NFPA Fluid Power VEHICLE Challenge

NFPA Education and Technology Foundation

FINAL PRESENTATION
Iowa State
Dr. Brian Steward
April 15, 2020

Ramsey Arneson

- Year
  - Senior
- Major
  - Agricultural Engineering
    - Power & Machinery
- Hobbies
  - Hanging out with friends
  - Snowmobiling
  - Golfing

Hadley Heitshusen

- Year
  - Senior
- Major
  - Agricultural Engineering
    - Power & Machinery
- Hobbies
  - Wood working
  - Motorcycles
  - Snowboarding

Blake Hughes

- Year
  - Senior
- Major
  - Agricultural Engineering
    - Power and Machinery
- Hobbies
  - Track and Field
  - Fishing
  - Hiking

Mentor: Dr. Brian Steward

- Professor of Agricultural and Biosystems Engineering at Iowa State University
- Education:
  - BS and MS in Electrical Engineering from South Dakota State University
  - Ph.D. in Agricultural Engineering from the University of Illinois at Urbana-Champaign.
- Teaching areas include:
  - Fluid power engineering and technology
  - Sustainable engineering
  - Dynamic systems modeling and simulation
- Research topics:
  - Fluid Power: Modeling and simulation, sensors, contamination control
  - Virtual prototyping of off-road machine systems

Problem Statement and Objective

Design and build a human powered hydraulic vehicle for the National Fluid Power Association Fluid Powered Vehicle Competition. The vehicle must utilize a human as the prime mover with a hydraulic link somewhere between the prime mover and the ground. The vehicle must utilize stored energy as well as regenerative braking in the hydraulic circuit. The vehicle should minimize losses and weight in order to be as efficient as possible, while satisfying our design criteria and competition constraints.

Design Objectives

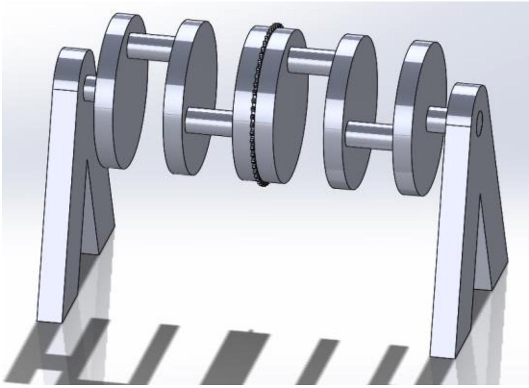
- The vehicle should minimize losses
- The vehicle should minimize weight
- Maximize vehicle performance
  - See above points
- Visually appealing
- No oil leaks
- Efficient and capable regenerative braking
- Safe to operate and be in the presence of operation
- High durability for extensive testing and competition
- Low rolling resistance (tires)
- Minimize drag force (recumbent)

Design Process

- Initial Research
- Initial Calculations
- Develop Schematic Concepts
- Hydraulic Concept Decision
- Source Bike Frame: CAD Analysis
- Hydraulic and Pneumatic Circuit Testing
- DAQ and Controls Design/Testing
- ~~Bike Assembly and Testing~~

Develop Schematic Concepts

1. Accumulator/Motor Pair
    a. Pros: Successful in the past
    b. Cons: Limited accumulator volume
2. Direct Drive with axial piston pump/motor pair
    a. Pros: High efficiency compared to gear pump/motor
    b. Cons: requires high speed for high efficiency and fixed displacement
3. Homemade pump (hand pumps on crank)
    a. Pros: High volumetric efficiency without high gear ratios and potentially variable displacement
    b. Cons: Low mechanical efficiency and high complexity of design



