# NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation


FINAL PRESENTATION
PURDUE UNIVERSITY
Dr. Jose Garcia-Bravo
April 15, 2020


PURDUE UNIVERSITY

# Agenda

- Project Importance
- Hydraulic Drivetrain Design
- Sizing of Hydraulics
- Electronic Control System
- Pneumatic Design
- Frame Design
- Vehicle Construction
- Lessons Learned

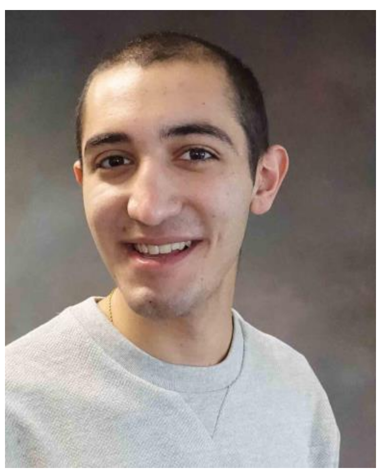
AGENDA

# Team Members

Alec Watkins

Yixuan Liu

Nick Moss



Ilyas Yilgor

Nicholas Formica

# Technical Advisor

Dr. Jose Garcia-Bravo

# Project Importance

- Gain first-hand experience with hydraulic systems and components
- Learn to design in a manufacturing environment
- Use CAD software for conceptual design
- Understand all phases of the design process
- Test and diagnose hydraulic and mechanical issues
- Work together as a diverse team

# Summary of Last Semester's Progress

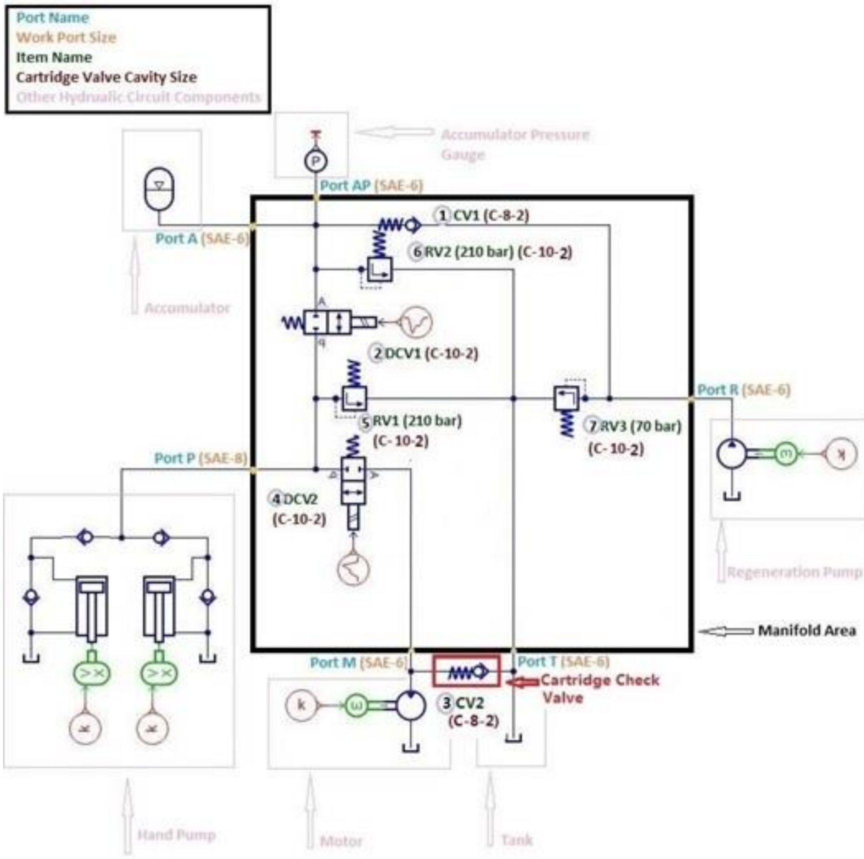
| | Weight | Handling | Cost | Customizable | Strength | Appearance | Safety | Total Score |
|---|---|---|---|---|---|---|---|---|
| Scores | 0.15 | 0.05 | 0.05 | 0.2 | 0.2 | 0.1 | 0.25 | 1 |
| Classic 2-Wheel | 3 | 2 | 3 | 2 | 2 | 2 | 2 | |
| | 0.45 | 0.1 | 0.15 | 0.4 | 0.4 | 0.2 | 0.5 | 2.2 |
| Recumbent Trike | 2 | 3 | 2 | 4 | 4 | 3 | 4 | |
| | 0.3 | 0.15 | 0.1 | 0.8 | 0.8 | 0.3 | 1 | 3.45 |
| Four Wheeler | 1 | 4 | 1 | 3 | 3 | 1 | 3 | |
| | 0.15 | 0.2 | 0.05 | 0.6 | 0.6 | 0.1 | 0.75 | 2.45 |
| Elliptigo | 4 | 1 | 4 | 1 | 1 | 4 | 1 | |
| | 0.6 | 0.05 | 0.2 | 0.2 | 0.2 | 0.4 | 0.25 | 1.9 |


- CAD partially done
- Most of Hydraulic Parts ordered
- FEA and AMESIM analysis
- Hydraulic Circuit Completed
- Overestimated a rider of 100 kg, with weight distributed uniformly along the seat.
- Static FOS of 5
- Fatigue FOS for 300 km of 2.4

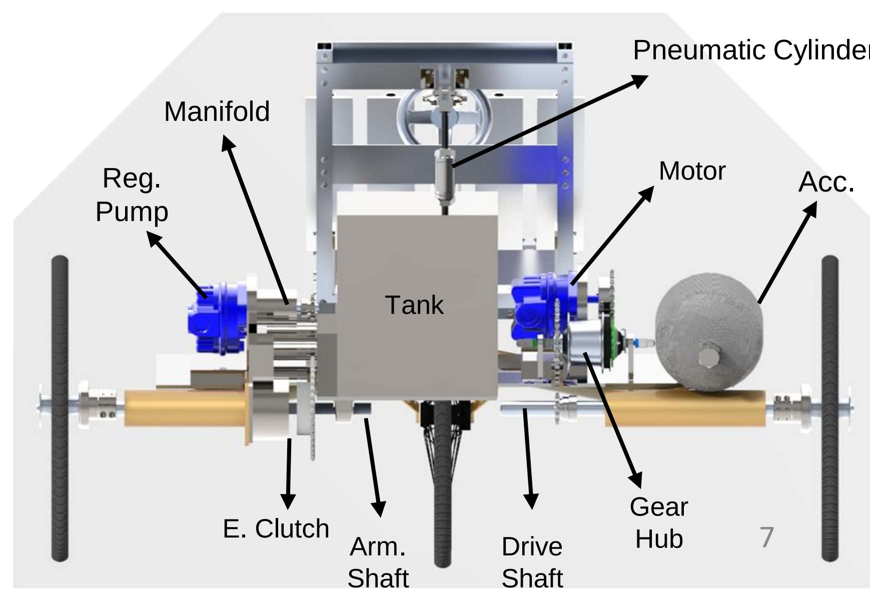
| | |
|---|---|
| Poisson's Ratio ($\nu$) | 0.33 |
| Young's Modulus ($E$) | 68.9 GPa |
| Tensile Yield Stress ($\sigma_y$) | 276 MPa |
| Ultimate Tensile Stress ($\sigma_{ut}$) | 310 MPa |

Table 1: Material properties used for 6061 aluminum [1].

