NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation

Final Presentation
University of Denver
Kevin Lingenfelter
March 12, 2018

University of Denver
Daniel Felix Ritchie School of Engineering & Computer Science

Agenda

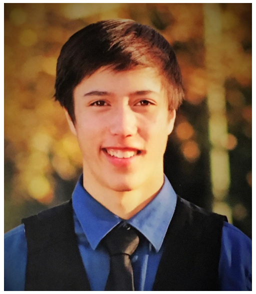
- Team Introductions
- Problem Statement & Objectives
- Current Design
- Summary of Midway Review
  - Design objectives
  - Vehicle design
  - Fluid power circuit design
  - Selection of hardware
  - Results and incorporation of analyses (e.g., finite element analysis)
- Vehicle Testing

Team Introductions

Matt Imrich
Lead CAD Engineer

Jason McLean
Lead Test Engineer

Ryan Ortiz
Financial Manager
Head of Research



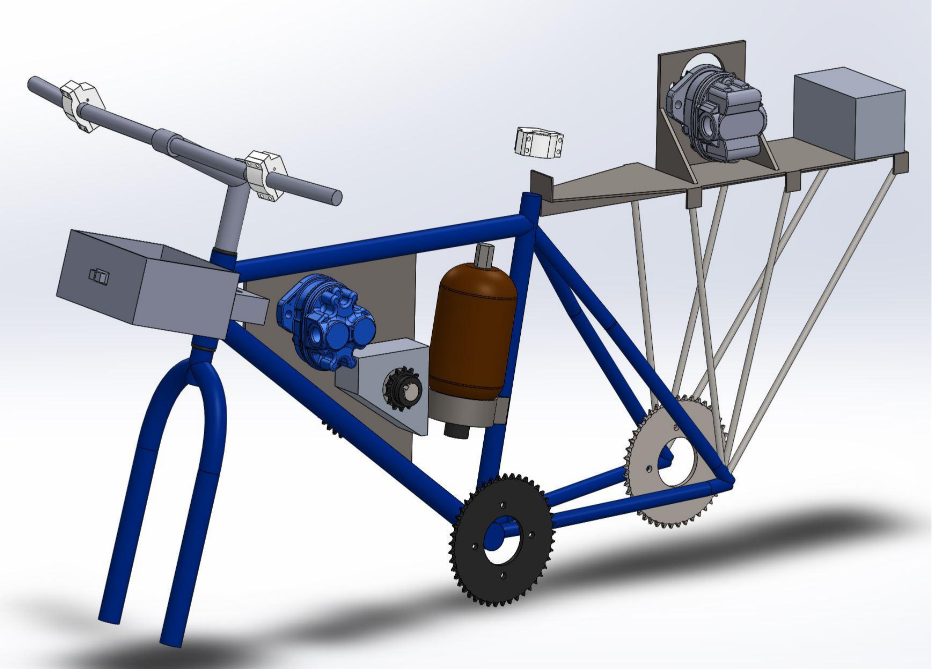
Kyle Sun
Co-Project Manager
Lead Technical Writer

Emma Willis
Co-Project Manager
Lead Systems Engineer

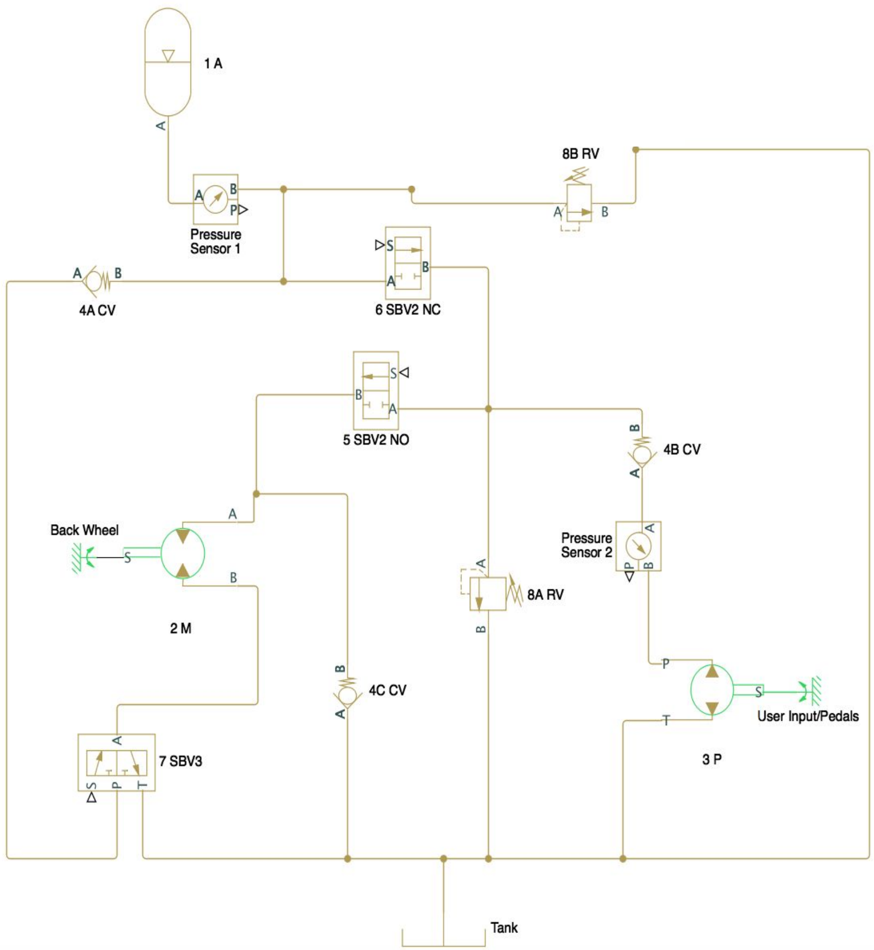
Problem Statement and Objectives

- **Problem Statement:** This project requires the design and construction of a single-rider vehicle that uses a fluid power system involving energy storage and regeneration technology
- The objectives of this project include:
  - Design
  - Analysis
  - Fabrication
  - Competition
- The requirements for the project are based on the NFPA FPVC rules and regulations.

Final Vehicle



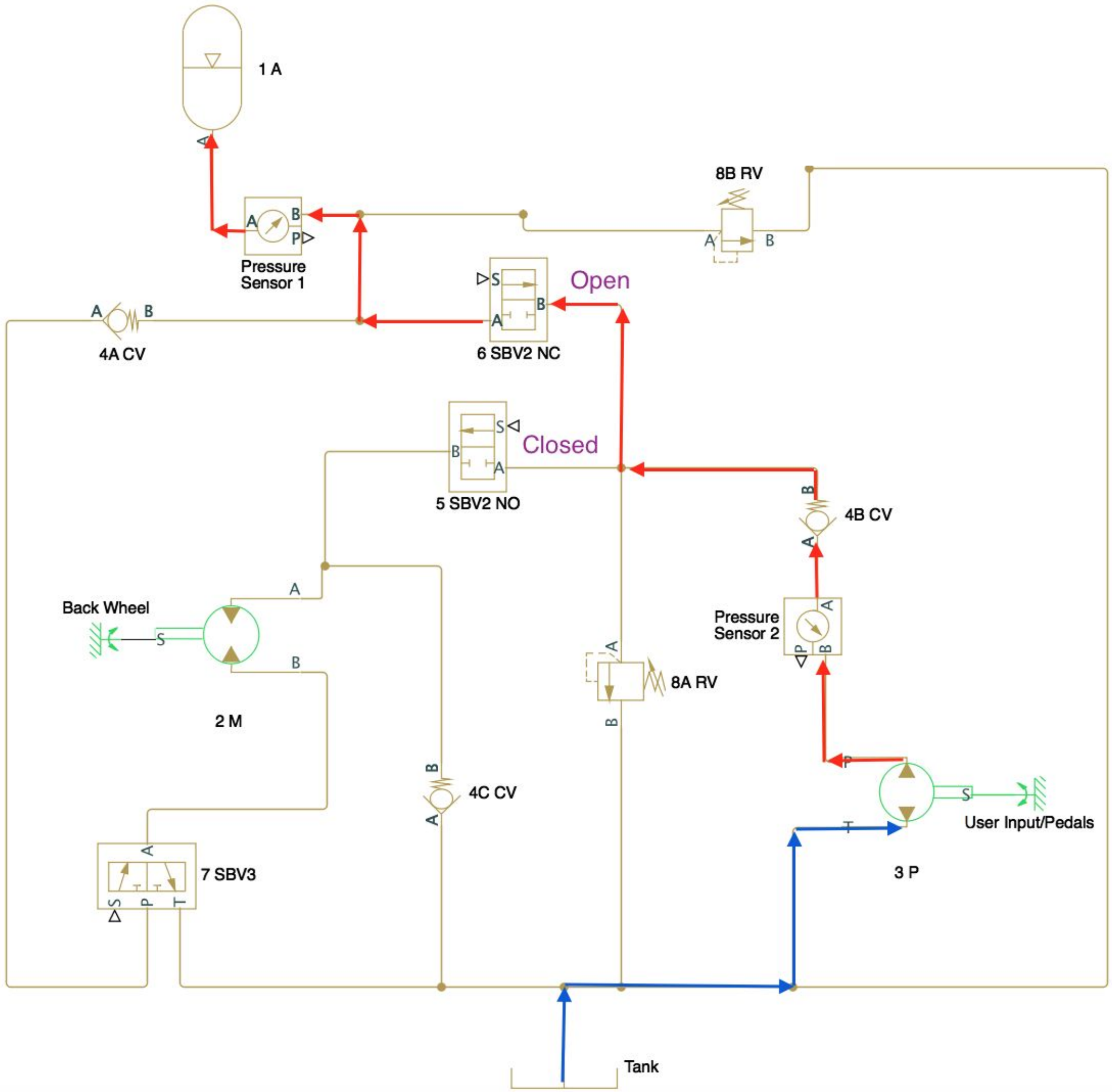
Fluid Power Circuit Design



Bill of Materials		
Item No.	**Description**	**Quantity**
1	1 quart accumulator	1
2	0.54 CID Motor	1
3	0.5 CID Pump	1
4	Check Valve	3
5	2 way solenoid valve (normally open)	1
6	2 way solenoid valve (normally closed)	1
7	3 way solenoid valve	1
8	Pressure Relief Valve	2

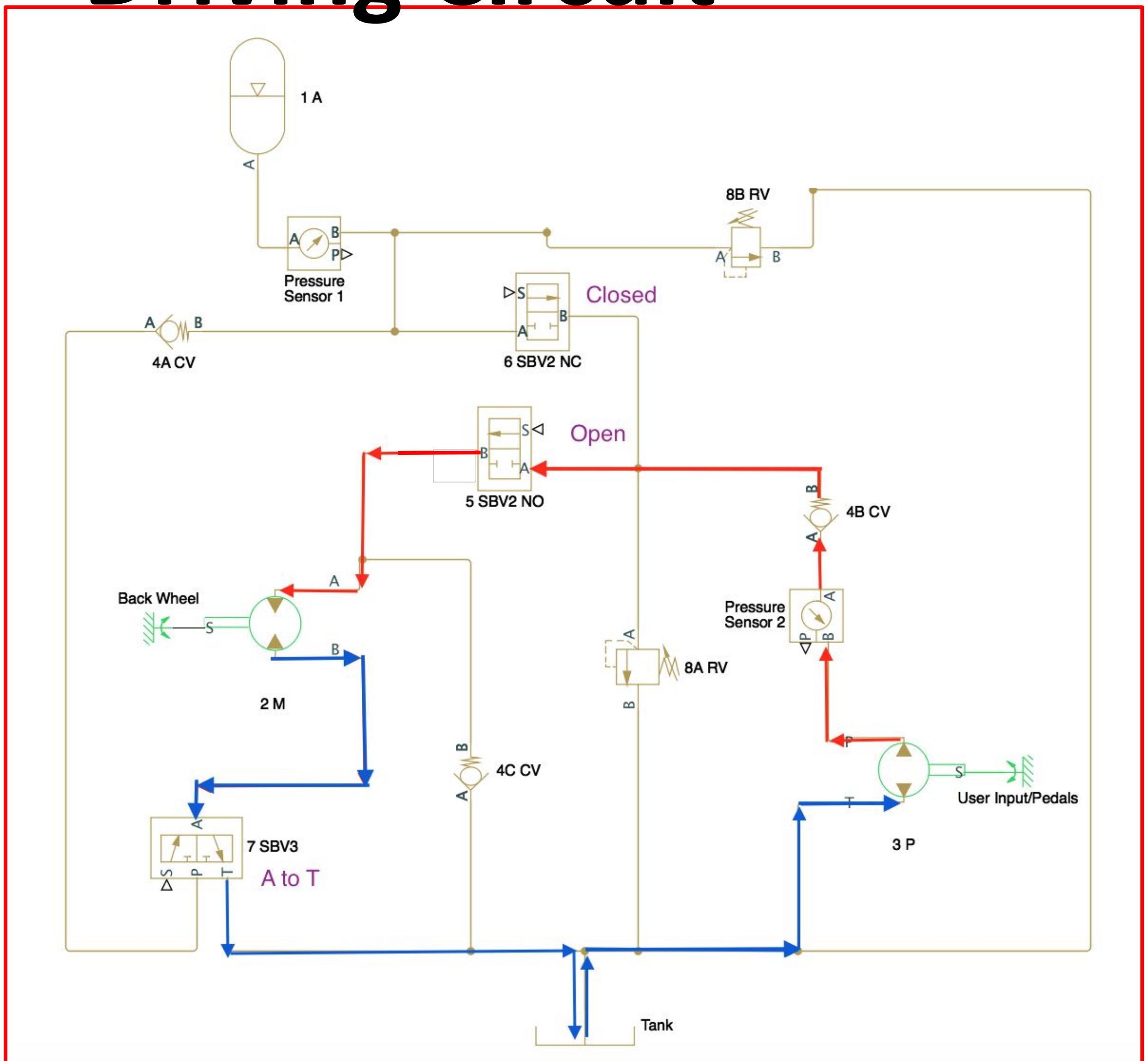
Key	
High Pressure Line	
Low Pressure Line	

Precharge Circuit



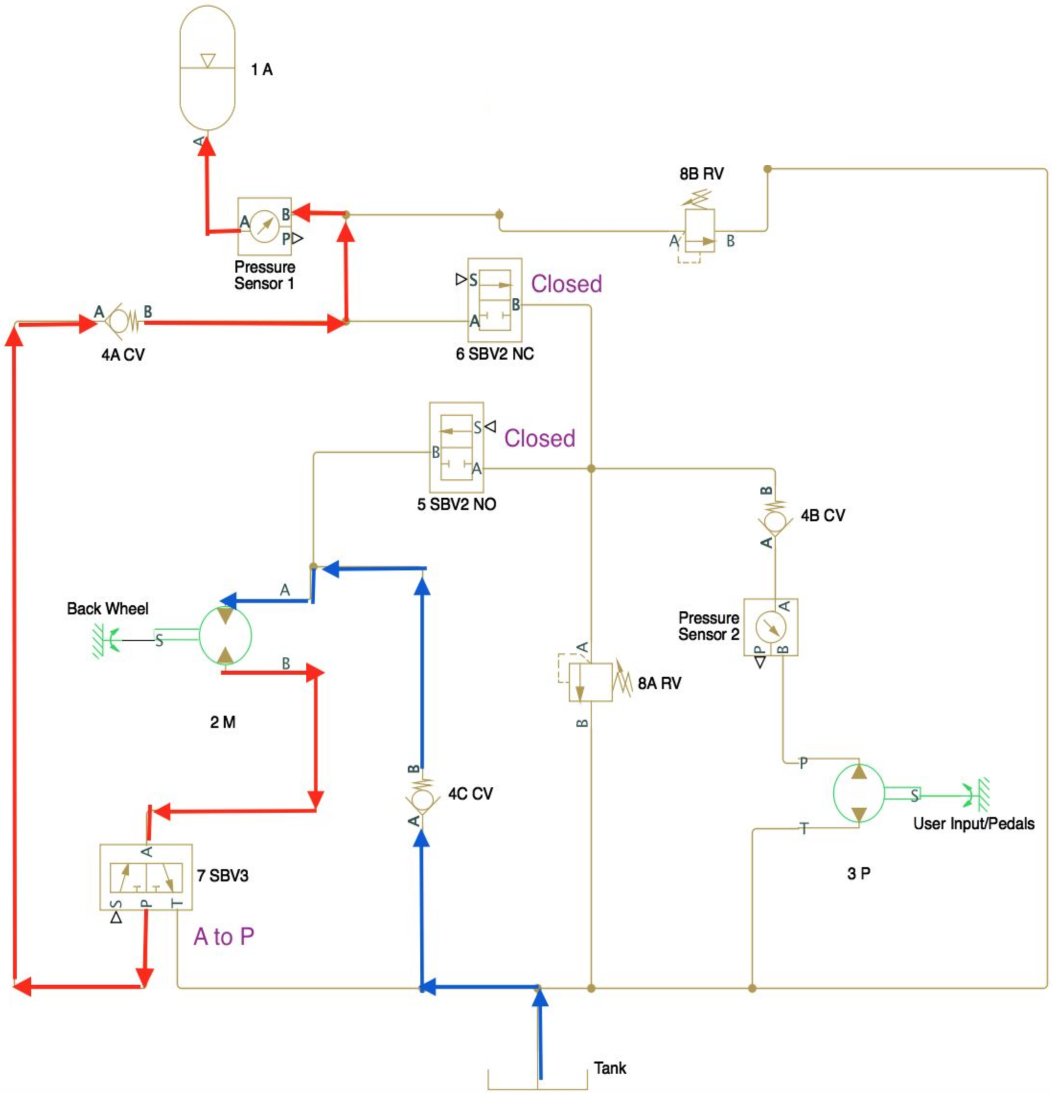
Key	
High Pressure Line	
Low Pressure Line	

Driving Circuit



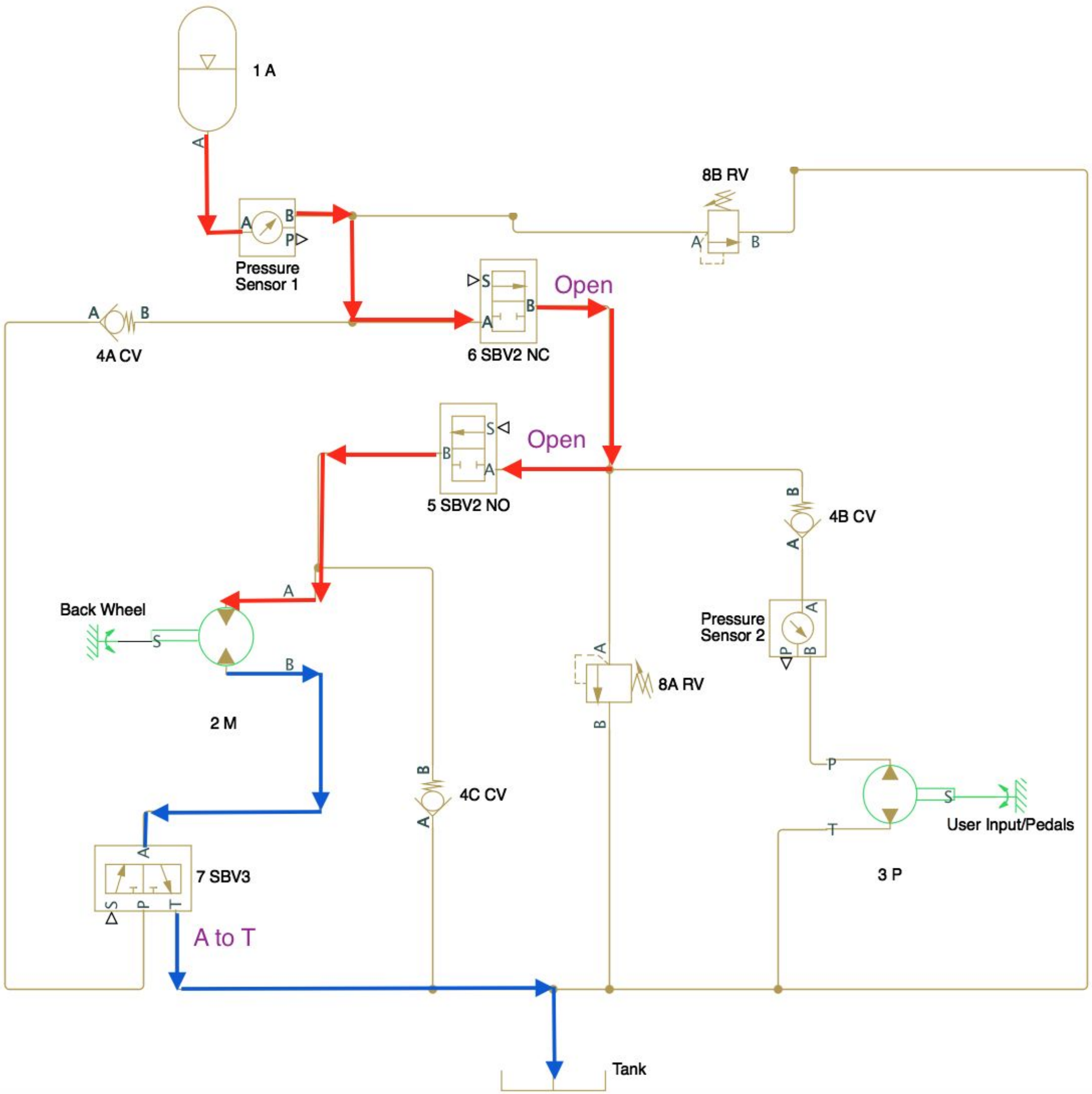
Key	
High Pressure Line	
Low Pressure Line	

Regeneration Circuit



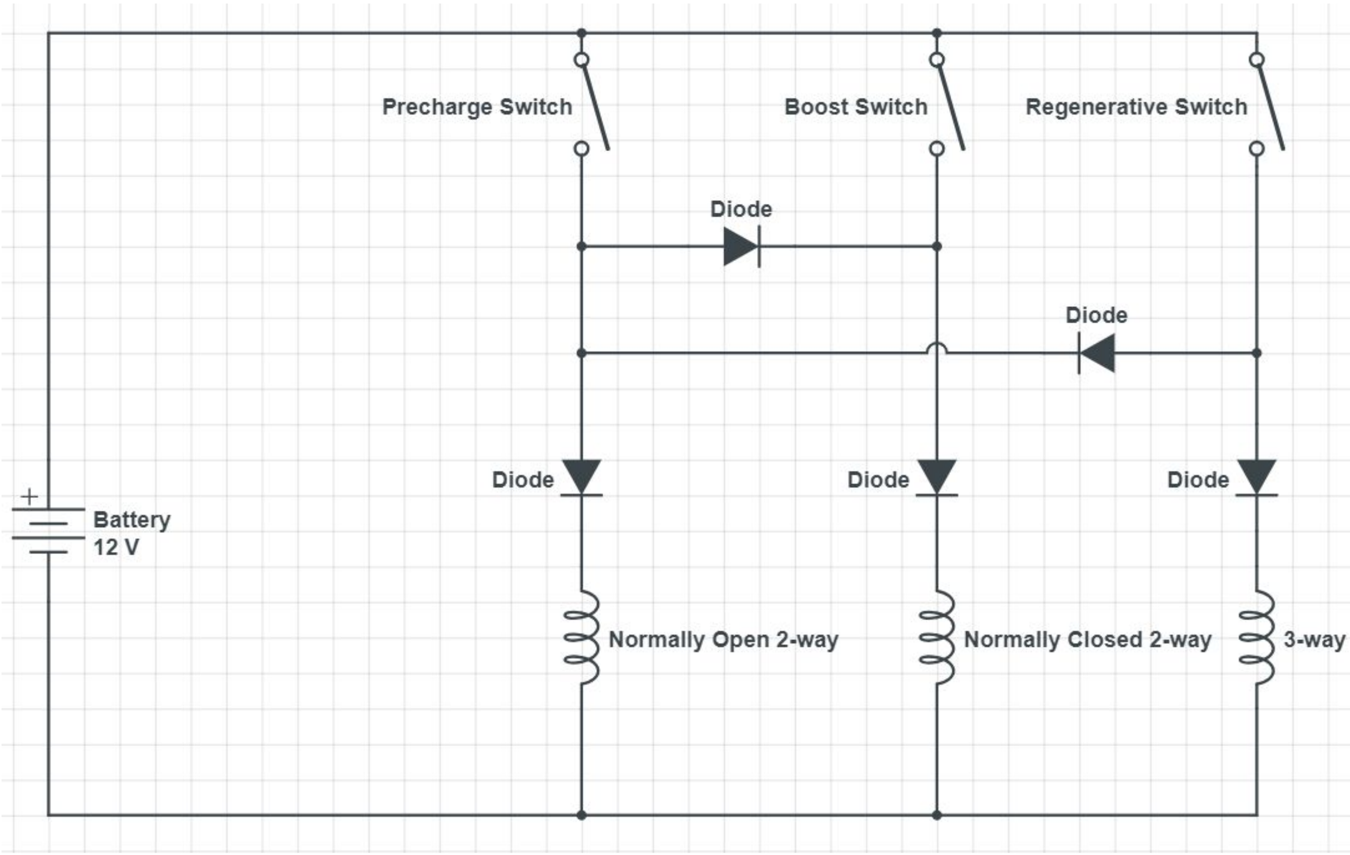
Key	
High Pressure Line	
Low Pressure Line	

Boost Circuit



Key	
High Pressure Line	
Low Pressure Line	

Electronic Circuit



Mode	V5	V6	V7
Precharge	1	1	-
Boost	0	1	0
Drive	0	0	0
Regenerative	1	0	1

Hardware Selection

Accumulator:

- Accumulators, Inc. A1QT3100-3
- 1 Quart
- Bladder
- Rated for 3000 psi

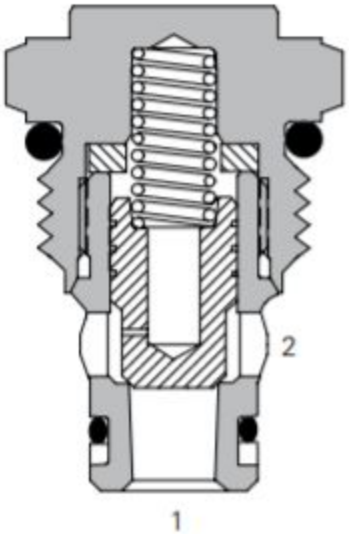
Pump

- Eaton 26002-RZG
- 0.5 CID
- Clockwise rotation

Motor:

- Eaton 26702-DAB
- 0.54 CID
- .625” Keyed shaft
- Bi-rotation
- Internal drain

Hardware Selection

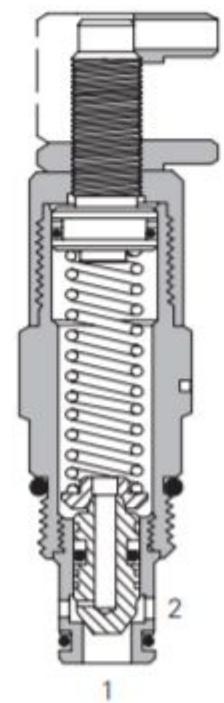


CV3-8 Check Valve (3):

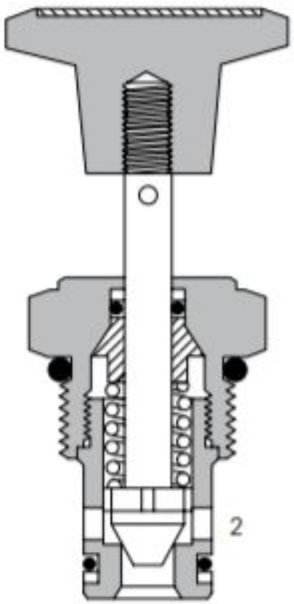
- Application pressure 5000 psi
- Valve remains closed until spring bias is reached at port 1, lifting poppet and allows flow from 1-2
- Hardened steel ball limits leakage and extends service life

RV1-10 Relief Valve (2):

- Application pressure 3000 psi
- Direct acting
- Remains closed until predetermined setting is reached at port 1
- Fast acting, low pressure rise
- Low internal leakage, high flow rate



Hardware Selection

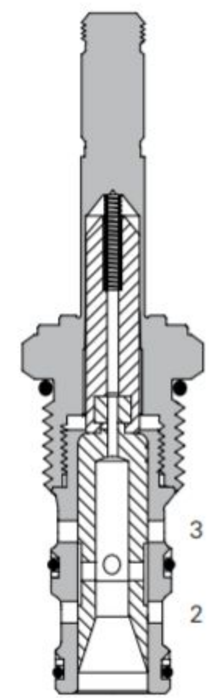


NV1-8 Flow Restrictor Valve (1):

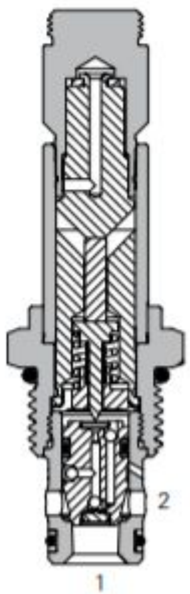
- Application pressure 5000 psi
- Needle valve that cause a pressure drop as it passes from port to port
- Adjustable pressure selection through rotation of the screw

SV1-10 3-way Solenoid Valve (1):

- Application pressure 3000 psi
- When de-energized, allows flow from 1-2 while port 3 is blocked
- When energized, allows flow from 3-1 while port 2 is blocked
- Low leakage, compact design



Hardware Selection

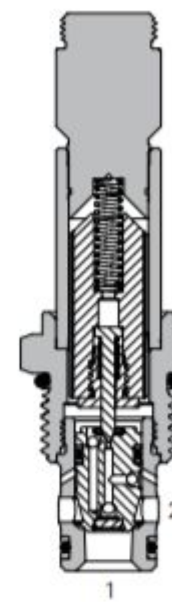


SBV11-10-O 2-way Solenoid Valve (1):

- Application pressure 5000 psi
- Normally open
- When de-energized, valve is open for full flow in both directions
- When energized, pilot poppet closes causing main poppet to close
- Low leakage, compact design

SBV1-10-C 2-way Solenoid Valve (1):

- Application pressure 3000 psi
- Normally closed, bi-directional
- When de-energized, valve is blocked in both directions
- When energized, pilot poppet is released allowing main poppet to open allowing flow in both directions
- Low leakage, compact design



Analysis

Road Grade	7%
Weight (Vehicle + Rider)	300 lbs
Rolling Resistence (Bike Tire on Rough Road)	0.008
Tire Radius	13 in
System Pressure	1000 psi
Motor Efficiency	0.9
Pump Efficiency	0.95
Bike Speed	10 mph
Fluid Velocity	20 ft/s
Pedal Rate (RPM)	60

Motor and Pump Sizing

	Motor	Pump
Required CID	2.1185	4.8972
Selected CID	0.54	0.5
Required Mechanical Advantage	4	10
RPM	129.2308	600
GPM	1.2084	1.2987

Tube Sizing

	Tube
Fluid Velocity	20 ft/s
Required Diameter	0.1569 in
Selected Diameter	0.25 in (0.375 in)

Pipe Calculations

- S = Allowable Stress → S = 8000 psi (Aluminum 6061)
- E = Quality Factor → E = 1 (Seamless)
- t = Wall Thickness → t = .091 in
- C = Depth of Thread → C = 0 (Not Threaded – Welded)
- D = Nominal Outer Diameter → D = 3/8 in

P = Working Pressure

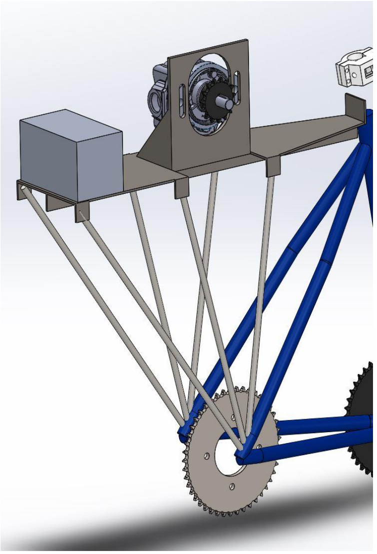
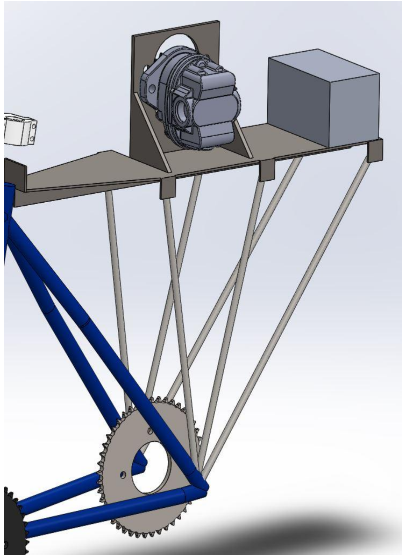
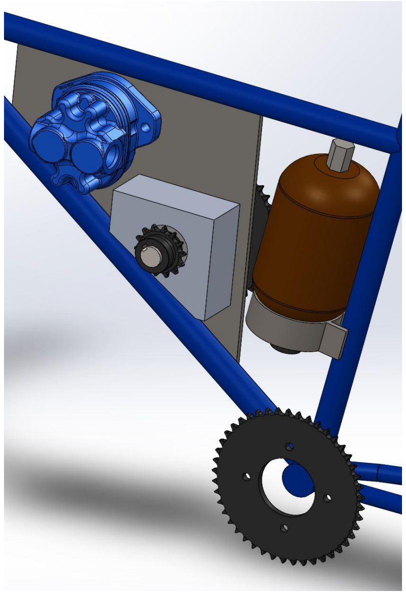
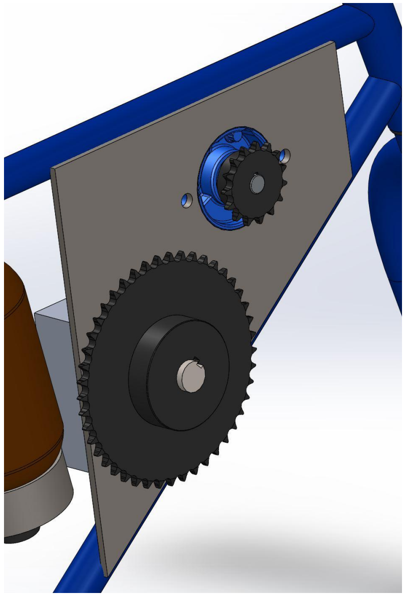
$$P = \frac{2 * SE(t - C)}{D}$$

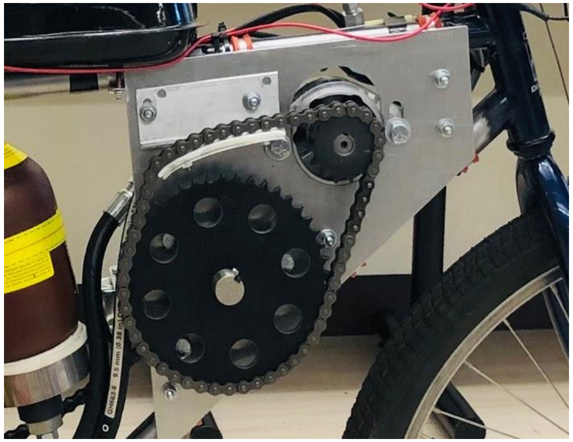
$$P = \frac{2 * 8000\, psi\, (1.0)(.091\, in - 0\, in)}{\frac{3}{8}\, in}$$

$$P = 3882.67\, psi$$

Safety Factor = 3882.67 psi / 3000 psi ~ 1.3

Mounting

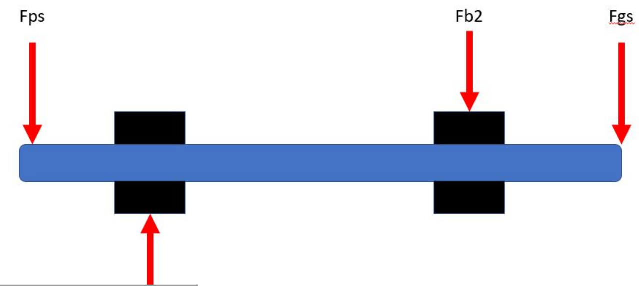


Bearing Analysis

$$L_p = K_R \left(\frac{C}{P}\right)^3 \qquad C = P\sqrt[3]{L_5/K_R}$$

For 800 hrs operation at 200 rpm ⟶ L~10 million cycles

5% Failure Rate ⟶ K_R = 0.62



Loading/Life Limitations		
	Worst Case (P = 3000 psi)	**Normal Operation (P = 1000 psi)**
C_1	1307.86 lbs	271.40 lbs
C_2	792.96 lbs	90.71 lbs
L_1	2.46 million cycles	275.8 million cycles
L_2	11.06 million cycles	7387.34 million cycles

Purchased Bearings:
C = 820 lbs

Shaft Analysis

Selected Shaft: Stainless Steel 316

S_{ut}=90 ksi S_y=40 ksi

D = 1 in, Machined Surface, 99.99% Reliability

	Safety Factor (N_f)
Worst Case (P = 3000 psi)	2.2669
Normal Operation (P = 1000 psi)	8.1079

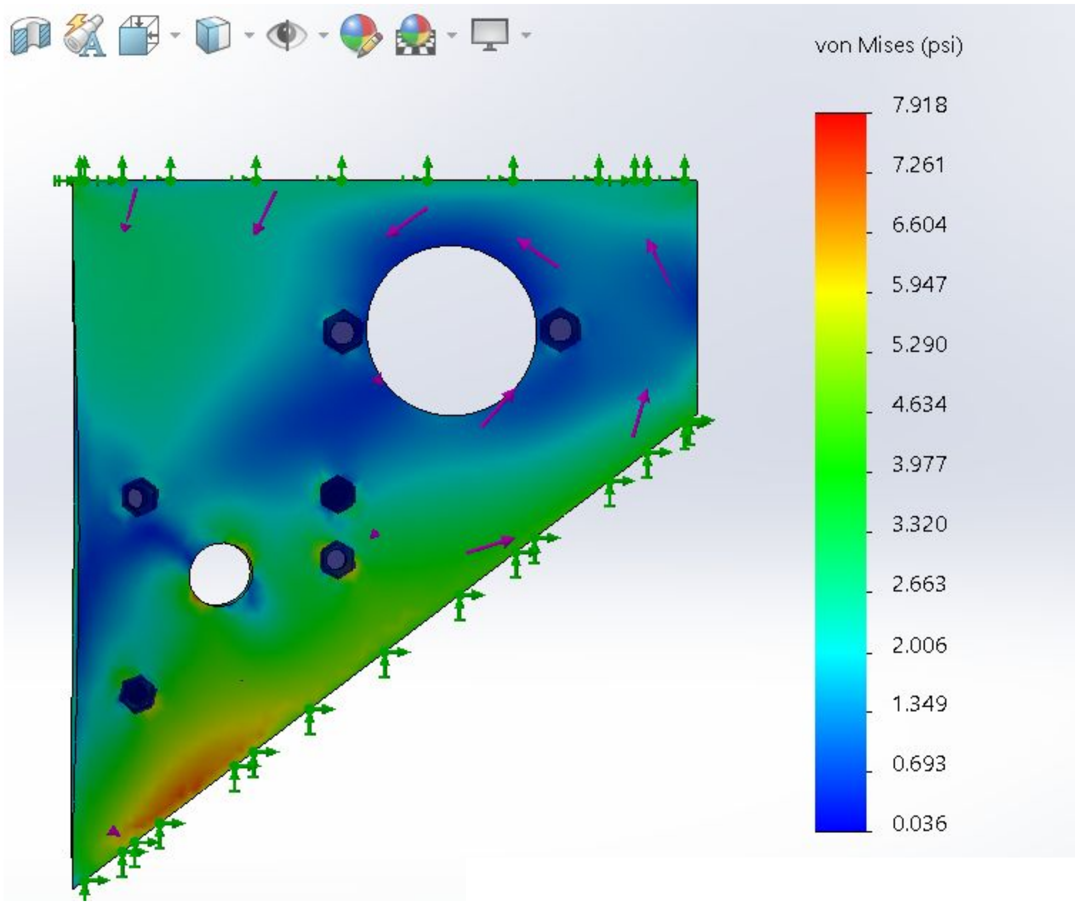
$$N_f = \frac{d^3\pi}{32}\left[\frac{\sqrt{(K_f M_a)^2 + \frac{3}{4}(K_{fs}T_a)^2}}{S_f} + \frac{\sqrt{(K_{fm}M_m)^2 + \frac{3}{4}(K_{fsm}T_m)^2}}{S_{ut}}\right]^{-1}$$

$$S_f = 0.5 * S_{ut}C_{load}C_{size}C_{rel}C_{surf}$$

Shaft Key Calculations

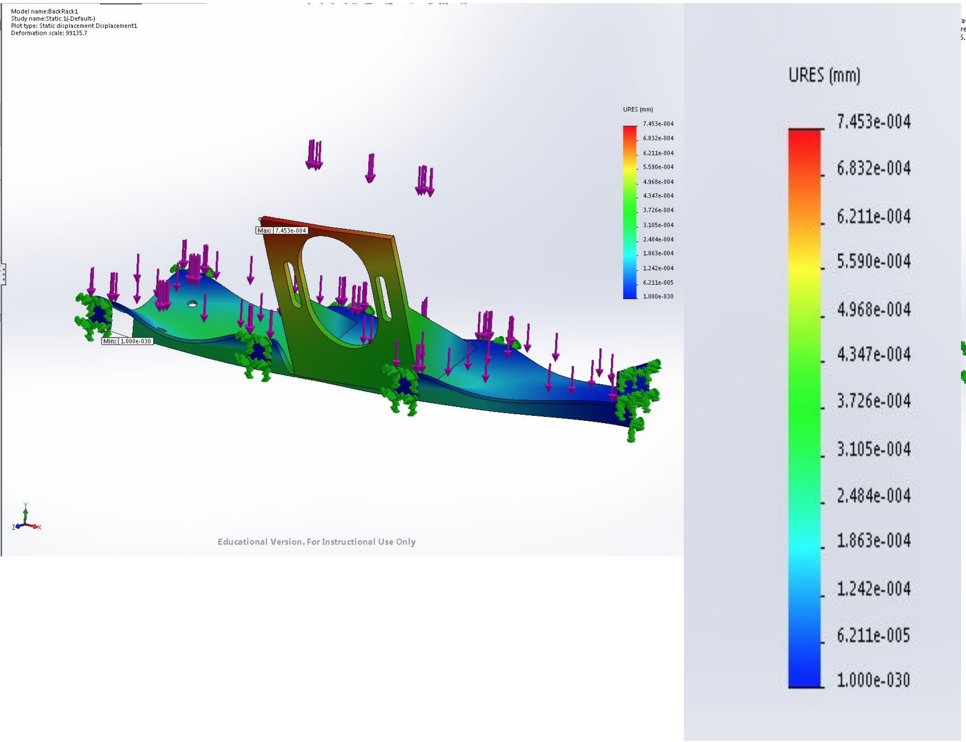
`	Pressure	Safety Factor
Large Sprocket Key	3000 psi	22.5
	1000 psi	64
Small Sprocket Key	3000 psi	5.84
	1000 psi	16.64

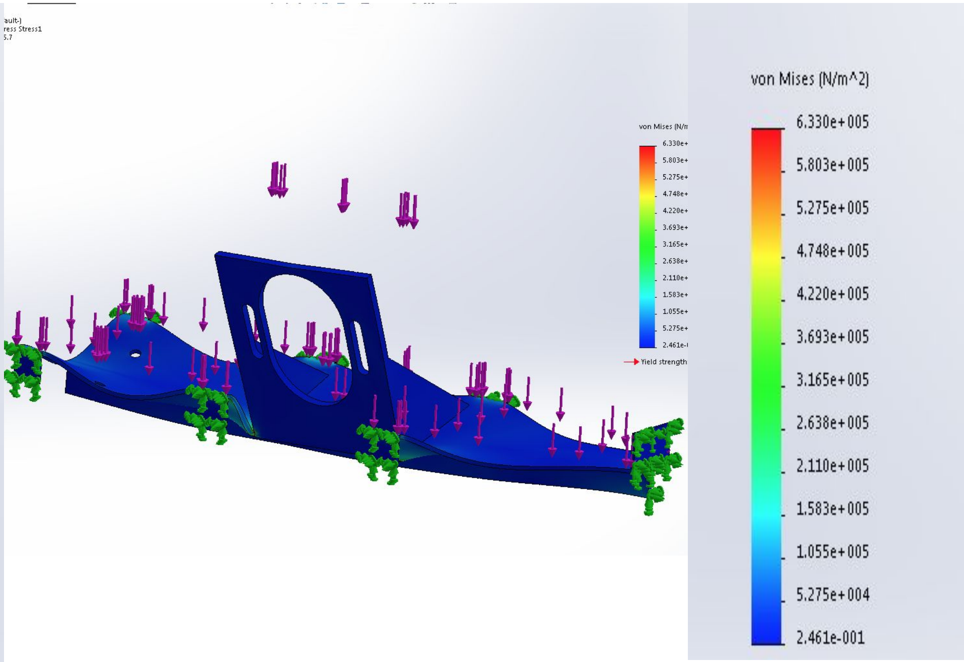
Load Analysis



Detailed design - Rear Gear

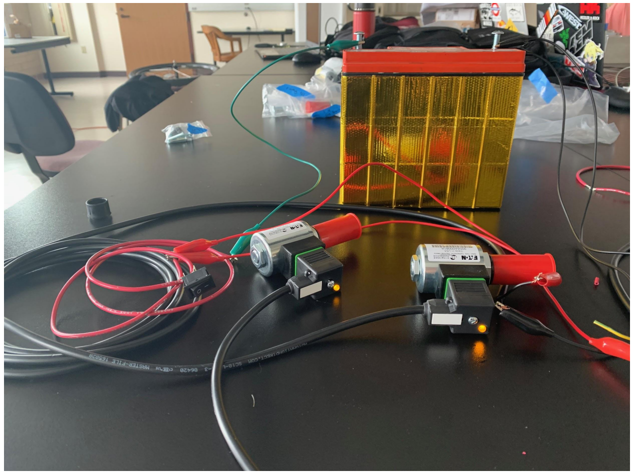
NFPA Fluid Power Vehicle Challenge





Electronic Verification

Components	Voltage	Peak Current
2-Way Solenoid Valve (Normally Open)	12 V	1.912 A
2-Way Solenoid Valve (Normally Closed)	12 V	1.912 A
3-Way Solenoid Valve	12 V	2.432 A



Electronic Verification

Components	Voltage	Amperage	Initial Current
EXP1250	12 V	5 A	1.5 A
EXP12180	12 V	18 A	5.4 A

Weight Verification

Weight Limit	Current Estimated Weight
210 lbs Excluding Rider Includes Fluid	181 lbs.

