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EML4551-2

Team 506: Fluid Powered Vehicle

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Abstract

The abstract is a concise statement of the significant contents of your project. The abstract should be one paragraph of between 150 and 500 words. The abstract is not indents.

Keywords: list 3 to 5 keywords that describe your project.

Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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Notation

A17	Steering Column Angle
A27	Pan Angle
A40	Back Angle
A42	Hip Angle
AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled

	Difference between the calculated and measured
Difference	BOFRP to H-point
DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point
IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

Project Description

The objective of the project is to design a fluid-powered vehicle that successfully integrates two fields not typically associated with each other: human-powered vehicles and fluid power. The aim is to compete ~~thewith this team~~the team-designed vehicle, such as a two or three wheeled bike, in a competition organized by the NFPA (National Fluid Power Association). Gears may not directly drive the bike but rather the design must incorporate a fluid link such as a pump, motor, and accumulator between the pedals and the wheels to provide power. Beyond the competition, the purpose of the event is to encourage the application and development of engineering principles in a real-world application and introduce mechanical engineering undergraduates to the fundamentals of fluid power; a field not often taught in engineering ~~curriculums. The~~curriculums. The competition also serves as a hub for networking between students and representatives from the fluid power industry.

Key Goals

The team's primary goals are to meet all the requirements of the challenge and ensure the seamless integration of all components within~~in~~ the fluid-powered bike~~vehicle~~. Meeting all the requirements is the bare minimum to allow the team to compete, while achieving seamless integration is a step beyond that, improving the chances of reaching performance goals. As this will be the team's first attempt at competing in this event, the aim is to complete all the races and place first in at least one award category. There are several categories in which the team will be competing for prize money, and the team specifically hopes to win an award based on presentations, as the team believes that this category is an even playing field. Another goal is to ensure that the final product is not only functional but also aesthetically pleasing. Since this competition emphasizes the values of engineering, much like in the real world where products are often purchased for both functionality and appearance, the team aims to do the same with the fluid-powered bike. Another key goal the team has is to ~~facilitate the understanding~~leave behind enough documentation and information of how the project was conducted so that future teams will be able to learn and improve the design. As the competition is also for networking a goal for the team is to standout and make connections with the representatives of the industry.

Assumptions

For the progression and completion of the project, the following assumptions have been made: The standard hydraulic fluid required for the competition will be provided. The environment and weather during the event are assumed to be ~~favorable~~operable conditions, without harsh conditions such as potholes or thunderstorms. Additionally, an able-bodied individual will power the system's primary mover, e.g. the pump. Another assumption is that the vehicle will not need to be designed for the general public as ~~As~~ the vehicle will be operated only by team members.~~, it does not need to be designed for a broad audience lacking operational knowledge.~~ Another assumption is that the vehicle does not need to be designed to withstand many uses as~~As~~ the sole purpose of this vehicle will be for the competition. Another assumption is that the team will purchase all components of the vehicle and will mainly ~~only~~ have to deal with the assembly of the vehicle.~~, it does not have to be commercially ready.~~

Markets

The primary market for this project is the NFPA competition, which serves as the main reason for developing the vehicle. The intended purpose of the vehicle is to compete and demonstrate the use of pneumatics and hydraulics in powering a small, one-person vehicle such as a bike or trike.

The secondary market is education, where the fluid-powered vehicle could be used to demonstrate engineering principles in a classroom setting. Another ~~potential~~ secondary market includes environmentally conscious individuals seeking a vehicle that does not rely on combustion. A third secondary market consists of commercial retail cycling specifically enthusiasts interested in a new type of recreational bicycle.

Stakeholders

Stakeholders in the project iInclude DOW inc., Dr.McConomy, Dr.Ali, and Team 506. Their roles are further expanded upon in Table 1 below.

Table 1 - Stakeholders

	Investors	Decision-Makers	Advisors	Receivers
Sponsor(s) Dow inc.	X	X	X	X
Manager Dr. McConomy		X	X	
Advisor Dr. Ali		X	X	
Operators Team 506		X	X	X
General Readers Primary Market Secondary Market				X

The table above outlines the various groups involved and their roles in the project. "Investors" are stakeholders who contribute financially to the project. "Decision-makers" are those who have a direct influence on the final design. "Advisors" provide guidance based on their expertise and experience. "Receivers" are the individuals or groups who will ultimately operate or benefit from the final product. Note that some stakeholders are categorized as decision-makers due to their influence on the outcome of the project.

1.2 Customer Needs

Investigating Needs

Once the project scope was established, the team conducted a thorough review of the rulebook provided by the NFPA and examined the evidence manuals from past teams to investigate the competition requirements. At the time of defining the customer needs, the team had not yet held a formal meeting with the sponsor, Dow, due to hurricane Helene. As a result, specific expectations from Dow have not been communicated, though it is anticipated that their involvement will be minor. Despite this, the team has been able to gather sufficient information, answer key questions, and establish expectations based on the overall competition guidelines and judging criteria.

For this project, the customers are the sponsor, Dow, and the NFPA fluid-powered vehicle competition, for which the vehicle is being built. The table below outlines the team's questions regarding the vehicle and competition, the responses drawn from the rulebook and past competitions, and how the team has interpreted these findings.

Table 2 Customer Needs Questions, Response, Interpretations

Question	Response	Interpreted Need
Are there any expectations for us from this project?	The vehicle has to be safe, reliable, and able to compete in the competition.	The team will follow the guidelines from the rule book and necessary precautions to compete.
There is no definitive answer as to which fluid we can use to power the vehicle, is there a specific fluid you are looking for us to use?	Vehicles must use fluids furnished by the competition.	The team will be provided with the fluid by the competition.

If we make it to competition, how will we deal with transporting the vehicle?	Vehicle must be shipped to competition.	Final vehicle design will be easy to disassemble and reassemble for transport
What budget do we have to work with?	The budget is $3000.	The team will be given $3000 to strategically order parts.
Is there a size limit?	The maximum weight of the vehicle is 210 pounds without a rider.	Each system will be allocated weight with the intention of minimizing it.
How many people can operate the vehicle?	Vehicle design must be for a single rider.	Choose specifications and design around team's physical attributes.
When and where will the competition be held?	The competition dates are: April 9-11, in Illinois, April 23-25 and April 30 – May 2 in Iowa.	The team will plan schedules accordingly to attend one of the competitions.
Is there a specific material for the chassis you want us to use?	Use any material you see fit.	The team will choose the materials they consider to be best for the vehicle design.
How can we best stand out from the rest of the competition?	Through a more innovative use of pneumatics and having a vehicle whose various systems function seamlessly.	Gain inspiration from other vehicles that use pneumatics to incorporate into project.
What parts are allowable in the competition?	On the website there is a permitted parts list which you can choose from.	The team will use the parts list and discuss the options available for each component.

Explanation of Results

Based on the questions, responses, and interpretations, Team 506 has identified the most important needs for the project. The competition rules governing eligibility to compete are the highest priority, as they dictate safety, reliability, and design constraints. Following that, the functionality of the vehicle, aesthetics, presentation, and the potential use of pneumatics are also critical, as these factors will influence the vehicle's overall performance in the competition. From these needs, the team will establish targets and metrics, aligning with the rules to meet the objectives outlined.

1.3 Functional Decomposition

The purpose of this section is to break down the vehicle system into subsystems and further into individual elements. This approach allows the team to identify key aspects for creating a successful fluid-powered vehicle. By simplifying the vehicle into manageable building blocks, each component can be thoroughly analyzed and improved, ensuring better overall performance.

