Project Proposal and Feasibility Study

Team 2: Recumbent
Hydraulic Bicycle

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Senior Design
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ENGR339
Calvin College

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Executive Summary

The goal of this project is to apply the technical knowledge and methods of thinking that are necessary to succeed at the challenge we face. Our team, “Recumbent Hydraulic Bicycle”, will be competing in the Parker Chainless Challenge which is sponsored by Parker Hannifin. This challenge requires our team to fabricate/modify a human powered bicycle so that it utilizes a hydraulic motive of power. Our bicycle will replace the typical chain drive with a hydraulic system in addition to complying with all of the rules and regulations that are required by the competition.

In addition to designing a human powered bicycle propelled solely by hydraulic means; we also desire to prototype a bicycle that will perform competitively with the other prototypes entering the contest. Our team has decided that the best design for the challenge will resemble a recumbent tricycle. Our means of propulsion will come from a hydraulic system involving a pump, accumulator, a throttle-controlling device, a motor, and possibly a regenerative braking system.

After analyzing the time, components, and material needed to fabricate this prototype, our team has determined that project is feasible. By using the resources at Calvin along with commercial suppliers, the project will be completed by April 2007.

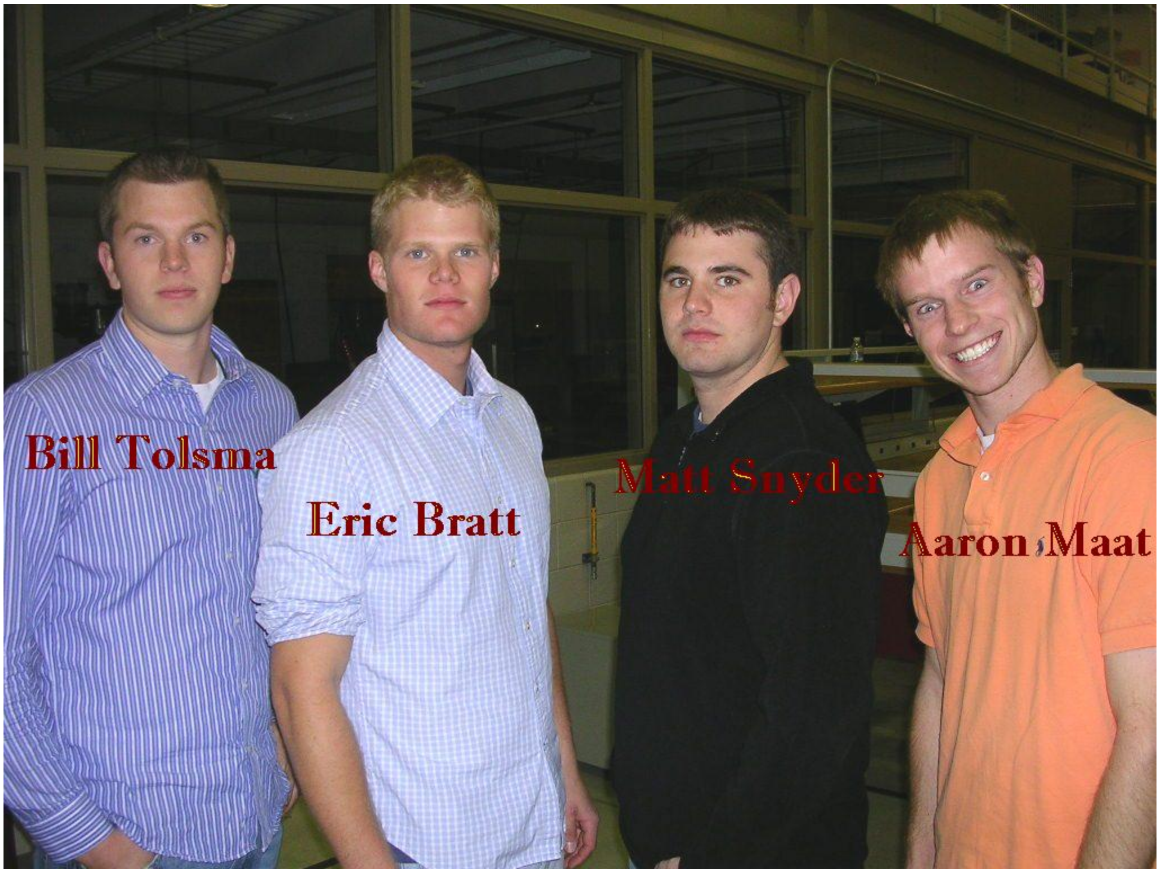
1 Introduction

1.1 PPFS Introduction

Calvin College is a liberal arts college located in Grand Rapids, MI. Calvin offers degrees in fields ranging from nursing, engineering, business, education and others. The engineering program at Calvin offers an Accreditation Board of Engineering and Technology (ABET) accredited Bachelor of Science in Engineering degree in Mechanical, Electrical & Computer, Civil, and Chemical concentrations. The senior year of study includes a design project and completion of Engineering 339 and 340, companion courses to the design project. The design project requires a group of 3-5 students to define and solve a problem using engineering methods. Engineering 339 requires a study of the feasibility of the proposed project. The following report, defined as the Project Proposal and Feasibility Study (PPFS), explores the feasibility of Team 2's proposed project.

1.2 Team Description

Calvin College Senior Design Team #2, shown in Figure 1, is composed of four mechanical engineering students: Bill Tolsma, Eric Bratt, Matt Snyder, and Aaron Maat.



Bill Tolsma is a senior mechanical engineering student at Calvin College. He has spent his past 11 summers working for Reiner Group, which is a mechanical contracting company in northern New Jersey. In the past summer Bill obtained his refrigerant license and became a lead installation HVAC mechanic. After graduation Bill plans to marry his fiancée in the summer of 2008 and continue his work with Reiner Group as a design engineer.

Eric Bratt is a senior mechanical engineering student at Calvin College. He grew up in Durham, North Carolina and attended C.E. Jordan High School. He spent the summer of 2006 at Fishbeck, Thompon, Carr, and Huber, an engineering firm in Grand Rapids, doing inspections on water systems. Eric is also a member of the club lacrosse team at Calvin.

