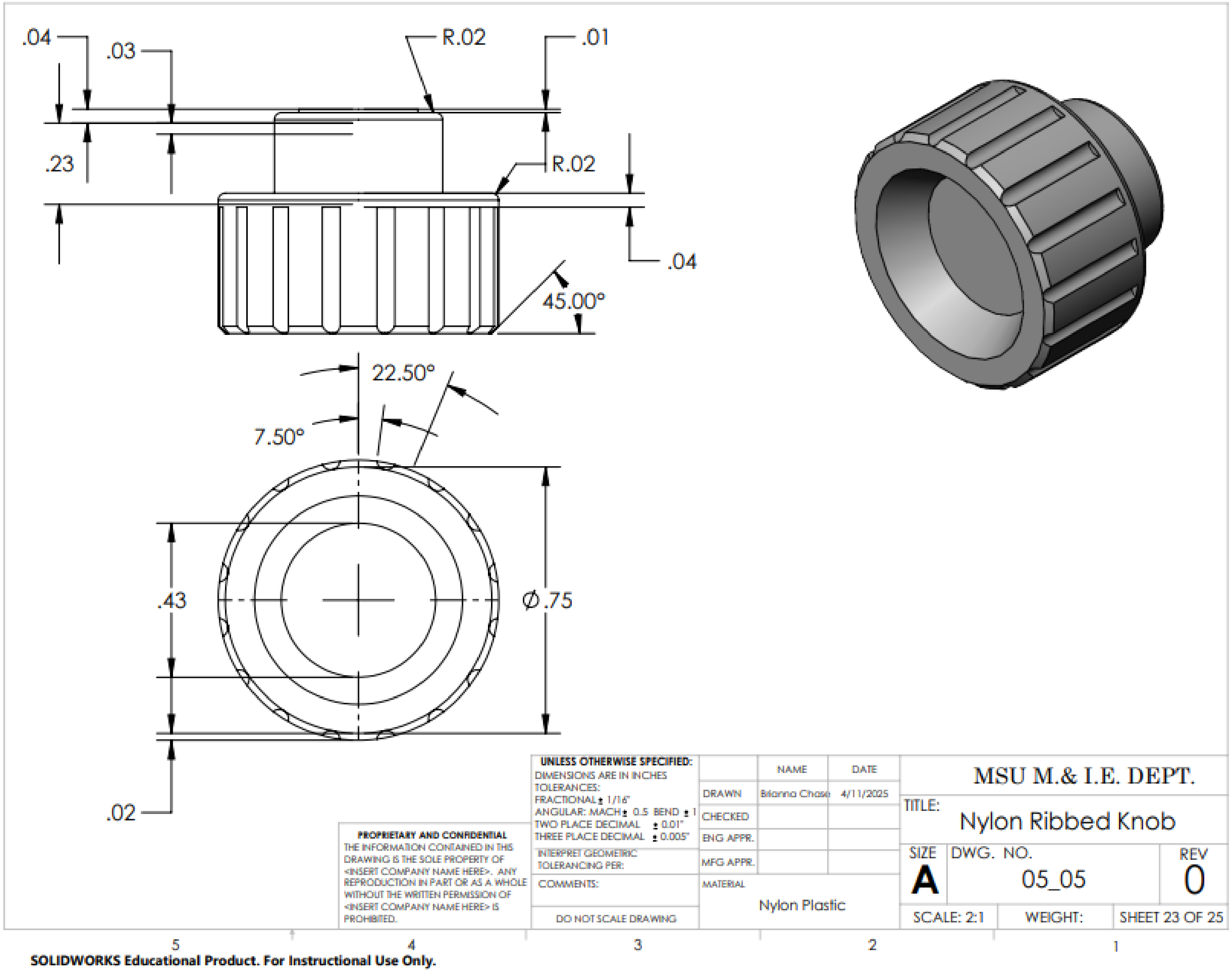
.04
.03
R.02
.01
.23
R.02
.04
45.00°
22.50°
7.50°
.43
Ø.75
.02
PROPRIETARY AND CONFIDENTIAL
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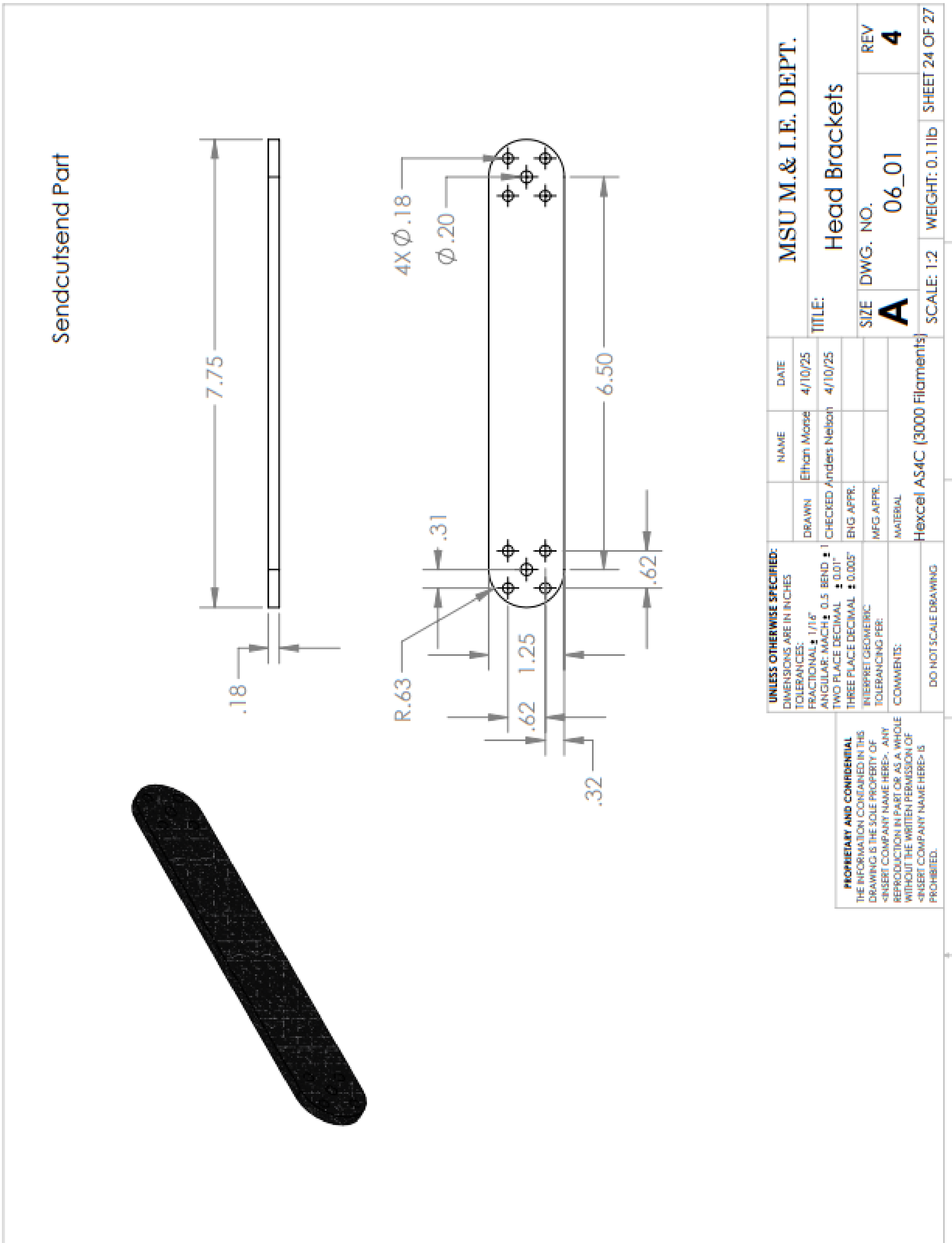
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Brianna Chase
4/11/2025
CHECKED
ENG APPR.
MFG APPR.
MATERIAL
Nylon Plastic
MSU M.& I.E. DEPT.
TITLE:
Nylon Ribbed Knob
SIZE
A
DWG. NO.
05_05
REV
0
SCALE: 2:1
WEIGHT:
SHEET 23 OF 25
5
4
3
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.



Sendcutsend Part
7.75
.18
4X Ø.18
Ø.20
.31
R.63
1.25
.62
.32
6.50
.62
MSU M.& I.E. DEPT.
TITLE:
Head Brackets
SIZE
A
DWG. NO.
06_01
REV
4
SCALE: 1:2
WEIGHT: 0.11lb
SHEET 24 OF 27
NAME
DATE
DRAWN Ethan Morse 4/10/25
CHECKED Anders Nelson 4/10/25
ENG APPR.
MFG APPR.
MATERIAL
Hexcell AS4C (3000 Filaments)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
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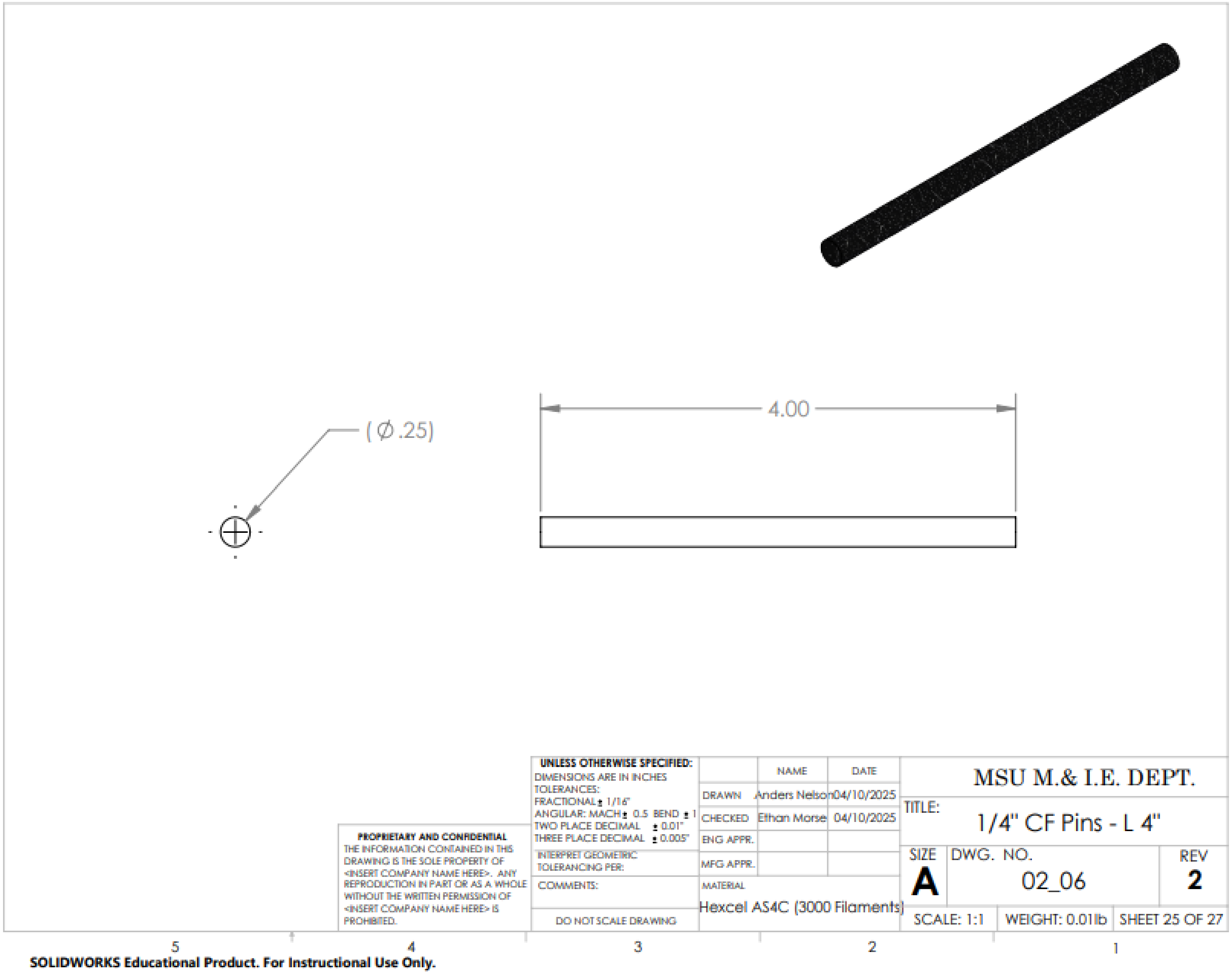
(Ø.25)
4.00
PROPRIETARY AND CONFIDENTIAL
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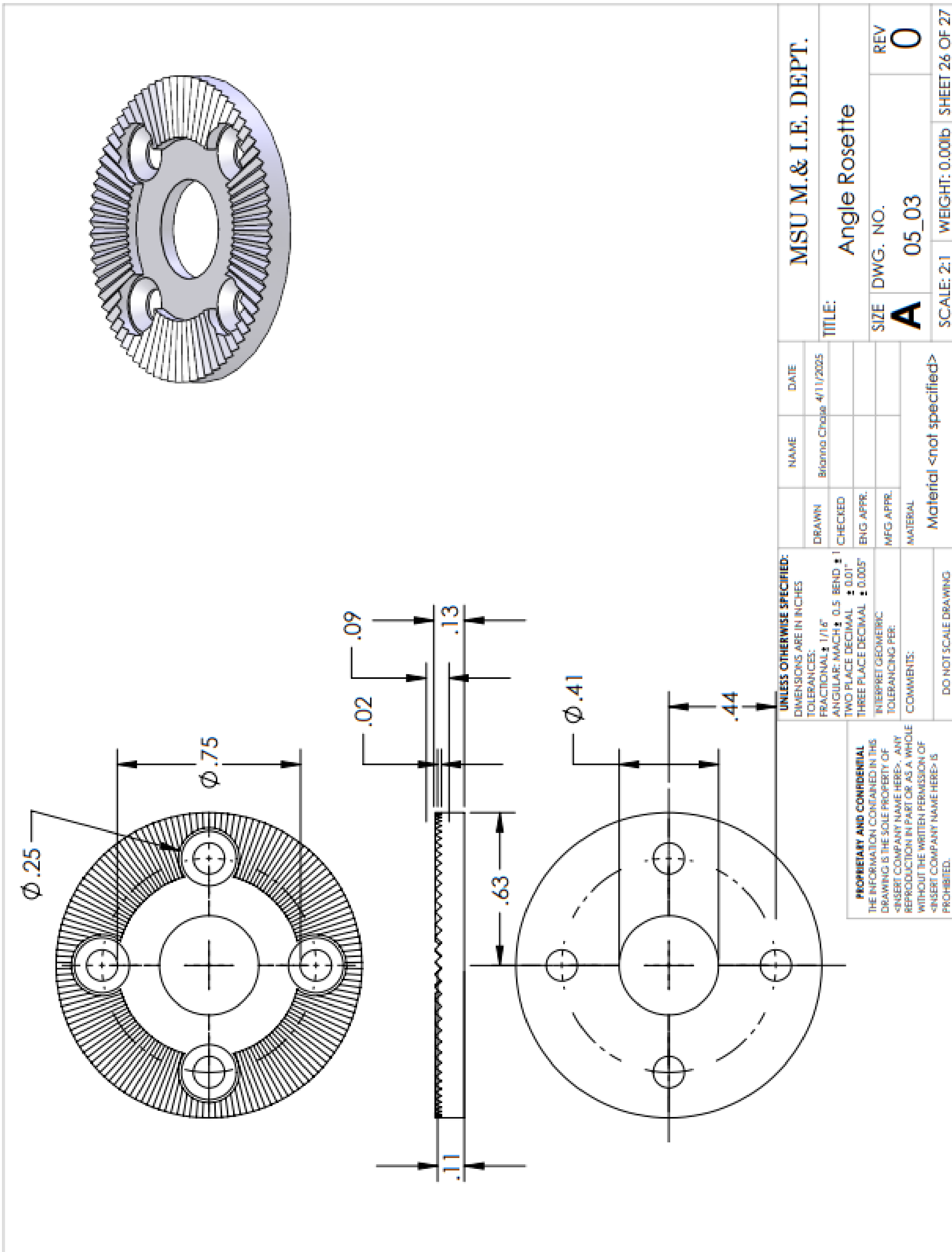
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Anders Nelson
04/10/2025
CHECKED
Ethan Morse
04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
Hexcel AS4C (3000 Filaments)
MSU M.& I.E. DEPT.
TITLE:
1/4" CF Pins - L 4"
SIZE
A
DWG. NO.
02_06
REV
2
SCALE: 1:1
WEIGHT: 0.01lb
SHEET 25 OF 27
5
4
3
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.


MSU M.& I.E. DEPT.
TITLE:
Angle Rosette
SIZE
A
DWG. NO.
05_03
REV
0
SCALE: 2:1
WEIGHT: 0.00lb
SHEET 26 OF 27
NAME
DATE
DRAWN
Brianna Chase 4/11/2025
CHECKED
ENG APPR.
MFG APPR.
MATERIAL
Material <not specified>
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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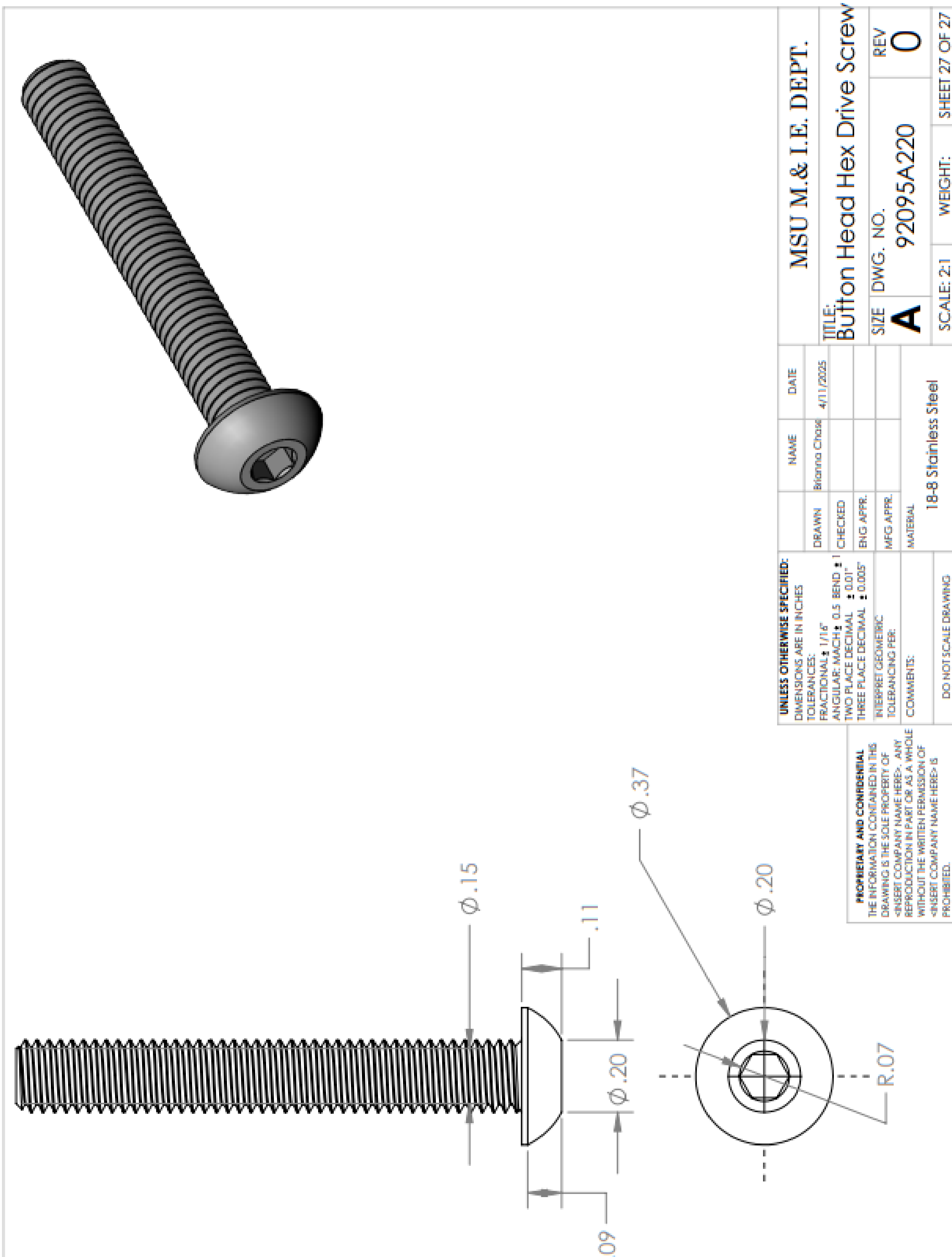
Ø.25
Ø.75
.63
.02
.09
.13
.11
Ø.41
.44
SOLIDWORKS Educational Product. For Instructional Use Only.



MSU M.& I.E. DEPT.
TITLE:
Button Head Hex Drive Screw
SIZE
A
DWG. NO.
92095A220
REV
0
SCALE: 2:1
WEIGHT:
SHEET 27 OF 27
NAME
DATE
DRAWN
Brianna Chase
4/11/2025
CHECKED
ENG APPR.
MFG APPR.
MATERIAL
18-8 Stainless Steel
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
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Ø.15
.11
Ø.20
.09
Ø.37
Ø.20
R.07
5
4
3
2
1
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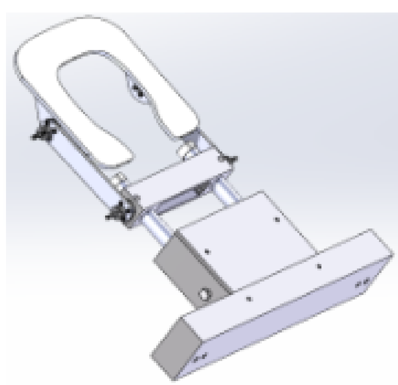
Appendix D1. Final Engineering Drawing Package

ETME 489/EMEC 489 ErGus Radiolucent Prototype Component/Assembly List

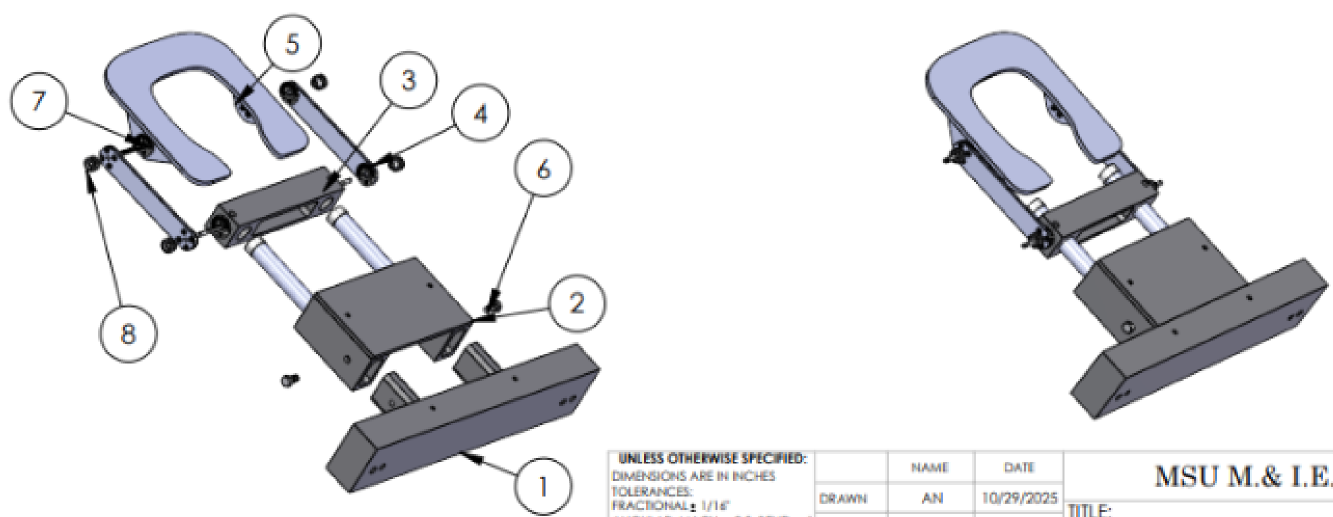
Designed Component	Assy Used On	Qty	Description
01	-	1	ErGus Prototype Assembly
02	01	1	Mounting Bracket Assembly
03	01	1	Chest Support Assembly
04	01	1	Sliding Rod Assembly
05	01	1	Head Rest Assembly
06	01	1	Head Support Bracket Assembly
02_01	01	1	SkyTron 6500 Elite/Steris Cmax Table Attachment Bracket
02_02	02	1	Chest Support Inserts
03_01	03	1	Chest Support Block
03_02	03	1	Chest Support Top Plate
03_03	03	2	Chest Piece Bushing Insert
03_04	03	2	ErGus Hollow Rods
03_06	03	2	Rod Caps
04_01	04	1	Sliding Rod Block
05_01	05	1	ErGus Head Rest
05_02	05	2	Head Flanges
05_03	05	2	Head Brackets
Purchased Parts	**Assy Used on**	**Qty**	**Description**
02_03	02	2	CF L3 pins
03_05	03	2	CF .75 pins
04_02	04,06,05	2	Angle Rosette
04_03	04	2	Threaded Dowel
#62935K16	01	4	Nylon Ribbed Knob
#92245A622	01	2	Stainless Steel Button Hex Head Screw
#92949A551	01	2	Stainless Steel Button Head Hex Drive Screw
#92141A005	06,05	8	Stainless Steel Washer
#90760A005	06,05	8	Steel Narrow Hex Nuts
#91500A126	04,05	8	Stainless Steel Phillips Flat Head Screw
#93365A230	04	8	Tapered Heat Set Inserts Plastic
#98827A422	04	2	Stainless Steel Grade B6 Threaded Rod



SHEET 1 OF 30

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	01	Mounting Bracket Assembly	1
2	03	Chest Support Assembly	1
3	04	Sliding Rod Block Assembly	1
4	06	Head Support Bracket Assembly	2
5	05	Head Rest Assembly	1
6	92245A622	Mil. Spec. 18-8 Stainless Steel Hex Head Screw	2
7	92949A551	18-8 Stainless Steel Button Head Hex Drive Screw	2
8	62935K16	Nylon Ribbed Knob	4

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
2	made spinal column view wider/removed chest support block	10/15/25	AN



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TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AN	10/29/2025
CHECKED	BC	10/29/25
ENG APPR.		
MFG APPR.		
MATERIAL	-	

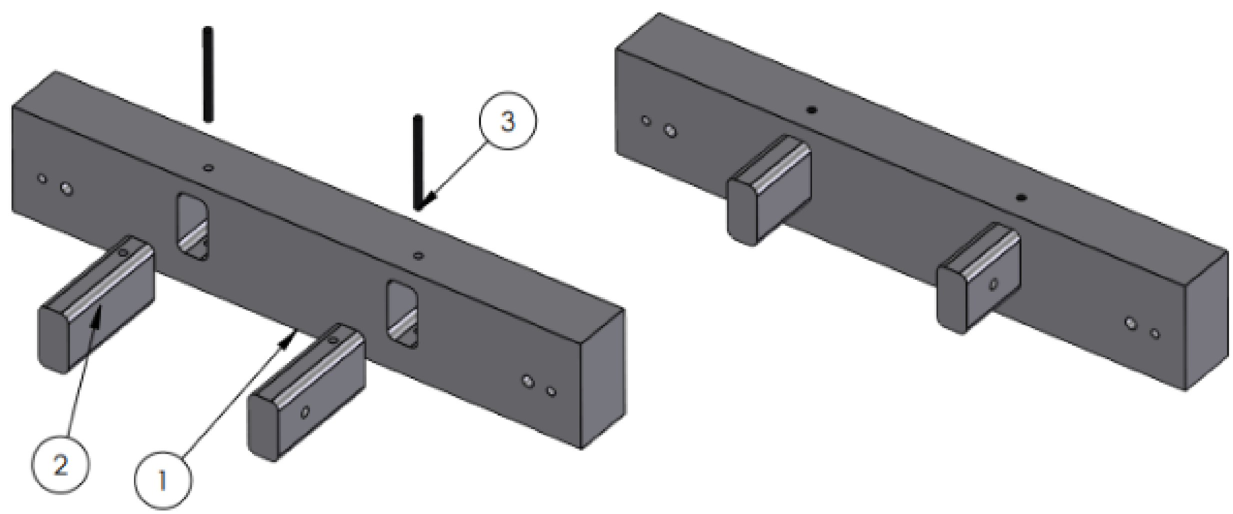
MSU M.& I.E. DEPT.
TITLE: ErGus Prototype Assembly
SIZE A | DWG. NO. 01 | REV 2
SCALE: 1:12 | WEIGHT: 7.52 | SHEET 2 OF 30

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02_01	Table Attachment Bracket	1
2	02_02	Chest Support Inserts	2
3	02_03	1/4" CF Pins L3	2

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
2	changed chest support block attachment	10/5/25	AN



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TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AN	10/28/2025
CHECKED	BC	10/29/25
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: Mounting Bracket Assembly

SIZE A | DWG. NO. 02 | REV 2

SCALE: 1:8 | WEIGHT: 4.88 | SHEET 3 OF 30

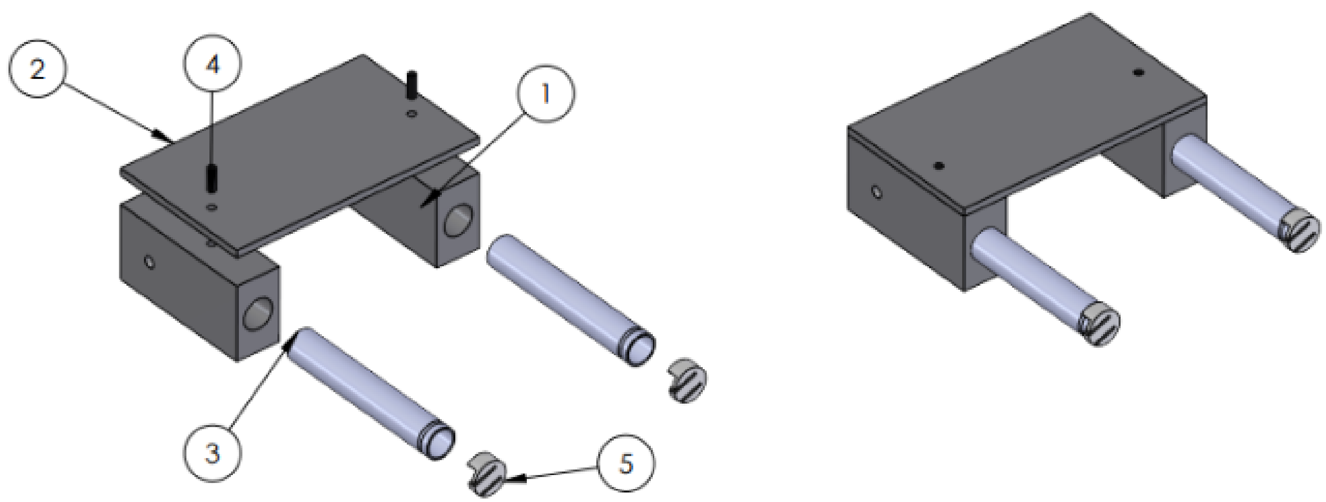
5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	03_01	Chest Support Block	2
2	03_02	Chest Support Plate	1
3	03_04	Hollow Rods	2
4	03_05	1/4" CF Pins L.75	2
5	03_06	Rod Caps	2

REVISIONS

REV.	DESCRIPTION	DATE	APPROVED
2	changed what CF rods go into	10/5/25	AN



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TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ±
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AN	10/28/2025
CHECKED	BC	10/29/25
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: Chest Support Assembly

SIZE A | DWG. NO. 03 | REV 2

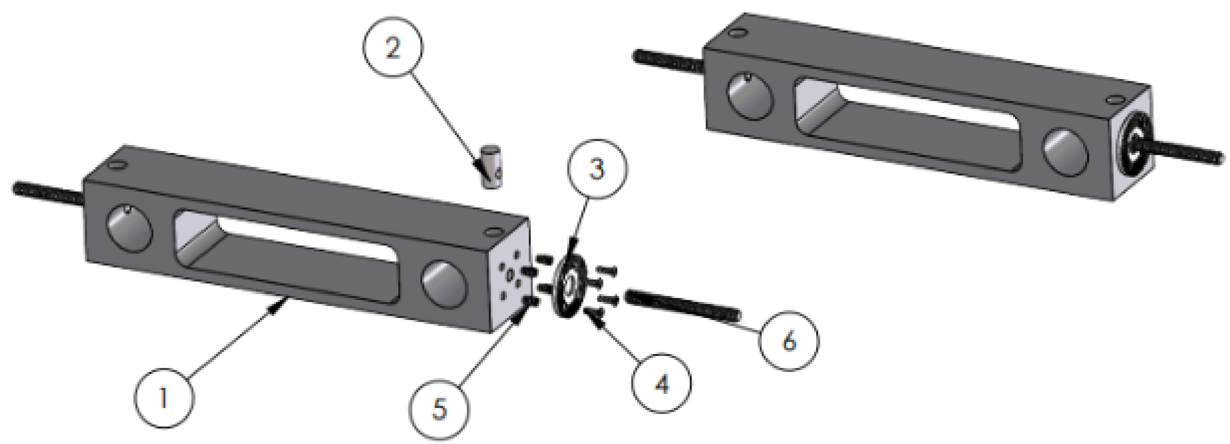
SCALE: 1:8 | WEIGHT: 1.35 | SHEET 4 OF 30

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	04_01	Sliding Rod Block	1
2	04_03	Threaded Dowel	2
3	04_02	Angle Rosette	2
4	91500A126	316 Stainless Steel Phillips Flat Head Screws	8
5	93365A230	Tapered Heat-Set Inserts for Plastic	8
6	98827A422	Grade B6 High-Strength 410 Stainless Steel Threaded Rod	2

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
1	cut out middle section for better image clarity and changed mechanical mechanism to secure head bracket	10/20/25	AN



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TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AN	10/2/2025
CHECKED	BC	10/29/25
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: Sliding Rod Block Assembly

SIZE A | DWG. NO. 04 | REV 1

SCALE: 1:4 | WEIGHT: 0.52 | SHEET 5 OF 30

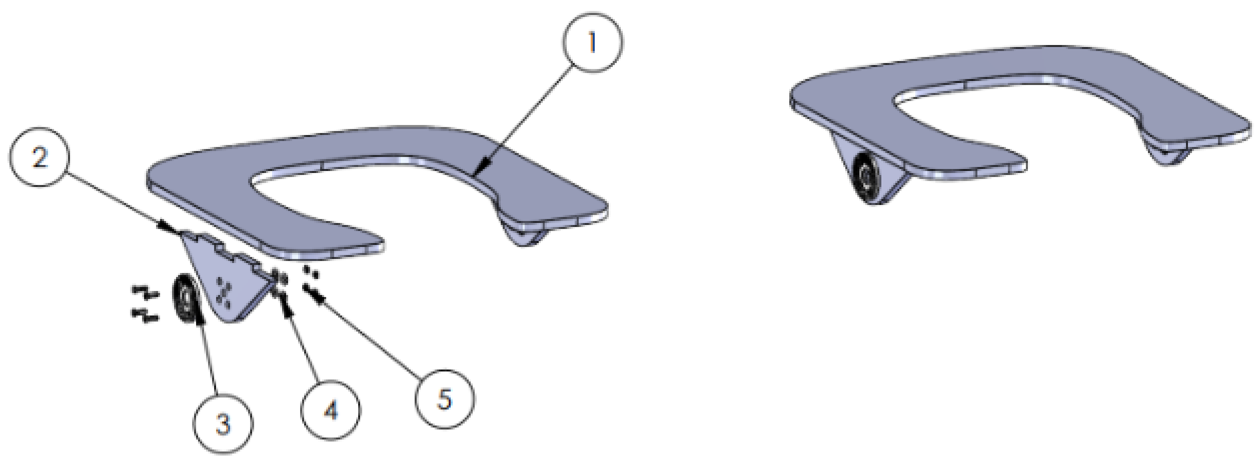
5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	05_01	ErGus Head Rest	1
2	05_02	Head Flanges	2
3	04_02	Default	2
4	92141A005	18-8 Stainless Steel Washer	8
5	90760A005	Steel Narrow Hex Nuts	8
6	91500A126	316 Stainless Steel Phillips Flat Head Screws	8

REVISIONS

REV.	DESCRIPTION	DATE	APPROVED
1	made head flanges more secure	10/10/25	EM



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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	BC	10/29/25
CHECKED	AN	10/29/25
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: Head Rest Assembly

SIZE A | DWG. NO. 05 | REV 1

SCALE: 1:4 | WEIGHT: 0.59 | SHEET 6 OF 30

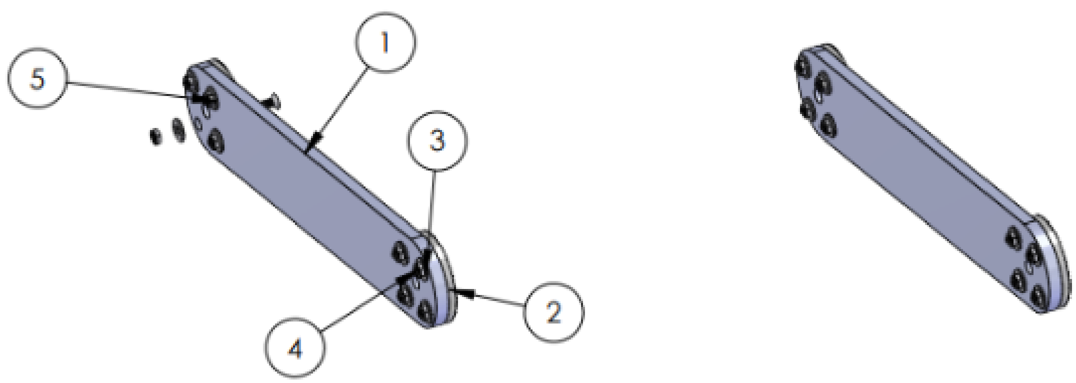
5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ErGusHeadBrackets		1
2	04_02	Default	2
3	92141A005	18-8 Stainless Steel Washer	8
4	90760A005	Steel Narrow Hex Nuts	8
5	91500A126	316 Stainless Steel Phillips Flat Head Screws	8

REVISIONS

REV.	DESCRIPTION	DATE	APPROVED
2	better secured to sliding rod block	10/12/25	EM



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TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ±
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	BC	10/28/2025
CHECKED	AN	10/29/25
ENG APPR.		
MFG APPR.		
MATERIAL	-	

MSU M.& I.E. DEPT.

TITLE: Head Bracket Assembly

SIZE A | DWG. NO. 06 | REV 2

SCALE: 1:2 | WEIGHT: 0.07 | SHEET 7 OF 30

5 4 3 2 1

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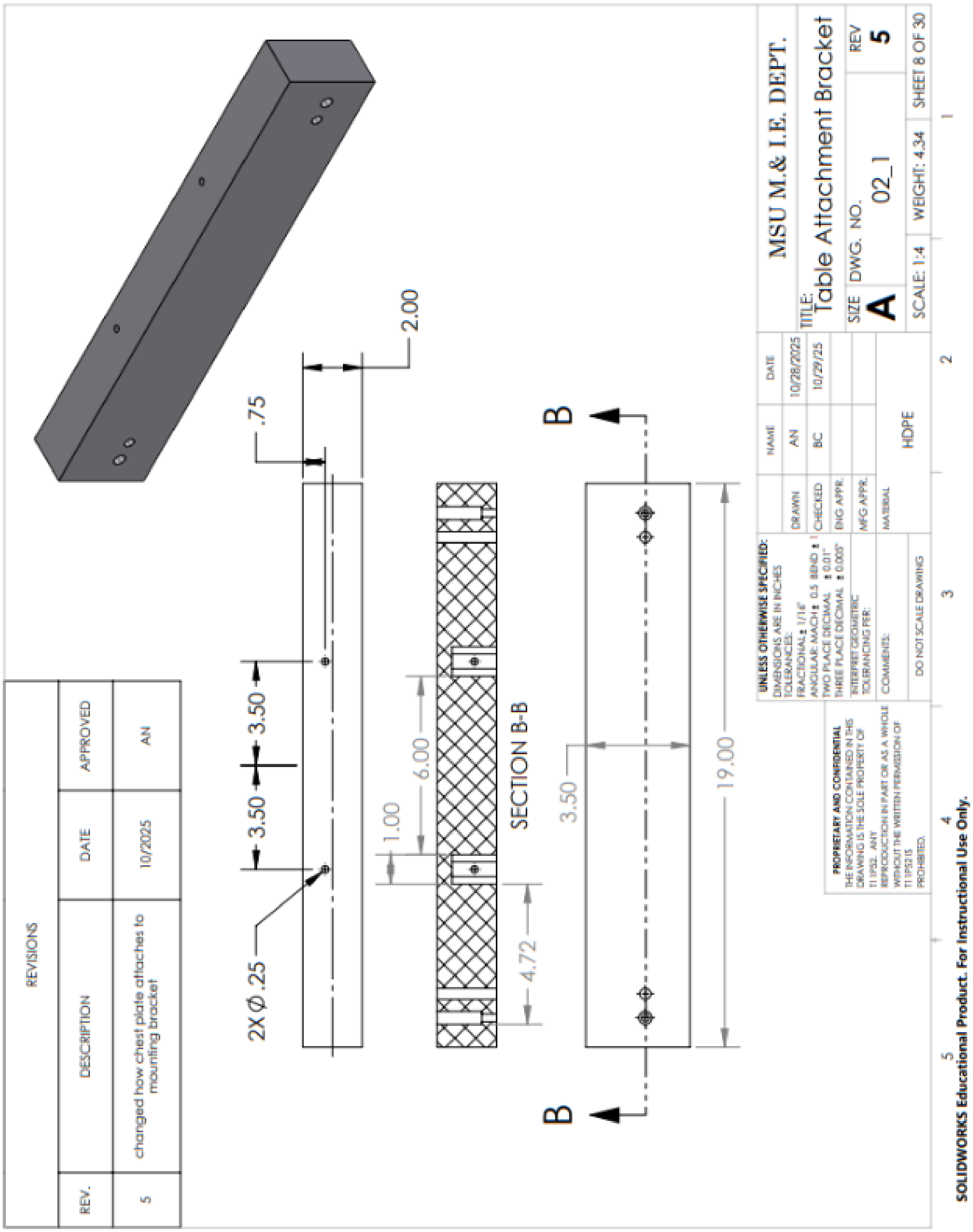
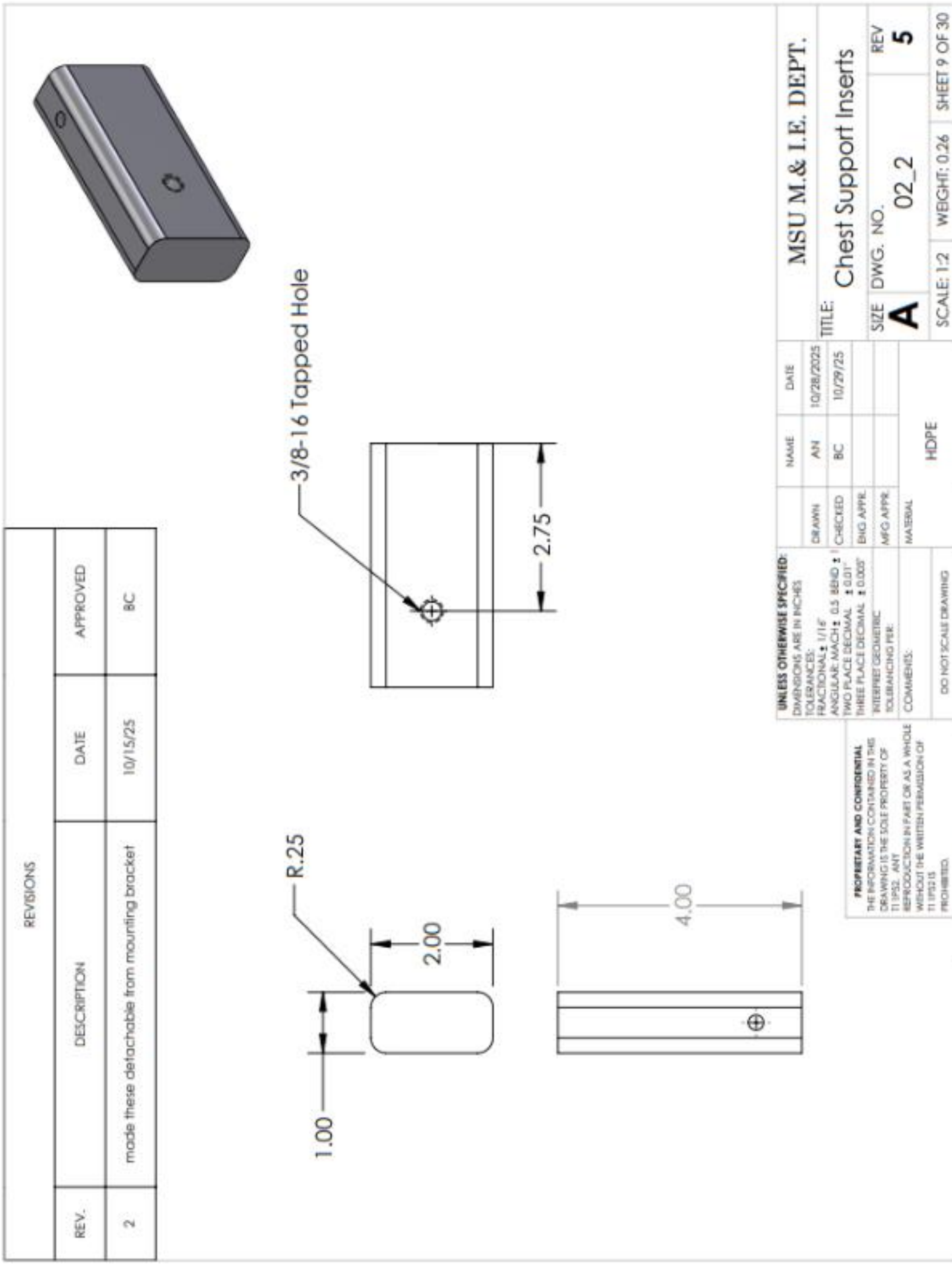
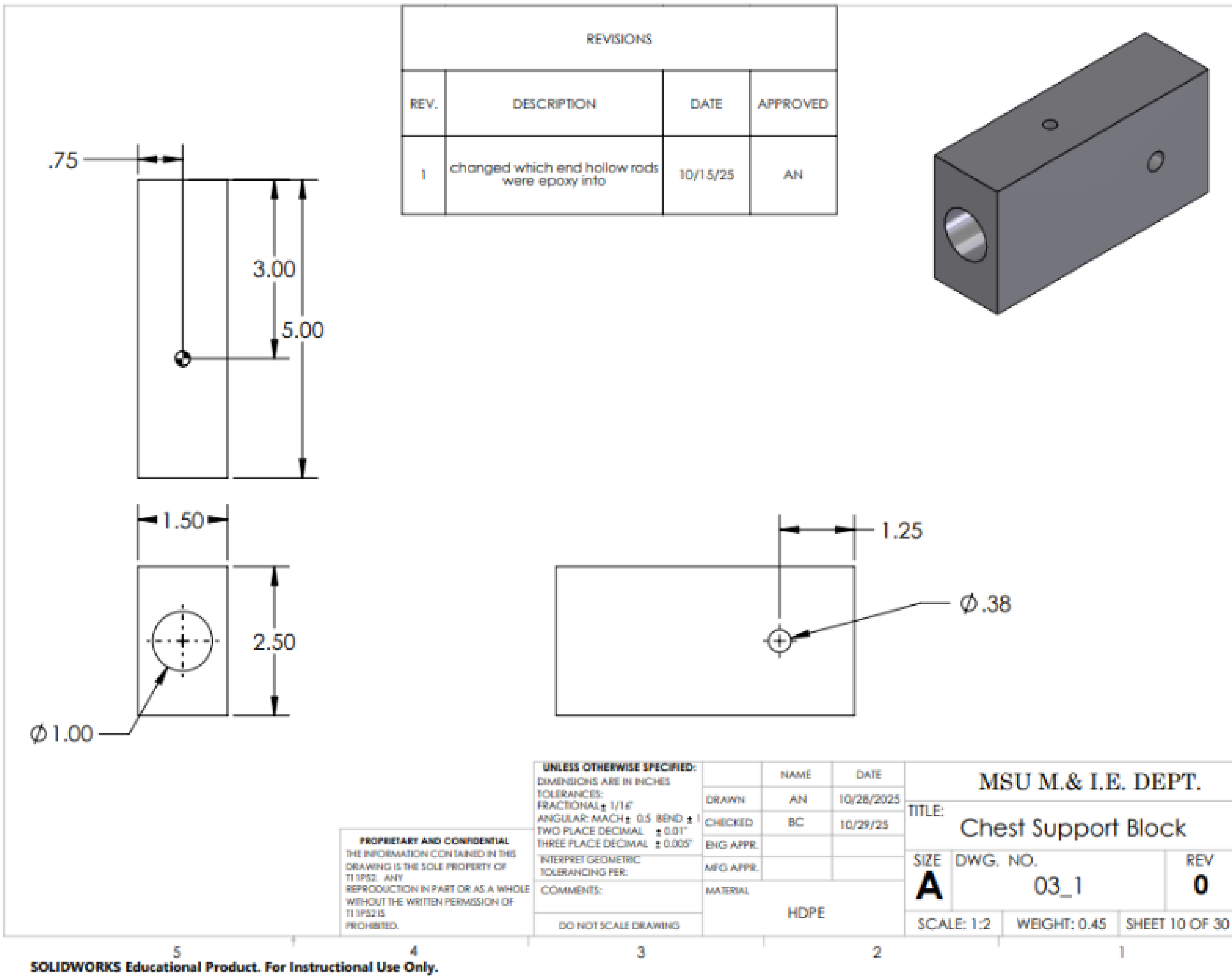

REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
5
changed how chest plate attaches to mounting bracket
10/2025
AN
2X Ø.25
3.50
3.50
.75
2.00
1.00
6.00
4.72
SECTION B-B
3.50
19.00
B
B
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN
AN
10/28/2025
CHECKED
BC
10/29/25
ENG APPR.
MFG APPR.
MATERIAL
HDPE
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
MSU M.& I.E. DEPT.
TITLE:
Table Attachment Bracket
SIZE
A
DWG. NO.
02_1
REV
5
SCALE: 1:4
WEIGHT: 4.34
SHEET 8 OF 30
SOLIDWORKS Educational Product. For Instructional Use Only.


REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
2
made these detachable from mounting bracket
10/15/25
BC
R.25
1.00
2.00
4.00
3/8-16 Tapped Hole
2.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ±
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
DRAWN
AN
10/28/2025
CHECKED
BC
10/29/25
ENG APPR.
MFG APPR.
MATERIAL
HDPE
MSU M.& I.E. DEPT.
TITLE:
Chest Support Inserts
SIZE
A
DWG. NO.
02_2
REV
5
SCALE: 1:2
WEIGHT: 0.26
SHEET 9 OF 30
SOLIDWORKS Educational Product. For Instructional Use Only.


REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
1
changed which end hollow rods were epoxy into
10/15/25
AN
.75
3.00
5.00
1.50
2.50
Ø1.00
1.25
Ø.38
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TOLERANCES:
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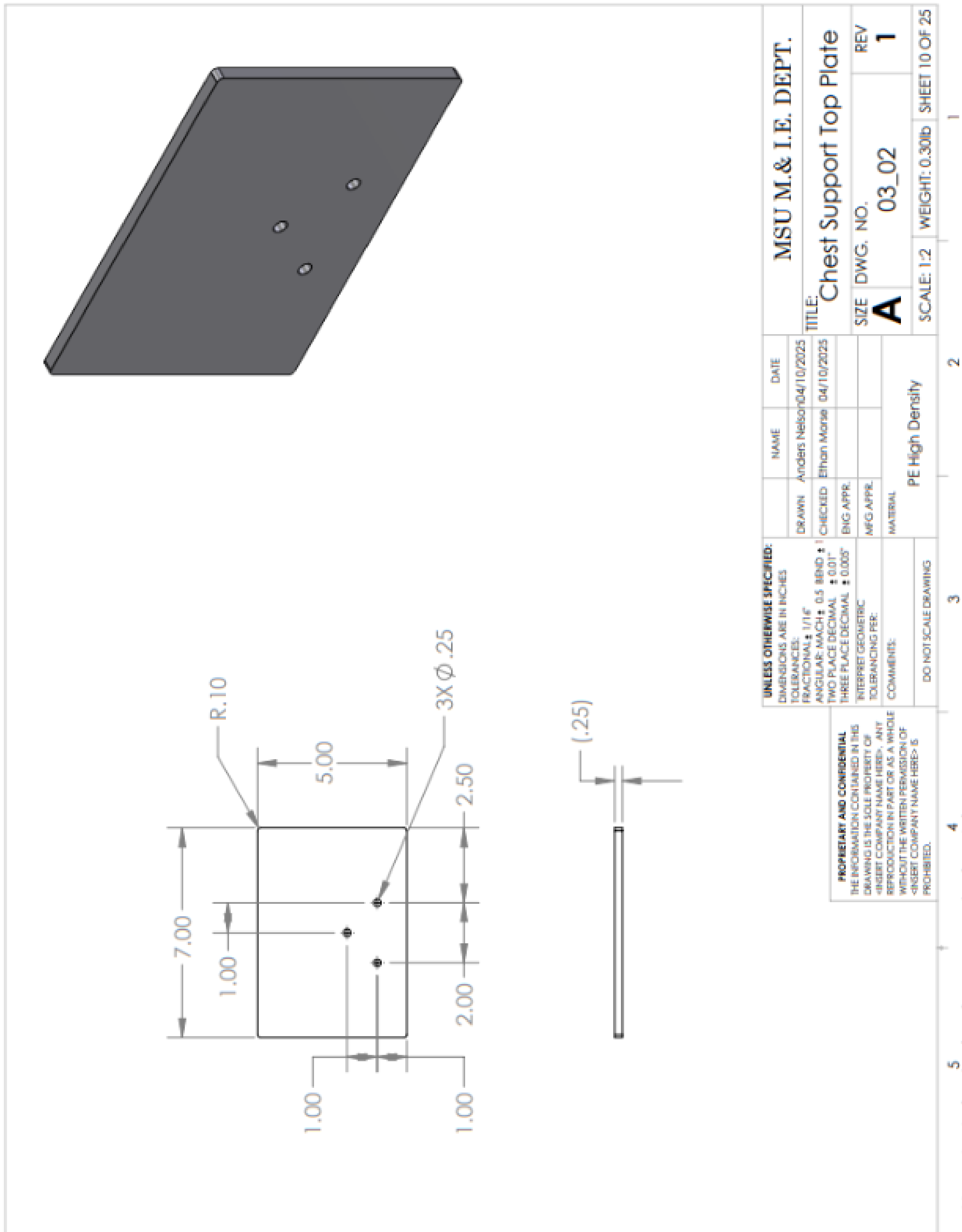
ANGULAR: MACH ± 0.5 BEND ±
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AN
10/28/2025
CHECKED
BC
10/29/25
ENG APPR.
MFG APPR.
MATERIAL
HDPE
MSU M.& I.E. DEPT.
TITLE:
Chest Support Block
SIZE
A
DWG. NO.
03_1
REV
0
SCALE: 1:2
WEIGHT: 0.45
SHEET 10 OF 30
5
4
3
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.



R.10
3X Ø.25
5.00
7.00
1.00
2.50
2.00
1.00
1.00
(.25)
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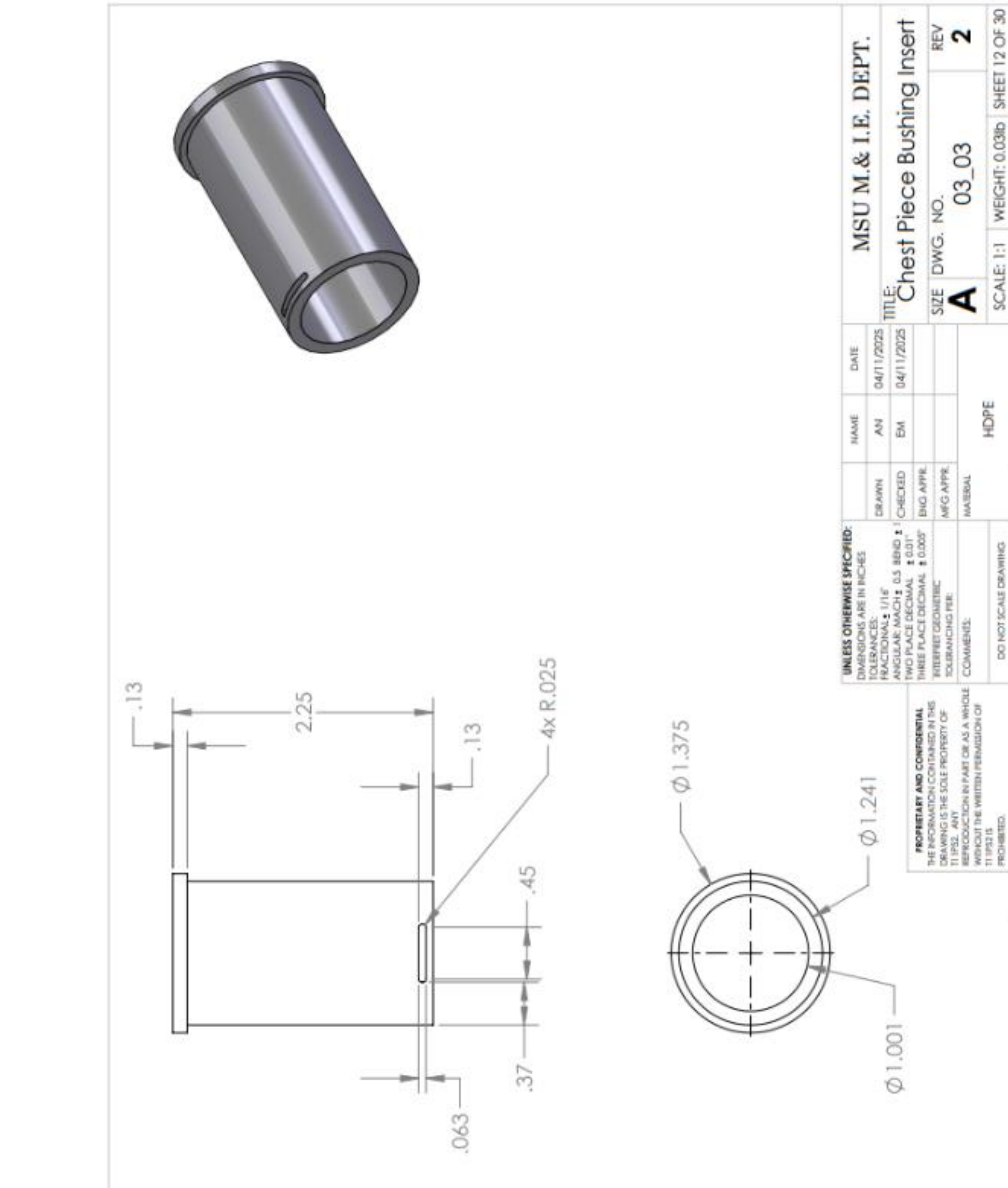
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
NAME
DATE
DRAWN Anders Nelson 04/10/2025
CHECKED Ethan Morse 04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
PE High Density
MSU M.& I.E. DEPT.
TITLE:
Chest Support Top Plate
SIZE A
DWG. NO. 03_02
REV 1
SCALE: 1:2
WEIGHT: 0.30lb
SHEET 10 OF 25
1
2
3
4
5
SOLIDWORKS Educational Product. For Instructional Use Only.


MSU M.& I.E. DEPT.
TITLE:
Chest Piece Bushing Insert
SIZE
A
DWG. NO.
03_03
REV
2
SCALE: 1:1
WEIGHT: 0.03lb
SHEET 12 OF 30
NAME
DATE
DRAWN
AN
04/11/2025
CHECKED
EM
04/11/2025
ENG APPR.
MFG APPR.
MATERIAL
HDPE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
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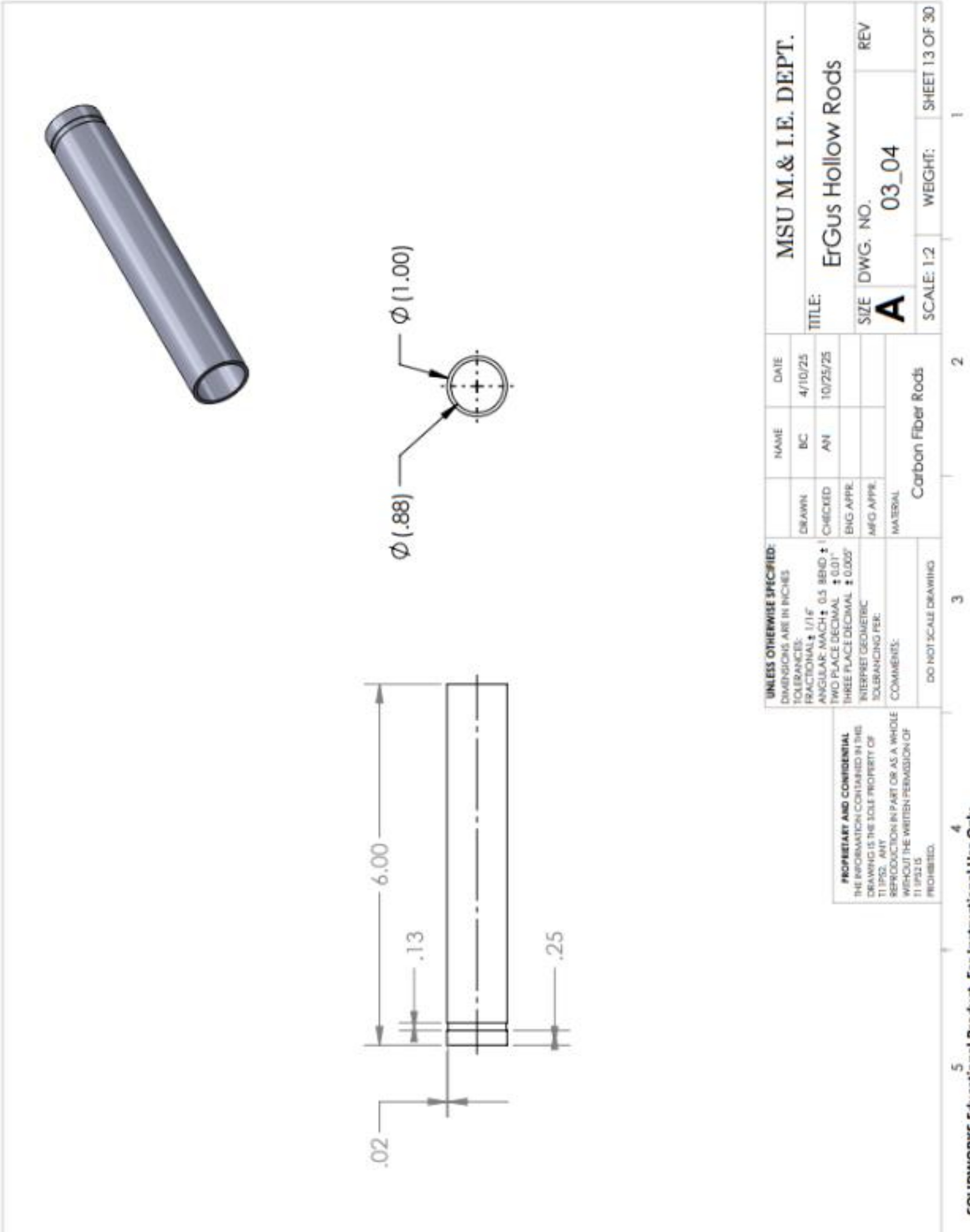
.13
2.25
.13
4x R.025
.45
.37
.063
Ø1.375
Ø1.241
Ø1.001
1
2
3
4
5
SOLIDWORKS Educational Product. For Instructional Use Only.


MSU M.& I.E. DEPT.
TITLE:
ErGus Hollow Rods
SIZE
A
DWG. NO.
03_04
REV
SCALE: 1:2
WEIGHT:
SHEET 13 OF 30
NAME
DATE
DRAWN
BC
4/10/25
CHECKED
AN
10/25/25
ENG APPR.
MFG APPR.
MATERIAL
Carbon Fiber Rods
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1°
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC
TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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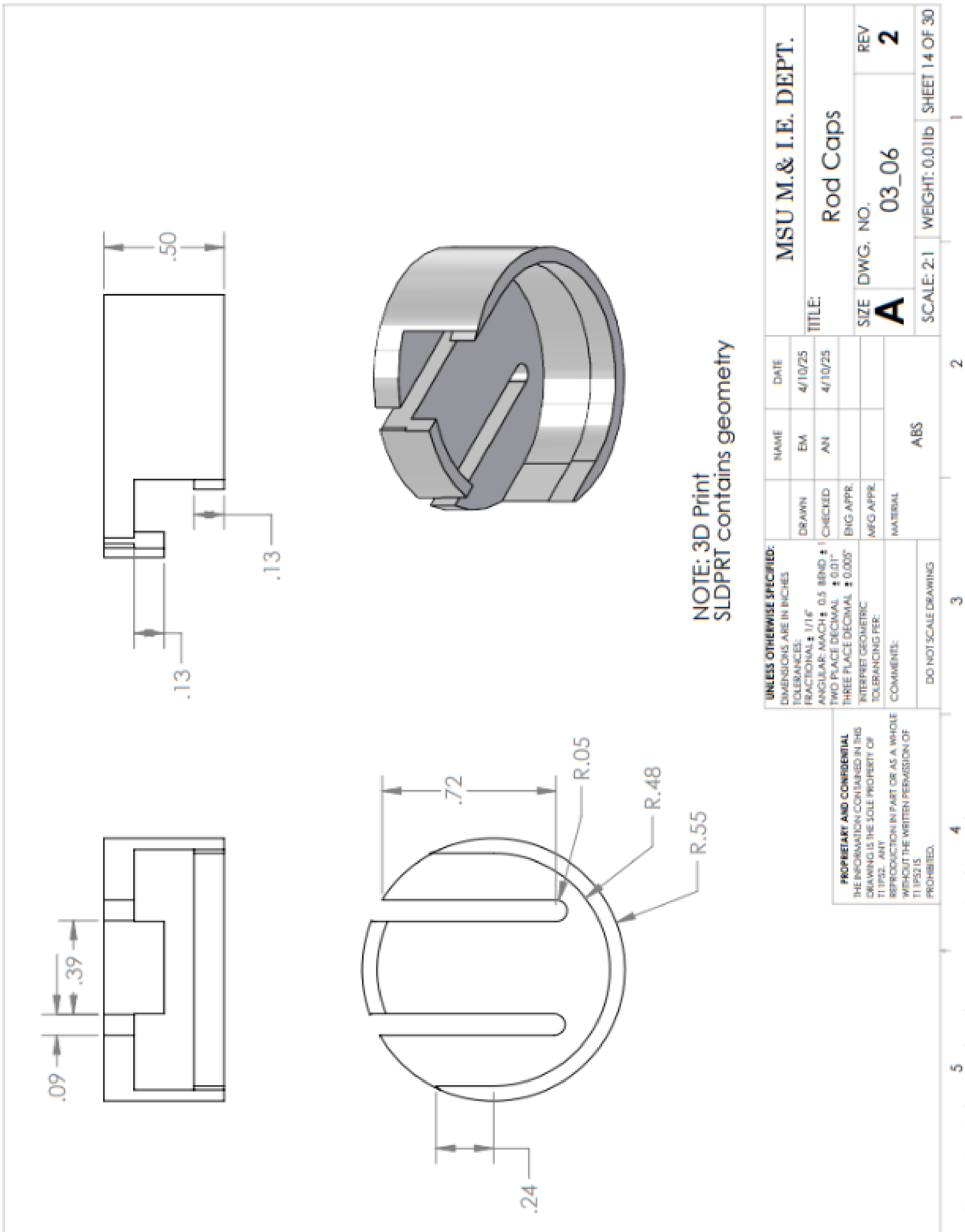
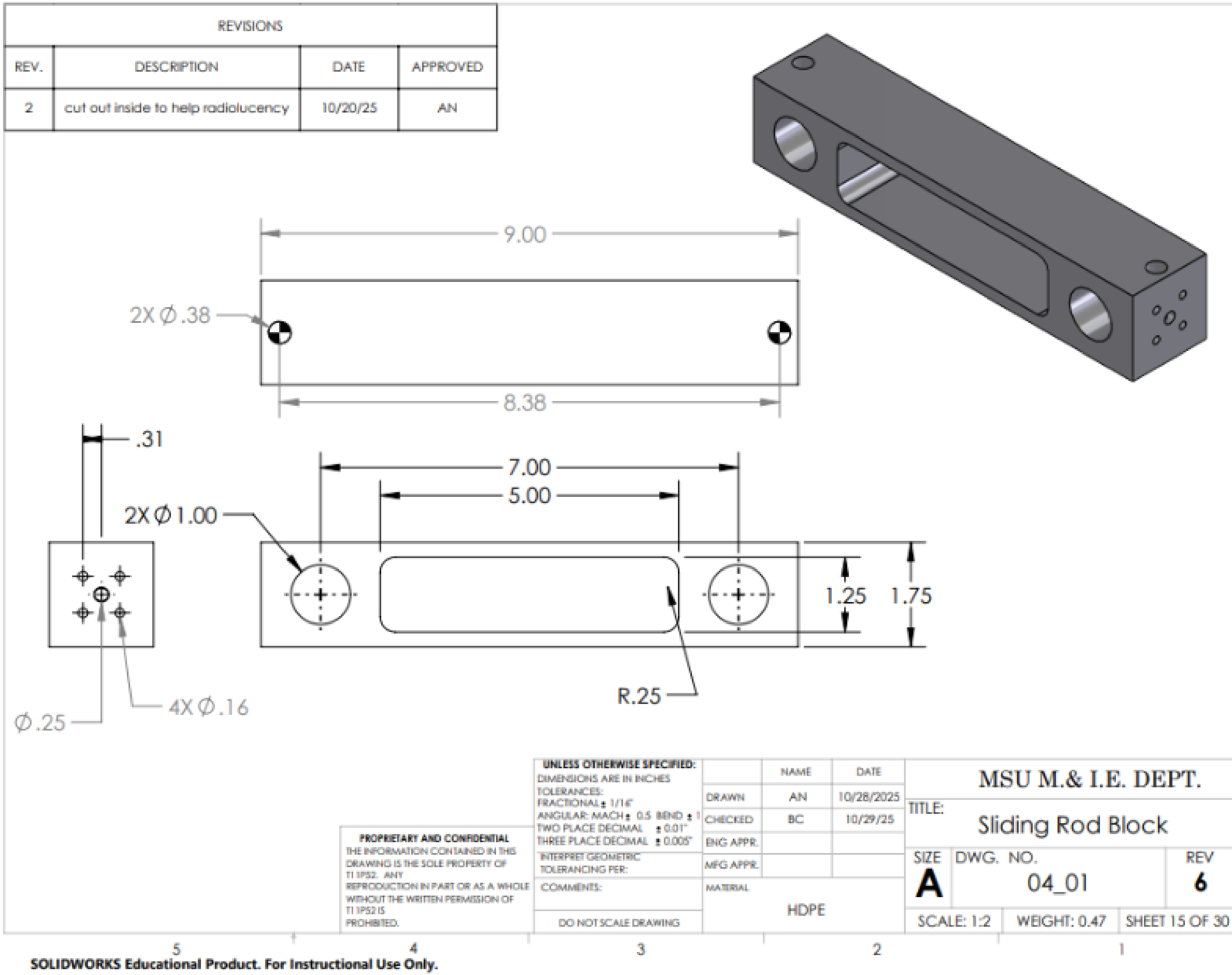
Ø (.88)
Ø (1.00)
6.00
.13
.25
.02
1
2
3
4
5
SOLIDWORKS Educational Product. For Instructional Use Only.


.50
.13
.13
.09
.39
.72
R.05
R.48
R.55
.24
NOTE: 3D Print
SLDPRT contains geometry
MSU M.& I.E. DEPT.
TITLE:
Rod Caps
SIZE
A
DWG. NO.
03_06
REV
2
SCALE: 2:1
WEIGHT: 0.01lb
SHEET 14 OF 30
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
EM
4/10/25
CHECKED
AN
4/10/25
ENG APPR.
MFG APPR.
MATERIAL
ABS
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Educational Product. For Instructional Use Only.



REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
2
cut out inside to help radiolucency
10/20/25
AN
9.00
2X Ø .38
8.38
.31
7.00
5.00
2X Ø 1.00
1.25
1.75
R.25
Ø .25
4X Ø .16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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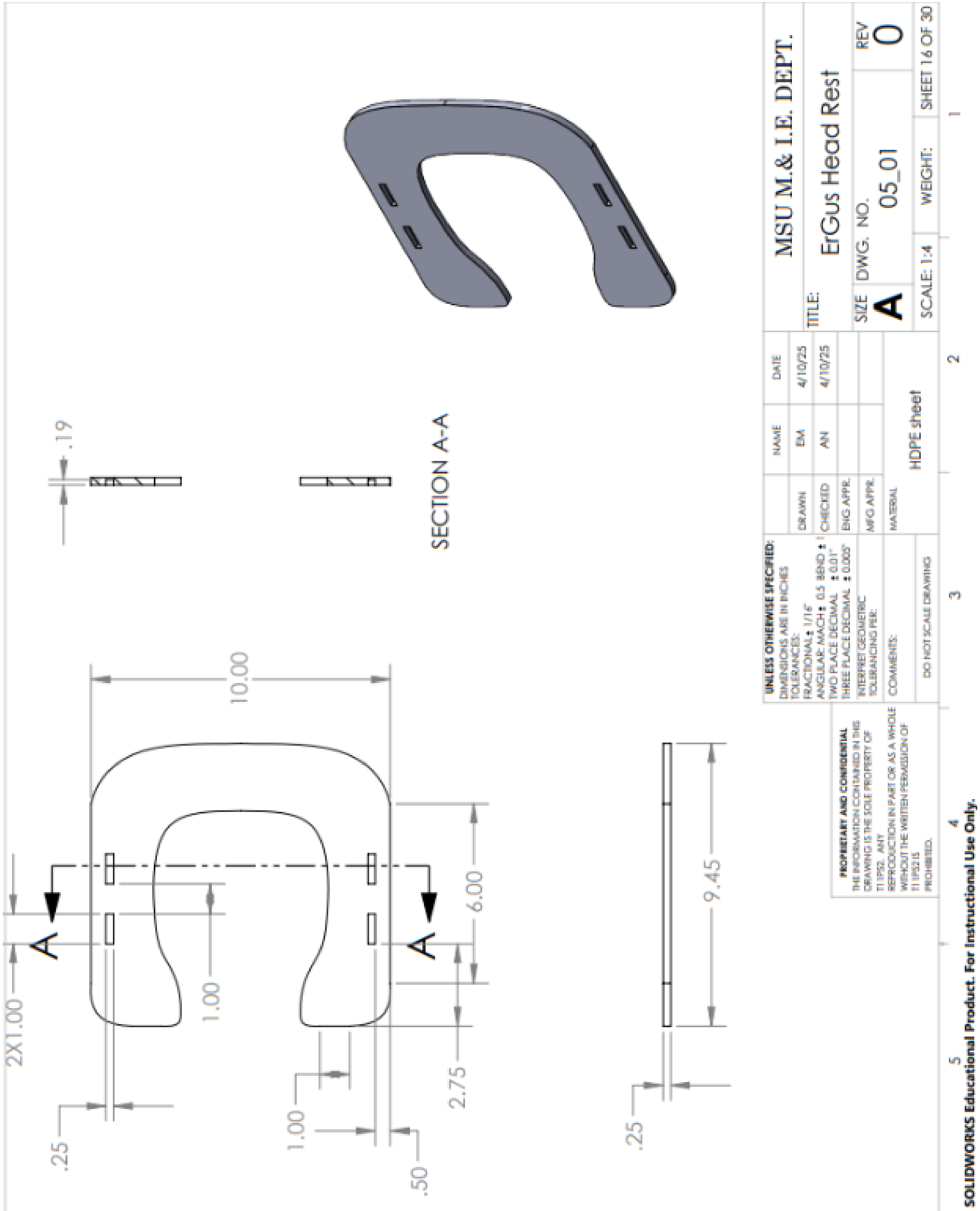
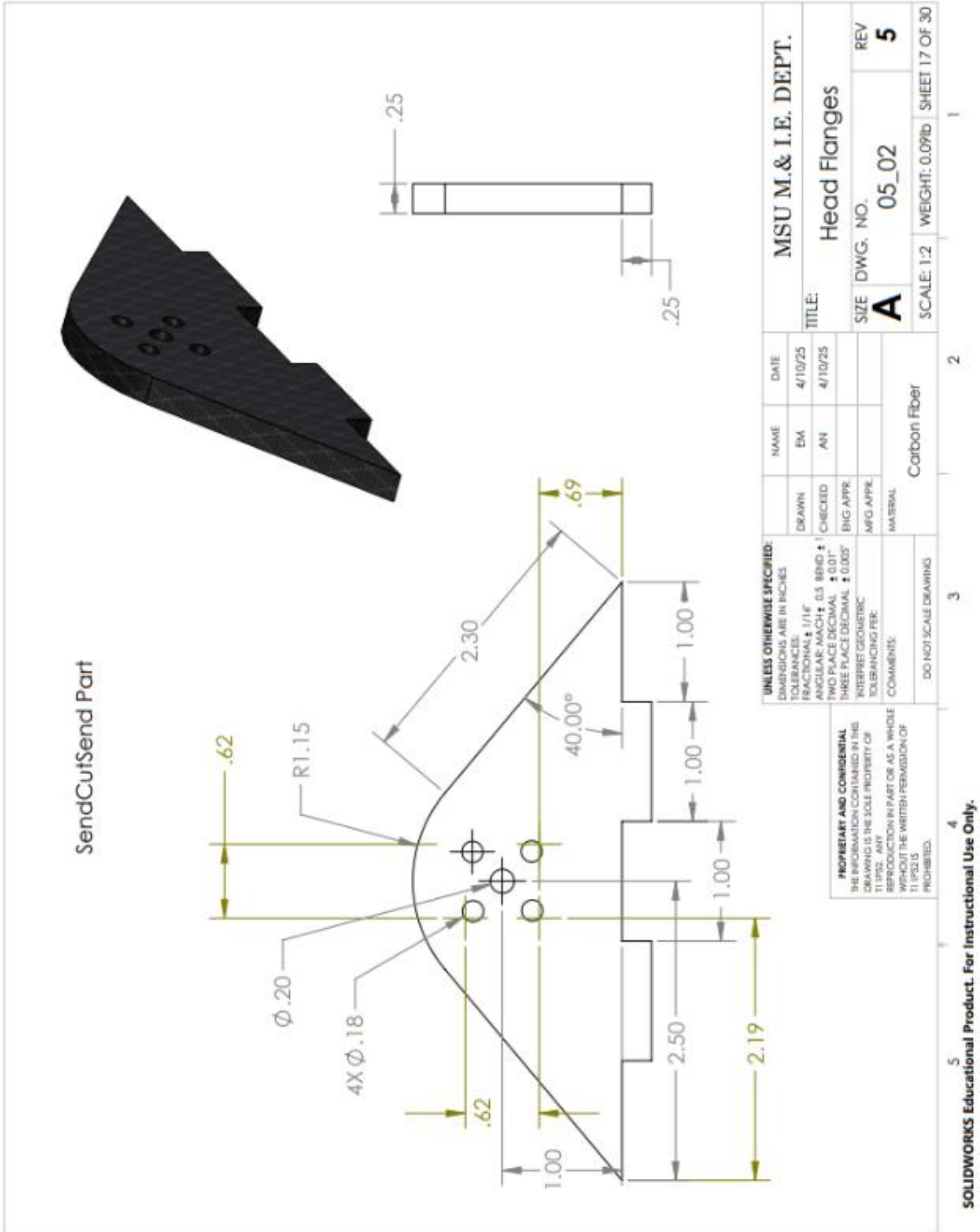
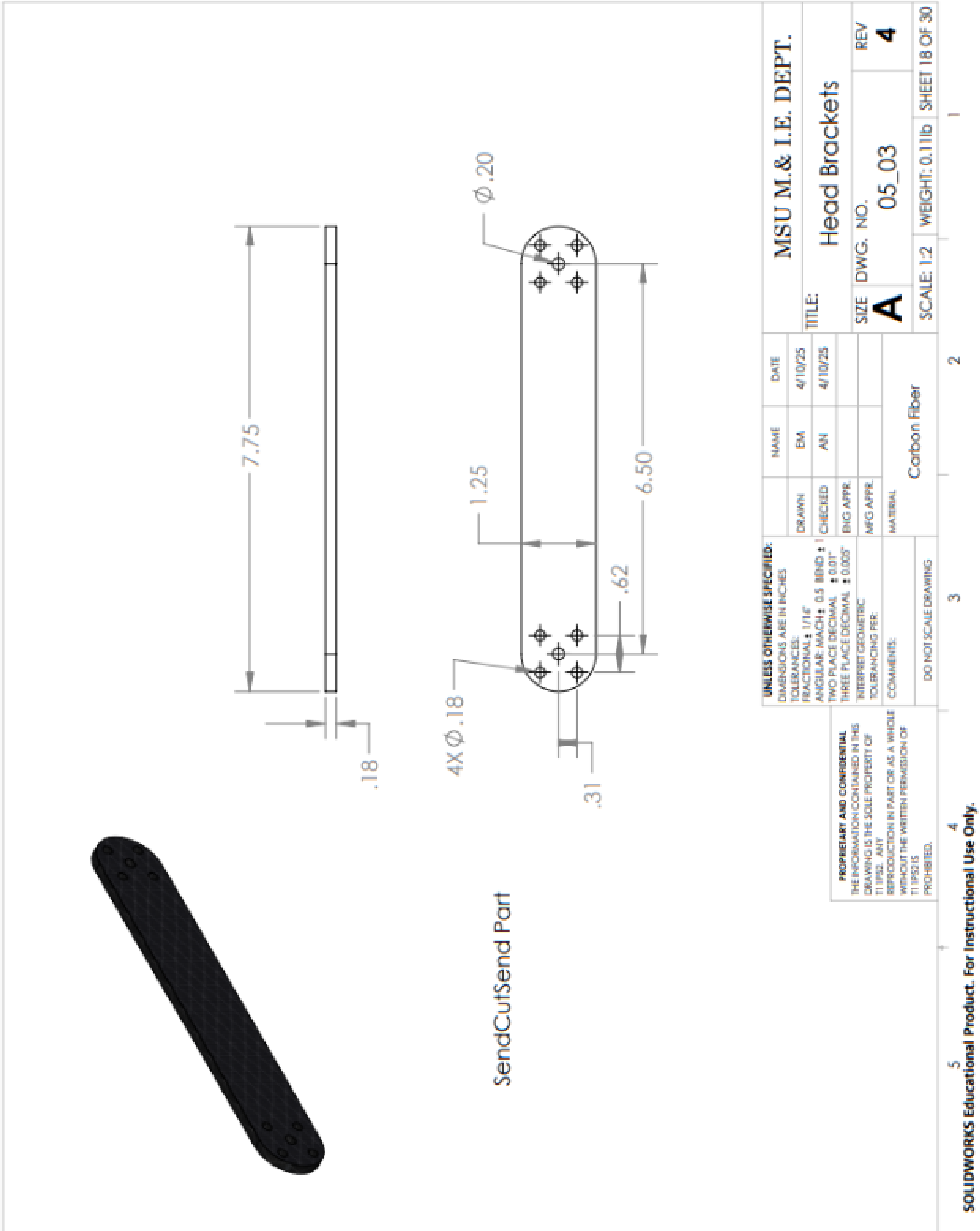
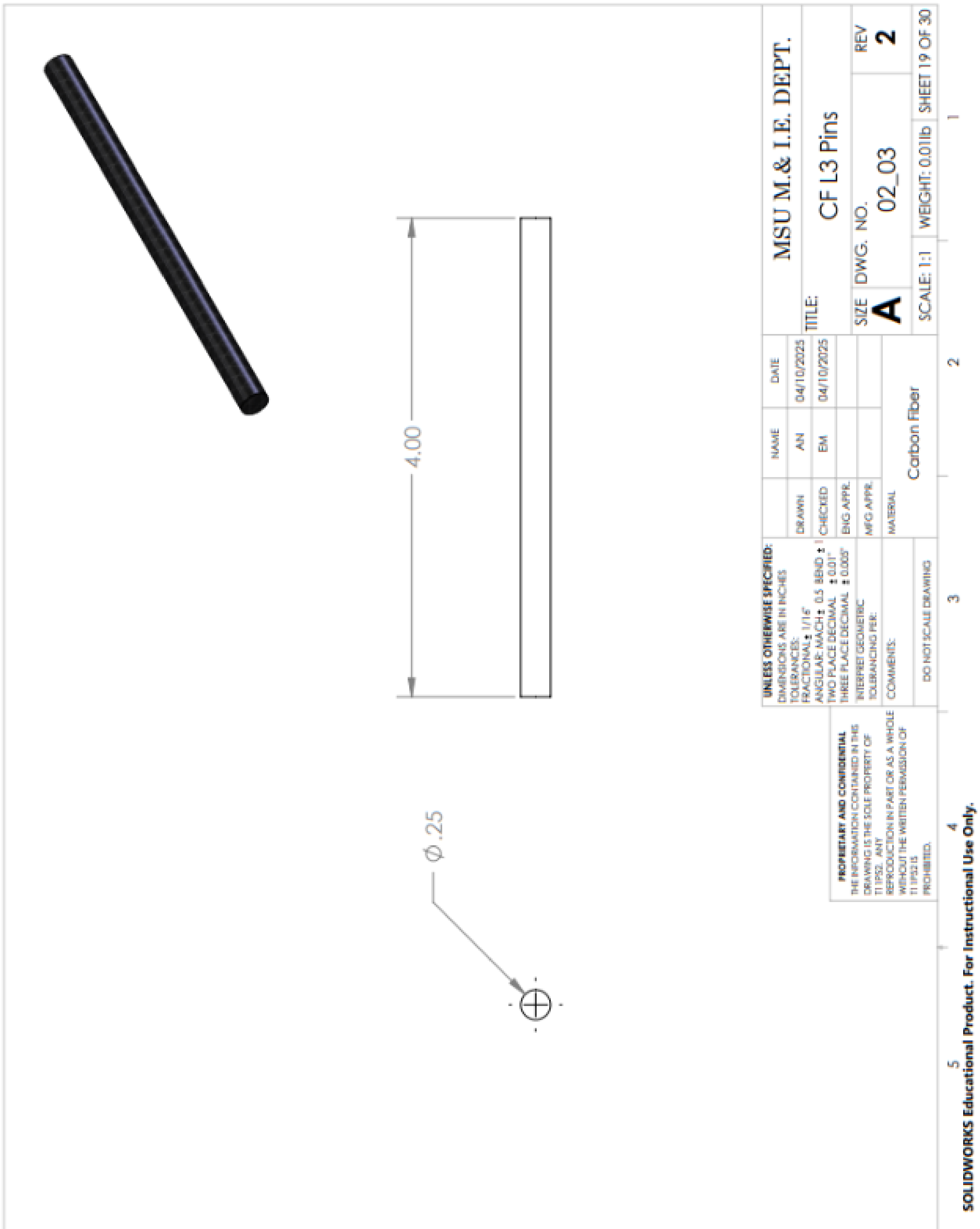
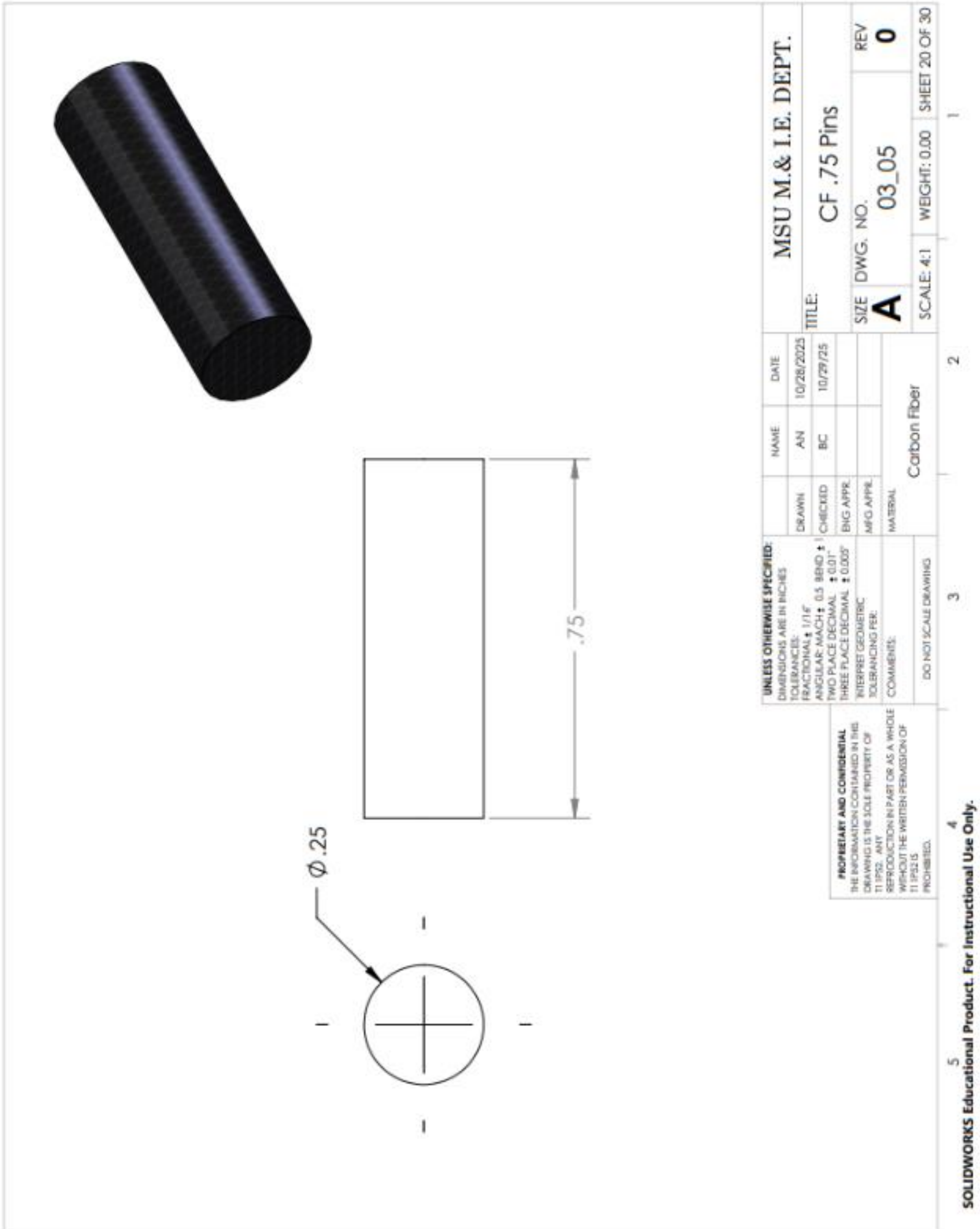
NAME
DATE
DRAWN
AN
10/28/2025
CHECKED
BC
10/29/25
ENG APPR.
MFG APPR.
MATERIAL
HDPE
MSU M.& I.E. DEPT.
TITLE:
Sliding Rod Block
SIZE
A
DWG. NO.
04_01
REV
6
SCALE: 1:2
WEIGHT: 0.47
SHEET 15 OF 30
5
4
3
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.

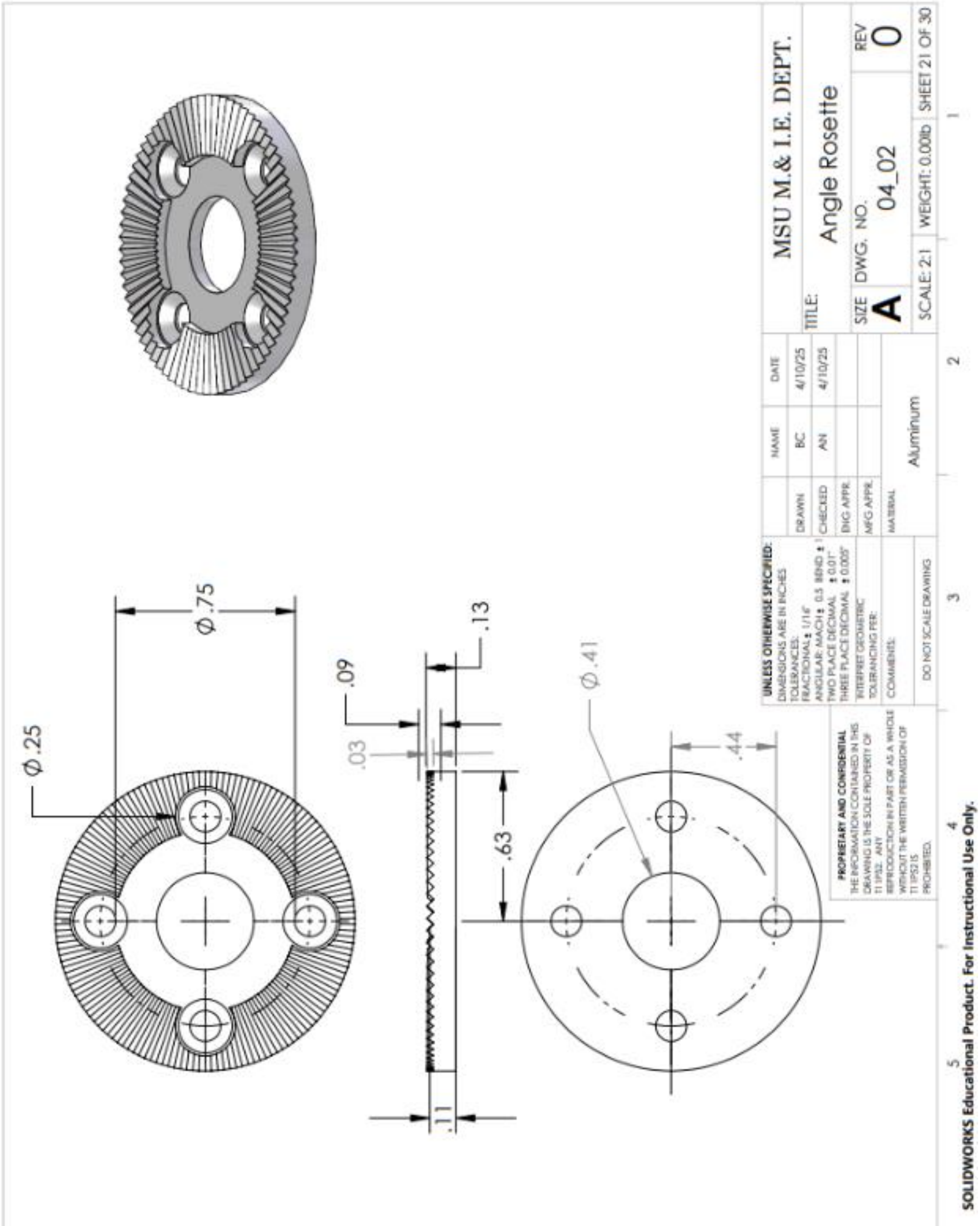

MSU M.& I.E. DEPT.
TITLE:
ErGus Head Rest
SIZE
A
DWG. NO.
05_01
REV
0
SCALE: 1:4
WEIGHT:
SHEET 16 OF 30
NAME
DATE
DRAWN
EM
4/10/25
CHECKED
AN
4/10/25
ENG APPR.
MFG APPR.
MATERIAL
HDPE sheet
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SECTION A-A
10.00
9.45
6.00
2.75
2X1.00
1.00
1.00
.25
.25
.50
.19
A
A
SOLIDWORKS Educational Product. For Instructional Use Only.


SendCutSend Part
R1.15
.62
2.30
.69
40.00°
1.00
1.00
1.00
1.00
1.00
Ø.20
4X Ø.18
.62
2.50
2.19
.25
.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
EM
4/10/25
CHECKED
AN
4/10/25
ENG APPR.
MFG APPR.
MATERIAL
Carbon Fiber
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
MSU M.& I.E. DEPT.
TITLE:
Head Flanges
SIZE
A
DWG. NO.
05_02
REV
5
SCALE: 1:2
WEIGHT: 0.09lb
SHEET 17 OF 30
SOLIDWORKS Educational Product. For Instructional Use Only.

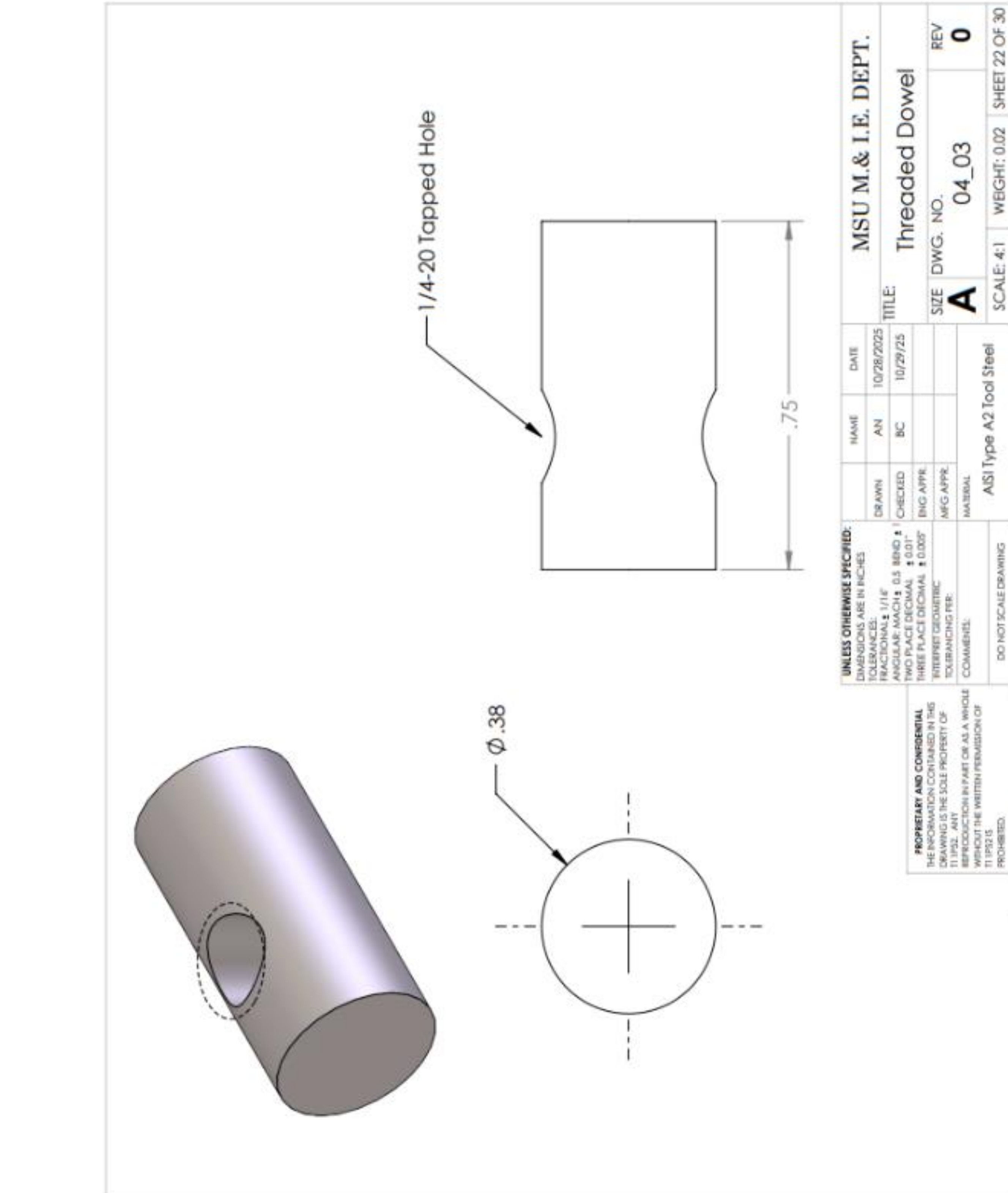

MSU M.& I.E. DEPT.
TITLE:
Head Brackets
SIZE
A
DWG. NO.
05_03
REV
4
SCALE: 1:2
WEIGHT: 0.11lb
SHEET 18 OF 30
DRAWN
EM
4/10/25
CHECKED
AN
4/10/25
MATERIAL
Carbon Fiber
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
PROPRIETARY AND CONFIDENTIAL
SendCutSend Part
7.75
.18
1.25
6.50
.62
.31
4X ∅.18
∅.20
SOLIDWORKS Educational Product. For Instructional Use Only.

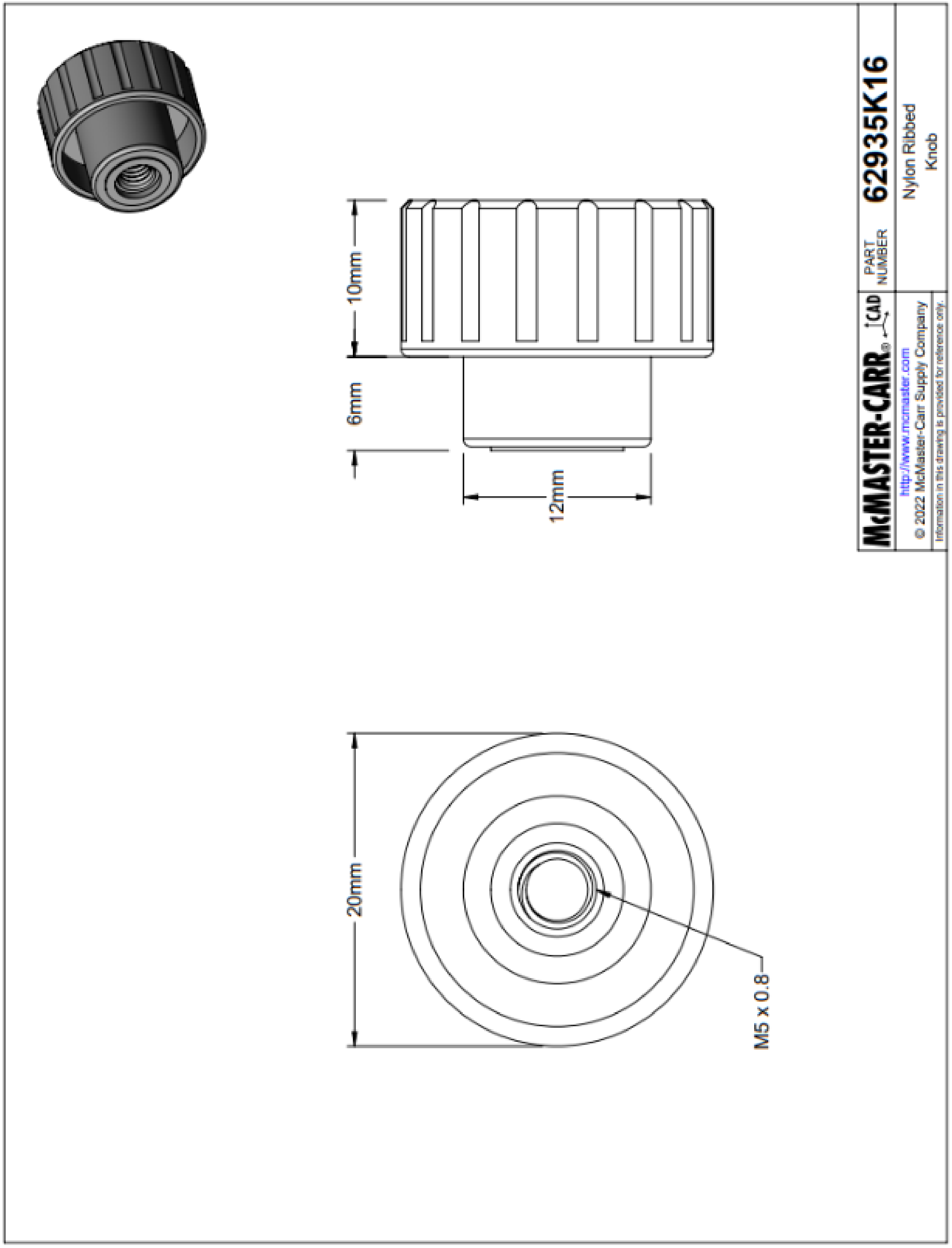

MSU M.& I.E. DEPT.
TITLE:
CF L3 Pins
SIZE
A
DWG. NO.
02_03
REV
2
SCALE: 1:1
WEIGHT: 0.01lb
SHEET 19 OF 30
NAME
DATE
DRAWN
AN
04/10/2025
CHECKED
EM
04/10/2025
ENG APPR.
MFG APPR.
MATERIAL
Carbon Fiber
DO NOT SCALE DRAWING
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
4.00
Ø.25
SOLIDWORKS Educational Product. For Instructional Use Only.

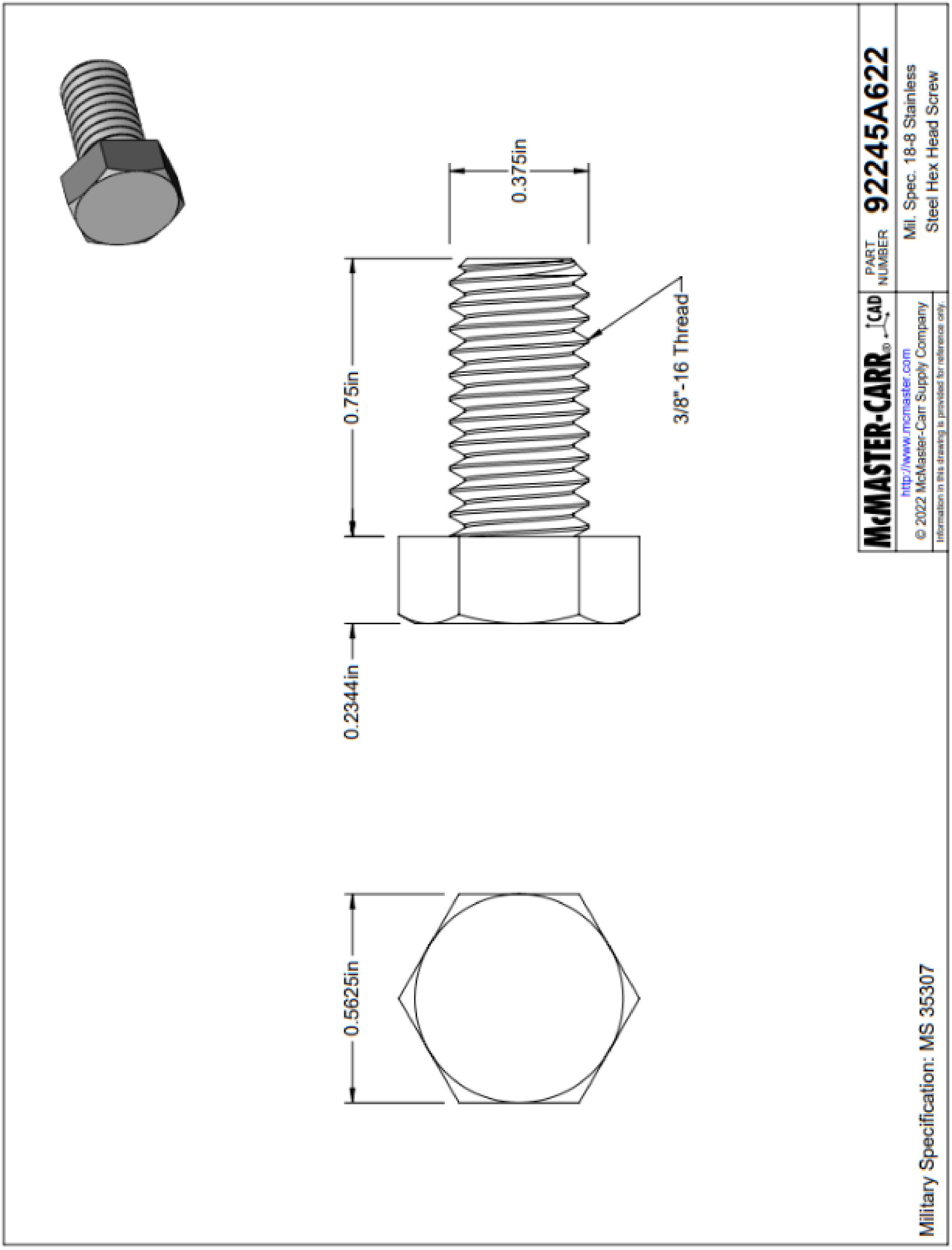

MSU M.& I.E. DEPT.
TITLE:
CF .75 Pins
SIZE
A
DWG. NO.
03_05
REV
0
SCALE: 4:1
WEIGHT: 0.00
SHEET 20 OF 30
NAME
DATE
DRAWN
AN
10/28/2025
CHECKED
BC
10/29/25
ENG APPR.
MFG APPR.
MATERIAL
Carbon Fiber
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
PROPRIETARY AND CONFIDENTIAL
DO NOT SCALE DRAWING
.75
Ø.25
SOLIDWORKS Educational Product. For Instructional Use Only.

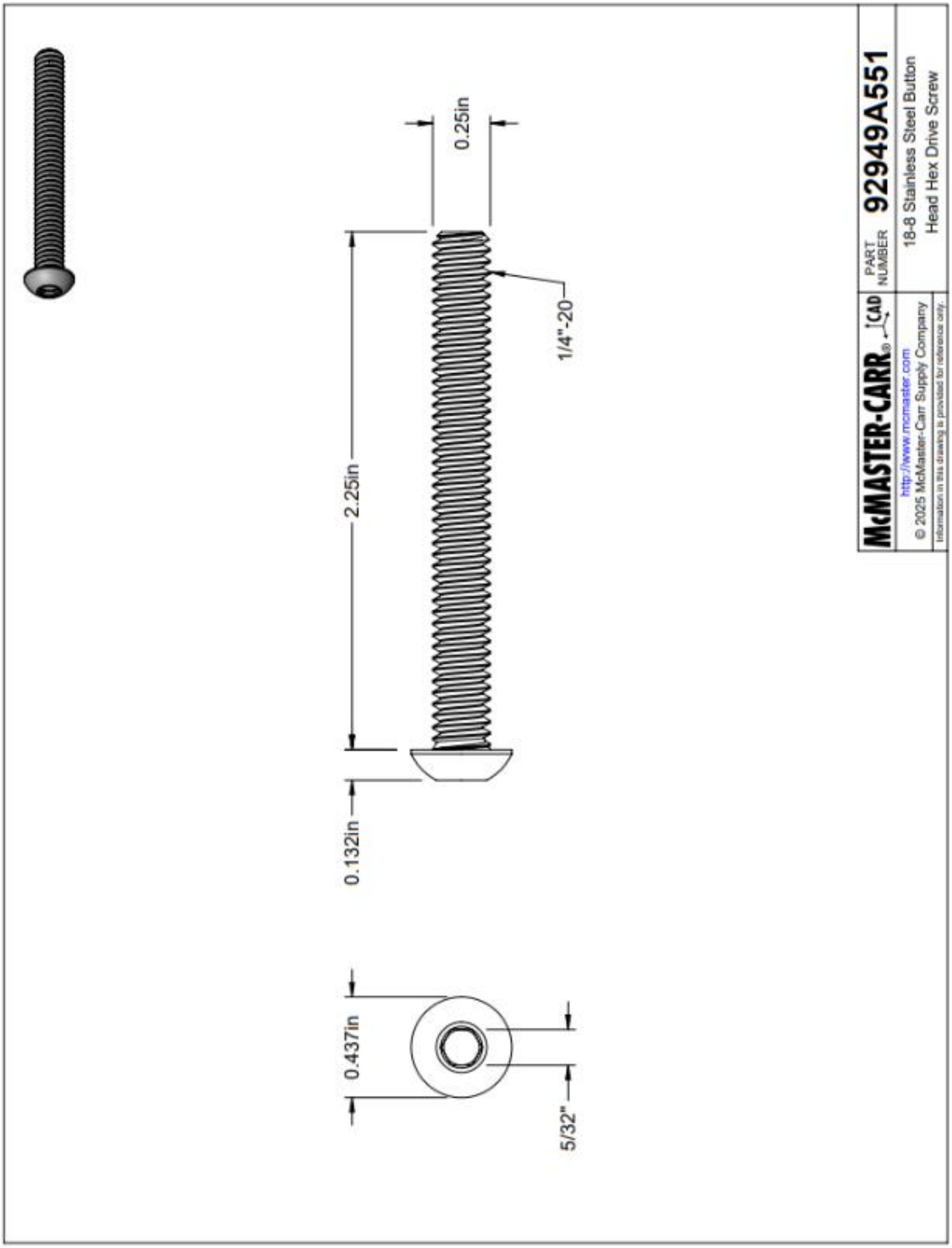


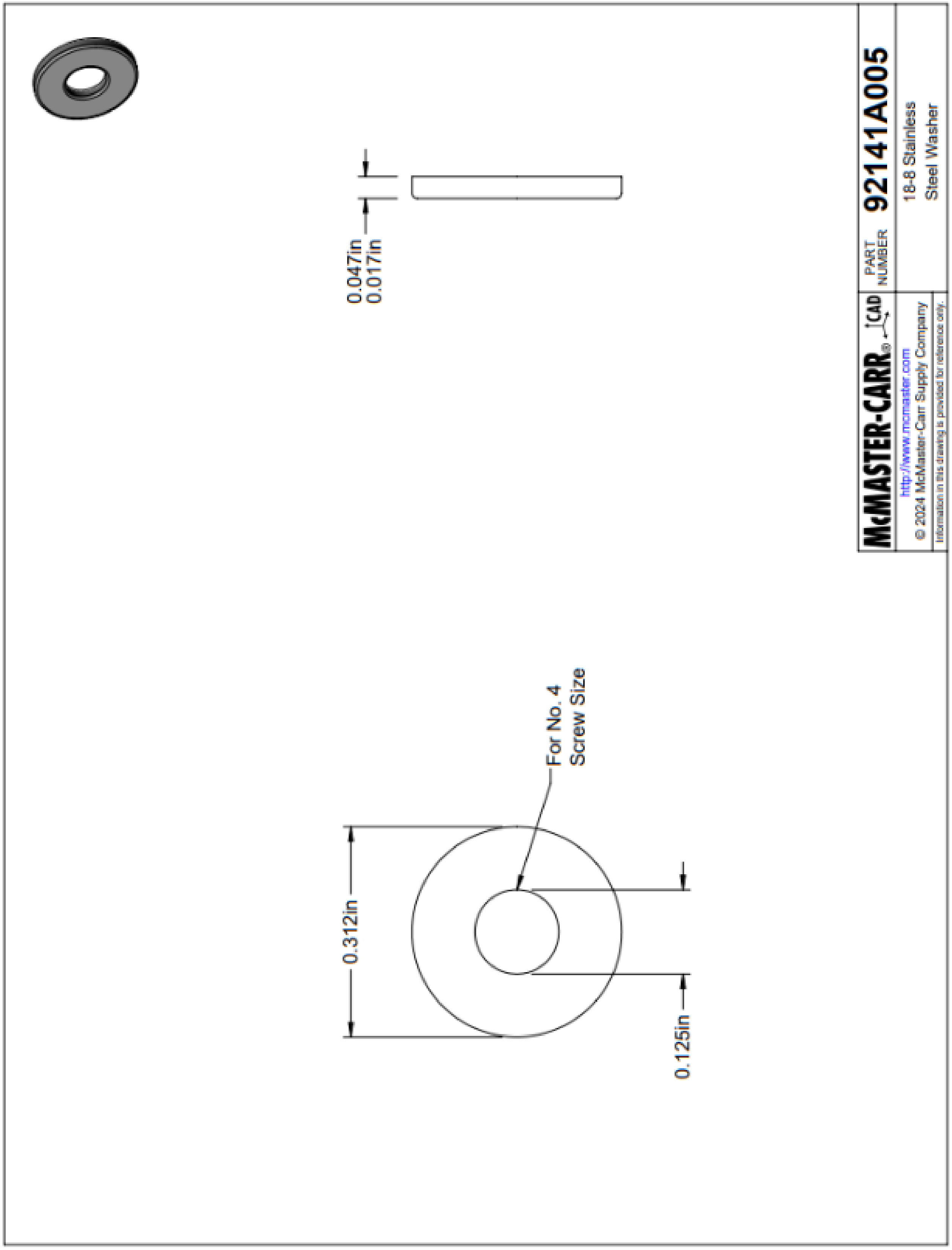
Ø.25
Ø.75
.09
.13
.03
.63
.11
Ø.41
.44
MSU M.& I.E. DEPT.
TITLE:
Angle Rosette
SIZE
A
DWG. NO.
04_02
REV
0
SCALE: 2:1
WEIGHT: 0.008lb
SHEET 21 OF 30
NAME
DATE
DRAWN
BC
4/10/25
CHECKED
AN
4/10/25
ENG APPR.
MFG APPR.
MATERIAL
Aluminum
UNLESS OTHERWISE SPECIFIED:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Educational Product. For Instructional Use Only.

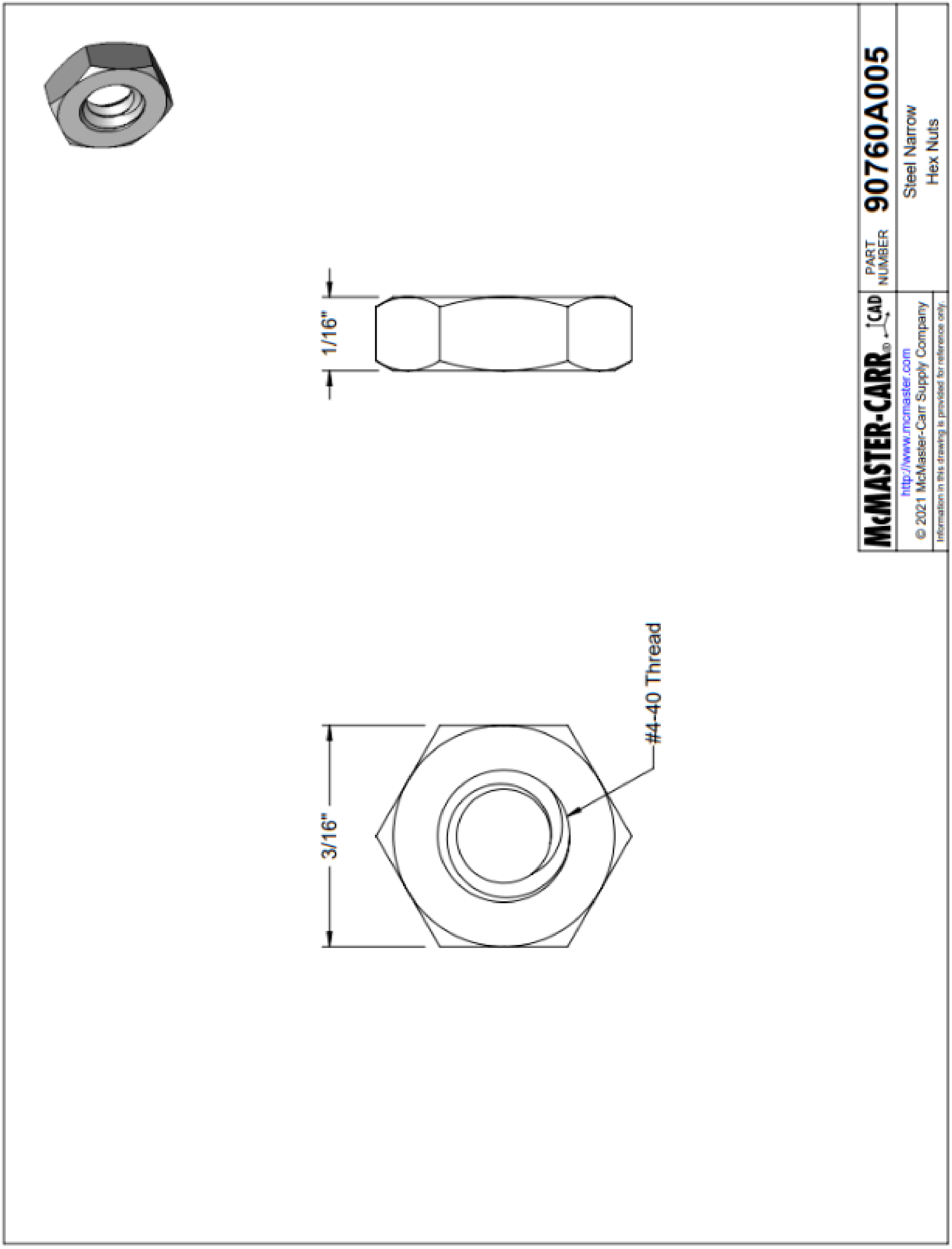

1/4-20 Tapped Hole
Ø.38
.75
MSU M.& I.E. DEPT.
TITLE:
Threaded Dowel
SIZE
A
DWG. NO.
04_03
REV
0
SCALE: 4:1
WEIGHT: 0.02
SHEET 22 OF 30
DRAWN AN 10/28/2025
CHECKED BC 10/29/25
ENG APPR.
MFG APPR.
MATERIAL
AISI Type A2 Tool Steel
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± 0.5 BEND ± 1
TWO PLACE DECIMAL ± 0.01"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Educational Product. For Instructional Use Only.


MCMASTER-CARR
CAD
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
62935K16
Nylon Ribbed Knob
10mm
6mm
12mm
20mm
M5 x 0.8

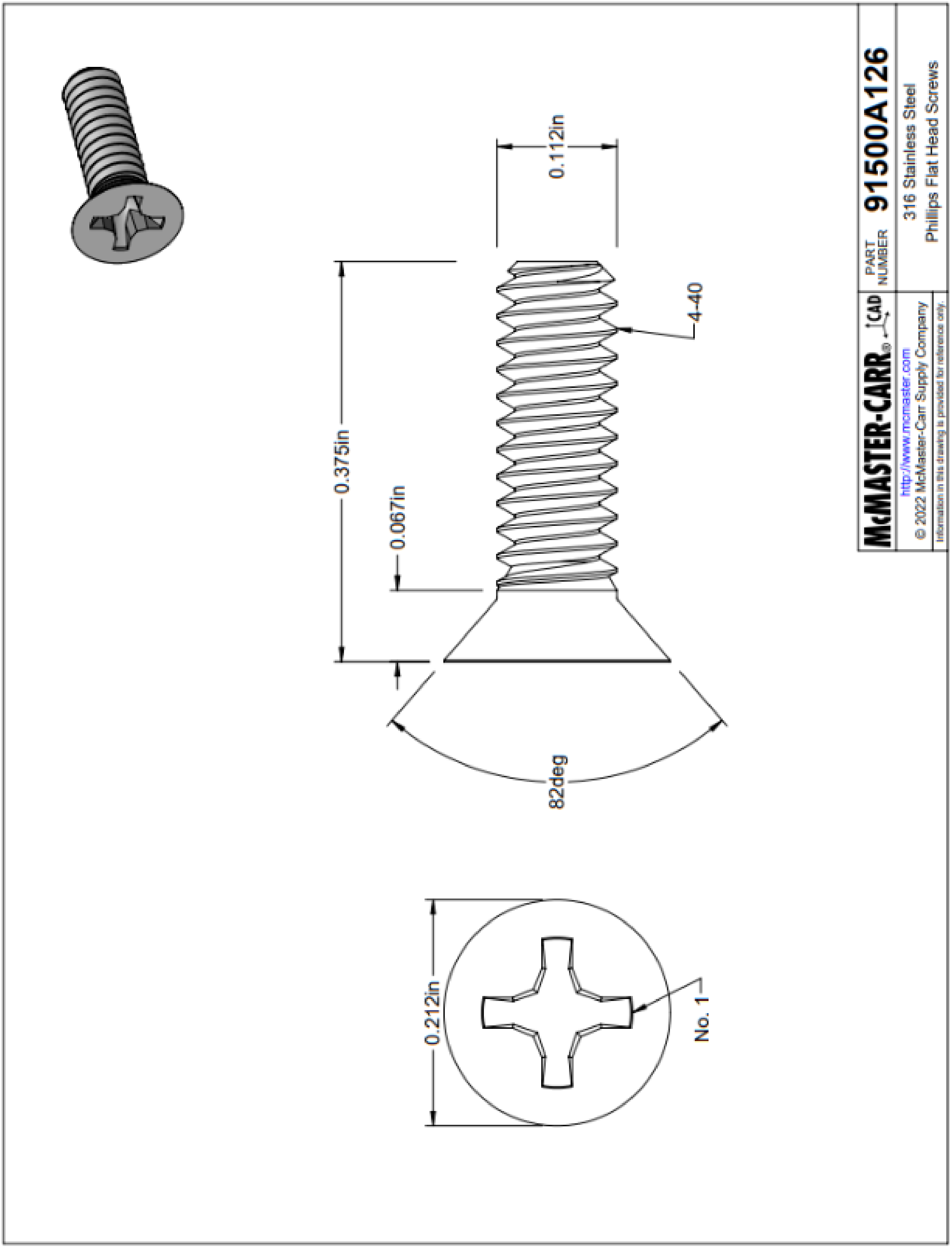

0.375in
0.75in
0.2344in
3/8"-16 Thread
0.5625in
Military Specification: MS 35307
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
92245A622
Mil. Spec. 18-8 Stainless Steel Hex Head Screw

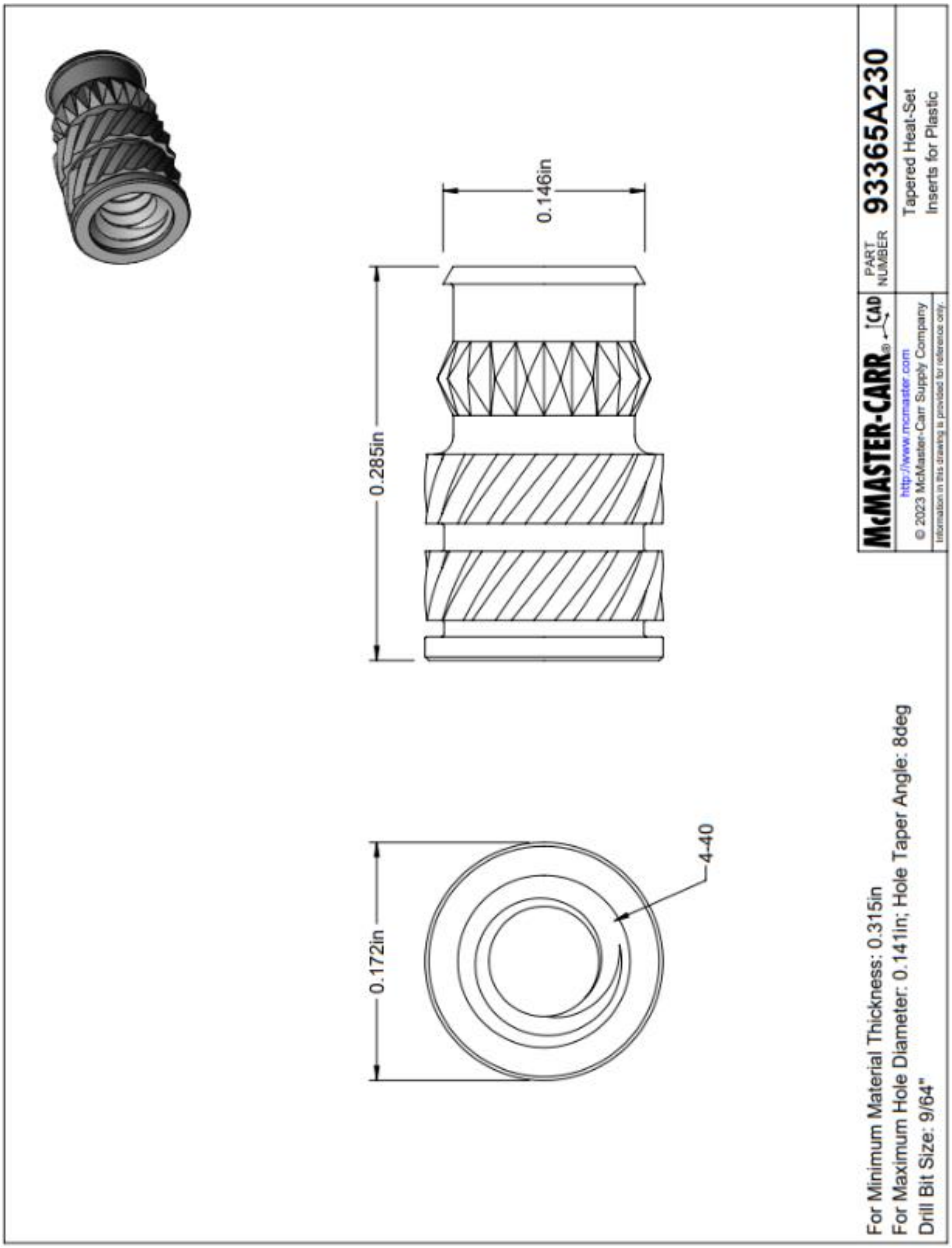

0.25in
2.25in
1/4"-20
0.132in
0.437in
5/32"
McMASTER-CARR®
CAD
PART NUMBER
92949A551
18-8 Stainless Steel Button Head Hex Drive Screw
http://www.mcmaster.com
© 2025 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.

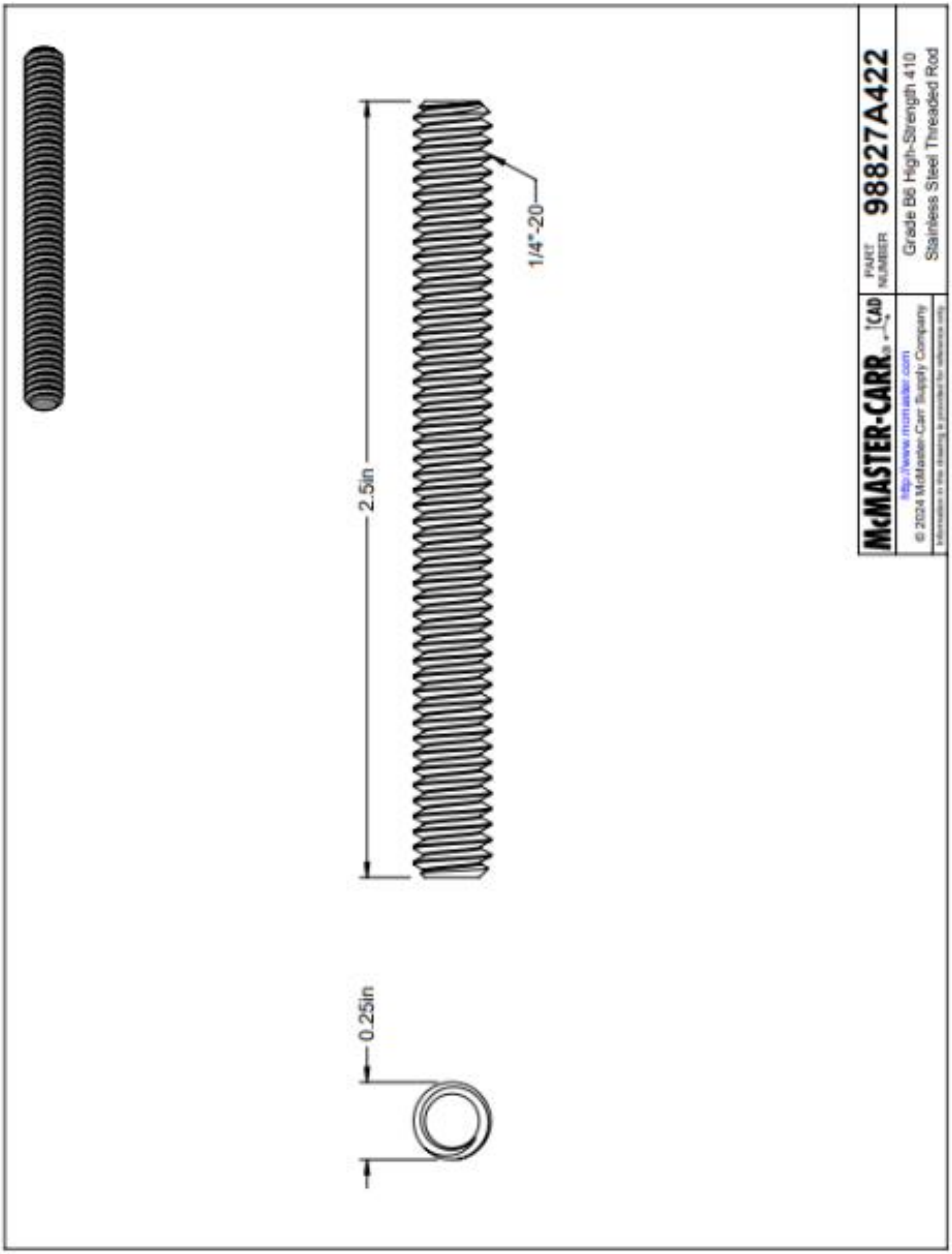

0.047in
0.017in
0.312in
0.125in
For No. 4
Screw Size
McMASTER-CARR®
CAD
PART NUMBER
92141A005
18-8 Stainless
Steel Washer
http://www.mcmaster.com
© 2024 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.



1/16"
3/16"
#4-40 Thread
McMASTER-CARR
CAD
PART NUMBER
90760A005
Steel Narrow Hex Nuts
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.


0.112in
4-40
0.375in
0.067in
82deg
0.212in
No. 1
McMASTER-CARR
PART NUMBER 91500A126
316 Stainless Steel
Phillips Flat Head Screws
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.


0.146in
0.285in
0.172in
4-40
For Minimum Material Thickness: 0.315in
For Maximum Hole Diameter: 0.141in; Hole Taper Angle: 8deg
Drill Bit Size: 9/64"
McMASTER-CARR
PART NUMBER
93365A230
http://www.mcmaster.com
© 2023 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Tapered Heat-Set Inserts for Plastic


2.5in
1/4"-20
0.25in
McMASTER-CARR
PART NUMBER
98827A422
http://www.mcmaster.com
© 2024 McMaster-Carr Supply Company
Grade B6 High-Strength 410
Stainless Steel Threaded Rod

MONTANA STATE UNIVERSITY CAPSTONE ENGINEERING CHANGE REQUEST			
ADMINISTRATIVE INFORMATION			
Requestor Name:	Anders Nelson	Request Date:	10/15/2025
Part Name:	Chest Support Inserts	Drawing Revision:	5
Drawing number:	02_2	ECR Number:	2
CHANGE INFORMATION			
Description of Change:			
These will be the blocks that slide into the table attachment bracket and pinned into place. The chest support blocks will then slide over these and have a threaded screw to allow for easy disassembly.			
Reason for Change:			
These will be required to attach the new chest supports to the table attachment bracket and have them out of the desired viewing window.			
Signature of Requestor:	Anders Nelson		
TECHNICAL EVALUATION			
	Feasible	Not Feasible	Other
Comments:			
Very feasible, will be an easier build than the original insert block.			
Name of Reviewer:	Brianna Chase	Review Date:	10/20/2025
Signature of Reviewer:	Brianna Chase		
APPROVAL INFORMATION			
	Approved	Rejected	
Comments:			
Approved. This part is directly required after the last change request to attach chest support to table mounting bracket			
Name of Approver:	Ethan Morse	Review Date:	10/22/2025
Signature of Approver:	Ethan Morse		

MONTANA STATE UNIVERSITY CAPSTONE ENGINEERING CHANGE REQUEST			
ADMINISTRATIVE INFORMATION			
Requestor Name:	Brianna Chase	Request Date:	10/15/2025
Part Name:	Chest Support Top Plate	Drawing Revision:	5
Drawing number:	03_2	ECR Number:	3
CHANGE INFORMATION			
Description of Change:			
Just changing the geometry and adding the patten number to the face of the plate.			
Reason for Change:			
This is being made to fit the new chest support parts.			
Signature of Requestor:	Brianna Chase		
TECHNICAL EVALUATION			
	Feasible	Not Feasible	Other
Comments:			
Feasible.			
Name of Reviewer:	Anders Nelson	Review Date:	10/20/2025
Signature of Reviewer:	Anders Nelson		
APPROVAL INFORMATION			
	Approved	Rejected	
Comments:			
Approved.			
Name of Approver:	Ethan Morse	Review Date:	10/22/2025
Signature of Approver:	Ethan Morse		

MONTANA STATE UNIVERSITY CAPSTONE ENGINEERING CHANGE REQUEST			
ADMINISTRATIVE INFORMATION			
Requestor Name:	Ethan Morse	Request Date:	10/17/2025
Part Name:	Sliding Rod Block	Drawing Revision:	6
Drawing number:	04_1	ECR Number:	4
CHANGE INFORMATION			
Description of Change:	[redacted]		
through for adjustability. The middle of the block will also be milled out to reduce thickness while keeping			
Reason for Change:	[redacted]		
area while still leaving the protoype ergonomic. The reduced thickness is to improve radiolucency in the			
Signature of Requestor:	Ethan Morse		
TECHNICAL EVALUATION			
Feasible	Not Feasible	Other	
Comments:	[redacted]		
Feasible to do, only concern is radiolucency even in area that is milled to be thinner.			
Name of Reviewer:	Brianna Chase	Review Date:	10/22/2025
Signature of Reviewer:	Brianna Chase		
APPROVAL INFORMATION			
Approved	Rejected		
Comments:	[redacted]		
Approved. Despite the concern with radiolucency will go forward with this design and test when available.			
Name of Approver:	Anders Nelson	Review Date:	10/24/2025
Signature of Approver:	Anders Nelson		

MONTANA STATE UNIVERSITY CAPSTONE ENGINEERING CHANGE REQUEST			
ADMINISTRATIVE INFORMATION			
Requestor Name:	Ethan Morse	Request Date:	10/17/2025
Part Name:	Table Attachment Bracket	Drawing Revision:	5
Drawing number:	02_1	ECR Number:	5
CHANGE INFORMATION			
Description of Change:			
Instead of milling one hole in the center of attachment bracket, two holes will be milled farther out from center to hold chest support inserts with pin holes through the top.			
Reason for Change:			
This change is needed to accompany the changes to the chest support while still providing a structurally sound design.			
Signature of Requestor:	Ethan Morse		
TECHNICAL EVALUATION			
	Feasible	Not Feasible	Other
Comments:			
Feasible. Only concern is the arm support brackets may have to go into the table attachment bracket.			
Name of Reviewer:	Anders Nelson	Review Date:	10/23/2025
Signature of Reviewer:	Anders Nelson		
APPROVAL INFORMATION			
	Approved	Rejected	
Comments:			
Approved. The concern of the arm support brackets is minor as this new design would only move back an already adjustable part a couple of inches.			
Name of Approver:	Anders Nelson	Review Date:	10/24/2025
Signature of Approver:	Anders Nelson		

MONTANA STATE UNIVERSITY CAPSTONE ENGINEERING CHANGE REQUEST			
ADMINISTRATIVE INFORMATION			
Requestor Name:	Anders Nelson	Request Date:	10/15/2025
Part Name:	Chest Support block	Drawing Revision:	0
Drawing number:	03_1	ECR Number:	1
CHANGE INFORMATION			
Description of Change:	[redacted]		
This is a smaller version of the the first chest support block and now will need two of them. These are the supports that connect to the table attachment bracket via chest support inserts. The carbon fiber rods will also attach to the ends of these now			
Reason for Change:	[redacted]		
threshold for thickness is smaller than expected so the hope for this iteration is that the chest support is moved out to the sides more to not impede the desired viewing window and are thinner so if in the viewing			
Signature of Requestor:	Anders Nelson		
TECHNICAL EVALUATION			
	Feasible	Not Feasible	Other
Comments:	[redacted]		
This will be easily feasible but will have to change multiple parts in order to implement into the design			
Name of Reviewer:	Ethan Morse	Review Date:	10/20/2025
Signature of Reviewer:	Ethan Morse		
APPROVAL INFORMATION			
	Approved	Rejected	
Comments:	[redacted]		
Aproved. Although not expicitly necessary to do a second iteration of the design, these changes are believed to make a significant impact on the utility of the design.			
Name of Approver:	Ethan Morse	Review Date:	10/22/2025
Signature of Approver:	Ethan Morse		

Appendix E. Project Economic Analysis and Budget

Table E1: Breakdown of Parts to be Purchased

Purchased Parts/Material							
Part No.	Item	Description	Vendor URL	Price	Quantity	Shipping	Total
	block inserts	EcoCut: High-Density Polyethylene (HDPE) Natural Plastic Block 2" x 3" x 6" - for Machining, Home Improvements, Prototypes, DIY Projects, Engineering	https://www.amazon.com/EcoCut-High-Density-Polyethylene-Improvements-Engineering/dp/B0DLPF795X	$ 15.75	8	$ -	$ 126.00
	Braided Carbon Fiber Rectangular Tubing	2" x 4" x 48" carbon fiber tubing (0.085" wall)	https://dragonplate.com/braided-carbon-fiber-rectangular-tubing-2-x-4-x-48	$ 238.25	1	$ 59.68	$ 297.93
	Carbon Fiber Pins	Rod - Pultruded Unidirectional - 0.250" x 12 Inches	https://www.rockwestcomposites.com/47317-l12.html	$ 12.99	2	$ 10.00	$ 35.98
	Round carbon fiber Tubing	Tube - Filament Wound - Sanded - 0.875 x 1.000 x 12 Inch - - Available up to 84 Inches	https://www.rockwestcomposites.com/35138-s.html	$ 42.99	2	$ 20.20	$ 106.18
	Carbon Fiber Head Brackets	send cut send dimensions to cut	https://app.sendcutsend.com/customer?	$ 55.64	2	$ -	$ 111.28
	Carbon Fiber Head Flanges	send cut send dimensions to cut	https://app.sendcutsend.com/customer?	$ 30.79	2	$ -	$ 61.58
	Adhesion Component	WEST epoxy resin	https://www.jamestowndistributors.com	$ 51.47	1 qrt	$ -	$ 51.47
	Adhesion Component	WEST epoxy fast hardener	https://www.jamestowndistributors.com	$ 36.67	1 qrt	$ -	$ 36.67
	Sliding Bar and Adjustable Head Brackets Connective Support	HDPE Sheet | Natural High Density Polyethylene (2 inches x 2 inches x 9 inches)	https://www.interstateplastics.com/cart.php	$ 28.60	1	$ 40.66	$ 69.26
	Chest Support Body	HDPE Sheet | Natural High Density Polyethylene (4 inches x 5 inches x 5 inches)	https://www.interstateplastics.com/cart.php	$ 63.73	1	$ 40.66	$ 104.39
	Chest and Head Plate	0.250" X 24" X 48" Natural HDPE Sheet	https://www.eplastics.com/HDPENAT0-250SR24X48	$ 39.56	1	$ 19.30	$ 58.86
94459A821	Threaded Inserts	Threaded Inserts for rosettes	https://www.mcmaster.com/94459a821/	$ 5.65	2		$ 11.30
							$1,070.90

Appendix E1. Final Project Economic Analysis and Budget

Table E1.1: Breakdown of Final Parts Ordered and Money Spent

Purchased Parts/Material							
Part No.	Item	Description	Vendor URL	Price	Quantity	Shipping	Total
	block inserts	EcoCut: High-Density Polyethylene (HDPE) Natural Plastic Block 2" x 3" x 6" - for Machining, Home Improvements, Prototypes, DIY Projects, Engineering	https://www.amazon.com/EcoCut-High-Density-Polyethylene-Improvements-Engineering/dp/B0DLPF795X	$ 15.75	3	$ -	$ 47.25
	Braided Carbon Fiber Rectangular Tubing	2" x 4" x 48" carbon fiber tubing (0.085" wall)	https://dragonplate.com/braided-carbon-fiber-rectangular-tubing-2-x-4-x-48	$ 238.25	1	$ 59.68	$ 297.93
	Carbon Fiber Pins	Rod - Pultruded Unidirectional - 0.250" x 12 Inches	https://www.rockwestcomposites.com/47317-l12.html	$ 12.99	2	$ 10.00	$ 35.98
	Round carbon fiber Tubing	Tube - Filament Wound - Sanded - 0.875 x 1.000 x 12 Inch - - Available up to 84 Inches	https://www.rockwestcomposites.com/35138-s.html	$ 42.99	2	$ 20.20	$ 106.18
	Carbon Fiber Head Brackets	send cut send dimensions to cut	https://app.sendcutsend.com/customer?	$ 55.64	2	$ -	$ 111.28
	Carbon Fiber Head Flanges	send cut send dimensions to cut	https://app.sendcutsend.com/customer?	$ 30.79	2	$ -	$ 61.58
	Adhesion Component	WEST epoxy resin	m	$ 51.47	1 qrt	$ -	$ 51.47
	Adhesion Component	WEST epoxy fast hardener	https://www.jamestowndistributors.com	$ 36.67	1 qrt	$ -	$ 36.67
	Sliding Bar and Adjustable Head Brackets Connective Support	HDPE Sheet | Natural High Density Polyethylene (2 inches x 2 inches x 9 inches)	https://www.interstateplastics.com/cart.php	$ 28.60	1	$ 40.66	$ 69.26
	Chest Support Body	HDPE Sheet | Natural High Density Polyethylene (4 inches x 5 inches x 5 inches)	https://www.interstateplastics.com/cart.php	$ 63.73	2	$ 58.00	$ 185.46
	Heat set inserts	Heat-Set Inserts for Plastic, Bra	https://www.mcmaster.com/catalog/131/3643/94459A270	$ 10.55	1 pack	$ 13.18	$ 23.73
	Chest and Head Plate	0.250" X 24" X 48" Natural HDPE Sheet	https://www.eplastics.com/HDPENAT0-250SR24X48	$ 39.56	1	$ 19.30	$ 58.86
							$1,085.65

Appendix F. Failure Modes and Effects Analysis

Table F1: FMEA Scenarios

Part # & functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes/Mechanisms of Failure	Occurance (O)	Current Design Controls/Tests	Detection (D)	Recommended Actions
All carbon fiber elements	Delamination	High interlaminar stresses and environmental factors (temp, moisture)	8	weight loading impact of patients	3	No current controls	2	Overlay fibers in different directions and reduce stress concentrations
entire design	Fatigue Failure	Crack propagation	7	Cyclic loading	6	FEA in design and factor of safety	8	FEA analysis
Chest Support and Head Rest	Moisture Absorption/Chemical Resistance	Moisture infiltratrated into material can compromise strength and weaken structure	3	Not properly cured material	2	Chemical resistance coatings on material	5	Medical-grade cushions overlay bare strcture
Any Component Adhered with Adhesive	Adhesive Failure	Disassembly and loss of function of device	8	Improper surface preparation and Inadequate curing time	5	No current controls	4	Add pins to secure components
Sliding Chest Rods	Wear of Material	Durability and fit issues	4	Repeated use	3	Surface treatments and hard/tough material choice	7	Carbon fiber has high toughness and hardness
Arm Mount Bracket	Shear Failure	High interlaminar stresses and environmental factors (temp, moisture)	9	High impact, Excesive loading	1	High factor of safety	8	FEA analysis
Angle Adjustment Rods	Wear /Deformation at Pin Hole Locations	Loss of device rigidity	3	Repeated use	4	Reinforce with adhesives	3	Smooth edges to reduce stress consentrations
Any Plastic Components	Microbial Entrapment	Patient Infection Risk	8	Cracks or scratches created on surfaces	2	Surface Inspections	4	Ensuring non-porous finish and regular sterilization
Metal and Thicker Composite Components	Failure to Achieve Radiolucency	Disrupts X-Ray Imaging	3	Thick Composite materials and most metals are not very radiolucent	5	Test various materials at various profiles under an X-Ray	2	Move metal componets out of field of interest and use low profile composites in the field of interest

Appendix G. Project Academic Assessment

Table G1: Project Academic Assessment

Course Code	Course Name	Skills Attainment	Project Applicability (1-5)
EMEC 103	CAE I- Engineering Graphics Communication	2-D CAD and 3-D solid modeling, drawing standards, fits and tolerances	5
ETME 203	CAE II- Mechanical Design Graphics	3-D modeling, GD&T, design for manufacturing, fits, tolerances, drawing standards, final drawing package	5
EGEN 203	Applied Mechanics	Shear and moment distributions, distributed force systems, FBD, shear and moment diagrams	3
EMEC 250	Mechanical Engineering Materials	Properties of engineering materials and material selection for engineering applications	5
ETME 215/216	Manufacturing Processes	Basic application of manufacturing processes utilized in industry and equipment utilized	3
ETME 310	Machining and Industrial Safety	Use of machining equipment, machine shop safety	5
ETME 303	CAE Tools in Mechanical Design	Problem-solving with aid of FEA models	5
ETME 341	Machine Design	Factors of safety, life cycles and fatigue	3
EGEN 310R	Muli-Discipline Design	Project Management, Scheduling, Team Dynamics	5
EMAT 462	Manufacturing of Composites	Processes of manufacturing composites, strength analysis and logistics of composites	4

Appendix H. Project Test Plans

Original Test Plans:

Acceptance Testing: Pass/Fail

1.) Weight Limit Test (350 lbs)

Goal: Support a max load capacity of 350lbs without compromising safety or stability of the ergonomic patient positioning device

Test Procedure: 2 ways (person vs object testing)

Person = lay a 350lbs person on the patient positioning device and visually inspect device for any signs of failure

Object = stack on 350lbs of objects in the spinal column section of the patient positioning device with regards to where a human would have more or less mass and visually inspect device for any signs of failure

Data Acquired: Confirmation of patient positioning device being built to support max capacity load limit or not which allows our team to know if design changes must be made for safe operation of device.

Schedule of test: Anytime from November 10^{th}-23^{rd} before final test results and specifications are due.

Test Equipment and facilities: Either find somebody from campus that matches max capacity load or utilize heavy machinery equipment from innovation alley to do testing at Montana State.

Purpose of Test: Ensure safety and stability of the patient positioning device for weight limit to prevent injury.

What constitutes success/failure for test: Success = no signs of failure with max load capacity, Failure = signs of failure upon max load capacity

2.) Head Support Lateral Tilt (Steris Cmax: 20° and Skytron Elite: ±30°)

Goal: Ensure the current patient positioning device prototype can adequately adjust in the same way the metal prototype does to properly work with both surgical/medical tables.

Test Procedure: Lay the prototype on a flat surface/table and utilize a measuring device to ensure the headrest can go positive 30° and -30° from 0 to prove it will work with both medical tables.

Data Acquired: The angles at which the headrest can go (maximum and minimum values from a flat 0° start).

Schedule of test: Anytime from November 10th-23rd before final test results and specifications are due.

Test equipment and facilities: A protractor or potentially angle block or clinometer that can measure 20-30° to be done in innovation alley workspace at Montana State.

Purpose of Test: Validate the radiolucent patient positioning device has the same capabilities of adjustability as the old patented metal prototype.

What constitutes success/failure for test: Success = The headrest can successfully go up a positive 30° and down a -30° and therefore be within the range to work with both medical tables and validate the radiolucent prototype maintains the same adjustability. Failure = The headrest fails to rotate the +30° and the -30° from 0.

<u>Functional Performance Testing: Meets Numerical Value</u>

1.) Radiolucency Requirement (clear Xray images of spinal column)

Goal: Provide clear and hence darker pixel intensity images along the spinal column view of the patient positioning device

Test Procedures: Take several images of the patient positioning device prototype under the X-ray how it would be utilized in surgery. Upon collection of the images, analyze with a radiologist and/or software online that can provide numerical grey-level values for pixel intensity and determine if the area of interest (spinal column) provides clear images and none of the nearby components of the design cause unclear images.

Data Acquired: X-ray images taken to be put into software that analyzes the mean, median, and range of pixel values within a delineated region of interest (spinal column of a patient).

Schedule of test: November 4th after 3pm

Test equipment and facilities: X-ray imaging machine that uses digital radiographs at Livingston Hospital

Purpose of Test: See if the prototype built adheres to the project requirement and specification of being radiolucent and provide medical professionals with a piece of equipment that allows them greater chance of seeing a clear image compared to the traditional metal interference images they currently have.

What constitutes success/failure for test: Success = low gray level values (0-8 bit system) along the area of interest that appear as black, dark grey or grey signifying radiolucency. Failure

= high gray level values (255 in an 8 bit system) that appear as white, light grey, or bright white areas appearing radiopaque and indicating most X-rays were absorbed.

2.) Dynamic Performance

Goal: Observe and analyze the types of stresses on the patient positioning device to ensure it can operate within appropriate bounds and won't buckle/fail under scenarios it will encounter.

Test Procedures: Either as assembly models or part models given software used, perform FEA analysis to analyze the bending moments, axial, tensile, and shear stresses that occur in various areas considering varying weight and types of stress seen for each section of model.

Data Acquired: Values that correlate types of stress experienced including axial, shear and bending moments

Schedule of test: Anytime from November 10th-23rd before final test results and specifications are due.

Test equipment and facilities: SolidWorks or equivalent software that does FEA analysis and can look at various kinds of stress given a capacity load to be done in computer labs in Norm at Montana State.

Purpose of Test: Ensure that the way the patient positioning device is currently built can sustain everyday use it will have and all the varying types of stresses it will see on a daily basis.

What constitutes success/failure for test: Success = numerically and visually looking at the model given of results the prototype doesn't fail under the load given. Failure = numerically and visually the model shows signs of failure and buckling under the appropriate loads given for daily use of device.

Testing Planned vs Specifications Given

1.) Weight Testing --> Performance specification that states it must be able to accommodate a 350lbs max capacity load

2.) Head Tilt Testing --> Functional specification that states an angle of tilt necessary for each of the two tables the device accommodates and in problem requirements that state maintaining current metal prototype adjustability and range of motion needs.

3.) Dynamic Performance Testing --> Found in problem requirements structural integrity to endure repetitive stresses.

4.) Radiolucency Requirement Testing --> Found under performance specifications for a material not too dense and in problem requirements that state a deliverable that the chest support and structural components are radiolucent.

Modifications to Test Plans:

Weight Limit Testing- not able to be tested due to lack of access to one of the medical tables the Radiolucent Patient Positioning Device locks into to secure the prototype down before adding substantial weight.

Proven via FEA analysis by applying loads to simulate a 350lb weight downwards, and results deemed our prototype able to withstand this weight.

Head Support Lateral Tilt- proven through visual inspection with angled measuring tool, and both head supports (same for either table) easily rotated 45+ degrees to maintain metal prototype's adjustability needs.

Radiolucency Requirement- While Cat Scan imaging was performed to assess how spinal column area of interest images looked, clarity of the result wasn't determined by the pixel density but instead by Hounsfield Unit Density that evaluated the density of varying parts of the device and patient. While test performed was similar to Xray transmissibility, it was more geared towards differentiation of tissue to fat to bone to navigate an image for clarity to give a diagnosis. As shown in following appendix for test results, images for iteration two of the device came out radiolucent.

Dynamic Performance- According to the requirements of the project, the prototype created needed to be able to endure varying stresses including torque, moments, strain and stress to ensure safety and reliability of the prototype. Original testing methods were modified from a strain gage to FEA and hand calculations to ensure that the prototype wouldn't fail under given load bearings it would endure, and as shown in the analysis appendix, the final prototype successfully undergoes the typical stresses it would in industry without failure.

Appendix I. Test Results

The only tangible test results for this project not already shown previously in the analysis section are the ones that were performed to assess radiolucency transmission to ensure at least 80% which defines a radiolucent device.

Due to the several iterations done throughout the build process and limited knowledge of Xray imaging technology and densities of material in correlation to how they appear in these images, thorough images were taken and analyzed.

<u>Iteration 1 (Preliminary Testing):</u>

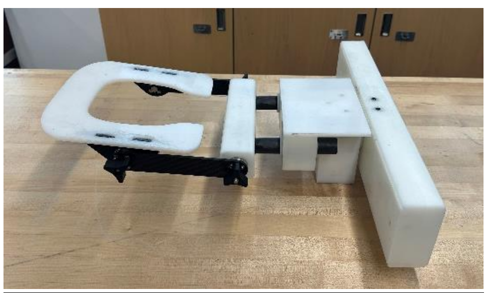


Figure I1: Visual of Iteration 1 when Initial Preliminary Testing was Performed

Figure I1.1: Xray Image Depicting Center Chest Support Block Radiolucency

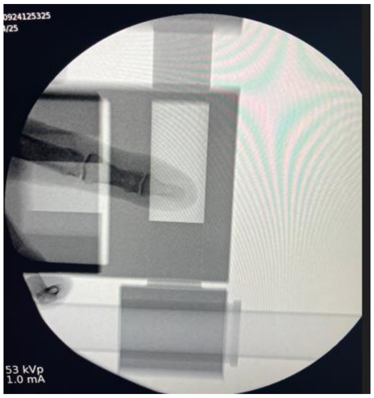


Figure I1.2: Closer Chest Support Block Xray Transmission Image

Figure I1.3: Xray Image Showing 'Artifacts' over Human Hand

Figure I1.4: Another View of Hand Over Block Thickness in Iteration 1

Conclusions from Testing Iteration 1:

The test results gathered from the first iteration provided valuable insight into how the main framework of our prototype looked in an Xray, as well as provided information on how dense tissue and material causes cupping or shading effects called ‘artifacts’ that interfere with a medical professional’s ability to diagnose due to the unclear blurring effect.

After collection of these initial images, plans to change the design began specifically where thickness gradients were large and more defined sharp edges on material was left.

The thick HDPE block causing such a dark and unclear image underperformed from what the group assumed since the material choice was due to the density. None of the group knew even a less dense material could come up as unclear on imaging when it exceeds a certain thickness.

Iteration 2 (Final Testing):

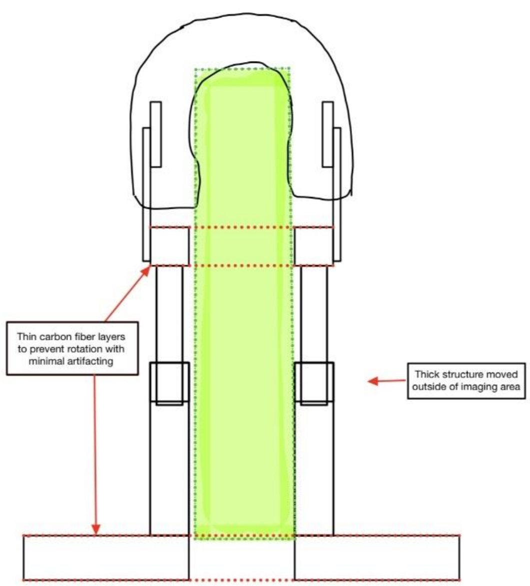


Figure I1.5: Design Changes Made Between Testing

Figure I1.6: Cat Scan of Entire Iteration 2 Design Moving Structural Components Outward

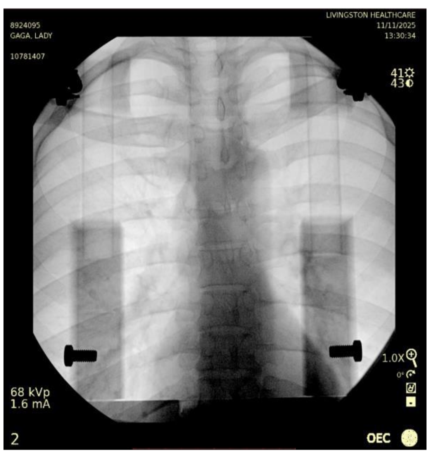


Figure I1.7: Iteration 2 Under Xray Depicting Clear, Radiolucent Image of Bone Tissue in Spinal Column View

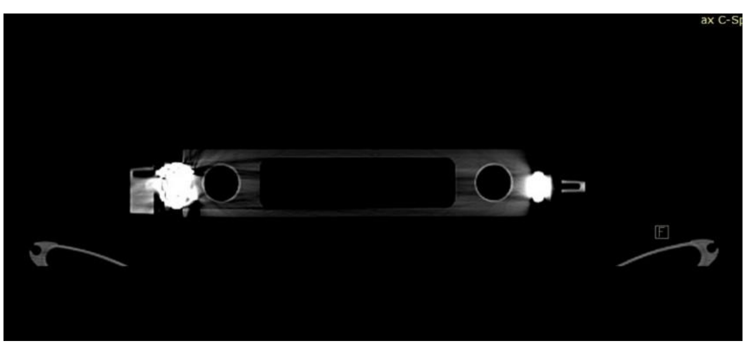


Figure I1.8: Sliding Rod Block Design Change Shows Improvement of Light Passing Through

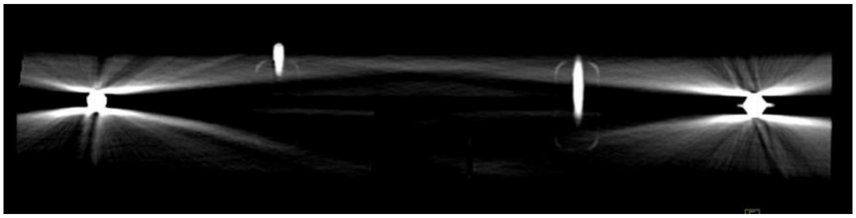


Figure I1.9: Another Cat Scan Image that Shows Only Metal Components Cause Scattering

Conclusions from Testing Iteration 2:

As shown in the figures provided above, it's clear that the iteration 2 changes made a difference when shown under an Xray imaging device. Only metal components caused slight scattering in light, but this wasn't an issue since all the metal and other structural components were moved outside the spinal column area of interest in this new design.

The breakdown of the central chest support block into two different parts for iteration 2 ensured smaller thickness gradient to reduce artifacts and adding chamfers on sharper corners near edges ensured more clarity on images. The final prototype having undergone the various design changes overperformed in its goal of radiolucency and pleased our sponsors and their ability to comfortably and confidently use the device to diagnose patients.

Appendix J. Final Prototype

Below are visuals of how the final prototype that go handed off to the wonderful sponsors of ErGus Surgical Innovations, LLC looked.

Figure J1: Image One of Final Prototype

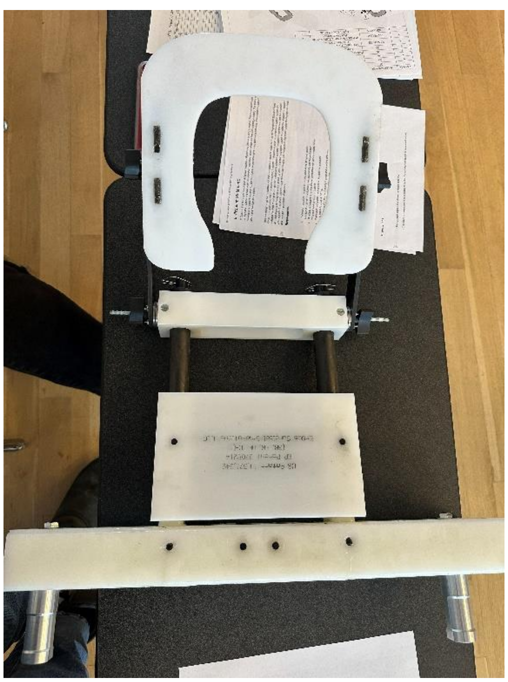


Figure J1.1: Image Two of Final Prototype

Figure J1.2: Handoff of Prototype to Sponsors Concluding Capstone 1 & 2 Project