Final Design Report:

Pedal-Powered Drivetrain System

June 3, 2017

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Sponsor: Geoffrey Wheeler
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Mechanical Engineering CAL POLY

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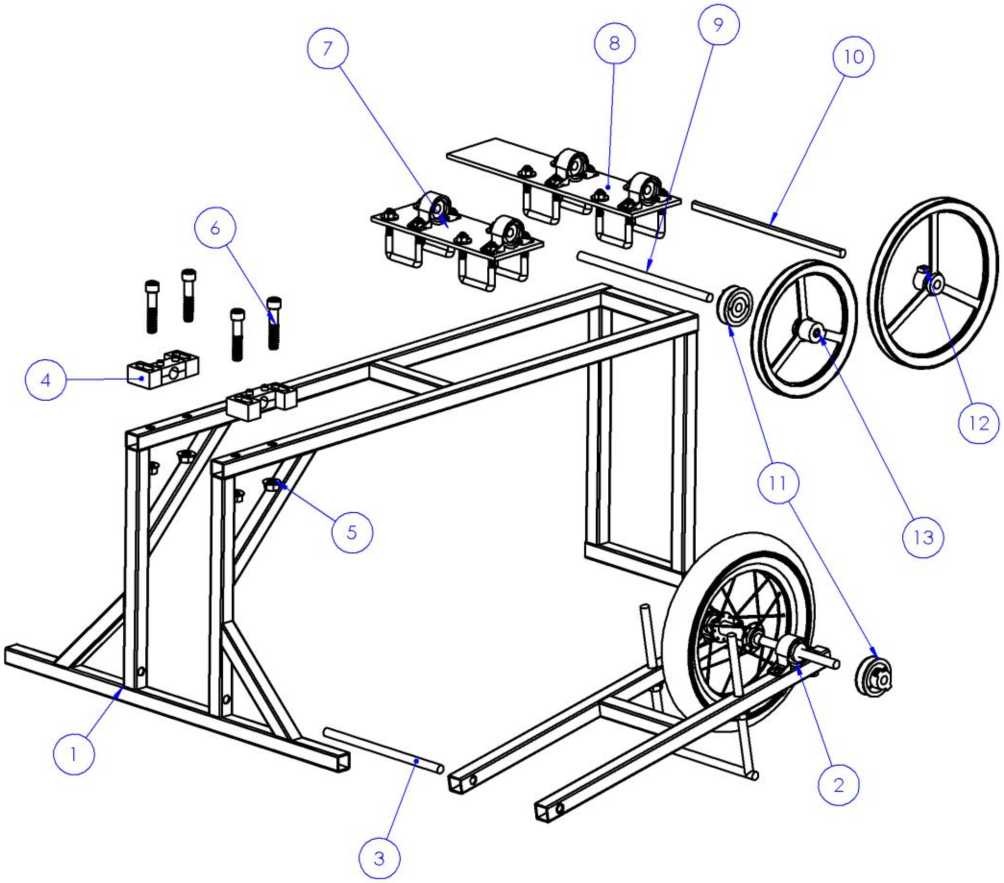
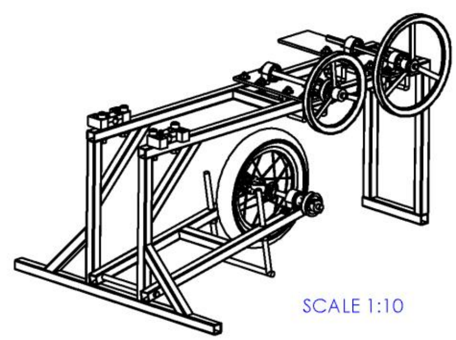


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame_	1" Steel Square Tube Frame	1
2	FD_Assem	Friction Drive Assembly	1
3	FD Arm&Frame Connection Shaft	1/2" FD Swingarm Pivot Axle	1
4	AxleSupportAssem	Bicycle Axle Supports	2
5	94612A104	1/2"-13 Steel Flange Nut	4
6	91251A722	1/2"-13, 2.5" Socket Head Screw	4
7	Adjustable shaft system_perp	Adjustable Shaft Assem - Intermediate	1
8	Adjustable shaft system_perpMounting	Adjustable Shaft Assem - Output	1
9	UpperShaft1	Intermediate Shaft	1
10	OutputShaft	Output D-Shaft	1
11	6245K18	2.25" OD, 1/2" Bore Zinc Pulley	2
12	6245K951	10" OD, 1/2" Bore Zinc Pulley	1
13	6245K55	8" OD, 1/2" Bore Zinc Pulley	1



Cal Poly Mechanical Engineering ME 429 - Winter 2017	Lab Section: 08	Pedal Power Sr. Project	Title: Main Assembly		Drwn. By: Geremy Patterson
	Dwg. #:	Nxt Asb:	Date: 2/5/17	Scale: 1:6	

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1 – INTRODUCTION

1.1 -- SUMMARY

In conjunction with another senior project team, our intention is to design a system that allows isolated communities to process their own maize. More specifically, our team will design a drive that transmits power from a human-pedaled bicycle to various other machines, (primarily a grinding mill) via multiple gearing reductions. The residents of Kumponda, Malawi are intended to be the primary users of our project's products. Our goals are to design and build a prototype, provide our sponsor (Mr. Wheeler) with detailed parts drawings, manufacturing instructions and an Operation Manual. Crucial design challenges will be reliability, reparability, and manufacturability. The nature of the project constrains our building materials and fabrication to what is available in and around the urban center of Blantyre (population - 1 million). The Cal Poly Chapter of Engineers Without Borders (EWB) has attempted this project before on multiple occasions with mixed results. EWB will be provided with our design and the results we have concerning the first iteration and the testing performed. They will have the option to implement our design at their discretion, and we plan to work in conjunction with them to the extent that each of our groups may maximize results. Mr. Wheeler will also have the opportunity to implement the design as he chooses.

1.2 – Persons Involved

Fourth year Mechanical Engineering students at California Polytechnic State University, San Luis Obispo; Callaghan Fenerty, Bradley Welch, and Geremy Patterson are the members of team 34. Career engineer and humanitarian Geoffrey Wheeler has past experience with human powered devices and sponsoring similar projects with the EWB Malawi team. Professor Eileen Rossman and the Cal Poly Mechanical Engineering Department will provide structure and guidance for the entire design process. Chris Apple (an Engineers Without Borders member who has previous experience with this project) along with assistance from other members of the EWB team will supply us with firsthand knowledge of the problem and feasibility of possible solutions. Note that EWB is currently working on their own version of this project separately from our senior project.

Mr. Wheeler provided us with contact information of a Brian Banda, a man he knows in Malawi. Mr. Banda recently completed engineering school at the polytechnic school in Blantyre and works in the engineering field in Malawi. He has been invaluable in providing answers for our part availability, price and manufacturing questions.

1.3 – Previous Efforts

The Cal Poly chapter of Engineers Without Borders (EWB) has sent student representatives to Malawi four times spanning from December 2013 to present. They have built at least one prototype at Cal Poly and have implemented two designs in Malawi, detailed briefly in later sections, with mixed results. We hope to learn from previous efforts in order to improve upon the existing solutions.

2 – Background

2.1 – Root Problem

Food insecurity experienced by the people of Malawi is the fundamental issue we hope to address. Food insecurity is: “the state of having unreliable access to a sufficient quantity of affordable nutritious food,” [1]. Rural communities in Malawi rely on subsistence farming for the vast majority of their food. Maize or cereal-corn is the major food crop covering 80% of farmed land and constituting 50% of their diet [2]. According to the International Fund for Agricultural Development (IFAD), "Malawi is able to produce around 3 million tonnes of maize, which is above the self-sufficiency level of 2.3 million tonnes. However, in poor seasons widespread food shortages are experienced. Many households with large families and small plots suffer chronic food insecurity and malnutrition." Furthermore, according to IFAD, "Post-harvest losses are estimated to be around 40 percent of production,” [3].

2.2 – Our Problem

Action for Environmental Sustainability (AFES), a NGO was started in 2007 to determine the most critical factors contributing to poverty and environmental degradation in communities in Malawi. Beginning in

2013 EWB began traveling to Malawi to determine how they might address the needs determined by AFES. Kumponda self-identified their greatest need as food security. Through meeting with residents and discussing their daily routines, EWB learned that villagers walk up to 3 hours with upwards of 15 kg of maize to an electric mill to have it ground into a fine flour. The entire country of Malawi is run from one power plant that is prone to outages. This poses a large problem for the villagers who have travelled to grind their maize because they do not have certainty that the mill will be operational when they need. Furthermore, the cost to use the electric mill is roughly one day's wages. In the case that electric mill remains non-operational, the villagers may need to carry their maize back and return a different day. The only other known alternative for the villagers to grind maize is by hand which is arduous and time consuming. We need to develop a power source for a custom-built maize mill and possibly other machines that will be implemented in Kumponda.

2.3 – Location (15.65°S,35°E)

The Kumponda group-village residents are intended users of the system we will design. They are a rural agricultural community dispersed over approximately a 40 square kilometers area in Southern Malawi (see Appendix A for maps). Malawi is a relatively small under-developed country located in southeast Africa. The federal government of Malawi is not fiscally solvent and relies heavily on foreign aid to function. Kumponda is on the north western outskirts of Malawi's major commercial and financial city, Blantyre [4]. We anticipate that our design will require manufacturing tools and processes not available within Kumponda. Therefore, we will consider the cost and logistics of transporting some parts, if not the entire system to the operation site.

Kumponda is a "group-village" comprised of 22 sub-villages with a total population of about 29,000. The term group-village means that although there are many separate groups of dwellings, the people there consider themselves members of a larger community politically centered around one. Kumponda is one of the most densely populated rural areas in the Blantyre district. The community is extremely underdeveloped, to the point where residents experience issues in basic daily needs like access to clean drinking water. Non-governmental humanitarian organizations such as “The Vibrant Village Foundation” and “Action for Environmental Sustainability” are currently involved in the area [5].

Central Kumponda is located 15 km north of Blantyre, and 2 km west of a major highway that runs north out of the adjacent urban area. There is a hardware store that is the Malawian equivalent of Home Depot [2], but with a smaller selection.

2.4 – Customers

2.4.1 – Mr. Wheeler (*Sponsor*)

Geoffrey Wheeler is a Cal Poly Mechanical Engineering graduate and acting director of the Center for Vocational Building Technologies. After graduating from Cal Poly, Geoffrey quickly took his talents overseas and founded the CVBT, a non-governmental-organization that promotes the manufacturing of building materials for employment creation [8]. Geoffrey has traveled to Malawi to assist EWB with their implementation of previous maize mill designs. With his travels to Malawi, he is a reliable source of

knowledge into the culture and day-to-day life in Malawi which will be extremely important throughout the project and specifically in the detailed design phase. Geoffrey will be an instrumental influence in ensuring the project develops correctly.

2.4.2 – Mr. Apple and EWB *(Consultant Organization)*

Chris Apple and other members of the EWB originally attempted the maize mill project in Malawi [8]. Their work on previous implementations will assist us in understanding the scope of the project, and also provide us with insight into the benefits and pitfalls of various aspects of the previous designs. Upon the completion of our portion of the project we will turn over our prototype and documentation to EWB in hopes they implement our design in Malawi.

2.4.3 – Local Machinists & Potential Entrepreneur *(Manufacturer)*

It is very likely that our project will involve some form of machining, and possibly a Kumponda resident willing to bring our project to the Malawian marketplace. It is hard to get a complete understanding of the machining capabilities without experiencing them in Malawi firsthand, but from the information we have gathered so far, both supplies and accurate machining ability are present but limited [7]. See Figures 1 and 2 for examples of manufacturing in Kumponda. It will be essential to provide the manufacturer with specific drawings so that miscommunications are minimized. We anticipate an emphasis on design for manufacturability as the project progresses. Hopefully a few EWB members will be able to assist with the new implementation of this project.

Figure 1. Local mechanic cutting L-bracket for one of EWB's earlier designs [7].

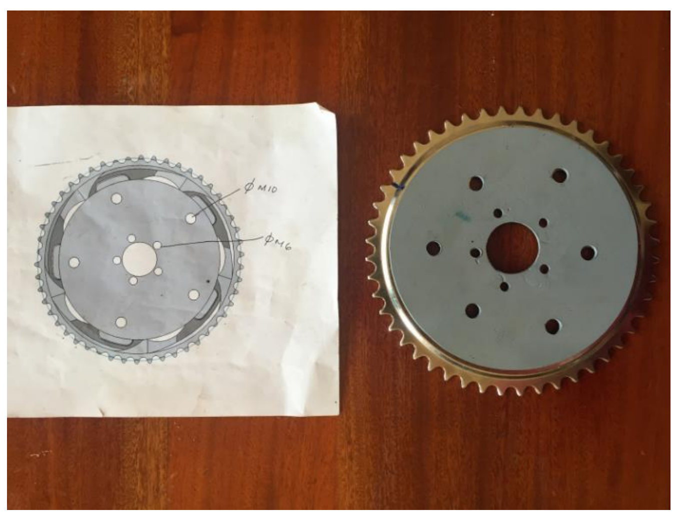

Figure 2. Side by side of drawing and part produced by machinist in Blantyre [7]

2.4.4 – Residents of Kumponda Group Village *(User and Maintainer)*

Malawi, and more specifically Kumponda, is a place that is not widely known partly due to the area's sparse electricity and internet usage. The per capita income in Malawi is less than $1.25 per day [3], so residents are not living lavishly by any means. Among other issues like clean drinking water, Kumpondan residents express a need for better food security. The majority of their diet is corn-based and requires the corn kernels be ground to fine flour which requires a maize mill. This flour is used to make a substance called nsima which is a staple part of the Kumponda diet and is eaten with every meal [2]. However, the nearest powered maize mill is about a 3 hour walk from the farthest village in Kumponda. Many times upon arriving at the electric mill with large bags of maize, the mill is not operating due to lack of electricity so the villagers must either wait until electricity is restored or walk back home empty-handed [2].

2.5 – Benchmarking

This section serves to survey some of the existing ideas and solutions to problems similar to our maize-milling problem in Malawi.

2.5.1 – Bicycle Kit for GrainMaker® Mill

The GrainMaker Mill with bicycle-powered kit [9] is sold online as two separate products. The hand-powered mill (Model No. 99) retails for $607.50. The "bicycle kit" accessory, which is sold separately for $256.50, enables the user to power the mill with a 26" wheel bicycle. Figure 3 shows both devices connected and in use during a pedaling/milling operation. The power transmission system can be broken down into a few stages of transmission. First, power is transferred from the spinning rear wheel of the bicycle directly to a roller that functions as a friction wheel. This friction wheel is fixed to a shaft. The other end of the shaft is fixed to a pulley wheel. The pulley on the bicycle kit's shaft is connected to a pulley on the grain mill via a belt. The grain wheel's pulley is the final speed reduction in the transmission system and is connected directly to the actual mill. This design satisfies most of the requirements, but is not practical for manufacture in Malawi.

Figure 3. Grainmaker® Mill Model No. 99 in use with attached bicycle kit [7].

2.5.2 – US Patent US6983948B2: Human powered device and removable flywheel power unit

This patent [10], published on January 10, 2010, details a self-contained mechanical device that can be connected to various machinery, more-specifically applicable for less-industrialized nations. The device is composed of a pedal assembly, a power unit frame, a flywheel assembly, and transmission assembly. The patent is currently listed as expired. The fundamental aspects of the device are shown in Figure 4.

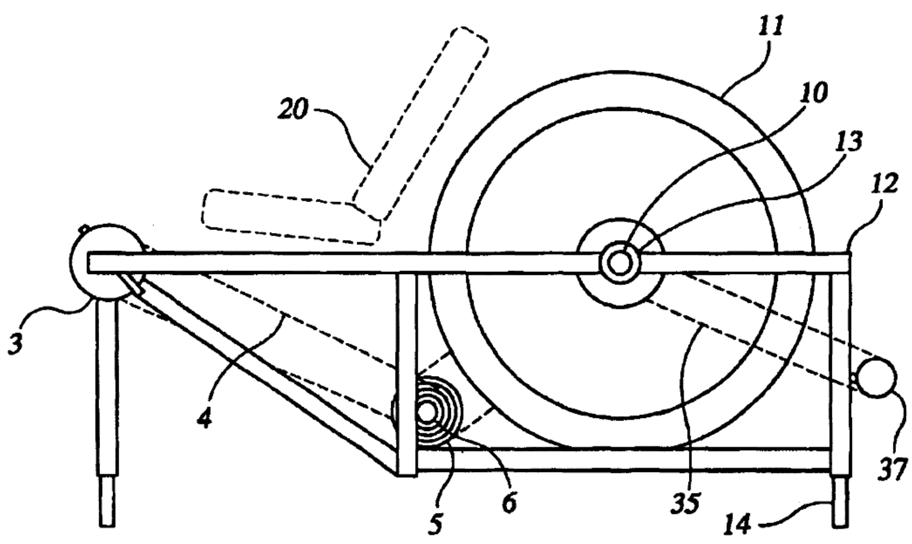

Figure 4. Basic schematic of the device described by US Patent #US6983948B2 [10].

2.5.3 – Fluid2 Cycling Trainer

The generic cycling trainer frame design [11], shown in Figure 5, is potentially applicable for project. It supports the bike by the rear axle and provides stability to the bike and rider during operation. The friction wheel is on an adjustable swing arm. The swing arm can be loosened by a bolt, adjusted to a new position about its pivot and then fastened again. The adjustable design accommodates 26''-29'' wheels. The radial adjustability to the tire allows for the friction wheel and the bike tire to be brought into proximity so that the normal force between the two is maximized to prevent slipping. An axially adjustable slotted bolt-action mechanism on the frame enables the bike to be mounted to the frame quickly and then locked in place for ensured stability. This mechanism can accommodate 120-135mm dropout spacing. When in the locked position the rear axle is limited to zero degrees of freedom. The friction wheel is a precision-machined polished alloy two-inch diameter cylindrical roller. The company website claims this reduces slipping. The friction wheel roller is connected to a fluid resisted flywheel and a fan.

Figure 5. The Fluid2 Cycling Trainer pictured without bicycle [11].

2.5.4 – Exercise Bike Flour Mill, Provident Living New Zealand

In New Zealand, Provident Living created a pedal-powered grain mill [12] that uses a slightly different form of pedal power which is shown below in Figure 6. Instead of using a traditional bicycle, Provident Living converted a twenty-dollar stationary trainer bicycle into the useable power source for a grain mill. The stationary bike itself uses a flywheel design that is located in front of the pedals. Provident Living connected this flywheel to a hand-powered mill via a belt so that as the user pedals, the flywheel rotates and drives the belt which turns the input wheel of the hand-mill. This design also satisfies most of the requirements, but is not manufacturable in Malawi.

Figure 6. Provident Living's stationary bike grain mill conversion [12].

2.5.5 – People Powered Flour Mill

The People Powered Flour Mill is "a bicycle-driven grain grinding mill designed to connect the community to its local food production" [13]. Like other pedal-power machines, this design uses a friction wheel; however, its implementation is slightly different. Where most friction drives in this application use some type of roller to meet the bicycle tire, this design uses a smaller tire so that the contact of the friction drive is rubber to rubber. A flexible driveshaft is connected directly to the shaft of the secondary wheel and provides the power input for the grain mill. Of the designs we've benchmarked, this is perhaps the most comparable to the implementation we would like to make in Malawi. Again though, this would be extremely difficult to manufacture in Malawi. This system is shown below in Figure 7.

Figure 7. The bike power portion of the People Powered Flour Mill with flexible driveshaft [13].

2.5.6 – Country Living Mill with custom bicycle power attachment

The Country Living Mill is a hand-powered grain mill that is sold by Country Living Productions Inc. Youtube user marthale7 fabricated a custom design [14] to attach a bicycle to this mill as a source of grinding power. Figure 8 shows a video snapshot of this design. This custom design consists of a belt that is wrapped around the profile of the bicycle's rear wheel and connected to the input wheel of the Country Living Mill. The bicycle's rear tire is removed to allow a surface for the belt to contact. A stationary frame supports the bicycle at the rear wheel so the user can remain stable while pedaling. This design does not meet the needs expressed in Kumponda because if a bicycle is used in the design, it must be easily removable and useable as a normal bicycle.

Figure 8. Direct belt-drive system from rear wheel to input wheel of Country Living Mill [14].

2.5.7 – EWB Design 1 - Friction Drive

The first design solution to be developed by EWB involved a bicycle paired to a friction wheel. A frame built from untreated construction wood, primarily 2x4, was built to support the rear wheel of the bicycle off the ground so that it can spin freely. Pegs attached to the rear axle of the bike were seated in notches at the top of two vertical 2x4. A wheel barrow hub attached to a steel pipe was used as the friction wheel. This axle was supported by a small a-frame structure. The axle ran through holes drilled in the wood and no bearing or bushings were used at this interface. Figure 9 pictures a prototype of this design built at Cal Poly. The design did not incorporate in adjustability to the distance between the center of the bike wheel and the friction wheel. The EWB design was based on the assumption that the power output of a bicycle rider is 150 watts/hr and the required torque to grind maize was 70 N-m.

Members from EWB identified issues with this design. The primary issue was that the tire of the bike and friction wheel hub could not consistently maintain contact. This occurred because the coefficient of friction and normal force between the tire and friction wheel were unable to match the required torque.

Figure 9. EWB initial prototype of their friction wheel design built at Cal Poly [8].

2.5.8 – EWB Design 2 - Chain Drive

The second EWB design stemmed from the issues faced from the first design. Changes made to the drive train revolved around replacing the friction wheel with a sprocket and driving the rotating shaft by a chain from the front sprocket of the bicycle. The idea behind this design is to eliminate slipping and provide continuous power delivery from the bicycle cranks to the drive shaft. The SolidWorks model shows the sprocket attached to the rotating shaft by a collar with screws attaching the sprocket and collar [8]. The hub is connected to the rotating shaft by two set screws [7]. The rear axle of the bicycle is supported in a horizontal slot allowing for the distance between the bike crank and rotating shaft sprocket to be adjusted. This adjustability enables the chain tension to be optimized. EWB members have expressed support for this design because it provided more reliable power delivery in their experience. See Figure 10 below for a picture of the Malawian prototype.

Figure 10. Early implementation of the chain-driven prototype in Malawi [7].

2.5.9 - Concrete Bicycle Flywheel

Maya Pedal Power is an organization based in Guatemala that designs and implements pedal-powered machines in underprivileged areas of Guatemala [15]. In their design for a pedal-powered grain mill, they use a bicycle wheel filled with concrete to act as a flywheel, as is shown in Figure 11. We believe this flywheel option has strong potential for success in Malawi because of the material accessibility and the rotational balance provided by using the bicycle wheel as structure. The full system that utilizes the Concrete flywheel is displayed in Figure 12 below.

Figure 11. Bicycle rear wheel in the process of being filled with concrete [16].

Figure 12. Full system [16].

2.6 - POTENTIAL POWER SOURCES

This section presents and discusses multiple power source possibilities for use in our project. Although human pedal power will be the primary input, we will consider additional sources of power to supplement human power.

2.6.1 – Electrical

Electricity from the grid is not a viable power source. Inconsistent electricity is a major issue as detailed in Section 2.4.4.

2.6.2 – Hydro

Hydro-mechanical power is not a viable power source. Malawi is currently experiencing a drought and many of the sub-villages are too far from running water.

2.6.3 - Fuel Combustion

Fuel combustion is not a viable power source. Fuel supply is limited in Kumponda and the design/manufacturing of any sort of combustion engine is beyond the budget and scope of this project.

2.6.4 – Wind

Wind was previously considered as a potential power source, supplemental or otherwise. However, given the mostly small amount of wind energy available, we have ruled out the possibility of wind energy for this reason and others.

2.6.5 - Human (Pedal Power)

Human power is likely our most realistic option. Our project will focus primarily on human pedal power. Although it will require the user to expend their own energy, it is an attractive alternative to the current method of transporting maize to a mill and back (which requires energy from the user anyway). We expect the male residents of Kumponda will be able to produce and sustain an average of roughly 2.22 W/kg body-mass (see Appendix C) [16]. This translates to 150W output for a 68kg male. For females,

(assuming 54kg body-mass) the expected power output is about 100W (at 1.83W/kg). Various factors such as (bodily) overheating due to lack of airflow, and the use of a flywheel to enable consistent and therefore easier power delivery will be considered.

2.7 – Maize Mill Project Team Relations

Bradley, as the primary contact for relations outside of our project team, will serve as the main communication link between our team and the maize mill project team. However, responsibility lies with all teammates to ensure proper communication with the maize mill team at all points in the design process. Communication between our two teams is essential so that we can ensure compatibility between the two mechanical devices. A large portion of design collaboration between the two teams will be discussing the interface from our output shaft to their power input.

3. – Requirements

3.1 – Problem Statement

Villagers in rural Malawi need a reliable source of rotary mechanical power to drive machinery, chiefly a maize flour mill, because current methods are inaccessible and reliant on inconsistent electrification.

3.2 – Goals

Our goals are:

- Design a robust, efficient drive system that can be sourced and fabricated in Blantyre which includes:
    - Human pedaling power as primary energy source
    - Rigid mountings for the machines that will receive power (vertical and horizontal)
    - Frame and drive train (with necessary reductions)
    - Emphasis in design will focus on the use of the system to power a maize mill. Other uses for the drive system will be considered secondarily.
- Build and test a prototype of the system here in San Luis Obispo.
- Specify parts in metric and compile technical drawings necessary for manufacturing.
- Create a document with sufficient instructions for construction in Malawi.
- Create an 'Operation' manual.

3.3 – QFD PROCESS

The QFD, or Quality Function Development, is a tool used in universities and industry. It aims to define customer requirements and engineering specifications in a more organized manner so that the project more accurately satisfies the customer's needs. We first began with defining all of the "customers" or people that will be affected by our project in some way. Then we compiled a list of their requirements and rated them on a scale of 1-10 of importance to each customer. From these customer requirements, we generated a list of engineering specifications that can be validated along with goals for each specification. Table 3.4.1 and Table 3.4.2 present these engineering specifications. To see the outcome of our entire QFD process, a completed QFD table can be viewed in Appendix D.

3.4 – ENGINEERING SPECIFICATIONS

In the tables below, risk is assessed in terms of high, medium, and low (H, M, L) and the compliance column letters refer to testing, analysis, or inspection (T, A, I) as means by which to measure how well we met each criteria.

Table 1. Quantitative Specifications (see Appendix D: QFD)

Spec	Parameter	Requirement	'Tolerance'	Risk	Compliance
1	Maximum Allowable Input Torque	250 (N m)	±5	M	T, A
2	Set-up Time	<5 (min)	Minimize	M	T
3	Compatible Wheel Sizes	60-68 (cm)	±1	L	I
4	Cost	$300	Minimize	M/H	A
5	Stability	90 (kg) unbalanced pedal load*	±5	L	T
6	Steady State Operation Tolerable Power	150 (Watts)	±10	H	A
7	Torque Required by Mill	40 (N m)	±10	H	A, I
8	Maximum Tolerable Power	250 (Watts)	±10	M	T, A
9	Highest Speed Range	2000 (RPM)	±150	H	T, A

Table 2. Qualitative Specifications (see Appendix D: QFD)

Spec	Parameter	Requirement	Risk	Compliance
1	Power	Maximize	L	T, A
2	Frame Strength	No critical deflection under load	H	A
3	Drivetrain Strength	No critical fatigue or vibration	M	A
4	Output Shaft Orientation	Horizontal	L	I
5	Corrosion/Rot	Vulnerable Surfaces Treated/Painted	L	I
6	Rotation Direction	Clockwise (looking at mill back or alternator front)	M	I
7	Efficiency	Frictional Losses do not imeede regular operation	l	T,i

3.5 – Discussion

For quantitative specification #1, efficiency, the 90% value refers to the ratio of the power our system receives to what it delivers. Our system will have as little frictional losses as possible but considering the potential variety in quality of parts available in Malawi we mainly expect to maximize efficiency. Furthermore, if our system happens to incorporate a full independent bicycle, we will be out of control of said bicycles frictional losses. The setup time parameter comes from our interview with Mr. Wheeler during which he expressed the importance of easy use. The wheel size parameter pertains to the anticipated use of existing bicycle components in our design (potentially an entire bike). The cost and output height parameters were given. From EWB documents we discerned that villagers prefer to pedal in high gear and thus we anticipate the full body weight of a male to applied to any pedal type inputs we may require. Our spec for maximum tolerable power corresponds to the maximum power output of a “healthy-men” cyclists over an hour time period. The steady state tolerable speed is what we plan to spec our drive train components for in fatigue analysis. Speed Range specification comes from the need for our device to run an alternator (2000 rpm ideally [6]), and also run a mill at high torque (40 ±10 Nm). The lower bound on the speed spec is less rigid because it depends on the needs of the mill team. The maximum torque experienced by our system will occur at highest power input and lowest output speed. At 400 W and 20 rpm the resulting torque is 239 (N m), hence the 250 (N m) specification, at least to start with. The rotation direction is only included because if the alternator in question is used for any AC applications, the phase will be 180 degrees off of normal. A DC setup such as battery charging system will not be direction dependent. The qualitative specs are mainly a basis to work from as we gather more information and the requirements from the mill become clarified.

4. – Design Development

The design process approach used will follow the outline shown below. These steps are based on the deliverables required for the project.

4.1 – Processes Overview and Methodology

4.1.1 – Problem Identification and Definition

This part of the process involves developing specifications for the project. The project proposal document is largely developed to establish a definition and scope for the problem. The first step in defining the problem is to understand the needs of the users. Research shown in this document regarding the people, environment, and challenges in Malawi has been used to develop the problem statement. The problem statement can be found in section 3.1. AFES and EWB have done on site observation and questioning in the community to determine the greatest needs faced in Kumponda. This information was used by our sponsors to present our team with the problem.

