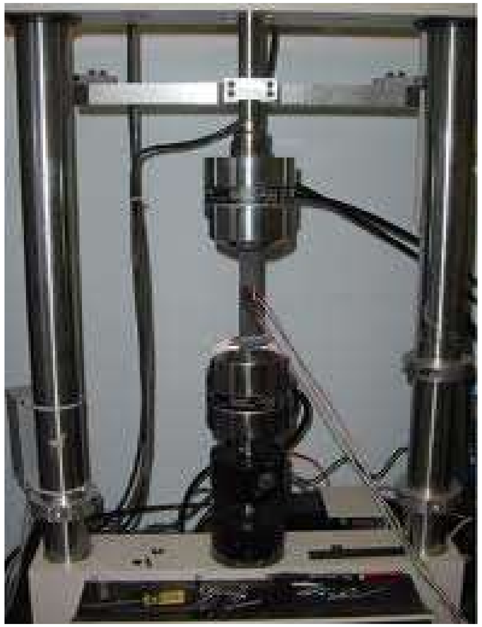
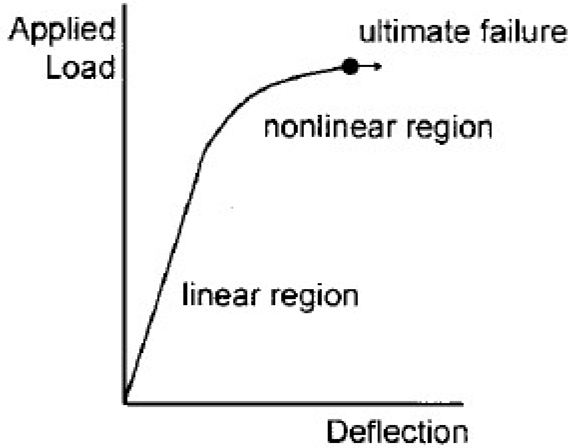
Ch. 2 Body Structure Requirements

- 2.1 Categories of structural requirements
- 2.2 The locate and retain function
- 2.3 Locate and retain for front suspension attachment structure
- 2.4 Flow down of requirements from vehicle-level functions
- Vehicle loads

Structural Requirements

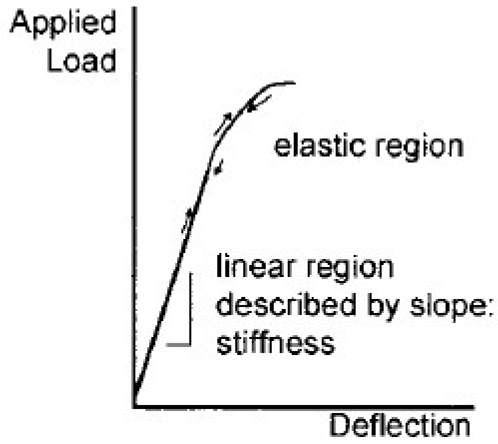
- Purpose of a structure
  - To react loads with an allowable deformation
- Tensile test
  - Load-deflection curve
- Categorization based on allowable deformation
  - Stiffness, Strength, Energy absorption at the required levels





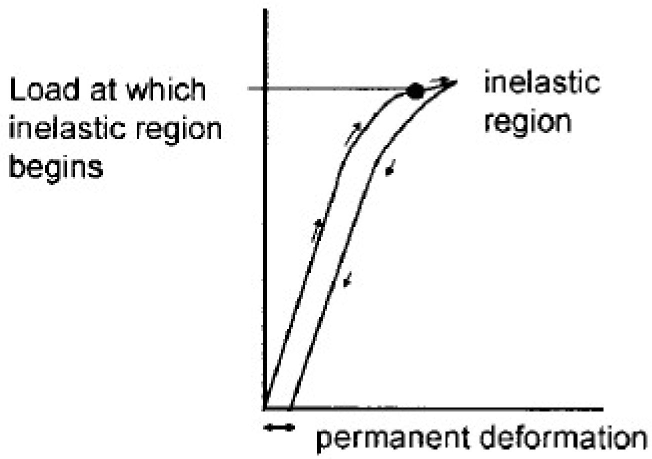
Structural Requirements: Stiffness

- Characterized by small and elastic deformation
- (applied load)/(unit of deformation)
- Body stiffness at a suspension attachment point
- Handling property: small elastic deformations relative to the vehicle center of mass
- Solidness of a panel: normal stiffness under a point load
- Related to vibration performance



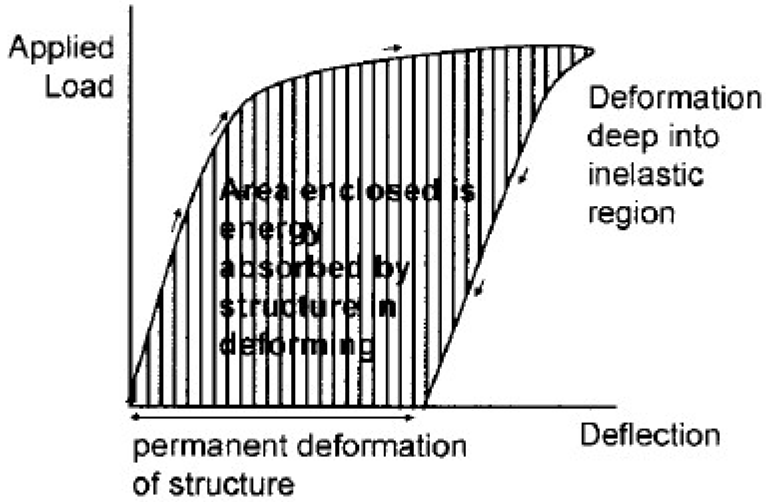
Structural Requirements: Strength

- Characterized by the onset of a small permanent deformation
- Lowest load at which a permanent deformation first appears
- Loading and unloading → loss of some functionality
- Body strength at a suspension attachment point
  - Small permanent deformation due to impact → realignment



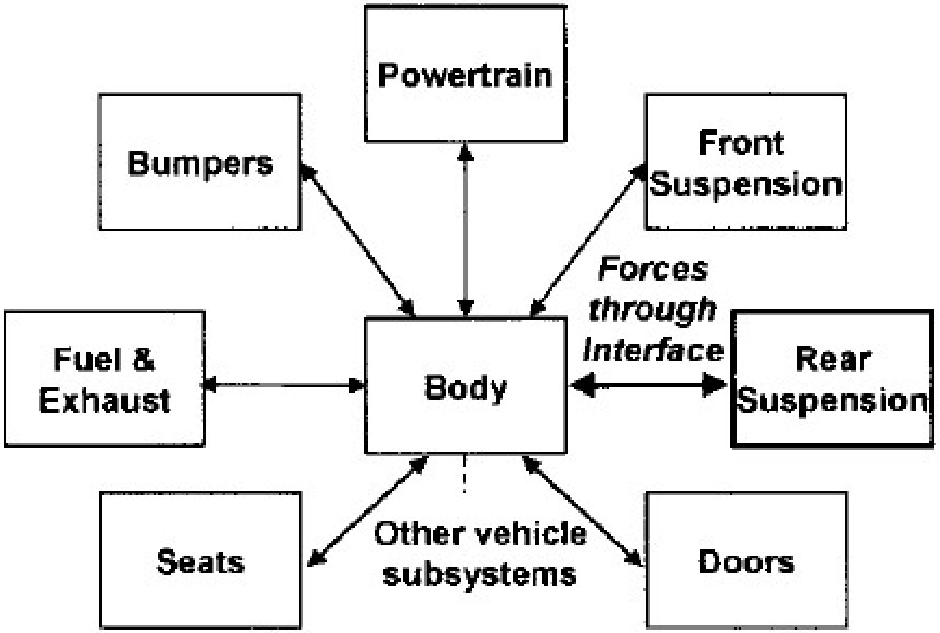
Structural Requirements: Energy Absorption

- Characterized by very large permanent deformations where the amount of energy absorbed by the structure
- Load and deformation performance in severe impacts
- Average crush force generated by the motor compartment midrail during front collision



Locate and Retain Function (1)

- Function as a vehicle
  - Locate all the pieces in a specific orientation
  - Retain in that orientation to form a usable vehicle



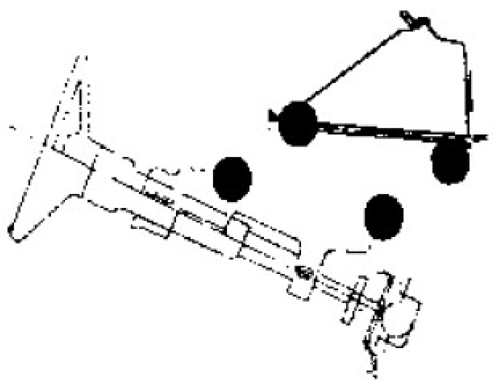
Locate and Retain Function (2)

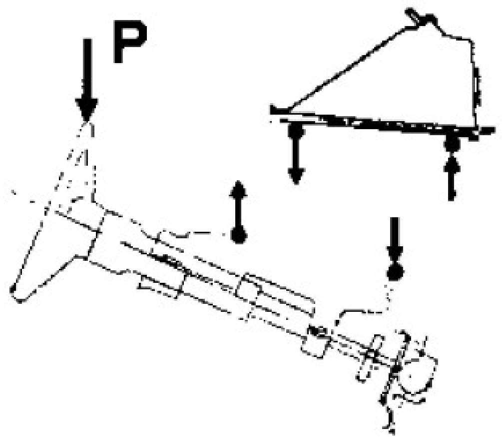
- Process to identify requirements
  - (1) Choose a mode-of-use for the subsystem
  - (2) Identify the loads being applied to the subsystem during this mode
  - (3) Identify how much deformation of the structure is allowable without a detrimental effect on functioning of this mode
  - (4) Using free-body analysis, determine the loads applied at the structure interfaces

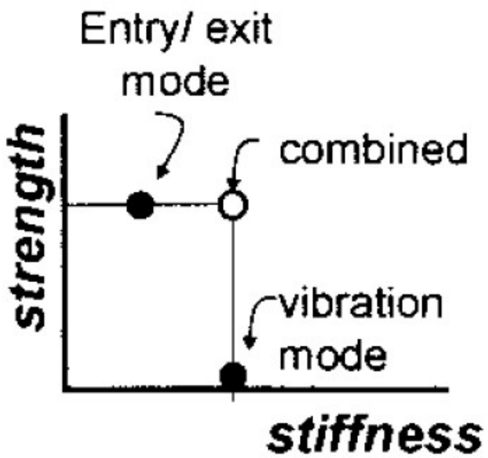
Example: Steering Column Mount Structure

* Steering column: device for connecting the steering wheel to the steering mechanism by transferring the driver's input torque from the steering wheel

mode-of-use	entry/exit	column vibration
load	1500N (large person)	Very small
deformation	Elastically up to 10mm Permanently smaller than 1mm	Resonance at least 35 Hz to avoid coupling with powertrain excitation at engine idle
stiffness		[mass = 5kg]
strength		

