NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation

Final Presentation
University of Akron
Scott Sawyer
January 22, 2024

Agenda

- Team Introductions
- Frame Design
- Manufacturing
- Hydraulic Circuit
- Electronics
- Pneumatics
- Testing
- Results & Conclusions
- Questions

Team Introductions

Team Introductions

The team consists of Mechanical Engineering Students graduating May 2024.

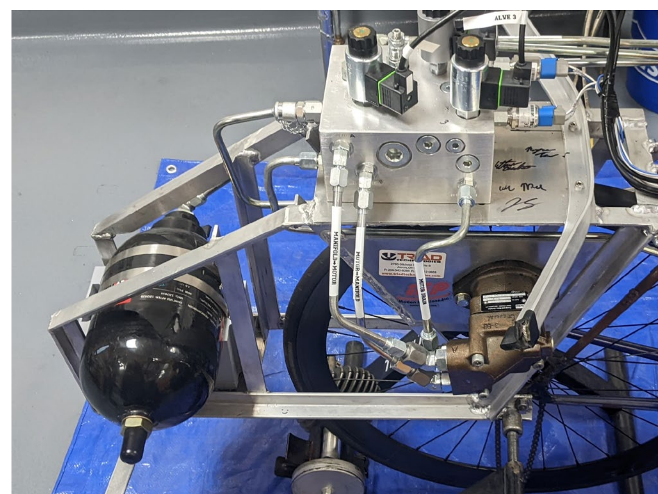
- Nick
  - Welding, Finances, & Rider
- Kim
  - CAD/3D Printing & Secretary
- Hana
  - Framework & Pneumatics
- Ryan
  - Hydraulics Circuit & Manifold
- Rachel
  - Electronics & Programming

Frame Design

Previous Team's Design:

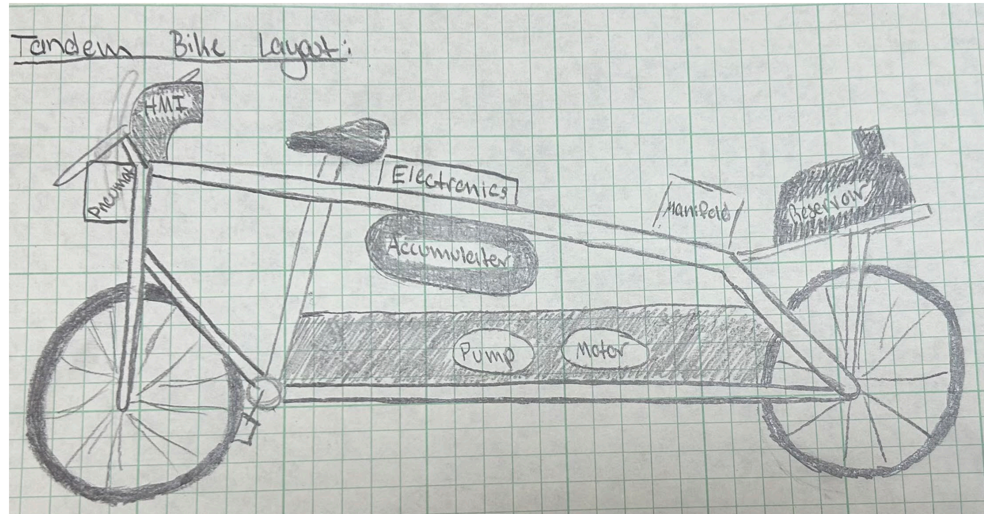
- **Previous Vehicle Chosen: Touring Bicycle**

- **Layout/Equipment:**
  - Reservoir and pump placed between seat and handles
  - Pedal extension was added
  - Electronics attached to handle beam
  - Truss, manifold, accumulator, and motor placed around back wheel
  - Hard lining used for fluids



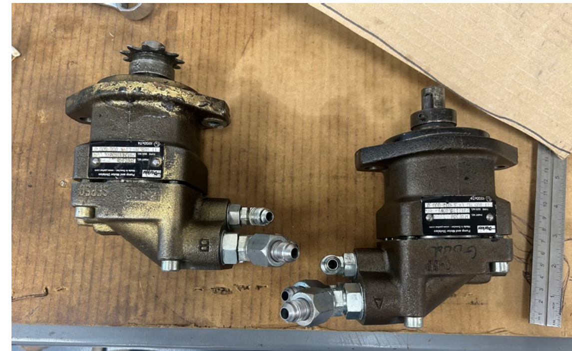
Our Team's Design:

- **Vehicle Chosen: Tandem Bike**
  - All hydraulic components can be placed behind the rider
  - Improves ergonomics
  - Creates safer vehicle for the rider
  - Center of gravity is shifted to the middle of the vehicle
  - Reduces risk of failure in tires
  - Creates stability
  - Shortened length needed for piping



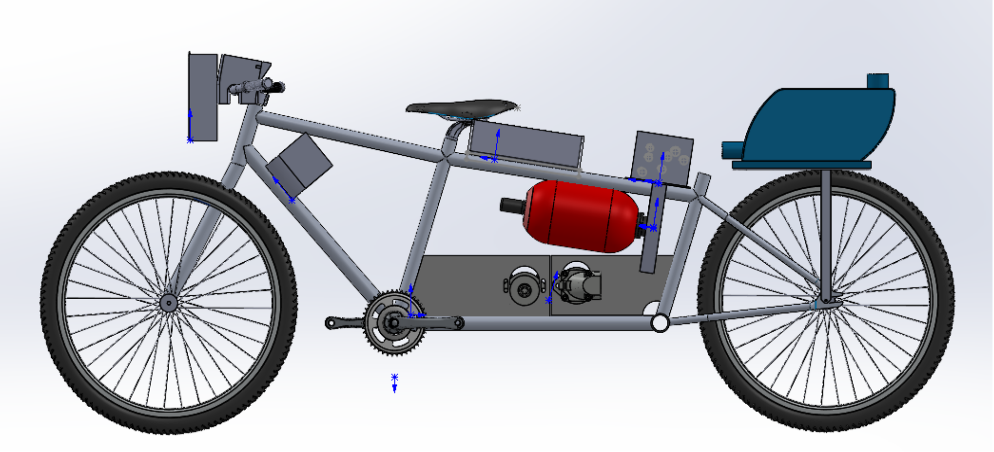
Our Team’s Design:

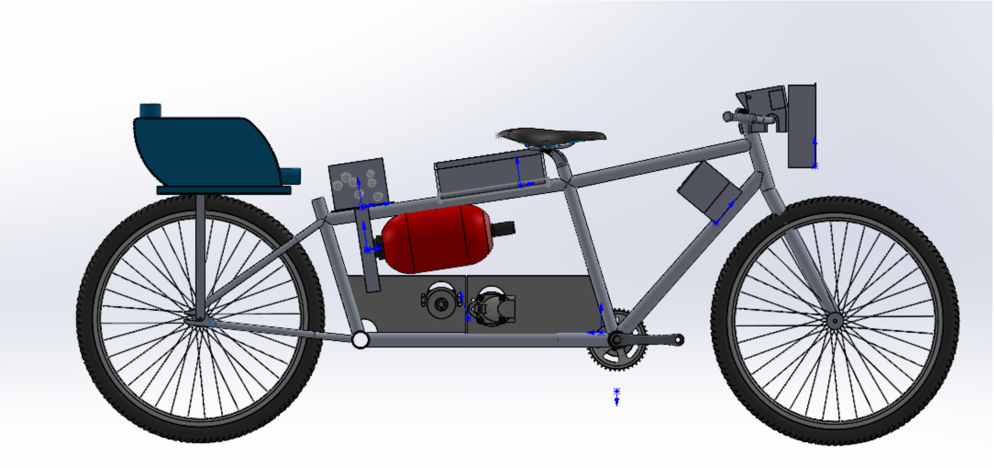
- **Equipment used:**
  - Pump & Motor
    - Parker Hannifin F-11-005 Bent Axis Piston Pumps
  - Accumulator
    - Parker Hannifin 3000 PSI Bladder Accumulator
  - Manifold
    - Custom made from IFP Motion Solutions INC.
  - Reservoir
    - Custom made from Schmidtproto
  - Electronics & Programming
    - Exor HMI (JMobile Studios)
    - IFM PLC (Codesys)
  - Pneumatics
    - Bimba pistons, valves, and regulator



