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Designing and Manufacturing a Human Powered Vehicle

Andrew Nordell
Union College - Schenectady, NY

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By

Andrew Nordell

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ABSTRACT

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This thesis will discuss the process of designing, manufacturing, and testing of a two-wheeled, front-wheel drive, adjustable recumbent bicycle. The design aims to create a more accessible, comfortable, efficient, and utilitarian bicycle. The design utilizes a two-wheeled, front-wheel drive system, and is adjustable for riders of different heights. The two-wheeled design was chosen for its simplicity, cost-effectiveness, and accessibility. The front-wheel drive system that this bicycle utilizes was chosen over a more traditional rear-wheel drive because it significantly reduced the length of the chain. The increased chain length from rear-wheel drive models is the primary cause of large frictional losses in the power transmission. Furthermore, the bicycle was designed with current road bike standards in mind, as wheel spacings, chain length, and gearing are all cross-compatible with upright bicycles. The frame is TIG welded and made from 4130 chromoly steel tubing. Steel was chosen for its high strength, manufacturability, and low cost. Testing was done on varied grades against a traditional drop-bar road bike, and the recumbent bike was ~30% faster than the road bike on flat to downhill terrain but lagged behind on steep uphills.

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1. Introduction

Overarching Objective

For my senior design project, I am designing, manufacturing, and testing an efficient, innovative, practical, and cost-effective human-powered vehicle. This design report and corresponding design will act as a stepping stone for future Union college ASME Human Powered Vehicle (HPV) engineering design competition teams. Due to the ASME HPV guidelines, this design project is not eligible to be entered into the competition as I am the singular designer, and there is a membership requirement. Due to this ineligibility, I chose to not follow the requirements laid out by the competition, instead, I chose to design around the four criteria listed above.

Most human powered vehicles that are commonly present in our society are based on the design of safety bicycles. Safety bicycles emerged in the 1880s as a safer alternative to penny farthings (Figure 1).

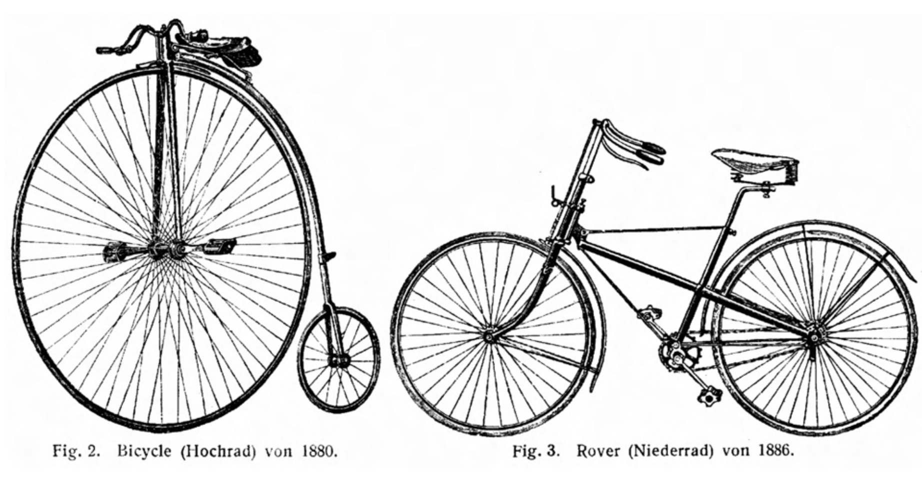

Figure 1. Shows a Penny Farthing (left) and Safety Bicycle (right) from the *Lexikon der gesamten Technik*, or Dictionary of Technology, written by Otto Lueger in 1904 [1].

Since then, the overall geometry and basic design of the common bicycle has not changed significantly and shares all of the general features of the first safety bicycle. Despite its popularity and clear advantages in terms of size, production cost, and efficiency, this design has some major disadvantages. These come from the rider's position on the bicycle. Despite the advantages of being able to put more power through the pedals by the rider standing up and using their weight, the position requires the rider to have an upright position. Even when hunched over when riding a performance road bike, the frontal area of the rider is still relatively large. The second major drawback due to the body position is the lack of comfort; the upright, or slightly hunched forward position of the rider puts a large amount of stress on the lower back, and can cause back problems. For example, more than 50% of riders report low back pain [2]. These two problems, the poor aerodynamics, and the uncomfortable riding position is something that this design project will address.

Recumbent bicycles solve the two problems of aerodynamics and comfort by moving the body position of the rider. It moves the rider from the upright position on a safety bicycle, to a reclined and relaxed position. Usually, most of the weight from the rider is supported by a large, reclined backrest, which alleviates the stress on the rider's low back from being hunched over. Additionally, this reclined position significantly reduces the frontal area of the rider, as the feet and head are in a relatively straight line, streamlined to some extent, to the oncoming wind. Figure 2 shows the differences between the two body positions. Notice the significant difference in frontal area between the two bicycles and the stress put on the safety bicycle rider's lower back.

Figure 2. The left image shows a traditional road biking position [3], and the right image shows a recumbent bike position [4].

In addition to the increased comfort and speed, recumbent bicycles are seeing considerable development when it comes to electrification. For example, some large companies and many startups are creating recumbent bicycle based, enclosed electric vehicles. They claim that these electrified recumbent bicycles will replace cars in cities. These companies include Canyon, PodBike, better.bike, PodRide, CitiQ, and Veemo, among others [5]. Over the past few years, as gas prices have skyrocketed, and with increased technological advancements in battery systems, E-Bike sales have surpassed electric cars and plug-in hybrids combined [6]. Batteries are useful and powerful tools, and this is why we are seeing such an increase. However, they are problematic because of the well-known issues with their sustainability in terms of disposal and the dwindling reserves of raw materials they require [7]. To address this battery problem, I am building an efficient and adjustable recumbent bicycle, fully human-powered with no batteries, for practicality, comfort, and speed.

General Background

The main components of a bicycle are simple but have niche names that are only applicable when speaking about bicycles. This section will act as a background to introduce some basic definitions, names of parts, and conventions used when speaking about bicycles in general. It will also serve as an introduction to different designs of existing recumbent bicycles. Figure 3 shows the parts of a bicycle and their names.

Figure 3. Names of bicycle parts [8].

With the design of this recumbent bicycle, most of the names from Figure 3 have stayed the same and will be referred to as such. From Figure 3, the dropouts are the parts of the frame that interface with the wheel. They are made of 3/16 in 4130 chromoly steel plate, the same material as the frame. In this design, they will be 3/16 in steel plate. The two tubes of the bicycle

that hold bearings are the bottom bracket shell and the head tube. The bottom bracket shell holds the bottom bracket (BB), the bearing that the crankset is attached to, and the headtube holds two bearings, one at the top, and one at the bottom, which allows the fork to freely rotate for steering purposes. Additionally, not shown in the figure is the ‘steerer tube,’ this tube is the straight tube that holds the fork blades and goes into the headtube, and interfaces with the bearings. This report will also feature the terms ‘front triangle’ and rear triangle’ throughout, to be specific, the front triangle is made up of the top tube, downtube, and seat tube, and the rear triangle is composed of the seat stays, chain stays, and seat tube.

2. Design Requirements

The goal of this design project is to create a recumbent bicycle design that is practical, an improvement on existing designs, innovative, efficient, cost-effective, adjustable and it needed to use standard bicycle components. Practicality was desired as many recumbent bicycle designs are extremely heavy, and do not have many places to attach racks or bags. This design needed to be innovative, and this was achieved through the unconventional front-wheel drive and adjustment mechanism. Efficiency was a design requirement because this bicycle must be an improvement in terms of speed and comfort on traditional and existing recumbent bicycles. The design needed to be cost-effective because of the budget constraints of senior projects, and because this bicycle is designed to be accessible to the masses as a more economical and sustainable option to other forms of transportation. Adjustability was also a major design requirement based on accessibility, because the goal of this design is to be a replacement, it needs to fit as many people as possible with just one frame arrangement. Finally, this design needed to utilize standard bicycle components. It would have been too costly, and impractical to

create a recumbent bicycle with custom standards. This design requirement is to increase accessibility and cost-effectiveness.

3. Alternative Concepts

Unlike traditional safety bicycles, which have maintained the same basic components and setup, the recumbent is an umbrella term that includes many disparate designs. There are three-wheeled, two-wheeled, four-wheeled, long-wheelbase, short-wheelbase, front-wheel drive, and rear-wheel drive models, just to name a few categories. There is incredible diversity when it comes to frame geometry, wheel size, and rider position

When initially brainstorming ideas, the tadpole design (Figure 4), was attractive because many previous Union College ASME HPV teams utilized it. However, after reading the literature associated with the design, it was apparent that it would have been too ambitious as an independent project. An entire senior thesis was devoted to just the steering, braking, and drivetrain in 2014 [9]. As a one-person team, with no previous experience building a bicycle frame, I did not want to choose a project that was overly complicated. Additionally, from the design requirements listed above, I wanted to use standard bicycle components that were accessible to everyone. If the tadpole design was chosen, wheels with single-sided hubs would need to be purchased, as well as a more complicated steering geometry, as discussed in the 2014 thesis, and an elaborate chain line that usually requires idler pulleys, which reduces drivetrain efficiency and accessibility.

Figure 4. Union College ASME HPV tadpole trike design

Another promising concept was the rear-wheel drive, two-wheeled model shown in Figure 2. This is by far the most popular design, and the first recumbent bicycle was developed in the late 1890s, not long after the safety bicycle [10]. Generally speaking, this design is the most connected to the original safety bicycle from Figure 1, just with altered geometry and a longer chain. The main reason this design was not chosen was the lack of originality and the long chain. The long chain was perhaps the largest drawback of this design, as it is less accessible and more expensive..

The design that ended up being chosen was the front-wheel drive, two-wheeled model, with the main advantage being the shorter chain, more accessible components, and a less common, innovative design. Table 1 shows the initial Pugh decision matrix that was used to whittle down feasible designs. The front-wheel drive model scored highest in most of the categories, and it is simple, and compact design (where all of the drive components are at the front), proved challenging but was feasible as an independent design project. The next section will outline the detailed design and give an overview of all of the subsystems.

Table 1. Pugh decision matrix, where 1 is worst, 5 is best

	30%	20%	20%	20%	10%	100%
	Cost	Feasibility	Creativity	Novelty	Safety	TOTALS
RWD two wheels	4	4	1	1	3	260
FWD two wheels	**5**	**3**	**3**	**3**	**3**	**340**
RWD Tadpole	1	2	1	2	4	200
RWD Tricycle	2	3	2	3	1	220
FWD Tricycle	3	3	3	4	1	280

4. Detailed Design

Figure 5. SOLIDWORKS render of the assembled frame.

4.1. Overview

The final design, shown in Figure 5, utilizes thin-walled 4130 Chromoly steel tubing as the frame material as it is a proven material for bicycle frames, with its high availability, manufacturability, strength, and high dampening characteristics. A front-wheel-drive system was selected as it does not require a long chain, and because of its improved front-end performance when climbing and cornering. Compared to other designs considered, the rider is relatively high with respect to the ground. This is for improved balancing and visibility in traffic, despite the small aerodynamic penalty. The seat will be modeled in SOLIDWORKS and will be made of fiberglass, for lightness, stiffness, high dampening characteristics, and affordability. Carbon fiber would have been a better material for this application but is too expensive. The wheels are quick-release 700c road bike wheels with standard spacing and the handlebars and drivetrain are standard for a road bike as well. Using SOLIDWORKS mass properties, the frame weighs just over 21.5 lb, making it about three times heavier than a traditional lightweight steel framed road bike with butted and tapered tubes, however, it is comparable to other similarly sized recumbent bicycles, whose complete weights are around 30 lb [11]. All of the components should weigh about 15-20 lb, so a final weight of 30-35 pounds could be achieved.

4.2. Subsystems

Frame

The frame was designed to be strong, and torsionally stiff while maintaining some vertical compliance. It is TIG welded using ER-70S filler rod. This was chosen over the commonly used stainless steel filler rod due to it’s increased longevity and decreased oxidation.

It was also designed to have some practical and utilitarian uses as well, which was accomplished by the large rectangular opening underneath the seat as well as eyelets in the rear dropouts. This opening is large enough to hold a frame bag that can carry a large number of supplies without needing a rack, however, a rack could be installed using the eyelets of the rear dropouts. When first designing the frame a diagonal member broke the rectangular opening into two triangles to increase strength, however, after simulating loading cases using weldments finite element analysis (FEA), the simulations showed that the member was not required to maintain structural integrity and was consequently removed. For images of the completed frame, see Appendix A.

Figure 6 shows the frame and the naming convention for tubes. The two main structural elements of the frame are the down tube and the top tube, these are long sections of 1 in diameter tubing that connect the head tube with the rear seat tube and connect to each other with the front seat tube. They experience the most stress from the rider and are the longest members in the frame. They each have one bend with a 6 in radius. The rear seat tube is designed to offer some compliance to the rider, as it is supported only on the bottom and acts as a cantilever on the rider's back. The seat stays and chain stays connect the rear seat tube with the rear dropouts and hold the wheel. These are designed to give maximum tire clearance for increased functionality and practicality. The dropouts are also designed with practicality in mind and feature triangular cutouts for weight reduction, while also maximizing strength for the submitted drawings, see Appendix B.

This design was chosen, as it was the simplest and strongest design developed. Other designs were attempted, such as the singular, thick-tubed frame, as seen in Figure 2, however, it lacked torsional stiffness, and the functionality to mount bags, so it wasn't chosen. For more information on alternative designs, see Appenix C.

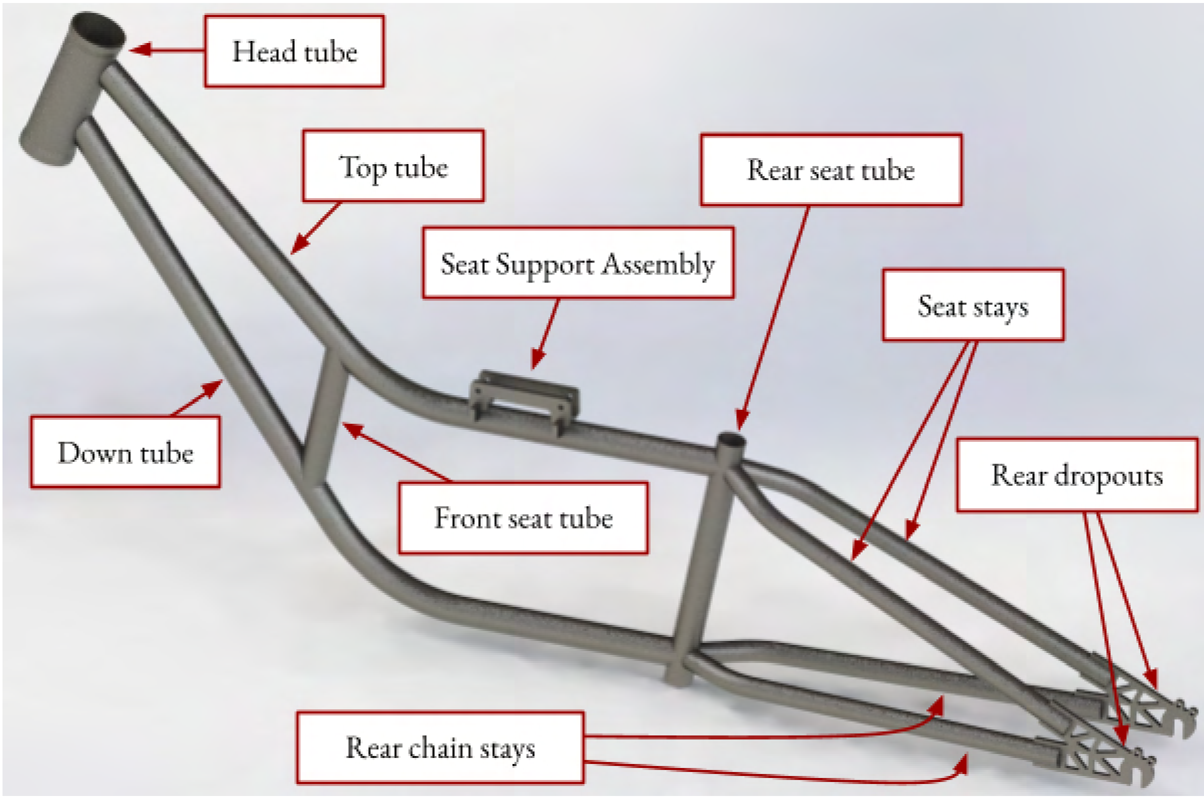

Figure 6. Frame Subsystem

Tubing Diameters

Tubing diameters were chosen for their strength, and the Union College machine shop's ability to bend them. The machine shop has tube bending dies for a variety of tubing sizes subject to minimum wall thicknesses for each bend radius and tubing diameter. Before selecting the optimal tubing for each frame member, the manufacturing capabilities of the machine shop were considered. These limitations did not hinder the design process but proved helpful as they set up bounds that reduced the number of variables to consider.

All tubes used to make the frame and steering assembly have a wall with a constant wall thickness of 0.048 in, except for the straight boom shown in Figure 7 which utilizes a wall

thickness of 0.058 in. Researching bicycle tubing and optimal wall thickness, this was a common number discussed. However, if more resources were available, butted (wall thickness variation) and tapered (diameter variation) tubing would have been utilized to reduce the weight of the frame. Bicycle-specific butted and tapered tubing is designed to be strongest at the places where it needs to be, and lightest where it can. Butted tubing has a greater wall thickness at the ends of the tubing where there are higher stress concentrations, and is thinner at the center where the stress is lower to minimize unnecessary weight. Tapered tubing is designed the same way, and is commonly utilized in bicycle forks, as the tubing is usually a larger diameter at the top of the fork blades, and smaller at the bottom.

The rear triangle – or more specifically what is referred to as the chain stays and seat stays in Figure 7 – usually has a smaller diameter than the other tubing in the frame; in this design, 0.75 in tubing is utilized. This is for two reasons; these tubes are subjected mostly to compression, which these tubes are adept at dealing with, and the geometry of the rear of the bicycle, which is inherently stiff. The rear axle (skewer) connects the two triangles and forms a tetrahedron (with one very short side), which is very strong. This triangulation and compression force leads to a reduction in the required diameter of the tubing.

For the application of the rear chain stays, two geometries of tubing were considered based on the tubing dies and recommended wall thicknesses by the machine shop. The first option was 0.625 in diameter with 0.065 wall thickness. Initially, this option was attractive because it had a smaller diameter, and withstood the FEA analysis, however, after an analysis of 0.75 in diameter tubing with 0.048 in wall thickness, the 0.625 in tubing was discarded. The larger tubing was not initially desired due to the slightly larger diameter, and the incorrect assumption that it was heavier. However, some quick calculations proved otherwise. Per unit

length, the 0.625 in diameter tubing weighs 13.7% more than the 0.75 in diameter due to the increased thickness, while also having a lower area moment of inertia of 0.00533 in^4 compared to 0.00722 in^4. Due to the increased strength and lower weight, the 0.75 in diameter tubing was selected.

Steering

The steering mechanism on this recumbent bike utilizes a built-in adjustment system. Compared to most recumbent bicycles, which are adjusted by fixing their pedaling platform and moving the seat on sliders relative to the pedals, this design fixes the seat and moves the pedaling platform with respect to the seat. This is achieved by creating an adjustable triangle with the pedaling platform, which gives just over 12 in of adjustment. To make the triangle adjustable, one of the sides, or members in this case, needs to change length. Here, the changing length member is the boom. The boom is composed of two parts, the straight boom, and the bent boom. The bent boom is a 1 in outer diameter tube that slides into the straight boom, which has an inner diameter of 1.009 in (due to the increased wall thickness of 0.058 in).

These sliding tubes are secured by an interface clamp shown in Figure 8. The boom is secured to the fork with the boom clamp shown in Figure 9. It holds both the steerer tube of the fork and the boom in place, while also allowing for angular adjustment between them by pivoting on one bolt. After sliding through the boom clamp, the straight boom is welded to the stem clamp which holds the handlebars.

The boom is connected to the BB shell with the BB clamp, which is welded to the bent boom and secures the leading edge of the steering triangle while allowing for angular adjustment. The BB clamp fits between the front chain stays, which are welded to the BB shell shown in Figure 7. At the bottom of the chain stays and fork, are the front dropouts, the 3/16 in

thick waterjet steel plates that hold the wheels in place. Finite Element analysis was performed on the front and rear dropouts and it was concluded that material could be removed to reduce weight.

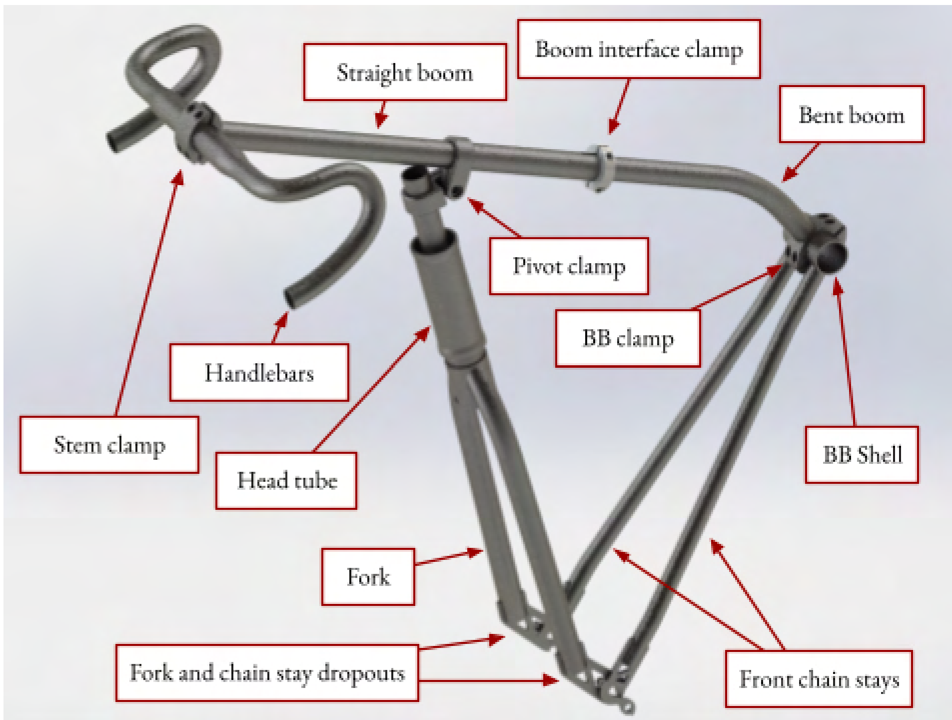

Figure 7. Steering subsystem without the interface clamp

Tubing Diameters

The steering assembly features two purchased, bicycle-specific tubings, the 1 ⅛ in steerer tube, and the bottom bracket shell. To be purchased from a bicycle frame building supplier, these hold the bearings for the fork and crankset, respectively. The fork is composed of the steerer tube, fork blades, and dropouts. The fork blades utilize custom spacing of 5.12 in (130 mm) to accommodate the wider-spaced rear wheel (front wheel on this design). This tubing was chosen based on positive finite element analysis results, and extensive research into optimal diameters

and wall thicknesses for bicycle frames and forks. The front chain stays feature the smallest diameter on the bicycle of 0.625 in. This is due to their straight geometry and their lower load, however, they are strong enough to withstand a significant head-on collision, outlined in the Weldments Frame Analysis section. A 1 in diameter tube was chosen for the bent boom as it experiences repeated bending forces from steering and a stiff tube was highly preferred for that application. The straight boom has an outer diameter of 1.125 in and a wall thickness of 0.058. The greater wall thickness was chosen to achieve an inner diameter of 1.009 in, for sufficient clearance (0.009 in) for the sliding bent boom which has an outer diameter of 1.000 in. This sliding clearance was tested and deemed to be sufficient for this design. Increasing from a 0.048 wall thickness gives a weight penalty of 0.185 lb, which was worth a tighter fit compared with other wall thicknesses.

Clamps

There are four clamps that secure the adjusting steering assembly shown in Figure 7. The bottom bracket, stem, boom interface, and pivot clamps. The bottom bracket and stem clamps share the same basic design and are milled from a 3-in-diameter 4130 steel rod. Figure 8 shows the bottom bracket and stem clamps.

They are milled 4130 Chromoly steel and consist of two halves secured to each other with four bolts on each corner, the counterbored clamps are shown in Figure 8. The clamp diameters were made 0.003 in larger than their clamping surface for sufficient clearance. The boom clamp secures the fork steerer tube to the boom shown in Figure 9, and while it holds the fork and boom in place, it allows for angular adjustment by pivoting on one bolt. FEA was done on each clamp, and they all achieved sufficiently high factors of safety (see Table 3 in the Finite Element Analysis section). Some of the clamps, specifically the stem and bottom bracket clamps

have factors of safety greater than 10. While this is overkill for this application, the size of the clamps is limited by the manufacturing capabilities of the machine shop, and by the materials that this project has access to. The clamps will be heavier and more robust than required, but for this application, it is not a drawback.

Figure 8. The bottom bracket clamp on the left, and the stem clamp on the right. Notice the counterbore locations for the bolts.

The boom interface clamp is purchased from McMasterCarr and is a two-piece 1 ⅛ in shaft collar. The straight boom has a small cutout, shown in Figure 9, which the shaft collar clamps down on to secure the interface between the straight and bent boom. Also shown in Figure 9 is the pivot clamp, which uses two, single bolt, P-shaped interlocking clamps to allow for angular adjustment between, and clamping of, the steerer tube with the straight boom.

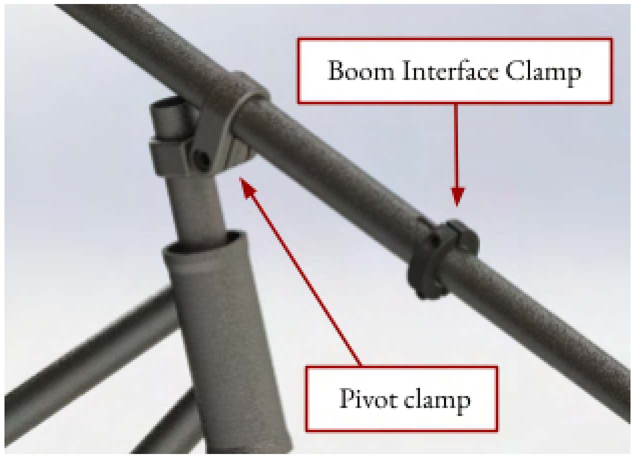

Figure 9. Pivot clamp and boom interface clamp.

Dropouts

The dropouts on the bicycle hold the front and rear wheels to the frame, two sets for the front wheel, one set for the fork legs, one for the front chain stays, and one set in the rear. They are manufactured using a waterjet and cut out of 3/16 in 4130 steel plates. They all use a notch and slot design and are welded to the frame, and protrude ⅛ in from the tubes on each side to leave room for welds. Figure 10 shows the notch and slot design. The front axle assembly, shown in Figure 7, shows the front chain stay dropouts and the fork dropouts interfacing and holding the wheel at the axle. The right chainstay dropout has an attachment to hold the rear derailleur in place. This assembly is secured by the axle and a quick-release skewer that clamps the dropouts to the axle.

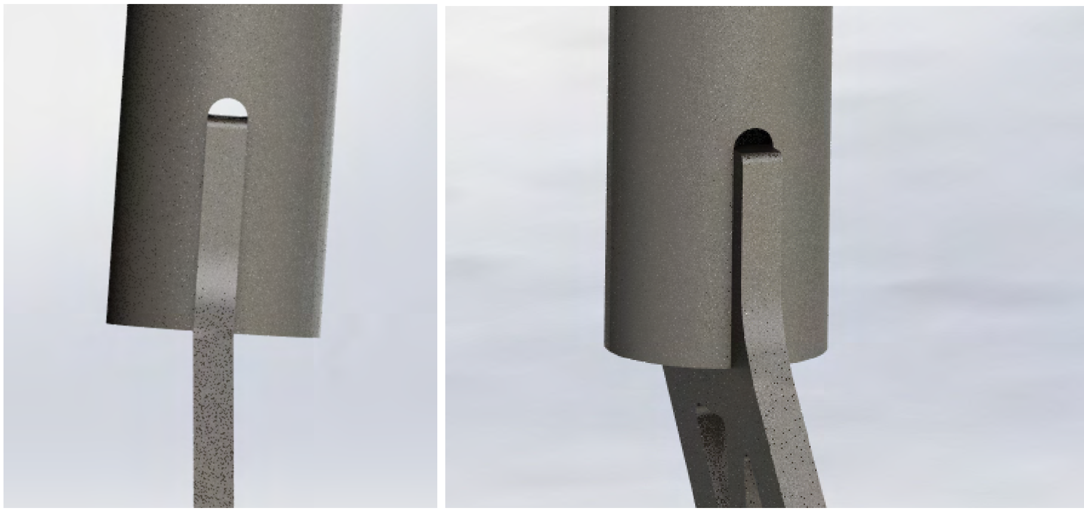

Figure 10. Notch and slot dropout design shown with the front dropouts for the fork. The rounded top is to account for the end mill used to cut this hole.

FEA was run on both the front and rear load-bearing dropouts and they both achieved sufficiently high factors of safety of 1.82 and 2.14, respectively. The loading and fixtures will be discussed in the Finite Element Analysis section. Figure 11 shows the front and rear dropouts connected to the frame.

Figure 11. Front dropouts (left) and rear dropouts (right) are attached to the frame with the notch and slot design. On the front dropouts, the extended segment holds the rear derailleur.

Shifting

On most bicycles, there are two places to change gears, at the front sprockets (the crankset), and at the rear sprockets (cassette). This bicycle uses this front and rear gear shifting system, as the components were taken from a road bicycle with a 2x9 drivetrain. 2x9 denotes, 2 gears on the crankset, and 9 gears on the cassette. In this case, 50 and a 34-tooth chainrings on the crankset, and a cassette that spans from 11 teeth to 34 teeth. To change gears, front and rear derailleurs are needed. These are cable-actuated devices that cycle the chain through the gears. In terms of integrating the front and rear derailleurs into the recumbent design, the rear derailleur was relatively straightforward to incorporate into the design as it mounts directly to the rear dropouts. Additionally, the rear derailleur has a fair amount of angular adjustment, so it can be adapted for a variety of different mounts. The left image in Figure 11 shows the rear derailleur mount utilized in this design, the extended section on the dropout. Figure 12 shows the derailleur installed on the mount.

Figure 12. Front derailleur on the completed bicycle.

Compared to the rear derailleur, integrating the front derailleur into the shifting system proved more challenging. The design requirements of the front derailleur mount were that it needed to be able to mount the existing derailleur that came from the road bike, which bolted onto the seat tube (Figure 3), which had a diameter of 1 $\frac{3}{8}$ in. It also needed to be made from $\frac{1}{8}$ in 4130 chromoly steel plate, and be welded to the bottom bracket shell on the chainstay assembly, and the entire system must be adjustable for different size chainrings. The main challenges were as follows: aligning the front derailleur at the angle about the axis of the bottom bracket, and the angle in relation to the chain, the distance the derailleur needed to be from the chain itself, the mounting assembly, and cable access. Figure 13 shows the final design of the front derailleur mount.

The mount on the road bike was measured, and a SOLIDWORKS model and subsequent drawings of the bent 4130 chromoly steel plate were developed. Sufficient clearance needed to be given to the chainstays and the bottom bracket clamp. To mount the front derailleur to the steel plate, a 3D printed mount was designed, as complex geometry could be easily achieved using 3D printing as opposed to traditional machining. Figure 13 shows the bent steel plate and 3D print assembly installed on the bicycle. The 3D printed mount is able to interface with both the sliding cutout in the $\frac{1}{8}$ in steel mount and the derailleur itself using two pairs of M5 bolts with nuts. The 3D print has hexagonal cutouts that the nuts sit in so only an Allen key is needed to disassemble it. After the 3D printed mount and $\frac{1}{8}$ in steel mount were completed, a cable was needed to reach the front derailleur. The angle was measured, and another 3D-printed mount was designed and installed. It holds the cable housing in place, allowing the exposed cable to connect to the derailleur.