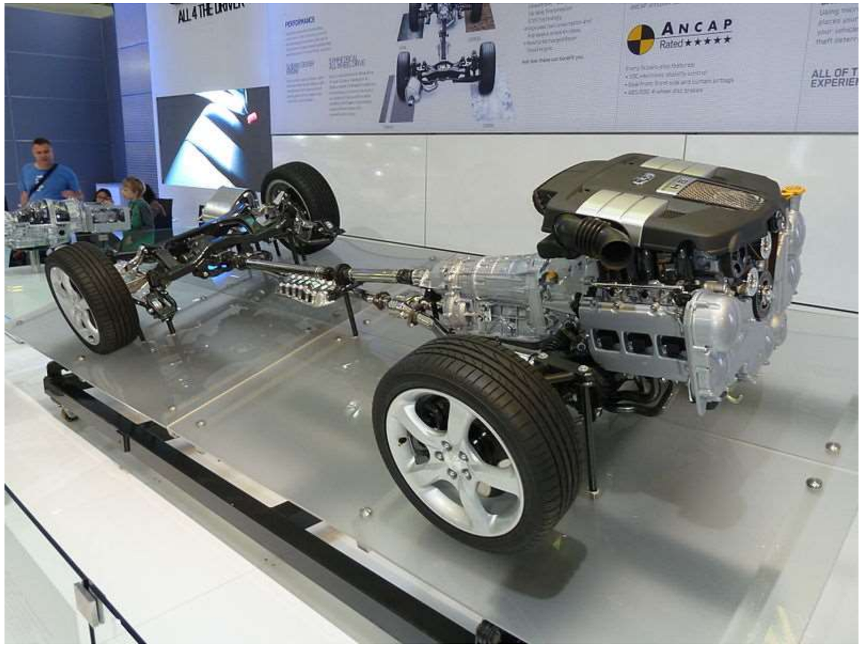






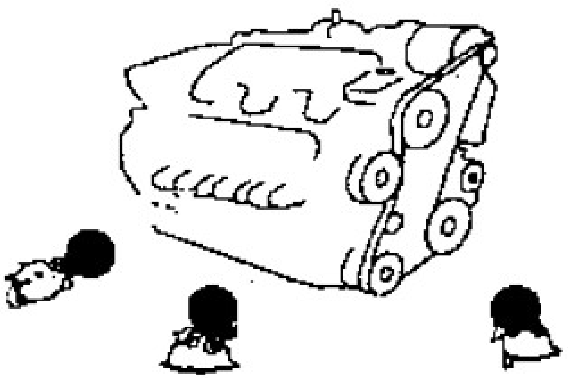
Example: Powertrain Mounting Structure (1)

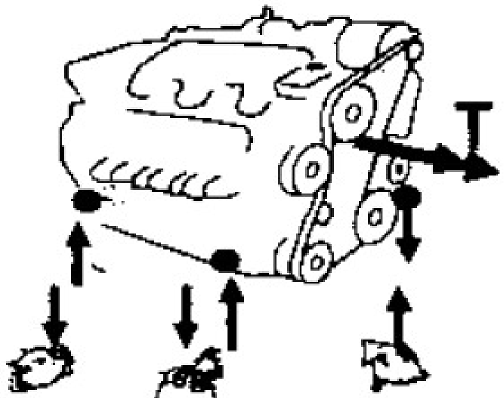
- Powertrain: group of components that generate power and deliver it to the road surface
  - wheels, suspension, drive shaft, exhaust system, engine and transmission

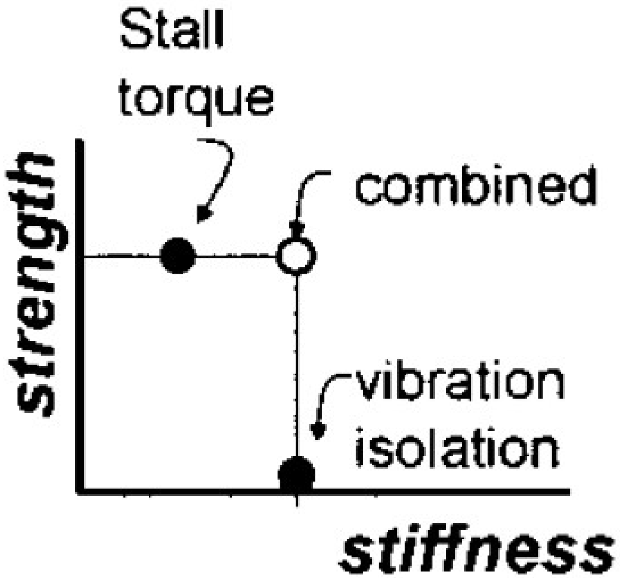


Example: Powertrain Mounting Structure (2)

mode-of-use	stall torque	vibration isolation
load	Maximum torque	Very small
deformation	2 mm	0.1~0.14 x (deflection across the mount) → 7~10 x (stiffness of elastomeric engine mount rate)
stiffness		
strength		

