NFPA

Fluid Power VEHICLE Challenge

NFPA Education and Technology Foundation

Final Presentation 2020

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Industry Mentor: Aaron Darnell

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Western Michigan University

Team Introduction

Problem Statement & Objective

- Design, build and test a fluid powered vehicle to compete in three performance competitions:
  - Sprint Race (400-600 ft. course length)
  - Efficiency Challenge (Accumulator power)
  - Endurance Challenge (Laps and/or slalomed course, 1 mile max)

Design Criteria

- Safety
  - Provide safe working vehicle
  - Hydraulic system relief valve protection
  - Safety shields over moving gears/chains
- Minimize vehicle weight
  - Reduce vehicle drag
  - Improve human power performance
- Maximize vehicle efficiency
  - Integrate on-board accumulators
- Cost effective
  - Build competitive vehicle using maximum resources available

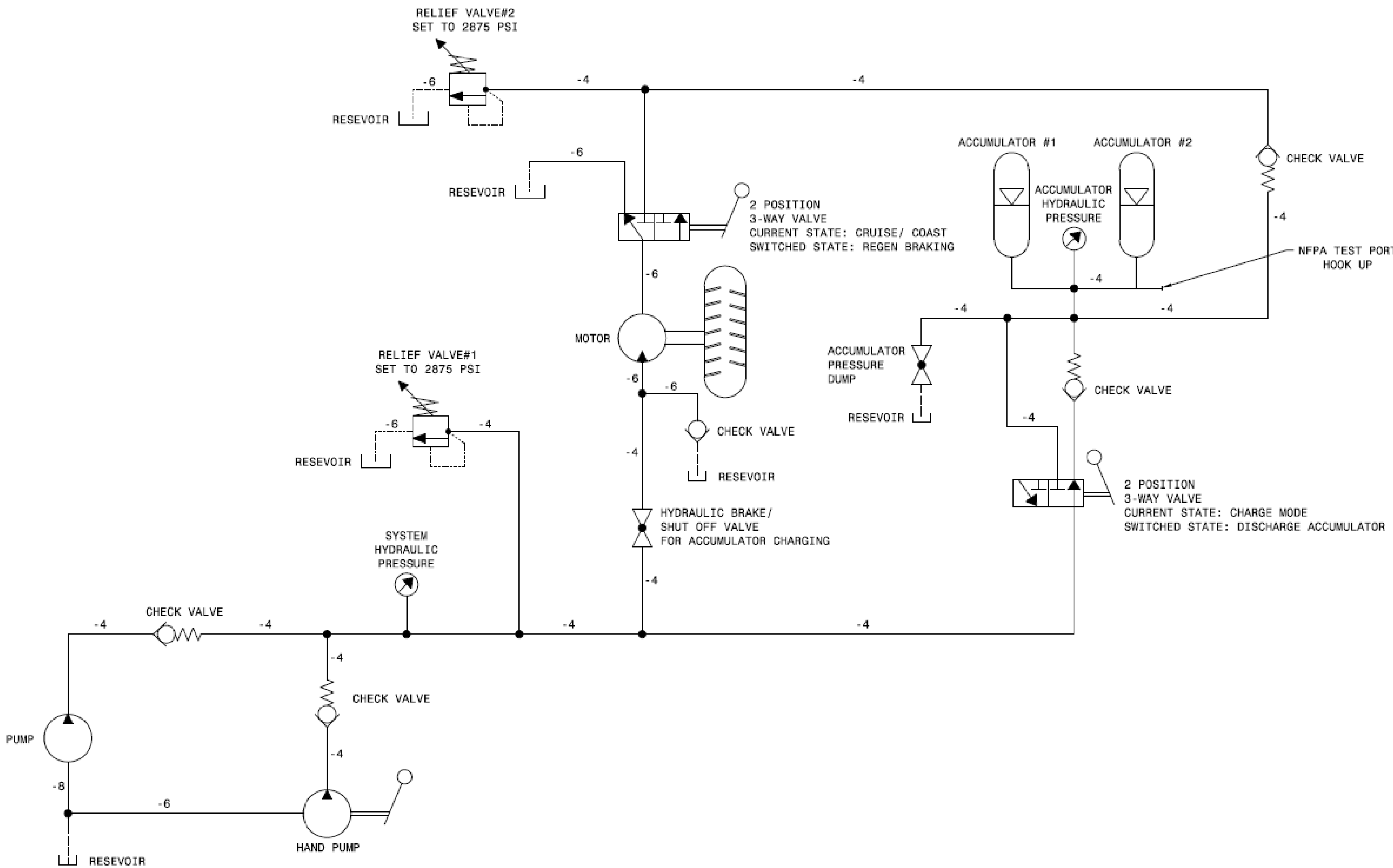
Design Constraints

- Vehicle powered using hydraulic propulsion
  - No internal combustion, electric engines
- Maximum vehicle weight to not exceed 210 lbs.
- No leaks permitted from vehicle
- Braking power to hold vehicle in position under load
- Follow all other rules and guidelines provided by NFPA

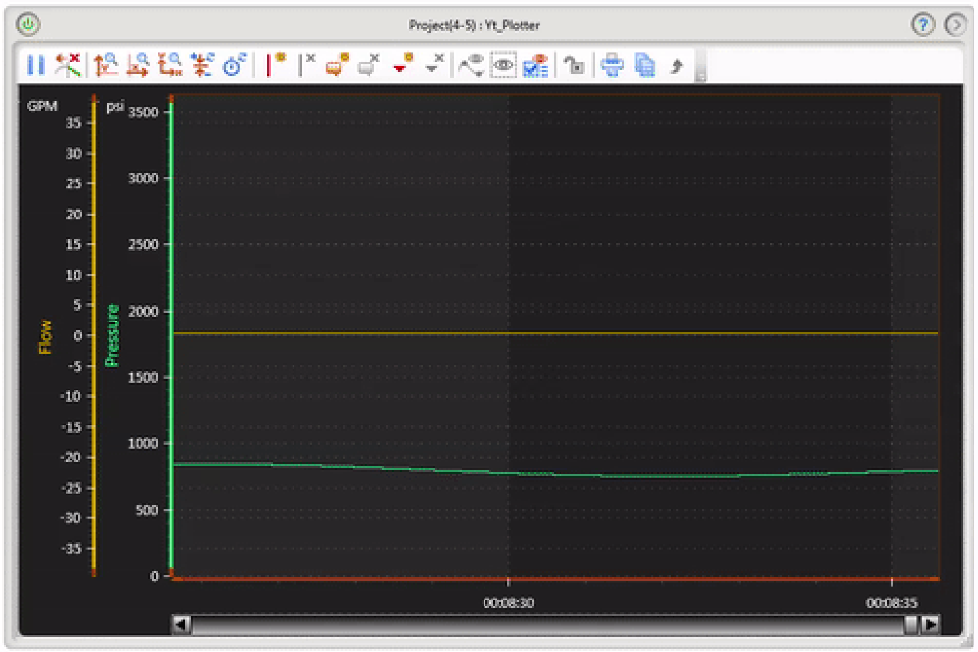
Engineering Design Process

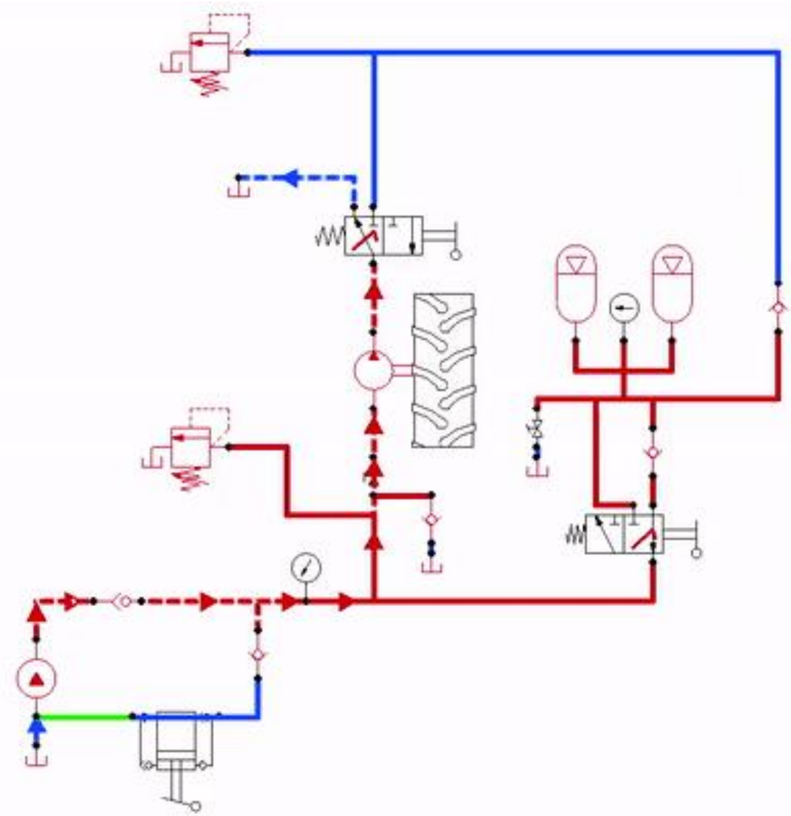
- Define problem
- Research and brainstorm
- Evaluate and choose design
- Specify and analyze design
- Develop prototype
- Testing and redesign

