Vehicle dynamics

Lesson n.5:

Ride

Outline

- Introduction

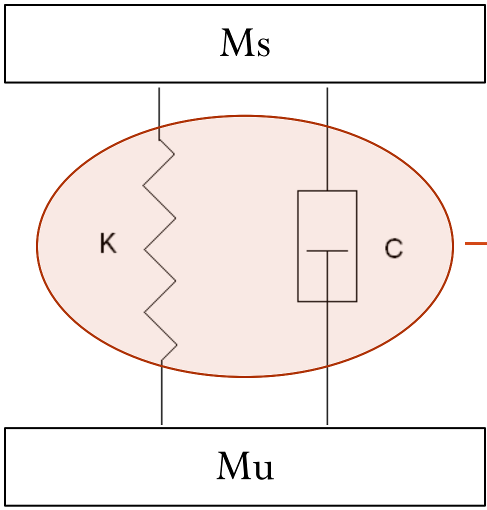
- Analysis of excitation sources
  - Road profile
  - Tires
  - Driveline
  - Powertrain

- Quarter-car model

- Other models

- Active and semi-active suspensions

Introduction



- Mechanism
- Spring
- Damper

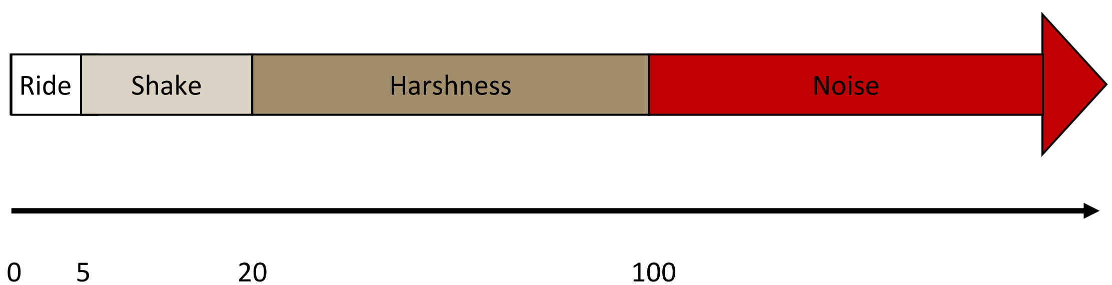
1. Isolate of Ms from Mu (comfort)
2. Transfer (react to) control forces
3. Limit roll motion
4. Limit load transfer
5. Control wheel motion (proper ranges for kinematic parameters

