



## NFPA - FPVC Hydraulic Bike

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## **ABSTRACT**

A hydraulic vehicle is one which uses fluid or specifically hydraulic oil to transfer mechanical energy provided by a rider into fluid energy and back into a mechanical output to drive a vehicle. This is performed using a chain setup to a pump that is then attached to a hydraulic reservoir where through a manifold with solenoids to direct the oil through different pathways you can run the hydraulic vehicle in different modes. Many different mechanical, hydraulic, and electrical components are used to help create this hydraulic vehicle. For our vehicle, the driving power source is provided by human energy like a standard bicycle as well.

## **Special Thanks**

Our team would like to formally thank the individuals who helped to design and build this vehicle. Special thanks to Dan Turner of GPM Controls, our mentor assigned to us through this competition, and Ernie Parker for their guidance in hydraulic and mechanical design. We would also like to thank Professor Abbey Yee for her instruction on the fundamentals of hydraulic systems. The team would also like to thank Jordan Graff for his assistance in frame fabrication. Special thanks to University of Cincinnati instructors Dave Conrad, Nick Plantaniotis and Brian Yockey for their assistance at the Victory Parkway Laboratory. Lastly, we would like to extend thanks to Bob Sheaf of CFC Industrial Training for his help with hydraulic tubing and Josh Scarbrough of IFP Motion Solutions Inc. For his assistance in controls design and implementation.

## PROBLEM DEFINITION

### *PROBLEM STATEMENT*

The goal of this challenge is to design and build a vehicle which is powered by hydraulics and human input. This design project is a submission to the Fluid Power Vehicle Challenge, sponsored by the National Fluid Power Association (NFPA). Specifically, the University of Cincinnati is in the Norgren Competition, as opposed to the Danfoss Power Competition. This challenge is an annual event where schools across the country design, build, and race their hydraulic vehicles. The competition itself is comprised of three separate challenges/races including an endurance, sprint, and efficiency race.

#### 1. **Sprint Race**

- a. This event will demonstrate the ability of the vehicle to move a distance where the weight of the vehicle is proportional to the human propulsion.

#### 2. **Endurance Race**

- a. This event will demonstrate the reliability, safety, replicability, and durability of the fluid power system design and assembly.

#### 3. **Efficiency Challenge**

- a. This event will demonstrate the ability of the vehicle to effectively store and most efficiently use the smallest amount of stored energy to propel the unassisted vehicle the greatest distance proportional to the vehicle's weight.

#### 4. **Regeneration Race**

- a. This event measures the effectiveness of a team's regenerative braking system. The team is given a maximum distance allowed to build up charge till or until their vehicle makes its initial stop going down the hill. Then all this charge will be released into the accumulator drive and the team that can travel the furthest off accumulator charge wins.

## DESIGN OVERVIEW

### **Vehicle Concept**

The 2023 vehicle design is highlighted by its three-wheeled design. The design was inspired by recumbent styled tricycles, where the rider is partially leaning back while riding. In addition, the tube frame of the vehicle also functions as a hydraulic oil reservoir. The vehicle utilizes a combination of manual toggle switches and an HMI device to switch between drive modes and monitor system pressure, respectively. The last major innovation in this year's vehicle is the usage of 3D-printed covers for the drive chains and over the manifold and electrical system hub.

### **Hydraulic System**

For the competition, the rules stated our vehicle must have four drive modes. The four modes are direct drive, accumulator drive, accumulator charge, and regenerative braking. As listed in Figure 1 below, each drive mode has its own path, and each path is determined by

using solenoids throughout the entire circuit. Figure 1 shows the entire schematic using the motor, pump, valves, pressure transducer, accumulator, and manifold in our system. Table 1 shows the bill of materials and the labels used in our circuit.

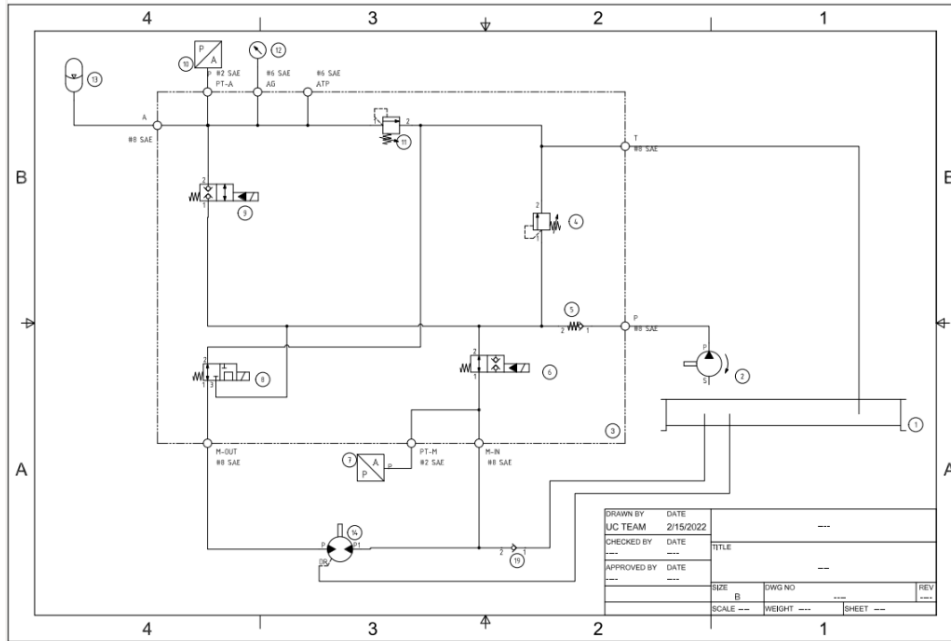


Figure 1: Hydraulic Circuit Schematic

ITEM	QTY	MODEL CODE	DESCRIPTION	MANUFACTURER
1	1	N/A	TANK	UC TEAM
2	1	111.20.370.00	PUMP (0.39 CIR)	DANFOSS
3	1	FV-14043-V1	MANIFOLD	SUNSOURCE
4, 11	2	RV10-10	DIRECT RELIEF	EATON
5	1	CV3-8	CHECK VALVE SIZE 8	EATON
6	1	SBV11-10-0-0-00	SOLENOID 2 POS. 2 WAY	EATON
7, 10	2	HDA-847K-G-3000-40 4	ANALOG PRESSURE TRANSDUCER	HYDAC
8	1	SV1-10-3	3/2 DIRECTIONAL VALVE	EATON
9	1	SBV1-10-C	2/2 BI-POPPET NC	EATON
12	1	N/A	ACCUMULATOR PRESSURE GAUGE	N/A
13	1	N/A	CARBON FIBER ACCUMULATOR (1 GALLON)	N/A
14	1	121.20.043.00	GEAR MOTOR (0.659 CIR)	DANFOSS
19	1	CV3-10	CHECK VALVE SIZE 10 (EXTERIOR, SPRING REMOVED)	EATON

Table 1: Hydraulic Circuit Component List

### Direct Drive

During this drive mode, our bike will directly convert human mechanical power to hydraulic power to power the back two wheels. The person on the bike will pedal forwards causing the fluid to be taken from the reservoir and head towards the pump. The pump will then convert the fluid to a higher pressure and will begin to send this fluid towards the motor. The hydraulic motor will then convert the hydraulic power to mechanical power allowing the bike to drive forwards.