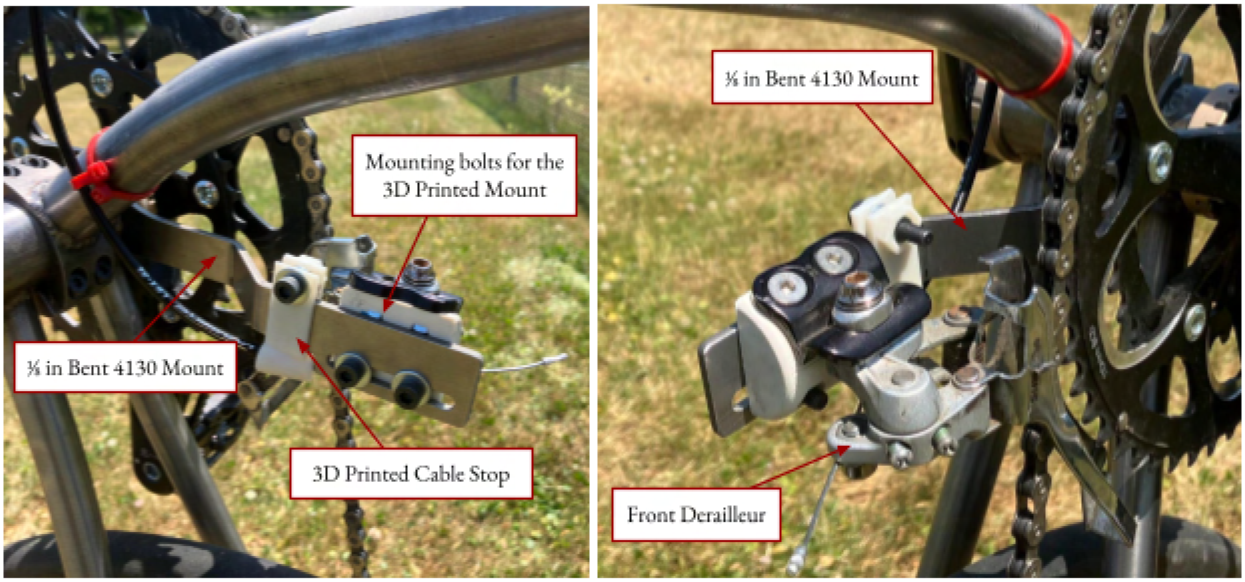

Figure 13. Two views of the front derailleur mounting assembly. Notice the curved black derailleur mounting system, which came with the derailleur, and how it interfaces with the 3D-printed mount. Notice also on the left image, the mounting bolts that the derailleur. Finally, note the slot in the bent metal mount, allowing for adjustment in the height of the derailleur in relation to the crankset.

4.3 Purchased Components

Seat

The seat employed in this recumbent design is an aftermarket seat made for the Sun EZ-1. This design utilizes a square top tube so a mounting system can easily clamp around the surface shown in Figure 14.

Figure 14. Sun EZ-1, notice the seat connection point with quick-release clamps and the square cross-section top tube [12].

The Sun EZ-1 seat was chosen, as it was available to purchase from Amazon, had a reasonably quick delivery date, and despite being more than $300, it was the most economical seat found. When the seat arrived, a fixture needed to be designed to fit the built-in quick-release clamping mechanism shown in Figure 15.

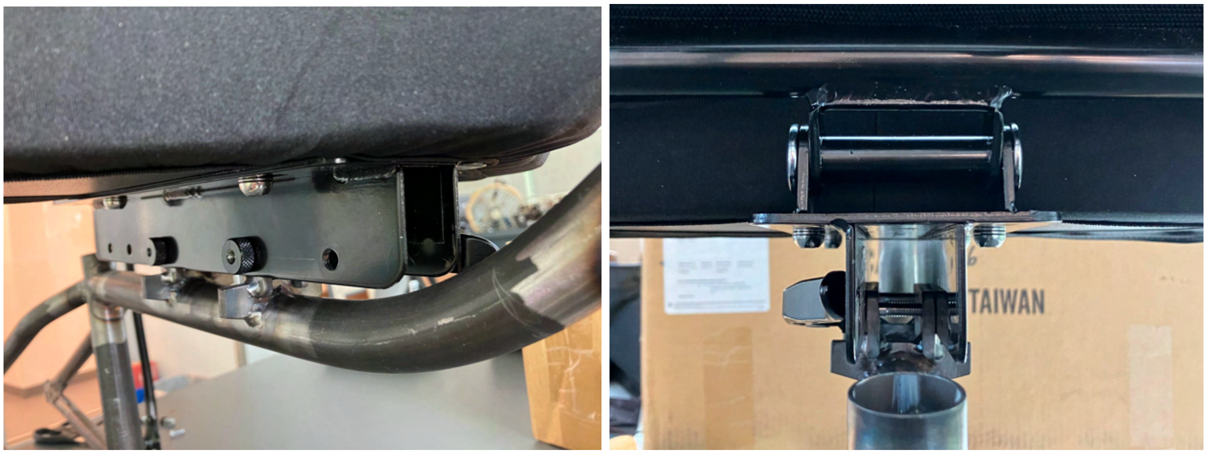

Figure 15. Built-in clamping system attached to the seat support assembly (3-D printed spacers are not shown)

Figure 16 shows the selected design and components of the seat support assembly. It utilizes a notched design that is waterjet from 3/16 in 4130 chromoly steel plate. It incorporates two 3-D printed spacers so the welds do not get put under unnecessary stress when clamping the seat in place with the seat's quick-release system. It is composed of four components with two duplicate parts, the frame interface, and the seat interface parts.

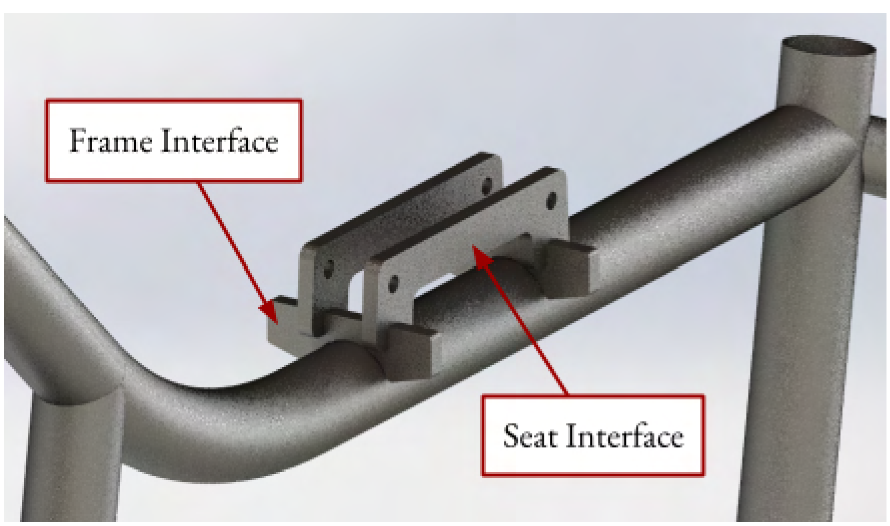

Figure 16. Seat support assembly.

Cost Breakdown

Table 2 shows the total purchased components for this bicycle. The tubing cost was not included because it was used from material that the machine shop had on hand. The estimated cost for the tubing was $425 from Onlinemetals.com. Additionally, the front and rear derailleurs, shifters, and wheels came from an existing road bike, aftermarket, these components are very expensive, a mid-range set of these components could easily cost over $500. Including the purchased component costs, the estimated total cost of the bicycle is $2,093. This value is considerably less than competing models like the Bachetta or Cruzbike, whose starting prices are in the $3,000 - $5,000 range [13,14].

Table 2. Purchased components with links.

Item	Price	Link	Quantity
6" x 12" x 0.19" 4130 sheet metal	$51.53	4130 Alloy Steel, 6" x 12" x 0.1900" | McMaster-Carr	1
Head tube	$37.66	130MM LENGTH -50/48MM OD HEAD TUBE BICYCLE FABRICATION SUPPLY	1
BB shell 74mm	$13.69	Bottom bracket shell - Framebuilder Supply	1
Steerer tube 9 x 1-1/2 x 1-1/8 in	$88.48	Steel Tapered Steerer - paragonmachineworks.com	1
1.125" OD, 0.058" th, 2 ft long	$28.50	Order 1.125" OD x 0.058" Wall x 1.009" ID - (onlinemetals.com)	1
Seat struts	$57.95	Recumbent Custom Seat Back Struts - Fits RANS, Bacchetta and Others | eBay	1
Headset	$97.37	Orbit ITA (I/E) Headset (fsaproshop.com)	1
Stem bolts	$11.62	Alloy Steel Socket Head Screw, Black-Oxide, M5 x 0.8 mm Thread, 22 mm Long | McMaster-Carr	1
Shaft collar clamp	$11.44	Clamping Two-Piece Shaft Collar, for 1-1/8" Diameter, Black-Oxide 1215 Carbon Steel | McMaster-Carr	1
Brake and shift cables	$23.99	Amazon.com : Jagwire Complete Brake & Shifter Cable and Housing	1
3" OD 1 ft 4130	$176.73	Easy-to-Weld 4130 Alloy Steel Rod, 3" Diameter | McMaster-Carr	1
Sun EZ-1 seat	$317.00	Amazon.com : Sun EZ-1 Replacement Seat Assembly	1
FSA Non-Series handlebars	$45.10	Amazon.com : FSA Road Bicycle Handlebar (31.8 x	1

		46cm)	
Brake bridge	$5.95	Brake bridge - 80mm wide, 11mm tube diameter – Framebuilder Supply	1
FSA Gossamer Road Bike Crank	$79.97	FSA Gossamer Road Bike Crank + BB - 50t 34t - 9/10 speed - 172.5mm - ebay.com	1
Chain	$20.32	Amazon.com : KMC KMC023 X9.93 9 speed Bicycle Chain	1
Handlebar tape (BLACK)	$10.99	Amazon.com : ALIEN PROS Bike Handlebar Tape	1
Pedals	$39.99	Amazon.com : MZYRH MTB Mountain Bike Pedals	1
Tires (WIRE BEAD, 32c)	$49.90	Continental Ultra Sport III Road Cycling Bike Tire (amazon.com)	2
TOTAL	**$1,168.18**		

4.4 Finite Element Analysis

Weldments Frame Analysis

The default SOLIDWORKS FEA splits the volume of the part into many elements in a three-dimensional tetrahedral mesh. With a large frame with many members, the simulation would be computationally expensive, and due to the nature of the 3D FEA, many hotspots would occur at the joints. Weldments FEA models structural frame members as beam elements that can experience bending in the *x* and *y*-planes and torsion along the *z*-plane. This makes the FEA simulation a bit smarter, reduces the computation time, and is more accurate than the three-dimensional default FEA with more accurate stress concentrations. Table 3 shows the results from the three loading cases. For all of the simulations, the bicycle is fixed at the front and rear dropouts. Figure 17 shows the normal loading FEA case, and Figure 18 shows the hotspots in the analysis. The forces in all of the loading cases were applied to simulate a 2G loading case.

It is important to note that the frame that this FEA was performed on does not perfectly match the final design of the frame. It was assumed that the changes to the frame were minimal enough (the removal of the extended portion of the seat tube and a slight geometry change on the fork) to use this iteration of weldments FEA as confirmation that the current design was safe to manufacture.

Table 3. Frame Weldments FEA results

Loading Case	Normal Loading (landing from jump)	Head on Collision	Side Collision
Rider weight	600 lb	300 lb	300 lb
Forces Applied	100 lb forward horiz. at BB	300 lb rearward horiz. at BB	150 lb axially at BB
Other forces applied	n/a	n/a	100 lb axially at handlebars
Factor of Safety	*3.106*	*2.304*	*1.831*

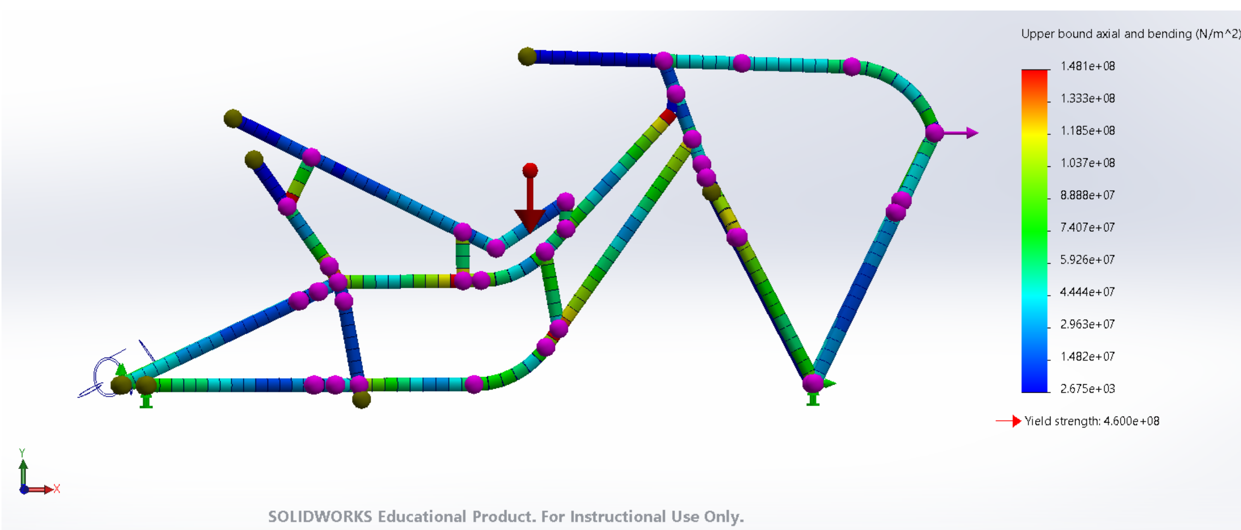

Figure 17. Normal loading weldments FEA case.

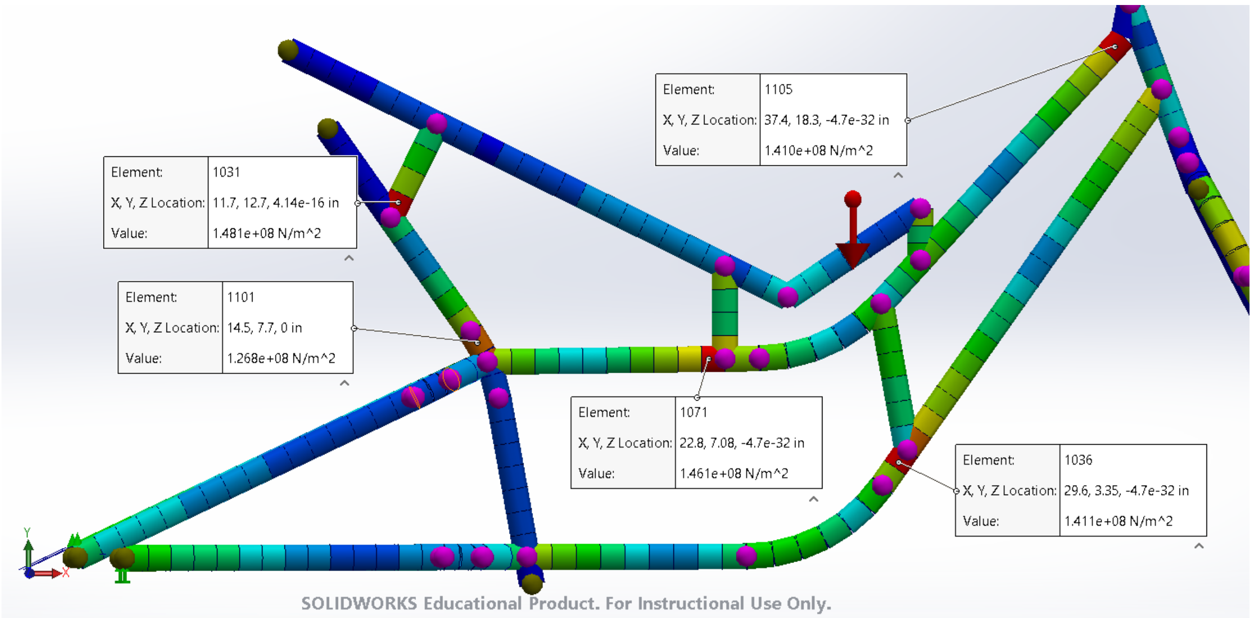

Figure 18. Hotspots in the normal loading weldments FEA case.

Component Analysis

Clamps

The results from the clamp finite element analysis are summarized in Table 4. The stem and bottom bracket clamps are the most overbuilt component on the frame with factors of safety greater than 10. They are small, but they will be subject to a large amount of clamping force, as well as torsional loads from the steering motion. As more force is applied to the clamp's radial surface, the clamp's rigidity increases because it is in tension, and it is more resistant to torsional loads. For example, the boom clamp, which will experience the highest torque as it is the

fulcrum in the middle of the boom and connects with the fork, the factor of safety increased from 1.43 to 1.83 when the radial force was increased from 800 lb to 1000 lb (the first two rows in Table 4). The FEA simulations were designed to model the clamps at three times their expected loads, however, as is shown in the first two rows of Table 4, for the Pivot Clamp specifically, increasing the radial force appears to “strengthen” the clamp (increasing factor of saftey). This same “strengthening” effect is seen in pressurized aluminum cans, which, when unpressurized, can be crushed by hand, but when pressurized (in tension), are significangly stronger due to the induced hoop stress. A similar scenario could be what is happening to the Pivot Clamp when the radial force is increased. In an attempt to lessen the induced hoop stress, the radial force was reduced for the third trial to 275 lb for a more realistic loading case. All three clamps were deemed to have a sufficiently high factor of safety.

Table 4. Clamp FEA results.

Clamp	Forces Applied	Other Forces	Fixtures	Max Stress (kN/m^2)	Factor of Safety
Pivot	800 lb radially on clamping surface	200 lb downward on edge to simulate turning torque	Thread face and head rest	320000	1.438
Pivot	1000 lb radially on clamping surface	200 lb downward on edge to simulate turning torque	Thread face and head rest	251200	1.831
Pivot	275 lb radially on clamping surface	200 lb downward on edge to simulate turning torque	Thread face and head rest	293300	1.568
Bottom Bracket	800 lb radially on clamping surface	n/a	Thread face	41990	10.95
Stem	800 lb radially on clamping surface	n/a	Thread face	44070	10.44

The fixtures and forces for the boom clamp are shown in Figure 19. The three other tests of the boom interface, stem, and BB clamps utilized identical fixtures and forces. An image of the FEA results for the stem clamp is shown in Figure 20. From these tests, it was deemed that the clamps all have a sufficiently high factor of safety, where the highest stress concentrations were at the thread fixtures.

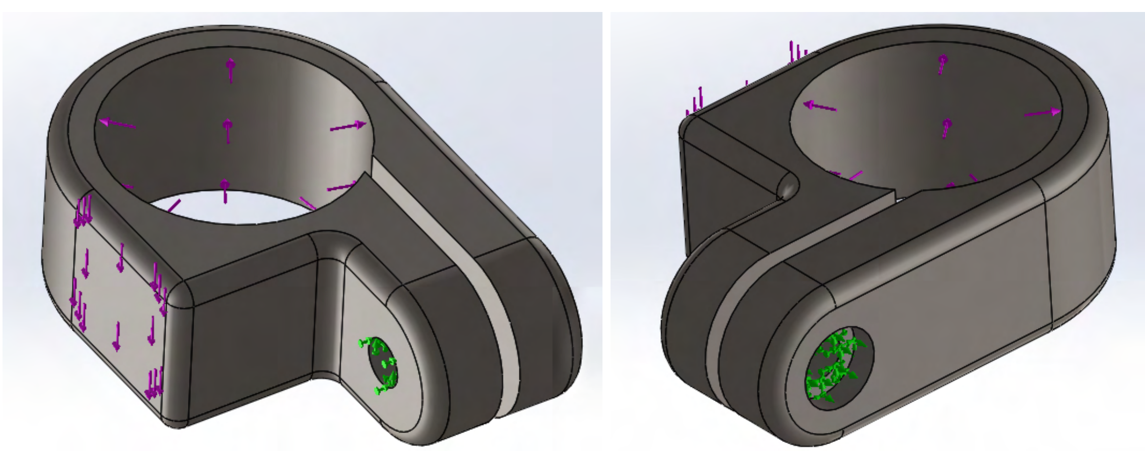

Figure 19. Fixtures and simulated forces on the pivot clamp FEA. The downward force on the side face is to simulate the torque of turning two to three times greater than the expected load.

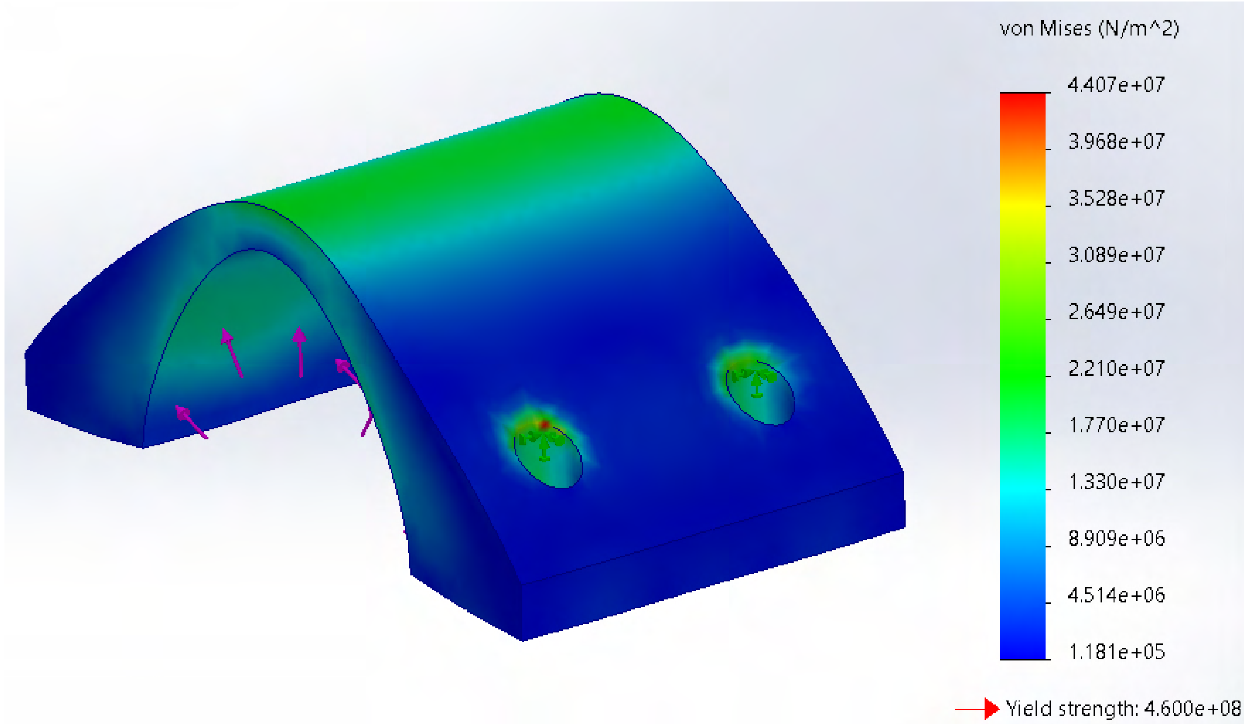

Figure 20. Stem clamp FEA results from loading case in Table 3. Notice the fixtures on the holes and the force being applied radially to the clamping surface.

Dropouts

The results of the dropout FEA are summarized in Table 5. The dropouts utilize 3/16 in thick 4130 steel plate and will be cut using the waterjet. After initially designing the dropouts, a significant amount of material was removed to reduce weight. The FEA was originally fixtured for both front and rear dropouts on the faces of the tabs that go into the notches in the frame. However, the results for the front dropouts appeared to be inaccurate, as the results showed an unusually high stress concentration next to the fixture (Figure 21). This was adjusted by adding a fileted cube to where the dropouts are welded to the fork tubes (Figure 22).

Table 5. FEA results for the front and rear load bearing dropouts.

Dropout	Forces Applied	Other Forces	Fixtures	Max Stress (kN/m^2)	Factor of Safety
Front	450 lb to the axle interface curve	n/a	Fixed fileted cube that simulates weld beads	251800	1.827
Rear	450 lb to the axle interface curve	n/a	Fixed at the edge of the welded tabs	211100	2.179
Rear	450 lb to the axle interface curve	200 lb at the eyelets to model loading a rack	Fixed at the edge of the welded tabs	214800	2.142

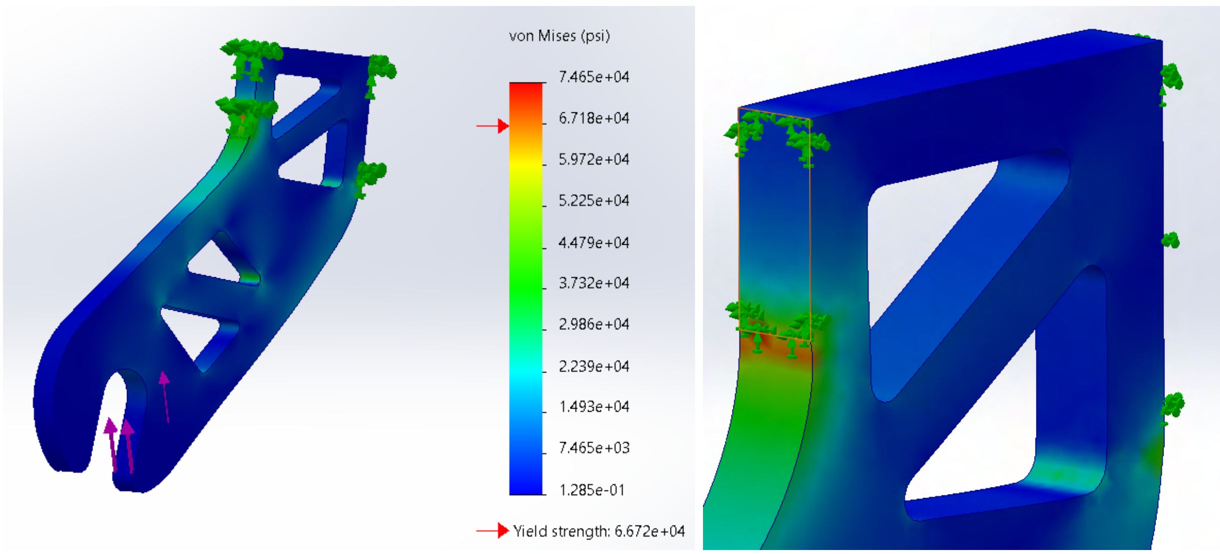

Figure 21. Initial FEA Loading case, which led to an inaccurately high stress concentration very close to the fixture, as it did not account for weld radius.

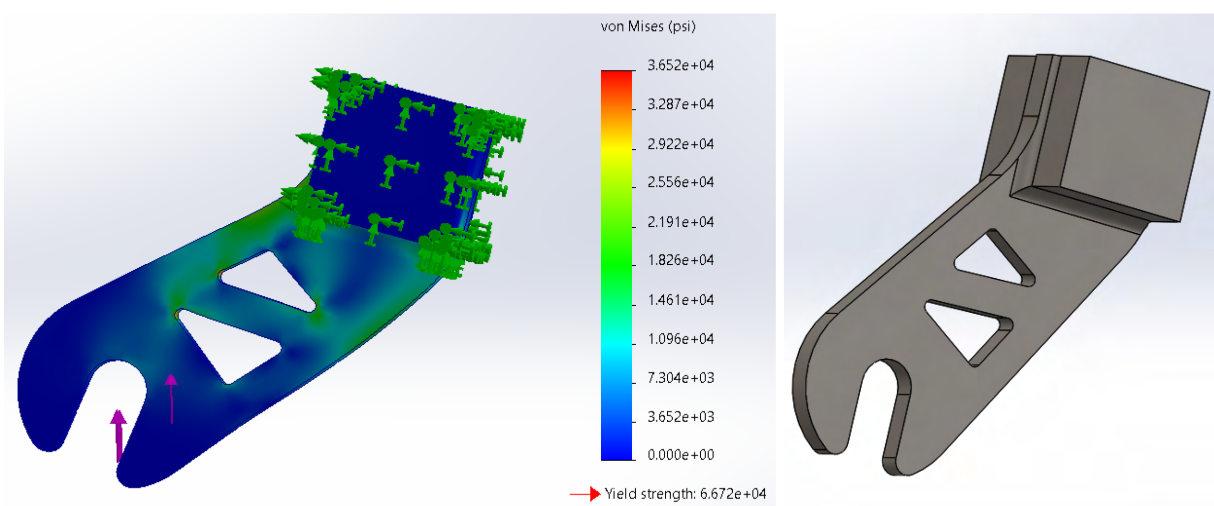

Figure 22. Fixtures and loading for the front dropout FEA.

The rear dropouts did not experience the same error even though they were fixtured in the same location as the front dropouts. This may be because it had four faces which were fixed instead of two. The results are listed in Table 5, and the image of the final result which led to the lowest factor of safety is shown in Figure 23.

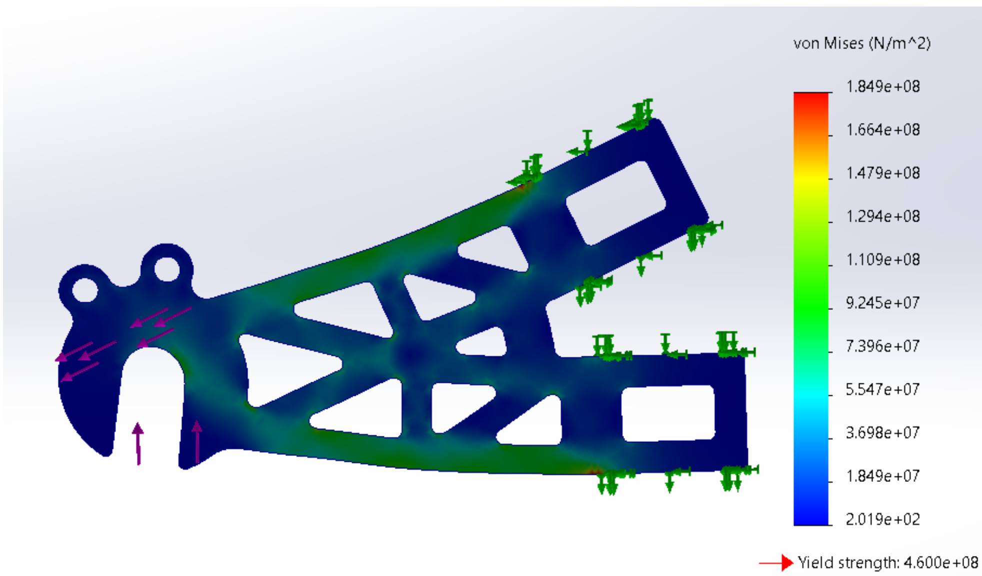

Figure 23. Fixtures, forces, and stress concentration results from the second loading case in Table 4.

Seat Support Assembly

FEA was also performed on the seat support assembly. The assembly i, one that interfaces with the frame, and it achieved a factor of safety of 6.23. The loads and fixtures are summarized in Table 6, and the results can be seen in Figures 21-22.

Table 6. FEA results for the seat support assembly.

Forces Applied	**Fixtures**	**Max Stress (kN/m^2)**	**Factor of Safety**
300 lb downward on the face of a small cylindrical bolt at each eyelet	The 1 in diameter curves on the frame interface part are fixed geometry, slider fixtures are placed on the seat interface parts.	73870	6.227

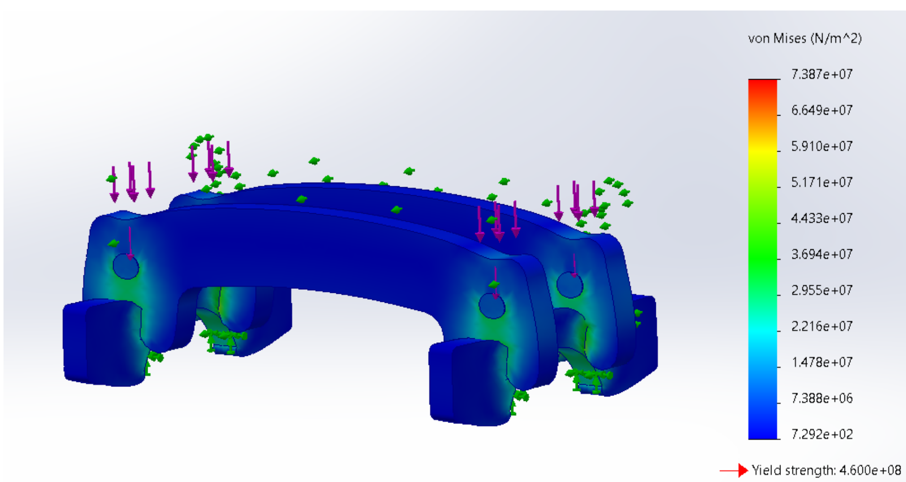

Figure 23. FEA fixtures and results for the seat support assembly. Note the small bolts that extend slightly outward from the face of the seat interface components.