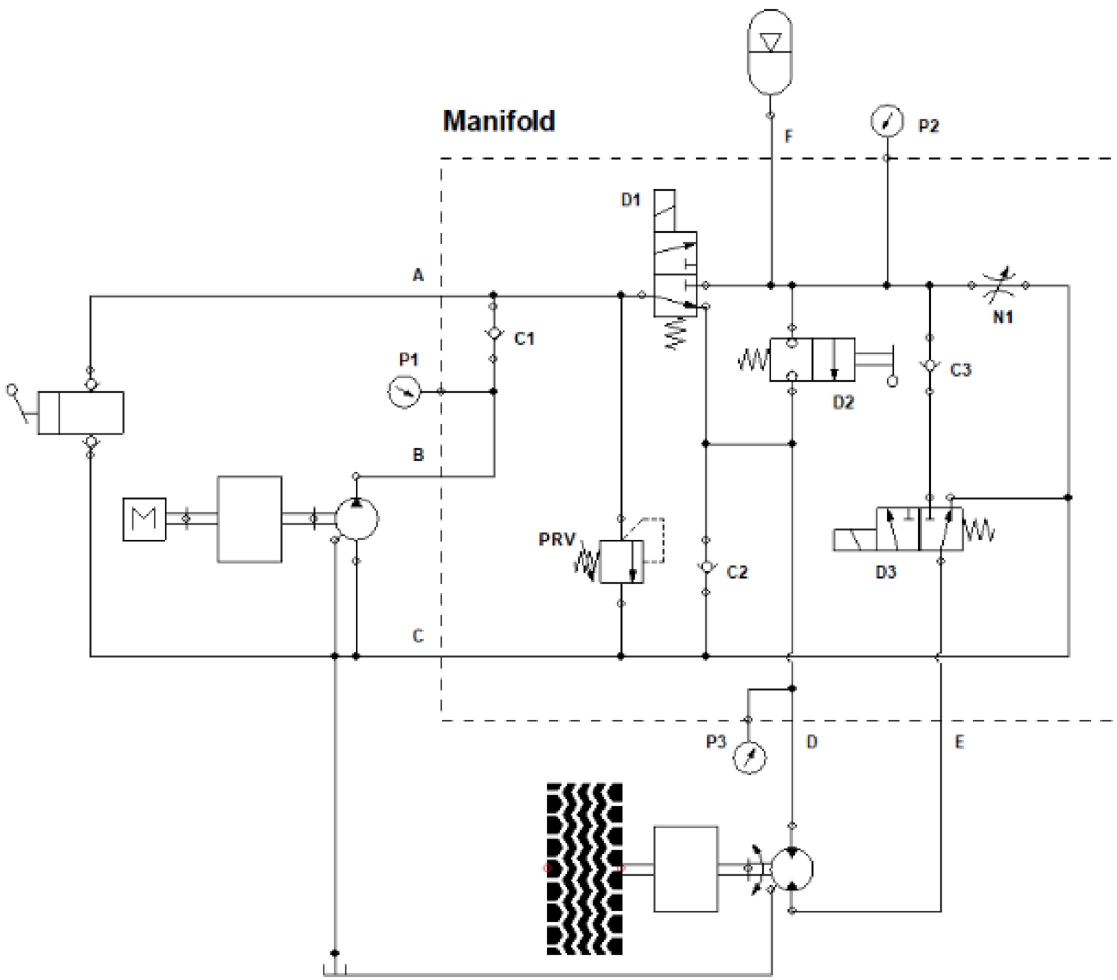
Direct Drive Motor/Pump

- Created a single spreadsheet to allow simulation of full HST
- Included estimated efficiencies of different pumps
- Allowed us to change parameters such as human inputs, bike weight, efficiencies, gear ratios, etc.
  - Wanted to match parameters as closely with our research as possible
  - Minimize the size of our pump/motor in order to maximize efficiency
- This spreadsheet allowed us to settle on a 5 cc/rev motor
  - Chose axial piston due to efficiency advantages over other styles
  - See next slide for more motor information

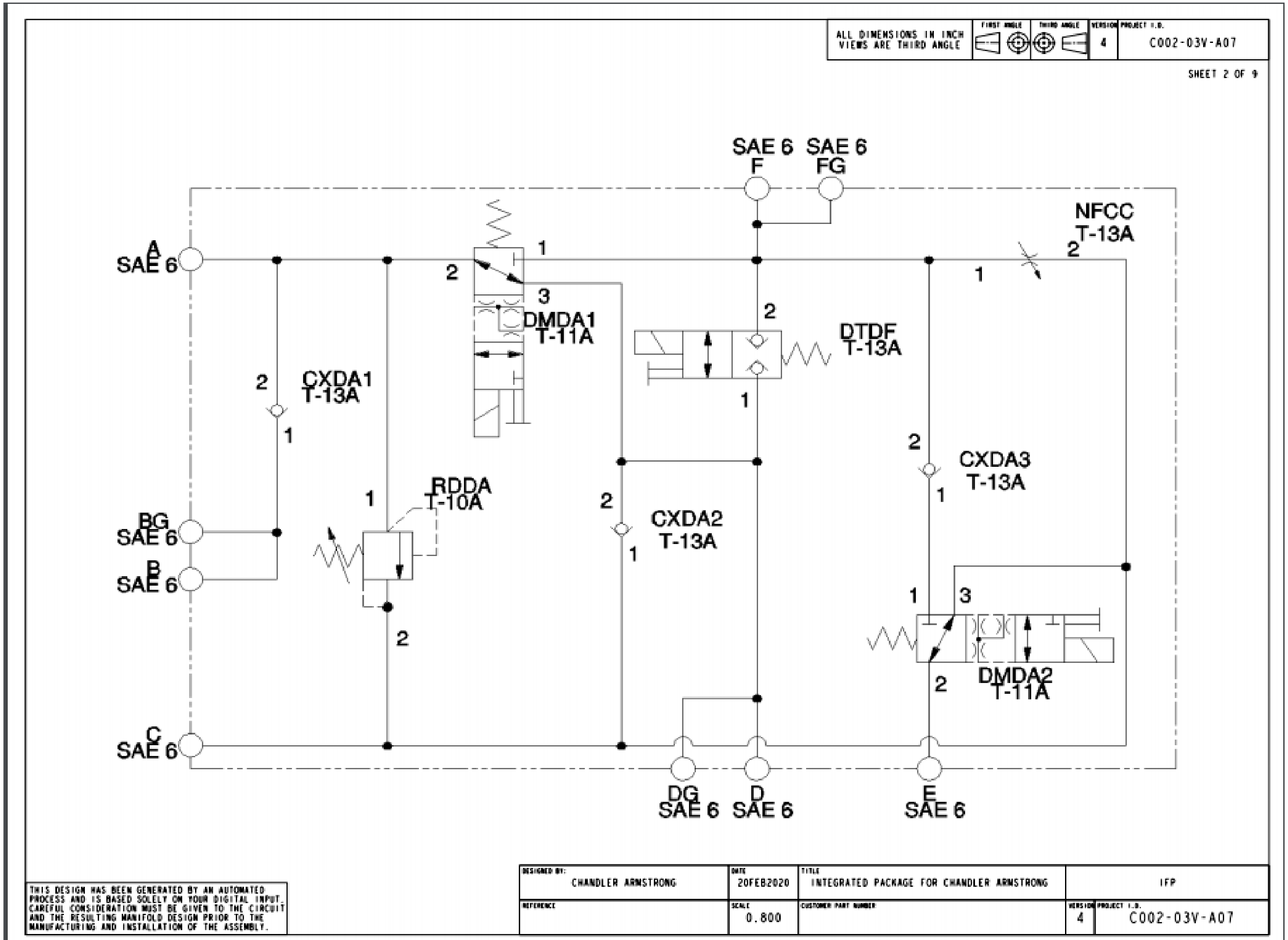
HST Sizing Spreadsheet

Human Characteristics		Pump Characteristics		Motor Characteristics		Bike Characteristics	
Human Input (lb)	20	Pump Drive Ratio	15.9	Estimated V_eff	0.95	Rolling Radius (in)	10
Pedal Lever (mm)	175	Pump Displacement (cc/rev)	5	Motor Displacement (cc/rev)	5	Final Drive Ratio Max	3.99
Pedal Lever (ft)	0.57	Pump Speed (rpm)	1909	Motor Speed (rpm)	1723	Final Drive Ratio Min	18.40
Human Input Torque (ft-lb)	11.5	Estimated V_eff	0.95	Mech_eff	0.85	Wheel Speed (rpm)	432.0
Human Input Speed (rpm)	120	Pump Flow (L/min)	9.07	Motor Torque (ft-lb)	0.5	Ground Speed (mph)	25.7
Power (hp)	0.26	Estimated Pressure (psi)	500	Accumulator Pressure (psi)	400	Ground Force (lb)	2.4
Power (W)	195.7	Pump Power (hp)	0.70	Accumulator Torque (ft-lb)	1.4	Wheel Speed Min (rpm)	93.7
		Chain Efficiency	0.98	Accumulator Volume (in3)	125.6	Ground Speed Min (mph)	5.6
		Input Torque (ft-lb)	0.71	Accumulator Revs	329.3	Ground Force Max (lb)	11.1
Sprocket 1	50	Calculated Pressure (psi)	149	Estimated Accum. Eff	0.8	Claimed Total Efficiency	0.626
Sprocket 2	11	Mech_eff	0.85			Chain Efficiency	0.9801
	4.55	Flow GPM	2.40			Power Max (hp)	0.16
Sprocket 3	42					Power Max (W)	122.6
Sprocket 4	12					Power Min (hp)	0.16
	3.50					Power Min (W)	122.6
	15.9					Accumulator Force Max (lb)	29.8
						Accumulator Force Min (lb)	6.5
						Accumulator Distance (ft)	1724.4

