Design Parameters

- F_{bp}= the force output of the brake pedal assembly
- F_d = the force applied to the pedal pad by the driver
- P_{mc} = the hydraulic pressure generated by the master cylinder
- A_{mc} = the effective area of the master cylinder hydraulic piston
- P_{cal} = the hydraulic pressure transmitted to the calliper
- F_{cal} = the one-sided linear mechanical force generated by the caliper
- A_{cal} = the effective area of the calliper hydraulic piston(s) found on one half of the calliper body
- F_{cl} = the clamp force generated by the caliper
- $F_{friction}$ = the frictional force generated by the brake pads opposing the rotation of the rotor
- μ_{bp} = the coefficient of friction between the brake pad and the rotor
- T_r = the torque generated by the rotor
- R_{eff} = the effective radius (effective moment arm) of the rotor (measured from the rotor centre of rotation to the centre of pressure of the caliper pistons)
- F_{tire} = the force reacted between the tire and the ground (assuming friction exists to support the force)
- F_{total} = the total braking force reacted between the vehicle and the ground (assuming adequate traction exists)
- a_v = the deceleration of the vehicle
- m_v= the mass of the vehicle= 500 Kg
- D_s = the stopping distance of the vehicle
- V_v =velocity of moving vehicle
- V_f = the front axle vertical force (weight)
- V_r = the rear axle vertical force (weight)
- WT = the absolute weight transferred from the rear axle to the front axle
- g = the acceleration due to gravity (effectively expressing av in units of g's)
- h_{CG} = the vertical distance from the CG to ground.
- $V_{f,d}$ = the front axle dynamic vertical force for a given deceleration
- $V_{r,d}$ = the rear axle dynamic vertical force for a given deceleration
- $F_{tires,f}$ = the combined front tire braking forces
- $F_{tires,r}$ = the combined rear tire braking forces
- $\mu_{peak,f}$ = the maximum effective coefficient of friction between the front tires and the road
- $\mu_{peak,r}$ = the maximum effective coefficient of friction between the rear tires and the road

Braking Calculation

ASC Requirement

As per ASC2022 10.5.C :

Solar cars must be able to repeatedly stop from speeds of 50 km/h (31 mph) or greater, with an average deceleration, on level wetted pavement, exceeding 4.72 m/s^2. Performance shall be demonstrated with mechanical braking only.

For buffer, we have selected the velocity to be 60km/h and the deceleration to 6 m/s^2.

Brake Pedal Force (F_{bp})

$$\mathrm{F}_{bp} = \mathrm{F}_d * \frac{l_2}{l_1}$$

F_d = the force applied to the pedal pad by the driver = 130 N

l_1 = The distance from the brake pedal arm pivot to the output rod clevis attachment

l_2 = The distance from the brake pedal arm pivot to the brake pedal pad

$\frac{l_2}{l_1}$ = Pedal ratio = 5.1

$$\mathrm{F}_{bp} = 130 * 5.1 = 663N$$

Master Cylinder Pressure (P_{mc})

$$\mathrm{P}_{mc} = \frac{F_{bp}}{A_{mc}}$$

MC Bore = 0.625 in = 0.01587 m

A_{mc} = Effective area of the master cylinder = $\frac{\pi*(0.0158)^2}{4}$ = $1.98 * 10^{-4}$

$$\mathrm{P}_{mc} = \frac{663}{1.98 * 10^{-4}} = 3348484.84\ Pa$$

Force generated by caliper piston (F_{cal})

A_{cal} = $3in^2$ = 0.001935 m^2

P_{cal} = P_{mc} = 3348484.84

$$\mathrm{F}_{cal} = \mathrm{P}_{cal} * A_{cal}$$

$$\mathrm{F}_{cal} = 3348484.84 * 0.001935 = 6479.3\mathrm{N}$$

Caliper Clamp Load (F_{cl})

$$F_{cl} = F_{cal} * 2$$

$$F_{cl} = 6479.3 * 2 = 12958.6\,N$$

Force on disc by brake pads ($F_{friction}$)

