Machine Theory and Design
Fall 2020

Final Project

Submitted by:

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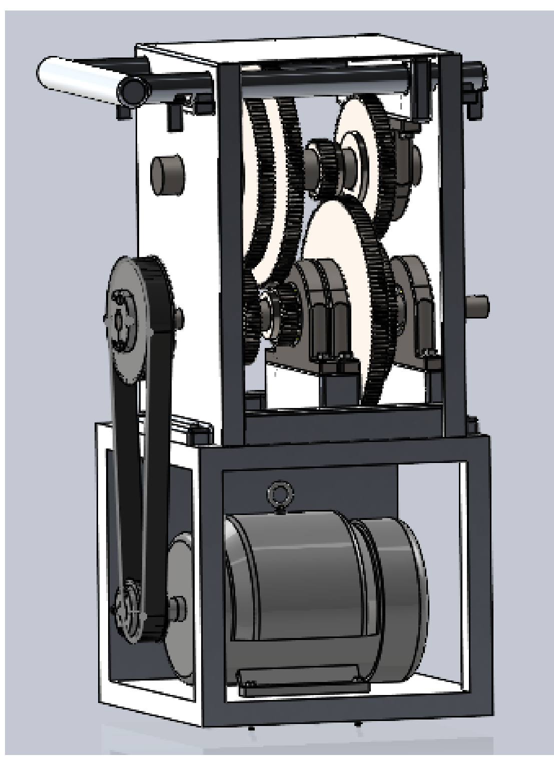

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Problem Statement

The goal of the project is to design a power transmission speed reducer compound reverted gearbox for a prototype heavy duty lathe machine that is capable of two speeds. Starting with the motor delivering a power of 10 horsepower and speed of 1600 rpm, there must include a timing belt between the motor and input shaft with a 2:1 speed ratio, then there includes two sets of gears where one set has an output speed of 400 rpm and the other set has an output speed of 50 rpm. The input and output shafts must be in-line with each other, and each of those shafts must extend 4-in outside the gearbox. The maximum size of the gearbox is 16-in x 16-in base and 24-in height. In order to keep the gearbox mounted, there must be 4 bolts at the base of the gearbox, centered, and 10-in apart. The shaft must achieve infinite life, while the gears and bearings must have a life of 24000 hours. The combined reliability is 90% and the minimum factor of safety is 1.5.

Power and Torque Requirements

Table 1: *Torque Table for* ***High Speed*** *Configuration*

Element	Torque (lbf*in)	RPM	Ft(LBF)	D(in)	Pitch	Teeth(n)	P(hp)
Motor	393.9062	1600					10
Timing belt	787.8125	800					10
Gear 1	787.8125	800	262.6041	6	10	60	10
Gear A	1575.625	400	262.6041	12	10	120	10
Gear D	1575.625	400	350.1388	9	10	90	10
Gear 4	1575.625	400	350.1388	9	10	90	10

Table 2: *Torque Table for **Low Speed** Configuration*

Element	Torque (lbf*in)	RPM	Ft(LBF)	D(in)	Pitch	Teeth(n)	P(hp)
Motor	393.9062	1600					10
Timing belt	787.8125	800					10
Gear 2	787.8125	800	437.6736	3.6	10	36	10
Gear B	3151.25	200	437.6736	14.4	10	144	10
Gear C	3151.25	200	1750.694	3.6	10	36	10
Gear 3	12605	50	1750.694	14.4	10	144	10

Shaft layout

To successfully construct a gearbox that meets the requirements, the design consists of three separate shafts. The shafts include the input, output that are in-line with each other as well as an intermediate shaft. For the spur gears, there are two on the input shaft as well as the output. The intermediate will contain 4 gears in making the design of a multi speed gearbox possible. For the high-speed configuration, gear one on the input shaft meshes with gear A on the intermediate shaft. The power is transmitted through the intermediate shaft where gear D will mesh with gear 4 on the output shaft as depicted below. To transition from high to low speed, the intermediate shaft is shifted to the right to engage gears two and B together on the input shaft side, and gears C and three on the output shaft side. With there being extra space to work with on the intermediate shaft, we were able to move bearing D closer to gear D to provide room for the shaft to shift. By making this change, it will create a smaller bending moment as the reaction force is closer to the forces created by the gears.

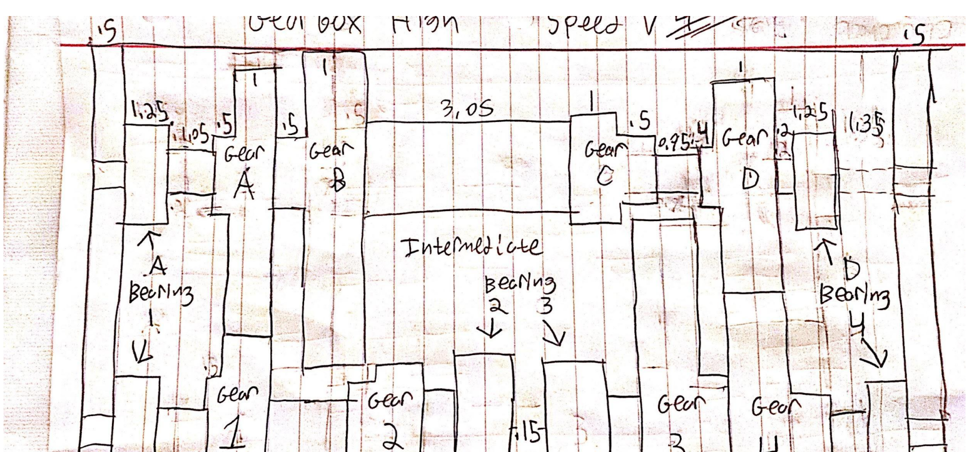


Figure 1: *Initial Gearbox Layout*

Motor Selection

In order to supply power to the gearbox, a motor is required. The problem statement specifies that the selected motor must fulfill two requirements; it has to be able to generate 10 horsepower and it must be able to operate at a speed of 1600 rpm. After evaluating the three motors found on Grainger's catalog, the motors did not fit the criteria. The 208-230/460V AC, NEMA 215T motor found on Mcmaster Carr is the best readily available option that fits the criteria of the project with a rating of 10HP at 1760 RPM, fulfilling the horsepower requirement and getting as close as possible to the rpm requirement.

Another reason for the selection of the 208-230/460V AC, NEMA 215T motor is due to the diameter of the output shaft. The motors shaft diameter is compatible with the 1-3/8" SD Style Quick-Disconnect Bushing used to mount the H-Type 24 tooth timing belt pulley. The reason for the bushing is to alleviate the need for extra shoulders and retaining rings typically needed to mount a pulley to a shaft.

Analysis of Force and Moments

To analyze the forces acting upon each shaft, a free body diagram for each shaft must be drawn. Since the tangential forces (that act on the gears) found from the torque table are at an angle we must take the component force and turn it into a resultant force. This can be done by dividing each tangential force by the cos(20°). Then we can use this force in order to find the reaction forces at the bearings. After we know our reaction forces, we can use the cut method to find out bending moment and shear values which will enable us to make our bending moment and shear diagrams for each shaft. These diagrams will be used to identify the critical locations which will allow us to calculate the minimum diameters. The selection of the critical locations depends on the stress concentrations of the shoulders and keyways.

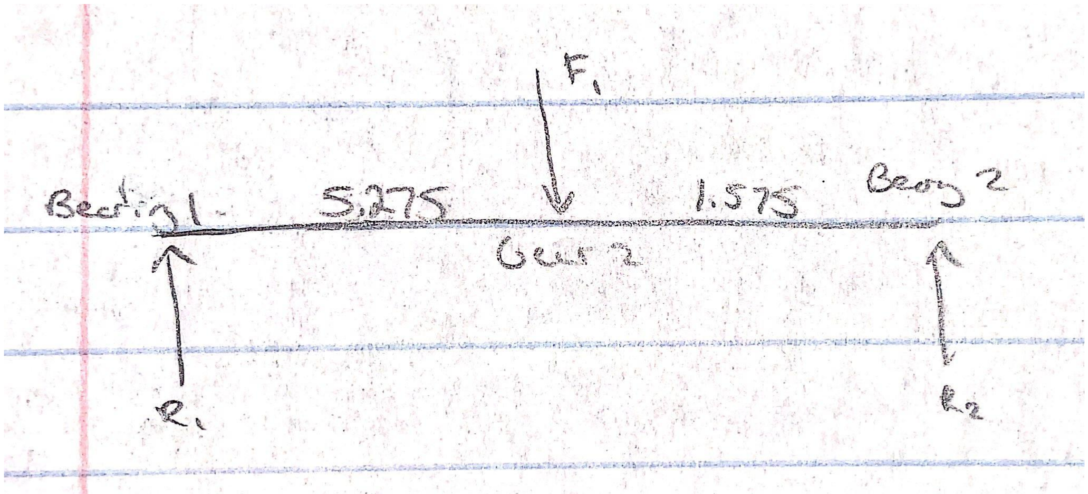


Figure 2: *FBD Input Shaft (Low Speed)*

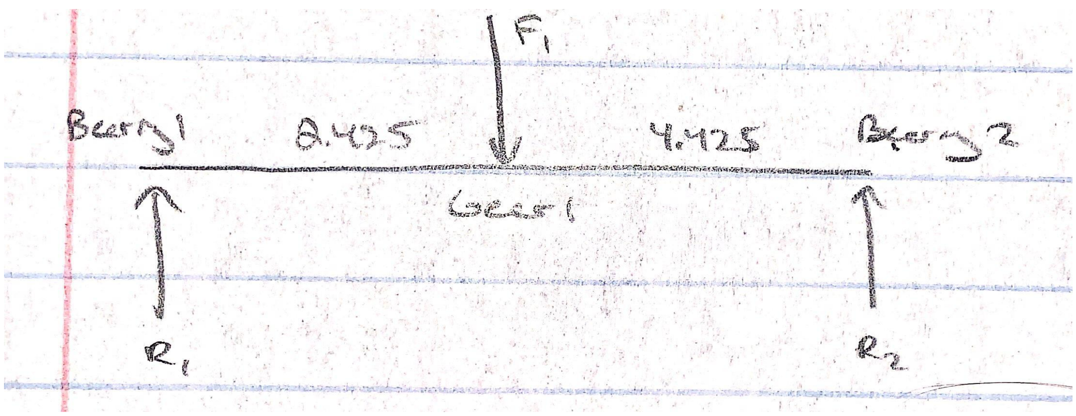


***Figure 3**: FBD Input Shaft (High Speed)*

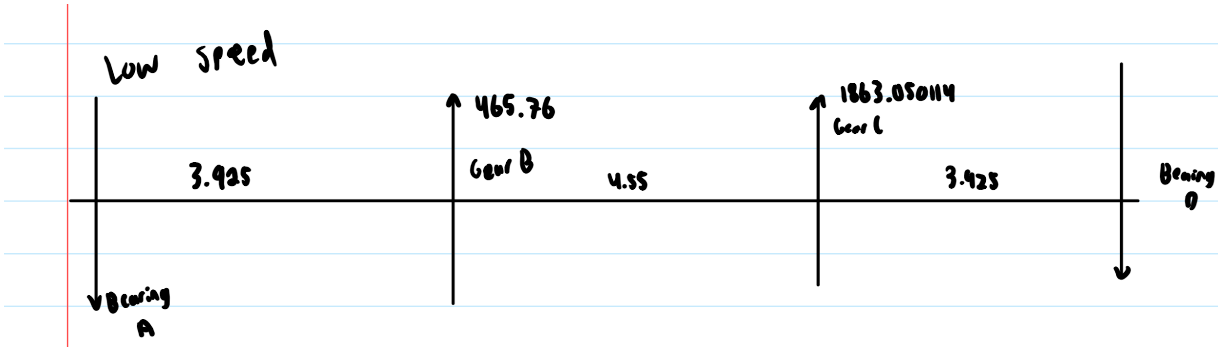


***Figure 4:** FBD Intermediate Shaft (Low Speed)*

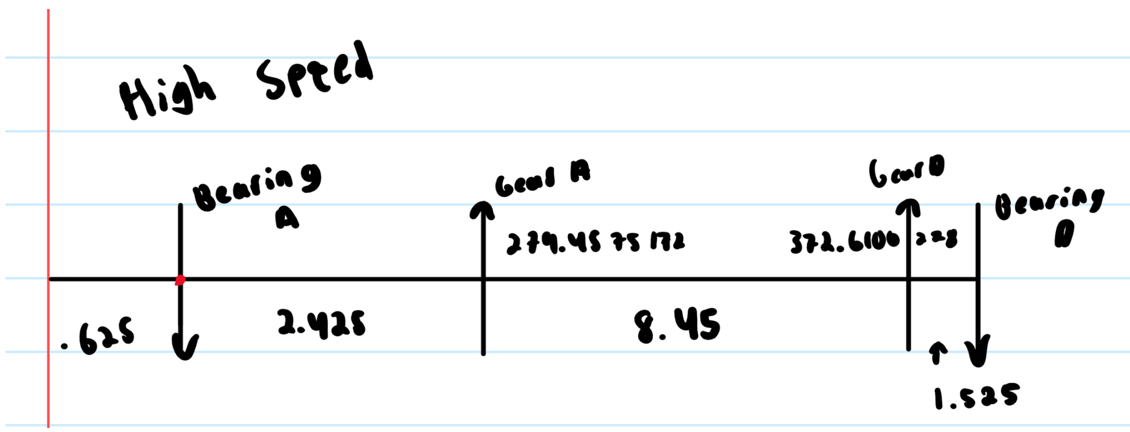


***Figure 5:** FBD Intermediate Shaft (High Speed)*

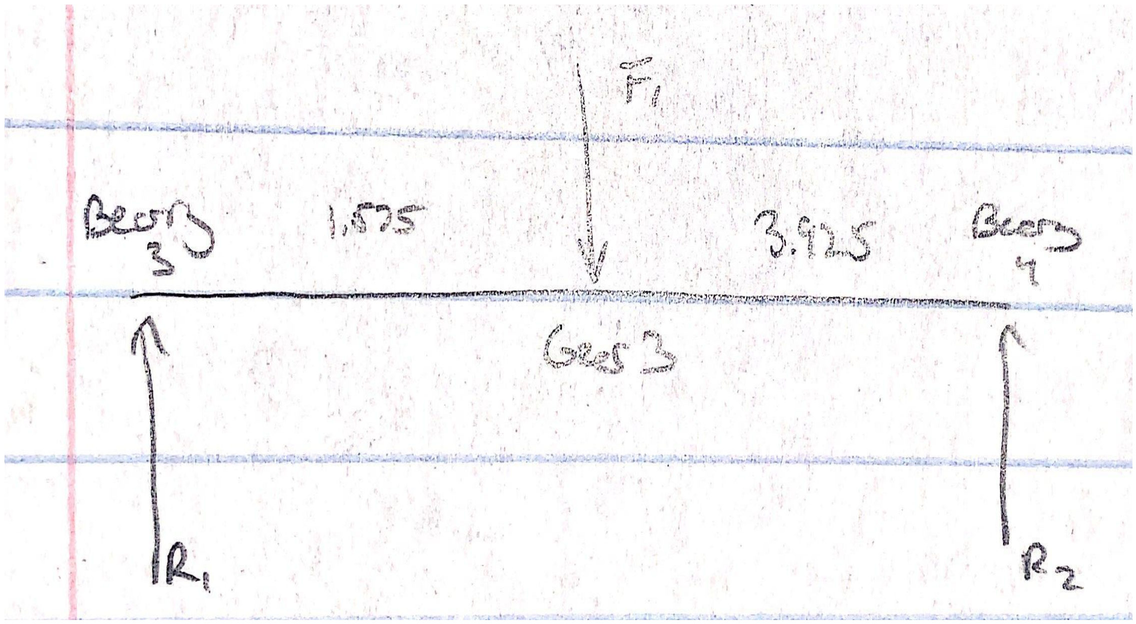


Figure 6: *FBD Output Shaft (Low Speed)*

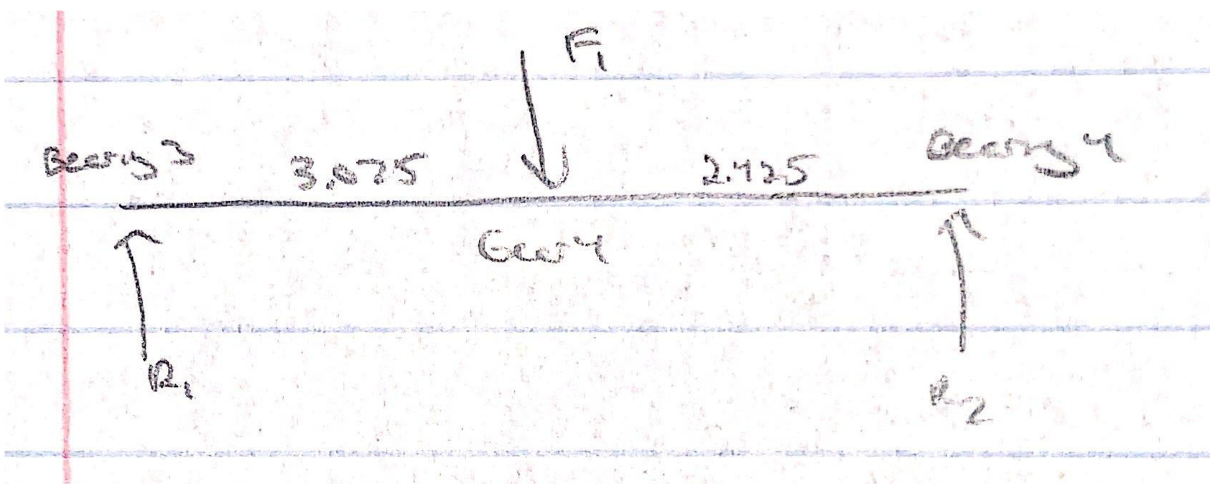


Figure 7: *FBD Output Shaft (High Speed)*

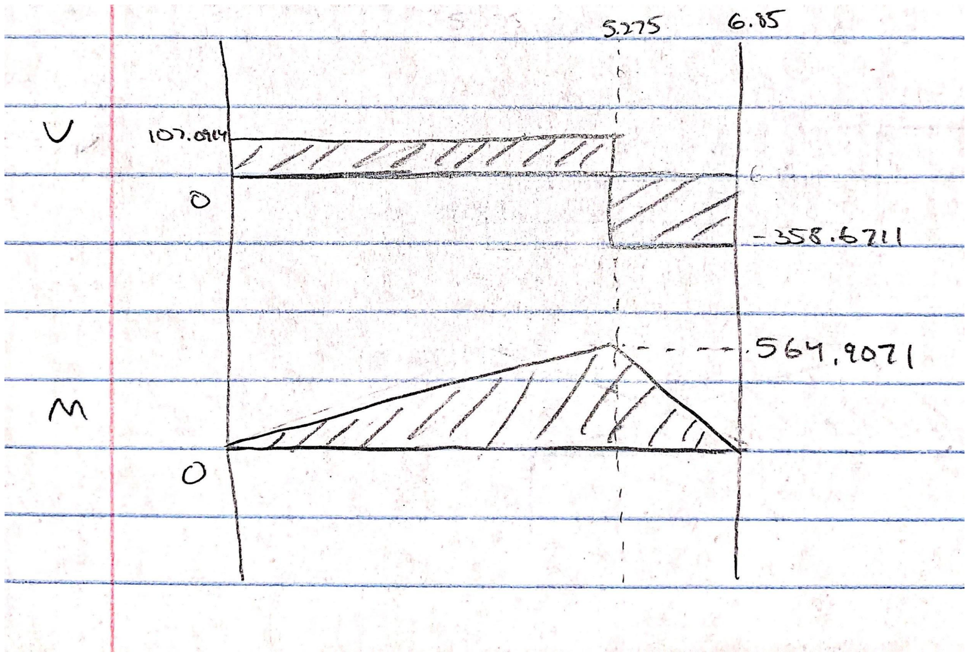


Figure 8: *Shear and Bending Moment Diagrams for Input Shaft (Low Speed)*

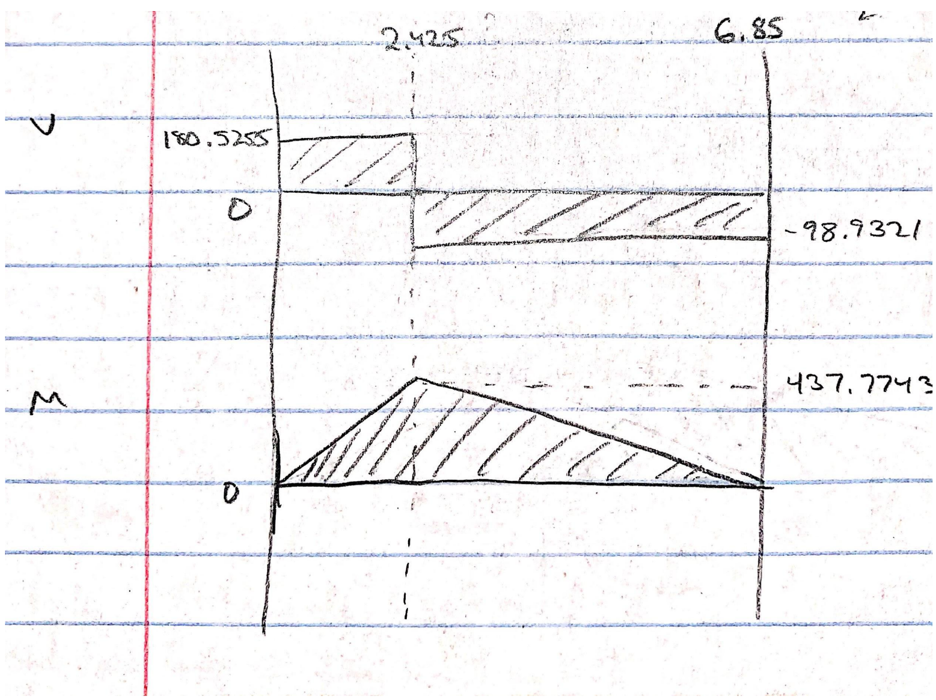


Figure 9: *Shear and Bending Moment Diagrams for Input Shaft (High Speed)*

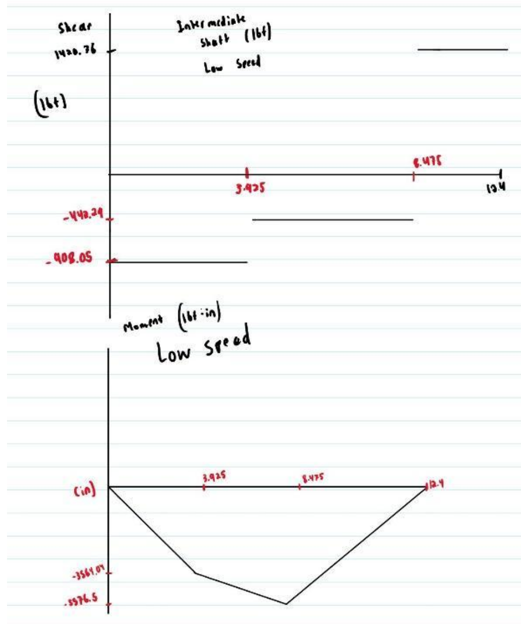


Figure 10: *Shear and Bending Moment Diagrams for Intermediate Shaft (Low Speed)*

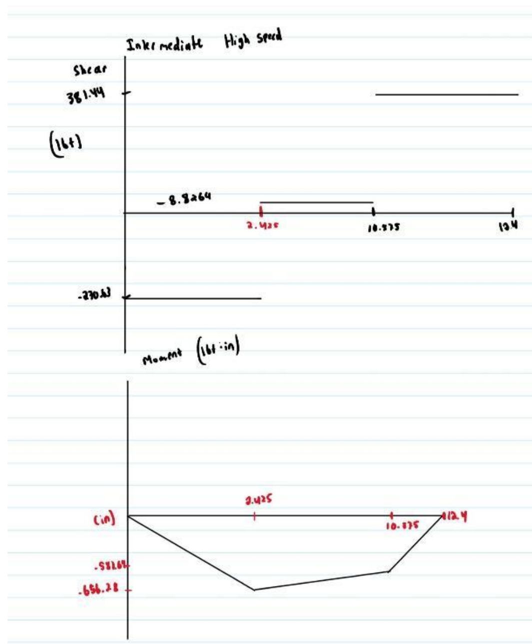


***Figure 11**: Shear and Bending Moment Diagrams for Intermediate Shaft (High Speed)*

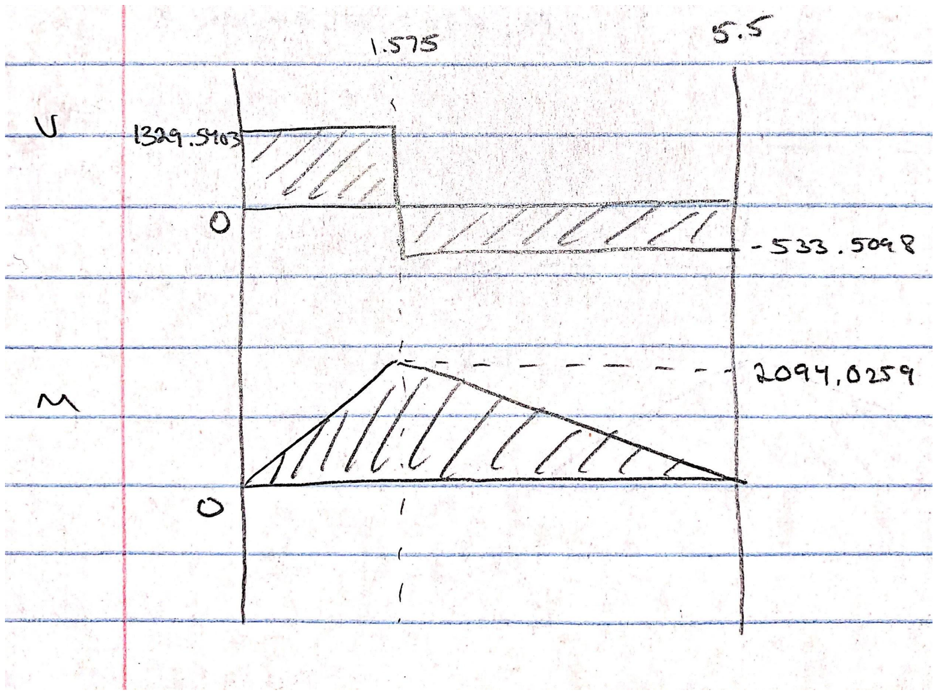


***Figure 12:** Shear and Bending Moment Diagrams for Output Shaft (Low Speed)*

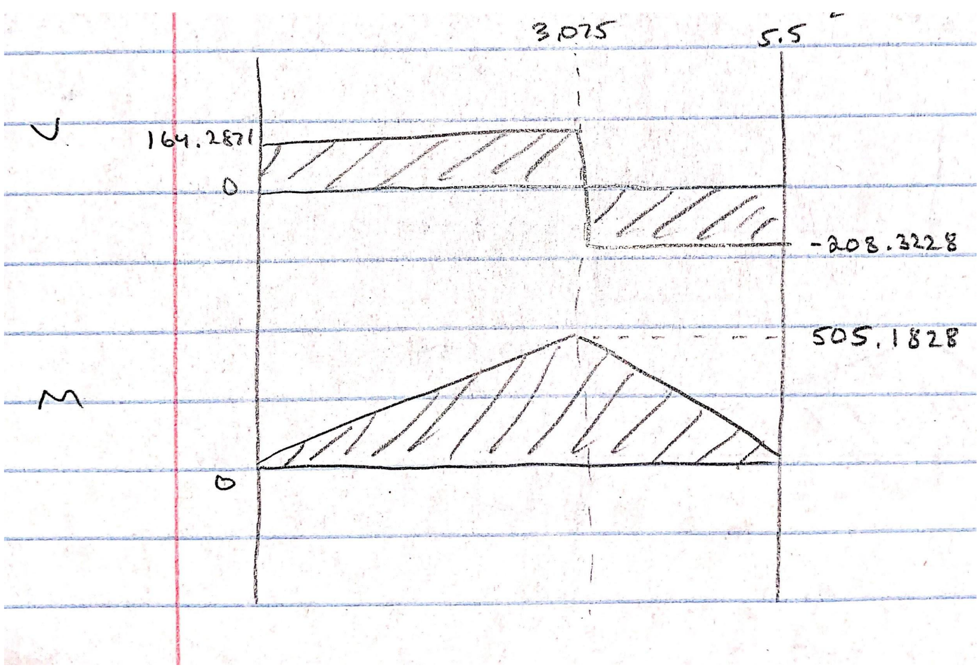


Figure 13: *Shear and Bending Moment Diagrams for Output Shaft (High Speed)*

Table 3: *Bending Moment at each location on* ***Input Shaft***

Critical Location	Low Speed (lbf-in)	High Speed (lbf-in)
Shoulder 1	40.0532	67.5183
Shoulder 2	340.0152	363.5753
Shoulder 3	484.5885	230.0169
Shoulder 4	176.5129	48.6873
Keyseat 1	259.6966	437.7743
Keyseat 2	564.9071	155.8179

Table 4: *Bending Moment at each location on* ***Intermediate Shaft***

Critical Location	Low Speed (lbf-in)	High Speed (lbf-in)
Shoulder 1	553.7099	165.0846
Shoulder 2	3895.8016	636.41848
Shoulder 3	5244.7818	600.4963
Shoulder 4	3161.1988	587.8703
Shoulder 5	867.0067	244.2112
Keyseat 1	2202.0191	656.2771
Keyseat 2	3564.0928	643.0387
Keyseat 3	5576.4968	572.8761
Keyseat 4	2166.6643	581.6914

Table 5: *Bending Moment at each location on* ***Output Shaft***

Critical Location	Low Speed (lbf-in)	High Speed (lbf-in)
Shoulder 1	758.9893	93.7859
Shoulder 2	1096.8707	135.5368
Shoulder 3	220.5529	86.1206
Keyseat 1	2904.0257	258.7521
Keyseat 2	1293.7612	505.1828

By evaluating the two configurations, it is clear that the low speed generates higher bending moments compared to the high-speed configuration. Therefore, each of the shafts in the gearbox are engineered with regards to the operating conditions of the low speed configuration. By incorporating a minimum factor of safety of 1.5 in the low speed design, it is guaranteed to have an even high factor of safety in the high-speed configuration.

Timing Belt Selection

To transfer power from the motor to the input shaft with a 2:1 ratio, a timing belt is used. Utilizing timing belts is important because they do not stretch or slip while transmitting power with a constant angular velocity ratio. Restrictions on speed are also eliminated due to the teeth on the belt. In order to properly select a timing belt, we utilized a Misumi timing belt selection guide that can be found below. To begin, we chose a pitch of ½ in. and a Heavy, H designation from Table 17-18 in Shigley's Mechanical Engineering Design. By using the Misumi guide, we select a load correction factor (Ko), speed ratio correction coefficient (Kr), and an idler correction coefficient (Ki). These values are used to calculate the design power. We chose a value of 1.8 for Ko figuring the heavy-duty lathe machine would be running for 8 to 12 hours a day with continuous use (A1). With a speed ratio of 2:1, we chose a speed ratio correction coefficient, Kr, of 0.2 (A2). Since we do not have an idler pulley for our design, the idler correction coefficient, Ki, is 0 (A3). The sum of Ko, Kr, and Ki is the overload factor, Ks, and is a value of 2. To calculate the transmission power (Pt), the power delivered (10 Hp) is multiplied by the minimum FOS resulting in a Pt of 15. Now, we can calculate for design power(Pd), with a result of 30 HP or 22.371 kW. Using the design power (Pd) and the given motor speed, we can analyze A4 and conclude that our timing belt designation is in fact heavy, H, and our pitch will be ½ in.

Moving onto the next step of the timing belt guide, we determined that based on our motor speed of 1600 RPM and our H timing belt designation, the minimum number of teeth for our small pulley is 18 according to A5. This means that the minimum number of teeth for our large pulley must be 36 for the 2:1 speed ratio to maintain intact. Knowing our pitch, we can multiply our pitch with the minimum number of teeth and divide it by pi to get the pitch diameter of the small pulley. The same applies to the minimum number of teeth of the large pulley to get the pitch diameter of the larger pulley. These values are initially subject to change based on the number of teeth. Based on the motor we chose, the size of our gearbox housing, and the position of our input shaft, we determined that the approximate center to center distance between the location of the mounted motor and the input shaft is 17.5 in. This is only an approximation and this value will be solved for later on. Now, we will determine our belt width. Using the pitch diameter of the small and large pulley along with the estimate for center to center distance we can calculate our contact angle, theta. Theta can then be used in conjunction with the number of teeth of the small pulley to calculate our number of teeth engaged, Zm. Zm will be a number greater than 6 so according to A6 our engagement correction coefficient, Km, is 1. Using Table A9, the reference transmission capacity of a timing belt with H designation, and knowing the number of teeth of our small pulley, the diameter of our pitch circle, and the motor speed we can find our reference transmission capacity value, Ps, of 4.99. Our reference belt width, Wp, was chosen to be 25.4 based on Table A7. Now using our values for Pd, Ps, Km, and Wp, we can calculate our belt width, Bw. Based on the calculated Bw, we will move one size up in A8 and select a belt width of 1.5 in.

Now that we have an approximate center to center distance, pitch, belt width, minimum number of teeth for our small and large pulley, and the pitch diameters for the small and large pulley we can determine the length of our timing belt and the number of teeth on the belt. The length of the timing belt is calculated using equation 17-16a from Shigley's Mechanical Engineering Design. The number of teeth on the belt is the length of the timing belt divided by the pitch. Remember, our center to center distance is an initial approximation and will now be changed based on the timing belt options available to us on McMaster-Carr. Based on the initial value calculated for the length of the timing belt and our initial number of teeth of the timing belt, we determined that the closest length on McMaster-Carr was 54 in. long with 108 teeth. We then inputted the equations for the length of the timing belt and number of teeth on the belt along with the center to center distance between the motor and input shaft into an Excel file. Setting the length to be 54 in. and the number of teeth to be 108, we used the solver to determine the correct center to center distance to make this true. We ended up with a timing belt of designation H with a length of 54 in., a center to center distance between the motor and input shaft of 17.89 in., a belt width of 1.5 in., and the number of teeth on the small pulley to be 24 and the large pulley 48 (satisfying the 2:1 speed ratio).

Timing- Belt Pulley Selection

In selecting the appropriate pulley to use for this project, the timing belt pulley for 1-1/2" Maximum Belt Width, H Series Quick-Disconnect, 8.02" OD is selected for it to be compatible with the bushing connection of the motor shaft and it's compatibility with our belt. While maintaining a constant ratio, additional teeth are added to the minimum requirement for each pulley. The theory behind adding more teeth to the pulleys is to increase the number of teeth engaged on the belt. The more teeth that are engaged, the bending stress per tooth is reduced in doing so. By lowering the bending stress on each tooth, not only will it last longer, but it will be able to accommodate for unexpected oscillations or loads during operation. The width of the pulleys are dependent on the horsepower and the RPM ratings of the motor that is chosen for the project. The final chosen pulleys were a 24 and 28 pully of the series described above.

Gear Selection

In order to fulfill the two-speed output requirement of the project the gear train consists of two systems. The timing belt reduces the output speed from the motor by a 2:1 ratio from 1600 to 800 rpm. This fixed the rpm of the input shaft at 800 rpm. This means that the speed must be reduced by a total 2:1 ratio in the high speed configuration to output 400rpm and a total 16:1 ratio in the low speed configuration to output a speed of 50 rpm.

In order to reduce the speed by a factor of 2 in the high-speed configuration two pairs of gears are used. Gear 1 on the input shaft meshes with Gear A on the intermediate shaft to reduce the speed to 400 rpm by utilizing a tooth and diameter ratio of 1:2. From there Gear D on the intermediate shaft meshes with Gear 4 on the output shaft with a 1:1 ratio to keep the rpm the same to achieve the 400 rpm output requirement.

In order to reduce the speed by a factor 4 in the low speed configuration two pairs of gears are also used, Gear 2 on the input shaft meshes with Gear B on the intermediate shaft to reduce the speed to 200 rpm by utilizing a tooth and diameter ratio of 1:4. From there Gear C on the intermediate shaft meshes with Gear 3 on the output shaft to reduce the speed to the desired output of 50rpm by utilizing a ratio of 1:4.

Outputting two different speeds from a one speed input requires some sort of shifting mechanism to shift from high to low speed and vice versa between the two sets of four gears each. To do this a shifter bar was designed that the intermediate shaft could mount to from the bearing housings to an intermediate shaft mount which can be slid on and off the shifter bar. These mounts are kept in place by four retaining rings and the side walls of the housing as it is shifted, as well as the shoulders and retaining rings of the intermediate shaft which fix the bearings in place that are press fitted into their respective housings. The shifter bar has two slots cut on each end of its two shafts which four locking blocks slide through to keep the shifter bar in place. These locking blocks are supported by four slots incorporated into the housing design and are locked in place themselves by four keys which can be inserted and locked into the housing. The design of the housing, shifter bar, locking blocks, and keys provides an easy way to shift back and forth from high to low speed. All that is required is that the four keys are unlocked, the four blockers are slid out of the shifter slits and into their slots in the housing, then the shifter is pushed or pulled into the high or low speed position. After this the locking blocks are slid back into the shifter bar slots and the keys are replaced. The keys can be removed two at once with both hands and the same goes for the blocks. The shifter bar can be moved with one or both hands using the handle allowing for a quick and easy shift between high and low speed.

The shifter bar and intermediate shaft mounts are constructed from 7075-T6 Aluminum to keep them lightweight but strong enough to support the weight of the intermediate shaft and its components. The locking blocks and keys are not load bearing, so they are constructed of 6061-T6 aluminum to reduce cost and increase machinability of the parts.

In the selection of our gears we elected to utilize the toolbox from Solidworks to create our gears. However, it was kept in mind that these gears should be something that you could find in a catalog or could be manufactured easily. Therefore, all of the gears used in this project have a nominal fractional inch bore and keyseat. The number of teeth on each gear is also reasonable for the pitch used. Each gear has a face width of 1 inch to reduce the space they take up in the gearbox. All gears have a hub width of ½ inch except for Gear D which has a hub width of 0.4 inches to give clearance from Gear 3 in the high-speed configuration.

The pitch for each gear was set to 10 to make finding the center to center distance between the input shaft and intermediate shaft, and intermediate shaft and output shaft easier as these two distances must be the same in order to fulfill the input and output shafts in-line requirement. This pitch gave us the largest center to center distance that could fit within our gearbox. The minimum number of teeth for each pinion was found using the 20 degree pressure angle and the speed ratio from each pinion to gear. The number of teeth for each gear mating with its pinion was found from the predetermined speed ratio between each pair of mating gears.

In order to analyze the bending fatigue and surface fatigue the AGMA criteria was used. A Matlab code was created from Quiz 10 to make this analysis easier(Appendix D). Several assumptions had to be made in this analysis including the quality factor, shock level, uncrowned teeth, gearing condition, temperature factor, and all other conditions for gearing adjustment in Ce when finding Km. The quality factor was assumed to be 10 from the table given in Quiz 10 as this gearbox should be closest to an automotive transmission. First the contact ratio for each pair of gears was determined and was found to be between 1 and two for all gears so the load applied at highest point of single-tooth contact curves were utilized in figure 14-6 from the textbook to find the geometry factor J. In calculating the load distribution factor Km, Cpm was the only component to change as it is based on the placement of the gears on the shaft and their relation to the centers of each shaft bearing. Kb was assumed to be 1 as the rims of our gears are many times larger than the heights of the teeth. The overload factor Ko was assumed to be 1.25 as the power source is uniform and the shock level that a lathe should experience would be light in the worst case. These factors used were along with the tangential load on each gear were used to find the allowable bending stress. After choosing an initial material the elastic coefficient could be calculated and the allowable hertzian contact stress could be found. The number of cycles for each gear was found by multiplying the required hours by 60 to find the required minutes and multiplying this value by the rpm that each gear would spin at when engaged. This allowed us to find the stress cycle factors Yn and Zn to find our working bending stress and hertzian contact stress. From here we would compare the working stress and allowable stress to find the factor of safety for Bending fatigue failure and Surface fatigue. The material for gears 1, A, 2, B, 4, and D was chosen to be Flame or induction hardened steel with type A pattern, Grade 1. Gears 3 and C spin at a much lower rpm and therefore are experiencing a much larger tangential load than the rest of the gears so the material for these two was selected to be carburized and hardened steel Grade 3.

Table 6: *Dimensions of* ***Gears***

Gear	Face Width(in)	Hub Width(in)	# Of Teeth	Pitch	Pitch Diameter(in)	ID(in)	Material
Gear 1	1	0.5	60	10	6	1.53125	Flame or Induction Hardened Steel Type A Patten Grade 1

Gear 2	1	0.5	36	10	3.6	1.875	Flame or Induction Hardened Steel Type A Patten Grade 1
Gear 3	1	0.5	144	10	14.4	1.75	Carburized and Hardened Steel Grade 3
Gear 4	1	0.5	90	10	9	1.75	Flame or Induction Hardened Steel Type A Patten Grade 1
Gear A	1	0.5	120	10	12	2.4375	Flame or Induction Hardened Steel Type A Patten Grade 1
Gear B	1	0.5	144	10	14.4	2.4375	Flame or Induction Hardened Steel Type A Patten Grade 1
Gear C	1	0.5	36	10	3.6	2.453125	Carburized and Hardened Steel Grade 3
Gear D	1	0.4	90	10	9	2.40625	Flame or Induction Hardened Steel Type A Patten Grade 1

Bearing Selection

The SKF Bearing Catalog was crucial to selecting the proper bearings for each shaft. We began by finding the reaction forces at our bearings to find the radial force at our bearings. The axial force on the bearings was found by multiplying the largest reaction force by 40% as is described in the project outline. Due to the ratio of forces and the calculated contact angle, a 40 degree angular contact ball bearing was selected for all shafts. The two bearings on each of the shafts are arranged in the face to face configuration as described in the SKF Catalog on page 401. Going forward, the effective axial load on each bearing can be calculated. The calculation factors used later are taken from table 10 from page 400 of the catalog as relating to suffix b for a 40 degree angular contact ball bearing.

The Lnm is calculated based on the required hours of the bearings and the maximum rpm that each bearing will experience. The reliability factor a1 is interpolated from page 90 of the SKF catalog based on the combined reliability of 90% from all components on each respective shaft. The life modification factor askf is assumed to be 1 as a lathe should be in a machine shop with a clean environment, average viscosity oil and a moderate load. The exponent of life is taken as 3 for ball bearings.

To begin the iteration process in finding the appropriate bearing to withstand the specified reaction force, we picked an initial angular contact bearing. A Matlab code was created from Quiz 9 to make this iterative process easier(Appendix C). From pages 408-414, we chose bearings and tabulated the basic dynamic load ratings as well as the fatigue load limits. Using the ratio of radial load to axial load for each bearing, we could determine which relationship to use to calculate our equivalent dynamic loads using our calculation factors that were found earlier. After this value was calculated we could calculate our working dynamic load by using the SKF

Rating Life equation on page 89 of the catalog. From here we were able to compare the dynamic load ratings and the design loads to find our factors of safety for each bearing.

After iterating and finding suitable bearings for our shafts, it was found that bearing D would not be able to remain a suitable size to fit within our gearbox unless the lift of this part was reduced to 7000 hours to maintain a factor of safety of 1.5. The reason for this reduction is that if we were to go with a larger bearing, the intermediate shaft would become too large with the shoulder steps up to gear C that gear C would not be able to fit on the shaft. Also, in a machine shop environment if the lathe is operating 100% of the time at the highest rpm for 8 hours per day, 5 days per week and 50 working weeks per year, this bearing will need to be replaced every 3.5 years compared to 12 years if the other bearings were to be used. As this working schedule for the lathe is an overestimation and the likelihood that the bearing is run at the highest rpm 100% of the time is low, this reduction was deemed an acceptable sacrifice by our team.

The housing for the bearings were designed custom to our bearings after basing the design from a mounted steel ball bearing housing from McMaster. The design was intended to fit our largest 130mm OD bearing and the design was modified to fit the other smaller bearings as well. Screw slots were cut into these housings to allow for easy removal from the housing and mounting points if needed. These housings were constructed from AISI 1045 CD Steel so they should be strong enough to stand up to the radial and axial loads that the bearings are subject to. The bearings are intended to be press-fit into these housings which will keep the shaft mounted rigidly to the frame while the bearings are axially constrained by shoulders and retaining rings.

Table 7: *SKF Bearing List*

Bearing	Part #	ID(mm)	OD(mm)	Width(mm)
1	7306 BECBP	30	72	19
2	7307 BECBP	45	100	25
3	7311 BECBP	55	120	29
4	7307 BECBP	35	80	21
A	7312 BECBP	60	130	31
D	7312 BECBP	60	130	31

Key and Retaining Ring Selection

In order to analyze and select the keys, we must use the final shaft diameters determined in Tables 6, 7, and 8. The key dimensions (width, height, and length) for each gear are listed below and were determined using Table A16, Key Size Versus Shaft Diameter. All keys except the keys at gear 3 and 4 are made of AISI 1050 CD Steel. The keys at gear 3 and 4 are made of AISI 4130 Q&T 400℉. The keys are all designed to have a factor of safety of at least 1.5 against shear and bearing stress by following example 7-6 in the textbook. To properly select the retaining rings, we had to calculate the axial loads present on our shafts because the ring must be able to withstand this load. The retaining rings chosen withstand axial loads higher than the ones calculated on our shafts and the thickness of each retaining ring was chosen with spacing on the shaft in mind. We wanted to conserve as much space as possible while still choosing a ring robust enough to hold up to the axial loads and choosing the proper ring for each shaft diameter.

Table 8: *Dimensions of* ***Keys*** *throughout Gearbox*

Location	Width(in)	Height(in)	Length(in)	Material
Key @ Gear 1	⅜	⅜	½	AISI 1050 CD Steel
Key @ Gear 2	½	½	½	AISI 1050 CD Steel
Key @ Gear A	⅝	⅝	½	AISI 1050 CD Steel
Key @ Gear B	⅝	⅝	½	AISI 1050 CD Steel
Key @ Gear C	⅝	⅝	½	AISI 1050 CD Steel
Key @ Gear D	⅝	⅝	½	AISI 1050 CD Steel
Key @ Gear 3	⅜	⅜	½	AISI 4130 Q&T 400℉
Key @ Gear 4	⅜	⅜	½	AISI 4130 Q&T 400℉

Shaft Design

The diameters on the ends of our shafts were already predetermined by the size of our bearings. As these diameters are rather large, especially on the intermediate shaft, we felt comfortable picking a material for these shafts and using these diameters to begin the design. A Matlab code was written from Quiz 7 to make this iterative process less time consuming(Appendix B). Various materials were tried for these calculations. Once shaft materials were chosen, we calculated the minimum diameters for each section of the shaft using Goodman failure criteria and iterated until the difference in our iteration before was less than 5% of the next iteration. A separate Matlab code was written for this part (Appendix F). Those minimum diameters were iterated to withstand static failure and achieve infinite life at a factor of safety of 1.5.

Due to the rather large proportion of our bearings we were able to achieve a much higher factor of safety at the shoulders of our bearings. By using small steps up for our shoulders, we are able to reduce the factor of safety for the inward sections of the shaft while still keeping above a factor of safety of 1.5. The proper kt and kts values were selected based on r/d and D/d ratios to ensure that stress concentration locations were evaluated properly. Once we found diameters whose factors of safety, we were comfortable with we rounded those up to the next nominal fractional inch diameter and evaluated the factors of safety for those diameters.

For the intermediate and input shaft we were able to select a low-quality steel as we were already beginning with large diameters on the ends. The material chosen for the input and intermediate shafts was AISI 1006 CD Steel. The output shaft is spinning at a lower rpm in the low speed configuration and therefore is subject to a larger torque and larger tangential force on the shaft. For this reason, a stronger material was used to construct the shaft; AISI 1141 Steel, quenched and treated at 600 degrees Fahrenheit.