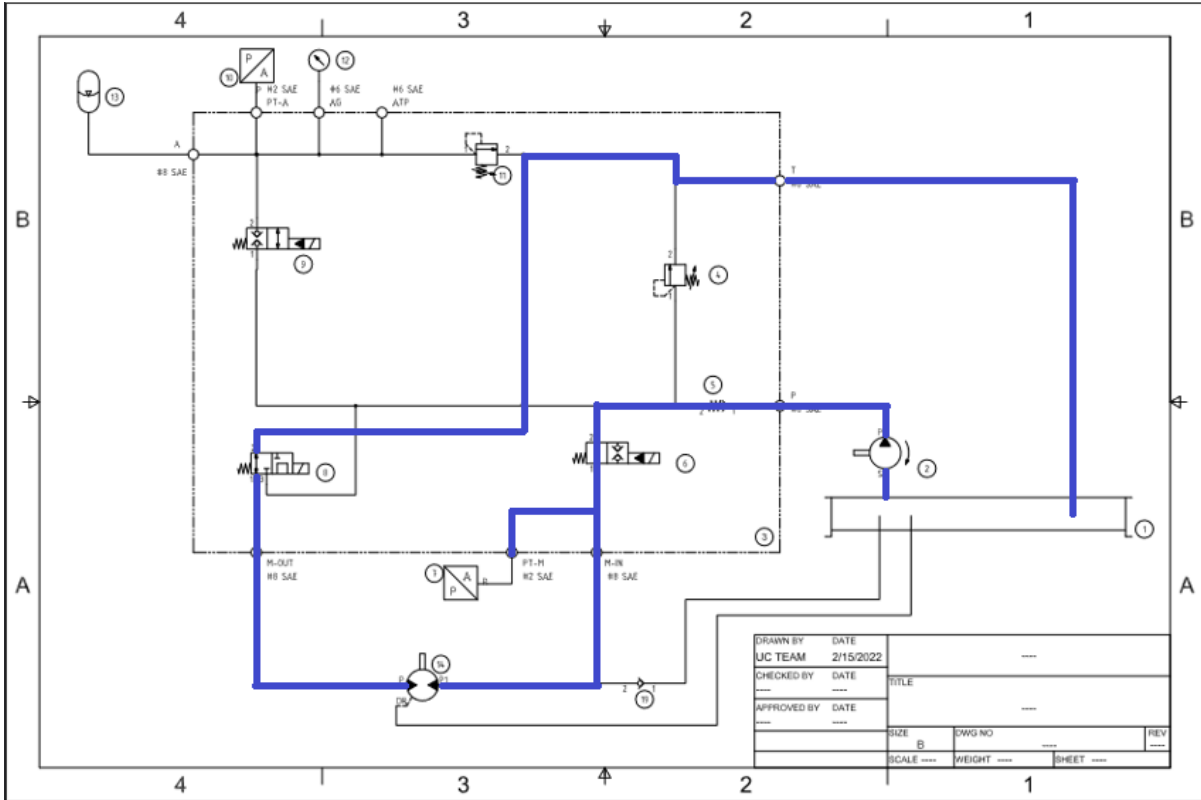


Figure 2: Direct Drive Flow Path (Begin at Item #2)

**Accumulator Charge**

During this charging mode, the bike will use fluid to begin charging the accumulator. This mode will be done while the bike is stationary and will not result in any movement of the bike’s wheels. The rider will pedal the bike forward which will begin pulling fluid from the reservoir. The fluid will travel into the accumulator which will begin to fill up and gain pressure. This fluid in the accumulator will be used for the accumulator driving mode.

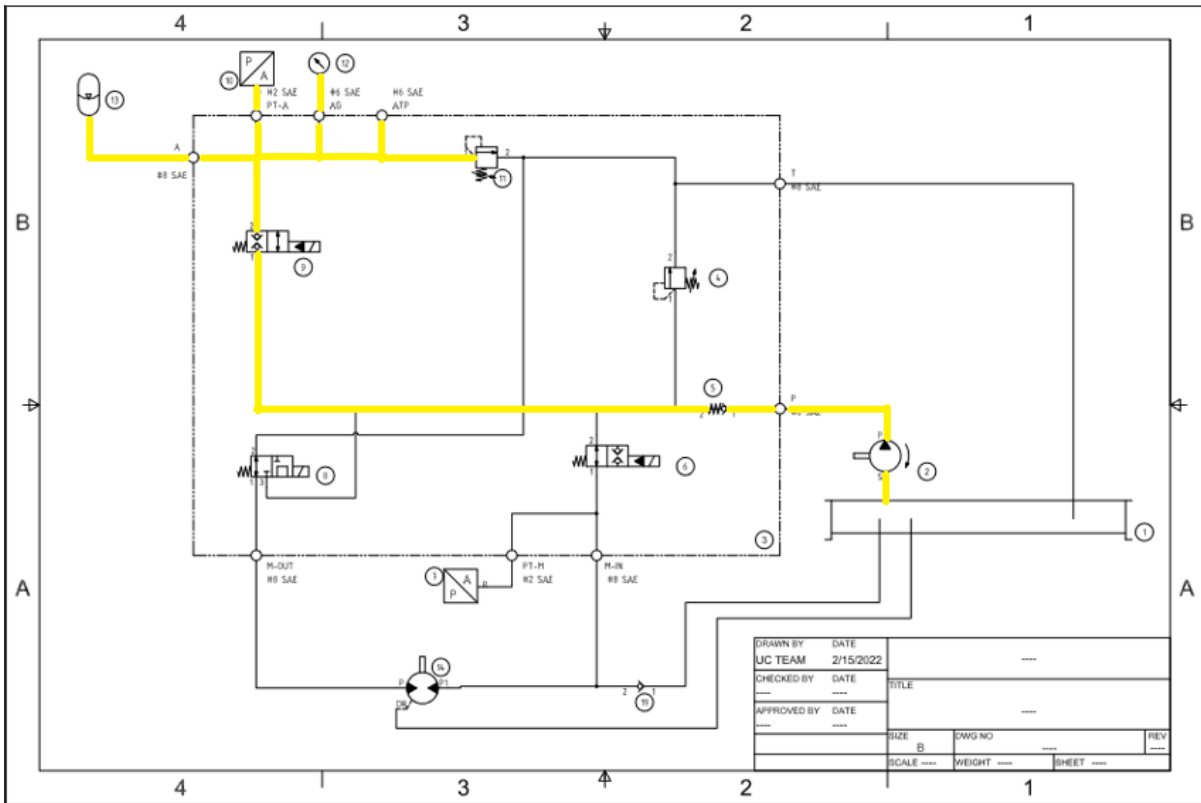


Figure 3: Accumulator Charge Flow Path (Begin at Item #2)

**Accumulator Drive**

This drive mode will use the accumulated pressure within the accumulator from the accumulator charge mode. The charged and pressurized fluid from the accumulator will be allowed to flow directly to the hydraulic motor. This pressurized fluid will allow the bike to move forwards solely based on the power of the fluid itself, meaning no mechanical power of the person pedaling will be necessary.



