NFPA

Fluid Power Vehicle Challenge

NATIONAL FLUID POWER ASSOCIATION · NFPA ·

NFPA
Education and
Technology
Foundation

FINAL PRESENTATION
Fluid Raider Racers
Dr. Luis A. Rodriguez
04/16/20

MSOE
UNIVERSITY

Team Introduction

Top picture left to right:

- Luke Ponga, ME, MSOE
- Justin Zielinski, ME, MSOE
- Johanna Borschel, ME, THL
- Frerich Asmus, ME, THL
- Kristof Barantke, ME, THL
- Trevor Howard, ME, MSOE

Problem Statement & Motivation

- Designing and building a human-operated vehicle that will transfer human power into propulsion incorporating fluid power.
- Take part in competition of National Fluid Power Association (NFPA)
  - Sprint race
  - Endurance Race
  - Efficiency Challenge
- Gain an improved understanding of the fluid power industry
- Build future career skills

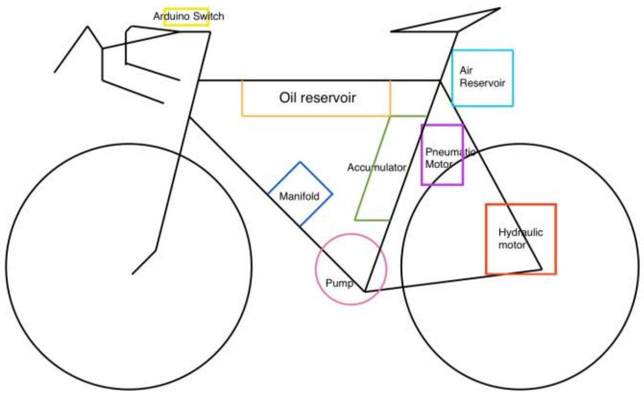
Objectives

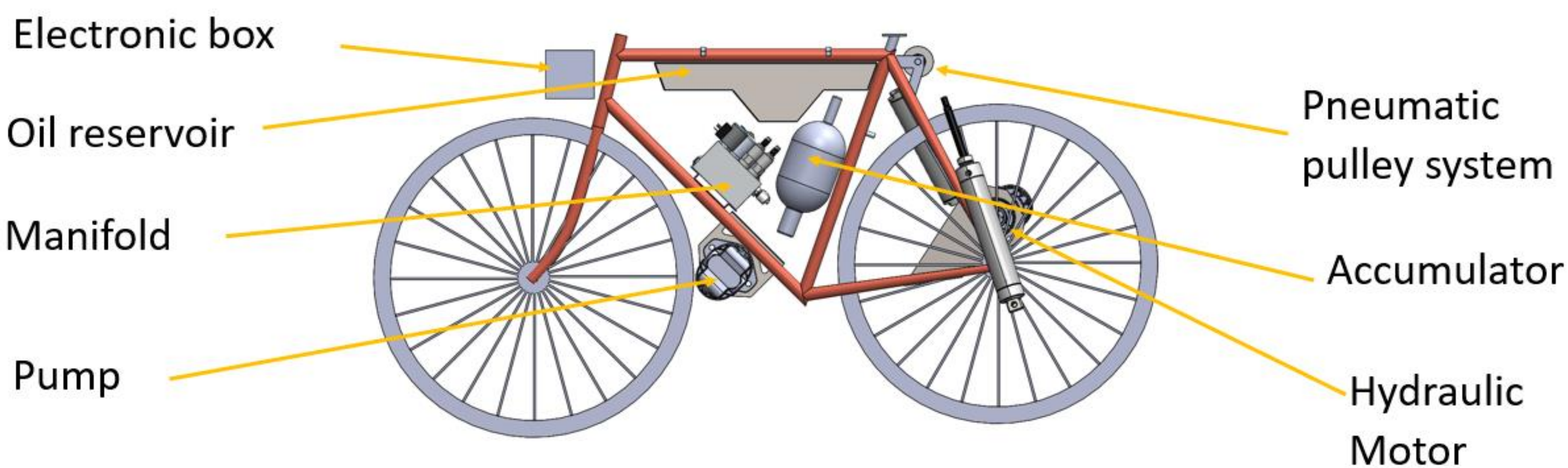
- Incorporate pneumatics into hydraulic design
- Place in top 3 in all three races but focus on endurance and efficiency race
- Create clean and compact design
- Place rider in riding position to be able to deliver maximum power
- Vehicle should be safe for the rider
- Hydraulic control components are easily accessible
- Include electrically controlled valves

Choosing a frame

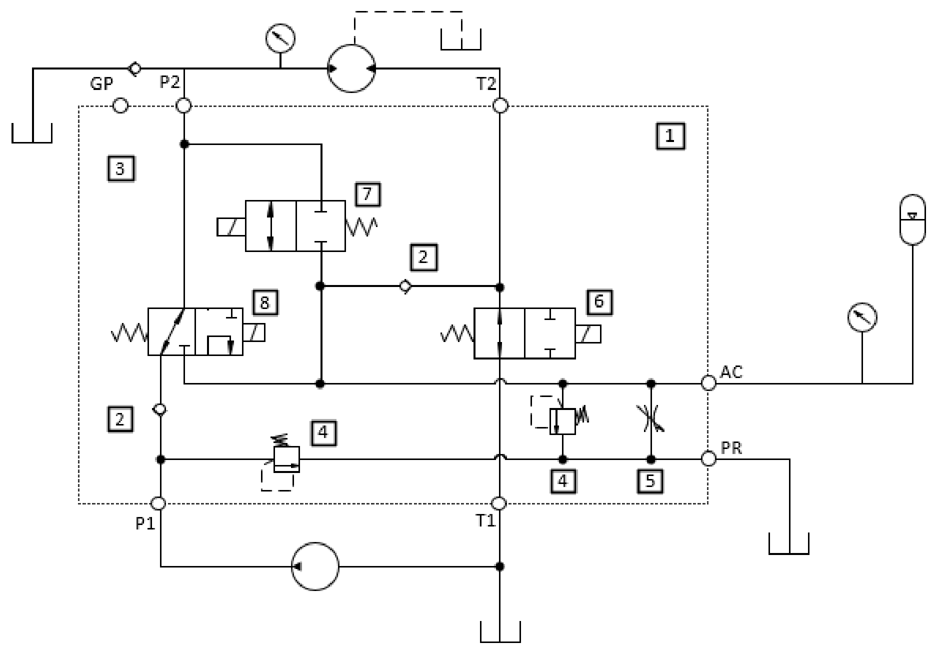
	Safety	Perfor-mance	Efficiency	Manu-facturing	Various	Costs	Sum with weighting	Sum without weighting
Weighting	20.00%	40.00%	20.00%	10.00%	5.00%	5.00%		
Road bike	3	5	5	3	4	5	4.35	25
Cruiser bike	2	4	4	2	2	5	3.35	19
Trike 2013	4	2	2	3	2	3	2.55	16
Scooter	1	4	3	1	4	2	2.8	15
Wheelchair	1	3	1	2	1	1	1.9	9
Go-Kart	5	2	1	4	5	1	2.7	18

Positioning of parts





Hydraulic Circuit

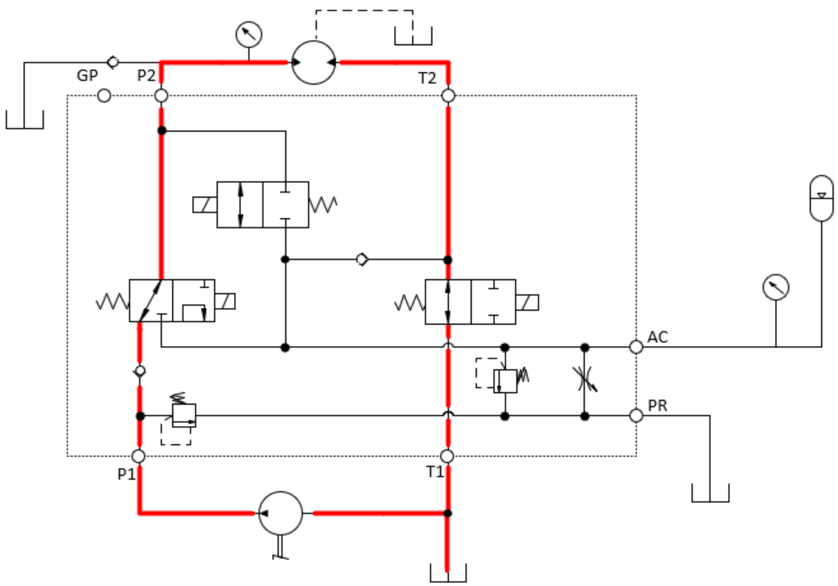


1. Manifold Body
2. x2 – CV3-8-P-0-004: Check, 1 to 2 (Size 8, 4 PSI)
3. x1 – CV3-10-P-0-3: Check, 1 to 2 (Size 10, 3 PSI)
4. x2 – RV1-10-S-0-30: Relief, Direct Acting
5. x1 – NV1-8-S-0: Flow Control, Needle Valve
6. x1 – SBV11-10-0-0-00: Solenoid, 2 pos. 2 way Bi-poppet, normally open
7. x1 – SBV1-10-C-0-00: Solenoid, 2 pos. 2 way Bi-poppet, normally closed
8. x1 – SV1-10-3-0-00: Solenoid, 2 pos. 3 way Spool 1-2/1-3
9. x1 – CV06N: 3/8" External Check Valve

Note: all numbered parts, except for number 9, were chosen from the provided competition catalog.