4.1.2 – Conceptualization

For this portion of the process, the team will generate concepts using creative processes such as brainstorming and brain-writing to ideate. All the background research and benchmarking shown in this document will be used as references for us to generate ideas that address the problem definition.

4.1.3 – Evaluation and Analysis

Designs will be evaluated based on how they satisfy both quantitative and qualitative engineering specifications shown in Tables 3.4.1 and 3.4.2. For quantitative specifications, analysis will be performed to determine how well the design characteristics meet required parameters. This analysis will be carried out either by hand or calculation tools such as Excel, SolidWorks, FEA, and Matlab. Qualitative requirements will be evaluated based on speculation of how the design will meet the requirements and promote overall operation of the device.

4.1.4 – Detail Design

Once a particular design has been evaluated and determined to successfully fulfill requirements, a detail design will be developed using SolidWorks. We will produce individual part detail drawing as well as assembly drawings. The detail design should be developed in such a way that it will be easily understood and repeated by the intended manufacturers and users.

4.1.5 – Manufacture

Manufacture will be conducted in shops on campus with the tool limitations of Malawian machinist and villagers in mind. Fabrication processes will be limited to non-computer-controlled machining methods. Welding will be GMAW (or MIG) type on the frame and other components that require welding. Ride it

4.1.6 – Validation

Prototype parts and the full assembly will be tested for operational functionality. Physical testing and measurements will be performed to compare to the engineering specifications. This will be the ultimate

test of validation for designs. If parts fall short of the target specifications the impact will be evaluated. If it is determined that any part of the design will not work, it will be redesigned and manufactured until it can be validated against the requirements.

4.1.7 – Documentation

A full report will be developed that will encompass all stages of the process outlined above. It will explain the criteria for design selection and reasoning behind why the final design was ultimately chosen. The report will include instructions on how to repeat development and manufacture of the design. It will include operation and maintenance instructions.

4.2 – Functional Break-down

We began ideating by establishing crucial functions our design should perform. Note that these functions are intended to constrain the creative process as little as possible.

4.2.1 -- Transmit Power

More specifically, our device must receive mechanical energy from some prime mover and convey said energy through the system to some rotatory output. One goal for the power transmission function is to maximize efficiency of the transfer. The power at the output shaft should ideally have minimal losses through the system and be as close as possible to the power applied by the prime mover.

4.2.2 - Supply Required Work Rates and Magnitudes at the Output

Our system must produce sufficient torque at the appropriate speed. Different applications that may be attached to the drive system will require different operating speeds for their functions. Our project is primarily focused on providing the speeds and torques that will best suit the operation of the maize mill. However, even the maize mill application may require various operating speeds and torques depending on its design.

4.2.3 – Self Support

Our design must be free standing with only a flat concrete slab beneath it. The support must be able to maintain enough stability for other functions to properly work, ensure safety, and reduce fatigue on system components while in operation. The system must be able to support its own weight which includes structural components and the drivetrain and possibly the prime mover and attached applications as well.

4.2.4 -- Support and Interface with Prime Mover

Our design must able to accommodate, stabilize, and couple to whatever primary power source we select. Some challenges that may need to be addressed include supporting lateral weight transfer, torques, and dynamic imbalances of rotating components due to imperfect manufacturing.

4.2.5 -- Support and Interface with Driven Machine

Our design must incorporate a way for external machines, chiefly a mill, to mount on to and receive power from our device. Ideally for other applications such as an alternator or water pump there would

be some way to adjust the location of the attachments relative to the output shaft as well as providing support to accommodate different sizes of applications.

4.3 – Concept Generation

4.3.1 – Rotation

This function was ideated in order to determine the various ways rotatory motion may be generated. Ideas included:

- Water wheel
- Human mouse wheel
- Treadmill rollers
- Worm gear
- Rack and pinion from rowing machine motion
- Livestock moving rigid pole connected to center point of circle
- Wind mill
- Hand crank shaft
- Foot pedal shaft
- Two rollers underneath bike tire

From these function we concluded that human pedaling power met our requirements the best because of on demand usability and the power generated. The environmental sources of power mentioned could not be counted on to be adequate when the user needed. We determined that pedaling was the most powerful and efficient way for a person to produce rotary motion themselves.

4.3.2 -- Support

This ideation session focused on different methods of supporting the user, drivetrain, and attachments. The following concepts were generated:

- Bicycle work stand
- Rollers in a box for bicycle
- Down tube support with adjustable power screw
- Rear axle of bike supported by steel A-frame
- Block support for independent crank and spindle
- Tie down straps at corners of bicycle
- U-Shaped support for rear wheel of bicycle
- Adjustable bolt action hollow tube to clamp bolts of rear axle
- Concrete block with angled slots for bike wheel and hole for input shaft
- Box steel frame with incorporated bike components for drivetrain

4.3.3 -- Power Transmission

Various methods of transferring power from the source to the input shaft were explored. These concepts were developed under the assumption that human pedaling power would be used. Further,

the concepts were split into two general subsets. The first assumed the incorporation of a bicycle, and the second assumed a completely independent system not requiring a bike to be attached. These concepts by nature do incorporate both of the previous functions and are therefore closer to the system level. The following concepts were generated for bicycle incorporation:

- Friction wheel on input shaft contacts bicycle tire
- Pulley on input shaft attached by belt around rear wheel of bicycle
- Sprocket on input shaft attached to rear cassette of bicycle
- Sprocket on input shaft attached to front crank of bicycle

The following concepts are for self-contained systems:

- Pedals directly rotate input shaft and flywheel if used
- Bicycle cranks connected by chain to sprocket on input shaft supported by rigid frame
- Cranks attached to pulley transmit motion by a belt to pulley on the input shaft

These concepts are evaluated in the next section by a series of structured decision processes.

4.4 – Concept Development and Selection

4.4.1 – Go/No-Go

The first decision method used focused on the viability of concepts on a go-no go basis. Function concepts that were obviously infeasible or unnecessary were eliminated. For example, the human mouse wheel was determined to be a no-go as it was unnecessary for the scope of our problem. Only concepts that were determined to be viable were kept for further methods of consideration

4.4.2 – Pugh Matrices

Concepts that passed the go-no go criteria were then evaluated in a Pugh matrix with other concepts pertaining to the same function. Each Pugh matrix shows concepts sketches across the top and criteria down the left side. One concept is selected as the datum by which the criteria are measured. The other concepts are evaluated on they perform for a given criteria relative to the datum. The possible ratings are either worse than (-), equal to (=) or (s), or better than (+) the datum performance. There were three Pugh matrices developed for the functions of power sources, structure, and power transmission. The first function considered was power sources and its matrix may be found in Appendix E. The matrix allowed us to quantifiably determine human pedal power as the preferred power input.

This Pugh matrix for power source used pedaling as the datum concept. All concepts were evaluated for each criterion relative to the pedaling power and were determined to be less suitable to our project. The criteria considered for power source performance were immediacy of use, power availability, reliability, source fatigue, sustainability, size, cost, and finally complexity. This decision process validated our decision to focus on human pedaling power as the source of energy for our system. This consideration was incorporated into later decision matrices. The next function considered was how structural support in our system could be achieved.

The last Pugh matrix we developed considered the function of power transmission through our system given pedaling as the input mode having already been selected. These concepts were ultimately more system level concepts than specific function concepts because there is no way to productively consider how power transmission may be achieved without incorporating it into system structures.

4.4.3 – System Concepts

Two general categories of systems concepts resulted after the first phase of the idea selection process. The first group of concepts involves a bicycle incorporated into an external system. The second group removes the bicycle and instead is focused around a self-contained device for the entire system.

External System with Incorporated Bicycle

Concept 1: Friction Wheel with Belt Transmission

The first concept that involves an external system attached to a bicycle centers around a friction wheel and belt. As seen in Figure 13, a bicycle is mounted to the external system, and power is transmitted from the rear wheel of the bicycle to the system via a friction wheel. This concept is one that has been previously explored by EWB. The friction wheel then spins the output shaft through the use of a belt.

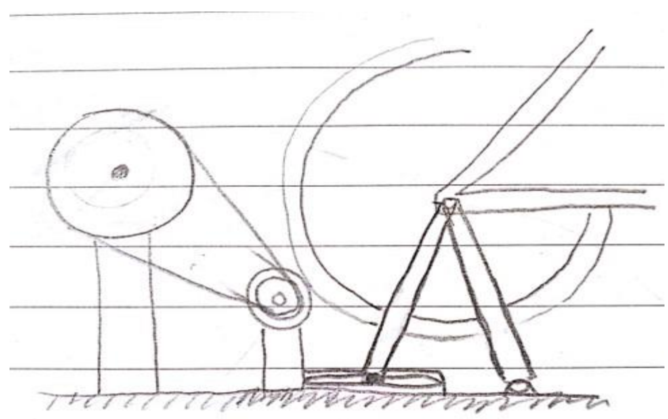

Figure 13. Sketch of the bicycle-driven friction wheel design.

Concept 2: Friction Wheel with Chain

This concept is virtually the same as Concept 1 shown in Figure 13, but uses a chain and sprocket system to transmit power from the friction drive to the output shaft instead of the belt. A chain-drive decreases the need for adjustability due to the slackening and wear that all belts experience. However, this chain-drive does add some complexity to the system as compared to the belt.

Concept 3: Secondary Chain Drive

The chain and sprocket direct drive eliminates the use of a friction wheel for power transfer. In doing so, issues with slippage between the bicycle tire and friction wheel no longer exist. This design is another concept that was explored by EWB. Their design required the removal of the rear wheel with a chain from the bicycle cranks to a sprocket on the input shaft. Another iteration of this concept is to leave the rear wheel on and add a secondary chain that is attached between the sprocket on the bike and a cog

on the input shaft of the external system. Therefore, as the bicycle's rear wheel spins, the chain transfers power to the input shaft, which in turn transfers power to the connected application. This concept requires a bicycle with a multiple cogs on the rear sprocket. A sketch of this design concept is shown in Figure 14 below.

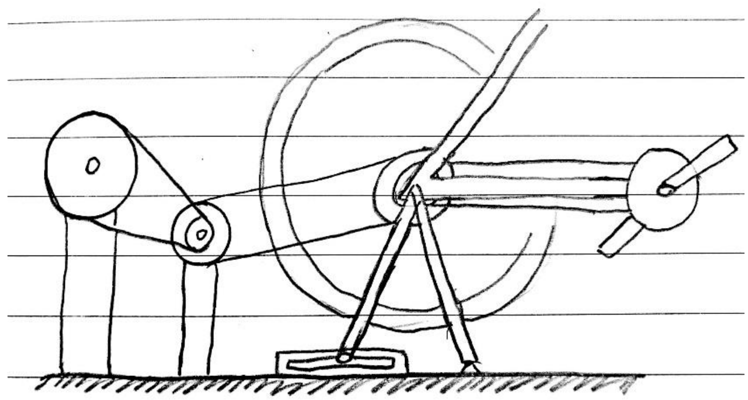

Figure 14. Sketch of the secondary chain drive design

Self-Contained System

Concept 4: Directly pedal flywheel + chain transmission

This concept utilizes the simplest method to power the rotating shaft which is to pedal the input shaft directly. Bicycle cranks are directly mounted to the input shaft which the user sits directly above and pedals from a seat. In the illustration shown below in Figure 15 the pedals are actually mounted to either side of the flywheel which is mounted on the input shaft. From the input shaft a chain or belt is used to transfer power to the output shaft where the attachments would be located. Drawbacks to this concept are the challenge of mounting pedals that can spin freely from the flywheel to ensure safety for the user, and a loss of opportunity for gear reduction.

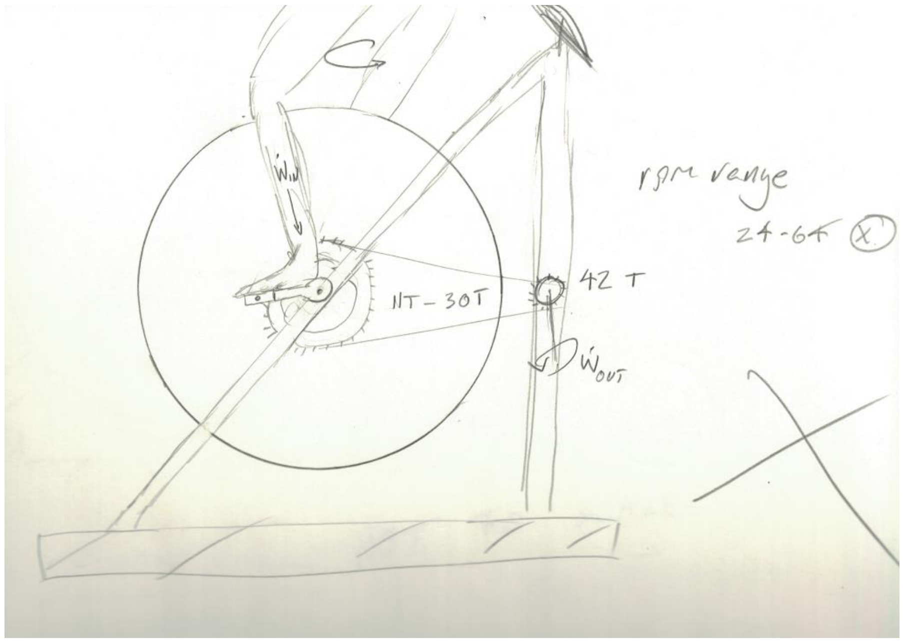

Figure 15 Pedals fixed to flywheel w/ one reduction concept

Concept 5: Bike pedals – flywheel – output w/ chain transmission

This concept also uses a frame with a self-contained drivetrain. However, as the layout in Figure 16 shows the user pedals conventional bicycle cranks and cogs which are connected by a chain to a freewheel sprocket from a bicycles rear wheel that is attached to the input shaft. This enables the user to stop pedaling and not be directly connected to the momentum of the flywheel which is rigidly connected to the input shaft. Another cog is attached to the input shaft as well and transfers power to the output shaft via a chain. This secondary transfer further allows for torque and speed adjustability by selecting different ratios.

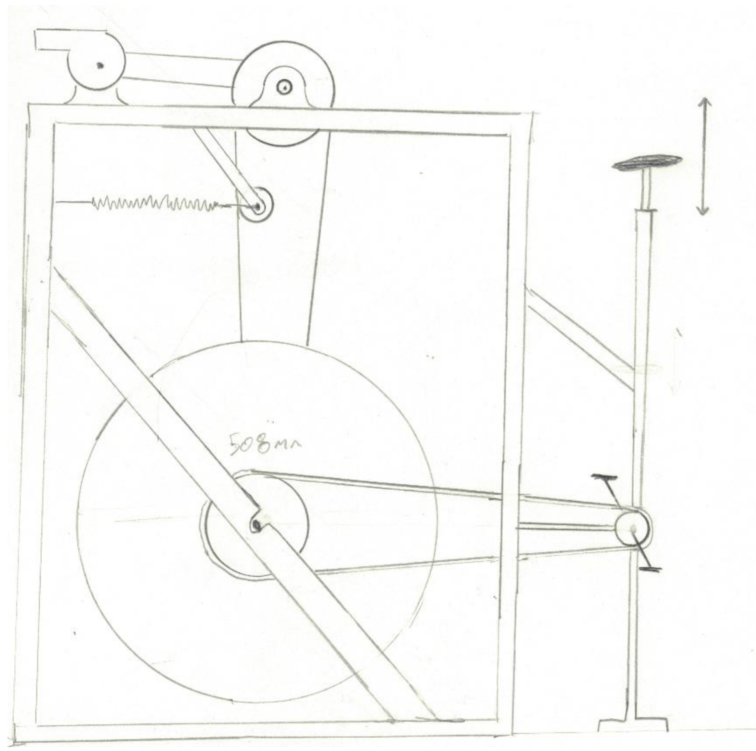

Figure 16. Side view system level concept with belt and chain.

Concept 6: Bike pedals – flywheel – output w/ chain and belt transmission

The final concept discussed here is very similar to concept 5 in that its layout is identical. The difference is that the power transmission from the input shaft to output shaft is achieved by using a belt. This enables the use of stepped pulleys on either the input or output shaft to achieve a variety of speed and torque combinations. A third pulley attached to a spring is used as a tensioning mechanism to ensure the belt stays in correct contact with the pulleys for different settings. Further this mechanism ensures the system maintains enough tension as the belts stretch over time. This concept is shown above in Figure 16.

4.4.4 – Weighted Decision Matrix

A weighted decision matrix was used to evaluate the top concepts. Each concept was evaluated based on how it met criteria that were chosen to reflect the specifications and requirements of our project. Each criterion is assigned a weight depending on how important it is in relation to the other criteria to the overall function of the system. As the decision matrix in Table 4.4 shows, manufacturability, cost, and power transmission are each given twice the weight of the other specifications, at 20%, because they are critical. Manufacturability, for example, is a requirement that must be met because if the design is unable to be manufactured in Malawi there is no way for the project to be successful. Similarly, if the system is incapable of transferring an adequate amount of power to the mill, the entire system is rendered useless. While cost specifications may be slightly more flexible than the previous requirements, it is still highly important because if the system is unaffordable it will never reach

implementation. This method of decision processing enables the relative importance of specifications to be evaluated.

Each concept is given a rating from 1 to 5 (1: poor, 5: excellent) based on how well it meets a given specification. This rating is then multiplied by the specifications weight to give a weighted rating. The weighted rating reflects both how the concept meets the requirement and how important it is. Weighted ratings for each concept are added together to give the total weighted rating which is an indication of how well the concept satisfies requirements. This provides a quantitative approach to determine which concept is "best".

The concepts considered in this decision matrix include the two basic approaches reflected in the system concepts section 4.4.3. The top two sections of concepts in the table incorporate the use of a bicycle. The first three concepts are various structural ways of supporting and adjusting a friction wheel input shaft connection to the rear bicycle wheel. The fourth and fifth concepts are structure and adjustment ideas for a system transmitting power from the bike cog to the input shaft by a chain. The final three concepts are different approaches to drivetrain systems that do not rely on the use of a bicycle.

As the table indicates, the concept that best met our specifications was a self-contained concept that uses a chain to transfer power from the user to the application. This concept performed well because it is highly usable and has good power transmission. One drawback to this concept is that it ranked relatively low in terms of cost because more parts need to be bought or manufactured than in other concepts. Ultimately this conclusion drove the final concept selection which is further discussed in the next section.

Table 3. Weighted decision matrix of system level concepts for power transfer and structure.

			Specifications							Total
			Manufact-urability	usability	cost	complexity	power transmission	maintenance	durability	
	Concept	Weight	20%	10%	20%	10%	20%	10%	10%	100 %
Friction Wheel with Bike	Swing arm	Rating	5	3	3	4	3	4	3	--
		Weighted	1	0.6	0.6	0.8	0.6	0.8	0.6	5
	Vertical slot for bike	Rating	3	3	3	3	2	2	2	--
		Weighted	0.6	0.6	0.6	0.6	0.4	0.4	0.4	3.6
	Vert/Hor. Input shaft adjust	Rating	3	2	3	3	2	2	2	--
		Weighted	0.6	0.4	0.6	0.6	0.4	0.4	0.4	3.4
Chain drive with Bike	Bike support on horizontal adjust	Rating	2	1	3	2	4	3	2	--
		Weighted	0.4	0.2	0.6	0.4	0.8	0.6	0.4	3.4
	Input shaft horizontal	Rating	2	1	3	2	4	3	2	--
		Weighted	0.4	0.2	0.6	0.4	0.8	0.6	0.4	3.4
Bike Independent Systems	Direct drive	Rating	4	2	4	3	2	3	4	--
		Weighted	0.8	0.4	0.8	0.6	0.4	0.6	0.8	4.4
	Chain drive	Rating	3	4	1	4	4	3	4	--
		Weighted	0.6	0.8	0.2	0.8	0.8	0.6	0.8	4.6
	Pulley drive	Rating	3	4	2	4	3	3	3	--
		Weighted	0.6	0.8	0.4	0.8	0.6	0.6	0.6	4.4

4.5 – Final Concept

Ultimately, the selection process resulted in the pursuit of the "swing arm" concept. However, initially we had selected concept 6 which was shown in the Preliminary Design Review and was a self-contained pulley driven system. This system was designed to transmit power from the PEDALS to an intermediate shaft, then from the intermediate shaft to the output shaft with a belt. After receiving feed-back from our sponsor we decided against further developing self-contained concept. This was due to learning that reusing old bicycles in Malawi is unrealistic since the community does not throw away old bikes. The self-contained concept was designed to reuse the bottom bracket from a bicycle which would have required the bike to be cut up. The manufacturing complexity of building our own bottom bracket made the self-contained system less feasible than using an existing functional bicycle incorporated into the system. This change was incorporated into the weighted decision matrix shown in Table 3 and a new top concept was selected. The new selected concept is explained in detail below. The Initial development of the self-contained pulley driven system can be found in Appendix H.

With our final system concept selected, we generated a preliminary design that conveyed the basic layout of system and showed how the components would interface with each other. Through revision based on feedback from our sponsor and further consideration within our team we have developed our critical design. Our critical design with a bicycle paired to the system is shown below in Figure 17. The main goal of this critical design is to detail the form and functions of the device and the method of power transmission from the user's pedal power to the output shaft. The output shaft is designed to supply power to external devices such as the maize mill.

A driving influence in our design thinking was to ensure the adjustability of our system. We identified this as an important criterion since there are two key uncertainties that our system will encounter. The first unknown variable is the power delivered to the system by the user. The second unknown variable is the torque demand from the maize mill. While we have worked to develop reasonable estimates for these values we recognize that both the supplied power and load demand can vary over a significant range. Because of this our design decisions were focused on accommodating this uncertainty by incorporating adjustability and room for changes.

Figure 17 Full system assembly with 700c bicycle attached

4.5.1 – Design Safety Hazard Identification Checklist

To begin this section, we must state the system we plan to create is not a consumer item but rather a piece of farm/food processing equipment and will therefore will not be confined by strict safety criteria. Having said that, safety is still a concern of ours and influences the design decisions that dictate the form and layout of our system. The potential hazards we have identified of design are:

- Rotating components
  - wheels
  - Pulleys and belts
  - Shafts
- Pinch points at belt pulley interface
- Overheating and exhaustion of the user
- Sharp edges

Long hair and or lose clothing present the biggest conceivable safety concerns regarding our design. Additionally, we expect our system to be used indoors in potentially hot (for humans) temperatures. It will be important to make the device easy to operate so that the users do not exert themselves fully and overheat.

A couple of safety modifications that are possible include enclosing the frame with plywood or another material so that the inner components are not as easily accessible during use. This would effectively remove the dangers of the rotating components mounted to the frame. Table 3 below shows the hazards we identified our system to be susceptible to and corrective actions that we are considering to address these

Table 4 – Safety Hazards and Corrective Actions

Number	Hazard	Corrective Actions
1	Hair/Clothing/Digit gets caught between friction drive components	Place the friction drive in a place that is hard to come into contact unintentionally
2	Hair/Clothing gets caught in belt(s)	Design drivetrain such that the moving components are as far from user as possible and covered adequately
3	User overheats pedaling	Design gearing ratios such that the torque required from user is minimized while maintaining grinding at a rate of at least 4 [kg/hr]. Also, warn of potential hazard in instructions.
4	Bike falls out of device with user on it	Design robust axle clamp screws. Possibly add a fail-safe feature to stop the bike from falling should the axle clamp fail.
5	Drivetrain failure results in torque loss at the pedals which can harm the user if he hits part of the bike or falls off	Design robust (high safety factor) drivetrain to avoid failure
6	System tips over when user sits on bike	Design base for adequate stability

The six hazards shown above in Table 4 were identified based on the safety hazard checklist which can be found in Appendix L.

5 – Detailed Design

5.1 – Functions / Requirement Satisfaction

We designed the pedal power system to meet the specifications established by our sponsors. The primary function the system is to supply the specified torque to the maize mill. To most clearly understand the functions of our system, we will describe the components flow of power through the system.

The user will attach his or her own bicycle to mounts on the system's frame. Once the bicycle is in place a friction wheel assembly will be adjusted into place such that the friction wheel is firmly in contact with the rear wheel of the bicycle. At this point the user will mount their bicycle and begin pedaling normally. The rotation of the rear bicycle wheel will cause the rotation of the friction wheel. A pulley mounted onto the friction wheel shaft transfers power to one of two pulleys mounted to an intermediate shaft. The intermediate shaft is rotating with a different speed and torque due to a change in pulley sizes. The second pulley on the intermediate shaft

5.1.1 – Output Capability and Range

Our system must be capable of providing power to a range of applications. Because various applications have different operating torques and speeds our system must be able adjustable in this respect to provide the appropriate type of power. The high torque requirement, of 60 N-m, for our system is based on the highest torque estimate provided from the maize mill team. This requirement defines the highest torque and lowest speed setting of our system.

The other end of our range is defined by the requirements of an alternator. The alternator needs to run at 2000 rpm. Our system accommodates this speed by re-oriented pulleys in the drivetrain from the maize mill application set up. By changing the order of the pulleys, speed increases are achieved relative to the input as opposed to torque increases as is the case for the mill. Drivetrain components were specifically designed to meet these two power output requirements.

5.1.2 – Accommodates Various Bike Sizes

The system has two features that have been designed to accommodate different bicycle sizes. The first bicycle feature affecting our design is the variation in rear axle lengths. Rear axle width can range from 100 to 130 mm for the bicycles we expect to be paired to the system. Adjustable axle mounts have been designed to connect bicycles in this range to our system. The second variable feature we have designed for is a range of bicycle wheel sizes from 26 to 29 inches. In order to allow for this variation, the friction wheel, which is the point of contact of the system drivetrain to the bicycle, is adjustable to different positions. The friction wheel is mounted on a swing arm that can move closer or further from the bicycle wheel as needed.

5.2 – Major Components

These components are the ones that provide critical functions in the overall device. Screws, nuts and other smaller components will not be discussed in this section, but can be viewed in the Technical Drawings and Bill of Materials in Appendix K and Appendix N, respectively. The overall system is shown below in Figure 18 with the major components and sub-assemblies Annotated. Each component and sub-assembly is explained in detail in this section.

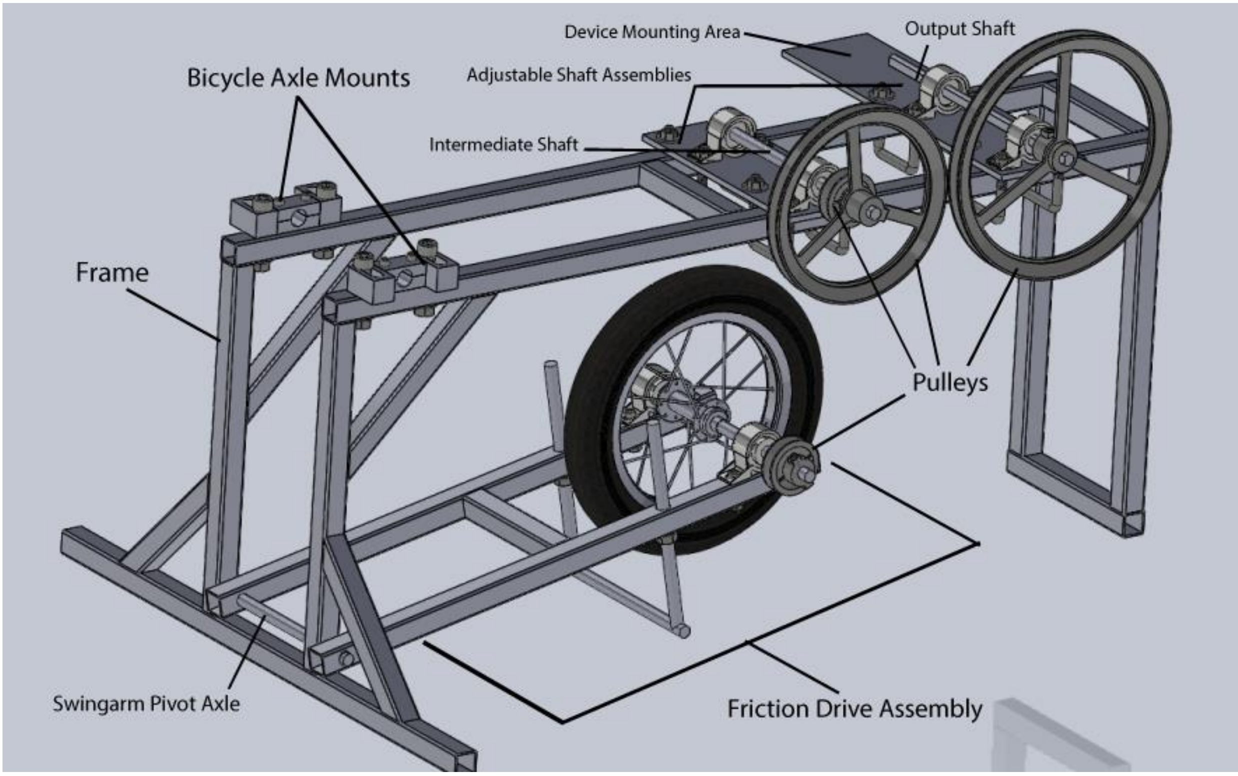

Figure 18. Sub-Assembly and Component Names

5.2.1 – Frame

The form of our system is defined by the frame. The frame supports the bike as well as all of the system components and external applications such as the maize mill. The frame assembly is shown below in Figure 19. Every part of the frame is made from 1x1 inch steel square tubing with 0.125 (1/8) in thickness. The cross-sectional dimension was chosen based on its proximity to 25 mm steel tubing which is a common stock in Malawi. Wall thicknesses of 0.0625 to 0.125 in for square tubing are locally available in San Luis Obispo. For weld-ability, 0.125 in thickness was selected. No analysis was performed to prove the structural integrity of the frame because it was not necessary to optimize for any reason. Based on intuition and experience we are confident that the frame will support all internal and external loading without yielding.