Hydraulic Circuit



Manifold



ALL DIMENSIONS IN INCH
VIEWS ARE THIRD ANGLE
FIRST ANGLE
THIRD ANGLE
VERSION 4
PROJECT I.D. C002-03V-A07
SHEET 2 OF 9
SAE 6 F
SAE 6 FG
NFCC T-13A
A SAE 6
DMDA1 T-11A
DTDF T-13A
CXDA1 T-13A
CXDA3 T-13A
RDDA T-10A
CXDA2 T-13A
BG SAE 6
B SAE 6
DMDA2 T-11A
C SAE 6
DG SAE 6
D SAE 6
E SAE 6
THIS DESIGN HAS BEEN GENERATED BY AN AUTOMATED PROCESS AND IS BASED SOLELY ON YOUR DIGITAL INPUT. CAREFUL CONSIDERATION MUST BE GIVEN TO THE CIRCUIT AND THE RESULTING MANIFOLD DESIGN PRIOR TO THE MANUFACTURING AND INSTALLATION OF THE ASSEMBLY.
DESIGNED BY: CHANDLER ARMSTRONG
DATE 20FEB2020
TITLE INTEGRATED PACKAGE FOR CHANDLER ARMSTRONG
IFP
REFERENCE
SCALE 0.800
CUSTOMER PART NUMBER
VERSION 4
PROJECT I.D. C002-03V-A07

Component Selection (Motor)

5 cc/rev bent axis Hydro Leduc hydraulic motor

- Axial Piston Configuration
  - Higher efficiency than gear
  - Better overall performance
- IFP able to supply this type of motor

Motor model	Displacement		Continuous max. speed (1)	Intermittent max. speed (1)	Max. flow absorbed		Torque		Torque at 350 bar (5100 psi)		Theoretical maximal power at 5800 psi 400 bar		Max. allowable pressure continuous / peak		Weight (kg)	
	cu.in/rev	cc/rev	rpm	rpm	gpm	l/mn	lbf.ft/psi	N.m/bar	lbf ft	N.m	HP	kW	psi	bar	lbs	Kg
M 5_093840	0.31	5	8000	8800	10.6	40	0.0040	0.08	21	28	35.7	26.6	5800 / 6525	400 / 450	9.7	4.4
M 12	0.73	12	8000	8800	25.4	96	0.0097	0.19	49	67	85.7	64	5800 / 6525	400 / 450	12.1	5.5
M 18	1.10	18.0	8000	8800	38.0	144	0.0145	0.29	74	100	128.7	96	5800 / 6525	400 / 450	12.1	5.5
M 25	1.52	24.9	6300	6900	41.4	157	0.0201	0.40	102	139	140.1	104.5	5800 / 6525	400 / 450	25	11.5
M 28	1.69	27.7	6300	6900	46.1	175	0.0223	0.44	114	154	155.9	116.3	5800 / 6525	400 / 450	25	11.5

Component Selection

- 1 gallon composite accumulator
- 5 cc/rev Hydro Leduc bent axis motor x2
- Direct acting pressure relief valve x2
- Check valves x5
- Hand Pump
- Flow control needle valve
- SAE -6 hoses of 36 and 12 inches in length
- 2 position, 2 way, bi-poppet NC solenoid valve
- 2 position, 2 way, NC manual valve
- 3 way ball valve x2
- 2 way ball valve
- Required line bodies and fittings for above components
- Manifold made by IFP

Component Selection (Bike)

- TerraTrike Rover x8
- 2x2” structural steel
  - Easy to modify
- Lightweight
  - 44 lb
- Recumbent
  - Lower drag forces
- Affordable

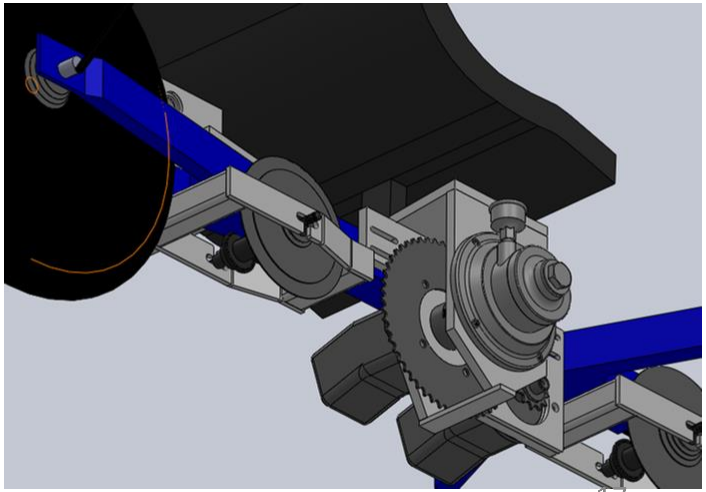
Pneumatics

Concepts

- Actuate air motor/wheel combo onto the ground
  - pros: no parasitic losses
  - cons: added weight and complexity
- Run air motor on hydraulic motor shaft/chain
  - pros: low weight, low complexity
  - cons: parasitic loss on hydraulic system when not active