SolidWorks Model

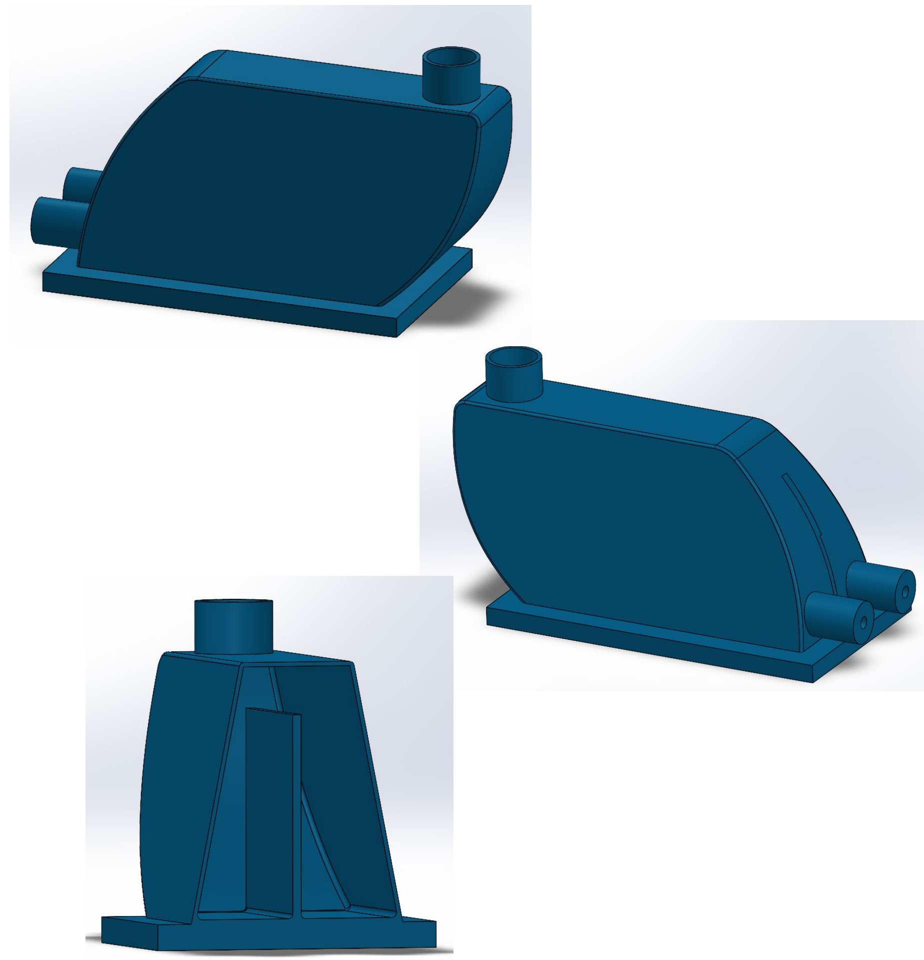
- **All components included on model**
  - This aided us in designing and manufacturing the steel/aluminum plates
  - These CAD files were then sent to UA's plasma cutter for the pump/motor plates, manifold plate, and the reservoir plate
- **Greatly aided in final placement of components with ergonomics in mind**





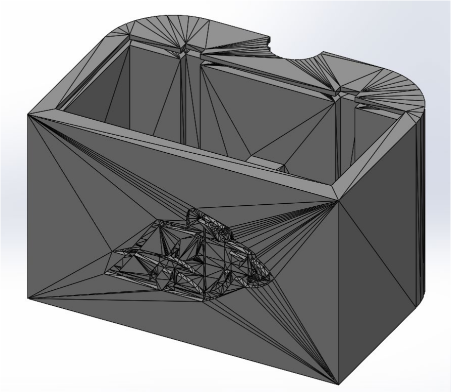
Reservoir

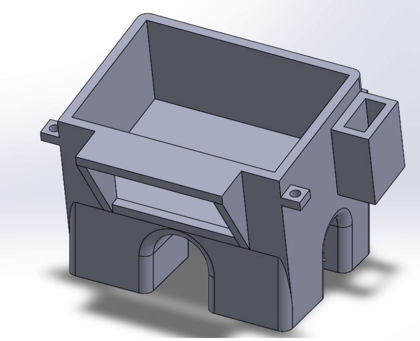
- **Designed to:**
  - Enable easy filling/draining
  - Sit flush on the aluminum plate, and be bolted directly to it
  - Holds 2 gal of fluid required for the system
- **Printed in PETG**
  - Filament selected for its resistance to chemicals, thus making it the best option for use with hydraulic fluid

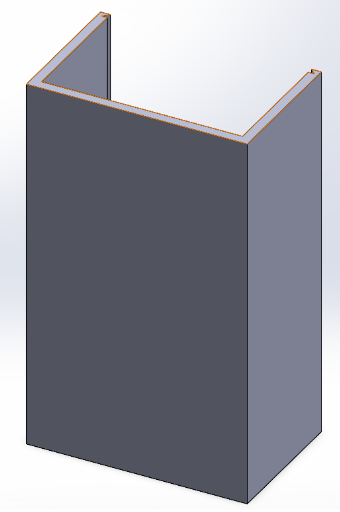


Electronics & Pneumatic Boxes

- **Electronics boxes:**
  - Battery box holds the vehicle's batteries to support the PLC and HMI
  - HMI box houses the touch screen (to move between modes), as well as an "on/off" switch for the electronics
- **Pneumatic Box:**
  - Houses the piston for the pneumatic system, as well as hides the celebratory Zippy

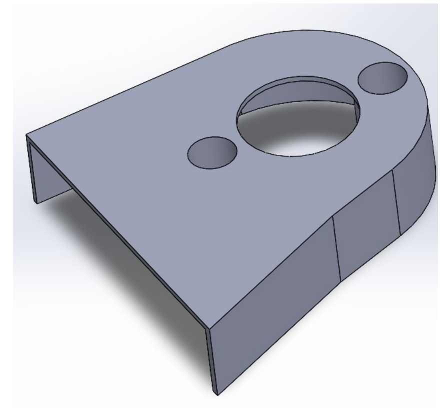


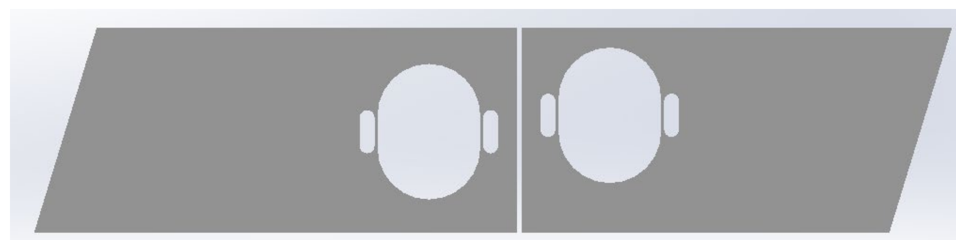


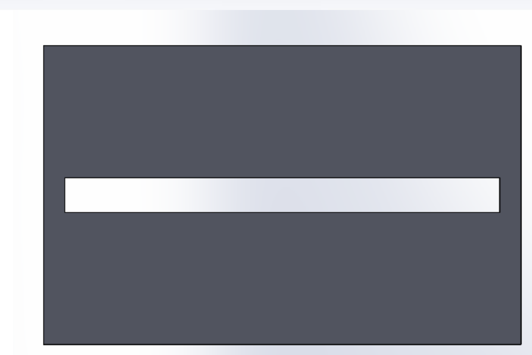


Chain Guard & Plates

- **Chain Guard:**
  - Attaches to the plate, just above the pump
  - Protects the rider from the pinch point present with the chain connected to the pump
- **Plates:**
  - Pump and motor plates cut out of steel to be welded to the frame
  - Manifold plate cut out of steel to be welded to the frame
  - Reservoir plate and attaching arms cut out of aluminum for weight and support







Manufacturing

Manufacturing:
Main Bike Assembly

- Plasma cutting:
  - All metal plates were plasma cut to shape
- Welding:
  - 1/8” 4130 chrome moly used for vertical plates
  - 1/8” 1008 carbon steel used for manifold plate
- End milling
  - 1/8” Aluminum milled for bolt holes
- Reservoir platform assembled with hardware
  - Replicated original bike rack

Manufacturing:
Hydraulic Assembly

- Connections
  - Originally planned for hard-lining
    - Prevented by lead times
  - 3/8” soft-lines rated for 3000 psi utilized
    - Low profile of vehicle maintained

Manufacturing:

Reservoir Issues

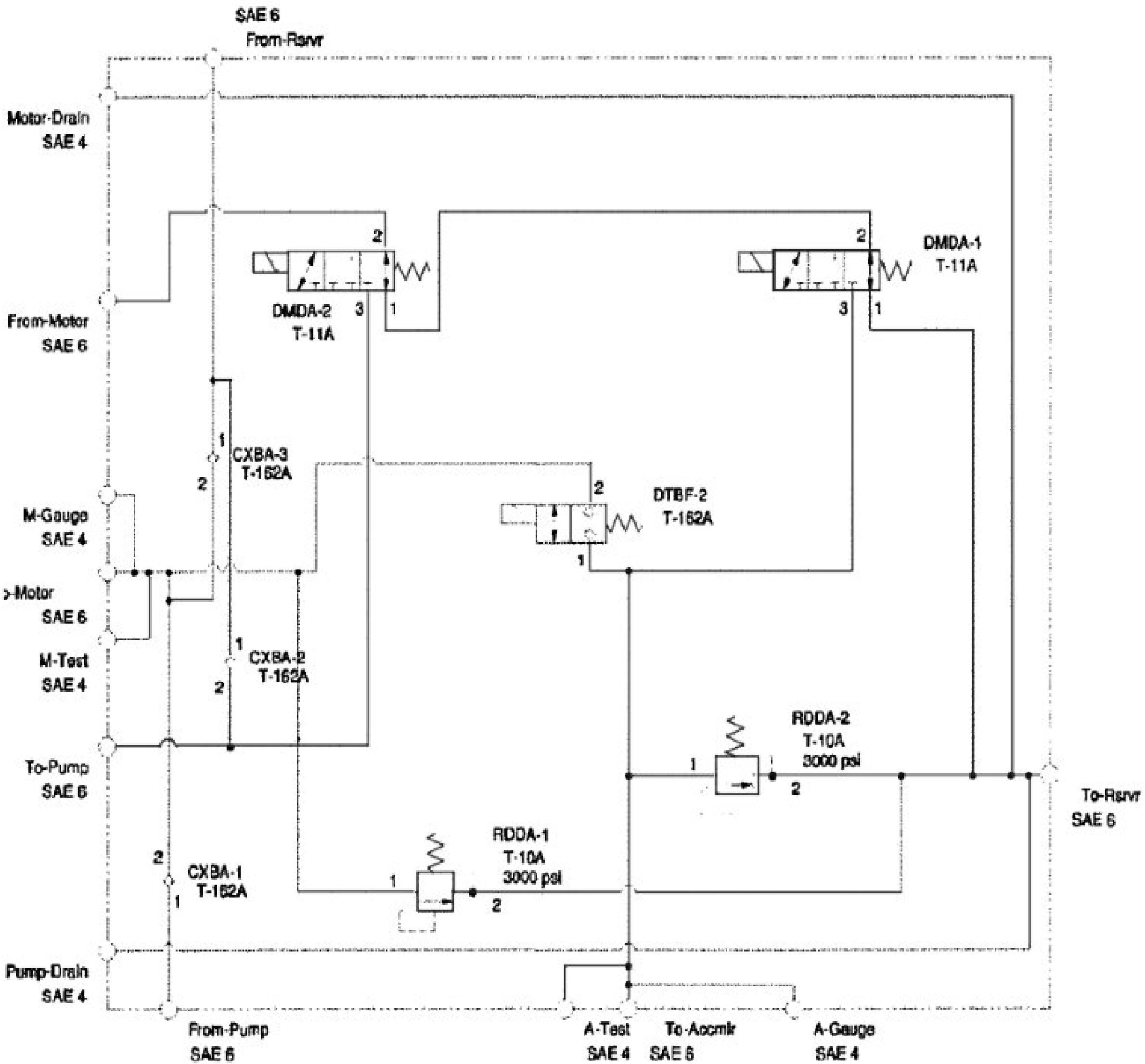
- Leaks found after sealing reservoir
  - Layer separating tank floor from base failed
    - Fluid filled base where mounting holes were drilled
- Solution:
  - Used JB Weld on top and bottom of holes with bolts and washers attached
  - Extra layers added to isolate leaks
  - Reservoir base flex-sealed as a final prevention measure

