SD 2 – Team 17

# Pneumatic Paddle Shifting

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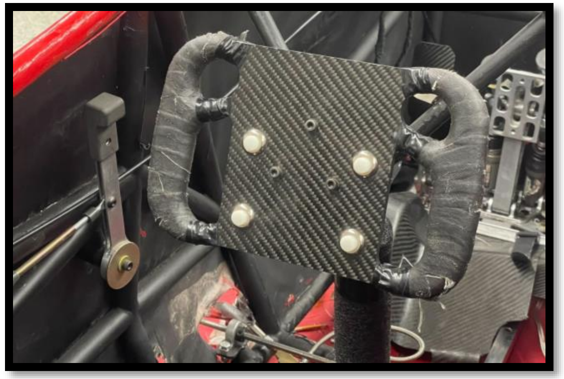
Instructor: Dr. Riggio

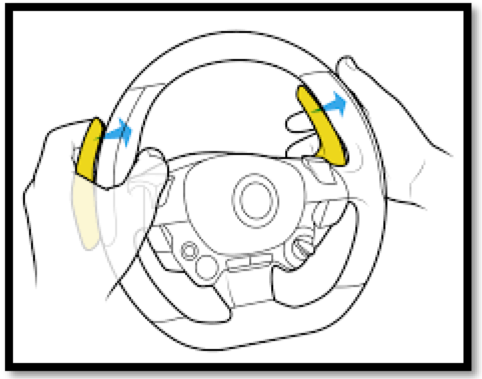
Advisor: Aaron Snyder

College of Engineering

# Project Overview

- FSAE competition
  - Demands 50+ shifts per lap
  - 0.5s slower per turn than 1st
    (FSAE Endurance results 22’ & 23’)
- Replace manual shift system
  - One hand lever → finger paddles
  - Safety & focus improvements
- Develop system on testing bench
  - Correlate data to components
  - Provide design platform for TFR





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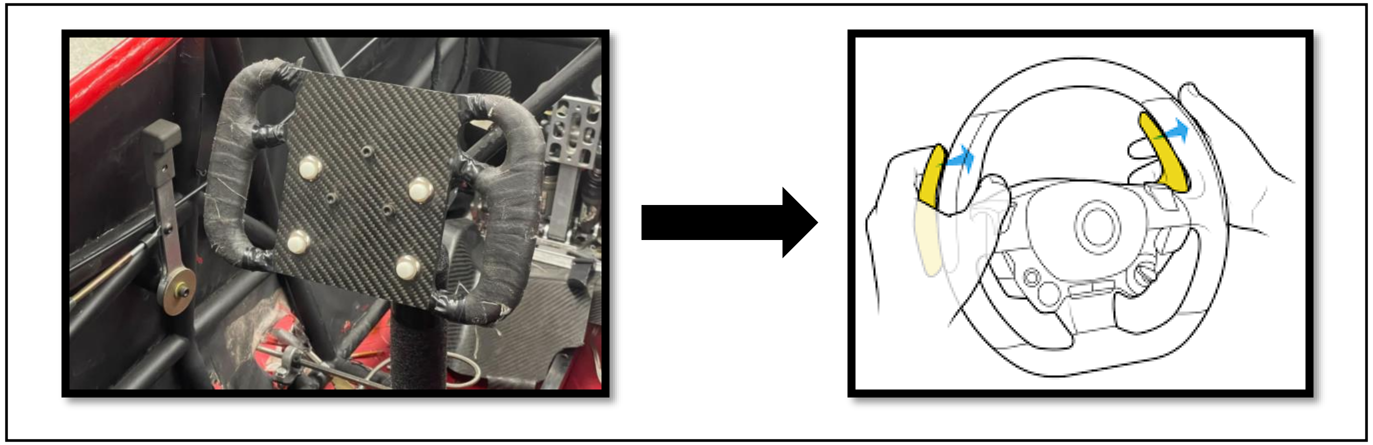

# Problem Description

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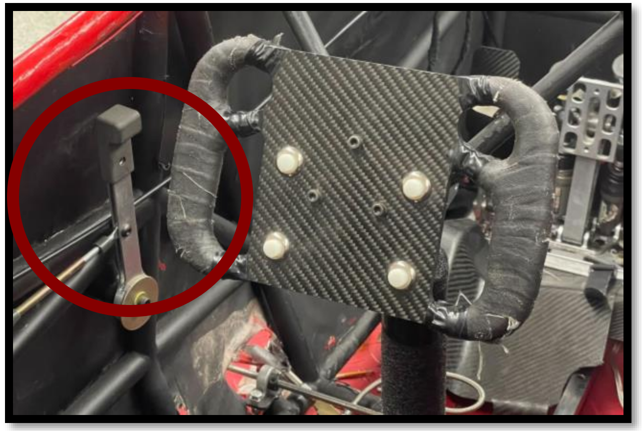
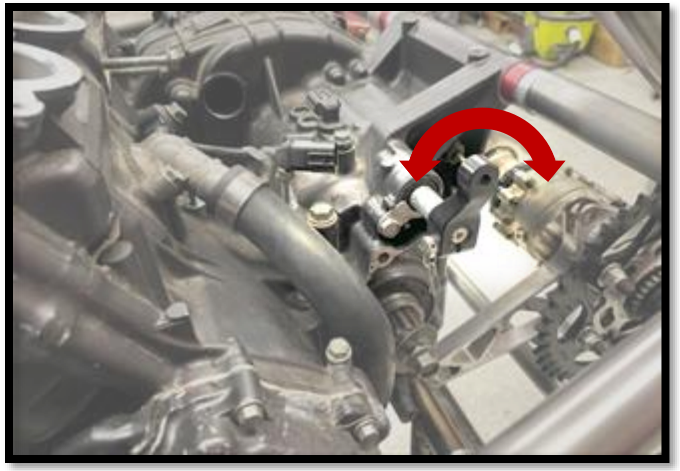
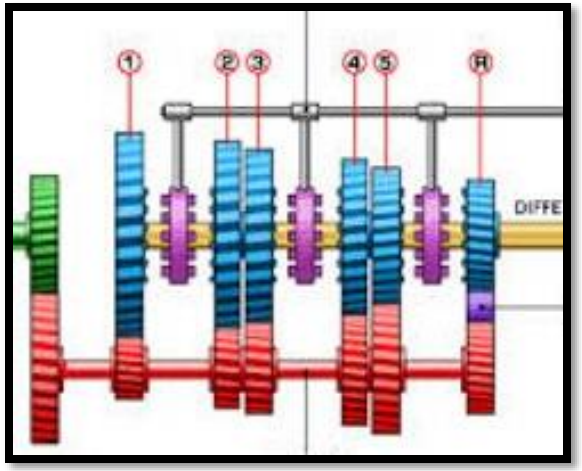




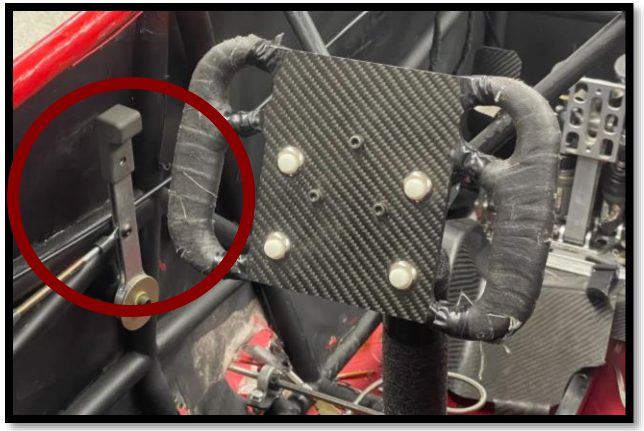


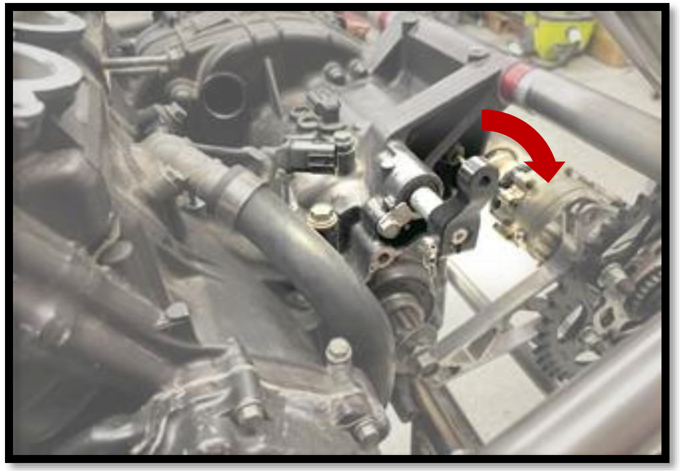

Driver input → Shift linkage rotates → Transmission changes gears

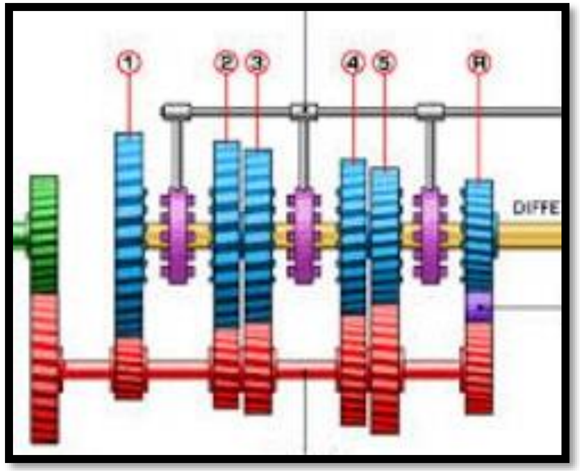
**Shifting Mechanism Constraints:**

- Rotate shifting linkage minimum engagement distance ~ 0.4”
- Provide enough force/torque to engage transmission ~ 90lbs
- Provide repeatable shift every ~ 0.3s
- Operate on 12V battery

