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Coaxial Beam eAxle Modeling and Analysis for GAWR Limits

Alexander Cebriak
ac300@uakron.edu

Jackson Foster
jnf@uakron.edu

Chris James
cmj98@uakron.edu

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Alexander Cebriak

In collaboration with Jackson Foster and Chris James

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Contents

1) Introduction

Ansys® Workbench is a program that allows the user to solve complex models for the resulting reactions. The program is very flexible and can provide the user with any answer they could want as well as any answer they would not want. Ansys® relies on the simulation criteria, or loading condition, being as realistic as possible to give the most accurate results but this also results in simulations being able to run despite those simulations not fully encapsulating the scenario.

Simulations in Ansys® are made up from a variety of components such as the coordinate system, the connection groups, the mesh, the boundary conditions, and the solution information that pertains to the problem in question. For the results in the simulation to be accurate, these components must be detailed as to reflect the realistic scenario as best as possible.

2) Background and Goals

The industry project in question has the goal of investigating the effects of three different load levels on a coaxial beam eAxle assembly. This assembly has also been modified with the discovered findings to deliver three different variations of said assembly to account for the three load levels. These load levels will be referred to in pounds for clarity while referenced in this paper unless referring to inputs for Ansys®. The loads will then be applied in metric quantities at that time. The goal of these different load levels is to assist Schaeffler in understanding how the general assembly of the eAxle can be scaled up to fit a variety of production needs. The focus on the analysis of this eAxle would be centered on the bolted connection in the housing portion. The analysis of these models, taking place in Ansys®, occurs because of the difficultly in hand calculating the reactions within the assembly. Minimal calculations are applied to individual bolts but attempting to analyze the entire assembly by hand calculation would be unnecessary.

3) Verification and Validation Processes

3.1 Verification Process

The value of Ansys® results are only realized when the results are tested against hand calculations. These are hand calculations that are used to solve the same problem that is set up in Ansys® to confirm that results that are provided by the simulation are realistic and line up with expected results. In the case of this project, the hand calculations that would have been required to provide results for the full beam eAxle

were not achievable nor necessary given the provided scope. As a portion of the design project, the eAxle was stripped down to just a separate Solidworks® assembly, as shown in figure 3.1, of a bolted joint that was identical to the joint found in the eAxle. The primary difference is in loading with this separate assembly being loaded axially rather than in the eccentric loading of the eAxle. This was done to provide a greater reliability for the hand calculations.

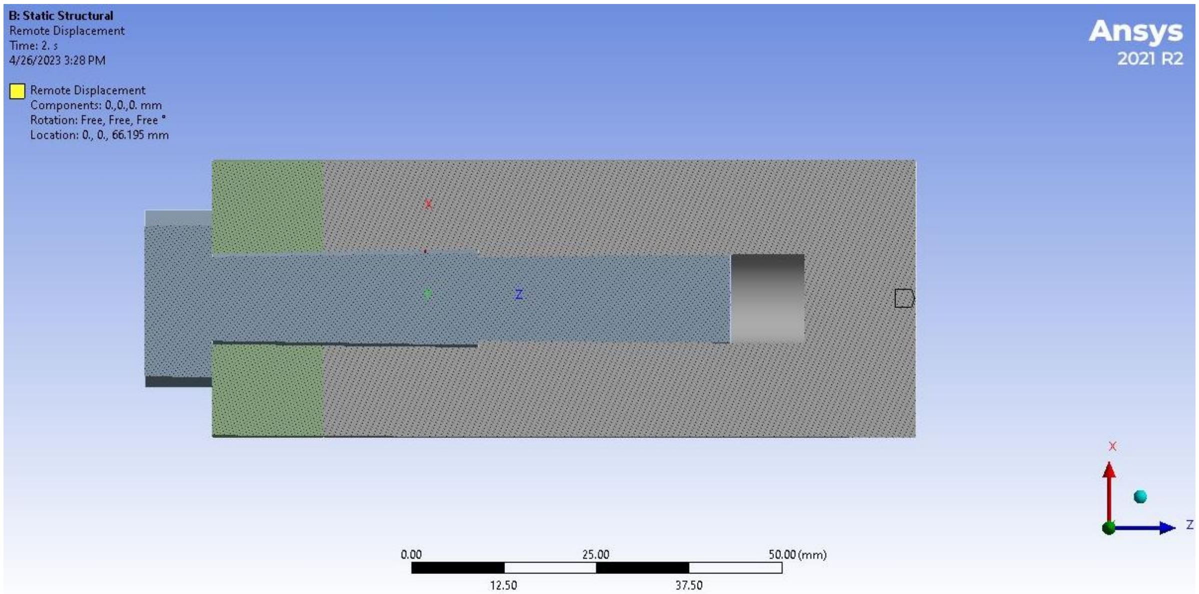


Figure 3.1: section view of the verification and validation assembly in Solidworks®

3.2 Validation Process

The evaluation criteria, as stated previously, was the value for the working load on the bolt. Normally the working load on the bolt could be calculated using the equation for the resultant bolt load:

$$F_b = \frac{K_b P}{K_b + K_m} + F_i = \frac{(3.91E8)(13464.225)}{(3.91E8) + (2.59E9)} + (71625) = 73392.61\ N$$

Where K_b equals the bolt stiffness, K_m equals the member stiffness, and F_i equals the preload on the bolt. Unfortunately, when using this calculation to determine F_b initially, there were large answer discrepancies between the hand calculations and Ansys®. Looking further into the equation and the bolt setup together, it was determined that K_b was being incorrectly calculated.

$$K_b = \frac{A_t A_d E}{A_d \ell_t + A_t \ell_d} = \frac{K_t K_d}{K_t + K_d}$$

Where A_t equals the tensile-stress area, A_d equals the area of the unthreaded portion of the bolt, E equals the modulus of Elasticity, ℓ_t equals the threaded length in grip, and ℓ_d equals the unthreaded length in grip.

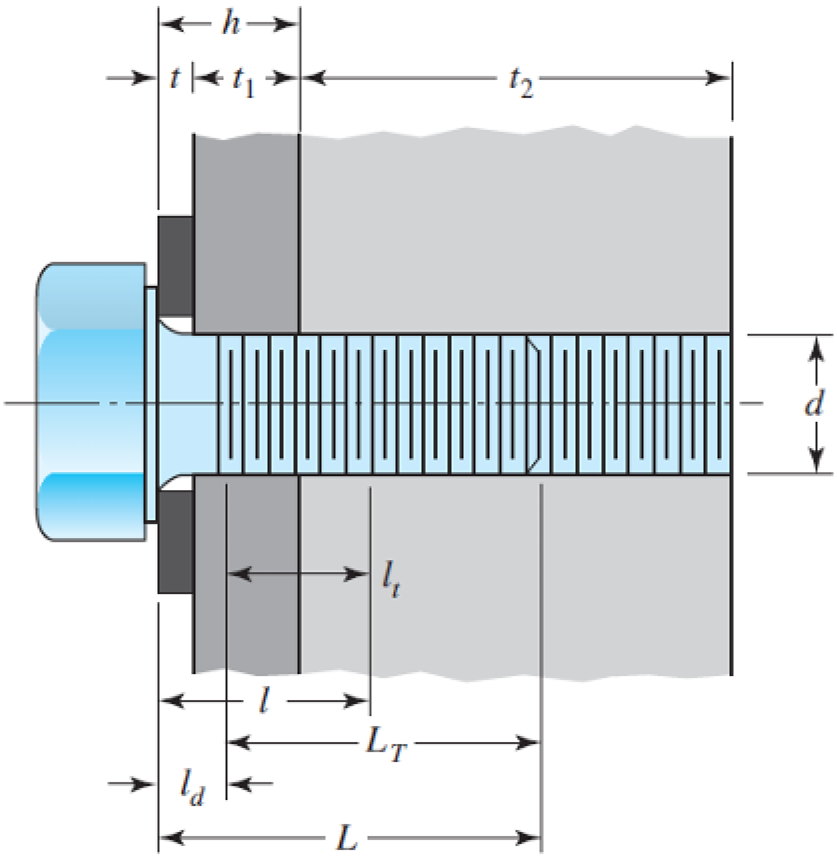


Figure 3.2: ideal diagram for bolt utilizing a tapped hole for clamping

Figure 3.2 shows that when calculating K_b normally with a tapped hole condition, it would be expected for the threading on the bolt to come into contact with both members. However, in the condition specified by Schaeffler, this was not the case. The result of this difference meant changing the equation K_b to look more like this:

$$K_b = \frac{A_t A_d E}{A_t(L - L_T) + A_d L_T} = \frac{K_t K_d}{K_t + K_d} = \frac{(115)(154)(207E6)}{(115)\big((70) - (34)\big) + (154)(34)} = 3.91E8\ N/mm$$

After making these changes to the calculations, the resultant load on the bolt is now only 20 N removed from the result displayed by the Ansys® simulation. The simulation was run using a remote displacement on the rear of the assembly, a remote force of 13,464 N applied to the front of the assembly, and a pretension load of 71,625

N applied to the shank of the bolt. The resulting force on the bolt is displayed in figure 3.3 as 73,372 N.

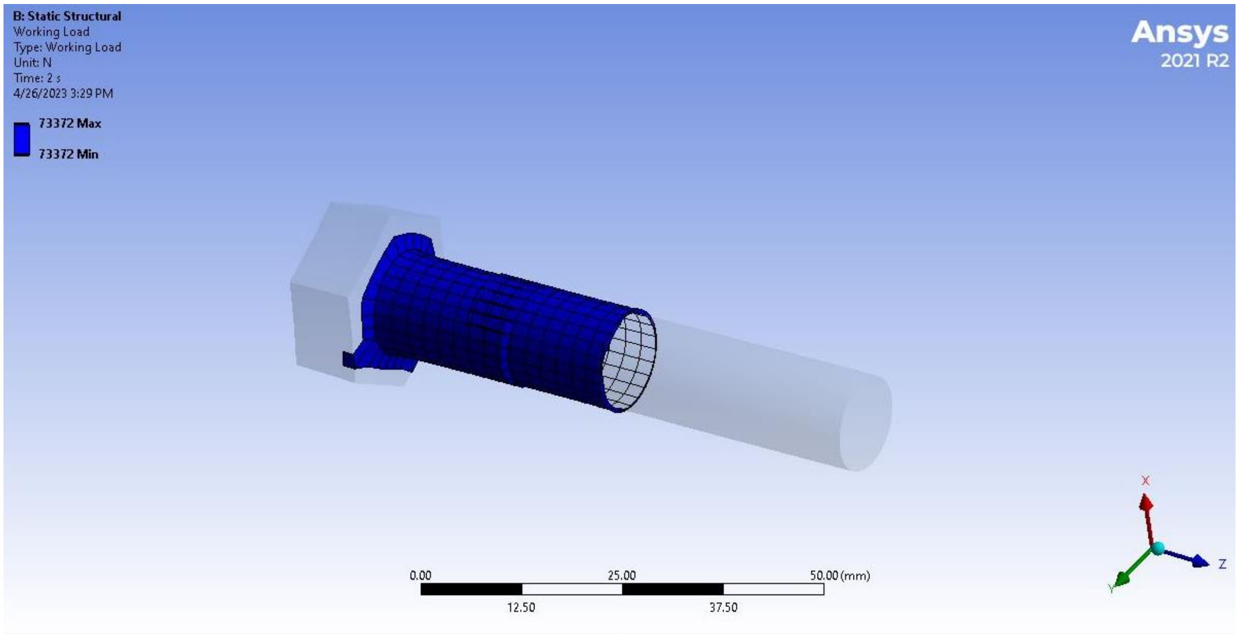


Figure 3.3: working load on bolt assembly

4) Procedure

Starting with the coordinate system, the triad that determines the location of everything else in the simulation is usually pulled from the CAD model. However, there is occasionally the need to manually position this triad to better suit the simulation. When selecting the location of the coordinate system for these simulations, the tube and spindle bodies were selected to provide the most centered location for the triad.

The connections groups are what determine how the bodies within the assembly will interact with each other. When the model geometry is initially linked with the mode of analysis, Ansys® will pull in automatic connections where bodies fall within a certain threshold of each other. This is not always ideal as there might be too many faces interacting with each other or not enough so manual contact regions can be put in place. Additionally, the style of connection can be modified to emulate different interactions such as a frictional connection that would allow movement with specific resistances or a bonded connection that would allow no movement at all. In the case of this model, all connections were bonded with the exception of two regions. These regions are where the GBH flange and the EMH flange come into contact, and where the bottom face of each bolt head comes into contact with the GBH flange.

These regions were specified as frictional contacts to allow for an accurate assessment of the model. If there is undesired movement at these locations, then there would be changes made to the forces at those locations. Additionally, a frictional coefficient may be applied to those frictional contacts and in this case Schaeffler dictated that to be a value of 0.15. A layout of the frictional contact interface may be seen in figure 4.1.

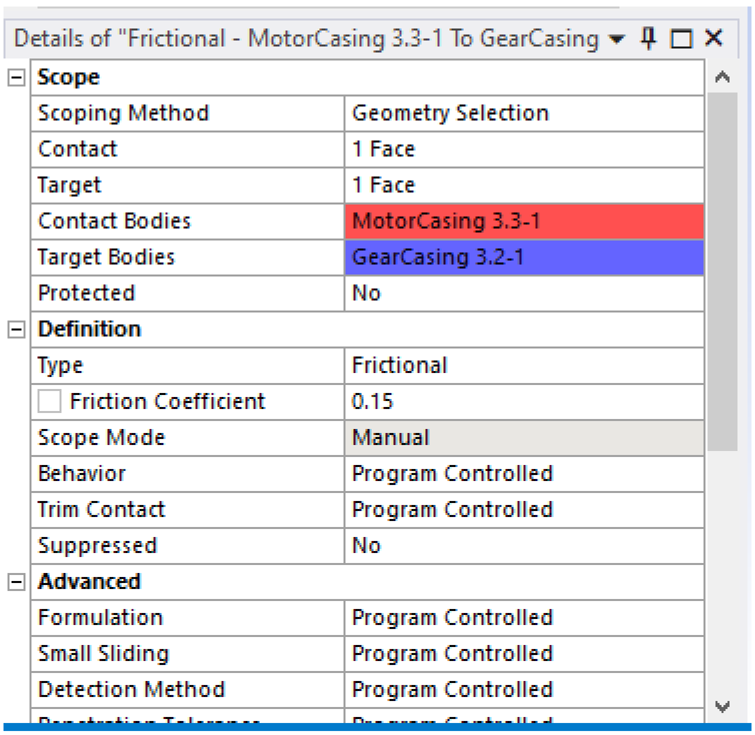


Figure 4.1: frictional contact layout

The next stage in the setup process involves the meshing of the geometry for calculation purposes. The mesh is made up of a series of nodes that lay out over the surface of the model and serve as points for specified loads to be applied. Additionally, nodes may serve as points of constraint for boundary conditions that are laid out for the model. The relations between groups of nodes are referred to as elements and often take the form of square or triangular shapes. The mesh as a whole can be edited to the user's design whether that be concentrating the mesh in a certain location by increasing the mesh density or by ensuring the distribution of nodes is as even as possible across the model. Various functions may be applied to fully customize and refine the mesh but only two were utilized in this project due to time constraints. These include the method function and the sizing function. The method function serves to determine how the elements of a mesh are generated and how the nodes are arranged as a result. This process is done automatically by default. However, in most circumstances this is not the

most efficient. In this project the hex dominant method and the multizone method were both used. The sizing function controls the maximum allowable element size in a mesh and can frequently be used in conjunction with the method function to allow for the mesh to generate properly. This could be due to irregularly shaped geometry that could otherwise be difficult to mesh. Additionally, the sizing function can be used to help calculate a more accurate representation of a body. In this project, a sizing function was used to stipulate a distance of 2 mm on each of the bolts due to the bolts being a primary concern of this project. A sizing function was also utilized to ensure a node size no larger than 8 mm on the spring perches and 10 mm of the remainder of the model to allow the model to mesh properly. The resulting mesh for the final version of the 3000lb load level can be seen in figure 4.2.

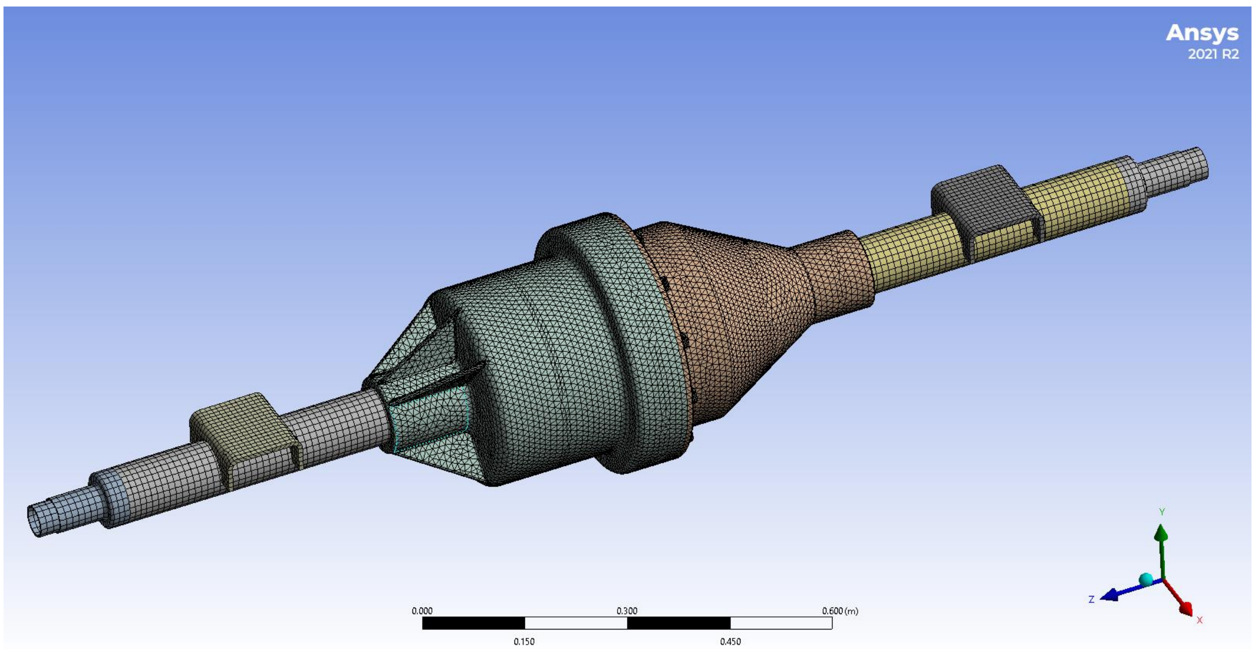


Figure 4.2: Version 3.3 mesh

The loads and boundary conditions that are applied to the geometry can be considered the variables in the Ansys® simulation. They represent interactions between the geometry and the scenario that is being designed. In the case of this project, the functions of remote displacement, remote force, and pretension were utilized. Additionally, the sequence of these functions can be controlled in the analysis settings. In the case of this model, two steps take place with the pretension and remote displacements being applied first while the remote forces are applied second.

Remote displacement allows the user to select portions of a body and control its location directly in relation to whichever coordinate system is chosen. It also allows for control of the reaction to external forces acting on the geometry. In this project, two

remote displacements were inserted, and each referenced one face of each of the two spindles in the model as shown in figure 4.3. Using the details tab, each remote displacement was set to 0 movement in the x, y, and z axes as well as 0 degrees of rotation about the z axis. This can be seen in figure 4.4.

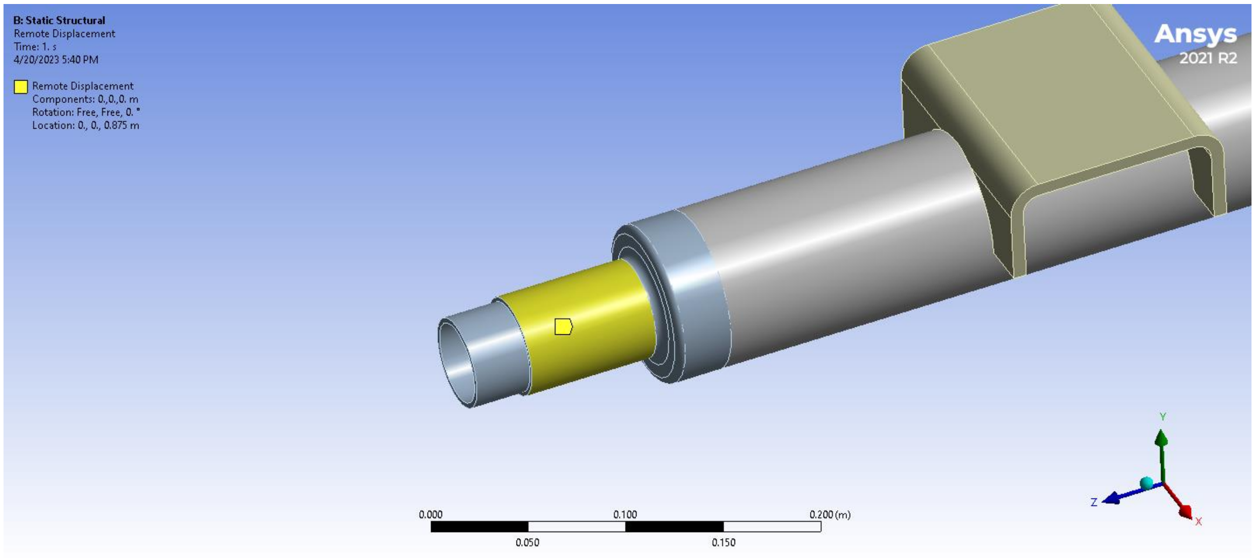


Figure 4.3: Yellow face indicating location of remote force

Details of "Remote Displacement"

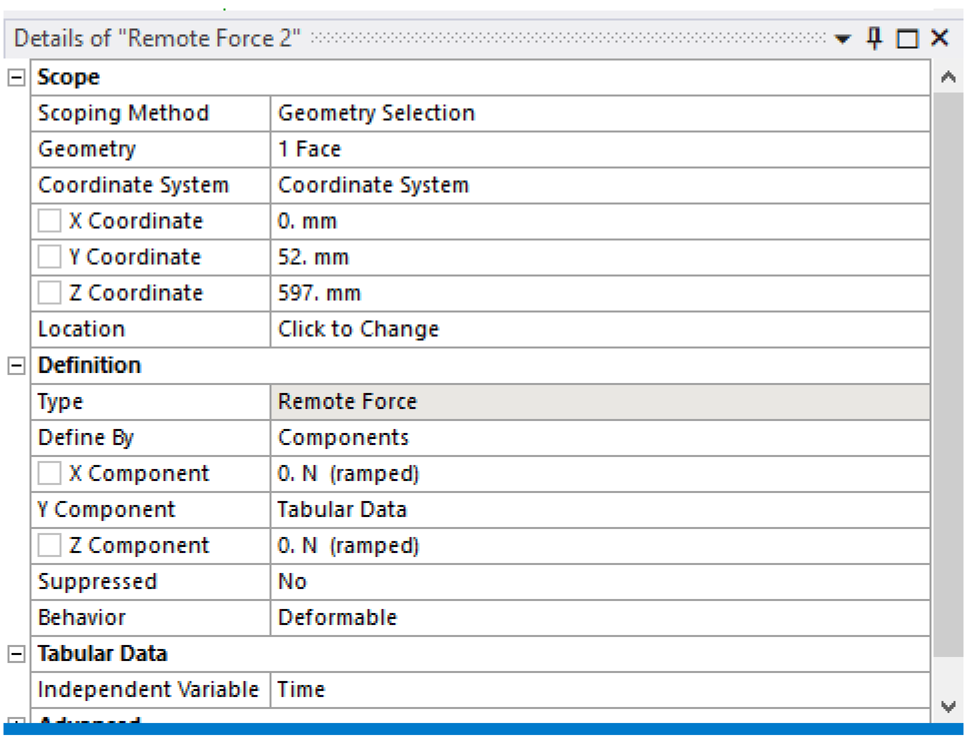
Scoping Method	Geometry Selection
Geometry	1 Face
Coordinate System	Coordinate System
X Coordinate	0. m
Y Coordinate	0. m
Z Coordinate	0.875 m
Location	Click to Change
Definition	
Type	Remote Displacement
X Component	0. m (ramped)
Y Component	0. m (ramped)
Z Component	0. m (ramped)
Rotation X	Free
Rotation Y	Free
Rotation Z	0. ° (ramped)
Suppressed	No
Behavior	Deformable
Advanced	

Figure 4.4: details window of the above remote displacement

Remote forces function similarly to Remote displacements in the way that they are applied to the geometry. A location is selected on a given body as a geometry

reference and then coordinate location can be controlled in relation to a coordinate system. The coordinate system must be selected first if the numerical coordinates are not known. The components of the forces are then determined as seen in figure 4.5. Two of the three remote forces in this model are located on spring perches with one for each top face as seen in figure 4.6. These forces are then located to 0 on the x axis. The forces are applied with loads calculated from the below equation, where GAWR equals the Gross Axle Weight Rating, the wheel end mass equals the expected mass of the wheel, the unsprung mass equals the expected mass of the assembly, 3 equals the safety factor, and g equals gravity. The loading is then inserted tabularly and this is done to hold better control over which time step these forces are applied in during the simulation. This can be seen in figure 4.7.

$$\frac{\left((GAWR\ -\ wheel\, end\, mass\ -\ unsprung\, mass)\cdot 3g\right)}{2}$$



Details of "Remote Force 2"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Coordinate System	Coordinate System
X Coordinate	0. mm
Y Coordinate	52. mm
Z Coordinate	597. mm
Location	Click to Change
Definition	
Type	Remote Force
Define By	Components
X Component	0. N (ramped)
Y Component	Tabular Data
Z Component	0. N (ramped)
Suppressed	No
Behavior	Deformable
Tabular Data	
Independent Variable	Time

Figure 4.5: detail pane of remote force 2

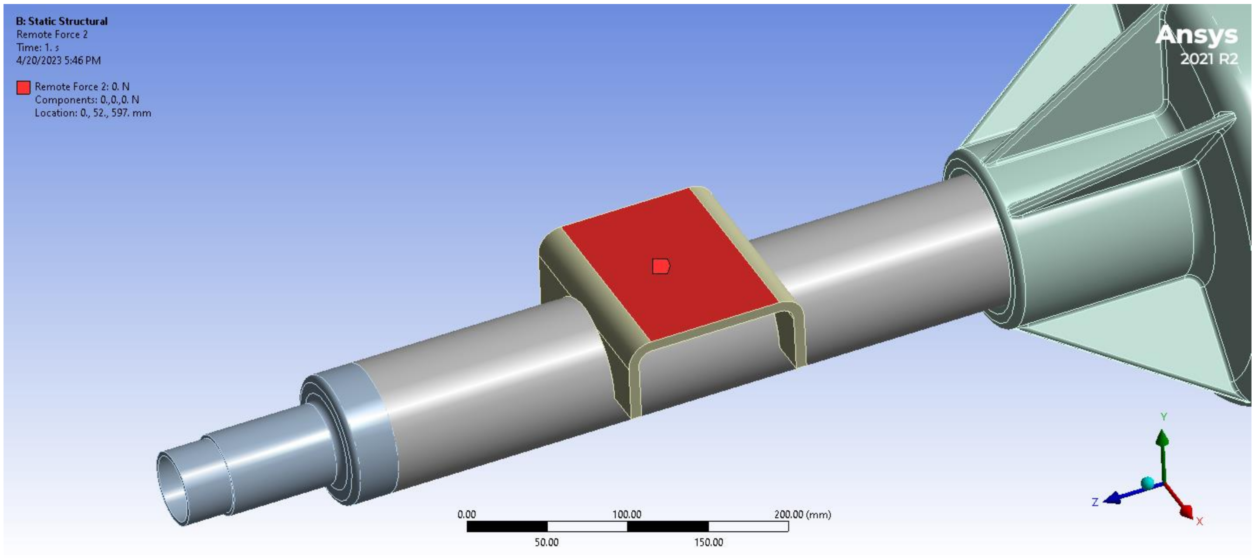


Figure 4.6: geometry selection for remote force 2

Tabular Data

	Steps	Time [s]	X [N]	Y [N]	Z [N]
1	1	0.	= 0.	0.	= 0.
2	1	1.	0.	0.	0.
3	2	2.	= 0.	-13464	= 0.
*					

Figure 4.7: tabular data reflecting forces for remote forces 2 and 3

The third remote force is applied in a similar manner but utilizes multiple faces in the inside of the model to place the force at 0, 0, 0. The force component is again applied tabularly with a static value of -5886 N applied in the negative Y direction as dictated by Schaeffler and calculated in the equation below. The setup for this remote force can be seen in figure 4.8.

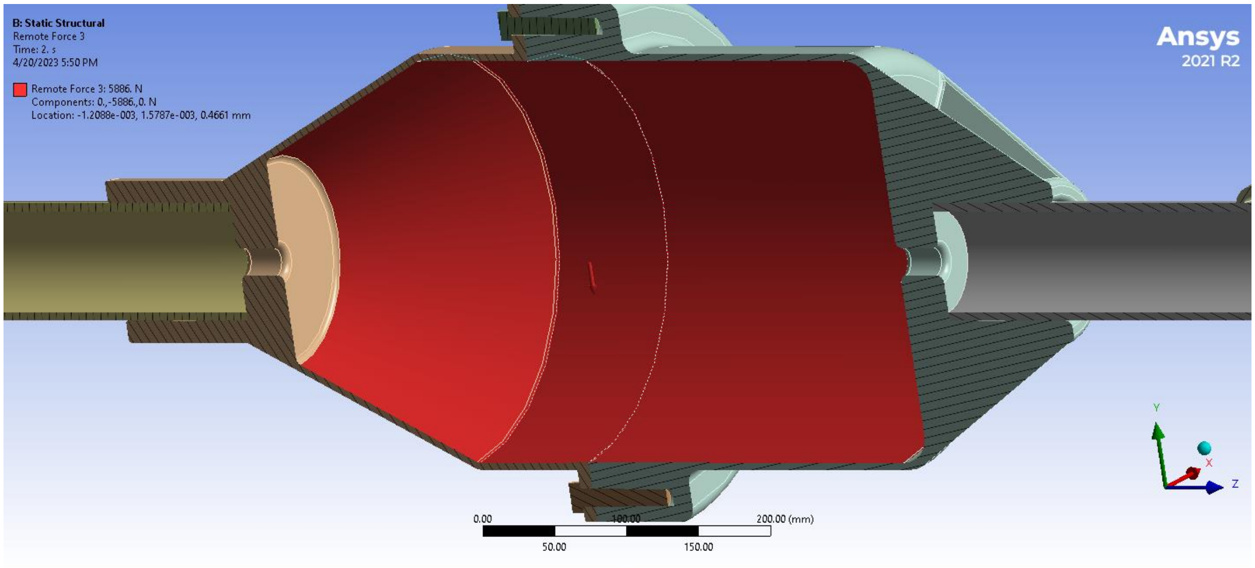


Figure 4.8: geometry selection for remote force 3

Lastly, pretension is a function that allows for the simulation of a pretension being applied to a bolt and a preload being applied to the assembly. The purpose of this preload is to reduce the forces on acting on the members and to allow the bolt or bolts to bear more of the load. It should be applied to the portion of the bolt that is unthreaded to represent the portion of the bolt that is under load directly. This can be done by breaking up the face, that is the shank of the bolt within the CAD modeling software.

As described in section 3, the setup of a separate Ansys® simulation has shown that the resulting working load of the bolt is inaccurate when the bolt has a pretension applied in addition to a bonded contact. In the context of this project, the pretension function was applied to all 12 bolts with a preload of 71,625 N and can be seen in figure 4.9. This number represents 75% of the proof load of M14 x 2 ISO 10.9 hex head bolts or the recommended preload. A depiction of the working load on a set of preloaded bolts can be found in figure 4.10. The important features in this figure are the working load color gradient on each of the bolts and the orientation of this gradient in relation to a positive Y axis. These details were used to make decisions about new iterations of the model. This helped to ensure that a stable model was developed.

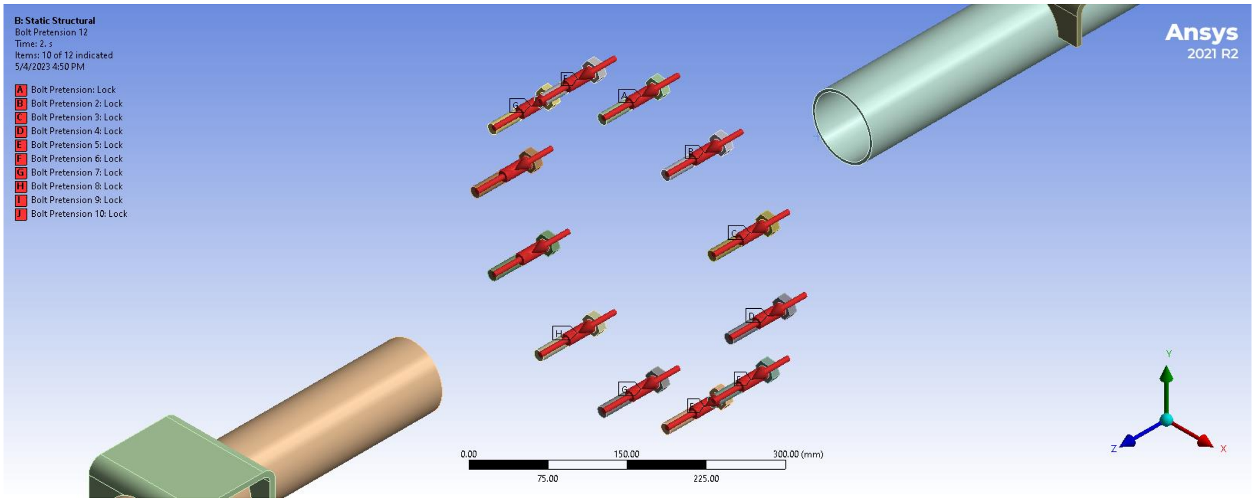


Figure 4.9: selected geometry for bolt pretension tool

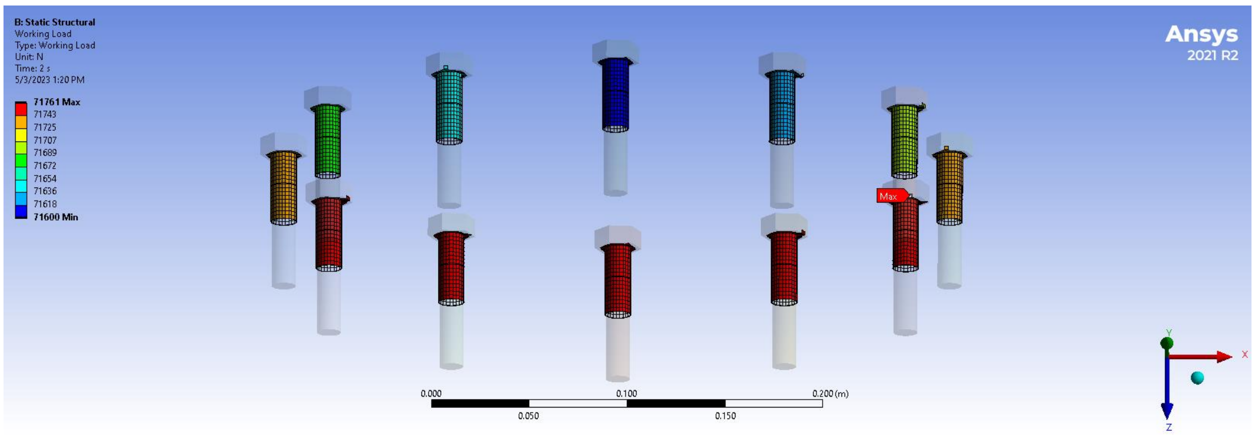
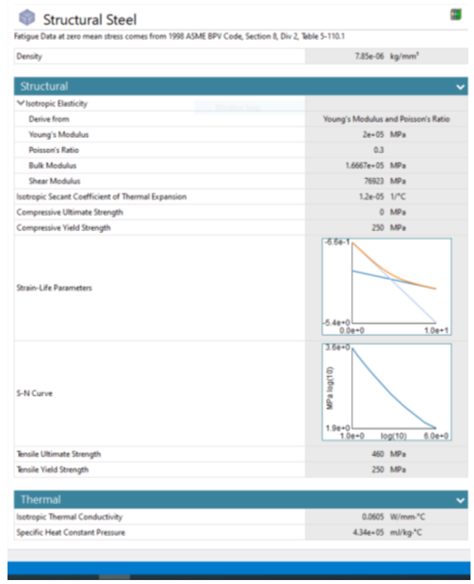


Figure 4.10: working load on bolt plot for Version 3.3

5) Iterations

The initial design was based off the requirements put forth by Schaeffler. This version 1.0 served as a base point from which to iterate on. The 3000 lb load level was chosen as the load condition for the purpose of understanding what would happen to the model at the base level. This design was composed of replications of Schaeffler's requirements for parts. Additionally, the flange was a solid piece where the GBH and EMH would come together and controlled with a bonded contact. This can be seen in figure 5.2 and figure 5.3. All components were run in this simulation as though they were all the default structural steel provided by Ansys® and a view of the material chart can be seen in figure 5.1 at right.