Data Generation

The subsystems and functions within them were identified based on customer needs and information gathered from online resources about the competition, helping to understand and evaluate the system's requirements. The following diagram illustrates the breakdown of the fluid-powered vehicle into four subsystems and their respective functions

Hierarchy Chart

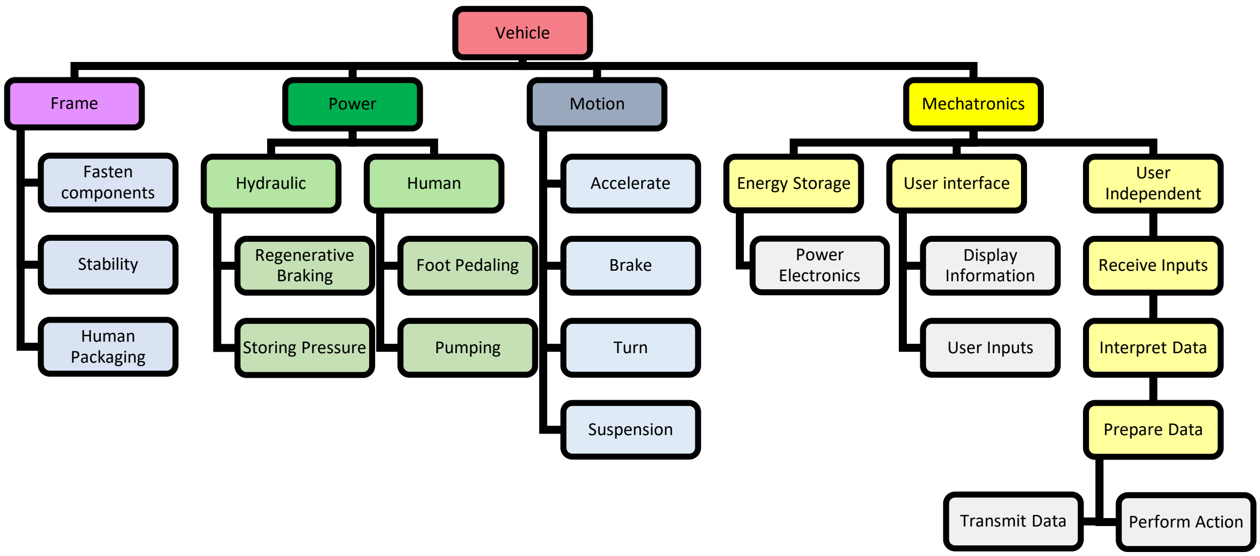


Table 3 – Cross Functional Relationship Matrix

		Systems			
		Frame	**Power**	**Motion**	**Mechatronics**
Functions	**Fasten Components**	x	x	x	x
	Stability	x			
	Human Packaging	x			
	Foot pedaling		x	x	
	Pumping		x	x	
	Regenerative Breaking		x	x	
	Pressure Storage		x	x	

Accelerate		x	x	
Brake		x	x	
Turn		x	x	
Suspension	x		x	
Power Electronics				x
Display information				x
User Input				x
Transmit Data				x
Perform Action		x		x

Connection to Systems

The project is broken down into four main systems: frame, power, motion, and mechatronic systems. The frame should house components from the rest of the systems securely. This ensures components in the power system will function properly without ruining the system when in motion. For example, proper framing allows for the prevention of loosening parts and therefore prevents potential leaks from the hydraulic system. This will result in maximum efficiency in components designed for motion, so as to not waste vital power allowing for maximum output for motion. By allowing for mechatronic components to be held securely, it will allow for any sensors to read information as intended without extra disturbance from being loosely secured. The frame will be built so it can allow for one rider only.

The power system implies the use of the hydraulic sub-system being the sole source of output power for motion of the vehicle. The human power sub-system is simply the input power to initiate the hydraulic system into working which will be through pumping or pedaling. Regenerative breaking will reduce losses in energy to the environment so that it can be recycled back into the system.

The motion system refers to the movements that the vehicle should be able to handle. This includes the acceleration, braking, turning, and suspension of the vehicle. Acceleration will be a result of the power outputted from the hydraulic sub-system. Braking and turning will be manual movements that the rider will have direct control of. Good suspension while in motion will help reduce noise readings in sensors, give a more comfortable experience for the reader, and prevent any damaging to the hydraulic systems.

The mechatronics system of the vehicle is the electronics centered portion of the vehicle, there will be sensors, throughout the system that will read valuable data like pressure, speed, and distance traveled. From this data, the controller will be able to make actions depending on what the most appropriate action should be.

Smart Integration

One of the power generating functions is foot pedaling. Foot pedaling generates torque. Torque can be converted into fluid power in the form of pressure through pumping, which can then be accumulated and stored. Pressure can also be converted back into mechanical power directly. Regenerative braking is induced by pressure. Electrical energy may be used to control the system by energizing valves (solenoid). Electrical energy is converted into mechanical energy in controls. Components of the system will be fastened in static equilibrium onto or into the frame. The direction of motion will be determined by the front wheel's angle while steering.

Actions and Outcomes

The actions the fluid-powered vehicle will perform include accelerating, storing energy, braking, and regenerative braking, all driven by the user's pedaling and pumping. Additionally, the vehicle will switch between hydraulic systems based on user inputs.

Function Resolution

The vehicle will be user operated taking inputs from the user via steering and an interface to the mechatronics. The user will manually pedal and pump to store energy to power the vehicle. Switching between hydraulic systems will allow the vehicle to perform different functions such as regenerative braking, accumulation boost, and driving.

1.4 Target Summary

Targets are set values that guide the design process, while metrics are used to validate those targets. The Functional Decomposition hierarchy chart and the NFPA guidelines were used to establish the targets and metrics outlined below. The team selected specific targets and metrics as critical, prioritizing those most essential for building the best possible vehicle and winning the competition. Some of these targets and metrics were benchmarked using previous projects, while others were calculated by the team. A comprehensive list of the targets and metrics can be found in Appendix C.

Table 4 – Critical Function– Metrics and Targets

Functions	Targets	Metrics
Storing Pressure	2750 [psi]	Pressure
Accelerating	<13.5 [Seconds]	Time
Foot Pedaling	200 [Watts]	Watts

User Inputs	50 [Milliseconds]	Time
Perform Action	60 [Milliseconds]	Time

Storing Pressure

The competition's limit for storing pressure is 3000 psi for safety reasons, so the target is set just below this threshold. High pressure is crucial for both the sprint race and the efficiency race, as these events rely on the accumulator's pressure. Designing the hydraulic system to operate near this specified pressure limit will optimize performance while ensuring safety compliance

Accelerating

A time of less than 13.5 seconds was chosen for the vehicle to reach its top speed, based on benchmarking with the California Polytechnic State University 2019-2020 team. The goal is to reach top speed before crossing the 600 ft finish line, ensuring competitive performance in the sprint race.

Foot Pedaling

For the system to function as intended, one assumption is that an able-bodied individual will pedal to provide energy to the system. To remain competitive in some of the races, the team identified an additional critical metric: the power output of the user, measured in watts. Based on research, an average person can produce around 100 watts of power while cycling, and a professional can produce up to 400 watts. The team set a target of 200 watts, as none of the races will require extreme endurance from the rider.

User Inputs and Perform Action

User inputs are essential in this project for switching between the vehicle's functions. The faster the user input is relayed, the quicker the vehicle can change functions, allowing for smooth transitions during and between races. A time of 50 milliseconds was chosen for the signal to reach the solenoid valve, with an additional 60 milliseconds for the valve to close.

Functionless Targets and Metrics

The functionless objectives are not included in the functional decomposition, which is why they are referred to as functionless objectives. These are goals that the team aims to achieve based on the objectives established through the functional decomposition process shown in table 5 below.

Table 5 – Functionless Objectives – Targets and Metrics

Objectives	Targets	Metric
Speed Race	<30 [Seconds]	Time
Efficiency Race	>20[]	Efficiency Score
Endurance Race	>2000 [Feet]	Distance

Speed Race

This objective was established by benchmarking against previous competitors from the 2019 competition, where the first-place team completed the 600-foot race in 14.71 seconds.

Ideally, the team aims to outperform other competitors and achieve a faster time in the sprint race.

Efficiency Race

The efficiency score was determined by benchmarking against previous competitors from the 2019 competition, where the first-place team achieved a score of 31. This unitless score is calculated using the equation: $(W \times L)/(P \times V)$, where W is the weight of the bike and rider in pounds, L is the distance traveled in inches, P is the pressure in the accumulator in psi, and V is the volume of the accumulator in cubic inches. A higher efficiency score indicates a more efficient design, so the team aims to achieve a score higher than that of previous competitors.

Endurance Race

The desired target for the endurance race was obtained from the FPVC rulebook, where the winner is determined by the vehicle that travels the farthest distance. To qualify for placement, however, the vehicle must be able to travel at least 2000 feet within 15 minutes.

Method of Validation

The validation of pressure storage will be conducted by checking the reading on the gauge. The time it takes for the vehicle to reach top speed will be validated by measuring the velocity using an encoder on the wheel shafts, along with a timer to track when the vehicle achieves its maximum speed.