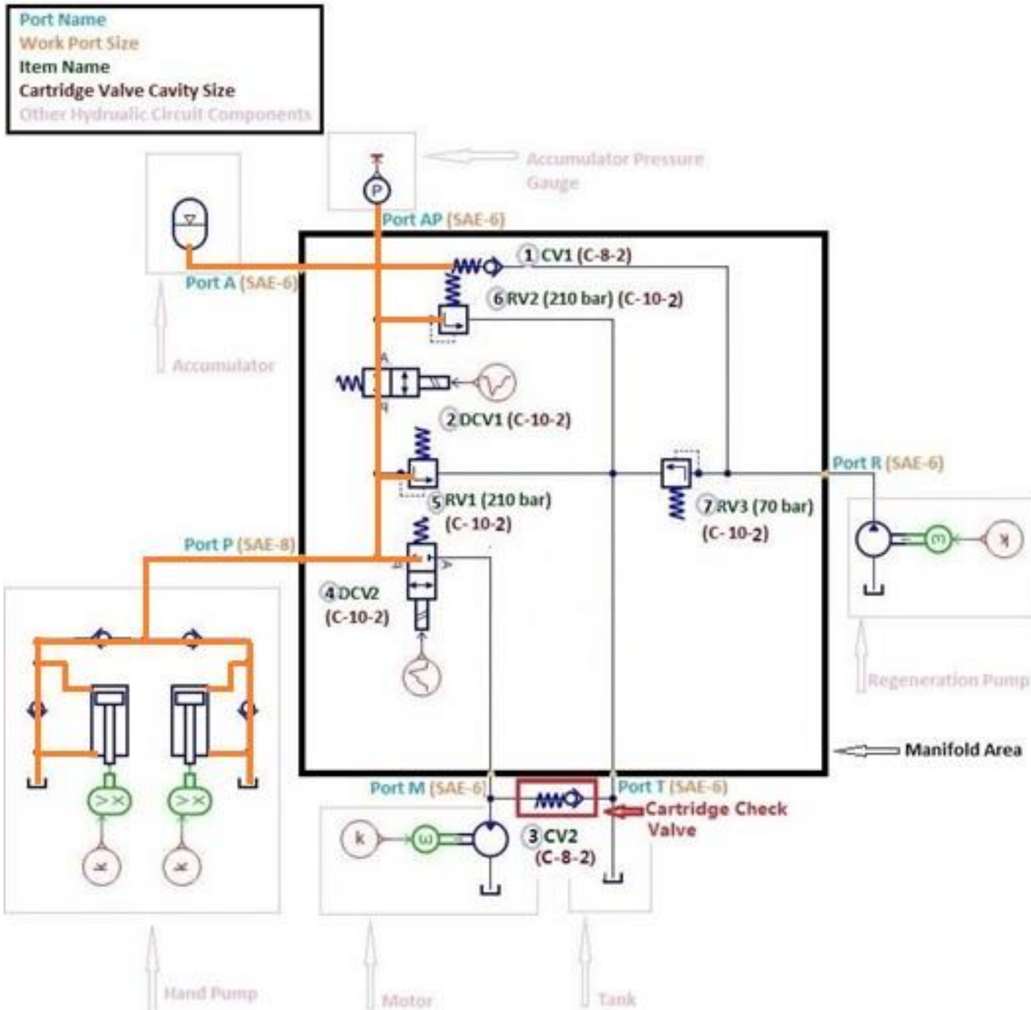
# Final Hydraulic System Design



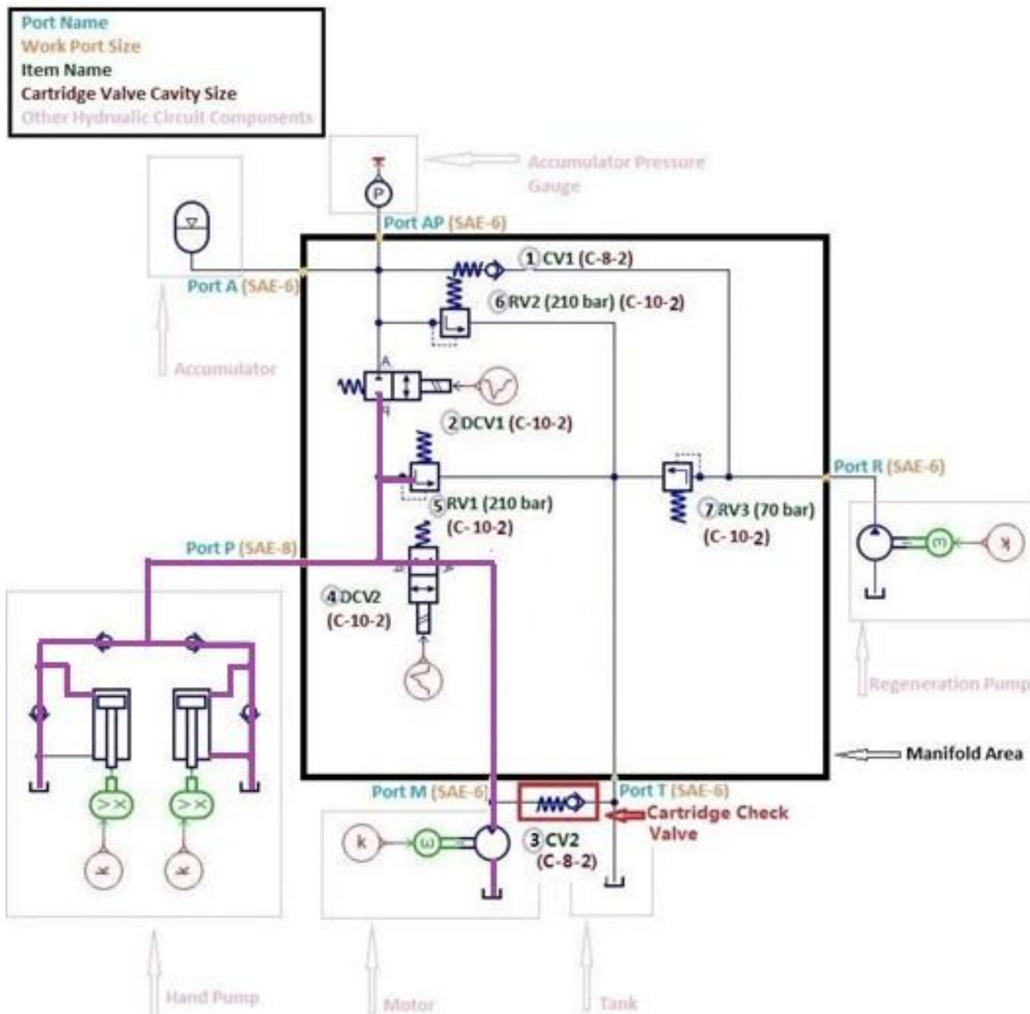

| Modes | DCV1 | DCV2 |
|---|---|---|
| Charging | on | off |
| Pedaling | off | on |
| Boosting | on | on |
| Regeneration | off | off |