Matt Snyder, a native of Canton, MI, is a senior mechanical engineering student at Calvin College. Matt spent the summer of 2007 as an Intern at Extol, Inc. in Zeeland, Michigan. Matt is engaged to be married in June 2008 to his fiancée, Jennifer and is currently pursuing job opportunities for post graduate employment.

Aaron Maat is a senior mechanical engineering student. He is currently working for Steelcase Inc., an office furniture manufacturer in Grand Rapids. Aaron grew up in Holland, Michigan and attended Holland Christian High School. After graduation Aaron is hoping to pursue a position in the Michigan area in the mechanical engineering field.

1.3 Problem Statement

The problem presented to the team is to design a hydraulic system to replace the direct chain drive typically found on bicycles. The system may use either a direct hydraulic pump drive or a series of chain drives connected to hydraulic pumps. The problem is based on the Parker Hannifin Chainless Challenge, in which the team hopes to compete in July of 2008.

The Chainless Challenge requires all entrants to construct a bicycle without a direct chain connection from the pedaling sprocket to the drive sprocket, replacing it with a hydraulic system. The hydraulic system must use a biodegradable hydraulic fluid to power the system. The bicycle must complete the entire 4-mile competition course and comply with appropriate safety codes implemented by Parker Hannifin. Each team must also provide documentation of its design. The team's design will to conform to all the specifications set by the Parker competition.

2 Project Objectives

2.1 Design Functionality

2.1.1 Project Scope

The overall goal of our senior design project is to compete in the Parker Chainless Challenge. In order to achieve this goal our group must abide by a list of rules and regulations provided by Parker Hannifin including: minor design requirements, safety and environmental regulations, and some design documentation.

2.1.2 Cost

One main objective for our design is to keep the costs to a minimum. When creating a novelty item such as a hydraulic bicycle, the costs must be low in order to allow for marketability. In addition to making our product marketable, our design must meet a specified budget that has been specified by the Calvin College Engineering Department.

2.1.3 Reliability

The reliability of our vehicle needs to be a main driver of our design in order to maintain marketability. Consumers will not be interested in a product that requires a large amount to maintenance and repairs.

2.1.4 Performance

The hydraulic bicycle must be able to finish the 4-mile test course provided by Parker Hannifin™. Our design will be subject to both a straight lined sprint race and the test course.

Parker Chainless Challenge Specifications[1]:

- We have 1 year to complete the design and build.

- The design must employ a hydraulic motive of power.

- There can be no direct chain connection between the rider and the drive wheel.

- It must be powered by only one person.

- Must use a biodegradable hydraulic fluid.

- Must complete the competition course.

2.2 Design Norms/Christian Perspective

We defined a number of design norms for our project that extend the design functionality specifications listed above. Design norms are requirements we hold for our project that constrain

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[1] Specifications were obtained from the Chainless Challenge Website: http://www.parker.com/training/cc/ppt/1/slide1.htm

the design to achieve a certain degree of respect, for either cultures or individuals, or in some way improve the overall quality of the project. We chose stewardship, caring, transparency, and trust as the refining factors on our project.

2.2.1 Stewardship

Stewardship refers to our calling to respect our resources on earth and to use them wisely. The regenerative braking system proposed for our project would embody this design norm, both physically in the act of conserving the energy exerted by the rider as well as symbolically as a method of raising awareness to the available technologies for regenerative braking in mass-production vehicles.

2.2.2 Caring

Our design involves the involvement of a human rider and therefore measures must be taken to ensure the safety of the rider. Measure will be taken to prevent injuries to the passage caused from pinch points, hydraulic leaks, and collisions.

On top of our responsibility to human safety, Parker imposes some safety standards. In order to compete in the Parker Chainless Challenge, our team is required to abide by many safety regulations. Some of these regulations include[1]:

1) Passing an inspection by the judging committee.
2) Having multiple, fully active, independent brakes that provide a dependable braking condition.
3) Operational rearview mirrors.
4) The rider must wear a helmet that complies with a nationally recognized standards organization.
5) Guards to protect the rider from such components as sprockets, etc.
6) The accumulator precharge cannot exceed the safe working limits of the storage device and system components.

Bicycles deemed unsafe by the judging committee will be disqualified. The judging committee’s decision is final.

2.2.3 Transparency

We would like to design the bicycle so that its functions and operation are easily understandable by the general public. The throttle and braking systems should be easily mastered. Furthermore, we’d like the operation of the hydraulic system easily displayed for educational purposes.

2.2.4 Trust

The components that are selected for the design will need to have to be durable in order to perform as expected when subjected to extended use and race conditions. Our design must be able to withstand the high levels of stress that are expected in a sprinting condition, in addition to withstanding prolonged normal use over an extended time.

2.3 Educational Opportunities

2.3.1 For Our Team

Our team will learn about design and prototyping, stress analysis, financial management, time management, conflict resolution, teamwork, and the practice of effectively engineering from a Christian perspective.

2.3.2 For Others

One of the major educational opportunities of our project lies within the design of the regenerative braking system. With increased awareness of environmental concerns and fuel prices on the rise, it is important to increase the efficiency of vehicles that burn fossil fuels. Implementing a regenerative braking system on this small scale, low budget project will help to prove the viability and raise awareness of regenerative braking systems.

One major benefit of regenerative braking systems is the increased efficiency of the vehicle. By utilizing the energy lost to friction by stopping the vehicle, the size of the engine used to power the vehicle can be decreased; resulting in higher fuel economy. This is applicable to our project not so much in reduction of engine size, but rather as reduced effort required from the rider.

3 Project Management

3.1 Schedule

The Gantt chart in Appendix A displays the tentative schedule for Team 2 through the end of the semester.

3.2 Team Organization

The team consists of four mechanical engineers, requiring each member to define a more specific role within the team to prevent overlap of responsibilities. All four team members participate in research and design activities, brainstorming, and engineering calculations. Each team member also has separate responsibilities. Bill Tolsma is responsible for much of the outside knowledge about bicycles and bicycle components, pairing his experience with research into various options. Eric Bratt is in charge of organization and deliverables, putting together reports, presentations, and other required material. Matt Synder is in charge of creating, managing, and updating the team website. Aaron Maat is in charge of the CAD work due to his experience using Pro-E engineering software.

3.3 Task Breakdown

The breakdown of tasks and the time required to complete each is listed in Appendix B. The table displays date of work performed, work accomplished in each session, and approximate hours spent in each meeting. The team logged a total of 262 billable hours on the project.

4 Design and Alternatives

4.1 Frame Design Requirements

Our frame design began with the rules set out by Parker Hannifin Corp. for their annual Chainless Challenge. The rules that apply to the frame design are as follows. First, only a single-rider bicycle is allowed. Second, the number of wheels in the design is optional. Third, the design style is open (conventional two-wheel, recumbent, multi-wheel drive, etc.). Fourth, the bicycle must have multiple, fully active, independent brakes that provide a dependable braking condition. Fifth, all bicycles must have operational rearview mirrors. These rules set a basis for what our frame needs to encompass.

4.1.1 Design Style Alternatives and Solution

One of the first decisions that had to be made regarding our frame was the configuration. We needed to decide on the number of wheels as well as either a recumbent or conventional seating style. We proposed 4 different solutions and looked at the advantages and disadvantages of each solution. Table 4.1.A displays the decision matrix that was used to help us decide which design style would be the best fit.

Table 4.1.A: Decision Matrix for Bicycle Style

Criteria	Weight	Two Wheels Conventional	Two Wheeled Recumbent	Three Wheeled Recumbent	Four Wheeled Recumbent
Balance	8	2	2	10	10
Cost	10	8	7	6	4
Weight	6	8	8	6	4
Drag	4	6	7	6	5
	Total	**168**	**162**	**200**	**164**

The criteria were weighted based on our perception of their importance to the success of the project as a whole. Balance was an issue in the general function of the bike. We rated it an 8 because the increase in the weight of the bicycle from the hydraulic components makes the balance of the bicycle very critical. Cost was given a weighting value of ten because the project is already constrained to a somewhat low budget and we would prefer to spend the majority of our budget on hydraulic components rather than the frame. Weight was rated at a 6 as it is relatively important to the performance of the bike though not critical to its operation. Finally, the drag was rated a 4 as it strictly applies to the speed and performance of the bike, which are not of the utmost concern for this portion of the project. As shown above, these parameters resulted in the decision to pursue a three-wheeled recumbent design. Following the decision to pursue a three-wheeled recumbent bicycle design, we needed to decide whether to purchase the frame or make one from scratch. After some online research and phone conversations with local companies we found that the best deal for a basic frame was going to be about $300. This frame would provide a lightweight and strong basis for the rest of our bicycle, but at a significant cost. Table 4.1.B displays the decision matrix used to decide whether to purchase or build our frame.

Table 4.1.B: Design Matrix for Frame Acquisition

Criteria	Weight	Purchased Frame	Self Constructed Frame
Cost	10	2	8
Labor Time	7	10	4
Design Adaptiveness	5	4	10
Weight	5	8	6
	Total	**172**	**188**

The cost of the frame, as shown in Table 4.1.B, was the essential issue in our decision. The lower the cost of the frame, the larger the portion of our budget would remain for other parts of the project. Labor time was also a factor. The self-constructed frame would require more construction time then the purchased frame. We also wanted to make the frame design adaptable to a wide variety of other features. A self-constructed frame would allow complete freedom in this area as we choose the entire design, while a purchased frame would need to be adapted into our overall design. The weight of the frame was also an issue of concern as the self-constructed frame would probably be built out of a lower quality alloy, which would be significantly heavier then the chromoly frame available for purchase. After this analysis the group agreed to pursue a self- constructed frame.

4.1.2 Steering System

A basic four bar linkage steering system was adopted similar to those viewed on other recumbent bicycle designs. The four bar linkage maintains an equal distance from the ground pivots which insures symmetrical turning throughout the entire range of motion. A four bar linkage analysis was performed in order to find the relative motion between the handlebars and the wheel turn angle.

4.1.3 Frame Design Details

Further small-scale details that do not determine the feasibility of this project (such as seating, exact frame dimensions, etc.) have been omitted or not yet been determined. Figure 4.1.C shows an isometric view of a possible three wheeled recumbent frame design.

