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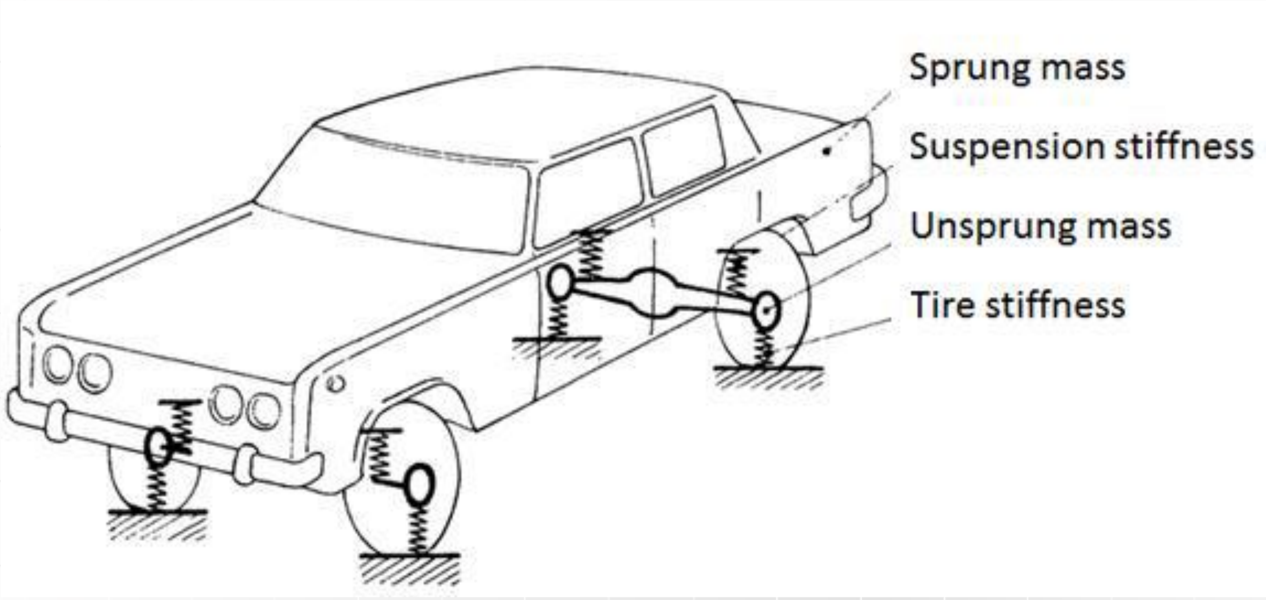
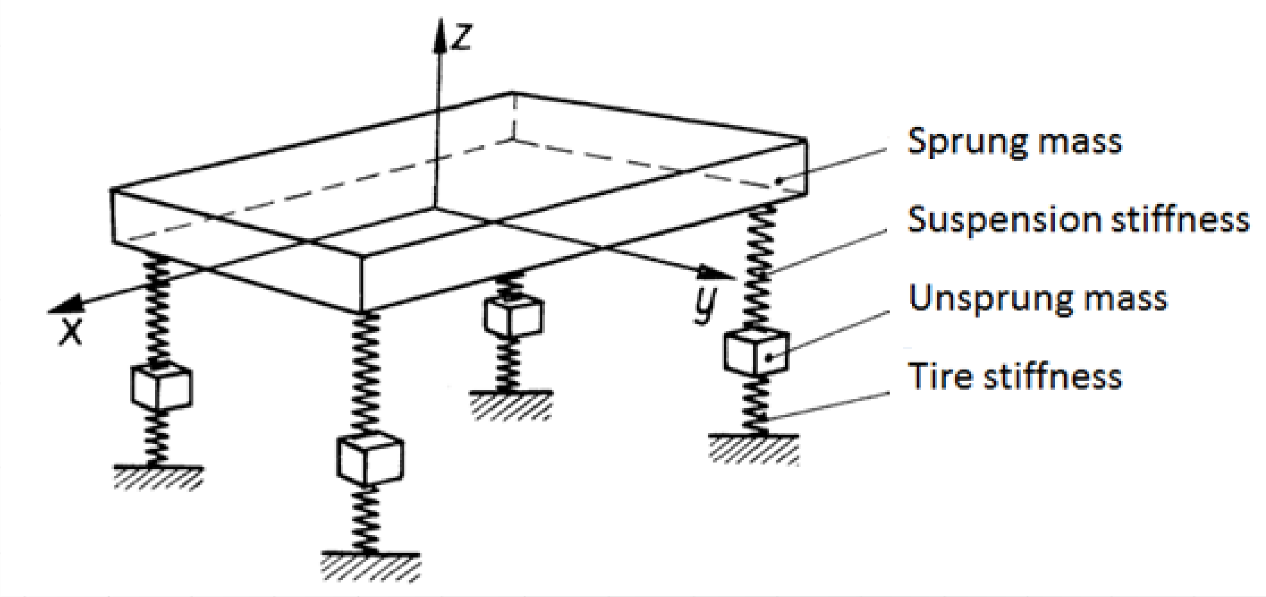
Suspension systems

Suspension systems

To understand vehicle performance and cornering, it is essential to have an in-depth understanding of the basic geometric properties of roads and suspensions, *Including characteristics such as bump steer, roll steer, the various kinds of roll centre, and the relationships between them.*

Suspension system



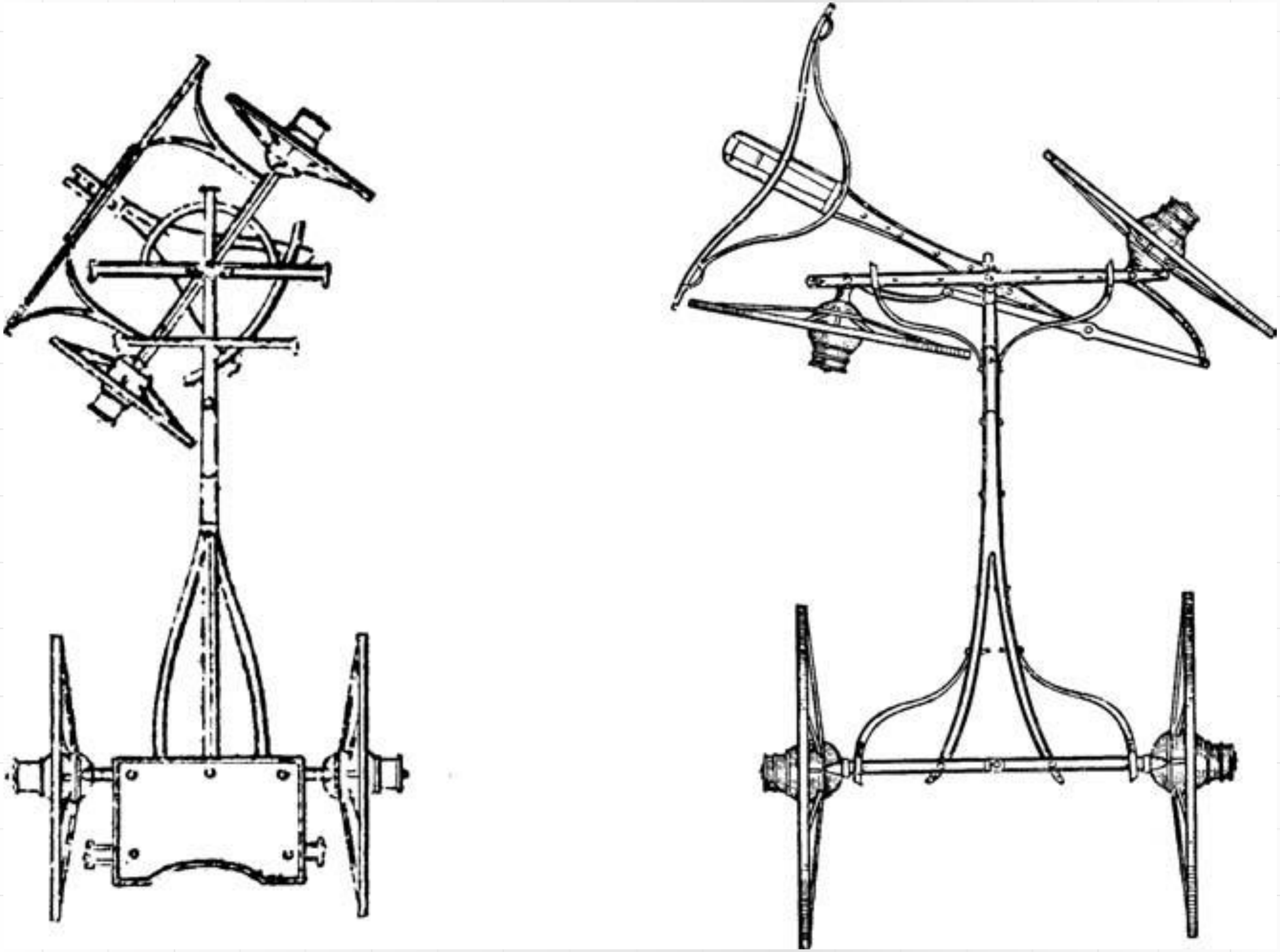


Suspension system

1. To provide good ride and handling performance –
2. To ensure that steering control is maintained during maneuvering
3. To ensure that the vehicle responds favorably to control forces produced by the tires as a result of longitudinal braking and accelerating forces, lateral cornering forces and braking and accelerating torques
4. To provide isolation from high frequency vibration arising from tire excitation

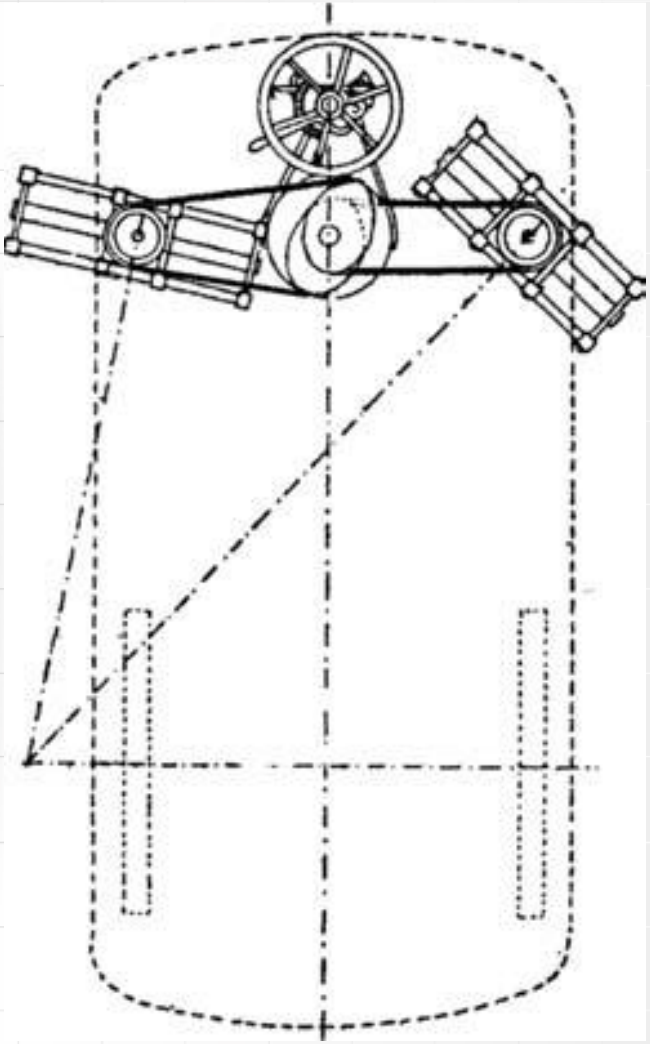
The wheels, through the suspension linkage, must propel, steer, and stop the vehicle, and support the associated forces.

Suspension systems

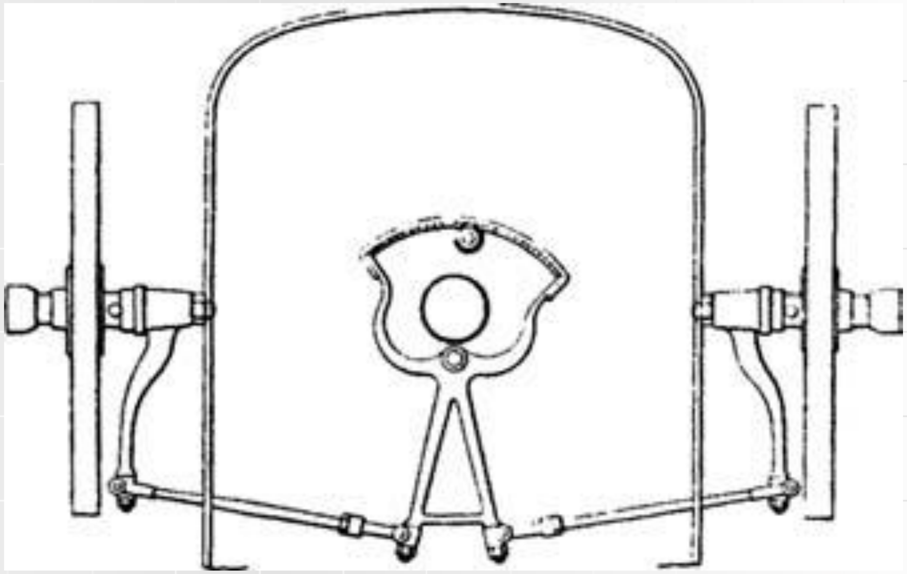


Langensperger’s independent steering of 1816

Suspension systems

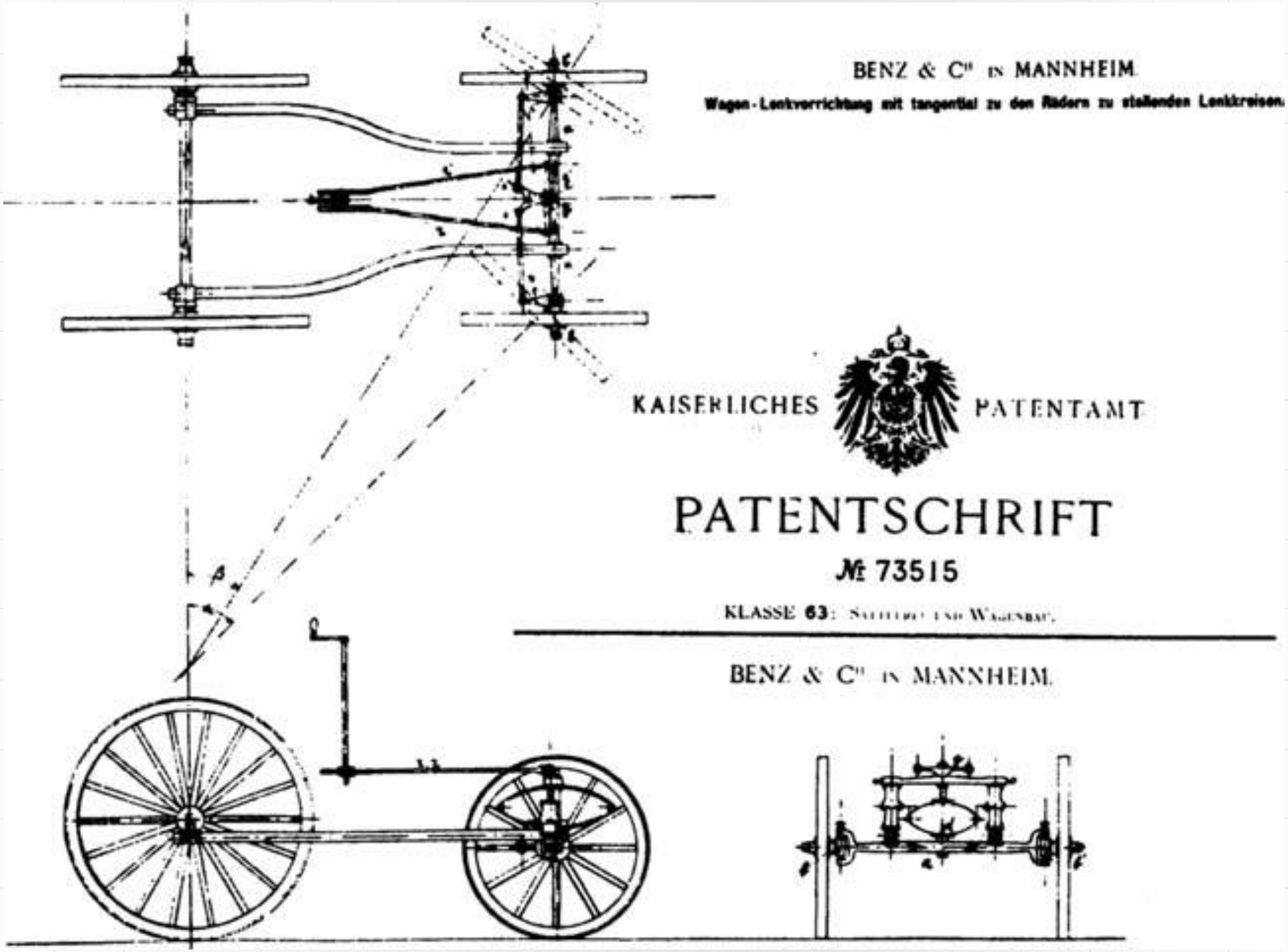


Ackermann steering effect achieved by two cams on L’Obeissante, designed by Amedee Bollee in 1873.



