NFPA – Fluid Power Vehicle Challenge Hydraulic Bicycle

A Baccalaureate thesis submitted to the

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Abstract

Hydraulic Vehicles are a series of vehicles that utilize some form of fluid to transfer power between mechanical input, fluid energy, and mechanical output. As opposed to a traditional bicycle, this hydraulic vehicle utilizes a chain connected from the pedals to the motor as the main form of power transfer and energy generation. This orientation allows the rider in this case to generate fluid power through mechanical input and build pressure within the hydraulic circuit. To transfer the fluid energy/ power into mechanical output, a series of solenoids throughout the circuit can be used to control the flow direction, allowing for multiple functional hydraulic circuits on one vehicle. Applications of hydraulics, pneumatics, and electronics are used for the circuit development, while Finite Element Analysis, welding, and machining applications are utilized for the development of the framework. The main source of power generation for this vehicle is human energy, like a standard bicycle.

Special Thanks

The University of Cincinnati 2024-2025 Hydraulic Bicycle Team would like to extend a thank you to those who made our success a possibility. Special thanks to Dan Turner, President of GPM Controls, for his mentoring in partnership with the National Fluid Power Association and Ernie Parker, who was a technical liaison and guide through the development of our circuits. Our team would like to thank Abbey Yee for providing an education in the fundamentals of hydraulics and hydraulic circuits. We would like to extend our thanks to Jordan Graff, for his assistance and guidance in fabrication, and Chris from Affordable Hydraulics and Hose, for the use of his shop space and hose/ fitting guidance. Special thanks to the University of Cincinnati Victory Parkway staff and instructors Nick Plantaniotis, Kate Ashby, and Grant Aspenwall. A special thanks to A&P Technologies for supplying the project with BIMAX-H-33. Finally, our team would like to thank Josh Scarbrough of IFP Motion Solutions Inc, for his continuous guidance in touch-screen controls and implementation.

Problem Definition

Problem Statement

The purpose of this project is to design and build a hydraulic vehicle within a set of constraints to use at the National Fluid Power Association (NFPA) sponsored Fluid Power Vehicle Challenge. The vehicle must be powered by human input, and hydraulics, which work in tandem to create a fast and efficient vehicle. The University of Cincinnati competed at the IMI competition site against eight other schools from across the country. This is an annual challenge for schools across the country to design, build, and implement a vehicle that then will compete. The competition consists of three races: Endurance, Efficiency, and Sprint, and a Regenerative Braking Challenge.

1. **Endurance Race**
   a. This event consists of a 15-minute time constraint, and serves the purpose of demonstrating vehicle safety, reliability, consistency, and durability of the hydraulic vehicle, while also demonstrating an ability to maintain speed as pressure and fluid are built up within the circuit.
2. **Efficiency Race**
   a. This event demonstrates the vehicle and circuit ability to store energy and dispense the energy unassisted with the greatest amount of efficiency to propel the vehicle forward a certain distance in proportion to the vehicle and rider's weight.
3. **Sprint Race**
   a. This event allows for the demonstration of top vehicle speed in relation to weight and human propulsion, over a certain distance.
4. **Regenerative Braking Challenge**
   a. This event demonstrates a vehicle's ability to build accumulator pressure through a regenerative braking circuit over a certain distance and measures the distance the vehicle will travel exclusively from this built-up accumulator pressure.

Design Overview

Vehicle Concept

Hydraulic System

The main function of the hydraulic system is to transmit and control the power produced by the rider to the rest of the system. This hydraulic circuit contains a reservoir, dual pump, motor, accumulator, check valves, relief valves, and directional control valves. The energy can be controlled through "hydraulic shifting". This is achieved by utilizing a difference in displacement between the pump and the motor. The motor has a fixed displacement of 8.4 cc/rev and the pump has two sides with displacements of 4.5 and 11.5 cc/rev. Using a directional control valve the rider can choose to use either pump displacement separately or combined. When each side of the pump is used separately the other side of the pump is directed to the oil reservoir to reduce efficiency losses from pumping through unnecessary components. By using these hydraulic gears, the rider can achieve gear ratios of 5.4:1, 1.4:1, and 1.9:1. Directional control valves are also used to switch between the different configurations of the circuit.

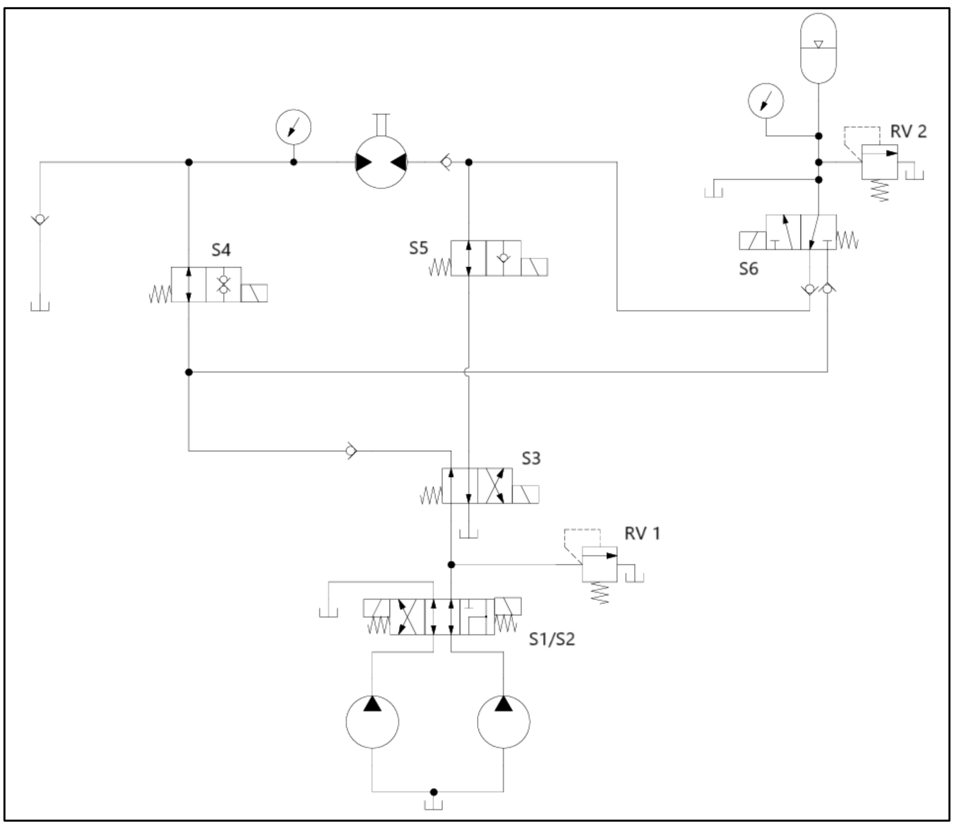


Figure 1: Hydraulic Circuit

Direct Drive

The direct drive configuration is used to direct power from the rider's pedals to the rear wheel and can be used in conjunction with the hydraulic gears to allow the rider to pedal easier.