Manufacturing:
Chain Issues

- Unable to acquire fixed-gear wheel
  - Stuck with original cassette wheel
  - Fixed gear cassette w/ hose clamps
  - Derailleur unusable with regen
- Without derailleur, chain disconnected often
- Solution:
  - Fixed two metal rods to the frame to align the chain

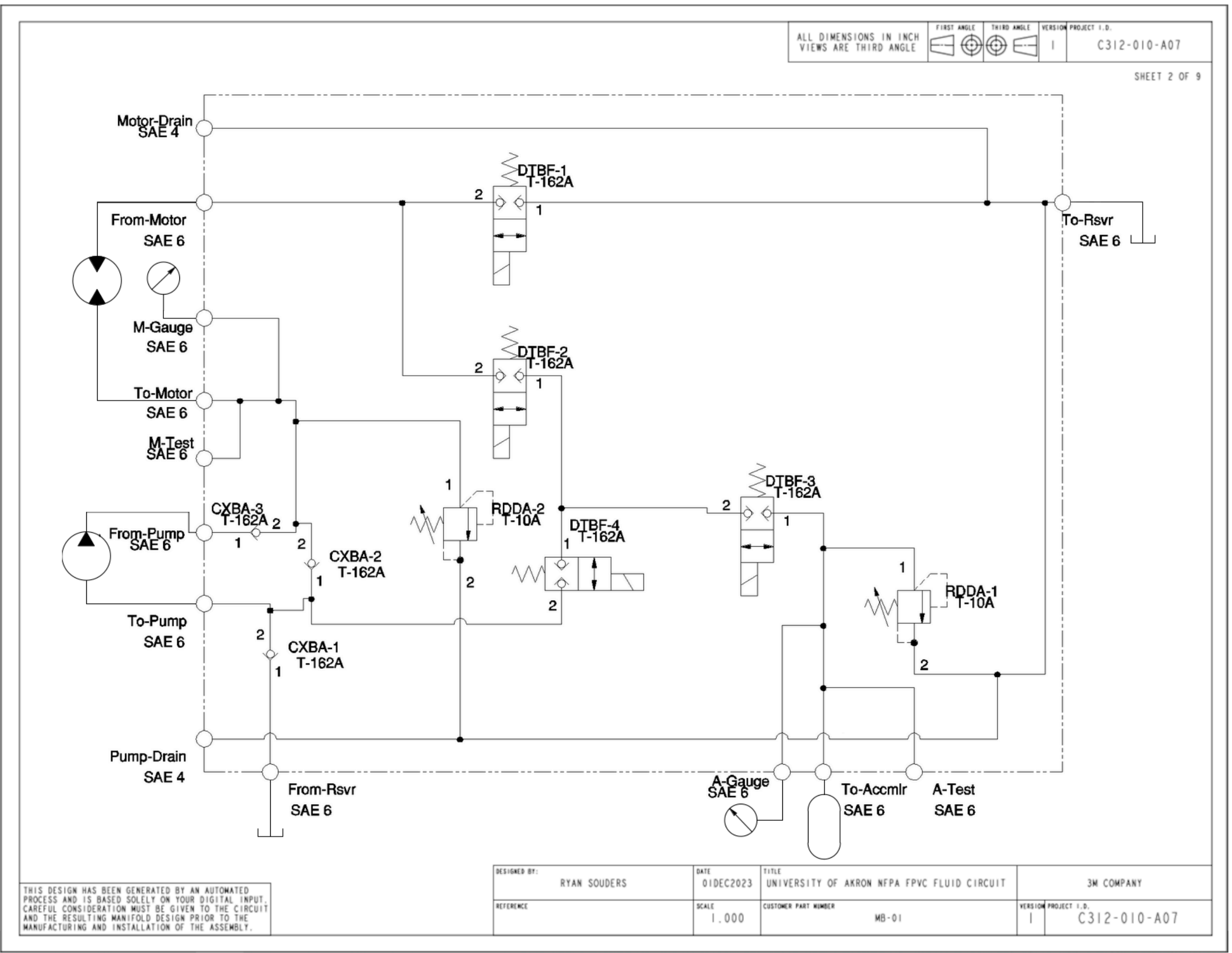
Hydraulic Circuit

Hydraulic Circuit: Previous Team's Design



- **Components:**
  - 2 DMDA 3-Way Solenoids
  - 1 DTDF 2-Way Solenoid
  - 3 CXBA Check Valves
  - 2 RDDA Relief Valves, set at 3000 Psi
- **Main Issues:**
  - Large amount of pressure leak when accumulator is fully charged
  - Port sizes were incorrect for Gauge and Test ports
  - Cavitation would occur if rider stopped pedaling in Closed Loop mode

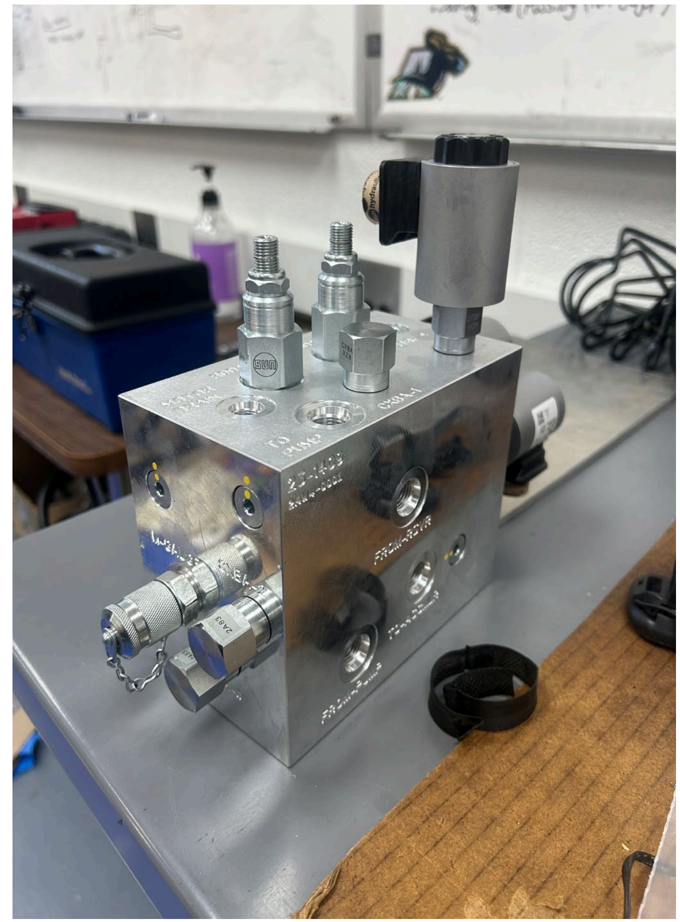
Hydraulic Circuit: Current Team's Design



- **Components:**
  - 4 DTDF 2-Way Solenoid
  - 3 CXBA Check Valves
  - 2 RDDA Relief Valves, set at 3000 Psi
- **Addressing Issues:**
  - Broke 3-way solenoids down into 2-way solenoids to reduce leakage
  - Gauge and Test ports are correctly sized to SAE 6
  - Added a bypass route that allows the rider to stop pedaling in Closed Loop without caviation

Hydraulic Circuit: Manifold Block

- **Issue Encountered**
  - During the installation of the lines to the manifold block, the threads for the Pump Drain port were partially stripped
  - While welding on the mounting plate for the manifold, it heat warped slightly causing the manifold to not sit perfectly flush on the plate



- **How we resolved the issue**
  - We added tape to the threads of the fitting, which prevented it from leaking
  - We carefully threaded in the bolts securing the manifold to the plate, which subsequently bent the plate back into the correct position

- **Contingencies explored**
  - In the event the tape didn't seal the port from leaking, we discussed retaping the port to be SAE 6 instead of SAE 4 and run a bigger fitting
  - Provided mounting the manifold itself didn't fix the issue, we discussed using a flat piece of wood and a hammer to evenly bend the plate back into it's intended position