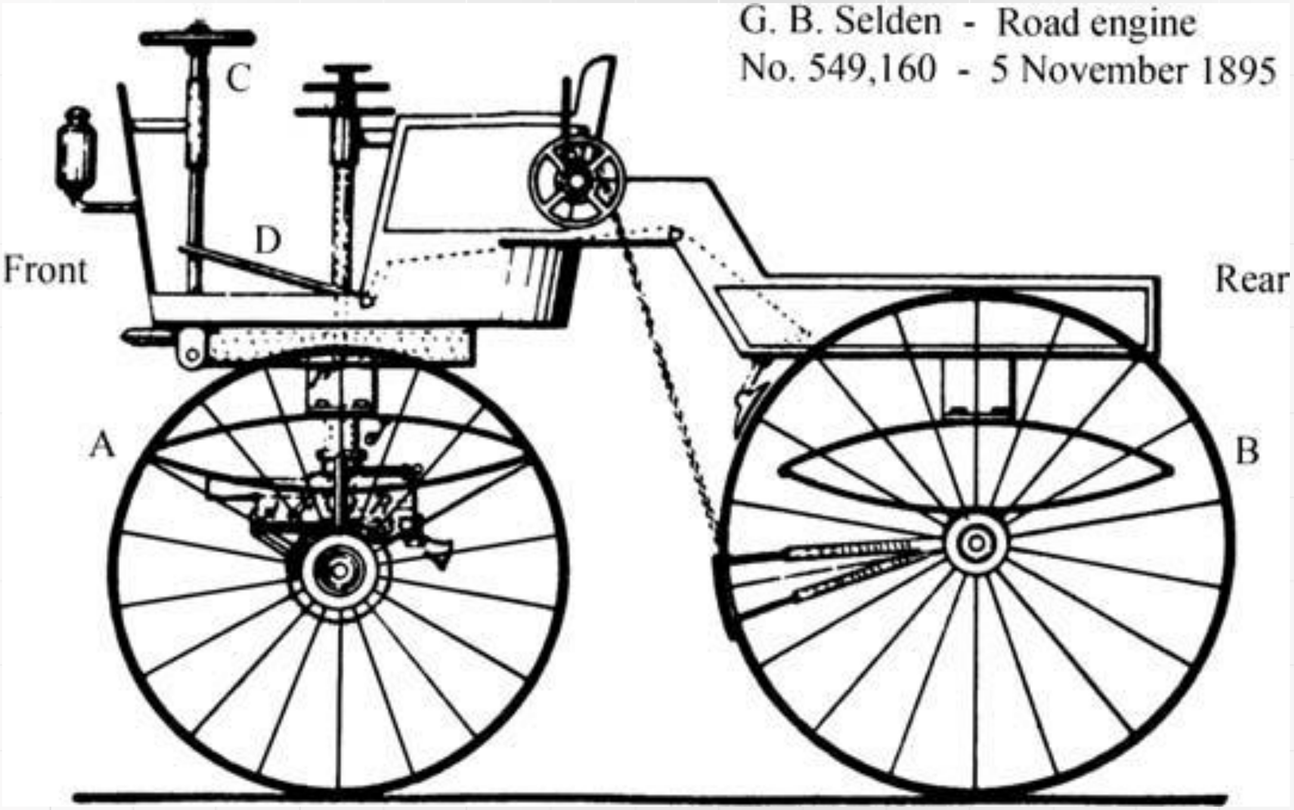
Ackermann steering effect achieved with parallel steering arms, by using angled drive points at the inner end of the track rods: ‘La Mancelle’, 1878.

Suspension systems



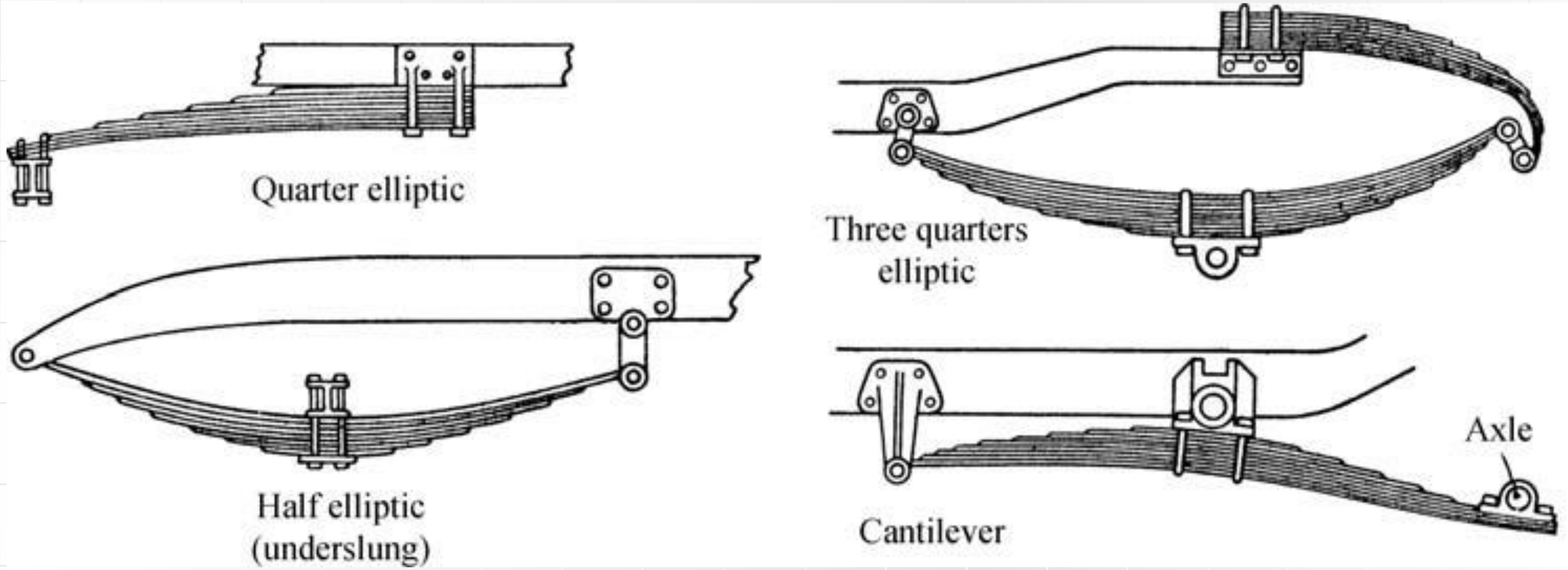
Suspension systems
leaf spring

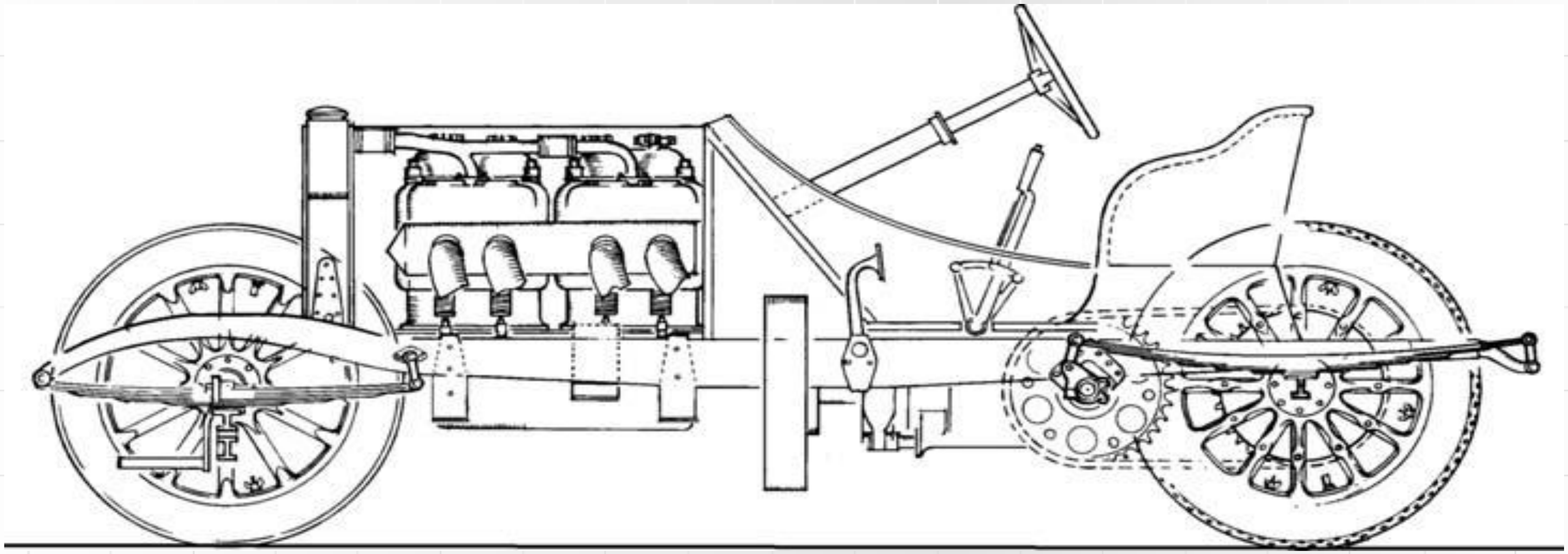
- To increase the compliance, a pair of leaf springs were mounted back-to-back
- They were curved, and so then known, imprecisely, as elliptical springs, or elliptics for short
- Single ones were called semi-elliptics



Suspension systems

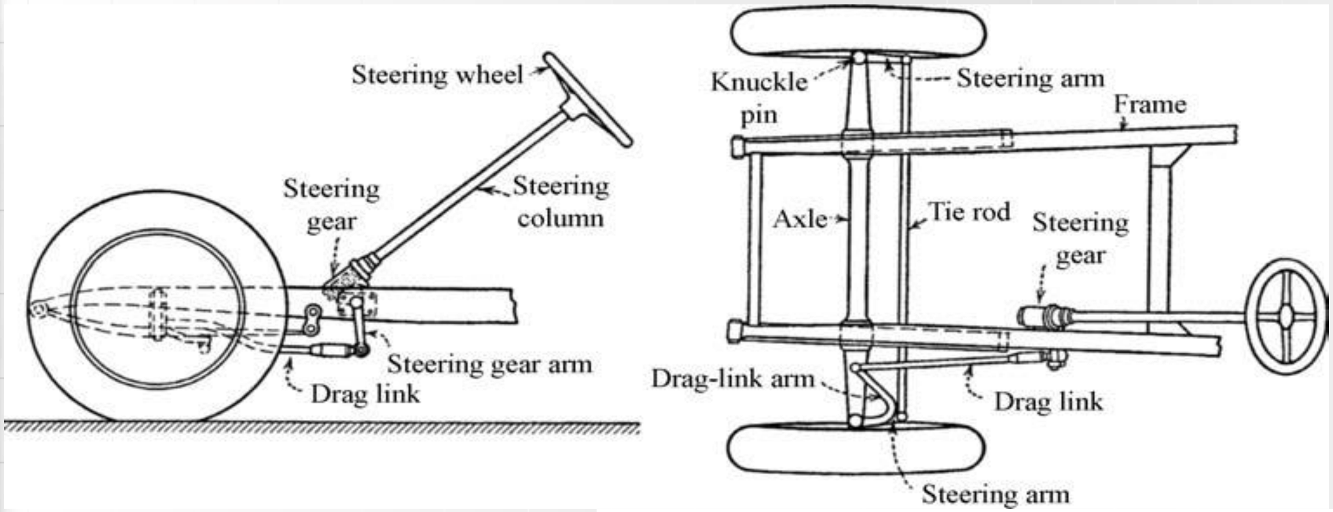
leaf spring

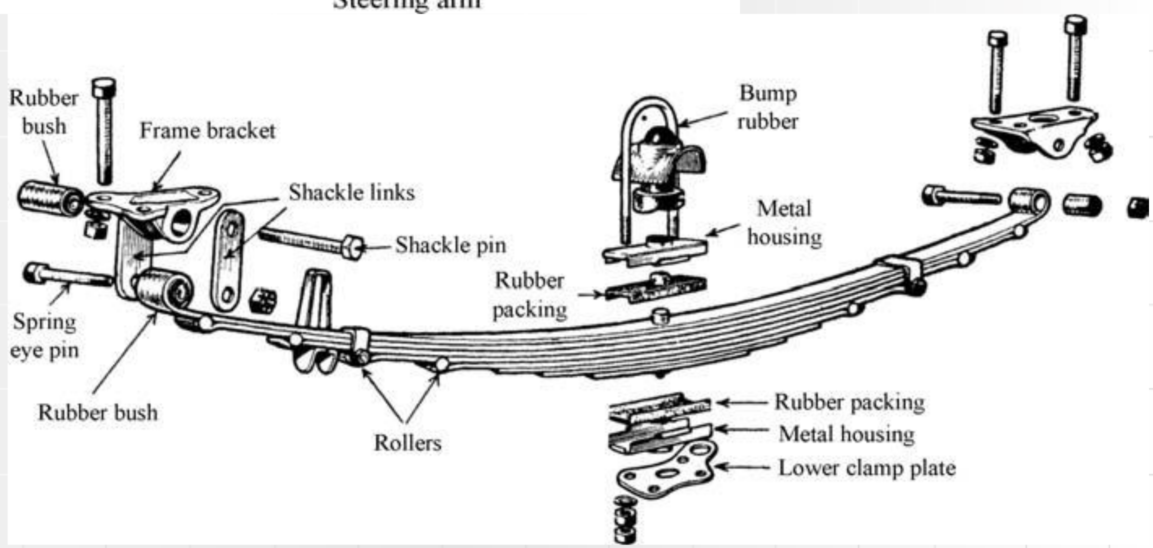




Suspension systems
leaf spring – **Front vs rear axle**

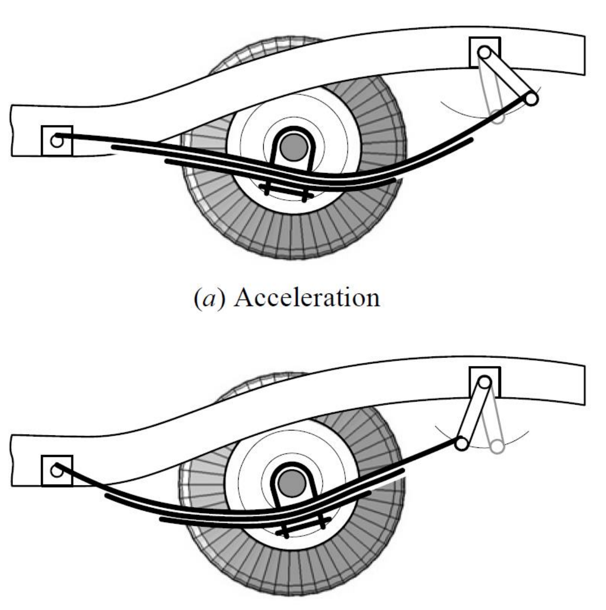
At the front, the leaf spring was much less satisfactory, because of the steering geometry difficulties (*bump steer, roll steer, brake wind-up steering effects, and shimmy vibration problems*)





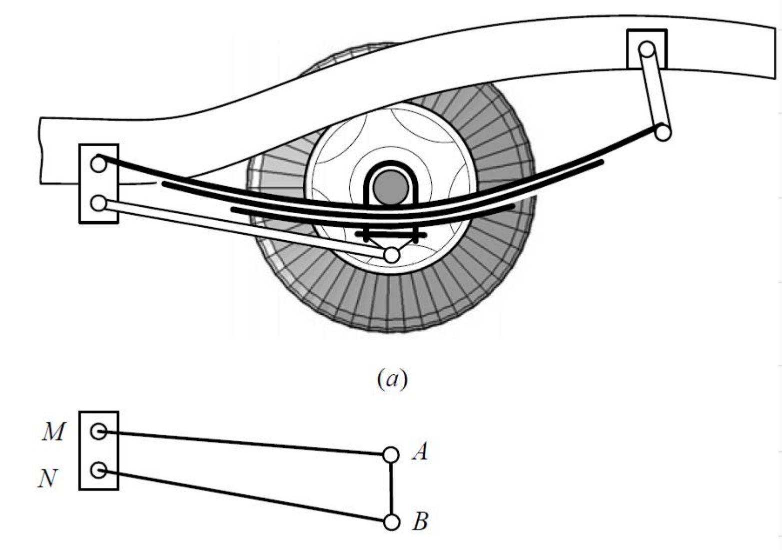
Suspension systems
leaf spring ***– Front vs rear axle***

Steering geometry was a major problem because of the variability of rigid axle movements



(*a*) Acceleration

(*b*) Braking

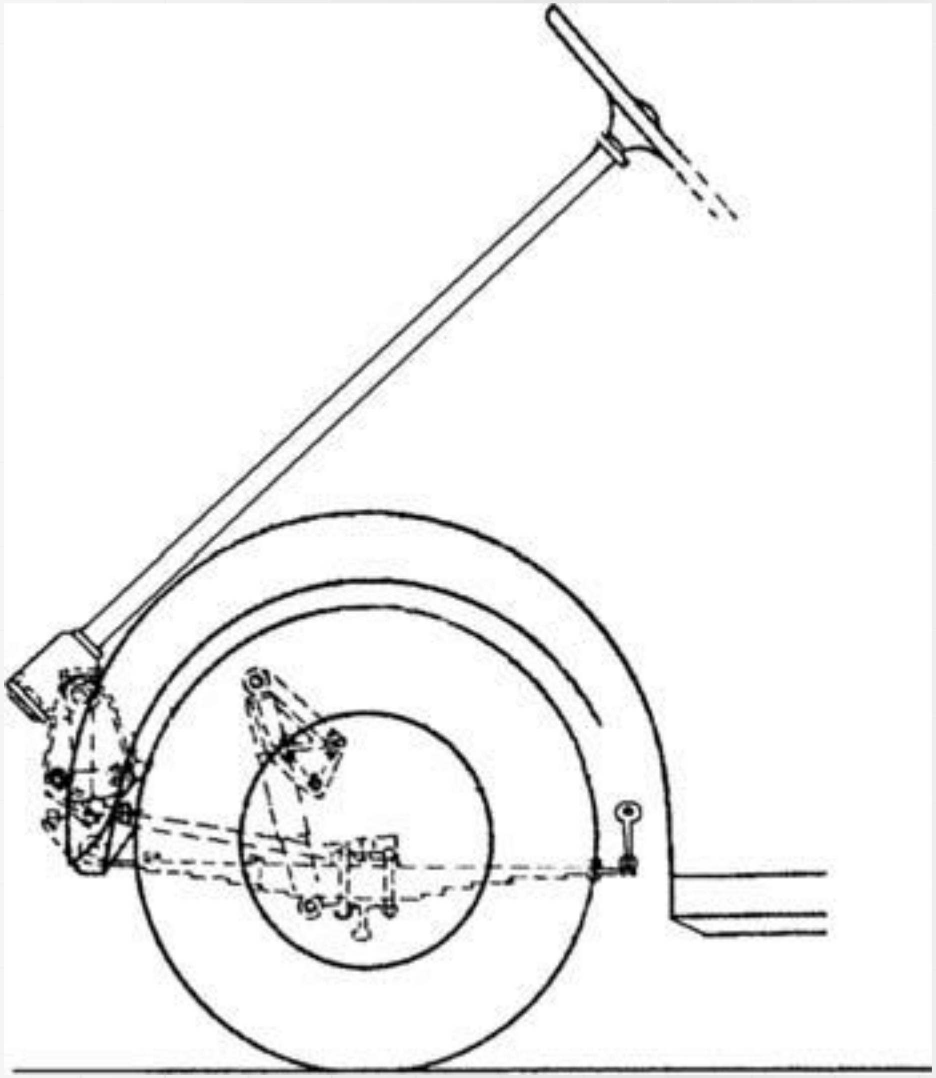


(*a*)

(*b*)