$$F_{friction} = F_{cl} * \mu_{bp}$$

$$\mu_{bp} = 0.4$$

$$F_{friction} = 12958.6 * 0.4 = 5183.44N$$

Torque of rotor (T_r)

$$T_r = F_{friction} * R_{eff}$$

R_{eff} = Effective rolling radius = 12 in = 0.3048 m

$$T_r = 5183.44 * 0.3048 = 1579.91\,N.m$$

Force on a tire (F_{tire})

$$F_{tire} = \frac{T_r}{R_t}$$

R_t = 0.254 m

$$Force\ on\ front\ wheels:\ F_{tire,f} = \frac{1579.91}{0.254} = 6220.12\,N$$

$$Force\ on\ rear\ wheels:\ F_{tire,r} = \frac{1579.91}{0.254} = 6220.12\,N$$

$$\sum F = F_{tire,f} + F_{tire,r} = 6220.12 * 4 = 24880.48\,N$$

Kinetic energy of the vehicle

KE = $\frac{1}{2}mv^2 = \frac{1}{2}(500)\left(60 * \frac{5}{18}\right)^2 = 69.4kJ$

Stopping Distance

F = $\mu * m * g = 0.6 * 500 * 9.8 = 2940N$

d_s = $\frac{KE}{F} = \frac{69444}{2940} = 23.6m$

Deceleration

a_v = $\frac{v^2 - u^2}{2d_s}$

v = 0; u = 60km/h = 16.67 m/s

a_v = $\frac{0^2 - 16.67^2}{2*23.6}$= -5.89 m/s^2

CG_f = Distance between front axle to CG = 1.47 m

CG_r = Distance between rear axle to CG = 1.47 m

WB = Distance between front axle to rear axle = 2.94 m

h_{cg} = Height of Centre of gravity = 0.5775 m

V_t = 500 * 9.8 = 4900 N

Rear axle vertical force (weight)

$$\mathrm{CG}_r = \frac{V_r}{V_t} * WB$$

$$V_r = \frac{\mathrm{CG}_r * V_t}{WB}$$

$$V_r = \frac{1.47 * 4900}{2.94}$$

$$V_r = 2450\ N$$

Front axle vertical force (weight)

$$\mathrm{CG}_f = \frac{V_f}{V_t} * WB$$

$$V_f = \frac{\mathrm{CG}_f * V_t}{WB}$$

$$V_f = \frac{1.47 * 4900}{2.94}$$

$$V_f = 2450\ N$$

Dynamic absolute weight transferred

$$\mathrm{WT} = \frac{a_v}{g} * \frac{h_{cg}}{WB} * V_t$$

$$\mathrm{WT} = \frac{5.89}{9.8} * \frac{0.5775}{2.94} * 4900 = 578.48N$$

Dynamic Vertical Force

Front Axle

$$V_{f,d} = V_f + WT$$

$$V_{f,d} = 2450 + 578.48 = 3028.48\ N$$

Rear Axle

$$V_{r,d} = V_r - WT = 2450 - 578.48 = 1871.52$$

Effect of weight transfer on Tire Output

Front Tire

$$\mathrm{F}_{tire,f} = \mu_{peak,f} * \mathrm{V}_f = 0.6 * 2450 = 1470 \mathrm{~V}$$

Rear Tire

$$\mathrm{F}_{tire,r} = \mu_{peak,r} * \mathrm{V}_r = 0.6 * 2450 = 1470 \mathrm{~V}$$

Maximum Braking Force Produced By axle

Front Axle

$$\mathrm{F}_{tire,f} = \mu_{peak,f} * \mathrm{V}_{f,d} = 0.6 * 3028.48 = 1817.09 \mathrm{~V}$$

Rear Axle

$$\mathrm{F}_{tire,r} = \mu_{peak,r} * \mathrm{V}_{r,d} = 0.6 * 1871.52 = 1122.91 \mathrm{~V}$$

Breaking Efficiency

$$\eta = \frac{Total\ braking\ Force}{Total\ Weight\ of\ vehicle} * 100$$

$$\eta = \frac{24880.48}{500 * 9.8} * 100$$

$$\eta = 507.76\%$$