Electronics

Electronics: Overview

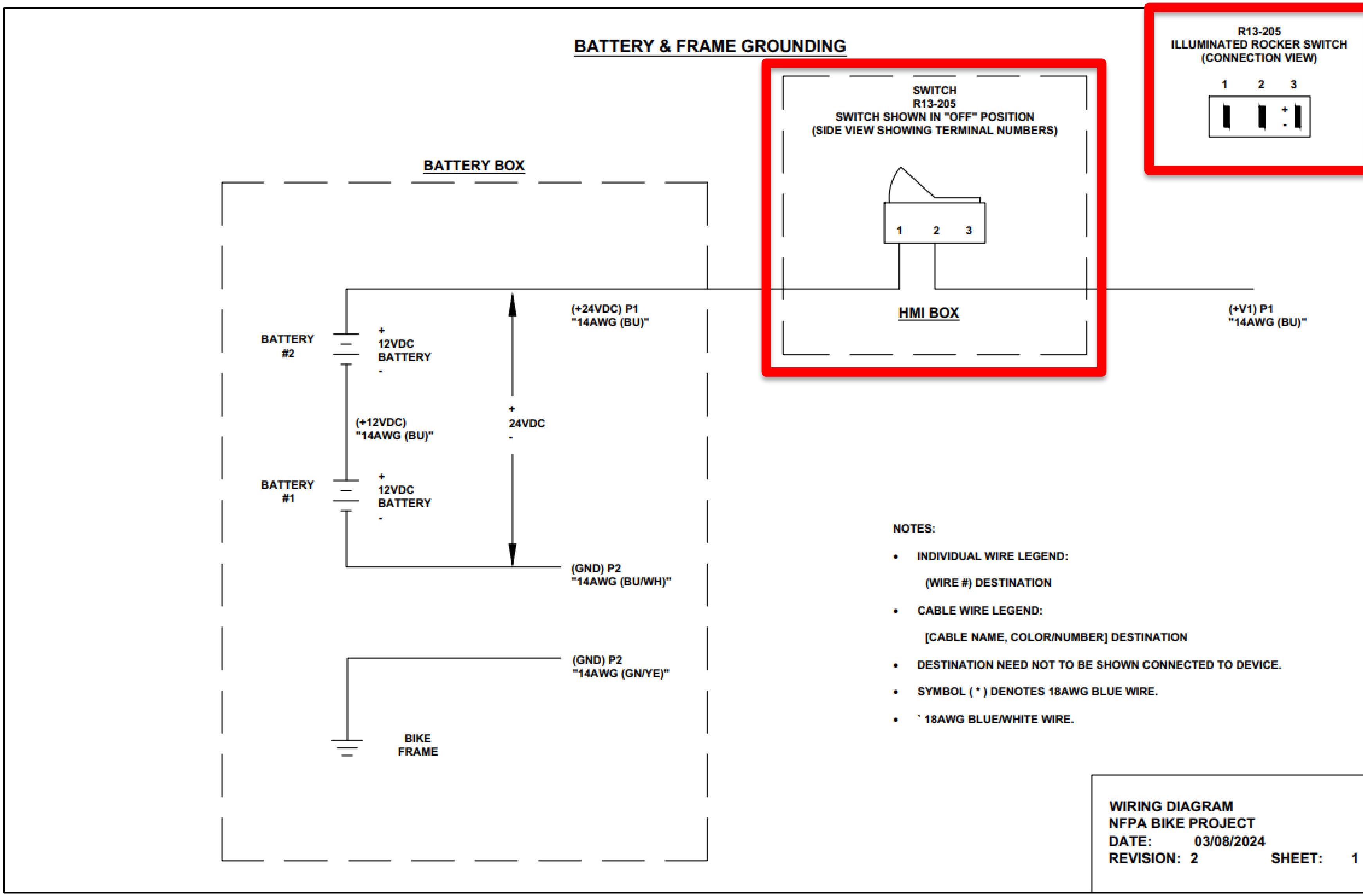
- IFM ecomatController CR710S (Codesys V3.5)
- Phoenix Power Distribution Block
- Phoenix Fuse Terminal Block
- Phoenix DIN Rail
- Eaton-Bussmann 2A & 15A Fuses
- Phoenix End Brackets
- Cable
- Wago 2-Wire Lever Nuts Conductor Compact Splicing Connectors
- Exor HMI (JMobile Studios)



