NFPA

Fluid Power VEHICLE Challenge

NFPA Education and Technology Foundation

Final Presentation
Premature Cavitation
Milwaukee School of Engineering
Luis A. Rodriguez
April 16, 2021

MSOE UNIVERSITY

NFPA Fluid Power VEHICLE Challenge

Team Introduction

Left to Right: Caleb Hummel, James Martin, Zachary Burrell, Riley Jones, Luis A. Rodriguez, Nathan Togstad, Yazdegard Daruwalla

Problem Statement

- Design a human powered vehicle which utilizes electro-hydraulic and electro-pneumatic technology to convert the rider's input into propulsion to compete in sprint, endurance and efficiency competitions while weighing under 210 pounds, allowing for a single rider to enter and exit without assistance, functioning safely, and implementing regenerative braking.

Objectives

- Vehicle designed to participate in all 3 competitions (Sprint race, Efficiency challenge, Endurance event)
- All aspects of the vehicle are being developed keeping the competition rules, constraints and criteria in mind.
- Our focus – The sprint challenge
- A few criteria of our own include placing 3rd or higher in all competitions

Design Objectives

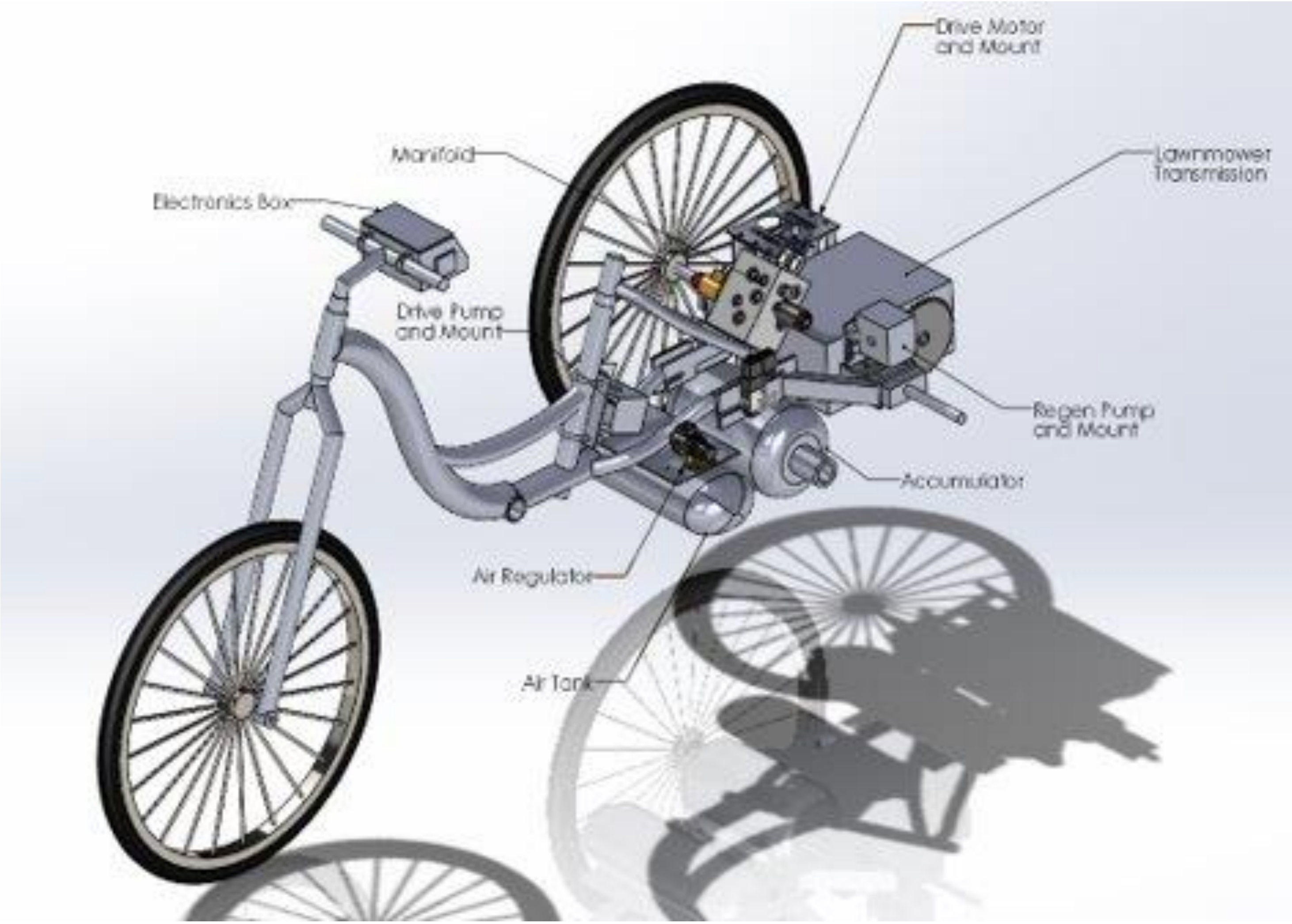
- **Competitive Design and Construction**
  - Third or better in each event
- **Technologically Advanced Design**
  - Must include electromechanical and pneumatic control
- **Stability and Safety**
  - Secure components
  - No leaks or wobbles
  - Safe to operate
- **Accessibility and Serviceability**
  - Comfortably access components
  - Accessible for maintenance