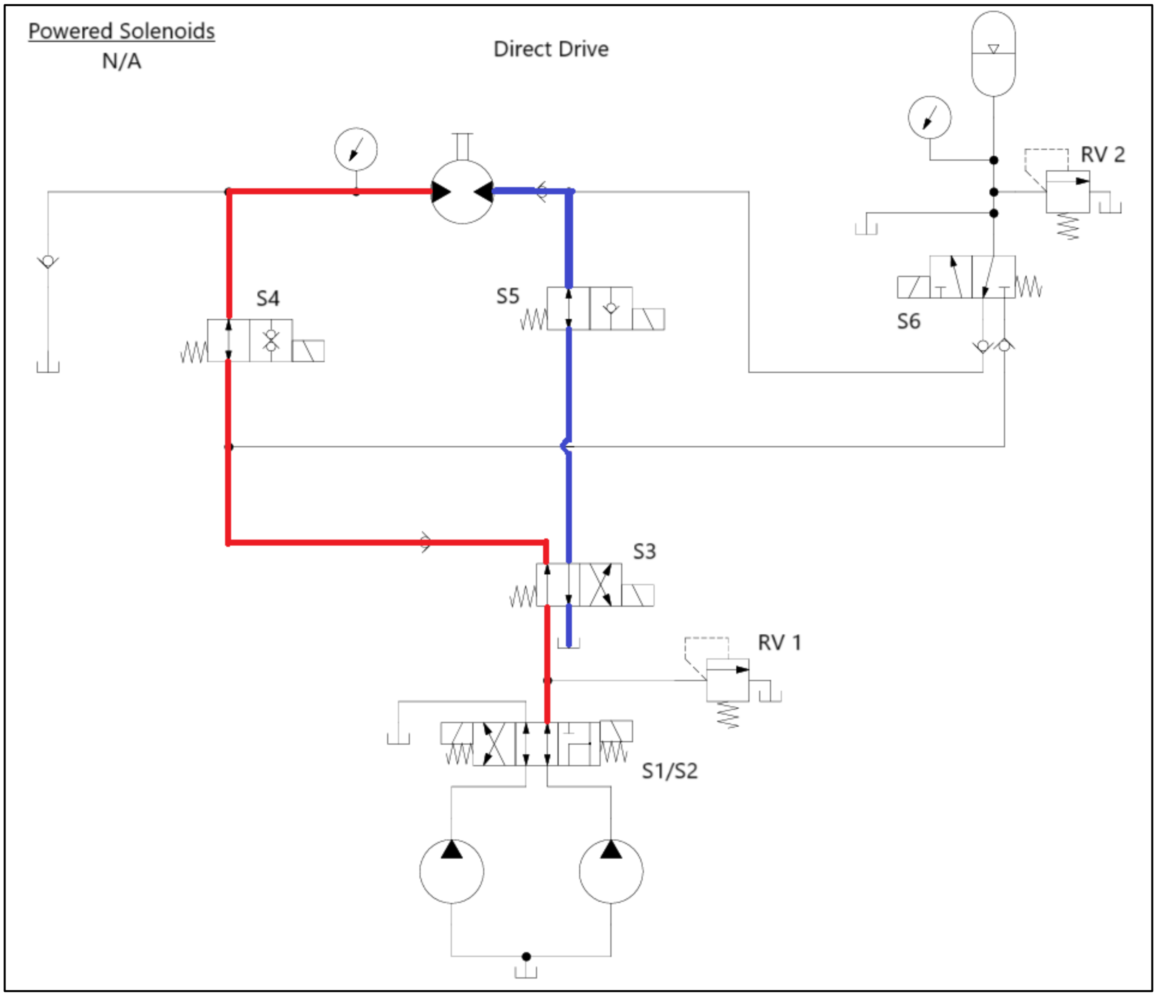


Figure 2: Direct Drive Configuration

Accumulator Charge

The accumulator charging circuit configuration is used to store the energy produced by the rider into the accumulator. This circuit can also be used in conjunction with the hydraulic gears and directs the flow through a check valve to prevent the accumulator from discharging while the rider is charging.

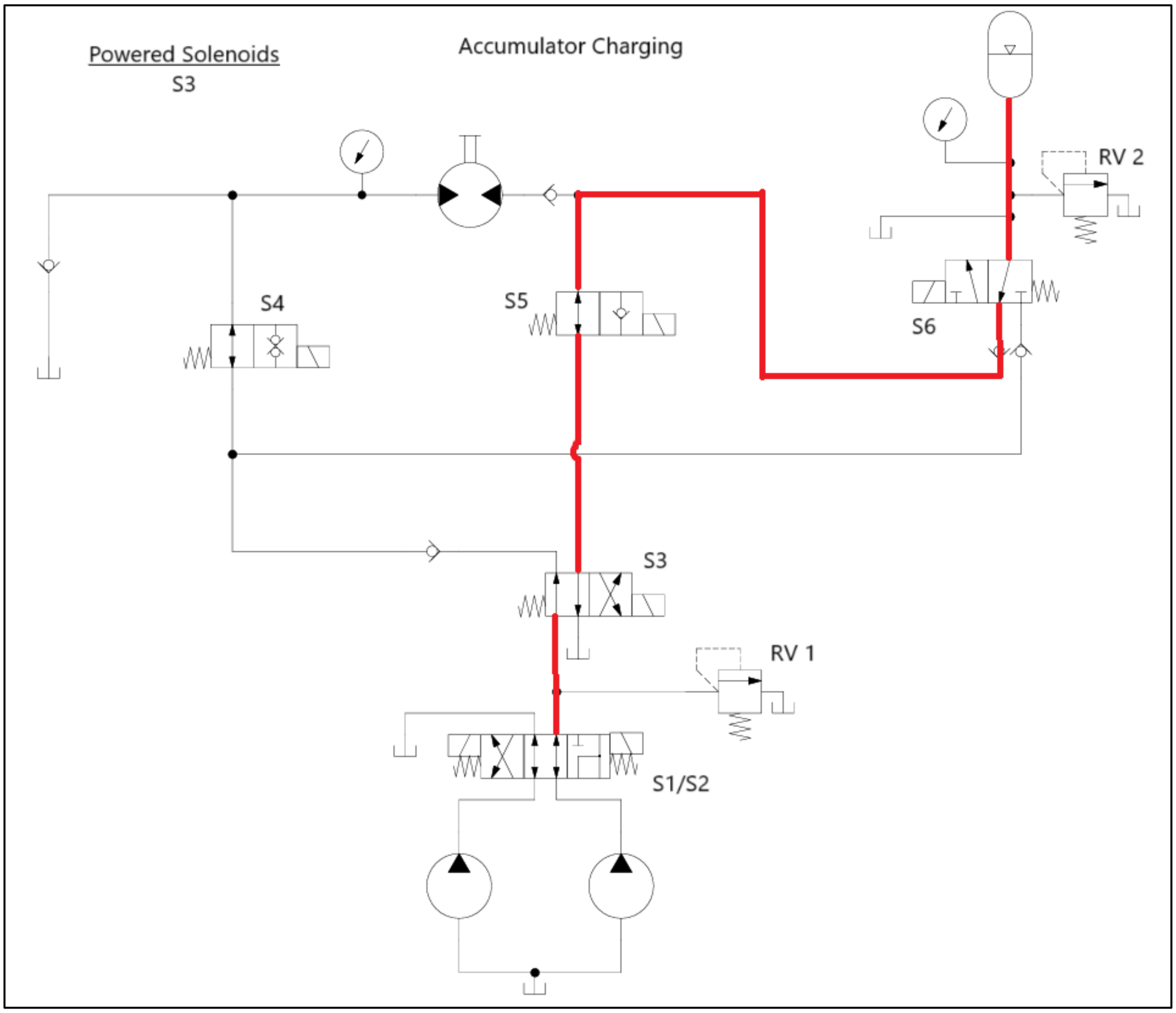


Figure 3: Accumulator Charging Configuration

Boost

The boost configuration is used to discharge the accumulator while riding to propel the bike. The boost configuration can be used in conjunction with the direct drive circuit and the hydraulic gears; however, the hydraulic gearing is independent from the accumulator and only affects the riders pedaling.

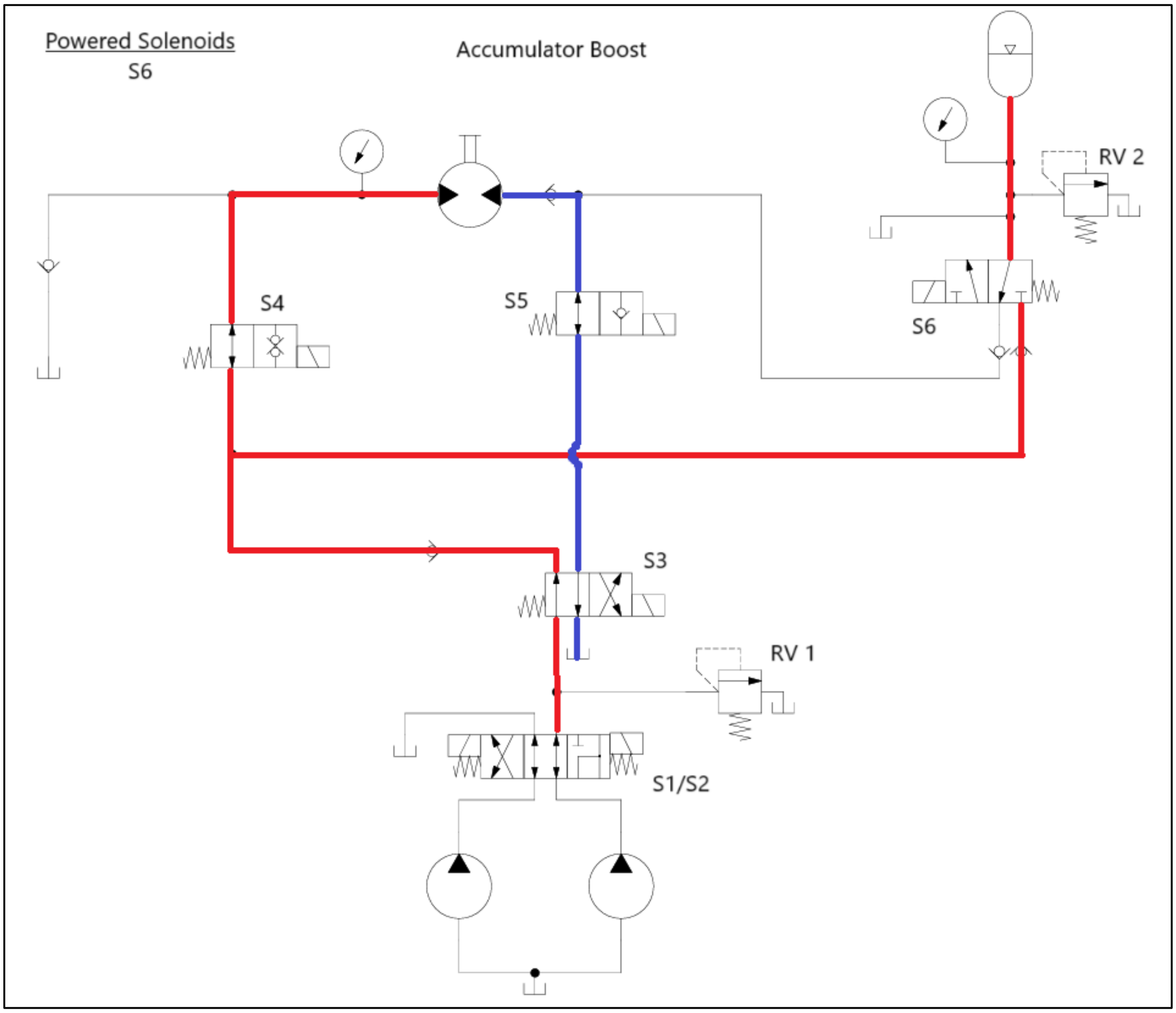


Figure 4: Accumulator Boost Configuration

Regenerative Braking

The regenerative braking configuration is used to slow down the bike and stores kinetic energy in the accumulator. This is achieved by allowing the rear tire of the bike to drive the motor, essentially using the motor as a pump. In this configuration the motor draws oil directly from the reservoir and into the accumulator through a check valve to prevent back flow. This configuration cannot be used in conjunction with other configurations and though the hydraulic gears can be enabled they do not affect the braking.