To test the time required for the signal to reach the solenoid valve, we will evaluate the mechatronics aspect of the project independently, measuring the time with a ticker built into the software. The time for the solenoid valve to open or close will be based on the manufacturer's specifications, with 60 milliseconds representing the average for commonly used solenoid valves.

The functionless objectives will be tested independently before the race under controlled conditions. The vehicle will be timed over distances of 600 feet and 2000 feet. The efficiency score will be calculated after selecting the accumulator, based on the maximum distance traveled by the vehicle.

1.4 Concept Generation

This section discusses the process of creating and developing effective ideas that can achieve the project's objectives and goals. During this process, the team will generate 100 potential concepts and further develop a few of these concepts to gain deeper insights into the design features and how they will enable the vehicle's functions.

Concept Generation Tools

Concept generation tools used by the team were a morphological chart, general brainstorming, crap-shooting, and gaining inspiration from vehicles done by previous competitors.

The morphological chart is a tool that allows for the rapid formation of many ideas by coming up with different 'limbs' of a concept. Then these 'limbs' are mixed and matched to form a variety of 'frankenstein' concepts.

General brainstorming and crap-shooting go hand in hand as they are both the process of saying ideas out loud and recording them. Crap-shooting specifically represents the idea of coming up with seemingly outlandish ideas to hopefully generate an out-of-the-box idea that wouldn't have been come up with before.

By gaining inspiration from previous competitors, the team enhances their knowledge of the project and will allow for an easier selection process for the team.

Medium Fidelity Concepts

Below are some medium fidelity concepts, which are deemed as medium fidelity due to their almost reasonable possibility of being done. These are concepts that seem feasible based on current knowledge and experience on the task. If given sufficient time and resources, they should be able to be accomplished fully.

Concept 1.

Concept 73 - A three-wheel bike that actively uses regenerative braking on turns during the endurance/sprint races where you would stop pumping, it would be advantageous to use the stored energy. The components would be placed behind the rider who would be sitting somewhere between an upright and laid-back position. Solenoids are actuated electronically. This design being a three-wheeled design would use a steering mechanism similar to that of a bike.

Concept 2.

Concept 70 - Purchase a recumbent bike, rear wheel drive on the back wheel and the front wheels for steering, most of the hydraulics and electronics would be placed behind the seat of the rider, who would be sitting in a laid-back position. The solenoids would be electronically activated. The recumbent vehicle would be steered via levers that if pulled in one direction will make the vehicle turn.

Concept 3.

Concept 51 - A four-wheeled vehicle that has all the hydraulic, mechatronic circuitry, and motor elements centered between the back wheels to allow for easy distribution of weight without having to worry about the rider balancing the vehicle by his own skill if two wheels were to be used. Since the vehicle is four-wheeled go-kart steering would be ideal. Adapt the suspension to allow for tighter corners. The rider would be seated in an upright position.

Concept 4.

Concept 80 - A Viking-themed vehicle designed to stand out in the aesthetics category of the competition. The frame and exterior would use wood and be painted to resemble a Viking ship, creating a unique and eye-catching design. The rider and team members would wear Viking-themed outfits to enhance the presentation. The vehicle would incorporate rowing as the method of pumping, adding to the Viking theme by mimicking the action of rowing a ship. This concept would focus on both the functionality of the pumping mechanism and the visual appeal of the design.

Concept 5.

Concept 66 - A three-wheel vehicle in a rear-wheel-drive configuration, using go-kart style steering for better maneuverability. The design prioritizes stability and control, making it suitable for the sprint and endurance races. The rear-wheel drive allows for efficient power transfer, while the go-kart steering provides precision during turns. Hydraulic components would be placed for optimal weight distribution, ensuring smooth handling.

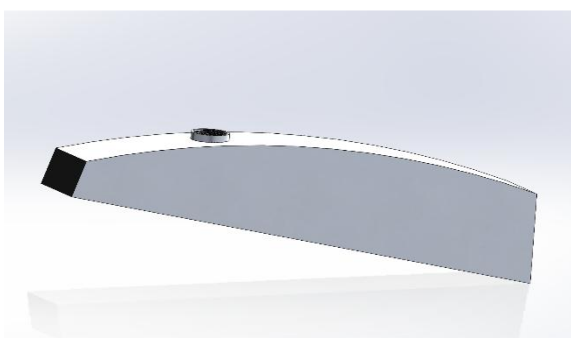
High Fidelity Concepts

Below are some high fidelity concepts which are deemed as high fidelity due to their very reasonable possibly of being done. They seem highly feasible given the time and resource constraints that the team has. They should be able to be accomplished fully in the planned time.

Concept 6.

Concept 58 - A custom-built frame specifically designed to accommodate all necessary components. The hydraulic reservoir is integrated into the frame itself to save space and improve weight distribution. This design uses pneumatics for the braking system, allowing for responsive and efficient stopping. The electronic system would control the solenoids and monitor various vehicle states, such as pressure levels and speed, ensuring seamless operation. The custom frame offers flexibility in component placement, making it ideal for optimizing the design for performance in various races.

Figure 1: Hydraulic Reservoir



Concept 7.

C**oncept 68 -** A three-wheeled design featuring bicycle-style steering and a three-speed transmission, with mechatronically actuated hydraulic lines for smooth transitions between speeds. The rider would be seated upright, providing a comfortable and efficient riding position.

The vehicle would include an electronically displayed dashboard to show real-time vehicle states, such as speed, pressure, and remaining energy in the accumulator. A pedal-pump system would be used for generating power, and an encoder would measure vehicle speed, providing precise data to optimize performance during races.

Concept 8.

Concept 79 - A design utilizing a purchased frame, allowing the team to focus on optimizing the hydraulic and mechanical systems rather than frame construction. The vehicle would include a transmission system between the motor and wheels to efficiently manage power delivery. This design focuses on simplicity and practicality, using off-the-shelf components for quick assembly and integration. The purchased frame would provide a stable foundation, while the transmission ensures effective use of power during acceleration and energy storage phases. This approach is highly feasible within the project's time and resource constraints, making it a strong candidate for the competition.

Figure 3: Conceptual Image of Potential Bike Frame

1.5 Concept Selection

Several tools are utilized to identify the most promising concept from those generated. These tools include Binary Pairwise Comparison (BPwC), House of Quality (HoQ), Pugh Charts, and Analytical Hierarchy Processes (AHP). The team also applied a methodical approach to select the concept that was deemed most likely to produce the best possible product. Appendix-F contains all the Tables and values used during the process for concept selection.

Binary Pair Wise Comparison

Customer requirements were evaluated against each other using a binary pairwise comparison matrix. A score of 1 indicates that a requirement is more important than the compared requirement. Each column was then tallied to determine the importance weight factors for each customer requirement. "Weight" and "Store Pressure" had the highest importance weight factors, with scores of 7 and 6, respectively, followed by "Regenerative Braking" and "Structural Integrity.

House of Quality

The House of Quality illustrates how effectively each engineering characteristic meets a specific customer requirement. A score of 0 indicates no significance, while a score of 9 signifies a strong dependence on the customer requirement. Each score is multiplied by the importance weight factor and tallied to produce a raw score. This raw score is then converted into a weight percentage and ranked, enabling each engineering requirement to be prioritized. "Force" emerged as the most important engineering characteristic, followed by "Components" and "Time."

Pugh Chart

The Pugh Chart is an effective method for identifying the most promising concepts. The high- and medium-fidelity concepts were selected and compared against a datum, which was the 2024 California Polytechnic State University design. For each criterion, a concept received a "+" if it was better than the datum, a "-" if it was worse, and an "S" if it was about the same. The number of "+" and "-" were then tallied for each concept. After this first comparison, a new datum was chosen concept 6 from the high-fidelity section. Concepts 5, 7, and 8 were then compared to this new datum.

Analytical Hierarchy Process (AHP)

In the AHP, a pairwise matrix was created using the criteria selected by the team. Values of 1, 3, 5, 7, or 9 were used to rank the importance of one criterion over another. The values for each criterion were summed, giving each concept a total score. A criteria-vs-criteria matrix was created by dividing each column by the sum of the respective concept values (normalizing). The criteria weight was then calculated by averaging each row. A weighted sum vector was used to generate the consistency vector. A concept-vs-concept matrix was then created for concepts 6, 7, and 8, for each engineering characteristic. Each consistency vector was below the ideal value of 0.1, indicating that the team maintained consistency throughout the rankings.