# Problem Description








Driver input → Shift linkage rotates → Transmission changes gears

# Needs Summary

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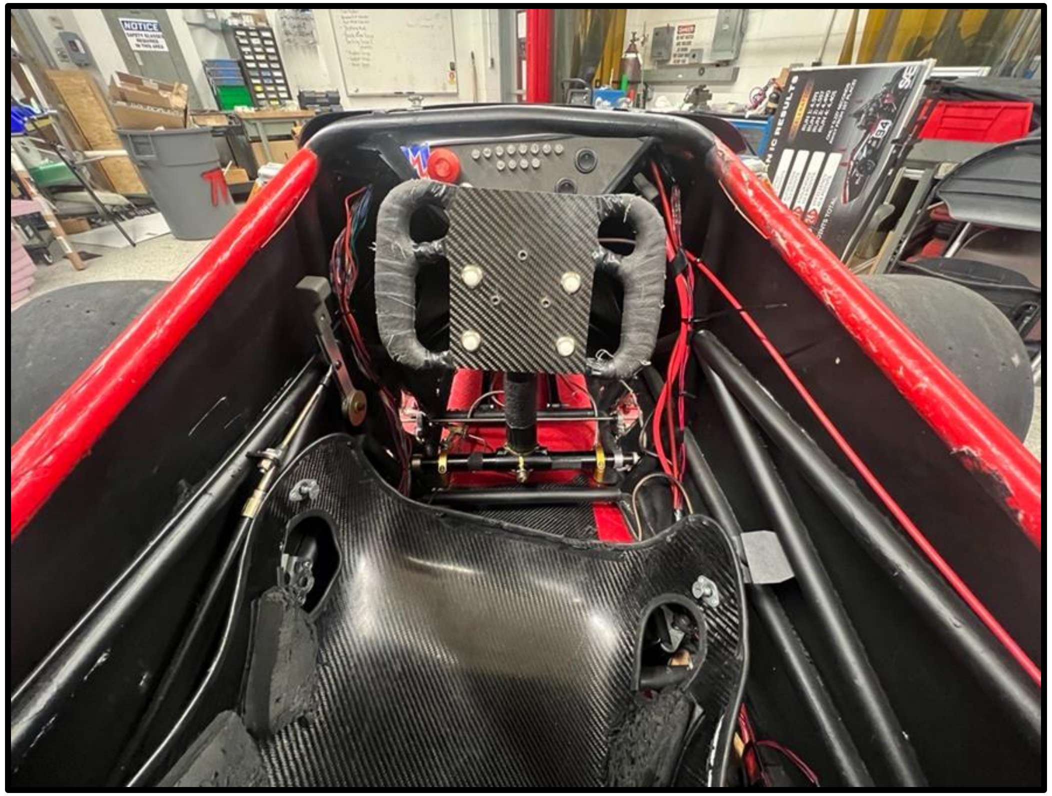
1. Design automated shift actuation system to replace mechanical system

2. Construct apparatus to test components in operating conditions

3. Utilize testing data to formulate optimization plans



# Problem  Solution: Electro-Pneumatic System

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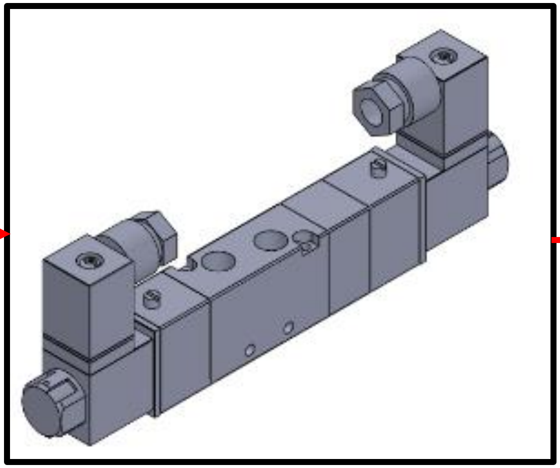
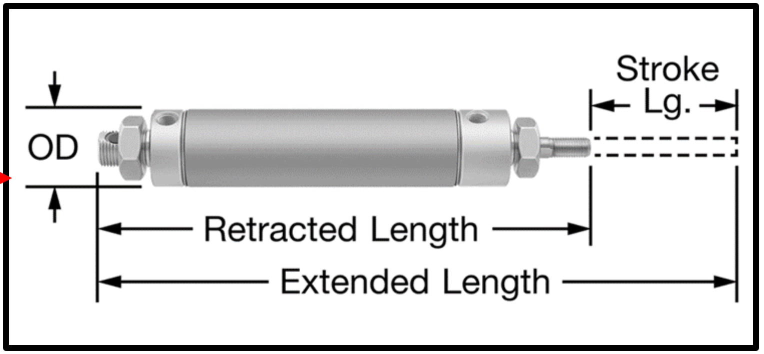
- Actuation of shift utilizing pneumatic cylinder
- Components: Gas tank, Pneumatic Cylinder, Pneumatic Solenoid Valve
- Components are light weight and compact
- Low operating pressure → reliable, low maintenance
- Easy integration to existing shifting system
- Other solutions explored
  - Electro-hydraulic actuating system
  - Electrical actuating system


*Gas Tank*



*Solenoid Valve*




*Pneumatic Cylinder*

# Design Constraints

| Priority | Design Constraint | Metric | Target | Justification |
|---|---|---|---|---|
| Non-negotiable | Rules Compliance | **A pressure regulator must be mounted directly onto a gas cylinder/tank** | Pass/Fail | Formula SAE Rules |
| Non-negotiable | Rules Compliance | **The gas lines and fittings must be appropriate for the designed operating pressure** | Range of 21 - 121 psi | Formula SAE Rules |
| Non-negotiable | Rules Compliance | **The working gas must not be flammable** | Pass/Fail | Formula SAE Rules |
| Non-negotiable | Rules Compliance | **All pressurized cylinders must be commercially manufactured** | Pass/Fail | Formula SAE Rules |
| Non-negotiable | Integration | **All electrical components should be compatible with TFR battery and Ecu** | Pass/Fail | Usability |
| Non-negotiable | Standard ISO 4414 | **Relevant information regarding the operation and maintenance of pneumatic systems.** | Pass/Fail | Pneumatic Standards |
| Negotiable | Aesthetically Pleasing | **Design is sleek and cohesive** | 80% of polled individuals find the design to be aesthetically pleasing | SAE competition points |

# Functional Requirement

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| Priority | Functional Requirement | Metric | Target | Justification |
|---|---|---|---|---|
| Non-negotiable | Air cylinder actuation must produce enough torque to shift gears | **Up-shift, down-shift** | [90,90] lbs | Client |
| Non-negotiable | Time/delay between shifts | **Timer on microcontroller** | 1 shift every 0.3 seconds | Client |
| Non-negotiable | Total quantity of shifts per tank | **Total amount of shifts per endurance race** | >500 shifts | Client |
| Non-negotiable | Improve vehicle performance | **Shifting time** | Decreased by 5% | SAE Competition points |
| Non-negotiable | Systems integration | **Microcontroller to facilitate input and output interactions** | Pass/Fail | Client |
| Non-negotiable | Data displayed after each shift | **Dashboard** | Pass/fail | Data processing |
| Non-negotiable | Integration | **Cylinder actuation length should mimic original manufacturer engine design** | 0.4 inches | Client |
| Negotiable | Mechanism weight | **Weight** | <10 lbs | Client |

# CBR 600RR Shifting Constraints

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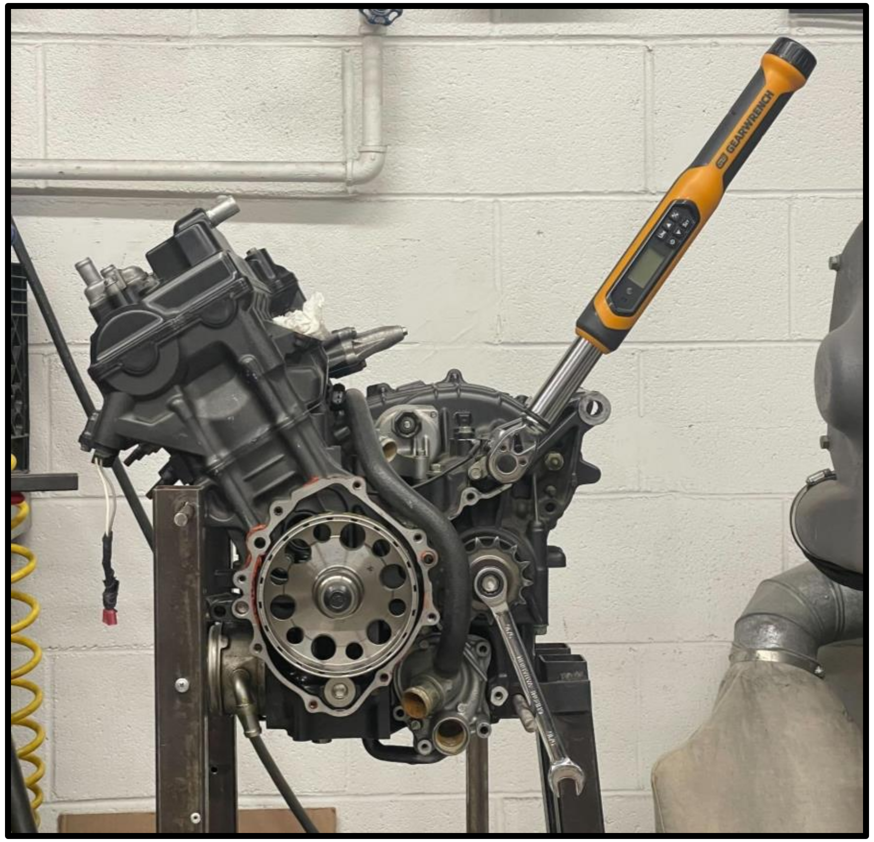
- Measured torque to shift through all 6 gears
  - Torque wrench w/ live readout
  - 5 trials – averaged data
  - Shift torque is dependent on gearbox loading
- Linkage shift distance recorded w/ calipers

| Shift Linkage Shift Distance | |
|---|---|
| Upshift [in] | Downshift [in] |
| 0.384 | 0.405 |
| Combined stroke [in] | |
| 0.789 | |



*Shifting Torque Test*

| CBR 600RR Shifting Torque | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Gear Change | 1st/2nd | 2nd/3rd | 3rd/4th | 4th/5th | 5th/6th | 6th/5th | 5th/4th | 4th/3rd | 3rd/2nd | 2nd/1st |
| Avg Torque [in-lbs] | 134 | 149 | 154 | 150 | 123 | 119 | 112 | 144 | 144 | 95 |
| Calc Force @ 1.5" [lbs] | 89 | 99 | 102 | 100 | 82 | 80 | 75 | 96 | 96 | 64 |
| Avg Force_total [lbs] | 88 | | | | | | | | | |

# Gas Selection & Calculations

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- Theoretically evaluate Nitrogen, Carbon Dioxide, and Compressed Air
- Select pneumatic cylinder
- Estimate working Temperature & Pressure
- Reduced Temperature & Pressure → Compressibility Factor
- Pneumatic Cylinder Geometry
- Calculate mass per shift
- Select gas tanks

$$Bore\ Diameter = \sqrt{\frac{4 * Force}{\pi * Pressure}}$$

Cylinder Bore Diameter

$$Z = \frac{pv}{RT}$$

Compressibility Factor

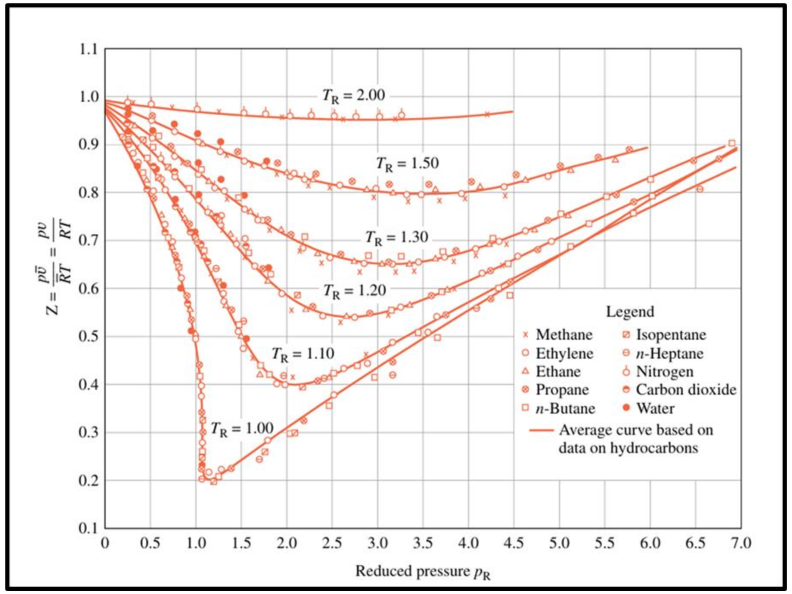
$$v = \frac{V}{m}$$

Specific Volume

$$p_R = p/p_c \qquad T_R = T/T_c$$

Reduced Temperature & Pressure

| Estimated Mass Per Shift Cycle | |
|---|---|
| Carbon Dioxide | 3.92 g |
| Nitrogen | 2.90 g |
| Air | 3.00 g |




