دانشگاه سمنان
Semnan University
Faculty of Mechanical Engineering

دانشکده مهندسی مکانیک

دانشکده مهندسی مکانیک

درس طراحی سیستم های شاسی خودرو

Vehicle Chassis Systems Design

Chapter 7 – Suspension
Class Lecture

- ***CONTENTS:***

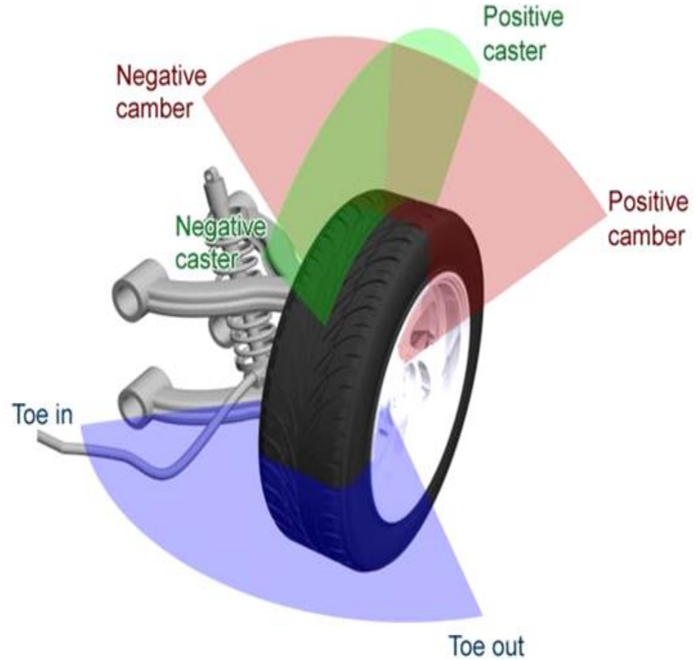
INTRODUCTION

- The primary functions of a suspension system:
  - Provide vertical compliance
  - Maintain the wheels in the proper steer and camber
  - React to the control forces produced by the tires
    - longitudinal forces, lateral forces, and braking and driving torques
  - Resist roll of the chassis
  - Keep the tires in contact with the road with minimal load variations

- Suspensions generally fall into either of two groups:
  - Solid Axles
  - Independent Suspensions

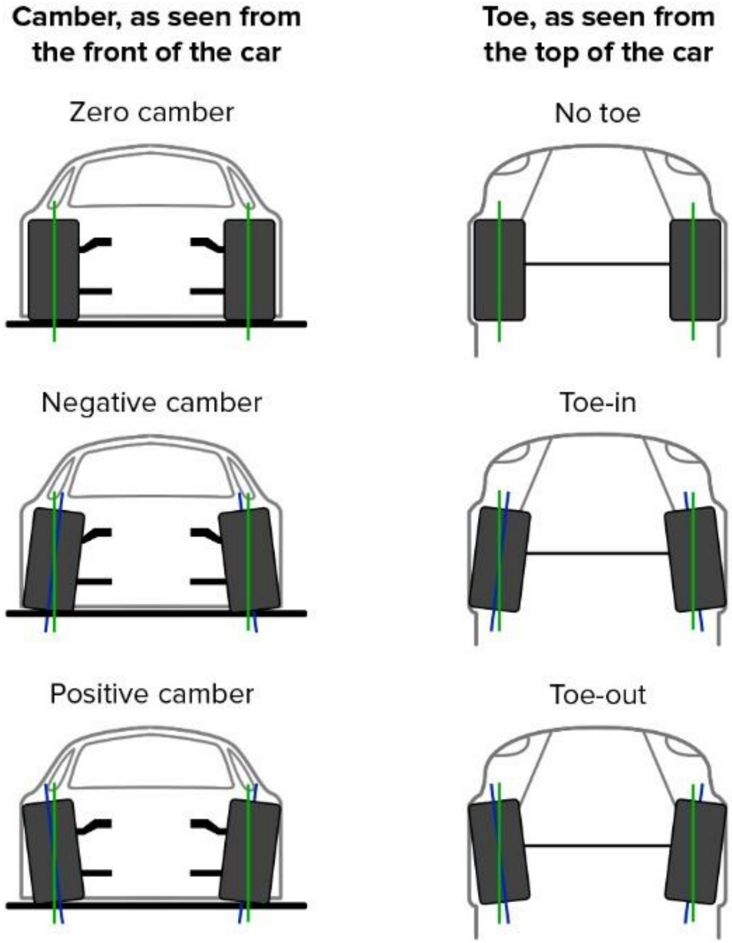
Introduction

- Wheel Geometry (Alignment)
  - Most manufactures provide adjustment methods for both front and rear wheel alignment.
  - Correct wheel alignment is essential for vehicle stability, lighten steering, prolong tire life and steering recovery (self centering)



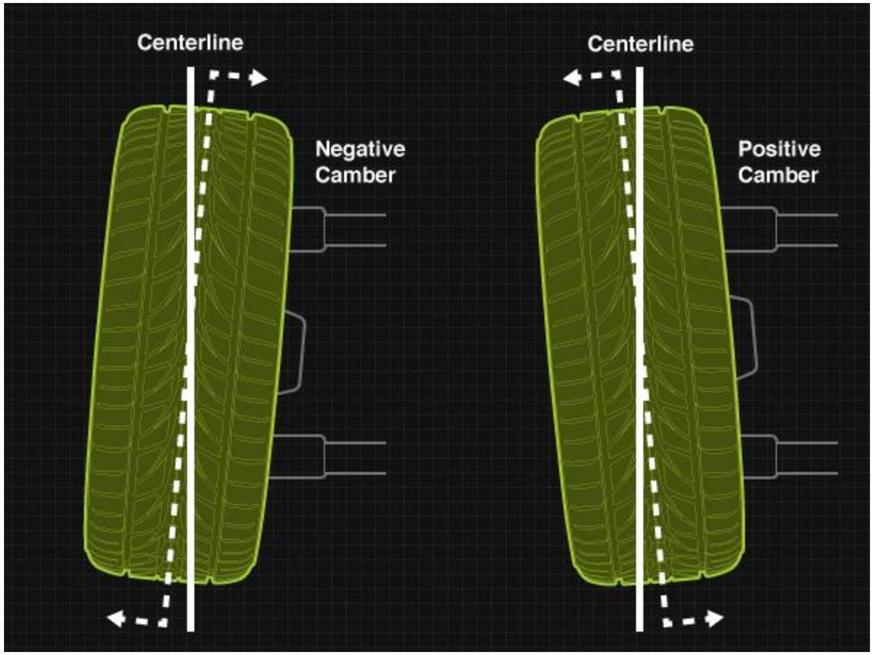
Introduction

- Wheel Angles:



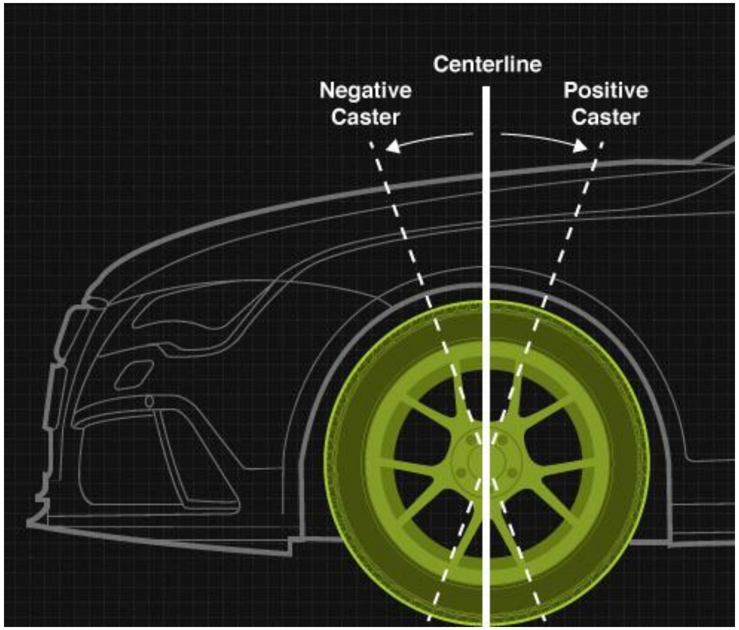
Introduction

- Wheel Angles:
  - Camber
    - The inward or outward angle of tire (when viewed from front of vehicle)
    - Aids steering
    - Prevents uneven tire wear on outer or inner tread



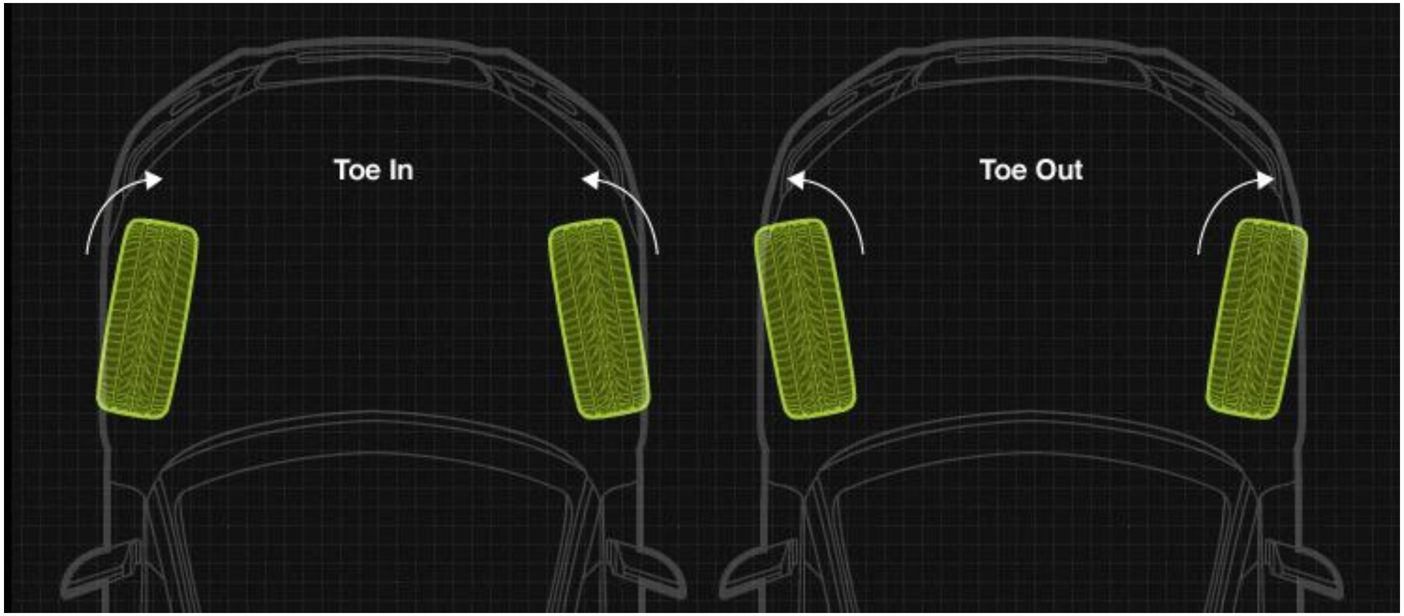
Introduction

- Wheel Angles:
  - Camber
    - The angle of steering axis (when viewed from side of vehicle)
    - Helps balance steering, stability and cornering
    - Causes the wheels to resist turning and tend to return to "straight ahead" position



