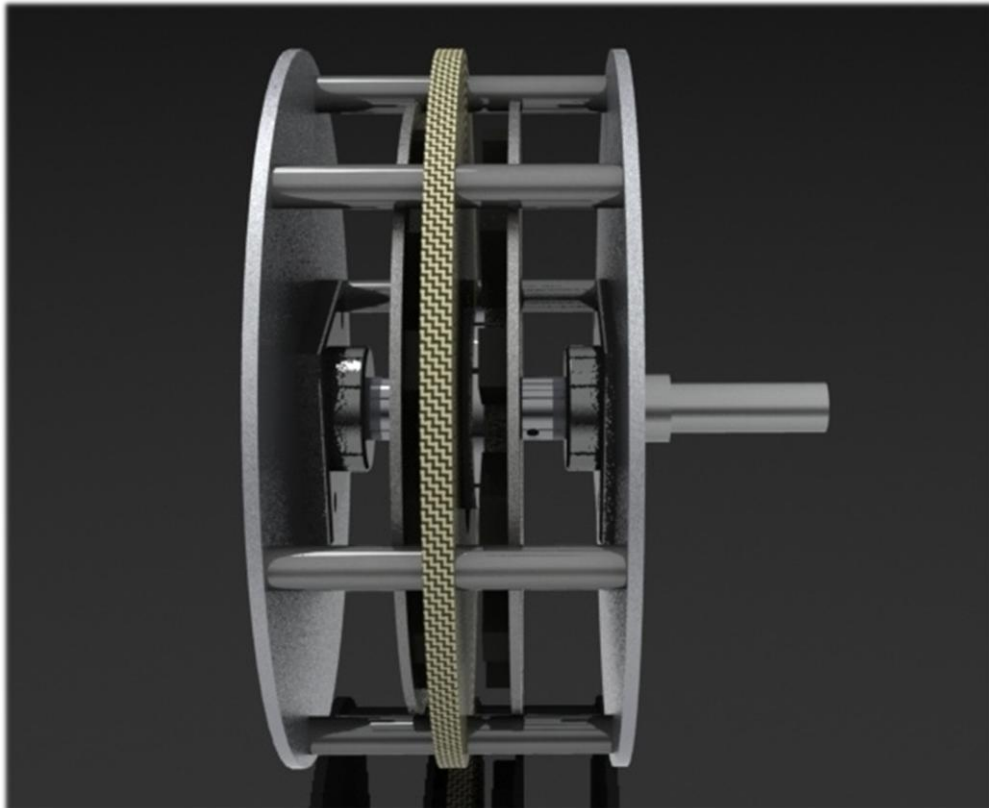


Spring 2010



UAF
WIND
TEAM

AXIAL-FLUX WIND TURBINE FOR RURAL ALASKA



Senior Design Project, Spring 2010 | UAF Wind Team

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1. FOREWARD

Disclaimer: This guide is meant as a general reference for those interested in seeing alternate designs and methods from the Hugh Piggott approach to axial-flux wind turbine construction. Any individual or group that decides to utilize this guide in any way does so at his/her/their own risk. Powerful magnets, electricity, resin fumes, machine tools and dynamic machinery can be dangerous and caution should always be exercised. The authors of this document, the University of Alaska–Fairbanks and the Center for Global Change are not responsible for any consequences of using this document.

1.1 ABSTRACT

The UAF Wind Team is developing a wind turbine that utilizes an axial-flux permanent magnet generator in order to examine viability for rural Alaska. The design is based on the work of Hugh Piggott of Scoraig Wind Electric but modified to accommodate Alaska’s wide range of seasonal weather conditions. The team is composed of two sub-teams: design and testing. The design team is composed of Ben Kellie and Patrick O’Callaghan and the testing team is composed of Jet Tasker and Tristan Kitchin.

The purpose of building this turbine is to study viability of axial-flux technology in rural Alaska. Axial-flux topology is mechanically simpler than that of the radial flux, which may have an effect on its maintenance. A prototype generator will be developed and tested to determine maintenance needs, performance and economics.

The wind turbine will be bench tested as well as field tested in Fairbanks, Alaska. Ultimately, our hope is that some “arctic recommendations” can be established for citizens who want to utilize the axial-flux technology in northern climates.

1.2 ACKNOWLEDGEMENT OF SUPPORT

This project was made possible through the support of the Center for Global Change, a UA foundation. Without their funding and support, we would not have been able to learn so much. The support is sincerely appreciated.

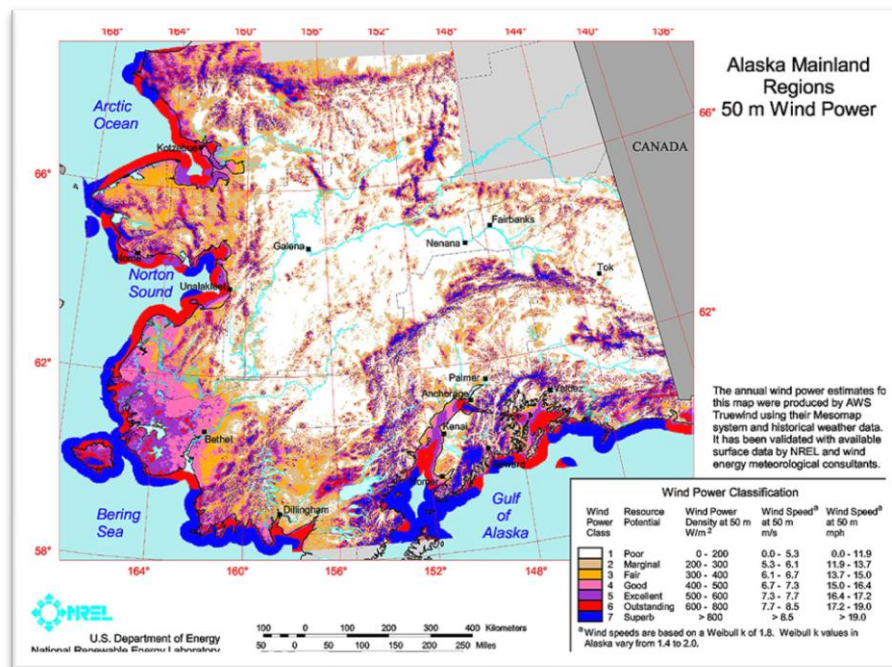
1.3 PROBLEM STATEMENT

1.3.1 A FINITE ENERGY SOURCE

Exploitation of the world's fossil fuel reserves and current global warming trends, as well as environmental changes in the Arctic due to human activity, have made it clear that we need to begin moving away from hydrocarbons as a primary source of heat energy. The production and transportation of hydrocarbon based fuels often require large amounts of hydrocarbon based fuels to accomplish. This means that every gallon of gasoline, diesel or oil produced is directly tied to the consumption of even more. All of these gallons of consumed fuels add greenhouse gases, primarily carbon dioxide, to our atmosphere and contribute to climate change and global warming.

Wind energy has the potential to offset the consumption of hydrocarbons and make significant contributions to the Alaska energy portfolio in the near future. Consider the wind resource of Alaska shown in Figure 1.

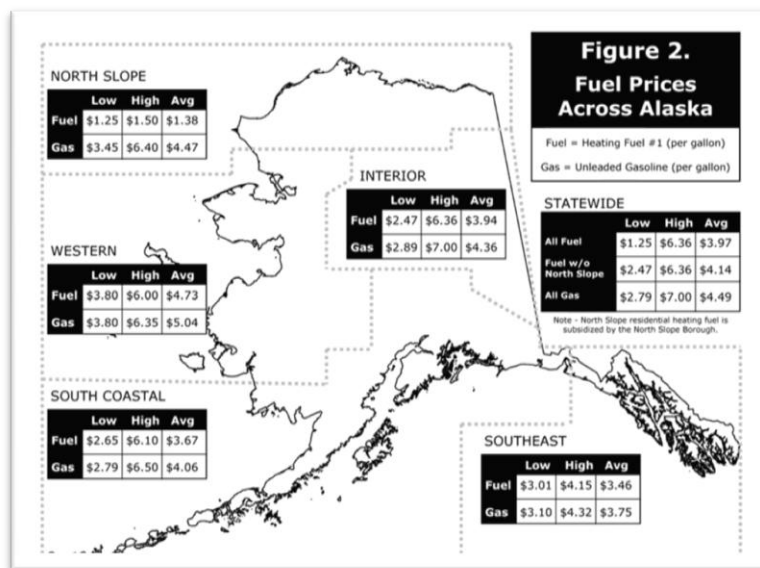
FIGURE 1: Wind Resource of Alaska (Source: US Dept. Of Energy's NREL)



In this figure the coastal regions of Alaska are colored red and blue, which correspond to class 6 and class 7 winds, respectively. These classes are the two highest on the Wind Power Classification and indicate that Alaska is a superb candidate for wind power. Furthermore, class 5 through class 3 winds, which correspond to colors purple through gold on the chart, extend inland hundreds of miles in many areas. In fact, Alaska has the largest total area of premium wind power in the nation, according to state and federal energy statistics. Harnessing this wind power can help to reduce costs by cutting down on fossil fuel consumption, as well as the carbon emissions due to transporting fossil fuels to the rural Alaska, and offset emissions with sustainable energy.

Beyond the environmental impact of transporting to, and burning fossil fuels in, our rural communities, one must also consider the economic impact. Fuel costs in rural Alaska have risen to unprecedented heights. In the summer of 2008 the price for a gallon of heating oil in Lime Village near Bethel reached a staggering \$9.50; more than twice the national average at the time (Stapleton, 2008). However fuel oil remains a staple of rural energy consumption. As the world moves beyond peak oil production and access to oil reserves becomes more restricted, the pressure on rural communities to afford heating oil each winter will continue to increase. In fact, the effects of this transition can already be felt as shown in Figure 2.

FIGURE 2: Fuel Prices Across Alaska



(<http://www.dced.state.ak.us>)

If the North Slope, where subsidies exist to equalize the price of fuel, is excluded then one can see that the average fuel cost in Alaska is roughly \$4.00 per gallon. This report was published in 2007 and prices have increased dramatically in rural Alaska since that time, demonstrated previously by the \$9.50 per gallon paid in Lime Village.

The production and consumption of hydrocarbon fuels impacts both our economy and our global climate. Investigating various forms of sustainable energy now is a prudent course of action that will benefit future generations when the full force of the energy crunch hits. Wind turbines utilizing axial-flux technology could be a useful component in clean energy production.

1.3.2 CURRENT AXIAL-FLUX “D.I.Y.” GENERATORS

The majority of the axial-flux “home brew” wind turbines are based on the Hugh Piggott design. However our design team feels that there are a number of short comings in the Piggott approach that must be addressed if the design is to be successful in Alaska. The first problem is that the Piggott turbine holds the stator in a separate plane of motion than the spinning rotors. The parts are in tight tolerance, however, and if the turbine undergoes a shock, the spinning parts could collide.

Second, the hardware on the turbine is all overhung and not well supported. This could cause the tight tolerances to come to zero and make the spinning rotors crash into the stator as well.

Finally, the turbine has no protective case on it. A good protective case will shield the turbine from corrosion, keep debris from becoming lodged in the inner workings and possibly extend the life of the device.

1.4 PROJECT ADVISORS

The team’s original adviser was Dr. Tomas Marsik of the electrical engineering department. He guided the team through the grant application process and helped to define the scope of the project. Since that time, Dr. Marsik has relocated to Dillingham, Alaska and was unable to continue advising the team directly. We still correspond by email occasionally.

Our main project advisor is now Dr. Rorik Peterson. He agreed to be the project advisor in September of 2009 when the design and build portion of the project was first underway. He is a good fit for the project as he

currently lives with a commercial-grade wind turbine at his home. This gives him unique insight and understanding of our project. Furthermore, his expertise with testing equipment and data analysis is beneficial to our team as we plan to collect operational data on our turbine.

We are also consulting Mr. Eric Johansen of the CEM Machine Shop as to proper manufacturing processes. He helps to vet our designs and confirm that they can be easily manufactured.

Chase Rixie, a senior electrical engineering student and co-author of the CGC grant, is also an adviser on the project. His knowledge of electrical systems and magnetic flux interactions is very useful.

Finally, we have reached out to a number of faculty in both the mechanical and electrical engineering departments who have expertise in the areas of mechanics, power electronics and aerodynamics in order to help us with the fuzzy areas that remain.

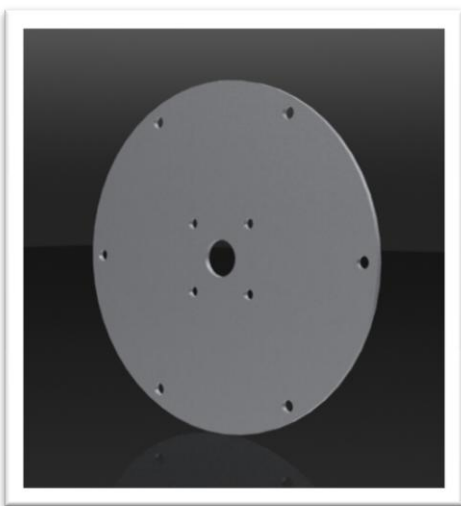
2. DESIGN OF WIND TURBINE

2.1 PERMANENT MAGNET GENERATOR (PMG)

The following sections detail the fabrication of each of the generator's major components. The final section details the assembly of the generator. It may be helpful to read the entire manual throughout in order to understand how all the pieces come together.

Full plans of each component with dimensions can be found in the appendix, at the end of the document.

2.1.1 END CAPS



The end caps are aluminum plates, one located at each end of the generator. The flange bearings mount to the end caps as well as the protective case, stator mounting bolts and test stand mounting plate. The inner four bolt pattern is the mounting location for the flange bearings. No radius for this bolt pattern is given as it will change based on the particular flange bearing selected. The outer six bolt pattern is where the six stator support bolts terminate.

The end caps can be fashioned easiest from a square piece of plate. First, lay out the circle and bolt holes on the plate. Then cut off each corner, creating a polygon. The polygon can be continually machined down in this manner until a near-circle is achieved.

Alternately, a handsaw or jig saw can be utilized to cut out a circular plate. Fine tuning can be achieved with careful filing or sanding.

Finally, the end caps can be cut by a fabrication company relatively cheaply or any appropriately sized round plate can be used.

The location of the bolt holes on each end cap with respect to the other is critical to the alignment of the turbine. However, since the end caps do not rotate, the overall shape and balance of each is of relatively lower importance. If there are any large shape differences between the two, however, it may make the outer casing harder to fit properly.

2.1.2 ROTORS



A rotor is composed of a thin steel plate, 1/8" thick and 12 inches in diameter, with permanent magnets arranged in a radial pattern around it. The plate is then put into a mold and Devcon Flexane-80 liquid is poured in until it is just below the level of the magnets. The Flexane-80 liquid urethane resin sets to a medium-hard consistency. This allows the plates to expand in the heat and contract in the cold without sacrificing the strength of the resin.

The rotor pictured to the left is a computer rendering of the magnets arranged on the plate before the Flexane-80 liquid is added. Explanation of the casting process is in the following sections.

The four bolt pattern is used to affix the rotor plates to the central rotor mount (or flange) which in turn attaches to the driveshaft.

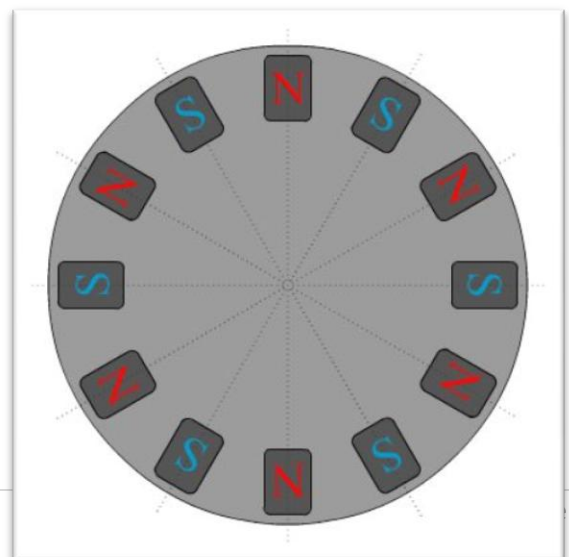
The team chose to use a 1/8" thick steel plate as the base of the rotor. It can be fabricated similarly to the end cap plate (see previous section). The magnets chosen are class 45 neodymium-boron rare earth magnets. There are twelve per rotor plate; twenty-four in total. They are arranged at a radius of 3.5" from center of plate to bottom edge of magnet. Magnets with a black epoxy coating were chosen specifically to protect against scratching and corrosion. The dimensions of the magnets are 2"x1"x1/2" (LxWxT). They are magnetized THROUGH their thickness (1/2" dimension). These magnets can be procured from a number of sources online.

When designing your generator, it is important to realize the relation between the number of coils and the number of magnets. For true alternating three-phase power, you need 1 1/3 magnets per coil. The following table may prove handy:

# Coils	# Mags/Plate
6	8
9	12
12	16
24	32

The magnets must alternate poles as they go around the plate. This means that they must alternate N, S, N, etc. as they go around. This also means that there must be an even number of magnets so that the alternation comes out properly (see above figure and table).

The magnets are arranged using a jig built from a piece of wood. It simply sits on pins that go through the four bolts holes on the rotor plates. The magnets are then gently tapped into position. This



greatly simplifies the magnet setting process and, if the jig is built carefully, offers repeatable results (see pictures in next section).

The rotor plates must be created opposite of one another with respect to magnet arrangement. That is, pick a starting position from which you will lay out the magnets in the jig. Mark that point on the plate. Lay out the first rotor, alternating poles all the way around. Then when starting the second rotor, start from the same point on the new plate as you did on the first. Mark that point as well. Now lay out the second rotor starting with the opposite pole as you started with on the first plate. Then alternate poles the rest of the way around as normal. When the generator is assembled, this ensures that opposite poles all face one another, enhancing the magnetic flux.

A note on safety: These magnets are powerful. Be careful not to keep loose metal objects such as tools or bolts lying around the work area. Also, when putting the magnets on the plate avoid possible pinching hazards. Finally, avoid letting the magnets slam down onto the metal plate. This can crack/shatter them and decay their magnetic potential over time.

2.1.2.A MAGNET JIG AND MOLD HARDWARE

This section contains explanations for the various parts utilized in casting the rotors. Plans and dimensions for these pieces are included in the appendix.



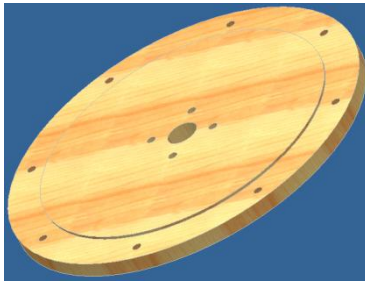
The magnet jig is a piece of wood we cut slots out of in order to help reliably arrange the magnets on the steel rotor plates. The four bolt pattern is at a radius of 1.375 inches from center. This matches the four bolt pattern in the steel rotor plate.

Since we are using 12 magnets per rotor plate in our construction, we have cut a slot every 30 degrees around the circumference of the jig. This allows us to bolt this jig to a steel plate and then gently tap the magnets into place around it. We then unbolt the jig and carefully lift it away.

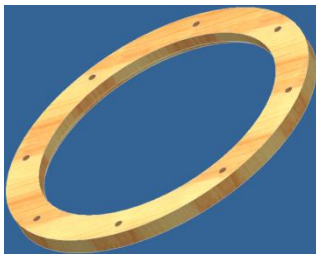
As always, a full plan with all dimensions is included in the appendix. Note that the overall diameter of the jig doesn't matter; rather the distance from center to the start of the slot (where the magnet fits in) is the critical dimension. However, choose a diameter that provides long enough slots for the magnets to be reliably located, but not so long that the jig is hard to remove later.

To ensure that the magnets don't get stuck in the corners, you can either cut the slots perfectly straight (shown above) or simply overcut them with a rounded tool:

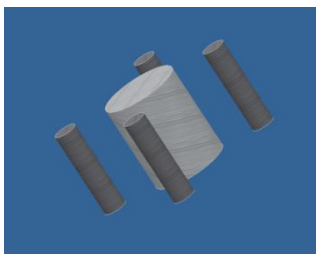




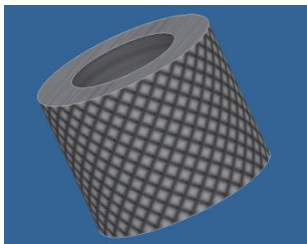
The bolt circle around the outside of the rotor mold base is used to bolt the entire mold together. The inner bolt circle will hold pins that will act as “dummy bolts” for the casting process and keep bushings in perfect alignment. A plug goes in the center hole which will allow the cast to mount to the flange. This part has a stepped thickness that corresponds with the top half that allows the two parts to lock together. This will prevent flexane from leaking out of the mold and keep the metal plate centered. This part is cut from MDF and stepped using a rotary table but can be left flat if the right equipment isn’t present.



The top of the mold is cut from MDF and contains the same bolt circle as the bottom. This piece has a stepped thickness that locks into the bottom’s planed surface. Again, if a rotary table isn’t handy this part can be made flat on both the top and bottom. The shape can be cut with a saw and sanded down until smooth.



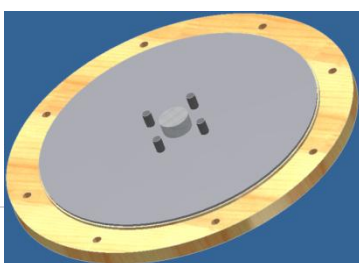
These pins can be made out of any material lying around. The crucial thing is making sure that they can be placed in and removed from the mold easily and fit nicely inside the bushings.



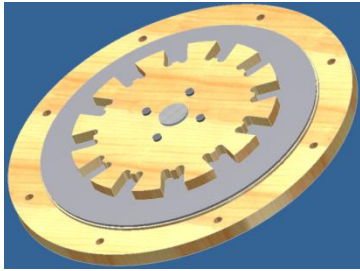
These bushings slide over the pins during the casting process and are knurled to ensure a strong bond with the Flexane-80. If the equipment necessary to knurl these bushings isn’t handy a very coarse sanding will suffice. Since this part rests on the steel plate in the rotor choosing a material other than steel for its fabrication may result in corrosion.

2.1.2.B MOLD ASSEMBLY

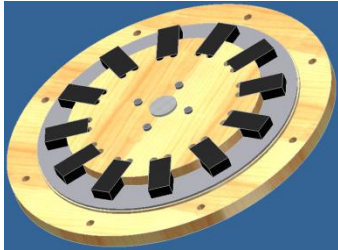
This is how the rotor mold will be assembled before casting. Make sure to properly prepare the plates before assembly, as detailed in the next section.



Roughen surface of rotor plates. Use either sand paper or a sand blaster, if available. Medium grit works fine. Wipe off debris. Clean with regular solvent 365. Lay the steel rotor plate on the base of the mold and set the pins and center plug through the holes until they are flush with the bottom.

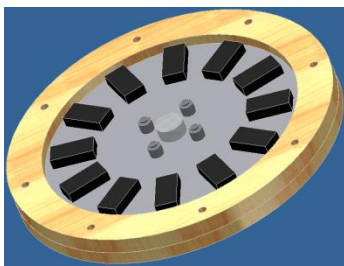


Set the magnet jig down onto the four pins and center plug until it is flush with the metal plate. Mark one part of the magnet jig as the top. Whatever pole you choose to face up in this slot for the first rotor, let an opposite pole face up when you lay out the second rotor. This allows for proper assembly with opposite poles facing one another later.



Slide the magnets into place on the steel plate with the help of the magnet jig. A rubber mallet works well to tap the magnets into place.

Make sure that the magnets alternate polarity as you move around the plate. This can be checked by holding the next magnet you are about to place over the one you just laid down. As you hold the magnet over they should **OPPOSE** one another. When they do, simply set the magnet you're holding down into the neighboring slot. Make sure not to change its orientation during this time.



When all the magnets have been laid, use a spare one to make sure that the magnet poles properly alternate. The magnet you are holding should alternately be attracted, then repulsed, as you move around the circumference.

BE CAREFUL NOT TO LET THE MAGNET SLIP FROM YOUR HAND! This could damage the magnets in the jig and ruin the rotor.

Carefully remove the magnet jig and place the knurled bushings onto the pins. After setting the top of the mold on and bolting it together the Flexane-80 liquid is ready to be poured.