Fluid Power Circuit Design

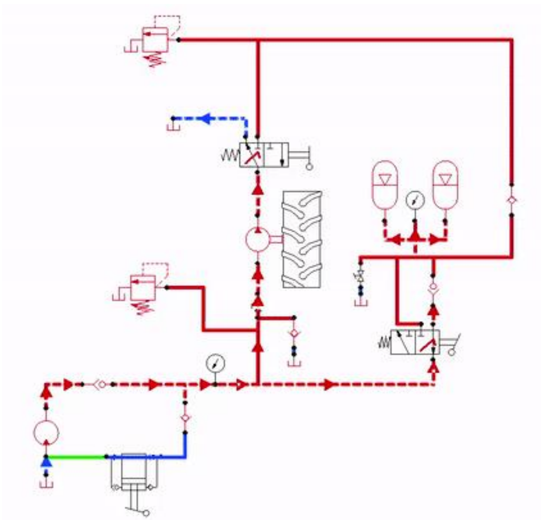


Normal Cruise

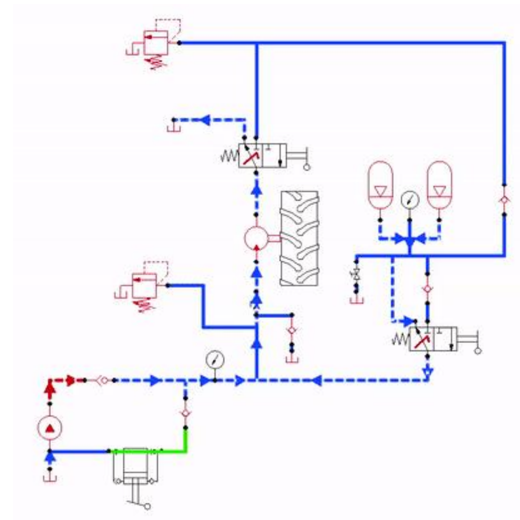




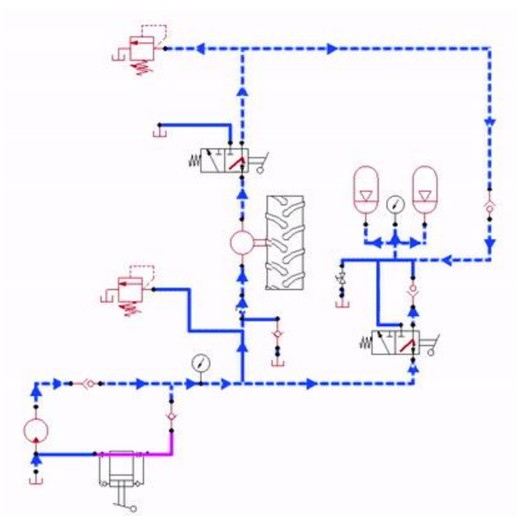
Hydraulic Circuit Modes



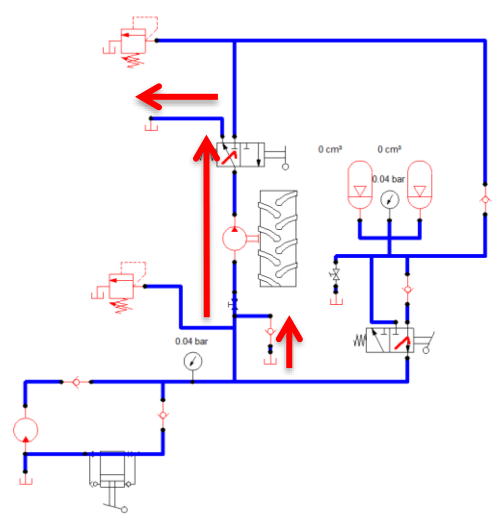
Charging the Accumulators



Discharging the Accumulators



Regenerative Braking



Cruise/ Coasting

Hardware Selection

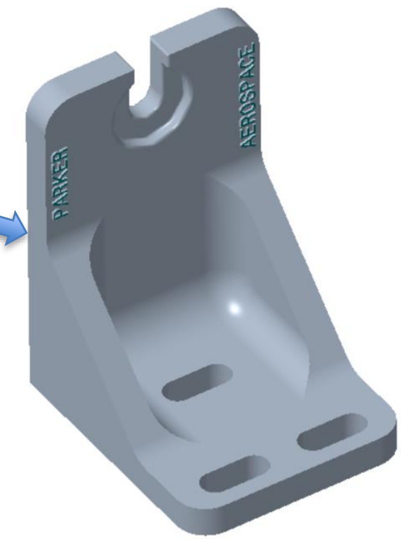
- Pump and Motor
  - Two Parker Aerospace engine driven pumps
  - 0.241 CIPR, fixed displacement
  - 6600 rpm
  - 2500 psig
  - 6.5 gpm
  - Weight: 3.44 lbs.

- Custom designed drive shafts for pump and motor
  - 3D Model & Drawing created
  - Procured from supplier

- Controls and plumbing
  - 2 Position, 3-way valves (3000 psi)
  - 3 speed Shimano internal hub

Hardware Selection

- Bracket(s)
  - PA12 High density engineering grade thermoplastic
  - Production part worthy material
  - Reducing vehicle weight



- Hand pump (handle not shown)
  - Increase system pressure for efficiency competition
  - Selected for its largest displacement (stroke cycle)
  - >3000 psi rating

- (2) System relief valves
  - Cartridge, Poppet style, 3000 psi rating

Hardware Selection

- Accumulator(s)
  - Two 100 in^3 accumulators, $\leq$ 231 in^3 Maximum Limit
  - Light weight aerospace products
  - 3000 psi rating