Table 9: *Minimum Diameter of Critical Locations of* ***Intermediate Shaft***

Location	Minimum Diameter
Material	AISI 1006 CD Steel
Shoulder @ Bearing A	1.147705632
Keyseat @ Gear A	1.674664686
Keyseat @ Gear B	2.006761148
Shoulder @ Gear B	1.967615004
Middle Section	2.01806671
Shoulder @ Gear C	2.149427891
Keyseat @ Gear C	2.270457688

Shoulder @ Gear D	1.792896765
Keyseat @ Gear D	1.667262366
Shoulder @ Bearing D	1.25011359

Table 10: *Minimum Diameter of Critical Locations of* ***Input Shaft***

Material	AISI 1006 CD Steel
Critical Location	Minimum Diameter
Shoulder @ Bearing 1	0.7712988648
Keyseat @ Gear 1	1.032919431
Shoulder @ Gear 1	0.9851606334
Middle Section	1.2465297
Shoulder @ Gear 2	1.051901102
Keyseat @ Gear 2	1.091473825
Shoulder @ Bearing 2	0.8615864314

Table 11: *Minimum Diameter of Critical Locations of* ***Output Shaft***

Material	AISI 1141 Q&T 600℉
Critical Location	Minimum Diameter
Shoulder @ Bearing 3	1.228566846
Middle Section	1.276592641
Shoulder @ Gear 3	1.276176036
Keyseat @ Gear 3	1.603112407
Keyseat @ Gear 4	1.027983602
Shoulder @ Bearing 4	1.165754582

Table 12: *Chosen Diameter of Critical Locations of* ***Intermediate Shaft***

Material	AISI 1006 CD Steel
Critical Location	Diameter
Shoulder @ Bearing A	60mm
Keyseat @ Gear A	2.4375in
Keyseat @ Gear B	2.4375
Shoulder @ Gear B	2.4375
Middle Section	2.5
Shoulder @ Gear C	2.453125
Keyseat @ Gear C	2.453125
Shoulder @ Gear D	2.40625
Keyseat @ Gear D	2.40625
Shoulder @ Bearing D	60mm

Table 13: *Chosen Diameter of Critical Locations of* ***Input Shaft***

Material	AISI 1006 CD Steel
Critical Location	Diameter (in)
Shoulder @ Bearing 1	30mm
Keyseat @ Gear 1	1.53125
Shoulder @ Gear 1	1.53125
Middle Section	1.9375
Shoulder @ Gear 2	1.875
Keyseat @ Gear 2	1.875
Shoulder @ Bearing 2	45mm

Table 14: *Chosen Diameter of Critical Locations of* ***Output Shaft***

Material	AISI 1141 Q&T 600℉
Critical Location	Diameter (in)
Shoulder @ Bearing 3	55mm
Middle Section	2.25
Shoulder @ Gear 3	1.75
Keyseat @ Gear 3	1.75
Keyseat @ Gear 4	1.75
Shoulder @ Bearing 4	35mm

Housing Analysis and Selection

The material for the housing was elected to be 7075-T6 Aluminum for its lightweight properties, material strength, and its relatively easy machinability. The housing has threaded holes for the bearing housings to mount to at the bottom as well as two large holes at the top for the shifter bar to slide through. It has one hole on each side for the input and output shafts to extend outside the walls of the gearbox to connect to the motor and the chuck of the lathe. Easily removable sliding doors were incorporated into this design to allow for quick access to the inside of the gearbox if needed. Slots for the shifter bar locking blocks are incorporated into the design to allow these blocks to be removed or to be slid out of the way to allow the shifter bar to move. Keyholes are also incorporated into this design to keep the locking blocks in place once shifting is complete. The gearbox is mounted to the frame that the motor sits on in such a way that both pulleys are in-line for the timing belt to be attached to. The gearbox is mounted by two bolts on each side that are centered and 10 inches apart as per the project requirement.

In order to analyze the factors of safety for the housing mounting bolts as well as the frame and housing a Matlab code was written from Quiz 8 Parts 2 and 3(Appendix E). Since the radial bearing reaction forces cancel out, the weight of the gearbox assembly was used to evaluate the bolts in tension and the axial bearing force was used to evaluate the bolts in shear. The frustum method was implemented to find the stiffness of the two members in the grip of the bolts. Joint Separation, Yielding, Shear Stress, Bending Stress, and Bearing stress for the housing, frame, and bolts were all evaluated. It was found that every factor of safety in this analysis was larger than the minimum factor of safety for this project except for the yielding of the bolts. This is because for a permanent connection which was assumed, the bolts are preloaded to 90% of their allowable load, making it impossible to reach a factor of safety over 1.5 unless the bolts are improperly preloaded. The torque wrench setting to preload these bolts should be 196.56. The final bolts to mount the housing were chosen to be ¼-20 3in long Grade 8 Steel partially threaded bolts. Washers and nuts to match these bolts are included in the parts list and assemblies.

Final Analysis

Table 15: *Diameter of Critical Locations of* ***Intermediate Shaft***

Material	AISI 1006 CD Steel	
Critical Location	Yielding Factor of Safety	Infinite Life Factor of Safety
Shoulder @ Bearing A	12.0311	8.8537
Keyseat @ Gear A	5.6621	3.4113

Keyseat @ Gear B	4.6137	2.4071
Shoulder @ Gear B	5.6158	2.3889
Middle Section	N/A	N/A
Shoulder @ Gear C	4.7233	1.9051
Keyseat @ Gear C	3.782	1.7482
Shoulder @ Gear D	6.3217	2.8284
Keyseat @ Gear D	5.6264	3.4072
Shoulder @ Bearing D	11.1083	7.2041

Table 16: *FOS of Critical Locations of* ***Input Shaft***

Material	AISI 1006 CD Steel	
Critical Location	Yielding Factor of Safety	Infinite Life Factor of Safety
Shoulder @ Bearing 1	5.0597	4.8623
Keyseat @ Gear 1	6.3325	4.2635
Shoulder @ Gear 1	7.4598	4.7191
Middle Section	N/A	N/A
Shoulder @ Gear 2	15.5846	8.2362
Keyseat @ Gear 2	10.558	6.4425
Shoulder @ Bearing 2	19.0626	13.665

Table 17: *FOS of Critical Locations of* ***Output Shaft***

Material	AISI 1141 Q&T 600℉	
Critical Location	Yielding Factor of Safety	Infinite Life Factor of Safety
Shoulder @ Bearing 3	11.4244	9.3697
Middle Section	N/A	N/A
Shoulder @ Gear 3	3.7947	3.2083

Keyseat @ Gear 3	2.6061	1.8817
Keyseat @ Gear 4	2.8564	2.5386
Shoulder @ Bearing 4	2.0119	2.1369

Table 18: *FOS of Gears*

Gear Component	*Bending Fatigue Failure **FOS** (S_f)*	*Surface Fatigue **FOS** (n)*
Gear 1	4.1569	2.3604
Gear 2	2.2173	1.5112
Gear 3	1.9147	1.7896
Gear 4	3.2797	2.3239
Gear A	4.3666	2.5973
Gear B	2.2173	1.8073
Gear C	1.6505	1.6332
Gear D	3.2797	2.3239

Table 19: *FOS of Keys*

Location	Bearing Factor of Safety	Shear Factor of Safety	Material
Key @ Gear 1	7.6532	8.8318	AISI 1050 CD Steel
Key @ Gear 2	12.495	14.4192	AISI 1050 CD Steel
Key @ Gear A	5.0761	5.8578	AISI 1050 CD Steel
Key @ Gear B	5.0761	5.8578	AISI 1050 CD Steel
Key @ Gear C	5.1086	5.8953	AISI 1050 CD Steel
Key @ Gear D	5.011	5.7827	AISI 1050 CD Steel

Key @ Gear 3	1.8395	2.1228	AISI 4130 Q&T 400℉
Key @ Gear 4	1.8395	2.1228	AISI 4130 Q&T 400℉

Table 20: *FOS of Bearings on Input Shaft*

Critical Location	Factor of Safety
Bearing 1	1.8672
Bearing 2	1.6162

Table 21: *FOS of Bearings on Intermediate Shaft*

Critical Location	Factor of Safety
Bearing A	1.6152
Bearing D	1.5105

Table 22: *FOS of Bearings on Output Shaft*

Critical Location	Factor of Safety
Bearing 3	1.5309
Bearing 4	1.6224

Table 23: *FOS of Bolts*

Stress Type	Factor of Safety
Joint Separation	72.2979
Yielding	1.1082
Shear Stress	7.5958
Bearing Stress	61.9783

Table 24*: FOS of Housing and Frame*

Stress Type and Location	Factor of Safety
Housing Bearing Stress	40.5958
Frame Bearing Stress	60.8937
Frame Bending Stress	12,966

We are very satisfied with the results of our engineering work on this project. We were able to achieve a factor of safety of over 1.5 for every component of our system. The combined reliability of the system was kept at 90% while ensuring non-fatal failure of the entire gearbox. We were able to meet all the requirements of the project, save for the decreased life of one bearing. Overall, this project was challenging but we learned a lot as we overcame setbacks, discovered methods that worked, and completed the design of the gearbox.

Parts

Table 25: *Procured Parts*

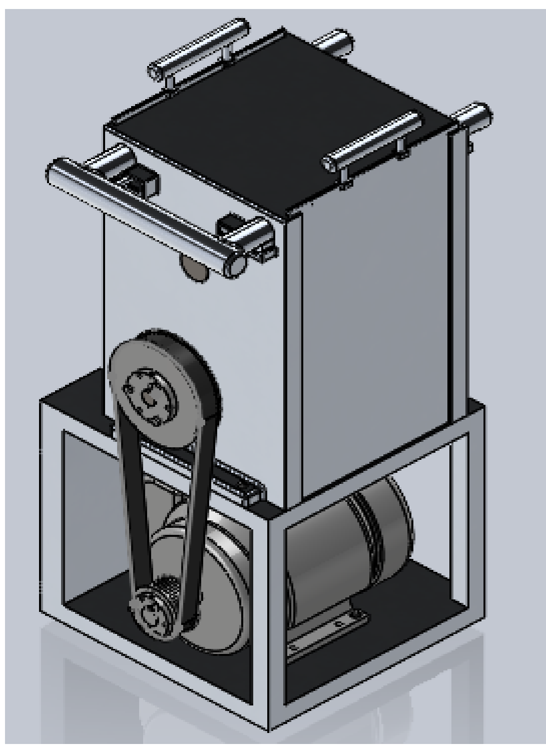
Component	**Source**
Totally Enclosed Three Phase AC Motor, 240V, 10 Hp, 1760 rpm	https://www.mcmaster.com/6136K512/
H Series Timing Belt, 540H150	https://www.mcmaster.com/6484K281/
24 Tooth Timing Belt Pulley for 1- 1 ½” Wide Belt, H Series Quick Disconnect	https://www.mcmaster.com/6495K616/

48 Tooth Timing Belt Pulley for 1- 1 ½" Wide Belt, H Series Quick Disconnect	https://www.mcmaster.com/6495K623/
Quick Disconnect Bushing, SK Style, Clamp on 30 mm Diameter	https://www.mcmaster.com/2344K44/
Quick Disconnect Bushing, SD Style, Clamp on 1 ⅜" Diameter	https://www.mcmaster.com/6086K422/
30 mm Angular Contact Ball Bearing- 7306 BECBP Bearing 1	https://www.skf.com/group/products/rolling-bearings/ball-bearings/angular-contact-ball-bearings/single-row-angular-contact-ball-bearings/productid-7306%20BECBP
45 mm Angular Contact Ball Bearing - 7309 BECBP Bearing 2	https://www.skf.com/group/products/rolling-bearings/ball-bearings/angular-contact-ball-bearings/single-row-angular-contact-ball-bearings/productid-7309%20BECBP
55 mm Angular Contact Ball Bearing - 7311 BECBP Bearing 3	https://www.skf.com/group/products/rolling-bearings/ball-bearings/angular-contact-ball-bearings/single-row-angular-contact-ball-bearings/productid-7311%20BECBP
35 mm Angular Contact Ball Bearing - 7307 BECBP Bearing 4	https://www.skf.com/group/products/rolling-bearings/ball-bearings/angular-contact-ball-bearings/single-row-angular-contact-ball-bearings/productid-7307%20BECBP
60 mm Angular Contact Ball Bearing - 7312 BECBP Bearing A and D	https://www.skf.com/group/products/rolling-bearings/ball-bearings/angular-contact-ball-bearings/single-row-angular-contact-ball-bearings/productid-7312%20BECBP
60 mm OD External Retaining Ring 1060 - 1090 Spring Steel Bearing A and D clip, 98541A174	https://www.mcmaster.com/98541A174/
62 mm OD External Retaining Ring 1060 - 1090 Spring Steel Gear C clip, 98541A490	https://www.mcmaster.com/98541A490/
30 mm OD External Retaining Ring 1060 - 1090 Spring Steel Bearing 1 clip, 98541A134	https://www.mcmaster.com/98541A134/
2 ⅜" OD External Retaining Ring, 15-7 PH Stainless Steel, Gear D clip, 91590A164	https://www.mcmaster.com/91590A164/
1 ½" OD External Retaining Ring, Black Phosphate 1060 - 1090 Spring Steel, Gear 1 clip 97633A380	https://www.mcmaster.com/97633A380/

1 ⅞" OD External Retaining Ring, Black Phosphate 1060 - 1090 Spring Steel, Gear 2 clip 97633A414	https://www.mcmaster.com/97633A414/
2-7/16" OD External Retaining Ring, Black Phosphate 1060 - 1090 Spring Steel, Gear B 97633A449	https://www.mcmaster.com/97633A449/
35 mm OD External Retaining Ring, Black Phosphate 1060 - 1090 Spring Steel, Bearing 4 98541A146	https://www.mcmaster.com/98541A146/
55 mm OD External Retaining Ring, Balck Phosphate 1060 -1090 Spring Steel, Bearing 3 98541A171	https://www.mcmaster.com/98541A171/
1 ¾" OD External Retaining Ring, Black Phosphate 1060 - 1090 Spring Steel, Gear A and Shifter 97633A410	https://www.mcmaster.com/97633A410/
45 mm OD External Retaining Ring Black Phosphate 1060 - 1090 Spring Steel, Bearing 2 98541A161	https://www.mcmaster.com/98541A161/
Grade 8 Steel, 1/2"-20 Thread Size, 2-1/2" Long, Fully Threaded Bolt	https://www.mcmaster.com/92620A749/
Grade 8 Steel, 1/2"-20 Thread Size, 4" Long, Fully Threaded Bolt	https://www.mcmaster.com/92620A752/
Aluminum Washer for 1/2" Screw Size, 0.515" ID, 0.875" OD	https://www.mcmaster.com/93286A049/
Grade 8 Steel, 3/8"-16 Thread Size, 2-3/4" Long, Fully Threaded Bolt	https://www.mcmaster.com/92620A635/
Grade 8, Zinc Yellow-Chromate Plated, 3/8"-16 Thread Size Nut	https://www.mcmaster.com/94895A031/
316 Stainless Steel Washer for 3/8" Screw Size, 0.406" ID, 0.75" OD	https://www.mcmaster.com/90107A127/
Zinc Yellow-Chromate Plated Hex Head Screw Grade 8 Steel, 1/4"-20 Thread Size, 3" Long, Partially Threaded	https://www.mcmaster.com/91257A554/
High-Strength Steel Hex Nut Grade 8, Zinc Yellow-Chromate Plated, 1/4"-20 Thread Size	https://www.mcmaster.com/94895A029/

316 Stainless Steel Washer for 1/4" Screw Size, 0.281" ID, 0.625" OD	https://www.mcmaster.com/90107A029/

Assembly and Engineering Drawings



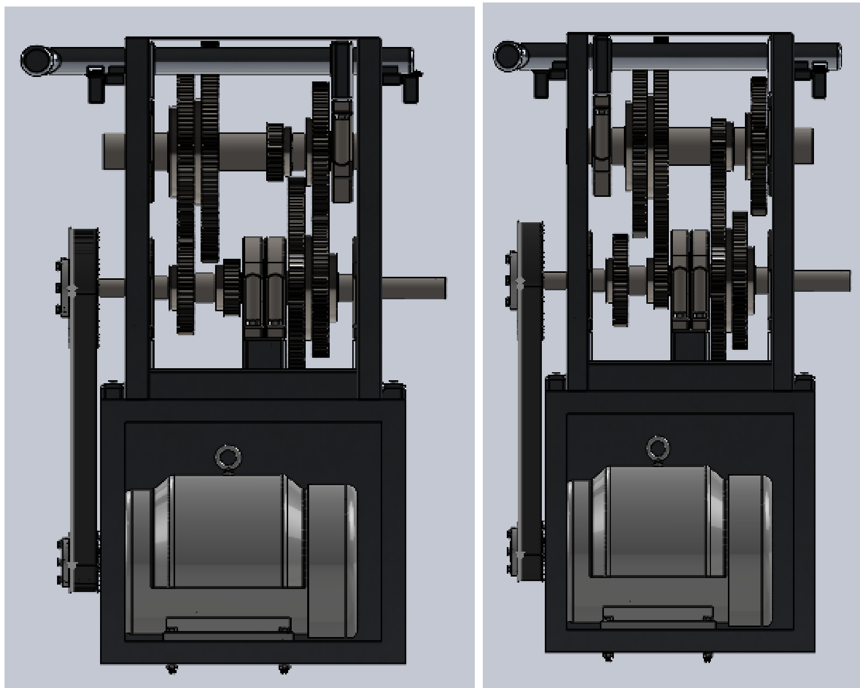


Figure 14: *Full Assembly Closed Doors, High Speed, and Low Speed Configurations*

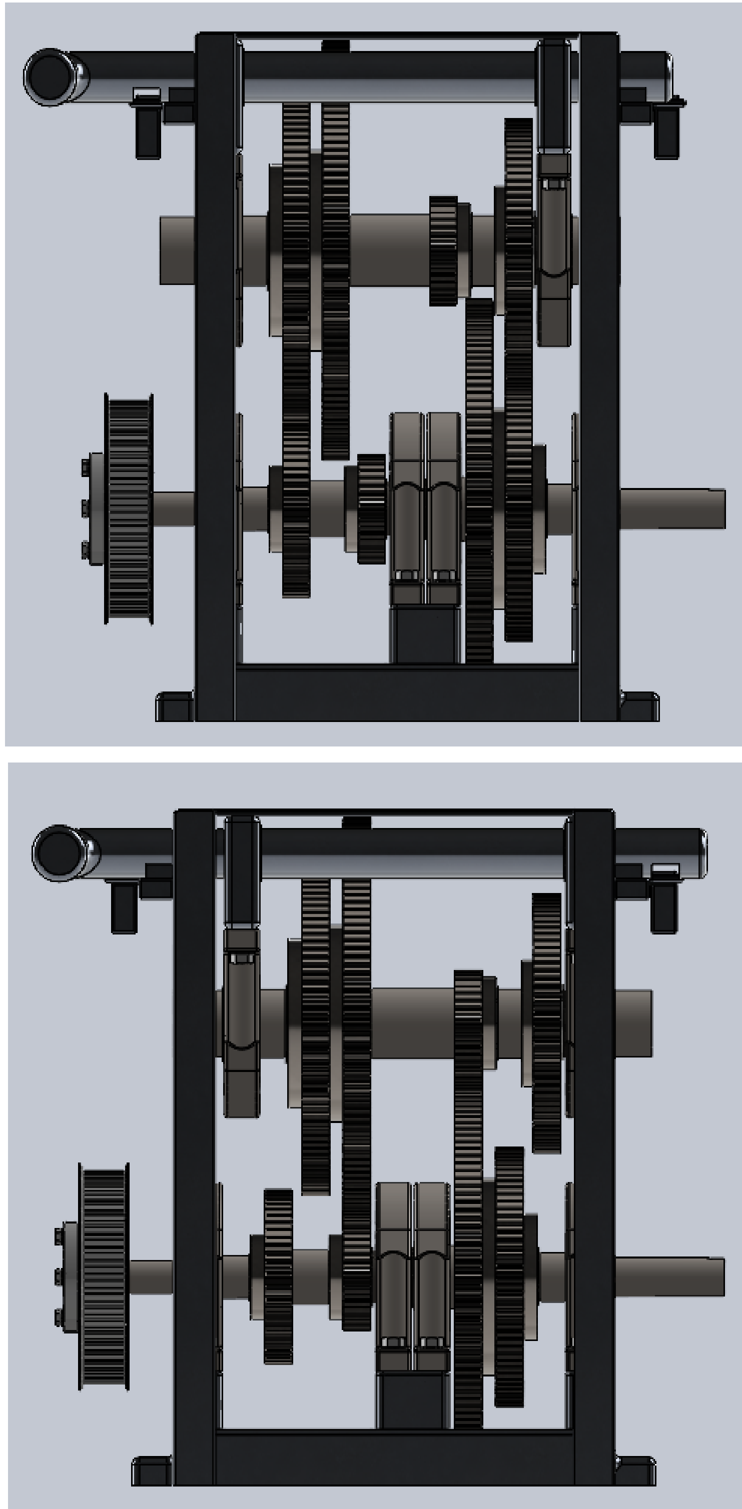
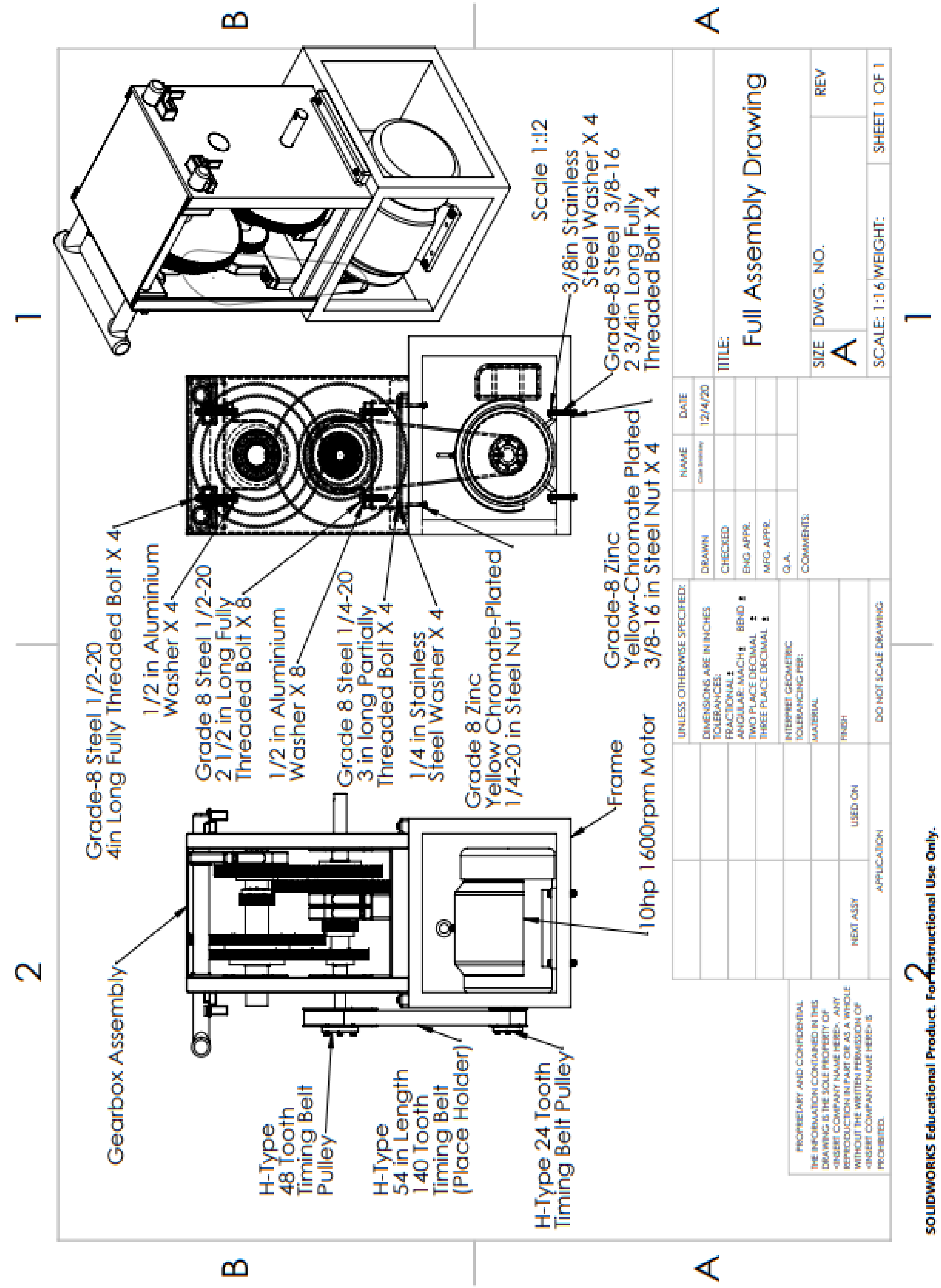


Figure 15: *Gearbox Assembly High Speed and Low Speed Configurations*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1/2 in Aluminium Washer X 4
Grade 8 Steel 1/2-20 2 1/2 in Long Fully Threaded Bolt X 8
1/2 in Aluminium Washer X 8
Grade 8 Steel 1/4-20 3 in long Partially Threaded Bolt X 4
1/4 in Stainless Steel Washer X 4
Grade 8 Zinc Yellow Chromate-Plated 1/4-20 in Steel Nut
Frame
10hp 1600rpm Motor
Grade-8 Zinc Yellow-Chromate Plated 3/8-16 in Steel Nut X 4
Scale 1:12
3/8in Stainless Steel Washer X 4
Grade-8 Steel 3/8-16 2 3/4in Long Fully Threaded Bolt X 4
H-Type 48 Tooth Timing Belt Pulley
H-Type 54 in Length 140 Tooth Timing Belt (Place Holder)
H-Type 24 Tooth Timing Belt Pulley
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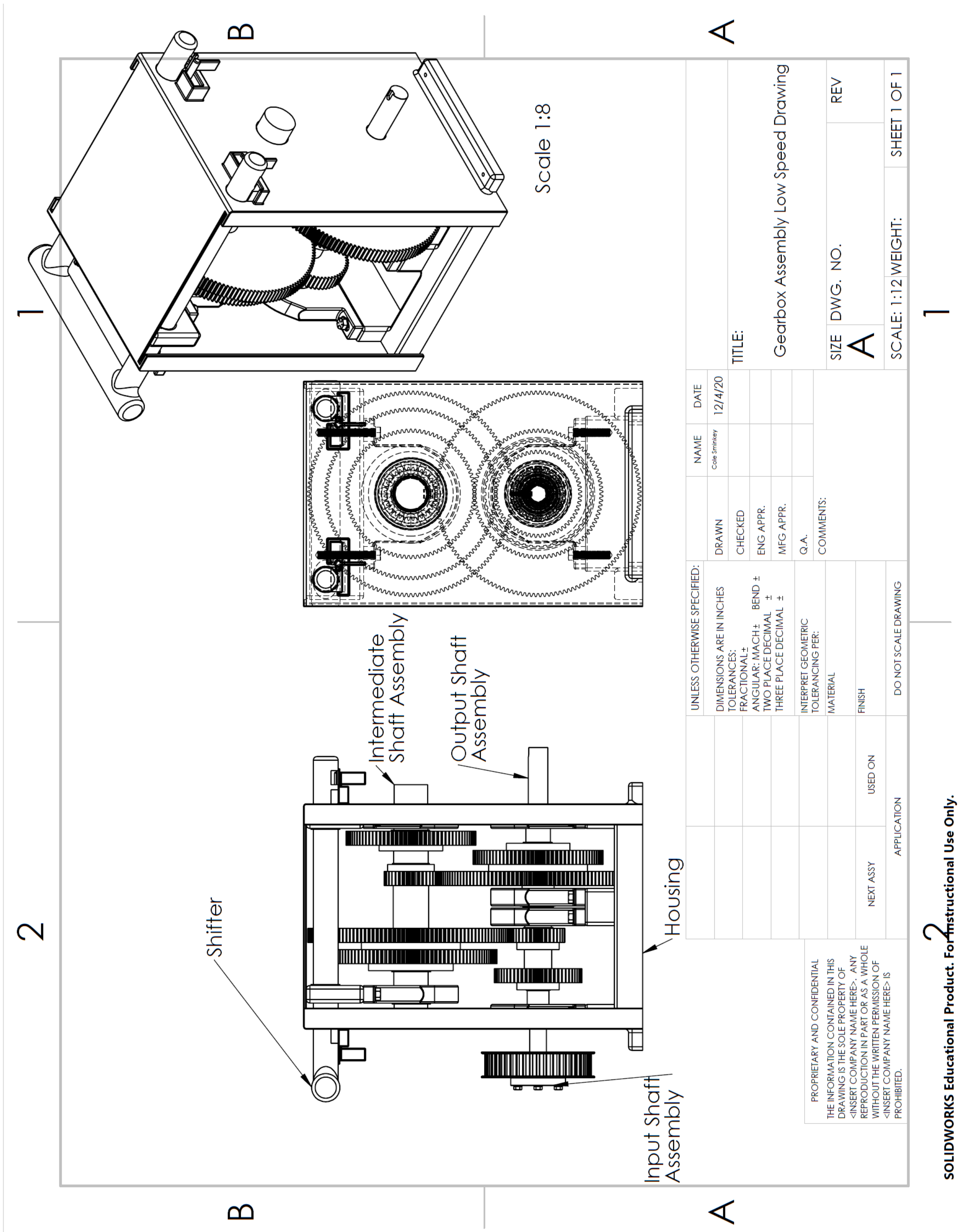
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Housing
Input Shaft Assembly
Intermediate Shaft Assembly
Output Shaft Assembly
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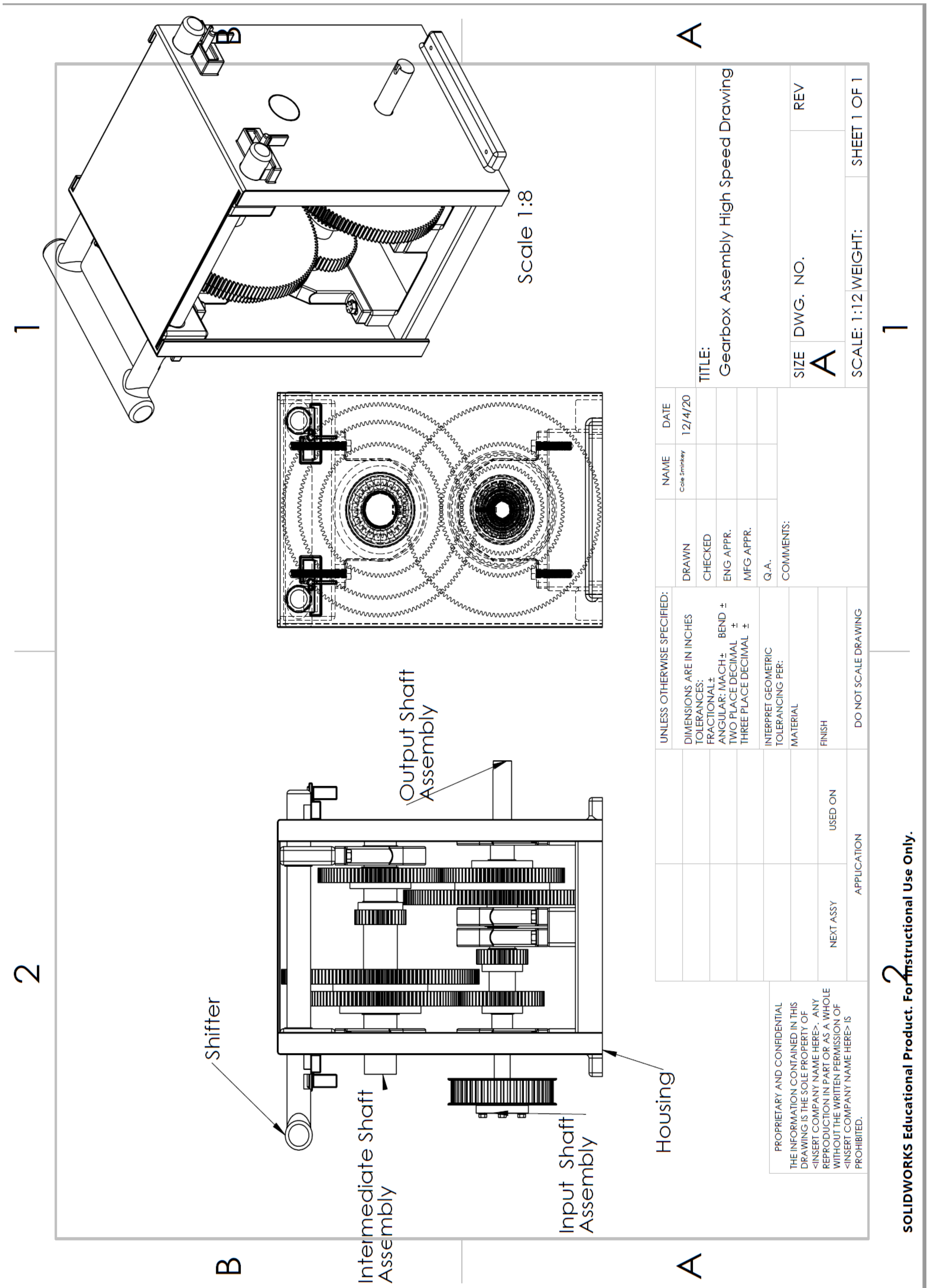
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Housing
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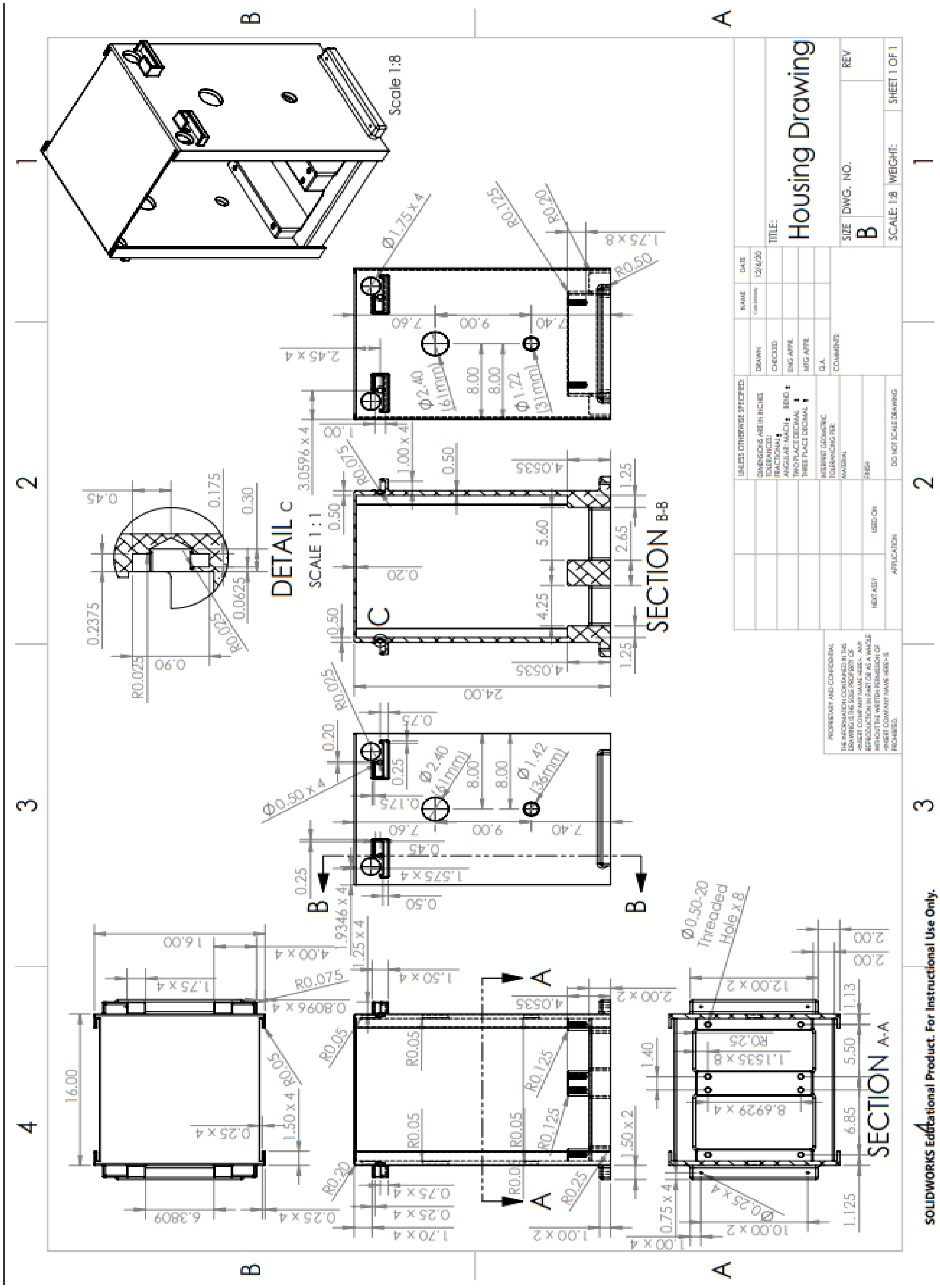
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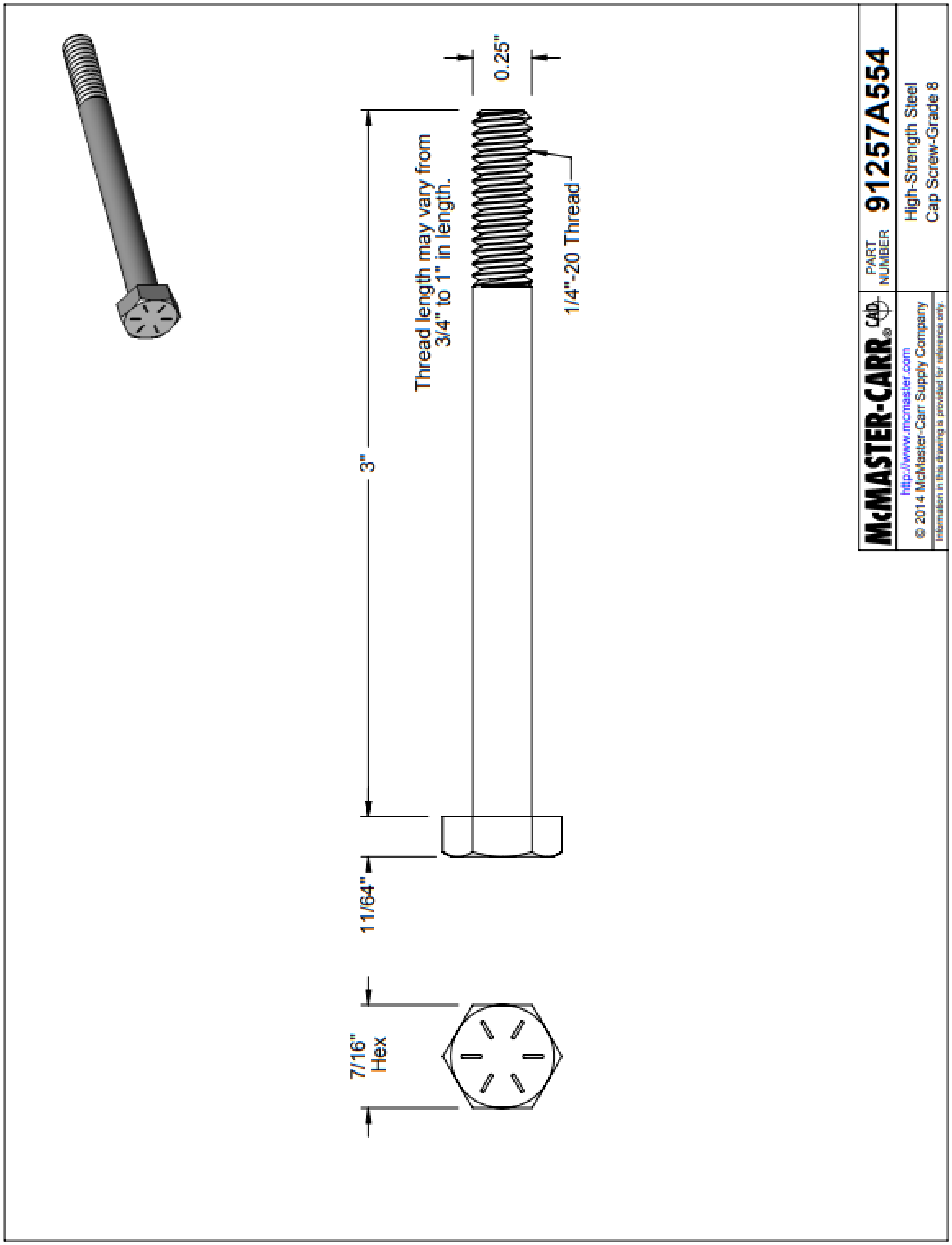
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1/4"-20 Thread
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11/64"
7/16"
Hex
McMASTER-CARR
http://www.mcmaster.com
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Information in this drawing is provided for reference only.
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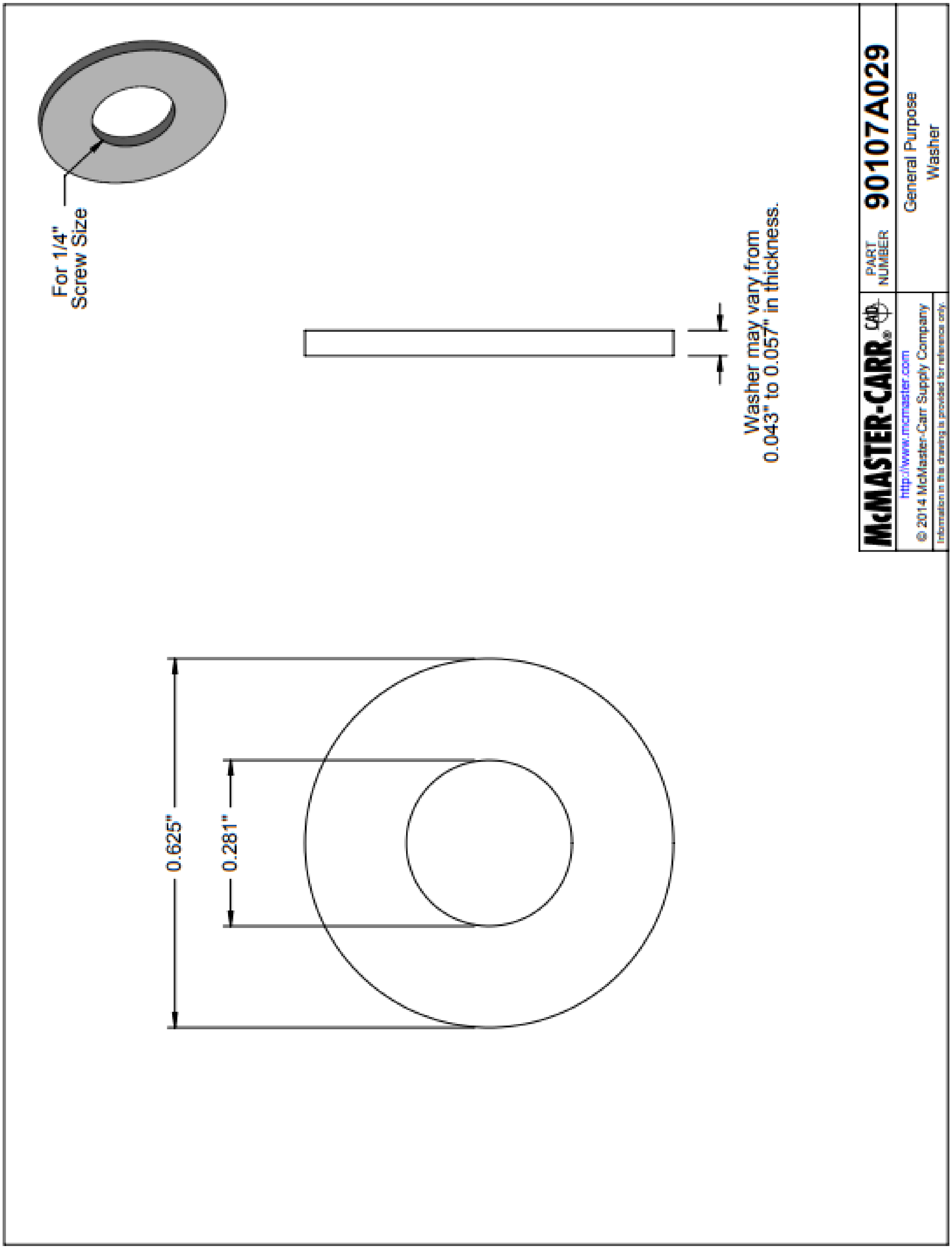
High-Strength Steel
Cap Screw-Grade 8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0.625"
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McMASTER-CARR
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General Purpose
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http://www.mcmaster.com
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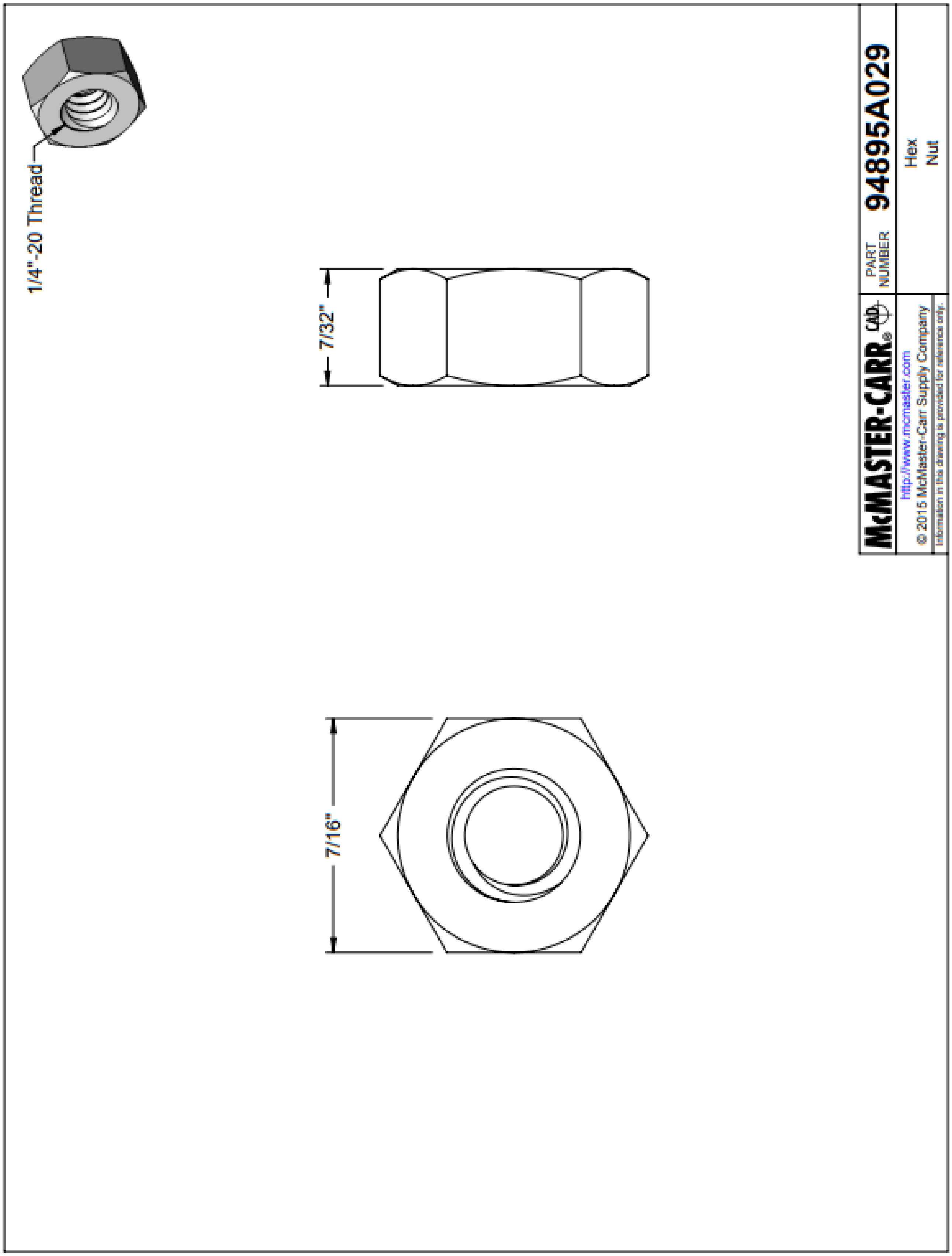
1/4"-20 Thread
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7/16"
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http://www.mcmaster.com
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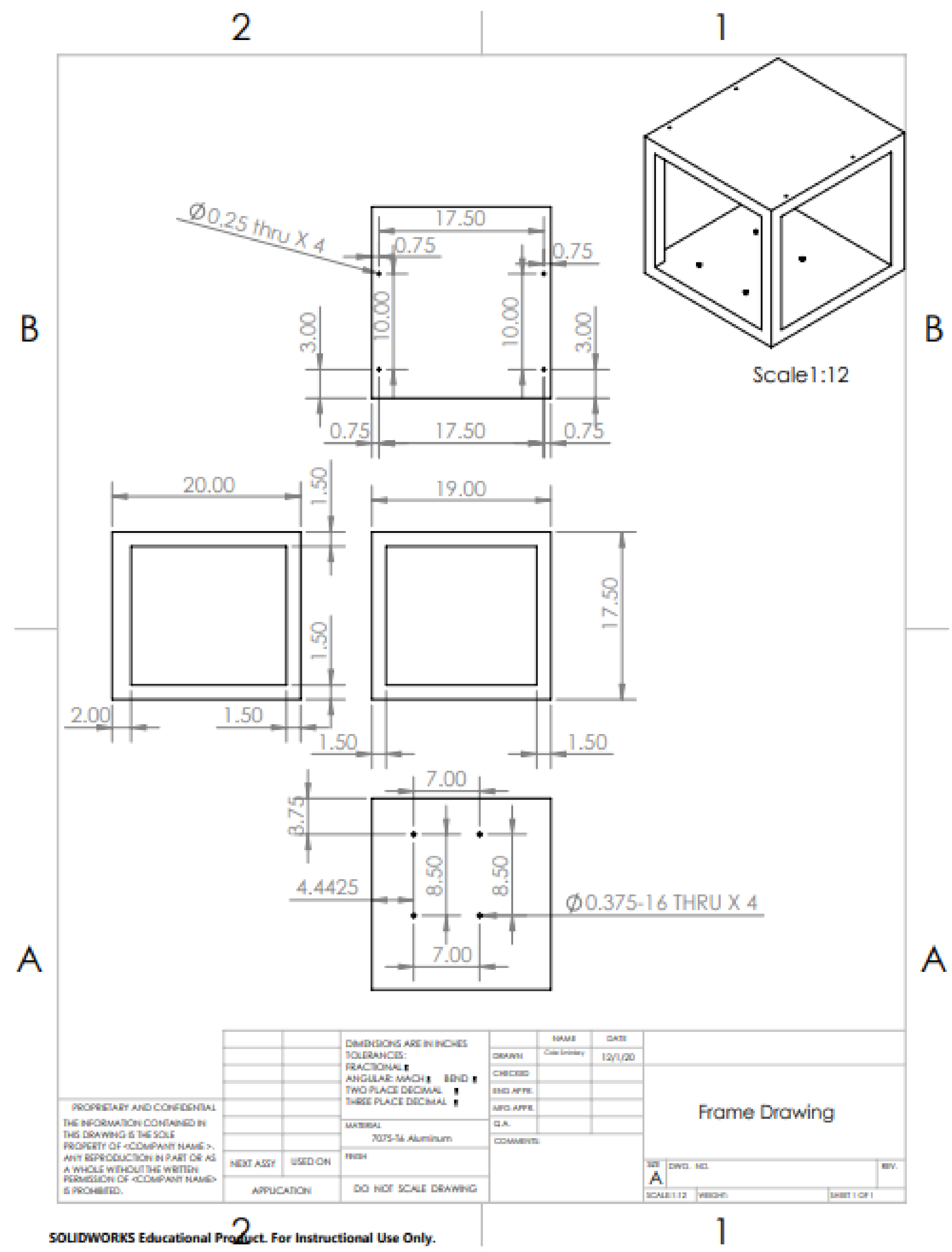
Hex Nut