2.1.2.C CASTING

MATERIALS:

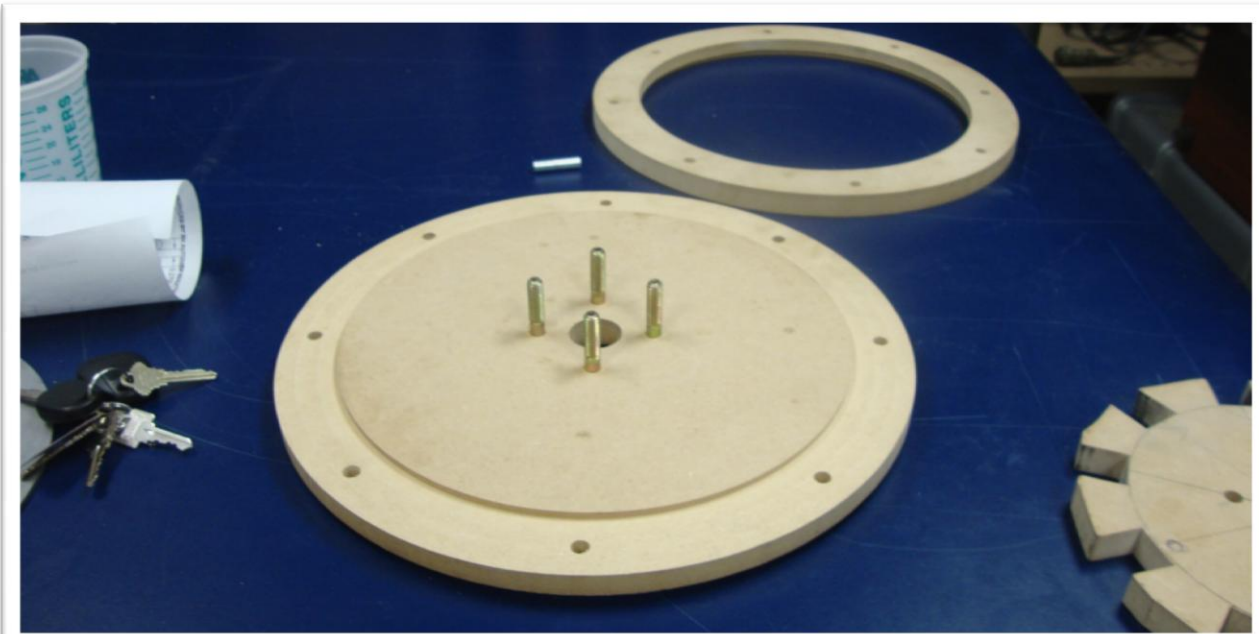
- (2) brushes with wood handles
- (2) Plastic mixing buckets
- Johnson paste wax (or similar) and rags
- Liquid silicon mold release
- Hot air gun
- Flexane 80 Liquid Resin
- Devcon FL-10 Primer
- Finished metal plates
- Magnet Jig
- Metal Bushings
- Metal Pins

A. PREP MOLD/SURFACES

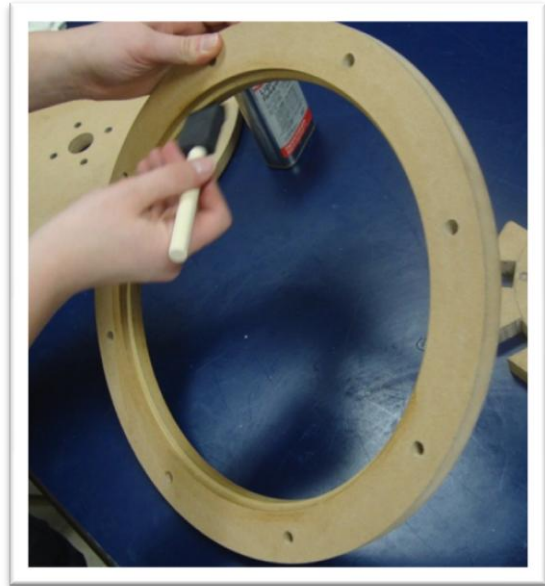
1. Prep the MDF mold. With the mold disassembled, rub Johnson paste wax into any part of the mold that the Flexane might touch. Let soak in for 10 minutes and repeat.



2. Assemble the mold. Rub Johnson paste wax into corners, where there is a slight gap between two pieces of MDF. Wipe away excess. This is so the Flexane doesn't leak between the MDF and create seams. Let dry for 10 minutes.



3. Using the liquid silicon, paint the interior of the mold once. The paste wax is doing most of the releasing, but liquid silicon was used on both our test molds and actual castings.



B. PRIME SURFACES

Again, ensure that there are NO loose metal objects around the magnets.

1. Set metal disc into mold.
2. At a different area than the mold, pour some Devcon FL-10 primer into a plastic cup.
3. Using a new brush, apply Devcon FL-10 primer to just the metal surfaces (steel rotor plate and bushings) with wood handled brush.

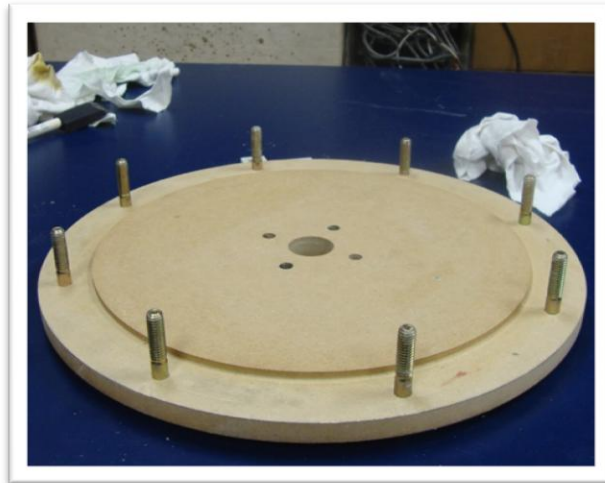


4. Let dry for 15 minutes or until tack-free. Apply a second coat.

5. Prop up mold on one side so there is a slight tilt before pouring the resin (in next section).

6. Assemble the mold:

Put in the bolt ring around the outside edge of the bottom piece. Put the four machined pins into the four bolt pattern. Make sure to coat them with a thin layer of mold release. Also insert the plug into the middle hole (not pictured). Coat with mold release.



Put on the top ring and secure tightly with nuts.

6. Mask the tops of the magnets so when pouring occurs, any resin that gets on magnet surface can be removed later.

C. MIXING/POURING

1. At a separate work area, mix up two (2) bottles of Flexane 80 and catalyst in a plastic bucket according to manufacturer's instructions. Mix for 2 minutes. Each rotor mold requires two bottles.
2. Bring plastic bucket and brushes with wood handles (non-metal things only) to the mold area.
2. Brush a thin coat of Flexane to the surfaces in the mold (both metal and MDF) with a brush.
3. With mold chucked up, pour Flexane into mold. Pour until flush, or just lower than magnets. The face of the magnets should be the highest point the surface.



4. After poured, set the mold flat again.

5. Use a hot air gun (metal object) to bring air bubbles out of the Flexane. De-bubble for 5-10 minutes.

Use caution to prevent the metal tip of the hot air gun from being attracted to the magnets!

6. De-mold in 10 hours.

7. Cure for 16 hours total before use.

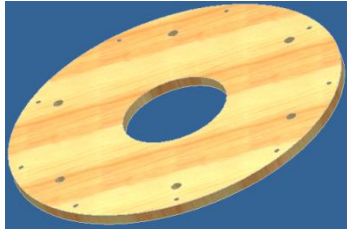
2.1.3 STATOR

The stator is an epoxy resin casting with nine coils arranged inside. Any number of coils can be used but there must be a multiple of three (since three phase power is produced). There is a six bolt pattern which matches the one on the end caps. Our design team decided to put small metal bushings at each of the bolt hole locations in order to strengthen the resin at the bolt-through points.

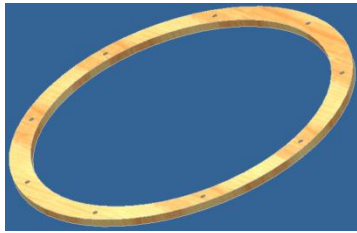
Small metal pieces were put in the center of each coil. This should help to focus the flux through the center of each coil, improving performance.



2.1.3.A MOLDS



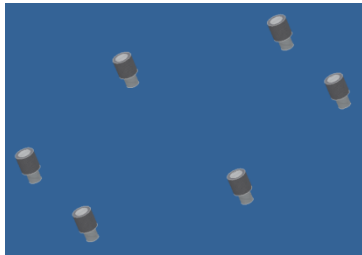
This mold base is cut from MDF using a rotary table, but can also be cut using a skill saw if one is not handy. The outer bolt circle is used to fasten the entire mold together and the inner bolt circle holds pins. These pins will keep bushings aligned precisely and will be punched out of the casted part. The hole in the center holds a center plug that allows the flange to sit inside of it.



This part acts as the bottom and top tier of the mold, so two are required. It is cut from MDF using a rotary table once again, but is still possible to make using a skill saw. The bolt circle corresponds to that of the base allowing bolts to be set through the entire mold so it can be fastened together.



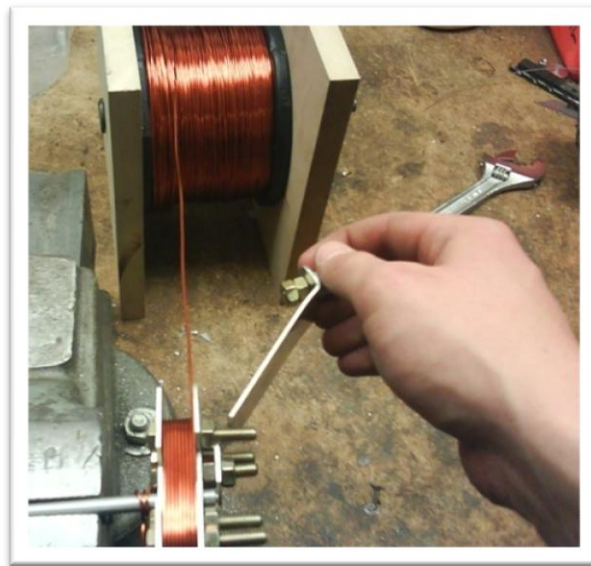
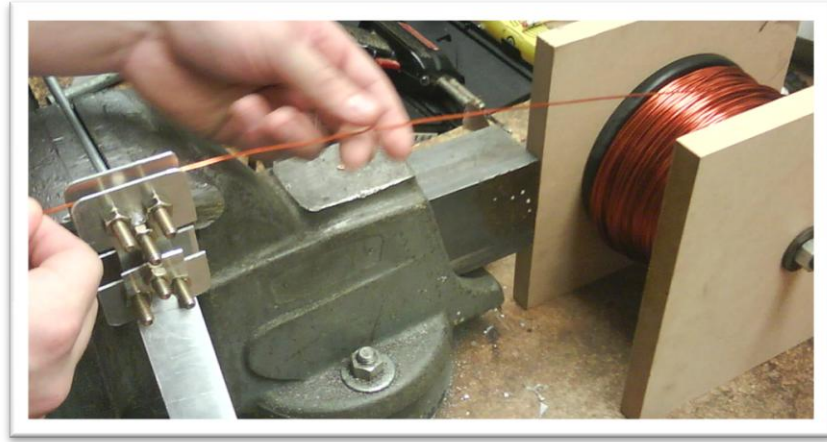
This piece was cut from MDF using a rotary table just like the other parts and is used to create a hole in the center of the cast. Any material will work but MDF or wood is best because it is cheap and easy to use. It is possible to use two different pieces of wood glued together to create this part but special care must be taken to be accurate. Also, the outer diameter of this plug will increase when it is coated with mold release so making sure that it fits right is essential.



The pins for this mold can be made of any material at hand, but the bushings must be made of steel to avoid corrosion due to dissimilar metals. Knurling these bushing is a great way to ensure a good bond with the surrounding resin, but sanding with a very coarse grit can work also.

2.1.3.B COILS

The coils are wound on a magnet jig. This jig will have to be constructed. It can be built simply from scrap material. Plans are included at the end of the document.



The coils are each approximately 100 turns of 16AWG enameled magnet wire. We hand wound each in order make them tight and evenly wrapped. In the above picture, those two boards are bolted together through the middle of the spool. They put a bit of drag on the side of the spool and that puts tension in the wire as we wrap the coils.



2.1.3.C RESIN CASTING

EPOXY TERMINOLOGY

1. Open time

Open time or wet lay-up time describes the working life of the epoxy mixture. It is the portion of the cure time, after thorough mixing, that the resin/hardener mixture will remain in a liquid state and be workable or suitable for application. The end of the open time (wet lay-up time) marks the last opportunity to apply clamping pressure to a lay-up or assembly and obtain a dependable bond.

2. Initial cure phase

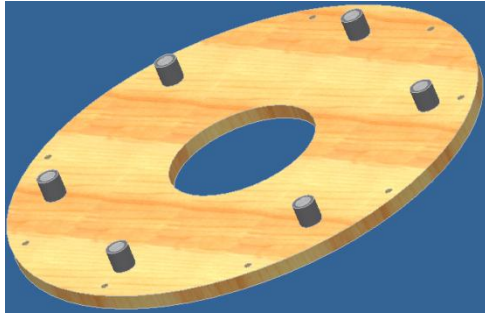
The open time is over when the mixture passes into an initial or partial cure phase (sometimes called the green stage) and has reached a gel state. At this point the epoxy will no longer feel sticky, but you will still be able to dent it with your thumb nail. It will be hard enough to be shaped with files or planes, but too soft to dry sand. Because the mixture is only partially cured, a new application of epoxy will still chemically link with it, so the surface may still be bonded to or recoated without sanding.

3. Final cure phase

In the final cure phase, the epoxy mixture will have cured to a solid state and will allow dry sanding and shaping. You should not be able to dent it with your thumbnail. At this point the epoxy will have reached about 90% of its ultimate strength, so clamps can be removed. The epoxy will continue to cure over the next several days at room temperature. A new application of epoxy will not chemically link to it, so the surface of the epoxy must be sanded before recoating to achieve a mechanical, secondary bond.

MOLD ASSEMBLY MOCK UP

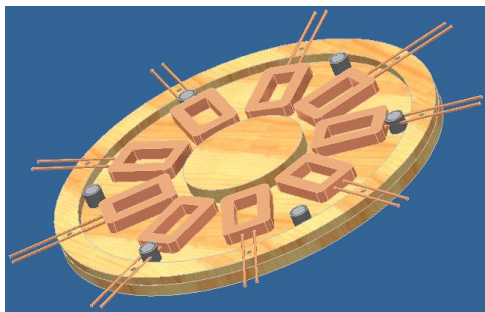
The following is a mockup of how the mold goes together. The full casting procedure is in the next section and should be followed. This section is just a general visual guideline.



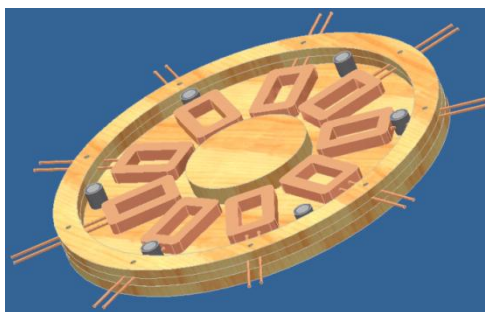
Set the pins into the inner bolt circle until they are flush with the bottom of the mold and slide the knurled bushing over them. The pins will keep the bushings in perfect alignment during the casting process.



Push the center plug into the molds base until it is flush with the bottom and set the first tier down. Bolt this piece to the base with $\frac{1}{4}$ " bolts and set it on a level surface. Before setting the coils into the mold in the next step an eighth inch of resin will have to be poured in and allowed to harden (at the end of the "open time" phase).



After the resin hardens remove the nuts from the bolts holding the stator mold together. Place the coils on the resin and make sure that the wires exiting the mold are close to the sides of the bolts; this will ensure a tight fit and keep resin from leaking out.



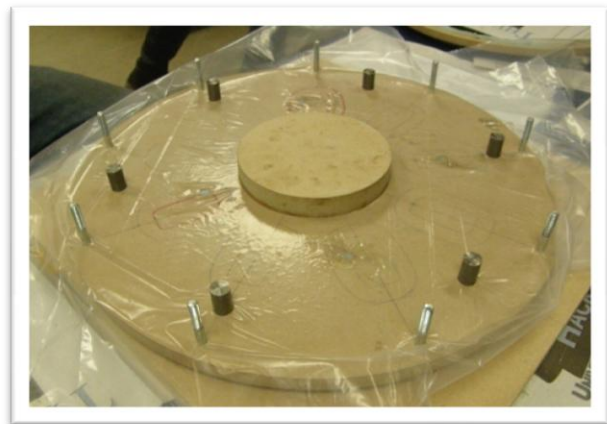
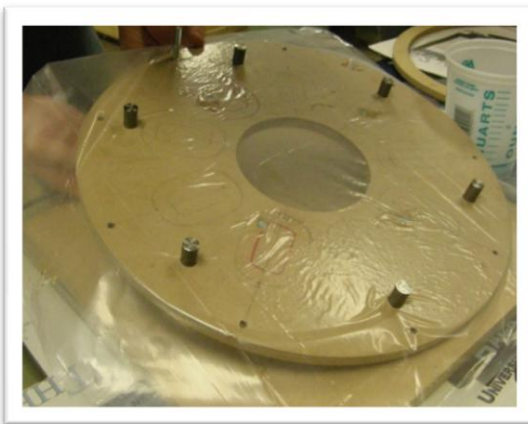
The last step is to fit the second tier onto the bolts so the wires exit in between tiers one and two. Note that in the plans for these molds notches are added to all the wires to come out of the mold while still keeping a tight fit. Once the nuts are tightened onto the bolts again, the rest of the mold can be filled with resin.

MATERIALS

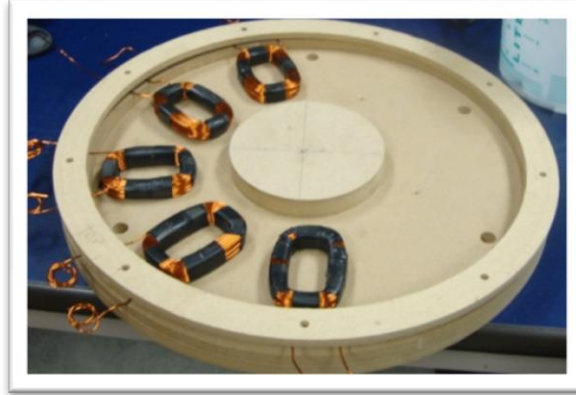
West Systems Epoxy 105 resin	Spray Adhesive
West Systems 206 slow hardener	Ruler
West Systems pump set	Utility Knife
Polyethelene film, 2 mil	Vaseline
Mold release paste	

PREPARING THE MOLD

1. With the mold disassembled, rub mold release paste into any part of the mold that the resin might touch. Let soak in for 10 minutes and repeat two more times.
2. Clean bushings with a solvent.
3. Trace pattern for the stator coils on film. Spray the other side of the film with adhesive spray then press and smooth onto the base board of the mold. Ensure wrinkles get removed.



4. To prevent leaks, apply excess mold release to bottom of second level on the mold. Bolt down the 2nd layer of the mold, keeping the film flat. Wipe away excess mold release.
5. Coat the inside of the bushings with vaseline. Set bushings in place with pins, wipe away excess.
6. Set the center plug into the mold. Make sure it has been prepared with release paste.
7. Place coils in mold and set the 3rd layer of the mold in place. Check to see the center plug is flush with the 3rd layer. Check to see that the coils sit 1/8" inch below the level of the mold. Remove coils, and 3rd layer of mold.



POURING EPOXY – DRY TIME TEST

8. This stator is poured in two layers. The first epoxy layer must set up to tack-free before pouring the next layer. This ensures the first layer is chemically bonded to the second and that the coils will not sink.

9. Using the manufacturers mixing instructions, mix up a test batch to determine the length of dry time. Next, pour an 1/8" thick layer of epoxy, and measure dry time. The epoxy will start from the consistency of syrup, then form peaks, then finally hold its shape with the consistency of jello. At this point the epoxy will become tack free, and it will be ready for the second layer. This team found the dry time to be 3 hours, but this time will vary with temperature, humidity and time of mixing.

POURING EPOXY – FIRST LAYER

10. Estimate the quantity of epoxy needed by volume. Add 10% for assurance.

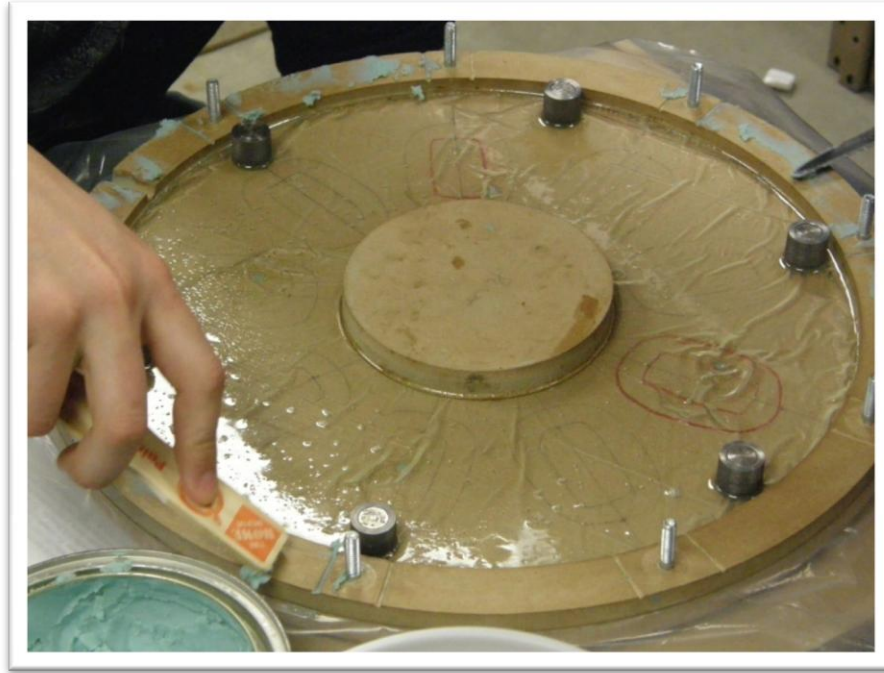
11. Using the West Systems epoxy system, take one pump from resin, then one pump from hardener. 1 pump resin + 1 pump hardener = .8 fl oz = 1.44 in². Mix for 3 minutes, scraping the sides. Transfer to another container, then mix for 1 minute. Transferring to another container alleviates the problem of unmixed resin in corners or divots in the container.

12. Pour into mold, let sit for the test dry time to set up to tack free. Note that in the picture below, the resin is hard to see since it is clear.

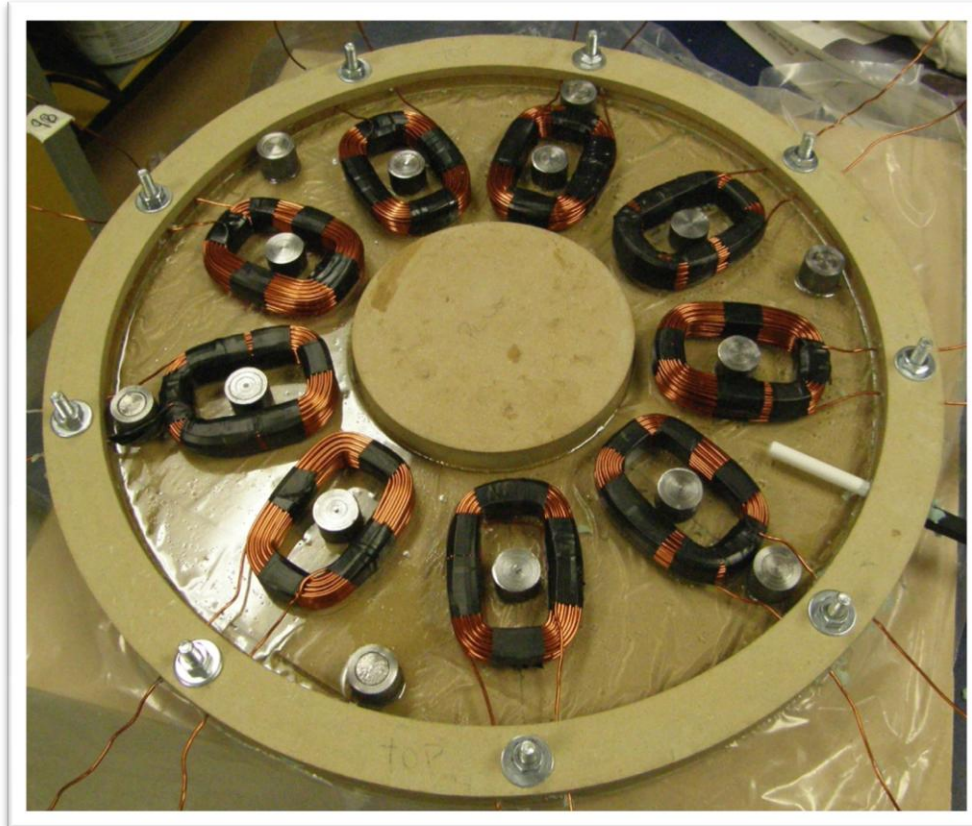


POURING EPOXY – SECOND LAYER

13. Set coils into mold. Apply excess release paste to outer edge of the bottom of the third layer carefully to avoid excess paste on inside wall of mold. Bolt 3rd layer of the mold down, and wipe away excess. The mold release prevents the resin from leaking out of gaps in the mold; especially where the coil wires stick out.