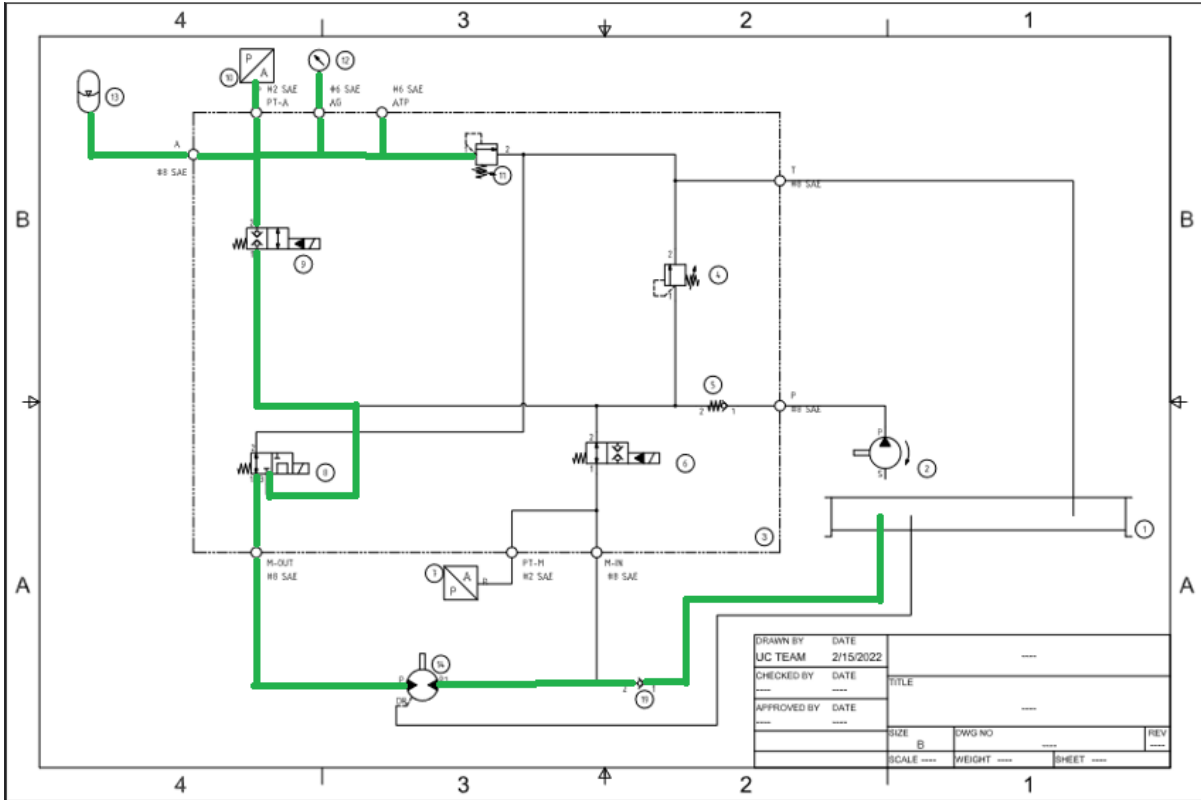


Figure 5: Regenerative Braking Flow Path (Begin at Item #1)

**Hydraulic Manifold**

A hydraulic manifold is a block used to allow for a much easier design and representation of our hydraulic system. The inside of the manifold is full of piping that allows the fluid to flow exactly where we needed to allow for the incoming fluid to flow to its designated outputs. This manifold also allows us to place all our solenoids within the same vicinity to control where fluid flows. Without this block, our hydraulic system would consist of a convoluted mess of various pipes and would consume more space.

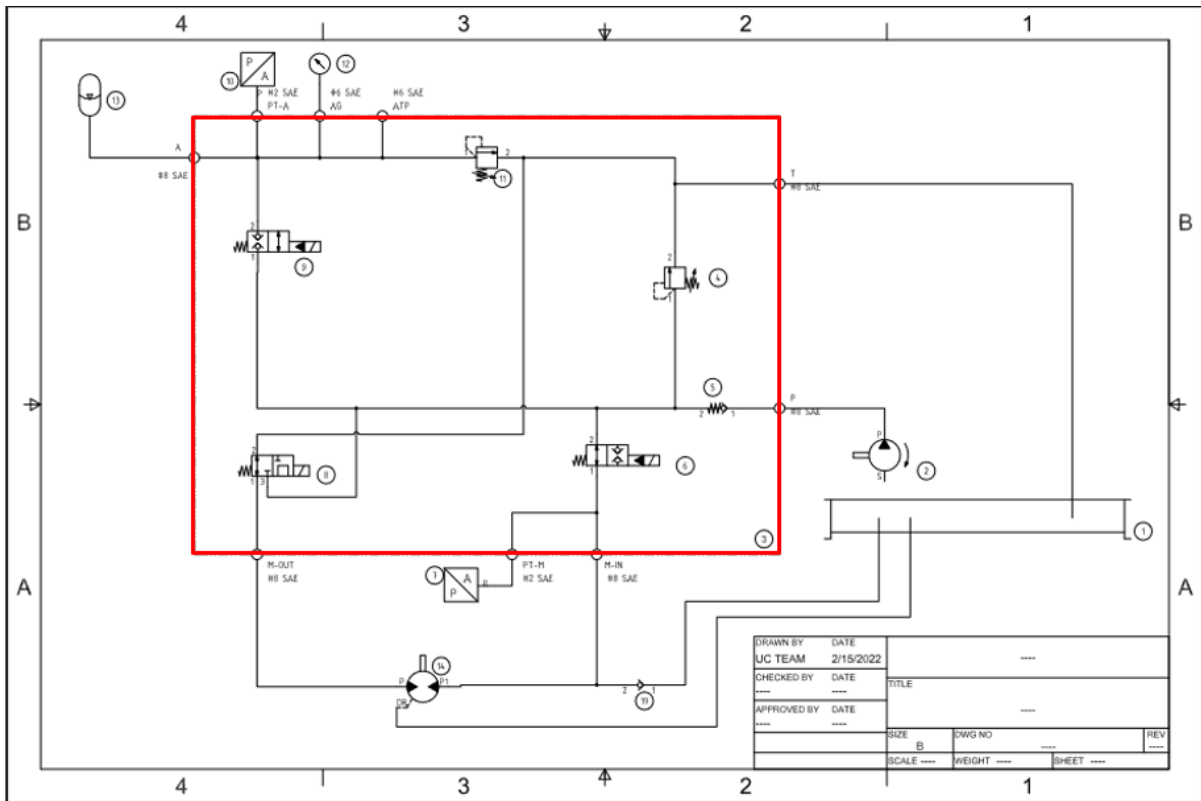


Figure 6: Circuit with Manifold Highlighted in Red

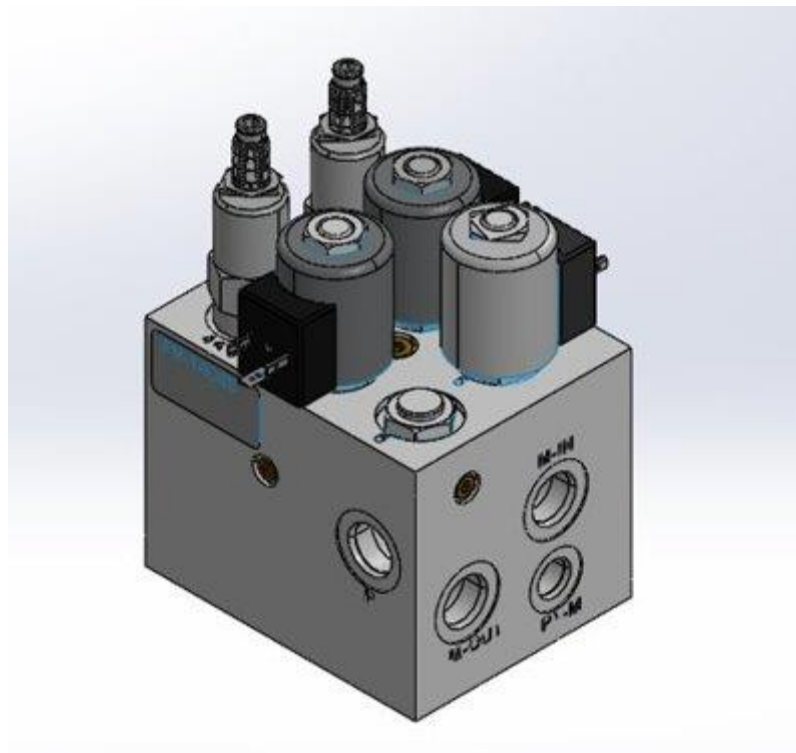


Figure 7: CAD Model of Manifold with Valves Attached

### Electronic System

Our original plan was to use an HMI screen that utilized a screen created in a software called JMobile. The code to control the screen, buttons, and solenoids would be done in a software called Codesys. The plan was to have buttons for each drive mode to activate the necessary solenoids to achieve each drive mode.



Figure 8: HMI Screen

Unfortunately, the Codesys software was unable to connect to any of our computers. On top of this, our computers received blue screen errors while attempting to install the software. We were only able to use the HMI to read the pressures of the fluid from two pressure transducers. This caused us to wire and use a failsafe toggle-switch system that controlled each solenoid. We 3D-printed a mount for the switches to indicate what switches needed to be toggled for each drive mode. This was the electronic system we used to control our bike.