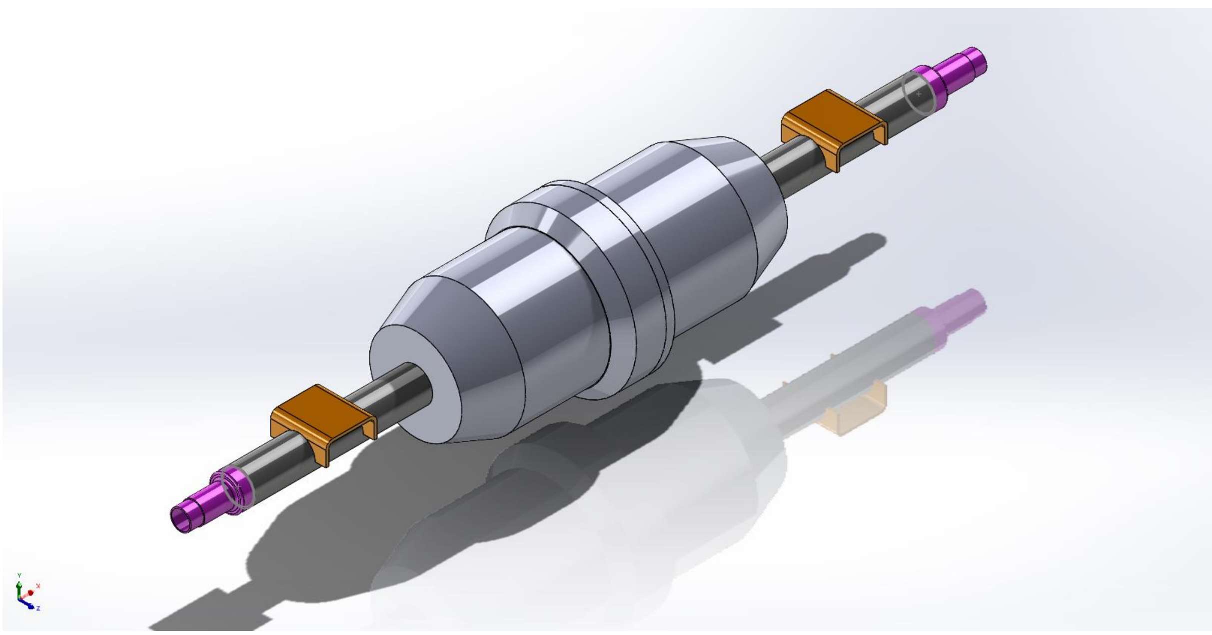


Figure 5.2: isometric view of Version 1.0

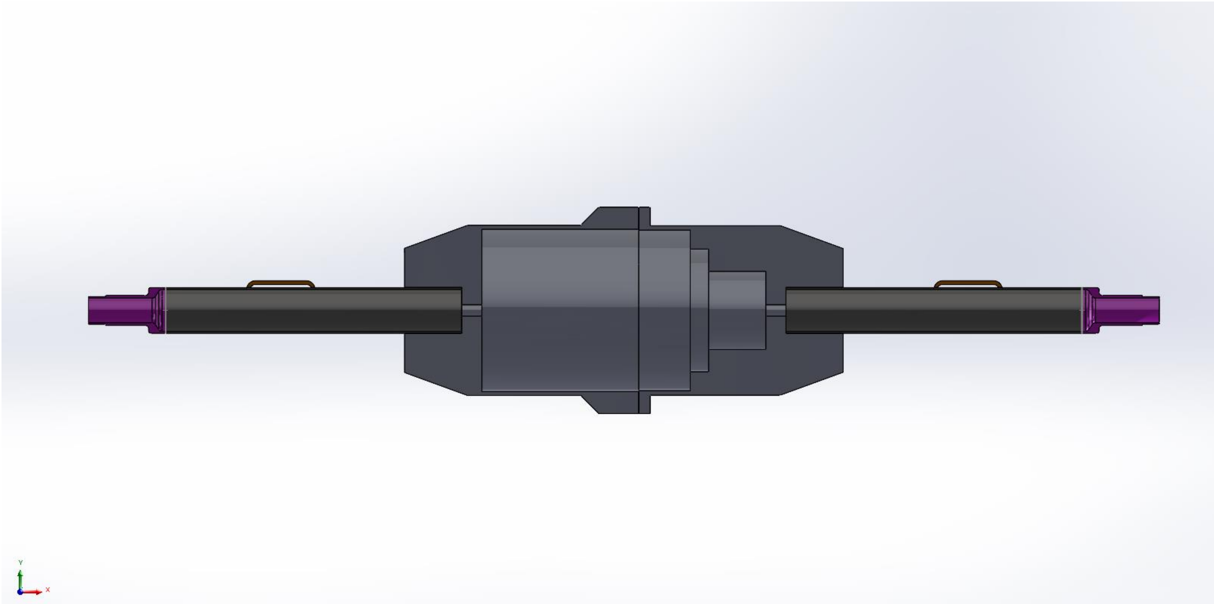


Figure 5.3: section view of Version 1.0

5.1: Version 2.0

The first fully designed concept resulted in version 2.0 as pictured below in figures 5.4 and 5.5. The design included a cut-out flange that the team assumed could be done to reduce weight, a trimming of the casing material that surrounded the EMH and GBH to again reduce weigh as well as make the shape more practical for casting operations, and an enclosed thread idea around the location of the bolts.

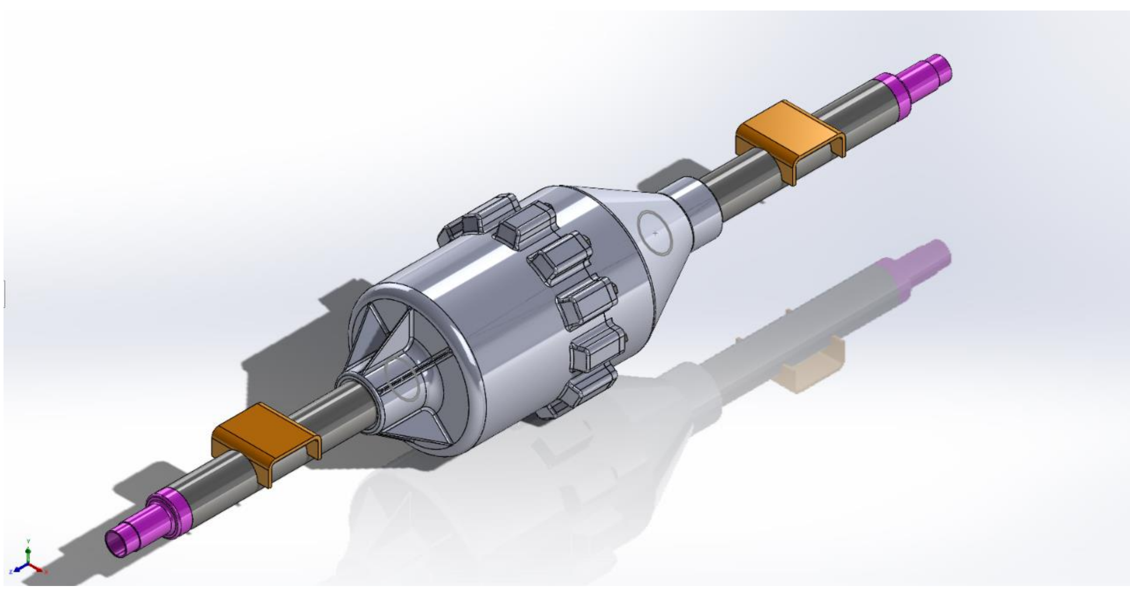


Figure 5.4: Isometric view of Version 2.0

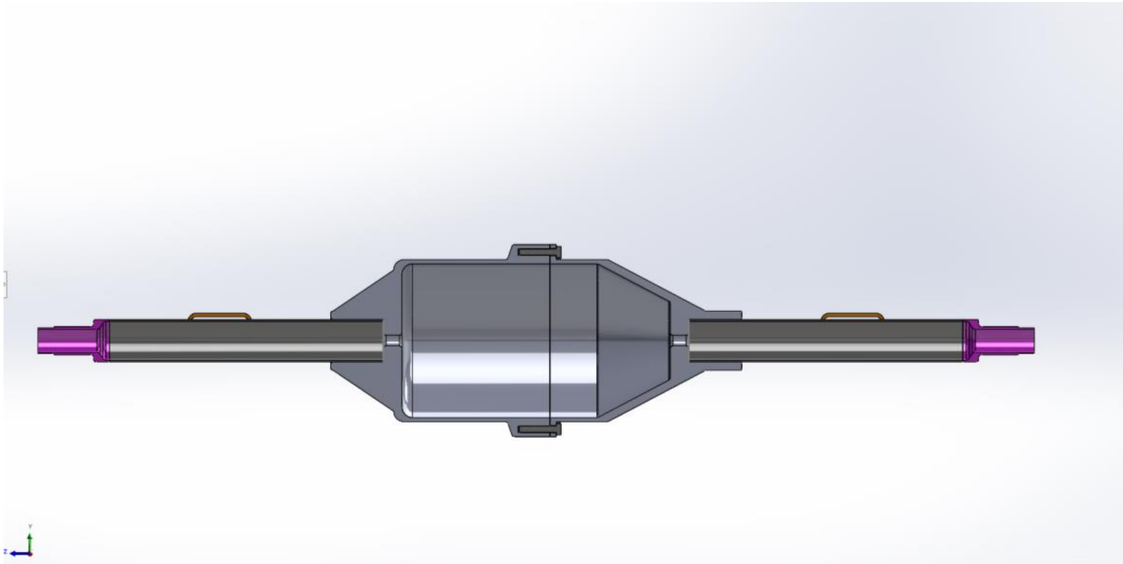


Figure 5.5: section view of Version 2.0

5.2: Version 3.0

The next major changes were to decrease the thickness of the housing to 8mm case thickness, and a 16mm thickness around where the tubes are. This was done because the initial models, version 1.0 - 2.0 were not designed with a casting process in mind. This production process had been suggested by Schaeffler and this was the design change for this iteration. Additionally, fillets were utilized to smooth out sharp edges in an effort to reduce any stress concentrations in the design. This choice was made preemptively as no stress concentrations had appeared yet but could be expected given that the load level would triple by the end of design. An isometric display of this version can be seen below in figure 5.6 and a section view can be seen in figure 5.7.

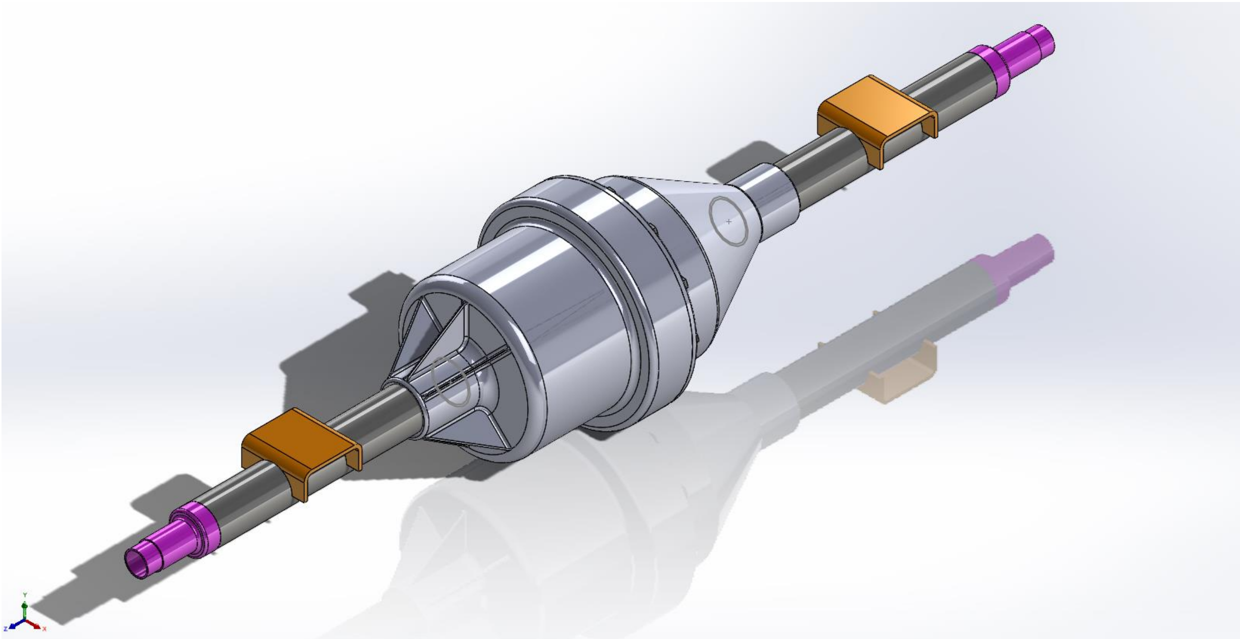


Figure 5.6: Isometric Version 3.0

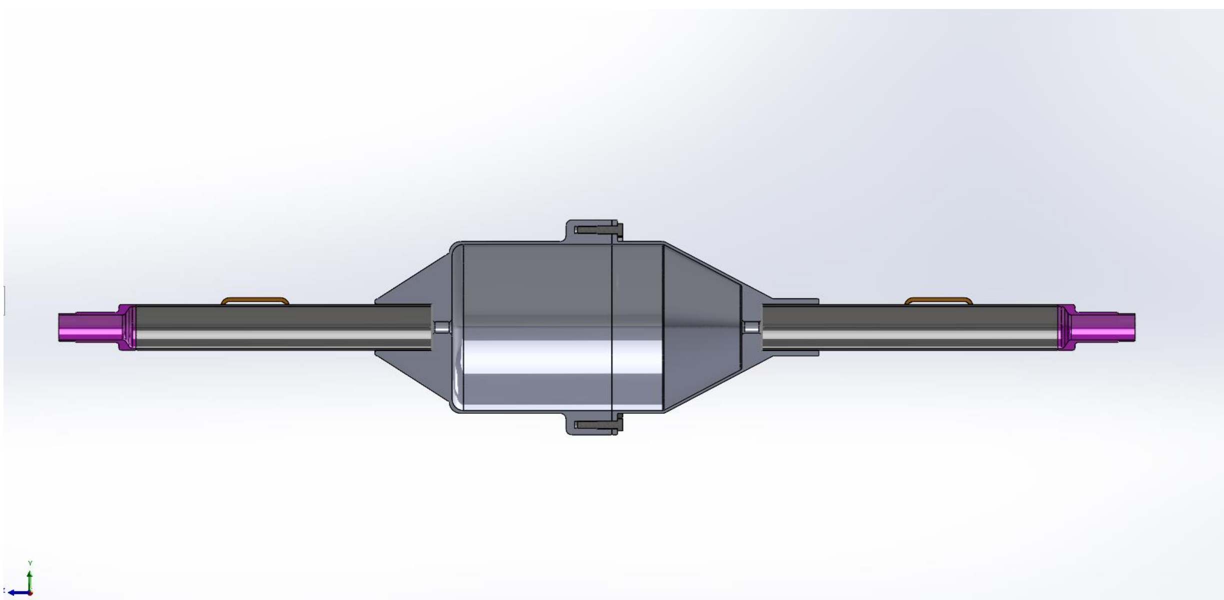


Figure 5.7: section view of Version 3.0

5.3: Version 3.3

As a result of time constraints, the team was unable to further iterate past this version and there are still several issues that should be addressed. These issues are discussed in the results section of this paper. This was the final version of the 3000 lb load level that was designed before scaling the model to support the greater load levels. Research into the casting manufacturing process, as well as recommendations from

Schaeffler, revealed that castings work best with walls closer to a 5mm thickness. These findings were taken into consideration and the thickness of the casing was reduced where possible. Ribbing was then added to make up for the thinner case. Additionally, in response to high stresses and deflection within the FEA, the tube was reinforced by increasing the thickness and diameter. An isometric view of this model can be seen in figure 5.8 and a section view of this model can be seen in figure 5.9.

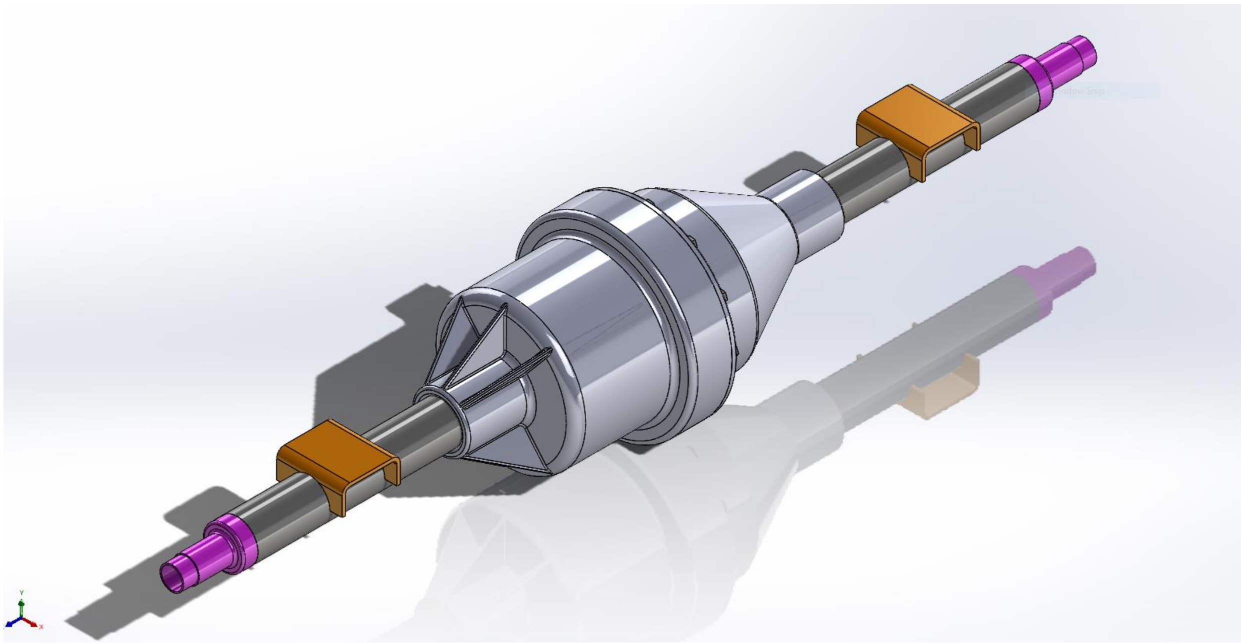


Figure 5.8: isometric view of Version 3.3

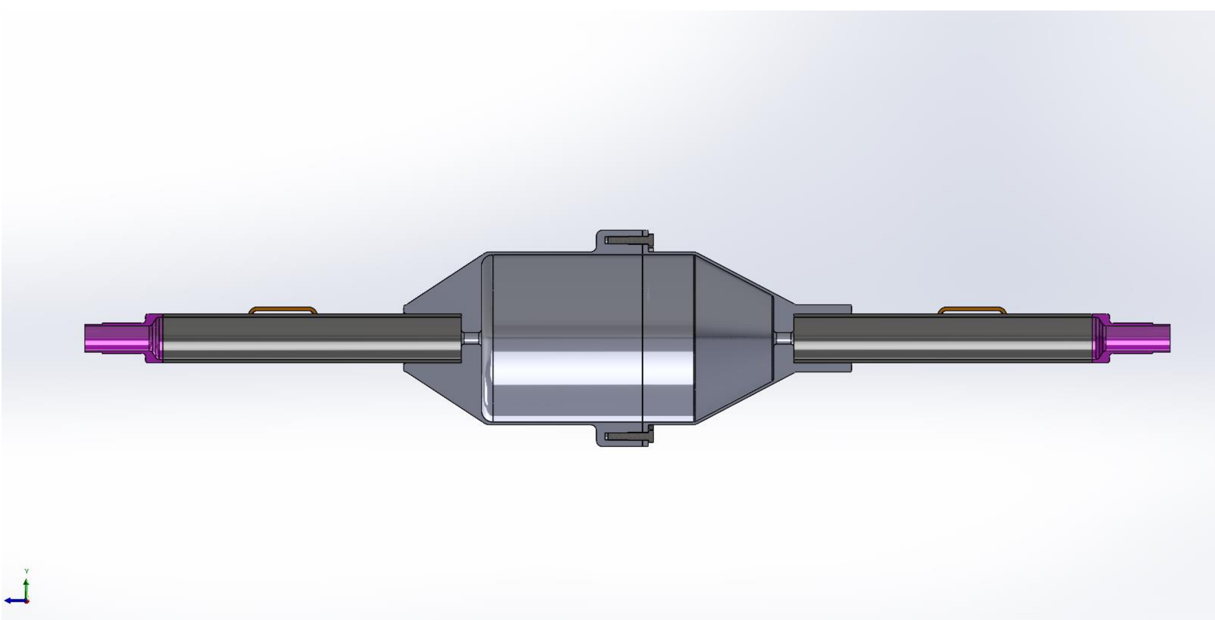


Figure 5.9: section view of Version 3.3

5.4: Version 4.0

Once the 3000lb loading condition passed testing, it was time to move on to the 7500lb loading condition. The changes made for these new loading conditions included thicker ribbing on the motor casing, as well as axle tubes with larger outer diameters, as well as larger corresponding inner diameters. These changes are discussed further in the attached paper. This version was changed to be made out of ductile iron grade 80-55-06 rather than the original aluminum alloy. This was done to keep many of the same features, while also increasing the strength of the housing. Images of the isometric view of this version as well as the section view can be found in figures 5.10 and 5.11 respectively.

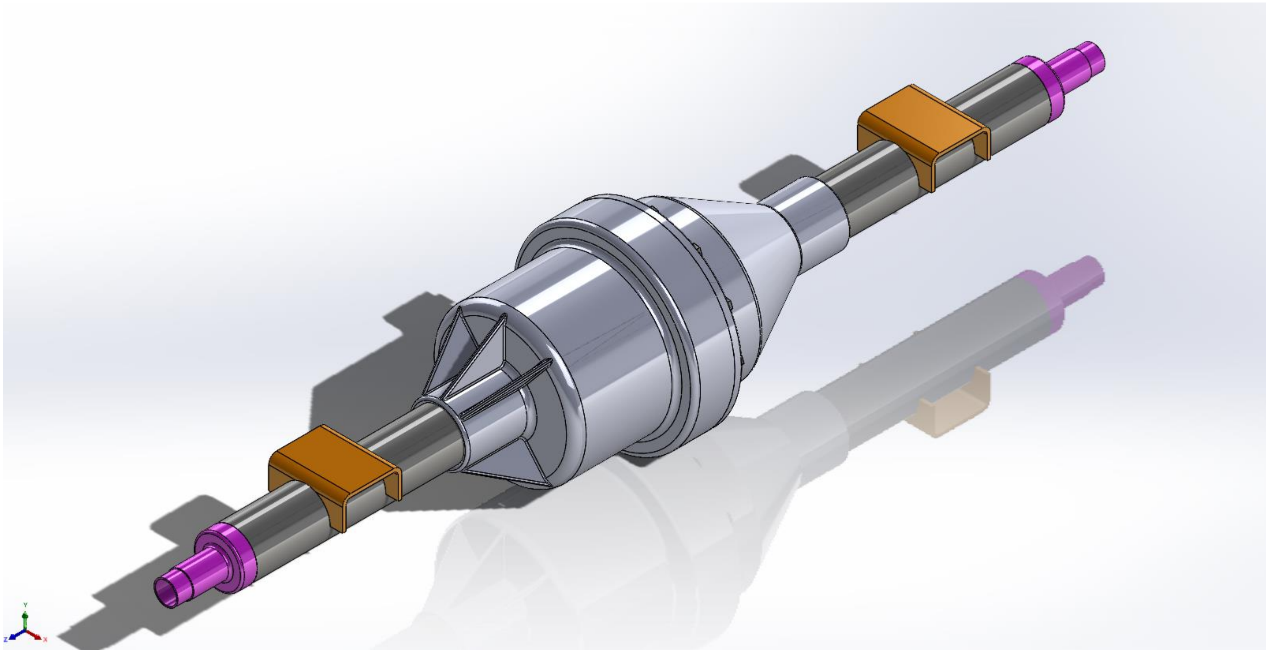


Figure 5.10: isometric view of Version 4.0

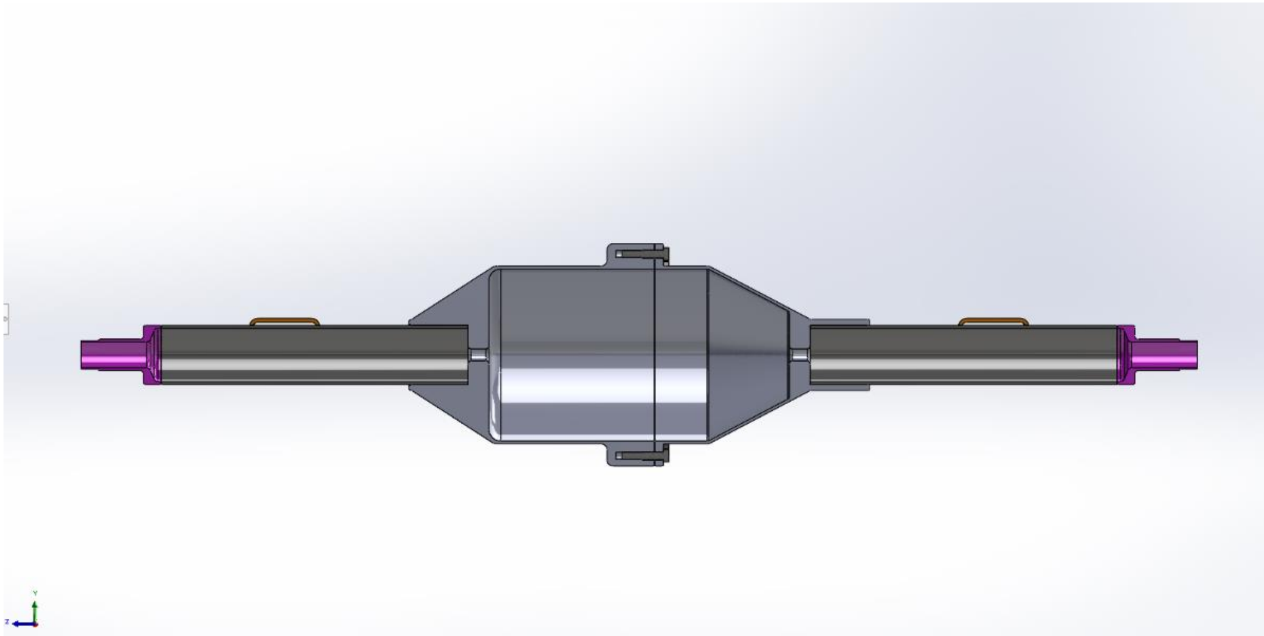


Figure 5.11: section view of Version 4.0

5.5: Version 5.0

The model utilizing the 10,000 lb load level had two specific changes applied. These changes were the utilization of the ductile cast iron grade 100-70-03 as the material for the GBH and EMH components, and the enlarging of the tubing diameters which in turn changed measurements in all other parts except the bolts. The choice of using the ductile cast iron grade 100-70-03 was discussed in the attached appendix. Additionally, the tube diameter was changed using the same equation the previous models utilized and to keep with Schaeffler's limitations, brought to a 115mm outer diameter and a 103.5mm inner diameter. All affected parts were adjusted accordingly. An isometric image of the model as well as a section view of the model can be found in figures 5.12 and 5.13 respectively.

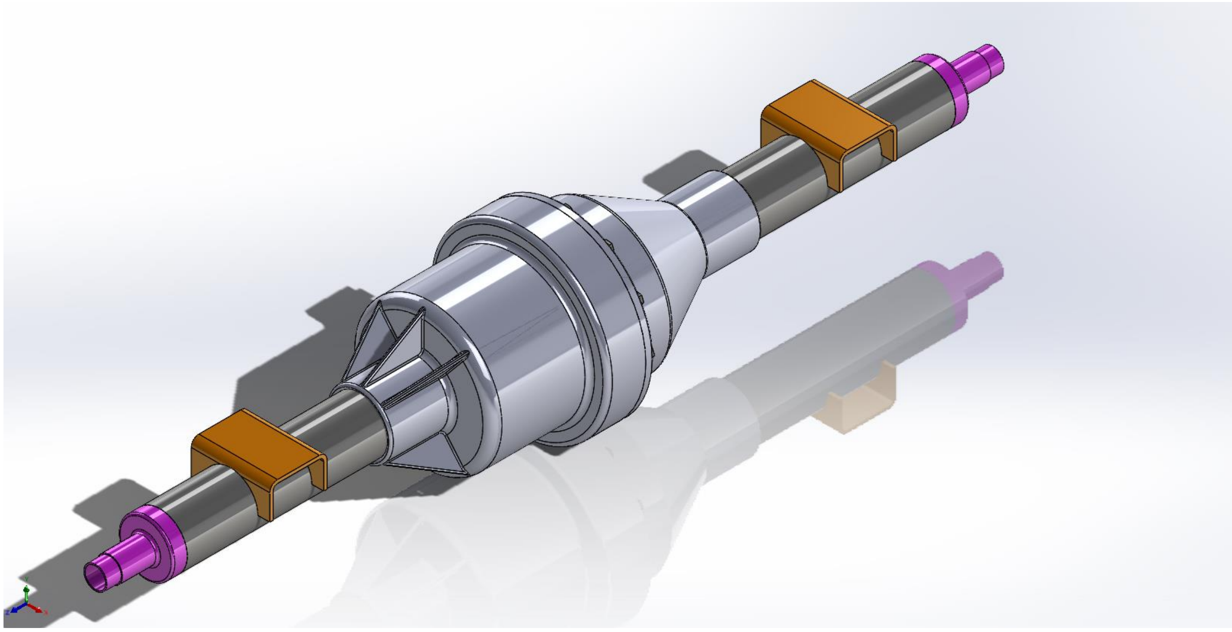


Figure 5.12: isometric view of Version 5.0

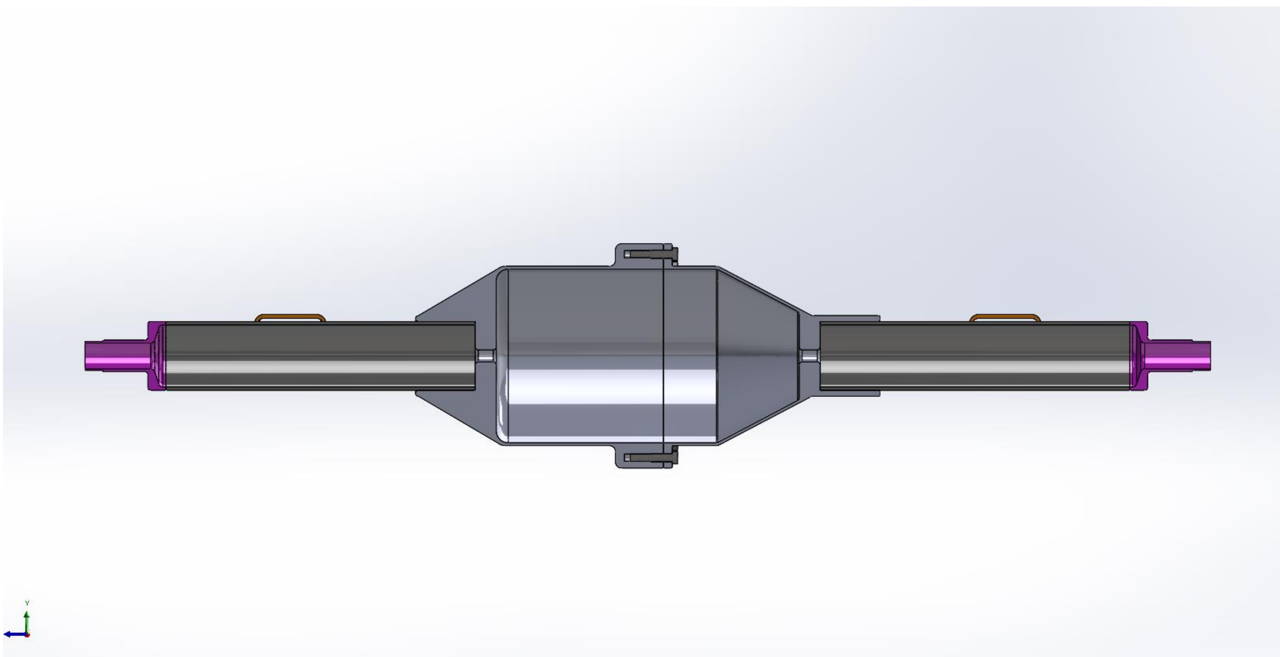


Figure 5.13: section view of Version 5.0

6) Results

6.1 Benchmark Values

The values that were checked most frequently were the values associated with the working load present in the bolts. This result from Ansys® was particularly helpful in

determining if the simulation was running correctly as it displays the resulting force taken by the bolts over the entire assembly. Different changes such as a working load pattern that did not turn out symmetrical, or forces that added up to a value greater than the sum of the forces in the assembly were signals that something was out of place. Over the course of the process the working load in the bolts transitioned from what is shown in figure 6.1 to what is shown in figure 6.3. The decrease in the range of values as well as the decrease in magnitude are both changes that were helped by reviewing the Ansys® simulations from each of the previous versions.

