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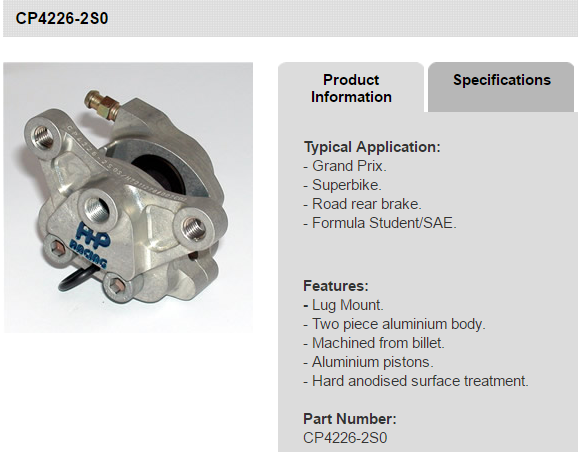
[Design 26](#_Toc482039051)

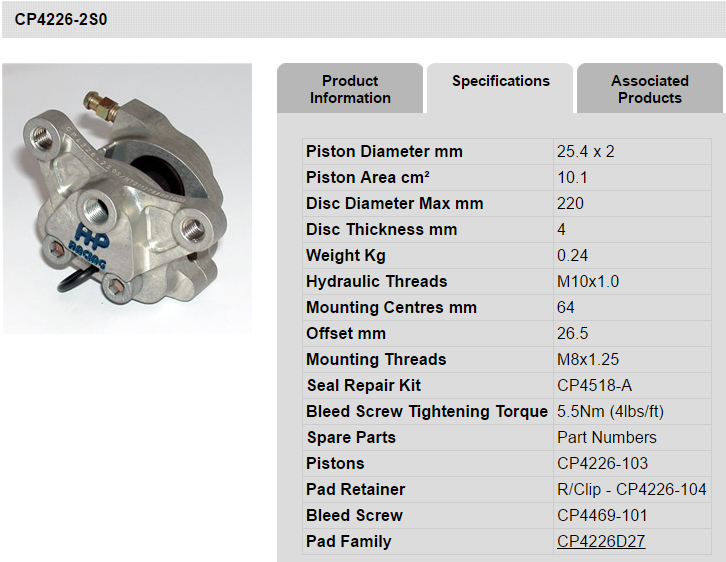
BRAKE SYSTEM

**SPECIFICATIONS**:

Calipers:

* Front : ISR 248-0B, 4 piston, 25mm dia, machined from billet aluminium, fixed





* + Pads: ISR 29-002, SBS-S-DC10-HH
* Rear: AP Racing CP4226-2S0, Two piston, 25.4 mm dia.,machined from billet aluminium, fixed



* + AP Racing CP4226D27, APH420 material

Master Cylinder: two independent systems front/rear

* Front: Tilton engineering series 77, 0.75" bore , adjustable balance bar
* Rear: Tilton engineering series 77, 0.70" bore and proportioning valve

Rotors:

* Front: Floating mild steel, hub mounted 200mm dia, 4.7 mm thick, laser cut
* Rear: Floating mild steel, hub mounted 200mm dia, 3 mm thick, laser cut

Oil:

* Dot 4

Brake lines: hard line aluminum, rated 3200 psi, 6061T6 vs braided hose we save 2.24lbs + 1.33 lbs of fittings

**CHOICE OF COMPONENTS:**

Sought after general characteristics:

1. Price
2. Accessibility of spare parts
3. reliability

Calipers: Diameter, number of pistons, weight impact, packaging, effective radius, weight

*Options considered*: AP for Front, Willwood, Brembo, akebono

Pads: Availability, information given on lining material, capability with rotor

Master Cylinder: Achieve certain pressure, light weight, spherical end

Advantages:

* Experience with components
* The team has many spare parts

**PROBLEMS FACED WITH THE SYSTEM:**

* Building pressure in the system (2016)
* Difficulties getting high in temperatures (2016)

**MODIFICATIONS**

* Balance bar
* Proportioning valve

ROTOR SIZING

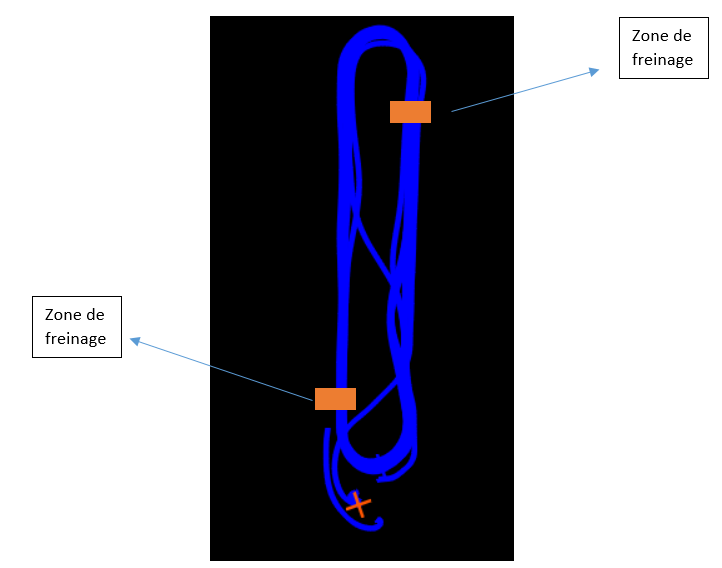
DESIGN OBJECTIVE

* Reduce weight
* Reach optimum temperature for pads

METHOD

* Iterations
* Lump capacitance method (temperature is considered equal in all rotor)

|  |  |  |  |
| --- | --- | --- | --- |
| Speed: | 16 | m/s |  |
| Diameter: | 0.2 | m |  |
| Nu : | 1.89E-05 |  |  |
| Ka : | 0.0285 |  |  |
| Re : | 1.69E+05 | - |  |
| h\_r : | 74.936 | W/m^2 \* K |  |
| Ar : | 0.02 | 0.019 | m^2 |
| Tr : | 0.0048 | 0.0032 |  |
| Rho\_r : | 7226 | kg/m^3 |  |
| rotor volume : | 0.000096 | 0.0000608 | m^3 |
| Mass : | 272.72 | kg |  |
| Decel : | 7.829 | g |  |
| To : | 7 | ⁰C |  |