Figure 9: Toggle Switch Mount with Mode Labelling

### Frame and Fabrication Design

The idea of the frame was to build it from scratch and to make it easier to balance while riding the vehicle and charging the accumulator. Therefore, a semi-recumbent frame was fabricated with the help of Iron Belle Metal Design, David Hirschberg Metal, and SolidWorks. The main feature of the frame was that part of the frame was the hydraulic tank as shown in Figure 10 with the arrows indicating where the tank is located. The frame was made using A513 DOM steel tubing, 1018 steel round stock, 1018 steel tubing, and 1018 .125" thick sheet metal. To make sure the frame was safe and structurally sound, a factor of

safety of four was added into the deformation simulation on SolidWorks. Making the reservoir part of the frame of the vehicle saved weight and used up empty space allowing room for more room for other components.



Figure 10: Hydraulic Tank as Part of the Frame



Figure 11: Final CAD Model of Vehicle in SolidWorks



Figure 12: Final Vehicle

### **Gearing Design**

The gearing on our vehicle was complex and consisted of eight sprockets. The biggest feature of our gearing system was the compound gear set up that had a total of three stages. The sprockets that ran the hydraulic pump had an overall gear ratio of 3:1. This included the sprockets that went from the pedals to the second stage and then to the pump. The first stage of the pump gear ratio was a 14-tooth sprocket to a 9-tooth sprocket. The second stage also had a 14-tooth to a 9-tooth sprocket. The third stage had a 22-tooth sprocket to a 22-tooth sprocket. The hydraulic motor to the axle had a ratio of 1:2 where the motor had a 9-tooth sprocket on it and the axle had an 18-tooth sprocket. To run all these sprockets, ANSI roller chain size 40 with a  $\frac{1}{2}$  in pitch was used.

The original goal of the gearing was to use a 20" diameter 125 tooth sprocket to make a gear ratio of 22:1. The idea behind the large gear ratio and multi-phase gearing system was to use the least amount of torque required to make the pump spin at higher RPM. The higher the pump RPM was, the more efficiently the hydraulic fluid would move and build pressure. Unfortunately, during testing, the team determined that this large sprocket was not going to work. The calculated torque required to rotate the large sprocket was over 700-foot pounds which was impossible to achieve during pedaling of the vehicle.

### ***DESIGN ALTERNATIVES AND SELECTION***

During the design process, the team developed multiple ideas for the overall design of the vehicle. The team narrowed down the designs to three individual designs before selecting one to proceed with. The designs included a traditional two wheeled vehicle, a three wheeled vehicle similar to a tricycle, and a recumbent-bicycle inspired three wheeled vehicle design. The team decided to proceed with the recumbent vehicle due to its lower center of gravity and increased stability. The below section provides a brief insight into the other designs that were considered:

## Bike Design



Figure 13: Traditional Bicycle Frame Design

Our original design was to base our frame around a standard bicycle. This matched what all of our previous teams designed which would allow us to better visualize how to organize all of our components. Our main change to this design was to implement a tank within our frame. This is shown by the thicker tubes around and under where the person would sit on the bike.

## Tricycle V1

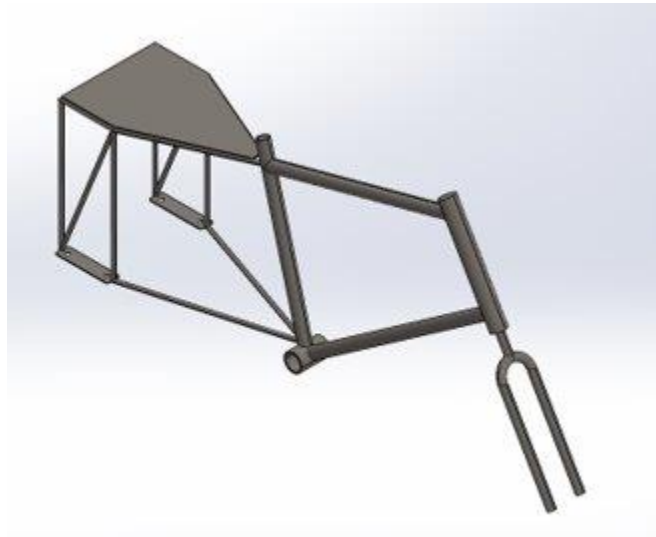


Figure 14: Traditional Tricycle Frame Design

We realized that it proved difficult to charge our accumulator as this requires the bike to be stationary. With a traditional bicycle we required two people to hold up the bike while a third pedaled and even then, charging was still difficult. This is the main reason we then adopted a three-wheel design to have balance while charging our accumulator. This would also allow us to have a wider space for components in the back end of our bike.

## Final Bike Design

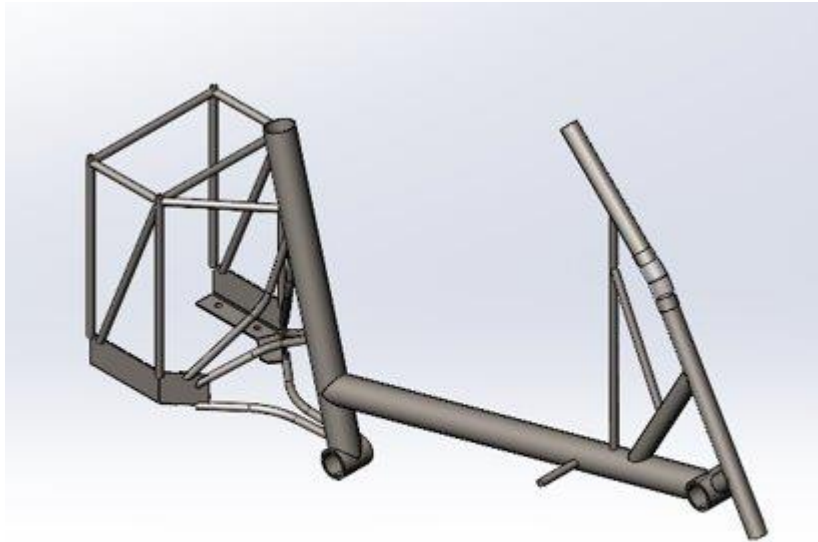


Figure 15: Recumbent-Inspired Frame Design

Our final design came about after talking with our industry mentor. He suggested that we adopt a recumbent style of vehicle similar to those that have been produced recently. The reasoning behind these designs is that the ride position allows for more torque on the pedals as well as a more comfortable riding position while peddling. We were also able to incorporate our frame tank into this design.

## *ENGINEERING CALCULATIONS*

### List of equations

Grade to radians

$$\text{Radians} = \text{Tan}^{-1}\left(\frac{\text{Grade}}{100}\right)$$

Pull of bike (Pull 1)

$$\text{Pull 1} = \text{Sin}(\text{Radians}) \cdot \text{Weight}$$

Pull of bike (Pull 2)

$$\text{Pull 2} = \text{cos}(\text{Radians}) \cdot \text{Weight} \cdot \text{Rolling Resistance}$$

Total Uphill Pull

$$\text{Total pull} = \text{Pull 1} + \text{Pull 2}$$

Torque Required

$$\tau = \text{Uphill Pull} \cdot r$$

Wheel RPM

$$RPM = \frac{(336 \cdot \text{Desired MPH})}{d}$$

Motor CIR M Calculated

$$CIR = \frac{\tau \cdot 2\pi}{CIR \text{ Chosen}}$$

Adjusted PSI

$$PSI \text{ Adjusted} = \frac{(\tau \cdot 2\pi)}{CIR \text{ Chosen}}$$

Motor CIR M Calculated

$$CIR \text{ Available} = \frac{CIR}{\text{Motor Efficiency}}$$

Gallons/Minute of Flow

$$GPM = \frac{(CIR \cdot REQ'd \cdot RPM)}{231}$$

Motor HP Required

$$HP = \frac{(GPM \cdot PSI \cdot \text{Adjusted})}{1714}$$

Motor HP Required (Check)

$$HP = \frac{(\tau \cdot RPM)}{63025}$$

Motor Efficiency

$$\text{Efficiency} = \frac{(\text{HP Check})}{\text{Motor Efficiency}}$$

Pump RPM

$$\text{Pump RPM} = \text{Pedaling RPM} \cdot \text{Gear Ratio}$$

Pump CIR Required

$$CIR = \frac{(GPM \cdot 231)}{RPM}$$

Pump CIR Available

$$CIR Available = \frac{(CIR Chosen)}{Pump Efficiency}$$

## Loading Conditions

After the main frame was created in Solidworks 3D, we were then able to use the built in stress analysis software to see where loading conditions were greatest and if they exceeded the chosen materials yield strengths. We also decided to put it into Ansys as a double check to ensure that this first test was accurate and according to Ansys it was. So, with two different software's confirming our material would hold we decided to go with our designed frame and chosen material and began fabrication of the frame.

