Preliminary Design Proposal for Bearing Characterization

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EXECUTIVE SUMMARY

For this project, the team is to a create a device that will test the friction experienced by Honeywell bearings of various sizes when subjected to the highest thrust and radial loads they endure in service. To begin, the team developed black box, and functional models to create a visual representation of the necessary inputs and outputs to make the system perform as intended. The team did research to determine if anything had been created to solve this problem, however, the team found nothing. The client, Honeywell, also provided no information regarding similar systems or their current system as the wanted to ensure our ideas were unique and did not succumb to design fixation. A quality function deployment (QFD) was then created to outline customer requirements and match them with engineering requirements. The team met with Honeywell to ensure the customer needs and engineering requirements were ranked and scored properly. The team then brainstormed and generated multiple concepts, most centered around using jacks to impart a force directly to the inner race of the bearing, and another to the outer race. The idea behind this was that reaction forces of the same magnitude experienced by the inner race would sufficiently simulate the forces it experiences in service. Unfortunately, Honeywell did not agree with that idea and stated that a force imparted on the outer race of the bearing instead of the shaft would not properly simulate the forces. Therefore, the team selected and perfected a design meant to impart radial and thrust loads directly to the inner race through applying all forces to the shaft.

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1 Background

1.1 introduction

This project was established by Haley Flenner, an employee of Honeywell. The Honeywell Bearing project's main objective is to measure the torque that is needed to affect the movement on a shaft when there is a variable force on a bearing in the radial and thrust direction. The Honeywell team benefits from the project's completion by having a new machine to test their bearings on one of their popular products a butterfly shaft. As it will be explained later in this report there isn't any current machines that test bearings in this specific way, although it was mentioned to the team that Honeywell currently has some ideas to test their bearings there was very limited information about other machines that can measure the torque with these specific inputs. The main issues that are accompanied to the project is keeping the system simple and safe. This involves safely meeting the force requirements which will be explained later and maintaining a safe shaft rotational speed. The team is attempting to keep the machine was simple as possible which would allow someone to use it without complicated calculations.

1.2 Project Description

The description of this project from Honeywell is:

"Design and manufacture a test fixture to test rolling element shaft bearings. The fixture will be used to record the torque required to rotate the inner race while simultaneously applying a radial and thrust load to the inner race. We want to quantify rotational friction as a function of radial and thrust loads".

Honeywell was very adamant that the goal of the project was to quantify friction, not to test the bearings themselves. The input for the machine must be adjustable to 4 different sizes of bearings, 38, R8, R12, and R14. The thrust and Radial load on the bearing depends on the overall size. The R14 bearing which is the largest bearing must be capable a of measuring the torque with a maximum of 8000 lb radial load and 4000 lb thrust load. As the bearings continue to get smaller the radial and thrust loads will also decrease. The rotation requirement for the inner race of the bearing is between 1 and 10 degrees/sec. One of Honeywell's original requirements for the project was to have an ability to test the bearings within their temperature extremes ranging from -65 degrees Fahrenheit to 1000 degrees Fahrenheit. Upon speaking with Honeywell and faculty advisors, this requirement was eliminated as it was deemed too difficult to achieve within reasonable costs. This project must output a real time plot that relates torque to the applied loads. The team must also solve for and display the static and kinetic friction experienced by the bearing under the specified loads. Finally, Honeywell stated that the volume of the testing machine must be less than 9 ft^3 and had to include a burst shield enclosure for safety.

2 Requirements

2.1 Customer Requirements

Must meet loading requirements- The loading requirements presented by Honeywell are Radial loads from 0 to 8000 lbf and Thrust Loads from 0 to 4000 lbf. The test fixture is required to impart these loads to the inner race of the bearing.

Must be Safe- The test fixture cannot injure someone in the event something breaks

Must be portable- Must be easily moved by two people working together.

Must be compatible with different bearing sizes- The test fixture needs to be able to accommodate the 38, R8, R12, and R14 bearing diameters. Honeywell does not want a step shaft to be used to accommodate these, the bearings must be mounted to their own uniform shaft.

Must output a torque vs load applied graph- Honeywell wants the test fixture to output a torque vs load applied graph.

Must fit in a office Space- Honeywell wants this system to fit within an office space. Additionally, the volume of this system had to remain under 9 cubic feet.

Only source of power should be electricity- Honeywell will only provide a 120V electrical outlet for power.

Must rotate the bearing- In order to test the bearing friction, the apparatus must rotate the bearing.

Affordable- Must cost less than $1,500 dollars

Easy Maintenance- The testing apparatus cannot require constant lube and must be durable. Honeywell does not want to have someone working on the device every month.

2.2 Engineering Requirements

Radial Loads - The test apparatus must be able to exert a maximum radial load of 8000 lbs.

Thrust Loads - The test apparatus must be able to exert a maximum Axial load of 4000 lbs.

Weight - The test apparatus must weigh less than 300 lbs.

Speed – Inner race must rotate at least 90 degrees

Cost - The test apparatus must cost less than $1,500 USD.

Voltage - The apparatus must be able to be powered by a standard 120V 60 HZ power outlet.