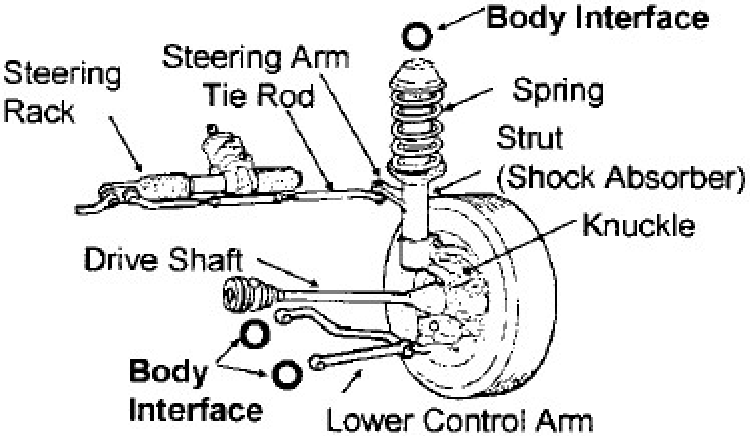


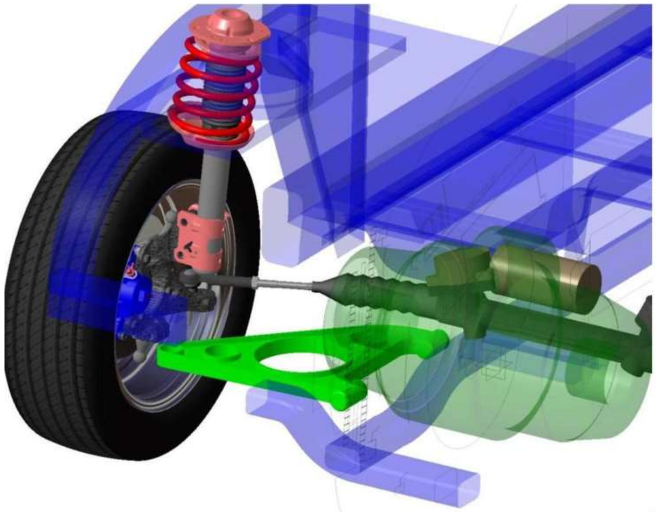




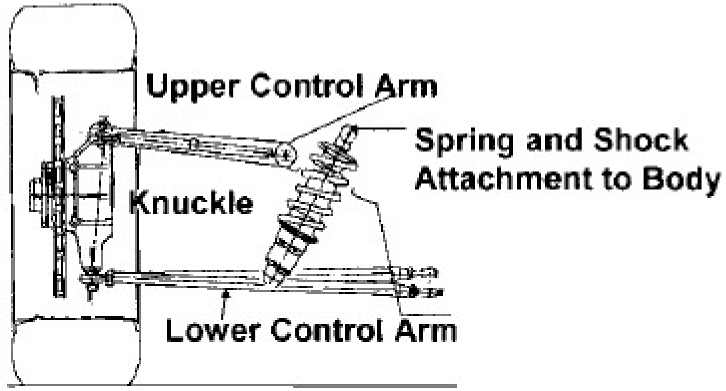
Front Suspension

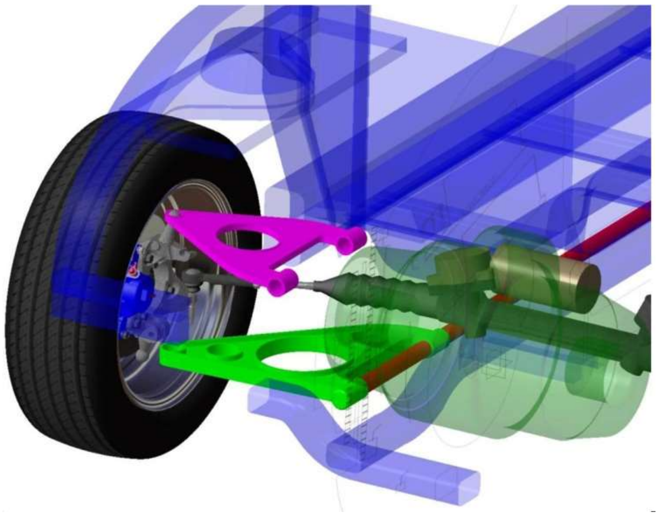
– McPherson





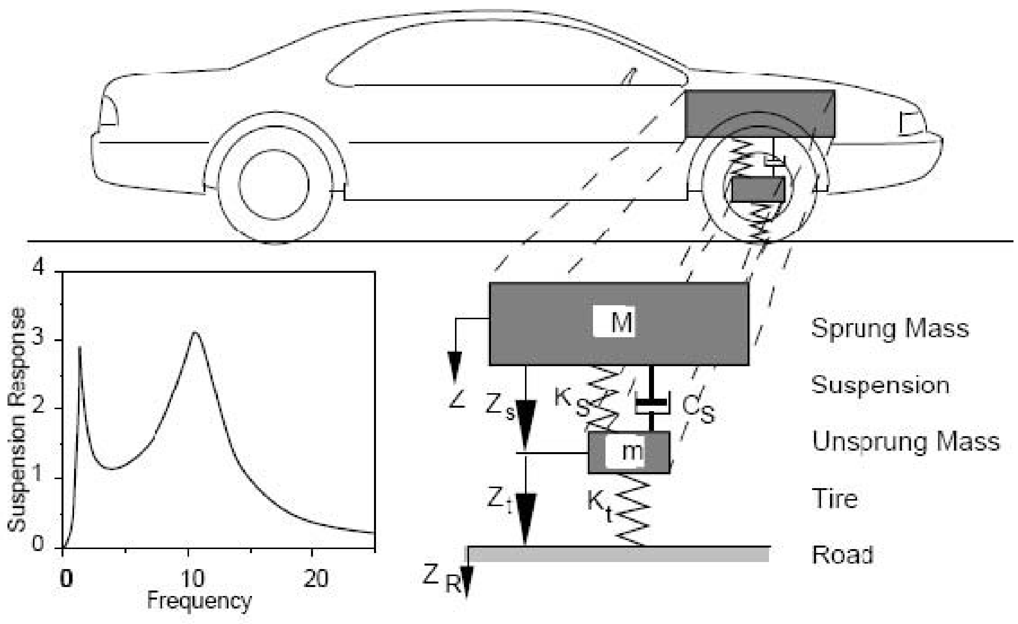
– Short and Long Arm

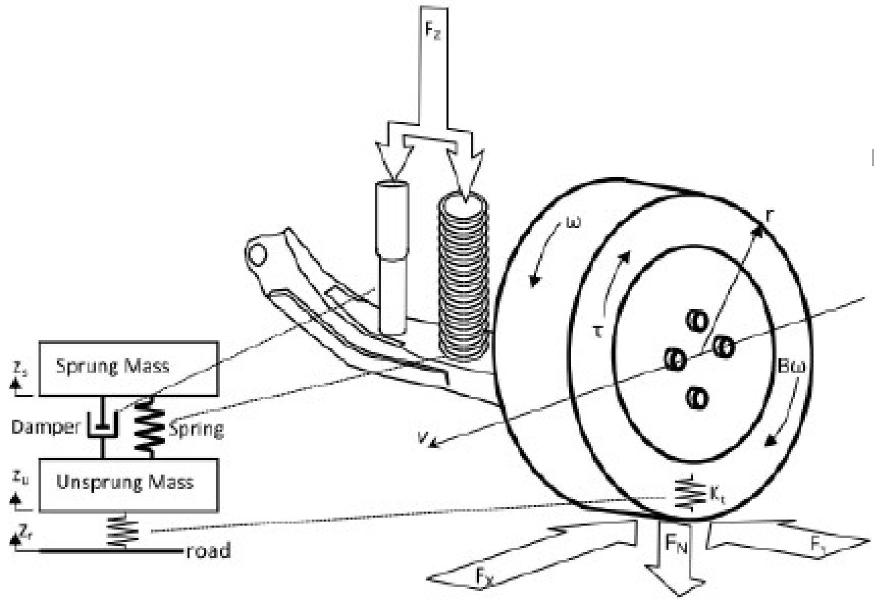


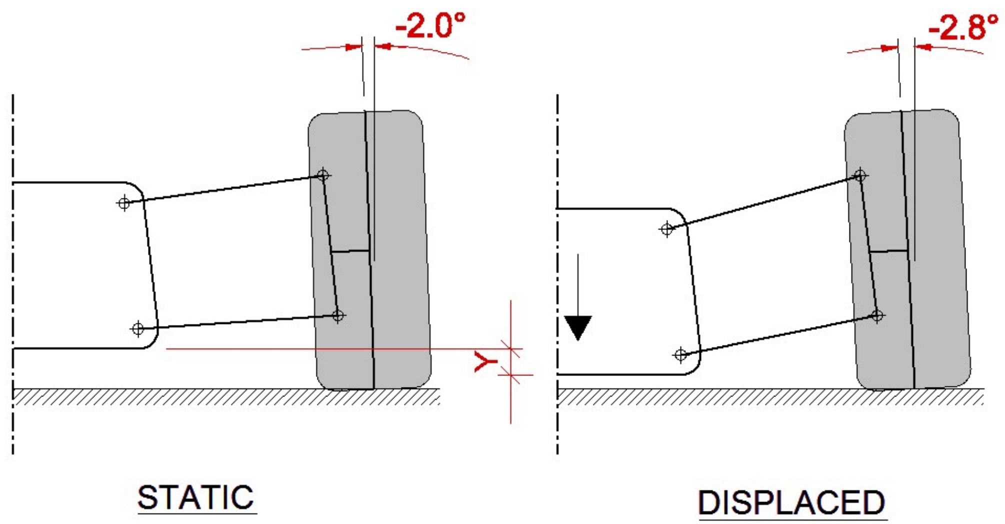


McPherson Strut

- Advantages
  - Most compact, lightweight and cost effective suspension design
  - Provides easy packaging solutions
  - More than 80% of passenger vehicles use this type of suspension
  - Additional unsprung mass saving potential have been realized by research
    - Sprung mass: mass supported by the suspension
    - Unsprung mass: mass between the road and the suspension
- Disadvantages
  - Minimal camber gain reducing performance
  - Requires a structural shock tower limiting exterior styling possibilities







STATIC CAMBER = -2.0°

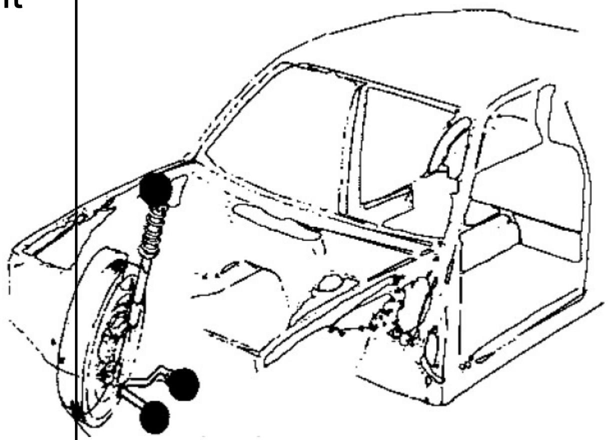
CAMBER GAIN = -2.0° - (-2.8°) = .8° for Y displacement

SLA (Double Wishbone)

- Advantages
  - High performance kinematics can be achieved (independent vertical wheel movement)
  - Does not intrude into luggage compartment
- Disadvantages
  - High cost premium
  - Additional fulcrums and links needed, increasing the number of parts
  - High level of design complexity

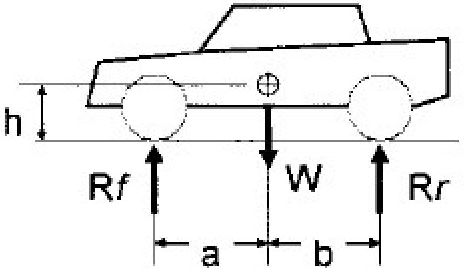
Front Suspension Attachment Structure

- Locates and retains the suspension at several points, the shock absorber, spring, control arm

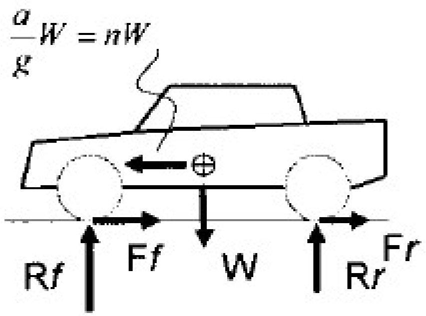
mode-of-use	braking, cornering, rollover, vertical bump	vibration isolation, handling
load	Maximum loads of all above	
deformation	1~2 mm of permanent deformation	7~10 x (suspension bushing stiffness)
stiffness		
Strength	Static equilibrium of the suspension → maximum loads at the body attachment point (McPherson) Lower control arm attachment: A_V, A_L, A_{FA} Strut attachment: S_V, S_L, S_{FA} (SLA) Strut tower: S_V Upper control arm attachment: A_U Lower control arm attachment: A_V, A_L	

Modes of Use: Strength

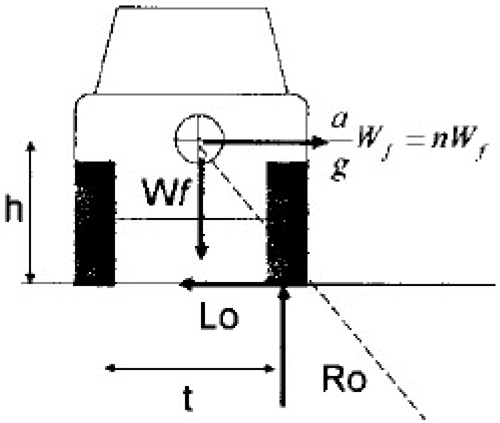
static



braking

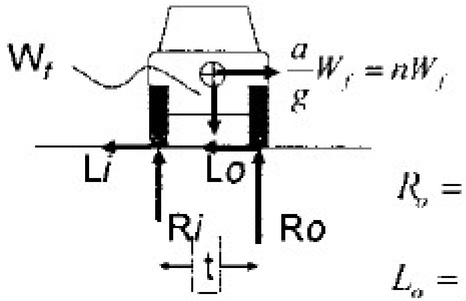


Incipient rollover



cornering

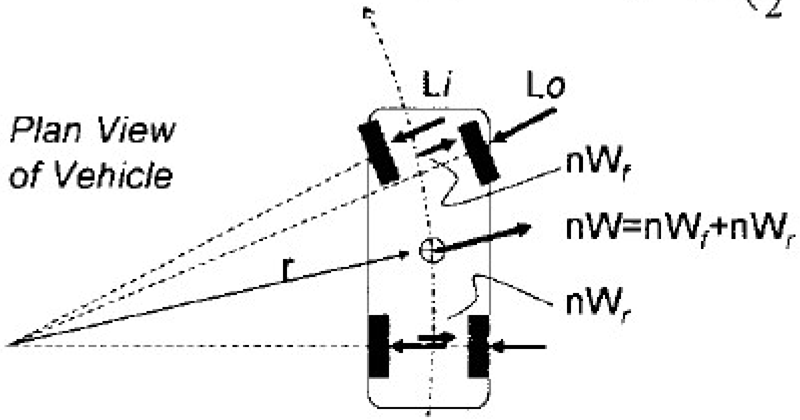
View of Front Axle



$$R_o = \left(\frac{1}{2} + \frac{nh}{t}\right)W_f$$

$$L_o = \mu\left(\frac{1}{2} + \frac{nh}{t}\right)W_f$$

Plan View of Vehicle

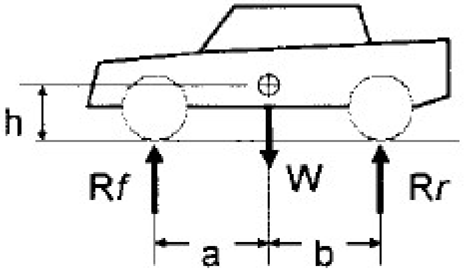


Front Tire Patch Loads

Mode	Lateral	Fore-aft	Vertical
Static			○
Braking		○	○
Cornering	○		○
Rollover	○		○
Maximum of all above → design load			