Decision Matrix used to Select Vehicle Design

Lightweight	Aesthetics	Safety	Speed	Comfortable	Ease of Fabrication	Cost	Wow Factor	Serviceability	Aero	Stability	Efficiency
3	2	8.5	9	1	3	5	2	6.5	1	6	6

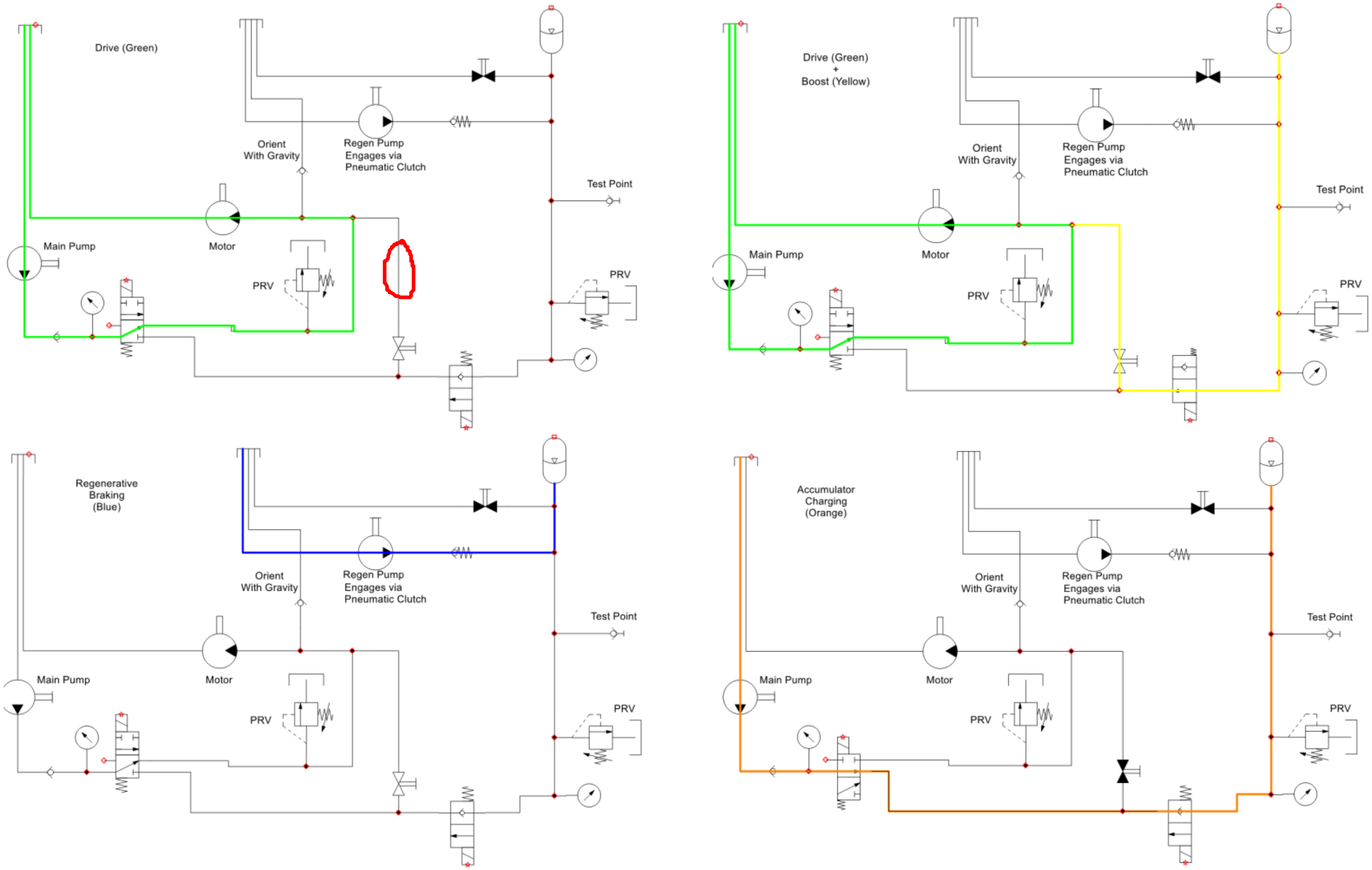
Bike Frame	Lightweight	Aesthetics	Safety	Speed	Comfortable	Ease of Fabrication	Cost	Wow Factor	Serviceability	Aero	Stability	Total
Example	2	5	6	8	3	7	9	2	9	10	4	304.5
James' Recumbent	3	7	9	6	10	10	2	7	5	6	8	299
Custom	2	4	7	6	7	3	7	9	8	6	8	295.5
James' Sprocket	6	5	4	8	5	7	8	3	3	5	4	253.5
James' Gear	6	5	7	9	5	7	8	3	3	5	4	288
Nathan Mower (Custom)	1	5	8	10	7	4	7	9	8	5	8	341
Nathan Rowing	1	5	1	10	9	1	3	10	2	7	7	212.5
Nathan Two Speed	6	5	5	8	5	7	8	5	2	5	4	257.5
Caleb Racer	6	7	7	5	5	6	9	2	4	5	4	263.5
Caleb Triple	3	5	8	5	6	8	7	4	7	5	7	295.5
Caleb Gramps	9	8	2	3	8	2	5	10	2	2	3	171
Riley Gas Frame	6	8	7	6	5	7	8	5	3	5	4	269
Riley Recumbent	3	7	9	6	10	10	2	7	5	6	8	299
Riley Cargo	4	7	4	5	6	3	5	7	8	4	8	258
Yaz Quad	2	8	10	4	10	4	4	9	10	3	10	324

