NFPA

Fluid Power VEHICLE Challenge

NFPA Education and Technology Foundation

FINAL PRESENTATION

TEXAS A&M UNIVERSITY

BRIAN TRITLE & KENSEY SYDNESS

APRIL 13th, 2023

Meet the 2022-23 Team

Mark P. Finley
Mechanical Design / Project Management

Aquiles A. Alonso
Electrical / Software Design Lead

Dalton J. Yingst
Hydraulic Design / Financial Management

Preston L. Baumgartner
Hydraulic Design

David A. Johnson
Mechanical Design

Ivan R. Franco
Electrical / Software Design

2021-22 Texas A&M Team

The SHAARE Group

Figure 1. The SHAARE Group w/ vehicle

2021-22 Vehicle Design

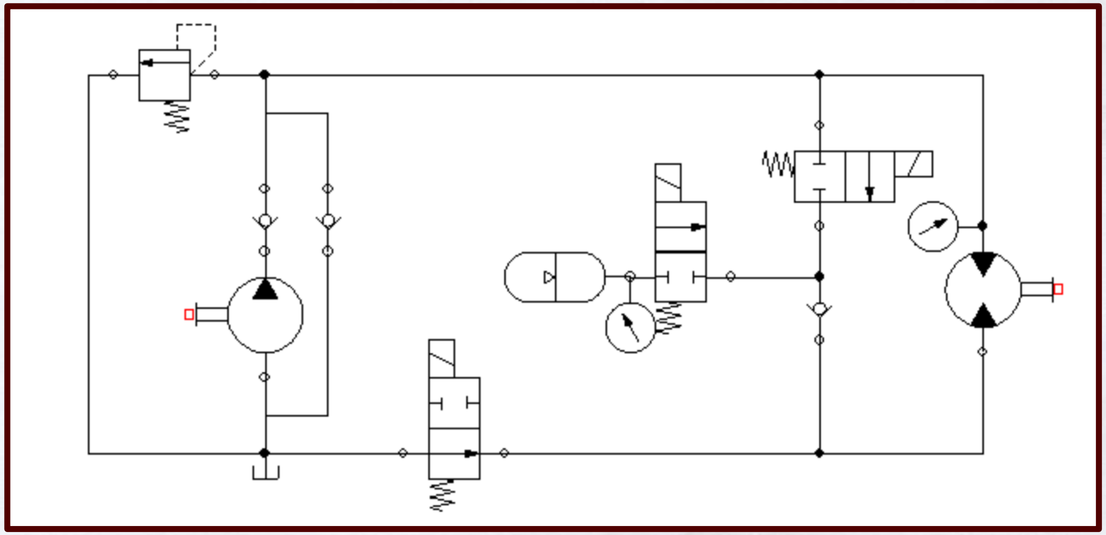

Figure 2. 2021-22 hydraulic circuit

Figure 3. 2021-22 vehicle

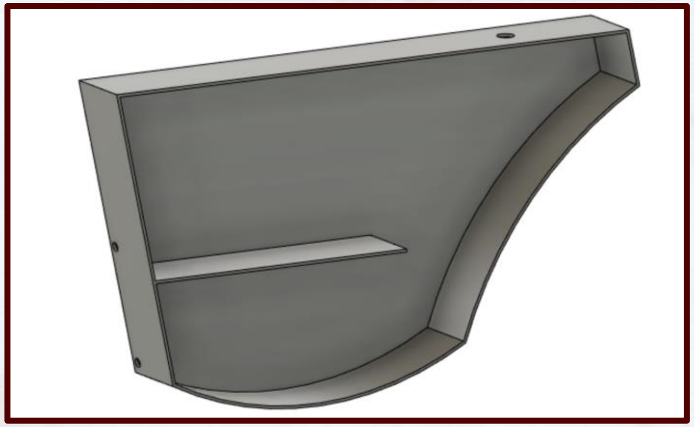

Figure 4. 2021-22 reservoir CAD (left) & fabricated component (right)

2022-23 Texas A&M Team

Figure 5. Team FPC

Figure 6. Team members w/ vehicle

Project Management

- Work Breakdown Structure (Figure 7)
- Project Schedule (Figure 8)
    - Percent Complete: 79%
    - Work hours estimated: 932
    - Actual Work Hours: 697
    - CPI: 1.05
    - FCAC: 886

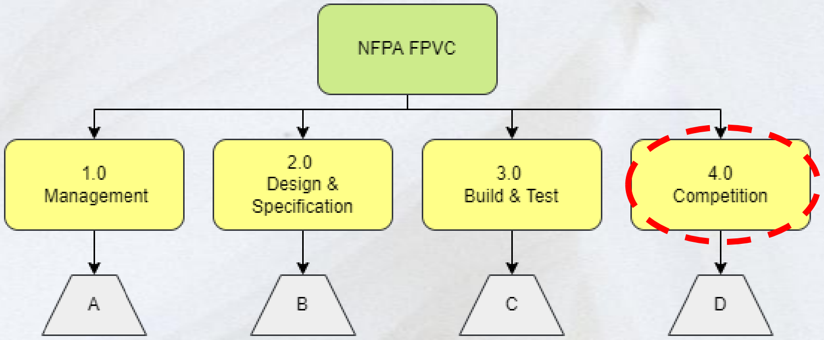

Figure 7. Work breakdown structure (WBS)

PERCENT COMPLETE	WBS ITEM/ACTIVITY	PLAN WORK (HRS)	ACTUAL WORK (HRS)	COST PERFORMANCE INDEX (CPI)	FORECAST COST AT COMPLETION (FCAC)
79%	WBS - NFPA FPVC	932	696.6	1.05	886.04
77%	Phase 1.0 Management	388	285.6	1.05	371.02
85%	WP 1.1 MMET 429/422 Assignments	203	181.8	0.95	214.5
88%	WP 1.2 NFPA Assignments	98	68.2	1.27	77.39
100%	WP 1.3 TAMU Fluid Power Club	55	17.6	3.13	17.6
100%	WP 1.4 Requirements	10	12	0.83	12
12%	WP 1.5 Project Closure	22	6	0.44	50
100%	Phase 2.0 Design & Specification	245	226	1.08	226
100%	WP 2.1 Overall Design Choices	29	30	0.97	30
100%	WP 2.2 Hydraulic Design	54	58.6	0.92	58.6
100%	WP 2.3 Electrical Design	49	47	1.04	47
100%	WP 2.4 Mechanical Design	87	76	1.14	76
100%	WP 2.5 Pneumatic Design	17	0	#DIV/0!	#DIV/0!
100%	WP 2.6 Ordering Components	9	14.4	0.63	14.4
100%	Phase 3.0 Build & Test	209	185	1.13	185
100%	WP 3.1 Fabrication	89	40	2.23	40
100%	WP 3.2 Construction	70	76	0.92	76
100%	WP 3.3 Testing	50	69	0.72	69
38%	Phase 4.0 Competition	90	0	#DIV/0!	#DIV/0!
75%	WP 4.1 Travel	80	0	#DIV/0!	#DIV/0!
0%	WP 4.2 Compete	10	0	#DIV/0!	#DIV/0!