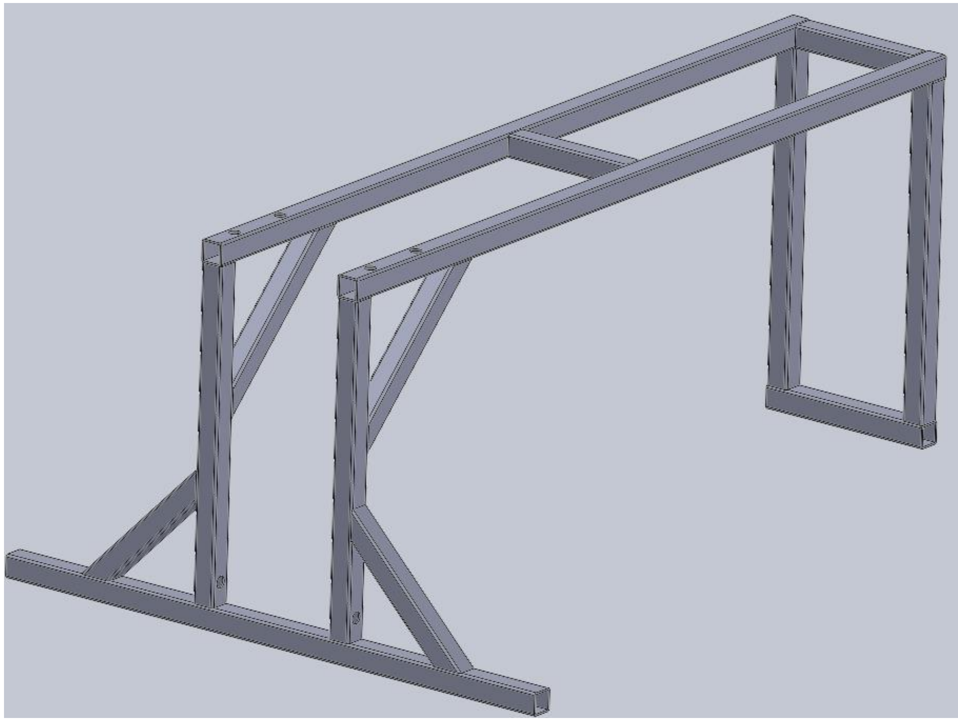

Figure 19. 3D Model of the Frame.

The top bars of the frame will support the bicycle rear axle at one end. The overall height of the frame has been minimized in order to keep the bike as close to the ground as possible while still allowing for smooth operation of the systems. Angled bracing will be welded on to reinforce high stress areas of the frame and ensure the integrity of the welds. The frame segment that lays on the ground is intentionally long to provide support for lateral movement induced by pedal loading and body movement from the bicycle rider.

5.2.2 – Rear Axle Mounts

The rear axle mount assembly is shown in Figure 20. The purpose of mounts is to support the rear wheel of the bicycle and constrain the bicycle movement relative to the frame. This is important in order to achieve reliable contact between the bicycle wheel and the friction wheel. The mounts are able to be adjusted in the direction of the bike axle to accommodate different bicycle dropout spacing's. This adjustability is achieved by having slots in the mounting assembly. The bolts that hold the mounts to the frame go through these slots and into the frame. The bolts can be set to different positions within the slot based on the bicycle rear axle length. The axle clamp works by having two surfaces with cut out space in-between them for the nut of the rear axle to fit into. These two surfaces are fastened together with ¼ in bolts (SCREWS?) so that the axle nut is firmly held in place and unable to move in any direction. This assembly is attached to the top tubes of the frame by ½ in bolts.

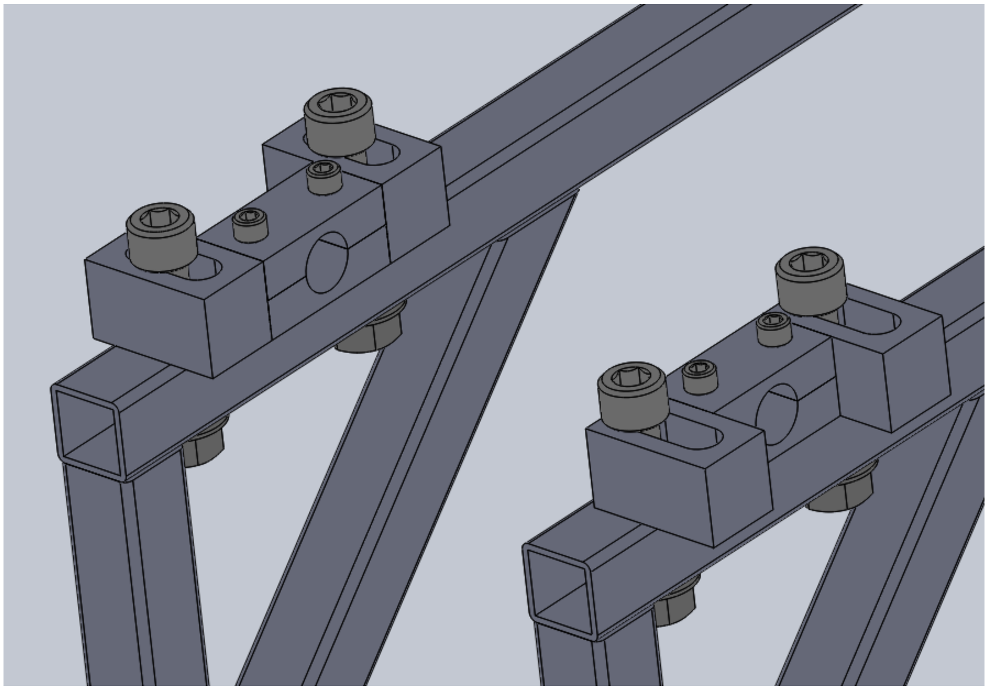

Figure 20. Bicycle axle mounting assemblies fastened to the frame.

The internal spacing of the frame and adjustability range of the rear axle mounts have been designed to accept rear bicycle dropout spacing's ranging from 130 mm to 100 mm. This range will allow a range of bicycles to be mounted to the system.

This design was selected because it provides some adjustability while minimizing the length over the frame that the mounts will be cantilevered. We wanted this component to be capable of taking the full load of the bike and rider without failing in a case where the friction wheel is disengaged. However, this design may prove to be challenging in trying to support bicycles with a rear derailleur. Since we expect this system to be primarily used with single speed bikes we have gone with this design. Modifications may be made later to allow the axle attachment to be more versatile.

5.2.3 – Friction Wheel

The friction wheel will transmit power from the bicycle wheel into the system. The two wheels transmit power through the friction established between their surfaces. The friction wheel is a made from the rear wheel of a bicycle with an outer diameter at the tire of 12 in. A ½ in shaft is rigidly mounted through the wheel hub. Two friction wheels have already been sourced from the bicycle scrap yard. In order for the friction wheel to operate correctly the tire will need to be properly inflated. Over time the tire will leak air and require inflation. Since the user's own bicycles, we anticipate they will have bicycle pumps and easily be able to inflate the friction wheel.

An alternative consideration for the friction wheel would involve manufacturing our own. This would be done by cutting two 12 inch circles from a ¼ inch thick piece of steel and bolting them together at 2 inches apart. A thin piece of metal would be wrapped around the circumference and an adhesive attached to this outer surface. A ½ inch shaft would be mounted through center holes. The disadvantage to this approach is that it requires more manufacturing time and may be challenging to successfully build a round and sturdy wheel. For this reason, we are initially working with the bike wheel as our

friction wheel. In the case that a 12-inch bike wheel cannot be affordably purchased in Malawi, our team will further develop the design of a self-manufactured friction wheel. Our Friction wheel assembly design is capable of accommodating different types of friction wheels as long as they can be mounted to a ½ in shaft.

5.2.4 – Driven Shaft and Swing Arm

The Friction wheel is mounted onto an adjustable swing arm assembly that enables the distance between the friction wheel and the bicycle wheel to be changed. This function allows the normal forces between the wheels to be optimized to maximum the friction force and thus allow for complete power transfer from the bicycle into the system. The friction wheel swing arm assembly can be seen in Figure 21. The swing arm frame is made from 1x1 in square steel tubing with 0.125 in thickness.

The friction wheel assembly is attached to the frame by a ½ in axle press fit into the frame. The swing arms have clearance holes that the axle is attached through allowing the assembly to swing up and down relative to the frame. On the other end of each swing arm a ½ in threaded rod is mounted normal to the arm and supports the swing arm from the ground. The threaded length to the swing arm assembly can be adjusted by moving two locking nuts to different positions on the rod. The swing arm assembly also supports the shaft the friction wheel is mounted to. A pillow block mounted bearing with a ½ in bore is bolted to each arm. A ½ in shaft is supported between these bearings by set screws in the bearings. The friction wheel is rigidly mounted between the bearings on the ½ in shaft. Outside of the bearings on the shaft a pulley is mounted that transmits power to the next stage of the drivetrain.

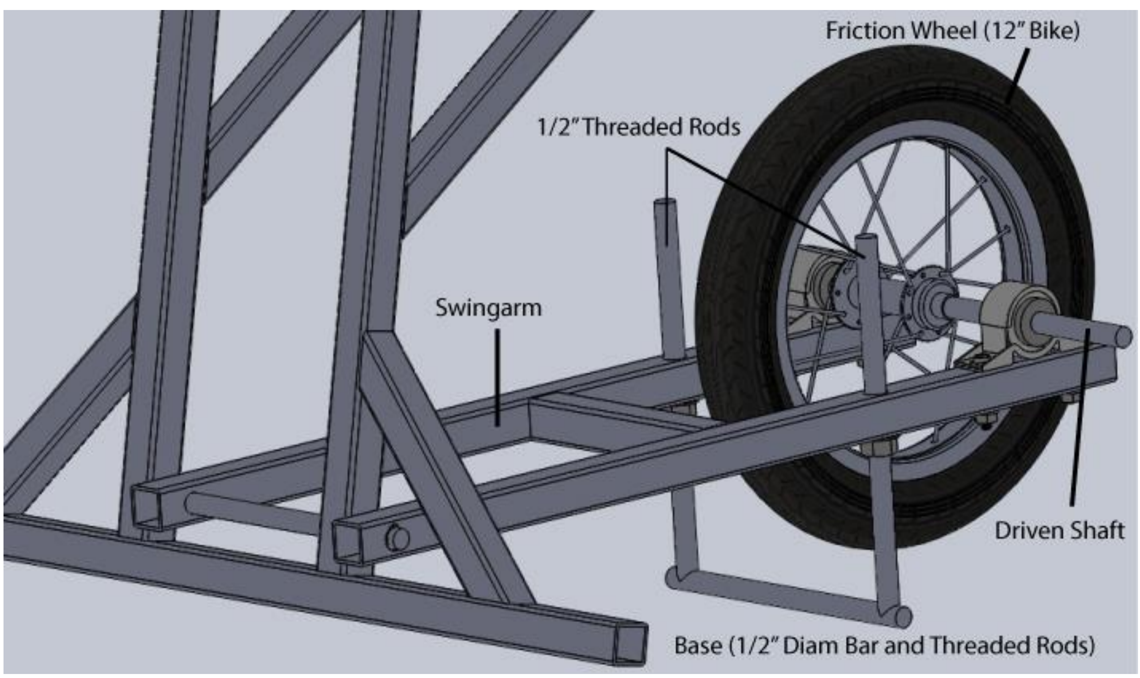

Figure 21. Friction wheel assembly mounted to the front of the frame.

5.2.5 – Pulleys and Belts

Shigley's [18] recommends using chains and cogs for applications in the speed range that our system experiences. However, based on the successful use of pulleys and belts being used in designs we benchmarked and lack of evidence for why not to use them at our speeds, our team chose to use pulleys and belts. One advantage to this choice that pulleys and belts are readily available in Malawi. All pulleys and belts are outboard of the frame on their respective shafts so that they can be easily interchanged based on the application. This also has the benefit of leaving the drivetrain easily accessible which makes adjustment and maintenance more convenient.

An additional advantage to using pulleys is that they are relatively safer than chains and cogs since there are less sharp edges. Also, they require less maintenance such as greasing which could be hazardous in close proximity to food production.

All Pulleys are made from zinc and make use of set screws for attachment to the shafts. Zinc was chosen based on pricing and size availability. They each have a ½ in bore and a V-shaped surface profile that accepts V-belts. The driven shaft pulley has a pitch diameter of 2 in. The first pulley on the intermediate shaft has a 7.75 in pitch diameter while the second pulley is 2 in. The pulley on the output shaft assembly is 9.75 in pitch diameter.

5.2.6 – Intermediate Shaft Assembly

The intermediate shaft assembly allows for torque and speed to be changed in order to reach the required demands set by the external applications. This assembly can be seen below in Figure 22. The assembly is oriented on the top tubes of the frame. The assembly is built on a ¼ in steel plate with mounting holes for bearings and u-brackets. Four U-brackets hold the assembly at the required position on the top of the frame. Two mounted steel pillow block bearing with ½ in bore hold a ½ in diameter steel shaft with set screws. At the end of this shaft two steel pulleys are mounted. One pulley with a 7.75 in diameter takes power from the friction wheel shaft and the other pulley, 2 in diameter, sends power to the final grinding shaft assembly. Because the bearings and shafts are made of steel galvanic corrosion is not a concern. Although the pulleys are zinc and will be mounted to the steel shafts we have determined from research that galvanic corrosion is not a necessary concern to address for these materials in this application.

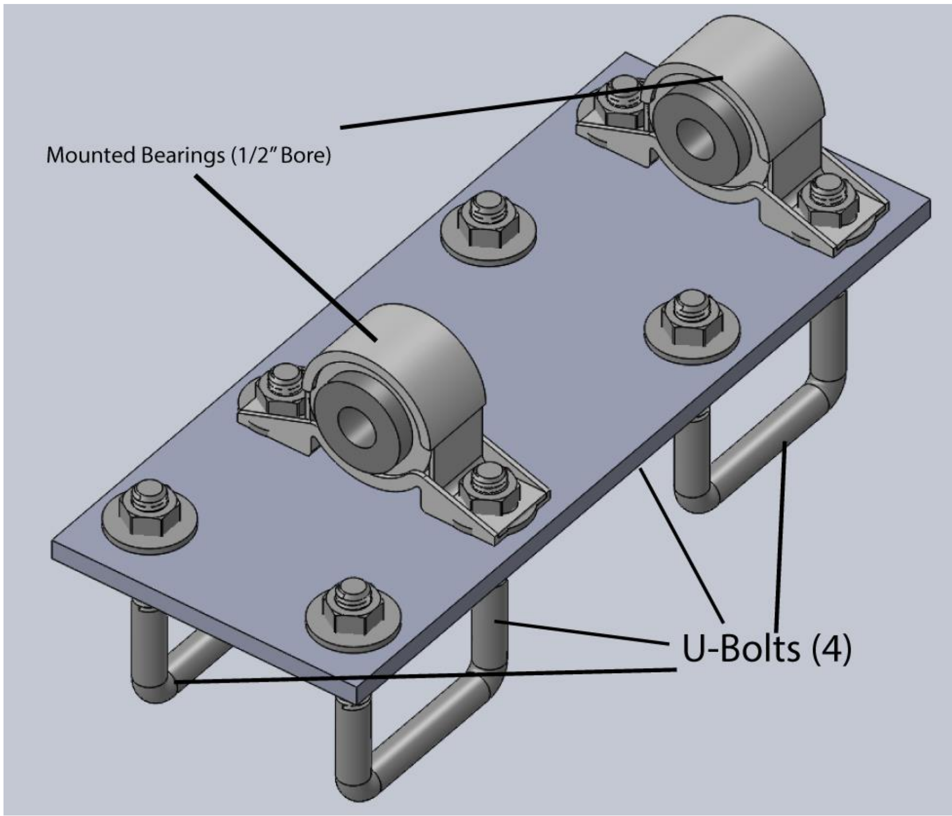

Figure 22. Intermediate Adjustable Shaft Assembly (no shaft shown).

5.2.7 – Output Shaft Assembly

The grinding shaft assembly has the same form as the intermediate shaft assembly but with a few minor changes. The first difference is that the ¼ in thick base plate is extended in length in order to provide a platform for the maize mill to be attached to. This change can be seen in Appendix K in the Output Shaft Mounting Plate Drawing. The steel shaft is a ½ in diameter d-shaft. This shape was selected so that the shaft could be mounted into the corresponding female end of the maize mill auger shaft and secured with a set screw. One 9.75 in diameter steel pulley is mounted on the shaft with a set screw. This pulley brings the system to its low speed, high torque setting required for the maize mill application. The grinding shaft assembly is also secured to the top of the frame by four U-brackets. The U-bracket part specifications are shown in Appendix J.

5.2.9 – Bearings

All bearings used in the system are steel mounted pillow block bearings with ½ in bore. These bearings were selected for their ease of installation and reliability. Further, using mounted bearings prevented the need to press fit bearings into the frame which would pose manufacturing challenges and a greater degree of difficulty in assuring proper alignment between bearings. This style of bearing also enables the design of the easily adjustable shaft assemblies which are critical to the flexible nature of our system. Each bearing can take up to 3° of misalignment, a maximum speed of 5800 rpm, and a dynamic radial load of 716 lbs. The part specifications are shown in Appendix J.

6 – JUSTIFICATION

This section will explain the reasoning behind decisions made over the course of the detailed design phase. The major areas of consideration are the drivetrain, input output interfaces, adjustability, and structural concerns. Much of the challenge in this design project involves material availability and manufacturability. We expect fairly low levels of power through our system which is key to many of our decisions.

We performed the majority of our calculations for quantitative analysis and justification in an Excel document. We built the spread sheet to take values for user inputs (power, speed, bicycle wheel size, efficiency and gear ratio) and component sizes (pulley diameters, belt lengths). It solves for speeds and torques at each point in the system, minimum allowable shaft diameters, pulley center spacing, and allowable belt power. This method of analysis allowed us to perform many iterations to select the optimal components for the requirements we had to work with.

The inherent variability in the prime mover of our system (human/ bicycle) lead us to make a series of assumptions as to the least desirable conditions under which our design should function.

Table 5. Various worst case scenario operating conditions

No.	Parameter	Value	Units
1	Bicycle Efficiency	90%	
2	Bicycle Wheel Diameter	28	cm
3	Bicycle Gear Ratio	2:1	
4	Minimum Power	100	Watts
5	Maximum Consistent Power	150	
6	Maximum Tolerable Power	250	
7	User Mass	90	kg

6.1 - DRIVE TRAIN

We require that our drive train operate in two distinct modes; high torque and high speed. Ultimately, our system uses two belt-pulley reductions in the grinding mode and one reduction in generation mode. We decided to use the same two pulleys for each mode but on different shafts in order to achieve the required range of outputs while minimizing number of parts. The drive train design process focused on providing torque at the levels required by the mill team. We feel that it is important to mention that we did not have a definitive value for much of our design process. We dealt with this issue of ambiguity by avoiding decisions that would limit how easily our design could be modified down the road. The output torque specification we received came with the caveat that they were scaled from measurements taken with a hand-driven mill.

Despite the lack of reliable information regarding torque requirements we proceeded with our detailed design using the values we were given. In order to compensate for this glaring issue, we plan to make our system compatible with a variety of pulley sizes. If we need more torque, we can switch out pulleys to achieve an affective ratio.

6.1.1 – Belt/Chain Dilemma

According to Shigley's , V-belts "encounter problems when run below 1000 [ft/sec]" [18]. In grinding mode, both belts fail this criteria, but we decided to press on with this design despite the potential issues related with low speeds of both belts. Our rationale rests on the following points.

- Entirely sprocket-chain drive is more expensive and requires lubrication.
- Allowable power for the belts in question exceeds the limits of power output that we expect our users to be able to maintain (150 W).
- Interchangeability of the pulleys is crucial to our design.
- Spinning pulleys could be considered "safer" than sprockets given they do not present a snagging hazard
- Systems that we benchmarked used predominantly belt drives

6.1.2 – Torque Output

To ensure that our system can provide adequate torque to the maize mill, we designed our drivetrain with the lower bounds of both input power and speed (100 [W] at 70 [RPM]). The largest wheel size we expect is 70 [cm] ~ 28 [in], and because the larger wheel results in smaller output torques we used it in our torque analysis. We assumed an efficiency of 90% and a gearing ratio of 2:1 for the bicycle in this analysis, resulting in a torque of 6.1 [Nm] at a speed of 140 [RPM].

Table 6. Torque requirements in grinding mode

		Reduction #					
		#1. Bike to Friction Wheel		#2. Shaft 1 to 2		#3. Shaft 2 to 3	
d [in]	**D [in]**	28	12	2	9.75	2	6
Ratio		2.33		.258		0.205	
Torque [Nm]		6.1	2.6	2.6	10.5	10.5	**49.7**

6.1.3 – Speed Output

In order to generate electricity with an alternator we require an output speed of 2,000 [RPM]. To achieve speeds this high, the pulleys on the first two shafts are switched and the third shaft is disconnected. Analysis of the high speed mode was conducted assuming smallest wheel size, minimum power and higher bound input pedaling cadence (100 [W] at 110 [RPM]).

Table 7. Speed requirements in generation mode

		Reduction #			
		#1. Bike to Friction Wheel		#2. Shaft 1 to 2	
d [in]	D [in]	26	12	9.75	2
Ratio		2.167		3.875	
Speed [RPM]		200	433	433	**1847**

Note that 2000 [RPM] speeds are achievable with an elevated pedaling cadence ([120RPM]).

6.1.4 – Friction Wheel Sizing

The speeds and torques achievable with our system rely heavily on the diameter ratio of the bicycle wheel to the friction wheel. In speed reduction, (grinding mode) said ratio increases rotational speed, taking us further from the high torques

6.1.5 – Belt Pre-Tension

Because of their characteristic shape, V-belts require relatively little pretension. However, the high torques from the mill result in significant loads in the second reduction (from shafts 2 to 3). Originally, the final pulley (on second shaft) was smaller but we switched to a larger one in order to reduce the tension induced when driven. Calculations regarding belt tension are found in Appendix I.

6.1.6 – Induced Belt Tension

In high-torque grind mode the drive train components experience the highest loadings. The belt tension loads on each pulley were calculated using models found in a V-belt design manual by a company called Bando [19]. Calculation can be found in Appendix I and summarized below. We used these values to size shafts and bearings. The high loading of belt 2 led us to choose a different V-belt section type for Belt 2. Belt 1 is a 4-L-section V-belt and Belt 2 is an A-section V-belt.

Table 8. Pulley loading induced by operation

Total Tension [N]	
Belt 1	Belt 2
255	778

6.1.7 – Allowable Power Transferable Belt

As stated above, V-belts are not often run below 1000 feet/sec, and there are not tabulated power ratings for V-belts at the speeds required for running the mill. In order to validate our design, we performed a linear extrapolation to the speeds in question using ratings found in table 17-12 of Shigley's [18]. Calculations can be found in Appendix G. The model used for this analysis yields an "allowable power" value that should not be exceeded during regular operation of the machine. Note that the

calculated values do not meet the maximum power specification of 250 W. The key is, these calculations are fatigue/lifetime calculations. We do not anticipate the users of our system to sustain pedaling anywhere near 250 W for a substantial amount of time. The allowable powers we found, are below are all well over the expected maintainable power input of 150 W.

Belt 2 experiences the highest loading and has a safety factor of 1.24. We find this acceptable given the model considers fatigue and application with a service factor.

Table 9. Allowable Belt Power

Condition/Speed	**Allowable Power [W]**	
	Belt 1	Belt 2
HIGH	237	n.a.
LOW	192	186

6.1.8 – Pulley Center Spacing

Through an iterative process, aided by a spreadsheet, we determined the spacing's listed below. Calculations can be found in Appendix I.

- Belt 1 - 42-inch inner circumference – Center Spacing = **10.60 inches**
- Belt 2 - 42-inch inner circumference – Center Spacing = **10.18 inches**

6.1.9 – Shaft Sizing

The various belt tensions developed during power transmission directly impact the strength requirements and therefore sizes of each shaft. In this portion of the design process shafts 1 and 2 are constrained to having the same diameter so that we are able to easily use the same pulleys on both shafts. From there, the goal was to minimize the diameter to reduce cost. We designed for the endurance limit of our shafts using the ASME Elliptic fatigue stress model, which yields the table below. We used the ASME fatigue model because it is not overly conservative. Shaft 3 is a "D-shaft" and is 15% weaker than the other shafts but must take the highest loads, resulting in 5% design factor. We concluded this is an acceptable level for prototyping. We did not consider whirling failure because there are no high mass components rotating on any of the shafts. See Appendix I for deflection analysis on the grinding shaft at the pulley, for angular pulley alignment verification.

Table 10. Shaft design factors

Shaft No.		**1**	**2**	**3**
Design Factor (d=1/2in)	Normal	1.79	1.36	1.10
	Max	1.77	1.31	0.91

6.1.10 – Bearing Selection

We selected bearings that fit our shafts. Once we determined our loads, we ensured they did not exceed the manufacturer's ratings. See Appendix I and J for load calculations (I) and bearing specifications (J) summarized below.

Table 11. Bearing specification satisfaction.

Parameter [unit]	Maximum Required	Tolerable
Speed [RPM]	2,000	5,800
Dynamic Load [N]	903	3,185

6.1.11 – Bearing Mount Friction

The assemblies that fix shafts 1 and 2 to the frame must withstand/provide the clamping force necessary to constrain the shafts. The calculations to verify sufficient clamping force used the more conservative limit of static friction coefficient values for steel-steel contact and are found in Appendix I. A clamping force of 991 N is the maximum required from each U-bolt. The U-bolts in question are rated to 4780 N (see Appendix J), giving us a design factor of 4.8 in this area.

6.2 – Interfaces

6.2.1 – Bicycle Interface

Our design is powered by the rotation of a rear bicycle wheel. This fact requires our system to support the bicycle and rider and provide clearance between the rear wheel and the ground. Furthermore, the structure of our machine cannot interfere with the rotation of the bike's pedals along with the user's feet.

6.2.2 – Mill Interface

Torque will be transmitted from shaft number 3 to the maize mill by a "D" shaft and a corresponding hole. The mill will mount on the end of the shaft assembly on the opposite side of the pulley train. The mill must be driven clockwise when viewed from the side where the shaft connects. The symmetry of our design allows us to change rotation direction by switching which ends of the shafts the pulley sheaves are on.

6.3 - Adjustable Components

6.3.1 – Friction Drive Swing Arm

The main concern we have with the swing arm is its ability to resist any moment that might result from the normal force a misaligned friction wheel and bicycle wheel. The swing arm 'fork' is wide in order to minimize the cantilevered distance between a bearing and the first pulley on shaft number 1. In order to shorten this cantilevered distance, we made the swing arm fork wider so that it could mount to the

outside of one side of the frame. In order to do this, we had to add a retaining ring to prevent the swing arm from sliding off of its ½" pivot axle that connects it to the frame.

6.3.2 – Axle Mounts

The axle mounts that will support the bicycle's rear axle needed to be able to accommodate various widths of bicycle rear axles. These mounts should be able to accommodate a bicycle with a rear axle width in the range of 100 – 130mm. We designed the mounts to accommodate bicycles with rear axle nuts, rather than a quick-release or through-axle, since these are not common on the bicycles in Malawi. The rear axle nuts will simply sit in the circular portion of the axle mounts.

6.4 - Structural Concerns

6.4.1 – Tipping

Due to the dynamic forces exerted on a bicycle while pedaling and therefore our frame that will be supporting the bicycle, we evaluated the possibility of tipping the frame about its length under a "worst-case-scenario." We first assumed that all of the normal force on the device from the ground was on the corner that the device would be tipping about. With this assumption, the goal was to calculate the total moment about that point to evaluate the possibility of tipping. After performing the calculation, it was found that the overturning moment about the tipping point was negative, and therefore the device would not tip. The actual calculation can be viewed in Appendix I.

6.4.2 – Swing Arm Legs

The Friction Drive Base, which consists of ½"-13 threaded rods welded to a ½" diameter steel bar stock, was a slight concern of ours when considering the loads on the friction wheel. This base must support part of the bike and rider, which will create shear and axial forces, and bending moments in the threaded rods. The bending moments the rods will experience were the driving factor in our design considerations for both the length of the threaded rods, and where the base will be mounted along the length of the swing arm. We wanted to minimize the length of the threaded rods so that the moment arm was smaller, but still have enough length to adjust the friction drive assembly to different bicycle wheel sizes.

6.5 - Justification Summary Table

The table below contains a synopsis of the critical loads experienced by our machine under highest expected sustained loading conditions (150 W @ 90). Note that both belt and shaft analysis involved fatigue calculations, and are therefore acceptable despite their proximity to unity.

Table 12. Critical parameters for viability ensurance.

Component	Parameter	Target	Achieved	Safety Factor
Frame	Load			
U-bolts	Clamping Load (per bolt)	990 N	4780 N	4.8
Shaft 1	Diameter	0.28 in	0.5 in	1.79
Shaft 2	Diameter	0.37 in	0.5 in	1.36
Shaft 3	Diameter	0.43 in	0.5 in	1.1
Shaft 3 Bearings	Speed	2,000 RPM	5,800 RPM	
Shaft 3 Bearings	Load	1000 N	3185 N	3.2
Belt 1	Max Power	150 W	202 W	1.35
Belt 2	Max Power	150 W	186 W	1.24

7. – PROJECT PLAN

7.1 – SCHEDULE (AS RELEVANT TO MR. WHEELER)

- 1/31 to 2/16 window -- Critical Design Review with Mr. Wheeler (exact date T.B.D.)
- 3/20 -- Project Update Report
- 5/1-- Prototype Completion
- 5/30 -- Final Report
- 6/2 -- Design Expo

7.2 – MANUFACTURING PLAN

The detailed manufacturing plan is to be used in conjunction with the engineering drawings from Appendix K. The process required for making each manufactured part is explained. Further, the steps and procedures for building assembled parts and constructing both sub-assemblies and the full assembly are explained in detail.