Vehicle Design

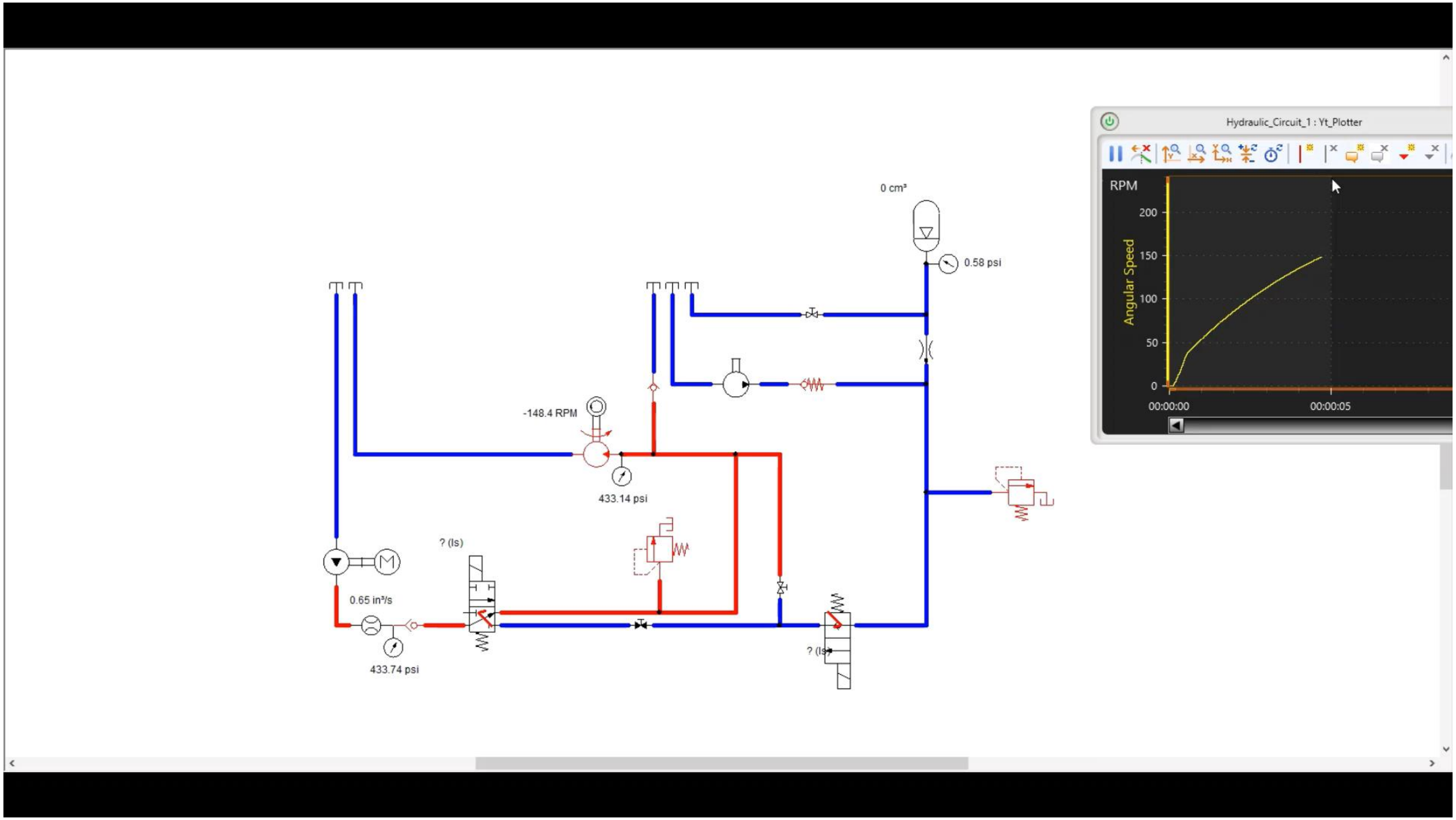


Hydraulic Circuit

Modes



Simulation



Hydraulic_Circuit_1 : Yt_Plotter
RPM
Angular Speed
200
150
100
50
0
00:00:00
00:00:05
0 cm³
0.58 psi
-148.4 RPM
433.14 psi
? (ls)
0.65 in³/s
433.74 psi

Hydraulic System: Pump Selection

- **Available Power Input from Rider**

$$T_{input} = 221 \text{ in-lb}$$

$$\omega_{input} = 80 \text{ rpm}$$

$$Power_{input} = \frac{T_{input} \cdot \omega_{input}}{63,000} = 0.28 \text{ hp}$$