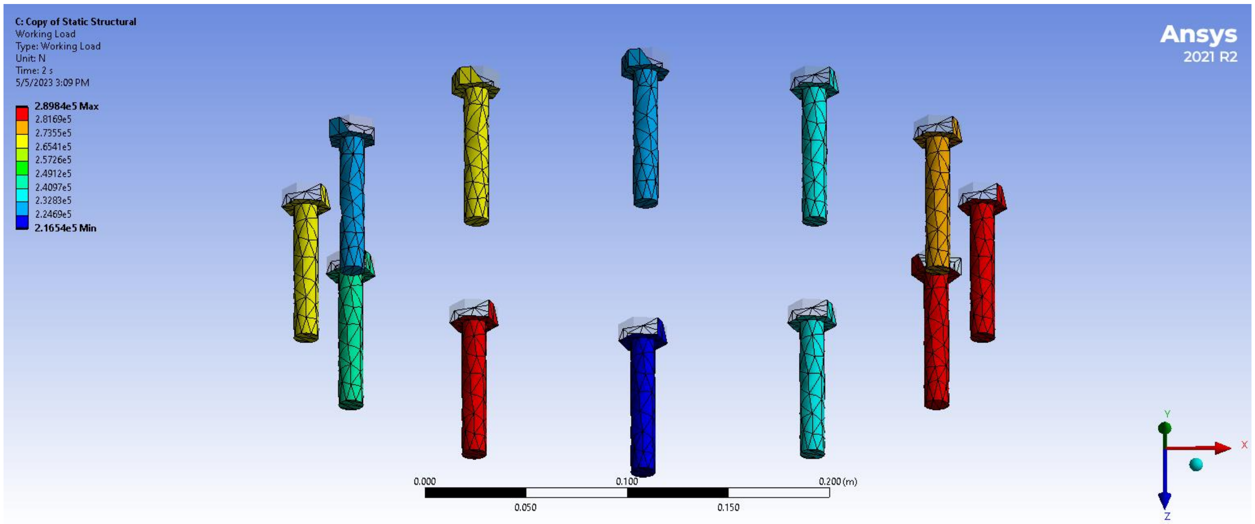


Figure 6.1: Version 2.0 working load

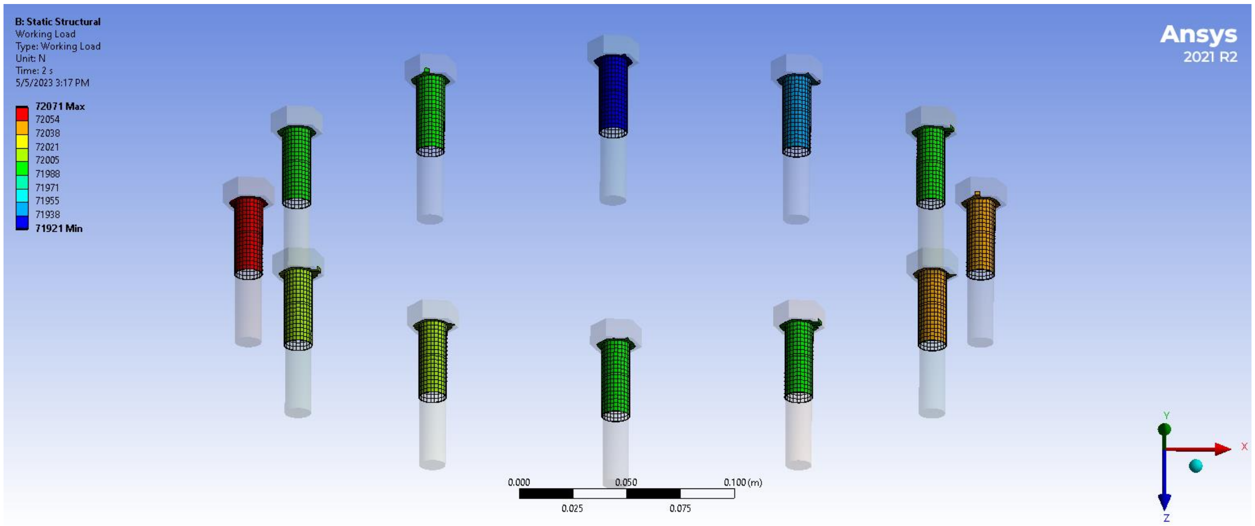


Figure 6.2: Version 3.0 working load

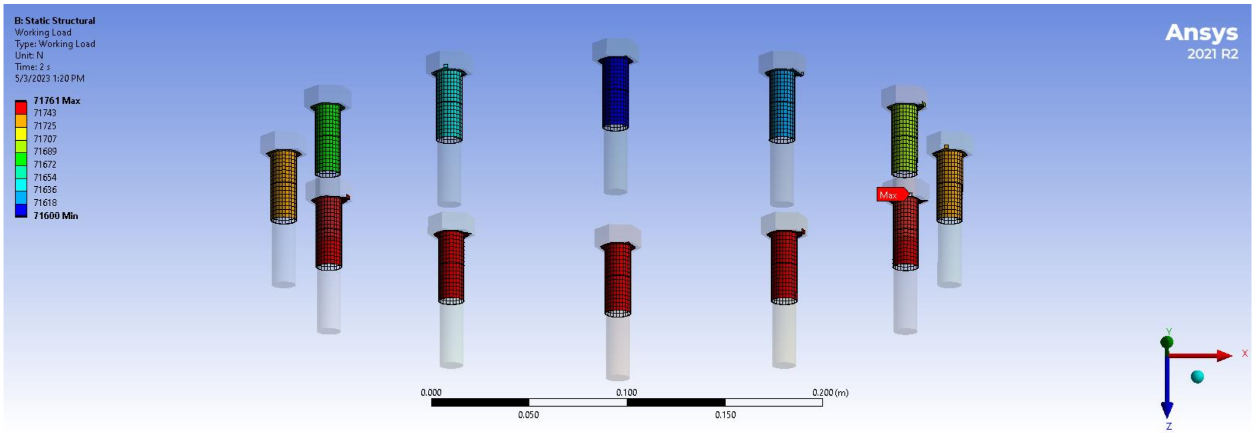


Figure 6.3: Version 3.3 working load

6.2 Future Changes

Unfortunately, not every change made it into the final designs due to the given time constraints. Given more time, changes to the support structure around the housings, adaptations to the axle tube diameters, and a shrinking of the bolts would have been applied for consideration. Starting with the support structure, the final versions 3.3, 4.0, and 5.0 all had similar issues where the structure of the housing was exceeding the yield strength of selected materials in locations such as the ribbing located on the EMH and the connections around the bolts. Due to these areas exceeding the yield strength of the selected material, it is possible that these models might be seen as unreliable given the linear nature of the materials utilized. Figures of these locations are pictured in figures 6.4 through 6.9 below.

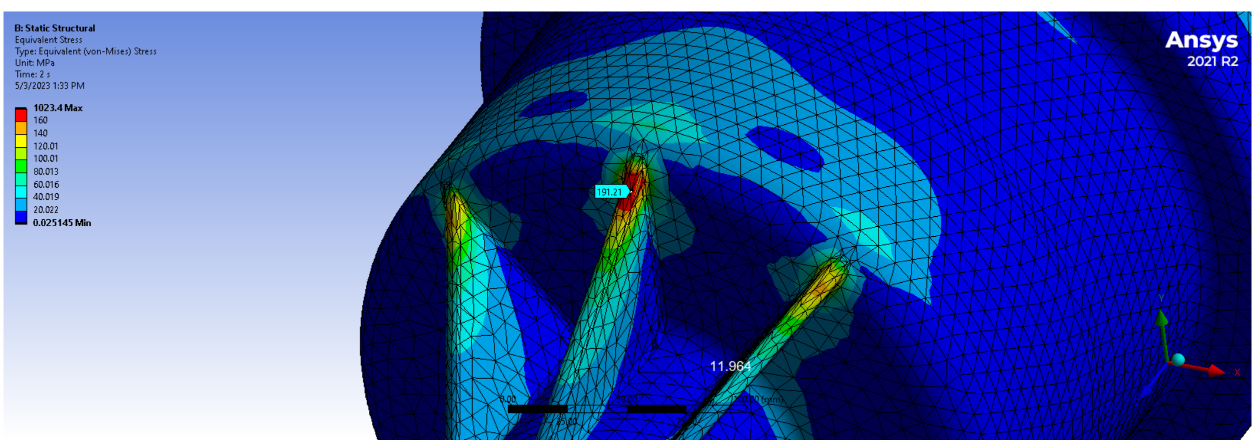


Figure 6.4: Version 3.3 ribbing exceeding 160 MPa

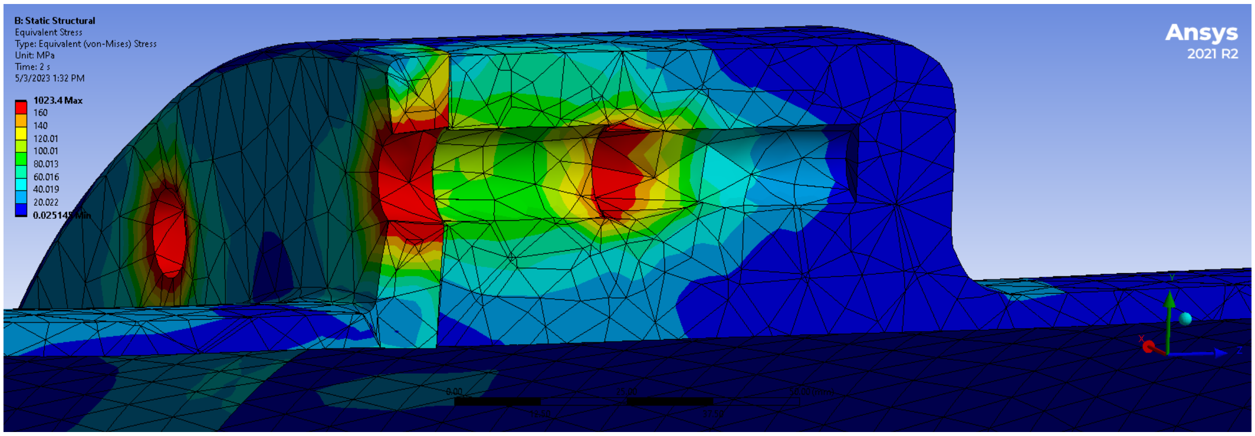


Figure 6.5: Version 3.3 bolted connection exceeding 160 MPa

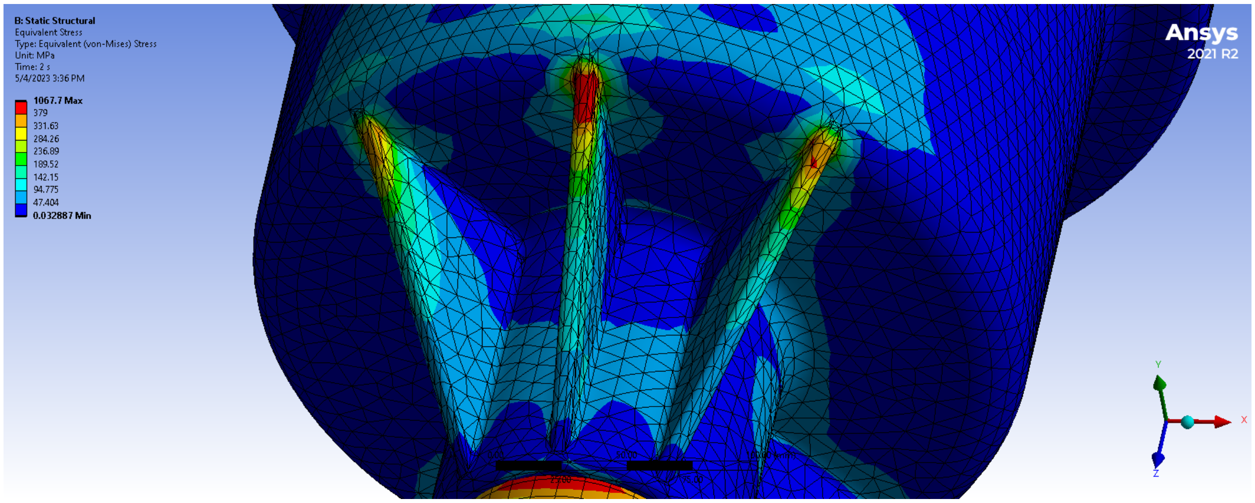


Figure 6.6: Version 4.0 ribbing exceeding 379 MPa

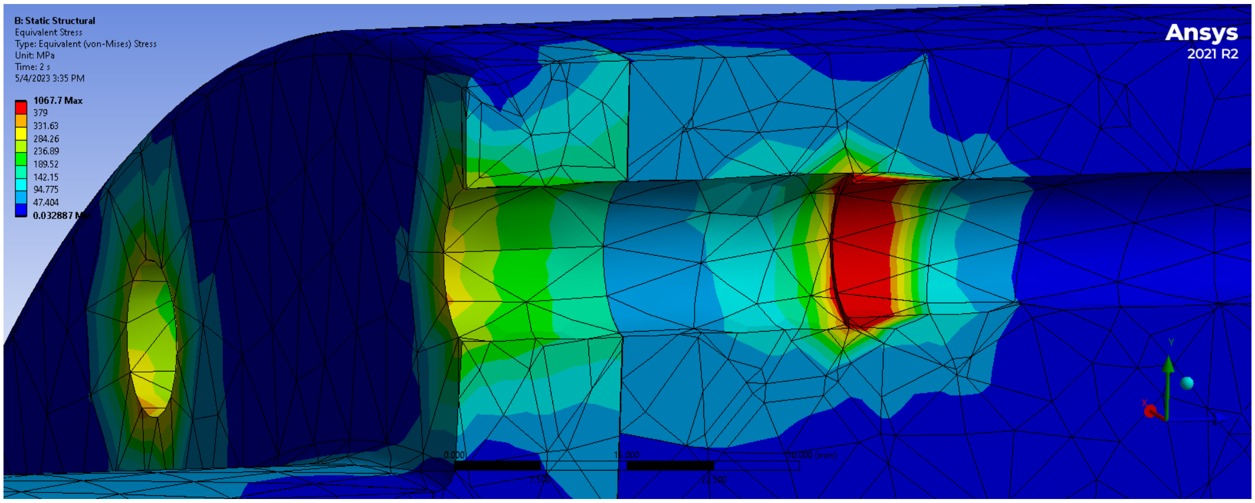


Figure 6.7: Version 4.0 bolted connection exceeding 379 MPa

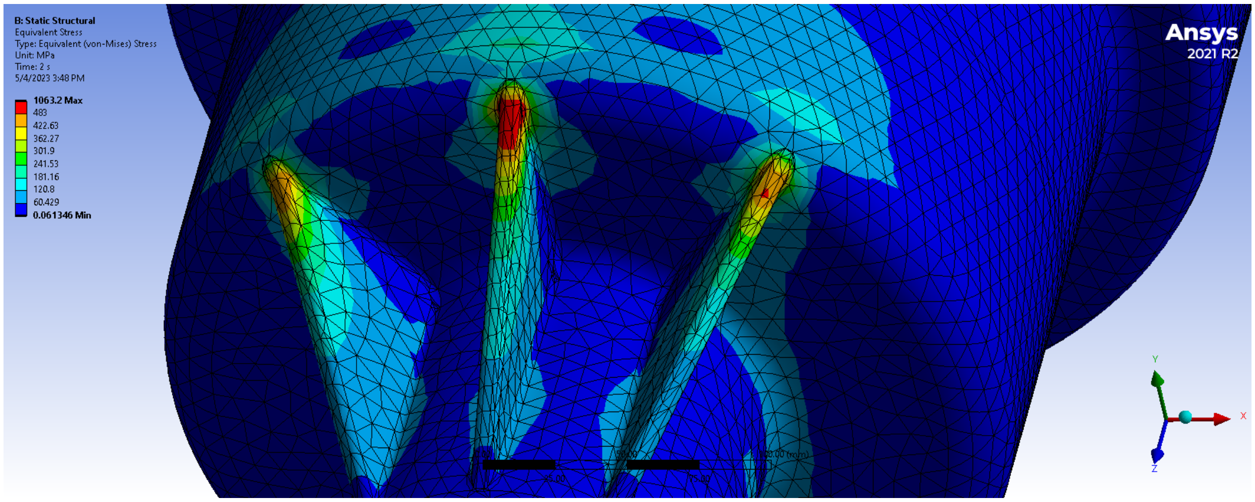


Figure 6.8: Version 5.0 ribbing exceeding 480 MPa

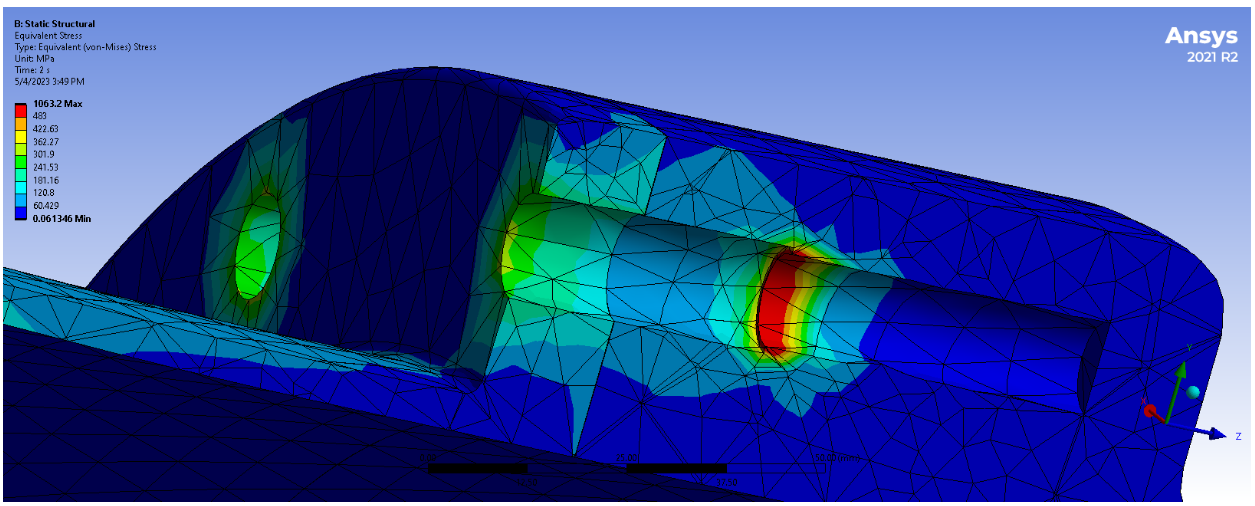


Figure 6.9: Version 5.0 bolted connection exceeding 480 MPa

One other item to adjust in the future would be the axle tubing diameters on the final iterations for versions 4.0 and 5.0. As seen in both figures 6.10 and 6.11, the red sections of the axle tubing show locations where the equivalent stress has exceeded the yield strength of the tubing material. This is again a problem as the results from these simulations could be considered unreliable. It would be best to either change the material or the tubing diameter to bring these areas back into linear modeling capability.

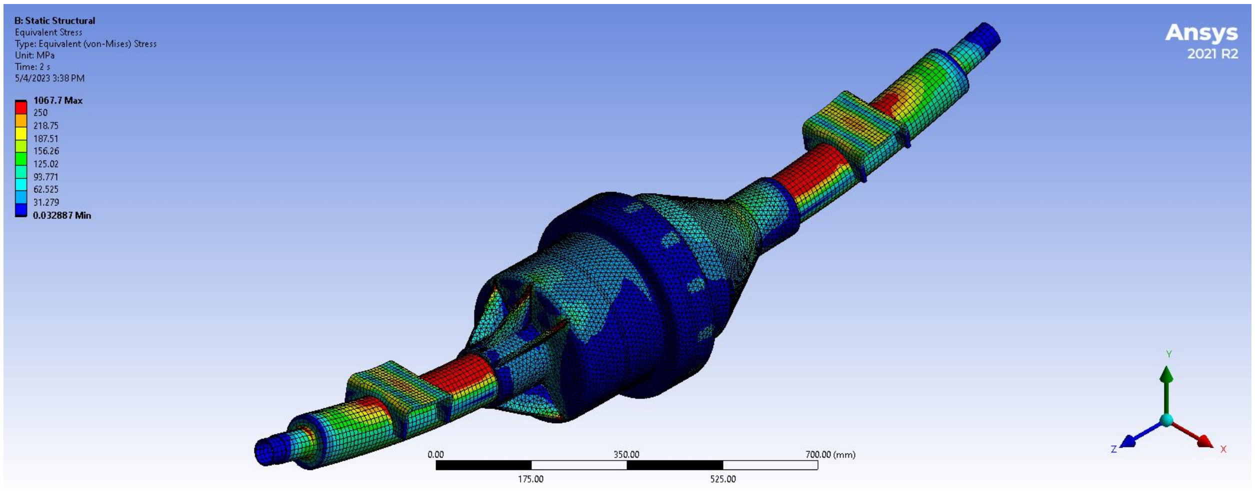


Figure 6.10: Version 4.0 tubing exceeding 250 MPa

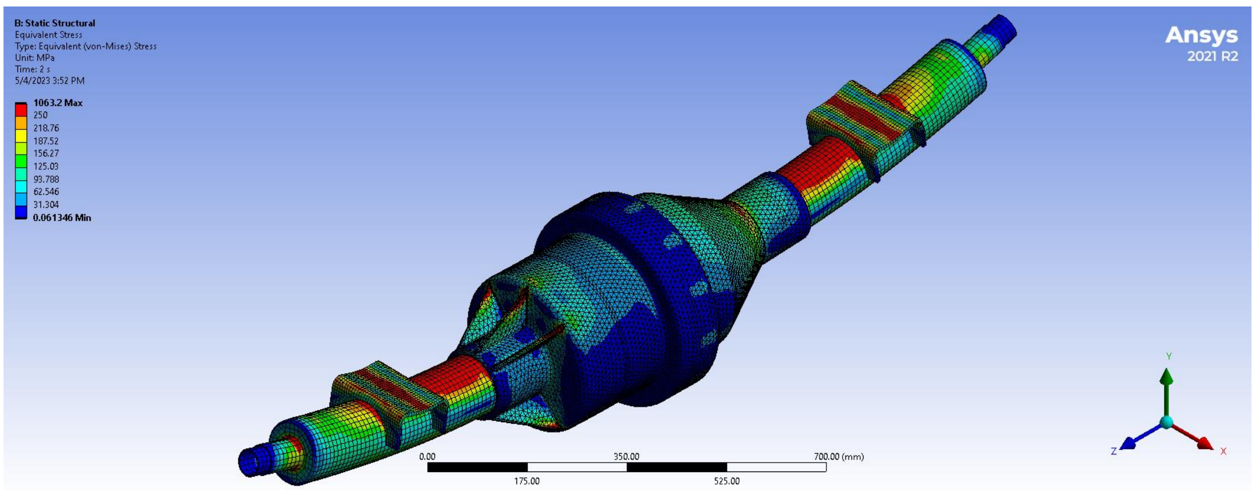


Figure 6.11: Version 5.0 tubing exceeding 250 MPa

7) Conclusion

In conclusion, the iterative process provided a significant amount of information to better understand the bolted connection present in this design. Between Ansys® plots reflecting the changes in the working loads present in the bolts and the various detailed red zones present from different material selections, the process still has work to be accomplished. The changes made to this project over the course of the iterations goes to show how vital the verification and validation process is. The process validates newer tools in the software through hand calculations rather than guessing and making the assumption that the process being followed has no flaws. Through this verification, details on the unusual bolting were caught as well as suggestions on how this project could be moved forward. The analysis of different portions of the Ansys® model with different materials showed weaknesses in the design that still require attending to if this design were to move towards production.

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Schaeffler: Coaxial eAxle FEA Report

Alexander Cebriak, Jackson Foster, Chris James

Mechanical Projects 801

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Mechanical Engineering Technology

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The University of Akron

Submitted to:

Dr. Mehmet Baysal

Abstract

The goal of this project was to design three different models of a coaxial beam eAxle for a range of electric vehicles. The requirement was to satisfy three different loading conditions, each characterized by a GAWR. These three loading conditions were 3000lb, 7500lb, and 10,000lb. This was done by first creating a model based on a basic outline given by Schaeffler. This model was then analyzed using Ansys®, and then iterated upon by designing new models using the 3D design program Solidworks. The iteration process was continued using more Ansys® analysis, as well as calculations to determine things like bolt size and axle tube length.

Table of Contents

1. Introduction

One of Schaeffler's new products is a coaxial beam eAxle that is internally referred to as the eAxle. Understanding the forces on a coaxial beam is very important for proper system design. The goal of this Senior Design Project is to research the coaxial beam design to help the client understand how it can be scaled for other applications and what its GAWR limits are.

1.1 Concepts

This project introduces concepts such as GAWR, or gross axle weight rating. Gross axle weight rating, according to National Highway Traffic Safety Administration, is *"the value specified by the manufacturer as the load-carrying capacity of a single axle system, as measured at the tire-ground interfaces."* This is essentially the maximum amount of weight that can safely be placed on one axle.

Another concept that is important to understand for this report is the two primary types of electric axles used in modern electric vehicles. The first is the coaxial beam axle. This is when the motor and gear box are all in line with the axles. It is the type being used for this project. The other common type is a parallel beam axle. This is when the motor is offset from the beam axle and turns an in-line gear box (CTI Symposium, 2023). This design is shown below in Figure B2.

1.2 Customer Needs

The main goal for this project was to design, model, and analyze three different housings for a coaxial beam electric motor and gearbox. Each of these three models must be designed to withstand one of three different loading conditions. The designed components must also be able to house the given dimensions and layout of both the gearbox and the electric motor, as well as follow the minimum guidelines for use within a vehicle.

The final customer for this project is ultimately automotive manufacturers who will be using this axle design in their vehicles. The criteria required by the end user are the following:

- There must be three different axle designs for three separate gross axle weight ratings (GAWRs), 3000lbs, 7500lbs, and 10000lbs
- The material chosen should be an industry standard material for availability and economic reasons
- The axle design must fit within the track width of cars or trucks as applicable
- There must be space within the axle casing for the electric motor and gear box as given by Schaeffler
- Considerations should be made for the casting process and how the design could be manufactured
- The design should be as light and economical as possible while still fulfilling the requirements

2. Preliminary Design

2.1 Components

There are several components of the beam eAxle that must be designed. These components are divided into two different categories below. The first are the critical components. These are the parts that will require the most design considerations and undergo the most changes. This category includes components such as:

- The motor half of the casing
- The gearbox half of the casing
- The axle tubes

The other category contains components that do not have much to do with the Senior Project design considerations, but are just there to complete the unit and allow us to run tests. These components only change to accommodate things like axle tube diameter changes. The following are secondary parts:

- The spindle
- The spring perch

The basic outline for the dimensions of the axle was provided by Schaeffler. This included the internal dimensions of the case, the track width of the vehicle, the rough spacing of the spring perches, and a rough idea of the tube design.

The flange for mounting the bolts was initially designed in a very basic way to make the analyzing process within the FEA program, Ansys® more simple. The team then decided to use ten M12 x 1.25 bolts based on what would fit in the designed flange. This was done to have a simple initial assembly to run in FEA in order to determine which components were over or under-designed and by how much.

2.2 Materials Research

Schaeffler limited the material selection for the designed housing. These materials are as follows: cast aluminum, gray cast iron, and ductile cast iron. Initial research has shown axle assemblies generally use a high-grade gray ductile iron for differential cases. Because a beam eAxle case is not too far removed from a conventional differential case, the team hypothesized that a good material to start with would be ductile iron. This was due to its physical characteristics such as ductility and strength, as well as its logistical benefits, with ductile iron currently being a common and cheap material.

Maintaining a compact and lightweight design was a limiting factor when considering the material selection for the eAxle. Cast iron proved to be too heavy for the 3000lb load limit and forced the consideration of lighter materials. That being said, other materials needed to be discussed. That leads the team to pick a grade of cast aluminum for its combination of strength and lower density.

As a design constraint, Schaeffler has given limits as to what materials the assembly can be. Schaeffler calls for using high-grade steel components besides the gearbox and motor casing. This was given to help calculate the total load on the spring perch plus the factor of safety and gravity as shown in Equation 2.

Schaeffler has said that the axle tubes will be high-grade steel. The thickness of the tubes should be no more than a ratio of 90%, meaning the inside diameter divided by the outside diameter must be equal to 0.9.

The team began by doing initial research on the three basic materials and comparing each. Research has shown what applications each material is typically used for. The design team then broke down each material into its respective grades. Each grade has its own properties and own temperaments. These will play a vital role in choosing the correct material for the final design.

Yield strength is defined as the stress limit a material can withstand without being elastically deformed. The material without reaching its maximum yield strength will still be good to use for its given purpose. Tensile strength is the material's resistance to failure through tensile loading conditions. This is the limit the material goes through before becoming plastically deformed. The material can no longer be used for the given purpose as its safety of factor significantly drops.

Ductile iron is a type of cast iron that has a higher degree of ductility and toughness compared to traditional gray iron. It is widely used in various applications due

to its excellent mechanical properties, good castability, and cost-effectiveness. Ductile iron can be used in a wide range of applications, including pipes and fittings, automotive components, machinery parts, and construction materials. It is particularly well-suited for applications that require high strength and toughness. One of the key advantages of ductile iron is its castability. It can be cast into complex shapes with high precision and detail, which makes it an ideal material for larger shapes like the 4.0 and 5.0 design of the eAxle assembly. Additionally, ductile iron can be easily machined, welded, and painted, which makes it a versatile material for several vehicle applications.

Gray cast iron is a type of cast iron that is widely used in various industrial applications due to its excellent castability, good machinability, and cost-effectiveness. It has excellent castability, which means it can be easily cast into complex shapes and designs. It is characterized by its gray appearance, which is a result of the graphite flakes that are present in its microstructure. Gray cast iron is commonly used in applications such as engine blocks, brake drums, and pump housings due to its excellent vibration damping properties. Though, gray cast iron has almost no ductility and will break if heated or cooled too rapidly, it has high tensile strengths. ASTM has devised several classes of gray cast iron, depending on its tensile strength. It also has good machinability, which means it can be easily machined and shaped using cutting tools. Gray cast iron does have its flaws. It is relatively brittle and has low ductility, which can make it prone to cracking or breaking under high stress. It is also prone to corrosion and can be difficult to weld.

Cast aluminum has several properties that make it an attractive material for various applications and very useful engineering material. It has a good strength-to-weight ratio, which means it is relatively strong for its weight. It also has good corrosion

resistance, which makes it suitable for use in automotive, outdoor, and marine environments. Cast aluminum is commonly used in applications such as automotive parts, cookware, and machinery components due to its good castability and ability to be easily machined.

3. Iterations

3.1 Design Changes

The initial design was based off of the most general requirements presented by Schaeffler. This version was the 1.0 version was made simply to have a general concept to build each successive version off of. This design did not initially have a bolted connection, and had very little in the way of actual calculated design choices. It was used to get a base reading from the Ansys®.

The first real version was version 1.1, where we added a basic bolted connection with two flanges, designed to be conjoined together with a nut and bolt. This was intended to be simpler to run in Ansys® to give a baseline. However, as the design team learned more about how the program worked, this was quickly abandoned in the following versions.

Versions 1.0 through 3.3 were all designed for the 3000lb loading condition, and were each designed with the housing made from Aluminum Alloy, and each of the other components made out of steel. The 4.0 and 5.0 are the 7500lb and 10,000lb loading

condition respectively, and were each constructed using high grade ductile iron for the casing, and once again steel for each of the other components.

3.1.1: Version 2.0

The initial design underwent many changes throughout the iteration process. The first major change was made after the first FEA was completed, revealing high stresses in both the bolted connection, as well as the axle tubes. The team first decided to improve the flange design by changing the bolt and nut connection to an enclosed threaded design. This was done to better distribute loads around the flange in order to reduce stress concentrations near this connection. The modification of the flange also allows for better serviceability and an increased resistance to corrosion. The team also increased the bolt sizes as the connection itself exceeded the desired bolt stiffness in the FEA. These changes were calculated using Equation 1.

3.1.2: Version 3.0

The next major changes were to decrease the thickness of the housing to 8mm case thickness, and a 16mm thickness around where the tubes are. This was done because the initial model was overdesigned, as well as being too thick in certain areas for casting. In response to research and recommendations, the team utilized fillets to smooth out any sharp edges to avoid stress concentrations. Additionally, the group

completed many quality-of-life changes to allow for much simpler editing in future versions. This was accomplished by rotating and mirroring features to allow for simple changes.

3.1.3: Version 3.3

This was the final version of the 3000lb GAWR load level. Research into casting and manufacturing, as well as recommendations from Schaeffler, revealed that castings work best with walls closer to a 5mm thickness. These findings were taken into consideration and the thickness all around the casing was reduced where possible. Ribbing was then added to make up for the thinner case. Additionally, in response to high stresses and deflection within the FEA, the tube was reinforced by increasing the thickness and diameter based on Equation 7.

3.1.4: Version 4.0

Once the 3000lb loading condition passed testing, it was time to move on to the 7500lb loading condition. The changes made for these new loading conditions included thicker ribbing on the motor casing, as well as axle tubes with larger outer diameters, as well as greater thickness. These changes were made based off Equation 7. as well as the material requirement calculated from the shear moment diagram. This version was changed to be made out of a high-grade ductile iron rather than the original Aluminum

alloy. This was done to keep many of the same features, while also increasing the strength of the housing.

3.1.5: Version 5.0

Finally, the 10,000lb GAWR loading condition was completed. This version further strengthened the axle tubes by increasing the thickness as well as the outer diameter. This was done based off Equation 7 and the preferred ratio provided by Schaeffler. Like version 4.0, this version's housing was also made out of ductile iron. This decision was made based from the decision matrix.

4. Ansys®

Ansys® Workbench is a program that allows the user to solve complex models for the resulting reactions. The program is very flexible and can provide the user with any answer they could want as well as any answer they would not want. Ansys® relies on the simulation criteria, or loading condition, being as realistic as possible to give the most accurate results but this also results in simulations being able to run despite those simulations not fully encapsulating the scenario.

Simulations in Ansys® are made up from a variety of components such as the coordinate system, the connection groups, the mesh, the boundary conditions, and the solution information that pertains to the problem in question. For the results in the simulation to be accurate, these components must be detailed as to reflect the realistic scenario as best as possible.

Starting with the coordinate system, the triad that determines the location of everything else in the simulation is usually pulled from the CAD model. However, there is occasionally the need to manually position this triad to better suit the simulation. When selecting the location of the coordinate system for these simulations, the tube and spindle bodies were selected to provide the most centered location for the triad.

The connections groups are what determine how the bodies within the assembly will interact with each other. When the model geometry is initially linked with the mode of analysis, Ansys® will pull in automatic connections where bodies fall within a certain threshold of each other. This is not always ideal as there might be too many faces interacting with each other or not enough so manual contact regions can be put in place. Additionally, the style of connection can be modified to emulate different interactions such as a frictional connection that would allow movement with specific resistances or a bonded connection that would allow no movement at all. In the case of this model, all connections were bonded with the exception of two regions. These regions are where the GBH flange and the EMH flange come into contact, and where the bottom face of each bolt head comes into contact with the GBH flange.

These regions were specified as frictional contacts to allow for an accurate assessment of the model. If there is undesired movement at these locations, then there would be changes made to the forces at those locations. Additionally, a frictional coefficient may be applied to those frictional contacts and in this case Schaeffler dictated that to be a value of 0.15. A layout of the frictional contact interface may be seen in Figure B1.

The next stage in the setup process involves the meshing of the geometry for calculation purposes. The mesh is made up of a series of nodes that lay out over the surface of the model and serve as points for specified loads to be applied. Additionally, nodes may serve as points of constraint for boundary conditions that are laid out for the model. The relations between groups of nodes are referred to as elements and often take the form of square or triangular shapes. The mesh as a whole can be edited to the user's design whether that be concentrating the mesh in a certain location by increasing the mesh density or by ensuring the distribution of nodes is as even as possible across the model. Various functions may be applied to fully customize and refine the mesh but only two were utilized in this project due to time constraints. These include the method function and the sizing function. The method function serves to determine how the elements of a mesh are generated and how the nodes are arranged as a result. This process is done automatically by default. However, in most circumstances this is not the most efficient. In this project the hex dominant method and the multizone method were both used. The sizing function controls the maximum allowable element size in a mesh and can frequently be used in conjunction with the method function to allow for the mesh to generate properly.

This could be due to irregularly shaped geometry that could otherwise be difficult to mesh. Additionally, the sizing function can be used to help calculate a more accurate representation of a body. In this project, a sizing function was used to stipulate a distance of 2 mm on each of the bolts due to the bolts being a primary concern of this project. A sizing function was also utilized to ensure a node size no larger than 8 mm on the spring perches and 10 mm of the remainder of the model to allow the model to

mesh properly. The resulting mesh for the final version of the 3000lb load level can be seen in Figure B2.

The loads and boundary conditions that are applied to the geometry can be considered the variables in the Ansys® simulation. They represent interactions between the geometry and the scenario that is being designed. In the case of this project, the functions of remote displacement, remote force, and pretension were utilized. Additionally, the sequence of these functions can be controlled in the analysis settings. In the case of this model, two steps take place with the pretension and remote displacements being applied first while the remote forces are applied second.

Remote displacement allows the user to select portions of a body and control its location directly in relation to whichever coordinate system is chosen. It also allows for control of the reaction to external forces acting on the geometry. In this project, two remote displacements were inserted, and each referenced one face of each of the two spindles in the model as shown in Figure B3. Using the details tab, each remote displacement was set to 0 movement in the x, y, and z axes as well as 0 degrees of rotation about the z axis. This can be seen in Figure B4.

Remote forces function similarly to Remote displacements in the way that they are applied to the geometry. A location is selected on a given body as a geometry reference and then coordinate location can be controlled in relation to a coordinate system. The coordinate system must be selected first if the numerical coordinates are not known. The components of the forces are then determined as seen in figure B5. Two of the three remote forces in this model are located on spring perches with one for

each top face as seen in Figure B6. These forces are then located to 0 on the x axis. The forces are applied with loads calculated from Equation 2 and inserted tabularly. This is done to hold better control over which time step these forces are applied in during the simulation. This can be seen in Figure B7. The third remote force is applied in a similar manner but utilizes multiple faces in the inside of the model to place the force at 0, 0, 0. The force component is again applied tabularly with a static value of -5886 N applied in the negative Y direction as dictated by Schaeffler and calculated in Equation 3. The setup for this remote force can be seen in Figure B8.

