Road Embedded Traffic Actuated Turbine (RETAT)

Critical Design Review (CDR)

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Abstract

The Critical Design Review (CDR) outlines the process that team Cleanergy has taken for the Road Embedded Traffic Actuated Turbine project. The team is comprised of four mechanical engineering students at California Polytechnic State University, San Luis Obispo. This document serves as a follow-up to the previous document, Scope of Work (SOW) which outlined the initial design process for this project. Since then, we have performed concept development and submitted a preliminary design report (PDR). The team has gathered feedback to alter our design in various ways listed in this report. We have improved our Computer-Aided Design (CAD) model to reflect these changes and provided detailed descriptions and drawings of all parts we plan to fabricate. This report addresses the design justification and details of the hand calculations. After this is addressed by the team, our manufacturing plan lays out how parts will be manufactured and procured. This includes all component specifications and drawings for the sub-assemblies. Finally, we discuss our plans for testing in our design verification plan and which tests will be performed to evaluate whether the design meets the specifications.

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1 Introduction

The Road Embedded Traffic Actuated Turbine (RETAT) project aims to develop a mechanism used to generate electricity from passing vehicles, reducing the carbon footprint, and providing a clean alternative to fossil fuels. The project involves designing and constructing a laboratory model, testing its force and energy output, and considering stakeholder needs. Key objectives include functional decomposition, researching existing technologies, designing a prototype, and optimizing its viability. The project also aims to ensure safety, durability, and sustainability while efficiently producing energy and positively impacting the environment. Collaboration with the electrical engineering team is another objective to create an interface between the turbine and generator for coordinated operation.

This paper describes design changes made to enhance the structural stability and durability of the project. The original pillow block bearings on the top pivot were replaced with pin bearings, bolted onto adjacent C-channels instead of tall supports. These changes improve support for moving parts, reduce the risk of damage or failure, and lower material costs. The paper outlines the design and implementation of these changes, along with their impact on project performance. The System Design section provides detailed descriptions and functionality explanations, including a complete description of the final design with labeled figures. Major subsystems and components are described, supported by figures, and a cost breakdown for the verification prototype by subsystem is also included.

The Design Justification section justifies design decisions with evidence, discussing how the design meets specifications through engineering evidence, simulations, analyses, and prototype tests. Safety, maintenance, repair considerations, and customer needs are addressed. The Manufacturing Plan section explains how the Verification Prototype will be produced, providing detailed instructions, procurement details, material/component sources, and discussing custom part manufacturing and outsourcing plans. Assembly procedures for all components are described. The Design Verification Plan section outlines tests to assess if the Verification Prototype meets specifications. Each specification is assessed, and an overview of planned tests, including special facility/equipment needs, is provided. At least one test involving data collection and analysis is included.

2 System Design

The System Design section explains how the RETAT system works and how much it might cost. It is divided into two parts: Design Description & Function and Cost Estimate.

In the Design Description & Function part, it talks about how the system turns linear motion into rotational motion using different parts like the pivot plate, down shaft, pitman arm, crankshaft, and flywheel. It also mentions the materials used, such as steel and plastic. There are some pictures to help understand how everything fits together.

The Cost Estimate part talks about how much money is needed to build the system. It mentions the main expenses, like the frame, flywheel, and one-way locking bearing, and how much they might cost. It also shows a budget to make sure the spending stays within a limit.

Breaking up the section this way makes it easier to understand how the system works and how much it might cost to build.

2.1 Design Description & Function

This project was designed to be completely innovative and functional while maintaining the basic mechanisms that allow for relatively simple manufacturing and assembly. The RETAT will have a square tubing frame surrounded by sheet metal and within this frame, all the mechanisms will be covered. Figure 1 shows the final assembly, and Figure 2 shows the assembly with the housing removed. To improve the visibility of the interior, Figure 3 indicates the main components of this project.

Figure 1 - Turbine Assembly

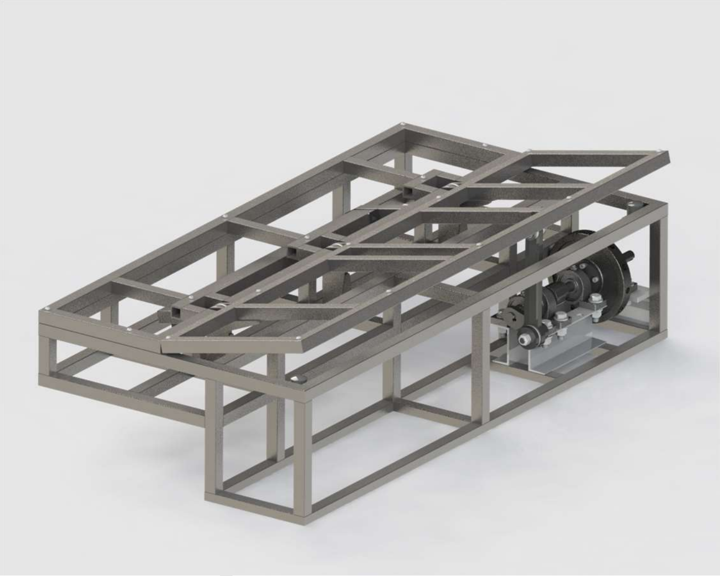

Figure 2 - Exposed Inner Turbine Assembly

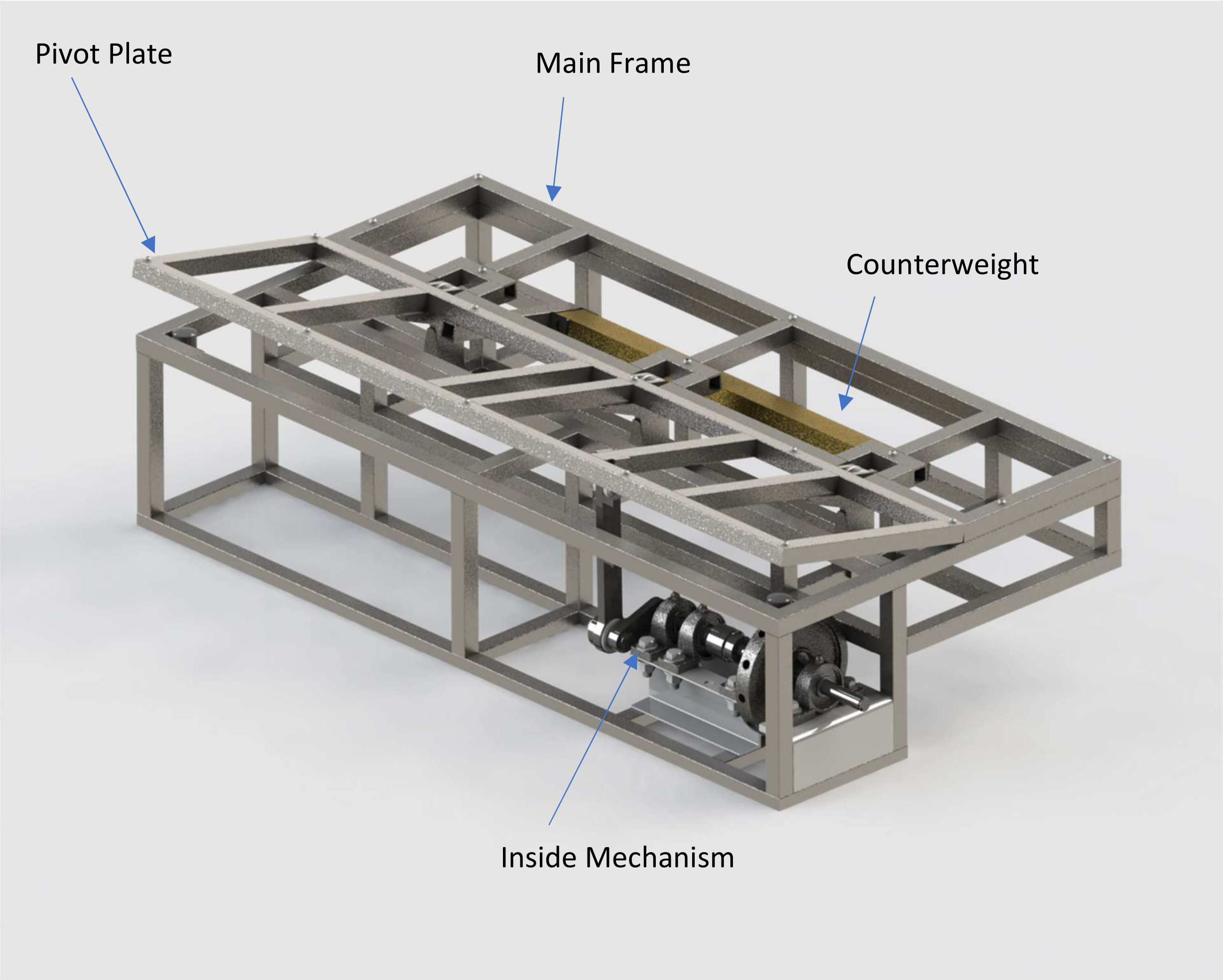

Figure 3 - Labeled Components within Assembly

One key objective of this project is to convert linear into rotational motion. To do this, the turbine will have to capture energy from moving vehicles that drive over its pivot plate. The input of energy will occur when the front wheels of the moving vehicles impact the pivot plate. The pivot plate will rotate about the pivot, which is supported by a bearing connected to the frame until it rests parallel to the ground. A small part of the energy obtained from the impact will be distributed through the pivot plate and transferred to the frame. Most of the energy obtained from the impact will be converted first to linear motion by pushing a down shaft. When the pivot plate is completely flush with the road, the frame will support it and act as a rest if vehicles are stopped over it. After the initial impact, when the front wheels stop pressing the pivot plate, a counterweight connected to the pivot plate will make it rise by utilizing gravitational force to the initial position. This will allow the rear wheels of the vehicle to press down the plate once again creating two pulses to the RETAT with once single standard vehicle.

