Final Paper

Hydraulic Regenerative Braking for a 20” Bicycle Wheel

ME 450: Design and Manufacturing III
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Team 2 Members
Nick Alanen
Jason Dykstra
Jason Muccioli
Jasem Yousuf

Section Instructor
Bogdan Epureanu

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Executive Summary

With the price of oil consistently increasing the need for alternative forms of propulsion is becoming more and more prevalent in today's society. This led the Environmental Protection Agency (EPA) to begin a search for an efficient and emission free form of transportation from which they formulated the idea to use a regenerative hydraulic braking system. Working with ME 450 teams from four previous years they were able to develop a working prototype for a standard 26" bicycle wheel that implements a regenerative braking system using incompressible fluid and a hydraulic motor capable of accelerating the rider back to speeds close to their original. The previous semester's goal was to take this and scale it down to a child's 20" wheel, however due to time constraints they were unable to finish this. Working with our sponsor David Swain we have been asked to finish their task while reducing the weight of the wheel to 16 lbs and getting the wheel ready for production.

Table 1 on Page 10 lays out the specifications that we have been asked to meet by our sponsor. To reduce the weight our sponsor has laid out several areas where he thinks that we could reduce the weight while making a more efficient wheel. Our areas of focus will be to reduce the weight and lost energy in the gear system currently employed on the prototype created by the previous semester. As well as decreasing the weight of the main bracket that holds the hydraulic system and the hub that keeps everything inside protected.

We generated numerous concepts keeping the most important customer requirements in mind; weight reduction and working prototype. We decided upon our alpha design by eliminating various concepts with the use of Pugh charts. We focused our efforts on reducing the weight of the super bracket by removing non-critical areas. We have been working with various suppliers to manufacture plastic gears that would meet our engineering specifications for our prototype. We have also performed calculations using the CES software to determine which materials would be best to use for the hub and spider gear (fiberglass epoxy matrix and 1020 steel respectively).

For the Design Expo on December 4th 2008 we had a nearly working prototype. Although a working prototype was a top priority, factors outside of our control prevented this goal from being achieved; however, before these uncontrollable events, we were on track to finish and have a working prototype. For the expo, we had the prototype on display with half of the hub off so that it would be easy to show/explain how the system worked.

Despite the setbacks, we feel that the project was a success and we completed all objectives that we set out to complete, with the exception of having a working prototype.

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1. Abstract

With gas prices approaching nearly five dollars a gallon, using gas in the most efficient way has become increasingly important, and one of the most popular ways of doing this has been hybrid technologies. The Environmental Protection Agency (EPA) has been pursuing research in hydraulic hybrids and has used it on many large commercial use vehicles, which have shown incredible increases in gas mileage. A particular form of this technology is hydraulic regenerative braking which works by pressurizing fluid while braking and then using the potential energy of the pressurized fluid to partially power the vehicle. The EPA has worked with previous ME 450 students to apply this technology to bicycles, and has successfully gotten it to work on an average 26" bicycle wheel; when stopped from 20 MPH, enough energy is stored to accelerate the bicycle back up to 17 MPH. Last term worked to get this system to work on a 20" bicycle wheel, however were unable to get the system working due to time constraints. Our goal this term is to have a working prototype on a 20" wheel, as well as reduce weight, and design for manufacturability. We will reduce weight by either replacing the super bracket with a lightweight material, or by cutting out sections of the current bracket. Also, we will look into reducing weight by using plastic gears, or by cutting out sections of the centers of them. Reducing the weight of the wheel is a major step in designing for manufacturing.

2. Introduction

2.1 Background and Motivation

The Environmental Protection Agency (EPA), created in 1970 by former president Richard Nixon, is assigned the task of protecting human health while taking care of our environment [1]. Run by Stephan Johnson the EPA is allocated an annual budget of $7 billion dollars which it uses towards its five goals; Clean Air and Global Climate Change, Clean and Safe Water, Land Preservation and Restoration, Healthy Communities and Ecosystems, and Compliance and Environmental Stewardship [2]. The automobile is documented as being the biggest cause of atmospheric pollution contributing 14% of world's carbon dioxide emissions [3]. This combined with the fact that the U.S. has been using more oil that it produces every year since 1976 [3] has led the EPA to explore the use of alternative forms of energy. With the cost of oil rising as well as America's reliance on the automobile the use of these alternative forms of energy is imperative.

One such area is hydraulic hybrids, and this is the area that we will be employing on our bike wheel; hybrid between human power and hydraulic power. The system works by converting the kinetic energy lost during braking into potential energy stored in a high-pressure accumulator. The rider then can release this potential energy, transforming it back into kinetic energy by accelerating the bike.

2.2 Project Summary

With a large portion of the world's population concentrated in major cities the use of the bicycle as a mode of transportation should be increasing. The problem is many people don't feel like putting in the energy necessary to peddle a bike to and from their destination. With the help of the EPA, University of Michigan students have been working for 4 years to create a Hydraulic launch assist system in a bicycle wheel that would fit any kid's bike. This technology uses a regenerative braking system (RBS) that stores the energy put into braking and uses it to propel the vehicle back to speeds close to its original. Previous terms have worked with our sponsors to create a working prototype for a 26" bicycle. Our goal for this semester is to finish the scaled down the prototype to a 20" bike, reduce the weight of it to 15lbs and getting it set to go into production.

3. Information Search

After being assigned the task of creating a hydraulic hybrid regenerative braking bike hub, we looked for as much information as possible on the subject of hydraulic hybrids. In the discussion below, many current technologies in the field of hydraulic hybrids will be discussed, including work completed by other ME 450 groups that were also assigned the same project.

The technology of using hydraulics for hybrid systems is described by HLA or Hydraulic Launch Assist. The HLA system recycles energy by converting kinetic energy into potential energy during deceleration via hydraulics, storing the energy at high pressure in a Nitrogen gas filled accumulator [8].

The closest design to the hydraulic bike hub is The RevoPower retrofit wheel, shown in Figure 1 on Page 5. It is a bike hub that can be attached to many bikes, but instead of being hydraulic hybrid powered, it is powered by gasoline. It has a two-stroke, 1HP engine connected directly to the axel of the front wheel. It is said to get over 100 miles to the gallon and the wheel can propel the bike up to 20 mph, while weighing only 15 pounds [7].

Figure 1: The RevoPower Wheel: gas engine hybrid bike hub

3.1 Research in HLA

The Environmental Protection Agency (EPA) is developing HLA technology to provide cost-effective, ultra-clean and ultra-efficient improvements for vehicles. With a hydraulic hybrid system, nearly all of the energy typically lost during vehicle braking is captured and used to propel the vehicle the next time it needs to accelerate. Benefits include 25 to 45 percent improvement in fuel economy for city driving, reduction of emissions by 20 to 30 percent, better acceleration, less brake maintenance, and reduced operating costs [4]. The EPA first designed a concept to prove that HLA technology will work. This is shown in Figure 2 on Page 6. The concept weighs as much as a family sedan (3800lbs), has fuel economy of 80 mpg and accelerates from 0 to 60 in 8 seconds. The EPA has also modified a Ford F-550 delivery truck and Ford Expedition to demonstrate the technology of the HLA system shown in Figures 3 and 4 on Page 6. The Expedition is said to attain 32 mpg according to David Swain of the EPA [4].

Figure 2: EPA Concept to prove HLA works

Figure 3: EPA F-550 Fleet Maintenance Truck with HLA

Figure 4: EPA Ford Expedition said to produce 32 MPG

The EPA has also begun work to demonstrate the application of a hydraulic hybrid in an urban delivery vehicle. Figure 5 on Page 7 shows a UPS truck with HLA. This truck attains 60-70% improvement in fuel mileage as well as a 40% reduction of carbon dioxide emissions [6]. The truck is not yet in production and is still being worked on at the EPA's Ann Arbor location. Figure 6 on Page 7 shows the Xebra, a completely electric maintenance vehicle with HLA. This is another ongoing ME450 Project.

Figure 5: UPS urban delivery truck with HLA

Figure 6: Xebra: fully electric HLA hybrid maintenance vehicle

In 2002, Ford debuted the F-350 Tonka with HLA at the Detroit Auto show. The truck was said to have 25-35% increase in fuel economy. In a new article and at the 202008 Detroit Auto Show, Ford hinted to the possibility of releasing the F-150 with HLA in 2009. Shown below (Figure 7) is the F-350 Tonka from the 2002 Detroit Auto Show [5].

Figure 7: Ford's F-350 Tonka with HLA debuted at the 2002 Detroit Auto Show

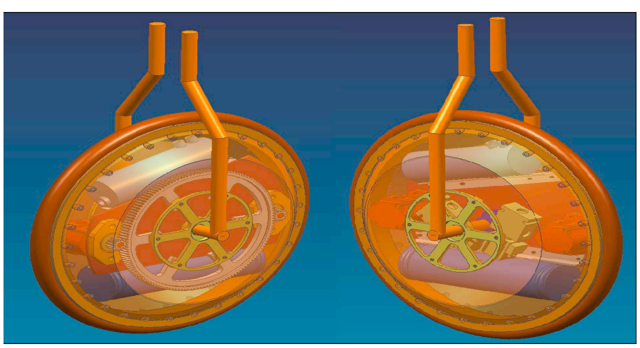
Companies other than the EPA have also tried to promote the use of HLA. Parker Hannifin Corp. holds an annual design competition they call the Chainless Challenge (Figure 8 shows a bike entered in the competition) where teams of engineering students from ten schools each have to design and race a human powered vehicle with a hydraulic assist without a direct connection between the petals and the wheel. Teams are allowed to choose the number of wheels that their vehicle would have.

Figure 8: The Chainless Challenge; Western Michigan University entry

3.2 Previous Bike Hubs

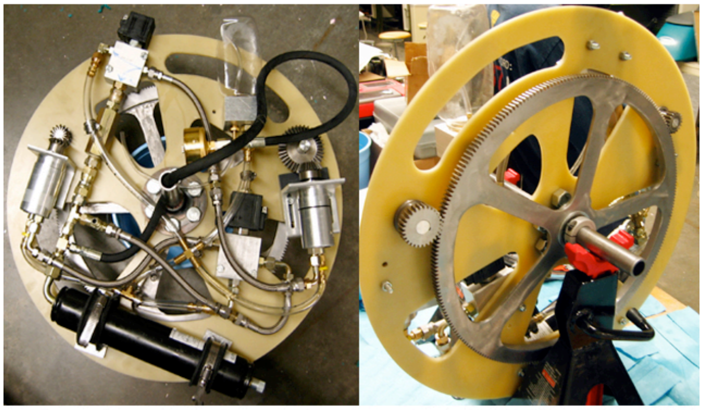
The original bike hub HLA system was patented (application # 20070126284) by Jason Moore in December 2006. Many of the calculations used for the Engineering Specifications were translated from this first bike hub. Calculations for the acceleration and deceleration of the bicycle, the pressure levels in the high and low pressure accumulator, calculations of forces and torques, and the volume of the pump, motor, and accumulator were all modeled from Jason's bike hub. Figure 9 on Page 8 shows Jason's bike hub.

Figure 9: Engineering Drawings by Jason Moore (Photo courtesy of Jason Moore)



In the winter of 2007, the ME450 team assigned to create the next version of the HLA bike hub came up with the design shown in Figure 10 on Page 9. The new design was more of a concept than an actual usable bike hub because it was designed without size measurements in mind. It did, however, incorporate the use of a plastic super bracket to lighten the design. In the winter 2007 design many of the parts used would be too large to fit inside of a children's front tire hub design, and obviously differ from our goals in that respect. Figure 10 on Page 9 shows the winter 2007 prototype.

Figure 10: Winter 07' EPA bike hub project



The latest bike hub was created by the winter 2008 team of Matthew Mierendorf, Ashley Murphree, Brett Rogers, and Sara Simmons. Their design was similar to Jason's patented design, however they redesigned and scaled down parts to fit on the smaller wheel. The design decreased weight, decreased the size of the rim down to 20" so that it would fit a children's bike, and increased usability. Figure 11 on Page 9 shows the final concept drawings for the design and the final prototype.

Figure 11: Final Concept – Engineering and Prototype Drawings for the Winter 202008 EPA bike hub

4. Customer Requirements and Engineering Specifications

4.1 Customer Requirements

The customer requirements and engineering specifications for our term have been determined based on the previous terms work and input, and also the requirements required for this term. Dr. David Swain has helped us determine the most important requirements, which are shown in our Quality Function Deployment Development Diagram (QFD) in Appendix A on Page 43. Table 1 on Page 10 shows a table of customer requirements used by previous terms as well as requirements that remain a priority for us this term.

Table 1: Customer Requirements

Old Requirements	**On Going Requirements**
Universal Application	Have working Prototype
Natural Braking Rate	Reduce Weight
Sufficient Top Speed	Design for Manufacturability
	Improve Hub Design (lighter, better integration)
Efficient	Aesthetics
Lightweight	
Reliable	
Safety	
Easy to Use	
Easy to Service	
Maintains Bicycle Function	
Hub Shell Design	
Improve Functionality With Clutches	
Reconfigure and Condense RBS	
Design for Child Use	

4.2 Engineering Specifications

The engineering specifications for our project have not changed from last terms. The specifications were determined based on customer requirements as well as previous team's specifications; the specifications are in Table 2 on Page 11. The dimensions for the hub were obvious because the purpose of this project is to have the regenerative braking system on a bicycle with a 20" wheel. The maximum launching torque and braking torque were determined so that it would be safe for a child to use the system. The weight put forth in the engineering specifications is a goal, however it is possible that we will not meet this goal this semester due to a lack of funds to purchase a carbon fiber accumulator; the idea is that in production carbon fiber accumulators will be used.

The QFD diagram shows that the most important parameters are the hub diameter and width, weight reduction and having a working prototype at the end of the term.

Table 2: Engineering Specifications

Description	Targets
Maximum Weight	< 16lb
Hub Width	≤ 4”
Hub Diameter	< 15”
Prototype Functionality	Able to ride the bicycle
Maximum Launching Acceleration	2.0- 2.5 m/s^2
Maximum Braking Deceleration	2.20- 3.63 m/s^2
Gear Ratio	18 : 1
Working Pressure	2700- 4000 psi
Maximum Volume of hydraulic fluid	0.30 - 0.32 L
Motor Displacement	0.50cc
Pump Displacement	0.64cc

4.3 Problem Analysis and Preliminary Ideas

Some of the major concerns are weight reduction and minimizing the overall width of the hub, while retaining the functionality desired. The previous group designed the hydraulic technology to work on a 20” wheel; however they were unable to complete a working prototype. We will use most of their design to produce a working model; however we will improve in some areas.

There are four main areas we will modify from the previous group’s design. The first idea we have is to use plastic gears, aluminum gears, or steal gears with sections cut out that wouldn’t compromise the gears integrity rather than the solid metal ones used on the current design. The purpose of this would be to reduce the overall weight of the hub, which is a major concern for us this term. The current metal gears were over engineered and can handle much higher torques then the system will undergo. By using other materials and different gear designs, significant weight could be dropped without losing any function ability.

The second idea we have is in regards to the “super bracket.” Right now the super bracket used by the last group is one solid piece of metal, which is quite heavy, and we are looking to reduce weight here as well. We perhaps may be using a completely new super bracket made out of a lighter material, such as plastic, if such a lightweight material is strong enough. Otherwise we will take the current super bracket and cut out areas that would not affect the structural integrity of the bracket to reduce weight.

We also thought to modify the drive gear. The baseline design used by winter 2008 for the drive gear was incomplete. The drive gear was supposed to be attached to the hub, but how they were going to do this was never clearly defined. We had many ideas on how to meet our customer needs in this area. These ideas were narrowed down to: connecting the drive gear directly to the hub using a spider gear, welding the drive gear directly to the axle, and making a separate super gear to translate from the drive gear. The super gear idea included making a gear that was as large as the bike rim and internally threaded. The drive gear, mounted on the axle by a bearing, would spin another translational gear that was between it and the super gear in order to translate power to the bike hub. The super gear would be mounted directly between one half of the hub and the rim. The second concept was: the drive gear, left over from winter 2008, would be connected directly to a spider gear that is inside of the fiberglass the makes one half of the hub. The last concept was: the drive gear, left over from winter 2008, would be welded directly to the axle.

The last idea was to modify the second half of the hub, which was never completed by the winter 2008 team. We could choose to stay with their idea of using fiberglass for the other half of the hub or create our own ideas. We came up with two main ideas for this component. One was to make the hub out of carbon fiber instead of fiberglass. We thought this was a good idea because it reduced the weight of the hub and if the bike hub was ever to be produce on a large scale the carbon fiber would be easier to make. The second idea was to continue with the fiberglass that winter 2008 started, except we would perform a stress analysis to see if we can use less layers to decrease the weight.

5. Concept Generation

In order to generate possible concepts for our project, functional decomposition was used. Functional decomposition helped us break down the problem into subsystems so that we could analyze separate aspects. For each subsystem, many concepts were generated as a team and by each member individually. From the generated concepts for each subsystem, only the most realistic concepts were kept for further analysis.