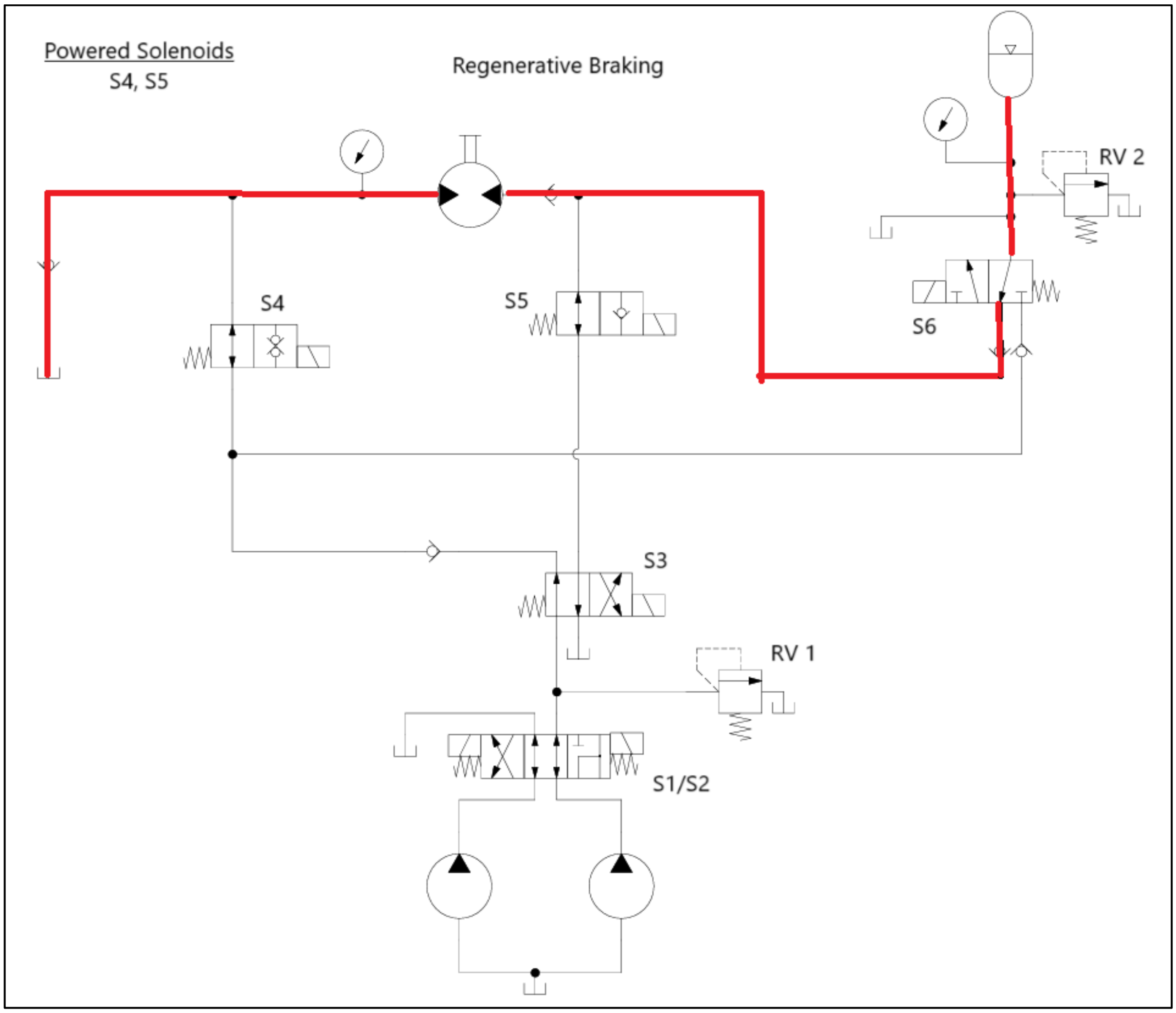
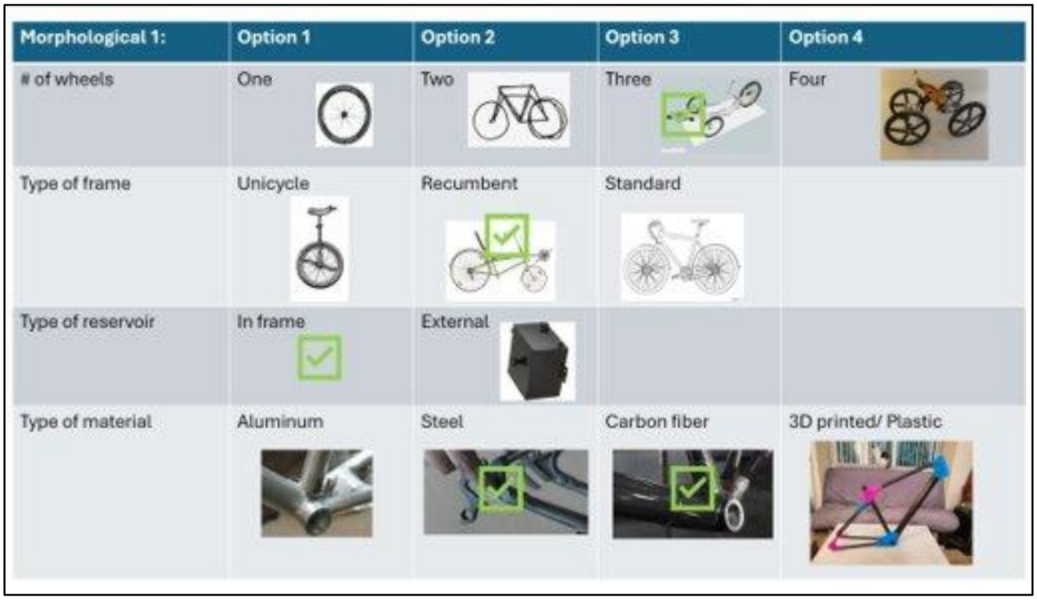


Figure 5: Regenerative Braking Configuration

Frame and Fabrication

When we initially started this project in August of last year, the frame was the first thing we decided to tackle. From the beginning, we knew that we wanted the frame to be innovative and unlike anything seen before at the University of Cincinnati. We set out to do this by including uncommon designs and methods to create the frame of our bike which everything else would be mounted to.



Morphological 1:	Option 1	Option 2	Option 3	Option 4
# of wheels	One	Two	Three	Four
Type of frame	Unicycle	Recumbent	Standard	
Type of reservoir	In frame	External		
Type of material	Aluminum	Steel	Carbon fiber	3D printed/ Plastic

Figure 6: Bike frame style morphological chart decision matrix

The most important decision we had to make at the time is what kind of bike we would make. Every team in UC's history has made somewhat of a standard style bike frame. Early years used a two-wheel design, and more recently have used two rear driven wheels and one front steering wheel design. We chose to make a recumbent style bike, as this has many benefits including stability, weight distribution, ang maximizing rider leg power.

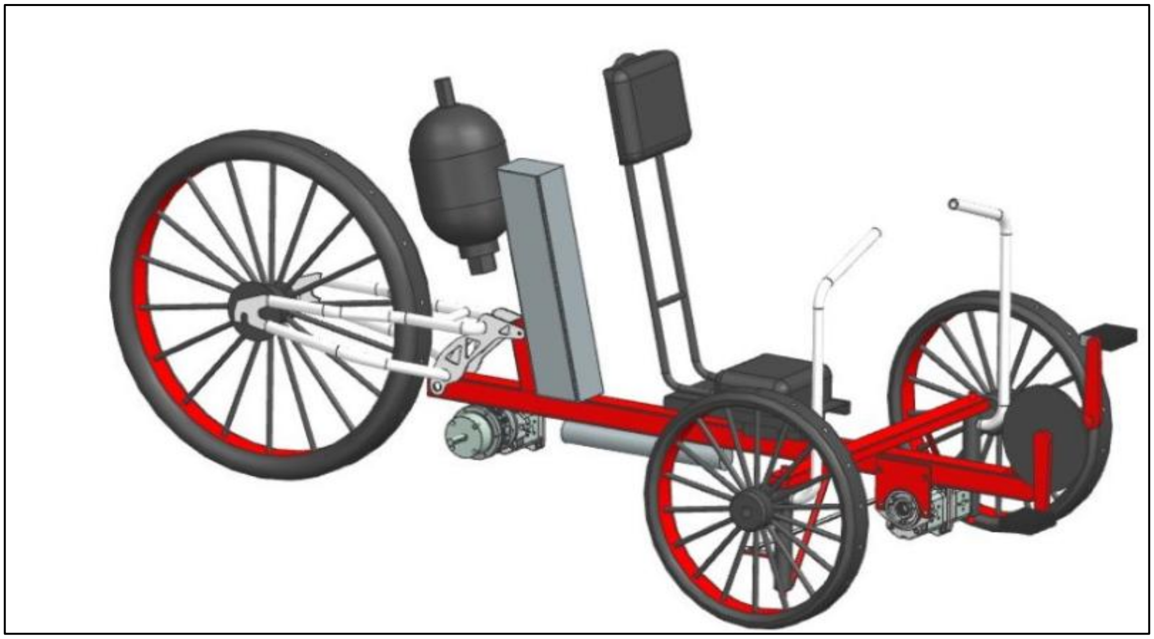


Figure 7: Colored CAD model of pre-production prototype

Once we had a style of bike decided, it was a matter of designing a simple and manufacturable bike frame with help of our fabricator, Jordan Graff. With Jordan's guidance, and performing force loading simulations in Siemens NX, we designed a suitable frame for our bike, ensuring it could withstand even extreme riding.