Lastly, pretension is a function that allows for the simulation of a pretension being applied to a bolt and a preload being applied to the assembly. The purpose of this preload is to reduce the forces on acting on the members and to allow the bolt or bolts to bear more of the load. It should be applied to the portion of the bolt that is unthreaded to represent the portion of the bolt that is under load directly. This can be done by breaking up the face, that is the shank of the bolt within the CAD modeling software.

The setup of a separate Ansys® simulation has shown that the resulting working load of the bolt is inaccurate when the bolt has a pretension applied in addition to a bonded contact. In the context of this project, the pretension function was applied to all 12 bolts with a preload of 71,625 N and can be seen in Figure B9. This number represents 75% of the proof load of M14 x 2 ISO 10.9 hex head bolts or the recommended preload. A depiction of the working load on a set of preloaded bolts can be found in Figure B10. The important features in this figure are the working load color gradient on each of the bolts and the orientation of this gradient in relation to a positive

Y axis. These details were used to make decisions about new iterations of the model. This helped to ensure that a stable model was developed.

5.Conclusion

5.1 Bolt Calculation Results

Due to time constraints, the team was unable to directly confirm the functionality of the final iterations of the eAxle, but utilizing a separate simulation as shown in figures 12 and 13, evidence was provided that Ansys® did calculate the working load on the bolts to a difference of 20 N. The separate simulation was set up in the same fashion as every other model described in Section 4. It was determined that due to the threaded section of the bolt not coming into contact with the gear box housing flange, the equations to determine the portion of the load taken by the bolt would need to be restructured. This change only effects an equation for K_b or the stiffness of the bolt. These calculations can be found in Equation 1.

In conclusion to the final bolt design, the team has decided to go with a M14 x 2.0 ISO 10.9 hex head bolt. This particular bolt has a grading of 10.9 for its tensile strength rating, yield strength, and it well known proof strength. The proof strength is defined at which the bolt would undergo permanent deformation. After looking at the proof load analysis from Ansys®, the team has found that the bolt used is much larger than what should be designed. A smaller sized bolt or possibly a lesser number of bolts could be used for the final design. Although, with the bolt being overdesigned, this allows ease of assembly and interchangeability across the three models. With the time

constraints being limited, a different bolt design would be ideal to look at more with Ansys® proof load calculations.

5.2 Material Results

As for the resulting 3.3 model, the team has gone with using the decision matrix ,Table A2, to choose the proper material. The team has started with a large list of different grade aluminum alloys via Ansys®, and done individual research of each. The important categories looked at were ultimate tensile strength, yield strength, temper, cost, and density. This is because the casing of the eAxle needs to be strong and lightweight at the same time. The design team then broke down the list of alloys to the four most commonly used within the automotive industry. By assigning a weight of 1-10, the design team were able to decide the importance of each category. Then, the team looked at the four different alloys and decided 1-10, 10 being most important, by comparison. For example, using Table A2 compare the yield strength of aluminum alloy A380 with the other three alloys, and then on Table A3 a number 1-10 importance is assigned.

Once this has been completed, the team uses a calculation of each column and link in the weight assigned to each row and get the totals. The largest total number under each alloy is going to be the most important alloy or resulting alloy that should be used for the design. According to that result, and highlighted green column from Table A2, aluminum alloy A380 is the resulting material to use for final design 3.3.

With the same decision matrix concept described before, the team was able to decide a material for resulting design 4.0 and 5.0. The difference here is that the alloys are changed from cast aluminum to cast gray iron and cast ductile iron. The important

properties here are ultimate tensile strength and yield strength of each grade material. Because of the yield strength being so low on the gray iron grades, the team decided to stay away from them and use the high yield strength on the ductile iron grades instead. As for the final 4.0 design, a ductile iron grade (80-55-06) was used for its yield strength meeting the 7500lb load limit. As for the final 5.0 design, a ductile iron grade (100-70-03) was used for its yield strength meeting the 10,000lb load limit.

5.3 Design Results

The final design (V3.3) for the 3000lb loading condition incorporated several aspects. The first was the thickness of the tube, which was calculated using Equation 7, which used a ratio of ID and OD provided by Schaeffler, as well as the shear moment diagram shown in Figure B17. The calculation resulted in an inner diameter of 73mm, and an outer diameter of 85mm. The other aspect the design team incorporated was the ribbing on the motor side of the casing. This was used to compensate for the thinner casing walls resulting from the casting thickness requirements of aluminum.

The 3000lb design was then iterated into a design with a GAWR of 7500lb. This version (V4.0) had yet another increase to the axle tube diameter, once again calculated using Equation 7. The inner diameter was calculated to be 90mm, and the outer diameter was determined to be 100mm. Additionally, the ribbing was made thicker to accommodate the heavier loading condition.

The final iteration (V5.0) of the ultimate loading condition of 10,000lb once again increased the axle tube diameter and thickness. This calculation resulted in an inner diameter of 103.5mm and an outer diameter of 115mm.

5.4 Timeline Adherence

Originally, the timeline laid out by the design group designated each of the three members to a loading condition. Each was to be done simultaneously with iterations happening at the same time and suggestions and research benefiting each version. This assumed every member would be a jack of all trades and work on every aspect of each version, modeling, calculations and Ansys®.

This did not happen however, as getting the bolted connections to properly work in Ansys® turned out to be more difficult than initially thought. This holdup meant the bolted connection could not be properly analyzed until later in the iterative process, meaning the design team had to rely on calculations. The design group also chose to specialize in different areas, and all work together on each version for the sake of time and efficiency.

The workload was split up in the following way. Jackson focused on the modeling and design, Chris focused on the calculations and iterative work, and Alex tackled designing and running the Ansys® simulation. Additionally, each group member contributed to the research and discussion for improvements to make in each iteration.

For the purpose of the honors research project, the portion of this paper labeled Ansys® was written and researched by Alex Cebriak in its entirety. All other written portions of the paper were written by Jackson Foster and Chris James.

5.5 Future Plans

While each version did pass the requirements laid out by Schaeffler, some of the versions are over designed in the bolted connection. If given more time, the design group would have run further simulations and done further calculations to make each version more economically viable by thinning out certain sections.

An additional design factor to the model design would be looking at the heat dispersion that the housings could handle. On the inside of the housings, there are moving parts that would require fluid dynamics and heat sinking needs. This is something that could be looked upon in future research for what materials or design of the gearbox housing and e-motor housing would handle.

Another consideration the design team would like to pursue different methods of improving the strength of the axle tubes, as well as explore alternative solutions to the ribbing. These changes would be done to address the excess stress in the axle tubes, as well as the stress concentrations present in the ribbing on the case.

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Calculations

Equation 1:

Bolt Stiffness:

Where:

A_d = unthreaded length:

A_t = Area of threaded portion

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ℓ_t = Length of threaded portion: ℓ-ℓ_d

ℓ_d = Length of Unthreaded portion: L-L_t

E = Modulus of Elasticity of Material:

Bolt Used: M14 x 2.0 Coarse thread Grade 10.9

Given:

Bolt head 21 mm

Threaded width 14 mm

L = Total Length 70 mm

ℓ_t = Threaded length 34 mm

ℓ_d = Unthreaded length 36 mm

A_t = Area of threaded portion = 115 mm^2 Using Table 8.1 Shigley's Mechanical Engineering Design Eleventh Edition

E = 207 GPa

$A_d = \frac{\pi d^2}{4}$ = 154 mm^2

$$K_b = \frac{A_t A_d E}{A_t(L - L_T) + A_d L_T} = \frac{K_t K_d}{K_t + K_d}$$

$K_b = \frac{(115)(154)(207E6)}{(115)\big((70)-(34)\big)+(154)(34)} = 3.91E8$ N/mm

Equation 2:

Spring perch load per side $=\frac{\big((GAWR - wheel\ end\ mass - unsprung\ mass)\cdot 3g\big)}{2}$

Where:

GAWR = Gross Axle Weight Rating

Wheel end mass = 250kg (given)

Unsprung mass = 200kg (given)

g = gravity = 9.81 $\frac{m}{s^2}$

Spring perch load (3000lb) $=\frac{\big((1365-250-200)\cdot 3(9.81)\big)}{2}$

= 13,464.22 N

Spring perch load (7500lb) = $\frac{((3410-250-200)\cdot 3(9.81))}{2}$ =

41,336.4 N

Spring perch load (10000lb) = $\frac{((4550-250-200)\cdot 3(9.81))}{2}$ =

60,331.5 N

Equation 3:

System mass load = $(Unsprung\ mass)\cdot\ 3\cdot g$

System mass load = $(200)\cdot\ 3\cdot(9.81)$

= 5886 N

Equation 4:

Confirm Length of Bolt for Assembly 3.3

$$L > h + 1.5d$$

Where:

h = gearbox thickness = 10 mm

d = diameter of bolt = 14 mm

L = 10 + (1.5)(14) = 31 mm

Confirm Length of Bolt for Assembly 4.0 and 5.0

$$L > h + 1.5d$$

Where:

h = gearbox thickness = 15 mm

d = diameter of bolt = 14 mm

L = 15 + (1.5)(14) = 36 mm

Equation 5:

Member Stiffness K_m

Values A and B are pulled from Table 8-8 from Shigley

$$K_m = EdAe^{\frac{Bd}{L}}$$

$K_m = (207E6)(14)(0.78715)e^{\frac{(0.62873)(14)}{(70)}} = 2.59E9$ N/mm

Equation 6:

Resultant bolt load F_b

$$F_b = \frac{K_b P}{K_b + K_m} + F_i = P_b + F_i$$

$F_b = \frac{(3.91E8)(13464.225)}{(3.91E8)+(2.59E9)} + (71625) = 73392.61$ N

Equation 7:

Diameter of stationary shafts in bending only
D = outside diameter of the shaft
K_m = combined shock and fatigue factor to be applied in every case to the computed bending moment
M = maximum bending moment
S = maximum allowable flexural (bending) stress in either tension or compression
All of these values correspond to sections in the Machinery's Handbook

$$D = B\sqrt[3]{\frac{10.2 \cdot K_m M}{S}}$$

Appendix A

SCHAEFFLER

Bolt Loads

Bolt Thread Size (Coarse)	Bolt Strength Class	Ultimate Load (N)	Proof Load (N)	75% Proof Load (Ref.) (N)	Strength Margin (25% Proof, N)
M4 X 0.7	8.8	7,020	5,100	3,825	1,275
	10.9	9,130	7,290	5,468	1,823
	12.9	10,700	8,520	6,390	2,130
M5 X 0.8	8.8	11,350	8,230	6,173	2,058
	10.9	14,800	11,800	8,850	2,950
	12.9	17,300	13,800	10,350	3,450
M6 X 1	8.8	16,100	11,600	8,700	2,900
	10.9	20,900	16,700	12,525	4,175
	12.9	24,500	19,500	14,625	4,875
M8 X 1.25	8.8	29,200	21,200	15,900	5,300
	10.9	38,100	30,400	22,800	7,600
	12.9	44,600	35,500	26,625	8,875
M10 X 1.5	8.8	46,400	33,700	25,275	8,425
	10.9	60,300	48,100	36,075	12,025
	12.9	70,800	56,300	42,225	14,075
M12 X 1.75	8.8	67,400	48,900	36,675	12,225
	10.9	87,700	70,000	52,500	17,500
	12.9	103,000	81,800	61,350	20,450
M14 X 2	8.8	92,000	66,700	50,025	16,675
	10.9	120,000	95,500	71,625	23,875
	12.9	140,000	112,000	84,000	28,000
M16 X 2	8.8	125,000	91,000	68,250	22,750
	10.9	163,000	130,000	97,500	32,500
	12.9	192,000	152,000	114,000	38,000
M20 X 2.5	8.8	203,000	147,000	110,250	36,750
	10.9	255,000	203,000	152,250	50,750
	12.9	299,000	238,000	178,500	59,500

Table A1

	Aluminum Materials			
Criterion	332	336	356	380
Ultimate Tensile Strength (MPa)	250	320	240	320
Yield Strength (MPa)	190	300	170	160
Temper	T5	T65	T6	F
Cost	10%	11%	9.50%	10%
Density (g/cc)	2.76	2.72	2.68	2.90

Table A2

	Ratings				
Criterion	Weight	332	336	356	380
Sut to Sy r	4	5	2	5	8
Sy	8	5	8	4	4
Temper	3	6	3	4	8
Cost	5	7	5	8	7
Density	6	6	7	8	6
Total		149	148	152	159

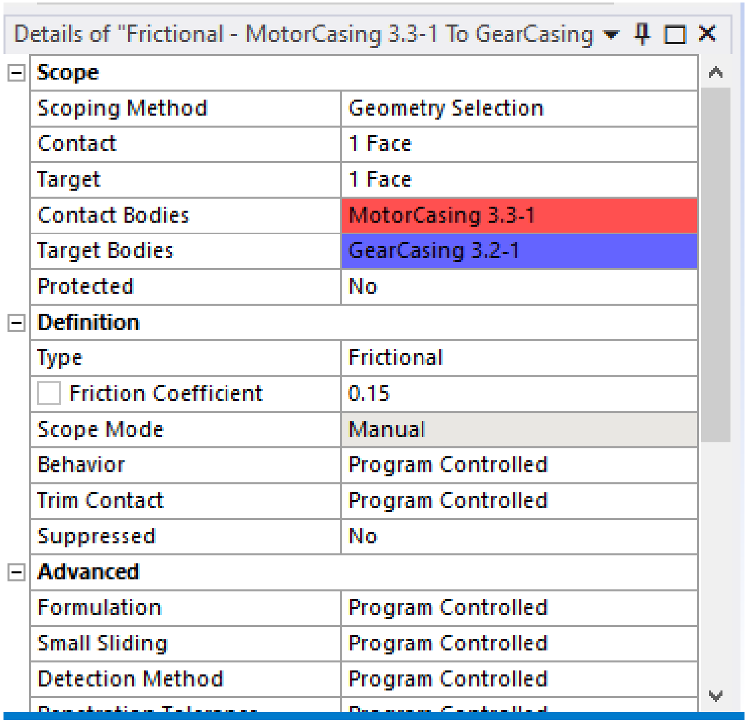
	Cast Iron Materials (ASTM A536)							
Criterion	Gray Iron ASTM A48 Class 20	Gray Iron ASTM A48 Class 30	Gray Iron ASTM A48 Class 40	Ductile Iron (Grade 60-40-18)	Ductile Iron (Grade 65-45-12)	Ductile Iron (Grade 80-55-06)	Ductile Iron (Grade 100-70-03)	Ductile Iron (Grade 120-90-02)
Ultimate Tensile Strength (MPa)	138	207	276	413	448	552	689	827
Yield Strength (MPa)	N/A	N/A	N/A	275	310	379	483	621
Elongation Min (%)	N/A	N/A	N/A	18	12	6	3	2
Density (g/cc)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Melting Temp (F)	2100	2100	2100	2100	2100	2100	2100	2100
Compressive Strength (MPa)	572	752	1034	2960	2960	2960	2960	2960

Table A4

	Cast Iron Decision Matrix Ratings								
Criterion	Weight	Gray Iron ASTM A48 Class 20	Gray Iron ASTM A48 Class 30	Gray Iron ASTM A48 Class 40	Ductile Iron (Grade 60-40-18)	Ductile Iron (Grade 65-45-12)	Ductile Iron (Grade 80-55-06)	Ductile Iron (Grade 100-70-03)	Ductile Iron (Grade 120-90-02)
Sut to Sy r	4	1	1	1	7	6	6	5	4
Sy	8	1	3	4	4	4	5	7	9
Total		12	28	36	60	56	64	76	88

Table A5

Appendix B



Details of "Frictional - MotorCasing 3.3-1 To GearCasing

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	MotorCasing 3.3-1
Target Bodies	GearCasing 3.2-1
Protected	No
Definition	
Type	Frictional
Friction Coefficient	0.15
Scope Mode	Manual
Behavior	Program Controlled
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	Program Controlled
Small Sliding	Program Controlled
Detection Method	Program Controlled

Figure B1

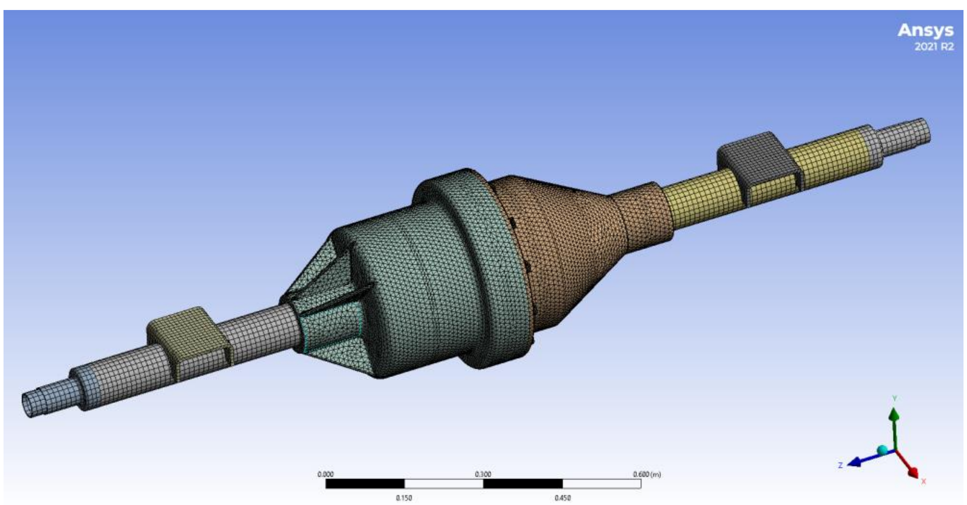


Figure B2

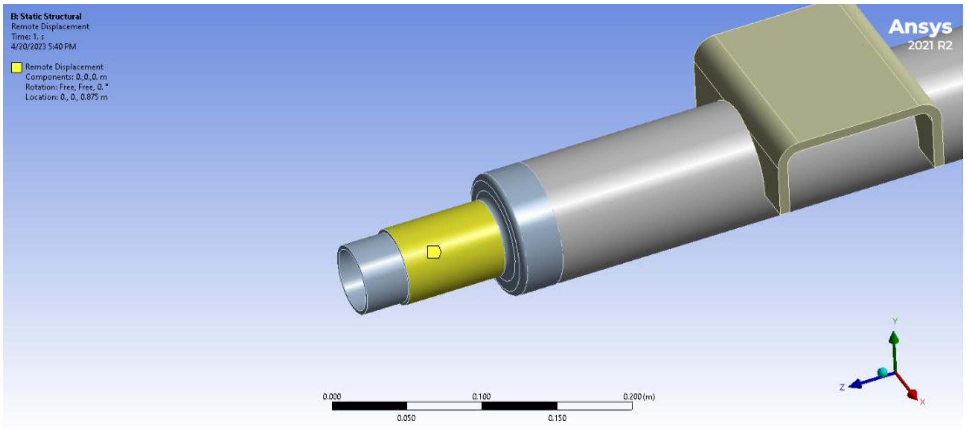
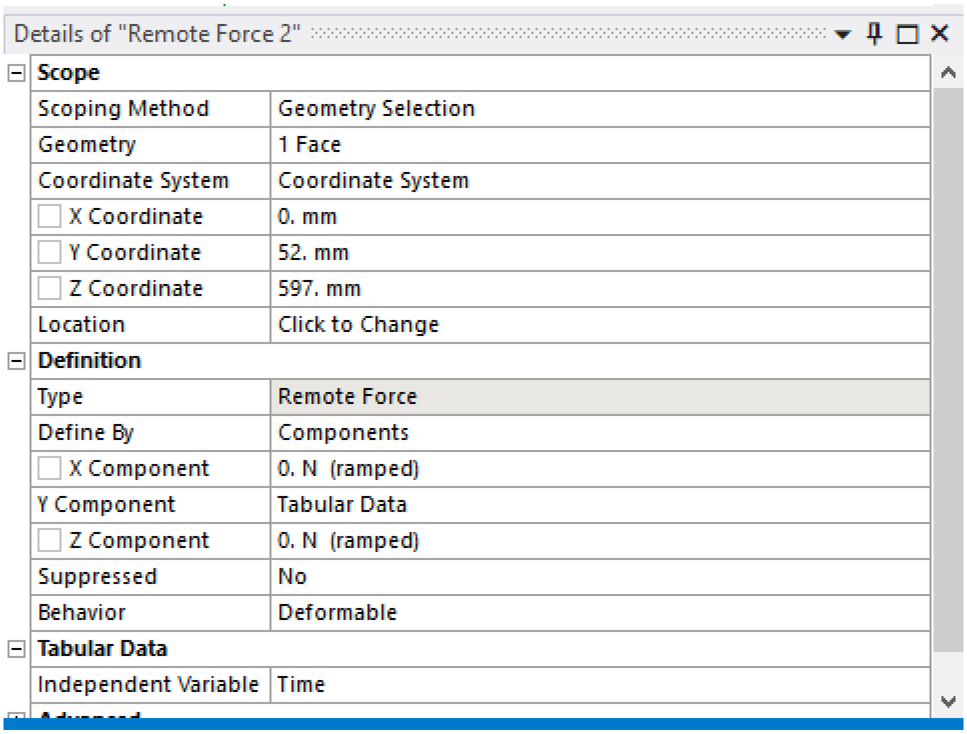


Figure B3

Details of "Remote Displacement 2"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Coordinate System	Coordinate System
X Coordinate	0. mm
Y Coordinate	0. mm
Z Coordinate	-875. mm
Location	Click to Change
Definition	
Type	Remote Displacement
X Component	0. mm (ramped)
Y Component	0. mm (ramped)
Z Component	0. mm (ramped)
Rotation X	Free
Rotation Y	Free
Rotation Z	0. ° (ramped)
Suppressed	No
Behavior	Deformable

Figure B4



Details of "Remote Force 2"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Coordinate System	Coordinate System
X Coordinate	0. mm
Y Coordinate	52. mm
Z Coordinate	597. mm
Location	Click to Change
Definition	
Type	Remote Force
Define By	Components
X Component	0. N (ramped)
Y Component	Tabular Data
Z Component	0. N (ramped)
Suppressed	No
Behavior	Deformable
Tabular Data	
Independent Variable	Time

Figure B5

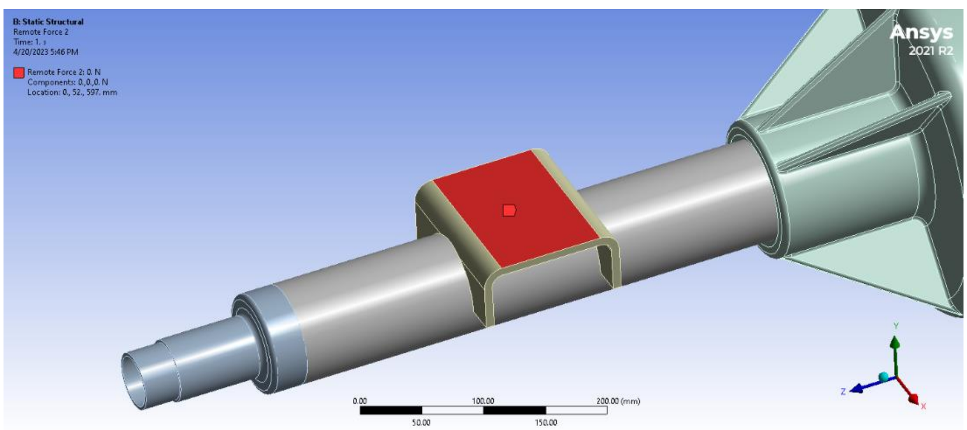


Figure B6

Tabular Data

	Steps	Time [s]	X [N]	Y [N]	Z [N]
1	1	0.	= 0.	0.	= 0.
2	1	1.	0.	0.	0.
3	2	2.	= 0.	-13464	= 0.
*					

Figure B7

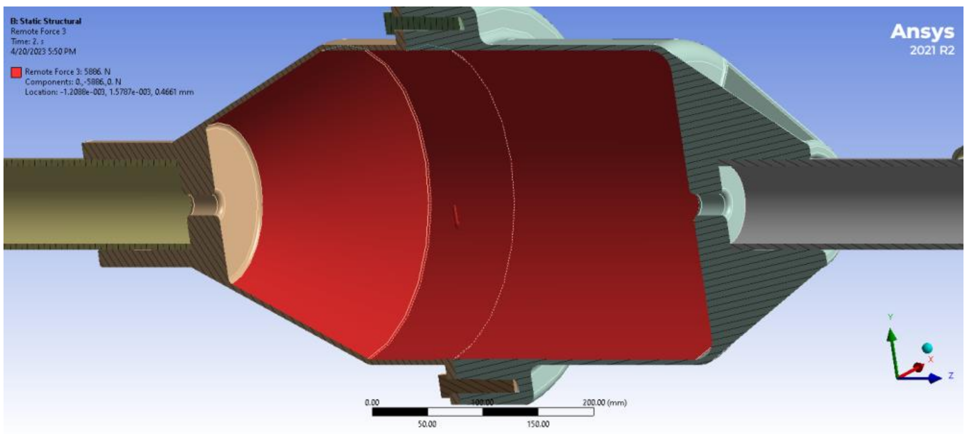


Figure B8

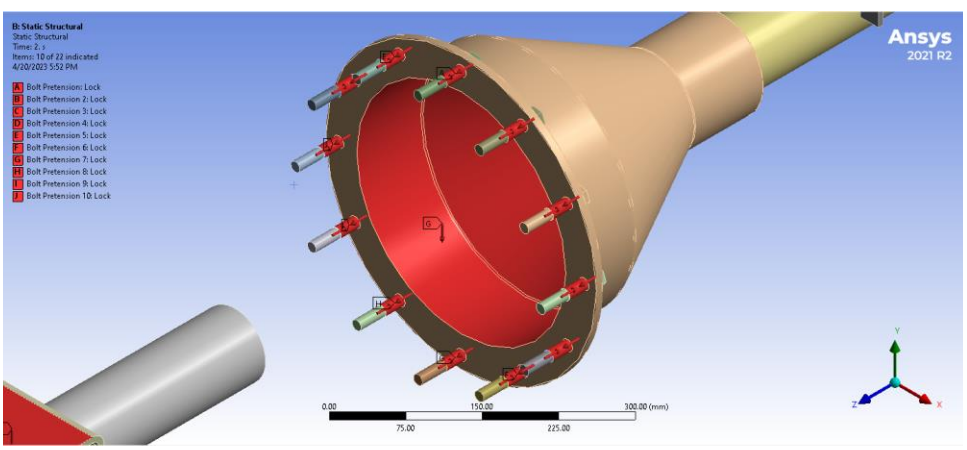


Figure B9

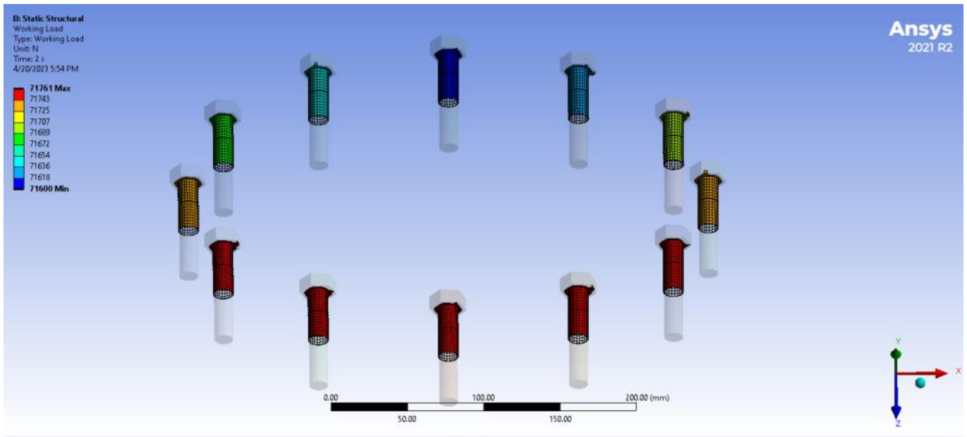


Figure B10

Tabular Data

	Steps	Define By	Preload [N]	Preadjustment [mm]	Increment [mm]
1	1.	Load	71625	N/A	N/A
2	2.	Lock	N/A	N/A	N/A
*					

Figure B11

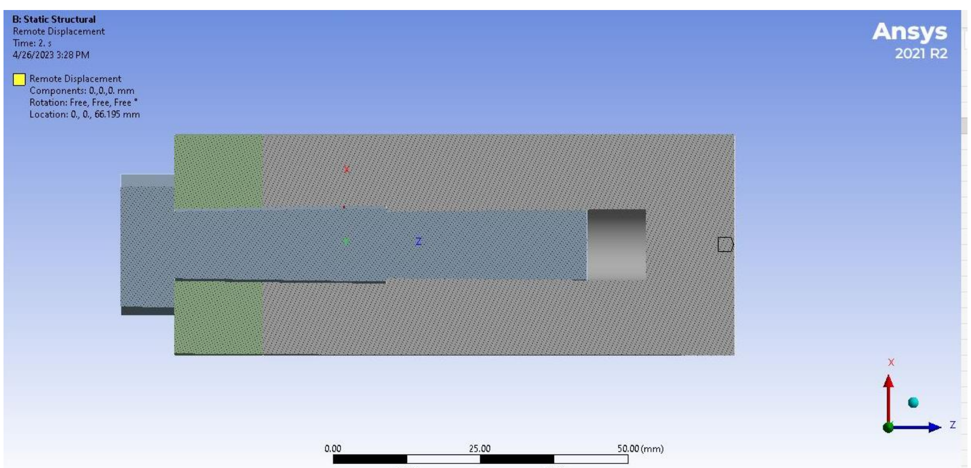


Figure B12

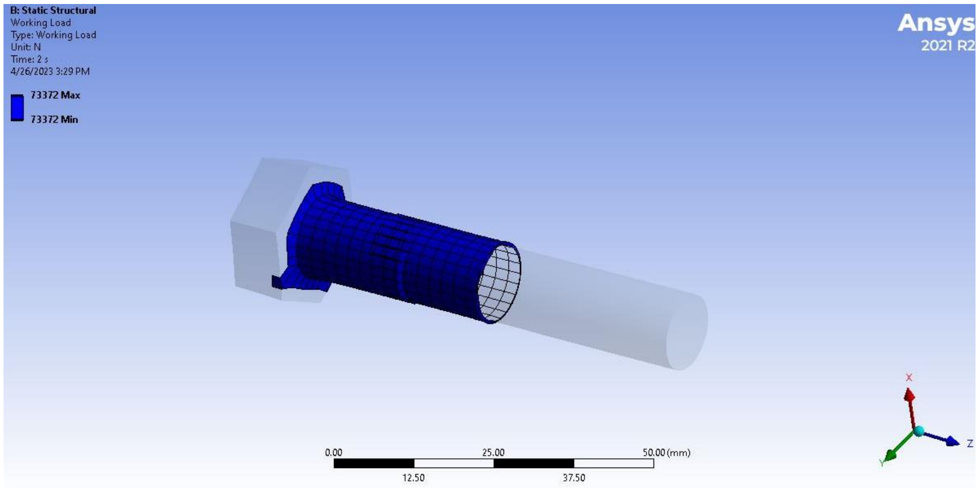


Figure B13

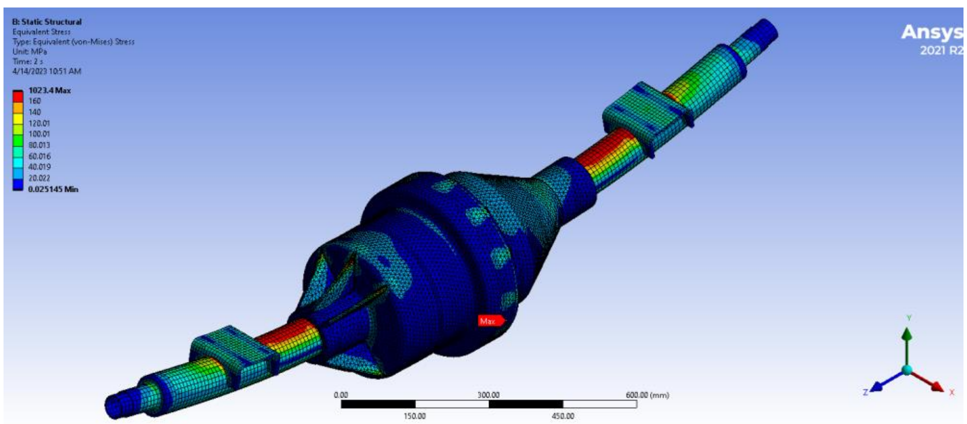


Figure B14

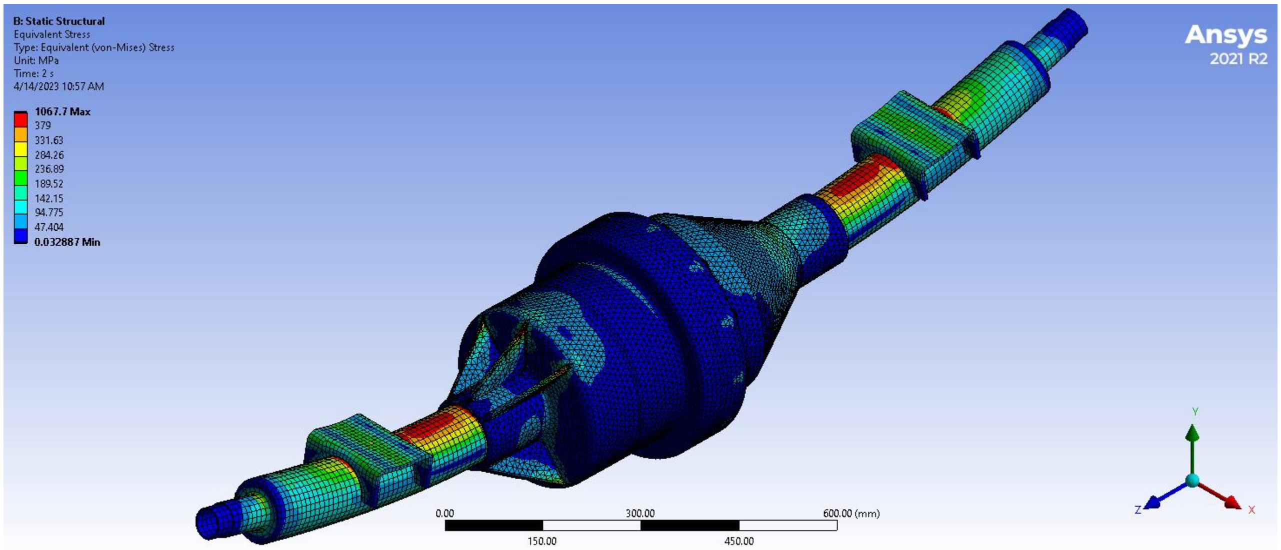


Figure B15

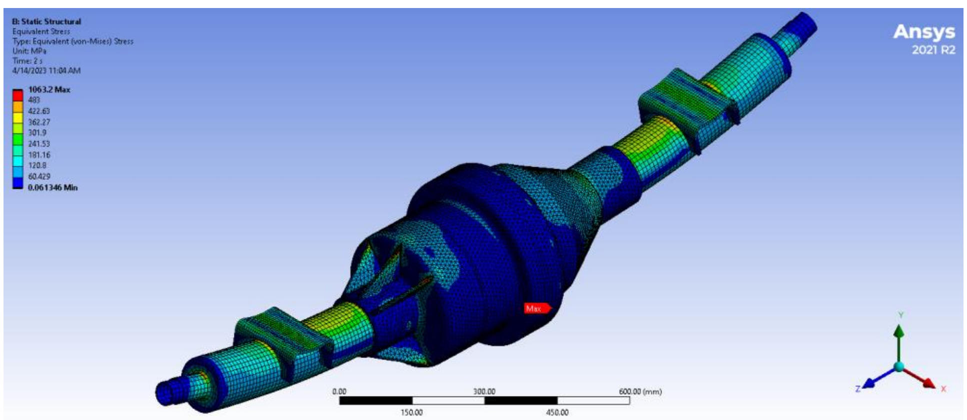
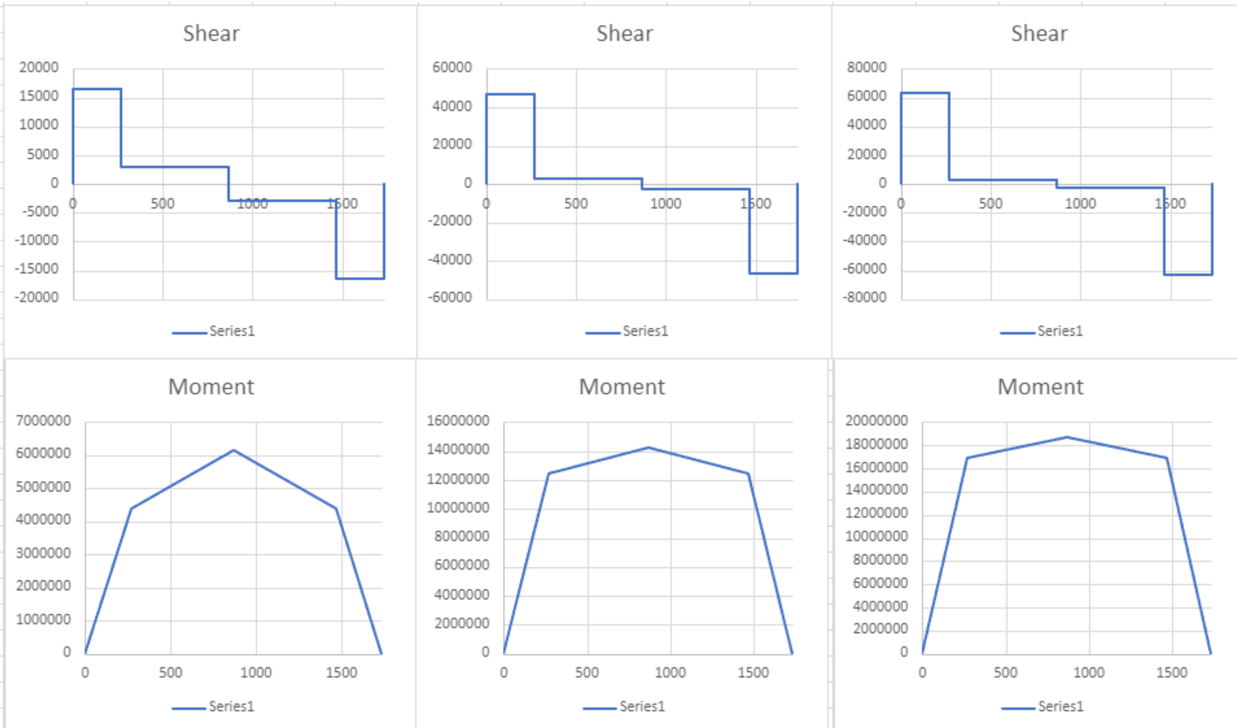


