APPLICATION OF GEARBOX DRIVETRAINS FOR COMMUTING BICYCLES

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By

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ABSTRACT

Application of Gearbox Drivetrains for Commuting Bicycles

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People all over the world are beginning to ride their bicycles more often to destinations which include work, school, and local markets. Most bicycles being used for these activities have an external drivetrain exposed to the elements of the road including water, mud, dirt, and debris. External drivetrains are very fragile and when damaged, pedaling efficiency is greatly reduced and the overall riding experience diminishes.

One solution to this issue is a gearbox specifically designed for a bicycle frame. A gearbox has several mechanical mechanisms operating inside a protective housing. Since the housing is fully sealed, outside elements are not able to contaminate the drivetrain system. A gearbox is also much more robust and requires less maintenance compared to a traditional external drivetrain.

This project documents the designing and prototyping of a gearbox drivetrain for a bicycle using the manufacturing facilities in the Gene Haas Advanced Manufacturing Lab at Cal Poly. Software was used to create models and toolpaths for machining all of the parts. Computer numeric controlled machines were used to manufacture and inspect all of the metal parts that would then be assembled into a functioning gearbox.

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1.0 Introduction

This project will start by describing the current problems with different drivetrain options for commuting bicycles, develop a new solution, and attempt to prove the solution's feasibility.

Today's modern bicycle commuter faces many issues while riding to work, school, or while running errands. One of these issues is the reliability of bicycle drivetrains. Traditional, cable actuated derailleurs, as seen in Figure 1, are exposed to the elements of city streets including dirt, dust, and water.

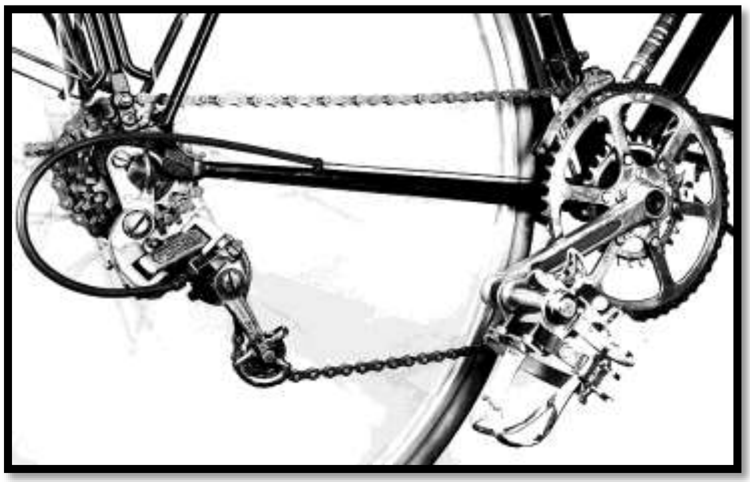

Figure 1 – Traditional Derailleur Based Drivetrain System

The derailleur's external positioning also serves to make it susceptible to damage from bicycle racks, accidents, or crashes. If not precisely tuned, derailleur systems can malfunction and result in inconvenience and can sometimes endanger the rider if the chain becomes jammed.

Another drivetrain option available to bicycle commuters is the internally geared hub. Internally geared hubs move some of the necessary components of a multi-speed drivetrain into the hub shell (Figure 2).

These hubs are readily available from several manufactures including Shimano, Sturmey-Archer, and Rolhoff. A design disadvantage is the shifting mechanisms for internally geared hubs are still mounted to the frame of the bicycle leaving them susceptible to damage or contamination.

Figure 2 – Cut-away View of an Internally Geared Hub

Single speed drivetrains are the simplest option available to cyclists. Instead of a range of gearing, one gear ratio is chosen. This option is the most robust design however it is not a realistic choice for the majority of bicycle commuters unless their commute happens to have minimal elevation variance. A variety of gears is needed on commuter bicycles as commuters commonly use their bicycles to carry heavy loads up to 40 pounds and face ascents and descents.

The final drivetrain solution currently available to bicycle commuters is the internal gearbox available from Pinion in Figure 3 below. Pinion's gearbox is of the highest quality but has drawbacks for a bicycle commuter such as price and frame selection. The gearbox is by far the most expensive option currently available on the market and requires a special frame for use.

Figure 3 – Pinion Gearbox

Current commuter bicycle drivetrains available are not adequate for a care free ride. The options available are unreliable, expensive, unsafe, or unrealistic.

In order to solve this problem, the following steps will be taken.

- Perform background research to fully understand operation of available drivetrain options
- Quantify variables of each drivetrain option including efficiency, price, weight, and reliability
- Design first prototype of solution using a combination of additive manufacturing processes machined parts, and purchased parts
- Manufacture first prototype and evaluate design for production
- Implement design onto a bicycle
- Perform economic analysis on manufacturing process

Finding a solution to the drivetrain issues of commuting orientated bicycles will require a careful, experimental approach. Background research presented in the Literature Review will ensure that all options are understood and will then be analyzed against each other. Knowledge learned will then be applied to the first prototype design. The prototype will employ machined metal parts and select sourced parts from outside vendors. When completed, the first prototype will be tested and evaluated. A bicycle frame will be made for implementing the prototype. A final economic analysis will be completed on the manufacturing process to determine the feasibility of producing a commuter bicycle drivetrain solution in small quantities.

2.0 Literature Review

Bicycles are becoming an increasingly popular option for commuting in urban areas across America. Local, State, and Federal governments have been increasingly investing in bicycle facilities including parking racks and bicycle lanes. As bicycle infrastructure grows, more bicycles will be on the road [1] and a solution to drivetrain issues must be implemented. In order to fully understand the components that make up a traditional commuting bicycle drivetrain, a breakdown of the components is provided below in Table 1 and Figure 4 below.

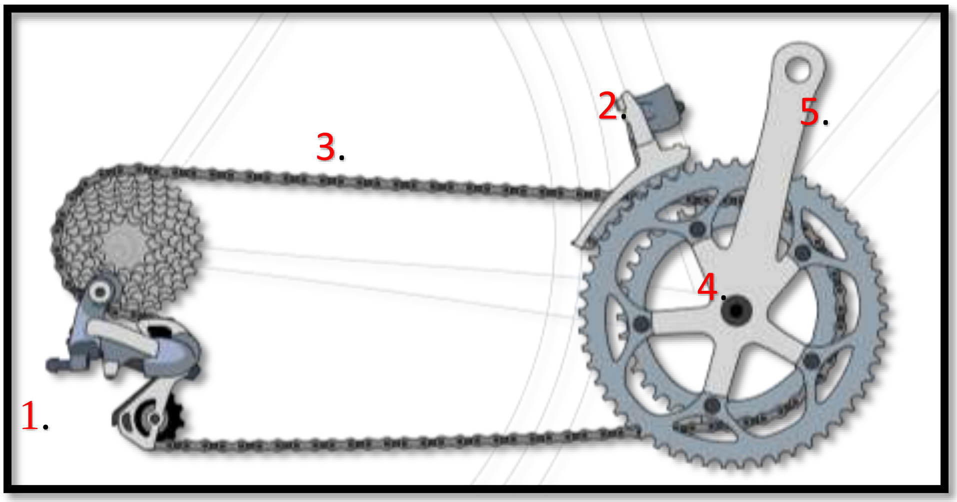

Figure 4 - Diagram of Traditional Derailleur Based Drivetrain System

1. Rear Derailleur	Changes position of chain on rear gear cluster
2. Front Derailleur	Changes position of chain on front gear cluster
3. Chain	Transfers rider power to rear wheel
4. Bottom Bracket	Houses bearings for crankset axle
5. Crankset	Allows rider to transmit power

Table 1 – Major Components of a Bicycle Drivetrain

The derailleur system was developed throughout Europe in the 1800's before the modern safety bicycle was even invented. At the 1869 Velocipede show in Paris, ancestors of bicycles were displayed with variable gear systems. [2] Several versions of derailleurs appeared in France and Britain in 1895 but widespread acceptance was not achieved until racers began using the devices on their bicycles in the 1920's. [2] Derailleur technology improved as racers demanded more from their equipment. Companies like Campagnolo produced derailleurs for different user groups and indexed shifting was brought to the masses by Shimano. Since its inception, the derailleur drivetrain system has been by far the most common drivetrain found on bicycles of all uses.

Although the derailleur has essentially run a monopoly on the bicycle drivetrain industry since the 1920's, there have been competitors throughout history. Internal geared hubs, such as the one patented by Shimano in 1964 (Figure 5), have had sporadic use since their invention. The hub which is powered by a typical roller chain houses a planetary gear set which allows the rider to change the gear ratio with a handlebar mounted gear selector. [3] Geared hubs use planetary gears (Figure 6) which allow the input and output of the gearing to share a common axis. Planetary gears are rugged because three gears spread the load over the ring gear. [4]

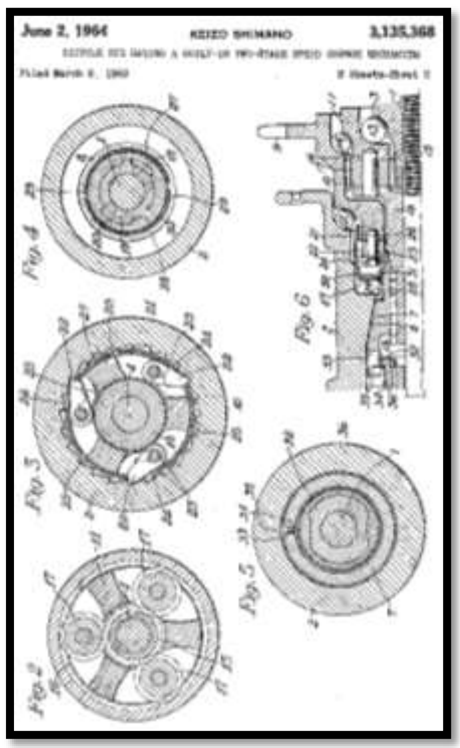

Figure 5 – Shimano Internal Hub Patent

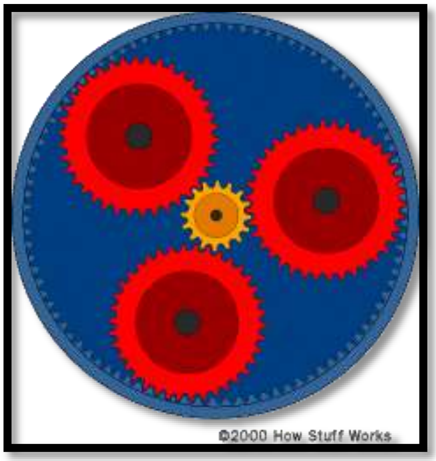

Figure 6 – Basic Schematic of Planetary Gear

In figure 6, the yellow gear is called the sun gear, the red gears are the planet gears, and the blue gear is a ring gear. By locking the rotation of different components, planetary gears can provide different gear ratios. Other than bicycles, planetary gears are also used in automatic car transmissions and small electric devices.

Gearboxes first emerged on bicycles in 1934, when the manufacturing company, Alder, produced a bicycle equipped with a gearbox as seen in Figure 7. Alder's gearbox suffered a large weight penalty and because of manufacturing limitations of the age, it was not reliable. [5]

Figure 7 – 1934 Alder Gearbox

The recent emergence of downhill mountain bike racing led to the re-evaluation of gearbox drivetrain use for bicycles. Downhill mountain biking is an extreme sport where bicycle technology is pushed to the limit at high speeds upwards of 40 miles per hour. Race teams were breaking derailleurs constantly and several manufacturers were put up to the test to design bicycles with a new gearbox design. Early designs simply employed modified internal gear hubs into custom housings built into the bottom bracket area of the frame. As time went on, several companies including Honda, GT, and Brodie designed unique gearboxes that did not rely on internal gear hubs. Gearbox drivetrains have been mostly abandoned by the downhill racing teams in modern times.

Pinion, a German company, is one of the only producers of consumer available gearboxes. Pinon released its first fully sealed gearbox in 2012. The P 1.18 model features 18 different gear ratios created by a spur gear with 2 different transmission structures connected in parallel (Figure 8). This particular model offers a 636% overall ratio and has a planned maintenance interval of 6,200 miles. By 2014, Pinion had sold over 1,000 of its gearboxes. [6] Pinion manufactures the gear box which is used by different frame designers who adhere to the G-CON mounting standard.

Figure 8 – Cut-away View of Pinion Gearbox

G-boxx is an organization that created the G-CON mounting system "To allow for all bicycle manufactures to build and design bicycles based around the bicycle gearbox, without actually having to invent the bicycle gearbox technology itself." [7] The G-CON mounting system has been widely accepted by the majority of companies who offer gearbox equipped frames.

Although bicycle commuters may face some rough environments on the road, most commutes do not face nearly the same amount of potential risk that downhill mountain bike racers face (Figure 9). The Pinion gearbox is designed for the ultimate extreme of the entire cycling genre.

Figure 9 – Typical Terrain Faced by Advanced Downhill Mountain Bike Racers

Bicycle commuting is becoming more popular and has grown across the United States by 62% from 2000 to 2013. The United States has seen a 105% increase in bike usage in bicycle friendly cities and even a 31% increase in non-bicycle friendly cities. [8] The most recent Census shows that the average bicycle commute is 19.3 minutes. [9] Assuming a typical commuter is riding at an average speed of 10 miles per hour, the average cycling commuter rides approximately 6.5 miles per day or about 1,500 miles per year on their commuting bicycle. Many commuters are also riding their bicycles to save money and often ride older or repurposed bicycles. Knowing these key facts points to the conclusion a successful gearbox design for commuter bicycles must be relatively inexpensive compared to current market options and must be able to withstand moderate usage in varying environments.

Several factors should be evaluated when comparing the drivetrain solutions discussed above. In Table 2 below, several criteria were compared and will be explained in depth.

Brand	Model	Type	Weight (g)	# of Gears	Overall Ratio (%)	Price ($)
Pinion	1.9CR	Gearbox	2200	9	364	~2000 + frame
Shimano	Alfine	Hub	1665	11	409	300
Shimao	Nexus	Hub	945	3	158	88
Sram	i-Motion	Hub	1210	3	186	112
Rolhoff	Speedhub 500	Hub	1700	14	526	1,400
Sturmey-Archer	RX-RF5	Hub	1950	5	243	98
Sturmey-Archer	S2	Hub	920	2	138	91

Table 2 – Common Bicycle Drivetrain Options

Weight is measured in grams and applies to the actual unit and does not include shifters, cables, cranksets, or housing. The only notable exception is Sram's i-Motion hub which has a combined weight of 1210 grams when matched with the included shifter. Number of gears is the total number of selectable gears in each unit. Overall gear ratio is the percentage differnence between the largest and smallest gear ratio available. Finally, price is the cost of the the unit and in most cases, necessary components such as shifters.

To put some of the information found in Table 2 into perspective, one of Shimano's mid tiered drivetrain options, the Deore group, weighs 1116 grams for front and rear derailleurs, shifters, and a 10 speed cassette. [10] The traditional Deore option has 30 avaialable gears although many are overlapped because of the 3x10 gearing system which uses three chain rings and a 10 speed geared rear cassette. The overall ratio of the group is 404 percent. Customers expect to pay 150 dollars for the four components mentioned above. On the other hand, arguably the best internally geared hub manufactured by Rolhoff costs 1,400 dollars and has a 526 percent range.

In order to design a solution to the problem, several drivetrain types were compared to determine the direction of the project's design. The four options available are the traditional derailleur, an internally geared hub, a gearbox, or a single speed drivetrain. A concept decision matrix was created to compare the different drivetrains found below in Table 3.

		Derailleur		Single Speed		Internal Gear Hub		Internal Gearbox	
Criteria	Criteria Factor	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Durability	5	2	10	4	20	4	15	5	25
Weight	3	2	6	3	9	2	6	1	3
Efficiency	3	3	9	3	9	2	6	2	6
Price	4	3	12	4	16	3	12	2	8
Service	3	2	6	3	9	3	9	3	9
			43		63		48		51

Table 3 – Drivetrain Concept Decision Matrix

The durability rating is a measure of the system's resistance to malfunction when the unit is subjected to dust, water, and unexpected impacts. Weight measures both the overall mass of the system as well as how effectively it is distributed on the bicycle. Efficiency is the measure of how much power provided by the rider actually gets transmitted to the rear wheel. A single speed chain is the most efficient option and efficiency can be measured at over 95%. [11] Friction from meshing of the gears found in internal gear hubs and gearboxes decrease efficiency. Price includes the total cost needed to set up a functioning bicycle with the drivetrain system. Finally, service is how often the system needs to be adjusted to maintain proper shifting performance. The overall highest scoring drivetrain was the single speed transmission. Although brilliantly simple, a single speed drivetrain is not suitable for many commuters because of the need to climb up steep inclines. The internal gearbox scored second highest and after much consideration, was chosen as the drivetrain system type for the project.

There are several different ways that gearboxes can be configured. As mentioned, Pinion brand gearboxes employ two shafts, planetary gears, involute gears, and helical gears. An involute gear is a gear with tooth profiles derived from the curve traced by a point on a straight line which rolls without slipping on the circle. [12] (Figure 10) Involute gears can still mesh together with some degree of shaft misalignment and are relative easy to manufacture but can be load and cause vibration.

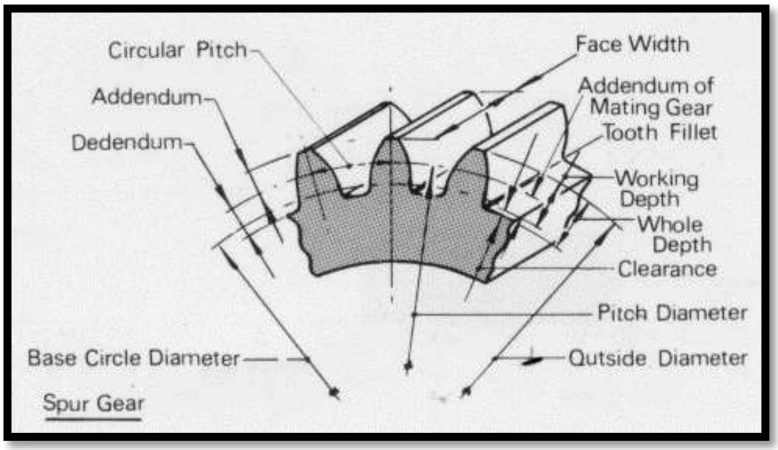

Figure 10 – Features of an Involute Gear

Helical gears on the other hand are smoother and quieter to operate due to the way their teeth interact (Figure 11). Manufacturing helical gears is much more difficult than straight spur and pinion gears and consequently more expensive. [13] Because the rotational speeds seen by a bicycle gear box are relatively low, vibration due to involute gear mesh will be minimal. Involute spur and pinion gears were chosen for this project because they are less expensive and can be manufactured with the equipment available in the Gene Haas Advanced Manufacturing Lab at Cal Poly.

Figure 11 - Helical Gear

3.0 Design

This section provides an overview of the customer requirements, design creation, and a design summary. Full annotated drawings of all the components of the gearbox can be found in the Appendix.

3.1 Customer Requirements

In order to solve the drivetrain problem faced by most commuting bicycles a good design is needed that fulfills the requirements and needs of potential customers. For the first prototype, the customer is assumed to be the author of this report. Below is a list of the customer requirements.

1. Must be fully sealed from outside elements
2. Weldable steel must be used for the housing material
3. Must weigh less than 8 pounds
4. Must contain 2 unique gear ratios
5. The output cog must have a 52mm chain line
6. The outer width of the housing should be approximately 100mm wide
7. Needs to be serviceable

3.1.1

The gearbox must be fully sealed because outside elements such as water, dirt, and dust will negatively affect the performance of the drivetrain. A full seal will also keep all lubricants and greases used inside the gearbox from leaking out. If the internals of the gearbox are kept lubricated and free from debris, the efficiency of the gears can be maximized. Since steel involute gears have a maximum efficiency of about 97% when in an oil bath [mitCalc] and there will be more of them in mesh than a standard roller chain drivetrain, contamination must be minimized. For example, a series of three gears with individual efficiencies of 97% will actually have a combined efficiency of 91.2%.

Equation

Combined efficiency = .97 * .97 * .97 = .912 = 91.2%

A standard roller chain combination in contrast has an approximate efficiency of 97-98% if cleanly lubricated. Many chains are not properly lubricated so there is an expected drop in efficiency. In order for involute spur and pinion gears to have comparable efficiency values to roller chains, they must be kept clean and oiled.

3.1.2

A weldable steel must be used for the housing material because the prototype gearbox will be welded directly to a modified chromoly steel bicycle frame. The Tungsten Inert Gas (TIG) welding technique will be used to install the housing to the frame for testing.

3.1.3

Most modern bicycles used for commuting weigh approximately 40 pounds if outfitted with racks and bags. The main design goal of the prototype gearbox is not weight minimization. However, if the prototype is too heavy, it will negatively affect the handling of the bicycle and testers will not be as interested in trying out the design. A value of 8 pounds is assigned as maximum prototype weight to encourage an efficient design. Future designs will need to reduce weight in order to be competitive with gearboxes from companies such as Pinion that offer a 6 speed drivetrain weighing in at 3.97 pounds. [pinion]

3.1.4

The prototype gearbox design must have 2 usable gear ratios. Originally the initial plans were brainstormed with 3 gear ratios. It was decided that due to the timeline of the project, a simpler design with 2 gear ratios would increase the chances of finishing the project in time for testing.