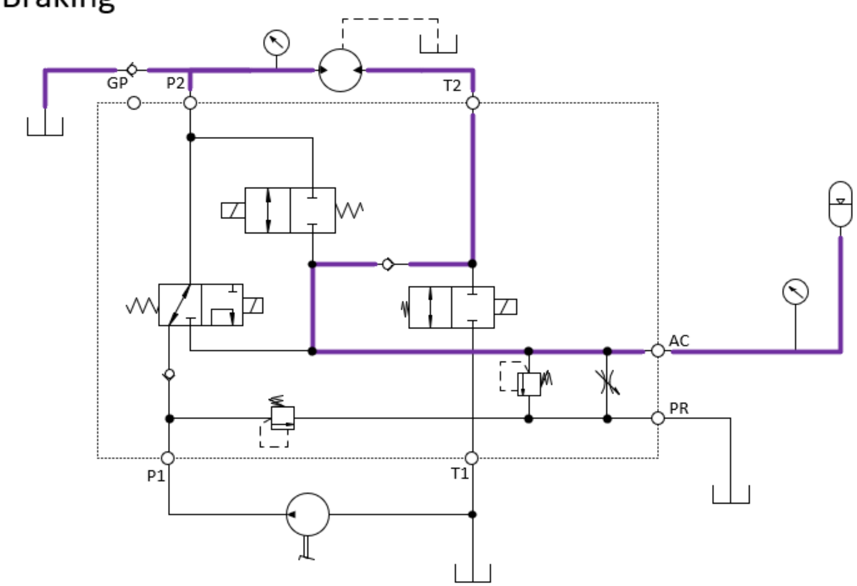
Hydraulic Circuit Modes

Direct Drive



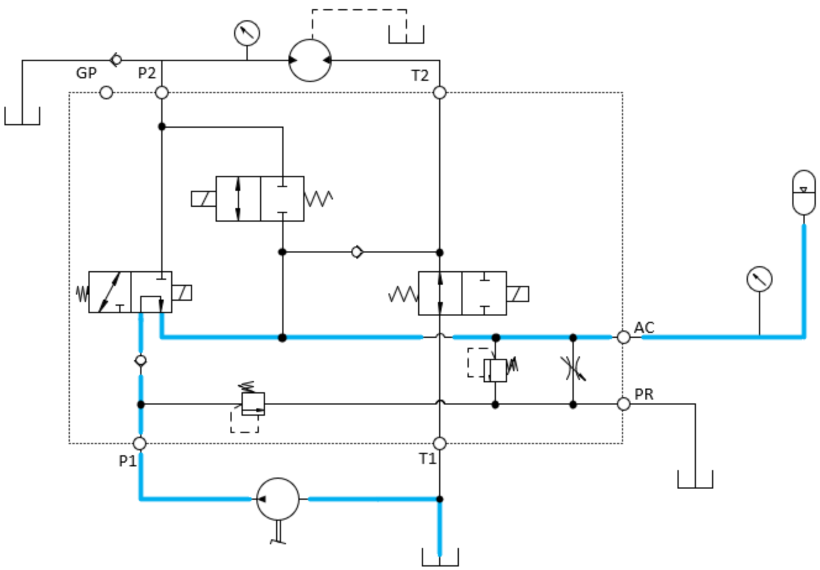
Key Features:
- Most components fit in manifold
- Ease of control with solenoid valves
  - Quickly change between circuits

Regenerative Braking

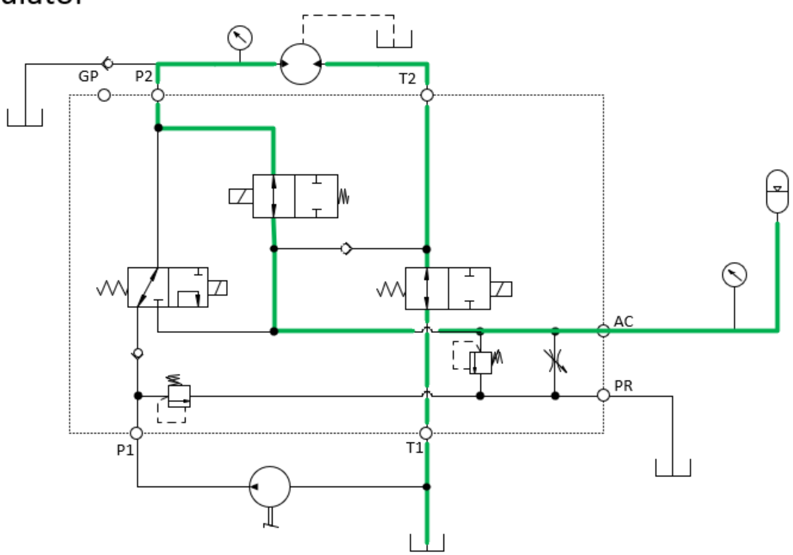


Hydraulic Circuit Modes

Charging the Accumulator



Discharging the Accumulator

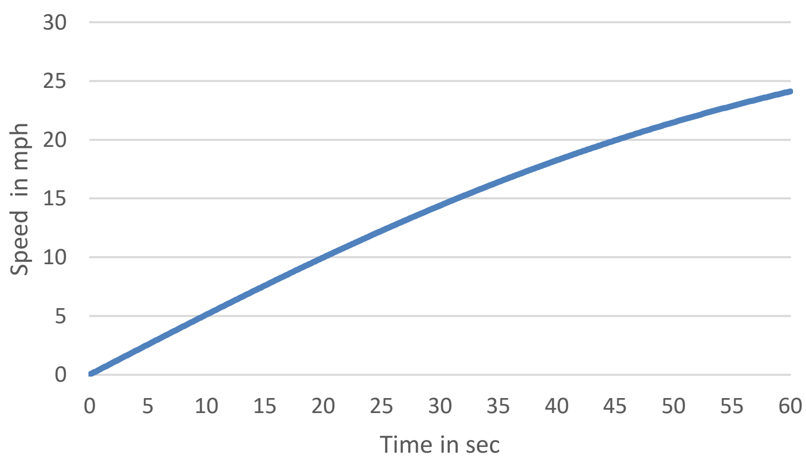


Selection of hardware

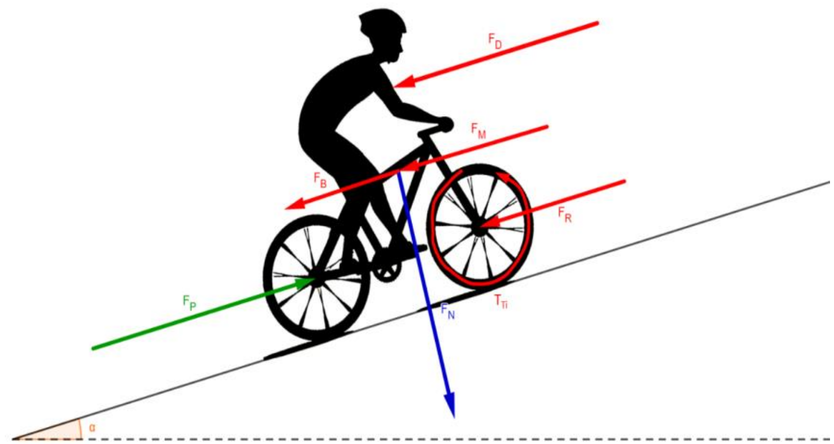
- Parts were selected and provided by the NFPA catalog.
  - Miscellaneous fittings and tubing were ordered from McMaster-Carr and Grainger.
- Hardware was chosen based on our calculations, research, and recommendations.

Forces on bike

- $F_D = Drag$
- $F_R = Rolling\ resistance$
- $F_B = Backforce$
- $F_P = Propulsion\ force$
- $F_N = Normal\ force$
- $a = \frac{F_P - F_D - F_B - F_R}{m}$



Bike velocity response to a constant propulsion force



Free body diagram

Pump & Motor Sizing

- Human Input
  - 80 rpm
  - 221 In-lbs.
- Gear Ratio
  - 5:1
- Assumed Pressure
  - 1500 psi

$$T_P = T_H \frac{d_P}{d_H} = \frac{T_H}{GR} = 44.2[in - lbs]$$

$$\omega_P = \omega_H \frac{d_H}{d_P} = \omega_H \times GR = 400[rpm]$$

$$Disp_P = \frac{2\pi T_P}{\eta_P p_P} = 0.21\left[in^3 / rev\right]$$

$$Q = \frac{p_P \times \omega_P}{231} = 0.32\left[gpm\right]$$

MGG20010 – 0.218 CID Pump

- Assumed Losses
  - 200 psi
- Required Torque
  - 90 in-lbs.

$$Disp_M = \frac{2\pi T_M}{\eta_M p_M} = 0.54\left[in^3 / rev\right]$$

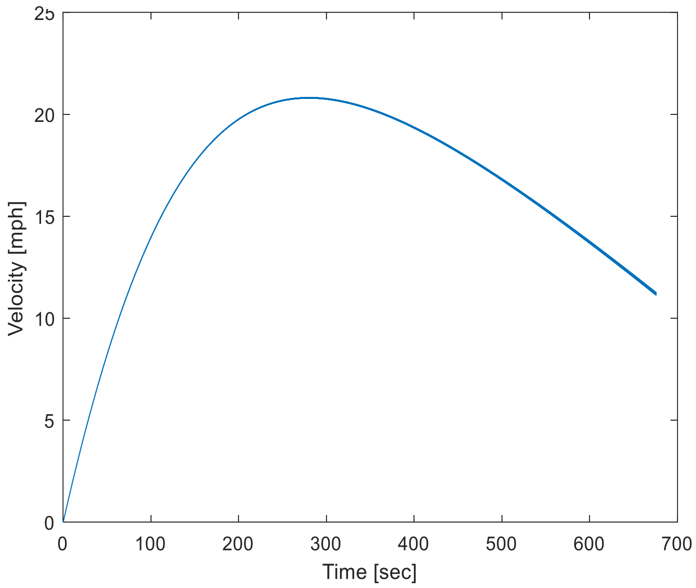
0.54 CID Eaton Gear Motor

Accumulator Sizing

- 1 Quart Volume
  - Size Constraints
- 1500 psi Nitrogen Pre-charge Assumed
- 3000 psi Oil Charge Assumed

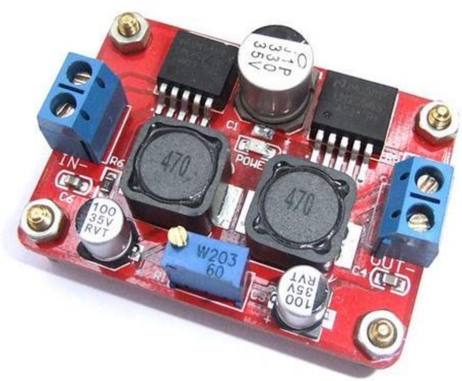
$$V_{N_2} = V_{N_1} \frac{P_{N_1}}{P_{N_2}} = 0.803[L] \frac{1014.7[psia]}{3014.7[psia]} = 0.2703[L]$$