Modes of Use: Strength

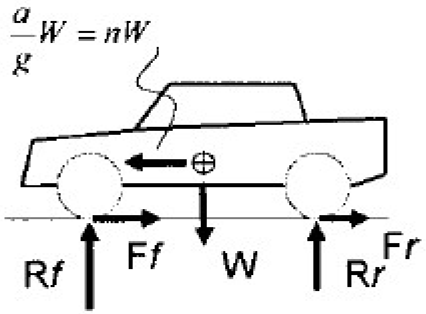
static



$$\begin{cases} 2\left(R_f + R_r\right) = W \\ bR_r - aR_f = 0 \rightarrow b\left(\dfrac{W}{2} - R_f\right) - aR_f = 0 \end{cases}$$

$$\rightarrow \begin{cases} R_f = \left(\dfrac{b}{a+b}\right)\dfrac{W}{2} \\ R_r = \left(\dfrac{a}{a+b}\right)\dfrac{W}{2} \end{cases}$$

braking



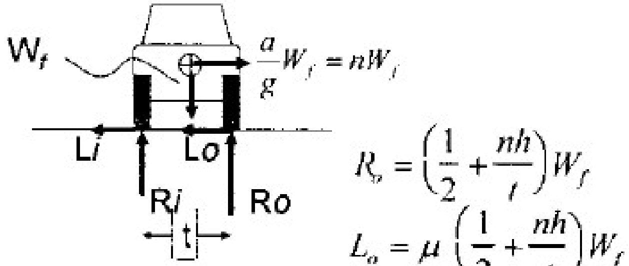
$$\begin{cases} 2\left(F_f + F_r\right) = 2\mu\left(R_f + R_r\right) = nW \rightarrow R_r = \dfrac{nW}{2\mu} - R_f = \left(\dfrac{n}{\mu} - \dfrac{b+nh}{a+b}\right)\dfrac{W}{2} \\ 2R_f\left(a+b\right) = nWh + Wb \rightarrow R_f = \left(\dfrac{b+nh}{a+b}\right)\dfrac{W}{2} \end{cases}$$

$$\rightarrow \begin{cases} F_f = \mu R_f = \mu\left(\dfrac{b+nh}{a+b}\right)\dfrac{W}{2} \\ F_r = \mu R_r = \mu\left(\dfrac{n}{\mu} - \dfrac{b+nh}{a+b}\right)\dfrac{W}{2} \end{cases}$$

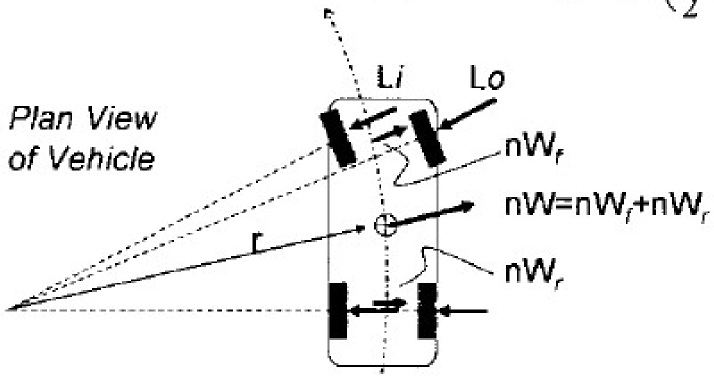
Modes of Use: Strength

cornering

View of Front Axle



Plan View of Vehicle



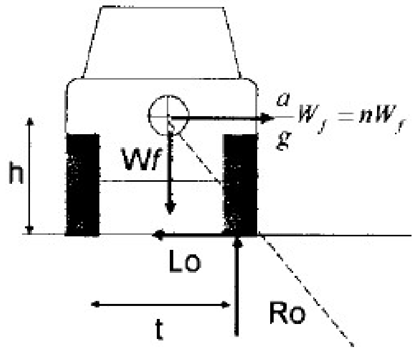
$$\begin{cases} R_i + R_o = W_f \\ L_i + L_o = nW_f \\ L_i = \mu R_i, L_o = \mu R_o \\ \frac{t}{2}(R_o - R_i) - h(L_i + L_o) = 0 \end{cases}$$

$$\rightarrow \frac{t}{2}(R_o - W_f + R_o) - h(nW_f) = 0$$

$$\rightarrow tR_o = \left(\frac{t}{2} + nh\right)W_f$$

$$\rightarrow R_o = \left(\frac{1}{2} + \frac{nh}{t}\right)W_f \rightarrow L_o = \mu\left(\frac{1}{2} + \frac{nh}{t}\right)W_f$$

Incipient rollover

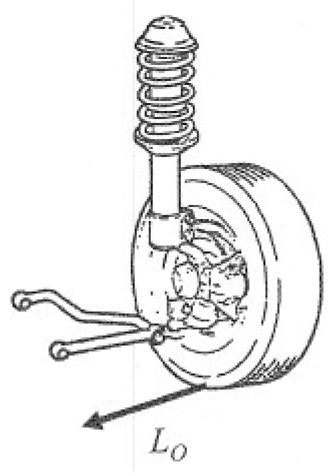


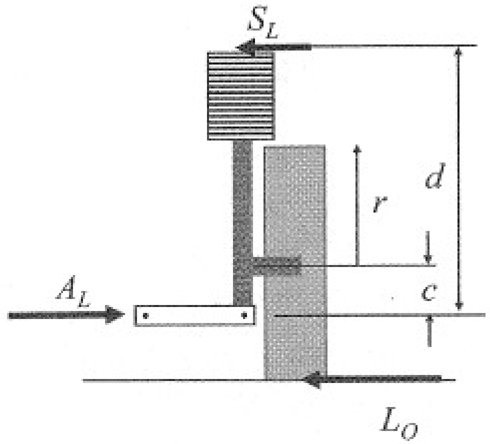
$$\begin{cases} R_i = 0, R_o = W_f \\ L_o = nW_f \\ \frac{t}{2}R_o - hL_o = 0 \rightarrow L_o = \frac{t}{2h}R_o \end{cases}$$

$$\rightarrow n = \frac{t}{2h}$$

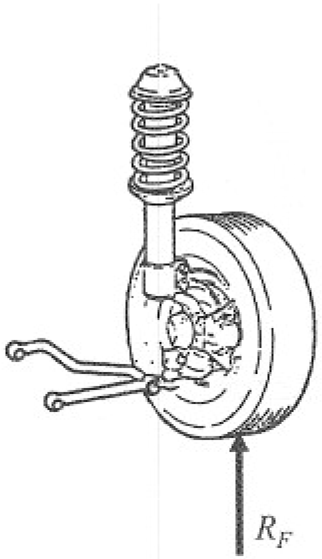
McPherson Strut Suspension (1)

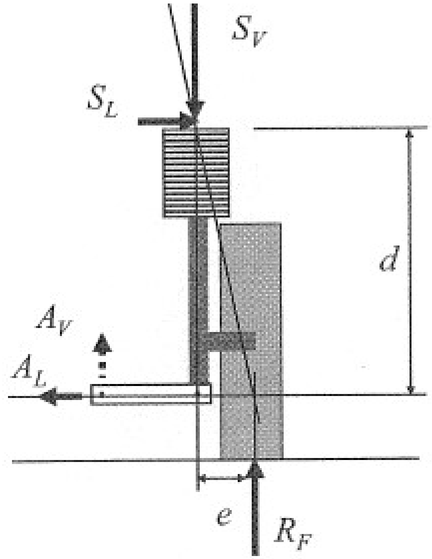
Lateral loading (rollover)





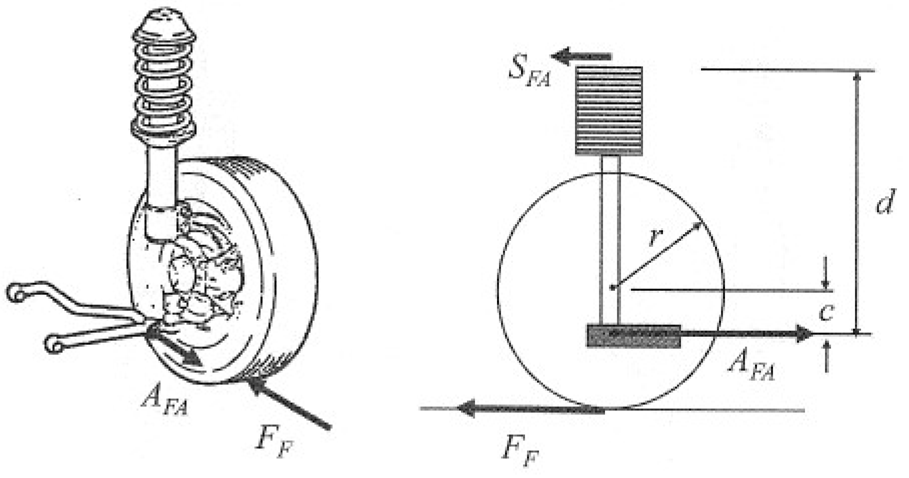
Vertical bump loading (bump mode)



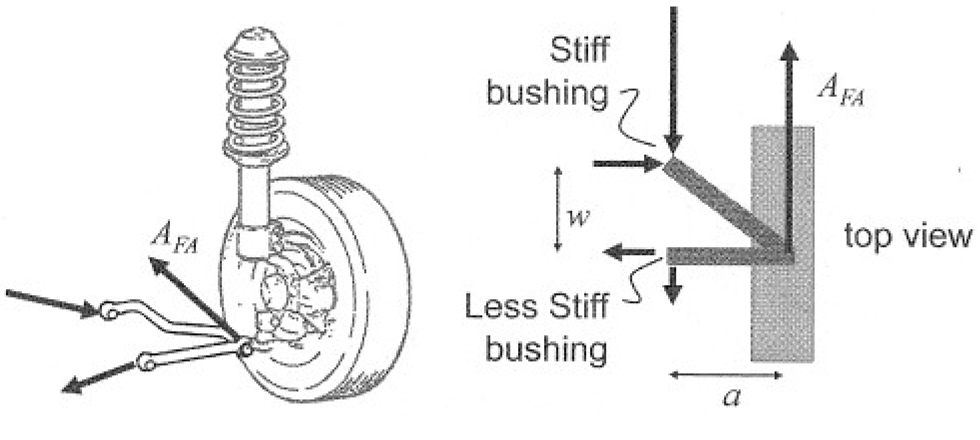


McPherson Strut Suspension (2)