While the design for this bike has been full of innovation, we used many ideas from past teams. Several of the components used on our bike were reused or found in the shop from past projects. Some of these items include the bike seat, the front tires, the pedal assembly, and the front dual pump, the accumulator, and many more. We tried to incorporate anything useful without having to buy it new, to reduce waste and create a sense of unity from other UC Hydraulic Bike teams.

Solenoid Controls

This year, our solenoids were controlled through a panel of switches on a control panel. These switches were wired to allow for multiple solenoids to be controlled from a single switch, enabling the rider to easily activate necessary hydraulic circuits. Within our controls circuit, because of our hydraulic gear shifting implementation, switches also would allow for the rider to shift gears as they worked through various competition requirements and races.

Figure 8: Control Panel and Switches Front View

Figure 9: Control Panel Wiring and Back View

A level of automation was utilized this year to improve upon the previous designs. Not only were various solenoids energized with a single switch being activated, but the rider could see the activation via an LED indicator which was next to the corresponding switch. The LED indicators were color coded and labelled so the rider knew exactly which switch was energizing the solenoids. This also improved the vehicle's regenerative braking competition results, as a competition requirement is a visual indicator of the system working, and we utilized two visual aids, as opposed to one.

The control panel is a 3D printed panel comprised of PLA material and is painted to better match the color of the bike frame. The panel was initially designed to house only the switches and LED indicators but was ultimately designed to house the battery as well. A mounting method of hose clamps was utilized to install the panel along the right-hand side of the steering mechanism, so the rider was able to engage circuits without removing their hands fully from the steering mechanism and brakes. For the switches, 3 position rocker switches were used, which is a newer method for the controls system of the hydraulic vehicles at the University of Cincinnati. From one switch, two different circuits could be controlled. However, for the control of the pneumatic clutch, a two-position toggle switch was used because the toggle is visually different, and can be identified by feel, without requiring any visual confirmation. 24V LED indicators were used as well, as opposed to utilizing the 12V LEDs that are easier to find. The selected LED indicator was decided as a safety feature to prevent the indicators from being damaged and potentially destroyed by the high voltage being used. As a result, 2.2K Ohm resistors still needed to be utilized to prevent inductive kickback from the solenoids to the indicators. In initial calculations, the resistor size was predicted to be much higher, at 4.8K Ohms, but the calculated level of resistance was found to be much too high. Our wire securing method was a combination of soldering and crimping, while using heat shrink covers. Most of our wires were managed by utilizing two different kinds of terminal blocks, spring-loaded fully enclosed blocks, and standard blocks that are tightened with a screw and are connected with metal plating. The usage of terminal blocks for providing a positive and negative connection was preferential in this case to preserve equipment for future teams as opposed to soldering, or another more permanent method.

As previously implied, the main power source for the controls and the solenoids was a 24 Volt battery, housed within the control panel. This was a rechargeable lithium-ion drill battery with a custom cover made by a previous team. To properly secure the wiring and the battery, carbon fiber covers were utilized with a hook-in-eye securing method which was bolted to the panel. This allowed for ease of access in any emergent matter, as well as for the easy removal of the battery for charging purposes.

Hydraulic Manifold

This year the hydraulic bike was made without the addition of a manifold. Our team had originally designed a single long bock manifold which would house all of our fittings and poppet valves. This manifold was to be a simple aluminum block manifold which contained all our poppet valves as well as fittings to control our fluid flow.

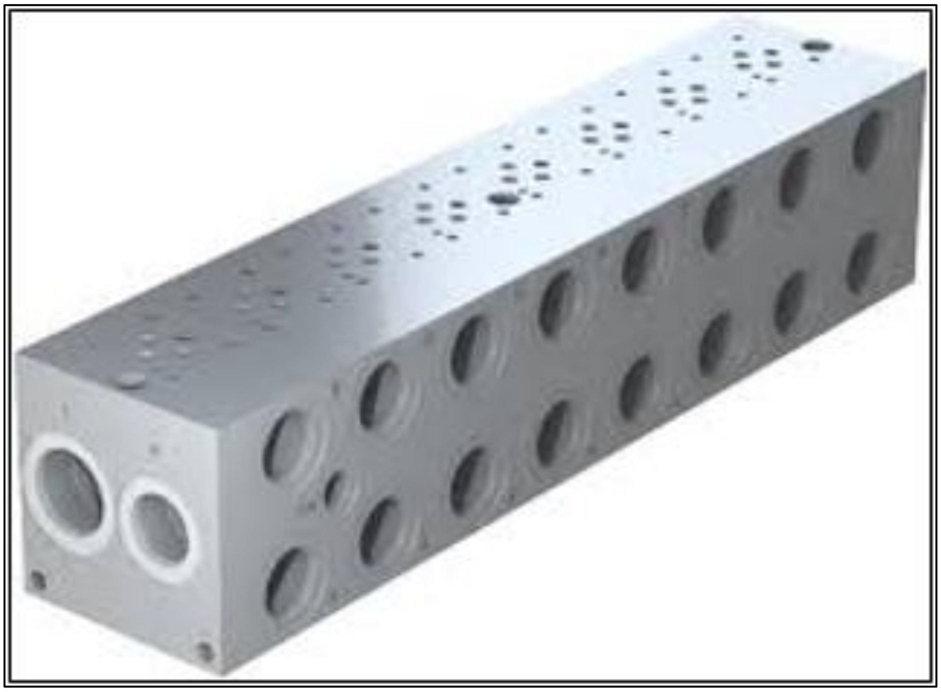


Figure 10: Manifold Example

Due to complications and communication troubles with the manufacturer as well as a circuit which was slightly delayed, the manifold idea had to be changed to a more spread-out idea and separated the poppet valves across the entire bike. I do believe this worked in our favor as over time we were able to be flexible and more open to new ideas and try slightly different ideas as the limitations of a manifold are the entire system must route through a single location. Having the circuit spread gives the bike a sleeker look and the flexibility to place piping and tubing across each other.

Pneumatics

The pneumatic application for this year's bike was a pneumatic clutch, designed to operate at a maximum pressure of 80 psi. The system included a 42.55 cubic inch reservoir, which was sized to allow at least 20 full clutch cycles before needing to be refilled. The primary motivation for using a clutch was to meet the requirements of two competition events that emphasized maximizing the use of stored energy. By disengaging the rear chain assembly from the motor once stored energy is depleted, the clutch prevents the motor from being back driven, which helps minimize energy losses and improves overall system efficiency. The pneumatic circuit consisted of a dump valve for rapid pressure release, a pop-off valve for overpressure protection, a pressure gauge for monitoring system pressure, a pressure regulator to maintain consistent downstream pressure, and a directional control valve (DCV) to operate the clutch. Additionally, mufflers were used on the exhaust ports to reduce the noise generated during each cycle, contributing to a quieter and more refined system.

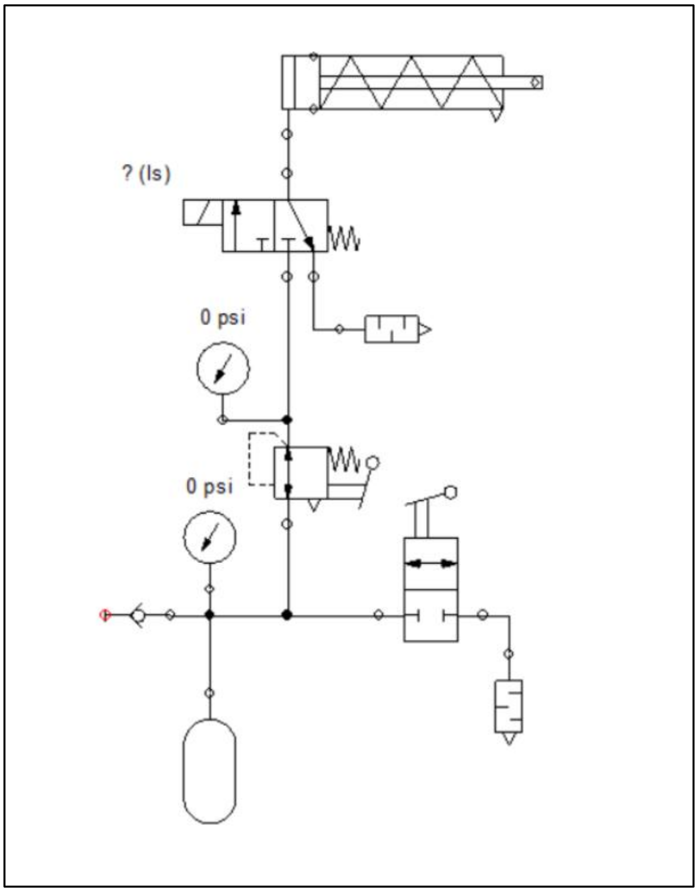


Figure 11: Final Draft of Pneumatic System

Power Transmission

The power transmission of the bike was a topic of debate for a while as the power required to make the motor turn as well as provide an easy enough riding experience for our rides was difficult. The innovation from this came in the form of the elliptical gear making pedaling easier for the rider in lower gears. From this as well we customized machined gearing for our clutch assembly to create a larger gear ratio to our back tire for increased torque for fear of our bike being too heavy for our clutch. Looking back, we can see that the torque and the weight of the bike were not a cause for concern and after completing this however during the time of creation we were attempting to make the bike bulletproof as so to not have failure as others did at our competition.

Figure 12: Elliptical Front Gear

Digital Display

The digital display screen was programmed using CODESYS. This year's setup differed from last year's due to the integration of a newer HMI system called Envision. Unlike the previous system, which only required JMobile and one version of CODESYS, the Envision HMI required two different versions: CODESYS V3.5 SP19 Patch 4 for programming the controller, and CODESYS V3.5 SP19 Patch 7 for programming the screen. Setting up two gateways proved to be a challenge, as both CODESYS versions had to be installed and configured separately. A successfully established gateway is indicated when the connection status shows a solid green light (no longer blinking), confirming communication between the controller and the PC.

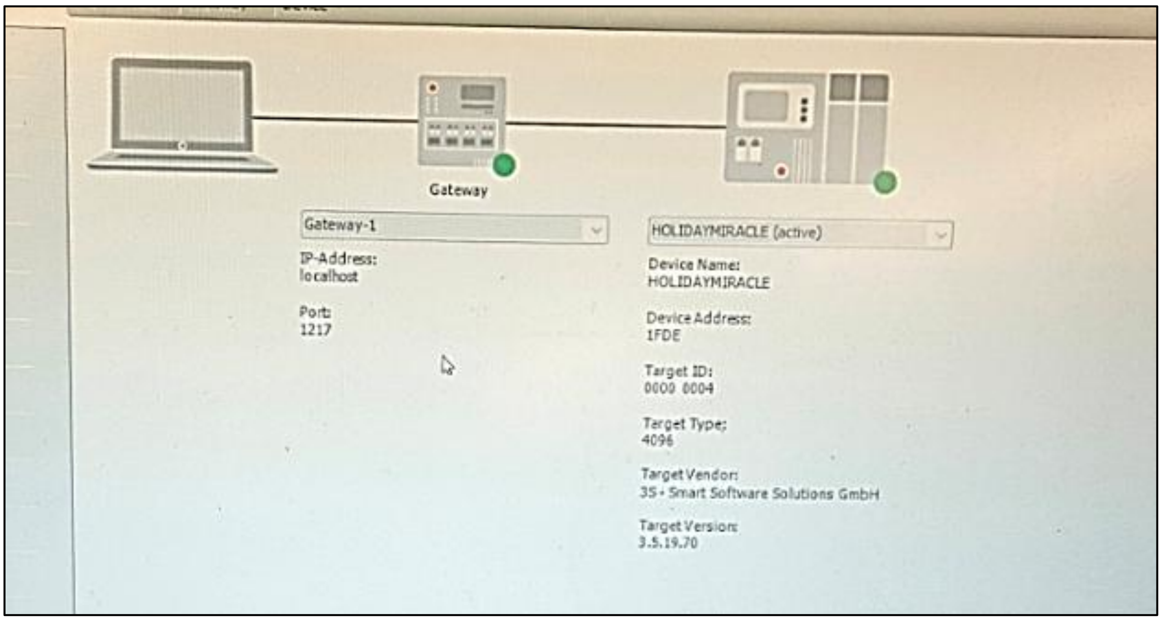


Figure 13: Secure Gateway Connection

This step is crucial, as uploading code in CODESYS requires the device to be properly added and recognized in the software. For this year's project, we identified three main Key Performance Indicators (KPIs):

1. Monitoring and regulating valve pressures
2. Displaying the on/off status of each operating mode (Regen, Charge, Discharge, Coast)
3. Continuously displaying system velocity

To meet these KPIs, the team first had to determine which operating modes wanted for the bike. From there, code was developed to match these functional goals—while being careful not to interfere with any prewritten NFPA code, which was clearly marked with warnings such as

“Don’t touch.” Support from Josh Scarbrough played a significant role in this process. While it’s possible to learn CODESYS independently, given the project’s time constraints and the demands of any other executive responsibilities within the senior design team, consulting Josh for a general overview and guidance is highly recommended.

As for powering on the HMI screen, research revealed that all grey wires needed to be grounded, and all red wires connected to a positive power source. Once the wiring was correctly set up and the gateway secured, the next hurdle was integrating the sensors needed to read pressure and speed. Unfortunately, properly connecting the sensors to the wiring harness proved difficult. The screen failed to display any readings, and with the competition fast approaching, the team ultimately could not get the display screen operational in time.

Final Vehicle Design

Figure 14: Final Bike

Engineering Calculations

Hydraulic Calculations:

To Calculate the Volumetric Displacement (GPM):

Using Pump Specifications from Manufacturer:

Large pump: 9.3 CC Small pump: 4.1 CC Combined:13.4

Converting to gallons:

$$Gal = 13.4CC * \frac{1\ gal}{3785\ CC} = 0.0035\ gal/rev$$

Assuming uniform pump performance:

$$GPM = \frac{0.0035gal}{rev} * 100\ RPM = 0.35\ gal$$

Pneumatic Calculations:

To Calculate the Volume of Air Used Per Charge:

Volume of Clutch Air Chamber in CIN:

New:0.266 CIN Old: 0.695 CIN AVG:0.43 CIN

Assuming 3 ft (36 in) of Length, 0.25 in:

$$V = l\pi r^2 = 36 * \pi * (.125)^2 = 1.77\ CIN$$

Total Volume for One Cycle:

$$V_{total} = V_{clutch} + V_{hose} = 1.77 + 0.43 = 2.20$$

Using Ideal Gas laws, the maximum operating pressure of the clutch, the volume of one cycle, and the pressure of the air reservoir:

$$P_1V_1 = P_2V_2 = 80 * 2.20 = 105V_2$$

$$V_2 = 1.74\ CIN$$

For 20 cycles:

$$V = 20 * 1.74 = 34.76\ CIN$$

Bill of Materials

Number on Budget Sheet	Part Number	NAME OF ITEM	DESCRIPTION	PROVIDER	QUANTITY
001	LHK0006 or ASIN# B09R1NJQVZ	Chain Tension	M MATI Chain Tensioner for Polaris Sportsman 90 110 Outlaw 90 110 Predator 90 RZR 170 0452954 0451686	Amazon	1
002	C042201	Toggle	2 Port - 2 Position (NC)	IMI	1
003	11044547 or 063G2404	Transducer	Pressure Transmitter (Deutsch)	Sun Source/ Danfoss	1
004	D1620-01-06SAE	Dynamic Test Point Test Point - Gauge Side	Fitting, Test Point- Accumulator Side. SAE -6 Male. M16-2 test thread.	Sun Source/ Danfoss	1
005	CV10-NP-0.3-B-00	Comatrol Valve	Cartridge Valve, Check, 1 to 2, size 10	Sun Source/ Danfoss	6
006	SV10 - 23 -01-00-00-B-00	Comatrol Valve	Cartridge Valve, Solenoid, 2 pos. 3 way Spool 1-2/1-3	Sun Source/ Danfoss	1
007	SVP10-NOR-R00-00-B-00	Comatrol Valve	Cartridge Valve, Solenoid, 2 pos. 2 way Uni-poppet Normally Open	Sun Source/ Danfoss	1
008	121.20.096.00	Motor Gear	Motor, Gear, 0.513 CID, Keyed Shaft .625", Bi-rotation, external drain	Sun Source/ Danfoss	1
009	ks2182	Sprocket	Sprocket 8 Tooth 5/8 Bore 40/41/420 Chain	Amazon	1
010	8175-12	JackShaft	5/8" Jackshaft x 12"	Amazon	1

011	D-2485-A-12	Reservoir - Aluminum End Caps	Size: 2" Stroke:12	IMI	1
012	M3V110-06-NC-24VDCFL	24V Solenoid Spring Return	3 Port - 2 Position (NC)	IMI	1
013	RV1-10-S-0-36 or RV1-10-B-S-0-0-30-XX	Relief Valve	Cartridge Valve, Relief, Direct Acting	Sun Source/ Danfoss	2
014	300AA00061A	Solenoid Coil	Cartridge Valve, Solenoid Coil, 12VDC Deutsch, P Type	Sun Source/ Danfoss	1
015	104BCD	Chainring	DECKAS 104BCD Narrow Wide 1X Chainring 32-52T Round/Oval CNC Black for 7-12S MTB	Ebay	1
016	802850	Air Engaged Shaft Mount Friction Clutch	F-450 * 0.875 Pilot Mount	Nexen	1
017	802500	Straight Bore Brushing	FW*Bushing 0.625 Bore	Nexen	1
018	X003W9W9XR39	20" Inner Tubes	20" Inner Tubes 2x	Amazon	1
019	X003TIC487 or UC205-16	Pillow Block Bearing	Pillow Block Bearing 2x	Amazon	1
020	X002EES5NP or CA-3220BA-4-new	Thread Adapter	1/4 to 1/8 NPT adapter 4x	Amazon	1
021	B0002SQYTQ or SRV187-18	Valve	Air compressor tank valve 2x	Amazon	1
022	X0036EXBDL or UCP202-10	Pillow Block Bearing	Pillow Block Bearing 2x	Amazon	1
023	B0083YQ81A	Sintered Bronze Exhaust	10x	Amazon	1

024	R16-24D-20W-DE	Cartridge Valve, Solenoid Coil	q	Sun Source/ Danfoss	4
025	SV11-8-C-0-00	Cartridge Valve, Solenoid Coil	Cartridge Valve, Solenoid, 2 pos. 2 way Bi-poppet, normally Closed	Sun Source/ Danfoss	1
026	SV10-34-05-00-00-B-00	Cartridge Valve, Solenoid Coil	Cartridge Valve, Solenoid, 3 pos. 4 way (3 blocked, 2-4-1 connected in neutral)	Sun Source/ Danfoss	1
027	SV10-24-01-00-00-B-00	Cartridge Valve, Solenoid Coil	Cartridge Valve, Solenoid, 2 pos. 4 way Spool 3-2,4-1	Sun Source/ Danfoss	1
028	ASIN : B08K5JB213 or UPC : 886103896050	Linear Motion Shaft Guide Chrome Hardened Steel Rod Cylinder	Product Dimensions : 19.69 x 1.97 x 1.18 inches; 1.54	Amzon	2
031	K26000109	Short+Long Tie Rod Kit	3/8-24 Short+Long Tie Rod Kit w/Ends Tie Rods & Ends Fits DIY Yerf Dog Go Kart Cart	Amazon	1
029	ASIN : B0BNZ8F667	Shaft Collar Bore	(Pack of 4) Shaft Collar Bore 15mm, Aluminum Alloy Two Halves Clamping Collar for Shaft, 35mm OD, 12mm Thickness, with M5 Set Screws	Amazon	1
030	10TCsprocket40	Sprocket 10 Tooth C Type	Sprocket 10 Tooth C Type, 40/41/420 Chain, 5/8 Bore, 3/16" Keyway	Amazon	1
032	E41-8622 or ASIN : B0BXR2FVYD	Jackshaft	**3/4" x 14"** Jackshaft with 3/16" Keyway for Go-Kart and Minibike - Replacement Solid	Amazon	1

			Steel Shaft/Axle with 14" Full-Length Keyed with Square **Unthreaded** Ends		
033	E41-8620 or ASIN : B08M446LWV	Jackshaft	**5/8" x 10"** Jackshaft with 3/16" Keyway for Go-Karts & Mini Bikes	Amazon	1
034	78700713	Display TouchScreen	S50, 5" TFT Projected Capacitive Touchscreen, 8GB Flash	IFP	1
035	58700010	PLC Controller	(MC-2-18-6) Mobile PLC/Controller with integrated valve driver (PWM and On/Off Solenoid)	IFP	1
036	None	Connection Harness	Connection Harness (Programming and Operation)	IFP	1
038	C20600400 or CPT250-1/8	Union Tee	Union Tee	IMI	1
039		Battery Charger		IFP/Amazon	1
021	B0002SQYTQ or SRV187-18	Valve	Air compressor tank valve 2x	Amazon	2
040	BES M12MG-PSC80F-BP05	Proximity Sensor	Inductive Sensor - 8 MM Distance - 3 Wire - NO contact - PNP - 5M - Non-Flush Mount Style	IFP	1
041		Pressure Sensor		IFP	1
042		Pressure Sensor Cable		IFP	1
043	B00NT33353E	Pressure Relief Valve	Brass relief valve	Amazon	1

044	B07HHY6MKY	Sanding disks	Sanding disks	Amazon	150
045	B0BDY27D6	Nitrile gloves	Nitrile gloves	Amazon	50
046	X2RFKJDZ	Bike hub mount	Bike hub mount	Amazon	2
047	X002DLQ1X	Mold release	Mold release	Amazon	1
048	X3ZOSF1	Chainring screws	Chainring screws	Amazon	10
049	X0042B6GWZ	Bike hub tool	Bike hub tool	Amazon	1
050	X001RHOKF7	Brushes	Brushes	Amazon	6
051	B00NT33353E	Pressure Relief Valve	Brass relief valve	Amazon	1
052	B00NT33353E	Pressure Relief Valve	Brass relief valve	Amazon	2
053	B0DM73Z84W	6in keyed shaft	6in keyed shaft	Amazon	1
054	X0017CHII3	Seat cushion	Seat cushion	Amazon	1
055	X002KXIKCL	Clear coat paint	Clear coat paint	Amazon	2
056	B003CT498A	Primer paint	Primer paint	Amazon	2
057	B07LFZ884K	Red paint	Red paint	Amazon	2
058	B06XGXYX4	Total Boat resin	Total Boat resin	Amazon	1
059	7GW-FER581lw08-6	Brass tank connector	3/4in female to 1in male	Amazon	36
060	49-F2U9-EQ5F	Rocker switch	3 pin 3 pos on off switch	Amazon	10
061	ULT-USB-C-to-USB-A-Short-fba	USB C cable	USB C cable	Amazon	1
062	MD-KN3-1	Toggle switch	2 pin 2 pos toggle switch	Amazon	1
063	KB291914TC	Plastic electric box	Clear plastic electric junction box	Amazon	2
064	DR-US-749-US	LED indicator lights	6mm 5 colors LED lights 12-24v	Amazon	10
065	B0DDH16TLB	Flat washers	15mm inner diameter flat washers	Amazon	10

Table 1: Main Bill of Materials

Component	Company	QTY	Price
4pcs Heavy Duty 1/4 NPT Male Thread to 1/8 NPT Female Thread Brass Reducer Hex Bushing Brass Fitting Pipe Hose Tube Adapter Convert	Amazon	1	$7.49
1/8" ASME Brass Safety relief Valve, American made, Compressed air pop off valve (150 PSI)	Amazon	1	$12
Sintered Bronze Brass Exhaust Muffler 1/8" NPT (Package of 10)	Amazon	1	$12
Milton S-684 1/8" NPT Tank Valve - Pack of 2	Amazon	1	$6.79
Air Engaged Shaft Mount Friction Clutch	Nexen	1	$573.46
Straight Bore Bushing	Nexen	1	$108.12
Gauge, 1/8" NPT thread, 0 to 160 psi range, bottom connection	IMI	1	$44.66
Bimba Air Reservoir	IMI	1	
2-Way 2-Position Valve	IMI	1	
3/2-way Normally Closed (NC) pneumatic directional control valve	IMI	1	
MINI REGULATOR, 1/8 NPT	IMI	1	
Union Tee	IMI	3	
Male- Female 1/8" Ports - 1/4" Tubing.	IMI	10	
Female-Male 1/8" Ports - 1/4" Tubing	IMI	1	

Table 2: Pneumatic Bill of Materials. Items without a listed price were provided by IMI.

Function	*Part #*	*Label*	*Qty*
Check Valve	*CV10-NP-0.3-B-00*	*N/A*	*6*
Relief Valve	*RV1-10-S-0-36*	*RV1, RV2*	*2*
DCV	*SV10-34-05-R00-00-B-00*	*S1/S2*	*1*
DCV	*SV10-24-01-R00-00-B-00*	*S3*	*1*
DCV	*SBV11-8-0-0-00*	*S4*	*1*
DCV	*SVP10-NOR-R00-00-B-00*	*S5*	*1*
DCV	*SV10-23-04-R00-00-B-00*	*S6*	*1*
Motor	*121.20.096.00*	*N/A*	*1*
Pump	*ALPP2-D-6-FA / ALPA2A-D-13*	*N/A*	*1*

Table 3: Solenoid Bill of Materials

Safety Factors

Safety is the number one priority. We wanted to uphold the standard of safety that has come to be expected of the University of Cincinnati. Rigorous bench testing and model simulations were conducted to ensure that our bike would perform as expected without any malfunctions. Again, we are proud to say that no malfunctions or breakages were experienced during testing or competition, as well as UC being awarded with the safest overall bike by the judges.

Since safety was at the forefront of our design from the get-go, we were able to design around a high safety factor. For our base frame, which is responsible for withstanding the most amount of force and shock, our modeled safety factor is about 4. This number is with an estimated weight and force of both a rider and the components which are mounted to the bike.