The specific timeline for the manufacturing order and construction can be found in the Gantt chart in Appendix F. All manufacturing and assembly will take place on the Cal Poly campus in, or near, the shops.

7.2.1 – Frame

Refer to the Frame Drawing in Appendix K for the following detailed manufacturing plan for the frame. All steel square tubing of the frame is cut with a chop saw to the length specified in the manufacturing drawings.

The top tubes of the frame will have holes to accommodate the rear axle mounts for the bicycle. The front legs will also have holes for the friction wheel swing arm assembly to be attached to. These holes will be clearance holes made with a drill press.

The frame assembly is joined by TIG welding the individual members together as is shown in the frame assembly drawing by the weldment marks.

7.2.2 – Rear Axle Mounts

Refer to the Rear Axle Mount Drawing in Appendix K for the following detailed manufacturing plan for the rear axle mounts. The rear axle mounts are assembled from two distinct pieces that are both machined from 1x1 in solid steel bar. The steel bar is cut to the specified lengths for each individual component. The blocks that attach to the frame have ½ in width slots that are machined on a mill. The center piece of the mount that supports the axle will have a ¾ in hole drilled through the middle on a drill press. Next, the piece is supported with clamps and cut in half such that the cut faces are parallel to the ground plane. This cut evenly intersects the central hole. Two clearance holes for ¼ in screws are drilled on a drill press as indicated by the drawings on the upper piece of the clamp. The lower piece of the clamp is internally threaded to fit the ¼ in screws. Finally, the slotted pieces will be TIG welded to each side of the bottom bracket.

The completed axle mount assemblies will be attached to the frame by two ½ in bolts that pass through the slots, through the holes in the frame, and are fastened with bolts on the underside of the frame.

7.2.3 – Friction Wheel

The bicycle wheel used for the friction wheel will have the original axle and bearings removed from the hub. A ½ in steel shaft is inserted through the bearing and tacked in place using so that the wheel and shaft are rigidly connected.

7.2.4 – Driven Shaft and Swing Arm

Refer to the Swing Arm Assembly Drawing in Appendix K for the following detailed manufacturing plan for the driven shaft and awing arm assembly. The three pieces of steel hollow square tubing used to build the swing arm frame are cut to length with a chop saw. Holes are drilled with a drill press though the swing arms for the adjustable threaded rods, bearing mounts, and axle attachment to the frame. The frame of the swing arm is welded together using TIG. The threaded rods are inserted through the swing arm holes and held in place by one nut above, and one nut below the arm. The bearings are attached to the arm with bolts. The driven shaft and friction wheel are inserted between the bearings and held in place by set screws on the bearings. The first pulley is mounted to the end of the driven shaft, outside the bearings, and is held to the shaft by a set screw. The Entire swing arm assembly is then attached to the frame by an axle that passes through holes in the end of the swing arms and front legs of the frame. Locking rings prevent movement of the swing arm assembly relative to the frame in the axial direction.

7.2.5 – Pulleys and Belts

All pulleys are secured to their respective shafts by a set screw. Belts are placed onto the pulleys and then the shaft assemblies are adjusted to positions that provide the correct amount of static tension in the belts.

As the belts age they will stretch out. This will require the repositioning of the adjustable shaft assemblies to maintain the correct amount of tension in all belts.

7.2.6 – Intermediate and Output Shaft Mount Plates

Refer to Mounting Plate Drawings in Appendix K for the following detailed manufacturing plan for the shaft mounting plate. The intermediate shaft plate is cut to size from ¼ in thick steel plate with a chop saw or plasma cutter depending on the stock dimensions. All holes are drilled in the specified locations with a drill press.

7.2.7 – Intermediate and Output Shaft Assemblies

Refer to the Shaft Assembly Drawing in Appendix K for the following detailed manufacturing plan for the shaft mounting assembly. Each U-bracket is inserted through the holes in the mounting plate. The bearing mounts are placed onto the protruding threaded end of the U-Bolt and fastened with a nut. Each shaft is inserted through the bearings and held in place with the bearing set screw. Pulleys are secured in their respective positions on each shaft by set screws.

7.3 – Verification Plan

The full design verification plan and report (DVP&R) is found in Appendix M. The DVP&R details the test plans for the system in order to determine how it satisfies the engineering specifications found in Table 1 and Table 2 of Section 3.4. We will evaluate the performance of our system on both qualitative and quantitative bases. Simply put, our system should allow the user to operate the mill with maintainable ease. We will measure speeds at the slow output by counting revolutions and at high speeds with a non-contact tachometer. The primary purpose of the testing is to validate the design and generate ideas for corrective solutions as challenges arise from the manufacturing and operation stages.

The testing will involve putting the system through sustained normal and extreme operating situations. For all tests we will be setting up and using the system the way we anticipate the user will. This begins with the user removing the top clamp of the rear axle mounts, placing the bike rear axle in the supports, and then fastening the tightening screws to securely attach the bicycle axle to the frame. Next the friction wheel assembly is adjusted to correctly contact the bike wheel by adjusting the nuts on the threaded rods to the appropriate location. The user will then move the intermediate and output shaft assemblies along the frame top rails so that the belts are properly tensioned. At this point the system is set up and ready for testing. The user will mount the bike regularly and begin pedaling.

There are seven specifications the system will be tested for. These are efficiency, set up time, stability, maximum tolerable power, speed range, maximum torque, and finally drivetrain fatigue or failure. Testing will be performed on the Cal Poly campus near the machine shops. Testing will begin after the manufacturing stage has been completed and the full system assembly has been built. For a detailed timeline of the test plan refer to the Gantt Chart in Appendix F.

8. Manufacturing

This section includes details of the manufacturing process used in the construction of our prototype. The information listed in this section is intended to be used for reference in implementing the device in Malawi. It is at the discretion of the build team in Malawi to change components or alter the design for

the best possible design with the parts available in Malawi. A recommended Bill of Materials is shown in Appendix O for possible parts in the Malawi implementation. Please reference the Bill of Materials in Appendix N for a complete list of the parts used for the Cal Poly prototype build, and the technical drawings in Appendix K. Please note that our prototype is different in small ways from the technical drawings. These differences will be listed under their respective sections.

8.1 - FRAME

To begin manufacturing, the square tubing for the frame must be cleaned then measured, marked and cut according to the lengths listed in the Individual Tubes drawing. All cutting of structural steel components was done with a steel chop saw. Once all the pieces have been cut to size, and the cuts have been ground smooth if necessary, the frame can be welded together according to the Frame Weldment drawing. MIG welding is recommended for all welds on the frame. Make sure to plan to weld and fix the work pieces in a manner so that they do not warp during welding.

Note that our prototype does not have the upper rails of the frame overhanging on the front of the frame, and that the axle mounts are behind the front legs instead of centered over them. We made this mistake in constructing the prototype because we built the frame from outdated drawings. The purpose of centering the axle mounts over the front legs is to move the bicycle forward relative to the frame to increase pedal clearance from the frame. However, we did not run into foot clearance issues during testing with our prototype manufactured from the older drawing revisions. Figure 23 below shows the frame in the process of being welded. Appropriate safety gear such as welding masks, gloves, long sleeved shirt, pants, and closed toed shoes were used. The figure also shows a large square that was used to measure the perpendicularity of parts as they were being welded in order to insure the construction of the frame matches the drawings.

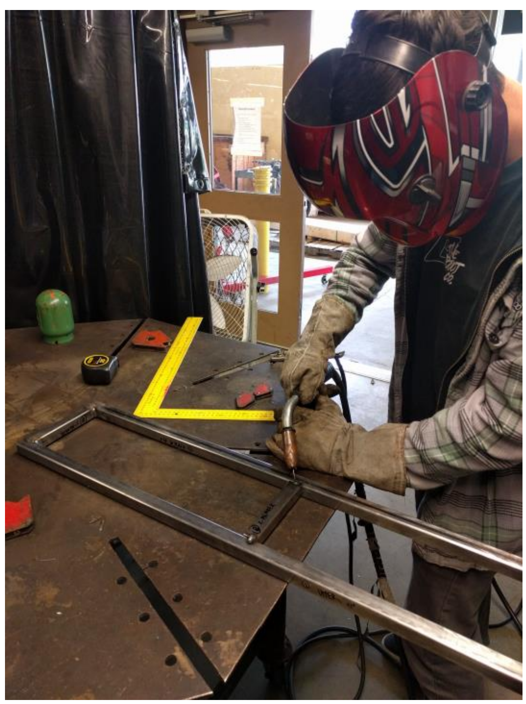

Figure 233. A photo of the prototype frame during MIG welding.

Figure 24 shows how welding magnets were used to hold parts in the correct orientation to one another while they were being tacked. This method of securing parts for tacking enabled the frame and friction drive swing arm to be manufactured within close resemblance to the drawings to ensure they function properly.

Figure 24. A photo of the welded friction drive swingarm.

8.2 - Friction Drive Assembly

8.2.1 – Friction Drive Swingarm

Similar to the manufacturing of the frame, the square tubing for the friction drive swingarm must be cleaned then measured, marked and cut according to the dimensions shown in the Friction Drive Swingarm drawing. After cutting the tube to length, MIG weld each piece together according to the dimensions shown in the Friction Drive Swingarm drawing. Again, try to fix the work pieces so that they do not warp during welding.

Figure 25. A photo of the welded friction drive swingarm.

8.2.2 – Friction Drive Base

Measure and cut the ½” Threaded Rods according to the Friction Drive Base technical drawing. Then clean the threaded rods and grind smooth if necessary. Now MIG weld the threaded rods together as shown in the drawing. Ensure that the cut end of the threaded rod is the end that is welded to the base. This is important because the uncut end of the threaded rod needs to accept a nut. Note that our prototype used a piece of 1”x1” square tubing as the lower piece of the friction drive base instead of a third piece of threaded rod. ½'' holes were drilled into the base for the threaded rod to sit in prior to being welded.

Figure 26. A photo of the friction drive base. In this photo the tops of the threaded rods are hidden in the friction drive swingarm.

8.2.3 – Friction Wheel and Friction Drive Shaft

The friction wheel and friction drive shaft needed some “on-the-fly” engineering to manufacture with parts the we found around campus. This portion of the design is somewhat open-ended so that it can be completed with parts available for free or extremely low cost. For the friction wheel in the Malawi implementation, there are a few possibilities we recommend. Some of these possibilities are a wheelbarrow wheel and tire, a wheelbarrow hub, a children’s bicycle wheel and tire (as we used on our prototype) or other parts that can accommodate shaft fixed to its center, while maintaining traction with the bicycle’s rear tire. The following details are how our team manufactured the friction wheel and friction drive shaft with parts that we found.

We first started with a 12” children’s bicycle wheel, and removed the hub’s internal pieces such as the bearings and axle. We had our ½” shaft to fit in the hub’s inner surface, which was about a 1 3/8” hole on one side and about a 1” hole on the other side. To fix the shaft to the hub, we found a piece of 1 ½'' cylindrical steel bar, and turned it on the lathe to match the inner profile of the hub. A photo of this stock being turned on the lathe is shown in Figure 27.

Figure 27. A photo of the cylindrical steel bar stock being turned on a lathe to match the inner profile of the bicycle wheel hub.

We then bored a ½" hole in the center of the steel bar to complete the collar that fixes our shaft to the hub. With the collar completed, we sand blasted the steel bicycle hub because it was chrome coated. The ½'' steel shaft was also sand blasted before welding to remove anodized coating. Next, the collar was MIG welded to the hub. The shaft was carefully MIG welded to the collar by tacking extensively and quickly before completely welding to prevent the shaft from bending from the welding heat. This manufacturing method produced a strong and concentrically rotating friction drive wheel at a very low cost. The completed friction wheel and shaft assembly is shown below in Figure 28.

Figure 28. A photo of the bicycle wheel, steel collar, and ½" shaft completed and welded together.

8.2.4 – Assembly

With each component of the Friction Drive Assembly completed, the assembly can put together. Please refer to the Friction Drive Sub-Assembly technical drawing for this section. Begin by mounting the friction drive shaft in its bearings. Then, secure the bearings on the friction drive swingarm by using the associated screws and bolts. For our prototype, the bearings are mounted with ¼"-20 hex cap screws and ¼"-20 nuts. With the bearings mounted, thread one flange nut on each arm of the friction drive base's threaded rods, then push the threaded rods through the corresponding holes in the friction drive swingarm. The assembled Friction Drive Sub-Assembly is shown below in Figure 29.

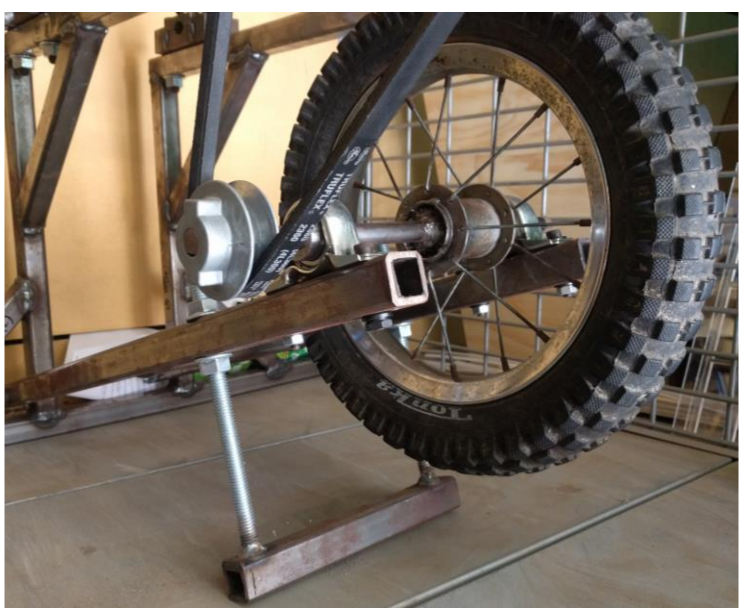

Figure 29. A photo of the completed friction drive assembly.

8.3 - Adjustable Shaft Assemblies

The adjustable shaft assemblies require minimal manufacturing effort. Essentially the only component that needs machining is the plate that acts as the base for the assembly. Once the holes are drilled in the plate, the entire assembly can be put together.

8.3.1 – Base Plates

There are two different base plates for the intermediate and output shaft assemblies. Please refer to the technical drawings Mounting Plate and Mounting Plate – Output in appendix K. Simply measure and cut the stock steel plate to size according to the technical drawings aforementioned. Then drill the eight holes in each plate and deburr as necessary.

8.3.2 – Assembly

With the base plates cut and drilled, both the intermediate and output assemblies can be put together. Refer to the Adjustable Shaft Sub-Assembly technical drawing to. Mount the proper bearings over their respective holes in the base plate and then push the U-bolts through their respective holes and fasten all the nuts securely. Please note that the U-bolts must also be mounted around the upper bars of the frame for the final assembly. See Figure 30 for a photo of one of the completed adjustable shaft assembly.

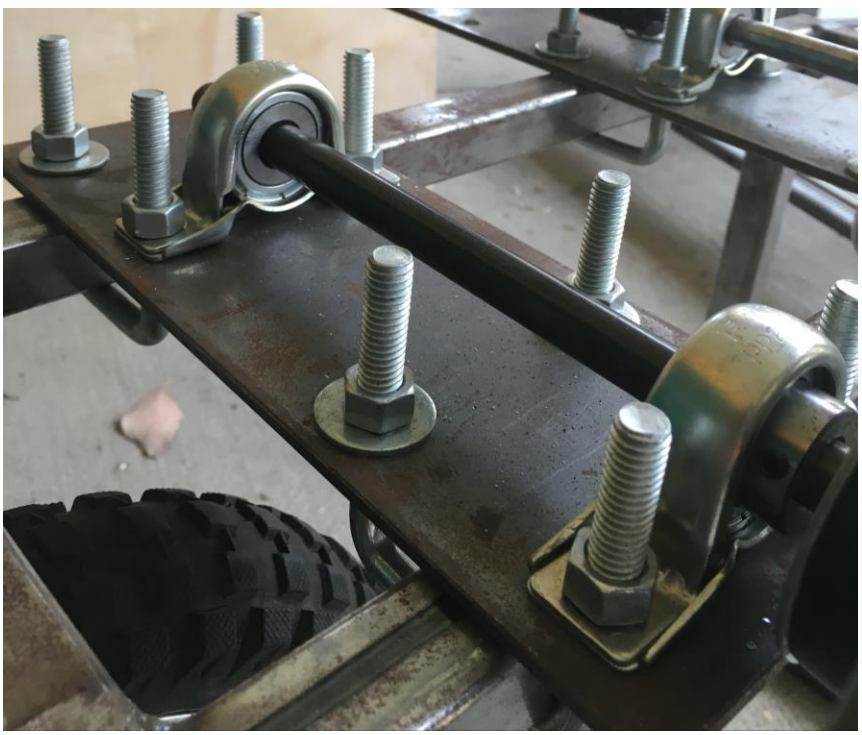

Figure 30. A photo of the completed intermediate adjustable shaft assembly.

8.4 - Axle Mounts

The axle mounts are one of the more complex components of the device to manufacture. They require cutting, milling, and welding.

8.4.1 – Sliding Blocks

The sliding blocks for the prototype are cut from 1"x1" bar stock. Refer to the technical drawing called Axle Mount Sliding Block in Appendix K for these pieces. Four (4) blocks of equal length must be measured and cut from square steel bar stock. Grind sharp edges as necessary. With the four equal blocks, now mill the slot through each of them as shown in the technical drawing. A photo of the finished sliding blocks is shown below in Figure 31.

Figure 31. A photo of the completed sliding blocks for the axle mounts.

8.4.2 – Upper and Lower Clamp Blocks

The upper and lower clamp blocks require cutting, milling, drilling and tapping. Please refer to the Axle Clamp Blocks technical drawing in Appendix K for technical information. We originally wanted to use 1"x1" square steel bar stock like the sliding blocks, then drill a hole in the center of two blocks and cut them in half to make the four clamp pieces, but we were told by a shop technician that this would not work because of the small parts could not be supported well enough to cut in half.

We changed the manufacturing method to buy ½"x1" steel bar stock, and cut that to the 4 equal lengths. We then drilled the clearance holes in the upper clamps, and tapped the holes in the lower clamps. With the holes drilled and tapped we milled out a semi-circle in each piece so that the upper and lower clamps would meet up to form a circle around the bicycle's axle nuts. A photo of the completed block clamps is shown below.

Figure 32. A photo of the completed upper and lower block clamps.

8.4.3 – Assembly

To assemble the axle mounts, please refer to the Axle Support Sub-Assembly technical drawing in Appendix K. With the sliding blocks, and the upper and lower clamps complete, place the lower block clamp in between two of the sliding blocks. Weld the lower block clamp to the sliding blocks only in the areas specified. It is important to keep welds off the upper surface of the lower block clamp so that the upper block clamp can sit flush on the lower. It is also important to keep welds off of the lower surface of the lower block clamp so that the axle mounts can slide above the frame unobstructed.

With the lower block clamp welded to the 2 sliding blocks, the top block can now be placed on the lower block and secured with the two hex cap screws.

Figure 33. A photo of the assembled axle mount installed on the frame.

8.5 – Assembly

With the sub-assemblies completed, the complete device can now be assembled. Please refer to the Top Level Assembly technical drawing in Appendix K.

8.5.1 – Friction Drive Assembly to Frame

We didn't use bar, used screws and nuts

To mount the friction drive assembly on to the frame, the friction drive assembly should be placed with arms of the swingarm on the right side of the frame, when looking at the frame from the front. Then the swingarm should be moved into a position so that the holes on the end of the swingarm are concentric with the holes in the front legs of the frame. Instead of using a ½" piece of cylindrical steel bar to act as the axle pivot for the swingarm, we recommend using a ½"-20 hex cap screw secured with a ½"-20 nut to secure both arms of the swingarm to the frame. See Figure 34 below for a picture of the friction drive assembly mounted to the frame with this hex camp screw and a nut.

Figure 34. A photo of the friction drive assembly installed on the frame.

8.5.2 – Upper Shaft Assemblies to Frame

To secure the upper shaft assemblies to the upper rails of the frame, first make sure that the shafts are oriented so that the pulleys will be on the correct side of the frame. Then simply repeat the process in Section 8.3.2 for assembling the upper shaft assemblies, but make sure that the upper rails of the frame are placed between the adjustable shaft assembly's mounting plate and the U-bolts. Tighten the square U-bolts as necessary to secure the adjustable shaft assembly to the frame.

8.5.3 – Axle Mounts to Frame

To install the axle mounts on to the frame, first locate the two ½" clearance holes on both of the frame's upper rails. Then place the axle mount assembly on the upper rails by aligning the ½" holes in the frame with the ½" holes in the axle mount assembly. Make sure that the upper and lower clamp blocks are facing the inside of the frame, so that the bicycle's axle can sit on them. Finally, place the ½" hex cap screws through the aligned holes, and fasten with a ½" flange nut placed on the bottom of the frame's upper rails.

8.5.4 – Pulleys on Shafts

The last step to assemble the device is to install the pulleys and belts. Install each pulley as shown in the technical drawing Top Level Assembly. We recommend the use of set screw pulleys for easy installation and removal. It is most ideal to have the pulleys installed as close to the frame as possible, so as to reduce the length of cantilevered shaft. Note that on the intermediate shaft, the small pulley must be installed first, and then the larger pulley. With the pulleys installed, the belts can now be placed on the pulleys. Adjust the upper shaft assemblies to reduce the center to center distance between the shafts to make it easier to install the pulleys. The belts can then be tensioned according to the Operation Manual in Appendix P.

8.6 – Device Setup and Adjustment

Before using the device, please refer to the Operation and Repair Manual for detailed instructions on preparing the device for operation.

9. Testing

A "catch-all" operationality test dominated our verification plan, and consisted of sustained ability to drive the fully loaded maize mill. Unfortunately, the mill was not completed in time for extensive testing of the coupled system. Various other tests allowed us to successfully determine the functionality and mechanical capability of the drive system. Thankfully, we were able to perform some tests with the mill team and clearly demonstrated our system's ability to run their mill.

9.1 Sub-System Testing

We inspected and manually tested each sub-assembly as they were manufactured in order to catch any crucial flaws as early as possible in the fabrication process.

9.1.1 Axle Clamps

We checked the top blocks for proper clearances to ensure alignment of the upper block with the lower piece. Also, we checked for the alignment of the through holes to their threaded counterparts.

9.1.2 Frame

We measured the parallelism of the horizontal portion of the frame to check the members for warpage during welding. We verified the frame's structural integrity (statically) by standing on it and found it to be sufficiently rigid in all directions.

NOTE- One member was significantly warped by welding and causes minimal rocking.

9.1.3 Friction Wheel Sub-Assembly

We verified the wheel would fit in the fork we made and checked the bearing mounting surfaces for planar alignment.

9.1.4 Sliding Shaft Assembly

We checked that the holes in the plates were properly spaced and that the plate width wouldn't affect our belt paths.

9.2 System Testing

This section details tests we performed independent of the maize mill.

9.2.1 Multiple Bike Wheel Sizes

We ensured our design is capable of functioning with bike wheels of both 26"and 29" diameters by hooking up three different bicycles and pedaling them. These test were successful in transmitting power.

9.2.2 Stability / Tipping

To test tipping we applied a 90 kg load to a pedal with the crank in a horizontal orientation and the brakes applied (to simulate worst case conditions). Our system rocks a little due to slight curvature in a frame member (mentioned above), but tipping is not at all likely and the system passed this test.

9.2.3 High Speed Range

We accomplish the high speed function of our device by re ordering the pulleys in the drivetrain to invert the design mill ratio. To test the high output speed we marked the output pulley and videotaped (at 60 frames per second) the device in operation. We counted rotations per time in slow motion and determined our device can produce 1900 (±200) rpm.

9.2.4 Maximum Output Torque

Aside from testing with the mill itself, this test was the most important in the verification process. The torque load from the mill is unknown, therefore to test our machine's torque performance we needed an alternative method of torque application. We ended up fitting our machine with an extra pulley and hoisting a known weight. We used a water jug and dumbbells as weight and rigged them on fishing line from a pulley hanging on an existing structure. We repeated this test 5 times for good measure, the system passing every time. We were mainly checking for failure in belt slippage of which none occurred.

9.2.5 Maximum Tolerable Power at Design Load

This test is essentially the same as 9.2.4 except we pedaled the input bicycle as hard as we could. With estimated human "burst" power output at 1500 watts, we considered our system sound in this regard, however we note that although it can withstand this amount of power for a few seconds at a time, the drive was not designed to be operated at such power levels.

9.3 Testing With Mill

First, we confirmed that the maize mill correctly mounts to and couples with our machine. Next, we operated the mill unloaded to verify the alignment of our shafts and work out any potential sizing issues. Lastly, we ran the mill loaded with maize and confirmed overall functionality. This test demonstrates the drive train's ability to operate the mill under full load, our overarching goal. Furthermore, we found that the drive produces adequate torque to start up (and grind maize) even when the mill is loaded.

We think that the torque requirement provided to us by the mill team was an over-estimate. We made our design choices with the higher torque value in mind as a requirement. In retrospect and for future work on this project, we see the most room for improvement in the optimization of the output torque to speed ratio (which we think could be lowered drastically).

Testing with the mill was cut short due to a failure inside the mill device. The test was successful from our end but only lasted 15 minutes. This inhibited our ability to verify the extended functionality of our prototype.

9.4 Tested Engineering Specifications

Table 13. Quantitative Test Results (see Appendix m: DVP&R)

Spec	Parameter	Requirement	'Tolerance'	Pass/Fail
1	Bike Clamp Time	<5 (min)	Minimize	Pass
2	Compatible Wheel Sizes	60-68 (cm)	±1	Pass
3	Stability	90 (kg) unbalanced pedal load*	±5	Pass
4	Steady State Operation Tolerable Power	150 (Watts)	±10	Pass
5	Maximum Output Torque	40 (N m)	±10	Pass
6	Maximum Tolerable Power	250 (Watts)	±10	Pass
7	Highest Speed Range	2000 (RPM)	±150	Pass
8	Maximum Allowable Input Torque	250 (N m)	±5	Pass

Table 14. Qualitative Test Results (see Appendix m: DVP&R)

Spec	Parameter	Requirement	Pass/Fail
2	Frame Strength	No critical deflection under load	Pass
3	Drivetrain Strength	No critical fatigue or vibration	TBD
4	Output Shaft Orientation	Horizontal	Pass
5	Corrosion/Rot	Vulnerable Surfaces Treated/Painted	Fail
6	Rotation Direction	Clockwise (looking at mill back or alternator front)	Pass
7	Efficiency	Frictional losses do not impede regular operation	Pass

10. CONCLUSIONS

Our prototype successfully meets nearly all of the specifications that were determined as goals for the design based on problem we were tasked to address. The pedal powered drivetrain system is able to transfer power from a human comfortably and safely. The system enables the output power to be adjusted from high torque, low speed to high speed, low torque to accommodate various applications. The device can accommodate different sized bicycles and does not require the bicycle to be modified in any way. Attaching the bike to the device is quick and can be done with simple tools. During operation the bike, rider, device, and attachment are stable and safe. No components in the drivetrain slip or fail during regular or extreme operation.

The biggest concern our team had with our design was that the bicycle wheel to friction wheel interface would slip or that the belts would slip on the pulleys under high loads. The testing of our prototype verified that analysis was valid and that our system operates as designed under fully loaded conditions. During one test a pulley slipped on its shaft even though the set screw was fastened. We resolved this by grinding flats into the shafts so that they were d-shafts which completely fixed the problem. Otherwise there were no slipping problems during any of our testing. The use of a friction wheel is a viable method of transmitting power for this application assuming there is an adjustability to produce adequate normal force between the wheels, and the wheels have material with a good coefficient of friction, such as rubber to rubber.

The only requirement our system did not pass was vulnerability to corrosion. The steel frame and untreated shafts showed some rust after having been left outside for several days. We expect this is a condition the device could experience throughout its lifetime of operation. Our recommendation is that the non-coated steel components of the device be painted or covered with a different corrosion resistant solution to prevent rust. Rust will eventually lead to a compromise of structural integrity which may lead to failure and possibly injury.

Additional testing with the mill could lead to improvements in our device. Speculation of the required load for the mill resulted in the need for our device to be highly adjustable. Having a more accurate understanding of the optimized operating condition of the mill could lead to simplifications in the drivetrain of our device. This would reduce the cost of our system and could lead to a significantly smaller device. Based on the limited testing we were able to perform with our device driving the mill we suspect that mill can operate at a higher speed and lower torque than our final shaft provides. This could enable us to eliminate the second shaft assembly, resulting in only one adjustable shaft assembly. Such a change would allow the length of the frame to be greatly reduced.

One improvement we would want to explore for future iterations would be the incorporation of a flywheel. Pedaling is not difficult when the mill is operating under full load but the power delivery is not as smooth as riding a bike normally. A flywheel in the drivetrain would aid in smoothing out the power delivery and improve the usability of the machine because it would be more comfortable to operate.