- Check Valves
  - Male JIC 37° flare connection

- Reservoir
  - Light weight polyethylene
  - 2.5 gallon capacity

Results & Analysis

- Calculations:
  - Input Hp: 0.3 Hp
  - Starting torque: 882 in-lb (approx. 73.5 ft-lb)
  - Cruising torque, 15 mph: 59 in-lb
  - At 15 mph:
    - Motor: 388 RPM
    - Pump: 322 RPM
    - Pedals:
      - 1st gear (.733:1): 48 RPM
      - 2nd gear (1:1): 35 RPM
      - 3rd gear (1.364:1): 26 RPM

Calculations

NFPA Fluid Power Vehicle Challenge

VEHICLE CALCULATIONS (GOAL)							
Goal Ratio (Motor)	Goal M/P (RPM)	Goal Flow Rate	Goal Ratio (Pump)	Goal Pedal (RPM)	Goal Pedal RPM		
					0.733	1.000	1.364
61.8	800	0.835	11	70	118	87	64
30.9	800	0.835	11	70	118	87	64
20.6	800	0.835	11	70	118	87	64
15.5	800	0.835	11	70	118	87	64
12.4	800	0.835	11	70	118	87	64
10.3	800	0.835	11	70	118	87	64
8.8	800	0.835	11	70	118	87	64
7.7	800	0.835	11	70	118	87	64
6.9	800	0.835	11	70	118	87	64
6.2	800	0.835	11	70	118	87	64
5.6	800	0.835	11	70	118	87	64
5.2	800	0.835	11	70	118	87	64
4.8	800	0.835	11	70	118	87	64
4.4	800	0.835	11	70	118	87	64
4.1	800	0.835	11	70	118	87	64

EFFICIENCIES	
Pump	0.95
Motor	0.90
System	0.85

System Ratios		
Pedal to Hub	53/23	2.3
Hub to Pump	36/9	4.0
Motor to Axle	24/12	2.00
Hub Gear Ratio	1st	0.733
	2nd	1.000
	3rd	1.364
Total Ratio @ Pump	1st	6.8
	2nd	9.2
	3rd	12.6