Each time the pivot plate is pressed, it is considered an input of energy to the system. The system operates based on pulses generated when a vehicle presses the plate. The number of pulses produced by a vehicle is equal to the number of axles it has. The mechanism responsible for converting linear motion into rotational motion consists of a pitman arm, a crankshaft and an initial shaft which rotates. When the down shaft is propelled downwards, it pushes the pitman arm, which in turn rotates a crankshaft. The crankshaft is connected to the first initial shaft that will be rotated along with the crankshaft. The first shaft is connected to a secondary shaft through the means of a one way bearing. Since the initial rotating shaft is connected to the crankshaft, it also rotates in the opposite direction when the down shaft is pulled up by means of the counterweight system. Each pulse causes the first shaft to rotate in one direction, and when the pivot plate returns to its initial position, the crankshaft is ready to receive the next impact. To prevent the shaft from rotating in the opposite direction, the one-way bearing will keep a one direction rotation possible. This bearing will transfer rotational motion to the second shaft when the first shaft rotates in the energy generation direction. This ratcheting mechanism is vital to be present during the transition from the first to the second shaft.

Attached the second shaft is a flywheel. The purpose of the flywheel is to store the kinetic energy from each pulse and allow it to dissipate through a prolonged amount of time to get the most energy generation possible. When there are no vehicles pressing the pivot plate, the stored energy in the flywheel is discharged into the shaft. The inertia of the flywheel keeps the generator running for a specific duration after the pivot plate is not being depressed. The generator produces electricity, which will be stored in a battery or connected to the grid, depending on the final application of the project.

2.2 Material Choices

The whole device will be built of multiple materials including mild steel (sheet metal, plates, and tubing), plastic, bearing, and general hardware (nuts, bolts, washers, and metal locking pins. The frame will be completely made from mild steel. The paint used to paint this frame will depend completely on the environment where the turbine is used. Ideally when this project is built for practical purposes the frame will cover the width of the road which is around 9 feet. We are not building a prototype for a vehicle to drive over but a scaled model in which we can test the inner mechanism and see how viable it is. The width of the frame we are building is going to be set 24 inches for now but it is not concrete since it depends on the size of the pivot plate. In addition, the system must physically interface with the generator, which we don’t know the exact dimensions of. It is necessary to keep the frame smaller than 48 inches long to prevent extra weight and avoid the extra cost to the project. The height of the frame will be around 12 inches from the lowest to the highest point.

The pivot plate material and geometry are not decided yet. The material for this part of the turbine will be metal and the shape should be designed to receive high impacts and support the weights of heavy vehicles. The pivot plate should be designed to be lightweight to avoid extra unwanted inertia and to have a small counterweight. This will help to avoid high impact on the wheel of the vehicles while transferring more energy into the system. The shape of the pivot plate will be determined by the analysis of the impact during future calculations. The down shaft, pitman arm, and crankshaft will be made from steel. The shape of these components also will depend on the size of the frame and the optimal torque-transferring position of the shaft. Both the first and second shafts will be made from steel and their thickness also depends on the stress that is created by the impact. The shafts will have a diameter of around 1.25 inches and the length depends also on the width of the frame. The ratcheting mechanism will also be made from steel, and it will have to be lightweight and have a low impact on the system to prevent damping forces. The second shaft will be connected directly to the generator using standard coupling.

2.3 Cost Estimate

To build the RETAT team Cleanergy must procure all the necessary components required to build and assemble everything. We have put an Indented Bill of Materials and attached it in Appendix A to demonstrate the costs we foresee necessary to bring this project into fruition. Our biggest expenses are going to be the square tubing for the frame and the square tubing plate, the flywheel, and the one-way locking bearing. These as seen in the iBOM have a price of about $650 together. Another $1000 is planned to go into other necessary smaller components. We also have our project budget included in Appendix B to show that we are keeping our sponsor in our best interest and not go over our spending limit as well as demonstrate how planned purchases are going to be conducted.

Table 1 – Prototype Cost Estimate

Subsystem	**Cost**
Frame Assembly	$550
Pivot Plate	$420
Inside Mechanism	$670
Testing	$750
Total Cost	$2390

3 Design Justification

This design has gone through many iterations while meeting the design specifications. The analyses done on the system will be provided to show that they are functioning optimally while meeting the standards. This also includes a thorough examination of the system's inputs and outputs and any potential problems. Finally, verification from the structural prototype will be shown to meet all functionalities.

3.1 Structural Prototype

Building a structural prototype is crucial for the development of complex systems like the RETAT as it provides a tangible representation of the design, allowing for testing, evaluation, and improvement. The prototype serves as a proof of concept, validating the functionality of the system's mechanisms and subsystems. It enables performance evaluation, identifying any issues or limitations early on, which can be addressed to enhance the system's efficiency and reliability. Additionally, the prototype facilitates testing and data collection, providing valuable insights for further development. Overall, the construction of a structural prototype is an essential step in ensuring the success and optimization of the final product.

The most critical subsystem for the structural prototype is to convert linear motion into rotational motion using a downshaft and then transfer it through the pitman arm to an input shaft attached to a one-way bearing clutch which is attached to a second shaft being able to spin freely. The figure of the structural prototype is shown in Figure 4. The function of the one-way bearing clutch is to allow the output shaft only rotates in one direction and move freely in the opposite direction. The structural prototype consists of a mixture of 3D-printed parts and off the shelf components. The frame is made of 80/20 aluminum extrusions. The flywheel was cut from a scrap aluminum plate utilizing a waterjet. Off the shelf components include a one-way bearing clutch and four ball bearings. Pillow blocks for ball bearings, the coupling for the one-way bearing, and various fittings were 3D printed. This proved the mechanism to be reliable and efficient that can convert linear motion to rotational motion. The team was able to rotate the shaft continuously without encountering any issues and this shows that the subsystem will generate electricity. The actual tests will be performed using the final prototype including a generator instead of the structural prototype. For testing, the team plans to implement a mechanism that simulates the downshaft being pushed down and thus rotating both shafts, but shortly after disengaging the output shaft which will be allowed to spin freely in one direction. This allows us to analyze and collect data to determine projected energy production for the project. Overall, the observed outcomes of the built structural prototype provided valuable insights and paved the way for further testing and development of the system. Figure 5 is included for closer pictures of the assembly.