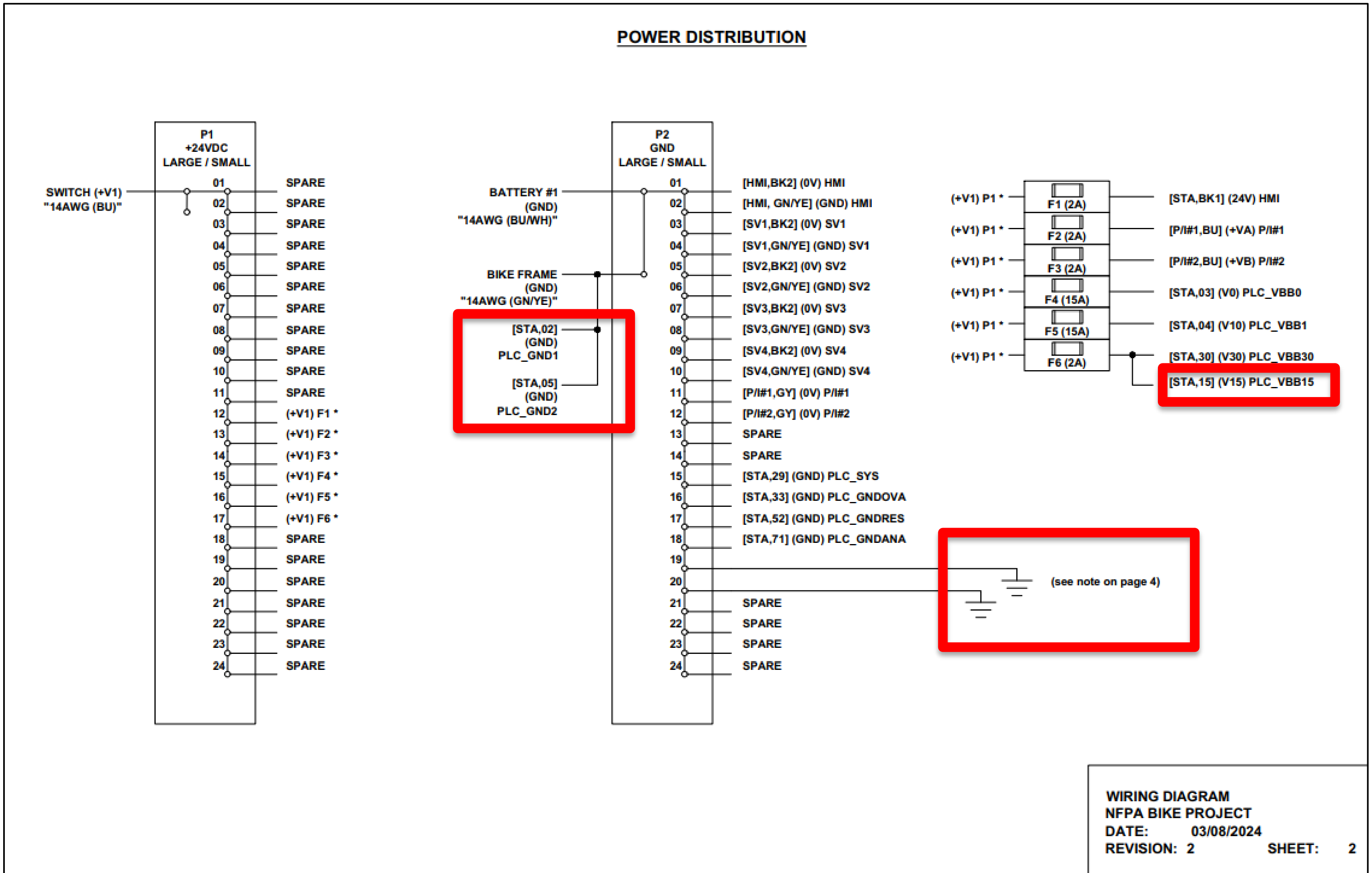




Electronics: Wiring Diagram

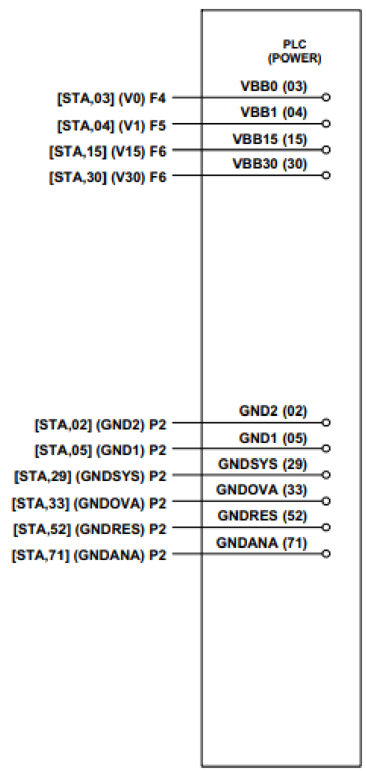


Electronics: Wiring Diagram



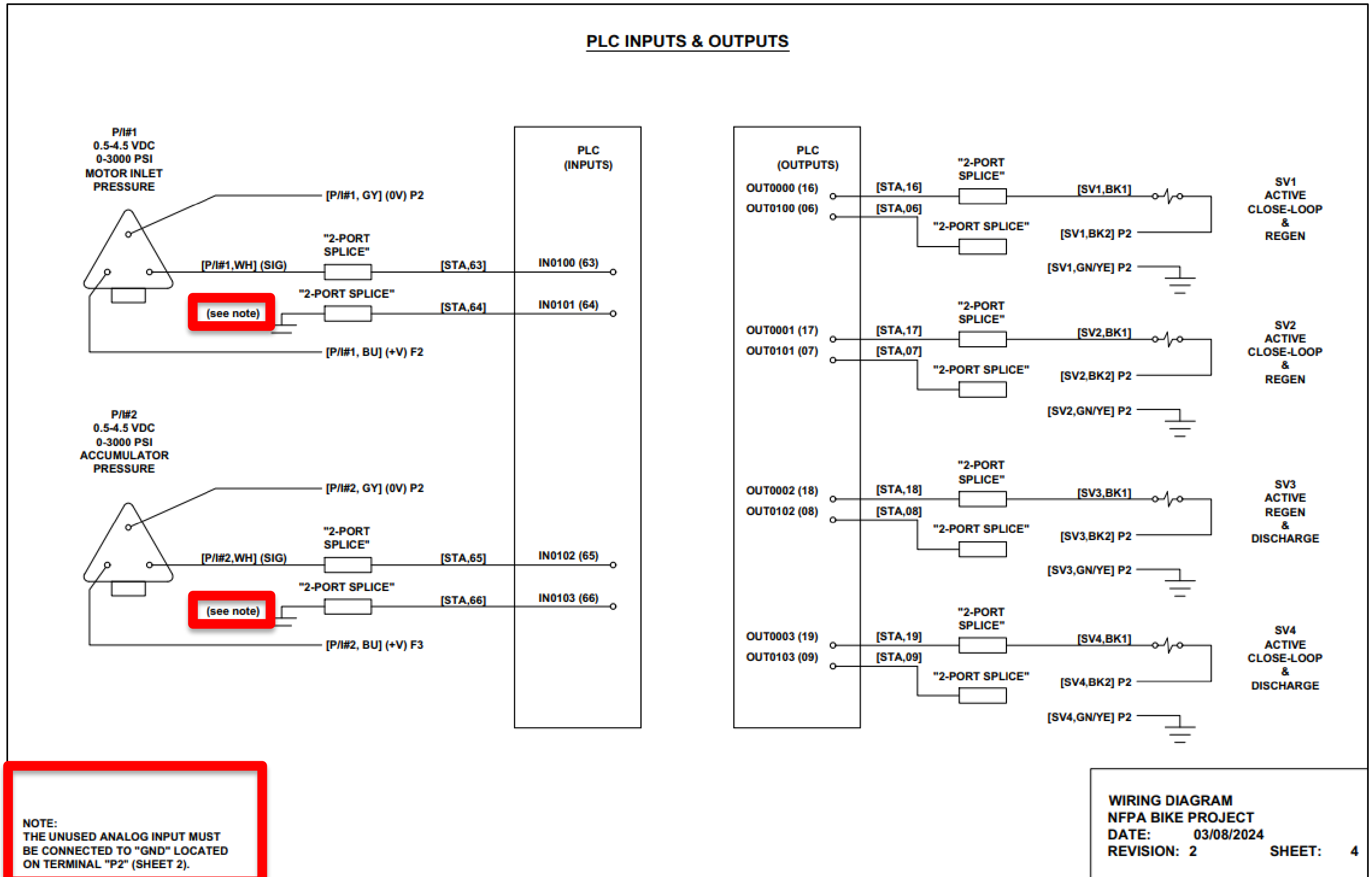
Electronics: Wiring Diagram

PLC POWER

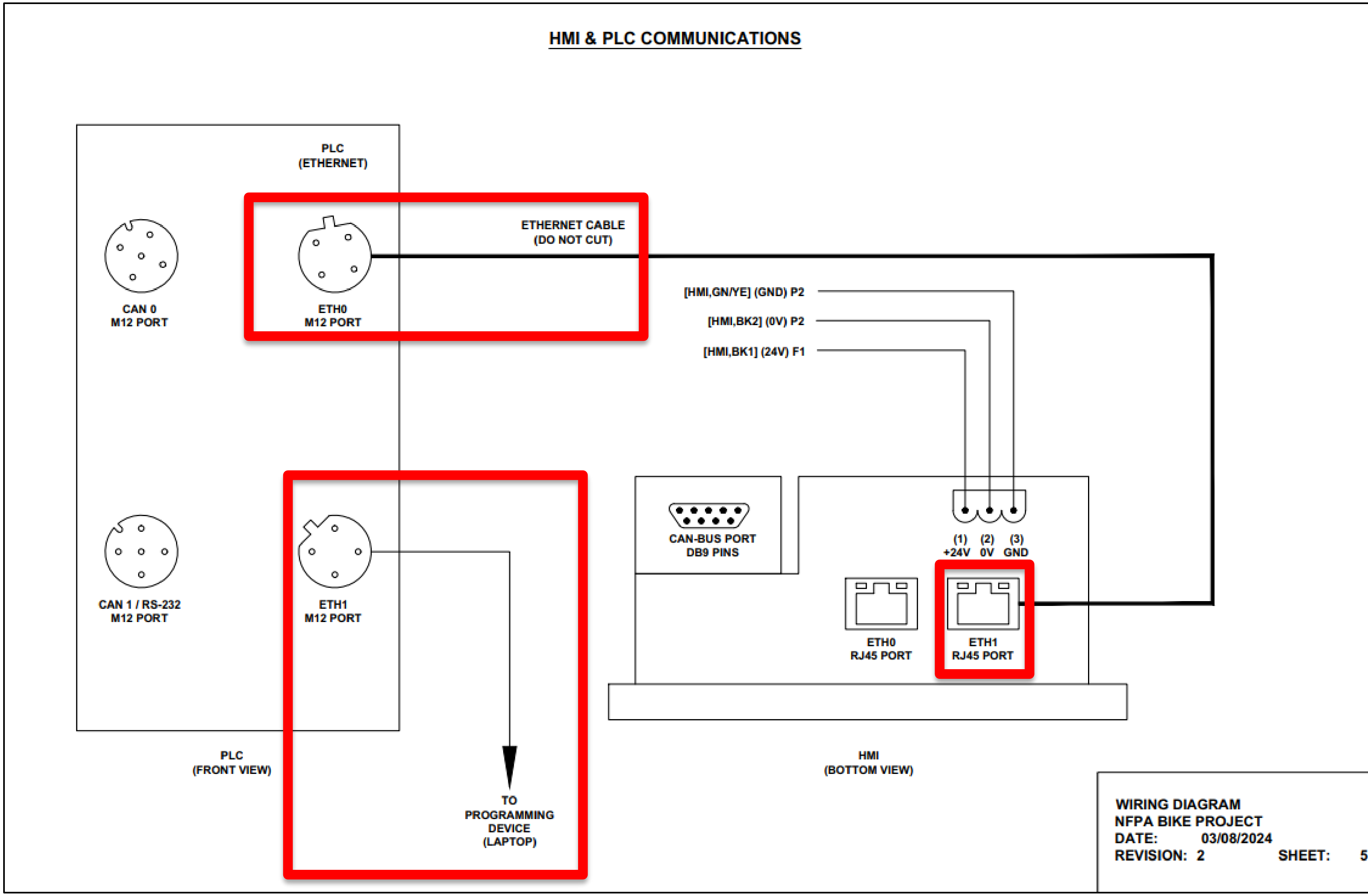


WIRING DIAGRAM
NFPA BIKE PROJECT
DATE: 03/08/2024
REVISION: 2 SHEET: 3

Electronics: Wiring Diagram



Electronics: Wiring Diagram



Electronics: Wiring Diagram

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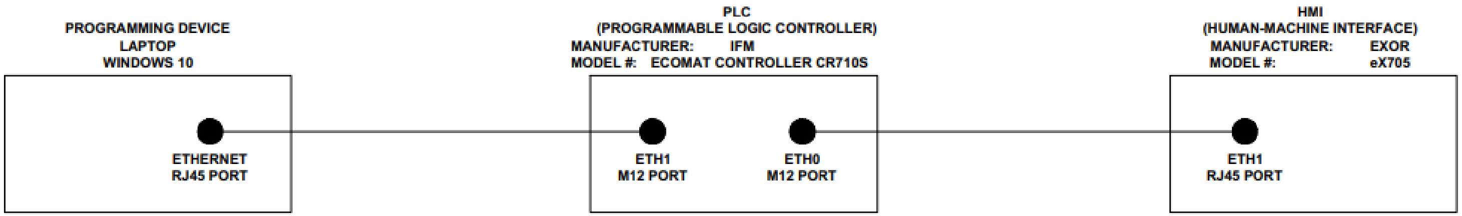
PROGRAMMING SETUP



IP ADDRESS: 192.168.82.205
SUBNET MASK: 255.255.255.0
GATEWAY: 0.0.0.0 "BLANK"

THIS SETTING IS TYPICALLY SET AS: "OBTAIN AN IP ADDRESS AUTOMATICALLY". SETTING FOUND UNDER "OPEN NETWORK & INTERNET SETTINGS" >> "ETHERNET" >> "INTERNET PROTOCOL VERSION 4 (TCP/IPv4)".

IP ADDRESS: 192.168.82.247
SUBNET MASK: 255.255.255.0
GATEWAY: 192.168.82.21

THE ABOVE IS THE DEFAULT SETTING.

VALUES CAN BE CONFIRMED USING IFM "MAINTENANCE" APP RELEASE - VERSION 3.10.17.0 INSTALLED ON LAPTOP. SELECT ECOMAT CONTROLLER >>ETHERNET ICONS.

IP ADDRESS: 192.168.82.1
SUBNET MASK: 255.255.255.0
GATEWAY: 0.0.0.0 "BLANK"
TYPE: LAN

USER NAME: user
PASSWORD: Ab@12345

USER NAME: admin
PASSWORD: Ab@12345

SOFTWARE INSTALLED ON PROGRAMMING DEVICE:

1. IFM MAINTENANCE TOOL
   VERSION 3.10.17.0
   USED TO ESTABLISH BASIC SETUP OF IFM PLC
2. CODESYS
   VERSION V3.5 (SP11) 32-BIT
   USED TO PROGRAM IFM CONTROLLER
   DO <u>NOT</u> HAVE ANY OTHER CODESYS VERSION INSTALLED PRIOR TO INSTALLING THIS APP.
3. IFM UPDATE TOOL
   VERSION V.2.0.3-3
   USED TO INSTALL FIRMWARE ONTO THE IFM CONTROLLER.
4. EXOR JMOBILE STUDIO
   VERSION V4.5.1.523
   USED TO PROGRAM THE EXOR HMI
5. RADZIO! MODBUS MASTER SIMULATOR
   VERSION 0.1.6
   USED TO TROUBLESHOOT THE MODBUS NETWORK. MORE SPECIFICALLY, THIS APP WAS USED TO VERIFY DATA IS GATHERED FROM THE CONTROLLER /OR/ DATA WAS BEING SENT TO THE CONTROLLER WHEN COMMANDED BY THE SIMULATOR APP.
6. ITEMS 1 THRU 3 SHOULD ONLY BE DOWNLOADED FROM THE IFM WEBSITE - INCLUDING THE CODESYS!

