NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation

FINAL PRESENTATION
Milwaukee School of Engineering
Dr. Luis A. Rodriguez
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MSOE UNIVERSITY

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Introduction

From Left to Right: Nick Herche, Chris Gloeckle, Paul Stran, Rob Lancaster, Juan Casiano

Problem Statement and Design Objectives

Problem Statement:

- Design and build a human powered vehicle that uses fluid power to transfer and store energy

Design Objectives:

- Integrated Design
- Simple Design
- Develop a competitive vehicle that is capable of placing in the top three designs for all events
- Reduce weight and complexity from previous team's design
- Improve the ease of how the rider operates and enters the vehicle
- Allow for a system that can be readily modified for future Senior Design teams to improve upon

Target Specifications

Sprint Race

- Achieve top speed of 25 MPH.
- Complete a 600ft course in less than 30 seconds
- Be able to pump the system to working pressure in less than 10 minutes

Efficiency Challenge

- Obtain efficiency challenge number no smaller than 150
- Achieve a system efficiency of 80**%**

Endurance Race

- Complete the entire race in under 4 minutes
- Be able to maneuver and turn easily
- Must be reliable enough to finish entire endurance course without needing any repairs during the event

Figure 1 Danfoss Track

Research

- Hydraulic Components
- Hydraulic Systems
- FPVC Designs
  - Includes other teams and previous MSOE team
- Regenerative Braking