Figure B16



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10000
5000
0
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500
1000
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Series1
Shear
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40000
20000
0
-20000
-40000
-60000
0
500
1000
1500
Series1
Shear
80000
60000
40000
20000
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-40000
-60000
-80000
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500
1000
1500
Series1
Moment
7000000
6000000
5000000
4000000
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2000000
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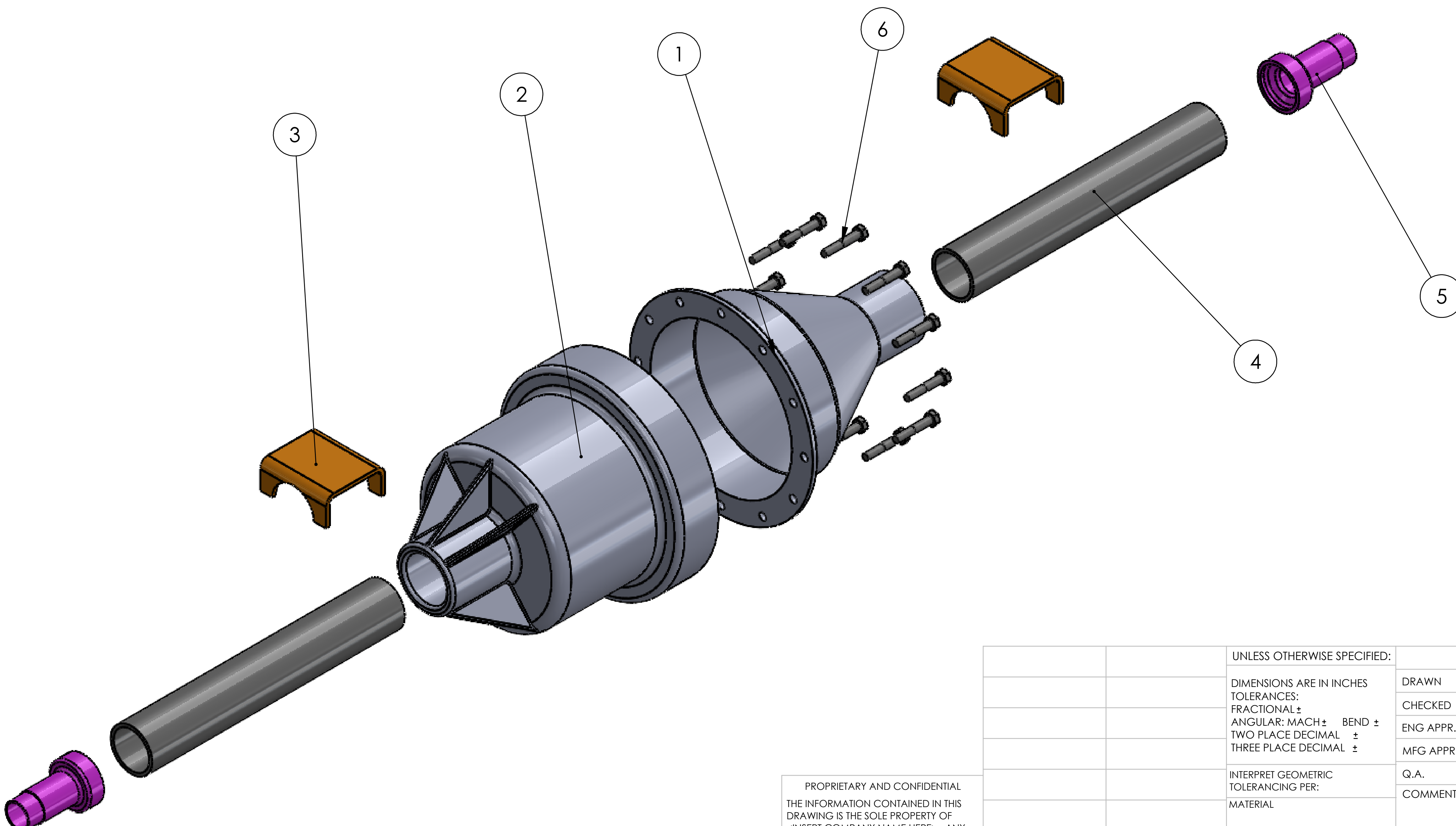
500
1000
1500
Series1
Moment
20000000
18000000
16000000
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
0
500
1000
1500
Series1

Figure B17

4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	GBH 3.2	Gearbox Housing	1
2	EMH 3.3	eMotor Housing	1
3	SP 2.0	Spring Perch	2
4	85mmTube	Axle Tube	2
5	Spindle 1.0	Spindle	2
6	M14B 1.2	Hexhead Bolt	12

B B



A A

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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

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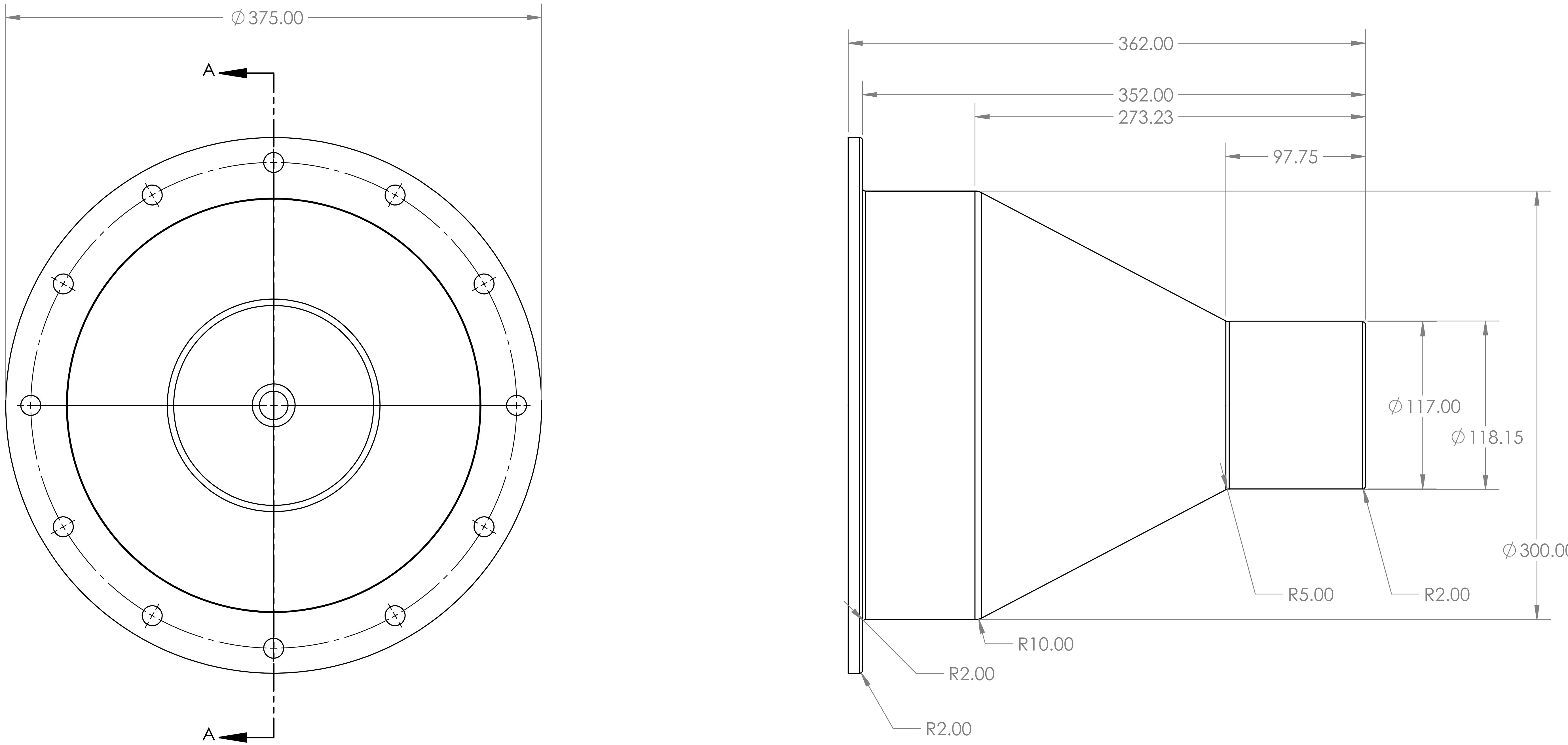
DRAWN	AC	4/13/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

SIZE B | DWG. NO. Assembly 3.3 | REV

SCALE: 1:7 | WEIGHT: | SHEET 1 OF 1

4 3 2 1



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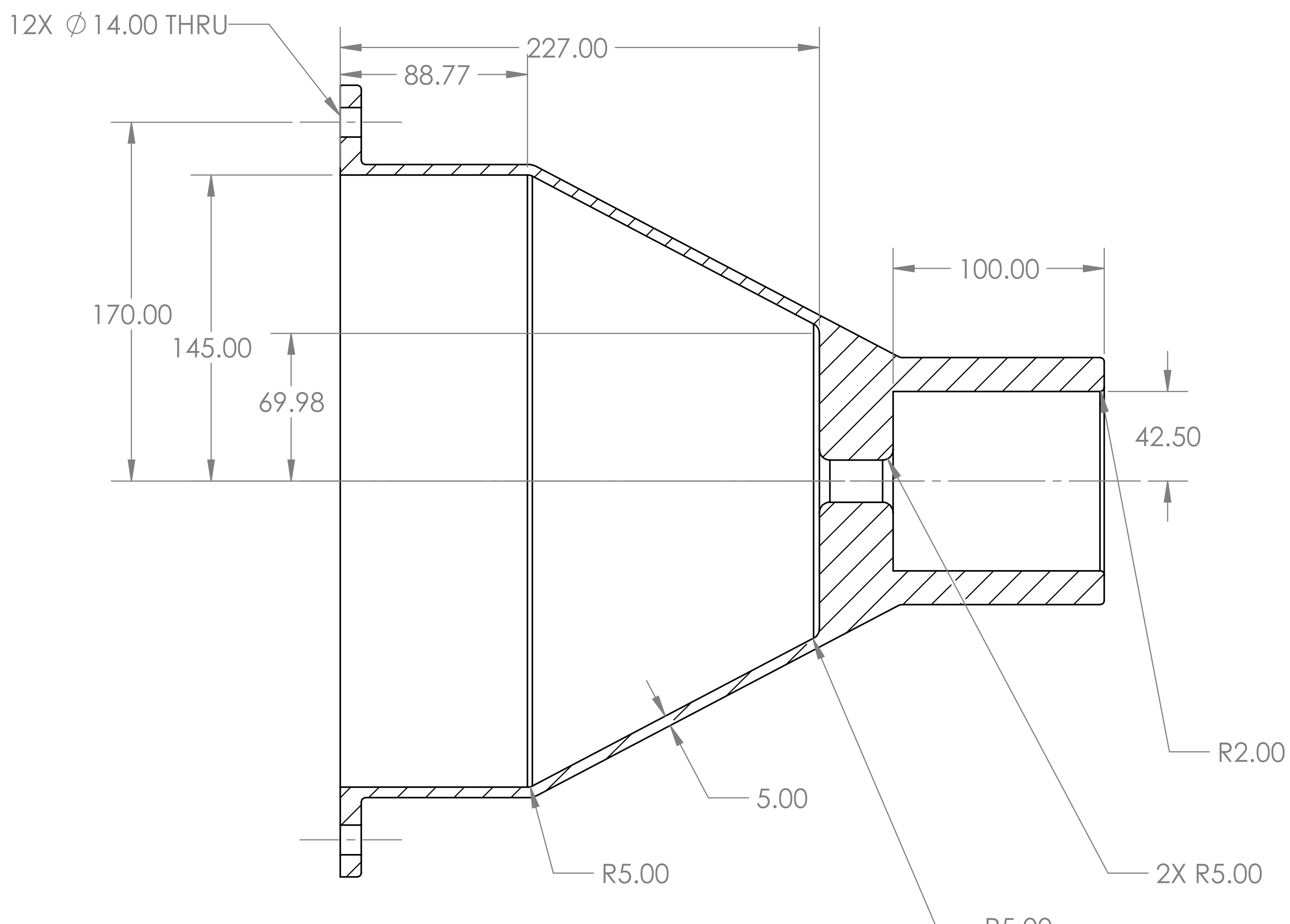
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Aluminum Alloy 380	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

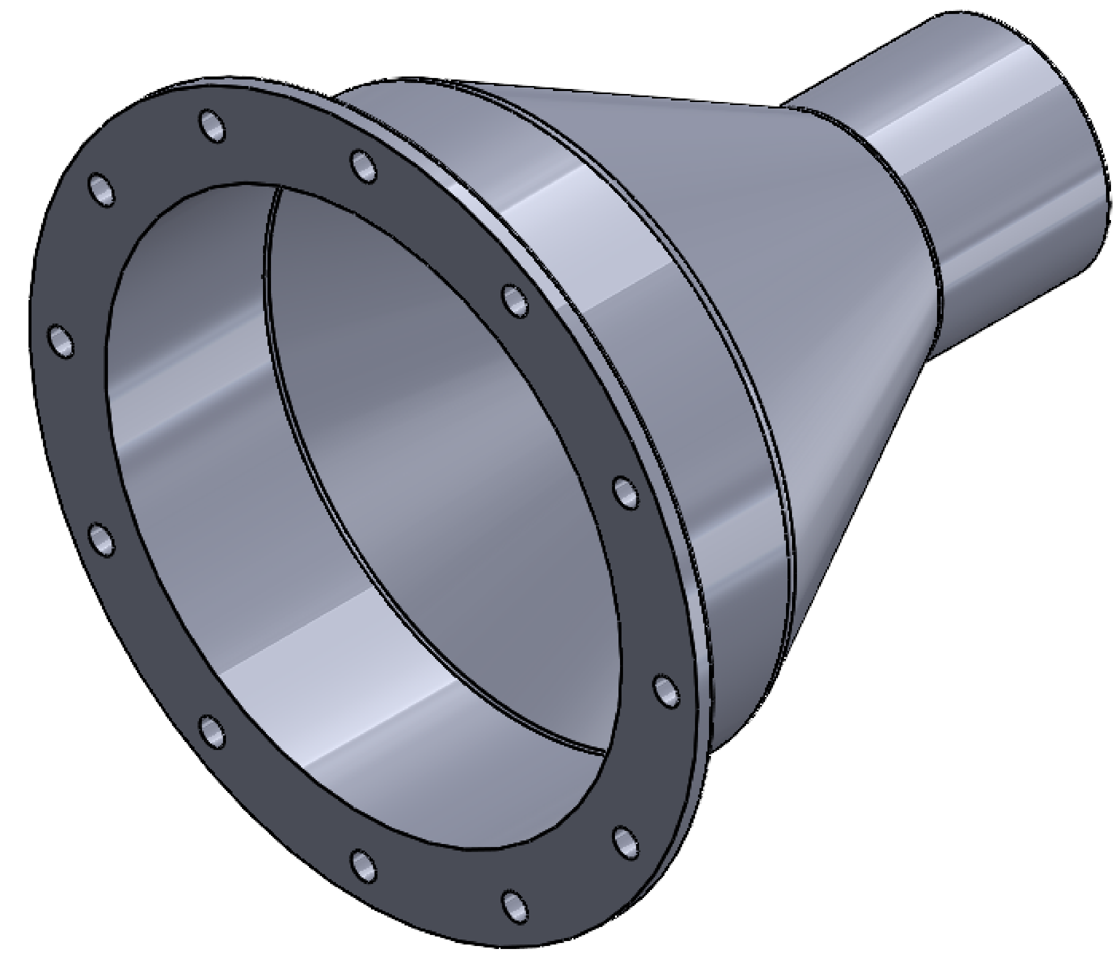
TITLE:

Gearbox Housing

SIZE	DWG. NO.	REV
B	GBH 3.2	
SCALE: 1:3	WEIGHT:	SHEET 1 OF 2



SECTION A-A



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	CHECKED			Gearbox Housing	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Aluminum Alloy 380	COMMENTS:			SIZE B	DWG. NO. GBH 3.2 / REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:3 WEIGHT:	SHEET 2 OF 2

NEXT ASSY	USED ON
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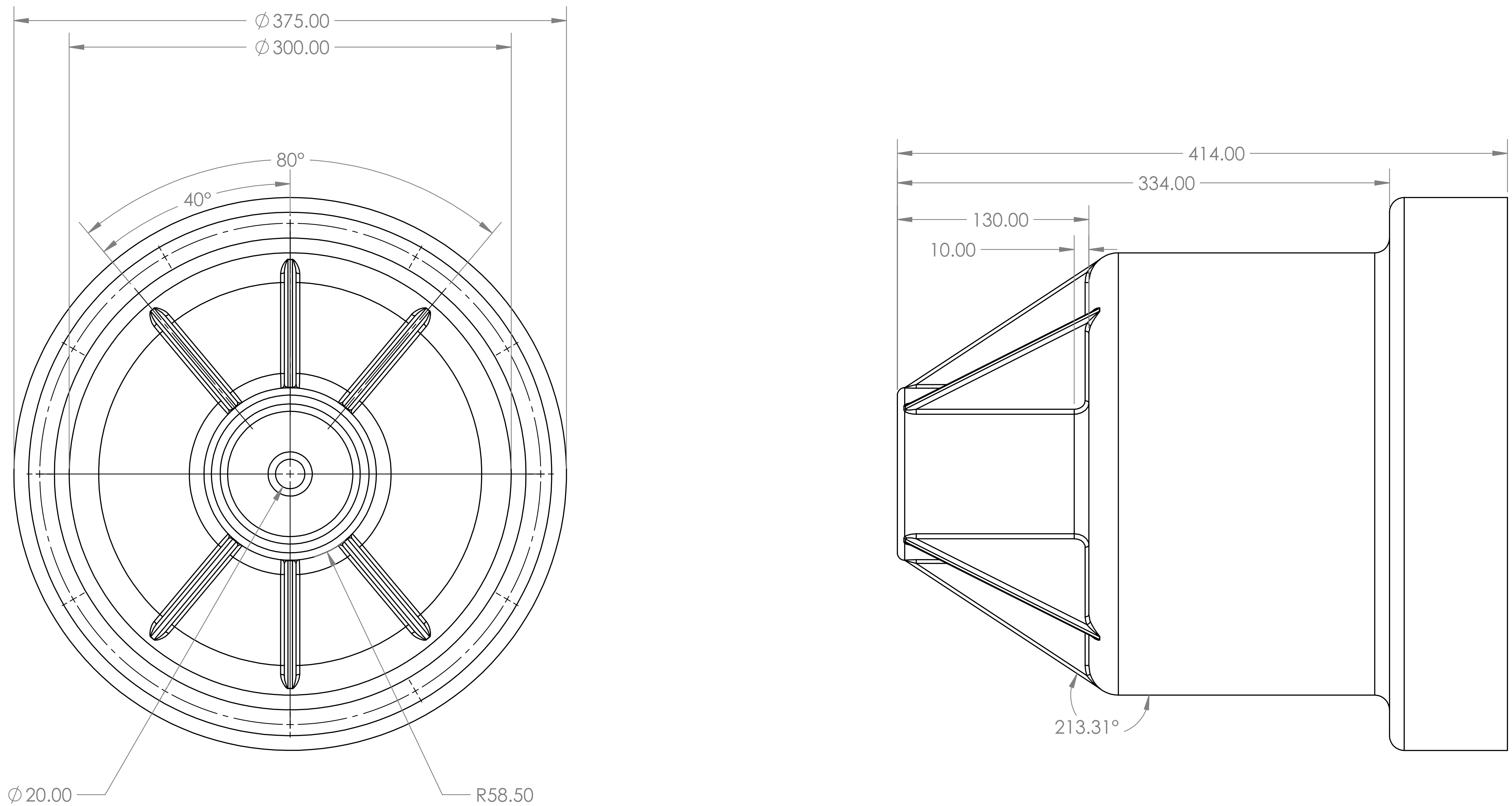

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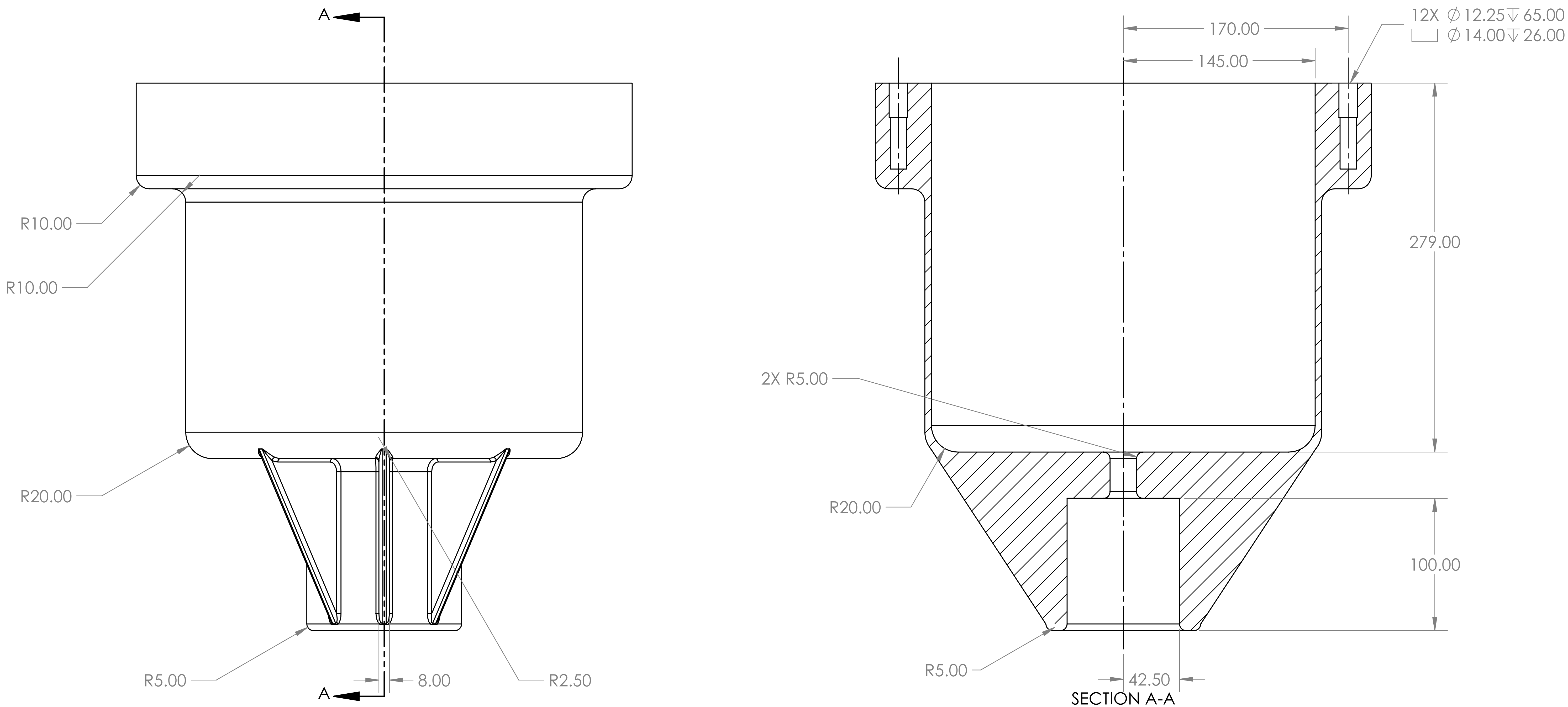
			CHECKED			TITLE: eMotor Housing
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminum Alloy 380	COMMENTS:			SIZE B DWG. NO. EMH 3.3 REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:3 WEIGHT: SHEET 1 OF 3



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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum Alloy 380

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/12/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

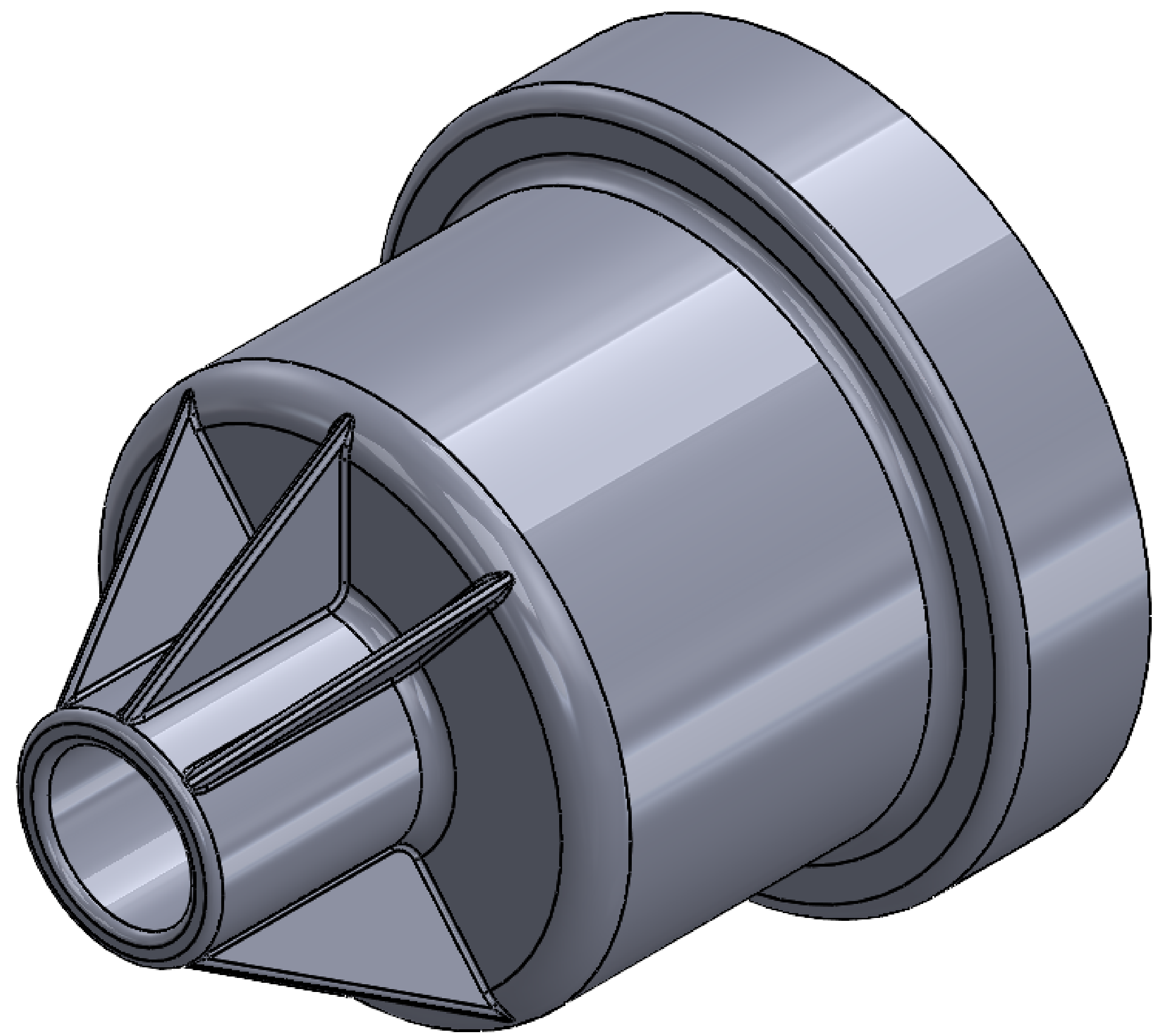
TITLE:
eMotor Housing

SIZE	DWG. NO.	REV
B	EMH 3.3	

SCALE: 1:3 WEIGHT: SHEET 2 OF 3

4 3 2 1

B



A

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APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum Alloy 380

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/12/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

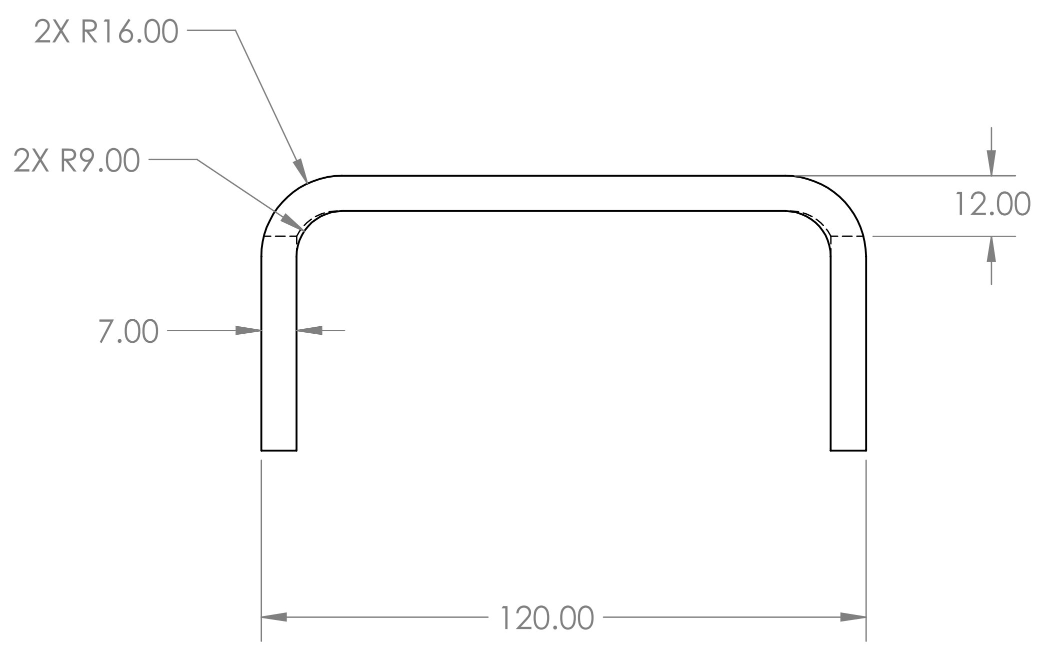
COMMENTS:

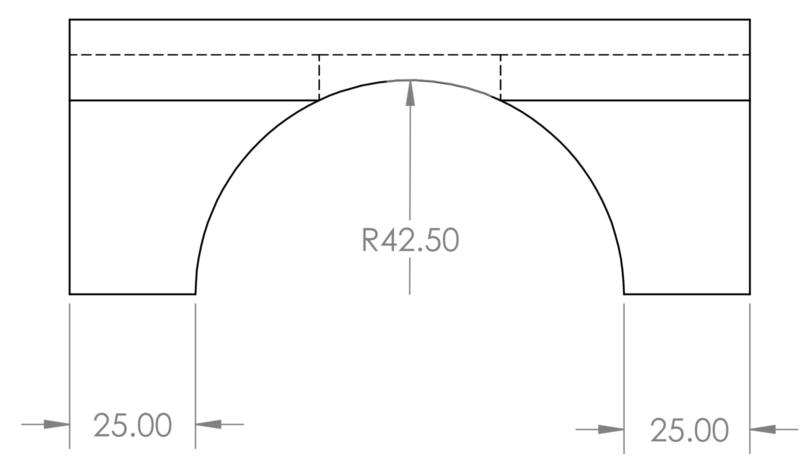
TITLE:
eMotor Housing

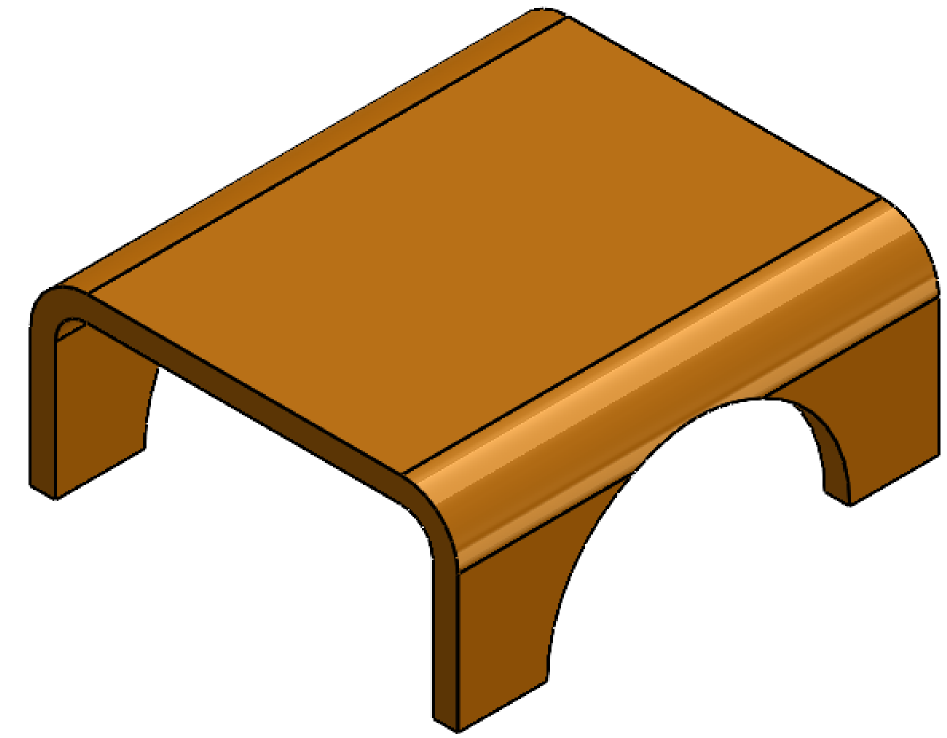
SIZE	DWG. NO.	REV
B	EMH 3.3	

SCALE: 1:3 WEIGHT: SHEET 3 OF 3

4 3 2 1







NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Structural Steel

FINISH

DO NOT SCALE DRAWING

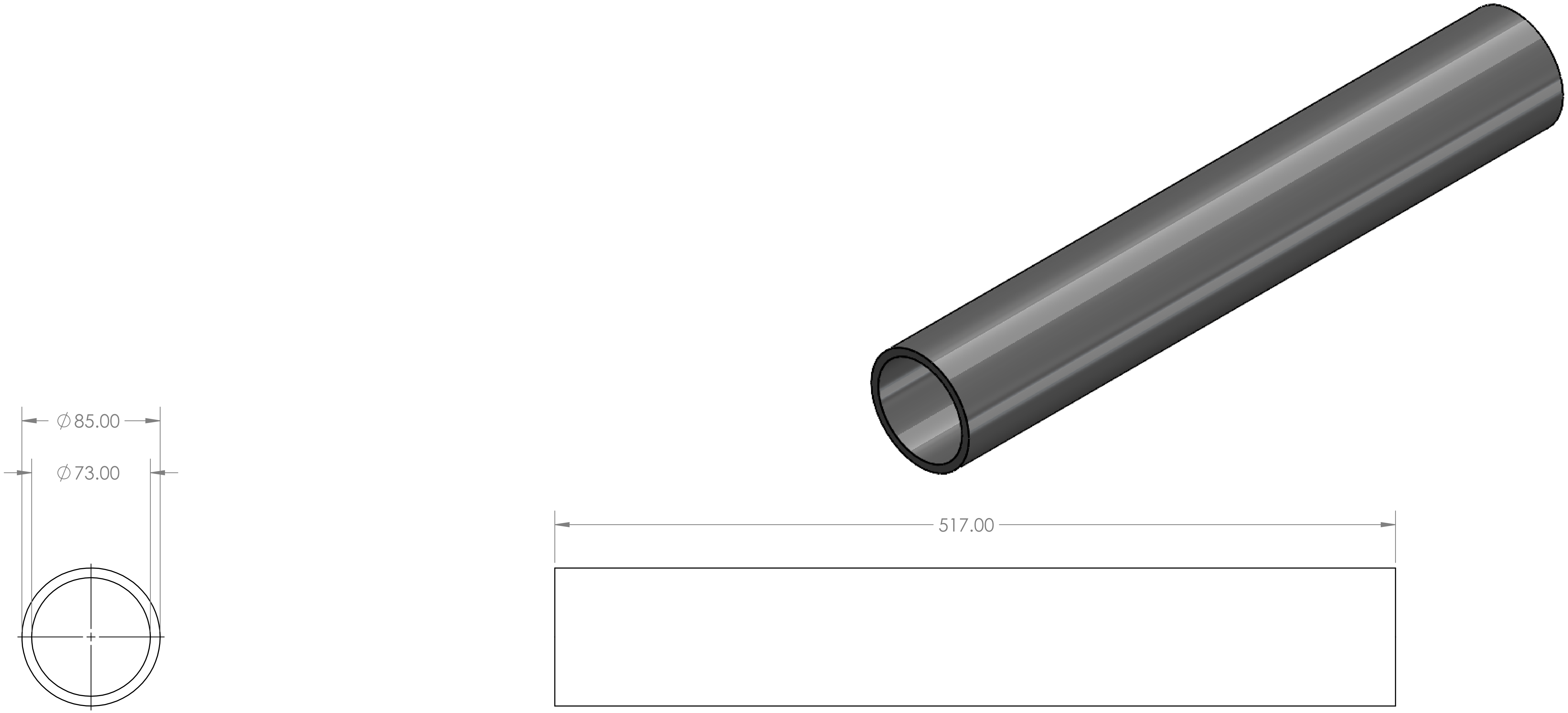
	NAME	DATE
DRAWN	AC	4/12/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Spring Perch

SIZE	DWG. NO.	REV
B	SP 2.0	

SCALE: 2:3 | WEIGHT: | SHEET 1 OF 1



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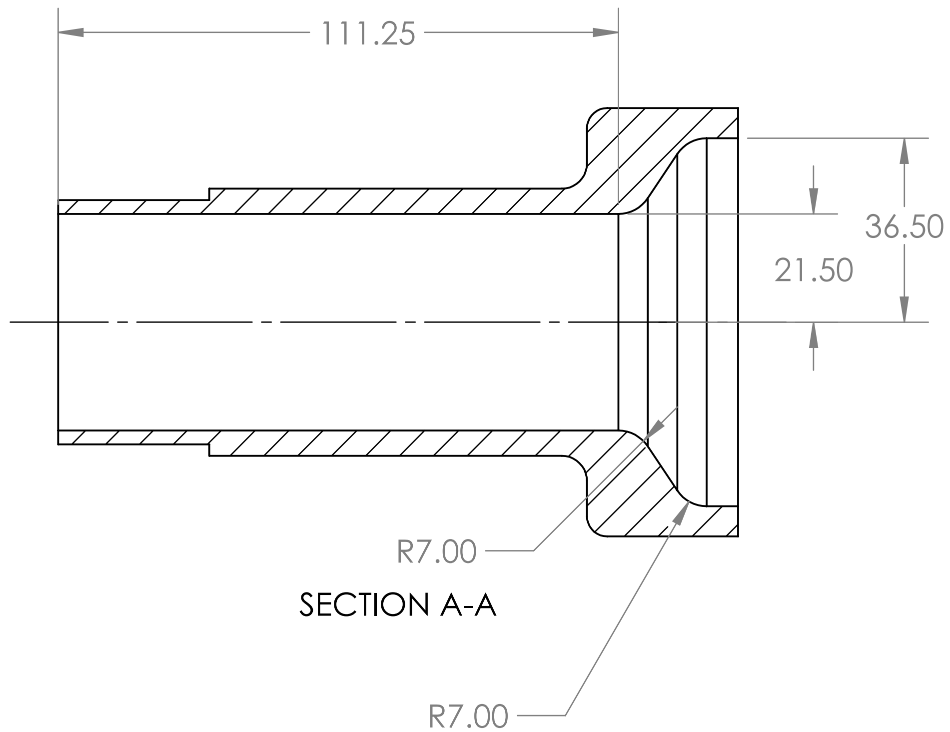
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Structural Steel	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

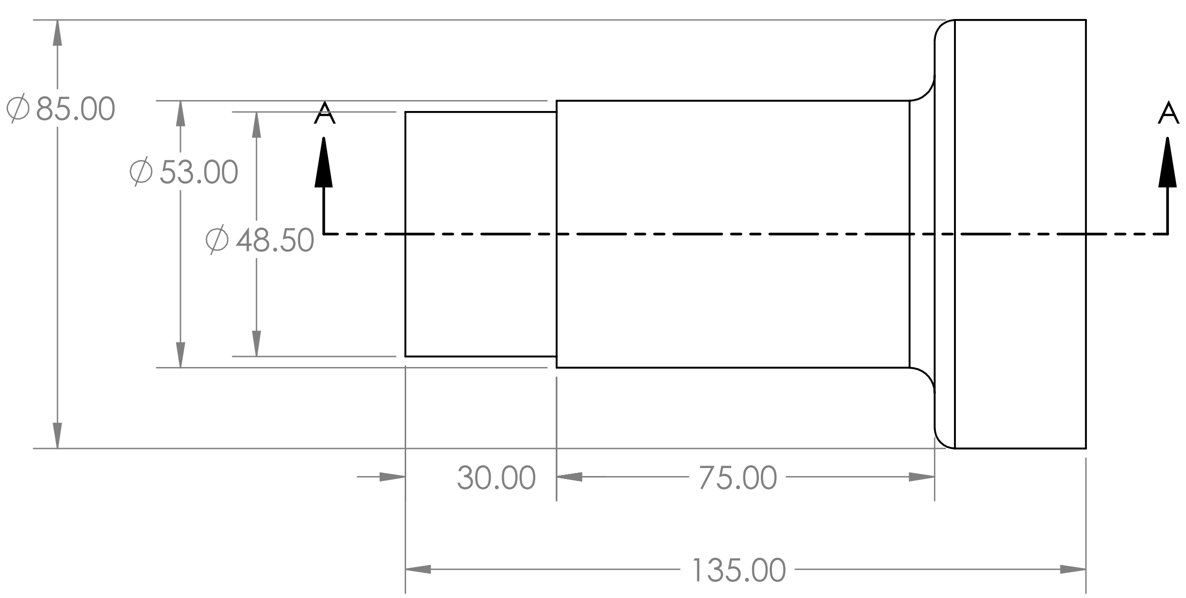
Axle Tube

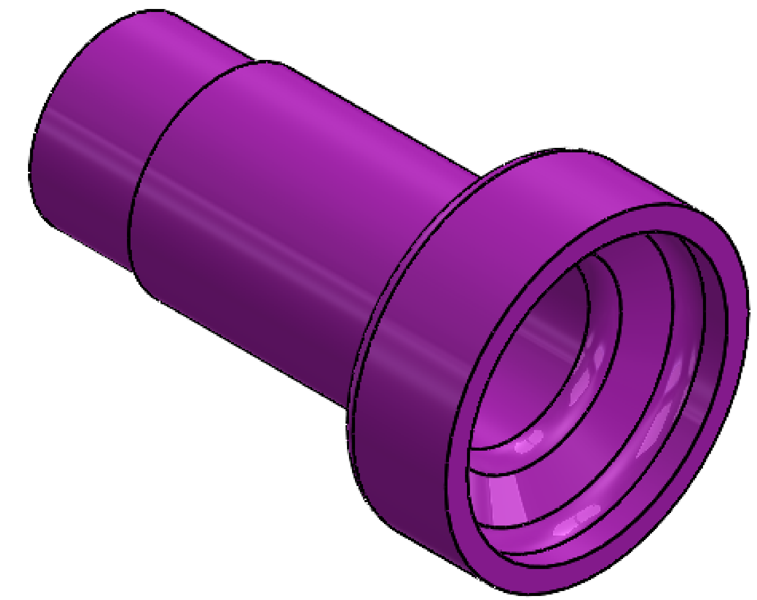
SIZE B | DWG. NO. 85mmTube | REV

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



SECTION A-A

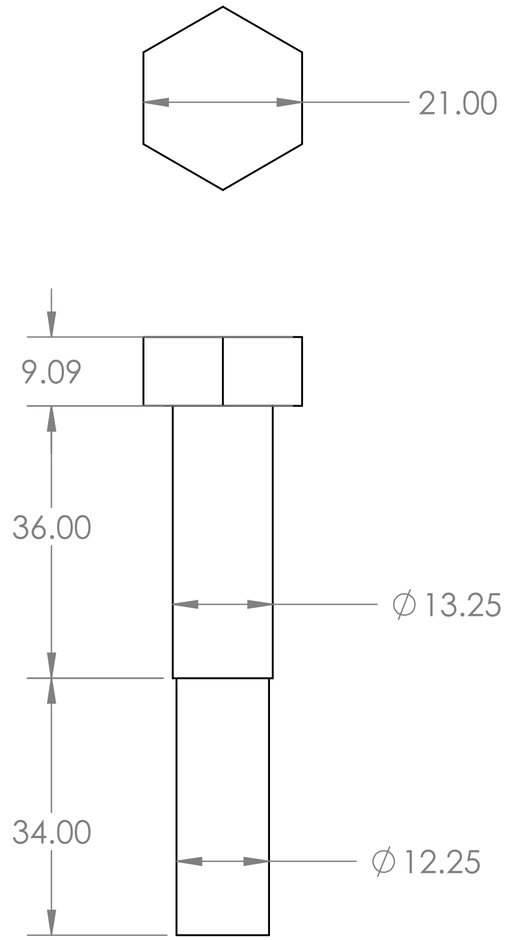


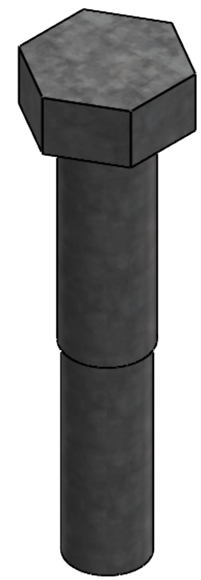


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AC	4/12/23	TITLE:
	CHECKED			Spindle
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Structural Steel	COMMENTS:			SIZE B DWG. NO. Spindle 1.0 REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 2:3 WEIGHT: SHEET 1 OF 1

NEXT ASSY | USED ON

APPLICATION





	NAME	DATE		
DRAWN	AC	4/10/23		
CHECKED				
ENG APPR.				
MFG APPR.				
Q.A.				
COMMENTS:				

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

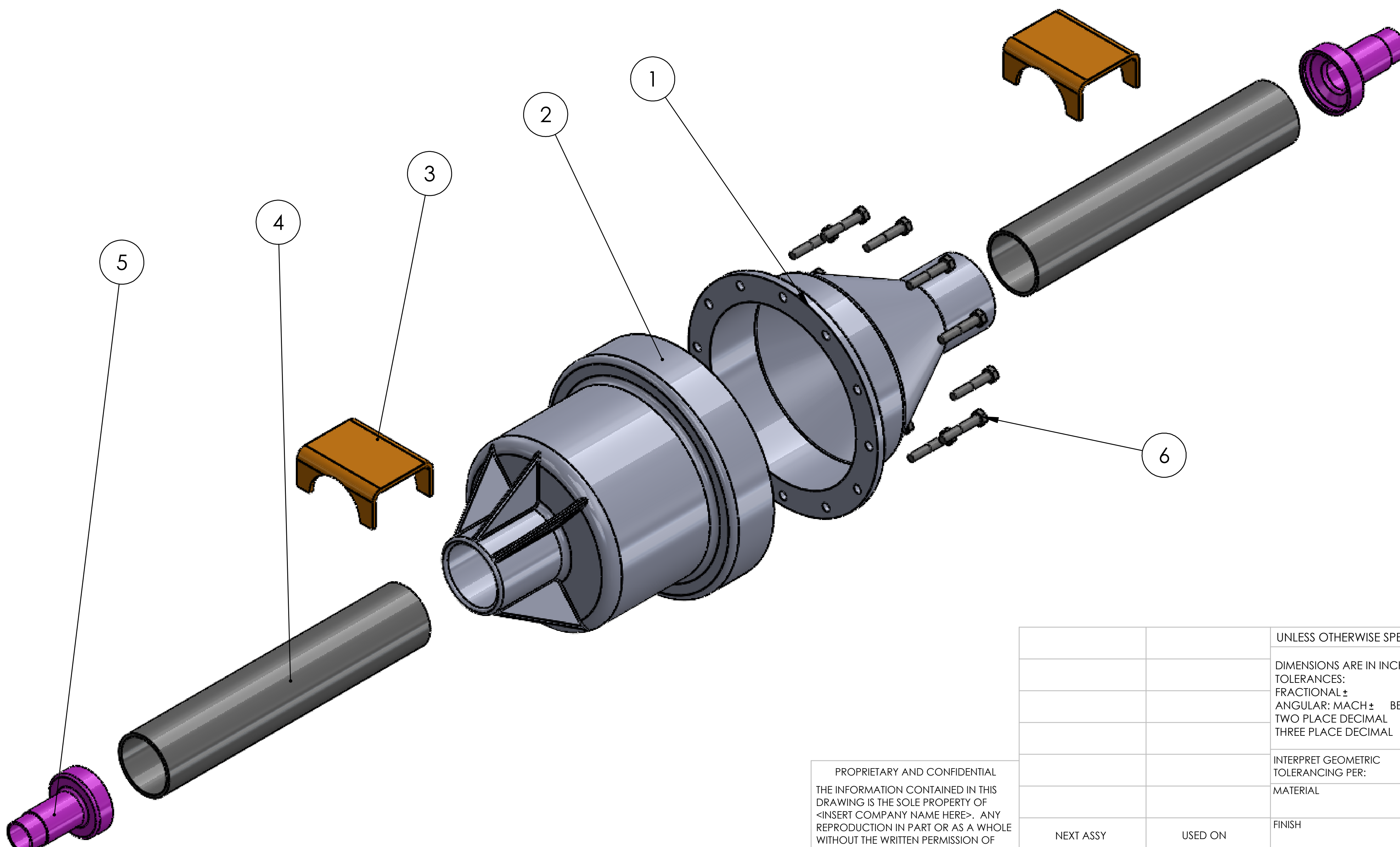
TITLE:

Hexhead Bolt

SIZE A | DWG. NO. M14B 1.2 | REV 1.2

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	GBH 4.0	Gearbox Housing	1
2	EMH 4.0	eMotor Housing	1
3	SP 2.1	Spring Perch	2
4	100mmTube	Axle Tube	2
5	Spindle 1.1	Spindle	2
6	M14B 1.2	Hexhead Bolt	12



NEXT ASSY | USED ON
APPLICATION

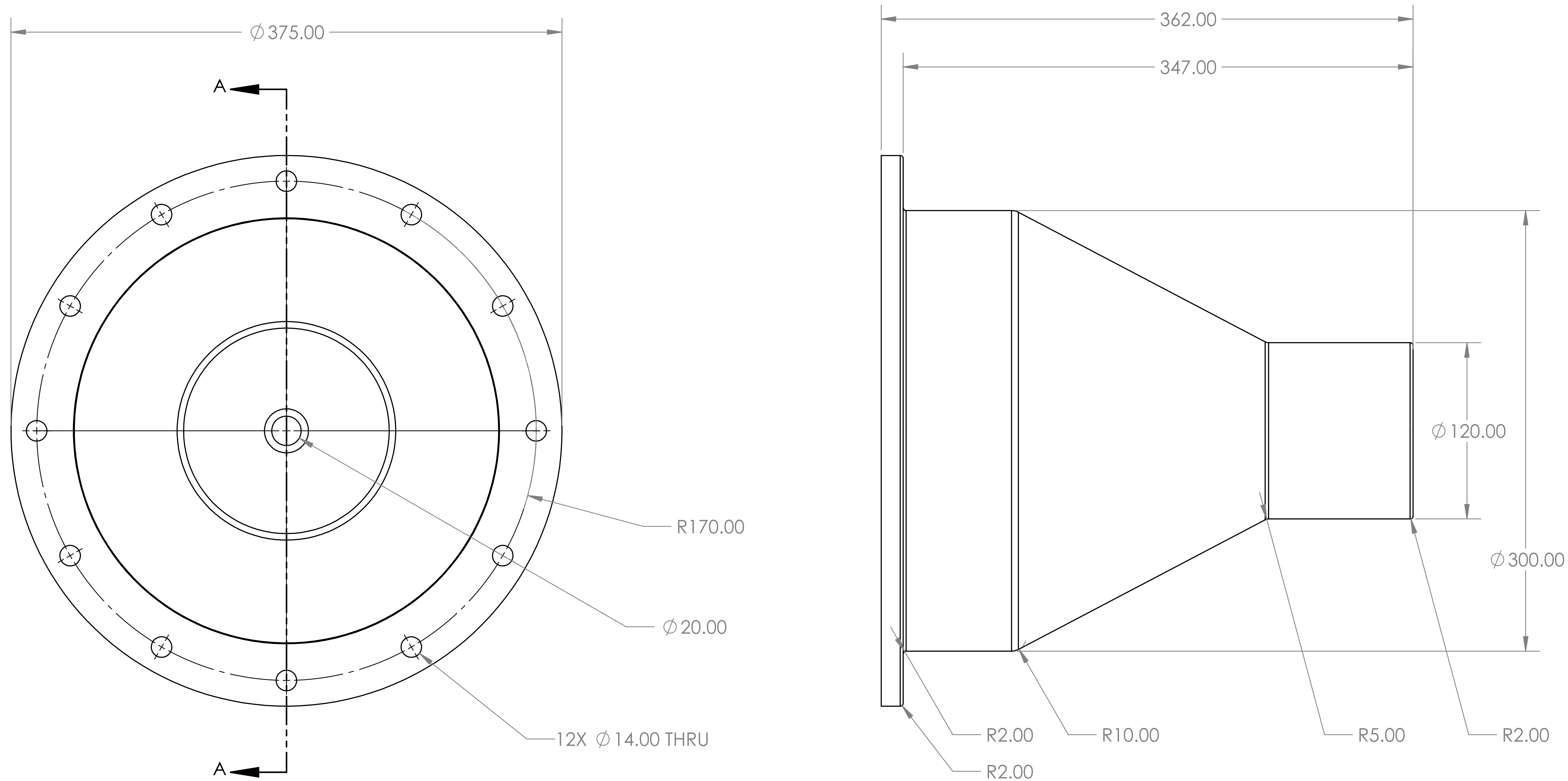
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/13/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE B | DWG. NO. Assembly 4.0 (7500) | REV
SCALE: 1:7 | WEIGHT: | SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Ductile Iron (Grade 80-55-06)

FINISH

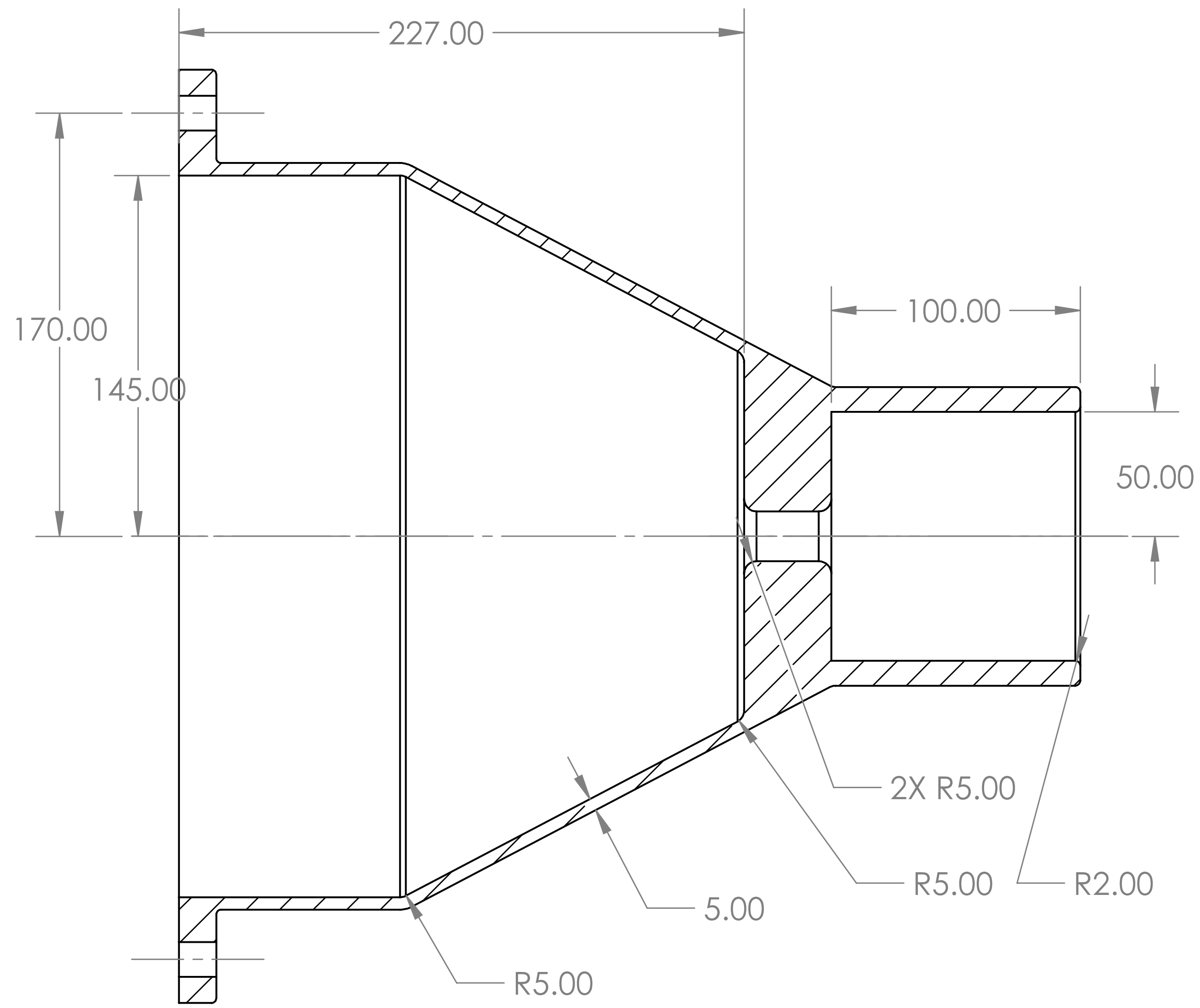
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

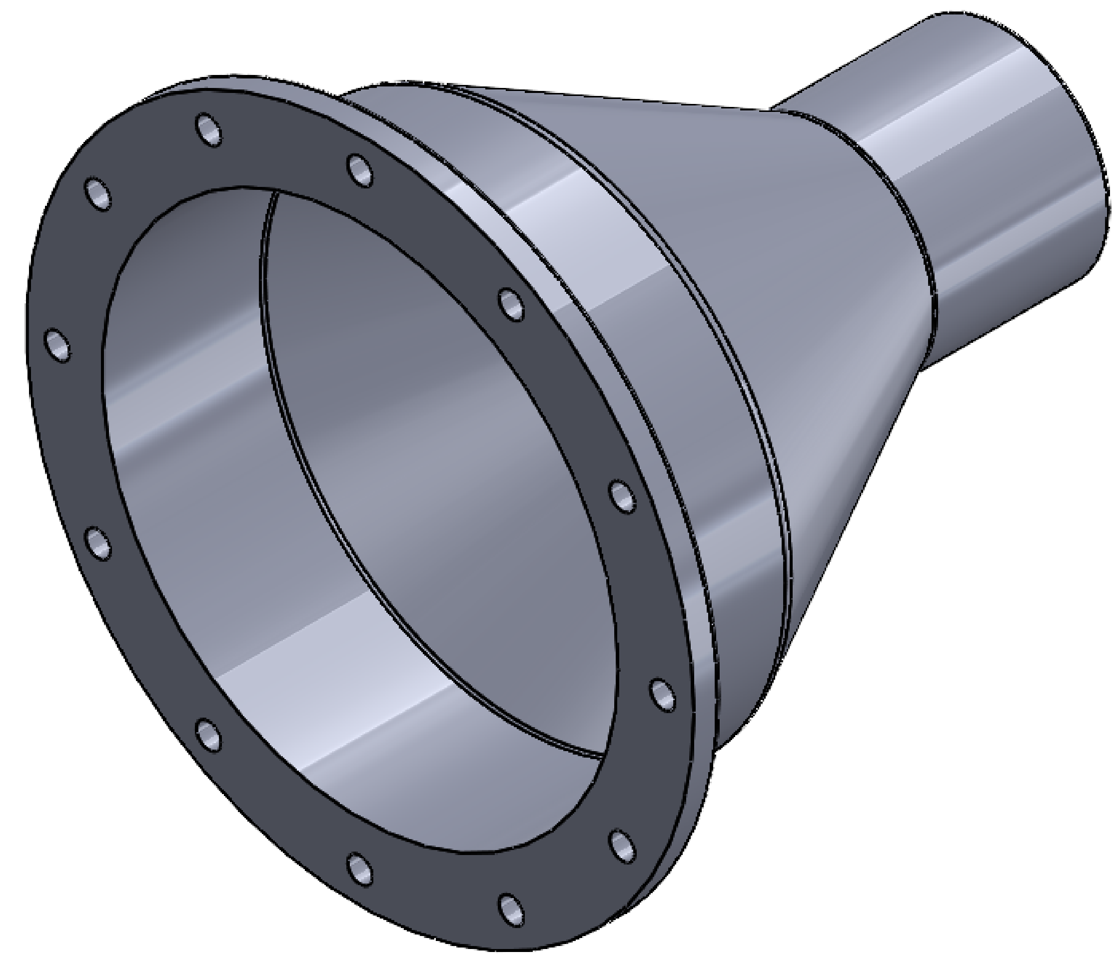
TITLE:
Gearbox Housing

SIZE B | DWG. NO. GBH 4.0 | REV

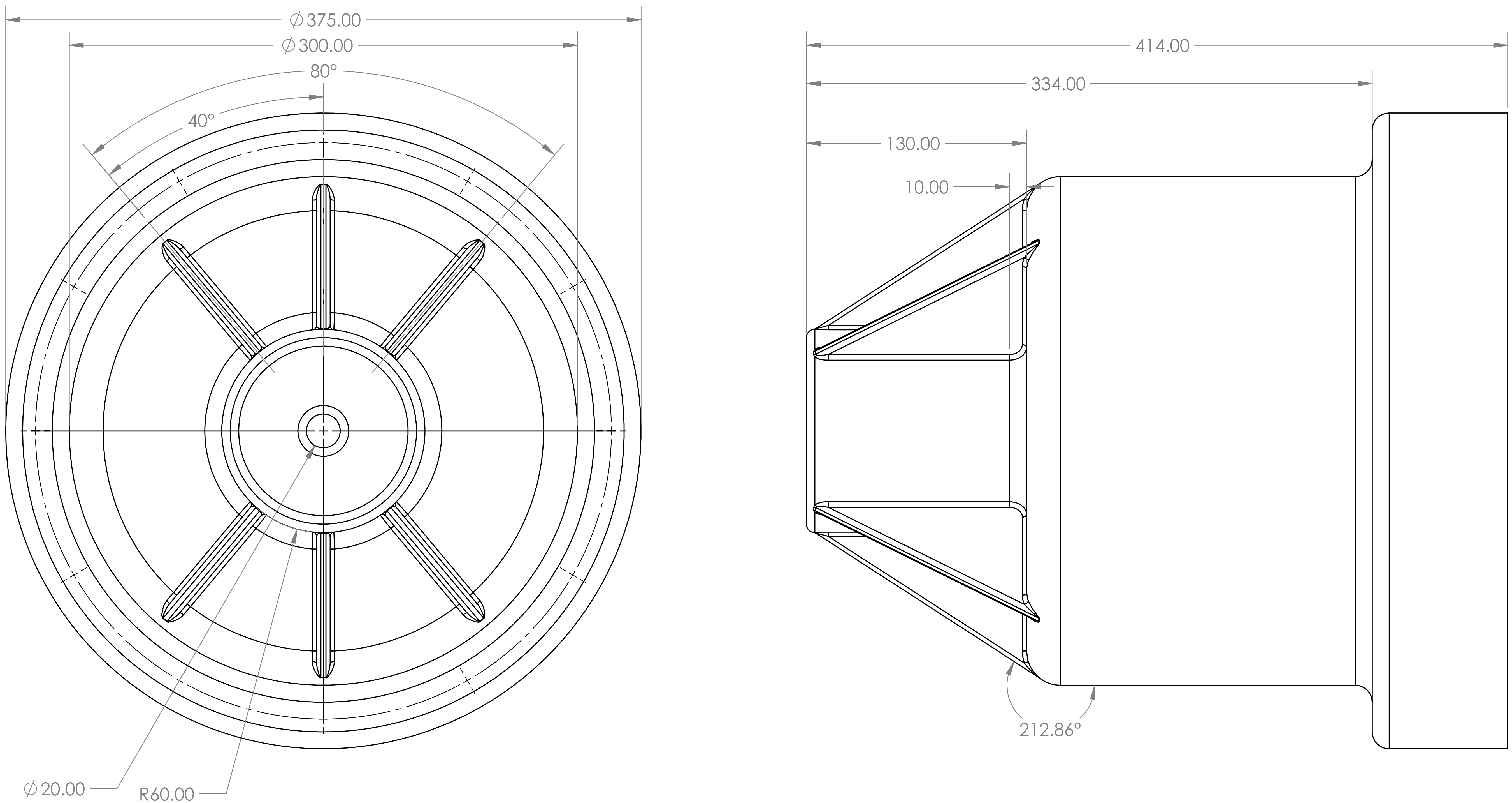
SCALE: 1:3 | WEIGHT: | SHEET 1 OF 2



SECTION A-A



PROPRIETARY AND CONFIDENTIAL	UNLESS OTHERWISE SPECIFIED:	DRAWN: AC, 4/11/23	TITLE: Gearbox Housing
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	CHECKED ENG APPR. MFG APPR. Q.A. COMMENTS:	SIZE: B DWG. NO.: GBH 4.0 REV
NEXT ASSY / USED ON	INTERPRET GEOMETRIC TOLERANCING PER:		
APPLICATION	MATERIAL: Ductile Iron (Grade 80-55-06)		
	FINISH		
	DO NOT SCALE DRAWING		SCALE: 1:3 WEIGHT: SHEET 2 OF 2



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AC	4/11/23
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Ductile Iron (Grade 80-55-06)	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

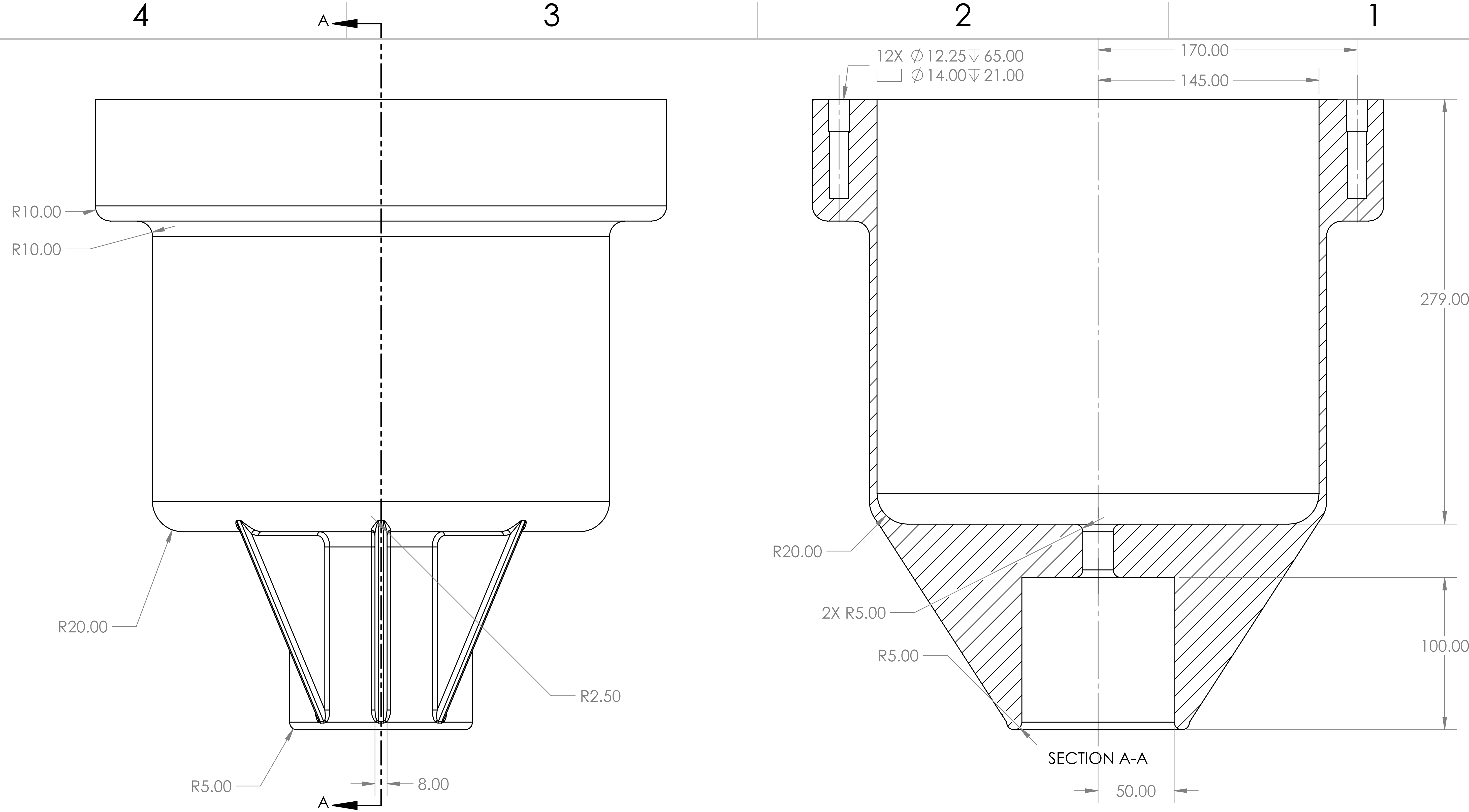
NEXT ASSY	USED ON
APPLICATION	

TITLE:

eMotor Housing

SIZE B DWG. NO. EMH 4.0 REV

SCALE: 2:5 WEIGHT: SHEET 1 OF 3



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NEXT ASSY	USED ON	
APPLICATION		DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Ductile Iron (Grade 80-55-06)

FINISH

	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

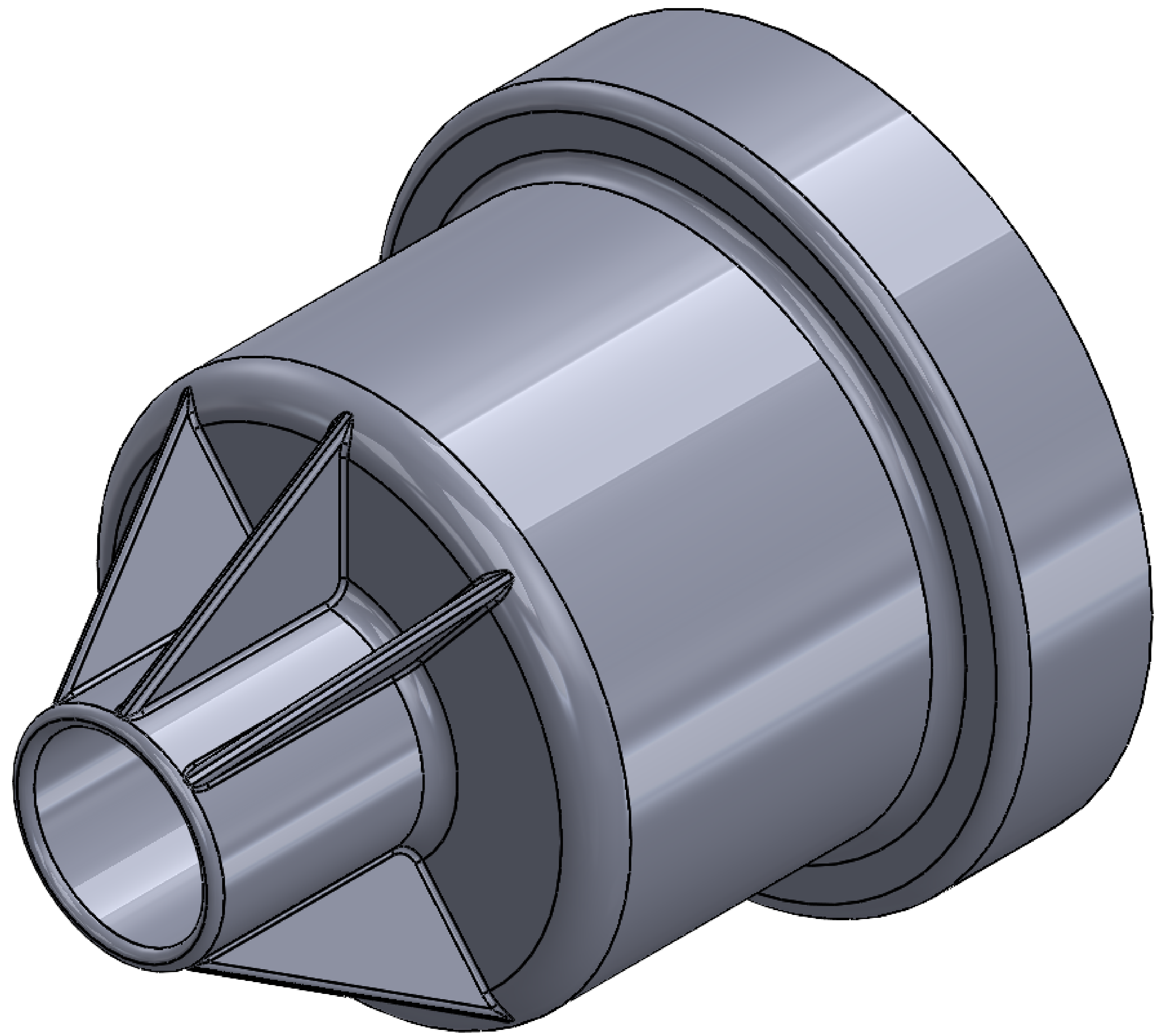
TITLE:
eMotor Housing

SIZE	DWG. NO.	REV
B	EMH 4.0	

SCALE: 2:5 WEIGHT: SHEET 2 OF 3

4 3 2 1

B B



A A

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Ductile Iron (Grade 80-55-06)

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

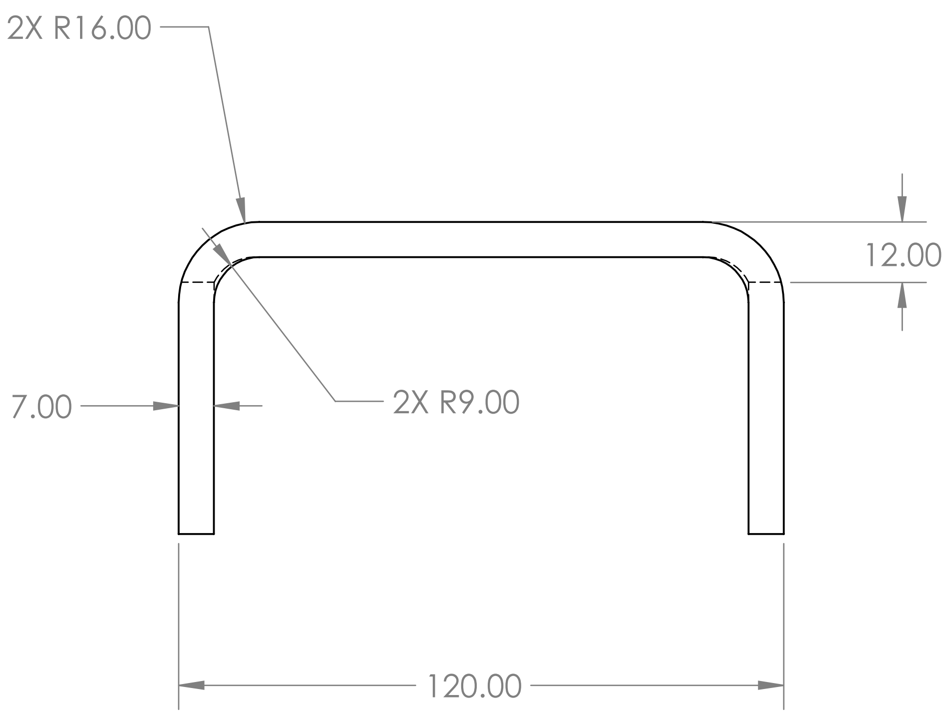
COMMENTS:

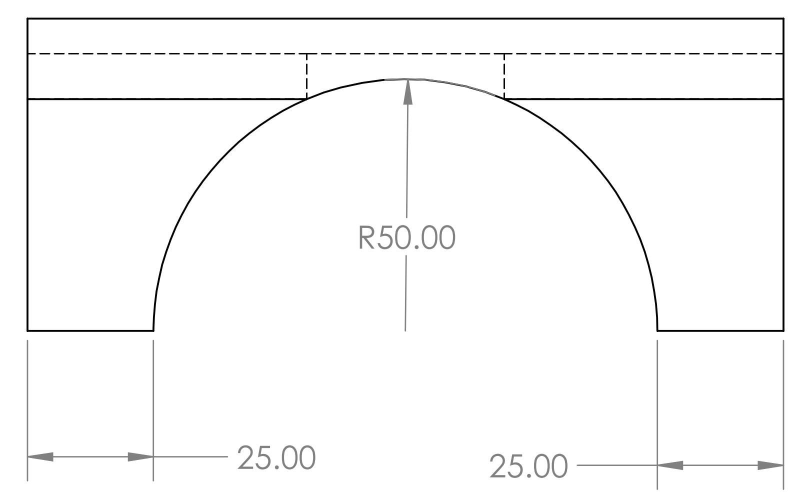
TITLE:
eMotor Housing

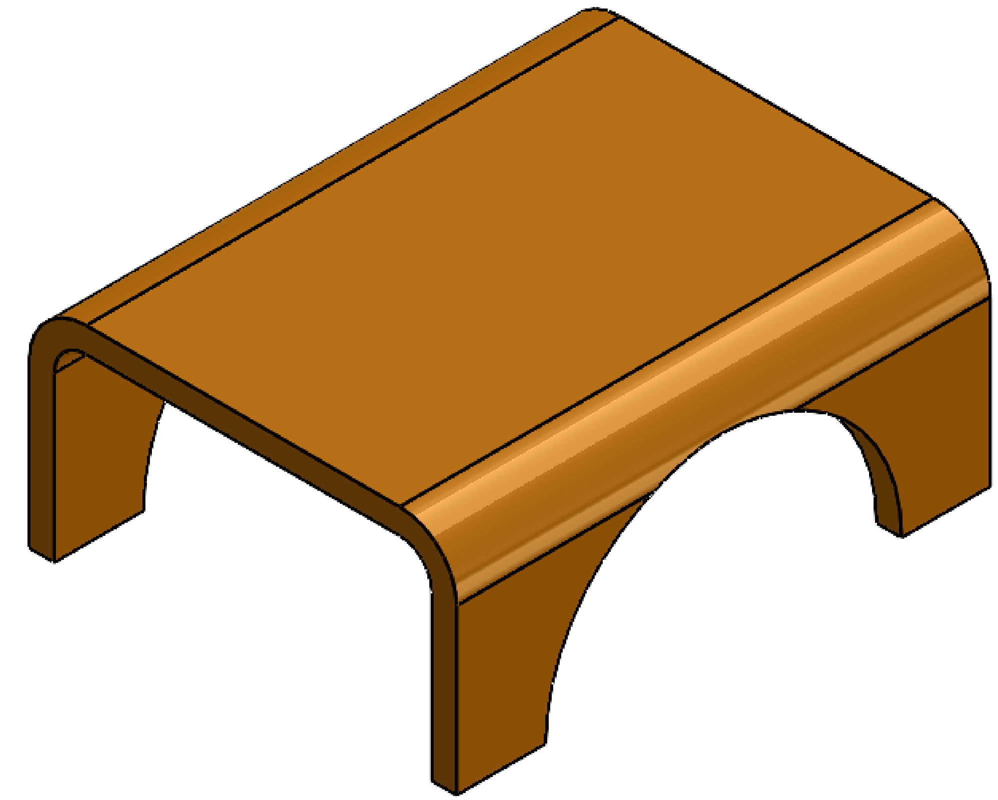
SIZE	DWG. NO.	REV
B	EMH 4.0	

SCALE: 2:5 WEIGHT: SHEET 3 OF 3

4 3 2 1







		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AC	4/11/23
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Structural Steel	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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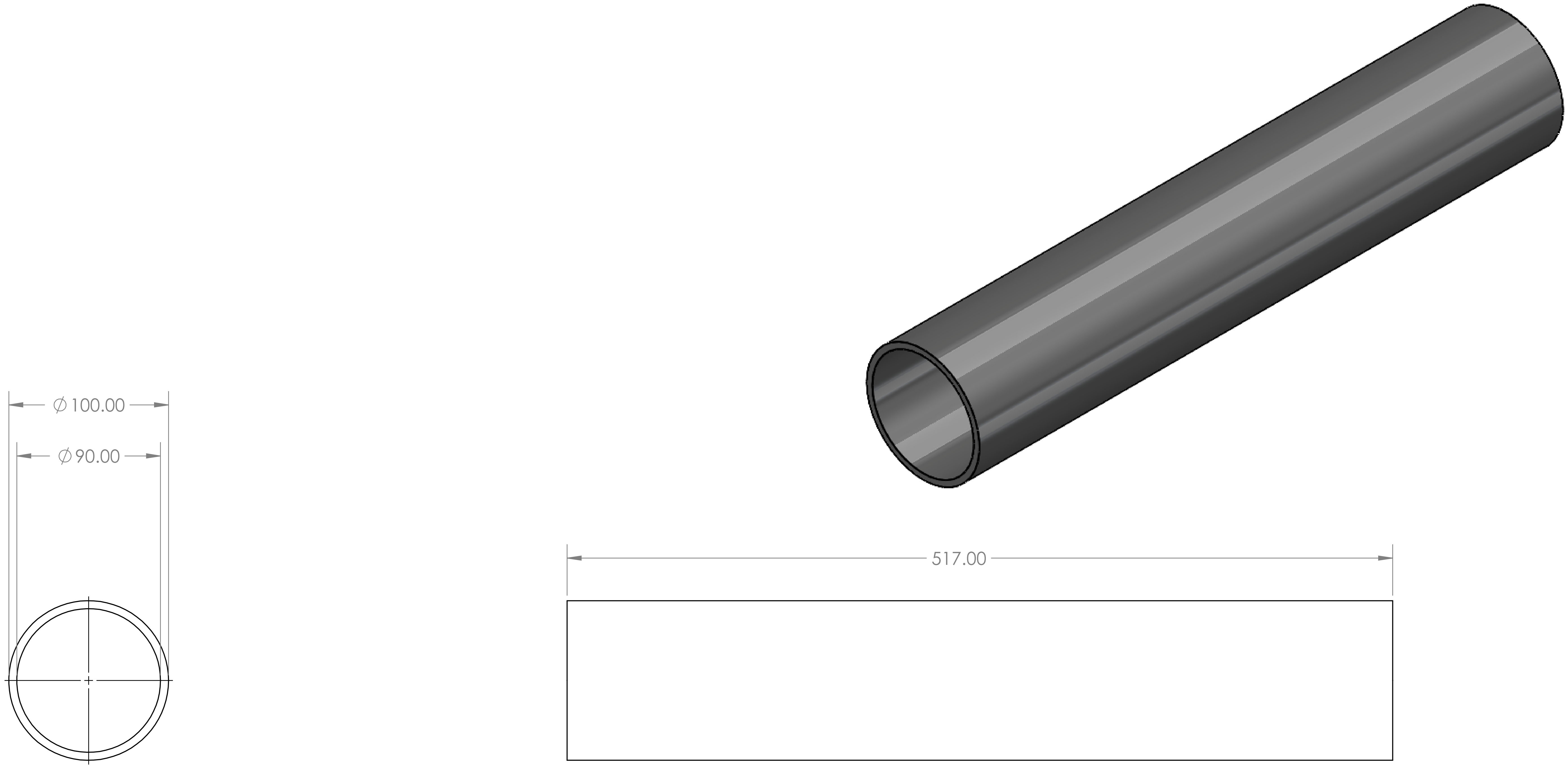
TITLE:

Spring Perch

SIZE	DWG. NO.	REV
B	SP 2.1	

SCALE: 2:3 WEIGHT: SHEET 1 OF 1



NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Structural Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

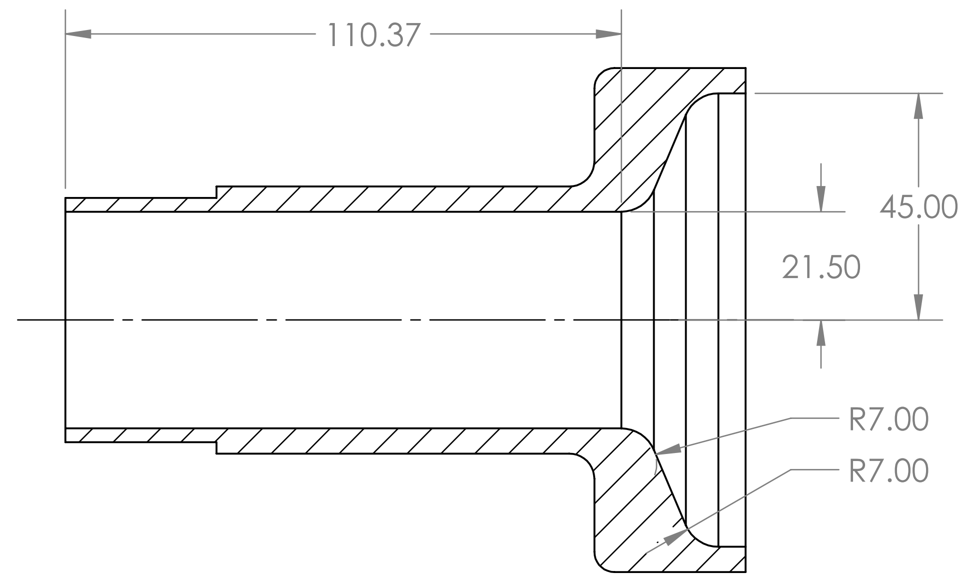
COMMENTS:

TITLE:
Axle Tube

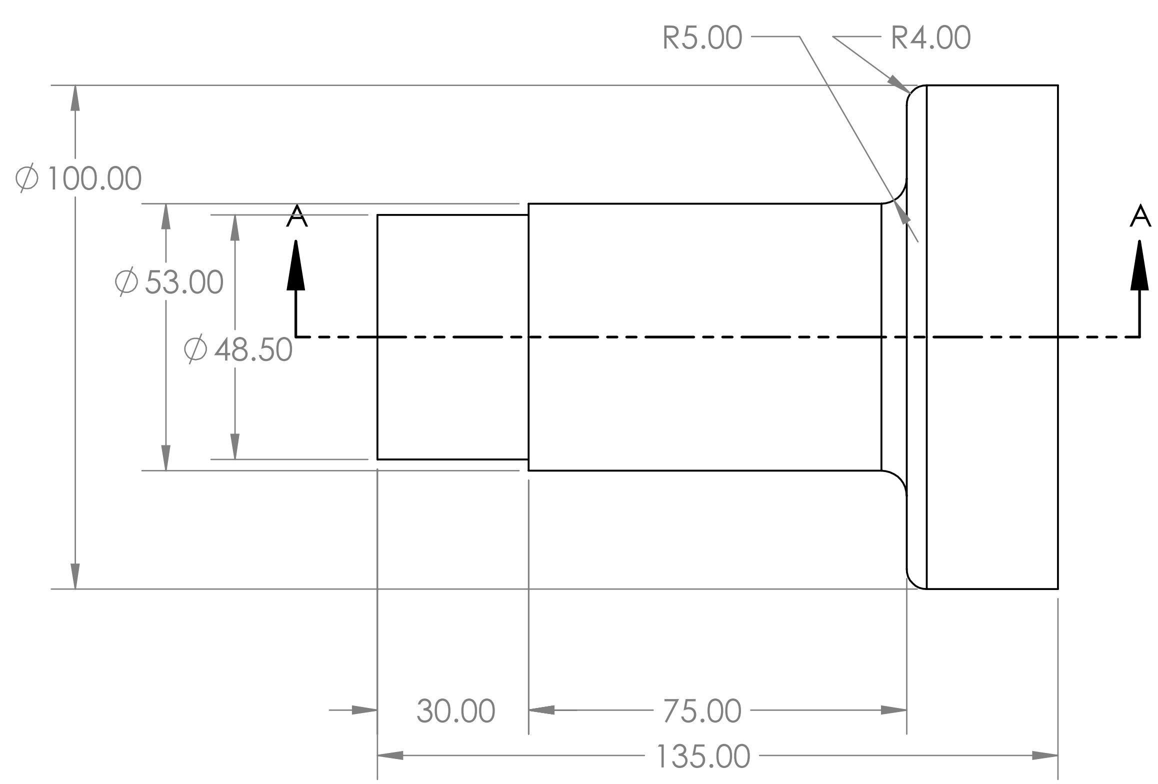
SIZE	DWG. NO.	REV
B	100mmTube	

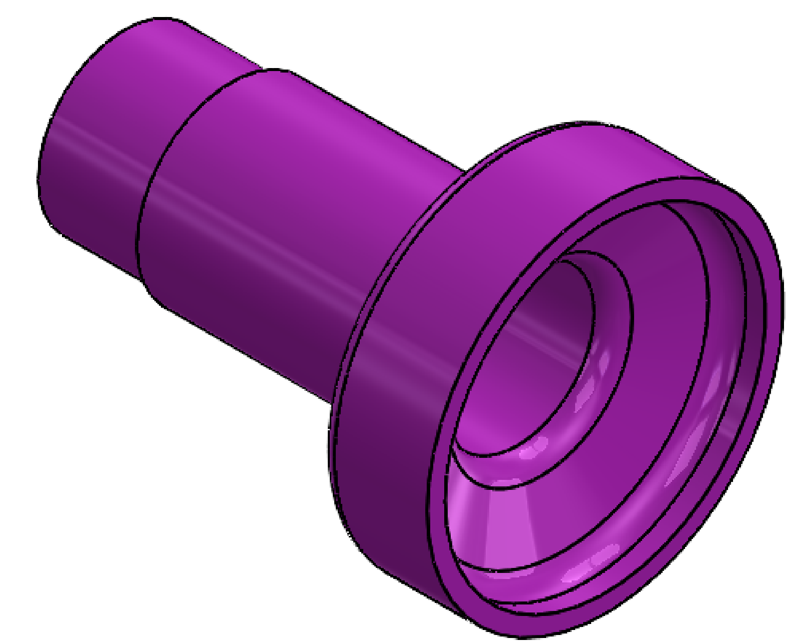
SCALE: 3:8 WEIGHT: SHEET 1 OF 1

4 3 2 1



SECTION A-A





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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Structural Steel

FINISH

DO NOT SCALE DRAWING

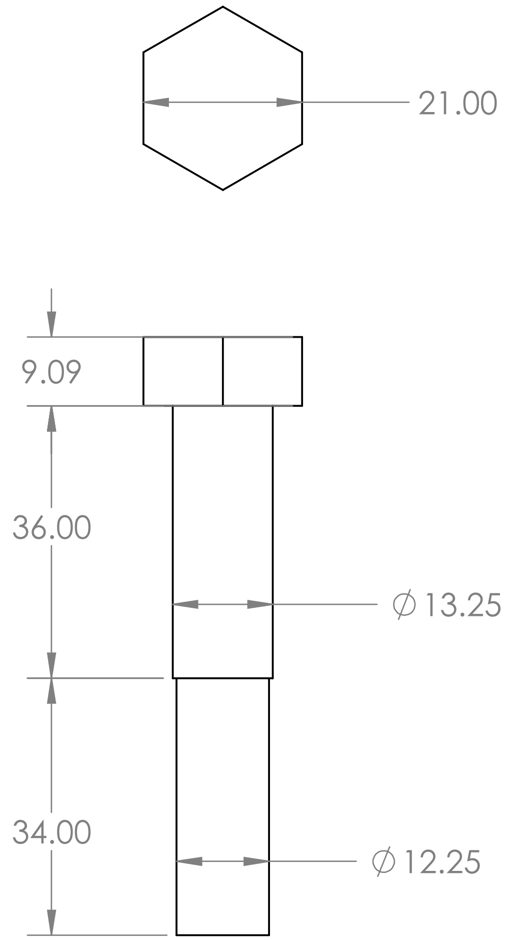
	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

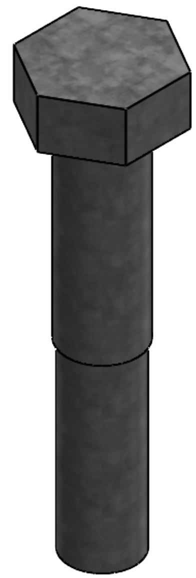
COMMENTS:

TITLE:

Spindle

SIZE	DWG. NO.	REV
B	Spindle 1.1	
SCALE: 2:3	WEIGHT:	SHEET 1 OF 1





PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/10/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

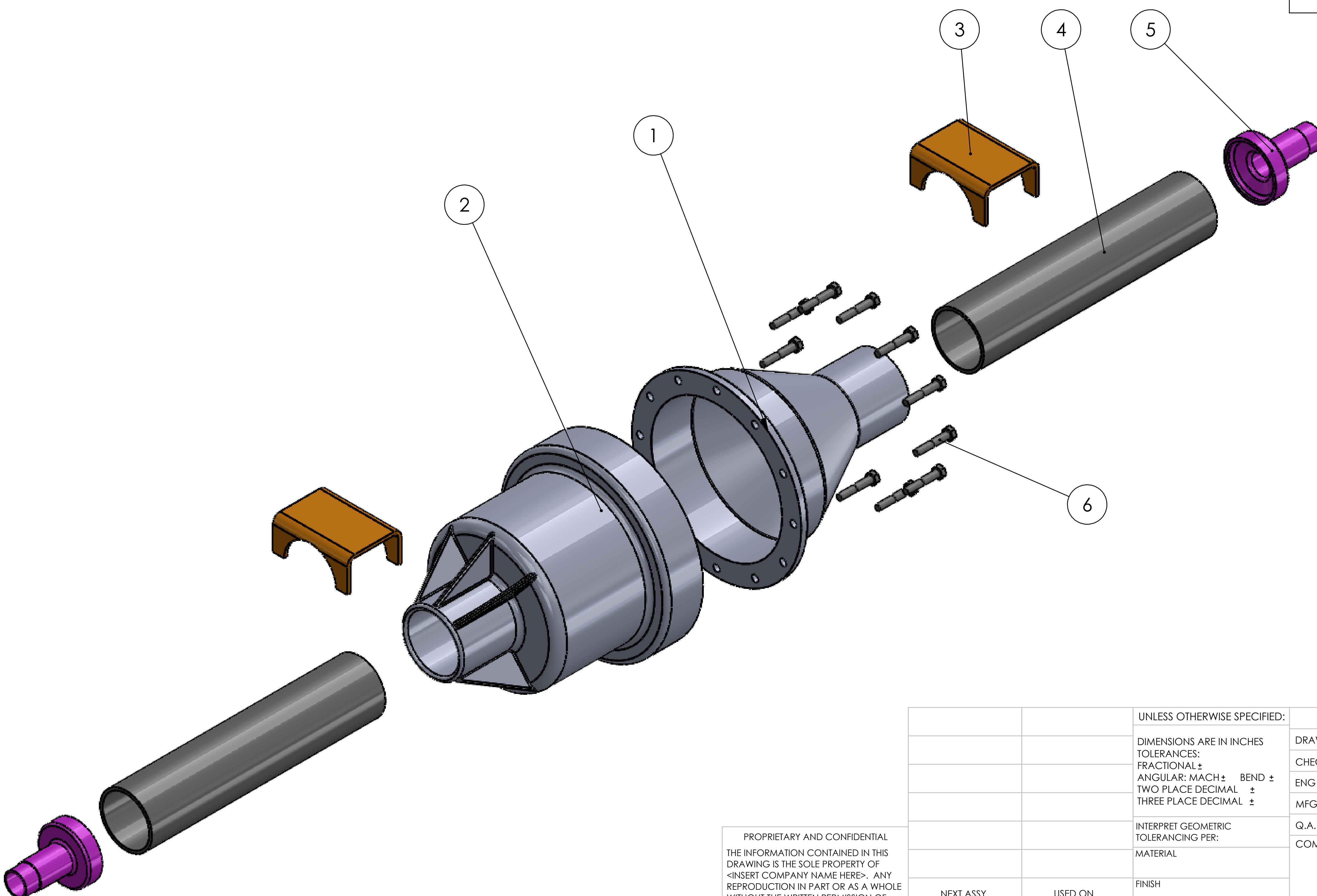
TITLE:

Hexhead Bolt

SIZE	DWG. NO.	REV
A	M14B 1.2	1.2

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	GBH 5.0	Gearbox Housing	1
2	EMH 5.0	eMotor Housing	1
3	SP 2.2	Spring Perch	2
4	115mmTube	Axle Tube	2
5	Spindle 1.2	Spindle	2
6	M14B 1.2	Hexhead Bolt	12



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

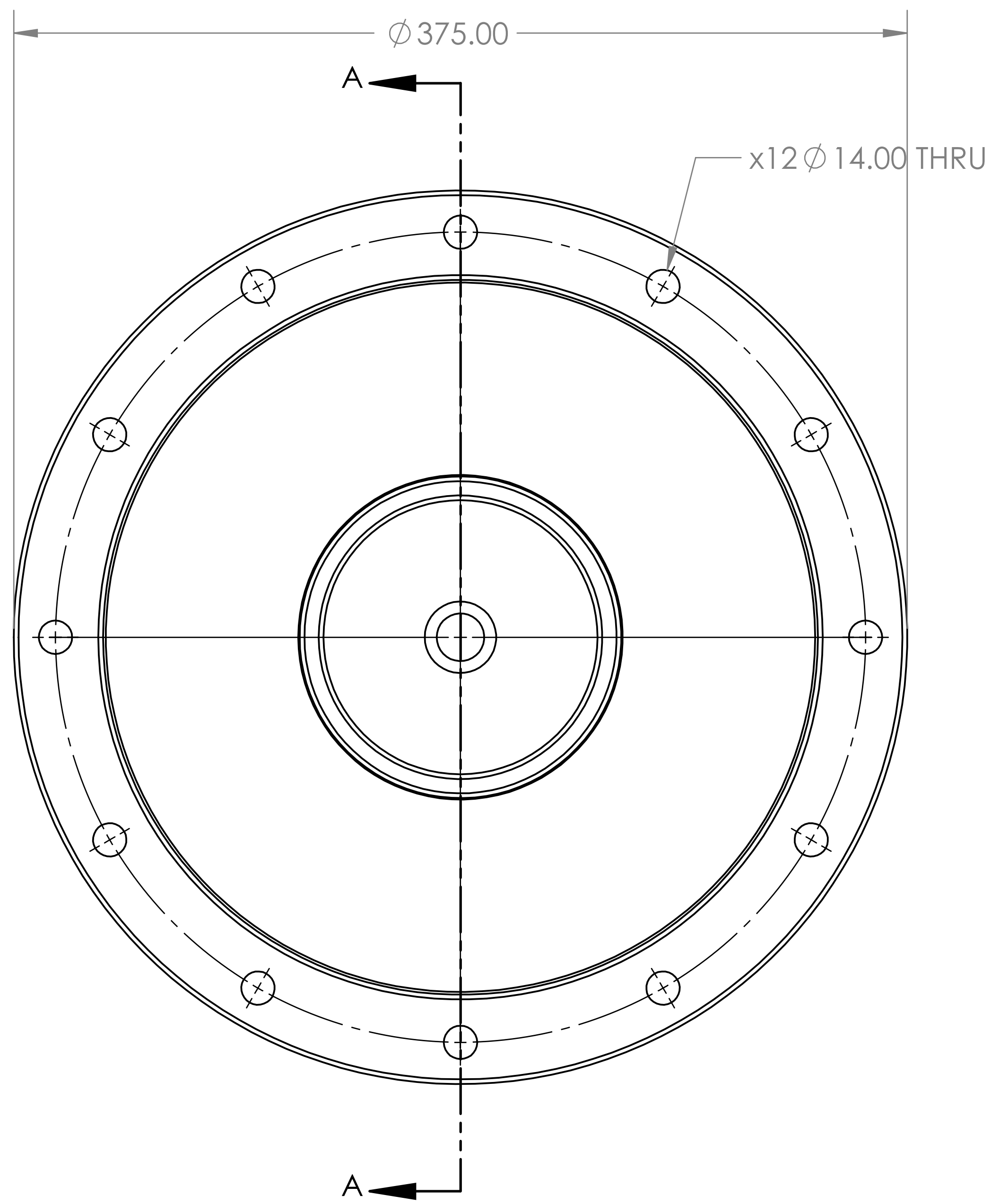
DO NOT SCALE DRAWING

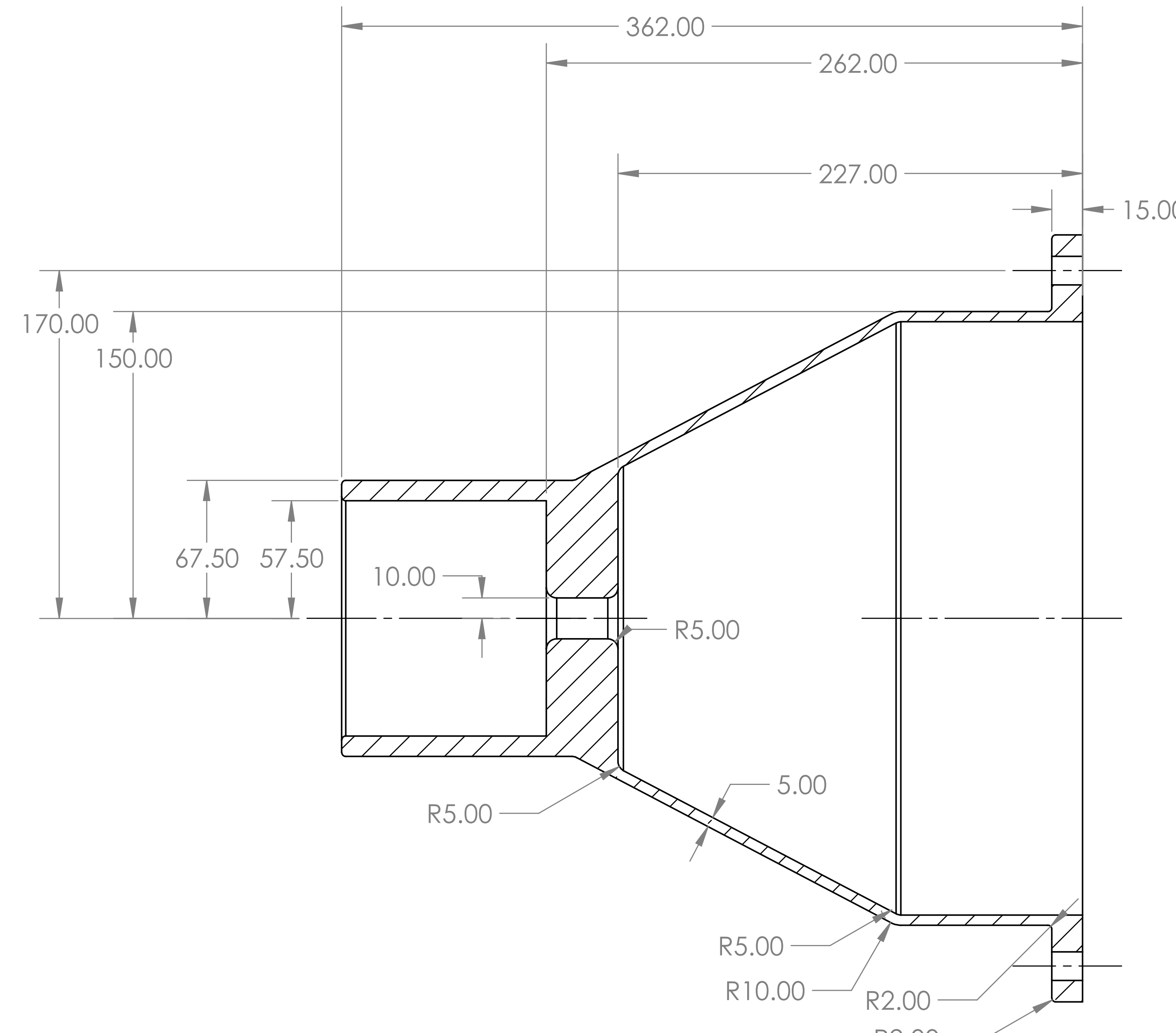
	NAME	DATE
DRAWN	AC	4/13/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Assembly 5.0 (10k)	
SCALE: 1:7	WEIGHT:	SHEET 1 OF 1