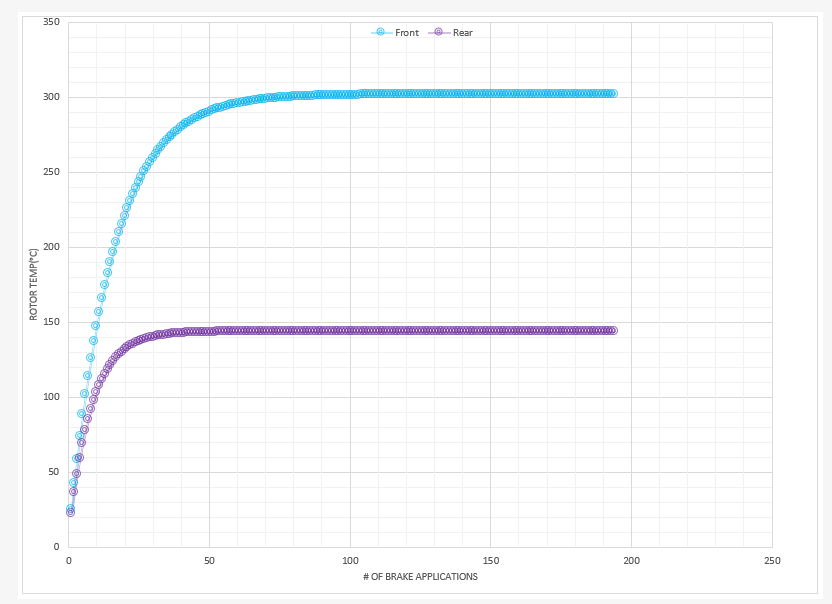


|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Brake applications | |  |  |  |
|  | T |  | a | b |
| 1 | 30.0364802 |  | 0.07747844 | 0.07747844 |
| 2 | 51.2881297 |  | 0.14895397 | 0.07747844 |
| 3 | 70.8932347 |  | 0.21489169 | 0.07747844 |
| 4 | 88.9793666 |  | 0.27572066 | 0.07747844 |
| 5 | 105.664213 |  | 0.33183669 | 0.07747844 |
| 6 | 121.056344 |  | 0.38360495 | 0.07747844 |
| 7 | 135.255916 |  | 0.43136227 | 0.07747844 |
| 8 | 148.355328 |  | 0.47541944 | 0.07747844 |
| 9 | 160.439818 |  | 0.51606312 | 0.07747844 |
| 10 | 171.58802 |  | 0.5535578 | 0.07747844 |

Front Rotor Temps:

Rear Rotor Temps:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Brake applications | |  |  |  |
|  | T |  | a | b |
| 1 | 22.5885956 |  | 0.11393662 | 0.11393662 |
| 2 | 36.4010792 |  | 0.21489169 | 0.11393662 |
| 3 | 48.6398152 |  | 0.30434428 | 0.11393662 |
| 4 | 59.4841108 |  | 0.38360495 | 0.11393662 |
| 5 | 69.0928441 |  | 0.45383492 | 0.11393662 |
| 6 | 77.6067907 |  | 0.51606312 | 0.11393662 |
| 7 | 85.150687 |  | 0.57120126 | 0.11393662 |
| 8 | 91.8350572 |  | 0.62005714 | 0.11393662 |
| 9 | 97.7578328 |  | 0.66334654 | 0.11393662 |
| 10 | 103.005787 |  | 0.7017037 | 0.11393662 |

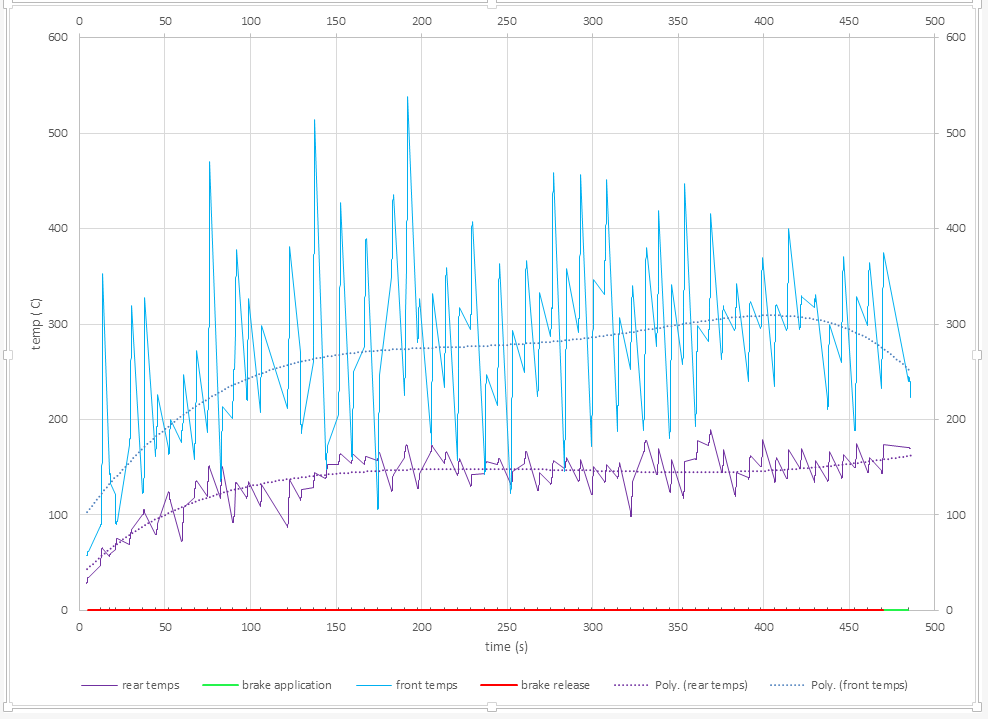


Hypothetic

VALIDATION

Thermocouples TYPE K were attached to pads to see if the temperature simulation was indeed true

Driver had to make 25 laps and brake 2 times each lap to recreate conditions in the hypothetic approach

