NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation

Final Presentation
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Mentor: Michael Haen
4-16-20

Agenda

- Meet the team
- Design Objectives
- Design Overview
- Frame Choice
- Component Overview
- Component Placement
- Accumulator Analysis
- Hydraulic Circuit
- Hose Sizing
- Similink
- Pneumatic Brake
- Vehicle Construction
- Next Steps
- Lessons Learned
- Acknowledgments

1 Quart Accumulator discharge: https://youtu.be/imWofLwup8g

Meet The Team

Riley Abbott - Mechatronics

Brady Patrias - Structural

Blake Franklin - Power Generation

Ross Millard - Power Storage

Donovan Daniel - Power Transfer

Lingqi Tang - Fluid Circuit

Design Objectives

Objective Name	Priority Rating	Measurement Method	Objective Direction	Target	Threshold	Expected
Speed	3	Timed mile	Increase	20 mph	11mph	✓✓
Acceleration	4	Timed 600ft from standstill	Increase	2.1 ft/s2	1 ft/s2	✓✓
Weight	4	Scale	Decrease	80 lbs	210 lbs	✓
Efficiency	5	Competition efficiency formula	Increase	25%	6%	✓
Reliability	5	1-(% Failures during testing)	Decrease	5**σ** (99.977%)	3**σ** (93.330%)	
Cost	2	% Budget Spent	Decrease	90%	100%	✓

Component Overview

Part	Description	Source
Pump	.31 in^3 / rev Bent Axial Piston Motor	Iowa Fluid Power
Motor	.62 in^3 / rev EATON gear motor	NFPA order 2019
Accumulator	1 quart steel accumulator	NFPA order 2019
Frame	2020 Raleigh Cadent 1 XL	Trek Store
Valve Type	Inline Solenoid Valves	EATON
Microcontroller	Arduino UNO	CSU
Hoses/Fittings	All hoses are -6 with accompanying JIC fittings/adapters	Eaton/Parker