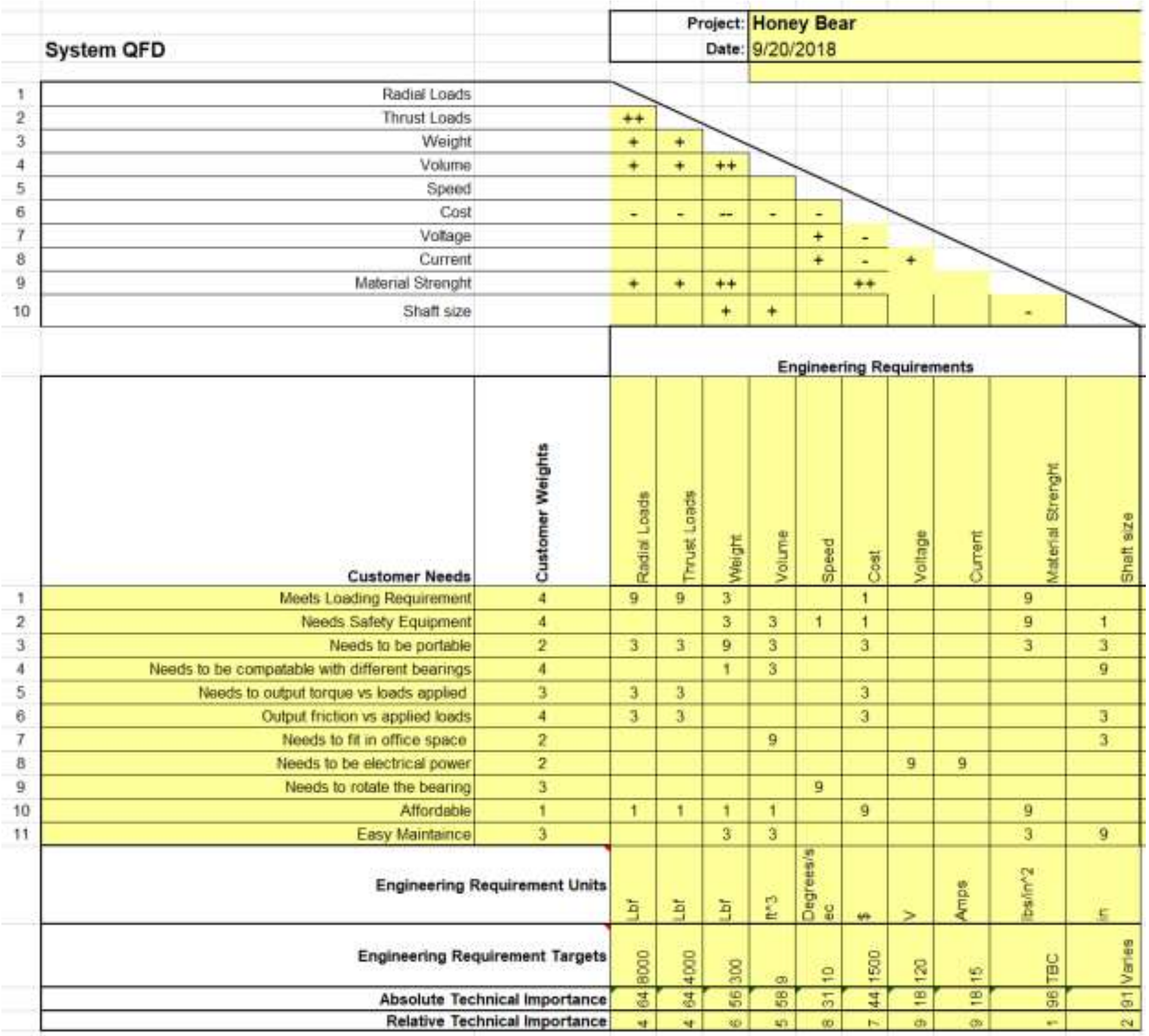
Current - The amperage draw of the test apparatus must be less than equal to 15 Amps.

Material Strength - The materials used for the shafts and the frame of the apparatus must be able to withstand the internal forces. The shafts must be able to handle the radial and the axial loads of 8000 lbs and 4000 lbs respectively. The frame must not bend while the loads are applied to the bearings.

Shaft Size - There must be a uniform shaft for each bearing size. This will result in shafts with diameters of 0.315in, 0.5in, 0.75in and 0.875 in all with a tolerance of +- 0.005in.

2.3 House of Quality

Table 1: QFD



System QFD

Project: Honey Bear
Date: 9/20/2018

		1	2	3	4	5	6	7	8	9	10
1	Radial Loads										
2	Thrust Loads	++									
3	Weight	+	+								
4	Volume	+	+	++							
5	Speed										
6	Cost	-	-	--	-	-					
7	Voltage					+	-				
8	Current					+	-	+			
9	Material Strenght	+	+	++			++				
10	Shaft size			+	+					-	

Engineering Requirements

	Customer Needs	**Customer Weights**	Radial Loads	Thrust Loads	Weight	Volume	Speed	Cost	Voltage	Current	Material Strenght	Shaft size
1	Meets Loading Requirement	4	9	9	3			1			9	
2	Needs Safety Equipment	4			3	3	1	1			9	1
3	Needs to be portable	2	3	3	9	3		3			3	3
4	Needs to be compatable with different bearings	4			1	3						9
5	Needs to output torque vs loads applied	3	3	3				3				
6	Output friction vs applied loads	4	3	3				3				3
7	Needs to fit in office space	2				9						3
8	Needs to be electrical power	2							9	9		
9	Needs to rotate the bearing	3					9					
10	Affordable	1	1	1	1	1		9			9	
11	Easy Maintaince	3			3	3					3	9
	Engineering Requirement Units		Lbf	Lbf	Lbf	ft^3	Degrees/sec	$	V	Amps	lbs/in^2	in
	Engineering Requirement Targets		8000	4000	300	9	10	1500	120	15	TBC	Varies
	Absolute Technical Importance		64	64	56	58	31	44	18	18	96	91
	Relative Technical Importance		4	4	6	5	8	7	9	9	1	2

The team ranked each customer requirement on a scale of 1-4. The rankings were shown to Honeywell, and they were pleased with the results. The engineering requirements were then related to customer requirements. A rating of nine indicated a strong correlation to customer needs, three indicated a moderate one, and one indicated a weak correlation. For engineering requirement targets, the team indicated the maximum values allowed. The maximum radial load is 8000 lbf and the maximum thrust load is 4000 lbf. The maximum weight the team felt two people could move is 300 lbf. Honeywell determined the maximum volume the device could occupy is 9ft^3. The maximum speed the bearing needs to achieve is ten degrees a second. The estimated budget for the final design is $1500 which is yet to be approved by Sarah Oman. The maximum voltage and amperage the device can operate on is 120V and 15 amps. The size of the shafts will fall between .315in to 1in. The maximum necessary yield strength of the materials is unknown currently, and will be determined later.

3 System Functionality

3.1 Functional Decomposition

In order to visualize how the device would function given certain inputs the team made a functional model. This is shown in figure 1 below.