Generalized Compressibility Chart

| Gas Tank Type | HPA | CO2 |
|---|---|---|
| Tank Capacity | 226.8 g | 340.2 g |


Carbon Dioxide Tank


HPA Tank

# Shift Time Baseline Test

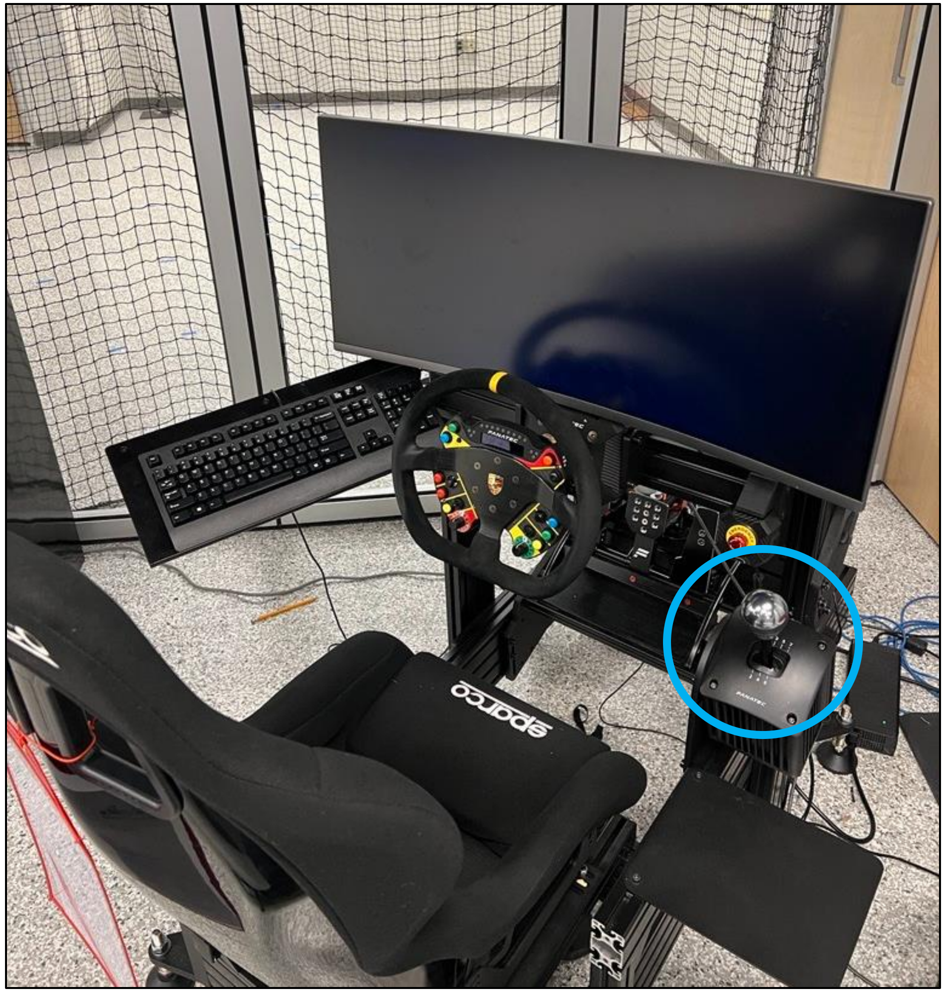
- Test subjects selected with varying driving experience
- Temple Formula Racing driving simulator (see figure)
- Sequential shifting set up on simulator (see blue circle in figure)
- Same track, car and shifting set up for each driver
- Shift time tracked for a single shift
- Timer started when driver took hand off wheel, stopped when hand returned to wheel

*Average Shift Time per Driver*

| Driver | #1 | #2 | #3 |
|---|---|---|---|
| Average shift time (s) | 0.84 | 0.39 | 0.44 |

*Total Average Shift Time*

| Total Average (s) | 0.56 |
|---|---|



*Temple Formula Racing's driving simulator located in IDEAS HUb*

# Shifting Mech Design

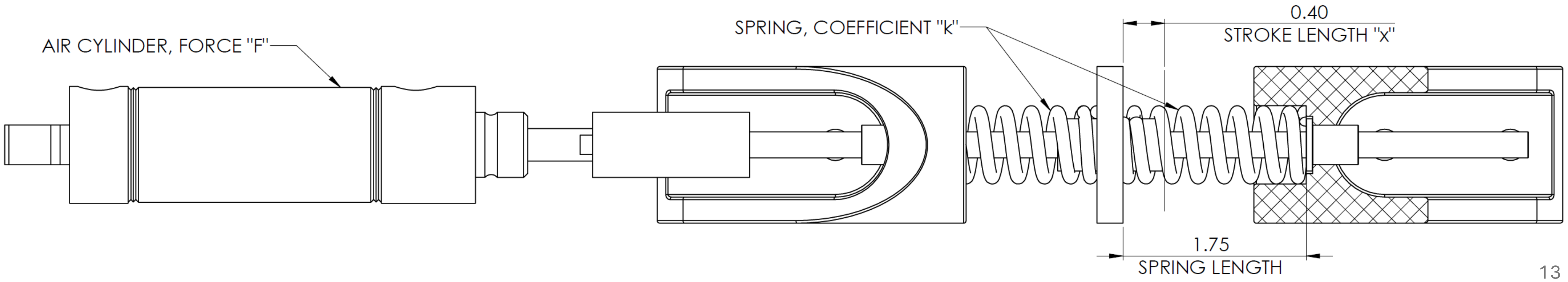
- Shifting force replicated with springs
  - Actuation distance result of force
  - Quickly produce data
- Shifting criteria = 88 lbs @ 0.4”
  - Required spring constant from Hooke’s Law
  - Matched springs from catalogue

$$k = \frac{F}{x}$$

Hooke’s Law

| | |
|---|---|
| Spring Type | Compression |
| System of Measurement | Inch |
| Length | 1.75" |
| OD | 0.75" |
| ID | 0.5" |
| Wire Diameter | 0.125" |
| Compressed Length @ Maximum Load | 1.06" |
| Maximum Load | 117.13 lbs. |
| Spring Rate | 221 lbs./in. |
| Material | Music-Wire Steel |

*McMaster-Carr Catalogue Details*



# Component Mechanical Design

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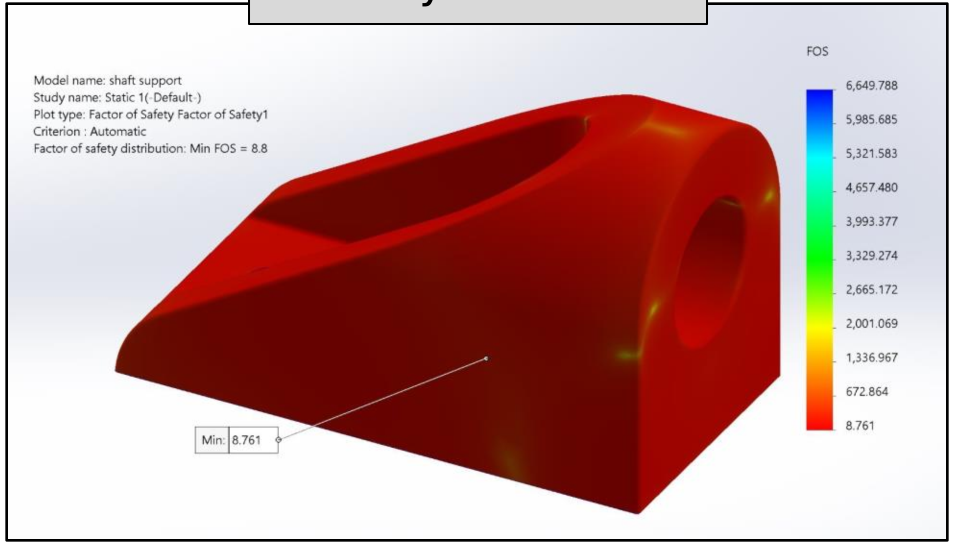
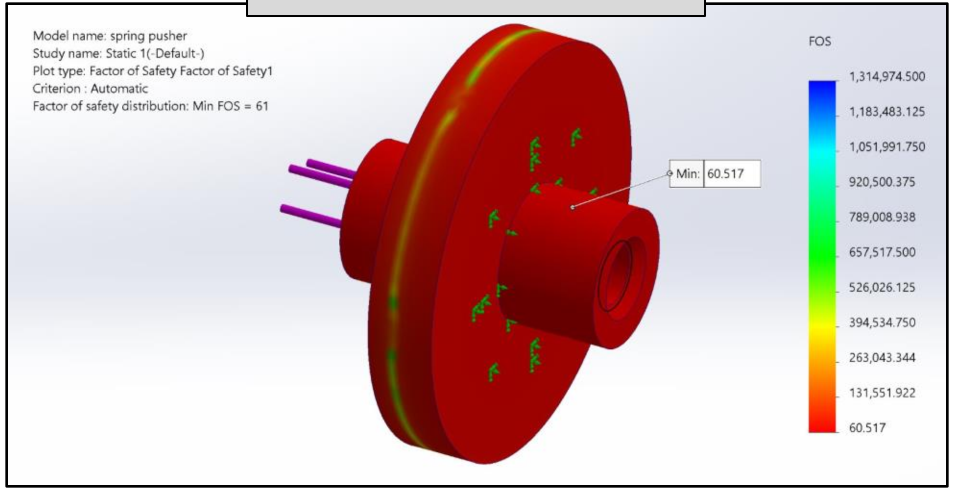
- Nylon 12 SLS 3D printing
  - Support parts
  - Rapid prototyping
  - 7000+ psi ultimate tensile strength
- <u>6061 Aluminum</u>
  - Shaft connections
  - Readily available
  - High strength
- Carbon Steel
  - Linear motion shaft
  - High rigidity and strength