5.1 Functional Decomposition

The functional decomposition diagram helped to split our problem into subsystems (See Figure 12 on page 13). Each subsystem also has one or more components. Of these subsystems and components, only the ones where we felt we could make the greatest impact were considered for analysis. These included: the super bracket, the gears, the drive gear, and the hub design. Subsystems of our project include:

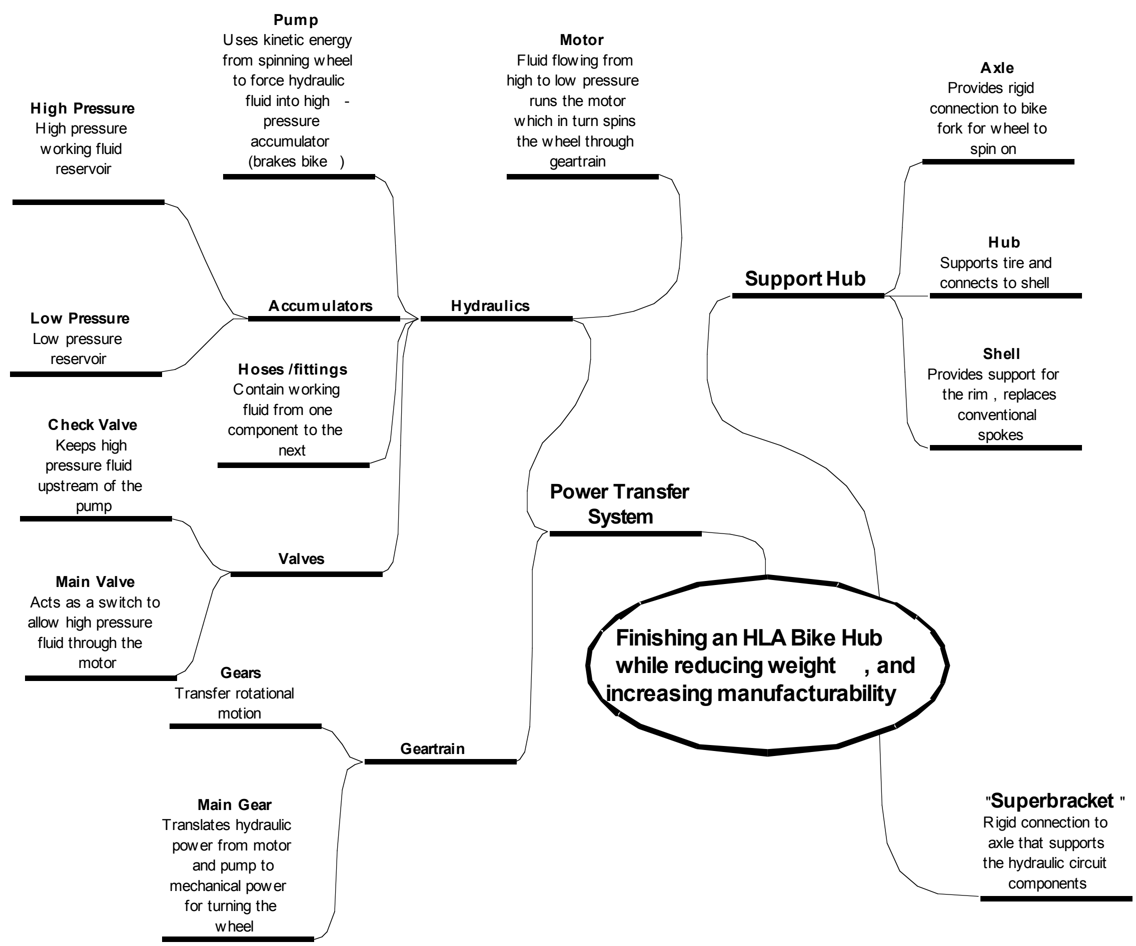
Hydraulic Circuit: Within the hydraulic circuit are many components and much room for design improvement. The pump and motor are used for energy conversion from potential to mechanical and back. The high and low-pressure accumulators are used for storing the hydraulic fluid and, thus, storing the energy (in the high pressure accumulator). The plumbing includes hoses, fittings, and valves. These direct the hydraulic fluid to and from the energy storage components (accumulator) to the energy conversion components (pump and motor), and make sure that the fluid does not flow in the wrong direction.

Power Transfer System: The power transfer system includes the gears and clutches. The gears transfer rotational motion and torque from the motor to the wheel or from the wheel to the pump. The clutches, a new component since previous semesters, prevent the pump from spinning when the bicycle is not stopping, and prevent the motor from spinning when the bicycle is not launching.

"Super bracket" Support: The "super bracket" and axle system support the hydraulic circuit and most of the power transfer system, and hold them all stationary relative to the axle.

Wheel Hub System: The wheel hub includes the wheel rim, the shell that rotates about the axle, and the axle itself. The shell provides the strength to hold up the bicycle, acts as a safety shield for the high-pressure system, and is also connected to the drive gear which transfers the torque to rotate the wheel. The axle support is another component holding the bicycle up and it also provides resistance to axle rotation relative to the bicycle fork.

Figure 12: Functional decomposition of the HLA Bike Hub



5.2 Brainstorming

After using functional decomposition to dissect the Bike Hub into subsystems, we discussed which components of these subsystems could be redesigned to accurately fulfill the customer's requirements of lighter weight, better manufacturability, and functionality. The four components we chose were the super bracket, gears, drive gear, and the hub. We then assembled and brainstormed many concepts for each component.

Once all of the design concepts for each of the components were drawn up, we analyzed each concept individually. The creator of each concept was given the chance to present their idea and explain it thoroughly to the rest of the group. After all the design concepts were presented, we debated on all aspects of the concepts. This is where possible suggestions and variations could be mentioned by people other than the creator of an idea.

6. Concept Selection Process

After our brainstorming phase, we used several methods to narrow down our options and eventually lead to the best design based on our customer requirements and their relative importance. The concepts were initially reduced by eliminating the ideas that were not physically possible or were infeasible. We then eliminated several ideas that were inferior to the baseline designs established by winter 2008.

6.1 Concept Selection

Finally, the primary selection tool was introduced. In order to help make an objective comparison of the designs, Pugh charts were set up. Each component was analyzed within its own Pugh chart. Each concept was compared to a baseline design (designs taken from winter 2008's project design) as well as the other concepts generated for that component. The customer requirements were listed as separate grading categories with appropriate weighting. The baseline design was rated as a zero for each of the categories. Then, each design was rated either positive (better than the baseline), negative (worse), or zero (comparable). The results were tabulated at the end of the table, and the design with the best score was selected.

Component 1 - Gear System

Design Goals	**Weight**	**Old Design** Solid steel gears	**Concept 1** Plastic gears	**Concept 2** Aluminum gears	**Concept 3** Cutout steel gears
Universal Application	9	0	0	0	0
Safe	9	0	0	0	0
Fit's 20" Wheel	9	0	-1(might be too wide)	0	0
Lightweight	9	0	+1(light weight material)	+1(light weight material)	+1(lost weight from old gears)
Working Prototype	9	0	+1(readily available at price)	-1(wouldn't fit budget)	+1(already have gears)
Low Cost	6	0	+1(cheap	-1	+1(cheap

			material)	(expensive material)	material)
Aesthetically Pleasing	6	0	0	0	0
Manufacturability	6	0	+1(easy to manufacture)	+1(easy to manufacture)	-1(requires advanced process)
Natural Rate of Braking	3	0	0	0	0
Efficient	3	0	+1(high precision)	+1(high precision)	0
Reliable	3	0	0	0	0
Easy to Use	3	0	0	0	0
Easy to Service	3	0	+1(easy to find and replace)	0	0
Maintains Bike function	3	0	0	0	0
Sufficient Top Speed	1	0	0	0	0
Total	**82 (max)**	**0**	**27**	**3**	**18**

Figure 13: For the gear subsystem it was determined that plastic gears are the best option if they can handle the stress

The Pugh chart for the gears subsystem shows us that the best option for our gears is to make them out of plastic; if they can handle the torques from the bike without requiring a width that is too large to fit inside the hub. They are extremely light in weight, which will help us achieve our specification of 16 lbs. They are low cost as plastic is a cheap material that is very readily available and is easily manufactured. They are also easy to replace as plastic gears are common and thus easy to find. If the plastic gears aren't able to handle the torques of the bike we will go with our second option, which is to take the old gears and cut out internal parts of the gear that will reduce the weight but won't wreck the structural integrity of the gear.

Component 2 – Super Bracket

Design Goals	**Weight**	**Baseline** Large steel bracket	**Concept 1** Non critical areas of super bracket removed	**Concept 2** Similar design composed of lighter material	**Concept 3** Outside radius of super bracket reduced
Universal Application	9	0	0	0	0
Safe	9	0	0	0	0
Fit's 20" Wheel	9	0	0	0	0

Lightweight	9	0	+1(reduce load of bracket)	+1(less dense material)	+1(reduce load of bracket)
Working Prototype	9	0	0	0	-1(not sure if feasible)
Low Cost	6	0	+1(bracket already made)	-1 (requires new material)	+1(bracket already made)
Aesthetically Pleasing	6	0	0	0	0
Manufacturability	6	0	0	0	0
Natural Rate of Braking	3	0	0	0	0
Efficient	3	0	0	0	0
Reliable	3	0	0	-1(weaker material)	0
Easy to Use	3	0	0	0	0
Easy to Service	3	0	0	0	0
Maintains Bike function	3	0	0	0	0
Sufficient Top Speed	1	0	0	0	0
Total	**82 (max)**	**0**	**18**	**0**	**6**

Figure 14: For the Super Bracket subsystem it was determined that using the current bracket with sections cut out would be the most economic and strong option

Last semester's design for the super bracket consisted of a solid 14" steel disk with an axle welded at its center. Several holes where drilled in the bracket to mount all of the system's components securely to the bracket. Although extremely strong, the bracket weighs 10lbs, which is a substantial amount and not only reduces the efficiency of the bike, but makes the bike almost inoperable for the target audience. To combat this problem, we have come up with several concepts on how to lose weight and maintain all the other important functions of the "super bracket". The concept that seems most logical to us would be to use the current design and remove material from non-critical areas that would have no affect on any other of the bike's components. Keeping the bracket composed of steel allows the bracket to retain its strength in areas with large loads, but also allows us to remove weight were it is unimportant. The main problem with using a different material would be too much stress at certain areas, which would then require additional strengthening that would add back the weight we are trying to remove. The flaw with decreasing the outside radius of the super bracket is that it would quickly interfere with the current component layout and would require further engineering to make it work if it is even feasible.

Component 3 – Drive Gear

Design Goals	**Weight**	**Baseline** unconnected main gear	**Concept 1** Drive Gear connected directly to hub	**Concept 2** "Super Gear"	**Concept 3** Drive Gear connected directly to axel
Universal Application	9	0	0	0	0
Safe	9	0	+1 (super gear does not spin)	+1 (super gear does not spin)	-1 (would cause shifts in weight within the hub)
Fit's 20" Wheel	9	0	0	-1 (would make for a tight fit within the hub)	0
Lightweight	9	0	0	-1 (large gear would be very heavy)	+1 (adds no extra parts to the design)
Working Prototype	9	0	+1 (can be added directly to the hub)	0	-1 (entire hub would spin with wheel)
Low Cost	6	0	+1 (can reuse the old drive gear)	-1 (custom gears are expensive)	+1 (can reuse the old drive gear)
Aesthetically Pleasing	6	0	0	0	0
Manufacturability	6	0	-1 (difficult to produce a hub with inlaid spider gear)	-1 (many gears would have to be made)	+1 (just one gear would have to be made)
Natural Rate of Braking	3	0	0	0	0
Efficient	3	0	0	0	-1(will create weight swing inside of hub)
Reliable	3	0	+1 (very sturdy design)	+1 (very sturdy design)	+1 (very sturdy design)
Easy to Use	3	0	0	0	0
Easy to Service	3	0	0	0	0
Maintains Bike function	3	0	0	0	0
Sufficient Top Speed	1	0	0	0	0
Total	**82 (max)**	**0**	**12**	**-18**	**3**

Figure 15: For the Drive gear subsystem it was determined that using a drive gear connected directly to the hub would be the most practical solution

The drive gear connected to the hub concept was the best for many reasons. First of all, using this design would allow the wheel to rotate without rotating the super bracket. Next, this design allows us to finish the bike hub in time for the design expo because we already have the drive gear and will have the fiberglass for the other hub. Lastly, it is also a very inexpensive option because we would reuse the drive gear from the winter 2008 bike that was never connected.

Component 4 – Hub

Design Goals	**Weight**	**Baseline** Enclosed shells with 45 degree bevel	**Concept 1** Fiberglass	**Concept 2** Carbon Fiber
Universal Application	9	0	0	0
Safe	9	0	+1 (hydraulics are contained)	+1 (hydraulics are contained)
Fit's 20" Wheel	9	0	0	0
Lightweight	9	0	+1(less layers will decrease weight	+1(carbon fiber is lighter than fiberglass)
Working Prototype	9	0	0	0
Low Cost	6	0	0	-1 (carbon fiber is very expensive)
Aesthetically Pleasing	6	0	0	0
Manufacturability	6	0	+1(quicker to make)	0
Natural Rate of Braking	3	0	0	0
Efficient	3	0	0	0
Reliable	3	0	0	+1 (very sturdy)
Easy to Use	3	0	0	0
Easy to Service	3	0	0	0
Maintains Bike function	3	0	0	0
Sufficient Top Speed	1	0	0	0
Total	**82 (max)**	**0**	**24**	**15**

Figure 16: For the Hub subsystem it was determined that using a fiberglass hub is the best option because it is strong and we already have the resources for it

As far as application goes, fiberglass and carbon fiber are equal except for the fact that carbon fiber is lighter, stronger, and more reliable than fiberglass. The limiting factors that rule out the use of carbon fiber are issues of feasibility; mainly what we will be able to accomplish this semester. First, a main concern is our budget, and fiberglass is nearly half the cost of carbon fiber. Another major factor is that the previous term already made half of the hub, using fiberglass (we would have to remake this half out of carbon fiber if we switched) also, we have extra fiberglass from their term that we can use.

7. Selected Concept (Alpha Design)

Our selected design (alpha design) will be the fusion of all the selected concepts made in the Pugh Charts (above). The designs that we are going to implement are plastic gears, assuming they can withstand the torques that will be applied to them (further calculations need to be done). Removing non-critical areas or material from the super bracket in order to reduce weight. The drive gear will be a typical gear attached directly to the hub due to the feasibility and weight reduction**.** The second half of the hub will be made out of fiber glass, rather than make two new halves out of carbon fiber; the design will be the mirror image of the "bowl" style hub on the other half of the wheel.

The interaction between the subsystems will all remain the same as the previous terms design (Figures 17-19 below). The only difference will be the materials that the subsystems are made of, or how much material is used.

Figure 17: Interaction of Subsystems

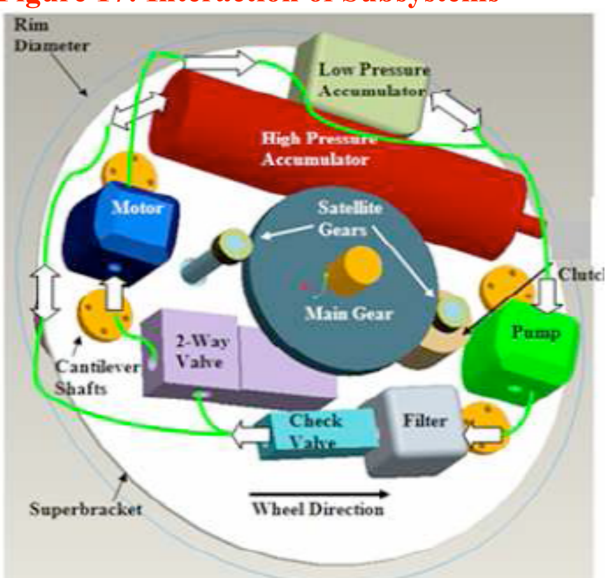


Figure 18: Interaction of Super Gear and Hub

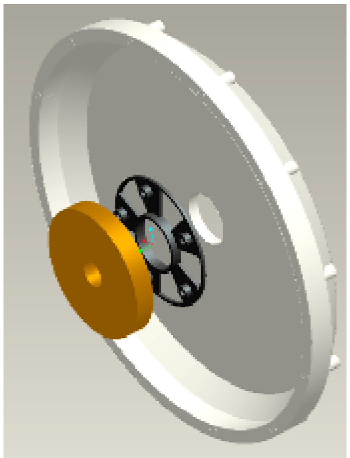
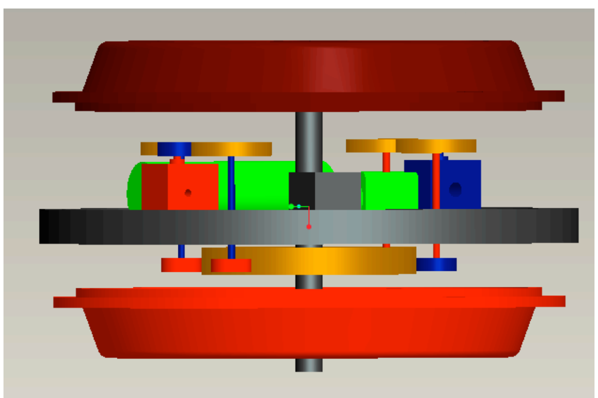


Figure 19: Interaction of ALL subsystems



8. Engineering Design Parameter Analysis

Super bracket: One of the subsystems picked to dissect in order to meet our customer needs was the super bracket. We did a visual inspection of the super bracket to determine if there was any way in which we could take weight off of it to fulfill the customer need of being lightweight. We determined the spaces of the super bracket that did not have holes drilled in it were not essential to a working prototype and could, therefore, be removed. The weight distribution of the super bracket will remain relatively unchanged since almost equal weights will be removed from opposite sides of the bracket.