Introduction

- Wheel Angles:
  - Toe In – Toe Out
    - ✓ The extent to which turns inward or outward (when viewed from above)

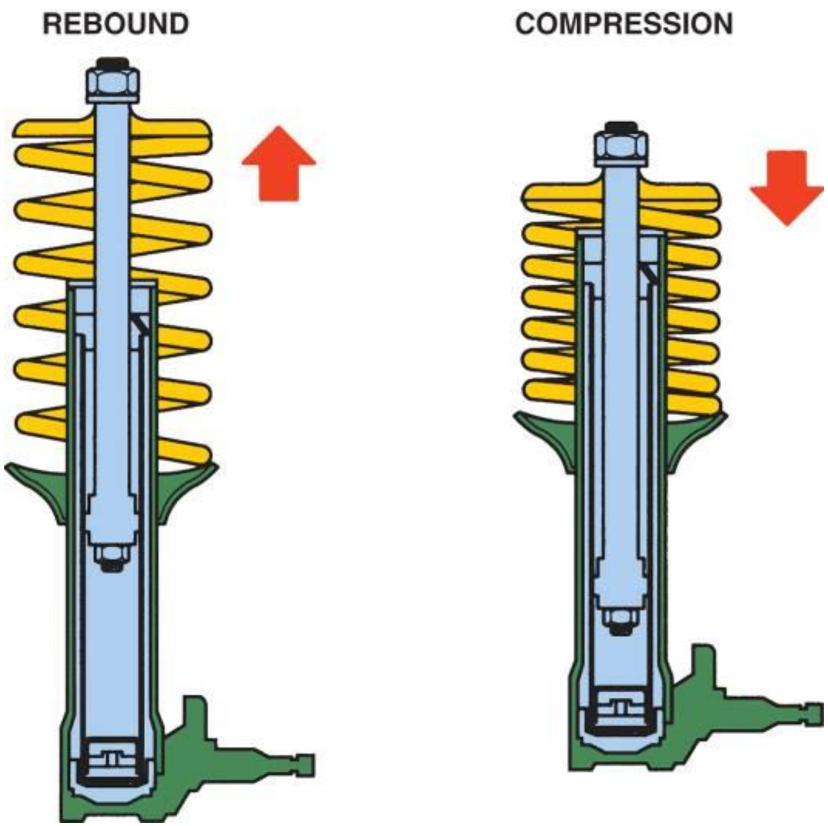


INTRODUCTION

- Wheel Angles:
  - Swivel Axis / Kingpin Inclination
    - The swivel axis inclination is the vertical axis of the ball joints, king pins or MacPherson strut tube.
    - This is normally an inward tilt.
    - In a similar way to caster, it aids directional stability, helping the steering wheel to return to the straight-ahead position.
    - This angle can also change the steering radius and camber.