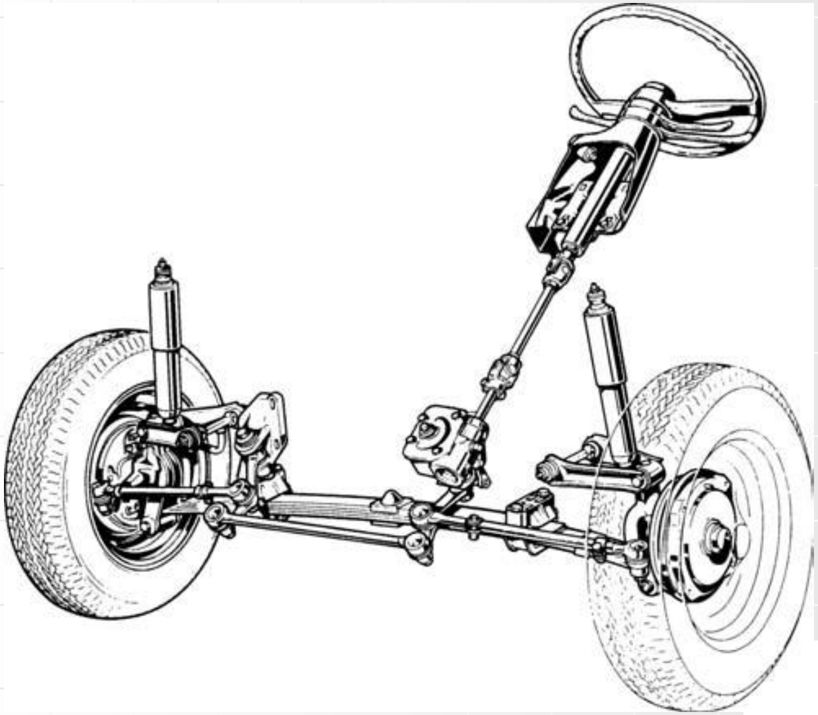
Suspension systems

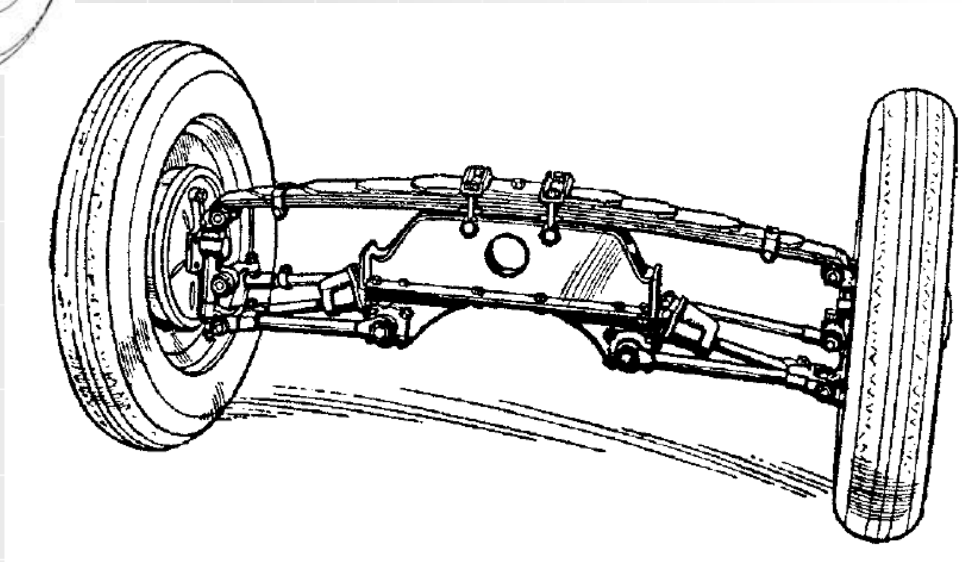
leaf spring – **Front vs rear axle**



Suspension systems

Transverse Leaf Springs

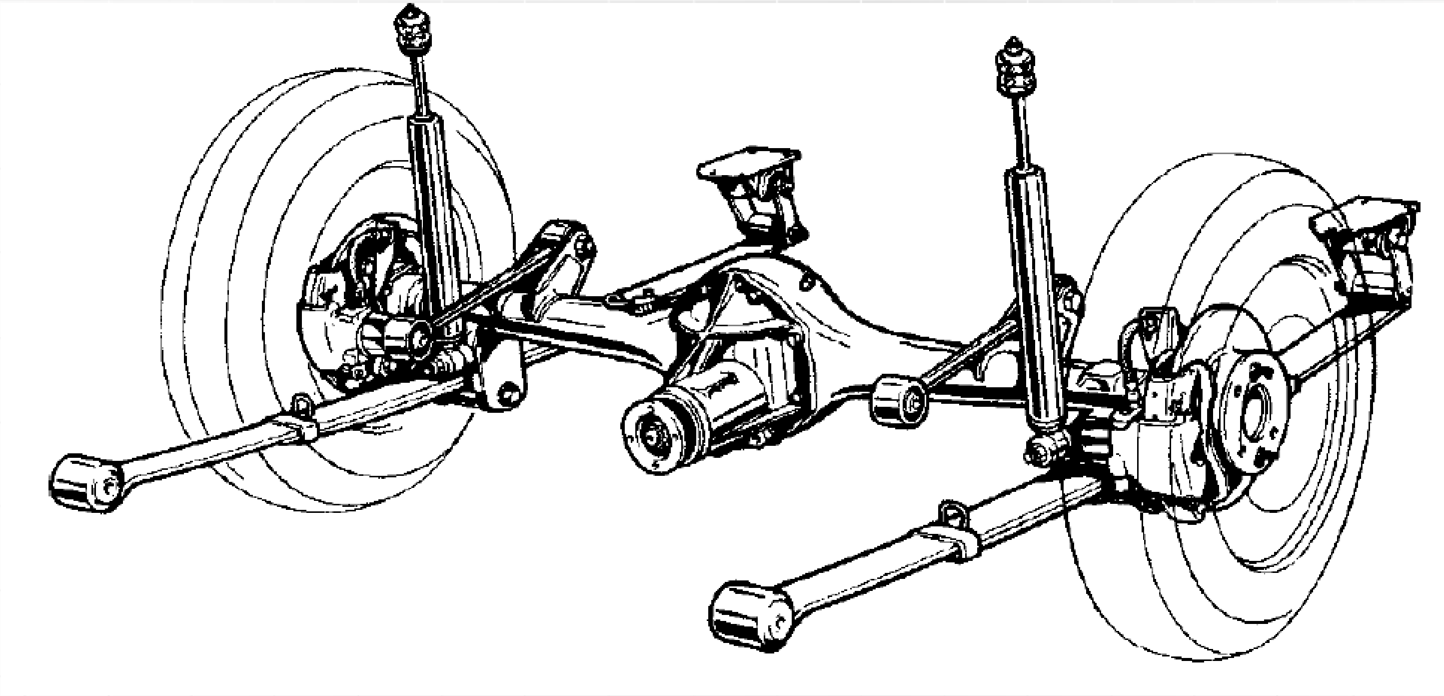




Dependent suspension

Solid-axle

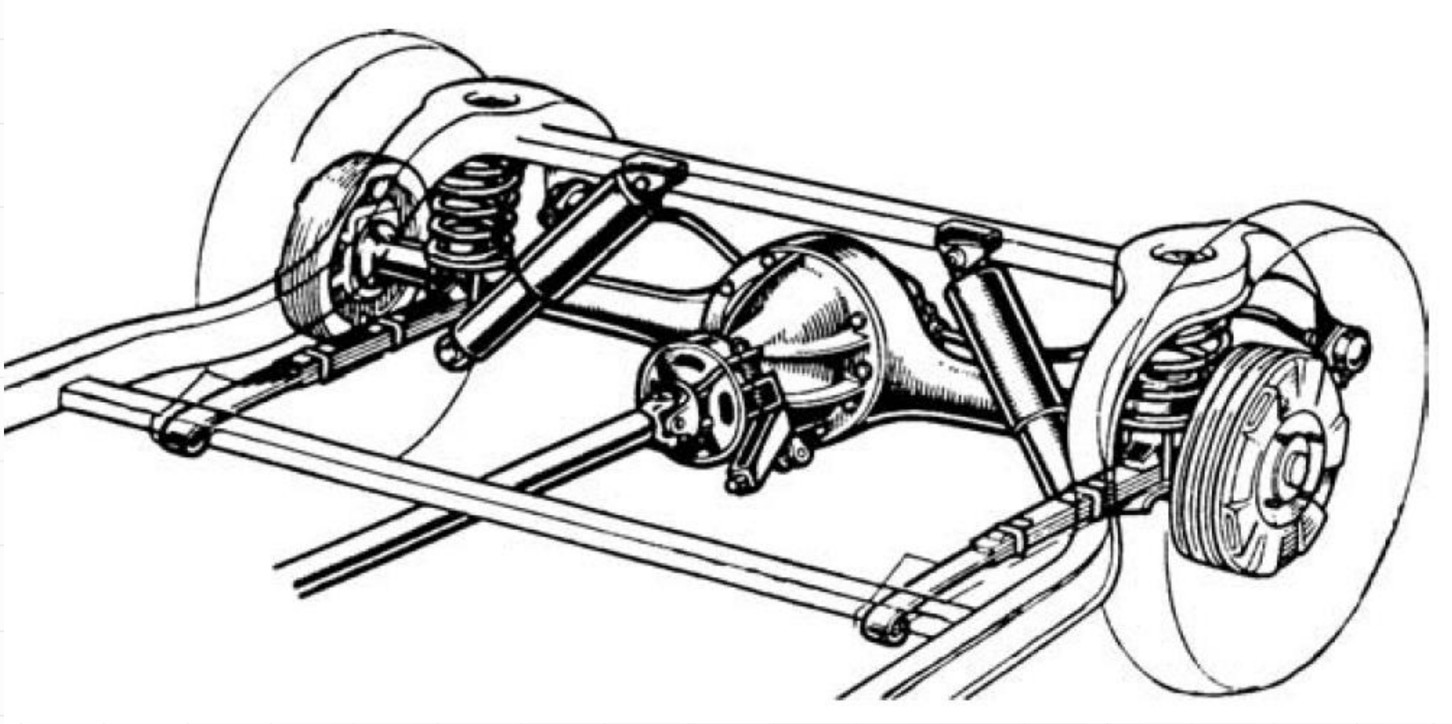
- In other cases, there have been problems, such as axle tramp, particularly when high tractive force is used. To locate the axle more precisely, or more firmly, sometimes additional links are used, such as the longitudinal traction bars above the axle, opposing pitch rotation



Dependent suspension

Solid-axle

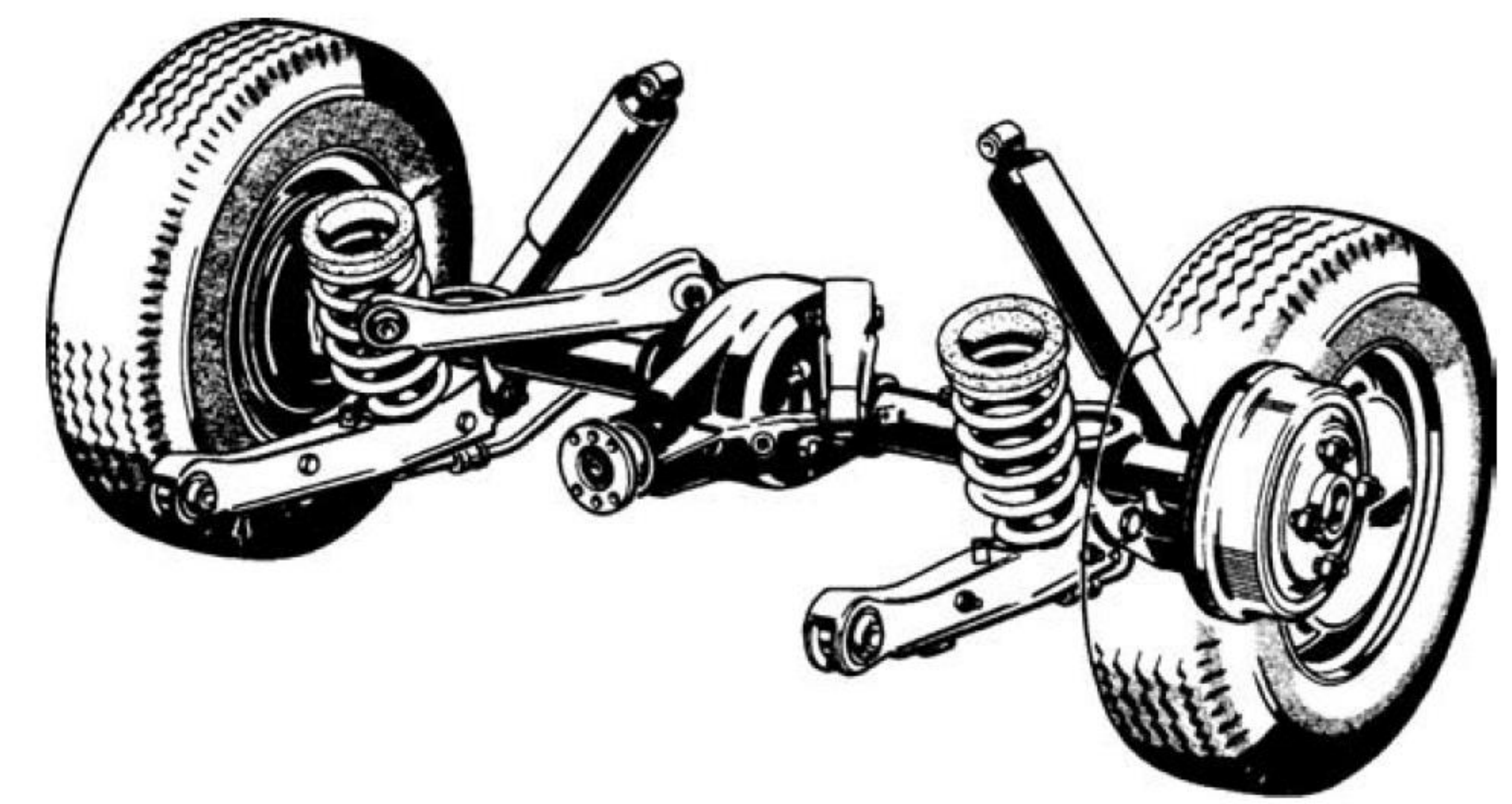
- In other cases, the leaf springs have been retained as the sole locating members but with the springing action assisted by coils, giving good load spreading into the body.



Dependent suspension

Solid-axle

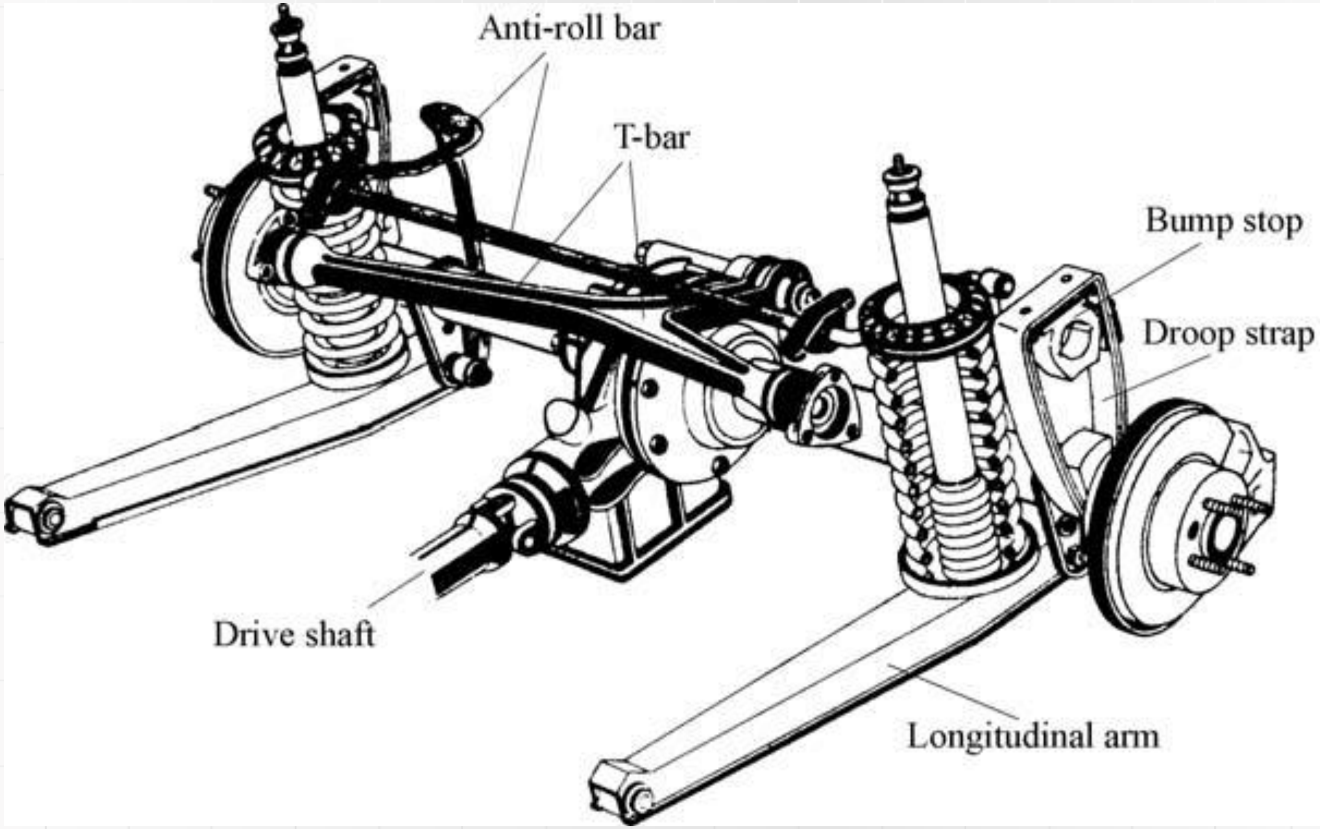
- In response to the shortcomings of leaf spring suspensions, **the four-link rear suspension**
- The lower control arms provide longitudinal control of the axle while the upper arms absorb braking/driving torques and lateral forces.



Dependent suspension

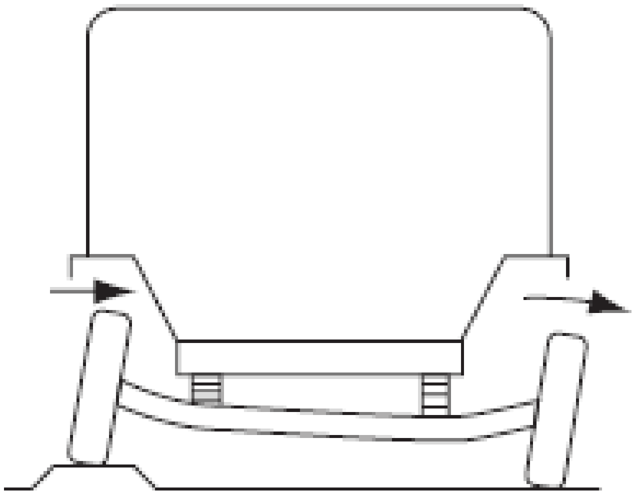
Solid-axle

- The basic geometry of the four-link system is retained in the T-bar system with the cross-arm of the T located between longitudinal ribs on the body, allowing pivoting with the tail of the T, connected to the axle, able to move up and down in an arc in side view.