- **Pump Displacement**

$$T_{pump} = \frac{T_{input}}{GR} = \frac{221 \text{ in-lb}}{5} = 44.2 \text{ in-lb}$$

$$D_{pump} = \frac{T_{pump} \cdot 2\pi}{P_{pump} \cdot \eta_{pump}} = \frac{44.2 \text{ in-lb} \cdot 2\pi}{1500 \text{ psi} \cdot 0.9} = 0.21 \frac{\text{in}^3}{\text{rev}}$$

- **Pump Flow**

$$\omega_{pump} = \omega_{input} \cdot GR = 80 \text{ rpm} \cdot 5 = 400 \text{ rpm}$$

$$Q_{pump} = \frac{D_{pump} \cdot \omega_{pump}}{231} = \frac{0.21 \frac{\text{in}^3}{\text{rev}} \cdot 400 \text{ rpm}}{231} = 0.36 \text{ GPM}$$

- **Pump Power**

$$Power_{pump} = \frac{T_{pump} \cdot \omega_{pump}}{63,000} = \frac{44.2 \text{ in-lb} \cdot 400 \text{ rpm}}{63,000} = 0.28 \text{ hp}$$

Hydraulic System: Pump Selection

Pump Selected:

Dynamic Fluid Hydraulic Gear Pump Model GP-F10-34-P-C

- 0.20 CIR Displacement
- Clockwise Rotation
- ½" Diameter Keyed Shaft
- SAE "AA" 2-Bolt Mounting Flange

Hydraulic System: Motor Selection

- **Required Motor Torque**

$$T_{wheel} = 108.21 \text{ in-lb}$$

$$T_{motor} = \frac{T_{wheel}}{GR} = \frac{108.21 \text{ in-lb}}{3} = 36.07 \text{ in-lb}$$

- **Motor Displacement**

$$D_{motor} = \frac{T_{motor} \cdot 2\pi}{P_{motor} \cdot \eta_{motor}} = \frac{36.07 \text{ in-lb} \cdot 2\pi}{1300 \text{ psi} \cdot 0.9} = 0.19 \ \frac{\text{in}^3}{\text{rev}}$$

- **Motor Speed**

$$\omega_{motor} = \frac{Q_{pump} \cdot 231}{D_{motor}} = \frac{0.36 \text{ GPM} \cdot 231}{0.19 \ \frac{\text{in}^3}{\text{rev}}} = 424.79 \text{ rpm}$$

- **Motor Power**

$$Power_{motor} = \frac{T_{motor} \cdot \omega_{motor}}{63{,}000} = \frac{36.07 \text{ in-lb} \cdot 424.79 \text{ rpm}}{63{,}000} = 0.24 \text{ hp}$$

- **Vehicle Speed**

$$v_{vehicle} = \frac{2\pi \cdot \omega_{motor} \cdot r_{wheel}}{\text{GR} \cdot 1056} = 10.95 \text{ mph}$$

Hydraulic System: Motor Selection

Motor Selected:

Dynamic Fluid Hydraulic Gear Motor Model GM-F10-34-P-C

- 0.20 CIR Displacement
- Clockwise Rotation
- ½" Diameter Keyed Shaft
- SAE "AA" 2-Bolt Mounting Flange

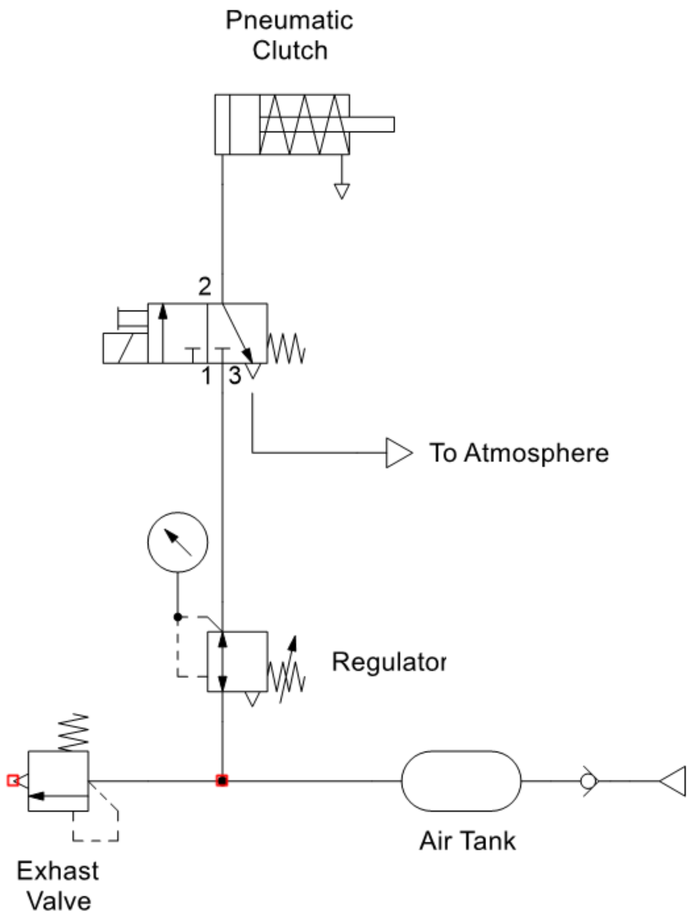
Hydraulic System: Accumulator Selection

Accumulator Selected:

Hydac Bladder Accumulator Model SB330-4A1/112S-210C

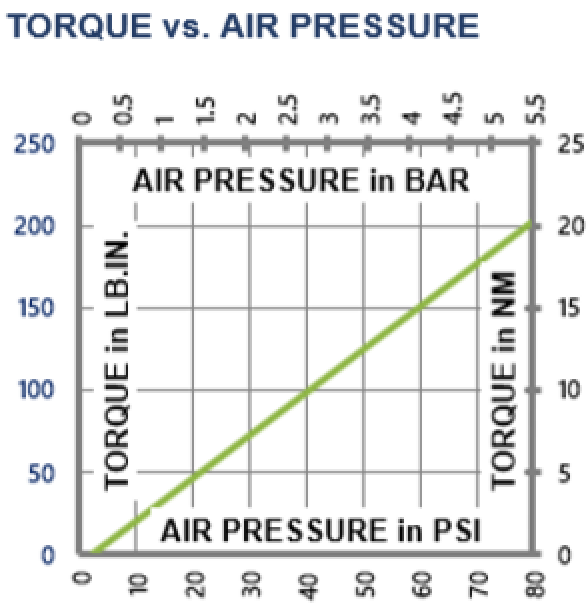
- 1 Gallon Bladder Accumulator
- 3000 psi Maximum Pressure
- 160 GPM Maximum Flow Rate
- Operating Temperature: 5 °F - 180 °F

Pneumatic Circuit Layout



Components:
- 1 Gallon Tank
- Exhaust Valve
- Quick-connect intake valve
- Pressure Gauge
- Pressure Regulator
- Solenoid Controlled Valve
- Pneumatic clutch
- ¼” Air line

Pneumatic Clutch

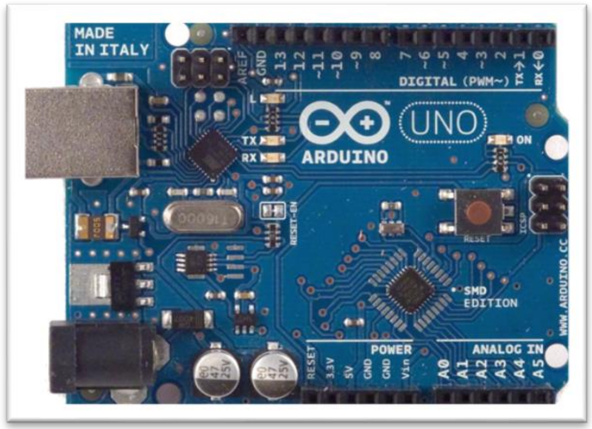


Mach III C2D2R-STH

- 200 in/lb @ 80 psi
- Air engagement, spring return
- 2 friction disks
- New Capacity – .10 cubic inches
- Worn air Capacity - .24 cubic inches