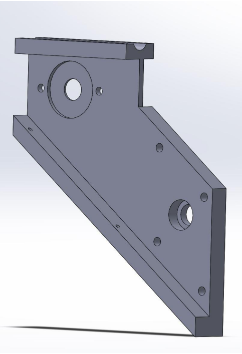
Key Components	Weight
Frame	30 lbs
Rear Wheel Assembly	9.8 lbs
Center Plate	1.2 lbs

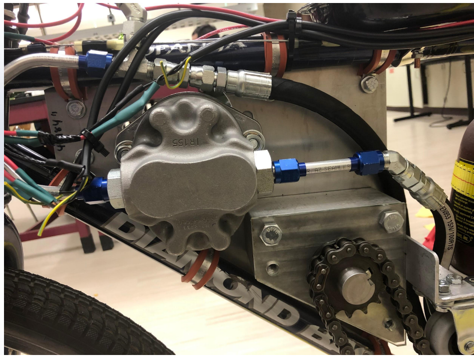
NFPA Fluid Power VEHICLE Challenge

Construction

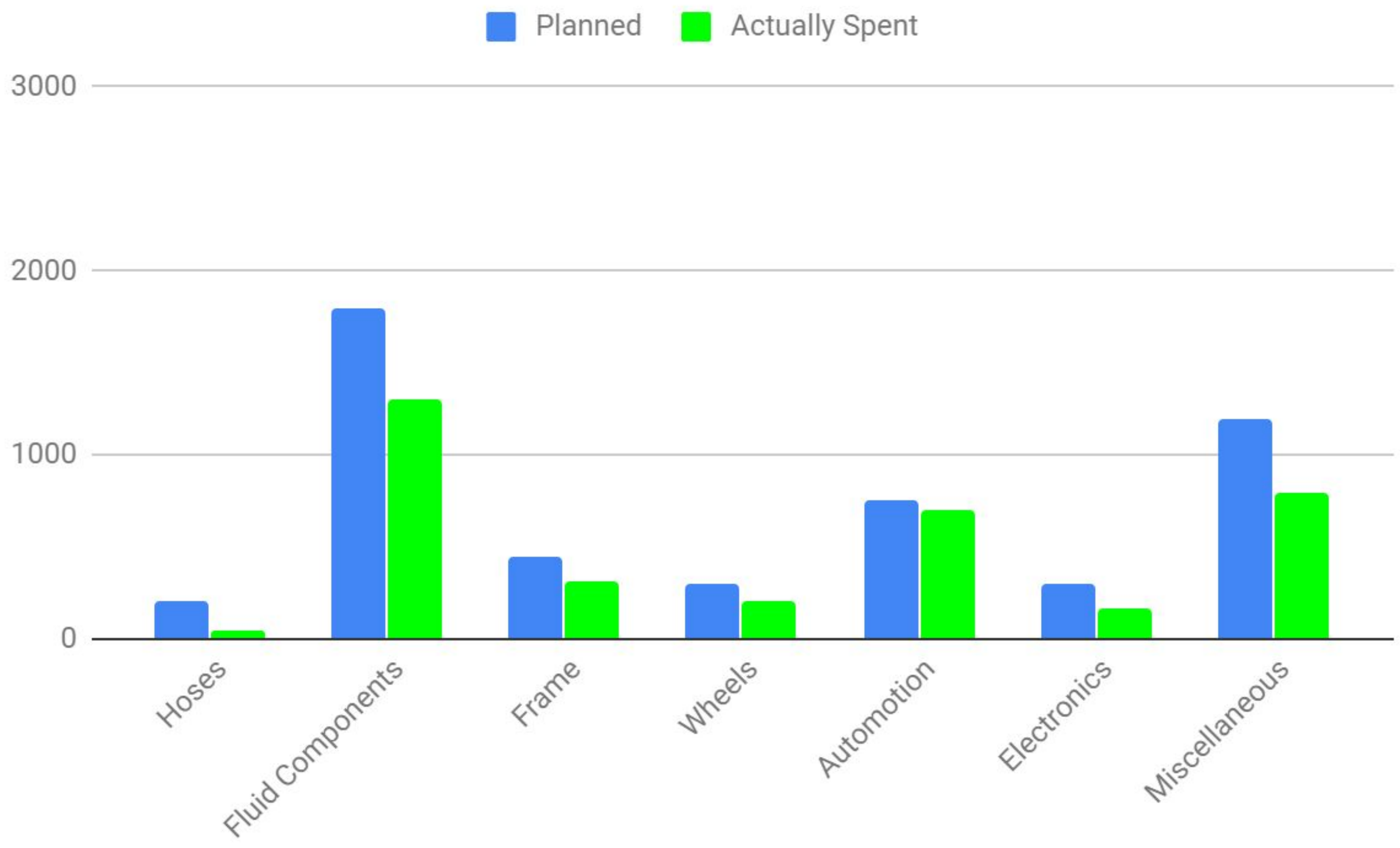
Key Design Changes

- Battery holder from 3D print to metal
- Center pump mount from u-bolt clamp to steel band hanger clamp
- Back rack from custom design to prefabricated
- New Battery to meet current demands
- Moved motor mount
- Added chain tensioners
- New diodes
- Wider pedal spindle





Budget Summary



Lessons Learned

- **Time management**
  - Leave time for unexpected problems and design changes
- **Use the resources available**
  - Others expertise is extremely helpful
- **Delegate tasks early**
  - Keeps the whole team engaged and productive;
- **Balance design objectives**
  - Torque vs speed
  - Weight vs feasibility

Thank you!

We would like to extend a huge thank you to all the people who helped us

- NFPA, Ernie Parker, Jeff McCarthy, Stephanie Scaccianoce
- Kevin Lingenfelter
- Adam York, Ronald Delyser, Ann Deml
- Hans Green & JILA
- Lucky Bikes Recyclery
- Shane Ware and DU Bike Shop

Motor Sizing

Torque Required

T = rad * pull = 303.4574 lb-in

Required Motor CID

Disp = Torque*2π / (Pressure*Motor Efficiency) = 2.1185

Motor Selected: 0.54 CID

Required Mechanical Advantage from Motor to Wheels

MA = required motor CID/ Selected motor CID = 3.9232 (~ 4)

Wheel RPM Required to Travel 10 mph: 129.2308 rpm

Fluid GPM to Achieve 10 mph:

GPM = MotorCID* MA * RPM / 231 = 1.2084 gpm

Pump Sizing

Required Pump CID:

CID = (GPM*231) / (RPM pedal*Pump Efficiency) = 4.8972

Pump Selected: 0.5 CID

Required Mechanical Advantage for Pedals to Pump:

MA = Required Pump CID / Selected Pump CID

MA = 9.7943 (~10)

Pump RPM:RPM = RPM pump * MA

RPM = 600

Pump GPM: GPM = RPM pump * Motor CID) / 231

GPM = 1.2987

Tubing

Fluid Velocity

vel = 20 ft/s

Net Area: A = 0.32*GPM/vel

A = 0.0193 in^2

Required Diameter: D = 2*sqrt(A/π)

D = 0.1569 in

Selected Diameter: ¼ in.

Accommodate Smaller Fluid Velocities: ⅜ in.

Burst Pressure: Pb = (2*St*tm) / D

Using a ¼-10S Small Pipe

Pb = (2 * 15000psi * 0.065in) / 0.540in

Pb = 3611.1 psi