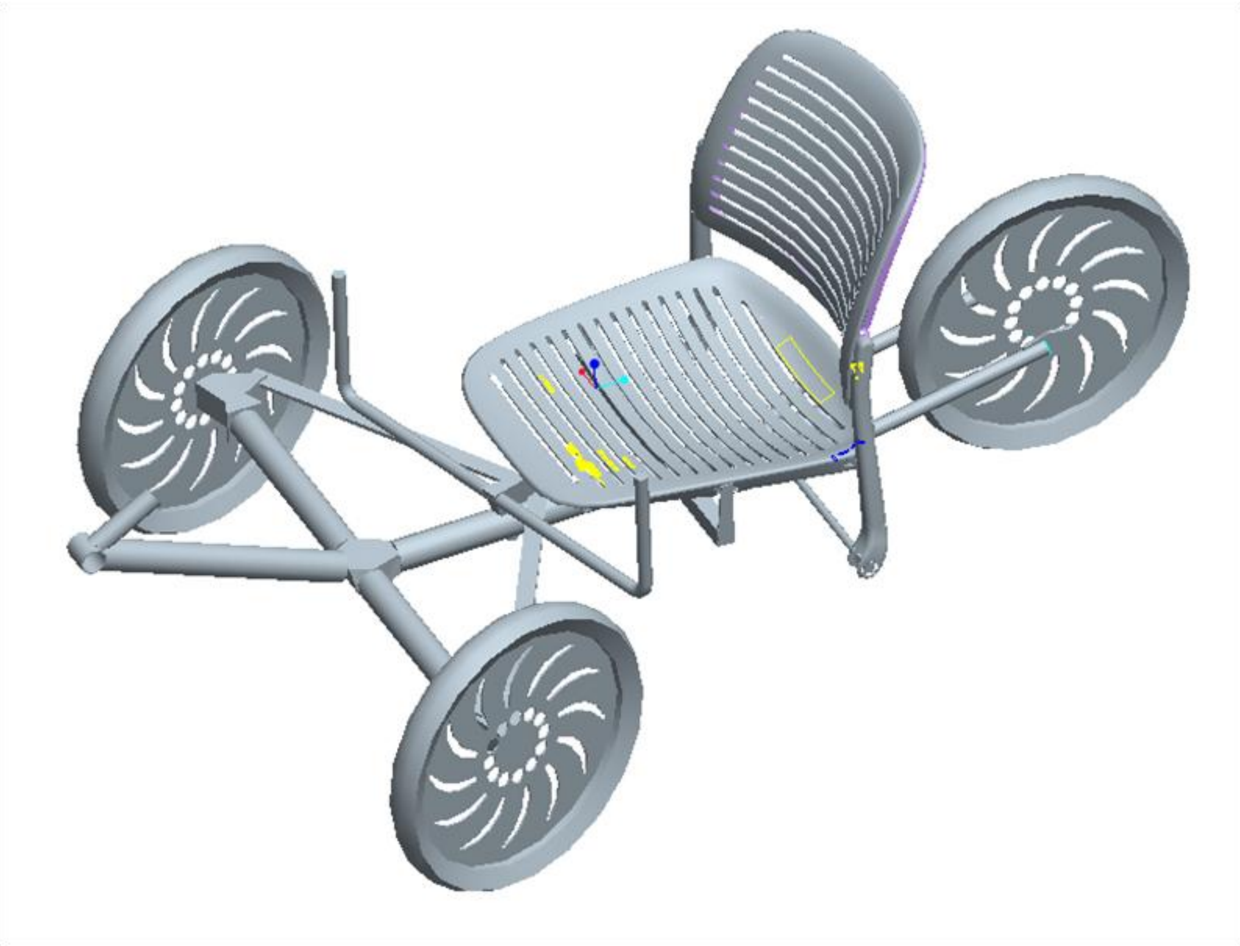


Figure 4.1.C

4.2. Transmission Design Requirements

The transmission of our bicycle is singularly constrained by the Chainless Challenge competition. This requirement states that the motive of power must be hydraulic and that no direct connection between the pedal drive and wheel drive may exist.

4.2.1 Transmission Alternatives and Solution

Our hydraulic bicycle has many options when it comes to the incorporation of transmissions into the hydraulic system. The bicycle could have both front and rear transmissions, a single front or rear transmission or no transmission at all. The front transmission would allow a change in the ratio between the pedal and the driving pump, while the rear transmission would allow a change in the ratio between the motoring pump and the wheel drive. The transmission design is extremely dependent upon the selection of a pump which will be discussed the in the upcoming hydraulic design section. If the pump selected is a fixed displacement pump then the design of both transmissions is critical to a comfortable and efficient bike ride. Building pressure in the accumulators will require varying gear ratios in order to efficiently store and transfer energy from the pedals. Alternatively if the pump selected is a variable displacement pump then no transmissions would be required at all. The pumps could be sized in such a way that they would accept a relatively equal torque without the need to change gear ratios. The rate of fluid displacement is changed inside the pump to accommodate higher or lower pressures thus eliminating the need for a transmission.

4.3. Hydraulic System Design Requirements

The only competition requirement for the hydraulic system is that the system must run on a biodegradable hydraulic fluid. However, in accordance with our design norms, requirements such as safe operating pressures in order to avoid fluid line bursts must also be considered.

4.3.1 Hydraulic System Design Alternatives

The hydraulic system used to power the bicycle offered a wide range of design options. The system that we are currently pursuing was initially designed to achieve the basic function (convert pedaling power to hydraulic power, then back to rotational power), then modified several times in order to satisfy new insights. Any major alterations made to the system were regarding the design of four key features of the system: regenerative braking, energy storage (via accumulator), pump type, and the hub used on the rear wheel. The design of these components is discussed in the following sections. Figure 4.3.A shows preliminary hydraulic design. The design is not yet finalized but will be upon the availability of prices and pump data.

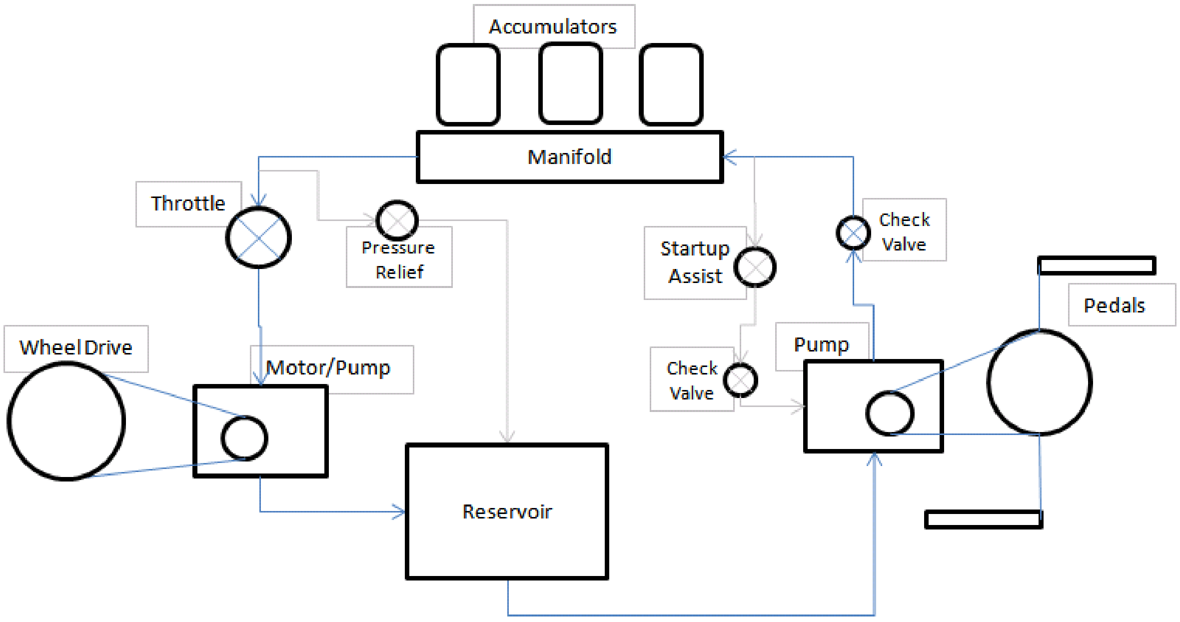


Figure 4.3.A

4.3.2 Regenerative Braking

One goal of this project dealt with trying to recover energy typically lost to friction in braking. This will allow a user to get more out of his pedaling, especially in situations that require frequent stop-and-go action. The choice of whether or not to pursue a regenerative braking system has not yet been finalized. Its design will most likely hinge on the cost and weight of the pumps being used in our system. If possible we would like to incorporate the driving pump into our regenerative braking system in a way that won't interfere with the regular operation of the bike. Two designs for regenerative braking are displayed in Appendices C and D.

