DESIGN, TESTING, AND EVALUATION OF STANDS TO FACILITATE TRACTOR CLUTCH REPAIRS

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2014

TITLE : Design, Testing, and Evaluation of Stands to Facilitate Tractor Clutch Repairs

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DATE SUBMITTED : June 6, 2014

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ACKNOWLEDGEMENTS

I would like to thank Dr. Zohns for being willing to take time to be my senior project advisor, Virgil for allowing me to work on my project in the shop and helping me with various issues, Matt Evers for sometimes keeping the shop open later, and my dad Dale Sperling for sponsoring the project.

ABSTRACT

This senior project highlights the design process, fabrication, testing, and evaluation of a set of stands used to support the midsection of a 1950's Minneapolis Moline GB tractor in order to separate the engine from the transmission for clutch repairs. This design consists of a stationary rear leg that bolts to the bottom of the transmission and a wheeled dolly that bolts to the engine frame rails. The stands are constructed of steel for strength and durability and fully adjustable to accommodate changing variables.

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INTRODUCTION

Background Information

On farm tractors, the clutch assembly is located in the transmission bell housing directly between the engine and transmission. This means that any repair work to a tractor's clutch requires the engine to be unbolted from the transmission. However, in farm tractors, the engine and especially the transmission housing provide most, if not all of the structural integrity of the tractor rather than a dedicated frame. This means that if clutch repair is required, the tractor must be physically separated front to back where the engine is mated to the transmission. Due to the heavy weight and pivoting front axle on most farm tractors, this is no simple task. There are a number of ways to accomplish this. Many people use some combination of blocks, jacks, and an overhead hoist like the one shown in Figure 1.

Figure 1: Splitting a tractor using blocks, a jack, and a hoist (HJCtractor 2009)

These methods, however, tend to be rather hazardous to those performing the work, especially with larger tractors.

The project's sponsor has a 1952 Minneapolis Moline GB he drove 20 years ago when he worked in the bean harvesting business which has recently sat idle for many years due to a broken clutch. The owner was not comfortable with the safety of previously mentioned methods and did not want the hassle and cost associated with taking it into a repair shop. This tractor has an un-ballasted weight of 7500lb and a wheelbase of 82.5 in making it a relatively large tractor. Additionally, an overhead hoist was not available which would create further difficulty in separating the tractor. As a result, a safe and reliable ground based system was needed.

Objective

The objective was to design, fabricate, test, and evaluate a safe and reliable ground based solution regarding the need to separate an early 1950's Minneapolis Moline GB tractor for clutch repair. After meeting with the tractor's current owner, previous users who had performed clutch repairs, and project advisor, the following design criteria were established:

- The front engine section must be mobile, although the rear section could be stationary.
- The dolly for the front engine section must have a wide stance to prevent the engine from tipping about the pivoting front axle.
- Direct steering control needed on the front dolly in order to easily line up the tractor when re-mating the engine and transmission.
- Both front and rear stands must have an adjustable height.
- The front dolly must be able to adjust the side to side tilt of the forward section.
- The engine must have an adjustable height independent from that of the engine frame rails.
- Both stands must be able to handle all shock and unforeseen load scenarios including horizontal side loading without danger of failing.
- Stands must be simple and durable enough to sit for long periods of time without significant detrimental effects.
- Front dolly should bolt to existing holes in the engine frame rails and support the bottom of the engine.
- Rear stand should bolt to existing holes in the bottom of the transmission housing.

LITERATURE REVIEW

Tractors have become a crucial aspect of modern farming practices. Modern farm tractors allow farmers to very precisely grow large acreages of crops without the need for large amounts of workers. However, with all the improvements that have been made since its introduction, modern farm tractors bear little resemblance to the early tractors. Because of all these improvements, modern tractors tend to be rather expensive. The purpose of this review is to provide a brief history of tractor development and address the high cost of modern tractors. Additionally, it will also highlight some clutch maintenance basics, and specs for a 1950's Minneapolis Moline model GB as it relates to the accompanying project.

History and Importance of the Farm Tractor

Prior to tractors, farming tasks were accomplished by horse or mule teams which, although effective, required extreme amounts of upkeep and were rather expensive to feed. Up to 25% of farmland was required to grow food for farm work animals (Goering 2008). The invention of the steam engine brought about steam tractors such as the one in Figure 2 as early as 1849, but these were cumbersome and not very practical.

Figure 2: Case 1923 steam tractor (Rob H. 2006)

However, as early as 1907, tractors with internal combustion engines (Figure 3) began to appear and started to revolutionize farming (Goering 2008).

Figure 3: 1927 John Deere D (Spiegelberg 2012).

The use of internal combustion engine tractors became crucial during the labor shortages of World War I (Gray 1945a). However, farmers had no objective or uniform comparison of these new tractors to separate the quality ones from the poorly designed ones. In order to create an objective uniform way to compare tractors, the Nebraska tractor tests were adopted as a standard for rating agricultural tractors (Gray 1945b). The first significant improvement to early tractors came in the form of a PTO (power take off) installed on an IHC (International Harvesting Company) tractor in 1918 (Goering 2004). A PTO is a splined output shaft on the rear of the tractors that can be used to mechanically drive implements. However, despite its benefits, these tractors were still poorly suited for cultivating row type crops and draft animals were still needed for these purposes. As a solution to this problem, IHC introduced their Farmall row crop tractor 1924 (Figure 4) which was much better suited for row crops and completely eliminated the need for draft animals (Goering 2008).

Figure 4: 1924 Farmall row crop tractor (Vossler 2009).

A third breakthrough in the tractor industry came with the advent of rubber tires in 1932. These rubber tires improved versatility and traction over the all-steel wheels (Gray 1945b). Later, in 1939, the Ford tractor company developed the first hydraulic system which they placed on their 9N tractors. The hydraulic system made it significantly easier for the operator to raise and lower implements and eliminated the need for the operator to physically raise and lower the implement. With the advent of hydraulics, 3 point hitch style implements began to gain popularity. However, each manufacturer had their own setup which made it difficult or impossible to interchange implements between tractor companies. As a result, in 1959, ASAE (American Society of Agricultural Engineers) standardized the 3 point hitch making implements interchangeable between brands and

easier to attach. Since the early 1970's the basic functionality of tractors has remained the same, although it has seen the introduction of many new safety, ergonomic, and performance improvements. Safety improvements include things such as PTO guards and rollover protective structures (ROPS). ROPS can be a roll bar, a structurally rigid cab, or any other structure that prevents the operator station from becoming crushed in a rollover accident. Ergonomic improvements include air-conditioned cabs and air ride seats allowing the operator to stay out of the dust and have to absorb much less jarring. Performance innovations include the advent of four wheel drive, front wheel assist, and GPS interfacing. Four wheel drive and front wheel assist are essentially the same thing. They both apply tractive force to the front wheels allowing tractors to pull larger implements. GPS interfacing allows tractors to create much straighter rows and continuously vary application rates to maximize productivity. As a result of over 100 years of development, the modern farm tractor has become an engineering feat that allows one farmer to perform the work that historically required many men (Goering 2008).

High Cost of Modern Tractors

Modern farm tractors have become a technological marvel. However, this means that they tend to be rather expensive. A new mid-size utility tractor, such as the John Deere 5085E (Figure 5) typically costs around $45,000 for the base model (John Deere 2013).

Figure 5: John Deere 5085E utility tractor (John Deere 2013).

A farmer who will use this tractor on a daily basis can likely justify this cost and may even pay extra for some upgrades. However, for someone who does not have a constant need for a tractor, such as a rancher or small landowner, this is not a justifiable investment. Instead, these people are likely to look at significantly older equipment since a decent, running 30-40 year old tractors can be found for around $12,000 (Ag Source 2013). However, these older tractors tend to require more maintenance than modern ones, especially in heavy wear components such as the clutch (Brake and Clutch Supply 2001).

Farm Tractor Clutches

A clutch is a device that engages/disengages the engine from the drive train and allows for smooth starts, stops, and gear changes (Thakur 1975). Since clutches are a high wear

point in the drive train, they require periodic maintenance and replacement (Brake and Clutch Supply 2001). There are many possible causes for a clutch to not function properly. Some of the most common problems are chattering, dragging, finicky engagement, slippage, and vibration. Chattering can be caused by misalignment, a bent clutch shaft, unequal or broken springs, warped or cracked pressure plates or disks, and contaminated friction surfaces. Dragging can be caused by misalignment, poor engine tuning, dirt accumulation, or damaged pressure plates. Finicky grabbing and releasing is likely due to oily, greasy, glazed, or worn out friction surfaces, or misalignment. Slippage can be caused by worn or greasy friction surfaces, weak or broken springs, or improper adjustment. Vibration is commonly caused by a bent clutch shaft, defective disk, or flywheel misalignment. Proper adjustment and maintenance are crucial to maximizing the life of a clutch and prevent unnecessary damage. As a rule of thumb, when adjusting a clutch, there should be a 2-3 mm gap between the thrust ring and release mechanism and the dead travel should be 20-30 mm (Thakur 1975). Additionally, symmetrically acting components such as springs and weights should all be replaced at the same time to maintain uniformity.

There are two main types of clutches: over-centering and spring loaded which can be classified as either wet or dry and single or multi disk. Over-centering clutches (Figure 6) have a driving plates attached to the flywheel with friction discs attached to the front and rear faces. The driving plates are sandwiched between two driven plates that are connected to an output shaft. This type of clutch is operated by a hand lever which engages or disengages the driven plates from the driving plate. This type of clutch is common on non-mobile industrial applications and tractor PTOs (power take off) since it will stay engaged or disengaged without input. These clutches were also used on some older tractors; however, all newer tractors utilize spring loaded clutches (Goering and Hansen 2004).

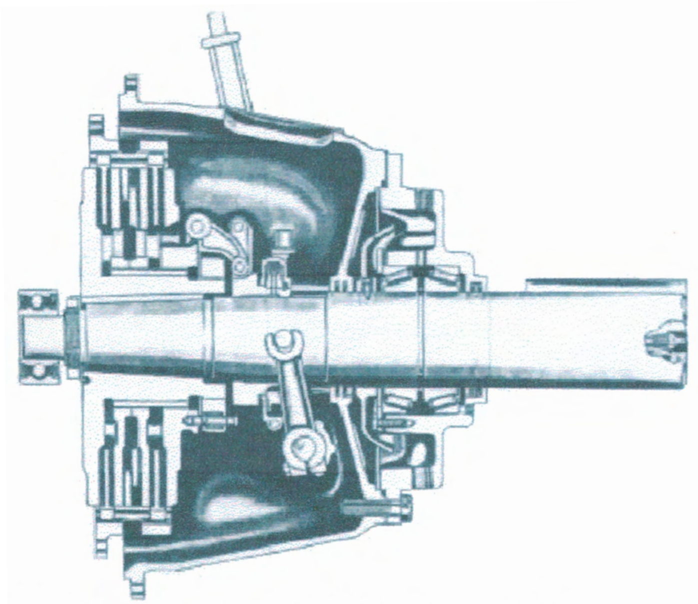

Figure 6: Over center clutch (Goering and Hansen 2004).

A spring-loaded clutch (Figure 7) consists of a pressure plate, friction disk, springs, and a throw-out, or release bearing and is typically operated by a foot pedal. The pressure plate housing is connected directly to the engine flywheel. The friction disk is between the flywheel and pressure plate and connected to a splined output shaft. Without operator input, the springs will keep the friction plate engaged against the pressure plate. When the clutch is disengage, the throw-out bearing is pushed into the spring arms forcing them to rotate away from the clutch which pulls the pressure plate back and allows the friction plate to disengage. Since these clutches are spring operated, they are always in the engaged position unless the operator is pushing the release pedal (Goering and Hansen 2004).

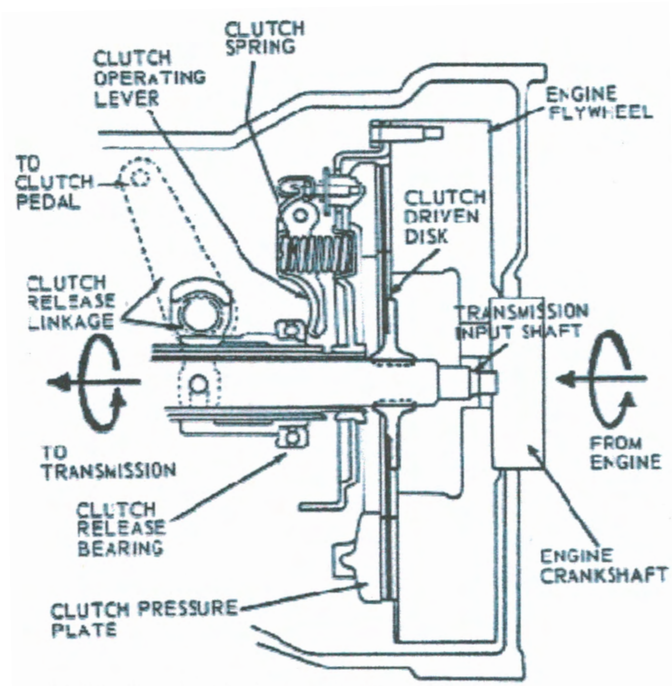

Figure 7: Spring loaded clutch (Goering and Hansen 2004).

Specs for a 1950's Minneapolis Moline Model GB

Early 1950's Minneapolis Moline GB tractors such as the one in Figure 8 utilized an over-center style clutch.

Figure 8: 1950's Minneapolis Moline to be split in half.

These clutches utilized a double dry disk that has a 10.75 inch outside diameter and a 5.375 inch inside diameter (TractorJoe 2013, Peter 2013). Although the clutch uses a double disk setup, aftermarket all-in-one self-contained clutch units are available to simplify clutch replacements.

Fuel type for these tractors was either gasoline, diesel, or LPG (propane) and could have a range of horsepower depending on the engine size and fuel type. The tractor this project will be used on is LPG powered and has a power rating of at 50 drawbar hp and 64 belt hp. Without ballast, this type of tractor weighs approximately 7340 lb. but weighed as much as 12100 lb. when subjected to the Nebraska Tractor Test. Without ballast this tractor has a weight distribution of 30% front and 70% rear, but the recommended ballasted distribution used for the Nebraska Tractor Test was 21% front and 79% rear (Larsen et.al. 1955).

PROCEDURES AND METHODS

Design Procedure

The stands to be designed have to both support the tractor's midsection during separation and allow the two halves to roll apart far enough for easy access to the clutch. To accomplish this, the design consists of two separate components. The first component was a dolly (Figure 9) that fits under the engine and bolts to existing holes the engine frame rails in addition to clamping to the frame rails (Figure 10).

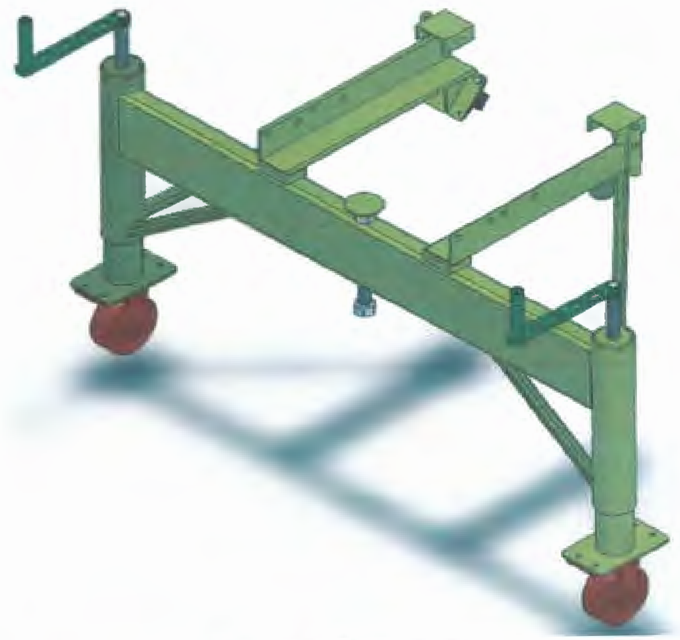

Figure 9: Front dolly

Figure 10: Front dolly bolts to existing holes and clamps to engine frame rails

This dolly allows the front portion to roll away from the rear portion. Because the front portion was mobile, the rear portion can be stationary to simplify the design. The second

component was a stand (Figure 11) that bolts to the bottom of the transmission to support the rear section (Figure 12) using existing threaded holes.

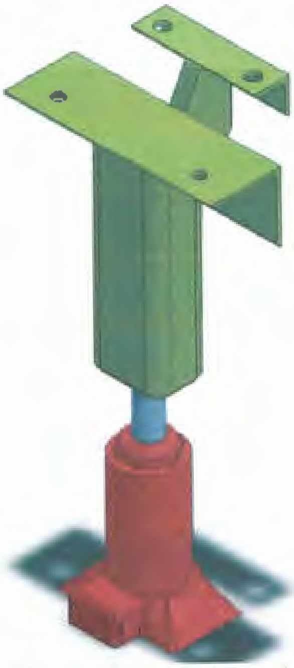

Figure 11: Rear stand

Figure 12: Rear stand bolts to existing threaded holes in bottom of transmission

Adjustment. In order to ensure that the stands will be exactly the right height initially and when re-mating the tractor, both front and rear components will have vertical adjustment so that varying tire pressures or sizes can be easily accounted for. The height of the front dolly has a 1"-8 lead screw controlled by a hand crank (Figure 13) on each side that will provide 8" of vertical adjustment.

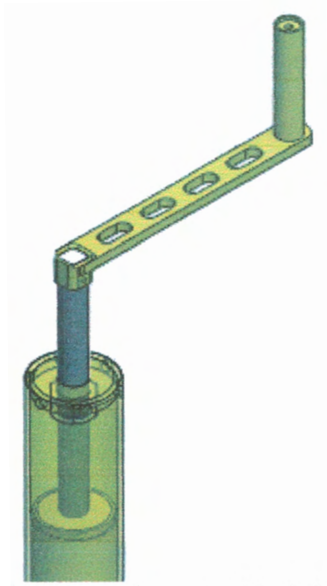

Figure 13: Lead screw and hand crank control height adjustment on front dolly

The rear component sits on top of an 8 ton bottle jack that sits captive inside the bottom of the stand (Figure 14) that provides 6.25" of vertical adjustment.

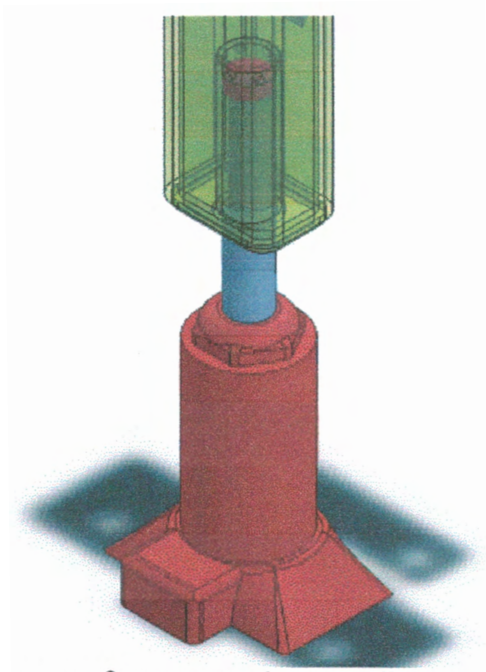

Figure 14: Adjustment for rear stand accomplished using a bottle jack

To hold the jack captive without damaging the cylinder's finish, a removable sleeve with a tight fit in the recess in the bottom if the stand was placed around the screw portion of the jack as shown in Figure 15

Figure 15: One-half of the sleeve used to create a tight fit

Additionally, when not being used, the jack can be removed from the stand and used for other purposes eliminating the need for a dedicated jack Figure 16.

Figure 16: Stand and sleeve are removable from jack

Additionally, it is possible that the tractor will not be level side to side, such as if the rear tires were mismatched. Rather than having to adjust the air pressures to make it level, the two vertical legs on the front dolly are independently adjustable allowing the front portion to be tilted within reason to match the angle of the back.

Maneuverability. Splitting the tractor requires at least one section to move away from the other; however, one section can remain stationary. In order to simplify the design, the rear portion will remain stationary while the front portion can roll away. The main reason for choosing to make the front mobile was because the front tractor wheels were free turning without the added resistance of the transmission and final drive making the front it easier to move. Additionally, the front wheels do not have weights in them and the Nebraska tractor test indicates that the front is lighter than the rear meaning that there is less inertia to contend with when moving the front portion.

In order to have precise directional control over the front section when moving it, it was desired to have direct steering input to the dolly wheels. Therefore, instead of using swivel casters, rigid casters were affixed to the height adjustment portion of the vertical legs as shown in Figure 17.

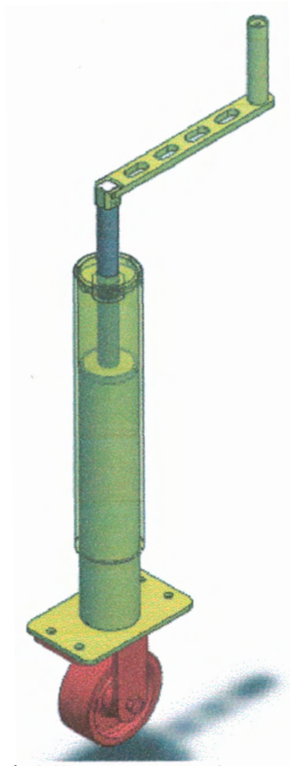

Figure 17: All thread rigidly connected to casters via the male tube

This way, the angle of the wheels can be directly controlled by turning the handle used to control the height screw. This does require the legs to be slightly raised or lowered to change the wheel angle. However, the screw being used has eight threads per inch so straightening the wheels from perpendicular to parallel with direction of travel (90 degree rotation) only changes the height by 0.063 inches which is within the tolerances of re-mating the tractor so it should not present an issue. Additionally, in order to minimize added rolling resistance, steel wheels were used to make separation as easy as possible.

<u>Safety</u>. Adequacy of members to prevent the possibility of failure was probably the most crucial design aspect. This is because if something was to fail and the tractor was to fall, it could very easily result in severe injury or even death. As a result, all structural members were designed to single-handedly support 7000 lb. even though this scenario is thought to be impossible under static loading. This was done because there is no information available regarding weight distribution throughout the tractor making the actual load to be on the dollies unknown. Additionally, this also guards against the possibility of shock loads or unforeseen loading conditions. Additionally, due to the potential ramifications of a failed stand, a minimum safety factor of 1.5 was used on top of the full tractor weight when designing structural components. The main cross member is designed to support 7000 lb that could be applied symmetrically 18 in apart or concentrated on one side 9 in away from the center. The symmetrically placed loads resulted in the highest internal stress of 5528 psi on a piece of 2 x 8 x 3/16 rectangular steel tubing and a safety factor of 5. This cross member could also see a torsion load if something caused a force at the bottom of one of the legs. However, to prevent this loading scenario, diagonal braced were added to handle these forces. The female tubes of the vertical legs are fully braced so they are not a potential point of failure in this design. The male tubes of each vertical leg were designed to support 3500 lb and support compression and potential bending forces. The given loading causes a stress of 21800 psi on 2-7/8 in J55 grade casing pipe resulting in a safety factor of 1.5. The main post of the rear stand is designed to support 7000 lb in compression and potential bending forces. This member is constructed of 4 x 3 x 3/8 rectangular steel tubing with a maximum internal stress of 18809 psi for a safety factor of 1.5. Structural design calculations can be found in appendix B.

<u>Ergonomics.</u> Due to constraints on the tractor, there was not a lot that could be done to the overall design from an ergonomic perspective. However, there were a few smaller design aspects that were incorporated to make things easier for the users. One the ergonomic improvements was to add rubber grips to the handles used to tilt the front dolly into place as shown in Figure 18 providing a better grip.

Figure 18: Rubber handgrips on handles used to tilt front dolly into place

Additionally, the height adjustment handles consist of a two-part assembly that allowed the grip to spin independent of the arm and have a knurled the surface for a better grip. On the rear stand, there are four handles, one on every side, so no matter how the user is positioned relative to the stand, there is always a convenient way to grab it. When rolling the front dolly under the tractor, the front edge rolls on the caster shown in Figure 19 rather than simply dragging on the ground making this step much easier.

Figure 19: Additional caster was added to make rolling under tractor easier

When the dolly is not being used, there is a removable third leg that can be installed (Figure 20) allowing the dolly to stand upright and easily movable as shown in Figure 21.

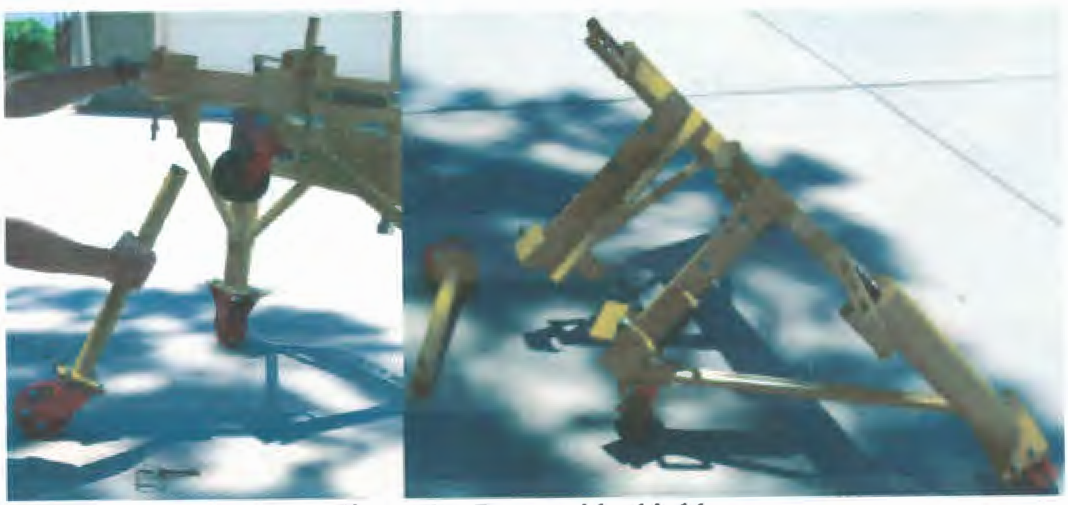

Figure 20: Removable third leg

Figure 21: Third leg allows for easy movement to work location

Construction Procedure

Materials Procurement. The project sponsor already had several pieces of structural members and reasonable effort was made to utilize these pieces of material in order to minimize costs. However, a couple components required additional materials. These additional materials were acquired from B&B steel's remnant supply at a discounted rate to further reduce cost.