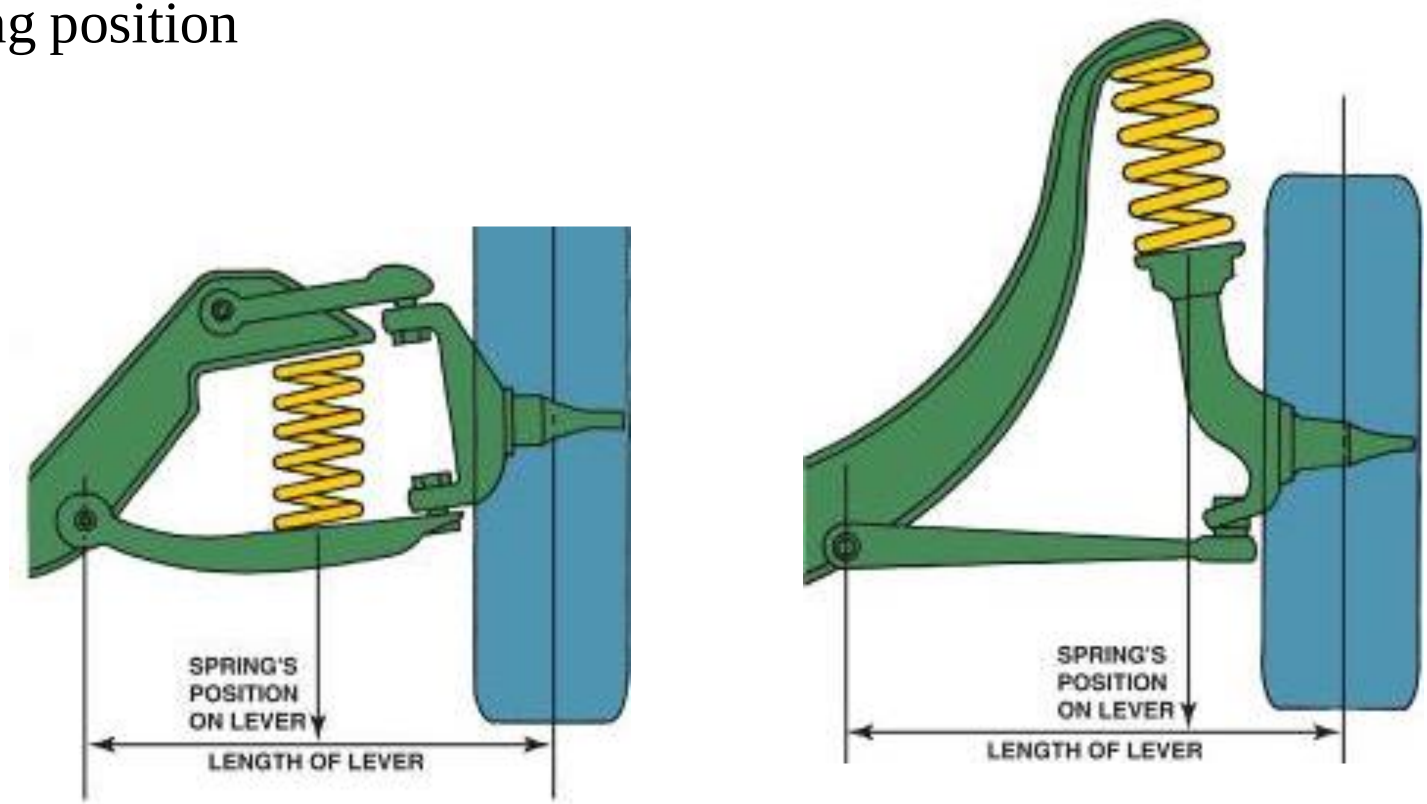
INTRODUCTION

- Jounce (compression) and Rebound



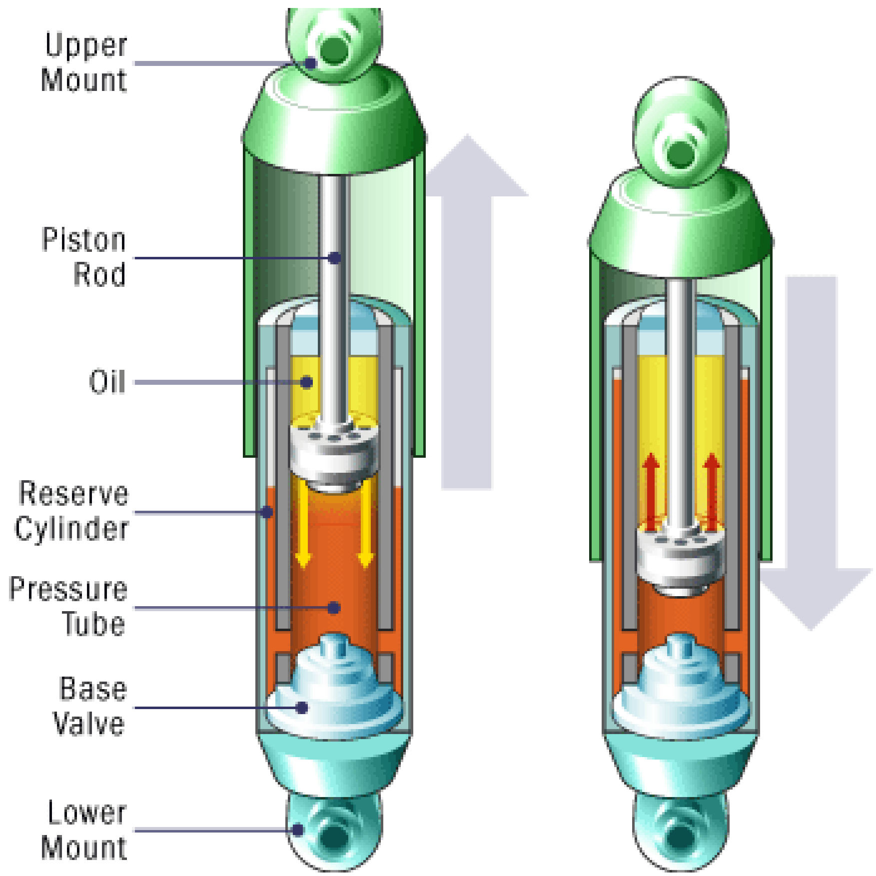
INTRODUCTION

- Spring position



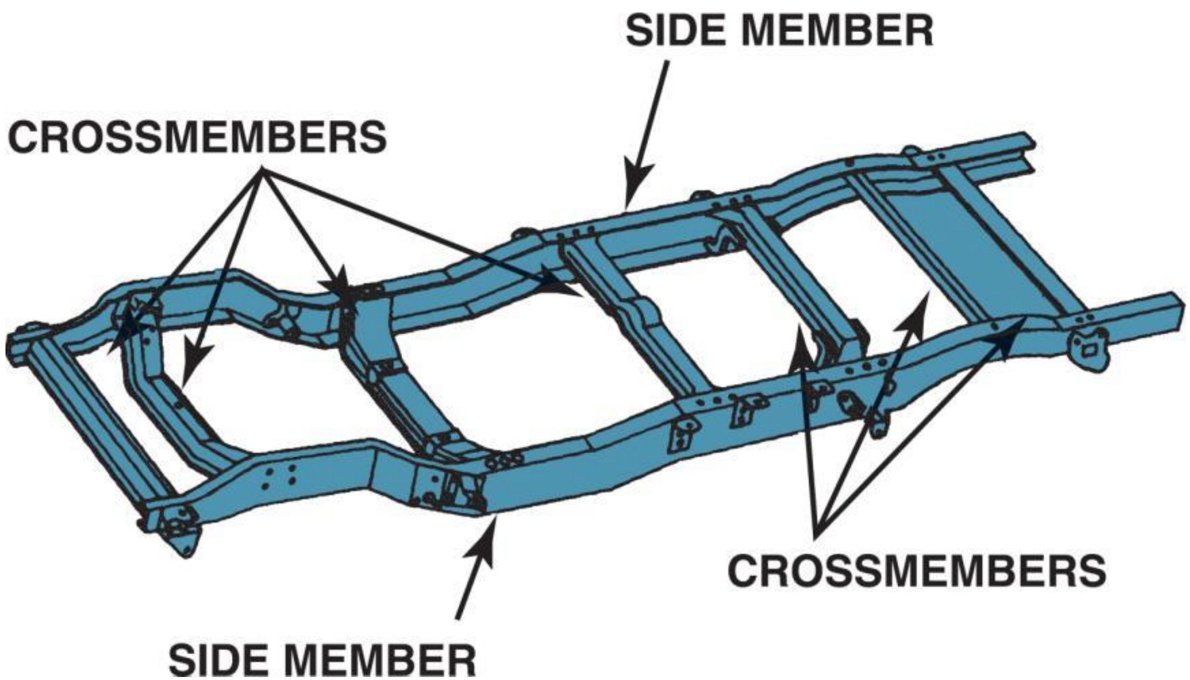
Introduction

- Damper



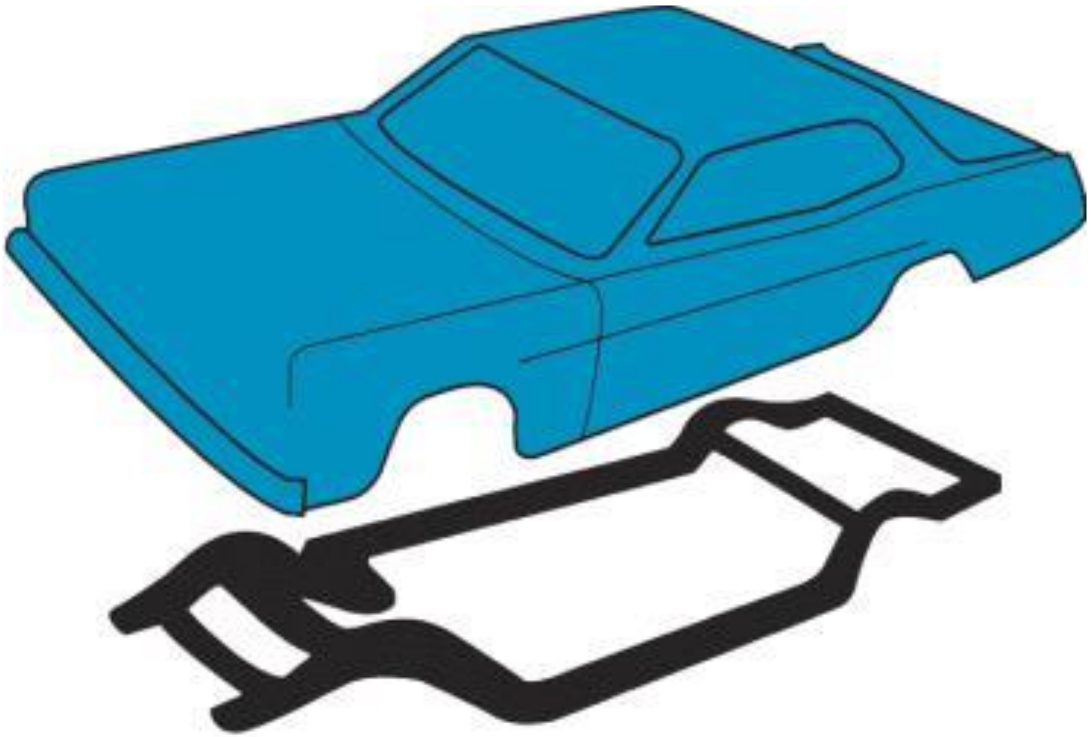
INTRODUCTION

- Frame types
  - Ladder type frame



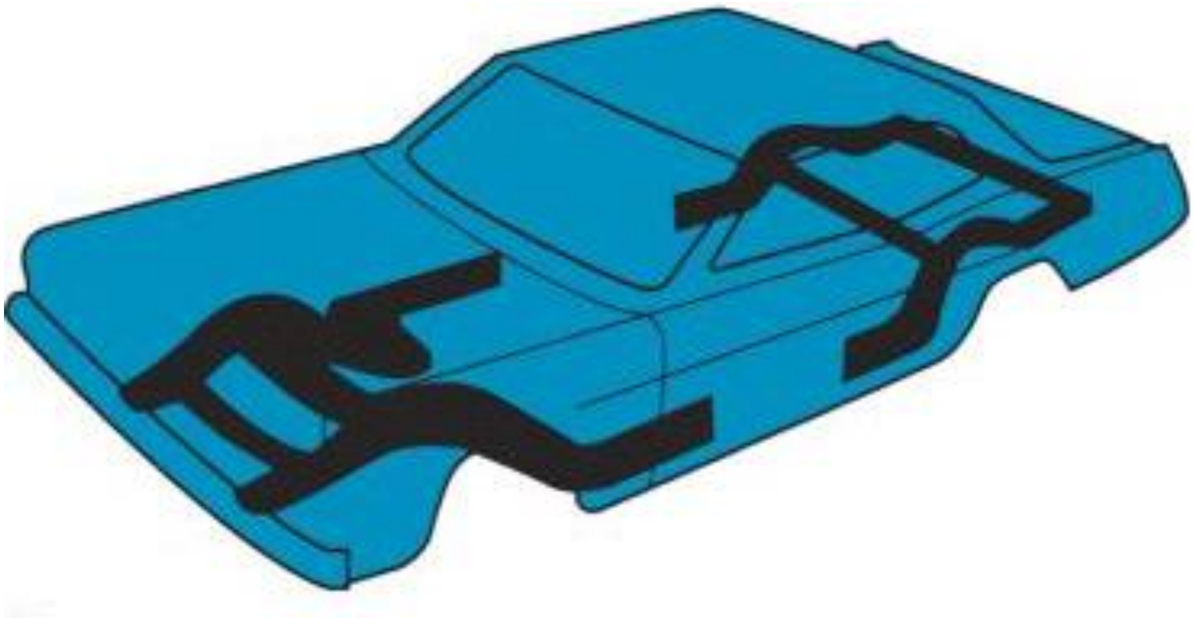
Introduction

- Frame types
  - Separate body and frame



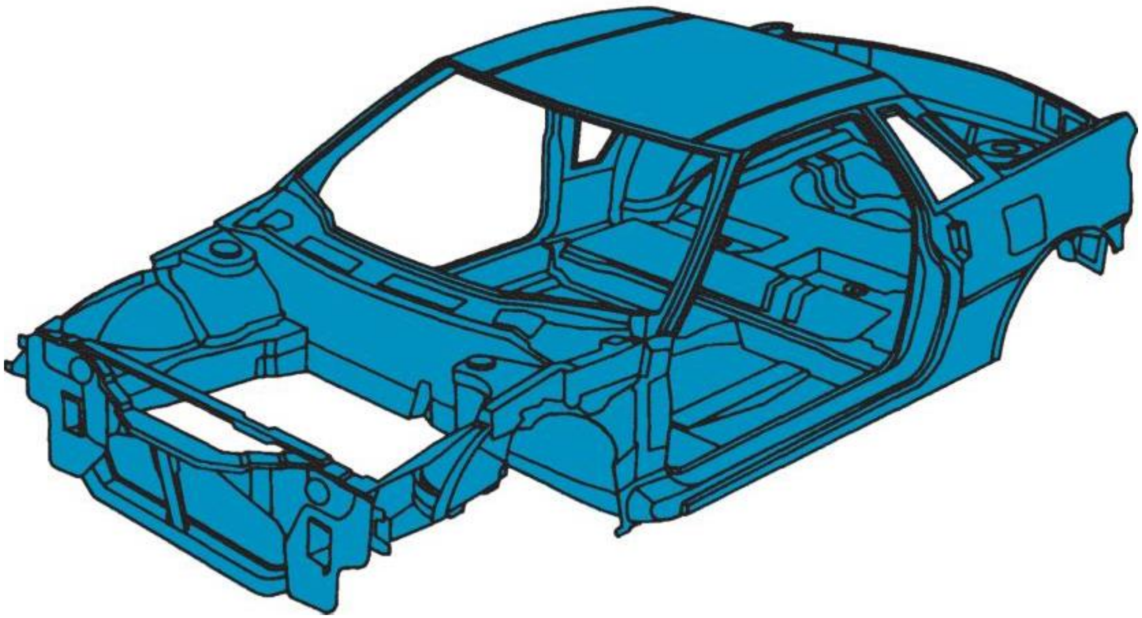
INTRODUCTION

- Frame types
  - Unitized construction



INTRODUCTION

- Frame types
  - Unit-body construction



INTRODUCTION

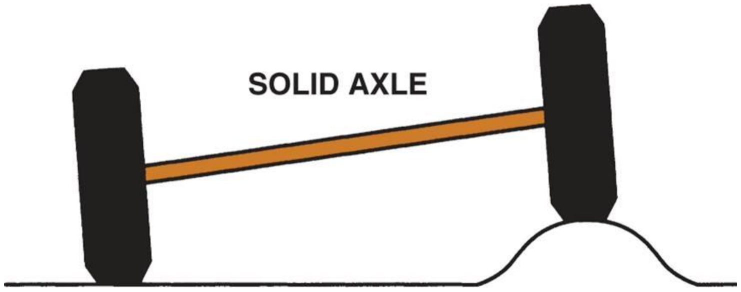
- Early suspension systems

Solid Axles

- A solid axle is one in which wheels are mounted at either end of a rigid beam so that any movement of one wheel is transmitted to the opposite wheel.

- Solid drive axles are used on the rear of many cars and most trucks and on the front of many four-wheel-drive trucks.

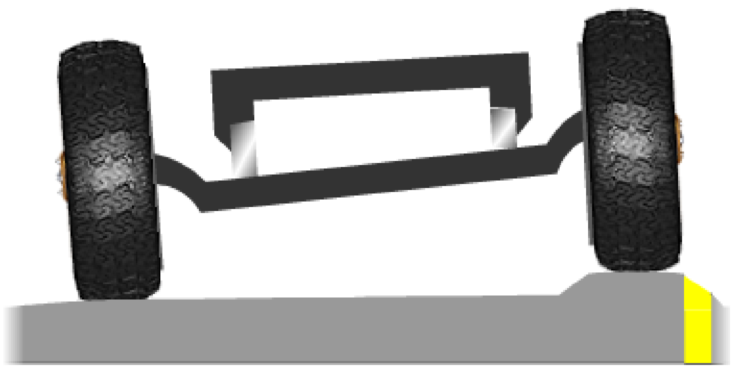
- Solid beam axles are commonly used on the front of heavy trucks where high load-carrying capacity is required.



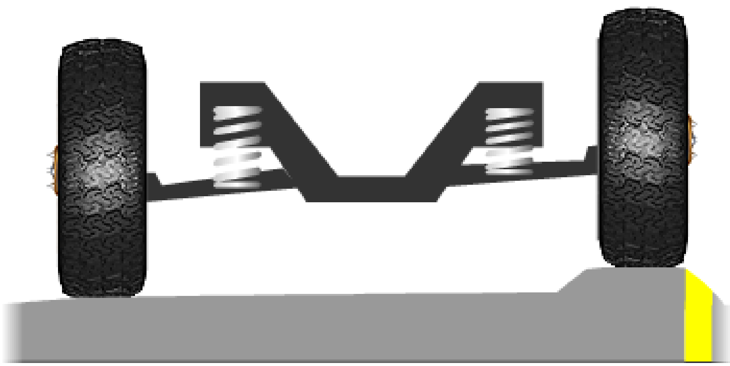
Solid Axles

- Solid axles vs Independent Suspension
  - A solid axle tilts with road bumps which causes both wheels to be tilted.
  - Independent suspension allows one wheel to move up or down without appreciably affecting the other.
  - The design of the control arm keeps the wheel upright.