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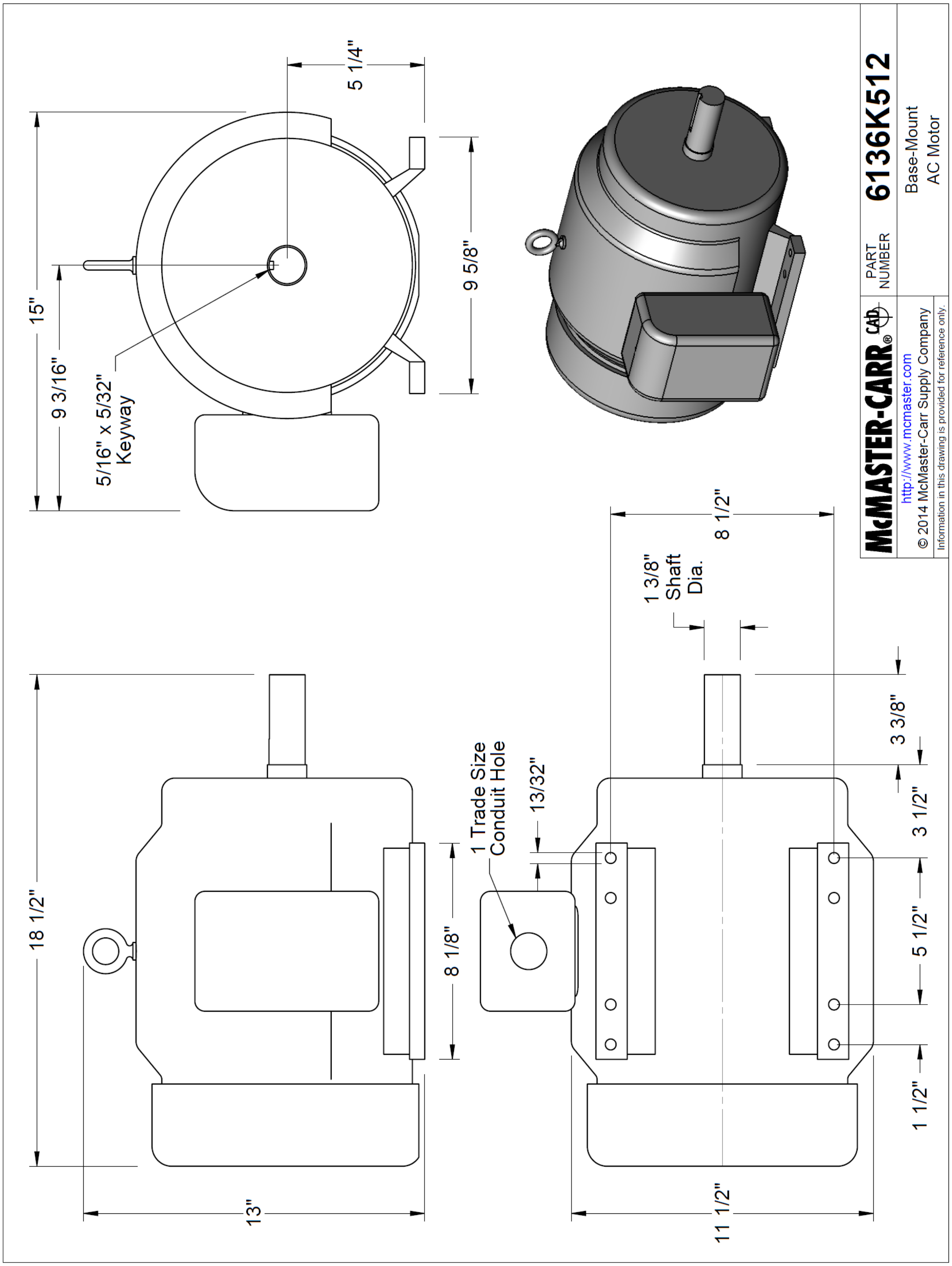

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9 3/16"
5/16" x 5/32"
Keyway
5 1/4"
9 5/8"
18 1/2"
13"
8 1/8"
1 Trade Size
Conduit Hole
13/32"
1 3/8"
Shaft
Dia.
8 1/2"
3 3/8"
3 1/2"
5 1/2"
1 1/2"
11 1/2"
McMASTER-CARR
CAD
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Information in this drawing is provided for reference only.
PART
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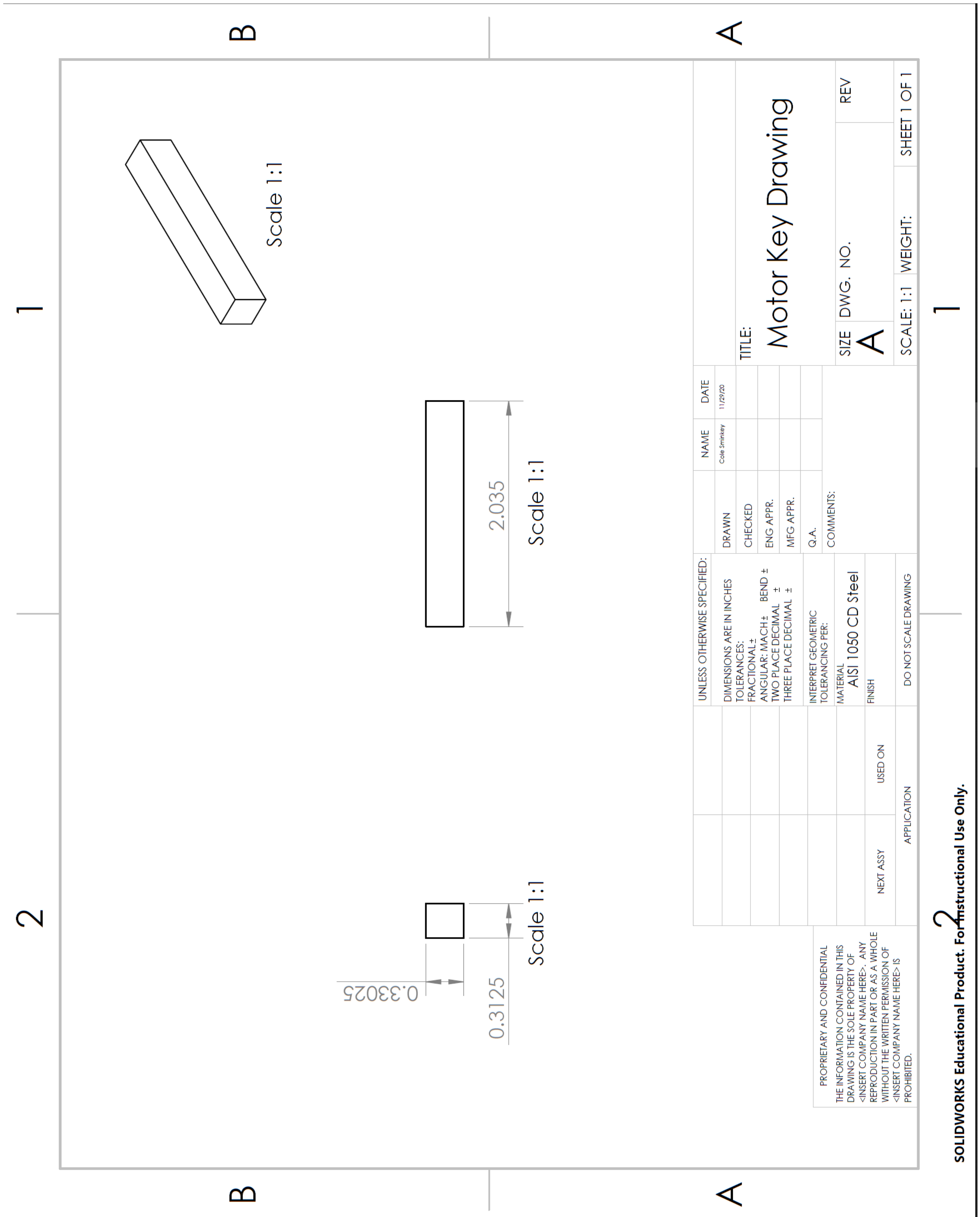
6136K512
Base-Mount
AC Motor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THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
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AISI 1050 CD Steel
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Cole Sminkey
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CHECKED
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MFG APPR.
Q.A.
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REV
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USED ON
APPLICATION
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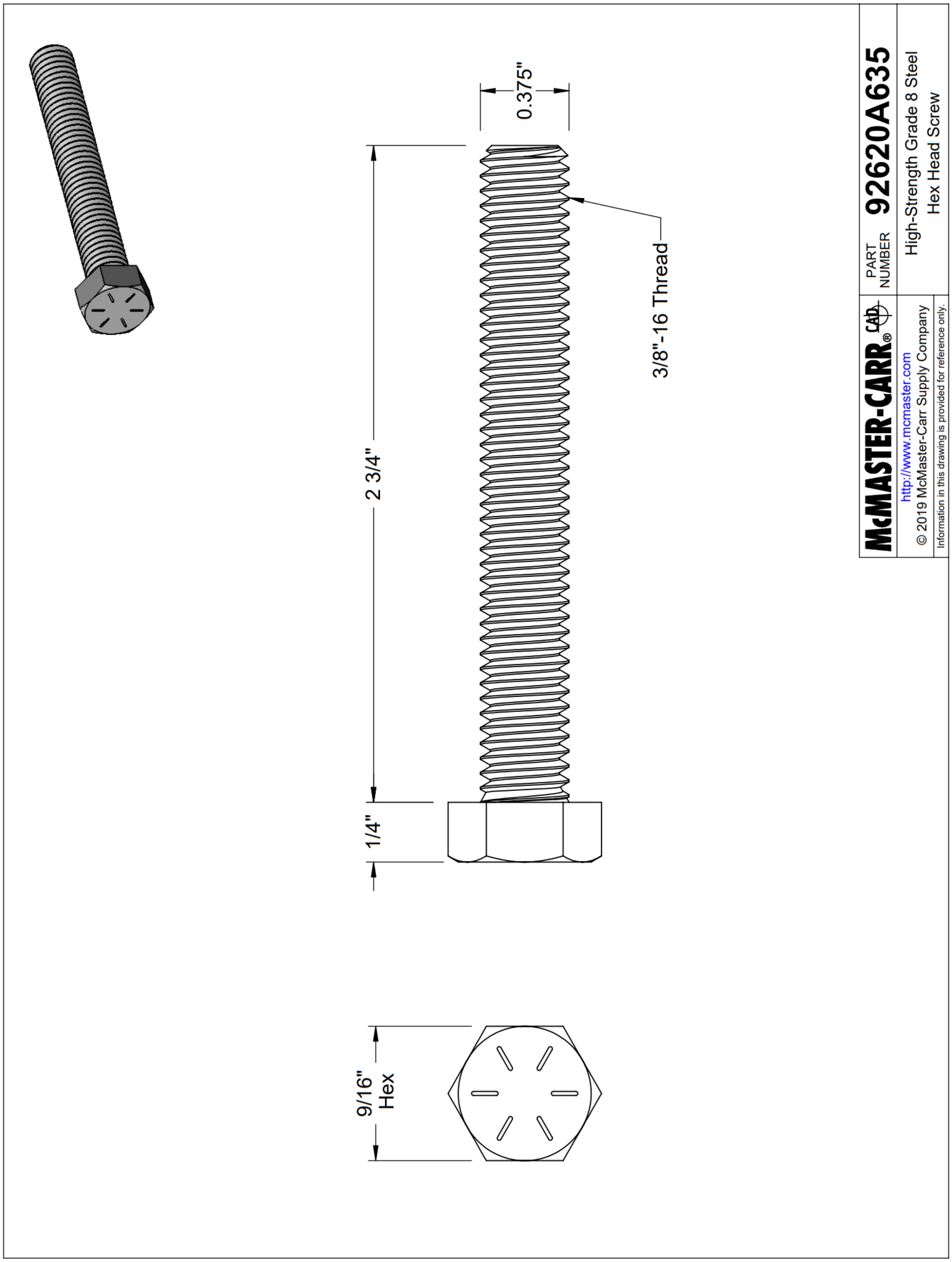
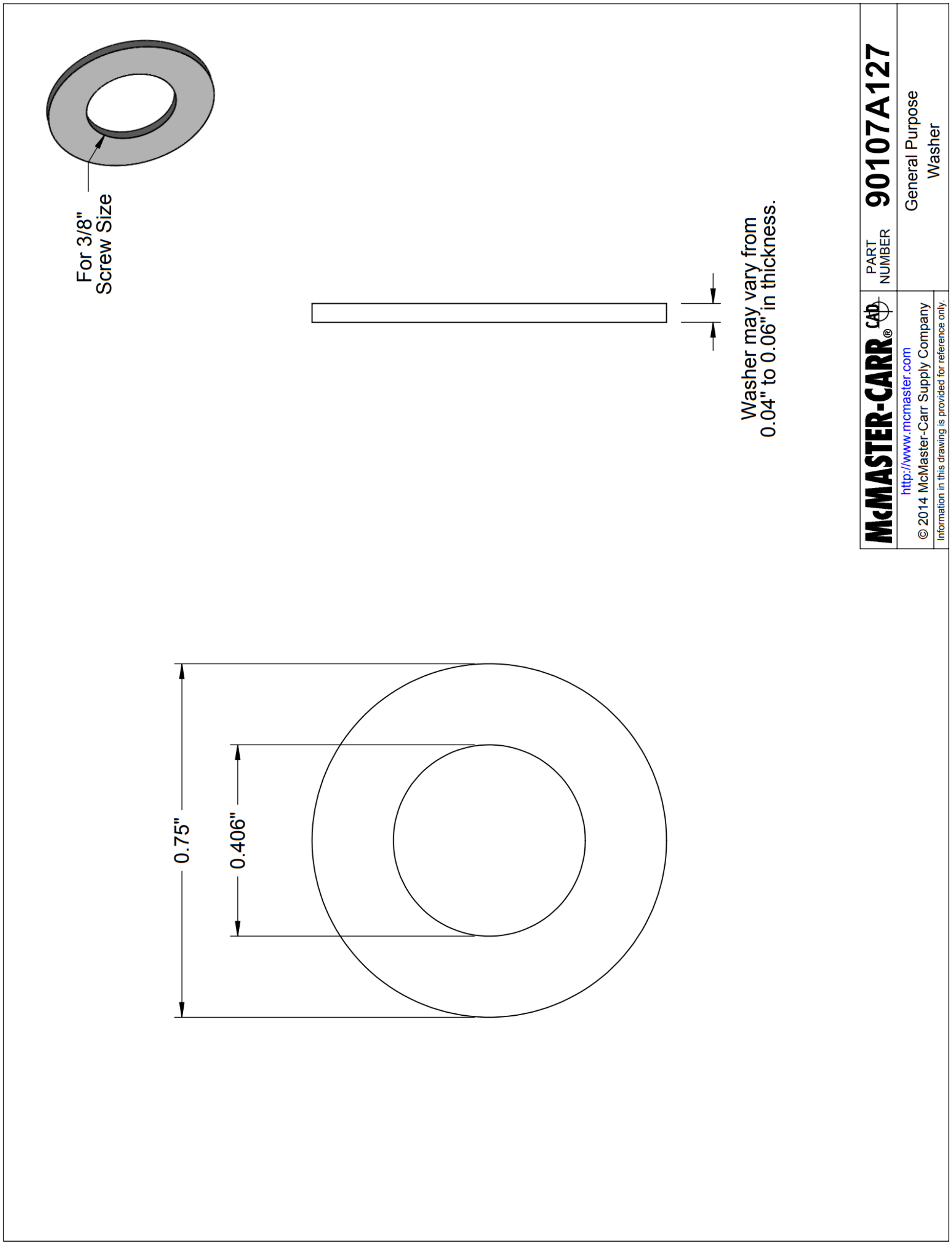
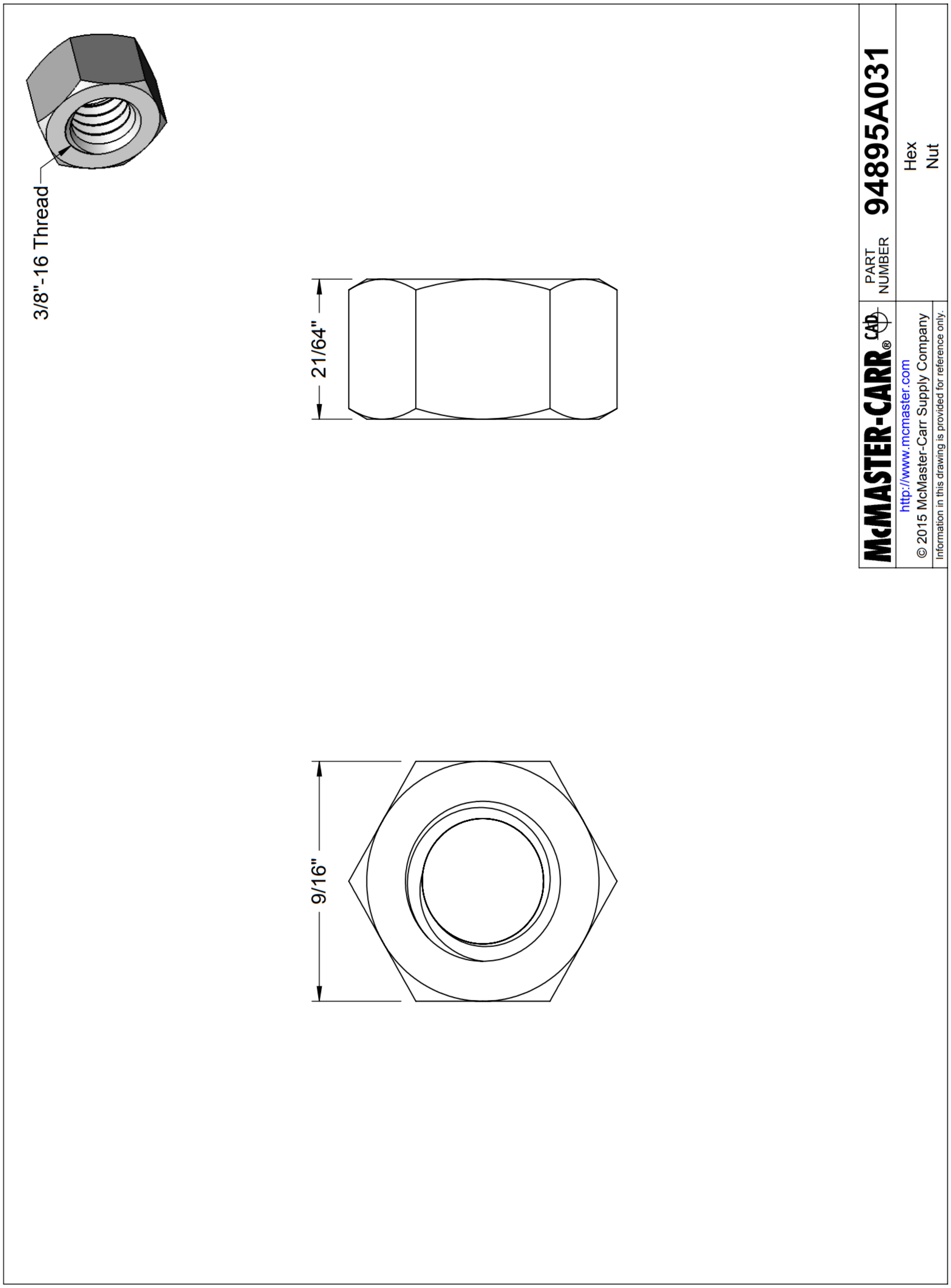

0.375"
3/8"-16 Thread
2 3/4"
1/4"
9/16"
Hex
PART
NUMBER
92620A635
High-Strength Grade 8 Steel
Hex Head Screw
McMASTER-CARR
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.


For 3/8"
Screw Size
Washer may vary from
0.04" to 0.06" in thickness.
0.75"
0.406"
McMASTER-CARR
CAD
PART
NUMBER
90107A127
General Purpose
Washer
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.


3/8"-16 Thread
21/64"
9/16"
McMASTER-CARR®
CAD
PART NUMBER
94895A031
Hex
Nut
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
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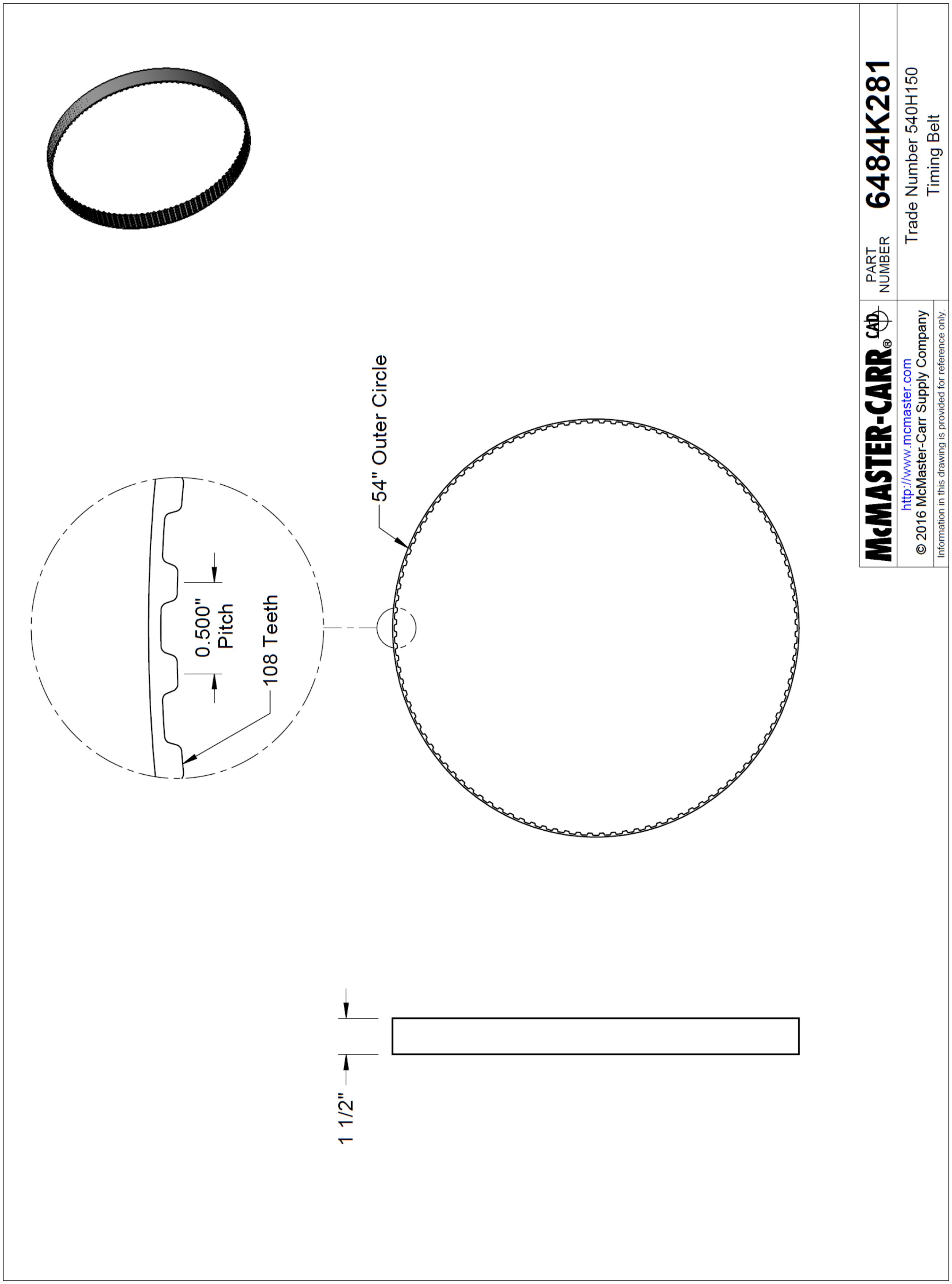
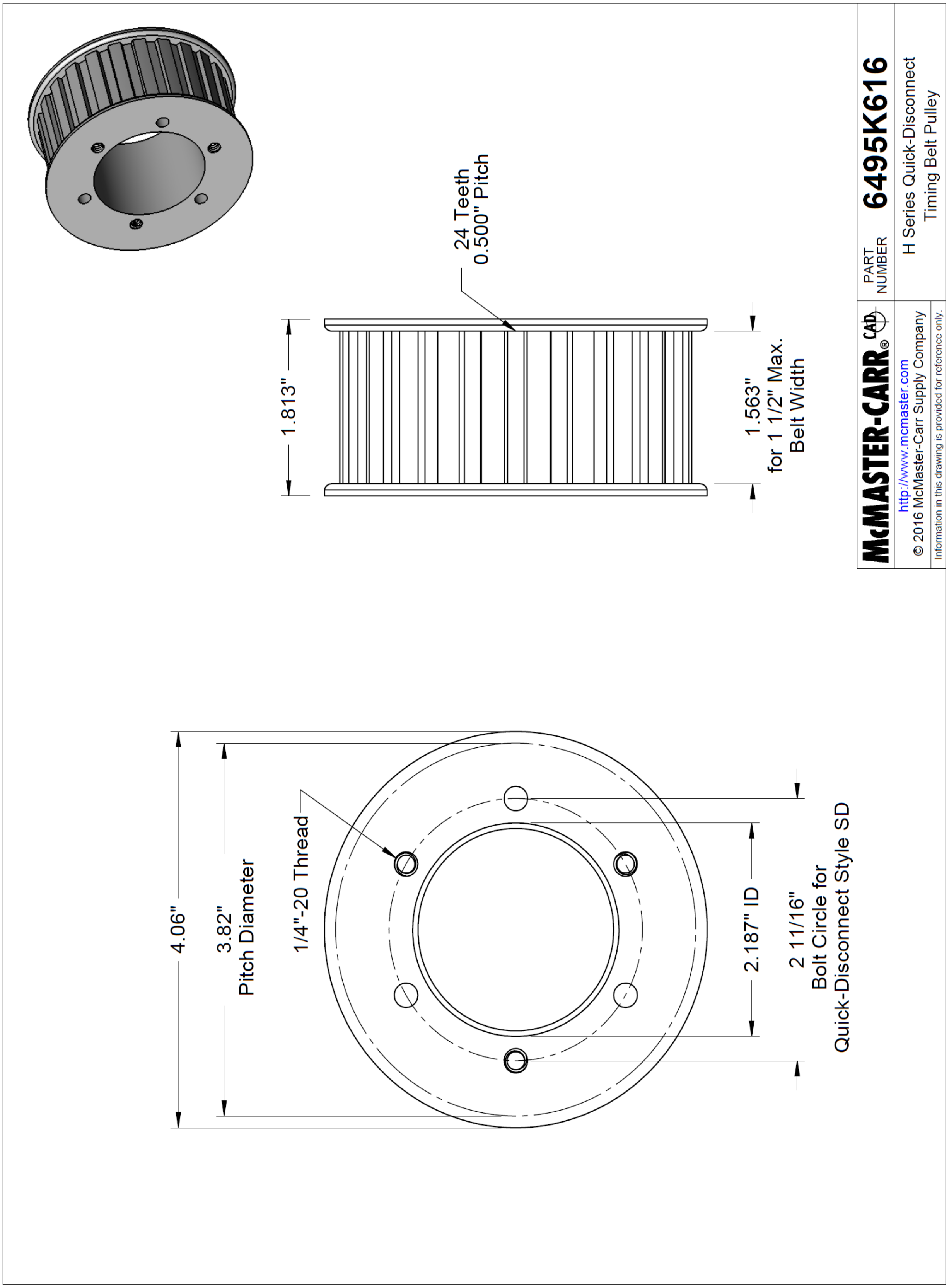


54" Outer Circle
0.500" Pitch
108 Teeth
1 1/2"
McMASTER-CARR® CAD
PART NUMBER
6484K281
http://www.mcmaster.com
© 2016 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Trade Number 540H150
Timing Belt



24 Teeth
0.500" Pitch
1.813"
1.563"
for 1 1/2" Max.
Belt Width
4.06"
3.82"
Pitch Diameter
1/4"-20 Thread
2.187" ID
2 11/16"
Bolt Circle for
Quick-Disconnect Style SD
McMASTER-CARR® CAD
http://www.mcmaster.com
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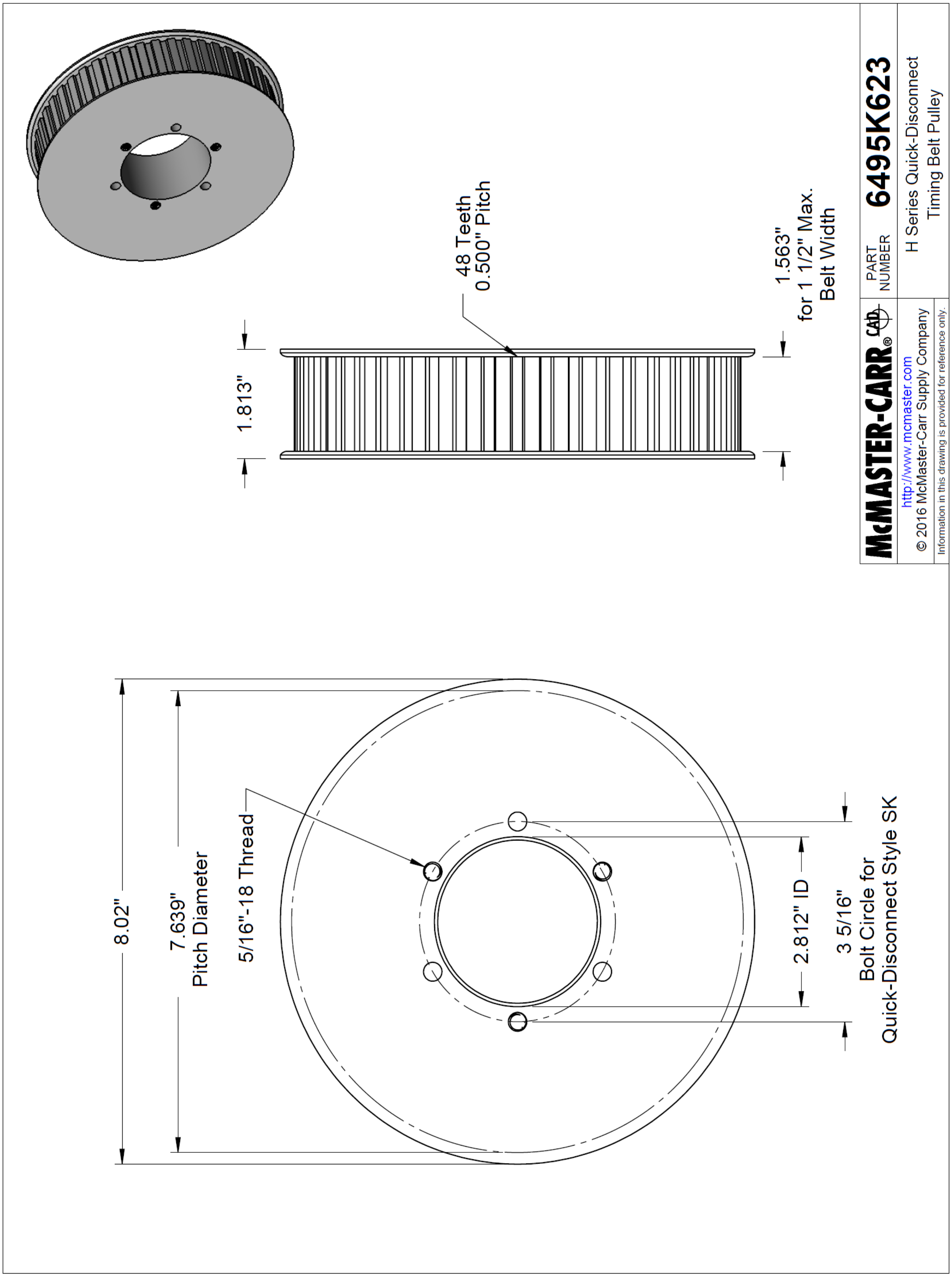
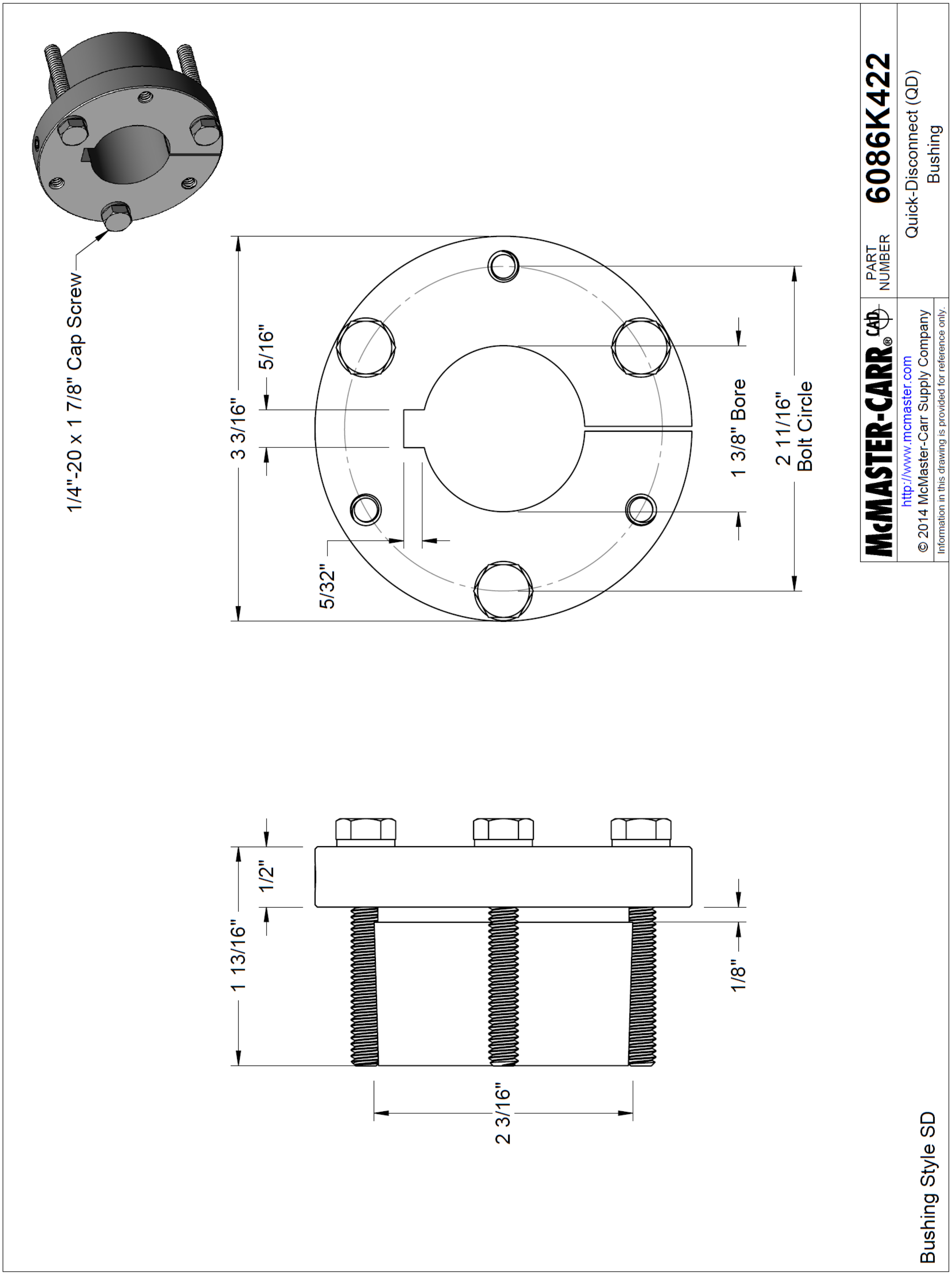
Information in this drawing is provided for reference only.
PART
NUMBER
6495K616
H Series Quick-Disconnect
Timing Belt Pulley


48 Teeth
0.500" Pitch
1.813"
1.563"
for 1 1/2" Max.
Belt Width
8.02"
7.639"
Pitch Diameter
5/16"-18 Thread
2.812" ID
3 5/16"
Bolt Circle for
Quick-Disconnect Style SK
McMASTER-CARR®
CAD
PART
NUMBER
6495K623
http://www.mcmaster.com
© 2016 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
H Series Quick-Disconnect
Timing Belt Pulley


1/4"-20 x 1 7/8" Cap Screw
3 3/16"
5/16"
5/32"
1 3/8" Bore
2 11/16"
Bolt Circle
1/2"
1 13/16"
1/8"
2 3/16"
Bushing Style SD
McMASTER-CARR
CAD
http://www.mcmaster.com
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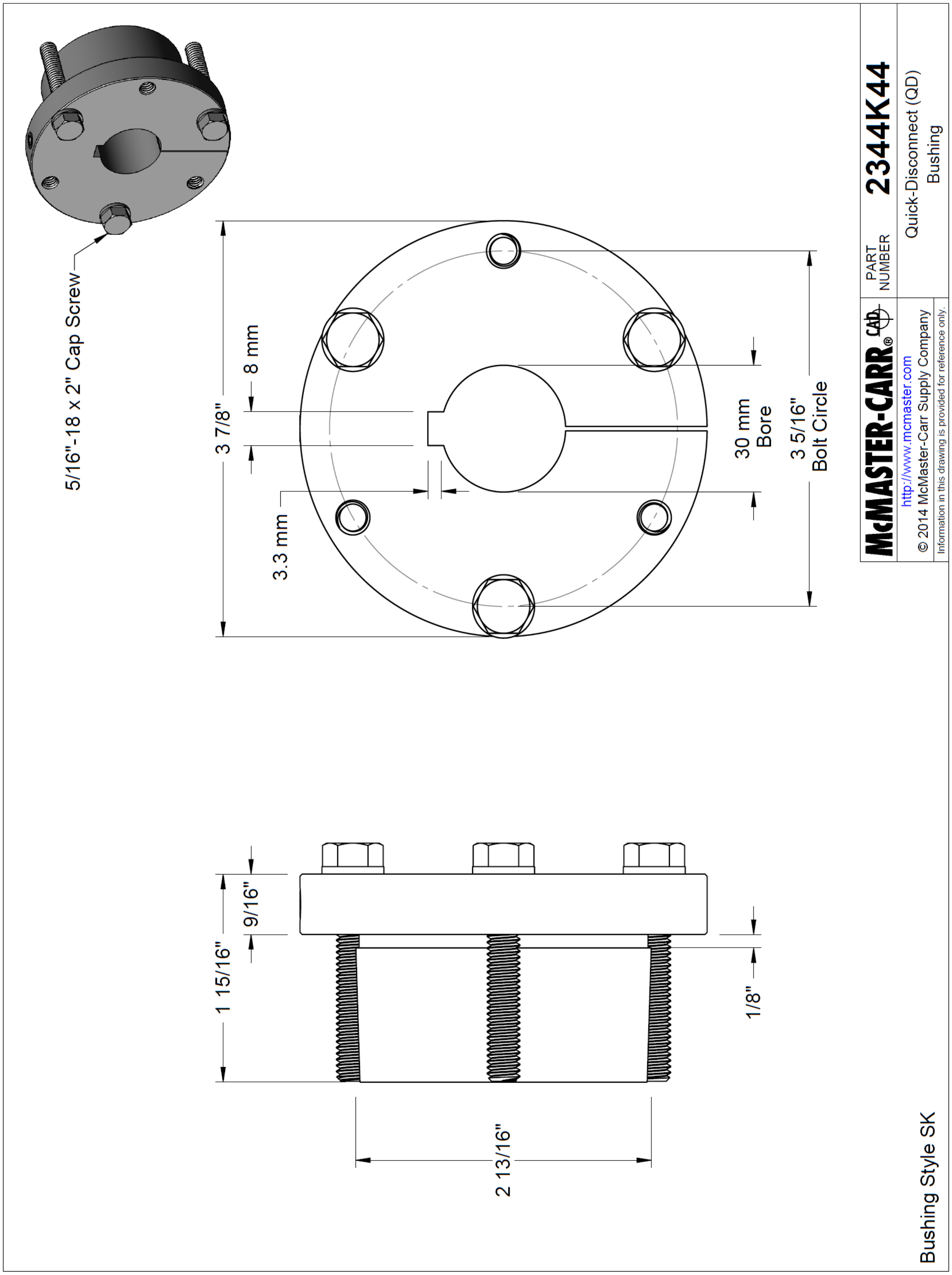
Information in this drawing is provided for reference only.
PART NUMBER
6086K422
Quick-Disconnect (QD)
Bushing


5/16"-18 x 2" Cap Screw
8 mm
3 7/8"
3.3 mm
30 mm
Bore
3 5/16"
Bolt Circle
9/16"
1 15/16"
1/8"
2 13/16"
Bushing Style SK
McMASTER-CARR CAD
PART NUMBER
2344K44
Quick-Disconnect (QD)
Bushing
http://www.mcmaster.com
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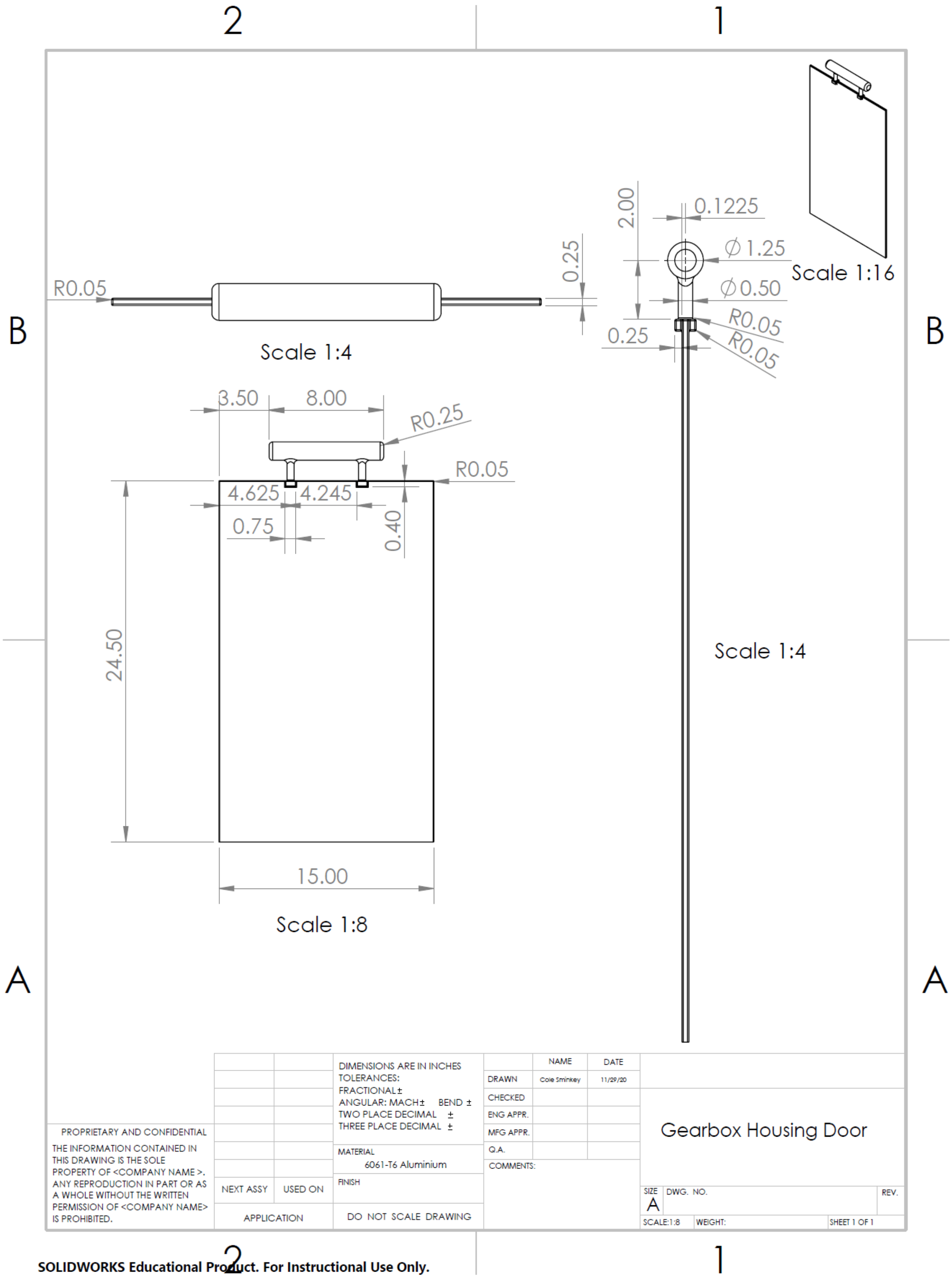
2
1
B
A
R0.05
Scale 1:4
0.25
2.00
0.1225
∅1.25
∅0.50
R0.05
R0.05
0.25
Scale 1:16
3.50
8.00
R0.25
R0.05
4.625
4.245
0.75
0.40
24.50
15.00
Scale 1:8
Scale 1:4
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
MATERIAL
6061-T6 Aluminium
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
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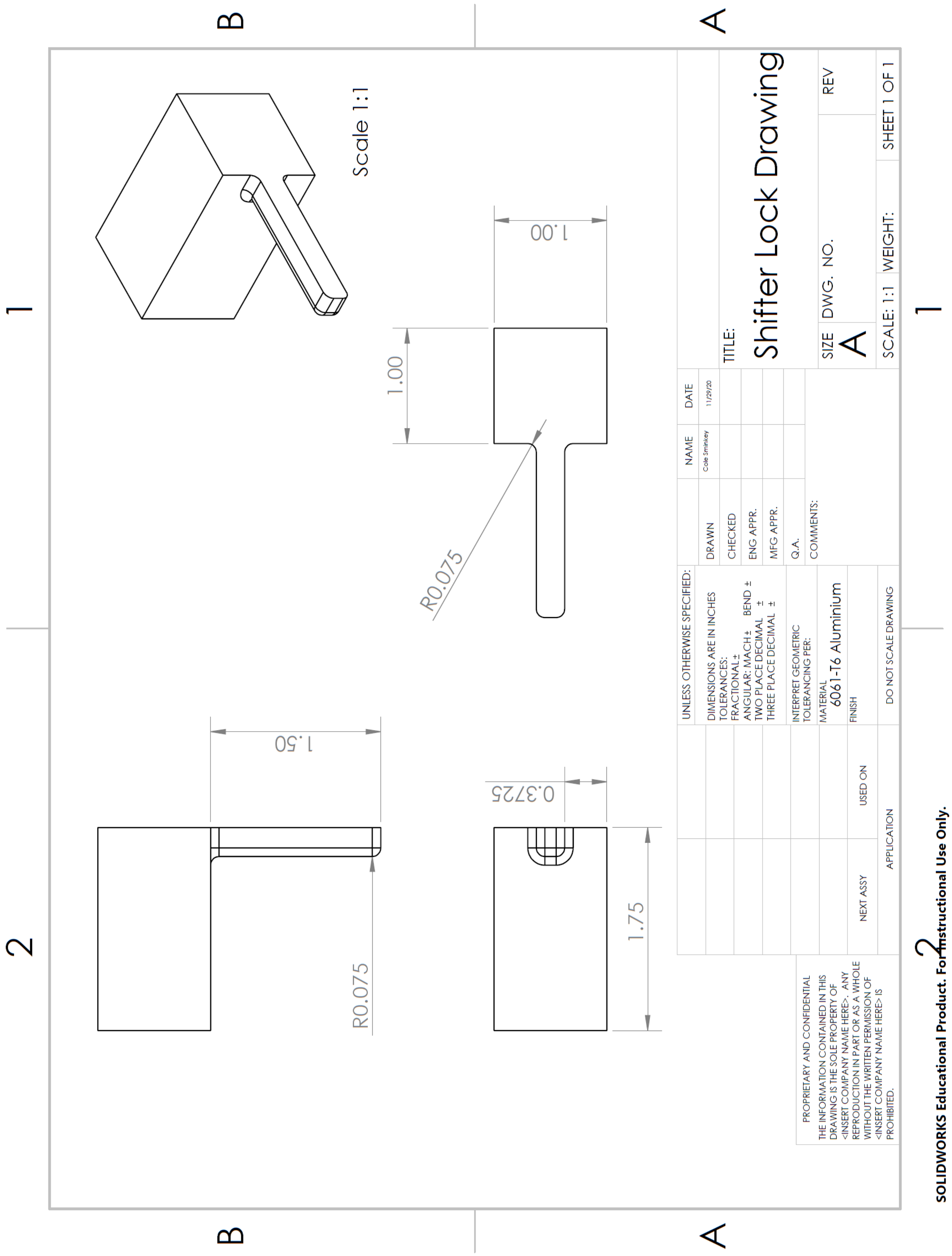
NAME
DATE
DRAWN
Cole Sminkey
11/29/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Gearbox Housing Door
SIZE
A
DWG. NO.
REV.
SCALE:1:8
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