Fabrication. Once the design was completed, it was completely fabricated in the BRAE shop. Some of the available pre-existing material was rather old and had developed a large amount of surface rust. As a result, the first step was to use a media blaster or wire wheel to clean it. After that, a band saw was used to cut all parts to the desired length (Figure 22).

Figure 22: A band saw was used to cut all parts to desired length.

A DRO (digital read out) was used to accurately drill holes in the mounting brackets (Figure 23**Figure 1**).

Figure 23: A mill with a DRO was used to precisely lay out holes

Additionally, a lathe was used to make custom end caps for the male and female vertical legs to attain the best possible load bearing properties (Figure 24).

Figure 24: A lathe was used to create custom end caps

Once all cutting, drilling, and machining processes were finished, the parts were then welded into their respective assemblies as shown in Figure 25.

Figure 25: Welding together finished parts

The same procedure was also repeated for the rear stand. The parts were cut with a band saw and a DRO was used to layout all holes. The end cap and gusset for the main post were created on a mill for the best possible load transfer. Additionally, the tube to hold the bottle jack captive required some additional lathing.

Once completed, the project would be primered for paint durability and painted the tractor's factory color scheme so it will match once the tractor is repainted to its correct color (Figure 26).

Figure 26: Project was painted to match the tractor's factory paint

Test Fitting. To minimize the amount re-doing required if there was an issue with the fit of the tractor, an initial test fit was performed before the project was completed. Once all the major parts and subassemblies had been fabricated, these major components were tack welded together and a field trip was made to test fit the project on the intended tractor.

Testing Procedure.

Testing was made somewhat complicated for a couple reasons. The first reason was due to the fact that the tractor was not available for most of the construction. This meant that continuous test fitting to ensure there were no fabrication or design errors was not

possible. Additionally, it was not practical to split the tractor before the due date due which limited what could be done for a final evaluation.

Simulated Shop Testing. It would be highly unfortunate to discover a critical design flaw or fabrication error once the weight of the tractor was placed on the stands. In order to prevent this from happening, a tractor pull sled weight weighing approximately 4500 lb. was placed on top of the front dolly as shown in Figure 27.

Figure 27: A tractor pull sled weight was used for testing with a simulated load

Unfortunately, since much of the stability of the dolly comes as a result of being bolted to the frame rails, stability during simulated testing was a significant issue. Due to the lack of independent stability, 4500 lb. was the most weight that could be safely applied without serious danger of tipping...

Unfortunately, the rear stand is not independently stable enough to safely place large simulated loads on. However, there are no moving parts (aside from the 8 ton bottle jack) and it has a high degree of structural integrity so there should be little possibility of its failure.

Final Testing. Unfortunately, it was not feasible to utilize the stands for a full tractor split prior to the project due date. Therefore, final evaluation will only consist of an installation on the tractor as shown in Figure 28 and Figure 29.

Figure 28: rolling front dolly under tractor

Figure 29: front dolly and rear stand installed on tractor

When performing the actual separation and clutch repair, the tractor will be moved onto a concrete pad for a more stable environment. However, for the final testing, since the tractor was not actually being separated, the installation was performed with the tractor still on dirt since the uneven height could be accounted for by the height adjustment. For the final testing, the dolly legs and jack were raised until they started to lift up the tractor since they were designed for full tractor weight.

RESULTS

Simulated Shop Testing

During the simulated shop testing, 4500 lb. was successfully placed on the dolly (Figure 30) everything functioned as desired under loaded conditions and there were no issues that arose.

Figure 30: Simulated testing

It was somewhat difficult to raise the height but the required force was reasonable given the weight, and theoretically, there should not need to be much height adjustment under loaded conditions.

Final Design and Testing

A dolly for the front half and stand for the rear half were successfully designed, built, and installed on the tractor. The components bolted on and functioned as desired as shown in Figure 31.

Figure 31: Both front and rear components work as intended

The dolly legs and jack were able to successfully start lifting the tractor off the ground. Since the setup was able to function under full tractor weight and the operating weight is only one portion of the tractor, I can be reasonably confident that it will function as desired.

Due to the removable third leg added after the initial test, the project can be easily wheeled to location by one person (Figure 32), although two people are recommended for the installation and needed for separation.

Figure 32: dolly easily moved to work location by one person

The final weight was 130 lb. for the front dolly and 30 lb. for the rear stand excluding the weight of the jack. 130 lb. for the front seems rather heavy, but that is the price to be paid for a sturdy dolly. Additionally, the dolly does not need to be lifted up, just tilted into position, which is not that hard with a person on each side.

When not in use, all parts needed for the stands can fit onto the front dolly as shown in Figure 33.

Figure 33: Rear stand can be hung on front dolly for easy storage

Additionally, the front dolly has a rather narrow footprint allowing it to be stored in small spaces (Figure 34).

Figure 34: Design has small footprint for easy storage

When starting out, this project had an initial budget of $550. However, due to the amount of remnant steel and wheels the sponsor already had, the entire project was able

to be completed significantly under budget with a final out of pocket cost of only $120 to the sponsor.

Although it required some modification, the final result worked as intended and came in under budget. As a result, the sponsor was pleased with the result, which is the true measure of the success of a project.

Figure 35: The sponsor and designer next to the installed completed project

DISCUSSION

Initial Testing.

As a generalization, the rear stand and front dolly worked as intended as seen in Figure 36. However, a few issues became apparent.

Figure 36: dolly rolled under and affixed to tractor

The first issue that was discovered was that two bolts on the transmission that were to be used to mount the rear stand also double as drain plugs (Figure 37).

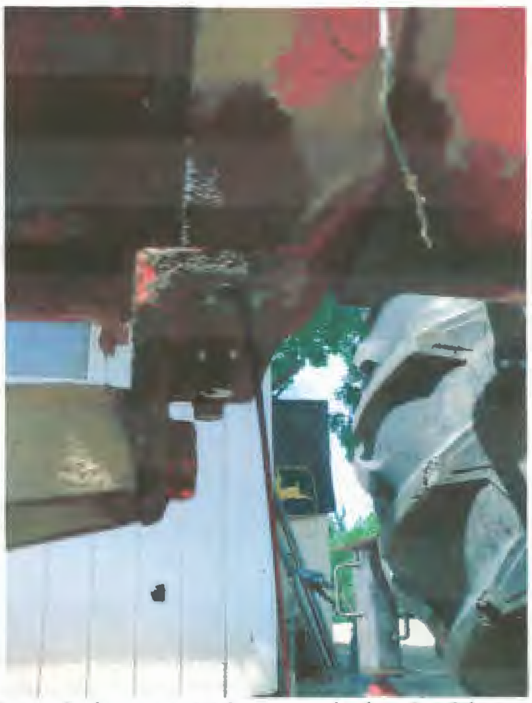

Figure 37: Intended rear stand mount bolts double as drain plugs.

However, after a quick analysis, it was determined that they were only a drain for fluid that had leaked into the clutch cavity, which needed to be drained before separation

anyway. As a result, it was concluded that a design change was not necessary and the bolts could still be used. Additionally on the rear stand, some welding deformation became apparent (Figure 38) requiring a spacer to be welded on and a couple holes re-drilled.

Figure 38: Welding deformation caused the rear stand to not fit properly

On the front dolly, it was discovered that there was slightly different geometry between the holes on each frame rail as shown in Figure 39, which had not been previously noticed. Additionally, the sponsor has a second similar tractor that the stands should fit for if that clutch ever breaks. This second tractor, although thought to be identical, had different hole locations.

Figure 39: Hole location was not the same on both engine frame rails.

To solve this problem, the frame rail mounting pieces were re-made with two sets of holes (Figure 40) so that it would match both tractors.

Figure 40: two unique sets of holes were needed to match both tractors

Additionally, a design flaw on the front dolly became apparent. The clamp on the front end of the frame rail could not be used to suck the front end of the angle iron up to the frame rail because a bolt long enough to initially reach would interfere with other parts as the clamp was tightened. The problem was avoided using a c-clamp to clamp it tight before using a shorter bolt as shown in Figure 41 but this was not a good final solution.

Figure 41: clamping bolt long enough to reach initially would interfere with the caster.

To solve this problem, the clamp was relocated to eliminate the interference.

Final Testing

The final testing went fairly well, although a few issues did arise. Most notably was some misalignment on a couple of holes. This was solved by slightly over sizing the holes or notching them as necessary. Although these modifications were not desired, they will not have a detrimental impact on the operation of the design and will still allow it to function as desired.

RECOMMENDATIONS

The stands work well as built. However, there are a couple of improvements that could have been made. The first improvement would be to use locking swivel casters rather than rigid ones.

Figure 42: Locking swivel casters would be a good improvement

This way the height could be raised or lowered without the added friction of having to twist the wheel, but the wheel direction could still be locked to the handles to provide directional control when separating and re-mating the tractor. Additionally, the use of fine thread for the height adjustment in the front dolly would help make it easier to raise and lower. Additionally, the incorporation of an electric motor and brake on the front dolly to assist with movement would be nice. However, given that the project will likely be used very infrequently after the initial repair, the added cost and upkeep could not be justified for this particular project.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience.
The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design Process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria. Project objectives & criteria are established to meet the needs and expectations of the sponsor who will be performing the work. See *Design Parameters and Constraints* below for specific design parameters for the project.

Synthesis and Analysis. The project incorporates bending stress calculations and evaluates the stands' functionality and effectiveness.

Construction, Testing and Evaluation. The stands were designed, constructed, tested by splitting the tractor, and evaluated.

Incorporation of Applicable Engineering Standards. The project utilizes AISC standards for allowable bending stresses and SAE standards for allowable fastener stresses.

Capstone Design Experience
The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/ skills from key courses.

Design Parameters and Constraints
This project addresses a significant number of the categories of constraints listed below.

Physical. The front engine section must be mobile, although the rear section could be stationary. The dolly for the front engine section must have a wide stance to prevent the engine from tipping about the pivoting front axle. Direct steering control is needed on the front dolly in order to easily line up the tractor when re-mating the engine and transmission.

Adjustability. Both front and rear stands must have an adjustable height. The front dolly must be able to adjust the side-to-side tilt of the forward section. The engine must have an adjustable height independent from that of the engine frame rails.

Safety. Both stands must be able to handle all shock and unforeseen load scenarios without danger of failing including horizontal side loading.

Economic. An effort must be made to utilize pre-existing materials and otherwise minimize costs.

Durability. Stands must be simple and durable enough to sit for long periods without significant detrimental effects.

APPENDIX B

DESIGN CALCULATIONS

Front Main Cross member.

Giv'n: A HSS rectangle steel tube spans the distance between the vertical legs. Legs are rigidly connected with support braces in all axis creating fixed-fixed end conditions

member size =	2 in	x	6 in	x	0.188 in	
L =		50 in				
w =		9.42 lb/ft =			0.785 lb/ft (AISC 1-86)	
P =		3500 lb				
k =		18 in				
Sy (yield strength) =		46000 psi				
I		10.5 in^4 (AISC 1-86)				
E =		29000000 psi				
A =		2.58 in^2 (AISC 1-86)				

Req'd: a) max applied bending moment Mmax

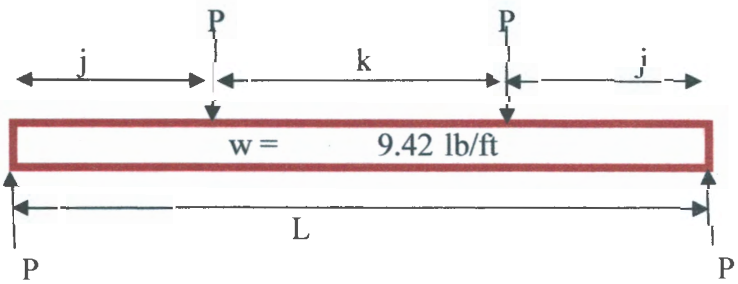
b) max applied shear Vmax

c) max stress σ1 using Mohr's circle

d) choose worst case and determine beam adequacy

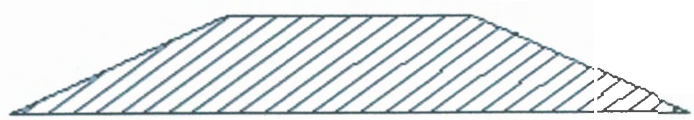
e) deflection

FBD: case 1:



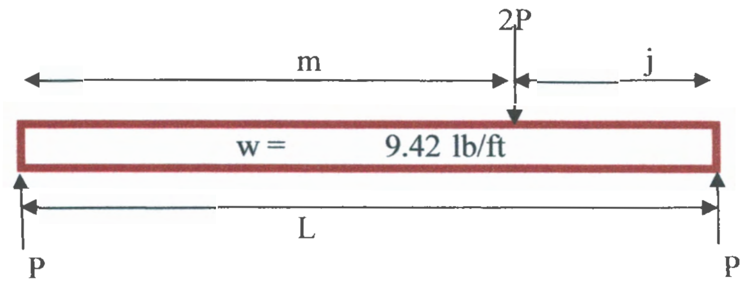
shear diagram

moment diagram

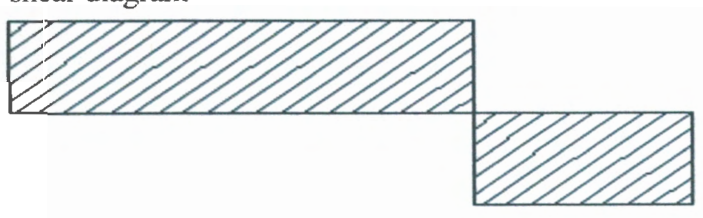


case 2 FBD's to follow

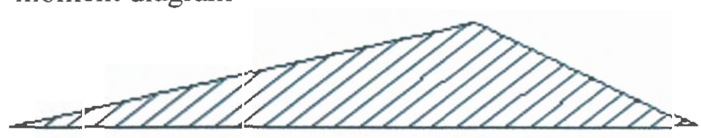
case 2:



shear diagram



moment diagram



Sol'n: case 1: static loading

a) j = (L - k) / 2 = 16 in

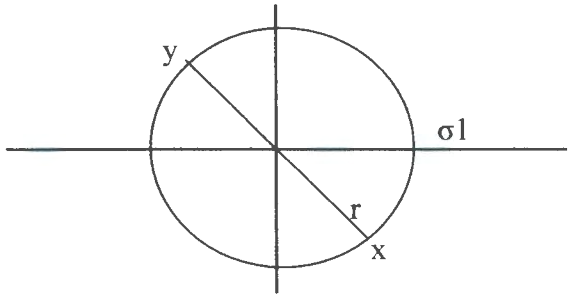
Mmax = [P * j] + [w * L^2 / 8] = **56245** in-lb

**no derived equations for equal loads symmetrically placed for fixed/fixed ends so beam was treated as pinned/pinned to simplify math resulting in a conservative answer.

b) Vmax = [P] + [w * L / 2] = **3520 lb**

c) $\sigma = M * c / I =$ 5357 psi

$\tau = V / A =$ 1364 psi



x = (σ, -τ)
y = (-σ, τ)

$\sigma 1 = r = (\sigma^2 + \tau^2)^{.5} =$ **5528 psi**

σallow = Sy * .60 = 27600 psi

case 2: all weight concentrated on one side

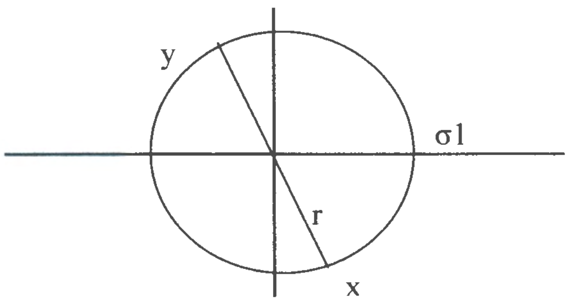
a) m = L - j = 34 in

Mmax= [2P * m^2 * j / L^2] + [w * L^2 / 12]= 51952 ft-lb

b) Vmax = [(2P * m^2 / L^3) * (m + 3*j)] + [w * L / 2] =
5328 lb

c) $\sigma = M * c / I =$ 4948 psi

$\tau = V / A =$ 2065 psi



x = (σ, -τ)
y = (-σ, τ)

$\sigma 1 = r = (\sigma^2 + \tau^2)^{.5} =$ **5362 psi**

σallow = Sy * .60 = 27600 psi

d) case 1 is the worst case since it results in a higher stress

S.F. = σallow / σ1 = **5.0**

e) Δmax = [(4*2P * m^3 * j^2)/(3*E*I*(3*m+j))] + (w * L^4)/(348*E*I) =
2.61 in

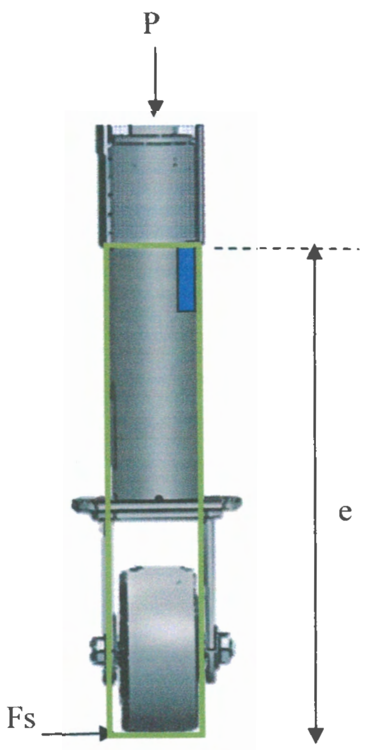
Front Male Tube Sizing.

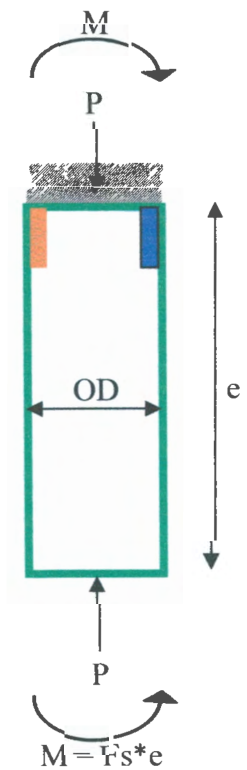
Giv'n: P is the static weight on the leg and Fs is the max potential bending moment applied by sliding the wheel while it is turned the wrong direction. Assume the legs are fully extended maximizing e. Member is constructed of 2-7/8" grade J55 oil pipe.

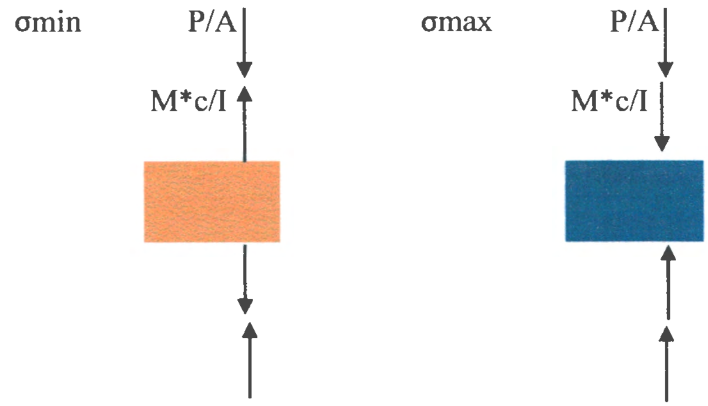
P =		3500 lb	
e =		15 in	
μ_s (steel on concrete) =		0.40	
final tube size =	2.88 in	x	0.203 in
ID =	2.47 in		
Sy (yield strength) =		55000 psi (Anson Steel)	
E =		29000000 psi	

Req'd: a) max friction force Fs
b) moment M and sheer force V applied by Fs
c) max stress $\sigma 1$
d) member adequacy

FBD:







Sol'n: a) $Fs = \mu_s * P =$ **1400 lb**

b) M = Fs * e = **21000 in-lb**

V = Fs = **1400 lb**

c) worst case due to compression + bending

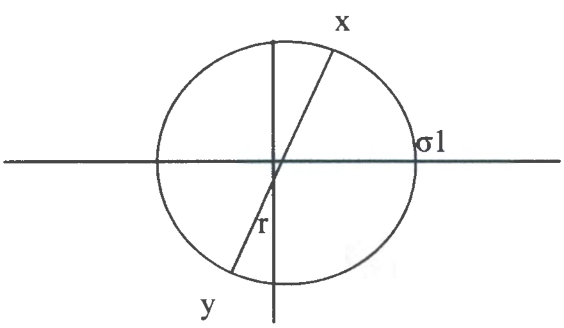
I = pi * (od^4 - id^4) / 64 = 1.53 in^4

A = pi * (od^2 - id^2) / 4 = 1.70 sq.in

σmax = M * c / I + P / A = 21790 psi

σmin = -M * c / I + P / A = -17682 psi

τ = V / A = 822 psi



x = (σmax, -τmax)
y = (-σmax, τmax)

$\sigma avg\ (\sigma max + \sigma min) / 2 =$	2054 psi
$r = (\sigma max - \sigma avg)^2 + \tau^2)^{.5} =$	19753 psi
$\sigma 1 = \sigma avg + r =$	**21807 psi**
d) $\sigma allow = Sy * .60 =$	33000
actual S.F. = $\sigma allow / \sigma 1 =$	**1.5**

Front All-thread Sizing.

Giv'n: A force H is applied to the handle to turn the lead screw to raise the leg. Assume legs are fully retracted to maximize b. No grade markings present on lead screw so assume grade 1.

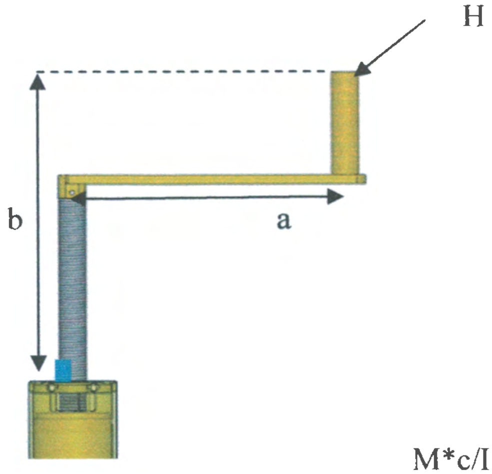
a =	6 in
b =	14 in
H =	100 lb
Sy =	36000 psi (Shigley table 8-9 p433)
all thread size =	1.00 in

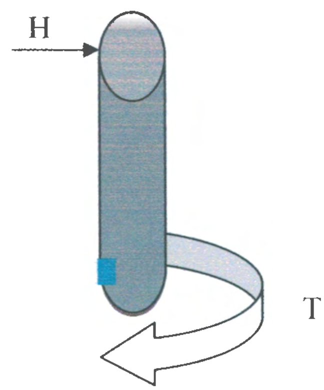
Req'd: a) moment M and torque T applied by H

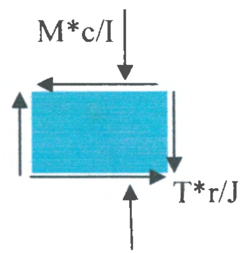
b) max stress σ1

c) adequacy

FBD:







Sol'n: a) equivalent shaft size = dm = 0.944 in

Mmax = b * H = **1400 in-lb**

T = H * a = **600 in-lb**

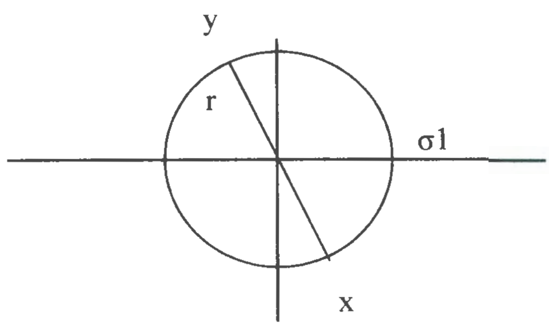
b) $J = pi * r^4 / 2 =$ 0.078 in^4

$I = pi * d^4 / 64 =$ 0.05 in^4

$A = pi * d^2 / 4 =$ 0.74 sq.in

$\sigma = M * c / I =$ 10186 psi

$\tau max = V / A + T * r / J =$ 3762 psi



x = (σmax, -τmax)
y = (-σmax, τmax)

$\sigma 1 = r = (\sigma^2 + \tau max^2)^{.5} =$ **10858 psi**

c) $\sigma allow = Sy * .60 =$ 21600

S.F. $= \sigma allow / \sigma 1 =$ **2.0**

Rear Main Post.

Giv'n: A rectangular tube is used as a vertical leg and loaded as shown. The leg is fully extended maximizing b and d. Determine member adequacy. Assume the gusset provides adequate reinforced in member's the weak direction.