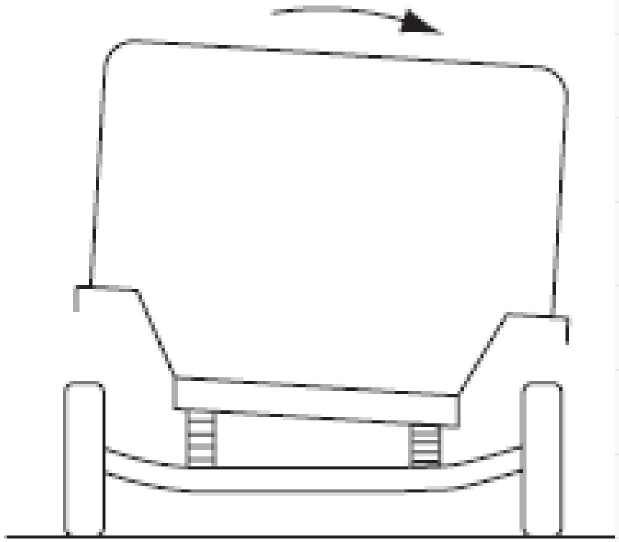


Dependent front suspension

Front axle



Both wheels tilt when either passes over an obstacle

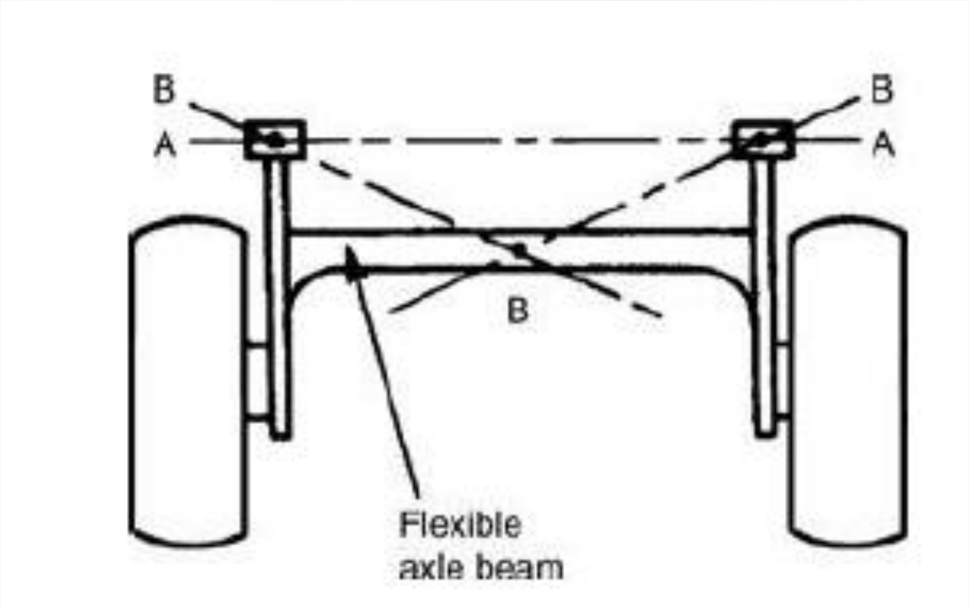


Both wheels remain upright during body roll

Dependent front suspension

Rear axle

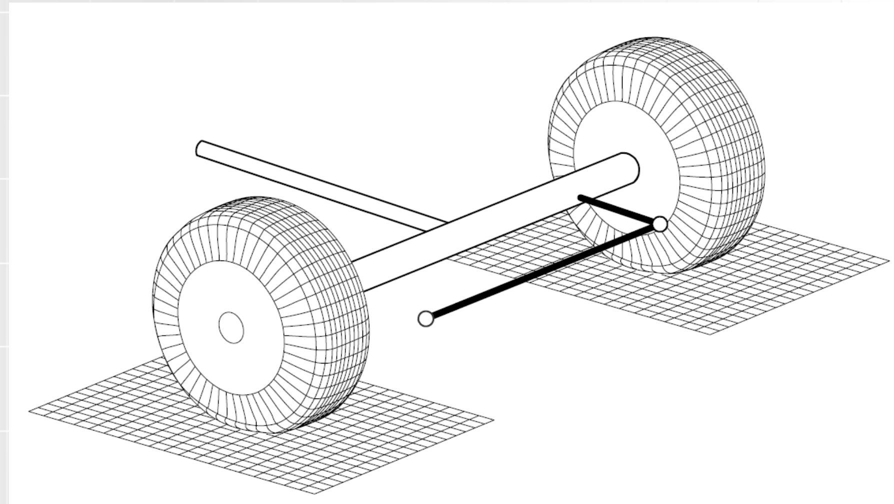
- Each wheel is mounted on a trailing arm that pivots from rubber bushes carried by the b structure,
- both arms are connected together by a flexible axle beam that lies between the axes of pivot bushes and wheel bearings.
- The axle beam is made flexible in torsion and stiff in bending, such that on the one hand allows the trailing arms and wheels to move up and down almost independently of each other, while on the other hand it prevents the wheels from tilting to the same extent as they were attached directly to the ends of the axle beam.
- both wheels can move in unison about a purely trailing axis A–A while a single wheel ca move about a semi-trailing axis B–B.

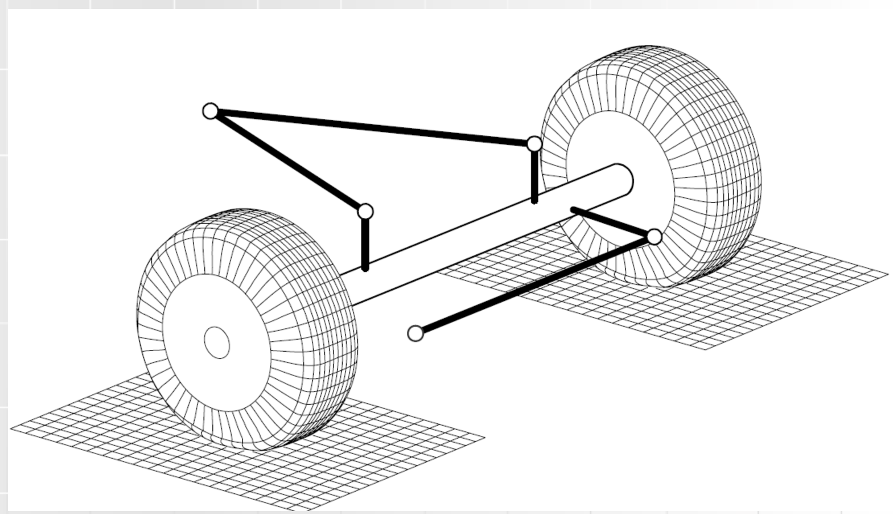


Dependent front suspension

Panhard arm

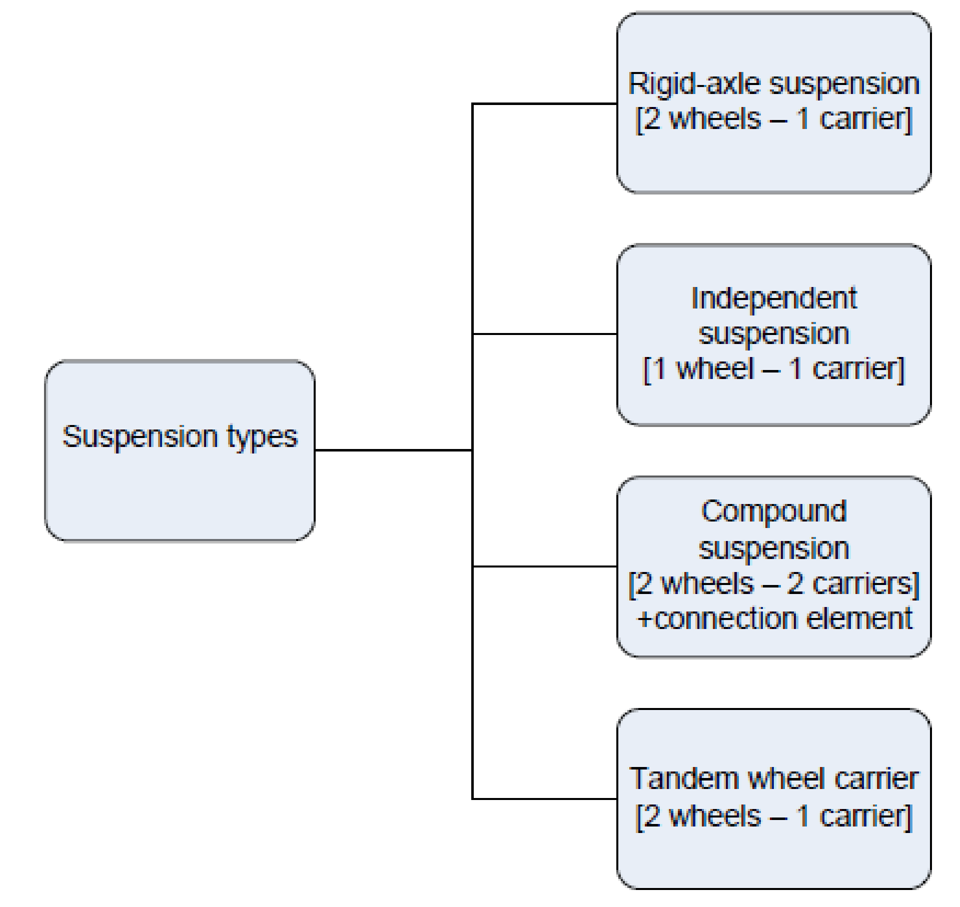
A Panhard arm is a bar that attaches a solid axle suspension to the chassis laterally

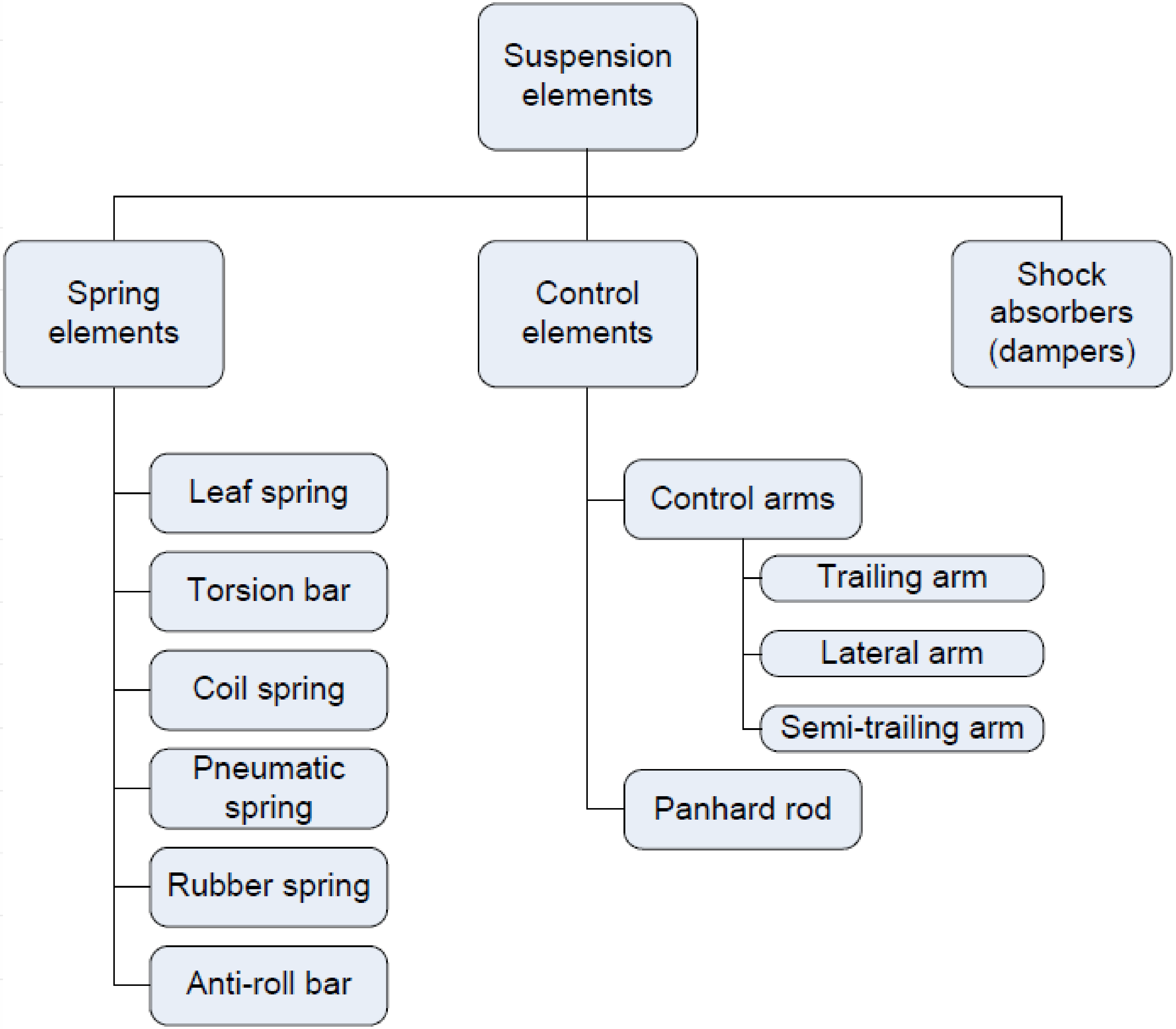




Types of suspension system

- Each spatial body with six degrees of freedom can be constrained with suitable elements like rod links – to reduce the number of DoF
- A suspension system should provide one degree of freedom for the wheel. This can be dor in different ways for example by adding 5 rod link – each of which would "fix" one degree c freedom.
- In real suspension systems links constrain wheel carriers – which can be "carry" one or mor wheels.




Suspension elements
Spring elements
Control elements
Shock absorbers (dampers)
Leaf spring
Torsion bar
Coil spring
Pneumatic spring
Rubber spring
Anti-roll bar
Control arms
Trailing arm
Lateral arm
Semi-trailing arm
Panhard rod

Types of suspension system

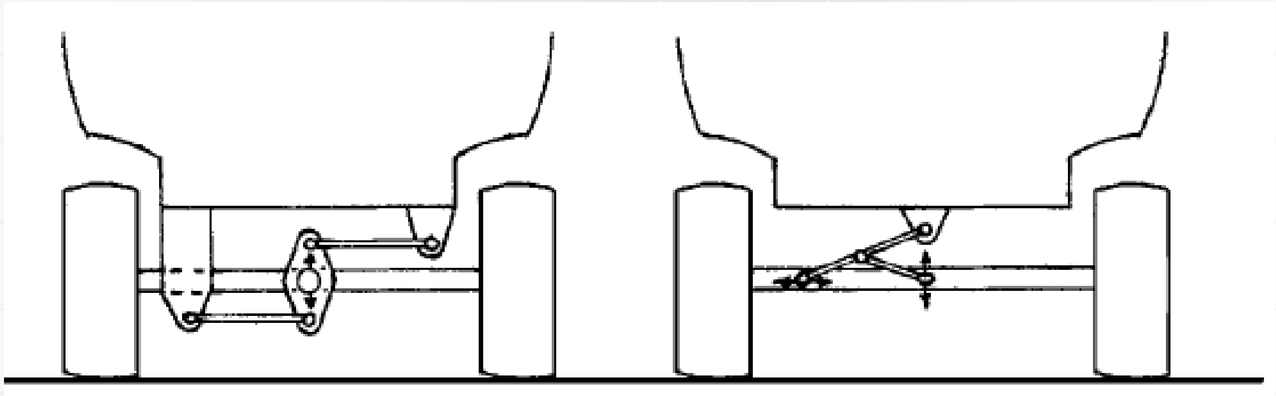
Factors which primarily affect the choice of suspension type at the front or rear of a vehicle are **engine location** and whether the wheels are **driven/undriven** and /or **steered /unsteered.** In general, suspensions can be broadly classified as dependent or independent types.

- **Dependant suspension system** (rigid). Both wheels are mounted to jointed, rigid axle which is fixed with frame or body by means of spring elements.
- **Independant suspension system**. Each wheel is fixed to the body (or frame) individually.

Dependent front suspension

Rear axle

- The elements which control the motion of a rigid rear axle must allow translation in the vertical direction as well as rotation about the vehicle's longitudinal axis.
- To enable these motions, the axle must be connected to the vehicle's body with at least one ball joint and one link element.
- Lateral forces are transmitted between the axle and the vehicle's body by a Panhard rod or one of the other types of linkages.
- The motion of a Panhard rod causes the vehicle's body to shift laterally during compression and rebound
- This lateral motion can be eliminated by using a Watt's linkage for lateral control.