Another area of interest for future development of the device is to convert as much of the frame as is possible to bamboo which can be locally grown in Malawi. This would be an improvement because it

would allow the development of the device in Malawi to be more independent of imported materials such as steel. The economic sustainability and impact of the device would be an excellent focus for future development. In the case that steel is still used to build the frame there are also improvements to be made. We used square steel tubing with 1/8'' wall thickness because it made it easy for us to confidently weld. However, this thickness is overdesigned for the structural needs of the device. A more skilled welder could easily build this from thinner steel and it would be strong enough for all of our designed loads. This improvement would have the benefits of making the device lighter and more portable as well cheaper.

Reducing costs was not a high priority when we were selecting vendors to buy materials from for our prototype. The prototype cost could be reduced by selectively purchasing materials from more competitive sources. The most significant way to reduce the cost of this device is to simplify the design by using less components where possible. As previously mentioned we believe the torque and speed range was overdesigned for actual needs of the maize mill. Reducing the range capability of the device would result in a considerable reduction in the number of components and frame size required to still provide the mill sufficient operating power. A smaller, lighter, and simplified device would be much cheaper and even more usable. This simplified design would still be able to achieve the high speed output configuration needed to power an alternator.

Throughout the design and manufacturing process of this project our team communicated with people in Malawi and students from EWB who have visited Malawi to ensure the materials, components, and processes we involved will be available and replicable in Malawi. To do this we selected components available to us in Standard Units that had close metric counterparts. When this device is built with all metric materials the builders will need to thoughtful about the function of various parts when they size and select parts. For example simply selecting the nearest sized bearings, pulleys, and shafts may not result in sizes that are compatible with one another which is critical for their function. Therefore it is imperative that the through holes of the pulleys and bearings are the same size and match the diameter of the shaft they are mounted to. Otherwise there is a good amount of flexibility in the design.
Our team is pleased with the performance of our prototype as it has verified specified functions we designed for our project. Our design has provided the necessary flexibility to perform successful testing that will enable more specific sets of specifications and allow for more refined and optimized future iterations of this design.

11. Appendices

A: Map

Figure A-1: Southern Malawi (pin - Central Kumponda)

B: References

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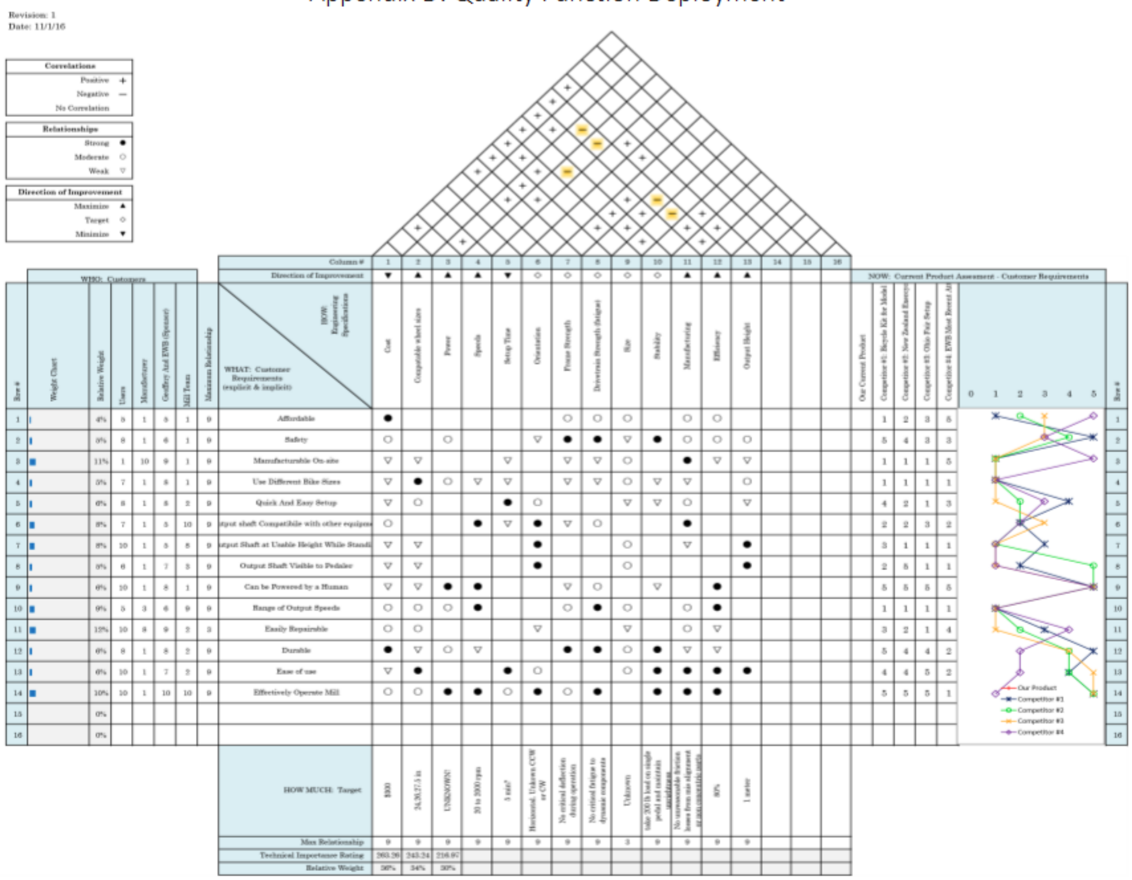
C: Power Output Table

	Maximal Power Output (in W/kg)							
	Men				Women			
	5 s	1 min	5 min	FT	5 s	1 min	5 min	FT
	25.180000	11.50000	7.600000	6.600000	19.42000	9.290000	6.740000	5.690000
	24.877391	11.38260	7.494348	6.504783	19.19978	9.197391	6.642609	5.606087
	24.574783	11.26521	7.388696	6.409565	18.97956	9.104783	6.545217	5.522174
	24.272174	11.14782	7.283043	6.314348	18.75934	9.012174	6.447826	5.438261
World class	23.969565	11.03043	7.177391	6.219130	18.53913	8.919565	6.350435	5.354348
	23.666957	10.91304	7.071739	6.123913	18.31891	8.826957	6.253043	5.270435
	23.364348	10.79565	6.966087	6.028696	18.09869	8.734348	6.155652	5.186522
	23.061739	**10.67826**	**6.860435**	**5.933478**	**17.87847**	**8.641739**	**6.058261**	**5.102609**
	22.759130	10.56087	6.754783	5.838261	17.65826	8.549130	5.960870	5.018696
	22.456522	10.44347	6.649130	5.743043	17.43804	8.456522	5.863478	4.934783
Exceptional	22.153913	10.32608	6.543478	5.647826	17.21782	8.363913	5.766087	4.850870
	21.851304	10.20869	6.437826	5.552609	16.99760	8.271304	5.668696	4.766957
	21.548696	10.09130	6.332174	5.457391	16.77739	8.178696	5.571304	4.683043
	21.246087	**9.973913**	**6.226522**	**5.362174**	**16.55717**	**8.086087**	**5.473913**	**4.599130**
	20.943478	9.856522	6.120870	5.266957	16.33695	7.993478	5.376522	4.515217
	20.640870	9.739130	6.015217	5.171739	16.11673	7.900870	5.279130	4.431304
Excellent	20.338261	9.621739	5.909565	5.076522	15.89652	7.808261	5.181739	4.347391
	20.035652	9.504348	5.803913	4.981304	15.67630	7.715652	5.084348	4.263478
	19.733043	9.386957	5.698261	4.886087	15.45608	7.623043	4.986957	4.179565
	19.430435	**9.269565**	**5.592609**	**4.790870**	**15.23587**	**7.530435**	**4.889565**	**4.095652**
	19.127826	9.152174	5.486957	4.695652	15.01565	7.437826	4.792174	4.011739
	18.825217	9.034783	5.381304	4.600435	14.79543	7.345217	4.694783	3.927826
Very good	18.522609	8.917391	5.275652	4.505217	14.57521	7.252609	4.597391	3.843913
	18.220000	8.800000	5.170000	4.410000	14.35500	7.160000	4.500000	3.760000
	17.917391	8.682609	5.064348	4.314783	14.13478	7.067391	4.402609	3.676087
	17.614783	**8.565217**	**4.958696**	**4.219565**	**13.91456**	**6.974783**	**4.305217**	**3.592174**
	17.312174	8.447826	4.853043	4.124348	13.69434	6.882174	4.207826	3.508261
	17.009565	8.330435	4.747391	4.029130	13.47413	6.789565	4.110435	3.424348
Good	16.706957	8.213043	4.641739	3.933913	13.25391	6.696957	4.013043	3.340435
	16.404348	8.095652	4.536087	3.838696	13.03369	6.604348	3.915652	3.256522
	16.101739	7.978261	4.430435	3.743478	12.81347	6.511739	3.818261	3.172609
	15.799130	**7.860870**	**4.324783**	**3.648261**	**12.59326**	**6.419130**	**3.720870**	**3.088696**
	15.496522	7.743478	4.219130	3.553043	12.37304	6.326522	3.623478	3.004783
	15.193913	7.626087	4.113478	3.457826	12.15282	6.233913	3.526087	2.920870
Moderate	14.891304	7.508696	4.007826	3.362609	11.93260	6.141304	3.428696	2.836957
	14.588696	7.391304	3.902174	3.267391	11.71239	6.048696	3.331304	2.753043
	14.286087	7.273913	3.796522	3.172174	11.49217	5.956087	3.233913	2.669130
	13.983478	**7.156522**	**3.690870**	**3.076957**	**11.27195**	**5.863478**	**3.136522**	**2.585217**
	13.680870	7.039130	3.585217	2.981739	11.05173	5.770870	3.039130	2.501304
	13.378261	6.921739	3.479565	2.886522	10.83152	5.678261	2.941739	2.417391
Fair	13.075652	6.804348	3.373913	2.791304	10.61130	5.585652	2.844348	2.333478
	12.773043	6.686957	3.268261	2.696087	10.39108	5.493043	2.746957	2.249565
	12.470435	6.569565	3.162609	2.600870	10.17087	5.400435	2.649565	2.165652
	12.167826	**6.452174**	**3.056957**	**2.505652**	**9.950652**	**5.307826**	**2.552174**	**2.081739**
	11.865217	6.334783	2.951304	2.410435	9.730435	5.215217	2.454783	1.997826
	11.562609	6.217391	2.845652	2.315217	9.510217	5.122609	2.357391	1.913913
Novice 2	11.260000	6.100000	2.740000	2.220000	9.290000	5.030000	2.260000	1.830000
	10.957391	5.982609	2.634348	2.124783	9.069783	4.937391	2.162609	1.746087
	10.654783	5.865217	2.528696	2.029565	8.849565	4.844783	2.065217	1.662174
	10.352174	**5.747826**	**2.423043**	**1.934348**	**8.629348**	**4.752174**	**1.967826**	**1.578261**
	10.049565	5.630435	2.317391	1.839130	8.409130	4.659565	1.870435	1.494348
	9.746957	5.513043	2.211739	1.743913	8.188913	4.566957	1.773043	1.410435
Novice 1	9.444348	5.395652	2.106087	1.648696	7.968696	4.474348	1.675652	1.326522
	9.141739	5.278261	2.000435	1.553478	7.748478	4.381739	1.578261	1.242609
	8.839130	5.160870	1.894783	1.458261	7.528261	4.289130	1.480870	1.158696
	8.536522	5.043478	1.789130	1.363043	7.308043	4.196522	1.383478	1.074783
	8.233913	4.926087	1.683478	1.267826	7.087826	4.103913	1.286087	0.990870

D: Quality Function Deployment

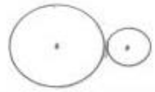
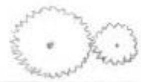
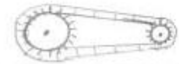
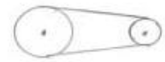
Appendix D: Quality Function Deployment



E: Pugh Matrices

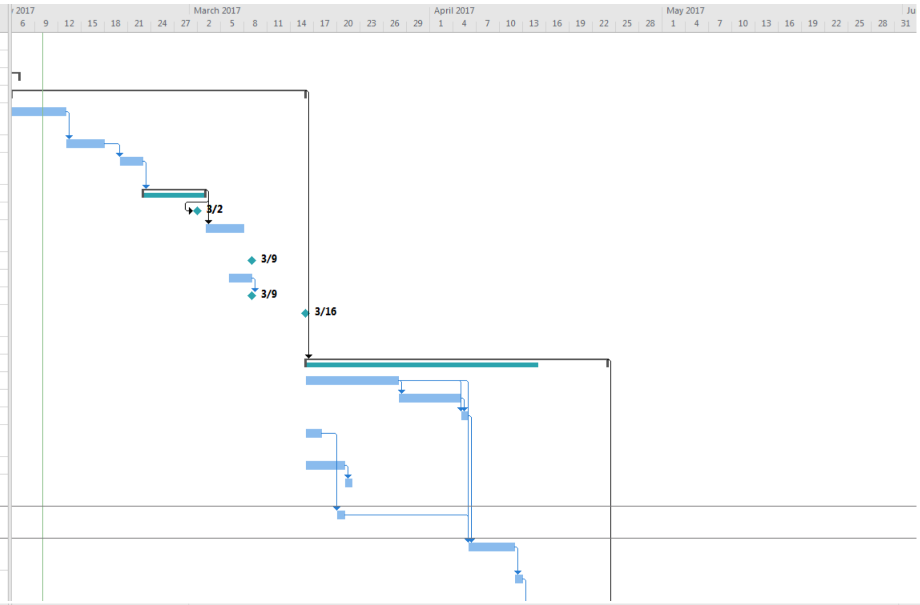
CONCEPT / RITERIA	CON BICI			SIN BICI		
	CHAIN TAKE OFF	BELT TAKE OFF	FRICTION WHEEL TAKE OFF	DIRECT	CHAIN	RECIPROCATING PEDA
USEABILITY	−	−	D	+	+	−
EFFECTIVNESS	+	+	A	+	+	+
COMPLEXITY	−	−	T	=	=	=
MANUFACTURABILITY	−	−	U	=	=	−
RELIABILITY	+	=	M	+	+	+
COST	=	−		−	=	−
MAINTAINENCE	=	−		+	=	=
OPERATION RANGE (ω,+T)	=	=		−	=	−
Σ	−1	−4	0	+2	+3	−2

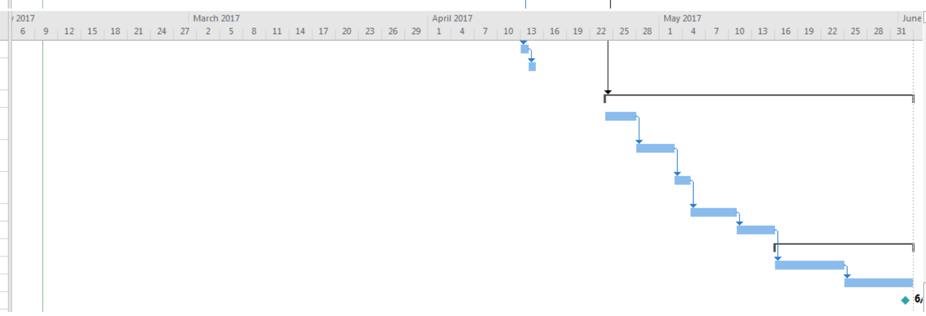
CONCEPT / CRITERIA	WATER	WIND					
IMMEDIATE USE	-	-	D	=	=	=	-
POWER OUTPUT	=	-	A	-	+	+	-
RELIABILITY	-	-	T	=	-	=	-
FATIGUE	+	+	U	-	+	-	+
SUSTAINABILITY	=	=	M	-	-	-	+
SIZE	-	-		+	-	-	=
COST	=	=		=	-	-	-
COMPLEXITY	-	-		=	-	-	-
Σ	-3	-4	DATUM	-2	-4	-4	-4

RITERIA					
AINTAINENCE	=	=	D	=	−
ELIABILITY + EFFECTIVNESS	−	=	A	+	+
ANUFACTURABILITY	+	−	T	+	+
OST	−	−	U	−	−
IZE/SPACE REQ.	=	+	M	−	−
FFICIENCY	−	=		=	=
OMPLEXITY & THER FUNC. REQ.	−	−		=	−
SPEED VARIABILITY	−	−		+	+
$\sum$	−4	−3	DATUM	+1	−1

F. Gantt Chart

Task Name	Duration	Start	Finish	Predecessors	Resource Names
PDR	**30 days?**	**Mon 10/24/1**	**Fri 12/2/16**		
Detailed Design	**36 days**	**Fri 12/2/16**	**Mon 1/23/17**	**31**	
CDR	**12 days?**	**Tue 1/24/17**	**Tue 2/7/17**	**32**	
Prep for Building	**29 days?**	**Mon 2/6/17**	**Thu 3/16/17**		
Get CDR Approval	5 days	Mon 2/6/17	Sun 2/12/17		
Revise CDR Design	5 days	Mon 2/13/17	Fri 2/17/17	49	
Coordinate Manufacturing Details	3 days	Mon 2/20/17	Wed 2/22/17	50	
Order Parts	**6 days**	**Thu 2/23/17**	**Thu 3/2/17**	**51**	
Part Ordering Deadline	0 days	Thu 3/2/17	Thu 3/2/17	52	
Write Operator's Manual	4 days	Fri 3/3/17	Tue 3/7/17	52	
Operator's Manual Due	0 days	Thu 3/9/17	Thu 3/9/17		
Write Ethics Memos	3 days	Mon 3/6/17	Wed 3/8/17		
Indiv. Ethics Memo	0 days	Thu 3/9/17	Thu 3/9/17	60	
Project Update Report Due	0 days	Thu 3/16/17	Thu 3/16/17		
Spring Break	1 day?	Mon 10/24/1	Mon 10/24/1		
Build	**5.6 wks**	**Thu 3/16/17**	**Sun 4/23/17**	**48**	
Weld Frame	8 days	Thu 3/16/17	Mon 3/27/17		
Machine Axle Supports	6 days	Tue 3/28/17	Tue 4/4/17	65	
Mount Axle Supports	1 day	Wed 4/5/17	Wed 4/5/17	65,66	
Weld Shaft to Friction Wheel	2 days	Thu 3/16/17	Fri 3/17/17		
Weld FD Linkage	3 days	Thu 3/16/17	Mon 3/20/17		
Mount Bearings to FD Arm	1 day	Tue 3/21/17	Tue 3/21/17	69	
Mount Pulley to FD Shaft	1 day	Mon 3/20/17	Mon 3/20/17	68	
Build Upper Shaft Assemblies	4 days	Thu 4/6/17	Tue 4/11/17	71,65,67	
Mount Upper Shaft Assemblies	1 day	Wed 4/12/17	Wed 4/12/17	72	
Mount Pulleys to Shafts	1 day	Thu 4/13/17	Thu 4/13/17	73	
Mill D in Output Shaft for Mill Connection	1 day	Fri 4/14/17	Fri 4/14/17	74	
Test	**30 days**	**Mon 4/24/17**	**Fri 6/2/17**	**64**	
System Functionality Testing	4 days	Mon 4/24/17	Thu 4/27/17		
Strength/Fatigue Testing	3 days	Fri 4/28/17	Tue 5/2/17	77	
Compatibility Testing with Maize Mill	2 days	Wed 5/3/17	Thu 5/4/17	78	
Total system Testing	4 days	Fri 5/5/17	Wed 5/10/17	79	
Tweaks/Adjustments	3 days	Thu 5/11/17	Mon 5/15/17	80	
FDR	**14 days**	**Tue 5/16/17**	**Fri 6/2/17**		
Outline	7 days	Tue 5/16/17	Wed 5/24/17	81	
Write FDR	7 days	Thu 5/25/17	Fri 6/2/17	83	
FDR Due	0 days	Fri 6/2/17	Fri 6/2/17		





G. Failure Modes Effects and Analysis

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Power is tranmitted through Drivetrain	Power is NOT transmitted under load	Operationality of powered impliment is comprimised	7	Tire/Friction Wheel Interface Slip	4	28	Correct material selection	Bradley - 1/20	Rubber on Rubber			
				Jamming	5	35	Covers for puleys		Perform Analysis			
				Belt Failure	5	35	Perform belt calculation	Cal - 2/1				
				Belt Slip	4	28	Design tensionable belt reductions	Team - 12/10				
	Power transmission is reduced	Powered implimant slows/stops	5	Belt Slip	4	20						
				Misalignment	5	25	Alignability emphasis in drive design					
Supports Bike and User	Tipping	Injury	5	Poor Design	3	15	Design for no tipping	Geremy - 1/20				
		Break mill/pump/generator	8			24						
		Upset work Piece (Maize)	8			24						
	Does not Support Bike and User	Overload Friction Wheel Shaft	6	Bike Fixture Failure	2	12	Fixture weld calculations					
		1 to 6 inch drop experienced by rear wheel	6			12						
		Destructive interference with other components	7	Violent Pedaling	4	14	Liberal design factors					
Fly Wheel Provides Momentum Storage	Whirling	Large vibrations	7	Eccentricity	2	21	Perform whirling calculations	Cal - 2/1	Gearing ratio to avoid natural frequency at op speed			
	Jamming	Reduced efficiency or fully locking up	7	Clothing wrapping up	3	21	Cover/place inside frame					
Wheel Size Adjustment Stand	Fracture	Device ceases to function	8	Droping, repeated misuse	3	24	Instuctions					
			8	Set to wrong height and loaded	4	32	Make so only able to extend so far down					
	Bending	Potential Desructive interference	7			28						
		Misalignment of Friction Wheel	6			24						

H. Preliminary Design

4.5.1' – Preliminary Design Concept

With our final system concept selected, we then generated a preliminary design that conveys the basic layout of the components and how they interface with each other. It is important to note that this preliminary design is no representation of the final structure or implementation that will result from the rest of our design process throughout the project. The main goal of this preliminary design is to describe the fundamental form of the device and the method of power transmission from the user's pedal power to the output shaft that supplies power to an attached device such as the maize mill.

Before discussing the features of the current basic design, we should bring a few considerations to attention that are currently not present but will be implemented during the next phase of the design process. One major function that is absent in the current design is the interface between the output shaft and the powered-device. This will be a large area of focus in the detailed design phase, and will be designed in a manner that ensures compatibility with the maize mill and other devices in the future. Another large design consideration that is not currently represented is the safety and comfort of the user. We plan to implement safety features that will prevent the user or bystanders from harming themselves while the device is in user. The ergonomics of the device will also be improved with an area in front of the user that allows him to rest his arms on the structure of the device like a form of bicycle handlebars or a flat, desk-like surface.

Now we will discuss the functions that are currently implemented on the preliminary design. Please refer to Figure 4.5.1 as the components of the system are discussed. A base frame provides the overall structure for the device as well as mounting points for each of the components. The user sits on a seat that is supported by the frame and pedals the crank assembly in an identical manner that a bicycle is pedaled. From the sprocket of the crank assembly, a chain extends to a cog (or cogs with a derailleur for shifting) on the intermediate shaft. The intermediate shaft will also contain a flywheel of some form which must be able to disengage from the cogs so that the user can stop pedaling and the device maintains motion. A belt

will then connect from a pulley on the intermediate shaft to a pulley (or system of a pulleys for torque/speed variation) on the output shaft. Also in the belt system is an adjustable tensioning pulley that will be able to adjust the belt tension as the belt stretches. This adjustable tensioning pulley also has potential to enable different gear ratios to be used. The output shaft will be supported by bearings or bushings so as to minimize energy losses on the output shaft. Also note that the output shaft is intentionally placed on top of the frame so that the attached powered-device can be operated at standing height.

Figure 4.5.1. Solid model and component description of the preliminary design concept.

4.5.2' – Materials and Manufacturing

Frame – The frame will most likely be constructed out of a readily available, relatively cheap metal. The proprietary method of construction will be cutting and welding members together, but there is a potential to have some portions of the frame bolted together for easier maintenance and repair.
Seat/Seatpost – The seat and seat post will be taken off of a bicycle so that pedaling is natural and close to the conception that the user has of pedaling a bicycle. The seatpost will have the capability to be raised and lowered to accommodate for different user heights.
Crank Assembly – The crank assembly will consist of cranks, a crank spindle, bottom bracket, and pedals. This assembly will be integrated into the frame in a similar fashion to a bicycle. Another potential option is to cut the bottom bracket housing and seat tube out of an existing bicycle frame to reduce costs and manufacturing time. A bicycle chain will connect the sprocket of the crank assembly to the intermediate shaft.
Intermediate Shaft /Flywheel – At this time, we are intending to use a bicycle wheel as the basis for both the intermediate shaft and the flywheel. In doing so, the cogs (and freewheel) are already in place, which would remove a significant portion of the manufacturing needed. This also allows for the potential implementation of a cassette/derailleur combination for one system of torque/speed control. Concrete is an option to add mass to the bicycle flywheel as benchmarked in Section 2.5.9. Opposite of the chain-drive side, a pulley will be attached to the intermediate shaft which is connected to the output shaft via a belt.
Adjustable Belt System – The belt system that connects the intermediate shaft to the output shaft will be adjustable via a tensioning pulley. The specific belt type and material will be determined in the detailed design phase.
Output Shaft/Pulley – The output shaft will likely be made of steel to deal with the alternating loads experienced during use of the system. On the shaft will be the output pulley that is attached by press-fit or other methods. This pulley may be machined from metal or plastic, or possibly derived from a previous product such as a wheelbarrow hub or wire spool.
Bearings/Bushings – Bearings that can be purchased in Blantyre are desired for greater efficiency. However, if bearings are found to be too expensive or otherwise illogical to incorporate, bushings and other forms of load bearing can be explored.

4.5.3' – Validation with Basic Calculations

Assuming an input power of 150 W at a speed of 90 rpm:

- Input Torque = 16 Nm
    - OK - Well below max torque of 250 Nm
- Approximate Shaft Whirl Critical speed (flywheel) = 1750 rpm
    - First reduction must avoid spinning flywheel near this speed
- Achievable Speed out = 450 rpm

    (see appendix G for calculations)

4.5.4' – Preliminary Cost Analysis

Prototype Cost:

Chain – 2000 MWK (Malawian Kwacha) = $ 2.81

Crank – 3000 MWK = $ 4.21
Spindle – 1000 MWK = $ 1.40
Rear derailleur – MWK 3000 = $ 4.21
Concrete (80 lb) {Cost estimate US} = $ 8.00
4-L V Belt (25in) {Cost estimate US} = $ 6.15
Bearings (10mm) {Cost estimate US} $ 24.88 X2 = $ 49.76
Steel Shaft (10mm diameter x 400mm) = $ 8.02
Frame (30ft of 3/4in steel tube) {Cost estimate in US}= $ 66.40
Steel Angle Iron (.5' x .5" x 3ft) {Cost estimate US} $ 6.94 X 2 = $ 13.88
Adjustable-Speed V Belt Pulleys (1.5, 2, 2.5in) {Cost estimate US} $ 13.35 X2 = $ 26.70
TOTAL MATERIAL COST: $ 188.73

Malawi Implementation Cost:
No in-depth cost analysis has been performed for an implementation in Malawi. However, an initial cost estimate of individual bike parts from a local Malawian Brian Banda indicates that material costs are much cheaper in Malawi than in the United States. With this in mind, we expect that our team should be able to meet the target product cost of $100.

4.5.4' -- Preliminary Design Safety Hazard Identification Checklist

To begin this section, we must state the system we plan to create is not a consumer item but rather a piece of farm/food processing equipment and will therefore will not be confined by strict safety criteria. Having said that, safety is still a concern of ours. The potential hazards the we can identify in our preliminary design are:

- Rotating components
  - Sprockets
  - Chains
  - Shafts
- Pinch points at belt pulley interface
- Overheating

Long hair and or lose clothing present the biggest conceivable safety concerns regarding our preliminary design. Additionally, we expect our system to be used indoors in potentially hot (for humans) temperatures. It will be important to make the device easy to operate so that the users do not exert themselves fully and overheat.

A couple safety modifications that are possible include enclosing the frame with plywood or another material so that the inner components are not as easily accessible during use. This would effectively remove the dangers of the rotating components inside the frame. We also plan to implement a chain guard around the pedals' sprocket so that loose clothing will not get caught in between the chain and sprocket.

4.6 – Modification

After performing a brief cost analysis of our original preliminary design we concluded that, with a budget of $100 our design was a bit of a stretch. Furthermore; we do not think all of the requirements put forth in this project are attainable with the given budget. Moving forward we plan to modify our system to address the most pressing needs determined.