Scale 1:1
1.00
1.00
R0.075
1.50
0.3725
R0.075
1.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-T6 Aluminium
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Cole Smirkey
11/29/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Shifter Lock Drawing
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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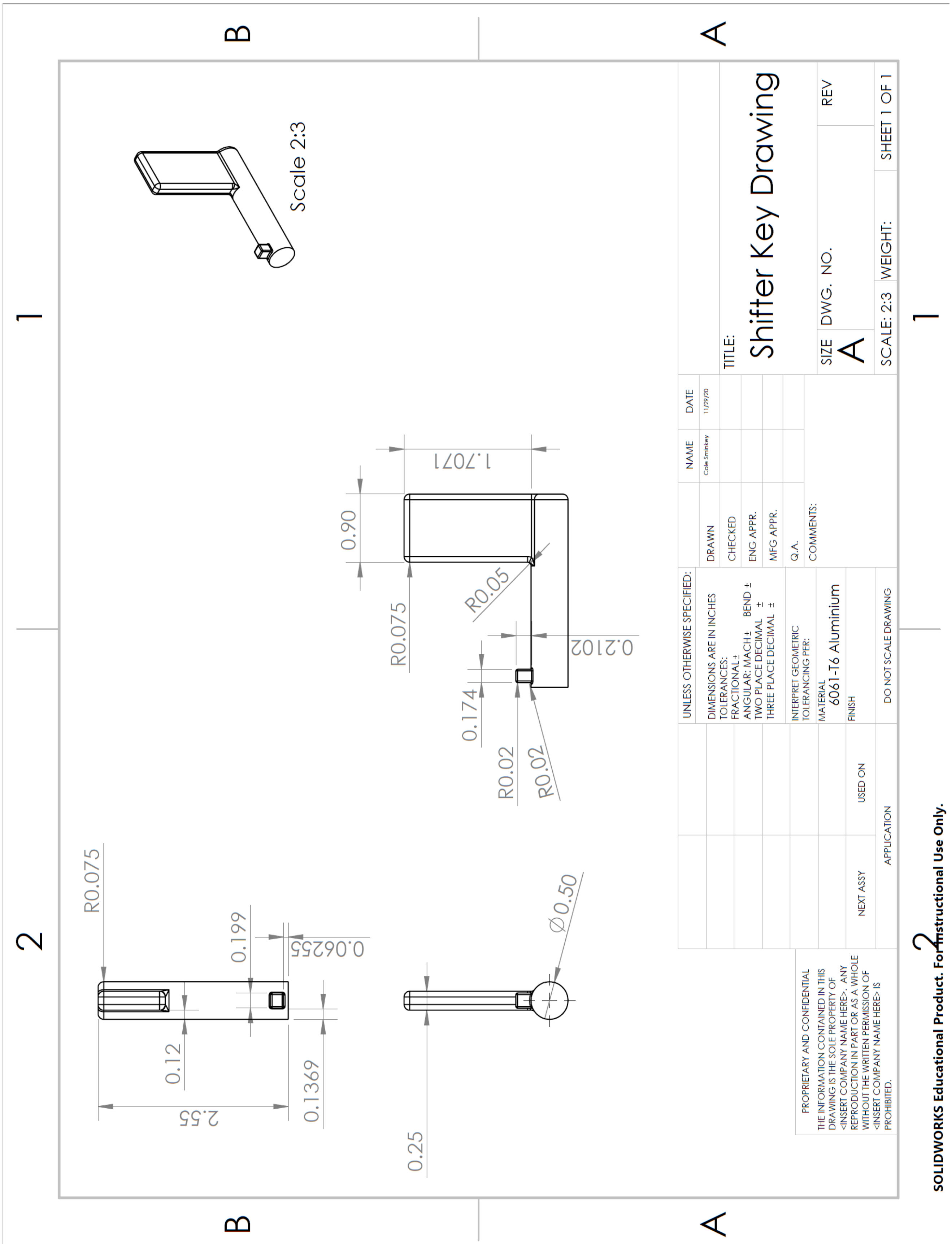

Scale 2:3
R0.075
0.12
2.55
0.199
0.06255
0.1369
0.25
Ø0.50
0.90
1.7071
R0.075
R0.05
0.2102
0.174
R0.02
R0.02
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-T6 Aluminium
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Cole Smirkey
11/29/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Shifter Key Drawing
SIZE
A
DWG. NO.
REV
SCALE: 2:3
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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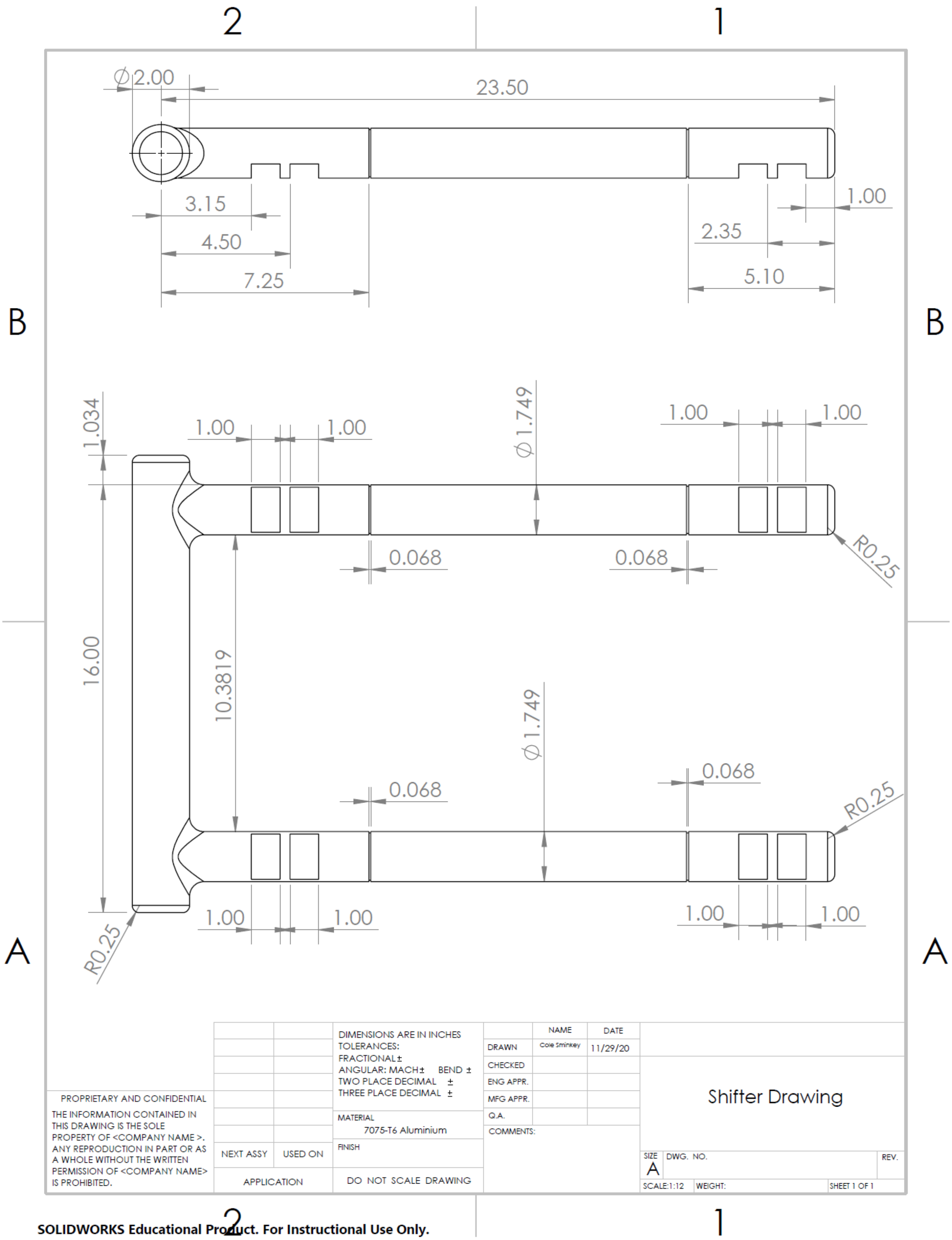
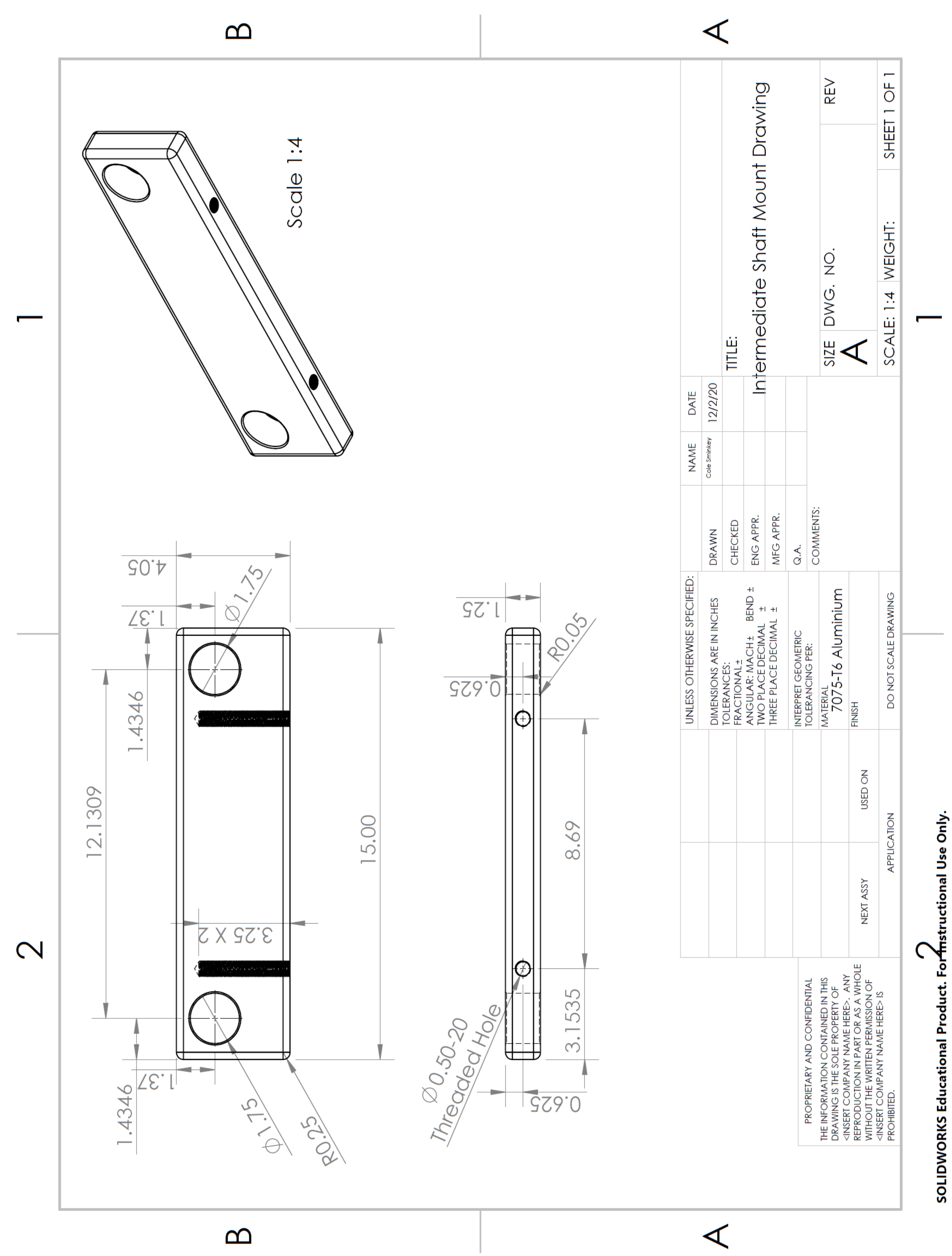


SOLIDWORKS Educational Product. For Instructional Use Only.


Scale 1:4
4.05
1.37
Ø1.75
1.4346
12.1309
3.25 X 2
15.00
1.25
0.625
R0.05
8.69
3.1535
Ø0.50-20
Threaded Hole
0.625
1.37
1.4346
Ø1.75
R0.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
7075-T6 Aluminium
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
Cole Smirkey
12/2/20
TITLE:
Intermediate Shaft Mount Drawing
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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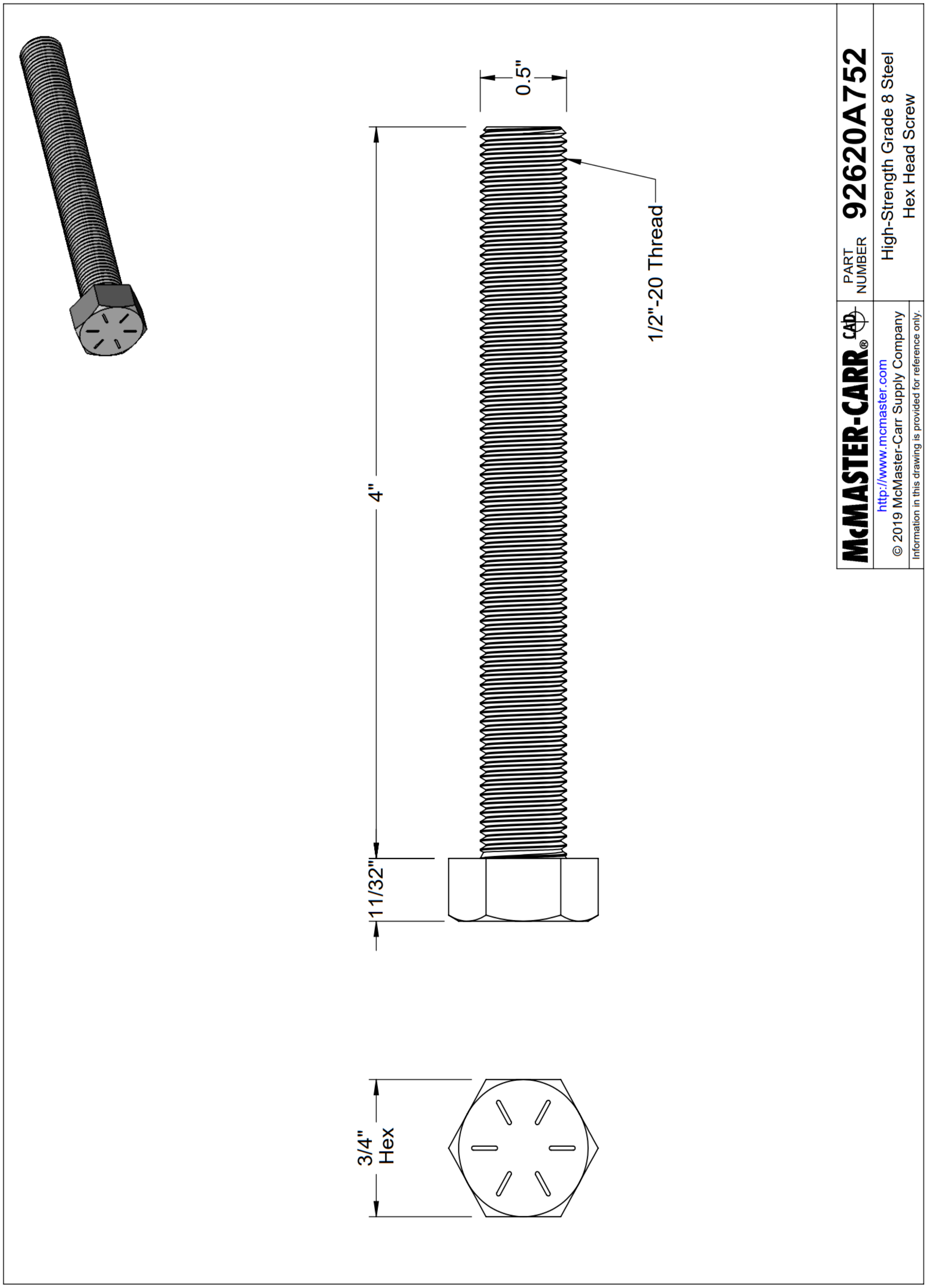
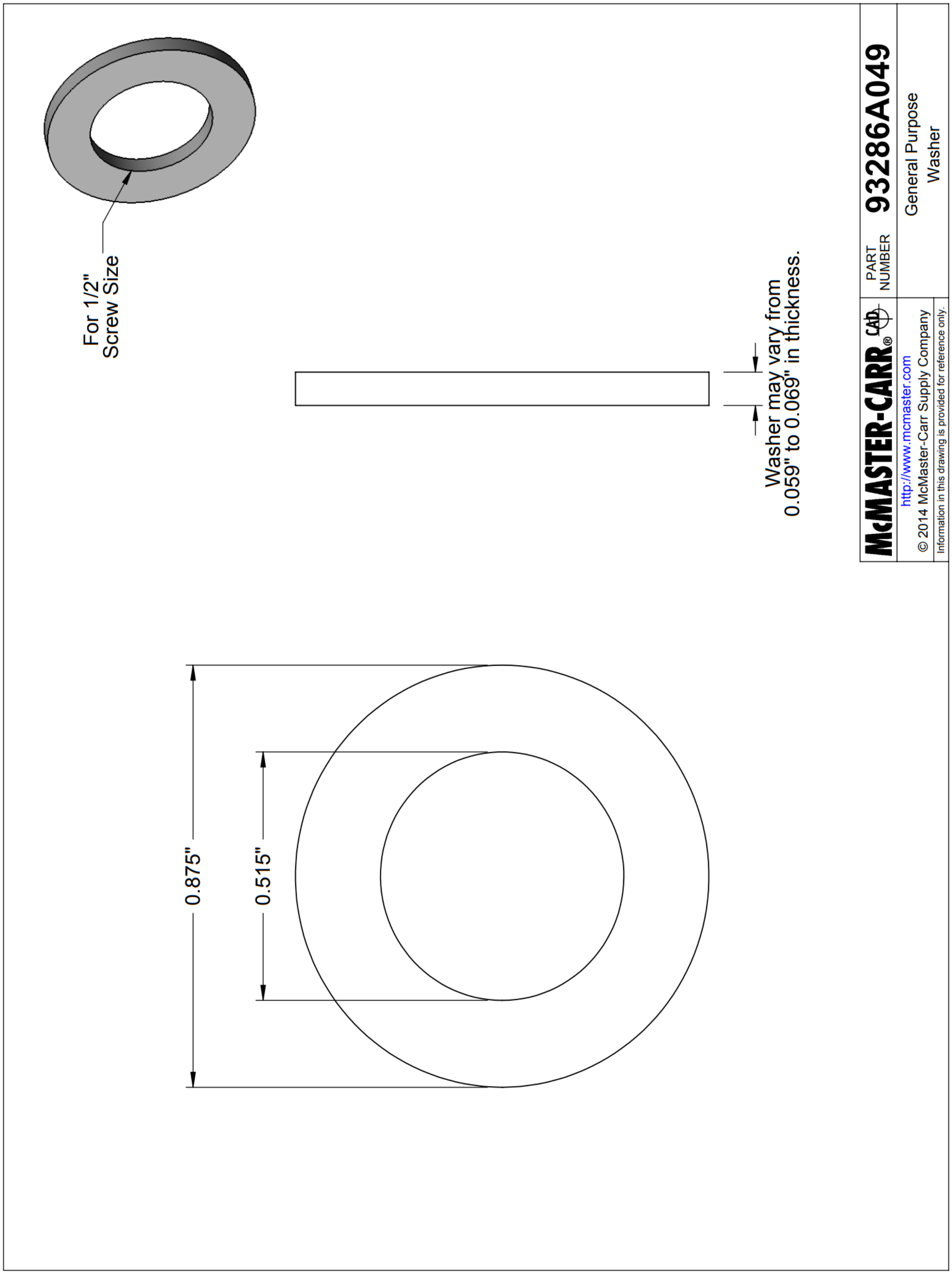

0.5"
4"
1/2"-20 Thread
11/32"
3/4" Hex
McMASTER-CARR
CAD
PART NUMBER
92620A752
High-Strength Grade 8 Steel Hex Head Screw
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.


For 1/2"
Screw Size
Washer may vary from
0.059" to 0.069" in thickness.
0.875"
0.515"
McMASTER-CARR®
CAD
PART
NUMBER
93286A049
General Purpose
Washer
http://www.mcmaster.com
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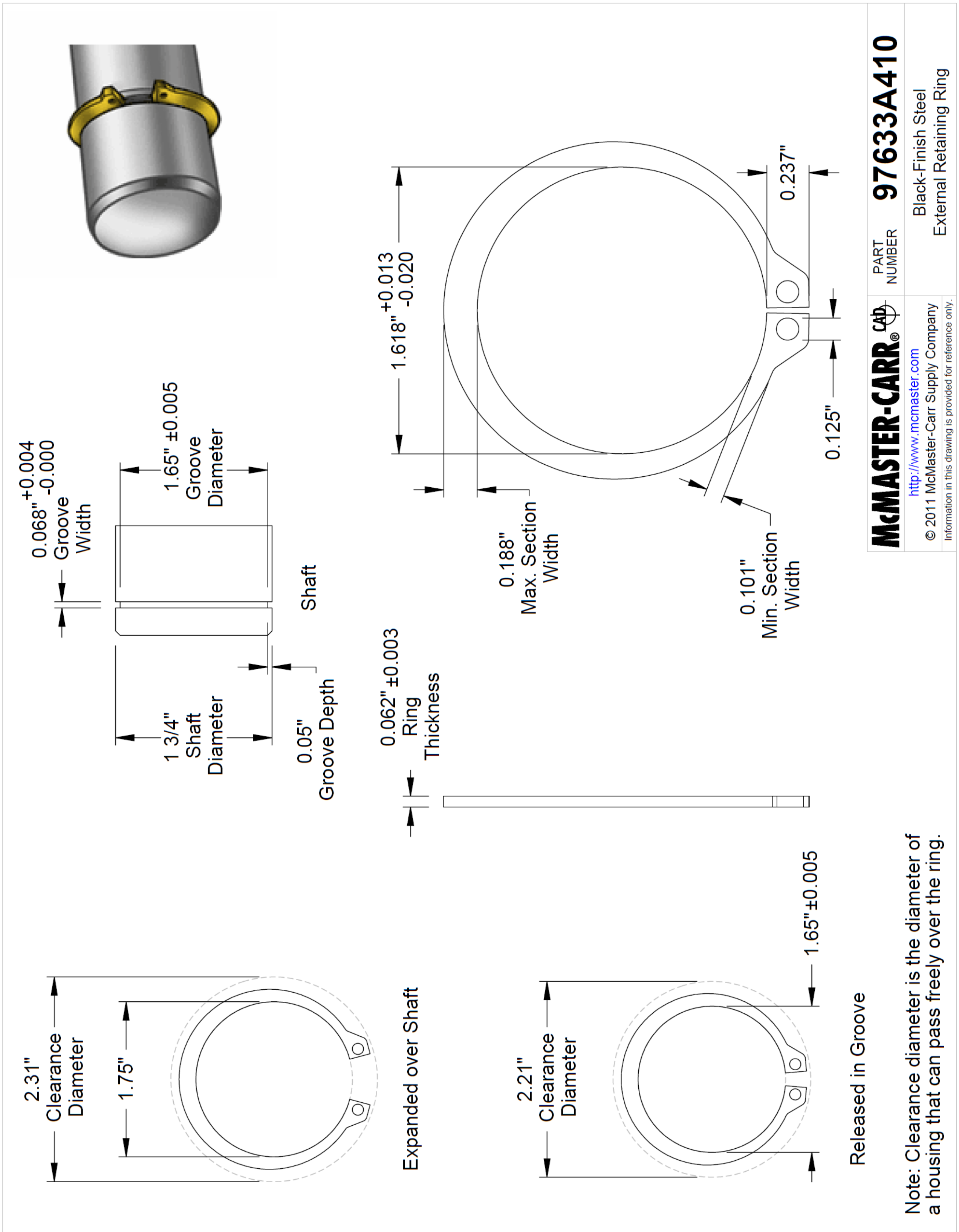

0.068" +0.004 -0.000 Groove Width
1.65" ±0.005 Groove Diameter
1.618" +0.013 -0.020
0.237"
97633A410
PART NUMBER
Black-Finish Steel External Retaining Ring
McMASTER-CARR®
http://www.mcmaster.com
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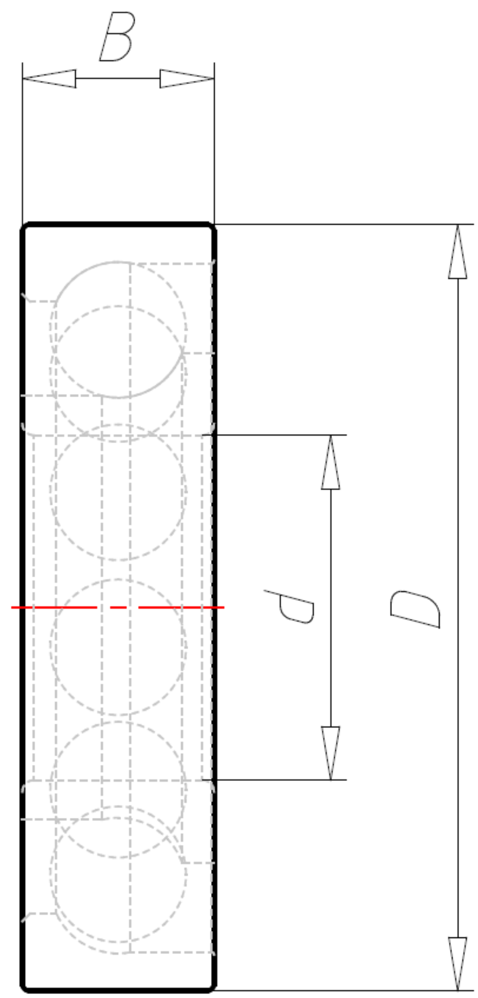
1 3/4" Shaft Diameter
0.05" Groove Depth
Shaft
0.062" ±0.003 Ring Thickness
0.188" Max. Section Width
0.101" Min. Section Width
0.125"
2.31" Clearance Diameter
1.75"
Expanded over Shaft
2.21" Clearance Diameter
1.65"±0.005
Released in Groove
Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.

This section lists all the bearings. For simplicity, we used a master drawing from the SKF catalog and placed the dimensions in increasing bore diameter. 60 mm bearing is on both ends of the Intermediate Shaft. 30 mm and 45 mm bearing are on the Input Shaft. 35 mm and 55 mm bearing are on the Output Shaft**.**

Technical drawings



Technical Data

Designation	7306 BECBP
d - Bore diameter	30 (mm)
D - Outside diameter	72 (mm)
B - Width	19 (mm)
C - Basic dynamic load rating	35.5 (kN)
C0 - Basic static load rating	21.2 (kN)
Pu - Fatigue load limit	0.9 (kN)
Reference speed - Reference speed	12000 (r/min)
Limiting speed - Limiting speed	13000 (r/min)
Designation bearing	7306 BECBP

Technical Data

Designation	7307 BECBP
d - Bore diameter	35 (mm)
D - Outside diameter	80 (mm)
B - Width	21 (mm)
C - Basic dynamic load rating	41.5 (kN)
C0 - Basic static load rating	26.5 (kN)
Pu - Fatigue load limit	1.14 (kN)
Reference speed - Reference speed	11000 (r/min)
Limiting speed - Limiting speed	11000 (r/min)
Designation bearing	7307 BECBP

Technical Data

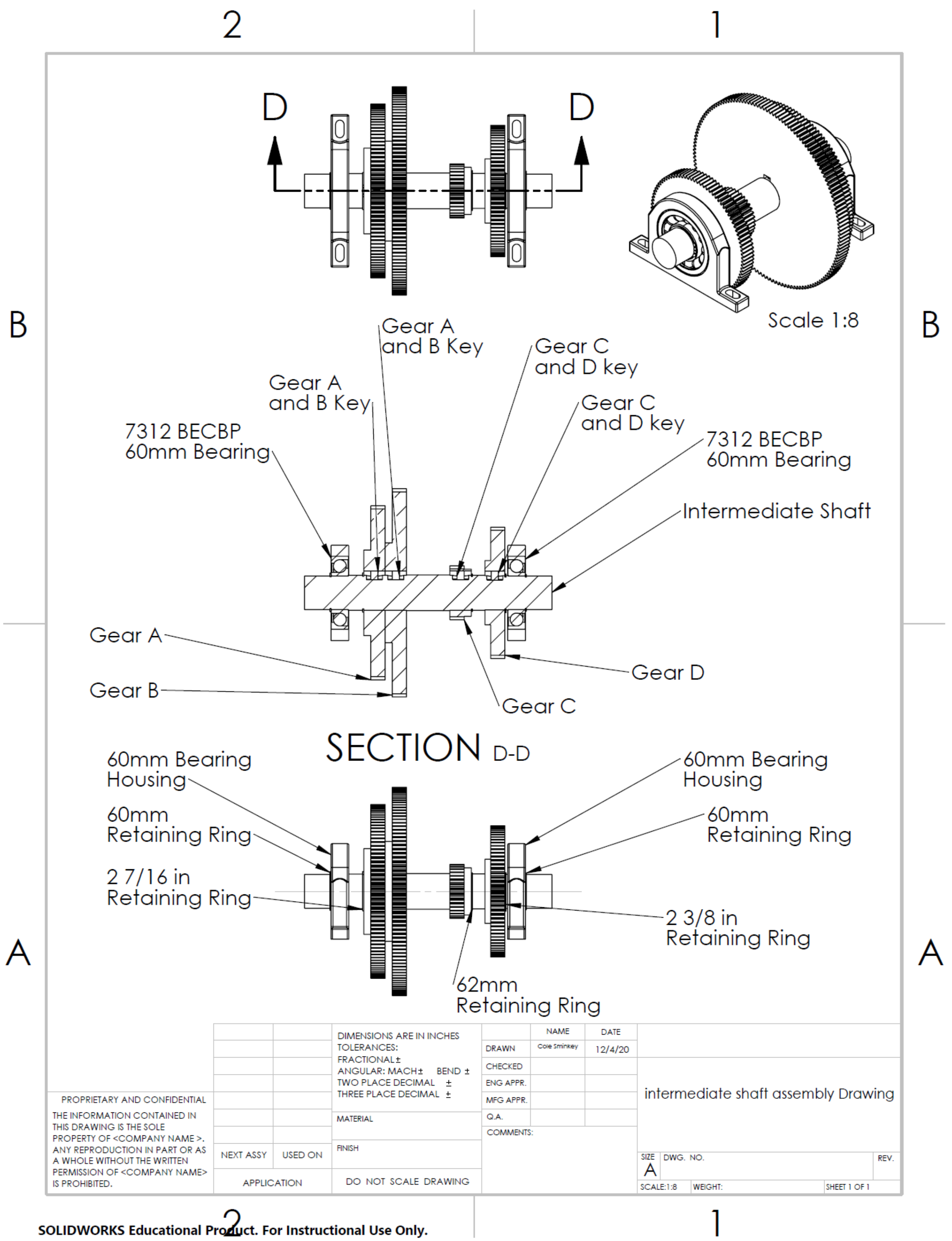
Designation	7309 BECBP
d - Bore diameter	45 (mm)
D - Outside diameter	100 (mm)
B - Width	25 (mm)
C - Basic dynamic load rating	61 (kN)
C0 - Basic static load rating	40.5 (kN)
Pu - Fatigue load limit	1.73 (kN)
Reference speed - Reference speed	8500 (r/min)
Limiting speed - Limiting speed	9000 (r/min)
Designation bearing	7309 BECBP

Technical Data

Designation	7311 BECBP
d - Bore diameter	55 (mm)
D - Outside diameter	120 (mm)
B - Width	29 (mm)
C - Basic dynamic load rating	85 (kN)
C0 - Basic static load rating	60 (kN)
Pu - Fatigue load limit	2.55 (kN)
Reference speed - Reference speed	7000 (r/min)
Limiting speed - Limiting speed	7000 (r/min)
Designation bearing	7311 BECBP

Technical Data

Designation	7312 BECBP
d - Bore diameter	60 (mm)
D - Outside diameter	130 (mm)
B - Width	31 (mm)
C - Basic dynamic load rating	104 (kN)
C0 - Basic static load rating	76.5 (kN)
Pu - Fatigue load limit	3.2 (kN)
Reference speed - Reference speed	6300 (r/min)
Limiting speed - Limiting speed	6700 (r/min)
Designation bearing	7312 BECBP


2
1
D
D
Scale 1:8
B
B
Gear A
and B Key
Gear C
and D key
Gear A
and B Key
Gear C
and D key
7312 BECBP
60mm Bearing
7312 BECBP
60mm Bearing
Intermediate Shaft
Gear A
Gear B
Gear D
Gear C
SECTION D-D
60mm Bearing
Housing
60mm Bearing
Housing
60mm
Retaining Ring
60mm
Retaining Ring
2 7/16 in
Retaining Ring
2 3/8 in
Retaining Ring
A
A
62mm
Retaining Ring
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
Cole Sminkey
12/4/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
intermediate shaft assembly Drawing
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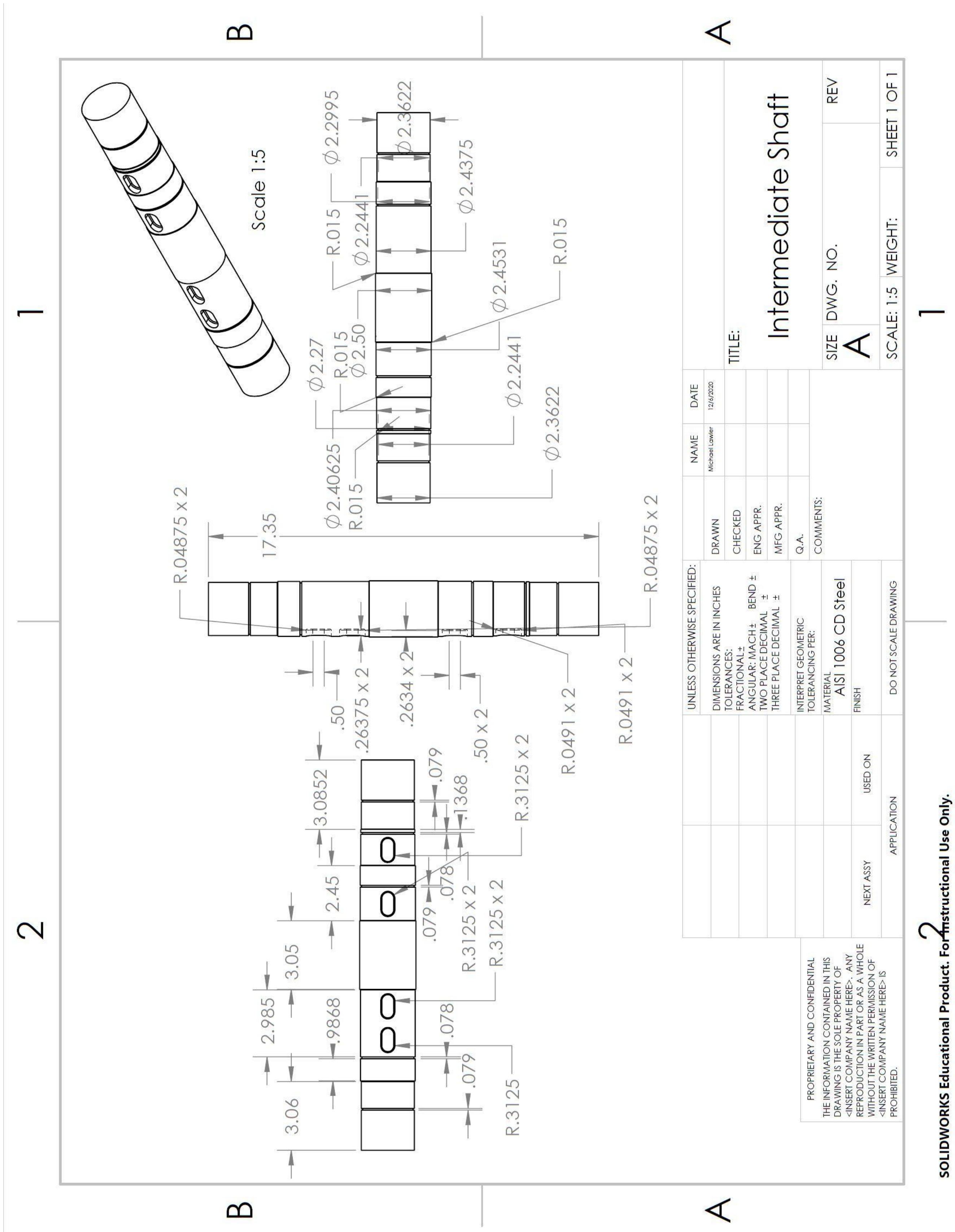
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
REV.
SCALE:1:8
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.
2
1


Scale 1:5
17.35
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1006 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Michael Lawler
12/6/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Intermediate Shaft
SIZE
A
DWG. NO.
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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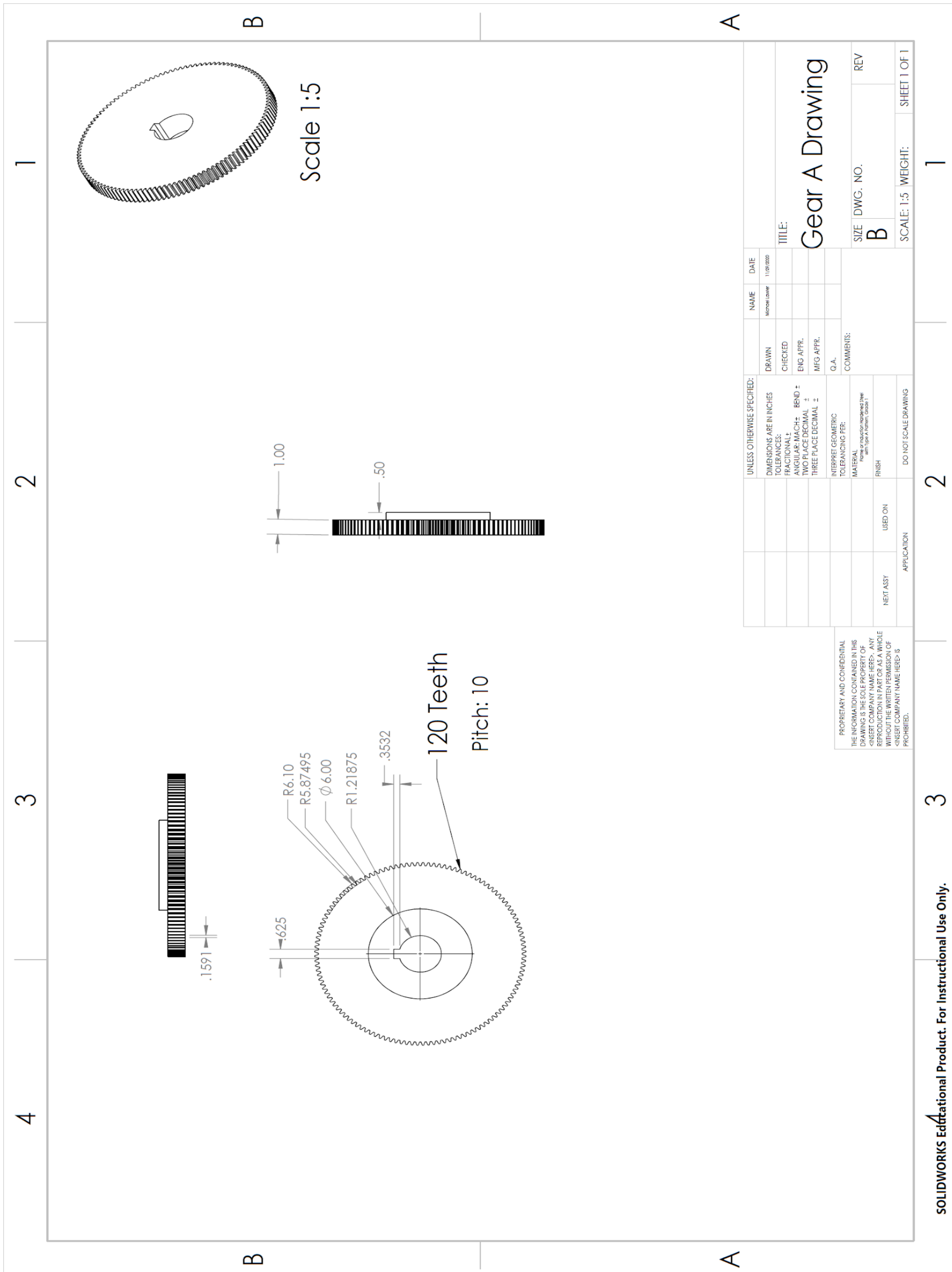
Scale 1:5
1.00
.50
R6.10
R5.87495
⌀6.00
R1.21875
.3532
120 Teeth
Pitch: 10
.625
.1591
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Gear A Drawing
SIZE
B
DWG. NO.
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
DO NOT SCALE DRAWING
APPLICATION
NEXT ASSY
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FINISH
MATERIAL
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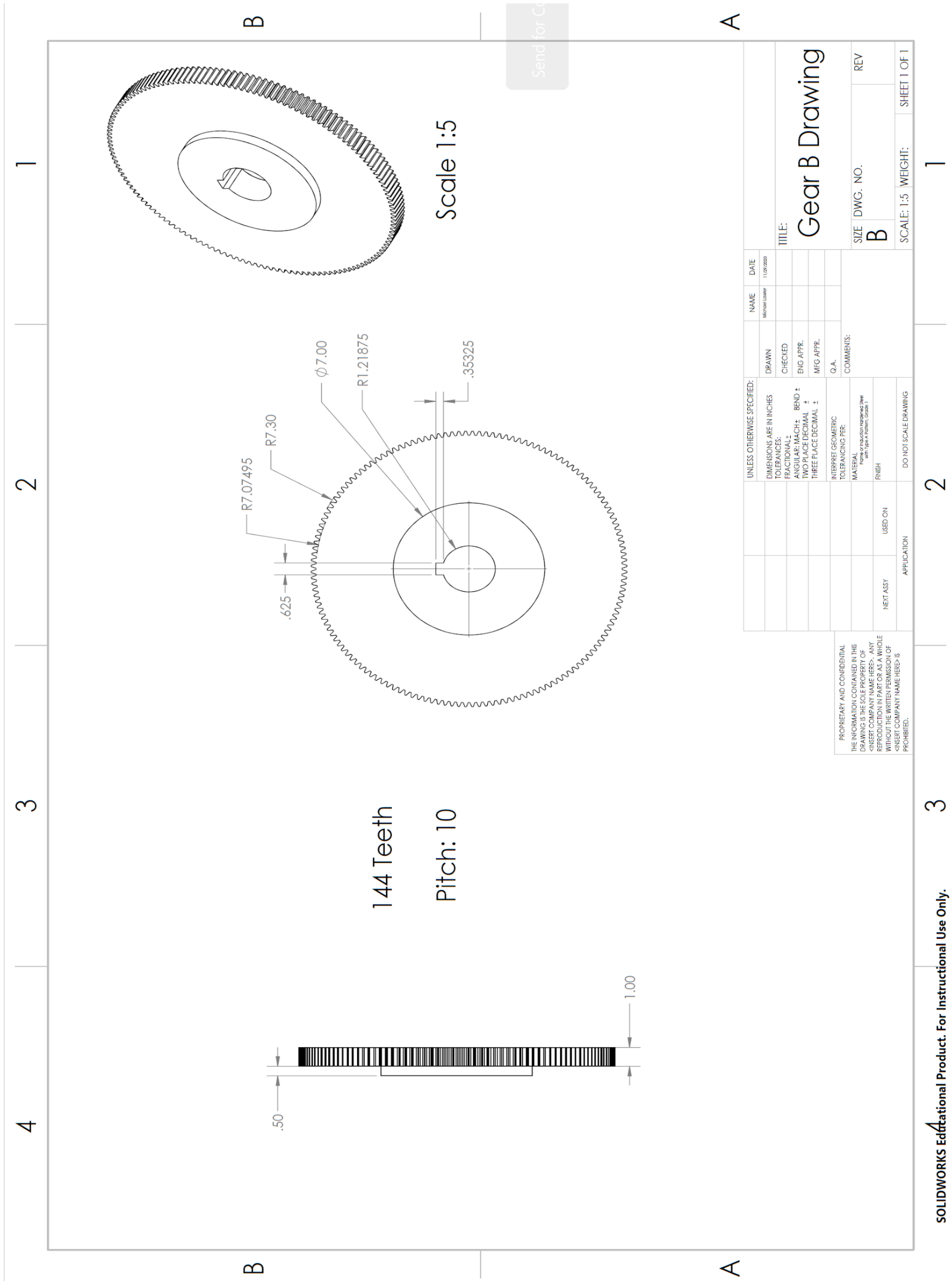