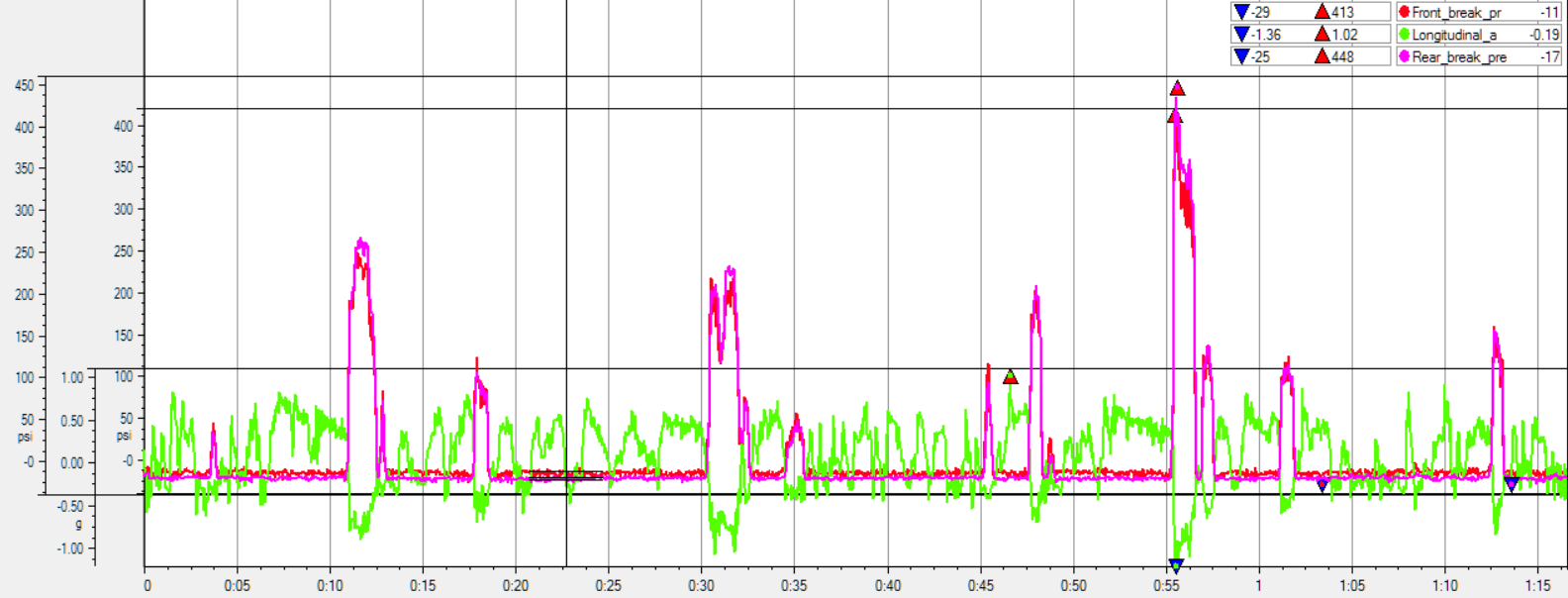


Experimental test

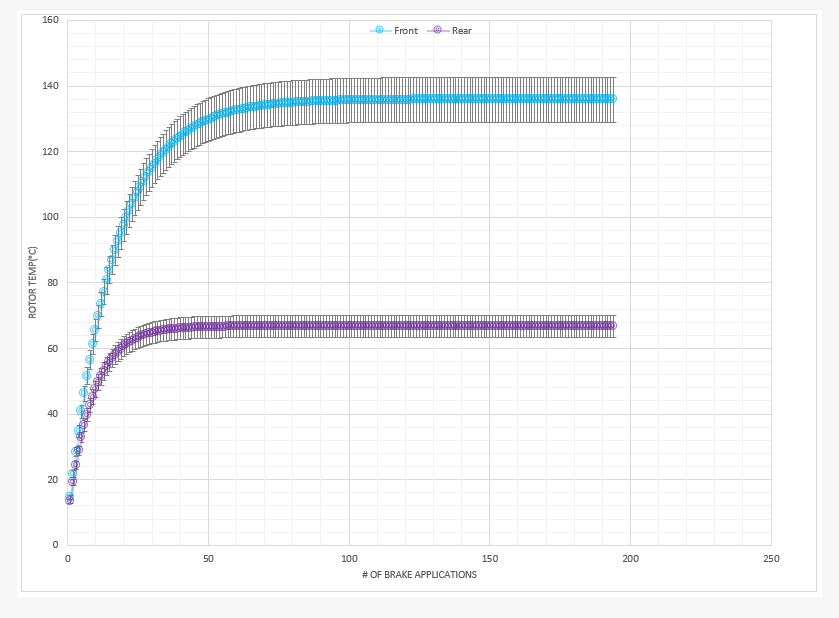
FUTUR IMPROVEMENTS:

There is a lot of noise in front temps signal, maybe use a different way to attach the thermocouples.

Projected temperature of Michigan 2016 endurance



|  |  |
| --- | --- |
| Brake mean time | 0.467 seconds |
| Cooling mean time | 7.34 seconds |



Stagnation temperature of rotors Michigan endurance 2016

BRAKE COMPONENTS SIZING

DESIGN OBJECTIVES

* reliable
* no possible failures

METHOD

With loads previously obtained, it is essential to respect maximum ratings of standard (non-designed) components such as hydraulic hoses, master cylinders and calipers (if applicable). A spreadsheet has been made in order to assure constant respect of these limitations during all stages of braking.