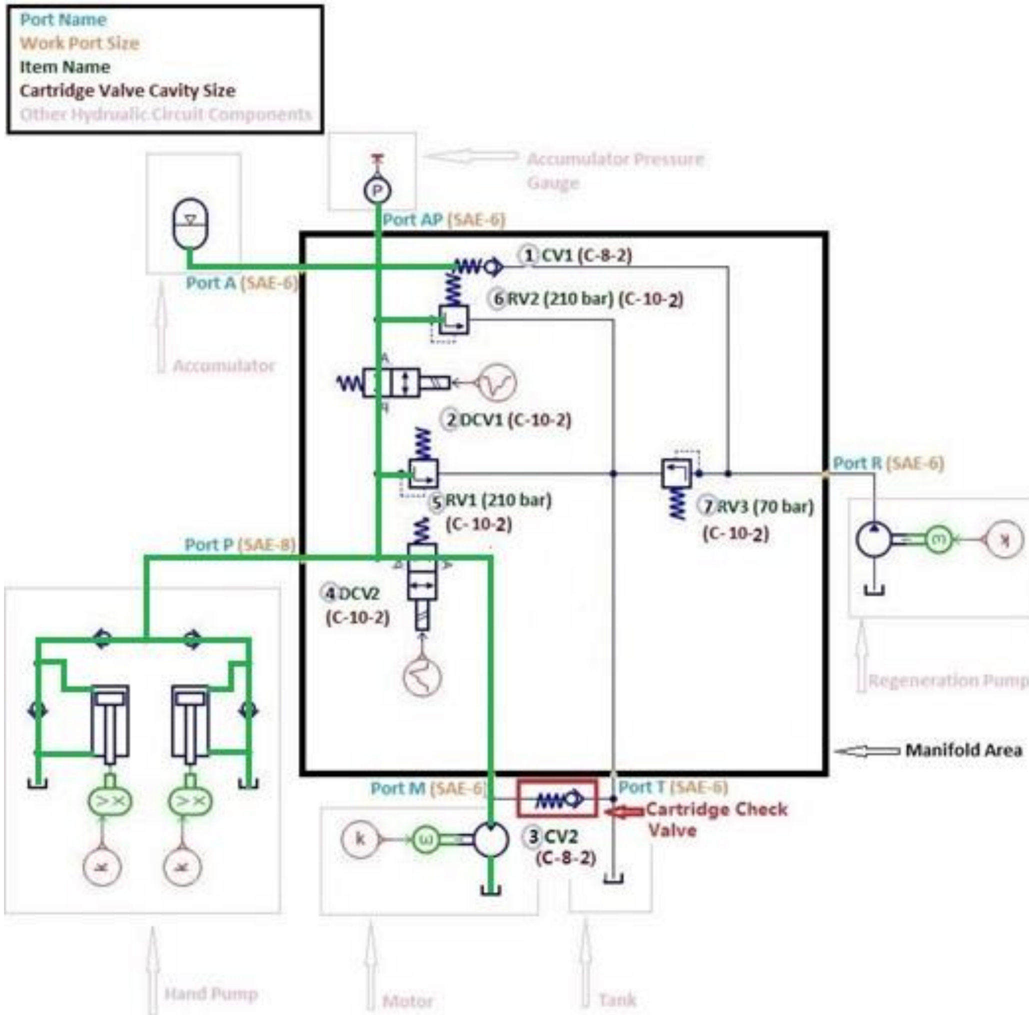
# Charging Mode



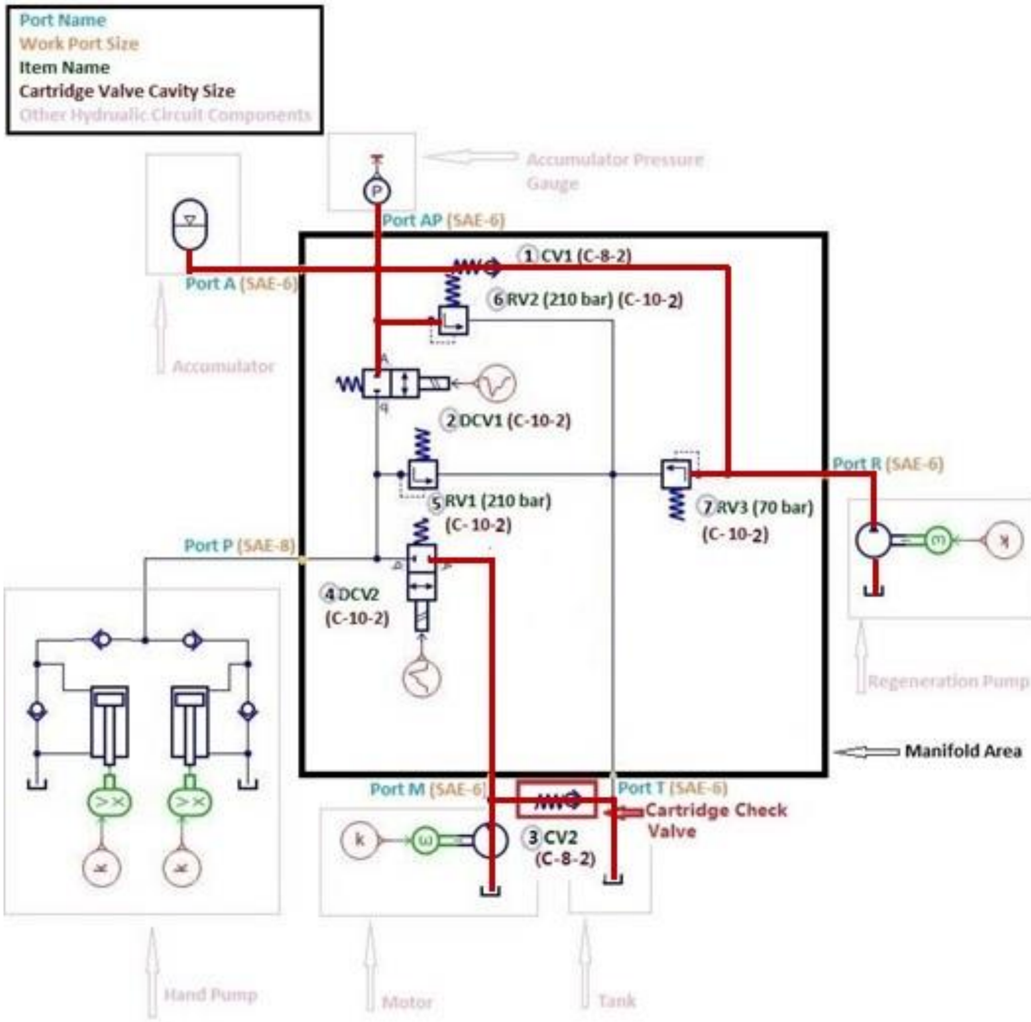
# Pedaling Mode



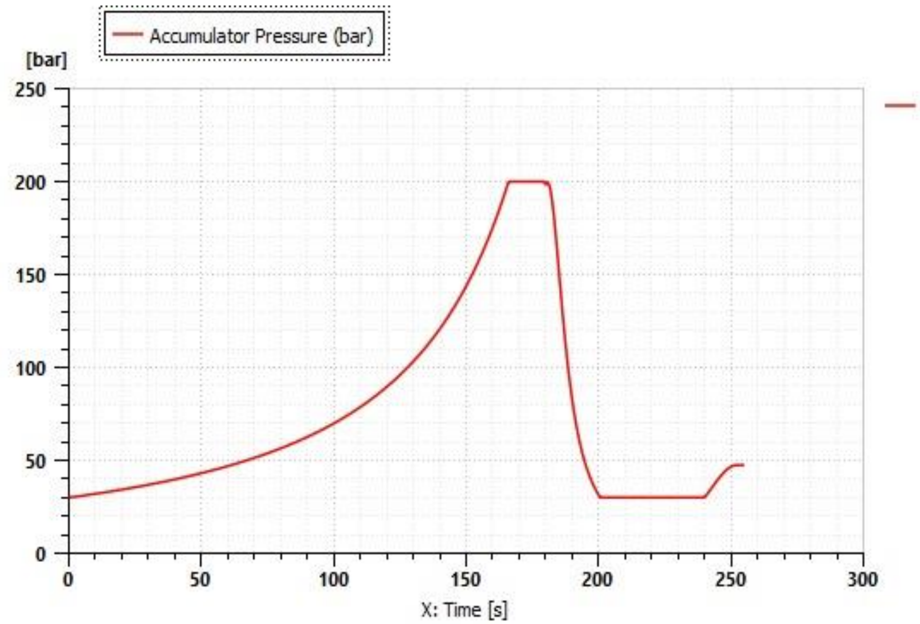
# Boosting Mode

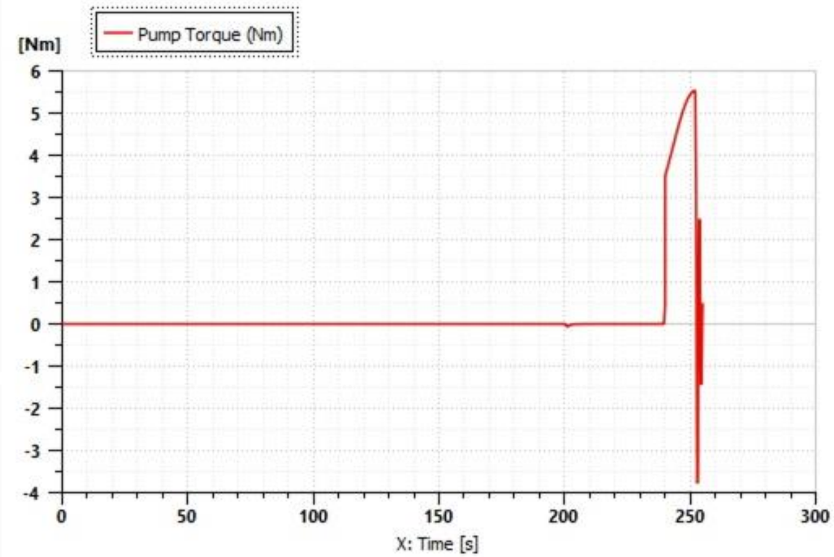


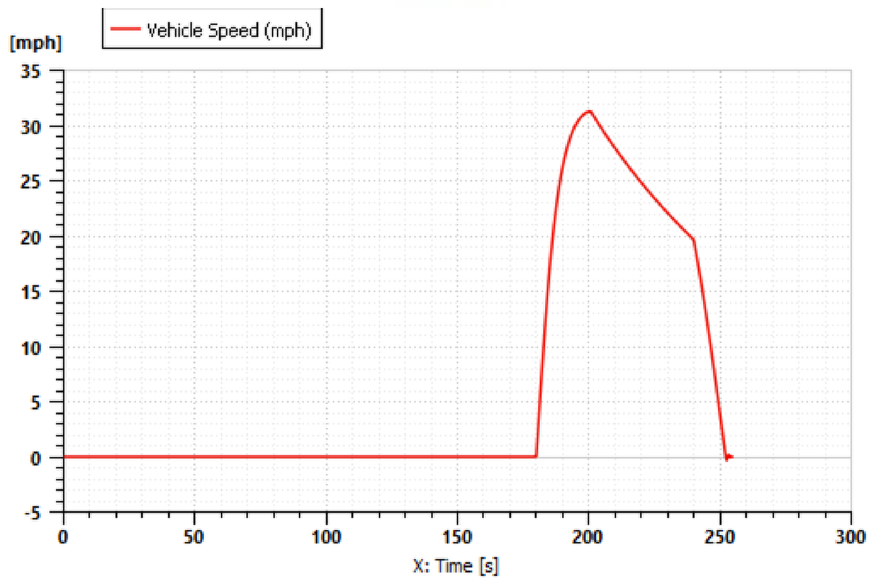
# Regeneration Mode

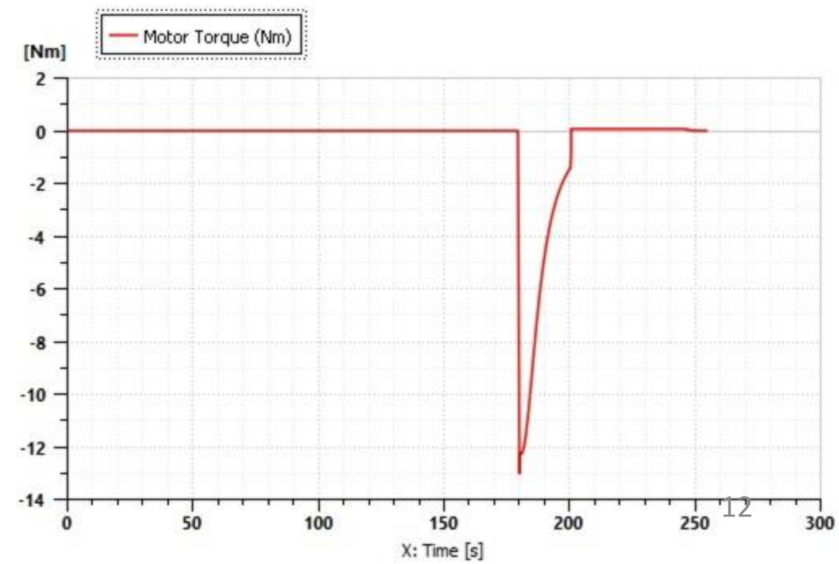


# Simulation Results

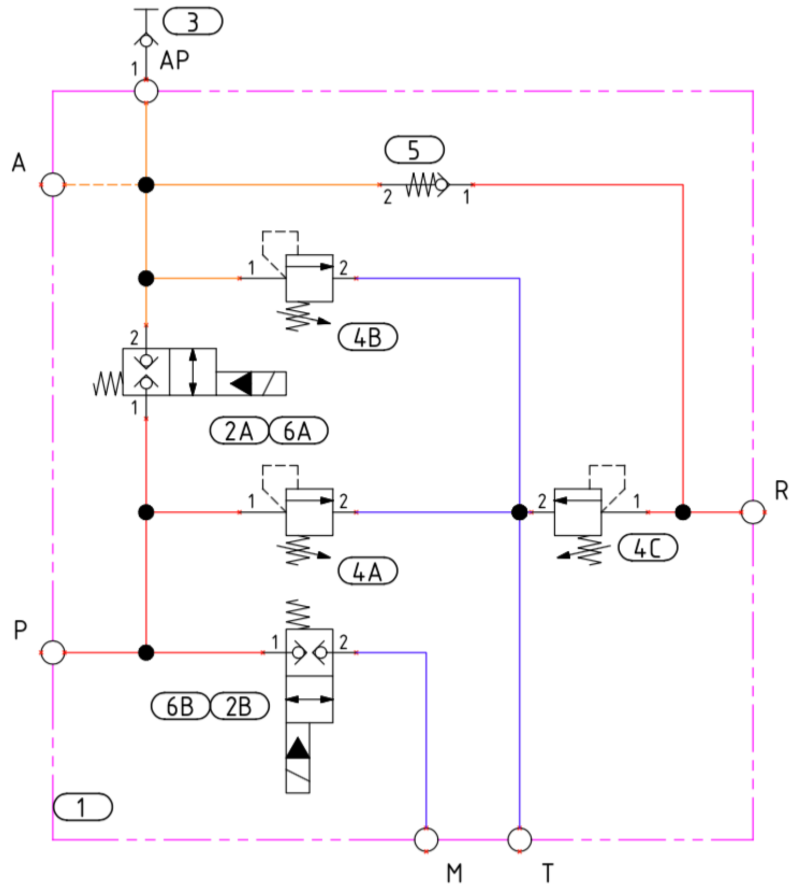


# Manifold Design




| ITEM ID | PORT TYPE | PORT SIZE |
|---|---|---|
| A, AP, M, R, T | SAE O-RING | #6 SAE |
| P | SAE O-RING | #8 SAE |

Note:
-3000 PSI max
-Team to procure all BOM items listed seperately
-Team to install all BOM items

| Item | Qty | Model Code | Description | Manufacturer |
|---|---|---|---|---|
| 1 | 1 | FV-13436-M1 | Manifold body, aluminum | SunSource |
| 2 | 2 | SBV1-10-C-0-00 | Solenoid 2 pos. 2 way | Eaton |
| 3 | 1 | D1620-01-06SAE | Test Point Fitting, M16 x 2 | Dynamic |
| 4 | 3 | RV1-10-S-0-30 | Relief Direct Acting | Eaton |
| 5 | 1 | CV3-8-P-0-004 | Check 1-2, 4 PSI Spring | Eaton |
| 6 | 2 | 300AA00081A | Coil 12VDC, DIN | Eaton |

SUNSOURCE

| | | |
|---|---|---|
| Creation Date 1/2/2020 | Drawn By J. McCarthy | Customer Name Purdue |
| Material Aluminum | Print Checked By D. Rikala | Title NFPA FPVC 19-20 |
| Protective Finish None | Sheet Name Sheet 1 of 1 | Part Number FV-13436-V1 schem |
| Size B Dimensions are in inches. | Third Angle Projection | Proprietary and Confidential Rev A |

Thank you SunSource

JIC-6 fittings used whenever possible