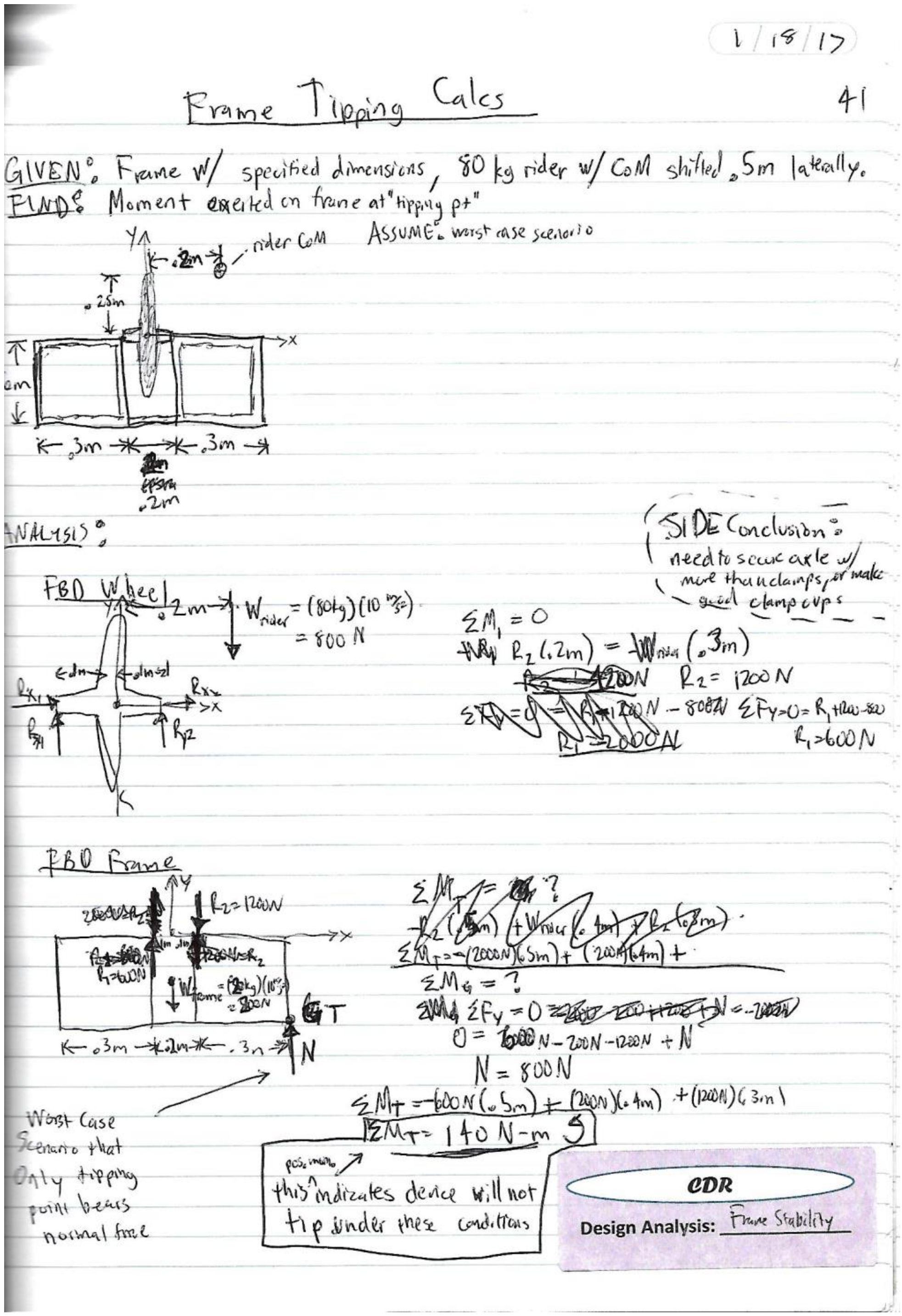
I. Analysis

List of Calculations

1. Tipping
2. Tabulated Power Rating Extrapolation
3. Pulley Calculations

- Center Spacing
- Allowable Power

4. Belt Tension
5. Shaft Sizing
6. Rail Friction
7. Spread Sheet



ENGINEERING DATA SHEET	Sheet No.	I-2	Date
Appendix I: Extrapolation	Prepared	CF	1/25/17
	Checked		
	Approved		

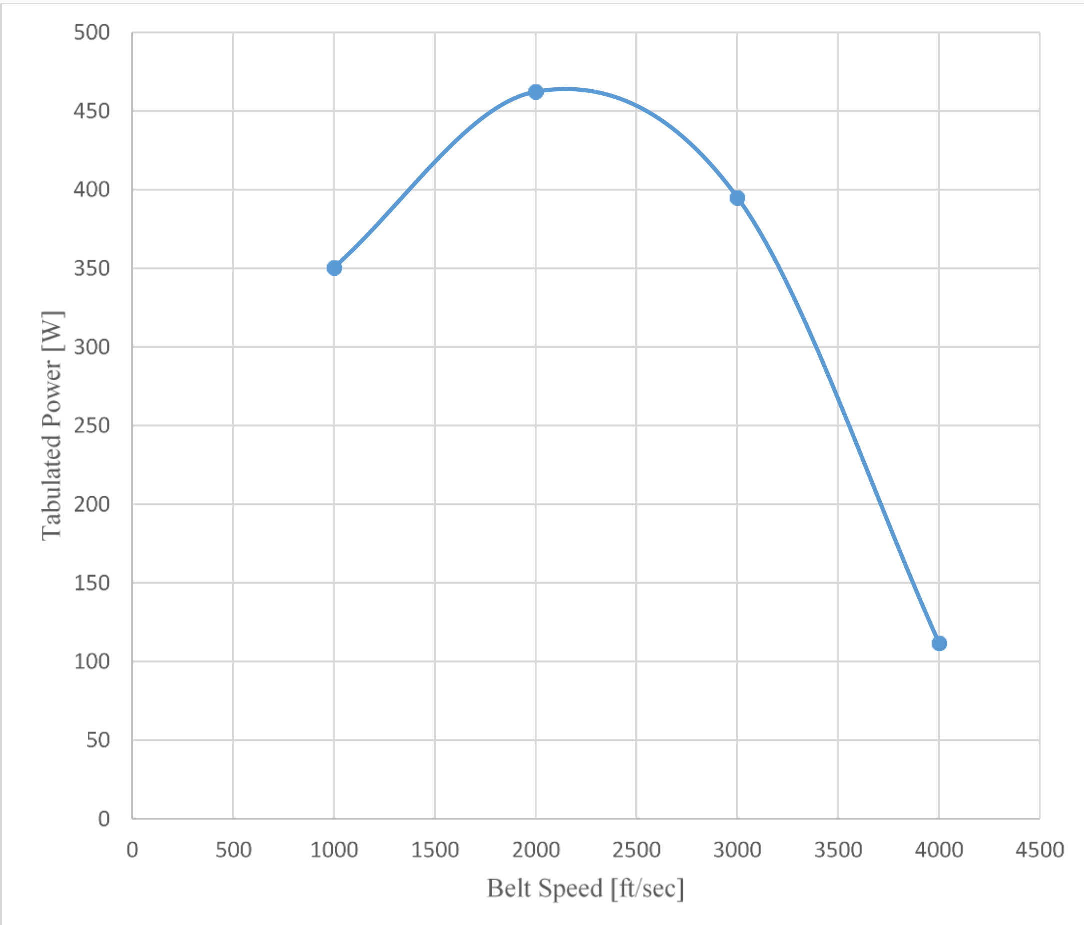


Figure I.1 – Represents the row corresponding to 2.6 inch tabulated power ratings for A-section belts. Although the distribution appears parabolic there is not nearly enough data to conclude upon a second order fit. For our belt calculations we used a linear extrapolation of the data (from the 1000 and 2000 [ft/sec] ratings).

- TABULATED POWER RATINGS FOR V-BELT FOR SHEAVE $D_p = 2.6''$

BELT SPEED [ft/s]	HP [HP]
1000	.47
2000	.62
3000	.53
4000	.15

→ TABLE 17-12 SHIGLEY'S

EXTRAPOLATION: (LINEAR, SEE FIG. G-1)

FOR BELT SPEED = 159 ft/min

159	X
1000	.47
2000	.62

$$\frac{(.62-.47)}{2000-1000} = \frac{.47 - X}{1000-159}$$

$$X = .3439 \text{ HP} \times 745.7 \frac{W}{HP}$$

$$= 256 \text{ W}$$

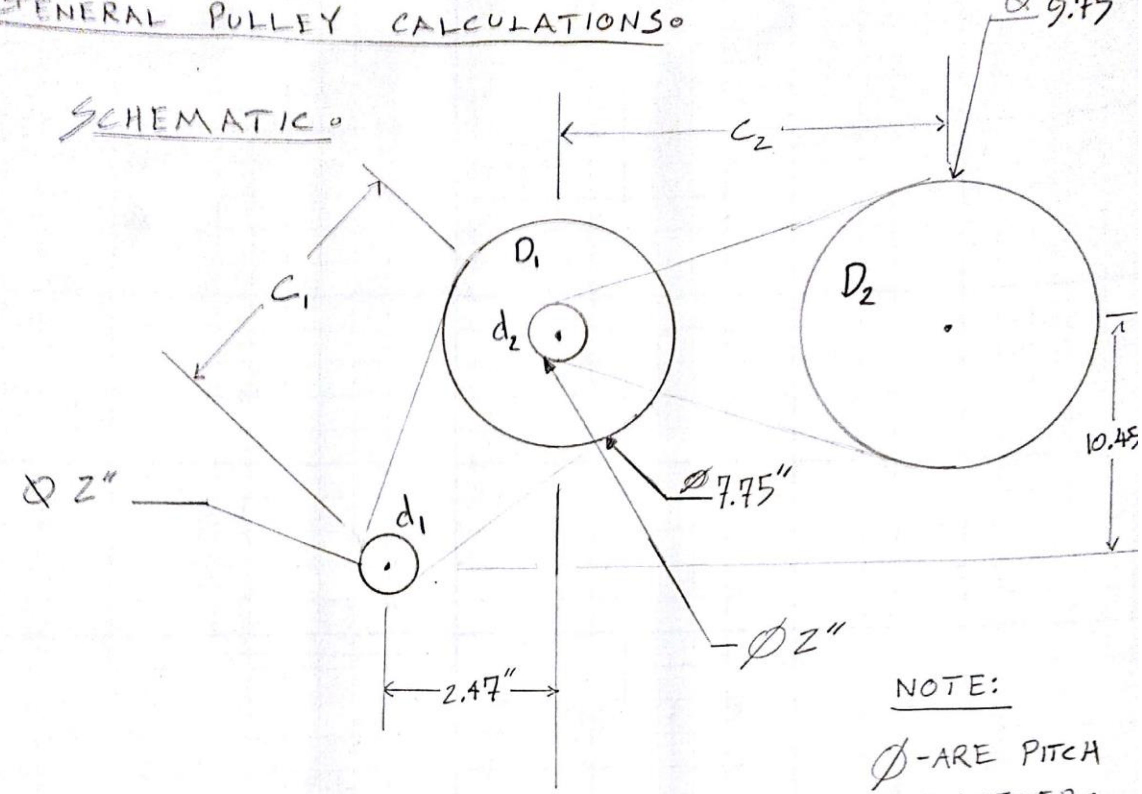
SIMILARLY

FOR BELT SPEED = 49 + 635

.326 HP, 243 W | .415 HP, 310 W

GENERAL PULLEY CALCULATIONS:

SCHEMATIC:



ANALYSIS:

INITIAL RANGE OF CENTER SPACE

$$D < C < 3(D+d)$$

$\rightarrow 7.75 < C_1 < 29.75$

$\rightarrow 9.75 < C_2 < 35.25$

- PICK BELT SIZE + ITERATE (CALC SHOWN IS FOR FINAL SELECTION)

Pitch length = 1.3 + inner circumfrence belt TABLE 17-11 SHIGLEY'S

$L_{P_1} = 1.3 + 36" = 37.3"$

$L_{P_2} = 1.3 + 39" = 40.3"$

CENTER SPACE CONT.D

$$C = .25\left\{\left[L_p - \frac{\pi}{2}(D+d)\right] + \sqrt{\left(L_p - \frac{\pi}{2}(D+d)\right)^2 - 2(D-d)^2}\right\}$$

EVALUATED IN EXCEL SHEET

$C_1 = 10.6''$

$C_2 = 10.18''$

ALLOWABLE POWER

EQN 17-17

$$H_a = K_2 K_1 H_{tab}$$

- H_{tab} → see APPENDIX I pg. 2
- K_1 → ANGLE OF WRAP FACTOR TABLE 17-13
- K_2 → LENGTH FACTOR TABLE 17-14

$$H_{a_1} = (0.9)(0.83)(0.3439\ HP)$$

$$= 0.26\ Hp \times \frac{745.7\,W}{HP}$$

$$= 192\ W$$

$$H_{a_2} = (0.9)(0.848)(0.326)$$

$$= 0.2488\ HP$$

$$= 186\ W$$

▷ BELT TENSION CALCULATION ∘ → BELT No. 2

$$F_c = \left(\frac{V}{1000}\right)^2 K_c$$ "Centerfugal Tension" EQN [17-21] SHIGLEY'S

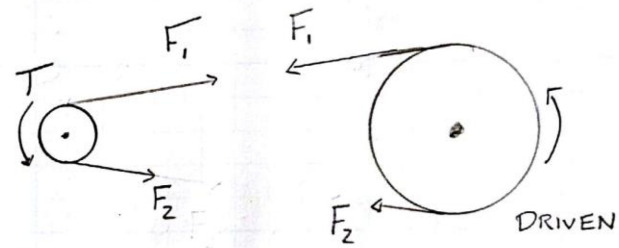
V = belt velocity (linear) [ft/s]

K_c = 0.561 → A SEC. BELTS TABLE 17-16 SHIGLEY'S

$$F_c = \left(\frac{57 \frac{ft}{min}}{1000}\right)^2 0.561$$

$= .00182$ lbf

SCHEMATIC ∘



$\Delta F = F_1 - F_2$

$$\Delta F = \frac{63{,}025\ H}{n\left(\frac{d}{2}\right)}$$ EQN 17-22 MOD.

H = power in [Hp]

n = small sheave speed [rpm]

d = small sheave pitch diameter [in]

$$150\,w \ \frac{Hp}{745.7\,w} = .2\ Hp$$

$$\Delta F = \frac{63025(0.2)\ Hp}{108\ rpm\left(\frac{2\,in}{2}\right)} = 117\ lbf$$

BELT No. 2 CONT.

$$F_1 = F_c + \frac{\Delta F e^{.5123\,\Theta}}{e^{.5123\,\Theta} - 1} \qquad \text{EQN } 17\text{-}23$$

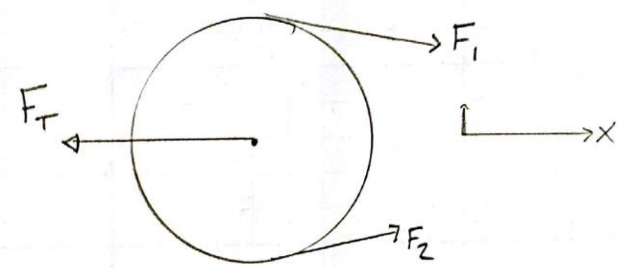
$$= .00182 + \frac{117\, e^{.5123\left(133^\circ \cdot \frac{\pi\ \text{rad}}{180^\circ}\right)}}{e^{.5123\left(133 \cdot \pi/180\right)} - 1}$$

$F_1 = 168$ lbf

$F_2 = F_1 - \Delta F$

$F_2 = 168 - 117$

$F_2 = 51.2$ lbf



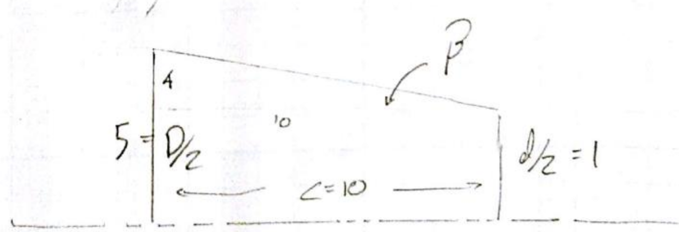
$\beta = \tan^{-1}(4/10)$

$= 21.8^\circ$

$\Sigma F_x = 0$

$F_T = (F_1 + F_2)\cos\beta$

$F_T = (219.2)\cos 21.8$

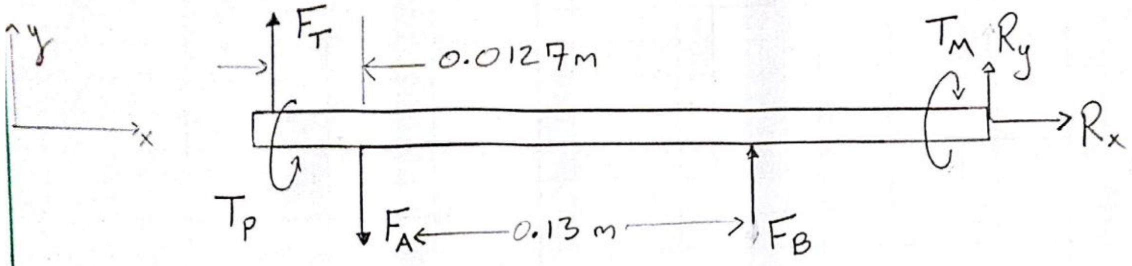


$F_T = 203$ lbf $\quad \frac{4.448\ \text{N}}{\text{lbf}}$

$F_T = 903$ N

SHAFT 3:

SCHEMATIC:



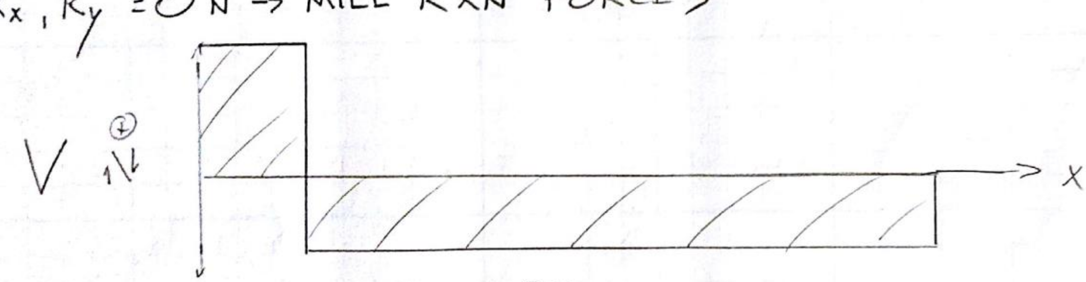
F_T = Pully Load = 903 N

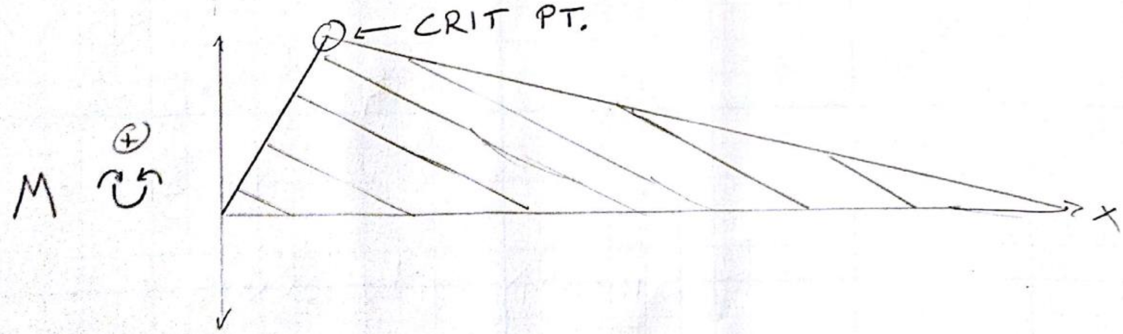
$F_A + F_B$ = BEARINGS

$T_p = T_M$ = MILL TORQUE MAX → 50 Nm

→ STEADY STATE OPERATION

R_x, R_y = 0 N → MILL RXN FORCES





$$M_{CRIT} = F_T * 0.0127 m$$

SHAFT 3 CONT.

$M_{CRIT} = 973\,N \times 0.0172\,m$

$M_{CRIT} = \underline{\underline{11.4\ Nm}}$

→ Alternating Moment

ASME ELLIPTIC (DISTORTION ENERGY)

$$d = \left[\frac{16n}{\pi} \left(4\left(\frac{K_f M_a}{S_e}\right)^2 + 3\left(\frac{K_{fs} T_a}{S_e}\right)^2 + 4\left(\frac{K_f T_m}{S_y}\right)^2 + 3\left(\frac{K_{fs} T_m}{S_y}\right)^2 \right)^{1/2} \right]^{1/3}$$

where:

n = safety factor (assumed = 1 then $d/d_{nom} = n$)

K_f, K_{fs} = stress concentration factors (=1)

M_a = alternating moment

T_a = alt. torque

M_m = midrange moment

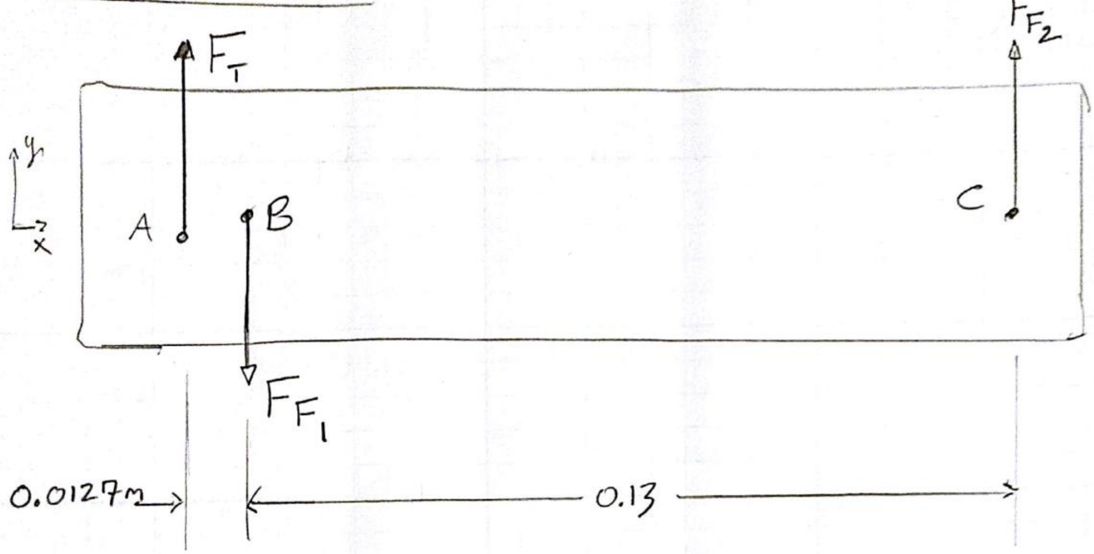
T_m = mid torque

note - for all calcs mid range load is approximated by 0.1 × alternating

ANALYSIS CONTINUED IN SPREAD SHEET

RAIL – BEARING MOUNT FRICTION

OUTPUT SHAFT



ANALYSIS:

$F_F \rightarrow$ FRICTION FORCE

GIVEN $\rightarrow$ $F_T = 903\ N$

$\Sigma M_B = 0$

$F_T\ (0.0129m) = F_{F_2}\ (.137m$

$$\frac{903N(0.0127m)}{0.13m} = 88.2\ N = F_{F_2}$$

$\Sigma F_y = 0$

$F_T + F_{F_1} = F_{F_1}$

$F_{F_1} = 903N + 88.2N = \underline{991\ N}$ $\leftarrow$

FRICTION CONT.

$$F_{RICTION} = \mu \cdot N$$

$\mu_{STEEL \cdot STEEL} = 0.5$ CONSERVATIVE

$$\frac{F_{F_1}}{\mu} = N_{REQ}$$

$$\frac{991\,N}{0.5} = 1982\,N$$

$$F_{LEG} = \frac{1982\,N}{2 \text{ U-bolts per plate}}$$

$$= 991\,N$$

OUTSIDE OUR SYSTEM	USER INPUT					
	Power	100	Watts			
	Speed	70	RPM			
	Torque	13.6	Nm			
	BICYCLE					
	Wheel Size	28	in	0.7112	m	
	Efficiency	0.9	--			
	Chain Ring	24	teeth			
	Sprocket	12	teeth			
	Ratio	2.0	--			
	Power	90	Watts			
	Speed	140	RPM			
	Torque	6.1	Nm			
TAKE OFF						
Swing Adjust	Arms	Normal Force	5	N		
		Length		m		
		Load		N		
		Angle	5.0	deg	0.0873	rad
		X-sec Area		m^2		
	Legs	Length		m		
		Load		N		
		Angle	87.0	deg	1.5184	rad
		X-sec Area		m^2		

System	Part	Pararmeter	Value	Units	Alt	Units
Shaft #1	Shaft	Length cantelever	0.036576	m	1.44	in
		Pulley Load	255.0	N		
		Se	2.75E+08	Pa		
		Sy	4.83E+08	Pa		
		Su	5.49E+08	Pa		
		n	1.0	--		
		M_a	9.3	Nm		
		M_m	0.9	Nm		
		T_a	0.3	Nm		
		T_m	2.6	Nm		
		K_t	1.0	--		
		K_ts	1.0	--		
		q	1.0	--		
		K_f	1.0	--		
		K_fs	1.0	--	1.80199	
		Diameter	7.05	mm	0.277	in
	Bearings	Loading	127.5	N		
		Speed	326.7	RPM		
	Pulleys	#1Diameter (Slow)	2.00	in		
		#2 Diameter (Fast)	7.75	in		
	Friction Wheel	Friction Coeff.	1.2	--		
		Diameter	12	in	0.3048	m
		Ratio	2.333	--		
		Speed	327	RPM		
		Torque	2.6	Nm		
		Force	17.26331	N		
		Normal Force	14.88216	N		

System	Part	Pararmeter	Value	Units	Alt	Units
Shaft #2	Shaft	Length cantelever	0.031877	m	1.255	in
		Pulley Load	648.0	N		
		Se	2.75E+08	Pa		
		Sy	4.83E+08	Pa		
		Su	5.49E+08	Pa		
		n	1.0	--		
		M_a	20.7	Nm		
		M_m	2.1			
		T_a	1.0			
		T_m	10.2			
		K_t	1.0	--		
		K_ts	1.0	--		
		q	1.0	--		
		K_f	1.0	--		
		K_fs	1.0	--	1.37342651	
		Diameter	9.24694	mm	0.36405297	in
	Bearings	Loading		N		
		Max Speed	1266	RPM		
	Pulleys	#3 Diameter (Slow)	7.75	in		
		#4 Diameter (Fast)	2.00	in		
	Slow	Ratio	0.2581	--		
		Speed	84	RPM		
		Torque	10.2	Nm		
	Fast	Ratio	3.875	--		
		Speed	1266	RPM		
		Torque	0.7	Nm		

System	Part	Pararmeter	Value	Units	Alt	Units
Shaft #3	Shaft	Length cantelever	0.01270	m	0.5	in
		Pulley Load	900.0	N		
		Se	2.75E+08	Pa		
		Sy	4.14E+08	Pa		
		Su	5.49E+08	Pa		
		n	1.0	--		
		M_a	11.4	Nm		
		M_m	1.1			
		T_a	5.0			
		T_m	49.7			
		K_t	1.0	--		
		K_ts	1.0	--		
		q	1.0	--		
		K_f	1.0	--	1.21126388	
		K_fs	1.0	--		
		Diameter	10.48	mm	0.413	in
	Bearings	Loading		N		
		Max Speed	17.3	RPM		
	Pulley	#5 Diameter (Slow)	9.75	in		
		Ratio	0.2051	--		
		Speed	17	RPM		
		Torque	49.7	Nm		

Part	Pararmeter		Value	Units	Tables and Such	
Belt #1	Center Distance Range	min	7.75	in		
		max	29.25	in		
	Inner Circumfrence		36	in	Table 17-10	
	Length Conversion		1.3	in	Table 17-11	Type 4-L
	Pitch Length		37.3	in		
	Center Spacing		10.60	in		
	Low Belt Speed		171	ft/min		
	High Belt Speed		663	ft/min		
	Htab_interp		0.3439	HP	256	Watts
	Wrap Angle Factor	D-d/C	0.54	in/in		
		Theta	145	deg	Table 17-13	
		K	0.83			
	Length Factor		0.9		Table 17-14	
	H Allowable		0.26	HP	192	Watts
Belt #2	Center Distance Range	min	9.75	in		
		max	35.25	in		
	Inner Circumfrence		39	in	Table 17-10	
	Length Conversion		1.3	in	Table 17-11	Type A
	Pitch Length		40.3	in		
	Center Spacing		10.18	in		
	Low Belt Speed		44	ft/min		
	Htab		0.326	HP		
	Wrap Angle Factor	D-d/C	0.76	in/in	243	Watts
		Theta	133	deg	Table 17-13	
		K	0.848			
	Length Factor		0.9		Table 17-14	
	H Allowable		0.2488	HP	186	Watts

J. Part Specification Sheet

Figure J-1 – Specification sheet for steel mounted ball bearings

Self-Aligning 52100 Steel Bearings with Steel Housing

For Shaft Dia.	Center Ht.	Ht.	Overall Lg.	Overall Wd.	Dynamic Radial Load Capacity, lbs.	Max. Speed, rpm	Temperature Range, °F	Misalignment Capability	Mounting Holes Ctr.-to-Ctr.	Mounting Hardware Included		Each
Double Sealed												
1/2"	7/8"	1 23/32"	3 3/8"	31/32"	716	5,800	0° to 210°	3°	2 43/64"	Yes	5913K61	$10.95