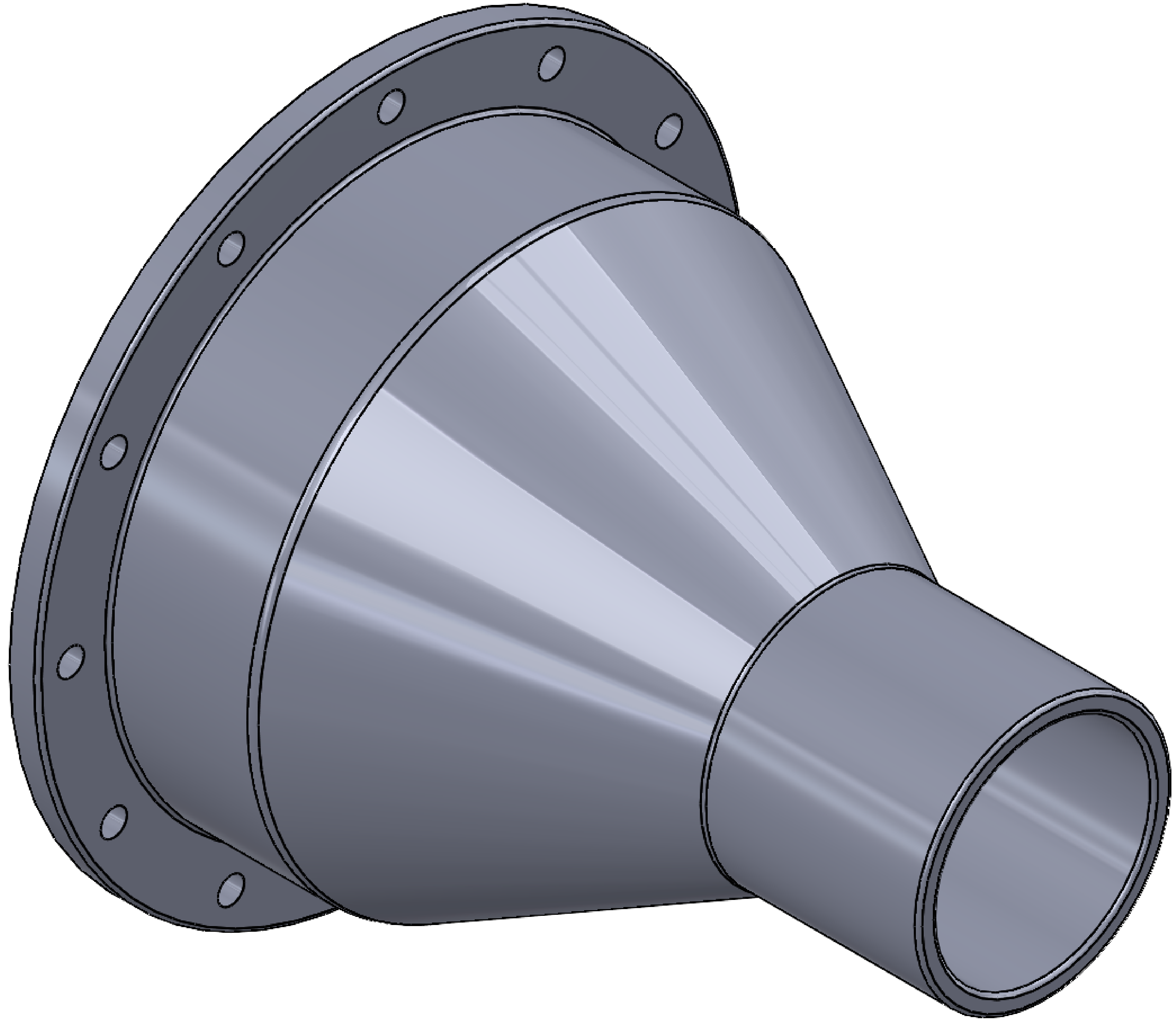




SECTION A-A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AC	4/10/23	TITLE:	Gearbox Housing
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Ductile Iron (Grade 100-70-03)	COMMENTS:			SIZE B	DWG. NO. GBH 5.0 — REV 5.0
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:3	WEIGHT: — SHEET 1 OF 2

NEXT ASSY	USED ON
APPLICATION	



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AC	4/10/23	
	CHECKED			TITLE: Gearbox Housing
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Ductile Iron (Grade 100-70-03)	COMMENTS:			SIZE B / DWG. NO. GBH 5.0 / REV 5.0
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 / WEIGHT: / SHEET 2 OF 2

NEXT ASSY	USED ON
APPLICATION	

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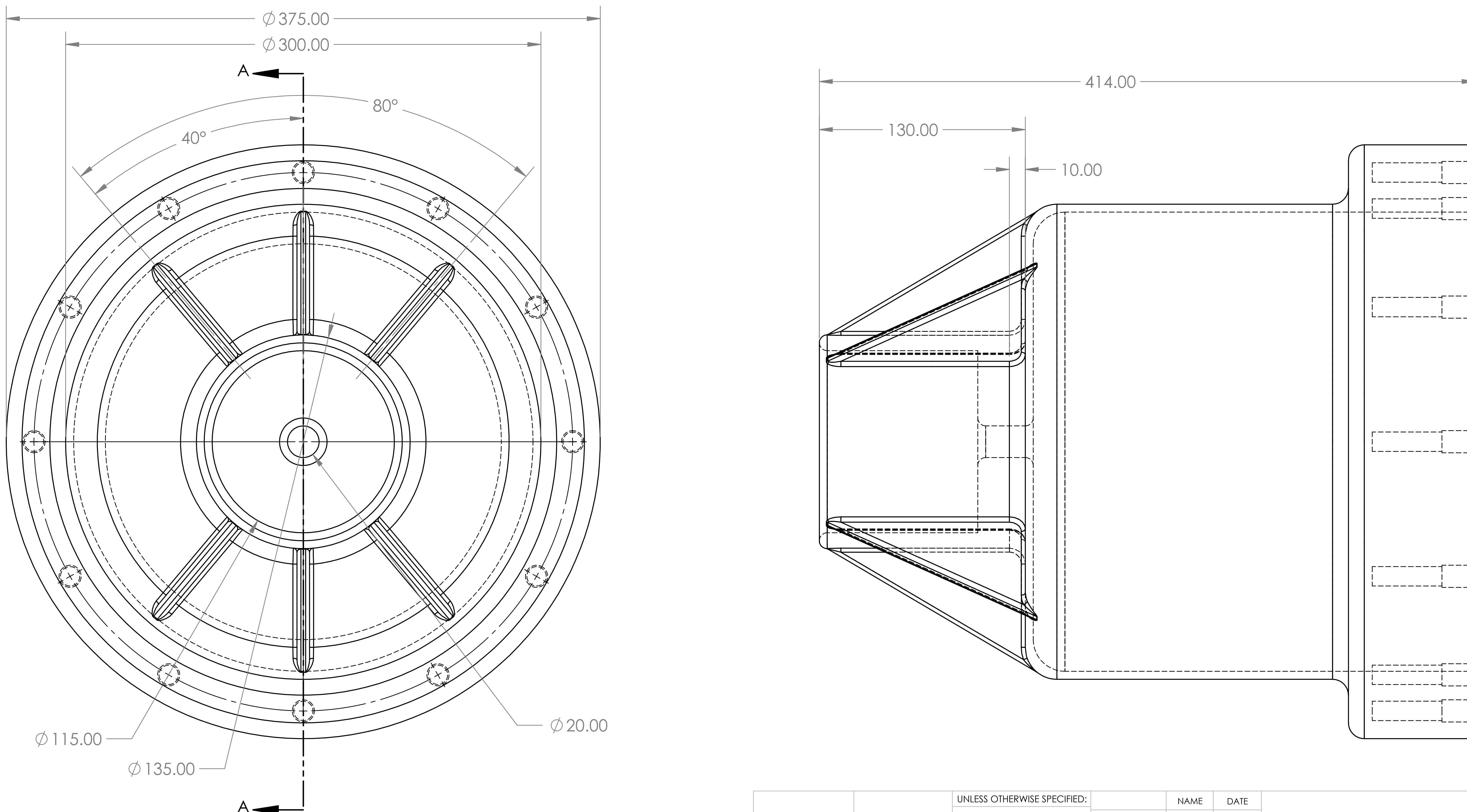

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Ductile Iron (Grade 100-70-03)

FINISH

DO NOT SCALE DRAWING

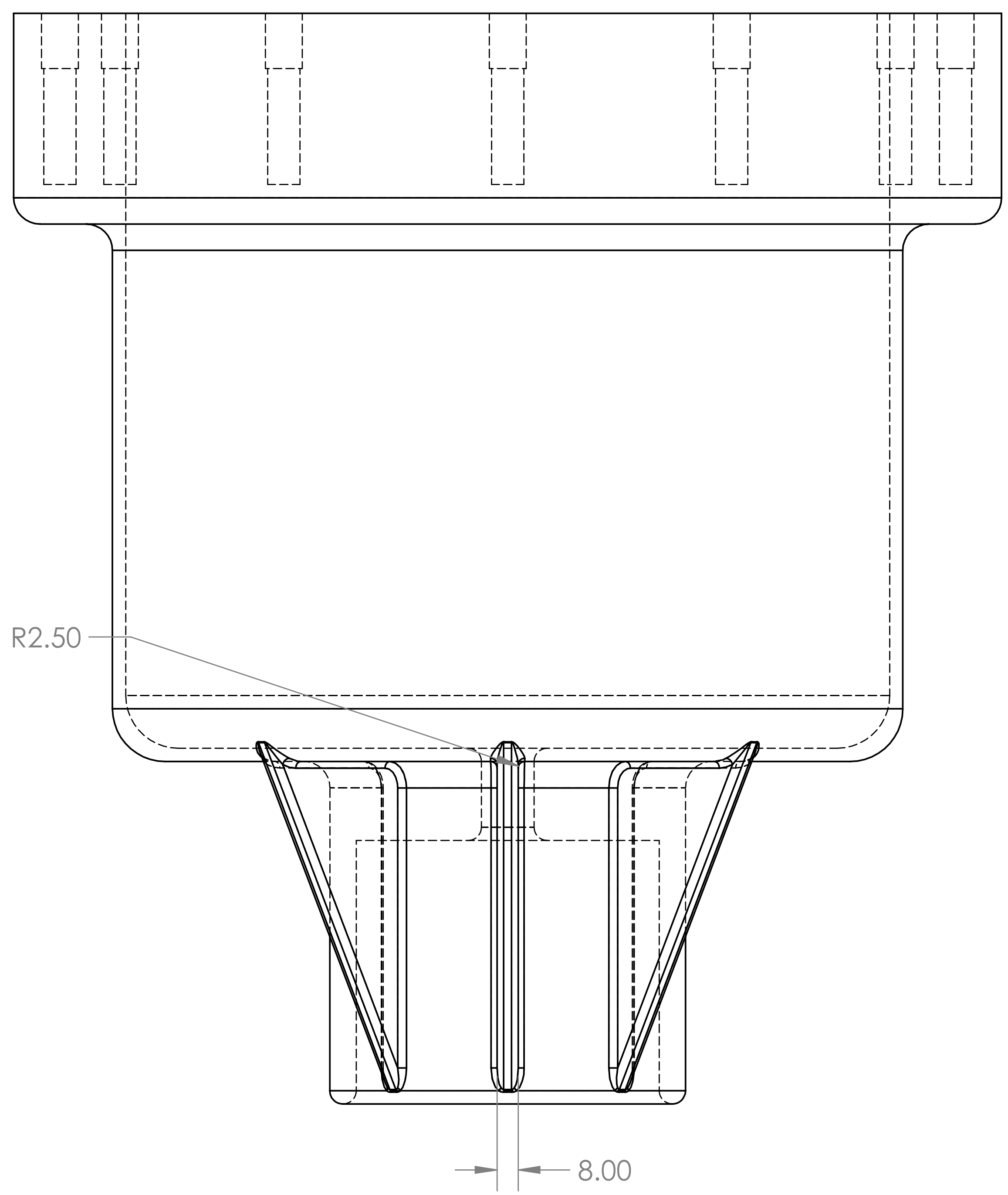
	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

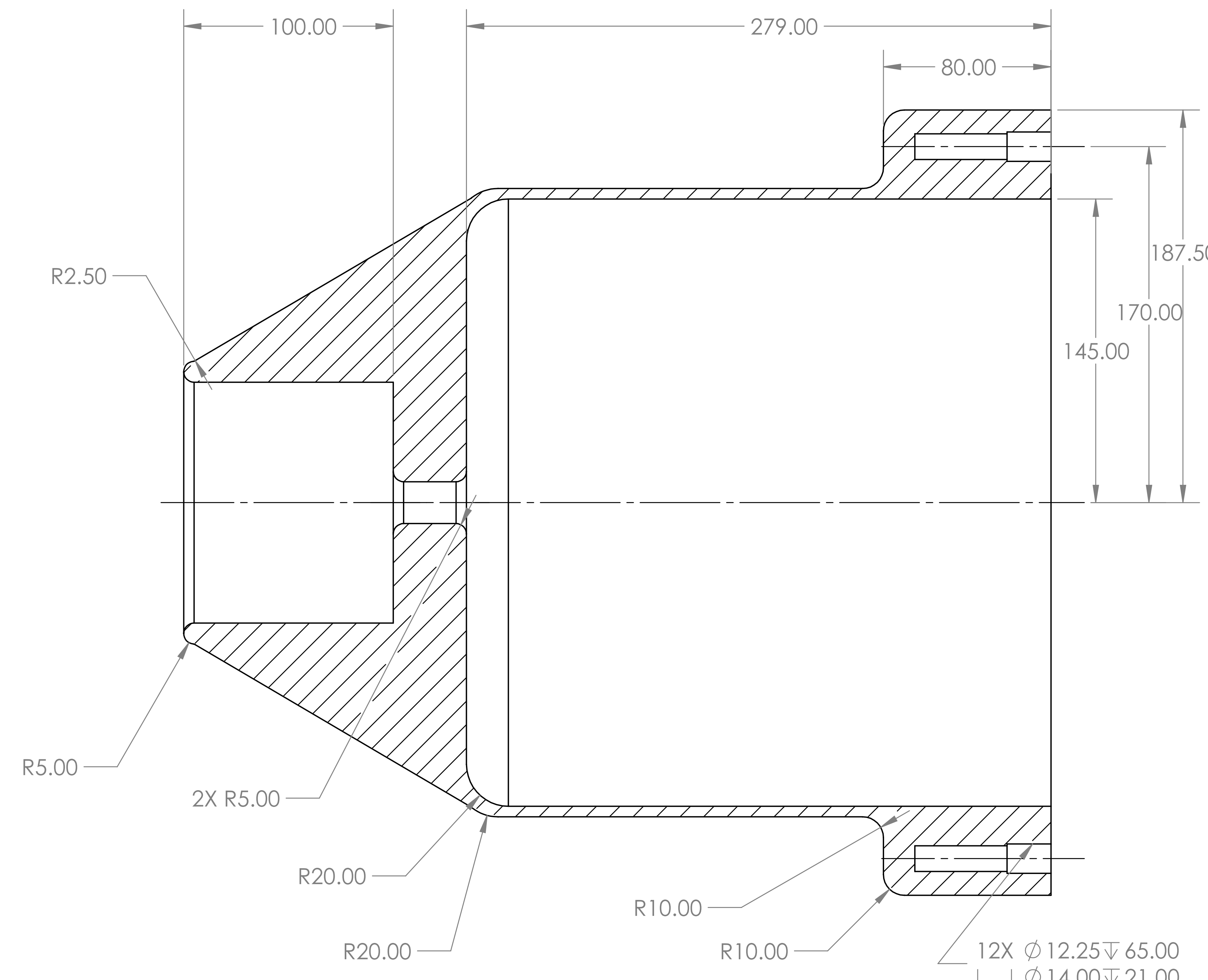
COMMENTS:

TITLE:
eMotor Housing

SIZE	DWG. NO.	REV
B	EMH 5.0	

SCALE: 2:5 WEIGHT: SHEET 1 OF 3





SECTION A-A

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Ductile Iron (Grade 100-70-03)
FINISH
DO NOT SCALE DRAWING

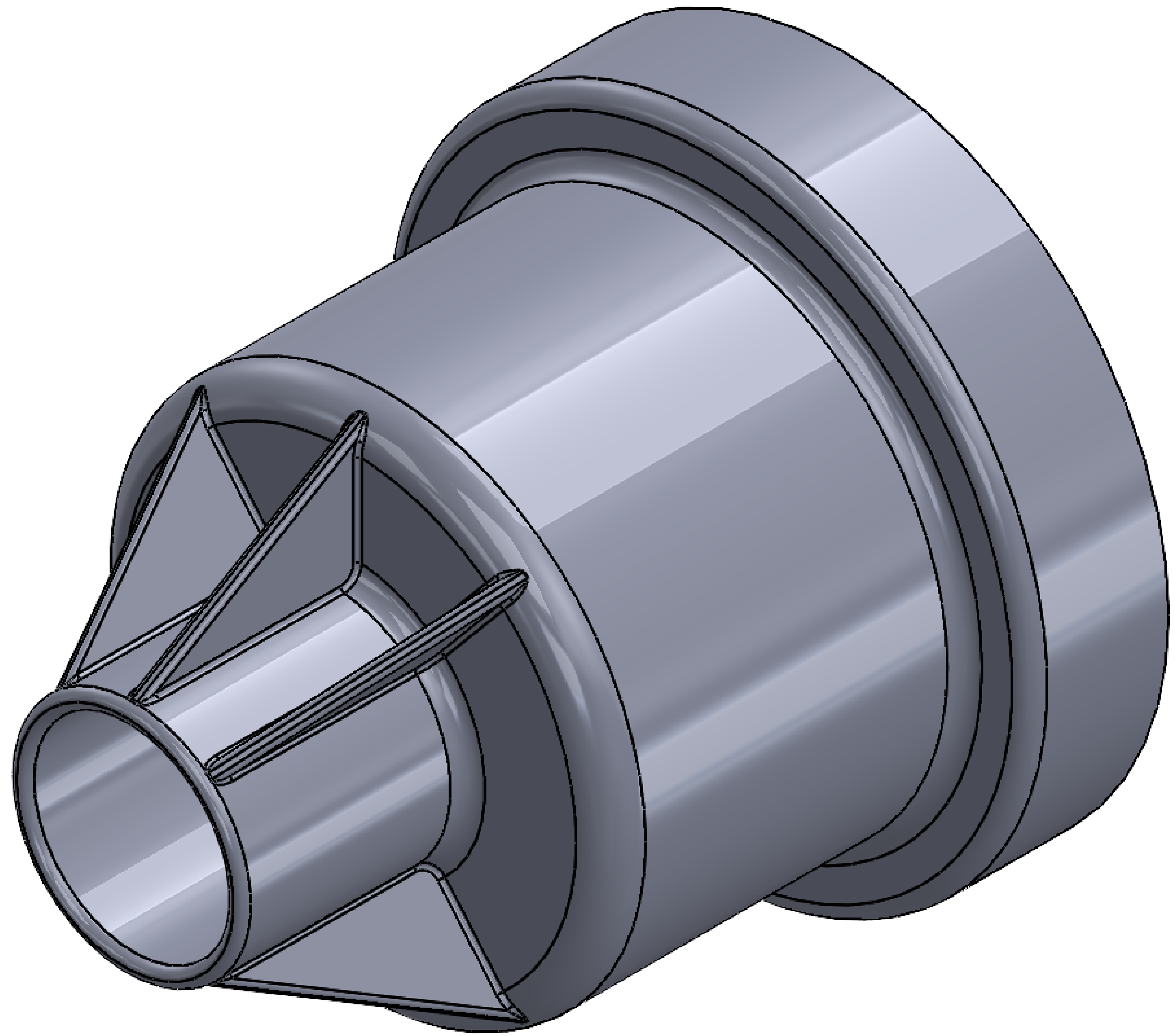
	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
eMotor Housing

SIZE	DWG. NO.	REV
B	EMH 5.0	
SCALE: 2:5	WEIGHT:	SHEET 2 OF 3

B B



A A

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Ductile Iron (Grade 100-70-03)

FINISH

DO NOT SCALE DRAWING

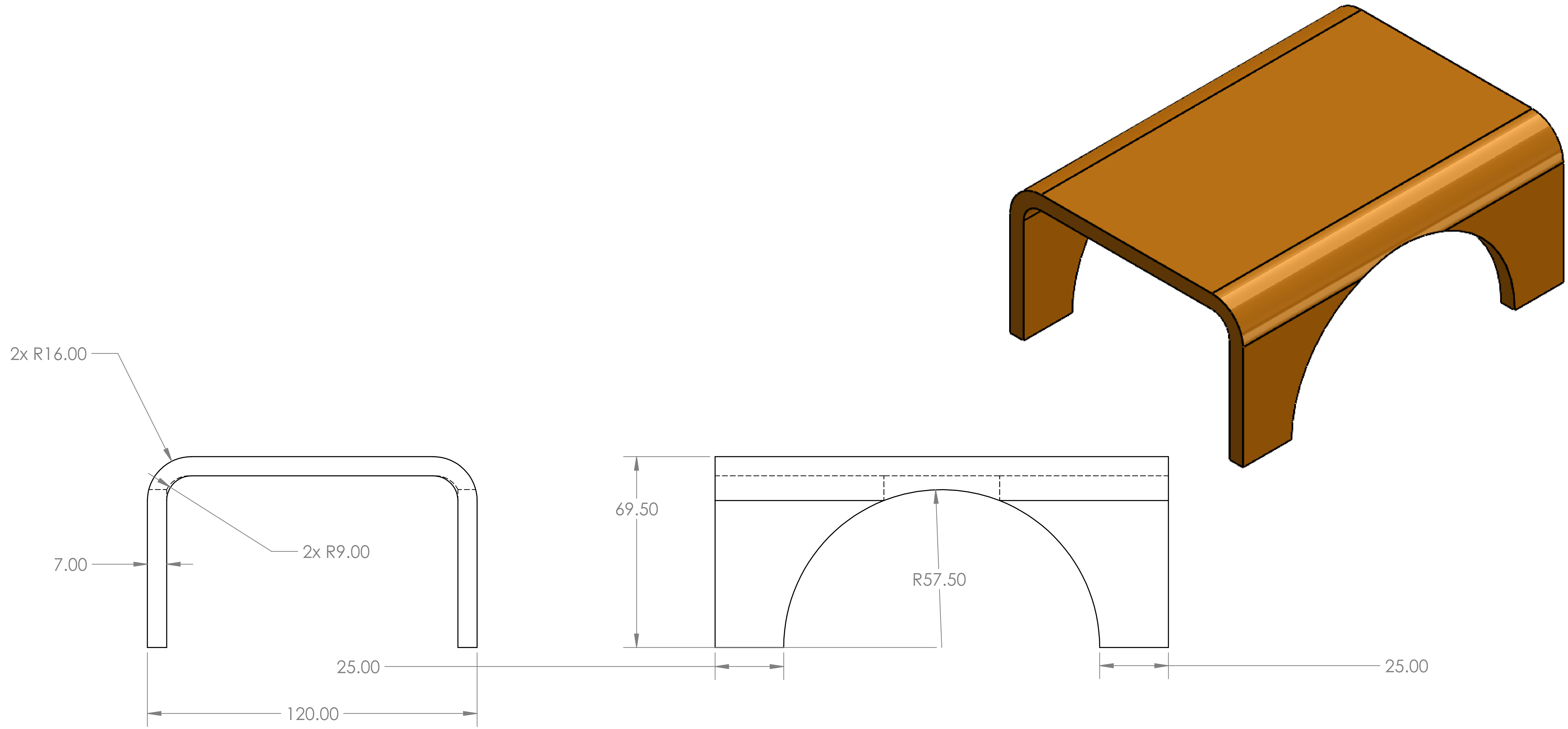
	NAME	DATE
DRAWN	AC	4/11/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
eMotor Housing

SIZE	DWG. NO.	REV
B	EMH 5.0	

SCALE: 2:5 WEIGHT: SHEET 3 OF 3



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Structural Steel

FINISH

DO NOT SCALE DRAWING

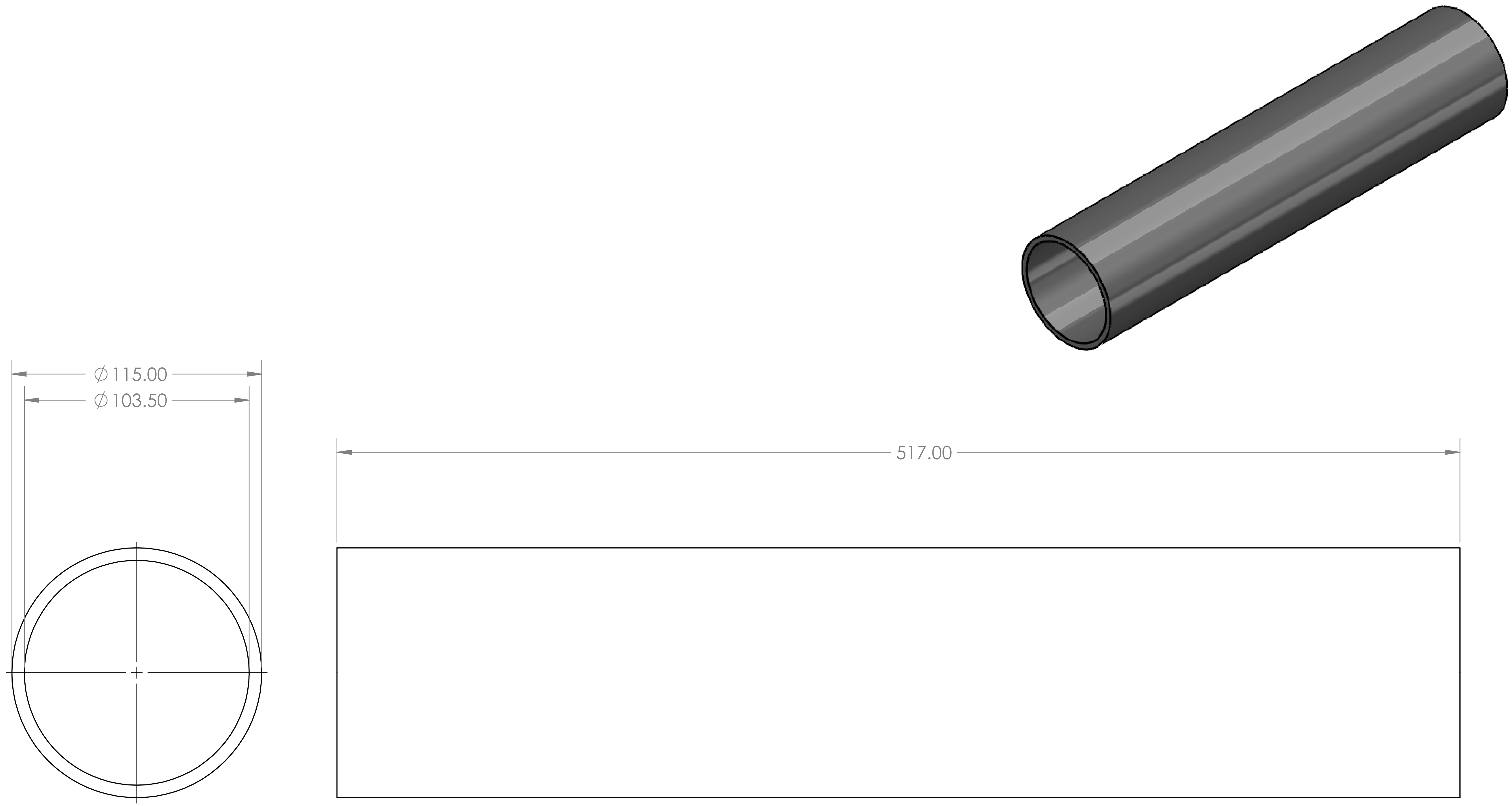
	NAME	DATE
DRAWN	AC	4/10/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Spring Perch

SIZE	DWG. NO.	REV
B	SP 2.2	1.3

SCALE: 2:3 WEIGHT: SHEET 1 OF 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Structural Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/10/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

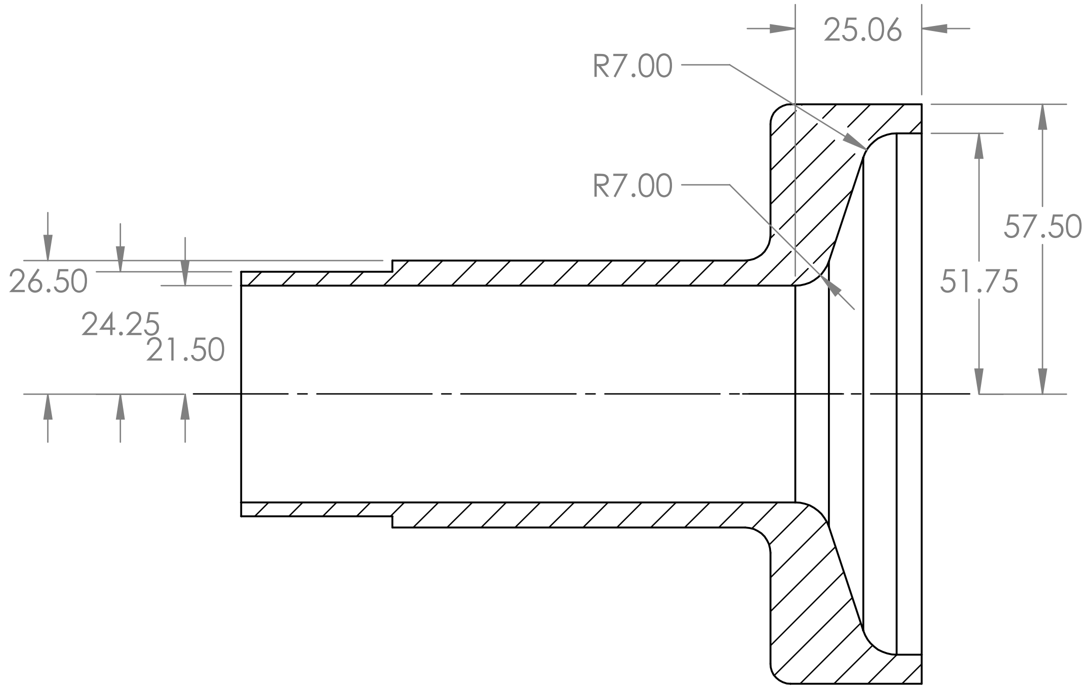
COMMENTS:

TITLE:

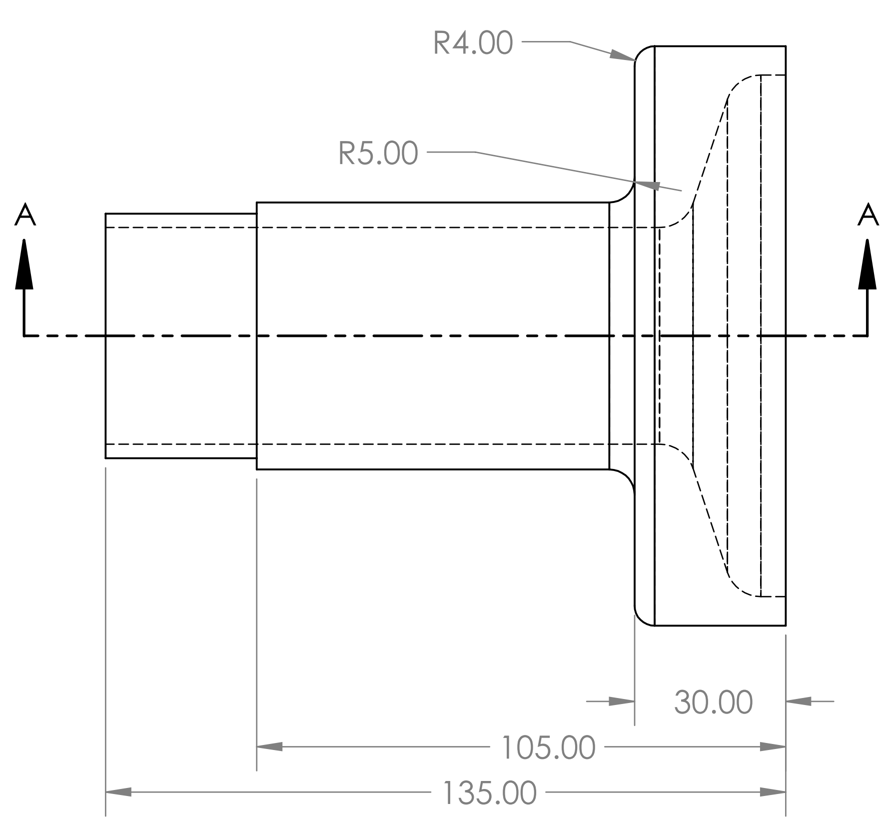
Axle Tube

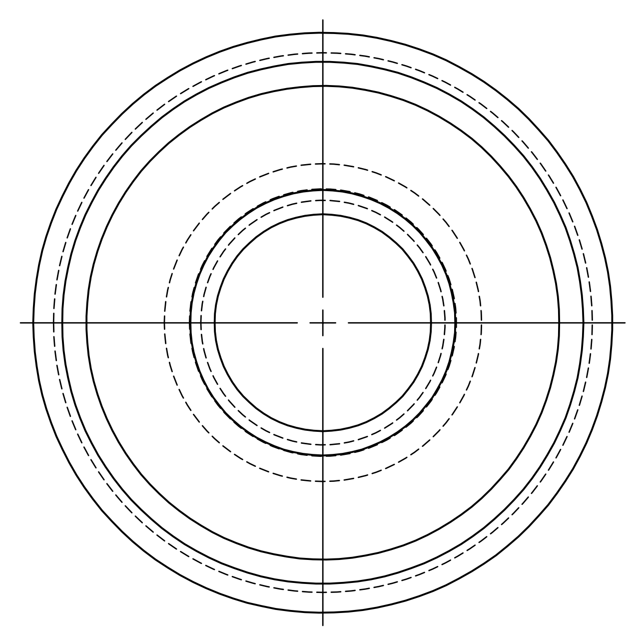
SIZE B DWG. NO. 115mmTube REV

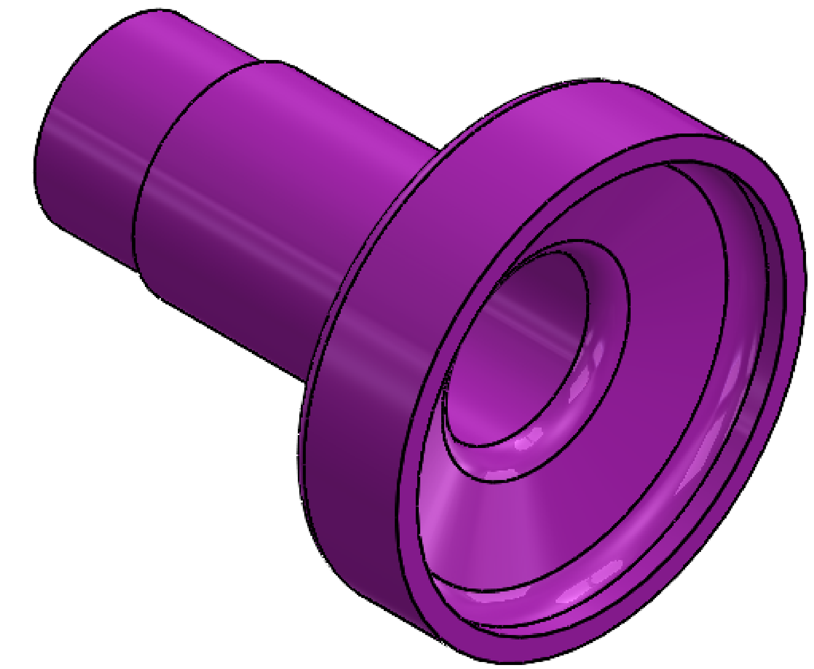
SCALE: 1:2 WEIGHT: SHEET 1 OF 1



SECTION A-A







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NEXT ASSY	USED ON		
APPLICATION			

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Structural Steel

FINISH

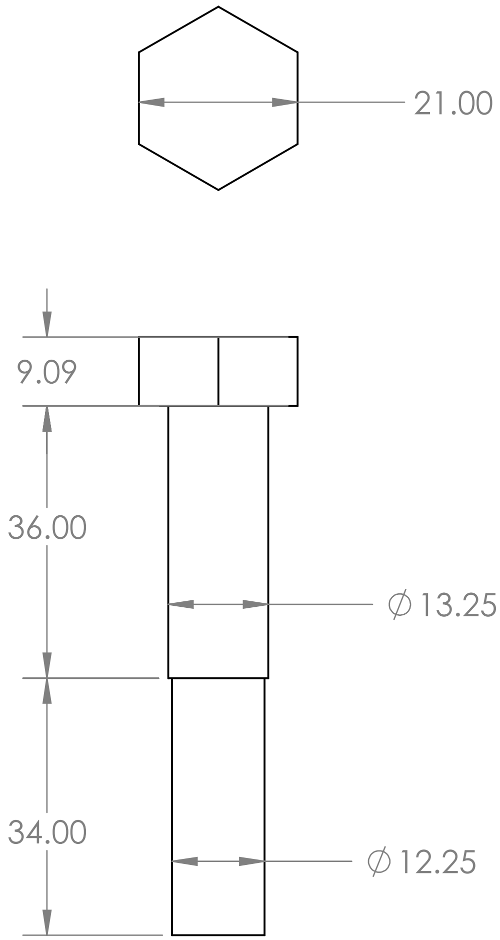
DO NOT SCALE DRAWING

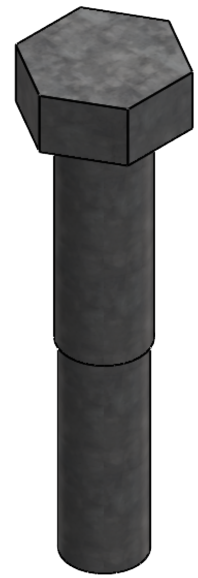
	NAME	DATE
DRAWN	AC	4/10/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:
Spindle

SIZE	DWG. NO.	REV
B	Spindle 1.2	1.3

SCALE: 2:3 WEIGHT: SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AC	4/10/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Hexhead Bolt

SIZE A | DWG. NO. M14B 1.2 | REV 1.2

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1