# Sizing of Hydraulic Components

- Relief Valves: 200 bar cracking pressure to maximize vehicle performance/boosting; 210 bar manifold limit
- Accumulator: 1 gallon due to competition constraints and 30 bar precharge based on Amesim simulations
- Motor sized to be as small as possible (6.6 cc/rev) based on equation: $$n = \frac{Q_{actual} \cdot e_{volumetric}}{V}$$
- Regeneration pump sized to be 6.6 cc/rev based on equation: $T = V_m \cdot \Delta P_m$
- Tank volume sized to be 2 gallons based on calculations:

$$\mathrm{V_{tank}} = \mathrm{FS} \cdot \mathrm{V_{sys,max}} \cong \mathrm{FS} \cdot (\mathrm{V_{accum,max}} + \mathrm{L} \cdot \frac{\pi}{4} \cdot \mathrm{D}^2) = 2 \cdot (0.793 + 0.133)\mathrm{gal.} \cong 2\mathrm{gal.}$$

# Hydraulic Design - Components

| Description | Manufacturer | Part Number | Install in Line Body Part Number: |
|---|---|---|---|
| Gear Motor, 0.43 CID, Keyed Shaft, .625" SAE A mount, CW rotation, external case drain. Code: ADMAR01AMA01AD0000000B0A | Eaton | 26701-RSC | |
| Pump, Lever Operated, Push to pump, .601 CID | Doering | 241871-S | 876700 |
| Gear Pump, 0.4 CID, 9 tooth spline SAE A mount, CW rotation. Code: ACNAR01AAA0030000000000A | Eaton | 26001-RZJ | |
| Pump Handle, Doering | Doering | 241016 | |
| Relief, Direct Acting | Eaton | RV1-10-S-0-30 | 876700 |
| Check, 1 to 2 | Eaton | CV3-8-P-0-004 | 02-160731 |
| Solenoid, 2 pos. 2 way Bi-poppet, normally Closed | Eaton | SBV1-10-C-0-00 | 876700 |