Note: The white cylindrical probe seen in the bottom picture is a thermistor. We cast one into the stator for testing purposes and it is not a necessary part for casting or generator success.



14. Check vaseline on the tops of exposed pins and bushings. Add more to cover if necessary to seal these areas against epoxy spillover.
15. Using the mixing procedure above, pour epoxy into mold. Use stir sticks to drag epoxy around the narrower channels between the bushings and wall of mold. Fill to just flush with top of mold.
16. Place a flat board that has been prepared with mold release on top of the mold, letting it rest on the center plug and walls of the mold. Weight the board with textbooks. This layer of epoxy will set up very quickly because it is thicker. The board can be removed in roughly three hours.

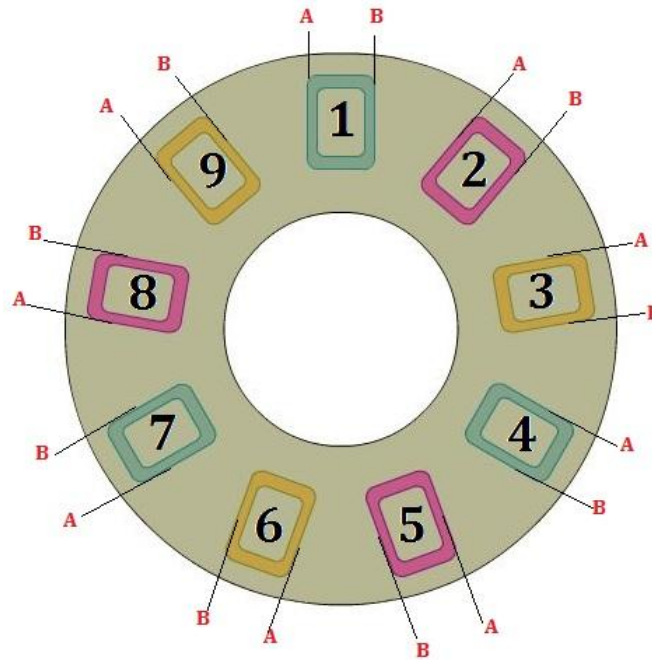
DEMOLDING

17. Demold in 24 - 48 hours, but let fully cure for four to five days.
18. The bottom side will have a clear finish because it was released with film. The top side will have a cloudy layer from mold release. This side can be cleaned with soap and lightly sanded with a fine grit (starting with 80 grit and working to 120 grit). Then a thin layer of epoxy can be brushed and let cure for a transparent finish.

Note: If your stator comes out rough, or too thick, and it cannot be smoothed out there are two options. One can either make the rotor flange thicker or shim the rotor plates. Information on the former can be found in the next section, info on the latter can be found in the next section, Air Gap Optimization.

2.1.3.D STATOR WIRING

Three-phase alternators can be wired in two configurations: Y-configuration or delta. We chose to wire our generator in delta in order to produce higher voltages and attempt to keep the current in the phases down. This means that each phase is wired in series:



Phase 1			
Red Lead to 1A	1B to 4A	4B to 7A	7B to Ground
Phase 2			
Blue Lead to 2A	2B to 5A	5B to 8A	8B to Ground
Phase 3			
Green Lead to 3A	3B to 6A	6B to 9A	9B to Ground

The first column of the table (1A, 2A, 3A) should just have lengths of wire soldered onto them. We chose to color each phase differently in order to distinguish them easily later. The next two columns show which leads to connect with pieces of wire, for example 1B should be soldered to 4A and then 4B should be soldered to 7A. The last column shows which leads to solder ground wires to (7B, 8B, 9B). This arrangement wires each phase in series and brings the power out of each phase individually.

The three phases can be utilized in many ways but based on our production we are going to rectify the signal.

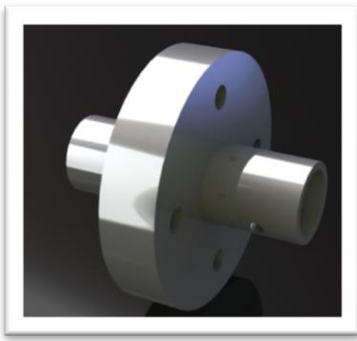
2.1.3.E AIR GAP OPTIMIZATION

The air gap is the space between the face of the rotor and the face of the stator on each side. By carefully casting each, this gap can be adjusted to be very small. Magnetic potential falls off quickly across air so any small change in the air gap can make an impact on generator performance.

Assembling the generator with all-thread and nuts, as mentioned in Section 2.1.7, can make optimizing the air gap very simple. Once the final position of the stator is determined, tension spacers can then be cut and the all-thread replaced with high strength bolts.

If the air gap is very small, monitor performance of the generator carefully at first to ensure that the rotors are not striking the stator at any point. This could cause a failure at high speeds.

2.1.4 ROTOR MOUNT (FLANGE)



The flange serves as a mounting piece for the rotor plates. They mount face-to-face on this piece. The four bolt pattern matches that on the rotors. This is how the rotors align to one another.

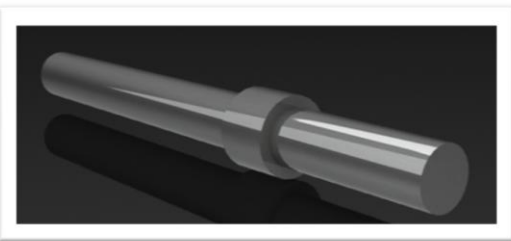
The outer diameter of the tube section is the same as diameter of the hole through the rotors. This gives the rotors support through their thickness.

The rotor mount is machined from a solid piece of aluminum. Aluminum was chosen because of its resistance to corrosion and its lightweight. However it can also be made from alternate materials using different methods. A piece of appropriately sized steel or aluminum tubing can have a steel or aluminum ring welded to it. If this is done, one must be careful to weld evenly so that rotating balanced is maintained.

The thickness of the rotor mount should match the thickness of the stator. As a result, it should be produced after the stator is cast so that an accurate size can be determined. Our stator casting warped slightly on the top side which made the stator thicker than the designed size. As a result, the flange had to be resized.

The two holes through the tube of the flange allow for attachment to the driveshaft. The design team decided to use a single taper pin to lock our rotor to the shaft; however this requires a tapered reamer and some know-how. If simplicity is desired, two bolts can be used. Have them offset 90 degrees to one another. This helps to offset forces that may occur in different planes of action.

2.1.5 DRIVESHAFT



The driveshaft is the object that the flange and bearings mount to. This piece spins at a high rate of speed, so proper materials must be chosen. It was suggested to the design team to use stainless steel for this part because of resistance to corrosion in the elements. Despite the high galvanic potential between stainless steel and aluminum (the flange) this advice was heeded.

In general, our calculations show that carbon steel is strong enough to serve as a driveshaft. Carbon steel also has a lower galvanic potential with aluminum. However, no matter what material is used, Permatex Anti-Seize (or similar) and caution should be exercised when assembled to prevent galling and corrosion.

The driveshaft will have to have a hole(s) drilled through it to match the hole(s) that are put through the legs of the flange. This allows the taper pin or bolts to securely lock the flange to the shaft.

Another advantage to using carbon steel is that the back of the blade hub can be welded directly in front of the collar on the driveshaft. Caution must be exercised, however, because deformations could be created which will cause the blades to spin with an eccentricity.

Our team purchased fiberglass blades online and they came with a blade hub. We discovered that the blade hub had a tapered mounted surface. As a result, the front end of our driveshaft (the end to the right of the collar in the picture) had to be carefully tapered and a proper taper fit had to be calculated.

We then threaded the end of the driveshaft and used a castle nut with a cotter pin to secure the blade hub. Alternately, one could tap the end of the driveshaft and use a thrust washer and bolt combination. Finally, one could bolt through the driveshaft and hub. Careful attention should be paid as to the amount of torque that the wind turbine produces and an appropriate amount/size of bolts should be used to properly secure the hub.

2.1.5A BEARING SELECTION

The bearings used in our generator are simple flange bearings available at any bearing house. Rather than using shaft locks to keep the bearings from sliding, we machined a collar into the driveshaft which butts up against the back of the bearing. In addition, the flange fits perfectly between the two bearings on the shaft and keeps the shaft from sliding in the bearings. These features can be seen in the drawings and generator assembly section.

2.1.6 CASING

2.1.6.A PURPOSE OF CASING

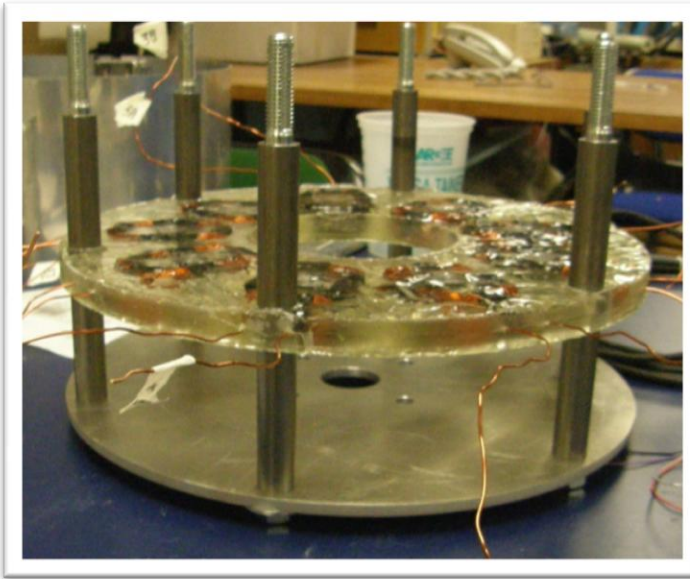


The purpose of the casing is to protect the generator from the elements. This is especially important when operating in marine, winter, forested conditions or any combination of the above. The case can help protect against everything from ice buildup to organics buildup to animal strikes. If implemented properly, it may be able to extend the life of the generator and help prevent corrosion of the assembly and wear on the bearings.

2.1.6.A IMPLEMENTATION

The case is shown here sitting with one of the end caps (before the end cap had been drilled). It is made from thin aluminum sheet and attached at the top and bottom to two aluminum boxes. They were folded out of remaining aluminum sheet and riveted together. The box which you can see inside of in the photo is actually the bottom box. It has Dzus connectors which provide quarter-turn access. Also, the fasteners stay in the material so there is no way to lose them when you open the case. The case attaches to each side of the top box via hinges. This allows each side of the case to be opened separately. The boxes will be bolted to the inside face of each end cap. Anti-chafe tape will be used on all edges that come in contact with the generator to facilitate a strong seal and prevent vibration noise and wear. To get the rounded shape of the aluminum shown here, use a roller setup or carefully hand roll it yourself around a mandrel of similar size.

2.1.7 TENSION SPACERS



The tension spacers are the hollow pieces fitted over the long mounting bolts. They are used to align the stator and their length (as well as the width of the rotor mount flange) dictate how close the stator will be to the rotors. It should be designed so that the faces of the stator are close to the rotor on each side, but not touching.

Our team had difficulty with the tension spacers causing “cogging” in the machine. We would recommend using a strong but non-ferrous material, such as brass/bronze, for these. Aluminum may also be a good choice since it is strong in compression, however it expands/contracts thermally at a different rate than the surrounding materials which

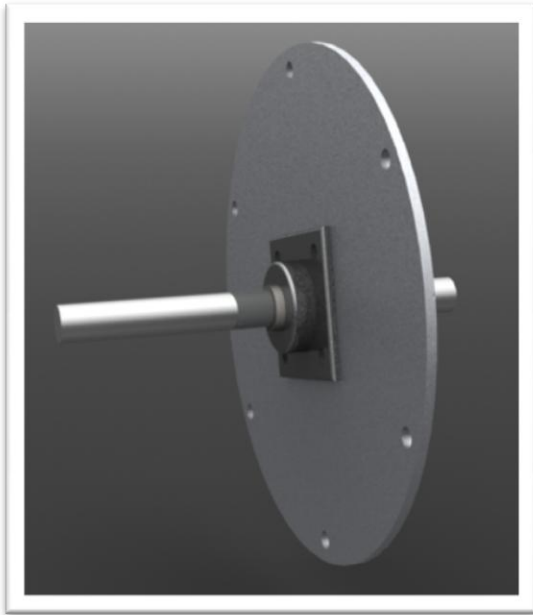
could cause issues.

When the generator is first assembled, the long bolts and tension spacers can be replaced with pieces of all-thread and nuts. This can help quickly and easily optimize the size of the air gap.

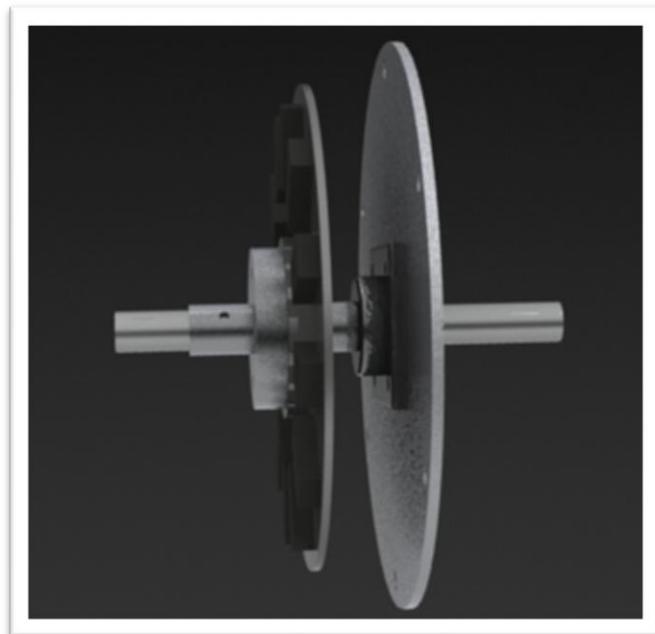
Note: Long term use of all-thread and nuts is not recommended. The tension spacers allow uniform tension to be pulled through the bolts. This puts the generator into a state of overall compression. When the generator is mounted on a cantilever, as is done with the outdoor stand, the driveshaft will be less likely to sag and the device will be more sturdy overall. In addition, parts may be less subject to large vibration and better able to withstand environmental shocks.

2.1.8 GENERATOR ASSEMBLY

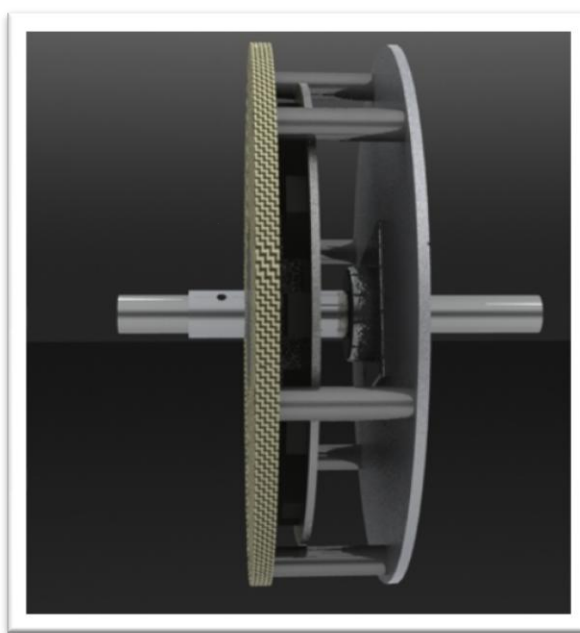
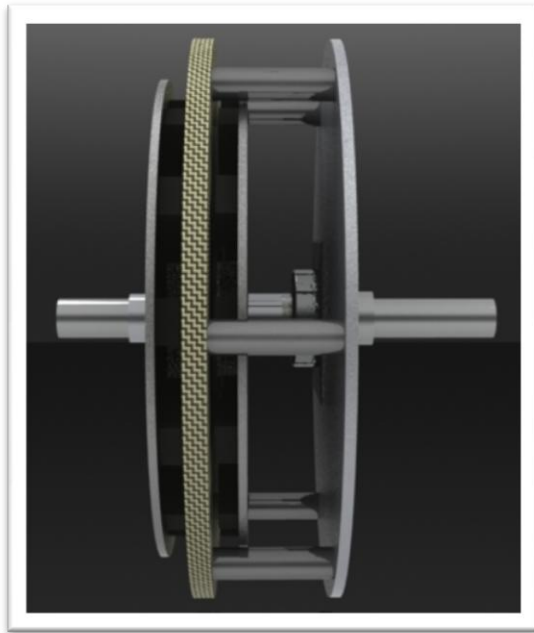
The following diagrams show a step-by-step assembly of the finished generator using CAD models.



Mount the bearing to the end cap and slide the assembly down the driveshaft until it butts up against the collar. Tighten the set screws (or whatever locking system your bearings came with).

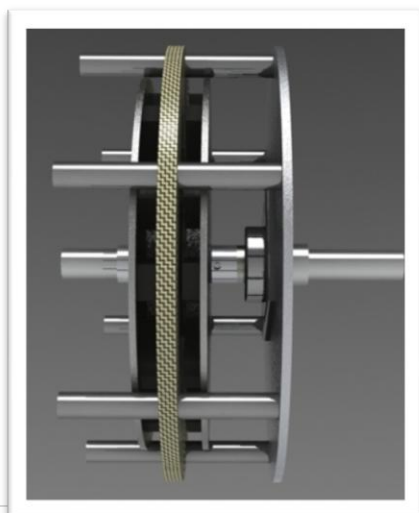


Put one rotor on the backside of the flange and slide bolts through the four-bolt pattern. Consider using anti-seize or similar to prevent galling. Slide the flange down the driveshaft until it butts up against the bearing face. Insert your locking taper pin or bolt set up to lock the flange in place. This is important to keep the rotor from pulling the flange assembly back off the shaft as the second rotor is being set on.



Using either the tension spacers with bolts or the all-thread and nut setup, lower the stator into position over the first rotor. Ensure that the rotor does not contact the face of the stator. If you are using an all-thread and nut setup, this is a simple matter of adjusting the nuts up and down. In short: we recommend starting with this setup, finding the proper tolerances and then fabricating tension spacers to those lengths.

Carefully set the next rotor in position. Make sure that the magnets are properly aligned. You'll know because the rotors will be attracted to one another. **The opportunity for injury to you, others or the generator is high at this point.** These rotors are very strong and will pull down with a force that you cannot safely control. It is recommended to find a system of lowering the second plate into place, such as using wedges or small jacks. We used pieces of wood stuck in at 90 degrees and set the plate on. Then we inserted thinner pieces of wood next to them and pulled the larger ones out, thus slowly lowering the rotor. This was repeated until the rotor was in place.



Put the rest of the tension spacers in place and slide on the back bearing. Lock it into place with the set screws (if that is the system your bearings use).

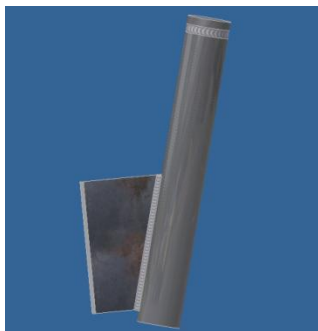


Bolt on the second end cap to the bearing and secure the end cap to the through-bolts using nuts. Consider using Loctite (or similar) to prevent fasteners from shaking loose from the generator.

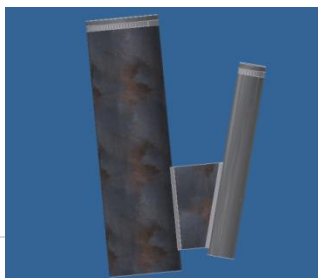
You now have a completed generator ready to be mounted. But first, you'll need a mounting bracket and stand. Details on our implementation follow.

2.2 FURLING TAIL/MOUNTING BRACKET

Main Chassis Construction:



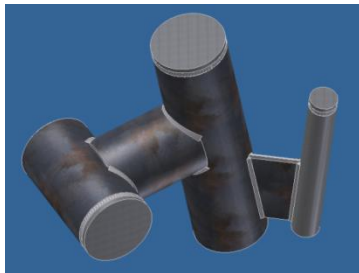
Weld the inner tail pivot cap to the inner tail pivot and clean it up. Loctite will be used to fasten bushings to this pipe so it needs to be buffed to a shine. For this build the tail bracket was welded to the inner tail pivot $\frac{1}{2}$ " from the bottom. The tail bracket shown here sets the inner tail pivot at 15° but other angles may work as well. The steeper the angle used, the higher the tail will lift when it furls. Needless to say, this angle directly affects the wind speed the turbine will furl at.



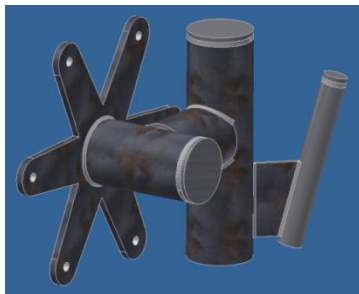
After welding the main pivot cap to the main outer pivot, weld the tail bracket assembly from the last step on. For this build the tail bracket was welded onto the main outer pivot 1" from the bottom. Welding it on in other spots would probably work as well, but you want to keep it low so the main pivot doesn't feel the need to fly off.



For this build the pivot arm was welded to the main outer pivot 135° from the tail bracket. Also, the bottom of the pivot arm was level with the top of the tail bracket. The angle of separation has an effect on the furling of the turbine because it directly impacts the moment forces acting about the pivot.



After welding the bracket mount cap and the bracket mount together, finish up by welding it to the pivot arm. For this weld make sure that the generator mounting bracket will clear the main pivot and that welding has not distorted any of the parts. If the heat from welding makes the bracket mount angle downward the turbine blades will be closer to the stand and have a greater chance of colliding with it in high winds.

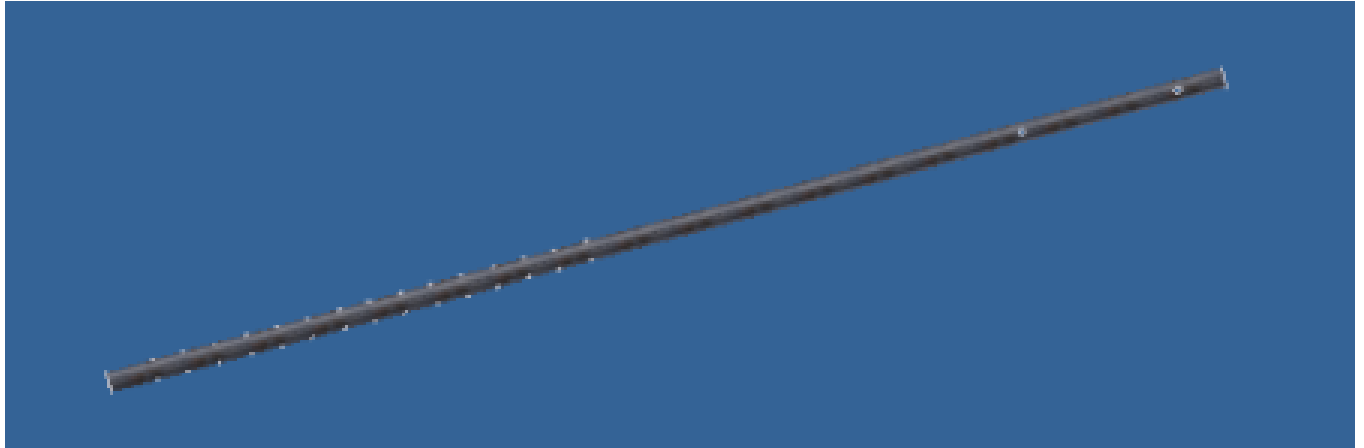


Weld the generator mounting bracket to the bracket mount. Be sure to weld it as close to the center as possible, and that two bolt holes are at the very bottom. This will result in better support for the rather hefty generator. Remember, if the pivot arm or bracket mount are crooked the generator mount will be angled up or down so be very careful.

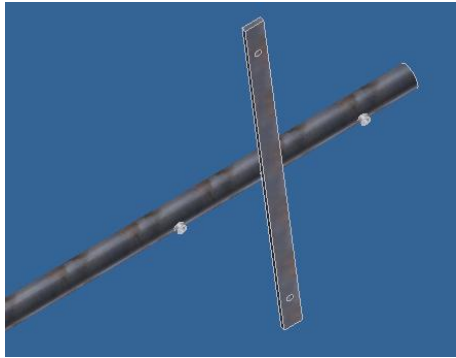


The last step is to Loctite the tail bushing and slotted tail bushing to the inner tail pivot. These brass bushings allow the tail to turn freely and are extremely durable. Also, a brass thrust washer is placed on top but not glued down. This will support the weight of the tail and protect the outer tail pivot from wear. If these bushings become old and need to be replaced, simply heating them with a torch will melt the Loctite and they will slide off.