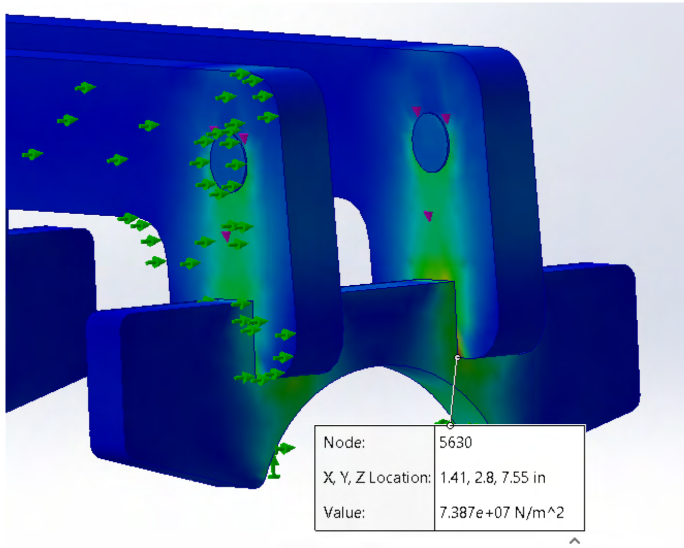

Figure 24. Maximum stress occurs at the base of the seat interface parts.

5. Conclusions

Designing a bicycle from scratch is a complicated process, and one that requires commitment, and time. It is a three-step process: design, modeling, and drawings. Design is comprised of brainstorming ideas, and developing a concept and rough outline of the model on paper. Modeling is comprised of transferring the hand-drawn concept to Solidworks or another 3D CAD software and running theoretical tests of the modeled components to determine if they are safe for their applications. Finally, the Drawing step is composed of communicating with the machinists and transmitting part and assembly drawings to them in a way that can be understood quickly without confusion. For those who have not completed a project like this one, the drawings might seem like the easiest part as all of the decisions have been made, however, I found that it was the step that required the most thought and communication (Appendix B shows the drawings).

Head-to-Head Testing

Setup

Head-to-head testing was performed on the Mowhawk Hudson Bikeway from Union College to Knolls Atomic Laboratories and back. Figure 23 shows the route taken from Strava, a popular phone application that uses the built-in GPS module to track activity. One advantage of Strava is its segment feature. The segment feature breaks routes up into segments and allows for a head-to-head comparison between rides, and in this case between bikes. The route was chosen due to its diversity in topography. There are long flat sections and steep hills, and it is in a controlled environment where traffic will not be a factor.

Figure 23. GPS data from Strava.

The tests were done on the same day under the same conditions and with a moderate effort. Utilizing a power meter with a GPS module would have been a preferred and more precise method of measurement, however, that was out of the scope of this project financially. In its place, the test rider, myself, rode the bikes at a moderate effort. I am a fairly strong rider, so my moderate effort differs from someone who does not ride regularly. However, on hills, I pushed harder because that was where some of the largest differences occurred between the two bicycles. I have made statements about my experience and impressions of the differences between the bicycles below, and many of those claims are qualitative and are usually backed up by quantitative results.

The traditional road bike was chosen to test against the recumbent, and the two bikes are shown in Figure 26. The road bike chosen is a steel-framed 1989 Bianchi Axis. It is a good comparison as it is made of the same material and is setup for touring, which denotes a more relaxed riding position, designed for long outings on the saddle.

Figure 26. The completed recumbent on the left, and the road bike on the right.

Results

Using the Strava segment feature, a plot was made of the average speed vs the average percent grade (Figure 27). Analyzing the graph shows that the recumbent is consistently about 5 mph faster on flat to slightly downhill terrain, and slower on uphill terrain. Additionally, on one particular uphill section, the road bike performed significantly better, with a roughly 5 mph advantage. Furthermore, climbing hills on the recumbent proved a challenging task, despite many similar times on the uphill sections, I found it much more difficult to maintain momentum and that I was expending more energy compared to the traditional road bike. I also found that the front wheel occasionally would slip and skid while going uphill. Some of this sluggishness may be due to the fact that the rider cannot change positions to stand up on the pedals and use their body weight when going uphill. Instead, the rider is forced to only use their leg muscles.

Not shown on the graph are the top-speed results. The top speeds were 43.0 mph and 48.4 mph for the traditional road bike and recumbent, respectively. Achieving the top speed for the road bike required noticeably more effort than the recumbent, which did not require heavy pedaling to achieve its top speed. This is likely due to the aerodynamic advantage of the reclined position of the recumbent, compared to the more upright position of the road bike.

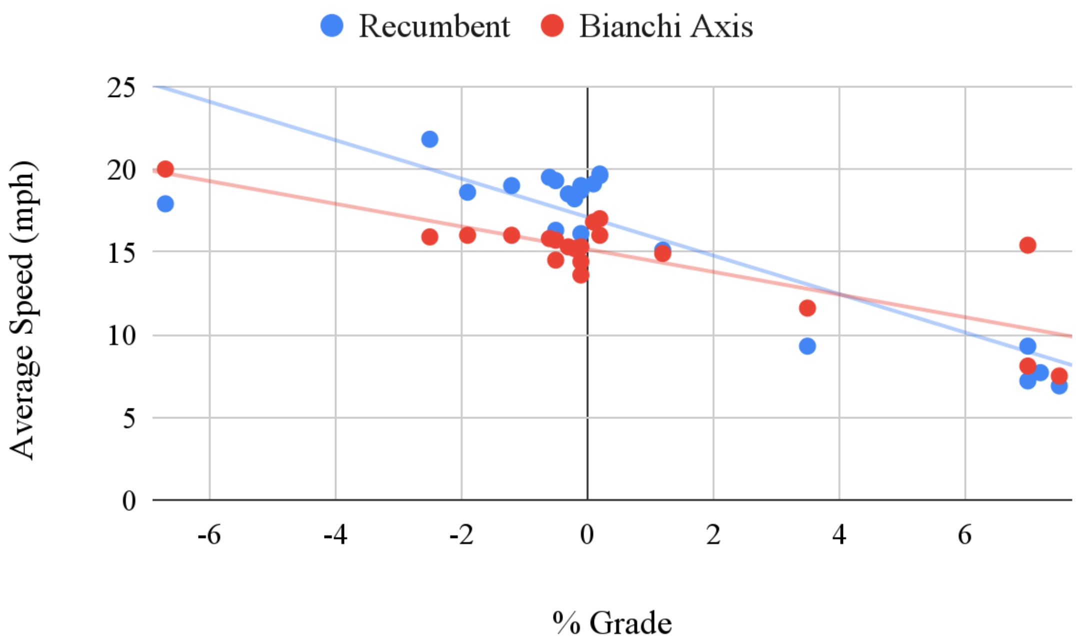

Figure 27. A plot of the average speed vs the percent grade for each Strava segment. The percent grade is a measure of how steep an incline is, the higher the number, the steeper the uphill, the lower the number the steeper the downhill, and at zero, it is flat.

Overall, the recumbent exceeded on flat to downhill terrain where momentum could be more easily maintained but struggled on uphill sections. ese test results are consistent with common knowledge about recumbent bicycles. They are accepted as faster on flat terrain but are thought of as sluggish uphill due to the inability to stand up on the pedals. In summary, if the terrain is relatively flat with some rolling hills, a recumbent is the best choice, it will be faster and more comfortable. However, if the terrain is more variated with some longer ascents, the recumbent is not the optimal choice, as it requires more effort and is slower than a traditional bicycle.

Recommendations for Future HPV Clubs

There are a few areas that I could have improved significantly during this project. Firstly, it would have saved time if I had utilized the 3D sketch feature in SOLIDWORKS and created a weldment model of the frame. Doing it this way avoids the unnecessary hassle of editing parts inside assemblies, and having a part file for each tube member that can easily get lost in folders. Creating the frame in weldments not only makes it easier to construct the frame and run tests, but it also streamlines the drawing process, as all of the parts can be drawn using the ‘select bodies’ option when you start a new SOLIDWORKS drawing, from the same weldment ‘part’ file.

Additionally, taking advantage of the SOLIDWORKS sheet metal feature is vital when creating sheet metal parts, this may seem like a silly piece of advice, as it may seem obvious, but I was unaware of the sheet metal add-in until I used it for this project.

In terms of drawings, work with the machinists, and ask about the drawing conventions for tubing. They are both machinists, but also educators, and they want to help motivated students. Do not hesitate to go and meet with them to look over the drawing drafts. There were times when I had them look at 2-3 iterations of the same drawing until it was in good shape to submit.

Finally, I believe the main reason I was unable to start the HPV club on my own was simply the lack of invested leadership besides myself. I was hoping to get members to join and help me run it but that did not happen. Leading a design competition team is not something that one person can start on their own. There need to be at least 2-3 passionate students who can share the load. As a Senior mechanical engineer, the time commitment to organize and start everything was simply not feasible.

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Appendices

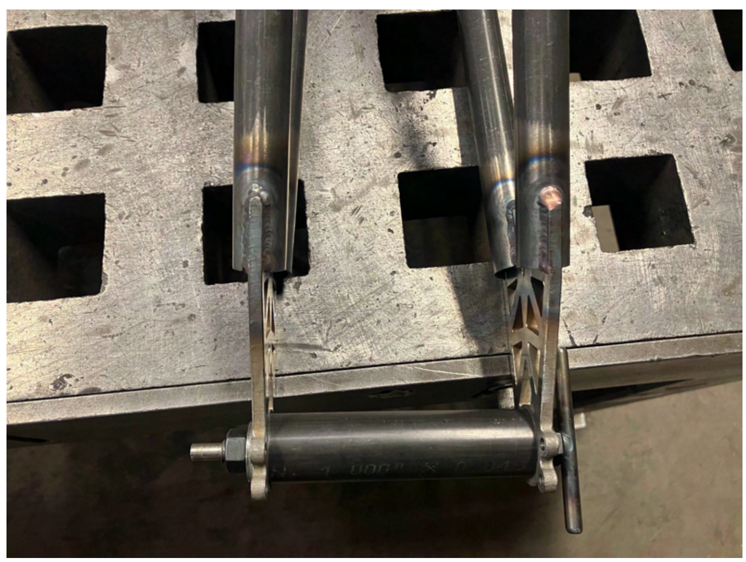
Appendix A - Photo Gallery

Section 1: Initial Frame Completion

The completed rear frame section on the welding table, just after completion.

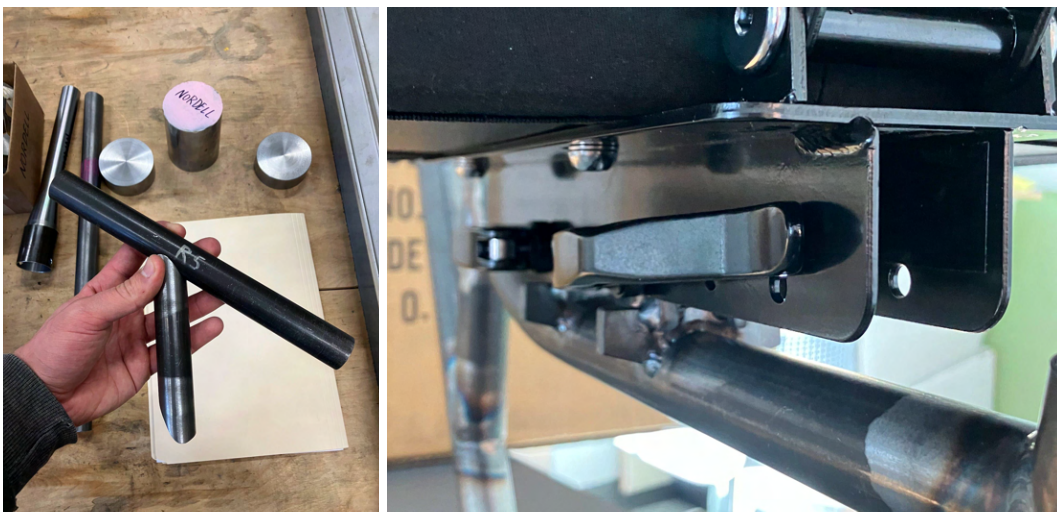
Views of the rear dropouts, with a spacer to ensure proper hub spacings.

View of the oxidation in the rear seat tube that occurred on the inside backside of the weld.



The headtube tacked to the top tube and down tubes, and a closeup view of the rear dropout spacer.

Waterjet small parts on the plate and assorted completed parts. Notice the pink rod labeled NORDELL, this is the material that the clamps were milled from.



Other assorted parts (left), and the seat attached to the completed frame utilizing the quick-release attachment system (right).

Section 2. Modifications to Seat Fixtures

Utilizing scrap wood to drill holes in the seat mount interface with the seat support assembly on the frame.

The clamping mechanism utilized to drill holes in the seat support bars to shorten them to adjust the seat back angle.

Section 3. Completed Bicycle

The bicycle without the front derailleur mount completed.

The designer and the writer of this report, all smiles after the first ride on the Mowhawk Hudson Bike Trail.

The completed bicycle, with the front derailleur installed.

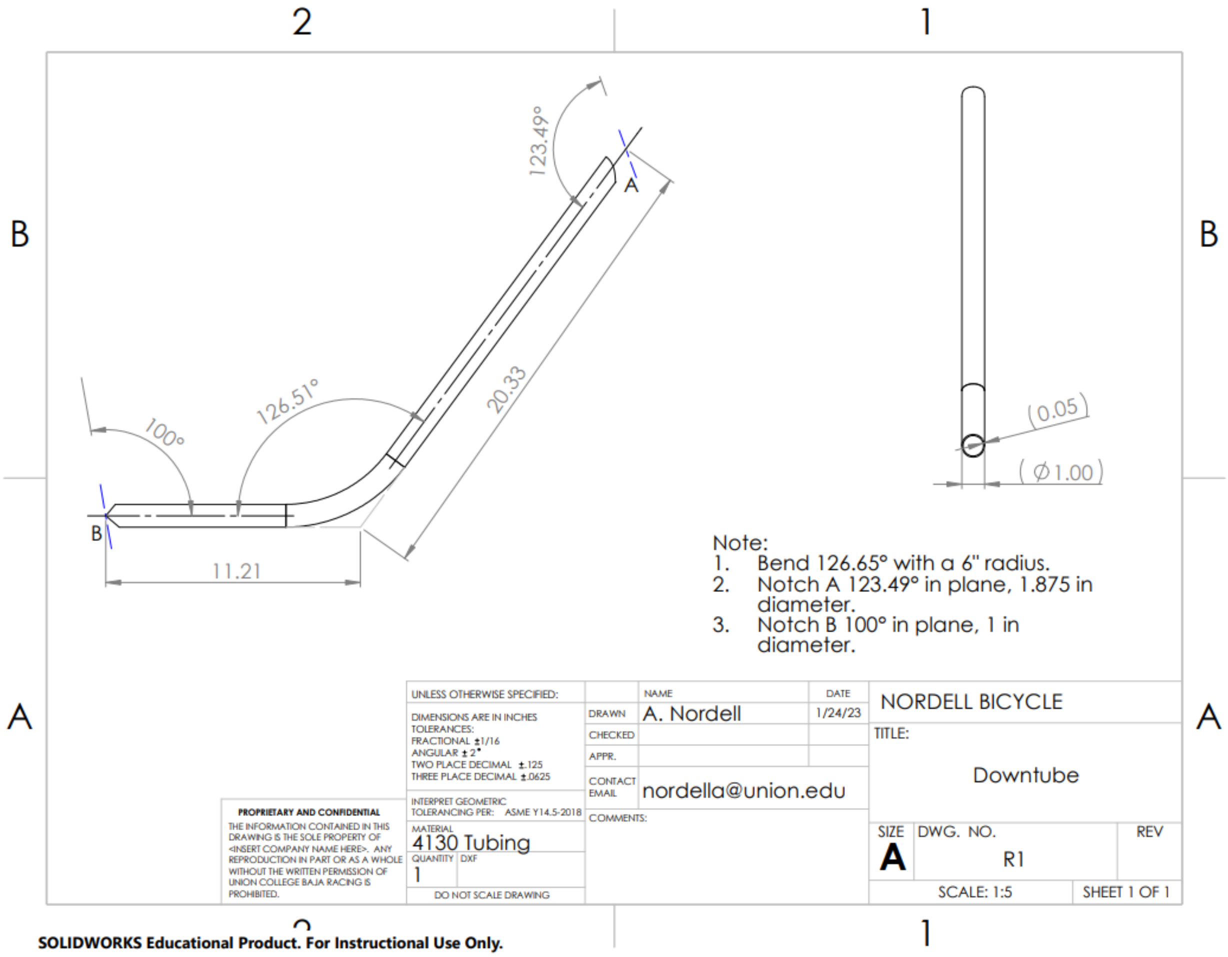
Close-up of the rear wheel.

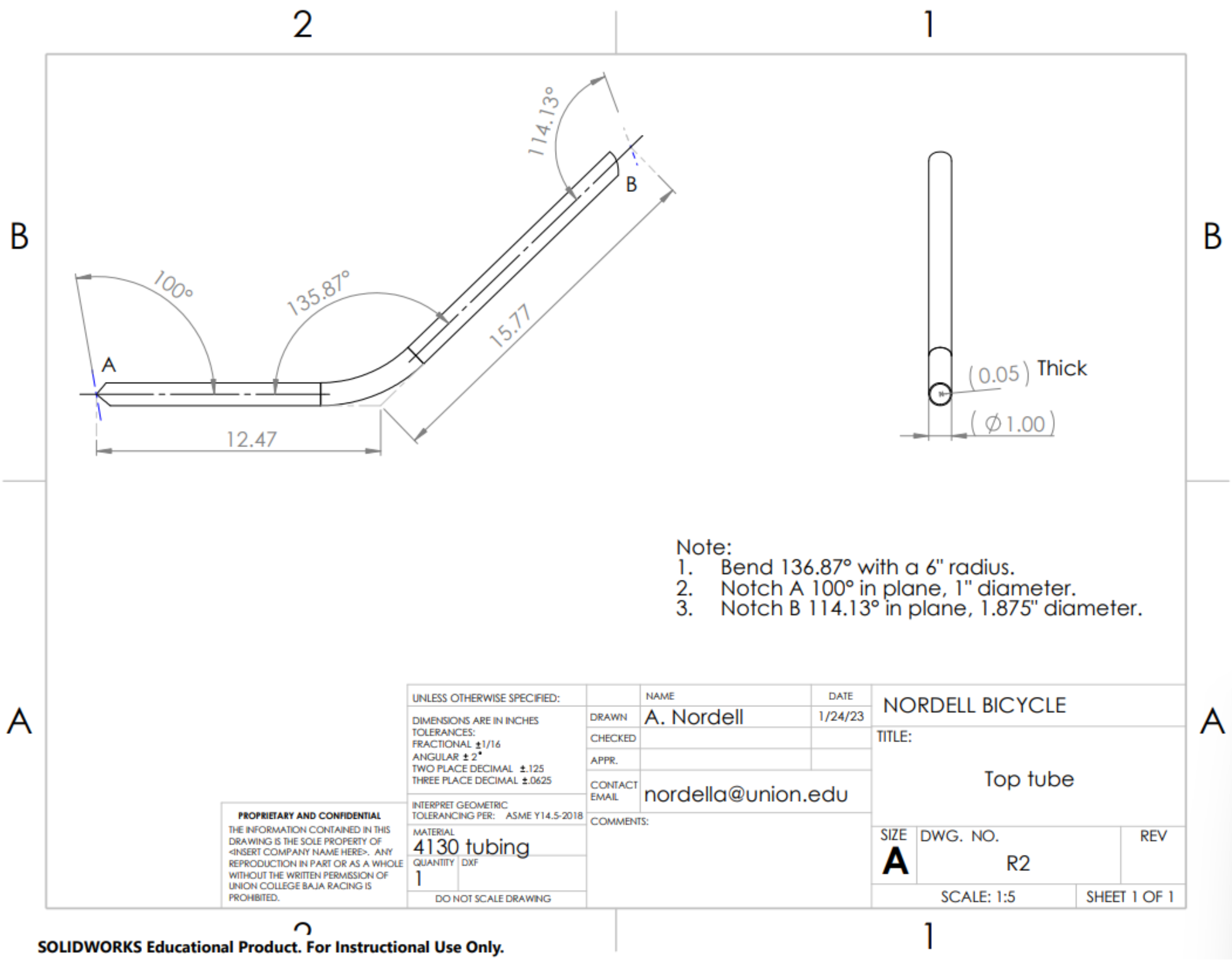
Front View.

A close-up of the cable stop on the front derailleur mount.

Appendix B - Drawings

Section 1. Frame Assembly





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B
A
100°
135.87°
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B
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(⌀1.00)
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1. Bend 136.87° with a 6" radius.
2. Notch A 100° in plane, 1" diameter.
3. Notch B 114.13° in plane, 1.875" diameter.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY
DXF
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DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF UNION COLLEGE BAJA RACING IS PROHIBITED.
NAME
DATE
DRAWN
A. Nordell
1/24/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Top tube
SIZE
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DWG. NO.
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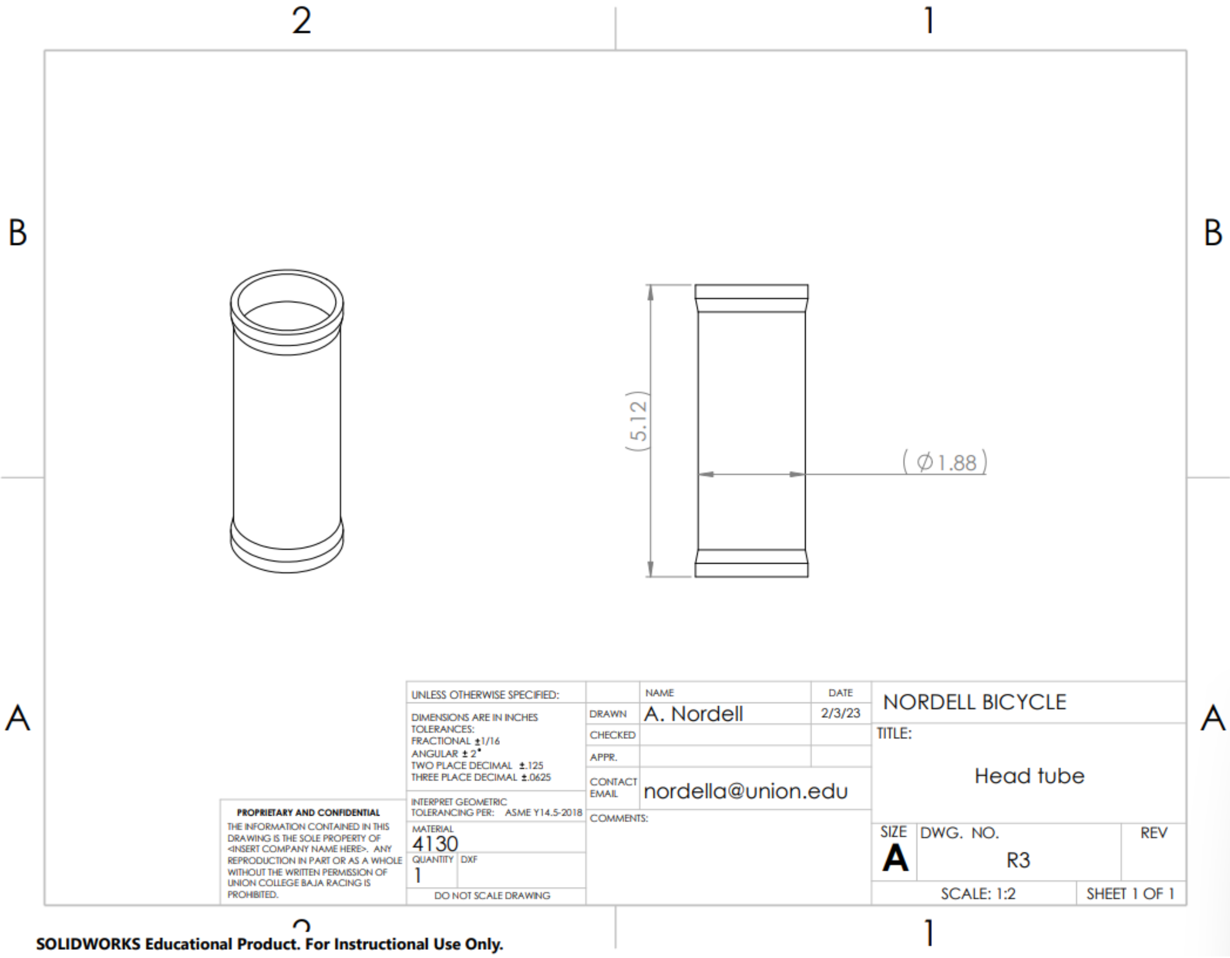
SCALE: 1:5
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.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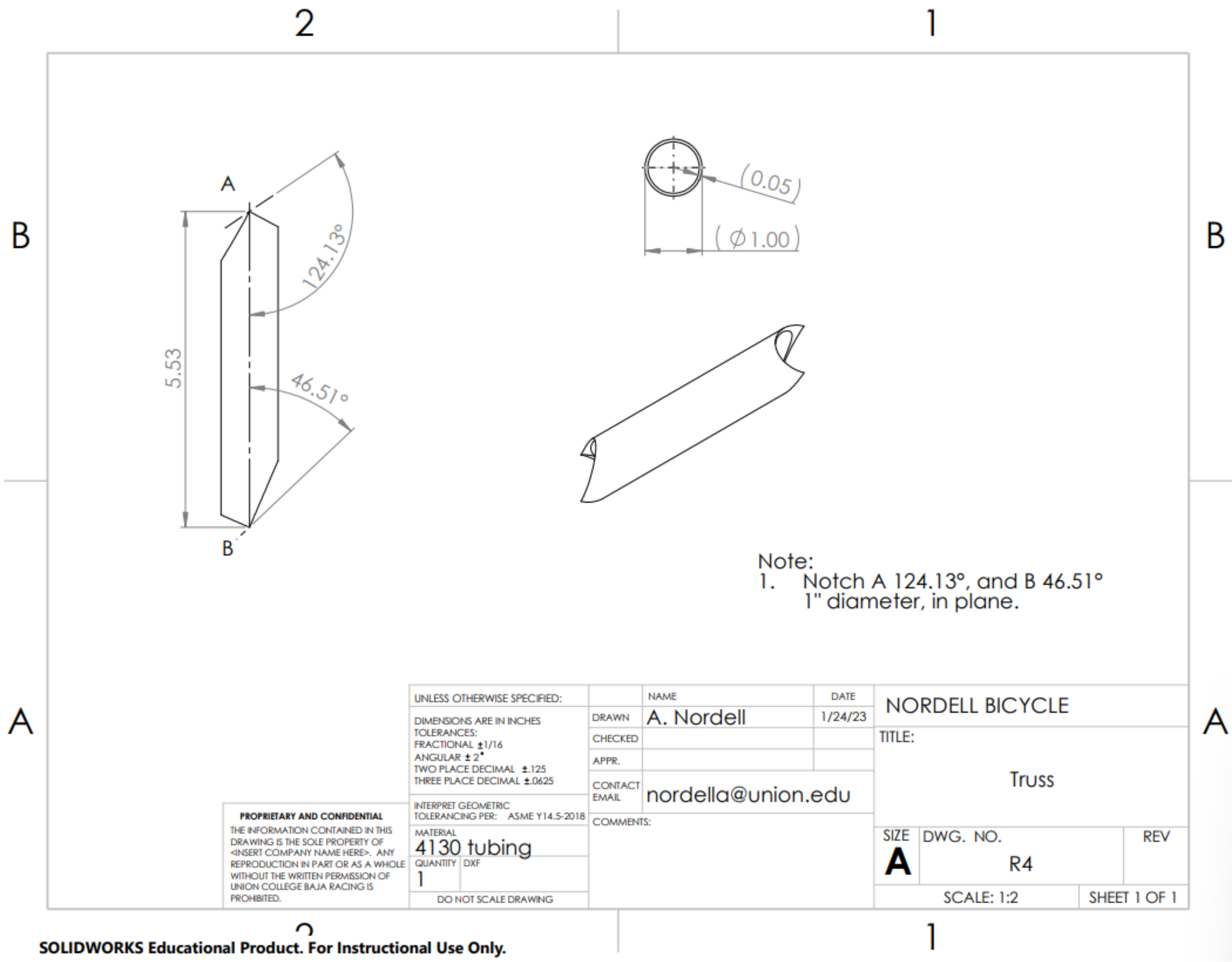