# Hydraulic Components

Motor
Displacement: 6.6 cc/rev

Regeneration Pump
Displacement: 6.6 cc/rev

Hand Pump

# Hydraulic Components


Two gallon
Tank

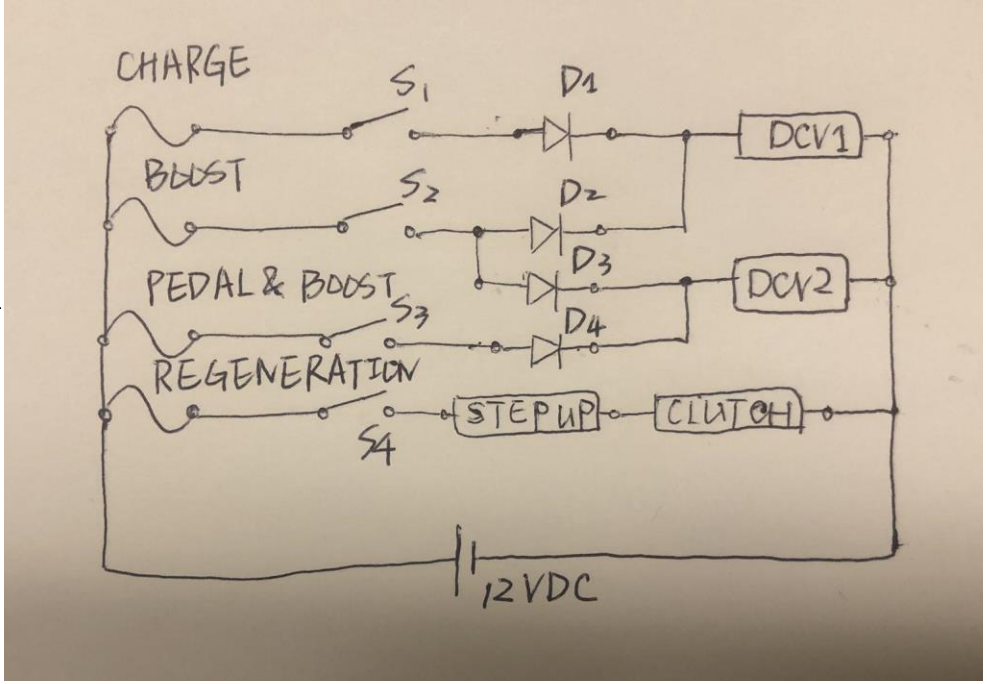

Accumulator

# Electrical System Design

Circuit Parameters:

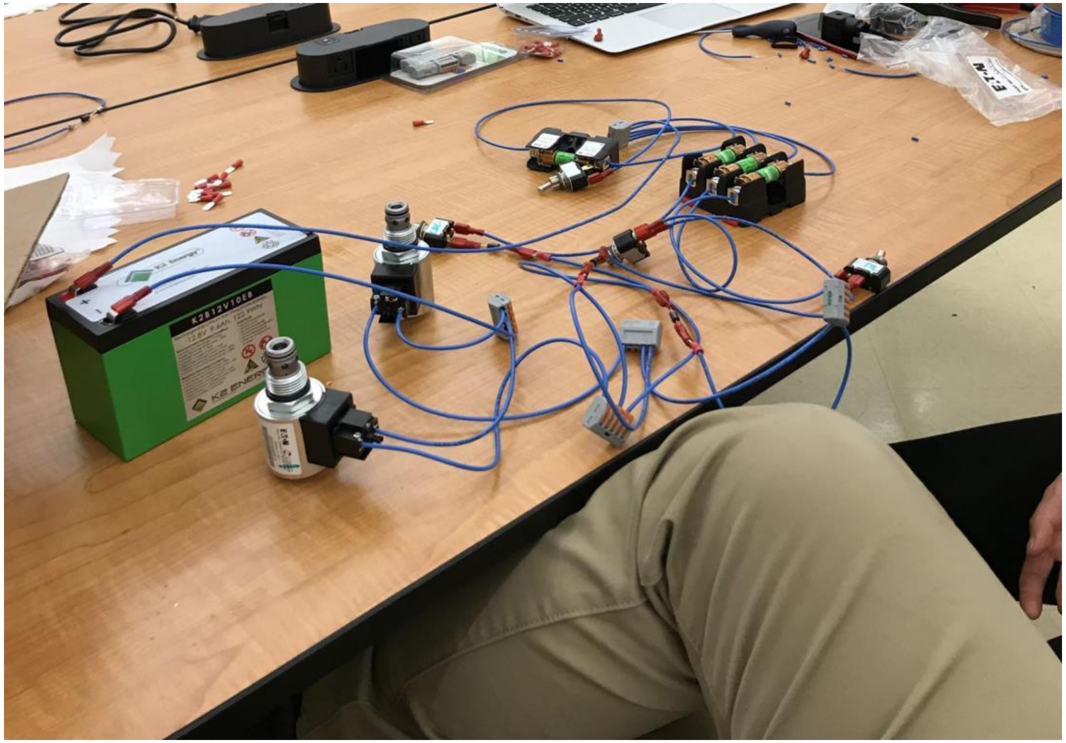
- Battery: IMax = 12A;
  V = 12VDC
- Clutch: I = 0.322A;
  V = 24V
- DCV 1&2: I = 1.92A;
  V = 12V
- Max Switch Current: 6A
- Max Wire (18 awg) Current: 7.0A
- IN5404 Diodes: Imax = 200A

| Modes | DCV1 | DCV2 |
|---|---|---|
| Charging | on | off |
| Pedaling | off | on |
| Boosting | on | on |
| Regeneration | off | off |



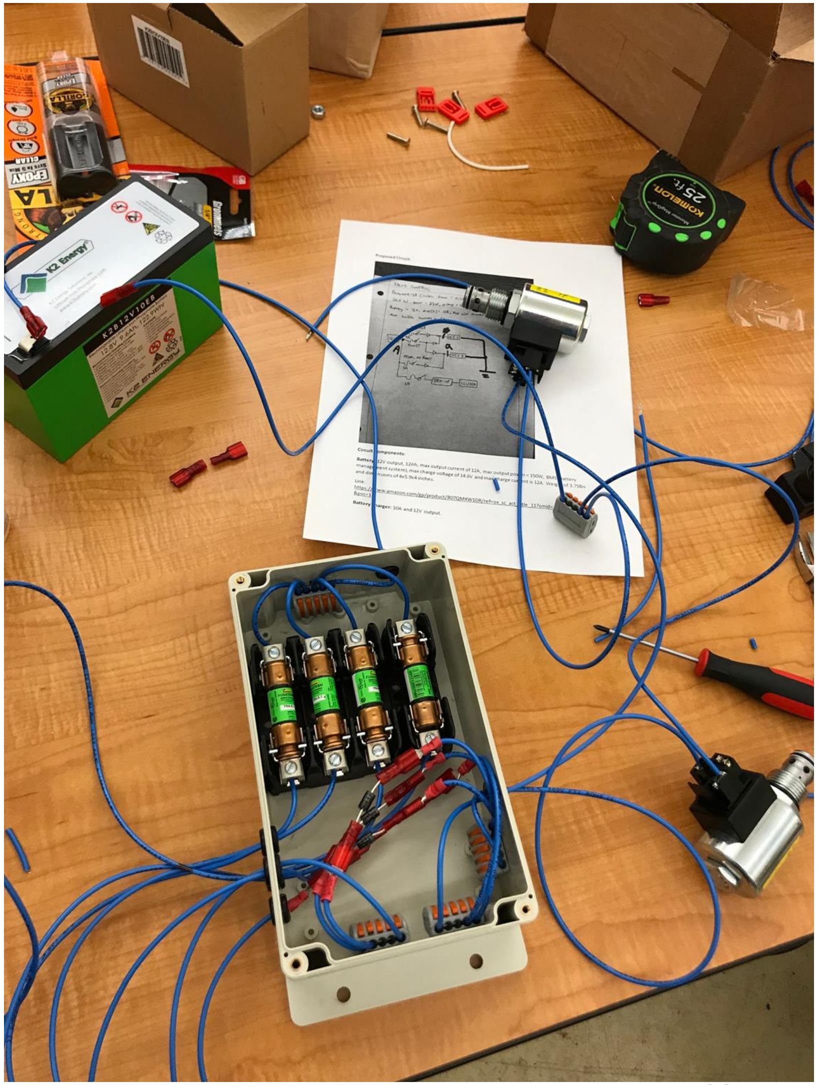
# Prototype Testing - Electrical System

- Male & Female Quick Disconnect (single, 22-18 AWG)
- Metric Stranded Wire (18 AWG, Blue, 50 ft)
- Li-Ion Battery (12V, 9Ah, Quick Disconnect Tab)
- Charger for 12V Large-Cell Battery
- UL Class RK5 Fuse (5A, 250V AC/125V DC)
- UL Class RK5 Fuse (1A, 250V AC/125V DC)
- Fuse Block (for 3 RK1 & RK5 1-30A, 250V DC)
- WAGO Lever Nuts used as Electrical Nodes