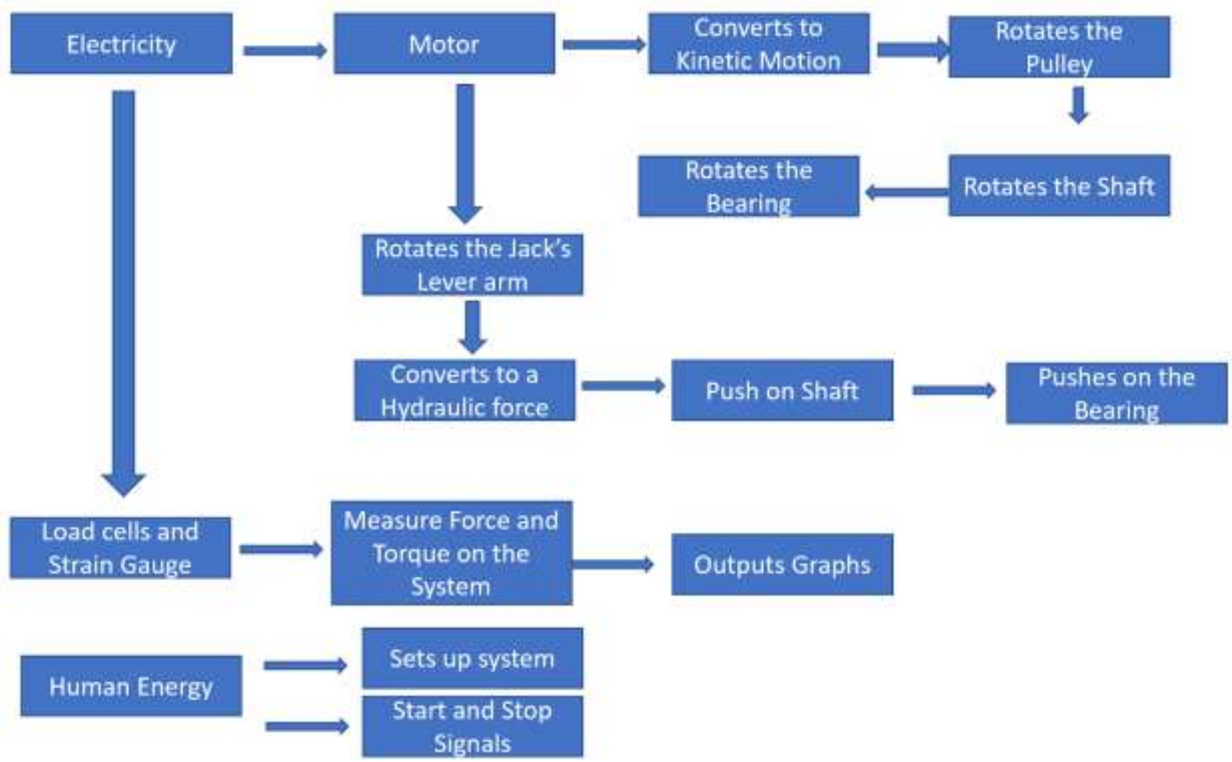


Figure 1: Functional Model

Figure 1 shows that the main energy input is electricity which will power most subsystems. Electricity will power the motor which will convert the electricity to kinetic energy. This kinetic energy will then end up spinning the bearing. Someone will then actuate the jack via a lever arm which will cause a buildup of hydraulic forces. The forces will then be applied to shaft which will transfer the forces to inner race of the bearing giving us the radial and thrust loads. The last subsystem is also powered by electricity. This includes the force measuring devices which will measure the force and torque in the system. Once these measurements are acquired the data will be organized and displayed on the computer as graphs.

Human energy is also a major part of this design. It will be needed to set up the test fixture, meaning the correct shaft and bearing combination must be attached to the system. After completing the system set up, someone must initiate the test, and terminate it when completed.

3.2 Potential subcomponents

This project deals with multiple subsystems including the shafts, shaft retainers, the frame, shaft rotation mechanisms, power transmission systems, force application systems, and force measurement systems. Each of these components addresses a specific part of the design requirement.

3.2.1 Subsystem #1: Shafts

The shaft will provide a place for the bearings to be mounted on and will need to withstand the loads that will be imparted upon the system.

3.2.1.1 Step shaft

The team considered using a step shaft first as it would allow us to mount every bearing simultaneously thus simplifying the design. Additionally, there would be no need to switch out shafts, so it could be permanently affixed to a retainer with a spline or press fit. This could reduce costs, and enable the team to use a stronger mount. A drawback to this design is that a stress concentration exists at the shoulder of each step [1], therefore the total stress the shaft can withstand is reduced.

3.2.1.2 Uniform shaft

The team also considered utilizing uniform shafts. This would eliminate stress concentrations on the shaft, thus increasing its strength. However, this also necessitates developing a way to quickly change out shafts when a new bearing must be tested. Resultantly, this increases the cost and complexity of the design as an adaptor must be designed, and/or a large chuck must be purchased.

3.2.2 Subsystem #2: Frame

The frame will be used to contain all components; therefore, it must be strong enough to contain all loads. All forces must be absorbed by the frame to keep the system stationary. It is crucial that the frame stays together and does not bend so results will be accurate.

3.2.3 Subsystem #3: Torque application

3.2.3.1 Electric motor

The team determined that the shaft will be spun by an electric motor, as it seems to be the only feasible power source available that will impart a torque strong enough to spin the shaft, while not taking up too much space. The team does not know what the necessary performance parameters for the motor will be. The team will conduct those calculations later, and order a motor based upon those results.

3.2.4 Subsystem #4: Power transmission

The team determined that a thrust force cannot be directly applied to the shaft, or the bearing when affixed to an electric motor. Therefore, the team had to consider systems that would transfer the torque from one position to another.

3.2.4.1 Belt and Pulley

A flat belt and pulley combination exhibit a high efficiency of about 98% [1], which is desirable as transmission losses will have a minimal effect on test bearing friction measurements. Due to elastic creep, however, the belt moves at a speed slower than the pulley [1], therefore adjustments will have to be made to ensure the shaft turns the full 90°. Another advantage to consider is that a belt can be easily wrapped around a shaft or an adaptor, so torque could be transferred to the bearing with little modification. A small flat belt could be had for around \$22.00 dollars [2], and an accompanying drive pulley will cost around \$13.00-\$22.00 dollars [3].

3.2.4.2 Chain and sprocket

A chain and sprocket combination will exhibit roughly the same efficiency as a flat belt and pulley [1], however there will be no issues with slip. Additionally, there will be no concern for wear due to the fact the motor will only turn 90°. However, extra modification will be needed to enable this to spin the shaft, as another sprocket will be needed to do so. The necessary sprockets and chain cost about \$47.00 dollars combined [4,5].

3.2.5 Subsystem #5: Force measuring systems

It is necessary to collect data on how much force is being applied to the system to ensure correct parameters are attained, and to utilize those measurements to calculate friction.

3.2.5.2 Strain gauge

A strain gauge is a device containing a thin metal wire that stretches or compresses with a material given an applied load [6]. Based upon the resistance measured over that wire, one can tell how much a material has deformed, and back out a force measurement based on that. The team can take advantage of this phenomenon to obtain the torque required to spin the shaft and determine how much thrust and radial force has been imparted upon the system. The strain gauge kit will cost about $332 dollars [7].

3.2.5.3 Load cell

The team also investigated compression load cells, which include four strain gauges packed into a small steel casing [8]. This device therefore works on the same principle as strain gauges do. When the steel casing compresses, the strain gauges inside it either stretch or compress, changing resistance, and thereby giving a strain value that can be used to back out force. These devices are only 1 inch in diameter and 1 inch tall, and can withstand forces up to 10,000lbs [9], therefore the team can directly mount them to the force application system. This would allow the team to get a direct measurement of the force applied in real time. However, these devices are expensive as they cost around $350 each [9], and the team will likely need more than one since thrust loads act horizontally, and radial loads act vertically. Additionally, load cells cannot measure torque.