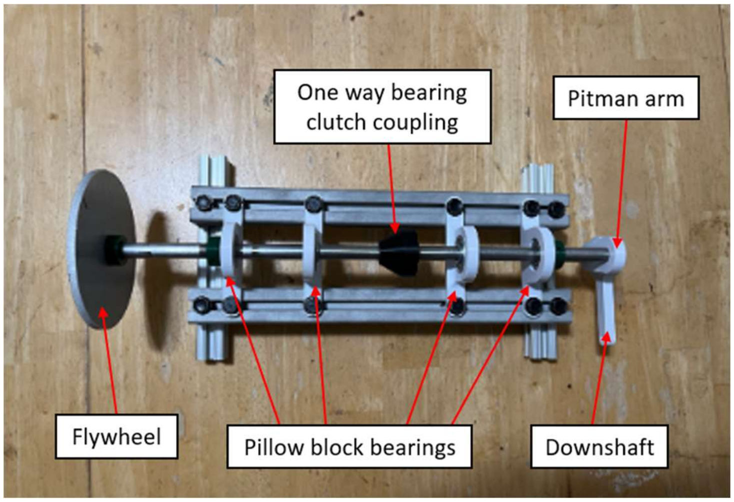

Figure 4: Structural Prototype

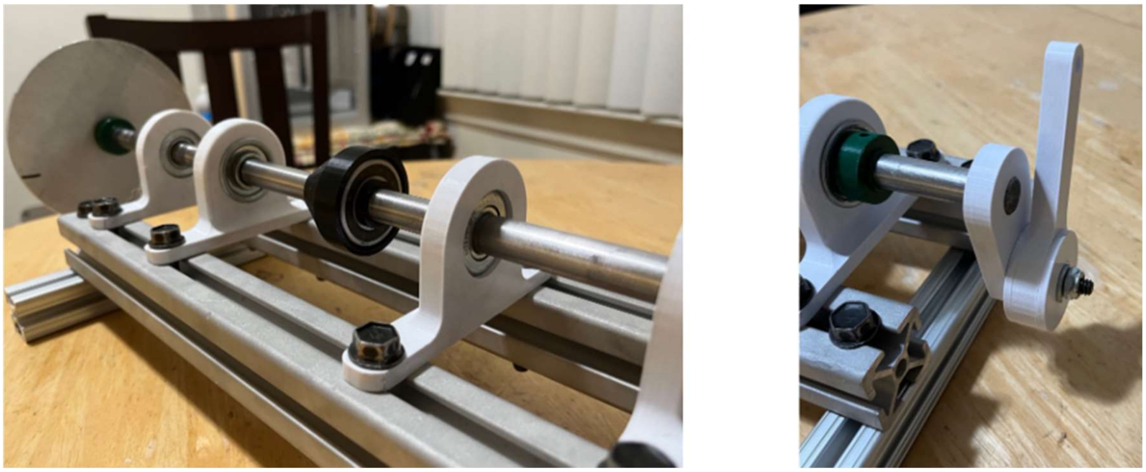

Figure 5: Close up view

3.2 Preliminary Calculations & Simulations

Since we have been developing and redesigning the CAD model of the prototype, we haven't been able to take a deep dive into FEA. However, we have conducted rough hand calculations to prove our design concept. To begin our analysis, we performed hand calculations on finding the minimum diameter of the pitman arm's pin using the safety factor of 1.5, ultimate and yield strengths of AISI 1018 CD which can be found in Figure 6 under Appendix C. Using the same material strength and the safety factor of 1.5, we determined the diameter of 0.75 inch for both input and output shafts based on the impact loading of 500 lbf.

We modeled the mechanism that converts linear motion to rotational motion as a four-bar linkage to allow us to find the angular speed of each link shown in Figure 7 under Appendix C. To perform rapid iterations of the angular speed for the ramp and pitman, we created a velocity analysis tool using Excel shown in Figure 8 under Appendix C. Once the angular speed of the pitman arm is known, we can use it to adjust the motor's speed to simulate the vehicle passing over a ramp. While the input angular speed may not be sufficient to produce the expected energy, incorporating a gearbox into the system would boost energy production. We plan to test the system without a gearbox first and verify that it can produce at least 500 W by a generator. With the flywheel weighing 20 lb_m and a radius of 3 inches rotating at 1200 rpm, the rotational kinetic energy is roughly 225 J. To determine the counterweight, the front plate is assumed to weigh 30 lb_m and through the calculation, we found that the counterweight needs to weigh more than 22.5 lb_m to achieve the maximum height clearance of 4 inches. The hand calculation can be found in Figure 9 under Appendix C.

3.3 Considerations

When it comes to building or testing the prototype, we must consider any kind of risk. We will ensure that any metal components with sharp edges are not visible during assembly and operations. We are expecting that stored energy in the flywheel will spin at high rpm which may pose a high risk. To prevent people, animals, or litter from falling into the system between the plate and the frame, an acrylic sheet will be assembled around the plate and frame as well. While working on the system, we will refer to the design hazard checklist can be seen in Appendix E.

3.4 Remaining Concerns

The biggest concern is that the system will not be able to achieve the projected electricity. To increase energy production, we are certain that adding a gearbox to the system will help to generate electrical energy. This addition will facilitate better utilization of the energy and allow the system to operate at its desired capacity, thus maximizing the overall performance of the system. Another biggest concern is the testing method that we want to simulate the vehicle driving over the ramp that can generate the greatest amount of torque. A motor with a cam mechanism is feasible to produce with sufficient resources but we are concerned that it may not yield realistic outputs and that the loading cycle of a motor may pose any risks. We will monitor the motor’s behavior during the testing phase.

4 Manufacturing Plan

The manufacturing plan of this project involves many manufacturing, fabrication, and assembly techniques which requires that all steps must be followed with a very strict approach. It is important to have a reference for all materials and minimum manufacturing steps in order not to get lost during the process. Appendix F shows a table with all the required materials and fabrication steps for each component on each subsystem. For this project, most of the components should be built in a machine shop since they are very specific parts that cannot be obtained from a vendor other than raw material. This manufacturing plan section provides a clear roadmap for the project’s manufacturing and serves as a valuable resource for anyone involved in the manufacturing process. A broader overview of remaining procedures and associated dates can be seen in the team's Gantt chart in Appendix H.

4.1 Procurement

Most of the components will be obtained from local vendors such as: Tractor Supply, Miner's Hardware, and only specific parts will also be obtained from McMaster-Carr. Local vendors are less expensive than McMaster-Carr and that could help in order to overspend. Also, thanks to the support from the Cal Poly machine shops, some parts can be made from the extra material that is saved specifically for senior projects.

4.2 Manufacturing

The plan for the team is to divide tasks to manufacture and fabricate most parts before the assembly process. This project consists of 3 subsystems, and they are labeled in Appendix F. The order of building and assembly are listened from 1 to 3 and if not followed in that order would result in time lost because the process of assembly is systematically designed to test each component at a time.

4.3 Assembly

The assembly of this project will be made in a specific space reserved for this project. All material and necessary tools will be stored in the same room or a given cage that is provided by the Mustang 60 machine shop.

5 Design Verification Plan

Once all the components have been procured, manufactured, and assembled accordingly there will be a series of tests that will be implemented in order to verify that the processes outlined above have been followed and completed carefully. There are three tests that the team will perform in order to verify key components in the design. For more details and dates on the test that will be outlined in this section please refer to Appendix G.

The first of these tests will be simply to measure that the final prototype's pivot plate does not protrude more than 4 inches from the rest of the housing, which will be flush with the road, utilizing a tape measure. As stated in the team's previous document, the sponsors have requested this maximum height for the plate after conducting extensive research and arriving at an average asphalt to bumper distance of 5 inches, giving the pivot plate an inch of clearance and preventing it from contacting vehicles' bumpers. To evaluate whether a value passes or fails we will be utilizing the following range 1.5" ≤ x ≤ 4". If results fall within this range, they will be considered passing, but if they fall outside the range, they will be considered failing. We estimate 100 measurements. A bar graph will be generated utilizing Excel to visualize measurement distribution. From there better estimates can be taken depending on the type of distribution (i.e., Gaussian, Exponential, Bernoulli...)

The second of these tests will utilize a motor in order to simulate a minimum of 500 lbs impact load on the final prototype's pivot plate. This test will need to be implemented utilizing a test rig, that the team will have to develop in conjunction with the electrical engineering team in order to facilitate testing. The test rig will utilize a motor attached to a cam that will be able to repeatedly and reliably simulate the 500 lbs of force that the team has estimated each wheel will provide the turbine within order to activate the pivoting plate.

This test will measure the power able to be generated by the turbine under ideal operating conditions. At the moment, the team has decided upon a 500 W benchmark for which to judge this specification by. The team plans to implement a small system with an Arduino in order to collect data from this test to create a model which could be utilized to quantify the power generation of this device were it to be scaled up. For a more detailed view of the test rig please see Figure 6 below.

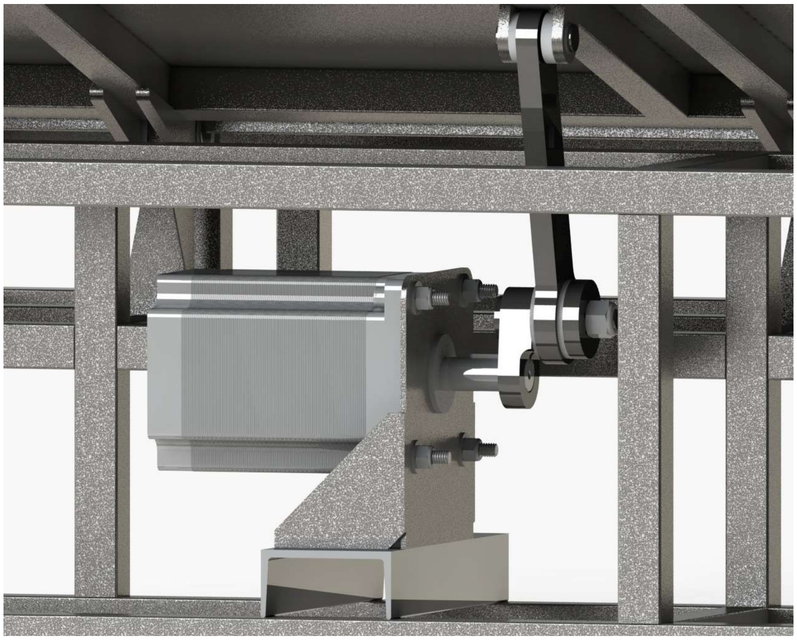

Figure 6 - Testing Rig

6 Conclusion

There has been significant progress that has been done to the RETAT project in order to accelerate and streamline every step of the manufacturing process. The team has made changes to all subsystems that will significantly reduce cost and improve overall structural rigidity while keeping a unique and innovative design aimed at implementing widespread clean energy generation. Such changes include the addition of C-channels to the frame as supports for the pillow block bearings that will be used for spinning the shafts in order to generate power. In addition to this, the bearings attaching the pivoting plate to the frame have been modified to only utilize pins to further reduce cost. One last sizeable change involved changing the location of the gearbox to be outside the RETAT's frame to allow for a more modular design for both maintenance as well as ease of manufacture. With this the team now aims to focus their efforts on part and material procurement, in order to begin manufacturing the final prototype, which will be used for testing; with manufacturing scheduled to officially begin this upcoming fall quarter.