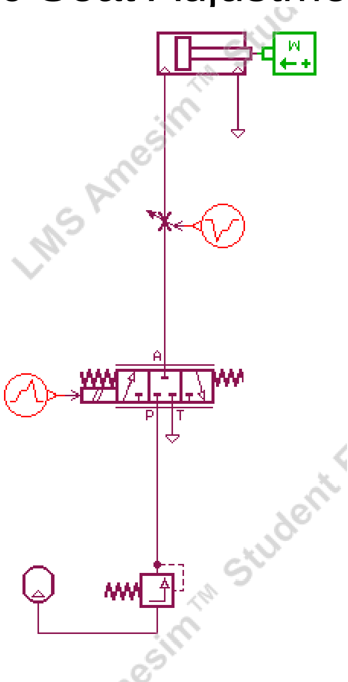
# Final Electrical System

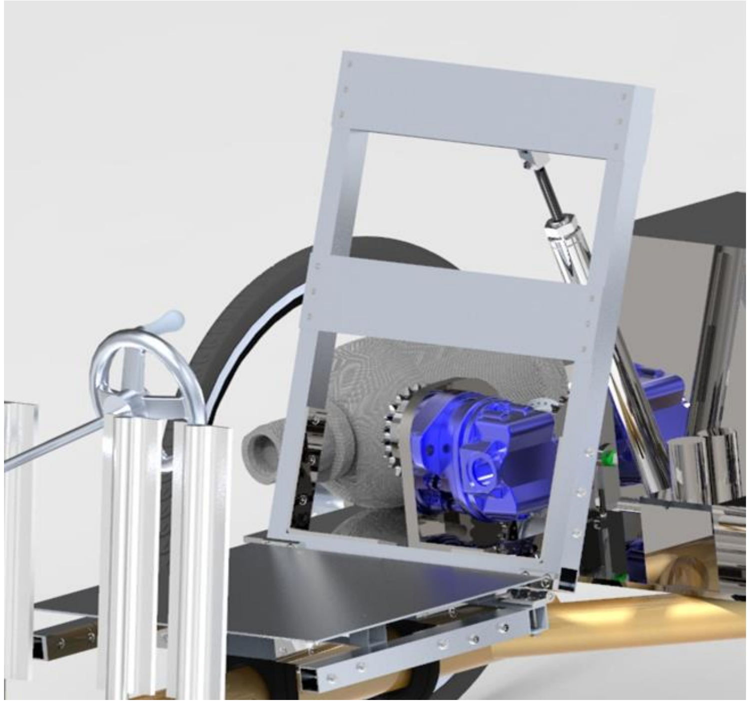
- All components secured inside IP65 box
- Superglued nodes and fuse boxes
- Put electrical tape on diodes
- Grommets to protect wire and epoxy to waterproof grommet holes
- Desired valve actuation achieved
- Still needed to mount switches onto plate/box near handlebars & secure battery inside another box



# Pneumatic Design

Pneumatic Seat Adjustment



- 6 inch stroke with 1.25 inch bore size.
- Max system psi of 100 with pressure regulator
- Hand pump to compress air into tank
- Mechanical switch near the seat.
- Adjust orifice size to change speed of recline
- 30 degrees of seat adjustment.