3.2.6 Subsystem #6: Force Application Systems

The team must impart a maximum of 8000 lbs of force radially, and 4000 lbs of force axially onto the bearings. Honeywell is providing nothing in terms of hydraulic, or pneumatic pressure. Therefore, the team only considered systems that would be able to impart the necessary forces on their own.

3.2.6.1 Bottle Jacks

Bottle jacks are typically used to lift cars in emergency situations. They utilize fluid actuated by a hand crank to impart forces strong enough to lift vehicles. There are bottle jacks rated at 4-tons available for about $20.00 [10]. Additionally, these jacks have a minimum height of 7.625in and a maximum height of 15.125in [10] which means these fit well within the team's 9ft^3 constraint, thus allowing for design flexibility. A potential drawback with these systems is that these jacks must be hand cranked potentially reducing the precision of the measurements, and they do not have a pressure readout therefore a sensor will need to be used to determine how much force they are imparting. Tapping these could give more precise readouts, however, this also has drawbacks. In the worst case, tapping the jack could break it rendering it unable to impart its maximum force. Assuming tapping is done successfully, delivering a pressure near four tons could require a manometer that is too tall and unwieldy to be practical.

3.2.6.2 Electric Jacks

Electric jacks utilize an electric motor to twist a power screw which in turn provides a lifting force. These jacks are considerably smaller than the hydraulic jacks and are actuated with a button rather than a lever, which would make operating the system more straight-forward. However, they are also considerably more expensive, costing around $234 dollars [11]. They are also subject to issues with directly measuring force, just as bottle jacks are.

3.2.7 Subsystem #7: Shaft Retainers

This is necessary for mounting the shaft to the system and allowing for a way for uniform shafts to be interchanged.

3.2.7.1 Lathe chuck

A lathe chuck could be used to very quickly change out shafts. It is made to be strong and will have no problem withstanding the applied loads. Furthermore, a belt can be wrapped around it creating an easy way for the torque to be transferred from the motor to the shaft. However, when heavy loads are applied the could dig into the shaft, compromising the integrity of the shaft. Additionally, some chucks may not be able to fit the smallest shafts. Finally, lathe chucks tend to be expensive costing around $175.00 dollars [12].

3.2.7.2 Thrust bearing

A thrust bearing is a specific type of ball bearing meant to withstand high thrust loads. This is ideal as it will likely hold up to the axial forces subjected to it through the shaft. It is also a cheap option costing around $51.00 dollars [13]. However, given the inner diameter of this bearing cannot be changed, an adaptor would have to be made to accommodate different shafts.

4 Designs Considered

The team separately created two designs each in order to ensure that we had multiple ideas and different approaches to solving the problem.

4.1 Design #1: Funnel Design

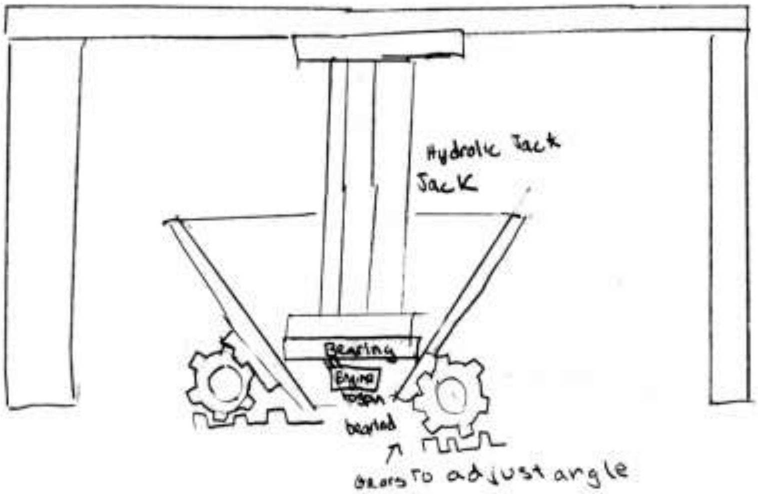


Figure 3: Funnel deign

This design would place the bearing in the funnel that is adjusted with a gear system. The angle is changed to adjust how the load it applied. Once the bearing is in place the jack applies a load to the face of the bearing. Based on the angle the funnel a resultant force will exist whose components will make up the thrust and radial loads. This was the cheapest of all the designs, as it does not require the operator to change shafts and would not risk breaking shafts due to deflection. The biggest problem with this design it that the test fixture applied both loads to the outer race bearing and the client wants the load directly on the inner race of the bearing.

4.2 Design #2: Stepped Bearings

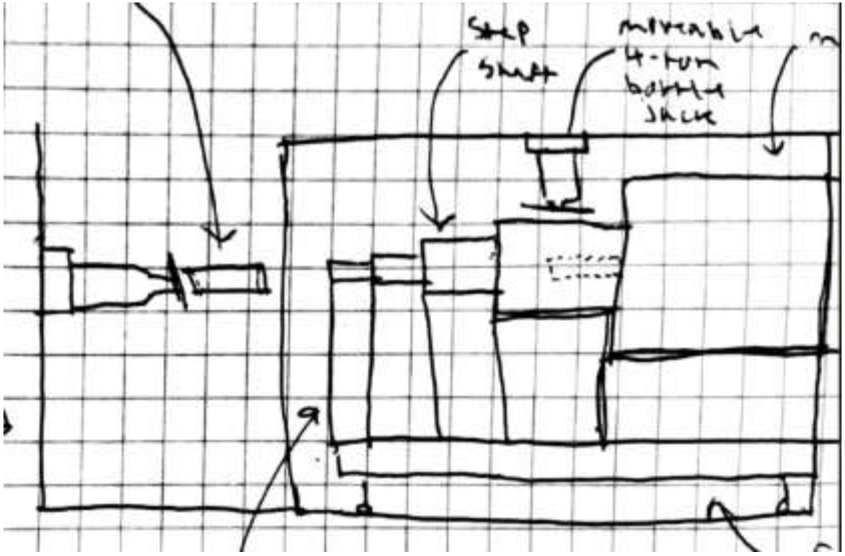


Figure 4: Stepped Bearings

This design utilizes a step shaft directly mounted to an electric motor to mount the bearings without the need to switch out shafts. A bracket will support the bearings so when a force is imparted upon them a moment will not be experienced by the shaft. The forces will be imparted by two bottle jacks. The first jack will impart a force directly to the outer race of a bearing, as it is expected that the inner race will experience a reaction force of the same magnitude. This jack will be moveable so one can select which bearing to test. The second jack will be mounted horizontally and will push a hollow tube directly into the inner race of the bearing to impart the thrust load. It was proposed that industrial scales be used to measure the forces, however this would not have worked as these scales could not handle forces the team needs to impart. Therefore, load cells would be mounted to each jack instead. This design allows for each bearing to be quickly tested as there is no need to switch out shaft assemblies. Additionally, calculations are made easier as the forces are applied directly to the bearings, and no transmission losses would have to be considered given the shaft is directly attached to the motor. Because of this, however, the motor will experience the full thrust force which could break it. Honeywell ultimately determined that this method of testing the bearings is too great a departure from simulating the loads experienced by these bearings when attached to a butterfly valve, and therefore rejected it outright.