Solid axle



Independent suspension



Solid Axles

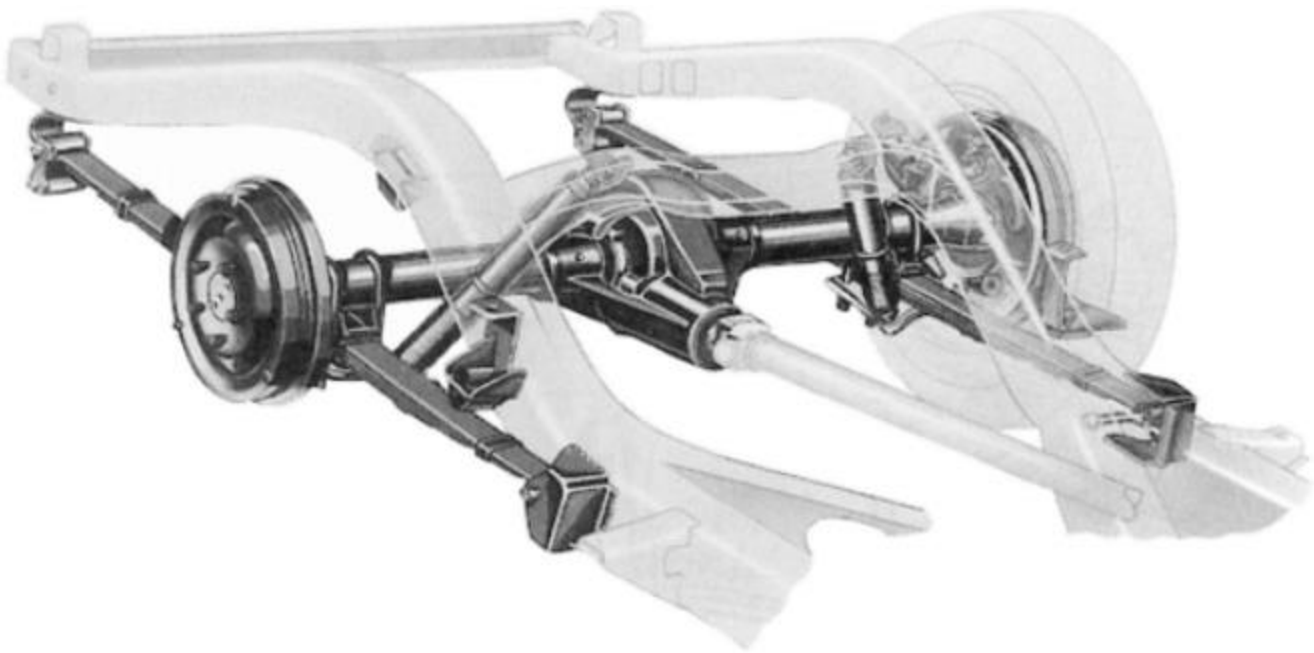
- Solid axles have the advantage that wheel camber is not affected by body roll.

- In addition, wheel alignment is readily maintained, minimizing tire wear.

- The major disadvantage of solid steerable axles is their susceptibility to steering vibrations.

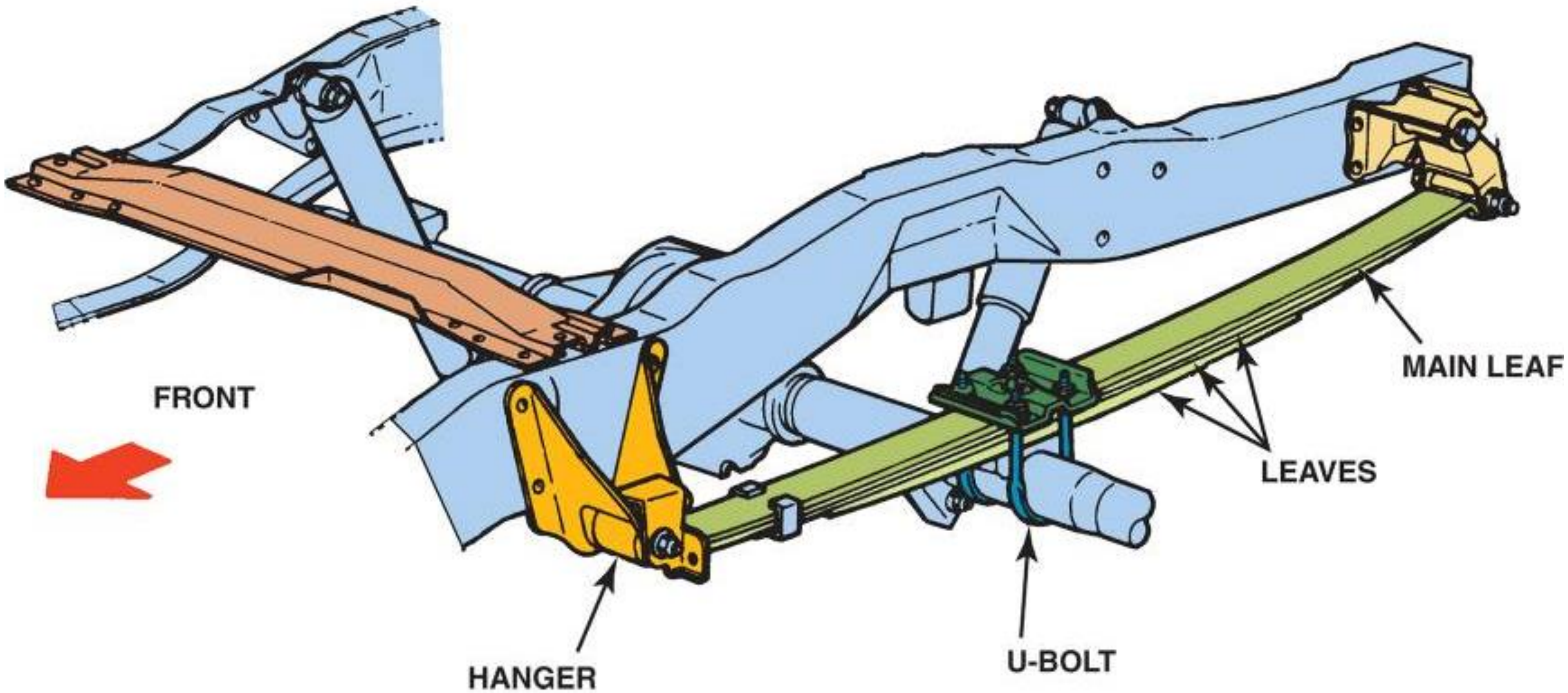
Solid Axles

- Hotchkiss
  - The most familiar form of the solid drive axle is the Hotchkiss drive.



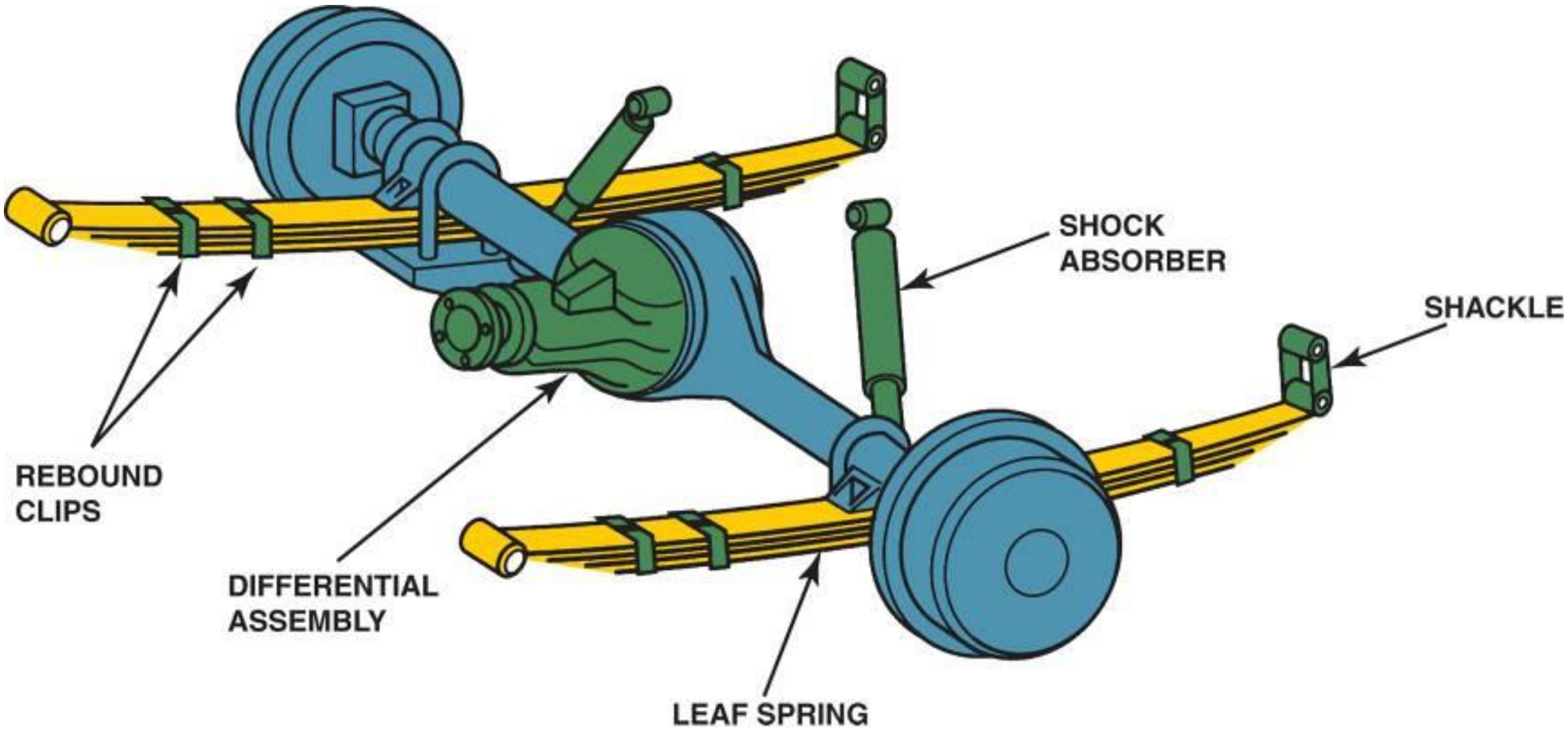
Solid Axles

- Hotchkiss
  - Using Leaf Spring



Solid Axles

- Hotchkiss

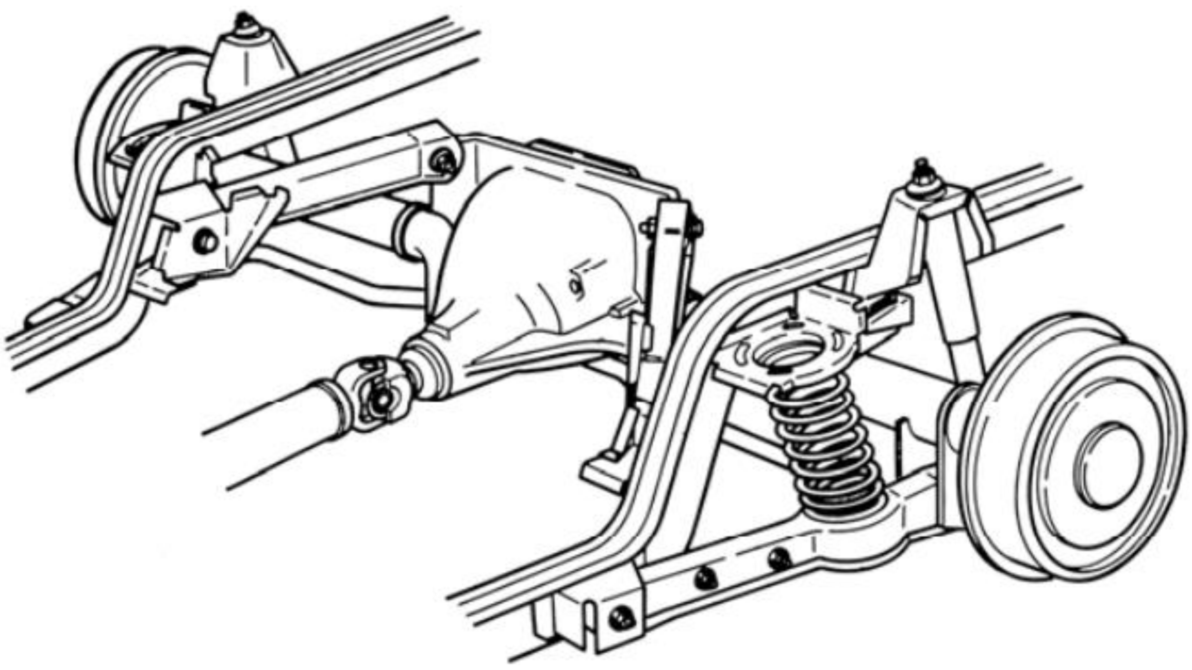


Solid Axles

- Hotchkiss
  - Leaf springs are perhaps the simplest and least expensive of all suspensions.
  - While compliant in the vertical direction, the leaf is relatively stiff in the lateral and longitudinal directions, thereby reacting the various forces between the sprung and unsprung masses.
  - The Hotchkiss was used widely on the rear axle of passenger cars into the 1960s, and is still used on most light and heavy trucks.