Parts

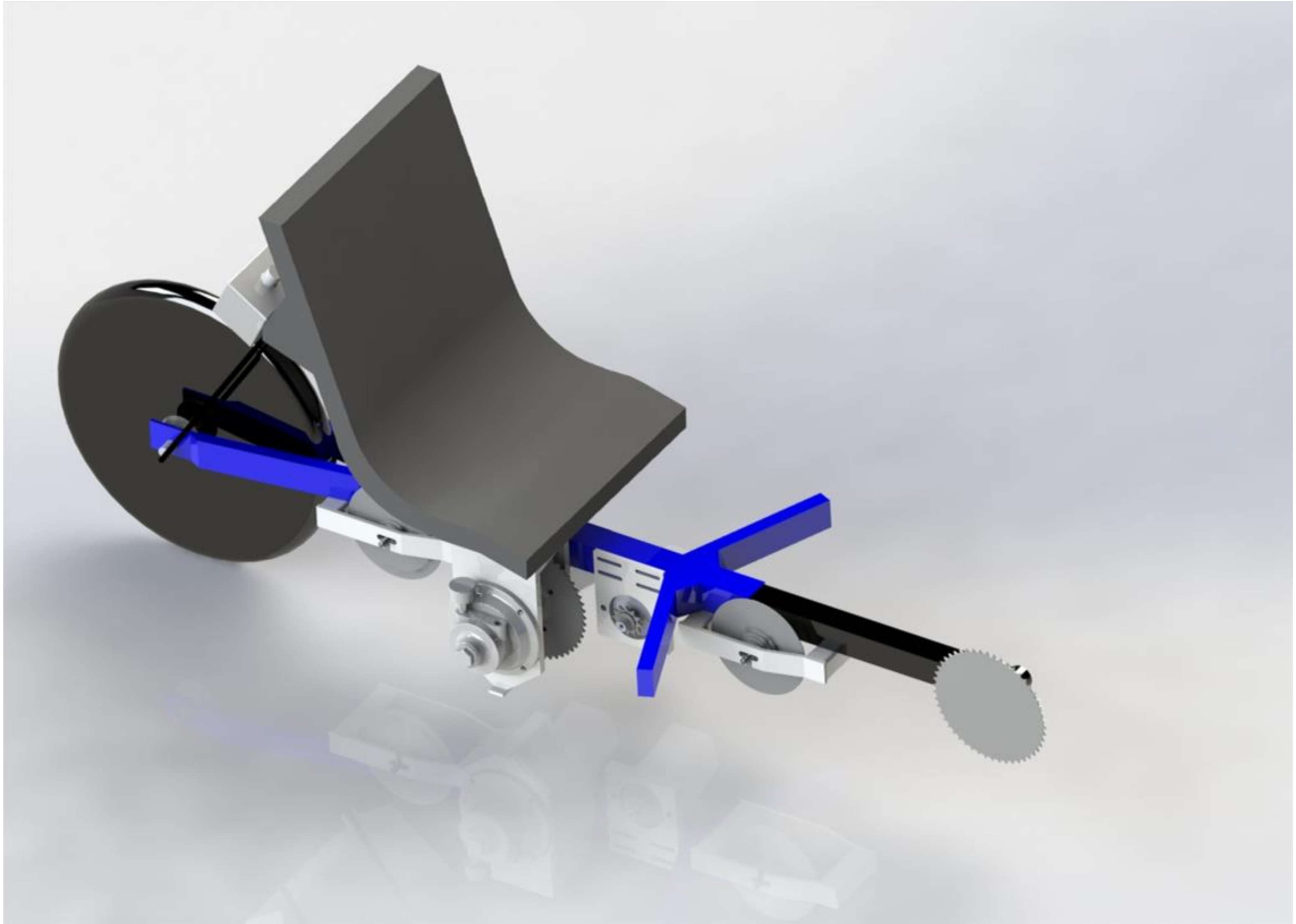
- 0.95 hp air motor
- Necessary coupling and mount
- Valving, air line, and controls