4.3 Design #3: Inner Race Design

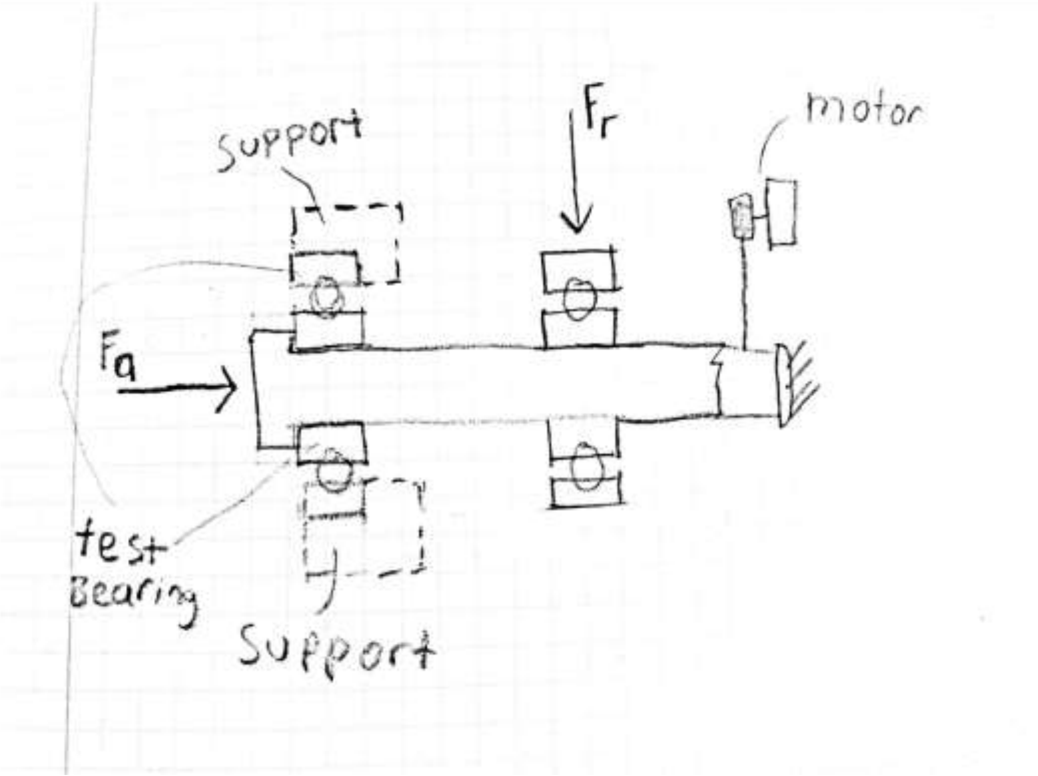


Figure 4: Inner Race Design

The rationale behind this design is that loads are applied directly to the shaft to ensure that the forces act on the inner race of the test bearing. The thrust load is applied to the shaft and the radial load is applied to another bearing which deflects the shaft thus ensuring the radial load is applied to the inner race of the test bearing. The design is supported by the frame which connects the bearings. An oversight on this iteration of the design is that the system is supported where the radial load is applied. To ensure that the radial load is applied to the shaft, the shaft must be supported elsewhere. However, since this design does not apply the loads directly to the test bearing, it is the design that the Honeywell engineers preferred. No support exists where the shaft must be deflected, and a support has been envisioned to enable the thrust force to be imparted upon the inner race.