Nylon 12

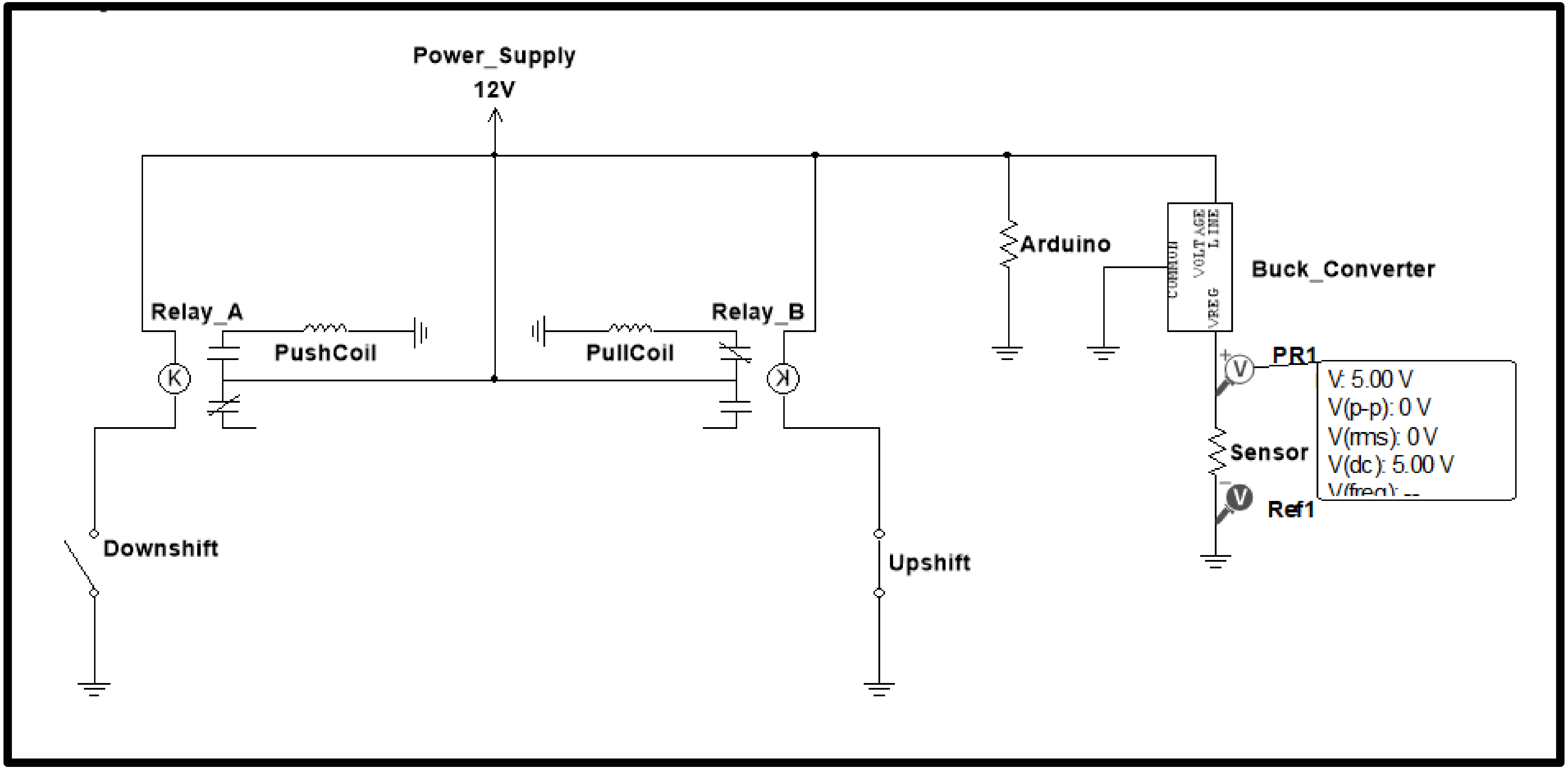



6061 Aluminum

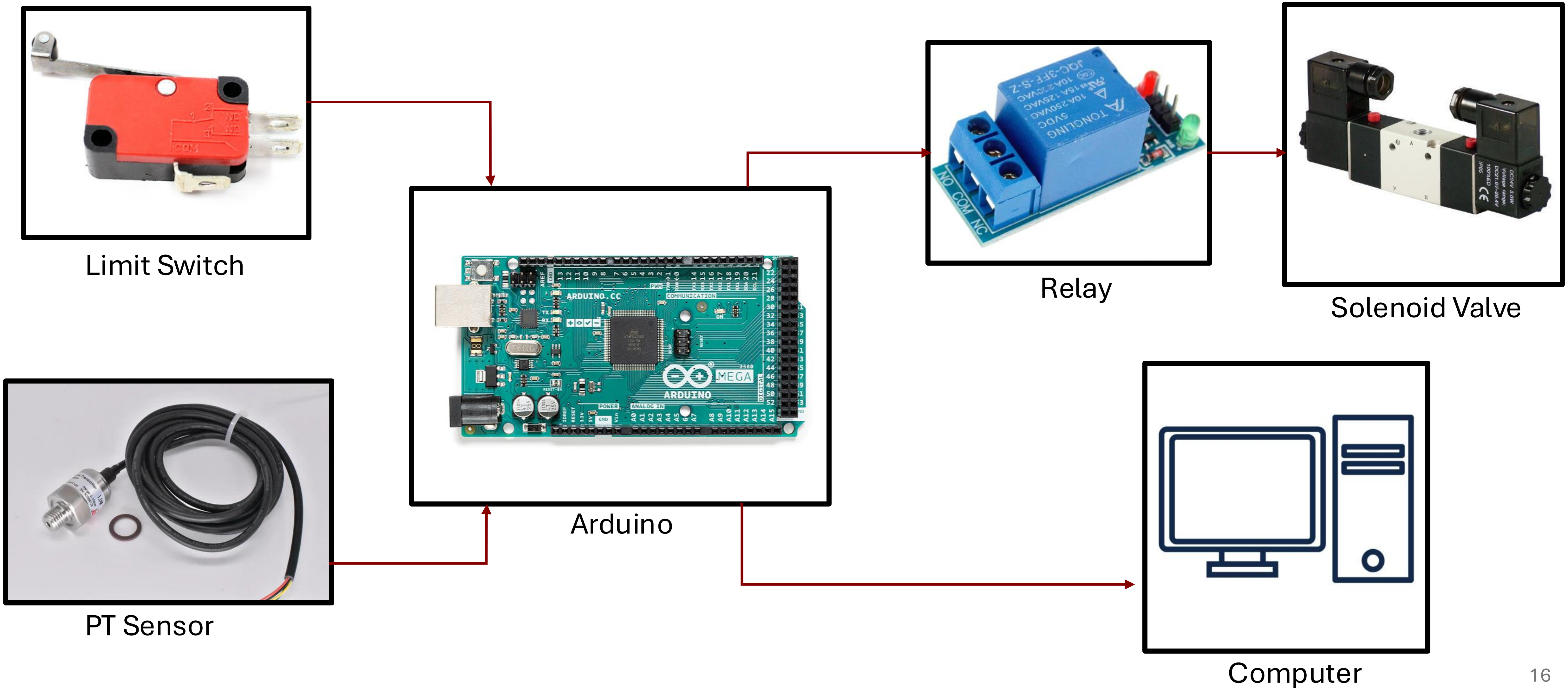



| Item | Minimum FoS |
|---|---|
| Spring pusher | 60 |
| Spring support | 8.8 |
| Cylinder support | 8.9 |
| Linear shaft | 32.6 |
| Shaft coupler | 9.2 |

# Electrical Components - Power



# Electrical Components - Data

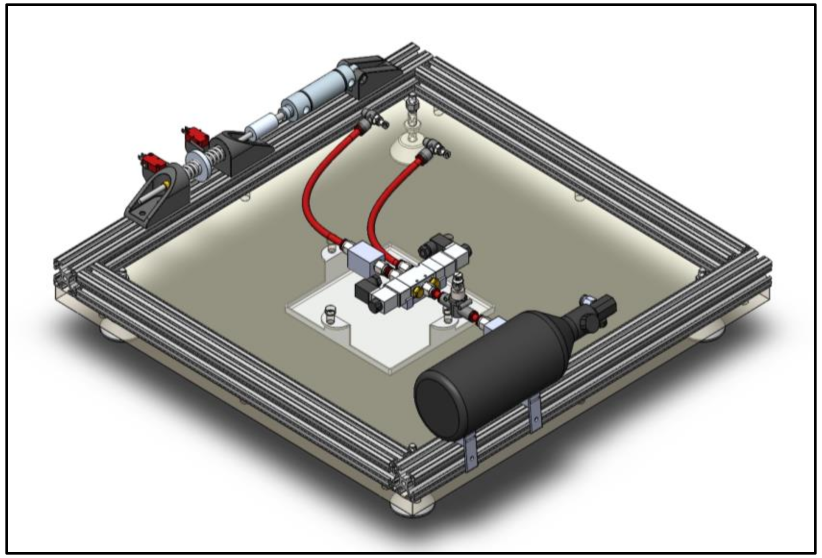


# Component Selection & Assembly

## Component Selection & CAD

- 8020 rail selected for modularity
- Solenoid valve
- Pneumatic tubing
- Push to connect fittings
- On/Off control valve
- Tank pressure regulator

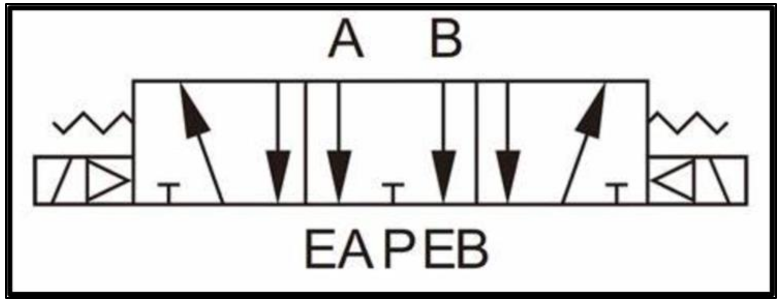
*Push-to-connect on/off valve*



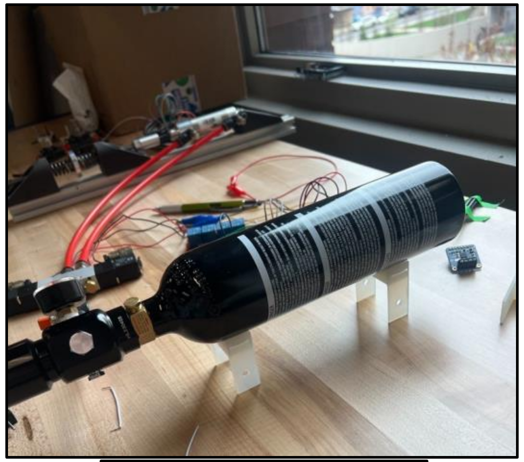
*Test Bench Assembly*

## Manufacturing & Prototyping

- 8020 rail cut and milled to size
- Mounts with complex geometry 3D printed
- Small aluminum pieces machined on lathe
- MDF board machined on router
- Bench is easily serviceable
  - 10-minute removal time
  - 15-minute install time