Thank you! IMI/BIMBA

# Pneumatic Design

$$t = V\,(p_1 - p_2) / C\,p_a$$

t = Time

V = Volume of Tank

$p_1$ = Maximum Pressure

$p_2$= Minimum Pressure

C = Free air needed

$p_a$ = Atmospheric Pressure

t = 11.64 cycles

V = 1.23 cubic inch

$p_1$ = 100 psi

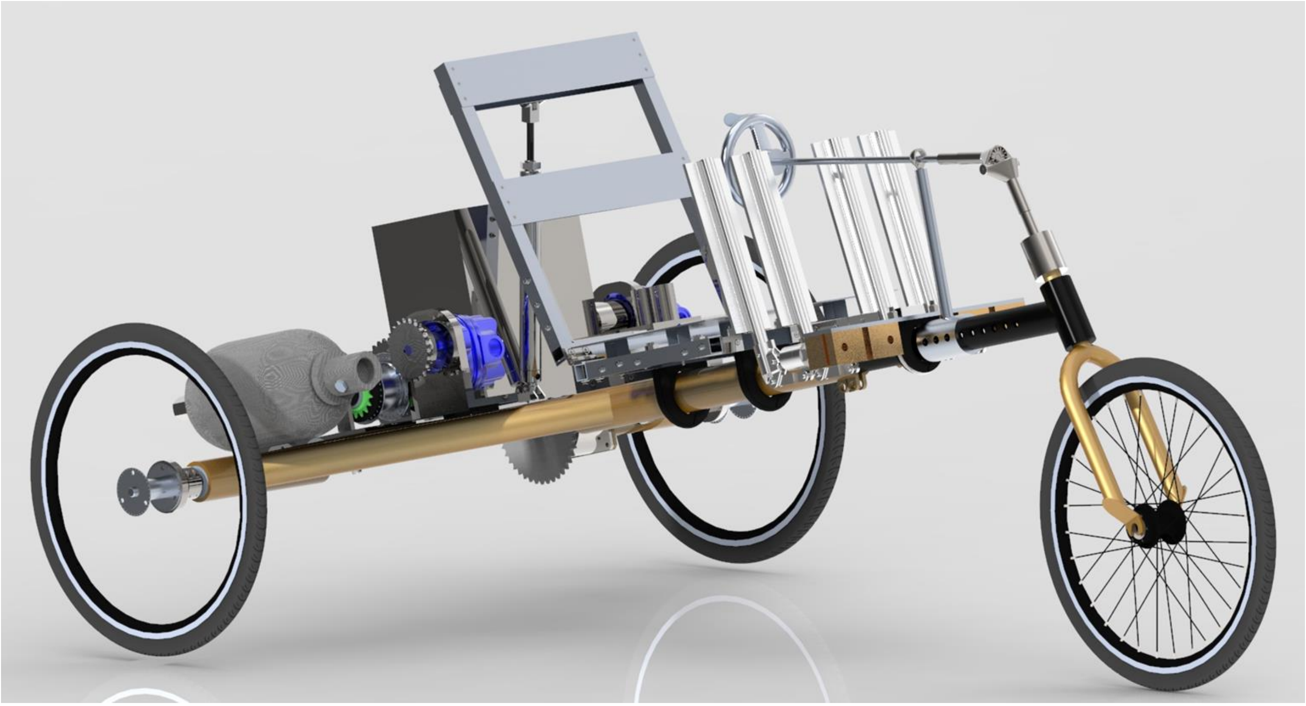
$p_2$ = 14.7 psi

C = .613 cubic inch/extension

$p_a$ = 14.7 psi

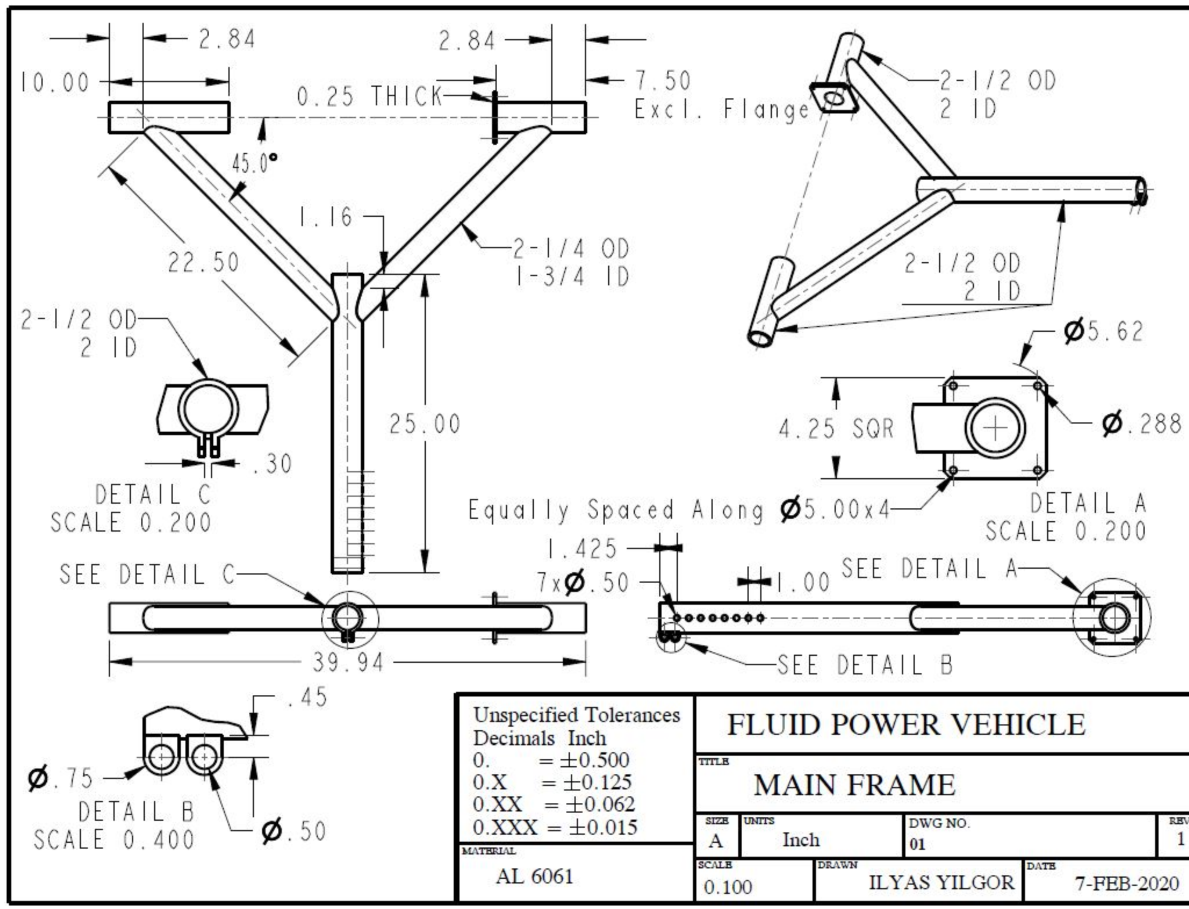
- 0.613 cubic inch represents the volume of inside cylinder at max extension
- Since it is not continuous flow, t can be replaced with the number of max extensions.
- Loses air during valve switch, less cycles than expected

# Mechanical Components



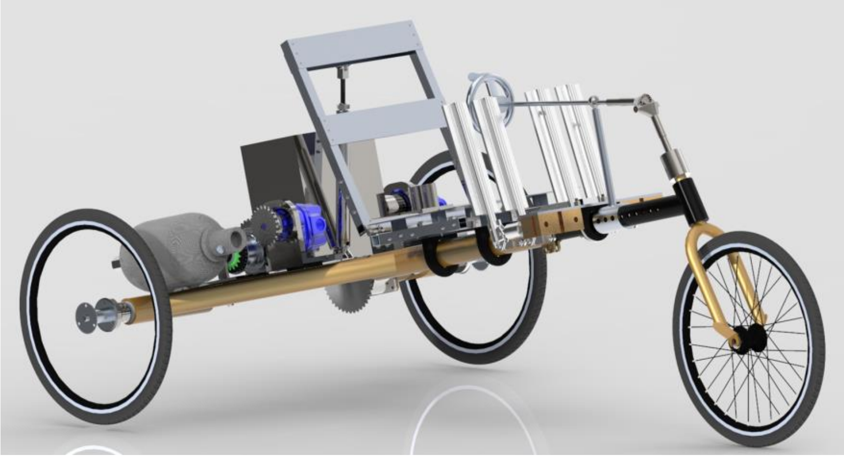
# Main Frame

- 5 aluminum 6061 tubings welded together
- Flange to mount electric clutch for regeneration purposes.
- Has pin holes and tighteners for the telescopic extension.
- Provides just enough space for hydraulic components.