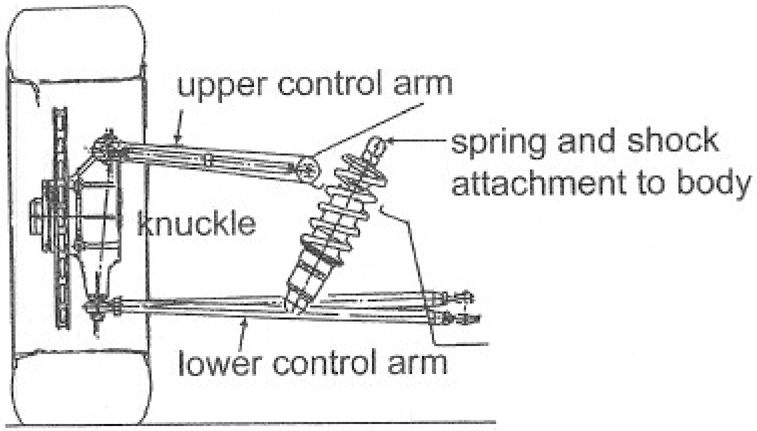
Fore-aft loading (braking)
@ ball joint

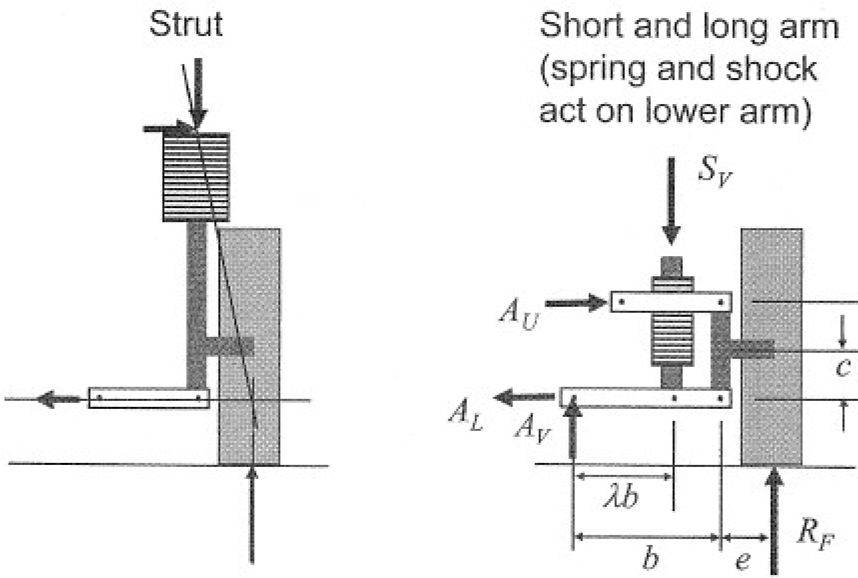


Fore-aft loading (braking)
@ lower control arm attachment



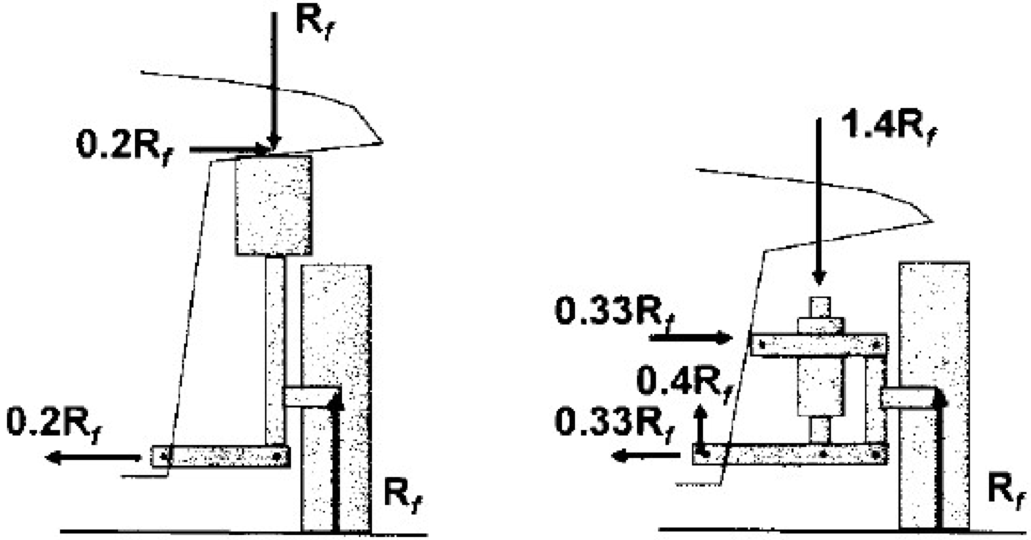
Short and Long Arm Suspension



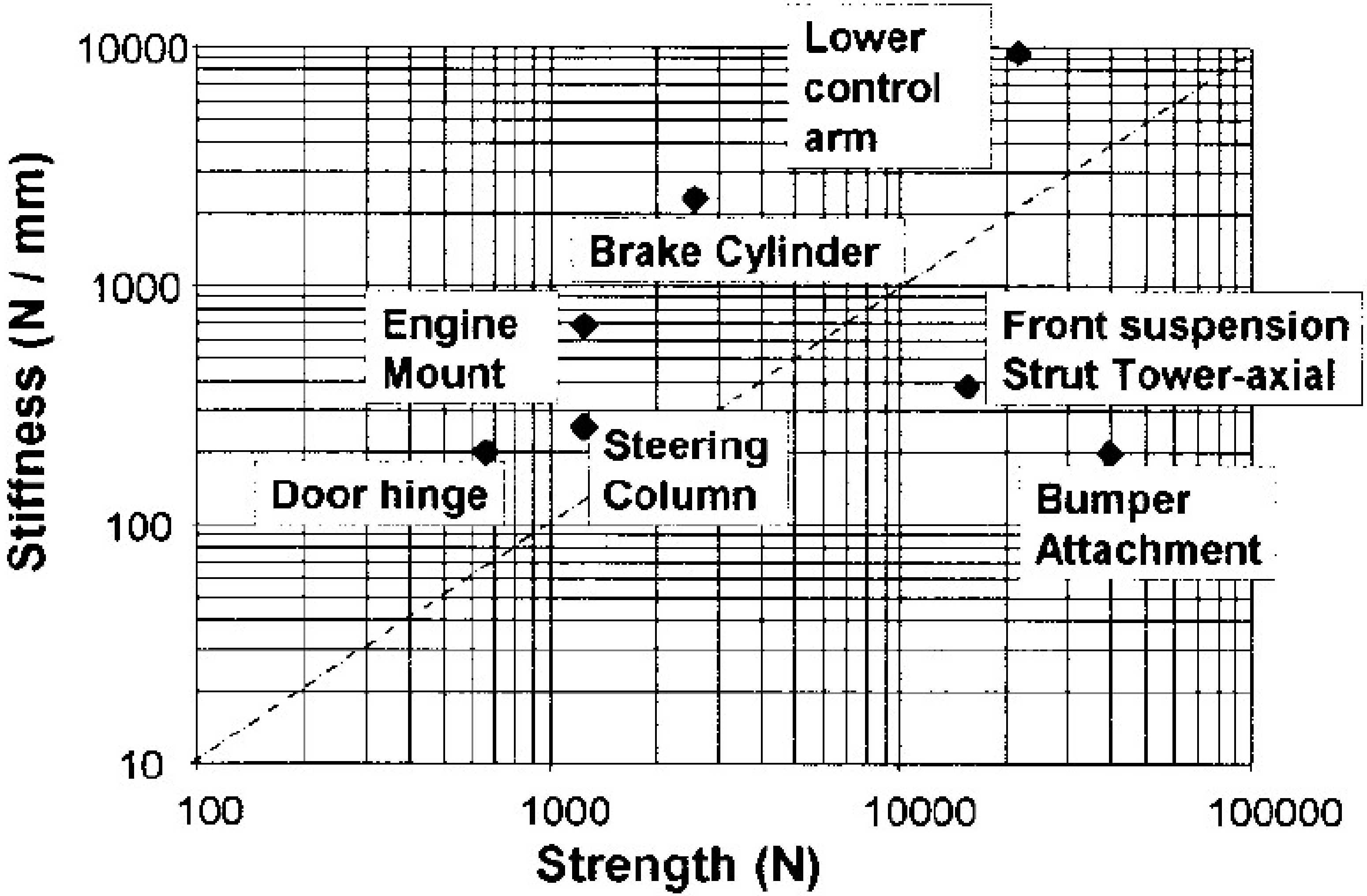


(Problem 2.5)