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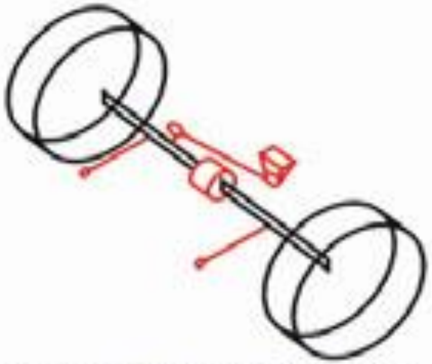
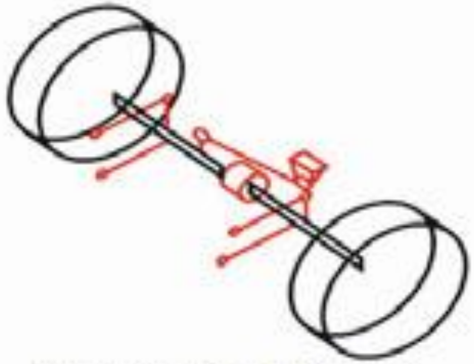
Dependent front suspension

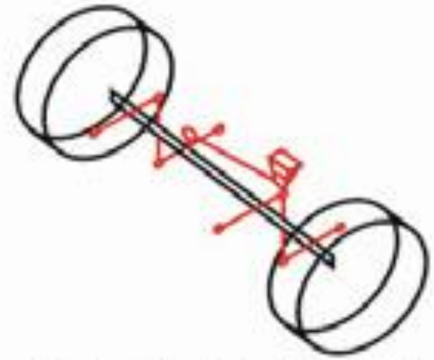
Rear axle



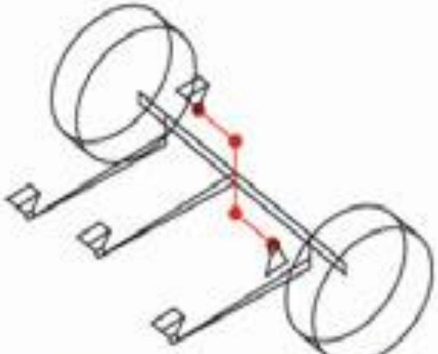
2 longitudinal links & Panhard rod



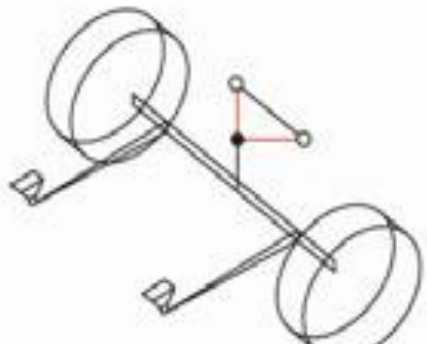
4 longitudinal links & Panhard rod



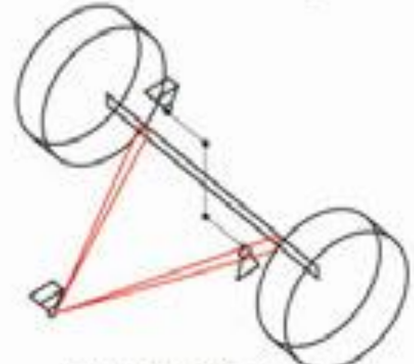
4 longitudinal links & Watt's linkage



3 longitudinal links & Watt's linkage



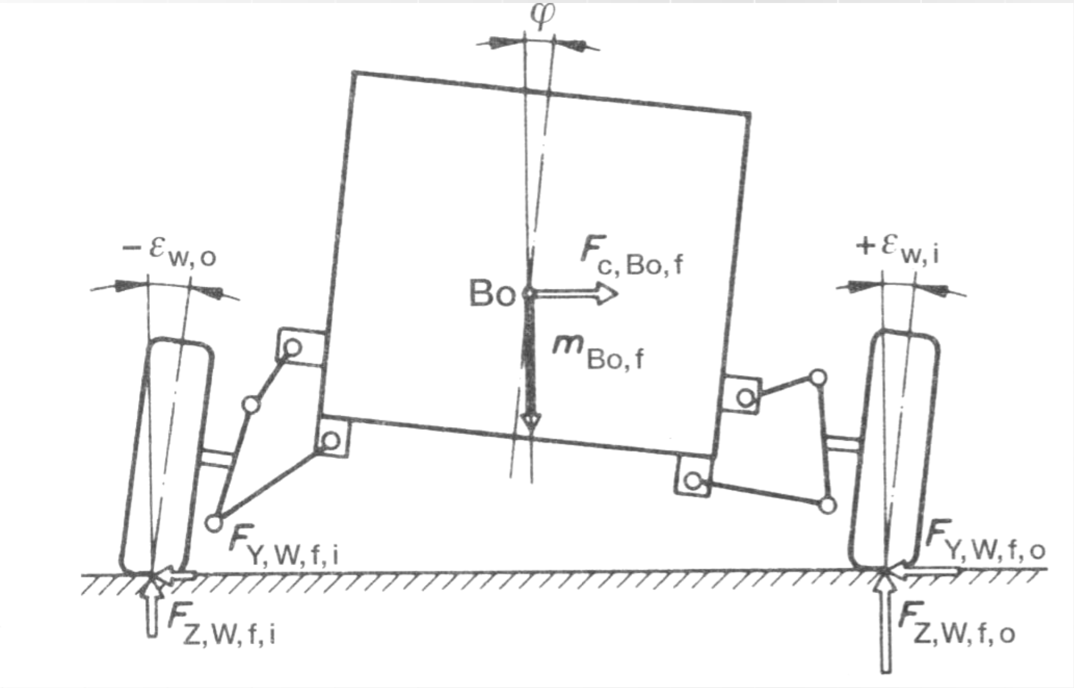
2 longitudinal links & triangular link



Parabolic axle & Watt's linkage

Independent Suspension

Every independent suspension system consists of a kinematic linkage (a collection of articulating jointsand rigid elements) which connects the vehicle’s body (the main element) to the wheel carrier (the coupling element) using intermediate links

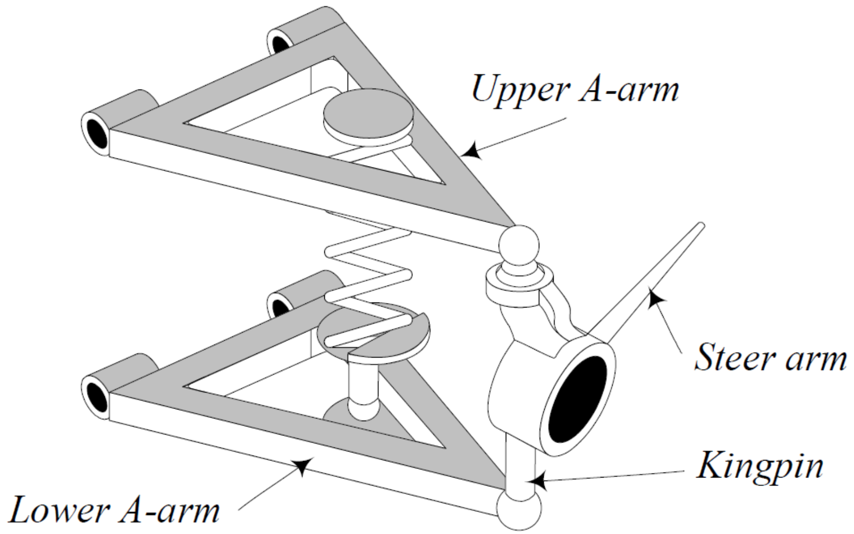


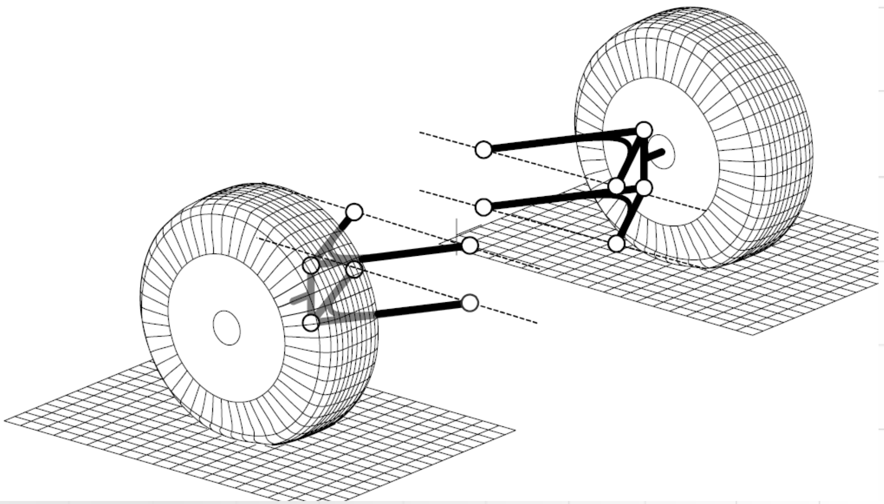
Independent Suspension

Double A-arm, double wishbone, or short/long arm

the lower or the upper arm, which supports the spring, is made stronger and the other arm acts as a connecting arm.

Kinematically, a double A-arm suspension mechanism is a four-bar linkage with the chassis as the ground link, and coupler as the wheel carrying link.





Independent Suspension

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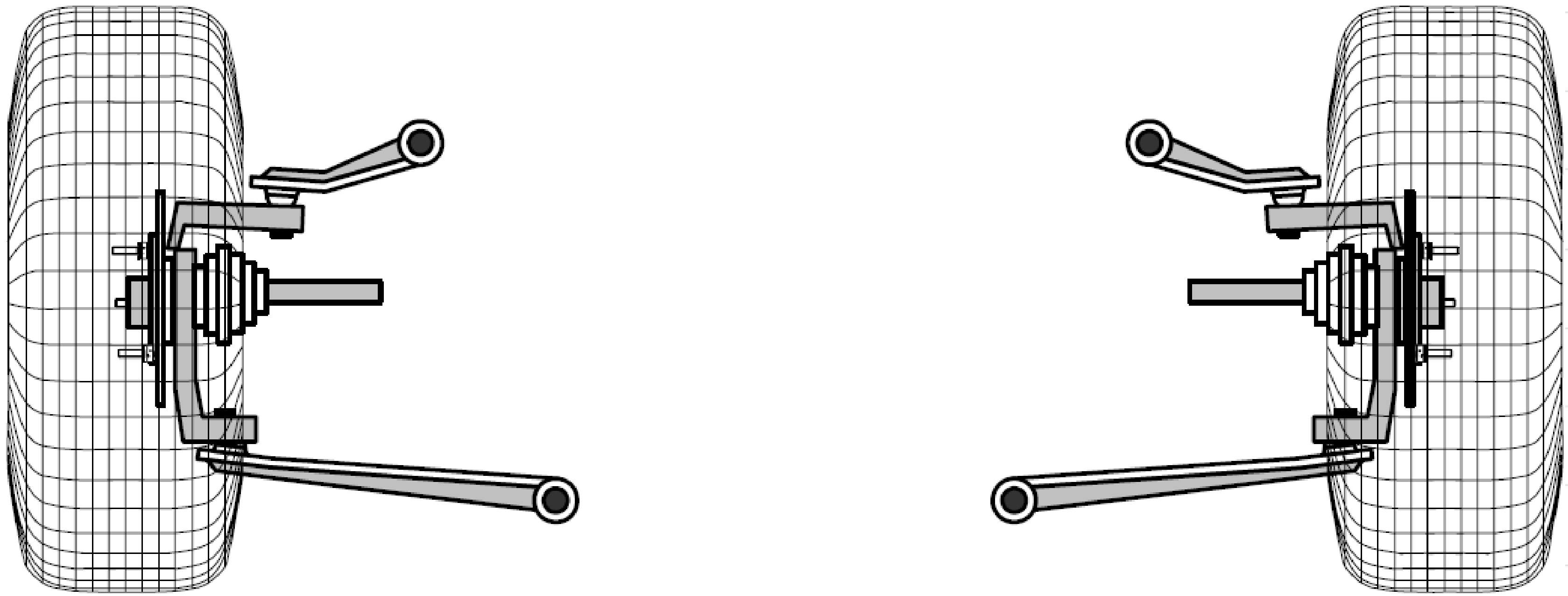
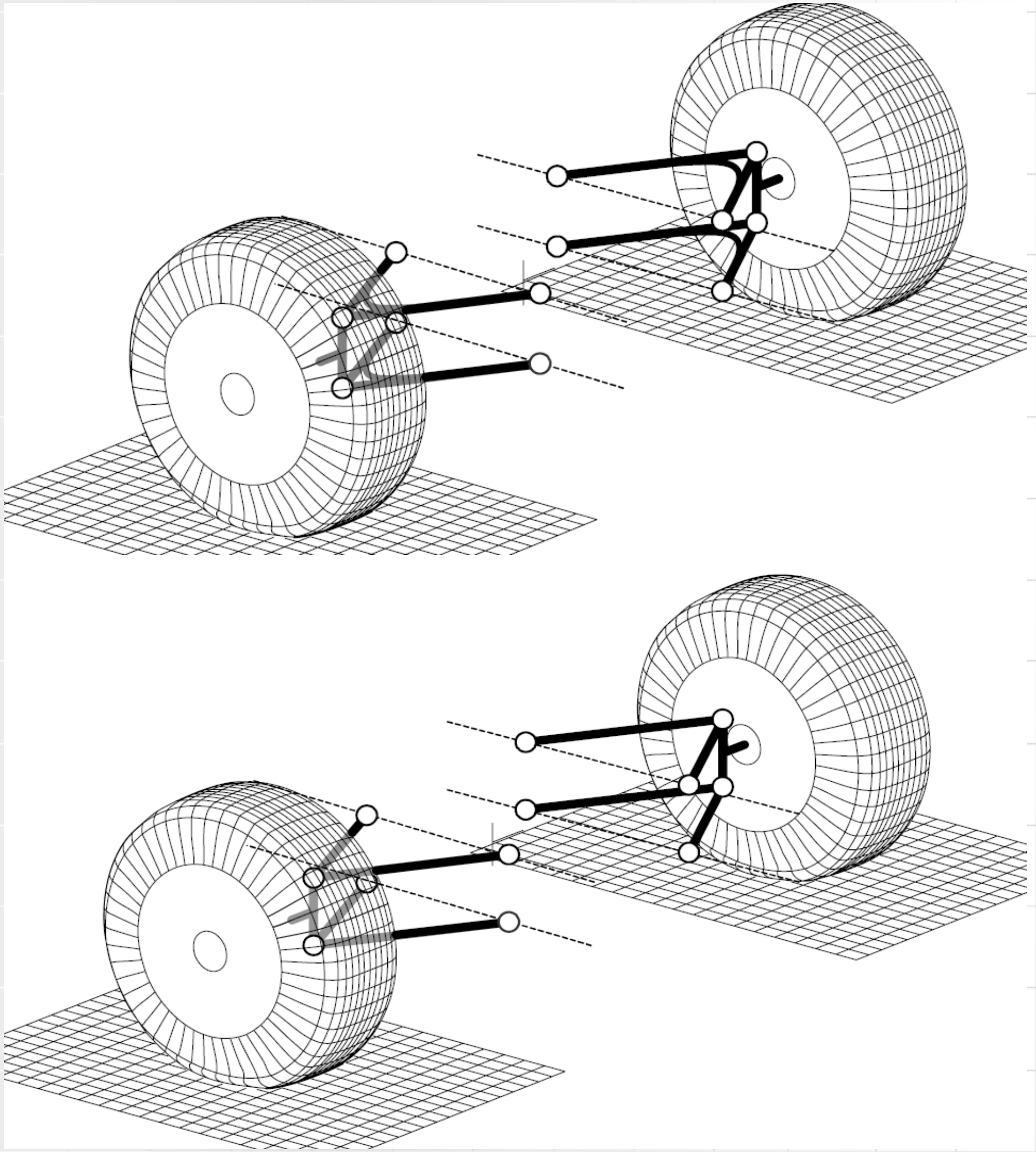


Independent Suspension

Multi-link suspension mechanism

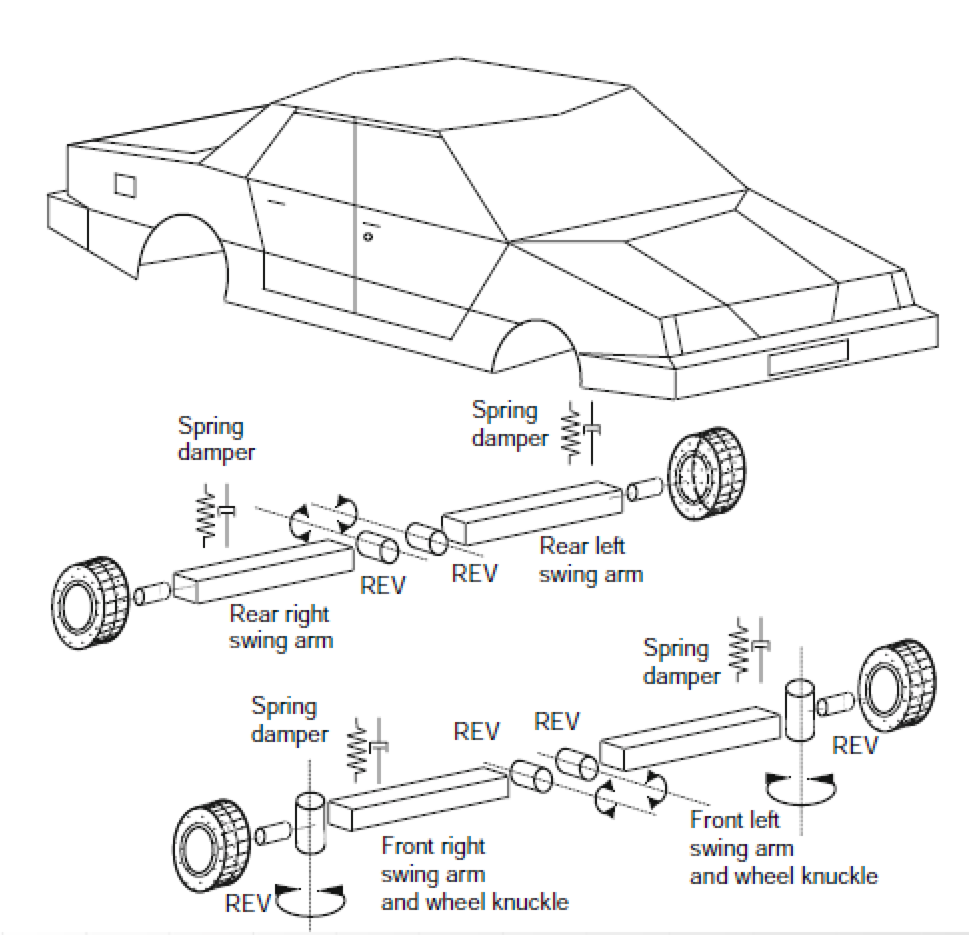
When the two side bars of an A-arm are attached to each other with a joint then the double A-arm is called a **multi-link mechanism**

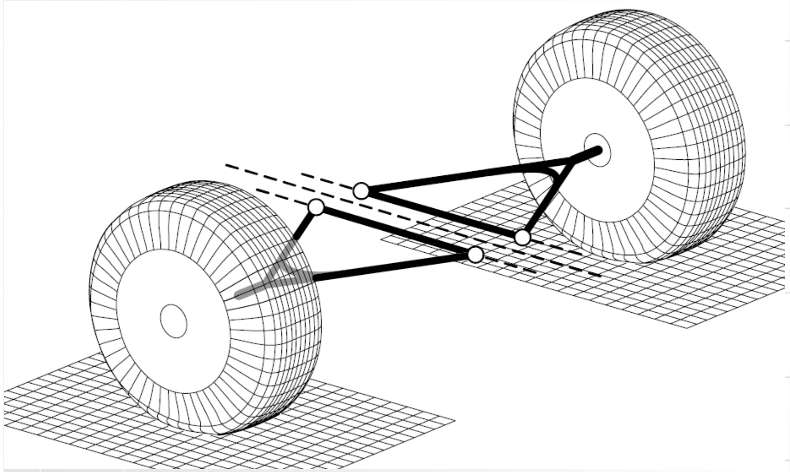


Multi-link mechanism is a six-bar mechanism that may have a better coupler motion than a double A-arm mechanism

Independent Suspension

Swing arm suspension



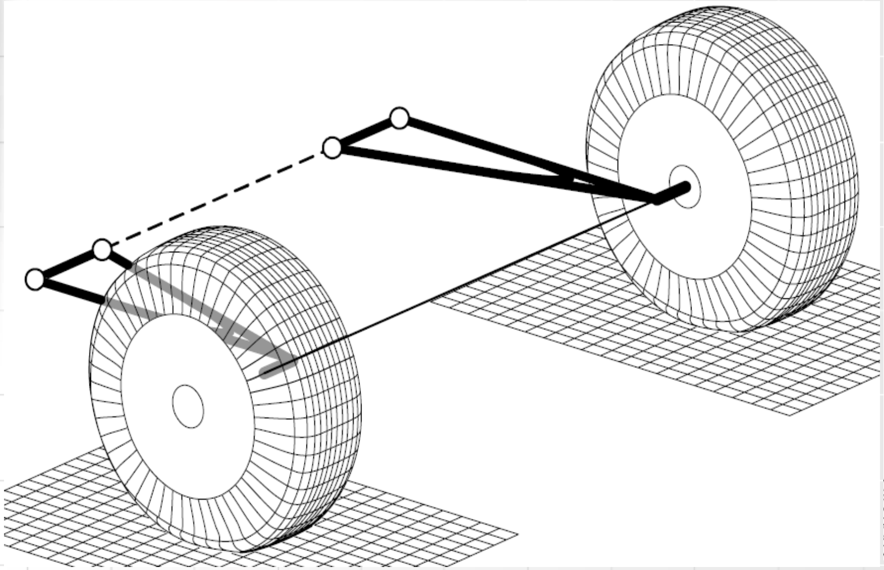


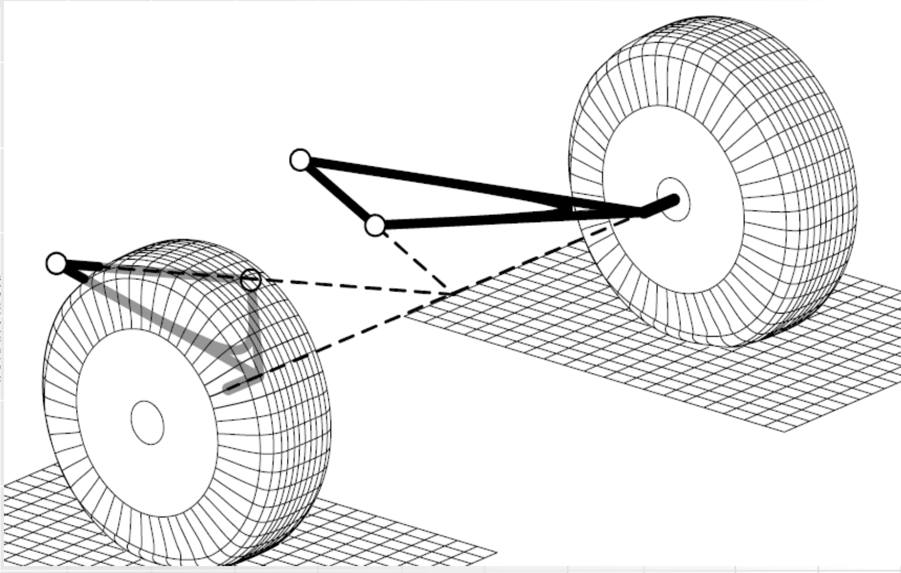
Independent Suspension

Trailing arm suspension and Semi-trailing arm

- The camber angle of the wheel, supported by a trailing arm, will not change during the up and down motion.
- Trailing arm suspension has been successfully using in a variety of front wheel-drive vehicles, to suspend their rear wheels.

