Gravity Powered Light

A Technical Report submitted to the Department of Mechanical and Aerospace Engineering

Presented to the Faculty of the School of Engineering and Applied Science

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In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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1 Introduction

For the fourth year capstone project, a group of five students has designed a portable light powered by a falling weight, which has been called the gravity powered light. The device has made improvements upon the existing GravityLight ("GravityLight," n.d.) which was developed for use in developing countries. The GravityLight's success has led the group to believe they can create a similar device tailored to the camping community. This market has proven interest in sustainable lighting solutions displayed by the success of solar-powered lights. While these lights may leave users in the dark with no opportunity to recharge, a gravity powered light can be powered at any time of day. The primary improvements to GravityLight that the group has made are in the portability and outdoor usability of the product, crucial to customer development in the camping community. The group built one full prototype and began work on a second; however, the group was not able to finish a second prototype or build the final design due to the coronavirus pandemic of 2020. Enough information has been gathered from initial tests and theory to suggest that the next prototype would work well and be a feasible market commodity.

2 Device Description

The gravity powered light can be packed into an overnight pack to bring light anywhere the user goes. Popular solar-powered camp lights may fall short as they require the user to charge the device in daylight, which may not provide enough power. The gravity powered light avoids this problem by using gravity, an ever-present resource. The device can be secured to a tree around the trunk or hanging from a branch. The user then attaches a weight (in the form of a backpack, water bottles, tent bag, etc.) in order to activate the gear train within the device. The mechanically disadvantaged gear train increases the angular velocity of each subsequent gear, allowing the slow descent of the weight to rapidly turn the generator. The generator powers four LEDs shining down on the camp.

The descent time of the hanging weight and brightness of the LEDs depend on the amount of weight applied. More weight results in a faster descent and brighter LEDs. The device has been designed to operate under a range of weights while providing light for a usable amount of time.

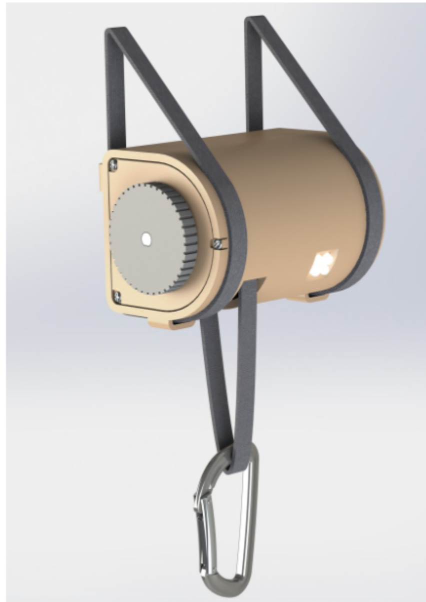


Figure 1: A final rendering of the gravity powered light

The device contains a rewind mechanism to reset the device when the weight reaches the ground. The user can temporarily detach the weight and turn the wheel located on the outside of the device. A one-way gear deactivates the gear train, allowing the user to recoil the rope within the device without engaging the gear train. When complete, the weight can be reattached to the rope to provide more light.

3 Specifications

The primary goal that was originally set for this device was to be able to passively (without any user input) power a light for up to 20 minutes. In order to do this, we set out to create a method that would allow the hanging weight to fall for that amount of time, all the while producing enough power to turn on the lamp. Due to the COVID-19 Global Pandemic interrupting the semester in the midst of the testing and redesign phase, it was impossible to completely build and test a final prototype to see if it could meet the original specifications. However, calculations (see Figure 9) based off of the final design iteration suggest that a 7 kg hanging weight would have powered the light for approximately 14-15 minutes. While these calculations demonstrate that the group was unable to reach a 20 minute light time, the group believes that further design modifications

Ergonomics	Does it appeal to the user? Is it easy to handle? Too bulky? Too heavy? Can it fit in a backpack?
6 Foot Drop Test	Can the device survive a fall from the height that it will typically be placed in a tree? Does the housing crack? Do any of the internal mechanisms break?
Portability Test	How easy is it to set up/tear down? Can one person use it by themselves? How long does it take to set it up?
Usability Test	Is the function of the device clear and intuitive? Can someone who has never used the device before follow instructions and use it?
Fall Time/ Weight Test	How long does it take the weight to fall over various weights? Is it consistent? Is the device strong enough to support the added weight?
Light Tests	Does the device produce enough light to be useful? Is the light directed in the appropriate manner?

Table 1: Criteria for prototype testing

that would come from being together in the normal, collaborative setting would have led to the achievement of the lighting goal. In addition, certain design features were added to allow the user to easily reuse the device. The implementation of a one-way bearing connected to a hand crank on the exterior housing makes it easy to rewind the rope gear and reuse the device.

Designing a device that was portable was a secondary goal for this project. The group wanted to ensure that the device would be suitable for camping and outdoor applications. To address this goal, two different methods were developed for strapping the device to a tree, making it more versatile. Ladder lock strap adjusters were implemented to make adjusting the strap configuration a seamless process (see Figures 4 and 5).

Ideally, the device would have been completely assembled in order for the group to test these factors, along with the durability of the device. If we had been able to test our device upon its completion, the following are the tests we would have performed to ensure that our solution was adequate. By doing this, we would have been able to fine tune the device into a product that was feasible, ready for market, and met all of our initial criteria.

4 Problem Statement

Gravity accelerates objects towards the ground, converting the potential energy of an elevated object into the kinetic energy of a falling object. This project seeks to convert this kinetic energy into electrical energy. One significant challenge encountered in solving this is maintaining a slow and steady motion. The design must slow the motion of the falling weight in order to provide a steady energy source to perpetuate consistent illumination. Existing gravity powered lights have been designed, but these do not address the portability and durability needed for hiking and camping. This project's goal is to use gravity as a means to turn a generator and provide enough power to light LEDs in a device that is easy to use, durable, portable, and that improves on other designs. Deciwatt is a company that has designed and built gravity powered lights (called GravityLights) for developing countries. The capstone design aims to improve on two key characteristics. One is portability, since the GravityLight is meant to be stationary. The other characteristic that the design seeks to improve on is outdoor usability. The GravityLight is mainly for indoor and not outdoor use.

5 Design

Figure 2 shows the final design. Key components are pointed out, which will be discussed in depth in the following sections. The rewind mechanism is on the far left, followed by the rope gear to the right, which connects to the planetary gear train with a one-way bearing. This gear train drives two DC motors as generators, which produce electricity to power LEDs in the front.

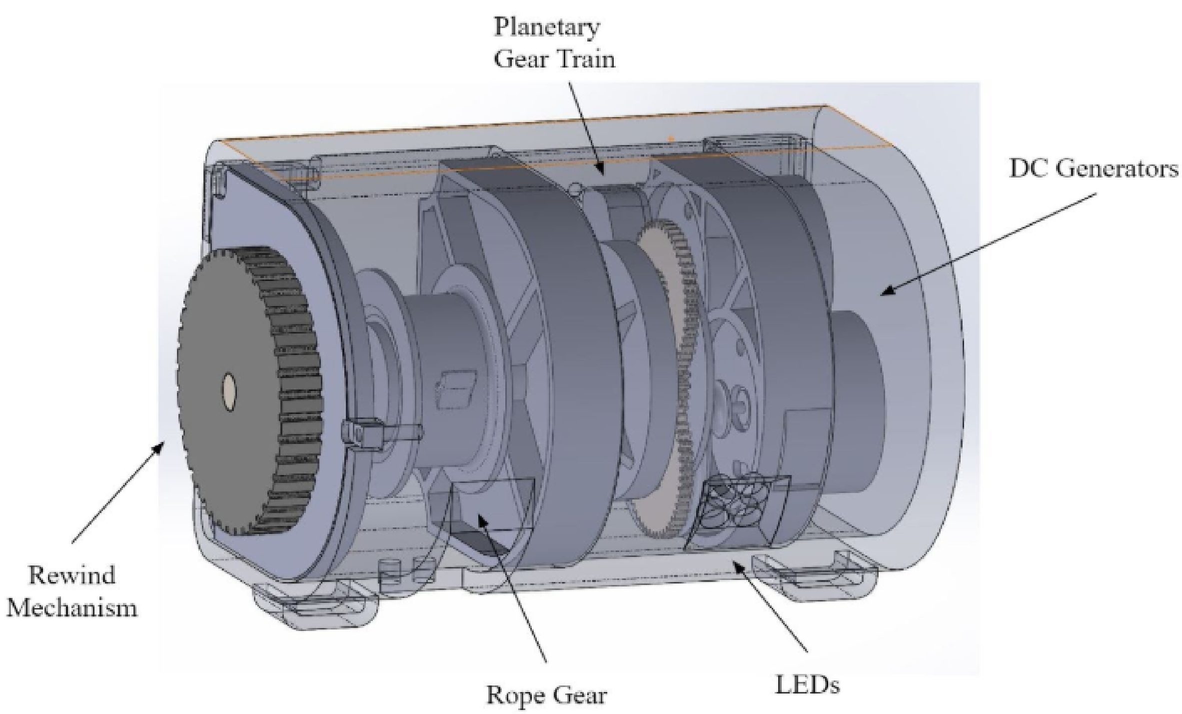


Figure 2: Transparent assembly showing key components of the gravity powered light

5.1 Housing

Figure 3 shows the housing. The housing's features were developed as improvements over previous design iterations. The opening on the bottom front left of the housing is a hole for the rope to pass through. The rope gear connects the rope and weight to the gear train. In the final design, the rope gear is located inside the housing, unlike previous designs where the rope gear was outside. Placing it inside the housing provides better support for the rope gear and shelter from the elements. The housing is curved, which supplies strength to the overall assembly and has an aesthetic appeal.

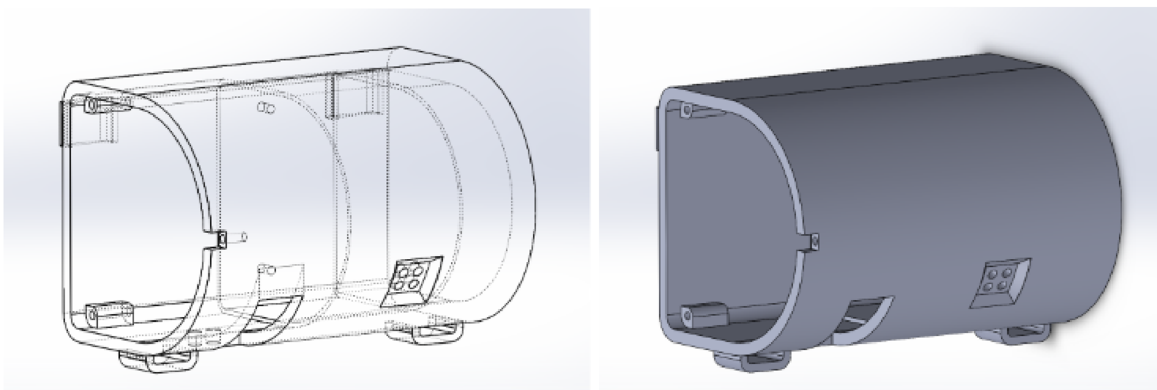


Figure 3: Housing

The LED array in the final design is fixed, and it shines from the bottom front of the housing. Previous designs had the lights shining from the end of the housing, which was awkward since mounting the light to a branch would only illuminate the end of the branch. Moving the LED array to the front so that is shining forward and downward at an angle allows the light to reach the area where campers are located, assuming the mechanism is placed around head height.

The final design is also more compact, at 5.17 inches in length and 3 inches in height. The first prototype was 12 inches long and 4.5 inches high. A more compact design is more portable and ergonomic, a major concern for the outdoorsmen expected to use this product.

Four loops are on the housing: two on the back and two on the bottom. Two straps, one on each side, pass through these loops to support the gravity powered light and hold it from a tree trunk or branch. In previous designs, the loops for the straps were only on the back of the housing. This was a less stable configuration and produced high stress concentrations on the back of the housing where the straps were located.

5.2 Securing To Tree

There are two main methods to attach the gravity powered light to a tree, illustrated in Figure 4. In the trunk method, a strap wraps around a tree trunk. The straps that surround the gravity powered light loop around the trunk strap, holding the light in place securely. In the branch method, the straps that surround the gravity light simply loop around a tree branch. The straps are secured in place with a ladder lock strap adjuster, which is shown in Figure 5. This holds two ends of the strap together through friction, but is also easily adjustable. The strap is permanently sewn at one end, and can be pulled to tighten.

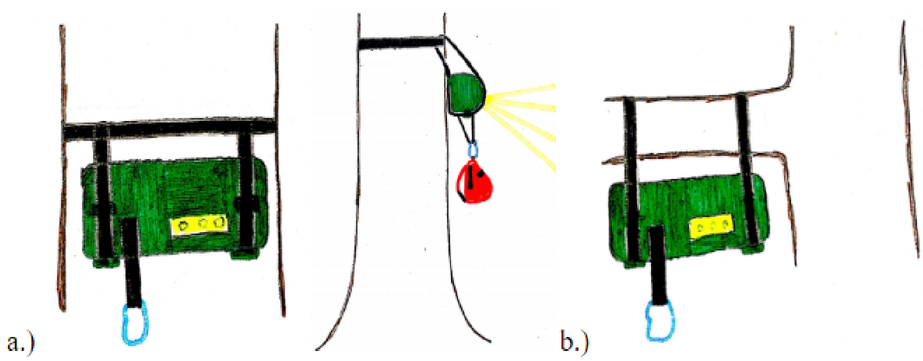


Figure 4: Tree attachment methods: a.) Trunk method b.) Branch method

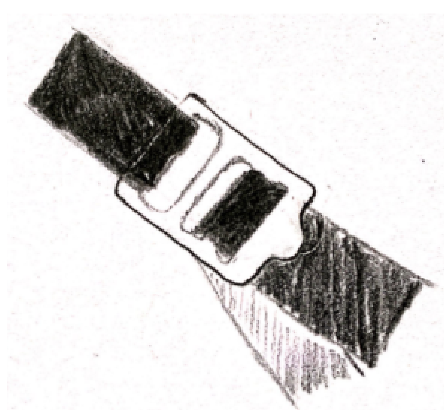


Figure 5: Ladder lock strap adjustment

5.3 Rope Gear

Figure 6 depicts the rope gear, which is located inside the housing. This connects the gear train with a flat, nylon rope holding the weight. A hook on the top of the gear in the picture holds one end of the rope in place. The rope then wraps around the gear. In previous design iterations, the rope gear had several pegs projecting from its surface. The rope had holes sized and spaced out so that it would engage the pegs and drive the rope gear as the weight fell. This design, however, had two main problems. The pegs did not grip the nylon strap very well, with the risk that the rope might slide without grabbing the pegs. Also, it was very difficult to make the holes in the rope the correct size and distance apart so that they would engage with the pegs correctly. The current design is much easier to attach and engage. The rope passes out of the housing through a hole, then

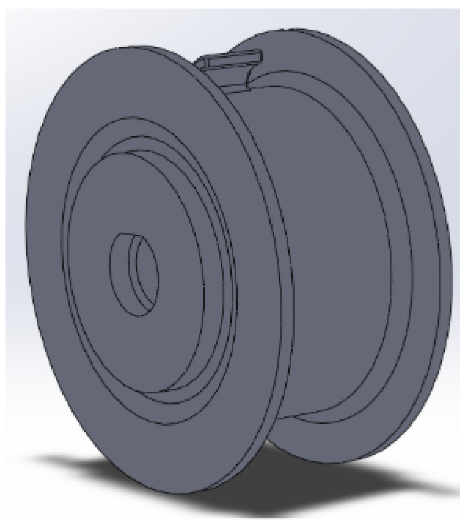


Figure 6: Rope Gear

through a carabiner that is attached to a weight, such as a backpack. The end of the rope that passes through the carabiner is riveted to the bottom of the housing. Thus, as the weight pulls down on the rope, the carabiner acts as a pulley and doubles the gear ratio of the gravity powered light. This configuration is illustrated in Figure 1.

5.4 Gear System

Figure 7 shows the planetary gear train in our gravity powered light. This gear train design is based on Deciwatt's GravityLight gear design. Previous designs were a linear gear train, with several spur gears in a row meshing to produce a high mechanical advantage. A planetary gear train, however, is a better design because it reduces stress on the gear teeth, while still providing a high mechanical advantage. This makes the design more durable, which is important for our product. The total gear ratio is 318. The total mechanical advantage, including the carabiner pulley, doubles to equal 636.