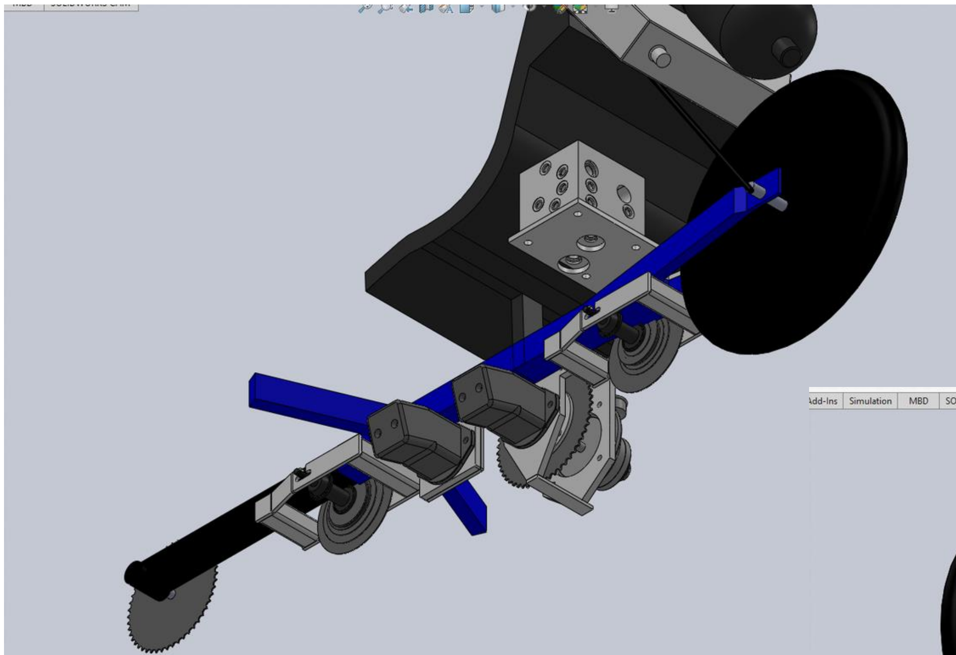
Progress made

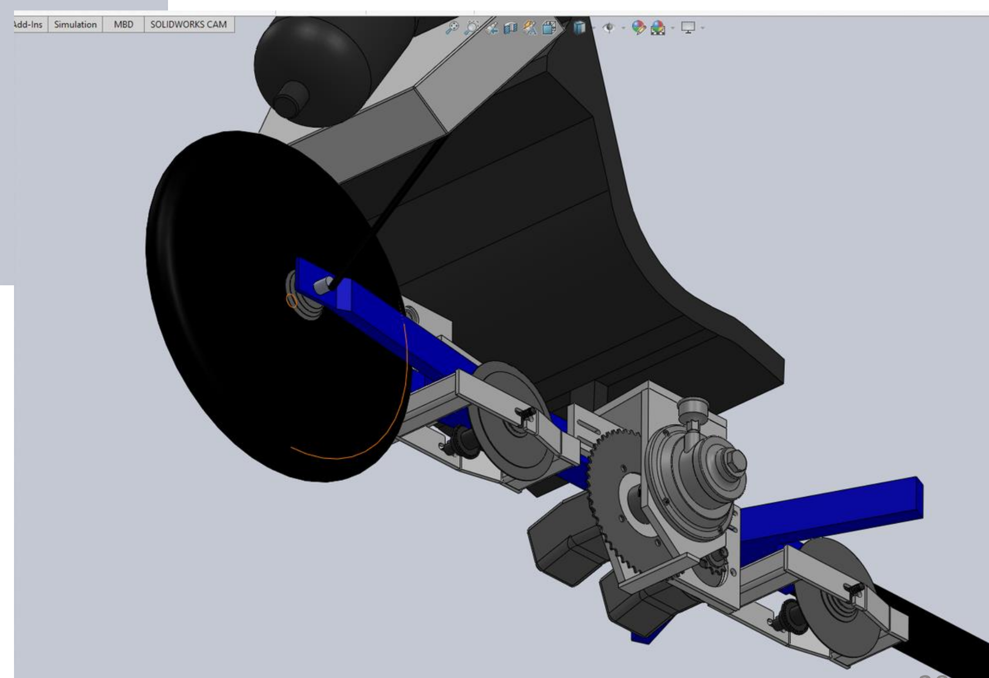
- Design work is complete
  - All hydraulic components and brackets modeled
  - Hydraulic system has been simulated and modeled
- Parts
  - All hydraulic components have arrived
  - Manifold has been delivered from IFP
  - Brackets are machined and ready to go
- Unable to assemble due to COVID-19, younger members unable to contribute

Vehicle Design



Vehicle Design





Controls

Battery

- Use Li-on to save weight
  - Modify Milwaukee power supply

System

- Logic: Arduino
- Drivers: SS microcontroller relays
- Inputs: Switches (momentary, latching)

Testing - Simulation

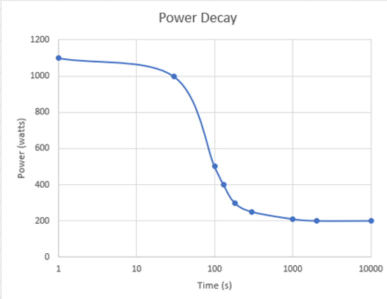
- Attempt to model would-be bike performance

Bike Information		
Weights:		
Bike	45	lb
Pump	9.7	lb
Motor	9.7	lb
Battery	2	lb
Rider	180	lb
Valves	15	lb
Manifold	10	lb
Pneumatics	15	lb
Total:	286.4	lb
Total less rider:	106.4	lb
Wheels	3	
Rolling Radius	10	in
C_d	0.35	
Fluid Density (air)	1.225	kg/m3
Acceleration	0.5	mph/s
Rolling Resistance	0.005	
Grade	0.1	
Headwind	0	mph
Cross Section Area	0.5	m2
Conversions		
	1.46666	ft/s/mph
	2.23694	mph_m/s
	4.45	N/lb
	746	watt/hp
	16.3871	cm3/in3

Hydraulic Information		
Pump/Motor Displacement	4.93	cc/rev
Efficiency (via rpm)		
500	0.8	
750	0.85	
1000	0.9	
System Efficiency	0.8	
Accumlator:		
V1, Volume Total	231	in3
P1, Pre-Charge	1000	psi
P2, Max Pressure	3000	psi
Gas Volume at P2	77	in3
n	1.4	
VX, Output	173	
Output Flow	0.5	gpm

Drivetrain Information		
Pump Gear Ratio:	15.9	
Gear 1	50	teeth
Gear 2	11	teeth
Gear 3	42	teeth
Gear 4	12	teeth
Motor Gear Ratio:	7.8	
Gear 1	53	teeth
Gear 2	22	teeth
Gear 3	42	teeth
Gear 4	13	teeth
Efficiency per step	0.99	

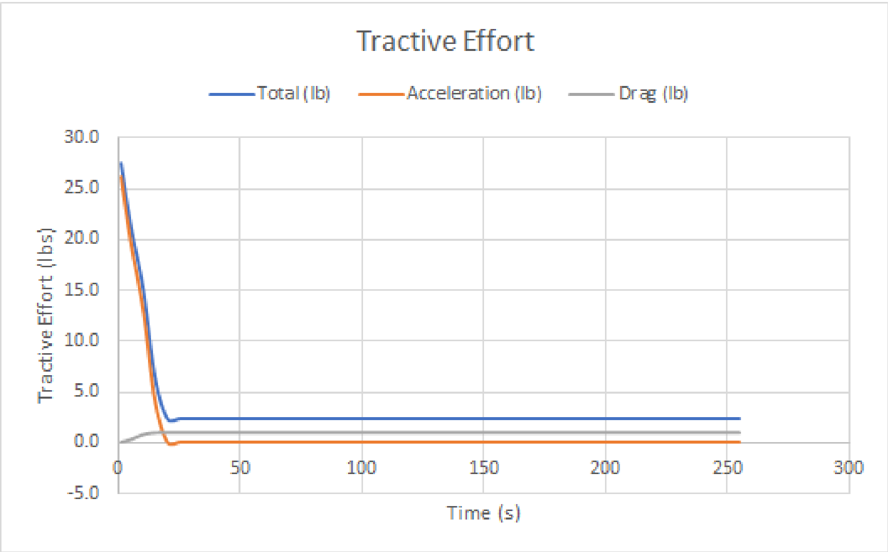
Human Input Information		
Max Speed	130	rpm
SS Speed	80	rpm
Min Speed	60	rpm
Max Power	1100	watts
SS Power	200	watts
Power Decay		
1	1100	watts
30	1000	watts
100	500	watts
130	400	watts
180	300	watts
300	250	watts
1000	210	watts
2000	200	watts
10000	200	watts