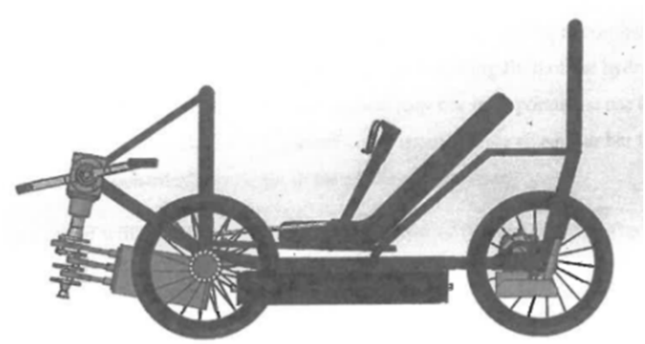


Figure 2 MSOE Fluid Bike Design from 2013

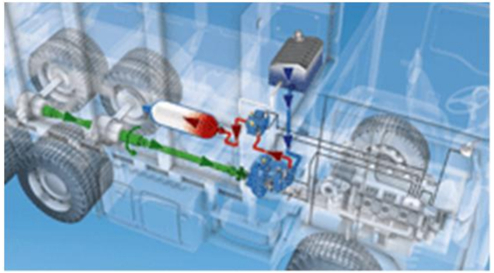


Figure 3 Regenerative Braking System

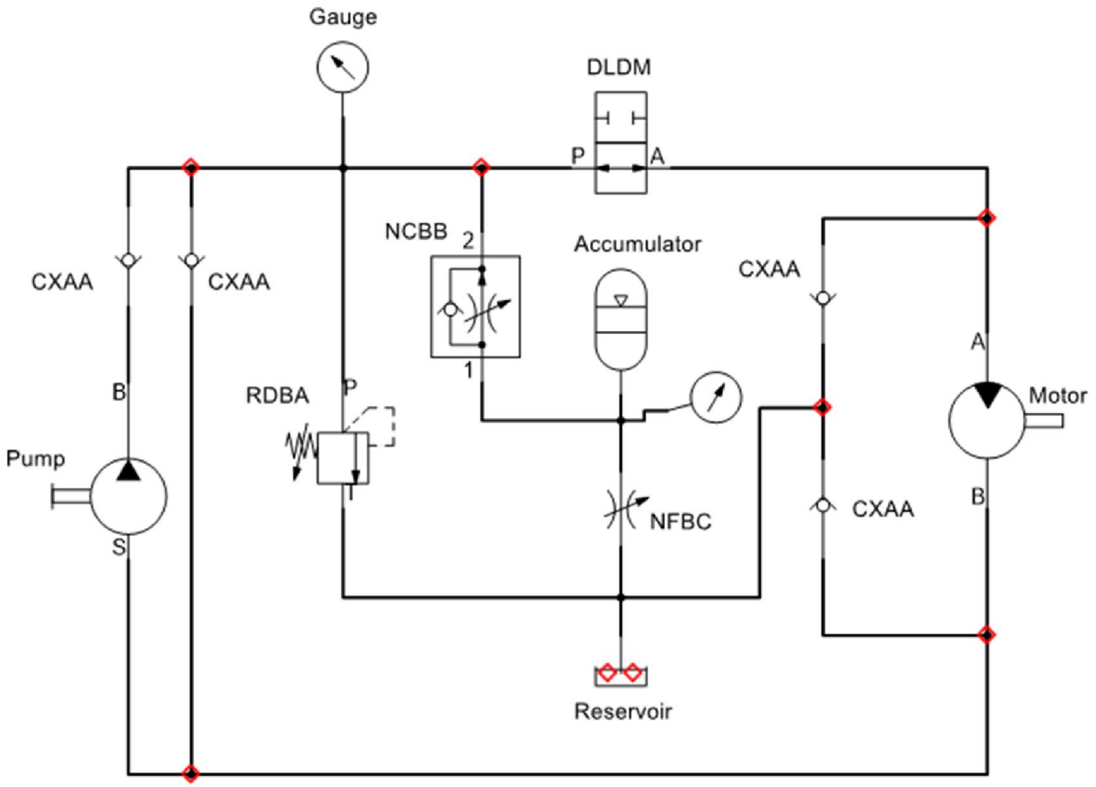
Frame Selection

Table 1 Vehicle Frame Selection Matrix

CATEGORY	Performance (28%)			Efficiency (20%)				Manufacturing (46%)				Miscellaneous (6%)		Total
CRITERIA	STABILITY	VERSATILITY	WEIGHT	RIDEABILITY	ROLLING RESISTANCE	COMPONENT ROUTING	AERODYNAMICS	COMPONENT SPACE	COST OF MODIFICATIONS	MODIFICATION TIME	WELDABILITY	AESTHETICS	ERGONOMICS	
DESCRIPTION	How the bike handles as the bike is moving.	The bikes ability to go from one event to the next (Sprint, Enduro, Efficiency) and perform well in each even without major modifications.	The weight of the frame before hydraulic modifications	The ability of the rider to easily ride the bike and pedal	The resistance that is present due to the rolling of the wheel	The ability to rout fluid lines efficiently and minimize losses	The resistance from the air as a result of movement due to the cross section of the frame and rider	The available space on the bike where components can be placed with minimal brackets and frame modification.	The total cost to modify and equip the bike for competition	The amount of time it will take to modify the frame to be used for the competition	The ease in which the bike material can be welded onto	How good the bike looks	How good the bike feels to be on	
METHODOLOGY	Takes into account the ability to place components on the bike without changing the center of balance, and the natural stability of the frame		Measurement from a scale	Takes into account rider position		Takes into account the lengths and shapes of the frames, which affect the length of lines, and where they can go	Takes into account the shape of the frame and the position of the rider, looked at Aerodynamics of HPV article		Takes into account the cost of new parts		Takes into account the material of the frame			
FRAME														
PREVIOUS FRAME (TRIKE DESIGN)	9	5	4	3	6	7	8	9	4	5	9	5	4	61.6
MOUNTAIN BIKE	6	7	7	8	7	7	6	7	6	5	6	7	8	63.7
ROAD BIKE	6	7	9	7	9	7	9	7	6	5	8	7	7	67.8
WEIGHTING FACTOR	1.4	0.8	0.6	0.5	0.6	0.4	0.5	1	1.2	1.8	0.6	0.1	0.5	10

Figure 4 Selected Vehicle Frame

Fluid Power Circuit Design



CXAA - Check Valve
DLDM - 2W2P Valve
NCBB - Check/Choke Valve
NFBC - Needle Valve
RDBA - Pressure Relief Valve

Figure 5 Annotated Hydraulic Circuit

Design Formulas

Grade to Degrees

$$-tan^{-1}\left(\frac{Grade}{100}\right) = Degrees$$

Pull of Bike (lbs)

$$-sin(Degrees) * (Weight) * (Rolling\ Resistance) = Pull_1$$

Pull from Weight (lbs)

$$-cos(Degrees) * (Weight) * (Rolling\ Resistance) = Pull_2$$

Total Uphill Pull (lbs)

$$Pull_1 + Pull_2 = Uphill\ Pull$$

Torque Required (lb. in.)

$$(Uphill\ Pull) * (r) = \tau$$

Motor CIR (in³/rev)

$$\frac{\tau * (2\pi)}{PSI} = CIR_m$$

Wheel Speed (rev/min)

$$\frac{(336 * MPH\ Desired)}{d} = RPM$$

Gallons per Minute of Flow (gal/min)

$$\frac{(CIR_m * RPM)}{231} = GPM$$

Motor Needed (HP_a)

$$\frac{(GPM * PSI)}{1714} = HP_a$$

Motor Sizing Check (HPc)

$$\frac{(\tau * RPM)}{63025} = HP_1$$

$$\frac{\frac{HP_1}{Pump\ Efficiency}}{Motor\ Efficiency} = HP_c$$

Pump CIR (in³/rev)

