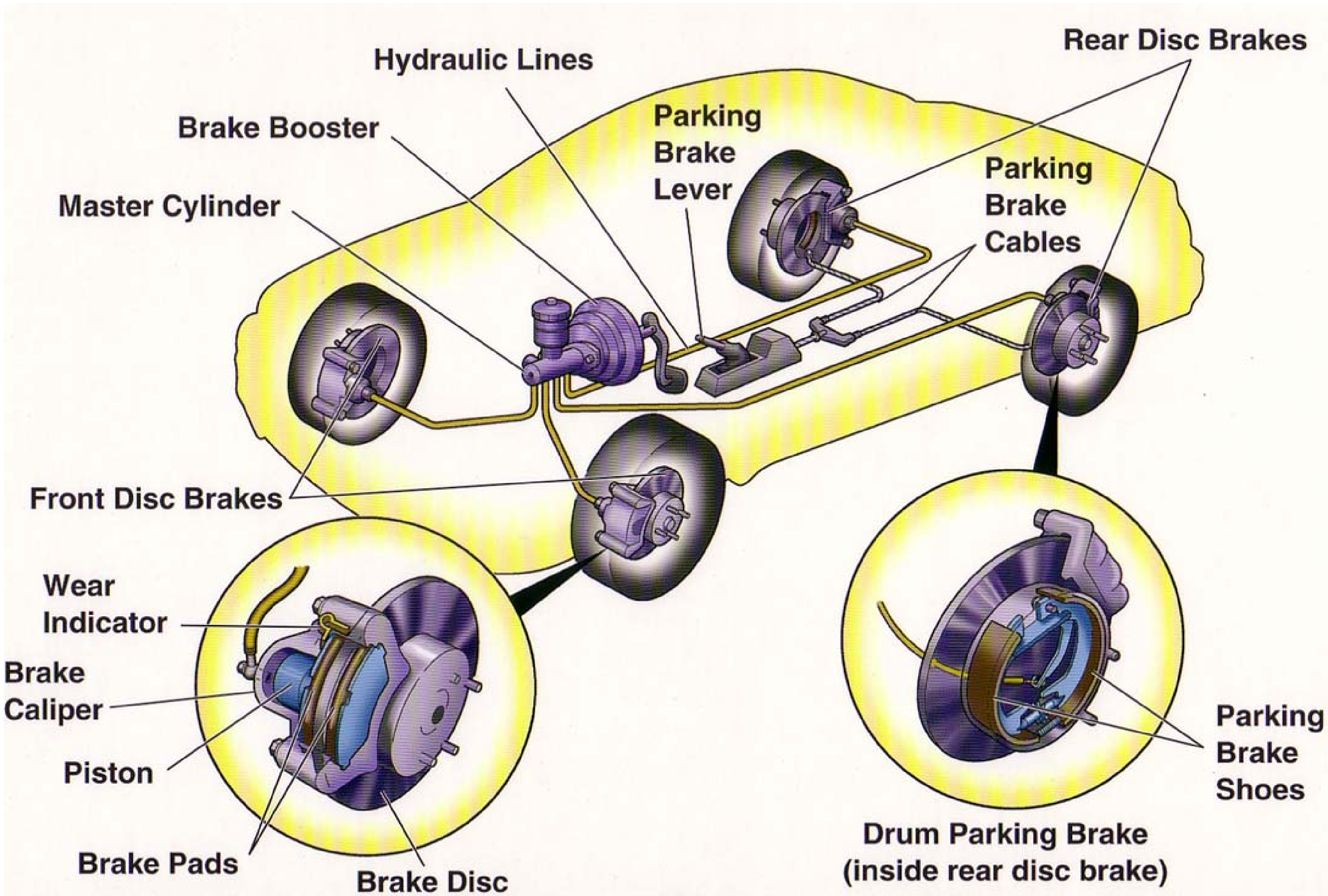
# Project #2

- Design an optimum configuration and specifications for caliper disc brakes for vehicle
- Design criteria: minimum stopping time