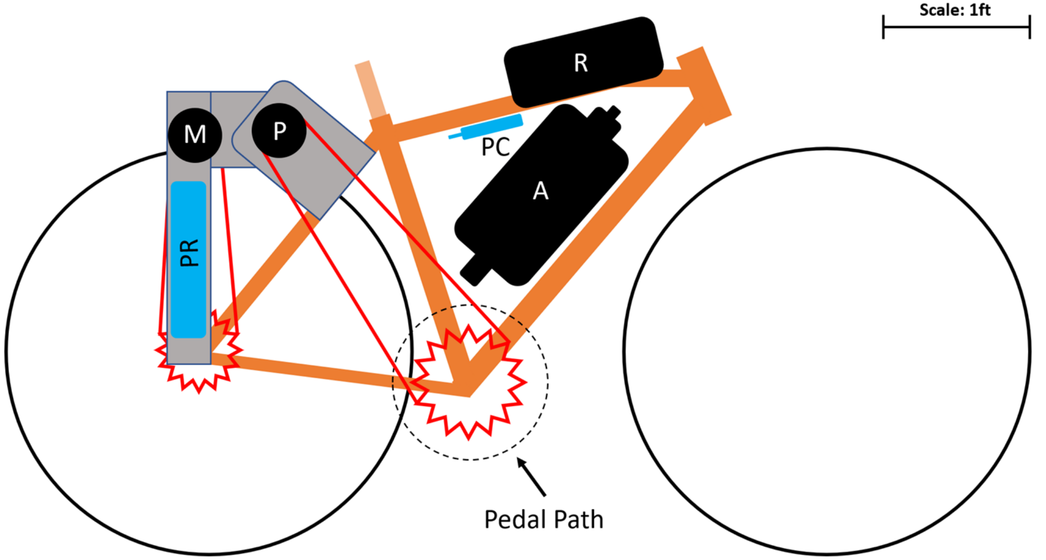
Component Placement

Goals

- Balanced design
- Maintain rider comfort

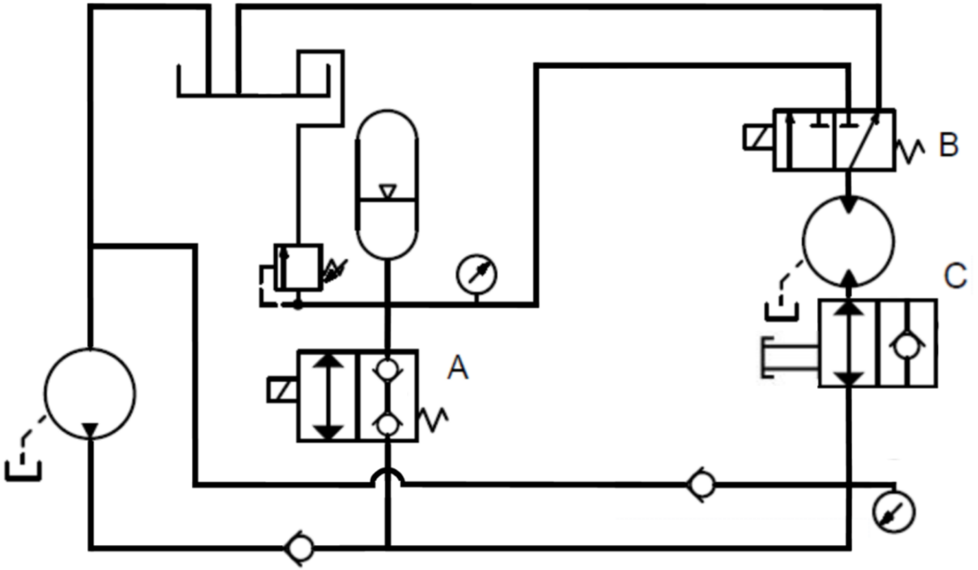
Current Layout

- Large 1 gallon accumulator
- 1 gallon oil reservoir
- Fabricated steel framework for pump and motor
- Pneumatic components for an additional rear brake
- Electronics, valves, and plumbing not shown



R: reservoir **PC**: pneumatic cylinder **M**: motor **P**: pump **A**: accumulator **PR**: pneumatic reservoir

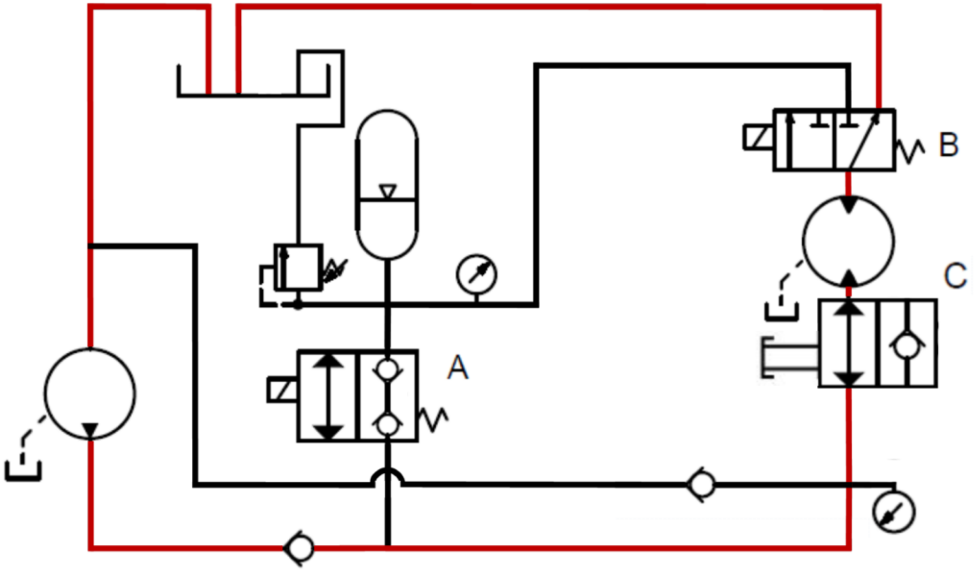
Hydraulic Circuit



Circuit Modes:

- Direct Drive
- Charging
- Discharge
- Regenerative Braking

Hydraulic Circuit



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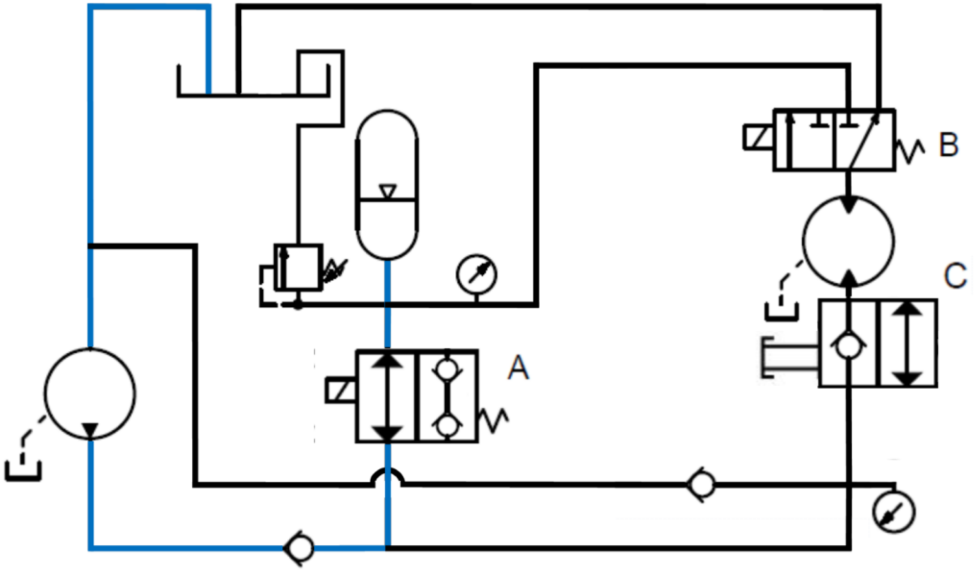

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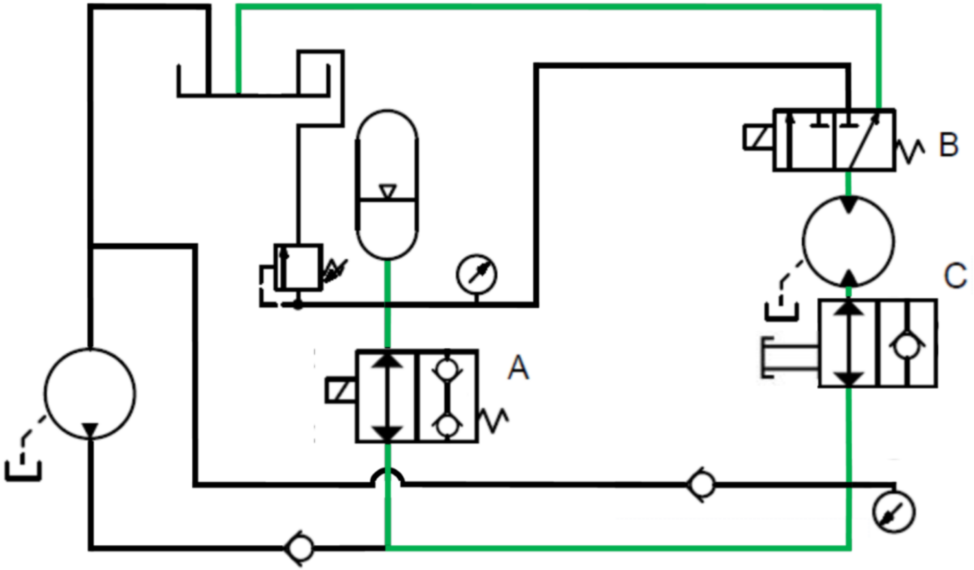