$$\frac{GPM * 231}{RPM} = CIR_p$$

Pump CIR with Efficiency (in³/rev)

$$\frac{CIR_p}{Pump\ Efficiency} = HP_c$$

Table 2 Motor System Displacement

N F P A

				Pump speed, efficiency included, flowrate, US			Pump speed, efficiency included, flowrate, METRIC		
Pressure		displacement		98%	96%	95%	98%	96%	95%
Pressure MPa	pressure PSI	CIR	CC/rev	GPM at 600rpm	GPM at 300RPM	GPM at 200RPM	LPM at 600RPM	LPM at 300RPM	LPM at 200RPM
3.4474	500	1.026	16.813	2.7194	1.3880	0.9351	10.3064	5.2605	3.5439
4.1369	600	0.855	14.011	2.2661	1.1567	0.7792	8.5886	4.3838	2.9533
4.8263	700	0.733	12.010	1.9424	0.9914	0.6679	7.3617	3.7575	2.5314
5.5158	800	0.641	10.508	1.6996	0.8675	0.5844	6.4415	3.2878	2.2150
6.2053	900	0.570	9.341	1.5108	0.7711	0.5195	5.7258	2.9225	1.9689
6.8948	1000	0.513	8.407	1.3597	0.6940	0.4675	5.1532	2.6303	1.7720
7.5842	1100	0.466	7.642	1.2361	0.6309	0.4250	4.6847	2.3912	1.6109
8.2737	1200	0.428	7.006	1.1331	0.5783	0.3896	4.2943	2.1919	1.4766
8.9632	1300	0.395	6.467	1.0459	0.5338	0.3596	3.9640	2.0233	1.3631
9.6527	1400	0.366	6.005	0.9712	0.4957	0.3340	3.6808	1.8788	1.2657
10.3421	1500	0.342	5.604	0.9065	0.4627	0.3117	3.4355	1.7535	1.1813
11.0316	1600	0.321	5.254	0.8498	0.4338	0.2922	3.2207	1.6439	1.1075
11.7211	1700	0.302	4.945	0.7998	0.4082	0.2750	3.0313	1.5472	1.0423
12.4106	1800	0.285	4.670	0.7554	0.3856	0.2597	2.8629	1.4613	0.9844
13.1000	1900	0.270	4.425	0.7156	0.3653	0.2461	2.7122	1.3844	0.9326
13.7895	2000	0.257	4.203	0.6798	0.3470	0.2338	2.5766	1.3151	0.8860
14.4790	2100	0.244	4.003	0.6475	0.3305	0.2226	2.4539	1.2525	0.8438
15.1685	2200	0.233	3.821	0.6180	0.3155	0.2125	2.3424	1.1956	0.8054
15.8579	2300	0.223	3.655	0.5912	0.3017	0.2033	2.2405	1.1436	0.7704
16.5474	2400	0.214	3.503	0.5665	0.2892	0.1948	2.1472	1.0959	0.7383
17.2369	2500	0.205	3.363	0.5439	0.2776	0.1870	2.0613	1.0521	0.7088
17.9264	2600	0.197	3.233	0.5230	0.2669	0.1798	1.9820	1.0116	0.6815
18.6159	2700	0.190	3.114	0.5036	0.2570	0.1732	1.9086	0.9742	0.6563
19.3053	2800	0.183	3.002	0.4856	0.2479	0.1670	1.8404	0.9394	0.6328
19.9948	2900	0.177	2.899	0.4689	0.2393	0.1612	1.7770	0.9070	0.6110
20.6843	3000	0.171	2.802	0.4532	0.2313	0.1558	1.7177	0.8768	0.5907