Tail Construction:

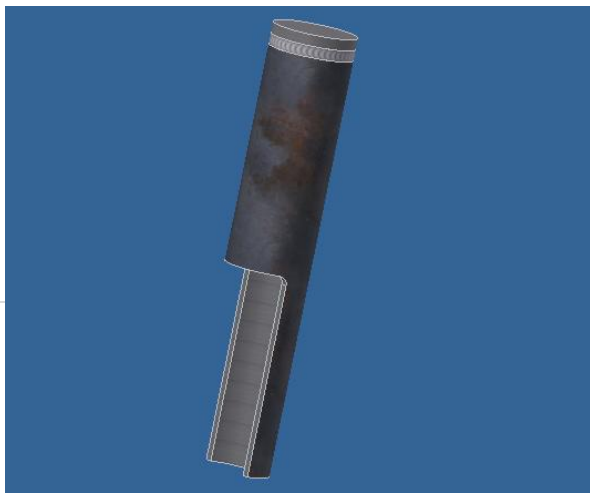
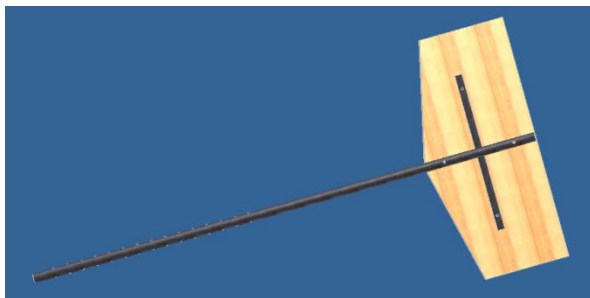


The tail consists of two separate parts to form a telescope. The inner telescope is a piece of 1" scheduled 40 pipe that has holes drilled in it every 2 inches as well as holes drilled for mounting the tail. The outer telescope has the same pattern of holes every two inches so the inner and outer telescopes can be bolted together



The tail vane support gets welded to the inner telescope and has two bolt holes in it. The plywood tail vane gets bolted to this support and the inner telescope itself. Washers are used to fill the gap between the tail vane and the inner telescope when it is fastened on.

This is the completed inner telescope complete with tail vane:



Creating the second half of the tail assembly starts with the outer tail pivot and outer tail pivot cap getting welded together. This piece will fit over the bushings.

Not at rest



At rest against the tail bracket



The ten degree angle at rest



In order to make a successful furling tail, it needs to sit at a ten degree angle when it is at rest as seen in the picture. It can do this because the outer tail pivot comes into contact with the tail bracket at precisely the right moment. To correctly fabricate this feature set the main chassis up with a stand or vice and slide the outer tail pivot over the brass bushings. By either making a template or sketching the geometry onto something below chassis the outer telescope can be held against the outer tail pivot at the correct angle for welding. Make sure that before welding happens the outer tail pivot is turned all the way counter clockwise so it touches the bracket.



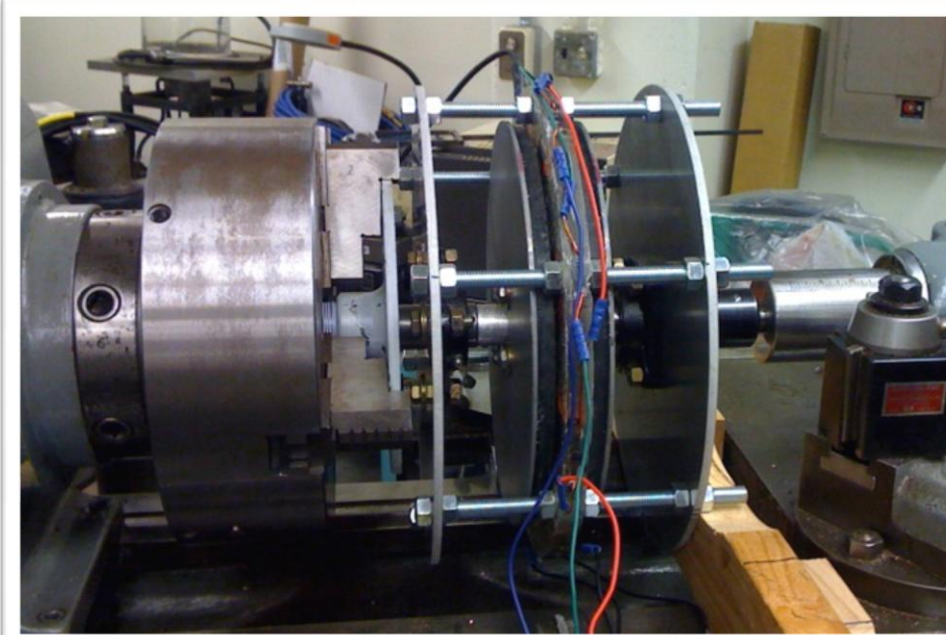
A tail stop must be fabricated to keep the tail at a ten degree angle when fully furled. This keeps the tail from colliding with the blades, and allows the blades to produce power when they are safely furled out of the wind. We do not have blue prints for this piece because we drew the geometry out on a table below the chassis and fabricated a piece of steel wide enough to bridge the gap between the outer telescope and main pivot.



The last step is to weld a tail support to connect the outer telescope and outer tail pivot. For this build we actually went with a different support that reached further down the outer telescope. You can do this without interfering with the bolt holes by welding the support to the sides of both pipes. Making this support reach further out reduces the maximum moment seen by the outer telescope and making this support reach two feet down the telescope results in a safety margin of 4.5.

3. TESTING RESULTS

3.1 BENCH TESTING



We tested our prototype using a large lathe in the University machine shop. Since we turned our driveshaft between live centers we were able to chuck up the blade hub on one end (seen on the left) and put a live end in the quill to support the other end (pictured on the right). In order to bench test properly, two things must be

known. First is the open circuit voltage of the generator. That is, the voltage produced when the generator is spun with no load attached. The second important piece of information is the internal resistance of each coil. This can be measured using a multi-meter; however the resistance of the wire is so low that this is probably not an accurate way to proceed. Instead, knowing how many turns of wire, and therefore the length of wire, per coil is a better approach. The following equation can be used:

$$R_i = \frac{\rho L}{A}$$

Where ρ is the resistivity of the wire used, L is the length of wire per coil and A is the cross-sectional area of the wire chosen. These values can be found easily online through wire supply sites. Perform this calculation for each coil and then sum the results. This will yield the total internal resistance.

According to our sources, a dummy load equal to the total internal resistance of the generator must be attached. The maximum power is achieved when the load on the generator equals this internal resistance. This maximum power can be described by the following equation:

$$P_{max} = \frac{V_o^2}{4R_i}$$

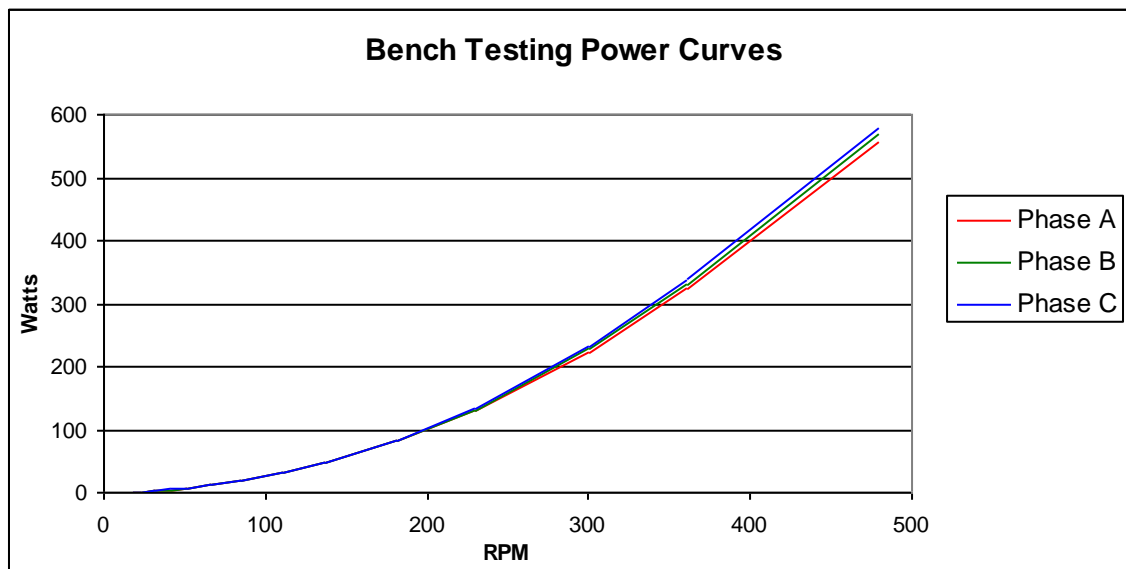
Where V_o is the open circuit voltage at a given RPM and R_i is the internal resistance calculated previously.

3.1.1 SAFETY FIRST

Testing the generator can be dangerous. Ensure that your testing setup is used is safe, secure and controlled. The generator turns at high rates of speed and is a serious hazard if it breaks or comes loose. Make sure that all people are at a safe distance and that common sense is exercised.

3.1.2 POWER CURVES

The figure below graphs the available theoretical maximum power, per phase, for the generator.



The maximum open circuit voltage was 40 volts per phase, resulting in 570 watts of available power per phase. The total output of the generator is the sum of all three phases. So the generator has a maximum theoretical power output of 1.7kW. The generator has a very high power factor (PF), so there are negligible losses in power from the AC source. To use this power to charge a battery, the current will need to be passed through a rectifier, resulting in a loss of voltage. For battery charging, the maximum theoretical power output is 1.1kW.

Note that during this test the generators power output did not peak, rather it was the inability to safely test in on the lathe at higher speeds that stopped our testing.

3.2 TRUCK TESTING

Truck testing provides an opportunity to see the turbine in motion under controlled conditions. This is a great chance to find out how the turbine operates as a unit without fully turning it loose in the wild. The main challenge we faced was finding an open road free from traffic, pedestrians and potholes.



3.2.1 SAFETY FIRST

Truck testing is an especially dangerous operation. The blades spin, the generator can pivot and things can come loose if careful thought is not put into the preparation. Ensure that the generator is supported securely and that the truck is operating in an area free of traffic and other people.

3.2.2 TRUCK TESTING RESULTS

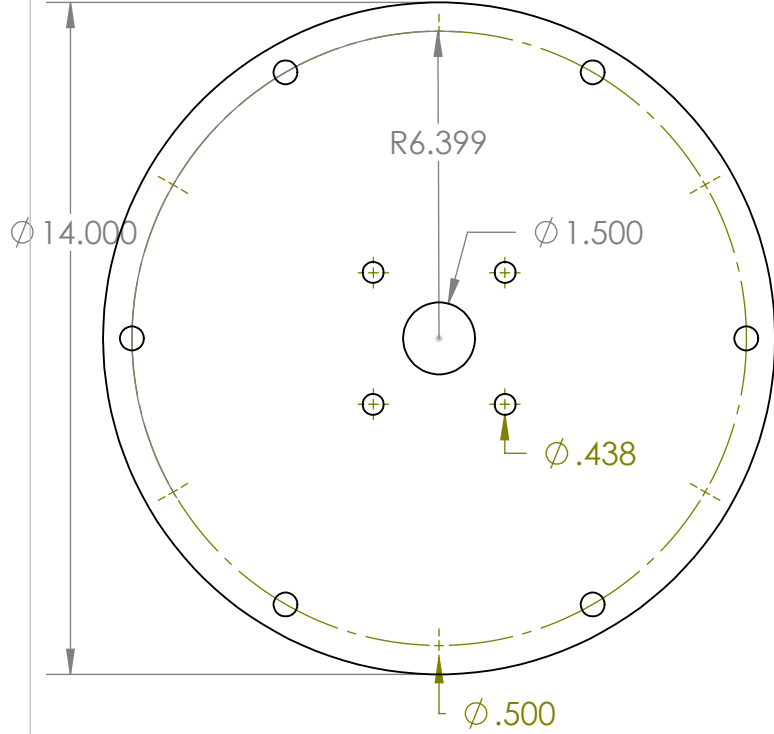
Generally the speedometer of the vehicle is not accurate enough to determine wind speeds. Of course, this is all fairly rough testing because the shape of the truck causes turbulent effects in the blades and changes the air speed. Our team used a hotwire anemometer to test our turbine. This is a handheld device that allows us to take air speed readings near the turbine blades in order to get the best approximation of overall air speed.

As of the publishing of this document, we have limited truck testing results. However, the generator starts in approximately 10MPH of wind and runs smoothly. From bench testing we know that we have a solid generator, and preliminary truck testing results seem to indicate that we can achieve high power outputs in realistic wind conditions.

4. APPENDIX

4.1 COMPONENT DRAWINGS AND MODELS

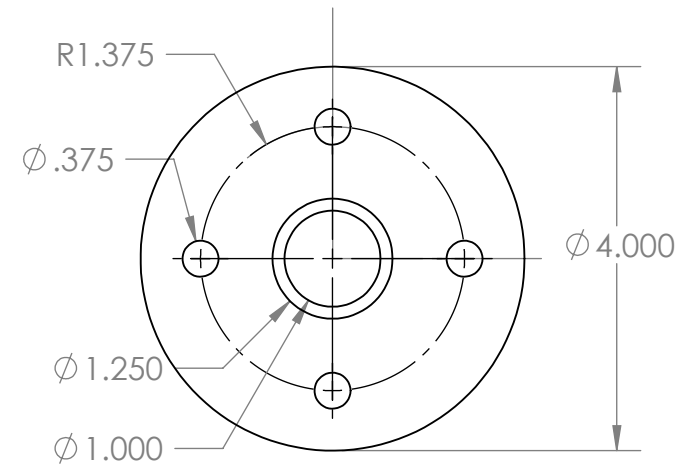
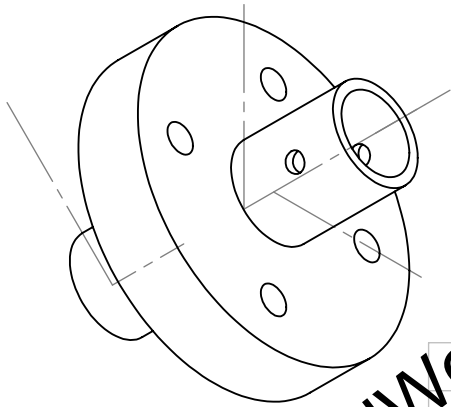
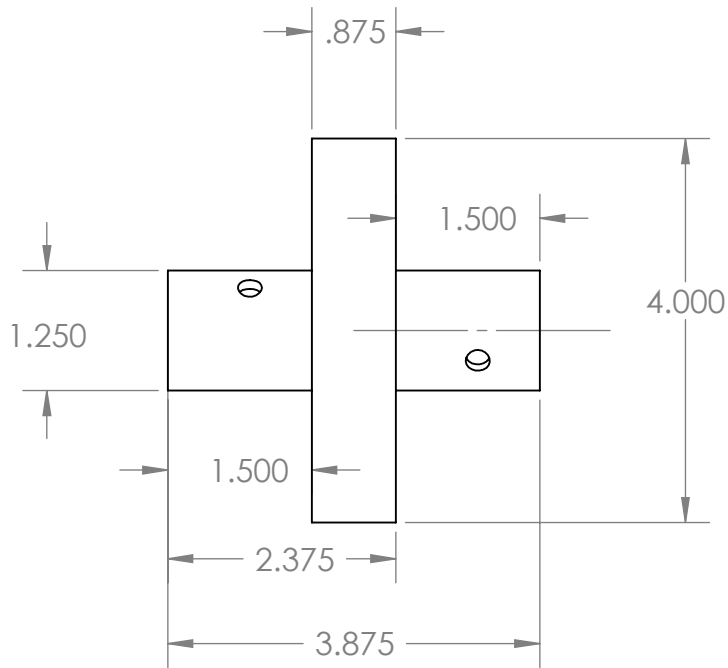
Drawings for each component are contained in the following pages. Dimensions for your prototype may change as you make modifications.



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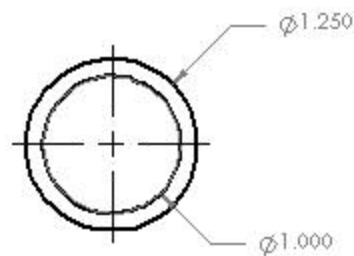
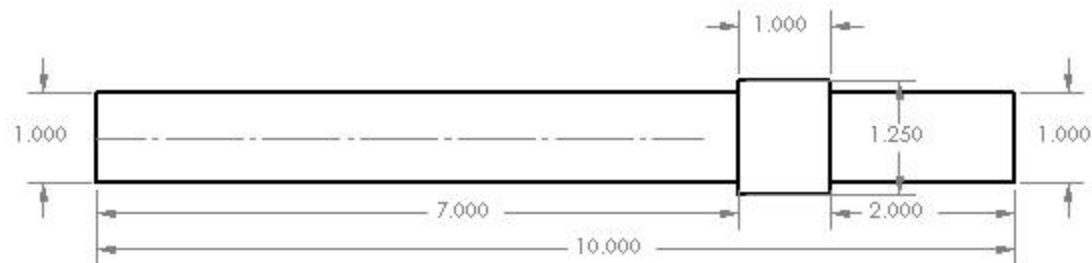
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		ANGULAR: MACH ± BEND ±		MFG APPR.			
		TWO PLACE DECIMAL ±		Q.A.			
		THREE PLACE DECIMAL ±		COMMENTS:			
		INTERPRET GEOMETRIC TOLERANCING PER:				SIZE	DWG. NO.
		MATERIAL				A	End Cap
		FINISH					REV
NEXT ASSY	USED ON					SCALE: 1:8	WEIGHT:
APPLICATION		DO NOT SCALE DRAWING				SHEET 1 OF 1	



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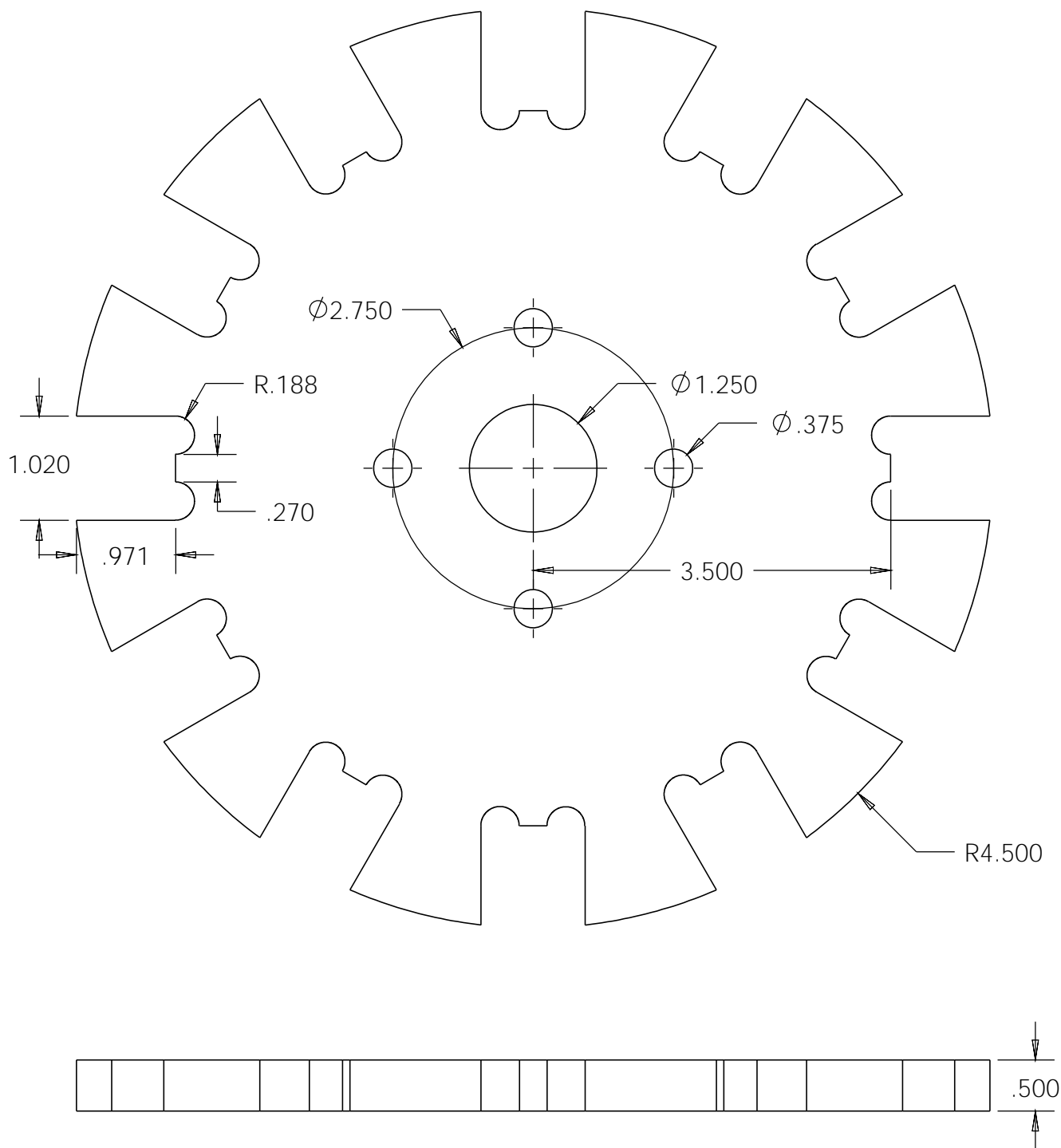
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		TWO PLACE DECIMAL ±		Q.A.			
		THREE PLACE DECIMAL ±		COMMENTS:		A Flange_real	
		INTERPRET GEOMETRIC TOLERANCING PER:					
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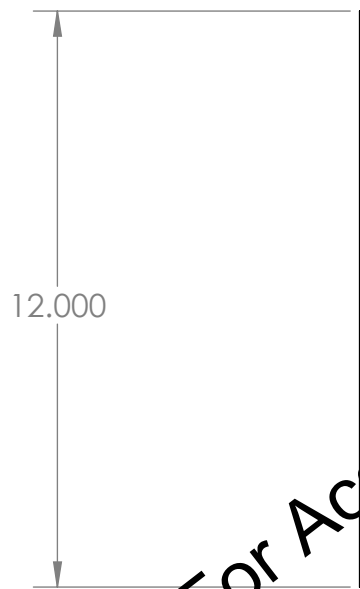
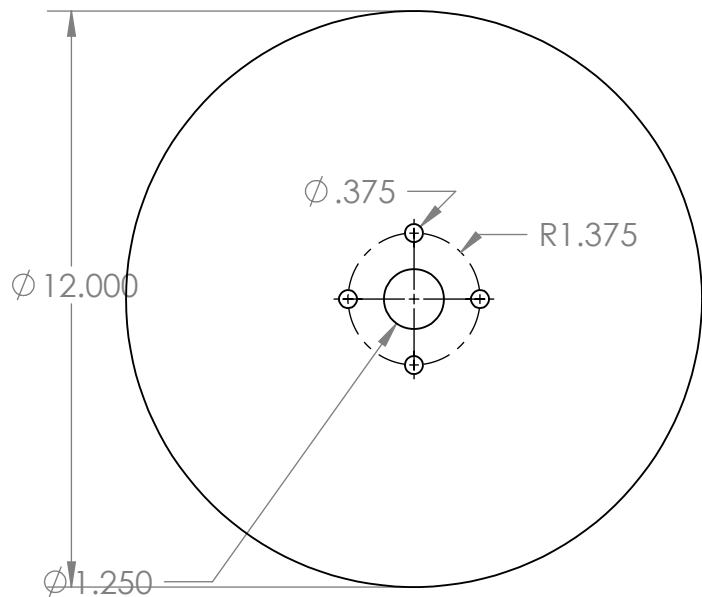
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		ANGLES ARE IN DEGREES		PLG APPR			
		TWO PLACE DECIMALS		MTG APPR			
		THREE PLACE DECIMALS		Q.A.		SIZE DWG. NO. REV A Drive Shaft	
		INTEREST DIMENSIONS		COMMENTS:			
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WGT ASSY	USED ON	FINISH		SCALE: 1:2 WEIGHT: SHEET 1 OF 1			
APPLICATION		DO NOT SCALE DRAWING					