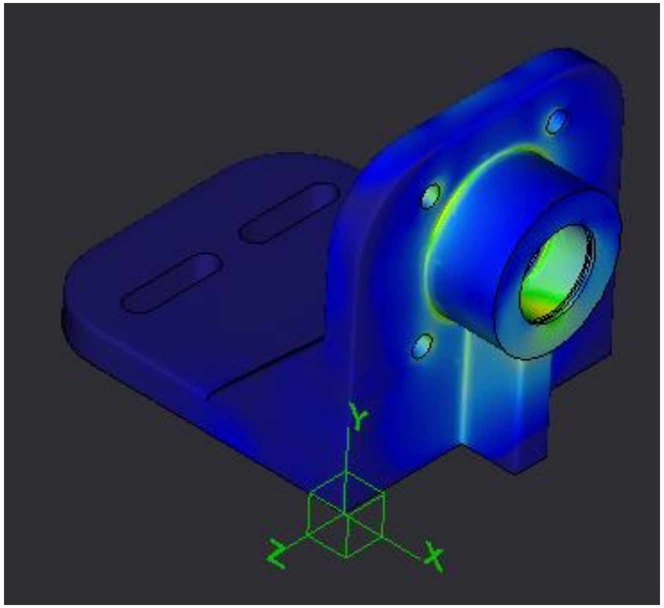
CONSTANTS		
Displacement Volume		
q=	0.241	in3/rev
Wheel Diameter		
D=	26	inches
Wheel Circumference		
C=	81.7	inches
C=	6.8	feet
Revolutions per mile		
	776.5	rev. per mile
Motor Charateristics		
Q=	6.8	gpm
N=	6600	rpm
Pressure Motor=	2500	psi
Efficiency=	0.91	

Calculations

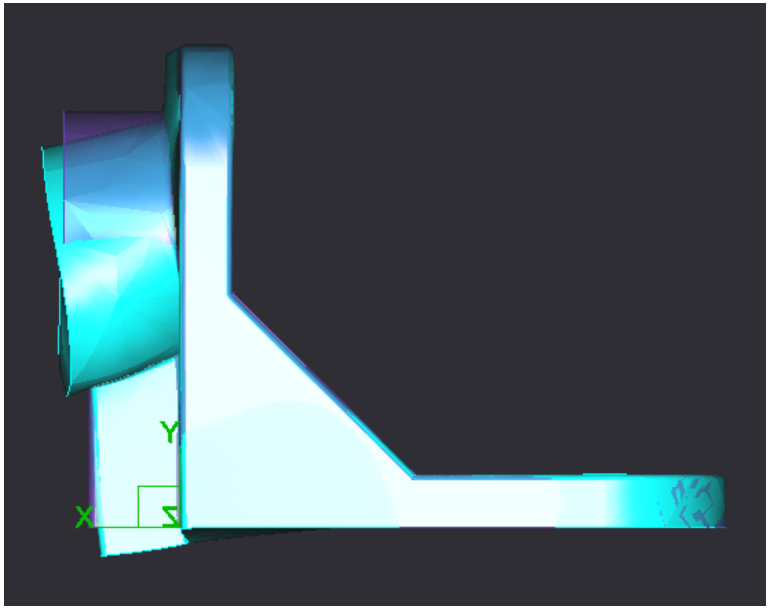
VEHICLE CALCULATIONS BASED ON SPEED (ACTUAL)														
Speed (MPH)	Wheel (RPM)	Motor (RPM)	Actual Flow Rate (Motor)	Actual Flow Rate (Pump)	Actual RPM (Pump)	Actual Pedal RPM			Power (Input)	Torque (lb-in)	Efficiency Motor/Pump	Pressure (Pump)	System HP	Pressure (Motor)
						0.733	1.000	1.364						
1	12.9	25.9	0.025	0.022	21.433	3.172	2.325	1.705	0.300	882.2	0.91	510.250	0.273	561
2	25.9	51.8	0.049	0.045	42.866	6.345	4.651	3.410	0.300	441.1	0.91	510.250	0.273	561
3	38.8	77.6	0.074	0.067	64.300	9.517	6.976	5.114	0.300	294.1	0.91	510.250	0.273	561
4	51.8	103.5	0.098	0.089	85.733	12.689	9.301	6.819	0.300	220.5	0.91	510.250	0.273	561
5	64.7	129.4	0.123	0.112	107.166	15.862	11.626	8.524	0.300	176.4	0.91	510.250	0.273	561
6	77.6	155.3	0.147	0.134	128.599	19.034	13.952	10.229	0.300	147.0	0.91	510.250	0.273	561
7	90.6	181.2	0.172	0.157	150.032	22.206	16.277	11.933	0.300	126.0	0.91	510.250	0.273	561
8	103.5	207.1	0.197	0.179	171.465	25.378	18.602	13.638	0.300	110.3	0.91	510.250	0.273	561
9	116.5	232.9	0.221	0.201	192.899	28.551	20.928	15.343	0.300	98.0	0.91	510.250	0.273	561
10	129.4	258.8	0.246	0.224	214.332	31.723	23.253	17.048	0.300	88.2	0.91	510.250	0.273	561
11	142.4	284.7	0.270	0.246	235.765	34.895	25.578	18.752	0.300	80.2	0.91	510.250	0.273	561
12	155.3	310.6	0.295	0.268	257.198	38.068	27.904	20.457	0.300	73.5	0.91	510.250	0.273	561
13	168.2	336.5	0.319	0.291	278.631	41.240	30.229	22.162	0.300	67.9	0.91	510.250	0.273	561
14	181.2	362.4	0.344	0.313	300.064	44.412	32.554	23.867	0.300	63.0	0.91	510.250	0.273	561
15	194.1	388.2	0.369	0.335	321.498	47.585	34.879	25.571	0.300	58.8	0.91	510.250	0.273	561