Bump: McPherson vs. SLA

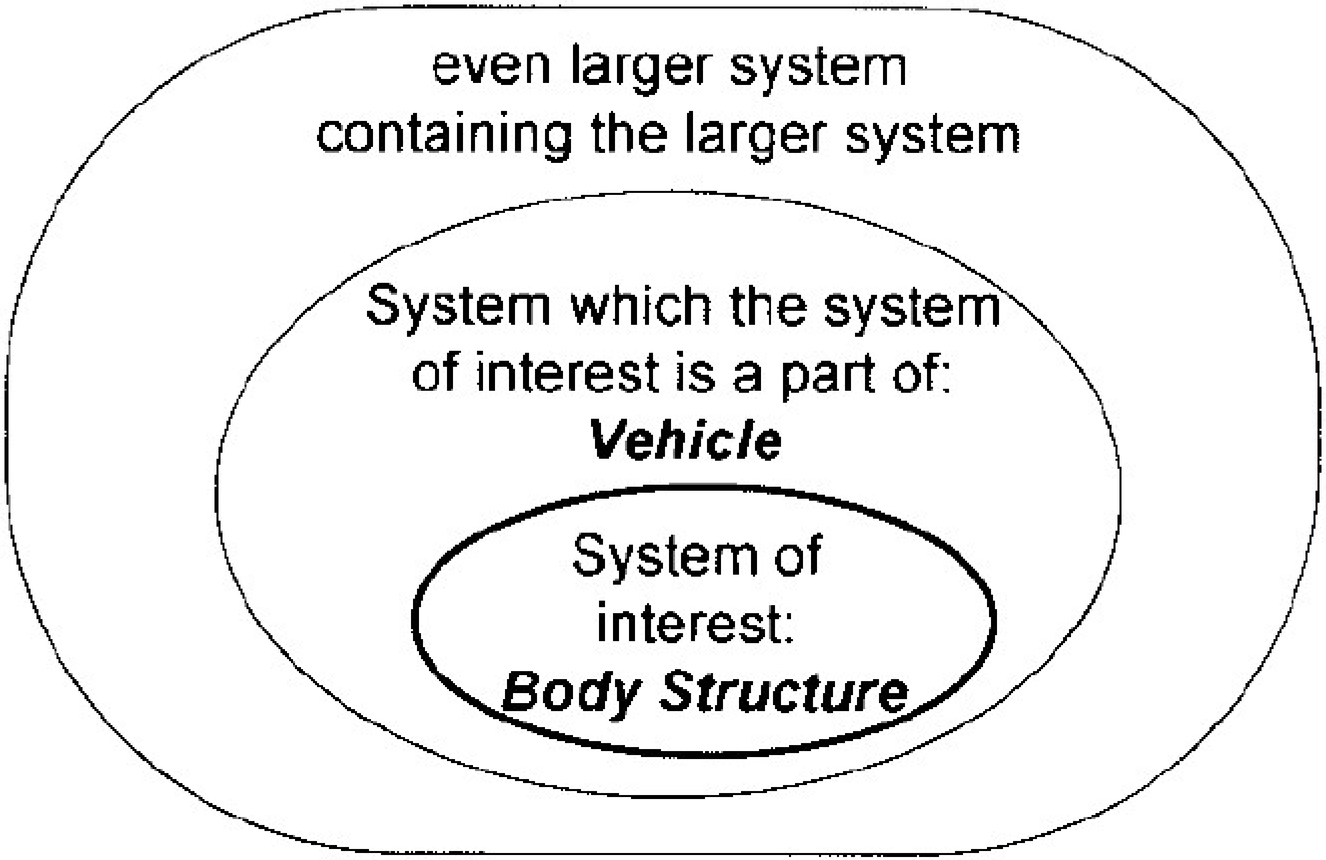


Interface Structure Requirements

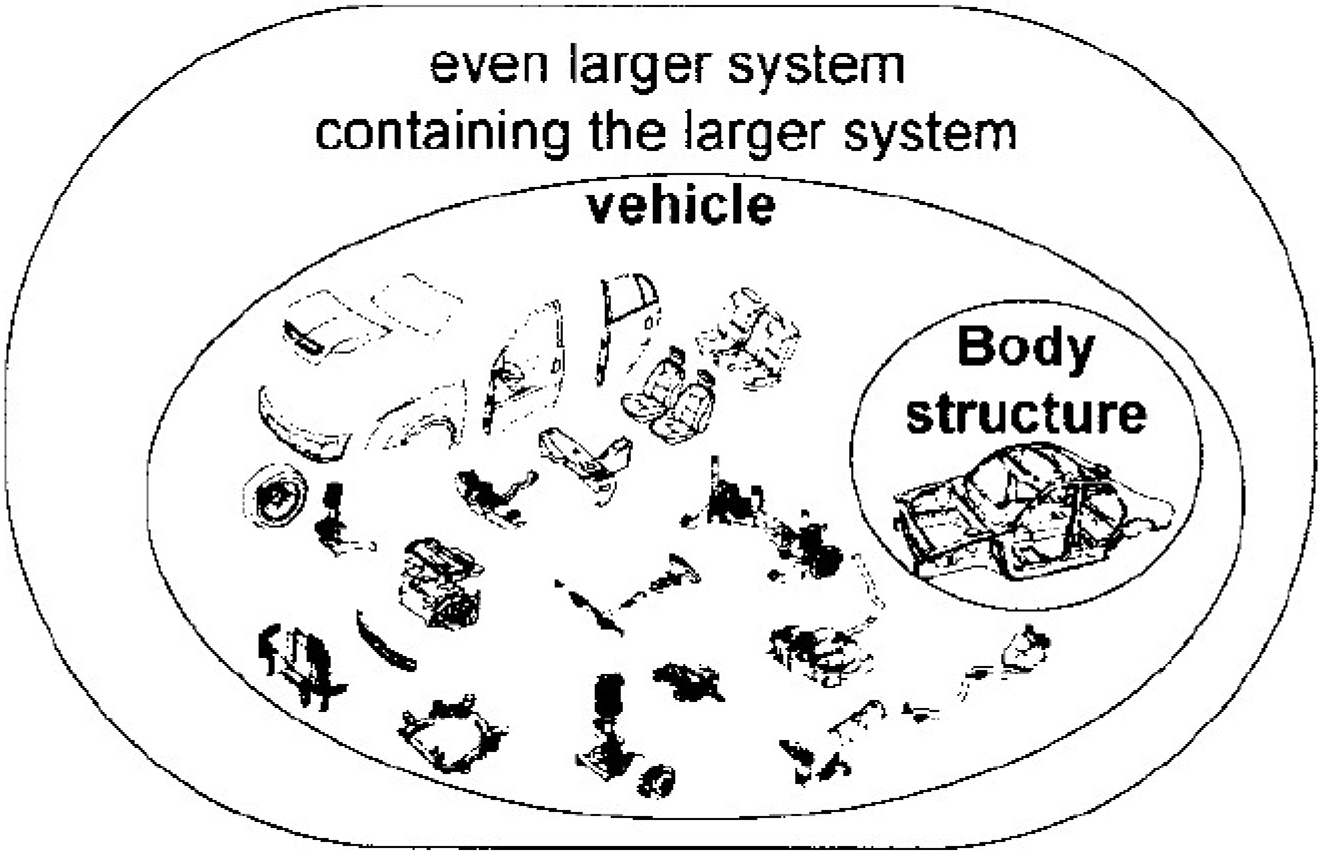


Expanding System Boundaries

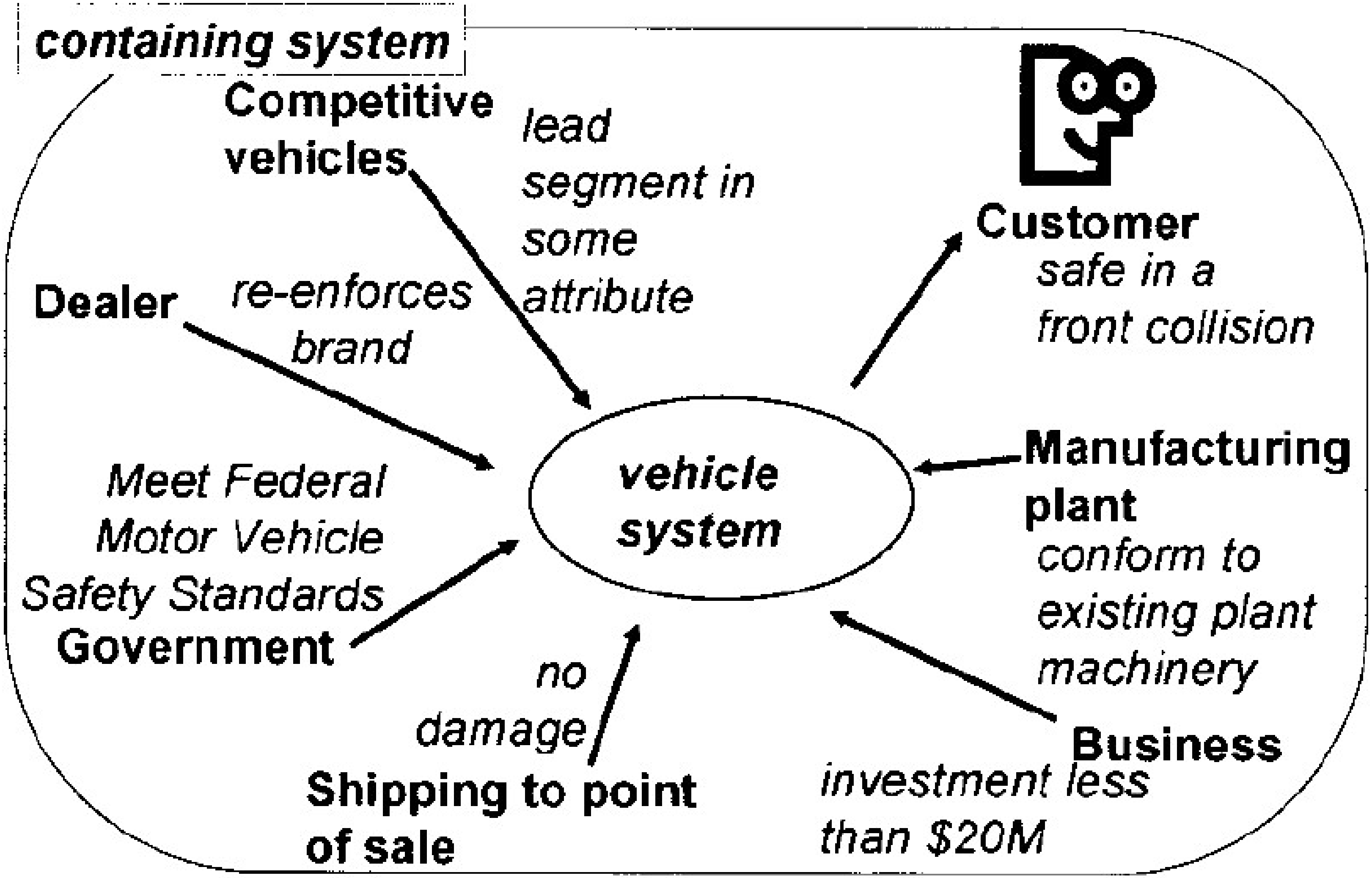
Defining the interaction role of the system with its environment creates requirements or constraints



Automobile System Boundaries



Example Functions Performed by Vehicle



Functions Supporting the Customer

containing system

vehicle system →  **Customer**

Ride & Handling
- Ride Isolation
- Handling, stability
- turn circle
- Braking

Noise & Vibration
- Quietness
- tolerable vibration
- Squeaks & rattles
- Quality of sounds

Styling
- Appealing look
- Interior/Exterior

Human Factors
- Occupant roominess
- Entrance / Egress
- Controls accessible

Package
- Cargo Space
- Cargo Access
- Efficiency

Value
- Price
- trade in value

Energy use
- Acceleration
- Fuel economy
- Range
- Aerodynamics
- Emissions
- Drive quality

Safety
- Crash protection
- Crash avoidance
- Security

Quality, Reliability, Durability

Thermal Environment
- Interior climate
- Interior air quality

Flow Down from Vehicle Level Functions

- (1) Identify the vehicle function to be accomplished
- (2) Define how the vehicle subsystems will work together to provide that function: function strategy
- (3) Analyze the role of the body structure in accomplishing the strategy
- (4) Flow down the overall body structure requirements to requirements on structural subsystem and elements

Front Impact Structural Requirements

- (1) function: minimize injury in a 30 mph front barrier
- (2) strategy:
  - Decelerate cabin by absorbing energy of impact with no cabin distortion and acceleration less than 20g. ACRS deploys at 10 ms with optimal spatial relationship to seated occupant. Interior elements the occupant may impact are crushable. Elements in motor compartment translate longitudinally with maximum crushable space.
- (3) role:
  - decelerate cabin by absorbing energy of impact with no cabin distortion and acceleration less than 20g → determine the amount of energy to be absorbed
- (4) vehicle body system → motor compartment subsystem → structural elements

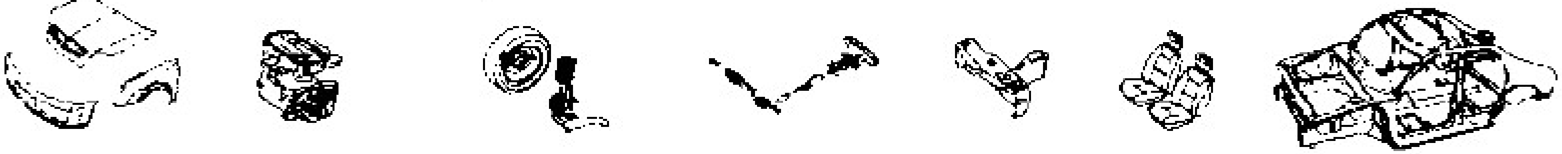
Function: Safety in a Front Impact

Customer

Safety: safe in a front impact

vehicle system

Sheet metal	Power-train	Wheels suspension	steering column	ACRS	Seats belts	Body structure



Strategy: Decelerate cabin by absorbing energy of impact with no cabin distortion and acceleration less than 20g. ACRS deploys at 10 msec with optimal spatial relationship to seated occupant. Interior elements the occupant may impact are crushable. Elements in motor compartment translate longitudinally with maximum crushable space.