VIBRATIONS

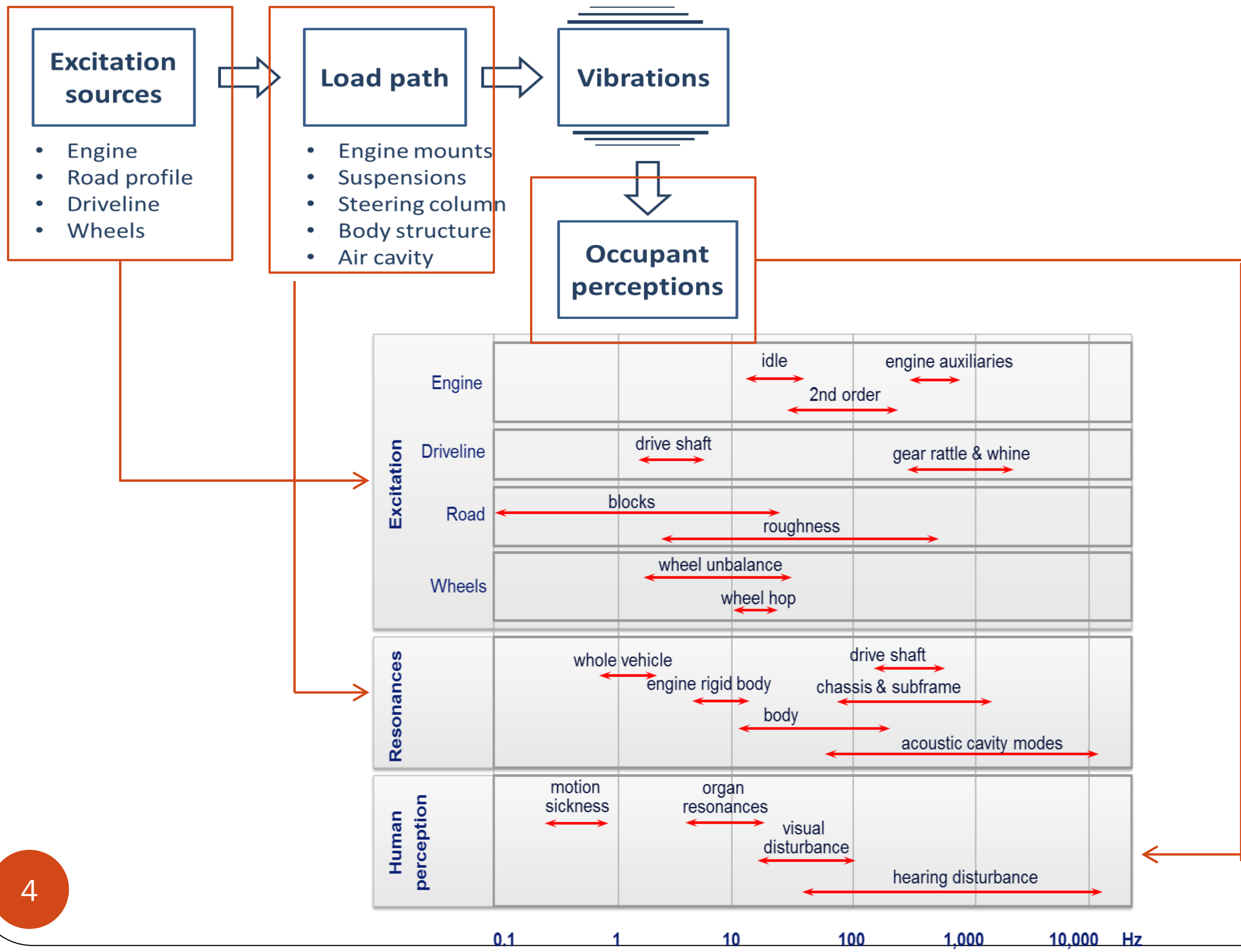
$f < 100$ Hz → Comfort or ride

100 Hz $< f <$ 20 kHz → Noise

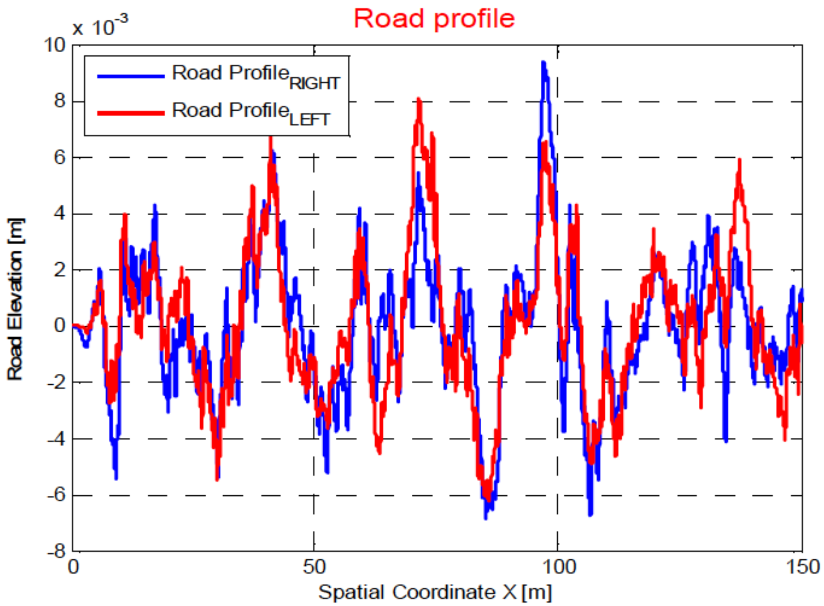
SAE Classification

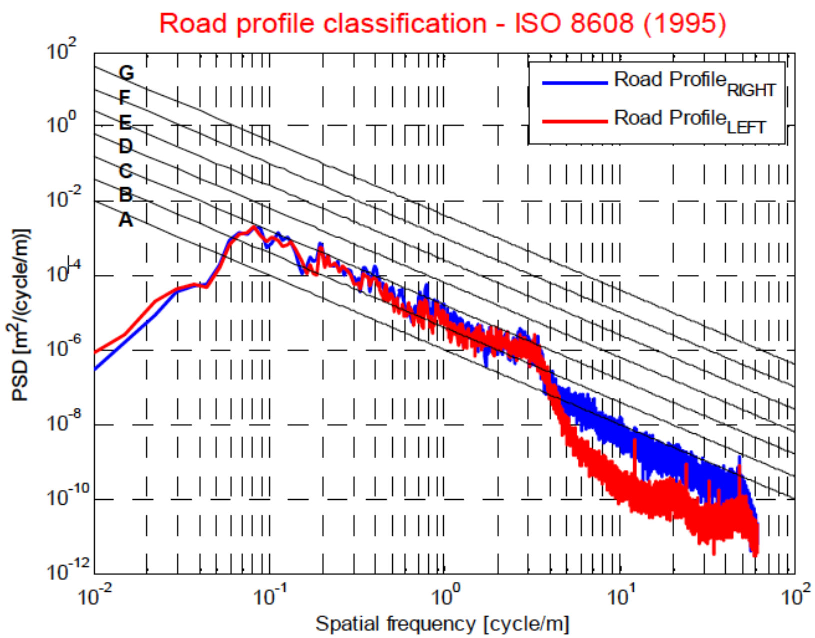


Excitation sources



Road profile





- Random signal
- Average features depending on the road type
- Road profile synthesis:

$$g(x) = \sum_{n=0}^{\infty}\left[d_n \sin\left(\frac{2\pi n}{L}x\right) + e_n \cos\left(\frac{2\pi n}{L}x\right)\right]$$

PSD: power-spectral density

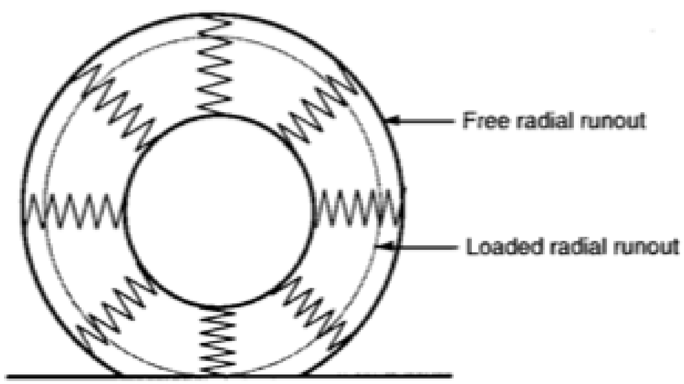
Tires/wheels

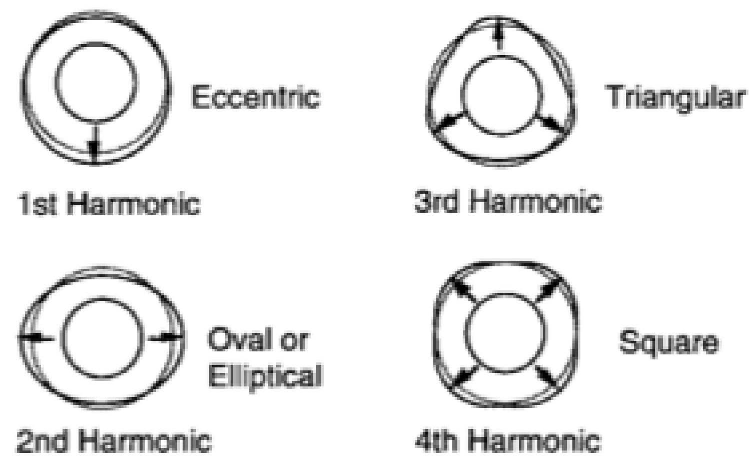
1. Static and dynamic unbalance of rotating bodies (tires, wheels,…)