MODBUS MASTER SIMULATOR OPERATION INSTRUCTIONS:

1. AFTER TURNING ON THE APP, PERFORM THE FOLLOWING:
2. FILE > NEW. THIS OPENS A VIEWING WINDOW.
3. MAKE SURE THE LAPTOP IS CONNECTED TO THE PLC.
4. DISCONNECT THE ETHERNET CABLE AT THE HMI.
5. CONNECTION > SETTINGS. POP UP APPEARS.
6. CHECK THE "MODBUS TCP" PROTOCOL.
7. IP ADDRESS: 192.168.82.247 . THIS IS THE ADDRESS OF THE IFM CONTROLLER.
8. TCP PORT: 502 . THIS MUST MATCH THE PORT NUMBER FOUND ON THE IFM MODBUS TCP SLAVE DEVICE FOLDER.
9. TIMEOUT (MS): 5000.
10. DELAY BETWEEN POLLS (MS): 50.
11. PRESS "OK".
12. CONNECTION > CONNECT.
13. VERIFY THE FOLLOWING "DEVICE SETTINGS":
    - 13.1. DEVICE ID: 1 THIS IS THE MODBUS ADDRESS (UNIT) ID.
    - 13.2. ADDRESS: 0 THE STARTING ADDRESS".
    - 13.3. LENGTH: 10 THIS IS HOW MAY REGISTERS IS BEING REVIEWED.
14. VERIFY THE "DISPLAY OPTIONS" IS SET TO "DECIMAL".
15. FOR READING VALUES FROM THE PLC:
    - 15.1. DEVICE SETTINGS: SELECT "INPUT REGISTERS".
    - 15.2. VALUES IN THE PLC SHOULD MATCH THE SIMULATOR.
    - 15.3. WHEN CHANGING VALUES IN THE PLC, THE NEW VALUES WILL AUTOMATICALLY APPEAR.
16. FOR WRITING VALUES TO THE PLC:
    - 16.1. DEVICE SETTING: SELECT "HOLDING REGISTERS".
    - 16.2. VALUES IN THE PLC SHOULD MATCH THE SIMULATOR.
    - 16.3. WHEN WRITING VALUES IN THE SIMULATOR, THE NEW VALUES WILL BE AUTOMATICALLY UPDATED IN THE PLC.
17. WHEN FINISHED WITH THE SIMULATOR APP:
    - 17.1. FILE > EXIT.
    - 17.2. RECONNECT THE ETHERNET CABLE AT THE HMI.

WIRING DIAGRAM
NFPA BIKE PROJECT
DATE: 03/08/2024
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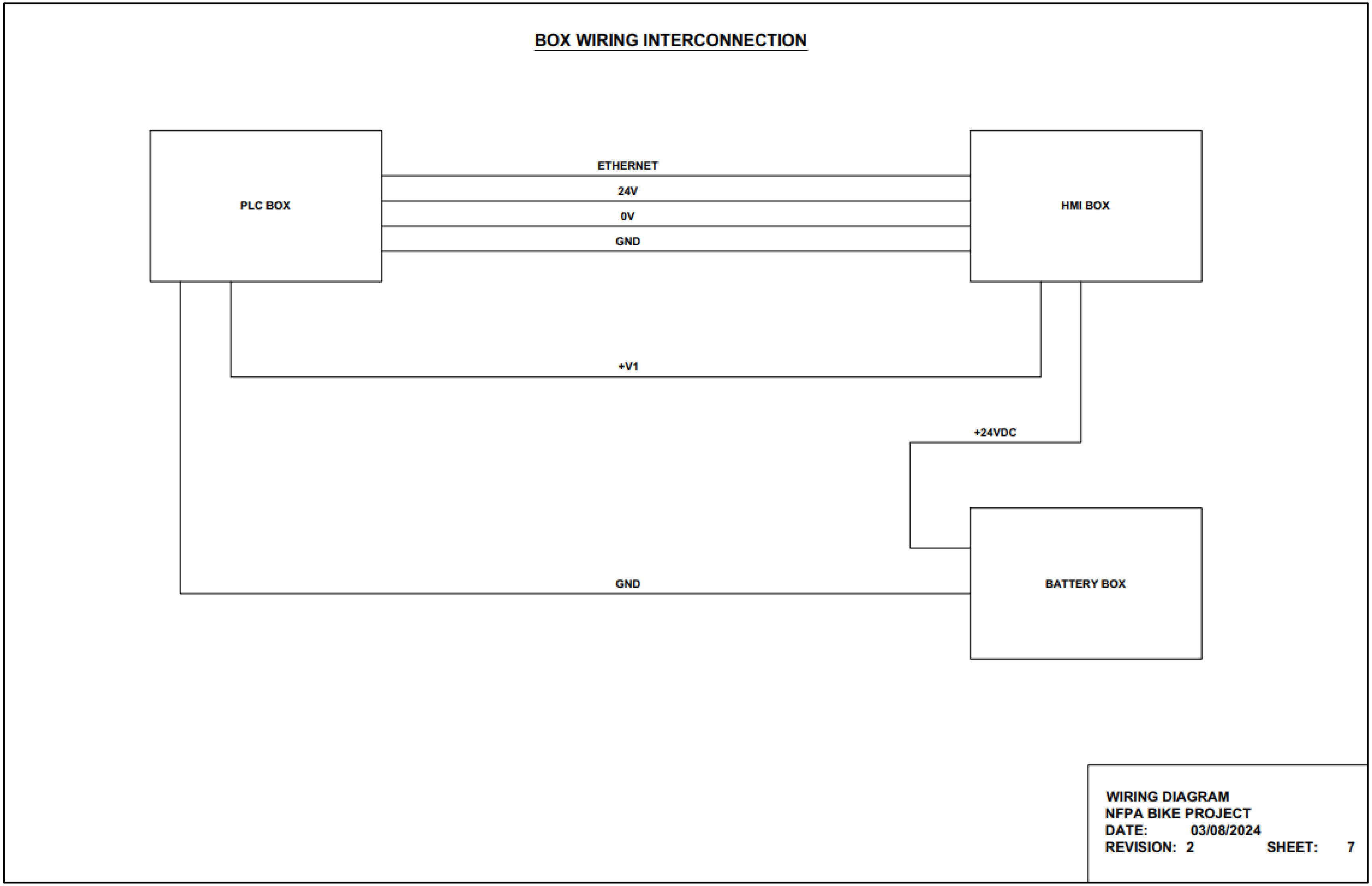
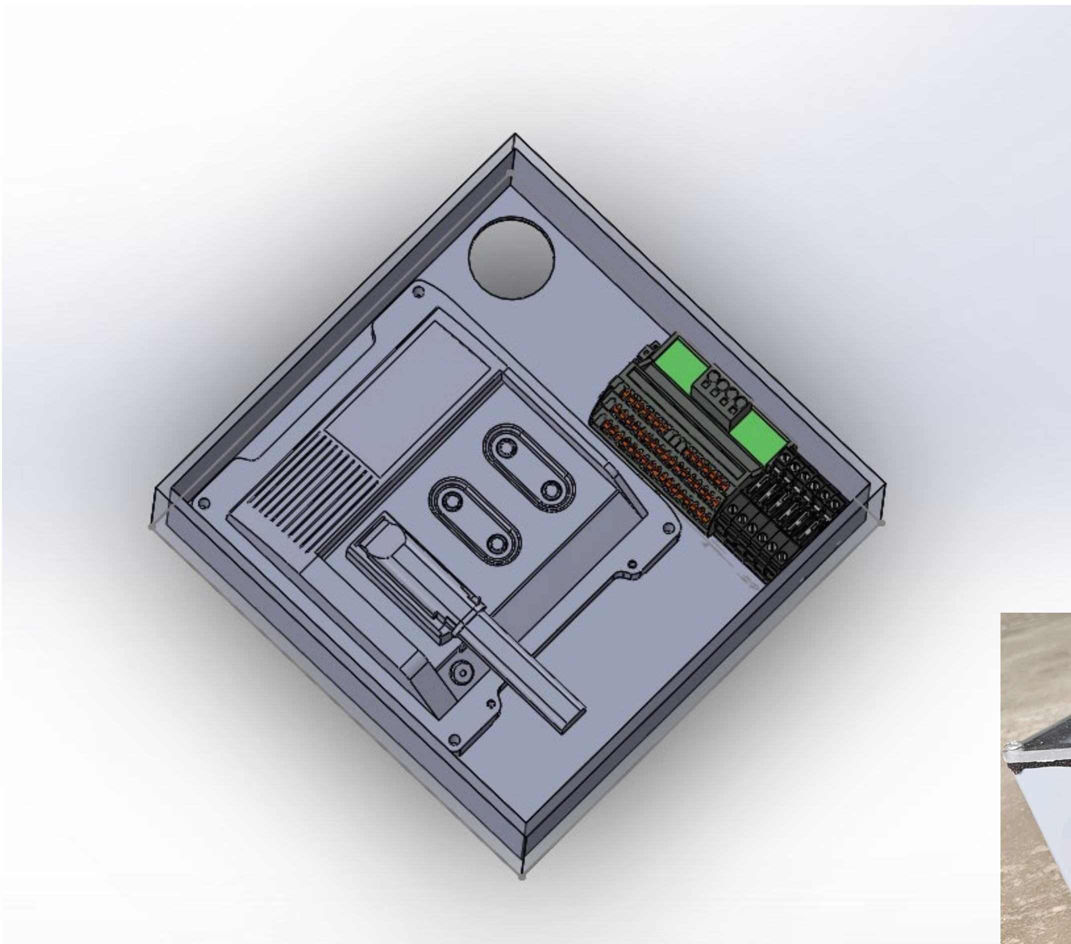
Electronics: Wiring Diagram