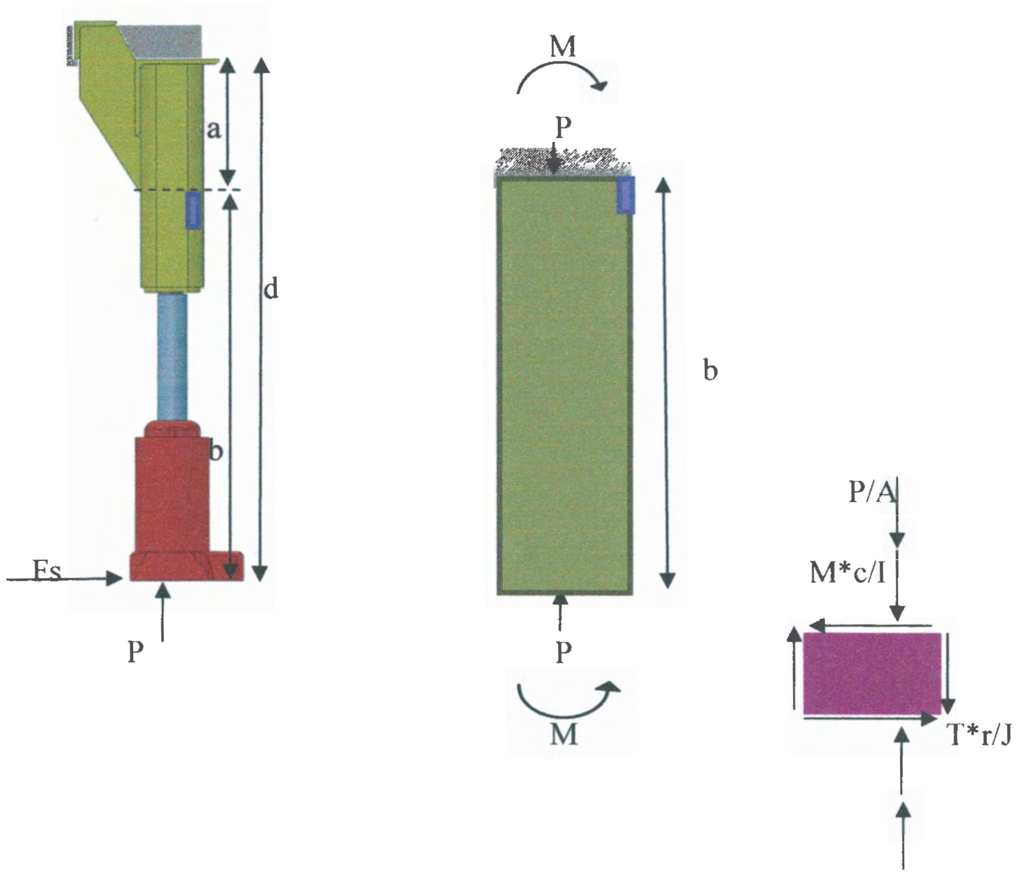
P =		7000 lb			
a =		7.00 in			
b =		20.38 in			
d =		27.38 in			
μ_s (steel on concrete) =		0.4			
tube size =	4 in	x	3 in	x	0.375 in
ID =	3.25 in	x	2.25 in		
Sy		46000 psi			
E =		29000000 psi			
I =		5.01 in^4 (AISC 1-88)			
A =		4.09 in^2 (AISC 1-88)			

Req'd: a) max friction force Fs

b) moment M and shear force V applied by Fs

c) max stress σ1 and adequacy

FBD:



Sol'n: a) $Fs = P * \mu_s =$ **2800 lb**

b) M = Fs * b = **57058 in-lb**

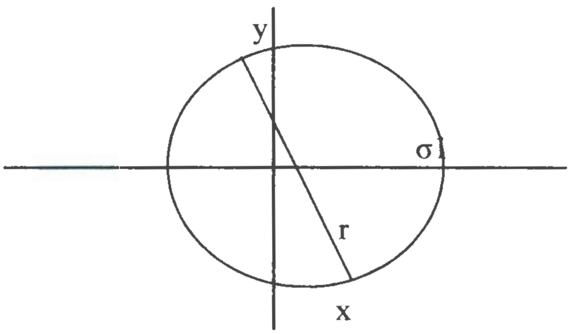
V = Fs = **2800 lb**

c) worst case due to compression + bending

$\sigma max = [M * c / I] + [P / A] =$ 18795 psi

$\sigma min = -[M * c / I] + [P / A] =$ -15372 psi

$\tau = V / A =$ 685 psi



x = (σmax, -τmax)
y = (-σmax, τmax)

σavg (σmax + σmin) / 2 = 1711 psi

r = ((σmax - σavg)^2 + τ^2)^.5 = 17097 psi

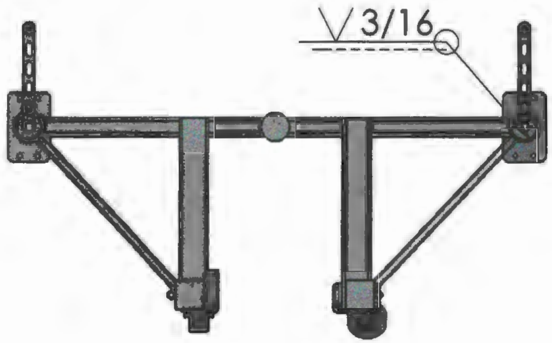
σ1 = σavg + r = **18809 psi**

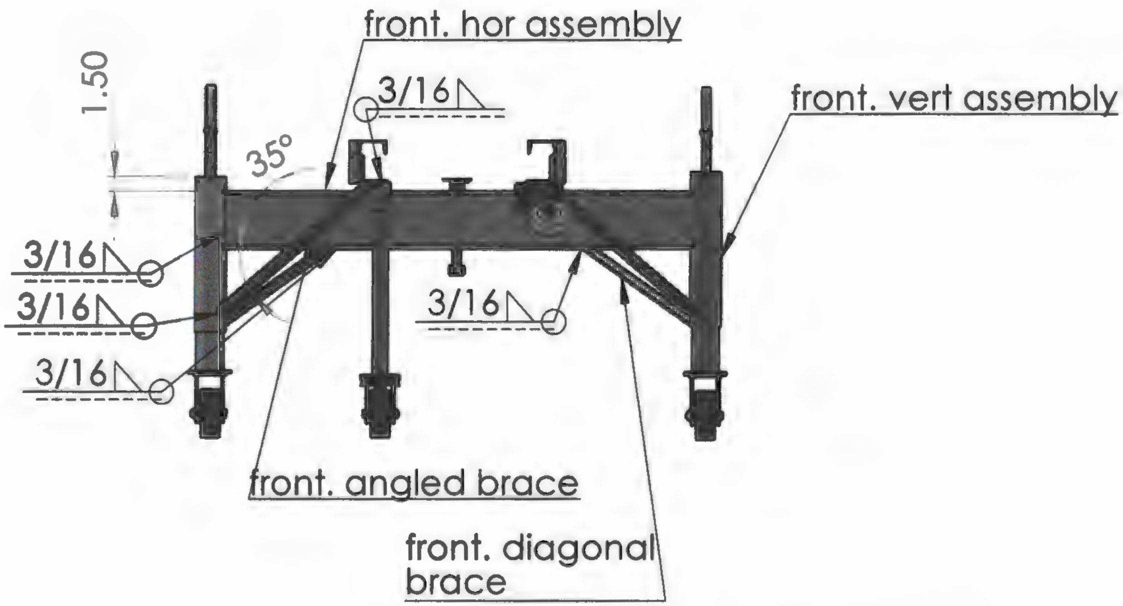
σallow = Sy * .60 = 27600 psi

S.F. = σallow / σ1 = **1.5**

APPENDIX C

CONSTRUCTION DRAWINGS





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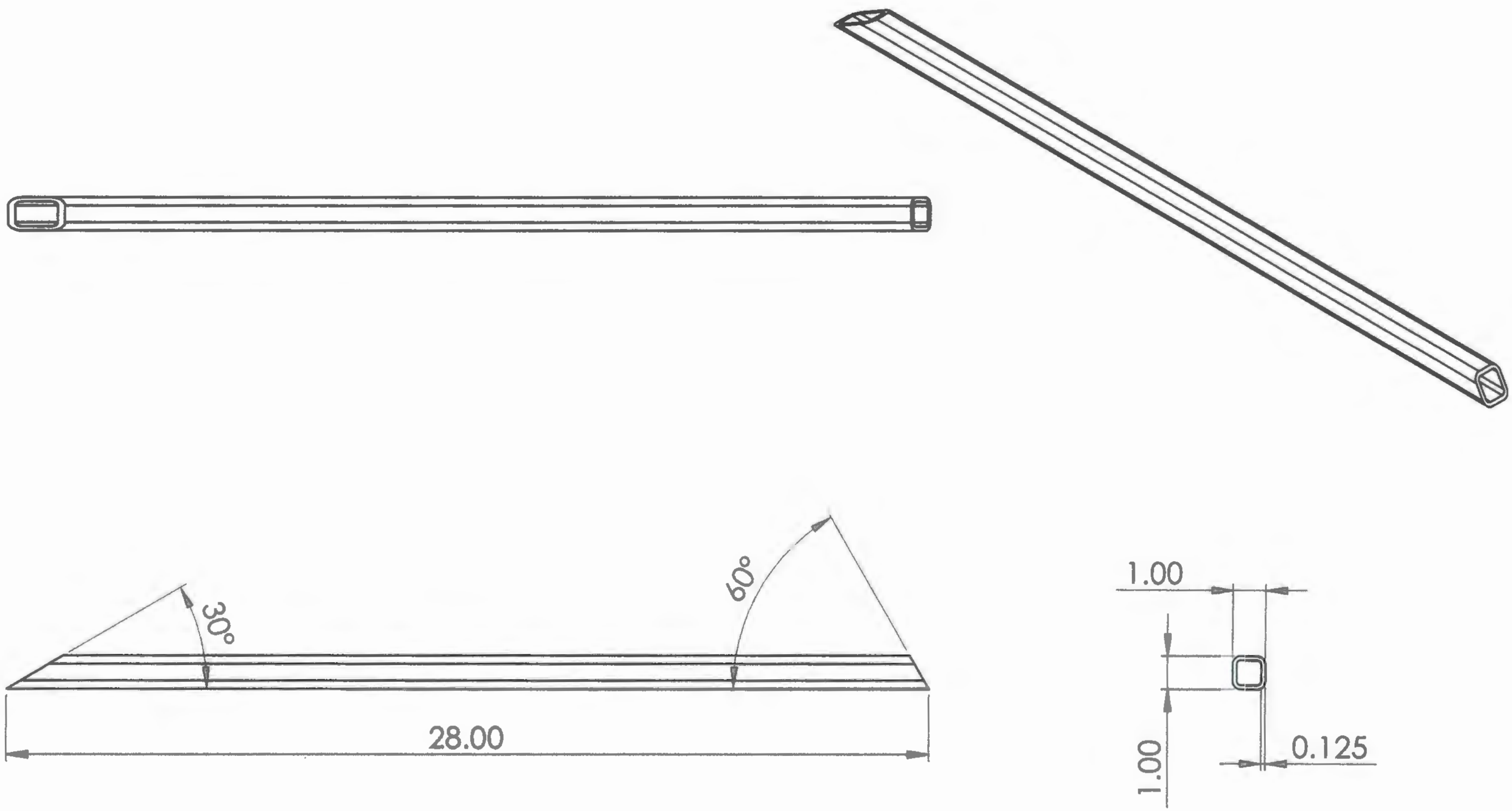
UNLESS OTHERWISE SPECIFIED:	BRAE 461/462	TITLE:	Senior Project: tractor stands
DIMENSIONS IN INCHES TOLERANCES: 1/16"	DESIGNER NATHAN SPERLING		
	ADVISOR DR. ZOHNS		
MATERIAL steel	COMMENTS:		DWG. NO. front assembly
FINISH Painted			
DO NOT S[illegible] DRAWING			SCALE: 1:20 WEIGHT: [illegible]EET 1 OF 1

5 4 3 2 1

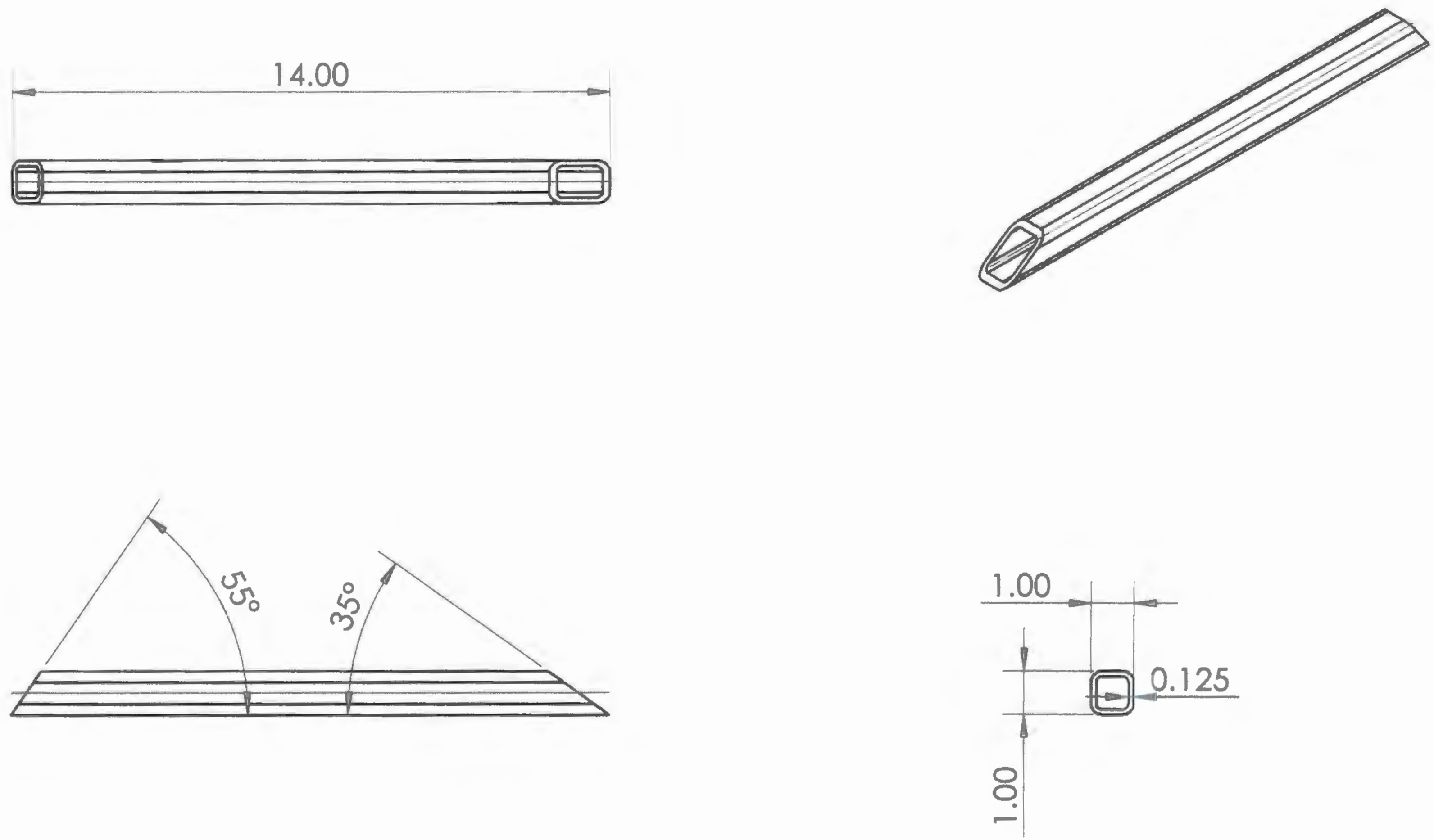


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	Senior Project		TITLE: BRAE 461/462 tractor stands
MATERIAL 1" x 1" x 1/8" steel square tube	designer	Nathan Sperling	
	advisor	Dr. Zohns	DWG. NO.

front. angled brace

QUANTITY: 2   DO NOT SCALE DRAWING   SCALE: 1:5   WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

BRAE 461/462

TITLE: Senior Project: tractor stands

designer Nathan Sperling

advisor Dr. Zohns

MATERIAL
1" x 1" x 1/8" steel square tube

DWG. NO.

front. diagonal brace

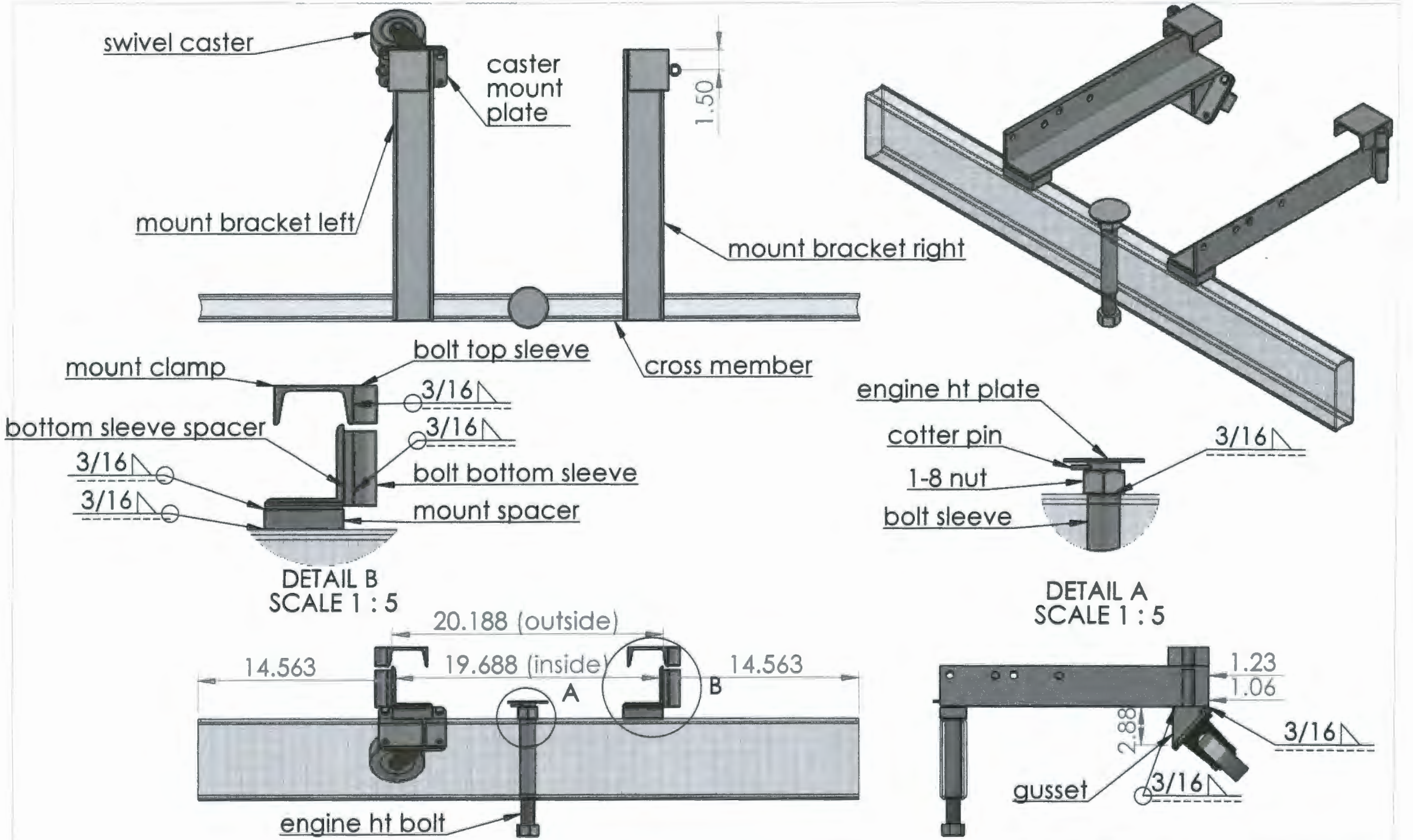
QUANTITY: 2

DO NOT SCALE DRAWING

SCALE: 1:4 WEIGHT:

EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

Senior Project

designer: Nathan Sperling

advisor: Dr. Zohns

MATERIAL: steel

TITLE: BRAE 461/462 tractor stands

DWG. NO.

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front. hor assembly

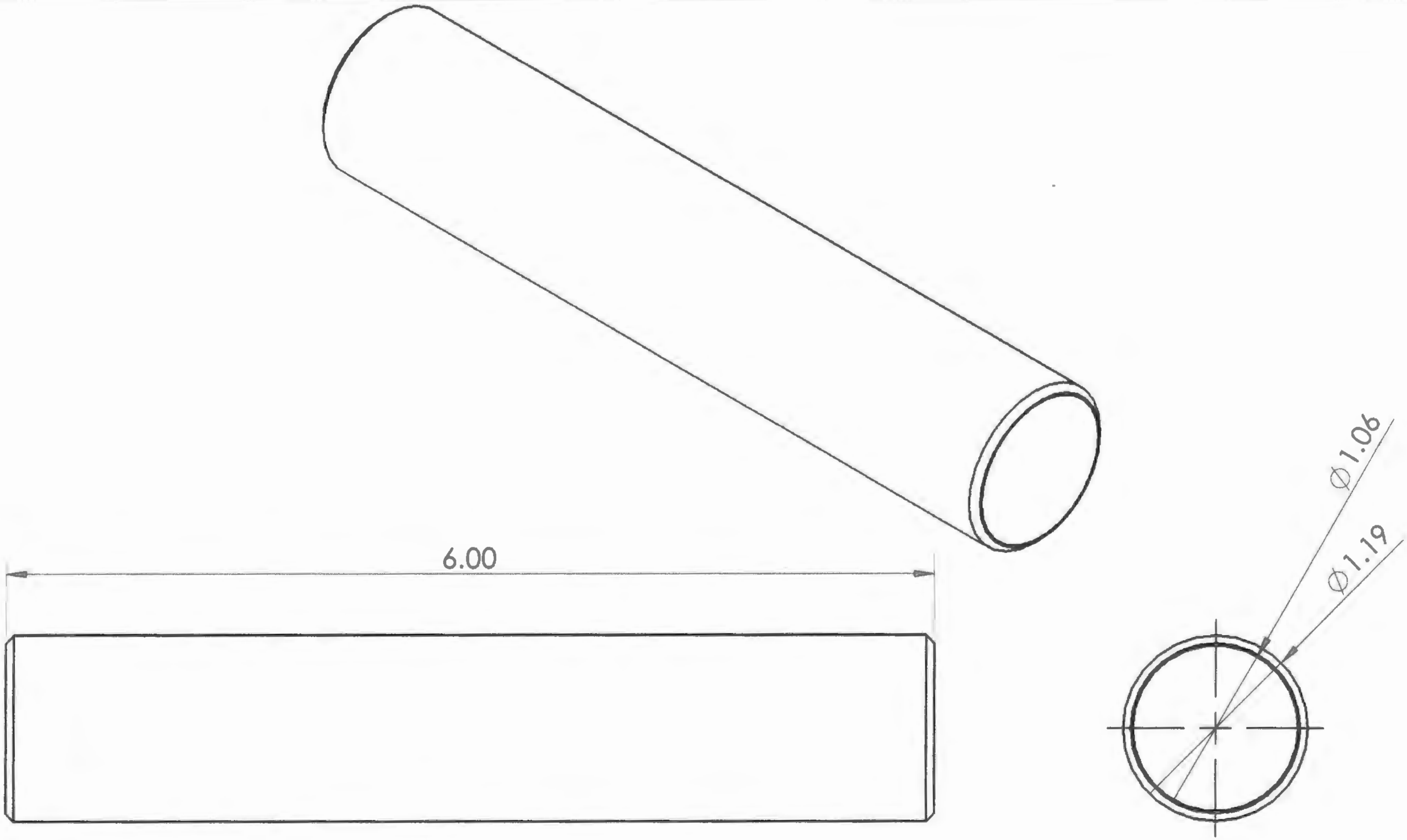
QUANTITY: 1

DO NOT SCALE DRAWING

SCALE: 1:10 WEIGHT:

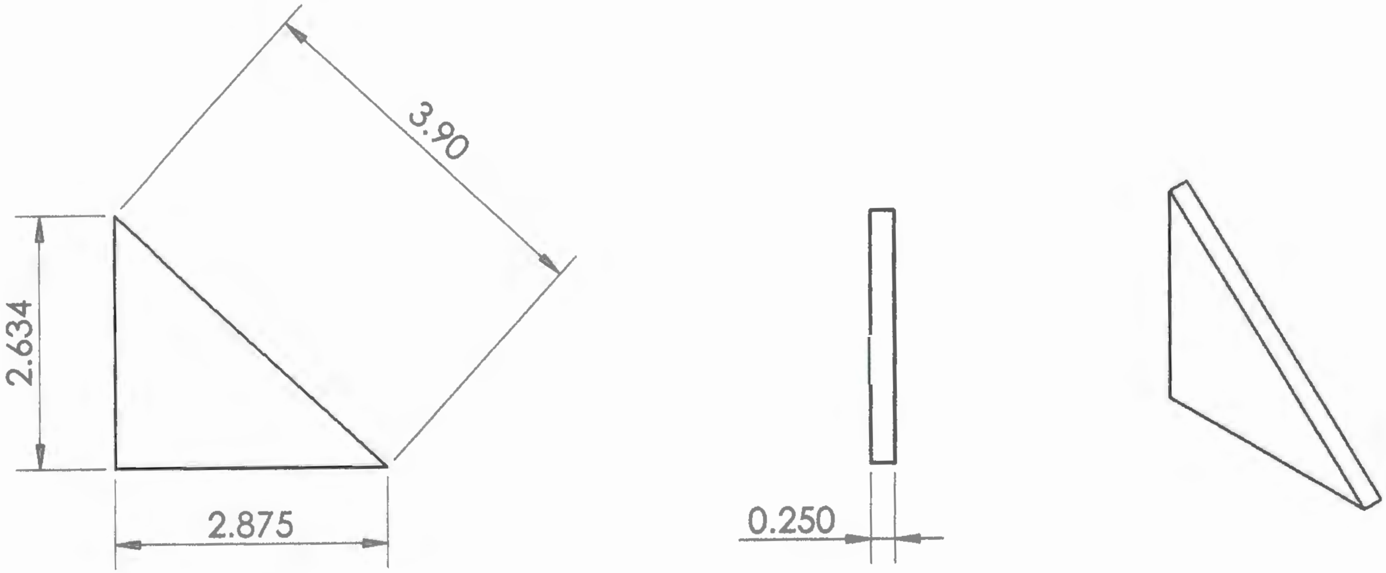
'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL c.r. steel	designer	Nathan Sperling	
	advisor	Dr. Zohns	DWG. NO.
front. hor. bolt tube			
QUANTITY: 1	DO NOT SCALE DRAWING		SCALE: 1:1 WEIGHT: IEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
1/4" c.r. steel sheet

BRAE 461/462

designer	Nathan Sperling
advisor	Dr. Zohns

TITLE: Senior Project: tractor stands

DWG. NO.