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Appendices

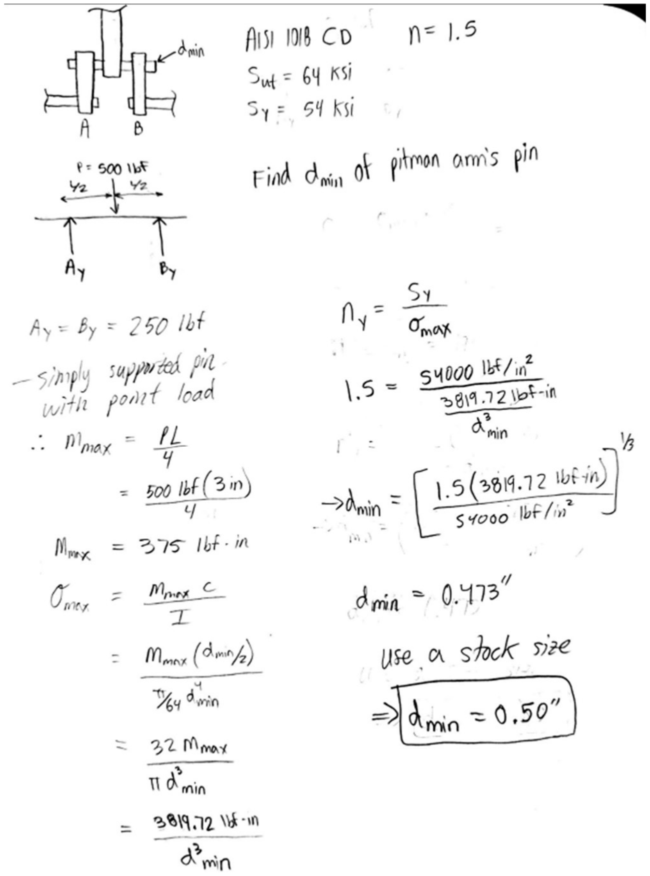
Appendix A – Indented Bill of Materials (iBOM)

Assy Level	Part Number	Descriptive Part Name	Qty	Part Cost	Total Part Cost	Source	Serial Code	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4						
0	0	RETAT Assembly	1					
1	Frame - 00	Main Frame Assembly	1					
2	F-00	Square Tubing Frame	1	$250.00	$250.00	Metals Depot		1x1x.12" - Square Tubing - Mild Steel
3	F-01	Top Frame - Square Tubing	1	$50.00	$50.00	Metals Depot		1x1x.12" - Square Tubing - Mild Steel
3	F-02	Top Frame Plate	1	$20.00	$20.00	Metals Depot		Acrylic Sheet
3	F-03	Top Frame End Cap	3	$1.00	$3.00	Metals Depot		Acrylic Sheet
3	F-04	Bumper Base	4	$5.00	$20.00	McMaster-Carr		Mild Steel Plate
3	F-05	Frame - Side Plate	2	$20.00	$40.00	Home Depot		Acrylic Sheet
3	F-06	Frame - Back Plate	1	$20.00	$20.00	Home Depot		Acrylic Sheet
3	F-07	Frame - Front Plate	1	$20.00	$20.00	Home Depot		Acrylic Sheet
3	F-11	Pivot Base	3	$20.00	$60.00	Metals Depot		Mild Steel Plate
3	F-12	Pivot Base Support	3	$20.00	$60.00	Metals Depot		Mild Steel Plate
3	F-20	Channel A	2	$50.00	$100.00	Metals Depot		Mild Steel
3	F-22	Angle Iron	1	$1.00	$1.00	Metals Depot		Mild Steel
	Plate - 00	Pivot Plate Assembly	1					
3	P-01	Square Tubing Plate	1	$100.00	$100.00	Metals Depot		1x1x.12" - Square Tubing - Mild Steel
2	P-02	Pivot Bracket	6	$5.00	$30.00	Metals Depot		Mild Steel Plate
2	P-03	Pivot Shaft	3	$5.00	$15.00	Metals Depot		3/4" Mild Steel Round Bar
2	P-04	Pivot Shaft Spacer	6	$2.00	$12.00	Metals Depot		Delrin
2	P-09	Plate Assembly	1	$250.00	$250.00			48 in. x 96 in. x 0.118 (1/8) in. Acrylic Sheet
2	P-10	Top Plate	1	$0.00	$0.00	Home Depot		Acrylic Sheet
2	P-11	Side Guard	2	$0.00	$0.00	Home Depot		Acrylic Sheet
1	P-12	Front Guard	1	$0.00	$0.00	Home Depot		Acrylic Sheet
2	P-13	Pivot Downshaft	2	$5.00	$10.00	Metals Depot		Mild Steel Plate
3	P-14	Downshaft Shaft	1	$20.00	$20.00	Metals Depot		3/4" Mild Steel Round Bar
3	P-15	Downshaft Spacer	2	$2.00	$4.00	Metals Depot		Delrin
3	P-21	Counter Weight Square Tubing	2	$20.00	$40.00	Metals Depot		1x1x.12" - Square Tubing - Mild Steel
3	P-22	Mass	1	$100.00	$100.00	Metals Depot		Mild Steel
2	P-23	Mass Support	2	$1.00	$2.00	Metals Depot		Mild Steel Plate
2	M-00-A	Inside Mechanism - Assembly A	1					
2	M-01	Pitman Arm	1	$10.00	$10.00	Metals Depot		Mild Steel Plate
2	M-10	Shaft A	1	$15.00	$15.00	Metals Depot		3/4" Mild Steel Round Bar
3	M-12	Pitman Arm Shaft	1	$5.00	$5.00	Metals Depot		3/4" Mild Steel Round Bar
2	M-13	Pitman Arm Shaft Nut	1	$5.00	$5.00	Metals Depot		Mild Steel Plate
2	M-22	Ball-Bearing	1	$20.00	$20.00	McMaster-Carr	2342K167	
3	M-00-B	Inside Mechanism - Assembly B	1					
3	M-05	Flywheel	1	$150.00	$150.00	Metals Depot		Mild Steel Plate
2	M-06	Flywheel Retainer	2	$20.00	$40.00	Metals Depot		Mild Steel Round Bar
2	M-11	Shaft B	1	$15.00	$15.00	Metals Depot		3/4" Mild Steel Round Bar
2	M-13	Coupling	1	$20.00	$20.00	Metals Depot		Mild Steel Round Bar
2	M-23	One-way locking bearing	1	$150.00	$150.00	McMaster-Carr	4752N52	
	G-00	Fastener in different sizes	1	$100.00	$100.00	ACE Hardware		
		Total Cost of Assembly =			$1,757.00			