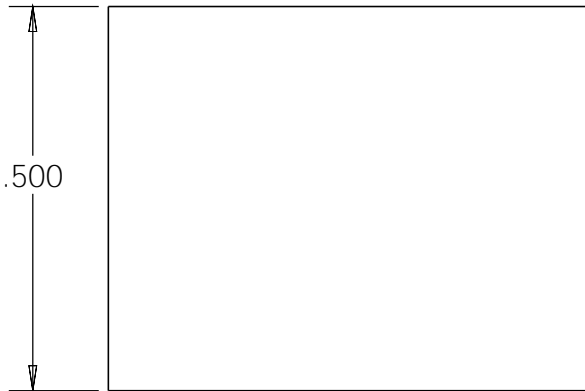
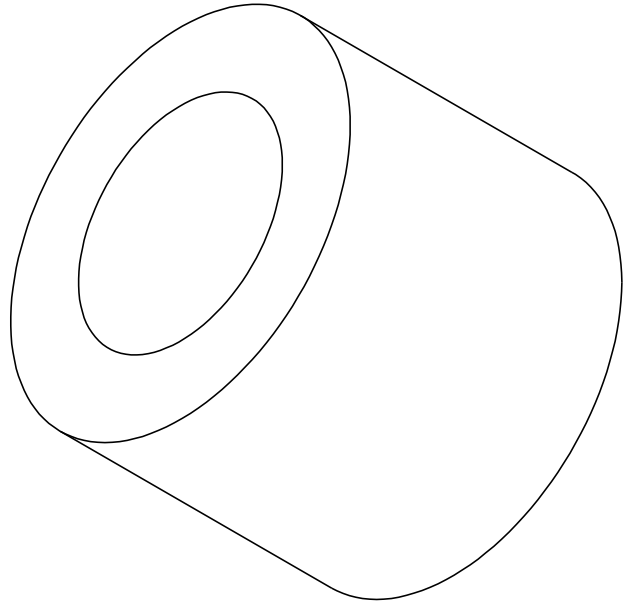
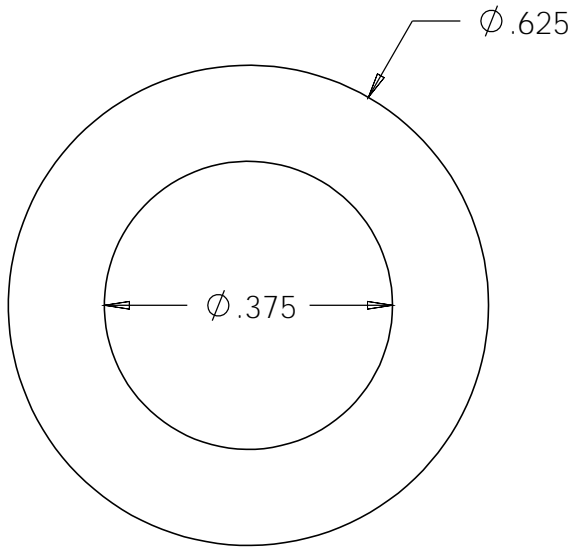
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					DRAWN			
					CHECKED			
					ENG APPR.			
					MFG APPR.			
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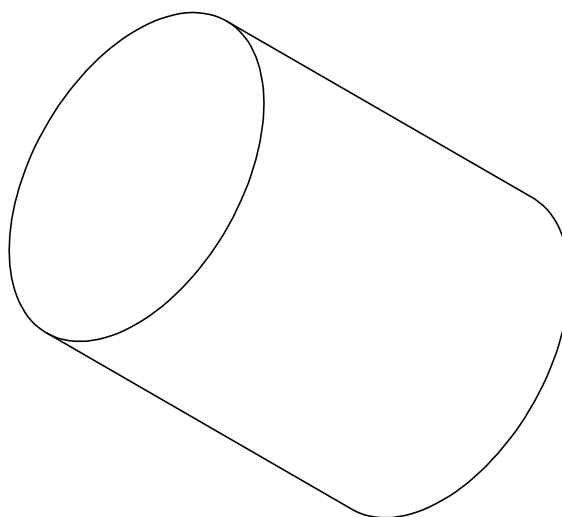
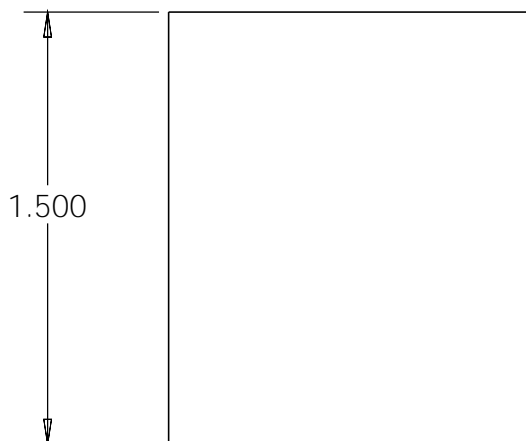
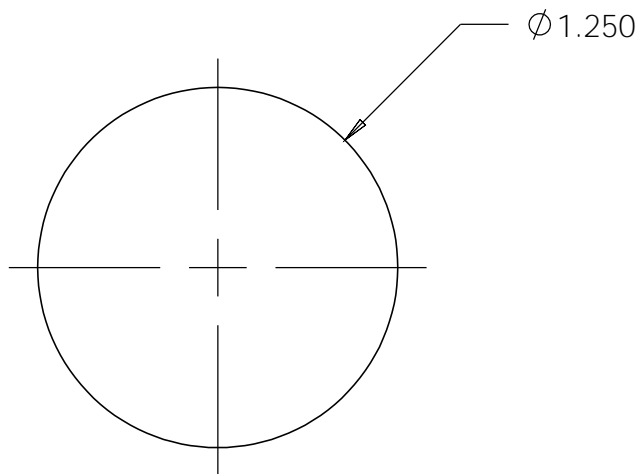
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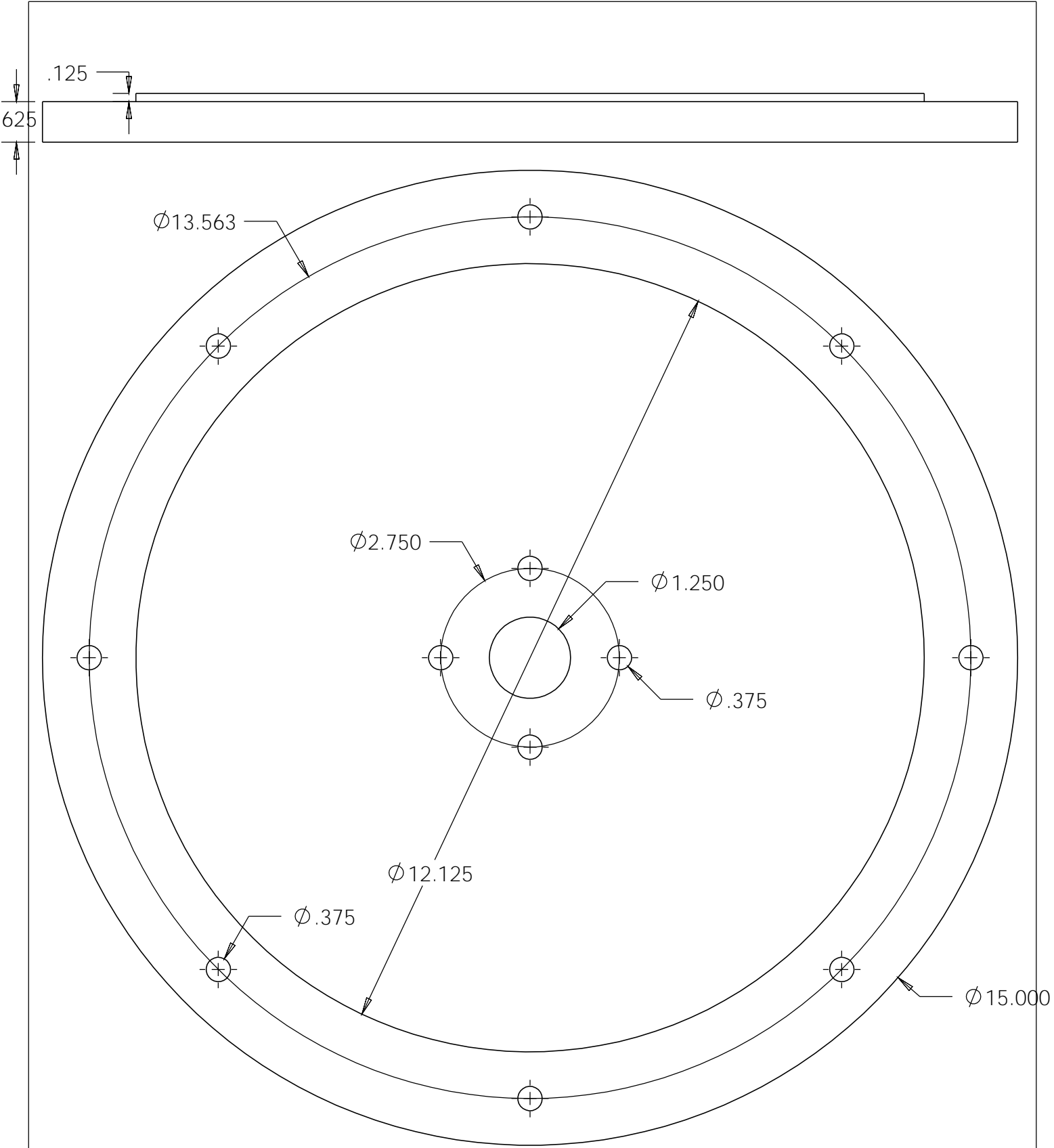
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		THREE PLACE DECIMAL ±	COMMENTS:				
		INTERPRET GEOMETRIC TOLERANCING PER:				SCALE: 1:4 WEIGHT: SHEET 1 OF 1	
		MATERIAL Mild Steel					
NEXT ASSY		USED ON					
APPLICATION		DO NOT SCALE DRAWING					



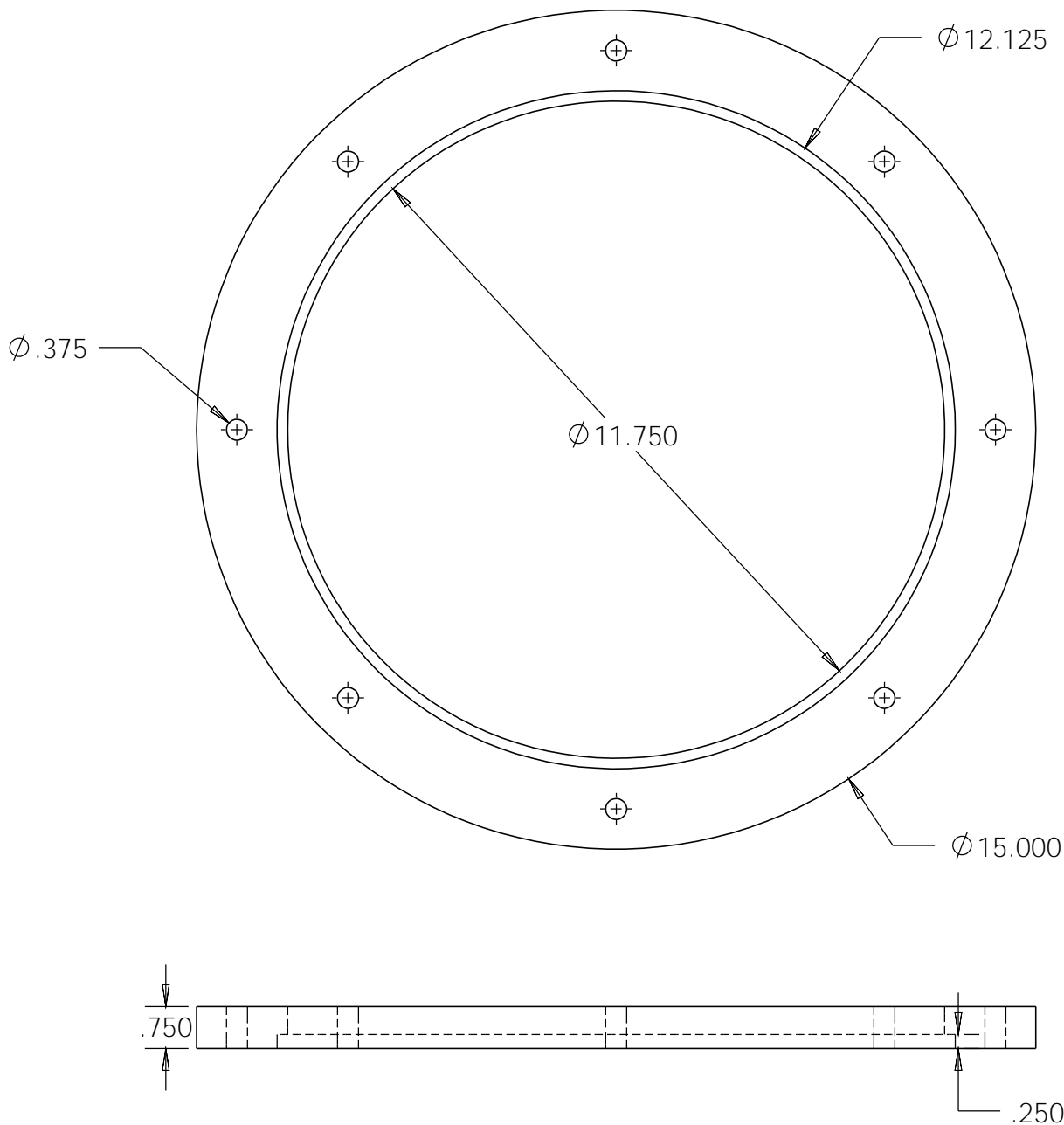
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				DRAWN					
				CHECKED					
				ENG APPR.					
			MFG APPR.						
			Q.A.						
			COMMENTS:						
	NEXT ASSY	USED ON	FINISH				SIZE A	DWG. NO. Rotor Bushing	REV.
APPLICATION		DO NOT SCALE DRAWING			SCALE: 4:1		WEIGHT:	SHEET 1 OF 1	



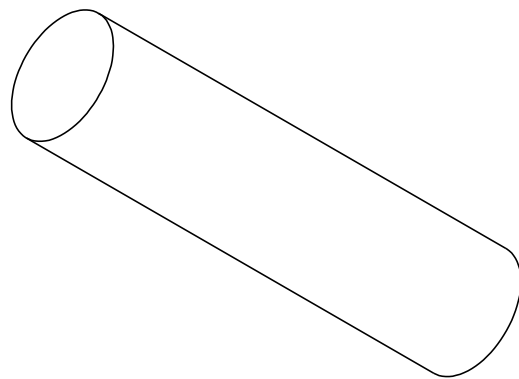
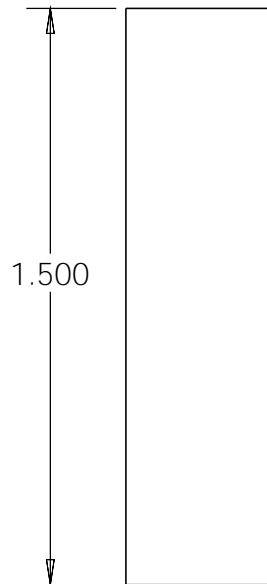
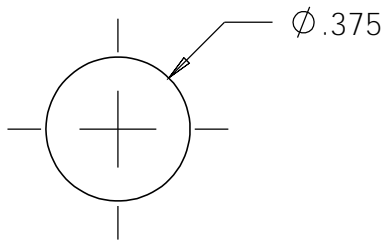
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				CHECKED				
				ENG APPR.				
				MFG APPR.				
		MATERIAL		Q.A.				
		FINISH		COMMENTS:				
NEXT ASSY	USED ON							
APPLICATION		DO NOT SCALE DRAWING						
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				A	Rotor Center Plug			
				SCALE:1:1	WEIGHT:		SHEET 1 OF 1	



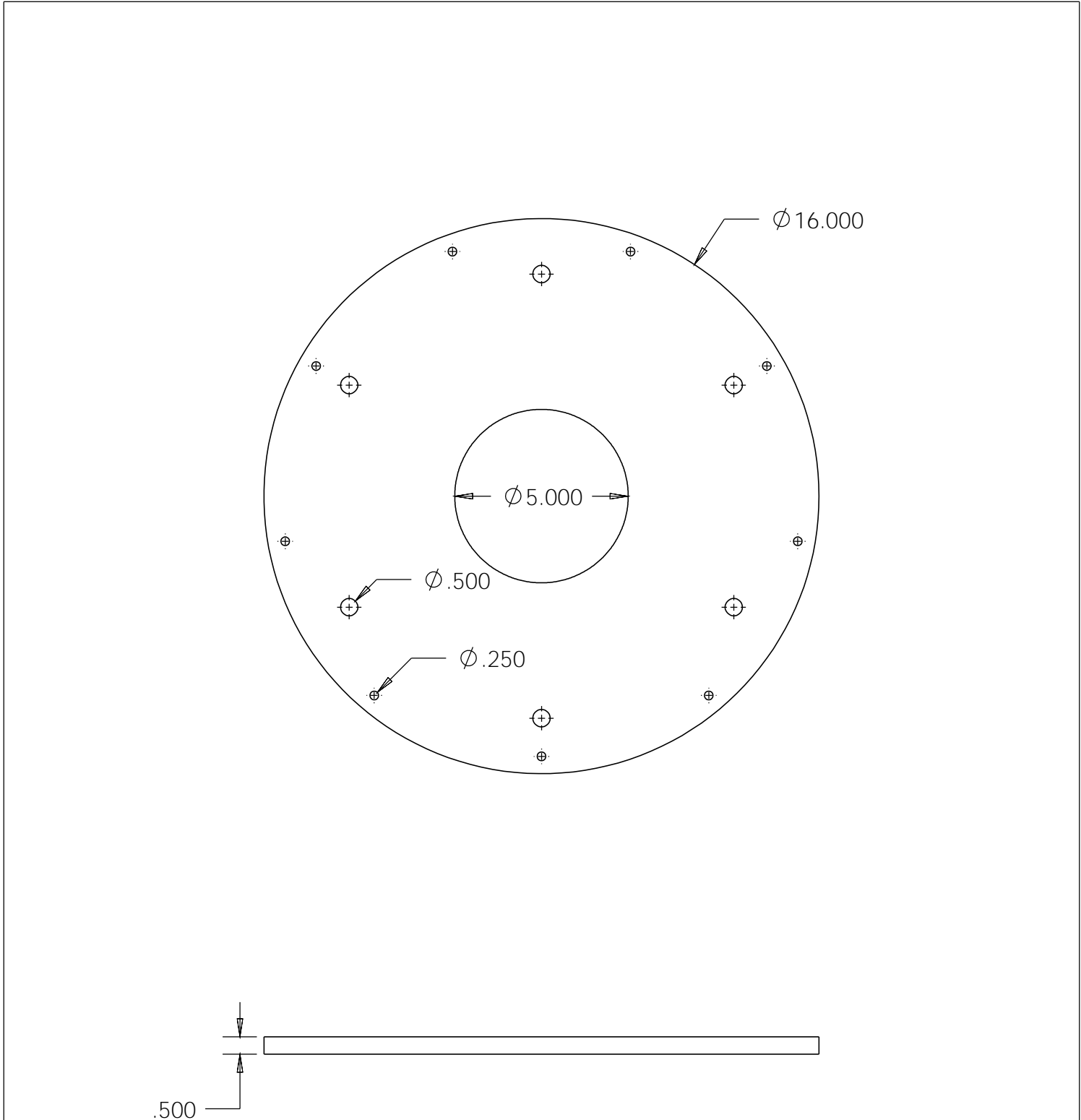
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			CHECKED					
			ENG APPR.					
			MFG APPR.					
		MATERIAL	Q.A.					
		COMMENTS:						
NEXT ASSY	USED ON	FINISH				SIZE	DWG. NO.	REV.
APPLICATION		DO NOT SCALE DRAWING				A	Rotor Mold Base	
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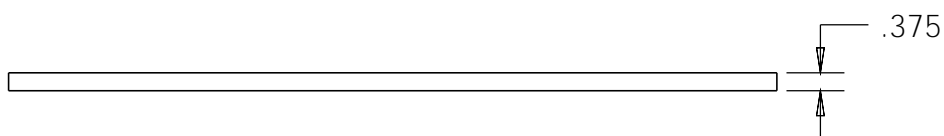
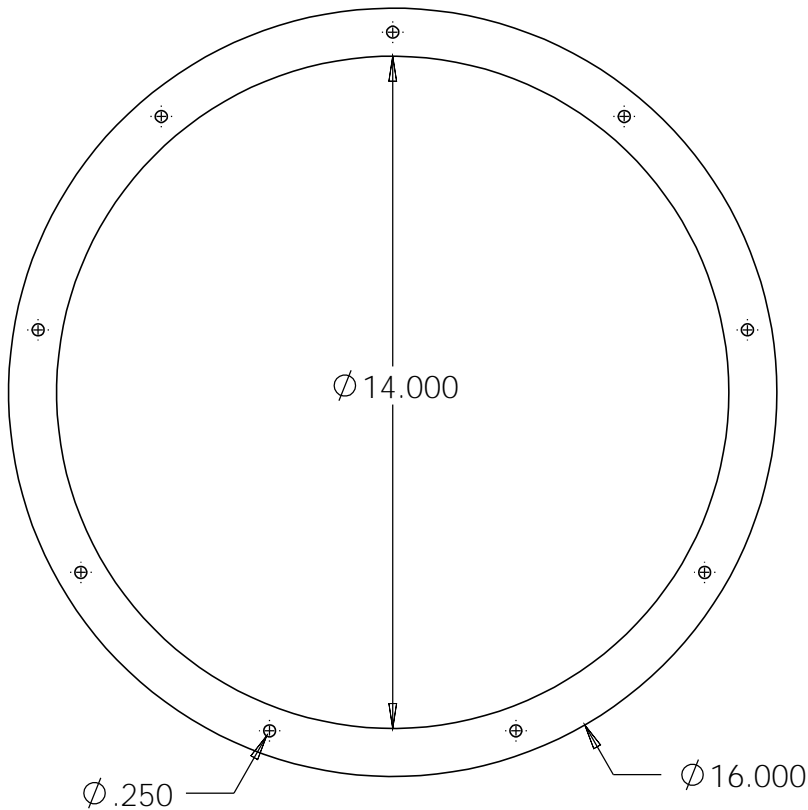
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			CHECKED					
			ENG APPR.					
			MFG APPR.					
		MATERIAL	Q.A.					
		COMMENTS:						
NEXT ASSY	USED ON	FINISH				SIZE	DWG. NO.	REV.
APPLICATION		DO NOT SCALE DRAWING				A	Rotor Mold Top	
			SCALE:1:4		WEIGHT:	SHEET 1 OF 1		



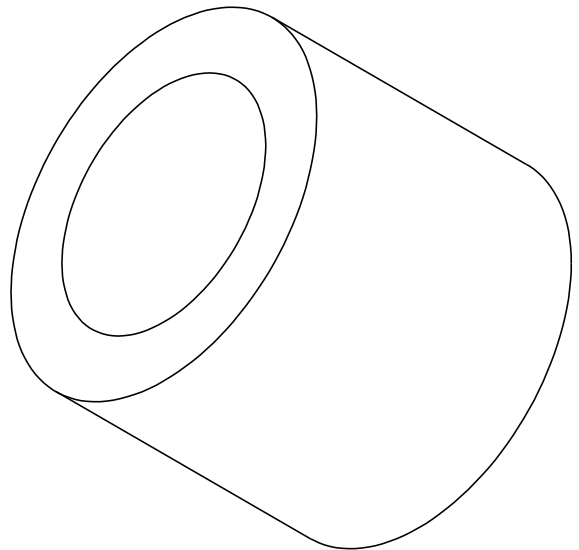
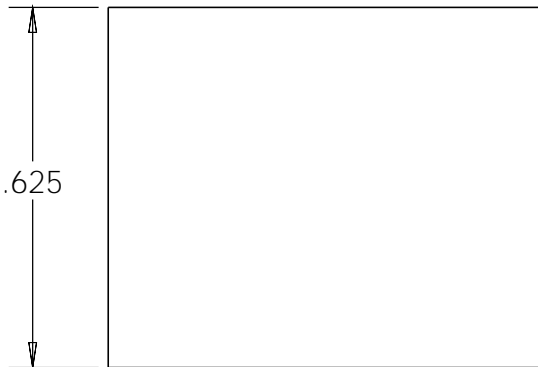
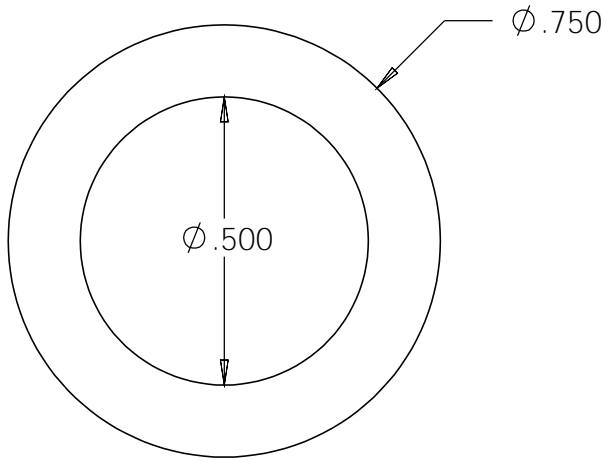
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					DRAWN						
					CHECKED						
					ENG APPR.						
					MFG APPR.						
					MATERIAL			Q.A.			
		FINISH			COMMENTS:						
NEXT ASSY	USED ON										
APPLICATION		DO NOT SCALE DRAWING						SIZE A	DWG. NO.	Rotor Pin	REV.
								SCALE:2:1	WEIGHT:		SHEET 1 OF 1



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				DRAWN								
				CHECKED								
				ENG APPR.								
				MFG APPR.								
				Q.A.								
				COMMENTS:								
	NEXT ASSY	USED ON								SIZE A	DWG. NO. Stator Base	REV.
	APPLICATION			DO NOT SCALE DRAWING						SCALE:1:4	WEIGHT:	SHEET 1 OF 1



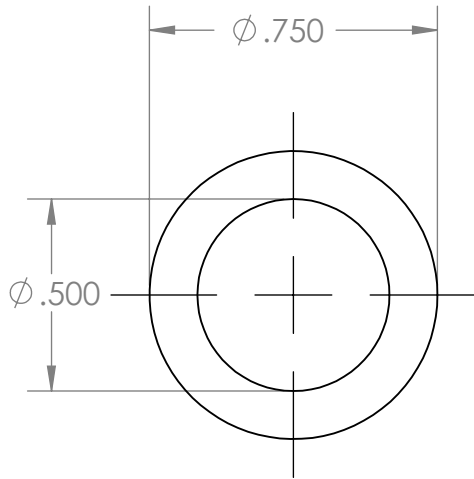
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					CHECKED			
					ENG APPR.			
					MFG APPR.			
				MATERIAL	Q.A.			
				FINISH	COMMENTS:			
NEXT ASSY		USED ON						
APPLICATION		DO NOT SCALE DRAWING						
				SIZE A DWG. NO. Stator Top Halves REV.				
				SCALE: 1:4		WEIGHT:		SHEET 1 OF 1



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			CHECKED			
			ENG APPR.			
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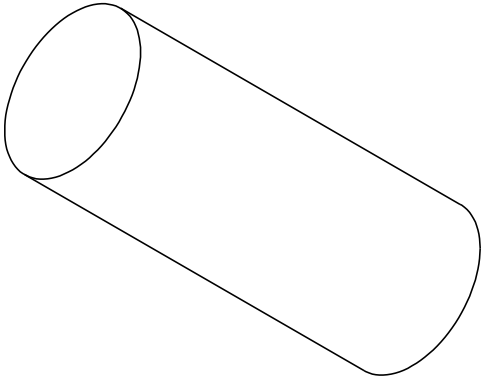
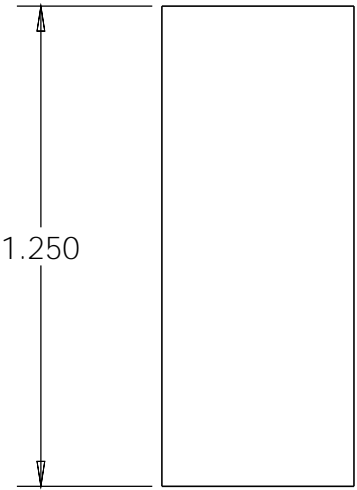
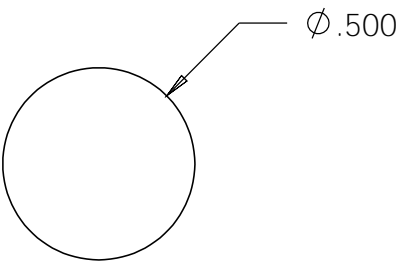
SIZE	DWG. NO.	REV.
A	Stator Bushing	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

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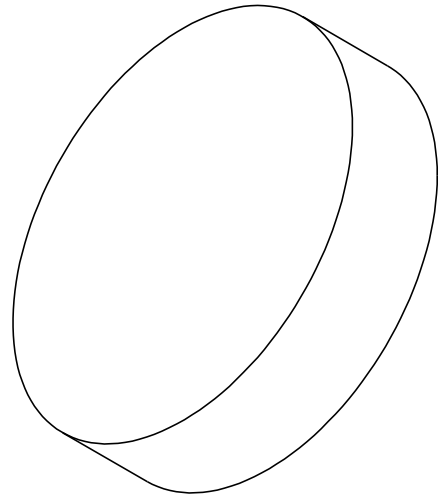
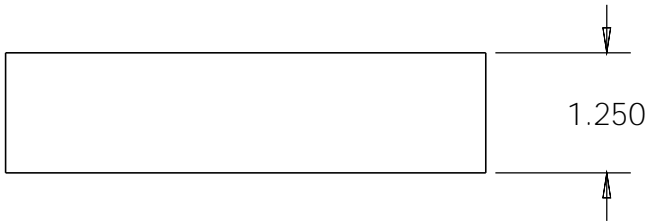
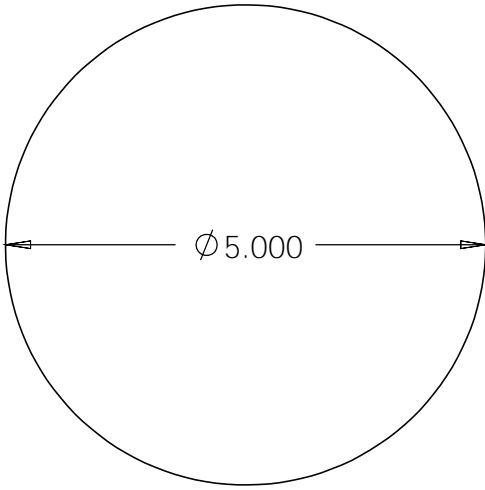


These are the tension spacers. The length is based on the thickness of your stator.

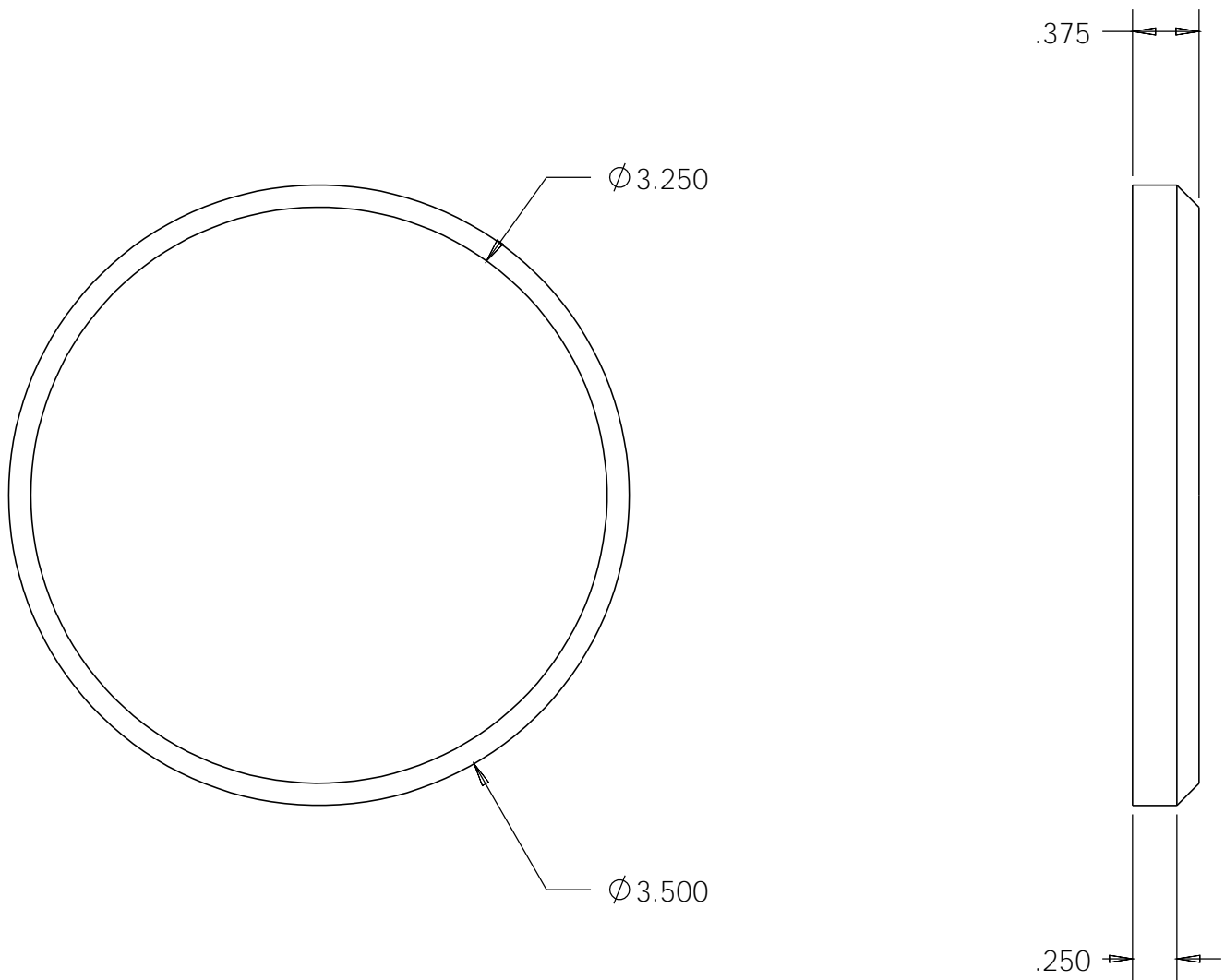
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				ANGULAR: MACH ± BEND ±	MFG APPR.				
			TWO PLACE DECIMAL ±	Q.A.			SIZE DWG. NO. REV A Stator Spacer		
		THREE PLACE DECIMAL ±	COMMENTS:						
			INTERPRET GEOMETRIC TOLERANCING PER:				SCALE: 2:1 WEIGHT: SHEET 1 OF 1		
			MATERIAL						
			Carbon Steel						
			FINISH						
NEXT ASSY		USED ON							
APPLICATION		DO NOT SCALE DRAWING							



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					DRAWN					
					CHECKED					
					ENG APPR.					
			MATERIAL					MFG APPR.		
								Q.A.		
			FINISH	COMMENTS:						
	NEXT ASSY	USED ON	APPLICATION	DO NOT SCALE DRAWING	SIZE A		DWG. NO.	Stator Pin	REV.	
					SCALE:2:1	WEIGHT:		SHEET 1 OF 1		

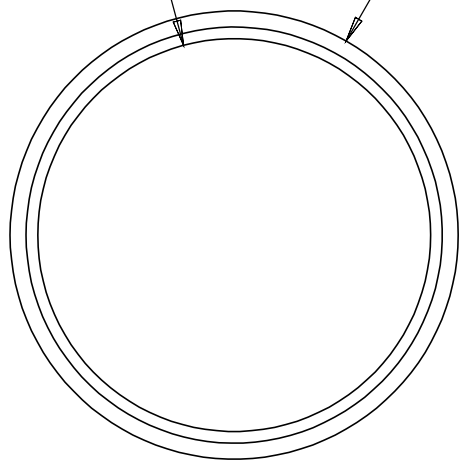


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					CHECKED			
					ENG APPR.			
			MATERIAL		MFG APPR.			
					Q.A.			
			FINISH	COMMENTS:				
	NEXT ASSY	USED ON						
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				SIZE A	DWG. NO. Stator Plug		REV.	
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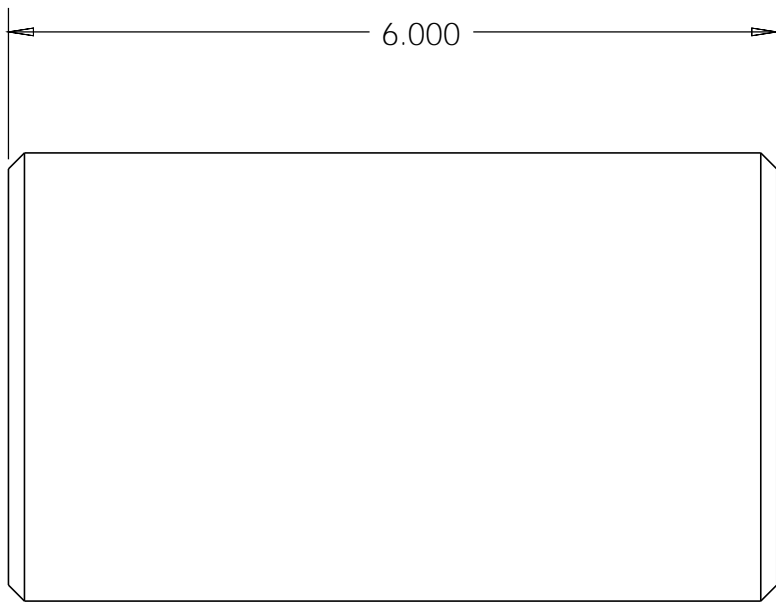


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				CHECKED							
				ENG APPR.							
				MFG APPR.							
			MATERIAL	Q.A.			COMMENTS:				
		NEXT ASSY	USED ON	FINISH					SIZE A	DWG. NO. Bracket Mount Cap	REV.
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Ø 3.068 Ø 3.500

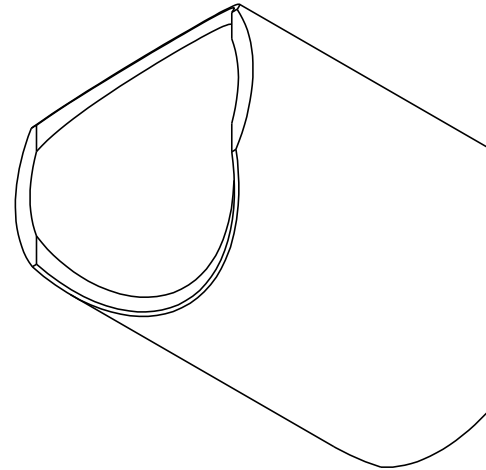
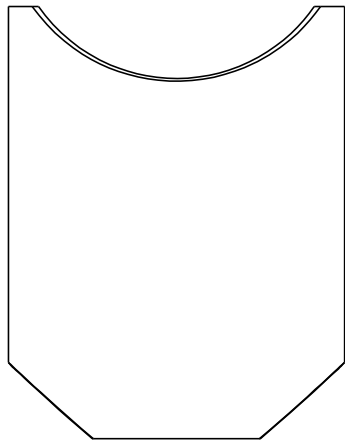
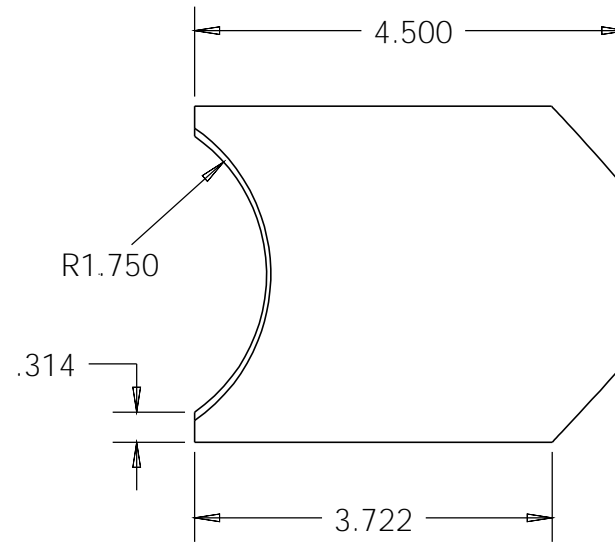
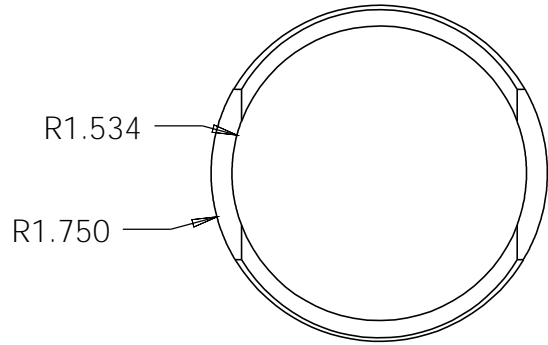


The edges of this part
are chamfered to
increase weld
penetration.



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		TOLERANCES:	CHECKED					
		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±				Bracket Mount		
		THREE PLACE DECIMAL ±						
		INTERPRET GEOMETRIC	Q.A.			SIZE DWG. NO. REV		
		TOLERANCING PER:	COMMENTS:					
		MATERIAL						
		FINISH						
NEXT ASSY	USED ON							
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 WEIGHT: SHEET 1 OF 1		



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		TOLERANCES:	CHECKED					
		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±	Q.A.			SIZE DWG. NO. REV		
		THREE PLACE DECIMAL ±	COMMENTS:					
		INTERPRET GEOMETRIC TOLERANCING PER:				<div>Generator Arm</div>		
		MATERIAL						
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING	SCALE: 1:2			WEIGHT:		SHEET 1 OF 1

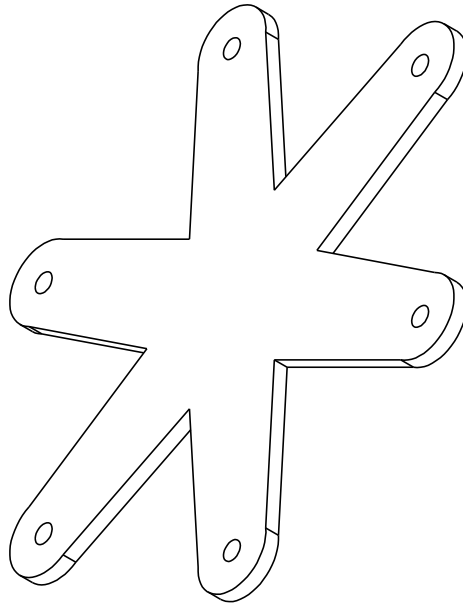
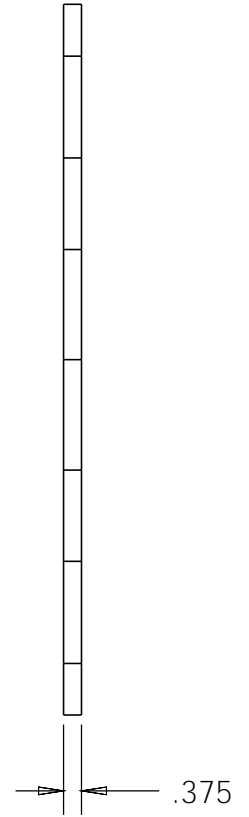
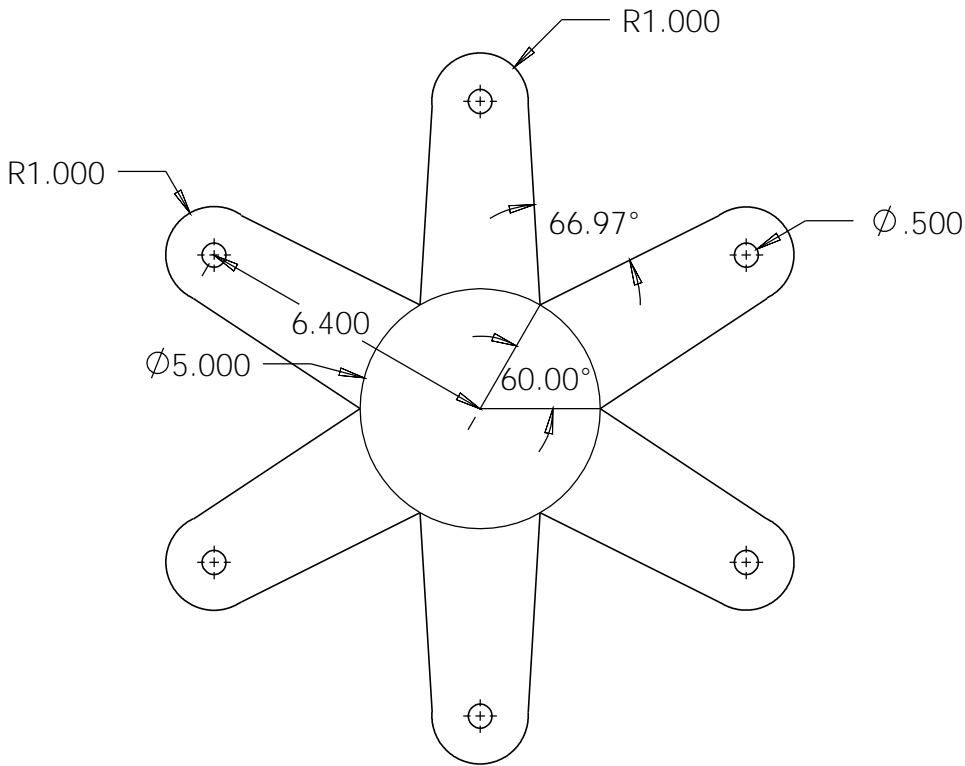
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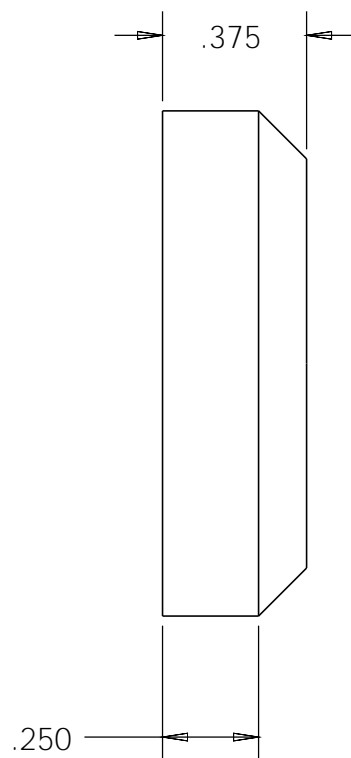
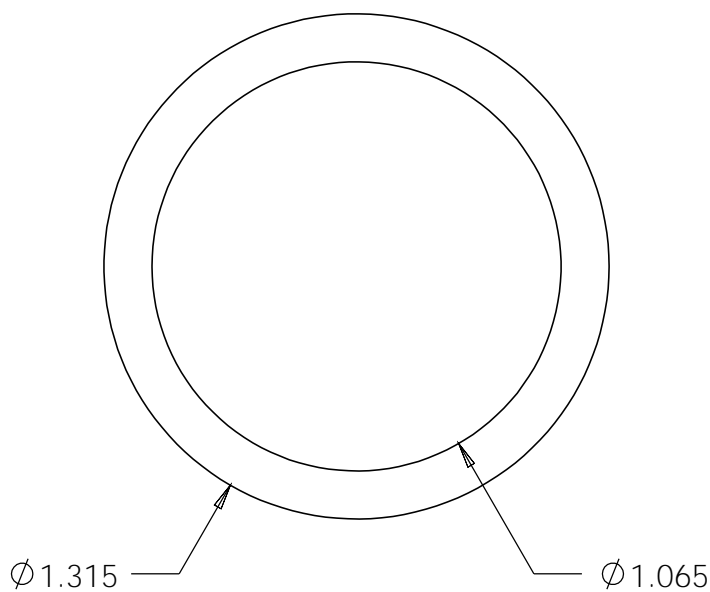
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1



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				CHECKED							
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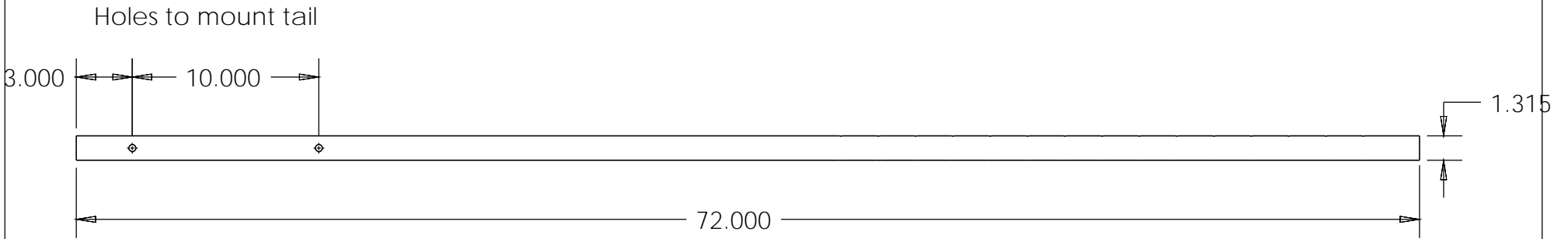
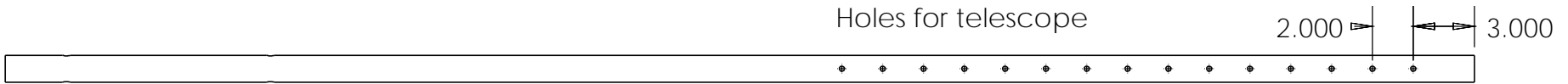
SIZE	DWG. NO.		REV.
Generator Mounting Bracket			
SCALE:1:4		WEIGHT:	SHEET 1 OF 1