2
1
B
A
A
B
5.53
124.13°
46.51°
(0.05)
(Ø1.00)
Note:
1. Notch A 124.13°, and B 46.51°
1" diameter, in plane.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ±2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY
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DXF
DO NOT SCALE DRAWING
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DRAWN
A. Nordell
1/24/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Truss
SIZE
A
DWG. NO.
R4
REV
SCALE: 1:2
SHEET 1 OF 1
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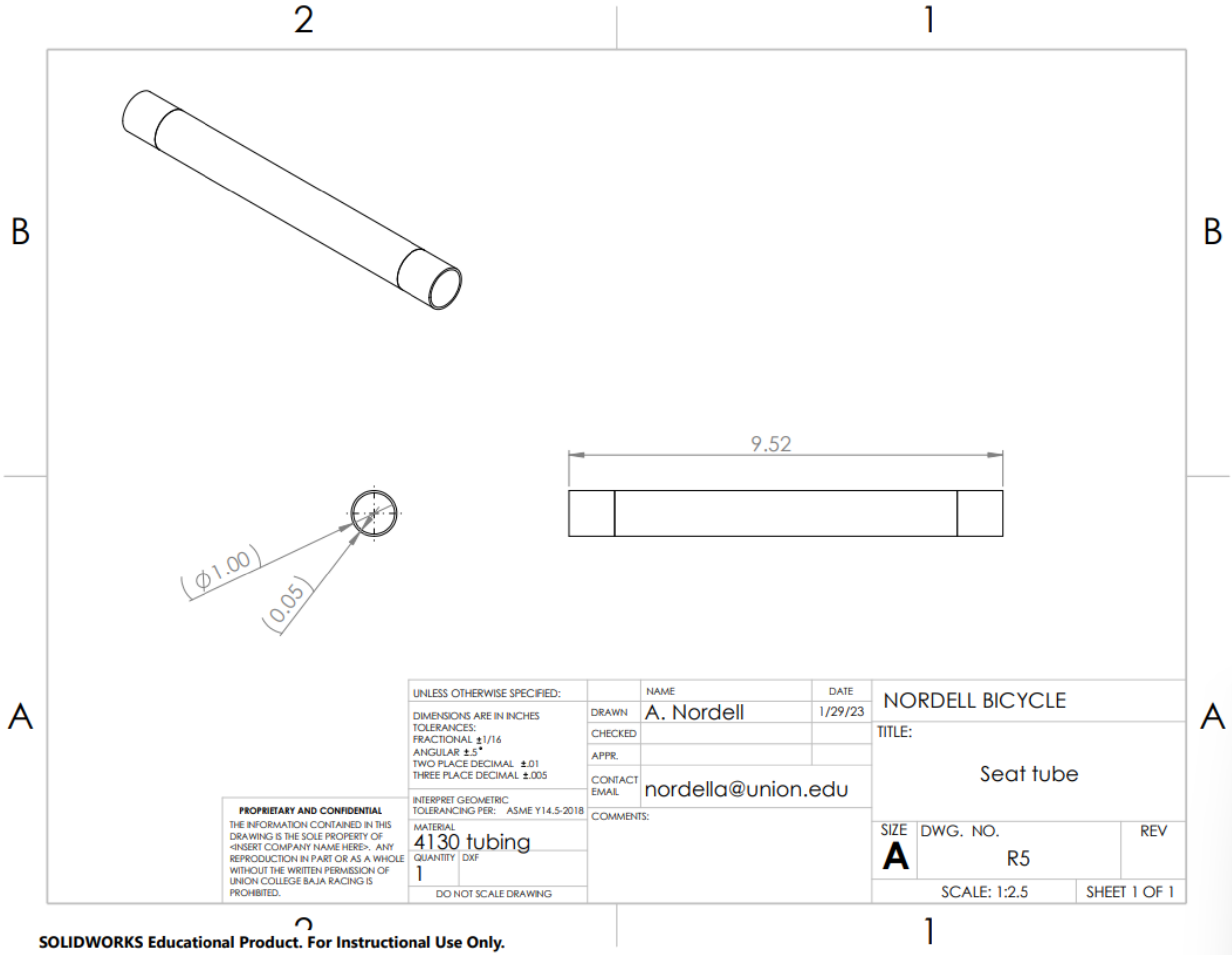
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ANGULAR ±.5°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
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CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Seat tube
SIZE A
DWG. NO. R5
REV
SCALE: 1:2.5
SHEET 1 OF 1
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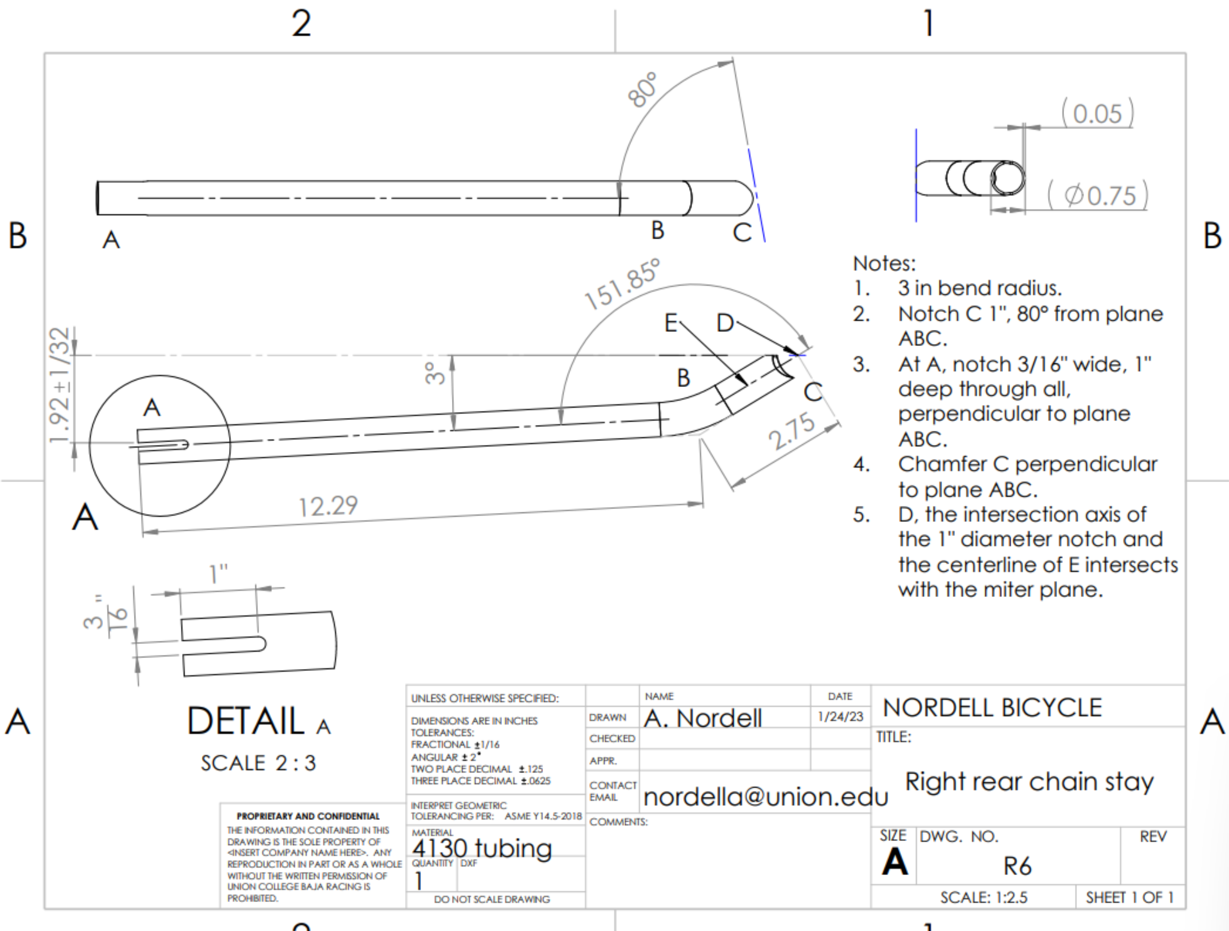
80°
(0.05)
(Ø0.75)
A
B
C
151.85°
E
D
3°
1.92±1/32
12.29
2.75
1"
3/16"
DETAIL A
SCALE 2 : 3
Notes:
1. 3 in bend radius.
2. Notch C 1", 80° from plane ABC.
3. At A, notch 3/16" wide, 1" deep through all, perpendicular to plane ABC.
4. Chamfer C perpendicular to plane ABC.
5. D, the intersection axis of the 1" diameter notch and the centerline of E intersects with the miter plane.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ±2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY 1
DXF
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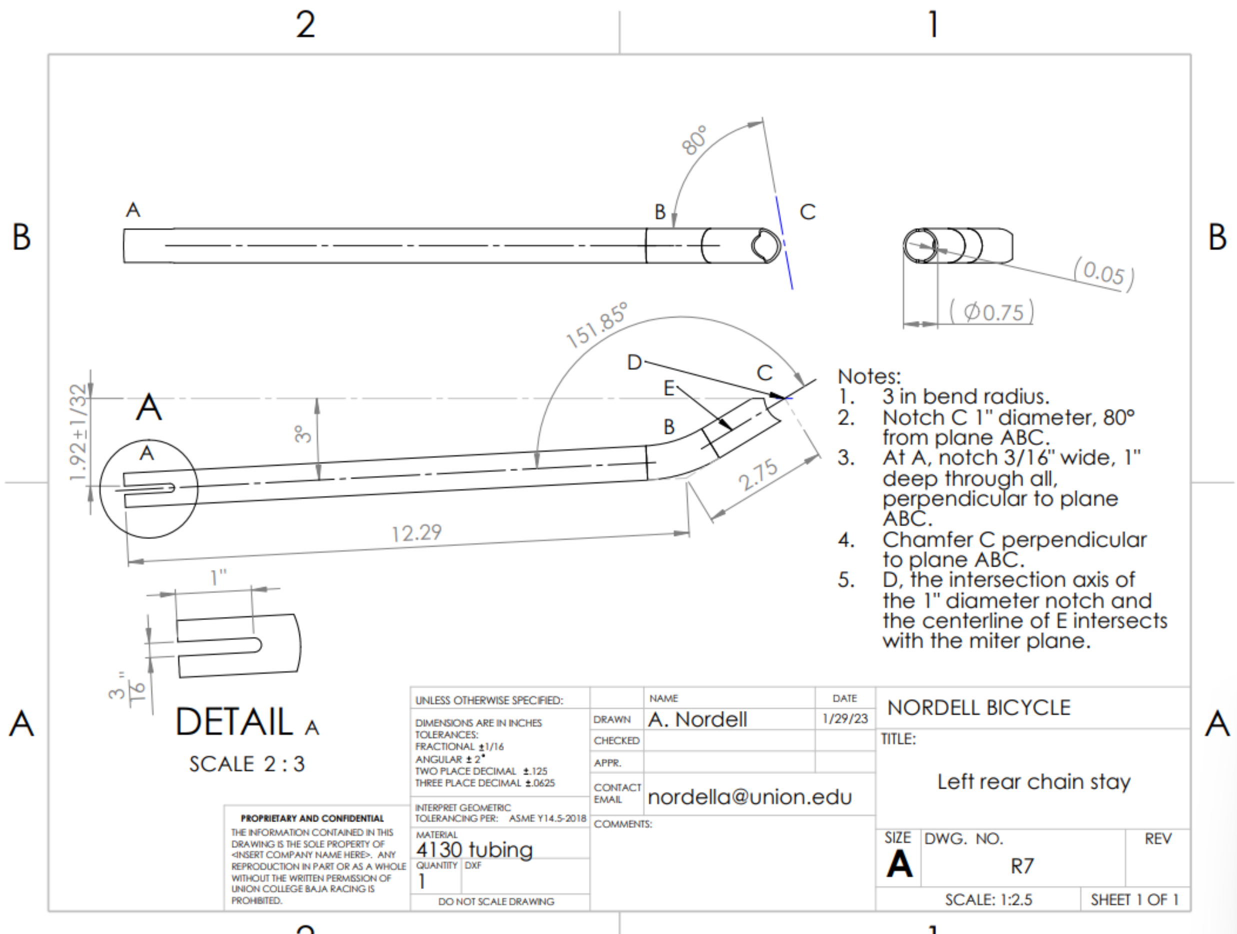
NAME
DATE
DRAWN A. Nordell 1/24/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Right rear chain stay
SIZE A
DWG. NO. R6
REV
SCALE: 1:2.5
SHEET 1 OF 1



80°
151.85°
3°
1.92±1/32
12.29
2.75
(0.05)
(Ø0.75)
1"
3/16"
DETAIL A
SCALE 2 : 3
Notes:
1. 3 in bend radius.
2. Notch C 1" diameter, 80° from plane ABC.
3. At A, notch 3/16" wide, 1" deep through all, perpendicular to plane ABC.
4. Chamfer C perpendicular to plane ABC.
5. D, the intersection axis of the 1" diameter notch and the centerline of E intersects with the miter plane.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY 1
DXF
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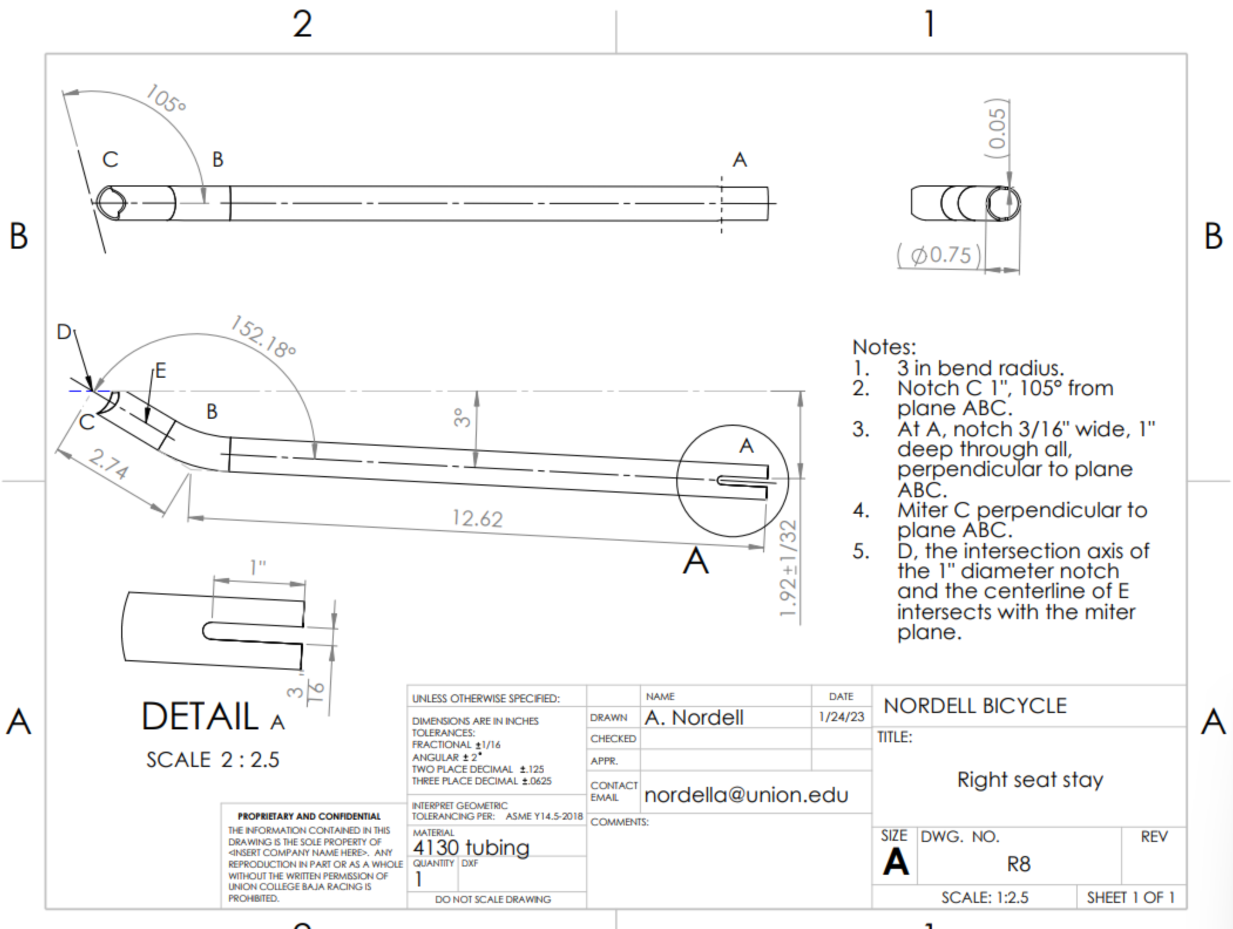
NAME
DATE
DRAWN A. Nordell 1/29/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Left rear chain stay
SIZE A
DWG. NO. R7
REV
SCALE: 1:2.5
SHEET 1 OF 1


105°
C
B
A
(0.05)
(∅0.75)
D
E
152.18°
3°
2.74
12.62
1.92±1/32
Notes:
1. 3 in bend radius.
2. Notch C 1", 105° from plane ABC.
3. At A, notch 3/16" wide, 1" deep through all, perpendicular to plane ABC.
4. Miter C perpendicular to plane ABC.
5. D, the intersection axis of the 1" diameter notch and the centerline of E intersects with the miter plane.
1"
3/16
DETAIL A
SCALE 2 : 2.5
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ±2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY 1
DXF
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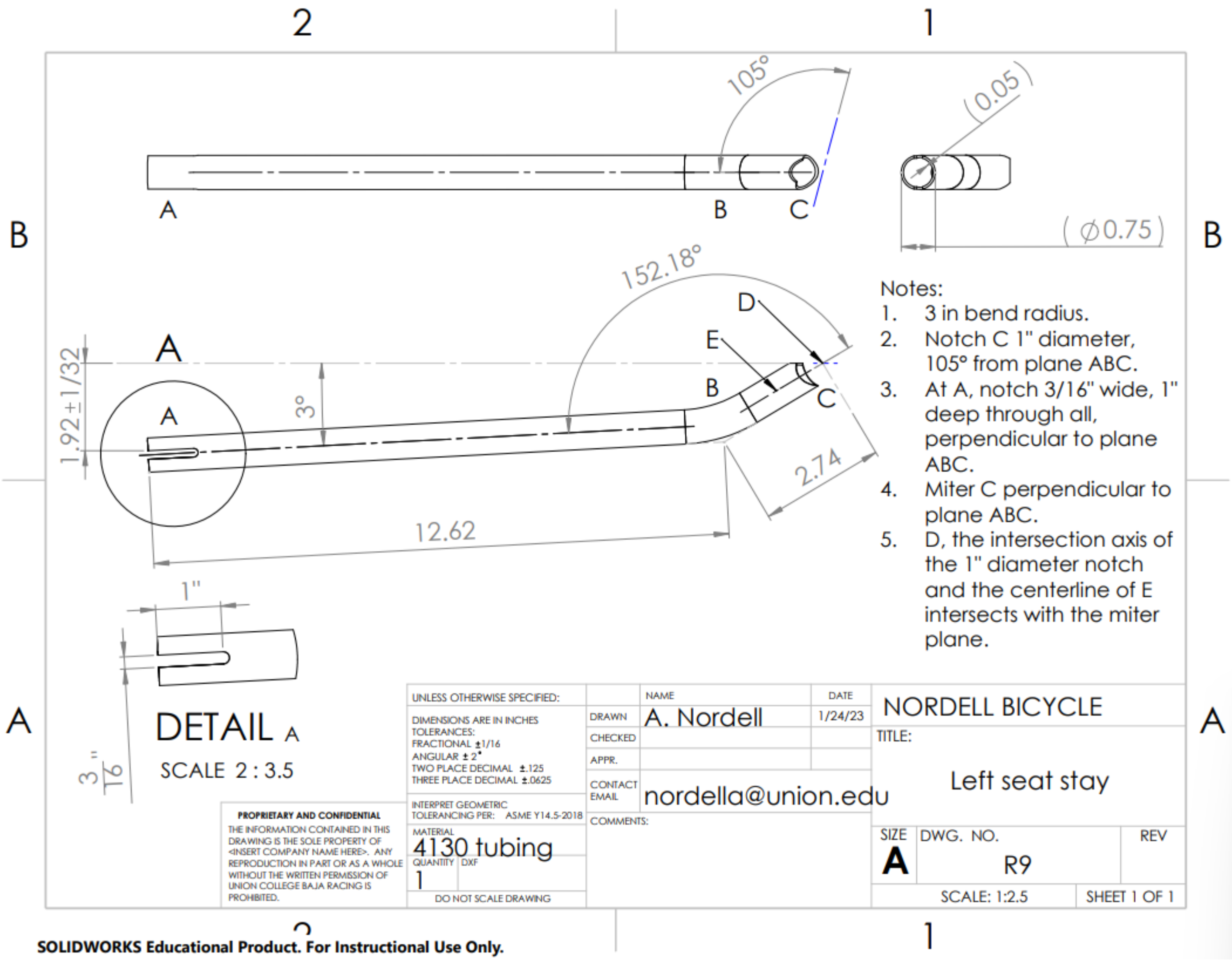
NAME
DATE
DRAWN A. Nordell 1/24/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Right seat stay
SIZE A
DWG. NO. R8
REV
SCALE: 1:2.5
SHEET 1 OF 1



105°
(0.05)
(⌀0.75)
A
B
C
152.18°
D
E
1.92±1/32
3°
2.74
12.62
1"
DETAIL A
SCALE 2 : 3.5
3/16"
Notes:
1. 3 in bend radius.
2. Notch C 1" diameter, 105° from plane ABC.
3. At A, notch 3/16" wide, 1" deep through all, perpendicular to plane ABC.
4. Miter C perpendicular to plane ABC.
5. D, the intersection axis of the 1" diameter notch and the centerline of E intersects with the miter plane.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY
1
DXF
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
A. Nordell
1/24/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Left seat stay
SIZE
A
DWG. NO.
R9
REV
SCALE: 1:2.5
SHEET 1 OF 1
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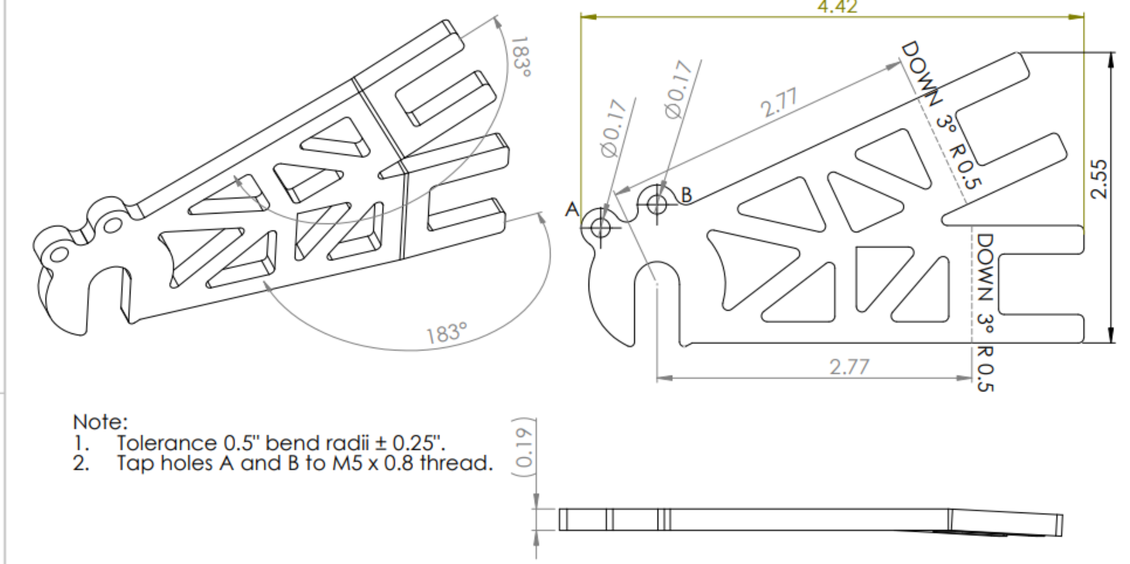


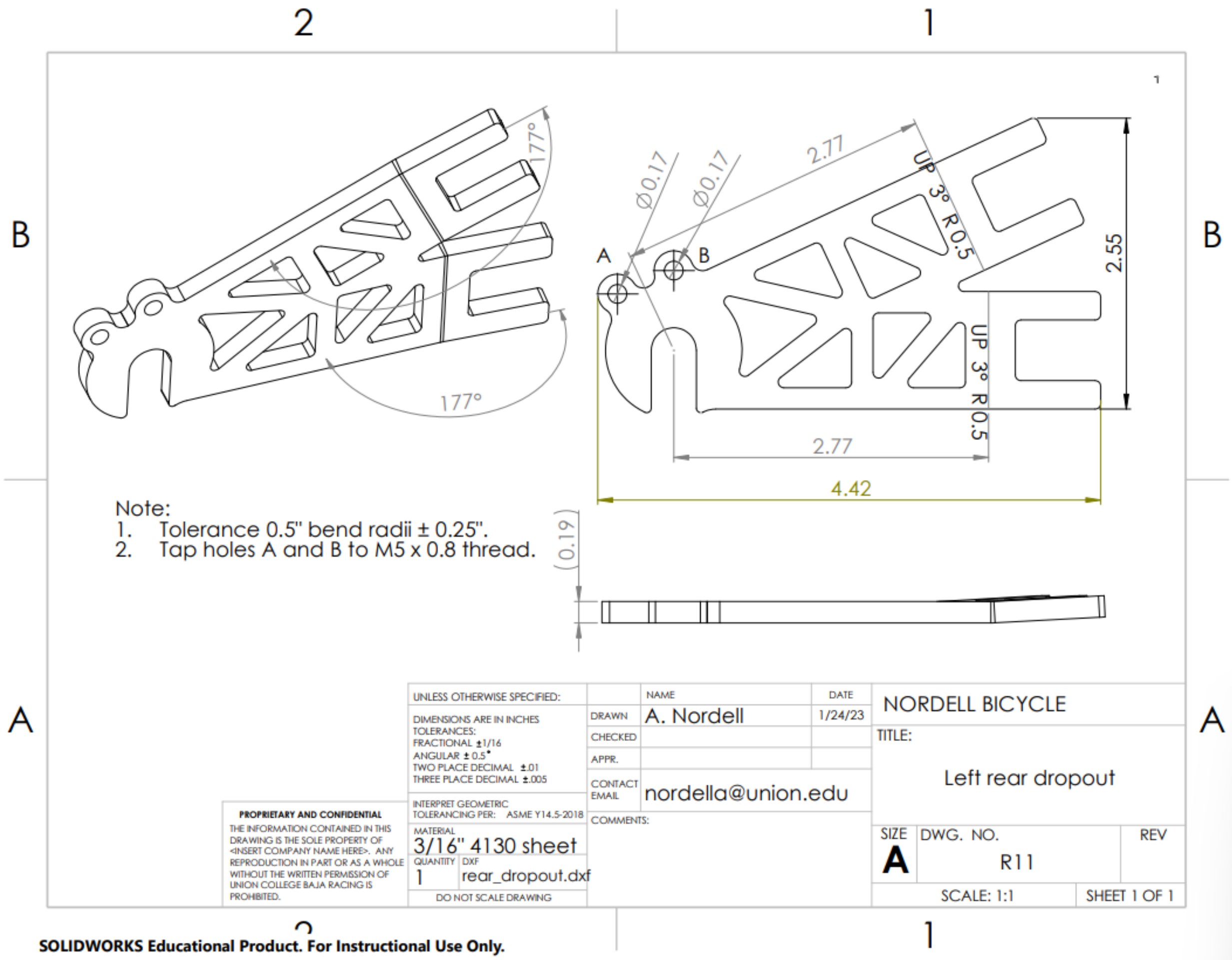
Note:
1. Tolerance 0.5" bend radii ± 0.25".
2. Tap holes A and B to M5 x 0.8 thread.

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/16 ANGULAR ± 0.5° TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	A. Nordell	1/24/23
	CHECKED		
	APPR.		
	CONTACT EMAIL	nordella@union.edu	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018	COMMENTS:		
MATERIAL 3/16" 4130 sheet			
QUANTITY 1	DXF rear_dropout.dxf		
DO NOT SCALE DRAWING			

NORDELL BICYCLE

TITLE: Right rear dropout

SIZE	DWG. NO.	REV
A	R10	
SCALE: 1:1	SHEET 1 OF 1	



2
1
B
A
177°
177°
Ø0.17
Ø0.17
2.77
UP 3° R0.5
2.55
A
B
UP 3° R0.5
2.77
4.42
(0.19)
Note:
1. Tolerance 0.5" bend radii ± 0.25".
2. Tap holes A and B to M5 x 0.8 thread.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 0.5°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 sheet
QUANTITY
1
DXF
rear_dropout.dxf
DO NOT SCALE DRAWING
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NAME
DATE
DRAWN
A. Nordell
1/24/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Left rear dropout
SIZE
A
DWG. NO.
R11
REV
SCALE: 1:1
SHEET 1 OF 1
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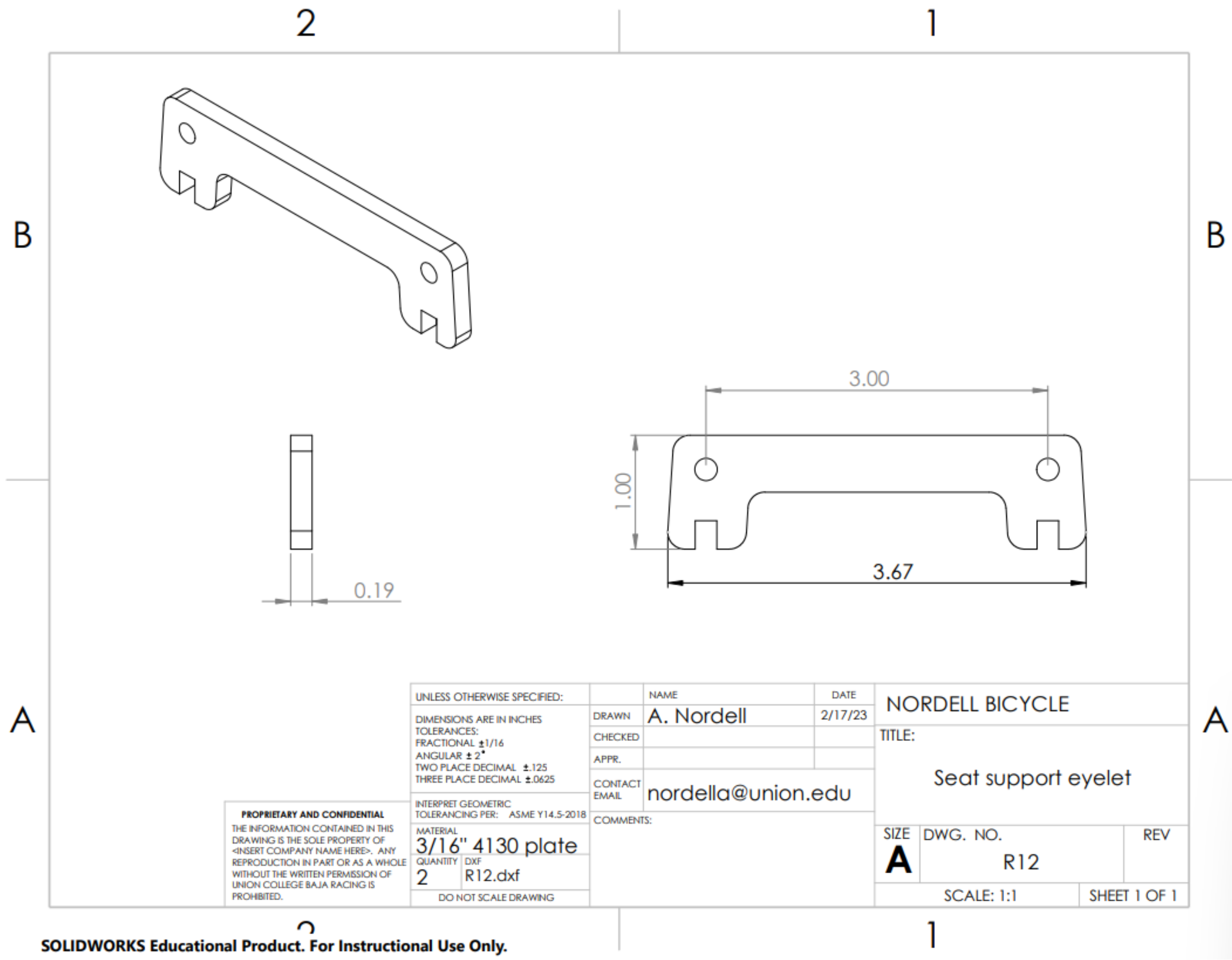