* 270 N/g of deceleration
* Force to lock up 375 N
* Variable pedal ratio
* Bias 0.5
* Setup was selected to outcome the small friction coefficient of pads in the rear

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Master Cylinder sizes** | |  | **Pedal ratios** |  | Force applied to pedal | | |  | **Front/rear bias** | | 0.5 |
| In | mm |  | - |  |  | lbf | N |  | **Max caliper rating (PSI)** | | 1500 |
| 0.625 | 15.875 |  | 2 |  | min | 70 | 311.3755134 |  |  |  |  |
| 0.75 | 19.05 |  | 2.5 |  | max | 449.6189 | 2000 |  |  |  |  |
| 0.8125 | 20.6375 |  | 3 |  |  |  |  |  |  |  |  |
| 0.875 | 22.225 |  | 3.5 |  |  |  |  |  |  |  |  |
| 1 | 25.4 |  | 4 |  |  |  |  |  |  |  |  |
| 1.125 | 28.575 |  | 5 |  |  |  |  |  |  |  |  |

DESIGN TABLES

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Resulting min line pressure REAR (psi)** | | | | | |
| **mc size/pedal ratio** | **2** | **2.5** | **3** | **3.5** | **4** | **5** |
| **15.875** | 228 | 285 | 342 | 399 | 456 | 570 |
| **19.05** | 158 | 198 | 238 | 277 | 317 | 396 |
| **20.6375** | 135 | 169 | 203 | 236 | 270 | 338 |
| **22.225** | 116 | 146 | 175 | 204 | 233 | 291 |
| **25.4** | 89 | 111 | 134 | 156 | 178 | 223 |
| **28.575** | 70 | 88 | 106 | 123 | 141 | 176 |
|  |  |  |  |  |  |  |
|  | **Resulting min line pressure FRONT (psi)** | | | | | |
| **mc size/pedal ratio** | **2** | **2.5** | **3** | **3.5** | **4** | **5** |
| **15.875** | 228 | 285 | 342 | 399 | 456 | 570 |
| **19.05** | 158 | 198 | 238 | 277 | 317 | 396 |
| **20.6375** | 135 | 169 | 203 | 236 | 270 | 338 |
| **22.225** | 116 | 146 | 175 | 204 | 233 | 291 |
| **25.4** | 89 | 111 | 134 | 156 | 178 | 223 |
| **28.575** | 70 | 88 | 106 | 123 | 141 | 176 |

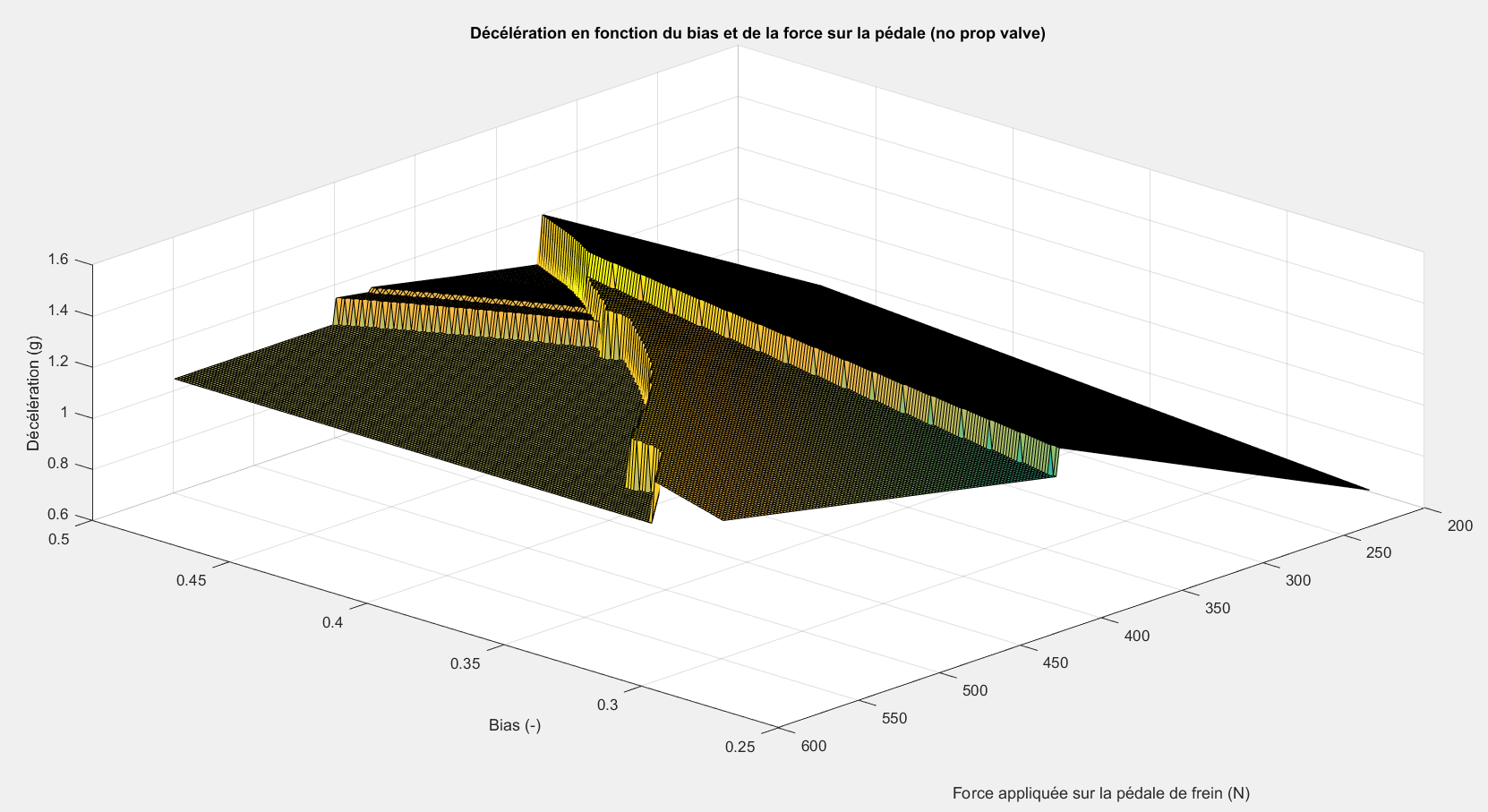
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Resulting max line pressure REAR (psi)** | | | | | |
| **mc size/pedal ratio** | **2** | **2.5** | **3** | **3.5** | **4** | **5** |
| **15.875** | 1466 | 1832 | 2198 | 2565 | 2931 | 3664 |
| **19.05** | 1018 | 1272 | 1527 | 1781 | 2035 | 2544 |
| **20.6375** | 867 | 1084 | 1301 | 1518 | 1734 | 2168 |
| **22.225** | 748 | 935 | 1122 | 1309 | 1495 | 1869 |
| **25.4** | 572 | 716 | 859 | 1002 | 1145 | 1431 |
| **28.575** | 452 | 565 | 678 | 792 | 905 | 1131 |
|  |  |  |  |  |  |  |
|  | **Resulting max line pressure FRONT (psi)** | | | | | |
| **mc size/pedal ratio** | **2** | **2.5** | **3** | **3.5** | **4** | **5** |
| **15.875** | 1466 | 1832 | 2198 | 2565 | 2931 | 3664 |
| **19.05** | 1018 | 1272 | 1527 | 1781 | 2035 | 2544 |
| **20.6375** | 867 | 1084 | 1301 | 1518 | 1734 | 2168 |
| **22.225** | 748 | 935 | 1122 | 1309 | 1495 | 1869 |
| **25.4** | 572 | 716 | 859 | 1002 | 1145 | 1431 |
| **28.575** | 452 | 565 | 678 | 792 | 905 | 1131 |