3.1.5

The output cog of the gearbox must have a 52mm chain line. Chain line is defined as the distance from the center line of the bicycle to the centerline of the active chain ring on a bicycle. (Figure 12) Industry standard for single speed mountain bikes include a 52mm chain line when using a 135mm rear axle spacing. When using a gear box, the output chain or belt is routed directly to the rear hub, just as a single speed bike would do. A 52mm chain line will ensure that an off the shelf rear wheel can be used with the prototype gear box. Keeping the chain line parallel with the center line of the bicycle is important to reduce friction, which causes loss in efficiency, and to reduce noise.

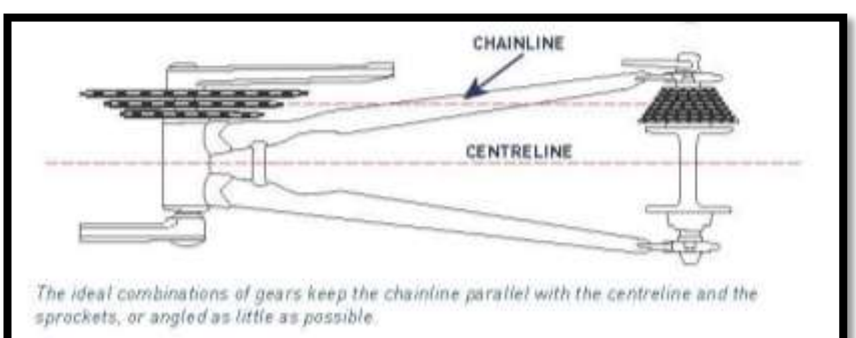

Figure 12 – Chain Line Illustration

3.1.6

The gearbox housing width must be approximately 100mm wide. The width of the gearbox has some correlation to the positioning of the pedals in relation to the centerline of the bicycle. In order to position the pedals in a position that promotes proper bio mechanics, 100mm width was chosen. Typical bicycles have a bottom bracket width of 68mm to 73mm plus the width of the externally housed bottom bracket bearings.

3.1.7

Finally, the gearbox must be fully serviceable so that it can be cleaned, disassembled for inspection, and modified if needed. This requirement is important because throughout testing the internals of the prototype need to be examined to track wear and sealing properties of the design.

3.2 Design Creation

As explained in the Literature Review above, several companies are currently designing, manufacturing, and marketing gearbox drivetrains for bicycles. Designing a gearbox from the ground up requires advanced calculations, experienced engineers, and precise understanding of manufacturing methods. This section is meant to guide readers through the design process used to arrive at the prototype gearbox.

Knowing that the design required 2 gear ratios, the first step was to figure out these ratios. The customer currently rides a single speed mountain bike as a commuter bicycle with a gear ratio of 1.89 using a 34 tooth chain ring and an 18 tooth cog. This ratio is slightly low for riding on the street. Maximum speed gained by pedaling on mild and steep descents tops out at about 25mph. Ideally with a higher gear ratio, higher speeds could be reached to keep pace with bicycle traffic. The first gear ratio for the gear box needs to be close to 1.89 so that steep hills can still be climbed while the second gear ratio needs to be higher than 1.89 so that a higher maximum speed can be achieved.

Since the bicycle that will use the prototype gearbox has a different wheel size than the current bicycle, simply comparing gear ratios will not suffice. The theory of Gain Ratio [Sheldon] allows gearing comparison between bicycles with different size wheels, gears, and crank arm lengths. Below is the calculation to determine the Gain Ratio of the current bicycle.

Radius Ratio * front(teeth) / rear(teeth) = Gain Ratio

1.886 * (34/18) = 3.562

(Radius ratio is defined as wheel radius divided by crank arm length)

Solving for Gain Ratio provided information to properly design the gear ratios for the gear box. The Radius Ratio for the prototype frame is 1.954. Dividing the Gain Ratio of the current bicycle by 1.954 yields 1.823. From here it was important to begin considering the gears available from current industrial suppliers to avoid the need for custom manufactured gears, ultimately lowering the manufacturing costs. The following gear box layout was chosen and is shown below in Figure 13. The layout gives a climbing gear ratio of 2.0 and a climbing gain ratio of 3.908. The higher speed gear ratio is 3.125 with a gain ratio of 6.106. This layout only uses 4 different gears minimizing the number of SKU's.

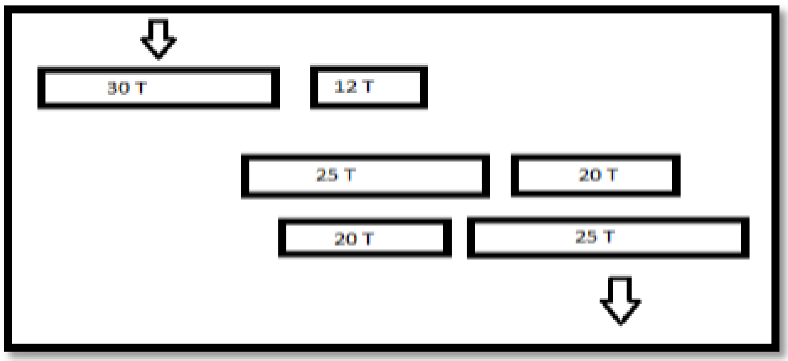

Figure 13 – Gear Layout

Once the tooth counts of all the gears were chosen the pitch needed to be decided. This phase of the design process utilized the Effigear gearbox as a bench mark. Pictured below in Figure 14 the Effigear gearbox utilizes a series of involute gears of varying sizes. Utilizing a pitch value of 10 for all of the gears allows the prototype gearbox to have similar dimensions to the Effigear gearbox which has been successfully tested on a wide variety of bicycles.

Figure 14 – Effigear Gearbox

While the gear design was being laid out, the shaft layout was simultaneously being designed and engineered. The input shaft, powered by the attached crank arms, would have a precision turned 30mm diameter in order to utilize the current industry standard. Modern bicycles utilize a 30mm 7005 aluminum crankset shaft that turns in 6806 sealed cartridge bearings. The output shaft would also be 30mm diameter 7005 aluminum in order to utilize the same bearings, retaining rings, and raw material. Examining other bicycle gear boxes and some motorcycle gear boxes led to the conclusion that a three shaft design would allow for the simplest shifting mechanism, eliminating the need for planetary gears like those used in the Pinion gear box.

Once a three shaft, two gear ratio design was chosen, focus shifted to designing the shifting mechanism. The shifting mechanism needed to be able to switch back and forth between gear ratios with the use of a standard bicycle shifter. Modern shifters have an indexing function allowing riders to press the upshift or down shift button making the chain shift precisely to the next cog. The issue with indexing is that restraining the movement of the shift cable to the set indexed amounts would severely constrain the shifting mechanism's design solution. Instead a friction shifter was selected as the shifting mechanism. A friction shifter pulls the shifter cable and relies on friction to hold it in place. As the shifter is released, a spring in the derailleur forces the chain to down shift.

Two gearbox shifting design options were considered. The first was a dog tooth design which utilizes a ring located concentrically with the mid shaft between both the 25 tooth and 20 tooth gears. (Figure 15) This ring has a series of slots on both faces that similarly shaped teeth that are machined onto the inward faces of the two gears. As the rider shifts up and down, the ring slides back and forth on the mid shaft engaging either the 25 tooth or 20 tooth gear.

Figure 15 – Dogtooth Shifting Design Concept

The second shifting design concept was a pawl-engagement mechanism. A shifting bulb would house spring loaded balls that would engage on hardened steel pawls. These pawls when engaged would catch on small teeth cut into the inner diameter of the 20 tooth and 25 tooth gear, locking them to the mid shaft.

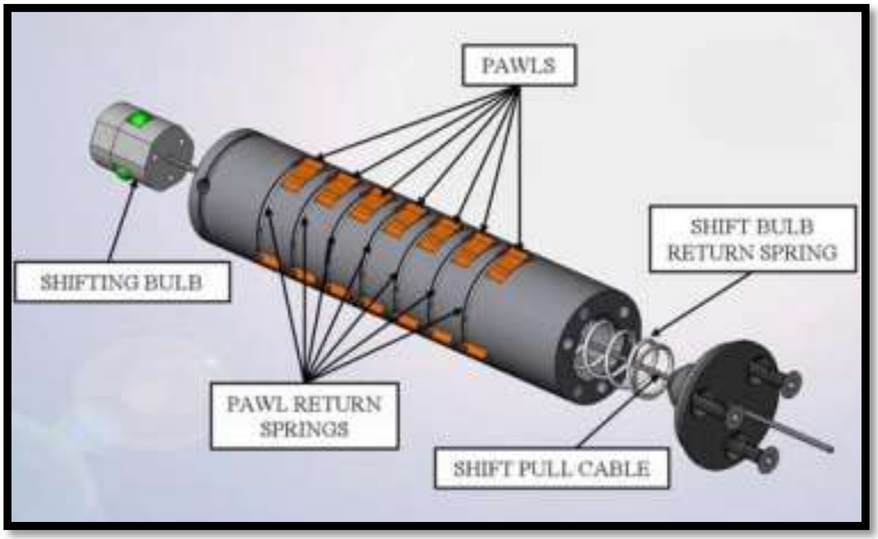

Figure 16 – Pawl Shifting Design Concept

Both of these shifting mechanism designs were feasible so a decision matrix was created to compare the options. The first design criteria was weight, since one of the customer requirements was a total gearbox weight under 8 pounds. The second design criteria, and the most important, was manufacturability. In order to keep prototype gearbox costs down, it was desired that all parts could be manufactured using the Gene Haas Advanced Manufacturing Lab at Cal Poly. Finally, the third design criteria was complexity. The design needed to be easy to assemble and minimize components. The shifting mechanism decision matrix can be found below in Table 4.

		Dogtooth		Pawl	
Criteria	Criteria Factor	Rating	Score	Rating	Score
Weight	3	2	6	3	9
Manufacturability	5	4	20	2	10
Complexity	3	3	9	2	6
			35		**25**

Table 4 - Shifter Decision Matrix

Based on the shifter design matrix the dogtooth design was chosen as the better option for the commuter bicycle gearbox design. The dogtooth design ranked heavier, however it is much simpler and easier to manufacture with the equipment and facilities available at Cal Poly. After discussing dogtooth mechanisms with the project technical advisor, the following design was generated using SolidWorks. (Figure 17)

Figure 17 – Exploded Mid Shaft Assembly Schematic

The dogtooth gear is keyed to the mid shaft to prevent rotation. Socket head cap screws thread into a shifting bulb which is free to slide in the bore inside of the mid shaft. A small bearing pressed into the shifting bulb prevents the shift cable from twisting as the mid shaft spins. The spring used is a 22.0 lbs./in rated steel spring chosen to closely mimic a spring from a traditional external derailleur. It is held in place with an internal retaining ring and pushes the dogtooth gear against the smaller 20 tooth gear. Using the shifter, the cable compresses the spring, disengages from the 20 tooth gear, then engages the 25 tooth gear. While riding, a brief pause in pedaling will allow this shifting action to happen smoothly with minimal gear meshing issues.

After the three shafts were designed, the gear housing was designed. The design criteria was to minimize the overall size of the gearbox while still providing adequate room for the gear profiles and all three shafts. 1018 low carbon steel was chosen for the housing material because it can be welded to the 4130 steel frame that was obtained for the prototype. At approximately 75mm wide, the housing closely resembles a traditional 73mm bottom bracket shell found on many bicycles. For simplicity it was decided that grease would be used to lubricate the internals of the gearbox so an O-ring groove was not designed into the housing for sealing oil between the housing covers and housing. This decision also allowed the walls of the housing to be thinner ultimately, reducing weight. Eight M6 low profile socket head cap screws per side fasten the housing covers onto the housing. Figure 18 below shows the SolidWorks model of the gearbox housing design.

Figure 18 – Housing Model

The gearbox housing covers are constructed out of 6061-T6 aluminum and feature a series of bearing bores, clearance holes for shafts, and clearance holes for the M6 mounting bolts. (Figure 19) The two housing covers were designed nearly identical except that the drive side cover has a clearance hole for the output shaft. This symmetrical design will ultimately lower tooling and manufacturing costs. Finally, while designing the housing covers, special care was taken to ensure there was clearance for all of the internals of the gear box.

Figure 19 – Drive Side Housing Cover Model

The shafts were designed based on dimensions and materials used in standard bicycle bottom bracket assemblies. Both the output and input shafts are made out of 7005 aluminum which provides an improved strength to weight ratio. The mid shaft is made of 8620 steel for several reasons. First, the mid shaft has an involute gear profile machined onto it. This gear will be meshing with the 30 tooth spur gear and needs to have a similar strength and hardness to prevent premature wear. The mid shaft also has a thru bore unlike the other two shafts so steel was chosen to increase the rigidity of the shaft under load. Steel keys and retaining rings are used to lock the gears into place in proper locations on the shafts as shown in Figure 20.

Figure 20 – Mid Shaft Shifting Assembly

3.3 Design Summary

In summary, the design process explained above, yielded a SolidWorks assembly model of a two speed gear box that can be attached to a steel bicycle frame via TIG welding. The gear box will be powered by the rider via the input shaft and has a series of spur and pinon gear trains that provide 2.0 and 3.125 gear ratios. The shifting mechanism utilizes a dogtooth design allowing precise gear selection while minimizing backlash. (Figure 21)

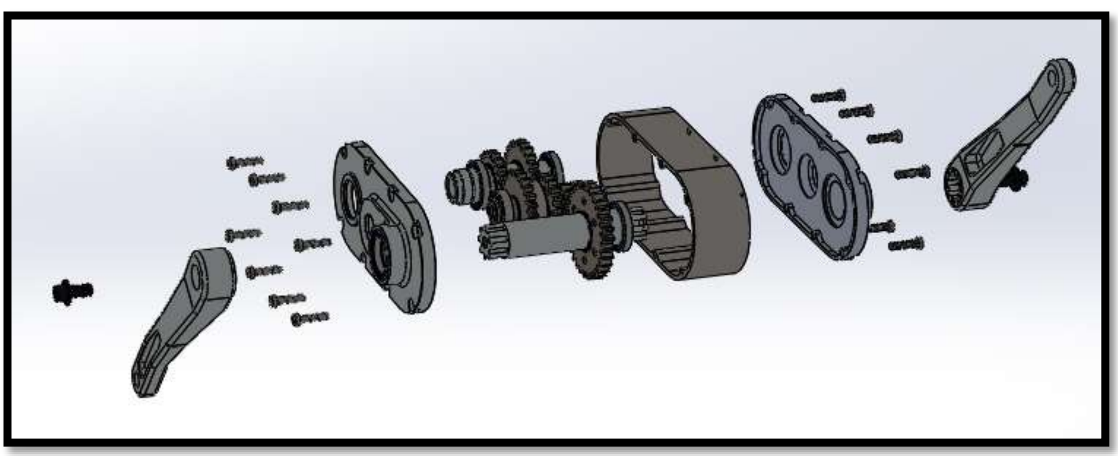

Figure 21 – Exploded Gearbox Assembly Schematic

The commuter bicycle gearbox design utilizes 17 machined components and 16 standard purchased parts. The bill of materials can be found below in Table 5.

Assembly Number: 02-001						
Assembly Name: 2 Speed Weld-on Gearbox						
Assembly Revision: A						
Approval Date: 11/16/16						
BOM Level	Part Number	Part Name	Revision	Quantity	Unit of Measure	BOM Notes
1	02-101	Drive Side Housing Cover Assembly	A	1	ea.	
2	02-201	Drive Side Housing Cover	A	1	ea.	
2	02-202	6806 Bearing	A	2	ea.	
2	02-203	6904 Bearing	A	1	ea.	
1	02-102	Non-Drive Side Housing Cover Assembly	A	1	ea.	
2	02-204	Non-Drive Side Housing Cover	A	1	ea.	
2	02-202	6806 Bearing	A	2	ea.	
2	02-203	6904 Bearing	A	1	ea.	
1	02-103	Housing	A	1	ea.	
1	02-104	Input Shaft Assembly	A	1	ea.	
2	02-205	Input Shaft	B	1	ea.	
2	02-206	30mm External Retainer Ring	A	2	ea.	
2	02-207	A Gear	A	1	ea.	
2	02-208	.5inx.5in undersize steel key, .39in long	A	1	ea.	
1	02-105	Mid-Shaft Assemly	A	1	ea.	
2	02-209	Mid-Shaft	B	1	ea.	
2	02-210	.875in External Retainer Ring	A	4	ea.	
2	02-211	C Gear	A	1	ea.	
2	02-212	D Gear	A	1	ea.	
2	02-213	Dog Gear	B	1	ea.	
2	02-214	.5inx.5in undersize steel key, .5in long	A	1	ea.	
2	02-215	.5in Internal Retainer Ring	A	1	ea.	
2	02-216	Spring	A	1	ea.	
2	02-217	Shifting Bulb Assembly	B	1	ea.	
3	02-301	Shifting Bulb	B	1	ea.	
3	02-302	R2-2Z Bearing	A	1	ea.	
2	02-218	Cable End	A	1	ea.	
2	02-219	1/8x36 set screw, .375in long	A	1	ea.	
2	02-220	8-32 SHCS, .75in long	A	2	ea.	
2	02-221	Shift Cable	A	1	ea.	
1	02-106	Output Shaft Assembly	A	1	ea.	
2	02-222	Output Shaft	A	1	ea.	
2	02-223	30mm External Retainer Ring	A	7	ea.	
2	02-224	.5inx.5in undersize steel key, .29in long	A	2	ea.	
2	02-225	E Gear	A	1	ea.	
2	02-226	F Gear	A	1	ea.	
1	02-107	Cable Guide Elbow	A	1	ea.	
1	02-108	M6x1.0 Low Profile SHCS, 25mm long, SS	A	16	ea.	
1	02-109	13 Tooth Odyssey Freewheel, M30x1.0	A	1	ea.	
1	02-111	Crank Arm	A	2	ea.	
1	02-112	30mm Wave Washer	A	1	ea.	
1	02-113	M10x1.5 Flanged SHCS	A	2	ea.	

Table 5 – Bill of Materials

4.0 Method

In order to produce a functioning prototype gearbox, a careful series of steps was taken. After the design was finalized in SolidWorks, engineering drawings of all the manufactured parts were created. Next, manufacturing routing were created to determine the steps needed to manufacture the parts from start to finish. Subsequently, HSMWorks Computer Aided Manufacturing (CAM) software was used to generate the tool paths to machine the components. Computer Numeric Controlled (CNC) mills, lathes, and manual machinery were used to manufacture the prototype. After each part was manufactured, it was inspected and compared against its design tolerances from the engineering drawings. Once all parts were machined and inspected, the parts were assembled into a functioning gearbox.

4.1 Manufacturing

All of the machined parts were manufactured in the Industrial and Manufacturing Engineering (IME) Department's Gene Haas Advanced Manufacturing Lab. The machines available in this lab included a Haas VF-2 CNC mill with 4^{th} axis capability, a Haas ST-10 CNC lathe with live tooling, a Haas TL-1 CNC Lathe, a manual lathe, and a Bridgeport knee mill. Support equipment included a horizontal band saw, belt sanders, drill press, arbor press, and a variety of hand tools. Tooling was either already owned or borrowed from the shop with the exception of the arbor mounted gear cutter, .063" external grooving tool, and the .05" internal grooving tool. In order to machine the parts using the CNC machines, HSMworks was used to program the toolpaths and generate NC code. All of the routing sheets with detailed manufacturing steps can be found in the Appendix.

The first part manufactured was the steel housing. The housing was machined in two operations using the Haas VF-2 CNC mill. Although this part required a lot of material removal, it was a fairly easy part to manufacture. One issue arose as the part was entering the final stages of operation two. Since so much material had been removed, the thin walls of the housing began to vibrate near the end of the program. To solve this issue, a small aluminum block was cut to fit inside the housing to support the walls as they were finished.

The two housing covers were also machined on the Haas VF-2 CNC mill. Both of these parts had several features with very tight positional and size tolerances. By using very careful finish passes and cutter compensation, the parts were machined within tolerance for the bearings to be press fit into the housing covers.

The input shaft was machined on the Haas ST-10 CNC lathe using the live tooling options. The input shaft required turning operations as well as live axial and radial tooling operations to cut the tapered splines that the crank arms attach to. Figure 22 shows the first operation of the input shaft with the spline machined on the outside surface.

Figure 22 – Testing Radial Live Tooling on Input Shaft

After machining the final input shaft, the gear machining started. Using custom soft jaws to hold the standard gear stock, the Haas VF-2 CNC mill was used to face the gears to the proper thickness and bore the proper inner diameter to fit onto the shafts. The dogtooth gear was machined using similar soft jaws and toolpaths were created to leave a very good surface finish and straight edges on the teeth, increasing surface contact with the C and D gear dogteeth.