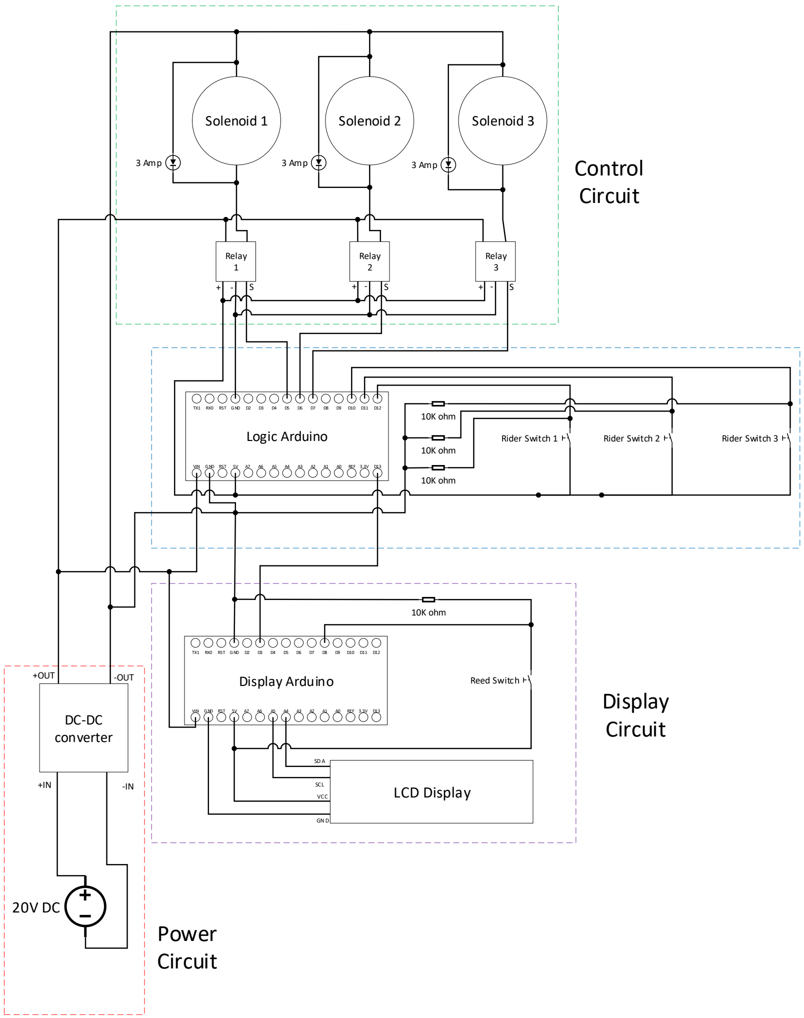
$$V_O = V_{Tot} - V_N = 0.6757[L]$$



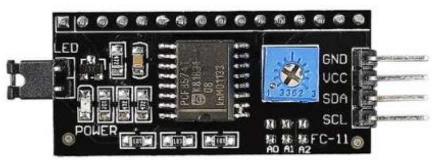
Velocity profile of vehicle during accumulator discharge