PLC Box Manufacturing



CanBus to Modbus

- Biggest challenge is establishing communications between PLC and HMI
  - Original design: CanBus (based on prior team's design)
- 3 different companies: IFM (PLC hardware), Codesys (PLC operating system), Exor (HMI hardware and operating system)
  - Hard to align the support between the companies
  - Ethernet based options offers more support
    - Modbus: Ethernet Based (TCP/IP)
    - CanBus: Serial Bus
- Modbus drivers already built into the PLC and HMI program
  - Verifed setup with Radzio! Modbus Master Simulator
    - This software is written for testing Modbus slave devices
    - Wasn't a tool available to CanBus

Electronics: Modbus

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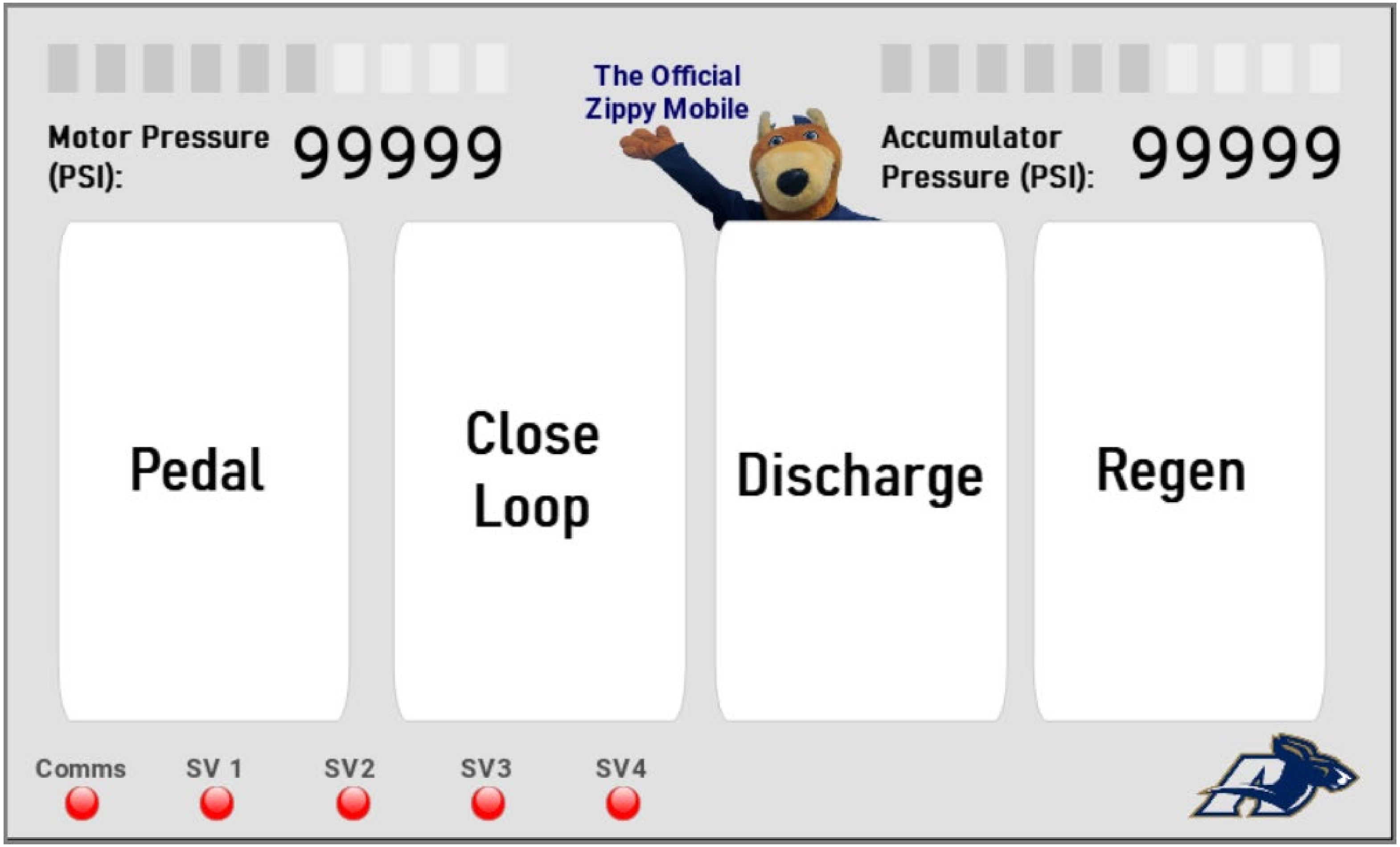
FROM PLC >> TO HMI

IFM PLC								EXOR HMI		
PLC Tag (Global)	PLC Tag (local "HMI Data")	Tag name type	Modbus declared Variable	PLC hardware address	Modbus Input Register	Modbus Address	Data Flow Path	Modbus Address	Tag name type	Tag name
GVL.PI1_psi	p_h_pi1_psi	word	Application.HMI_data.p_h_pi1_psi	QW52	0.00	300000.00		300000.00	unsigned short	PLC/p_h_pi1_psi
GVL.PI2_psi	p_h_pi2_psi	word	Application.HMI_data.p_h_pi2_psi	QW53	1.00	300001.00		300001.00	unsigned short	PLC/p_h_pi2_psi
		boolean		QW54.00 (QX108.0)	2.00	300002.00		300002.00	boolean	
		boolean		QW54.01 (QX108.1)	2.10	300002.01		300002.01	boolean	
		boolean		QW54.02 (QX108.2)	2.20	300002.02		300002.02	boolean	
		boolean		QW54.03 (QX108.3)	2.30	300002.03		300002.03	boolean	
		boolean		QW54.04 (QX108.4)	2.40	300002.04		300002.04	boolean	
		boolean		QW54.05 (QX108.5)	2.50	300002.05		300002.05	boolean	
GVL.SV1_boolean	p_h_sv1_bool	boolean	Application.HMI_data.p_h_sv1_bool	QW54.06 (QX108.6)	2.60	300002.06		300002.06	boolean	PLC/p_h_sv1_bool
GVL.SV2_boolean	p_h_sv2_bool	boolean	Application.HMI_data.p_h_sv2_bool	QW54.07 (QX108.7)	2.70	300002.07	>>>	300002.07	boolean	PLC/p_h_sv2_bool
GVL.SV3_boolean	p_h_sv3_bool	boolean	Application.HMI_data.p_h_sv3_bool	QW54.08 (QX109.0)	2.80	300002.08		300002.08	boolean	PLC/p_h_sv3_bool
GVL.SV4_boolean	p_h_sv4_bool	boolean	Application.HMI_data.p_h_sv4_bool	QW54.09 (QX109.1)	2.90	300002.09		300002.09	boolean	PLC/p_h_sv4_bool
GVL.close_loop_lt	p_h_close_loop_lt	boolean	Application.HMI_data.p_h_close_loop_lt	QW54.10 (QX109.2)	2.10	300002.10		300002.10	boolean	PLC/p_h_close_loop_lt
GVL.discharge_lt	p_h_discharge_lt	boolean	Application.HMI_data.p_h_discharge_lt	QW54.11 (QX109.3)	2.11	300002.11		300002.11	boolean	PLC/p_h_discharge_lt
GVL.pedal_lt	p_h_pedal_lt	boolean	Application.HMI_data.p_h_pedal_lt	QW54.12 (QX109.4)	2.12	300002.12		300002.12	boolean	PLC/p_h_pedal_lt
GVL.regen_lt	p_h_regen_lt	boolean	Application.HMI_data.p_h_regen_lt	QW54.13 (QX109.5)	2.13	300002.13		300002.13	boolean	PLC/p_h_regen_lt
		boolean		QW54.14 (QX109.6)	2.14	300002.14		300002.14	boolean	
		boolean		QW54.15 (QX109.7)	2.15	300002.15		300002.15	boolean	
GVL.Accumulator_Pressure_Range	p_h_acc_range	word	Application.HMI_data.p_h_acc_range	QW55	3.00	300003.00		300003.00	unsigned short	PLC/p_h_acc_range
GVL.Motor_Pressure_Range	p_h_motor_range	word	Application.HMI_data.p_h_motor_range	QW56	4.00	300004.00		300004.00	unsigned short	PLC/p_h_motor_range

FROM HMI >> TO PLC

EXOR HMI				IFM Controller					
Tag name	Tag name type	Modbus Address	Data Flow Path	Modbus Address	Modbus Holding Register	PLC hardware address	Modbus declared Variable	PLC Tag (local "HMI Data")	PLC Tag (Global)
PLC/h_p_close_loop_pb	boolean	400000.00		400000.00	0.00	%IW208.00 (%IX416.0)	Application.HMI_data.h_p_close_loop_pb	h_p_close_loop_pb	GVL.close_loop_pb
PLC/h_p_discharge_pb	boolean	400000.01		400000.01	0.01	%IW208.01 (%IX416.0)	Application.HMI_data.h_p_discharge_pb	h_p_discharge_pb	GVL.discharge_pb
PLC/h_p_pedal_pb	boolean	400000.02		400000.02	0.02	%IW208.02 (%IX416.0)	Application.HMI_data.h_p_pedal_pb	h_p_pedal_pb	GVL.pedal_pb
PLC/h_p_regen_pb	boolean	400000.03		400000.03	0.03	%IW208.03 (%IX416.0)	Application.HMI_data.h_p_regen_pb	h_p_regen_pb	GVL.regen_pb
		400000.04		400000.04	0.04	%IW208.04 (%IX416.0)			
		400000.05		400000.05	0.05	%IW208.05 (%IX416.0)			
		400000.06		400000.06	0.06	%IW208.06 (%IX416.0)			
		400000.07		400000.07	0.07	%IW208.07 (%IX416.0)			
		400000.08		400000.08	0.08	%IW208.08 (%IX416.0)			
		400000.09		400000.09	0.09	%IW208.90 (%IX416.0)			
		400000.10	>>>	400000.10	0.10	%IW208.10 (%IX416.0)			
		400000.11		400000.11	0.11	%IW208.11 (%IX416.0)			
		400000.12		400000.12	0.12	%IW208.12 (%IX416.0)			
		400000.13		400000.13	0.13	%IW208.13 (%IX416.0)			
		400000.14		400000.14	0.14	%IW208.14 (%IX416.0)			
		400000.15		400000.15	0.15	%IW208.15 (%IX416.0)			
		400001.00		400001.00	1.00	%IW209			
		400002.00		400002.00	2.00	%IW210			
		400003.00		400003.00	3.00	%IW211			
		400004.00		400004.00	4.00	%IW212			