- Semi-trailing arm suspension, is a compromise between the swing arm and trailing arm suspensions.
- Such suspensions have acceptable camber angle change, while they can handle both, the lateral and longitudinal forces

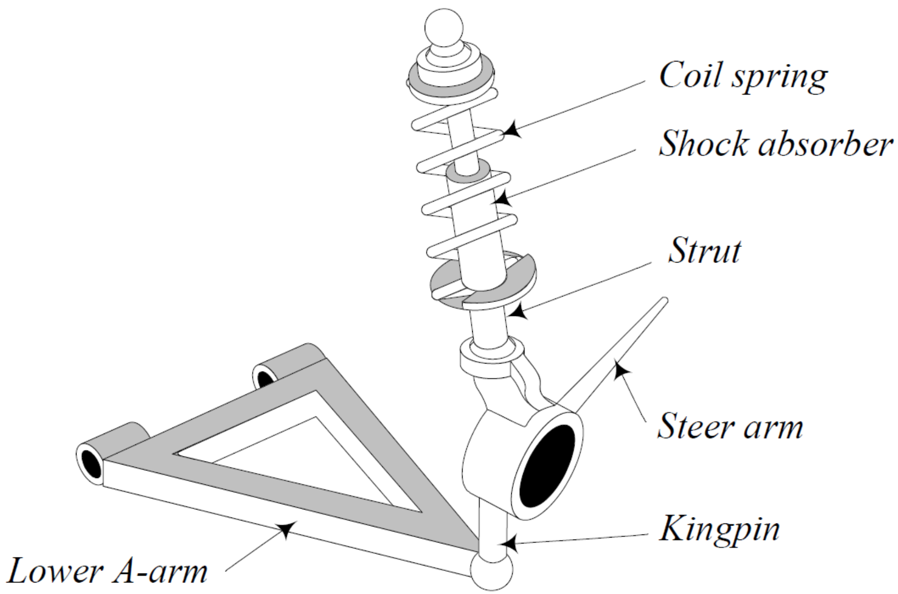


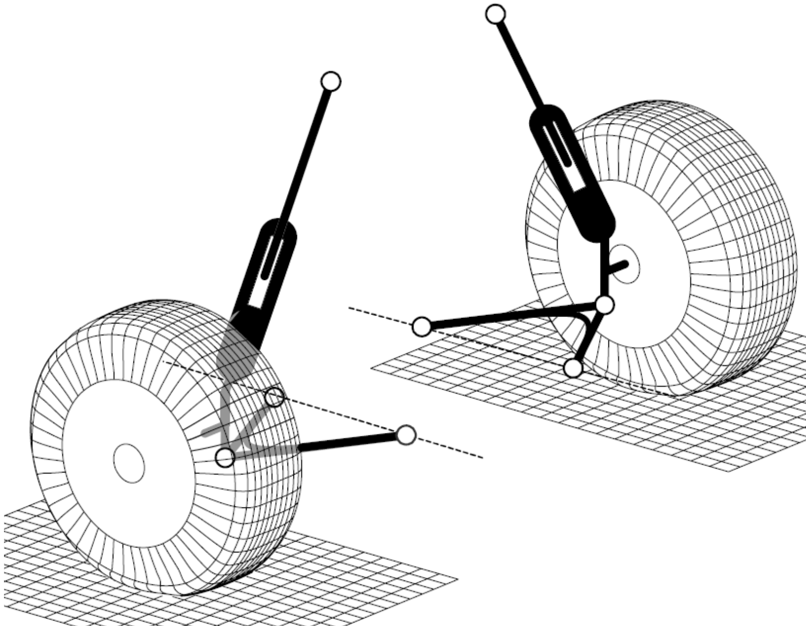


Independent Suspension

McPherson

A McPherson suspension is an inverted slider mechanism that has the chassis as the ground link and the coupler as the wheel carrying link

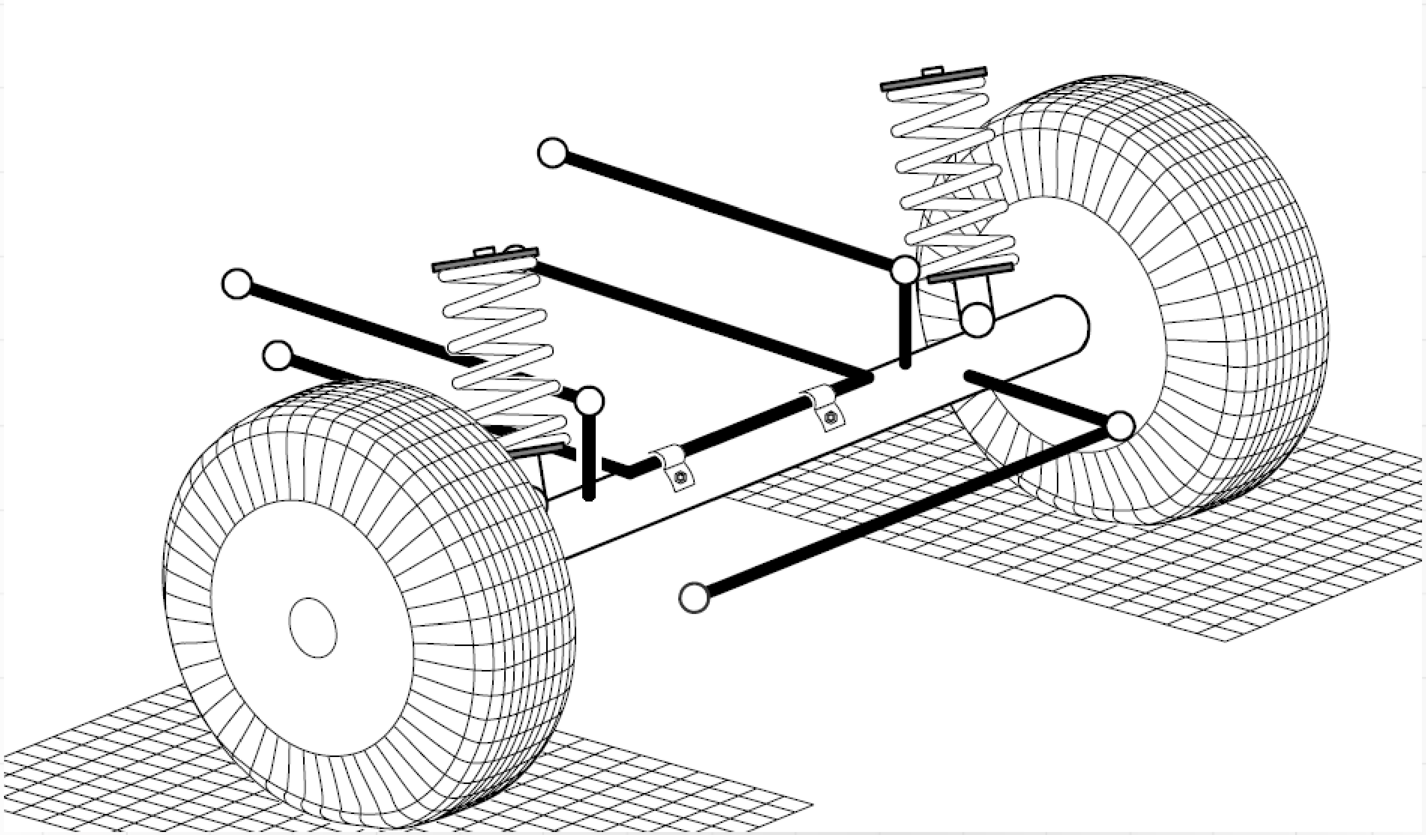




Coil springs

Antiroll bar

- Coil springs are used in vehicles because they are less stiff with better ride comfort compared to leaf springs
- Therefore, the roll stiffness of the vehicle with coil springs is usually less than in vehicles with leaf springs
- To increase the roll stiffness of such suspensions, an antiroll bar must be used



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Some manufactures describes suspension systems by their own definition, which only sometimes correctly defines the original designs, nevertheless it is common that typical systems are only different by its name.

- **Double wishbone** (Honda Accord, Jaguar S Type) independent suspension with double lateral arm; this solution has sport origin
- **Delta Link** (Volvo), **Multilink** (Mercedes) both are names of multi-arm suspension system where the only difference is various number and configuration of the control arms.
- **Scott-Russell rod** (Nissan Primera) - a kind of sectional lateral arm with two internal joints, that cooperates with torsion axle which connects the trailing arms; this system is similar to historical suspension of rigid axle laterally fixed by means of Watt rod.

Roll Centres

1. **the geometric roll centre (GRC);**
    - The GRC is a property of the suspension geometry, a point found by specified geometric method
2. **the kinematic roll centre (KRC);**
    - The KRC is the point about which the body rolls relative to the axle. This then controls the consequent lateral position of the sprung centre of mass, affecting th total load transfer
3. **the force roll centre (FRC);**
    - The FRC is a point at which the suspension links exert a lateral force on the sprung mass..
4. **the moment roll centre (MRC).**
    - *The MRC is the point about which moments are taken in dynamic analysis of the body. For a true dynamic analysis, the front and rearMRCs should generally be on the longitudinal principal axis of inertia*

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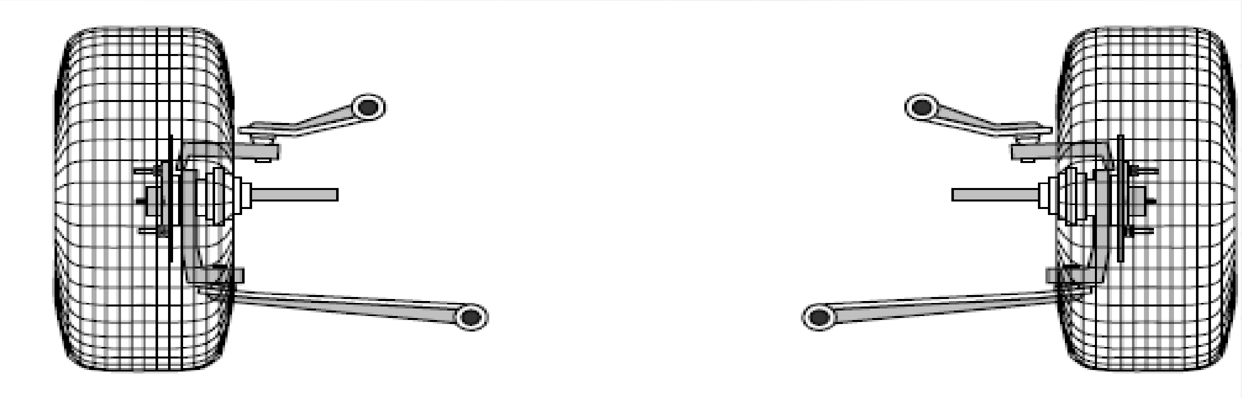
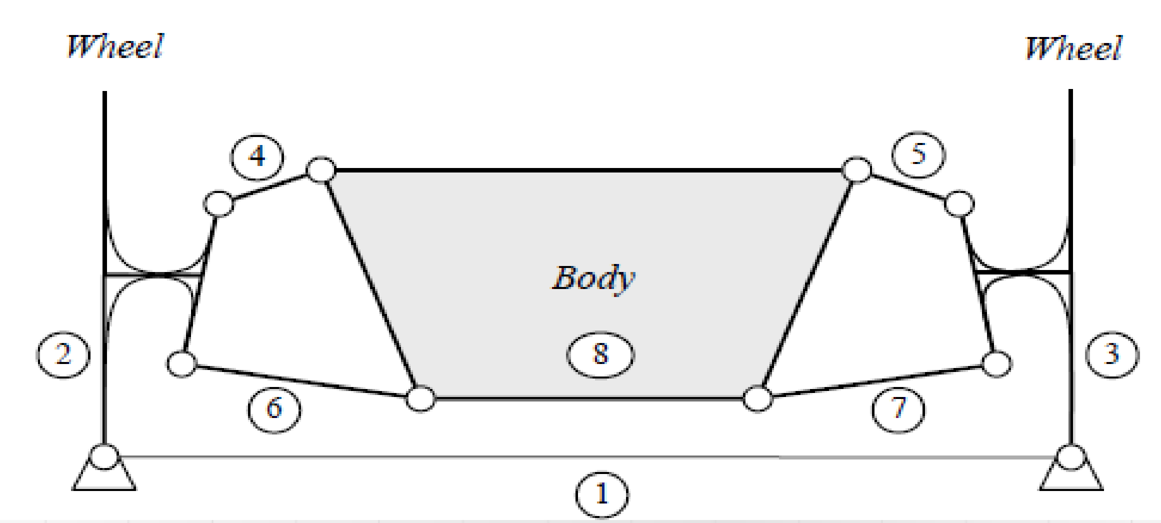
The Geometric Roll Centre

The geometric roll centre is a point in the transverse vertical plane of the suspension, being the intersection point of the two swing arm lines, one from each side



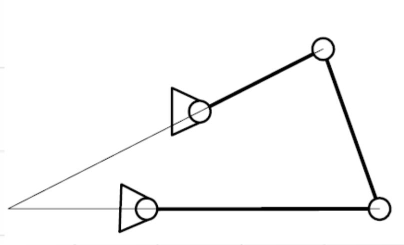


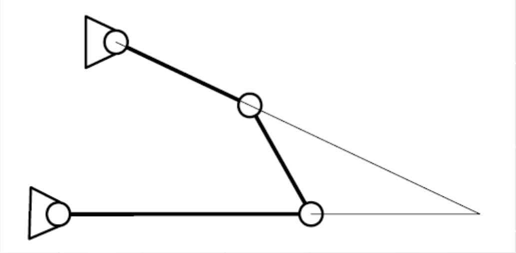
The Geometric Roll Centre

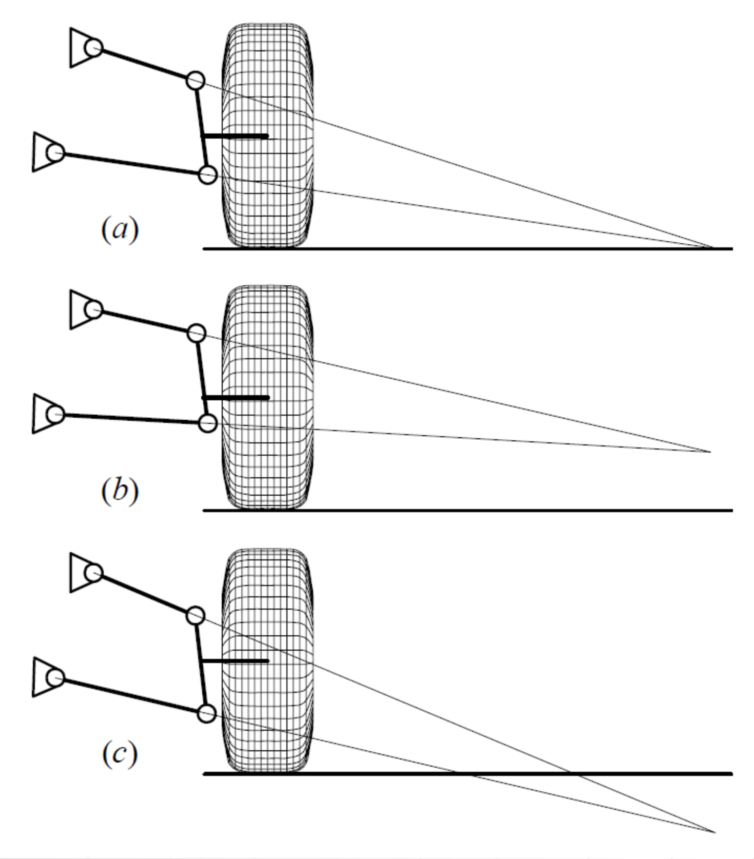
Suspension

The geometric roll centre is a point in the transverse vertical plane of the suspension, being the intersection point of the two swing arm lines, one from each side

- Roll center of an independent suspension can be internal or external.
- An internal suspension roll center is toward the vehicle body, while an external suspension roll center goes away from the vehicle body.
- A suspension roll center may be on, above, or below the road surface,