4.4 Design #4: Reaction Load Analysis

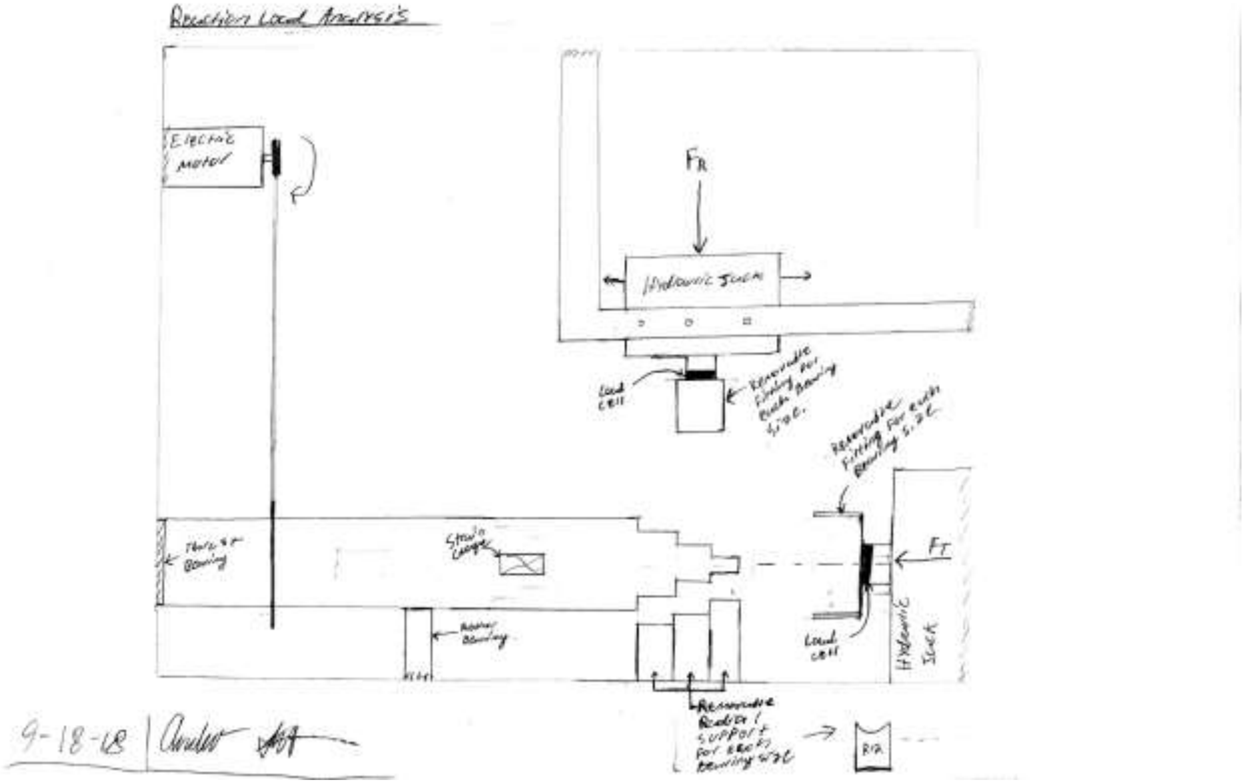


Figure 5: Reaction Load Analysis

This design focuses on applying the radial and axial loads to the outer race of the test bearing. A step shaft is used to make the test apparatus easy to use as a new shaft does not have to be installed to test a new bearing. An electric motor connected to a pulley provides the rotational motion needed to test the break force and kinetic friction within the bearing. There is a strain gauge on the shaft to measure strain which is necessary for calculating the rotational torque. There are removable radial supports for each bearing size to support the bearing while it is loaded radially. These supports lower the bending moment on the shaft and ensure the radial load is dispersed equally. The jack that supplies the radial load has removable fittings at the end that are unique to each bearing size. They are semicircular, so the load is equally distributed throughout the bearing. The jack is on a track so it can move to each bearing. The thrust load jack also has removable fittings that are unique for each bearing size. Both jacks apply the radial and thrust load to the outer race of the bearing. The reaction forces on the inner race are measured. There are load cells under the fittings of the jacks to output a live reading of the loads on the bearing. This design is simple and easy to maintain with minimal moving parts.

4.5 Design #5: Lever Arm

This design, shown in Appendix A, 10.1.1, utilizes a test fixture shaft that would be forced apart three ways to apply the radial load. The thrust load would be applied by a jack directly to the inner race. This design did not require the use of a shaft and applied the load directly to the inner race as required by Honeywell. The major problem was cost of this design. The small rods spreading apart would need a very high yield strength making them prohibitively expensive, it was therefore not considered by the team.

4.6 Design #6: Bearing-go-round

This design is meant to directly connect several uniform shafts to the bearing. These shafts, with the bearings attached, will be mounted to a carousel that will allow the user to quickly select a bearing to test, and connect it to the motor via a spline, or keyway. Everything will be connected to a slide, so the user can center each bearing and prepare it for a test. A bottle jack mounted to a slide on top of the frame will impart the radial load. The bearing will be placed on a bracket to avoid imparting a moment on the shaft. Another jack mounted horizontally will push a hollow pipe into the inner race imparting the thrust load. The problems with this design are numerous. For one, every sliding component adds complexity to the design as it introduces stress concentrations to the frame which is problematic as the frame must withstand all forces being imparted simultaneously. Additionally, a way to lock everything in place once has been centered, must be devised. Another problem is the input shaft on the electric motor may be too large to fit some of the smaller shafts. Finally, the electric motor will have to absorb the entire thrust force, which could lead to failure. The only advantage this design exhibits is that fact that uniform shafts are used which increases the stress they can take before failure.

4.7 Design #7: Four Points

This design, shown in Appendix A, 10.1.2, applies the thrust to the test bearing using a prong system attached to a jack. It also applies the radial load directly to a test bearing. However, Honeywell wants both loads applied to the inner race of the bearings so both methods of application do not satisfy the requirements. The design would be able to apply loads to the bearing, but since it does not meet Honeywell’s requirements, the idea was not considered.

4.8 Design #8: Gear Turner

This design shown in Appendix A, 10.1.3, is very similar to other designs in which two jacks are used to apply the forces to the shaft which are then reacted onto the inner race of the bearing. The gears are then attached to the motor input shaft and the testing shaft to apply the correct amount of torque needed. The main problem with this design is that the torque for the shaft may be large and could potentially damage the gears. It also isn’t simple enough for the team to feel comfortable designing because determining the gear ratios may be too cumbersome and extra gears may need to be used.

4.9 Design #9: Air Compress

This design, shown in Appendix A, 10.1.4, focuses on using air compressors to apply enough pressure to the shaft to match the required forces for a given area. The main problem with this is that the forces needed cannot be imparted by air compressors. The remaining portions of the design are very similar to the other designs in which strain gauges are used to measure the torque.

4.10 Design #10: Gravity Assist

This design shown in Appendix A, 10.1.5, utilizes a bolt and washer that would pull down on the inner race of the bearing to apply the thrust loads on the shaft and use jack to apply radial loads to outer bearing. Attached to washer and bolt would be weights. This design was one of the cheaper designs and used a unique thrust load delivery system. However, due to volume constraints and the safety the design made this design impractical.

5 Design Selected

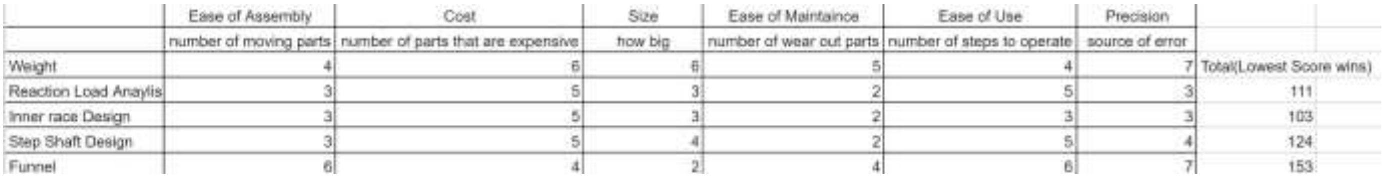
5.1 Rationale for Design Selection

Table 2: Pugh Chart

	Concepts									
Criteria	Reaction Load Analysis	Inner race Design	Funnel	Lever Arms	Merry go bearing	Stepped Bearing	Four Points	Gravity Assist	Gear Turner	Air compress
Meets Loading Requirements	D	+		+				-		-
Need Safety Equipment			+	-	-		-		+	+
Needs to be portable	A		-			+		+	-	
Needs to be compatable with the 4 Bearong sizes		-	+	+	+		+			
Needs to output torque vs applied load graphs	T	+								
Output friction vs applied load graph		+			-					
Needs to fit in an office Space							-	-	-	-
Electric power	U			-						
Need to rotate bearing				-	+					
Easy to maintain		+		-	-		-	-	-	-
Affordable	M		+				-			
sum +		4	3	2	2	1	1	1	1	1
sum –		1	1	3	3	0	4	3	3	3
sum		3	2	-1	-1	1	-3	-2	-2	-2

To start the selection process the team put all ten designs into a Pugh chart using its favorite design, the reaction load analysis design, as the datum. The team then compared how well this design meets the customer requirements as compared to all other designs. Then the team then eliminated any design that received 3 or more negative signs in the Pugh chart. The team set this as the cut off for consideration for the final design because it did not want show Honeywell anything that was worse than our Datum. The Datum, and the three design that passed this criterion were passed on to Honeywell, and were considered within the team's decision matrix.