Spider Gear: In order to finish the bike hub prototype by the design expo in December, many decisions about its working systems had to be made. One of these decisions was what method should be used to transfer power from the motor to the bike rim. For design review two, many ideas on how to complete this task were proposed. All of the ideas were scrutinized until one idea was concluded to be better than the rest. This idea was dubbed the spider gear. The spider gear is the best idea because it is cost effective, lightweight, and the most feasible of the ideas given the time constraints.

Once the idea for the spider gear was chosen, modes of failure for the system were looked at. It was decided through inspection of the proposed design that the spider gear would be the most likely to fail if the fiberglass epoxy matrix has a large stress on it from the spider gear causing it to tear.

We then designed a spider gear that will minimize shearing of the fiberglass epoxy matrix by increasing the area that the gear has perpendicular to the face that is in contact with the fiberglass epoxy matrix. The spider gear was designed as a gear with a 5" diameter, ¼" depth with ½" depth in the center, and also a 1.98" hole in the center so that we can press fit a bearing inside of it. The bearing will connect the hub to the axle of the super bracket, allowing the hub to spin freely around the axle and also allowing the super bracket to remain stationary.

The stress on the fiberglass epoxy matrix created by the spider gear can be roughly estimated by the equation stress = force/area. In this equation the force can be approximated from the torque on the spider gear, multiplied by it's radius. The area can be approximated as the cross sectional area perpendicular to the application of the force.

Using this equation to find an applied stress on the hub from the spider gear yields 116.95 psi. Calculations are shown in figure 20 below. Using the yield strength of the fiberglass epoxy matrix provided by last terms group, 6527 psi, we found that the proposed design for the spider gear should not fail due to stress in the hub.

In order to meet the customer requirement of being lightweight, we used CES software to find appropriate materials to make the spider gear out of. From this analysis, CES recommended many different types of steel and a few types of aluminum. The CES analysis is shown in appendix D on page 50. Of the recommended materials we decided that 1020 steel would be the most appropriate because it is very cheap, lightweight, and readily available.

Figure 20: Yield Strength of fiber glass epoxy matrix

$\tau = F/A$

τ = Shear Stress on Hub

F = Force exerted by Spider Gear on Hub (Torque transmitted from main gear)

A = Cross sectional area of the spider gear that is perpendicular to the applied force

Force = 30.7 ft-lbs (Torque on spider gear) / (2.5in (radius of spider gear)/12ft)*(1/1in)

= 147.36 lbs

A = [.125in x (4.75-2.23)in] x 4 surfaces = 1.26in^2

τ = (147.36lbs)/(1.26 in^2)

τ = 116.952381 psi

Yield strength of fiberglass epoxy matrix 6527 psi

Wheel Hub: The purpose of the hub shell is to enclose the inner workings of the system, and on one side it support the forces of the drive gear. The objective of the material selection is to minimize the weight and cost. As calculated by the previous team, the hub must support a load of 45.02 MPa.

Using CES software, we were able to determine that either carbon fiber or fiberglass would be viable materials by adjusting the load parameters and the cost per pound (to eliminate expensive materials); see appendix D.

We have decided to use fiberglass epoxy matrix because it is the cheaper option, as well as the fact that the previous team already made half of the hub out of this material.

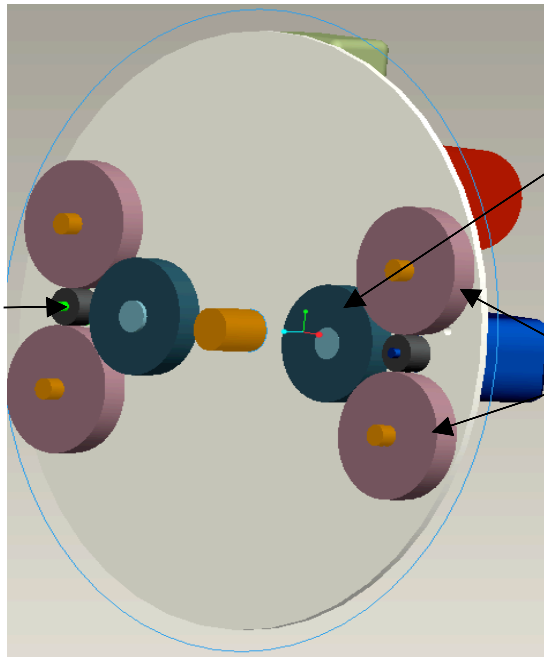
Gears: To improve on the current set of gears that the previous ME 450 team had assembled, we looked to significantly decrease the weight of the gears while keeping sufficient strength to meet our torque requirements. The previous team gave us a good base to work with as they established the gear sizes (see figure 21 below) necessary to keep a gear ratio of 18:1, while also establishing a diametrical pitch of 16 and pressure angle of 14.5 degrees for the gears.

Our initial goal for the gear systems was to try to reduce the weight of the 4 thrust gears as they were accounting for the most weight of all the gears. The approach we took was initially to make some basic calculations on the maximum torque and horsepower that each of the gears will experience during the life of the wheel. The sizes of the gears and number of teeth for each of the gears had already been determined and since our main goal was only to attempt to decrease the weight of the thrust gears, the sizes of all the gears had to be left as they were. These values are listed below in table 3 below.

Table 3: Gear specifications

Gear	# Teeth	Pitch Diameter (in.)	Max. RPM	Max. Torque (ft-lbs)	Design Horsepower
Axle	14	0.875	6034	1.71	1.49
Thrust	48	3.000	1760	2.93	0.74
Connector	44	2.750	1920	5.37	1.4
Satellite	14	0.875	1920	5.37	1.4
Main	80	5.000	336	30.68	2.97

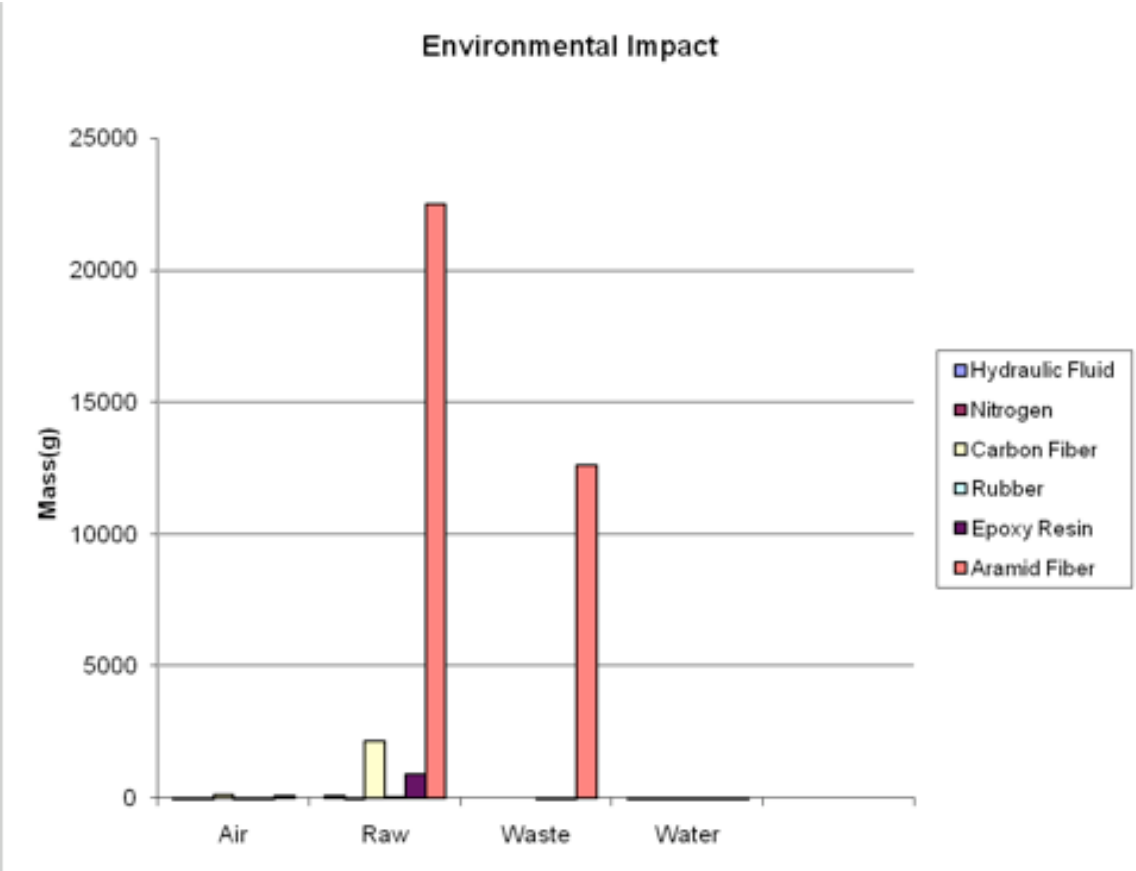
Figure 21: Gear Dimensions (all dimensions are pitch diameters)



Environmental Impact: A key concern of our project was to use materials that meet our specifications, but also have minimal impact on the environment. To determine the impact that our bike wheel has on the environment we used SimaPro 7.1, which uses the Eco-indicator 99 method. To determine the environmental impact we analyzed the components that we thought contained the most harmful materials in our project. The three elements that we choose to look at where the hubs, the high pressure accumulator, and the hydraulic fluid. To enter these things into SimaPro, we needed to come up with an estimate of the mass for the hubs, the high pressure accumulator, and the volume of hydraulic fluid in the system. The hubs were broken up into the epoxy resin and the aramid fiber. The high pressure accumulator was broken up into carbon fiber, rubber, and nitrogen. For the high pressure accumulator we had to make estimates as to the weights of the components as we were unable to find any documentation on the makeup of it. These calculations are shown in Appendix F on page 56.

From there, we were able to input these value into SimaPro, which gave us the total emissions into the air and water as well the mass of raw materials and solid waste. From Figure 22 on Page 24, it can be seen that the aramid fiber has the largest impact overall making significant impacts in raw materials as well as solid waste. The only other materials making an impact of any significance are carbon fiber and epoxy resin with small contributions to raw materials mass.

Figure 22: Total masses for air, water, and waste emissions as well as raw materials for our hubs, high pressure accumulator and hydraulic fluid



Next was an evaluation of each material with respect to the others for ten different environmental categories. Figure 23 shows that the carbon fiber has the greatest effect for six of the ten categories, with the lubricant oil or our hydraulic fluid having the greatest effect for two, and NBR(rubber) and aramid fiber having the greatest effect on the other two. Figure 24 shows the impact of the materials in three categories: human health, ecosystem quality, and resources. From this it can be seen that carbon fiber has the greatest impact on all three of these categories with aramid fiber also having an impact of significance on human health. This can also be seen in a slightly different manner in figure 25 which uses a point scale.

From these graphs we concluded that while they will have an environmental impact none of the materials creates a significant enough problem for us to look elsewhere for materials. The carbon fiber and aramid fiber have the greatest overall impact on the environment but neither was big enough to create major problems. Overall our results have led us to believe that none of our materials needs to be swapped out for another more environmentally safe material.

Figure 23: Relative impact of materials in ten separate environmental categories

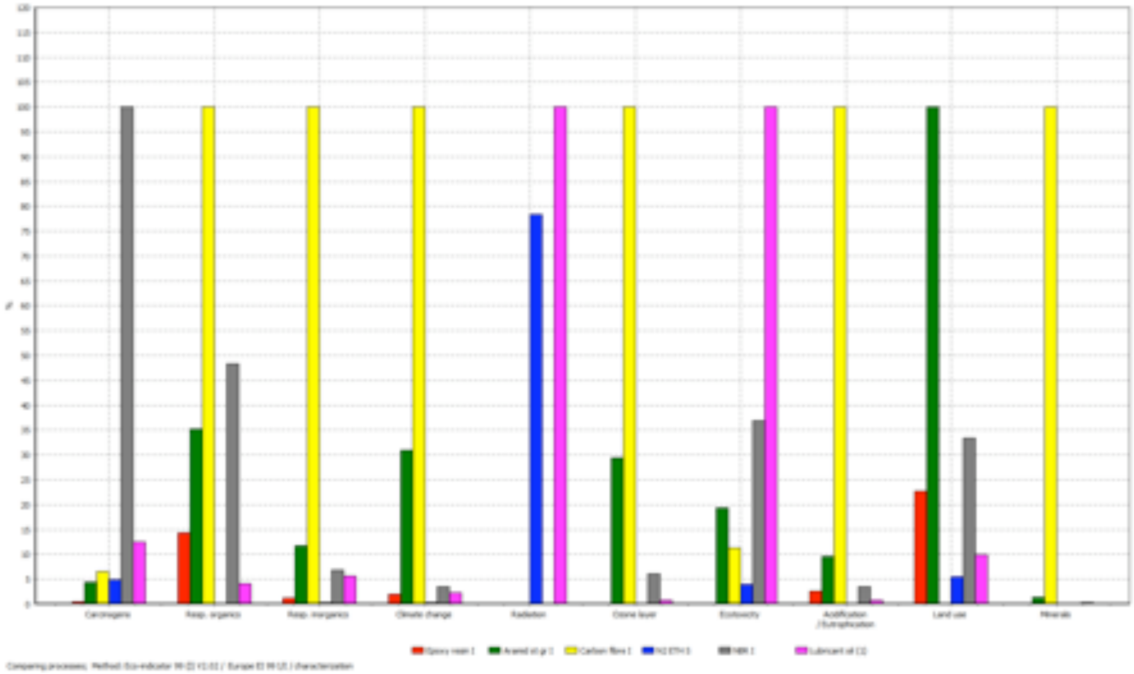


Figure 24: Normalized score for impact of materials on human health, ecosystem quality and resources

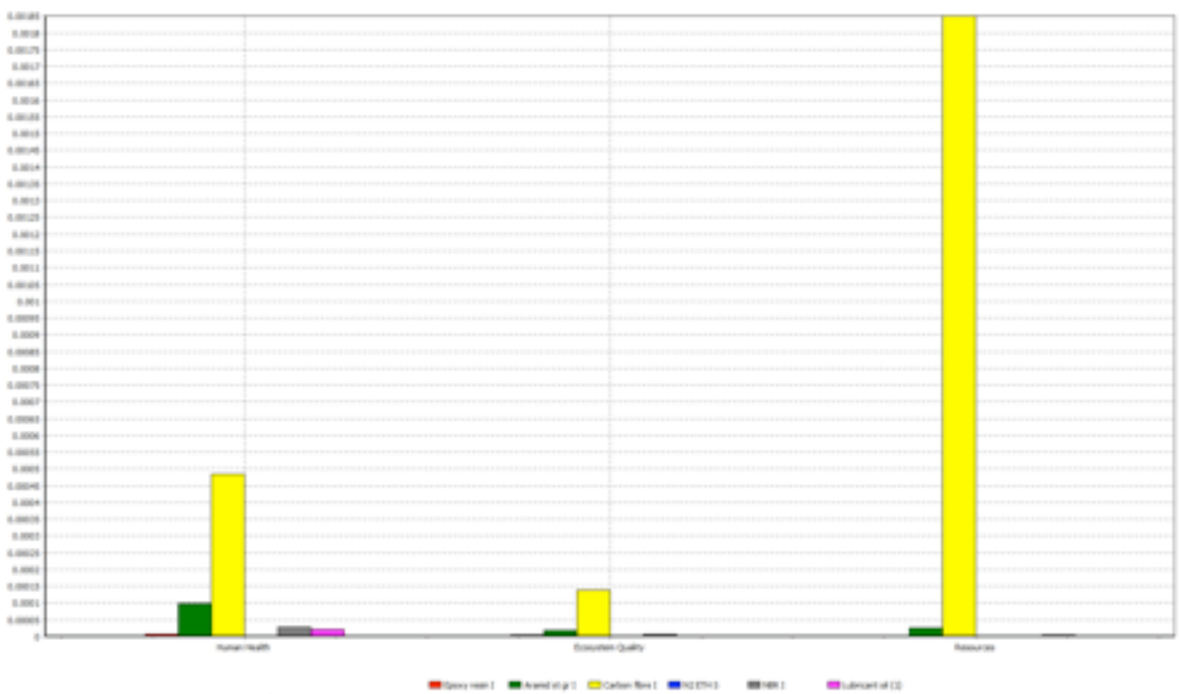
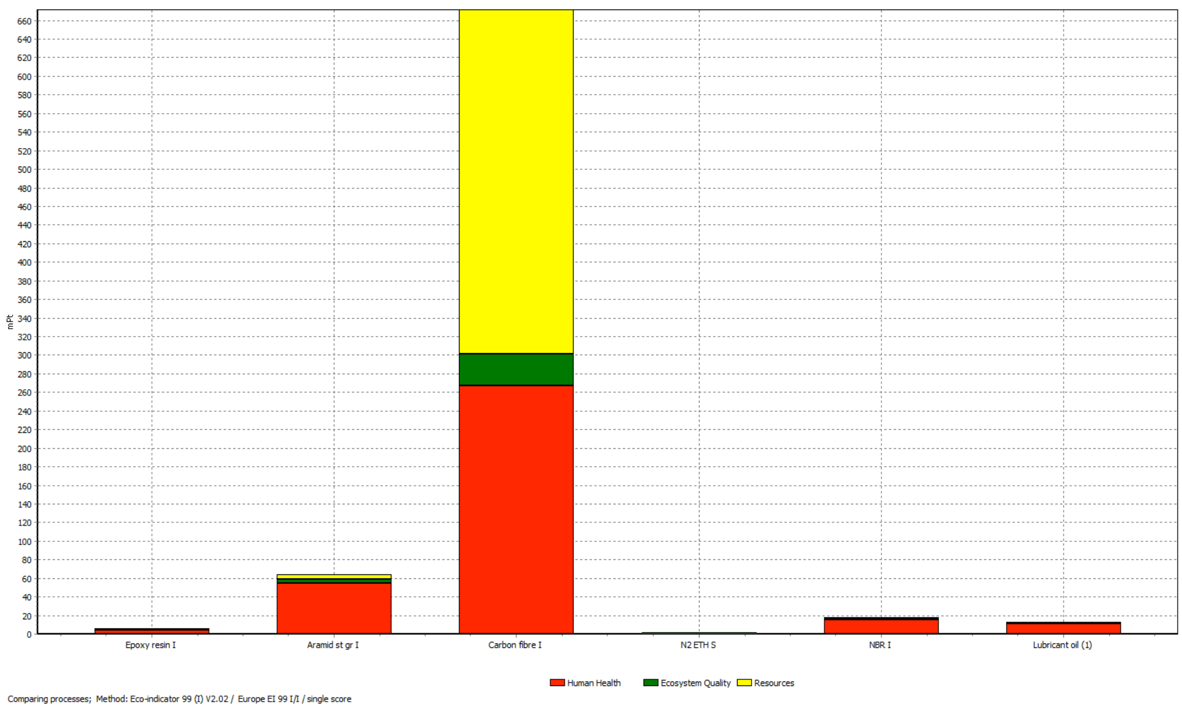