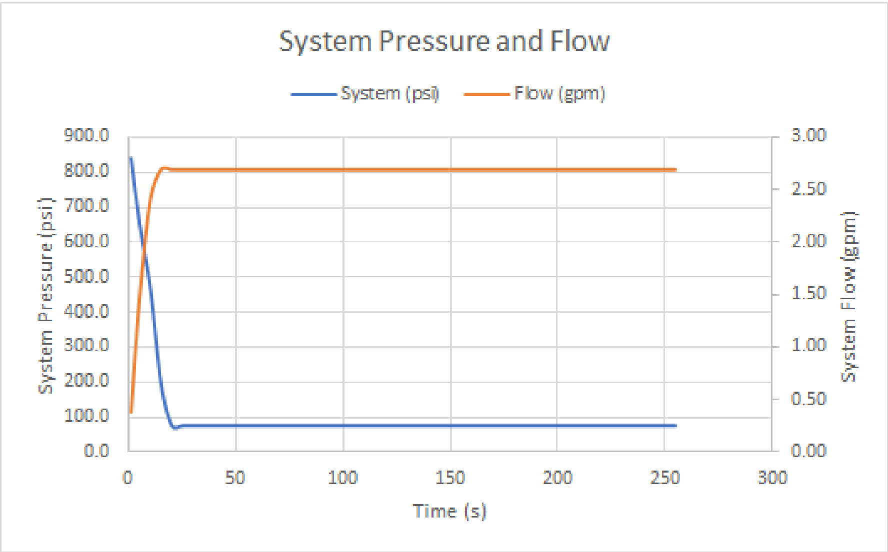


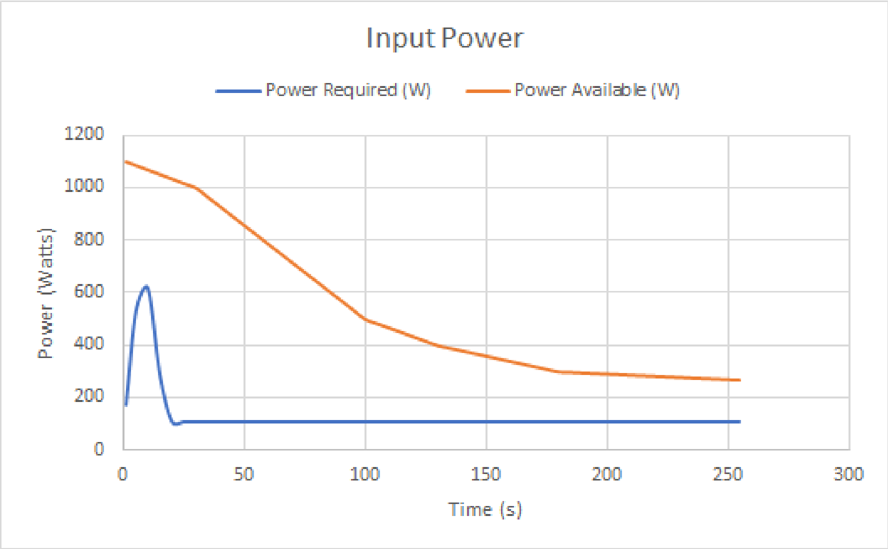
	Human Input					Movement			Tractive Force					Speeds (flow)			
Time (s)	Power Availab	Speed (rpm)	Torque (ft/lb)	Power Requirec	Torque Required	Acceleration (mph/s)	Speed (mph)	Distance (ft)	Grade (%	Acceleration (lb)	Drag (lb)	Rolling-Grade (lb)	Total (lb)	Wheel (rpm)	Motor (rpm)	Flow (gpm)	Pump (rpm)
1	1100	20.3	381	174	60	2	2	3	0	26.1	0.0	1.4	27.5	34	262	0.38	323
5	1086	79.6	96	527	47	1.5	8	6	0	19.6	0.3	1.4	21.3	132	1026	1.48	1266
10	1069	129.3	58	615	33	1	13	10	0	13.0	0.8	1.4	15.3	214	1667	2.41	2058
15	1052	144.3	51	285	14	0.3	14.5	14	0	3.9	1.0	1.4	6.4	239	1859	2.69	2295
20	1034	144.3	50	110	5	0	14.5	18	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
25	1017	144.3	50	110	5	0	14.5	22	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
30	1000	144.3	49	110	5	0	14.5	27	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
35	964	144.3	47	110	5	0	14.5	31	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
40	929	144.3	45	110	5	0	14.5	35	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
45	893	144.3	44	110	5	0	14.5	39	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
50	857	144.3	42	110	5	0	14.5	44	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
55	821	144.3	40	110	5	0	14.5	48	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
60	786	144.3	38	110	5	0	14.5	52	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295
65	750	144.3	37	110	5	0	14.5	56	0	0.0	1.0	1.4	2.4	239	1859	2.69	2295

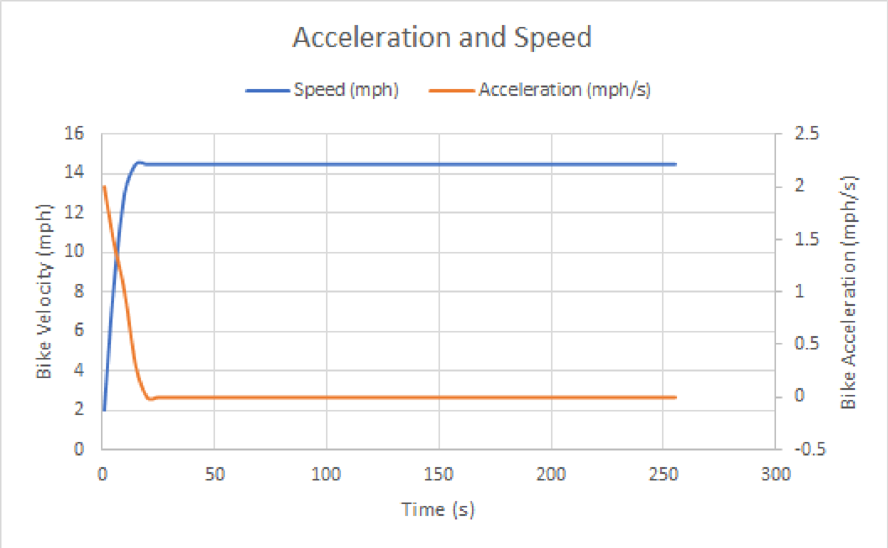
	Torques (pressure)				Accumulator					
Time (s)	Wheel (ft-lb)	Motor (ft-lb)	System (psi)	Pump (ft-lb)	Flow (gpm)	Volume Remain (in3)	Pressure (psi)	Motor (rpm)	Motor (ft-lb)	Status
1	23.0	3.0	837.8	3.7	0.5	171.0	2910	345.5	11.6	1
5	17.8	2.3	648.2	2.9	0.5	163.3	2599	345.5	10.4	1
10	12.7	1.7	465.1	2.1	0.5	153.7	2300	345.5	9.2	1
15	5.3	0.7	193.4	0.9	0.5	144.0	2067	345.5	8.2	1
20	2.0	0.3	74.3	0.3	0.5	134.4	1882	345.5	7.5	1
25	2.0	0.3	74.3	0.3	0.5	124.8	1731	345.5	6.9	1
30	2.0	0.3	74.3	0.3	0.5	115.2	1606	345.5	6.4	1
35	2.0	0.3	74.3	0.3	0.5	105.5	1501	345.5	6.0	1
40	2.0	0.3	74.3	0.3	0.5	95.9	1413	345.5	5.6	1
45	2.0	0.3	74.3	0.3	0.5	86.3	1337	345.5	5.3	1
50	2.0	0.3	74.3	0.3	0.5	76.7	1271	345.5	5.1	1
55	2.0	0.3	74.3	0.3	0.5	67.0	1215	345.5	4.8	1
60	2.0	0.3	74.3	0.3	0.5	57.4	1166	345.5	4.7	1
65	2.0	0.3	74.3	0.3	0.5	47.8	1124	345.5	4.5	1