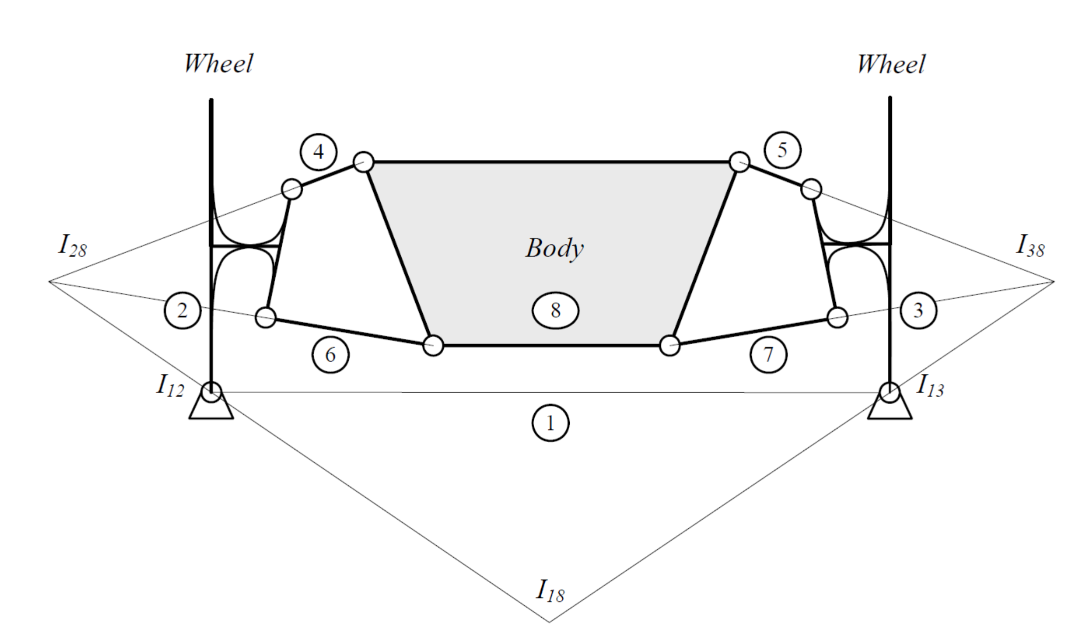


The Geometric Roll Centre

To find the roll center of the body with respect to the ground, we analyze the two-dimensional kinematically equivalent mechanism

1. The center of tireprint is the instant center of rotation of the wheel with respect to the ground, so the wheels are jointed links to the ground at their center of tireprints
2. The instant center I18 is the roll center of the body with respect to the ground
3. To find I18, we apply the Kennedy theorem and find the intersection of the line I12I28 and I13I38

The Kennedy theorem *states that the instant center of every three relatively moving objects are colinear*

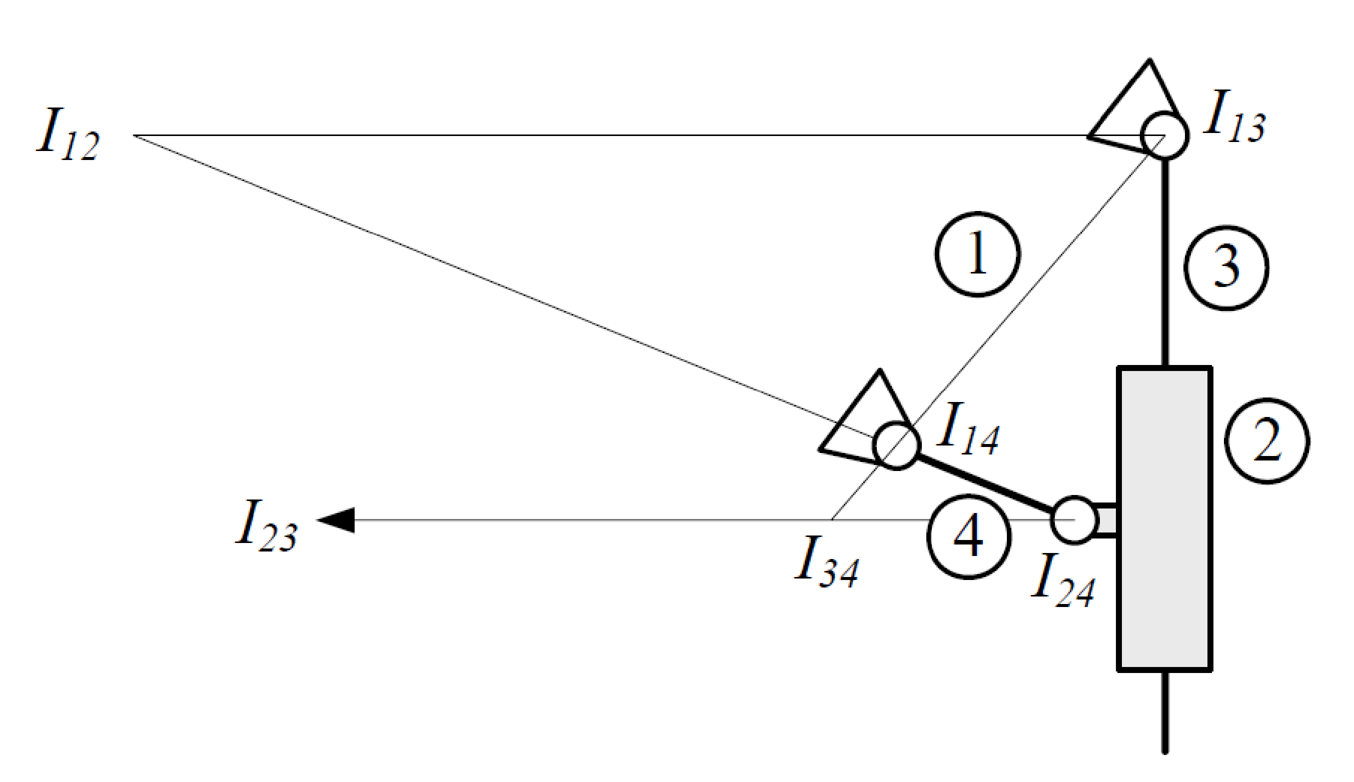


The Geometric Roll Centre

McPherson suspension roll center.

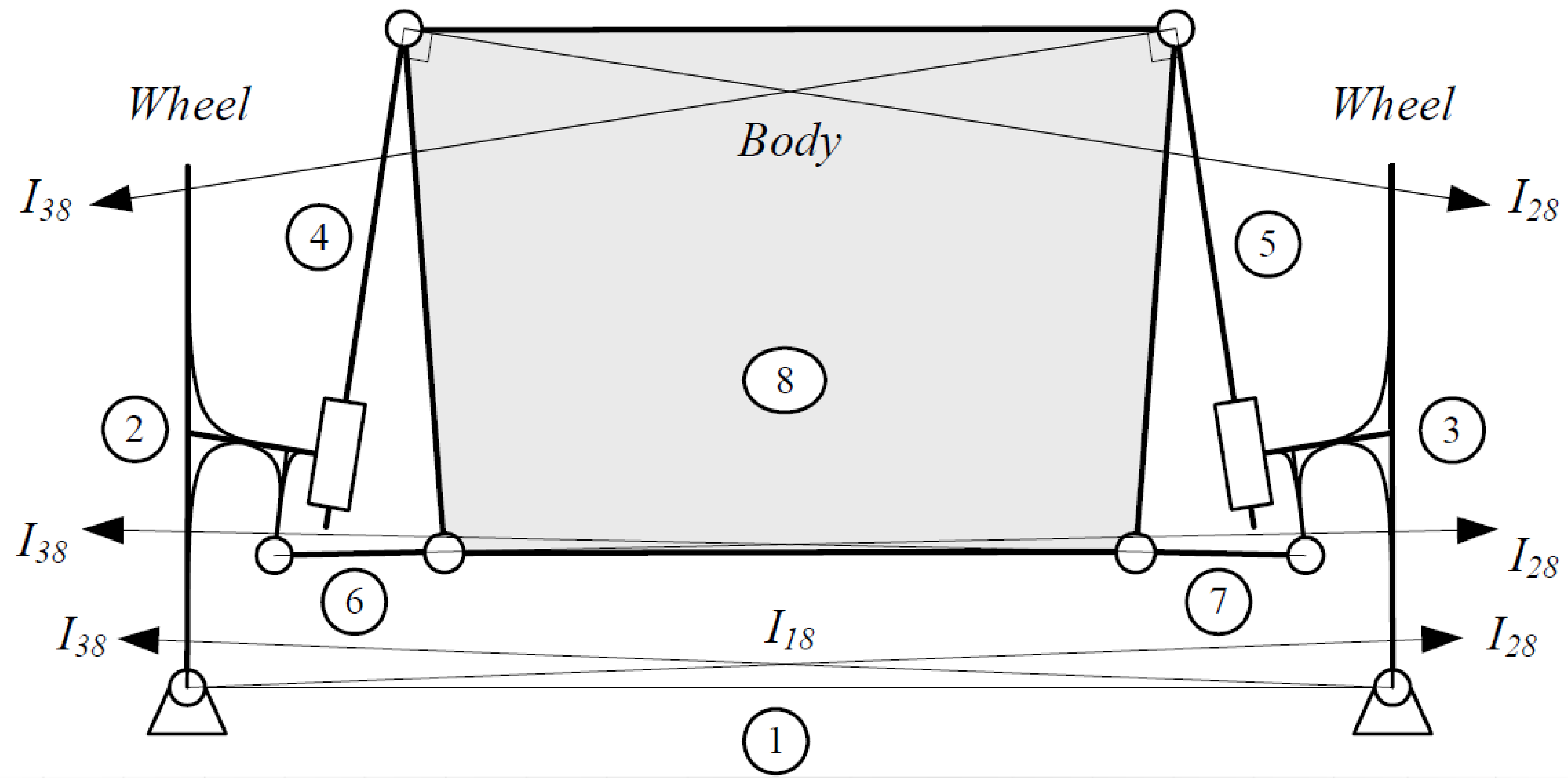
A McPherson suspension is an inverted slider crank mechanism

- the point I_{12} is the suspension roll center, which is the instant center of rotation for the wheel link number 2 with respect to the chassis link number 1.



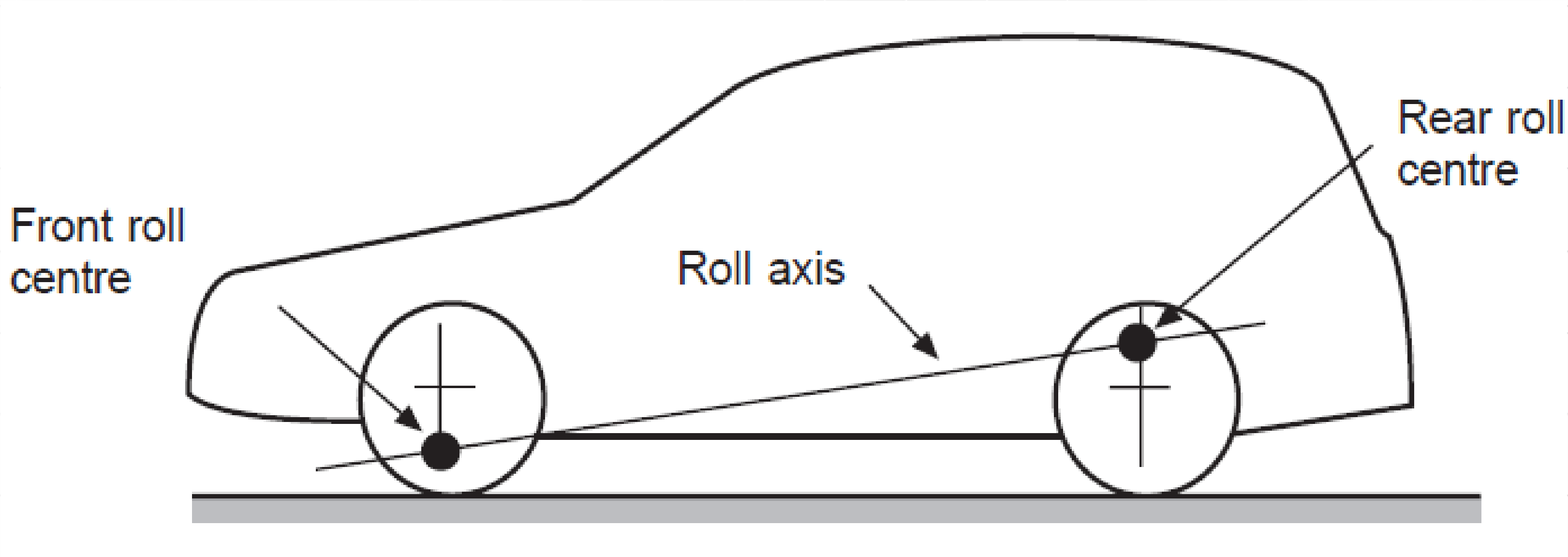
The Geometric Roll Centre

McPherson suspension roll center.



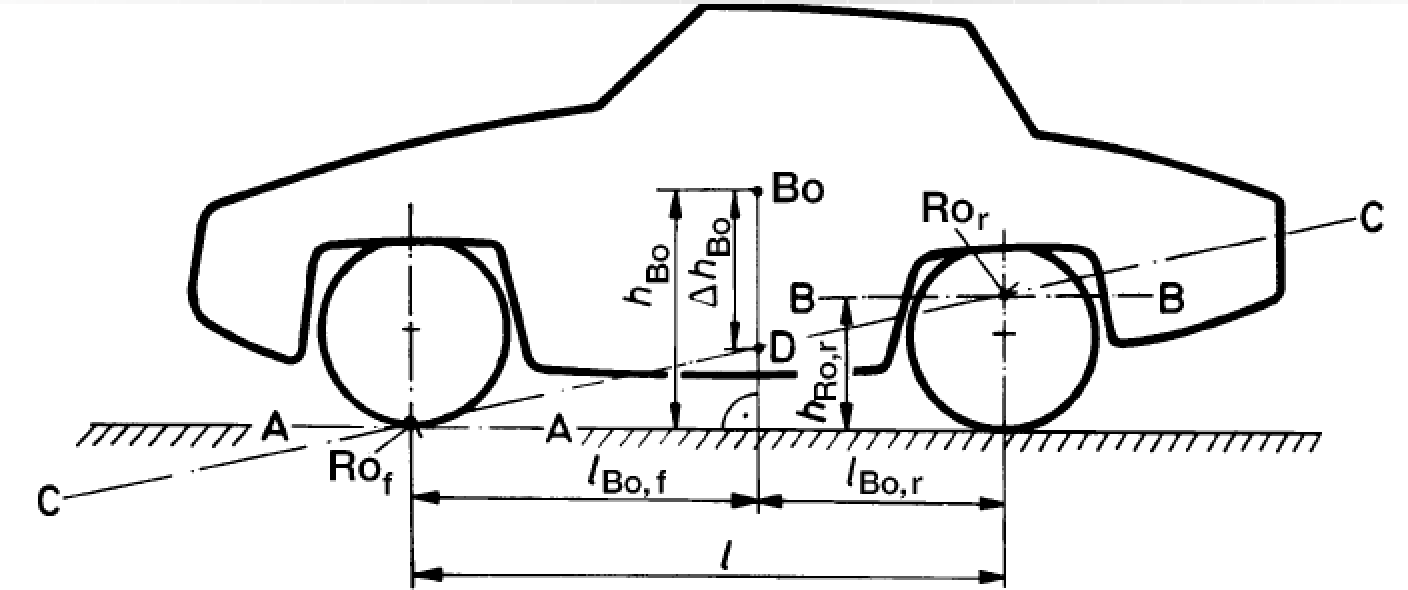
Roll axis

When a force acts on a car from the side, making the body tilt or roll, the motion will be about some line lying in the vertical plane containing the longitudinal axis of the car. This line is called the *roll axis*.



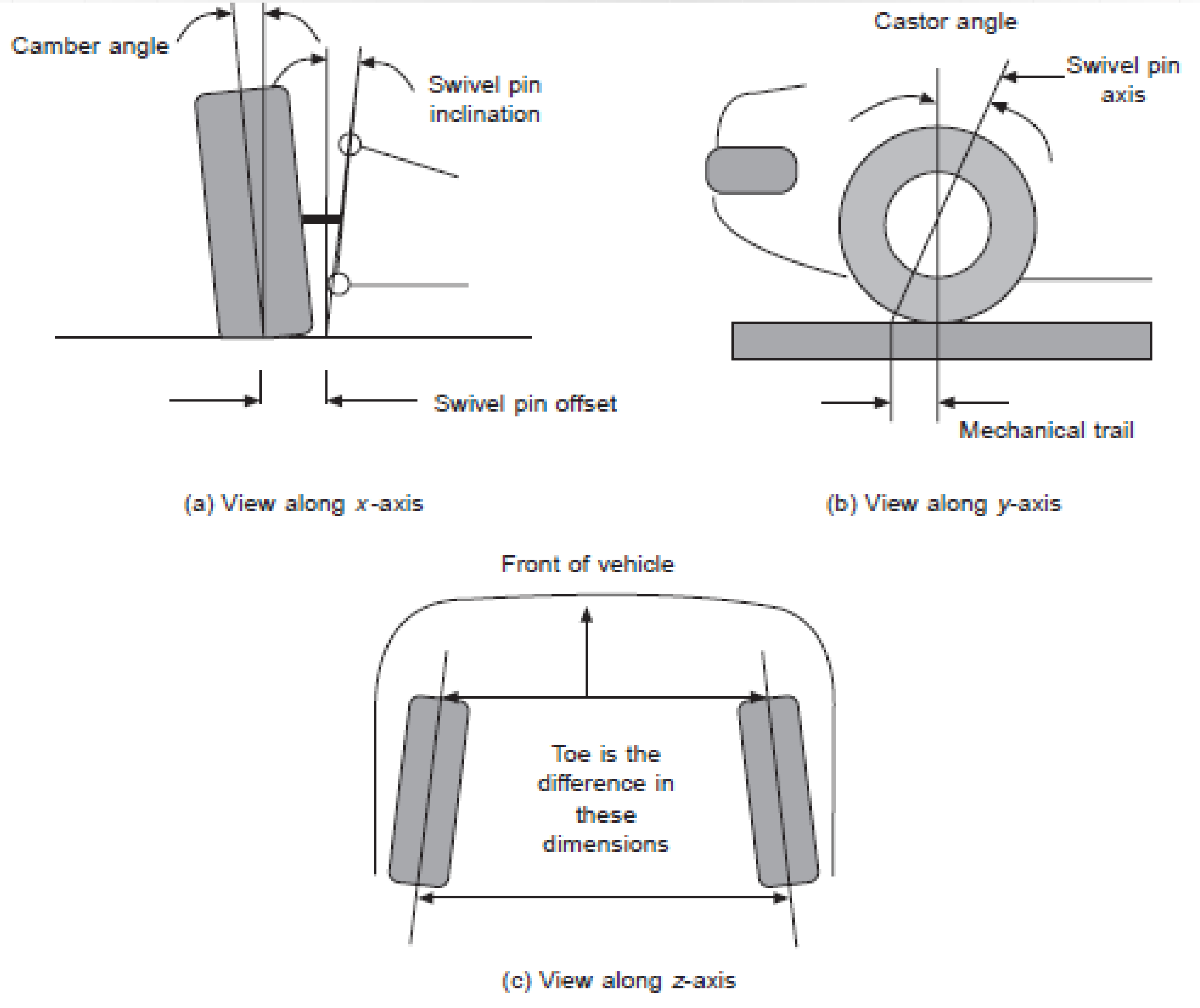
Roll axis

- The design of a chassis firstly requires the determination of the height $h_{Ro,f}$ of the front body roll center (dependent on the track alteration) so that, in a second step, an appropriate rear axle can be provided; in the case of independent wheel suspensions with a slightly higher
- If the vehicle is fitted with a rigid axle, the body enjoys less anti-roll support on bends as a result of the shorter effective distance of the springs relative to the track
- To balance this out, it is recommended that the body roll center be designed slightly higher at the rear