Requirements: Vehicle → Body Structure

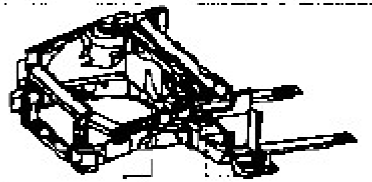
Safety — safe in a front impact

Strategy: Decelerate cabin by absorbing energy of impact with no cabin distortion and acceleration less than 20g. . .

vehicle body system

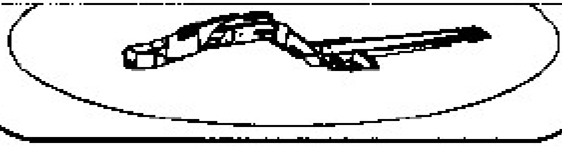
Absorb 80 kNm of energy in 30mph rigid barrier impact with no cabin deformation

motor compartment subsystem



Motor compartment average crush load of 160 kN

Structural Elements



mid rail beam crush load of 80 kN

Vehicle Loads

- Sampling of the customer load environment on public roads
- Principal loads applied to first order and early FEA
  - Gross simplifications of actual complex road loading events
- Proving ground tests → laboratory tests

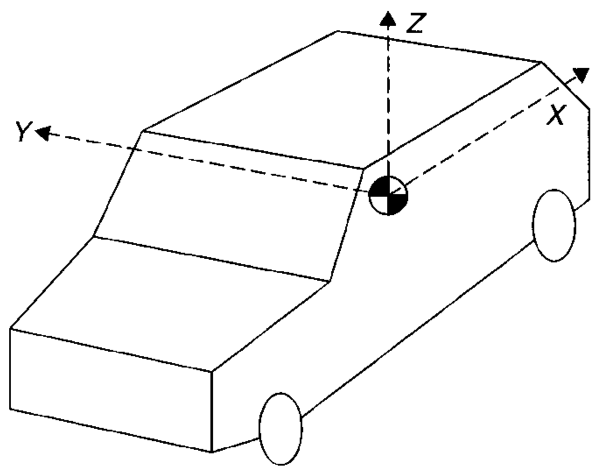
Type of load	Number of event repetitions	Load amplitude (N)	Acceptance criteria	Proving ground event examples
Instantaneous load	Low (< 10)	High (10^4)	Limited permanent deformation	Large pot-holes, curb bumps, large bumps, panic braking, high g cornering, high-power-train torque
Fatigue	High (10^2)	Moderate (10^3)	Cycles to crack initiation	Cobblestone track, medium size pot-holes, Belgium block road, twist course

Load Cases

- Assumption at the early design stage
  - If the structure can resist the (rare) worst possible loading, then it is likely to have sufficient fatigue strength.
- Worst or most damaging loads to ensure
  - Structure will not fail in service due to instantaneous load
  - Satisfactory fatigue life
- Actual dynamic loading ?
  - (static load) x (dynamic load factor) x (safety factor)
- Global road load cases → Local load cases
  - Affecting the structure as a whole
- Crash ? out of the elastic regime
  - Support forces for an energy absorbing part: static load case

Basic Global Load Cases

- Vertical symmetrical loads: bending (Y-Y)
- Vertical asymmetrical loads: torsion (X-X) + bending (Y-Y)
- Fore and aft loads: braking, acceleration, obstacles, towing
- Lateral loads: cornering, nudging curb
- Local loads: door slam
- Crash loads



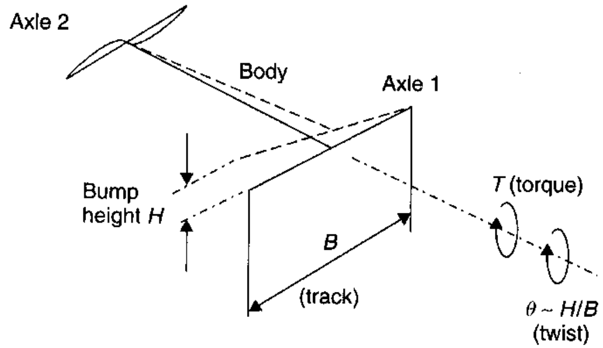
Vertical Symmetric Load

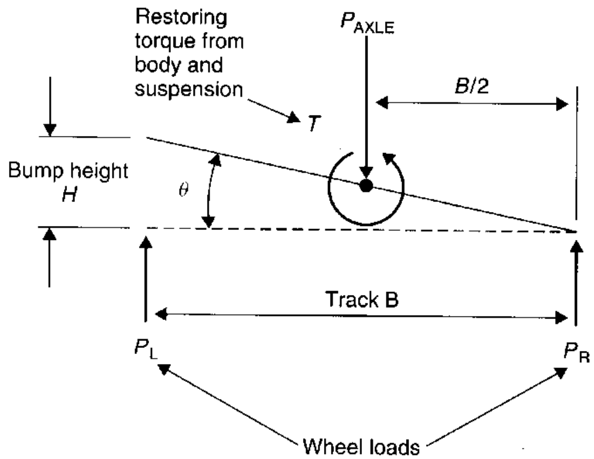
- When both wheels on one axle encounter a symmetrical bump simultaneously
- Bending moment about a lateral axis

	Commonly used
Dynamic factor	3
Safety factor	1.5

Vertical Asymmetric Load

- When only one wheel on an axle strikes a bump
- Torsion (more severe) as well as bending
- P_R, P_L , H_{max}?





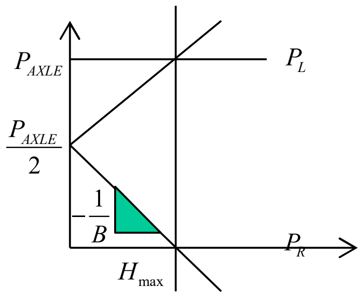
Vertical Asymmetric Load

- When only one wheel on an axle strikes a bump
- Torsion (more severe) as well as bending

$$P_{AXLE}, T, B \rightarrow P_L, P_R, H_{\max}\ ?$$

$$\begin{cases} P_L + P_R = P_{AXLE} \\ T = \left(P_L - P_R\right)\dfrac{B}{2} = \left(P_{AXLE} - 2P_R\right)\dfrac{B}{2} \end{cases}$$

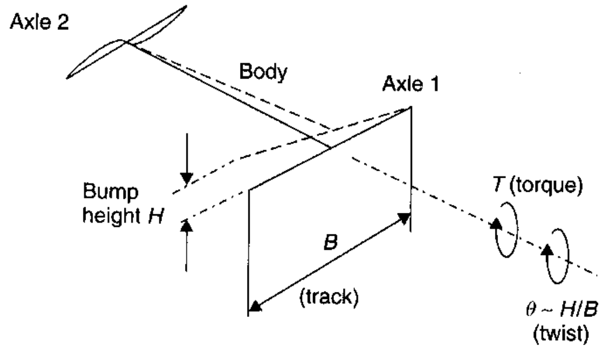
$$\rightarrow \begin{cases} P_R = \dfrac{P_{AXLE}}{2} - \dfrac{T}{B} \\ P_L = \dfrac{P_{AXLE}}{2} + \dfrac{T}{B} \end{cases}$$

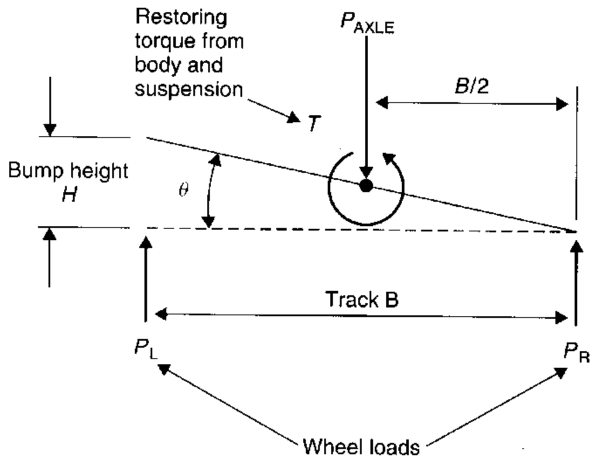


$$T = K_T\theta \approx K_T\frac{H}{B}$$

$$\frac{1}{K_T} = \frac{1}{K_F} + \frac{1}{K_B} + \frac{1}{K_R} \approx \frac{1}{K_F} + \frac{1}{K_R}$$

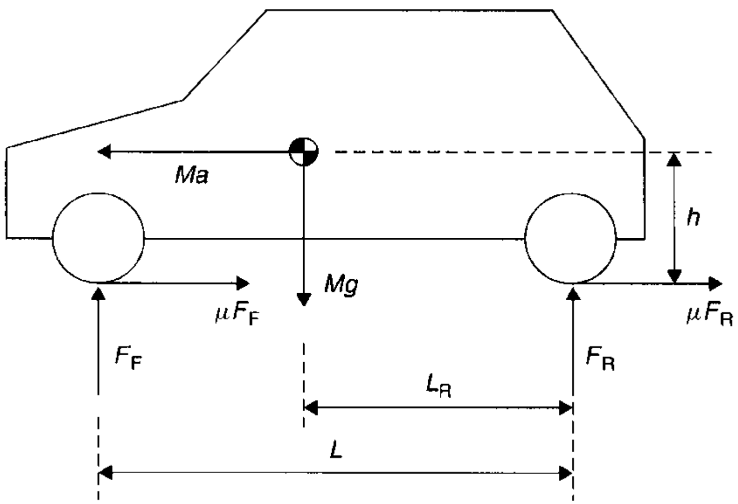
$$\text{when } P_R = 0 \rightarrow T = P_{AXLE}\frac{B}{2}\left[= K_T\frac{H_{\max}}{B}\right] \rightarrow H_{\max} = \frac{P_{AXLE}B^2}{2K_T}$$

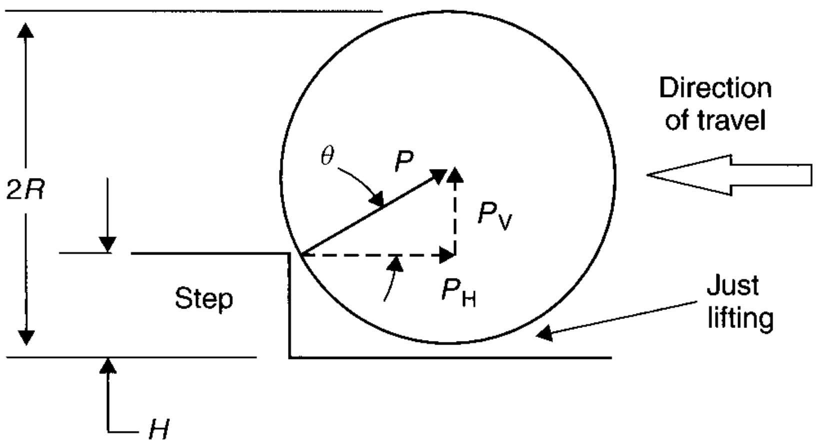




Longitudinal Load

- Braking
  - Weight transfer from the rear to the front wheels
  - Load factor: 1.1g~1.84g
  - F_F, F_R ?
- Striking a bump
  - Given H, P_v → $P_H = f(R)$
  - Dynamic load factor: 4.5
  - P_H / P_v vs. H/R



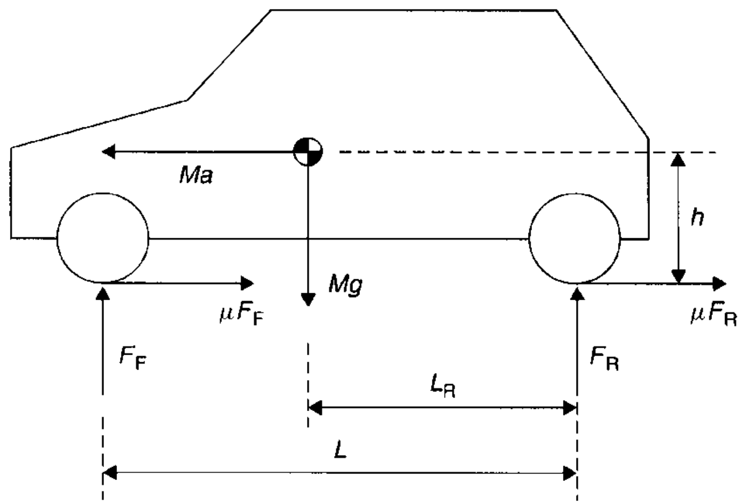


Longitudinal Load

- Braking
  - Weight transfer from the rear to the front wheels

$$L, L_R, M, \mu \rightarrow F_F, F_R\ ?$$

$$\begin{cases} Ma = \mu\left(F_F + F_R\right) \\ Mg = F_F + F_R \\ F_F L = MgL_R + Mah \end{cases} \rightarrow \begin{cases} F_F = \dfrac{Mg\left(L_R + \mu h\right)}{L} \\ F_R = \dfrac{Mg\left(L_F - \mu h\right)}{L} \end{cases}$$