Final Selection

Based on the evaluation processes and using a Final Rating Matrix, concepts 6, 7, and 8 had alternative values of 0.302, 0.379, and 0.394, respectively. The highest value represents the most ideal concept according to the methodology and criteria applied. Following this approach, concept 8 emerged as the top choice. A more detailed description of this concept is provided below and general image can be seen in concept generation figure 3.

Concept 8

This design uses a purchased frame, allowing the team to focus their time and efforts on optimizing the hydraulic and mechanical systems rather than building a frame. The vehicle includes a transmission system between the motor and wheels to efficiently manage power delivery. This concept prioritizes simplicity and practicality, using off-the-shelf components for faster assembly and integration. The purchased frame offers a stable foundation, while the transmission system ensures efficient power utilization during acceleration and energy storage phases.

Key features include an elliptical sprocket for improved pedaling mechanics, a single motor in a rear-wheel-drive setup, two rear wheels, and one front wheel with bike-style steering. The hydraulic fluid will be stored in a tank, and a manifold will manage all hydraulic connections. Regenerative braking will be included but will not be a primary focus of the project. Mountain bike wheels will be used for durability and performance.

The vehicle will feature a display to show the current drive mode, with an encoder measuring and displaying the vehicle’s velocity. Hydraulic hoses will enable fluid movement within the system. A microcontroller will control electronics and solenoids, powered by an onboard battery. This approach is highly feasible within the project's time and resource constraints, making it an excellent candidate for the competition.

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

Team 506's mission is to collaborate effectively to produce an original design for the Fluid Power Vehicle Challenge that meets the goals and needs of the customer. We commit to prioritizing this project throughout the duration of our senior design course, putting forth our best efforts. By applying the engineering principles and knowledge gained during our undergraduate studies, we aim to deliver a high-quality solution. We will uphold respect, ethics, and professionalism in accurately representing the FAMU-FSU College of Engineering.

Outside Obligations

The team will meet at least twice a week. General meetings will take place during the remaining hours of the Senior Design lecture. Additional meetings will be scheduled as needed, based on the team's availability on Microsoft Teams calendar. Team members must promptly notify others of any schedule changes.

Communication

Microsoft Teams/Email

Microsoft Teams will be the primary platform for messaging and sharing information. It will be used to update the team on tasks and for sending or receiving files. Each team member's calendar on Microsoft Teams must be kept up to date, including class times, work schedules, meetings, personal commitments, and any additional responsibilities. ~~Changes must be updated within 72 hours.~~ Team members are expected to check Microsoft Teams frequently to stay informed about tasks and scheduled meetings.

Communication with individuals outside the team, including but not limited to project advisor, sponsors, Dr.McConomy, and other College of Engineering faculty, will be handled via email. When sending emails related to the project, each member is expected to CC the entire team. Team members are encouraged, but not required to be active on both Microsoft Teams and email during weekends and holidays.

Text Messaging

A team group chat will be established, primarily for sending reminders, communicating absences, and scheduling impromptu meetings. The group chat can also be used for informal communication, such as friendly banter among team members. All members are free to message in the group chat at any time, but should be mindful of the time of day or night when sending messages.

How to notify group in cases of urgency

In cases of urgency, default to notify by text messaging and also alert via email, to ensure that communication was attempted and giving other team members the opportunity to view the notification. In case of emergency notify appropriate emergency services immediately.

Team Roles

Team Member & Role	Description
Adonay Almanza-Enriquez Controls Engineer	The Controls Engineer is responsible for necessary electronic components and software.
Trace Flowers Modeling & Simulation Engineer	The Modeling & Simulation Engineer is responsible for the mechanical calculation of the project's drive system.
Daniel Garmendia Quality Engineer	The Quality Engineer is responsible for the materials selection and the design analysis.
Ethan Mercado Systems Engineer	The Systems Engineer is responsible for the seamless integration of each subsystem necessary for this project.
Gabriel Vazquez Design Engineer	The Design Engineer is responsible for the CAD and the building of the design.

Dress Code

For sponsor meetings or Virtual Design Reviews, the team will dress in business casual attire, which includes a dress shirt with black or beige pants—no jeans allowed. For meetings with our advisor or general team meetings, no specific dress code is required. On Engineering Design Days, suits and ties are mandatory. For impromptu events or meetings not covered above; the dress code will be discussed with the team as needed.

Attendance Policy

Group Meetings

For group meetings most of the team members are expected to be in attendance. There should be a valid reason for a person to not be able to attend the meeting and it should be stated within a 24-hour period. In case of an emergency, the team will be considerate and expect an answer as soon as the team member is able to send one. If a group member is not able to attend a meeting, they will be provided with details of what took place during the meeting.

Sponsor/Advisor Meetings

For meetings with the sponsor and advisor most of the team members are expected to be in attendance. There should be a valid reason for a person to not be able to attend the meeting and it should be stated within 24- hour period. In case of an emergency, the team will be considerate and expect an answer as soon as the team member is able to send one. If a group member is not able to attend a meeting, they will be provided with details of what took place during the meeting.

Presentations

For presentations all team members are expected to be in attendance. In case of an emergency, the team will be considerate and expect an answer as soon as the team member is able to send one.

How to Respond to People in Professional Meeting

In a professional meeting, all members will be respectful of the attendees in the meeting, this includes but is not limited to the use of appropriate language, and being as informed as possible about the subject of the meeting. Appropriate language for a meeting means no vulgar or slang language. Keep it technical and simple. To be well informed is to be able to answer questions confidently and thoroughly.

What to do Before Contacting McConomy or Advisor

If the reason for contact is a problem or question about the project, do all that can be done to solve the problem before contact. If all attempts fail, do as much research and information gathering before contacting and meeting with McConomy and/or our Advisor. This allows for a guided meeting with a clearly established reason for meeting.

If the reason for contact is an issue with a member of the team, attempt to solve the issue by discussing it with the member of the team either individually or with the rest of the team. If attempts to solve the issue fail, contact McConomy and/or our Advisor. Inform McConomy and/or our Advisor of failed attempts.

When meeting with McConomy/Advisor, they should already be well informed via method of contact for the reason to meet with them. When notified for the reason, they should also be informed of the course of action that we are looking for them to take, whether that be to settle a decision or dispute or to provide a new insight into the project.

Intervention Policy

When a member has repeatedly gone against the Code of Conduct and other intra-group measures have failed, McConomy will be contacted to seek his guidance on further actions to be taken towards the member.

How to Amend

This code of conduct may be amended at any time at the team's discretion. To make an amendment, all members must be present to discuss and vote. An amendment will only be accepted if at least four out of five members vote in favor of it.

Code of Conduct Acknowledgement

I have read the guidelines and understand my responsibility to follow and uphold these values and procedures throughout the duration of the project. I hereby agree to adhere to everything outlined in this document and accept the consequences for any failure to comply.

Signatures: Dates:

Adonay Almanza-Enriquez 24/09/10

Daniel Garmendia 24/09/10

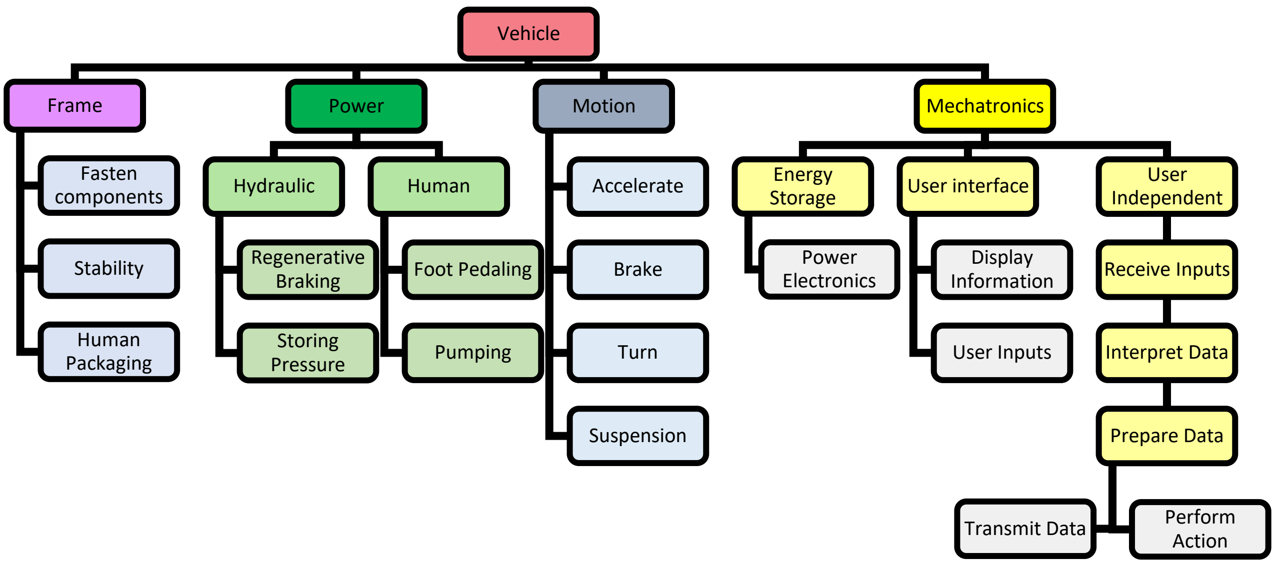
Ethan Mercado 24/09/10

Trace Flowers 24/09/10

Gabriel Vazquez 24/09/10

Appendix B: Work Breakdown Structure

Appendix C: Functional Decomposition



Appendix D: Target Catalog

Functions & Objectives	Targets	Metrics
Storing Pressure	2750 [psi]	Pressure
Accelerating	<13.5 [Seconds]	Time
Foot Pedaling	200 [Watts]	Watts
User Inputs	50 [Milliseconds]	Time
Power Electronics	12 [Volts]	Energy Potential
Brake	5 [Seconds] 1 [Meter]	Time Displacement
Turn	2.5 [Meters]	Turning Radius
Suspension	2 [Centimeters]	Vertical Displacement
Human Packaging	200 [Pounds]	Human Weight on Seat
Stabilize	<10 [degrees]	Angle Normal to Ground
Fasten Components	0 [Centimeters]	Displacement
Regenerative Braking	75 [%]	Ratio of energy conserved to energy lost
Display Information	3 [Volts]	Signal from Photocell detecting if display is on
Transmit Data	50 [Milliseconds]	Time
Pumping	2750 [psi]	Pressure
Perform Action	60 [Milliseconds]	Time
Speed Race	<14.71 [Seconds]	Time
Efficiency Race	<31 [%]	Efficiency Score
Endurance Race	>2000 [Feet]	Distance
Weight	< 150 [lbs]	Weight of vehicle (no rider)
Ergonomic	<10 [sec]	Time to enter and exit vehicle

Appendix E: Concept Generation

		Options		
		1	2	3
Design Configurations	Number of Wheels	Two Wheels	Three Wheels	Four Wheels
	Ride Position	Seated Upright	Seated Laid Back	Standing
	Motor	1.025 CID	0.659 CID	0.39 CID
	Pump	.659 CID, 9-tooth spline	.659 CID, keyed shaft	.513 CID, keyed shaft
	Pump Power	Pedal-Pump	Hand-Pump	
	Frame Material	Steel Alloy	Carbon Fiber	Aluminum Alloy
	Piping	Tubing	Hoses	
	Accumulator	1 gallon	1 quart	
	Mode Shifting	Electronic	Mechanical	
	Manifold	Has Manifold	No Manifold	

Concept Idea	Concept Description
Morphological Chart	
1	The two-wheeled laid-back seating design utilizes 0.659 CID on both ends with a 9-tooth spline, powered by a pedal-pump, constructed from steel alloy with hoses, has a 1-quart capacity, an electronic control system, and includes a manifold.
2	The two-wheeled standing design uses a 1.025 CID and 0.513 CID keyed shaft, driven by a hand-pump, made from carbon fiber with tubing, has a 1-gallon capacity, features a mechanical control system, and has no manifold.
3	The three-wheeled upright seating design employs a 0.39 CID and 0.659 CID 9-tooth spline, driven by a pedal-pump, made from aluminum alloy with hoses, has a 1-quart capacity, an electronic control system, and includes a manifold.
4	The three-wheeled laid-back seating design uses a 1.025 CID and 0.513 CID keyed shaft, powered by a hand-pump, constructed from steel alloy with tubing, has a 1-gallon capacity, a mechanical control system, and no manifold.
5	The four-wheeled standing design features 0.659 CID on both ends with a keyed shaft, driven by a pedal-pump, made from carbon fiber with hoses, has a 1-quart capacity, an electronic control system, and includes a manifold.
6	The four-wheeled upright seating design uses a 1.025 CID and 0.659 CID 9-tooth spline, powered by a hand-pump, made from aluminum alloy with tubing, has a 1-gallon capacity, a mechanical control system, and no manifold.
7	The two-wheeled upright seating design employs a 0.39 CID and 0.659 CID keyed shaft, driven by a pedal-pump, constructed from steel alloy with hoses, has a 1-quart capacity, an electronic control system, and includes a manifold.
8	The two-wheeled standing design uses a 1.025 CID and 0.659 CID 9-tooth spline, powered by a hand-pump, made from carbon fiber with tubing, has a 1-gallon capacity, a mechanical control system, and no manifold.
9	A two-wheeled design features an upright seating position, a 1.025 CID and 0.659 CID configuration with a 9-tooth spline, a pedal-pump system, steel alloy frame, tubing, a 1-gallon capacity, and an electronic control system with a manifold.

10	A two-wheeled design with a laid-back seating position utilizes 0.659 CID on both ends with a keyed shaft, driven by a hand-pump, constructed from carbon fiber with hoses, a 1-quart capacity, a mechanical control system, and no manifold.
11	A three-wheeled design with a standing rider configuration uses a 0.39 CID and 0.513 CID keyed shaft, driven by a pedal-pump, made from aluminum alloy with tubing, a 1-gallon capacity, an electronic system, and a manifold.
12	A four wheeled design with a seated upright driver position. This design would use a 0.39 CID and 659 CID keyed shaft hand driven pump. The frame will be made out of an aluminum alloy and will use hoses for tubing. A 1 gallon capacity accumulator, mechanical system, and no manifold would be used.
13	The two wheeled design includes a seated upright driver position with a 0.659 CID and .659 CID 9-tooth spline pedal driven pump. A steel alloy framed will be used, as well as hoses for tubing, a 1 quart accumulator, an electronic system, and a manifold.
14	This two wheeled design has a standing driver position, 1.025 CID and .513 CID keyed shaft hand driven pump, a carbon fiber frame, Tubing, 1 gallon, Mechanical, No manifold
15	A three wheeled, seated laid back driver design. Uses a 1.025 CID and .659 CID 9-tooth spline pedal power pump. An aluminum alloy will be used for the frame, hoses for pumping, a 1 gallon accumulator, uses an electronic system, and has a manifold
16	A three wheeled design using a standing driver position. Includes a 0.659 CID and .659 CID keyed shaft hand driven pump. Steel Alloy for the frame. Tubing, A 1 gallon accumulator and a mechanical system with no manifold will be used.
17	This four wheeled design has a seated upright driver position, as well as a 0.39 CID and .513 CID keyed shaft pedal driven pump, with a Carbon Fiber frame. Hoses will be used for tubing, a 1 quart accumulator, an electronic system, and a manifold will be used.
18	The four wheeled design has a seated laid back driver position. It includes a 1.025 CID and .659 CID 9-tooth spline hand driven pump, with an aluminum alloy frame will be used. Tubing and a 1 gallon accumulator, with a mechanical system, No Manifold

19	A two wheeled design that has: A standing driver position, 0.659 CID and .513 CID keyed shaft pedal driven pump, steel alloy frame, hoses for tubing, a 1 quart accumulator, an electronic system, and a manifold.
20	A two wheeled design with a seated laid back driver position. A 1.025 CID and .659 CID keyed shaft hand driven pump will be used to charge the vehicle. A carbon fiber frame will be used to lower the weight of the vehicle. Steel tubing for the flow and a 1 gallon accumulator will be used. A mechanical system with no manifold.
21	A three wheeled with a seated upright driver position design. It has a 0.39 CID and .659 CID 9-tooth spline pedal driven pump with an aluminum alloy frame. Hoses, will be used for tubing, a 1 quart accumulator, an electronic system, and a manifold will be included.
22	This three wheeled design has a standing driver position. It will include a 1.025 CID and .513 CID keyed shaft hand driven pump. A Steel Alloy frame will be used and steel tubing, a 1 gallon accumulator with a mechanical system will be used.
23	A four wheeled design with a seated laid back driver position. It includes a 0.659 CID and .659 CID 9-tooth spline pedal driven pump, a carbon fiber frame, hoses for tubing, a 1 quart accumulator, an electronic system, and a manifold.
24	The four wheel design has a seated upright driver position. A 1.025 CID and .513 CID keyed shaft hand driven pump. An aluminum alloy for the frame for pricing and weight will be used. Steel tubing and a 1 gallon accumulator with a mechanical system will be included.
25	This two wheeled design includes a seated upright driver position, a 0.39 CID and a .659 CID keyed shaft pedal driven pump, a steel alloy for the frame, hoses for tubing, a 1 quart accumulator, an electronic system, and a manifold.
26	This two-wheeled design includes a standing driver position, a 1.025 CID and a .659 CID 9-tooth spline hand-pump, carbon fiber tubing, a 1-gallon capacity, a mechanical system, and no manifold.
27	A three-wheeled design which has a seated laid-back driver position, a 0.659 CID and a .513 CID keyed shaft pedal-pump, an aluminum alloy frame, hoses for tubing, a 1-quart capacity, an electronic system, and a manifold.

28	A three-wheeled design has a seated upright driver position, a 1.025 CID and a .659 CID keyed shaft hand-pump, a steel alloy frame, steel tubing, a 1-gallon accumulator, a mechanical system, and no manifold.
29	This two-wheeled design includes a seated upright driver position, a 1.025 CID and a 0.659 CID 9-tooth spline pedal-pump, an aluminum alloy frame, hoses for tubing, a 1-gallon capacity, an electronic system, and a manifold.
30	This four-wheeled design includes a seated laid-back driver position, a 1.025 CID and .513 CID keyed shaft hand-pump, an aluminum alloy frame, tubing for fluid flow, a 1-gallon accumulator, a mechanical system, and no manifold.
31	A two-wheeled design that includes a seated laid-back driver position, a 0.39 CID and .659 CID 9-tooth spline pedal-pump, a steel alloy frame, hoses for tubing, a 1-quart accumulator, an electronic system, and a manifold.
32	A two-wheeled design that has a standing driver position, a 0.659 CID and .513 CID keyed shaft hand-pump, a carbon fiber frame, tubing for fluid flow, a 1-gallon accumulator, a mechanical system, and no manifold.
33	A three-wheeled design which has a seated upright driver position, a 1.025 CID and .659 CID keyed shaft pedal-pump, an aluminum alloy frame, hoses for tubing, a 1-quart accumulator, an electronic system, and a manifold.
34	This three-wheeled design features a seated laid-back driver position, utilizes a 0.39 CID and .659 CID 9-tooth spline hand-pump. The frame is constructed from steel alloy, with tubing for fluid transport, a 1-gallon capacity, and a mechanical system that operates without a manifold.
35	This four-wheeled design incorporates a standing driver position and features a 0.659 CID and .513 CID keyed shaft pedal-pump. It utilizes a carbon fiber frame, hoses for fluid transport, a 1-quart capacity, an electronic system, and includes a manifold.
36	This four-wheeled design features a seated upright driver position and includes a 1.025 CID and .659 CID 9-tooth spline hand-pump. A frame constructed from aluminum alloy, it utilizes tubing for fluid flow, has a 1-gallon capacity, and operates with a mechanical system that has no manifold.

37	A two-wheeled design that includes a seated upright driver position and features a 1.025 CID and .513 CID keyed shaft pedal-pump. It is constructed with a steel alloy frame, incorporates hoses for fluid transport, has a 1-quart capacity, and operates with an electronic system, and includes a manifold.
38	A two-wheeled design features a standing driver position and incorporates a 0.39 CID and .659 CID keyed shaft hand-pump. A frame made from carbon fiber, it utilizes tubing for fluid flow, has a 1-gallon capacity, and operates with a mechanical system, and does not include a manifold.
39	This three-wheeled design features a seated laid-back driver position and includes a 1.025 CID and .513 CID keyed shaft pedal-pump. A fame built with an aluminum alloy, it utilizes hoses for fluid transport, has a 1-quart capacity, and operates with an electronic system that includes a manifold.
40	This three-wheeled design includes a standing driver position and features a hand-pump with both a 0.659 CID and a .659 CID 9-tooth spline. A frame made from steel alloy, it utilizes tubing for fluid transport, has a capacity of 1 gallon, and operates with a mechanical system, and lacks a manifold.
41	A four-wheeled design that has a seated upright driver position and incorporates a pedal-pump with a 0.39 CID and .659 CID keyed shaft. A frame made from carbon fiber, it has hoses for fluid transport, has a 1-quart accumulator, and operates with an electronic system, and is equipped with a manifold.
42	A four-wheeled design that features a seated laid-back driver position and utilizes a hand-pump with a 1.025 CID and .513 CID keyed shaft. Made from aluminum alloy, it incorporates tubing for fluid flow, has a 1-gallon accumulator, and operates with a mechanical system and does not include a manifold.
43	The two-wheeled design has a seated laid-back driver position and includes a pedal-pump with a 0.659 CID and a .659 CID 9-tooth spline. A frame constructed from steel alloy, it utilizes hoses for fluid transport, has a 1-quart accumulator, and operates with an electronic system. It includes a manifold.
44	A two-wheeled design features a standing driver position and includes a hand-pump with a 1.025 CID and a .513 CID keyed shaft. A frame made from carbon fiber, it utilizes tubing for fluid flow, has a 1-gallon accumulator, and operates with a mechanical system that does not include a manifold.

45	This three-wheeled design features a seated upright driver position and includes a pedal-pump with a 0.39 CID and a .659 CID 9-tooth spline. A frame built from an aluminum alloy, it incorporates hoses for fluid transport, has a 1-quart accumulator, and operates with an electronic system. Includes a manifold.
46	A three-wheeled design features a seated laid-back driver position and a hand-pump with a 1.025 CID and a .513 CID keyed shaft. A steel alloy, frame, it utilizes steel tubing for fluid flow, has a 1-gallon accumulator, and operates with a mechanical system. Does not include a manifold.
47	A four-wheeled design that has a standing driver position and a pedal-pump with a 0.659 CID and a .659 CID keyed shaft. A frame made from carbon fiber, it utilizes hoses for fluid transport, has a 1-quart accumulator, and operates with an electronic system. It includes a manifold
48	This four-wheeled design features a seated upright driver position and a hand-pump with a 1.025 CID and a .659 CID 9-tooth spline. A frame constructed from an aluminum alloy, it utilizes steel tubing for fluid flow, has a 1-gallon accumulator, and operates with a mechanical system and does not include a manifold.
49	This two-wheeled design has a seated upright driver position and includes a pedal-pump with a 0.39 CID and a .659 CID keyed shaft. A frame made from steel alloy, it incorporates hoses for fluid transport, has a 1-quart accumulator, and operates with an electronic system. It includes a manifold.
50	This two-wheeled design features a standing driver position and includes a hand-pump with a 1.025 CID and a .659 CID 9-tooth spline. A carbon fiber frame, it utilizes steel tubing for fluid flow, has a 1-gallon accumulator, and operates with a mechanical system and does not include a manifold.
51-	A four wheeled vehicle that has all the hydraulic, mechatronic circuitry, and motor elements centered between the back wheels to allow for easy distribution of weight without having to worry about the rider balancing the vehicle by his own skill if two wheels were to be used. All wheels will be 30 inch wheels.
Brainstorming	
52	A 4 wheeled vehicle with four motors (1 on each wheel). 30- inch mountain bike tires for stability and to stay low to the ground. Manual changing between different drive modes. Hydraulics and circuits will be placed behind the seat in an open box.