Appendix B – Project Budget

Item No.	Part Code	Part Name	Vendor	Serial Code	Qty	Item Cost	Shipping Cost	Tax	Total Cost	How Purchased	Account Used	Date Purchased	Location
1	0	RETAT Assembly											
2	Frame - 00	Main Frame Assembly											
3	F-00	Square Tubing Frame	Metals Depot		1	$250.00	$1.00	$1.00	$252.00				
4	F-01	Top Frame - Square Tubing	Metals Depot		1	$50.00	$1.00	$1.00	$52.00				
5	F-02	Top Frame Plate	Metals Depot		1	$20.00	$1.00	$1.00	$22.00				
6	F-03	Top Frame End Cap	Metals Depot		3	$3.00	$1.00	$1.00	$11.00				
7	F-04	Bumper Base	McMaster-Carr		4	$20.00	$1.00	$1.00	$82.00				
8	F-05	Frame - Side Plate	Home Depot		2	$40.00	$1.00	$1.00	$82.00				
9	F-06	Frame - Back Plate	Home Depot		1	$20.00	$1.00	$1.00	$22.00				
10	F-07	Frame - Front Plate	Home Depot		1	$20.00	$1.00	$1.00	$22.00				
11	F-11	Pivot Base	Metals Depot		3	$60.00	$1.00	$1.00	$182.00				
12	F-12	Pivot Base Support	Metals Depot		3	$60.00	$1.00	$1.00	$182.00				
13	F-20	Channel A	Metals Depot		2	$100.00	$1.00	$1.00	$202.00				
14	F-22	Angle Iron	Metals Depot		1	$1.00	$1.00	$1.00	$3.00				
15	Plate - 00	Pivot Plate Assembly	0										
16	P-01	Square Tubing Plate	Metals Depot		1	$100.00	$1.00	$1.00	$102.00				
17	P-02	Fasteners	Metals Depot		6	$30.00	$1.00	$1.00	$182.00				
18	P-03	Fasteners	Metals Depot		3	$15.00	$1.00	$1.00	$47.00				
19	P-04	Fasteners	Metals Depot		6	$12.00	$1.00	$1.00	$74.00				
20	P-09	Fasteners	0		1	$250.00	$1.00	$1.00	$252.00				
21	P-10	Top Plate	Home Depot		1	$0.00	$1.00	$1.00	$2.00				
22	P-11	Side Guard	Home Depot		2	$0.00	$1.00	$1.00	$2.00				
23	P-12	Front Guard	Home Depot		1	$0.00	$1.00	$1.00	$2.00				
24	P-13	Pivot Downshaft	Metals Depot		2	$10.00	$1.00	$1.00	$22.00				
25	P-14	Downshaft Shaft	Metals Depot		1	$20.00	$1.00	$1.00	$22.00				
26	P-15	Downshaft Spacer	Metals Depot		2	$4.00	$1.00	$1.00	$10.00				
27	P-21	Counter Weight Square Tubing	Metals Depot		2	$40.00	$1.00	$1.00	$82.00				
28	P-22	Mass	Metals Depot		1	$100.00	$1.00	$1.00	$102.00				
29	P-23	Mass Support	Metals Depot		2	$2.00	$1.00	$1.00	$6.00				
30	M-00-A	Inside Mechanism - Assembly A	0										
31	M-01	Pitman Arm	Metals Depot		1	$10.00	$1.00	$1.00	$12.00				
32	M-10	Shaft A	Metals Depot		1	$15.00	$1.00	$1.00	$17.00				
33	M-12	Pitman Arm Shaft	Metals Depot		1	$5.00	$1.00	$1.00	$7.00				
34	M-13	Pitman Arm Shaft Nut	Metals Depot		1	$5.00	$1.00	$1.00	$7.00				
35	M-22	Ball-Bearing	McMaster-Carr	2342K167	1	$20.00	$1.00	$1.00	$22.00				
36	M-00-B	Inside Mechanism - Assembly B	0										
37	M-05	Flywheel	Metals Depot		1	$150.00	$1.00	$1.00	$152.00				
38	M-06	Flywheel Retainer	Metals Depot		2	$40.00	$1.00	$1.00	$82.00				
39	M-11	Shaft B	Metals Depot		1	$15.00	$1.00	$1.00	$17.00				
40	M-13	Coupling	Metals Depot		1	$20.00	$1.00	$1.00	$22.00				
41	M-23	One-way locking bearing	McMaster-Carr	4752N52	1	$150.00	$1.00	$1.00	$152.00				
42	G-00	Fastener in different sizes	ACE Hardware		1	$100.00	$1.00	$1.00	$102.00				
						Total Cost			$2,613.00				

Appendix C – Supporting Evidence



AISI 1018 CD $\quad n = 1.5$

$S_{ut} = 64$ ksi

$S_y = 54$ ksi

Find d_{min} of pitman arm's pin

$A_y = B_y = 250$ lbf

– simply supported pin with point load

$$\therefore M_{max} = \frac{PL}{4}$$

$$= \frac{500 \text{ lbf} (3 \text{ in})}{4}$$

$$M_{max} = 375 \text{ lbf} \cdot \text{in}$$

$$\sigma_{max} = \frac{M_{max} c}{I}$$

$$= \frac{M_{max} (d_{min}/2)}{\frac{\pi}{64} d^4_{min}}$$

$$= \frac{32 M_{max}}{\pi d^3_{min}}$$

$$= \frac{3819.72 \text{ lbf-in}}{d^3_{min}}$$

$$n_y = \frac{S_y}{\sigma_{max}}$$

$$1.5 = \frac{54000 \text{ lbf/in}^2}{\frac{3819.72 \text{ lbf-in}}{d^3_{min}}}$$

$$\rightarrow d_{min} = \left[\frac{1.5 (3819.72 \text{ lbf-in})}{54000 \text{ lbf/in}^2} \right]^{1/3}$$

$$d_{min} = 0.473''$$

Use a stock size

$$\Rightarrow \boxed{d_{min} = 0.50''}$$

Figure 6: Hand calculation of pitman pin diameter

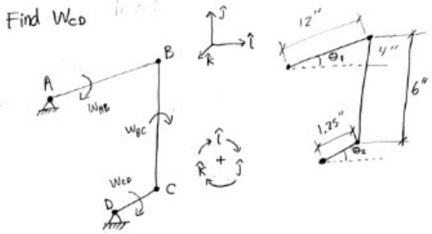
Principle of angular impulse and momentum

$$H_i + \sum \int_{t_i}^{t_f} M_0 = H_f$$

$$0 + \tau(t_f - t_i) = I\,w_{AB}$$

$$w_{AB} = \frac{\tau}{I}(t_f - t_i)$$

Find w_{CD}



1) $V_B = V_A + V_{B/A}$

$= 0 + w_{AB} \times r_{AB}$

$= -w_{AB}\hat{k} \times (r_{AB}\cos\theta_1\,\hat{\imath} + r_{AB}\sin\theta_1\,\hat{\jmath})$

$= -w_{AB}[r_{AB}\cos\theta_1\,\hat{\jmath} + r_{AB}\sin\theta_1\,\hat{\imath}]$

2) $V_C = V_B + V_{C/B}$

$= V_B + w_{BC} \times r_{BC}$

$= V_B - w_{BC}\hat{k} \times (-r_{BC}\,\hat{\jmath})$

$= -w_{AB}[r_{AB}\cos\theta_1\,\hat{\jmath} + r_{AB}\sin\theta_1\,\hat{\imath}] - w_{BC}r_{BC}\,\hat{\imath}$ ①

3) $V_C = V_D + V_{C/D}$

$= 0 + w_{CD} \times r_{CD}$

$= -w_{CD}\hat{k} \times (r_{CD}\cos\theta_2\,\hat{\imath} + r_{CD}\sin\theta_2\,\hat{\jmath})$

$= -w_{CD}[r_{CD}\cos\theta_2\,\hat{\jmath} + r_{CD}\sin\theta_2\,\hat{\imath}]$ ②

* equate ① to ②

$$-w_{AB}[r_{AB}\cos\theta_1\,\hat{\jmath} + r_{AB}\sin\theta_1\,\hat{\imath}] - w_{BC}r_{BC}\,\hat{\imath} = -w_{CD}[r_{CD}\cos\theta_2\,\hat{\jmath} + r_{CD}\sin\theta_2\,\hat{\imath}]$$

$\hat{\imath}$: $-w_{AB}r_{AB}\sin\theta_1 - w_{BC}r_{BC} = -w_{CD}r_{CD}\sin\theta_2$

$\hat{\jmath}$: $-w_{AB}r_{AB}\cos\theta_1 = -w_{CD}r_{CD}\cos\theta_2$

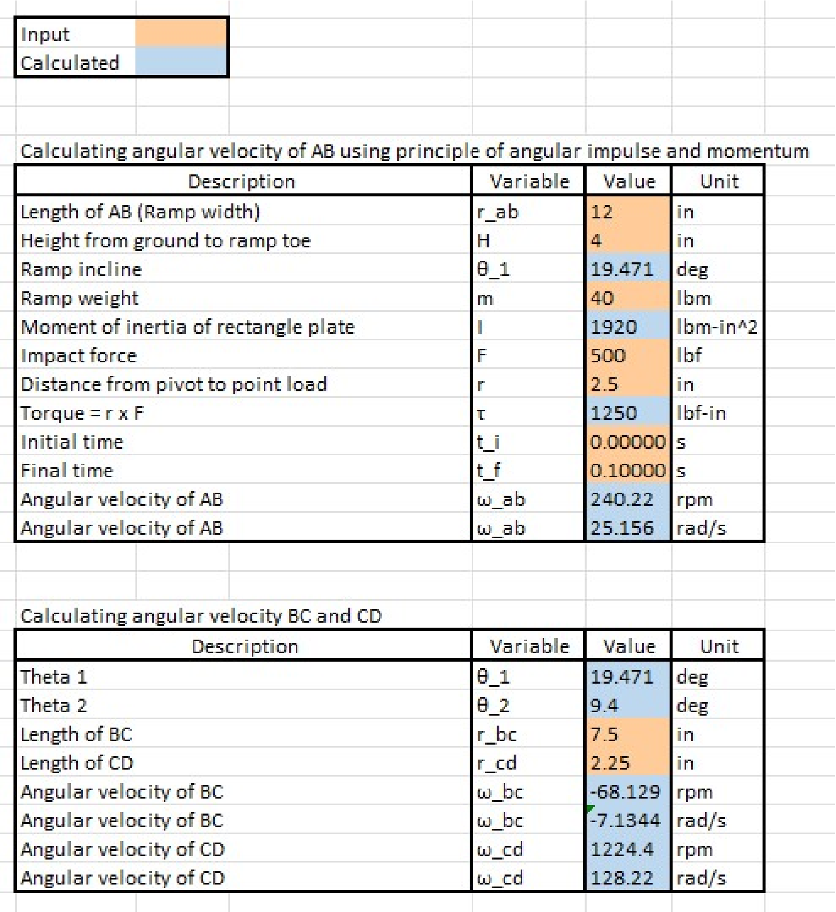
* solving for w_{BC} and w_{CD}...