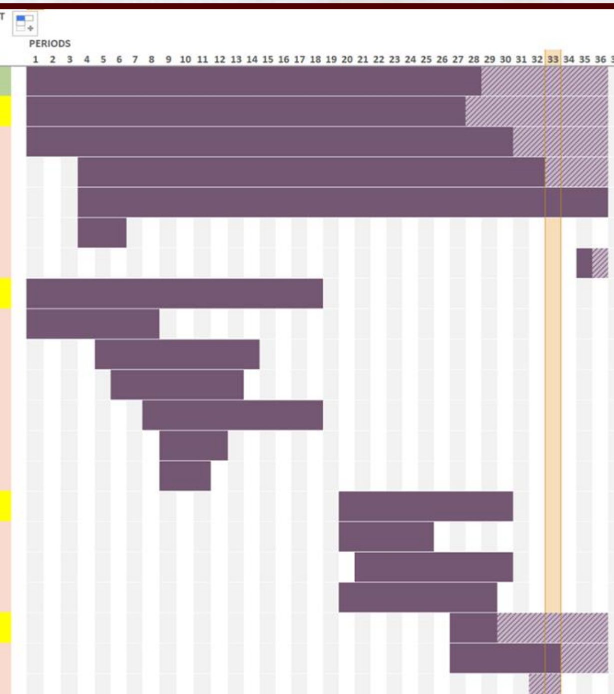

Figure 8. Project schedule Gantt chart

Hydraulic Design

Table 1. Schematic key

Label	Component
P#	Pump
T#	Tank
J#	T-Joint
CV#	Check Valve
PRV#	Pressure Relief Valve
ACM#	Accumulator
TP#	Test Point
G#	Pressure Gage
DCV#	Directional Control Valve
M#	Motor

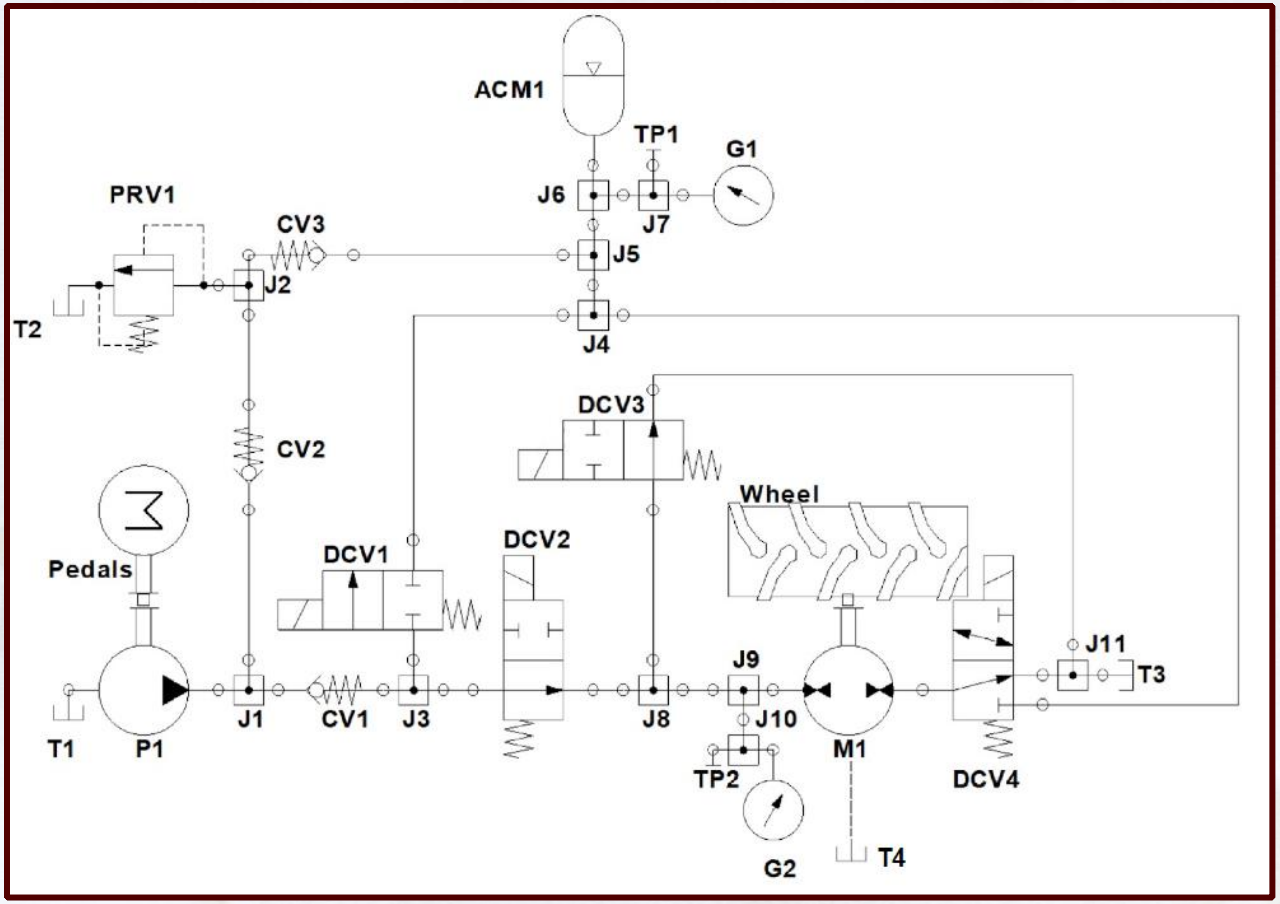

Figure 9A. 2022-23 hydraulic circuit schematic

Hydraulic Design (cont.)

Table 1. Schematic key

Label	Component
P#	Pump
T#	Tank
J#	T-Joint
CV#	Check Valve
PRV#	Pressure Relief Valve
ACM#	Accumulator
TP#	Test Point
G#	Pressure Gage
DCV#	Directional Control Valve
M#	Motor