Electronics And Controls – Key Components

Milwaukee Tool 18V Li-ion Battery

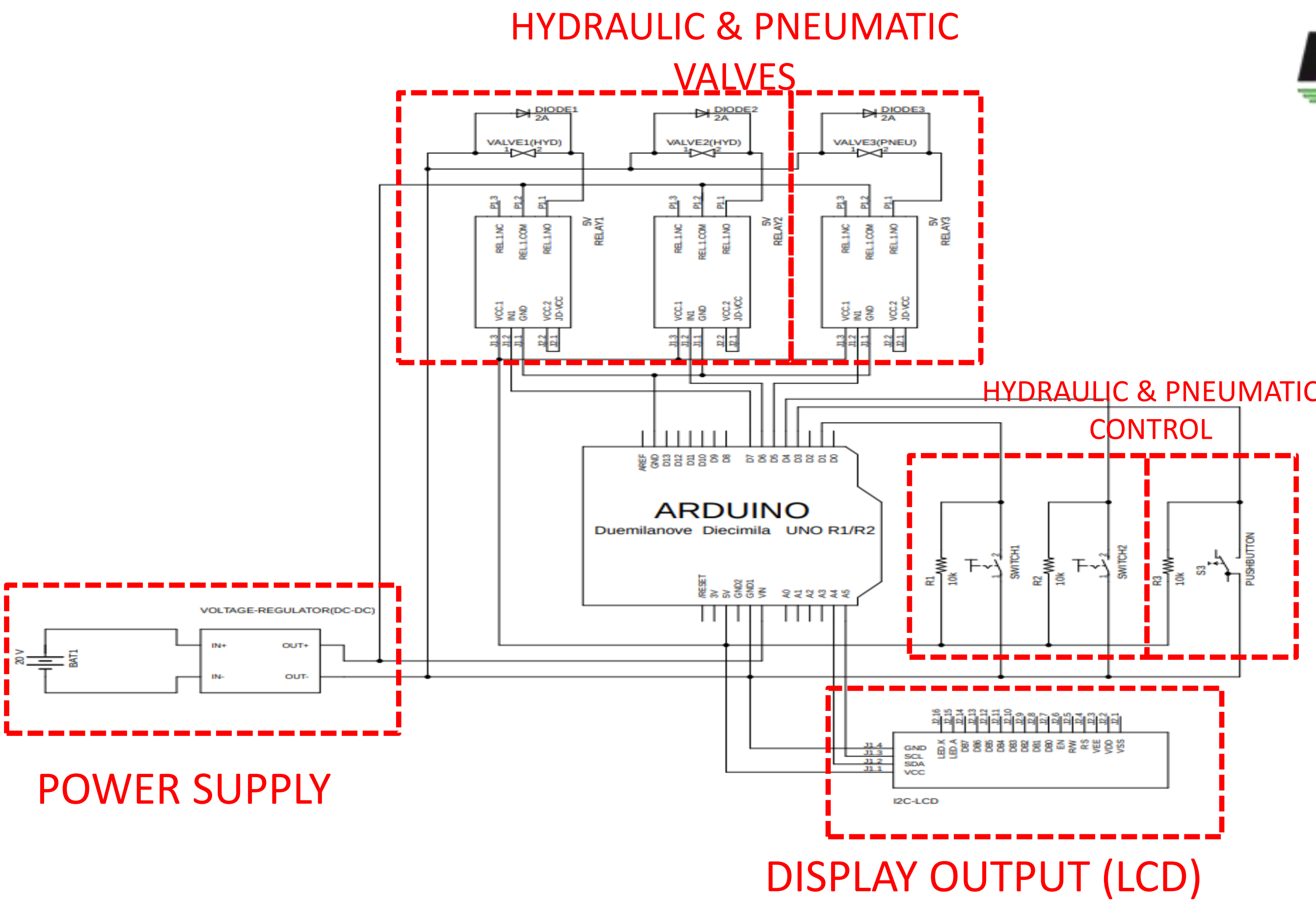


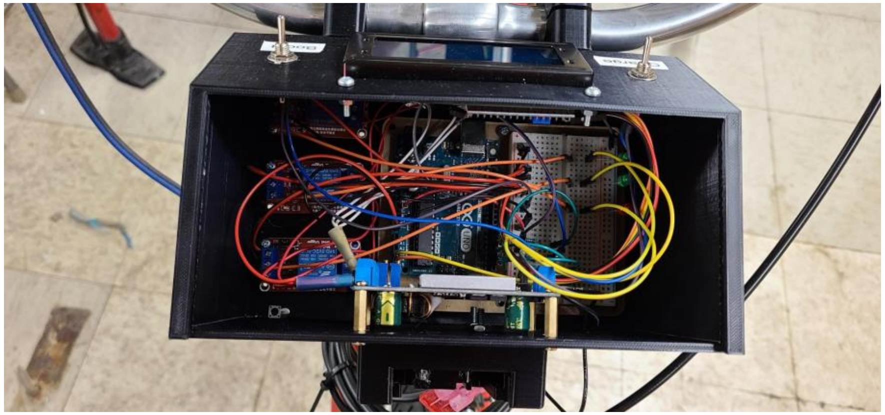
Arduino Uno Microcontroller

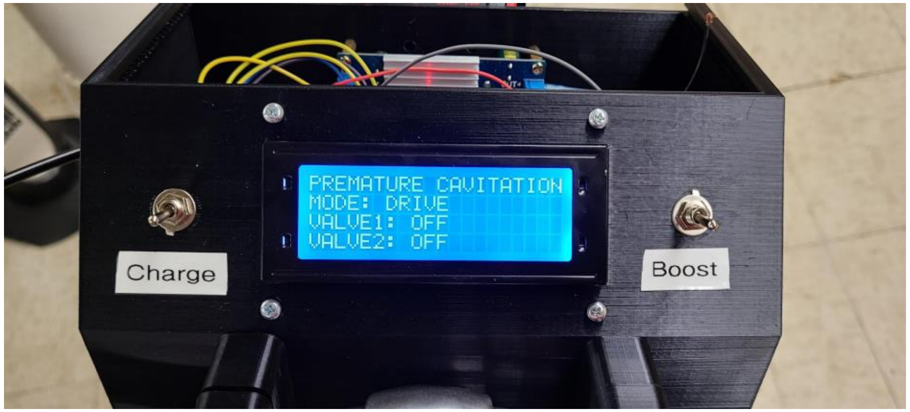
5V Relay Module

Toggle and Pushbutton Switches

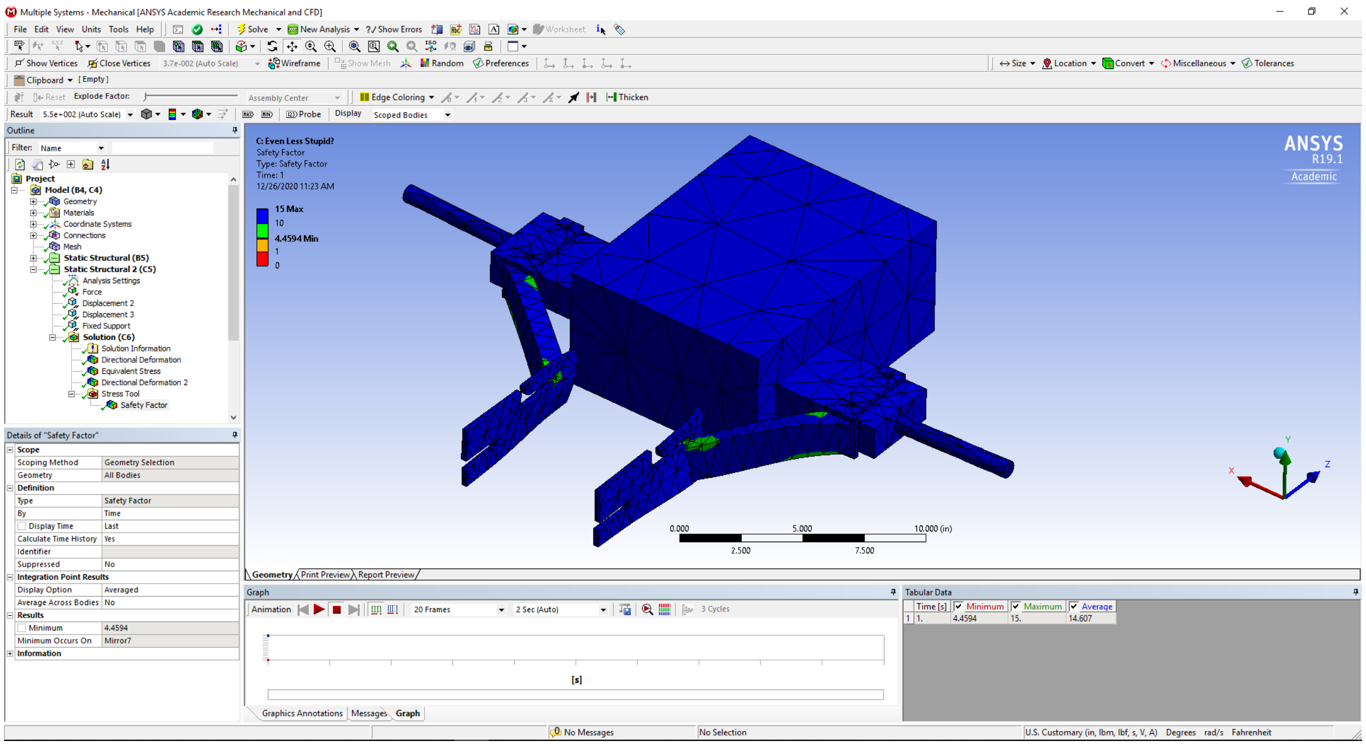
I2C LCD Display Module


HYDRAULIC & PNEUMATIC VALVES
DIODE1 2A
DIODE2 2A
DIODE3 2A
VALVE1(HYD)
VALVE2(HYD)
VALVE3(PNEU)
5V RELAY1
5V RELAY2
5V RELAY3
HYDRAULIC & PNEUMATIC CONTROL
ARDUINO
Duemilanove Diecimila UNO R1/R2
SWITCH1
SWITCH2
PUSHBUTTON
VOLTAGE-REGULATOR(DC-DC)
IN+
IN-
OUT+
OUT-
20 V
BAT1
POWER SUPPLY
I2C-LCD
DISPLAY OUTPUT (LCD)