$$w_{CD} = \frac{w_{AB}r_{AB}\cos\theta_1}{r_{CD}\cos\theta_2}$$

$$w_{BC} = \frac{1}{r_{BC}}\left[-w_{AB}r_{AB}\sin\theta_1 + \left(\frac{w_{AB}r_{AB}\cos\theta_1}{r_{CD}\cos\theta_2}\right)r_{CD}\sin\theta_2\right]$$

$$= \frac{1}{r_{BC}}\left[-w_{AB}r_{AB}\sin\theta_1 + w_{AB}r_{AB}\cos\theta_1\tan\theta_2\right]$$

Figure 7: Angular velocity analysis



Input	🟧
Calculated	🟦

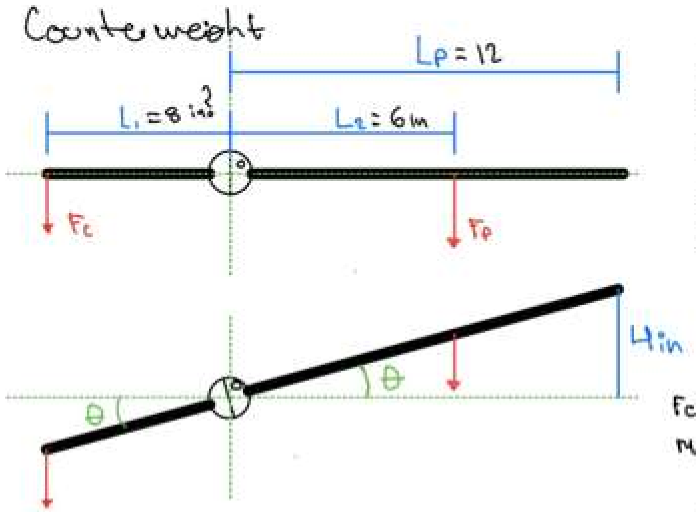
Calculating angular velocity of AB using principle of angular impulse and momentum

Description	Variable	Value	Unit
Length of AB (Ramp width)	r_ab	12	in
Height from ground to ramp toe	H	4	in
Ramp incline	θ_1	19.471	deg
Ramp weight	m	40	lbm
Moment of inertia of rectangle plate	I	1920	lbm-in^2
Impact force	F	500	lbf
Distance from pivot to point load	r	2.5	in
Torque = r x F	τ	1250	lbf-in
Initial time	t_i	0.00000	s
Final time	t_f	0.10000	s
Angular velocity of AB	ω_ab	240.22	rpm
Angular velocity of AB	ω_ab	25.156	rad/s

Calculating angular velocity BC and CD

Description	Variable	Value	Unit
Theta 1	θ_1	19.471	deg
Theta 2	θ_2	9.4	deg
Length of BC	r_bc	7.5	in
Length of CD	r_cd	2.25	in
Angular velocity of BC	ω_bc	-68.129	rpm
Angular velocity of BC	ω_bc	-7.1344	rad/s
Angular velocity of CD	ω_cd	1224.4	rpm
Angular velocity of CD	ω_cd	128.22	rad/s

Figure 8: Analysis tool using Excel



$$F_p = mg$$

$$F_p = (30\ lb_m)\left(32.174\ \frac{ft}{s^2}\right)$$

$$F_p = 965.22\ lb_f$$

$$\Sigma M_0 = 0$$

$$L_1 F_c = L_2 F_p$$

$$F_c = \frac{L_2}{L_1} F_p = \frac{6\ in}{8\ in}(965.22\ lbF)$$

$$= 723.915\ lbF$$ in equilibrum.

$$F_c = m_c g$$

$$m_c = \frac{F_c}{g} = \frac{723.915\ lb_m \frac{ft}{s^2}}{32.174\ \frac{ft}{s^2}} = 22.5\ lb_m$$

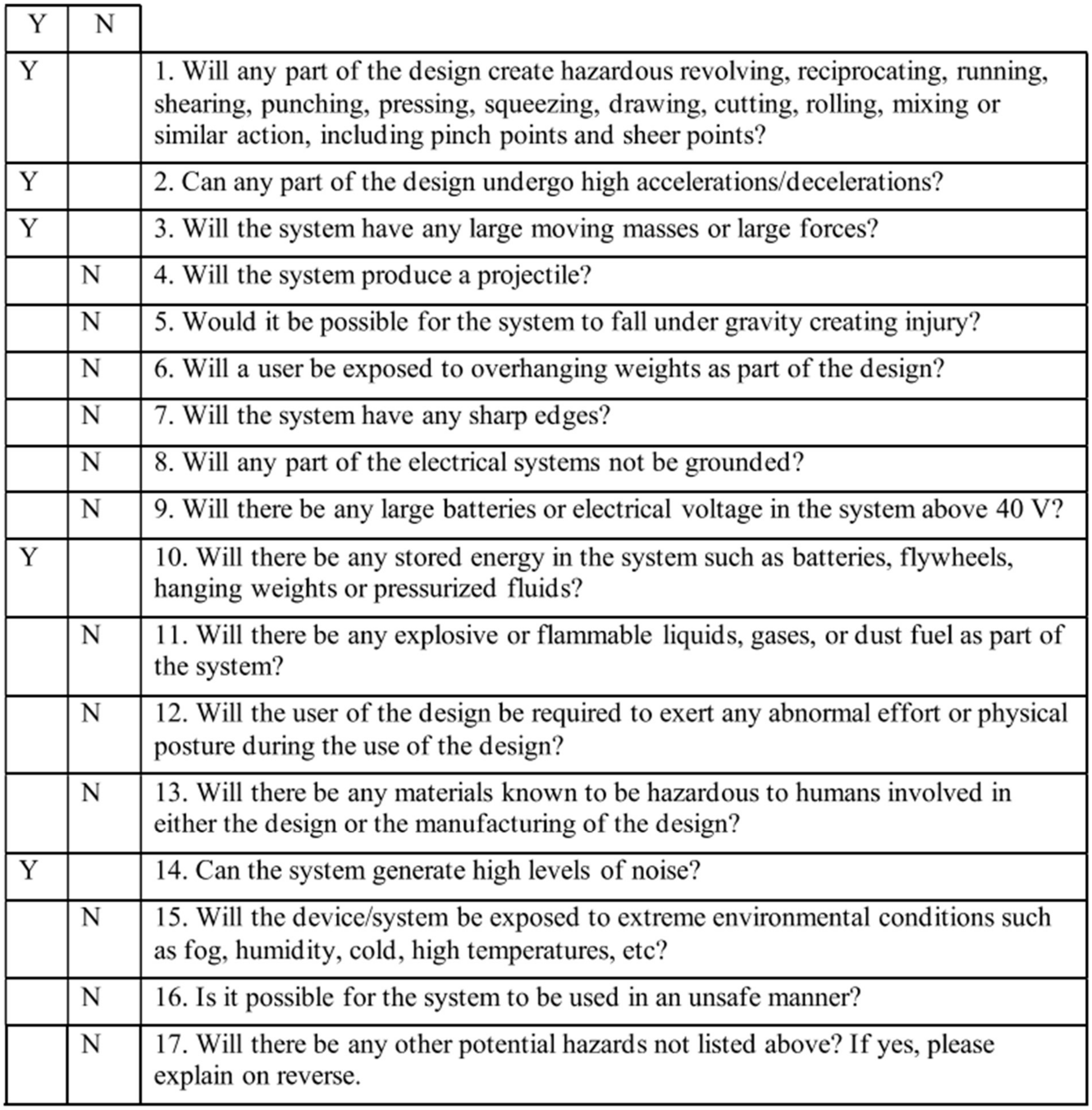
∴ The conterweight need to weight more than 22.5lbs