Testing - Simulation



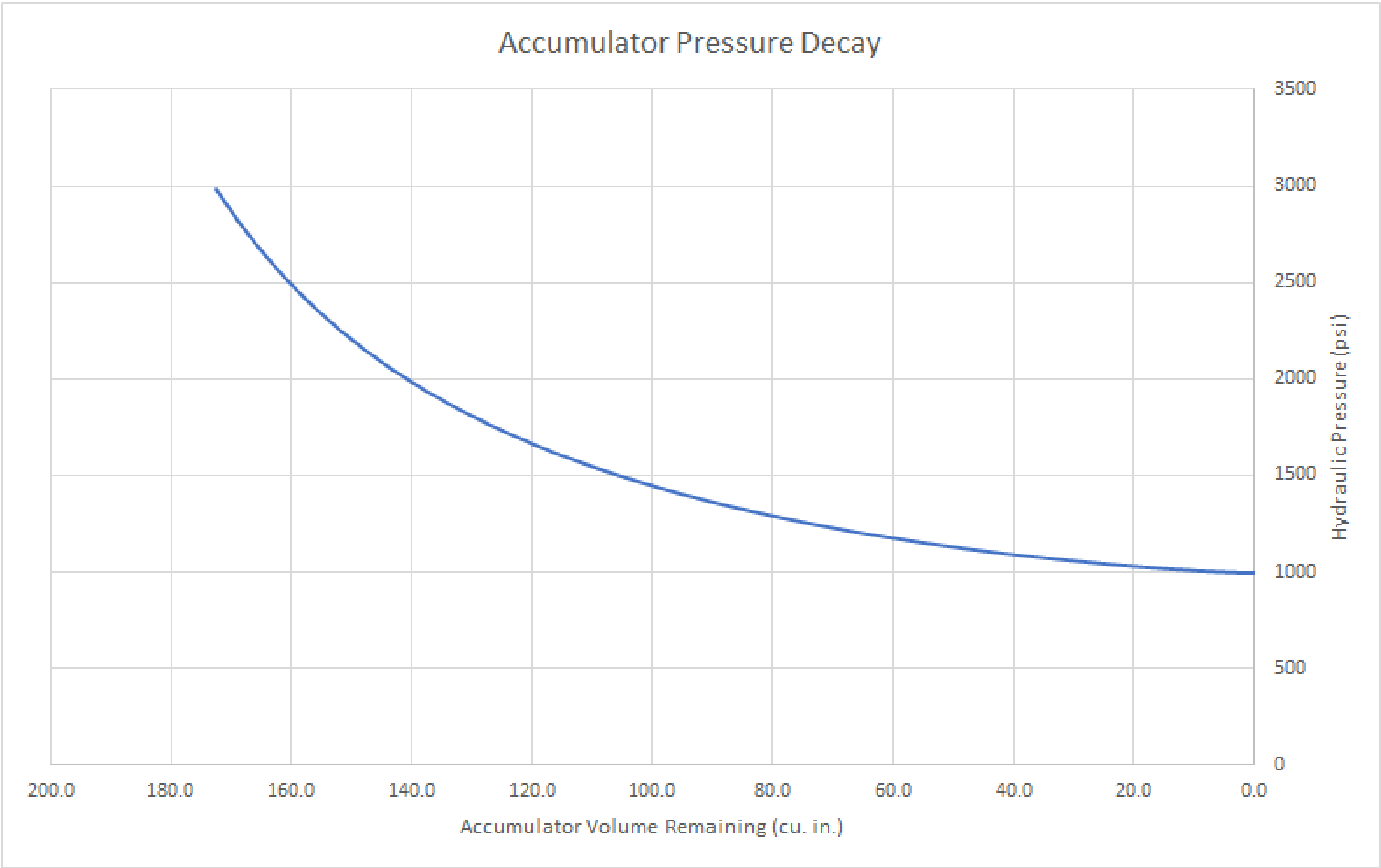




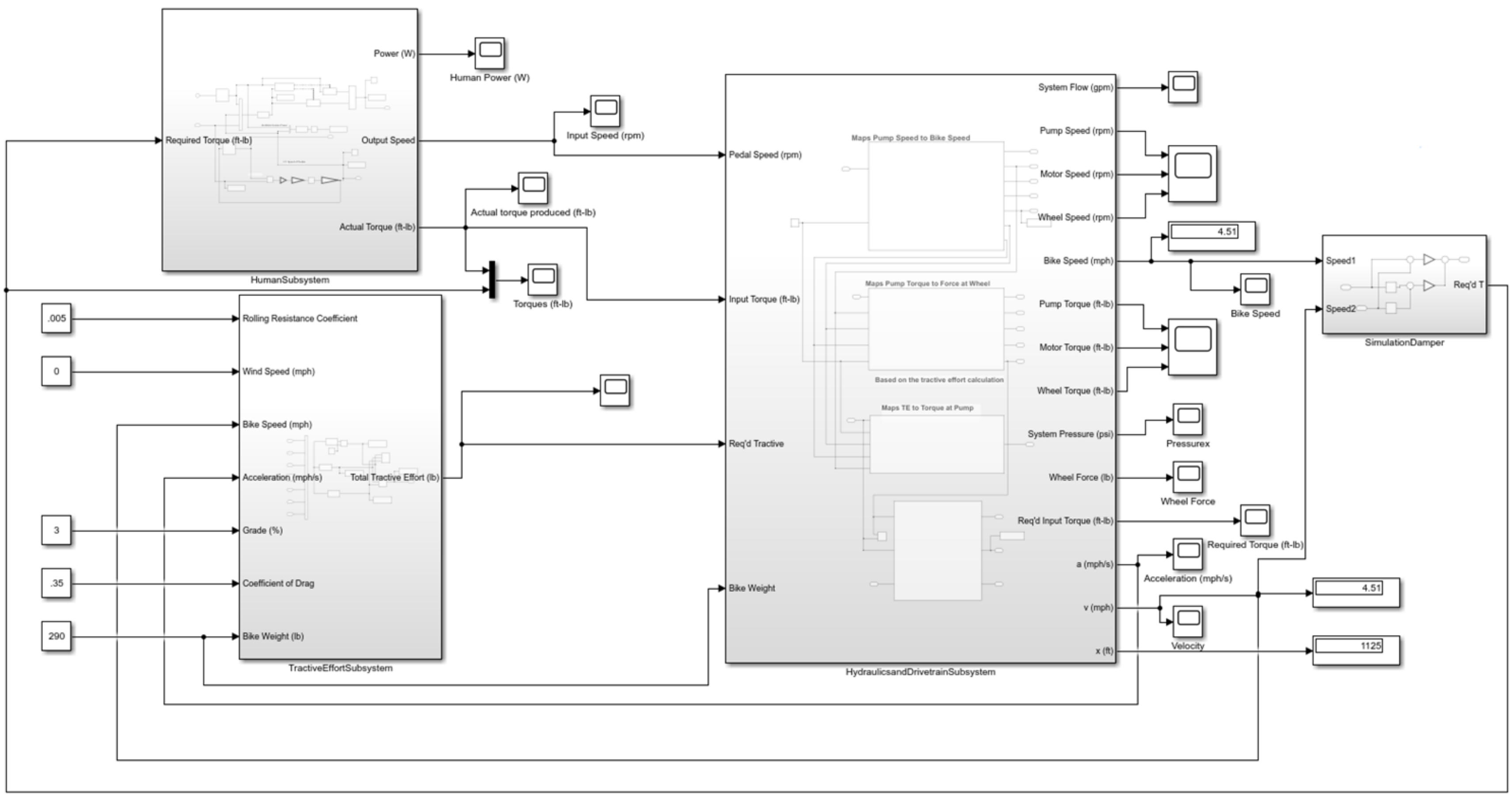


Accumulator Discharge

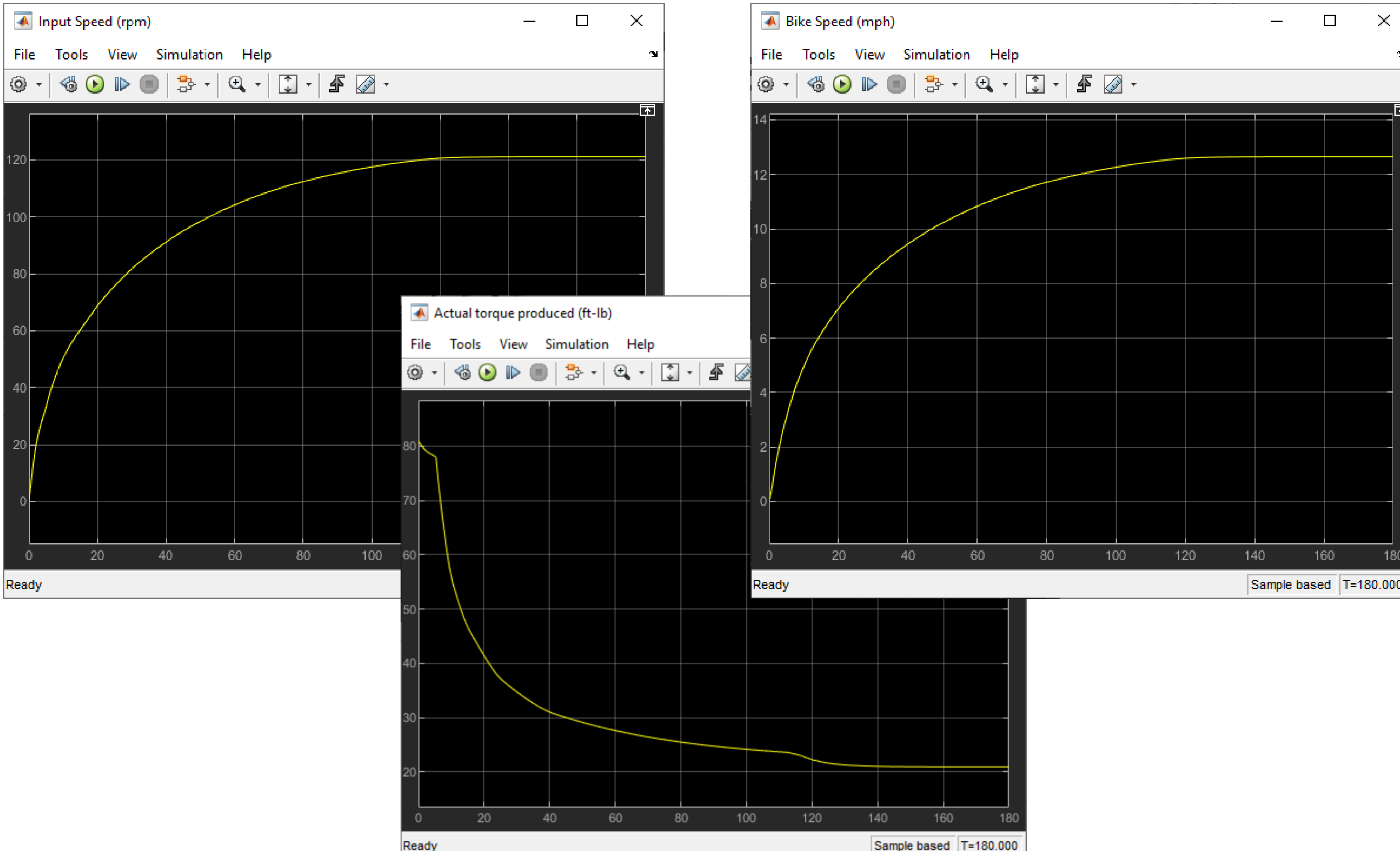
1000 psi pre-charge



Testing - Simulation



Testing - Simulation



Lessons learned

- Time management is essential
- Important to consult others and ask for help
- Application of knowledge gained in the classroom to the real world
- Adapting to adversity is often required