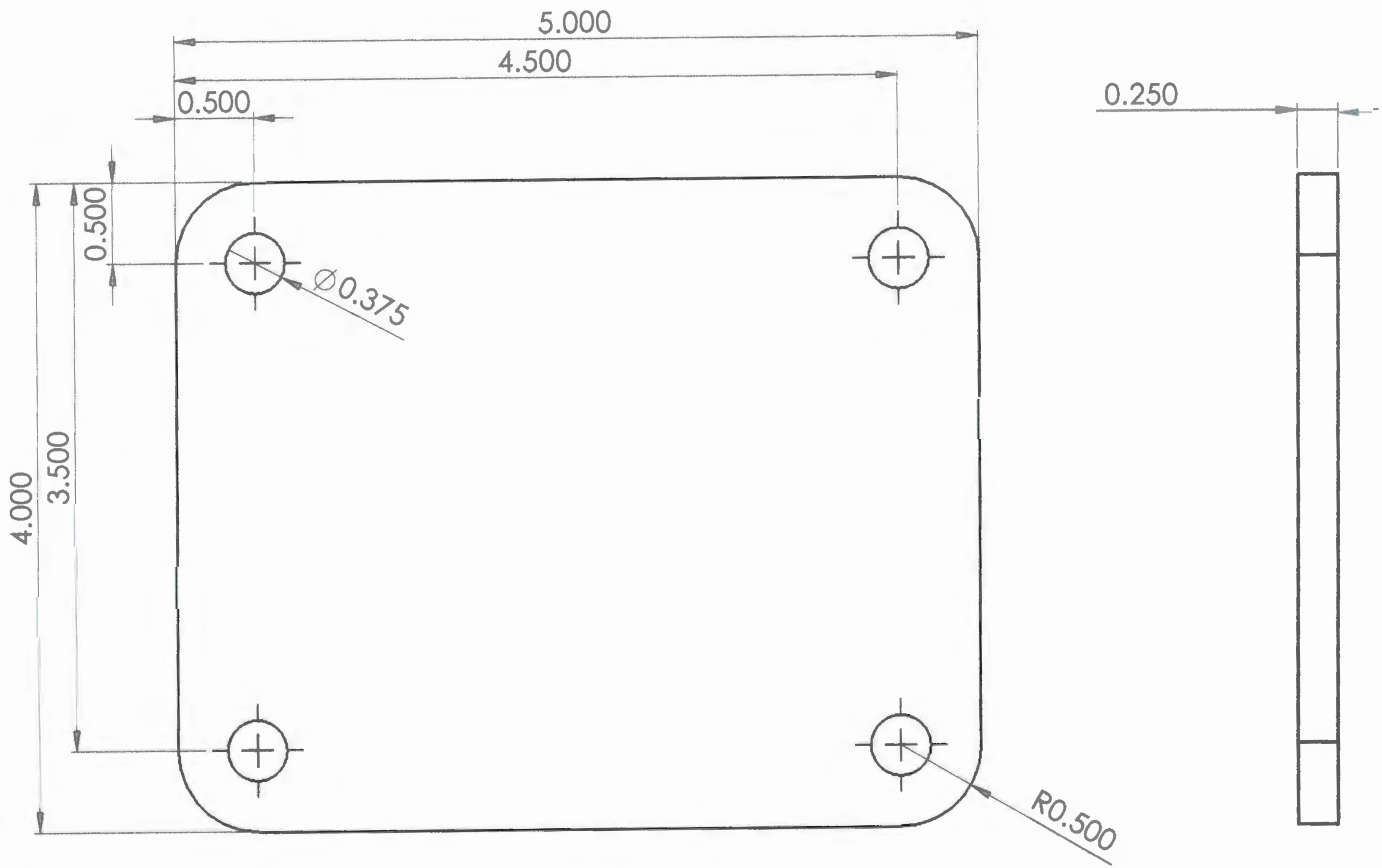
front. hor. caster gusset

QUANTITY: 1

DO NOT SCALE DRAWING

SCALE: 1:2 WEIGHT: IEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
1/4" c.r. steel sheet

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

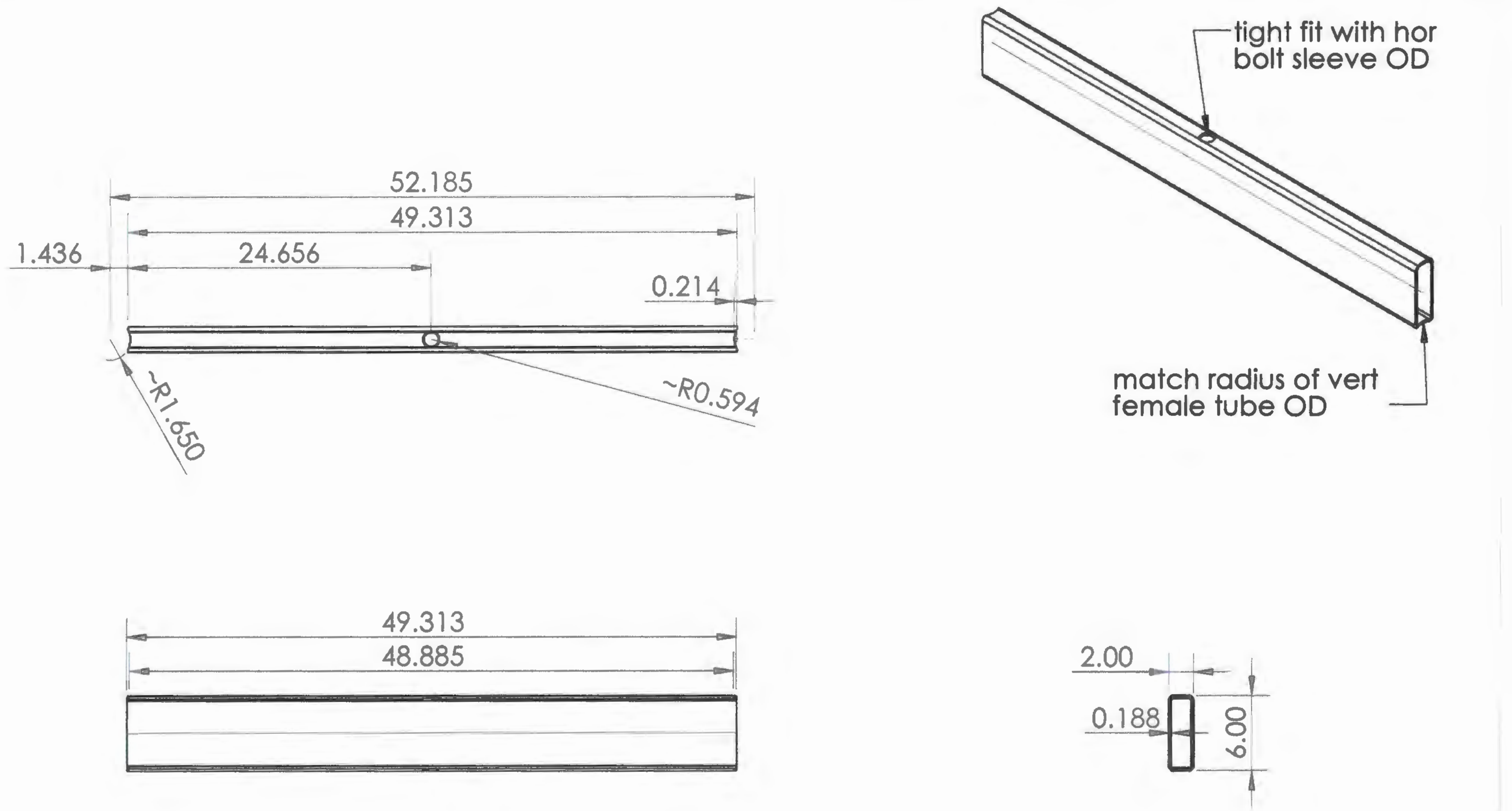
TITLE: BRAE 461/462 tractor stands

DWG. NO.

front. hor. caster mount plate

QUANTITY: 1 | DO NOT SCALE DRAWING | SCALE: 1:1 | WEIGHT: | IEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

BRAE 461/462

TITLE: **Senior Project: tractor stands**

designer	Nathan Sperling
advisor	Dr. Zohns

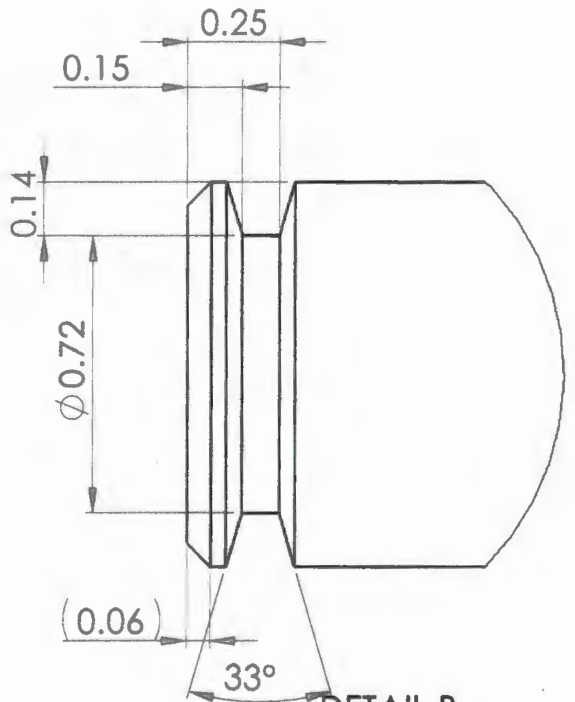
MATERIAL
2" x 6" x 3/16" HSS steel rectangle

DWG. NO.

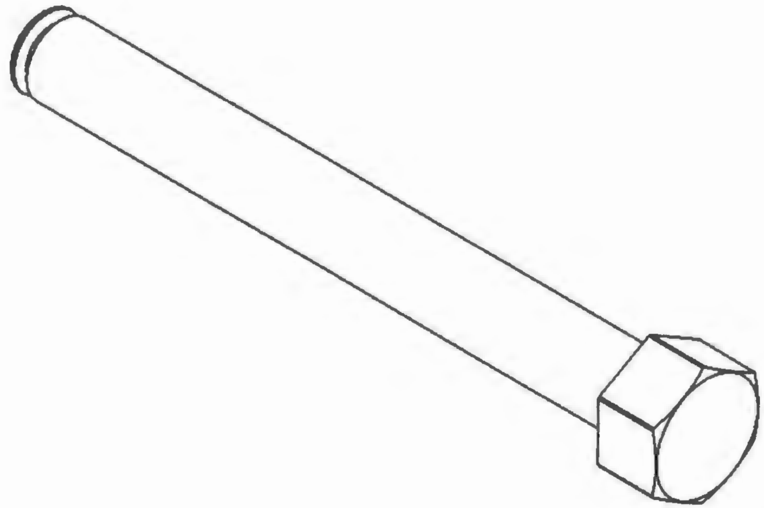
front. hor. cross member

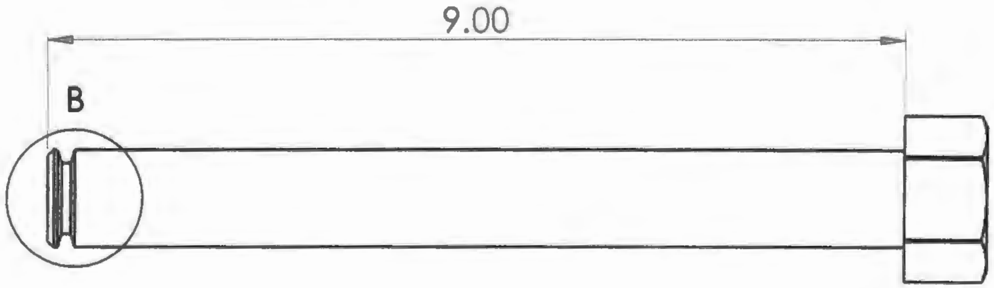
QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:12 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



DETAIL B
SCALE 2 : 1





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.005

MATERIAL
1"-8 x 9" bolt (any grade)

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

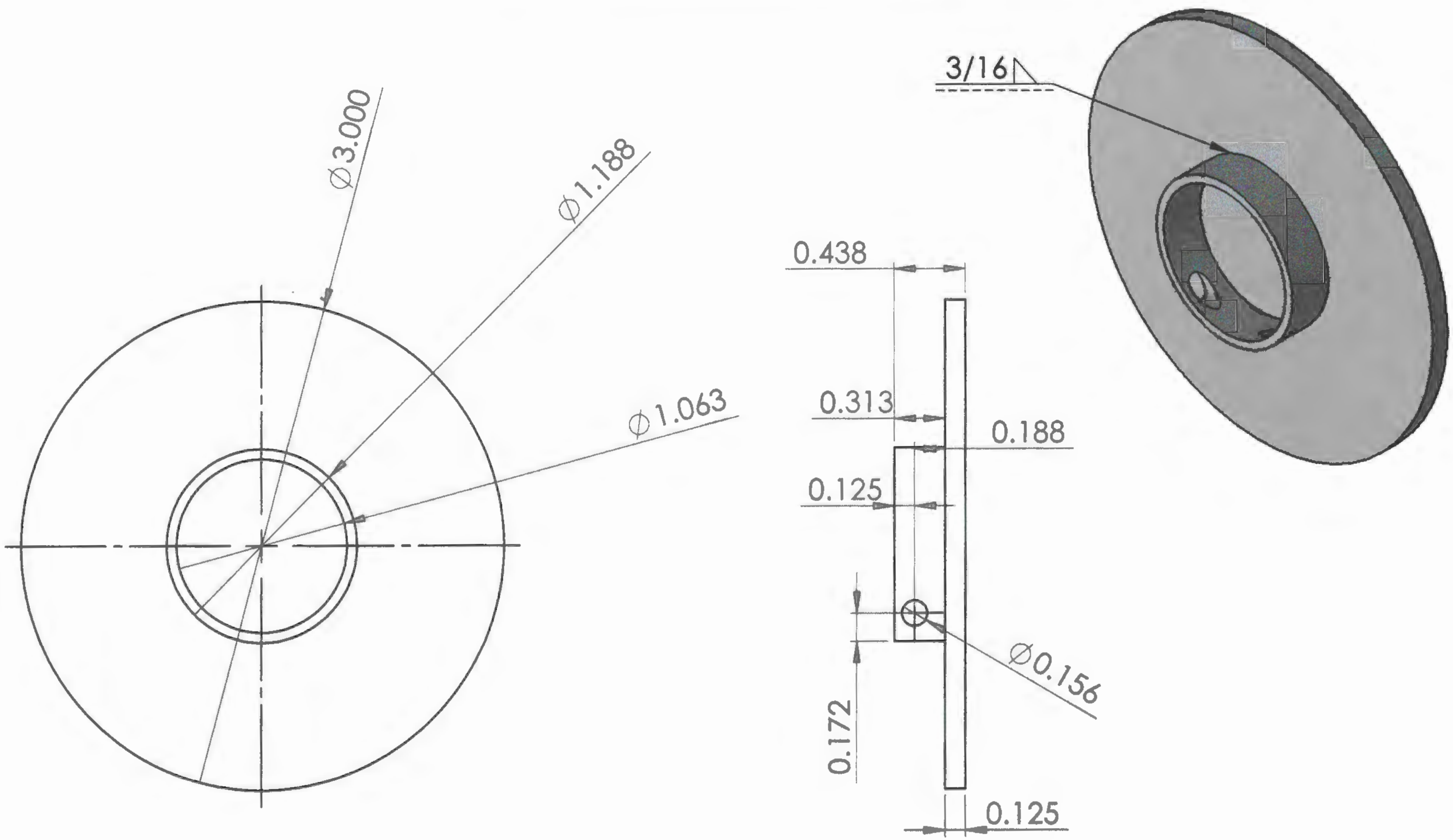
TITLE: BRAE 461/462 tractor stands

DWG. NO.

front. hor. engine height bolt 1"

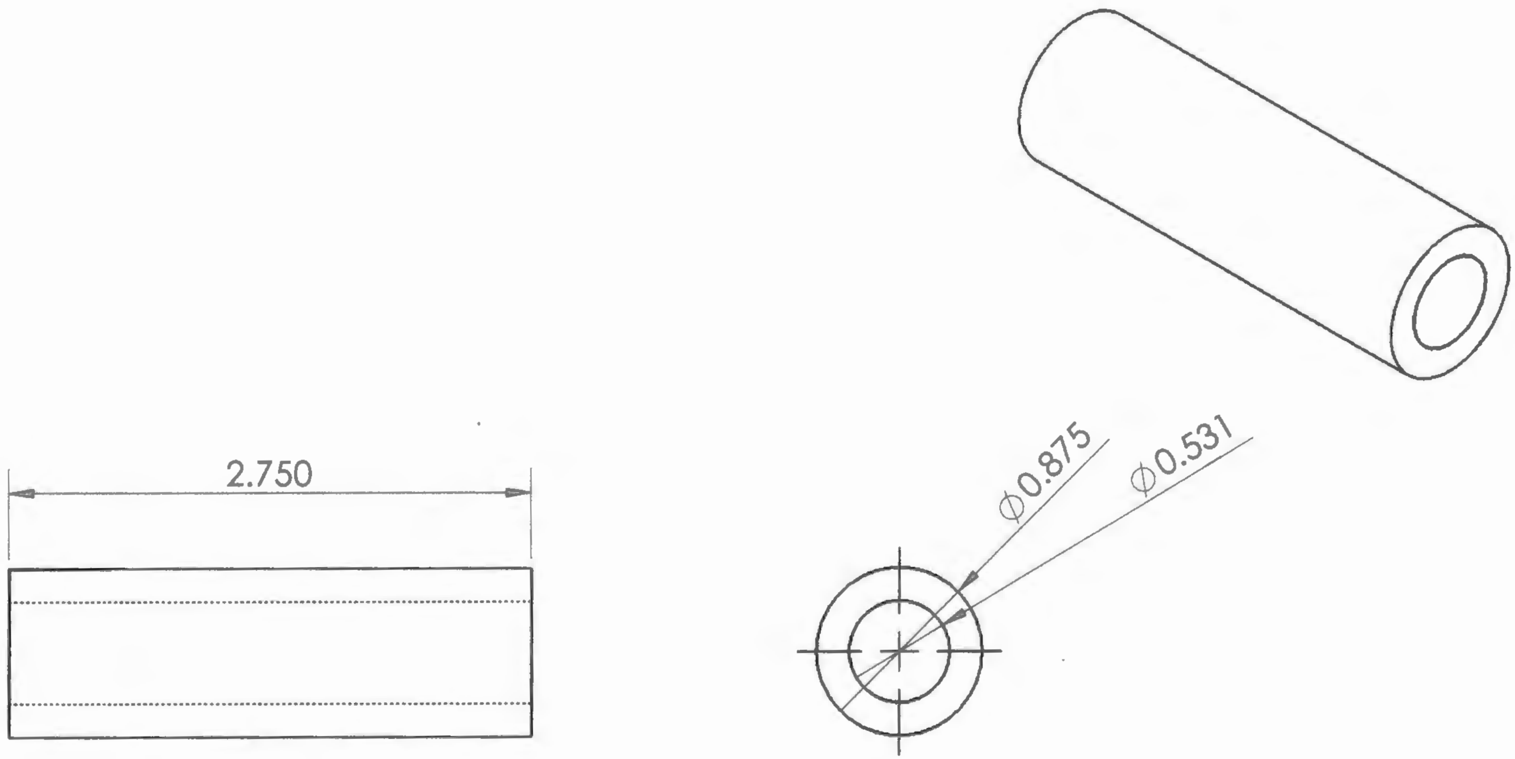
QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	Senior Project	TITLE: BRAE 461/462 tractor stands
MATERIAL c.r. steel	designer: Nathan Sperling advisor: Dr. Zohns	
front. hor. engine height plate		DWG. NO.
QUANTITY: 1	DO NOT SCALE DRAWING	SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



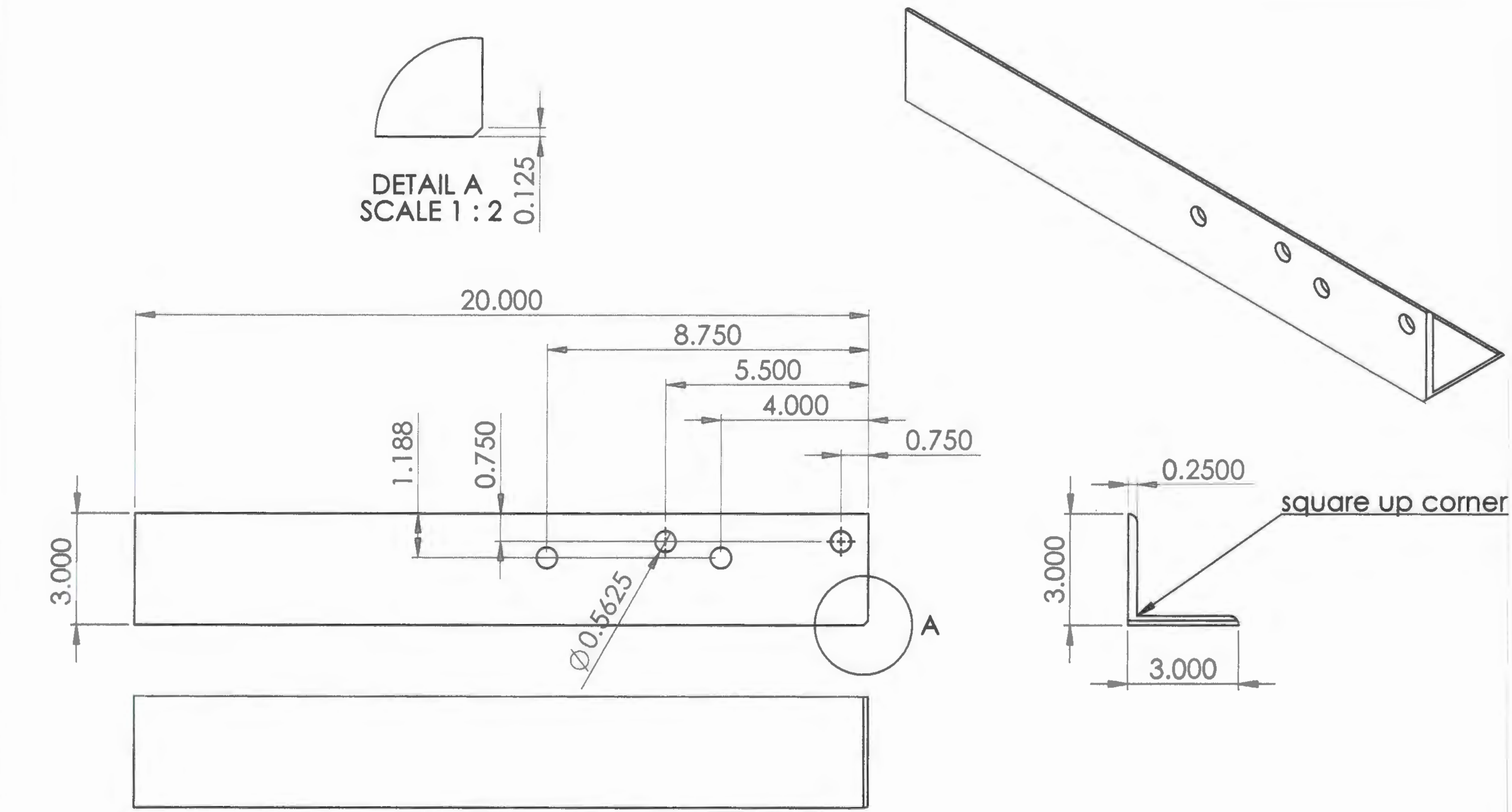
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 7/8" x 5/32" steel round tube	designer	Nathan Sperling	
	advisor	Dr. Zohns	

DWG. NO.

front. hor. mount bottom bolt sleeve

QUANTITY: 2 | DO NOT SCALE DRAWING | SCALE: 1:1 | WEIGHT: | EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
3" x 3" x 1/4" h.r. steel angle

Senior Project

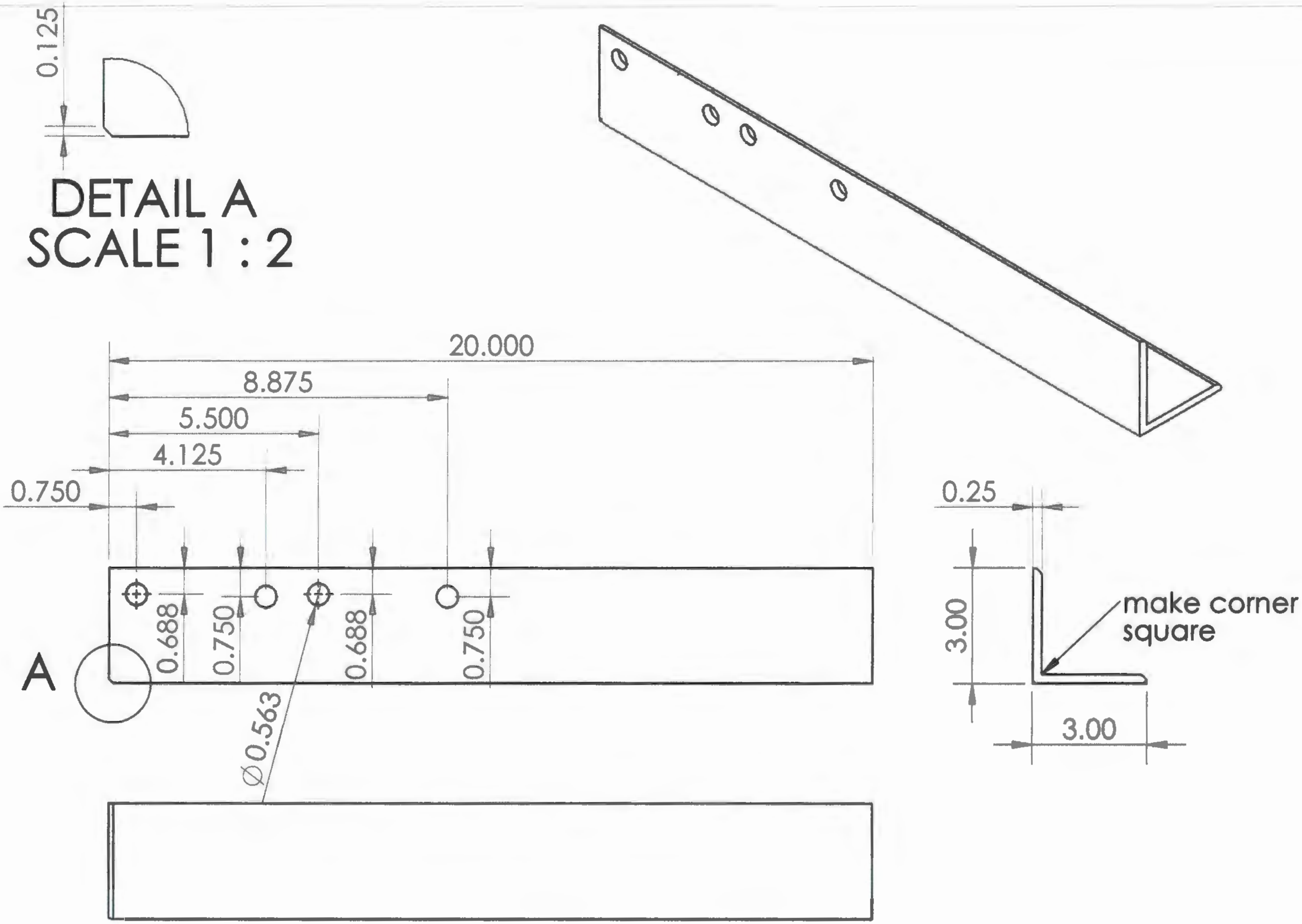
designer	Nathan Sperling
advisor	Dr. Zohns