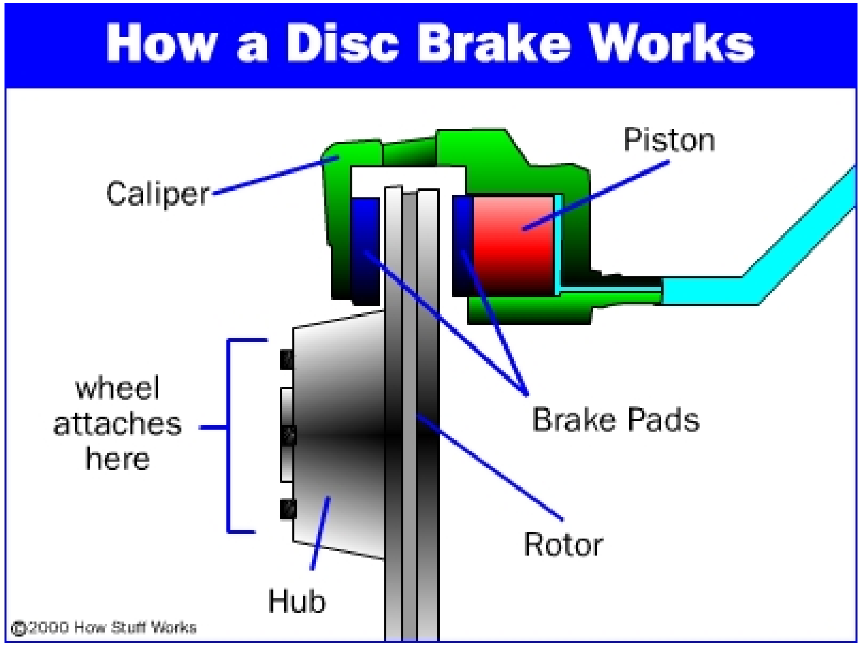
# History

- Caliper disc brakes first came into their own on European cars
- The first applications being on competition and sports cars where their superior fade resistance and stability were particularly significant
- The first problem encountered in adapting disc brakes to American cars was the greater weight of American cars as compared to European cars
- This requires either much higher lining pressure or higher effective brake radius
- But wheel rim configurations and space restrictions are assumed and will represent constraints on the design for maximum effective brakes radius