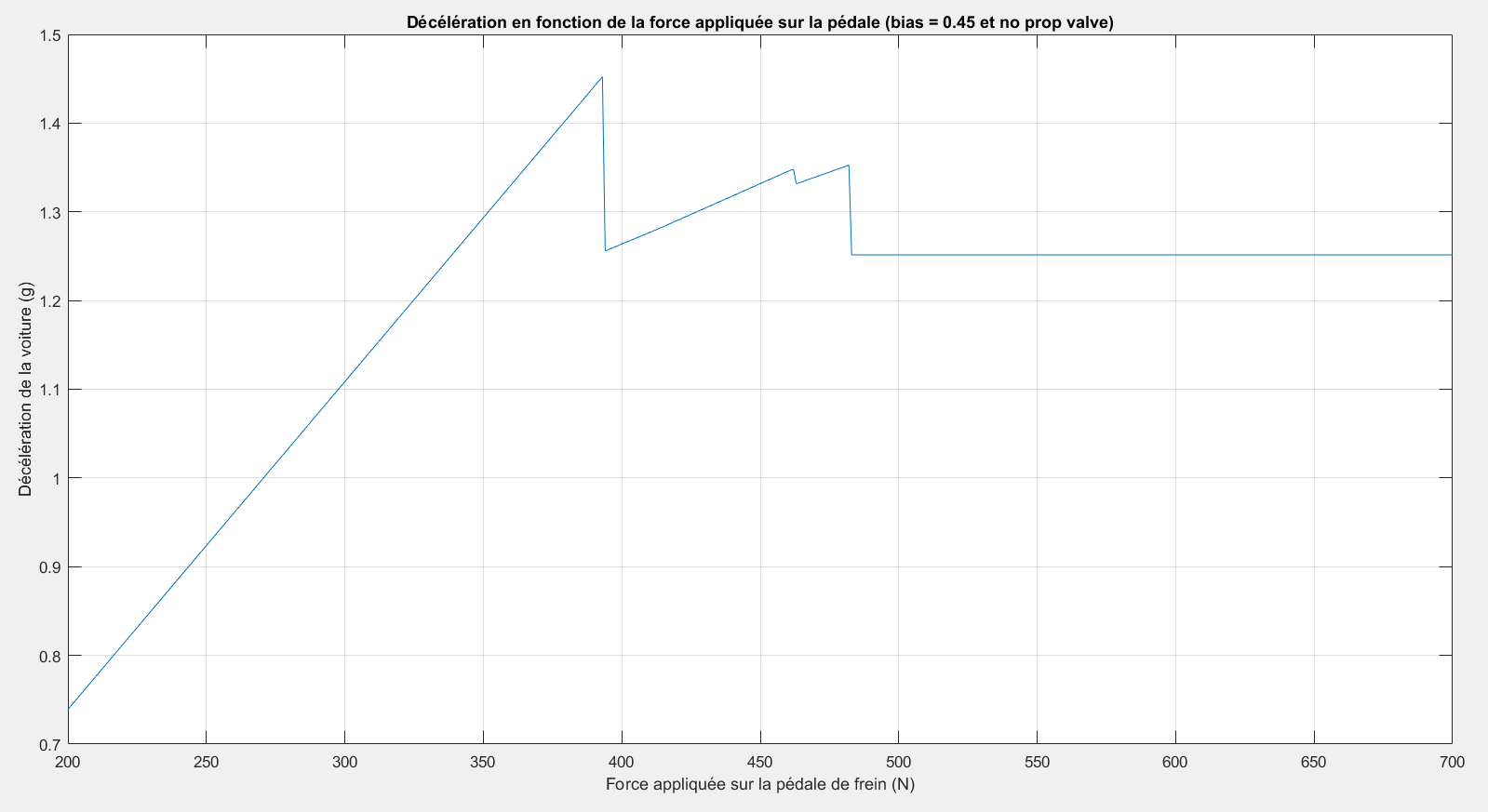
**Pressure needed to lock up the wheels**