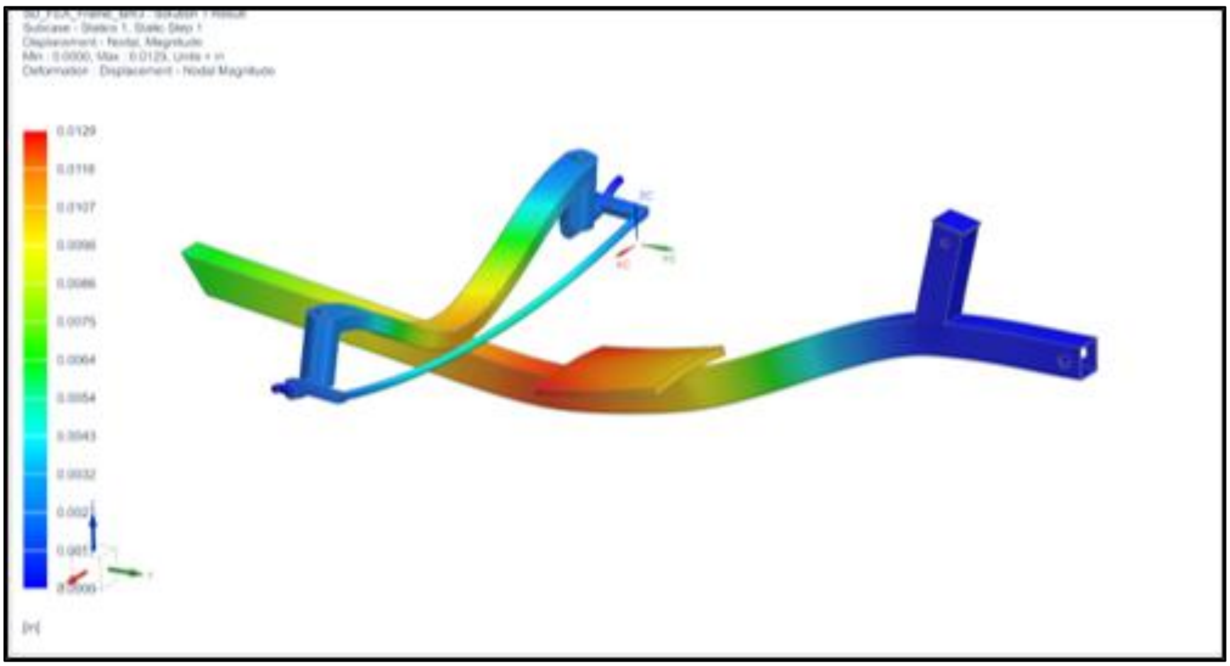


Figure 15: Siemens NX FEA analysis of the main base frame

The next big component to help protect the rider was the carbon fiber safety panel. This component had the purpose of shielding the rider from all electrical and hydraulic lines that ran underneath the rider's legs during operation. This panel was mounted with 3 bolts with 1.65” standoffs to ensure a strong mounting position to the frame. This component is also designed to withstand the impact of a person standing or falling on it without sustaining damage.

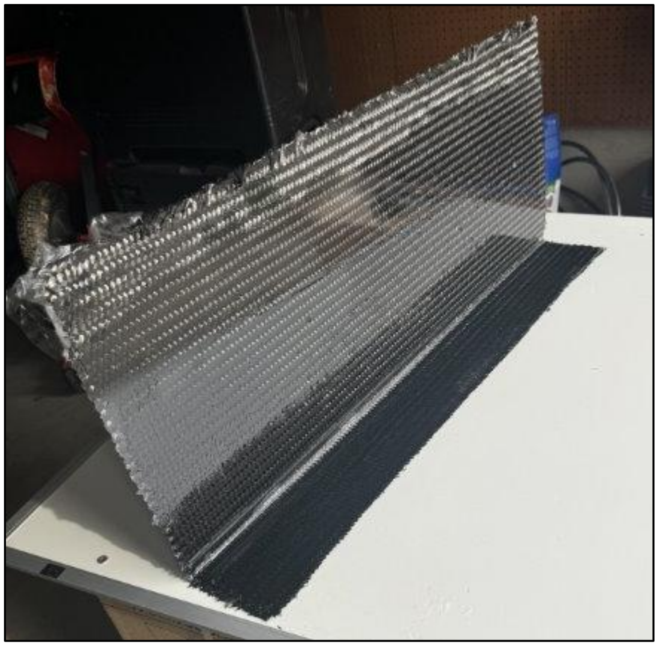


Figure 16: Carbon Fiber Safety Panel

The final safety measure we used was a chain-guard. A chain-guard is a critical component for ensuring that the rider does not get pinched and or caught on the chain during bike operation. The design was built to be multifunctional as stated in the Frame Fabrication section, but the idea was that based off the strength of carbon fiber and abs plastic the rider would not have to worry about the component failing.

Figure 17: 3D Printed ABS Chain guard

Build and Test

Manufacturing Processes

The manufacturing process started by making drawings to give to our fabricator Jordan. Not everything was made with Jordan and not everything required a drawing. The base frame and steering assembly were made at Iron Bell Metal Works. The rest of the components got manufactured at UC Victory Parkway.

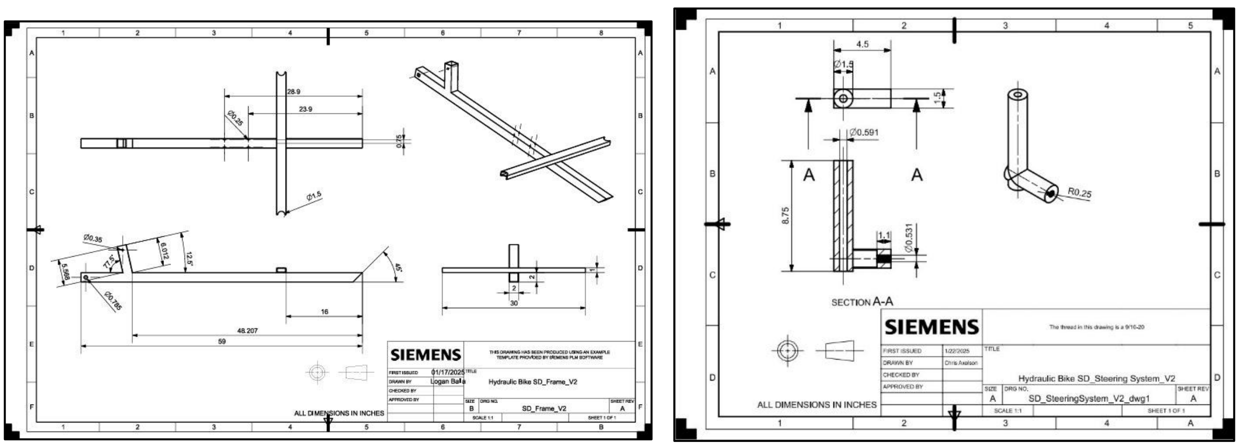


Figure 18: Manufacturing Prints

Assembly and Fabrication Complications

One of the most challenging things we faced in our design was the clear reservoir. Luckily, we had the insight to buy two of the plastic conduit boxes we used to make our reservoir. The reservoir required 5 large holes drilled into it with a universal brass bung and gasket inserted into each hole. These connection points constantly leaked on the first one we made. The box also had a front panel which opened, we needed to seal this opening with a liquid sealant to prevent leakage. On our first design, every part leaked. The holes drilled were too large and the sealant used was incorrect for this application. On our second iteration, we drilled the holes the correct size and used the correct type of sealant. This second iteration did not leak after some minor modification with extra sealant.

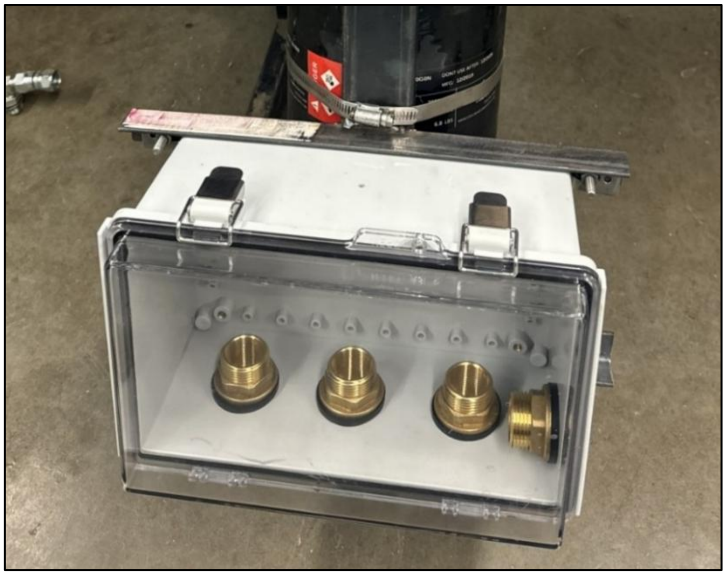


Figure 19: Clear conduit box used as our hydraulic fluid reservoir

An additional complication was with the chain guard. Originally, the plan was to use the carbon fiber provided by A&P Technologies like we did for the Safety Pannel, but we ran into time and manufacturing problems. The big issue was not having time to make it right; the job was a rushed job since our timeline for the entire project was getting set back consistently at what felt every turn. The manufacturing process was good and would have worked given the time it needed. With a rushed job like this it is not uncommon for things to cure in the way and for delamination to occur. Due to the part not looking the way the team wanted, we decided to keep the original ABS chain guard.

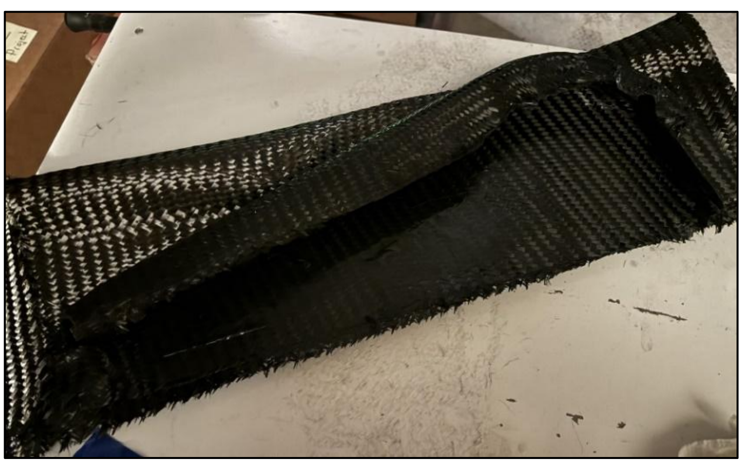


Figure 20: Carbon Fiber Chain Guard

Testing Procedures

For testing events, the very first thing implemented was ensuring that the vehicle rider was wearing a helmet at all times. The rider also needed to wear closed toe shoes to prevent any significant injuries. Once safety was established, the testing checklist was used. This checklist was composed of checking for leaks, checking gauges, closing any bleeder valves, locking the seat in place, filling the air cylinder, energizing and de-energizing the solenoids, and clearing a path to bring the vehicle out into the parking lot.