TITLE: BRAE 461/462
tractor stands

DWG. NO.
front. hor. mount bracket left

QUANTITY: 1 | DO NOT SCALE DRAWING | SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



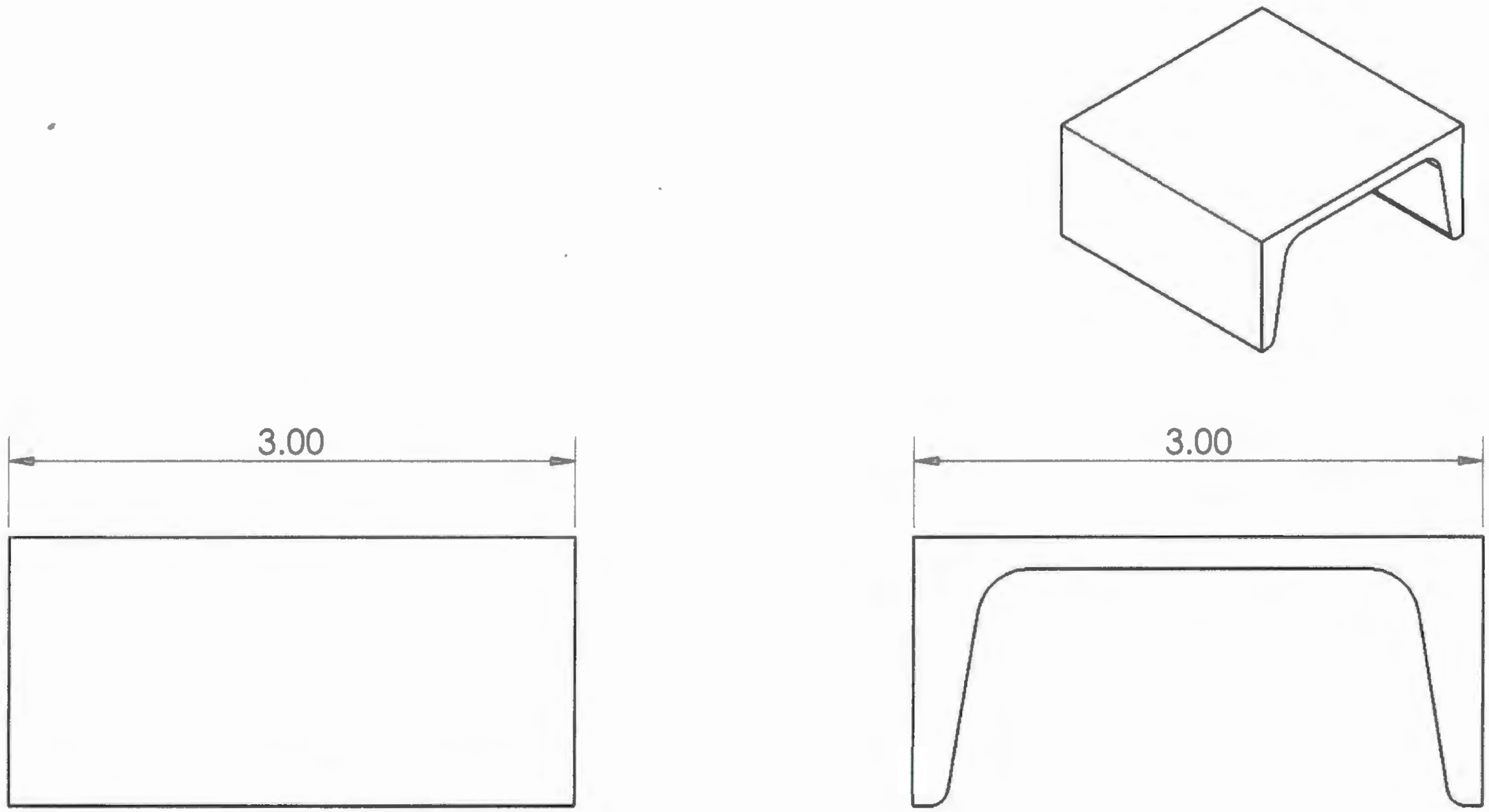
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 3" x 3" x 1/8" h.r. steel angle	designer	Nathan Sperling	
	advisor	Dr. Zohns	

DWG. NO.

front. hor. mount bracket right

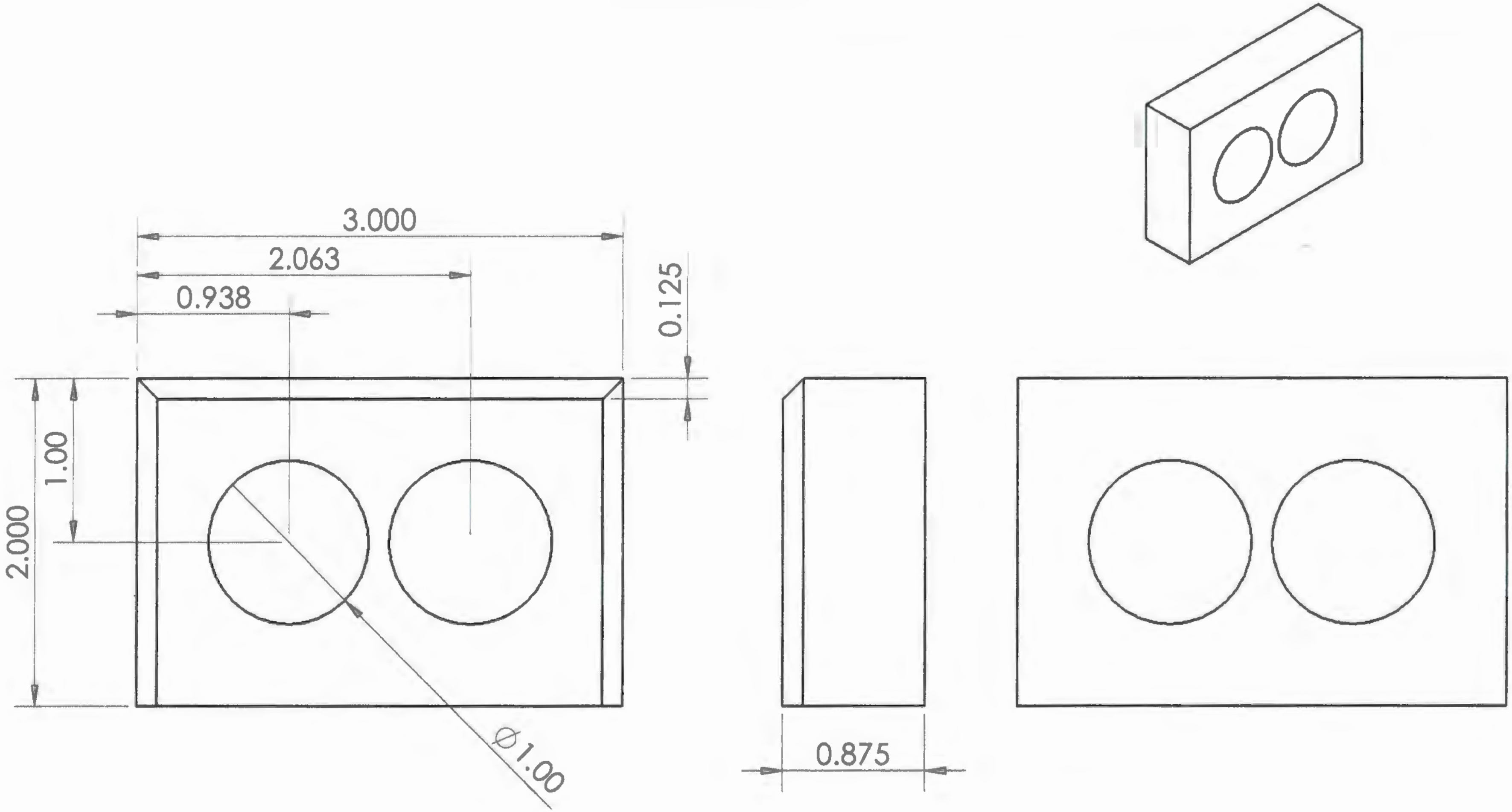
QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:4 WEIGHT: IEET 1 OF 1

5 4 3 2 1



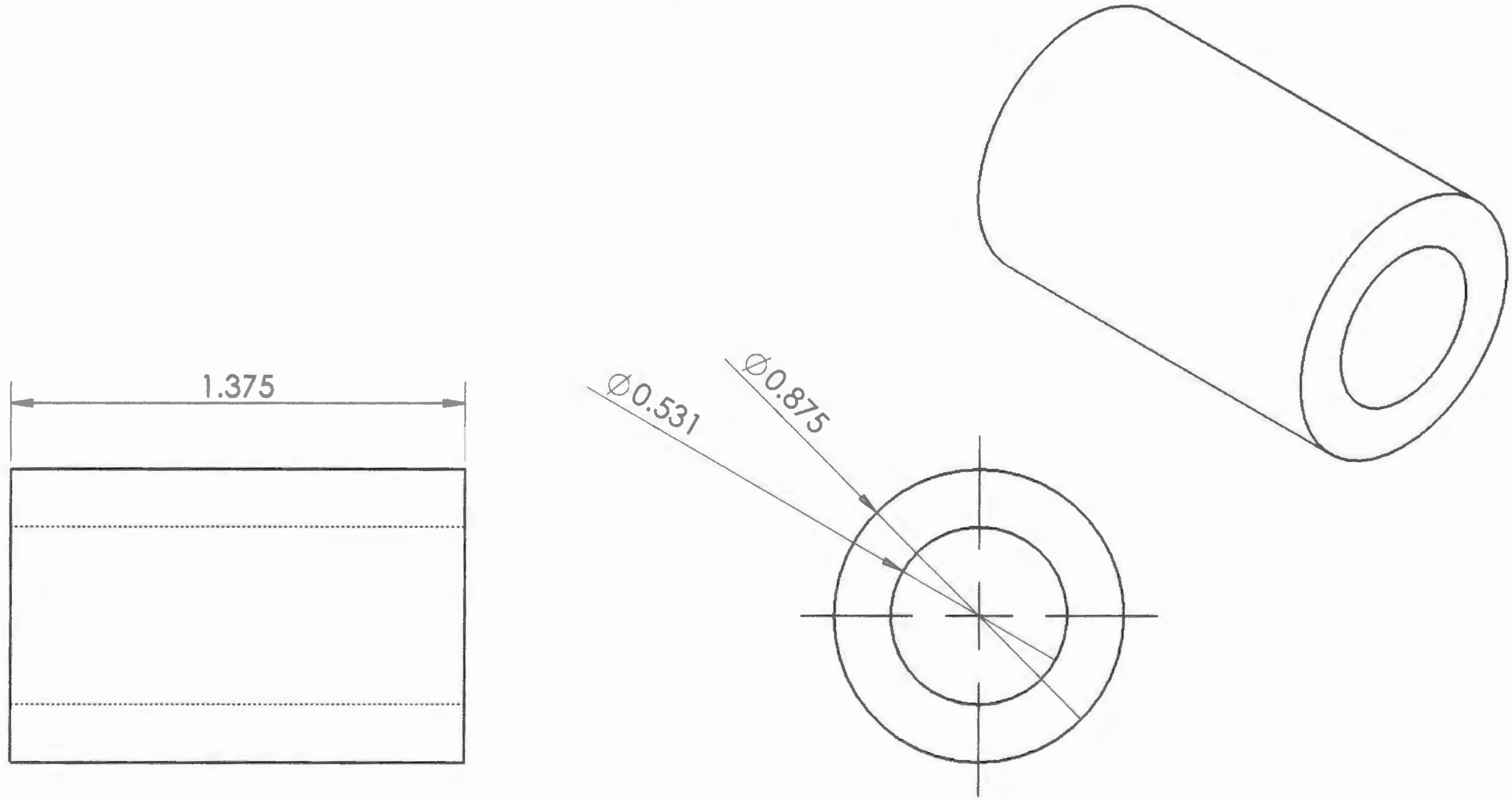
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462	TITLE: Senior Project: tractor stands
MATERIAL 3 x 4.1 steel C channel	designer: Nathan Sperling advisor: Dr. Zohns	DWG. NO.
front. hor. mount clamp		
QUANTITY: 2	DO NOT SCALE DRAWING	SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 7/8" c.r. steel plate	designer	Nathan Sperling	
	advisor	Dr. Zohns	
front. hor. mount spacer			DWG. NO.
QUANTITY: 2	DO NOT SCALE DRAWING	SCALE: 1:1	WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
7/8" x 5/32" steel round tube

BRAE 461/462

designer	Nathan Sperling
advisor	Dr. Zohns

TITLE: Senior Project: tractor stands

DWG. NO.

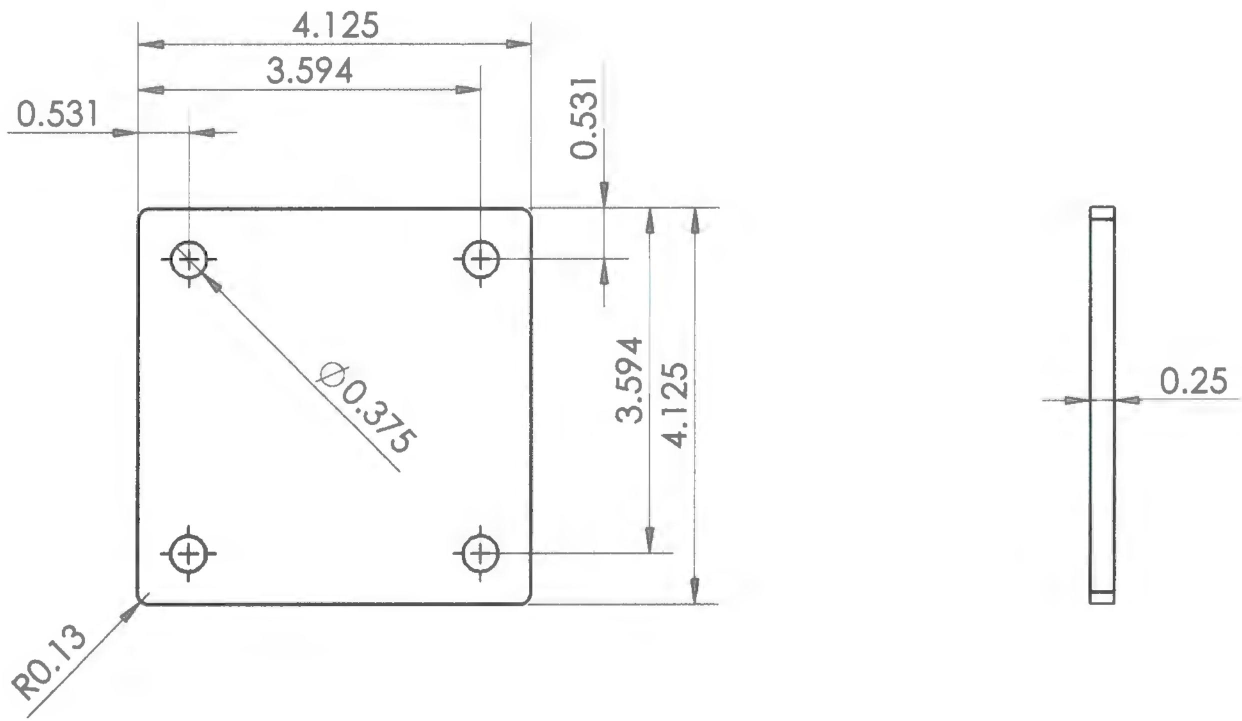
front. hor. mount top bolt sleeve

QUANTITY: 2

DO NOT SCALE DRAWING

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



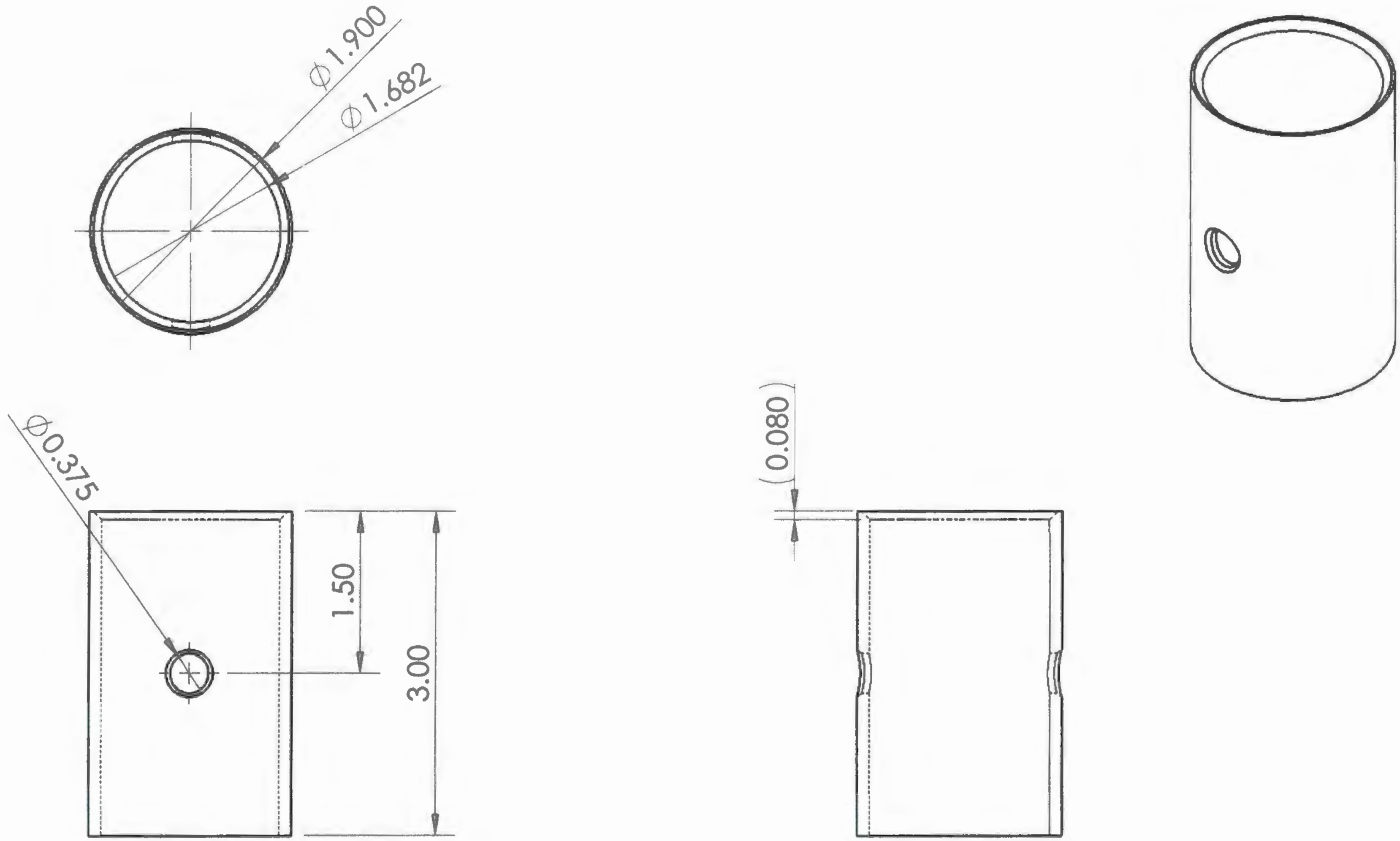
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 1/4" c.r. steel sheet	designer	Nathan Sperling	
	advisor	Dr. Zohns	

DWG. NO.

front. third leg. caster mount plate

QUANTITY: 1 | DO NOT SCALE DRAWING | SCALE: 1:2 | WEIGHT: | IEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
1-1/2" sch 10 steel pipe

BRAE 461/462

designer	Nathan Sperling
advisor	Dr. Zohns

TITLE: Senior Project: tractor stands

DWG. NO.

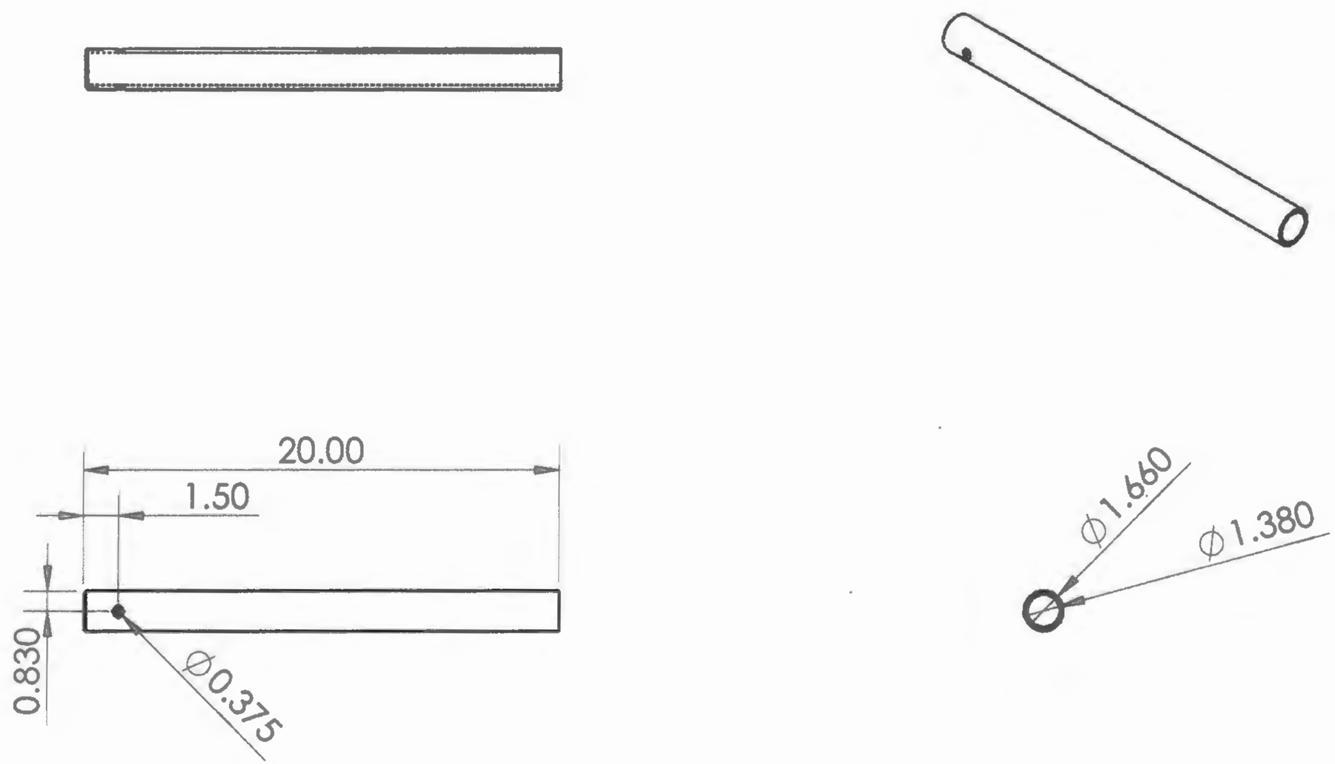
front. third leg. female sleeve

QUANTITY: 1

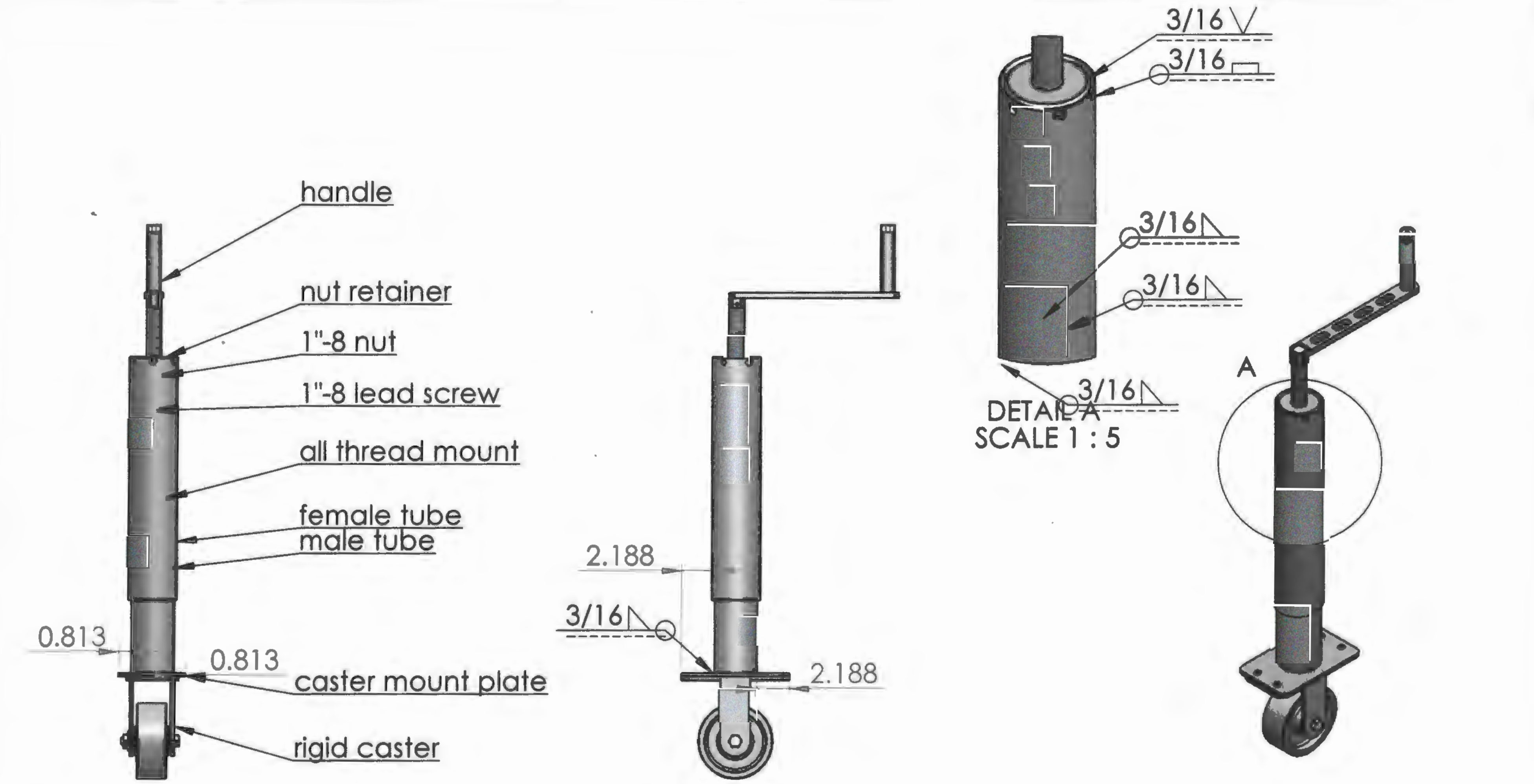
DO NOT SCALE DRAWING

SCALE: 1:1.5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 1-1/4" sch 40 steel pipe	designer	Nathan Sperling	
	advisor	Dr. Zohns	DWG. NO.
front. third leg. male post			
QUANTITY: 1	DO NOT SCALE DRAWING		SCALE: 1:8 WEIGHT: 'EET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	Senior Project	TITLE: BRAE 461/462 tractor stands
MATERIAL steel	designer Nathan Sperling advisor Dr. Zohns	DWG. NO.