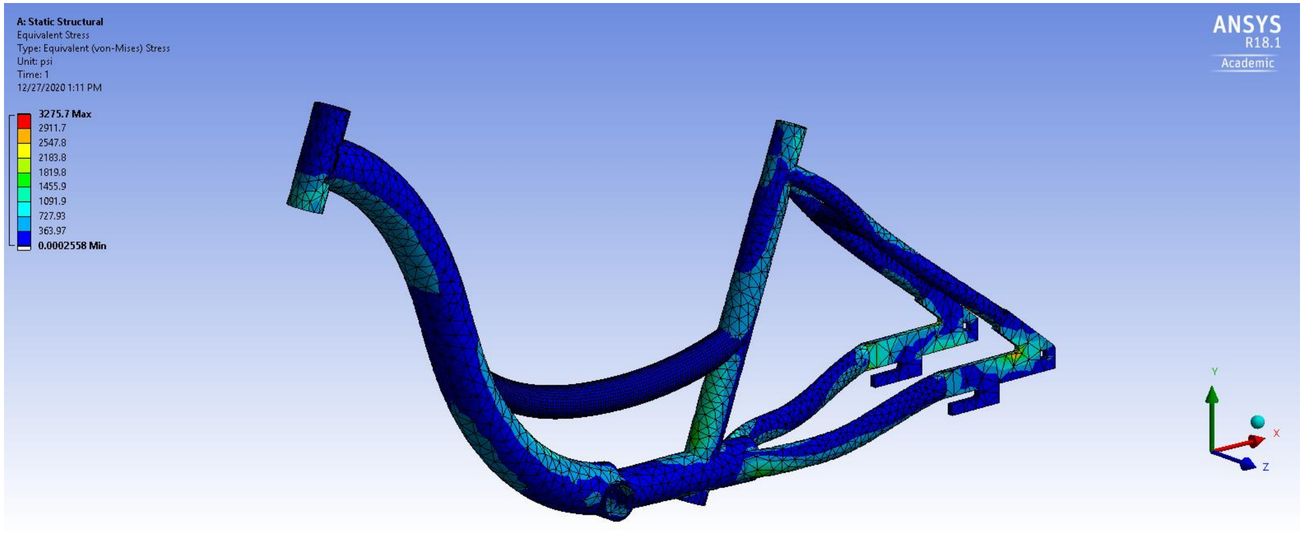



PREMATURE CAVITATION
MODE: DRIVE
VALVE1: OFF
VALVE2: OFF
Charge
Boost

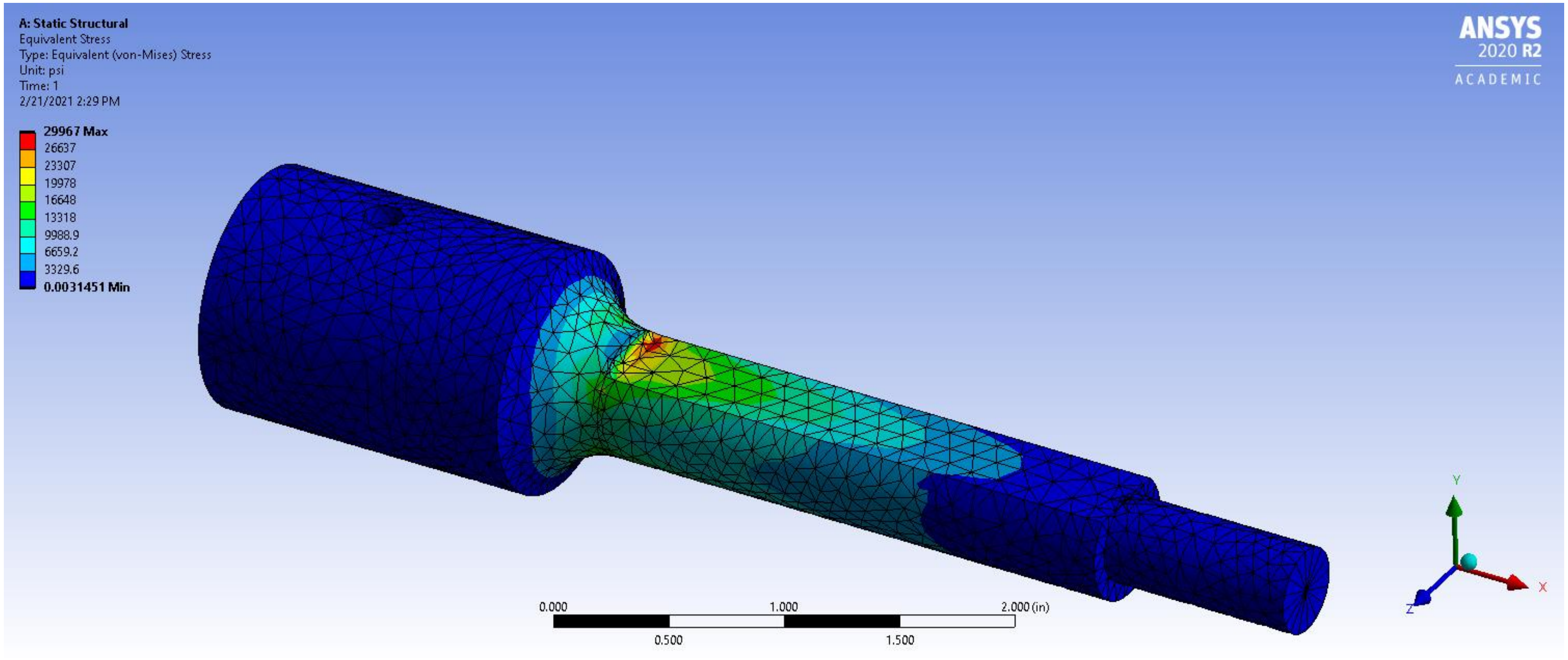
Transmission Adapter



Trike Frame FEA Analysis



Wheel Adapter FEA Analysis



Vehicle Construction

Rear-End Adapter Welding

Revisions during assembly

- Accumulator and pneumatic tank placement
- Motor orientation
- Pump mount bracing
- Welding wheel adapters and accumulator brackets
- Shifting mechanism

Progress Made Toward Final Vehicle

- Final Vehicle Completed

- Design appears reliable
  - No malfunctions during competition events
  - No component failure under high-stress loading

- Design appears safe
  - Most moving parts (i.e., chains and sprockets) are located away from the rider
  - Mechanical brakes can stop vehicle with full accumulator charge
  - If electronics malfunction, the vehicle will default into the “drive” mode

Lessons Learned

- Bigger Electronics Box
- Plan Line Paths
- Add check valve
- Clutch Placement and Gear Ratio
- Too Much Rotational Inertia
- Material Selection/Use the Correct Alloy in ANSYS
- Placement and Orientation Matters
- Take Fluid Power Circuits Before Building Fluid Power Bike

Acknowledgements

- Mike Helbig
- Luis A. Rodriguez
- National Fluid Power Association
- SunSource
- Iowa Fluid Power
  - Chandler Armstrong
  - Josh Scarbrough

Questions