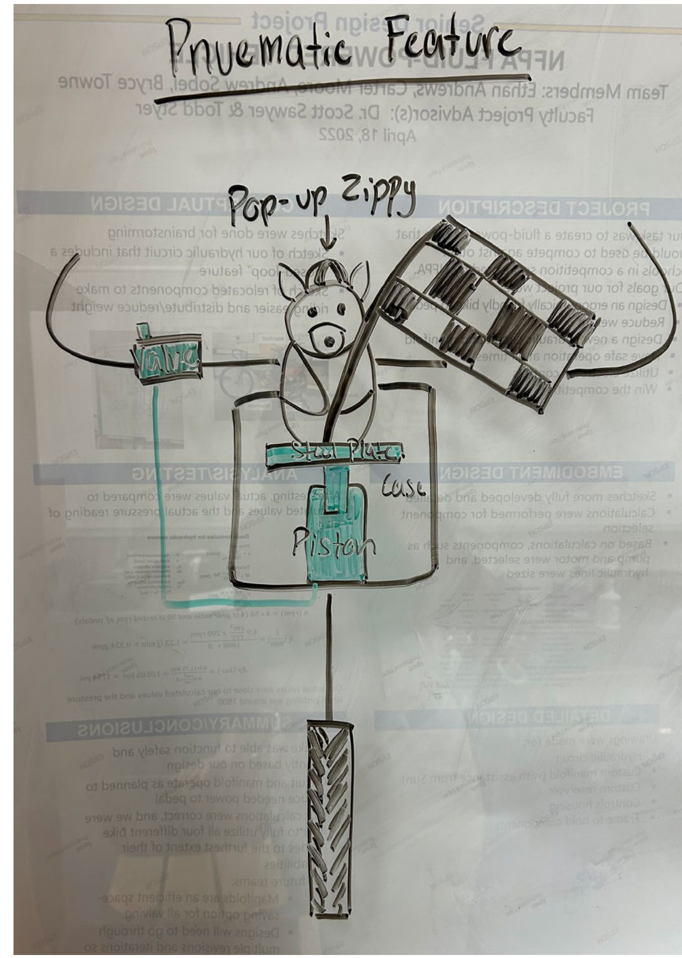
Electronics: HMI



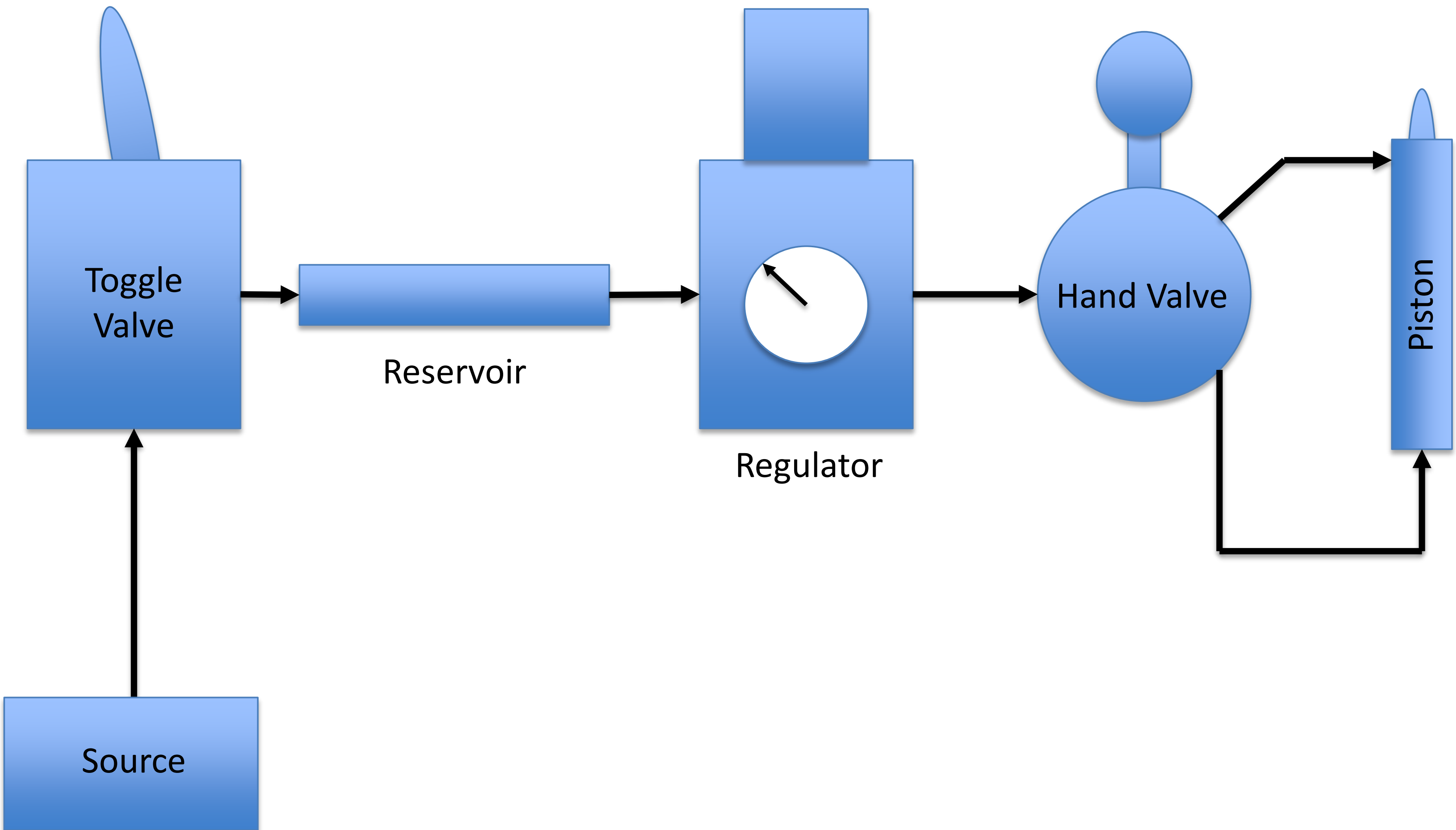
Pneumatics

Initial Idea

- Create a hidden, Pop-up Zippy
- Piston will lift Zippy as the bike crosses the finish line
- Valve will be placed near handle, so rider has access



Pneumatic Circuit



Results

- Pneumatics operate successfully
- Air remains in the system for multiple uses
- Additional material was added in box to increase height from piston

Testing

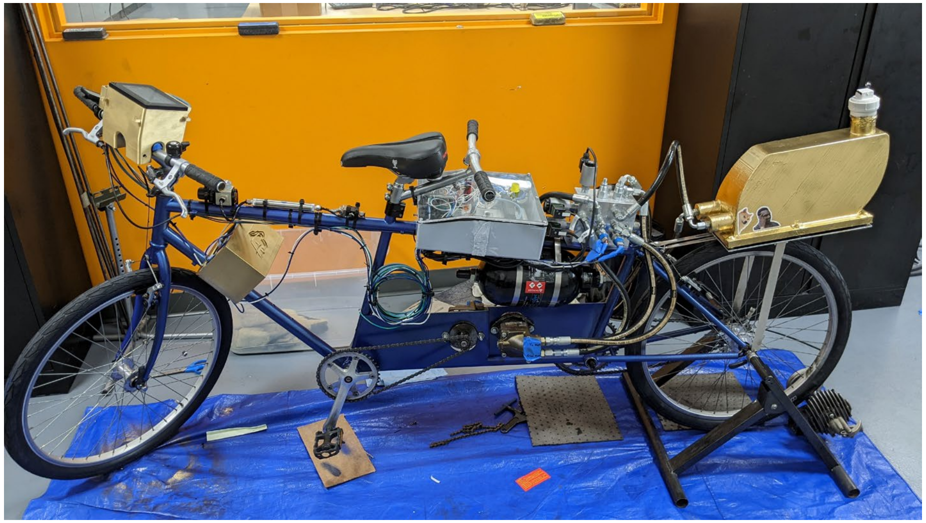
Testing:

- Vehicle was operated utilizing all modes on the circuit
  - University of Akron campus used as testing ground
- Data
  - Top speed of bike on flat ground: ~10 mph
  - Accumulator charges to ~1000 psi on gravity alone
- Weather and time prevented further quantitative testing

Results & Conclusion

Results

- Bike reached top speed of 10 mph
- Stability of the vehicle was balanced
- Shipping company removed the crate, and the vehicle got damaged in the shipping process
- Damages attempted to be mitigated at the competition



Lessons Learned

- Communication among team members is key
- Schedules keep everyone on track, and help the process move along smoothly
- Plan ahead of schedule, so when mishaps occur, you are on track
- Test often

Thank You's

NFPA Fluid Power Vehicle Challenge

- Mary Pluta
- Pat Green
- Ernie Parker
- Jared Amundson
- Scott Sawyer
- Saikishan Suryanarayanan
- Aaron Trexler
- Bill Wenzel
- Gopal Nadkarni