4.3.3 Energy Storage

A critical portion of our design is in the choice and adaptation of our accumulator. The accumulator selection determines the amount of energy that can be stored and the pressures that will be needed in order to store the energy. The larger the accumulator selected, the more energy storage available; however, larger accumulators are much heavier which will cause slower acceleration. At this point we are going to pursue an accumulator in our model that can be easily installed or removed in about 5 minutes. This will be done through the use of quick disconnects and accumulator support brackets that will allow easy slide-out removal of the device. The advantage of a removable accumulator would be that one can fit the bike to the desired application. For instance, if a rider will be taking a short stop-and-go trip the accumulator will probably serve him or her well; however, if the rider is planning a long, uninterrupted bike ride the accumulator will only be a weight hindrance.

4.3.4 Pump Choice

The choice of which pump to use in both the pedaling and driving applications is critical to the ease of operation of the bicycle. The pump choice is also critical for decisions in other portions of the bicycle design. Pump displacements and most efficient pump operating speeds will strongly influence other decisions such as the installation of a transmission or singular gear ratios. The final decision on a pump will be made when further information, such as pricing and availability, is available from the event sponsor. We would like to get further information before we launch our design in one direction. With that being said, our group would ideally like to pursue the use of a variable displacement pump. This will allow for a self-adjusting condition where the rider does not need any knowledge of the inner workings of the hydraulic system in order to efficiently operate the bicycle. This would also be a great educational tool in which people can learn about effective applications for variable displacement pumps.

4.3.5 Fixed or Free Rear Hub

The choice of a fixed or free rear hub is a critical portion in our regenerative braking design and system design as a whole. Each system has its advantages and disadvantages. A fixed hub would allow a single pump to be used in the rear requiring only directional valves to direct the flow of fluid when braking or throttling. A fixed hub presents a problem when the rider wishes to coast. Since the rear wheel is directly tied to the rear pump the rider must always be cycling the pump. This pump work could be directed from inlet to outlet; however, pump inefficiencies would still take energy away from the coasting condition. A free hub would allow a nearly frictionless coast; however, one would need a clutch mechanism with which to apply the regenerative braking system. This would incorporate further design work but would increase the energy efficiency of the bike.

5 Feasibility Study

5.1 Prior Project Successes

The feasibility of the project which we have undertaken has been proven by the successes in previous years. The Parker Chainless Challenge has become an annual contest with many successes. Each year students from different colleges are allotted similar resources and complete the challenge that is presented. Our team feels that the project which we have chosen to take on is feasible on this basis alone. The resources that we will receive, both financial and otherwise, will provide means for our success in the contest.

5.2 4-Bar Linkage Analysis

In order to design an effective steering system for the bike, we did a four bar linkage analysis. Before beginning the analysis we decided to keep the 1:1 ratio between the steering bar angle and the wheel angle found in standard bicycles. Next, we determined what our known variables were. From our frame design, we were able to determine the ground link length and the length of the connection between the frame and the wheel. We were also able to find the angle of the ground link. Using EES, we were able to do a position analysis on the steering system to determine the required length of the steering bar input link and the required length of the connection link between the steering bar and the wheel. EES calculations also confirmed that the angle between the two steering axles remain the same. The EES worksheet and results are listed in Appendix E.

5.3 Potential Accumulator Energy

A simple analysis was performed in order to study the feasibility of our accumulators storing sufficient energy to reach our desired speed of 13 mph. This was performed using the Engineering Equation Solver (EES) program. An ideal simulation of energy storage capacity was performed using the known capacity and pressure limits of a specific accumulator that was

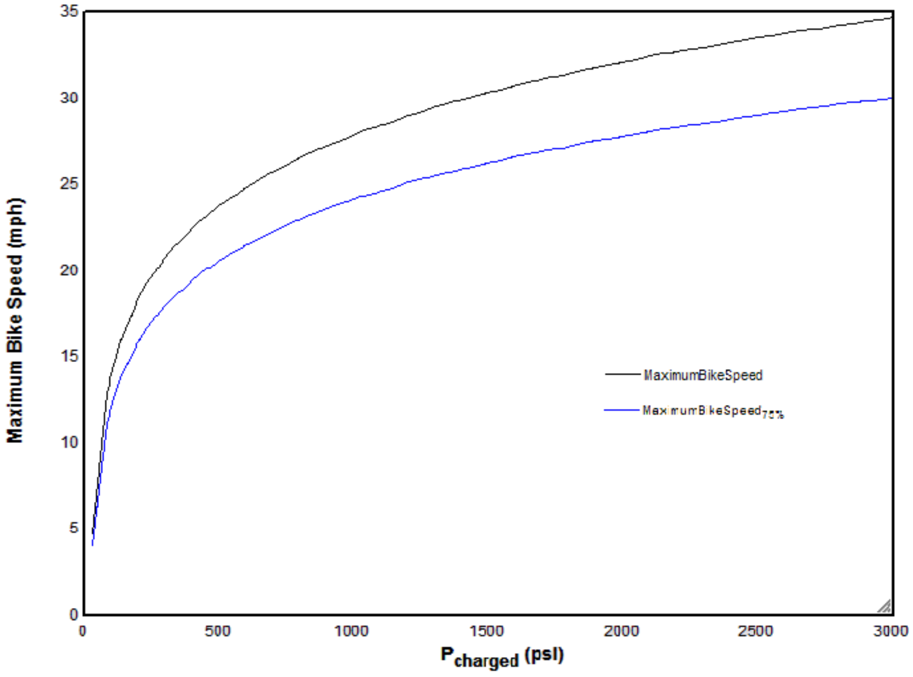


Figure 5.3.A: Speed as a Function of Pressure

selected by the Parker Hannifin program inPHorm. This analysis converts the energy stored in the high-pressure nitrogen gas to kinetic energy to find the maximum speeds we can expect to see. These calculations are rather ideal, however. Losses of energy such as rolling friction and air resistance are not accounted for, and the entire analysis makes the assumption that the hydraulic system will be set up in a way that a human could pedal the accumulator to the required pressure. Figure 5.3.A shows the potential speed given an accumulator pressure. Figure 5.3.B shows the amount of pedal time required to attain the given speed.