Selection of Hardware

- Zwei Inc.
  - Displacement 7 cc/rev

- Parker Hannifin 1L Gas Piston Accumulator
  - 4000 psi Capacity

- 2 Port 2 Way Rotary Valve

- Aluminum Reservoir
  - Weight Reduction

    1.66lb vs. 4.92lb
  - Heat Dissipation

Figure 6 Parker Hannifin Accumulators

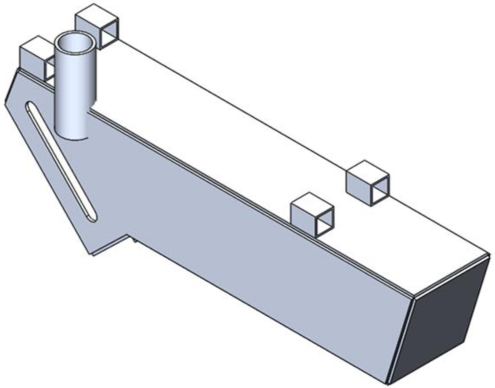
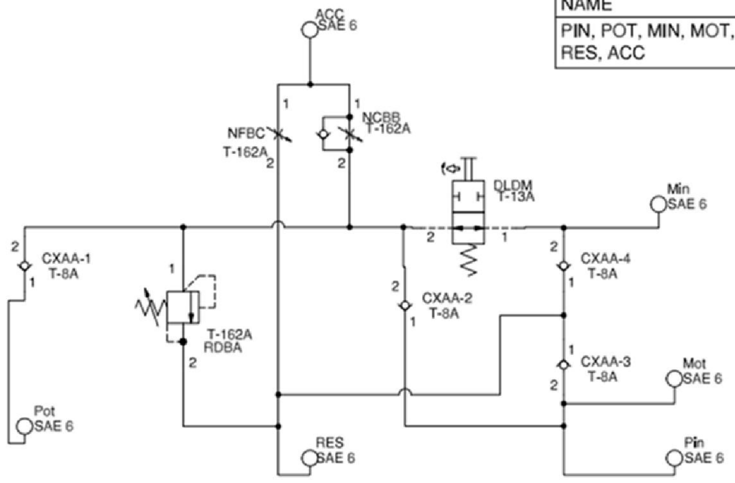


Figure 7 Aluminum Reservoir

Manifold Circuit

NAME	SIZE
PIN, POT, MIN, MOT, RES, ACC	SAE 6

For this project the height as well as the front to back dimension is not overly critical. The most critical dimension for this project is left to right, where we are confined to no more than 6 inches.



STAMPING	QTY	MODEL CODE	SETTING	DESCRIPTION
RDBA	1	RDBAKAN		RELIEF
NFBC	1	NFBCKCN		NEEDLE
NCBB	1	NCBBKCN		NEEDLE
DLDM	1	DLDM		DIRECTIONAL
CXAA-4	1	CXAAXZN		CHECK
CXAA-3	1	CXAAXZN		CHECK
CXAA-2	1	CXAAXZN		CHECK
CXAA-1	1	CXAAXZN		CHECK

DRAWN BY Herche	TITLE Manifold Fluid Power Bike v.2	MSOE (QD 18750)
DATE 18-Dec-2017		
REF.	PART NUMBER MSOE NFPC 2018	VERSION 1 / PROJECT I.D. B712-189-A06

CXAA - Check Valve
DLDM - 2W2P Valve
NCBB - Check/Choke Valve
NFBC - Needle Valve
RDBA - Pressure Relief Valve