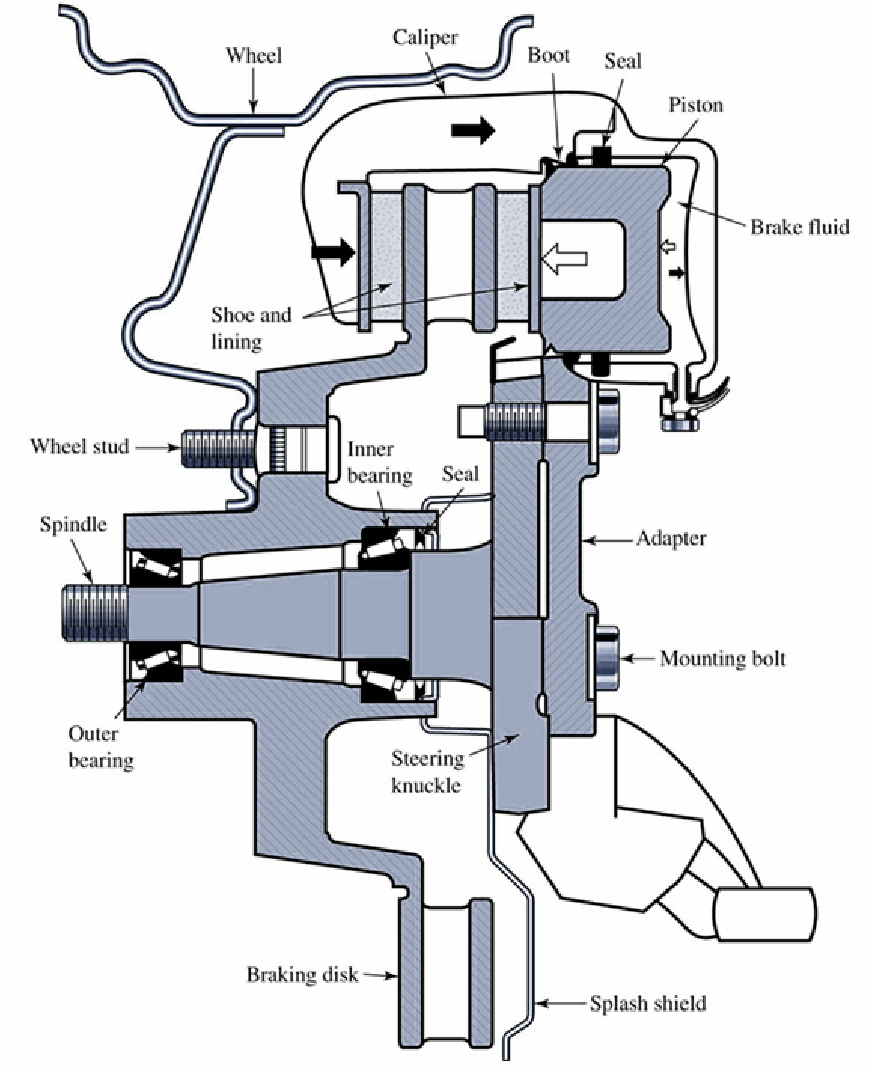
# Brake System of Automotive



# Disk Brake



How a Disc Brake Works
Piston
Caliper
wheel attaches here
Brake Pads
Rotor
Hub
©2000 How Stuff Works

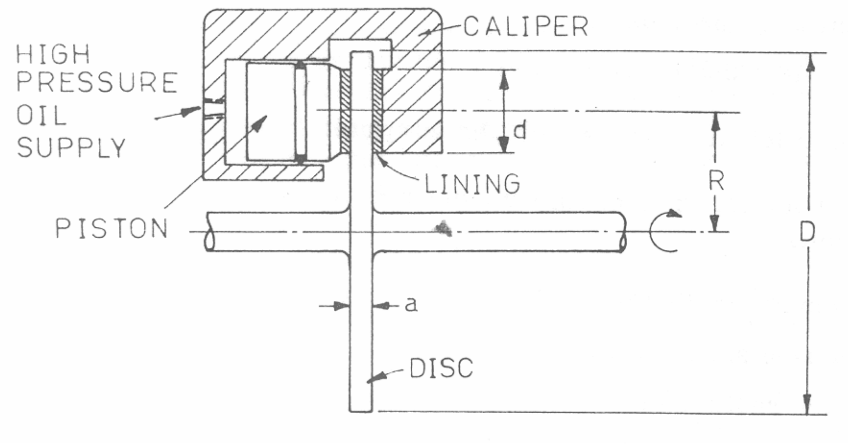



Wheel
Caliper
Boot
Seal
Piston
Brake fluid
Shoe and lining
Wheel stud
Inner bearing
Seal
Spindle
Adapter
Mounting bolt
Outer bearing
Steering knuckle
Braking disk
Splash shield

# Assumptions

- The disc is solid.
  - Disc: cast iron, caliper: ductile iron
  - Fastened together by bolts
- The lining is circular, and its diameter is not necessarily equal to the diameter of the piston
- The energy to be absorbed is equally distributed on all brakes
- The heat dissipated is due to a single stop and is stores in an equivalent planar disc of the same outer diameter and thickness