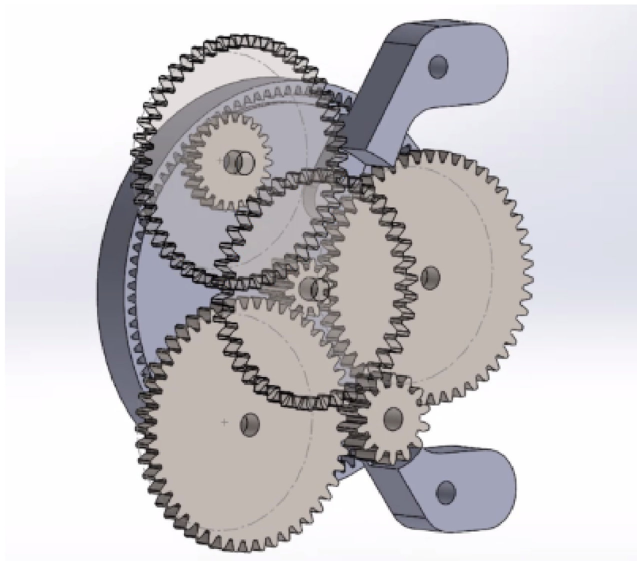


Figure 7: Planetary Gear Train

5.5 Generator Configuration

Figure 8 illustrates the generator configuration. The generators are Jameco 6V DC motors, which are driven by the gear train. A drive belt connects the motor shafts to the gear train through grooved wheels. Initially the design had just one motor, but a second one was added to improve speed regulation. The faster a motor spins, the more back emf the motor produces. Therefore, a faster motor produces higher emf. Adding another motor provides more internal resistance to help control the speed of the falling weight at the other end of the gear train. A rotary damper works similarly, but the energy lost in internal resistance is dissipated as heat. The internal resistance of a motor, however, produces electricity that powers lights. Previous iterations had an AC motor or smaller motors, which did not produce the proper amount and kind of electricity needed. The AC motor produced an oscillating current. The smaller motors did not produce enough back emf to slow down the falling weight sufficiently.

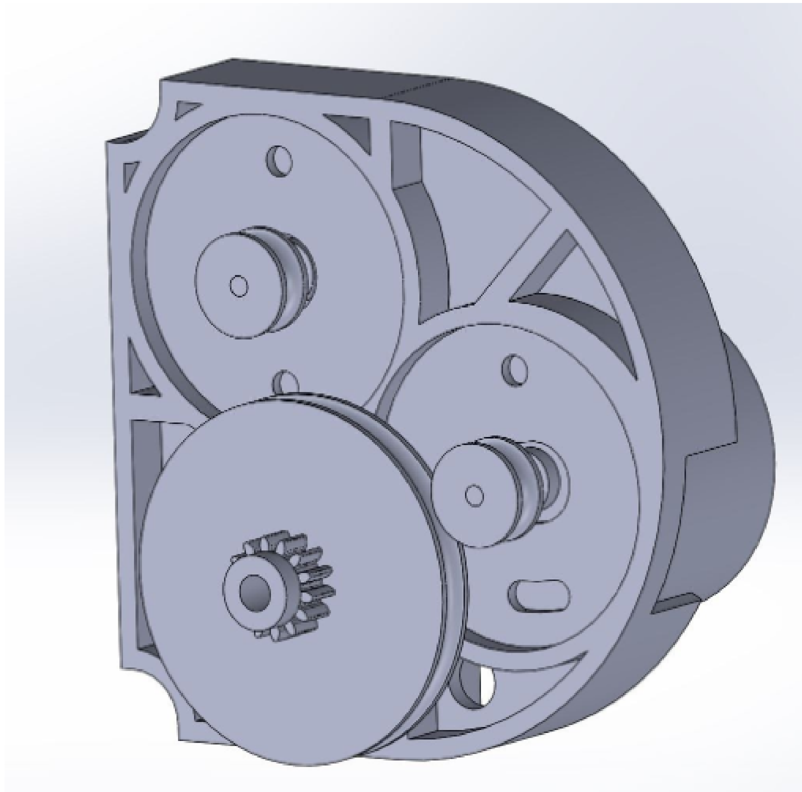


Figure 8: Generator configuration

5.6 Rewind Mechanism

In Figure 9, the rewind gear is located at the left end. The rewind gear attaches to the rope gear via a shaft through the covering at the end of the housing. It resets the falling weight by turning the rope gear in the opposite direction, winding the rope back up to let it fall again. The outside of the gear is textured with ridges to allow for an easy grip. A one way bearing attaches the rope gear's shaft to the gear train. When the rope gear is turned by the force of the falling weight, the one way bearing engages the gear train, powering the generators. When the rewind gear turns the rope gear in the opposite direction, the one way bearing does not engage, which allows a user to easily rewind the rope gear without engaging the whole gear train.

5.7 Motor Equations

Mathematical motor equations are used to determine what kind of motor to use, how the attached weight affected motor speed, and how weight and speed affected LED luminosity. Torque

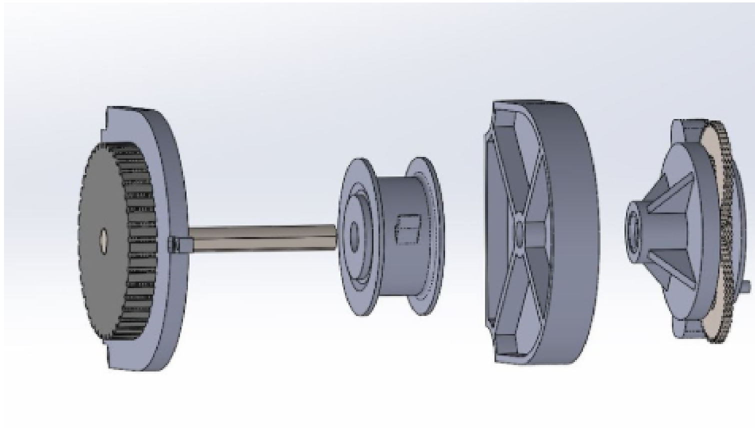


Figure 9: Rewind mechanism for rope

on the rope gear produced by weight is given by,

$$T_r = mgr \tag{1}$$

where *m* is the mass of the weight, *g* is the acceleration of gravity, and *r* is the radius of the rope gear. The torque applied to the motors is related to the torque on the rope gear by the equation:

$$T_g = \frac{eT_r}{N} \tag{2}$$

where *e* is the gear train efficiency, and *N* is the total gear ratio. The current produced by that torque is given by the equation:

$$I = \frac{T_g}{K_t} \tag{3}$$

where *K_t* is the motor constant. The velocity constant, *K_v*, is proportional to *K_t*. The velocity constant relates the amount of voltage produced to the speed of the generator. When using SI units, *K_y* = *K_t*. Voltage in the LEDs is related to the applied current by the equation:

$$V = \frac{1}{1.6ln(\frac{1000I}{0.126n})} \tag{4}$$

where *n* is the number of LEDs. This equation was derived from a graph depicting the relationship between voltage and current in the LEDs we are using. Speed of the generators is given by the equation:

$$\omega_g = \frac{V + RI}{K_t} \tag{5}$$

where R is the internal resistance of the motor. Speed of the rope gear is related to generator speed by the equation:

$$\omega_r = \frac{\omega_g}{N} \tag{6}$$

Fall time can then be determined by the following equation:

$$t = \frac{30\omega_g}{r} \tag{7}$$

One can use these equations to determine important design parameters. For example, if *m = 7kg*, *r = 0.02m*, *N = 625*, *e = 0.8*, *K_t= 0.0408*, *R = 2ohms*, and *n = 4*, then fall time is around 14.2 *minutes*.

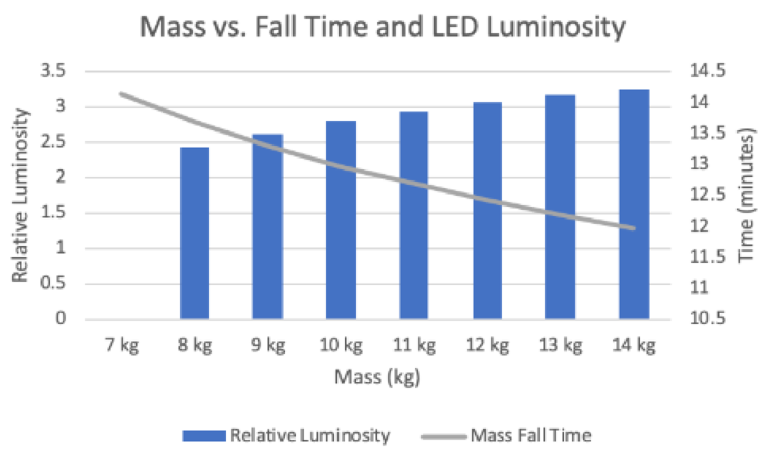


Figure 10: Mass vs Fall Time and LED Luminosity

The LED array in the gravity powered light consists of 4 3V LEDS wired in parallel. With 8 kg and 4 LEDs, the design can generate light for approximately 14 minutes. Figure 10 shows how time and relative luminosity vary with applied weight. The two motors keep the fall time within a narrow range relative to the range of weight. Fall time is inversely proportional to weight, and luminosity increases with weight.

5.8 Design for Manufacturing

All custom manufactured parts of the gravity light will be injection molded plastic to minimize cost and complexity of manufacturing. The electronics, generators, metal shafts, and bearings are stock parts that do not need to be manufactured by this group. The gravity powered light is designed

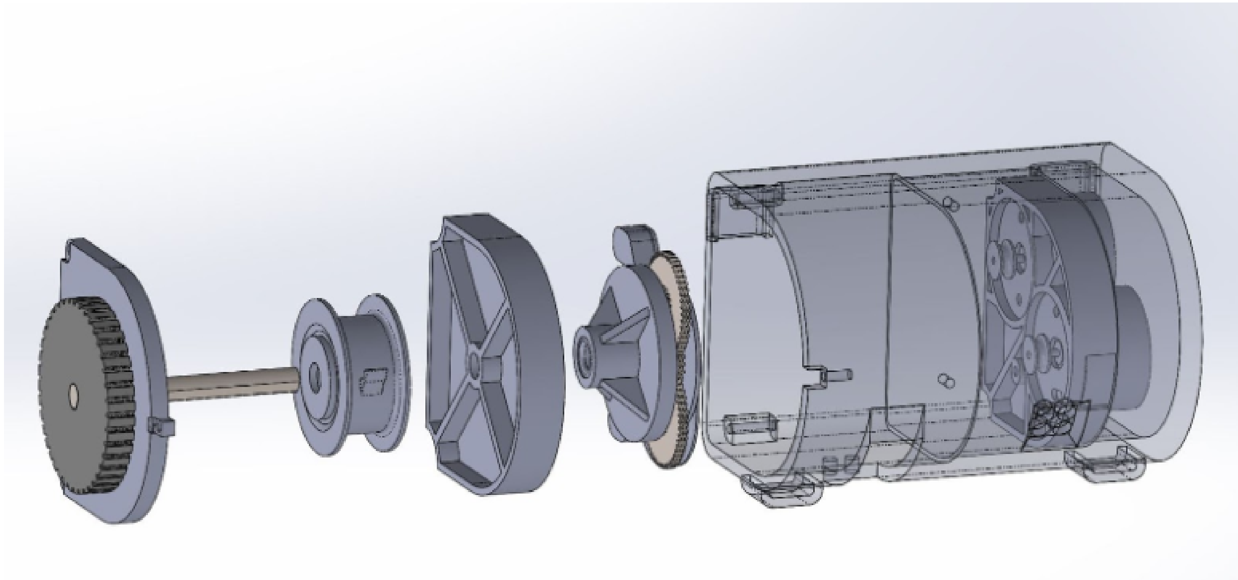


Figure 11: Exploded view of gravity powered light

to be easily assembled by hand. The complexity of the small parts in the gear train rules out the possibility of automated assembly. As Figure 11 shows, the generators are mounted to the back plate and the internal gearing is assembled outside of the housing and inserted into the housing. It is fastened in place by two screws on the backside of the housing. The internal mounting plates sit on ridges in the housing. The rope gear and reset knob are designed to be press-fit onto the d-shaft. A cover plate is secured with three screws to enclose the assembly.

5.9 Design for Outdoor Use

Outdoor environments will expose the gravity powered light to extreme conditions. Durability was a top priority to protect the device from damage when dropped. The housing encloses and protects the internal components of the device and is reinforced by the internal mounting plates. The housing also protects the electronics from rain, and the device could be made water-proof with silicone sealant. The screws that secure the housing down are galvanized, which protects against corrosion.

5.10 Design for Safety

This product will be catered to outdoor enthusiasts under the assumption they can safely lift 30 pounds. The small components will be mounted inside the housing. The housing will be bolted down, with bolt head covers that make it difficult for a child to gain access to the internal parts. Maximum load and shear stress were simulated on the housing and it will be able to withstand the max load of 30 pounds.

5.11 Design for Sustainability

Since all manufactured components will be ABS plastic, they will be recyclable and easily separated. This will make it possible for users to recycle/reuse material. Gears, lights, wires, strapping, and bolts could be disassembled and reused for other applications. Furthermore, the number of parts and amount of material was minimized We also cut down on material and unnecessary parts where possible. Throughout the design process, our design became much more compact which reduced material for the housing as well as significantly decreasing the number of screws needed to assemble the device. The reduction of material is important in considering our device's impact on the environment as harmful emissions are produced for every additional unit of material we use.

5.12 Design Codes and Standards

The Gravity Light will follow the following design codes and standards:

- Motor - ANSI/NEMA standards compliant
- Bolt Spec: ASME B18.6.3
- UNC for nuts and bolts
- Restriction of Hazardous Substances (RoHS)
- OSHA heavy metals compliant
- Gears AGMA
- Shafts REACH compliant

Semester 1 Itemized Purchases					
Part	**Manufacturer**	**Part Number**	**Material**	**Qty**	**Cost ($)**
Ball Bearing	McMaster-Carr	60355K504	Steel	6	34.68
Shaft	McMaster-Carr	1346K11	1566 Carbon Steel	1	7.69
Large Gear	McMaster-Carr	2662N6	Acetal Plastic	3	25.17
Mid Gear	McMaster-Carr	2662N2	Acetal Plastic	3	12.60
Rubber Tubing	McMaster-Carr	5394K22	Nitrile Rubber	1	3.80
Threaded Inserts	McMaster-Carr	93738A120	Brass	1 Carton (25)	11.14
Set Screws	Fastener Superstore	379742	Alloy Steel	1 Carton (10)	4.51
Housing	3D-Printed	-	ABS	1	100 (estimate)
Motor	SP Elemech	MDPJ030AF	-	1	12.98
LED Lights	-	-	-	-	10.00
Small Gear	McMaster-Carr	2662N1	Acetal Plastic	1	2.91
Total	-	-		-	225.48

Table 2: Itemized list of the first semesters purchases.

Semester 2 Itemized Purchases						
Part	Manufacturer	Part Number	Material	Count	Price ($)	Total ($)
Motor	Jameco	2173044	-	2	2.25	4.5
Housing/Gears	-	-	ABS Plastic	1	78.19	78.19
Screws	-	-	Galvanized	1 box	4.67	4.67
Nuts	-	-	Galvanized	1 box	3.37	3.37
One-Way Bearing	McMaster-Carr	2489K22	Steel	1	10.72	10.72
D-Profile Rotary	McMaster-Carr	8632T151	Stainless Steel	1	13.98	13.98
1/16" Rotary Shaft	McMaster-Carr	1327K83	12L14 Carbon Steel	1	2.85	2.85
1/8" Rotary Shaft	McMaster-Carr	1327K93	12L14 Carbon Steel	1	3.07	3.07
1/2" Nylon Webbing	Country Brook Design	WP-KGR-1.2-50	Polypropylene	1	16.95	16.95
Carabiner	Everbilt	42694	Steel	1	0.98	0.98
Total	-	-	-	-	-	139.28

Table 3: Itemized purchases for semester 2 had we completed the semester at UVA

6 Cost Analysis

6.1 Budget

Throughout the two semester project we were given a total budget of $800 to work with, $400 per semester. As expected, we had a few design changes within the first semester which amounts to higher material costs during testing. Table 2 shows the itemized purchasing list for the first semester.

The group had a more efficient design drawn up for the second semester that decreased the total number of parts. The gears were also changed from being outsourced, to being printed. The rubber tubing and threaded inserts were taken out of the design, and only one ball-bearing was needed. Table 3 shows the itemized purchasing orders for the second semester, assuming the group had completed the semester at UVA, and testing for the final design iteration had gone well. As shown, the project stayed within the allotted budget. The first and second semester summed to a total cost of $358.84, which is $441.16 under budget. A further breakdown of the teams budget usage is shown in figure 12.

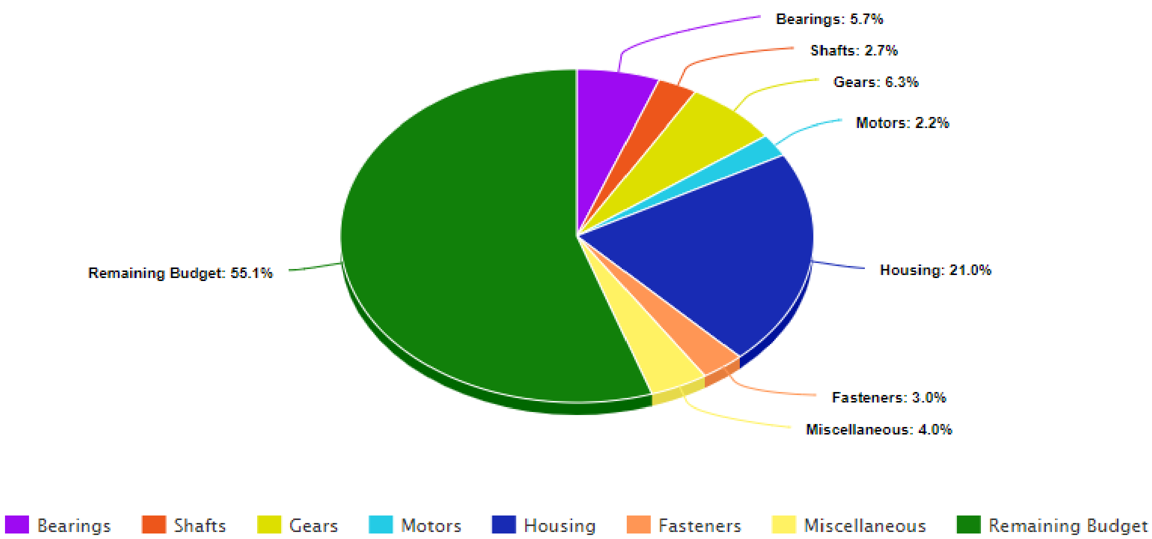


Figure 12: Total cost distribution

6.2 Expected Manufacturing Cost

Operating under an assumption that the Gravity Light becomes a successful product, the group decided that in the long run it would be profitable to transition from 3D printing to injection molding. Injection molding requires high start up costs due to creating the mold. The benefit to this one time upfront cost is that it gets amortized over the production lifespan. With each additional unit manufactured, the unit cost decreases because the start-up costs are being spread over the summed units. The cost per unit would then only consist of the materials used, which would dramatically decrease the cost per unit. Assuming a 20% wholesale discount for the outsourced parts, and factoring in a conservative injection molding savings of $70, one can get a ballpark estimate of $39.23 per unit, as shown in table 4.