Figure 25: Points comparison for impact of materials on human health, ecosystem quality and resources

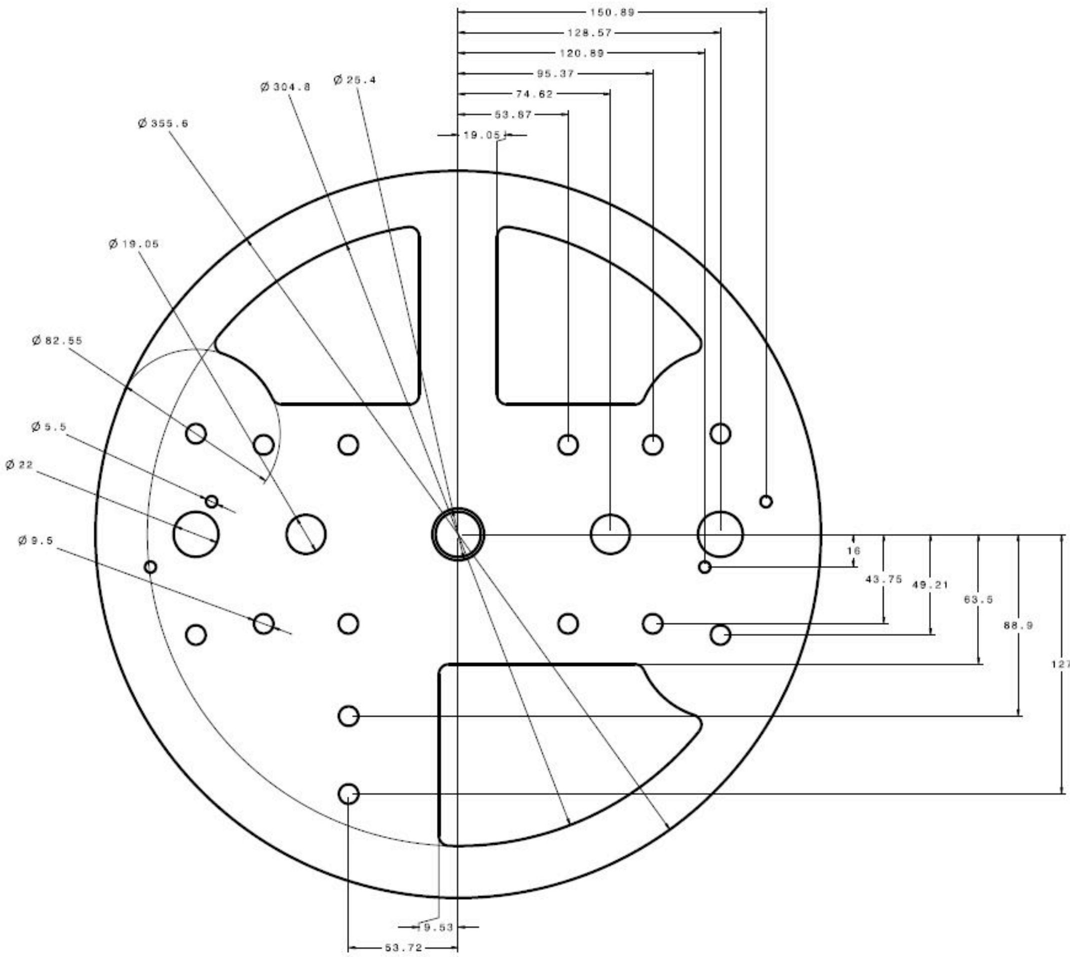


Designsafe: Using designsafe software it was determined that creating a regenerative braking bike hub would be moderately safe. Most of the danger associated with creating such an item comes by way of the weight of the hub, the hydraulic circuit that is under pressure within the hub, and the electric circuit needed to operate the clutches and valve. Specifically all of the problems with building the hub are listed in the table above. Ways that could be used to increase safety are also listed and a secondary safety rating of "low" became the new assessment. Appendix G on page 57 shows the design safe results.

9. Final Design Description

Super Bracket: To reduce weight further, the final design of the super bracket had the axles for the thrust gears welded on instead of using the current cantilever shafts. By doing this, we would reduce the unneeded support weight of the shafts and remove several nuts and bolts used to secure the cantilever shafts to the super bracket. Unfortunately, we were unable to do this because we wanted versatility of the thickness of the gears because it's likely that the future thrust gears will be made of a different material and require a larger thickness and therefore longer axles; a dimensioned drawing of the new super bracket is shown below in figure 26.

Figure 26: Super Bracket Dimensions



Spider gear: The spider gear suggested for the final design will be a cylinder that is 5" diameter and will be 1/4" in depth, with a ½" depth at the center. The center of the cylinder will be hollowed out to 1.98" in diameter so that a bearing can be press fit into it. Four holes will be placed between the inside 1.98" and 5" diameters so that dowel rods can connect it to the main gear. The spider gear will have four pieces cut out of it to increase the cross sectional area that is perpendicular to the face of the gear, to reduce stress on the hub. The spider gear will be made of 1020 steel as it is cheap, decently lightweight, and easily attained. The spider gear meets design parameters because we believe that we have reduced the stress on the hub enough to prevent failure. A picture of the CAD modeled spider gear is shown in figure 27 below, and dimensioned spider gear is shown in figure 28 below.

Figure 27: Isometric View of Super Bracket

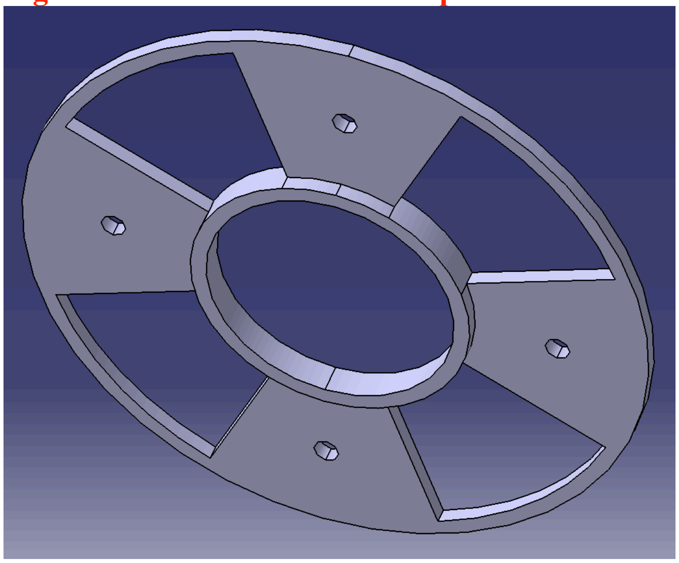
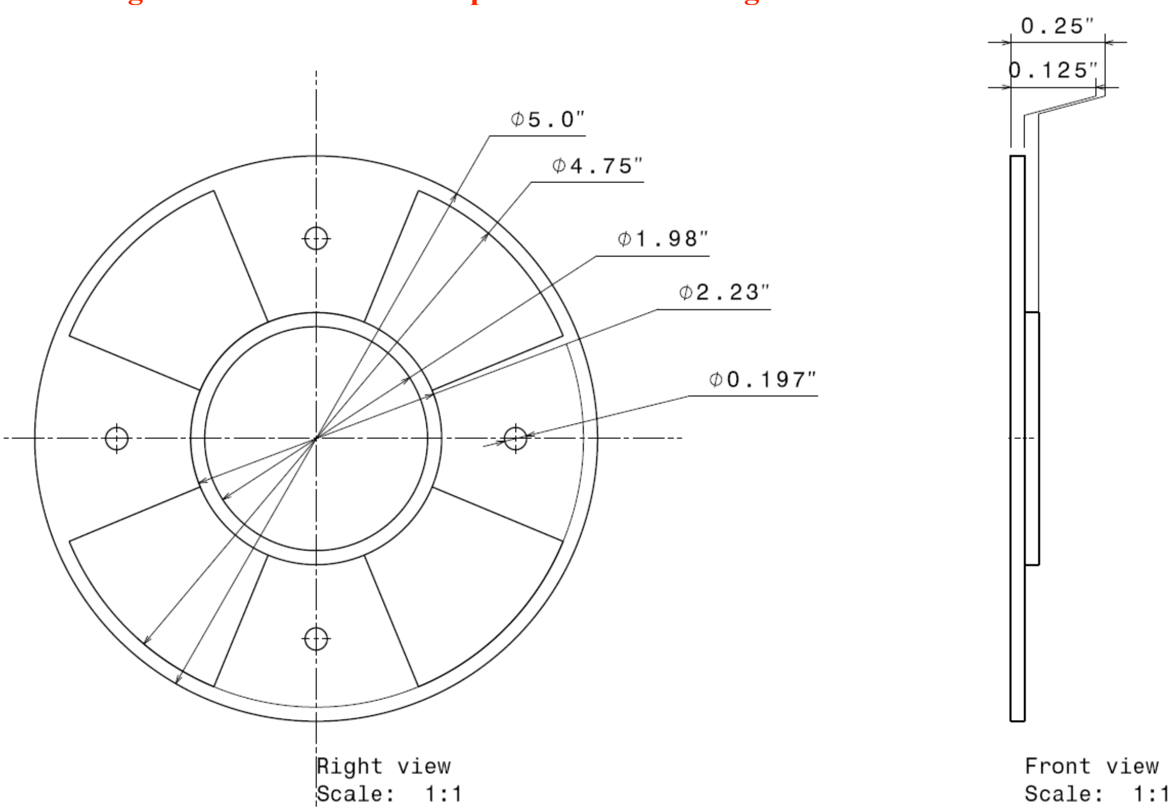


Figure 28: Dimensioned Super Bracket Drawing



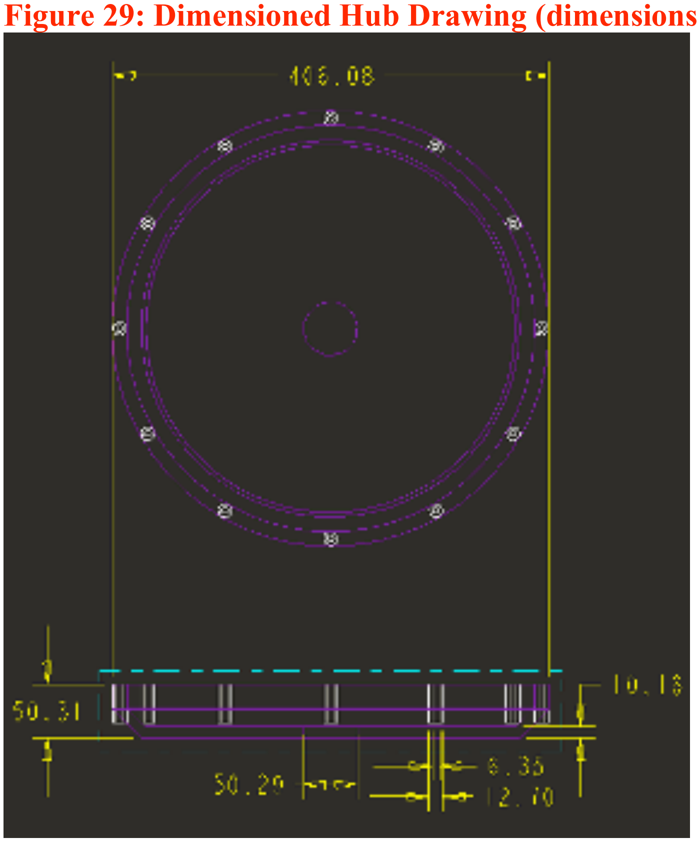
Gears: One thing that the prototype won't be able to accomplish is decreasing the overall weight of the gears. The difficulty in trying to decrease the weight of these gears is that our new gears will need to be custom made so that they will be as light as possible while still withstanding the torques and speeds of our system. We are currently working with a company that will be able to match these needs for our four thrust gears, however because these gears need to be custom made it is unlikely that they will reach us in time to be integrated into the prototype at the design expo. Another problem with integrating these gears before the design expo is that initial calculations show that the face width of the gears will have to slightly increase and if this happens we will need new connector and axle gears that match up with this increased width. Because we believe that we won't have sufficient time to implement these gears into the system we will also look at the possibility of decreasing the weight of the connector gears. Our goal for the rest of the semester is to have secured all the gears for the final design and to have the wheel set up so that the team following us will be able to quickly integrate them into the wheel.

Based on initial calculations, we believe that the new lighter gears will weigh between .2 and .25 pounds (per thrust gear), as opposed to one pound (per thrust gear). This will reduce the overall weight of the gears by approximately 35%.

We have taken into consideration the interaction of metal and plastic gears and asked Commercial Gear and Sprocket Co, Inc if this would be a problem. They said that as long as the proper lubrication was used between the metal and plastic teeth then it would not be a problem.

Hub: The CES analysis that we performed led us to choose a material (fiberglass epoxy matrix) that meets the desired engineering specifications. The fiberglass epoxy matrix meets the strength criteria, it is lightweight, and relatively cheap, and readily available to us; figure 29 shows a dimensioned drawing of the hub.

Figure 29: Dimensioned Hub Drawing (dimensions are in mm)



10. Prototype Description

Super bracket: Our initial design for weight reduction of the super bracket was to use a mill to precisely cut out the non-critical areas of material in the super bracket. Unfortunately, since the main axle was already welded onto the super bracket by the previous semester it made the super bracket very bulky and cumbersome. Therefore, the super bracket was very hard to mount properly on a mill and cut out the designated material. Since the areas we decided to cut out were not dimensionally critical, we cut out conservative amounts with a plasma cutter. By doing this we were able to show approximately what areas should be cutout without having to make a costly new prototype or re-weld the axle.

Spider Gear: The spider gear constructed for the prototype will be very close to the spider gear suggested for the final design. It will be a cylinder with a 5” outside diameter and a 1.98” inside diameter. The gear will also have four holes that will be used to connect it to the main gear. However, the prototype's spider gear will have a ½” height because we will not have time to reduce the thickness of the block of 1020 steel. The prototype's gear will not have four sections cut out of it in the same manner as the suggested final design spider gear. Due to time constraints, we will not have time to cut out the four symmetrical sections needed to produce the reduced stress on the hub. However, the prototype's spider gear will have holes drilled in it throughout to increase the cross sectional area perpendicular to the force and reduce weight. The prototype will accurately represent the suggested final design because it will have a similar cross sectional area to reduce stress on the hub and will be close to the same weight.

With this gear and the ones remaining from last semester we will have the gears necessary to have a working prototype by the expo. This prototype however will not be able to accomplish our goal of decreasing the weight of the gears. This is not a lost cause though as we are currently looking into and working with a company to secure much lighter thrust gears and we are looking into the possibility of getting lighter connector gears as well. This is explained more in depth in our final design section

Gears: When we first started on this project there were two clutches for the wheel, one that was electromagnetic and one one-way clutch. We were asked by our sponsor to replace the one-way clutch with another electromagnetic clutch. This required us to order one new connector gear as the old one would no longer work because its axle radius had been bored out too much to fit the bearing for the one way clutch. Last semester used a Martin sprocket gear and had the hub on the back machined off as well as having a 1/8”x1/16” keyway machined in. We have contacted Applied Industrial Technologies about getting another of these same gears from Martin and are waiting for a quote and ETA on it. With this we also need to acquire two 1/16” keys to secure the gears to their axles.

Hub: The prototype of the hub should be exactly the same as the hub for the final design.

Remaining Systems of Prototype: Many of the subsystems of our prototype have not changed from the previous teams design, see appendix E on page 54 for the prototype description of those systems.

11. Manufacturing Process

Super bracket: To create a future prototype of the super bracket, there would be some modifications to the manufacturing process. A 14” by 14” piece of steel would be milled out to our specifications. Once completed the main axle and the separate thrust gear axles would be welded on. By welding the axle on afterward, all the holes will be able to be precisely cutout on the mill because there will be no problems mounting the bracket when the axle is not attached. Figure 30 below shows the super bracket as completed by the winter 2008 team, and figure 31 shows our design for the super bracket.

Figure 30: Current super bracket

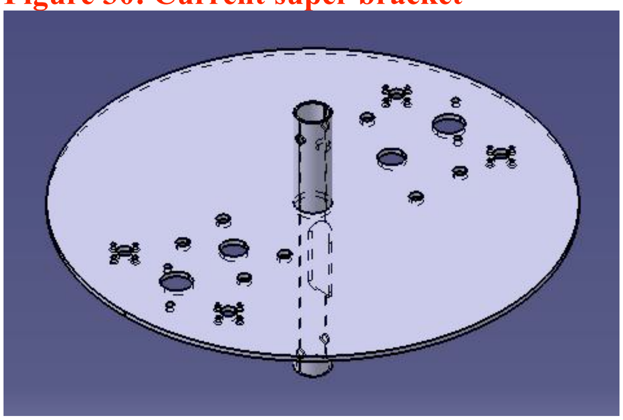
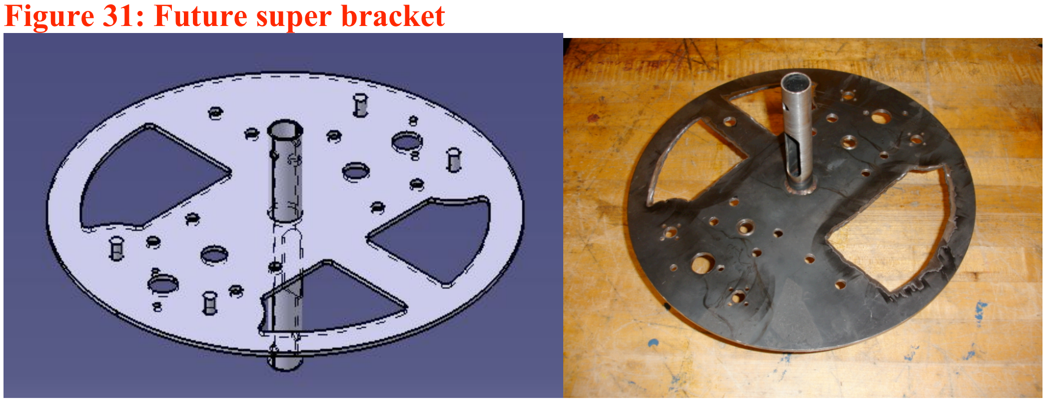


Figure 31: Future super bracket



Spider Gear: In order to manufacture the spider gear we will start with a 6” x 6” x ½” block of 1020 steel. The center of the block will be marked using a ruler and making a cross using diagonal corners. A circle will be drawn on the surface of the block the has a 5” diameter. Using a band saw, the steel will be cut along the circle to create a cylinder with a 5” diameter. The center will then be drilled out to make a hole with a 1.98” diameter in the center of a face of the cylinder. The main gear will then be clamped to the cylinder, aligning the cut out centers exactly. The four holes that will be used to connect the main gear to the spider gear will be made using a drill press. Holes will then be drilled over a face of the cylinder to increase cross sectional area perpendicular to the face.

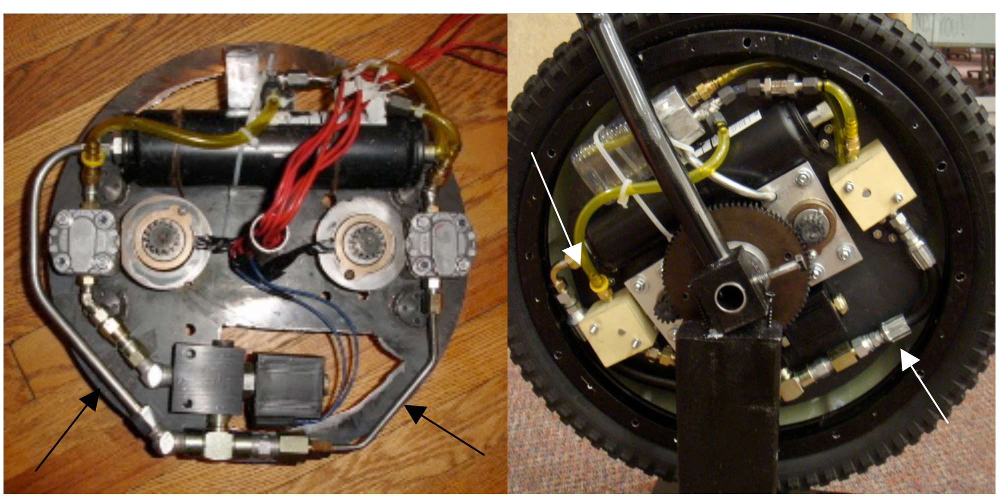
Gears: To create a working prototype there were a couple things that needed to be accomplished. We needed to replace one of the connector gears and find two new axle gears. The previous section had two connector gears but one was set up for use with a one-way bearing clutch. Because of this we needed to order a new connector gear similar to the one set up for the electromagnetic clutch. This gear that was ordered comes with a hub on it that needs to machined off. This will be done in the machine shop using a mill. We also need to replace the two axle gears as the current ones are attached to axle with a bushing which will compromise the strength of the gear. For this we are currently in the process of getting quotes from several companies for unbored gears. Once we are able to get these gears we will we will bore the center out and work Protomatic to have key ways cut out.

Hub: To make the second half of the hub with the drive gear attached we will use the same mold that was designed by the previous term and a fiberglass epoxy matrix. We will lay down 3 layers of the fiberglass and epoxy down in the mold, then the spider bracket we be placed in the mold, and the remaining (approximately) 15 layers of fiberglass will be placed on top, securing the spider bracket in place. The drive gear will then be attached to the spider bracket.

12. Engineering Changes Notice

Several components of our design were changed from Design Review 3 to the finished prototype. Upon assembly of the prototype, we had some clearance issues with the hydraulic circuit, high pressure accumulator, and low pressure accumulator. To remove all the bulky hydraulic fittings and allow the bike rim to fit snug around the super bracket, we had custom hard lines assembled. A 1/2" hard line was installed from the high pressure accumulator to the valve, allowing both the high pressure accumulator and hydraulic line to fit correctly. A 3/8" hard line was installed from the valve to the pump, also for fitment issues, shown in Figure 32 on below.

Figure 32: Hydraulic Line Change

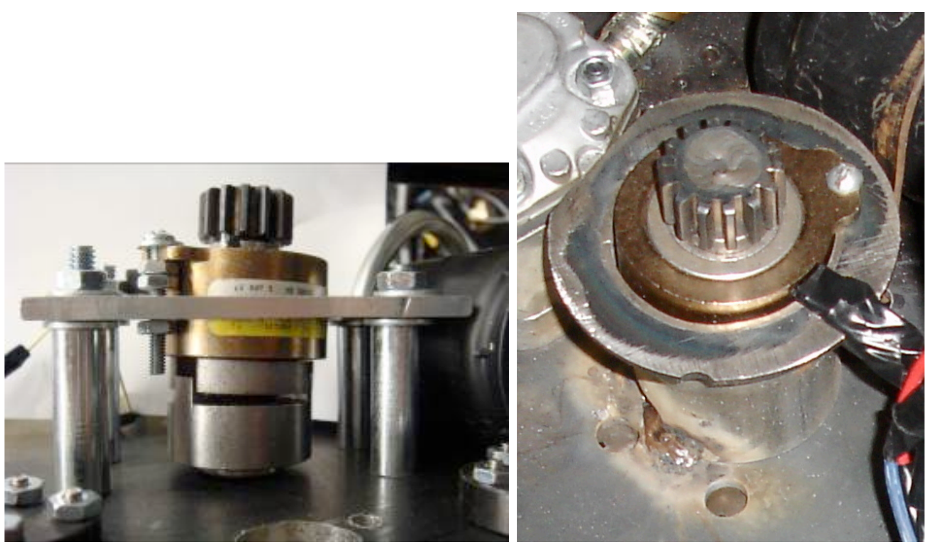


To allow the wheel hub that is integrated with the spider gear to fit onto the bike rim and match up with the other gear train, we had to modify the clutch brackets and the high pressure accumulator mounting bracket. The previous design for the clutch brackets were flimsy brackets made of 3/8" thick aluminum. To make a more robust design that would handle the forces of the system, we replaced those brackets with collar like brackets, shown in Figure 33 on Page 34. The new design allows the clutches to be positioned correctly and not tilt under load.

We also removed the old high pressure accumulator bracket and installed thin bail wire to hold the high pressure accumulator in place. This modification allowed for a larger clearance between the wheel hub and the high pressure accumulator.

With only a week remaining before the design expo, we realized that the existing electric circuit created by the previous semester's team did not work. This lead to a complete redesign of the circuit with the little time we had. The functional purpose of the circuit was to control the two clutches and the electronic valve. The clutch for the motor and the electronic valve were to be wired to the same circuit and same switch. This was because we wanted the valve to be rerouted to the motor from the high pressure accumulator while the clutch for the motor was engaged. The clutch from the pump needed to be wired to another switch and would be engaged during braking to draw low pressure hydraulic fluid from the reservoir and store it in the high pressure accumulator. Each circuit needed 24V in order to be actuated. To solve this we connected three 9V batteries in series creating 27V which is more than we needed.

Figure 33: Clutch Bracket Change



13. Discussion

In retrospect, the main thing we would have done differently would have been to carefully review the previous semester's work, assess the quality of their work, and decide if anything needed to be changed. Unfortunately, we blindly accepted all the work they completed and by doing so we have had several issues when we tried assembling our bike. Since we found all these issues so late in the semester and assembly process, it was extremely difficult to address all of them and it increased our work tenfold.

Looking back on our design, we still have the main problem of weight. After some calculations, we originally planned to replace the majority of the gears in the gear train with plastic gears. After a grueling process of contacting numerous vendors throughout the semester, we came to the realization that plastic gears were not cost efficient after being quoted approximately $400 per gear. Had we known this sooner, we could have drilled holes in the current gears to reduce weight.

Another problem we encountered was the construction of the wheel hub. No one in our group used fiberglass extensively before, so we added too many layers to the wheel hub. Looking back we realized that we could have used less layers of fiberglass, which would have allowed the wheel hub to still handle the stresses of the regenerative braking system and weight of the rider, but reduce the weight significantly.

After changing the clutch brackets and mounting bracket for the high pressure accumulator, it was possible to reduce more of the super bracket for weight reduction. In addition to removing more material, the super bracket could also be manufactured out of aluminum or another material that is lighter than steel. Just removing non critical material alone could drop the weight down approximately 25% in addition to what we already removed.

14. Validation Plan

In order to prove that our final design meets all engineering specifications set forth in Table 1, page 10, we need to find a way to validate our work.

Maximum Weight: The maximum weight of the final design should be less than 16 pounds. In order to determine if our final design meets this requirement we will weight each part individually while the bike is disassembled in order to determine a final weight.

Hub Width: After the hub is completely assembled, the width will be measured with a caliper to determine is our goal of less than 4" was met.

Hub Diameter: The goal for hub diameter was less than 16". Once both hubs have been produced, each diameter will be measured with a more exact ruler.

Prototype Functionality: The prototype for our final design is to be working by the design expo in December. We will have demonstrations and test rides of the prototype at the design expo to prove that this engineering specification was met.

Maximum Launching Acceleration/maximum braking deceleration: Once the prototype is fully assembled and is ready to ride, we will mark out a set distance that the bike will accelerate for and this trial will be timed. Many trials will be run to make sure we have an accurate reading of the acceleration/deceleration to prove that we can meet the goal of 2.0-2.5 m/s^2 and 2.20-3.63 m/s^2.

Gear Ratio: The gear ratio specified in the engineering specifications was 18:1. To prove that we achieved this ratio, calculations will be carried out that show how the gears we selected provide an 18 to 1 gear ratio.

Working Pressure: The desired working pressure specified in the engineering specifications was 2700-4000 psi. We did not design a device to show the pressure in the accumulators; therefore, we will not be able to prove that we have met this working pressure. However, based on the plumbing design from the Winter 2008 team, the working pressure should be between these values.

Maximum Volume of Hydraulic Fluid: The prescribed maximum volume of fluid in the prototype is 0.3 to 0.32 L. It will be easy to determine the maximum amount of fluid because this will be the same as the input hydraulic fluid into the system.

Hydraulic fluid filtration: The target for hydraulic fluid filtration is 4000 psi max pressure. This is determined by the filter that was installed upstream of the check valve by the Winter 2008 team. The filter is rated by the manufacturer. Correct installation of the filter will insure this requirement is met.

Motor/pump displacement: The target motor/pump displacement for our project was 0.51-0.64 cc. This is a specification that is met by the manufacturer. The pump and motor have been chosen to specifically meet these values.

15. Project Plan

Appendix B on page 44, details our schedule. Here, we show important deadlines that have a heavy impact on the completion of our project. Design Review 1 is on September 25th, Design Review 2 is on October 8th, Design Review 3 is on November 11th, Design Review 4 is on November 25th, and our Final Presentation is scheduled for December 4th.

Last semester's group has already completed the majority of the design for our project. Our goal is to refine their final project by reducing weight in the gears and super bracket as well as attach the drive gear to the hub in a suitable fashion. Ultimately are main goal is to have a working prototype. The main problems we are going to have to overcome is dealing with long lead times on special parts, meeting our sponsor's customer requirements, and matching parts that correctly meet our calculations.

To assemble our project and implement our concepts, our group requires several parts to be ordered from various vendors. Jasem took the position of dealing with all the vendors, ordering the parts, and making sure we receive the correct parts on time. So far we have ordered the clutches and double triple clamp fork. Jasem is in the process of finding the correct valve for our project and once the optimal material is chosen, he will order it for the gears. This position is very important because if we receive the wrong parts it could cause huge delays in our already tight schedule.

As for the actual model, Jason M. is going to create our CAD model in Catia to confirm the fitment of everything and perform FEA analysis on the "super bracket" to remove material that is not critical to the design to help reduce weight. The previous group created a model of the prototype in Pro Engineer that did not have much detail. The model Jason M. will create will have much higher detail to confirm the accuracy of our layout and that everything will work. Jason D. is doing calculations on the strength required by the gears to determine the material and sizes that would be most optimal for our project. After he choices what is best for us we will machine them out using the CNC machines in the lab. Nick and Jasem will also be working together to integrate the second half of the hub with the drive gear. It is important that they work closely together because a small error in the assembly of both pieces could be detrimental to the functionality of the bike.

We have experienced unexpected set backs due to long lead times and supplier difficulties, including parts being damaged during shipping, the fiber glass taking longer to be delivered than anticipated and difficulties communicating with three different parts suppliers.

Now that we have started to assemble the hub, we have noticed that there are many small issues that need to be addressed, such as missing hardware, issues with parts fitting, problems with the previous semester work which we thought had been completed.

16. Engineering Analysis

The most critical areas that need to undergo engineering analysis for our project are going to be the determination if plastic gears can withstand the torques of launching and braking, as well as which areas of the super bracket are non-critical to the structural integrity. These areas are very important because if either fail the entire system will fail; with out gears the bike will not brake or accelerate, and if the super bracket fails all of the internal components will come apart. Analysis has been performed on the hub by previous terms to determine if the fiberglass is strong enough.

To determine if plastic gears will be suitable, calculations to determine the torques on each gear will be calculated, and then those torques will be compared to the torque ratings for available gears.

We will perform finite element analysis on the super bracket to determine which areas will are non-critical, as well as the affect of removing certain areas.

16.1 Potential Problems

Gear Selection is critical. The gears must be able to withstand the maximum torques with out failing, as well as stay within our budget constraints.

Spatially the systems is already close to the maximum depths, and plastic gears may be ruled out due to the fact that they may need to be wider (than steel) in order to withstand the torques.

We will need to overcome long lead times. We will be ordering some specialty items (such as valves) which have long lead times, therefore we will need to ensure that we order the correct parts.

Assembly will be an issue due to the spatial issues. All of the components of the wheel theoretically fit inside of the hub, however, we may run into issues with the assembly not fitting quite as we plan, and we may have to change our design to accommodate for these issues.

17. Recommendations

There are several recommendations that we have for groups that continue this project in the future; there area several things that need to be done before the bike will run, and there things which we believe can be redesigned.

Fork
Due to the fact that the double triple clamp fork ordered was not the same dimensions as the clamp used on the previous bike (26" wheel) the fork needs to be re-bent wider to allow the hub to fit.

Electric Circuit
The electric circuit is set up right now; all that needs to be done is connect the leads. However there is room for improvement for the circuit, currently there are two stitches mounted to the frame of the bike, it would be ideal for the switch to activate the braking to be like a normal bike brake on the handle bar, and the switch to activate the acceleration should also be placed on the handle bars. To make the circuit even more useful, but complicated a circuit could be produced to allow different levels of braking.

Hub
The half of the hub with the spider gear and drive gear needs to be either modified or remade. If the current hub is to be modified, the drive gear needs to be pushed down to the fiberglass surface in order for the hub to close and fit in the fork properly. If a new hub is to be made the same is true, and also much less fiberglass could be used; the current hub is much thicker/stronger than it needs to be, which adds considerably to the weight.

Hydraulic Circuit
The hydraulic circuit is almost operational, all that needs to be done is put Teflon tape on all of the fittings (to prevent leaking) and make sure the hydraulic lines are all attached properly. Also, a poppet type valve should be ordered for to eliminate pressure loss.

Axle
The holes drilled in the axle to prevent the super bracket from spinning need to be re-drilled so that the super bracket is rotated approximately 30 degrees clockwise; this will allow the low pressure accumulator to function properly.

Gears
If plastic gears can be purchased for a reasonable cost, then all of the gears should be replaced with plastic ones to reduce weight. If not, non-critical areas of the current gears should be removed (similar to the super bracket) to reduce weight.

Super bracket
With the addition of the newly designed clutch brackets and high pressure accumulator mounting, more non critical material could be removed from the super bracket. In addition to removing more material, the bracket could be re design all together and be produced from a lighter material such as aluminum.

18. Conclusion

Our project is a continuation upon previous semesters work, attempting to apply a hybrid human-hydraulic powered system to a child's 20" bicycle wheel that is all contained in the front wheel. The motivation for this project is to encourage alternate forms of clean transportation and to help reduce the use of oil. We now have all of our customer requirements defined and prioritized; having a working prototype is the top priority, and the second is reducing weight of the system. We have the engineering specifications for our project set, based on the customer requirements; they are summarized in table 1 on page 10.

We have completed our primary concept generation and have currently decided upon an alpha design for our prototype. We broke our design into four subsystems where we will focus our attention; gears, super bracket, super gear, and hub. We used Pugh charts to determine which concepts were best in a non-biased way.

We will be implementing plastic gears in our system after we do final calculations to determine if the plastic will be strong enough to withstand the maximum torques applied to them. We will not be making a new super bracket, we will however be removing non-critical areas from the current super bracket in order to reduce weight. We will perform finite element analysis on the bracket to be certain. The main drive gear will be attached directly to the hub. This reduces weight and is the most feasible design. Finally, we will be finishing the hub out of fiberglass, similar to the half that the previous term has already made.

We have begun the assembly process and started by reducing the weight of the super bracket by removing non-critical areas. We have also been contacting various suppliers regarding manufacturing lightweight plastic gears. We have also performed calculations using the CES software to determine which materials should be used for the hub and spider gear (fiberglass epoxy matrix and 1020 steel respectively).

For the design expo a completed prototype was nearly achieved. Although creating a working prototype by the design expo was top priority, uncontrollable factors made this difficult and the product was not ready to be used. However, before the design expo it was possible for us to finish the project on time. The only things that needed to be completed were to add hydraulic fluid and finish connecting the electric circuit. The Tuesday before the expo, it was suggested to us by our GSI to stop all work on the prototype and to present what we had done because of the lost lab time. For the display at the expo, the prototype looked as though it could be ridden, but it was explained that a few things still needed to be completed in order for the prototype to be fully functional. Overall the project was a success and we completed all objectives we set out to complete except for being able to ride the finished product.

19. References

[1] http://en.wikipedia.org/wiki/United_States_Environmental_Protection_Agency

[2] http://www.epa.gov/ocfo/plan/plan.htm

[3] http://www.worldcarfree.net/resources/stats.php

[4] www.epa.gov/oms/technology/420f04024.pdf

[5] http://www.autoblog.com/2007/11/29/2009-ford-f-150-may-feature-hydraulic-launch-assist/

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[7] www.revopower.com

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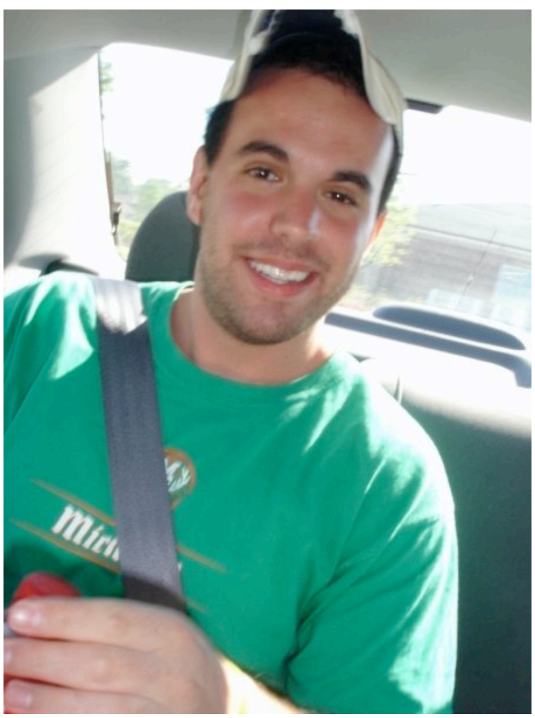
20. Biographies

Nick Alanen was born and raised in Marquette, Michigan. He currently lives on Dewey St in Ann Arbor. He has taken courses that have gone over Energy Transfer and Hydraulics, so he was excited when he was chosen for this project. He is a hands-on type of worker and enjoys building and constructing more than calculating. In his spare time, he enjoys trying to fix his broken car, watching movies, and playing with his dog. His undergraduate degree is in Mechanical Engineering and he wants to work in the automotive industry when he graduates.

Jason Dykstra was born in Grand Rapids, MI and attended Rockford Public Schools. He currently resides on Walnut St in Ann Arbor. He got into engineering because his strengths in high school were math and science and he has always liked figuring out how things worked. In his spare time he likes getting involved in any sport, but basketball has always been his first choice. He also enjoys watching sports on TV and is a diehard Detroit sports fan.

Jason Muccioli was born and raised in Farmington Hills, MI. He currently lives on Prospect Ave in Ann Arbor. He is known as the handy man of the house and is very good with metal and wood working. His main hobby is working on/modifying cars and he likes taking them to the drag strip and racing. His undergraduate degree is in Mechanical Engineering and he is trying to decide whether he wants to get a job or stay in school and obtain his Masters right away.



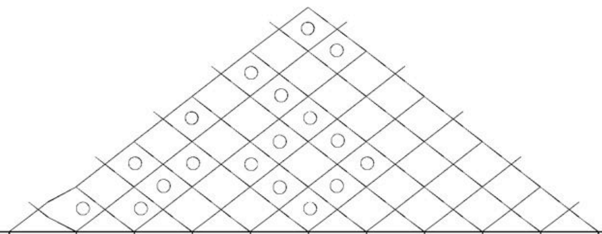
Jasem Yousuf was born in Elmira, NY and moved to Binghamton, NY when he was very young and lived there since. In high school he was able to take an engineering course that was offered in conjunction with the Rochester Institute of technology, which is what led him to study engineering in college. He is good with most CAD programs and an incredibly organized person. He decided upon University of Michigan for two reasons, it was one of the best schools for engineering and football.

21. Appendices

Appendix A: Quality Function Deployment

QFD Matrix:

- ● Strong Positive
- ○ Some Positive
- × Some Negative
- ⋇ Strong Negative

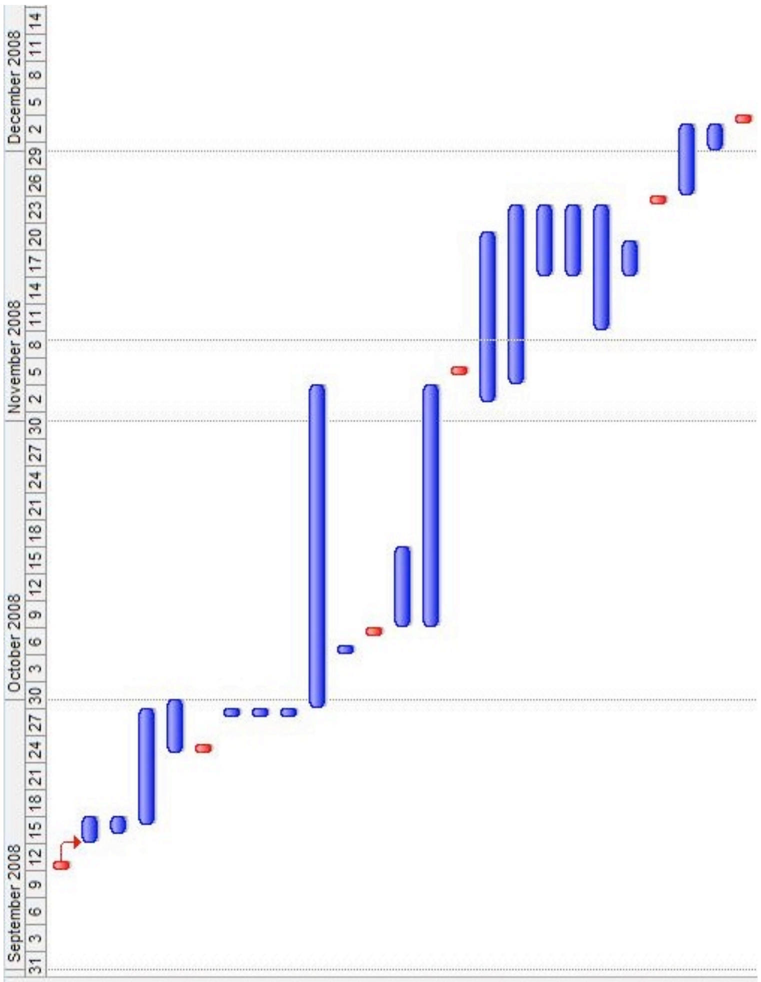


Customer Requirements \ Technical Specifications	Hub Width	Hub Diameter	Max. Sustained braking torque	Max. Weight << 16lb	Max. Sustained Launching Torque	Motor/Pump Displacement	Max. Pressure	Max. Volume of hydraulic fluid	Hydraulic Fluid Filtration	Prototype Functionality	Weightage	D: Total (weighted customer requirement)	E: Normalized to Total	F: Importance rating (% of total)	G: Winter 08 Bike	H: Fall 07 Bike	I: Winter 07 Bike	J: Fall 06 Bike	K: Winter 06 Bike	Fall 05 Bike
Have Working Prototype	1	1	1	1	1	1	1	1	1	9	9	162	0.6	60	3	6	6	6	6	9
Design for Manufacturability	3	3	0	6	0	0	0	0	0	9	6	126	0.5	47	3	3	1	3	1	3
Reduce Weight	3	3	6	9	6	3	0	0	0	1	6	0	0	0	9	6	1	3	3	1
Improve Hub Design	9	9	0	1	0	0	0	0	0	3	3	0	0	0	6	6	6	6	6	6
Universal Application	9	9	0	9	0	0	0	3	0	0	9	0	0	0	9	9	9	3	1	1
Natural Rate of Braking	0	0	9	0	0	3	3	3	0	0	3	0	0	0	9	3	9	3	3	3
Sufficient Top Speed	0	0	0	9	9	3	9	3	0	0	1	33	0.1	12	9	3	3	3	3	3
Efficient	0	0	1	9	9	1	9	1	3	3	3	108	0.4	40	9	9	9	3	3	3
Lightweight	3	3	0	9	0	3	1	3	0	0	9	198	0.7	73	9	1	9	3	1	1
Reliable	0	0	3	1	3	1	0	0	9	3	3	60	0.2	22	6	3	9	3	1	3
Aesthetics	9	3	0	3	0	0	0	3	0	0	9	162	0.6	60	6	9	3	3	3	3
Safety	0	0	9	0	9	0	3	0	0	9	9	270	1	100	3	9	9	3	1	1
Easy to Use	0	0	3	9	3	1	0	0	0	9	3	75	0.3	28	3	3	3	1	1	3
Easy to Service	3	3	0	0	0	0	3	0	9	0	3	54	0.2	20	3	3	3	3	3	1
Maintains Bicycle Function	9	9	3	9	3	0	0	0	0	9	3	126	0.5	47	9	9	3	3	3	3
Design Hub Shell	9	9	1	9	1	0	0	0	0	3	3									
Condense RBS	3	9	1	1	1	0	0	0	0	3	9									
Adapt Prototype to Bike	3	9	1	0	1	0	0	0	0	9	9									
Measurement Unit	in	in	N-m	lb	N-m	cc	kPsi	L	n/a	n/a										
Present Standard Bicycle	4	29	100	20	0	n/a	n/a	n/a	n/a	n/a										

9 - Strong Relationship
6 - Semi Strong Relationship
3- Weak Relationship
1 - Very Weak Relationship

Appendix B: Gantt Chart

	Task Name	Duration	Start	Finish
1	Meet the Sponsor	1 day	Fri 9/12/08	Fri 9/12/08
2	Define Problem	3 days	Mon 9/15/08	Wed 9/17/08
3	Develop Concepts	2 days	Tue 9/16/08	Wed 9/17/08
4	Make Prototype CAD Model	9 days	Wed 9/17/08	Mon 9/29/08
5	Disassemble Old Prototype	4 days	Thu 9/25/08	Tue 9/30/08
6	Design Review #1	1 day	Thu 9/25/08	Thu 9/25/08
7	Purchase 2 Electric Clutches	1 day	Mon 9/29/08	Mon 9/29/08
8	Purchase Double Triple Clamp Fork	1 day	Mon 9/29/08	Mon 9/29/08
9	Purchase Hydac Valve	1 day	Mon 9/29/08	Mon 9/29/08
10	Refine CAD Models	26 days	Tue 9/30/08	Tue 11/4/08
11	Purchase Gear Material	1 day	Mon 10/6/08	Mon 10/6/08
12	Design Review #2	1 day	Wed 10/8/08	Wed 10/8/08
13	Plasma Cut Bracket	7 days	Thu 10/9/08	Fri 10/17/08
14	Order Fiberglass	19 days	Thu 10/9/08	Tue 11/4/08
15	Design Review#3	1 day	Thu 11/6/08	Thu 11/6/08
16	Machine Gears	15 days	Mon 11/3/08	Fri 11/21/08
17	Make Fiberglass Hub	14 days	Wed 11/5/08	Mon 11/24/08
18	Fix Motor Gear Issue	6 days	Mon 11/17/08	Mon 11/24/08
19	Fix Electronic Clutch Mounting Issue	6 days	Mon 11/17/08	Mon 11/24/08
20	Assemble Model	10 days	Tue 11/11/08	Mon 11/24/08
21	Test Fitment	4 days	Mon 11/17/08	Thu 11/20/08
22	Design Review #4	1 day	Tue 11/25/08	Tue 11/25/08
23	Validation Testing	6 days	Wed 11/26/08	Wed 12/3/08
24	Paint Hub	3 days	Mon 12/1/08	Wed 12/3/08
25	Design Expo	1 day	Thu 12/4/08	Thu 12/4/08



Appendix C: Gear Calculations

Determined by previous team
Gear ratio: 18:1
Pump size = 0.64 cc/rev
Motor size = 0.51 cc/rev
Efficiency of pump and motor = 0.825
Max wheel RPM = 336 RPM
High pressure accumulator = 4000 psi = 27,579. 03 kPa

For calculation purposes only the pump side of the wheel is looked at due to the larger size of the motor. The gears on the pump and motor sides will be identical so anything capable of handling the HP and torque requirements for the pump side will be able to handle them for the motor side

Maximum Torques

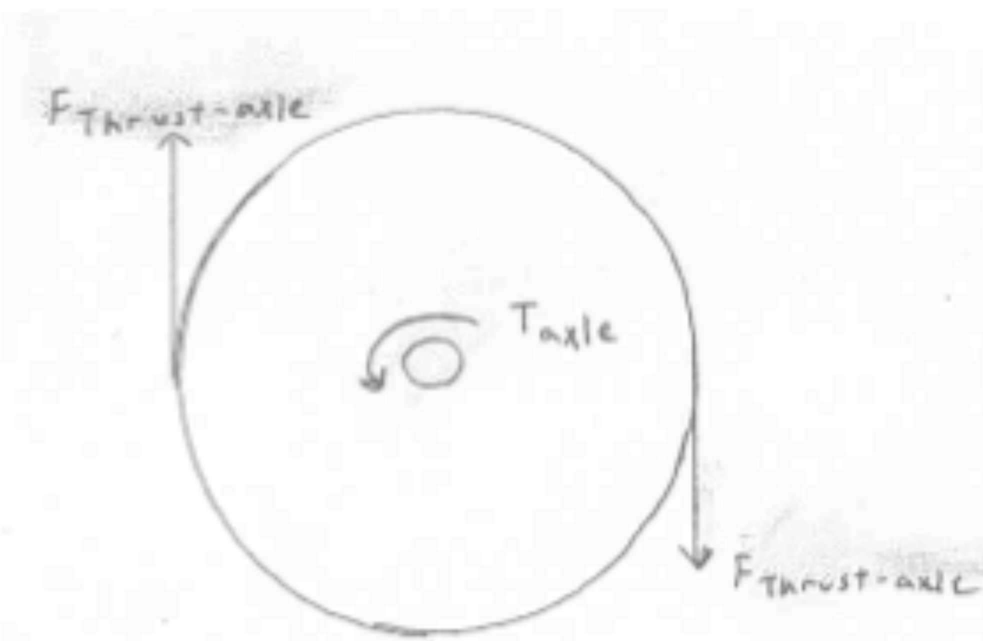
At Pump

$$T_{\max} = \frac{disp * P_{\max}}{2*\pi} = \frac{\frac{0.64cc}{1000\frac{cc}{L}} * 27579.03kPa}{2*\pi} = 2.81n*m*0.737\frac{ft*lbs}{n*m} = 2.07ft*lbs$$

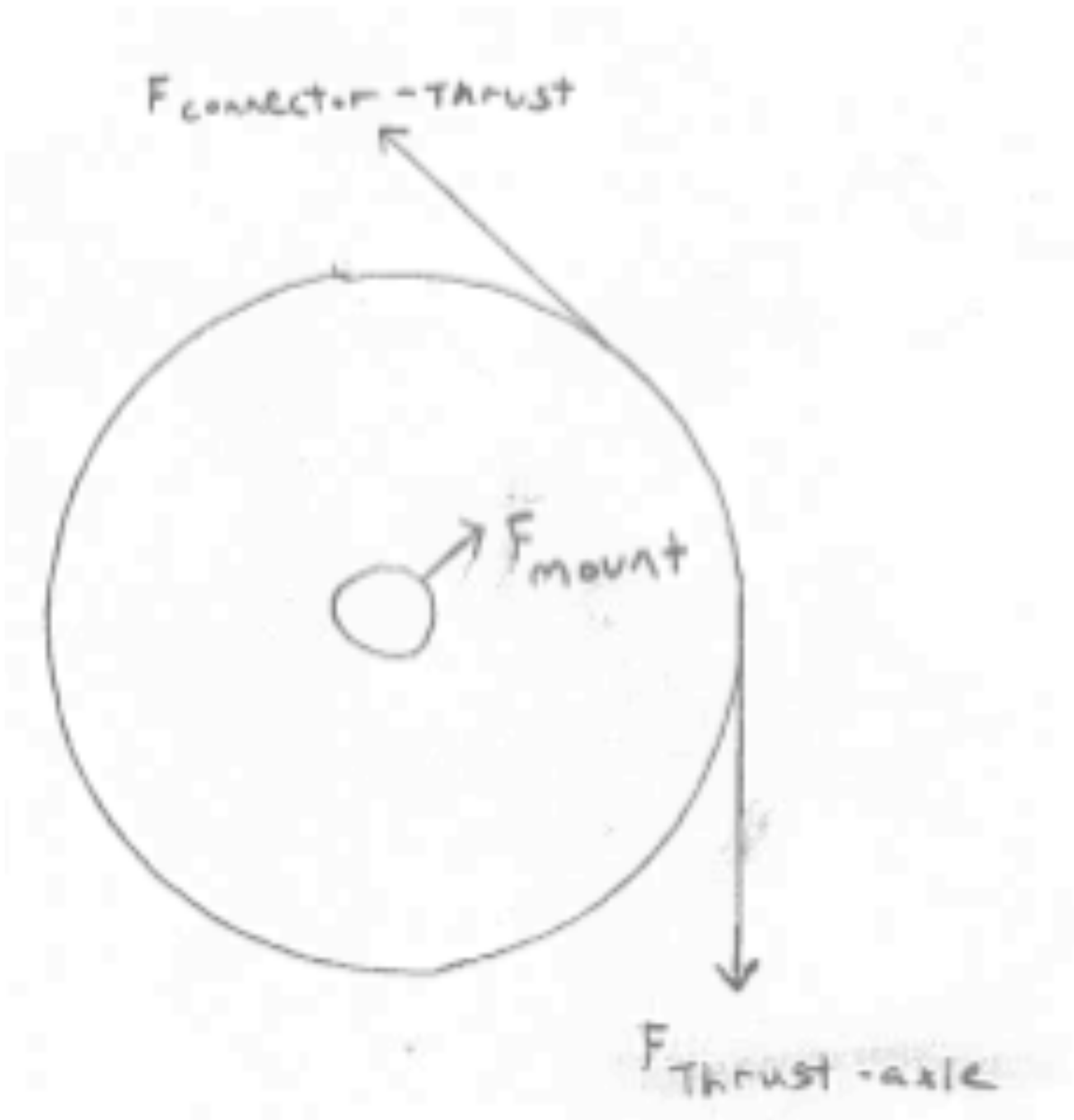
Torque on axle gears

$$T_{axle} = T_{\max} * \eta_{pump} = 2.07ft*lbs*0.825 = 1.71ft*lbs$$

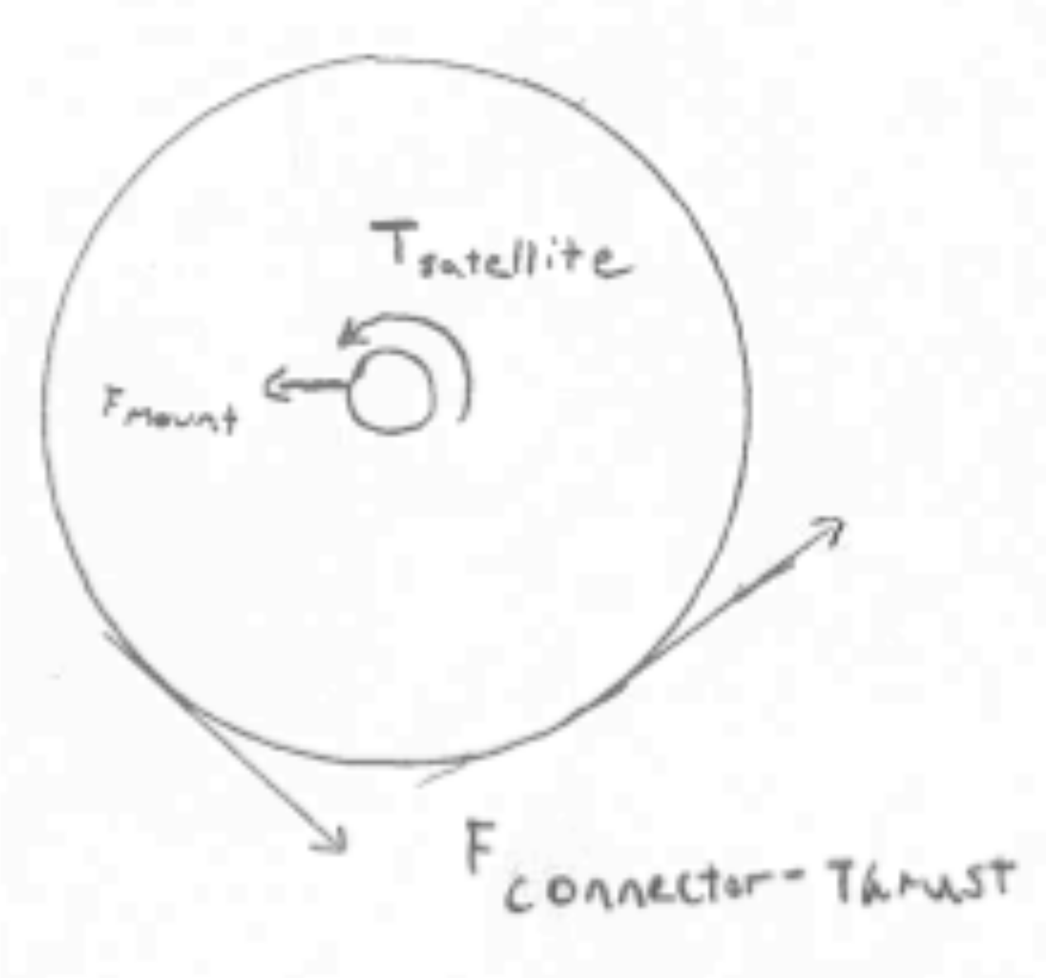
FBD for axle gear



FBD for Thrust Gear



FBD for Connector Gear



Torque on thrust gears (two per axle gear)

$$T_{thrust} = T_{axle} * \frac{Diam_{thrust}}{Diam_{axle}} * \frac{1}{2} = 1.71 ft * lbs * \frac{3in}{0.875in} * \frac{1}{2} = 2.93 ft * lbs$$

Torque on connector gears (one per two thrust gears)

$$T_{connector} = T_{thrust} * \frac{Diam_{connector}}{Diam_{thrust}} * 2 = 2.93 ft * lbs * \frac{2.75in}{3in} = 5.37 ft * lbs$$

The torque on the satellite gear will be the same as the torque on the connector gear as they share the same axle

Torque on the main gear

$$T_{connector} = T_{thrust} * \frac{Diam_{connector}}{Diam_{thrust}} * 2 = 2.93 ft * lbs * \frac{2.75in}{3in} = 5.37 ft * lbs$$

Maximum RPM

$$RPM_{main} = RPM_{wheel} = 336RPM$$

RPM on satellite gear

$$RPM_{satellite} = RPM_{main} * \frac{Diam_{main}}{Diam_{satellite}} = 336RPM * \frac{5in}{0.875in} = 1920RPM$$

RPM on connector gear

$$RPM_{connector} = RPM_{satellite} = 1920RPM$$

RPM on thrust gear

$$RPM_{thrust} = RPM_{connector} * \frac{Diam_{connector}}{Diam_{thrust}} = 1920RPM * \frac{2.750in}{3in} = 1760RPM$$

RPM on axle gear

$$RPM_{axle} = RPM_{thrust} * \frac{Diam_{thrust}}{Diam_{axle}} = 1760RPM * \frac{3in}{0.875in} = 6034.3RPM$$

Design horsepower of gears

High pressure accumulator one third charge

$$P_{1/3} = 2700psi + (4000psi - 2700psi)/4 = 3025psi = 20856.6kPa$$

Torque with pressure one third charge

$$T_{1/3} = \frac{\eta_{pump} * disp * P_{1/3}}{2 * \pi} = \frac{0.825 * \frac{0.64cc}{1000\frac{cc}{L}} * 20856.6kPa}{2 * \pi} * \frac{0.738 ft * lbs}{1n * m} = 1.29 ft * lbs$$

Axle gears

$$HP = \frac{RPM_{max} * T_{1/3}}{5252} = \frac{6034.3RPM * 1.29n * m}{5252} = 1.49HP$$

Thrust gears

$$HP = \frac{RPM_{\max} * T_{1/3}}{5252} * \frac{Diam_{thrust}}{Diam_{axle}} * \frac{1}{2} = \frac{1760RPM * 1.29 ft * lbs}{5252} * \frac{3in}{0.875in} * \frac{1}{2} = 0.74HP$$

Connector gears

$$HP = \frac{RPM_{\max} * T_{1/3}}{5252} * \frac{Diam_{conncector}}{Diam_{axle}} = \frac{1920RPM * 1.29 ft * lbs}{5252} * \frac{2.75in}{0.875in} = 1.49HP$$

Satellite gears have the same torque and maximum RPM as the connector gears and thus would have the same design horsepower

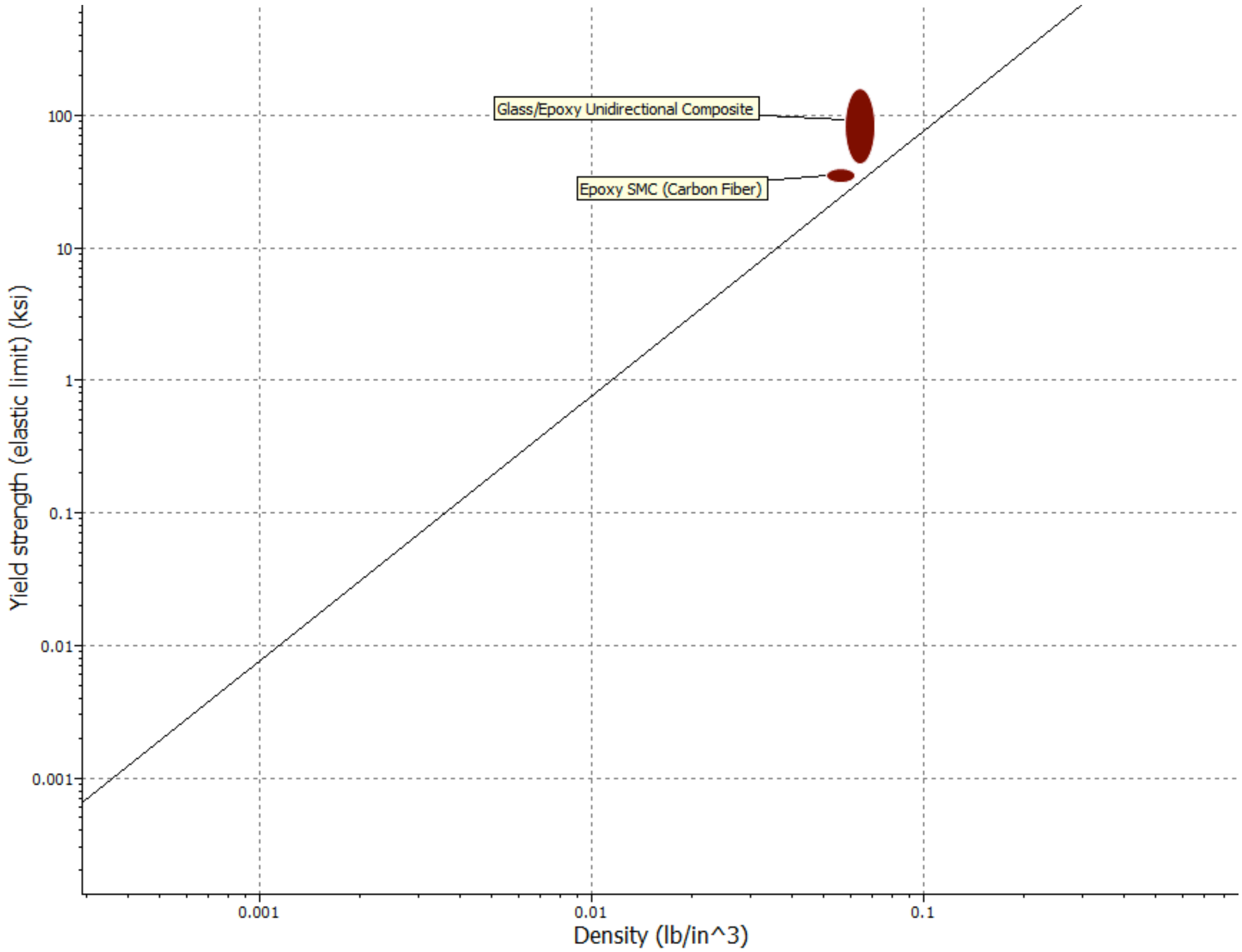
Main gear

$$T_{satellite} = T_{connector} = T_{1/3} * \frac{Diam_{conncetor}}{Diam_{axle}} = 1.29 ft * lbs * \frac{2.75}{0.875} = 4.05 ft * lbs$$

$$HP = \frac{RPM_{\max} * T_{satellite}}{5252} * \frac{Diam_{main}}{Diam_{satellite}} * 2 = \frac{336RPM * 4.05 ft * lbs}{5252} * \frac{5in}{0.875in} * 2 = 2.97HP$$

Appendix D: CES Design Analysis

Hub:



General properties

Designation

Epoxy Unidirectional Composite (Glass Fiber)

Density	0.0578	-	0.0704	lb/in^3
Price	* 8.82	-	9.7	USD/lb

Composition

Composition (summary)

Epoxy + Glass Fibers

Base	Polymer			
Glass (fiber)	40	-	60	%
Polymer	40	-	60	%

Mechanical properties

Young's modulus	5.08	-	6.53	10^6 psi
Shear modulus	* 2.1	-	2.7	10^6 psi
Bulk modulus	* 2.92	-	3.76	10^6 psi
Poisson's ratio	0.05	-	0.4	
Shape factor	6.8			
Yield strength (elastic limit)	43.5	-	160	ksi
Tensile strength	43.5	-	160	ksi
Compressive strength	52.2	-	128	ksi
Flexural strength (modulus of rupture)	43.5	-	131	ksi
Elongation	2	-	3	%
Hardness - Vickers	* 33	-	58	HV
Fatigue strength at 10^7 cycles	* 17.4	-	63.8	ksi
Fracture toughness	4.55	-	18.2	ksi.in^1/2
Mechanical loss coefficient (tan delta)	* 0.00278	-	0.00332	

Thermal properties

Glass temperature	212	-	356	°F
Maximum service temperature	* 338	-	374	°F
Minimum service temperature	* -189	-	-99.4	°F
Thermal conductivity	0.231	-	0.693	BTU.ft/h.ft^2.F
Specific heat capacity	0.263	-	0.334	BTU/lb.F
Thermal expansion coefficient	4.72	-	13.9	µstrain/°F

Electrical properties

Electrical resistivity	1e20	-	1e21	µohm.cm
Dielectric constant (relative permittivity)	3.5	-	5	
Dielectric strength (dielectric breakdown)	300	-	500	V/mil