Bracket Analysis

- Finite Element Analysis (FEA)
  - Bearing load, 150 lbf, downward
  - Constrained in 4 slots & mounting holes, fully fixed



- Max von Mises Stress: 972.19 psi



- Max displacement: .002 in

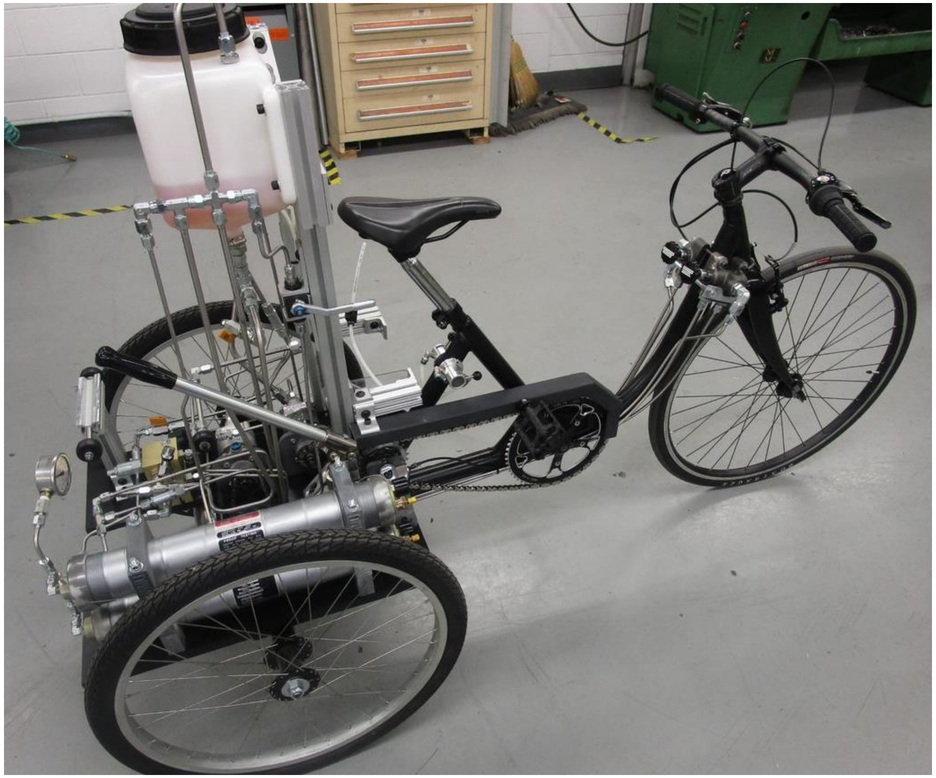
CAD Visualization

WMU Vehicle Construction

- Strip down and disassemble the pre-existing tricycle
- Paint frame and reassemble the tricycle with new braking hardware
- Install mounting plate and brackets for component mounting