53	A three wheeled vehicle that has all the hydraulic, mechatronic circuitry, and motor elements centered between the back wheels to allow for easy distribution of weight without having to worry about the rider balancing the vehicle by his own skill if two wheels were to be used. All wheels will be 30 inch wheels.
54	A two wheeled design with all components cleverly hidden within the frame of the bicycle to help with keeping a safe center of mass for the rider to focus on the competition at hand without preoccupying himself with stabilizing the bike with his own weight while pedaling.
55	A 2 wheeled vehicle with four motors (1 on each wheel). 30- inch mountain bike tires for stability and to stay low to the ground. Manual changing between different drive modes. Hydraulics and circuits will be placed behind the seat in an open box.
56	A 3 wheeled vehicle with 1 motor to power the back 2 wheels. 24- inch mountain bike tires for stability and to stay low to the ground. Electronic changing between different drive modes. Hydraulics and circuits will be placed behind the seat in an open box. A pedal pump will be used to more easily power the system.
57	A three wheeled designed that has all components at the back of the vehicle where to save space the motors are bought smaller and given a gearbox to compensate in the loss of torque from downsizing the motor. This allows for a better regulation of speed as the max RPM has been lowered.
58-	Custom built frame to accommodate components. The reservoir will be built into the frame to save space. Pneumatics will be used for breaking. An electronic system will be used to switch between drive modes by powering different solenoids that open and closed valves.
59	A 2 wheeled design with training wheels on the back wheel to stabilize the vehicle. Training wheels can be 6 inch wheels while the main bike wheels can be 30 inch wheels.
60	Use two pumps to power the system, one pump is powered by pedaling and the other by hand pumping. This will allow for max efficiency of pumping as more actions from the rider are being directed into powering the system. This quicker acquisition of power will allow for a better performance in races where quick pressure accumulation is required.
61	Instead of pumping by pedaling or by hand, incorporate rowing as the main form of pumping. If incorporated properly and with proper technique pumping may be more effective than the other options.

62	Pump with a motion similar to starting a weed-eater or chainsaw. Similar to rowing it may prove to be more efficient than the other options. This would require for the rider to be standing for this action, therefore a standing configuration.
63	A custom frame composed of materials, stronger and more expensive materials for structural support and lighter less expensive materials for other parts of the frame to reduce
64	An elliptical style version of pumping the pump that requires a vertical/standing rider and three wheels for stability.
65	Use two accumulators one that can be used to raise the efficiency score in the efficiency race and the other that would provide higher performance in the other two races.
66-	Use a 3-wheel vehicle in a rear wheel drive configuration and go-kart style steering
67	Make a carbon-fiber monocoque chassis with go-kart style steering, with all components stored inside the body of the chassis
68-	A three wheeled design that has bicycle style steering and three speed transmission with mechatronic actuated hydraulic lines, a pedal-pump, this would require for the rider to be seated upright, electronically displayed states of the vehicle and an encoder to measure vehicle speed
69	A rowing motion to pump both rear wheel motors, steer by leaning in the direction that you want to go
70-	Purchase a recumbent bike, rear wheel drive on the back wheels and the front for steering, most of the hydraulics would be place behind the seat of the rider
71	Base the design for the rider with non-functioning legs, most likely a three-wheeled seated design, which would implement some unique form of power input and steering for the rider
72	A vehicle that is inspired by a F1 car the design choices would include a spoiler that generates a lot of downwards force to maximize the force of the wheels on the ground
73-	A bike that actively uses regenerative braking on turns during the endurance/sprint races where you would stop pumping, it would be advantageous to use the stored energy
74	Incorporate pneumatics into the design by using air brakes

75	Using a motor that powers a fan that thrusts us forward, and rolls the vehicle forward
76	A vehicle that runs on tank tracks instead of wheels
77	For craftsmanship we will make a custom seated trike with an aesthetic of royalty being carried by his subjects, this could be shown by using a throne shaped seat for the rider to pedal from
78	Mix of custom and purchased frame, with rear-wheel drive, custom suspension
79-	Mix of custom and purchased frame, include a transmission between motor and wheels
Crap Shoot	
80-	For the aesthetics category of the competition, produce a viking themed vehicle, use wood and paint it to look nice. Make outfits based on viking outfits. Incorporate rowing as the way to pump to add to the theme of rowing a viking ship.
81	Monster Truck style bike that has giant wheels, motors, frame doesn't need suspension because the wheels are so big
82	Big wheel and the rider is inside and the moves the inside wheel like a hamster and it powers the outside wall, a monowheel
83	We make a chariot, and it is pulled by a hydraulic system, this would involve rowing to pump the system
84	Instead of traditional wheels, opt for a wheel that uses running blades to propel the vehicle forward taking advantage of the blades stiffness
85	The vehicle is environmentally conscious it uses environmentally friendly components
86	The vehicle uses ABS braking and has a fully decked out entertainment system
87	To help with youth outreach, we design it so that a child could use it during the competition
88	The vehicle is propelled by hitting something with a hammer which causes the pump to pump
89	Make a vehicle that crawls around, pulling itself forward
90	Place everything on a huge skateboard, requires a very talented rider

91	Make a vehicle that jumps forward like a frog
92	Tie a bunch of balloons that lift the vehicle off the ground and have a fan that blows and pushes the vehicle forward
93	Instead of pedaling use a self-propelled treadmill to generate power
94	Just push the vehicle with someone it
Fantasy	
95	We have a very well-trained hamster/dog that is running on a wheel and as the wheel spins it pumps the pump.
96	Our motor spins a fan, and the high speed generates backwards thrust causing the vehicle to fly
97	Our motor spins a fan, and the high speed generates upwards thrust causing the vehicle to fly like a helicopter
98	Incorporate pneumatics by shooting air at opponents
99	The vehicle will be self-driving, no rider will need to be piloting it
100	The vehicle is made from cinnamon sticks and it can be eaten after the race

Appendix F: Concept Selection

Table F.1 – Binary Pair Wise Comparison

	Binary Pair Wise Comparison								
	1	2	3	4	5	6	7	8	Total
1. Ease of Assembly	-	0	0	0	0	0	0	1	1
2. Structural Integrity	1	-	1	1	0	0	0	1	4
3. Ergonomic	1	0	-	1	0	0	0	1	3
4. Stability	1	0	0	-	0	0	0	1	2
5. Weight	1	1	1	1	-	1	1	1	7
6. Store Pressure	1	1	1	1	0	-	1	1	6
7. Regenerative Breaking	1	1	1	1	0	0	-	1	5
8. Responsiveness	0	0	0	0	0	0	0	-	0
Total	6	3	4	5	0	1	2	7	n-1=7

Table F.2 – House of Quality

Customer Requirements	Importance Factor Weight	Material	Time	RPM	Force	Height	Width	Length	Components	Pressure	Acceleration	Roll	Power	Strain
		Engineering Characteristics												
Improvement Direction														
Units														
Ease of Assembly	1	7	9	0	0	3	3	3	9	0	0	0	0	0
Structural Integrity	4	9	0	0	9	1	7	7	3	0	3	3	3	7
Ergonomic	3	0	9	0	7	9	9	9	7	7	3	9	1	0
Stability	2	7	0	0	7	7	7	3	1	0	7	9	0	3
Weight	7	9	0	0	9	7	7	7	7	0	0	0	0	0
Store Pressure	6	0	7	9	7	0	0	0	9	9	7	0	9	0
Regenerative Breaking	5	0	9	3	7	0	0	0	9	9	9	0	7	0
Responsiveness	0	0	9	7	7	0	1	7	9	9	9	0	7	0
Raw Score	1483	120	123	69	211	97	121	113	192	120	122	57	104	34
Relative Weight Percent		8.092	8.294	4.653	14.228	6.541	8.159	7.620	12.947	8.092	8.227	3.844	7.013	2.293
Rank Order		6	3	11	1	10	5	8	2	6	4	12	9	13

Table F.3 – Pugh Chart 1

Selection Criteria	2024 CalPoly	Concept 1	2	3	4	5	6	7	8
Material	Datum	S	S	S	-	S	+	S	S
Time		S	S	-	-	-	-	+	S
Force		-	S	+	-	+	+	+	+
Width		S	S	-	-	S	+	S	S
Components		+	S	+	-	-	+	+	-
Pressure		S	S	S	S	S	S	S	S
Acceleration		+	S	-	-	+	+	+	+
# of Pluses		2	0	2	0	2	5	4	2
# of Satisfactories		4	7	2	1	3	1	3	4
# of Minuses		1	0	3	6	2	1	0	1

Table F.4 – Pugh Chart 2

Selection Criteria	6	Concept		
		5	7	8
Material	Datum	-	S	S
Time		+	S	+
Force		-	+	+
Width		-	-	-
Components		-	S	S
Pressure		S	S	S
Acceleration		-	+	+
# of Pluses		1	2	3
# of Satisfactories		1	4	3
# of Minuses		5	1	1