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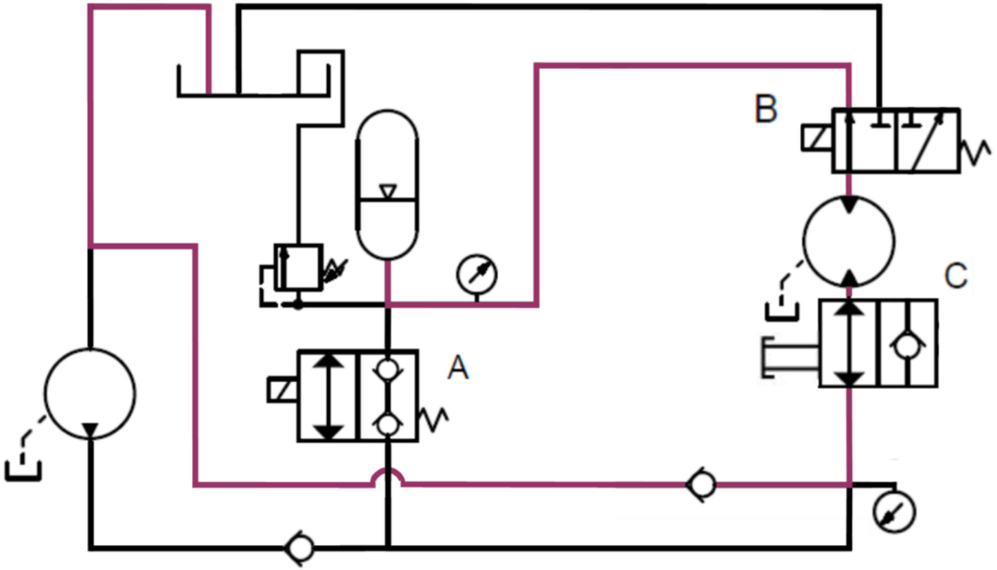
Hydraulic Circuit



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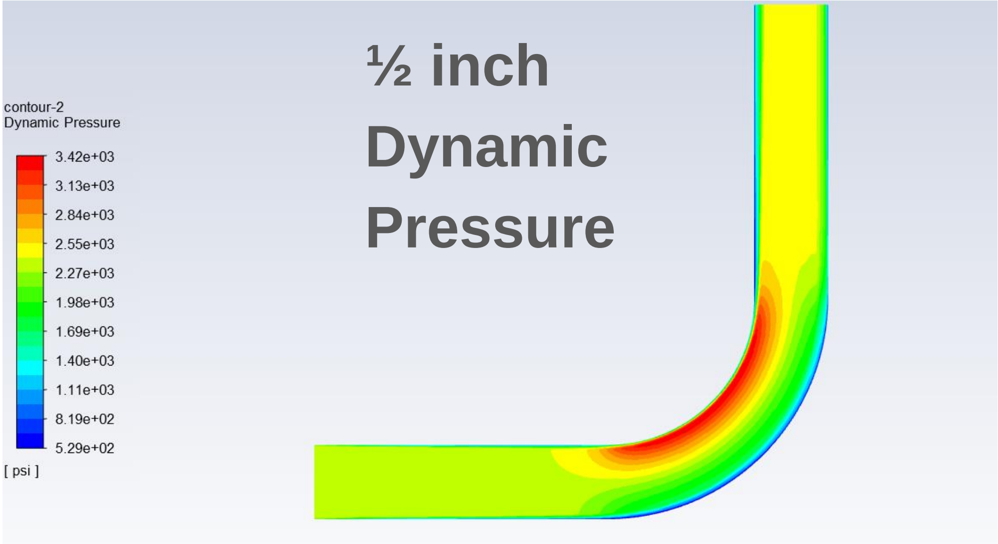
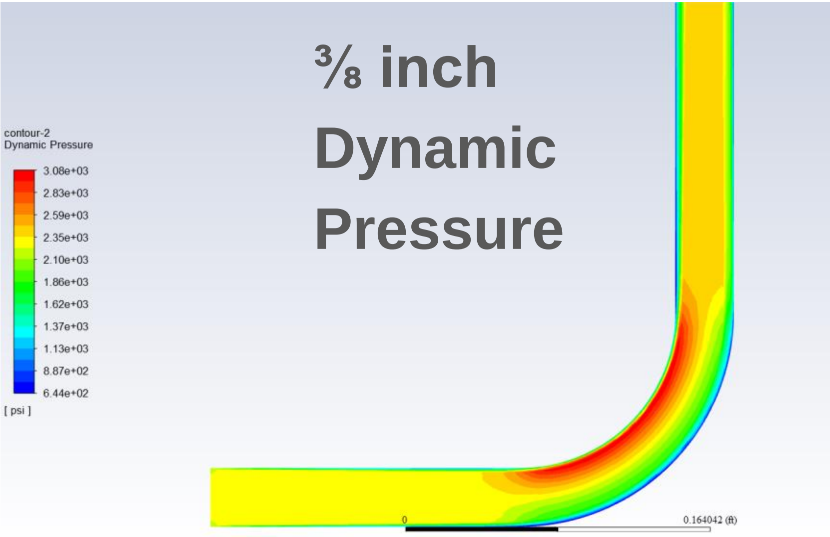
Hose Size CFD