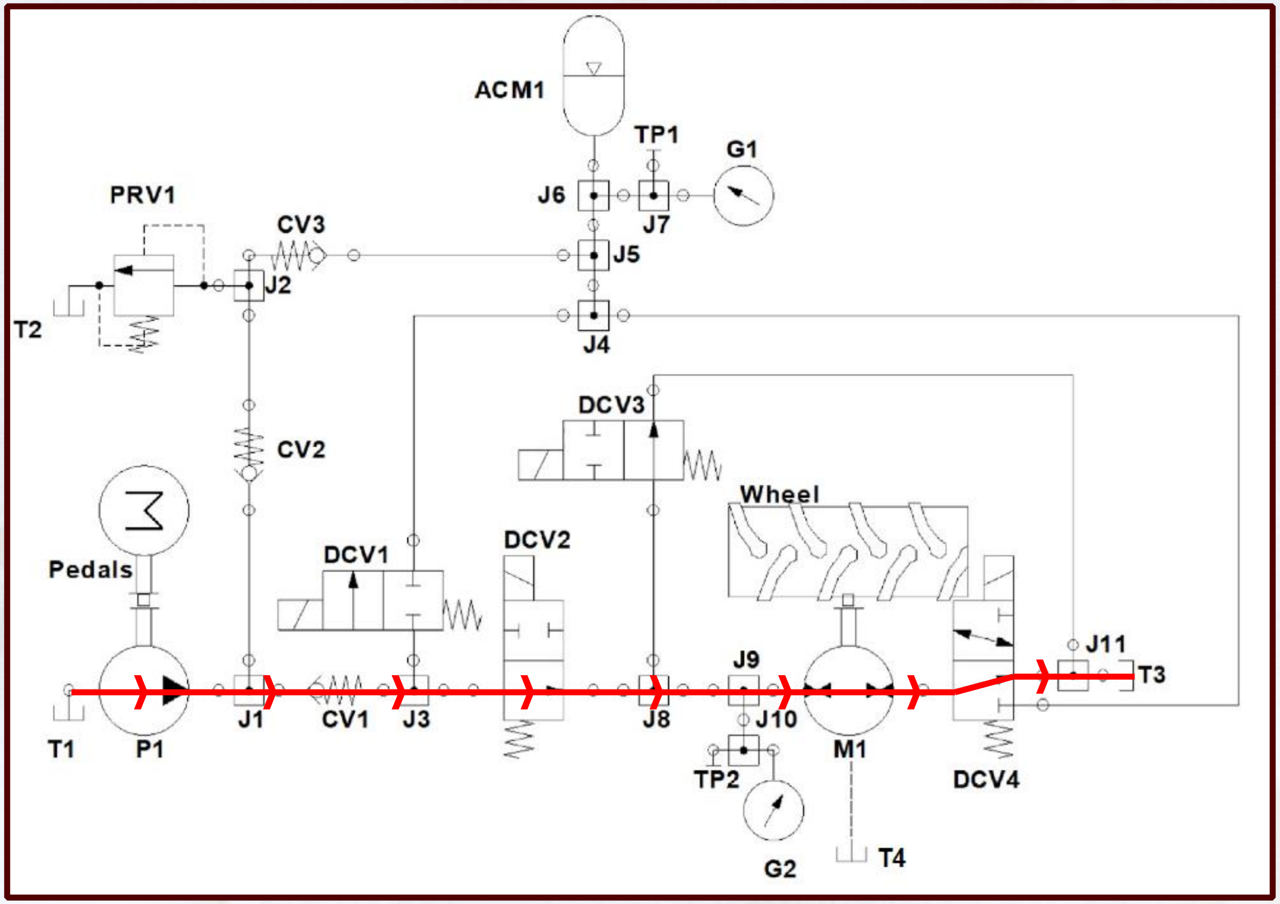

Figure 9B. Pedal propulsion mode

Hydraulic Design (cont.)

Table 1. Schematic key

Label	Component
P#	Pump
T#	Tank
J#	T-Joint
CV#	Check Valve
PRV#	Pressure Relief Valve
ACM#	Accumulator
TP#	Test Point
G#	Pressure Gage
DCV#	Directional Control Valve
M#	Motor

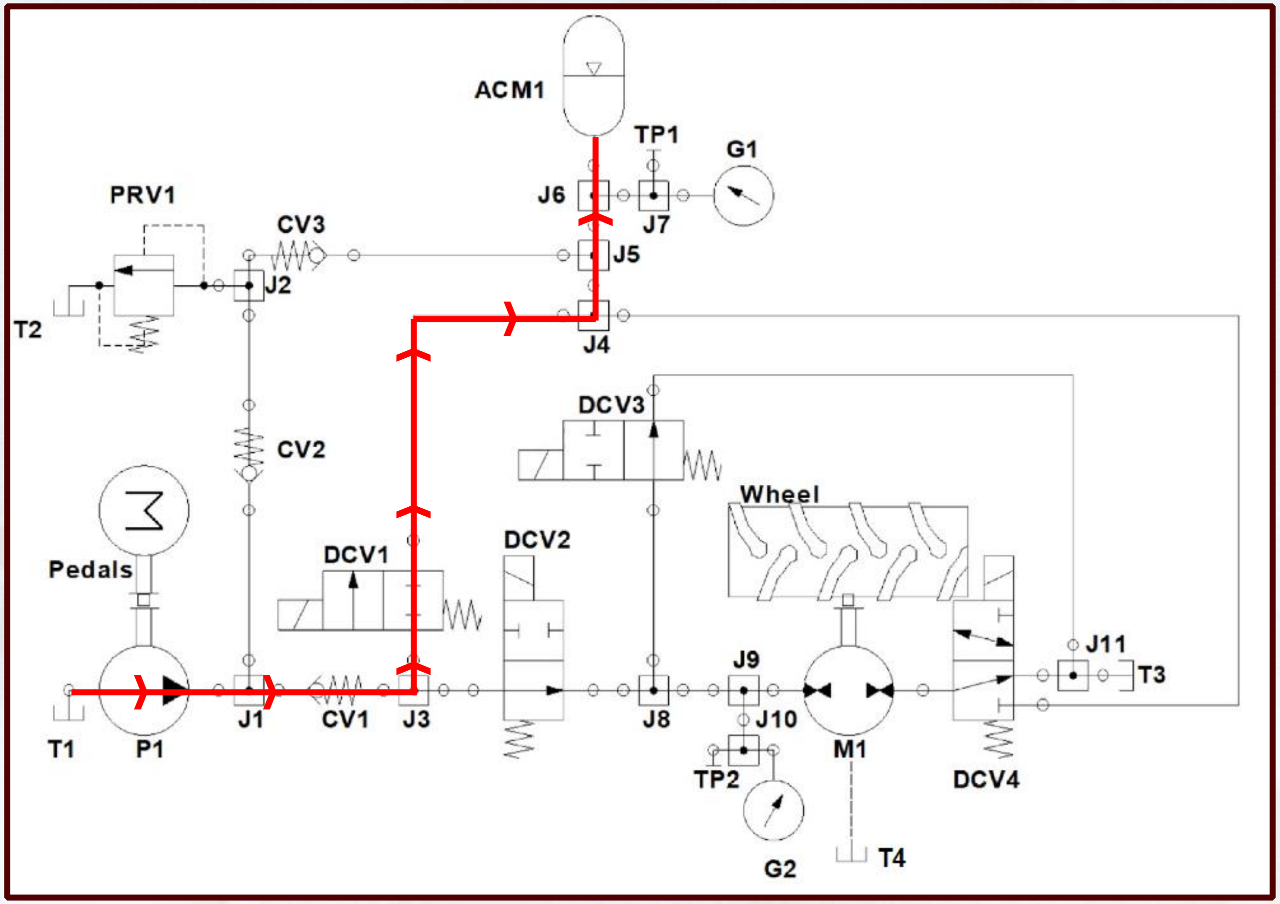

Figure 9C. Accumulator charge via pedalling

Accumulator Charge via Pedalling

Hydraulic Design (cont.)

Table 1. Schematic key

Label	Component
P#	Pump
T#	Tank
J#	T-Joint
CV#	Check Valve
PRV#	Pressure Relief Valve
ACM#	Accumulator
TP#	Test Point
G#	Pressure Gage
DCV#	Directional Control Valve
M#	Motor