Table 3: Decision Matrix



	Ease of Assembly	Cost	Size	Ease of Maintaince	Ease of Use	Precision	
	number of moving parts	number of parts that are expensive	how big	number of wear out parts	number of steps to operate	source of error	
Weight	4	6	6	5	4	7	Total(Lowest Score wins)
Reaction Load Anaylis	3	5	3	2	5	3	111
Inner race Design	3	5	3	2	3	3	103
Step Shaft Design	3	5	4	2	5	4	124
Funnel	6	4	2	4	6	7	153

After narrowing down our ten design to our top four design using the Pugh chart, the team selected its best design using a decision matrix. The team used six quantifiable values; Ease of Assembly, Cost, Size, ease of Maintenance, Ease of use, and Precision. The team assigned weighted values to each of these categories. In each category, shown in table 3, the team assigned scores based on quantifiable parameters; number of moving parts, number of expensive parts, how big, number of wear out parts, number of steps to operate, and sources of error. Because a higher number of parts was considered a negative virtue for all categories, the team determined that the design with the lowest score would win. For the size category, we had given ranges for each score so the team could continue using the same scoring system. After each design was scored and the weight for each category was applied the team the Inner race Design was the winner. The team presented this to Honeywell, and they agreed with the team's decision matrix.

5.2 Design Description

The winning design is shown in figure 7. It is a modified version of design #3. Since Honeywell liked that design the team decided to modify it based on the suggestions they gave. The axial load is applied to the shaft imparts a force upon the inner race of the test bearing. The bearing is connected to a support on its outer race to ensure that the bearing is stationary. The radial load is applied to another bearing so that the shaft can continue to rotate as the shaft is deflected imparting a radial load to the inner race of the test bearing. Torque will be measured with strain gauges attached to the shaft. The shaft is rotated by way of a stepper motor and pulley system. The shaft is supported at the far end by either a chuck or a thrust bearing. Since each shaft will be tailored to each bearing, they need to be easy to remove. If the thrust bearing is chosen, the shaft would have to be threaded so it can screw into an adapter connected to the thrust bearing supported on its other end. This design covers all requirements set by Honeywell and is relatively simple. Complexity could arise when trying to quantify the friction within the test bearing since there is another bearing that also succumbs to friction. The team will need to determine how much friction comes from the extra bearing and take that into account when doing calculations.

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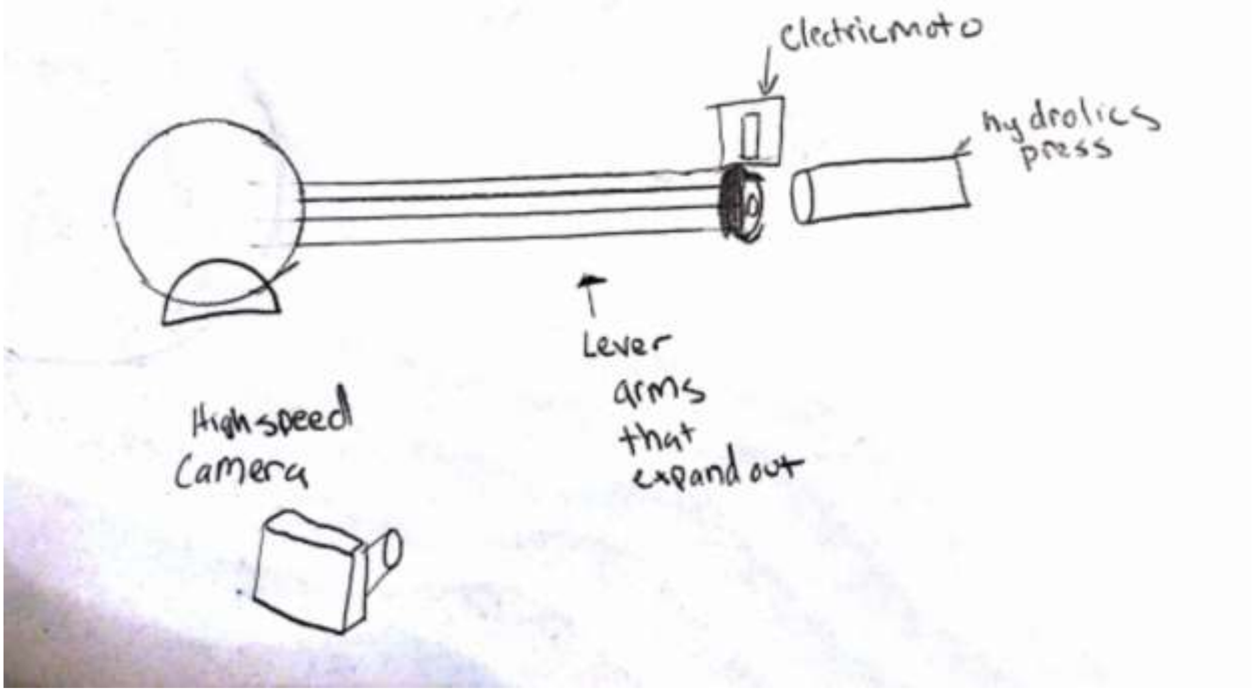
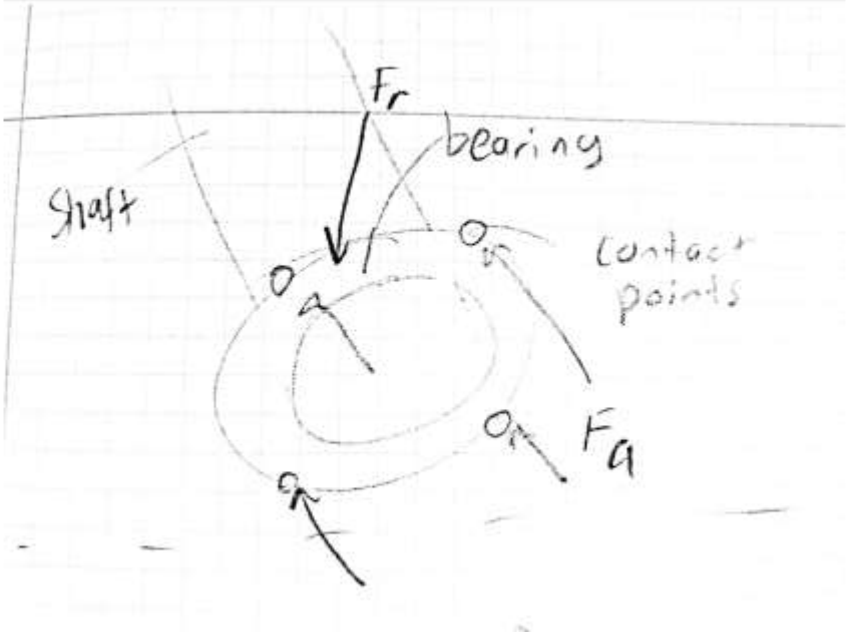
10 Appendices