CFD module of ½" and ⅜" hose dynamic pressure

- Negligible difference with efficiency
- Increase flowrate with ½" hose

*All findings backed by Handbook of Hydraulic Resistance by I.E. Idelchik

Simulink

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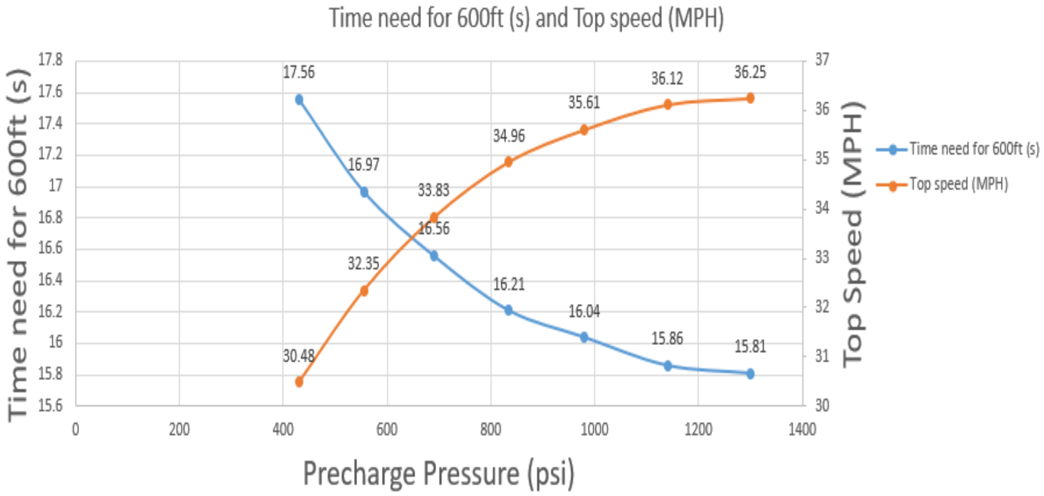
Fluid Power VEHICLE Challenge

- Built a model of the hydraulic and mechanical systems for propulsion
- Includes estimated rolling resistance, drag, and motor/pump friction
- Accurately predicted performance of last year's vehicle during discharge
- Reduced time committed to testing physical prototypes



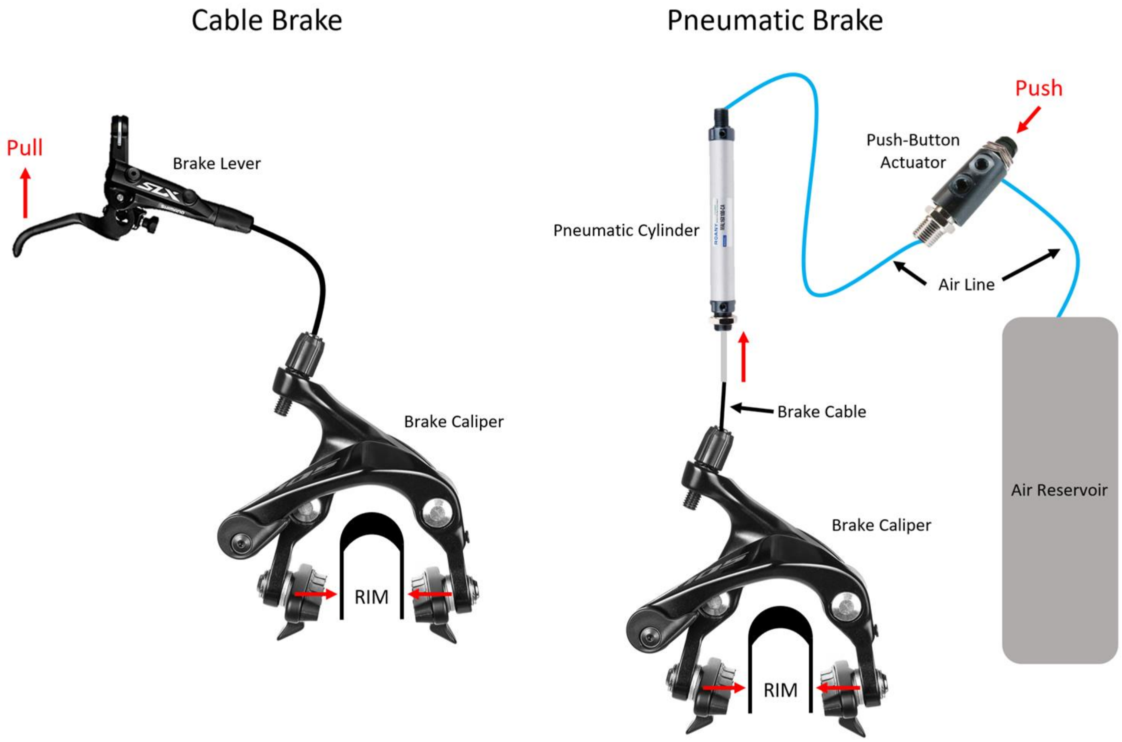
Final Concept: Pneumatic Brake

Goals

- Safety is a top priority
- Standard front/rear disc brakes
- Additional rim brake on the rear wheel
- Simple = reliable

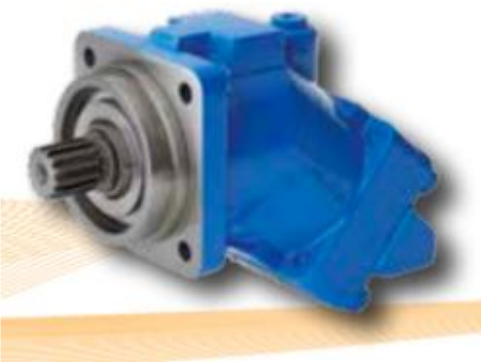
Estimated Figures

- ~400 actuations
- ~25lb of braking force
- Disk brake ~ 90lbf
- ~20% increase in braking performance