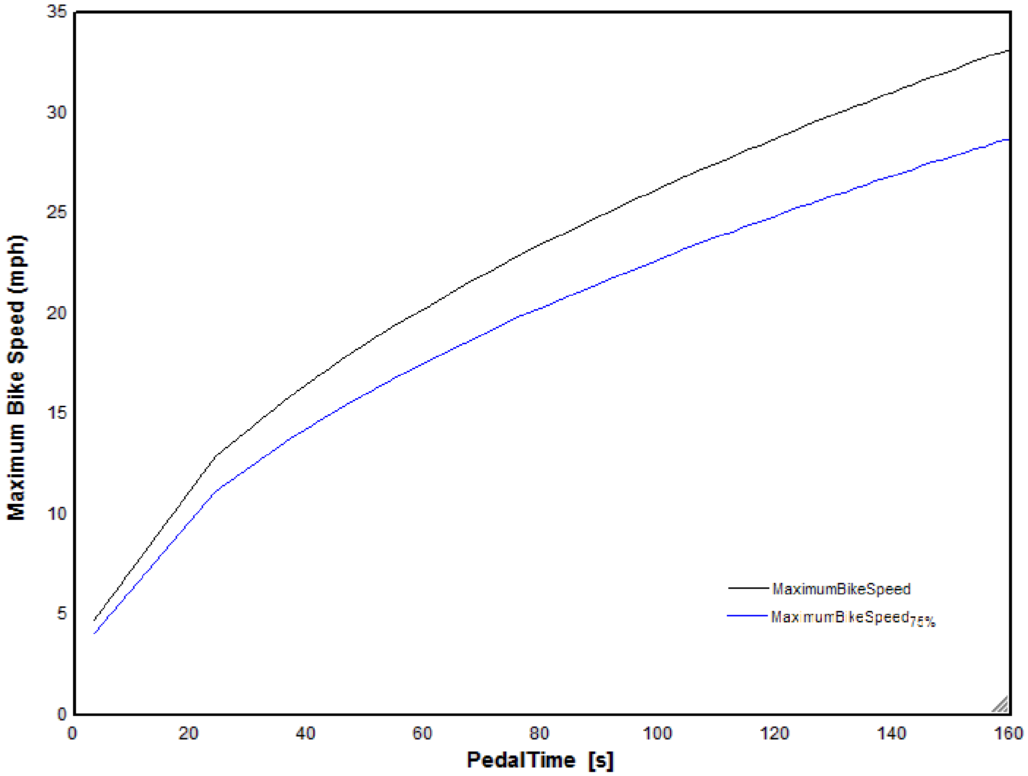


Figure 5.3.B: Speed as a Function of Pedal Time

Each figure contains an ideal case as well as a 75% overall efficiency case. This was included to see how much of an effect the efficiency of our pumps and storage system has on the maximum potential speed. This analysis suggests that our goal of 13 mph is attainable. The EES worksheet and results are listed in Appendix F.

5.4 FEA Analysis

The CAD model of the bicycle will be evaluated using a finite elemental analysis program such as Algor to determine points of stress in the frame, steering, and other mechanical components. Components will be tested to carry appropriate static or dynamic loads. This analysis will be performed during the interim period as the team does not have adequate knowledge of the FEA program at this point.

6 Business Plan

6.1 Marketing

Our bicycle design would not be able to compete in the standard bike market because of its weight, cost, and lack of efficiency (a hydraulic system is typically less efficient than standard chain drive). A niche market would have to be created in order to market the bicycle as a consumer product. The following are several possibilities for these niche markets.

One option is to market our design as an urban exercise bike. Because turning the pedals charges the hydraulic system rather than directly powering the bicycle, a rider could continue to pedal even when the vehicle is not in motion. A rider could use it to exercise while riding in a street or sidewalk and continue their workout while stopped at a red light or waiting to cross the street.

A second option is to market the bike as a novelty item. This would appeal to people who may be bored with a standard bike or those who just like to try new things. This bicycle design could be more fun to ride than a standard bicycle. The recumbent tricycle is an example of a novelty item that has gained popularity. While not inherently better than a typical item, its originality and notoriety make it appeal to certain buyers.

A third marketing option is for educational use. This bicycle could be marketed to high schools and colleges as a hands-on demonstration for hydraulic systems. This could be a good way for students to learn about the different components of a hydraulic system and how they fit into the system as a whole. The regenerative braking system can also be used as both an educational tool and a tangible example of green technology in that it practices energy stewardship.

6.2 Prototype Cost Estimates

The cost to produce the prototype of our bicycle, which will be the final deliverable for our senior design project, is outlined in Table 6.2.A. The costs include materials costs for frame construction, component costs for the hydraulic system, and man-hour costs for design and production.