*four-way three position solenoid with exhausted center schematic*



*Tank mounting prototype*

# Code

```
// ENDURANCE PROFILE
#define Endurance_Shifts 344
#define Endurance_Times 344
const int Endurance_Shift[] = {1,0,1,0,1,0,1,0,1,1,0,1,1,0,0,1,1,0,0,1,0,1,0,1,0,1,1,0,1,1,0,0,1,1,0,0,1,\
0,1,0,1,0,1,1,0,1,0,0,1,1,1,0,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,1,0,0,1,1,1,0,0,1,0,1,1,0,0,1,0,1,0,1,0,\
1,0,1,1,0,0,1,0,1,1,0,0,1,1,1,0,0,0,1,1,0,0,1,0,1,0,1,0,1,0,1,1,0,1,1,0,0,1,1,0,0,1,0,1,1,0,0,1,0,1,0,1,0,1\
                                                            0,1,1,0,1,0,0,1,0,1,0,1,0,1,1,1,0,0,0,1,1\
```

```
// Determine i
for(int i=0; i
  Serial.print
  if(pins[i] =
    shiftPin =
  }
  if (pins[i]
    shiftPin = downShiftPin;
  }
```

```
// Following loop terminates for either:
// A: Limit Switch is pressed
// B: Timer exceeds duration specified in function
while(digitalP                    millis()-startTime<duration){
  delay(2);
  readSensorDa
}
```

```
ould be checked
witchPin;
tSwitchPin;
```

```
,1.55,1.8,0.1,0.9,10.65,1.05,1.1,3.95
0.15,0.85,6.7,5.35,1.15,4.25,2.25,1.3
,7.25,1.35,4.35,3.0,0.8,2.7,1.1,15.9,
,0.95,2.05,1.6,3.65,3.3,1.15,1.45,6.1
,0.75,7.05,1.3,3.05,1.55,3.7,1.45,2.3
,6.9,4.4,1.25,2.85,1.3,0.95,2.55,0.45
```


```
0.5\
1.25\
.85,\
25,5.8\
3,3.45\
,0.9,8.1\
4,7.3,1.0\
```

# Project Budget

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| Category | Description | Qty | Price | Total Cost | Notes |
|---|---|---|---|---|---|
| Electrical | MAX31865 Temperature Sensor Amplifier | 2 | $15.00 | $30.00 | To convert temperature sensor into readable values for Arduino |
| Electrical | 12 V to 5 V Buck Converter | 1 | $9.99 | $9.99 | To power sensors |
| Electrical | 12 VDC 4 Channel Relay Module | 1 | $7.39 | $7.39 | |
| Electrical | Arduino mega | 1 | $0.00 | $0.00 | Free |
| Electrical | Pressure Sensor | 2 | $90.00 | $180.00 | |
| Mechanical | oil embedded flange bushings | 2 | $2.00 | $4.00 | |
| Mechanical | Springs 3x pack 1.75L x 0.75OD | 1 | $14.38 | $14.38 | |
| Mechanical | Test mechanism supports | 5 | $0.00 | $0.00 | Temple CoE |
| Mechanical | End-Feed Single Nut with Button Head 5/16"-18 Threa | 4 | $3.56 | $14.24 | |
| Mechanical | Hose clamps (SAE #64 2-1/2-4-1/2) | 1 | $12.99 | $12.99 | |
| Mechanical | Single 4-Slot Rail, Silver, 1.5" High x 1.5" Wide, Hollow | 1 | $60.49 | $60.49 | |
| Mechanical | Tight-Tolerance Low-Carbon Steel Rod | 1 | $8.67 | $8.67 | Replacement part for 6061K31 |
| Pneumatic | 4 way 3 postion solenoid valve | 1 | $101.79 | $101.79 | Select 12VDC when filling out order sheet. |
| Pneumatic | 5/16" (8mm) air hose - 100ft roll | 1 | $0.00 | $0.00 | Automation Direct - Free |
| Pneumatic | CO2 Refilling adaptor | 1 | $38.99 | $38.99 | |
| Pneumatic | CO2 Scale | 1 | $9.99 | $9.99 | |
| Pneumatic | CO2 tank | 1 | $29.95 | $29.95 | |
| Pneumatic | cylinder | 1 | $0.00 | $0.00 | Automation Direct - Free |
| Pneumatic | exhaust silencer/filter | 1 | $0.00 | $0.00 | Automation Direct - Free |
| Pneumatic | flow control valve | 2 | $0.00 | $0.00 | Automation Direct - Free |
| Pneumatic | male 1/8 NPT push to connect fitting | 3 | $0.00 | $0.00 | Automation Direct - Free |
| Pneumatic | N2 tank | 1 | $49.95 | $49.95 | 48 ci 3000 psi, black |
| Pneumatic | on-off valve | 1 | $0.00 | $0.00 | Automation Direct - Free |
| Pneumatic | Paintball Co2 Regulator Pressure Regulator Input 150( | 1 | $62.99 | $62.99 | |
| | | | Est. Total | $635.81 | |

# Test Results

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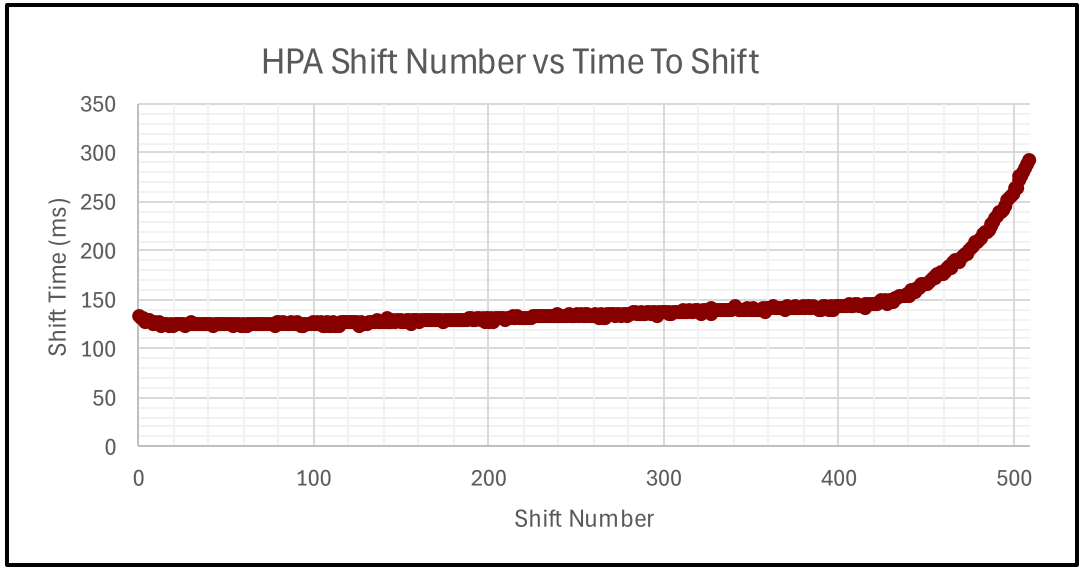
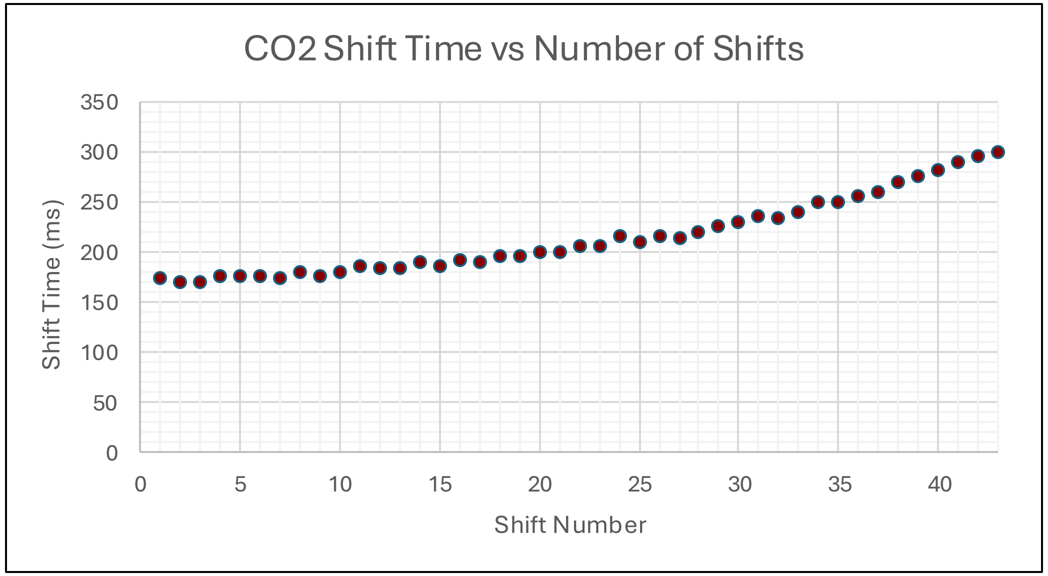
## High – Pressure Air Testing

- Single direction shifting profile
- 0.5 lb tank capacity
- 509 shifts produced
- 0.143 average shift time
- 115 psi operating pressure




## Carbon Dioxide Testing

- Shifting profile with varying up- and downshifts
- 0.75 lb tank capacity
- 43 shifts produced
- 0.215 average shifting time
- 100 psi operating pressure



# Short Comings

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| Challenges | Potential Solutions |
|---|---|
| **Handling of gasses:**<br>• Illegal to fill small tanks in PHL<br>• Unsuccessful filling tanks on own<br>• Ran through multiple tanks of gas | • Seek training for compressed gasses<br>• Develop tank filling protocol |
| **Data acquisition:**<br>• Fluid sensor failures<br>• Limited to GOOD/BAD shifts | • Deepen understanding of fluid sensors<br>• Implement **linear position** and **load** sensing |
| **Test mechanism:**<br>• Compression spring not accurate enough<br>• Limited accuracy in design criteria | • Design camming system to more accurately represent transmission |
| **Testing criteria**<br>• Only tested different gasses<br>• Too many variable components | • Test different sizes of mechanical parts<br>• Budget for more components |

# Summary

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| Non-negotiable | Rules Compliance | **A pressure regulator must be mounted directly onto a gas cylinder/tank** | Pass/Fail | Formula SAE Rules |
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| Non-negotiable | Standard ISO 4414 | **Relevant information regarding the operation and maintenance of pneumatic systems.** | Pass/Fail | Pneumatic Standards |
| ~~Negotiable~~ | ~~Aesthetically Pleasing~~ | ~~**Design is sleek and cohesive**~~ | ~~80% of polled individuals agree~~ | ~~SAE competition points~~ |

| Priority | Functional Requirement | Metric | Target | Justification |
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| Non-negotiable | Improve vehicle performance | **Shifting time** | Decreased by 5% | SAE Competition points |
| Non-negotiable | Systems integration | **Microcontroller to** | Pass/Fail | Client |
| Non-negotiable | Data displayed after each shift | **Dashboard** | Pass/fail | Data processing |
| Non-negotiable | Integration | **Cylinder actuation length should be OEM design** | 0.4 inches | Client |
| Negotiable | Mechanism weight | **Weight** | <10 lbs | Client |

# Thank you

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Dr. Riggio

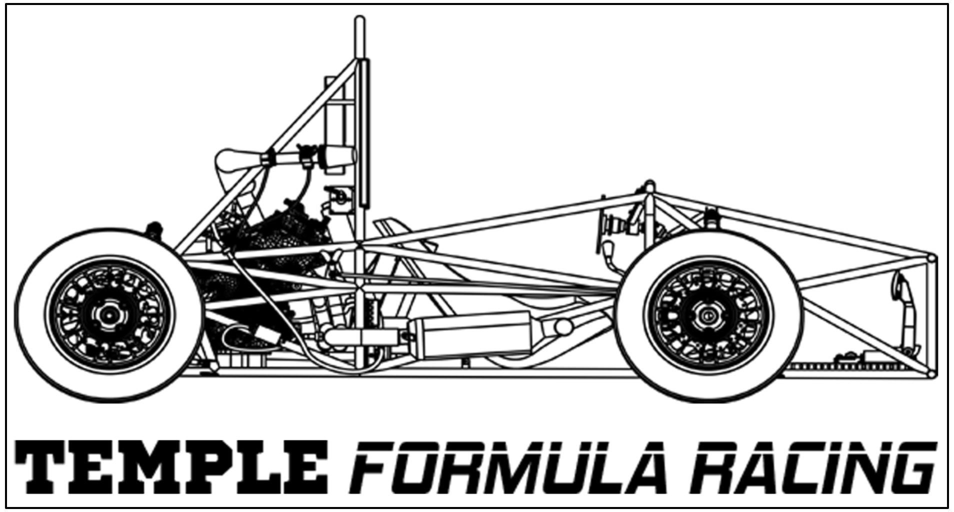
Aaron Snyder

Anthony Boehm

Christian Kelleher

Chip McDaniel from Automation Direct

Temple Formula Racing Team

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# Live Demonstration

# Questions?

# Appendix

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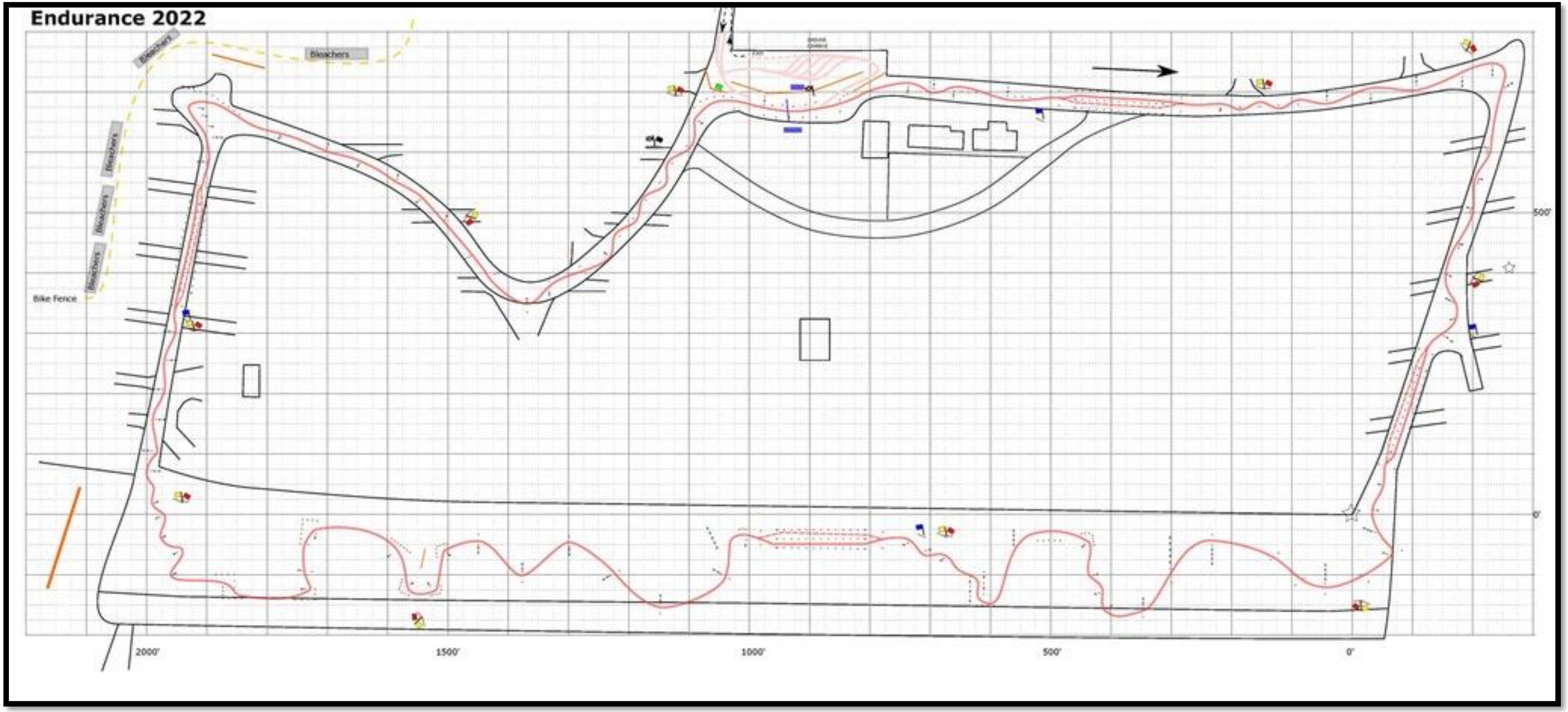
## FSAE Michigan 2022 – Endurance Track Map



# Simulated MoTeC Shifting Data

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# Appendix: Electro-Hydraulic

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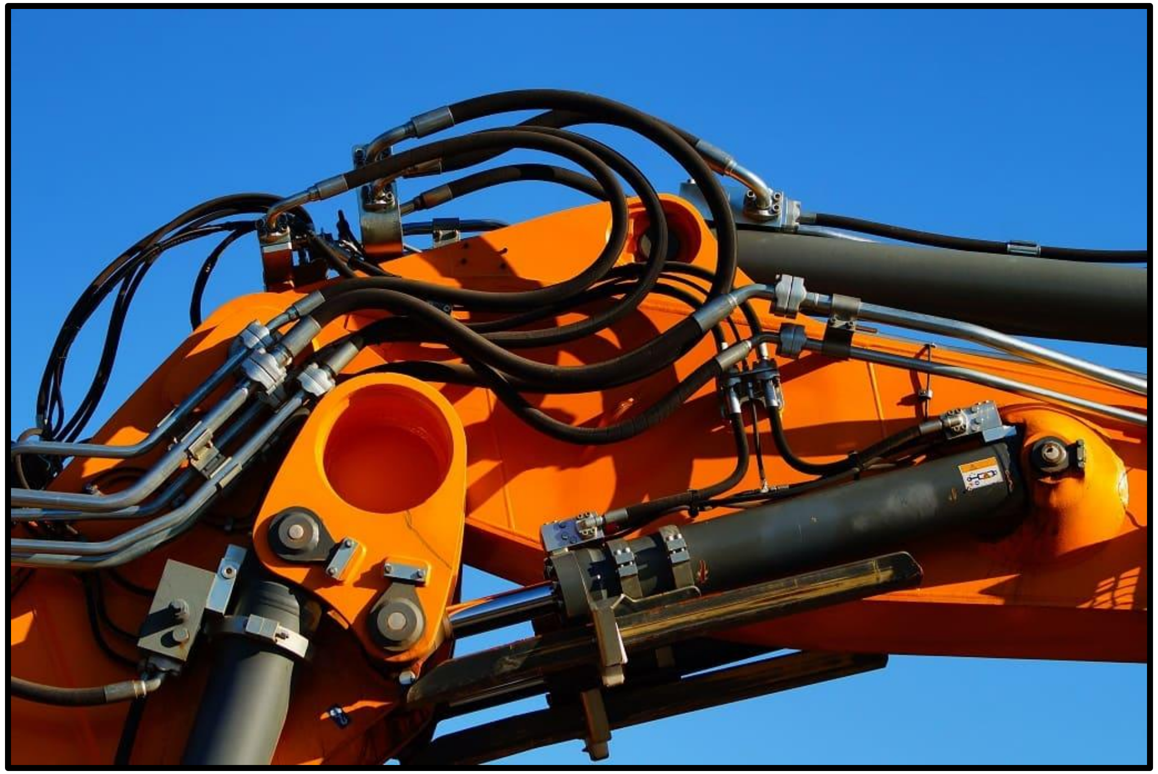
- Actuation of piston through hydraulic fluid and system of pump and motor
  - Paddles would act as switches to signal microcontroller to activate pump, motor and hydraulic cylinder
- Require high operation pressures > 500 psi
- Heavy components
  - More parts = more complexity
  - Hurdles with FSAE rules
- Known for difficult sealing and mess



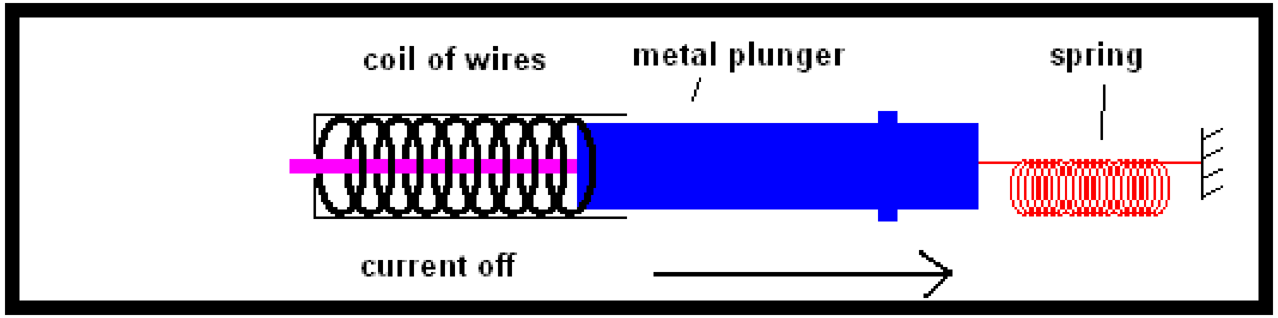
Hydraulic Lift

# Appendix: Electric System



- Actuation of lever by pushing magnetic plunger through center of solenoid
  - Induced current creates electromagnet that pushes magnetic material, and spring relaxes plunger back to original state when current is off
- Simplest design
- High electrical energy consumption > 5 A
  - Limited capacity in an on-car battery < 250 Ah

*Linear Electric Solenoid*




*Electric Solenoid Functionality*

# Appendix

College of Engineering

## FSAE Michigan 2022 & 2023 – Endurance Results

FORMULA SAE

SAE INTERNATIONAL

Endurance Event Results

Michigan May 2022

Minimum Time (seconds) 1402.045

Maximum Time (seconds) 2032.966 145%

| | | | | | 2 | 20 | sec | | |
|---|---|---|---|---|---|---|---|---|---|
| Place | Car Num | Team | Time | Laps | Cones | Off Course | Other Penalty | Adjusted Time | Endurance Score |
| 1 | 44 | Univ of Illinois - Urbana Champaign | 1400.045 | 10 | 1 | | | 1402.045 | 275 |
| 2 | 119 | Villanova Univ | 1463.401 | 10 | 3 | | | 1469.401 | 238.1 |
| 3 | 104 | Univ of Connecticut | 1380.664 | 10 | 9 | 4 | | 1478.664 | 233.3 |
| 4 | 67 | Univ of Florida | 1485.612 | 10 | | | | 1485.612 | 229.7 |
| 5 | 115 | Univ of Akron | 1517.308 | 10 | 2 | | | 1521.308 | 211.8 |
| 6 | 54 | Kettering Univ | 1453.519 | 10 | 6 | 2 | 30 | 1535.519 | 205.0 |
| 7 | 74 | Univ of Missouri | 1564.049 | 10 | | | | 1564.049 | 191.6 |
| 8 | 48 | North Carolina State Univ - Raleigh | 1565.730 | 10 | | | | 1565.730 | 190.8 |
| 9 | 65 | Univ of Nebraska - Lincoln | 1536.964 | 10 | 6 | 1 | | 1568.964 | 189.3 |
| 10 | 83 | Hope College | 1544.140 | 10 | 4 | 1 | | 1572.140 | 187.8 |
| 11 | 63 | Univ of Kansas - Lawrence | 1546.825 | 10 | 3 | 1 | | 1572.825 | 187.5 |
| 12 | 96 | University of Alabama - Tuscaloosa | 1556.520 | 10 | 1 | 1 | | 1578.520 | 184.9 |
| 13 | 68 | Louisiana State Univ | 1436.576 | 10 | 1 | 1 | 120 | 1578.576 | 184.9 |
| 14 | 95 | Saginaw Valley State Univ | 1541.676 | 10 | 1 | 3 | | 1603.676 | 173.7 |
| 15 | 55 | Oklahoma State Univ | 1599.264 | 10 | 3 | | | 1605.264 | 173.0 |
| 16 | 150 | Univ of North Florida | 1595.333 | 10 | 6 | 2 | | 1647.333 | 155.1 |
| 17 | 108 | Temple Univ | 1588.102 | 10 | 7 | 3 | | 1662.102 | 149.0 |

FORMULA SAE

SAE INTERNATIONAL

Endurance Event Results

Formula SAE 2023

Minimum Time (seconds) 1360.978

Maximum Time (seconds) 1973.419 145%

| | | | | | 2 | 20 | sec | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Place | Car Num | Team | Time | Laps | Cones | Off Course | Other Penalty | Adjusted Time | Time Score | Laps Score | Endurance Score |
| 1 | 115 | Univ of Texas - Arlington | 1310.978 | 10 | 5 | 2 | | 1360.978 | 250.0 | 25 | 275 |
| 2 | 33 | Purdue Univ - W Lafayette | 1391.334 | 10 | | | | 1391.334 | 232.4 | 25 | 257.4 |
| 3 | 55 | Univ of North Carolina - Charlotte | 1395.896 | 10 | | | | 1395.896 | 229.8 | 25 | 254.8 |
| 4 | 80 | Univ of Calif - San Diego | 1392.293 | 10 | 3 | | | 1398.293 | 228.5 | 25 | 253.5 |
| 5 | 88 | The Ohio State University | 1414.452 | 10 | | | | 1414.452 | 219.5 | 25 | 244.5 |
| 6 | 32 | Univ of Calif - Los Angeles | 1415.518 | 10 | 1 | | | 1417.518 | 217.9 | 25 | 242.9 |
| 7 | 144 | Kansas State Univ | 1403.954 | 10 | 11 | 1 | | 1445.954 | 202.7 | 25 | 227.7 |
| 8 | 19 | Univ of Illinois - Urbana Champaign | 1337.367 | 10 | | | 120 | 1457.367 | 196.7 | 25 | 221.7 |
| 9 | 18 | Univ of Missouri | 1387.554 | 10 | 5 | 3 | | 1457.554 | 196.6 | 25 | 221.6 |
| 10 | 14 | California Polytechnic State Univ-SLO | 1398.273 | 10 | 2 | 3 | | 1462.273 | 194.2 | 25 | 219.2 |
| 11 | 82 | Georgia Institute of Technology | 1463.487 | 10 | 2 | | | 1467.487 | 191.5 | 25 | 216.5 |
| 12 | 124 | Univ of Connecticut | 1341.121 | 10 | 8 | 7 | | 1497.121 | 176.7 | 25 | 201.7 |
| 13 | 34 | California State Univ - Northridge | 1455.964 | 10 | 5 | 2 | | 1505.964 | 172.4 | 25 | 197.4 |
| 14 | 53 | Michigan State University | 1528.812 | 10 | 2 | | | 1532.812 | 159.7 | 25 | 184.7 |
| 15 | 72 | Univ of Cincinnati | 1418.467 | 10 | 3 | 6 | | 1544.467 | 154.3 | 25 | 179.3 |
| 16 | 83 | Western Michigan Univ | 1524.195 | 10 | 5 | 1 | | 1554.195 | 149.9 | 25 | 174.9 |
| 17 | 131 | Wroclaw University of Technology | 1418.913 | 10 | 1 | 7 | | 1560.913 | 146.8 | 25 | 171.8 |
| 18 | 117 | Missouri University of Science and Tech | 1517.165 | 10 | 6 | 2 | | 1569.165 | 143.1 | 25 | 168.1 |
| 19 | 99 | Univ of Akron | 1398.785 | 10 | 1 | 3 | 120 | 1580.785 | 138.0 | 25 | 163.0 |
| 20 | 71 | Oklahoma State Univ | 1557.795 | 10 | 7 | 1 | | 1591.795 | 133.2 | 25 | 158.2 |
| 21 | 17 | Univ of Victoria | 1469.487 | 10 | 2 | | 120 | 1593.487 | 132.5 | 25 | 157.5 |
| 22 | 20 | Clarkson University | 1565.647 | 10 | 1 | 3 | | 1627.647 | 118.0 | 25 | 143.0 |
| 23 | 92 | Univ of Ottawa | 1551.342 | 10 | | 5 | | 1651.342 | 108.4 | 25 | 133.4 |
| 24 | 114 | Saginaw Valley State Univ | 1620.030 | 10 | 2 | 2 | | 1664.030 | 103.3 | 25 | 128.3 |
| 25 | 21 | Univ of Colorado - Boulder | 1532.567 | 10 | 7 | 6 | | 1666.567 | 102.3 | 25 | 127.3 |
| 26 | 110 | Univ of Illinois - Chicago | 1645.784 | 10 | 1 | 1 | | 1667.784 | 101.8 | 25 | 126.8 |
| 27 | 94 | Temple Univ | 1659.113 | 10 | 3 | 2 | | 1705.113 | 87.4 | 25 | 112.4 |

# Appendix

College of Engineering

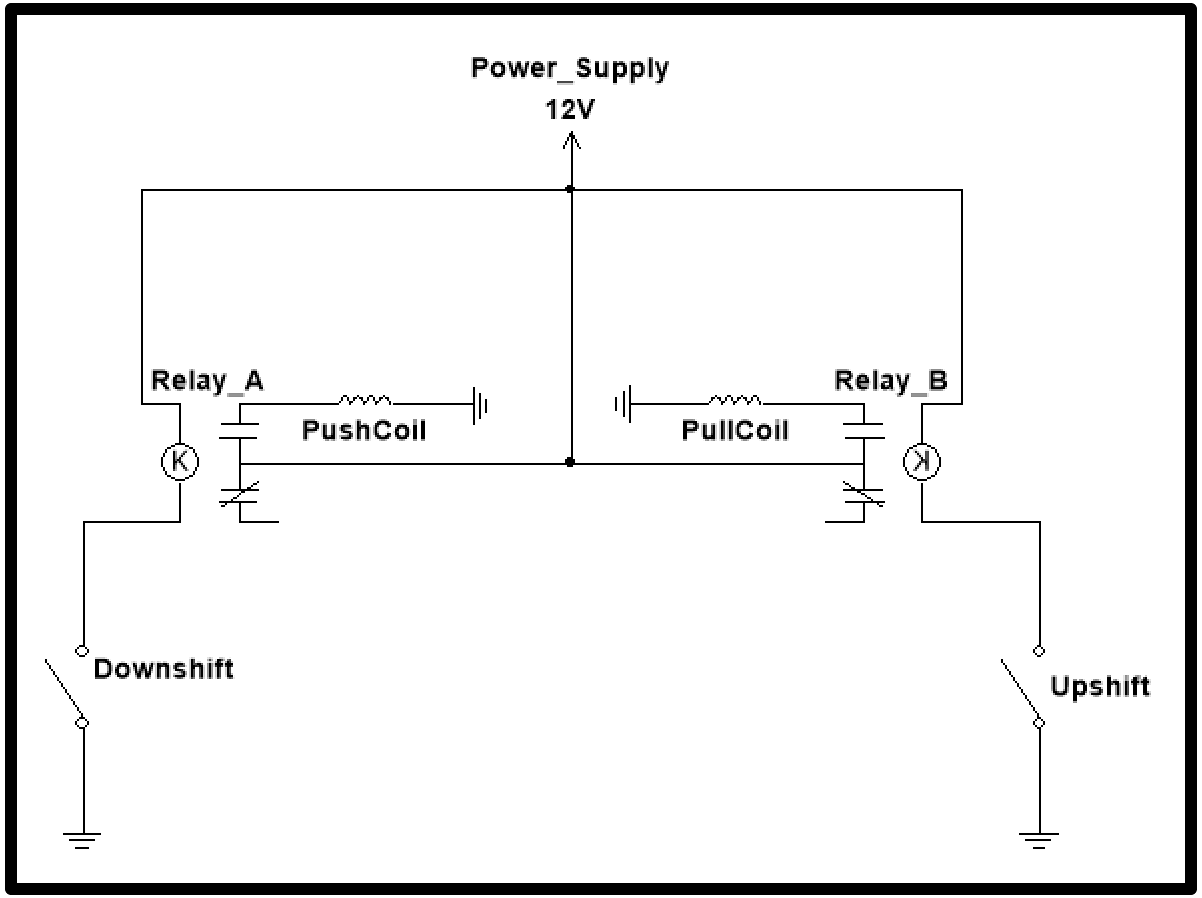
## Shifting Torque Test Results

| Trial | Engine OFF | | | | | | | | | | Engine ON | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shifting Torque [ft-lbs] | | | | | | | | | | Shifting Torque [ft-lbs] | | | | | | | | | |
| | 1st - 2nd | 2nd - 3rd | 3rd - 4th | 4th - 5th | 5th - 6th | 6th - 5th | 5th - 4th | 4th - 3rd | 3rd - 2nd | 2nd - 1st | 1st - 2nd | 2nd - 3rd | 3rd - 4th | 4th - 5th | 5th - 6th | 6th - 5th | 5th - 4th | 4th - 3rd | 3rd - 2nd | 2nd - 1st |
| 1 | 4 | 5.6 | 6.3 | 8.1 | 6.6 | 5.8 | 6.8 | 8.3 | 8.6 | 6.7 | | | | | | | | | | |
| 2 | 6.5 | 7.5 | 7.8 | 7 | 7.9 | 6.5 | 6 | 8.6 | 8 | 5 | | | | | | | | | | |
| 3 | 11.3 | 16.5 | 14.5 | 16.8 | 12.8 | 11.3 | 11.9 | 12.2 | 14.9 | 8 | | | | | | | | | | |
| 4 | 15.1 | 13.5 | 18.4 | 16.7 | 13.9 | 15.1 | 11.9 | 20 | 17.4 | 13 | | | | | | | | | | |
| 5 | 19 | 19 | 17 | 14 | 10 | 11 | 10 | 11 | 11 | 7 | | | | | | | | | | |
| | [in-lbs] | | | | | | | | | | [in-lbs] | | | | | | | | | |
| 1 | 48 | 67.2 | 75.6 | 97.2 | 79.2 | 69.6 | 81.6 | 99.6 | 103.2 | 80.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 78 | 90 | 93.6 | 84 | 94.8 | 78 | 72 | 103.2 | 96 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 135.6 | 198 | 174 | 201.6 | 153.6 | 135.6 | 142.8 | 146.4 | 178.8 | 96 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 181.2 | 162 | 220.8 | 200.4 | 166.8 | 181.2 | 142.8 | 240 | 208.8 | 156 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 228 | 228 | 204 | 168 | 120 | 132 | 120 | 132 | 132 | 84 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AVG | 132.4 | | | | | | | | | | 0.0 | | | | | | | | | |
| MEDIAN | 132 | | | | | | | | | | 0 | | | | | | | | | |

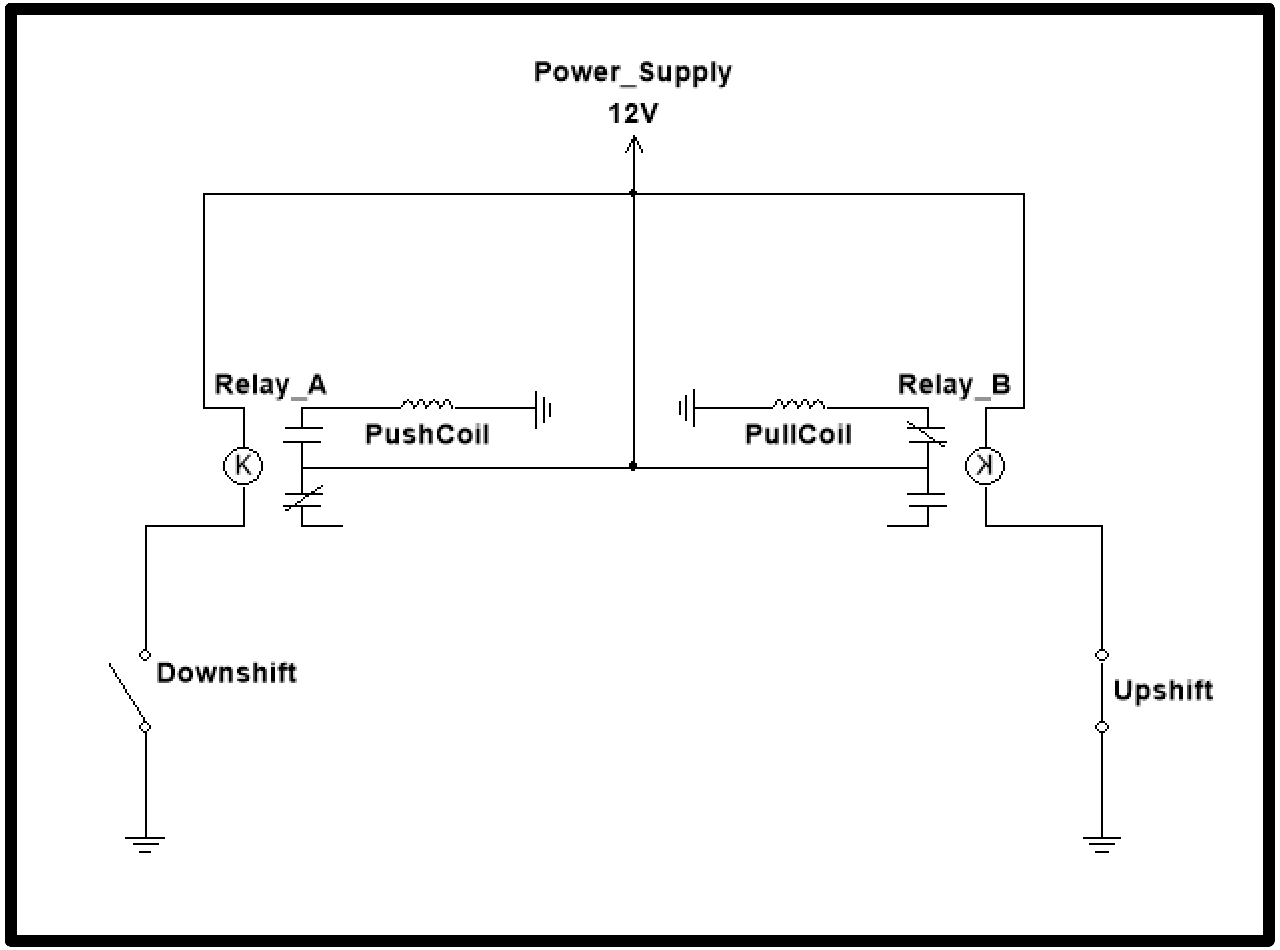
| Required | | |
|---|---|---|
| linkage | 1.5 | in |
| F | 88.3 | lbs |
| x | 0.3945 | in |
| k | 223.8 | lbs/in |

| McMaster check | | | |
|---|---|---|---|
| k | 221 | lbs/in | |
| F | 88.3 | lbs | |
| x | 0.399493 | in | 98.73% |

# Electric Power Schematic - Relay



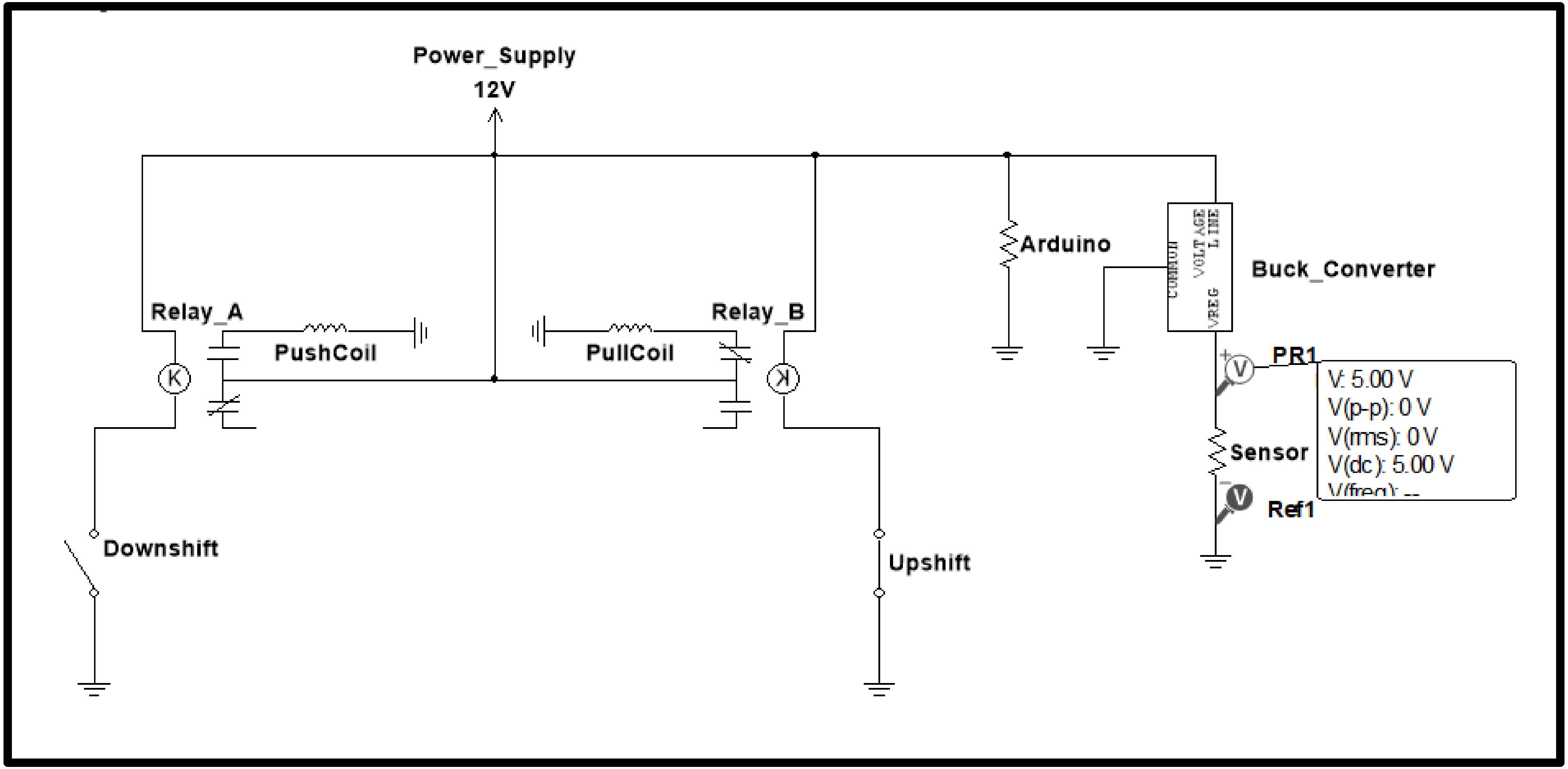

*Solenoid Actuation, Open Relay*




*Solenoid Actuation, Closed Relay*

# Electric Power Schematic (with all loads)

College of Engineering




*Complete Electric Power Overview*

# Code Example

College of Engineering

```
void controlSolenoid(int solenoidPin, float
duration) {

  // initializes limitSwitchPin variable
  int limitSwitchPin = 0;

  // This part of the code figures out which
limit switch should be checked
  if (solenoidPin == upShiftPin) {
    limitSwitchPin = upShiftLimitSwitchPin;
    Serial.println("Upshift");
  } else {
    limitSwitchPin =
downShiftLimitSwitchPin;
    Serial.println("Downshift");
  }

  // This makes the solenoid pin go high
(opens valve)
  digitalWrite(solenoidPin, HIGH);
```

```
  // Starts a timer
  unsigned long startTime = millis();

  // Following loop terminates for either:
  // A: Limit Switch is pressed
  // B: Timer exceeds duration specified in
function
  while(digitalRead(limitSwitchPin)==HIGH &
millis()-startTime<duration){
    delay(5);
  }

  // Once the loop terminates, set the
solenoid pin to low (close valve)
  digitalWrite(solenoidPin, LOW);

}
```