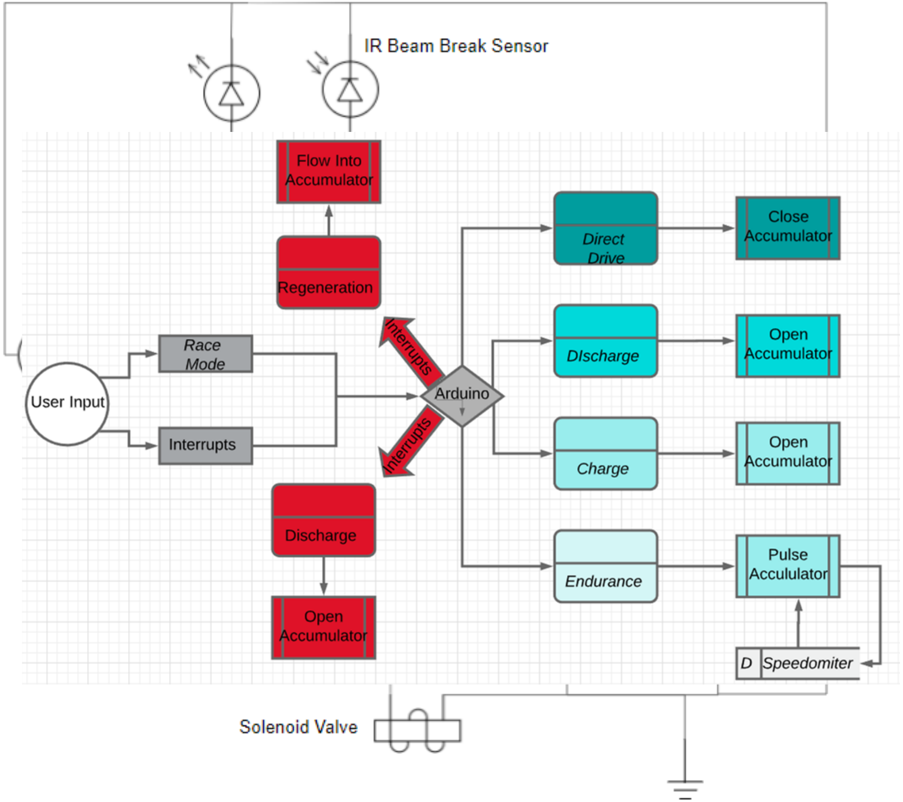
Vehicle Construction: Pump and Motor

- Used .31 cu.in/rev axial piston bidirectional motor as a pump.
- Used .62 cu.in/rev gear motor for the initial testing.
- Unfortunately, did not have time to put other .31 cu.in/rev axial piston motor on. It should increase the efficiency, especially at low RPM.
- Built steel bracket to hold both pump and motor and to withstand the 130 lb force from the motor on the chain during accumulator discharge.



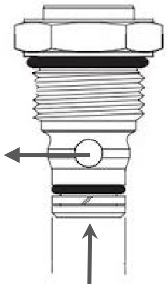
Vehicle Construction: Mechatronics

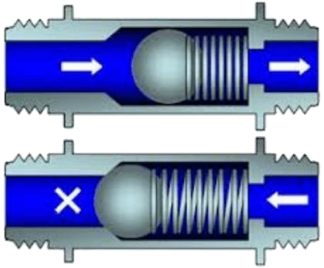
- Solenoid valves to switch hydraulic circuit mode
    - Solenoid triggered by Arduino opening relay connected to a battery
- Incorporating IR beam break sensor on tire to create speedometer
- Using Arduino as microcontroller



Vehicle Construction:
Fluid Circuit

- All hoses used were ⅜” diameter.
- JIC-6 fittings were used wherever possible.
- In-line check valves were needed to be used in the place of solenoid check valves.
- Pipe thread was unfortunately required for certain component connections such as check valves that were available at the time.
- A valve needed to be added in front of the motor to stop the motor from being pressurized from both directions.





Next Steps: Pump & Motor

For IFP's mistake, our team didn't get the motor we wanted.

This year:

- Continue use the IFP's motor by:
  - Change the gear ratios
  - Attach the correct hose couplings into the circuit
- Check if these methods can improve the efficiency of the motor

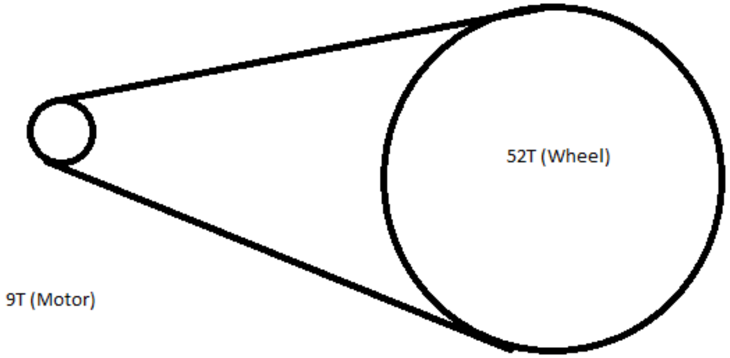
Next year:

- Get a bigger axial piston motor (no replacement for displacement)
- Try some new type of motors like gerotor, gear or vane motors.

This is wrong!!

Next Steps: Gearing

- Order custom 9T sprockets to fit 0.31 pumps/motors
- Lower gear ratio to increase discharge torque near traction limit.
- Increase pump and motor speed for increased efficiency
- Test and tune gear ratios to optimize direct drive speed
- Considered compound gear train for additional wheel torque