6.3 Market Price

The above calculations contribute to our total variable costs. However, several fixed costs must be considered when determining pricing and viability of the product. Using the Cost-Plus pricing method popular with many manufacturers, material costs, labor costs, overhead, and desired profits

Semester 2 Itemized Purchases						
Part	Manufacturer	Part Number	Material	Count	Price ($)	Total ($)
Motor	Jameco	2173044	-	2	1.8	3.6
Housing/Gears	-	-	ABS Plastic	1	8.19	8.19
Screws	-	-	Galvanized	3	0.03/screw	0.09
Nuts	-	-	Galvanized	3	0.02/nut	0.06
One-Way Bearing	McMaster-Carr	2489K22	Steel	1	8.57	8.57
D-Profile Rotary	McMaster-Carr	8632T151	Stainless Steel	1	11.18	11.18
1/16" Rotary Shaft	McMaster-Carr	1327K83	12L14 Carbon Steel	1	2.28	2.28
1/8" Rotary Shaft	McMaster-Carr	1327K93	12L14 Carbon Steel	1	2.45	2.45
1/2" Nylon Webbing	Country Brook Design	WP-KGR-1.2-50	Polypropylene	6	0.34/yard	2.03
Carabiner	Everbilt	42694	Steel	1	0.78	0.78
Total	-	-	-	-	-	39.23

Table 4: Manufacturing cost per unit assuming a 20% wholesale discount and a dramatic housing price decrease

can determine a final sales price, as shown below:

$$T_c = C_u + C_l + C_o \tag{8}$$

where *T_c* is the total cost, *C_u* is the unit cost, *C_l* is the labor cost, and *C_o* is total projected overhead. Once the total cost is found, one simply adds in a desired profit margin of the total cost to get the required sales price.

$$P_s = T_c + T_p \tag{9}$$

where *P_s* is the final sales price and *T_p* is the total profit desired per unit. Assuming hand-assembly during early production stages and that approximately three units could be assembled per hour, at a $21.00 per hour wage the labor cost would come to $7 per unit. Overhead costs including logistics, executive salaries, and marketing is assumed to be $20 per unit.

With our material cost of $39.23, labor cost $7.00, and overhead cost $20.00, we get a total cost of $66.23 per unit. The Gravity Light is currently priced at $79.99 in the United States. Using a competitive pricing model, the device can be priced $5 below that of its leading competitor at $74.99, yielding 15% profit. This price also aligns with the prices of REI's Best Camping Lanterns of 2019 which lists lamps from $20 to $130 (Rosemont, 2019).

7 Conclusion

As a group, we saw our knowledge grow in a variety of areas throughout the development of the gravity powered light. In the design phase, we learned the importance of selecting appropriate materials for our design, and we quickly realized that we needed to choose materials that were strong enough to support the loads we would be subjecting the device to without failing. In these steps, the importance of appropriately tolerancing our parts also became clear.

In our first prototype, parts were too loose or too tight in some areas. We found ourselves having to come up with workarounds to find solutions that proper tolerances would have done outright. We also saw our knowledge grow in the manufacturing and assembly stages of our prototype. We spent several nights in the machine shop, trying to figure out the best ways to drill holes in circular shafts or place set screws in our gears. This helped us gain an understanding about the important tradeoff that takes place between the functionality of a part and the ease with which it can be manufactured and assembled.

A couple of our group members were responsible for constantly refining and reworking the gear train that gave the device the desired mechanical disadvantage. This required a lot of creative thinking and diligence in figuring out the best way to maximize space. Eventually, the gear train evolved from the bulky, multiple shaft design in the first prototype, to a planetary gear system that takes up far less space and is able to achieve the same mechanical disadvantage.

As we were designing this device, we discussed several different motors, as well as the inclusion of supercapacitors, batteries, or other electrical components. This required several group members to expand upon their circuitry knowledge. Although we ultimately settled on a simple generator-LED circuit for the final design, we believe that enhancing the circuitry of the device could lead to a more robust solution in future work.

Throughout the device design, the group was challenged to create solutions to mechanical problems. These solutions have manifested themselves by means of a multi-generator system, planetary gear train, one-way bearing, exterior rewind knob, internal rope gear, and a compact housing. While we are proud of the product we have designed, we recognize that there are always ways to improve the device in the future. Currently, we feel that our efforts would be best applied if we focused on upgrading the electrical component of the device. If we had more time, we would consider implementing a battery and switch into the circuitry so that the electricity could be used to power the light at a different time. We also discussed adding a USB port to the device to redirect the battery's charge to an external source instead of the battery.

These are things that we hoped to address upon being able to achieve the desired power output from our mechanical design, but our inability to test the device due to the COVID-19 pandemic made this impossible. Moving forward, we believe the device would benefit from future work on the lights. Namely, implementing some method to achieve a multidirectional light as well as adding more LEDs to the system and a method to adjust the luminosity of the system by controlling the number of LEDs that are lit. To increase the number of LEDs in the system, we would also need to increase the power output in the system. Methods for doing this would include scaling the mechanical disadvantage, adding another generator to the system, or replacing the two existing motors with a motor with a torque constant better suited to generate more power. We believe that each of these additions to the gravity powered light would only help its feasibility as a marketable product.

References

[1] GravityLight: light from the lift of a weight. https://deciwatt.global/gravitylight

[2] Rosemont, C. (2019, April 26). The best camping lanterns of 2019 https://www.rei.com/blog/camp/best-camp-lanterns

[3] Maxon: Guide on using DC motors as generators https://drive.tech/en/stream-content/dc-motors-as-generators

A Appendix: Contributing Authors

- Introduction - Danny Beatty
- Device Description - Nathan Tumperi
- Specifications - William Hicks
- Problem Statement - Danny Beatty
- Design 5.1 - Danny Beatty and Arthur Hofer
- Design 5.2 - Danny Beatty and Nathan Tumperi (hand drawings)

- Design 5.3-5.6 Danny Beatty and Arthur Hofer
- Design 5.7 - Arthur Hofer, William Hicks, Timothy Tyree
- Design 5.8 - Nathan Tumperi
- Design 5.9 - Nathan Tumperi and Timothy Tyree
- Design 5.10 - Nathan Tumperi and Timothy Tyree
- Design 5.11 - Nathan Tumperi
- Design 5.12 - Timothy Tyree
- Cost Analysis 6.1 - Timothy Tyree
- Cost Analysis 6.2 - Timothy Tyree
- Cost Analysis 6.3 - Timothy Tyree and Nathan Tumperi
- Conclusion - William Hicks
- Solidworks Designs - The majority of designs were implemented by Arthur Hofer and Danny Beatty in solidworks.

B Appendix: Graphs, Tables, and Supporting Calculations

	Constants								
Weight	mass (kg)	7							
Rope Gear	radius (m)	0.02							
Gear Train	ratio	625							
	efficiency	0.8							
Generator	k_b = k_t (Nm/A)	0.0204							
	R	2							
LED	V vs. I graph								
	Luminosity graph								
	n1 (# of parallel paths)	6							
	n2 (# of LEDs in series)	1							
	T_rg = mg*r_rg	**T_g = E*T_rg/N**	**I = T_g/k_t**	**V = n2/1.6*ln(I*1000/(0.126*n1))**	**w_g = (V+RI)/k_t**	**w_rg = w_g/N**	**v_m = w_rg*r_rg**	**t_2 = 2/v_m**	**t_2 (min)**
	1.3734	**0.001757952**	**0.086174118**	**2.96005236**	**153.5490488**	**0.245678478**	**0.00491357**	**407.036061**	**6.78393435**
	T_rg = mg*(r_rg+0.01)	**T_g = E*T_rg/N**	**I = T_g/k_t**	**V = n2/1.6*ln(I*1000/(0.126*n1))**	**w_g = (V+RI)/k_t**	**w_rg = w_g/N**	**v_m = w_rg*r_rg**	**t_2 = 2/v_m**	**t_2 (min)**
	2.0601	**0.002636928**	**0.129261176**	**3.213468053**	**170.1956081**	**0.272312973**	**0.005446259**	**367.224517**	**6.12040862**

Table 5: Example Calculations for Data Points in Figure 9

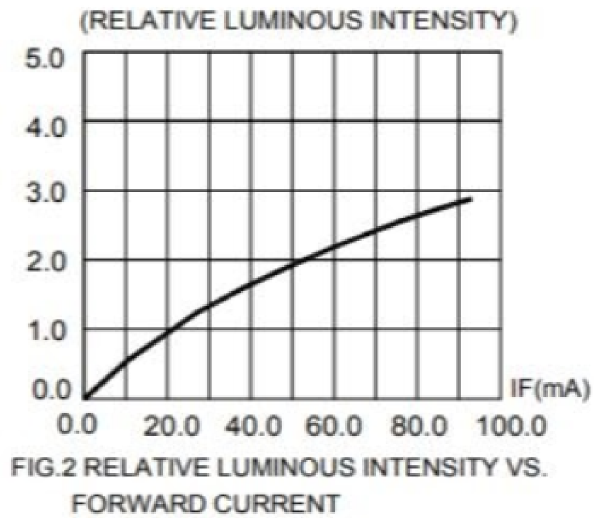


Figure 13: Relative Luminous Intensity vs. Forward Current

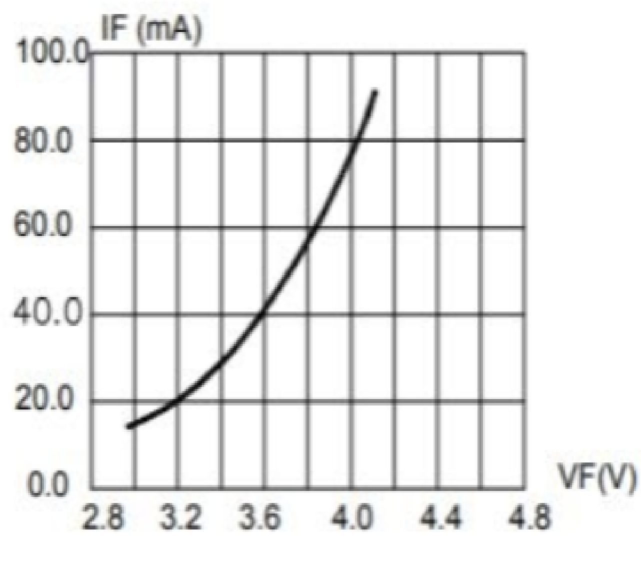


Figure 14: Forward Current vs. Forward Voltage

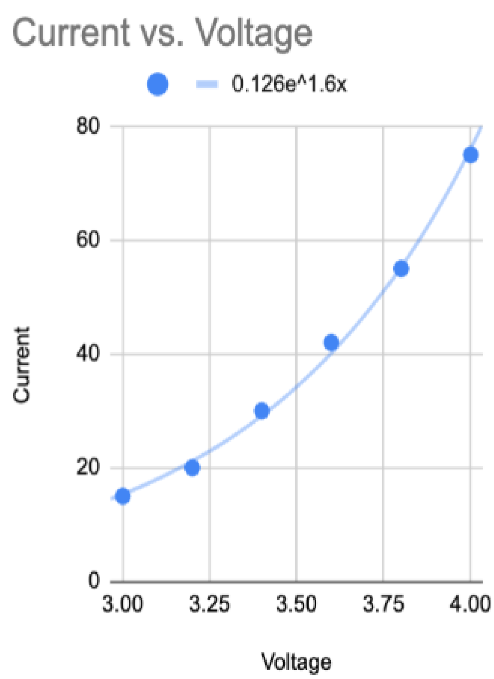


Figure 15: Recreated Current vs. Voltage Graph for use in Motor Calculations

C Appendix: Detail Drawings

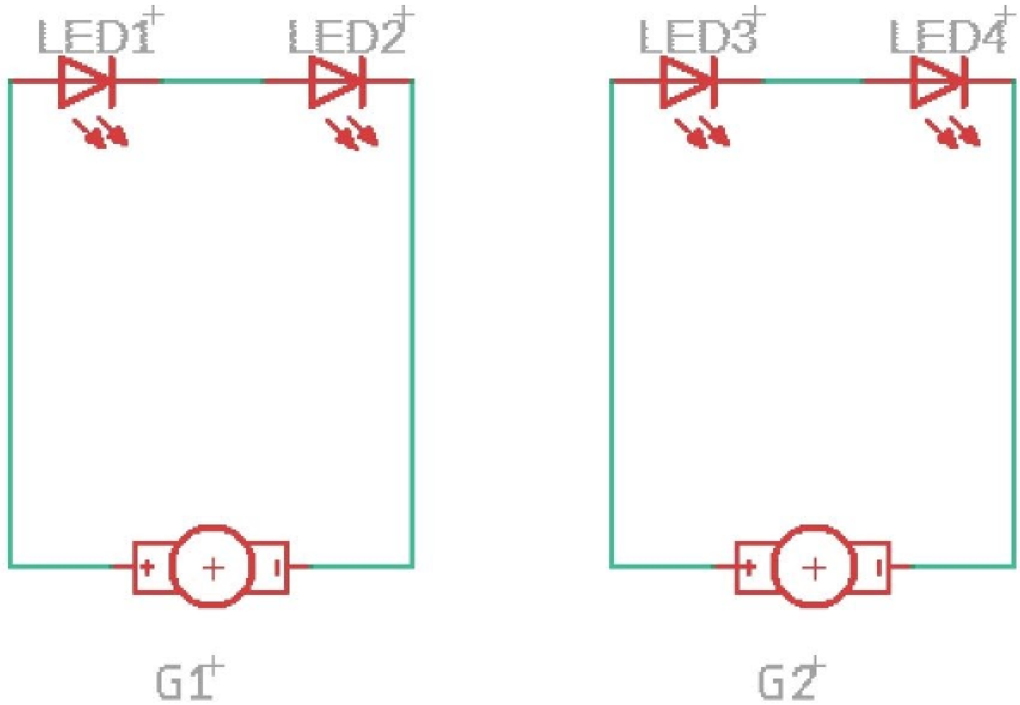


Figure 16: Wiring Schematic for 4 LEDs

Polypropylene Specs	
Assembled Height (in.)	216
Assembled Width (in.)	0.5
Tensile Strength (lb)	300

Table 6: Rope specifications

D Appendix: Part Schematics

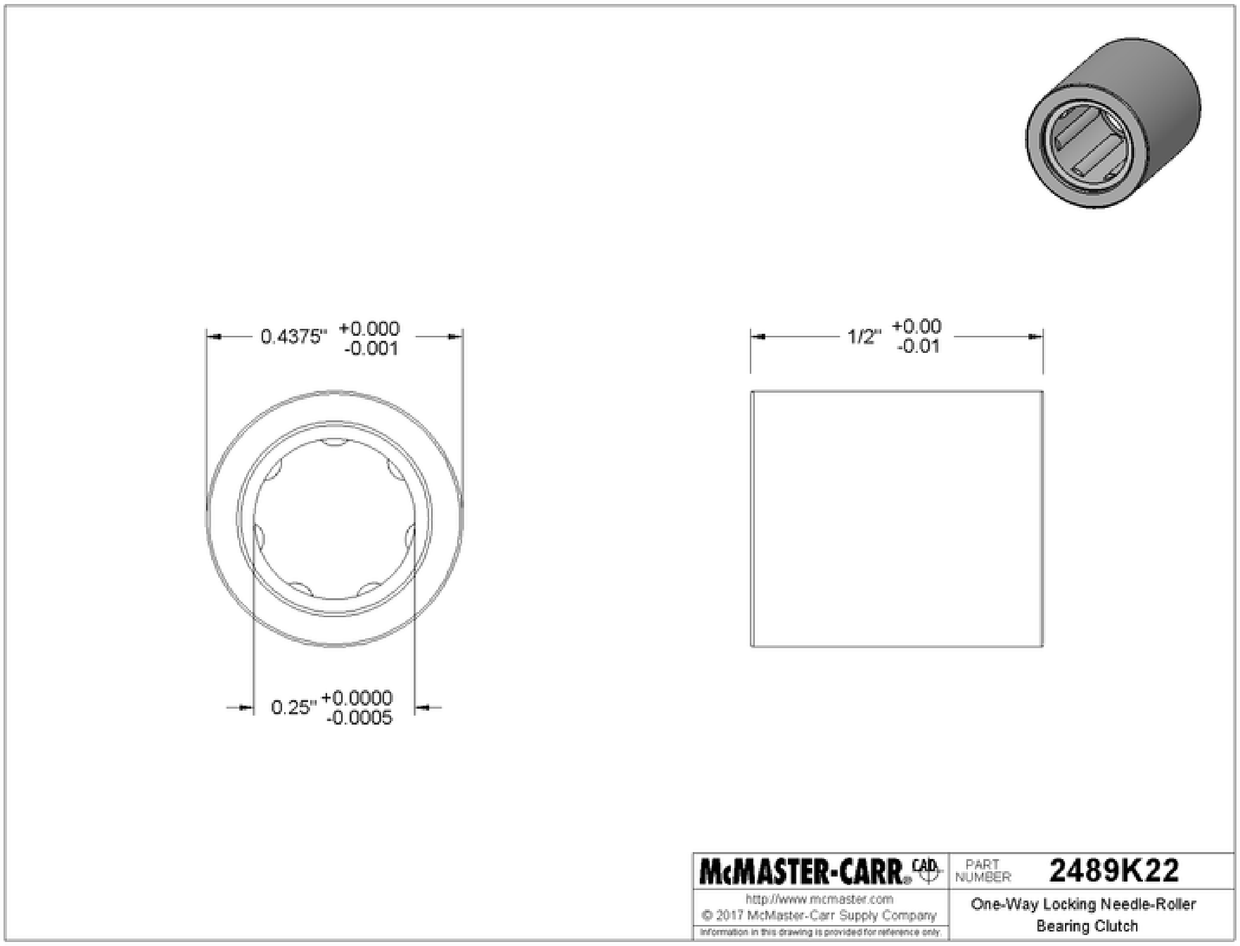


Figure 17: One Way Locking Needle-Roller Bearing Clutch

Carabiner Dimensions			
Assembled Depth (in.)	0.3 in	Fastener Length (in.)	0.381889
Assembled Height (in.)	3.00 in	Individual Product Width (in.)	1.720469
Assembled Width (in.)	1.70 in	-	-

Table 7: Carabiner Dimensions

For Shaft Diameter	1/4"
ID	0.25"
ID Tolerance	-0.0005" to 0"
For Housing ID	7/16"
OD	0.4375"
Min. OD Tolerance	-0.001"
Maximum OD Tolerance	0"
Width	1/2"
Width Tolerance	-0.01" to 0"
Ring Material	Steel
Roller Material	Steel
Cage Material	Acetal Plastic
Spring Material	Acetal Plastic
Maximum Speed	20,000 rpm
Maximum Torque	1.5 ft.-lbs.
Lubrication	Required
For Shaft Surface Smoothness (Ra)	16 microinch
Shaft Mount Type	Press Fit
Temperature Range	-20° to 200° F
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/16/2020, 205 SVHC) Compliant
Country of Origin	United States

Figure 18: Bearing Clutch specs

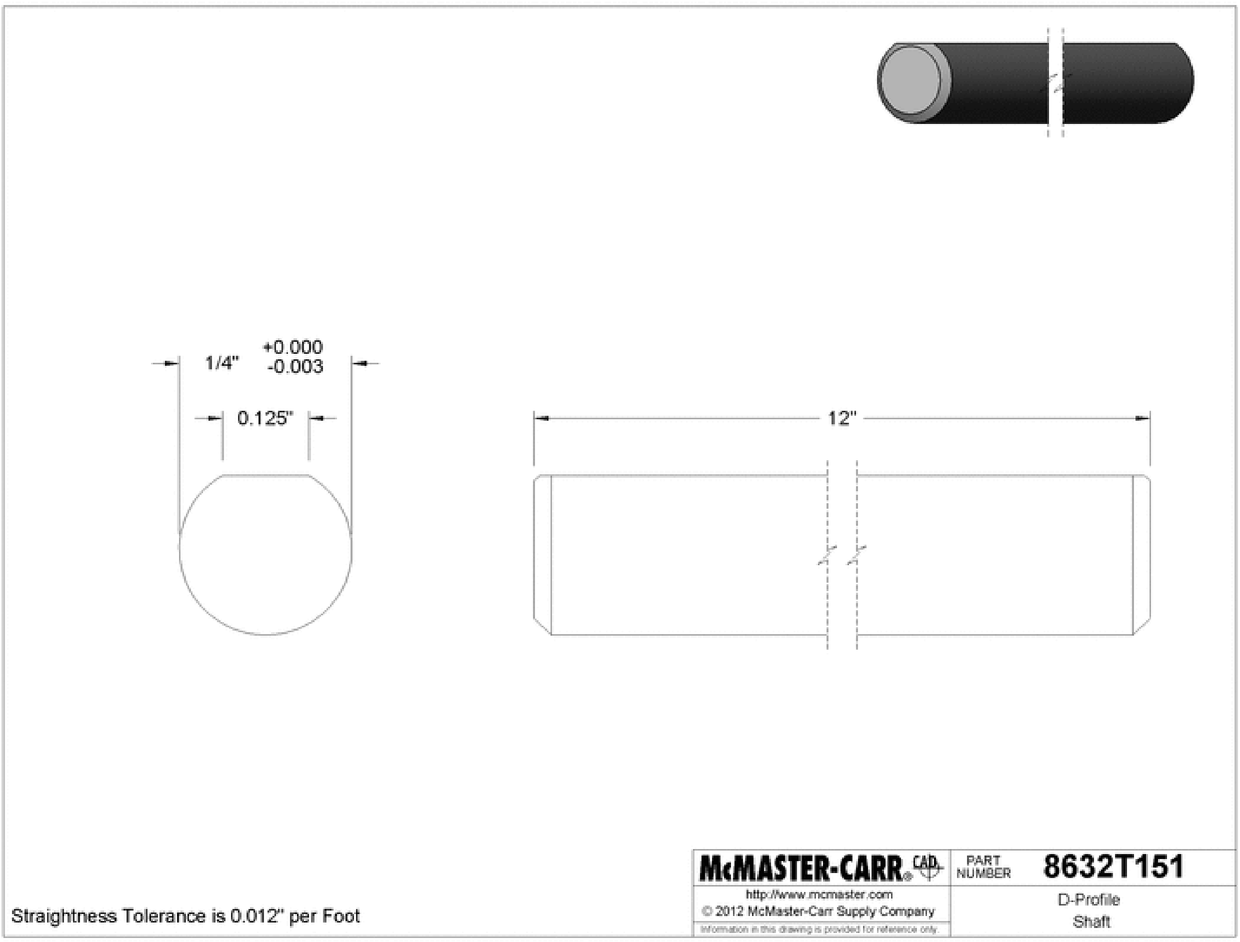


Figure 19: D-Profile Rotary Shaft

For Motion Type	Rotary
End Type	D-Profile
Material	303 Stainless Steel
Diameter	1/4"
Length	12"
Flat Width	1/8"
D-Profile Length	12"
Diameter Tolerance	-0.003" to 0"
Length Tolerance	-0.0625" to 0.0625"
Straightness Tolerance	0.012" per ft.
Edge Type	Chamfered
Hardness Rating	Medium
Hardness	Rockwell B83
Yield Strength	45,000 psi
Mechanical Finish	Turned, Precision Ground, Polished
System of Measurement	Inch
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/16/2020, 205 SVHC) Compliant
Country of Origin	United States

Figure 20: D-Profile Rotary Shaft specs

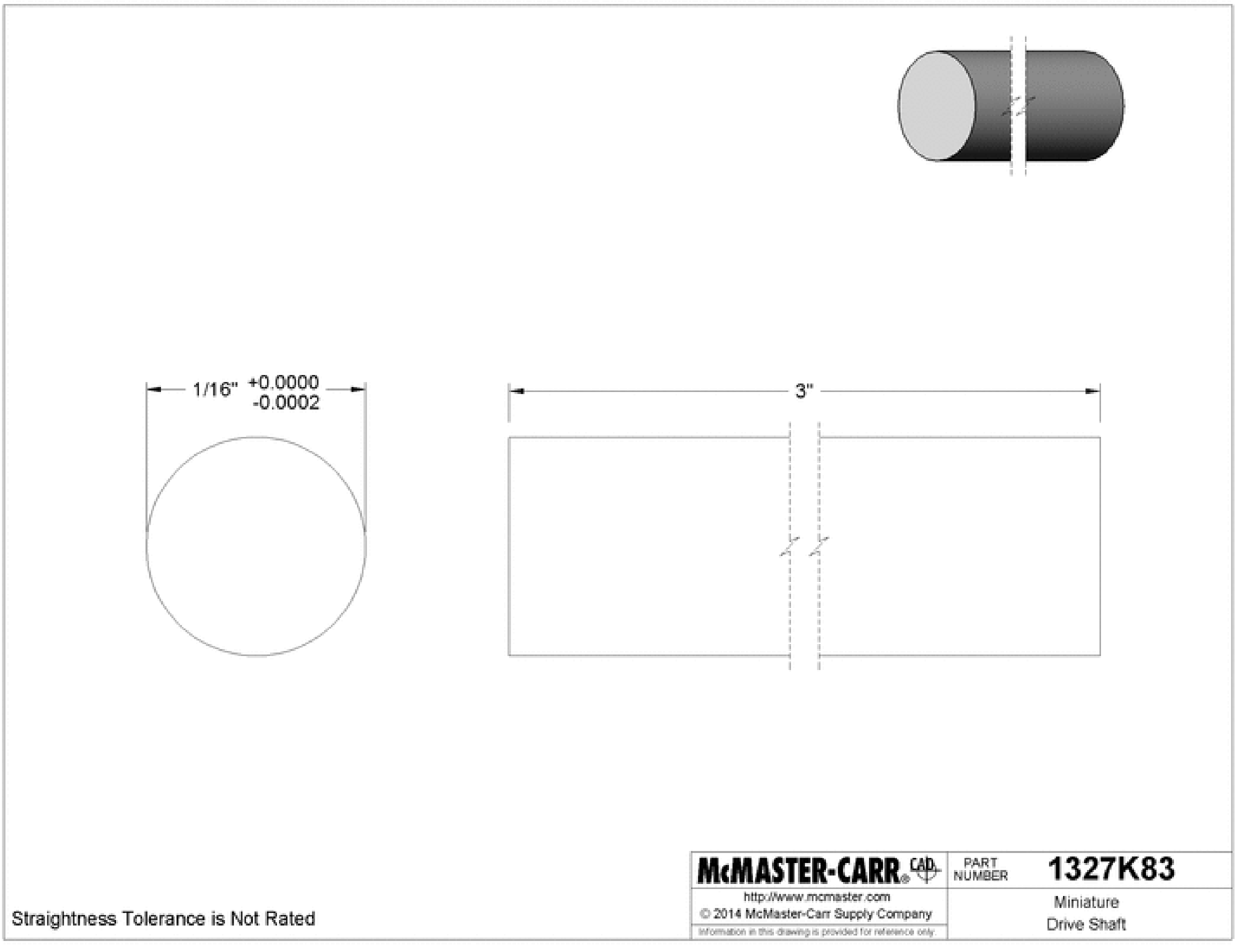


Figure 21: 1/16" rotary shaft

For Motion Type	Rotary
End Type	Straight
Material	12L14 Carbon Steel
Diameter	1/16"
Diameter Tolerance	-0.0002" to 0"
Length	3"
Length Tolerance	-0.01" to 0.01"
Straightness Tolerance	Not Rated
Edge Type	Straight
Hardness Rating	Medium
Hardness	Brinell 167
Yield Strength	70,000 psi
Mechanical Finish	Turned, Precision Ground, Polished
System of Measurement	Inch
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/16/2020, 205 SVHC) Compliant
Country of Origin	United States

Figure 22: 1/16" rotary shaft specs

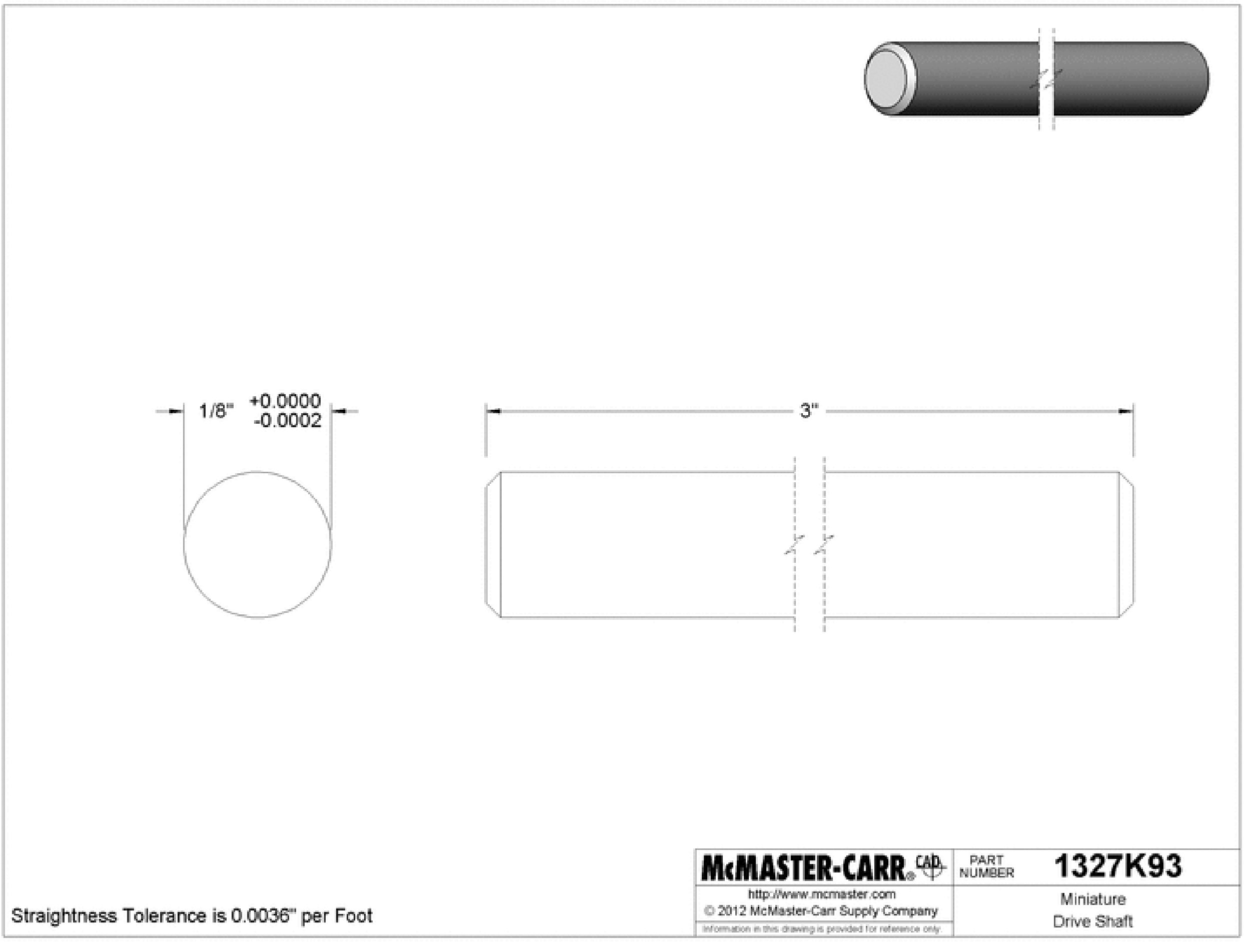
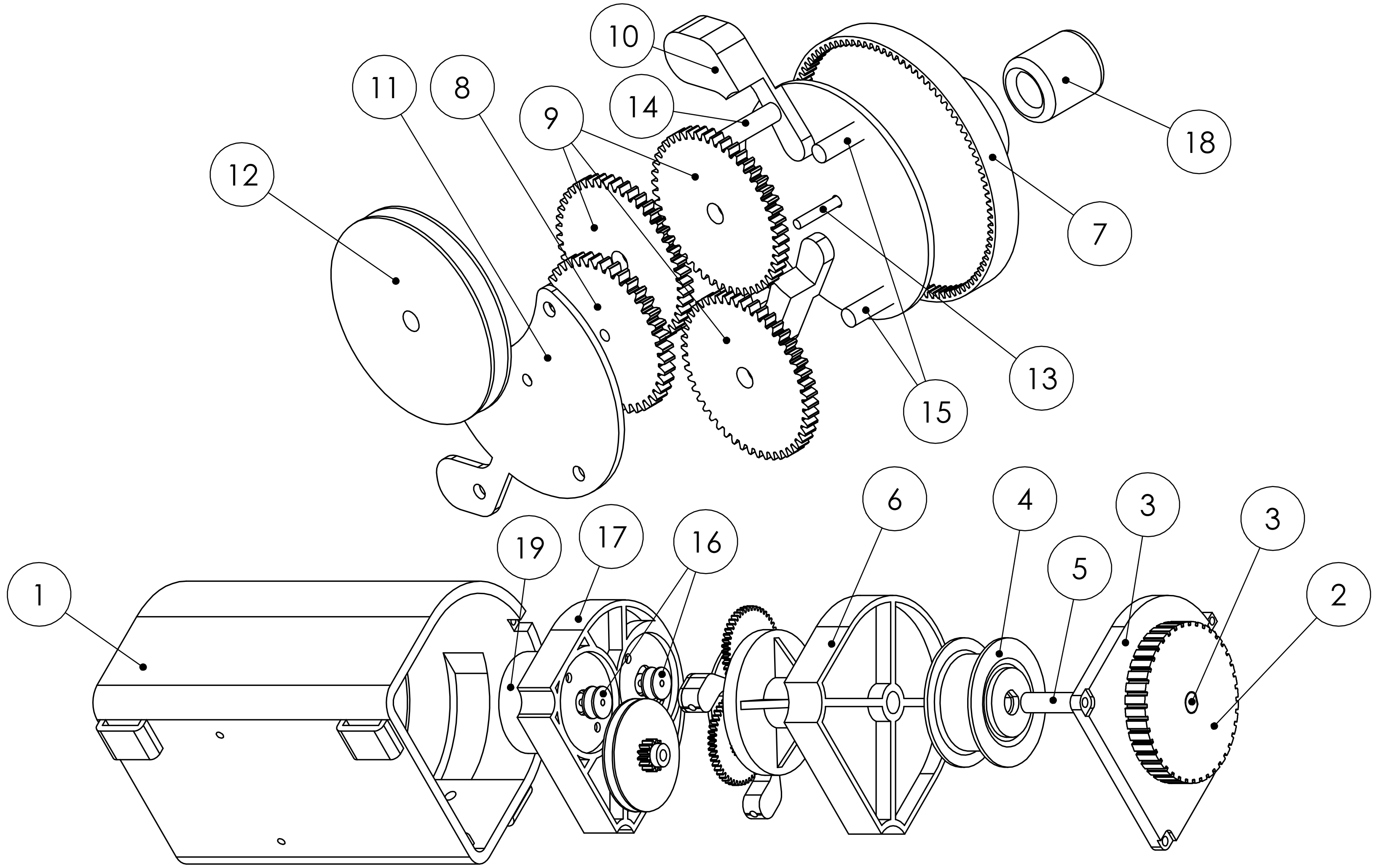


Figure 23: 1/8" rotary shaft

For Motion Type	Rotary
End Type	Straight
Material	12L14 Carbon Steel
Diameter	1/8"
Diameter Tolerance	-0.0002" to 0"
Length	3"
Length Tolerance	-0.01" to 0.01"
Straightness Tolerance	0.0036" per ft.
Edge Type	Chamfered
Hardness Rating	Medium
Hardness	Brinell 167
Yield Strength	70,000 psi
Mechanical Finish	Turned, Precision Ground, Polished
System of Measurement	Inch
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/16/2020, 205 SVHC) Compliant
Country of Origin	United States

Figure 24: 1/8" rotary shaft specs



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ANGULAR: MACH ± BEND ±
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THREE PLACE DECIMAL ±

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MATERIAL

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MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Exploded Assembly

SIZE	DWG. NO.	REV
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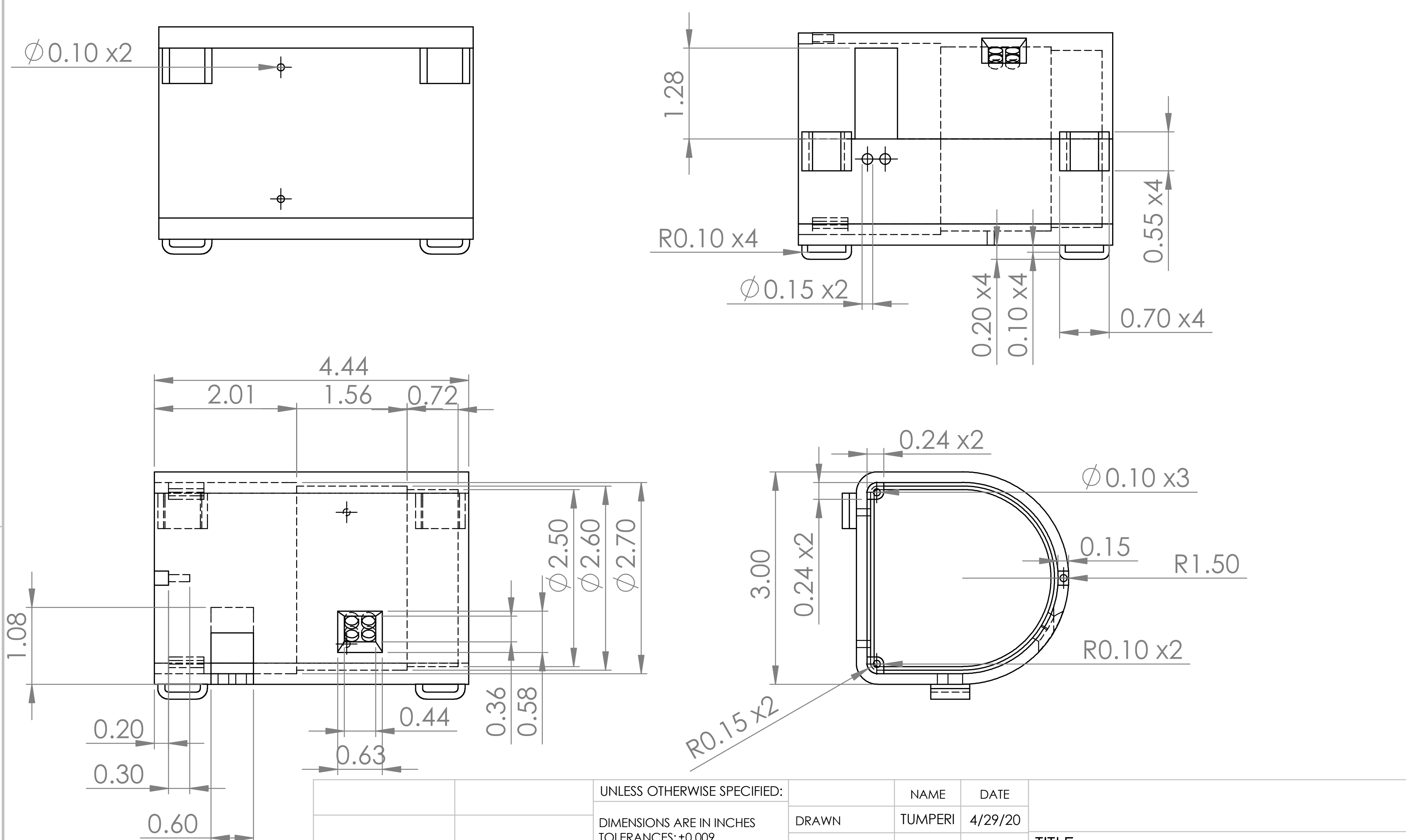

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MATERIAL
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COMMENTS:

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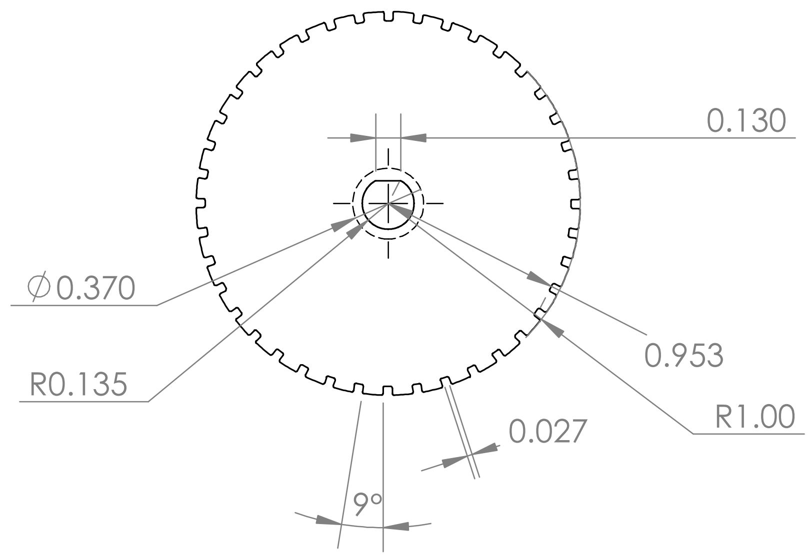

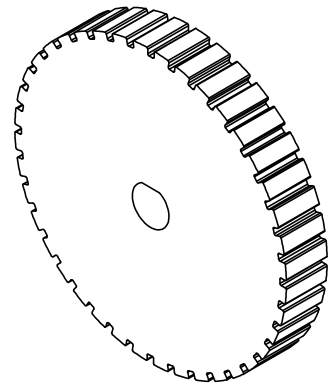

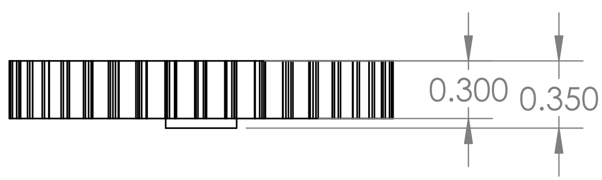

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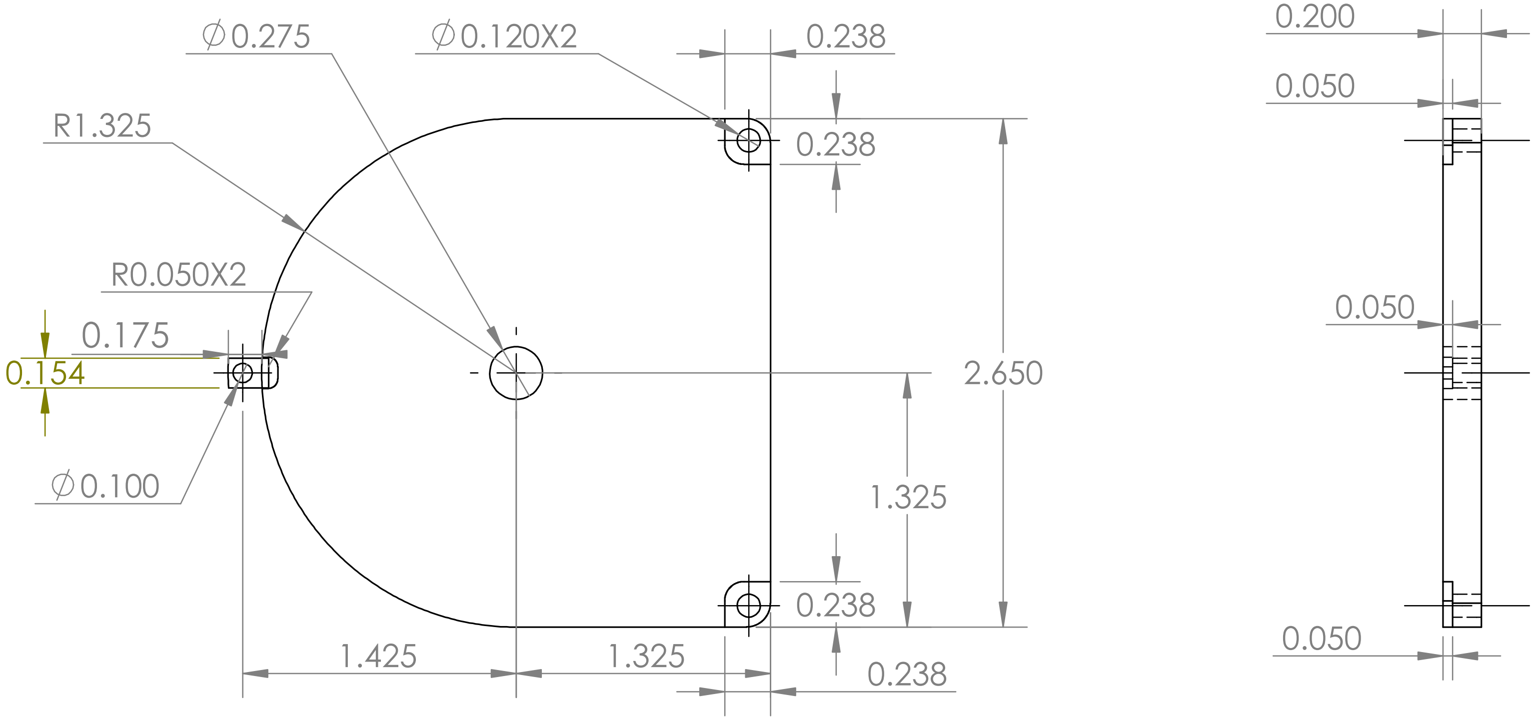

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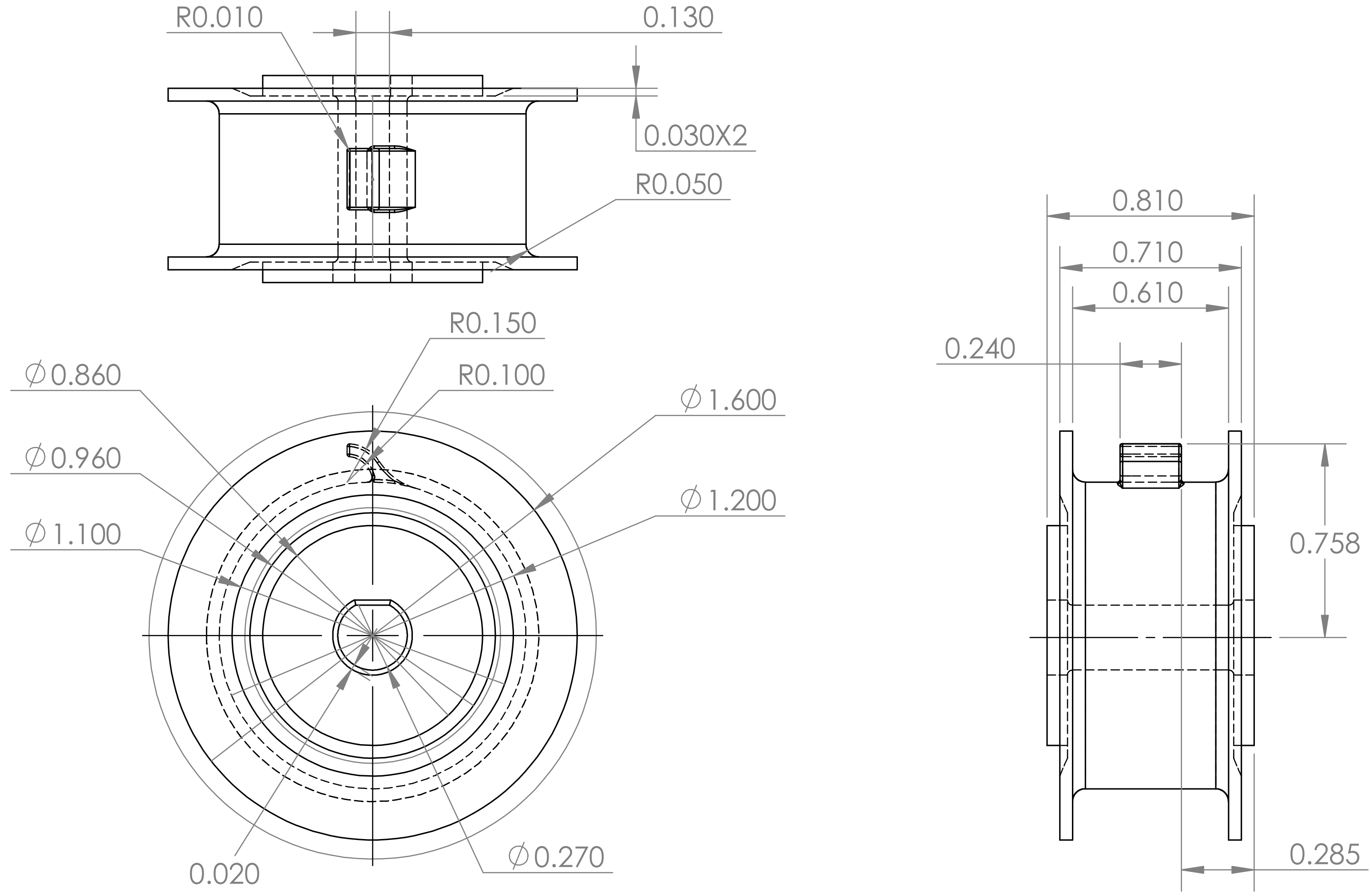

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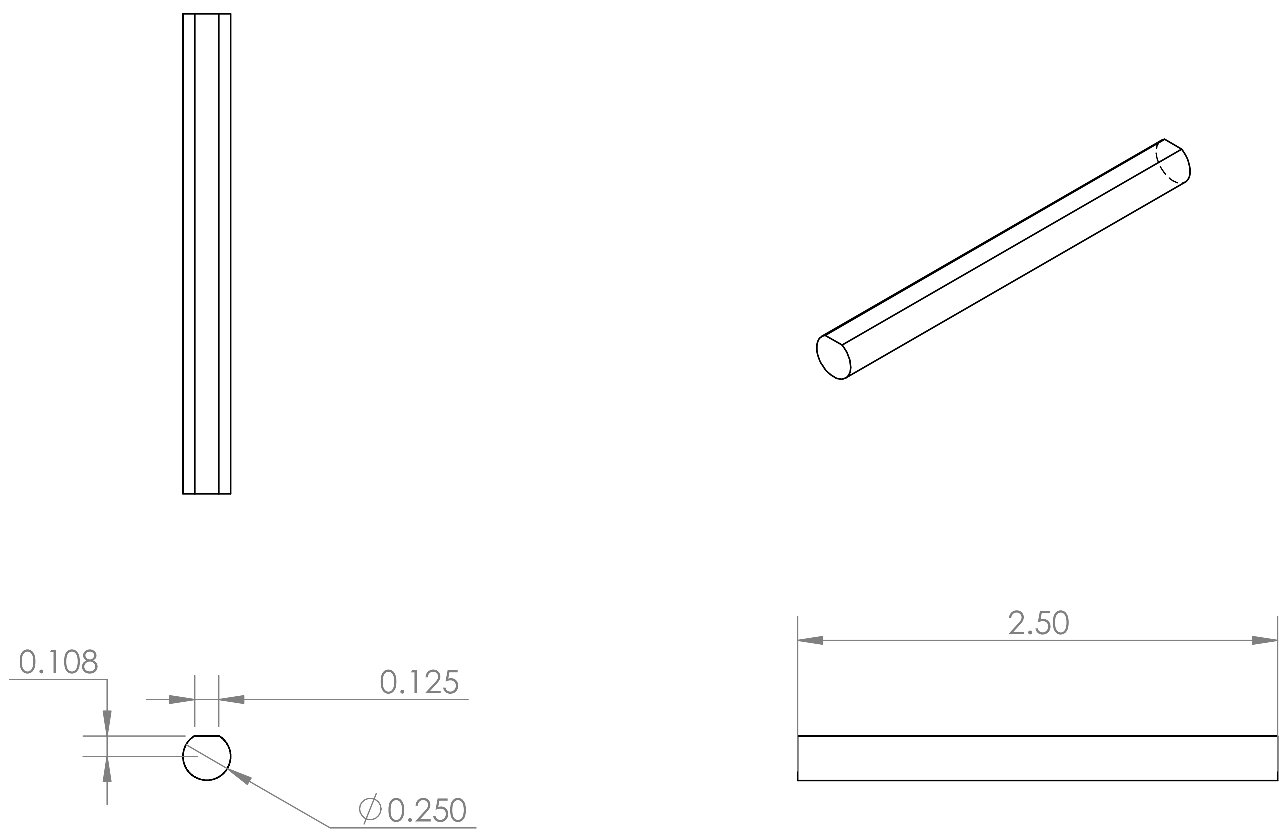

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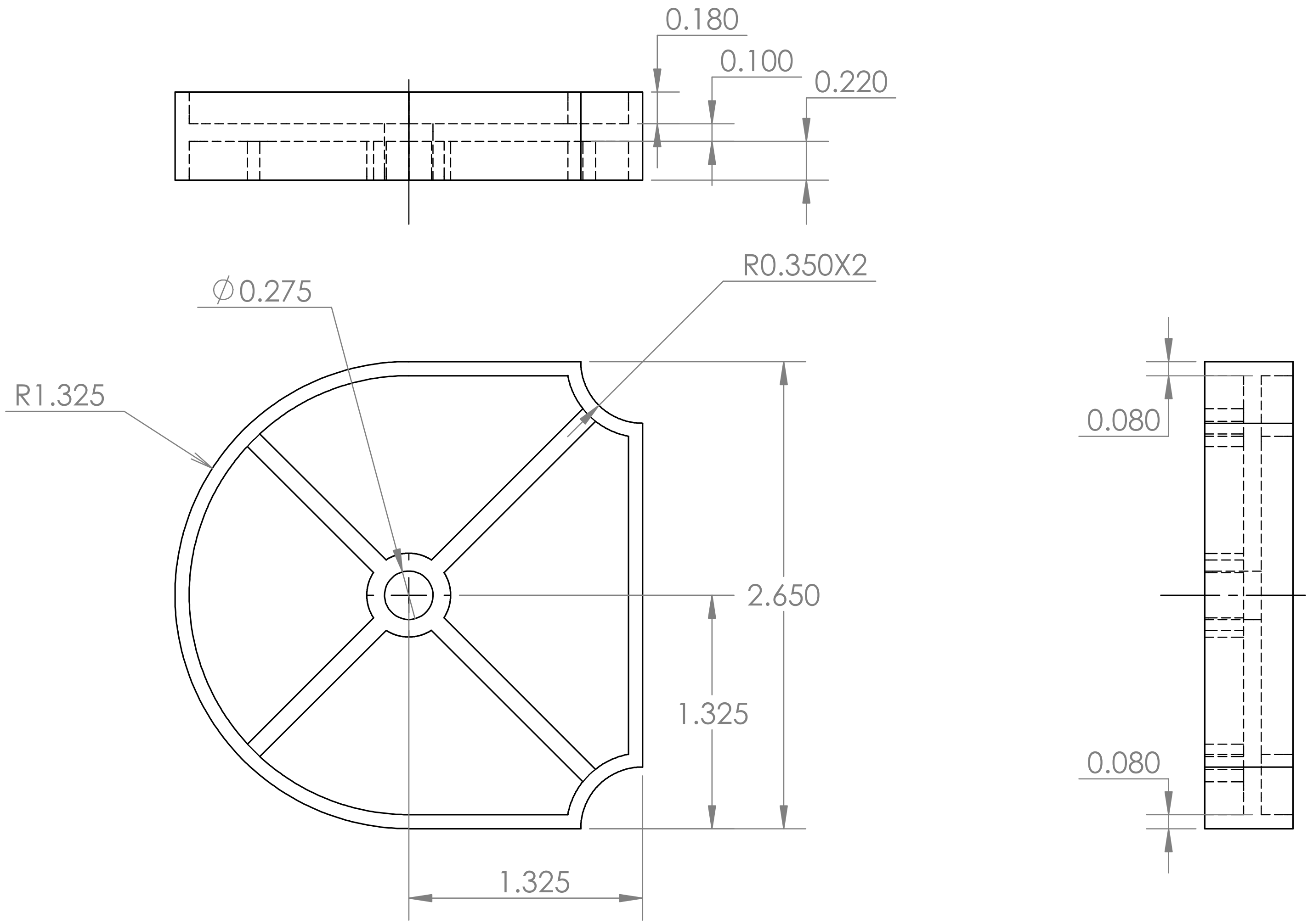

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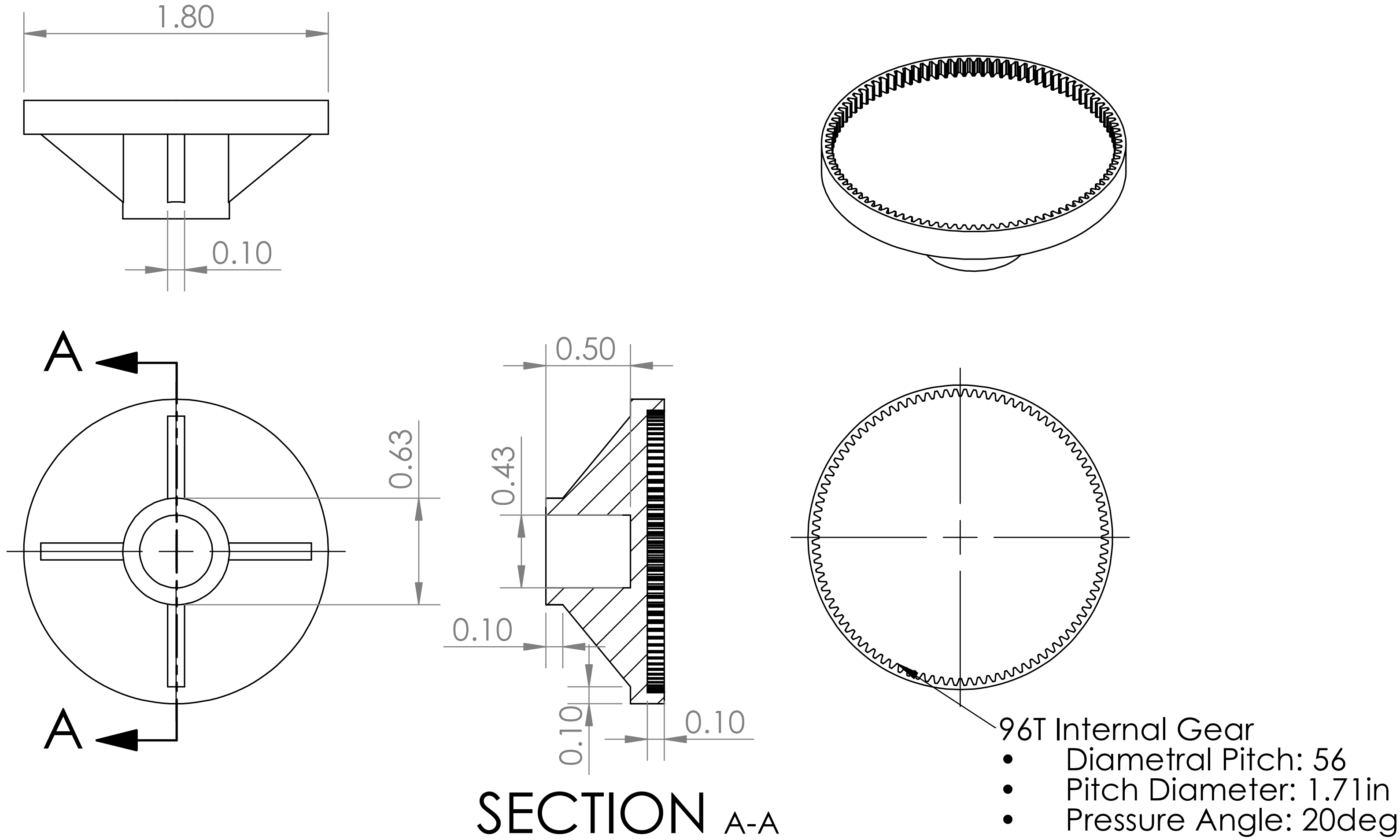

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TOLERANCES: ±0.009

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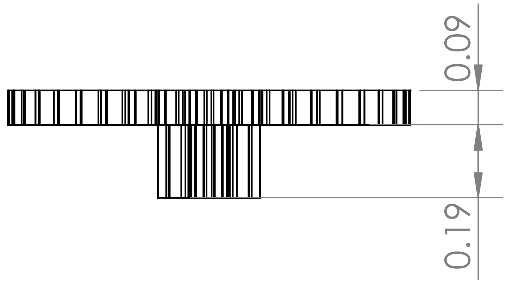

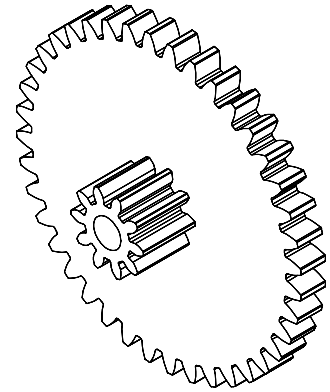

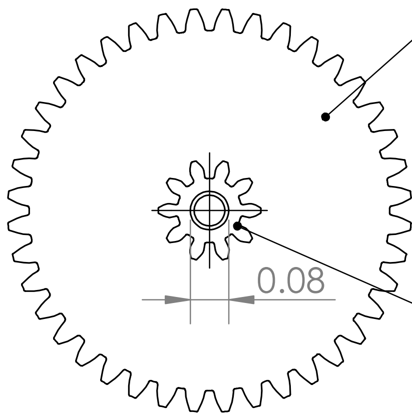

40-tooth Gear
- Pitch Diameter: 1in
- Diametral Pitch: 40
- Pressure Angle: 20 deg

10-tooth Gear
- Pitch Diameter: 0.22in
- Diametral Pitch: 45
- Pressure Angle: 20 deg

A A

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TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

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DRAWN	A. Hofer	4/30/19
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Q.A.		

COMMENTS:

TITLE:
10-40T GEAR

SIZE	DWG. NO.	REV
A	0008	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

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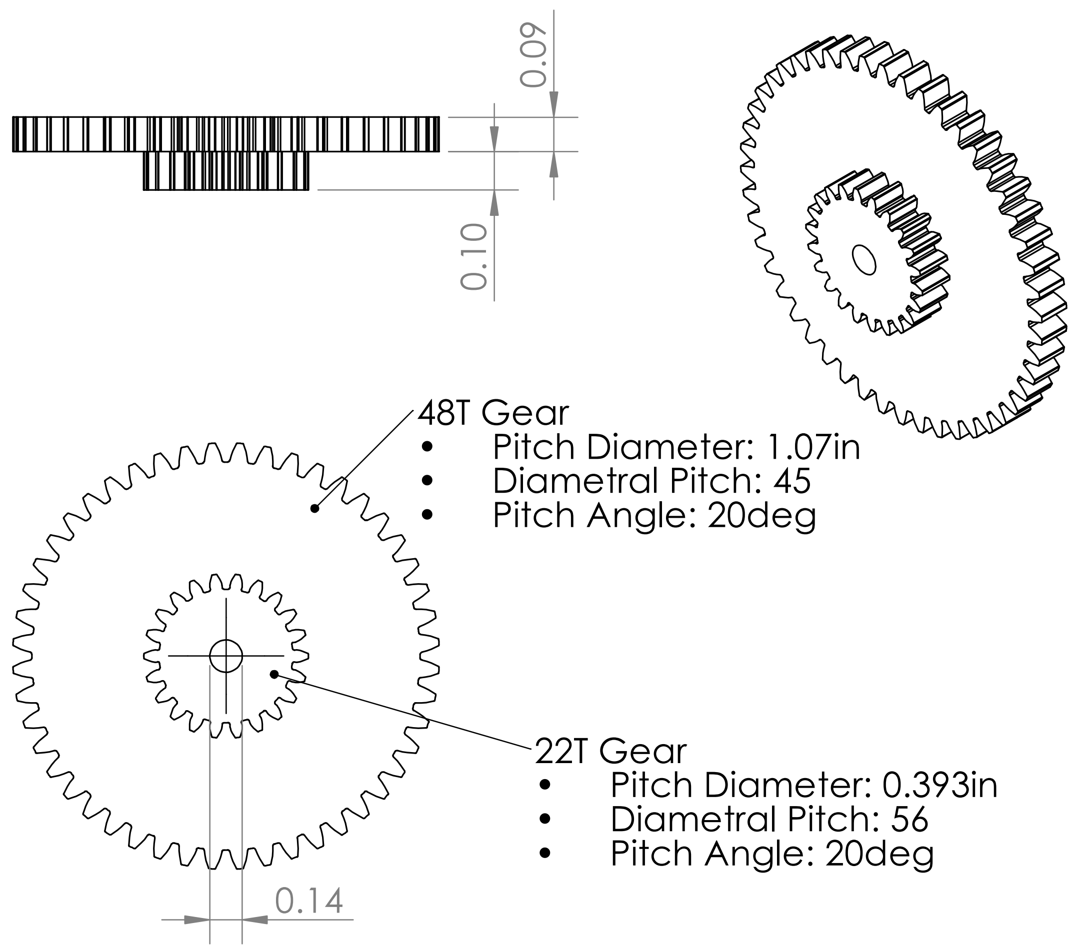

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TOLERANCES: ±0.009

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DRAWN	A. Hofer	4/30/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

48-22T GEAR

SIZE	DWG. NO.	REV
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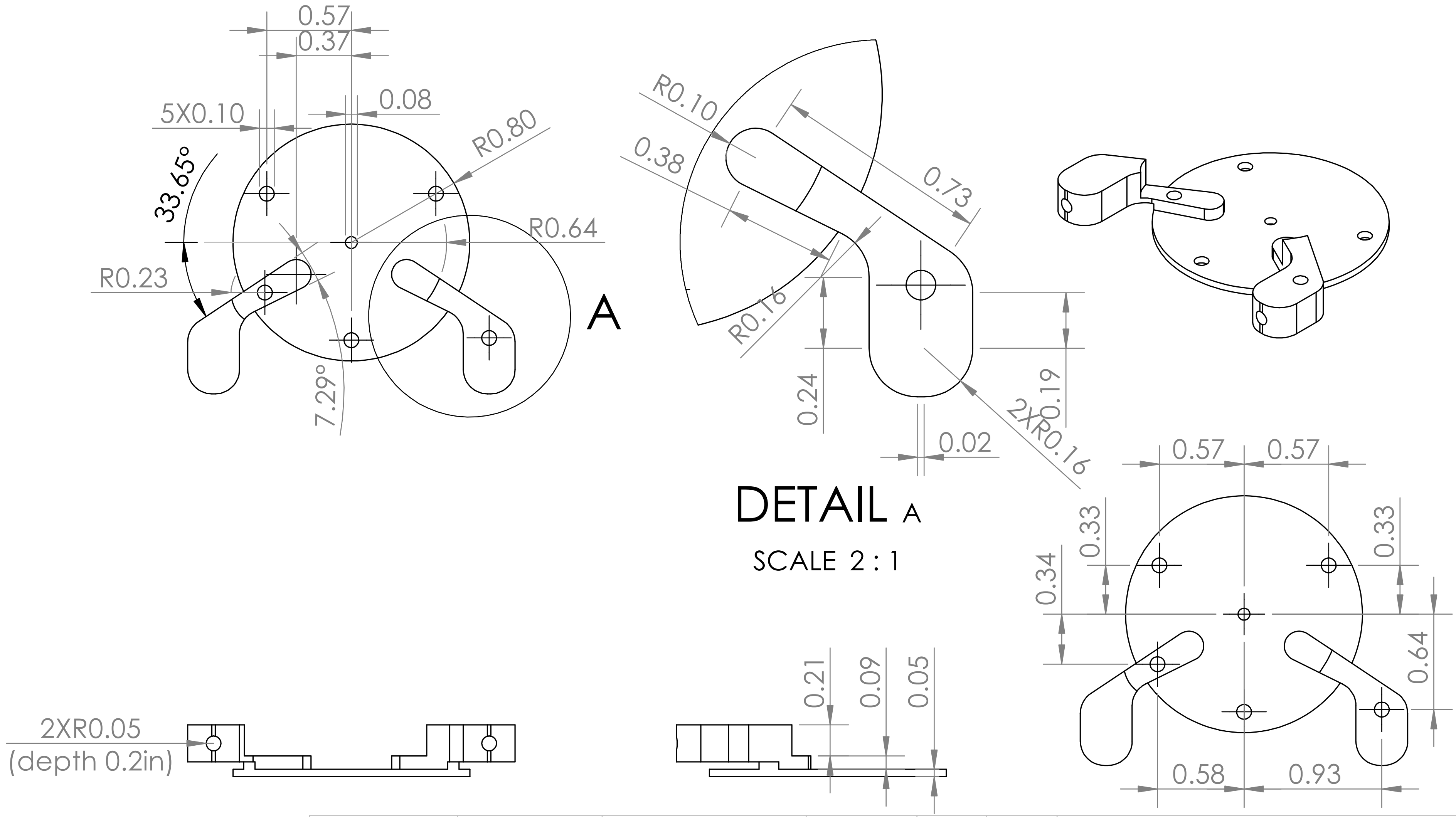

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	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL ABS PLASTIC	COMMENTS:			SIZE A DWG. NO. 0010 REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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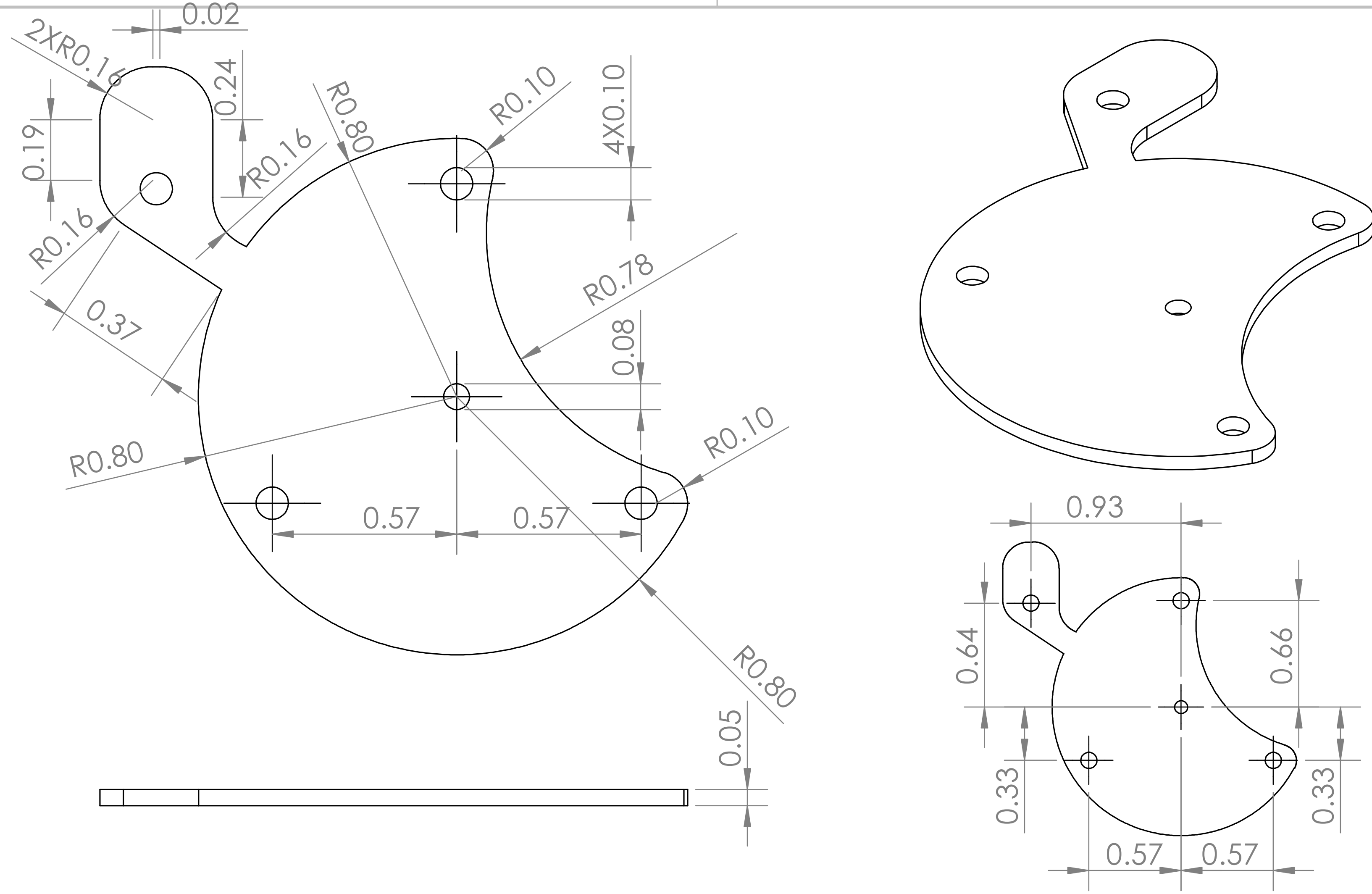

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TOLERANCES: ±0.009

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MATERIAL
ABS PLASTIC

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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

PLANET GEAR MOUNT TOP PLATE

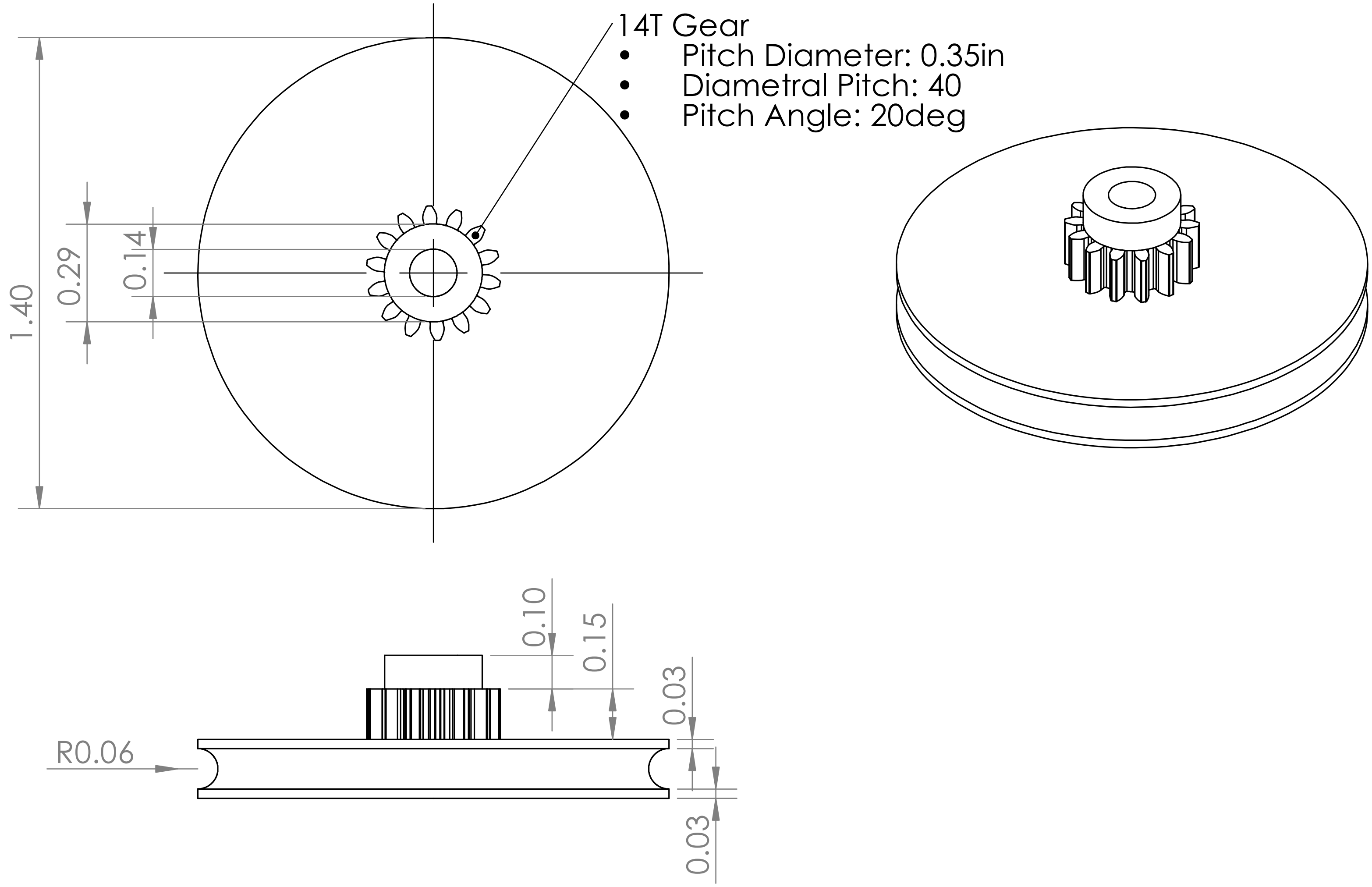
SIZE A | DWG. NO. 0011 | REV

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

2 1

2 1

B B



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DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.009

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
ABS PLASTIC

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. Hofer	4/30/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

LARGE BAND GEAR - 12T

SIZE	DWG. NO.	REV
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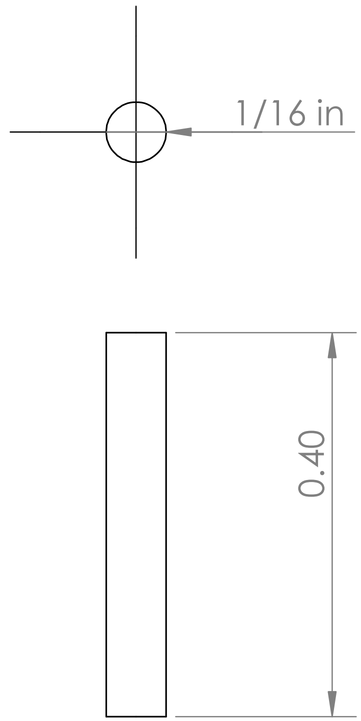
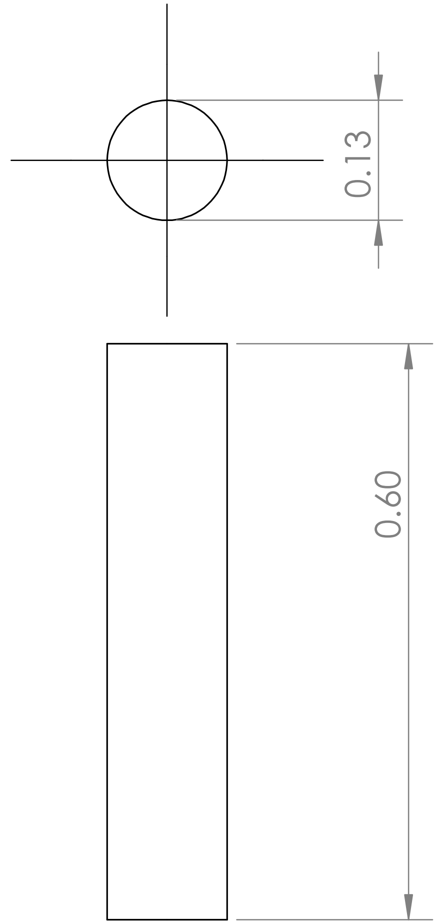


UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	A. Hofer	4/30/19	TITLE:	
	CHECKED			**1/16in Shaft**	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL 1566 Carbon Steel	COMMENTS:			SIZE **A** DWG. NO. **0013**	REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 5:1 WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

2 1

B B



A A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	A. Hofer	4/30/19
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 1566 Carbon Steel	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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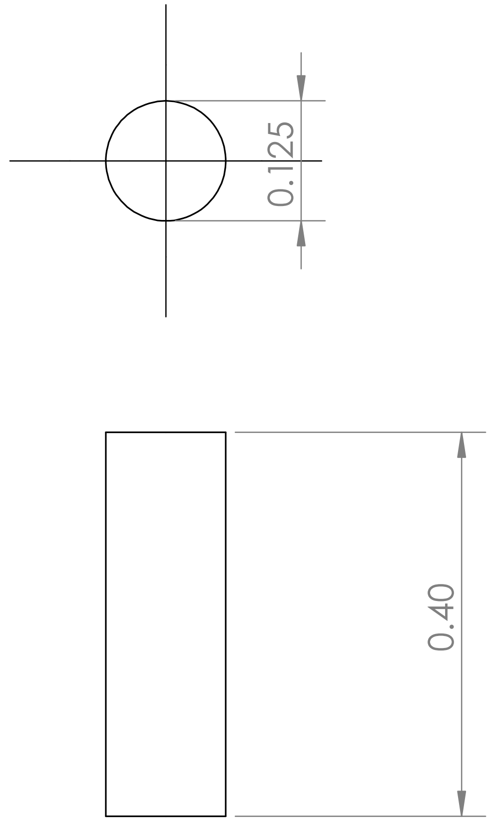
TITLE:

1/8in Shaft - 0.6in Length

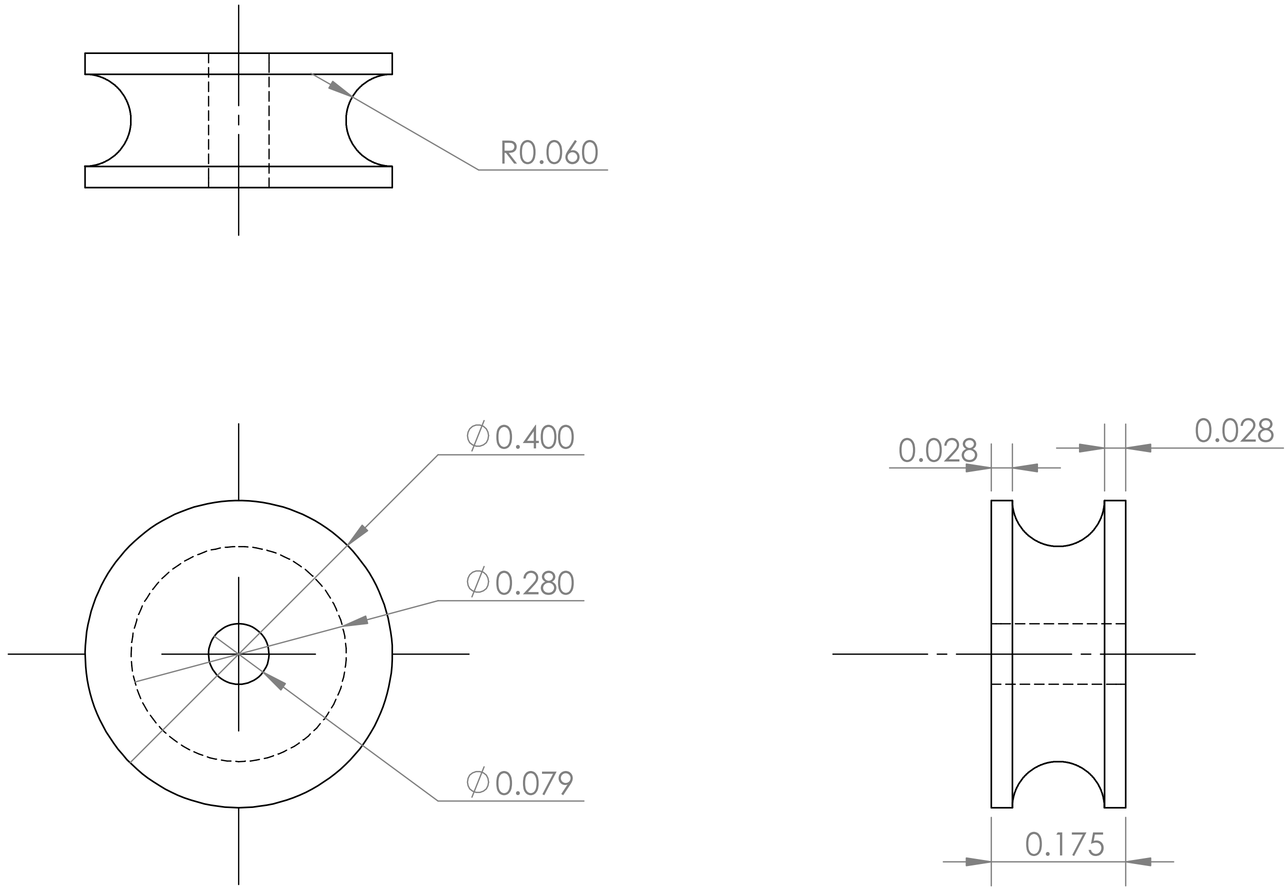
SIZE	DWG. NO.	REV
A	0014	
SCALE: 5:1	WEIGHT:	SHEET 1 OF 1