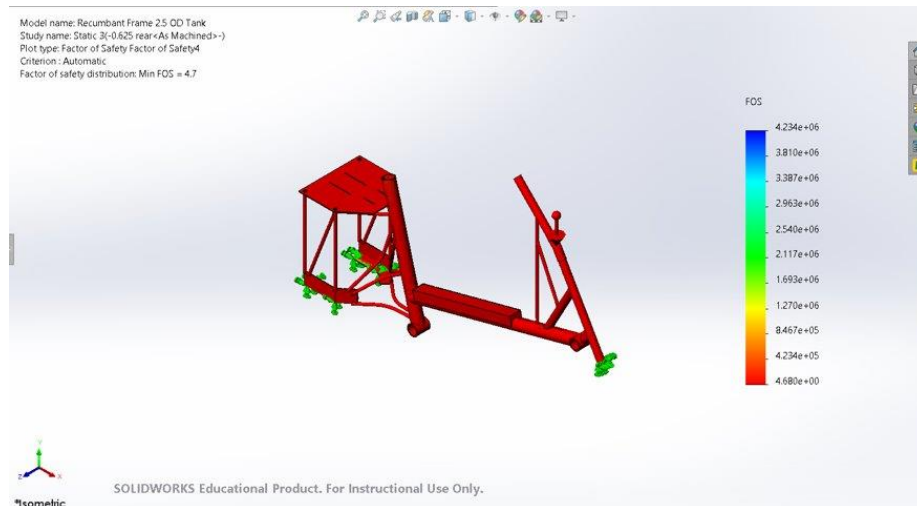


Figure 16: Deformation Simulation Performed in SolidWorks

## Material Selection

The material we decided to use for our bike frame was 1018 cold rolled steel, it had good strength and was priced below market value as well. Along with the supply chain issues that were present when we were ordering materials, ordering a plentiful type of steel would ensure we would be able to have enough material to actually make the bike. We also selected 1018 cold rolled steel as it had good welding properties as well and since we knew a lot of welding would need to be done on the bike making sure we picked a material that helped with this was crucial as well.

## Factors of Safety

A safety factor of 4.7 was targeted for the overall frame to ensure that unexpected failure of the bike was avoided, and it could withstand any sudden loads as well. When talking to our mentor Dan Turner, he had told us that having a factor of safety greater than 3 would make the bike frame more than reliable enough for our purposes.

MANUFACTURING DRAWINGS

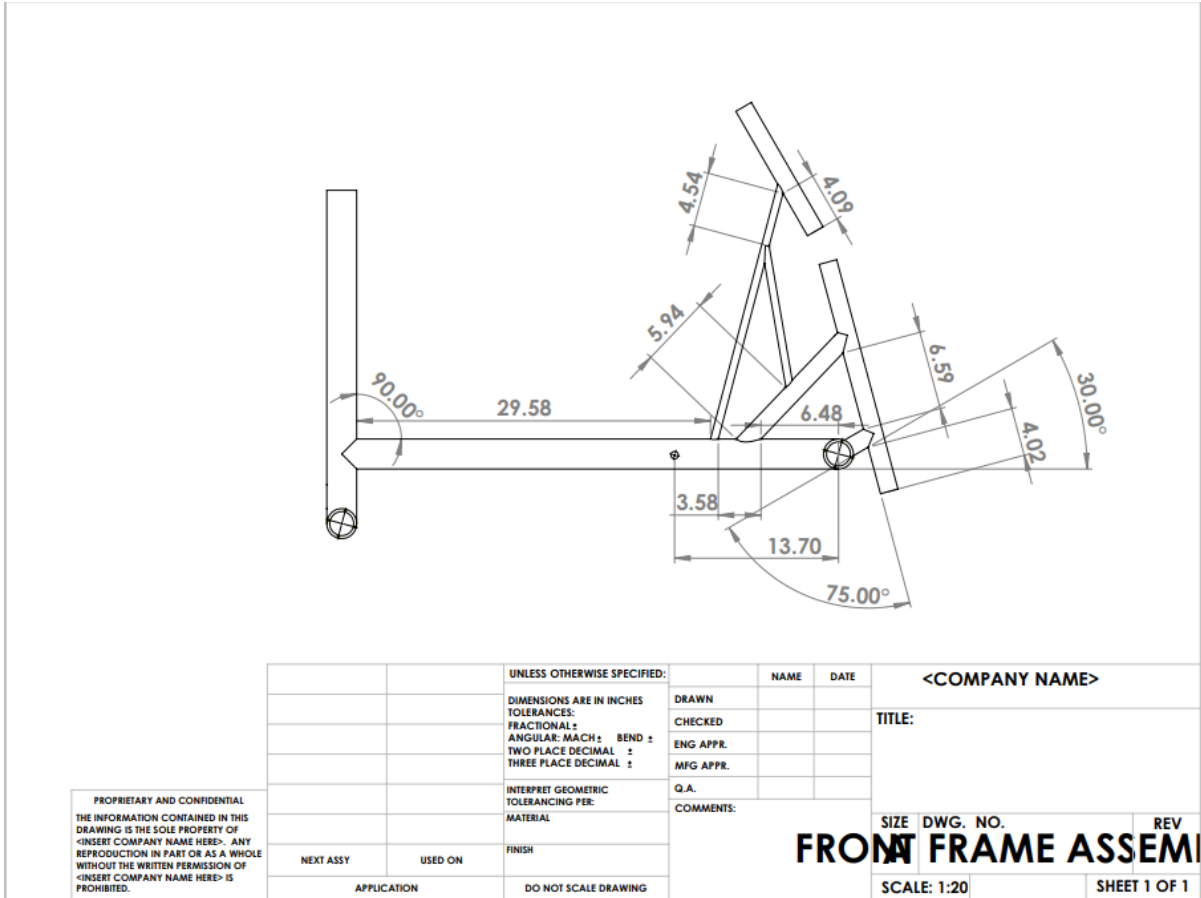


Figure 17: Frame Assembly Drawing

Bill of Materials

Item	Quantity	Value	Total Value	Supplier
2.5" OD x .065" Wall DOM Tube x 72"	1	\$48.00	\$48.00	David Hirschberg Steel
1.5" OD x .065" Wall DOM Tube x 76"	1	\$39.00	\$39.00	
2.5" OD x .250 Wall DOM Tube x 6"	1	\$95.00	\$95.00	
5/8" CR 1018 RND x12'	2	\$25.00	\$50.00	
4'x8' sheet of .125" 1018 Plate Steel	1	\$320.00	\$320.00	
5/8" OD x .120" Wall A513 Tube 22' x 8"	1	\$104.00	\$104.00	

1" OD x 0.083 wall A513 Tube x 48"	1	\$116.00	\$116.00	
1" OD RND 1045 Steel x 24"	1	\$16.62	\$16.62	Online Metals
Total:			\$788.62	

Table 2: Frame Bill of Materials

Item	Quantity	Value	Total Value	Supplier
.337 CIR Hydraulic Gear Pump	1	\$252.00	\$252.00	Hydraulic Controls
.657 CIR Hydraulic Gear Motor	1	\$349	\$349	SunSource
External Check Valve	1	Previous Team	Previous Team	Previous Team
Valve 6	1	\$98	\$98	SunSource
Valve 8	1	\$45	\$45	SunSource
Valve 9	1	\$65	\$65	SunSource
Check Valve	1	\$15	\$15	SunSource
Pressure Relief Valve	2	\$41	\$82	SunSource
Total:			\$906.00	