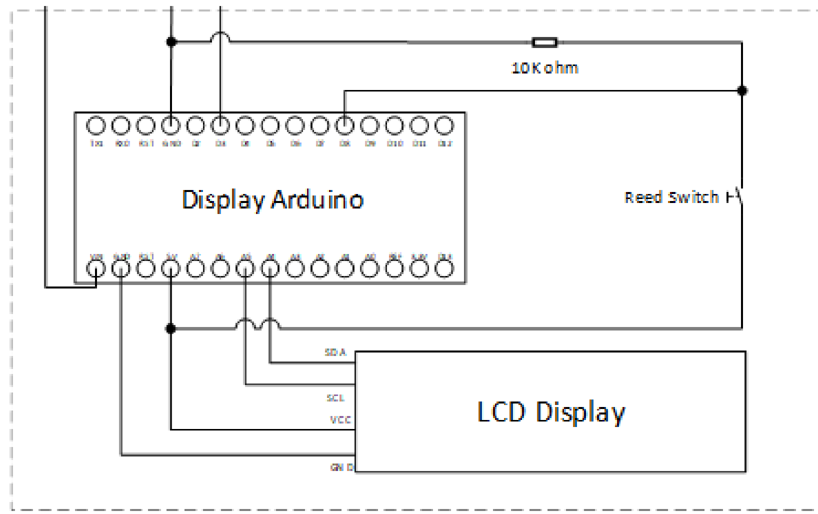
Electronic Circuit





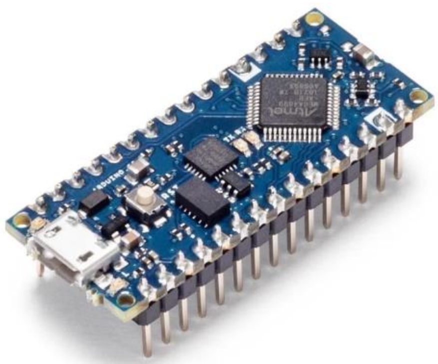
Display Circuit

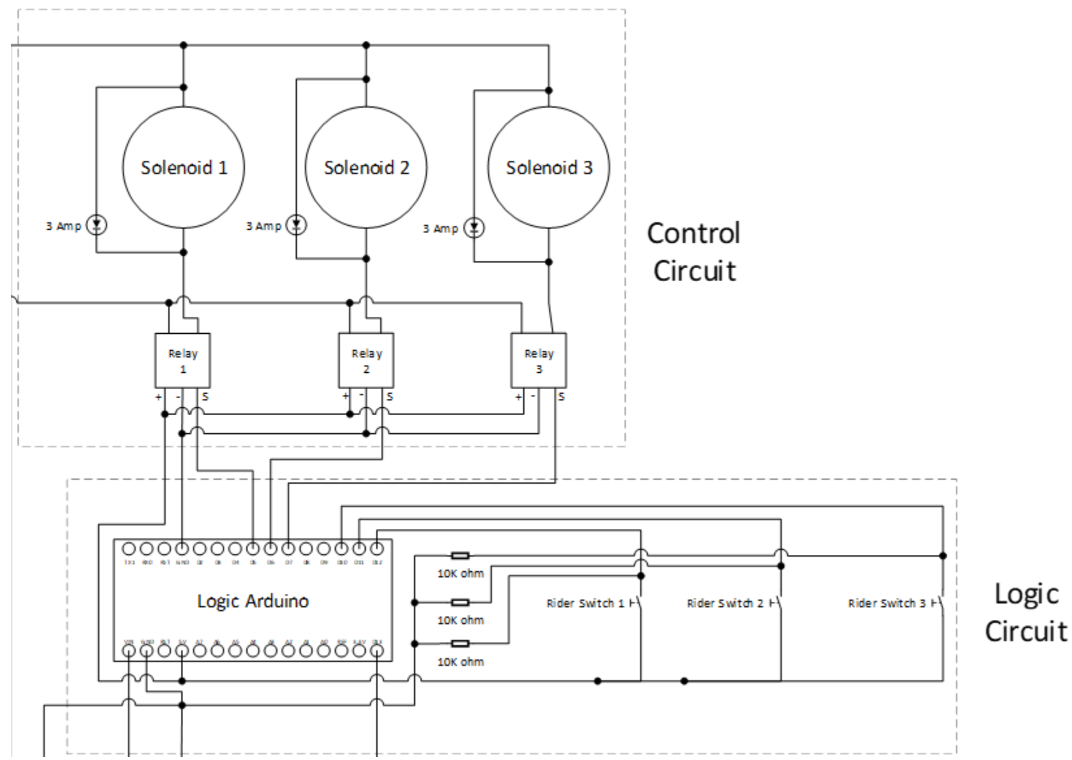




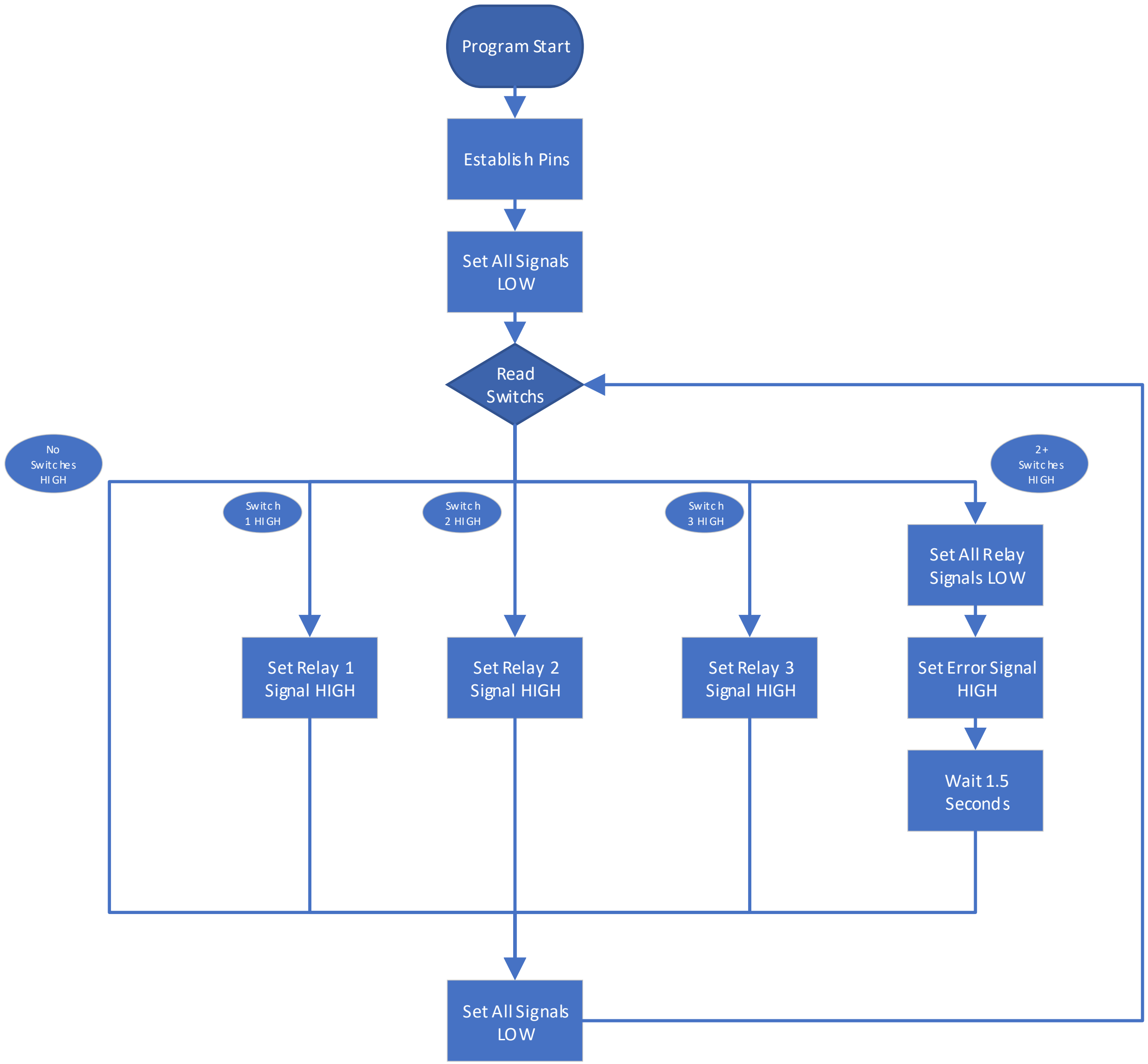
Display Circuit

Control & Logic Circuit

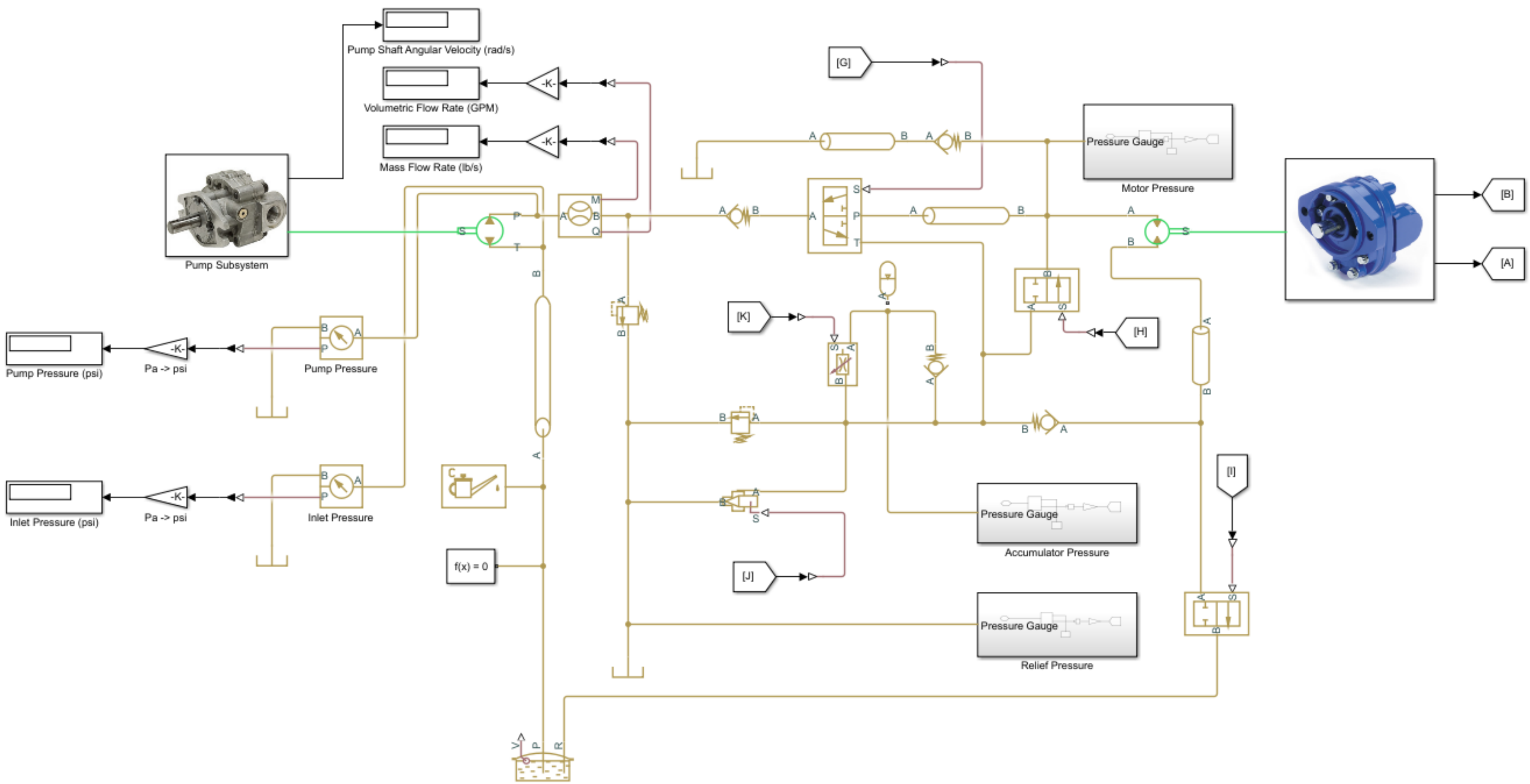




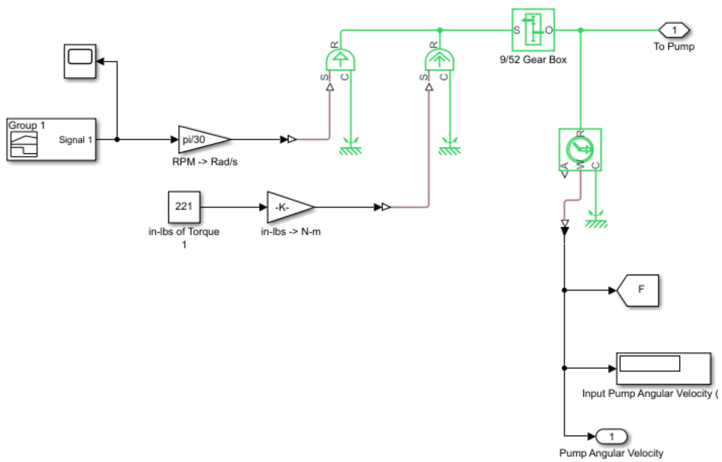
Control & Logic Flowchart



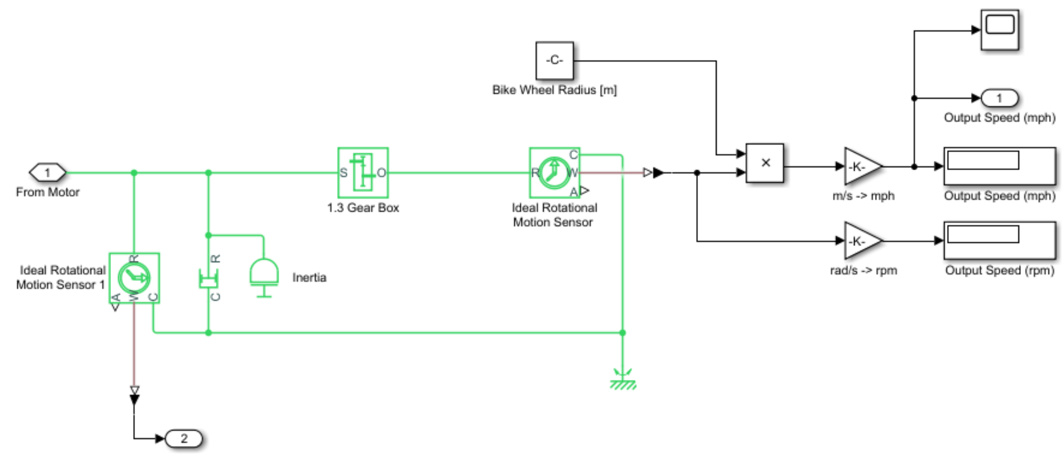
Incorporation of analyses - Simscape Fluids



Motor and Pump

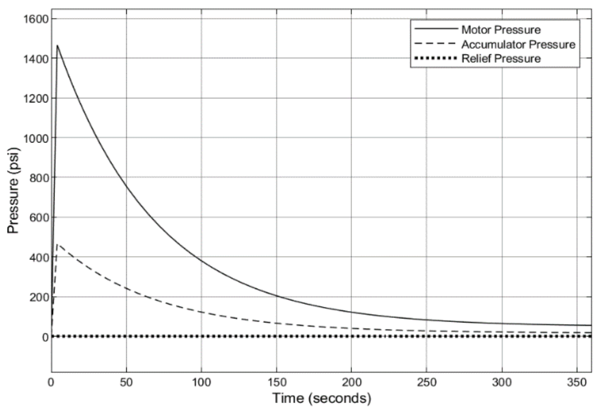


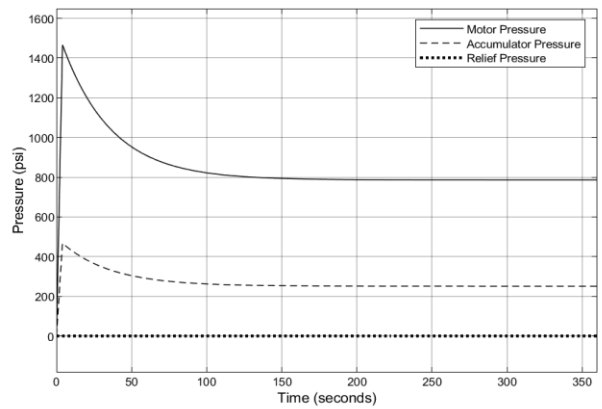
Pump Subsystem

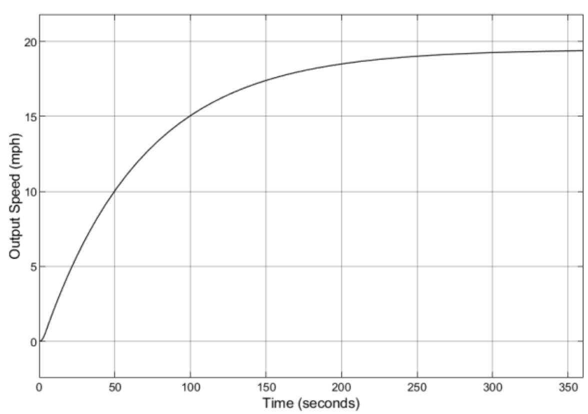


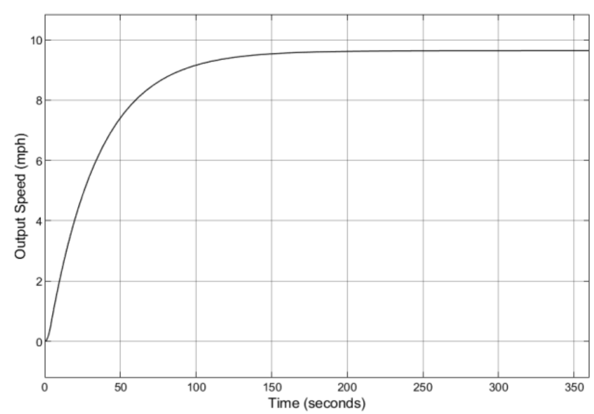
Motor Subsystem

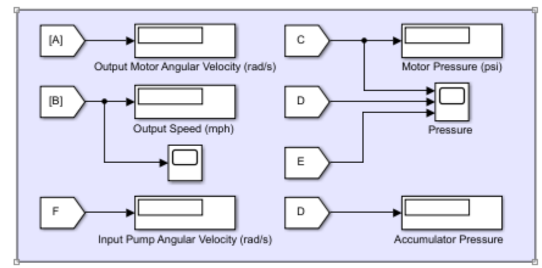
Organization and Results

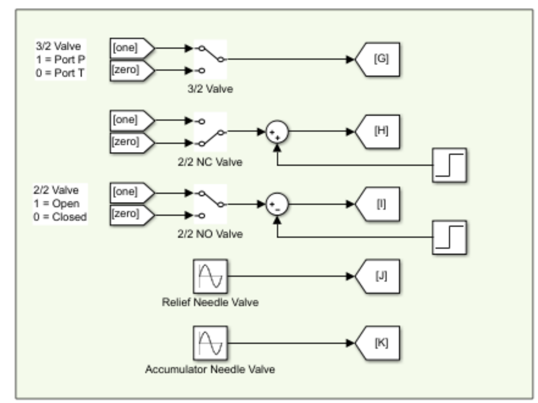






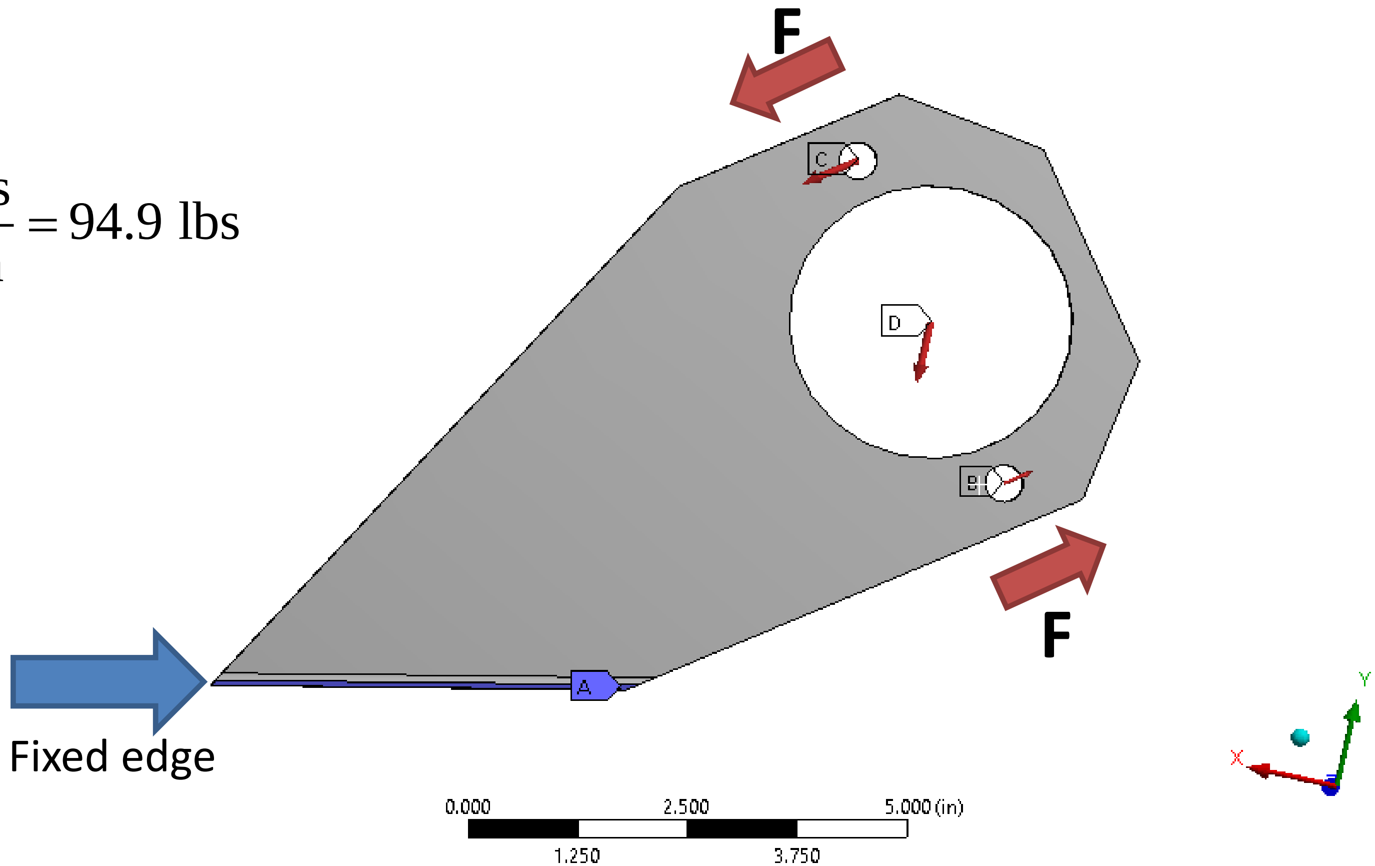




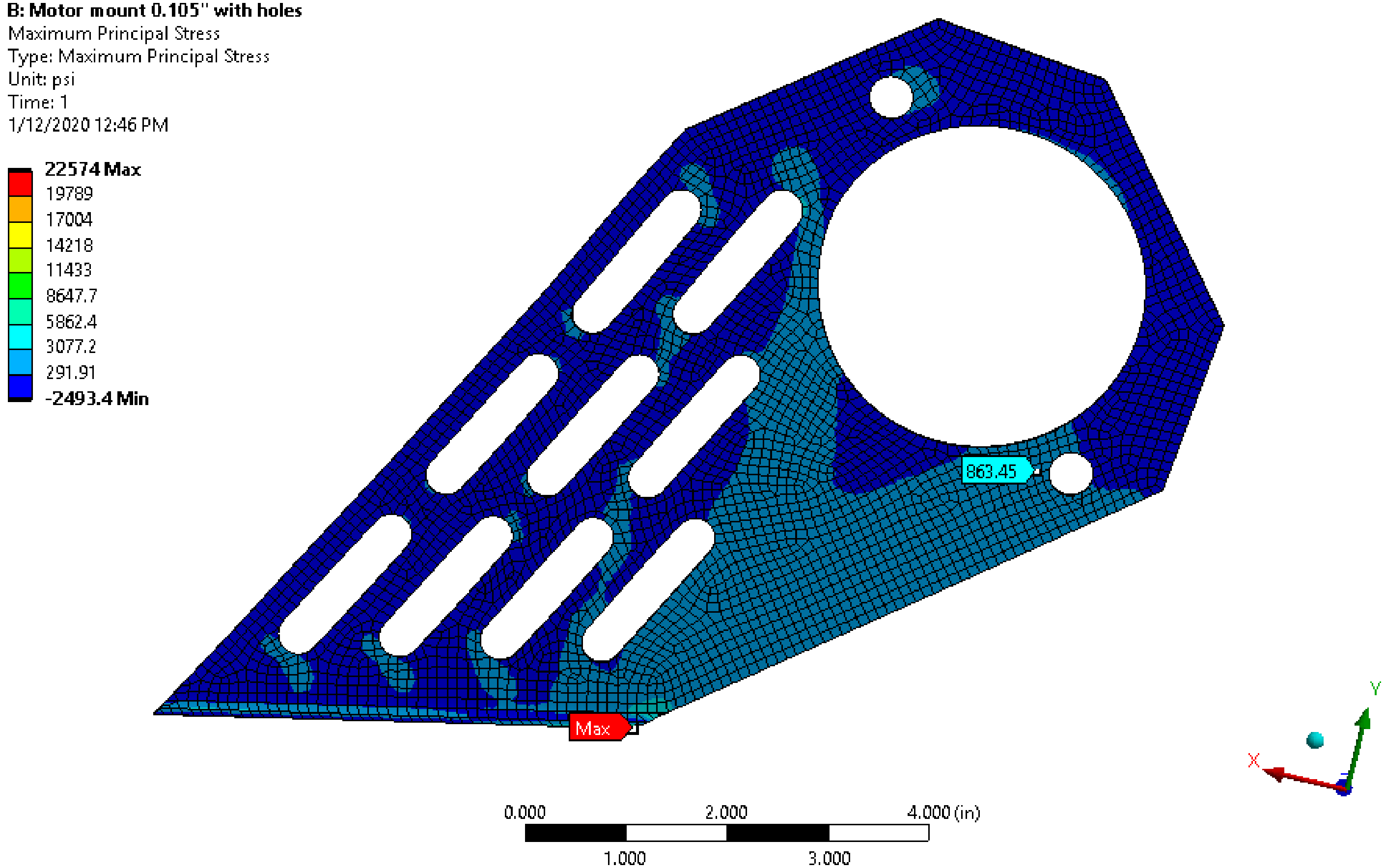


Boundary conditions

$$F = \frac{416 \text{ in-lbs}}{2 \cdot 2.19 \text{ in}} = 94.9 \text{ lbs}$$

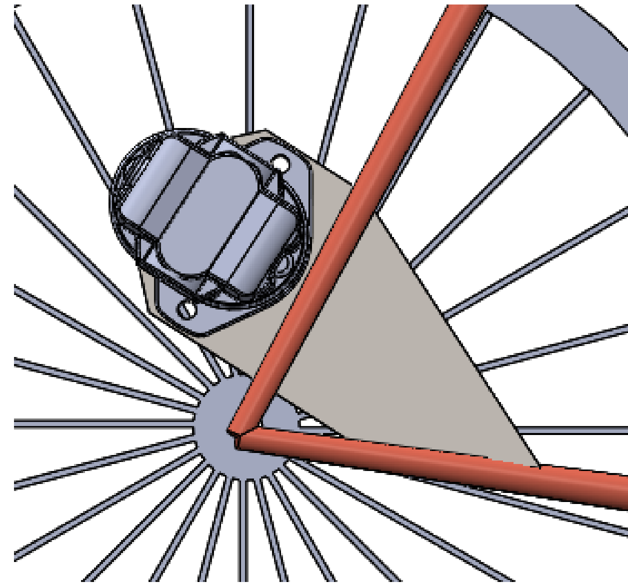


Results



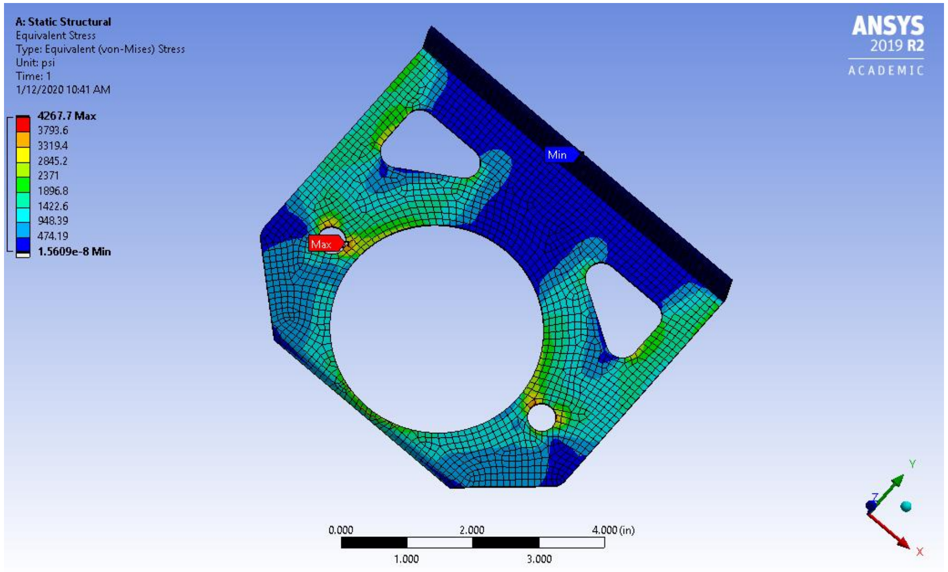
B: Motor mount 0.105" with holes
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: psi
Time: 1
1/12/2020 12:46 PM
22574 Max
19789
17004
14218
11433
8647.7
5862.4
3077.2
291.91
-2493.4 Min
863.45
Max
0.000
2.000
4.000 (in)
1.000
3.000
Y
X

Comparison of both variants

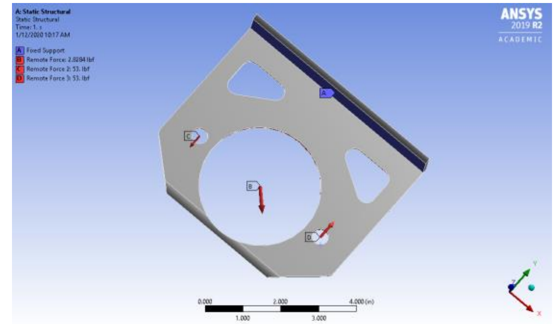


configuration	Max. principal stress in psi	Max. von Mises stress in psi	Max. deformation in inch	Weight in lbs.	Safety factor
Mount without holes	19 430	12 666	0.0028	1	1.8
Mount with holes	22 574	15 917	0.0036	0.7	1.6

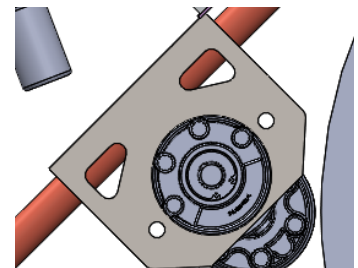
Pump mount



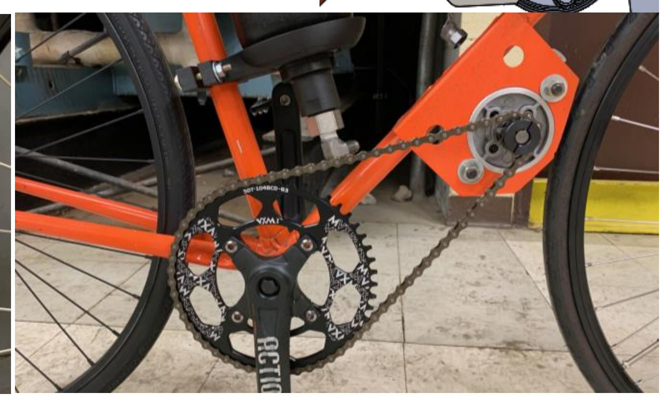
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: psi
Time: 1
1/12/2020 10:41 AM
4267.7 Max
3793.6
3319.4
2845.2
2371
1896.8
1422.6
948.39
474.19
1.5609e-8 Min
Max
Min
ANSYS
2019 R2
ACADEMIC
0.000
2.000
4.000 (in)
1.000
3.000



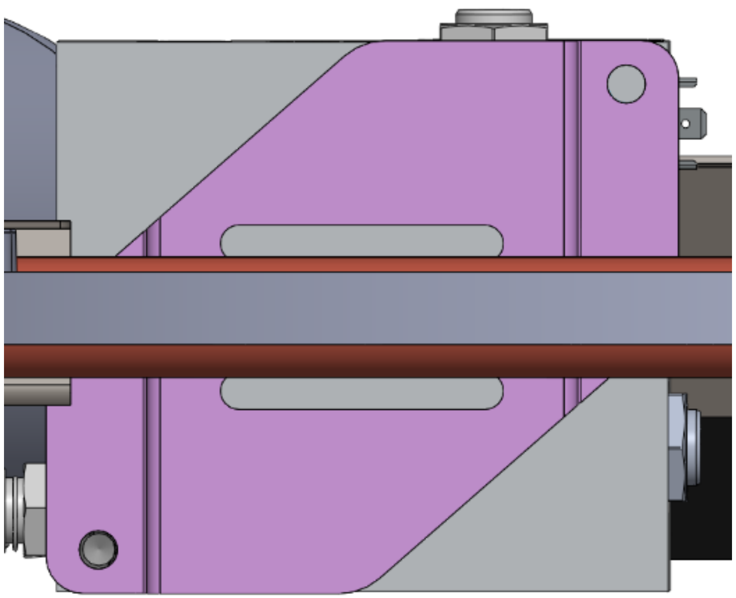
A: Static Structural
Static Structural
Time: 1. s
1/12/2020 10:17 AM
Fixed Support
Remote Force: 2.8284 lbf
Remote Force 2: 53. lbf
Remote Force 3: 53. lbf
ANSYS
2019 R2
ACADEMIC



GATORSKIN



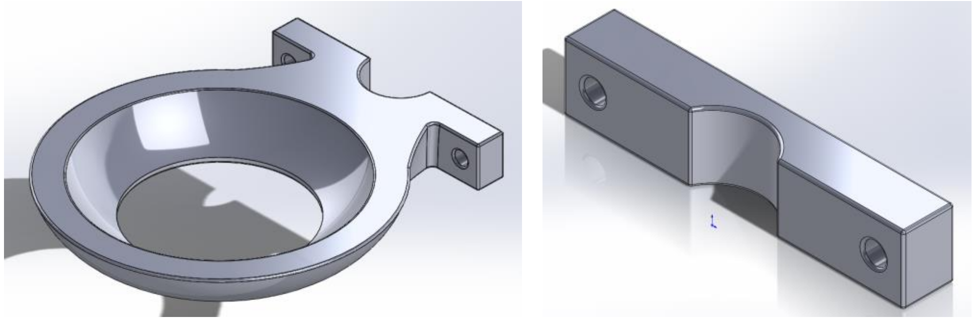
Manifold Mount



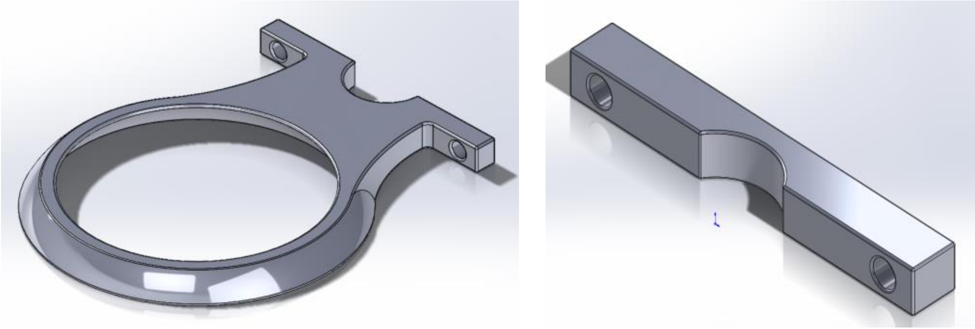
Accumulator Mount

- 3D Printed
  - Nylon 12CF

Component	Max Stress (psi)	Safety Factor	Max Deformation (in)
Bottom Mount	1687.8	2.47	0.0138
Bottom Mount Cap	2289.3	1.82	0.00194
Top Mount	2364.3	1.76	0.0044
Top Mount Cap	2709.2	1.54	0.0064



Accumulator Mount Bottom Bracket and Cap



Accumulator Mount Top Bracket and Cap

Accumulator Mount

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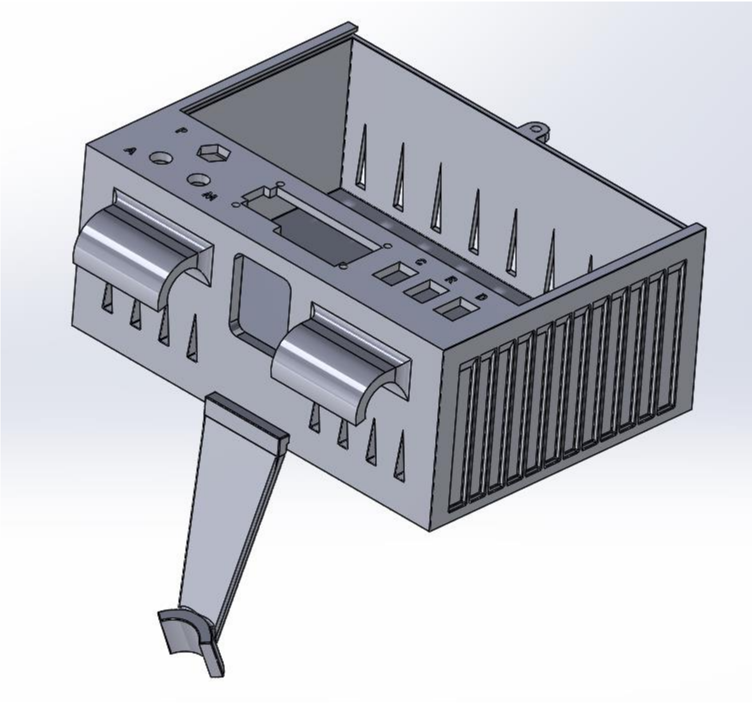
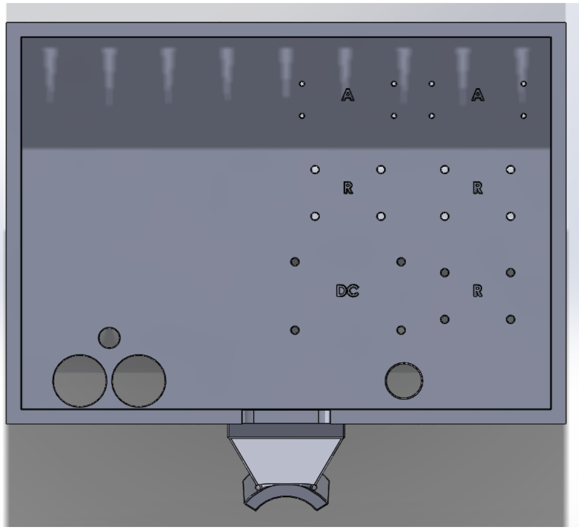
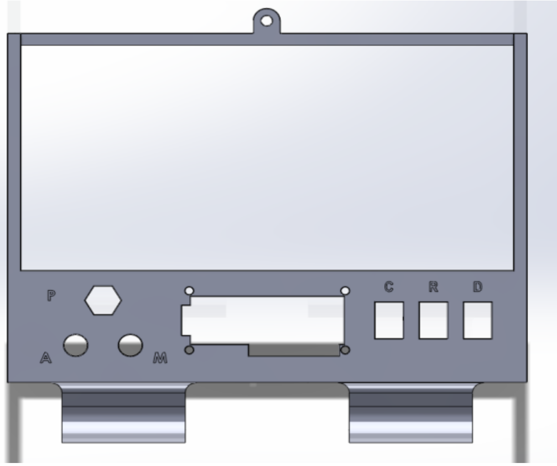
Electronics Box