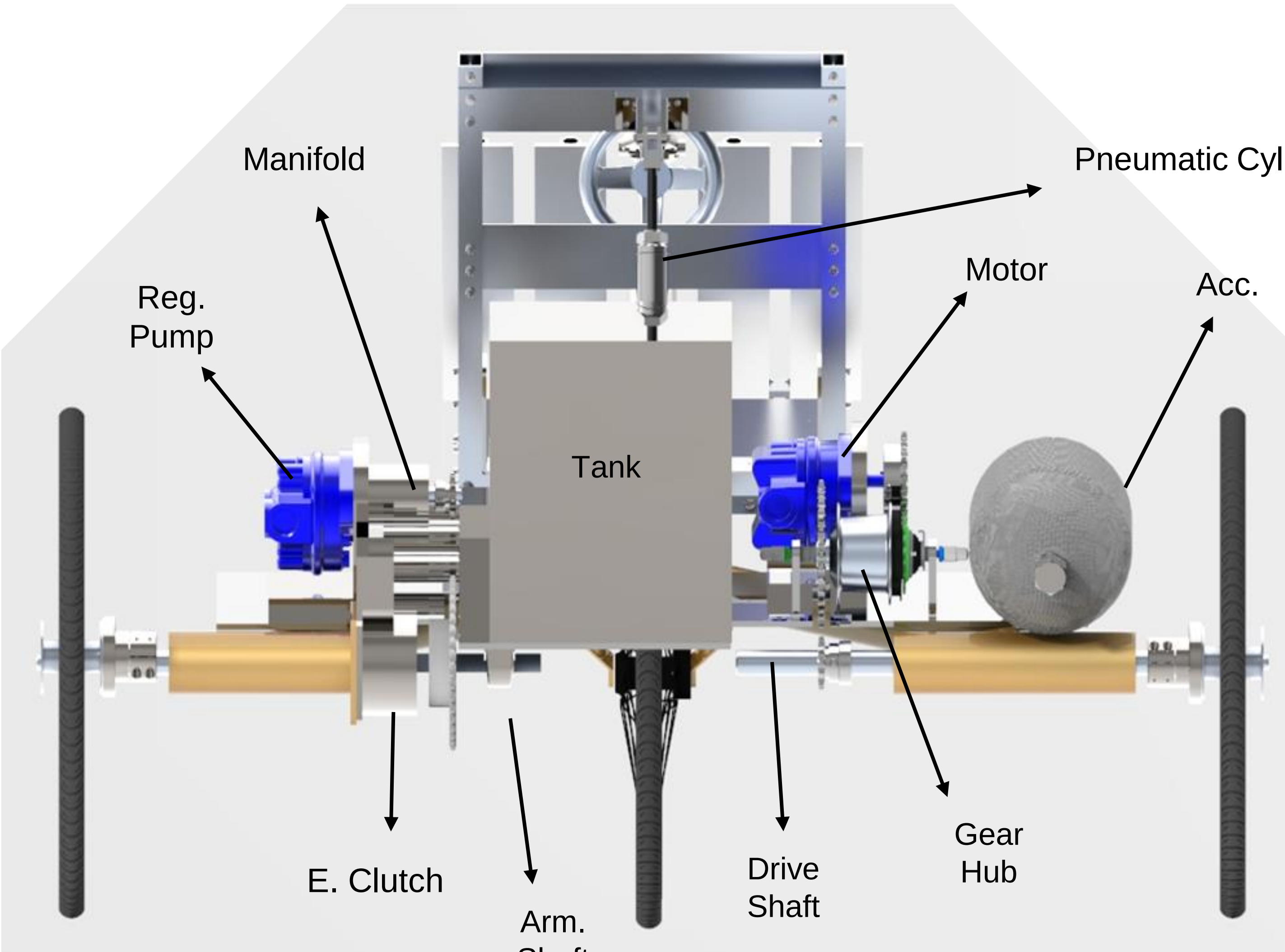


# Specifications

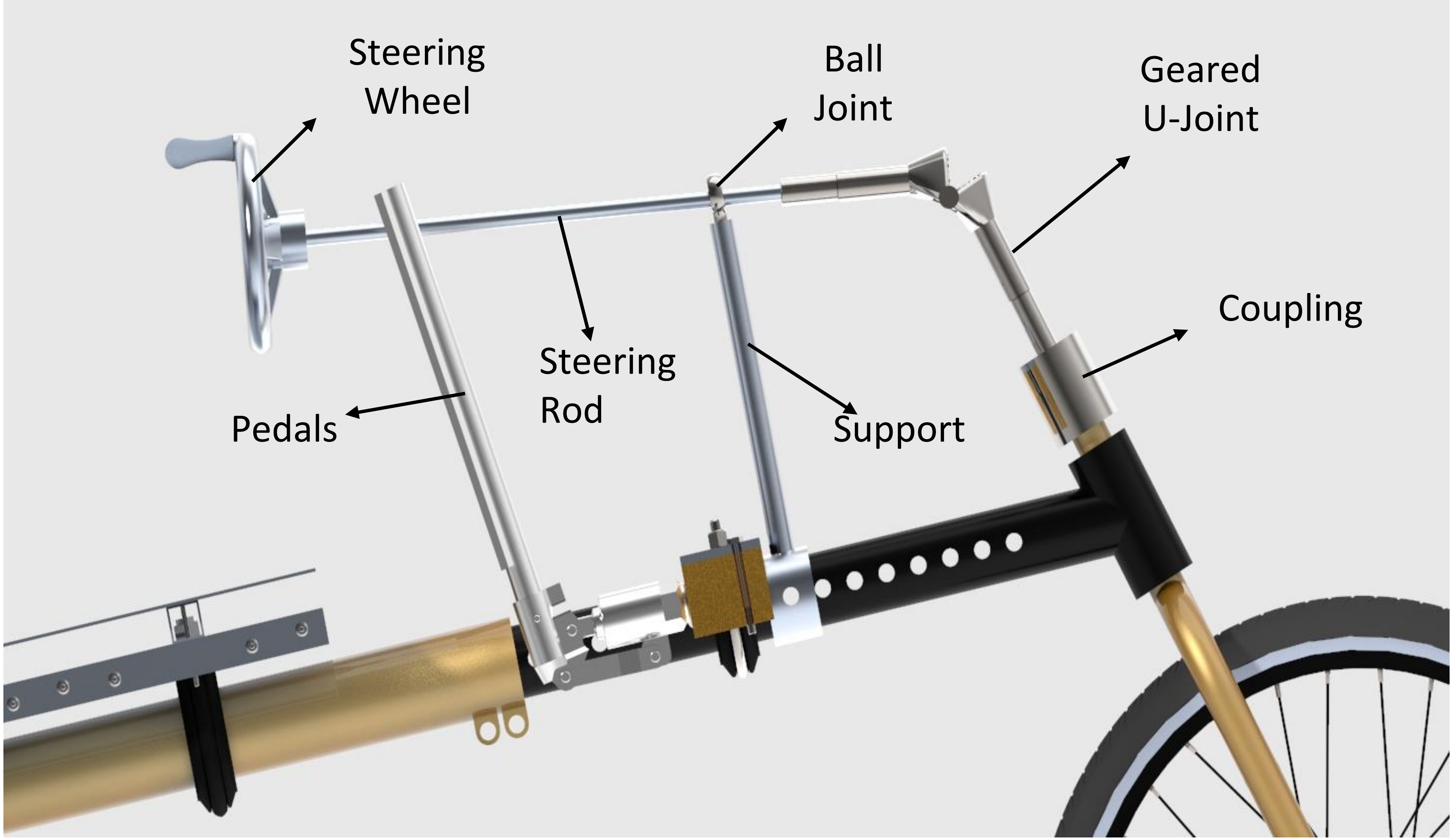
- 20’’ wheel size
- Weighs around 40 kg (90 lbs)
- Total vehicle length adjustable from 4 - 7.5 ft
- Two shafts, one for driving, one for regeneration, allows very tight turning radius and increased safety compared to a live axle
- “Delta” design offers higher ground clearance and increased maneuverability compared to standard tadpole
- Used vibration damping U-bolts to connect the seat and foot pumps
- 5 gear reduction from motor to drive shaft, 6 gear reduction from regen shaft to regen pump
- Memory foam padding on the seat
- Pneumatic seat adjustment



# Drive System



# Steering

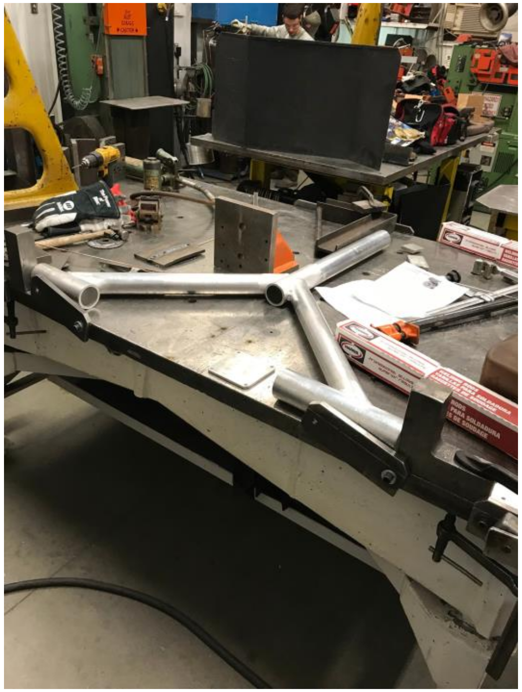


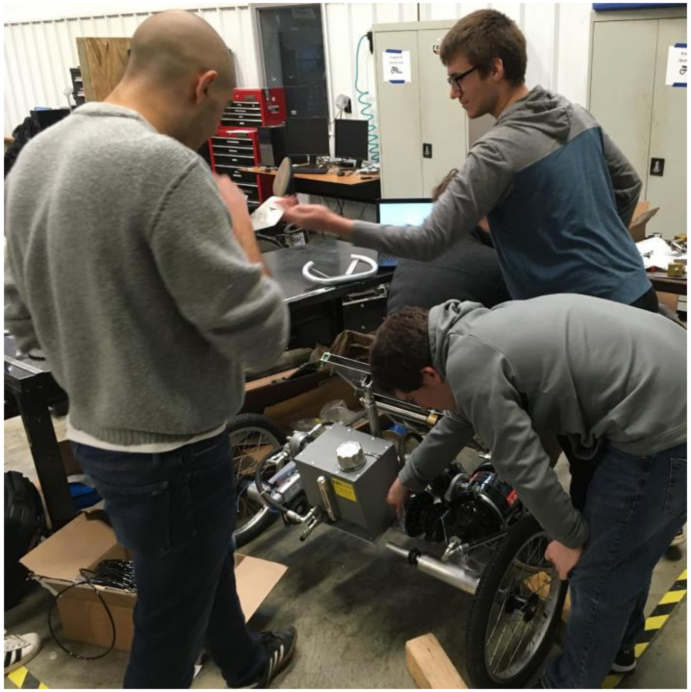
Steering Wheel
Ball Joint
Geared U-Joint
Coupling
Steering Rod
Pedals
Support

# Gear Shifting

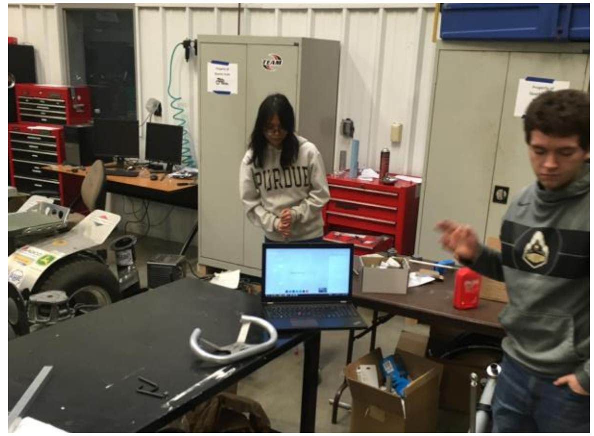
- Shimano Alfine Di2 Electronic Gear Shift
  - 306% gear ratio
  - Normally used as a hub within the rear wheel of a bicycle, we modified it such that a sprocket is connected to 6 spoke holes to drive the drive shaft.
  - The smaller manufacturer sprocket is driven by the hydraulic motor. Hydraulic motor sprocket was machined down to fit a bicycle chain.

# Assembly Process of Vehicle





# Assembly Process of Vehicle





# Assembled Vehicle

# Lessons Learned

- Have drawings printed and labeled before fabricating
- Have a more systematic approach to design process
- Working around bottlenecks
- Importance of modeling in design
- Correct fittings for hydraulics and pneumatics

# References


1. SAE Surface Vehicle Standard - J744
2. Aluminum Tubing Standard - ASTM B221-14
3. Involute Splines, Serrations, and Inspection - SAE J498b
4. Cycle Safety and Testing - ISO 4210
5. Cycle Rims - ISO 5775
6. Stem Angle ISO 8562:1990
7. Chains and Testing Methods ISO 9633:2001