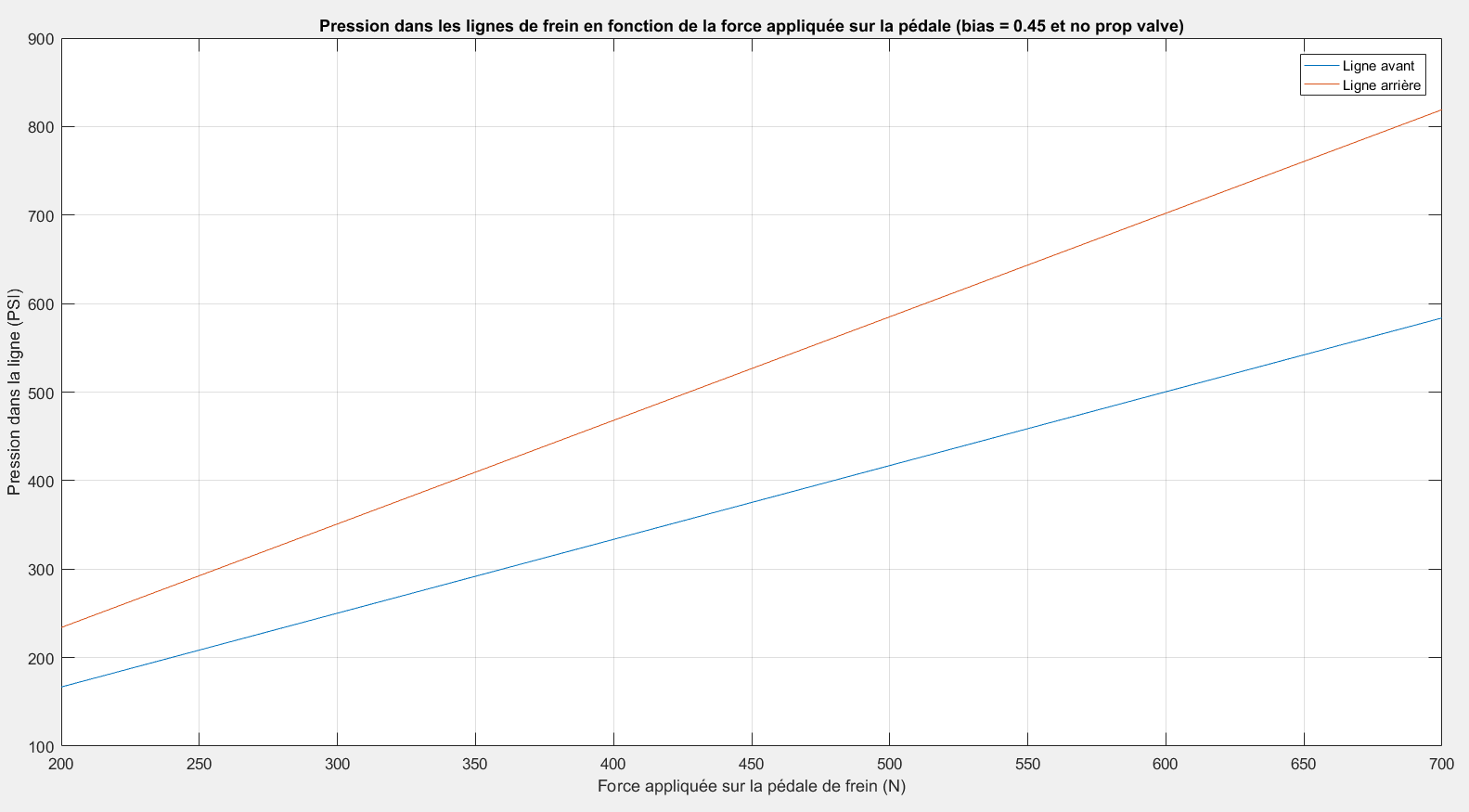
|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | piston dia(mm)/disc radius(m) | | **0.0889** | **0.09144** | **0.09398** | **0.09652** | **0.09906** |
| needed front pressure (Pa) | | **20** | 5508521.003 | 5355506.531 | 5210763.111 | 5073637.766 | 4943544.49 |
|  |  | **21** | 4996390.933 | 4857602.296 | 4726315.747 | 4601939.017 | 4483940.581 |
|  |  | **22** | 4552496.697 | 4426038.455 | 4306415.795 | 4193089.063 | 4085573.959 |
|  |  | **23** | 4165233.273 | 4049532.349 | 3940085.528 | 3836399.067 | 3738029.86 |
|  |  | **24** | 3825361.808 | 3719101.758 | 3618585.494 | 3523359.56 | 3433017.007 |
|  |  | **25** | 3525453.442 | 3427524.18 | 3334888.391 | 3247128.17 | 3163868.474 |
|  |  | **26** | 3259479.884 | 3168938.776 | 3083291.782 | 3002152.524 | 2925174.255 |
|  |  |  |  |  |  |  |  |
|  | piston dia(mm)/disc radius(m) | | **0.0889** | **0.09144** | **0.09398** | **0.09652** | **0.09906** |
| needed rear pressure (Pa) | | **20** | 4406816.803 | 4284405.225 | 4168610.489 | 4058910.213 | 3954835.592 |
|  |  | **21** | 3997112.746 | 3886081.837 | 3781052.598 | 3681551.214 | 3587152.465 |
|  |  | **22** | 3641997.358 | 3540830.764 | 3445132.636 | 3354471.25 | 3268459.167 |
|  |  | **23** | 3332186.618 | 3239625.879 | 3152068.423 | 3069119.254 | 2990423.888 |
|  |  | **24** | 3060289.446 | 2975281.406 | 2894868.395 | 2818687.648 | 2746413.606 |
|  |  | **25** | 2820362.754 | 2742019.344 | 2667910.713 | 2597702.536 | 2531094.779 |
|  |  | **26** | 2607583.907 | 2535151.021 | 2466633.425 | 2401722.02 | 2340139.404 |

BRAKE SETUP OPTIMISATION

* A math lab script was made to find optimum bias

****

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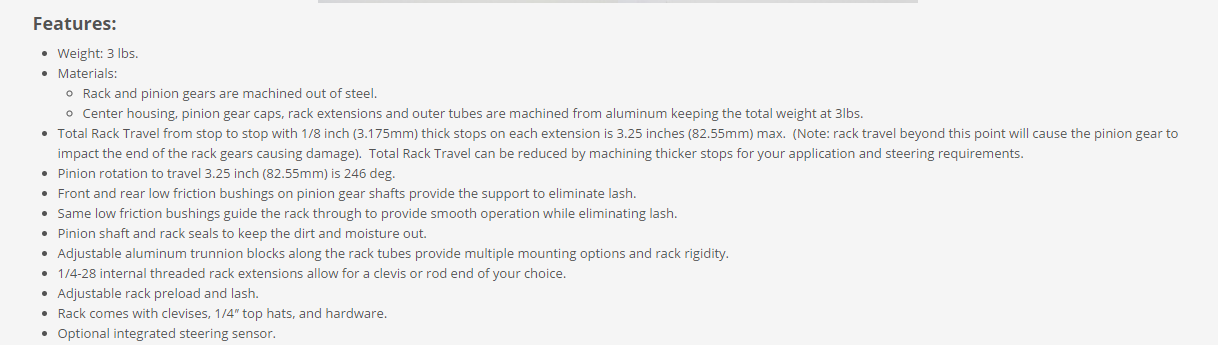
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CONTROLS