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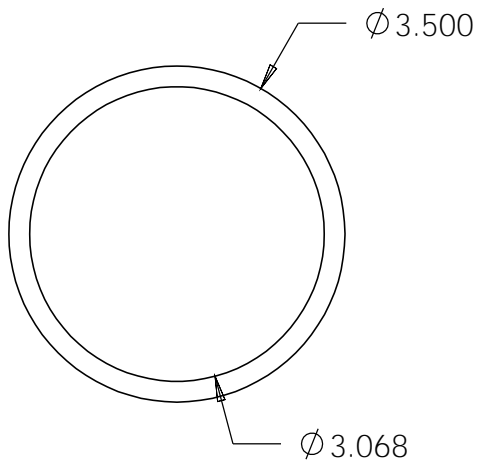
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			CHECKED			
			ENG APPR.			
			MFG APPR.			
		MATERIAL	Q.A.			COMMENTS:
		FINISH				
NEXT ASSY	USED ON					
APPLICATION		DO NOT SCALE DRAWING				

SIZE	DWG. NO.	REV.
A	Inner Tail Pivot Cap	
SCALE: 2:1		WEIGHT:
		SHEET 1 OF 1

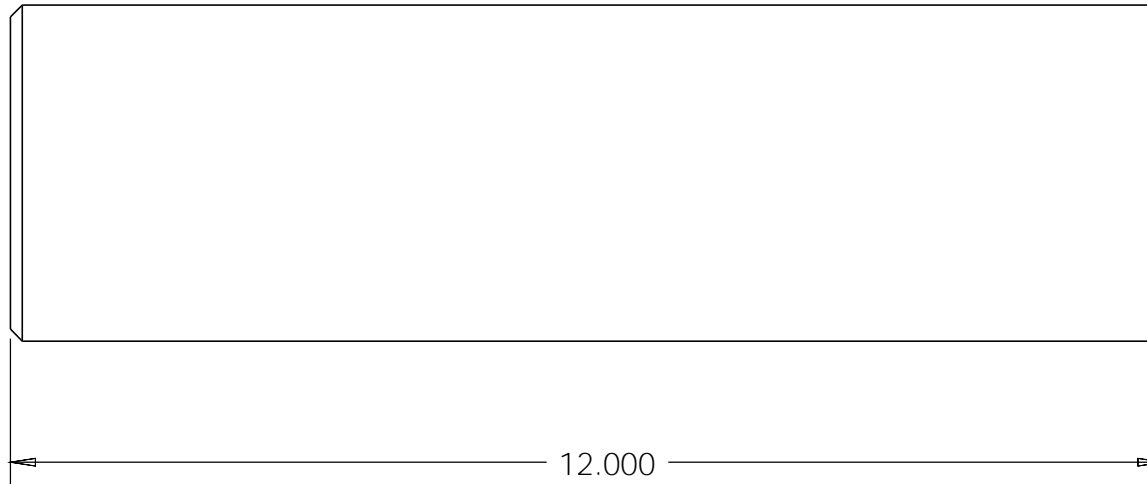


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			CHECKED						
			ENG APPR.						
			MFG APPR.						
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			SIZE DWG. NO. REV <div>Inner Telescope</div>			
		MATERIAL	COMMENTS:						
NEXT ASSY	USED ON	FINISH							
APPLICATION		DO NOT SCALE DRAWING							
						SCALE: 1:16		WEIGHT:	SHEET 1 OF 1

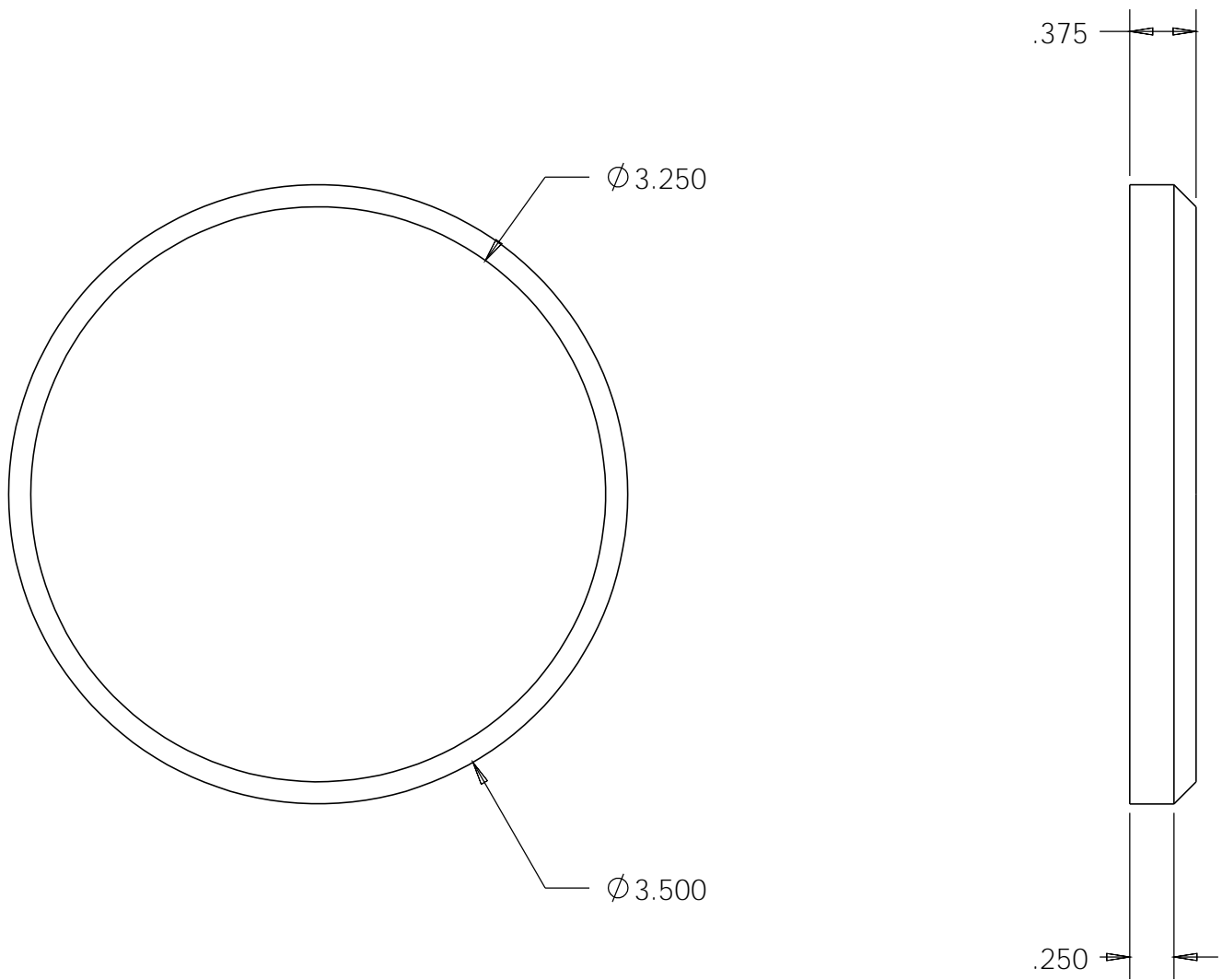


This end is chamfered to increase weld penetration

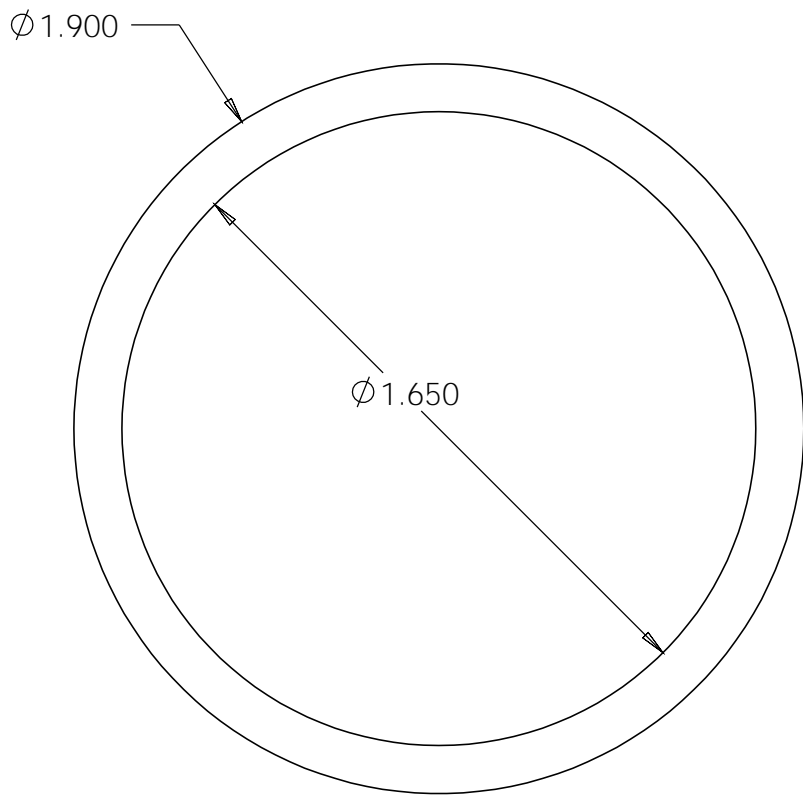


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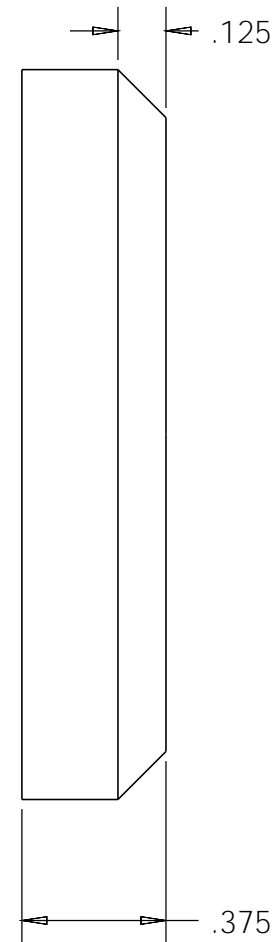
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		TOLERANCES:	CHECKED					
		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±				Main Outer Pivot		
		THREE PLACE DECIMAL ±						
		INTERPRET GEOMETRIC	Q.A.					
		TOLERANCING PER:	COMMENTS:					
		MATERIAL						
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING				SIZE	DWG. NO.	REV



		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE			
			DRAWN					
			CHECKED					
			ENG APPR.					
			MFG APPR.					
		MATERIAL	Q.A.					
		COMMENTS:						
NEXT ASSY	USED ON	FINISH				SIZE	DWG. NO.	REV.
APPLICATION		DO NOT SCALE DRAWING				A	Main Pivot Cap	
			SCALE:1:1		WEIGHT:		SHEET 1 OF 1	



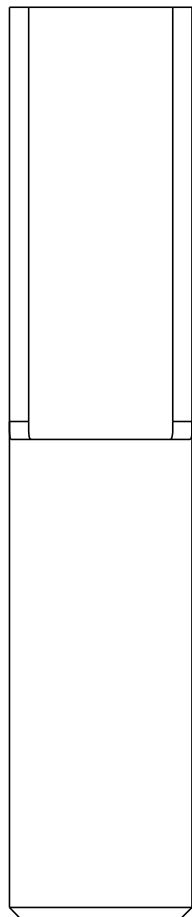
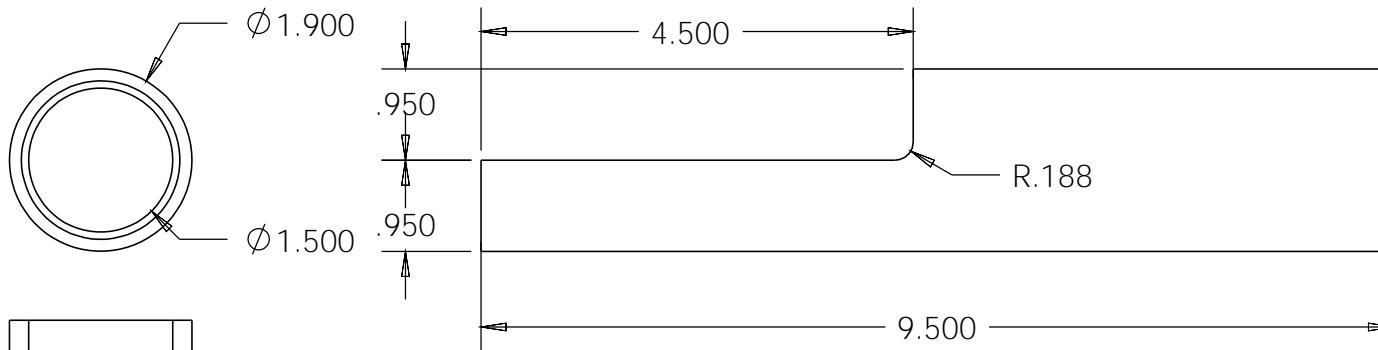
This edge is chamfered for maximum weld penetration.



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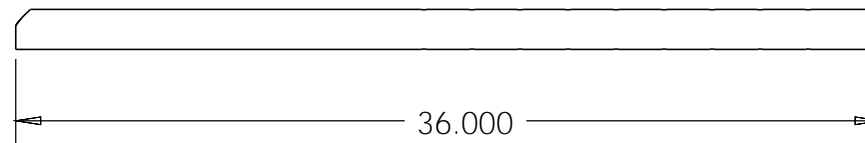
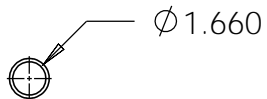
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		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±				Outer Tail Pivot Cap		
		THREE PLACE DECIMAL ±						
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			SIZE	DWG. NO.	REV
		MATERIAL	COMMENTS:					
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

Outer Tail Pivot Cap

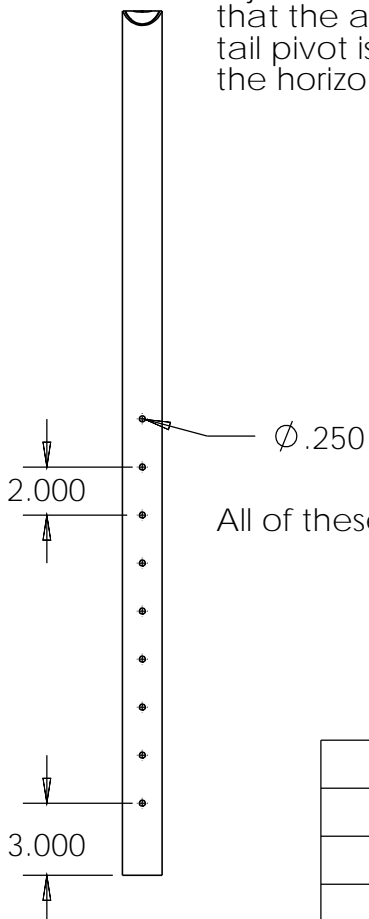


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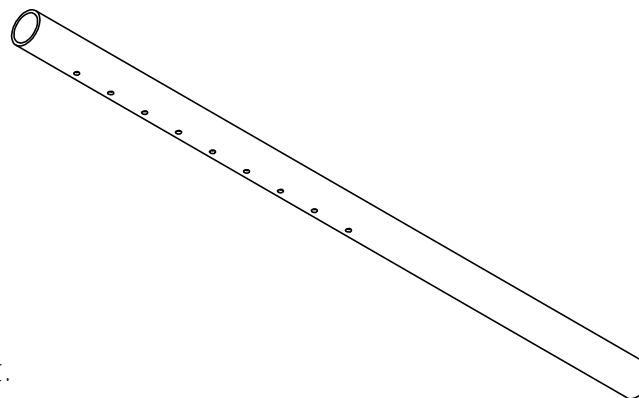
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		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±	Q.A.			Outer Tail Pivot		
		THREE PLACE DECIMAL ±	COMMENTS:					
		INTERPRET GEOMETRIC						
		TOLERANCING PER:						
		MATERIAL				SIZE	DWG. NO.	REV
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4	WEIGHT:	SHEET 1 OF 1



A joint should be cut in the pipe here so that the angle between this part and the outer tail pivot is 20 degrees. It will sit 5 degrees above the horizontal because of this.

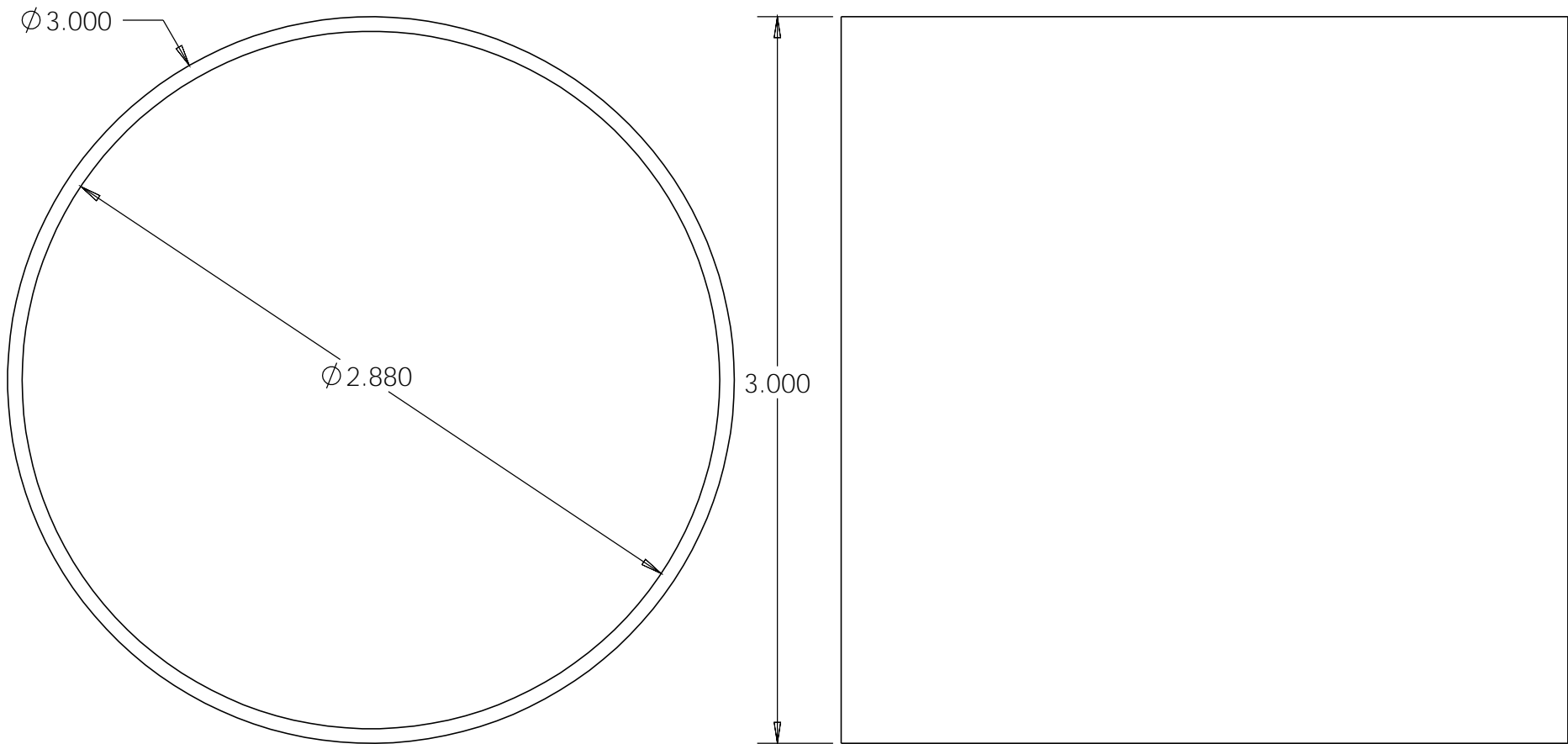


All of these holes are 2 inches apart.



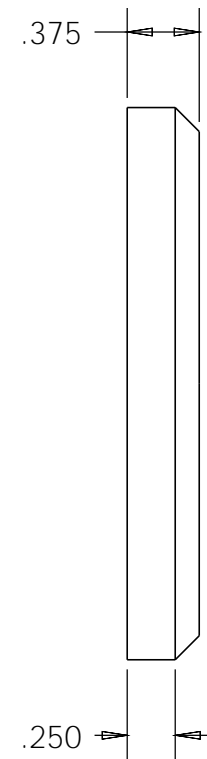
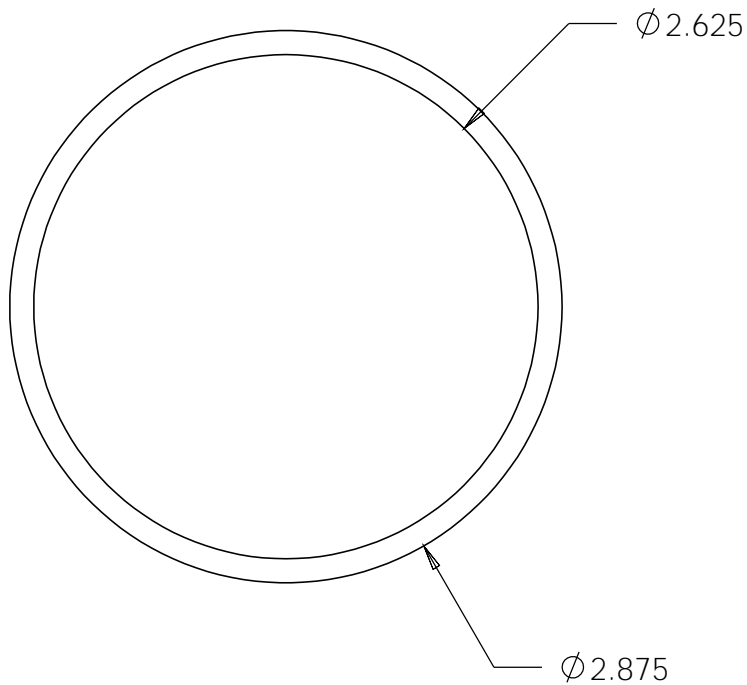
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		ANGULAR: MACH \pm BEND \pm	MFG APPR.					
		TWO PLACE DECIMAL \pm	Q.A.			SIZE	DWG. NO.	REV
		THREE PLACE DECIMAL \pm	COMMENTS:				Outer Telescope	
		INTERPRET GEOMETRIC						
		TOLERANCING PER:						
		MATERIAL				SCALE: 1:12	WEIGHT:	SHEET 1 OF 1
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING						



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			MFG APPR.					
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		MATERIAL	COMMENTS:					
		FINISH						
NEXT ASSY	USED ON					APole Bushing		
APPLICATION		DO NOT SCALE DRAWING						
						SCALE: 1:2 WEIGHT: SHEET 1 OF 1		



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			CHECKED					
			ENG APPR.					
			MFG APPR.					
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			SIZE DWG. NO. REV A Pole Cap		
		MATERIAL	COMMENTS:					
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING						
						SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