Table 3: Hydraulic Bill of Materials

Item	Quantity	Value	Total Value	Supplier
16 AWG Wire (Red)	9 ft	\$12.00	\$12.00	Autozone
16 AWG Wire (Black)	9 ft	\$12.00	\$12.00	Autozone
Batteries and Charger (24v)	1	Previous Team	Previous Team	Previous Team
Wire Connectors	49	\$18.00	\$18.00	Harbor Freight
Solenoid 82A	2	\$26.00	\$52.00	SunSource
Solenoid 142A	1	\$23.00	\$23.00	SunSource
Total:			\$117.00	

Table 4: Electronics Bill of Materials

Item	Quantity	Value	Total Value	Supplier
Overture 3D Printer Filament	4	\$25.00	\$100.00	Amazon
Tools	--	--	\$398.26	Harbor Freight
Welding of Frame	1	\$1600.00	\$1600.00	Iron Belle Metal Design
Water Jet	1	\$108.00	\$108.00	1819 Innovation Hub

Sprocket Material	1	\$206.91	\$206.91	Online Metals
U-Haul Trailers	2	\$75.08	\$75.08	U-Haul
Wood for Shipping Crate	1	\$89.11	\$89.11	Home Depot
Paint	3	\$7.60	\$22.82	Ace Hardware
Hydraulic Brake Hose	1	\$33.75	\$33.75	Amazon
ANSI 40 Chain – 10ft	2	\$35.85	\$71.70	Grainger
ANSI 40 Chain Connecting Links	3	\$8.80	\$26.40	Grainger
ANSI 40 Add and Connect Link	5	\$3.92	\$19.60	McMaster-Carr
Miscellaneous Hardware	--	\$127.88	\$127.88	McMaster-Carr
U-Joint	1	\$15.95	\$15.95	Amazon
Two Bolt Flange Bearings	4	\$11.33	\$45.32	McMaster-Carr
20° Pressure Angle Gears 16 Pitch 24 Teeth	1	\$36.65	\$36.65	McMaster-Carr
20° Pressure Angle Gears 16 Pitch 48 Teeth	2	\$75.18	\$150.36	McMaster-Carr
24” Mountain Bike Tires	3	\$44.99	\$134.97	Northern Tool and Equipment
Seat	1	\$49.58	\$49.58	Amazon
Seat Mount	1	\$69.99	\$69.99	Amazon
Protective Plastic U-Channel Covers	1	\$31.99	\$31.99	Amazon
Total:		\$3,414.32		

Table 5: Miscellaneous Bill of Materials

## BUILD AND TEST

### *DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED*

To manufacture our vehicle, the team utilized a multitude of processes and outside resources. The material for the frame of the vehicle was ordered through David Hirschberg Steel and brought over to Victory Parkway Campus where the team cut all the metal to the desired dimensions. Also at Victory Parkway Campus, is where the team utilized the machine shop to do tube bending and tube notching. After all the tubes were bent and notched, the parts were taken over to Iron Belle Metal Design in Cincinnati, OH where the owner of the shop, Jordan Graff, welded our frame together per the manufacturing drawing we gave him.

One of the team member’s shops, Specialty Manufacturing Solutions, machined bearing mounts on their CNC lathe for the project. After the frame came back from Jordan Graff’s

shop, the team started to assemble the vehicle. Although Jordan performed a majority of the welding, the team used the welding lab at Victory Parkway to add other brackets and more supports where we thought they were needed. Utilizing the machine shop at Victory Parkway, the team made bushing, shafts, and additional minor components on the manual lathes. We also used the CNC mill in the machine shop to make keyways on all the shafts that had a sprocket on it. After the keyways were completed, the team had to broach a few components for the keys to lock into.

The largest problem with the fabrication of the vehicle was supply chain issues. In order combat this problem, the team used 3D-printing for mocking up parts. The manifold was manufactured through Sun Source Fluid Power and with the help of Jeff McCarthy. The original delivery date of the machined manifold was in the middle of February, at this point the team was running out time to complete everything so we 3D-printed a scale model of the manifold to mount on the vehicle so hydraulic lines could be fitted.

CFC Industrial Training in Fairfield, OH supplied the hydraulic lines, where the team flared and bent hydraulic tubes with the oversight of the owner, Bob Sheaf. After all the tubes were bent and the manifold arrived, the lines were put on the vehicle. All the valves were inserted into the manifold by hand and torqued to a specific value. All the wiring for the controller, toggle switches, display, sensors, valves, and battery were done by the team.

Finally, the last thing to manufacture were the chain guards required for competition. All the chain guards were 3D-printed by team members. In order to put the chain guards on the vehicle, they were plastic-welded together and then put in the corresponding locations. Overall, the vehicle was completely made from scratch and only a handful of parts were bought off the shelf to create this vehicle.

### ***FABRICATION AND ASSEMBLY ISSUES***

Throughout the building process, a number of issues appeared that modified the design of the vehicle. The first main issue was concerned with the U-joint used in the steering of the vehicle. The U-joint was having issues with gripping the steering column, causing it to slip when steering. It was decided to remove the set screws in the U-joint and replace them with roll pins that run through the steering column. This modification resolved the issue and allowed for the desired steering of the vehicle.

After resolving the U-joint, it was found that the main sprocket located at the front of the vehicle had a number of issues, most notably being improper tooth engagement and continual chain slippage. Upon closer inspection, it was found that the sprocket experienced some sort of warping or was out of true. It was determined that due to these issues, the sprocket was unable to be used, and was subsequently replaced with a smaller sprocket, reducing the gear ratio from 3 to 1. Incidentally, the removal of the sprocket allowed for an increased turn radius for the vehicle.

The clutch system of this year's vehicle ultimately occupied the majority of our time with regards to troubleshooting. Originally, the plan was to utilize a derailer clutch to shift from a smaller motor to a larger motor to a neutral position. Upon installation, it was determined that the derailer was unable to function as desired due to the chain being too wide. In place of the derailer, the team designed a gearbox to perform a similar function. The way the gearbox operates is as follows: it involves a large gear attached to the pump chain via a sprocket on a shaft connecting the two on one end and the other large gear connects to

the drive shaft chain with a sprocket gear as well through a small shaft as well. Then these larger gears were connected via a smaller gear that could be inserted or removed between the two larger gears to allow for a “neutral” gear or to allow direct drive to be engaged. Ultimately due to not having enough resistance to ensure the smaller gear stayed in place between the two larger ones prevented us from being able to use this device on our final vehicle. As a result of the limited function of the gearbox, it was decided to remove one of the motors from the vehicle. While the gearbox design worked as intended, the gearbox itself also required some troubleshooting. Originally, it was intended to use a shifter cable to manipulate the spring to push the gear in and out. However, it was determined that the cable was not strong enough to push and pull the spring, and a linear actuator was utilized in replacement of the cable.

The last major issue that appeared in the assembly process was a failure with the controls system. In the process of wiring the controls system, it was found that the HMI controller was failing to communicate with the solenoids in the manifold. After troubleshooting, it was determined that the wiring harness was faulty, and a replacement needed to be ordered. In order to circumvent this problem so that the vehicle could be tested, a toggle switch system was implemented. This system allowed for manual switching of valve positions via the solenoids. As a contingency plan, the team decided to bring the toggle switch system to the competition in case the wiring harness failed or was damaged in shipping.

### ***TEST PROCEDURE AND CRITERIA***

For our tests we decided to run with a few tests from last year's team like top speed, time to reach top speed, and time to fully charge the accumulator. We also did unofficial testing on our regenerative breaking mode.

For each test, the criteria were as follows:

Top speed and time to direct drive— record time for bike to reach top speed or when rider is as fast and constant as can be with their speed to record the time. We also used the distance traveled and total time to do to help find these as well.

Time for max accumulator charge – first we ran a non-timed run to see what max pressure could be achieved for the accumulator. Then once we knew this information, we started a timer and then had people peddling the pedals with their feet/arms and once we reached our max pressure the timer would stop.