Scale 1:5
R7.07495
R7.30
Ø7.00
R1.21875
.35325
.625
144 Teeth
Pitch: 10
1.00
.50
Gear B Drawing
SIZE
B
DWG. NO.
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
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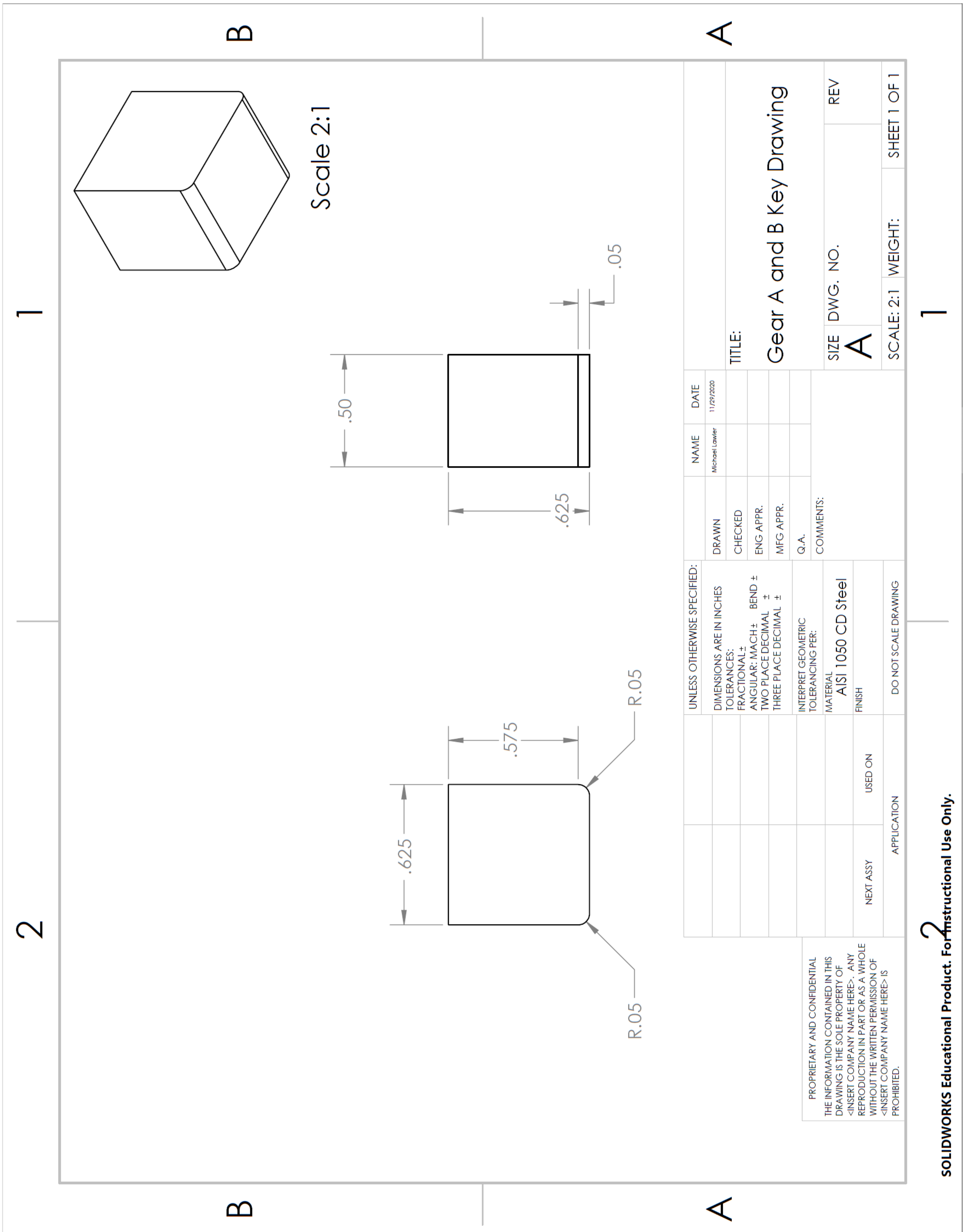

Scale 2:1
.05
.50
.625
.575
.625
R.05
R.05
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1050 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Michael Lawler
11/29/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gear A and B Key Drawing
SIZE
A
DWG. NO.
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
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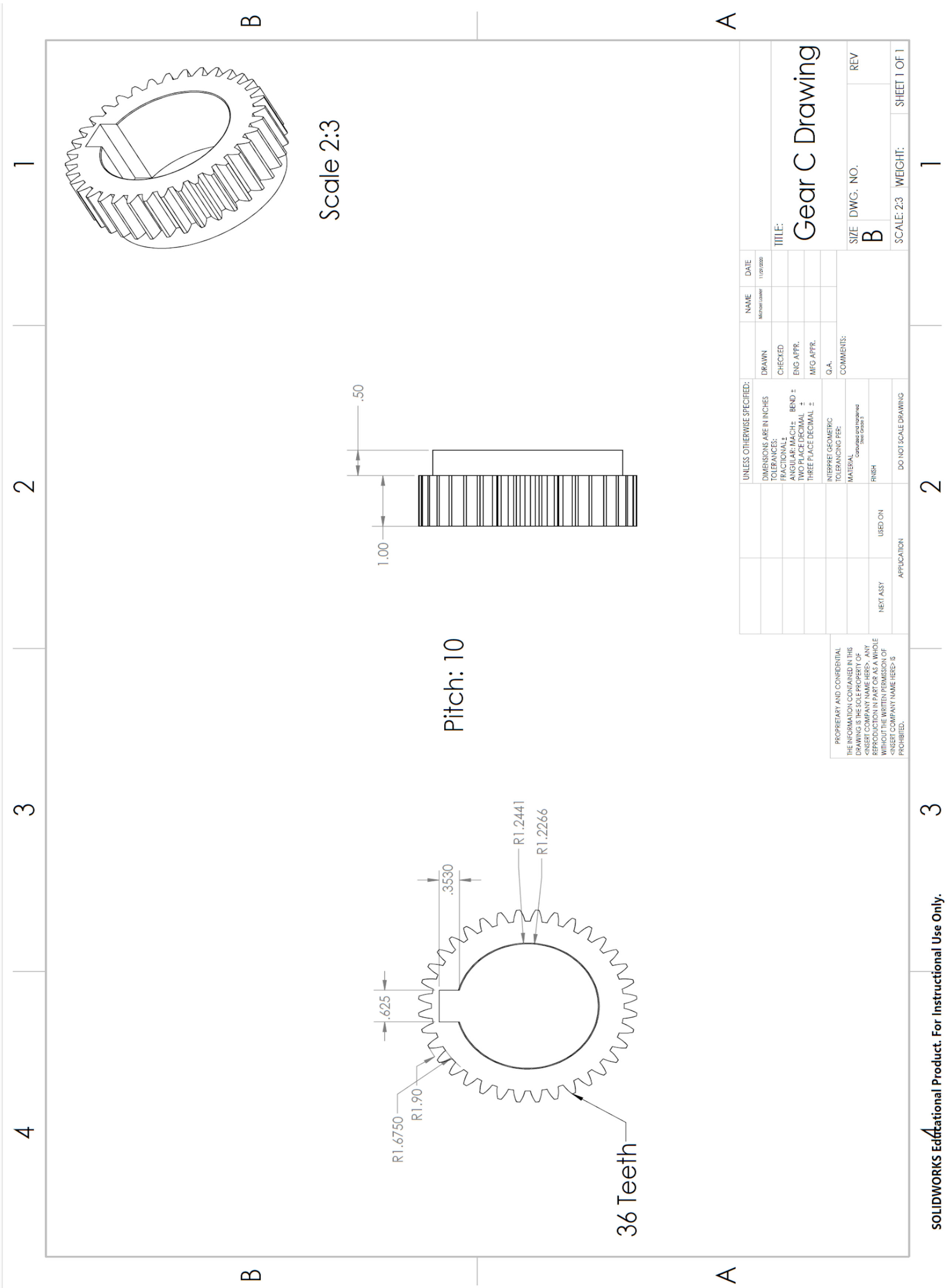

Scale 2:3
Pitch: 10
36 Teeth
.50
1.00
.3530
.625
R1.2441
R1.2266
R1.6750
R1.90
Gear C Drawing
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
SIZE DWG. NO.
B
REV
SCALE: 2:3 WEIGHT:
SHEET 1 OF 1
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
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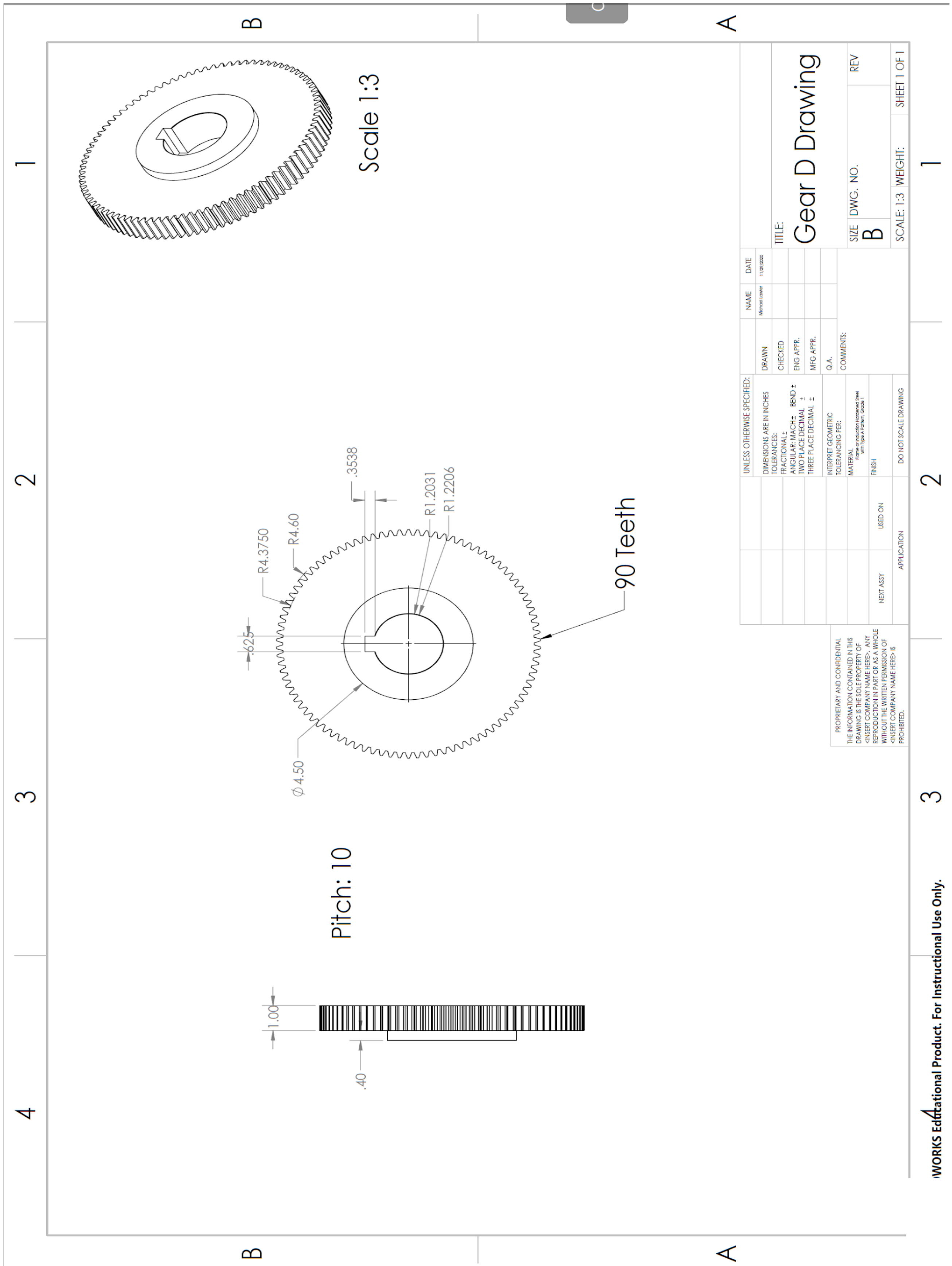
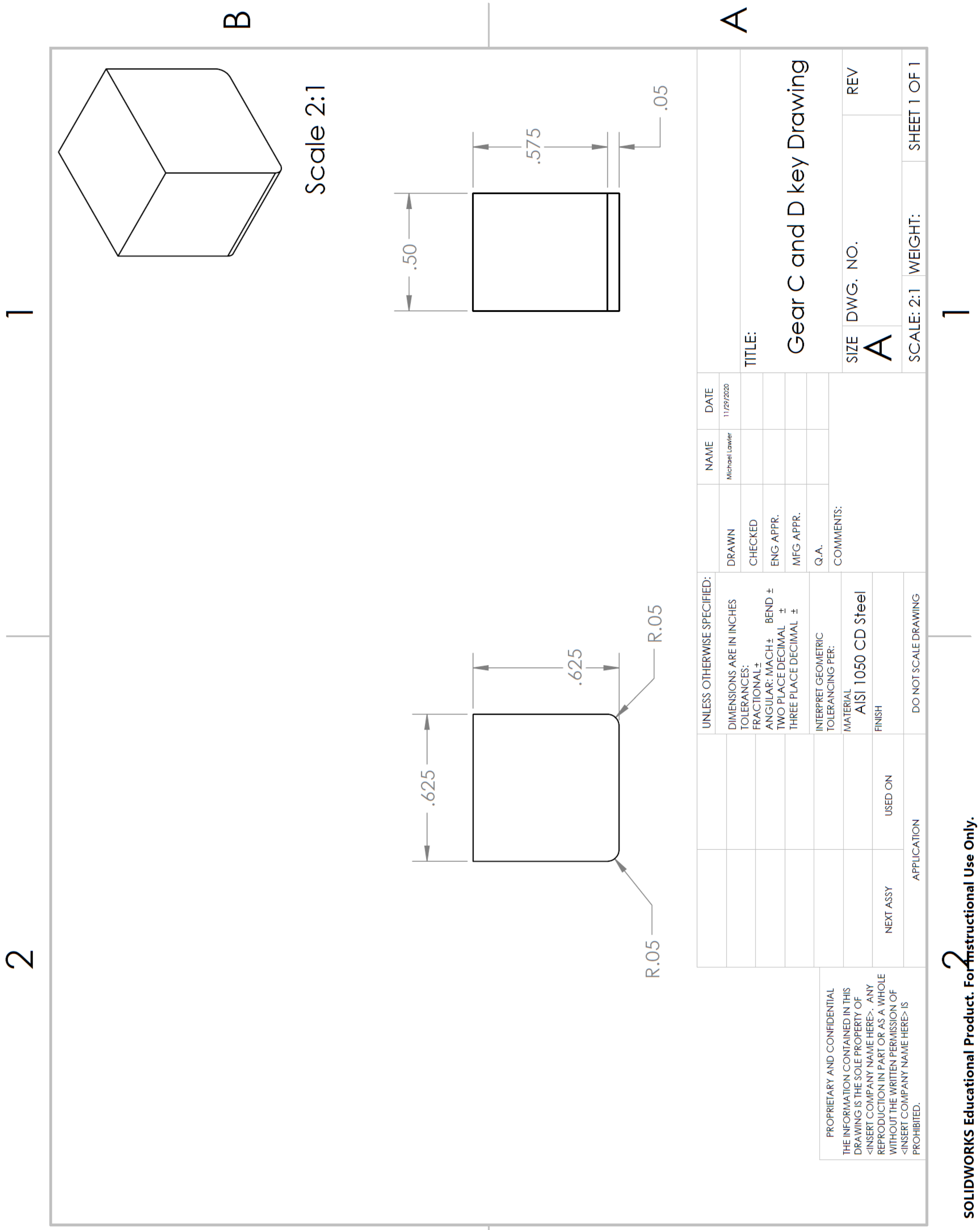


Scale 1:3
Pitch: 10
90 Teeth
.3538
R1.2031
R1.2206
R4.3750
R4.60
.625
Ø4.50
1.00
.40
Gear D Drawing
SIZE B
SCALE: 1:3
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
WORKS Educational Product. For Instructional Use Only.


Scale 2:1
.575
.05
.50
.625
.625
R.05
R.05
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1050 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Michael Lawler
11/29/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gear C and D key Drawing
SIZE
A
DWG. NO.
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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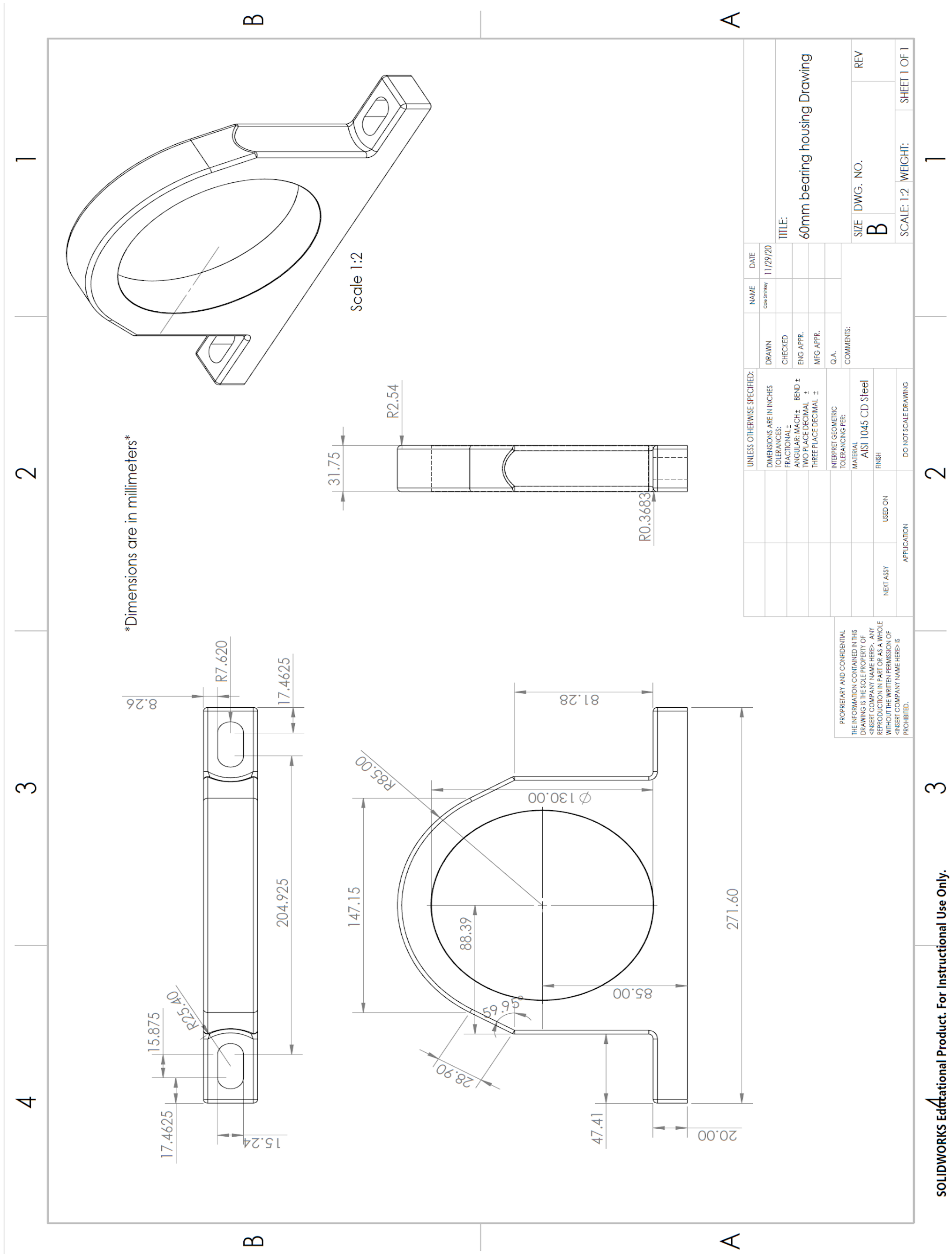
Dimensions are in millimeters
Scale 1:2
R2.54
31.75
R0.3683
8.26
R7.620
17.4625
204.925
15.875
R25.40
17.4625
15.24
81.28
R85.00
∅ 130.00
147.15
88.39
59.95°
85.00
28.90
47.41
271.60
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1045 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
11/29/20
TITLE:
60mm bearing housing Drawing
SIZE
B
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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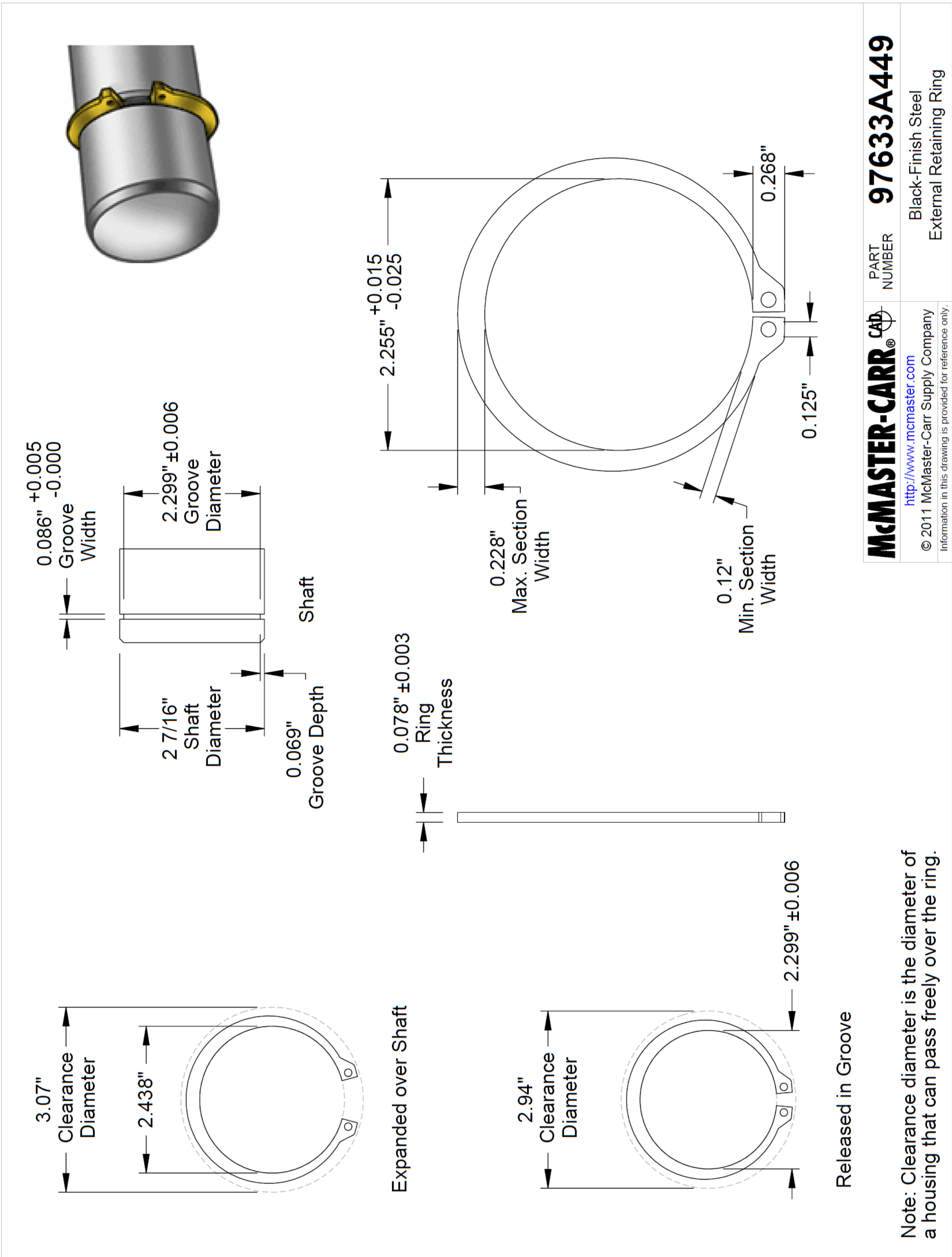
3.07"
Clearance
Diameter
2.438"
Expanded over Shaft
2.94"
Clearance
Diameter
2.299" ±0.006
Released in Groove
Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.
0.086" +0.005 -0.000
Groove
Width
2.299" ±0.006
Groove
Diameter
2 7/16"
Shaft
Diameter
0.069"
Groove Depth
Shaft
0.078" ±0.003
Ring
Thickness
2.255" +0.015 -0.025
0.228"
Max. Section
Width
0.12"
Min. Section
Width
0.125"
0.268"
McMASTER-CARR
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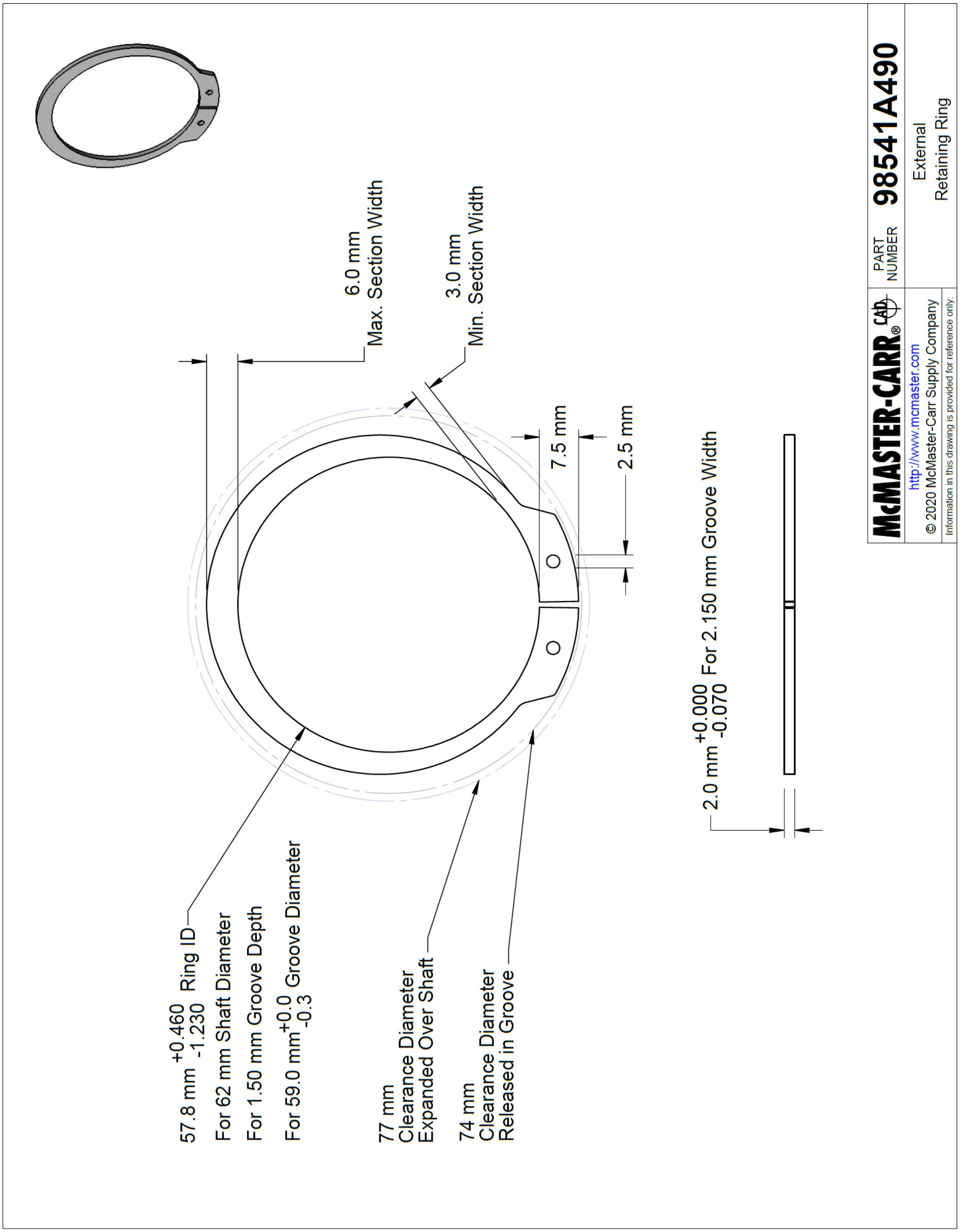
Information in this drawing is provided for reference only.
PART
NUMBER
97633A449
Black-Finish Steel
External Retaining Ring


6.0 mm
Max. Section Width
3.0 mm
Min. Section Width
7.5 mm
2.5 mm
2.0 mm $^{+0.000}_{-0.070}$ For 2.150 mm Groove Width
57.8 mm $^{+0.460}_{-1.230}$ Ring ID
For 62 mm Shaft Diameter
For 1.50 mm Groove Depth
For 59.0 mm $^{+0.0}_{-0.3}$ Groove Diameter
77 mm
Clearance Diameter
Expanded Over Shaft
74 mm
Clearance Diameter
Released in Groove
McMASTER-CARR®
http://www.mcmaster.com
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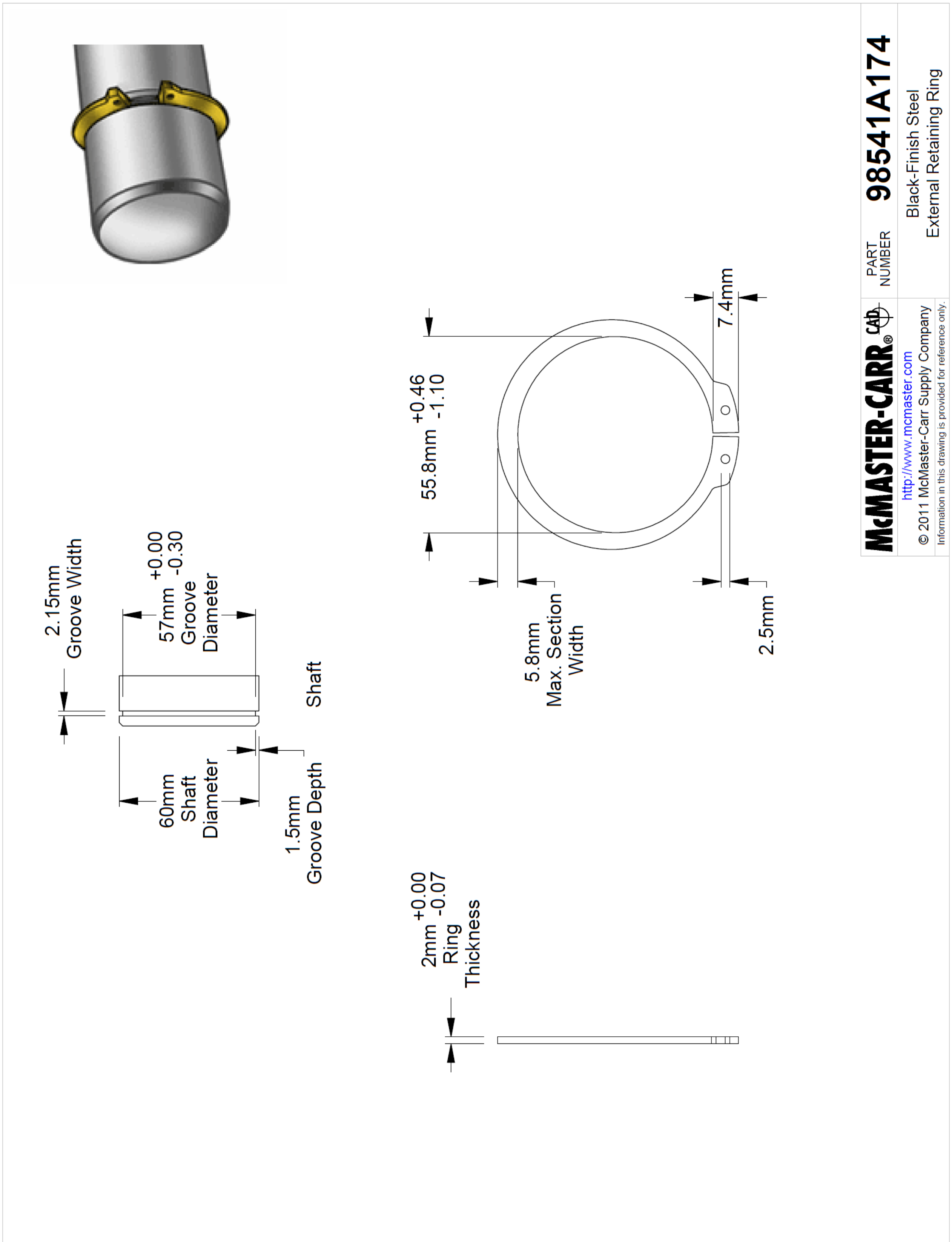
Information in this drawing is provided for reference only.
PART NUMBER
98541A490
External
Retaining Ring



PART NUMBER
98541A174
Black-Finish Steel
External Retaining Ring
McMASTER-CARR
http://www.mcmaster.com
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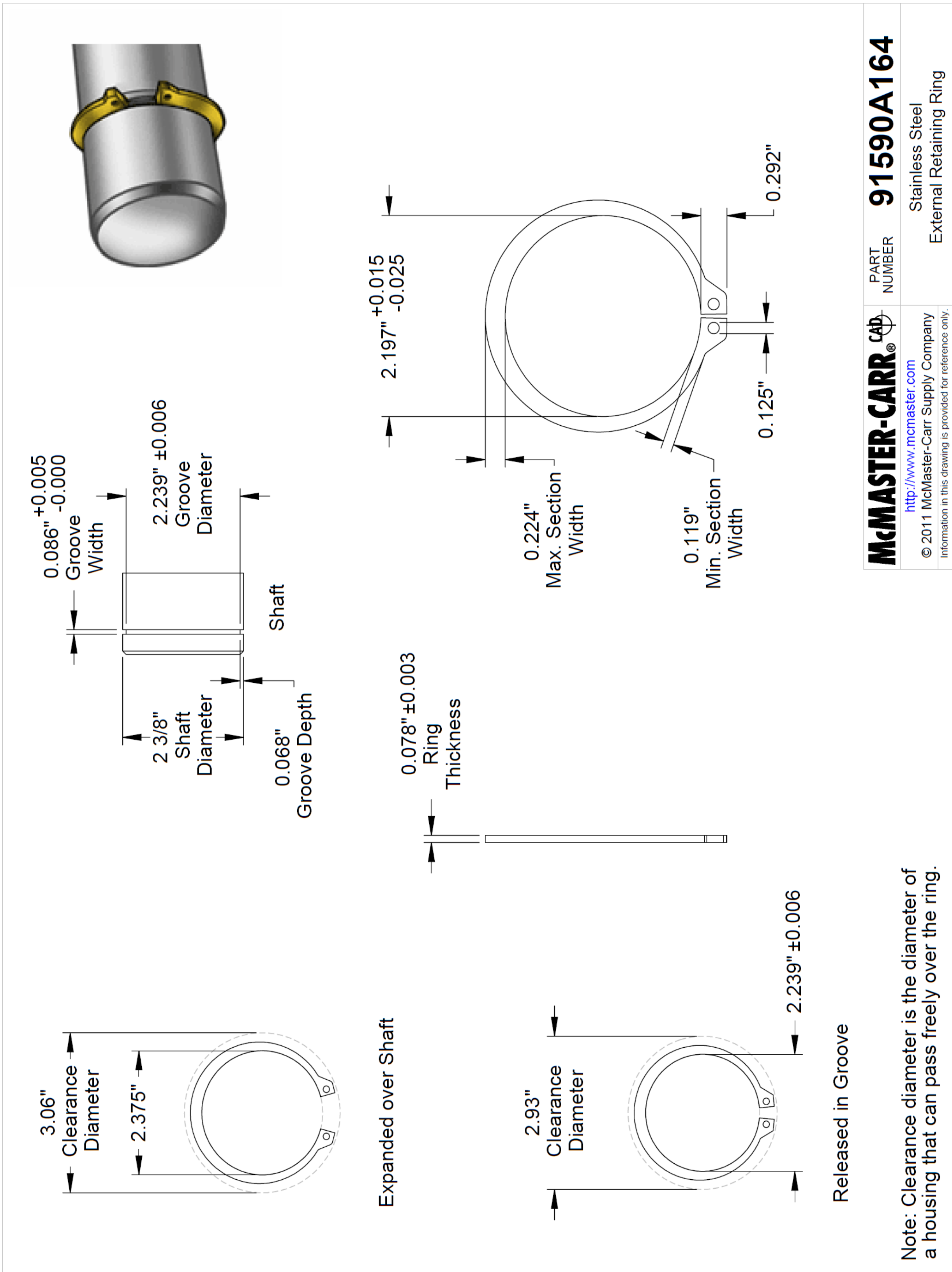
Information in this drawing is provided for reference only.
2.15mm Groove Width
57mm +0.00 -0.30 Groove Diameter
60mm Shaft Diameter
1.5mm Groove Depth
Shaft
55.8mm +0.46 -1.10
7.4mm
5.8mm Max. Section Width
2.5mm
2mm +0.00 -0.07 Ring Thickness


0.086" +0.005 -0.000
Groove Width
2.239" ±0.006
Groove Diameter
Shaft
2 3/8"
Shaft Diameter
0.068"
Groove Depth
0.078" ±0.003
Ring Thickness
2.197" +0.015 -0.025
0.224"
Max. Section Width
0.119"
Min. Section Width
0.125"
0.292"
3.06"
Clearance Diameter
2.375"
Expanded over Shaft
2.93"
Clearance Diameter
2.239" ±0.006
Released in Groove
Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.
McMASTER-CARR® CAD
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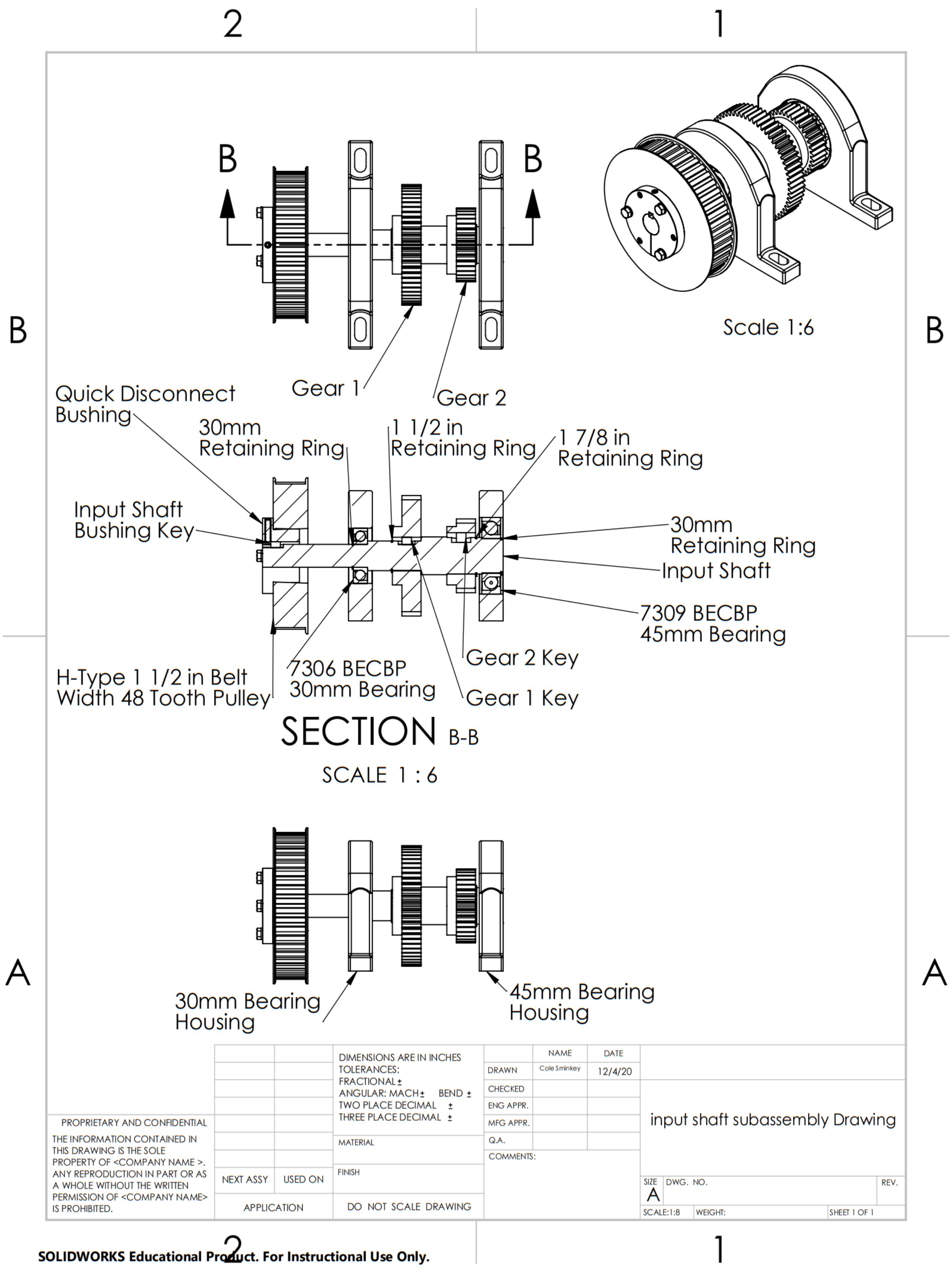
Information in this drawing is provided for reference only.
PART NUMBER
91590A164
Stainless Steel
External Retaining Ring



2
1
B
B
B
B
Scale 1:6
Gear 1
Gear 2
Quick Disconnect Bushing
30mm Retaining Ring
1 1/2 in Retaining Ring
1 7/8 in Retaining Ring
Input Shaft Bushing Key
30mm Retaining Ring
Input Shaft
7309 BECBP 45mm Bearing
Gear 2 Key
Gear 1 Key
H-Type 1 1/2 in Belt Width 48 Tooth Pulley
7306 BECBP 30mm Bearing
SECTION B-B
SCALE 1 : 6
A
A
30mm Bearing Housing
45mm Bearing Housing
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
Cole Sminkey
12/4/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
input shaft subassembly Drawing
PROPRIETARY AND CONFIDENTIAL
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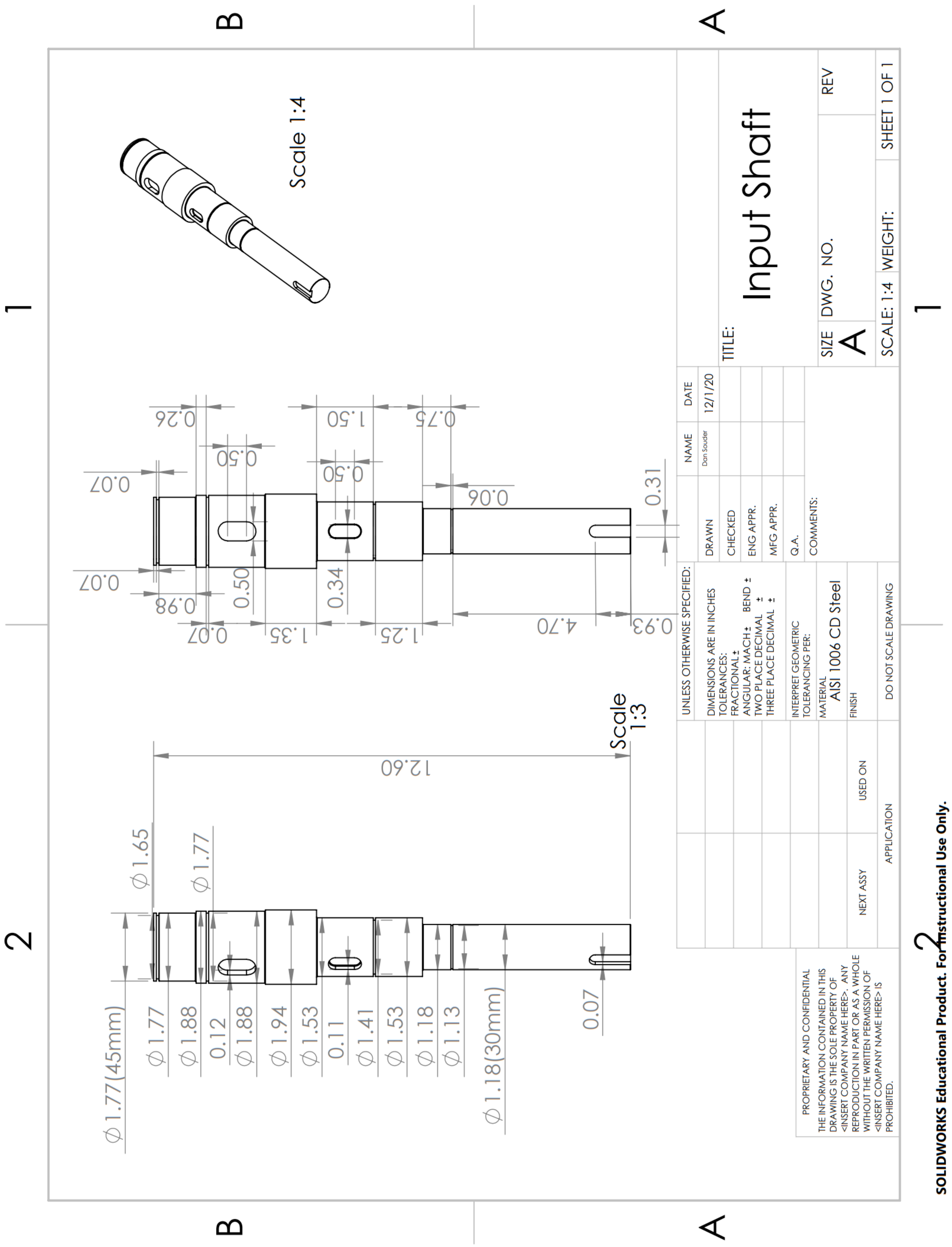
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
REV.
SCALE:1:8
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