2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	A. Hofer	4/30/19	
			CHECKED			TITLE:
			ENG APPR.			1/8in Shaft - 0.4in Length
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 1566 Carbon Steel	COMMENTS:			SIZE A
NEXT ASSY	USED ON	FINISH				DWG. NO. 0015
						REV
APPLICATION		DO NOT SCALE DRAWING				SCALE: 5:1 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ±0.009	DRAWN	D BEATTY	4/28/20
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL ABS PLASTIC	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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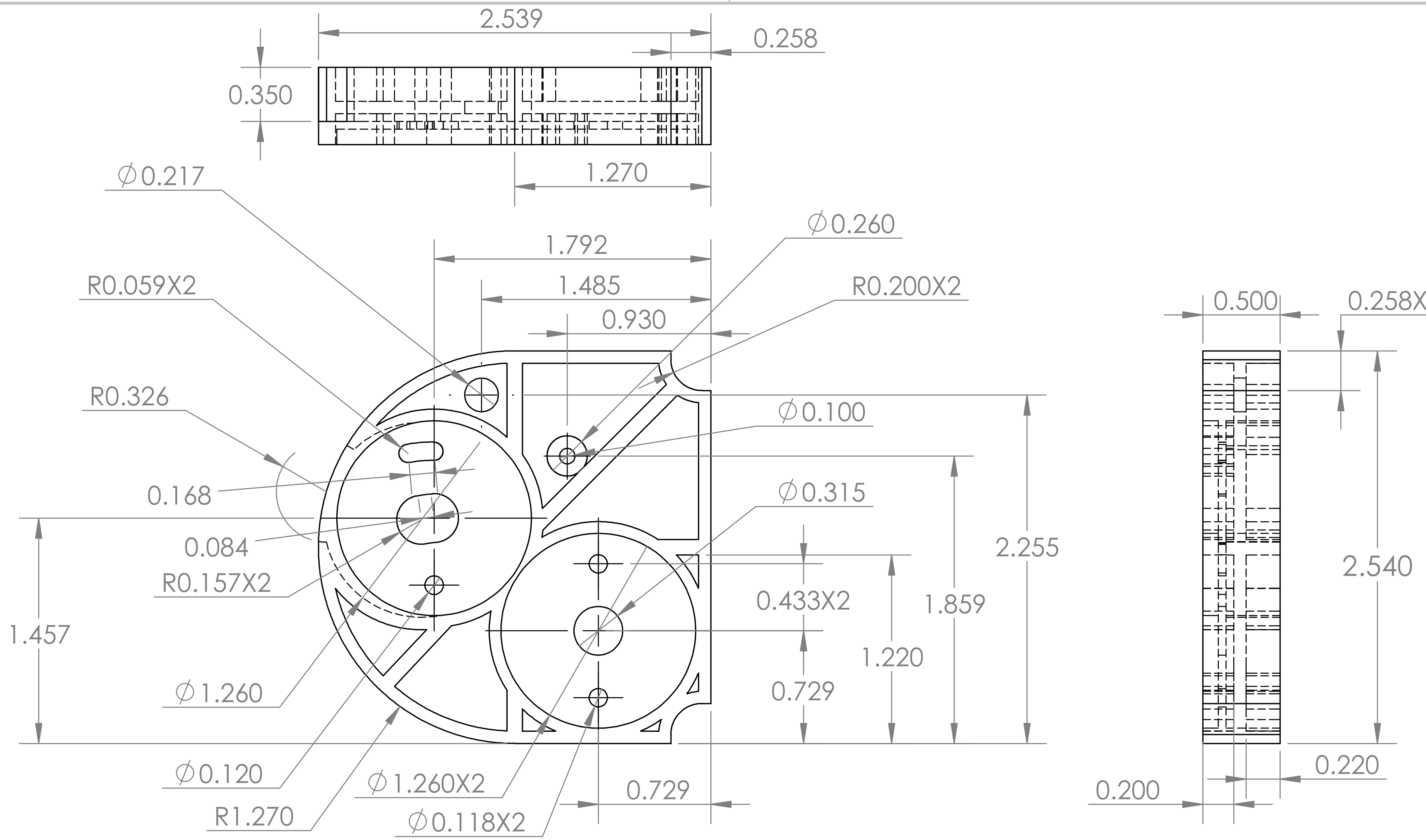
TITLE:

SMALL BAND GEAR

SIZE	DWG. NO.	REV
A	0016	

SCALE: 4:1 WEIGHT: SHEET 1 OF 1

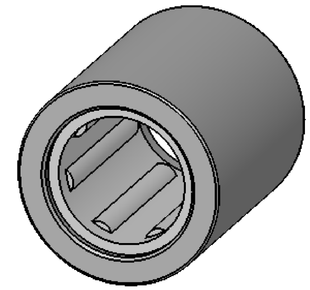


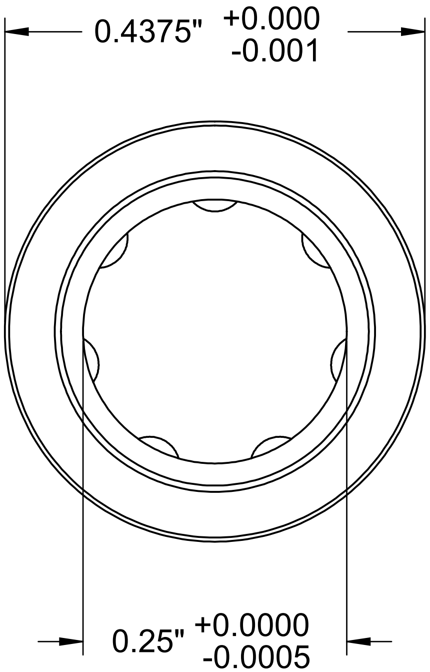
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ±0.009 RIBS ARE O.10 THICK	DRAWN	D BEATTY	4/29/20
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL ABS PLASTIC	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

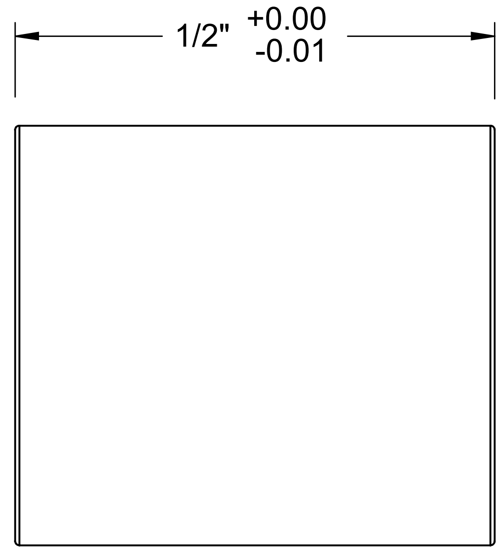
TITLE:

PLATE INSERT - MOTOR MOUNT

SIZE	DWG. NO.	REV
A	0017	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1







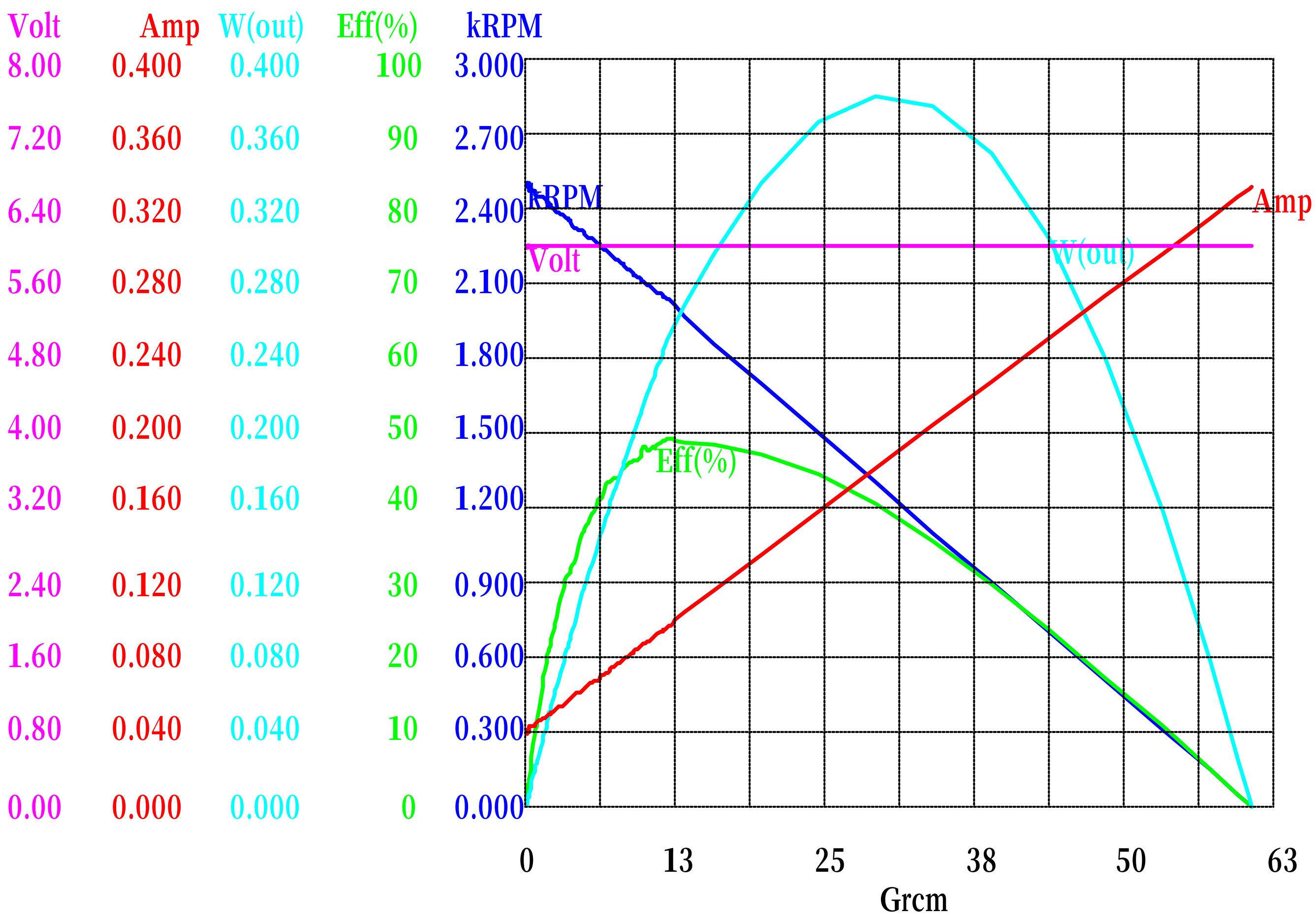
McMASTER-CARR® CAD	PART NUMBER	2489K22
http://www.mcmaster.com © 2017 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	One-Way Locking Needle-Roller Bearing Clutch	

中 貿 有 限 公 司
友 貿 電 機 廠
NICHIBO DC MOTOR

客戶名稱 (Customer)：[illegible]
資料檔名 (Filename)：樣品RF500机种
馬達型號 (Motor Model)：RF-500TB-12560-R[illegible]
額定電壓 (Voltage)：6.0V
額定輸出 (Rated Power Output)：0.23W

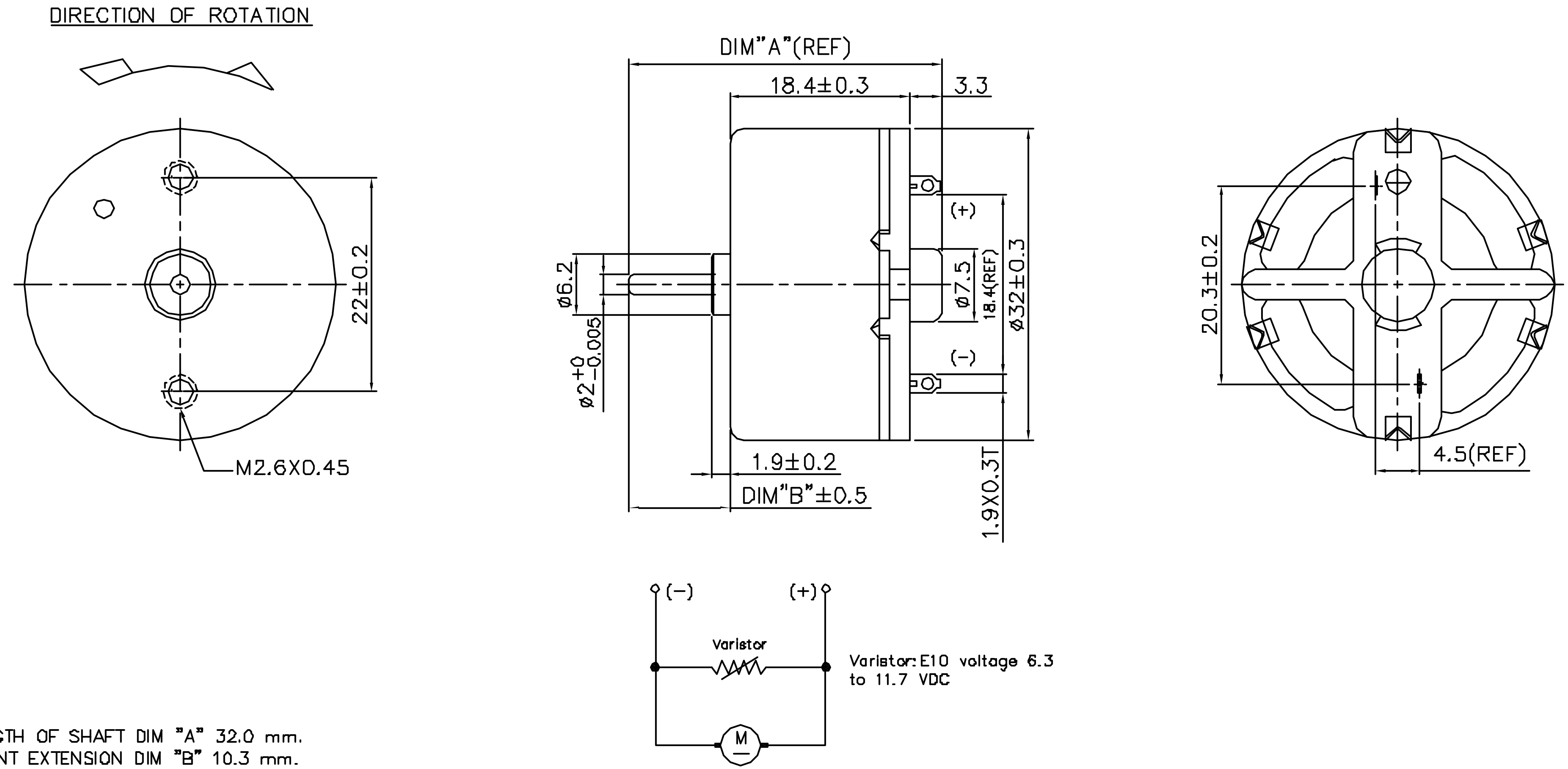
實驗室溫度 (Ambient Temperature)：25
無載轉速 (No-Load R.P.M)：2700
無載電流 (No-Load Current)：[illegible] mA
啟動轉矩 (Started Torque)：61.0g-cm
測試日期 (Test Date)：201[illegible]

	轉 速 R.P.M.	電 流 Amps	轉 矩 Grcm	效 率 Eff(%)	輸出功率 W(out)	輸入功率 W(in)
堵住狀態 (Locked Rotor)	0	0.331	61.079	0	0.000	1.760
最大扭力 (Max-Torque)	0	0.331	61.079	0	0.000	1.760
最大效率 (Max-Efficiency)	2089	0.090	10.820	50	0.232	0.463
最大輸出功率(Max-W(out))	1198	0.192	31.877	38	0.392	1.020



扭力常數(Torque Constant): 206.5322
馬達常數(Motor Constant): 28.2587

REV	A0



NOTE :
1. LENGTH OF SHAFT DIM "A" 32.0 mm.
2. FRONT EXTENSION DIM "B" 10.3 mm.
3. END PLAY : 0.05–0.50 mm.
4. ALL UNSPECIFIED DIMENSION TOLERANCE WILL BE ±0.10 mm.

中貿有限公司
NICHIBO TAIWAN CORP.
台北市104內湖區內湖路一段308號10樓之1
10F-1,NO.308, SEC.1, NEIHU RD., NEIHUAREA, TAIPEI, TAIWAN (R.O.C)
TEL:886-2-2797-7212 FAX:886-2-2658-8460
http://www.nichibo-motor.com

友貿電機廠
NICHIBO MANUFACTURING CO., LTD.
中國廣東省深圳市寶安區沙井蠔一村尚頭工業區
CANTOW IND. DIST., HOWEE, SHAJING, BAOAN, SHENZHEN CITY, GUANGDONG, CHINA
TEL:86-755-2969-7722 86-755-2969-5488
FAX:86-755-2969-5566

名稱 NAME	Jameco		
型號 MODEL	RF-500TB-12560-R-S		
單位 UNIT	mm	日期 DATE	2013/9/28