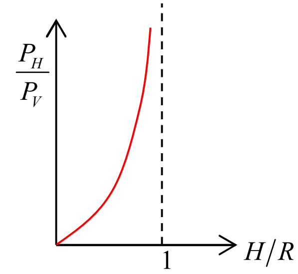


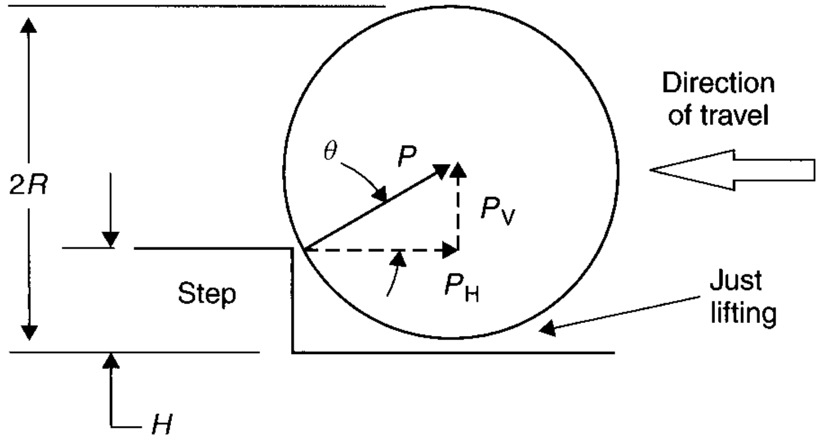
- Striking a bump

$$H, P_V \rightarrow P_H\ ?$$

$$\left.\begin{aligned} P_V &= P\sin\theta \\ P_H &= P\cos\theta \end{aligned}\right\} \rightarrow P_H = \underbrace{K_{DYN}}_{4.5}\frac{P_V}{\tan\theta}$$

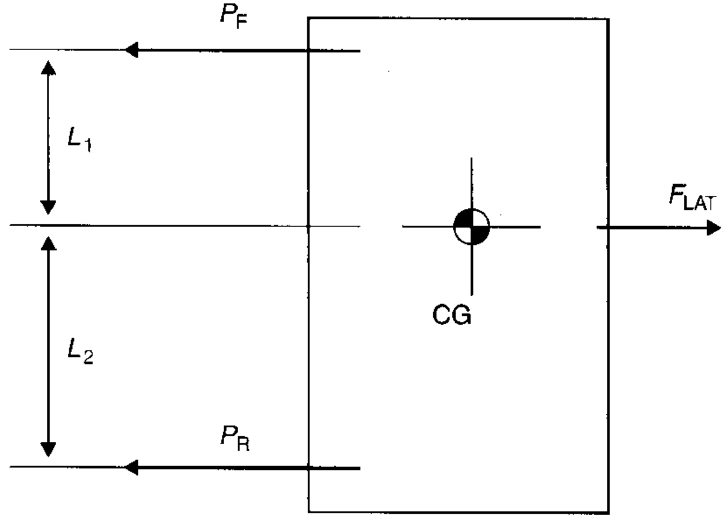
$$\sin\theta = \frac{R-H}{R} = 1 - \frac{H}{R}$$

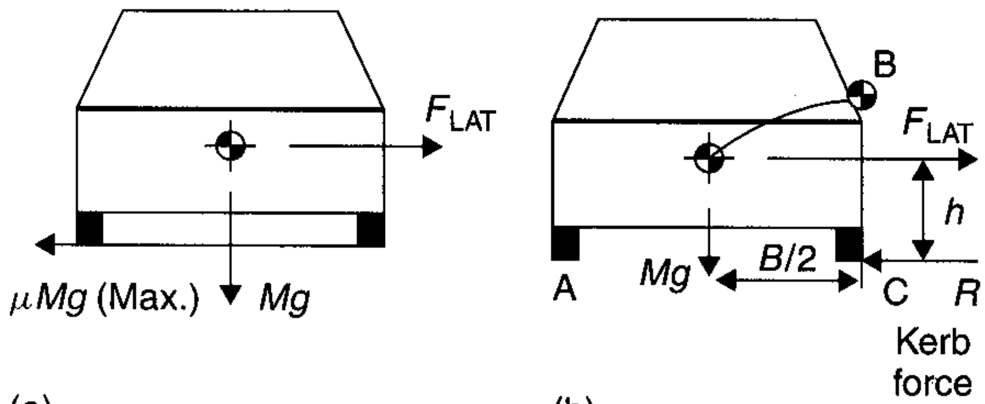




Lateral Load

- Sliding of tires
- Curb nudge: overturning
- Fore and aft distribution





(a) (b)

Lateral Load

- Sliding of tires
- Curb nudge: overturning
- Fore and aft distribution

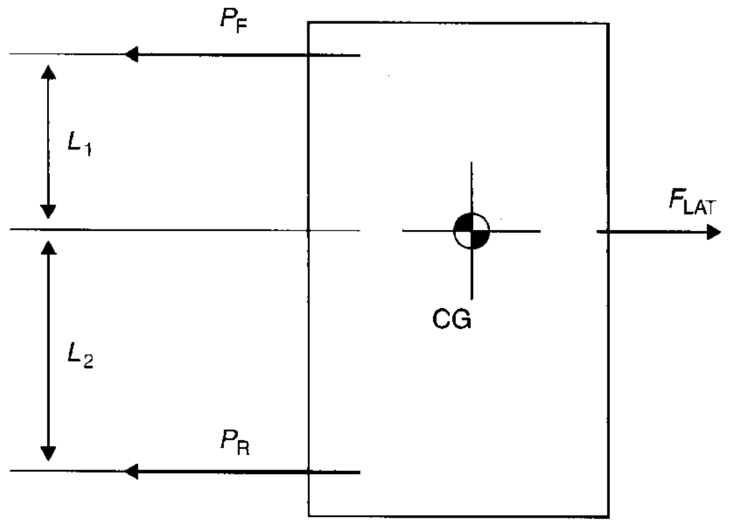
$$(a)\, F_{LAT} = \mu Mg$$

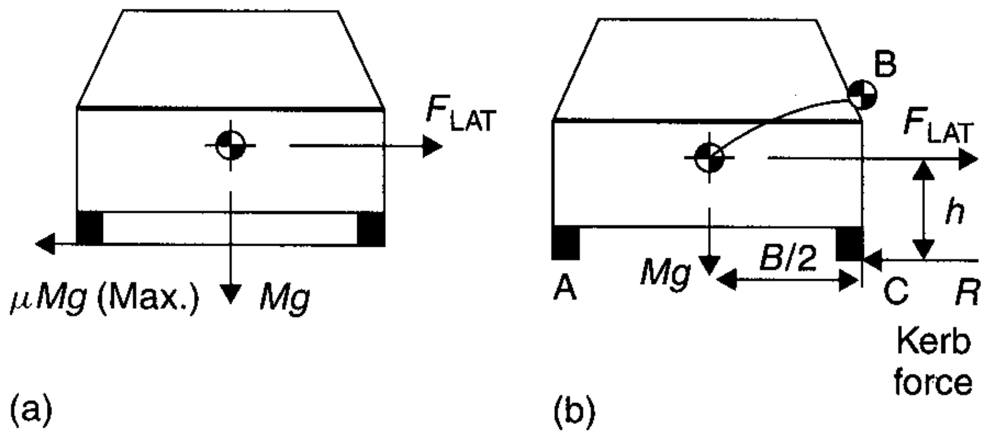
$$(b)\, F_{LAT} \times h = Mg\frac{B}{2} \times \underbrace{K}_{\text{dynamic safety factor: 1.75}}$$

$$\rightarrow F_{LAT} = \frac{MgB}{2h}K$$

$$(c)\begin{cases} P_F + P_R = F_{LAT} \\ P_F L_1 - P_R L_2 = 0 \end{cases}$$

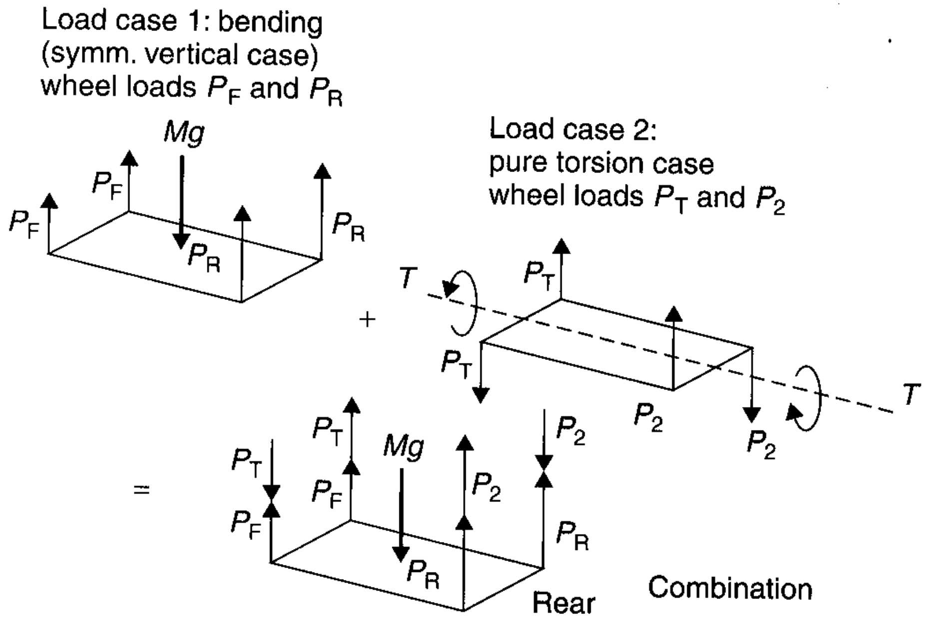
$$\rightarrow \begin{cases} P_F = \dfrac{F_{LAT} L_2}{L_1 + L_2} \\ P_R = \dfrac{F_{LAT} L_1}{L_1 + L_2} \end{cases}$$





Combinations of Load Cases

- Split into separate idealized cases
  - Bending, pure torsion, lateral cases, longitudinal cases
- Combined by addition (principle of superposition)



Vertical asymmetric loading as a combination of cases

Summary

- Four different load cases typically addressed in automotive design
  - Static
  - Transient short term
  - Transient long term
  - Cyclic