Figure 8 Hydraulic Circuit Sent to Sun Hydraulics

Manifold

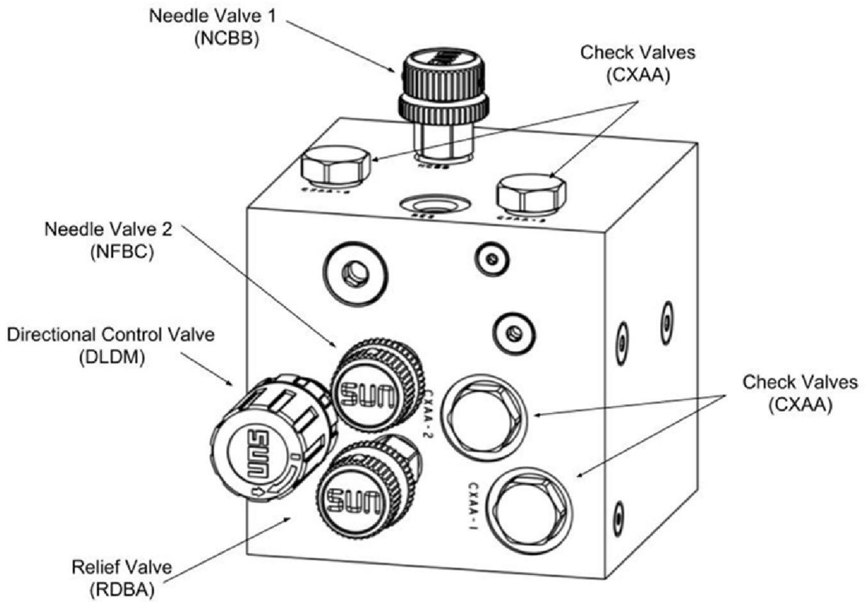


Figure 9 Manifold CAD with Annotations

Figure 10 Manifold

Figure 11 Manifold Motor, Pump, and Accumulator Ports

Simulink Circuit Model

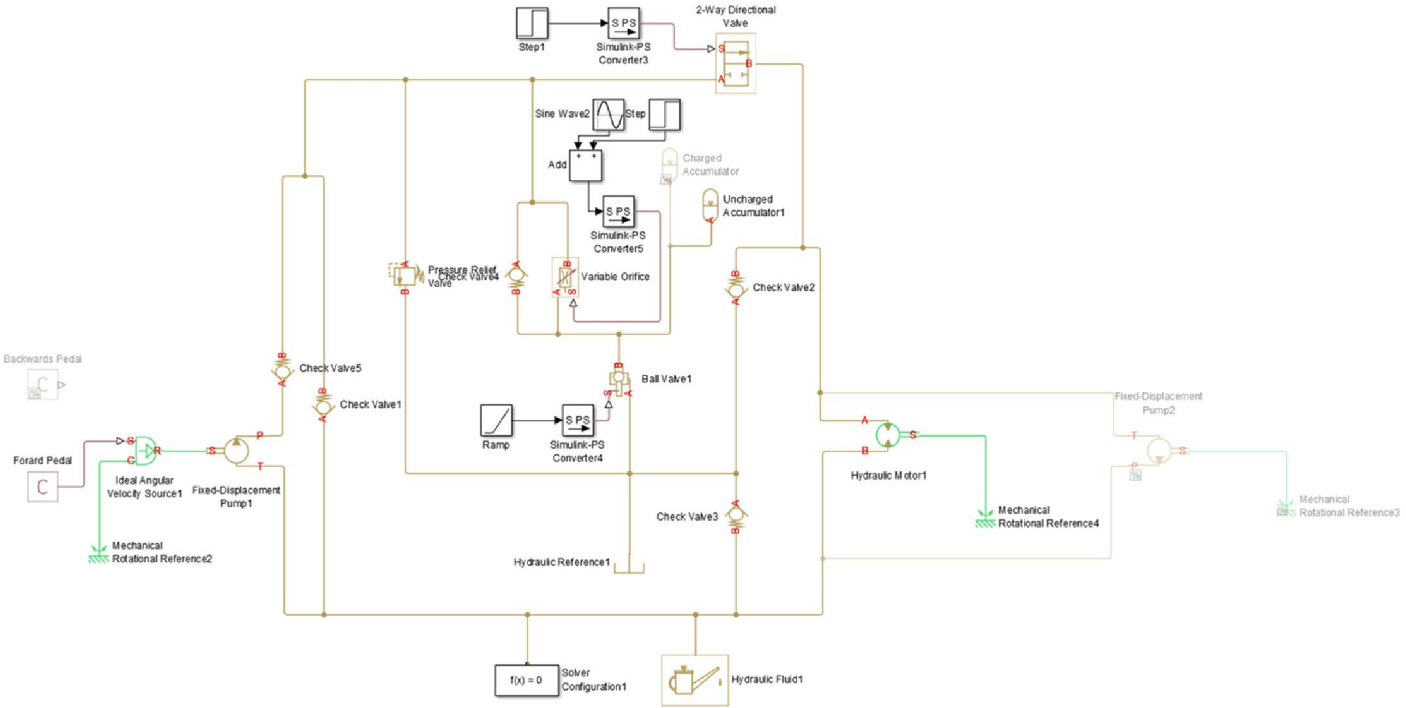


Figure 12 Simscape Model

Simulink (Cont.)