WMU Vehicle Construction

- Install control valves to frame of tricycle
- Install reservoir, gear hub, accumulators, relief valves, pump, and motor to mounting plate
- Connect fittings and tubing to the hydraulic circuit



WMU Vehicle Construction

- Install subassembly pneumatic system to tricycle
- Fill pneumatic tank with air and test pneumatic system
- Fill the hydraulic circuit with fluid and test system

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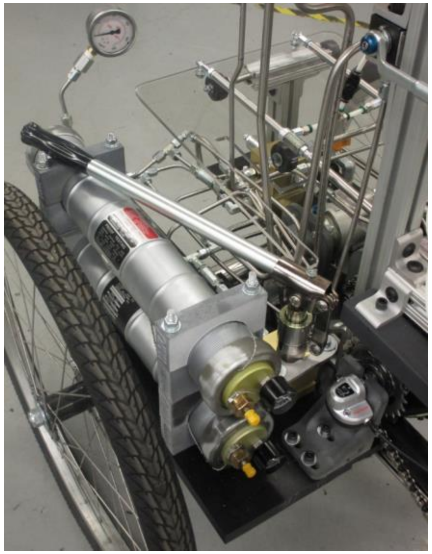
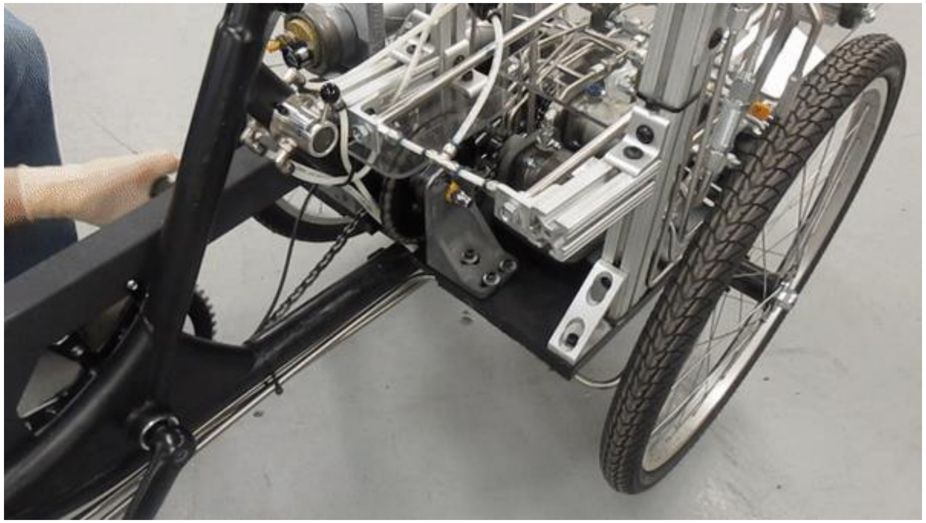
WMU Vehicle Progress

- Functional vehicle for competition, ready for Delivery!
- All required vehicle modes operational