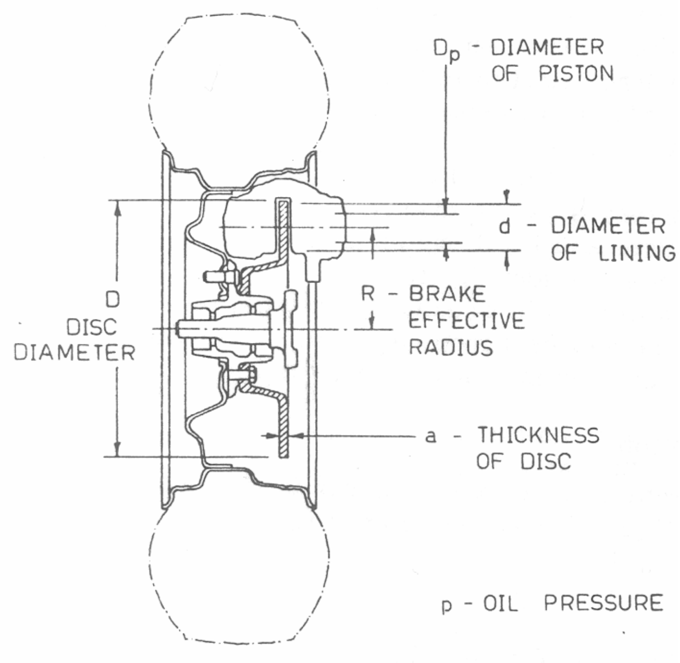
# Specifications




- W = vehicle weight per wheel
- V = vehicle speed
- Rt = tire radius
- Du = maximum disc diameter
- Dh = hub diameter
- tc = thickness of pressure cylinder wall
- Tmax = maximum allowable disc temperature
- $\mu$ = coefficient of friction between lining and disc
- Pu = maximum allowable lining pressure
- Pm = maximum available oil pressure
- $\mu$t = coefficient of friction between tire and road

# Design Variables

– R = radius of center line of lining
– d = diameter of lining
– Dp = diameter of piston
– a = thickness of disc
– p0 = oil pressure
– D = outside disc diameter



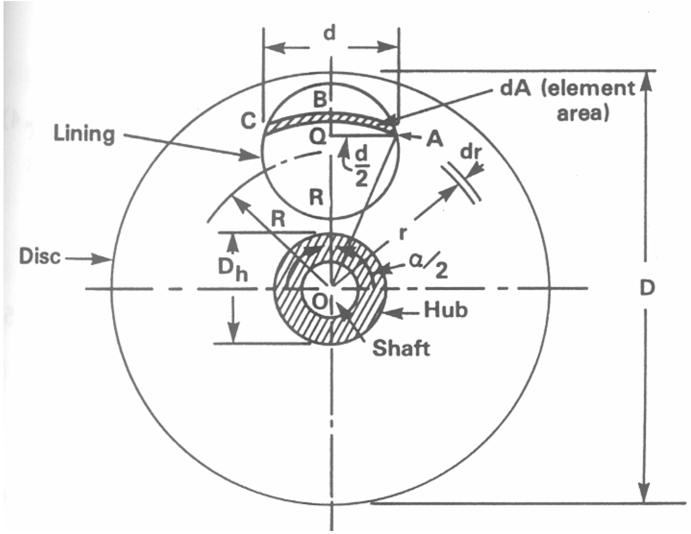
# Brake Design Theory (1)

- Wear $\propto$ (local pressure) x (sliding velocity)
  - pV = constant over the whole surface
  - This happens relatively quickly
- Total operating force of the pad on the disc

$$pV = c \xrightarrow{V \propto r} pr = c$$

$$F = \int_A p\,dA = \int_A \frac{c}{r}\,dA \xrightarrow{dA = l\,dr} F = \int_{R-0.5d}^{R+0.5d} \frac{c}{r}\,l\,dr$$

$$\rightarrow c = \frac{F}{I_1} \quad \text{where } I_1 = \int_{R-0.5d}^{R+0.5d} \frac{l}{r}\,dr, \quad F = p_0\left(\frac{\pi D_p^{\ 2}}{4}\right)$$




- Pressure: $p = \dfrac{c}{r} = \dfrac{F}{I_1 r} = \dfrac{\pi D_p^{\ 2} p_0}{4 I_1 r}$
- Braking torque:

$$Q = 2\int_A \mu p r\,dA = 2\int_{R-0.5d}^{R+0.5d} \mu \frac{F}{I_1 r} r l\,dr = 2\mu F \int_{R-0.5d}^{R+0.5d} \frac{l}{I_1}\,dr = 2\mu F I_2 \quad \text{where } I_2 = \int_{R-0.5d}^{R+0.5d} \frac{l}{I_1}\,dr$$