Table 6.2.A

Item	Quantity	Price
Pump	2	$100
Frame Materials	1	$175
Seat	1	$30
Wheels	4	$50
Gears and Pedals	1	$0
Derailers	2	$50
Accumulator	1	$0
Copper tubing	1	$75
Chains	2	$20
Brakes and cable	2	$55

Contigency	75%	$416.25
Materials Total		$971.25
Design Costs		$25,400
Total Costs		$26,371.25

Appendices

Appendix A: Project Schedule

Tasks	Sept. 22	Sept. 29	Oct.1	Oct. 8	Oct. 15	Nov. 3	Nov. 6	Nov.8	Nov. 13	Nov. 26	Dec.1	Dec. 7	Dec. 10
Design Hydraulic System	■	■	■										
Design Regen. Braking System		■	■	■									
Contact Genzink Steel			■										
Oral Presentations I				■	■								
Contact WizWheels			■	■	■	■							
Contact Parker re: Competition			■										
Industrial Consultant Review								■					
Design Frame						■	■		■				
Design Steering System							■		■				
Rough Draft PPFS									■	■			
Spec. Hydraulic Components									■	■	■		
Oral Presentations II										■	■	■	
Final PPFS										■	■	■	■

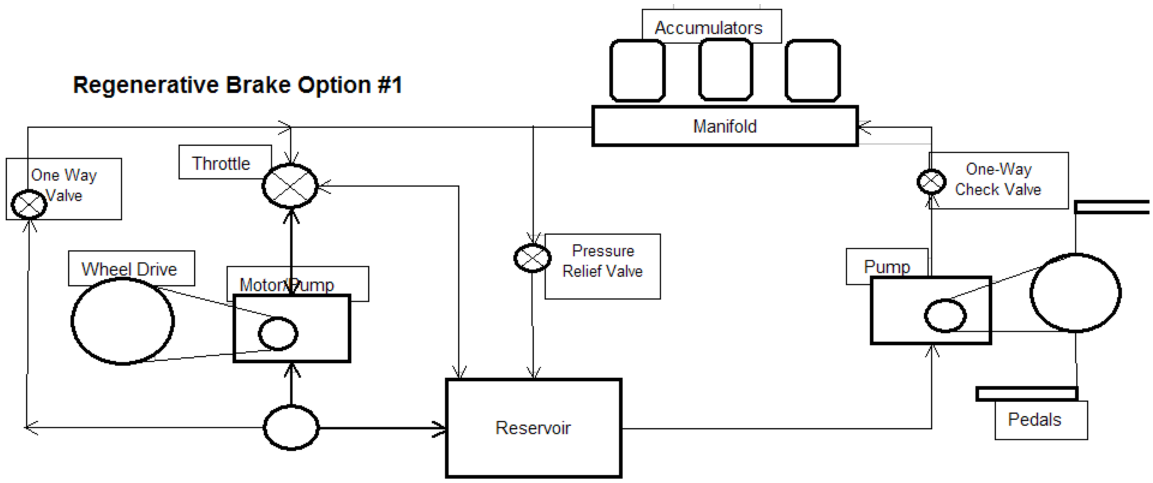
Appendix B: Project Work Log

Date	Work Performed	Hours
9/5/2007	Introduction to Senior Design	1
9/7/2007	Design Norms	1
9/10/2007	Design Norms	1
9/12/2007	Myers-Briggs Results	1
9/14/2007	Career Center Resources	1
9/17/2007	Library Research	1
9/19/2007	Safety	1
9/21/2007	Project Space/EB Organization	
9/24/2007	discussed design ideas weighed pros and cons of entering Parker Contest wrote team objectives researched costs of 3-wheel option	1
9/26/2007	Self-management	1
9/28/2007	Intellectual Property Rights	1
10/1/2007	Communication: Oral	1
10/2/2007	researched hydraulic pumps diagrammed hydraulic system to be used inspected recumbant trike owned by Prof. Hekman	1.5
10/3/2007	Conflict Resolution	1
10/5/2007	Presentation 1 preparation	2
10/8/2007	Oral Presentations	1
10/10/2007	Oral Presentations	1
10/12/2007	Oral Presentations	1
10/13/2007	discussed hydraulic system proposed design options brainstormed on bike layout	2
10/15/2007	Management of Relations	1

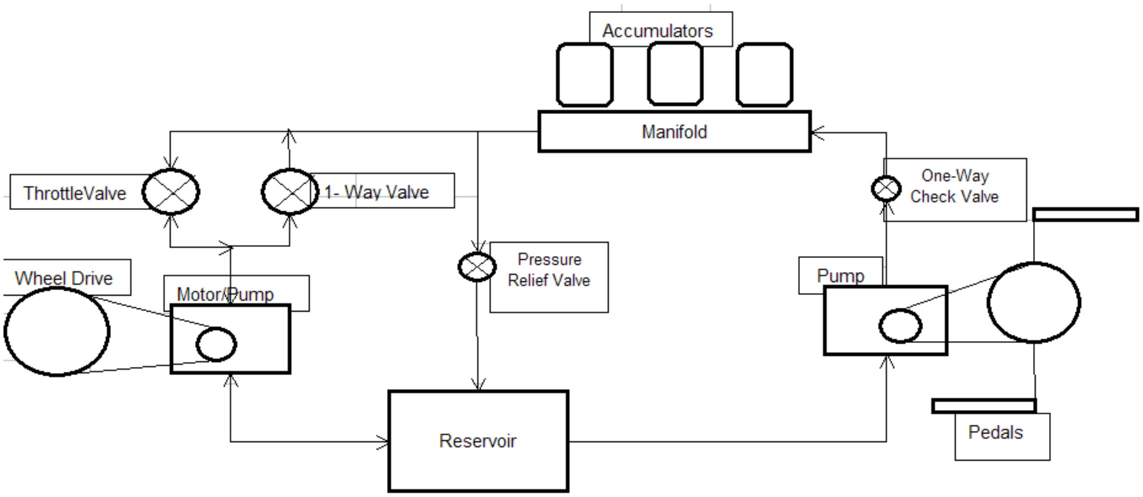
Date	Work Performed	Hours
10/17/2007	Ethics	1
10/19/2007	Professionalism	1
10/24/2007	Shop class: Cutting	1
10/26/2007	Project Management I	1
10/29/2007	Project Management II	1
10/31/2007	met with WizWheels purchased recumbent frame Shop Class: Drilling/Tapping	2
11/2/2007	Vocation with Nielsen	1
11/5/2007	Design	1
11/6/2007	designed frame determined frame should be built, not purchased designed steering drew up frame, steering in CAD	3
11/7/2007	prepared for industrial review collected relevant documents, data 21st Century Engineering Shop class: milling	3
11/8/2007	met with industrial consultant	1
11/9/2007	Total Quality Management	1
11/12/2007	Communication: Written	1
11/13/2007	designed seat performed 4-bar linkage analysis on steering system researched past PPFS reports, assigned parts of PPFS	2
11/14/2007	Professionalism Shop class: Lathe	2
11/16/2007	worked on PPFS contacted Parker regarding informational meeting updated website	1
11/19/2007	continued work on PPFS	1