Scale 1:4
Scale 1:3
12.60
Ø1.65
Ø1.77
Ø1.77(45mm)
Ø1.77
Ø1.88
0.12
Ø1.88
Ø1.94
Ø1.53
0.11
Ø1.41
Ø1.53
Ø1.18
Ø1.13
Ø1.18(30mm)
0.07
0.07
0.26
0.50
1.50
0.75
0.50
0.06
0.31
0.07
0.98
0.50
0.34
0.07
1.35
1.25
4.70
0.93
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1006 CD Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Dan Souder
12/1/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Input Shaft
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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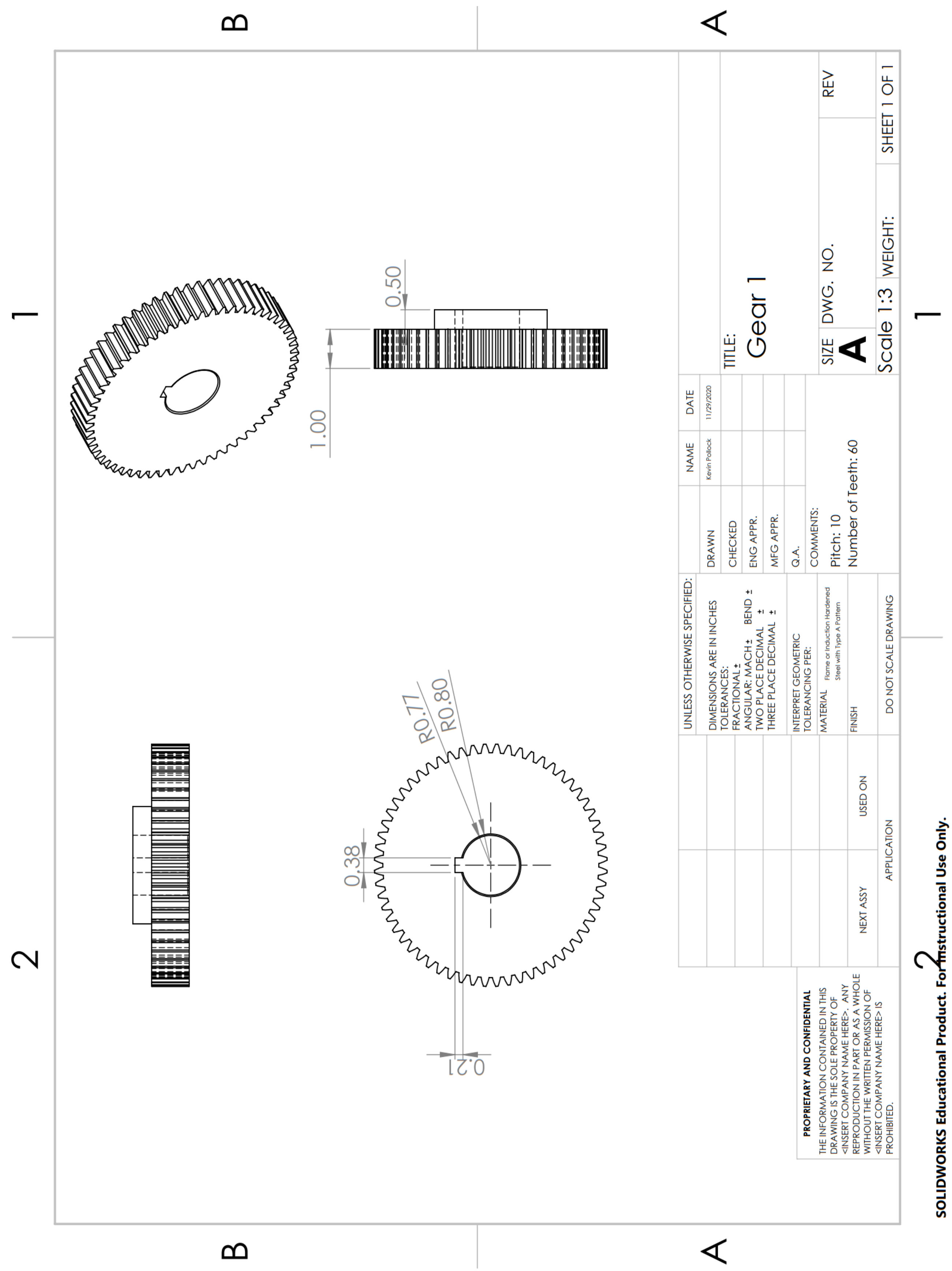
B
A
1
2
0.50
1.00
0.38
R0.77
R0.80
0.21
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
Flame or Induction Hardened
Steel with Type A Pattern
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Kevin Pollock
11/29/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pitch: 10
Number of Teeth: 60
TITLE:
Gear 1
SIZE
A
DWG. NO.
REV
Scale 1:3
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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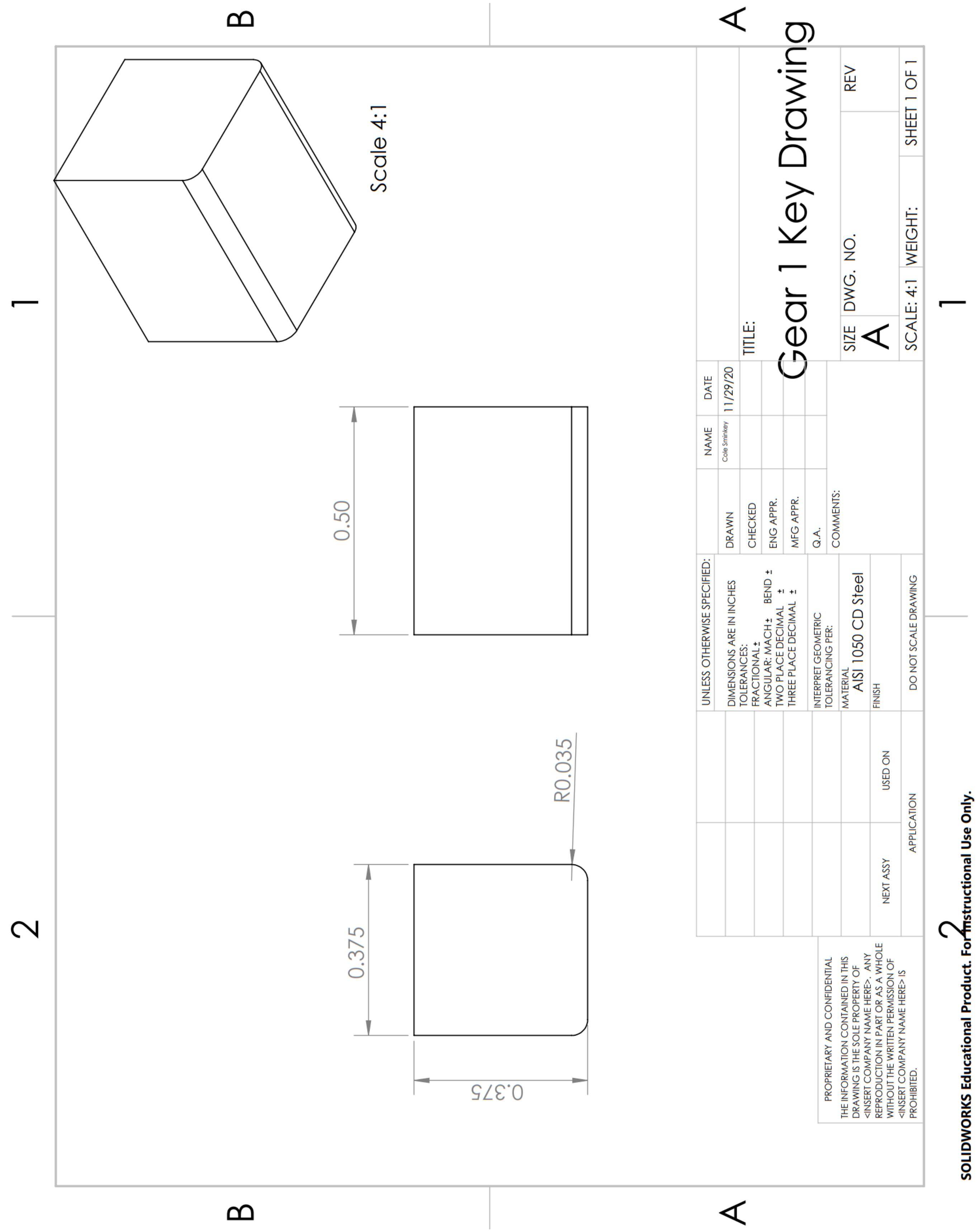
Scale 4:1
0.50
0.375
R0.035
0.375
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1050 CD Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Cole Sminkey
11/29/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gear 1 Key Drawing
SIZE
A
DWG. NO.
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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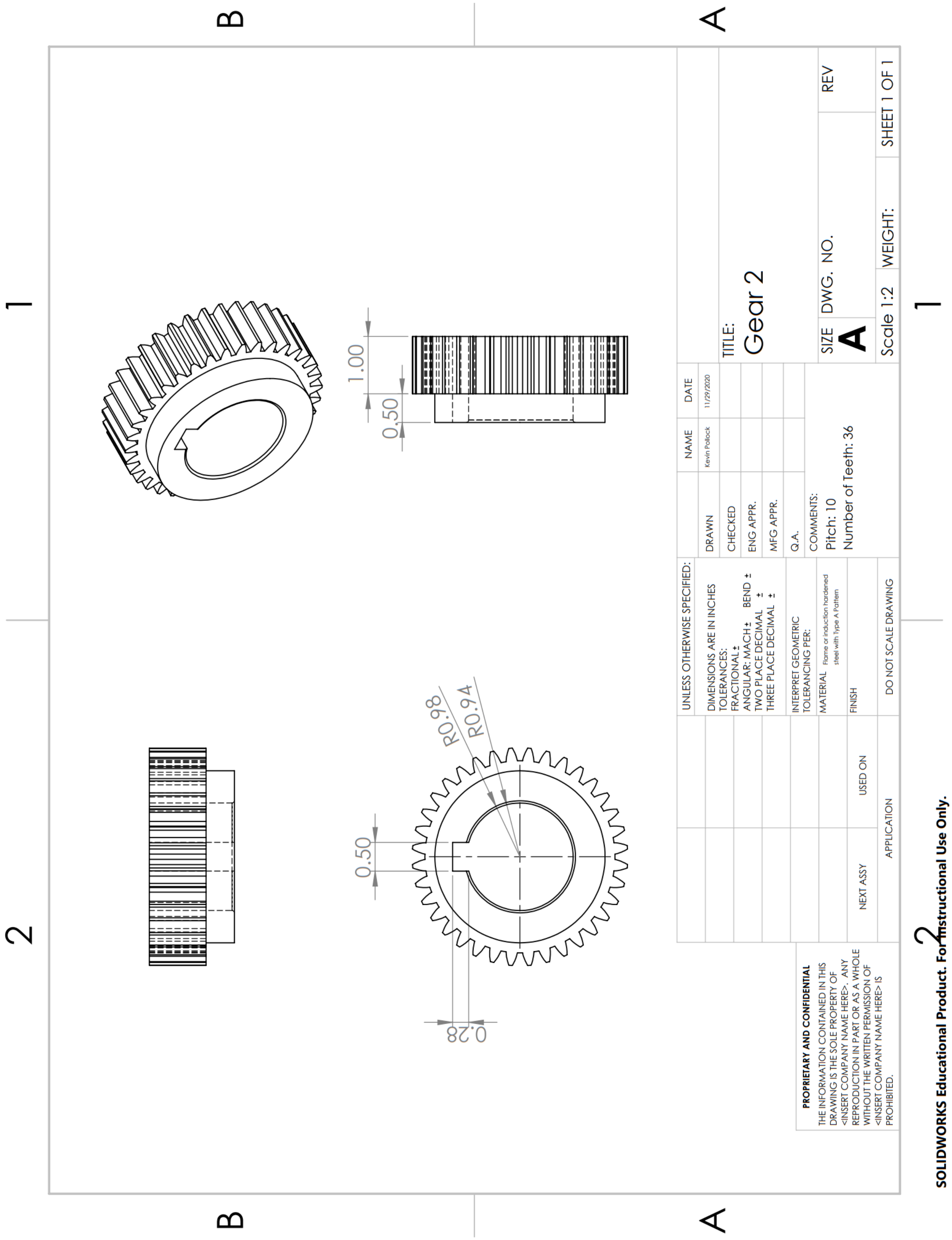
A
B
1
2



1.00
0.50
R0.98
R0.94
0.50
0.28
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Flame or induction hardened steel with Type A Pattern
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Kevin Pollock
11/29/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pitch: 10
Number of Teeth: 36
TITLE:
Gear 2
SIZE
A
DWG. NO.
REV
Scale 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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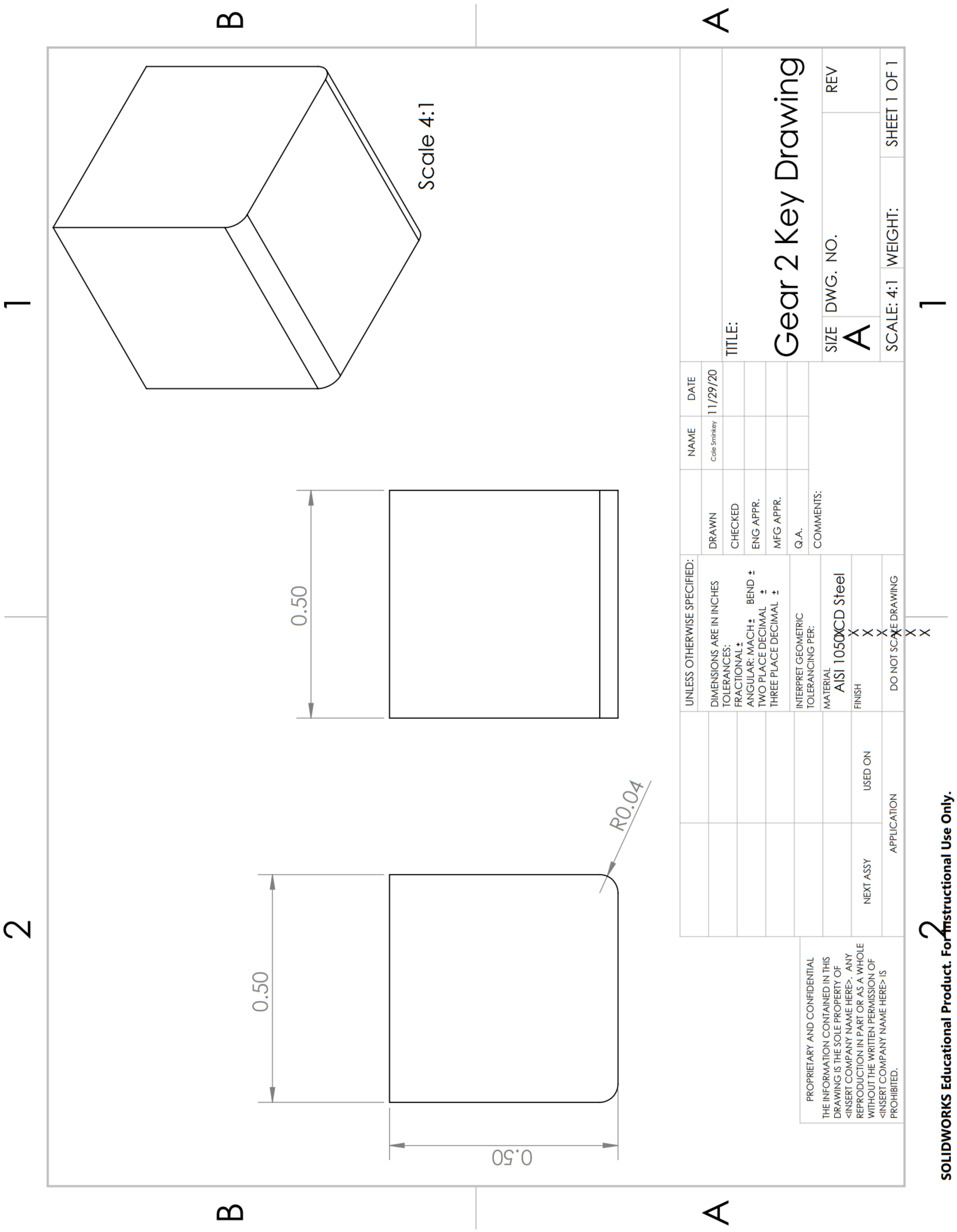
Scale 4:1
0.50
0.50
0.50
R0.04
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1050 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
Cole Sminkey
11/29/20
TITLE:
Gear 2 Key Drawing
SIZE
A
DWG. NO.
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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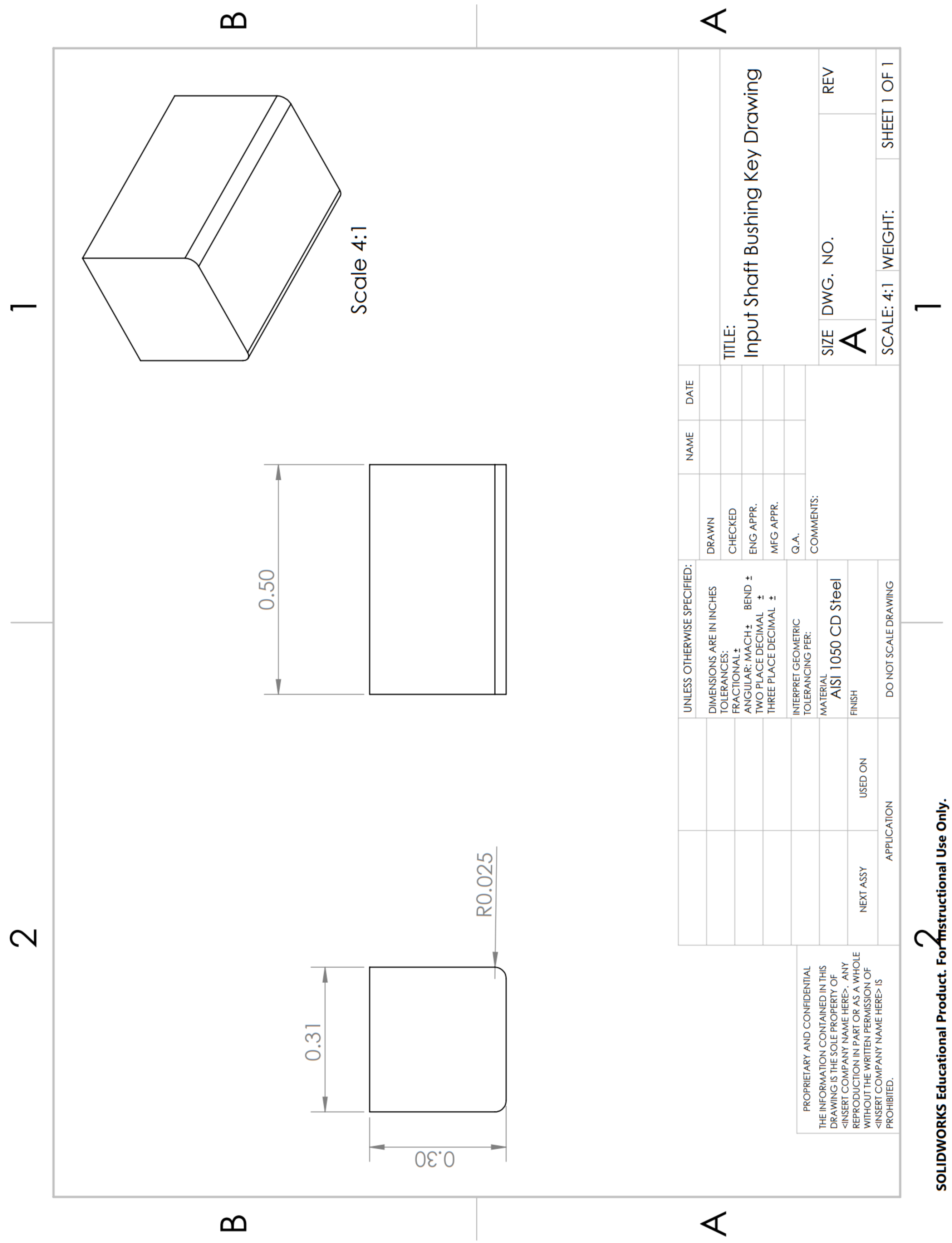
Scale 4:1
0.50
0.31
0.30
R0.025
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1050 CD Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Input Shaft Bushing Key Drawing
SIZE
A
DWG. NO.
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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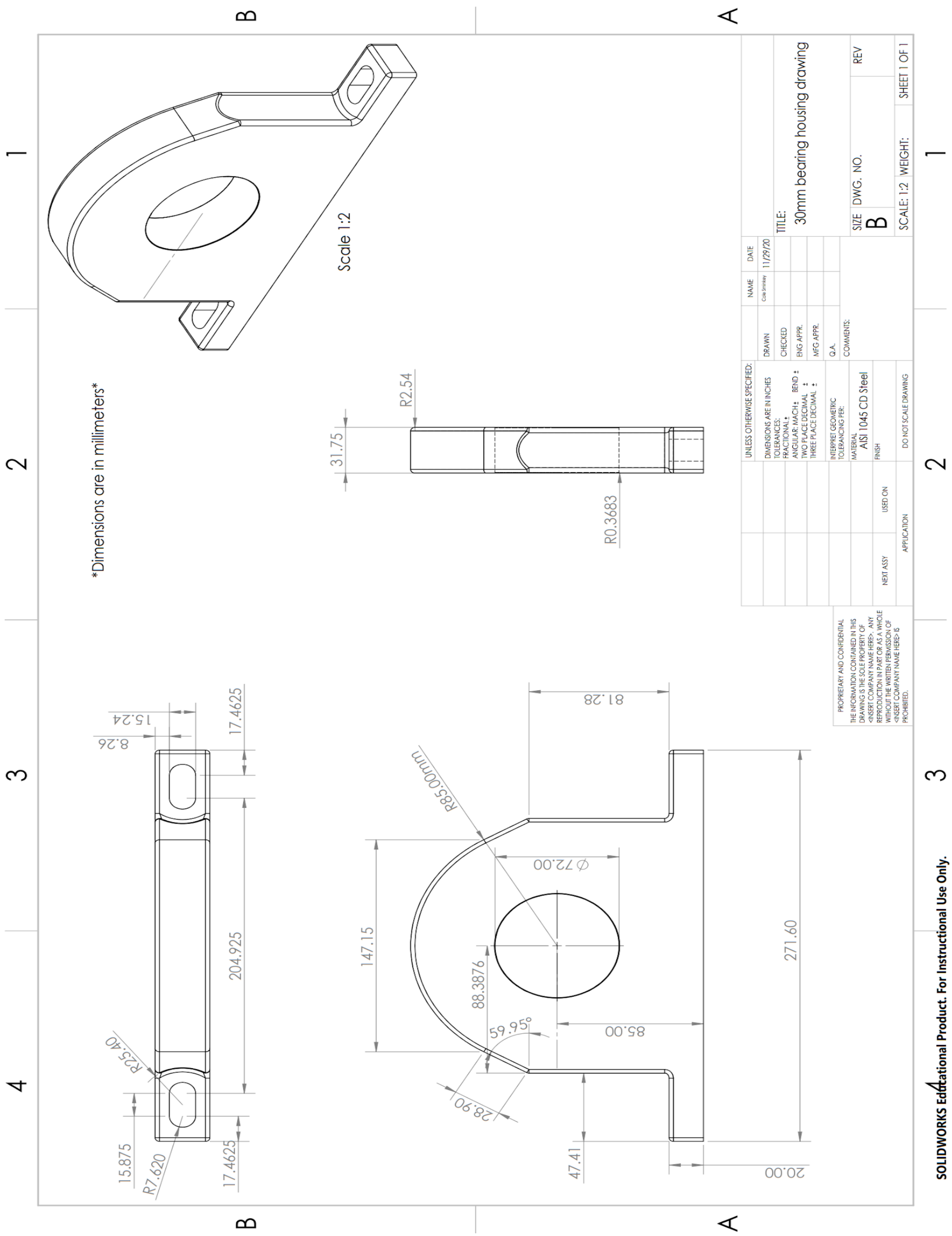
Dimensions are in millimeters
Scale 1:2
R2.54
31.75
R0.3683
15.24
8.26
17.4625
204.925
R25.40
15.875
R7.620
17.4625
147.15
R85.00mm
⌀72.00
81.28
88.3876
59.95°
85.00
28.90
47.41
271.60
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1045 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
11/29/20
TITLE:
30mm bearing housing drawing
SIZE
DWG. NO.
REV
B
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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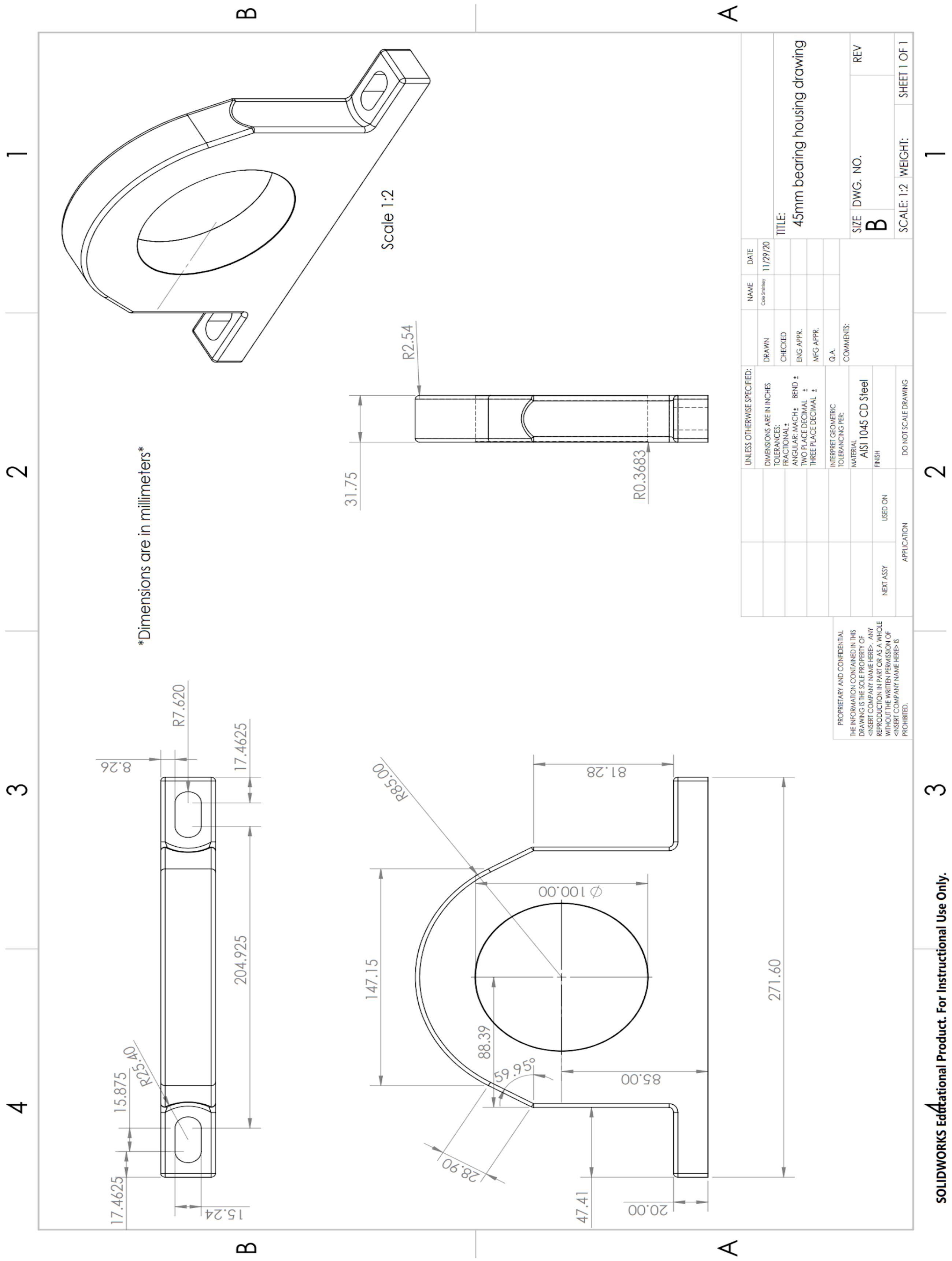
Dimensions are in millimeters
Scale 1:2
R2.54
31.75
R0.3683
R7.620
8.26
17.4625
204.925
15.875
R25.40
17.4625
15.24
R85.00
81.28
ϕ 100.00
147.15
88.39
59.95°
85.00
271.60
28.90
47.41
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1045 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
11/29/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
45mm bearing housing drawing
SIZE
B
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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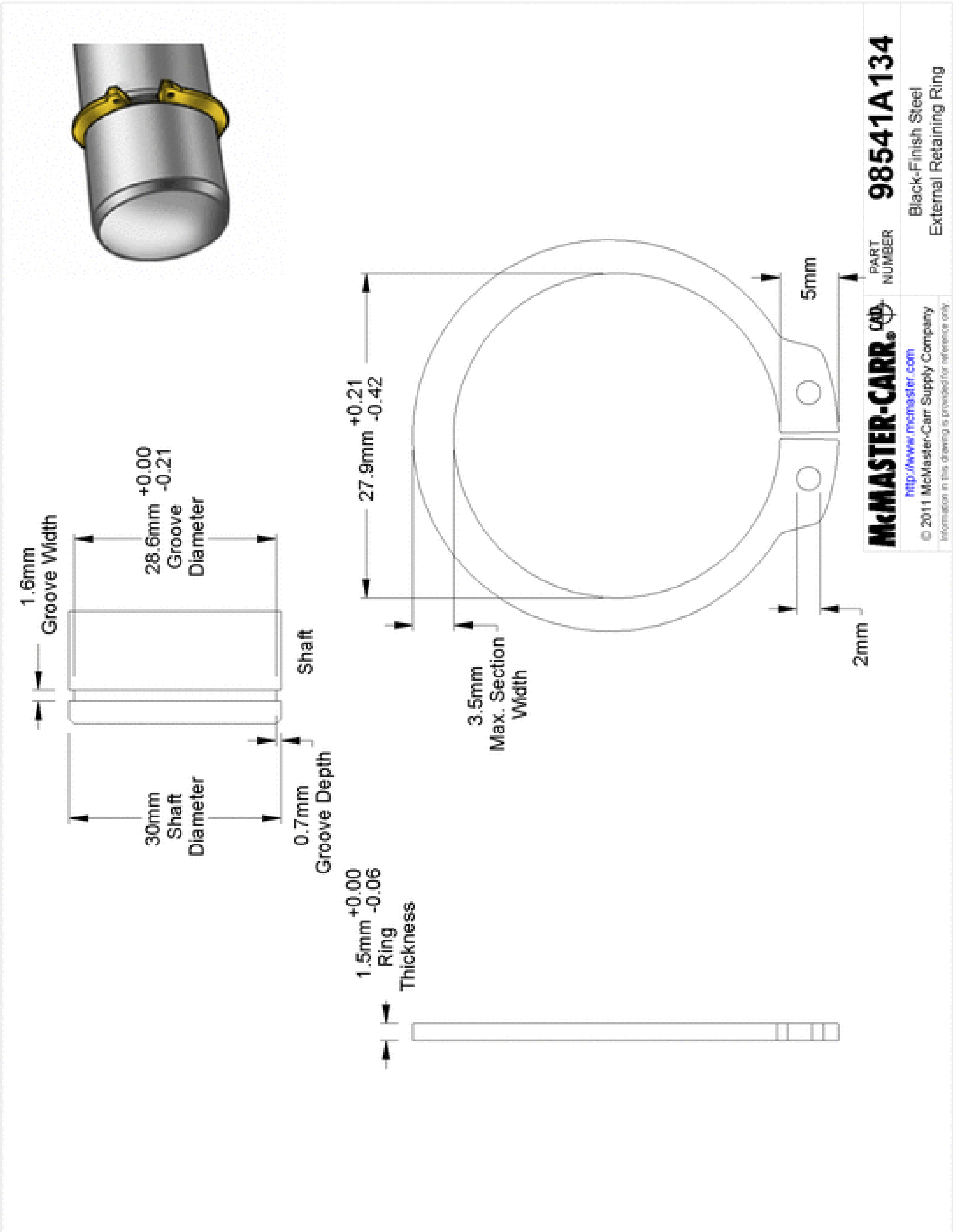
1.6mm
Groove Width
28.6mm +0.00 -0.21
Groove
Diameter
Shaft
30mm
Shaft
Diameter
0.7mm
Groove Depth
1.5mm +0.00 -0.06
Ring
Thickness
27.9mm +0.21 -0.42
3.5mm
Max. Section
Width
5mm
2mm
McMASTER-CARR
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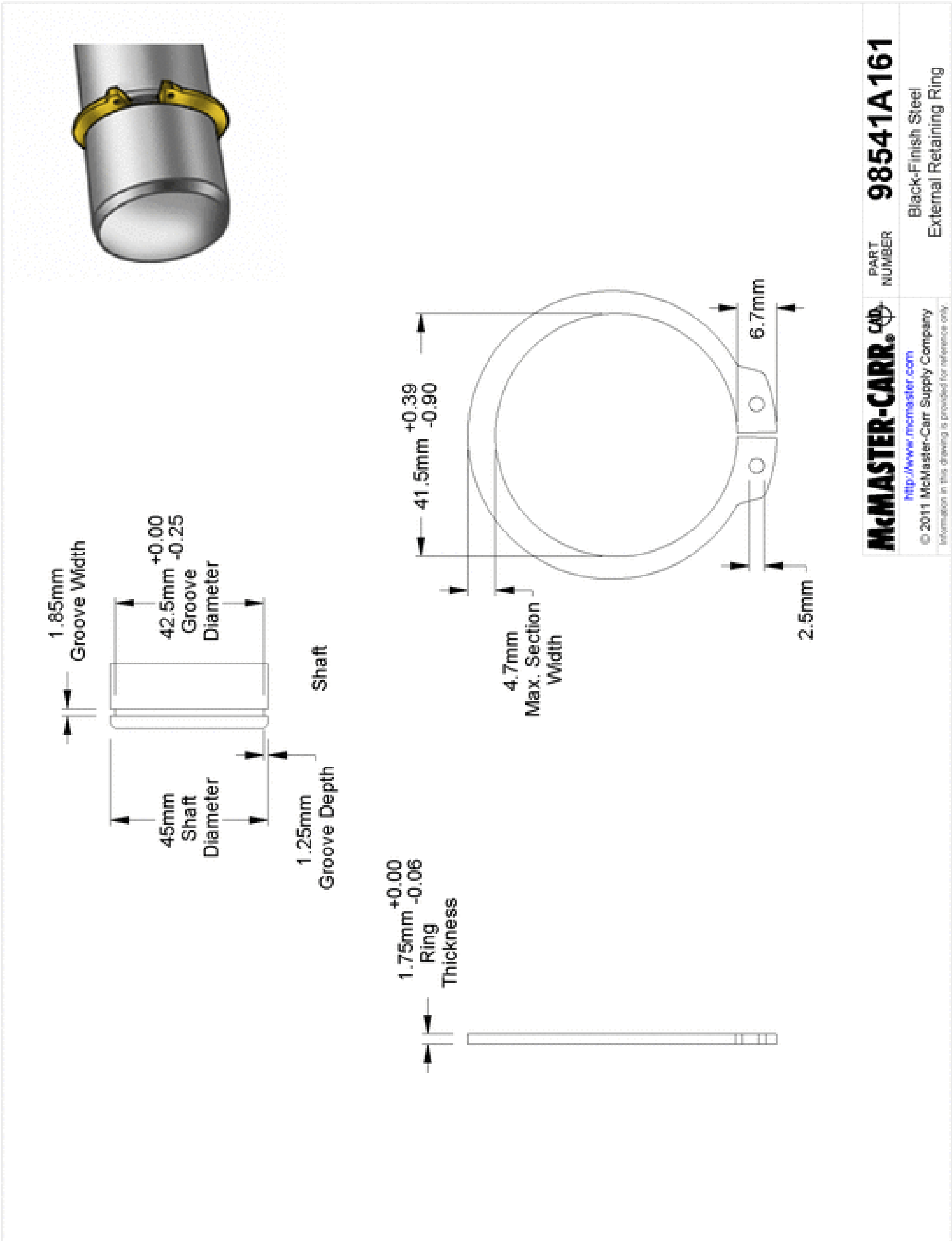
PART NUMBER
98541A134
Black-Finish Steel
External Retaining Ring


1.85mm
Groove Width
42.5mm +0.00 -0.25
Groove
Diameter
45mm
Shaft
Diameter
1.25mm
Groove Depth
Shaft
1.75mm +0.00 -0.06
Ring
Thickness
41.5mm +0.39 -0.90
4.7mm
Max. Section
Width
6.7mm
2.5mm
PART NUMBER
98541A161
Black-Finish Steel
External Retaining Ring
McMASTER-CARR
http://www.mcmaster.com
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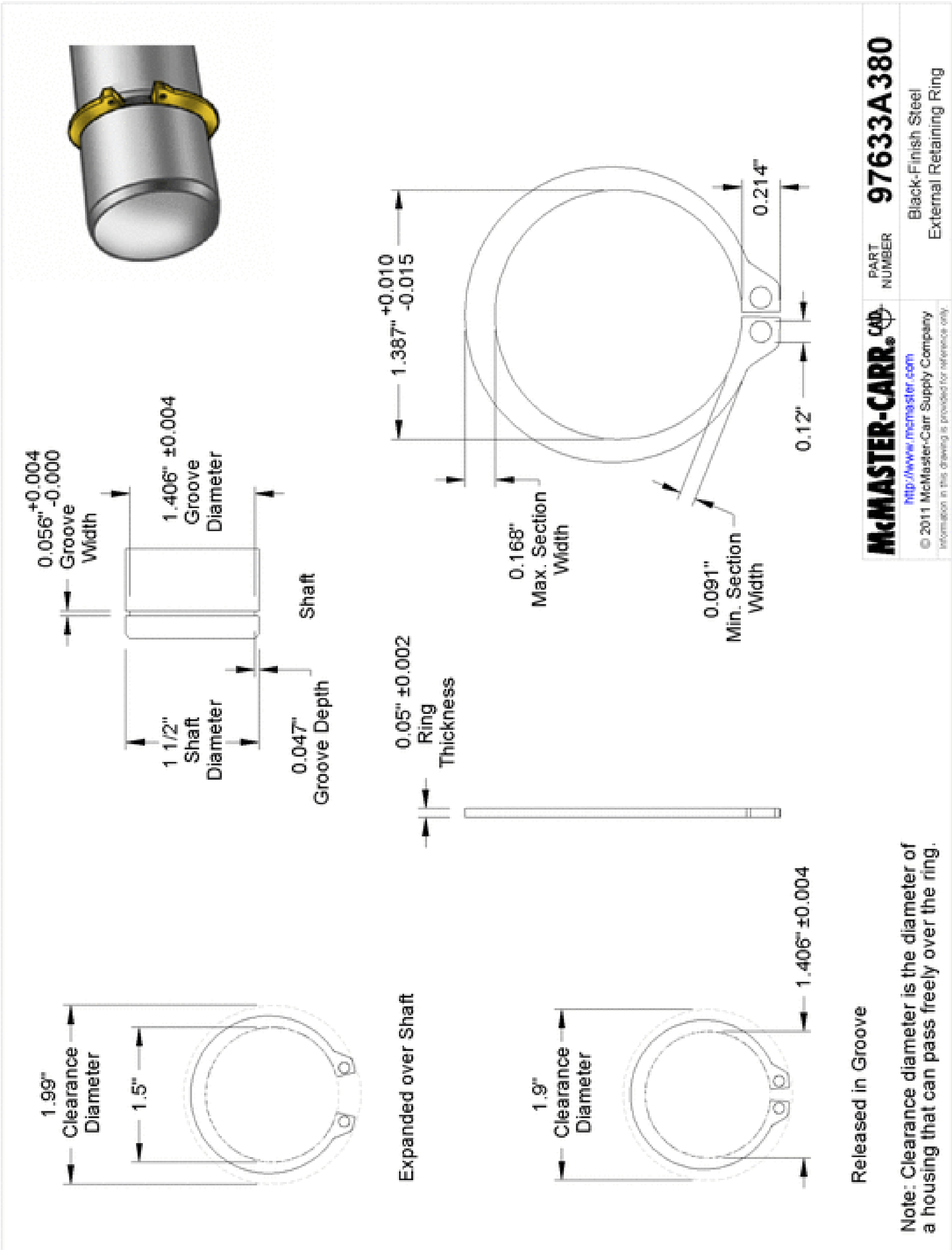
0.056" +0.004 -0.000
Groove Width
1.406" ±0.004
Groove Diameter
1 1/2"
Shaft Diameter
0.047"
Groove Depth
Shaft
1.387" +0.010 -0.015
0.168"
Max. Section Width
0.091"
Min. Section Width
0.12"
0.214"
0.05" ±0.002
Ring Thickness
1.99"
Clearance Diameter
1.5"
Expanded over Shaft
1.9"
Clearance Diameter
1.406" ±0.004
Released in Groove
Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.
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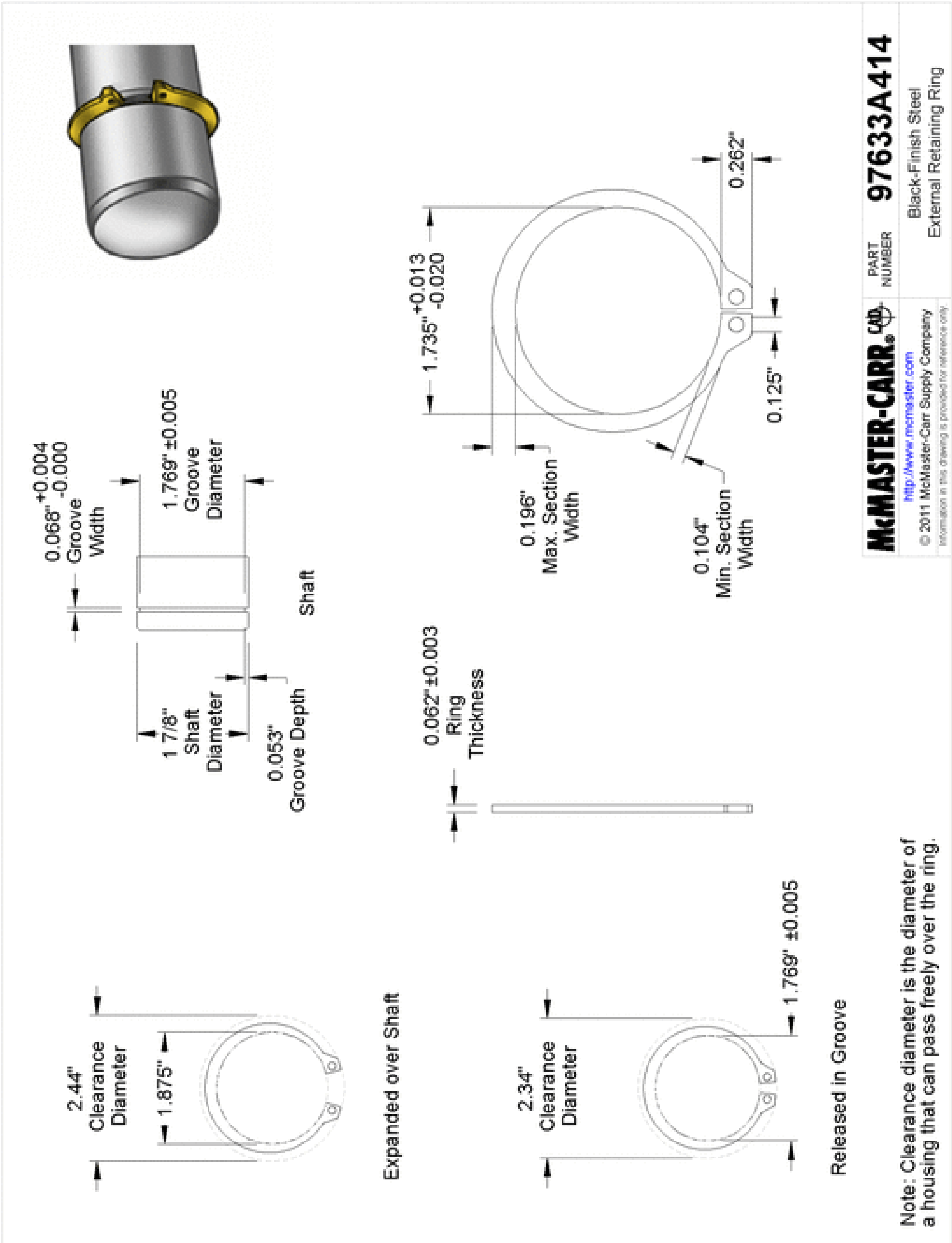
PART NUMBER
97633A380
Black-Finish Steel
External Retaining Ring


0.068" +0.004 -0.000
Groove
Width
1.769" ±0.005
Groove
Diameter
1 7/8"
Shaft
Diameter
0.053"
Groove Depth
Shaft
0.062"±0.003
Ring
Thickness
1.735" +0.013 -0.020
0.262"
0.125"
0.196"
Max. Section
Width
0.104"
Min. Section
Width
2.44"
Clearance
Diameter
1.875"
Expanded over Shaft
2.34"
Clearance
Diameter
1.769" ±0.005
Released in Groove
Note: Clearance diameter is the diameter of
a housing that can pass freely over the ring.
McMASTER-CARR
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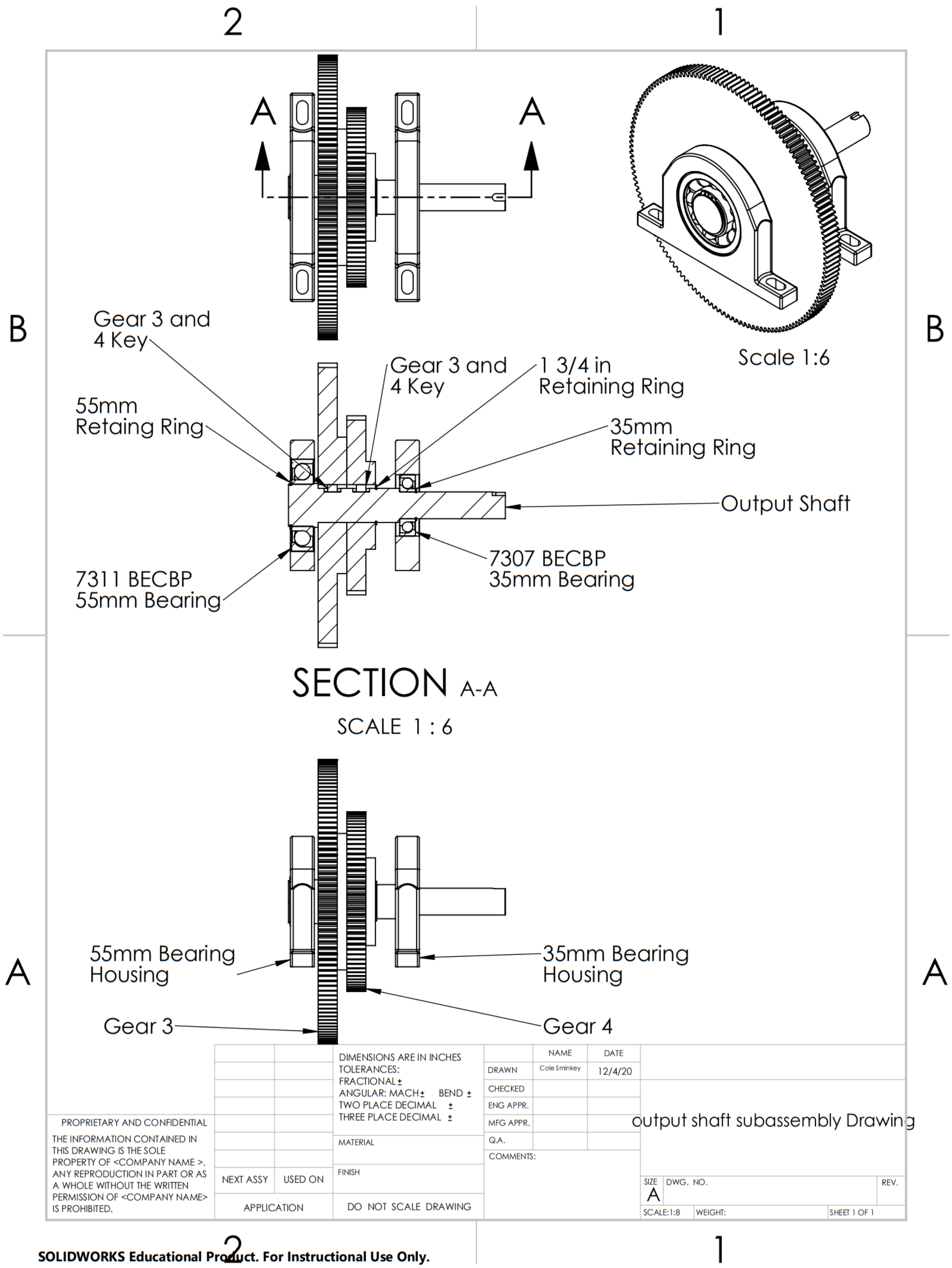
PART
NUMBER
97633A414
Black-Finish Steel
External Retaining Ring


2
1
A
A
B
B
Scale 1:6
Gear 3 and
4 Key
Gear 3 and
4 Key
1 3/4 in
Retaining Ring
55mm
Retaing Ring
35mm
Retaining Ring
Output Shaft
7307 BECBP
35mm Bearing
7311 BECBP
55mm Bearing
SECTION A-A
SCALE 1 : 6
55mm Bearing
Housing
35mm Bearing
Housing
A
A
Gear 3
Gear 4
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
Cole Sminkey
12/4/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
output shaft subassembly Drawing
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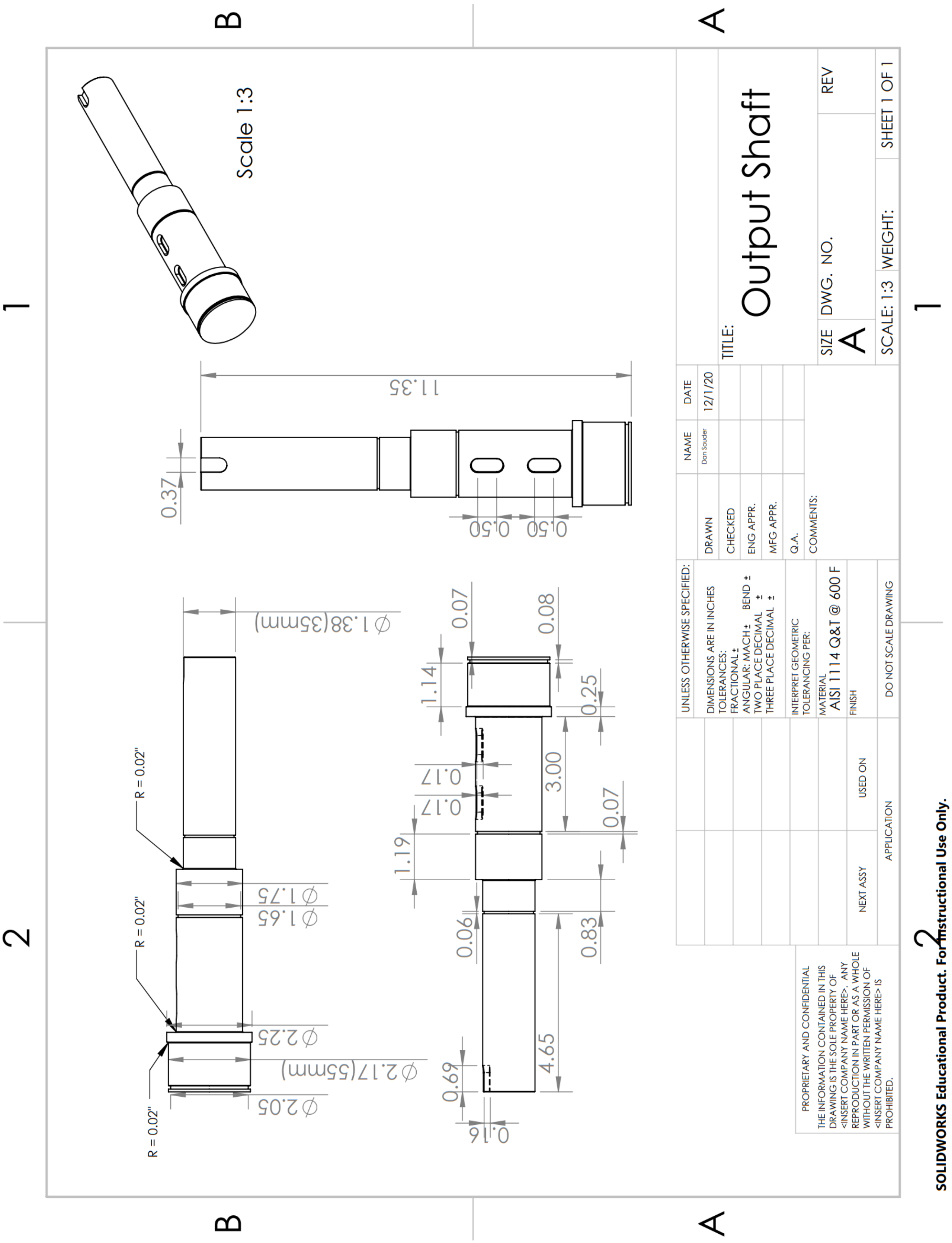
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
REV.
SCALE:1:8
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.
2
1


Scale 1:3
11.35
0.37
0.50
0.50
R = 0.02"
R = 0.02"
R = 0.02"
Ø1.38(35mm)
Ø1.75
Ø1.65
Ø2.25
Ø2.17(55mm)
Ø2.05
0.07
0.08
1.14
0.25
0.17
0.17
3.00
1.19
0.07
0.06
0.83
0.69
4.65
0.16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1114 Q&T @ 600 F
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Dan Souder
12/1/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Output Shaft
SIZE
A
DWG. NO.
REV
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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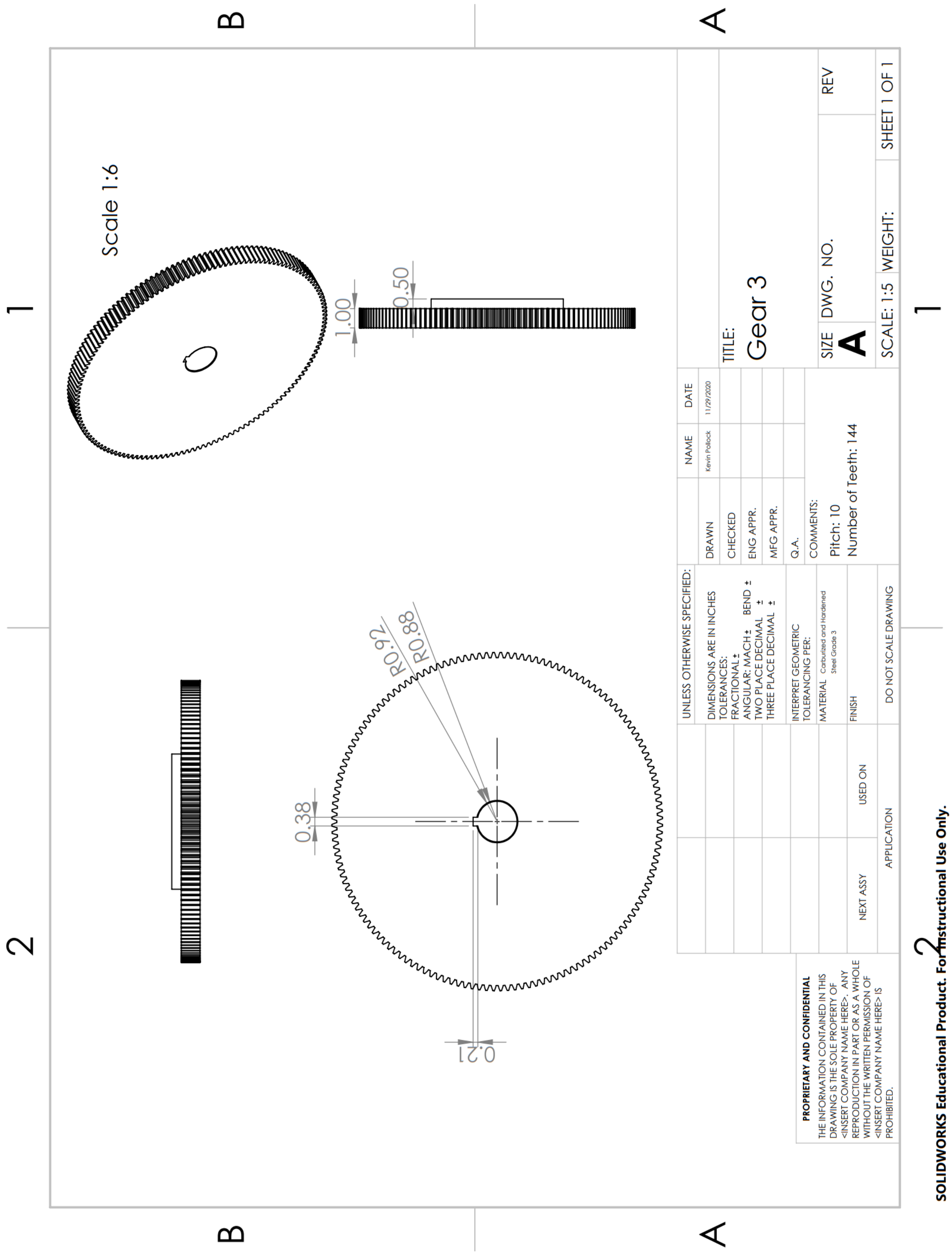
A
B
1
2



Scale 1:6
1.00
0.50
R0.92
R0.88
0.38
0.21
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Carburized and Hardened Steel Grade 3
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN Kevin Pollock 11/29/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pitch: 10
Number of Teeth: 144
TITLE:
Gear 3
SIZE A
DWG. NO.
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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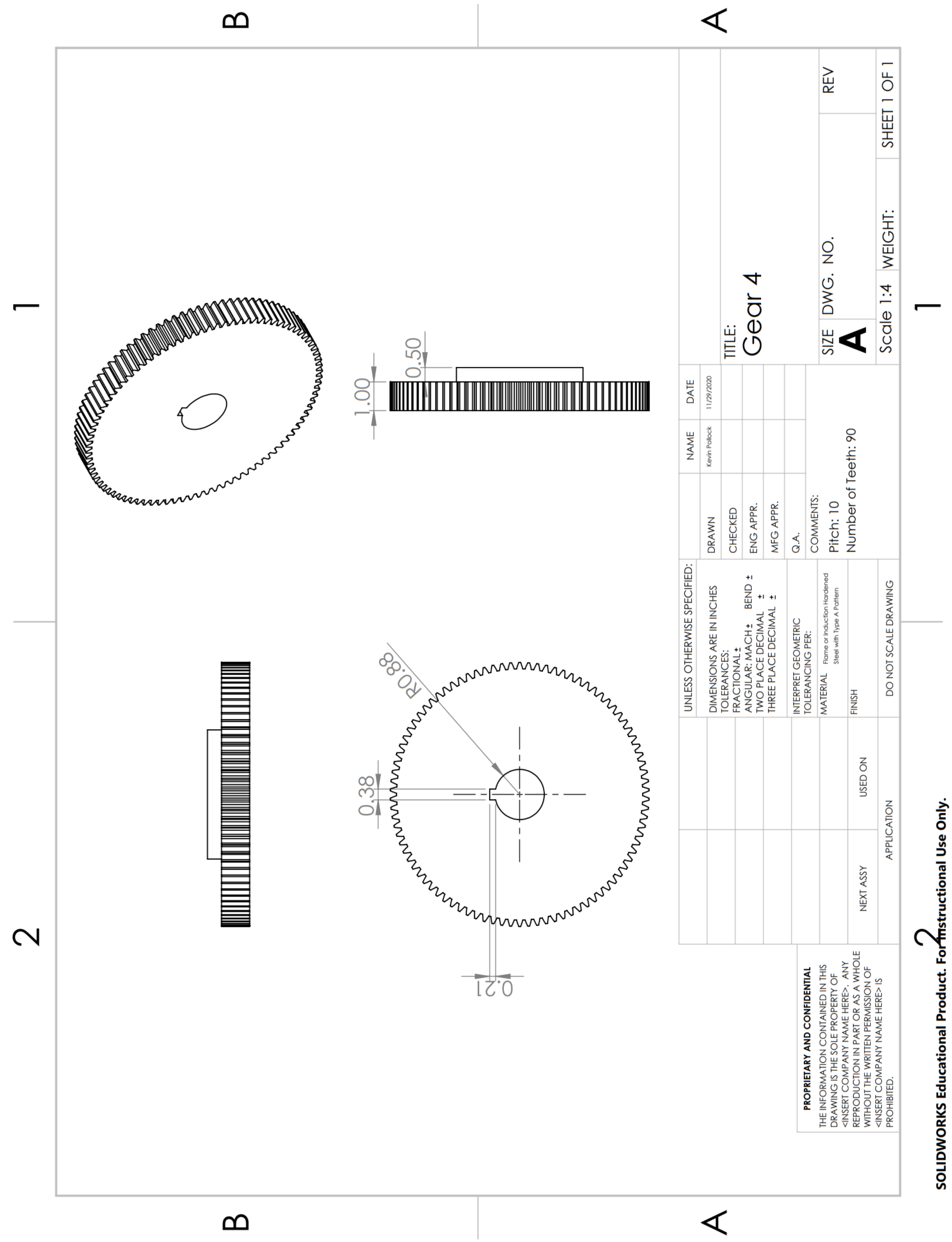

B
1
2
A
1.00
0.50
0.38
R0.88
0.21
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Flame or Induction Hardened Steel with Type A Pattern
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Kevin Pollock
11/29/2020
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pitch: 10
Number of Teeth: 90
TITLE:
Gear 4
SIZE
A
DWG. NO.
REV
Scale 1:4
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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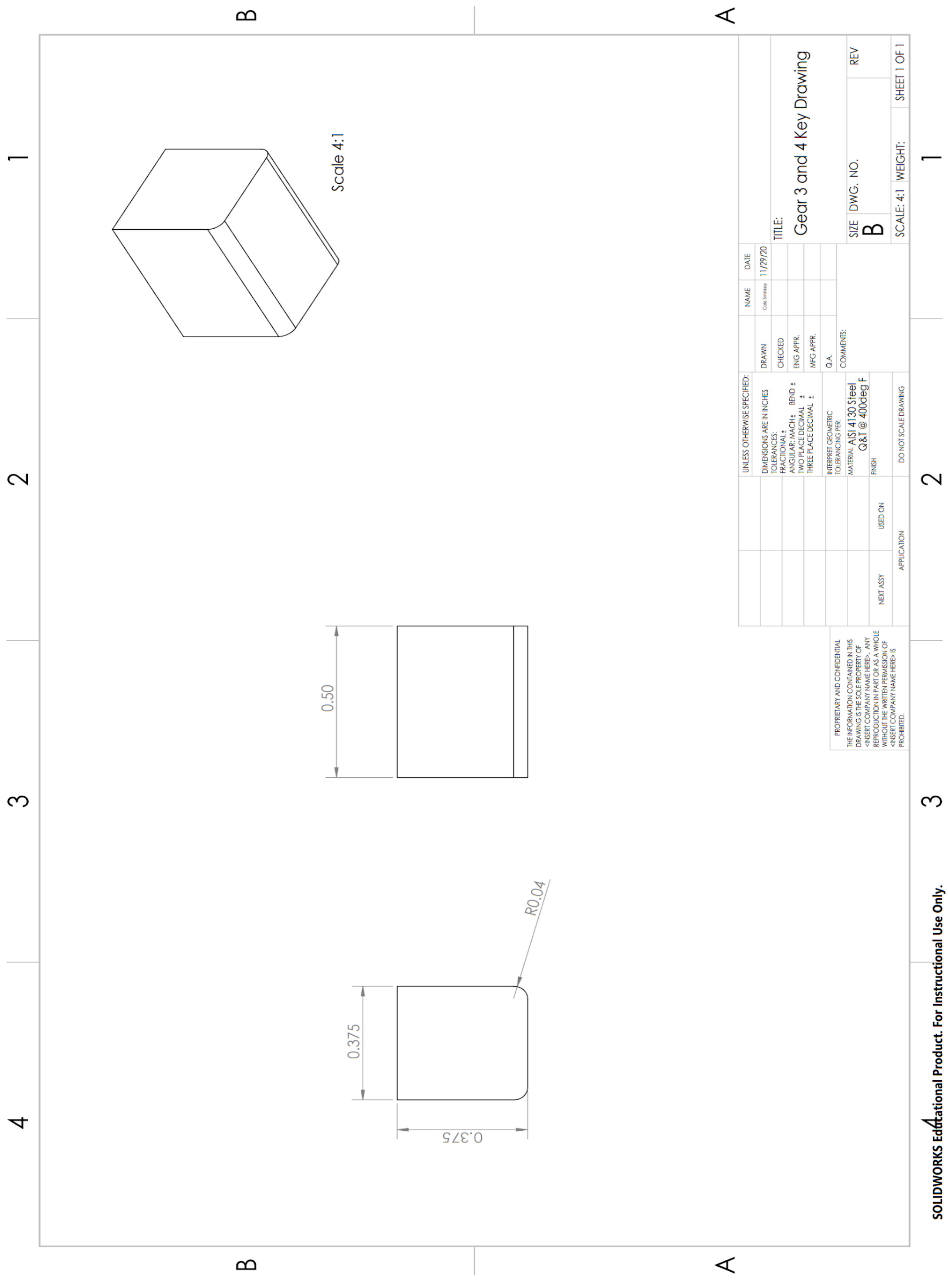
Scale 4:1
0.50
0.375
0.375
R0.04
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL AISI 4130 Steel Q&T @ 400deg F
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
11/29/20
TITLE:
Gear 3 and 4 Key Drawing
SIZE B
DWG. NO.
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
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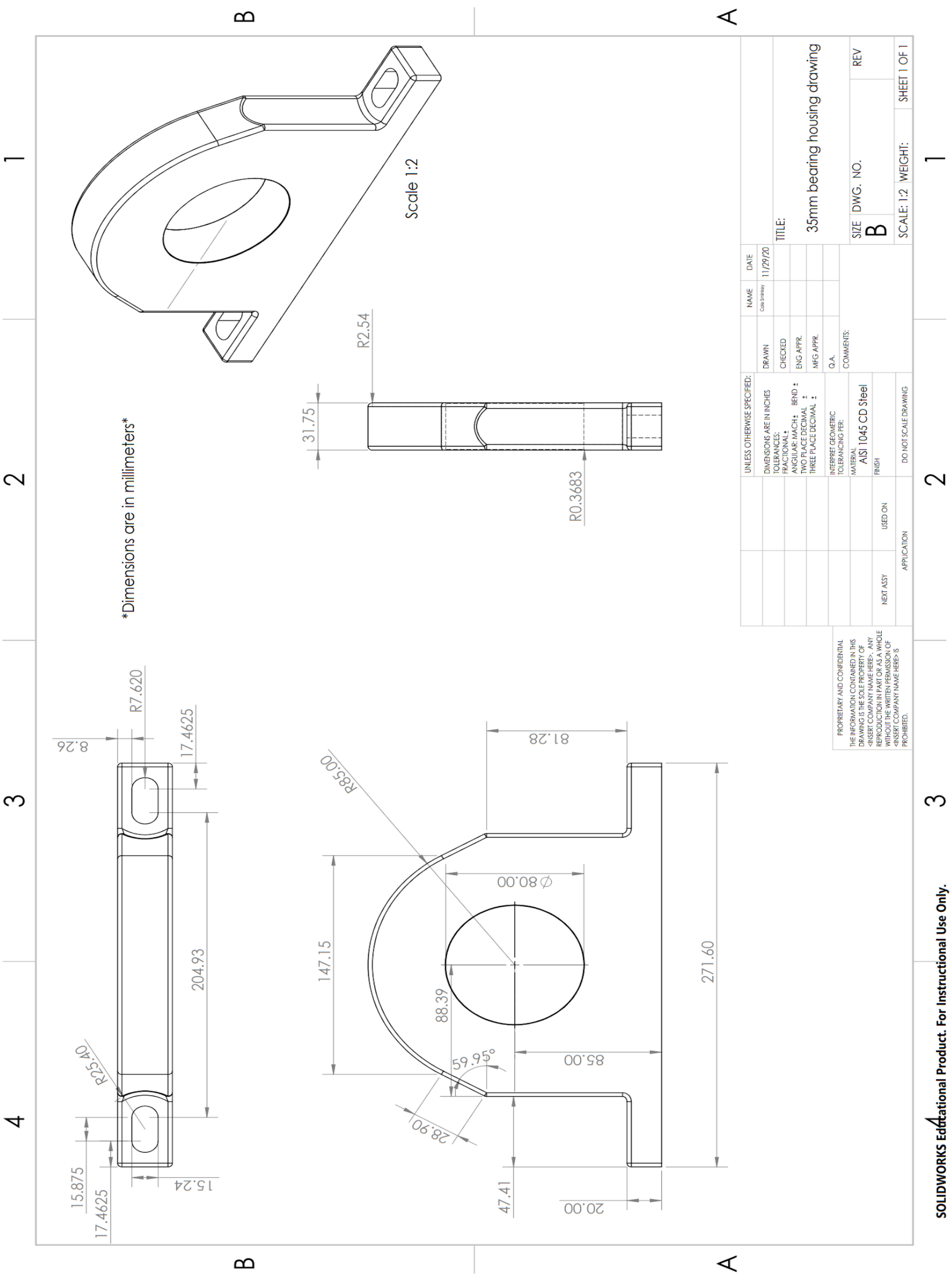
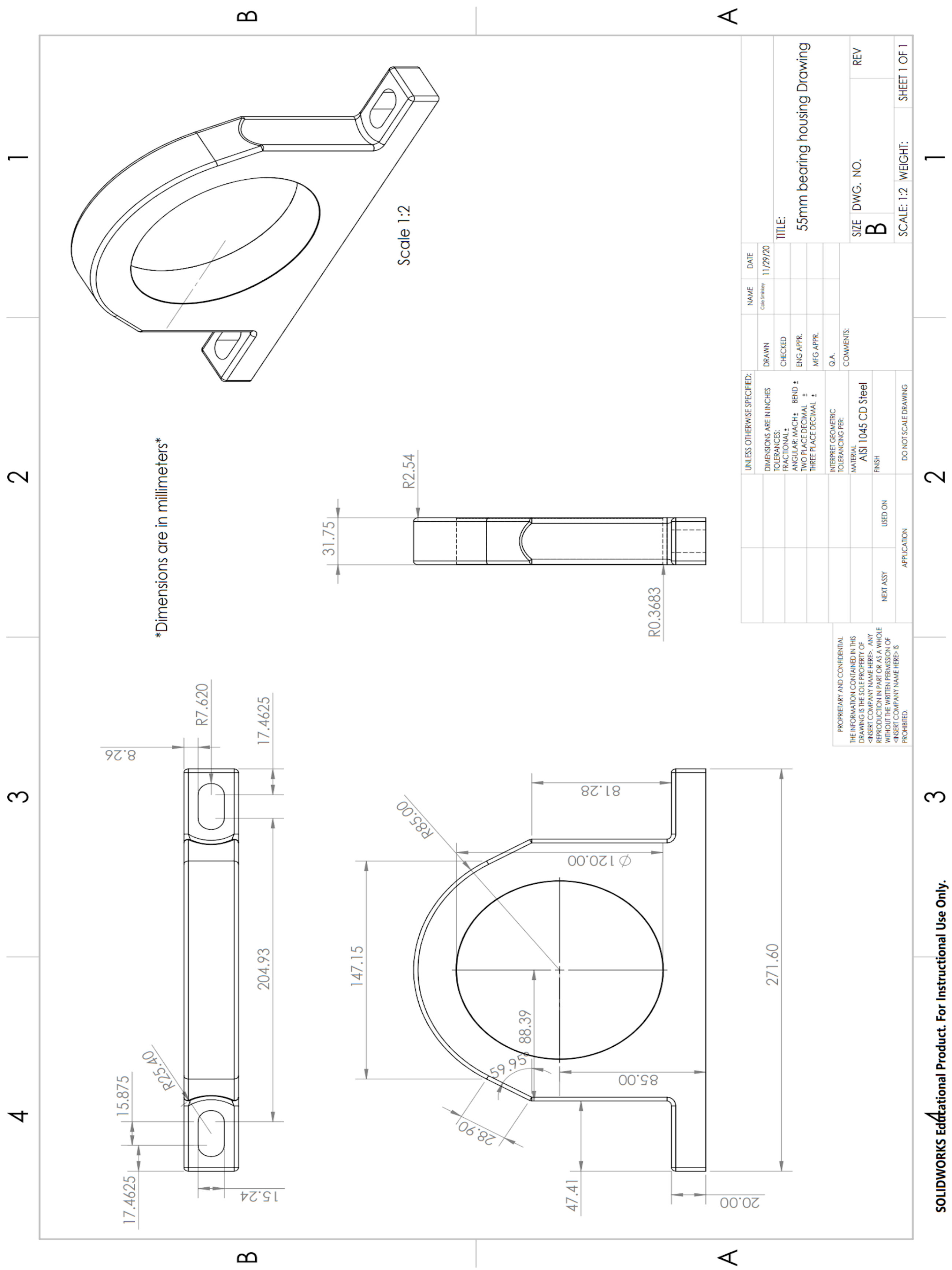


Dimensions are in millimeters
Scale 1:2
R2.54
31.75
R0.3683
R7.620
8.26
17.4625
204.93
R25.40
15.875
17.4625
15.24
R85.00
81.28
⌀80.00
147.15
88.39
59.95°
85.00
28.90
271.60
47.41
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1045 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
11/29/20
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
35mm bearing housing drawing
SIZE
B
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Educational Product. For Instructional Use Only.


Scale 1:2
Dimensions are in millimeters
R2.54
31.75
R0.3683
8.26
R7.620
17.4625
204.93
15.875
R25.40
17.4625
15.24
R85.00
81.28
⌀ 120.00
147.15
88.39
59.95°
85.00
28.90
47.41
271.60
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 1045 CD Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
11/29/20
TITLE:
55mm bearing housing Drawing
SIZE
B
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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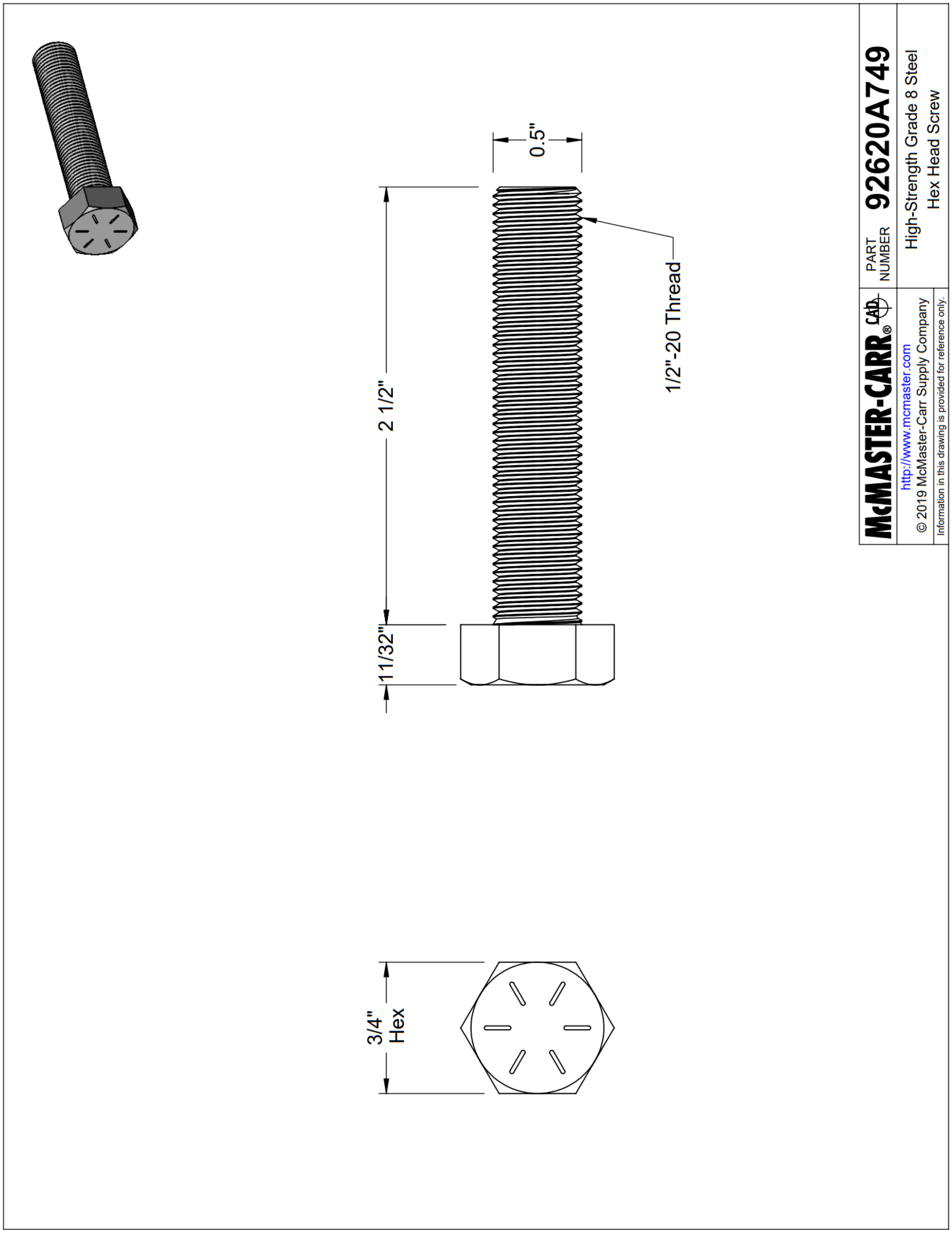
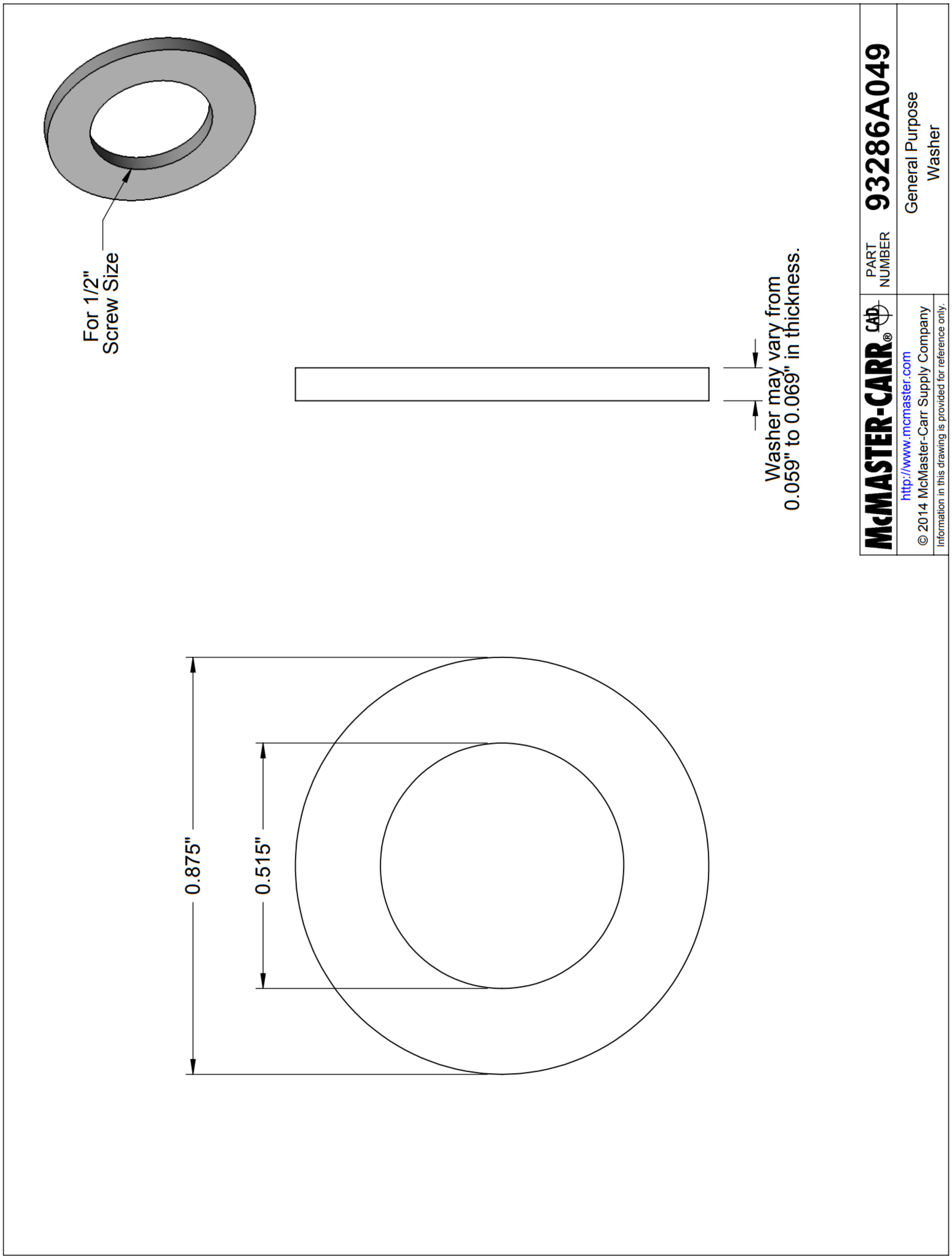

0.5"
2 1/2"
11/32"
1/2"-20 Thread
3/4"
Hex
McMASTER-CARR®
CAD
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
92620A749
High-Strength Grade 8 Steel
Hex Head Screw


For 1/2"
Screw Size
Washer may vary from
0.059" to 0.069" in thickness.
0.875"
0.515"
McMASTER-CARR
CAD
PART
NUMBER
93286A049
General Purpose
Washer
http://www.mcmaster.com
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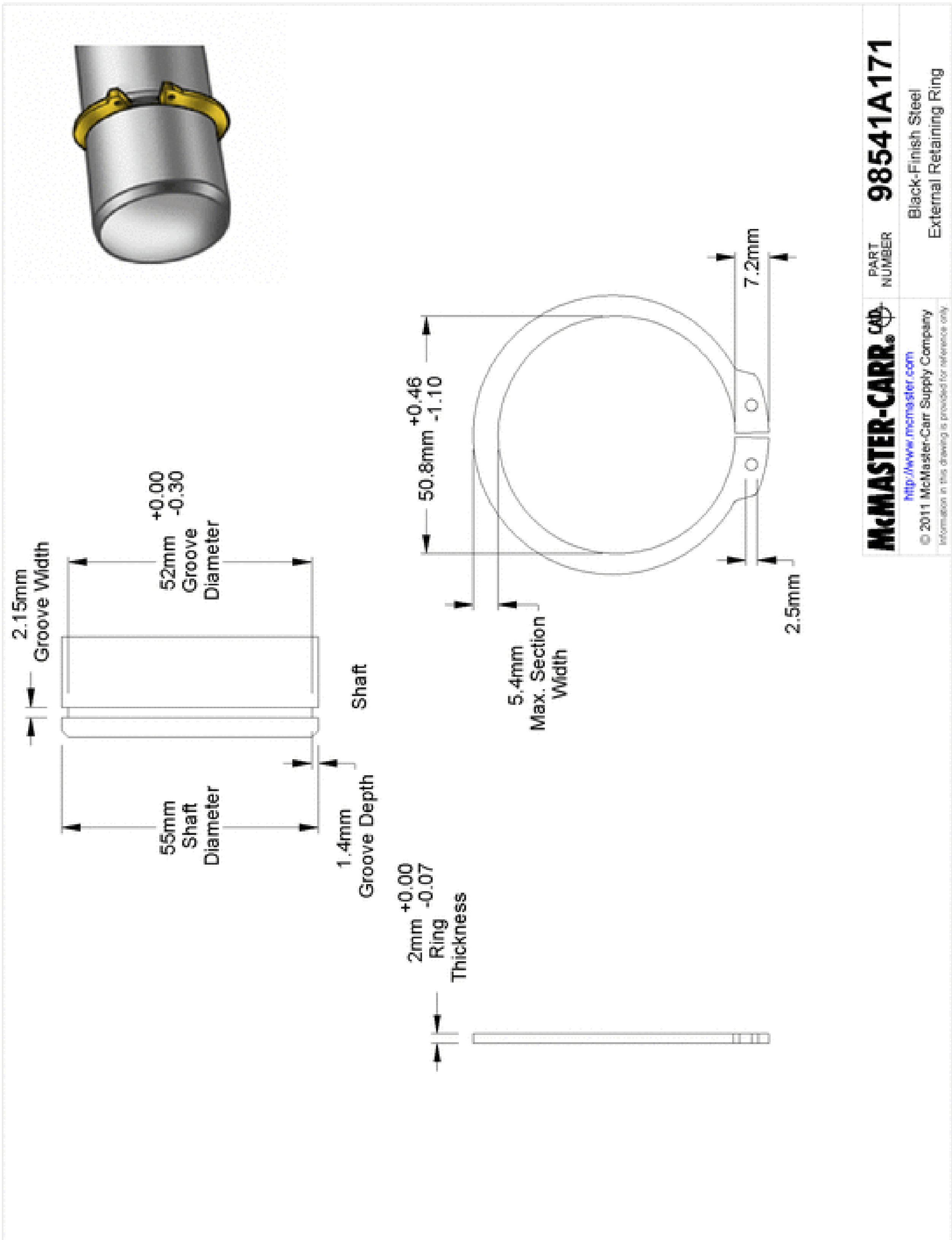
2.15mm
Groove Width
52mm +0.00 -0.30
Groove
Diameter
55mm
Shaft
Diameter
Shaft
1.4mm
Groove Depth
2mm +0.00 -0.07
Ring
Thickness
50.8mm +0.46 -1.10
5.4mm
Max. Section
Width
7.2mm
2.5mm
McMASTER-CARR
PART NUMBER
98541A171
Black-Finish Steel
External Retaining Ring
http://www.mcmaster.com
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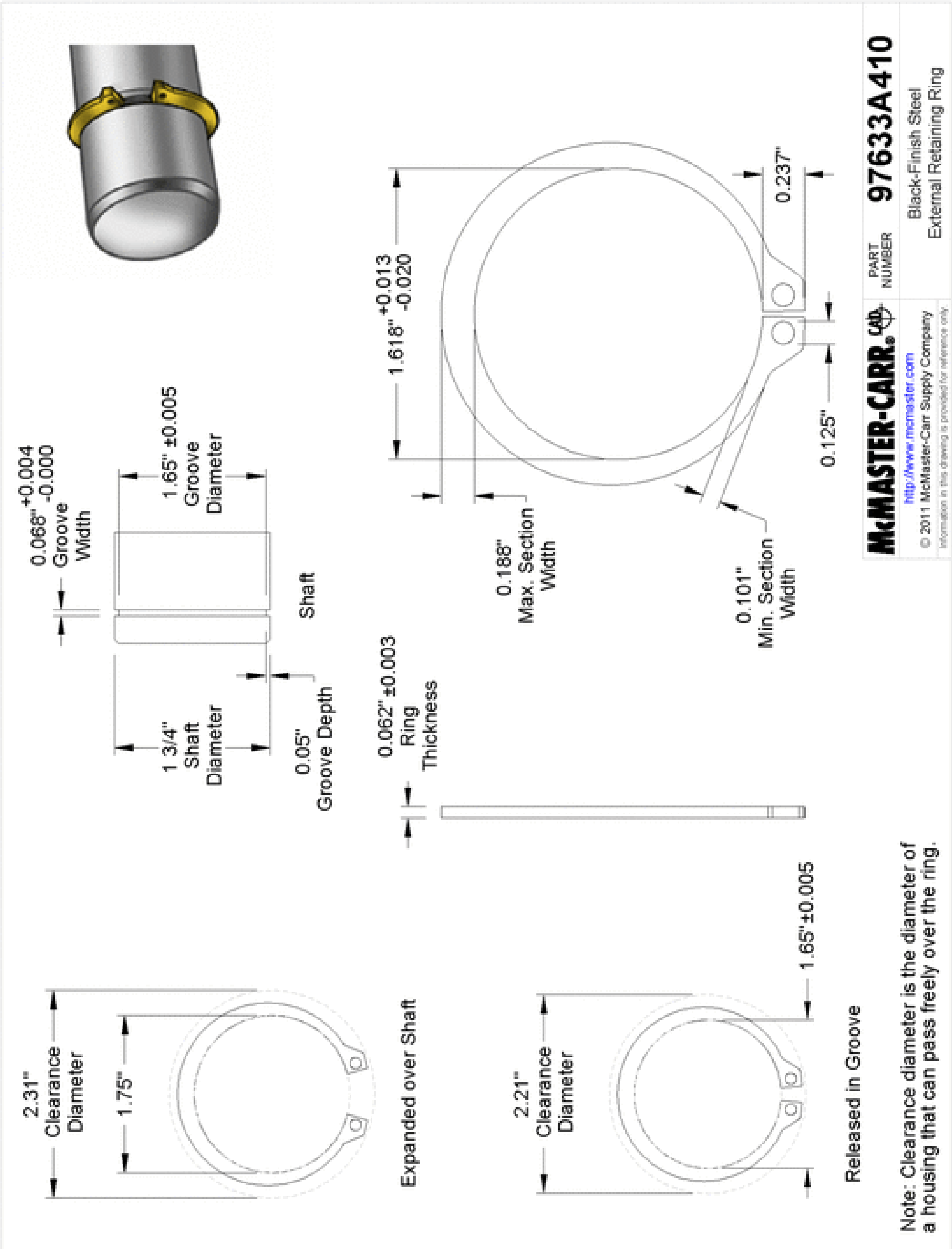
0.068" +0.004 -0.000
Groove
Width
1.65" ±0.005
Groove
Diameter
1 3/4"
Shaft
Diameter
0.05"
Groove Depth
Shaft
0.062" ±0.003
Ring
Thickness
1.618" +0.013 -0.020
0.188"
Max. Section
Width
0.101"
Min. Section
Width
0.125"
0.237"
2.31"
Clearance
Diameter
1.75"
Expanded over Shaft
2.21"
Clearance
Diameter
1.65"±0.005
Released in Groove
Note: Clearance diameter is the diameter of
a housing that can pass freely over the ring.
McMASTER-CARR
http://www.mcmaster.com
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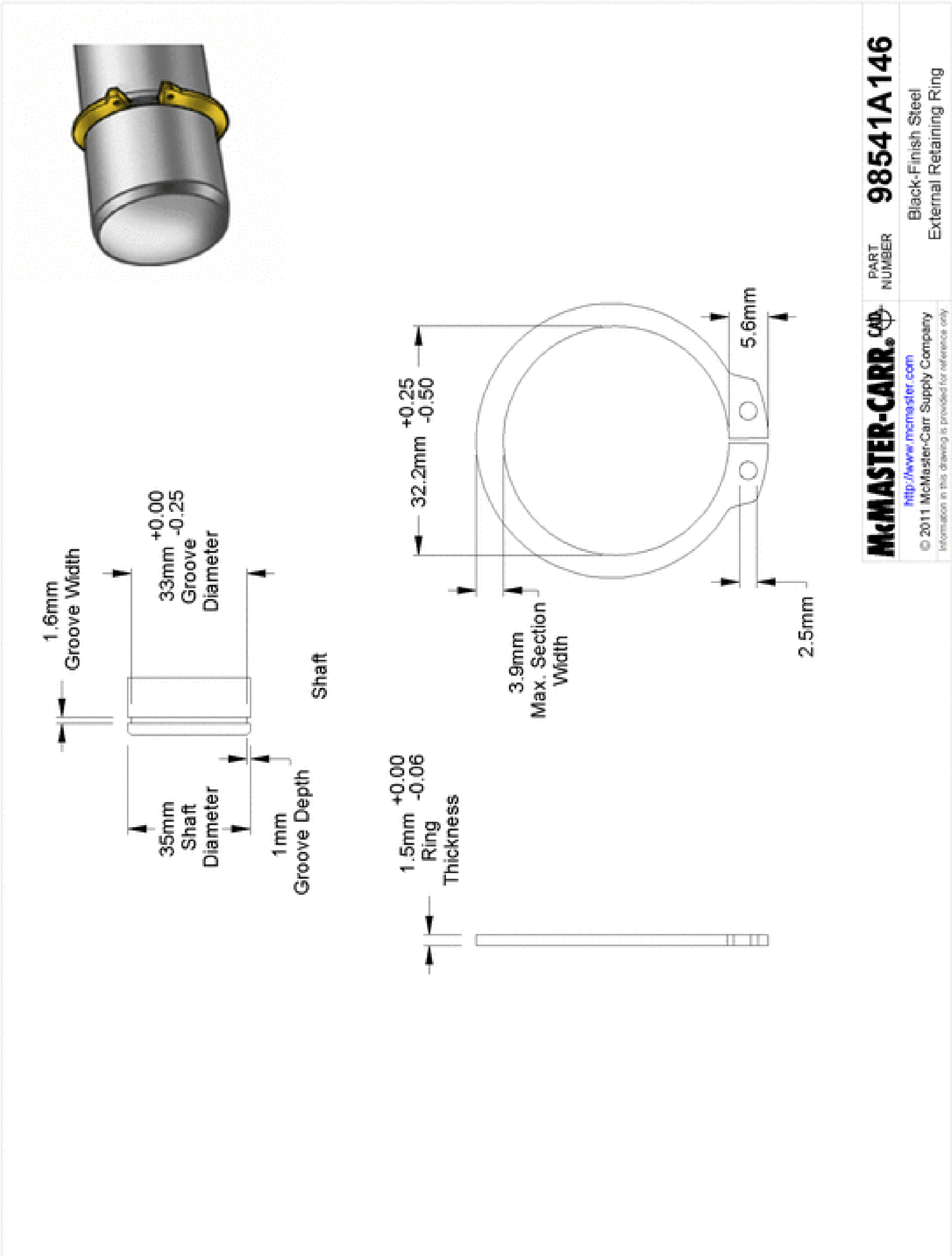
PART
NUMBER
97633A410
Black-Finish Steel
External Retaining Ring


1.6mm
Groove Width
33mm +0.00 -0.25
Groove
Diameter
Shaft
35mm
Shaft
Diameter
1mm
Groove Depth
1.5mm +0.00 -0.06
Ring
Thickness
32.2mm +0.25 -0.50
3.9mm
Max. Section
Width
5.6mm
2.5mm
McMASTER-CARR
PART NUMBER
98541A146
Black-Finish Steel
External Retaining Ring
http://www.mcmaster.com
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Appendix A: Tables and Charts

A1

Table 1. Load Correction Factor (Ko)

Typical Machines Using a Belt	Motor					
	Max. Output not Exceeding 300% of Rated Value			Max. Output Exceeding 300% of Rated Value		
	AC Motor (Standard Motor, Synchronous Motor) DC Motor (Shunt), Engine with 2 or More Cylinders			Special Motor (High torque), Single-Cylinder Engine DC Motor (Series), Operation with Lye Shaft or Clutch		
	Operation Hours			Operation Hours		
	Intermittent use 1 Day 3 to 5 hrs	Regular Use 1 Day 8 to 12 hrs	Continuous Use 1 Day 8 to 12 hrs	Intermittent use 1 Day 3 to 5 hrs	Regular Use 1 Day 8 to 12 hrs	Continuous Use 1 Day 8 to 12 hrs
Exhibit Instrument, Projector, Measuring Instrument, Medical Machine	1.0	1.2	1.4	1.2	1.4	1.6
Cleaner, Sewing Machine, Office Machine, Carpentry Lathe, Belt Sawing Machine	1.2	1.4	1.6	1.4	1.6	1.8
Light Load Belt Conveyor, Packer, Sifter	1.3	1.5	1.7	1.5	1.7	1.9
Liquid Mixer, Drill Press, Lathe, Screw Machine, (Circular Sawing) Machine, Planer, Washing Machine, Paper Manufacturing Machine (Excluding Pulp Manufacturing Machine), Printing Machine	1.4	1.6	1.8	1.6	1.8	2.0
Mixer (Cement and Viscous Matter), Belt Conveyor (Ore, Coal and Sand), Grinder, Shaping Machine, Boring Machine, Milling Machine, Compressor (Centrifugal), Vibration Sifter, Textile Machine (Warper and Winder), Rotary Compressor, Compressor (Reciprocal)	1.5	1.7	1.9	1.7	1.9	2.1
Conveyor (Apron, Pan, Bucket and Elevator), Extraction, Fan, Blower (Centrifugal, Suction and Discharge), Power Generator, Exciter, Hoist, Elevator, Rubber Processor (Calender, Roll and Extruder), Textile Machine (Weaving Machine, Fine Spinning Machine, Twisting Machine and Weft Winding Machine)	1.6	1.8	2.0	1.8	2.0	2.2
Centrifugal Separator, Conveyor (Flight and Screw), Hammer Mill, Paper Manufacturing Machine (Pulpapitor)	1.7	1.9	2.1	1.9	2.1	2.3

A2

Table 2. Speed Ration Correction Coefficient (Kr)

Speed Ratio	Coefficient (Kr)
1.00 to 1.25	0
1.25 to 1.75	0.1
1.75 to 2.50	0.2
2.50 to 3.50	0.3
3.50 or more	0.4

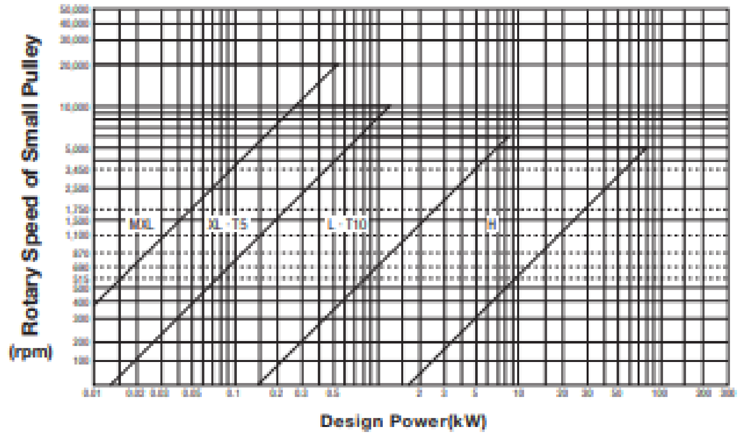
A3

Table 3. Idlers Correction Coefficient (Ki)

Position of Idler	Coefficient (Ki)
Inside the loose side of the belt	0
Outside the loose side of the belt	0.1
Inside the loose side of the belt	0.1
Outside the loose side of the belt	0.2

A4

Table 18. Selection Guide Table 1 (MXL,XL,L,H,T5,T10)



A5

Table 25. Min. Number of Teeth of Pulley

Rotary Speed of Small Pulley (rpm)	Type of Belt, Minimum Number of Teeth											
	MXL	XL	L	H	S2M	S3M	S5M	S8M	S14M	MTS8M	T5	T10
900 or Less	12	10	12	14	14	14	14	22	–	24	12	14
Over 900 1200 or Less	12	10	12	16	14	14	16	24	34	24	12	16
Over 1200 1800 or Less	14	11	14	18	16	16	20	26	38	24	14	18
Over 1800 3600 or Less	16	12	16	20	18	18	24	28	40	24	16	20
Over 3600 4800 or Less	–	16	20	24	20	20	26	30	48	24	20	22
Over 4800 10000 or Less	–	–	–	–	20	20	26	–	–	–	–	–

A6

Table 26. Engagement Correction Coefficient (Km)

No. of Teeth Engaged Zm	More than 6	5	4	3	2
Km	1.0	0.8	0.6	0.4	0.2

A7

Table 27. Reference Belt Width (Wp)

Type of Belt	MXL	XL	L	H	S2M	S3M	S5M	S8M	S14M	MTS8M
Reference Belt Width	6.4	25.4	25.4	25.4	4	6	10	60	120	60

Type of Belt	P2M	P3M	P5M	P8M	T5	T10
Reference Belt Width	4	6	10	15	10	10

A8

Table 28. Width Correction Coefficient(Kb)

Type of Belt	Belt Width Nominal	Belt Width mm	Width Correction Coefficient Kb
MXL	019	4.8	0.72
	025	6.4	1.00
	037	9.5	1.57
	050	12.7	2.18
XL	025	6.4	0.15
	031	7.9	0.21
	037	9.5	0.28
	050	12.7	0.42
L	050	12.7	0.42
	075	19.1	0.71
	100	25.4	1.00
	150	38.1	1.56
H	075	19.1	0.71
	100	25.4	1.00
	150	38.1	1.56
	200	50.8	2.14