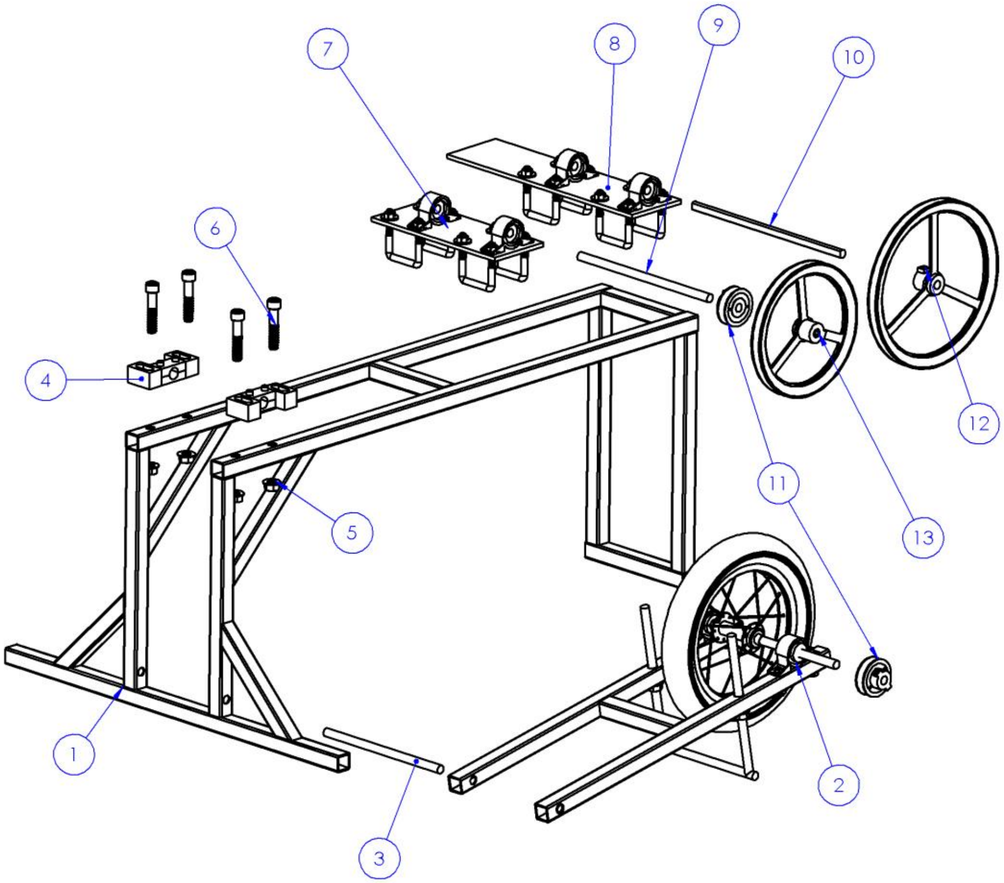
Figure J-2 – Specification sheet for Square U-bolts

Inside Wd.	Ht.	Thread Lg.	Capacity, lbs.	Ctr.-to-Ctr.	No. of Nuts Included	No. of Washers Included	Zinc-Plated Steel	Each	304 Stainless Steel	Each
3/8"-16 Thread Size										
2"	2 5/8"	1 1/2"	1,075	2 3/8"	2	2	3060T44	$2.46	3060T71	$7.88

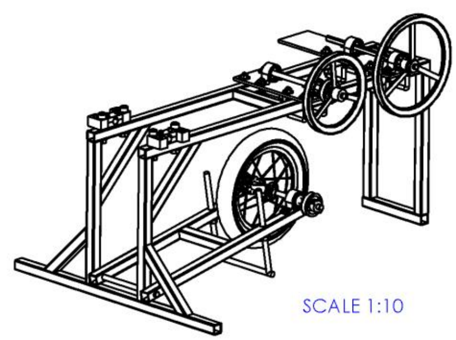
K. Technical Drawings

List:

1. Top Level Assembly
2. Frame Weldment
3. Individual Tubes
4. **Friction Drive Sub-Assembly**
5. Friction Drive Swing Arm
6. Friction Drive Base
7. Friction Drive Arm Pivot
8. **Axle Support Sub-Assembly**
9. Axle Support Sliding Block
10. Axle Clamp Blocks
11. **Adjustable Shaft Sub-Assembly**
12. Mounting Plate
13. Mounting Plate - Output

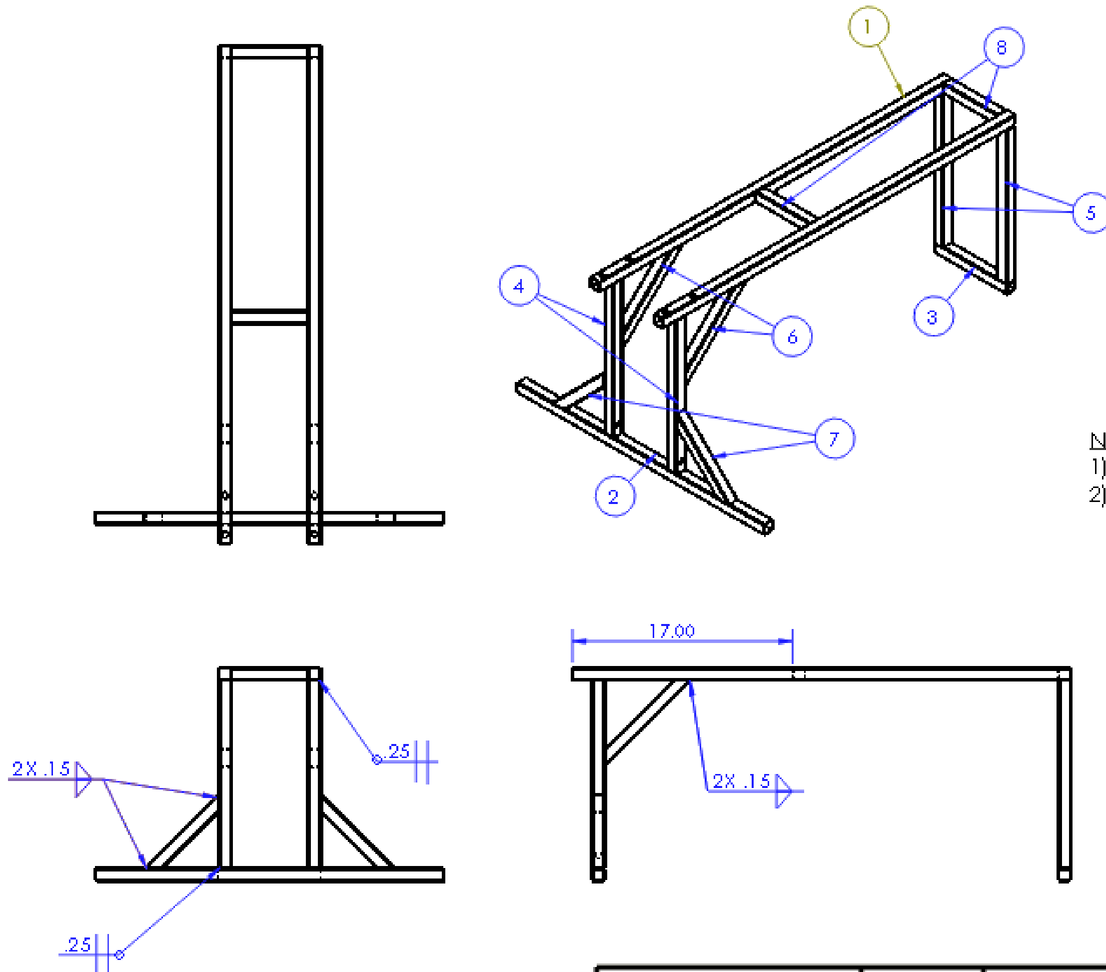


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame_	1" Steel Square Tube Frame	1
2	FD_Assem	Friction Drive Assembly	1
3	FD Arm&Frame Connection Shaft	1/2" FD Swingarm Pivot Axle	1
4	AxleSupportAssem	Bicycle Axle Supports	2
5	94612A104	1/2"-13 Steel Flange Nut	4
6	91251A722	1/2"-13, 2.5" Socket Head Screw	4
7	Adjustable shaft system_perp	Adjustable Shaft Assem - Intermediate	1
8	Adjustable shaft system_perpMounting	Adjustable Shaft Assem - Output	1
9	UpperShaft1	Intermediate Shaft	1
10	OutputShaft	Output D-Shaft	1
11	6245K18	2.25" OD, 1/2" Bore Zinc Pulley	2
12	6245K951	10" OD, 1/2" Bore Zinc Pulley	1
13	6245K55	8" OD, 1/2" Bore Zinc Pulley	1



SCALE 1:10

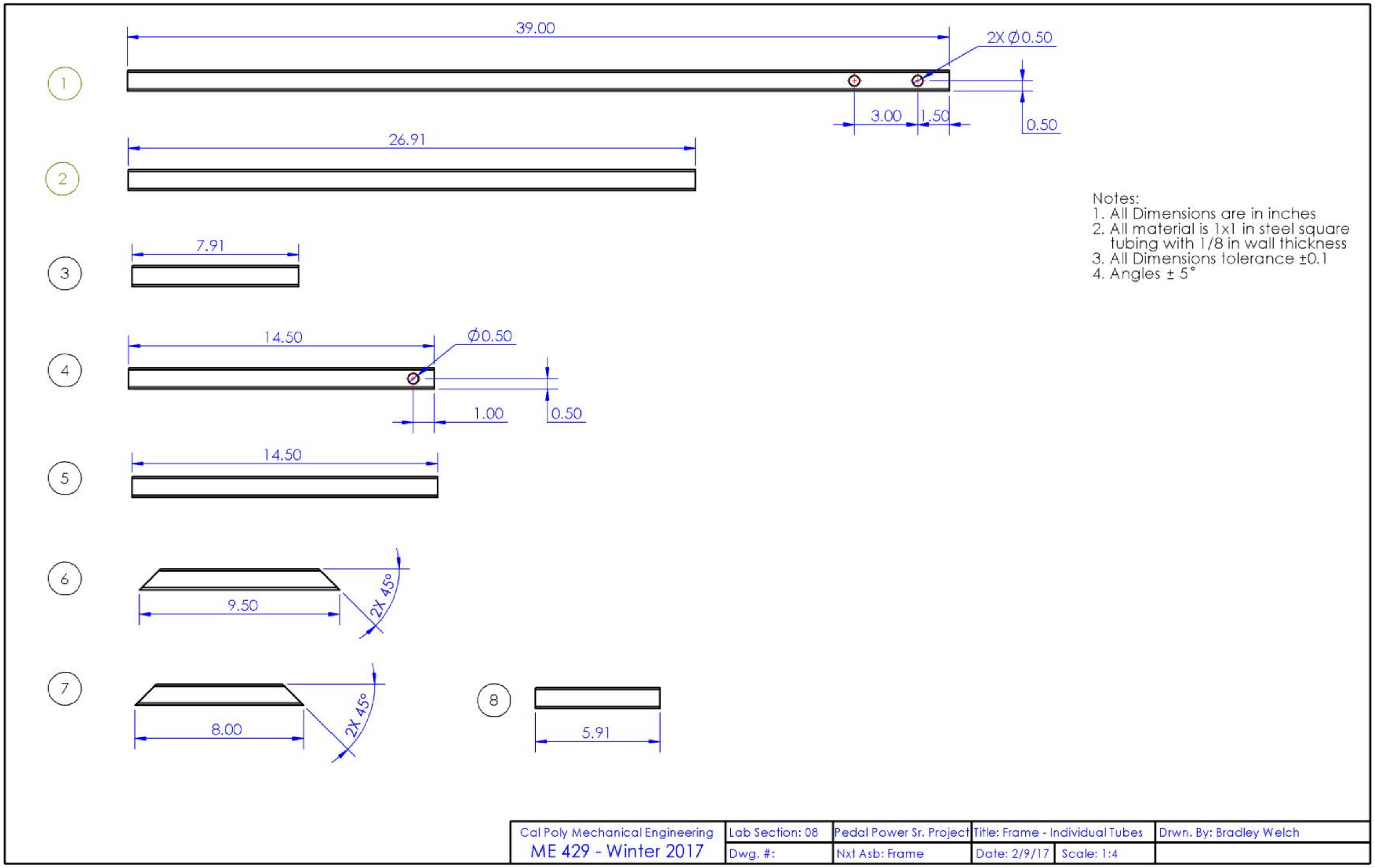
Cal Poly Mechanical Engineering	Lab Section: 08	Pedal Power Sr. Project	Title: Main Assembly	Drwn. By: Geremy Patterson
ME 429 - Winter 2017	Dwg. #:	Nxt Asb:	Date: 2/5/17 Scale: 1:6	



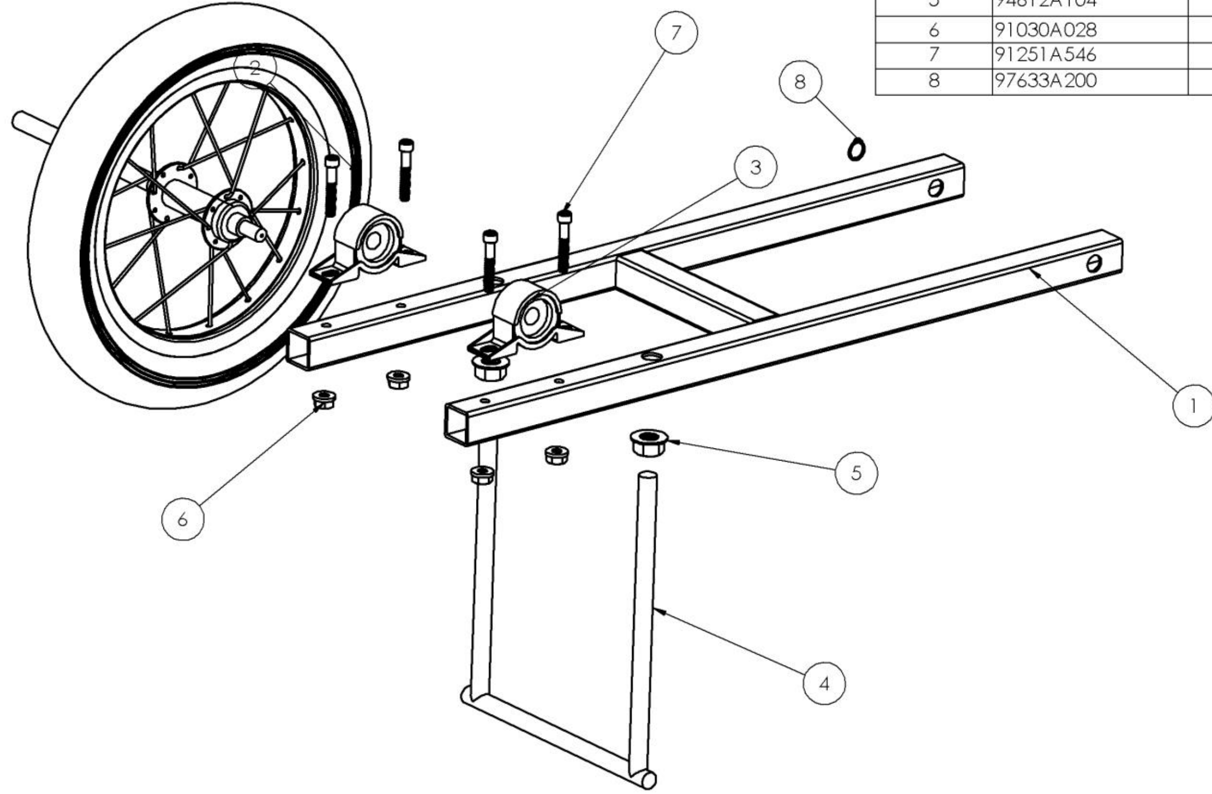
ITEM NO.	DESCRIPTION	QTY.
1	Upper Length	1
2	Lower Front Support	1
3	Lower Rear Support	1
4	Front Legs	2
5	Rear Legs	2
6	Upper 45° Support	2
7	Lower 45° Support	2
8	Center Cross Member	2

NOTES:
1) All dimensions in inches.
2) UNLESS OTHERWISE SPECIFIED:
- All 90° Joints: 0.15 Fillet Weld
- All Butt Joints: 0.15 Square Butt Weld

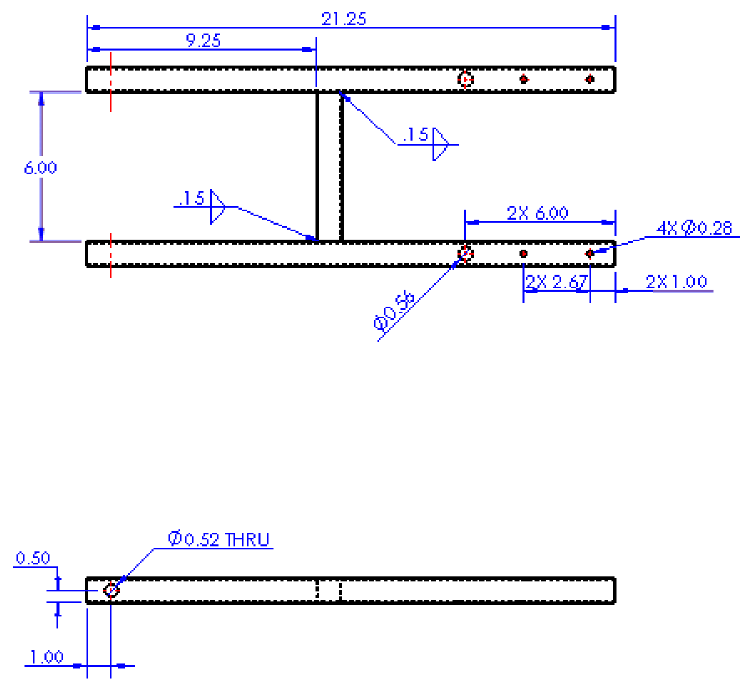
Cal Poly Mechanical Engineering ME 429 - Winter 2017	Lab Section: 08	Pedal Power Sr. Project	Title: Frame Assembly	Drwn. By: Geremy Pattenon
	Dwg. #:	Nxt Asb: Main Assembly	Date: 4/1/17 Scale: 1:8	


1
39.00
2X Ø0.50
3.00
1.50
0.50
2
26.91
3
7.91
4
14.50
Ø0.50
1.00
0.50
5
14.50
6
9.50
2X 45°
7
8.00
2X 45°
8
5.91
Notes:
1. All Dimensions are in inches
2. All material is 1x1 in steel square tubing with 1/8 in wall thickness
3. All Dimensions tolerance ±0.1
4. Angles ± 5°
Cal Poly Mechanical Engineering
ME 429 - Winter 2017
Lab Section: 08
Dwg. #:
Pedal Power Sr. Project
Nxt Asb: Frame
Title: Frame - Individual Tubes
Date: 2/9/17
Scale: 1:4
Drwn. By: Bradley Welch

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FDArm	Friction Drive Swingarm	1
2	12in bike wheel	12in Bike Wheel w/ 1/2" Shaft	1
3	5913K61	1/2" Bore Ball Bearings	2
4	FD_SetScrewBase	Base and 1/2" Threaded Rods	1
5	94612A104	1/2"-13 Steel Flange Nut	2
6	91030A028	1/4"-20 Socket Head Screw	4
7	91251A546	1/4"-20 Steel Flange Nut	4
8	97633A200	1/2" Retaining Ring	1

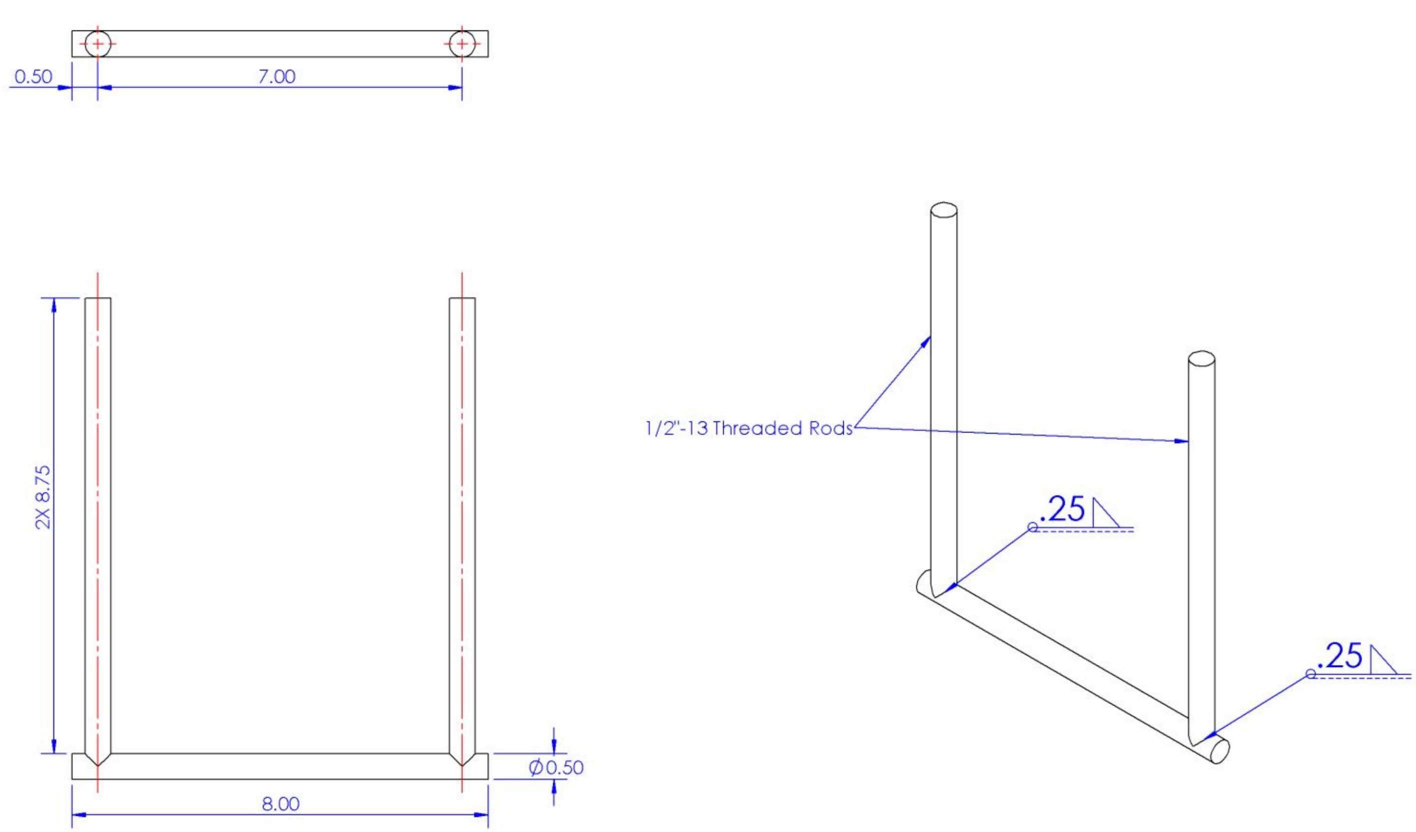


Cal Poly Mechanical Engineering	Lab Section: 08	Pedal Pwr Sr Proj.	Title: Friction Drive Assembly		Drwn. By: Geremy Patterson
ME 429 - Winter 2017	Dwg. #:	Nxt Asb: Main Asb	Date: 2/5/17	Scale: 1:3	



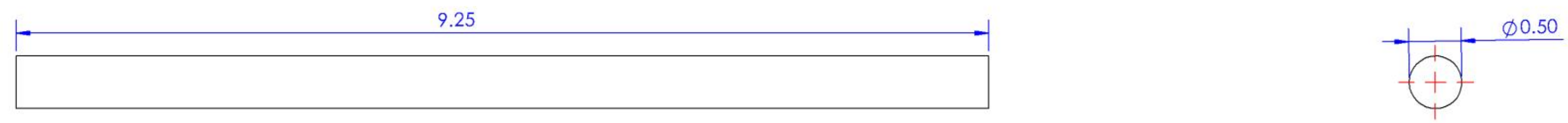
NOTES:
1) Unless otherwise stated:
- All Dimensions in Inches
- Tolerances ±.01
2) All Tubing is 1"x1"x.083" Steel

Cal Poly Mechanical Engineering ME 429 - Winter 2017	Lab Section: 08	Pedal Power Sr. Project	Title: Friction Drive Swingarm		Drwn. By: Geremy Patterson
	Dwg. #:	Nxt Asb: FD Assembly	Date: 4/1/17	Scale: 1:4	Material: Steel Square Tube



Cal Poly Mechanical Engineering ME 429 - Winter 2017	Lab Section: 08	Pedal Power Sr. Project	Title: Friction Drive Base	Drwn. By: Geremy Patterson
	Dwg. #:	Nxt Asb: FD ASsembly	Date: 2/9/17 Scale: 1:2	

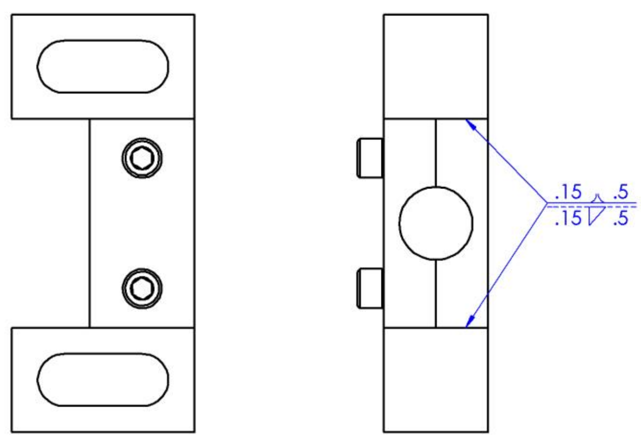
NOTES:
1) Unless otherwise stated:
-All Dimensions in Inches
-Tolerances ±.01

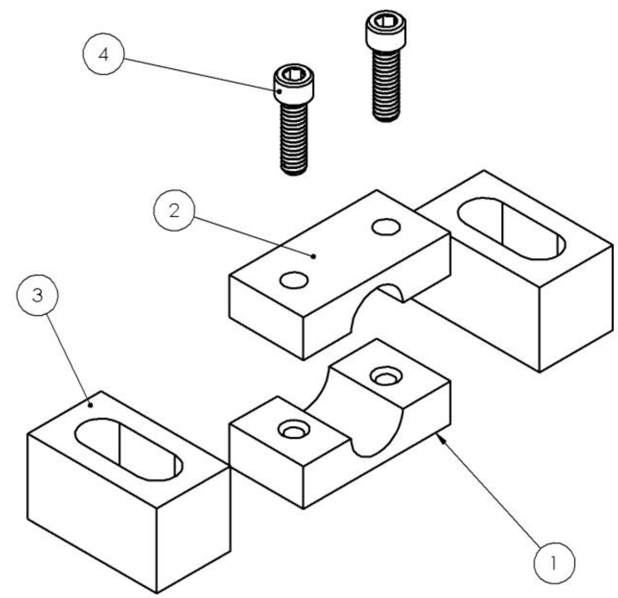


Cal Poly Mechanical Engineering ME 429 - Winter 2017	Lab Section: 08	Pedal Power Sr. Project	Title: Friction Drive Arm Pivot		Drwn. By: Geremy Patterson
	Dwg. #:	Nxt Asb: Main Assembly	Date: 2/5/17	Scale: 1:1	Material: Steel

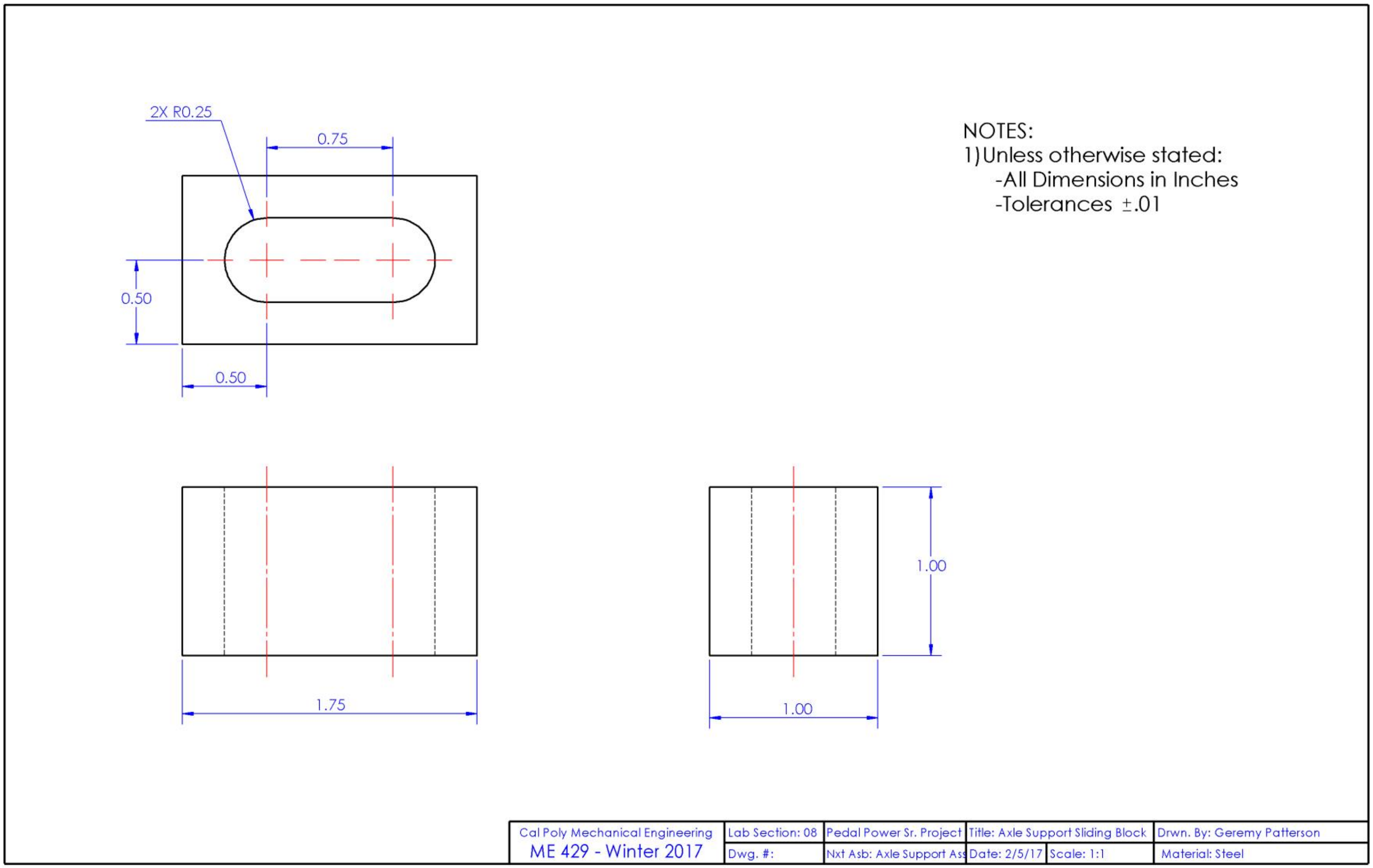
ITEM NO.	PART NUMBER	DESCRIPTION	Sploded/QTY.
1	Block Clamp_lower	Lower Block Steel	1
2	Block Clamp	Upper Block Steel	1
3	SlidingBaseSide	Slotted 1" Square Bar	2
4	91251A541	1/4"-20 7/8" Socket Head Screw	2