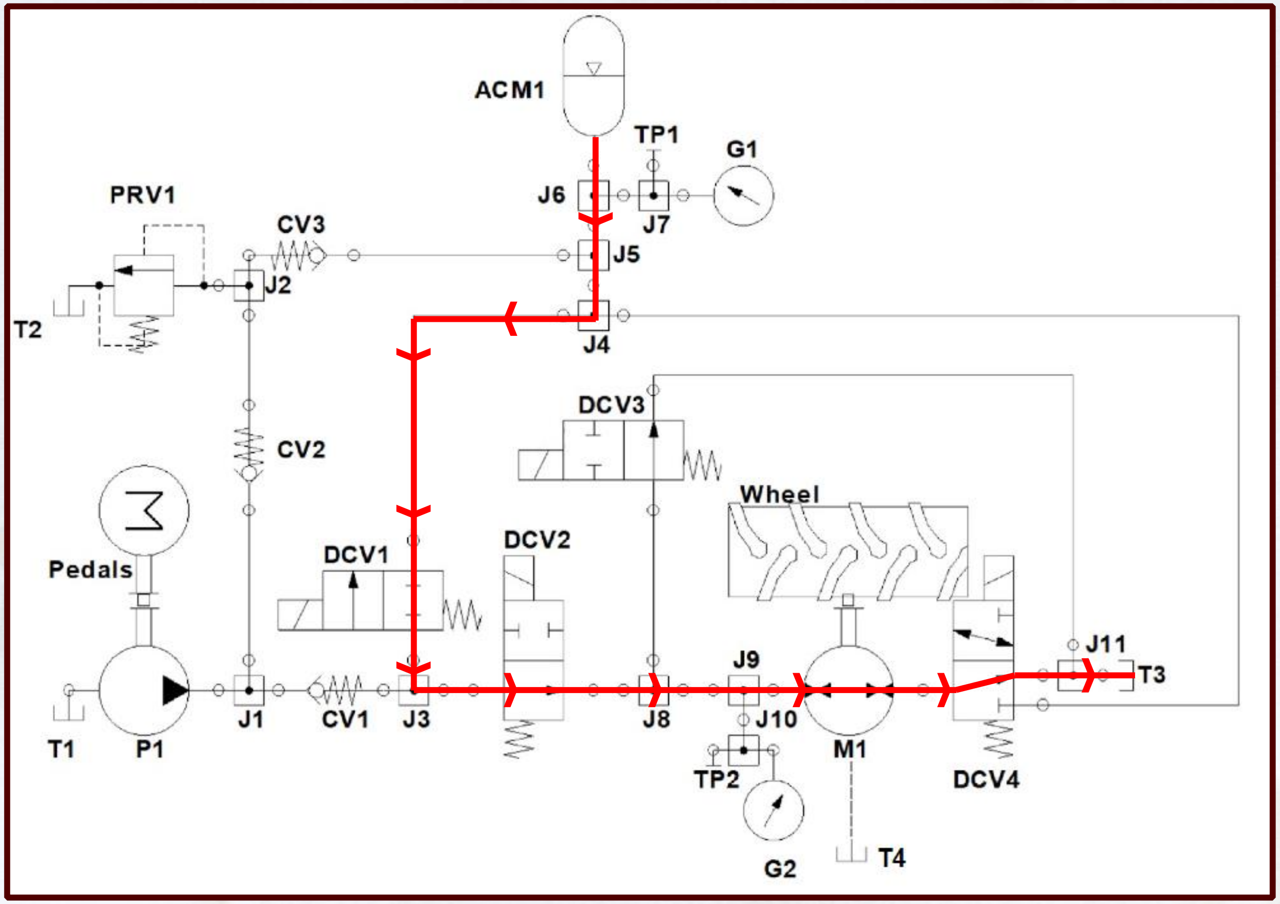

Figure 9D. Propulsion via accumulator discharge

Hydraulic Design (cont.)

Table 1. Schematic key

Label	Component
P#	Pump
T#	Tank
J#	T-Joint
CV#	Check Valve
PRV#	Pressure Relief Valve
ACM#	Accumulator
TP#	Test Point
G#	Pressure Gage
DCV#	Directional Control Valve
M#	Motor

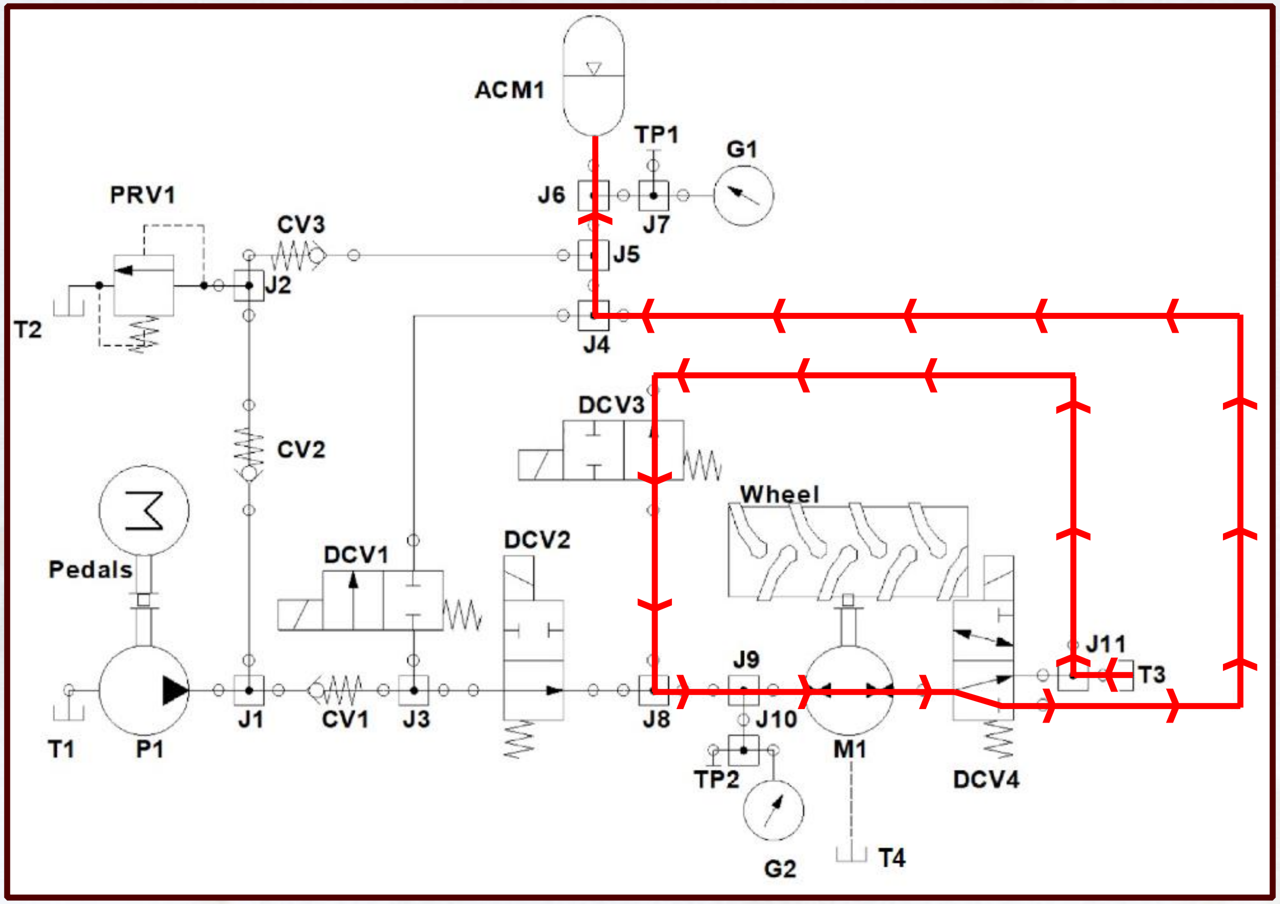

Figure 9E. Accumulator charge via regenerative braking

Accumulator Charge via Regenerative Braking

Hydraulic Design (cont.)

Table 1. Schematic key

Label	Component
P#	Pump
T#	Tank
J#	T-Joint
CV#	Check Valve
PRV#	Pressure Relief Valve
ACM#	Accumulator
TP#	Test Point
G#	Pressure Gage
DCV#	Directional Control Valve
M#	Motor

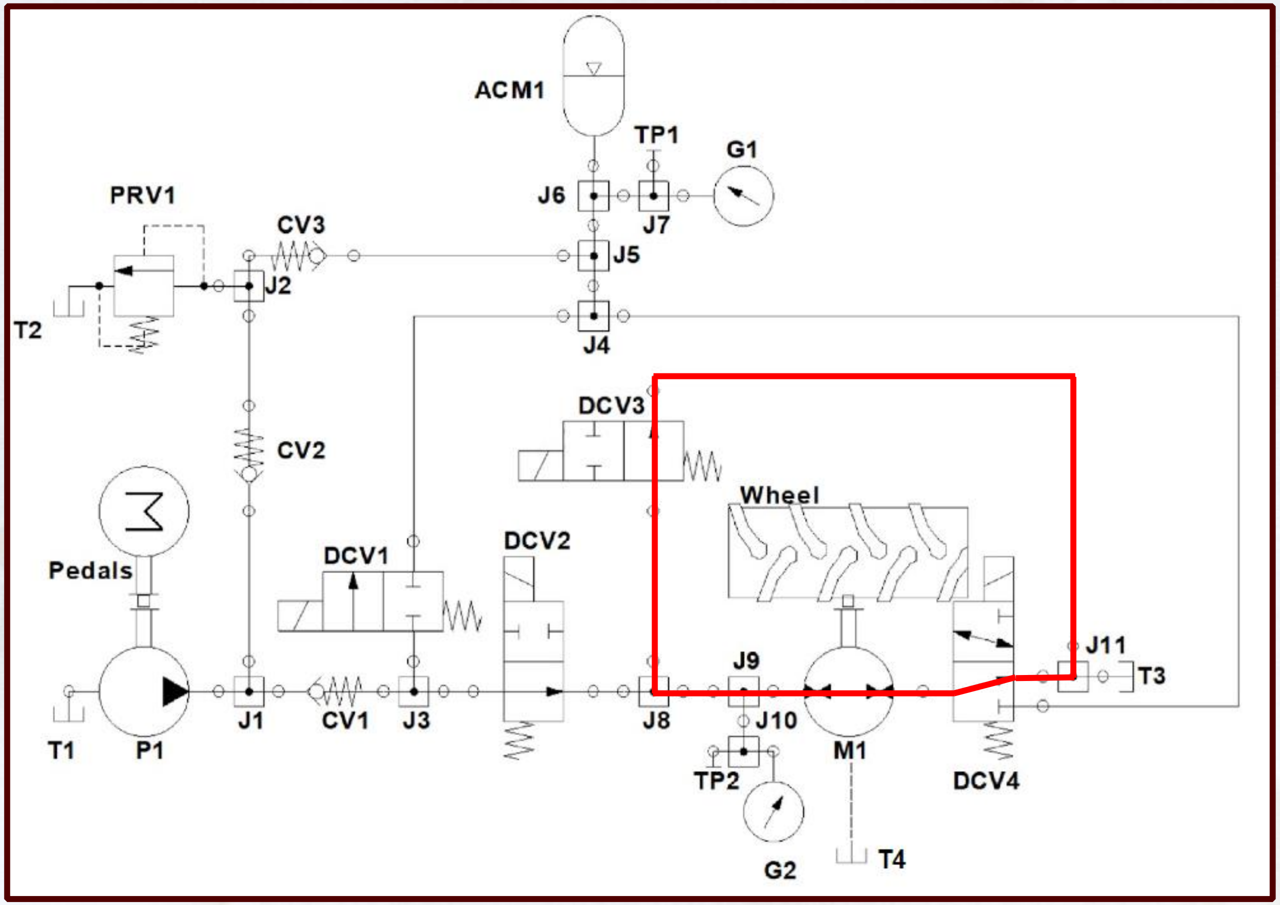

Figure 9F. Coast mode

Coast (Forward & Reverse)

Hydraulic Calculations

- Hose Diameters

$$D = \sqrt{0.408 * Q \ / \ V}$$

$$\begin{aligned} Where:\ D &= Inner\ Diameter\ of\ the\ Hose\ (in) \\ Q &= Flow\ Rate\ (gpm) \\ V &= Fluid\ Velocity\ (ft/s) \end{aligned}$$

  - Suction side of pump:

$$D = \sqrt{(0.408 * 2.5\ gpm) / (4\ ft/s)} = 0.505\ in$$

  - Outlet side of pump:

$$D = \sqrt{(0.408 * 2.5\ gpm) / (20\ ft/s)} = 0.225\ in$$

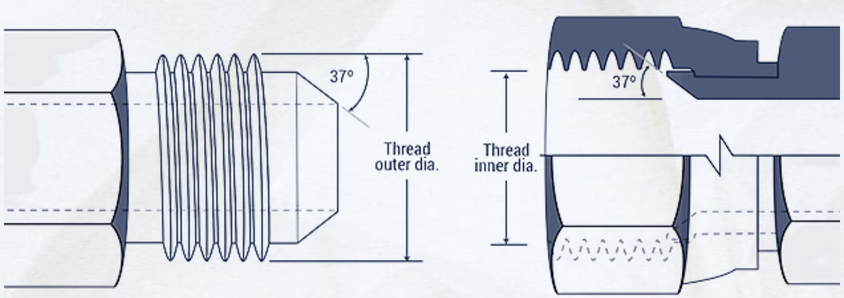

Figure 10. JIC 37-Flare cross-section

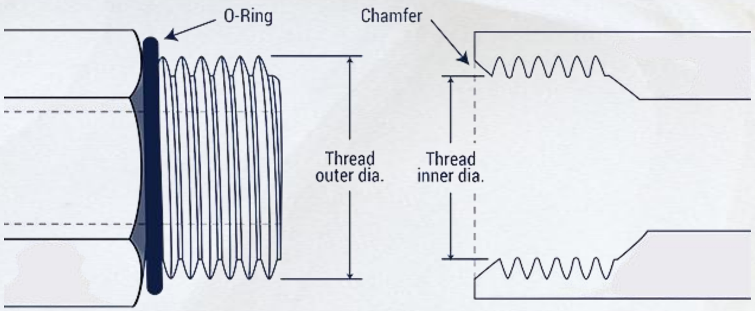

Figure 11. O-Ring Boss cross-section

Hydraulic Calculations (cont.)

- Motor Torque
  - Assuming a pressure of 100 bar (1450 psi) → torque ≅ 6 N.m (≅4 ft.lb)
  - Actual max pressure of ≅ 66.12 bar (≅ 960 psi) → torque ≅ 5 N*m (≅ 3.69 ft*lb)
- Gear ratio between motor & wheel: 1:5
  - Assumed torque at wheel 5×4 ≅ 20 ft.lbs
  - Actual torque at wheel 3.69×5 ≅ 18.45 ft.lb
- Wheel radius = 1.15 ft
  - Assumed driving force = Torque× radius ≅ 23 lb
  - Actual driving force ≅ 21.22 lb
- Force required to drive bike @ no incline
  - Assume weight of 300 lb and rolling coefficient of 0.04.

$$F_{required} = 300 \times 0.04 = 12 \text{ lb}$$

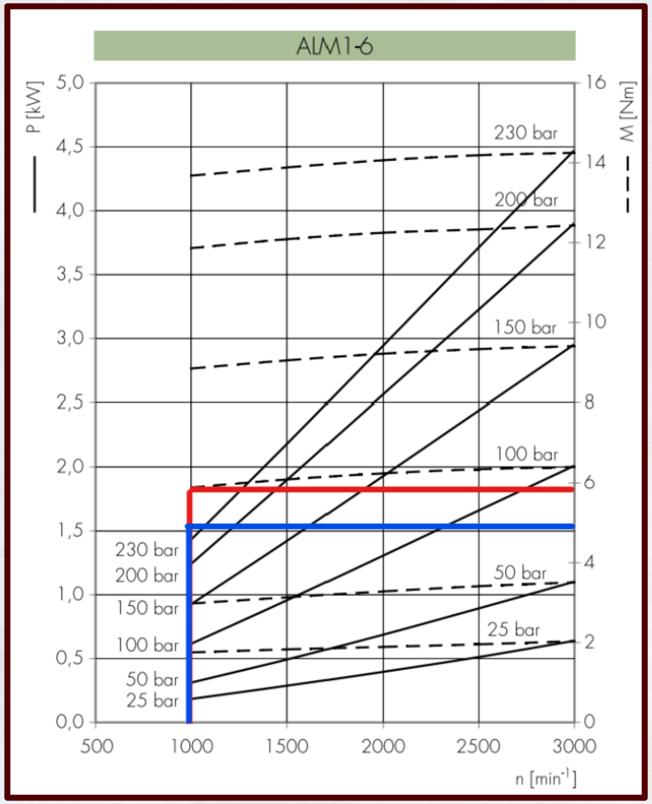

Figure 12. Torque ratings of selected motor
(Red) Assumed values
(Blue) Actual Values

HMI Display

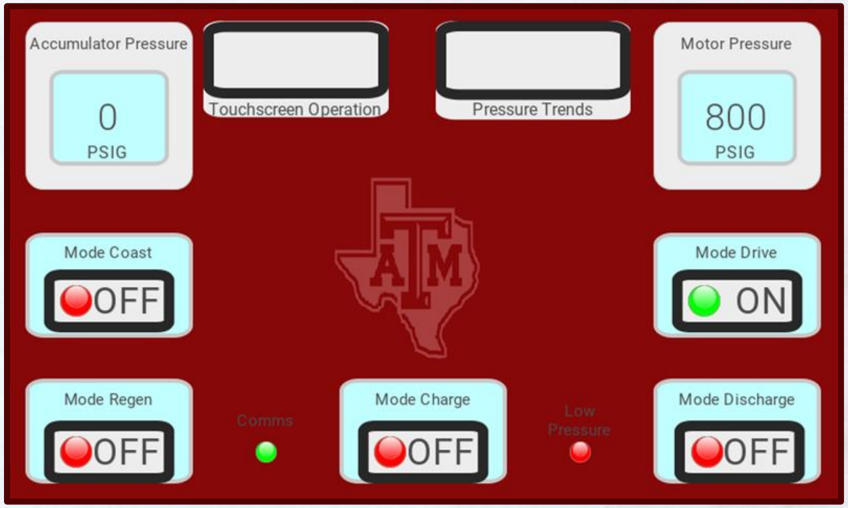

Figure 13. Operation via buttons

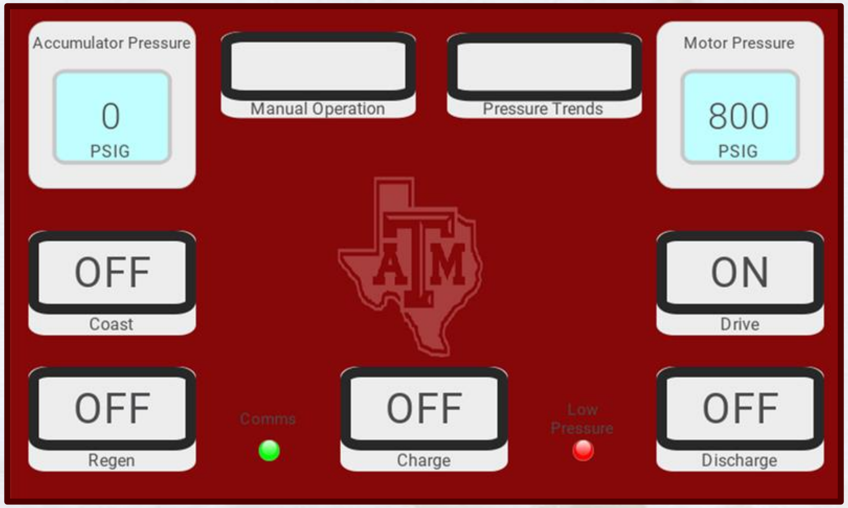

Figure 14. Operation via touchscreen

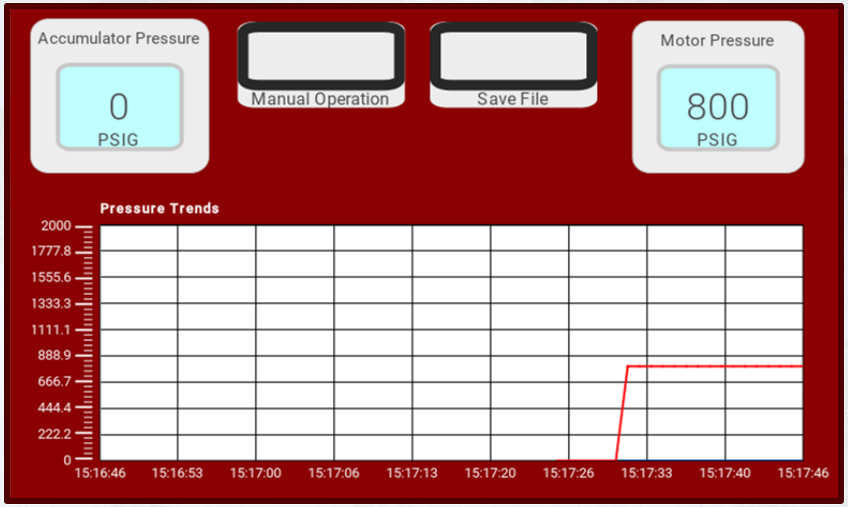

Figure 15. Pressure trend data

Vehicle Assembly

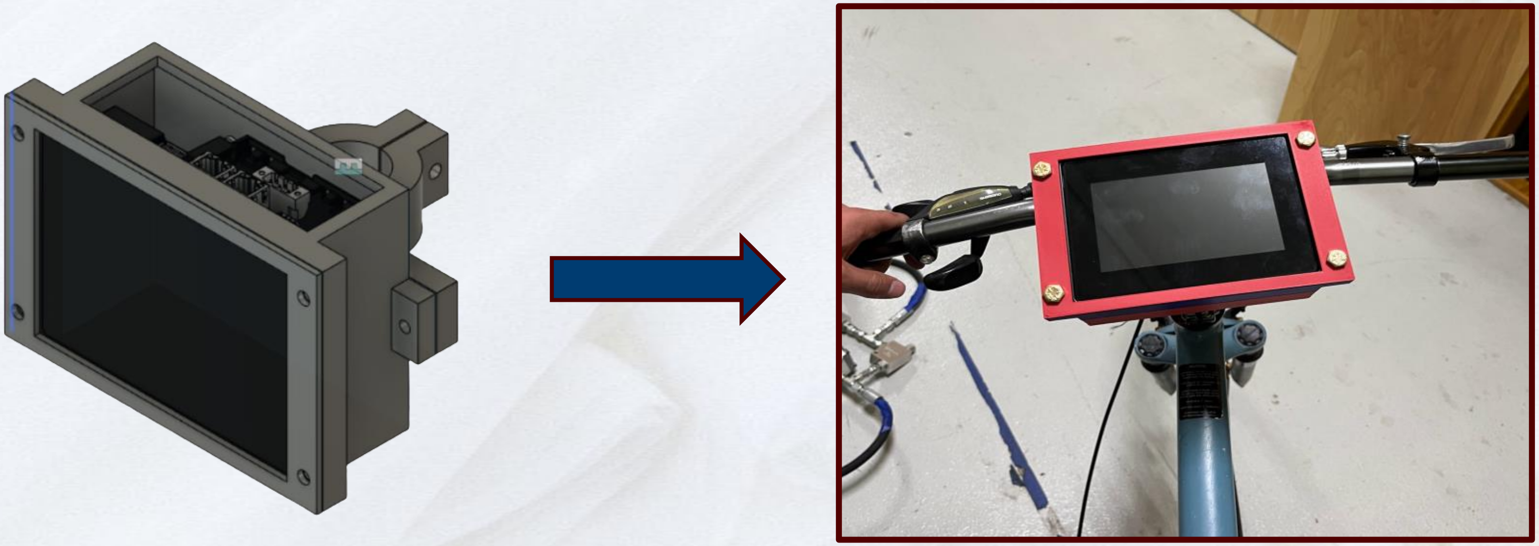

Figure 16. eX705 HMI mount CAD (left) & mounted unit (right)

Figure 17. HY-TTC 32-CD-00-000 PLC (left) & mounted PLC (right)

Vehicle Assembly (cont.)

- Safety switch that when activated puts the vehicle into coast mode.
  - Useful if rider falls during accumulator discharge to prevent injuries.

- Green slide moves along blue arrow when string leading to rider is pulled (Figure 16).
  - Activates limit switch (yellow), which sets vehicle to coast mode.
  - Slide spring-returns to non-contact position.