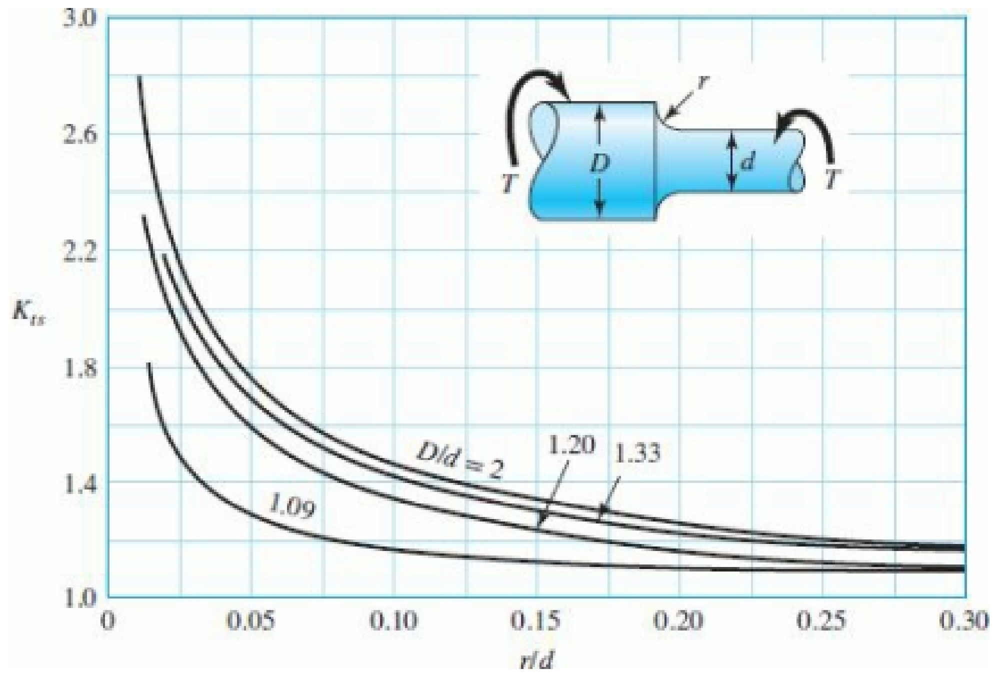
Type of Belt	Belt Width Nominal	Belt Width mm	Width Correction Coefficient Kb
S2M	040	4	1.00
	060	6	1.59
	100	10	2.84
S3M	060	6	1.00
	100	10	1.79
	150	15	2.84
S5M	100	10	1.00
	150	15	1.59
	250	25	2.84
S8M MTS8M	150	15	0.21
	250	25	0.37
	300	30	0.45
	400	40	0.63
S14M	400	40	0.29
	600	60	0.45

A9

Table 35. Reference Transmission Capacity of H Ps -Nominal Width of Belts 100(25.4mm)- (kW)

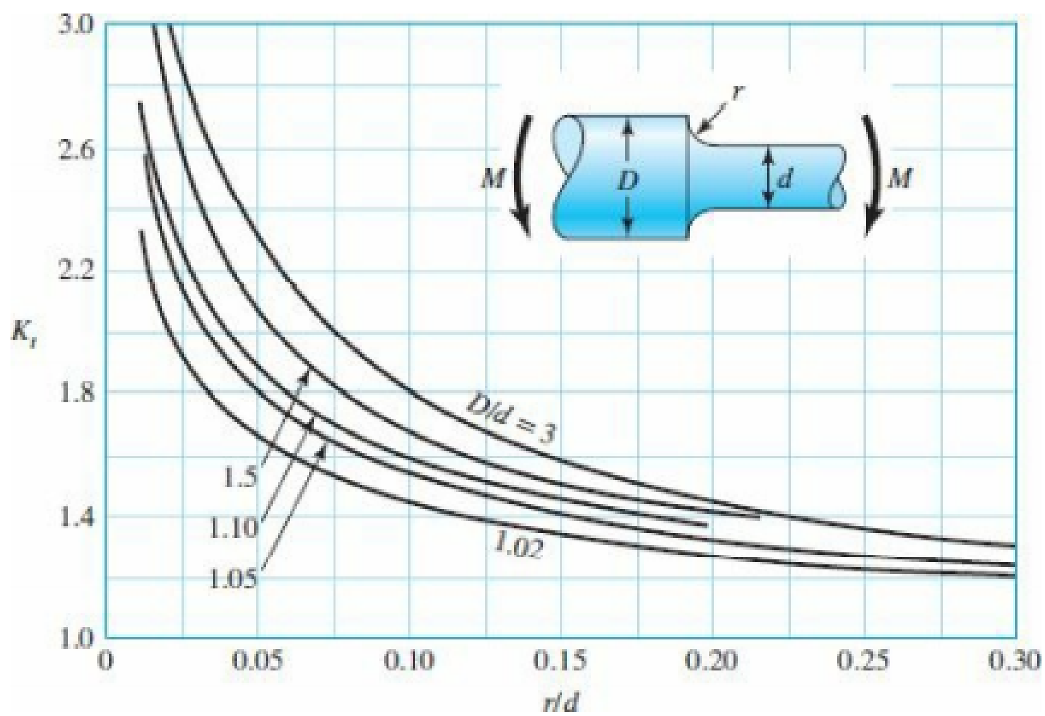
No. of Teeth of Small Pulley	14	15	16	18	19	20	21	22	24	25	26	28	30	32	36	40	48
Rotary Speed of Small Pulley(rpm) / Diameter of the Pitch Circle(mm)	56.60	60.64	64.68	72.77	76.81	80.85	84.89	88.94	97.02	101.06	105.1	113.19	121.28	129.36	145.53	161.70	194.04
725	1.33	1.43	1.52	1.71	1.81	1.90	2.00	2.09	2.28	2.38	2.47	2.66	2.85	3.04	3.41	3.79	4.53
870	1.60	1.71	1.83	2.05	2.17	2.28	2.40	2.51	2.74	2.85	2.96	3.19	3.41	3.64	4.08	4.53	5.41
950			1.99	2.24	2.37	2.49	2.61	2.74	2.99	3.11	3.23	3.48	3.72	3.97	4.45	4.93	5.89
1160			2.43	2.74	2.89	3.04	3.19	3.34	3.64	3.79	3.94	4.23	4.53	4.82	5.41	5.99	7.12
1425				3.35	3.54	3.72	3.91	4.09	4.45	4.63	4.81	5.17	5.53	5.89	6.59	7.27	8.61
1750				4.11	4.33	4.55	4.78	5.00	5.44	5.66	5.87	6.31	6.73	7.16	7.98	8.79	10.32
2850						7.27	7.61	7.95	8.61	8.93	9.25	9.87	10.48	11.06	12.16	13.15	14.80
3450						8.68	9.07	9.45	10.19	10.55	10.91	11.59	12.24	12.85	13.95	14.87	16.09
100	0.18	0.19	0.21	0.23	0.25	0.26	0.27	0.28	0.31	0.32	0.34	0.36	0.39	0.42	0.47	0.52	0.63
200	0.36	0.39	0.42	0.47	0.50	0.52	0.55	0.57	0.63	0.65	0.68	0.73	0.79	0.84	0.94	1.05	1.26
300	0.55	0.59	0.63	0.71	0.75	0.79	0.83	0.86	0.94	0.98	1.02	1.10	1.18	1.26	1.42	1.57	1.89
400	0.73	0.79	0.84	0.94	1.00	1.05	1.10	1.15	1.26	1.31	1.36	1.47	1.57	1.68	1.89	2.10	2.52
500	0.92	0.98	1.05	1.18	1.25	1.31	1.38	1.44	1.57	1.64	1.71	1.84	1.97	2.10	2.36	2.62	3.14
600	1.10	1.18	1.26	1.42	1.50	1.57	1.65	1.73	1.89	1.97	2.05	2.20	2.36	2.52	2.83	3.14	3.76
700	1.29	1.38	1.47	1.65	1.75	1.84	1.93	2.02	2.20	2.30	2.39	2.57	2.75	2.93	3.30	3.66	4.38
800	1.47	1.57	1.68	1.89	1.99	2.10	2.20	2.31	2.52	2.62	2.73	2.93	3.14	3.35	3.76	4.17	4.99
900	1.65	1.77	1.89	2.13	2.24	2.36	2.48	2.60	2.83	2.95	3.06	3.30	3.53	3.76	4.22	4.68	5.59
1000			2.10	2.36	2.49	2.62	2.75	2.88	3.14	3.27	3.40	3.66	3.92	4.17	4.68	5.19	6.18
1100			2.31	2.60	2.74	2.88	3.02	3.17	3.45	3.59	3.74	4.02	4.30	4.58	5.14	5.69	6.77
1200			2.52	2.83	2.99	3.14	3.30	3.45	3.76	3.92	4.07	4.38	4.68	4.99	5.59	6.18	7.35
1300				3.06	3.23	3.40	3.57	3.74	4.07	4.24	4.40	4.73	5.06	5.39	6.03	6.67	7.91
1400				3.30	3.48	3.66	3.84	4.02	4.38	4.55	4.73	5.09	5.44	5.79	6.48	7.16	8.47
1500				3.53	3.72	3.92	4.11	4.30	4.68	4.87	5.06	5.44	5.81	6.18	6.91	7.63	9.01
1600				3.76	3.97	4.17	4.38	4.58	4.99	5.19	5.39	5.79	6.18	6.57	7.35	8.10	9.55
1700				3.99	4.21	4.43	4.64	4.86	5.29	5.50	5.71	6.13	6.55	6.96	7.77	8.56	10.07
1800				4.22	4.45	4.68	4.91	5.14	5.59	5.81	6.03	6.48	6.91	7.35	8.19	9.01	10.57
1900						4.93	5.17	5.41	5.89	6.12	6.35	6.82	7.27	7.73	8.61	9.46	11.06
2000						5.19	5.44	5.69	6.18	6.43	6.67	7.16	7.63	8.10	9.01	9.89	11.53
2100						5.44	5.70	5.96	6.48	6.73	6.99	7.49	7.98	8.47	9.41	10.32	11.99
2200						5.69	5.96	6.23	6.77	7.03	7.30	7.82	8.33	8.83	9.81	10.73	12.43
2300						5.94	6.22	6.50	7.06	7.33	7.61	8.15	8.68	9.19	10.19	11.14	12.85
2400						6.18	6.48	6.77	7.35	7.63	7.91	8.47	9.01	9.55	10.57	11.53	13.25
2500						6.43	6.73	7.03	7.63	7.93	8.22	8.79	9.35	9.89	10.94	11.91	13.63
2600						6.67	6.99	7.30	7.91	8.22	8.52	9.10	9.68	10.24	11.30	12.28	13.99
2800						7.16	7.49	7.82	8.47	8.79	9.10	9.72	10.32	10.90	11.99	12.99	14.65
3000						7.63	7.98	8.33	9.01	9.35	9.68	10.32	10.94	11.53	12.64	13.63	15.21
3200						8.10	8.47	8.83	9.55	9.89	10.24	10.90	11.53	12.14	13.25	14.22	15.67
3400						8.56	8.95	9.33	10.07	10.42	10.78	11.45	12.10	12.71	13.81	14.75	16.02
3600						9.01	9.41	9.81	10.57	10.94	11.30	11.99	12.64	13.25	14.33	15.21	16.26
3800								10.28	11.06	11.44	11.80	12.50	13.15	13.75	14.80	15.60	16.38
4000								10.73	11.53	11.91	12.28	12.99	13.63	14.22	15.21	15.92	16.37
4200								11.18	11.99	12.37	12.75	13.44	14.08	14.65	15.56	16.16	16.23
4400								11.61	12.43	12.81	13.19	13.87	14.49	15.03	15.86	16.31	15.94
4600								12.03	12.85	13.23	13.60	14.28	14.87	15.37	16.09	16.39	15.51
4800								12.43	13.25	13.63	13.99	14.65	15.21	15.67	16.26	16.37	14.93

A10



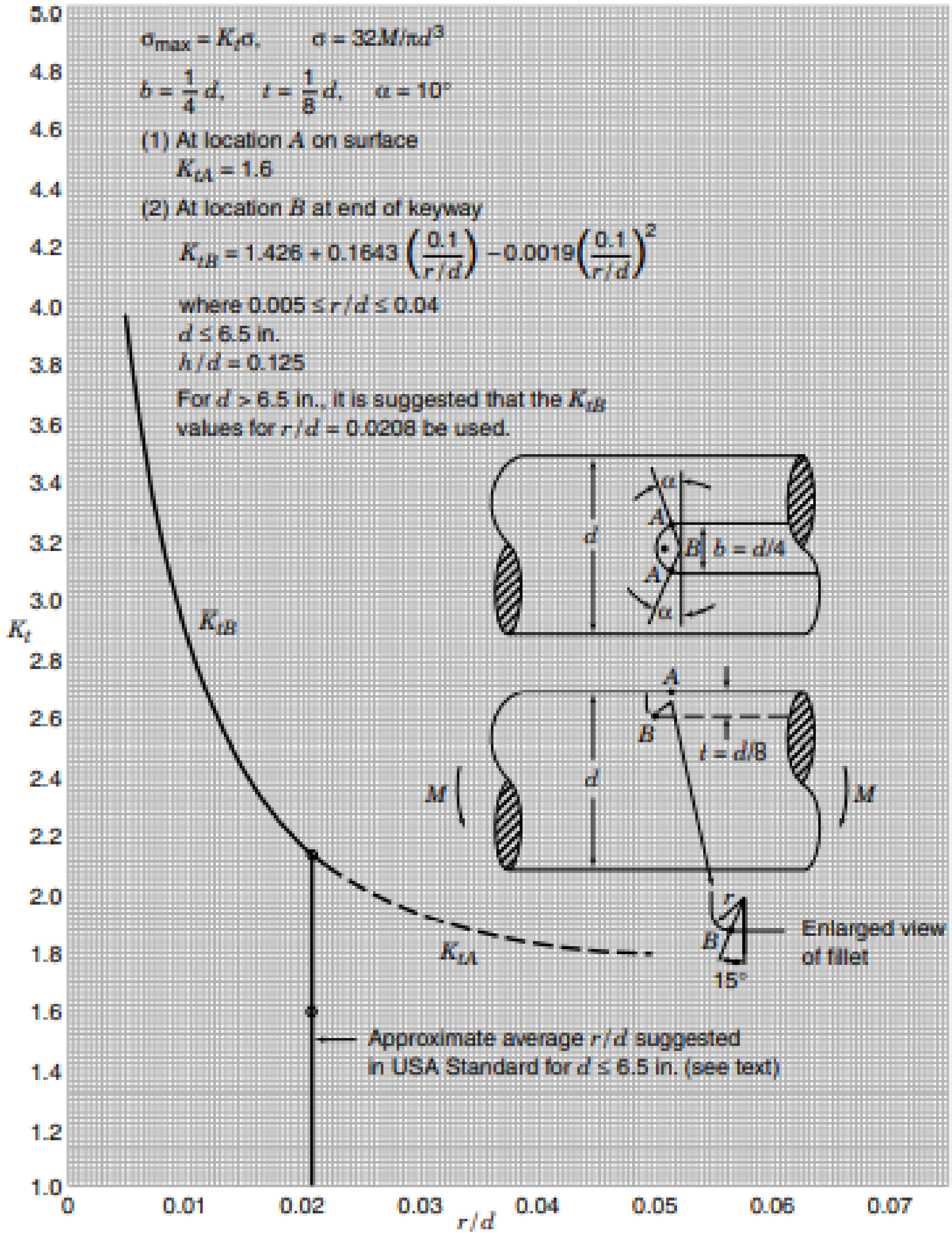
3.0
2.6
2.2
K_{ts}
1.8
1.4
1.0
0
0.05
0.10
0.15
0.20
0.25
0.30
r/d
T
D
d
r
T
D/d = 2
1.20
1.33
1.09

A11



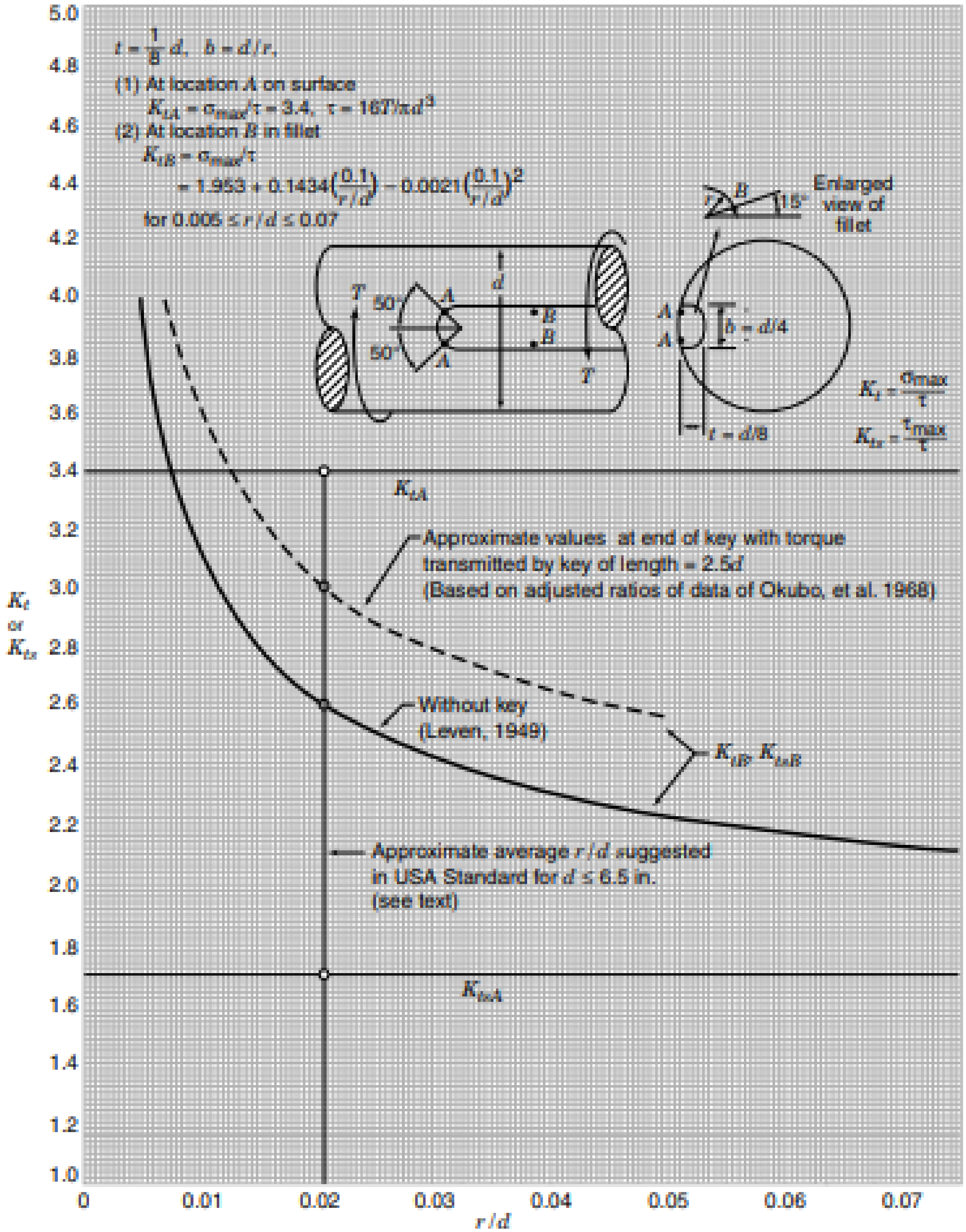
3.0
2.6
2.2
K_t
1.8
1.4
1.0
0
0.05
0.10
0.15
0.20
0.25
0.30
r/d
M
D
d
r
M
D/d = 3
1.5
1.10
1.05
1.02

A12



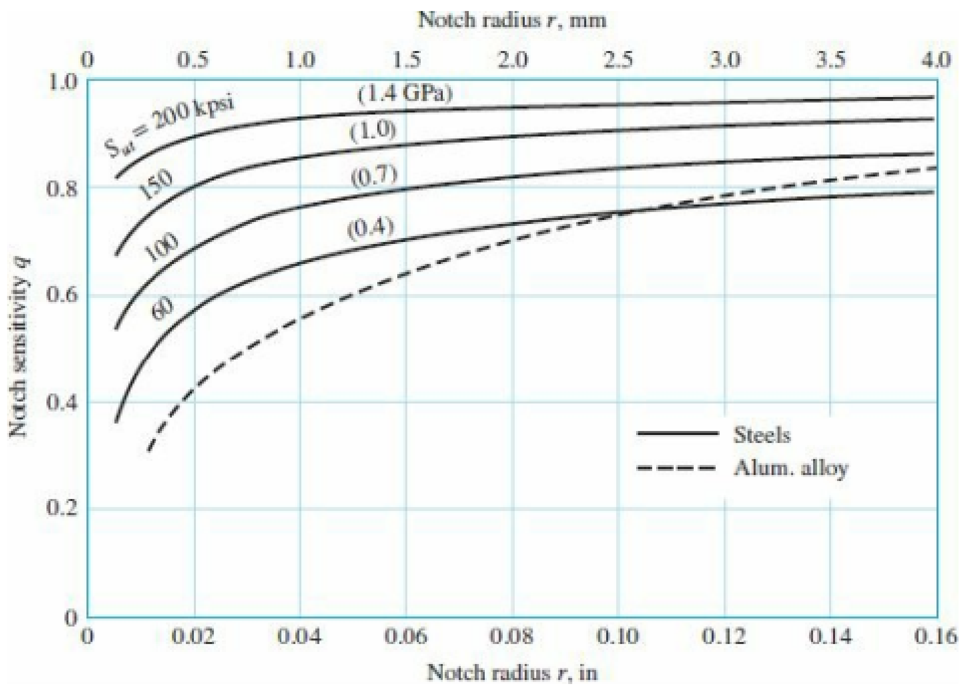
$\sigma_{max} = K_t\sigma, \quad \sigma = 32M/\pi d^3$
$b = \frac{1}{4}d, \quad t = \frac{1}{8}d, \quad \alpha = 10°$
(1) At location A on surface
$K_{tA} = 1.6$
(2) At location B at end of keyway
$K_{tB} = 1.426 + 0.1643\left(\frac{0.1}{r/d}\right) - 0.0019\left(\frac{0.1}{r/d}\right)^2$
where $0.005 \le r/d \le 0.04$
$d \le 6.5$ in.
$h/d = 0.125$
For $d > 6.5$ in., it is suggested that the K_{tB} values for $r/d = 0.0208$ be used.
K_t
K_{tB}
K_{tA}
r/d
$b = d/4$
$t = d/8$
M
d
A
B
α
r
15°
Enlarged view of fillet
Approximate average r/d suggested in USA Standard for $d \le 6.5$ in. (see text)
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07

A13

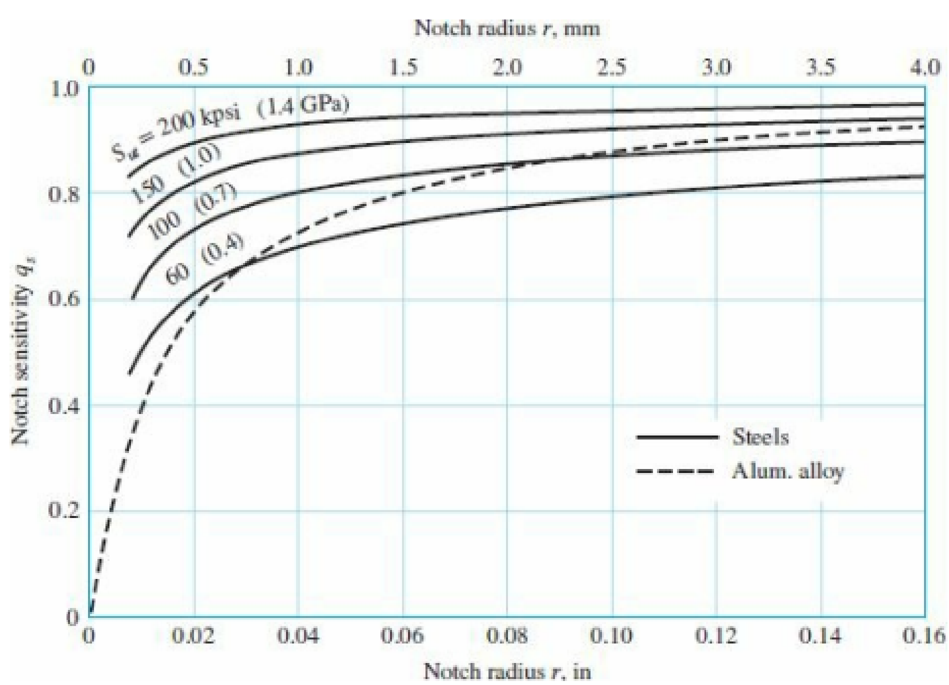


$t = \frac{1}{8}d,\ b = d/r,$
(1) At location A on surface
$K_{tA} = \sigma_{max}/\tau = 3.4,\ \tau = 16T/\pi d^3$
(2) At location B in fillet
$K_{tB} = \sigma_{max}/\tau$
$= 1.953 + 0.1434\left(\frac{0.1}{r/d}\right) - 0.0021\left(\frac{0.1}{r/d}\right)^2$
for $0.005 \le r/d \le 0.07$
Enlarged view of fillet
$b = d/4$
$t = d/8$
$K_t = \frac{\sigma_{max}}{\tau}$
$K_{ts} = \frac{\tau_{max}}{\tau}$
K_{tA}
Approximate values at end of key with torque transmitted by key of length = 2.5d
(Based on adjusted ratios of data of Okubo, et al. 1968)
Without key
(Leven, 1949)
K_{tB}, K_{tsB}
Approximate average r/d suggested in USA Standard for $d \le 6.5$ in.
(see text)
K_{tsA}
K_t or K_{ts}
r/d

A14


Notch radius r, mm
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
1.0
0.8
0.6
0.4
0.2
0
S_{ut} = 200 kpsi
(1.4 GPa)
150
(1.0)
100
(0.7)
60
(0.4)
Notch sensitivity q
Steels
Alum. alloy
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Notch radius r, in

A15


Notch radius r, mm
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
1.0
0.8
0.6
0.4
0.2
0
S_{ut} = 200 kpsi (1.4 GPa)
150 (1.0)
100 (0.7)
60 (0.4)
Notch sensitivity q_s
Steels
Alum. alloy
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Notch radius r, in

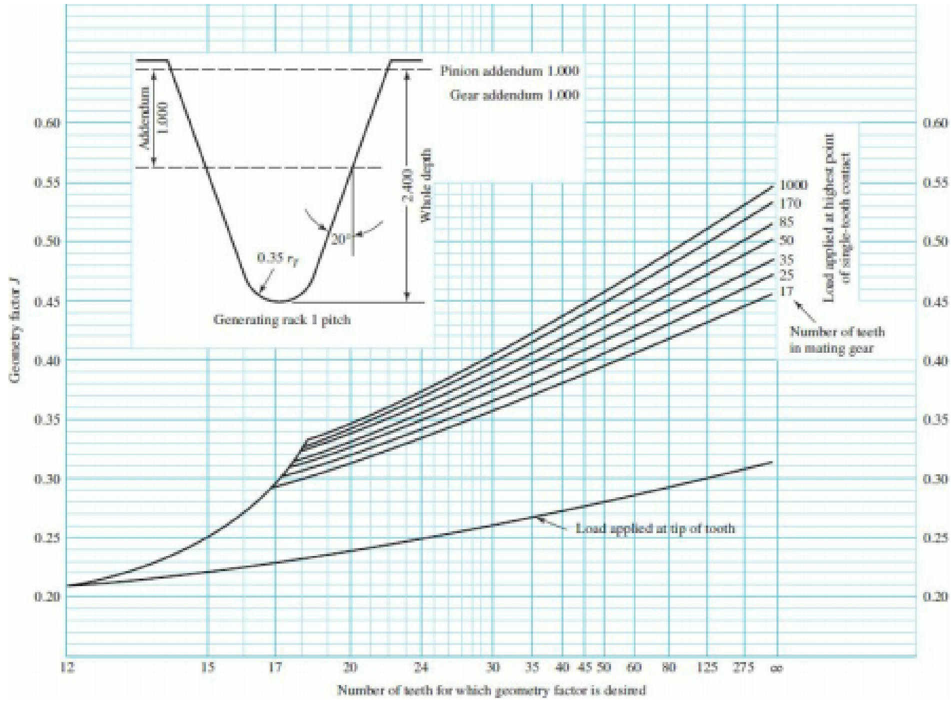
A16

Table 1. Key Size Versus Shaft Diameter ***ASME B17.1-1967 (R2013)***

Nominal Shaft Diameter		Nominal Key Size			Normal Keyseat Depth	
			Height, *H*		*H*/2	
Over	To (Incl.)	Width, *W*	Square	Rectangular	Square	Rectangular
5/16	7/16	3/32	3/32	...	3/64	...
7/16	9/16	1/8	1/8	3/32	1/16	3/64
9/16	7/8	3/16	3/16	1/8	3/32	1/16
7/8	1 1/4	1/4	1/4	3/16	1/8	3/32
1 1/4	1 3/8	5/16	5/16	1/4	5/32	1/8
1 3/8	1 3/4	3/8	3/8	1/4	3/16	1/8
1 3/4	2 1/4	1/2	1/2	3/8	1/4	3/16
2 1/4	2 3/4	5/8	5/8	7/16	5/16	7/32
2 3/4	3 1/4	3/4	3/4	1/2	3/8	1/4
3 1/4	3 3/4	7/8	7/8	5/8	7/16	5/16
3 3/4	4 1/2	1	1	3/4	1/2	3/8
4 1/2	5 1/2	1 1/4	1 1/4	7/8	5/8	7/16
5 1/2	6 1/2	1 1/2	1 1/2	1	3/4	1/2
Square Keys preferred for shaft diameters above this line; rectangular keys, below						
6 1/2	7 1/2	1 3/4	1 3/4	1 1/2[a]	7/8	3/4
7 1/2	9	2	2	1 1/2	1	3/4
9	11	2 1/2	2 1/2	1 3/4	1 1/4	7/8

[a] Some key standards show 1 1/4 inches; preferred height is 1 1/2 inches.

A17



A18

Size Factor k_b

Talking:

- The endurance limit of specimens loaded in bending and torsion has been observed to decrease slightly as the size increases.
- Larger parts have greater surface area at high stress levels, thus a higher probability of a crack initiating.
- Size factor is obtained from experimental data with wide scatter
- For bending and torsion or round rotating bars, the trend of the size factor data is given by

$$k_b = \begin{cases} (d/0.3)^{-0.107} = 0.879d^{-0.107} & 0.3 \le d \le 2 \text{ in} \\ 0.91d^{-0.157} & 2 < d \le 10 \text{ in} \\ (d/7.62)^{-0.107} = 1.24d^{-0.107} & 7.62 \le d \le 51 \text{ mm} \\ 1.51d^{-0.157} & 51 < d \le 254 \text{ mm} \end{cases} \qquad (6\text{–}19)$$

- For d less than 0.3 inches (7.62 mm), $k_b = 1$ is recommended.
- For axial load, there is no size effect, so $k_b = 1$.

A19

Recommended AGMA Gear Quality Numbers for Various Applications

Application	Q_v
Cement mixer drum drive	3–5
Cement kiln	5–6
Steel mill drives	5–6
Corn picker	5–7
Cranes	5–7
Punch press	5–7
Mining conveyor	5–7
Paper-box making machine	6–8
Gas meter mechanism	7–9
Small power drill	7–9
Clothes washing machine	8–10
Printing press	9–11
Computing mechanism	10–11
Automotive transmission	10–11
Radar antenna drive	10–12
Marine propulsion drive	10–12
Aircraft engine drive	10–13
Gyroscope	12–14

Appendix B: Matlab Shaft Code

```
function shaft()

%tm in lbf*in
% a and b for ka
% q_in and qs_in are first iteration estimates
%we will have to change n, ma,Sy,Su,mks,msh
% Syk, ktks,ktsh,ktssh,ktsks,W,h,ke,gw
n = 1.5;
Sy = 186;  %186 or 41
Su = 212; %212 or 48
gw = 1.5; %gear width
%mks = 2166.664364; %Moment at keyseat
msh = 758.989358; %moment at shoulder
ma = msh;
ta = 0;
mm = 0;
tm = 12605;
a = 2;
b = -.217;
q_in = .825;
qs_in = .85;

ktsh = 2.3 ;
ktssh = 1.35 ;

sqrtab = .246 - 3.08*(10^-3)*Su + 1.51*(10^-5)*Su^(2) - 2.67*(10^-8)*Su^(3);
sqrtat = .19-2.51*1e-3*(Su)+1.35*1e-5*Su^(2)-2.67*1e-8*(Su^3);

kf1= 1+q_in*(ktsh-1);
kfs1 = 1+qs_in*(ktssh-1);


d_in = 2.165354331
 %2.409448818897638 %
%d_in = ((16*n/(pi*Sy*1E3))*(4*(ma+mm)^2*kf1^2+3*(ta+tm)^2*kfs1^2)^0.5)^(1/3)
r_in = d_in*.02
D_in = 1.039090909*d_in
kfs = 1+(ktssh-1)/(1+sqrtat/sqrt(r_in));
kf = 1+(ktsh-1)/(1+sqrtab/sqrt(r_in));

% components = 7; %Number of components on shaft
% reliab = .9^(1/components)

%inter = (.897

Se_prime = Su*.5;
ka = a*Su^(b);
kb = .91*d_in^(-.157);
ke =.82865;
Se = ka*ke*kb*Se_prime;
```

```
f = 1.06 - 2.8*(10^-3)*Su+6.9*(10^-6)*Su^2;


I = pi*d_in^(4)/64;

sigma_a = ma*(d_in/2)/(I)/1000;
sigma_m= 0;
t_a = 0;
t_m = tm*(d_in/2)/(pi*d_in^(4)/32)/1000;

sig_pa = sqrt((kf*sigma_a+0)^(2)+3*(kfs*t_a)^(2));
sig_pm = sqrt((kf*sigma_m+1*sigma_m)^(2) +3*(t_m*kfs)^(2));

nf = (sig_pa/Se+sig_pm/Su)^(-1) % shaft factor of safety for infinite life
ny = Sy/(sig_pa+sig_pm) %n for yielding

fsut = f*Su;
a_ar = (fsut^2)/(Se);
b_ar = -1/3*(log10(fsut/Se));
sig_ar = sig_pa/(1-sig_pm/Su);

a_g = (4*(kf*ma)^(2)+3*(kfs*ta)^(2))^(1/2); % amplitude
b_g = (4*(kf*mm)^2+3*(kfs*tm)^2)^(1/2); % mean


n_ar = (sig_ar/a_ar)^(1/b_ar) %Number of cylces to failure



d_goodman = d_in%((16*n/pi)*((a_g/(Se*1E3))+(b_g/(Su*1E3))))^(1/3)

percentdiff = abs((d_goodman-d_in)/d_in)*100

%d_goodman =.661
Syk = 212*1e3; %Sy of the keyseat
ssy = .577*Syk;

W = .5 ; %width and height of keyseat
h = 0.5 ;
ft = tm/(d_goodman/2);

Lmax = (gw-d_goodman/(10))
%Lmm = 15
Lin =  .5 ;%Lmm/25.4


Ix = 1/12*(Lin*h^3);
Iy = 1/12*(Lin^(3)*h);
J = Ix+Iy;
```

```
shear_ks = tm*h/2/(J)
bs_ks = 2*shear_ks

ns = ssy*W*Lin/(ft)
nb = Syk*W*Lin /(ft*2)



L_fin = 1.5*ft*2/(ssy*W)
```

Appendix C: Matlab Bearing Code

```
function bearings()
%bearing type 7 for angular and 6 for deep groove
%Angular Contact
%Radial Force on bearing
n = 1.2 ; %application factor %Factor of safety
fr1 = 166.4935; %reaction force at left bearing
fr2 = 440.3559176; %reaction force at right bearing
Fr2 = fr2/ 224.8090247; % fr2 force in Kn
Fr1 = fr1/224.8090247;  % fr1 force in Kn
Fr = max([Fr1,Fr2]);
Fr_min = min([Fr1,Fr2]);
rpm = 1200;
rlife = 24000; %hours (required life)
p = 3;  %exponent of life
askf = 1;  % life modification factor
components = 7; %Number of components on shaft
reliab = .9^(1/components) %reliability of bearings
a1 = .4232; %interpolate from table 3 page 90 based on reliability
Co1 = 26.5 ;%basic dynamic load rating p.408-412
Co2 = 61 ; %basic dynamic load rating p.408-412


%Axial Force
Fa = Fr*.4;
contactangle = atan(Fr_min/Fa);
cad = rad2deg(contactangle)


%Face to face every case
R =0;
% if cad < 30
%     R = .5
%     e = .68
%     X = .67
%     Y1 = .92
%     Y2 = 1.41
%     Y0 = .76
% else
    R = .88
    e = 1.14;
    X = .57;
    Y1 = .55;
    Y2 = .93;
    Y0 = .52;

if (Fr1 < Fr2 && Fa >= R*(Fr2-Fr1))
    Fa1 = R*(Fr1)
    Fa2 = Fa1+Fa
elseif( Fr1<Fr2 && Fa < (Fr2-Fr1))
    Fa2 = R*Fr2
    Fa1 = Fa2-Fa
```

```
elseif(Fr1>Fr2 && Fa > R*(Fr1-Fr2))
    Fa2 = R*(Fr2)
    Fa1 = Fa2+Fa
elseif( Fr1>Fr2 && Fa < R*(Fr1-Fr2))
    Fa1 = R*Fr1
    Fa2 = Fa1-Fa
end

if( Fa2/Fr2 <= e)
    P2 = Fr2+Y1*Fa2
else
    P2 = X*Fr2+Y2*Fa2
end

if( Fa1/Fr1 <= e)
    P1 = Fr1+Y1*Fa1
else
    P1 = X*Fr1+Y2*Fa1
end

Lnm = 60*(rpm)*rlife/(1e6)
C1 = ((Lnm/(a1*askf))^(1/p))*P1
C2 = ((Lnm/(a1*askf))^(1/p))*P2

C1n = C1*n
C2n = C2*n
n1 = Co1/C1n
n2 = Co2/ C2n
```

Appendix D: Matlab Gear Code

```
function stressconcgear()


format long
%have to change pitch,Np,Ng
P = 10;% diametral pitch
Np = 36; % Number of teeth - pinion
Ng = 144;% Number of teeth - gear
phi = 20; % Pressure angle
radd = deg2rad(20);
mg = Ng/Np ;


a= 1/P % T13-1 pg 688
b = 1.25/P
c = b-a% pg 673
dg = Ng/P;
dp = Np/P;
p = pi*dg/Ng % circular pitch

% pictch circle radii

rp = dp/2; % pinion
rg = dg/2; % gear

%base circle radii
rbg = dg*cosd(phi)/2
rbp = dp*cosd(phi)/2

%center distance
C = (dp+dg)/2

%interference check - en 13.11 pg 678
k = 1; % for full depth pg. 678

Np_min = 2*k/((1+2*mg)*(sind(20))^2) * (mg + sqrt(mg^2+(1+2*mg)*(sind(20))^2));

if (Np>Np_min) %& (Ng_max>Ng)
    display('no interference')
else
    display('interference')
end

%contact ratio check Eqn. 14.25
pb = p*cosd(phi);

cr=(((rp+a)^2-(rp*cosd(phi))^2)^.5+((rg+a)^2-(rg*cosd(phi))^2)^.5-(C*sind(phi)))/pb

rpm = 800

rf = .3/P;
```

```
H = .34 - .4583662*radd
L = .316 - .4583662*radd
M = .290 + .4583662*radd

T = 10*63025/rpm
Wt = T/rp  %Either rp or rg
%Wt = T/rg


l = 1/5 + 1.25/5
r = ((.25-rf)^(2))/(2+.25-rf)
x = 3*.422/(2*5)

% Interpolate Y
upperbound = 34;
lowerbound = 38;
uppervalue = .384;
lowervalue = .371;
desired = 36;
y = (desired-lowerbound)*(uppervalue-lowervalue)/(upperbound-lowerbound) + lowervalue
%y = .4422 %.4522 Table 14-2

t = (4*l*x)^.5

fw = 1
Kf = H +((t/r)^(L)  *(t/l)^M)

V = pi*4*rpm/12
Kv = (50+sqrt(V))/50
sigma = Kv*(Wt)*5/(fw*.322)



%nd  = 30000/(Kf*sigma)
%Have to change face width

Cmc = 1;
Cma = .0675+.0128*fw+(-.926e-4)*(fw^2);
Cpm = 1.1;
Cpf = (.05)-.025;
Km = 1+(Cmc*(Cpm*(Cpf)+Cma*1))

%have to change quality factor
Qv = 10
b = .25*(12-Qv)^(2/3)
a = (50+56*(1-b))

kv = ((a + sqrt(V))/(a) )^(b)

ks = 1.192*(fw*sqrt(y)/P)^(0.0535)
```

```
if ks < 1
    ks = 1
end
J = .415; %.485 Figure 14-6 %.4625
Ko = 1.25;
Kb = 1;

sigagma = Wt*kv*Ko*ks*(P/fw)*((Km*Kb)/(J))

%Have to change with value
St = 45000;
numcyc = 24000*60*rpm
Yn = 1.6831*(numcyc)^(-.0323)
components = 7 ;
Kt = 1;
rel = .9^(1/components);
if ( rel >.5 && rel < 0.99)
    Kr = .658-.0759*log(1-rel)
else
    Kr = .5 - 0.109*log(1-rel)
end


Sf = (St*(Yn/(Kr*Kt)))/(sigagma)

% E is the modulus of elasticity
% V is the poisson's ratio

ep = 30e6;
vp = .291;
eg = 30e6;
vg = .291;

Cp = sqrt(1/(pi*((1-(vp^2))/ep + (1-(vg^2))/eg)))
r1 = dp*sin(radd)/2;
r2 = dg*sin(radd)/2;

Hc = -Cp*sqrt((Kv*Wt/(fw*cos(radd)))*((1/r1)+(1/r2)))

%Hctest = sqrt(Wt/(pi*2.5*cos(radd))*((1/r1)+(1/r2))/((
Sc = 170000; %Table 14.6
Ch = 1;
Zn = (2.466*numcyc^(-0.056)) %figure 14-15
Sc_corrected = Sc*Zn*Ch/(Kt*Kr)

Sh = sqrt((Sc_corrected^2)/((Hc)^2))
```

Appendix E: Matlab Bolt and Housing Code

```
function bolts()
format short
%Tension
K=.2;
Fl=258.35;
n=4;
D=.25%.5;
Dhead=7/16%.75;
alpha=30;
rad=alpha*(pi/180);
Grip=2.557%2.569;
At=.0364%.1599;
Ad=(pi*D^2)/4;
Lt=.75%1.25;
L=3%3.25;
ld=L-Lt;
lt=Grip-ld;
Est=30e6;
EAl=10.3E6;
kb=(Ad*At*Est)/((Ad*lt)+(At*ld));
lf1=.57%.069;
lf2=1.2155;
lf3=1.2785%1.2845;
Df2=Dhead+2*lf1*tan(rad);
k1=(.5774*pi*Est*D)/log((((1.155*lf1)+Dhead-D)*(Dhead+D))/...
    (((1.155*lf1)+Dhead+D)*(Dhead-D)));
k2=(.5774*pi*EAl*D)/log((((1.155*lf2)+Df2-D)*(Df2+D))/...
    (((1.155*lf2)+Df2+D)*(Df2-D)));
k3=(.5774*pi*EAl*D)/log((((1.155*lf3)+Dhead-D)*(Dhead+D))/...
    (((1.155*lf3)+Dhead+D)*(Dhead-D)));
km=((1/k1)+(1/k2)+(1/k3))^-1;
C=kb/(km+kb);
Sp=120000;
Fp=At*Sp;
LpB=Fl/n;
preload=Fp*.9;
Ftotal=preload+C*LpB;
Fmember=(1-C)*LpB-preload;
maxallow=preload/(1-C);
njointsep=maxallow/LpB
nyeild=(Sp*At)/(Ftotal)
Twrench=preload*K*D

%Shear
r1=8.5;
r2=5;
r=sqrt((r1^2)+(r2^2));
sy1=78600;
sy2=sy1;
Sp1=Sp;
M=11935.82129;
```

```
Sf=793.103;
Sfpri=Sf/n;
Sfsec=M/(4*r);
theta1=atan(r2/r1);
theta1deg=theta1*(180/pi);
theta2deg=180-theta1deg;
theta2=theta2deg*(pi/180);
Sfhigh=sqrt((Sfpri^2)+(Sfsec^2)+(2*Sfpri*Sfsec*cos(theta1)))
Sflow=sqrt((Sfpri^2)+(Sfsec^2)+(2*Sfpri*Sfsec*cos(theta2)))
Vstress=Sfhigh/Ad;
nshearbolt=Sp1/(sqrt(3)*Vstress)
t1=1;
t2=1.5;
Ab1=t1*D;
Ab2=t2*D;
Bstress1=Sfhigh/Ab1;
n1b=sy1/Bstress1%bearing fos for plates
Bstress2=Sfhigh/Ab2;
n2b=sy2/Bstress2
nbbolts=Sp1/Bstress1%bearing fos for bolts
critbendlocmom=Sf*.75;
w2=20;
halfctc=5;
I=(((t2*w2^3)/12)-(2*(((t2*D^3)/12)+((halfctc^2)*t2*D))));
Maxbendstress=(critbendlocmom*(w2/2))/I;
nbending=sy2/Maxbendstress%bending stress fos for bottom plate
```

Appendix F : Matlab Minimum Shaft Diameter

```
function minshaft()

%tm in lbf*in
% a and b for ka
% q_in and qs_in are first iteration estimates
%we will have to change n, ma,Sy,Su,mks,msh
% Syk, ktks,ktsh,ktssh,ktsks,W,h,ke,gw
n = 1.5;
Sy = 186;  %186 or 41
Su = 212; %212 or 48
gw = 1.0; %gear width
%mks = 2166.664364; %Moment at keyseat
msh = 1293.761278; %moment at shoulder
ma = msh;
ta = 0;
mm = 0;
tm = 1575.625;
a = 2;
b = -.217;
q_in = .825;
qs_in = .85;

ktsh = 2.14;
ktssh = 3 ;

sqrtab = .246 - 3.08*(10^-3)*Su + 1.51*(10^-5)*Su^(2) - 2.67*(10^-8)*Su^(3);
sqrtat = .19-2.51*1e-3*(Su)+1.35*1e-5*Su^(2)-2.67*1e-8*(Su^3);

kf1= 1+q_in*(ktsh-1);
kfs1 = 1+qs_in*(ktssh-1);
```

```
d_in = 0.5;
 %2.409448818897638 %
%d_in = ((16*n/(pi*Sy*1E3))*(4*(ma+mm)^2*kf1^2+3*(ta+tm)^2*kfs1^2)^0.5)^(1/3)
r_in = d_in*.02;
D_in = 1.031875*d_in;
kfs = 1+(ktssh-1)/(1+sqrtat/sqrt(r_in));
kf = 1+(ktsh-1)/(1+sqrtab/sqrt(r_in));

% components = 7; %Number of components on shaft
% reliab = .9^(1/components)

%inter = (.897
nf = 1;
ny = 1;
while ( nf < 1.5) %nf < 1.5 &&
    d_in = 1.00001*d_in;

Se_prime = Su*.5;
ka = a*Su^(b);
kb = .879*d_in^(-.107);
ke =.82865;
Se = ka*ke*kb*Se_prime;



f = 1.06 - 2.8*(10^-3)*Su+6.9*(10^-6)*Su^2;


I = pi*d_in^(4)/64;
```

```
f = 1.06 - 2.8*(10^-3)*Su+6.9*(10^-6)*Su^2;


I = pi*d_in^(4)/64;

sigma_a = ma*(d_in/2)/(I)/1000;
sigma_m= 0;
t_a = 0;
t_m = tm*(d_in/2)/(pi*d_in^(4)/32)/1000;

sig_pa = sqrt((kf*sigma_a+0)^(2)+3*(kfs*t_a)^(2));
sig_pm = sqrt((kf*sigma_m+1*sigma_m)^(2) +3*(t_m*kfs)^(2));

nf = (sig_pa/Se+sig_pm/Su)^(-1); % shaft factor of safety for infinite life
ny = Sy/(sig_pa+sig_pm) ;%n for yielding

 end
disp(d_in)
disp(nf)
disp(ny)
```