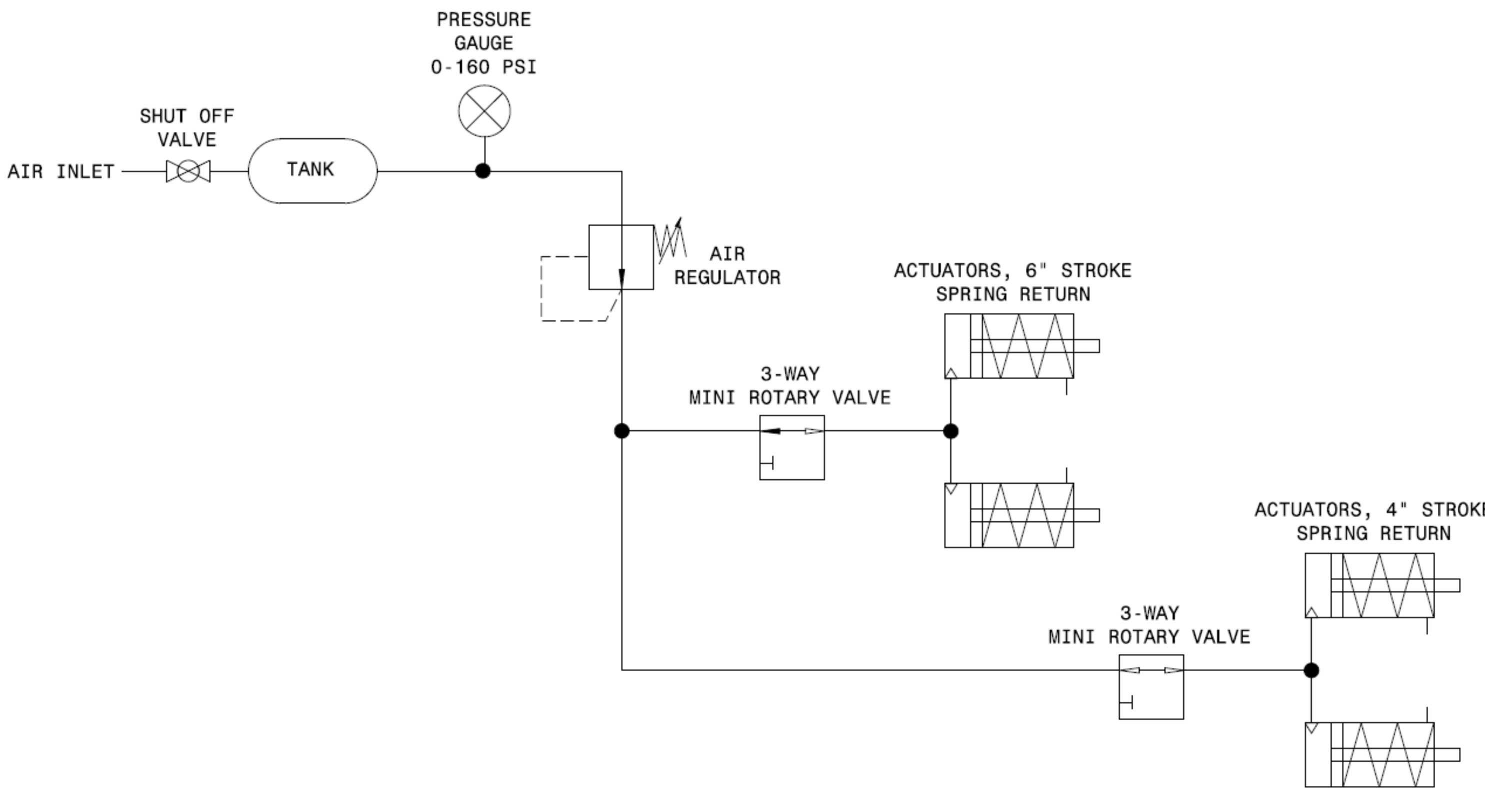


WMU Vehicle Progress

(WMU fluid powered vehicle shown above)

WMU Vehicle Progress

Best Use of Pneumatics Competition



Fluid power vehicle system schematic

WMU Vehicle Progress

- Pneumatic system implemented to operate Safety Shield
- Vehicle major parts and component listing:

  Reservoir

  Air shut off valve

  Air regulator

  (2) rotary mini control valves

  (2) flow control valves

  (2) 6” stroked actuators

  (2) 4” stroked actuators

  Push-Lok style fittings

  ¼” pneumatic tubing

Testing

- Endurance: 6-minute mile
- Efficiency Challenge: approx. 1,200ft, with 2500 psi in accumulators

Lessons Learned

- Stay on schedule
- Stick to the Design Process for theoretical calculations/analysis prior to building
- Use resources to the team's max potential
- Check vehicle hydraulic system with hoses before hard lining
- Verify pump and motor builds pressure in only 1 direction
- Do not disassemble an internal bicycle gear hub
- Always have food during a team build day

To Our Support Team

WMU advisors,
Dr. Alamgir Choudhury
Dr. Jorge Rodriguez

NFPA technical advisor,
Aaron Darnell

Parker HSD
(for their use in facility resources)

NFPA Workforce Program Manager,
Stephanie Scaccianoce

For their above and beyond, technical knowledge and support during this project.