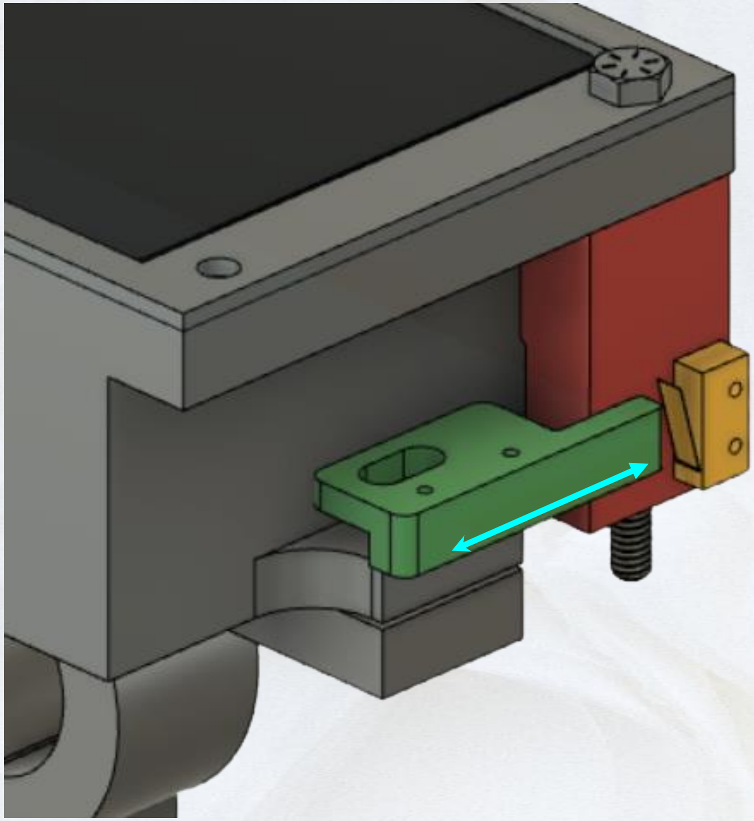

Figure 18. Safety switch mounted to screen unit

Vehicle Assembly (cont.)

Figure 19. Pump mount plate (⅛" A36 Steel, waterjet cut)

Figure 20. Crank arm w/ adaptor plate to #40 sprocket

Figure 21. Vented reservoir fill port

Vehicle Assembly (cont.)

Figure 22. Welded reservoir (vertical baffle not shown)
(Rust-Oleum clear-coat to prevent corrosion)

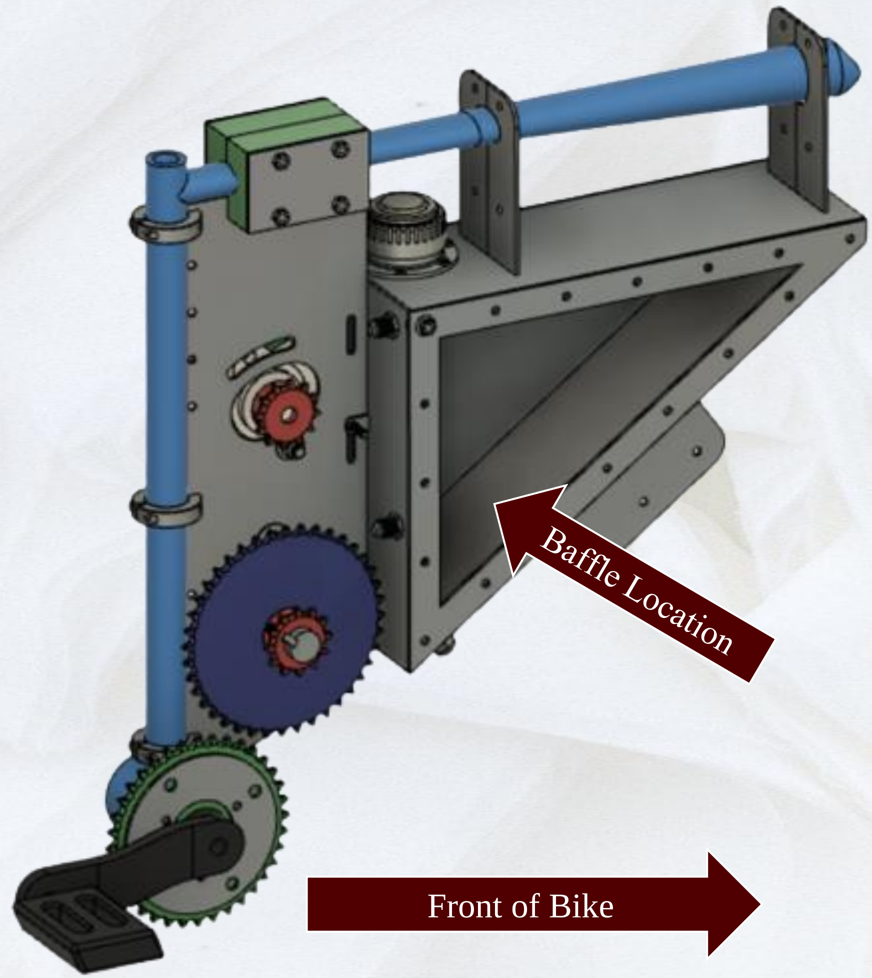

Figure 23. Bicycle main triangle assembly CAD
(5.2cc ALP1A-D-7 gear pump)

Vehicle Assembly (cont.)

- #40 roller chain is used, however rear sprocket is designed for 420 roller chain.
  - #40 and 420 chain share the same pitch, but 420 sprockets are narrower.
  - This allows for more error in sprocket alignment since chain can use a larger approach angle without catching.

Figure 24. 60T 420 sprocket w/ adaptor plate to free wheel thread

Figure 25. Bicycle main triangle assembly w/ chain guard

Vehicle Assembly (cont.)

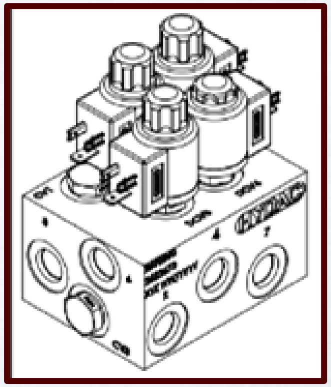

Figure 26. HYDAC designed manifold

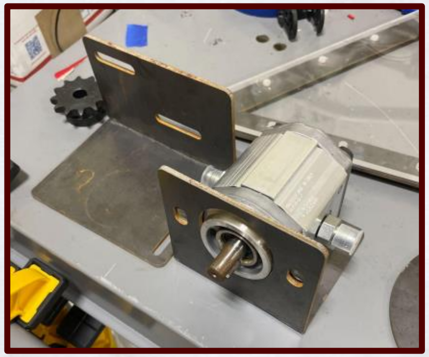

Figure 27. 4.1cc ALM1A-R-6-E2 gear motor

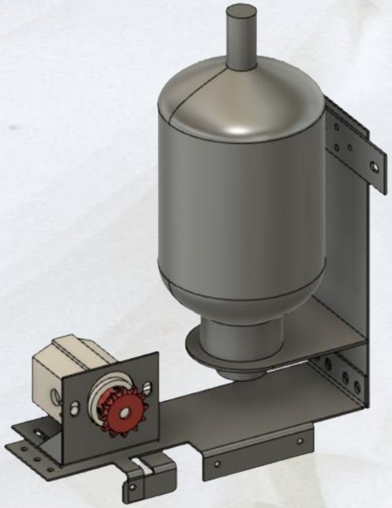

Figure 28. Rear rack assembly CAD

Figure 29. Rear rack

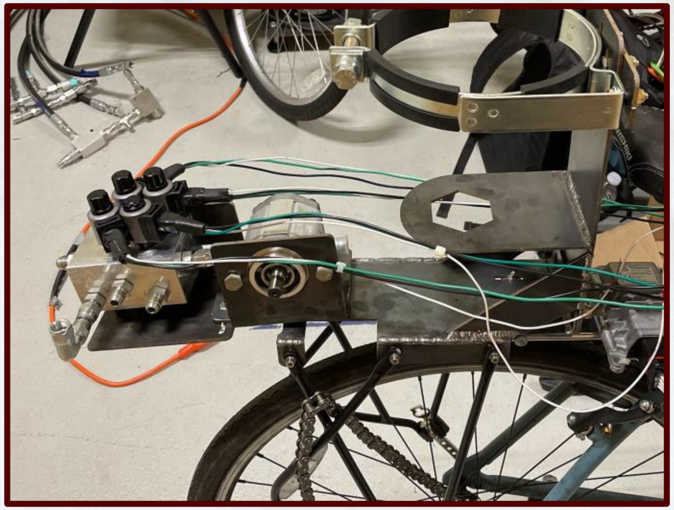

Figure 30. Manifold & motor mounted to rear rack

Vehicle Start to Finish

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Figure 31. Bare frame

Figure 32. Shipping crate

Figure 33. Finished vehicle (updated electronics housing)