Solid Axles

- Four Link
  - In response to the shortcomings of leaf spring suspensions, the four-link rear suspension evolved as the suspension of choice for the larger passenger cars with solid rear-drive axles.

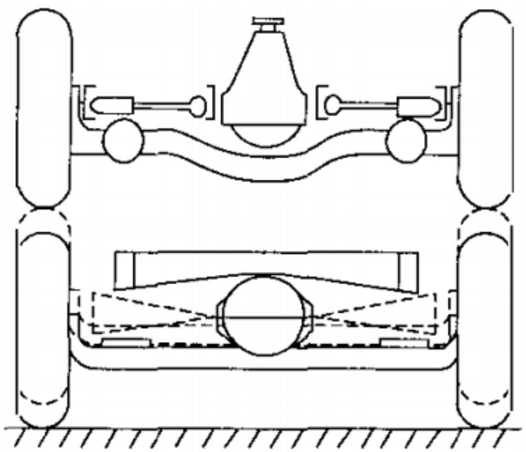


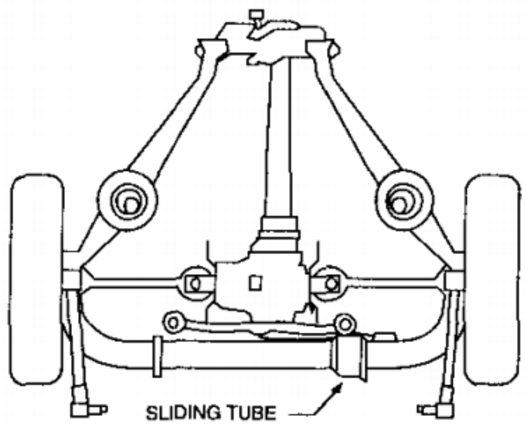
Solid Axles

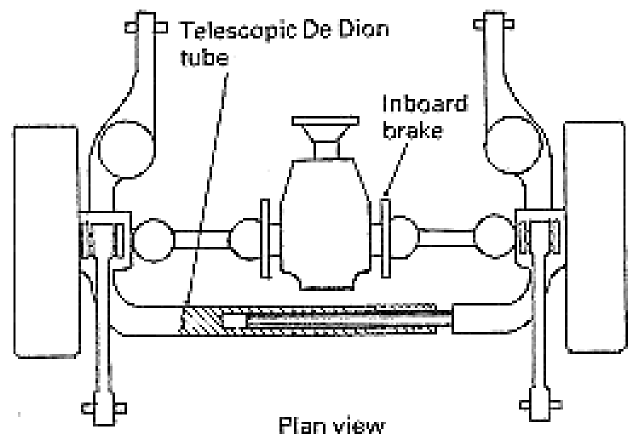
- Four Link
  - The lower control arms provide longitudinal control of the axle while the upper arms absorb braking/driving torques and lateral forces.
  - The ability to use coil springs (or air springs) instead of leaf springs provides better ride by the elimination of the coulomb friction characteristic of leaf springs.
  - Although more expensive than the leaf spring, the geometric design of the four-link allows better control of roll center location, anti-squat and anti-dive performance, and roll steer properties.

Solid Axles

- De Dion
  - A cross between the solid axle and an independent suspension is the classic, but little used, de Dion system







Solid Axles

- De Dion
  - It consists of a cross tube between the two driving wheels with a chassis-mounted differential and halfshafts.
  - Like a solid axle, the de Dian keeps the wheels upright while the unsprung weight is reduced by virtue of the differential being removed from the axle.
  - Axle control is provided by any of a variety of linkages from leaf springs to trailing arms.
  - The design also has advantages for interior space because there is no need to provide differential clearance.
  - One of the main disadvantages of the de Dian is the need to have a sliding tube or splined halfshafts, which can add friction to the system.

Independent Suspensions

- In contrast to solid axles, independent suspensions allow each wheel to move vertically without affecting the opposite wheel.

- Nearly all passenger cars and light trucks use independent front suspensions, because of the advantages in providing room for the engine, and because of the better resistance to steering vibrations.

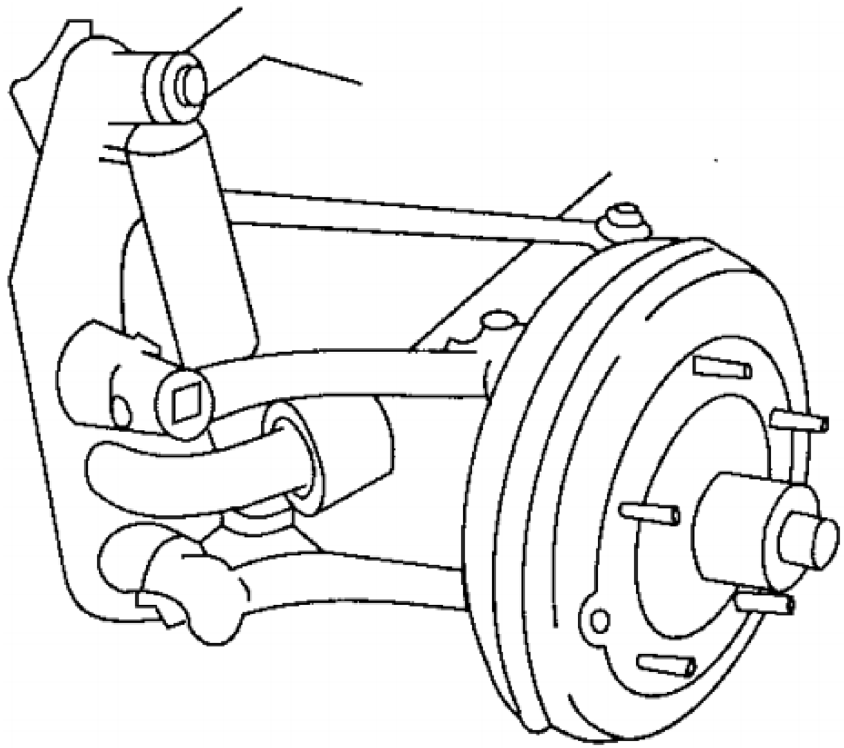
- The independent suspension also has the advantage that it provides an inherently higher roll stiffness relative to the vertical spring rate.

Independent Suspensions

- Further advantages:
  - Easy control of roll center by choice of the geometry of the control arms
  - The ability to control tread change with jounce and rebound
  - Larger suspension deflections,
  - Greater roll stiffness for a given suspension vertical rate

INDEPENDENT SUSPENSIONS

- Trailing Arm Suspension
  - One of the most simple and economical designs of an independent front suspension is the trailing arm.

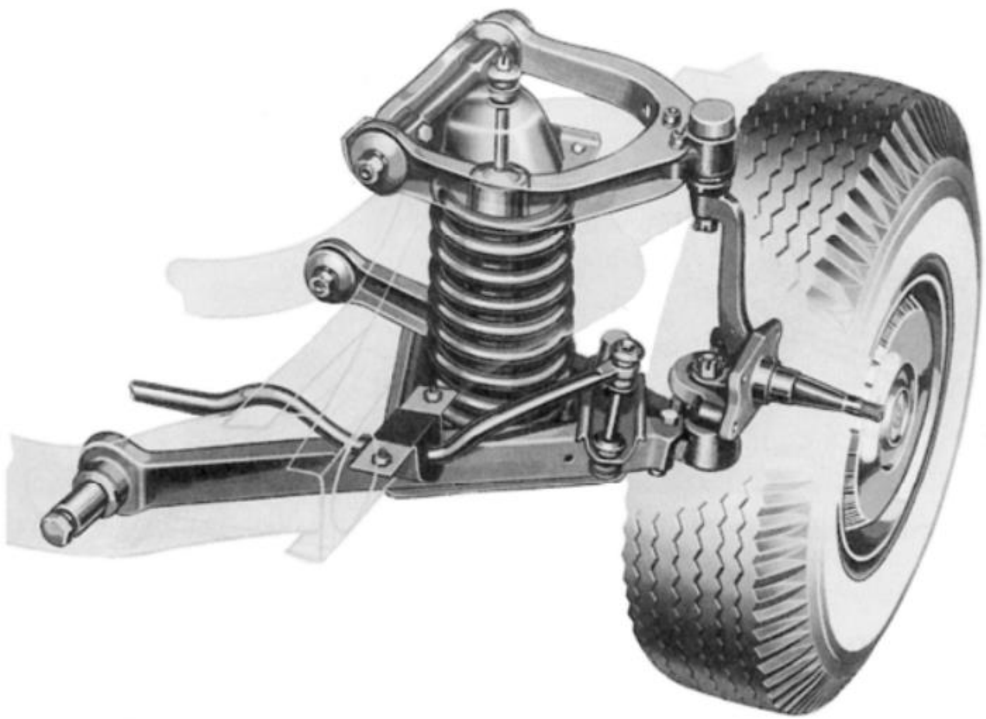


Independent Suspensions

- Trailing Arm Suspension
  - It was used by Volkswagen and Porsche around the time of World War II.
  - It uses parallel, equal length trailing arms connected at their front ends to lateral torsion bars, which provide the springing.
  - With this design the wheels remain parallel to the body and camber with body roll.