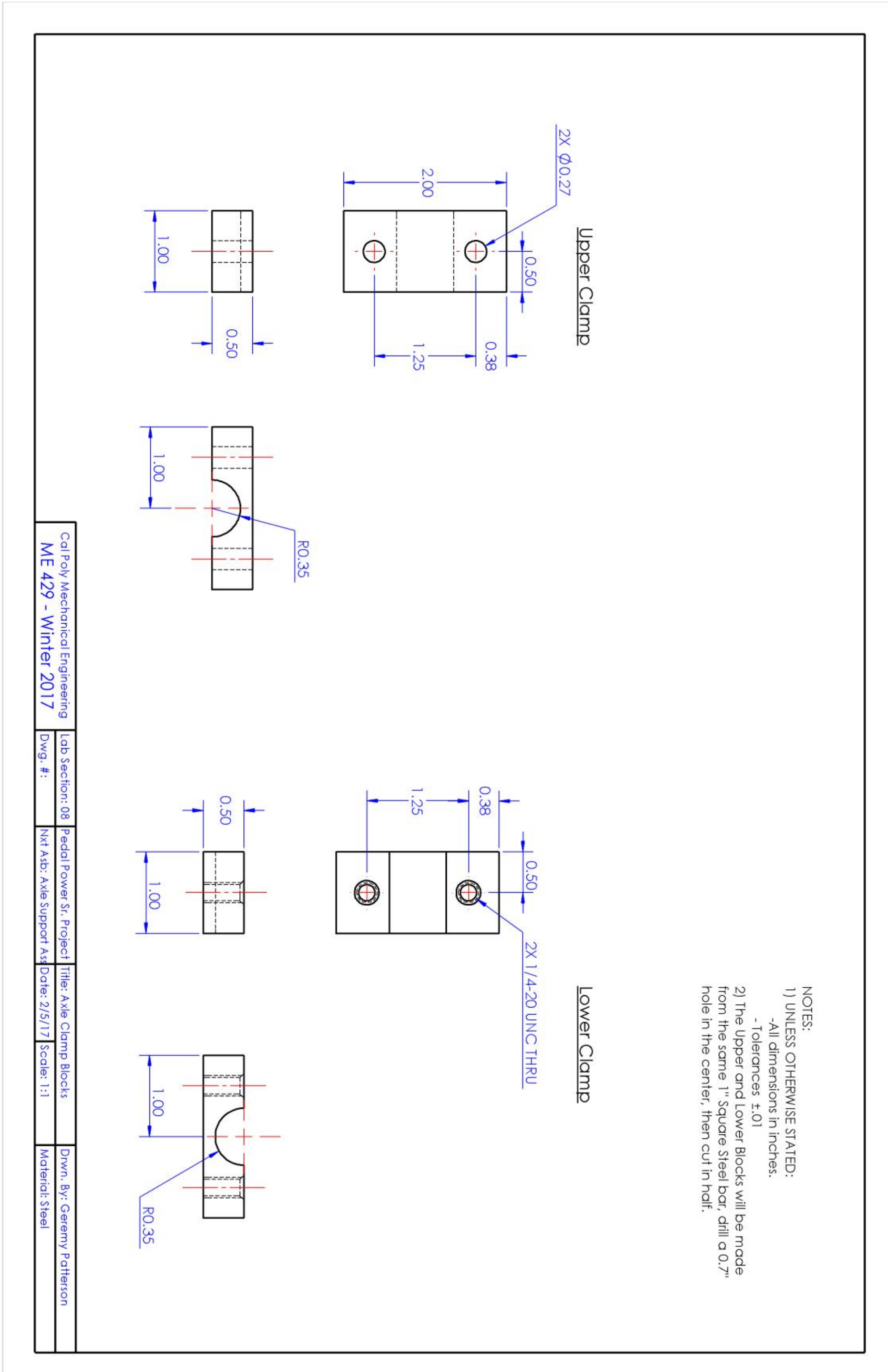
NOTES:
1) UNLESS OTHERWISE STATED:
-All dimensions in inches.
- Tolerances ±.01
2) The Upper and Lower Blocks will be made from the same 1" Square Steel bar, drill a 0.7" hole in the center, then cut in half.
3)Only the Lower Block is welded to the Slotted Side Pieces. The upper block must fit well when screwed down.



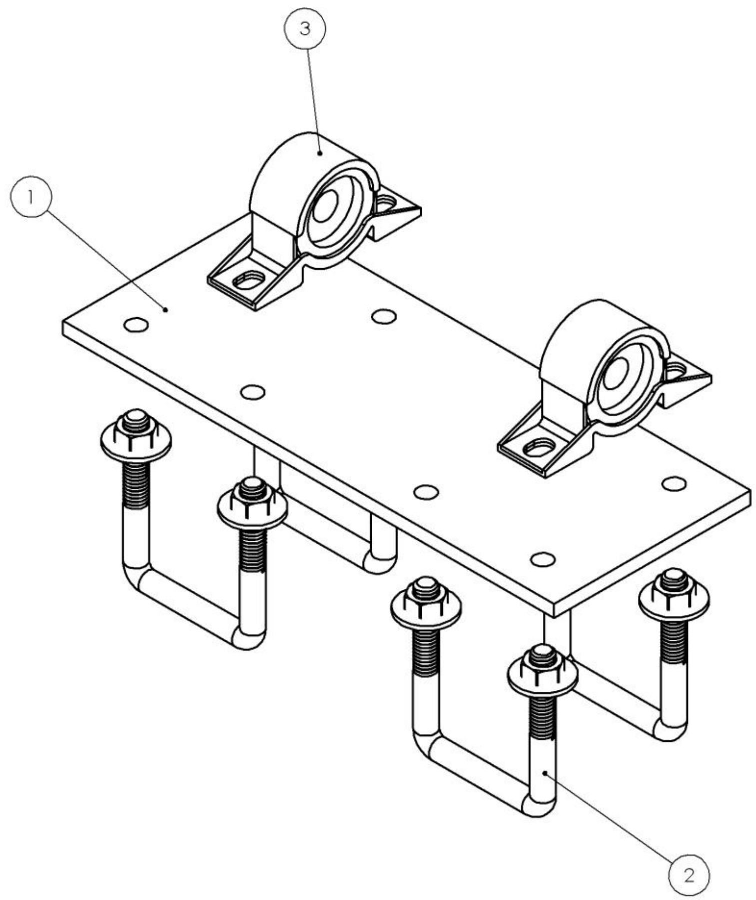


Cal Poly Mechanical Engineering	Lab Section: 08	Pedal Power Sr. Project	Title: Axle Support Assembly	Drwn. By: Geremy Patterson
ME 429 - Winter 2017	Dwg. #:	Nxt Asb: Main Assembly	Date: 2/5/17 Scale: 1:1	


2X R0.25
0.75
0.50
0.50
1.75
1.00
1.00
NOTES:
1)Unless otherwise stated:
-All Dimensions in Inches
-Tolerances ±.01
Cal Poly Mechanical Engineering
ME 429 - Winter 2017
Lab Section: 08
Dwg. #:
Pedal Power Sr. Project
Nxt Asb: Axle Support Ass
Title: Axle Support Sliding Block
Date: 2/5/17
Scale: 1:1
Drwn. By: Geremy Patterson
Material: Steel

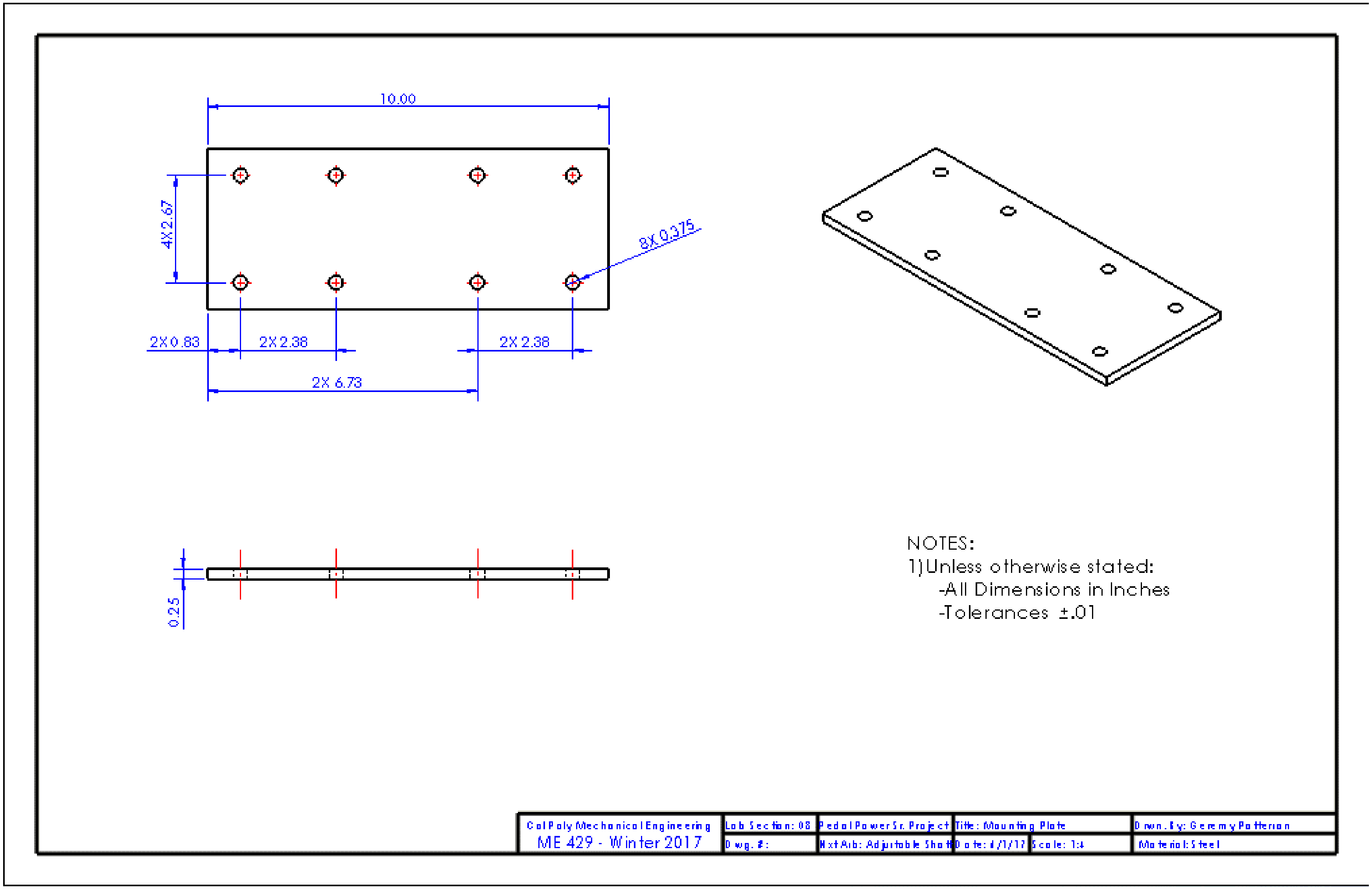

Upper Clamp
2X Ø0.27
2.00
0.50
1.25
0.38
1.00
0.50
1.00
R0.35
Lower Clamp
2X 1/4-20 UNC THRU
1.25
0.38
0.50
0.50
1.00
1.00
R0.35
NOTES:
1) UNLESS OTHERWISE STATED:
-All dimensions in inches.
- Tolerances ±.01
2) The Upper and Lower Blocks will be made from the same 1" Square Steel bar, drill a 0.7" hole in the center, then cut in half.
Cal Poly Mechanical Engineering
ME 429 - Winter 2017
Lab Section: 08
Dwg. #:
Pedal Power Sr. Project
Nxt Asb: Axle Support Ass
Title: Axle Clamp Blocks
Date: 2/5/17
Scale: 1:1
Drwn. By: Geremy Patterson
Material: Steel

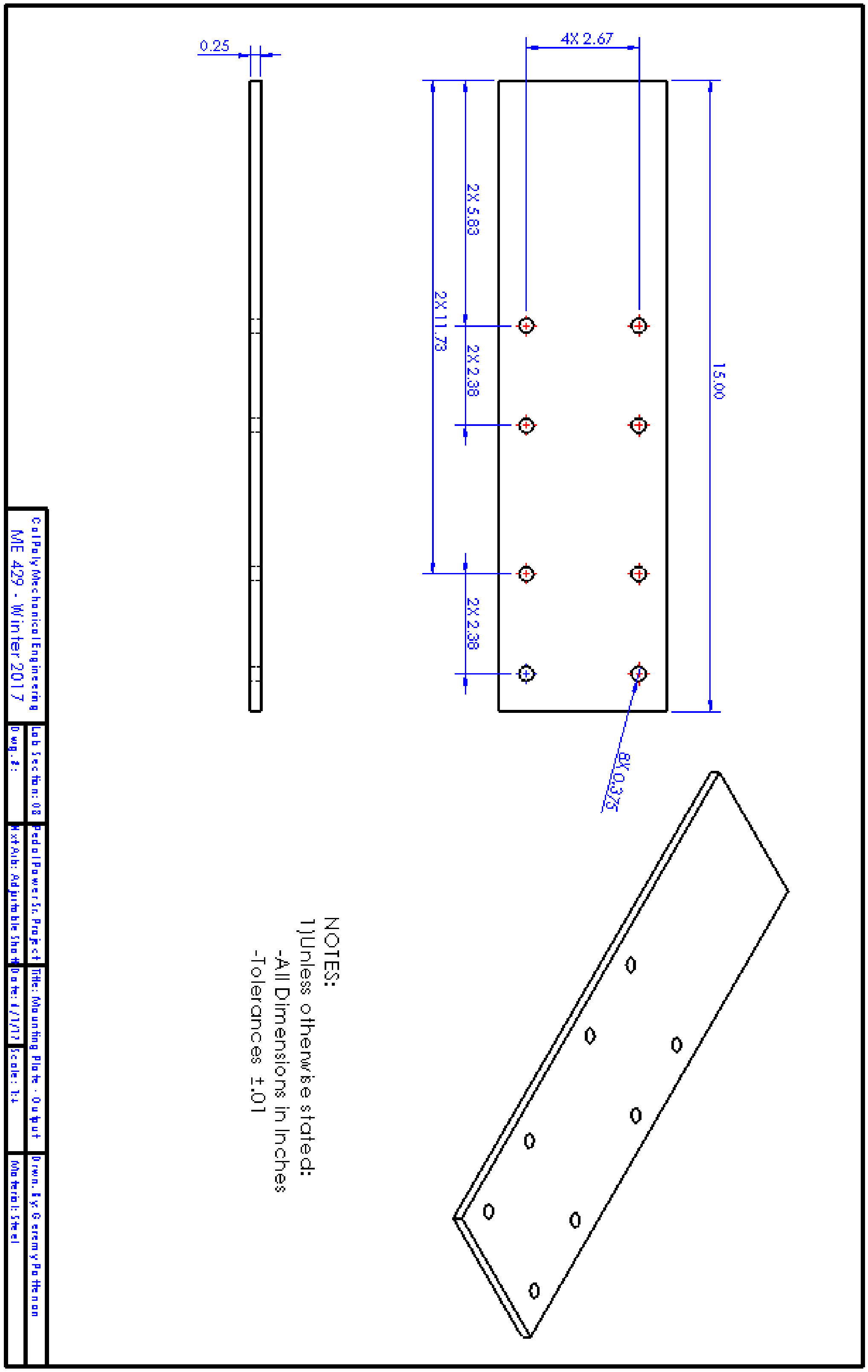
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Adjustable Plate_perp	Mounting Plate	1
2	3060T44	2" Wide U-Bolts	4
3	5913K61	1/2" Bore Ball Bearings	2



NOTES:
1) This assembly is included twice in the Main Assembly, but the second version of this assembly features a longer mounting plate.

Cal Poly Mechanical Engineering	Lab Section: 08	Pedal Power Sr. Project	Title: Adjustable Shaft Assembly	Drwn. By: Geremy Patterson
ME 429 - Winter 2017	Dwg. #:	Nxt Asb: Main Assembly	Date: 2/5/17 Scale: 2:3	


10.00
4X2.67
8X 0.375
2X 0.83
2X 2.38
2X 2.38
2X 6.73
0.25
NOTES:
1)Unless otherwise stated:
-All Dimensions in Inches
-Tolerances ±.01
Cal Poly Mechanical Engineering
ME 429 - Winter 2017
Lab Section: 08
Dwg. #:
Pedal Power Sr. Project
Nxt Asb: Adjustable Shaft
Title: Mounting Plate
Date: 1/1/17
Scale: 1:4
Drwn. By: Geremy Patterson
Material: Steel



0.25
4X 2.67
2X 5.83
2X 11.73
2X 2.38
2X 2.38
15.00
8X 0.375
NOTES:
1)Unless otherwise stated:
-All Dimensions in Inches
-Tolerances ±.01
Cal Poly Mechanical Engineering
ME 429 - Winter 2017
Lab Section: 08
Dwg. #:
Pedal Power Sr. Project
Title: Mounting Plate - Output
Drwn. By: Geremy Pattenon
Material: Steel

L. Safety Hazard Checklist and Recommended Actions

DESIGN HAZARD CHECKLIST

Team: 34 Advisor: Rossman

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

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Figure 4: Design Hazard Checklist, Page 1

Number	Hazard	Corrective Actions
1	Hair/Clothing/Digit gets caught between friction drive components	Place the friction drive in a place that is hard to come into contact unintentionally
2	Hair/Clothing gets caught in belt(s)	Design drivetrain such that the moving components are as far from user as possible and covered adequately
3	User overheats pedaling	Design gearing ratios such that the torque required from user is minimized while maintaining grinding at a rate of at least 4 [kg/hr]. Also, warn of potential hazard in instructions.
4	Bike falls out of device with user on it	Design robust axle clamp screws. Possibly add a fail-safe feature to stop the bike from falling should the axle clamp fail.
5	Drivetrain failure results in torque loss at the pedals which can harm the user if he hits part of the bike or falls off	Design robust (high safety factor) drivetrain to avoid failure
6	System tips over when user sits on bike	Design base for adequate stability

M. Design Verification Plan (DVP&R)

DVP&R														
Report Date			Sponsor						Component/Assembly			REPORTING ENGINEER:		
TEST PLAN										TEST REPORT				
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsi	Test Stage	SAMPLES TESTED: Quantity	SAMPLES TESTED: Type	TIMING: Start date	TIMING: Finish date	TEST RESULTS: Test Result	TEST RESULTS: Quantity Pass	TEST RESULTS: Quantity Fail	NOTES	
1	Efficiency	Ensure operation of mill despite inherent friction	mill operates with ease	Brad	PV	4	qualitative	5/31/2017	5/31/2017	Pass	4	0	Could potentially run mill at higher speed	
2	Set up Time	perform any necessary adjustment and setup for user to operate the system	<5 min	Geremy	PV	5	quantitative	5/24/2017	5/24/2017	Range: 0.75 to 10 min	4	1	Adjusting between high and low speed modes is time consuming	
3	Stability	95 kg static load applied to individual pedal	no perminant deformation or causation of system failure or safety hazards	Cal	DV	1	qualitative	5/15/2017	5/15/2017	Pass	5	0		
4	Maximum Tolerable Power	Input 500 Watts (vigorous pedaling) into system for short duration X5	No drivetrain component damage	Brad	DV	3	qualitative	5/31/2017	5/31/2017	Pass	3	0		
5	Speed Range	measure output speed range using video or tachometer device	necessary operable speed range for maize mill application (20-1950rpm)	Brad	DV	2	quantitative	5/15/2017	5/15/2017	Pass	2	0		
6	Maximum Torque	apply maximum torque of 250 N m	No drivetrain component slip or damage	Cal	DV	3	quantitative	5/22/2017	5/22/2017	Pass	3	0		
7	Overall system fatigue	Operate system for 5 hours under expected loading conditons from maize mill	produces adequate power continuously with no system damage	Geremy	PV	1	qualitative	na	na	na	na	na	na	

N. Bill of Materials

	Indented Bill of Material (BOM) Bicycle Power Take Off Assembly												
Assy Level	**Part Number**	**Description**				**Matl**	**Vendor**	**Qty Needed**	**Qty Units**	**Cost/unit**	**Cost (Needed)**	**Qty Bought**	**Total Cost**
		Lvl0	Lvl1	Lvl2	Lvl3								
0	A-100	Bicycle Power Take Off Assembly					------	------		------			
1	F-101		Frame										
2	FF-101			top piece		1/8"x1" steel square tub	McCarthy Steel	2					
				front legs		1/8"x1" steel square tub	McCarthy Steel	2					
				angle supports		1/8"x1" steel square tub	McCarthy Steel	4					
				bottom piece		1/8"x1" steel square tub	McCarthy Steel	1					
				cross piece		1/8"x1" steel square tub	McCarthy Steel	3					
				back legs		1/8"x1" steel square tub	McCarthy Steel	2					
				Entire Frame		.083"x1" Steel Square Tu	McCarthy Steel	18.53	ft	$ 1.89	$ 35.02	30	$ 56.70
1			Bike Fixtures (2 - both accounted for)										
2	9143K21			Slotted Pieces and Block Clamps		1" Steel Square Bar	McMaster	11	in	-		12	$ 14.59
2	91251A541			1/4"-20 7/8" Socket Head Screws		Steel	McMaster	4	-	-		50	$ 8.09
2	91251A722			1/2"-13 Socket Head Screws		Steel	McMaster	4	-	-		10	$ 12.97
2	94612A104			1/2"-13 Steel Flange Nut		Steel	McMaster	4	-	-		25	$ 8.90
1			Friction Wheel Assembly										
2				12" Bicycle Wheel			Scrap	1	-		$ -		$ -
2	8920K155			1/2" Pivot Axle and Base		Steel	McMaster	1.44	ft	-	$ 7.72	3	$ 7.72
2	5913K61			1/2" Bearings with Steel Housing		Steel	McMaster	2	-	$ 10.95	$ 21.90	2	$ 21.90
2				1" Square Tube		Steel	McCarthy Steel	4.42	ft	$ 1.89	-	5	$ 9.45
2	91251A546			1/4"-20 1.5" Socket Head Screws		Steel	McMaster	2	-				$ 10.79
2	91030A028			1/4"-20 Steel Flange Nut		Steel	McMaster	4	-	$ 1.93	$ 7.72	4	$ 7.72
2	90034A059			1/2"-13 Threaded Rod		Steel	------	1.33	ft			1.5	$ 2.33
2	94612A104			1/2"-13 Steel Flange Nut		Steel	McMaster	2	-			0	$ -
			Adjustable Shaft Assemblies (2 - both accounted for)				------	2					
2	8910K584			1/4"x4"x15" Plate		Steel	McMaster	25	in	$ -		36	$ 39.76
2	5913K61			1/2" Bearings with Steel Housing		Steel	McMaster	4	-	$ 10.95	$ 43.80	4	$ 43.80
2	3060T440			Sqr U-Bolts, 2" In Width, 2-5/8" H		Steel	McMaster	8	-	$ 2.46	$ 19.68		$ 19.68
			Drivetrain				------	1					
	6245K63			2" Pitch Diameter Sheave		Zinc	McMaster	2	-	$ 6.91	$ 13.82	2	$ 13.82
	6245K75			7.75" Pitch Diameter Sheave		Zinc	McMaster	1	-	$ 21.70	$ 21.70	1	$ 21.70
	6245K95			9.75" Pitch Diameter Sheave		Zinc	McMaster	1	-	$ 35.05	$ 35.05	1	$ 35.05
	6191K29			36" Outer Circ 4L360 V-Belt		Rubber/Polyester	McMaster	1	-	$ 7.35	$ 7.35	1	$ 7.35
	6186K136			39" Outer Circ A37 V-Belt		Rubber/Polyester	McMaster	1	-	$ 9.57	$ 9.57	1	$ 9.57
	8920K155			Intermediate Shaft		Steel	McMaster	10.5	in			12	$ 3.09
	8632T7			D-Profile Output Shaft		Steel	McMaster	12?	in			12	$ 9.93
											TOTAL COST:		**$ 364.9**

O. Bill of Materials Recommended for Malawi Build

Indented Bill of Material (BOM) Bicycle Power Take Off Assembly						
Assy Level	Description			Material/Description	Min. Qty Needed	Qty Units
	Lvl0	Lvl1	Lvl2			
0	Bicycle Power Take Off Assembly				------	
1		Frame				
2			Top Pieces	25x25x3mm Steel Square Tube	2	-
			Front Legs	25x25x3mm Steel Square Tube	2	-
			Angle Supports	25x25x3mm Steel Square Tube	4	-
			Bottom piece	25x25x3mm Steel Square Tube	1	-
			Cross Piece	25x25x3mm Steel Square Tube	3	-
			Back Legs	25x25x3mm Steel Square Tube	2	-
			Entire Frame	25x25x3mm Steel Square Tube	5.65	m
1		Bike Fixtures (2 - both accounted for)				
2			Slotted Pieces and Block Clamps	25mm Steel Square Bar	280	mm
2			M6, 25mm Socket Head Screws	Steel	4	-
2			M12 Socket Head Screws	Steel	4	-
2			M12 Steel Flange Nut	Steel	4	-
1		Friction Wheel Assembly				
2			12" Children's Bicycle Wheel/Tire		1	-
2			12mm Diameter Pivot Axle and Base	Steel	440	mm
2			12mm Bore Bearings with Steel Housing	Steel	2	-
2			25x25x3mm Square Tube	Steel	115	mm
2			M6 35mm Socket Head Screws	Steel	2	-
2			M6 Steel Flange Nut	Steel	4	-
2			M12 Threaded Rod	Steel	405	mm
2			M12 Steel Flange Nut	Steel	2	-
1		Adjustable Shaft Assemblies (2 - both accounted for)			2	
2			5x100x380mm Plate	Steel	2	-
2			13mm Bore Bearings with Steel Housing	Steel	4	-
2			Sqr U-Bolts, 25mm Width, 65mm Height	Steel	8	-
1		Drivetrain			1	
2			50mm Pitch Diameter Sheave	Zinc	2	-
2			200mm Pitch Diameter Sheave	Zinc	1	-
2			250mm Pitch Diameter Sheave	Zinc	1	-
2			900mm Outer Circ 4L360 V-Belt	Rubber/Polyester	1	-
2			1000mm Outer Circ A37 V-Belt	Rubber/Polyester	1	-
2			12mm Diameter Intermediate Shaft	Steel	265	mm
2			12mm Diameter D-Profile Output Shaft	Steel	350	mm

Operator's Manual: Bicycle Power Transmission Device

Before proceeding with the setup or use of this device, please be aware of the following safety concerns:

- Check that loose clothes and or hair has been secured and is not near moving parts
- Check that bicycle is securely mounted to frame before mounting
- Maintain intended bicycle seating position while operating to ensure stability
- Be wary of heavily loading the pedals, in the case of a catastrophic failure in the drive train, injury is possible

DEVICE SET UP:

1) Inspect Device for Wear or Broken Parts:

Check for:

- Cracks, stretching, or tears in belts.
- Loose fasteners.
- Cracks or permanent bends in structural components
- Corrosion
- Debris in bearings

2) Insert Bicycle into Device's Axle Support Clamps

2a) Remove the upper Axle Clamp Block by loosening the top screws (2).

2b) Place the bicycle's rear axle nuts in the lower block of the Axle Clamp. Make sure the bike's rear tire is centered above the friction wheel.

2c) Loosen the two sliding base screws and adjust the axle clamps laterally so that the bicycle's rear axle is well supported. Tighten the screws in the sliding base.

2d) Place the upper Axle Clamp Block over the bicycle's rear axle nuts, and replace and tighten the two screws so that the bicycle is now secured in all directions.

2e) Lift the front wheel of the bike and place a riser under the front wheel so that the bike is level.

3) Adjust Friction Wheel to Bicycle's Rear Tire:

3a) Rotate the nuts on the underside of the swingarm so that the swingarm raises the friction wheel until the friction wheel presses sufficiently against the bicycle's rear tire.

4) Adjust Belt Tension in First Belt

4a) Loosen the four nuts securing the shaft assembly plate to the frame.

4b) Slide the assembly back towards the rear of the device, pre-tensioning the first belt to approximately 10 lbf.

Note- A board or shovel handle maybe used as a lever to make this portion easier

4c) Tighten down the U-bolts to securely clamp the plate to the frame rails

4d) Ensure the bottom plate of the assembly is square with the frame and adjust if necessary

Note- This can likely be performed by visual inspection but a block or speed square could be used to check

5) Adjust Belt Tension in Second Belt

- Repeat steps 4a-4d for the second reduction.

6) Connect Powered Device (ie Maize Mill) to Output Shaft

IMPORTANT

6a) Mate the mill with the output shaft

6b) By hand, spin the output shaft and observe the mill

6c) If it wanders from side to side noticeably there is likely an issue that should be investigated prior to use

6d) If mill auger and output shaft seem reasonably aligned, tighten fixture clamping mill to plate

DEVICE USE:

1) Begin pedaling

2) Increase cadence to desirable speed

3) Introduce maize to hopper

IMPORTANT- Do not stop pedaling until there is no maize remaining in the mill

Doing so will result in the potential for binding

4) Continue pedaling