Following all of the preparation work, trials were established. Most often, one individual would set a timer for a pre-charge, two individuals would charge the circuit and check the gauges, and one individual would hold the vehicle in place for charging. The grade and direction for the trial would be established, and the pre-charge would be released with a timer to establish how long the vehicle could run with no intervention.

Test Results and Test Conclusions

During our testing, we realized that some of our components were not up to the task. For the frame, this manifested as a poor braking performance. We remedied these issues by tightening everything as intended. An additional thing we found was that the bike was much harder to pedal than originally expected. For this issue the best course of action was to reduce the number of teeth on the front gear. Going from a 52 tooth to the 42 tooth allowed us to pedal 20% easier.

Project Management

As a result of a larger team than usual, seven people on one team, two different management tools were used. For the majority of the fall semester, an automatically updated Gantt chart was used to track and organize progress. As the spring semester came to pass, the team transitioned over to a more standard calendar style with specific dates plotted out up to four months in advance.

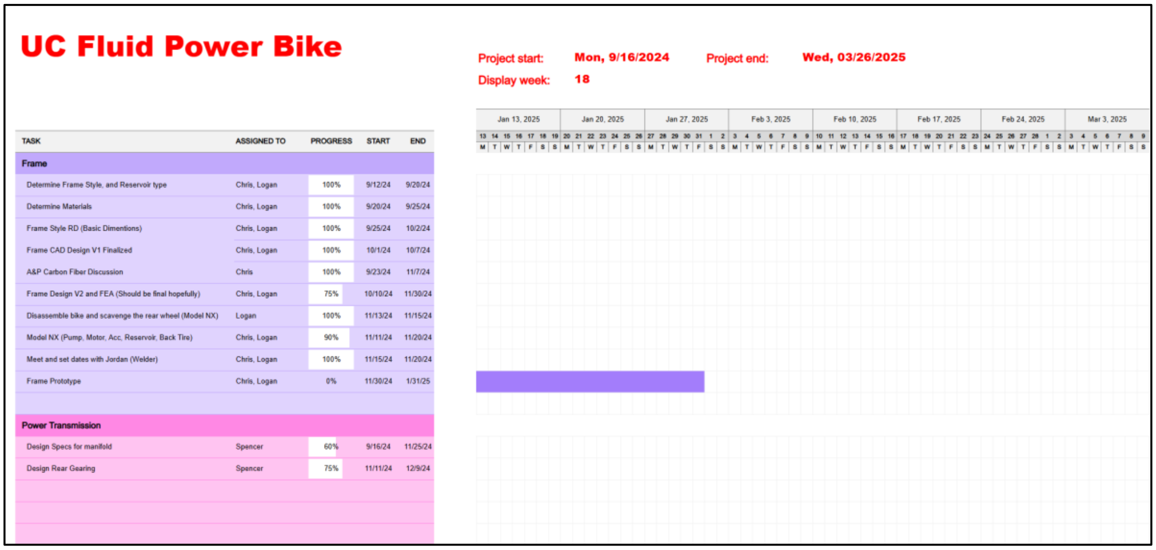


Figure 21: Gantt Chart for Frame and Power Transmission Sub-teams

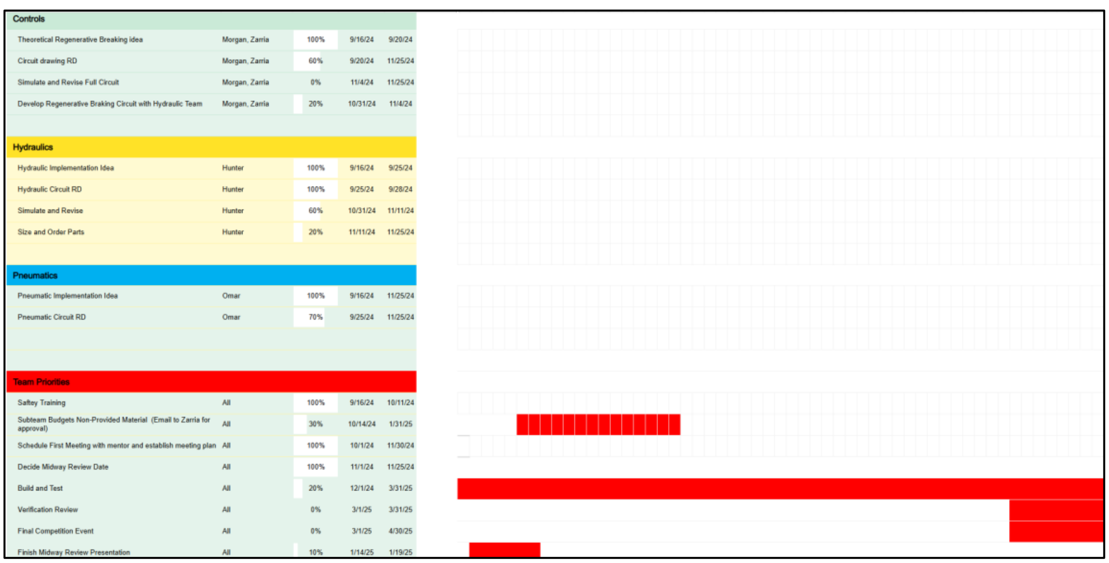


Figure 22: Gantt Chart Controls, Hydraulics, Pneumatics Sub-teams, and Whole Team

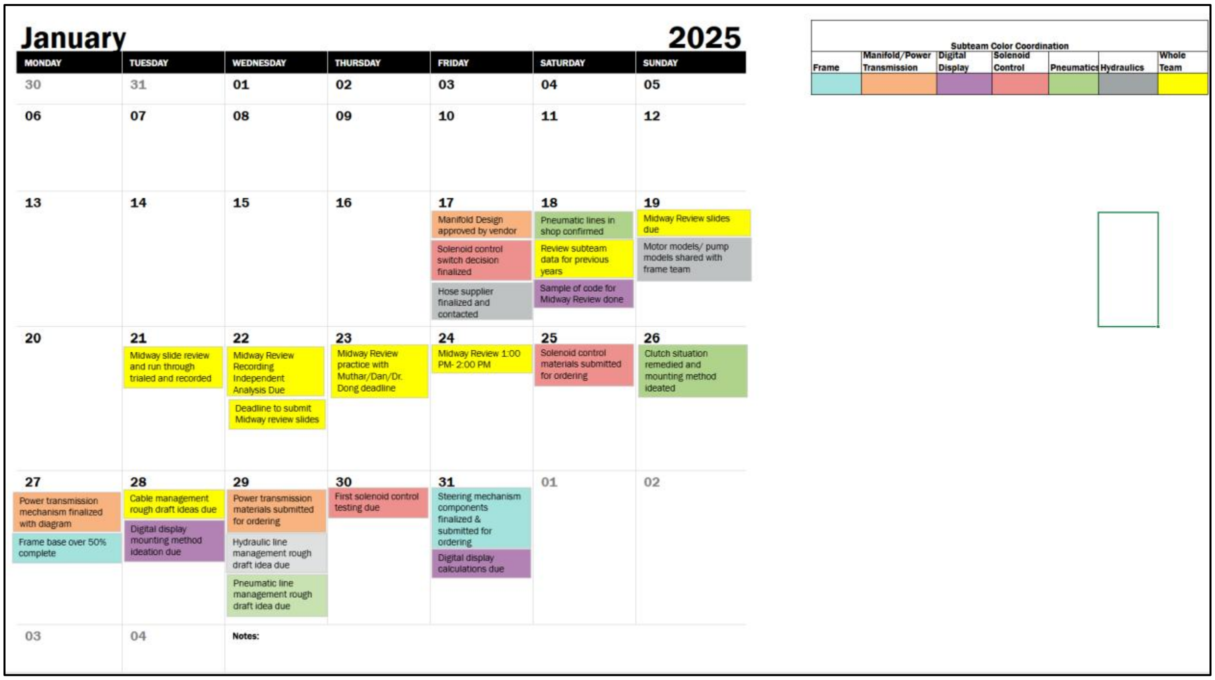


Figure 23: Calendar with Daily Tasks for all Sub-teams

Continuous Improvement Concepts and Suggestions

As this project comes to an end, we reflected on our successes and the challenges we faced. This project has challenged all of us on a communication and technical level. The timeline for this project is rigorous and only allows a small margin of error when it comes to making mistakes. That's why we made a list of suggestions every team after us can use to get a better picture of how to be more successful.

- Prioritize completing the hydraulic circuit and ordering the manifold early in the process
- Consider integrating a gearbox or continuous variable transmission (CVT)
- A pre-manufactured frame is far more practical and time-efficient
- Incorporating a digital display and innovative controls will set your bike apart
- Foster greater inter-team communication and collaboration opportunities
- Be strict with internal deadlines to maintain project momentum

Conclusion

The vehicle performed well in the competition, earning the Safety Award. Despite facing significant technical and logistical challenges, our team succeeded in participating in all three NFPA competitions. While the bike did not place first in any individual event, being able to compete across all categories was a major accomplishment, especially considering the bike was finished only three weeks out of the competition. This project demonstrated not only our technical abilities, but also our adaptability, teamwork, and commitment to delivering a functioning hydraulic-powered vehicle under pressure.