SPECIFICATIONS

Steering wheel: momo mod.12, 250mm, spa quick connect



Steering rack: kaz technologies FSAE steering rack 

Steering column: double u-joint system

Clutch lever: stock brp ds450 clutch lever, by wire, launch control possibilities, adjustable position and motion ratio, off the shelf easy and fast to have

Shifter: Electro-pneumatic system, HPA

Throttle pedal: machined 6061T6 aluminum, cam pivot, hidden components, inverted, adjustable cups, by wire, adjustable sensitivity and travel

Brake pedal: machined 6061T6 aluminum, hidden components, inverted, adjustable cups

CHOICE OF COMPONENTS

Sought after general characteristics:

1. Price
2. Accessibility of spare parts
3. reliability

Steering wheel: Quality, comfortable, acceptable size, no worries about failures

Quick release: **SPA Steering Wheel Quick Releases conform to the latest FIA technical specification, no worries about failures**

**Steering column: Minimising compliance in the system for optimal feedback for drivers, good steering effort**

**Steering rack: adjustable pre-load and lash, travel, durability, adjustable setup, weight price ratio**

**Shifter: Stability and feedback, weight, simplicity**

**Throttle pedal: rigid, good feedback, adjustable**

**Brake pedal: rigid, minimal compliance, good feedback, comfortable**

STEERING SYSTEM

DESIGN OBJECTIVES

* Reduce weight
* Have more turning radius → one turn at Lincoln 2016 was barely enough
* Good feedback

METHOD

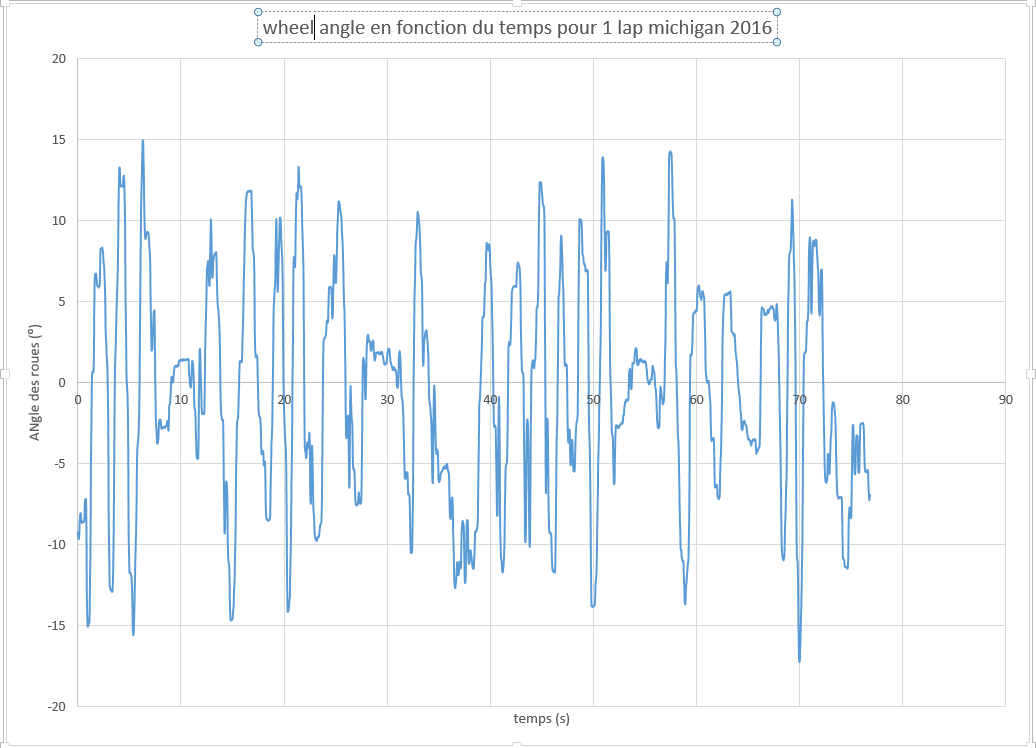
* We don’t use the rack full travel, we are using bushing that minimize the travel.
* New clevis were made to simplify and have less different spacers and bushing on the car, bushings are now same as the suspension.

VALIDATION

Steering angle characterisation

|  |  |
| --- | --- |
| wheel angle | steering angle |
| -24.2 | -104 |
| -20 | -83 |
| -16 | -66 |
| -12 | -51 |
| -8 | -33 |
| -4 | -18 |
| 0 | -2 |
| 4 | 13 |
| 8 | 30 |
| 12 | 46 |
| 16 | 62 |
| 20 | 79 |
| 23.5 | 99 |
|  |  |

Michigan 2016 wheel angles analysis



Compliance analysis based on Steve Fox cockpit efforts (100N\*m \* 1.35FS)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **CONSTRAINT+DEFORMATION ANALYSIS FOR STEERING TUBES** | | | | | | | | | | | | |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | MATERIAL PROPERTIES | | | | | |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| NORMAL MAXIMAL INPUT TORQUE | | | | (Nm) | 61 |  | MATERIAL | | | | (-) | Steel 4130 chromoly |
| DESIGN TORQUE | | | | (Nm) | 135 |  | YIELD STRENGTH | | | | (Mpa) | 435 |
|  |  |  |  |  |  |  | G | | | | (Mpa) | 80000 |
| EXTERNAL DIAMETER | | | | (mm) | 19.05 |  | DENSITY | | | | (g/cm3) | 7.85 |
| INTERNAL DIAMETER | | | | (mm) | 17.339 |  |  |  |  |  |  |  |
| LENGTH | | | | (mm) | 192.66 |  |  |  |  |  |  |  |
| J | | | | (mm4) | **4056** |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **IMPORTANT RESULTS** | | | | | | | | | | | | |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| SHEAR CONSTRAINT | | | | (Mpa) | **634.1** |  | WEIGHT | | | | (g) | **73.96** |
| ANGULAR DEFORMATION | | | | (˚) | **0.08** |  |  |  |  |  |  |  |