**TEST RESULTS AND FINDINGS**

The results from our preliminary tests like top speed, time to reach top speed, and time to fully charge the accumulator is shown below.

Testing Data				
Team	Top Direct Drive Speed (MPH)	Top Direct Drive Speed (FPS)	Time to Top Direct Drive Speed (s)	Time to Max Accumulator Charge
2022	9.67	14.18	38.7	3:38
2023	5.66	8.31	19.5	1:47

Table 6: Testing Data

Table 6 shows the testing data that was recorded between the 2022 team and 2023 team. Our goal for this year's team was to get a higher top speed for direct drive, unfortunately, that goal was not met. On the other hand, the time to fully charge our accumulator was half of last year's team.

**PROJECT MANAGEMENT**

In order to complete the vehicle on time and allow for proper testing, the team developed strict deadlines for high importance items. These deadlines were for items such as finalizing the hydraulic circuit design, completion of frame design, fabrication of the frame, etc. The team utilized a spreadsheet for tracking the status and completion of minor tasks as assembly progressed. This system allowed for the tracking of progress on tasks, as well as assigning importance to tasks and personnel to each task. Figure 18 shows a screenshot of what the spreadsheet looked like during the assembly process. In addition to tracking tasks, the team held weekly meetings to establish goals for the week and what tasks needed to be completed.

Task That Needs Completed	Status	Desired Completion Date	Personnel	
Weld HMI Mount		2/28/2023	Jacob	Completed
Bearing Mount		2/28/2023	Jack	Low Importance/Severity
Gearbox Spring Test		3/1/2023	Jacob, Jack	Medium Importance/Severity
Chain		3/3/2023	Jack, Jacob	High Importance/Severity
Brake Lines		3/3/2023	Jacob, Jack, Evan	Immediate Importance/Severity
New Wheels		3/6/2023	Jacob	
Bushings	Pending New Wheels	3/7/2023	Jack	
Design Chain Covers		3/10/2023	Jacob	
Hydraulic System Reassembly		3/10/2023	Jack, Jacob	
Wiring		3/10/2023	Will, AJ	
Design Manifold Cover		3/10/2023	Evan	
Print Chain Covers		3/10/2023	Jacob	
Axel		3/10/2023	Jack, Jacob	
Paint		3/10/2023	Evan	
Mentor Meeting #4		3/10/2023	ALL	
Linear Actuator		3/15/2023	Jacob/ Jack	
Order Approved Helmet	Has to fit Jack's and Jacob's big ass head	3/17/2023	Jacob, Evan	
Weld Manifold Cover		3/24/2023	Evan, Jacob	
Poster Board	Start Spring Break	3/31/2023	ALL	
Cover Decal	Pending Completion of Manifold Cover	3/31/2023	Evan	
Final Presentation	Start Spring Break	3/31/2023	ALL	
Prepare Travel Tool List		3/31/2023	Jacob, Jack, Evan	
Video for NFPA	Proof of working vehicle	4/1/2023	ALL	
Video for Tech expo	Spring Break	4/1/2023	ALL	
Build Crate		4/3/2023	Jacob, Jack, Evan	
Proof of Working Vehicle		4/5/2023	Evan	
Deflate Accumulator	Prepackaging	4/6/2023	Jack	
Package Vehicle		4/6/2023	ALL	
Ship Vehicle		4/7/2023	ALL	
Submit Presentation		4/10/2023	Evan	
Final Report	Start Spring Break, Outlined	4/21/2023	ALL	

Figure 18: Task Tracking Spreadsheet

## CONCLUSIONS

Overall, the vehicle presented at the Fluid Power Vehicle Challenge this year failed to match the performance of other universities. The regression in performance for this year’s vehicle can be traced to two main factors: improper pump and motor sizing and unoptimized gearing. However, the vehicle did experience some improvements, most notably the accumulator and regenerative braking functions. The biggest improvement with regards to the vehicle was to the overall safety and reliability of the vehicle, which the University of Cincinnati was awarded. This award was achieved through the creative usage of the 3D-printed chain guards that protect the rider from being caught in the chains during operation.

## Suggestions for Improvement

- Design vehicle for ideal gearing
- Use metal tubing to conserve weight as opposed to round stock
- Utilize pneumatic clutch
- Research pump and motor sizing further
- Look into utilizing a differential if reusing this frame
- Consider using a traditional recumbent tricycle for next frame
  - Teams that used this style experienced great success
  - Research Ackerman steering
- Design seating for shortest rider
  - Pedal to seat distance prevented shorter team members from being able to efficiently pedal the vehicle
- Find an ideal pressure to pre-charge the accumulator
  - Ideal pressure makes it easier to charge while also allowing for the optimal use of the accumulator

# APPENDIX

## Code Inputs-

```
0001(*INPUT MAPPING *)
0002
0003
0004
0005
0006IF analog_input_one_fresh THEN
0007 IF analog_input_one_val > 100 THEN
0008     scale_Transducer( r_Raw := analog_input_one_val, (*bit that states value exists to read*)
0009                     r_RawMin := 500.0, (*reading directly from pin J4 *)
0010                     r_RawMax := 4500.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 500.0 would be our minimum input voltage*)
0011                     r_OutMin := 0.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 4500.0 would be our maximum input voltage*)
0012                     r_OutMax := 4000.0, (*Minimum value in PSI*)
0013                     r_Out := r_transducer_1_PSI); (*Maximum value in PSI*)
0014 ELSE
0015     r_transducer_1_PSI := 0.0;
0016 END_IF
0017 END_IF
0018
0019
0020IF analog_input_two_fresh THEN
0021 IF analog_input_two_val > 100 THEN
0022     scale_Transducer( r_Raw := analog_input_two_val, (*bit that states value exists to read*)
0023                     r_RawMin := 500.0, (*reading directly from pin H4 *)
0024                     r_RawMax := 4500.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 500.0 would be our minimum input voltage*)
0025                     r_OutMin := 0.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 4500.0 would be our maximum input voltage*)
0026                     r_OutMax := 4000.0, (*Minimum value in PSI*)
0027                     r_Out := r_transducer_2_PSI); (*Maximum value in PSI*)
0028 ELSE
0029     r_transducer_2_PSI := 0.0;
0030 END_IF
0031 END_IF
0032
0033
0034IF analog_input_three_fresh THEN
0035 IF analog_input_three_val > 100 THEN
0036     scale_Transducer( r_Raw := analog_input_three_val, (*bit that states value exists to read*)
0037                     r_RawMin := 500.0, (*reading directly from pin A4 *)
0038                     r_RawMax := 4500.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 500.0 would be our minimum input voltage*)
0039                     r_OutMin := 0.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 4500.0 would be our maximum input voltage*)
0040                     r_OutMax := 4000.0, (*Minimum value in PSI*)
0041                     r_Out := r_transducer_3_PSI); (*Maximum value in PSI*)
0042 ELSE
0043     r_transducer_3_PSI := 0.0;
0044 END_IF
0045 END_IF
0046
0047
0048IF analog_input_four_fresh THEN
0049 IF analog_input_four_val > 100 THEN
0050     scale_Transducer( r_Raw := analog_input_four_val, (*bit that states value exists to read*)
0051                     r_RawMin := 500.0, (*reading directly from pin A3 *)
0052                     r_RawMax := 4500.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 500.0 would be our minimum input voltage*)
0053                     r_OutMin := 0.0, (*in millivolts, this specific sensor is setup to range from 5v to 4.5v 4500.0 would be our maximum input voltage*)
0054                     r_OutMax := 4000.0, (*Minimum value in PSI*)
0055                     r_Out := r_transducer_4_PSI); (*Maximum value in PSI*)
0056 ELSE
0057     r_transducer_4_PSI := 0.0;
0058 END_IF
0059 END_IF
0060
0061
0062(* Convert to whole number and cast to WORD for CAN *)
0063w_transducer_1_PSI := REAL_TO_WORD(r_transducer_1_PSI);
0064w_transducer_2_PSI := REAL_TO_WORD(r_transducer_2_PSI);
0065w_transducer_3_PSI := REAL_TO_WORD(r_transducer_3_PSI);
0066w_transducer_4_PSI := REAL_TO_WORD(r_transducer_4_PSI);
0067
0068
0069(*Speed Pickup Example pin E3*)
0070IF
0071 speed_pickup_one_AvgFreqVal > 0
0072 THEN
0073     r_wheelRPS := speed_pickup_one_AvgFreqVal / (u_teeth_count * r_gear_ratio); (*Wheel RPS is = to speed pickup frequency divided by (teeth count * gear ratio) // This will be different depending on your methods of pickup*)
0074     r_wheelMPH := ((r_wheelRPS * r_wheel_circum) * 3600) / 63360; (*MPH*)
0075 ELSE
0076     r_wheelRPS := 0;
0077     r_wheelMPH := 0;
0078 END_IF
0079
0080o_speed := REAL_TO_BYTE(r_wheelMPH);
0081
0082
0083(*Speed Pickup Example pin D3, getting RPM of the gear based on picking up the teeth as they pass by the inductive sensor*)
0084IF
0085 speed_pickup_two_AvgFreqVal > 0
0086 THEN
0087     r_gearRPS := speed_pickup_two_AvgFreqVal / r_gear_teeth;
0088 ELSE
0089     r_gearRPS := 0;
0090 END_IF
0091
0092w_gearRPS := REAL_TO_WORD(r_gearRPS);
0093
0094
```

## Code Logic-

```
0001 F
0002 PLC_PRG_x_Initialized = TRUE
0003 THEN
0004 controller_on := TRUE;
0005 ELSE
0006 controller_on := FALSE;
0007 END_IF
0008
0009 F
0010 controller_on = TRUE
0011 AND
0012 CAN0_rx_comms_confirm = TRUE
0013 THEN
0014 comms_confirm_return := TRUE;
0015 END_IF
0016
0017 (*Below is a simple comparison to turnon the low pressure output on the screen if the PSI in the accumulator is lower than 500 PSI*)
0018 F
0019 inputs_r_transducer_1_PSI < 500
0020 THEN
0021 low_pressure := TRUE;
0022 ELSE
0023 low_pressure := FALSE;
0024 END_IF
0025
0026 (*Below are basic examples of looking for a value and setting a value based on the value we look at*)
0027 (*This is setup in a way to control a circuit that has 4 modes. Coast, Charge, Discharge and Regen.
0028 Coasting: No Valves
0029 Charging: Valve 1
0030 Discharge: Valve 2
0031 Regen: Valve 3
0032 The logic below has been setup in a way that will allow a defined mode to control whatvalves are "fired" *)
0033 (*Check for Command One*)
0034 F
0035 CAN0_rx_command_one = TRUE
0036 THEN
0037 mode_dd := TRUE;
0038 ELSE
0039 mode_dd := FALSE;
0040 END_IF
0041 (*Check for Command Two*)
0042 F
0043 CAN0_rx_command_two = TRUE
0044 THEN
0045 mode_ac := TRUE;
0046 ELSE
0047 mode_ac := FALSE;
0048 END_IF
0049 (*Check for Command Three*)
0050 F
0051 CAN0_rx_command_three = TRUE
0052 OR
0053 digital_input_one_val = TRUE
0054 THEN
0055 mode_ab := TRUE;
0056 ELSE
0057 mode_ab := FALSE;
0058 END_IF
0059 (*Check for Command Four*)
0060 F
0061 CAN0_rx_command_four = TRUE
0062 THEN
0063 mode_regen := TRUE;
0064 ELSE
0065 mode_regen := FALSE;
0066 END_IF
0067 (*Check for Command Five*)
0068 F
0069 CAN0_rx_command_five = TRUE
0070 THEN
0071 mode_ad := TRUE;
0072 ELSE
0073 mode_ad := FALSE;
0074 END_IF
0075
0076 (*If no commands are currently being sent then set all logic to false to turn off all outputs *)
0077 F
0078 CAN0_rx_command_one = FALSE
0079 AND
0080 CAN0_rx_command_two = FALSE
0081 AND
0082 CAN0_rx_command_three = FALSE
0083 AND
0084 CAN0_rx_command_four = FALSE
0085 AND
0086 CAN0_rx_command_five = FALSE
0087 AND
0088 digital_input_one_val = FALSE
0089 THEN
0090 mode_dd := FALSE;
0091 mode_ac := FALSE;
0092 mode_ab := FALSE;
0093 mode_regen := FALSE;
0094 mode_ad := FALSE;
0095 END_IF
0096
0097
```

## Code Outputs-

```
0001 (* The pins on the PLC are being set to the value of their assigned logic control, if enable_out_one is true in the logic program, the pin assigned will also be on *)
0002
0003
0004 (*
0005 digital_output_one_val := (*PIN G1*)
0006 digital_output_two_val := (*PIN F1*)
0007 digital_output_three_val := (*PIN E1*)
0008 digital_output_four_val := (*PIN D1*)
0009 digital_output_five_val := (*PIN C1*)
0010 digital_output_six_val := (*PIN K1*)
0011 digital_output_seven_val := (*PIN J1*)
0012 *)
0013
0014 (*Below are basic examples of looking for a value and setting a value based on the value we look at *)
0015
0016
0017 (*dd*)
0018 F
0019 logic.mode_dd = TRUE
0020 AND
0021 logic.mode_ac = FALSE
0022 AND
0023 logic.mode_ab = FALSE
0024 AND
0025 logic.mode_regen = FALSE
0026 AND
0027 logic.mode_ad = FALSE
0028 THEN
0029     digital_output_one_val := FALSE;
0030     digital_output_two_val := FALSE;
0031     digital_output_three_val := FALSE;
0032 (*ac*)
0033 ELSIF
0034 logic.mode_dd = FALSE
0035 AND
0036 logic.mode_ac = TRUE
0037 AND
0038 logic.mode_ab = FALSE
0039 AND
0040 logic.mode_regen = FALSE
0041 AND
0042 logic.mode_ad = FALSE
0043 THEN
0044     digital_output_one_val := TRUE;
0045     digital_output_two_val := FALSE;
0046     digital_output_three_val := TRUE;
0047 (*ab*)
0048 ELSIF
0049 logic.mode_dd = FALSE
0050 AND
0051 logic.mode_ac = FALSE
0052 AND
0053 logic.mode_ab = TRUE
0054 AND
```

```

0055 logic.mode_regen      = FALSE
0056 AND
0057 logic.mode_ad         = FALSE
0058 THEN
0059     digital_output_one_val := FALSE;
0060     digital_output_two_val := FALSE;
0061     digital_output_three_val := TRUE;
0062 (*REGEN*)
0063 ELSIF
0064     logic.mode_dd      = FALSE
0065 AND
0066     logic.mode_ac      = FALSE
0067 AND
0068     logic.mode_ab      = FALSE
0069 AND
0070     logic.mode_regen   = TRUE
0071 AND
0072     logic.mode_ad      = FALSE
0073 THEN
0074     digital_output_one_val := TRUE;
0075     digital_output_two_val := TRUE;
0076     digital_output_three_val := TRUE;
0077 (*ad*)
0078 ELSIF
0079     logic.mode_dd      = FALSE
0080 AND
0081     logic.mode_ac      = FALSE
0082 AND
0083     logic.mode_ab      = FALSE
0084 AND
0085     logic.mode_regen   = FALSE
0086 AND
0087     logic.mode_ad      = TRUE
0088 THEN
0089     digital_output_one_val := FALSE;
0090     digital_output_two_val := FALSE;
0091     digital_output_three_val := TRUE;
0092 ELSE
0093
0094     digital_output_one_val := FALSE;
0095     digital_output_two_val := FALSE;
0096     digital_output_three_val := FALSE;
0097     digital_output_four_val := FALSE;
0098     digital_output_five_val := FALSE;
0099     digital_output_six_val := FALSE;
0100     digital_output_seven_val := FALSE;
0101 END_IF
0102

```