11/20/2007	compiled PPFS assigned calculation roles outlined Presentation 2	1
11/21/2007	contacted Parker rep. Mark Ludtke regarding competition and product information compiled PPFS Shop class: Sheet Metal	3
11/24/2007	PPFS work Presentation 2 preparation	4
11/26/2007	Oral Presentations II	1
11/28/2007	Oral Presentations II Shop class: welding	2
11/30/2007	Oral Presentations II	1
12/3/2007	Oral Presentations II	1
12/4/2007	PPFS Revisions Variable Pump Research	1
12/5/2007	PPFS Revisions	2
12/6/2007	PPFS Revisions	2
12/8/2007	PPFS Revisions	2
	Total Man-hrs:	262

Appendix C: Hydraulic System: Regenerative Braking Option #1



Appendix D: Hydraulic System: Regenerative Braking Option #2



Appendix E: 4-Bar Linkage Steering Worksheet

$r_1 = 17.6369$ [in]

$r_4 = 2$ [in]

$\theta_1 = 29.74$ [deg]

$\theta_3 = 29.74$ [deg]

$\theta_2 = \theta_4$

$r_3 \cdot \cos(\theta_3) = r_1 \cdot \cos(\theta_1) + r_4 \cdot \cos(\theta_4) - r_2 \cdot \cos(\theta_2)$

$r_3 \cdot \sin(\theta_3) = r_1 \cdot \sin(\theta_1) + r_4 \cdot \sin(\theta_4) - r_2 \cdot \sin(\theta_2)$

$\sin^2(\theta_2) + \cos^2(\theta_2) = 1$

Appendix F: Potential Accumulator Energy Worksheet

$$\text{AccumVolume} = 2.5 \quad [\text{gal}]$$

$$T_{\text{amb}} = 25 \quad [\text{C}]$$

$$P_{\text{empty}} = 25 \quad [\text{PSI}] \cdot \Bigg| 6.895 \cdot \frac{\text{kPa}}{\text{PSI}}$$

$$P_{1500} = 1500 \quad [\text{PSI}] \cdot \Bigg| 6.895 \cdot \frac{\text{kPa}}{\text{PSI}}$$

$$P_{3000} = 3000 \quad [\text{PSI}] \cdot \Bigg| 6.895 \cdot \frac{\text{kPa}}{\text{PSI}}$$

$$\text{AccumNitrogenMass} = \rho\left(\text{'N2'}, T = T_{\text{amb}}, P = P_{\text{empty}}\right) \cdot \text{AccumVolume} \cdot \Bigg| 0.003785412 \cdot \frac{\text{m}^3}{\text{gal}}$$

$$h_{\text{uncharged}} = \mathbf{h}\left(\text{'N2'}, P = P_{\text{empty}}, s = s_{\text{uncharged}}\right)$$

$$s_{\text{uncharged}} = \mathbf{s}\left(\text{'N2'}, T = T_{\text{amb}}, P = P_{\text{empty}}\right)$$

$$h_{\text{charged}} = \mathbf{h}\left[\text{'N2'}, P = P_{\text{charged}} \cdot \Bigg| 6.895 \cdot \frac{\text{kPa}}{\text{PSI}} \Bigg|, s = s_{\text{uncharged}}\right]$$

$$h_{\text{charged,3000}} = \mathbf{h}\left(\text{'N2'}, P = P_{3000}, s = s_{\text{uncharged}}\right)$$

$$\text{EnergyStored} = \text{AccumNitrogenMass} \cdot \left(h_{\text{charged}} - h_{\text{uncharged}}\right)$$

$$\text{EnergyStored}_{3000} = \text{AccumNitrogenMass} \cdot \left(h_{\text{charged,3000}} - h_{\text{uncharged}}\right)$$

$$\text{BikeMass} = 300 \quad [\text{lbm}] \cdot \Bigg| 0.4536 \cdot \frac{\text{kg}}{\text{lbm}}$$

$$\text{MaximumBikeSpeed} = \left[2 \cdot \frac{\text{EnergyStored}}{\text{BikeMass}}\right]^{0.5} \cdot \Bigg| 70.74 \cdot \frac{\text{mph}}{(\text{kJ/kg})^{.5}}$$

$$\text{MaximumBikeSpeed}_{3000} = \left[2 \cdot \frac{\text{EnergyStored}_{3000}}{\text{BikeMass}}\right]^{0.5} \cdot \Bigg| 70.74 \cdot \frac{\text{mph}}{(\text{kJ/kg})^{.5}}$$

$$\text{MaximumBikeSpeed}_{75\%} = \left[2 \cdot \text{EnergyStored} \cdot \frac{0.75}{\text{BikeMass}}\right]^{0.5} \cdot \Bigg| 70.74 \cdot \frac{\text{mph}}{(\text{kJ/kg})^{.5}}$$

$$\text{MaximumBikeSpeed}_{3000,75\%} = \left[2 \cdot \text{EnergyStored}_{3000} \cdot \frac{0.75}{\text{BikeMass}}\right]^{0.5} \cdot \Bigg| 70.74 \cdot \frac{\text{mph}}{(\text{kJ/kg})^{.5}}$$

$$\text{PedalTime} = \frac{\text{EnergyStored}}{\text{PedalWork} \cdot 0.75} \cdot \Bigg| 1000 \cdot \frac{\text{J}}{\text{kJ}}$$

$$\text{PedalWork} = 125 \quad [\text{W}]$$

$$\text{Volume}_{\text{Fluid}} = 2.5 \ [\text{gal}] - \text{AccumNitrogenMass} \cdot \frac{\left| 264.2 \cdot \frac{\text{gal}}{\text{m}^3} \right|}{\rho \left[\text{'N2'} , P = P_{\text{charged}} \cdot \left| 6.895 \cdot \frac{\text{kPa}}{\text{PSI}} \right| , T = T_{\text{amb}} \right]}$$