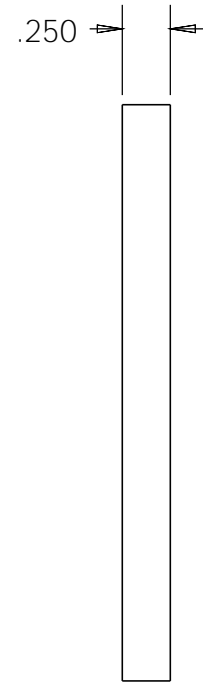
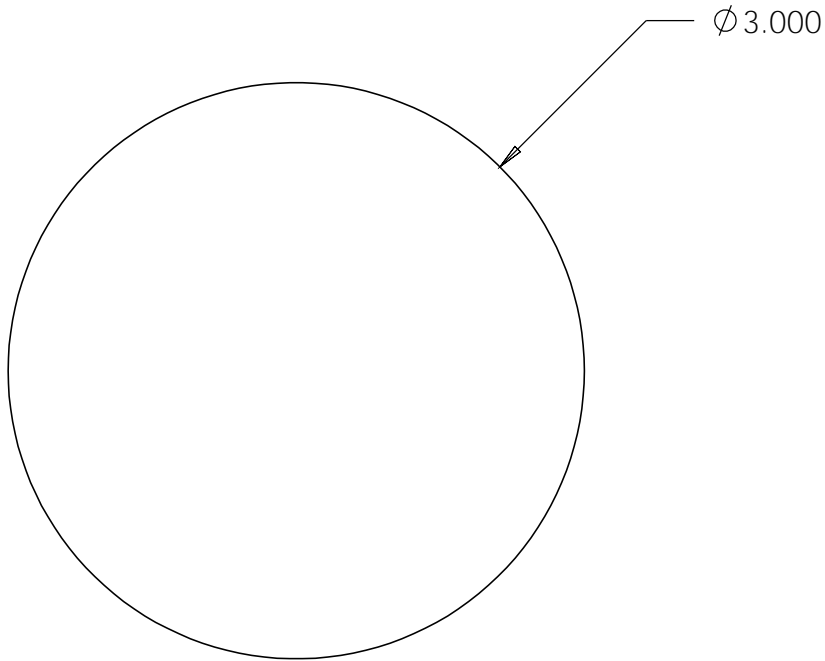
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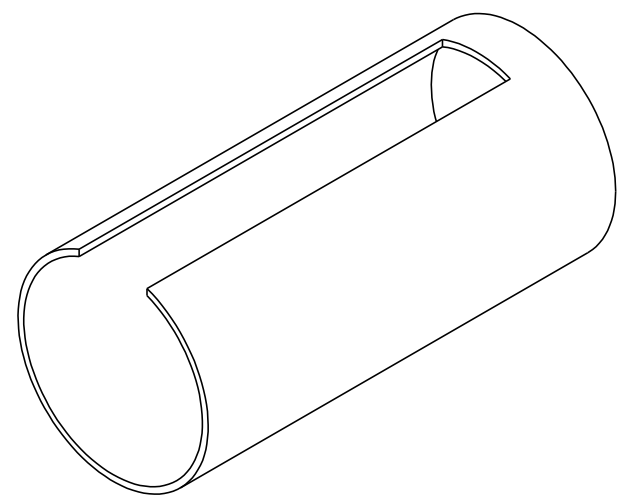
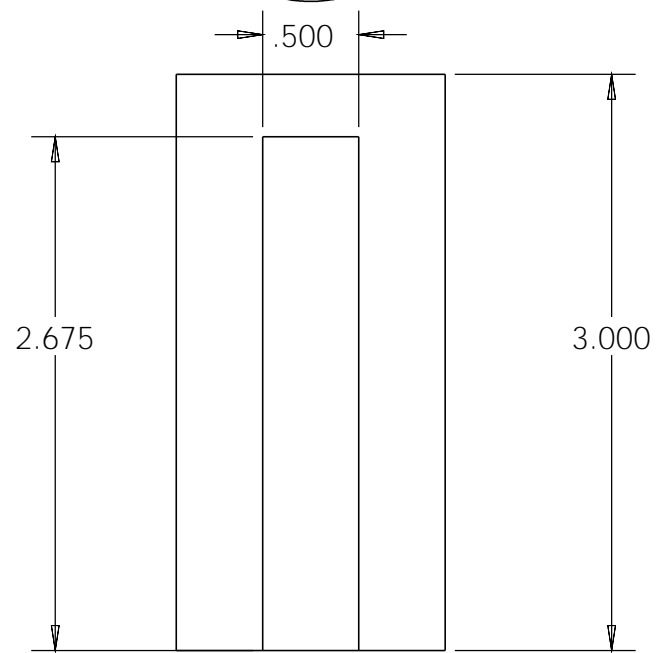
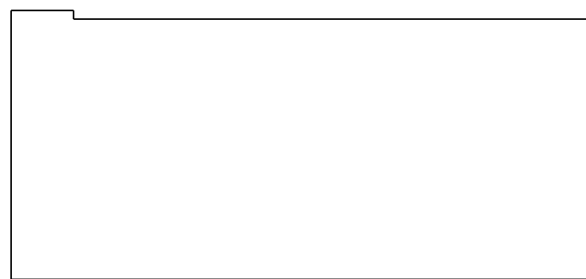
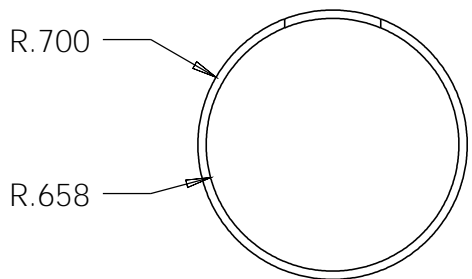
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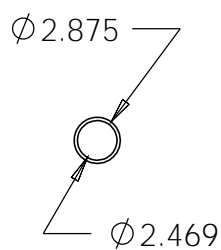
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		ANGULAR: MACH± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±				SIZE DWG. NO. REV		
		THREE PLACE DECIMAL ±						
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.					
		MATERIAL	COMMENTS:			POLE Thrust Washer		
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

Pole Thrust Washer



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		TWO PLACE DECIMAL \pm	Q.A.			SIZE	DWG. NO.	REV
		THREE PLACE DECIMAL \pm	COMMENTS:				Slotted Tail Bushing	
		INTERPRET GEOMETRIC						
		TOLERANCING PER:						
		MATERIAL				SCALE: 1:1	WEIGHT:	SHEET 1 OF 1
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING						



This end is chamfered for maximum weld penetration with the pole cap

102.000

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		TWO PLACE DECIMAL ±	MFG APPR.					
		THREE PLACE DECIMAL ±	Q.A.			SIZE DWG. NO. REV A Stand Pole		
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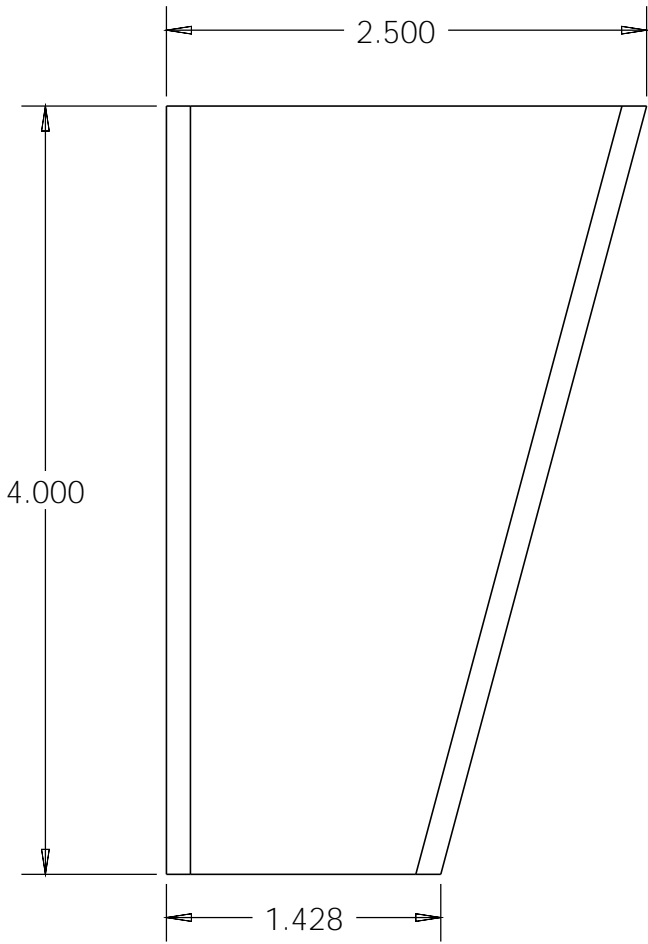
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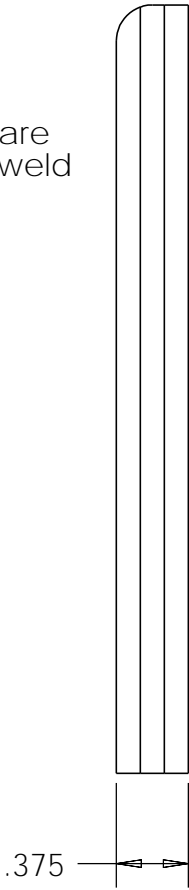
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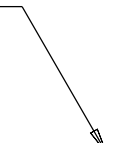
The edges of this piece are chamfered to increase weld penetration.



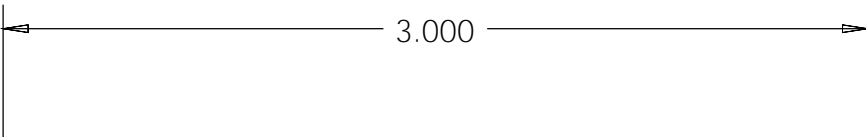
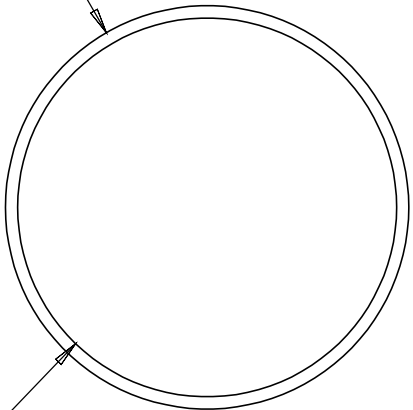
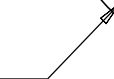
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			MFG APPR.					
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NEXT ASSY	USED ON							
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1		

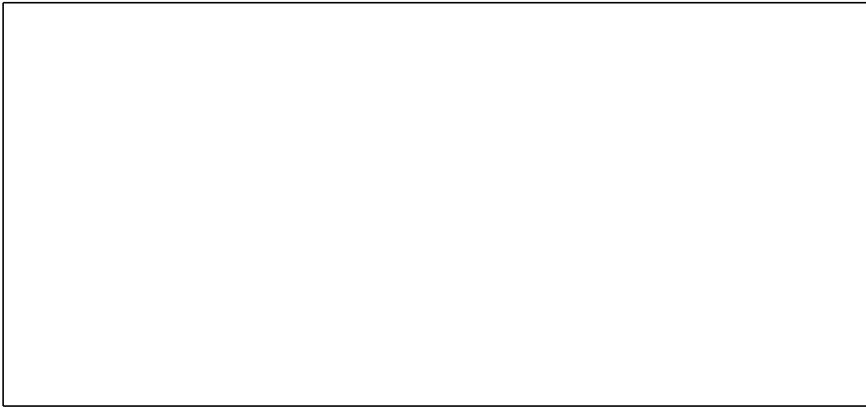
Ø 1.400



Ø 1.315



3.000



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			ENG APPR.					
			MFG APPR.					
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		MATERIAL	COMMENTS:					
		FINISH						
NEXT ASSY	USED ON							
APPLICATION		DO NOT SCALE DRAWING						
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A Tail Bushing

SCALE: 1:1

WEIGHT:

SHEET 1 OF 1

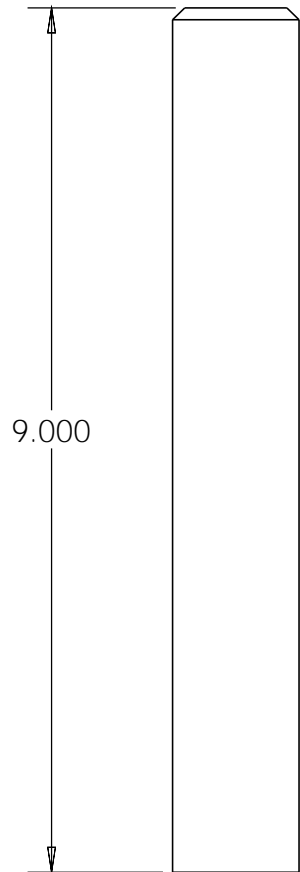
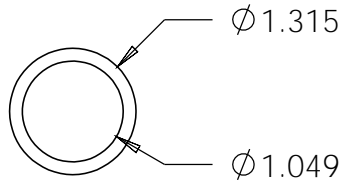
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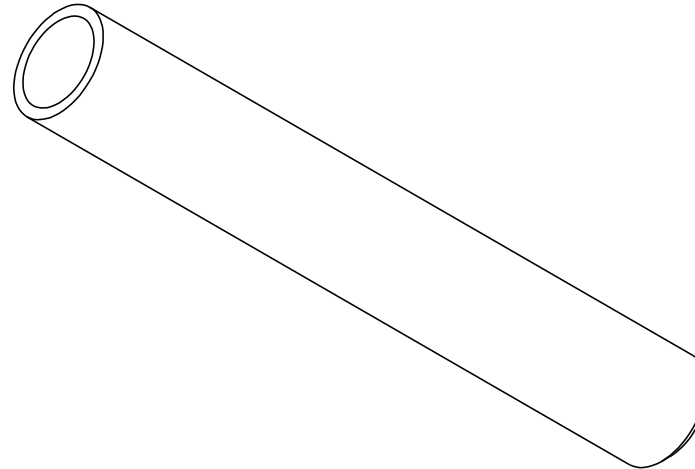
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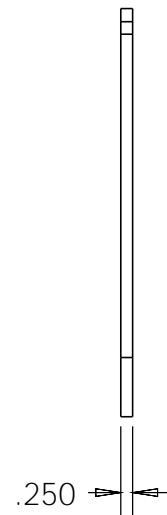
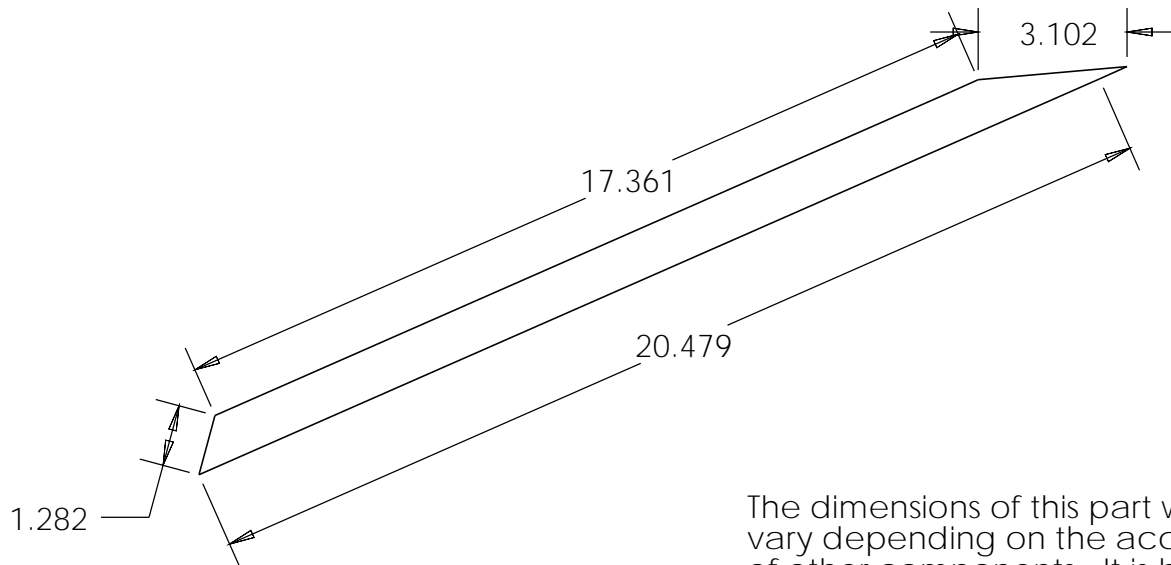
The top of this pipe is chamfered to increase weld penetration.



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		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±	Q.A.			SIZE DWG. NO. REV		
		THREE PLACE DECIMAL ±	COMMENTS:					
		INTERPRET GEOMETRIC TOLERANCING PER:						
		MATERIAL				Aail Pivot Inner		
		FINISH						
NEXT ASSY	USED ON					SCALE: 1:4 WEIGHT: SHEET 1 OF 1		
APPLICATION		DO NOT SCALE DRAWING						

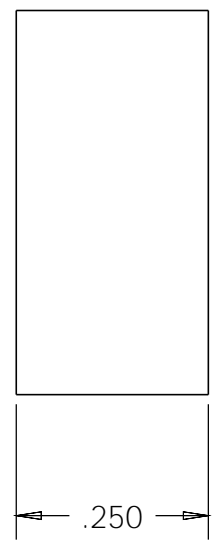
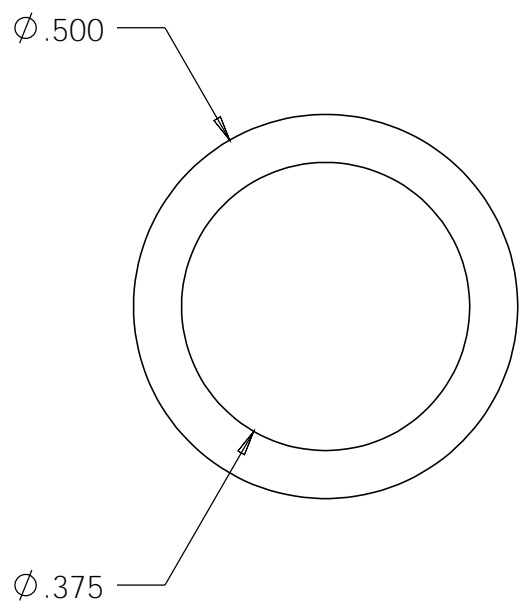
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The dimensions of this part will vary depending on the accuracy of other components. It is best to take the measurements from the tail assembly.

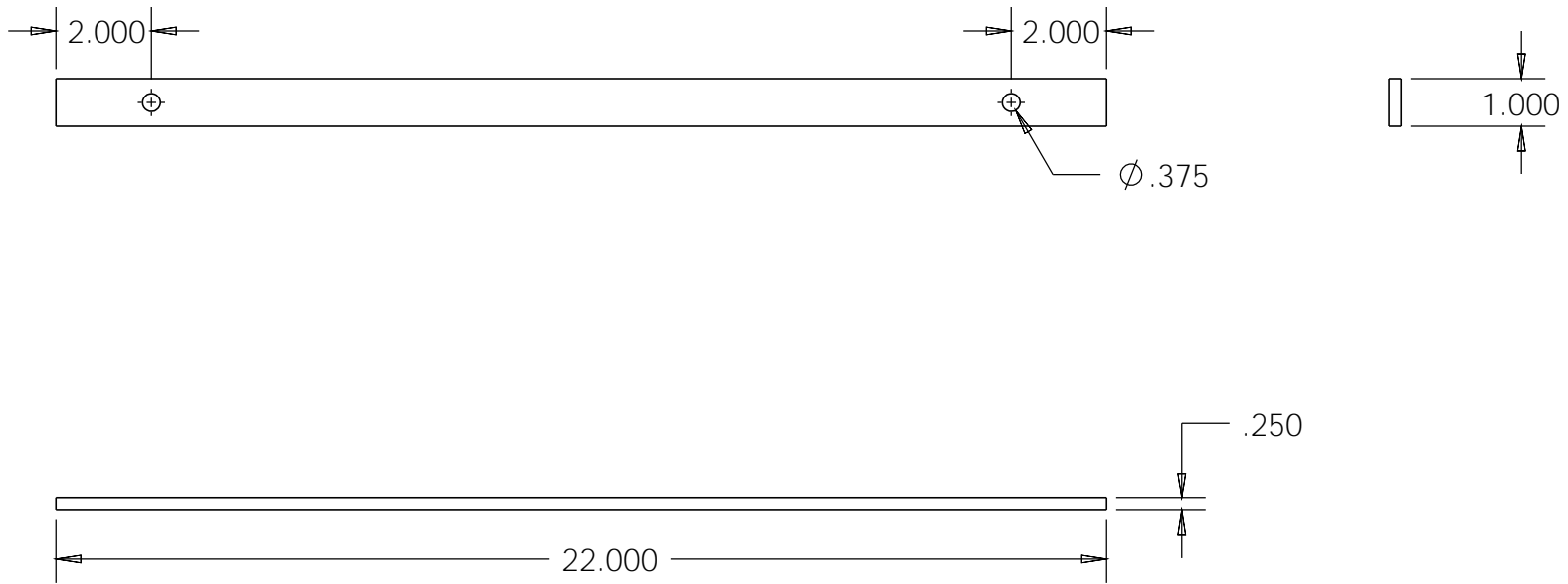
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		TOLERANCES:	CHECKED					
		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±	Q.A.			SIZE DWG. NO. REV		
		THREE PLACE DECIMAL ±	COMMENTS:					
		INTERPRET GEOMETRIC TOLERANCING PER:						
		MATERIAL						
NEXT ASSY	USED ON	FINISH				A Tail Support		
APPLICATION		DO NOT SCALE DRAWING						
						SCALE: 1:4	WEIGHT:	SHEET 1 OF 1



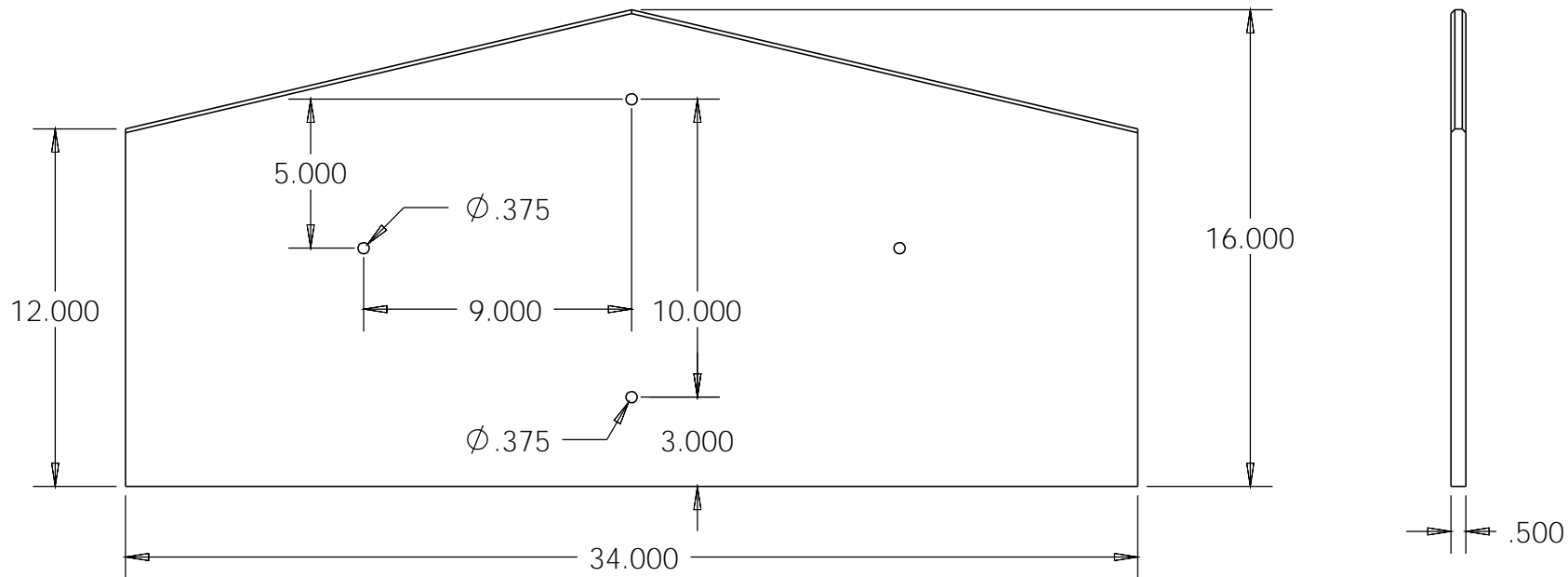
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		DIMENSIONS ARE IN INCHES	DRAWN					
		TOLERANCES:	CHECKED					
		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±				Tail Vane Spacer		
		THREE PLACE DECIMAL ±						
		INTERPRET GEOMETRIC	Q.A.			SIZE DWG. NO. REV		
		TOLERANCING PER:	COMMENTS:					
		MATERIAL						
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING				SCALE: 4:1 WEIGHT: SHEET 1 OF 1		



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		DIMENSIONS ARE IN INCHES	DRAWN					
		TOLERANCES:	CHECKED					
		FRACTIONAL \pm	ENG APPR.					
		ANGULAR: MACH \pm BEND \pm	MFG APPR.					
		TWO PLACE DECIMAL \pm	Q.A.			SIZE	DWG. NO.	REV
		THREE PLACE DECIMAL \pm	COMMENTS:			Tail Vane Support		
		INTERPRET GEOMETRIC TOLERANCING PER:						
		MATERIAL				SCALE: 1:4	WEIGHT:	SHEET 1 OF 1
NEXT ASSY	USED ON	FINISH						
APPLICATION		DO NOT SCALE DRAWING						



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		DIMENSIONS ARE IN INCHES	DRAWN					
		TOLERANCES:	CHECKED					
		FRACTIONAL ±	ENG APPR.					
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±				SIZE DWG. NO. REV		
		THREE PLACE DECIMAL ±						
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.					
		MATERIAL	COMMENTS:			A Tail Vane		
		FINISH						
NEXT ASSY	USED ON							
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:8 WEIGHT: SHEET 1 OF 1		

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