3.00
1.00
3.67
0.19
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY 2
DXF R12.dxf
DO NOT SCALE DRAWING
NAME DATE
DRAWN A. Nordell 2/17/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Seat support eyelet
SIZE A
DWG. NO. R12
REV
SCALE: 1:1
SHEET 1 OF 1
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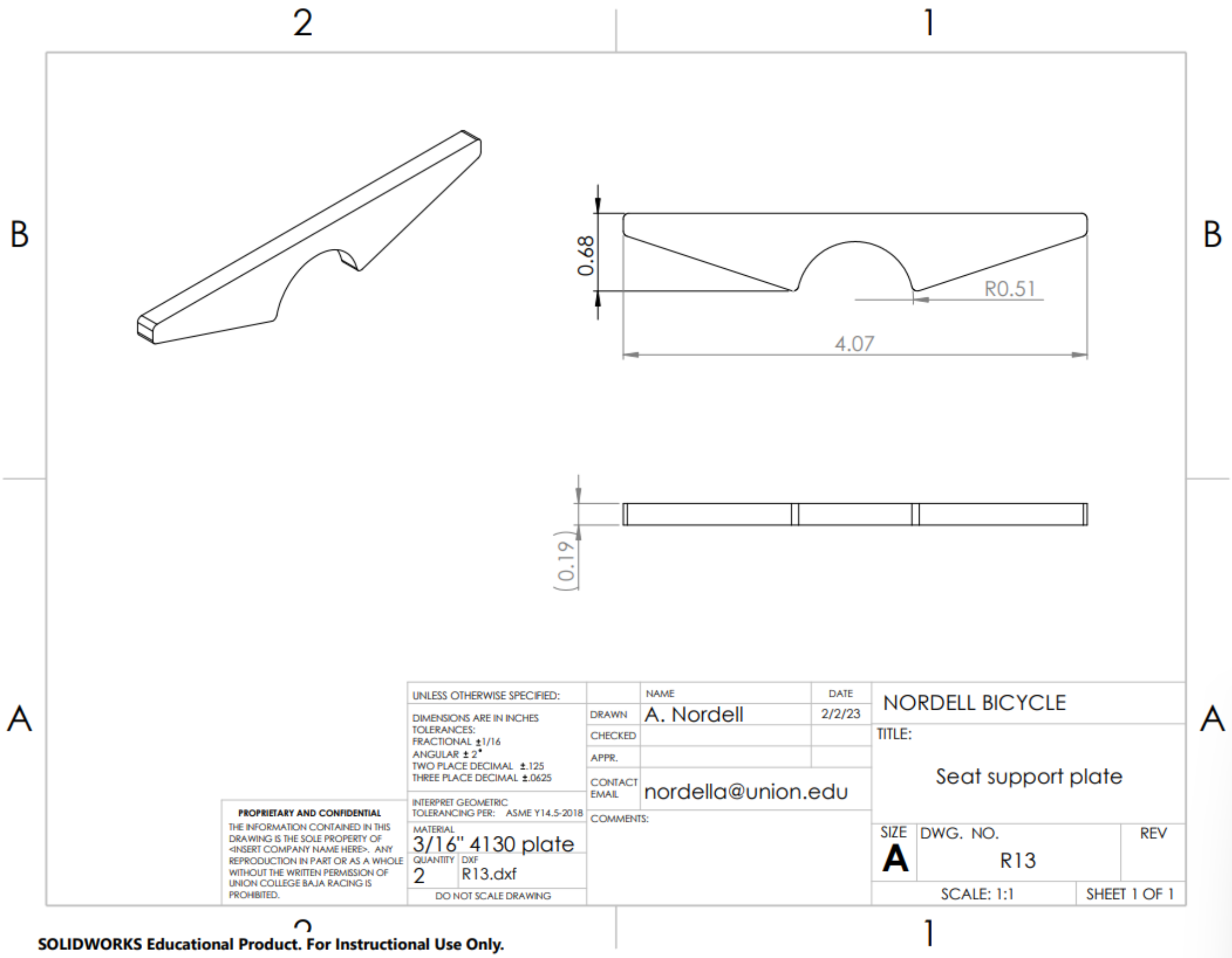
2
1
B
A
0.68
R0.51
4.07
(0.19)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY
2
DXF
R13.dxf
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
A. Nordell
2/2/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Seat support plate
SIZE
A
DWG. NO.
R13
REV
SCALE: 1:1
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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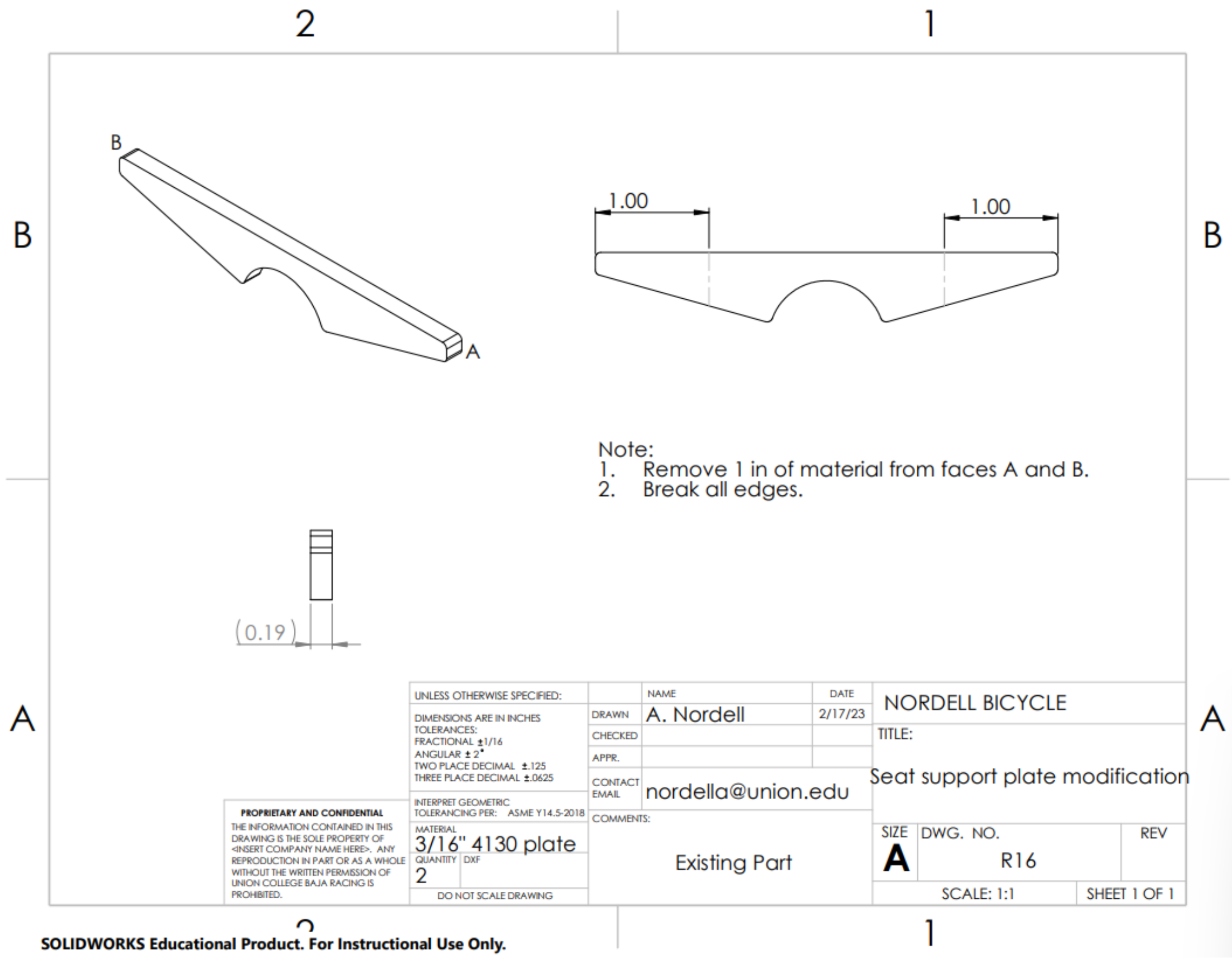

2
1
B
A
B
1.00
1.00
Note:
1. Remove 1 in of material from faces A and B.
2. Break all edges.
(0.19)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY 2
DXF
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NAME
DATE
DRAWN A. Nordell 2/17/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
Existing Part
NORDELL BICYCLE
TITLE:
Seat support plate modification
SIZE A
DWG. NO. R16
REV
SCALE: 1:1
SHEET 1 OF 1
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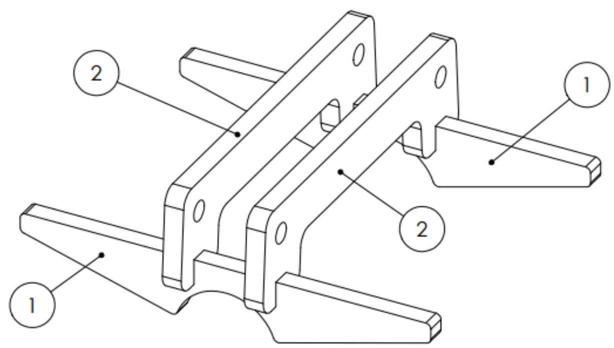
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	R16	Seat support plate modified	2
2	R12	Seat support eyelet	2

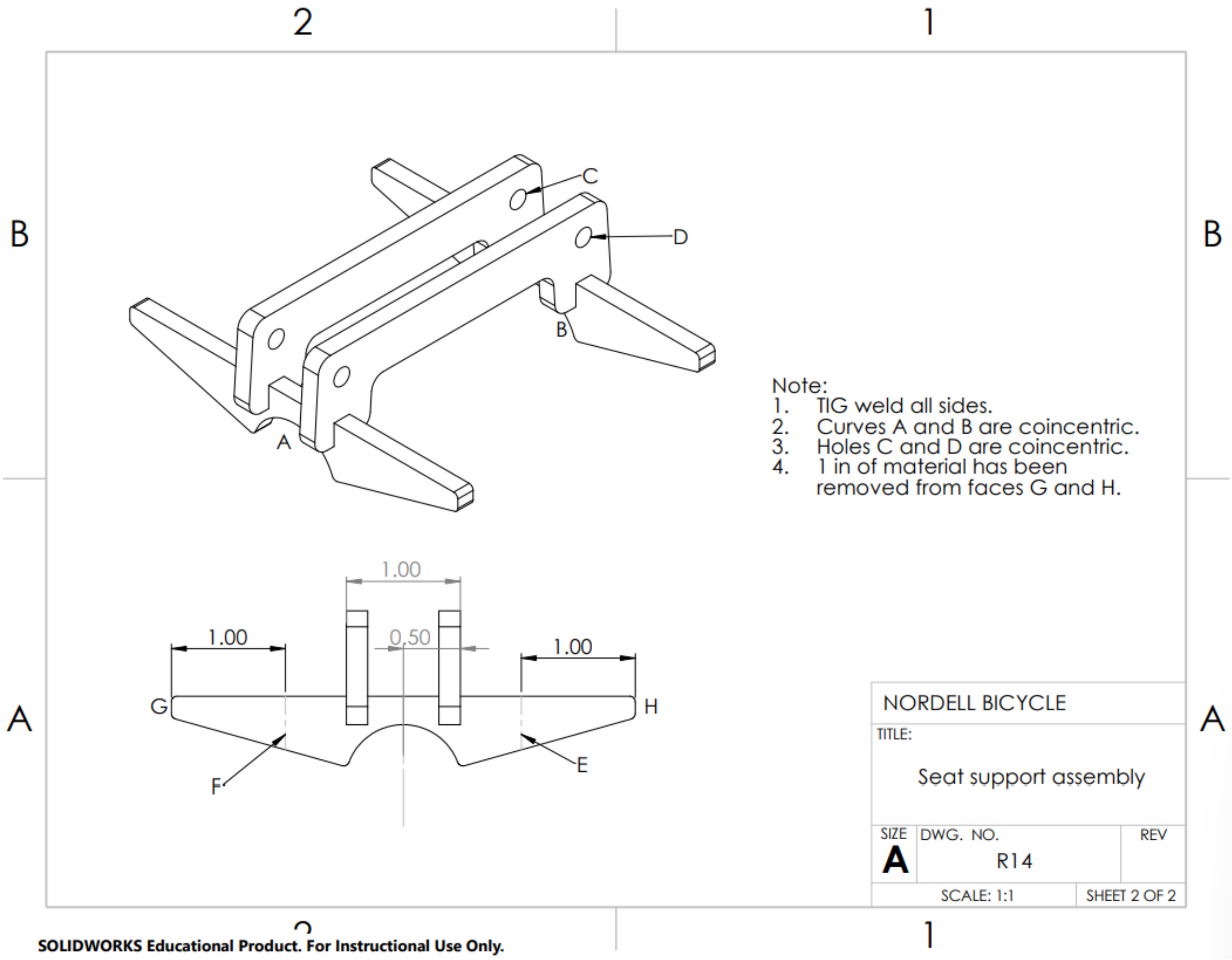


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL 4130
QUANTITY 1 DXF
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. Nordell	3/3/23
CHECKED		
APPR.		
CONTACT EMAIL	nordella@union.edu	

COMMENTS:

NORDELL BICYCLE
TITLE: Seat support assembly
SIZE A DWG. NO. R14 REV
SCALE: 1:1 SHEET 1 OF 2


2
1
B
B
C
D
B
A
Note:
1. TIG weld all sides.
2. Curves A and B are coincentric.
3. Holes C and D are coincentric.
4. 1 in of material has been removed from faces G and H.
1.00
1.00
0.50
1.00
G
H
F
E
A
A
NORDELL BICYCLE
TITLE:
Seat support assembly
SIZE A
DWG. NO. R14
REV
SCALE: 1:1
SHEET 2 OF 2
1
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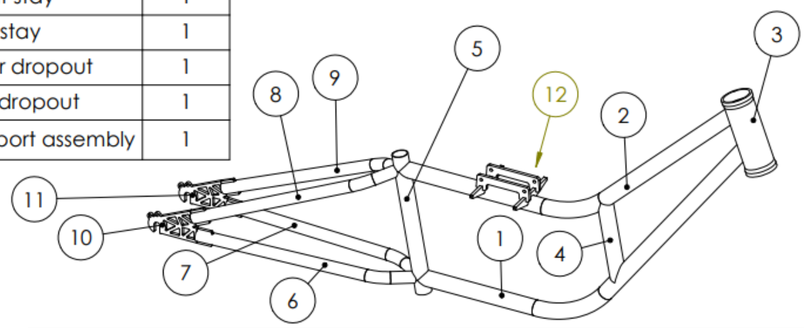
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	R1	Down tube	1
2	R2	Top tube	1
3	R3	Head tube	1
4	R4	Truss	1
5	R5	Seat tube	1
6	R6	Right rear chain stay	1
7	R7	Left rear chain stay	1
8	R8	Right seat stay	1
9	R9	Left seat stay	1
10	R10	Right rear dropout	1
11	R11	Left rear dropout	1
12	R14	Seat support assembly	1

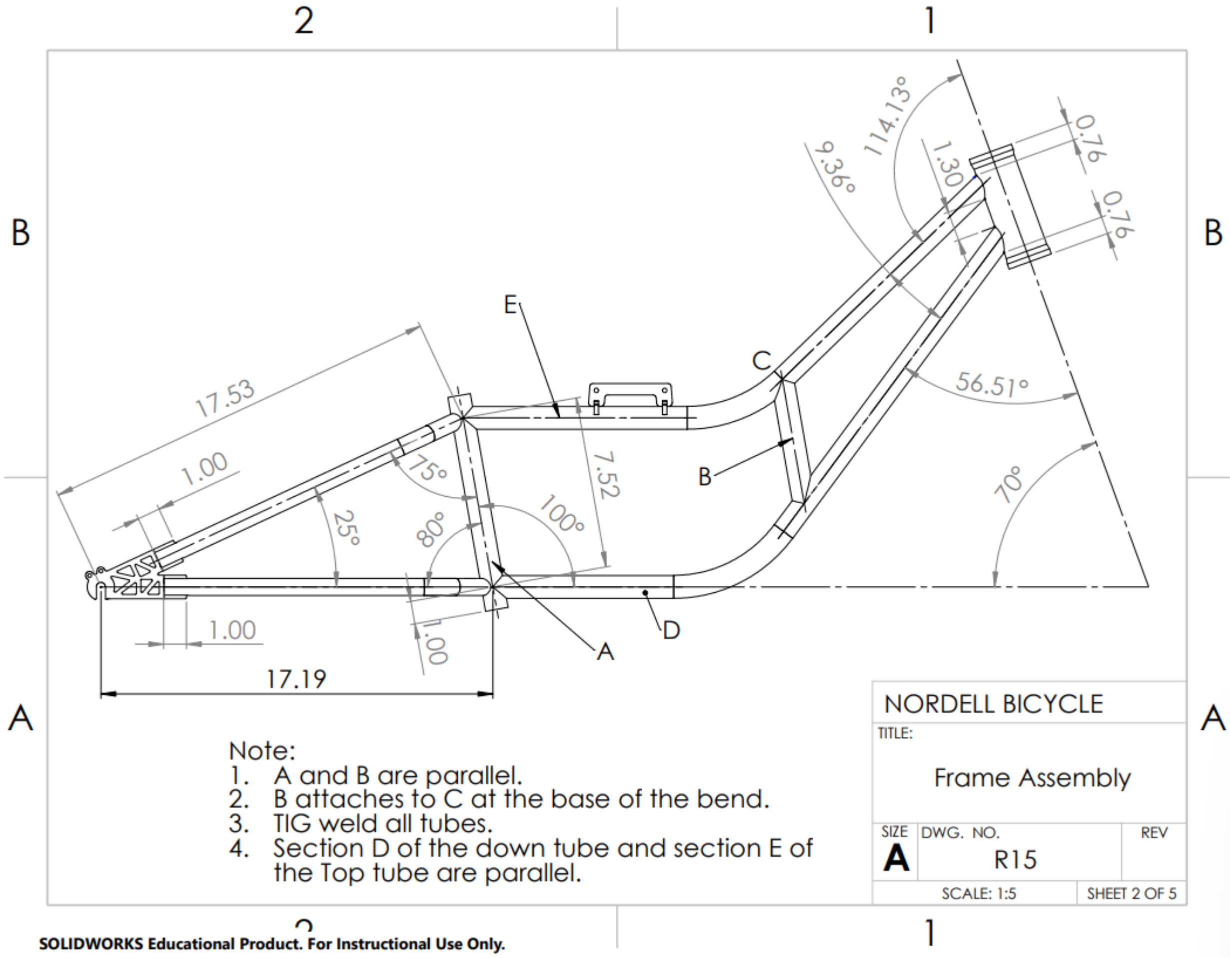


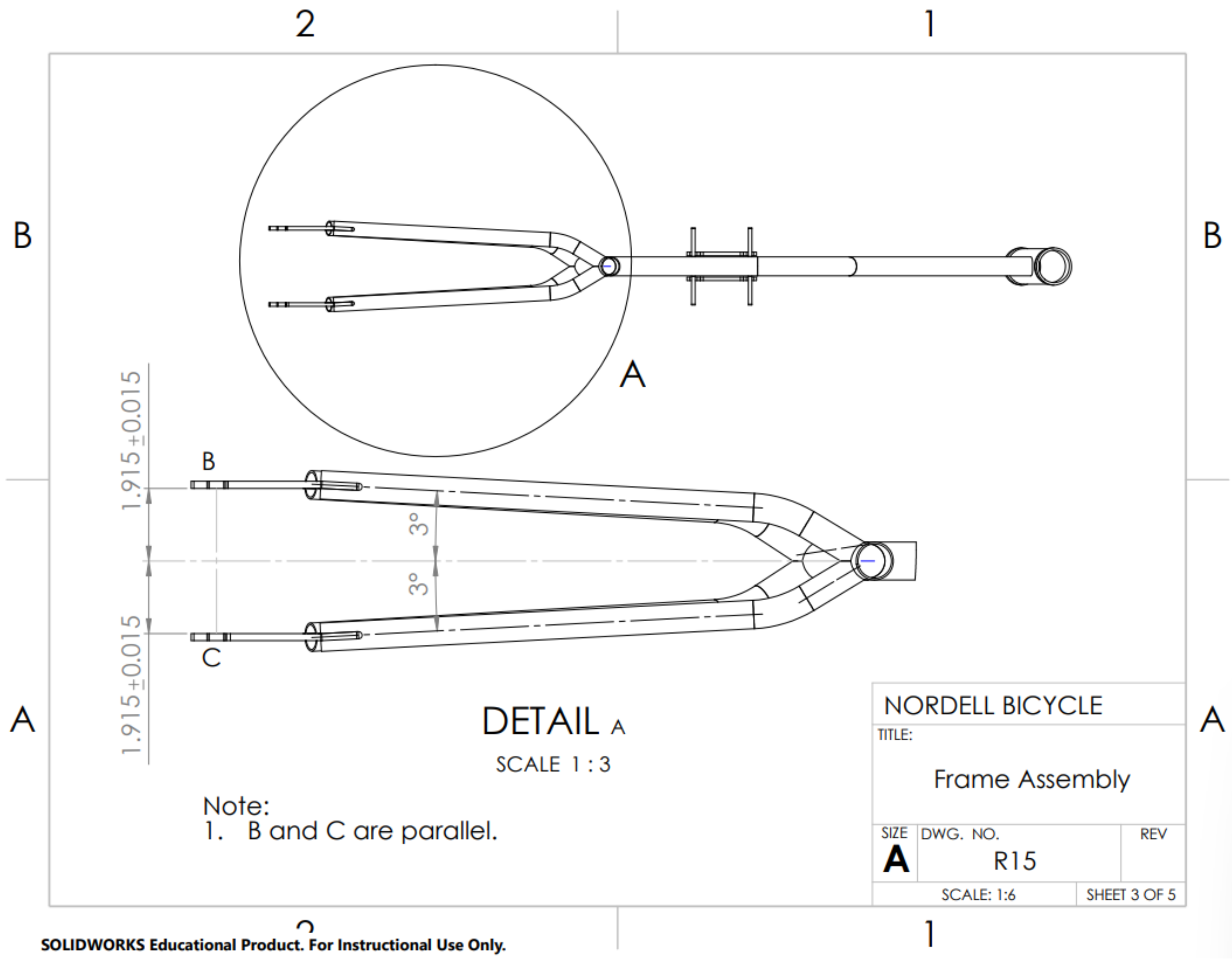
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL 4130
QUANTITY 1 | DXF
DO NOT SCALE DRAWING

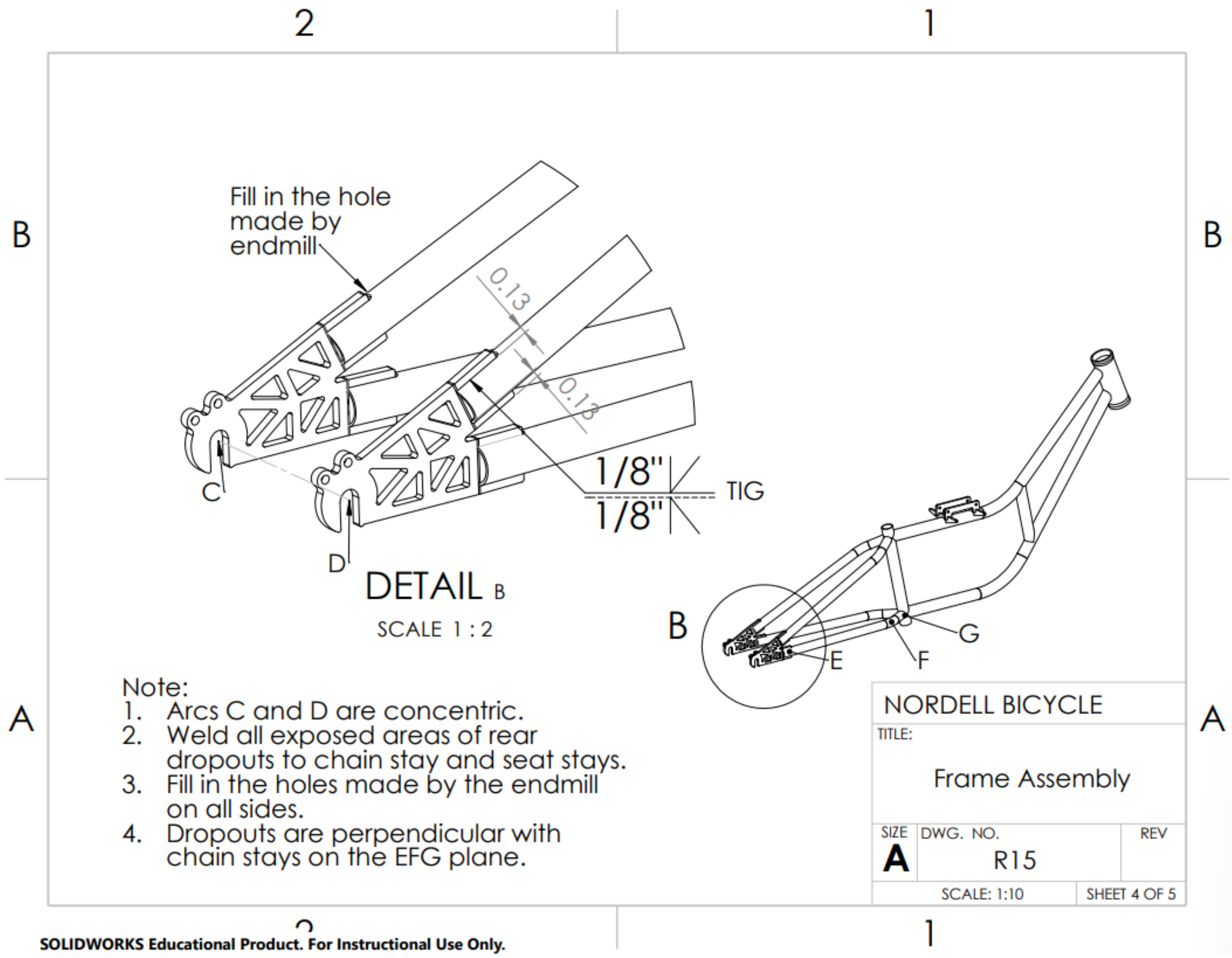
	NAME	DATE
DRAWN	A. Nordell	2/1/23
CHECKED		
APPR.		
CONTACT EMAIL	nordella@union.edu	

COMMENTS:

NORDELL BICYCLE
TITLE: Frame Assembly
SIZE A | DWG. NO. R15 | REV
SCALE: 1:7 | SHEET 1 OF 5


2
1
B
A
17.53
1.00
1.00
1.00
17.19
25°
75°
80°
100°
7.52
E
C
B
A
D
9.36°
114.13°
1.30
0.76
0.76
56.51°
70°
Note:
1. A and B are parallel.
2. B attaches to C at the base of the bend.
3. TIG weld all tubes.
4. Section D of the down tube and section E of the Top tube are parallel.
NORDELL BICYCLE
TITLE:
Frame Assembly
SIZE
A
DWG. NO.
R15
REV
SCALE: 1:5
SHEET 2 OF 5
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
B
A
1.915±0.015
B
3°
3°
C
1.915±0.015
A
DETAIL A
SCALE 1 : 3
Note:
1. B and C are parallel.
NORDELL BICYCLE
TITLE:
Frame Assembly
SIZE A
DWG. NO. R15
REV
SCALE: 1:6
SHEET 3 OF 5
A
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
B
Fill in the hole
made by
endmill
0.13
0.13
1/8"
1/8"
TIG
C
D
DETAIL B
SCALE 1 : 2
B
G
E
F
A
A
Note:
1. Arcs C and D are concentric.
2. Weld all exposed areas of rear dropouts to chain stay and seat stays.
3. Fill in the holes made by the endmill on all sides.
4. Dropouts are perpendicular with chain stays on the EFG plane.
NORDELL BICYCLE
TITLE:
Frame Assembly
SIZE
A
DWG. NO.
R15
REV
SCALE: 1:10
SHEET 4 OF 5
2
1
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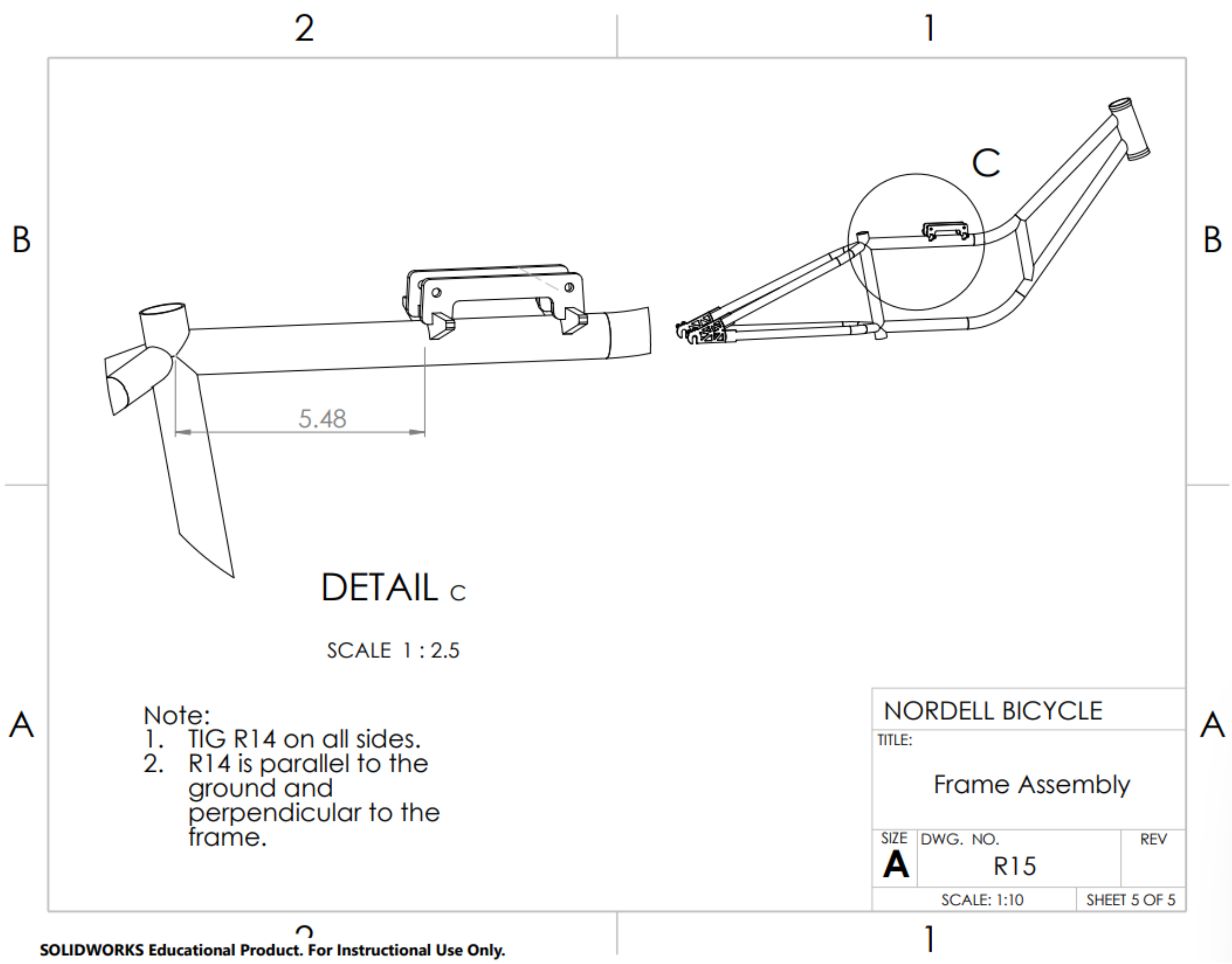
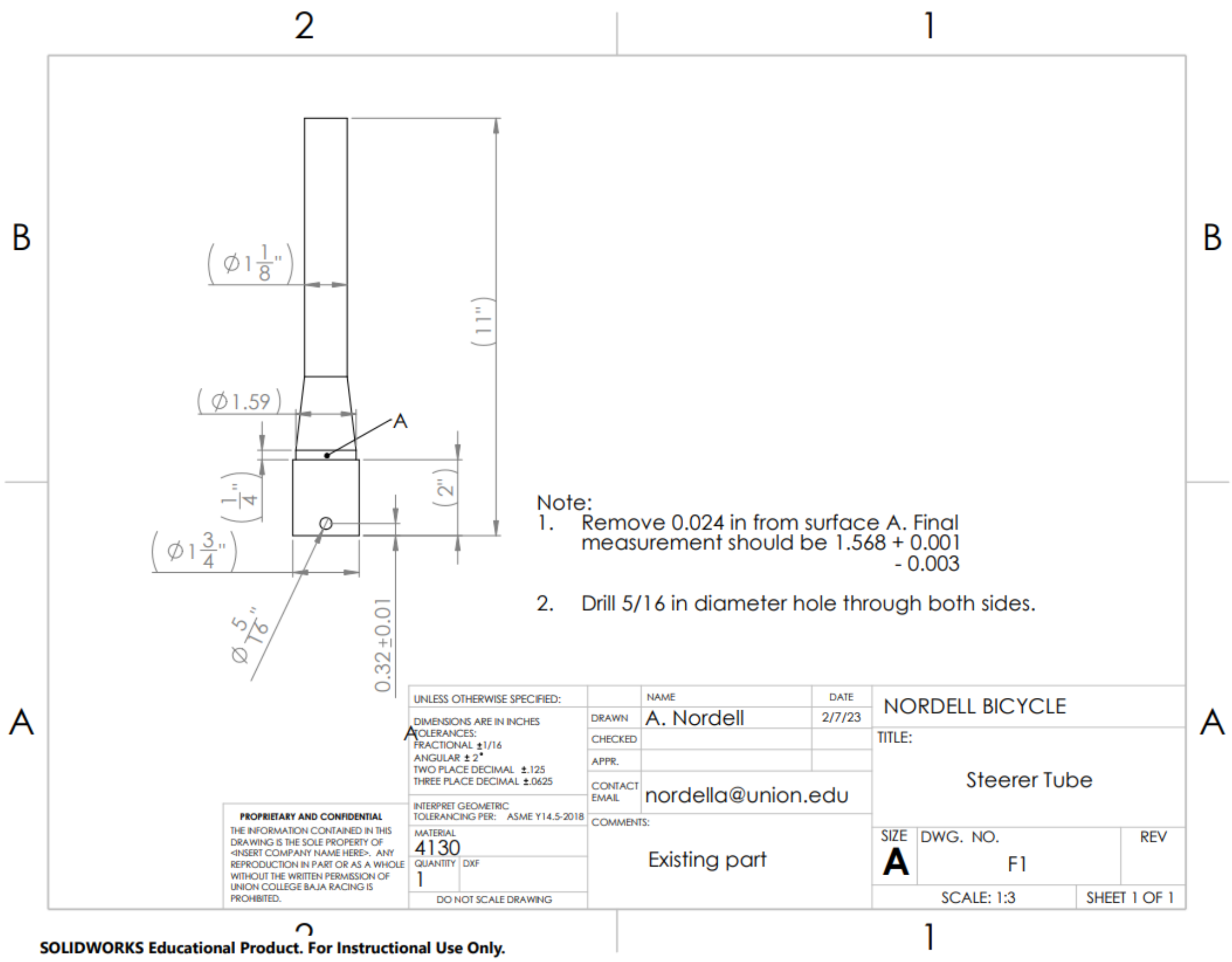
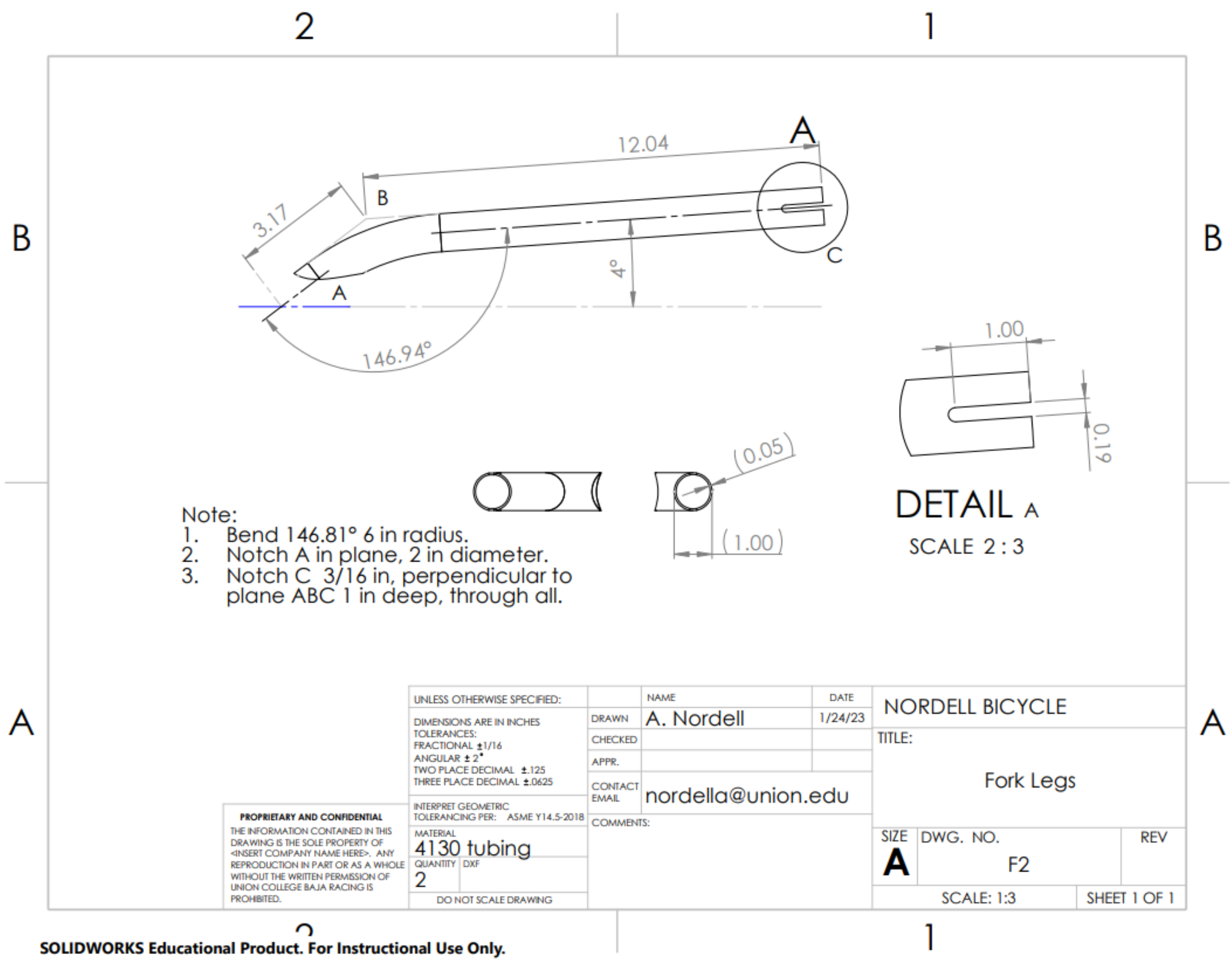

2
1
B
B
C
5.48
DETAIL C
SCALE 1 : 2.5
Note:
1. TIG R14 on all sides.
2. R14 is parallel to the ground and perpendicular to the frame.
A
A
NORDELL BICYCLE
TITLE:
Frame Assembly
SIZE
A
DWG. NO.
R15
REV
SCALE: 1:10
SHEET 5 OF 5
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.

Section 2. Fork Assembly




2
1
B
A
12.04
3.17
B
C
A
4°
146.94°
1.00
0.19
(0.05)
(1.00)
DETAIL A
SCALE 2 : 3
Note:
1. Bend 146.81° 6 in radius.
2. Notch A in plane, 2 in diameter.
3. Notch C 3/16 in, perpendicular to plane ABC 1 in deep, through all.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY
2
DXF
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
A. Nordell
1/24/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Fork Legs
SIZE
A
DWG. NO.
F2
REV
SCALE: 1:3
SHEET 1 OF 1
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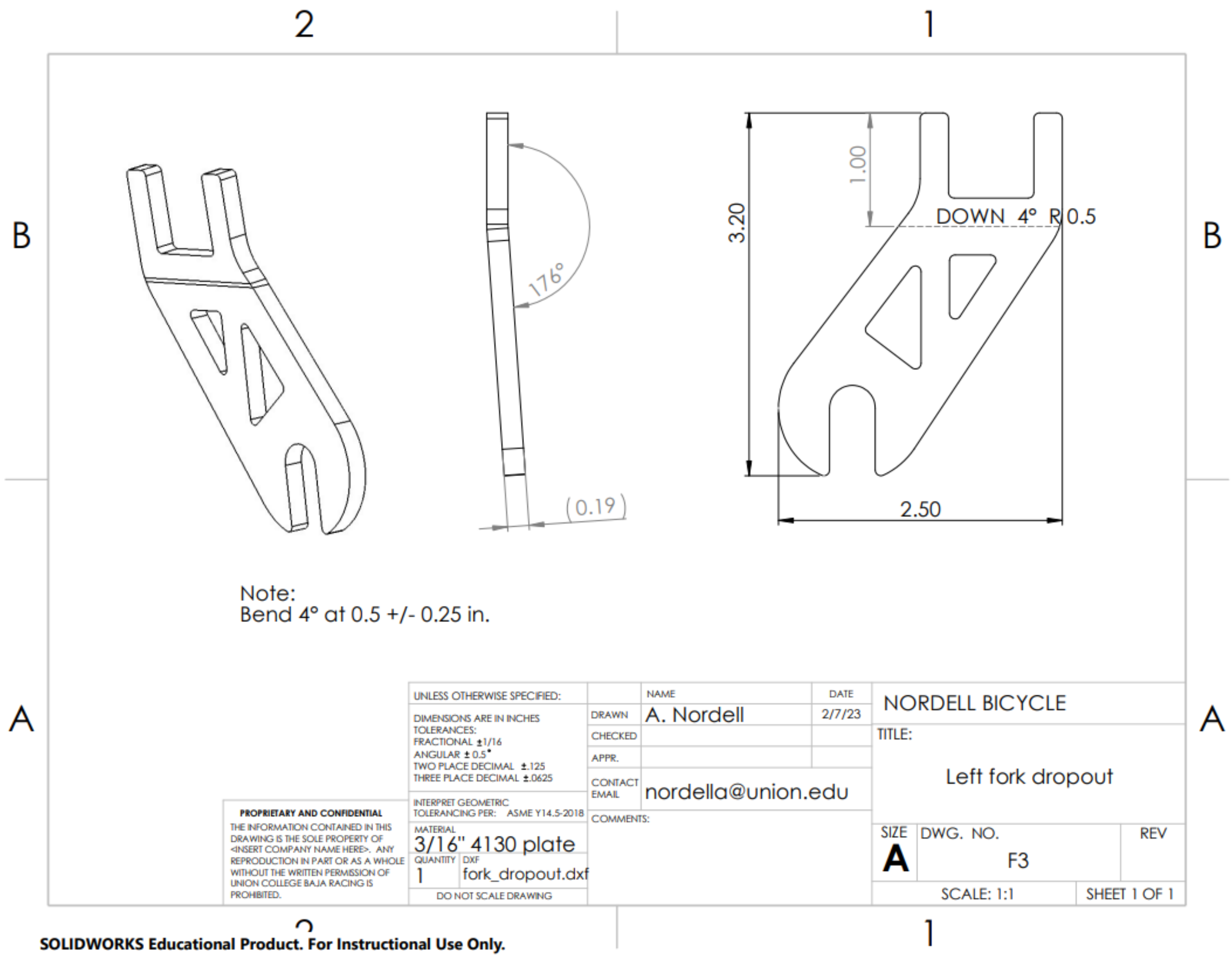
2
1
B
A
1.00
3.20
DOWN 4° R 0.5
176°
(0.19)
2.50
Note:
Bend 4° at 0.5 +/- 0.25 in.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 0.5°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY
1
DXF
fork_dropout.dxf
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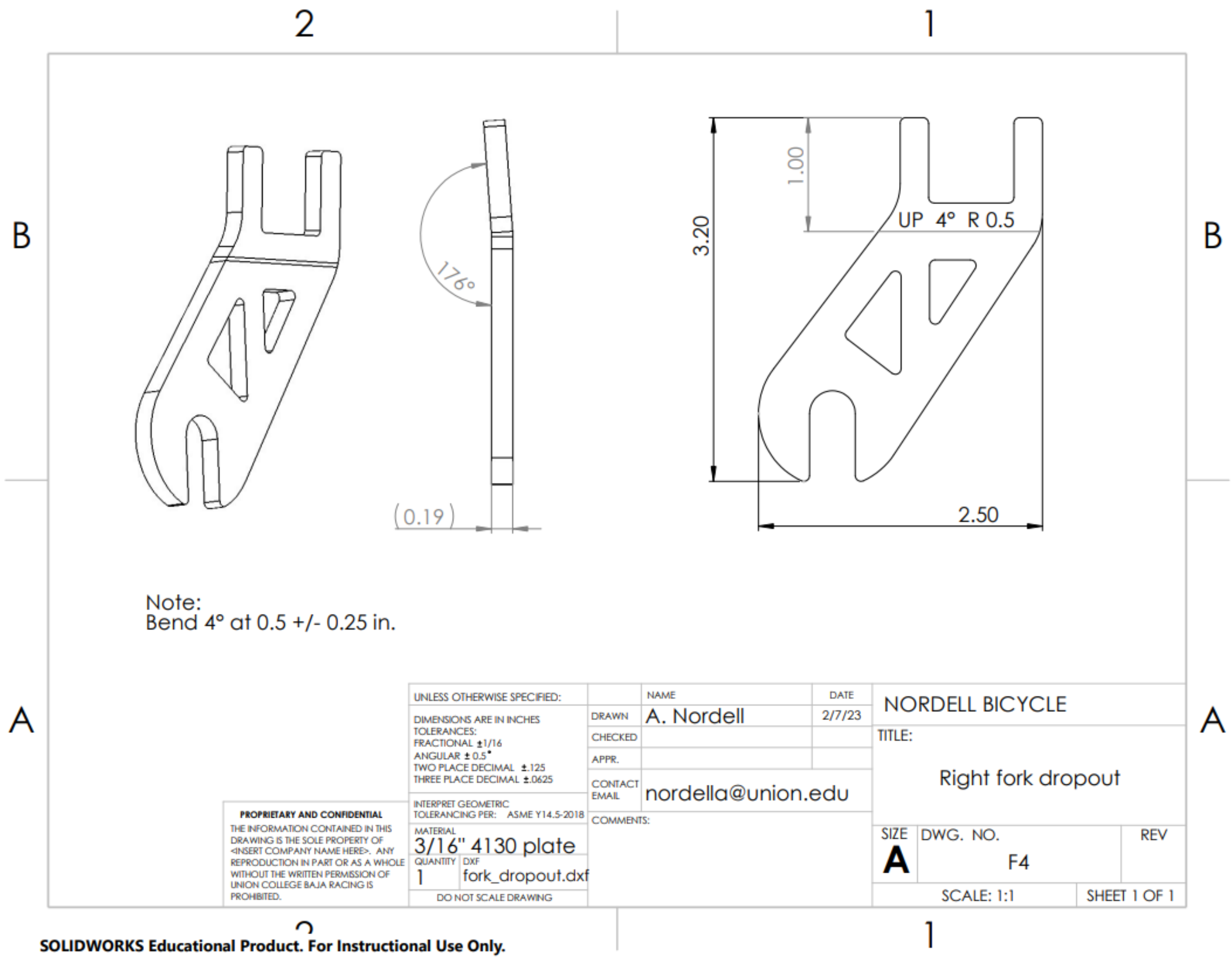
NAME
DATE
DRAWN
A. Nordell
2/7/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Left fork dropout
SIZE
A
DWG. NO.
F3
REV
SCALE: 1:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



2
1
B
A
176°
(0.19)
3.20
1.00
UP 4° R 0.5
2.50
Note:
Bend 4° at 0.5 +/- 0.25 in.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 0.5°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY
1
DXF
fork_dropout.dxf
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
A. Nordell
2/7/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Right fork dropout
SIZE
A
DWG. NO.
F4
REV
SCALE: 1:1
SHEET 1 OF 1
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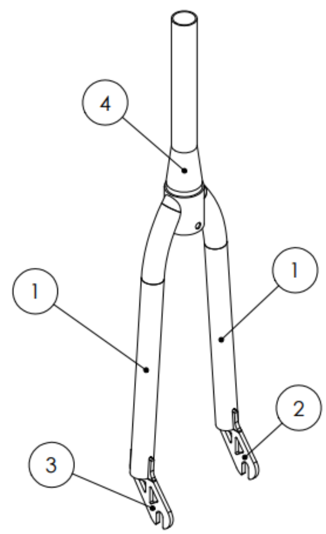
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	F2	Fork Legs	2
2	F3	Left fork dropout	1
3	F4	Right fork dropout	1
4	F1	Steerer tube	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018

MATERIAL: 4130

QUANTITY: 1 DXF

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. Nordell	2/7/23
CHECKED		
APPR.		
CONTACT EMAIL	nordella@union.edu	

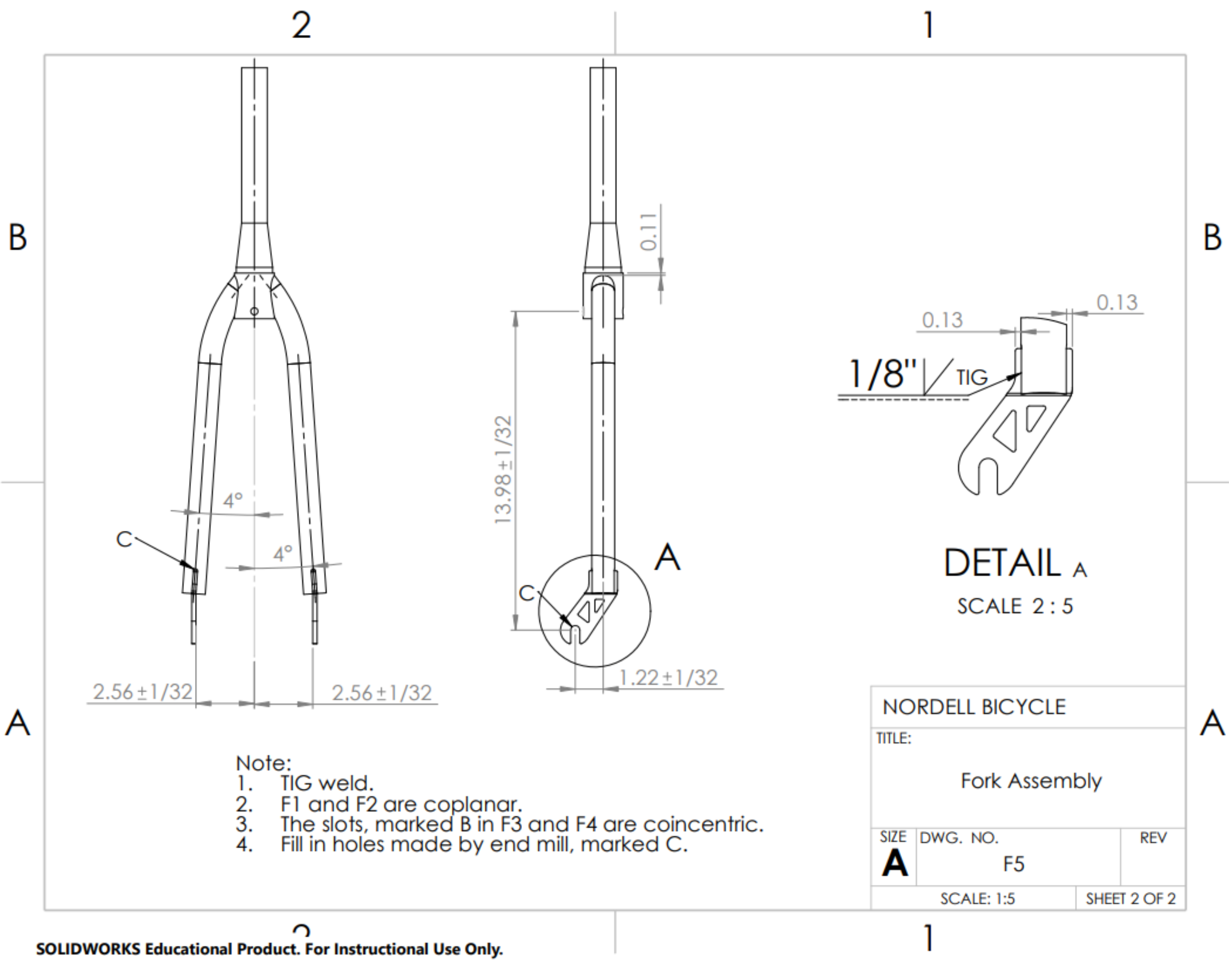
COMMENTS:

NORDELL BICYCLE

TITLE: Fork Assembly

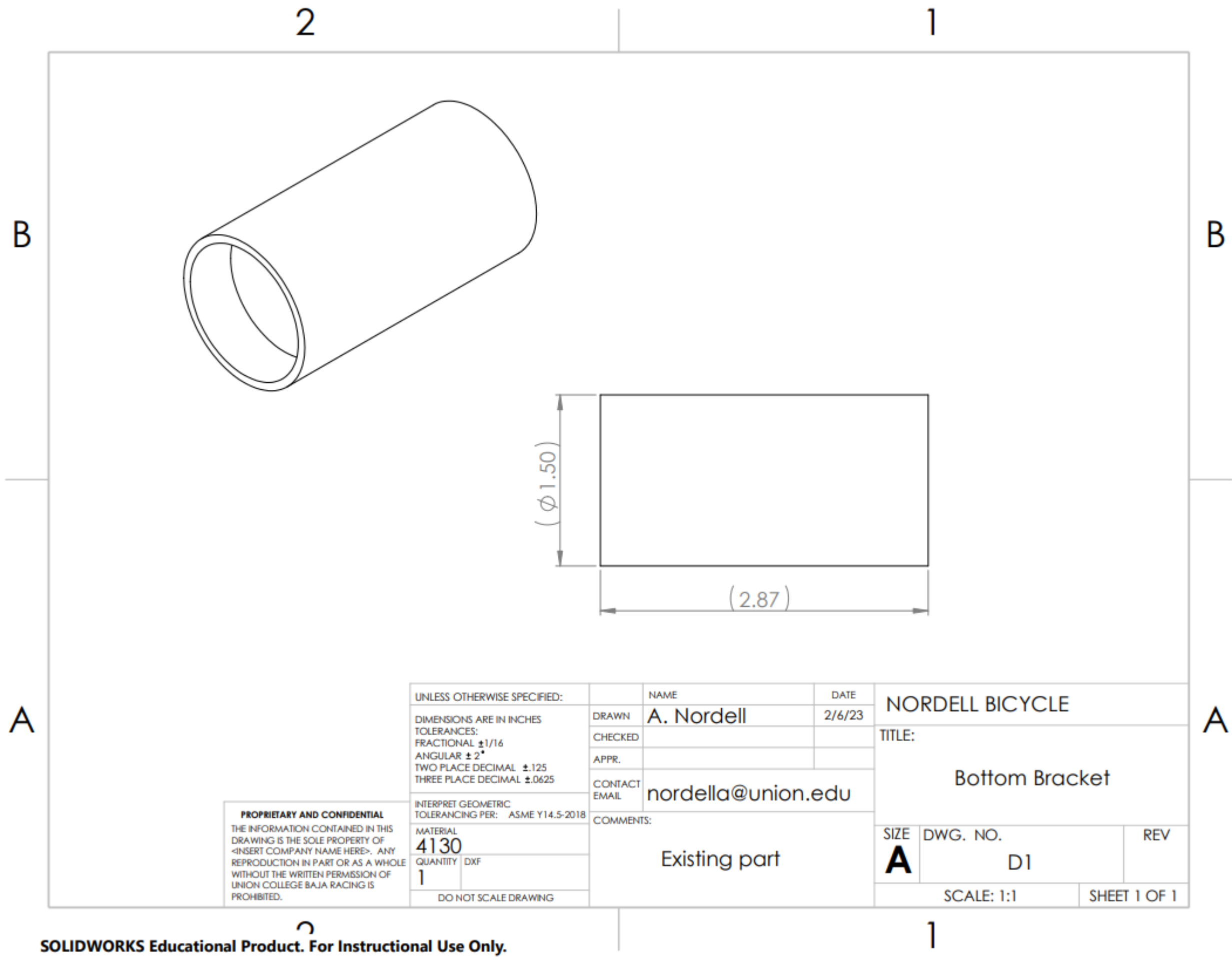
SIZE: A DWG. NO. F5 REV

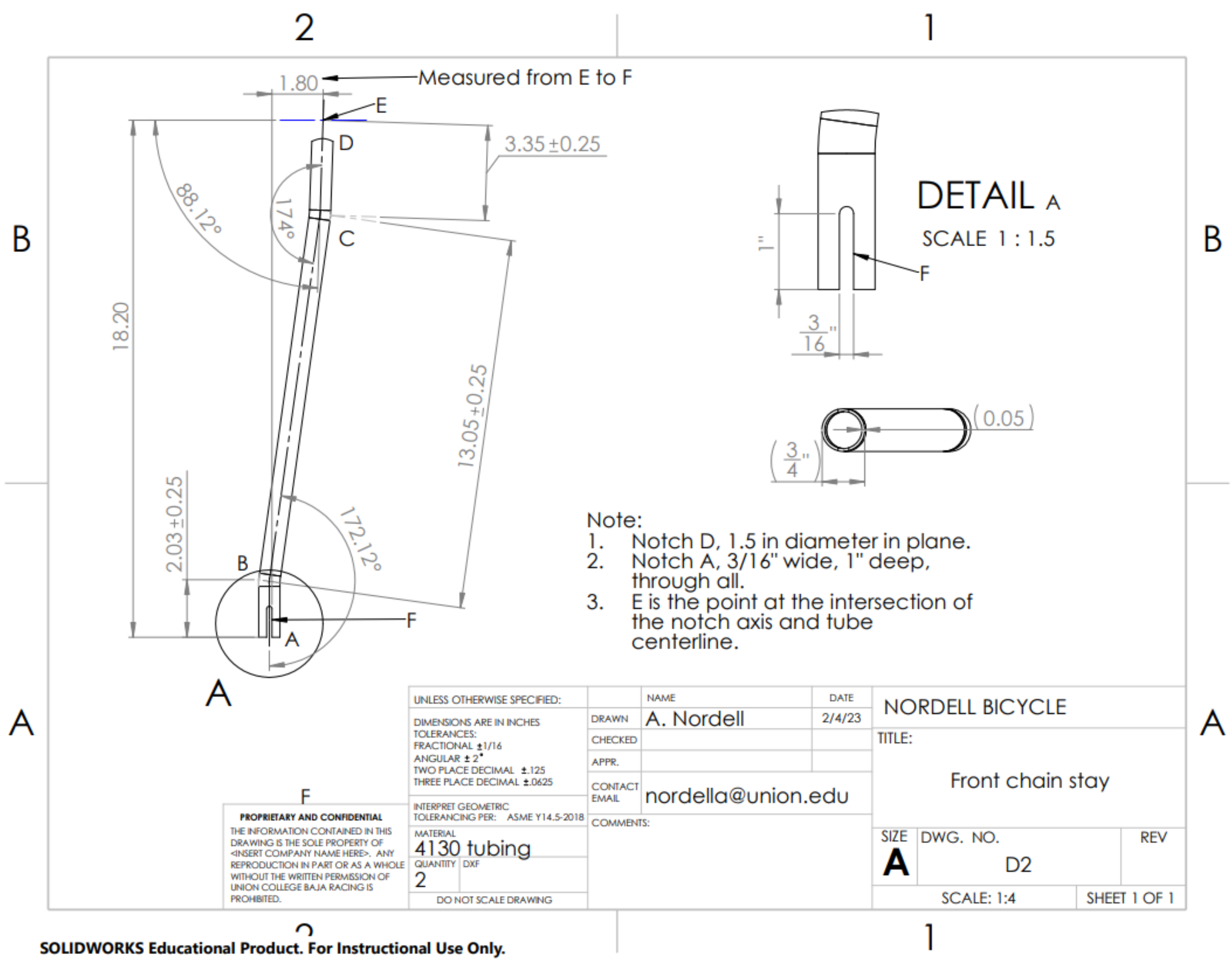
SCALE: 1:5 SHEET 1 OF 2



2
1
B
A
4°
4°
C
13.98±1/32
0.11
C
A
2.56±1/32
2.56±1/32
1.22±1/32
0.13
0.13
1/8" TIG
DETAIL A
SCALE 2 : 5
Note:
1. TIG weld.
2. F1 and F2 are coplanar.
3. The slots, marked B in F3 and F4 are coincentric.
4. Fill in holes made by end mill, marked C.
NORDELL BICYCLE
TITLE:
Fork Assembly
SIZE
A
DWG. NO.
F5
REV
SCALE: 1:5
SHEET 2 OF 2

Section 3. Drive Assembly





1.80
Measured from E to F
E
D
3.35±0.25
88.12°
174°
C
18.20
13.05±0.25
172.12°
2.03±0.25
B
F
A
A
DETAIL A
SCALE 1 : 1.5
1"
F
3/16"
(0.05)
3/4"
Note:
1. Notch D, 1.5 in diameter in plane.
2. Notch A, 3/16" wide, 1" deep, through all.
3. E is the point at the intersection of the notch axis and tube centerline.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130 tubing
QUANTITY
2
DXF
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
A. Nordell
2/4/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Front chain stay
SIZE
A
DWG. NO.
D2
REV
SCALE: 1:4
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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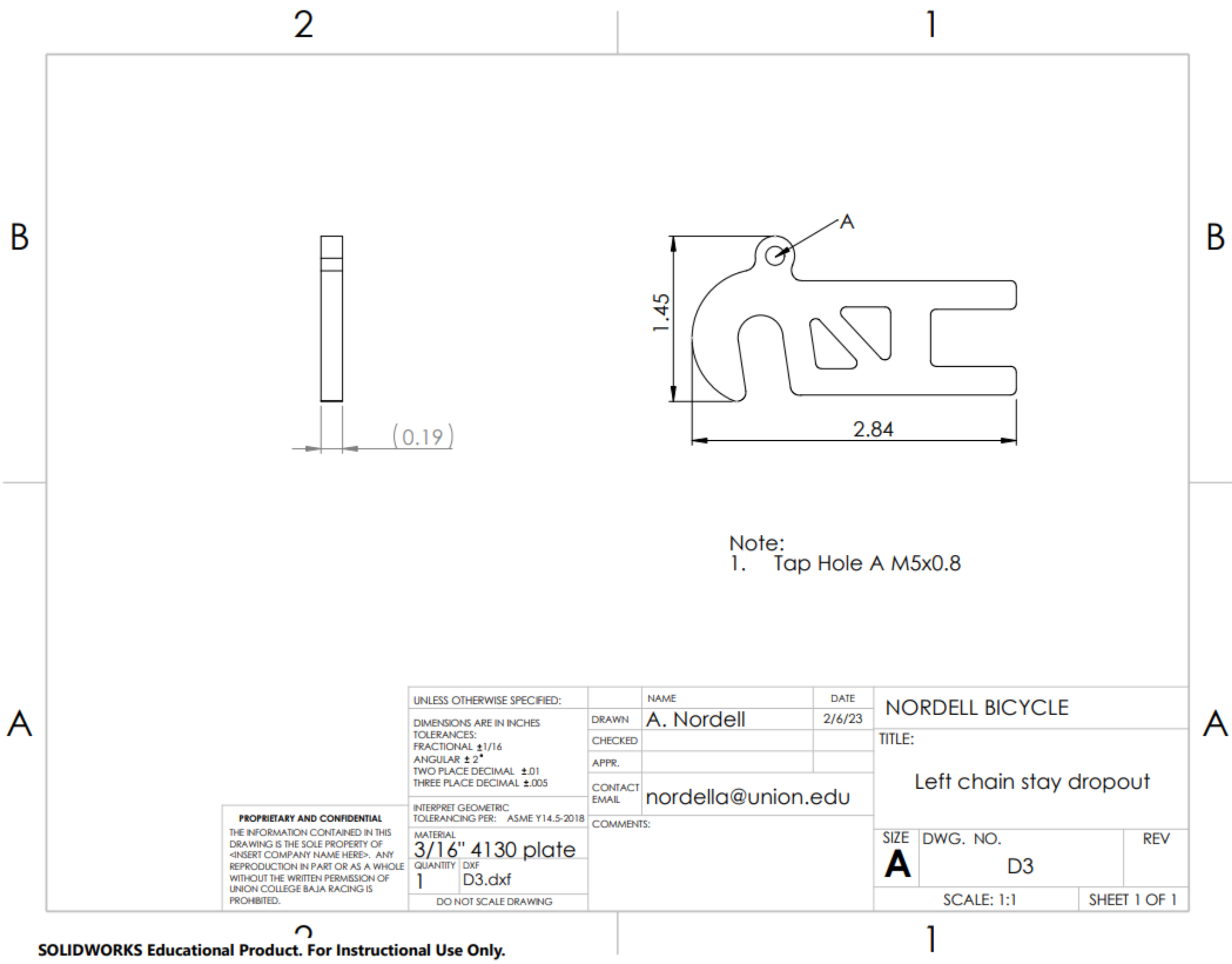
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
B
A
A
(0.19)
1.45
2.84
A
Note:
1. Tap Hole A M5x0.8
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY
1
DXF
D3.dxf
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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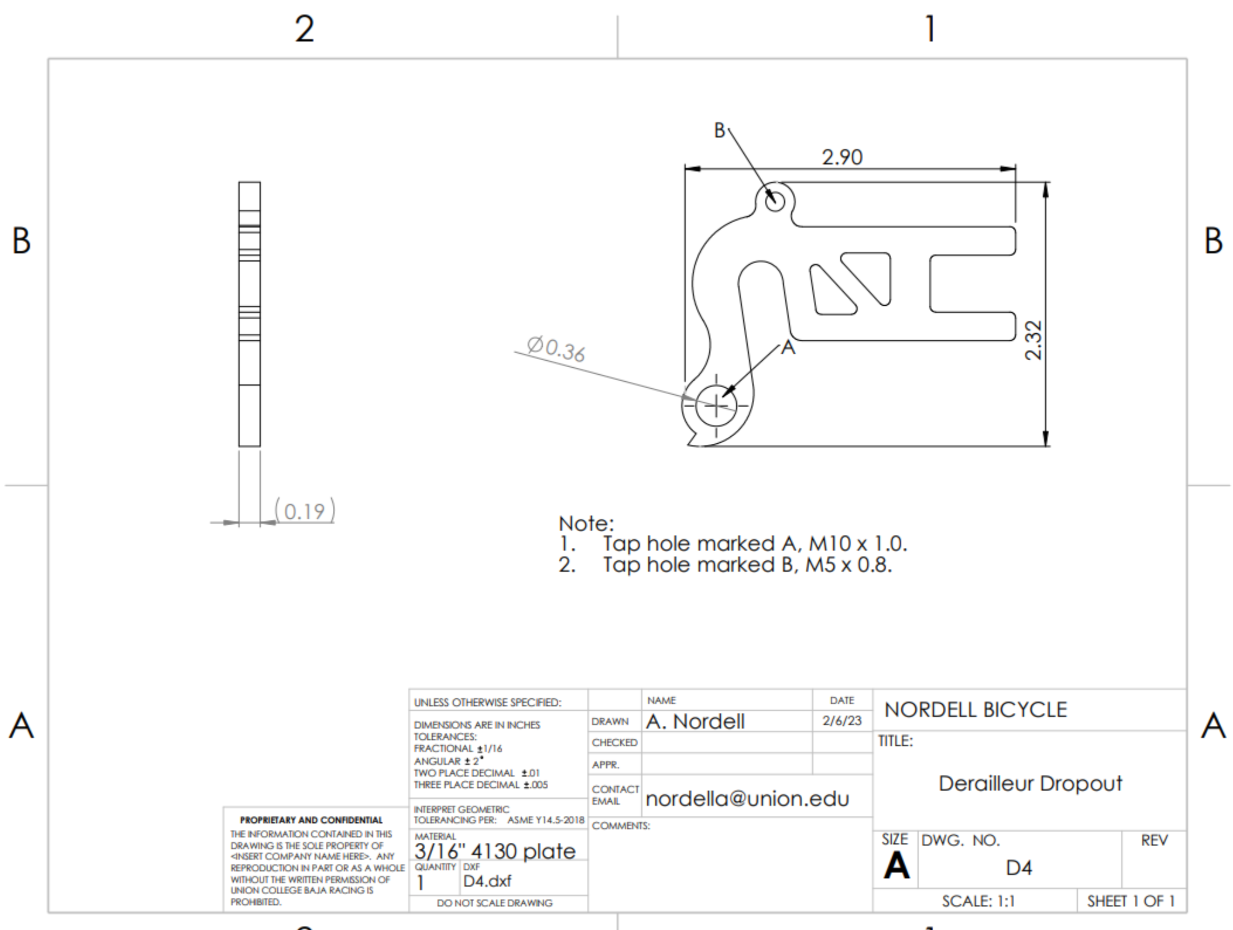
NAME
DATE
DRAWN
A. Nordell
2/6/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Left chain stay dropout
SIZE
A
DWG. NO.
D3
REV
SCALE: 1:1
SHEET 1 OF 1
2
1


2
1
B
A
2.90
2.32
Ø0.36
(0.19)
Note:
1. Tap hole marked A, M10 x 1.0.
2. Tap hole marked B, M5 x 0.8.
PROPRIETARY AND CONFIDENTIAL
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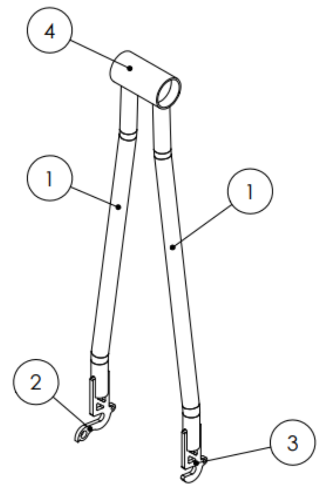
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
3/16" 4130 plate
QUANTITY
1
DXF
D4.dxf
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
A. Nordell
2/6/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Derailleur Dropout
SIZE
A
DWG. NO.
D4
REV
SCALE: 1:1
SHEET 1 OF 1

2 1

ITEM NO.	PART NUMBER	PART NUMBER	QTY.
1	D2	Front chain stay	2
2	D4	Derrailuer dropout	1
3	D3	Left chain stay dropout	1
4	D1	Bottom Bracket	1

B B



A A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018

MATERIAL
4130

QUANTITY 1 | DXF

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. Nordell	2/6/23
CHECKED		
APPR.		
CONTACT EMAIL	nordella@union.edu	

COMMENTS:

NORDELL BICYCLE

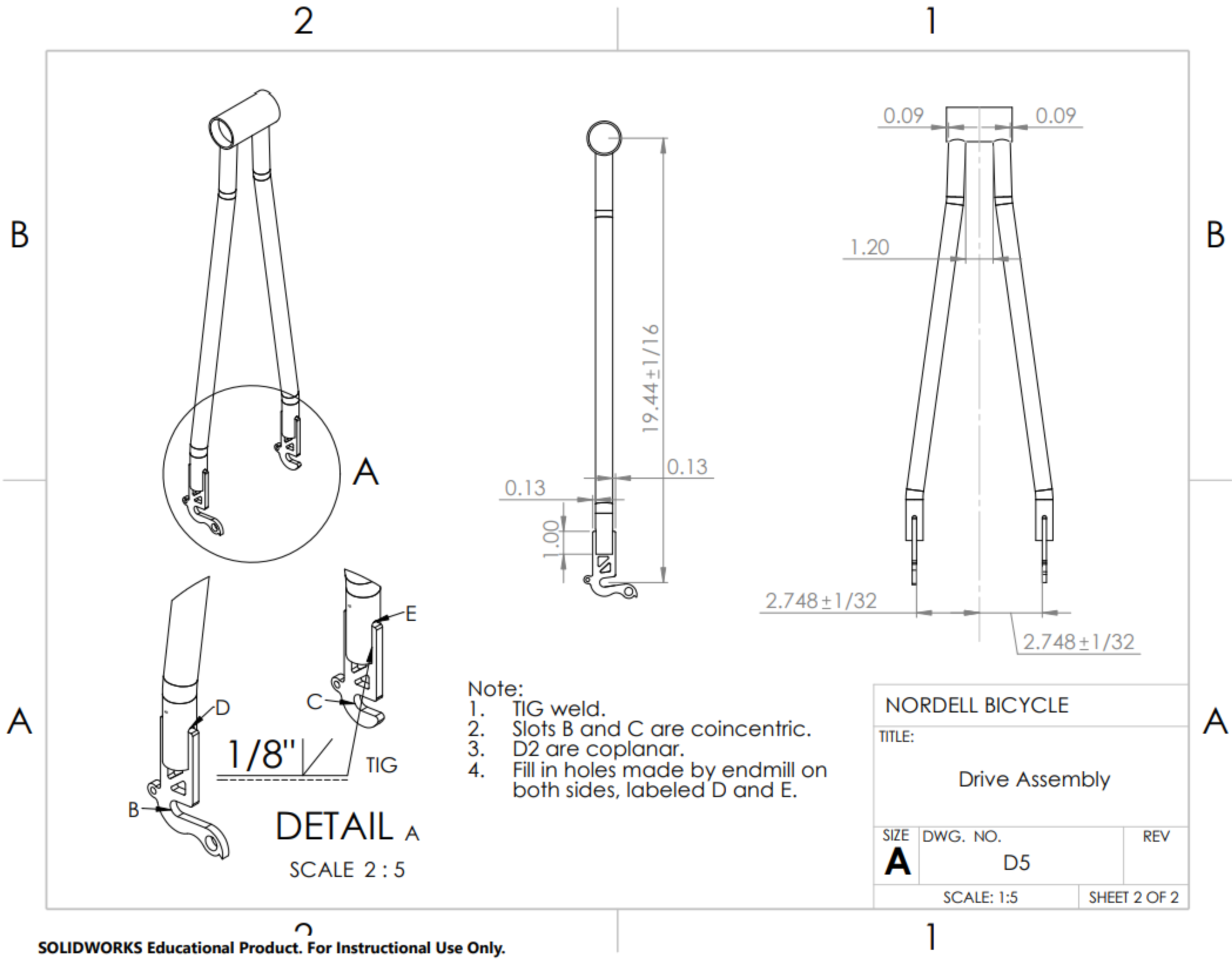
TITLE:

Drive Assembly

SIZE	DWG. NO.	REV
A	D5	

SCALE: 1:5 SHEET 1 OF 2

2 1



2
1
B
A
0.09
0.09
1.20
19.44±1/16
0.13
0.13
1.00
2.748±1/32
2.748±1/32
E
C
D
1/8"
TIG
B
DETAIL A
SCALE 2 : 5
Note:
1. TIG weld.
2. Slots B and C are coincentric.
3. D2 are coplanar.
4. Fill in holes made by endmill on both sides, labeled D and E.
NORDELL BICYCLE
TITLE:
Drive Assembly
SIZE A
DWG. NO. D5
REV
SCALE: 1:5
SHEET 2 OF 2
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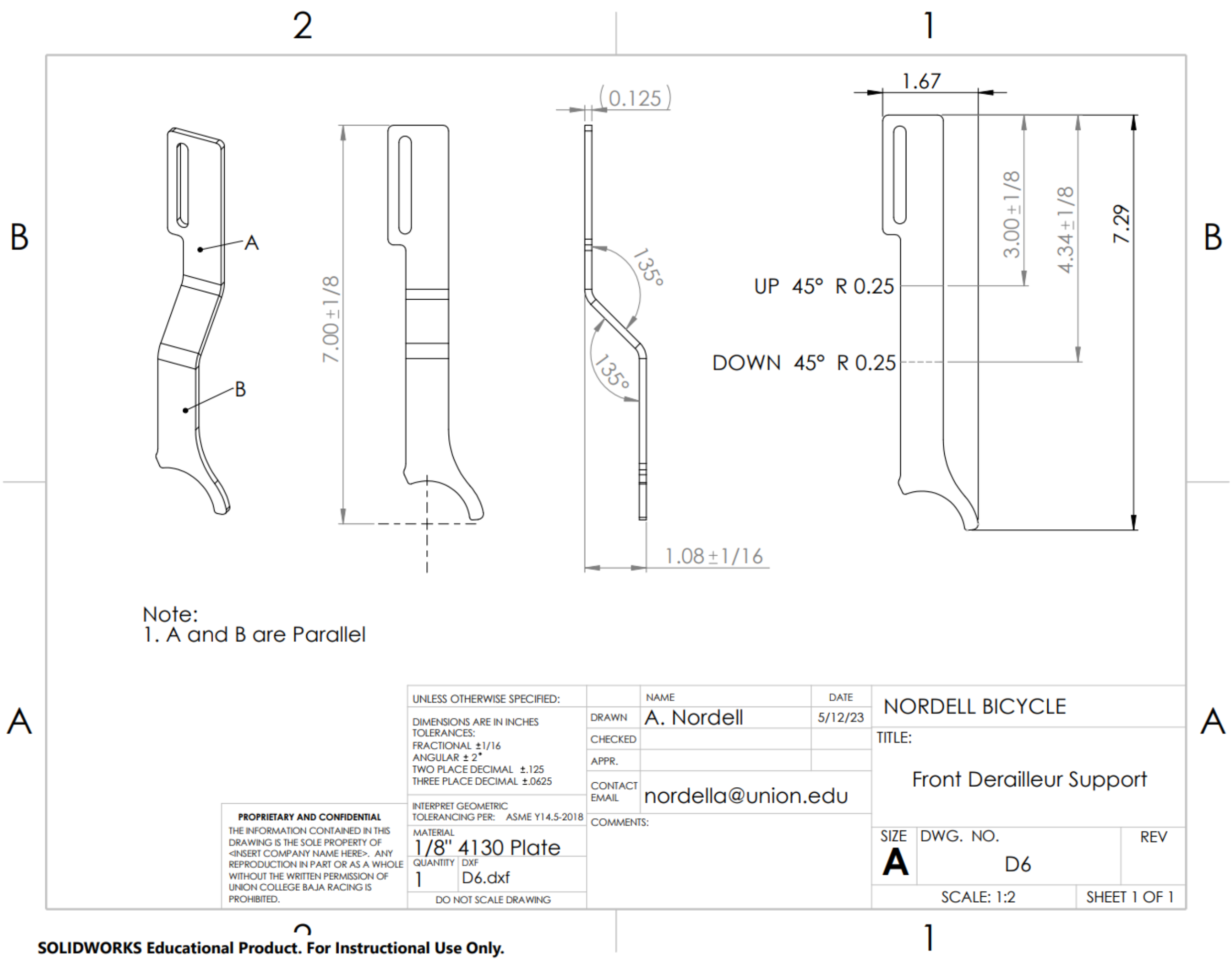
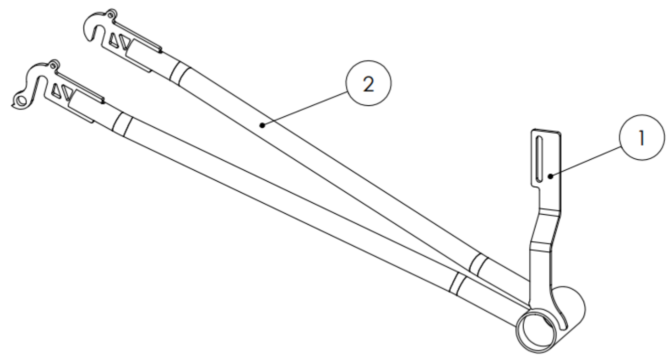


SOLIDWORKS Educational Product. For Instructional Use Only.

2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	D6	Derailleur Support	1
2	D5	Drive Assembly	1

B B



A A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018

MATERIAL: 4130 tubing

QUANTITY: 1 | DXF

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. Nordell	5/12/23
CHECKED		
APPR.		
CONTACT EMAIL	nordella@union.edu	

COMMENTS:

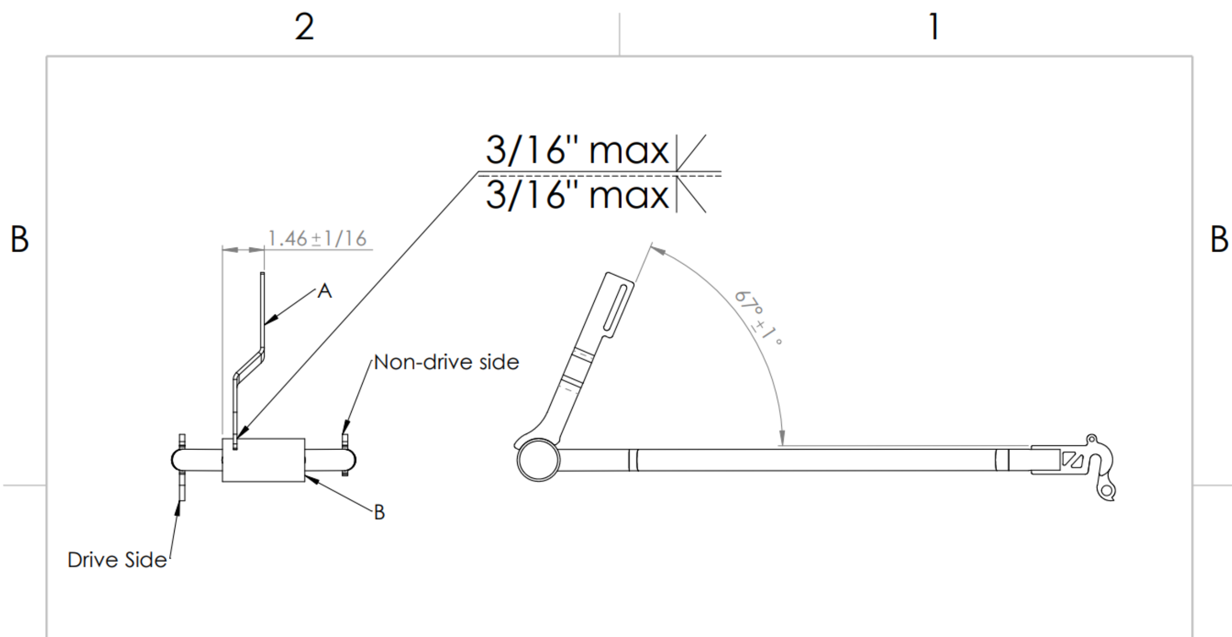
NORDELL BICYCLE

TITLE: Derailleur Support Assembly

SIZE: A | DWG. NO.: D7 | REV

SCALE: 1:4 | SHEET 1 OF 2

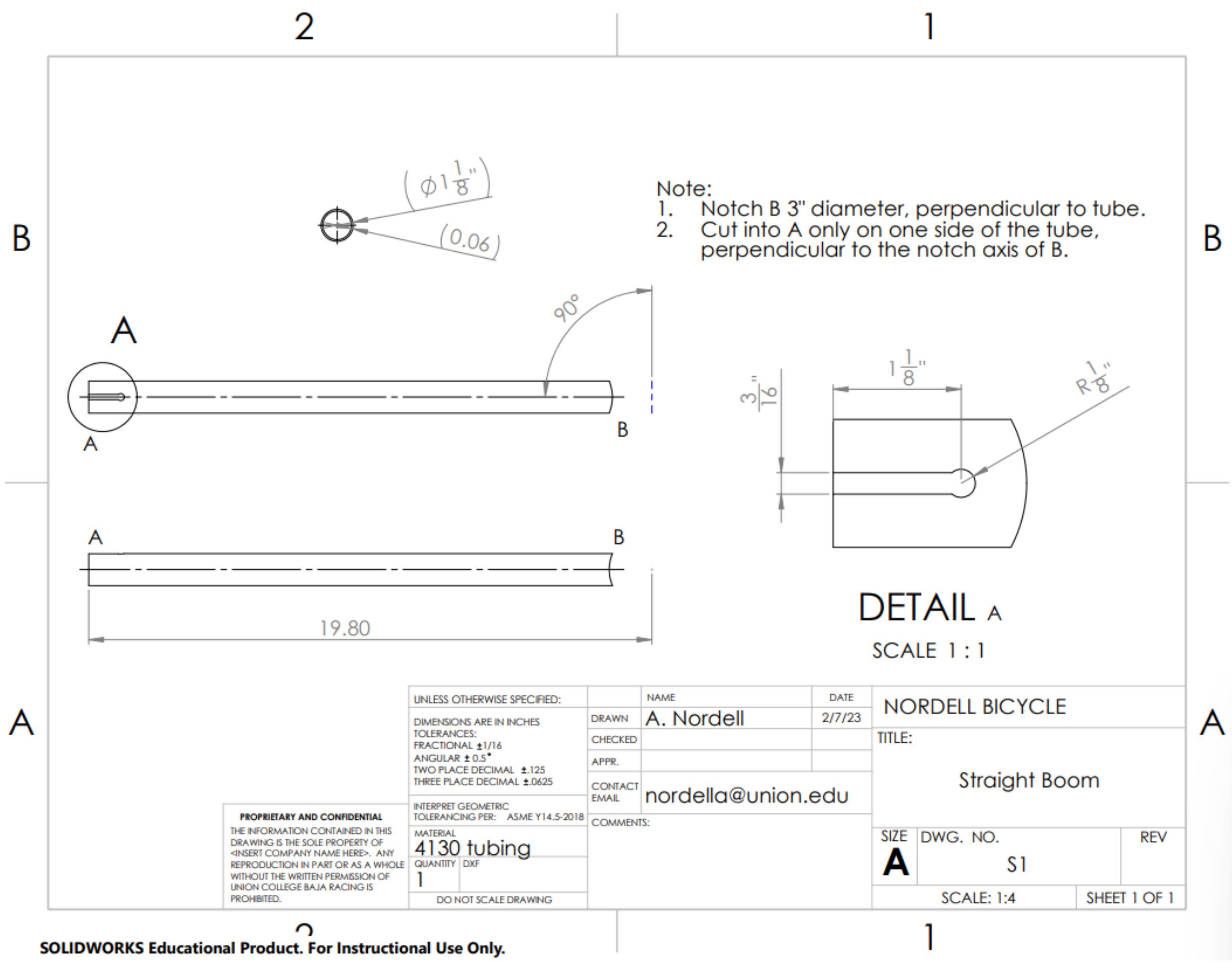
2 1

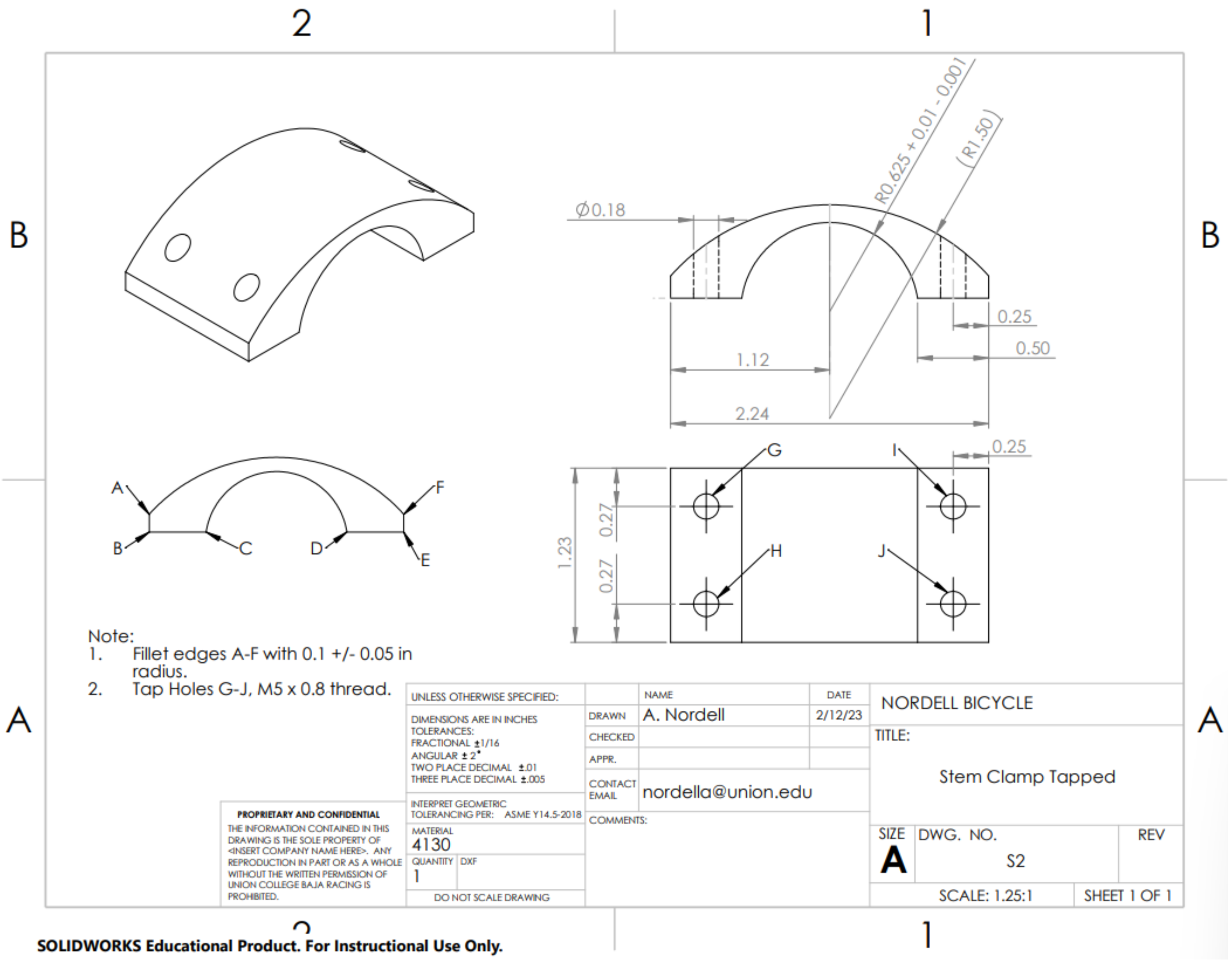


Note:
1. TIG weld D6 to D5 with ER70s
2. Plane A is parallel to plane B
3. D6 goes on the drive side of D5

NORDELL BICYCLE		
TITLE: Derailleur Support Assembly		
SIZE A	DWG. NO. D7	REV
SCALE: 1:4		SHEET 2 OF 2

Section 4. Straight Boom Assembly





Ø0.18
R0.625 +0.01 - 0.001
(R1.50)
0.25
0.50
1.12
2.24
0.25
G
I
H
J
1.23
0.27
0.27
A
B
C
D
E
F
Note:
1. Fillet edges A-F with 0.1 +/- 0.05 in radius.
2. Tap Holes G-J, M5 x 0.8 thread.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130
QUANTITY 1
DXF
DO NOT SCALE DRAWING
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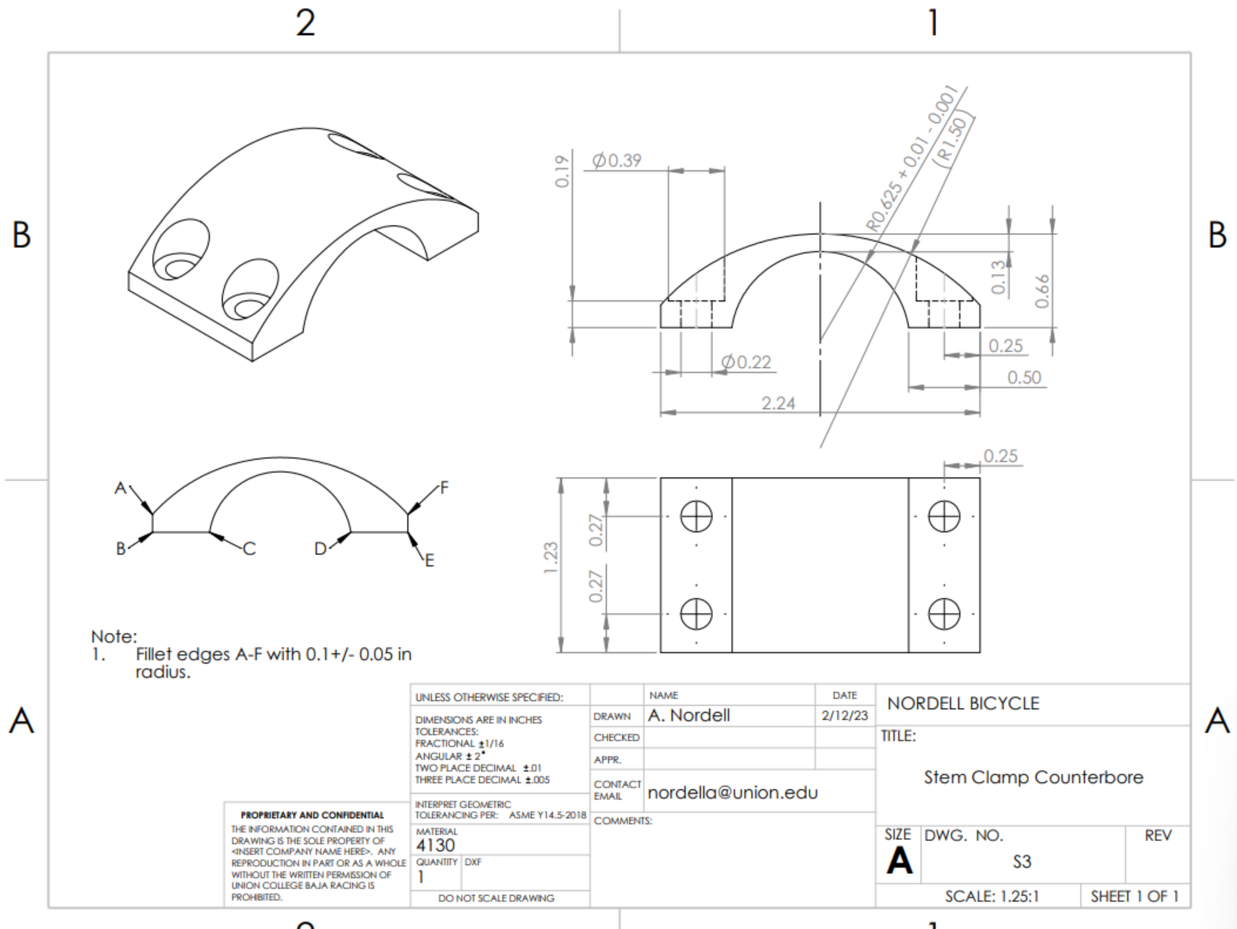
NAME
DATE
DRAWN A. Nordell 2/12/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Stem Clamp Tapped
SIZE A
DWG. NO. S2
REV
SCALE: 1.25:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
A
Ø0.39
0.19
R0.625 +0.01 - 0.001
(R1.50)
0.13
0.66
0.25
0.50
Ø0.22
2.24
0.25
0.27
0.27
1.23
A
B
C
D
E
F
Note:
1. Fillet edges A-F with 0.1+/- 0.05 in radius.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130
QUANTITY
1
DXF
DO NOT SCALE DRAWING
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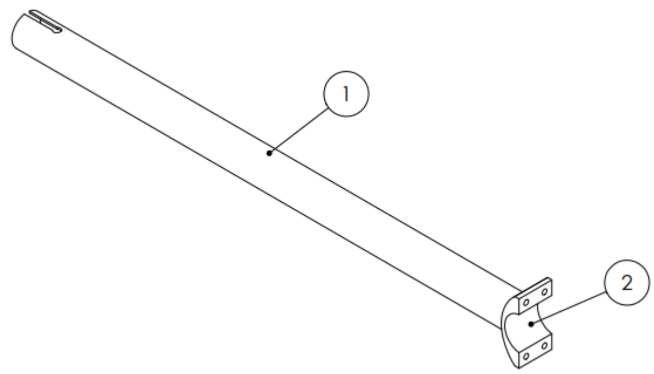
NAME
DATE
DRAWN
A. Nordell
2/12/23
CHECKED
APPR.
CONTACT EMAIL
nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
Stem Clamp Counterbore
SIZE
A
DWG. NO.
S3
REV
SCALE: 1.25:1
SHEET 1 OF 1

2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S1	Straight Boom	1
2	S2	Stem Clamp Tapped	1

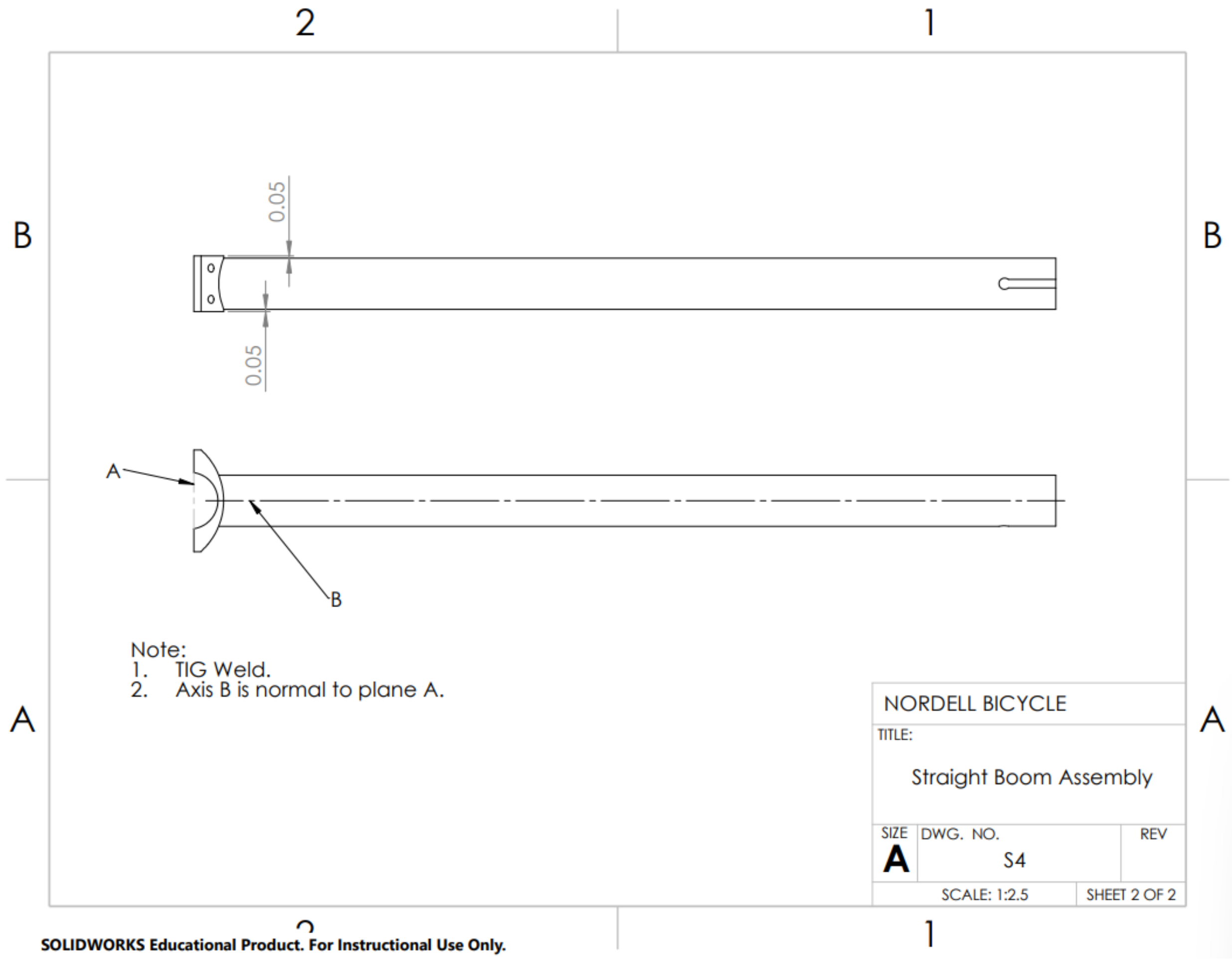
B B



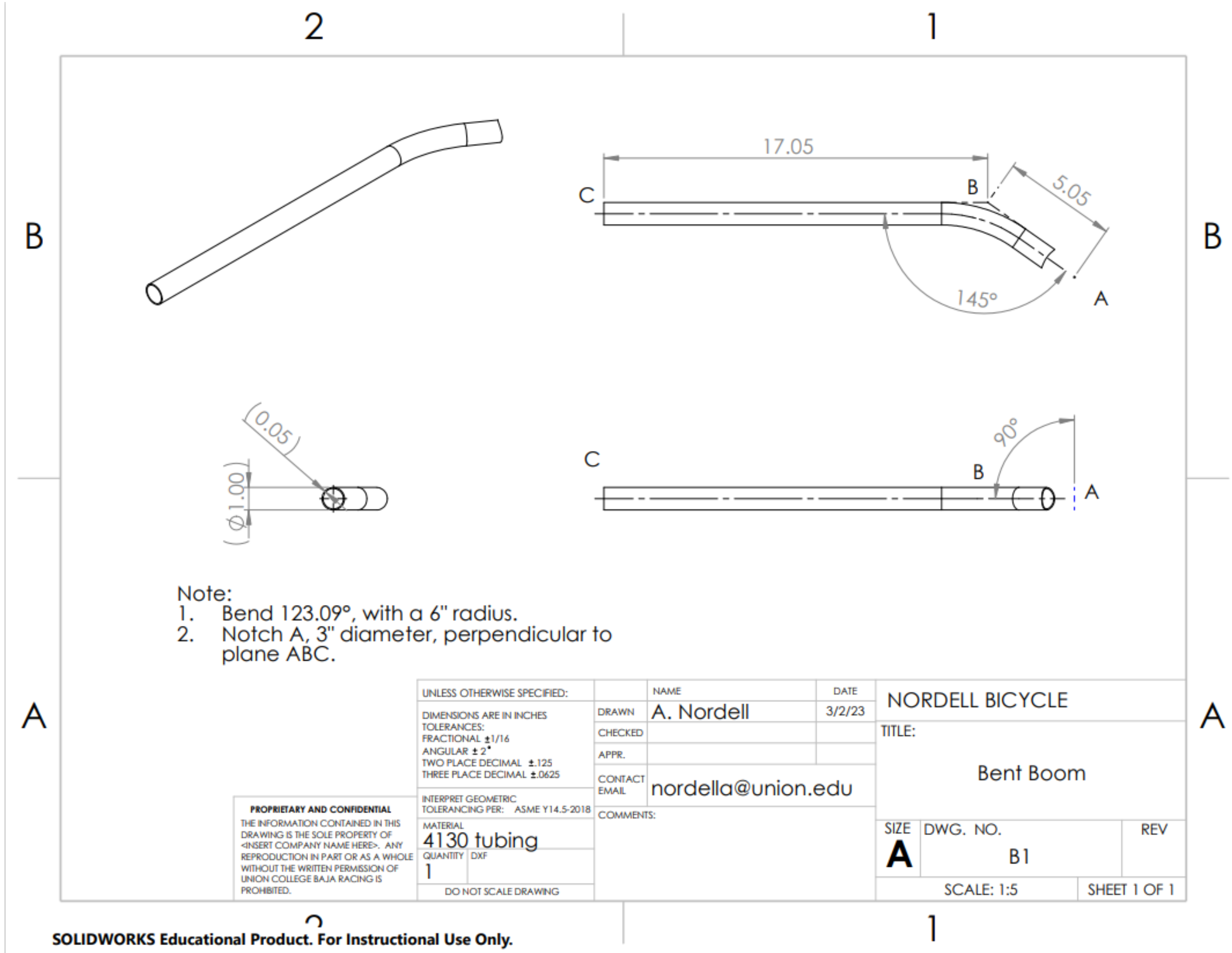
A A

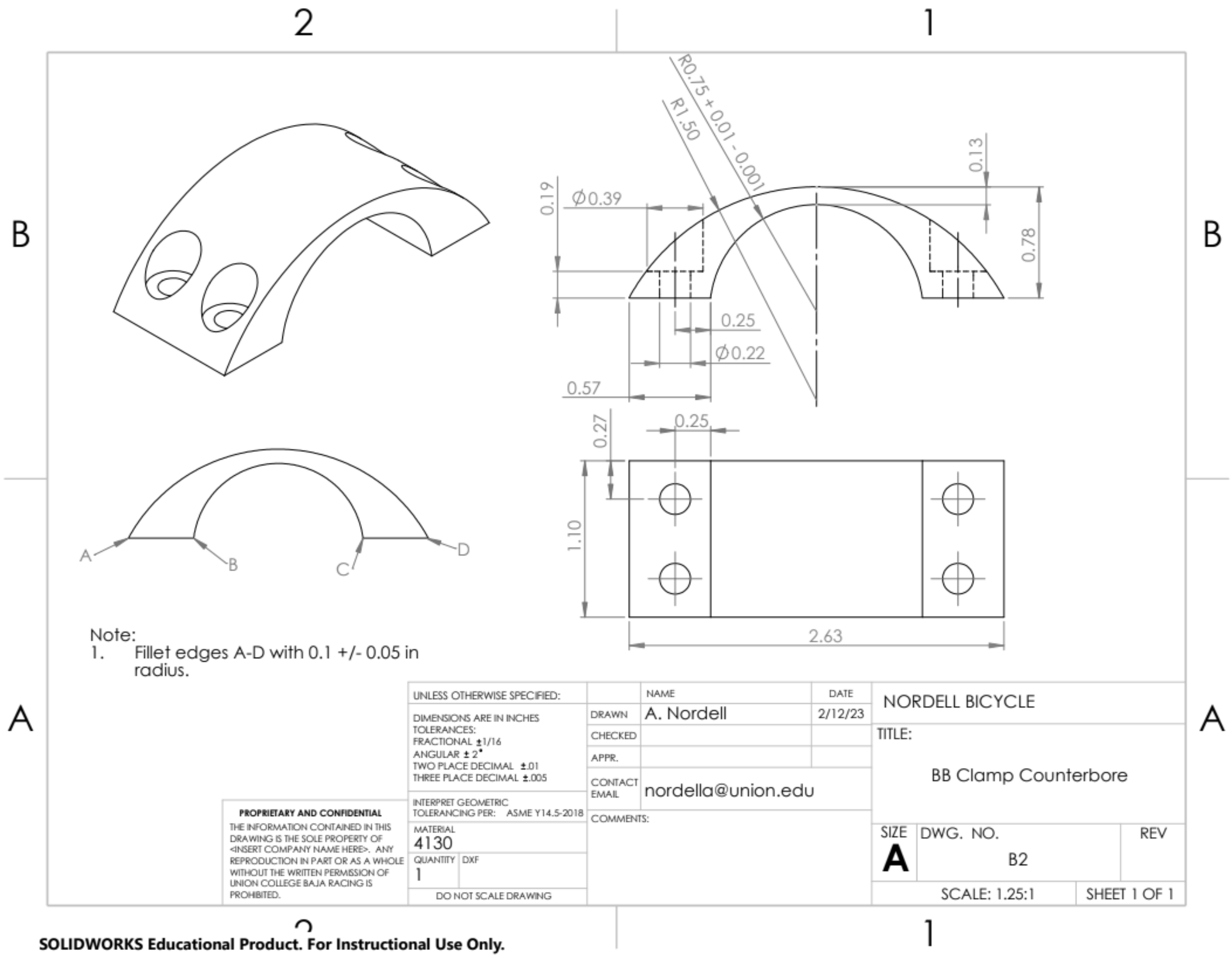
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/16 ANGULAR ± 2° TWO PLACE DECIMAL ±.125 THREE PLACE DECIMAL ±.0625	NAME: DRAWN A. Nordell, DATE 2/12/23; CHECKED; APPR.; CONTACT EMAIL nordella@union.edu	NORDELL BICYCLE
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018	COMMENTS:	TITLE: Straight Boom Assembly
MATERIAL 4130		SIZE A; DWG. NO. S4; REV
QUANTITY 1; DXF		SCALE: 1:3; SHEET 1 OF 2
DO NOT SCALE DRAWING		

2 1

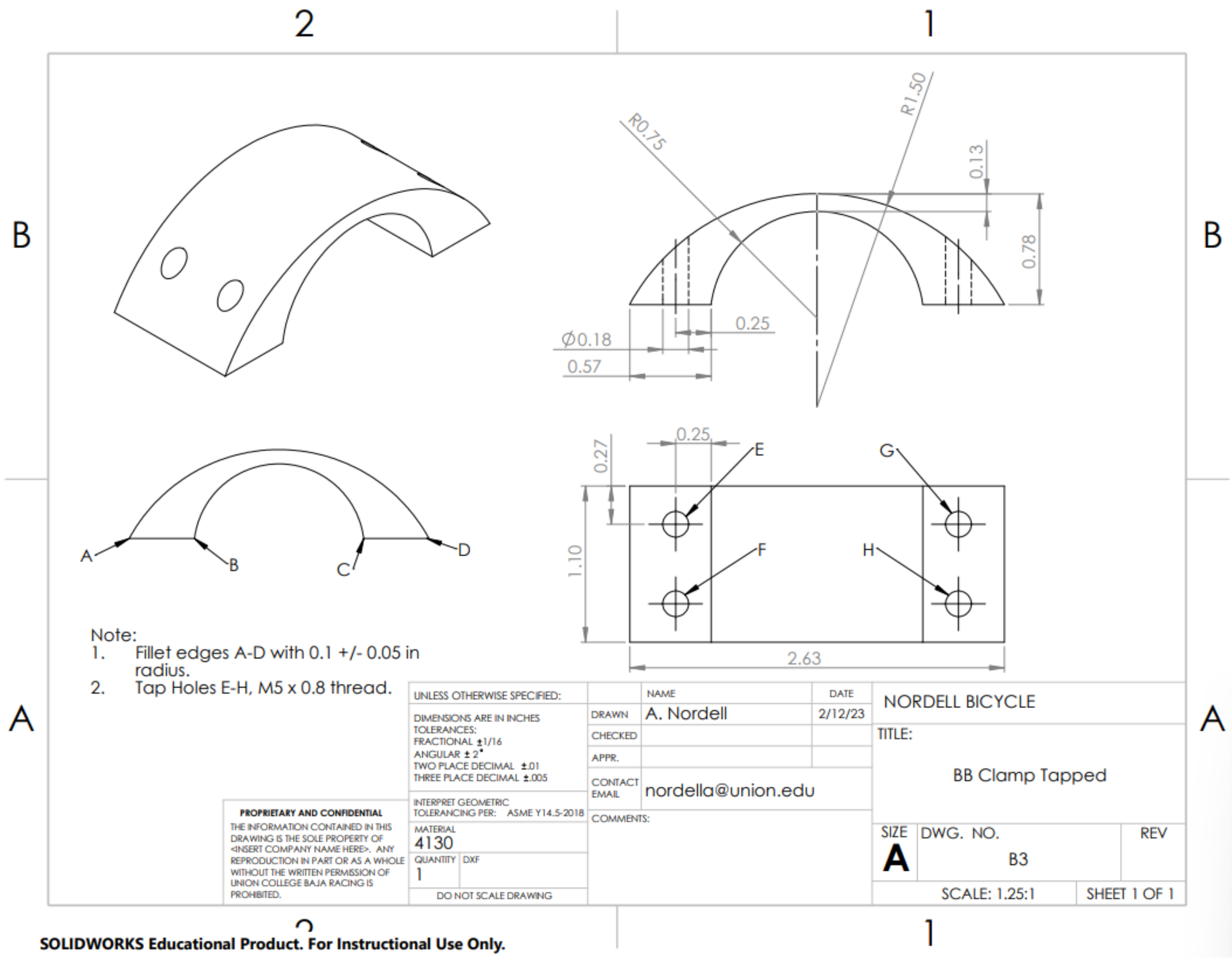

2
1
B
A
0.05
0.05
A
B
Note:
1. TIG Weld.
2. Axis B is normal to plane A.
NORDELL BICYCLE
TITLE:
Straight Boom Assembly
SIZE
A
DWG. NO.
S4
REV
SCALE: 1:2.5
SHEET 2 OF 2
SOLIDWORKS Educational Product. For Instructional Use Only.

Section 5. Bent Boom Assembly





SOLIDWORKS Educational Product. For Instructional Use Only.


R0.75
R1.50
0.13
0.78
0.25
Ø0.18
0.57
0.27
0.25
1.10
2.63
A
B
C
D
E
F
G
H
Note:
1. Fillet edges A-D with 0.1 +/- 0.05 in radius.
2. Tap Holes E-H, M5 x 0.8 thread.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130
QUANTITY 1
DXF
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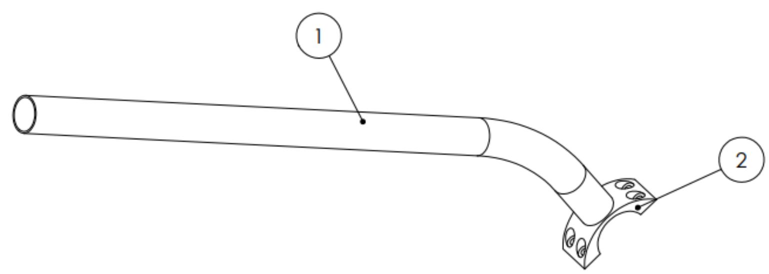
NAME
DATE
DRAWN A. Nordell 2/12/23
CHECKED
APPR.
CONTACT EMAIL nordella@union.edu
COMMENTS:
NORDELL BICYCLE
TITLE:
BB Clamp Tapped
SIZE A
DWG. NO. B3
REV
SCALE: 1.25:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	B1	Bent boom	1
2	B2	BB clamp Counterbore	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.125
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL: 4130 tubing
QUANTITY: 1
DXF
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. Nordell	1/24/23
CHECKED		
APPR.		
CONTACT EMAIL	nordella@union.edu	

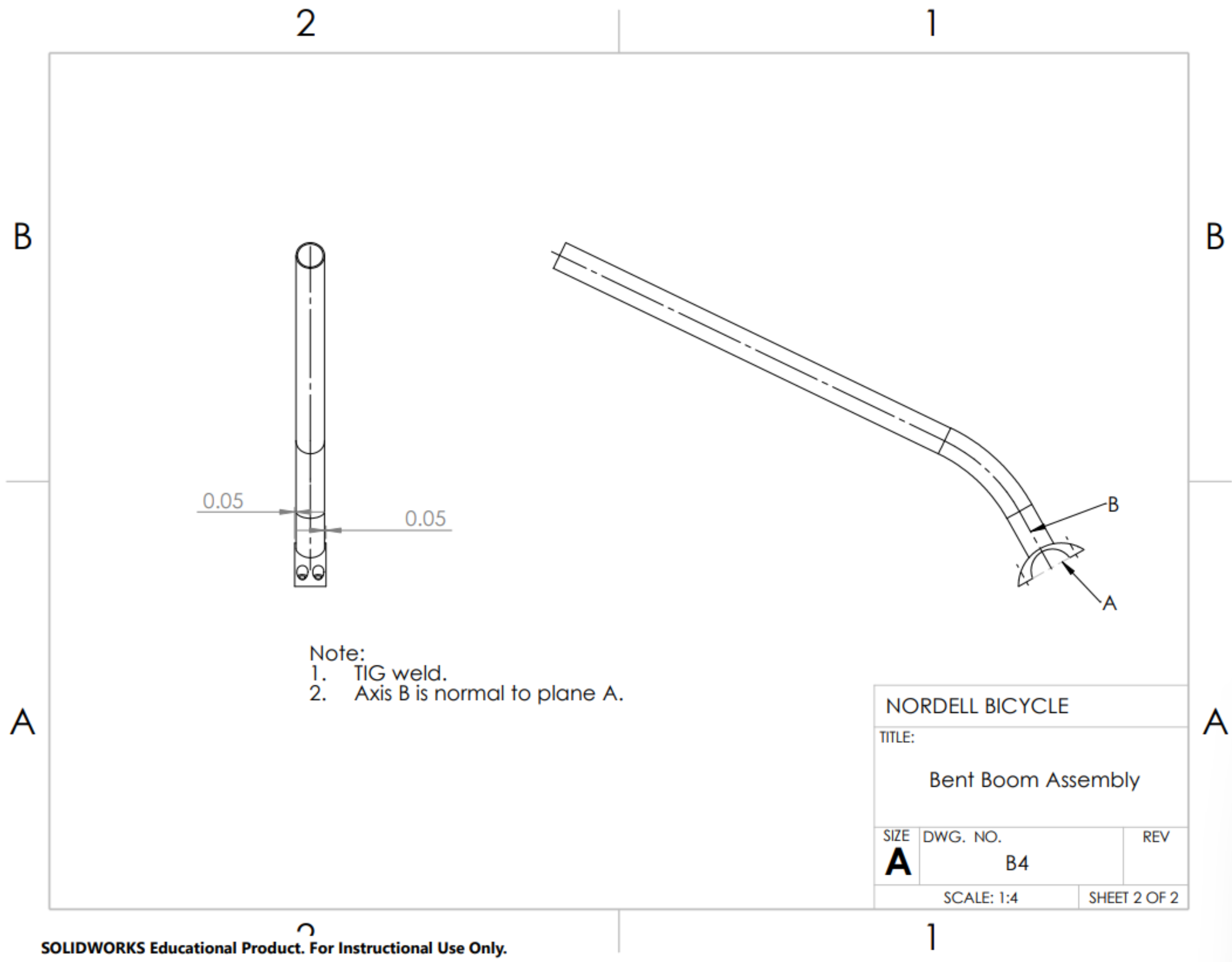
COMMENTS:

NORDELL BICYCLE

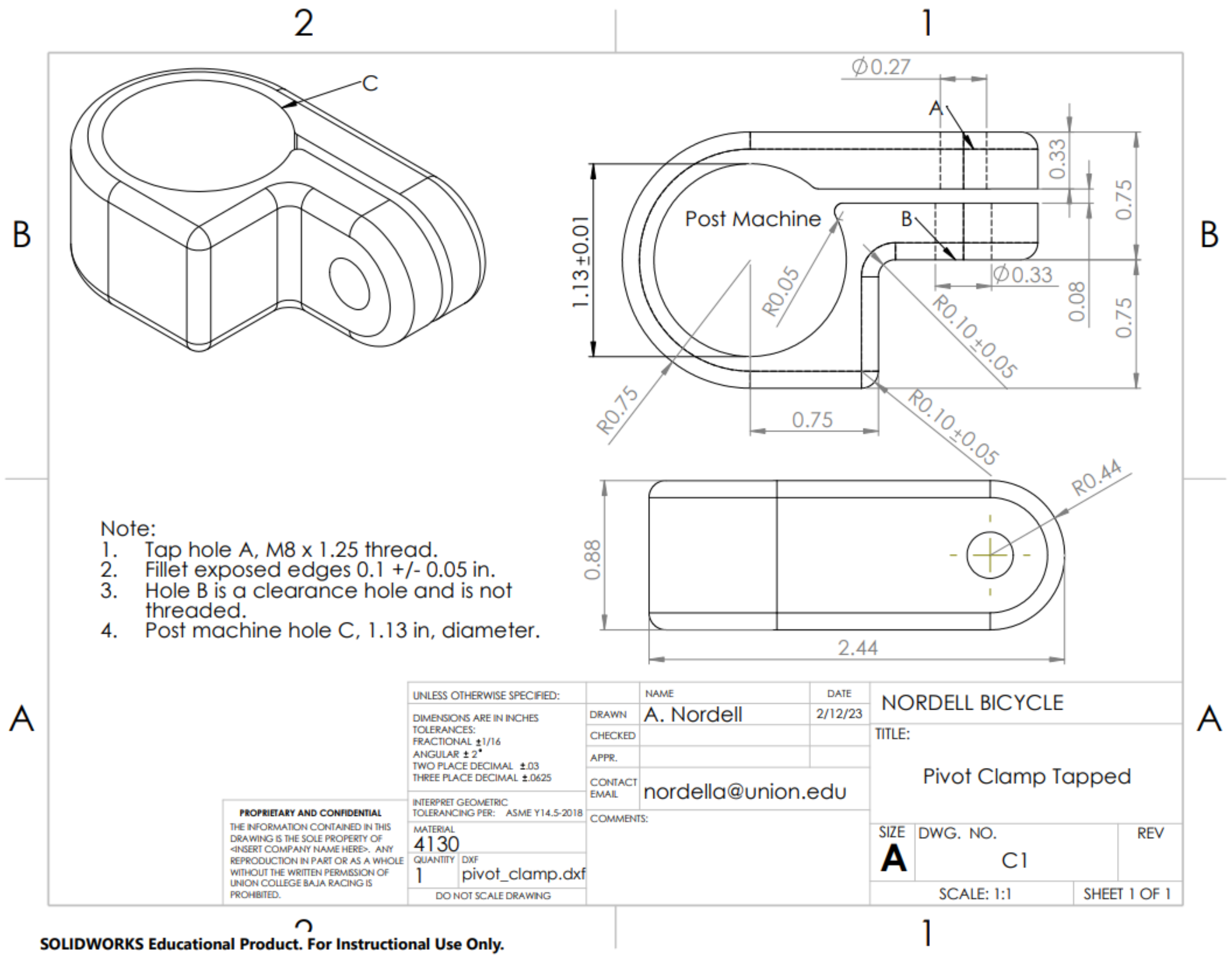
TITLE: Bent Boom Assembly

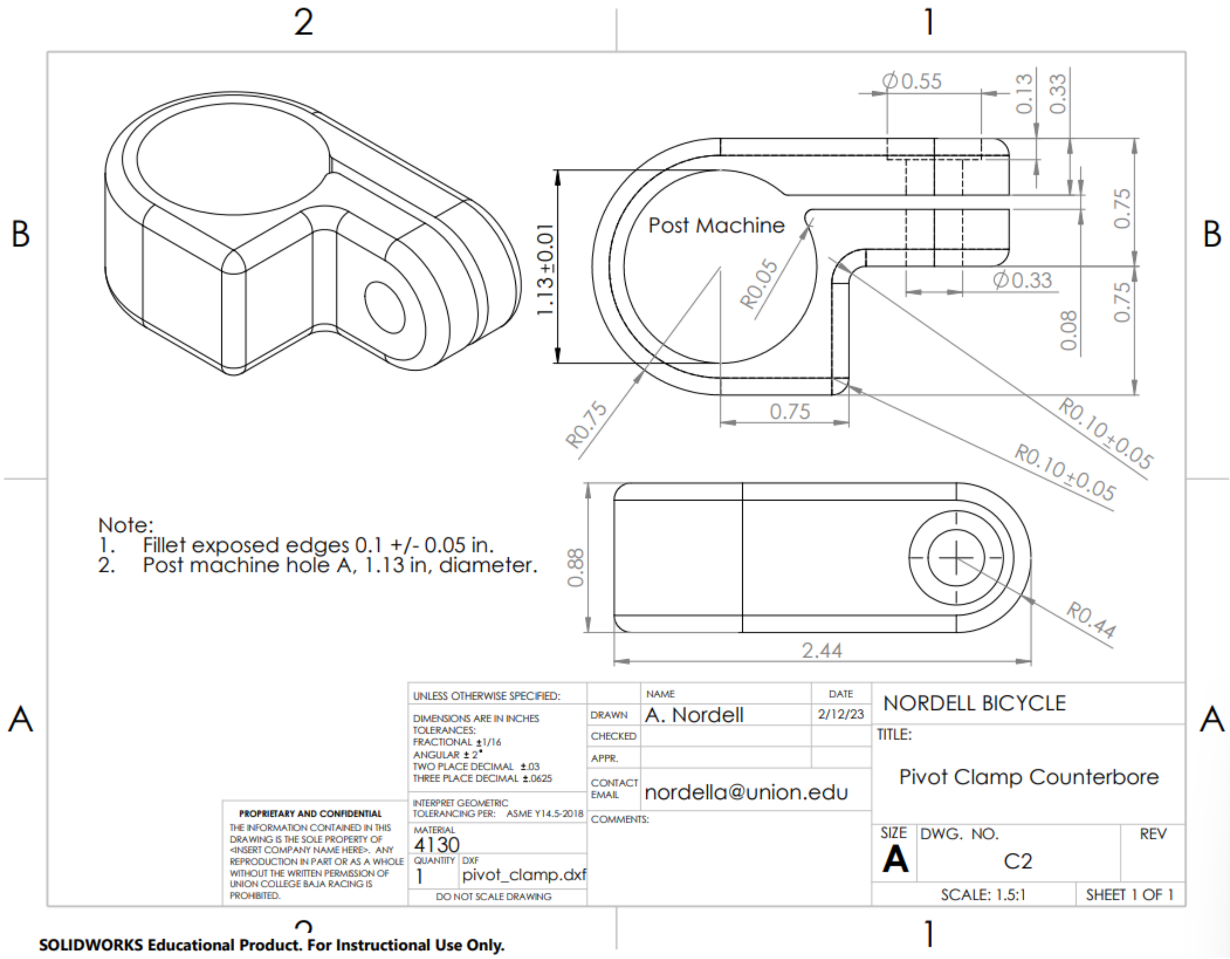
SIZE: A | DWG. NO.: B4 | REV

SCALE: 1:3 | SHEET 1 OF 2


2
1
B
B
0.05
0.05
B
A
A
A
Note:
1. TIG weld.
2. Axis B is normal to plane A.
NORDELL BICYCLE
TITLE:
Bent Boom Assembly
SIZE
A
DWG. NO.
B4
REV
SCALE: 1:4
SHEET 2 OF 2
2
1
SOLIDWORKS Educational Product. For Instructional Use Only.

Section 6. Pivot Clamp





Ø0.55
0.13
0.33
Post Machine
R0.05
1.13±0.01
Ø0.33
0.08
0.75
0.75
0.75
R0.75
R0.10±0.05
R0.10±0.05
0.88
R0.44
2.44
Note:
1. Fillet exposed edges 0.1 +/- 0.05 in.
2. Post machine hole A, 1.13 in, diameter.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR ± 2°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.0625
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2018
MATERIAL
4130
QUANTITY 1
DXF pivot_clamp.dxf
DO NOT SCALE DRAWING
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CONTACT EMAIL nordella@union.edu
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NORDELL BICYCLE
TITLE:
Pivot Clamp Counterbore
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SHEET 1 OF 1
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Appendix B - Alternative Concepts and Designs

Figure X. Previous detailed design from the end of the first term of the senior thesis.

Figure X shows a previous detailed design from the end of the Fall term. It features a similar structure and layout, however, some design changes were made to the fork, seat tube of the frame and clamps.

When first designing the fork, I did all of it by connecting two-dimensional sketches and using the sweep function in SOLIDWORKS. As mentioned in the report, when creating drawings for tubing, it is very convenient to use the weldments feature. Additionally, when the fork was first designed, I was unaware of how to use the SOLIDWORKS Sheet Metal feature, so I shied away from creating any bends in sheet metal pieces. The fork in Figure X shows this. I did not know how to make a bend in a part, so I designed the fork blades as parallel. Once I joined the Union College SAE Baja team, however, I designed the CVT cover and learned SOLIDWORKS Sheet metal. This experience changed the way I could approach designing the frame. The final fork differed as the blades were not parallel, but expanded to account for the

widening wheel from tire to hub, this gives the forks a more professional look, as well as slightly reducing the amount of material required. Figure X+1 shows the final detailed design.

Figure X+1. Final detailed design, notice the shorter seat tube, and slightly altered fork.

When first designing the frame, I used a rough guide to fit an average-height human. Initially, I included an extended and bent seat tube to add some spring to the support of the seat, however, when doing some physical testing by putting a 3-D model of a dummy in the SOLIDWORKS model, it was determined that for maximum adjustability of the seat angle, and that the seat that was selected incorporated it's own supports (see Figure X+1), it would be optimal to remove it, so the bend was removed and the member was so half an inch extended beyond its intersection with the top tube.

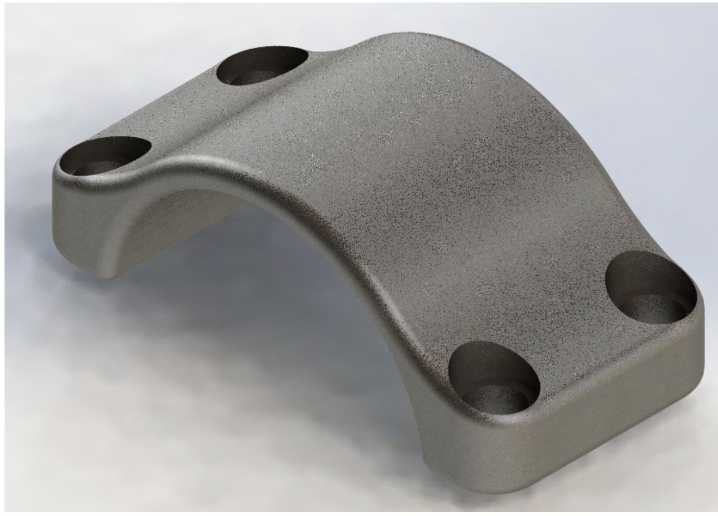

Figure X+2. The original design for the stem, boom interface, and BB clamps.

Figure X+2 shows the original design for all the clamps, with an exception for the pivot clamp of the bicycle. They were modeled after stem clamps from bicycles, are lightweight, and have the advantage of being strong where they need to be, and light where they don't. These were not made due to manufacturing constraints. The complex geometry, the inner bore, the three radii on the outside, and the fillets made this part more of a nightmare for manufacturing than I had intended. Due to this, the design chosen is shown in Figure X+3.

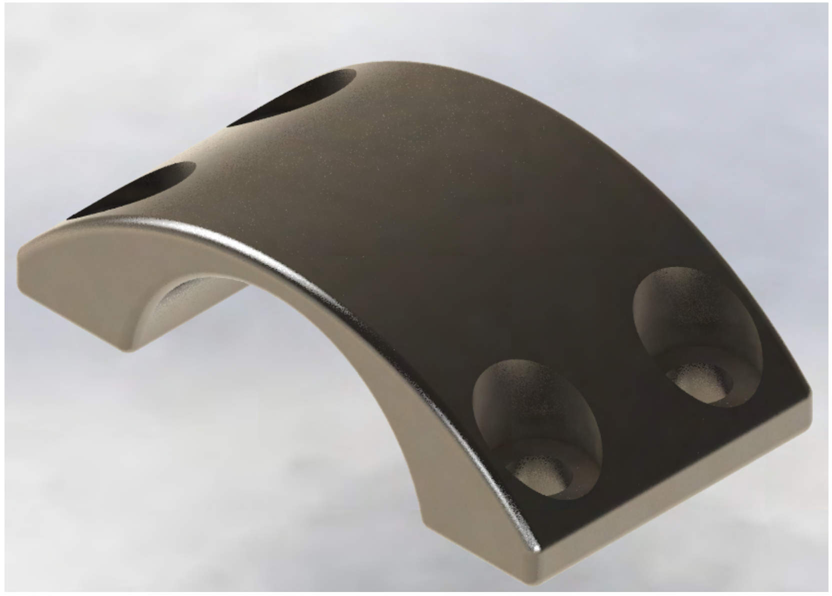

Figure X+3. Current design for the clamps.

As mentioned in the report, this design was much simpler than the other designs considered. It utilized the 3-in-diameter rod as the outer radius of the clamp. This reduced the number of machine processes that needed to be performed, as there were only about three major steps in getting the basic shape: cutting the height from the rod stock, the width, and the bore. Compared to the first iteration, it is clear why the chosen design was preferred.