Suspension relative angles

Vehicle geometry



(a) View along x-axis

(b) View along y-axis

(c) View along z-axis

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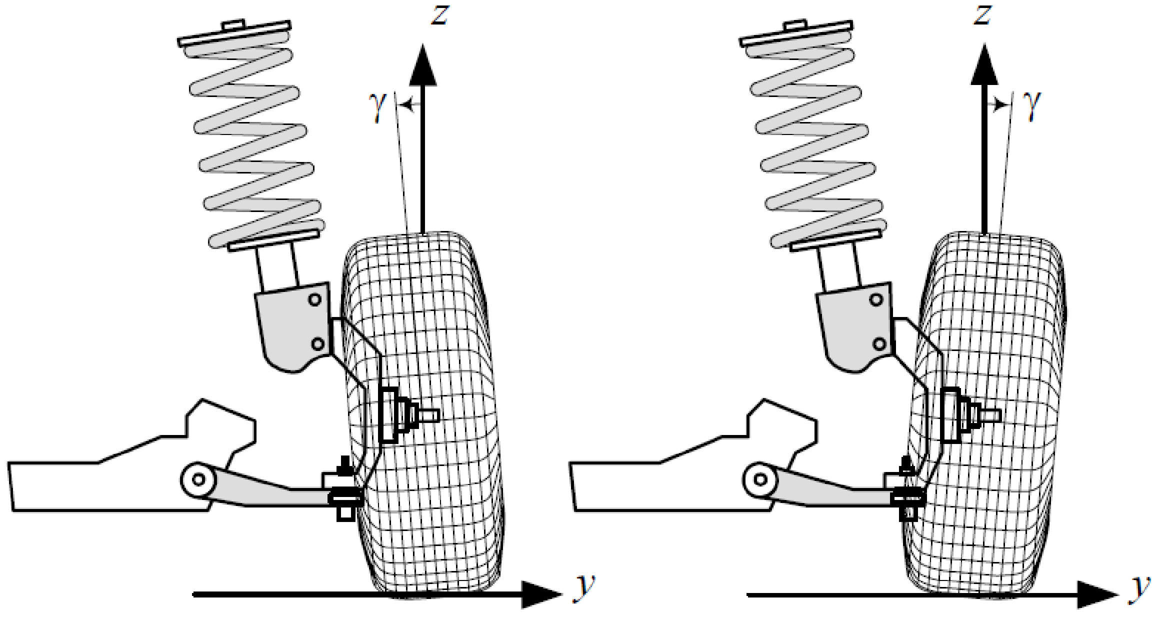
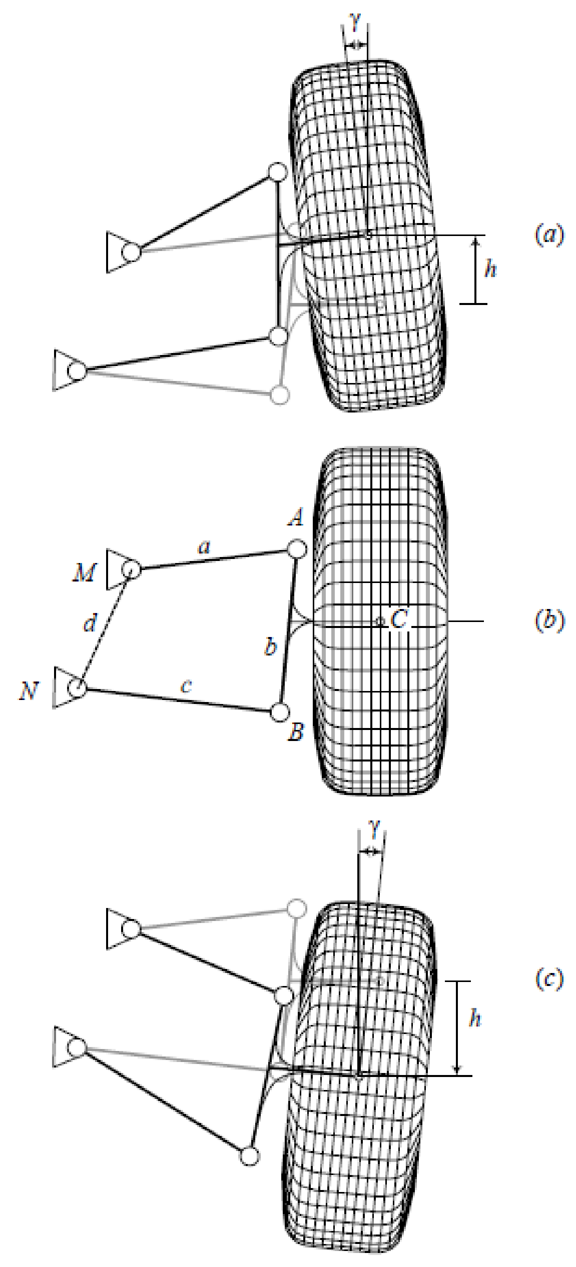
Suspension relative angles

Camber

- A tire develops its maximum lateral force at a small camber angle.
- Camber doesn't improve turn-in as the positive caster does.
- Camber is not generally good for tire wear.
- Camber in one wheel does not improve directional stability. Camber adversely affects braking and acceleration efforts.



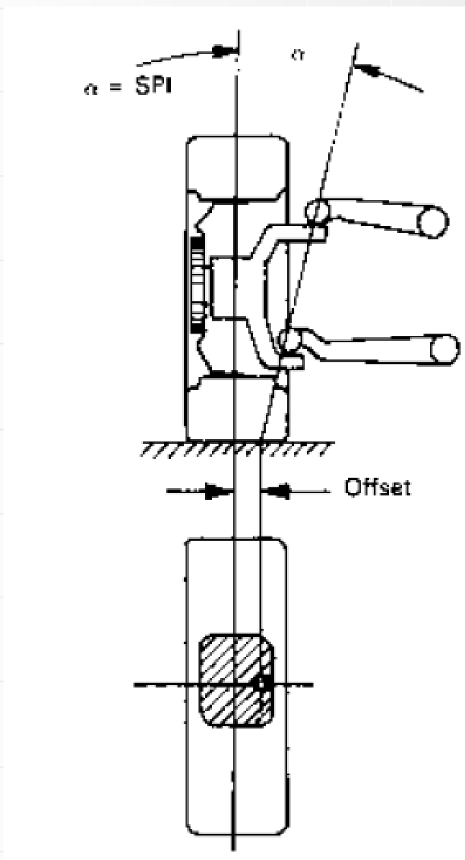
Positive camber *Negative camber*

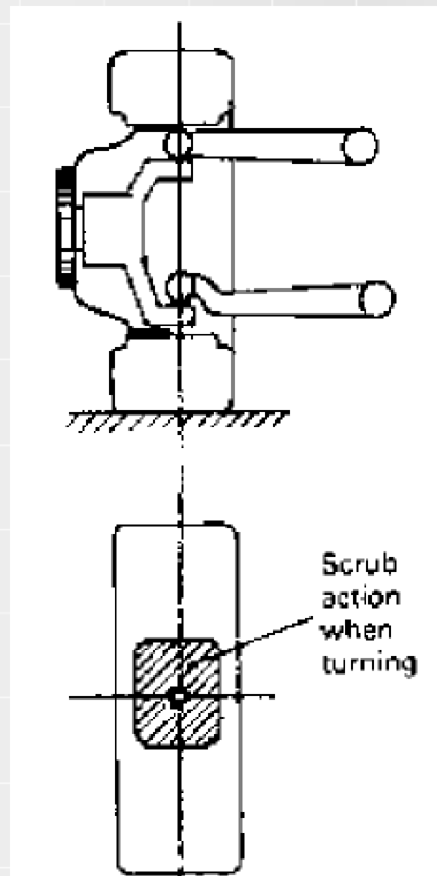


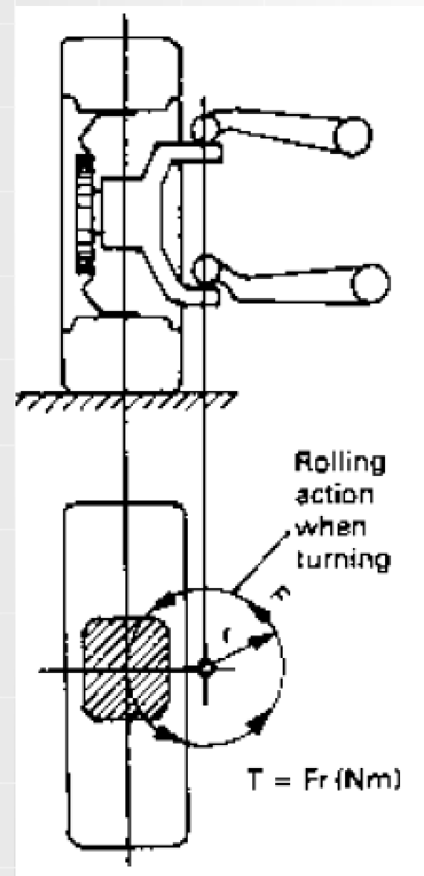
Suspension relative angles

Swivel pin offset

Pivot inclination produces a self-centring action which is independent of vehicle speed or traction but is dependent upon the weight concentration on the swivel joints and their inclin-ation. A typical and popular value would be something like 8 or 12°.







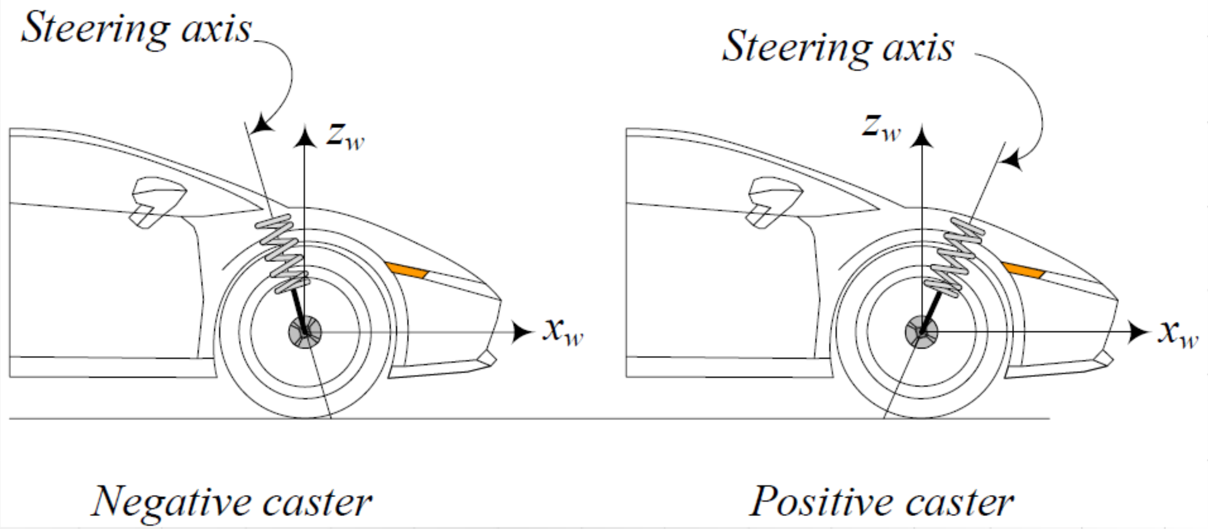
Suspension relative angles

Caster

- Negative caster aids in centering the steering wheel after a turn and makes the front tires straighten quicker thus is used to enhance straight-line stability.
- Most street cars are made with 4–6deg negative caster

- **Negative caster provides**:
  - low steering into the corner,
  - easy steering out of the corner,
  - more straight-line stability,
  - high tireprint area during turn,
  - good turn-in response,
  - good directional stability,
  - good steering feel

- **Zero castor provides:**
  - easy steering into the corner,
  - low steering out of the corner,
  - low straight-line stability.

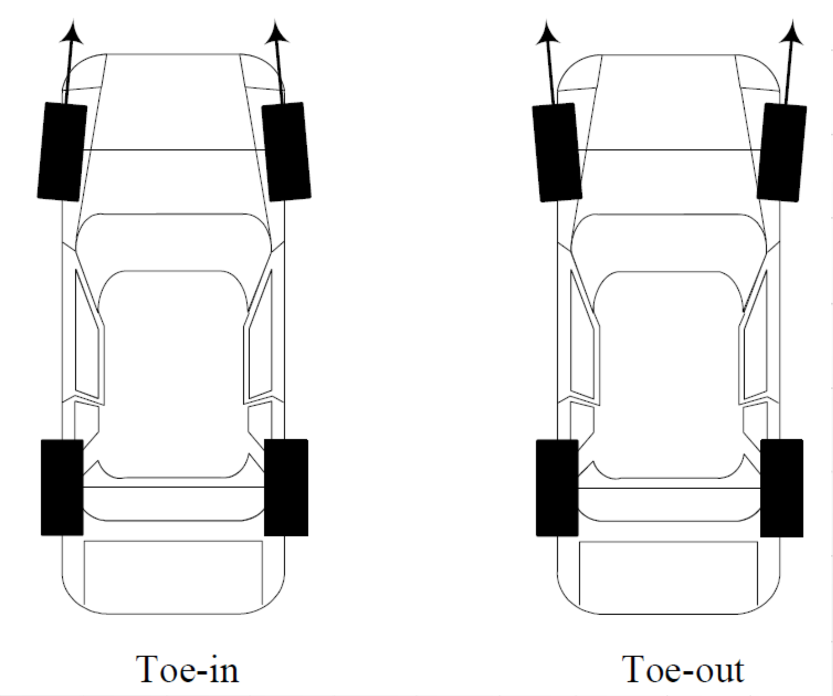


Suspension relative angles

Toe

- **Toe-in** increases the directional stability of the vehicle (makes the steering function lazy)
- **toe-out** increases the steering response (makes the vehicle unstable)

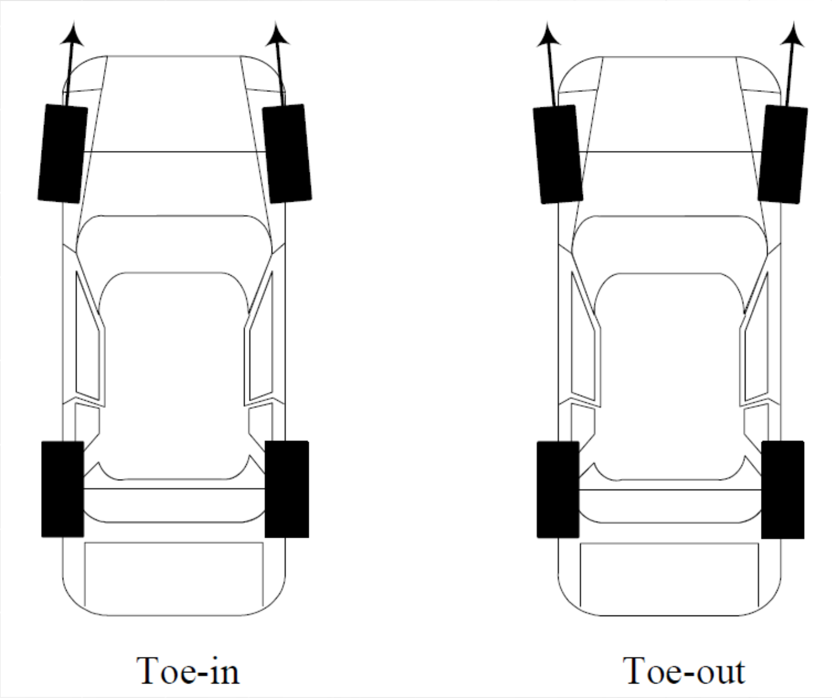
When driving torque is applied to the wheels, they pull themselves forward and try to create toe-in. Furthermore, when pushed down the road, a non-driven wheel or a braking wheel will tend to toe-out.



Suspension relative angles

Toe

- **Front toe-in**: slower steering response, more straight-line stability, greater wear at the outboard edges of the tires.
- ***Front toe-zero****: medium steering response, minimum power loss, minimum tire wear.*
- **Front toe-out**: quicker steering response, less straight-line stability, greater wear at the inboard edges of the tires.
- **Rear toe-in**: straight-line stability, traction out of the corner, more steerability, higher top speed.



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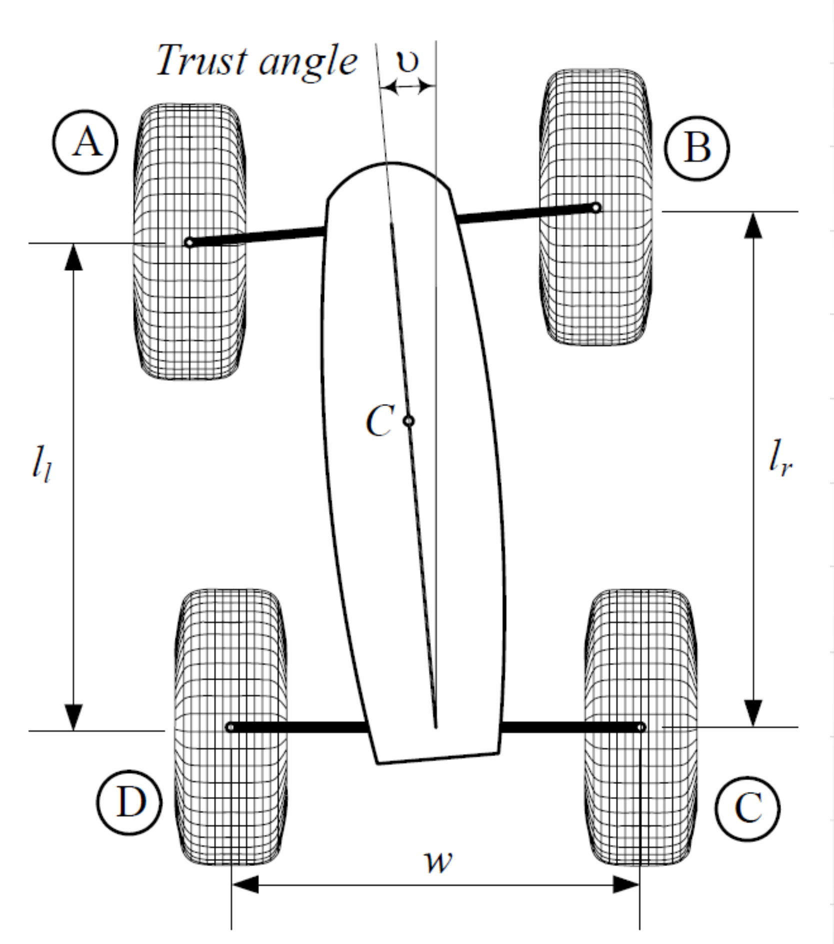
Suspension relative angles

Trust angle

- The trust angle υ is the angle between vehicle's centerline and perpendicular to the rear axle. It compares the direction that the rear axle is aimed with the centerline of the vehicle.

- Zero angle confirms that the rear axle is parallel to the front axle, and the wheelbase on both sides of the vehicle are the same.



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