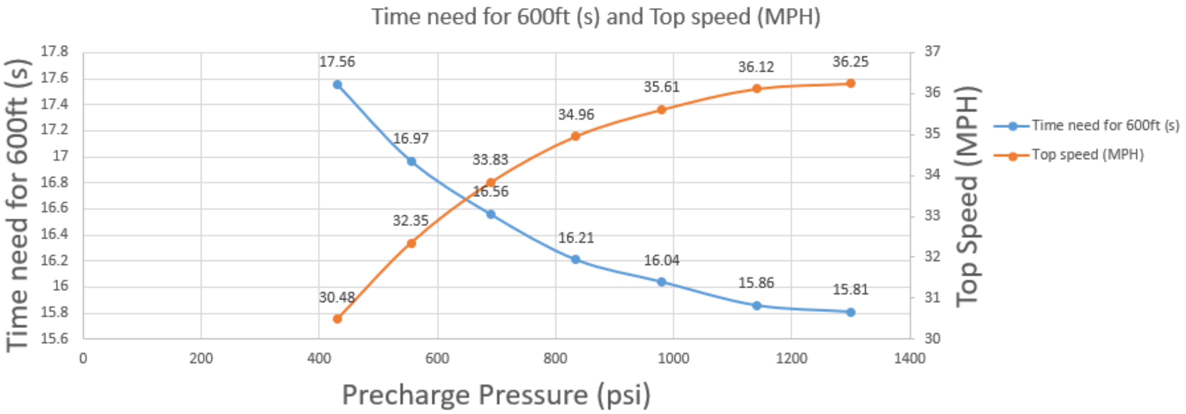
Next Steps: Accumulator

Accumulator size:

In the original plan, a huge accumulator with 1 gallon capacity will be used.

Accumulator Precharge:

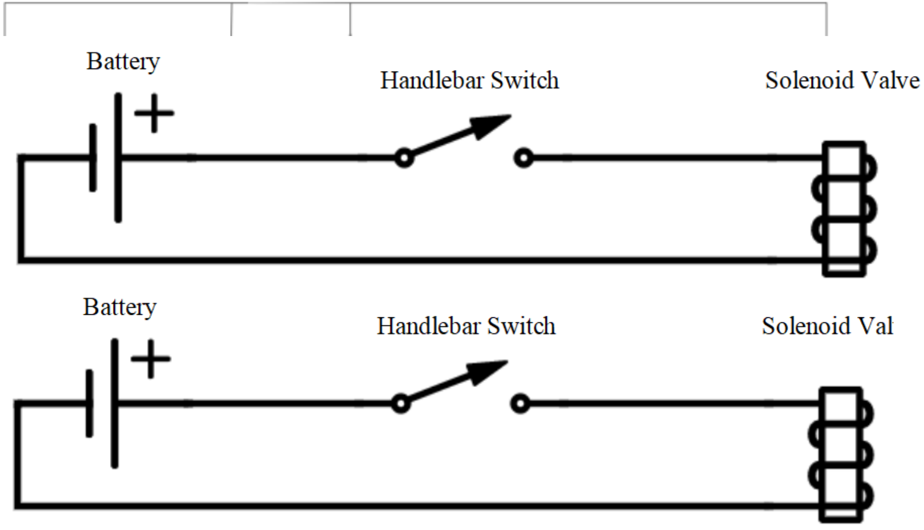
Through computer simulation, we get 1300 psi will be the best precharge value. During this precharge value and 5.77 gear ratio, our vehicle's top speed can reach 36.25 MPH. It can run 600 feet in 15.81 seconds.



NFPA Fluid Power Vehicle Challenge

Next Steps: Mechatronics

- Reliability is top priority!
  - Simplify circuit to decrease failure
- Valve actuation controlled directly
- Create redundancy with wiring



Criteria	Weight	With Arduino	Without Arduino
Reliability	4	3	5
Efficiency	3	3	2
Ease of riding	2	4	3
Safety	3	2	3
Total		**35**	**41**

Next Steps: Fluid Circuit

Main Objectives:

- Minimize the amount of adapters that are used throughout the fluid circuit.
- Shorten hose lengths as much as possible.
- Reduce any sources of head loss throughout the system in general (fewer bends and adapters, etc…)

Additional Objectives:

- Substitute flexible hydraulic lines for hard lines for a more sleek and efficient design.

Lessons Learned

1. Fully discharge accumulator as quickly as possible during sprint to maximize speed
2. Accelerate at the traction limit of the rear wheel, but not over
3. Gear motors tend to leak with current design
4. Find minimum of motor leakage and air drag to maximize efficiency distance
5. Component placement is very challenging with a standard bicycle frame
6. Sturdy mounting hardware necessary for heavy components and powerful accumulator discharge
7. Hydraulic plumbing with multiple valves requires significant planning for a streamlined design

Acknowledgements

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Kent Sowatzke - Bimba Contact

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