Table F.5 – Criteria AHP

	Criteria Comparison Matrix[C]						
	1	2	3	4	5	6	7
Material	1.000	1.000	0.200	5.000	0.143	0.111	0.143
Time	1.000	1.000	0.333	7.000	0.143	0.143	0.200
Force	5.000	3.000	1.000	9.000	0.333	1.000	0.333
Width	0.200	0.143	0.111	1.000	0.200	0.143	0.143
Components	7.000	7.000	3.000	5.000	1.000	1.000	1.000
Pressure	9.000	7.000	1.000	7.000	1.000	1.000	1.000
Acceleration	7.000	5.000	3.000	7.000	1.000	1.000	1.000
Sum:	30.200	24.143	8.644	41.000	3.819	4.397	3.819

Criteria Weights	0.046	0.058	0.147	0.025	0.249	0.232	0.244

	Normalized Criteria Comparison Matrix[NormC]							Criteria Weights
	1	2	3	4	5	6	7	{W}
Material	0.033	0.041	0.023	0.122	0.037	0.025	0.037	0.046
Time	0.033	0.041	0.039	0.171	0.037	0.032	0.052	0.058
Force	0.166	0.124	0.116	0.220	0.087	0.227	0.087	0.147
Width	0.007	0.006	0.013	0.024	0.052	0.032	0.037	0.025
Components	0.232	0.290	0.347	0.122	0.262	0.227	0.262	0.249
Pressure	0.298	0.290	0.116	0.171	0.262	0.227	0.262	0.232
Acceleration	0.232	0.207	0.347	0.171	0.262	0.227	0.262	0.244
Sum:	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{W}
0.352
0.442
1.167
0.176
2.014
1.861
1.947

Consistency Vector
{Cons}={Ws}./{W}
7.710
7.622
7.953
7.165
8.093
8.014
7.980
Average
7.791

RI
1.35
Consistency Index
0.132
Consistency Ratio
0.098

Table F.6 – Material AHP

	Material Comparision Matrix[C]		
	6	7	8
Concept 6	1.000	0.333	0.200
Concept 7	3.000	1.000	0.333
Concept 8	5.000	3.000	1.000
Sum:	9.000	4.333	1.533

Criteria Weights	0.106	0.260	0.633

	Normalized Material Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.111	0.077	0.130	0.106
Concept 7	0.333	0.231	0.217	0.260
Concept 8	0.556	0.692	0.652	0.633
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
0.320
0.790
1.946

Consistency Vector
{Cons}={Ws}./{Pi}
3.011
3.033
3.072
Average
3.039

RI
0.52
Consistency Index
0.019
Consistency Ratio
0.037

Table F.7 – Time AHP

	Time Comparison Matrix[C]		
	6	7	8
Concept 6	1.000	3.000	5.000
Concept 7	0.333	1.000	1.000
Concept 8	0.200	1.000	1.000
Sum:	1.533	5.000	7.000

Criteria Weights	0.655	0.187	0.158

	Normalized Time Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.652	0.600	0.714	0.655
Concept 7	0.217	0.200	0.143	0.187
Concept 8	0.130	0.200	0.143	0.158
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
2.005
0.563
0.476

Consistency Vector
{Cons}={Ws}./{Pi}
3.058
3.015
3.015
Average
3.029

RI
0.52
Consistency Index
0.015
Consistency Ratio
0.028

Table F.8 – Force AHP

	Force Comparison Matrix[C]		
	6	7	8
Concept 6	1.000	0.333	0.333
Concept 7	3.000	1.000	1.000
Concept 8	3.000	1.000	1.000
Sum:	7.000	2.333	2.333

Criteria Weights	0.143	0.429	0.429

	Normalized Force Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.143	0.143	0.143	0.143
Concept 7	0.429	0.429	0.429	0.429
Concept 8	0.429	0.429	0.429	0.429
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
0.429
1.286
1.286

Consistency Vector
{Cons}={Ws}./{Pi}
3.000
3.000
3.000
Average
3.000

RI
0.52
Consistency Index
0.000
Consistency Ratio
0.000

Table F.9 – Width AHP

	Force Comparison Matrix[C]		
	6	7	8
Concept 6	1.000	0.333	0.333
Concept 7	3.000	1.000	1.000
Concept 8	3.000	1.000	1.000
Sum:	7.000	2.333	2.333

Criteria Weights	0.143	0.429	0.429

	Normalized Width Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.600	0.600	0.600	0.600
Concept 7	0.200	0.200	0.200	0.200
Concept 8	0.200	0.200	0.200	0.200
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
1.800
0.600
0.600

Consistency Vector
{Cons}={Ws}./{Pi}
3.000
3.000
3.000
Average
3.000

RI
0.52
Consistency Index
0.000
Consistency Ratio
0.000

Table F.10 - Components AHP

	Components Comparision Matrix[C]		
	6	7	8
Concept 6	1.000	0.333	0.333
Concept 7	3.000	1.000	1.000
Concept 8	3.000	1.000	1.000
Sum:	7.000	2.333	2.333

Criteria Weights	0.143	0.429	0.429

	Normalized Components Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.143	0.143	0.143	0.143
Concept 7	0.429	0.429	0.429	0.429
Concept 8	0.429	0.429	0.429	0.429
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
0.429
1.286
1.286

RI
0.52
Consistency Index
0.000
Consistency Ratio
0.000

Consistency Vector
{Cons}={Ws}./{Pi}
3.000
3.000
3.000
Average
3.000

Table F.11 – Pressure AHP

	Pressure Comparision Matrix[C]		
	6	7	8
Concept 6	1.000	1.000	1.000
Concept 7	1.000	1.000	1.000
Concept 8	1.000	1.000	1.000
Sum:	3.000	3.000	3.000

Criteria Weights	0.333	0.333	0.333

	Normalized Pressure Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.333	0.333	0.333	0.333
Concept 7	0.333	0.333	0.333	0.333
Concept 8	0.333	0.333	0.333	0.333
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
1.000
1.000
1.000

Consistency Vector
{Cons}={Ws}./{Pi}
3.000
3.000
3.000
Average
3.000

RI
0.52
Consistency Index
0.000
Consistency Ratio
0.000

Table F.12 – Comparison AHP

	Acceleration Comparision Matrix[C]		
	6	7	8
Concept 6	1.000	0.333	0.333
Concept 7	3.000	1.000	1.000
Concept 8	3.000	1.000	1.000
Sum:	7.000	2.333	2.333

Criteria Weights	0.143	0.429	0.429

	Normalized Acceleration Comparison Matrix[NormC]			Criteria Weights
	6	7	8	{Pi}
Concept 6	0.143	0.143	0.143	0.143
Concept 7	0.429	0.429	0.429	0.429
Concept 8	0.429	0.429	0.429	0.429
Sum:	1.000	1.000	1.000	1.000

Weighted Sum Vector
{Ws} = [C]{Pi}
0.429
1.286
1.286

Consistency Vector
{Cons}={Ws}./{Pi}
3.000
3.000
3.000
Average
3.000

RI
0.52
Consistency Index
0.000
Consistency Ratio
0.000

Table F.13 Alternative Value

Final Rating Matrix			
Selection Criteria	6	7	8
Material	0.106	0.260	0.633
Time	0.655	0.187	0.158
Force	0.655	0.429	0.429
Width	0.600	0.200	0.200
Components	0.143	0.429	0.429
Pressure	0.333	0.333	0.333
Acceleration	0.143	0.429	0.429

Criteria Weights
0.046
0.058
0.147
0.025
0.249
0.232
0.244

Alternative Value
[Final Rating Matrix]^T*{W}
0.379
0.394

Tranposed Matrix						
0.106156324	0.65548654	0.65548654	0.6	0.143	0.333333333	0.143
0.260497956	0.18674948	0.42857143	0.2	0.429	0.333333333	0.429
0.63334572	0.15776398	0.42857143	0.2	0.429	0.333333333	0.429

	Alternative Value
	[Final Rating Matrix]^T*{W}
6	0.302
7	0.379
8	0.394

Appendix A: APA Headings (delete)

Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

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Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.

Figure 1. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 1
The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

Level of heading	Format
1	**Centered, Boldface, Uppercase and Lowercase Heading**
2	**Flush Left, Boldface, Uppercase and Lowercase**
3	***Indented, boldface lowercase paragraph heading ending with a period***
4	***Indented, boldface, italicized, lowercase paragraph heading ending with a period.***
5	*Indented, italicized, lowercase paragraph heading ending with a period.*

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