Figure 9: Counterweight analysis

Appendix D – Failure Modes & Effects Analysis (FMEA)

												Action Results				
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**RPN**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Detection**	**RPN**
Pivot Plate / Support Impact from wheels	Plate bends up	Car gets damaged	10	1) Cars going too fast 2) Broken Pivot components	1) impact factor 2) stress analysis 3) fatigue strength	1	Design Analysis	1	10	Perform Deflection Simulation	Alejandro by Spring 2023					
Pivot Plate / Transfer Energy to Down Shaft	Plate Stucks	No electrcity generated	2	Trash under Pivot Plate	Sealed design	3	n/a	1	6	Stress Test the prototype	Derek by Spring 2023					
Pivot Plate / Support Weight	Plate bends into the frame	Car gets damaged	7	1) Pivot Plate rest support bukle 2) Too much weight	Rest brackets stress analysis	1	Design Analysis	1	7	Perform Deflection Simulation	Yosef by Spring 2023					
Pivot / Support Impact from Wheels	Components Break	Pivot Plate is free	4	1) Incorrect Assembly / Welding 2) No maintenance	Design the frame to keep the pivot plate from moving	4	n/a	4	64	Perform Stress Analysis Simulation and Compare to Hand Calculations	Jairo by Spring 2023					
Frame / Support Weight	Vertical Tubbing buckles	Pivot Plate is under road level	5	Too Much Weight	1) design factor 2) stress analysis 3) fatigue strength	1	Design analysis	1	5	Perform Stress Analysis Simulation	Yosef by Spring 2023					
	Horizontal Tubing bends	Car gets damaged	5	Too Much Weight	1) design factor 2) stress analysis 3) fatigue strength	1	Design analysis	1	5	Perform Deflection Simulation	Alejandro by Spring 2023					
Linear to rotational motion mechanism / Support Impact from Pivot Plate	Components Break	Zero energy transferred	2	Wear from friction	Design Analysis	7	Design analysis	6	84	Perform Stress Analysis Simulation and Compare to Hand Calculations	Jairo by Spring 2023					
Linear to rotational motion mechanism / Convert Linear into Rotational Motion	Gets Stuck	No electricity generated	2	Trash or debris among components	Design Enclosure	3	n/a	1	6	Actuate Prototype n Number of Times	Yosef by Spring 2023					
Flywheel / Support Acceleration	Square Key breaks	a) No energy stored b) Generator stops sooner	4	High Acceleration	Design Factor	2	Design analysis	6	48	Perform Preliminary Calculations and Compare to Stress Simulation	Jairo by Spring 2023					
Generator	Coils burn	No electricity generated	2	Jumps speed limits	Out of the Scope	4	n/a	5	40	Consult with EE team	Derek by Spring 2023					

Appendix E – Design Hazard Checklist



Y	N	
Y		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
Y		2. Can any part of the design undergo high accelerations/decelerations?
Y		3. Will the system have any large moving masses or large forces?
	N	4. Will the system produce a projectile?
	N	5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
	N	7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
	N	9. Will there be any large batteries or electrical voltage in the system above 40 V?
Y		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	N	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	N	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
Y		14. Can the system generate high levels of noise?
	N	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	N	16. Is it possible for the system to be used in an unsafe manner?
	N	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Shaft spins at a high rate of speed	Provide a protective housing around it or make a warning sign that rotating shaft can cause severe injury.	11/23	
Engaging pivot plate increases shaft's or flywheel's acceleration	Gearbox can be used to change speed to ensure that the flywheel is either sped up or down. A clutch plate can also be applied.	11/23	
Energy stored in flywheel	Make a warning sign that you should not approach a flywheel spinning at a high speed. E-stop system can also be included.	11/23	
The system may generate high levels of noise	Wear hearing protection. A damping can be added to reduce vibration.	11/23	
The system will have some large moving masses such as flywheel and shaft.	Flywheel will be in a protective housing and keep its size minimal while maximizing the output energy	11/23	

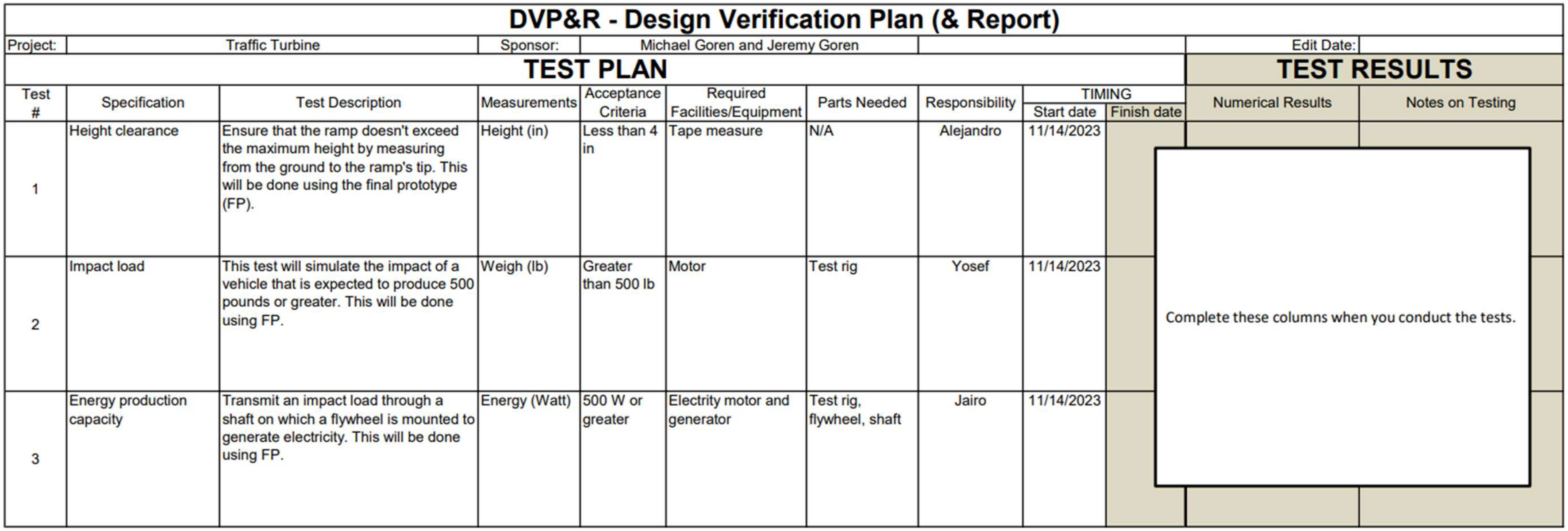
Appendix F – Manufacturing Plan

Assy #	Subsystem	Component	Purchase (P) Modify (M) Build (B)	Raw Materials Needed to make/modify the part (only M & B)	Where/how procured?	Equipment and Operations anticipate using to make the component	Key limitations of this operation places on any parts made from it
1	Frame	Square Tubing Frame	B	1x1x.12" - Square Tubing - Mild Steel	Metals Depot	1. Cut with horizontal bandsaw. 2. Deburr and clean welding area with angle grinder and acetone 3. Weld with MIG welding machine 4. Spray paint after welding all components	General fixturing is a problem. As a result, it will need three people to do it.
		Top Frame - Square Tubing	B	1x1x.12" - Square Tubing - Mild Steel	Metals Depot	1. Waterjet 2. Deburr	N/A
		Top Frame Plate	B	Acrylic Sheet	Metals Depot	1. Waterjet 2. Deburr	N/A
		Top Frame End Cap	B	Acrylic Sheet	Metals Depot	1. Waterjet 2. Deburr	N/A
		Bumper Base	B	Mild Steel Plate	McMaster-Carr	1. Waterjet 2. Deburr	N/A
		Frame - Side Plate	B	Acrylic Sheet	Home Depot	1. Waterjet 2. Deburr	N/A
		Frame - Back Plate	B	Acrylic Sheet	Home Depot	1. Waterjet 2. Deburr	N/A
		Frame - Front Plate	B	Acrylic Sheet	Home Depot	1. Waterjet 2. Deburr	N/A
		Pivot Base	B	Mild Steel Plate	Metals Depot	1. Waterjet 2. Deburr	N/A
		Pivot Base Support	B	Mild Steel Plate	Metals Depot	1. Waterjet 2. Deburr	N/A
		Channel A	M	Mild Steel	Metals Depot	1. Cut to length with horizontal saw 2. Drill holes with drillpress	N/A
		Angle Iron	M	Mild Steel	Metals Depot	Cut to length with horizontal saw	N/A