$$F_i = (m\,r)\,\omega^2$$

Steering wheel vibrations

2. Stiffness and dimensional variations

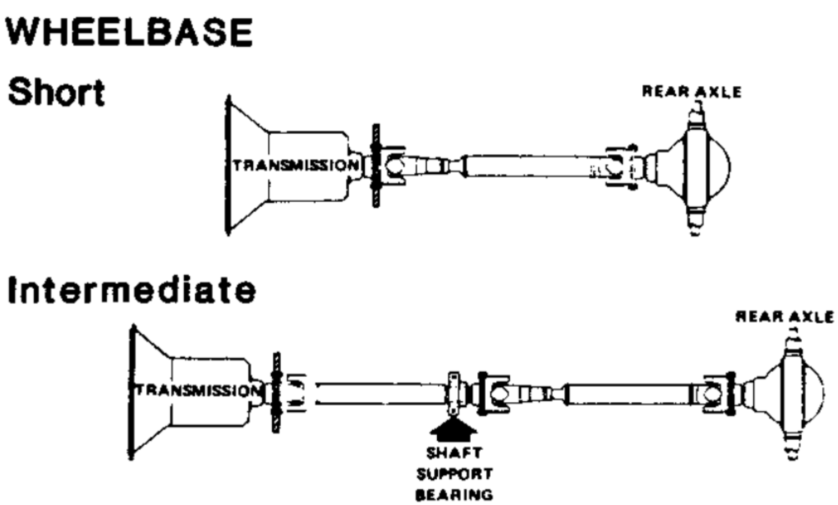




Parametric excitation

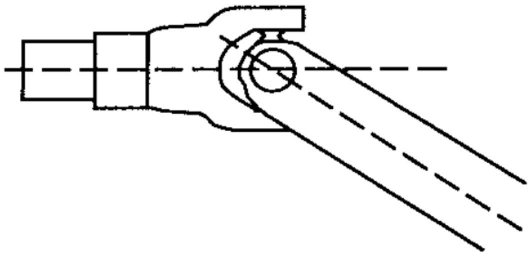
Driveshaft

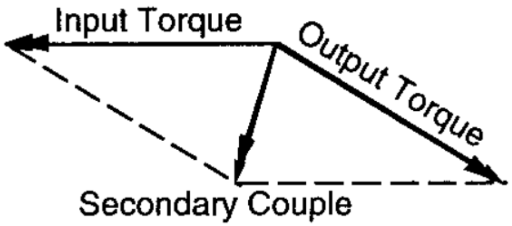
Unbalanced masses



Unbalance due to:
-Assembly errors;
-Geometric asymmetry;
-Deflection under load;
-Clearance in the joints.

Cardan joint

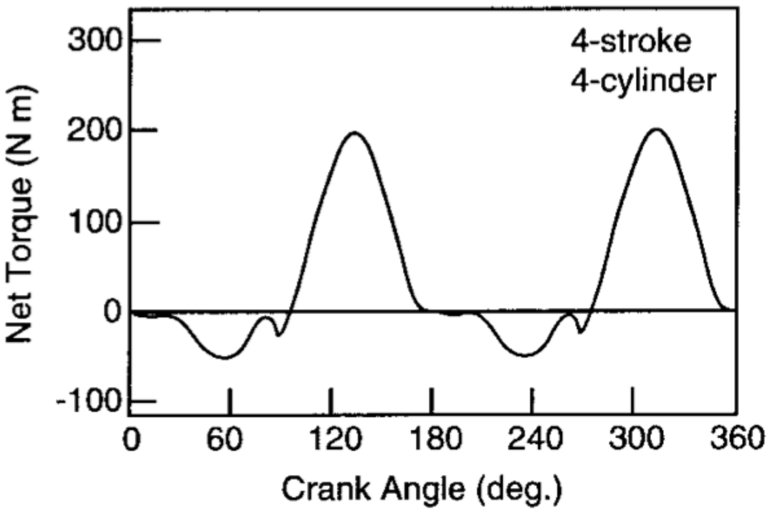




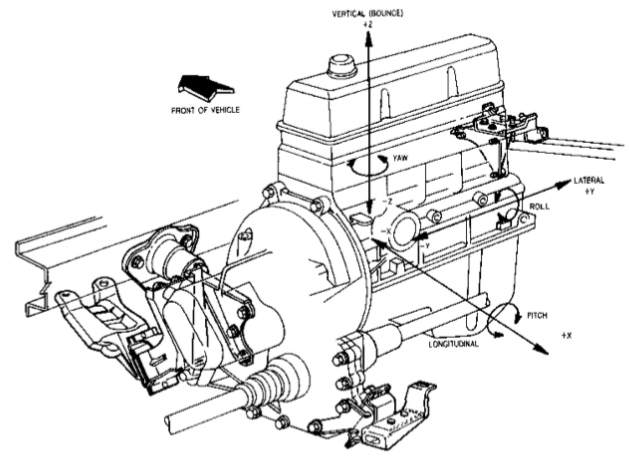
$$\frac{\omega_o}{\omega_i} = \frac{\cos\theta}{1 - \sin^2\beta \sin^2\theta}$$

Engine

Time varying engine torque



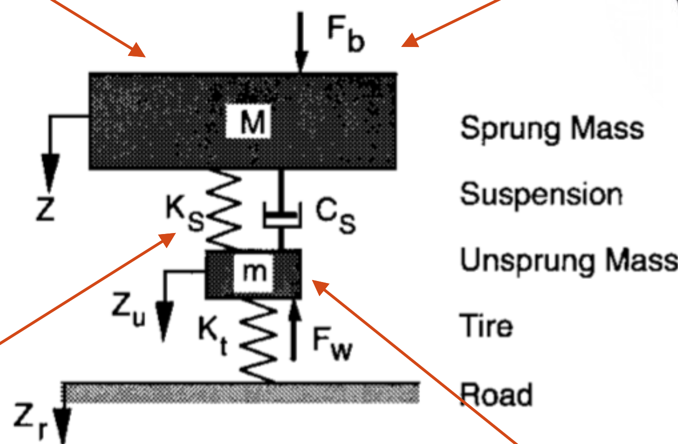
Shaking forces and moments (inertia)



Multi-cylinder engines

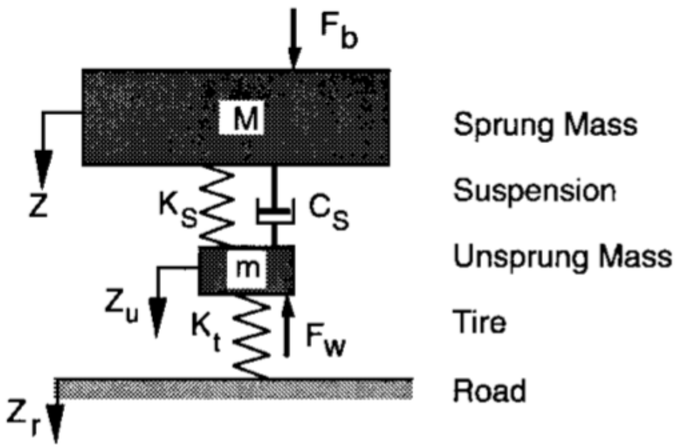
- Force balancing
- Proper sizing and positioning of bushings

Quarter Car Model



Quarter-car model

Dynamic model



$$RR = \frac{K_s K_t}{K_s + K_t}$$ Ride Rate = effective stiffness

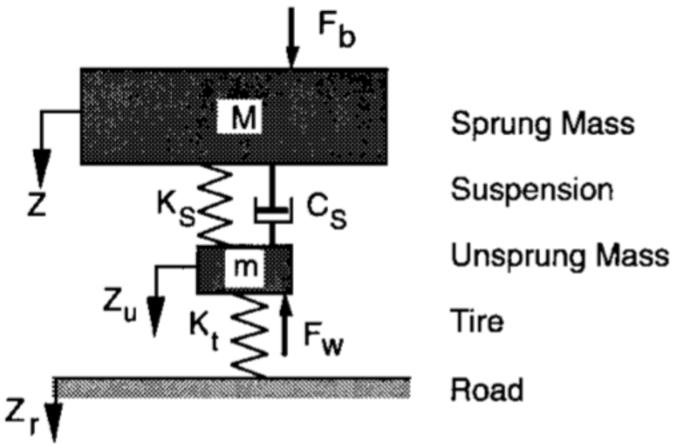
$$\omega_n = \sqrt{\frac{RR}{M}}$$ Undamped frequency

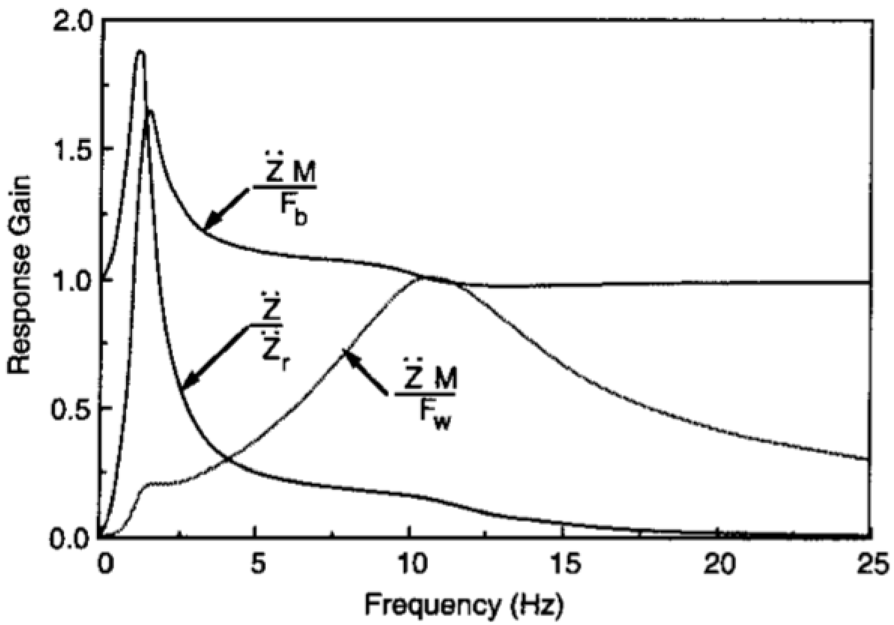
$$\omega_d = \omega_n \sqrt{1 - \zeta_s^2}$$ Damped frequency

Damping ratio: 0.2-0.4

Quarter-car model

Dynamic model: 2 d.o.f.





$$M\ddot{Z} + C_s\dot{Z} + K_s Z = C_s\dot{Z}_u + K_s Z_u + F_b$$

$$m\ddot{Z}_u + C_s\dot{Z}_u + (K_s + K_t) Z_u = C_s\dot{Z} + K_s Z + K_t Z_r + F_w$$

Frequency Responce Finctions (FRF):

- Excitation of Ms
- Excitation of Mu
- Road profile

Quarter-car model: analytical frequencies

Eigenvalue problem

$$\det(-\omega^2 M + K) = 0 \qquad \det\begin{bmatrix} k_s - m_s\omega^2 & -k_s \\ -k_s & k_s + k_t - m_u\omega^2 \end{bmatrix} = 0$$

$$\omega^2 = \frac{k_t + k_s}{2m_u} + \frac{k_s}{2m_s} \pm \frac{\sqrt{(k_t + k_s)^2 m_s{}^2 + m_u{}^2 k_s{}^2 - 2(k_t - k_s)k_s m_u m_s}}{2m_u m_s}$$

Eigenfrequencies

If kt>>ks $\Rightarrow$ $k_s + k_t \approx k_t - k_s \approx k_t$ $\Rightarrow$

$$\boxed{\omega_1 = \sqrt{\frac{k_s}{m_s}}}$$

$$\boxed{\omega_2 = \sqrt{\frac{k_t}{m_u}}}$$

Exercise in AMESim

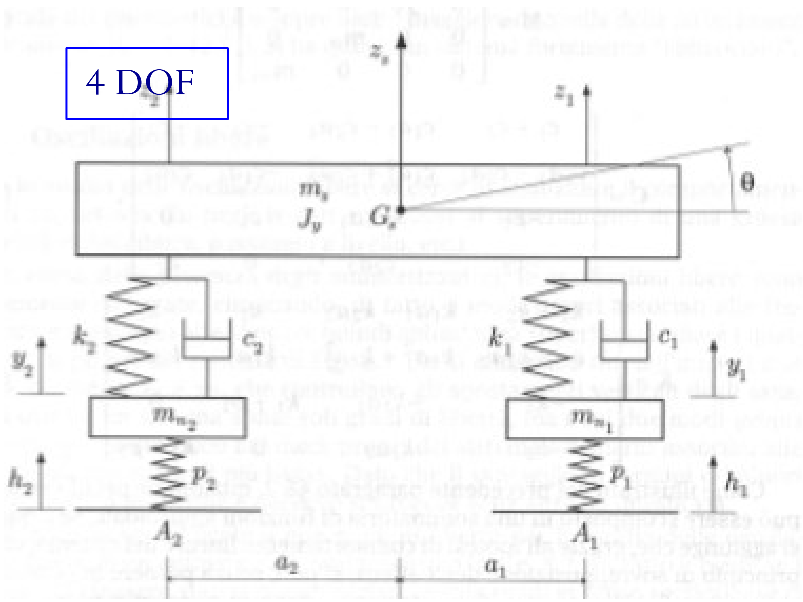
Quarter-car model: AMESim

Exercise:

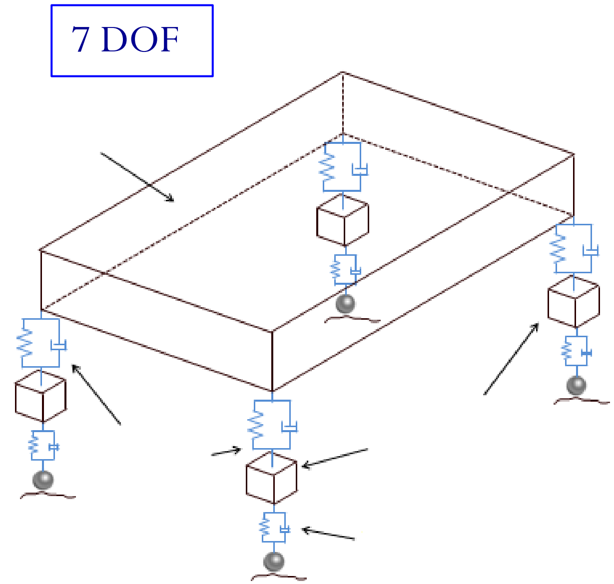
1. Create the model
2. Compute the relevant FRF
3. Compare numerical frequencies with analytical values
4. Analyse the harmonic response to estimate the modal shapes
5. Analyse the acceleration of the sprung mass to road excitation

Other models

Half-car model



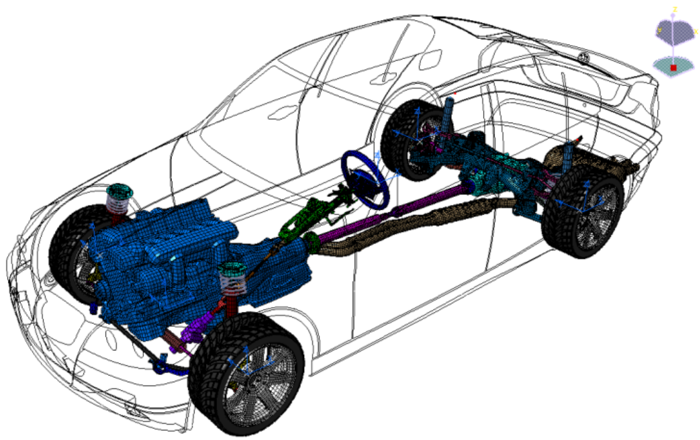
Full-car model



High-fidelity models

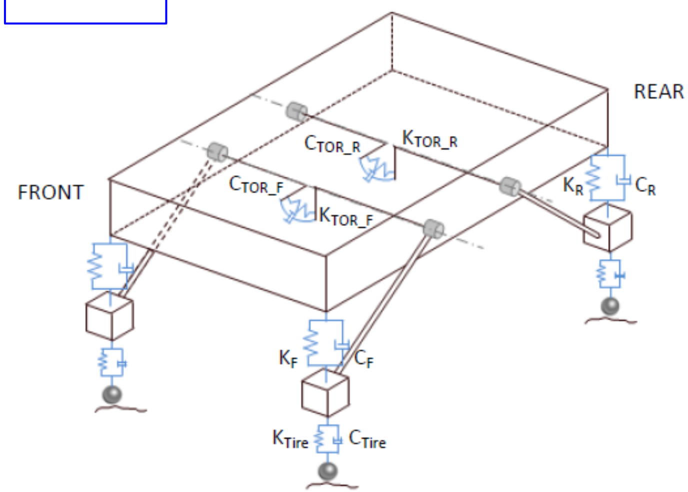
Multibody (MB) full-car model

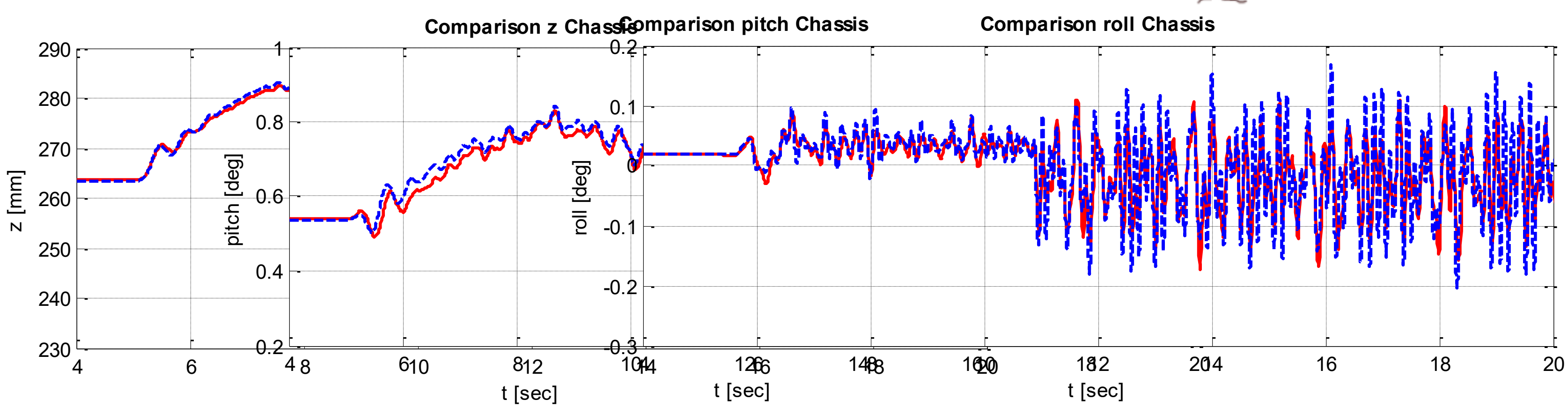
164 DOF



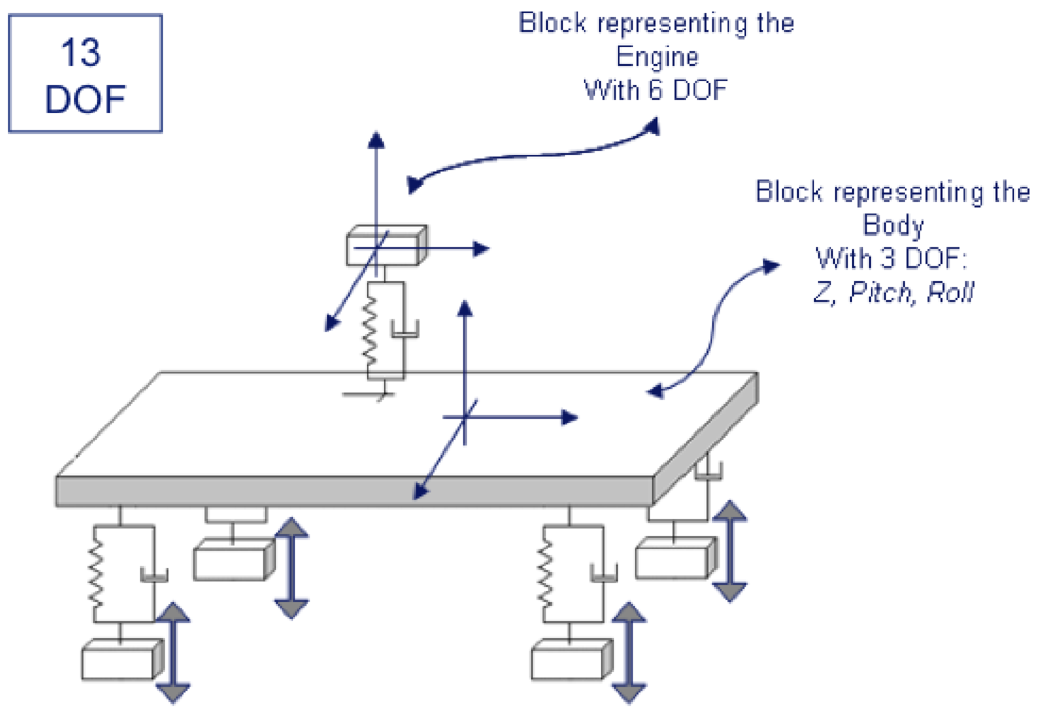
Lumped parameter full-car model with trailing arm

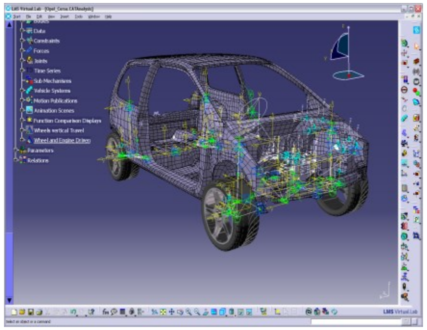
8 DOF

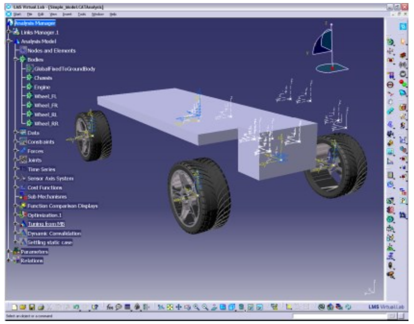




13 DoF full-car model

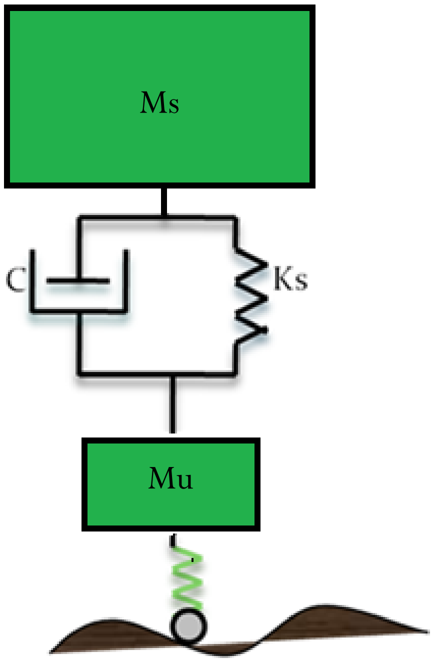




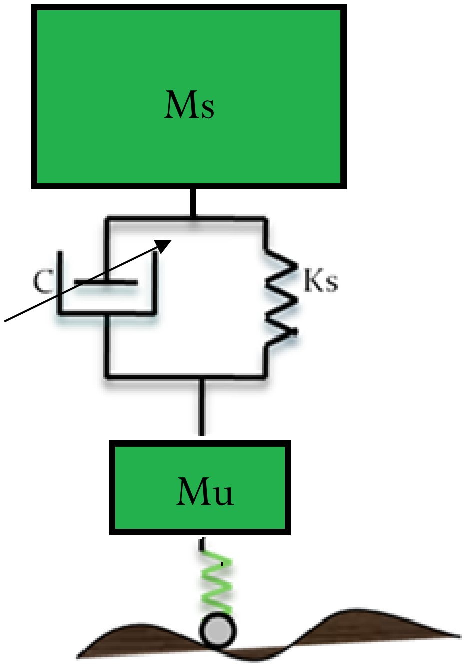


Suspensions types

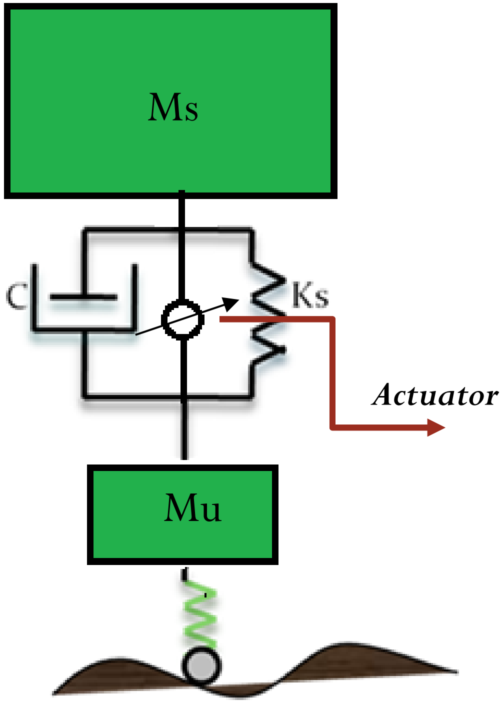
Passive suspensions



Semi-active suspensions

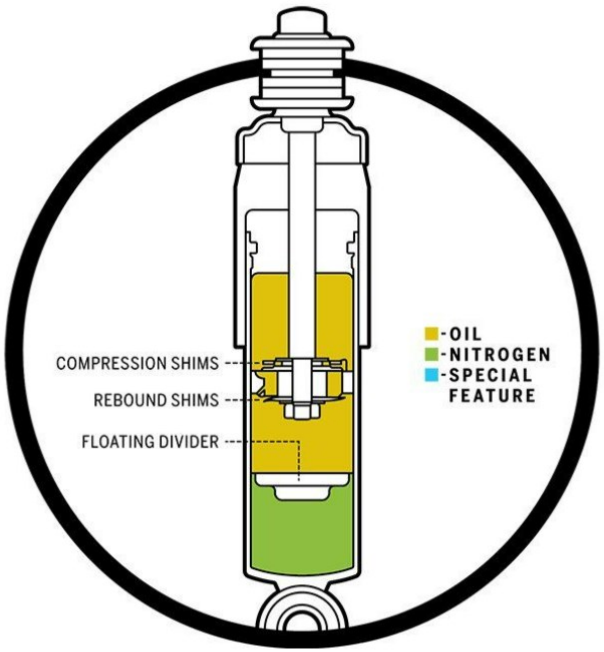


Active suspensions

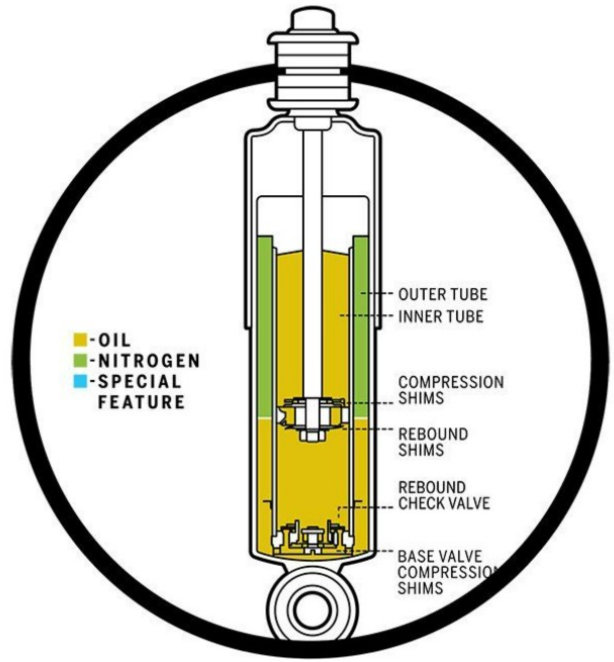


Automotive dampers

Mono-tube damper



Twin-tube damper

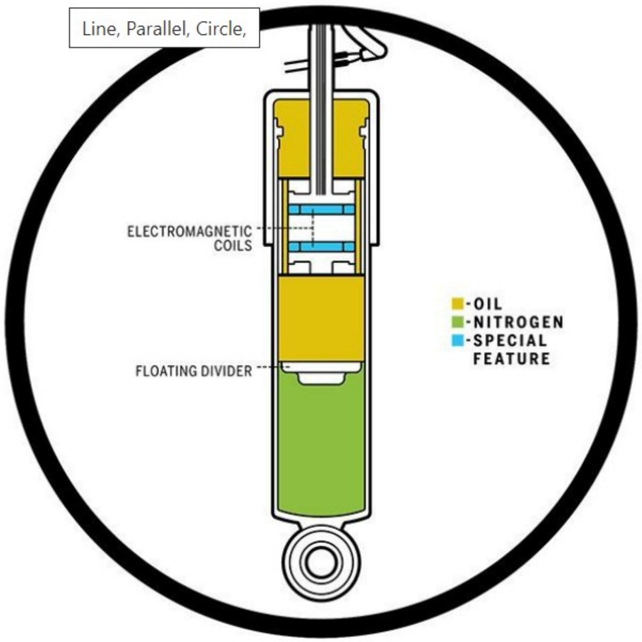


Damping force is determined by the shape, size, and number of shims (which control the flow) on the piston, the shaft diameter, the cylinder diameter, and gas pressure.

https://www.caranddriver.com/

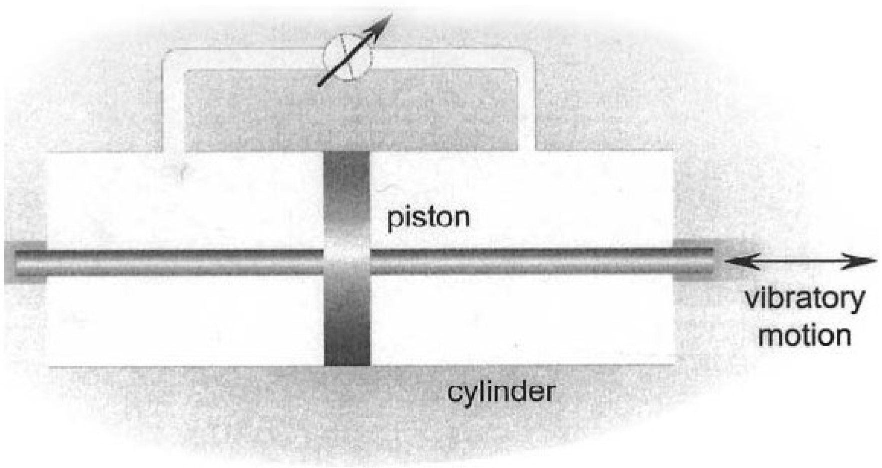
Semi-active suspensions

Magneto-rheologic suspensions



- Electromagnetic coils located in the piston to generate a localized magnetic field around the piston's passages
- The hydraulic fluid inside the dampers contains tiny iron particles, distributed randomly before electric current is applied to the piston coils
- Applying current to the coils creates a magnetic field, which arranges the particles into lines, making the fluid more resistant to flow.

Hydraulic suspensions



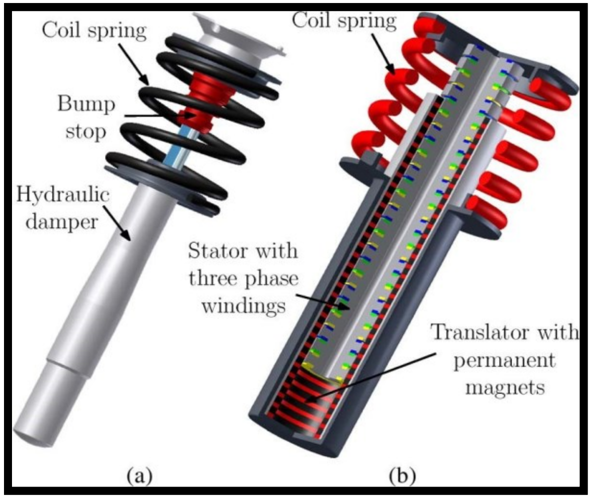
Variable-size orifice → Variable damping

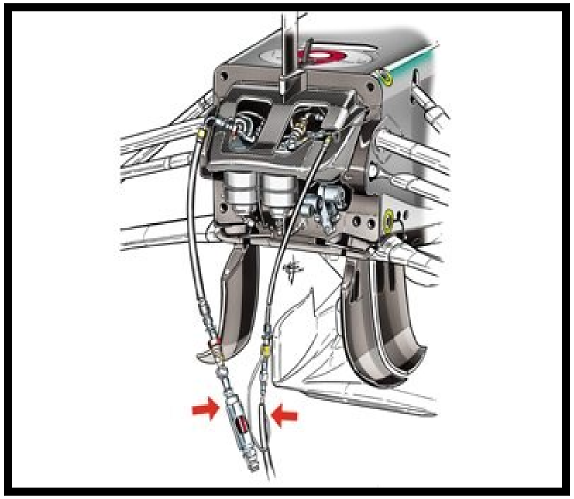
Active suspensions

Electro-magnetic suspensions

Pneumatic suspensions

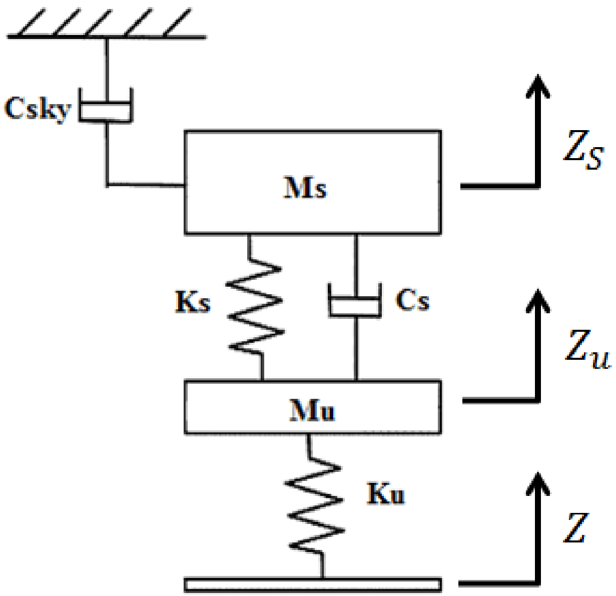
Hydraulic suspensions



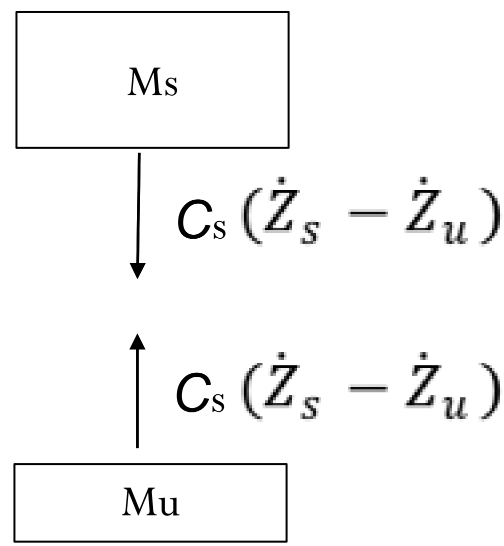


[Bose active suspension - YouTube]

Skyhook control for semi-active suspensions



$$C_s = \begin{cases} C_{max}, & \dot{Z}_s\,(\dot{Z}_s - \dot{Z}_u) \geq 0 \\ C_{min}, & \dot{Z}_s\,(\dot{Z}_s - \dot{Z}_u) < 0 \end{cases}$$



Let’s try to model SemiActive suspensions in AMESim

Exercise:

1. Use AMESim quarter-car model to simulate a ride on bumps/rumble stripes manoeuvre for passive vehicle
2. Same as at point 1, but with semiactive suspensions