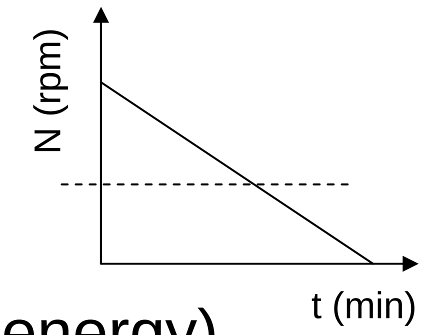
# Brake Design Theory (2)

- Work done in one revolution

$$H = 2\int_A \mu p\left(2\pi r\right)dA = 2\int_{R-0.5d}^{R+0.5d} \mu \frac{F}{I_1 r}\left(2\pi r\right)l\,dr = 4\pi\mu F\int_{R-0.5d}^{R+0.5d} \frac{l}{I_1}dr = 4\pi\mu F I_2$$

- Number of revolutions until the disc stops
  - RPM of disc vs. time

$$n_s = \frac{N}{2}t$$



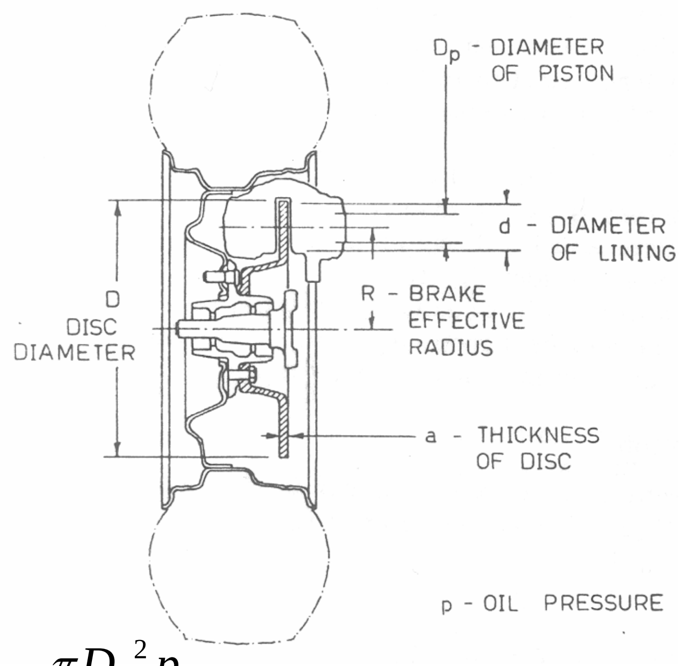

- (total work done) = (kinetic energy) = (heat energy)
  - c: specific heat capacity

$$E = 4\pi\mu F I_2\left(\frac{N}{2}t\right) = \frac{1}{4}\left[\frac{1}{2}\left(\frac{W}{g}\right)V^2\right] \rightarrow t = \frac{WV^2}{16\pi\mu g F I_2 N} \xrightarrow{F=\frac{\pi D_p{}^2 p_0}{4}} t = \frac{WV^2}{4\pi^2\mu g D_p{}^2 p_0 I_2 N}$$

$$E = mc\Delta T = \left(\rho\frac{\pi D^2}{4}a\right)c\left(T_f - T_i\right) \rightarrow T_f = T_i + \frac{E}{\left(\rho\frac{\pi D^2}{4}a\right)c}$$

# Constraints

- Configuration: $$D \le D_u$$ $$\frac{D_h}{2} + \frac{d}{2} \le R \le \frac{D}{2} - \frac{d}{2}$$ $$\frac{D_h}{2} + t_c + \frac{D_p}{2} \le R$$




- Oil pressure: $p_0 \le p_m$
- Lining pressure: $$p = \frac{\pi D_p^{\,2} p_0}{4 I_1 r} \rightarrow p_{\max}\Big|_{r=r_{\min}} = \frac{\pi D_p^{\,2} p_0}{4 I_1 \left( R - \dfrac{d}{2} \right)} \le p_u$$
- Heat capacity: $$T_f = T_i + \frac{E}{\left( \rho \dfrac{\pi D^2}{4} a \right) c} \le T_{\max}$$
- Against skidding: $$\left( Q = \mu F I_2 \right) \le \left( Q_s = \mu_t W R_t \right)$$