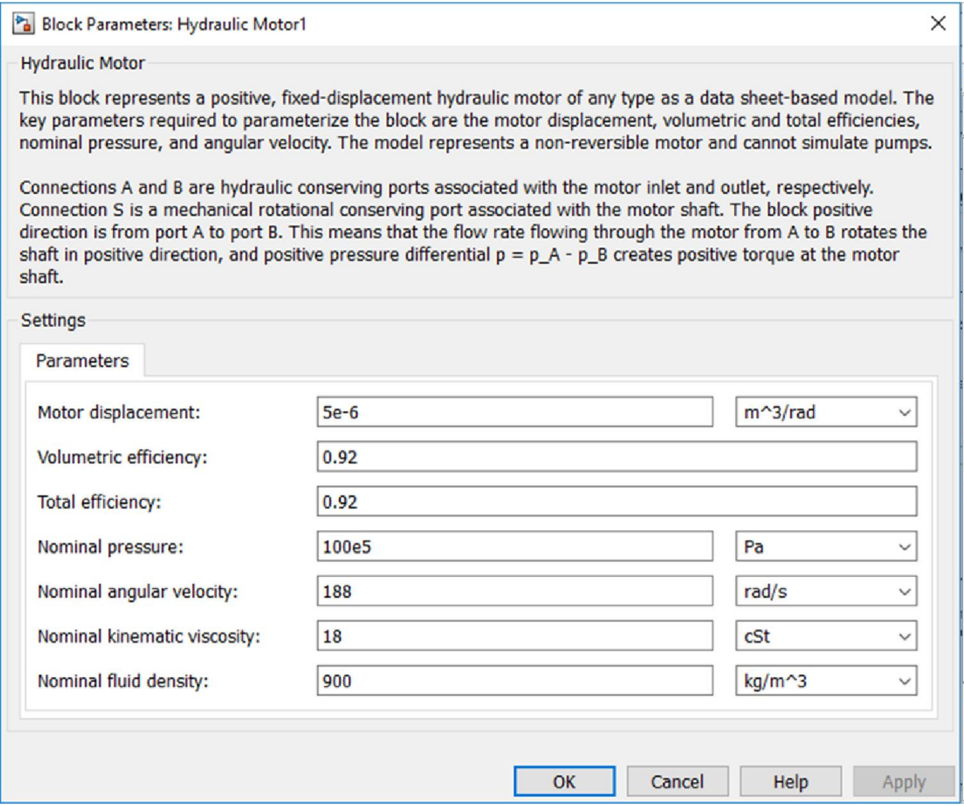


Figure 13 Block Parameters

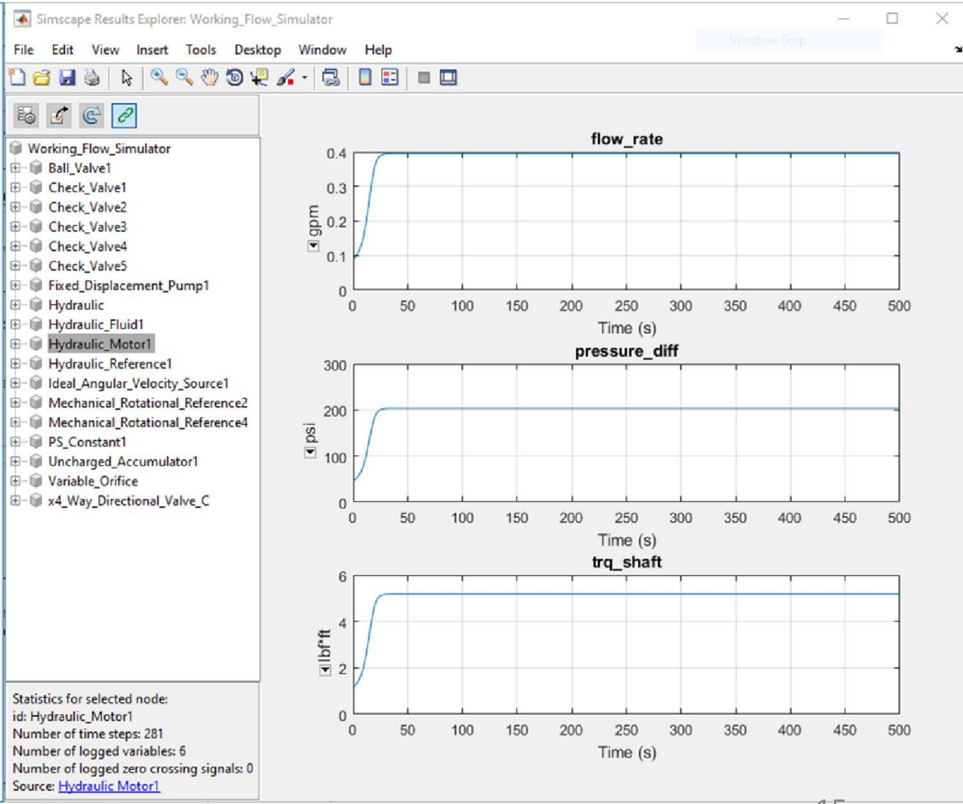


Figure 14 System Response

Finite Element Analysis

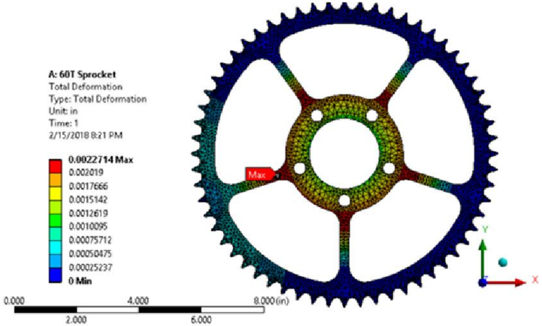


Figure 15 Sprocket

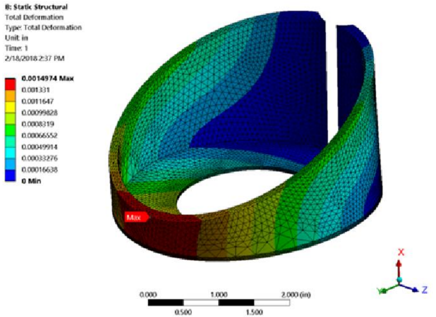


Figure 16 Accumulator Mount

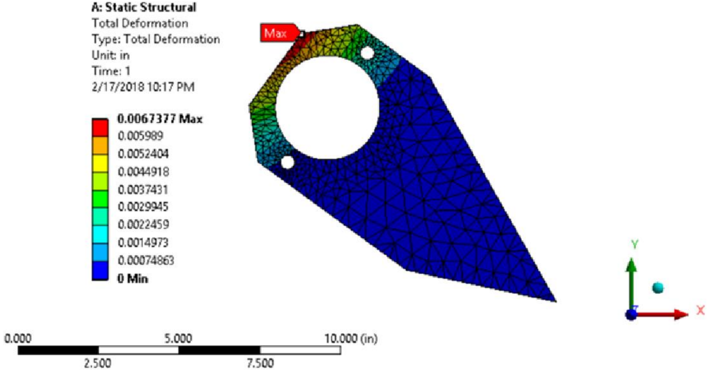


Figure 17 Motor Mount

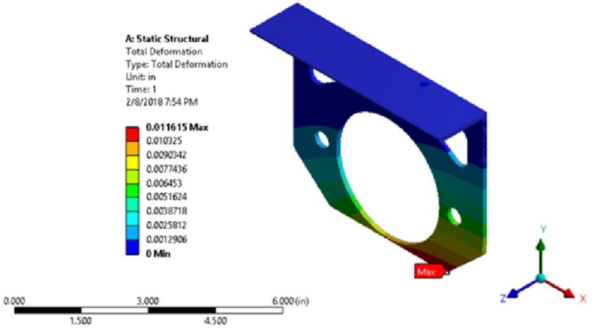


Figure 18 Pump Mount

FEA on Motor