SHIFTER SYSTEM

COMPONENTS

Bottle: HPA, 4500 psi , 68cc, carbon

Actuation: Buttons on steering wheel

Valve:  5/3, high reliability, SCORPION

Piston : Festo 25mm

Engine transmission lever: aluminum casted

ECU : ignition cut feature for up shifts

DESIGN OBJECTIVE

* Constant shifts
* Enough gas in bottle for endurance
* Keep driver focused

VALIDATION

* The bottle allows 2040 shifts at a 150 psi pressure
* The number of shifts is roughly 1056 according to data of Michigan 2016 endurance (Worst case 12 braking X Accel and Decel X 2 gear at max = 1056)
* Driver keeps his hands always on wheel

Force needed to shift is 100N (looked with a fish weight) and to be sure to shift we had a FS of 3.5

PEDAL BOX

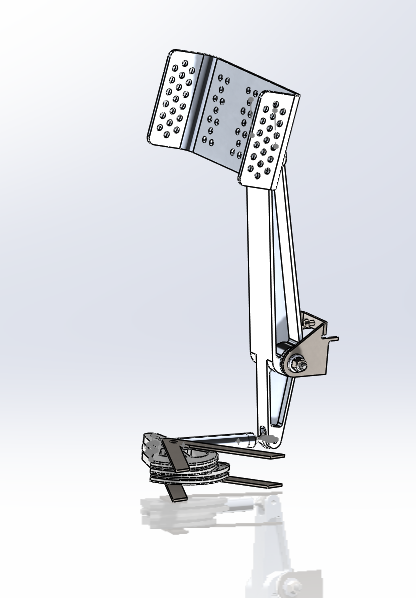
Design objectives

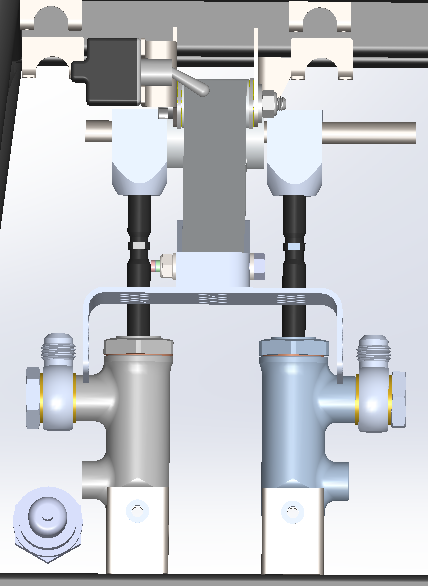
* Reduce mass
* Make something cost efficient
* Adjustability
* More sensitive
* Linear feel

METHOD

We changed the layout of the pedals vs last year:

* The pedals are in bending but this allowed us to reduce chassis length and save weight afterward, so it is a good compromise
* Brake pedal is now bulkier but with all the modifications made to chassis including pedal box we saved 21.5 lbs to the chassis, with only a 0.132 lbs added to the pedal vs last year.
* Inverted layout made all components go underneath the floor and reduce chassis length
* Pedal box area is cleaner
* Cup are easily changeable to driver’s need (Ergo wise)
* Travel is adjustable on throttle pedal
* Sensitivity is adjustable on throttle pedal ( linear to be in sync with engine map)
* Same machining setup reducing cost
* Bearing setup is lighter with needle + thrust bearing





DRIVER’S POSITION / ERGONOMICS / SAFETY

SPECIFICATIONS

DRIVER’S POSITION / ERGONOMICS:

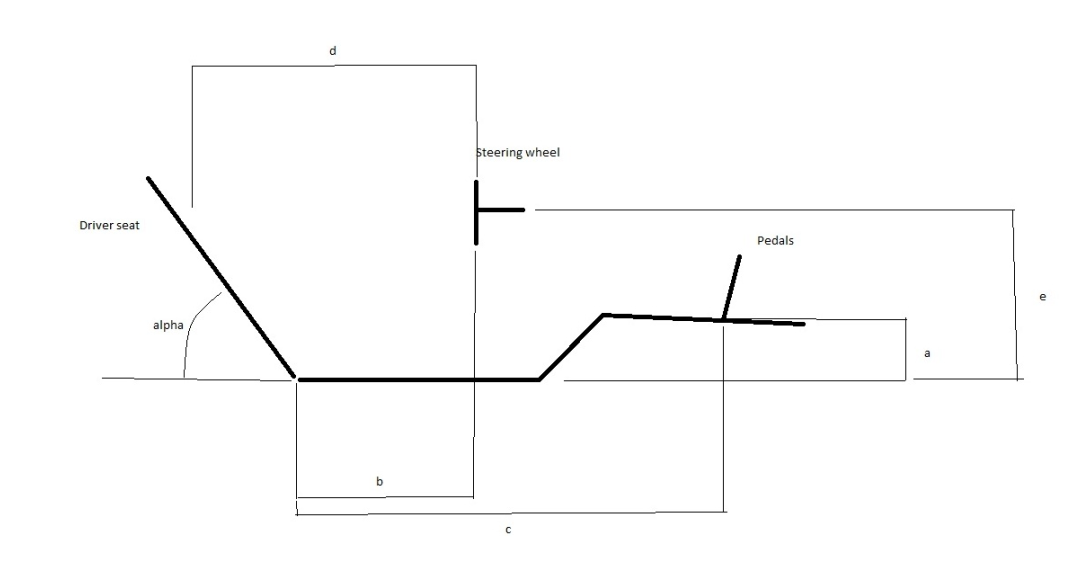
* Hands always on wheel
* Comfortable wheel
* Seat comfortable and able to sleep in the car
* Blind fold test easy to achieve
* Everything is easy to see on the dash and is well identified
* As said earlier pedal cups are interchangeable to accommodate drivers

SAFETY:

* Tubes higher than side impact
* Engine mounts can take up to 57 g before failure, a lot higher than the recommended 20 g

Design

Dimensions of the car were based on the fastest driver, and other drivers fit in the car with custom seat inserts for each.



|  |  |  |
| --- | --- | --- |
| distance | measures | unit |
| a | 88.9 | mm |
| b | 319.31 | mm |
| c | 985.98 | mm |
| d | 604.38 | mm |
| e | 400.74 | mm |
| α | 52 | ⁰ |

Final measures of the car

With this setup the car accommodates the 5th female percentile and the 95th male percentile.

Angle: The angle of the seat is a compromise between visibility and CG height, the fact that the driver is more comfortable may allow him to do better lap time.

Comparison to F1 cars:

