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Introduction to vehicle suspension

Springs

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MT304

Suspension

What does it do?

- Supports the weight of the vehicle
- Isolates the vehicle body, passengers and contents from road surface irregularities
- Maintains the wheel and tyre in contact with the road surface
- Comfort
- Handling and traction

Suspension

Road surfaces

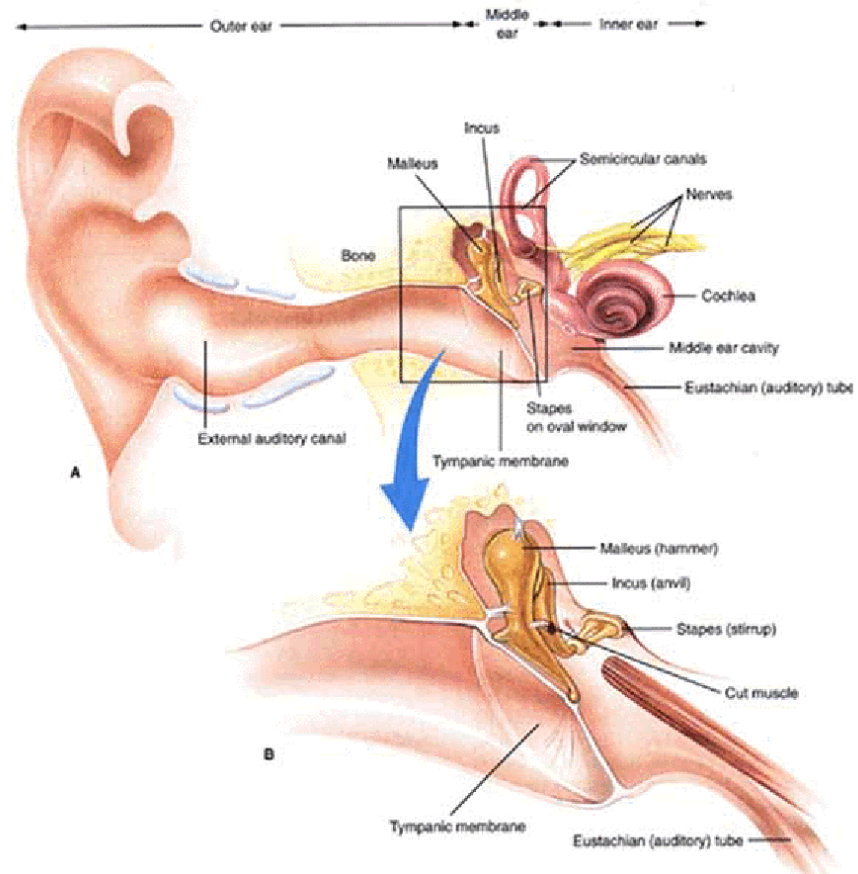
- Medium quality- amplitudes of 13mm
- High Quality – amplitudes of 5mm
- Average pitch < 4m
- Typical road wheel rolling circumference 2m
- Other road surfaces
 - Pave, Belgium blocks
 - Cobbles
 - Washboard, unmade road surface or 'slow down' ribs

Pave Punto



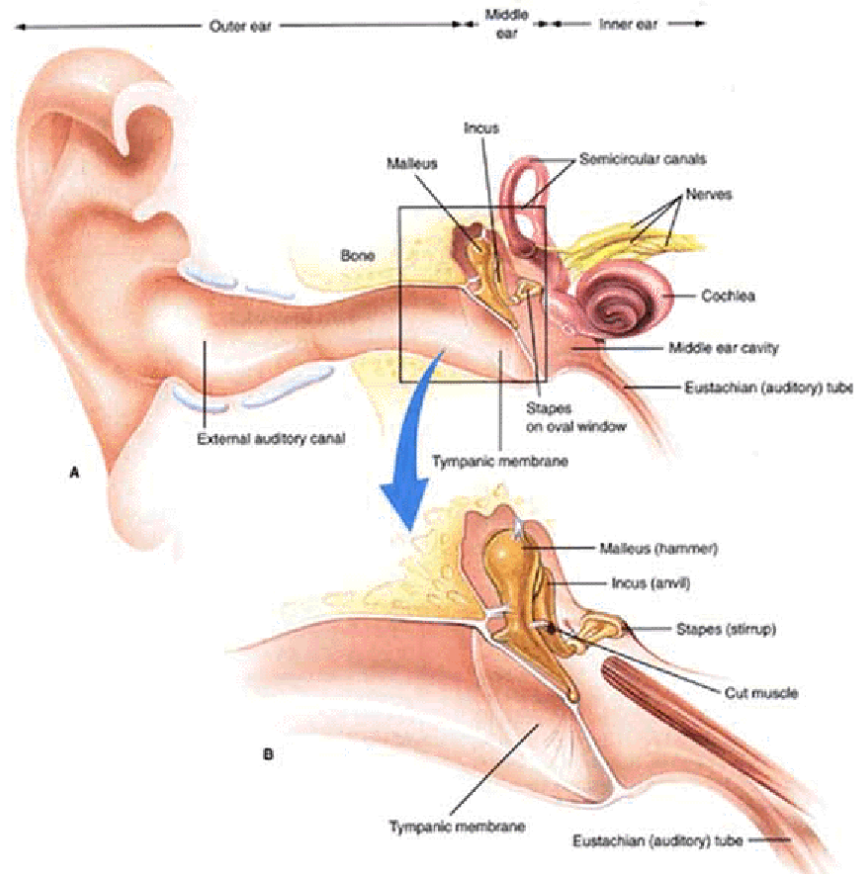
Human aspects

- Inner ear inputs are decoded along with muscle tensions to unscramble the motion of the support platform – the so-called “seat of the pants”
- Although less complex than visual processing, there is still a delay around 300 msec associated with this processing route



Human aspects

- Aircraft experience clearly shows the need for visual “re-anchoring” of inner ear sensations
- Dizziness is a symptom of the inner ear’s own ongoing “re-anchoring” process



Suspension

Ride comfort and frequencies

- Generally considered that vertical frequencies based on walking are comfortable
 - 2.4-4 mph gives 1.5-2.3 Hz
- Fore-aft and lateral head movement should be $<1.5\text{Hz}$ but are best avoided, heads are heavy, neck fatigue occurs
- If the inner ear is subjected to frequencies between 0.5 and 0.75 Hz dizziness and sickness are liable to result (travel and sea sickness)

4 Poster



MIRA – Man shaker



Suspension

Ride comfort and frequencies

- Serious discomfort will be felt in important organs at around 4-8 Hz
- In summary
- A 1950's US saloon would have a 1 Hz spring frequency
- A modern European vehicle would have a 1.3/1.4 Hz frequency
- A performance vehicle would have 2-2.5 Hz

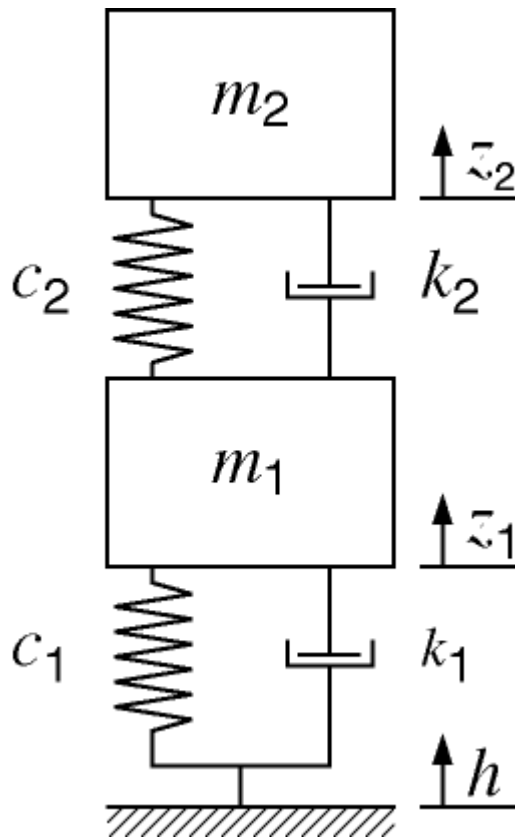
ISO number and pictures of ears/testing

Suspension Springs

- When the wheel hits a bump it rises rapidly. If there were no springs considerable shock would be transmitted into the body and occupants
- With springs the only force transmitted into the body is that required to compress the spring far enough to allow the wheel to ride over the bump
- The force causes the body to rise up but at a smaller rate than would otherwise be experienced.
- When the wheel falls into a depression (i.e. after a bump) the spring acting on the (relatively light) unsprung mass, forces it down rapidly, almost before the body has time to descend

Suspension

Ride comfort and frequencies



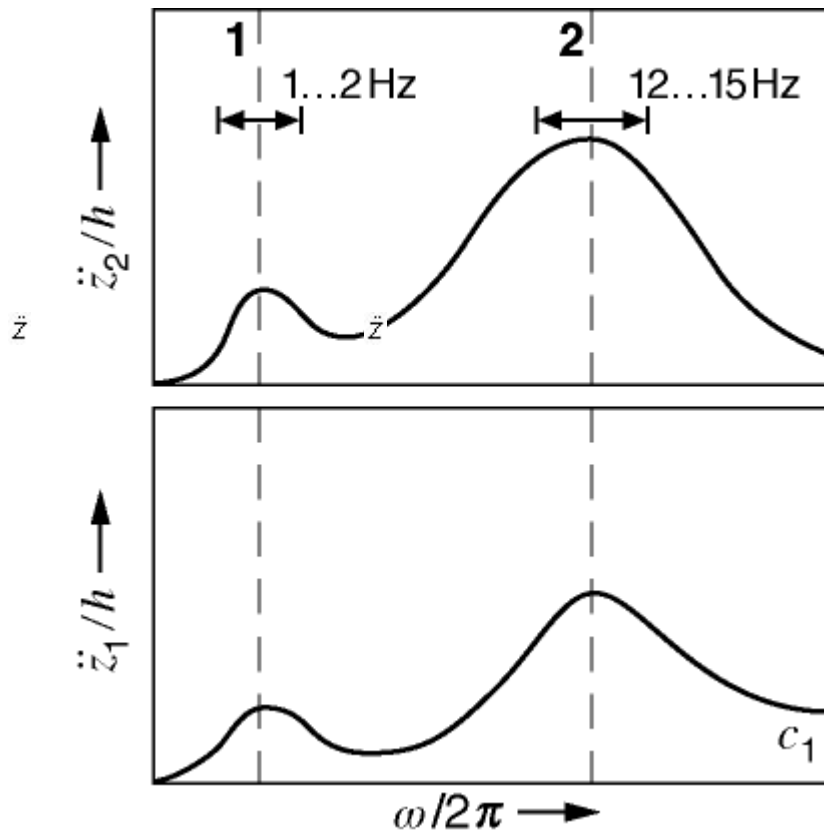
Dual-mass model as quarter-vehicle model

h Excitation amplitude,
 z Oscillation amplitude, c Spring
resistance, k Damping constants,
 m Mass.

Subscripts: 1 Tires and axle,
2 Body.

Suspension

Ride comfort and frequencies



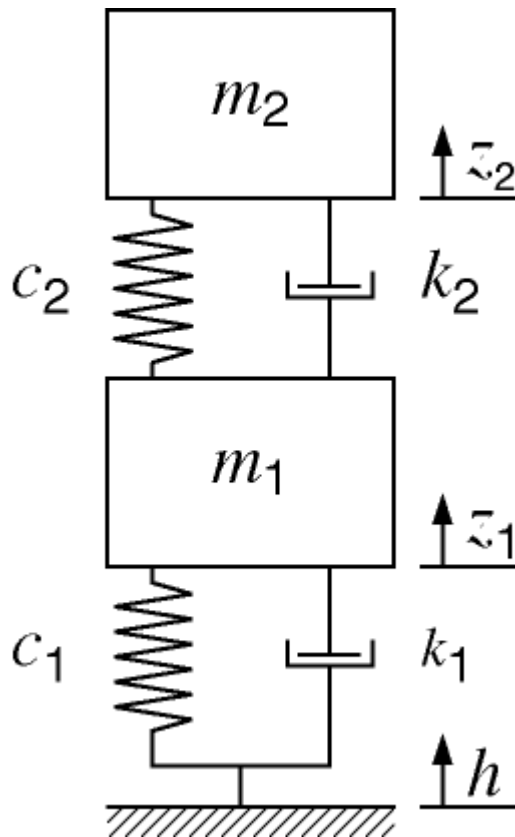
Effect of frequency on kinematic amplitudes

$_1$ Amplitude of axle acceleration,

$_2$ Amplitude of body acceleration, h Excitation amplitude. 1 Natural body frequency, 2 Natural axle frequency.

Suspension

Spring - Ride Rate RR

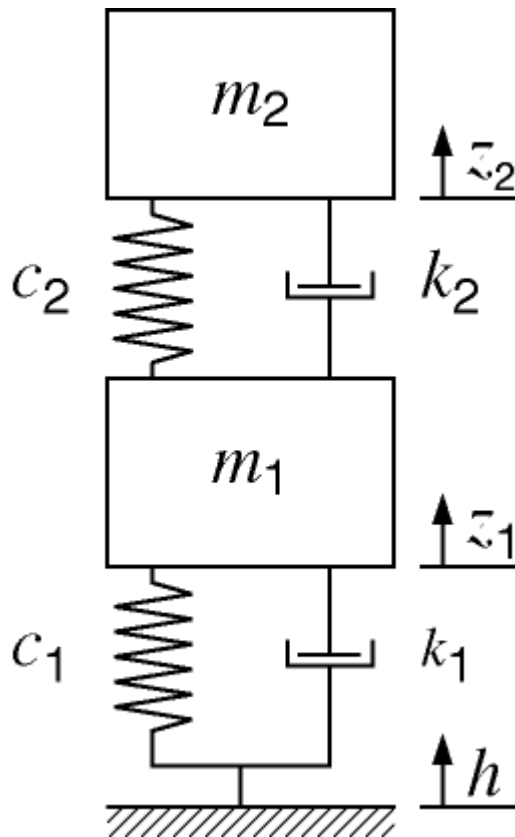


$$RR = \frac{K_2 \cdot K_1}{K_2 + K_1}$$

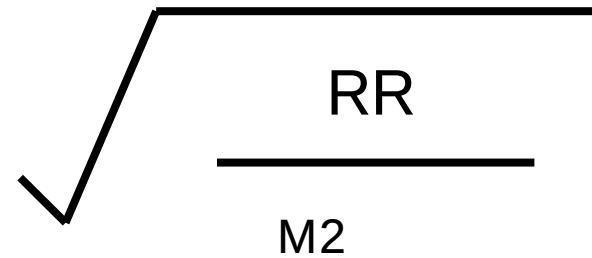
Effective stiffness of tyre and suspension
Springs in series

Suspension

Spring – bounce natural frequency



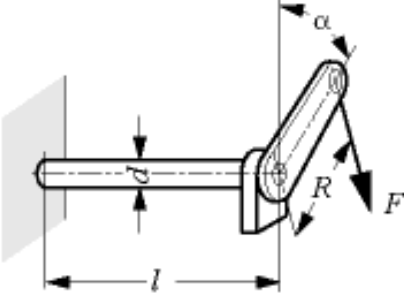
$$\text{freq} = 0.159$$



Bounce natural frequency

Suspension

Spring types – Torsion bar

Type	Torsional stress	Spring rate
Torsion-bar spring of circular cross-section (DIN 2091) 	$\tau = \frac{16}{\pi \cdot d^3} M$ where $M = F \cdot R$	$c = \frac{M}{\alpha} = \frac{G \cdot \pi \cdot d^4}{57,3 \cdot 32 \cdot l}$

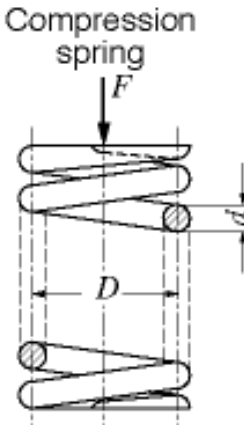
To improve fatigue life torsion bars are 'scragged' overloaded in torsion during production creating a residual stress in the outer surface

Can provide some interesting package solutions

Challenges occur in holding the fixed end of the torsion bar and allowing adjustment for ride height

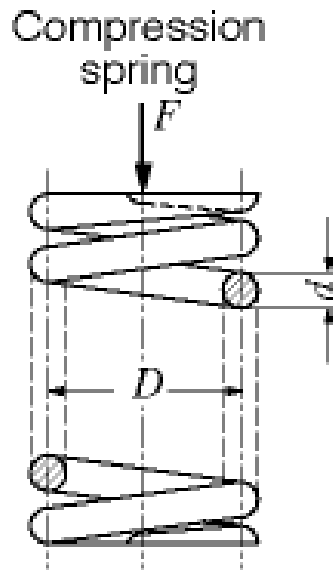
Suspension

Spring helical

Type	Torsional stress	Spring rate														
Helical springs made of round wire (DIN 2089) Compression spring  Extension spring  Above: half "German" loop, Below: hifo® hook see Helical extension springs.	a) In the case of a static or infrequently alternating load, allowance need not be made for the effect of the wire curvature: $\tau = \frac{8 \cdot D}{\pi \cdot d^3} F$ b) In the case of a pulsating load, the non-uniform distribution of torsional stresses must be taken into consideration: $\tau_k = k \cdot \tau = \frac{8 k \cdot D}{\pi \cdot d^3} F$ The curvature correction factor k depends on the spring index D/d. <table><tr><td>D/d</td><td>3</td><td>4</td><td>6</td><td>8</td><td>10</td><td>20</td></tr><tr><td>k</td><td>1.55</td><td>1.38</td><td>1.24</td><td>1.17</td><td>1.13</td><td>1.06</td></tr></table> Avoid $D/d < 3$ and > 20.	D/d	3	4	6	8	10	20	k	1.55	1.38	1.24	1.17	1.13	1.06	$c = \frac{F}{s} = \frac{G \cdot d^4}{8 \cdot n \cdot D^3}$ In the case of compression springs with only 1 ... 3 coils, the load deflection curve is no longer a straight line; spring rate c is initially smaller and then larger than the calculated rate.
D/d	3	4	6	8	10	20										
k	1.55	1.38	1.24	1.17	1.13	1.06										

Suspension

Spring helical



To increase fatigue life helical springs are shot peened on their surface to induce compressive stresses and minimise any micro cracks that would act as a stress raiser and crack propagation start point

Springs are coated for corrosion and stone chip resistance

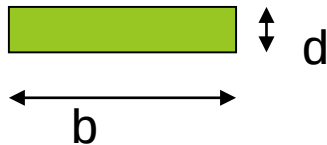
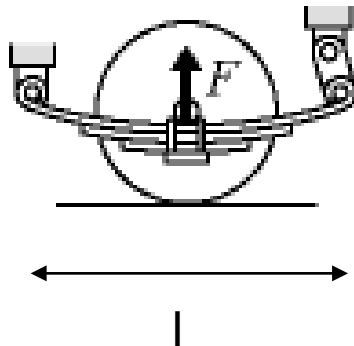
Helical springs package well / compact
Helical springs can be straight wound, Barrel or conical in order to achieve Different characteristics

Suspension Springs – leaf springs

Steel springs

Leaf spring

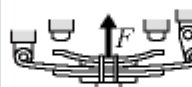
Car leaf spring



$$\text{Rate} = E. \frac{b.d^3}{4.l^3}$$

Suspension

Springs – leaf springs

Chassis systems Suspension			
Suspension design elements	Diagram	Effect of vehicle load on natural frequency of body	Characteristics
Steel springs			
Leaf spring	Car leaf spring 	Truck leaf spring with auxiliary spring 	$\frac{v_{\text{loaded}}}{v_{\text{empty}}} = \sqrt{\frac{m_{\text{empty}}}{m_{\text{loaded}}}}$ Natural frequency decreases with increase of payload. Characteristics are generally linear. Single or multi-leaf. Is also used to determine wheel travel in some applications. Interleaf friction in some types, can be reduced with plastic inserts (noise possible). Generally without inserts in trucks, maintenance required. Good transfer of forces to chassis.

Single or layered
 Flat or tapered
 Leaf stacks have relative motion – lubrication
 Adds to unsprung mass
 Low energy storage (0.25)
 Compared to helical spring
 Can align axle/wheel

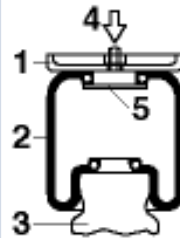
Suspension

Springs – air springs

Air spring

Roll-gaiter air spring

Element with constant gas volume.
1 Chassis frame, 2 Roll-gaiter air spring,
3 Piston, 4 Compressed air,
5 Mounting plate.
Roll bellows



$$\frac{v_{\text{loaded}}}{v_{\text{empty}}} = 1$$

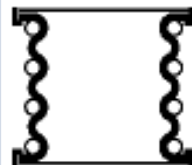
Natural frequency remains constant when vehicle loaded.

Characteristics are dependent on gas properties, piston shape, direction of plies in the gaiter.

Used as suspension strut or spring particularly on commercial vehicles and busses. Increasingly widespread use in passenger cars for level control at rear axle and for suspension on all wheels. Achieves high vertical compliance (increased comfort). Wheel travel must be defined by separate suspension components. Low pressure (< 10 bar) demands large volume. Low vertical spring rate not achievable due to geometry of toroid air bellows.

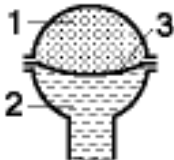
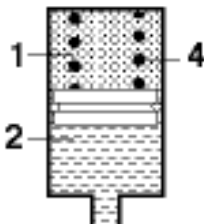
Toroid bellows

Toroid bellows



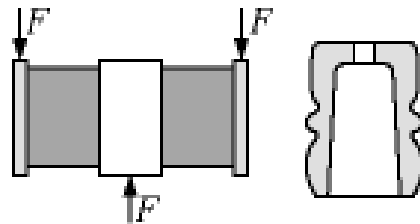
Suspension

Springs – air over hydraulic

Hydropneumatic suspension Hydraulic diaphragm accumulator	Hydropneumatic spring element with constant gas mass. 1 Gas, 2 Oil, 3 Diaphragm, 4 Steel spring. Hydraulic diaphragm accumulator 	$\frac{v_{\text{loaded}}}{v_{\text{empty}}} = \sqrt{\frac{m_{\text{loaded}}}{m_{\text{empty}}}}$ Natural frequency increases with payload. Characteristics are progressive and dependent on initial charge pressure of reservoir. The gas volume in a reservoir (separated from oil by a piston) determines its spring characteristics. The fluid compresses the gas according to wheel load. Damper valves are integrated in the shock absorber and the junction between suspension strut and reservoir. The rubber diaphragm requires maintenance due to gas diffusion.
Piston accumulator	Piston accumulator 	

Suspension Springs - rubber

Rubber springs

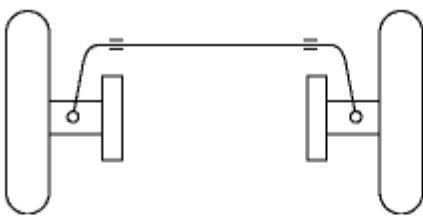


Natural frequency is affected by payload due to the non-linear spring characteristics.

Vulcanized rubber compression spring between metal components, increasingly with integral hydraulic damper. Used as engine/transmission mountings, suspension-arm mountings and auxiliary springs.

Suspension

Springs – Anti-roll bar (stabiliser)

Stabilizer		No effect if both sides simultaneously moved in same direction. If one side moved up/down half of anti-roll bar rigidity effective, if two sides moved in opposing directions full rigidity of anti-roll bar effective. Reduces body-roll tendency and influences vehicle cornering characteristics (over or understeer). Generally made of U-shaped bar or tube, sides frequently flattened to cope with flexural loads. Attachment points must be at extreme outside of axle to allow minimal stabilizer diameter. Suspension link fulcrums must be arranged relative to the anti-roll bar in such a way that it is subjected only to torsion and not bending.
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Rate as for torsion bar
Adjustable types used in motorsport

Active types used in some vehicles esp offroad –handling verses suspension articulation