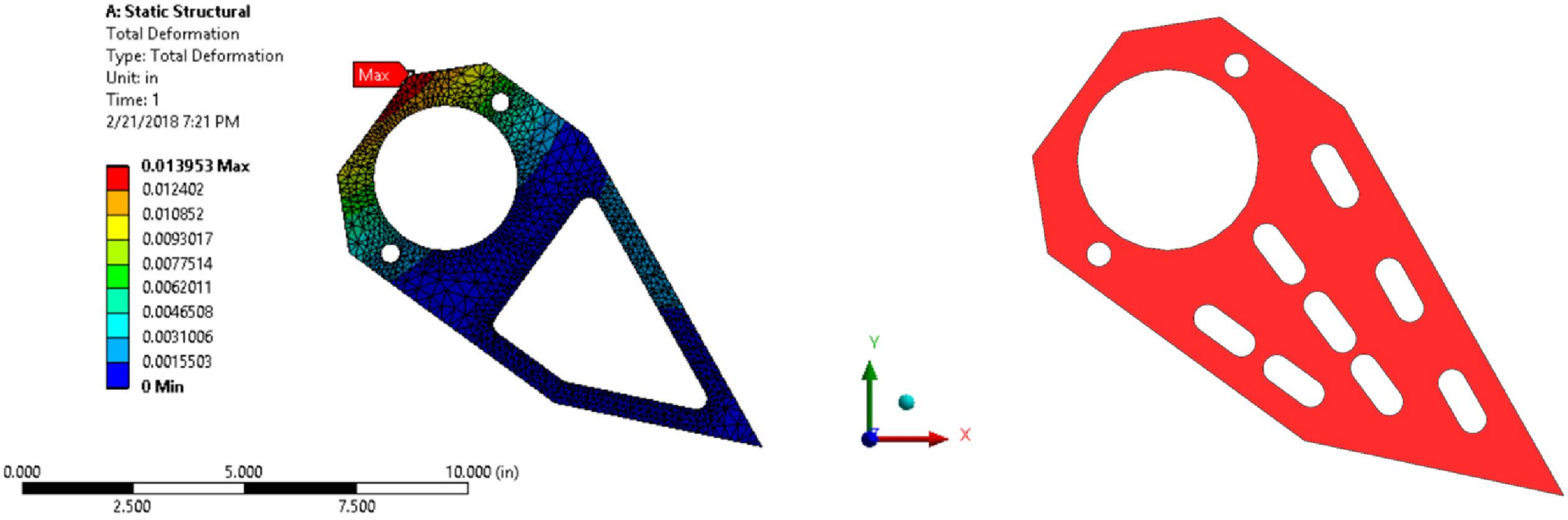


Figure 19 Motor Mount Revision and Final Implementation

Virtual Prototype

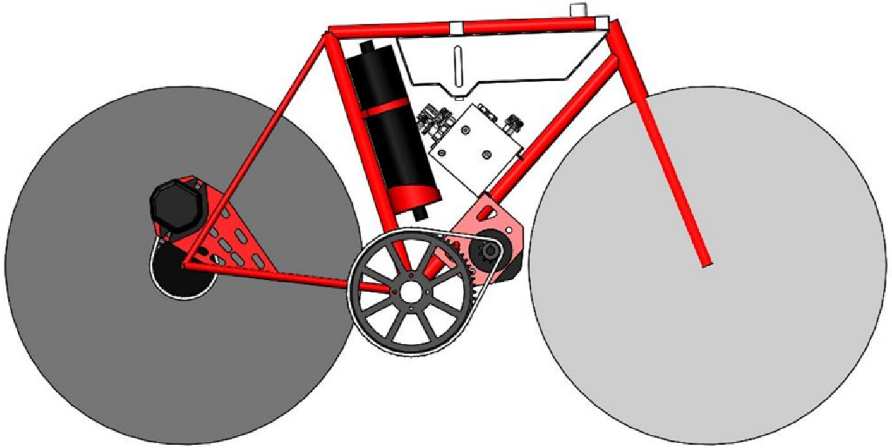


Figure 20 Side View

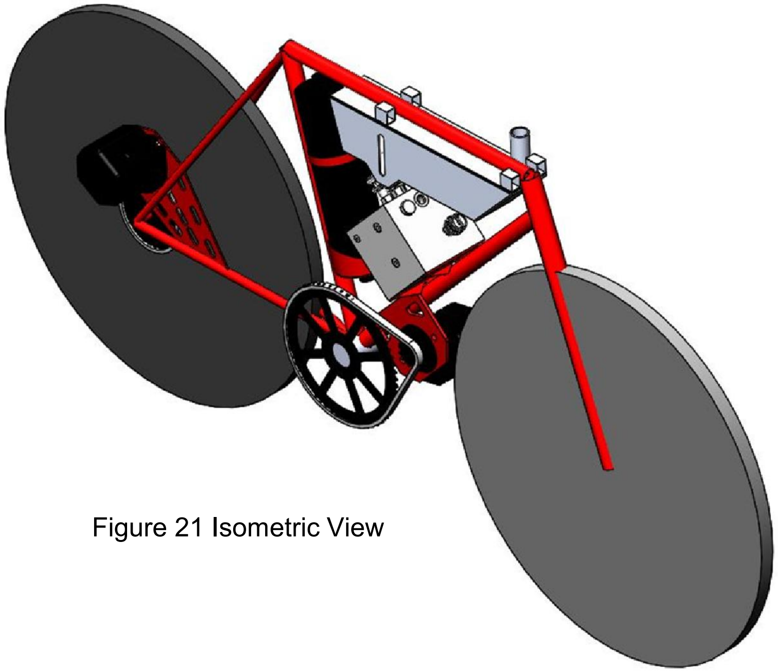


Figure 21 Isometric View

Manufacturing

- Materials
  - A36
  - 1018
  - 1020 - 1026
  - 6061

- Processes
  - CNC
  - Milling
  - Welding
  - Turning

Figure 22 Frame and Components

Figure 23 Pump Test Fit

Data Acquisition