Gear A, E, and F as well as the dogtooth gear require a key slot. In order to manufacture this feature, an arbor press and push broach set was used. Custom broach guides were manufactured to ensure perfect alignment since the key ways needed to be straight. (Figure 23)

Figure 23 – Push Broach Cutting Keyways into Gears

The mid shaft, was the most complex and difficult part to machine. Since the mid shaft had several operations completed on three different machines, it was critical to be very precise with the set ups between operations. Cutting the involute gear tooth profiles was done by hand writing G code to cut each tooth out one at a time. A 4th axis indexer was installed in the Haas VF-2 CNC mill to precisely rotate the mid shaft between tooth cutting cycles. (Figure 24) The involute gear tooth profile was manufactured with an arbor mounted gear cutter specifically designed to cut 12 tooth gears with a pitch of 10 and a pressure angle of 20 degrees. (Figure 25)

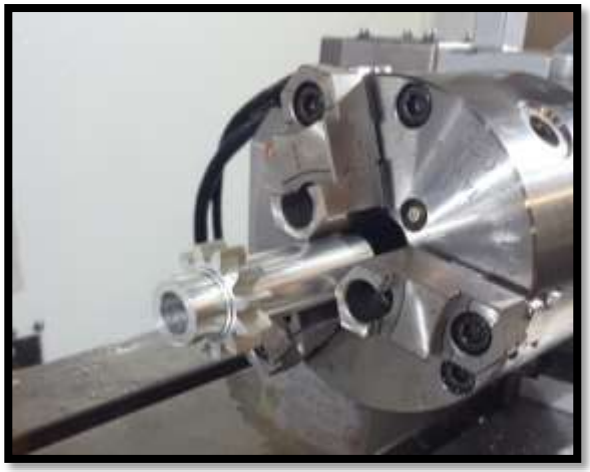

Figure 24 – Test Mid Shaft After Cutting Gear Tooth Profiles

Figure 25 – Arbor Mounted Gear Cutter Used for Mid Shaft

The output shaft was machined using the ST-10 and TL-1 Lathe. Unfortunately, the lab did not have a proper tool holder to use the grooving tool in the ST-10, otherwise the process could have been simplified by machining the retaining ring grooves while the part was in the ST-10 lathe. The shifting bulb and cable end were manufactured on the Haas TL-1 CNC lathe using quick code due to their simplicity.

Due to time restrictions, the crank arms and cable guide elbow have not been manufactured yet although plans exist to finish these parts in the near future.

4.2 Inspection

Many of the components manufactured for the gearbox required very precise features. In order to ensure that the parts were made to specification, a variety of inspection methods were used. For simpler, less precise features, calipers and micrometers sufficed for proper inspection. However, due to the complexity of some parts such as the housing covers, more advanced metrology methods were used.

To measure both housing covers, a Coordinate Measuring Machine (CMM) was used to measure feature size and location. Using the Microvu optical CMM shown in Figure 26, and their metrology software, a measuring routine was created that measured all of the critical design features and checked the results against the tolerances in the drawings.

Figure 26 – Input Shaft Inspected by Optical Scanner

The three shafts used for the prototype gearbox also had very precise tolerances. The Input Shaft and the Mid Shaft are both two operation lathe parts meaning they had to be flipped in the chuck jaws of the lathe. When flipping parts in a lathe like this, special care must be taken to ensure that concentricity and straightness are preserved and both of these shafts needed to be very straight in order to fit through the bearings pressed into both housings. The Mid Shaft also has an involute gear machined into it after the turning operations are complete. After machining the gear teeth, inspection showed that the dedendum diameter of the gear was too big. The part was repositioned and the gear profile was cut deeper to a proper value.

The C gear, D gear, and dogtooth gear that assemble onto the Mid Shaft had some features with very critical clearances. Another measuring program was developed for the Microvu optical CMM to measure the profiles of the teeth machined onto the faces of the C and D gear. The optical scanner uses surface light and a camera to precisely inspect parts with a resolution of .0001 inches.

Fortunately, due to carefully planned tool paths and machining practices, only one part during the manufacturing phase had to be rejected.

4.3 Assembly

During the manufacturing phase, several parts were partially assembled to check fitment. After the Output Shaft was machined and inspected, the first full assembly was done. The gearbox is designed to be very easy to service therefore it is also very easy to assemble. A total of 73 parts make up the final assembly shown in Figure 27.

Figure 27 – Majority of Components Ready for Assembly

All of the bearings were pressed into their respective bores including the R2-2Z bearing into the Shifting Bulb. Using internal retaining ring pliers, the internal retaining ring is then installed into the Mid Shaft. The spring and Shifting Bulb Assembly were placed into the Mid Shaft as well. Retaining rings, C and D gears, the dogtooth gear, and a steel key are then assembled, completing the Mid Shaft assembly.

The Input Shaft assembly consists of the Input Shaft, A gear, a steel key, and two 30 millimeter retaining rings. The Output Shaft assemble consists of the E and F gear, steel keys, and several retaining rings. After the three shaft assemblies were completed, they are ready to be installed into the gear box. (Figure 28)

Figure 28 – Three Shaft Assemblies Ready for Installation

Next, the Non Drive Side Housing cover is installed to the housing using 8 M6 bolts. The three shaft assemblies are then slipped into their proper bearings as shown in Figure 29.

Figure 29 – Three Shafts Installed into Housing

The Drive Side Housing cover is slipped over the three shafts and bolted to the housing using the remaining M6 bolts. Finally, the shift cable and cable end are installed through the shifting bulb in the Mid Shaft.

5.0 Results

This section explains the current state of the gearbox prototype, testing results, and an economic analysis.

5.1 Observations

At the time this report was written, the prototype gearbox is fully assembled with the exception of the crank arms. (Figure 30) With the bearings pressed into the housing covers and the three shaft subassemblies constructed, the gearbox assembles in just a few minutes. The mid shaft and output shaft have no play and there is a very slight amount of backlash felt between the 30 tooth gear of the input shaft and the 12 tooth gear that is machined onto the mid shaft. By drawing a line on the input shaft, this backlash can be measured to be approximately 3 degrees.

Figure 30 – Prototype Gearbox

When a shifter cable is attached into the mid shaft assembly, the dogtooth shifting mechanism functions flawlessly. There is good feedback communicating a proper shift into both the high and low gear ratio.

Now that the gearbox is completed, it needs to be attached to a bicycle. After discussion with faculty at Cal Poly and the Technical Advisor it was decided that to test the gearbox, a bracket will be made to rigidly attach the prototype to a bicycle frame. Originally, the gearbox was designed to be welded to a modified steel bike frame. For sake of demonstration and testing that will occur in the future, the ability to remove the gearbox from the testing bicycle will be very advantageous.

Unfortunately, due to time constraints, testing will have to be done as part of future work and not as part of the current project scope. To test durability of the design, a small motor can be connected to the input shaft to simulate long term use. It will be interesting to see how the design holds up to constant rotation over an extended period. Testing in the field will also be necessary to gain more information from the prototype. Exposure to water, varying temperatures, and dust will test the sealing ability of the housing covers.

This prototype design is by no means the perfect solution to drivetrain issues experienced by bicycle commuters. It does however provide an opportunity to gain insight into the early stages of bicycle gearbox development in the United States.

5.2 Economic Analysis

Gearboxes are more expensive than derailleurs to manufacture. Derailleur manufacturers have established processes, equipment, supply chain, and produce in very high volume. In order to compare the cost of the prototype gearbox to a gearbox that might be found on the market, an economic analysis was performed between manufacturing one unit and a 25-unit batch. Using the routing sheets which are supplied in the Appendix, the operation and set-up costs were calculated. (Table 6)

					1 Unit				25 Unit Batch			
Part Number	Part Name	Revision	Quantity	Unit of Measure	Time (hr)	Set-up Time (hr)	Labor Rate ($ per hr)	Total Cost	Reduced Time	Set-up Time(hr)	Labor Rate ($ per hr)	Total Cost (25 units)
02-201	Drive Side Housing Cover	A	1	ea.	1.411	0.932	$ 60.00	$ 140.58	1.058	0.037	$ 60.00	$ 65.73
02-204	Non-Drive Side Housing C	A	1	ea.	1.395	0.932	$ 60.00	$ 139.62	1.046	0.037	$ 60.00	$ 65.01
02-103	Housing	A	1	ea.	2.666	0.849	$ 60.00	$ 210.90	2.000	0.034	$ 60.00	$ 122.01
02-205	Input Shaft	B	1	ea.	0.748	0.799	$ 60.00	$ 92.82	0.561	0.032	$ 60.00	$ 35.58
02-207	A Gear	A	1	ea.	0.603	0.357	$ 60.00	$ 57.60	0.452	0.014	$ 60.00	$ 27.99
02-209	Mid-Shaft	B	1	ea.	1.438	1.115	$ 60.00	$ 153.18	1.079	0.045	$ 60.00	$ 67.39
02-211	C Gear	A	1	ea.	0.327	0.315	$ 60.00	$ 38.52	0.245	0.013	$ 60.00	$ 15.47
02-212	D Gear	A	1	ea.	0.327	0.315	$ 60.00	$ 38.52	0.245	0.013	$ 60.00	$ 15.47
02-213	Dog Tooth Gear	B	1	ea.	1.036	0.688	$ 60.00	$ 103.44	0.777	0.028	$ 60.00	$ 48.27
02-301	Shifting Bulb	B	1	ea.	0.313	0.365	$ 60.00	$ 40.68	0.235	0.015	$ 60.00	$ 14.96
02-218	Cable End	A	1	ea.	0.332	0.189	$ 60.00	$ 31.26	0.249	0.008	$ 60.00	$ 15.39
02-222	Output Shaft	A	1	ea.	0.59	0.332	$ 60.00	$ 55.32	0.443	0.013	$ 60.00	$ 27.35
02-225	E Gear	A	1	ea.	0.394	0.24	$ 60.00	$ 38.04	0.296	0.010	$ 60.00	$ 18.31
02-226	F Gear	A	1	ea.	0.394	0.24	$ 60.00	$ 38.04	0.296	0.010	$ 60.00	$ 18.31
02-107	Cable Guide Elbow	A	1	ea.	0.5	0.5	$ 60.00	$ 60.00	0.375	0.020	$ 60.00	$ 23.70
02-111	Crank Arm	A	2	ea.	0.75	0.25	$ 60.00	$ 120.00	0.563	0.010	$ 60.00	$ 34.35
				TOTAL	13.224	8.418		$1,358.52	9.918	0.337		$ 615.28

Table 6 – Operation and Set-up Costs

Manufacturing a 25-unit batch cuts the cost per unit by approximately 55%. It was assumed that on average, a 25% reduction in operation time would occur due to more efficient tool paths and inspection methods.

Next, assembly time was recorded. The time to assemble one unit is the same as assembling one unit from the 25-unit batch so the cost per unit is the same. (Table 7)

Part Number	Part Name	Revision	Quantity	Unit of Measure	Time (hr)	Labor Rate ($ per hr)	Total Cost Per Unit	Total Cost Per Unit (25 batch)
02-001	2 Speed Weld-On Gear Box	A	1	ea.	0.25	12.46	$ 3.12	$ 3.12
02-101	Drive Side Housing Cover Assembly	A	1	ea.	0.083	12.46	$ 1.03	$ 1.03
02-102	Non-Drive Side Housing Cover Assembly	A	1	ea.	0.083	12.46	$ 1.03	$ 1.03
02-104	Input Shaft Assembly	A	1	ea.	0.025	12.46	$ 0.31	$ 0.31
02-105	Mid-Shaft Assemly	A	1	ea.	0.16	12.46	$ 1.99	$ 1.99
02-106	Output Shaft Assembly	A	1	ea.	0.05	12.46	$ 0.62	$ 0.62
02-217	Shifting Bulb Assembly	B	1	ea.	0.016	12.46	$ 0.20	$ 0.20
				TOTAL	0.667		$ 8.31	$ 8.31

Table 7 – Assembly Times

Raw material was sourced primarily from the vendor Online Metals. The raw material cost for the prototype was $548.41. Assuming Online Metals would still be used for a bulk order, the raw stock cost per unit when making a 25-unit batch is $315.74. Purchased parts for the prototype cost $127.07 and would cost $68.25 per unit for a 25-unit batch. Special tooling that needed to be purchased included an involute gear cutter, external grooving tool, and an internal grooving tool. (Table 8)

Tool	Description	Price
Gear Cutter	#8 10P 20deg. Involute, HSS	$ 81.00
External Grooving Tool	.061" blade width, carbide	$ 24.00
Internal Grooving Tool	.039" blade width, carbide	$24.00
	Total	$ 129.00

Table 8 – Special Tooling Costs

All of the costs above culminate into the total cost to produce the prototype gearbox. The cost of raw materials, purchased parts, operations (machining and inspection), set up, assembly, and tooling were all considered. (Table 9)

Cost	Prototype Cost	Cost per Unit (25-unit batch)
RAW MATERIAL COST	$ 548.41	$ 315.74
PURCHASED PARTS COST	$ 127.07	$ 68.25
OPERATION AND SET UP COST	$ 1,358.52	$ 615.28
ASSEMBLY COST	$ 8.31	$ 8.31
TOOLING COST	$ 129.00	$ 129.00
TOTAL COST	$ 2,171.31	$ 1,136.58

Table 9– Final Cost of Prototype and Unit Price Per 25 Unit Batch

The cost per unit (25-unit batch) value provides a valuable starting point for comparing the gearboxes feasibility in the bicycle industry. Pinion’s 1.9CR gearbox is commercially available to bicycle frame manufactures. Co-Motion Cycles based out of Oregon produces frames that can be fitted with the Pinion gearbox. A bicycle fitted with a traditional Shimano brand drivetrain can be purchased for $3,995. The same bicycle fitted with a Pinion gearbox costs $6,365.00. The extra labor to install the gearbox mounting brackets and the gearbox itself amounts to a $2370 upcharge. Assuming a 50% margin on marketing and distributing the prototype gearbox, the price of a Co-Motion Cycles bicycle outfitted with the gearbox would be $5,638.17, or $727 less than Pinion's offering. (Table 10)

Cost	Prototype	Pinion	Shimano Derailleur
DRIVETRAIN	$ 2,273.17	$ 3,000.00	$ 630.00
FRAME	$ 1,965.00	$ 1,965.00	$ 1,965.00
COMPONENTS	$ 1,400.00	$ 1,400.00	$ 1,400.00
TOTAL COST	$ 5,638.17	$ 6,365.00	$ 3,995.00

Table 10 – Drivetrain Cost Comparison

There were some critical assumptions made for this economic analysis. First off, engineering and design time were not taken into account. These costs were left out because pursuing the idea of an American manufactured gearbox will need to be done by an individual or group who truly believe in the benefits of gearbox drivetrains and are willing to work on the development of the project. The second assumption is manufacturing costs will not increase as the design develops into a product ready for consumer use. The prototype gearbox is still in the testing phase and is not ready to be distributed.

6.0 Conclusion

This project provides a large source of information for future work. Not only does the gear box function, it is also ready to be attached to a bicycle for testing. Future work includes designing a bracket to temporarily attach the prototype to bicycle frames and running a series of tests. The best way to test this design is to ride it in a wide variety of field conditions. A collection of field tests will provide even more insight into how the gearbox design reacts to usage.

Moving forward, there is also a lot that can be done to improve the design. The gearbox weighs 7 pounds 8 ounces. This is very heavy as many modern bicycles weigh less than thirty pounds. With the help of mechanical engineers and a more in depth strength of material analysis, the gearbox can be designed to be much lighter and most likely smaller. The more compact the design, the more appealing it will be to bicycle manufacturers looking to integrate gearbox technology to their commuting bicycles.

Examining the Economic Analysis points to a possible successful future for a simplified gearbox if costs can continue to decrease. This project was a true test of a Cal Poly Manufacturing Engineer’s design and manufacturing skillset along with the resources available at Cal Poly.

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Figure Sources

Figure 1 – Sheldon Brown

Figure 2 – Bicycling.com

Figure 3 – Old Glory Mountain Bike

Figure 4 – Bike Gremlin.com

Figure 5 – Shimano

Figure 6 – How Stuff Works

Figure 7 – Alder

Figure 8 – Pinion

Figure 9 – Wikipedia

Figure 10 – Helicron

Figure 11 – Machine Design

Figure 12 – Ride on Magazine

Figure 14 – MTB-News

Figure 15 – Super Street Design

Figure 16 – North Eastern University

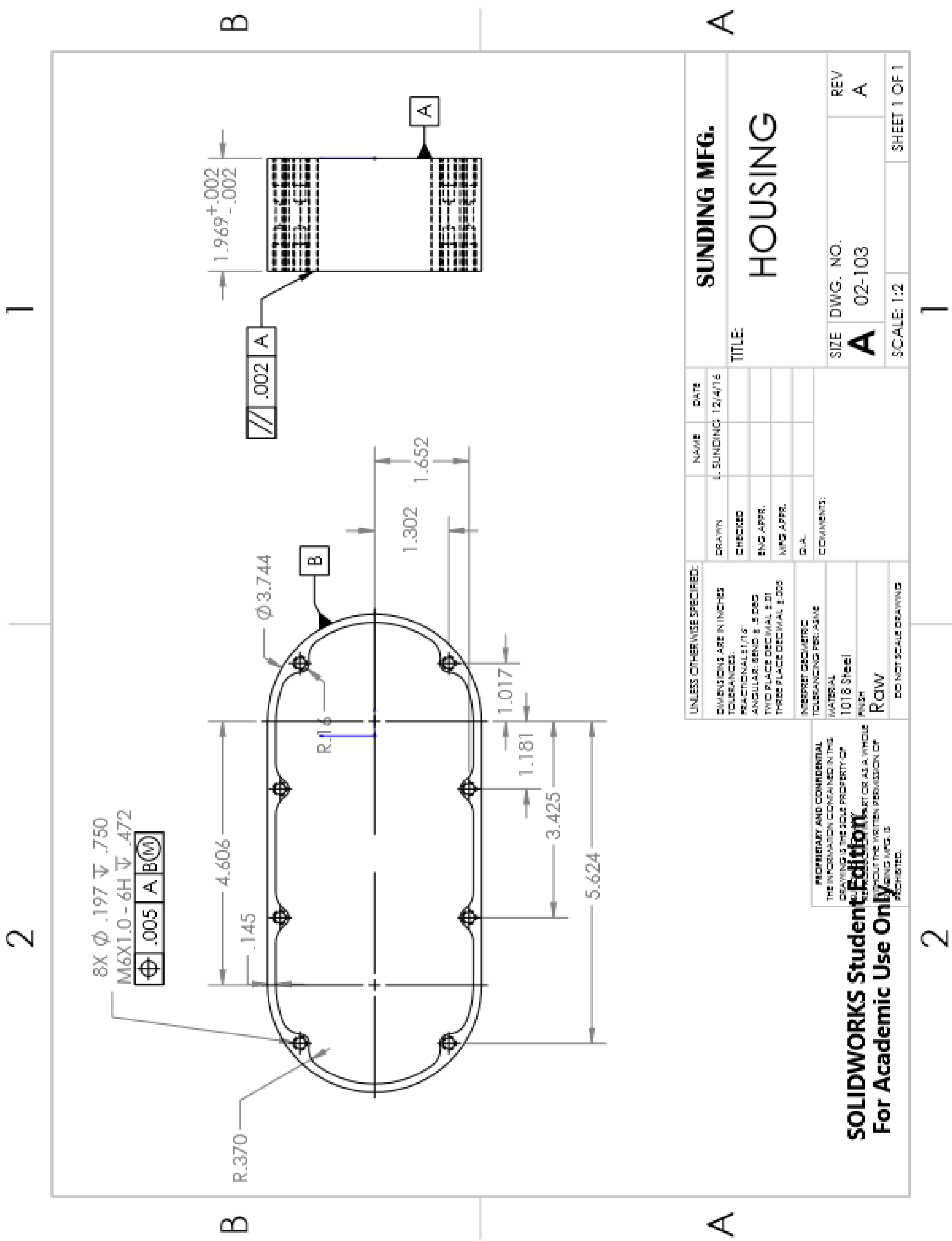
* All other figures generated by report Author

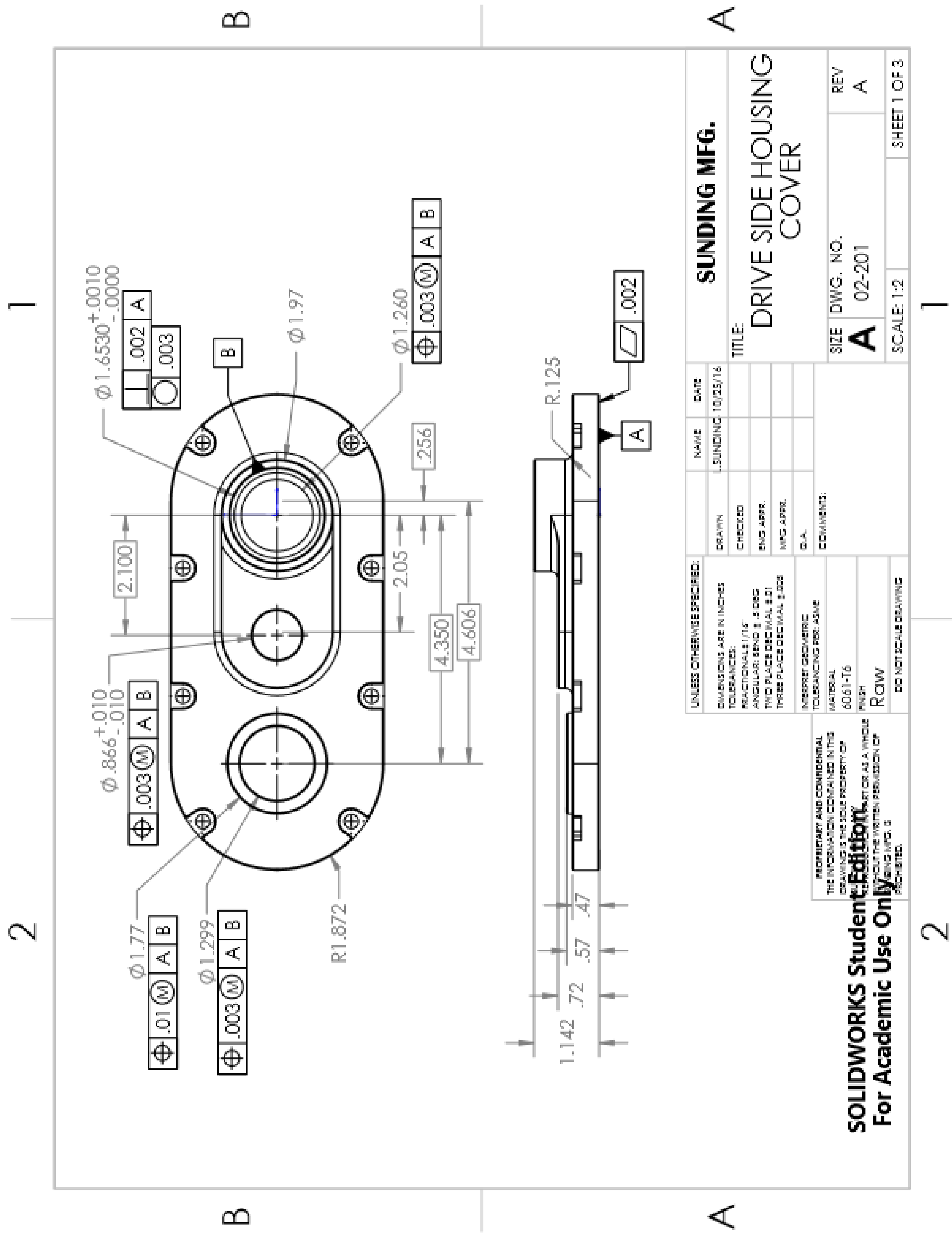
Appendix

A) Bill of Materials

Assembly Number: 02-001						
Assembly Name: 2 Speed Weld-on Gearbox						
Assembly Revision: A						
Approval Date: 11/16/16						
BOM Level	Part Number	Part Name	Revision	Quantity	Unit of Measure	BOM Notes
1	02-101	Drive Side Housing Cover Assembly	A	1	ea.	
2	02-201	Drive Side Housing Cover	A	1	ea.	
2	02-202	6806 Bearing	A	2	ea.	
2	02-203	6904 Bearing	A	1	ea.	
1	02-102	Non-Drive Side Housing Cover Assembly	A	1	ea.	
2	02-204	Non-Drive Side Housing Cover	A	1	ea.	
2	02-202	6806 Bearing	A	2	ea.	
2	02-203	6904 Bearing	A	1	ea.	
1	02-103	Housing	A	1	ea.	
1	02-104	Input Shaft Assembly	A	1	ea.	
2	02-205	Input Shaft	B	1	ea.	
2	02-206	30mm External Retainer Ring	A	2	ea.	
2	02-207	A Gear	A	1	ea.	
2	02-208	.5inx.5in undersize steel key, .39in long	A	1	ea.	
1	02-105	Mid-Shaft Assemly	A	1	ea.	
2	02-209	Mid-Shaft	B	1	ea.	
2	02-210	.875in External Retainer Ring	A	4	ea.	
2	02-211	C Gear	A	1	ea.	
2	02-212	D Gear	A	1	ea.	
2	02-213	Dog Gear	B	1	ea.	
2	02-214	.5inx.5in undersize steel key, .5in long	A	1	ea.	
2	02-215	.5in Internal Retainer Ring	A	1	ea.	
2	02-216	Spring	A	1	ea.	
2	02-217	Shifting Bulb Assembly	B	1	ea.	
3	02-301	Shifting Bulb	B	1	ea.	
3	02-302	R2-2Z Bearing	A	1	ea.	
2	02-218	Cable End	A	1	ea.	
2	02-219	1/8x36 set screw, .375in long	A	1	ea.	
2	02-220	8-32 SHCS, .75in long	A	2	ea.	
2	02-221	Shift Cable	A	1	ea.	
1	02-106	Output Shaft Assembly	A	1	ea.	
2	02-222	Output Shaft	A	1	ea.	
2	02-223	30mm External Retainer Ring	A	7	ea.	
2	02-224	.5inx.5in undersize steel key, .29in long	A	2	ea.	
2	02-225	E Gear	A	1	ea.	
2	02-226	F Gear	A	1	ea.	
1	02-107	Cable Guide Elbow	A	1	ea.	
1	02-108	M6x1.0 Low Profile SHCS, 25mm long, SS	A	16	ea.	
1	02-109	13 Tooth Odyssey Freewheel, M30x1.0	A	1	ea.	
1	02-111	Crank Arm	A	2	ea.	
1	02-112	30mm Wave Washer	A	1	ea.	
1	02-113	M10x1.5 Flanged SHCS	A	2	ea.	

B) Part Drawings

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DRIVE SIDE HOUSING COVER
SIZE A
DWG. NO. 02-201
REV A
SCALE: 1:2
SHEET 1 OF 3
DRAWN L.SUNDING 10/25/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 6061-T6
FINISH Raw
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Student Edition.
For Academic Use Only.
Ø1.6530 +.0010 -.0000
Ø1.97
Ø1.260
Ø.866 +.010 -.010
Ø1.77
Ø1.299
R1.872
R.125
2.100
2.05
4.350
4.606
.256
1.142
.72
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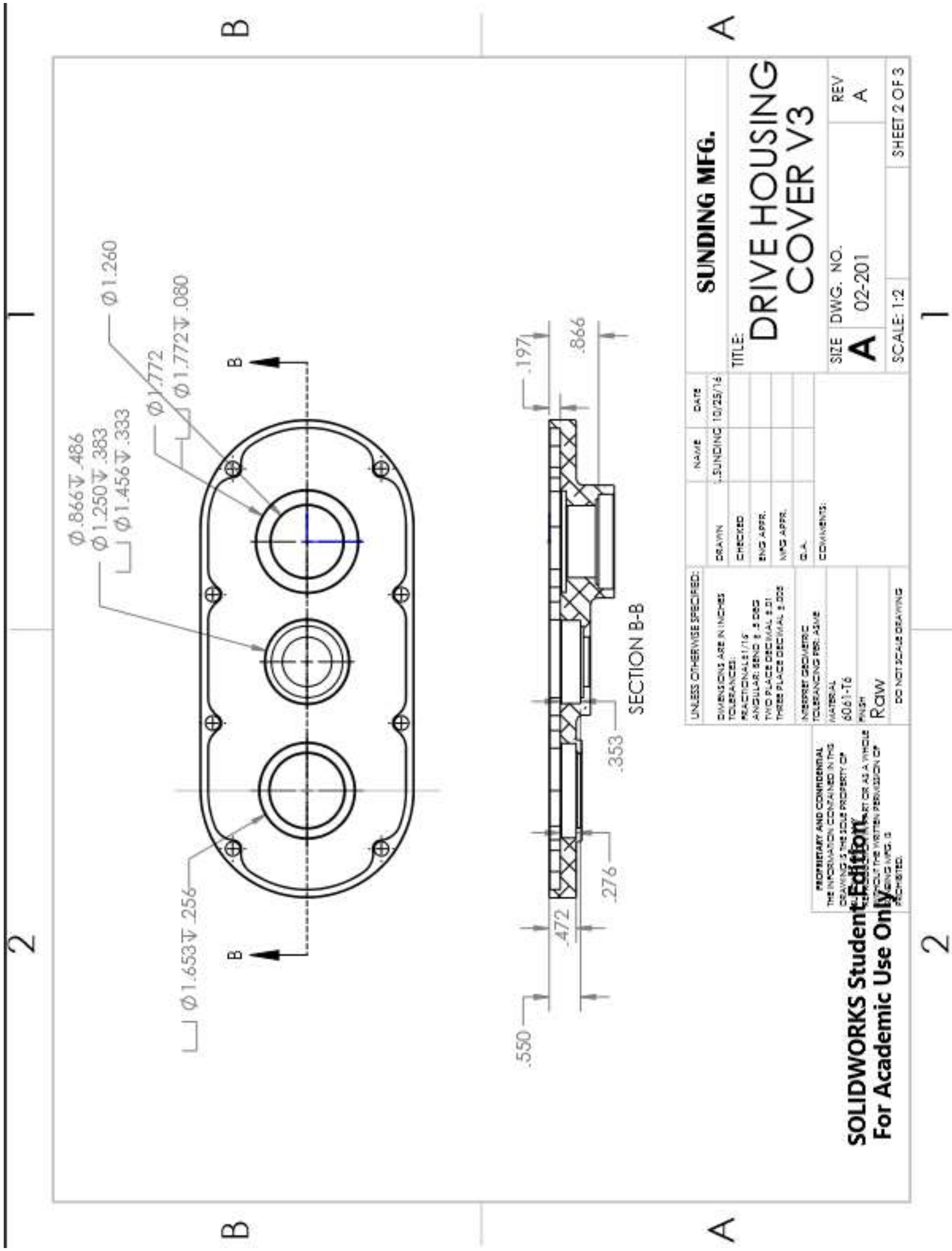
.002
.003



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TITLE:
DRIVE HOUSING COVER V3
SIZE A
DWG. NO. 02-201
REV A
SCALE: 1:2
SHEET 2 OF 3
SECTION B-B
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Ø1.250 ↧ .383
Ø1.456 ↧ .333
Ø1.772
Ø1.772 ↧ .080
Ø1.260
Ø1.653 ↧ .256
.197
.866
.353
.276
.472
.550
UNLESS OTHERWISE SPECIFIED:
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MATERIAL 6061-T6
FINISH Raw
DO NOT SCALE DRAWING
DRAWN L.SUNDING 10/25/16
CHECKED
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MFG APPR.
Q.A.
COMMENTS:
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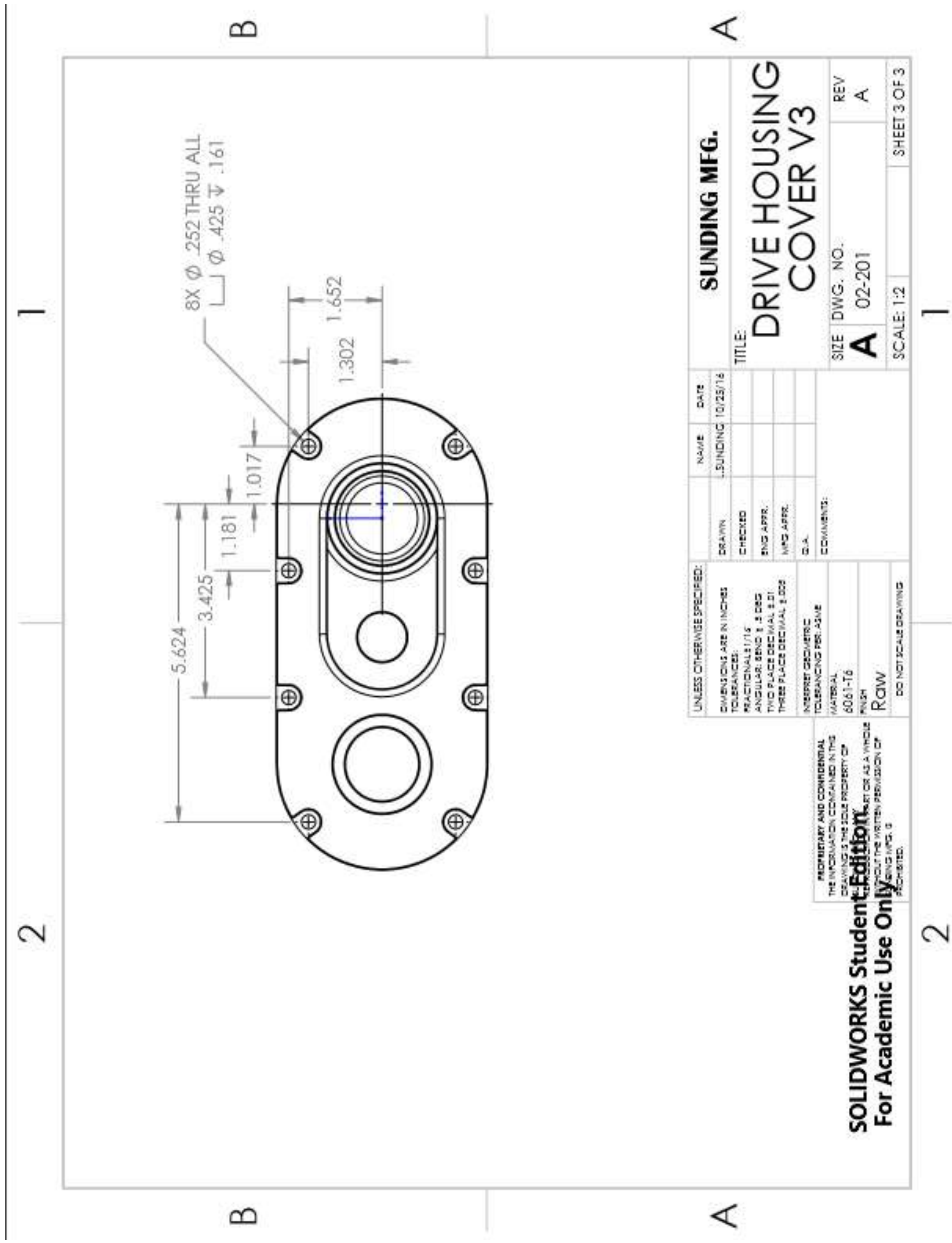

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1.017
1.181
3.425
5.624
SUNDING MFG.
TITLE:
DRIVE HOUSING COVER V3
SIZE A
DWG. NO. 02-201
REV A
SCALE: 1:2
SHEET 3 OF 3
DRAWN SUNDING 10/25/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
MATERIAL 6061-T6
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DO NOT SCALE DRAWING
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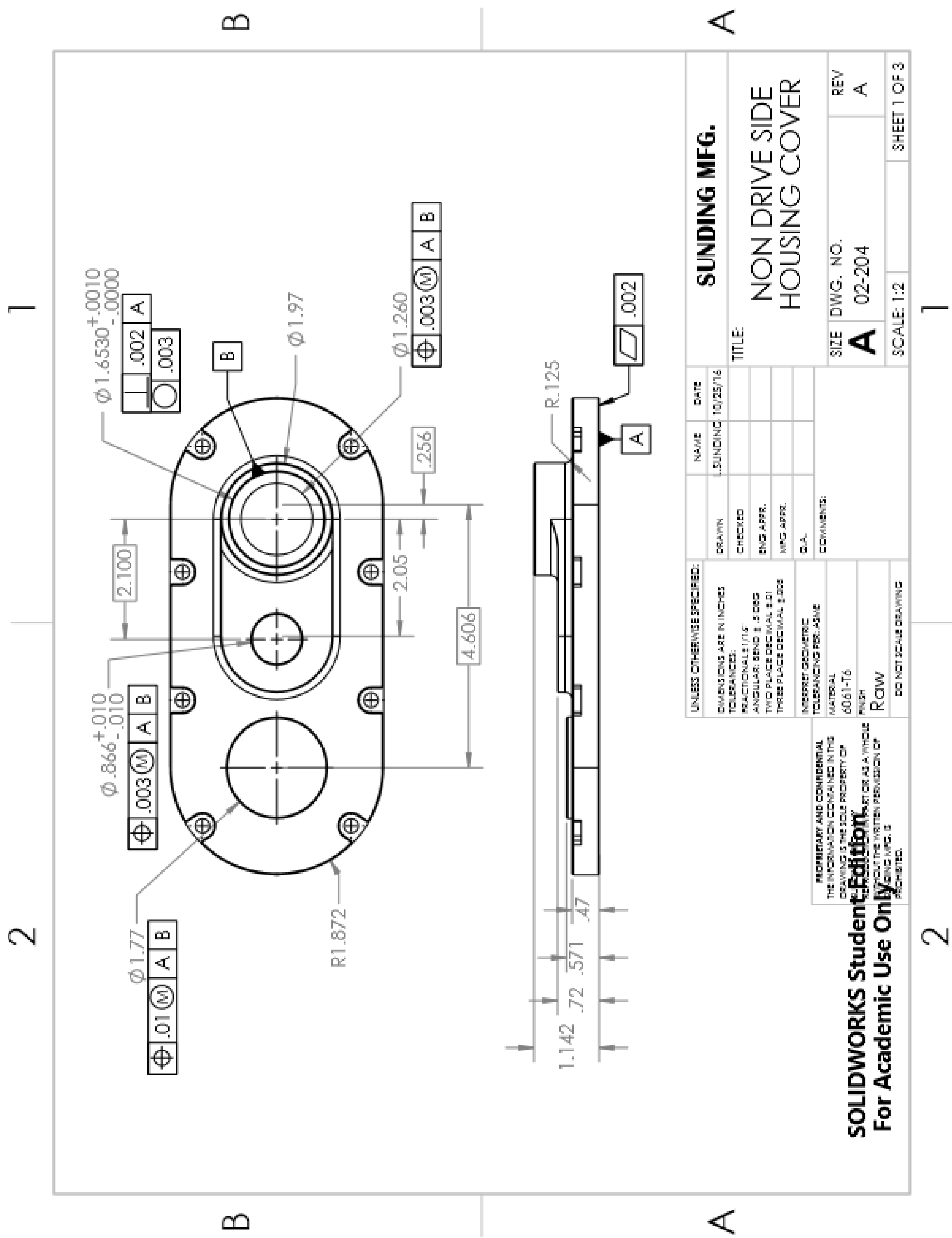

SUNDING MFG.
TITLE:
NON DRIVE SIDE HOUSING COVER
SIZE A
DWG. NO. 02-204
REV A
SCALE: 1:2
SHEET 1 OF 3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 6061-T6
FINISH Raw
DO NOT SCALE DRAWING
DRAWN J. SUNDING 10/25/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
Ø1.6530 +.0010 -.0000
Ø1.97
Ø1.260
Ø.866 +.010 -.010
Ø1.77
R1.872
R.125
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.002
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SOLIDWORKS Student Edition.
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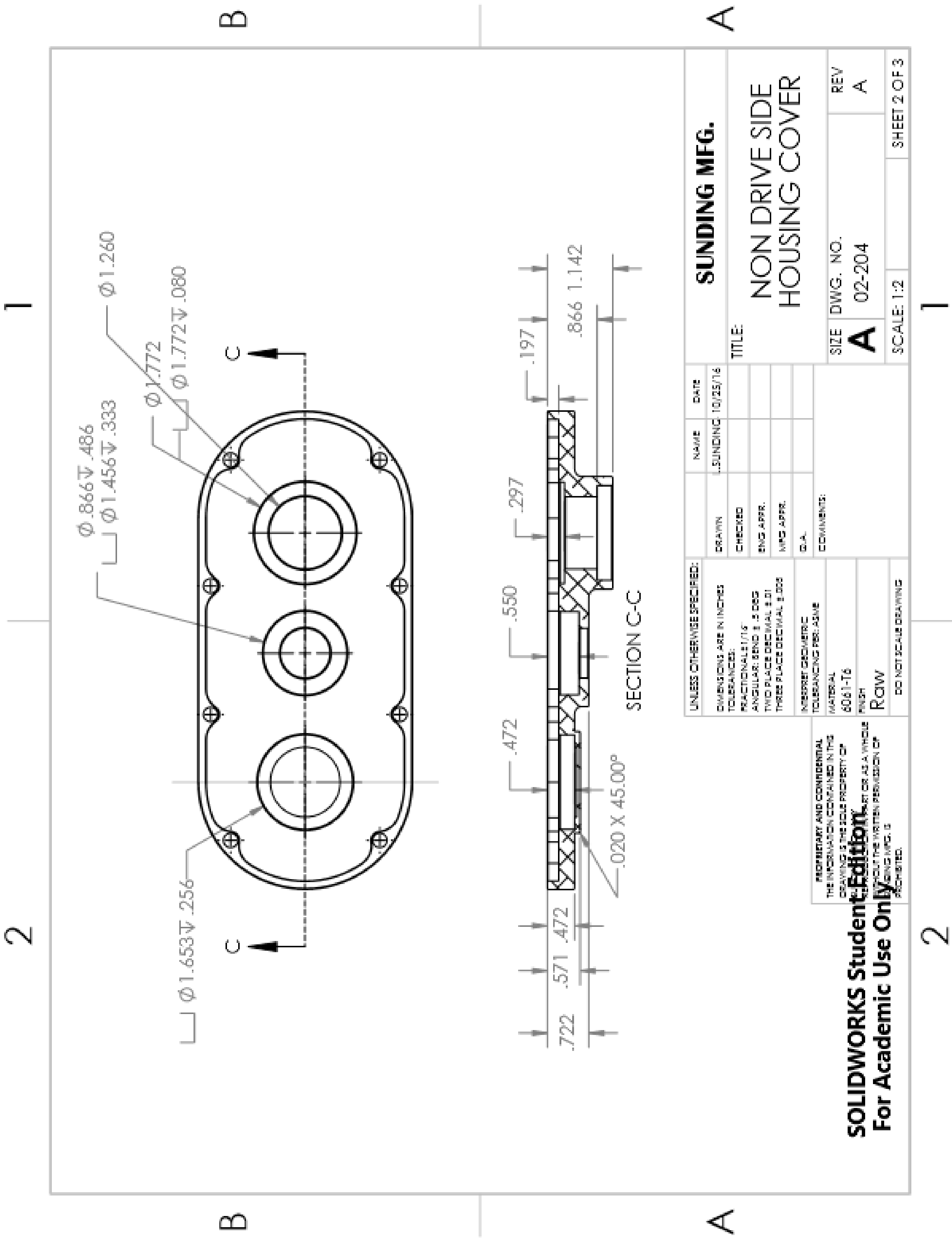
SUNDING MFG.
TITLE:
NON DRIVE SIDE HOUSING COVER
SIZE A
DWG. NO. 02-204
REV A
SCALE: 1:2
SHEET 2 OF 3
SECTION C-C
Ø1.260
Ø1.772
Ø1.772 ↧ .080
Ø.866 ↧ .486
Ø1.456 ↧ .333
Ø1.653 ↧ .256
.020 X 45.00°
.197
.297
.550
.472
.866
1.142
.722
.571
.472
C
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 6061-T6
FINISH Raw
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
J.SUNDING 10/25/16
PROPRIETARY AND CONFIDENTIAL
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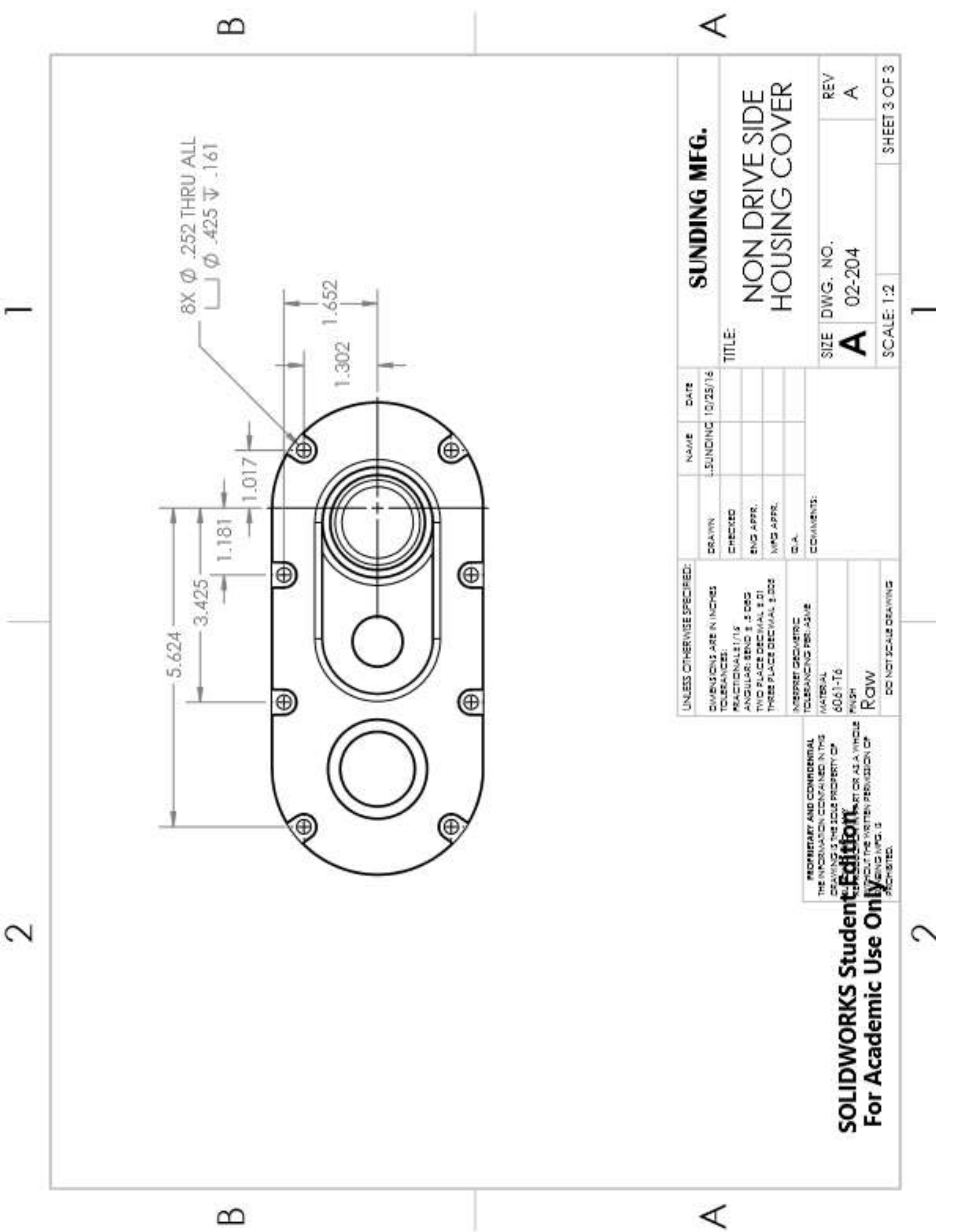
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1.017
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1.652
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TITLE:
NON DRIVE SIDE
HOUSING COVER
SIZE
A
DWG. NO.
02-204
REV
A
SCALE: 1:2
SHEET 3 OF 3
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
L.SUNDING
10/25/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
FINISH
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DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Student Edition.
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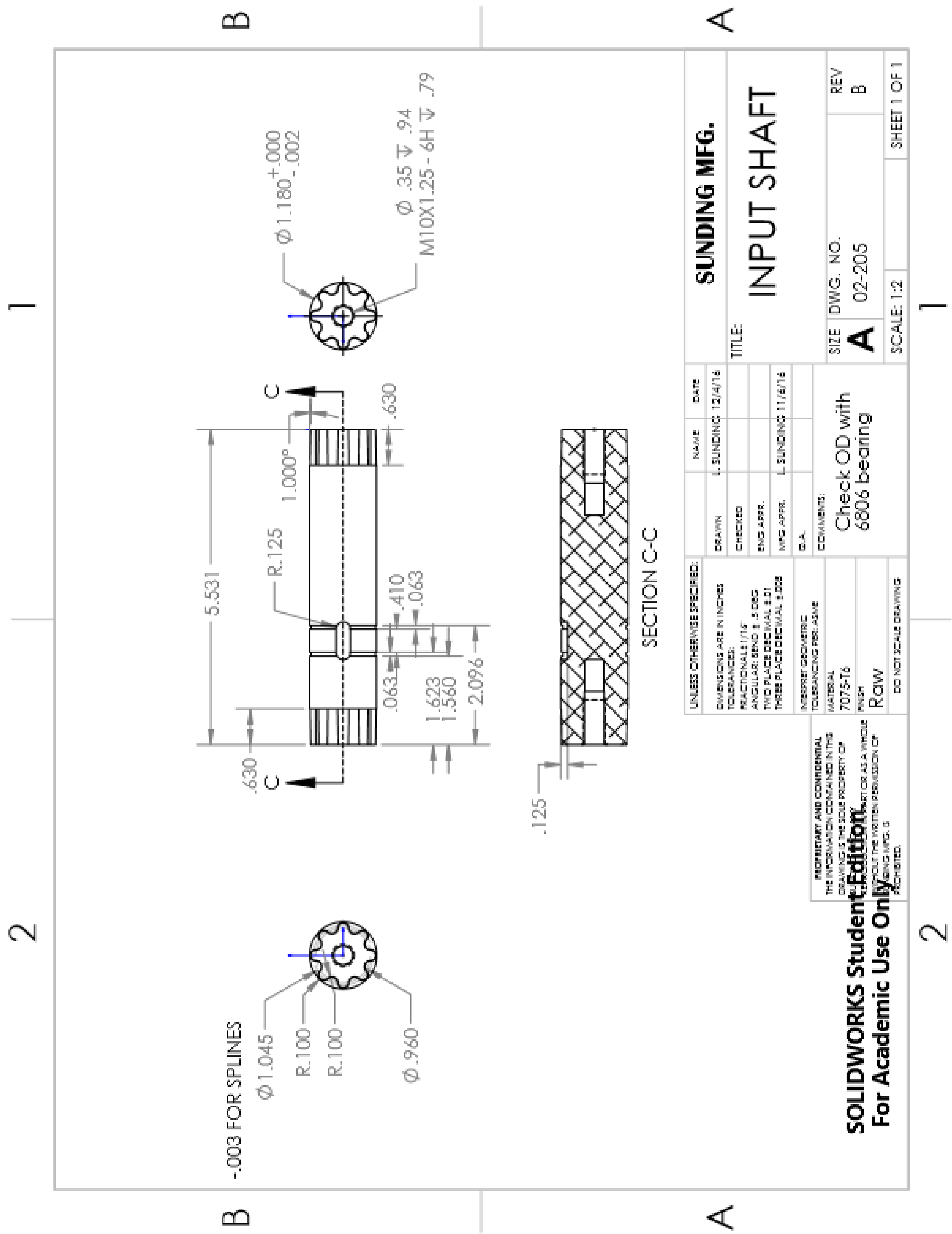
B
A
1
2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TITLE:
INPUT SHAFT
SIZE
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DWG. NO.
02-205
REV
B
SCALE: 1:2
SHEET 1 OF 1
SECTION C-C
5.531
R.125
1.000°
.630
.410
.063
2.096
1.623
1.560
.125
Ø1.180 +.000 -.002
Ø .35 ↧ .94
M10X1.25 - 6H ↧ .79
-.003 FOR SPLINES
Ø1.045
R.100
Ø.960
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
L. SUNDING 12/4/16
L. SUNDING 11/6/16
Check OD with 6806 bearing
UNLESS OTHERWISE SPECIFIED:
MATERIAL
7075-T6
FINISH
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DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Student Edition.
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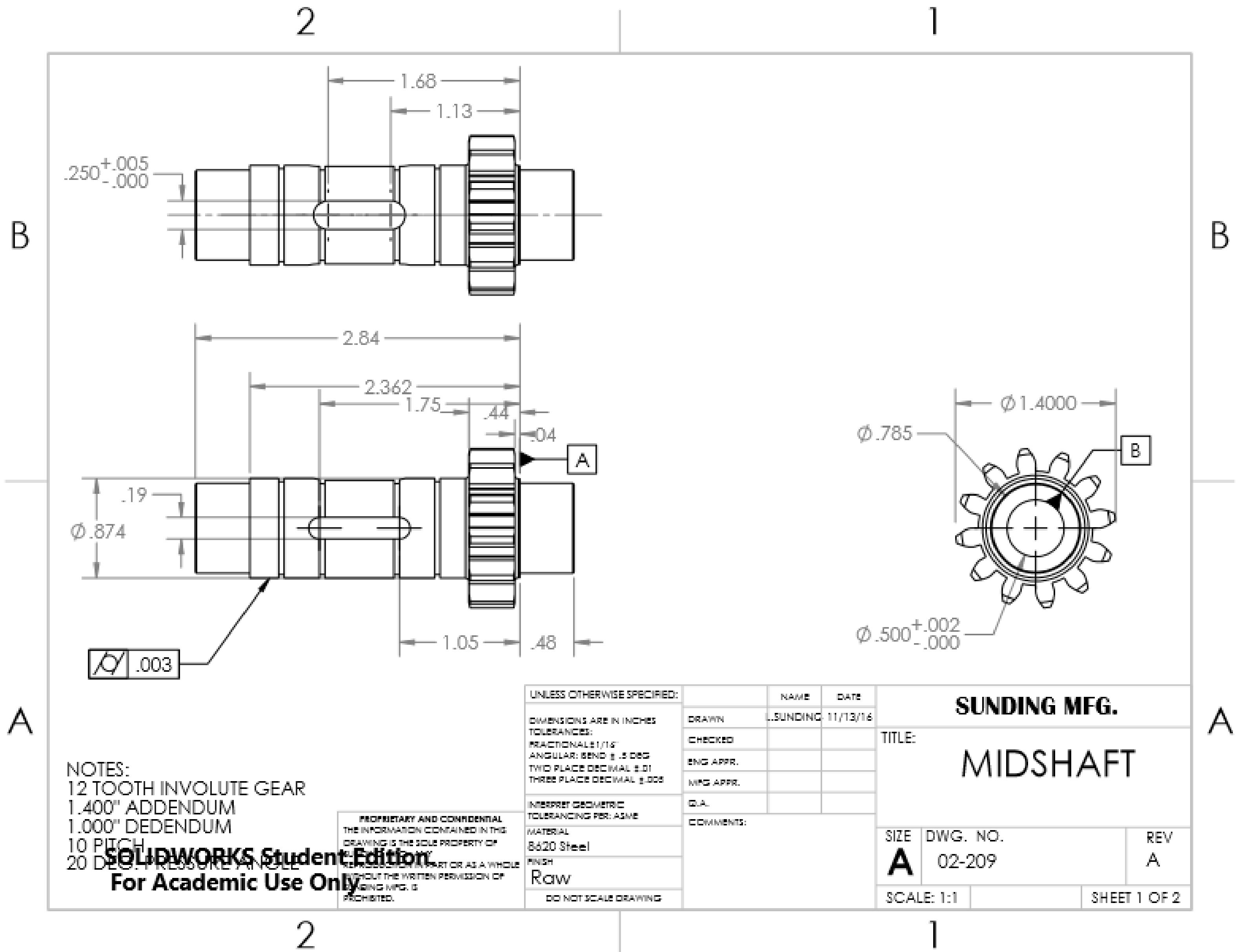
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.44
.04
A
.19
Ø.874
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.48
Ø1.4000
Ø.785
B
Ø.500 +.002 -.000
NOTES:
12 TOOTH INVOLUTE GEAR
1.400" ADDENDUM
1.000" DEDENDUM
10 PITCH
SOLIDWORKS Student Edition.
For Academic Use Only.
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
8620 Steel
FINISH
Raw
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
11/13/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
SUNDING MFG.
TITLE:
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SIZE
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DWG. NO.
02-209
REV
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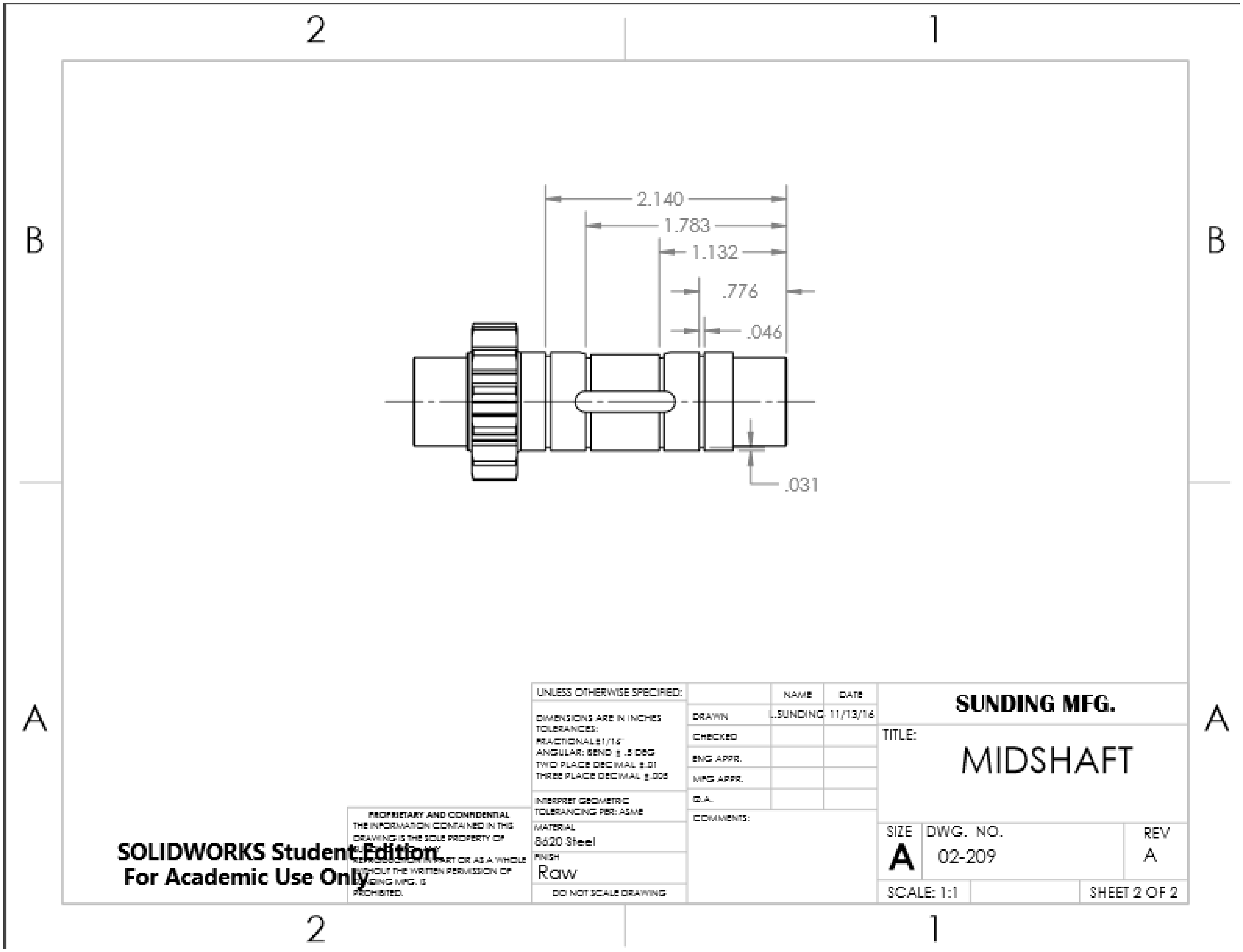
SCALE: 1:1
SHEET 1 OF 2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TOLERANCES:
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MATERIAL
8620 Steel
FINISH
Raw
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
.SUNDING
11/13/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
SUNDING MFG.
TITLE:
MIDSHAFT
SIZE
A
DWG. NO.
02-209
REV
A
SCALE: 1:1
SHEET 2 OF 2
PROPRIETARY AND CONFIDENTIAL
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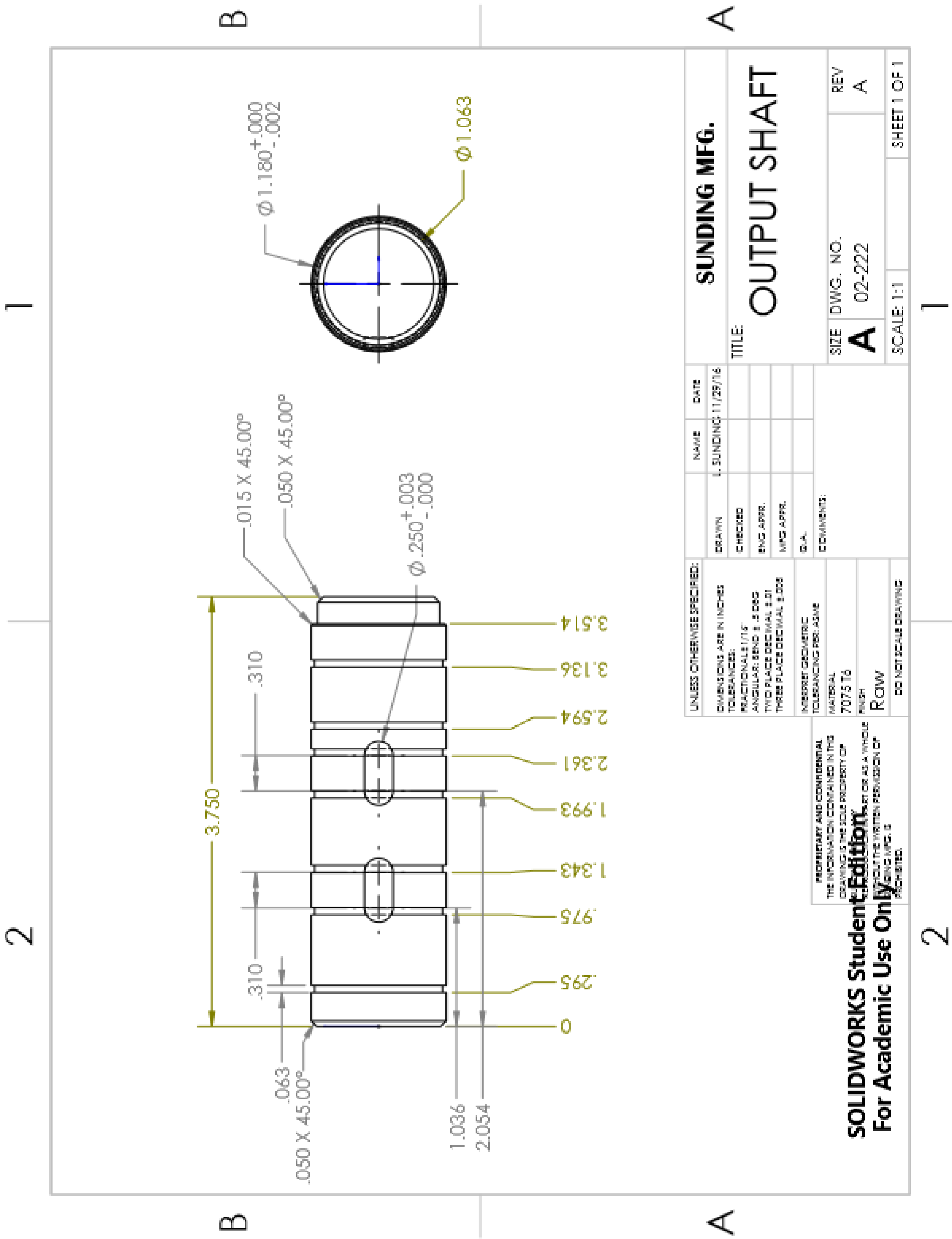

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TITLE:
OUTPUT SHAFT
SIZE
A
DWG. NO.
02-222
REV
A
SCALE: 1:1
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
7075 T6
FINISH
Raw
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
I. SUNDING
11/29/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Student Edition
For Academic Use Only
Ø1.180 +.000 -.002
Ø1.063
.015 X 45.00°
.050 X 45.00°
Ø .250 +.003 -.000
3.750
.310
.310
.063
.050 X 45.00°
1.036
2.054
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.295
.975
1.343
1.993
2.361
2.594
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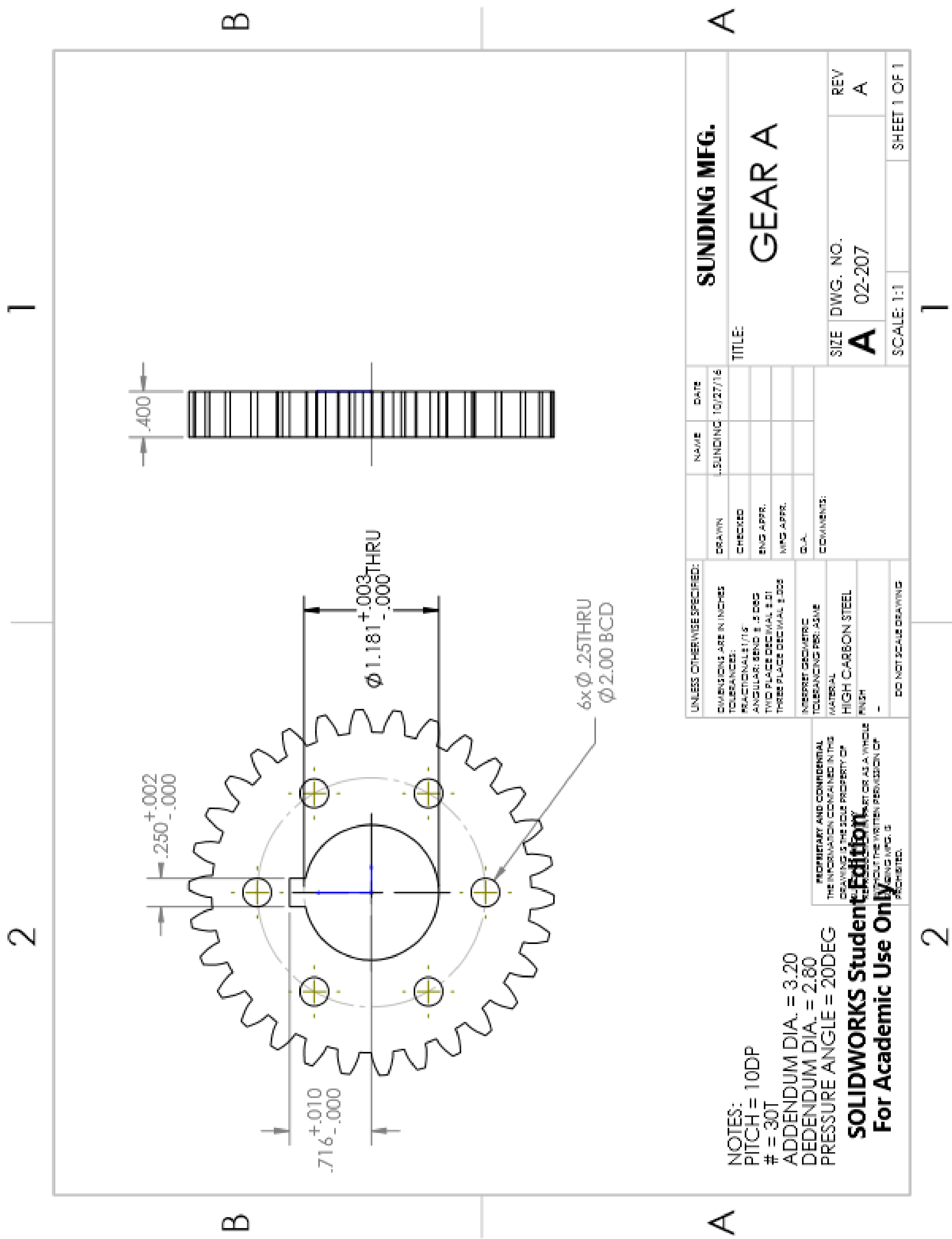
3.514
A
B
1
2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DEDENDUM DIA. = 2.80
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.250 +.002 -.000
Ø1.181 +.003 -.000 THRU
6x Ø .25THRU
Ø 2.00 BCD
.400
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TITLE:
GEAR A
SIZE A
DWG. NO. 02-207
REV A
SCALE: 1:1
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
MATERIAL
HIGH CARBON STEEL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
SOLIDWORKS Student Edition.
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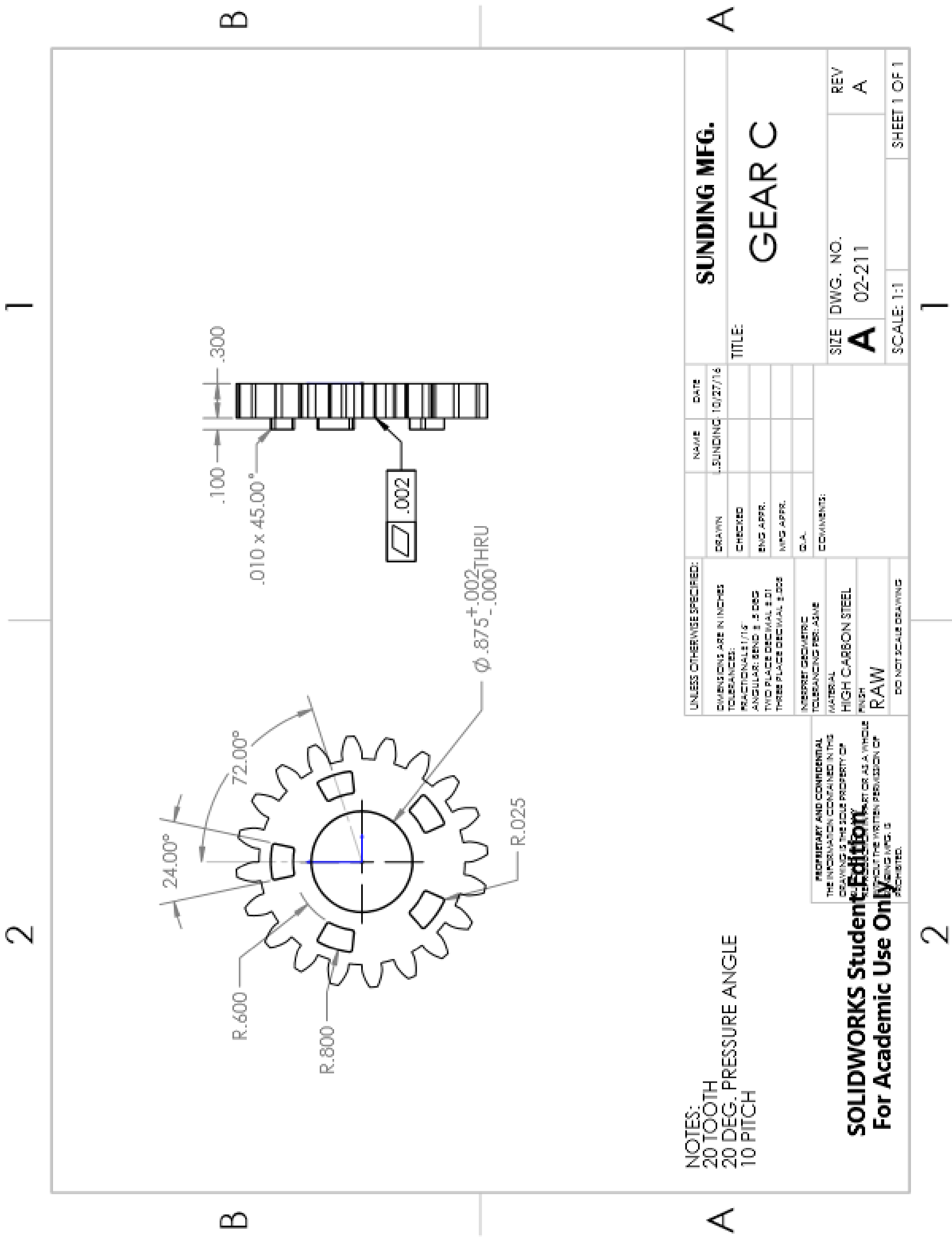
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20 DEG. PRESSURE ANGLE
10 PITCH
R.600
R.800
24.00°
72.00°
R.025
Ø.875 +.002 -.000 THRU
.010 x 45.00°
.100
.300
.002
SUNDING MFG.
TITLE:
GEAR C
SIZE
A
DWG. NO.
02-211
REV
A
SCALE: 1:1
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
HIGH CARBON STEEL
FINISH
RAW
DO NOT SCALE DRAWING
DRAWN
L.SUNDING
10/27/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Student Edition.
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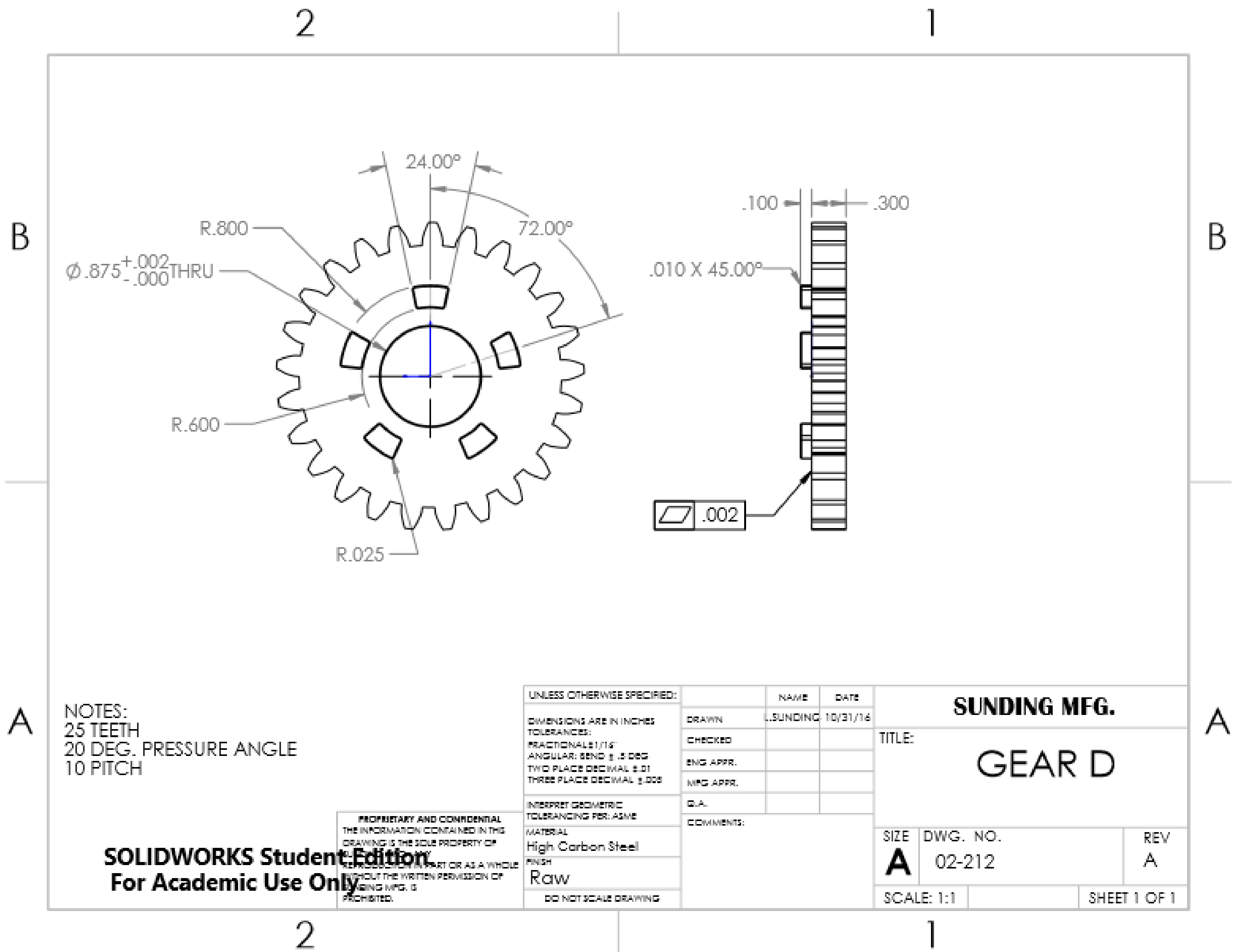
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72.00°
R.800
Ø.875 +.002 -.000 THRU
R.600
R.025
.100
.300
.010 X 45.00°
.002
NOTES:
25 TEETH
20 DEG. PRESSURE ANGLE
10 PITCH
SOLIDWORKS Student Edition.
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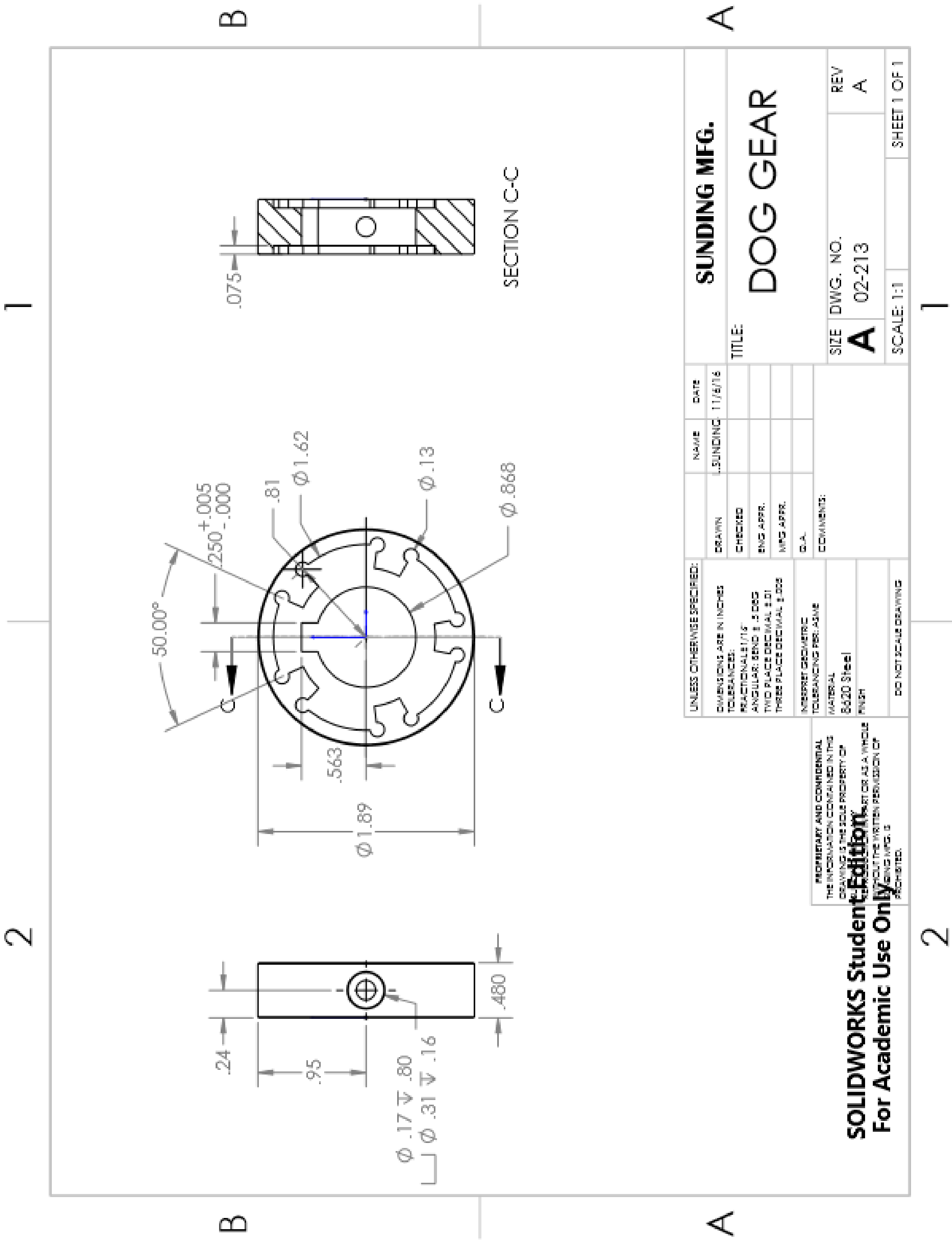
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/16"
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
High Carbon Steel
FINISH
Raw
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
L.SUNDING
10/31/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
SUNDING MFG.
TITLE:
GEAR D
SIZE
A
DWG. NO.
02-212
REV
A
SCALE: 1:1
SHEET 1 OF 1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TITLE:
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SIZE A
DWG. NO. 02-213
REV A
SCALE: 1:1
SHEET 1 OF 1
SECTION C-C
MATERIAL
8620 Steel
DRAWN
.SUNDING 11/6/16
UNLESS OTHERWISE SPECIFIED:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Student Edition.
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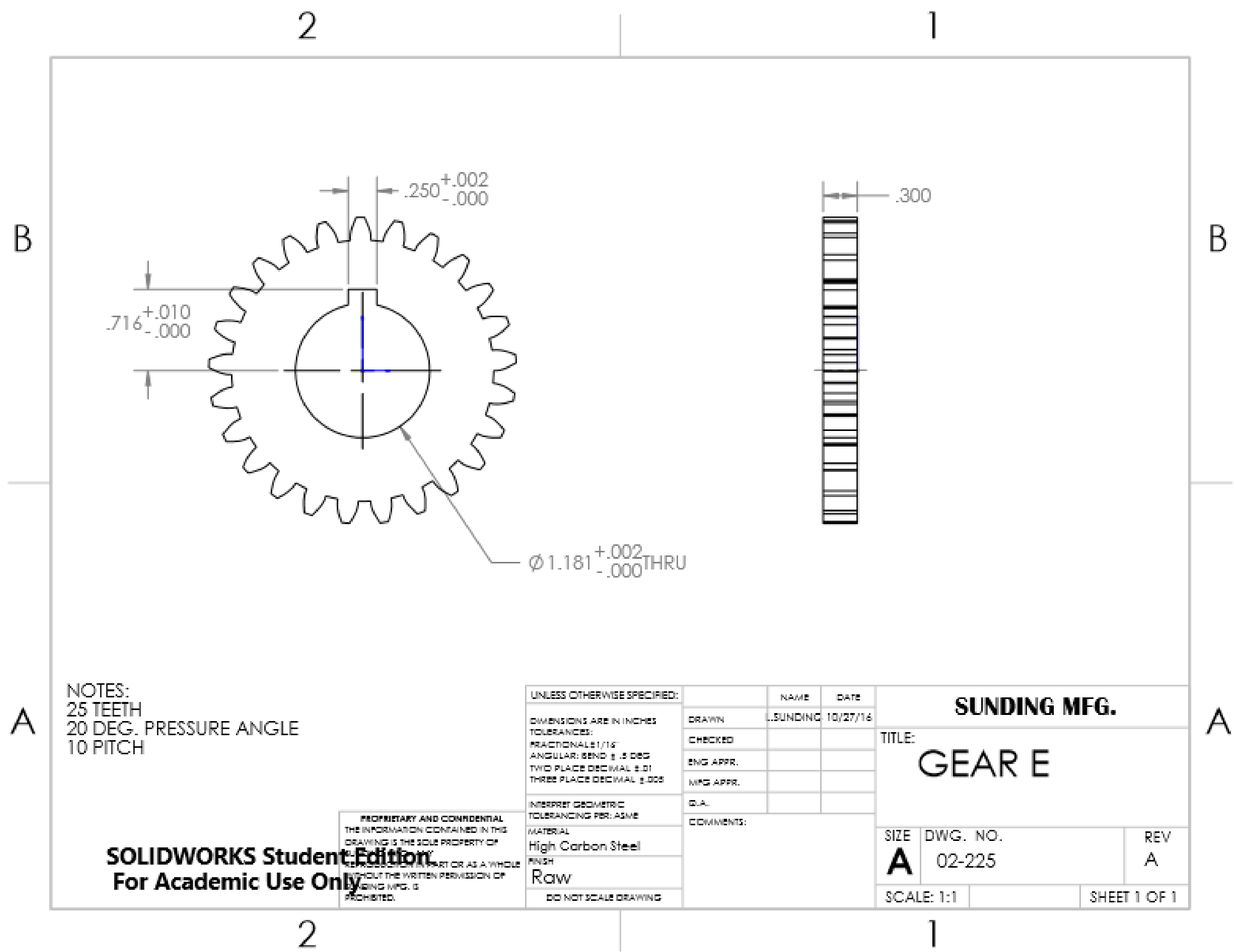
50.00°
.250 +.005 -.000
.81
Ø1.62
Ø.13
Ø.868
.563
Ø1.89
.075
.24
.95
.480
Ø .17 ↧ .80
⌴ Ø .31 ↧ .16



.250 +.002 -.000
.716 +.010 -.000
Ø1.181 +.002 -.000 THRU
.300
NOTES:
25 TEETH
20 DEG. PRESSURE ANGLE
10 PITCH
SOLIDWORKS Student Edition
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/16
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
High Carbon Steel
FINISH
Raw
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
.SUNDING
10/27/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
SUNDING MFG.
TITLE:
GEAR E
SIZE
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DWG. NO.
02-225
REV
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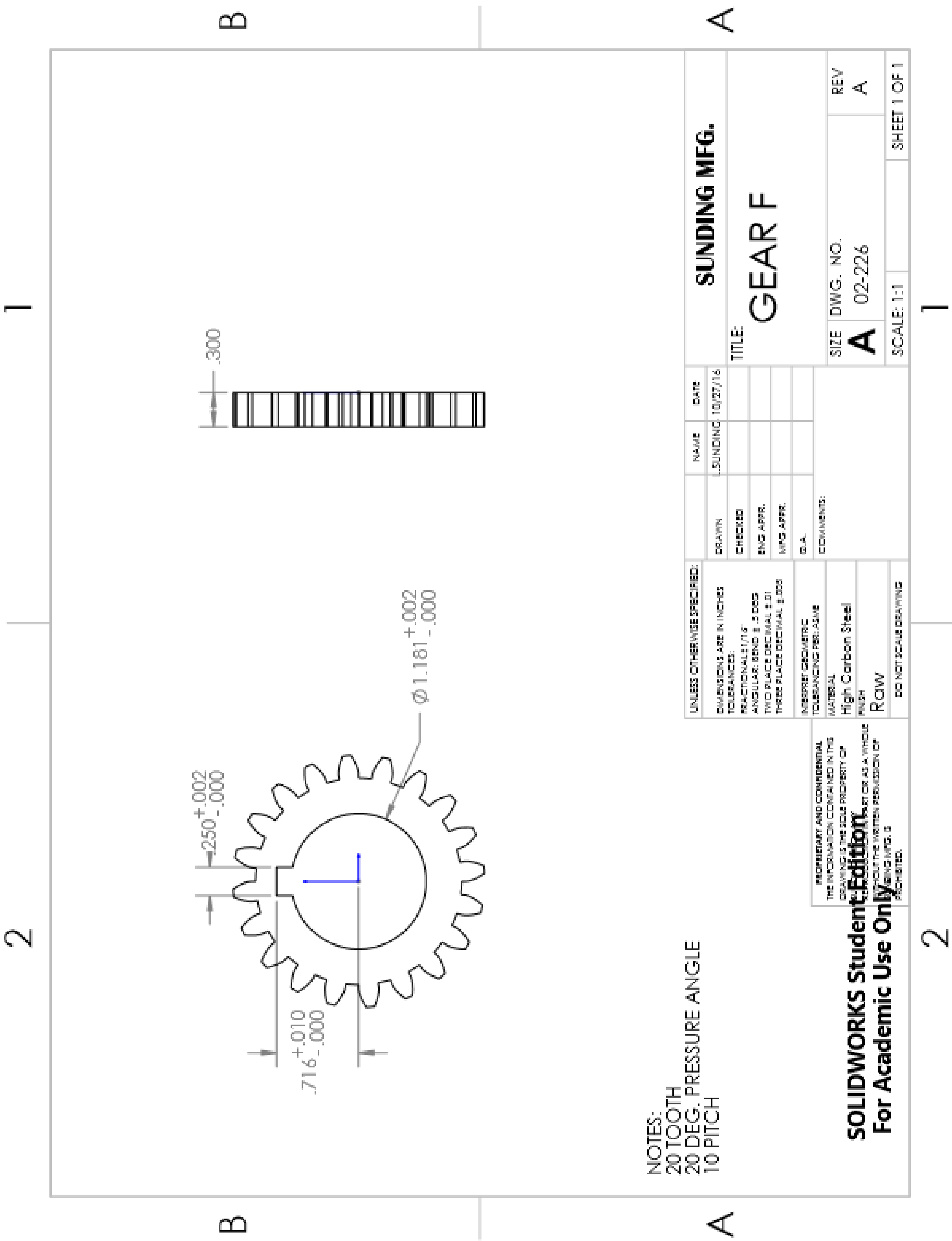
SCALE: 1:1
SHEET 1 OF 1


B
A
2
1
NOTES:
20 TOOTH
20 DEG. PRESSURE ANGLE
10 PITCH
.716+.010 -.000
.250+.002 -.000
Ø1.181+.002 -.000
.300
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
High Carbon Steel
FINISH
Raw
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
DRAWN
L.SUNDING
10/27/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
SUNDING MFG.
TITLE:
GEAR F
SIZE
A
DWG. NO.
02-226
REV
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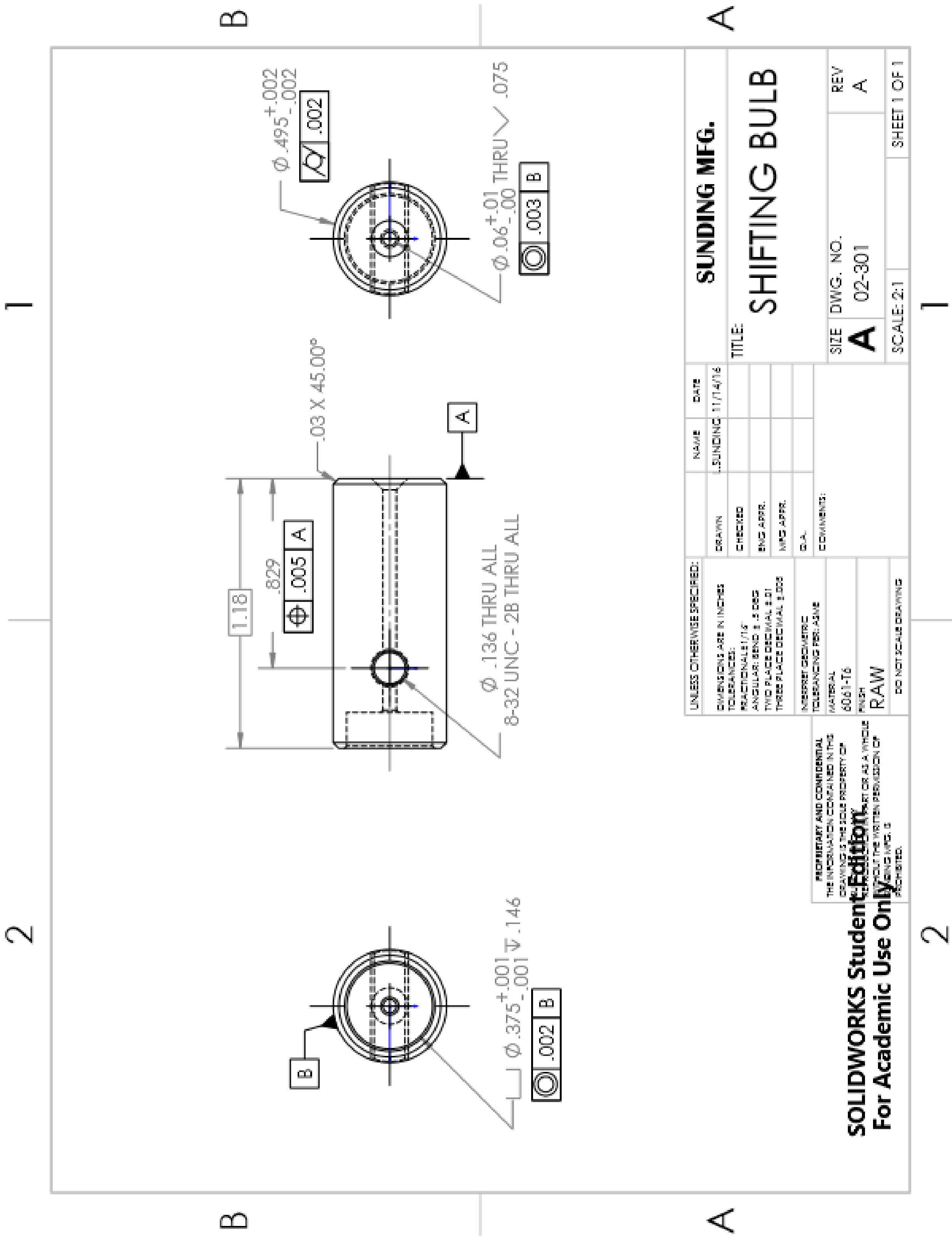
SCALE: 1:1
SHEET 1 OF 1


SUNDING MFG.
TITLE:
SHIFTING BULB
SIZE A
DWG. NO. 02-301
REV A
SCALE: 2:1
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
6061-T6
FINISH
RAW
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
1.18
.829
.005 A
.03 X 45.00°
Ø .136 THRU ALL
8-32 UNC - 2B THRU ALL
Ø.495 +.002 -.002
.002
Ø.06 +.01 -.00 THRU .075
.003 B
Ø.375 +.001 -.001 .146
.002 B
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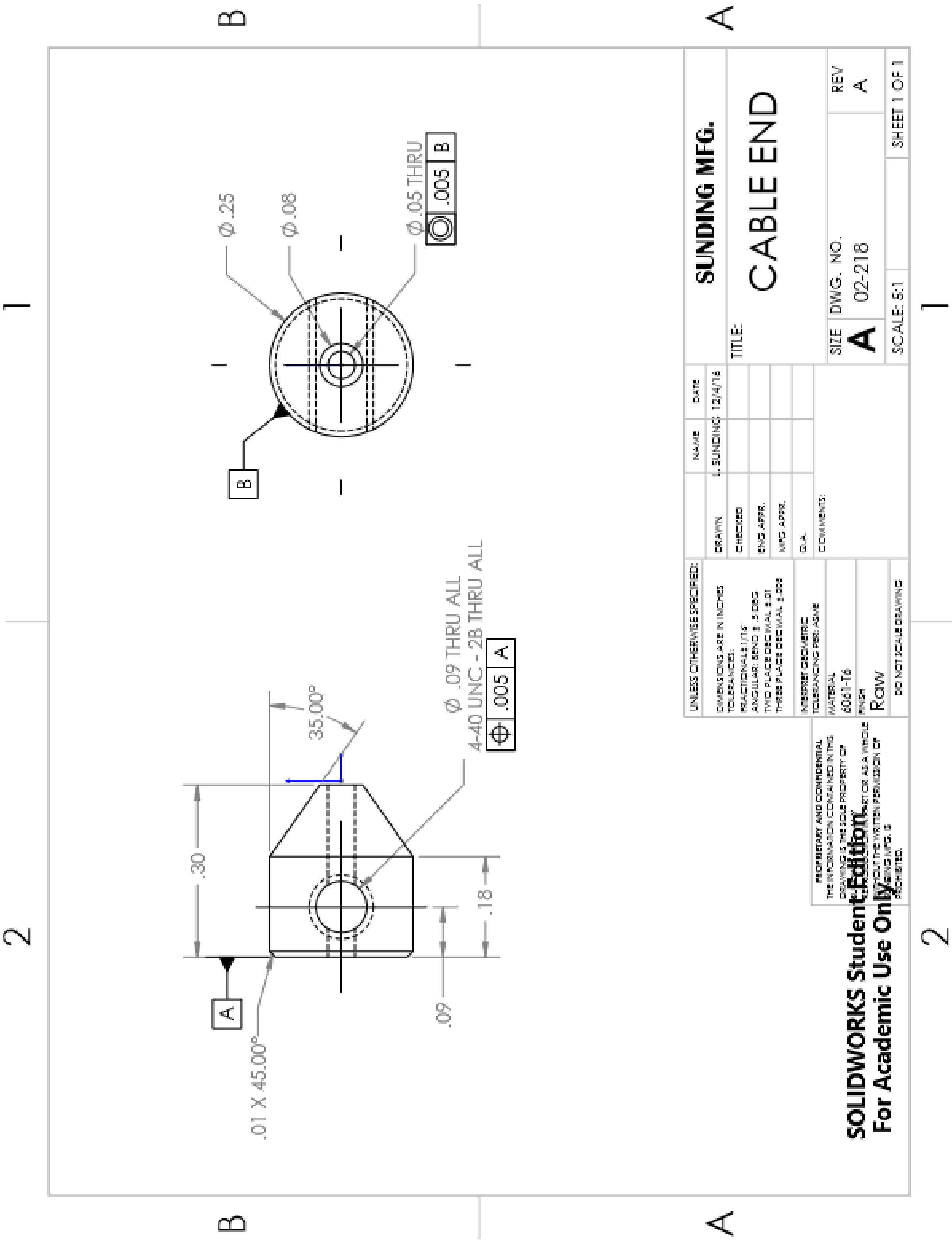

SUNDING MFG.
TITLE:
CABLE END
SIZE A
DWG. NO. 02-218
REV A
SCALE: 5:1
SHEET 1 OF 1
DRAWN I. SUNDING 12/4/16
NAME
DATE
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
MATERIAL
6061-T6
FINISH
Raw
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
Ø .25
Ø .08
Ø .05 THRU
.005 B
B
A
.01 X 45.00°
.30
.18
.09
35.00°
Ø .09 THRU ALL
4-40 UNC - 2B THRU ALL
.005 A
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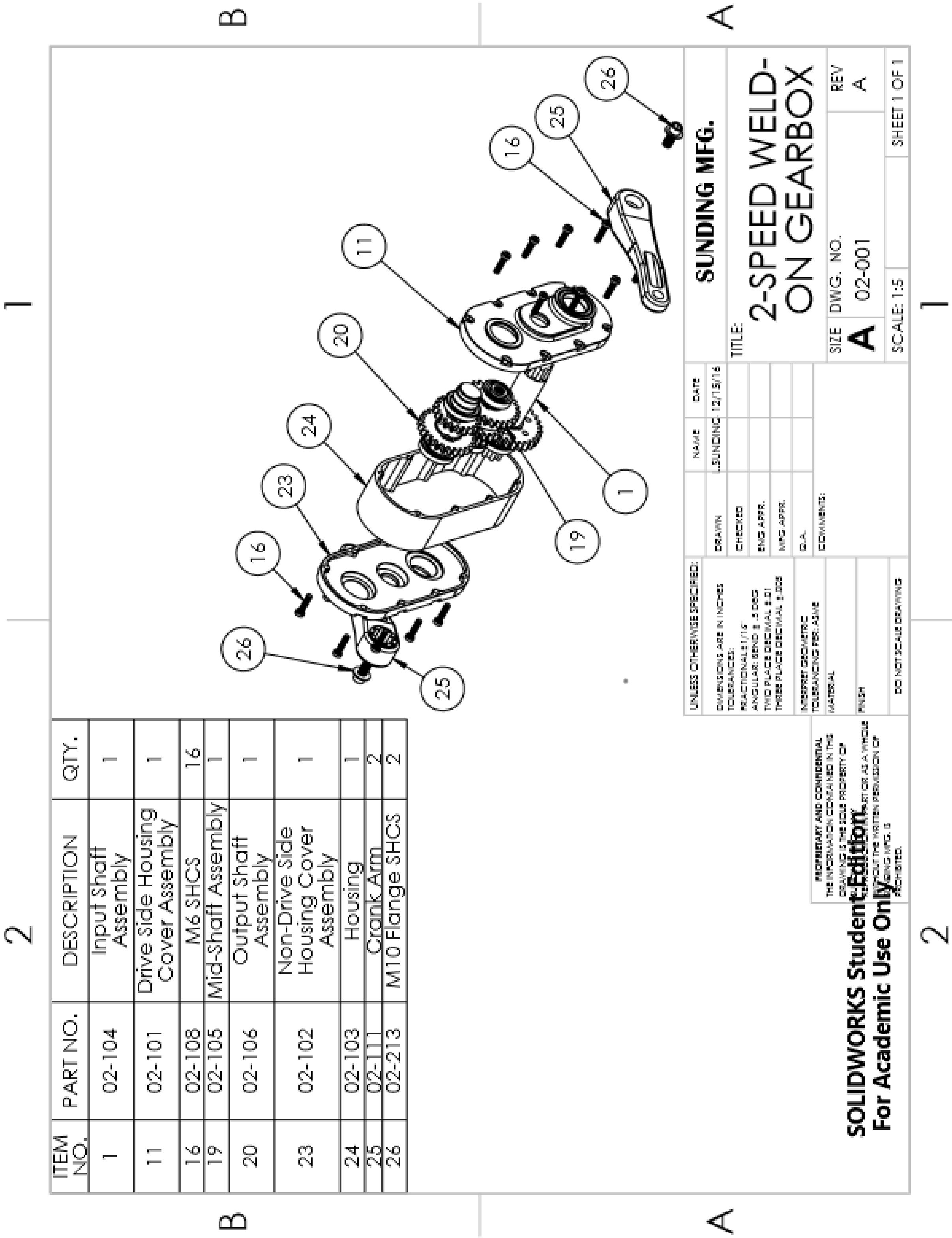
C) Assembly Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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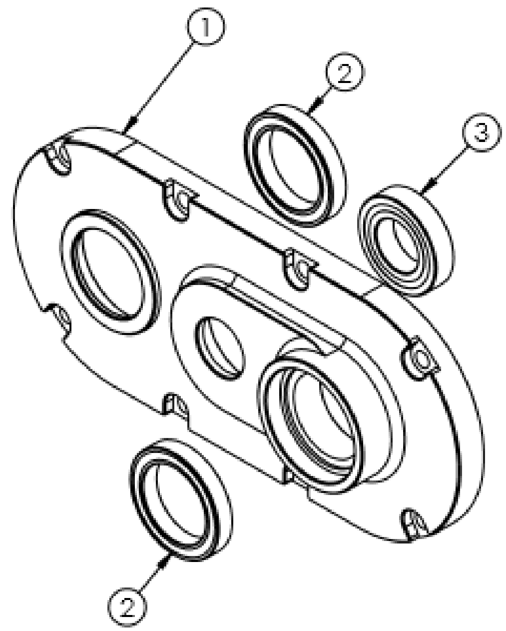
2	02-203	6904 Bearing	2
3	02-202	6806 Bearing	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/16"
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
FINISH
DO NOT SCALE DRAWING

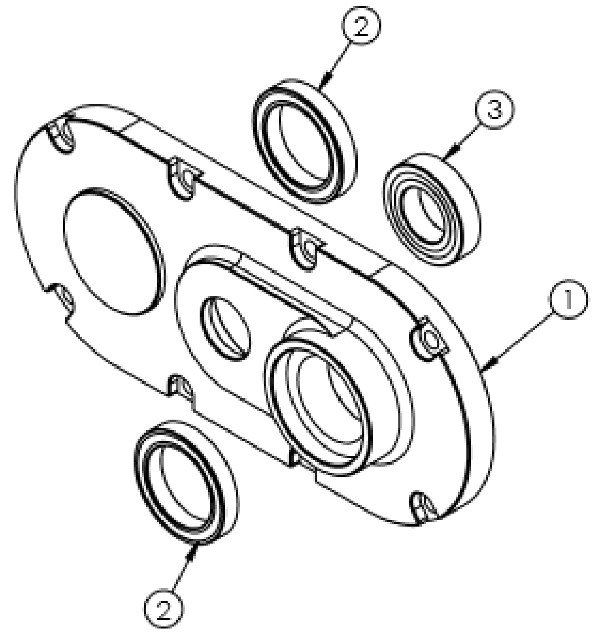
	NAME	DATE
DRAWN	12/1/16	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

SUNDING MFG.

TITLE:
DRIVE SIDE HOUSING COVER ASSEMBLY

SIZE A | DWG. NO. 02-101 | REV A
SCALE: 1:2 | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-204	Non-Drive Side Housing Cover	1
2	02-203	6904 Bearing	2
3	02-202	6806 Bearing	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/16"
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ASME
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	L.SUNDING	12/15/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

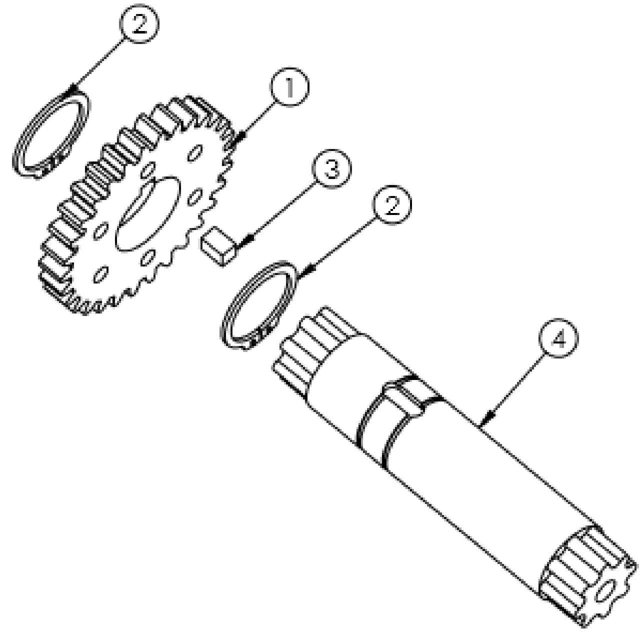
SUNDING MFG.

TITLE: NON-DRIVE SIDE HOUSING COVER ASSEMBLY

SIZE A | DWG. NO. 02-102 | REV A

SCALE: 1:2 | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-207	30 Tooth (A Gear)	1
2	02-206	30mm Retaining Ring	2
3	02-208	.25"x.25"x.39" undersize key	1
4	02-205	Input Shaft	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	I. SUNDING	12/5/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

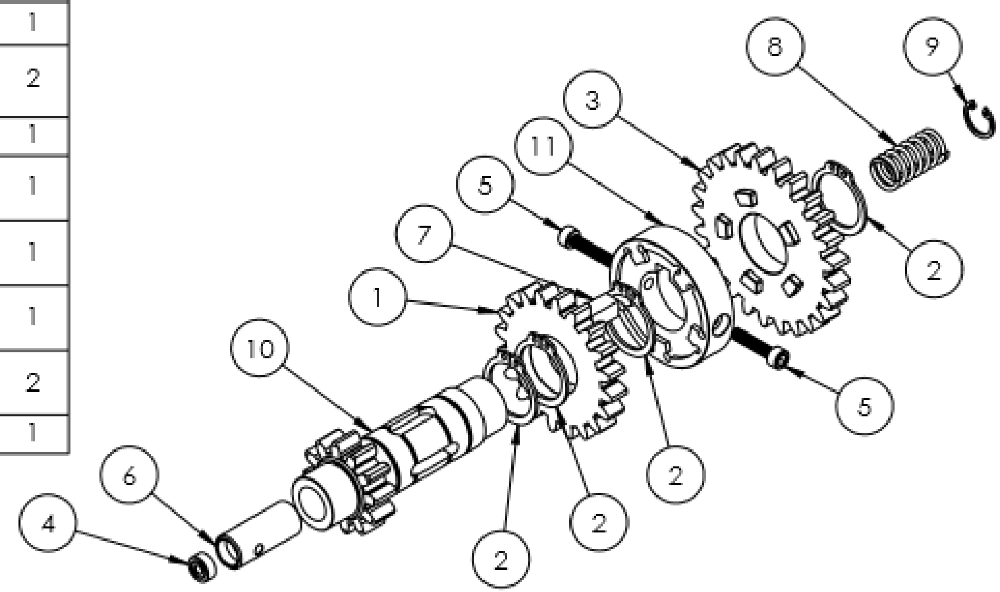
SUNDING MFG.

TITLE: INPUT SHAFT ASSEMBLY

SIZE A | DWG. NO. 02-204 | REV A

SCALE: 1:2 | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-211	20 Tooth (C)	1
2	02-210	.875" External Retaining Ring	4
3	02-212	25 Tooth (D)	1
4	02-302	R2-2Z Bearing	1
5	02-220	8-32 SHCS, .75in long	2
6	02-301	Shifting Bulb Body	1
7	02-214	.25"x.25"x.5" undersize key	1
8	02-216	Spring	1
9	02-215	.5" Internal Retaining Ring	1
10	02-209	Midshaft	2
11	02-213	Dog Tooth Gear	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER: ASME

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	I. SUNDING	12/5/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

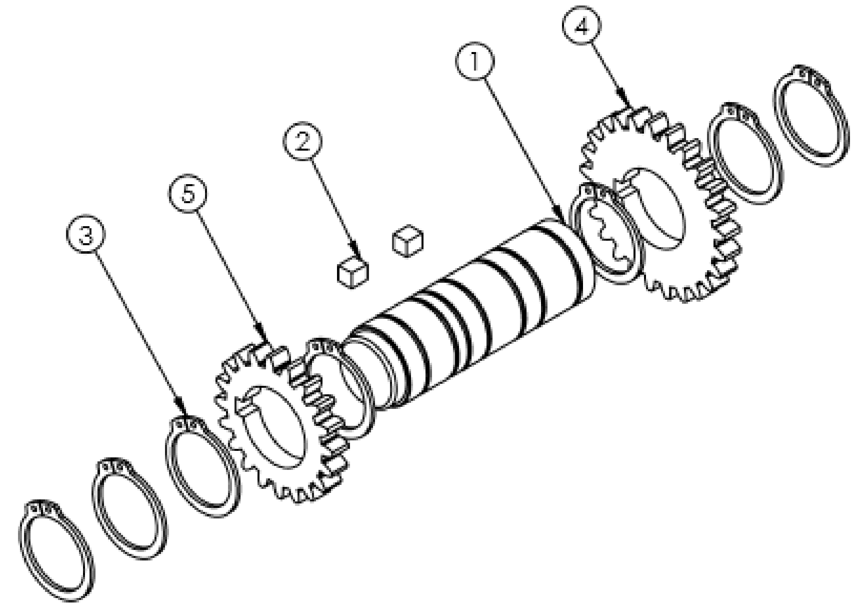
SUNDING MFG.

TITLE: MID-SHAFT ASSEMBLY

SIZE: A | DWG. NO. 02-105 | REV A

SCALE: 1:2 | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-222	OUTPUT SHAFT	1
2	02-224	.25X.25X.29 KEY	2
3	02-206	30MM RETAINING RING	7
4	02-225	25 TOOTH (E GEAR)	1
5	02-226	20 TOOTH (F GEAR)	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/16"
ANGULAR: BEND ± .5 DEG
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	L.SUNDING	12/12/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUNDING MFG.

TITLE:

OUTPUT SHAFT ASSEMBLY

SIZE A | DWG. NO. 02-106 | REV A

SCALE: 1:2 | SHEET 1 OF 1

D) Routing Files

Company	Sunding MFG.	Prepared By	Loren Sunding
Product	2 Speed Gearbox	Date	12/6/2016
Part Name	Housing	Part Number	02-103
Material	2.0"x4.0" 1018 Steel Bar Stock	Production Quantity	

Operation No.	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut stock to 8.5"	Horizontal Band Saw	Ruler	0.016	0.133
20	Face	Haas VF-2 CNC Mill	3.0" dia. 4 flute face mill	0.25	0.1
21	Outer Profile Rough	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.216
22	Pocket Rough	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.666
23	Outer Profile Finish	Haas VF-2 CNC Mill	.75" dia. 3 flute HSS endmill	0	0.1
24	Pocket Finish	Haas VF-2 CNC Mill	.75" dia. 3 flute HSS endmill	0	0.133
25	Center Drill Tap Holes	Haas VF-2 CNC Mill	#4 HSS center drill	0	0.008
26	Drill Tap Holes	Haas VF-2 CNC Mill	#4 HSS stub drill	0	0.066
27	Tap Holes	Haas VF-2 CNC Mill	M6x1 machine tap	0	0.066
28	Chamfer Edges	Haas VF-2 CNC Mill	.25" dia. 90deg. Carbide chamfer mill	0	0.05
30	Face	Haas VF-2 CNC Mill	3.0" dia. 4 flute face mill	0.083	0.1
31	Outer Profile Rough	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.216
32	Pocket Rough	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.666
33	Outer Profile Finish	Haas VF-2 CNC Mill	.75" dia. 3 flute HSS endmill	0	0.1
34	Pocket Finish	Haas VF-2 CNC Mill	.75" dia. 3 flute HSS endmill	0	0.133
35	Center Drill Tap Holes	Haas VF-2 CNC Mill	#4 HSS center drill	0	0.008
36	Drill Tap Holes	Haas VF-2 CNC Mill	#4 HSS stub drill	0	0.066
37	Tap Holes	Haas VF-2 CNC Mill	M6x1 machine tap	0	0.066
38	Chamfer Edges	Haas VF-2 CNC Mill	.25" dia. 90deg. Carbide chamfer mill	0	0.05
40	Clean	-	Towel and Simple Green	0	0.016
50	Inspection	Zeiss CMM	-	0.5	0.116
			TOTALS	0.849	3.075

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Non-Driveside Housing Cover		Part Number	02-204	
Material	1.5"x5.0" 6061-T6 Barstock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut Stock to 8.5"	Horizontal Band Saw	Ruler	0.016	0.083
20	Rough Clear 1	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0.25	0.083
21	Rough Profile	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.083
22	Rough Clear 2	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.083
23	Input Shaft Support Radius Clear	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
24	Face Mid Shaft Support	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.016
25	Input Shaft Bearing Bore (.010"undersize)	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.033
26	Mid Shaft Clearance Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.016
27	Input Shaft Support Radius Finish	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute ball endmill	0	0.041
28	Mid Shaft Support Radius Finish	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute ball endmill	0	0.05
29	Output Shaft Support Finish	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute ball endmill	0	0.033
30	Center Drill	Haas VF-2 CNC Mill	#3 HSS Center drill	0	0.016
31	M6 Bolt Clearance Hole Drill	Haas VF-2 CNC Mill	.25" dia. HSS Stub drill	0	0.041
32	M6 Bolt Head Clearance Pocket	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute endmill	0	0.041
33	Gap Clear	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute endmill	0	0.033
34	Finish Surface	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute endmill	0	0.05
35	Input Shaft Suport Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
36	Output Shaft Support Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
37	Profile Finish	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
38	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. Carbide chamfer mill	0	0.05
39	Engrave	Haas VF-2 CNC Mill	.25" dia. 60deg. Carbide engrave tool	0	0.016
40	Facing Pass	Haas VF-2 CNC Mill	3.0" dia. 4 flute face mill	0.166	0.083
41	Clearance Pocket	Haas VF-2 CNC Mill	.75" dia. HSS 3 flute end mill	0	0.15
42	Input Shaft Clearance Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.033
43	Mid Shaft Bearing Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.033
44	Output Shaft Bearing Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.066
45	Input Shaft Retaining Ring Clearance	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.016
46	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. Carbide chamfer mill	0	0.05
50	Clean	-	Towel and Simple Green	0	0.016
60	Inspection	Zeiss CMM	-	0.5	0.116
			TOTAL	0.932	1.395

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Driveside Housing Cover		Part Number	02-201	
Material	1.5"x5.0" 6061-T6 Barstock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut Stock to 8.5"	Horizontal Band Saw	Ruler	0.016	0.083
20	Rough Clear 1	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0.25	0.083
21	Rough Profile	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.083
22	Rough Clear 2	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.083
23	Input Shaft Support Radius Clear	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
24	Face Mid Shaft Support	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.016
25	Input Shaft Bearing Bore (.010"undersize)	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.033
26	Mid Shaft Clearance Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.016
27	Input Shaft Support Radius Finish	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute ball endmill	0	0.041
28	Mid Shaft Support Radius Finish	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute ball endmill	0	0.05
29	Output Shaft Support Finish	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute ball endmill	0	0.033
30	Center Drill	Haas VF-2 CNC Mill	#3 HSS Center drill	0	0.016
31	M6 Bolt Clearance Hole Drill	Haas VF-2 CNC Mill	.25" dia. HSS Stub drill	0	0.041
32	M6 Bolt Head Clearance Pocket	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute endmill	0	0.041
33	Gap Clear	Haas VF-2 CNC Mill	.25" dia. HSS 2 flute endmill	0	0.033
34	Finish Surface	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute endmill	0	0.05
35	Output Shaft Clearance Hole	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute endmill	0	0.016
36	Input Shaft Suport Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
37	Output Shaft Support Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
38	Profile Finish	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0	0.016
39	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. Carbide chamfer mill	0	0.05
40	Engrave	Haas VF-2 CNC Mill	.25" dia. 60deg. Carbide engrave tool	0	0.016
50	Facing Pass	Haas VF-2 CNC Mill	3.0" dia. 4 flute face mill	0.166	0.083
51	Clearance Pocket	Haas VF-2 CNC Mill	.75" dia. HSS 3 flute end mill	0	0.15
52	Input Shaft Clearance Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.033
53	Mid Shaft Bearing Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.033
54	Output Shaft Bearing Bore	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.066
55	Input Shaft Retaining Ring Clearance	Haas VF-2 CNC Mill	.5" dia. HSS 2 flute end mill	0	0.016
56	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. Carbide chamfer mill	0	0.05
60	Clean	-	Towel and Simple Green	0	0.016
70	Inspection	Zeiss CMM	-	0.5	0.116
			TOTAL	0.932	1.411

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Input Shaft		Part Number	02-205	
Material	1.5" dia. 6061-T6 Bar Stock		Production Quantity		
Operation No.	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Facing Pass	Haas ST-10	CNMG-432	0.25	0.006
11	Rough and F	Haas ST-10	CNMG-432	0	0.025
12	Center Drill	Haas ST-10	#3 Center Drill	0	0.008
13	Peck Drill	Haas ST-10	8.5mm Jobber Drill	0	0.016
14	Spline	Haas ST-10	Axial Live, .25" dia. HSS 1deg tapered end mill	0	0.216
15	Key Slot	Haas ST-10	Radial Live, .25" dia. HSS end mill, 2 flute	0	0.033
16	Part Off	Haas ST-10	.12" wide carbide parting tool	0	0.025
20	Facing Pass	Haas ST-10	CNMG-432	0.166	0.006
21	Rough and F	Haas ST-10	CNMG-432	0	0.025
22	Center Drill	Haas ST-10	#3 Center Drill	0	0.008
23	Peck Drill	Haas ST-10	8.5mm Jobber Drill	0	0.016
24	Spline	Haas ST-10	Axial Live, .25" dia. HSS 1deg tapered end mill	0	0.216
30	Groove	Manual Lathe	.063" wide grooving tool	0.166	0.083
40	Debur	-	File, machinists knife	0	0.033
50	Inspection	Optical Scanner	Micrometers	0.166	0.083
			TOTAL	0.748	0.799

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	A Gear		Part Number	02-207	
Material	Steel 30T 10P 20PA Gear Stock		Production Quantity		
Operation No.	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut Stock to .45"	Horizontal Band Saw	Ruler	0.016	0.083
20	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0.25	0.066
21	Drill	Haas VF-2 CNC Mill	.25" HSS Stub Drill	0	0.0416
22	Bore	Haas VF-2 CNC Mill	.5" dia. 4 flute carbide endmill	0	0.133
23	Chamfer	Haas VF-2 CNC Mill	.25" 90deg. Chamfer tool	0	0.016
30	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide endmill	0.05	0.066
31	Chamfer	Haas VF-2 CNC Mill	.25" 90deg. Chamfer tool	0	0.016
40	Inspection	-	Inside Micrometer	0	0.016
50	Broach	Arbor Press	.25" square push broach and shims	0.041	0.083
60	Debur	-	Jeweler's File Set	0	0.083
			TOTAL	0.357	0.6036

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Mid Shaft		Part Number	02-209	
Material	1.5" dia. 8620 Steel Rod		Production Quantity		
Operation No.	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut stock to 3.5"	Horizontal Band Saw	Ruller	0.033	0.05
20	Face	Haas ST-10 CNC Lathe	CNMG -432	0.25	0.008
21	Turn Profile	Haas ST-10 CNC Lathe	CNMG -432	0	0.033
22	Center Drill	Haas ST-10 CNC Lathe	#3 Center Drill	0	0.025
23	Drill	Haas ST-10 CNC Lathe	31/64" HSS Jobber Drill	0	0.041
30	Face	Haas ST-10 CNC Lathe	CNMG -432	0.166	0.008
31	Turn Profile	Haas ST-10 CNC Lathe	CNMG -432	0	0.025
32	Center Drill	Haas ST-10 CNC Lathe	#3 Center Drill	0	0.025
33	Drill	Haas ST-10 CNC Lathe	31/64" HSS Jobber Drill	0	0.041
40	Inspection	-	Micrometer	0	0.033
50	Bore	Haas TL-1 CNC Lathe	.375" boring bar	0.166	0.083
51	Grooving	Haas TL-1 CNC Lathe	.063" grooving tool	0	0.1
60	Gear Cutting	Haas VF-2 CNC Mill, 4th Axis	#8 10P Involute Gear Cutter	0.5	0.667
70	Slotting	Haas VF-2 CNC Mill, 4th Axis	.25" dia. 4 Flute carbide endmill	0	0.083
80	Debur	-	Jeweler's File Set	0	0.133
90	Inspection	-	Calipers	0	0.083
			Total	1.115	1.438

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Gear C		Part Number	02-211	
Material	Steel 20T 10P 20PA Gear Stock		Production Quantity		
Operation No.	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut to .5in	Horizontal Band Saw	Ruler	0.033	0.05
20	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide insert endmill	0.166	0.033
21	Profile Dog Teeth	Haas VF-2 CNC Mill	.25" dia. 4 flute carbide endmill	0	0.116
22	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. carbide chamfer mill	0	0.012
30	Debur	-	Jeweler's File Set	0	0.083
40	Inspect	Optical Scanner	-	0.116	0.033
			TOTAL	0.315	0.327

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Gear D		Part Number	02-212	
Material	Steel 25T 10P 20PA Gear Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut to .5in	Horizontal Band Saw	Ruler	0.033	0.05
20	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide insert endmill	0.166	0.033
21	Profile Dog Teeth	Haas VF-2 CNC Mill	.25" dia. 4 flute carbide endmill	0	0.116
22	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. carbide chamfer mill	0	0.012
30	Debur	-	Jeweler's File Set	0	0.083
40	Inspect	Optical Scanner	-	0.116	0.033
			TOTAL	0.315	0.327

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Dog Tooth Gear		Part Number	02-213	
Material	2.0" Dia. 8620 Steel Bar Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut to .5in	Horizontal Band Saw	Ruler	0.033	0.05
20	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide insert endmill	0.166	0.033
21	Bore	Haas VF-2 CNC Mill	.5" dia. 4 flute carbide endmill	0	0.133
22	Drill	Haas VF-2 CNC Mill	.125" HSS Stub Drill	0	0.041
23	Profile Dog Grooves	Haas VF-2 CNC Mill	.25" dia. 4 flute carbide endmill	0	0.116
24	Finish Dog Grooves	Haas VF-2 CNC Mill	.125" dia. 2 flute HSS endmill	0	0.075
25	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. carbide chamfer mill	0	0.012
30	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide insert endmill	0.166	0.033
31	Drill	Haas VF-2 CNC Mill	.125" HSS Stub Drill	0	0.041
32	Profile Dog Grooves	Haas VF-2 CNC Mill	.25" dia. 4 flute carbide endmill	0	0.116
33	Finish Dog Grooves	Haas VF-2 CNC Mill	.125" dia. 2 flute HSS endmill	0	0.075
34	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. carbide chamfer mill	0	0.012
40	Counter Bore	Bridgeport Knee Mill	#19 HSS Drill, .25" dia. 4 flute HSS endmill	0.166	0.1
50	Broach	Arbor Press	.25" square push broach and shims	0.041	0.083
60	Debur	-	Jeweler's File Set	0	0.083
70	Inspect	Optical Scanner	-	0.116	0.033
			TOTAL	0.688	1.036

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Shifting Bulb		Part Number	02-301	
Material	.625" Dia. 6061-T6 Bar Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut to 1.25in	Horizontal Band Saw	Ruler	0.033	0.008
20	Face	Haas TL-1 CNC Lathe	CNMG-432	0.166	0.005
21	Turn	Haas TL-1 CNC Lathe	CNMG-432	0	0.012
22	Center Drill	Haas TL-1 CNC Lathe	#3 Center Drill	0	0.008
23	Drill	Haas TL-1 CNC Lathe	.125" HSS Jobber Drill	0	0.041
24	Bore	Haas TL-1 CNC Lathe	.25" dia. HSS 2 flute endmill	0	0.033
25	Part Off	Haas TL-1 CNC Lathe	.12" wide carbide parting tool	0	0.025
30	Debur	-	Machinist's Knife	0	0.025
40	Center Drill	Bridgeport Knee Mill	#3 Center Drill	0.166	0.008
41	Drill	Bridgeport Knee Mill	#29 HSS stub drill	0	0.016
42	Tap	-	8-32 Tap and tap handle	0	0.033
50	Inspection	-	Inside Micrometer, Calipers	0	0.0833
60	Clean	-	Towel and Simple Green	0	0.016
			TOTAL	0.365	0.3133

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Cable End		Part Number	02-218	
Material	.25" Dia. 6061-T6 Bar Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
20	Face	Haas TL-1 CNC Lathe	CNMG-432	0.166	0.005
21	Turn	Haas TL-1 CNC Lathe	CNMG-432	0	0.012
22	Center Drill	Haas TL-1 CNC Lathe	#3 Center Drill	0	0.008
23	Drill	Haas TL-1 CNC Lathe	.125" HSS Jobber Drill	0	0.041
25	Part Off	Haas TL-1 CNC Lathe	.12" wide carbide parting tool	0	0.025
30	Debur	-	Machinist's Knife	0	0.025
40	Center Drill	Bridgeport Knee Mill	#3 Center Drill	0.166	0.008
41	Drill	Bridgeport Knee Mill	#43 HSS stub drill	0	0.016
42	Tap	-	4-40 Tap and tap handle	0	0.033
50	Clean	-	Towel and Simple Green	0	0.016
			TOTAL	0.332	0.189

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Output Shaft		Part Number	02-222	
Material	1.5" dia. 6061-T6 Bar Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
20	Face	Haas TL-1 CNC Lathe	CNMG-432	0.166	0.005
21	Turn	Haas TL-1 CNC Lathe	CNMG-432	0	0.012
22	Thread	Haas TL-1 CNC Lathe	60 deg. Carbide threading tool	0	0.033
23	Drill	Haas TL-1 CNC Lathe	.625" HSS Drill	0	0.025
24	Groove	Haas TL-1 CNC Lathe	.063" wide grooving tool	0	0.2
25	Part Off	Haas TL-1 CNC Lathe	.12" wide carbide parting tool	0	0.025
30	Debur	-	Machinist's Knife	0	0.025
40	Slot	Bridgeport Knee Mill	.25" dia. 2 flute HSS endmill	0.166	0.166
50	Clean	-	Towel and Simple Green	0	0.016
			TOTAL	0.332	0.507

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Gear E		Part Number	02-225	
Material	Steel 25T 10P 20PA Gear Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut to .4in	Horizontal Band Saw	Ruler	0.033	0.05
20	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide insert endmill	0.166	0.033
21	Bore	Haas VF-2 CNC Mill	.5" dia. 4 flute carbide endmill	0	0.1
22	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. carbide chamfer mill	0	0.012
30	Broach	Arbor Press	.25" square push broach and shims	0.041	0.083
40	Debur	-	Jeweler's File Set	0	0.083
50	Inspect	-	Inside Micrometer, Calipers	0	0.033
			TOTAL	0.24	0.394

Company	Sunding MFG.		Prepared By	Loren Sunding	
Product	2 Speed Gearbox		Date	12/6/2016	
Part Name	Gear F		Part Number	02-226	
Material	Steel 20T 10P 20PA Gear Stock		Production Quantity		
Operation No	Description	Machine	Tools	Set Up Time (hrs)	Operation Time (hrs)
10	Cut to .4in	Horizontal Band Saw	Ruler	0.033	0.05
20	Face	Haas VF-2 CNC Mill	1.0" dia. 2 flute carbide insert endmill	0.166	0.033
21	Bore	Haas VF-2 CNC Mill	.5" dia. 4 flute carbide endmill	0	0.1
22	Chamfer	Haas VF-2 CNC Mill	.25" dia. 90deg. carbide chamfer mill	0	0.012
30	Broach	Arbor Press	.25" square push broach and shims	0.041	0.083
40	Debur	-	Jeweler's File Set	0	0.083
50	Inspect	-	Inside Micrometer, Calipers	0	0.033
			TOTAL	0.24	0.394