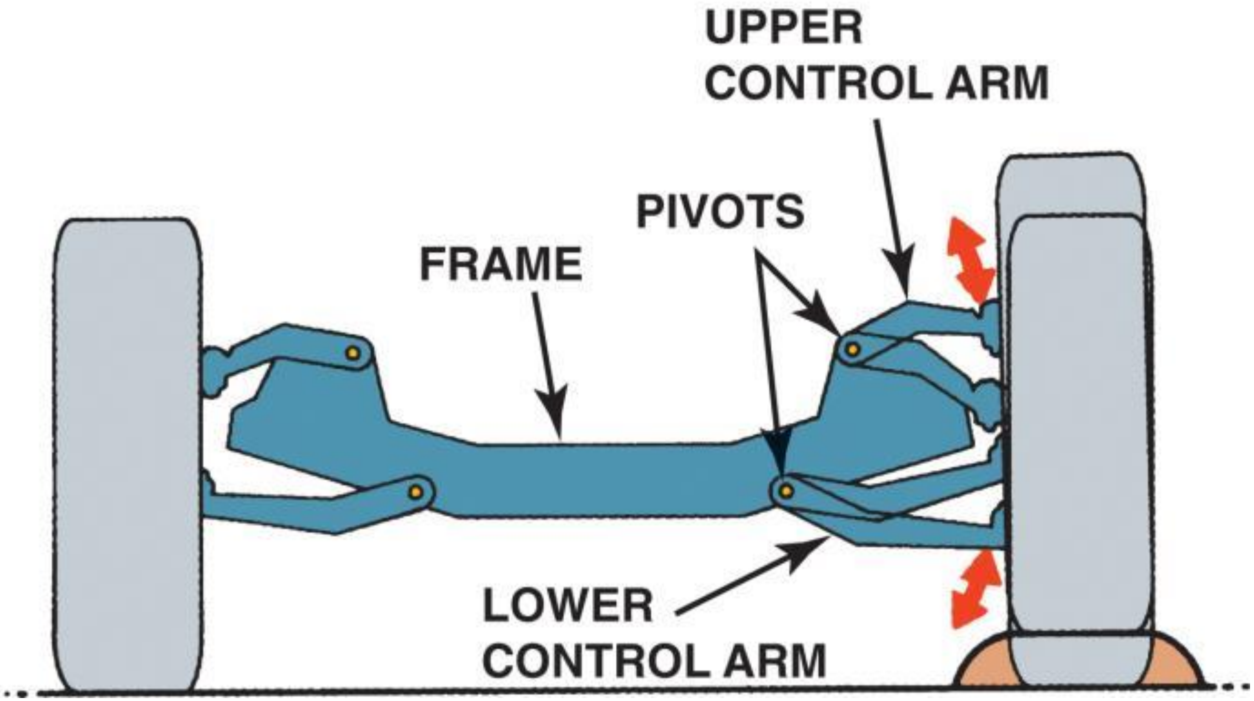
INDEPENDENT SUSPENSIONS

- SLA Front Suspension
  - It uses two lateral control arms to hold the wheel. The upper and lower control arms are usually of unequal length from which the acronym SLA (short-long arm) gets its name.