Vehicle Testing

- Pump displacement of 5.2cc and motor displacement of 4.1cc
  - 5.2cc / 4.1cc = 1.268 motor revolutions per pump revolution

- Assuming pedal speed of ~100 RPM, use 8:1 ratio to meet pump minimum speed of 800 RPM
  - 800 * 1.268 ≈ 1015 motor RPM

- Wheel diameter of 27.5” with a 1:5 reduction ratio from motor to rear wheel
  - 1015 / 5 = 203 wheel RPM

- Expected top speed: 27.5 * 203 / 336 = 16.61 MPH
  - Actual top speed of ~17 MPH while pedalling, with downhill accounting for the higher speed

GIF 1. Vehicle ride test

Vehicle Testing (cont.)

- Optimal accumulator nitrogen pressure was found to be 600 - 650 PSI (1 gallon accumulator)
  - Stepped down from 800 PSI in 50 PSI increments to test efficiency and travel distance
  - Charged accumulator for ~2:40 for each trial, resulting in <1 gallon of fluid in accumulator
    - Competition has 10 minute charging period, so distance traveled will be greater

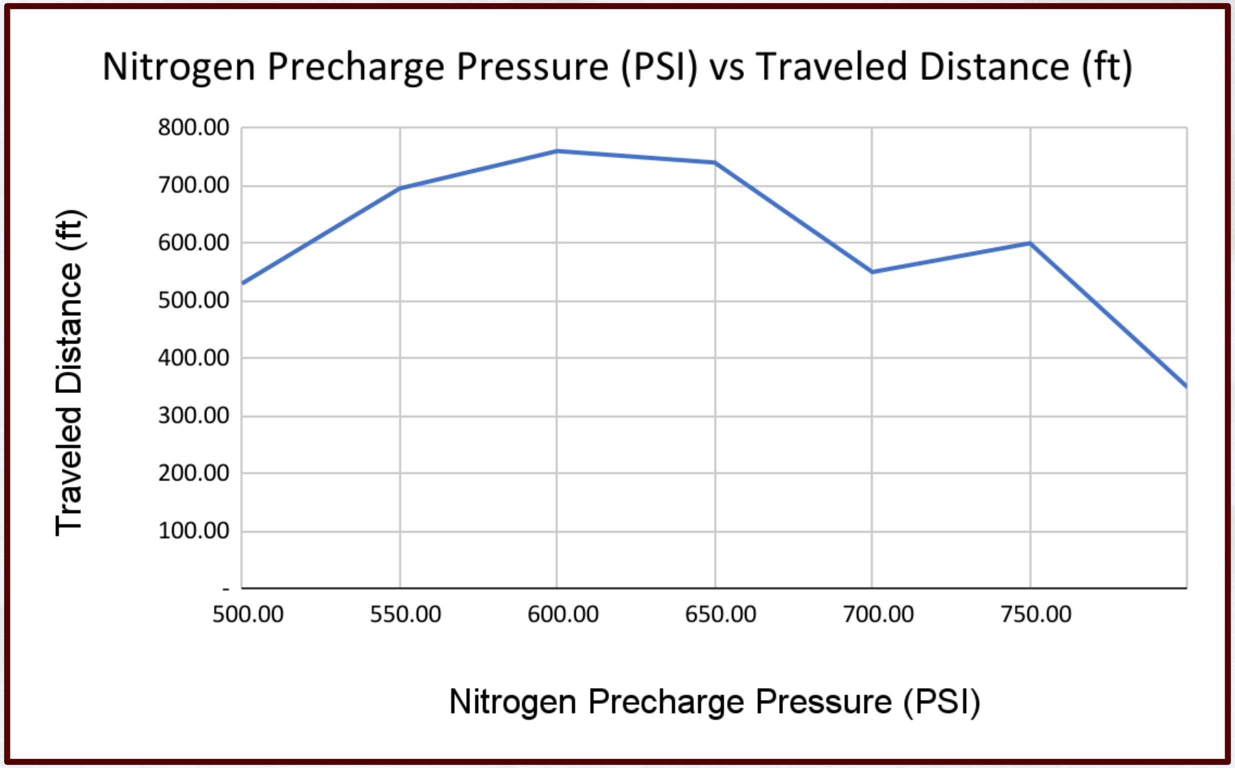


Figure 34. Traveled distance at varying precharge pressures.

Lessons Learned

- Bidirectional does not mean you can just flip the motor over and it will reverse the direction of rotation. You have to switch the direction of the inlet and outlet hoses due to gear pump design.
    - More fittings and hose turns cause additional losses.

- The rear wheel sprocket is screwed on, so when using regenerative braking the sprocket wants to unscrew itself. Currently the threads are chemically bonded together, however a mechanical system would be preferred.

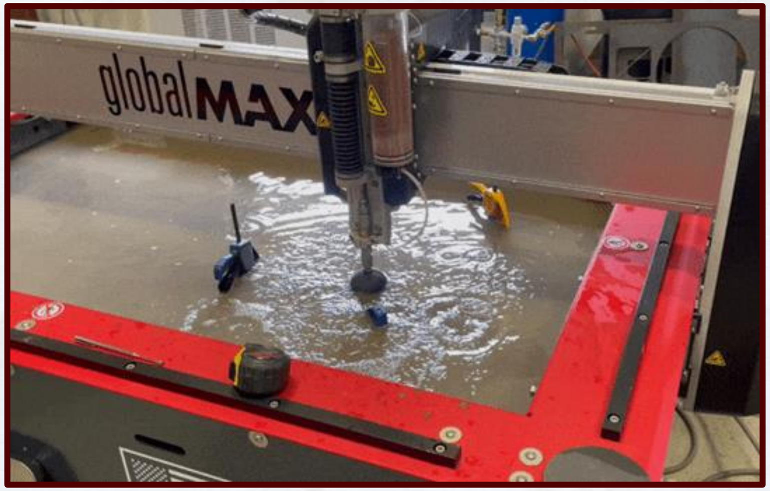
- There are a lot of thread designations, and direct adaptors from one to another are not always available. Multiple fittings cause increased pressure drop.

Figure 35. Waterjet table setup

Figure 36. David welding plate nuts to inside of reservoir port

Lessons Learned (cont.)

- Design tolerances into parts to account for mistakes.
- Keep design for manufacturability and assembly (DFMA) in mind.
  - DFMA allows for efficient assembly, testing, and modification of parts.
  - DFMA is harder to implement on bicycles compared to tricycles.
- Have extra valves and fittings as spare just in case, and be careful with valve installations to ensure o-ring health.
- Mechanical, hydraulic, and electrical design choices affect each other significantly and must be carefully coordinated to prevent misunderstandings and mistakes.
  - Frame choice can heavily drive these decisions.



GIF 2. Waterjet process

Figure 37. Eyewash & SDS station

Acknowledgements

NFPA Fluid Power VEHICLE Challenge

Dr. Ahmed Abdelaal
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Capstone Instructor

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Mr. Ernie Parker
Industry Rep., Fluid Power Hall of Fame

Mr. Chris Smith
Texas A&M ETID Lab Manager

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