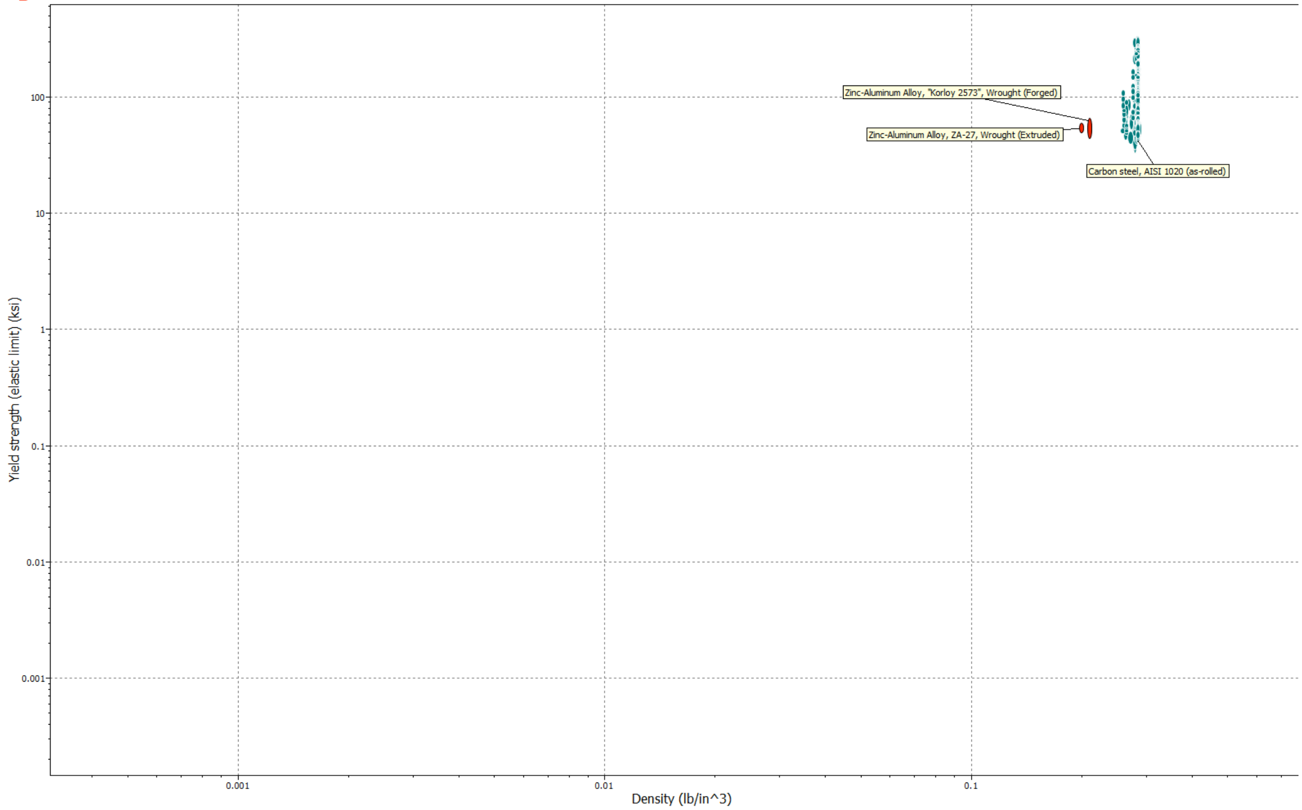
Optical properties

Transparency	Translucent

Durability

Flammability	Non-flammable (UL94: exceeds ratings)
Fresh water	Very Good
Salt water	Very Good
Weak acids	Good
Strong acids	Poor
Weak alkalis	Average
Strong alkalis	Very Good
Organic solvents	Average
Sunlight (UV radiation)	Good

Spider Bracket



General properties

Designation

Carbon steel: AISI 1020 (as-rolled)

Density	0.282	-	0.285	lb/in^3
Price	* 0.363	-	0.4	USD/lb

Tradenames

CS1020, Steelmark-Eagle & Globe (AUSTRALIA); LASALLE 1018, LaSalle Steel Co. (USA);

Composition

Composition (summary)

Fe/.17-.23C/.3-.6Mn/<.04P/<.05S

Base	Fe (Iron)			
C (carbon)	0.17	-	0.23	%
Fe (iron)	99.1	-	99.5	%
Mn (manganese)	0.3	-	0.6	%
P (phosphorus)	0	-	0.04	%
S (sulfur)	0	-	0.05	%

Mechanical properties

Young's modulus	29.7	-	31.2	10^6 psi
Shear modulus	11.5	-	12.2	10^6 psi
Bulk modulus	22.9	-	25.4	10^6 psi
Poisson's ratio	0.285	-	0.295	
Shape factor	59			
Yield strength (elastic limit)	42.8	-	52.9	ksi
Tensile strength	57.3	-	72.5	ksi
Compressive strength	42.8	-	52.9	ksi
Flexural strength (modulus of rupture)	42.8	-	52.9	ksi
Elongation	28	-	43	%
Hardness - Vickers	135	-	165	HV
Fatigue strength at 10^7 cycles	* 32.3	-	38.3	ksi
Fracture toughness	* 37.3	-	61.9	ksi.in^1/2
Mechanical loss coefficient (tan delta)	* 9.8e-4	-	0.00124	

Thermal properties

Melting point	2.7e3	-	2.77e3	°F
Maximum service temperature	* 644	-	673	°F
Minimum service temperature	* -90.4	-	-36.4	°F
Thermal conductivity	28.9	-	31.2	BTU.ft/h.ft^2.F
Specific heat capacity	0.111	-	0.121	BTU/lb.F
Thermal expansion coefficient	6.39	-	6.94	µstrain/°F

Electrical properties

Electrical resistivity	16	-	18	µohm.cm

Optical properties

Transparency	Opaque

Durability

Flammability	Non-flammable (UL94: exceeds ratings)
Fresh water	Good
Salt water	Average
Weak acids	Average
Strong acids	Poor
Weak alkalis	Good

Appendix E: Prototype Description for Previous Teams Subsystem Designs *

Wheel Axle: The wheel axle is a hollow 1" outer diameter steel pipe. The superbracket is welded to the axle off-centered, and a large hole is cut into the axle toward the back of the wheel. This allows us to run a pressure gauge line and electric wires for the electromechanical clutch and the 2-way valve up to the handlebars of the bicycle. Again, we choose steel stock from the College of Engineering machine shop for our prototype because it is free and we can weld our superbracket to it.

Clutch: The shaft in the clutch has a pin through it and the pinhole on the clutch to transmit the rotational power from the clutch to the shaft (Figure 33). To keep the shaft from falling out, there is a retaining ring on the inner end of the clutch. There is a screw through the coupler and the other side of the shaft to transmit rotational power from the pump connector gear to the clutch (Figure 34, right). There is also a keyway and key in the pump connector gear to transmit rotational power from the gear to the shaft that leads to the clutch. A needle roller thrust bearing between the coupler and superbracket allows low friction rotation.

Low Pressure Accumulator: An aluminum block with a space to epoxy the honey bottle's cap into provides a body to attach the hydraulic fittings without leaks. One fitting leads to the filter, pump, and motor. The other fitting is open to the air and on the inside of the low pressure accumulator connected to the same hole is a fitting with a tube to let the air in without letting the fluid leak out.

Connection to Fork: Our final design for fork attachment is to have essentially the same connection as standard bicycle wheels. Because of time restrictions, the prototype differs from our original hopes to make the axle attach to the fork in a similar way to standard wheels and having an arm attached to the fork to prevent the axle from rotating. To attach to the fork, steel blocks are welded to the fork arms and a hole for the axle is cut into the blocks. A pin sticking through the blocks and axle prevents the axle from rotating in the forks.

Circuit Design: The final design will incorporate a full electrical circuit in order to trigger the launch of the bicycle and the regenerative braking system. A single-pole, single-throw switch ((on)-off) will be utilized for both the braking and the propulsion activation. Both switches are spring loaded to the "off" position, so the switch must be actively thrown in order for the respective braking or propulsion event to occur. One switch will trigger the electromechanical clutch that will effectively engage the pump and brake the bike. The other will open the two way valve to allow high pressure fluid through the motor and effectively propel the bicycle. The circuit can be cut by the master on-off switch, which will act as a safety feature. The system is powered by three 9-volt batteries connected in series. A 3-amp fuse is included so that the circuit is never overloaded. Figure 36 illustrates the arrangementof the circuit components.

Circuit Component Layout: Placement of this circuit on the final design is crucial to the aesthetics of the bicycle. For convience, the trigger switch will be located on the right handlebar of the bike. As already mentioned, the safety switch will not be be near this trigger switch forcing the user to purposely make an effort to switch it to the "on" position when ready to launch or regenerate power through braking. This switch will be on the left handlebar. The batteries will be located with the two (on)-off switches where they can be conveniently accessed to change them if necessary.

Our goal for the prototype is to have the circuit as discrete as possible so that the bike is still aesthetically pleasing to a potential buyer. The only discrepancy between the prototype and final design will lie in the switch boxes or battery box, which may be less pleasing to the eye than the ultimate final design would be.

- **Winter 2008 ME 450 Final Report by Matthew Mierendorf, Ashley Murphee, Brett Rogers and Sara Simmons**

Appendix F: Environmental Impact weight Calculations

Hubs

Epoxy resin

$$\frac{146060mm^3\ per\ hub}{2} \times 2\ hubs = 146060mm^3$$

$$146060mm^3 \times (1.1072E-6)\ \frac{kg}{mm^3} = 0.1617kg$$

Aramid Fiber

$$\frac{146060mm^3\ per\ hub}{2} \times 2\ hubs = 146060mm^3$$

$$146060mm^3 \times (1.4394E-6)\ \frac{kg}{mm^3} = 0.2102kg$$

Accumulator

$$Total\ volume = \pi r^2 * l = \pi * (3.81cm)^2 * 22.86\text{cm} = 1042.5\ \text{cm}^3$$

$$Carbon\ Fiber\ Volume = \pi * (r_o^2 - r_i^2) * l = \pi * (3.81^2 - 3^2) * 22.86 = 396.15cm^3$$

$$Mass\ Carbon\ Fiber = V * density = 396.15cm^3 * 1.8\frac{g}{cm^3} = 713.07g$$

$$Rubber\ Volume = \pi * (r_o^2 - r_i^2) * l = \pi * (3^2 - 2.5^2) * 22.86 = 197.5cm^3$$

$$Mass\ Rubber = V * density = 197.5cm^3 * 1.5\frac{g}{cm^3} = 296.25g$$

$$Nitrogen\ Volume = 1042.5cm^3 - 396.15cm^3 - 197.5cm^3 = 449.85cm^3$$

$$Mass\ Nitrogen = \frac{P*V}{R*T} = \frac{18{,}616kPa * 0.00044985\,m^3}{.296 * 292.2K} = 0.097kg = 97g$$

Hydraulic Fluid

The volume change from 2700 to 4000 psi

$$\Delta V = V_{max} - \frac{P_{Pcharge} * V}{P_{max}} = 0.32L - \frac{2700psi}{4000psi} * 0.32L = 0.104L$$

Approximate volume hydraulic fluid needed

$$V = 3 * \Delta V = 3 * 0.104L = 0.312L$$

Appendix G: Design Safe Results

Identify Hazards | Assess and Reduce Risk

	Item Id	User	Task	Hazard Category	Hazard	Cause/Failure Mode
16	1-1-16	All Users	All Tasks	fluid / pressure	fluid leakage / ejection	hydraulic fluid could leak from lines

	Cause/Failure Mode	Severity	Exposure	Probability	Risk Level	Reduce Risk	Severity	Exposure	Probability	Risk Level
1	Some parts are heavy and could crush fingers	Serious	Remote	Unlikely	Moderate	carefully assemble the hub	Serious	Remote	Negligible	Low
2	while assembling, user could be cut by tools or parts	Serious	Remote	Negligible	Low	carefully assemble the hub	Serious	Remote	Negligible	Low
3	during operation, user could catch a limb in the hub	Serious	Remote	Possible	Moderate	be careful while operating	Slight	Remote	Unlikely	Low
4	circuit is live when switch is on	Slight	Remote	Possible	Moderate	make sure wires are loomed and away from the operator	Slight	Remote	Unlikely	Low
5	the electric circuit may not be adequately grounded	Slight	Remote	Unlikely	Low	ground the circuit to the frame	Slight	Remote	Unlikely	Low
6	if wires become exposed electric shock maybe possible	Slight	Remote	Possible	Moderate	make sure the entire circuit is loomed	Slight	Remote	Unlikely	Low
7	there is a possibility the wires are incorrect for the application	Slight	Remote	Unlikely	Low	make sure the application of the wire is correct	Slight	Remote	Unlikely	Low
8	there is no fuse to prevent overloading of the circuit	Slight	Remote	Possible	Moderate	add a fuse to the circuit to prevent overloading	Slight	Remote	Unlikely	Low
9	person could slip while operating	Slight	Occasional	Possible	Moderate	operate carefully	Slight	Remote	Unlikely	Low
10	person could trip while operating	Slight	Occasional	Possible	Moderate	operate carefully	Slight	Remote	Unlikely	Low
11	hub is heavy	Slight	Occasional	Probable	High	make future provisions to lighten the hub, but in the meantime operate carefully	Slight	Remote	Unlikely	Low
12	hydraulic fluid is a possible carcinogen	Serious	Remote	Unlikely	Moderate	make sure to wear proper safety equipment while plumping the hydraulic circuit	Slight	Remote	Unlikely	Low
13	hydraulic fluid is poisionous	Serious	Remote	Unlikely	Moderate	make sure not to get fluid on skin	Slight	Remote	Unlikely	Low
14	hydraulic lines could break	Serious	Remote	Unlikely	Moderate	design hydraulic lines with a high safety factor	Slight	Remote	Unlikely	Low
15	hydraulic lines could break	Serious	Remote	Unlikely	Moderate	design hydraulic lines with a high safety factor	Slight	Remote	Unlikely	Low
16	hydraulic fluid could leak from lines	Slight	Remote	Unlikely	Low	make sure all hydraulic fittings are tightened	Slight	Remote	Unlikely	Low

Appendix H: Bill of Materials

Part #	Part Name	Supplier/Manufacturer	Qty	Material	Size	Mass (g)	Total Mass (g)
	Super Bracket Disc	Alro Materials	1	1080 Steel	radius: 14" width: 0.186"	2231	2231
	Wheel Axle	Alro Materials	1	1080 Steel	length: 8' width: 1"	1361	1361
MSP_26TCF	Double Triple Clamp Fork	Wheelgoods.com	1	1080 Steel			
S10LWD024	Two Way Valve	Motion and Controls	1	N/A		1414	1414
2W,7/8-14,3/8NPT,EN	Two Way Valve Coil	Motion and Controls	1	N/A			
NB48A	Two Way Valve Body	Federal Fluid Power	1	Aluminum			
5909K31	Thrust Gear	Motion Industries	4	Steel	48 teeth, 1/2" face	439	1756
	Needle Thrust Bearing	McMaster	6	Steel	1/2" ID	3	18
	1/2" Washer	McMaster	6	Steel	1/2" ID	1	6
S1644	Connector Gear	Applied Industrial	2	Steel	44 teeth, 1/2" face, 1/8"x1/16"KW	360	720
U-FXFA 0.38 0.5 0.6	Cantilever Shaft	Misumi	4	Steel	3/8" shaft	51	204
	Countersink Screw	Lowes	16	Brass	1/8" x 3/4"	1	16
	1/8" Nut	Lowes	24	Steel	1/8"	1	24
NB14B	Pump and Motor Gear	Motion Industries	2	Steel	radius: 1"	52	104
	Reducer Bushing	Lowes	2	Steel	3/8"OD, 1/4" ID	5	10
	1/2" - 20 Counter	Lowes	8	Zinc	1/4" x 2.25"	12	96
	Standoff Spacer	Lowes	8	Zinc	1/2" x 1.5"	15	120
	1/2" Washer	Lowes	21	Zinc	1/2"	2	42
	1/4" Nut	Lowes	21	Zinc	1/4"	2	42
6117K31	Partially Keyed Shaft	McMaster	1	Steel	diameter: 1/2" keyway: 1/8"		
S1614HX1/2"	Satellite Gear	Applied Industrial	2	Steel	14 teeth, 1/2" face, 1/2" bore	116	232
	Electric Clutch	McMaster	2		1/2" ID	483	966
	Clutch Plate	Lowes	2	Aluminum	4" x 2"	47	94
	C Clamp	Lowes	1	Zinc	3" wide	109	109
	Motor Bolt	Lowes	4	Zinc	0.16" x 3"	6	24
	1/2" Nut	Lowes	4	Zinc	1/2" x 20	6	24
	Low Pressure Accumulator	Kroger	1	Plastic		400	400
ACP05AA032E1KTC	High Pressure Accumulator	Parker Hannifin	1	Steel	8" x 2.5"	2247	2247
S1680	Main Gear	Applied Industrial	1	Steel	5" x 0.5"	1033	1033
	Hub Assembly		2	Fiberglass		2120	4240
	1/4" Hub Bolt	Lowes	12	Zinc	1/4"-20 x 4.5"	30	360
5905K42	Needle Roller Bearing	McMaster	4	Steel	3/8" ID 1/2" OD	2	8
6384K373	Axle Flange Bearing	McMaster	2	Steel	1" ID	11	22
	Retaining Ring	Lowes	4	Steel	3/8" shaft	2	8
	Low Pressure Hose	Federal Fluid Power	1				
	High Pressure Hose	Federal Fluid Power	1				
	Hydraulic Fittings	Federal Fluid Power	1	Steel			
U 0.25 D 48	Motor	Marzocchi Pompe	1		0.77 l/min		
U 0.25 D 60	Pump	Marzocchi Pompe	1		0.96 l/min		
	Wheel/Tire		1	Rubber	20" Wheel	1380	1380
Total			179			13942	19311