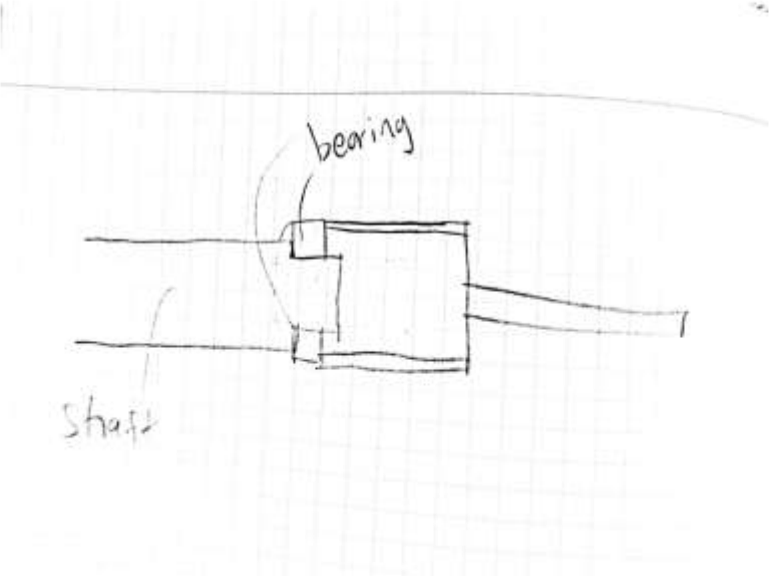
10.1 Appendix A: The Rejected Designs

10.1.1: Lever Arms

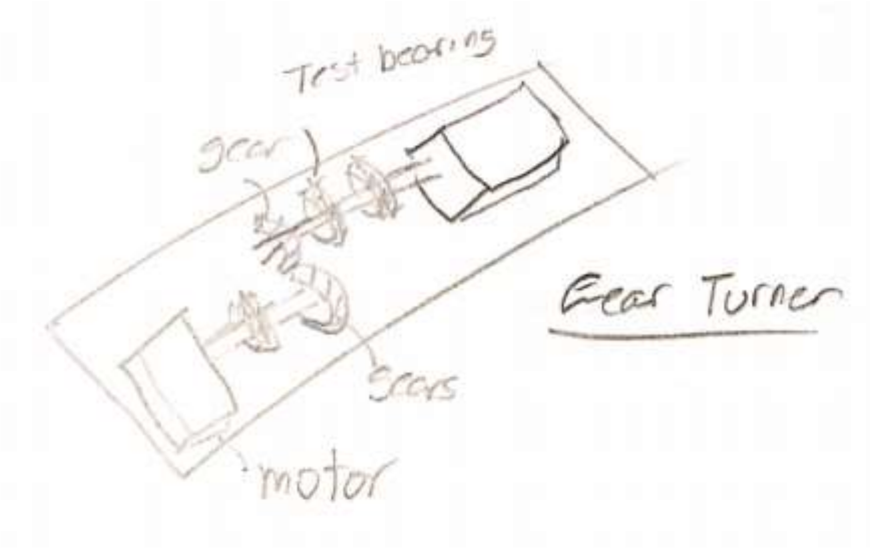


10.1.2: Four Points

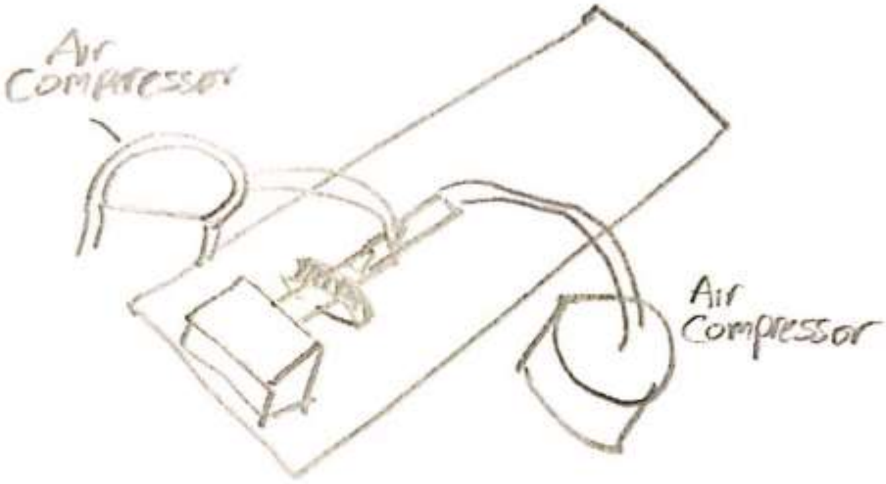




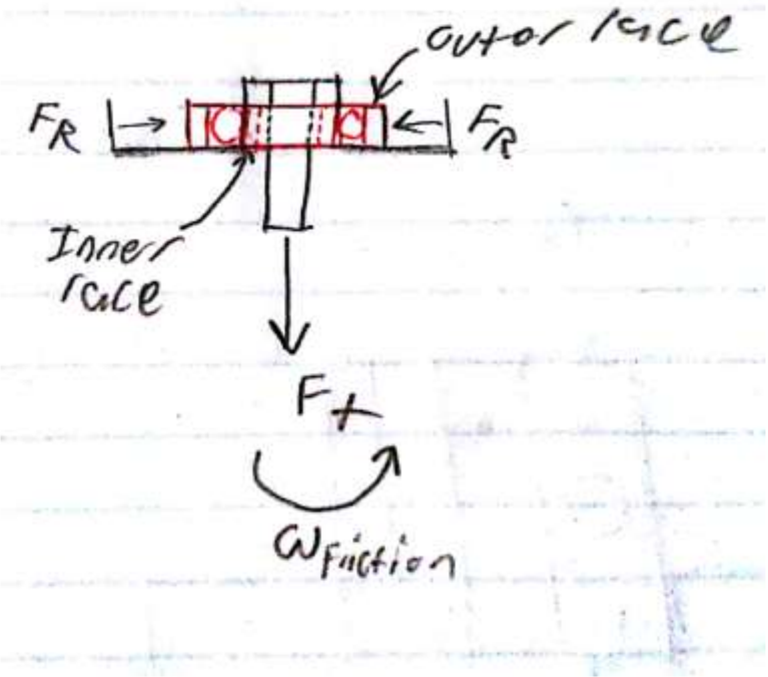
10.1.3: Gear Turner



10.1.4: Air Compress



10.1.5 Gravity Assist



10.1.6 Merry Go-round