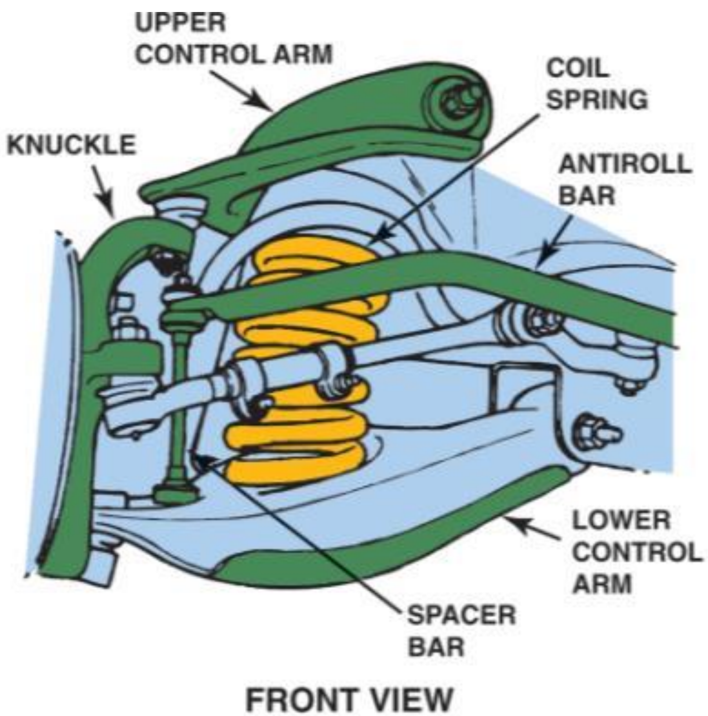
Independent Suspensions

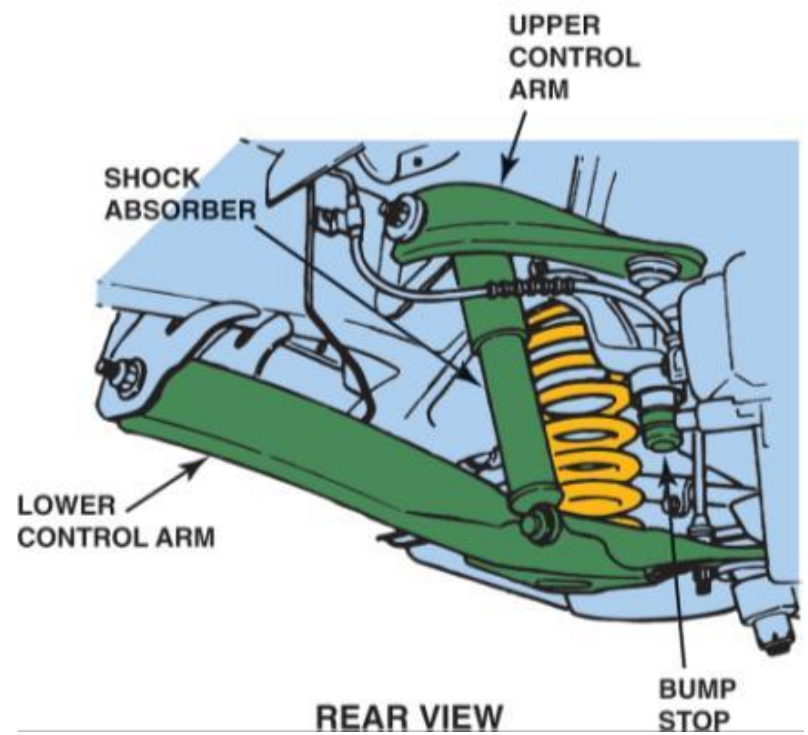
- SLA Front Suspension



Independent Suspensions

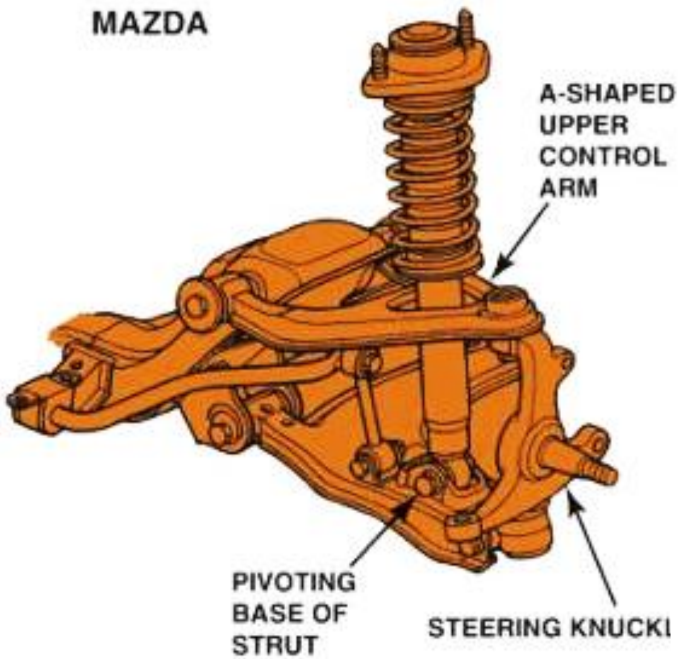
- SLA Front Suspension

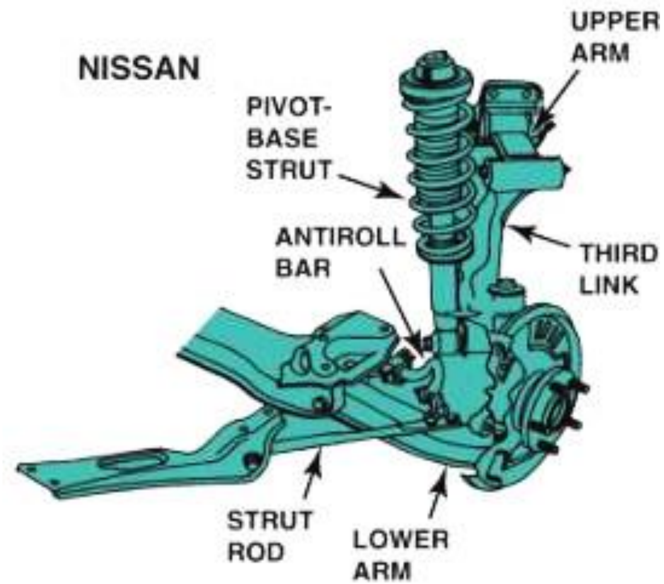


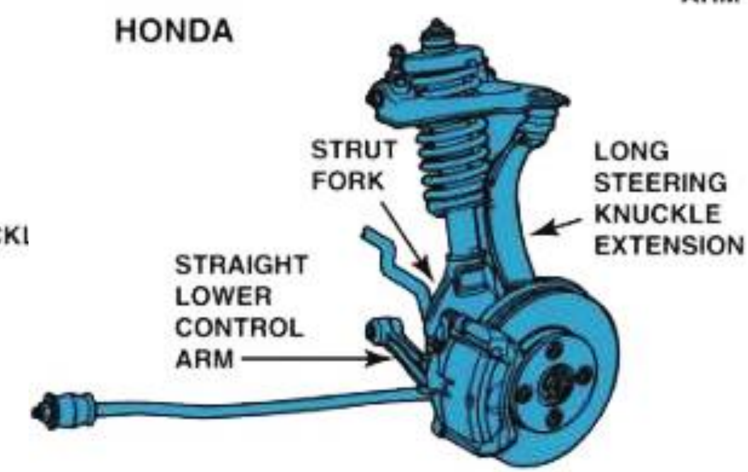


INDEPENDENT SUSPENSIONS

- SLA Front Suspension







Independent Suspensions

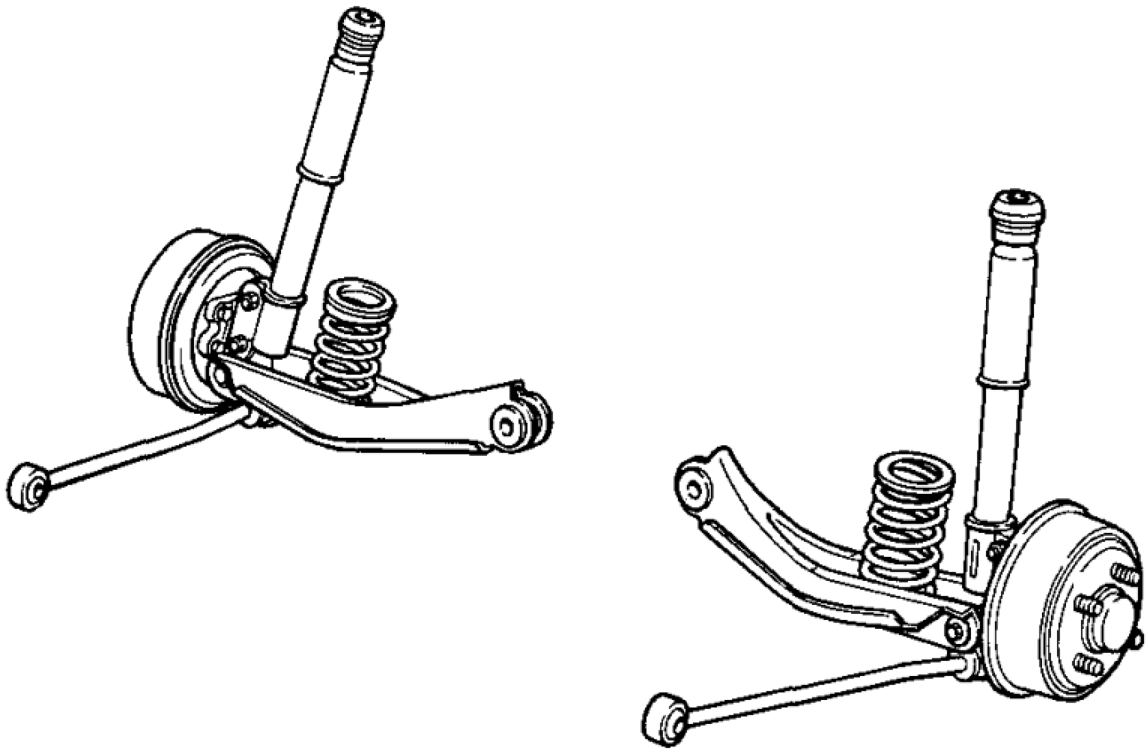
- SLA Front Suspension
  - It was the most common design for the front suspension of American cars following World War II.
  - The arms are often called "A-arms" in the United States and "wishbones" in Britain.
  - This layout sometimes appears with the upper A-arm replaced by a simple lateral link, or the lower arm replaced by a lateral link and an angled tension strut, but the suspensions are functionally similar.

Independent Suspensions

- SLA Front Suspension
  - The SLA is well adapted to front-engine, rear-wheel-drive cars because of the package space it provides for the engine oriented in the longitudinal direction.
  - Additionally, it is best suited to vehicles with a separate frame for mounting the suspension and absorbing the loads.
  - Design of the geometry for an SLA requires careful refinement to give good performance.

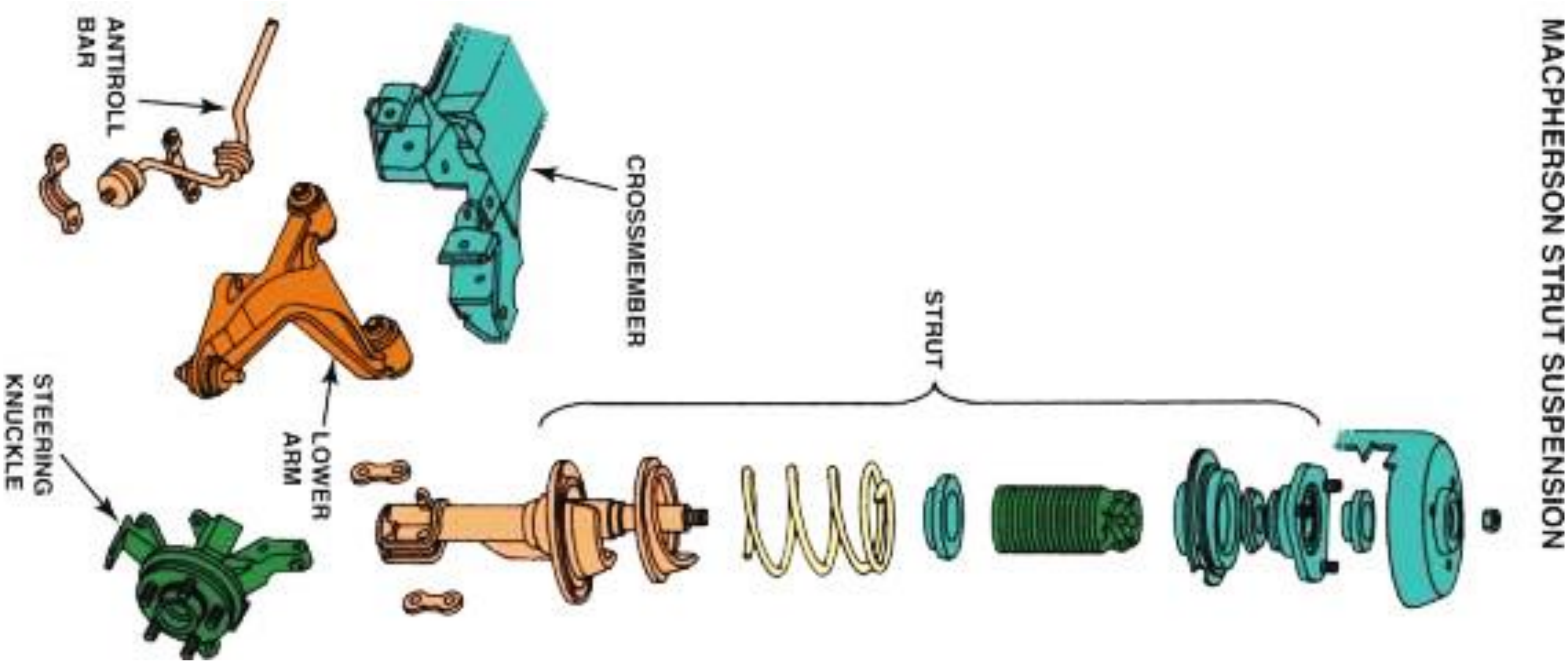
INDEPENDENT SUSPENSIONS

- MacPherson Strut
  - MacPherson developed a suspension with geometry similar to the unequal-arm front suspensions using a strut configuration



Independent Suspensions

- MacPherson Strut



Independent Suspensions

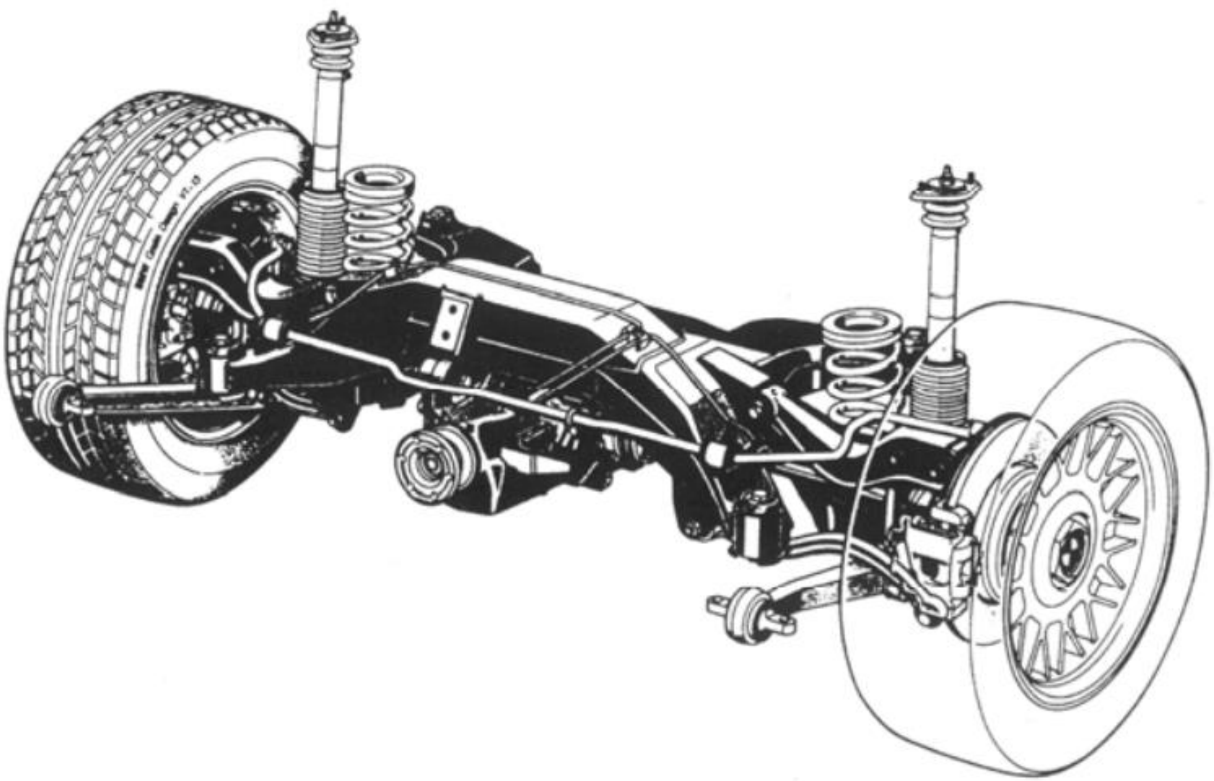
- MacPherson Strut
  - The strut is a telescopic member incorporating damping with the wheel rigidly attached at its lower end, such that the strut maintains the wheel in the camber direction.
  - The upper end is fixed to the body shell or chassis, and the lower end is located by linkages which pick up the lateral and longitudinal forces.
  - Because of the need to offset the strut inboard of the wheel, the wheel loads the strut with an overturning moment which adds to friction in the strut. This is often counteracted by mounting the coil spring at an angle on the strut.

Independent Suspensions

- MacPherson Strut
  - The MacPherson strut provides major advantages in package space for transverse engines, and thus is used widely for front-wheel-drive cars.
  - The strut has further advantages of fewer parts and capability to spread the suspension loads to the body structure over a wider area.
  - Among its disadvantages is the high installed height which limits the designer's ability to lower hood height.

INDEPENDENT SUSPENSIONS

- Multi-Link Rear Suspension
  - In recent years, multi-link versions of independent rear suspensions have become quite popular.

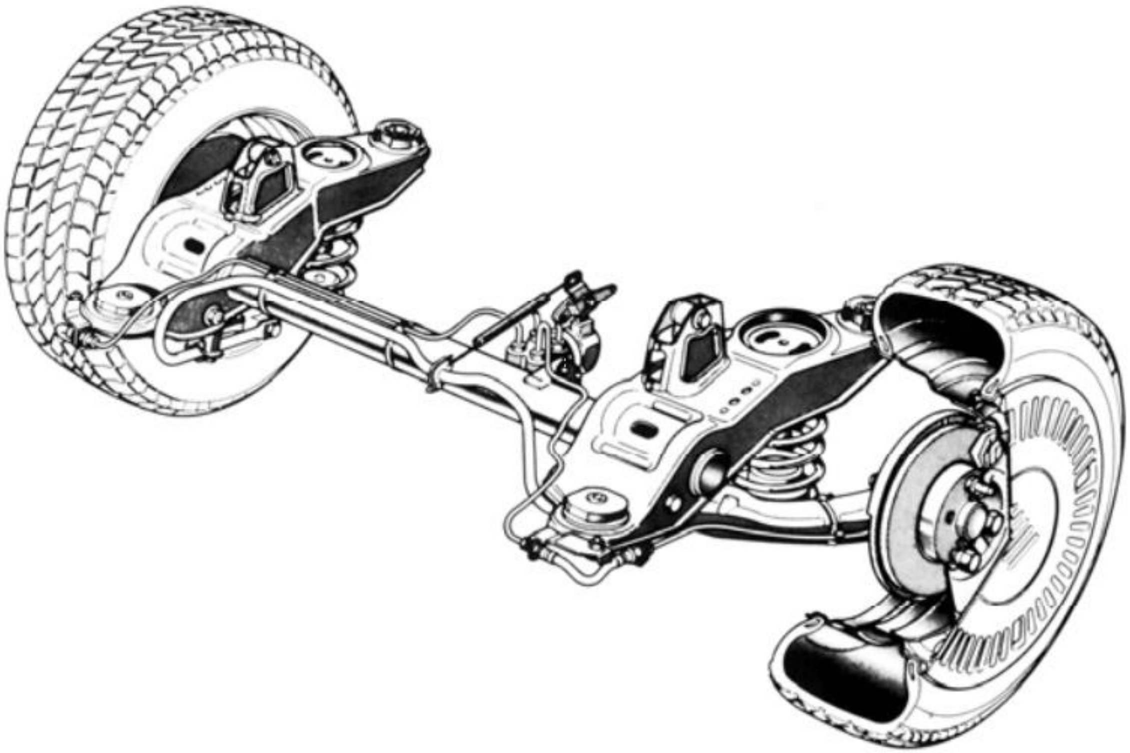


INDEPENDENT SUSPENSIONS

- Multi-Link Rear Suspension
  - The multi-link is characterized by ball-joint connections at the ends of the linkages so that they do not experience bending moments.
  - Four links are required to provide longitudinal and lateral control of the wheels, and react brake torques, but Occasionally five links are used.
  - The 5th link over-constrains the wheel, but capitalizes on compliances in the bushings to allow more accurate control of toe angles in cornering.
  - The use of linkages provides flexibility for the designer to achieve the wheel motions desired.