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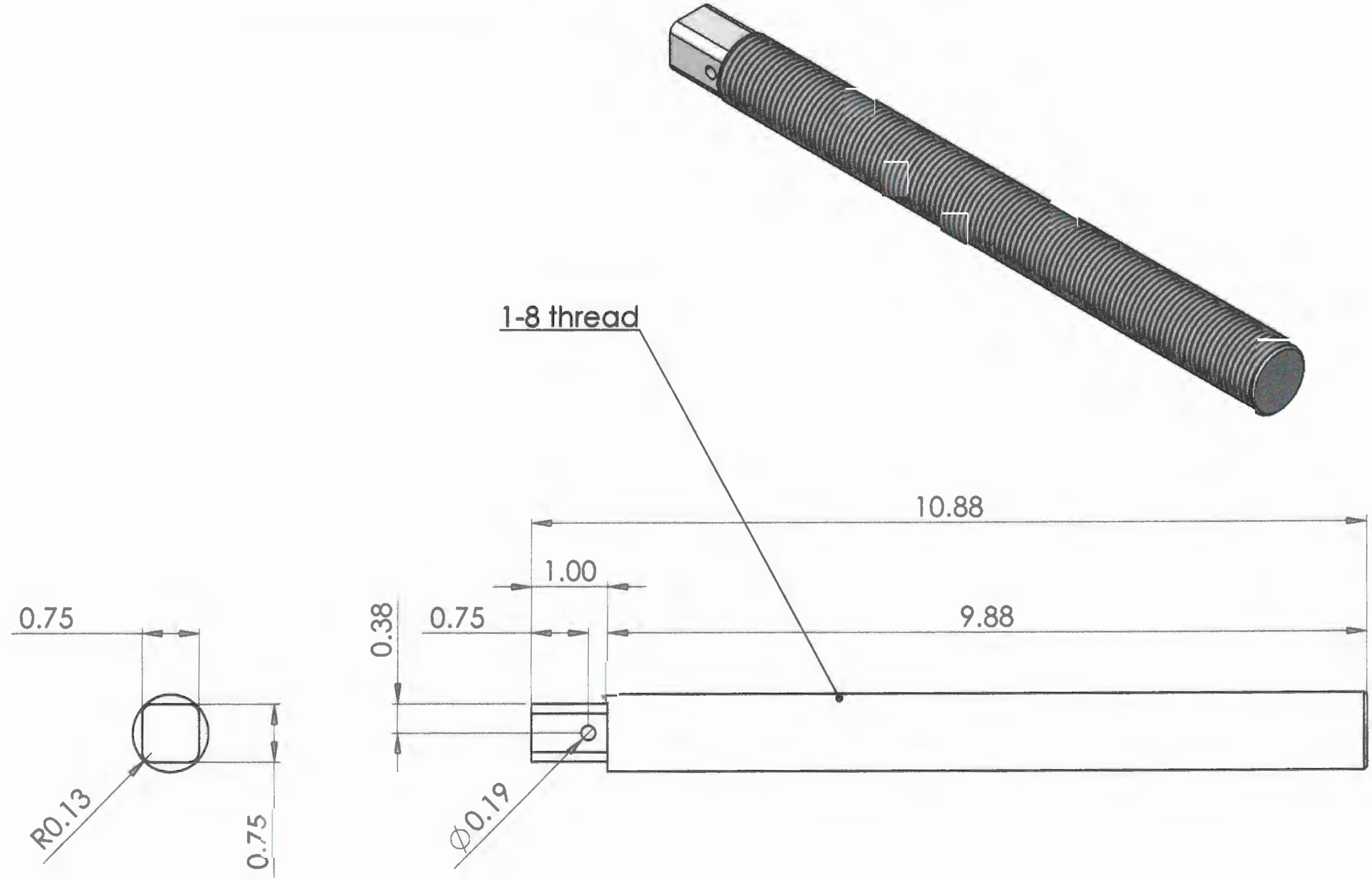
front. vert assembly

QUANTITY: 2 DO NOT SCALE DRAWING SCALE: 1:10 WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
steel all thread (any grade)

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

TITLE: BRAE 461/462 tractor stands

DWG. NO.

front. vert. all thread

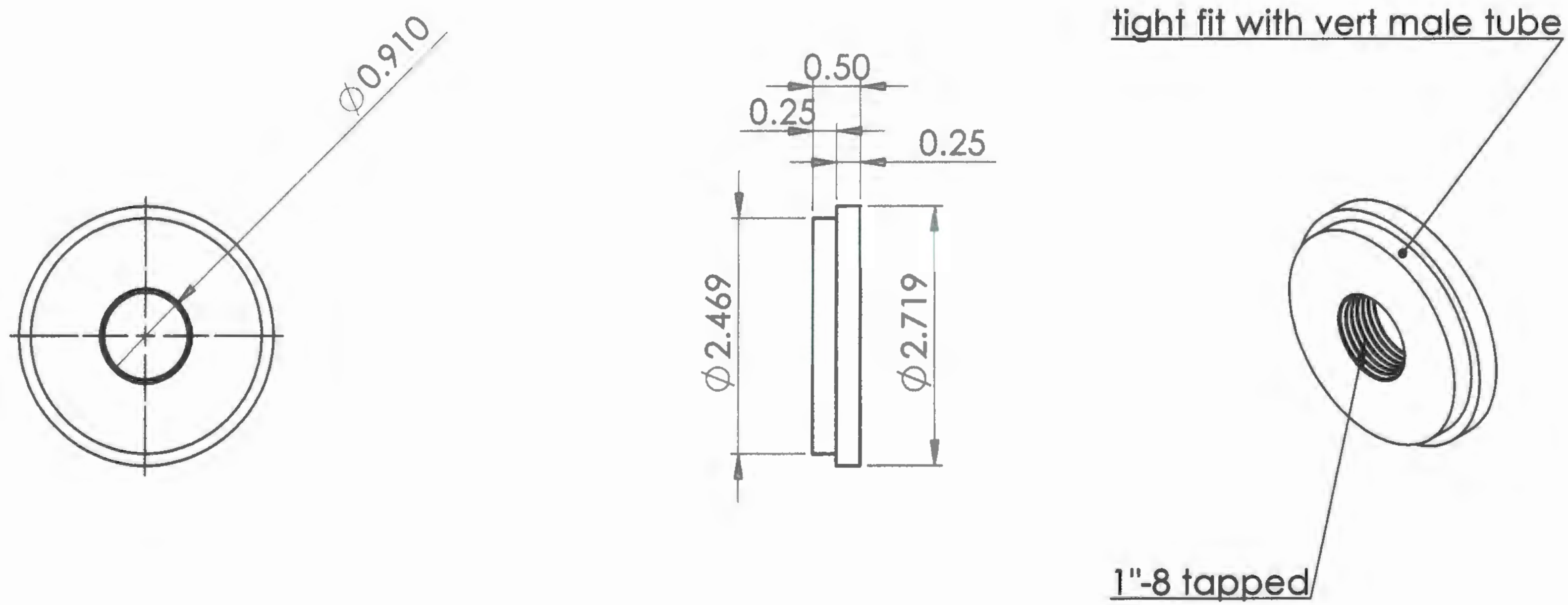
QUANTITY: 2

DO NOT SCALE DRAWING

SCALE: 1:2 WEIGHT:

'EET 1 OF 1

5 4 3 2 1



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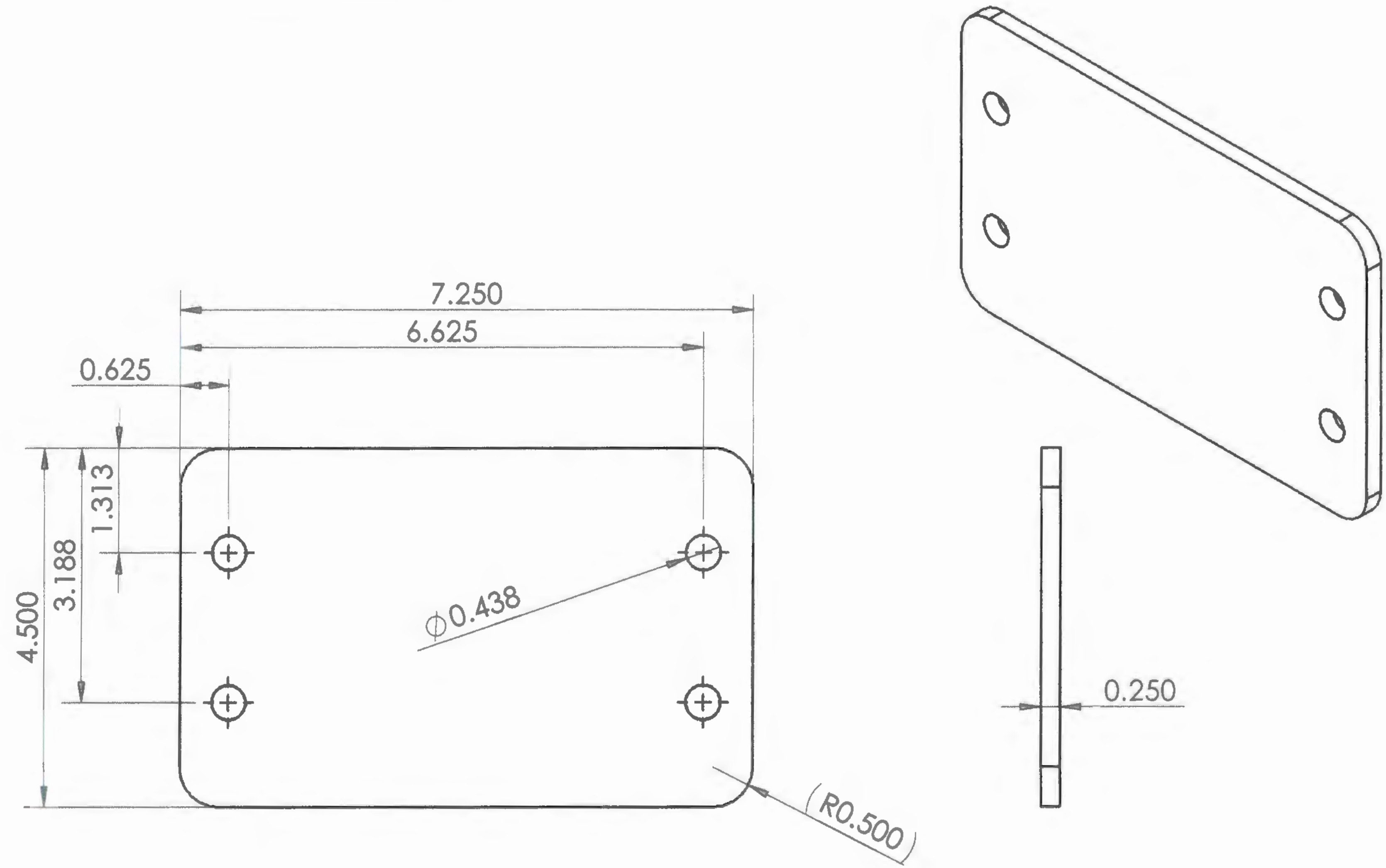
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	Senior Project	TITLE: BRAE 461/462 tractor stands
MATERIAL 3" c.r. steel round stock	designer: Nathan Sperling; advisor: Dr. Zohns	DWG. NO.

front. vert. all thread mount

QUANTITY: 2 | DO NOT SCALE DRAWING | SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



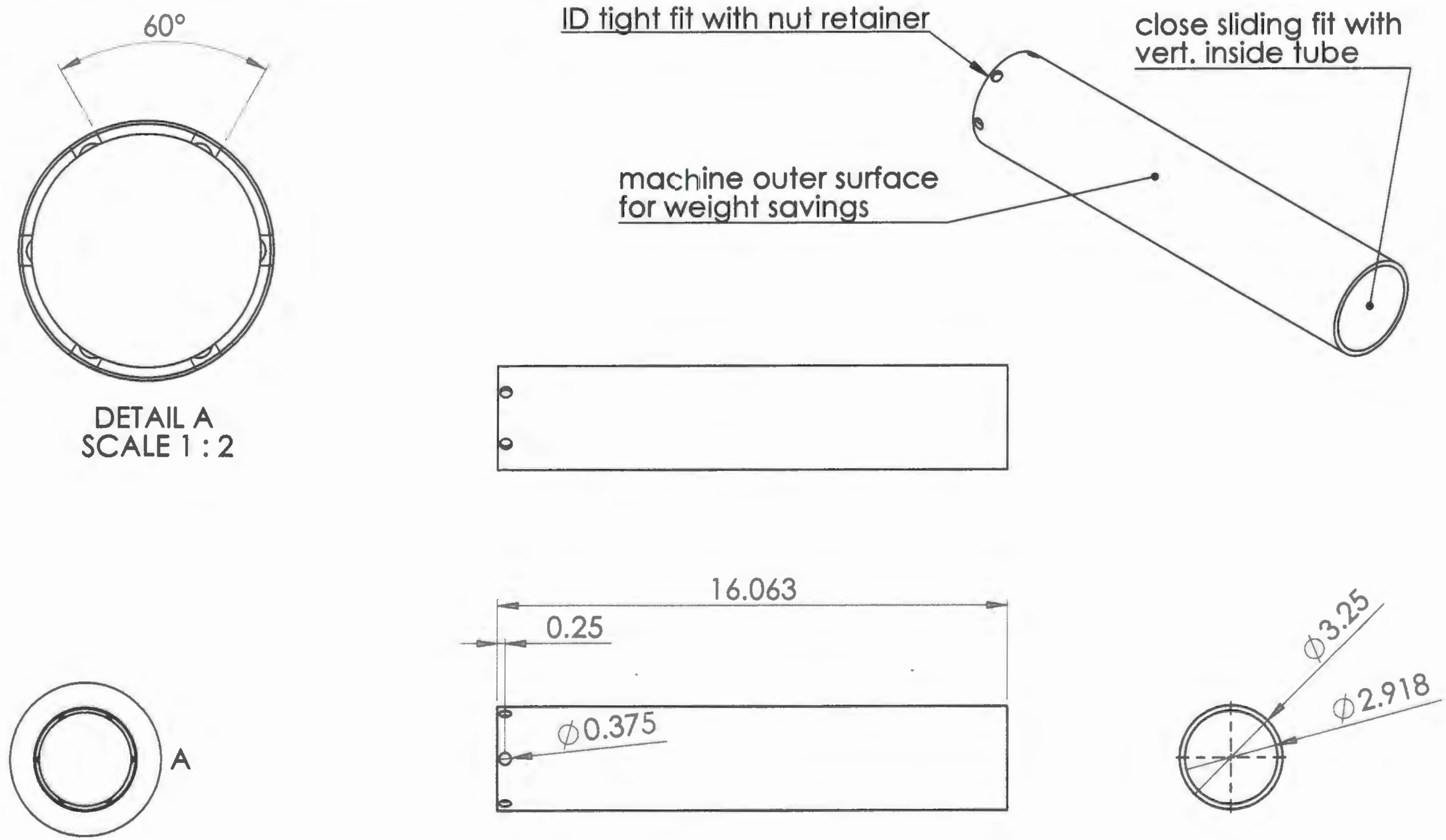
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
	designer	Nathan Sperling	
MATERIAL 1/4" c.r. steel sheet	advisor	Dr. Zohns	

DWG. NO.

front. vert. caster mount plate

QUANTITY: 2 | DO NOT SCALE DRAWING | SCALE: 1:2 | WEIGHT: | 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

MATERIAL
3.5 x .313 DOM steel round tube

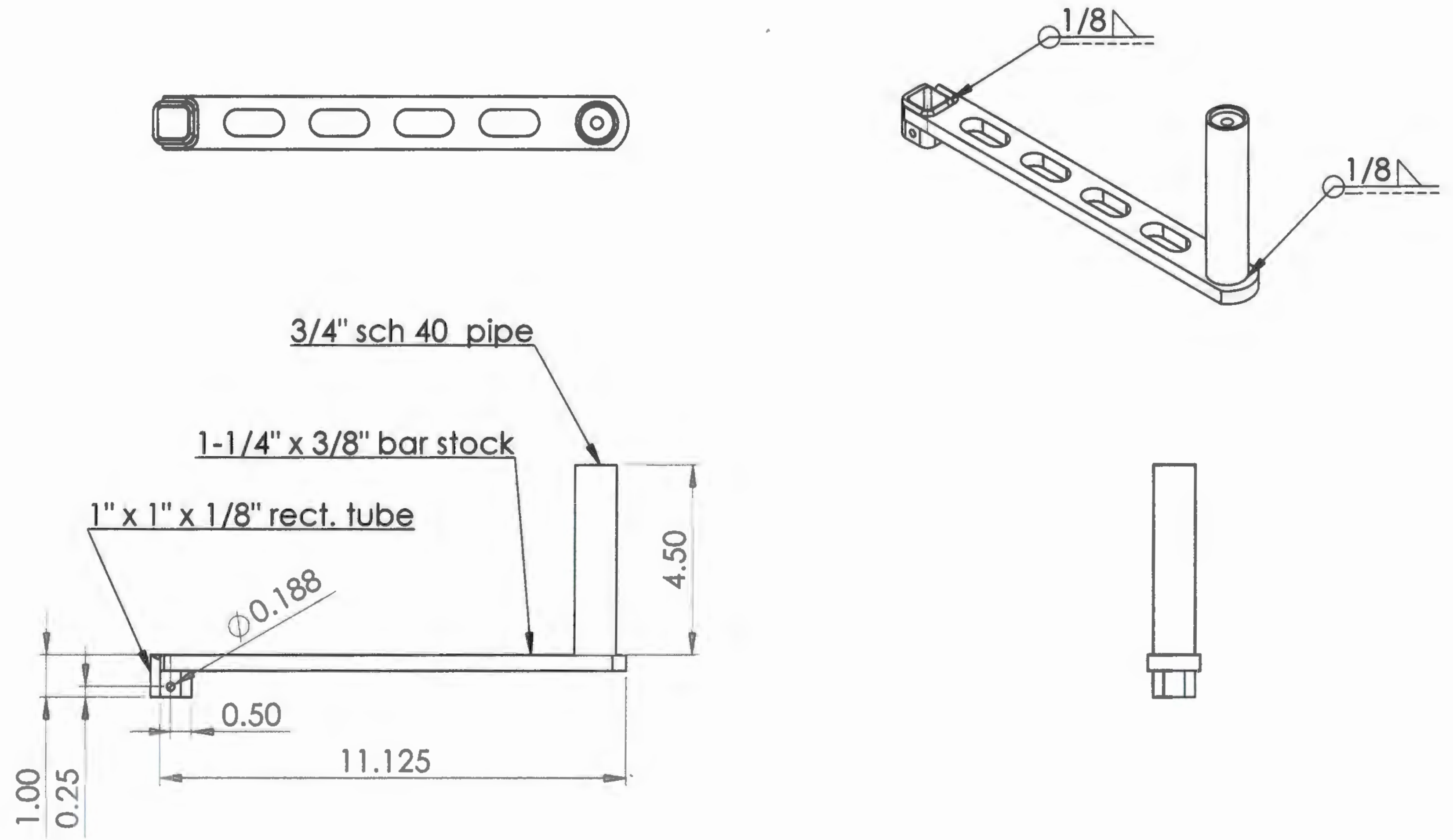
TITLE: BRAE 461/462 tractor stands

DWG. NO.

front. vert. female tube

QUANTITY: 2 DO NOT SCALE DRAWING SCALE: 1:5 WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
c.r. steel

Senior Project

designer Nathan Sperling

advisor Dr. Zohns

TITLE: BRAE 461/462 tractor stands

DWG. NO.

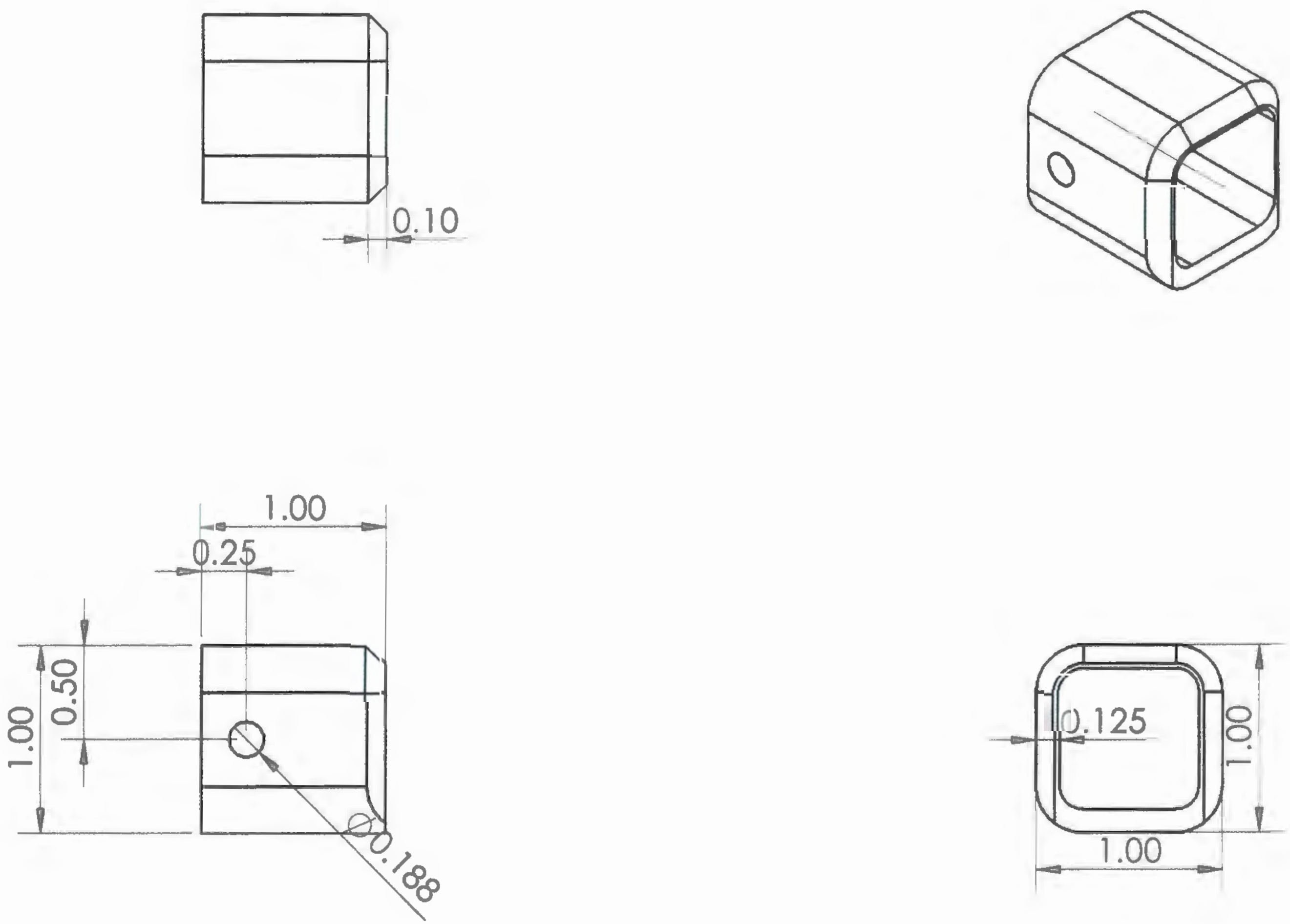
front. vert. handle

QUANTITY: 2

DO NOT SCALE DRAWING

SCALE: 1:4 WEIGHT: EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
1" x 1" x 1/8" cr steel square tube

BRAE 461/462

designer: Nathan Sperling
advisor: Dr. Zohns

TITLE: Senior Project: tractor stands

DWG. NO.

front. vert. handle. socket

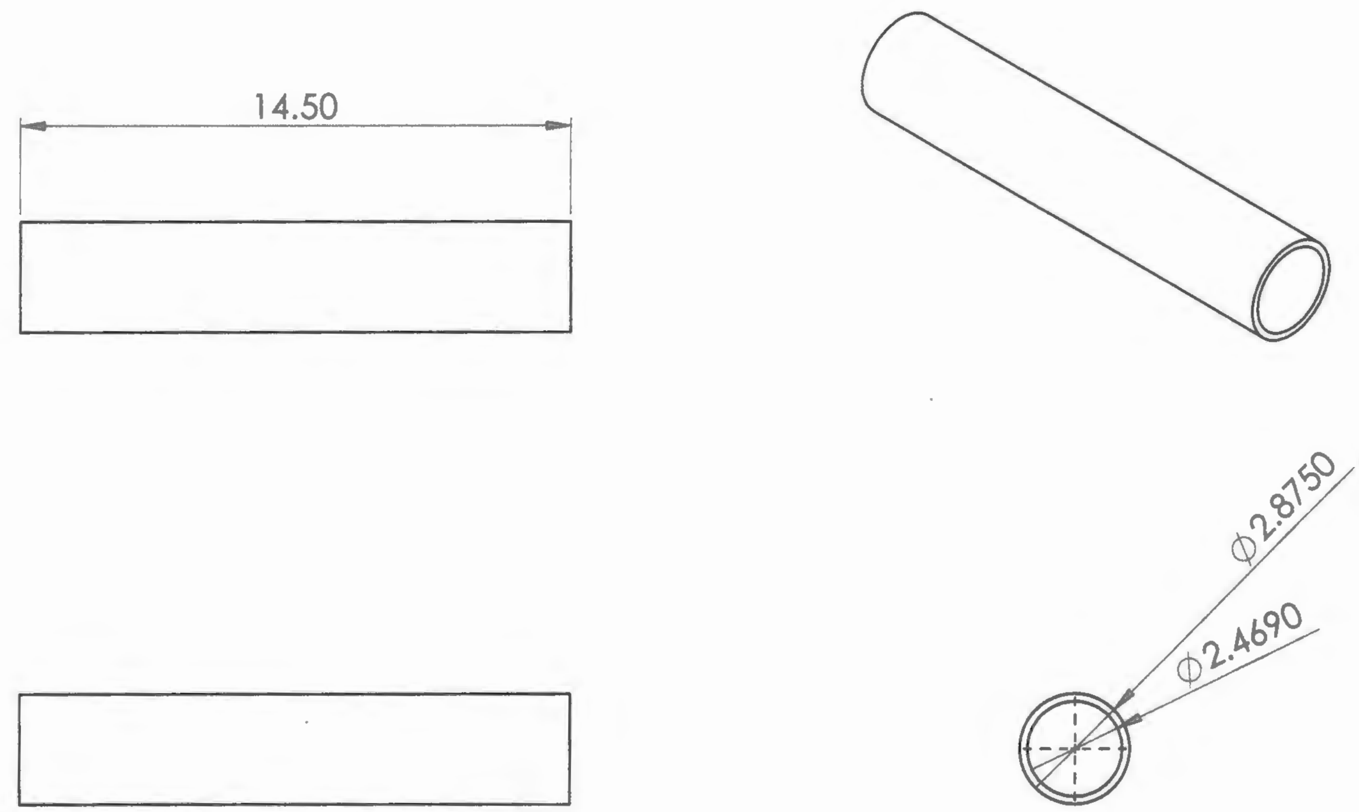
QUANTITY: 2

DO NOT SCALE DRAWING

SCALE: 1:1 WEIGHT:

'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
2-7/8" grade J55 casing pipe

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

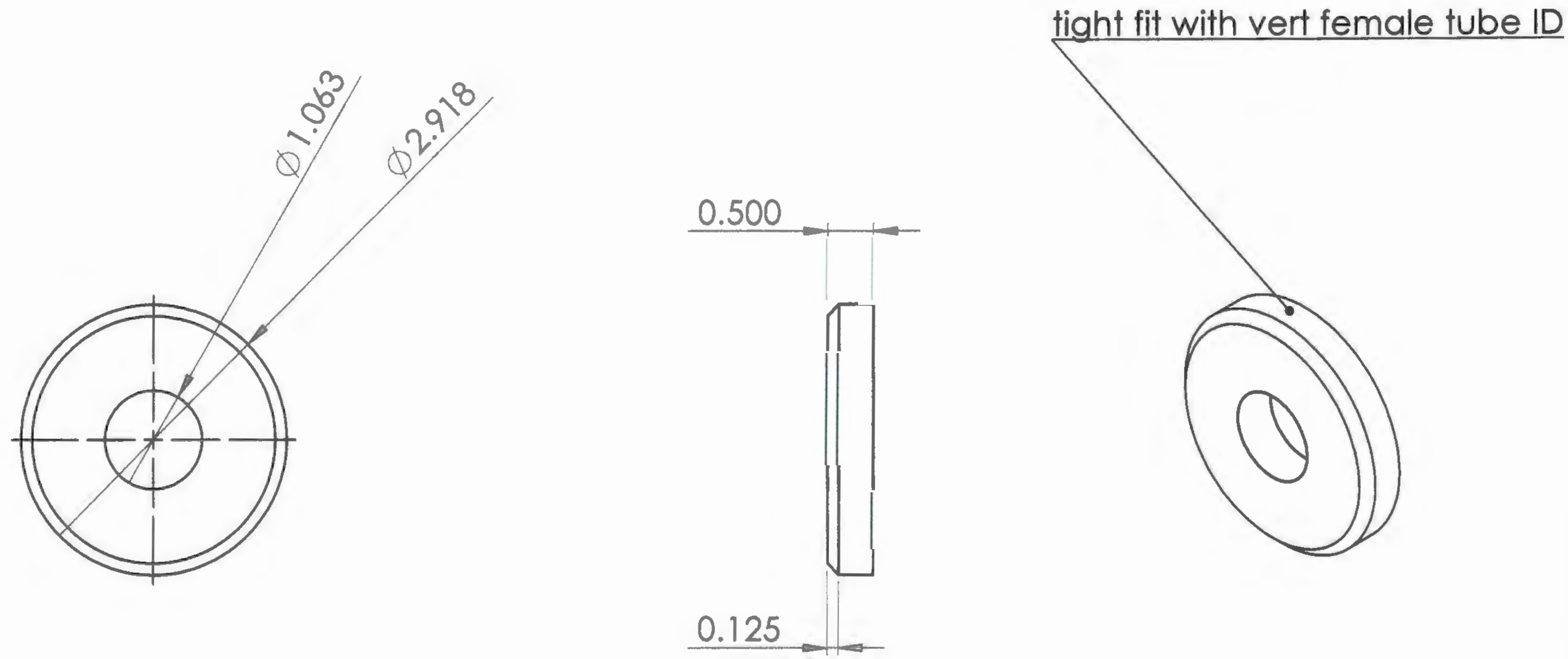
TITLE: BRAE 461/462 tractor stands

DWG. NO.

front. vert. male tube

QUANTITY: 2 | DO NOT SCALE DRAWING | SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



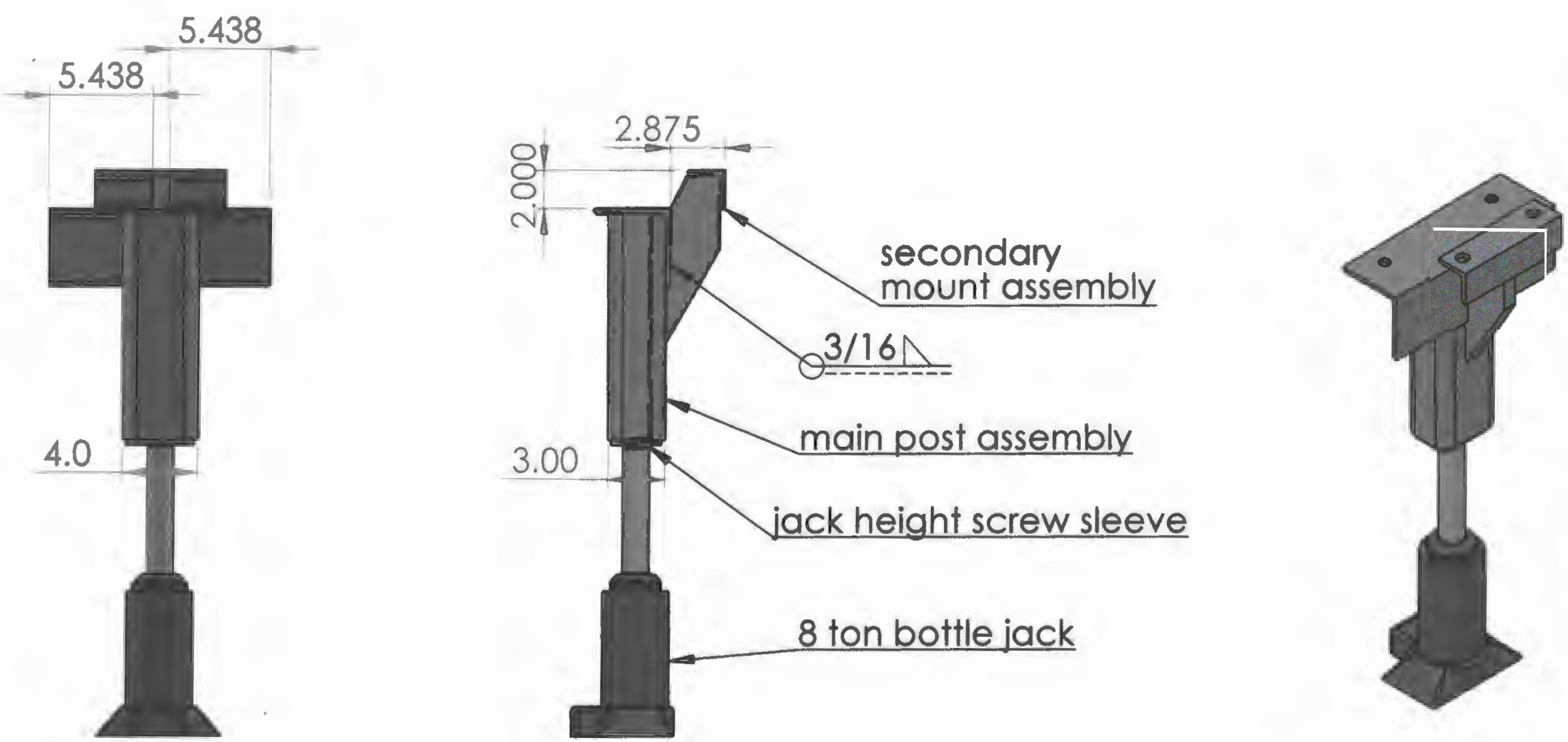
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	Senior Project	TITLE: BRAE 461/462 tractor stands
MATERIAL 3" c.r. steel round stock	designer: Nathan Sperling advisor: Dr. Zohns	DWG. NO.

front. vert. nut retainer

QUANTITY: 2 | DO NOT SCALE DRAWING | SCALE: 1:2 | WEIGHT: | EET 1 OF 1

5 4 3 2 1

Note: see part and subassembly drawings for additional dimensions



Unless otherwise specified DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16 in		Senior Project	
MATERIAL:	steel	designer	Nathan Sperling
FINISH:	painted	advisor	Dr. Zohns

TITLE: BRAE 461/462: tractor stands

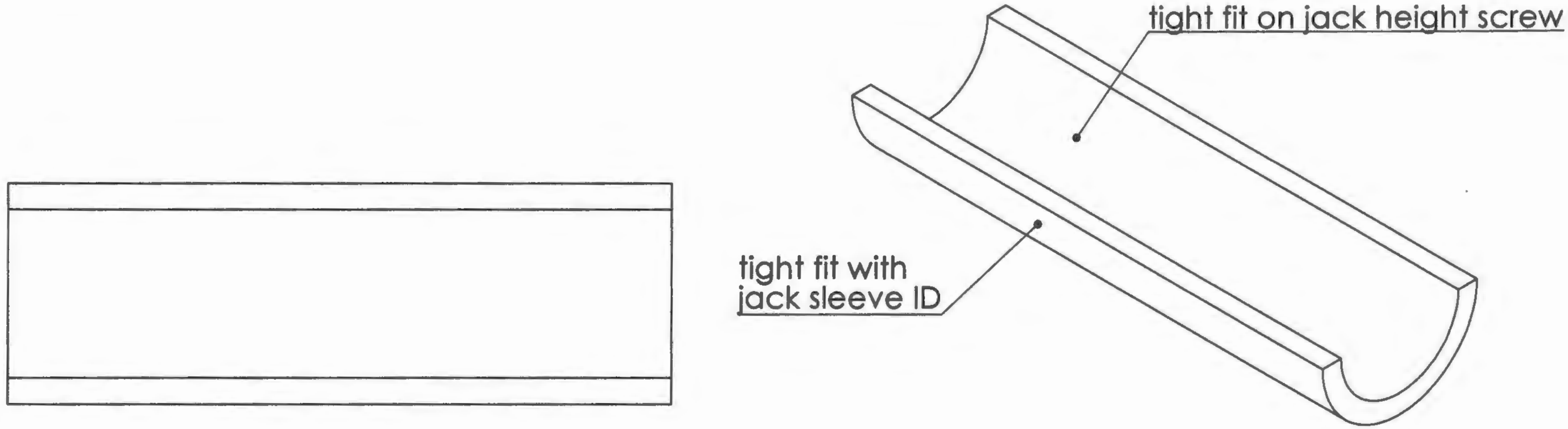
DWG. NO.

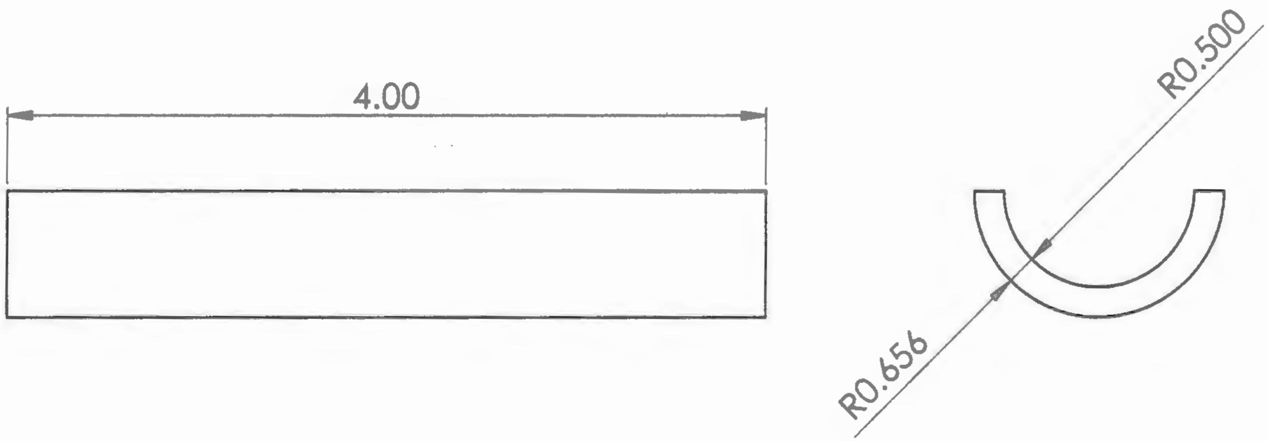
rear assembly

QUANTITY

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





note: start with round tube and cut in half to make two parts once final dimensions are reached

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
c.r. steel

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

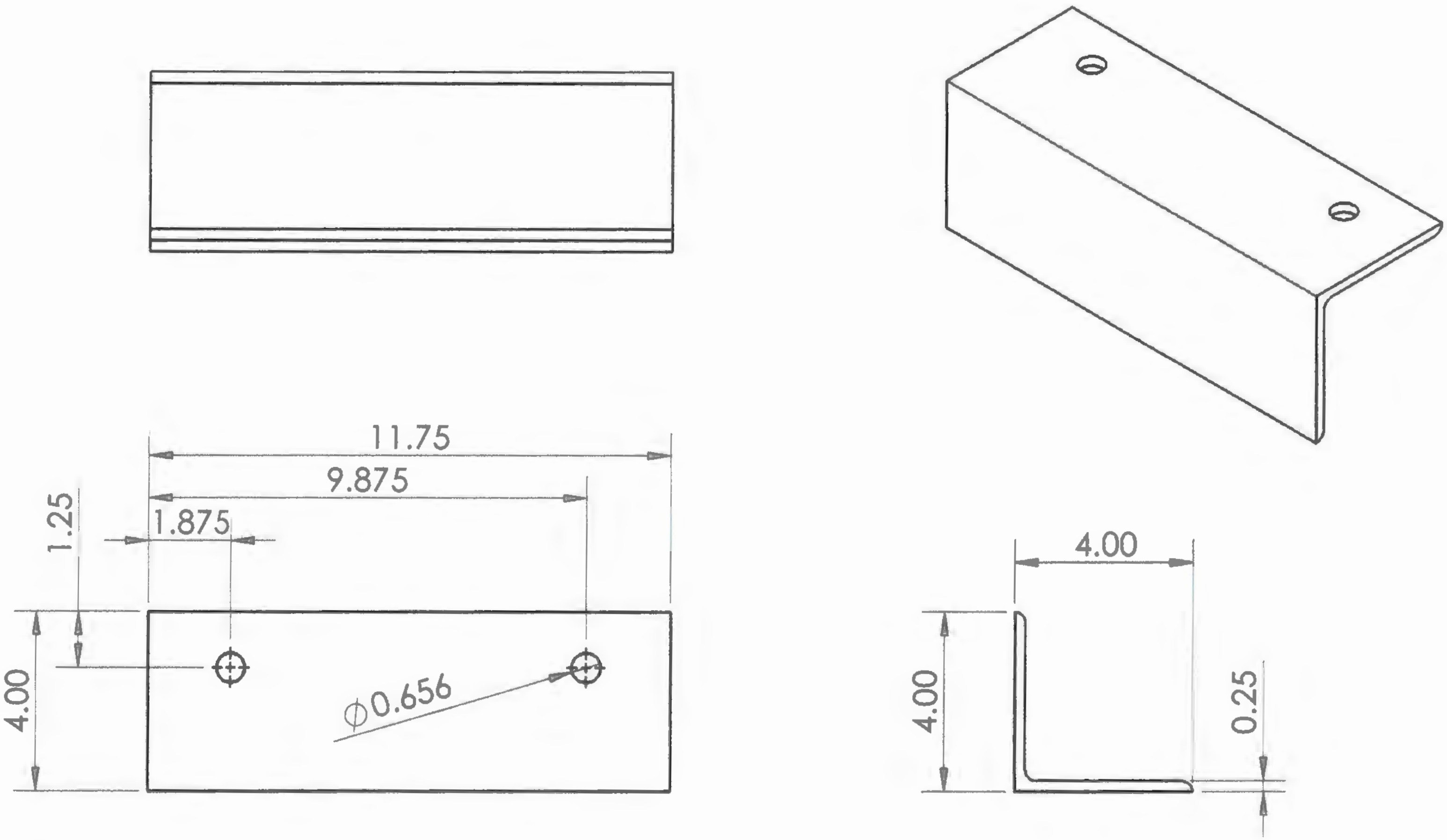
TITLE: BRAE 461/462 tractor stands

DWG. NO.

rear. jack. height screw sleeve

QUANTITY: 2 DO NOT SCALE DRAWING SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

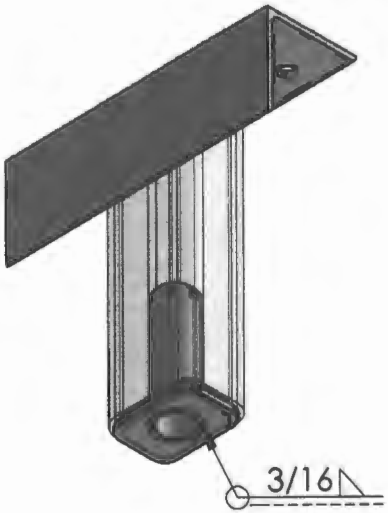


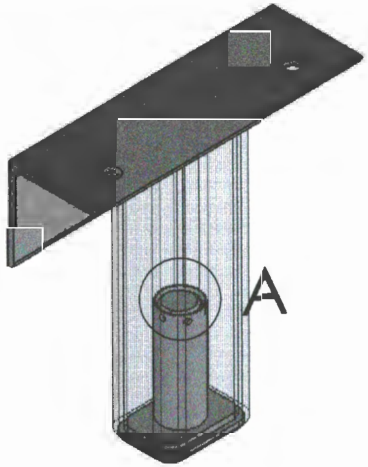
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 4" x 4" x 1/4" steel angle	designer	Nathan Sperling	
	advisor	Dr. Zohns	

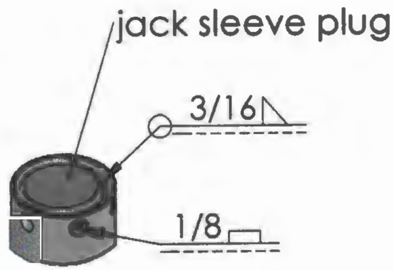
DWG. NO.

rear. main mount bracket

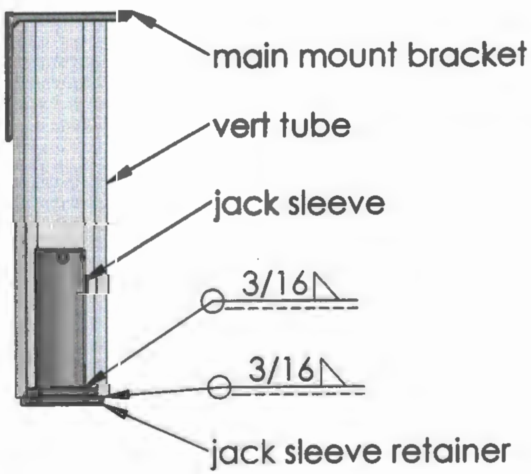
QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:4 WEIGHT: SHEET 1 OF 1

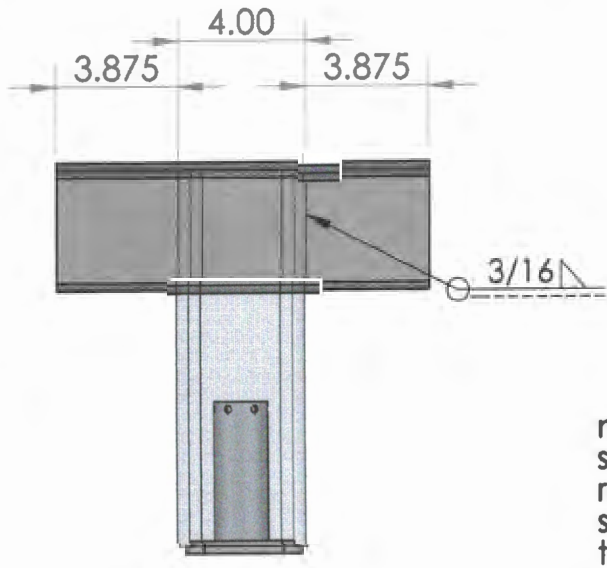






DETAIL A
SCALE 1 : 3

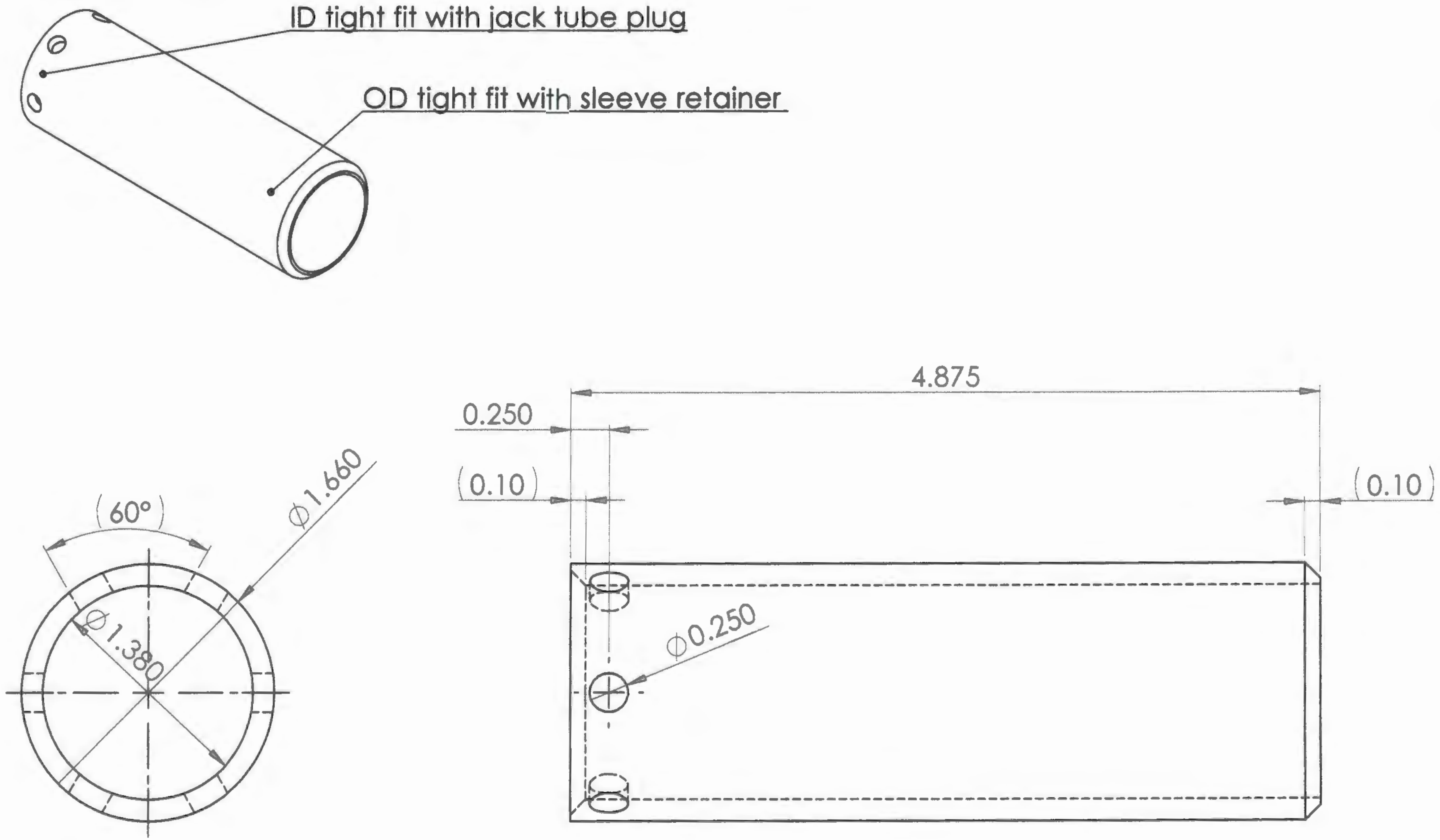




note: weld jack sleeve, sleeve retainer, and sleeve plug together 1st for best assembly

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL steel	designer	Nathan Sperling	
	advisor	Dr. Zohns	DWG. NO.
rear. post assembly			
QUANTITY: 1	DO NOT SCALE DRAWING		SCALE: 1:6 WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

MATERIAL
1-1/4" sch. 40 steel pipe

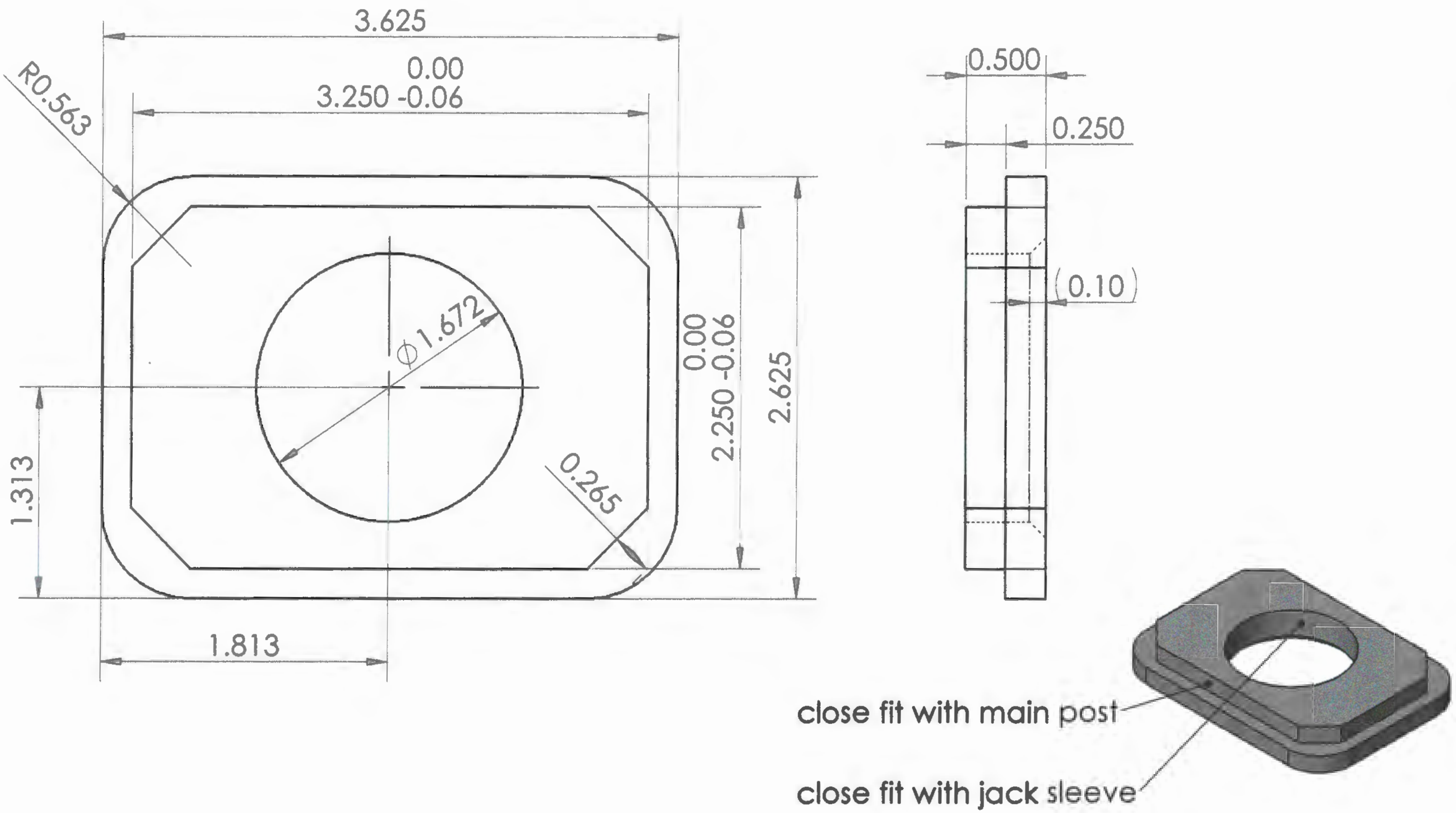
TITLE: BRAE 461/462 tractor stands

DWG. NO.

rear. main post. jack sleeve

QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:1 WEIGHT: IEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
c.r. steel

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

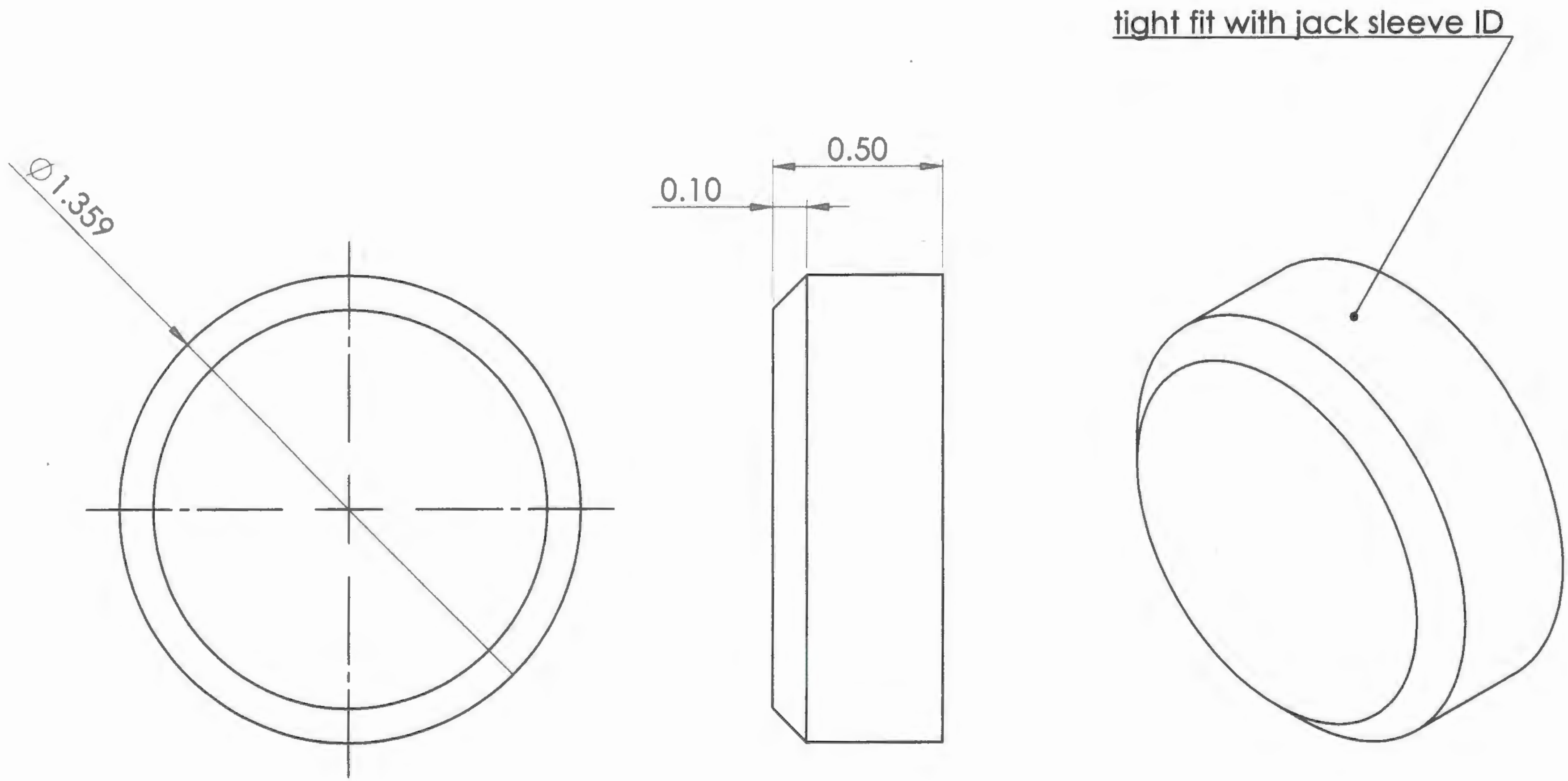
TITLE: BRAE 461/462
tractor stands

DWG. NO.

rear. main post. jack sleeve retainer

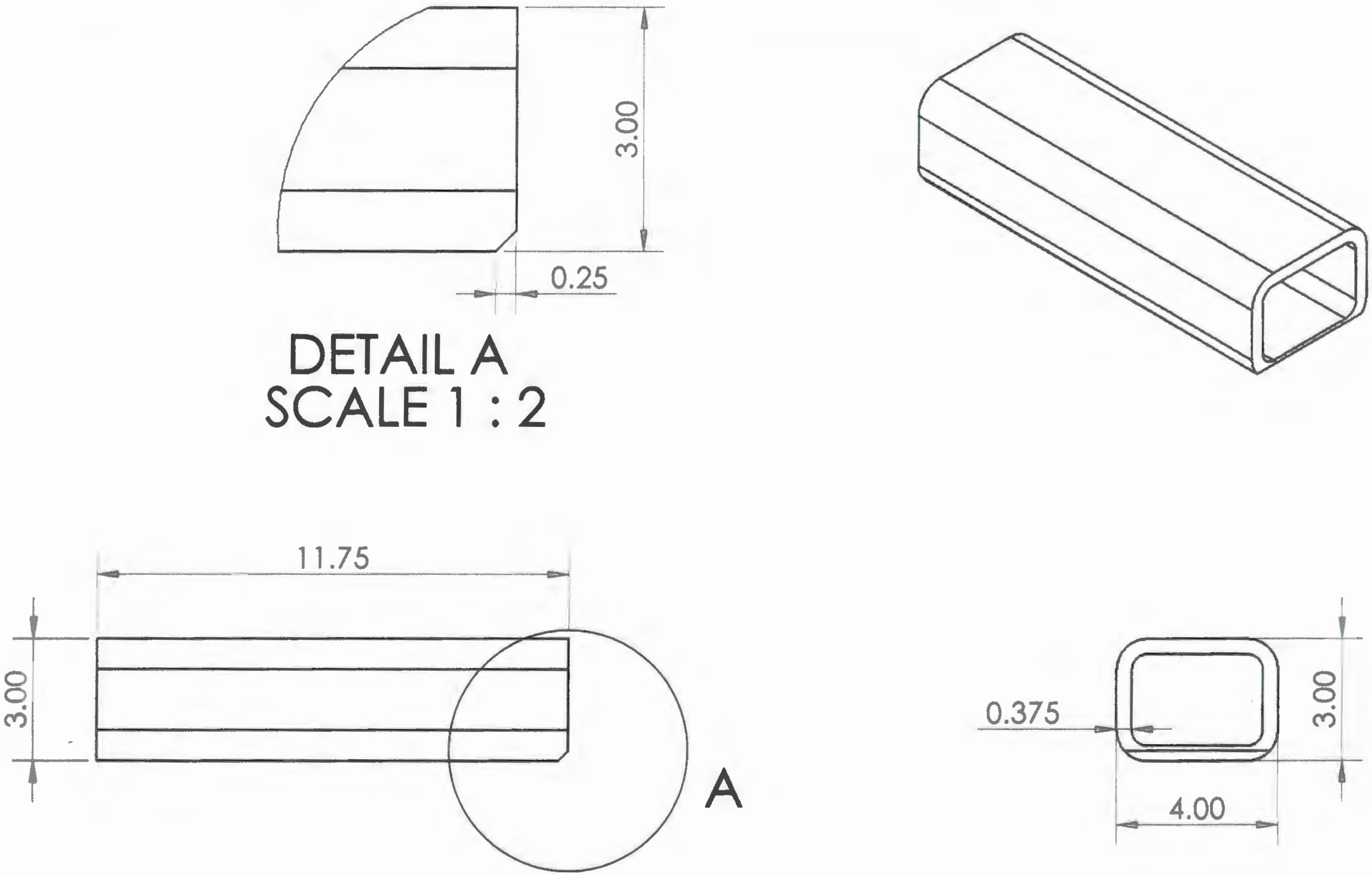
QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:1 WEIGHT: IEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	Senior Project	TITLE: BRAE 461/462 tractor stands
MATERIAL 1-1/2" c.r. steel round stock	designer: Nathan Sperling advisor: Dr. Zohns	
rear. main post. jack tube plug		DWG. NO.
QUANTITY: 1	DO NOT SCALE DRAWING	SCALE: 2:1 WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

BRAE 461/462

TITLE: **Senior Project: tractor stands**

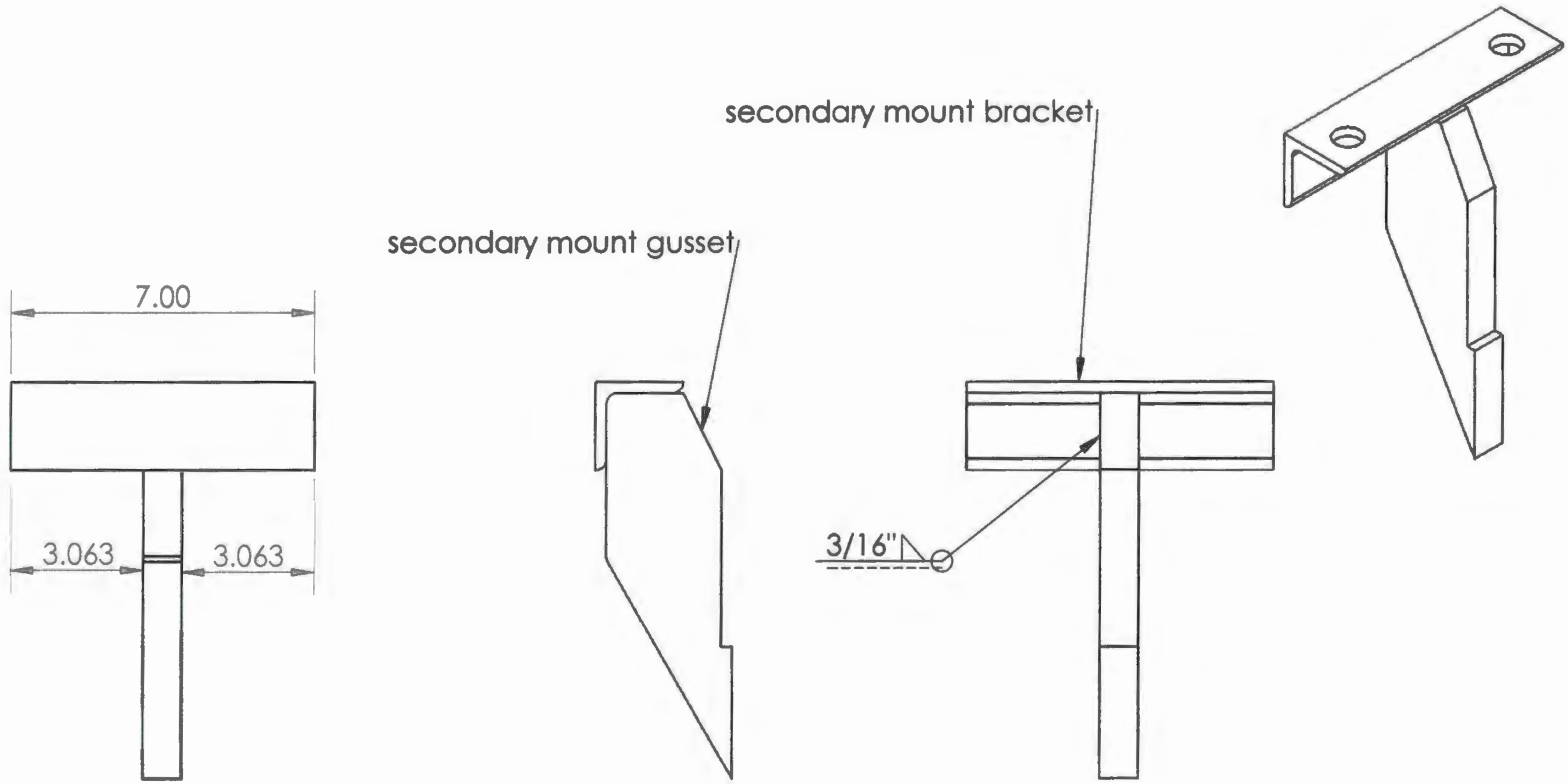
MATERIAL	3" x 4" x 3/8" HSS steel rectangle tube
designer	Nathan Sperling
advisor	Dr. Zohns

DWG. NO.

rear. main post. vert tube

QUANTITY: 1 | DO NOT SCALE DRAWING | SCALE: 1:4 | WEIGHT: | 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

MATERIAL
steel

BRAE 461/462

designer	Nathan Sperling
advisor	Dr. Zohns

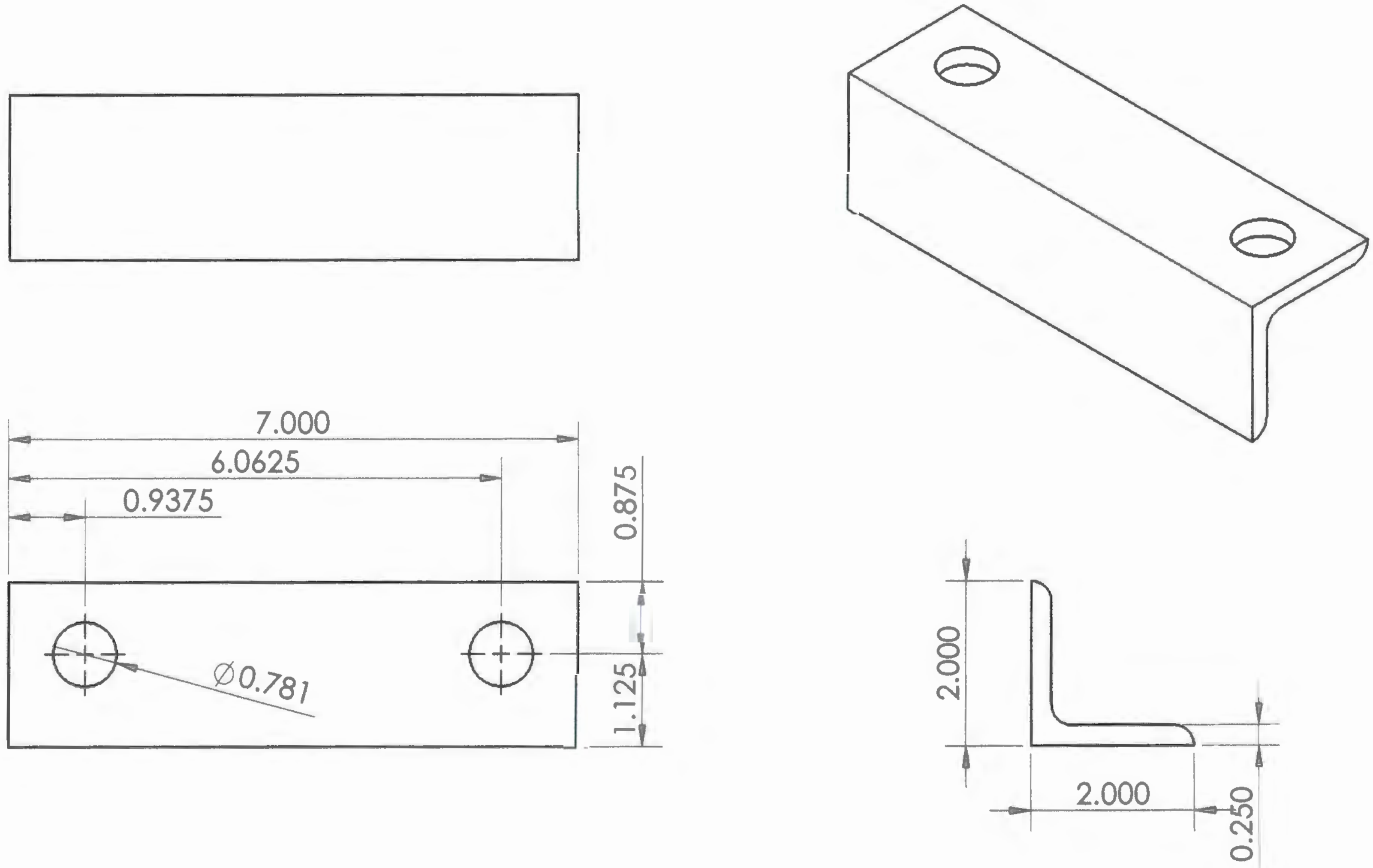
TITLE: Senior Project: tractor stands

DWG. NO.

rear. secondary mount assembly

QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:4 WEIGHT: 'EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±1/16

Senior Project

designer	Nathan Sperling
advisor	Dr. Zohns

TITLE: BRAE 461/462 tractor stands

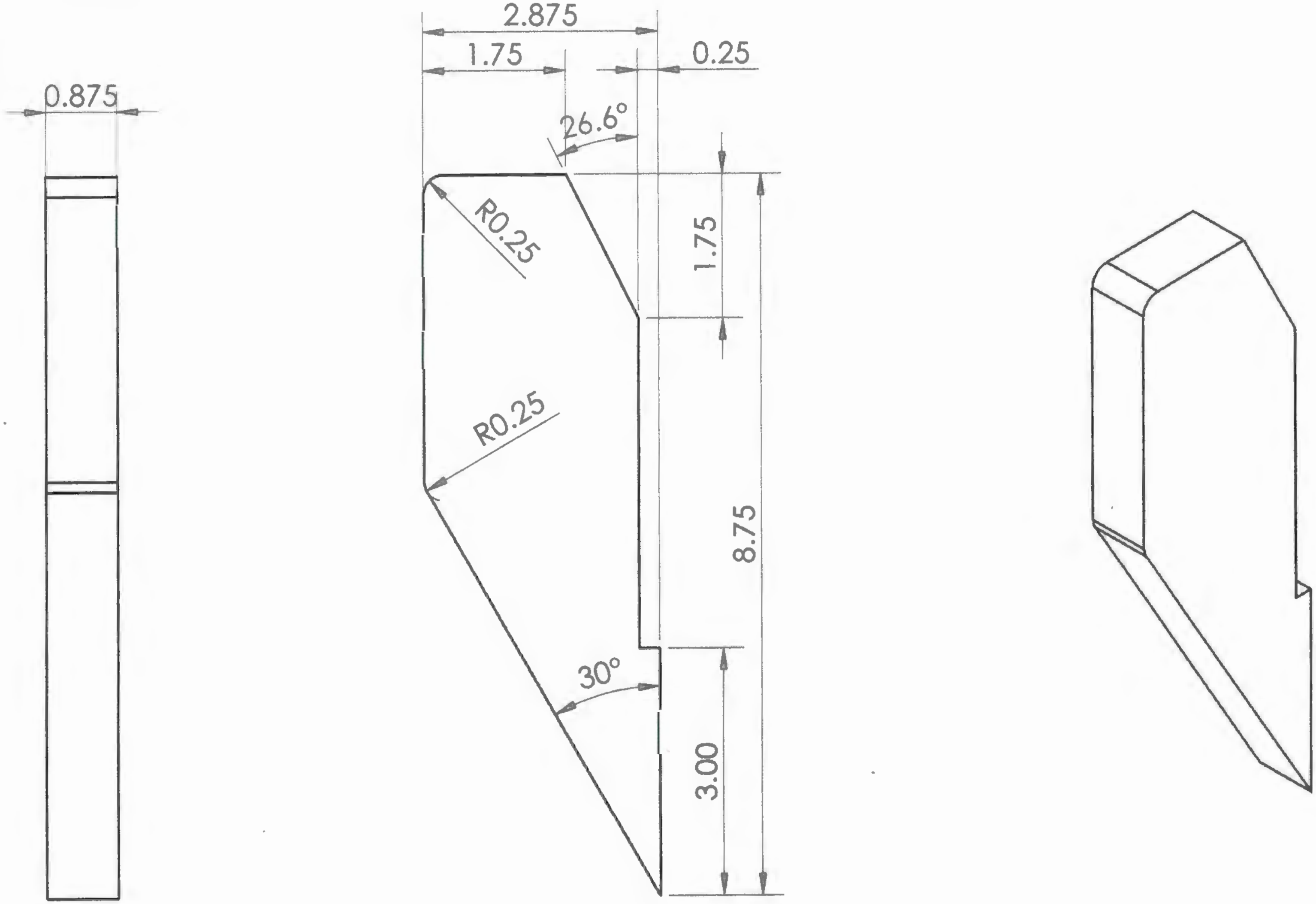
MATERIAL
2" x 2" x 1/4" h.r. steel angle

DWG. NO.

rear. secondary mount bracket

QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: EET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±1/16	BRAE 461/462		TITLE: Senior Project: tractor stands
MATERIAL 7/8" c.r. steel plate	designer	Nathan Sperling	
	advisor	Dr. Zohns	

DWG. NO.

rear. secondary mount. gusset

QUANTITY: 1 DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: 'EET 1 OF 1

5 4 3 2 1