Assy #	Subsystem	Component	Purchase (P) Modify (M) Build (B)	Raw Materials Needed to make/modify the part (only M & B)	Where/how procured?	Equipment and Operations anticipate using to make the component	Key limitations of this operation places on any parts made from it
2	Pivot Plate	Square Tubing Plate	B	1x1x.12" - Square Tubing - Mild Steel	Metals Depot	1. Cut with horizontal bandsaw. 2. Deburr and clean welding area with angle grinder and acetone 3. Weld with MIG welding machine 4. Spray paint after welding all components	Welding has to be good quality to support impact and pivot brackets should be aligned
		Pivot Bracket	B	Mild Steel Plate	Metals Depot	1. Waterjet 2. Deburr	N/A
		Pivot Shaft	B	3/4" Mild Steel Round Bar	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		Pivot Shaft Spacer	B	Delrin	Metals Depot	1. Waterjet 2. Deburr	N/A
		Pivot Downshaft	B	Mild Steel Plate	Home Depot	1. Waterjet 2. Deburr	N/A
		Downshaft Shaft	B	3/4" Mild Steel Round Bar	Home Depot	Face and turn in lathe	Turning to the right size and tolerances
		Downshaft Spacer	B	Delrin	Home Depot	1. Waterjet 2. Deburr	N/A
		Counter Weight Square Tubing	B	1x1x.12" - Square Tubing - Mild Steel	Metals Depot	Same as square tubing plate	Tolerances on holes for fasteners have to be met to have precision when mounting
		Mass	M	Mild Steel	Metals Depot	Cut with Horizontal Saw	Heavy
		Mass Support	B	Mild Steel Plate	Metals Depot	1. Waterjet 2. Deburr	Turning to the right size and tolerances

Assy #	Subsystem	Component	Purchase (P) Modify (M) Build (B)	Raw Materials Needed to make/modify the part (only M & B)	Where/how procured?	Equipment and Operations anticipate using to make the component	Key limitations of this operation places on any parts made from it
3	Inside Mechanisms	Pitman Arm	B	Mild Steel Plate	Metals Depot	1. Waterjet 2. Deburr 3. Drill and ream to exact hole dimensions in mill	Tight tolerances
		Shaft A	B	3/4" Mild Steel Round Bar	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		Pitman Arm Shaft	B	3/4" Mild Steel Round Bar	Metals Depot	1. Waterjet 2. Deburr 3. Drill and ream to exact hole dimensions in mill	Turning to the right size and tolerances
		Pitman Arm Shaft Nut	B	Mild Steel Plate	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		Ball-Bearing	P		McMaster-Carr		Tight tolerances
		Flywheel	B	Mild Steel Plate	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		Flywheel Retainer	B	Mild Steel Round Bar	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		Shaft B	B	3/4" Mild Steel Round Bar	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		Coupling	B	Mild Steel Round Bar	Metals Depot	Face and turn in lathe	Turning to the right size and tolerances
		One-way locking bearing	P		McMaster-Carr		Tight tolerances

Appendix G – Design Verification Plan (DVP)



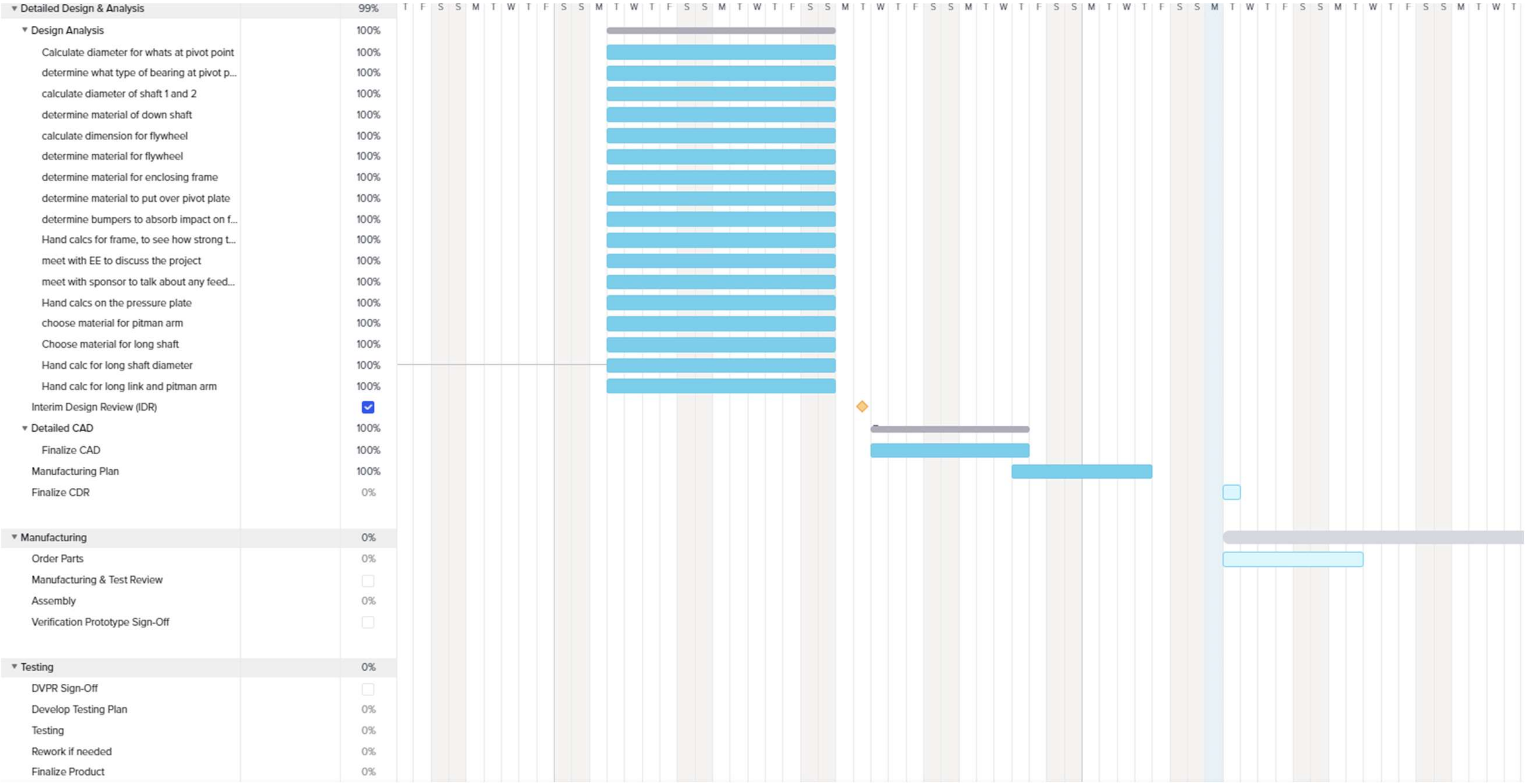
DVP&R - Design Verification Plan (& Report)

Project: Traffic Turbine
Sponsor: Michael Goren and Jeremy Goren
Edit Date:

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Height clearance	Ensure that the ramp doesn't exceed the maximum height by measuring from the ground to the ramp's tip. This will be done using the final prototype (FP).	Height (in)	Less than 4 in	Tape measure	N/A	Alejandro	11/14/2023			
2	Impact load	This test will simulate the impact of a vehicle that is expected to produce 500 pounds or greater. This will be done using FP.	Weigh (lb)	Greater than 500 lb	Motor	Test rig	Yosef	11/14/2023			
3	Energy production capacity	Transmit an impact load through a shaft on which a flywheel is mounted to generate electricity. This will be done using FP.	Energy (Watt)	500 W or greater	Electrity motor and generator	Test rig, flywheel, shaft	Jairo	11/14/2023			

Complete these columns when you conduct the tests.

Appendix H – Gantt Chart



▾ Detailed Design & Analysis	99%
▾ Design Analysis	100%
Calculate diameter for whats at pivot point	100%
determine what type of bearing at pivot p...	100%
calculate diameter of shaft 1 and 2	100%
determine material of down shaft	100%
calculate dimension for flywheel	100%
determine material for flywheel	100%
determine material for enclosing frame	100%
determine material to put over pivot plate	100%
determine bumpers to absorb impact on f...	100%
Hand calcs for frame, to see how strong t...	100%
meet with EE to discuss the project	100%
meet with sponsor to talk about any feed...	100%
Hand calcs on the pressure plate	100%
choose material for pitman arm	100%
Choose material for long shaft	100%
Hand calc for long shaft diameter	100%
Hand calc for long link and pitman arm	100%
Interim Design Review (IDR)	☑
▾ Detailed CAD	100%
Finalize CAD	100%
Manufacturing Plan	100%
Finalize CDR	0%
▾ Manufacturing	0%
Order Parts	0%
Manufacturing & Test Review	☐
Assembly	0%
Verification Prototype Sign-Off	☐
▾ Testing	0%
DVPR Sign-Off	☐
Develop Testing Plan	0%
Testing	0%
Rework if needed	0%
Finalize Product	0%