Figure 24 Arduino

- Reed Switch
- Arduino Uno
- SD Card Shield
- Sampling at 1 KHz
- Verified Velocity Data

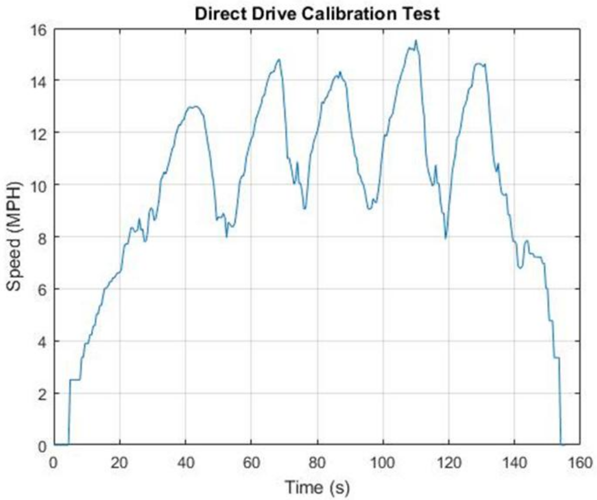


Figure 25 Sample Test Results

Lessons Learned

- Tolerances
  - Leave room for tubing and fittings
- Replacement parts
  - Make sure parts are easily acquired
- Hydraulic nuances, not just high level stuff
  - Learn Rules of Thumb early
- Time Management
  - Leave time for mistakes and problems

Questions?