- 3D Printed
  - Box
    - ABS-ESD7
  - Supporting Arm
    - Nylon 12CF

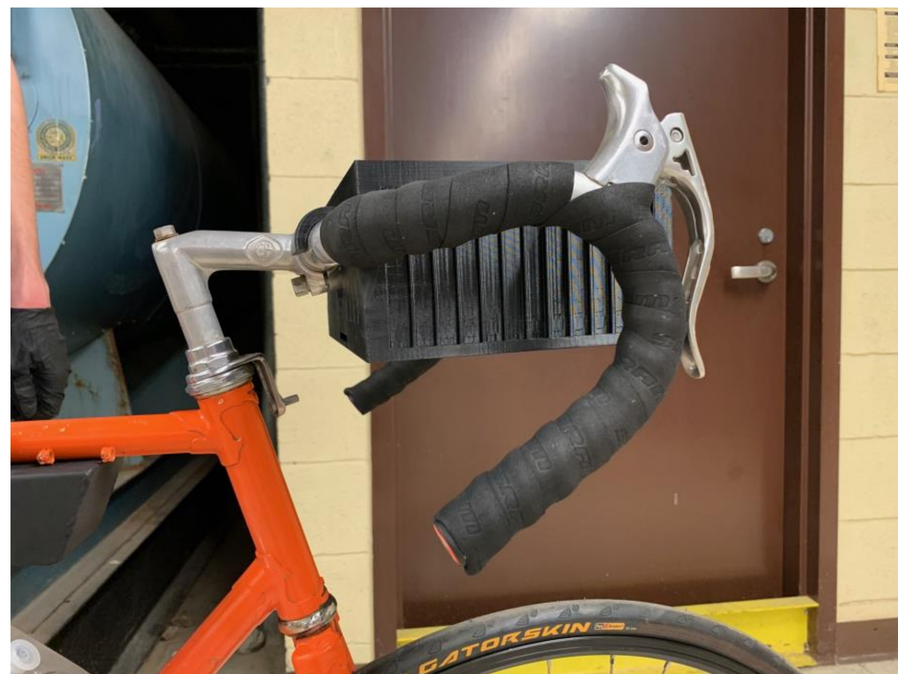






Electronics Box

NFPA Fluid Power Vehicle Challenge



Electronics Box

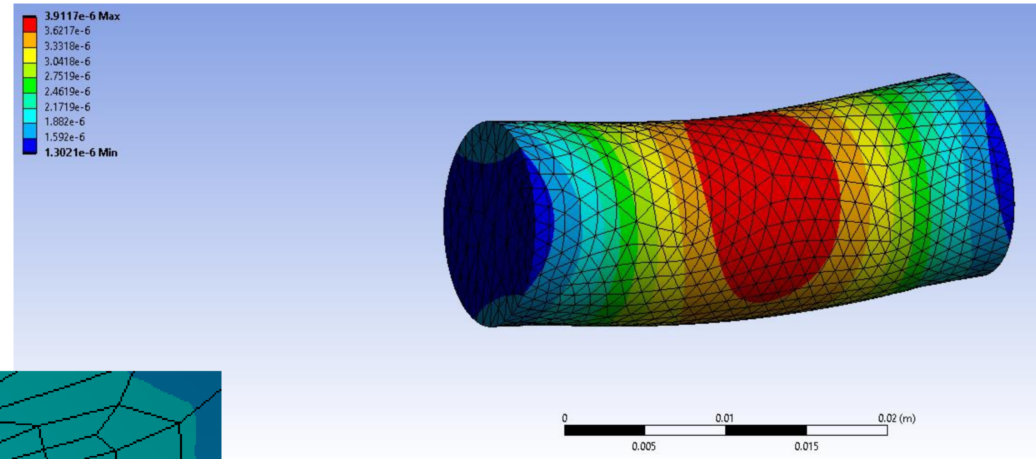
NFPA Fluid Power VEHICLE Challenge

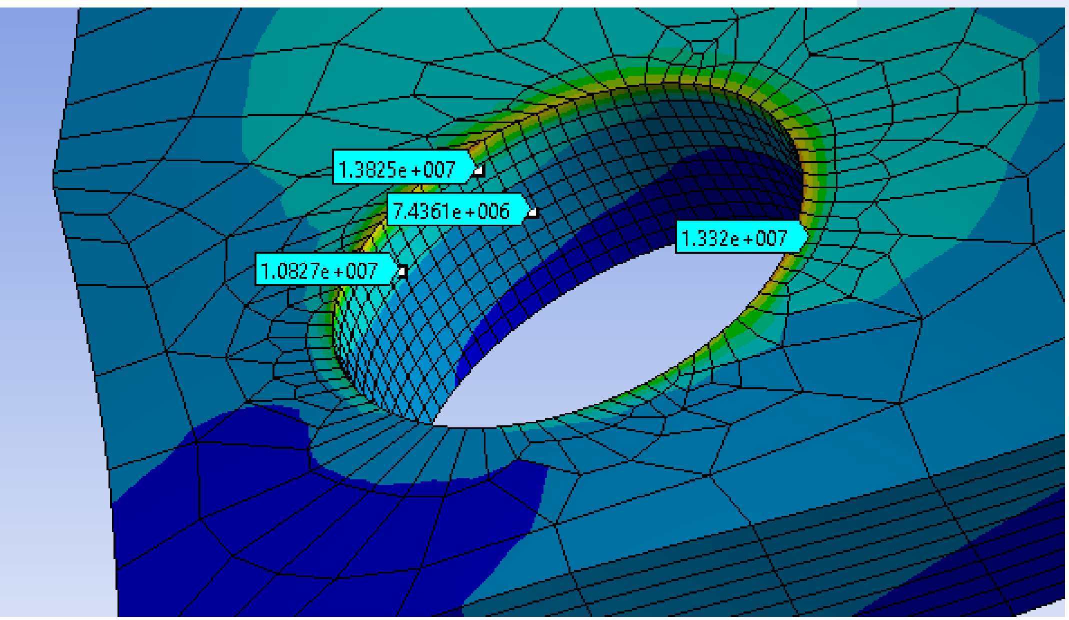
Pneumatics

Adjustable seat suspension

Watch our suspension motion study: https://www.youtube.com/watch?v=wtpmAJPt04g

FEA Simulated Results





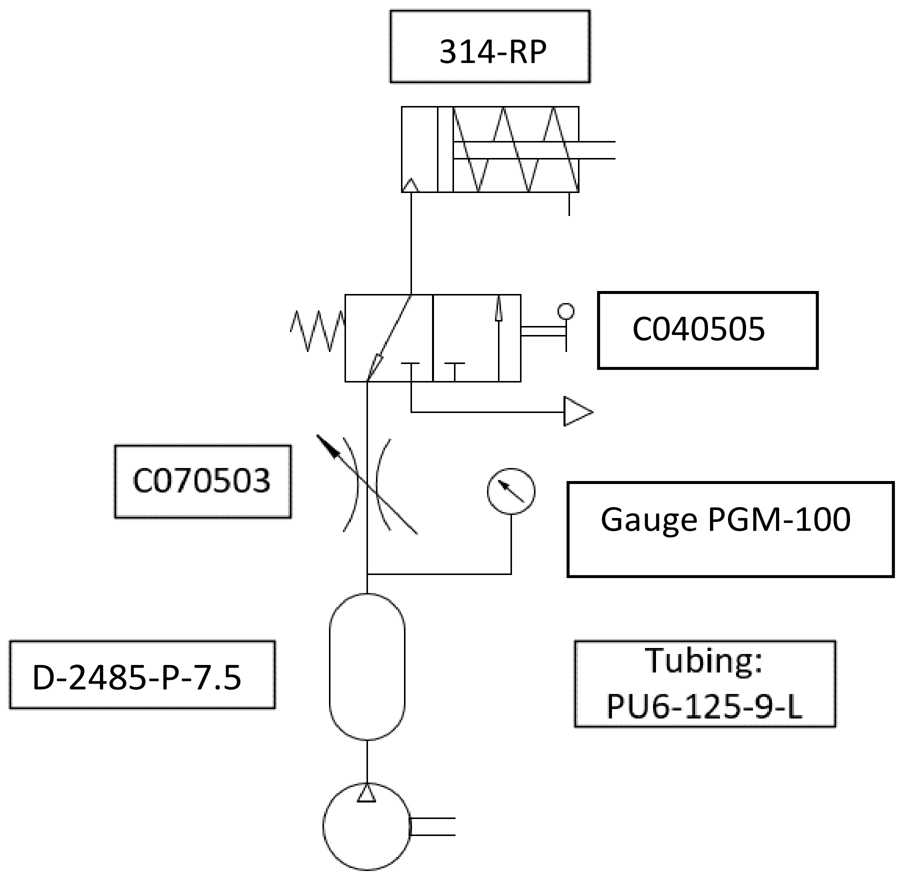
Hand Calculated Bearing stress:

$\sigma = \frac{F}{d \cdot s \cdot n}$ = 1.574 MPa

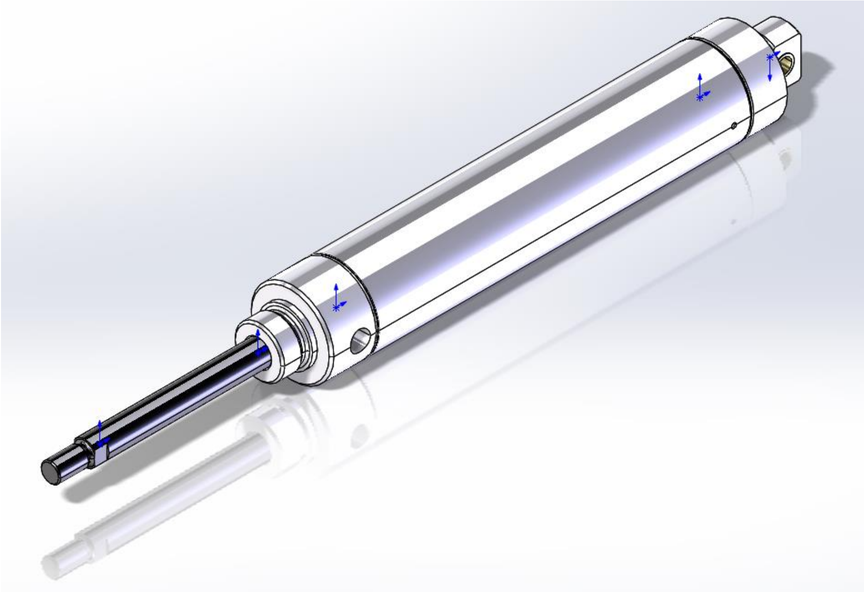
Yield Strength 1020 Steel:

350 MPa

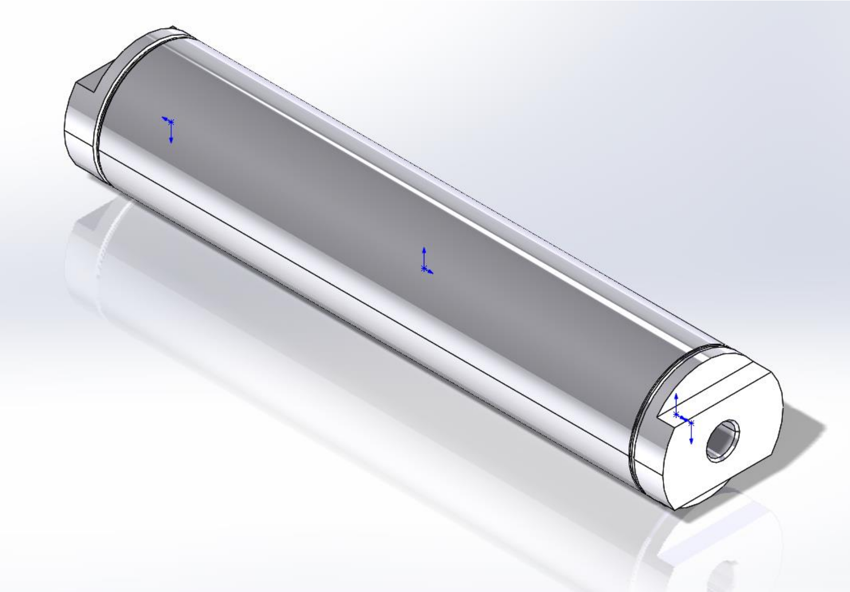
Pneumatic Seat Suspension Circuit



Calculations for Component Selection



Pneumatic Cylinder



Pneumatic Tank

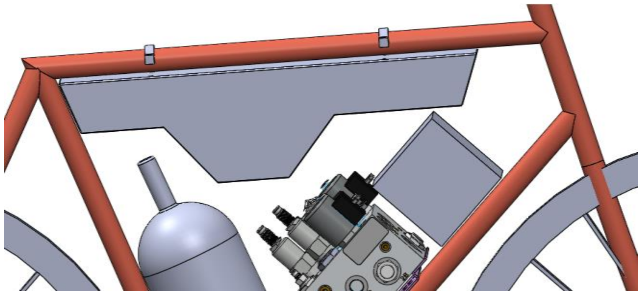
- Allowed pressure: 100 psi
- Assumed weight: 215 lbs.
- Cylinder Bore: 2 in
- Stroke: 4 in

- Required pressure: 88.05 psi
- Remaining pressure after one stroke: 90.889 psi

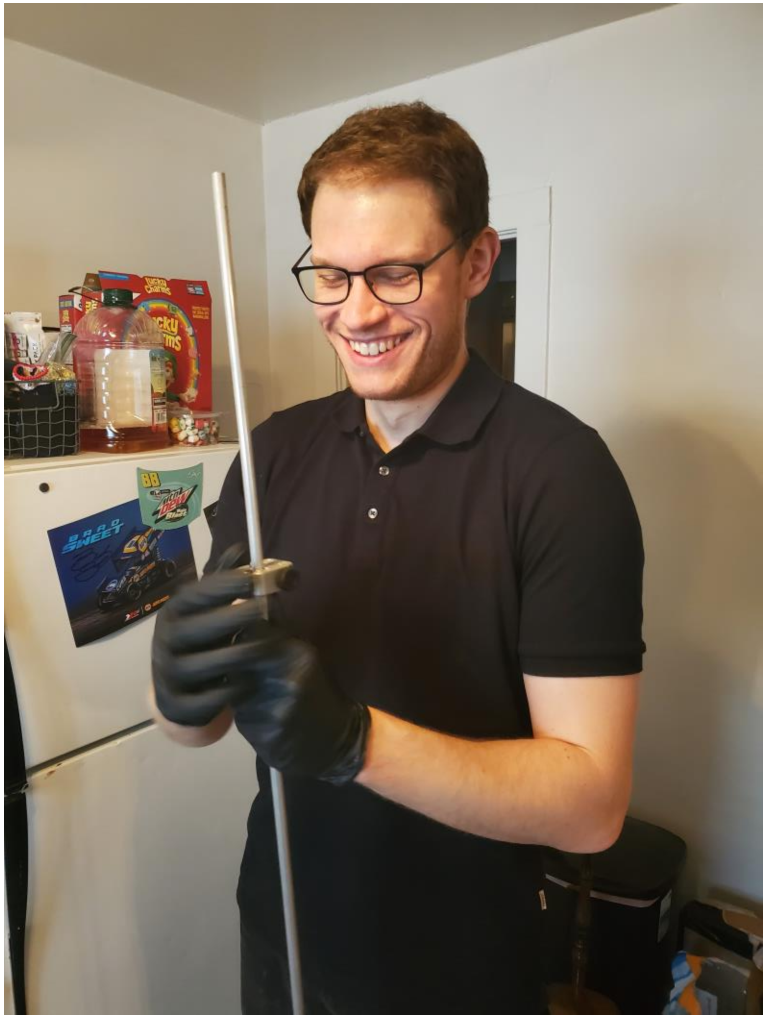
Vehicle Construction – Motor Chain

Vehicle Construction – Pump Chain

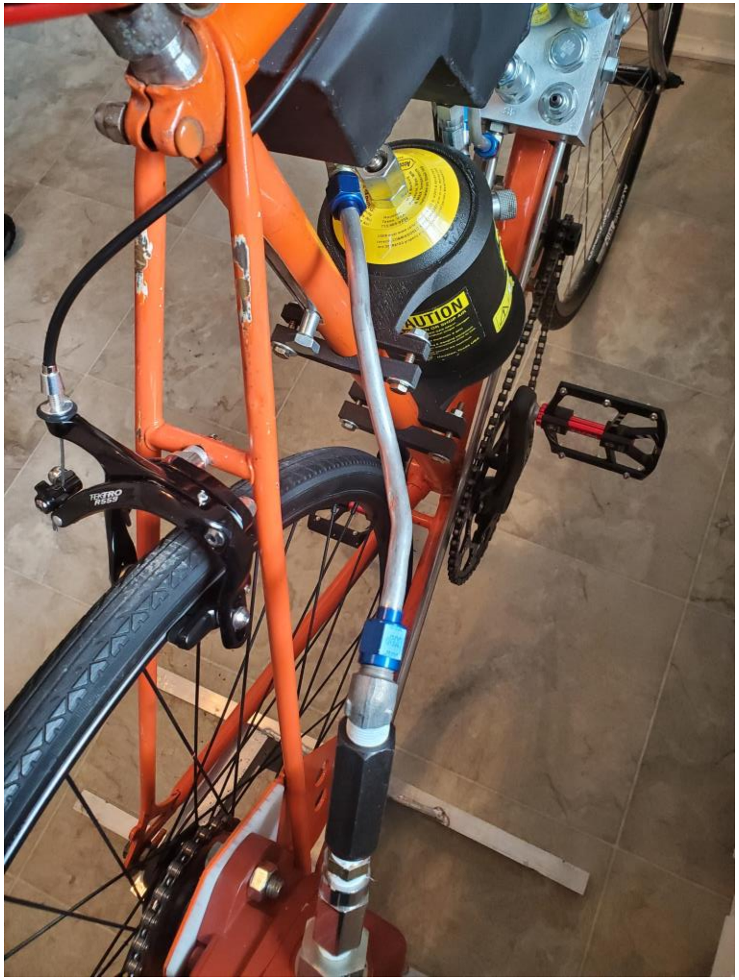
Vehicle Construction – Hydraulic Oil Reservoir



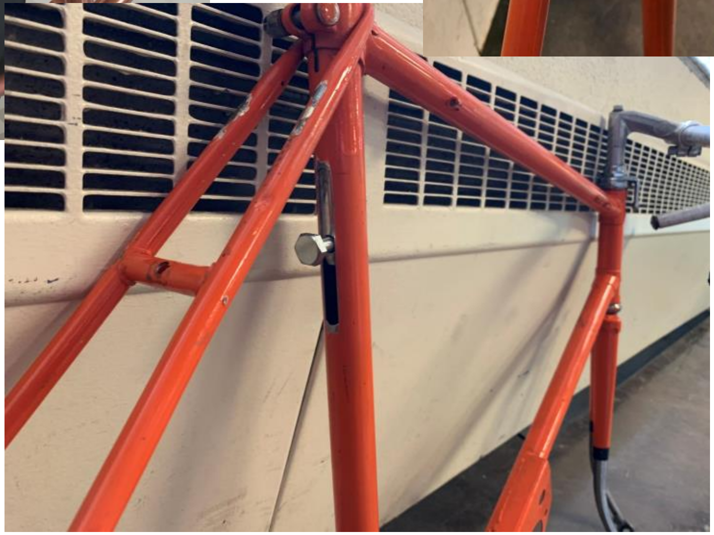
Vehicle Construction - Tubing



Vehicle Construction - Tubing



Vehicle Construction – Pneumatic Seat Suspension



- COVID-19 interrupted manufacturing
- Requires machine shop

Vehicle Assembly – Before Tubing

Progress Made Towards Final Vehicle

NFPA Fluid Power Vehicle Challenge

Lessons Learned

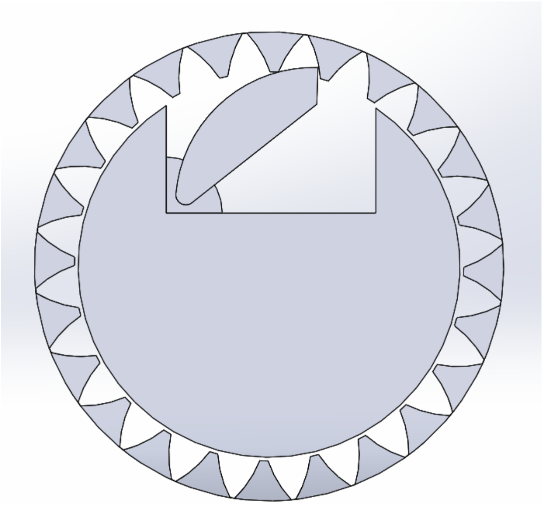
- Machine sprockets to fit on key shaft of motor and pump and also on a normal bike chain

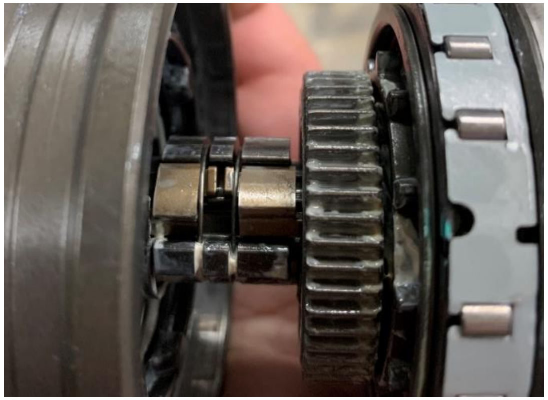
Lessons Learned – Bottom Bracket

- Old bracket was rusted
- Many different standards
- Outdated ‘RALEIGH’

Lessons Learned - Chain

Lessons Learned – Hub Gear





Lessons Learned

- Being flexible, adapt to unpredictable situations
- Working in a team to overcome obstacles
- Something will go wrong
- Sometimes you just have to get started – learning on the fly

Conclusion

- **Design Goals Achieved**
  - Clean and Safe Design
  - Pneumatics Incorporated into Design
  - Electrically Controlled Hydraulic Valves in Design
- **Possible Improvements**
  - Exchange rear wheel fixed sprocket for hub gear
  - Orientation of tubing/manifold ports

Thank you!

We want to especially thank:

- Dr. Luis A. Rodriguez
- NFPA
- Mike Helbig, Eric Holland, Matthew Loeffler (Force America)
- Todd Frandsen and Kent Sowatzke (Bimba)
- Jeff McCarthy (SunSource)
- Terry McCart, Tim Kerrigan (FPI)
- Jordan Weston, Kazi Rafizullah (MSOE RPC)