Independent Suspensions

- Trailing-Arm Rear Suspension
  - Suspensions of this type are often used on more expensive and high performance cars.

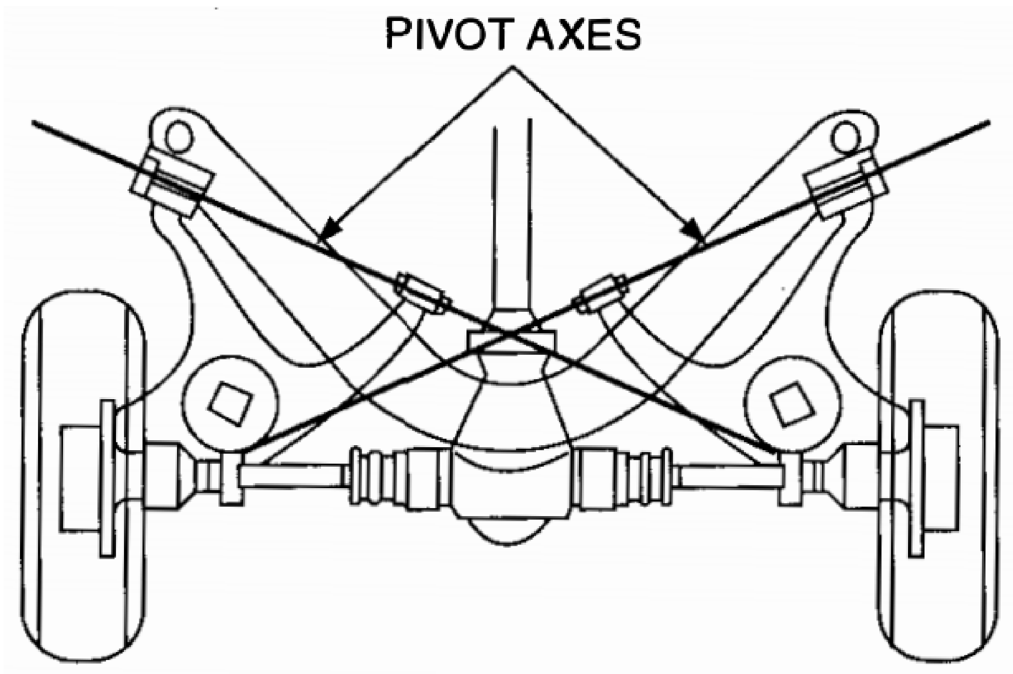


Independent Suspensions

- Trailing-Arm Rear Suspension
  - The control arms (trailing arms) absorb longitudinal forces and braking moments, and control squat and lift.
  - The independent suspension has the advantage of reducing unsprung weight by mounting the differential on the body.

Independent Suspensions

- Semi-Trailing Arm
  - The semi-trailing arm rear suspension was popularized by BMW and Mercedes Benz.

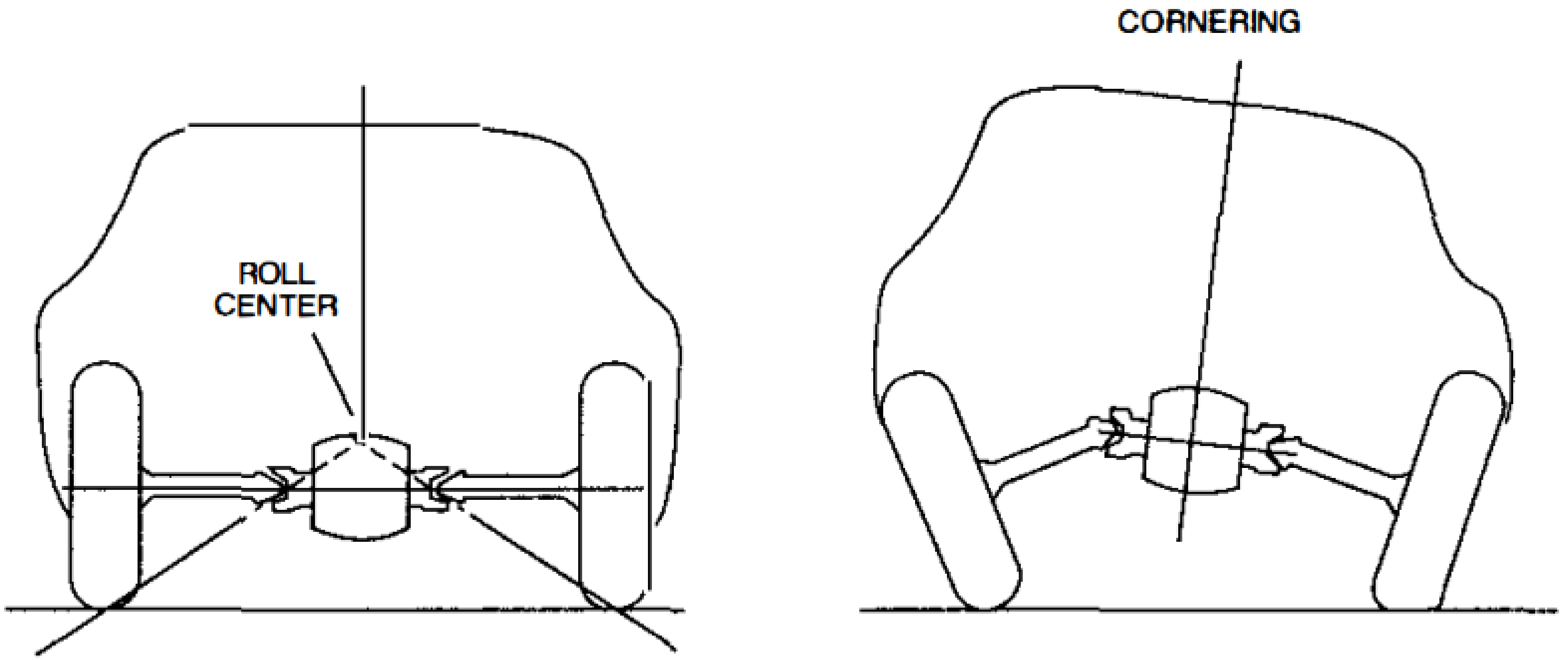


INDEPENDENT SUSPENSIONS

- Semi-Trailing Arm
  - This design gives rear wheel camber somewhat between that of a pure trailing arm (no camber change relative to the body) and a swing axle.
  - Its pivot axis is usually about 25 degrees to a line running across the car.
  - The semi-trailing arm produces a steering effect as the wheels move in jounce and rebound.
  - The steer/camber combination on the outside wheel acts against the direction of cornering, thus generating roll understeer on the rear axle, but lateral force compliance steer will contribute oversteer if not controlled.

Independent Suspensions

- Swing Axle
  - The easiest way to get independent rear suspension is by swing axles.

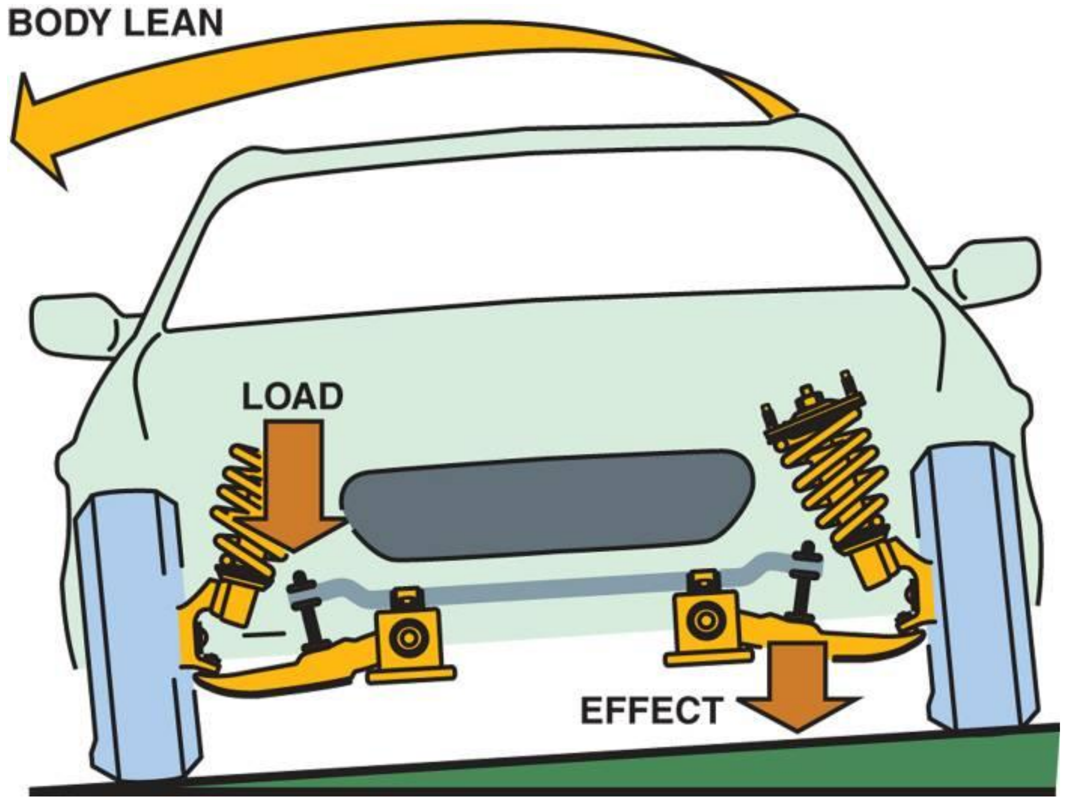


Independent Suspensions

- Swing Axle
  - The camber behavior is established entirely by the axle shafts pivoting at the U-joint adjacent to the differential.
  - The swing radius is small and thus the camber change with jounce and rebound movements can be large.
  - As a result, it is difficult to get consistent cornering performance from swing-axle arrangements

Independent Suspensions

- Stabilizer bar effect



Anti-squat and Anti-pitch Suspension Geometry

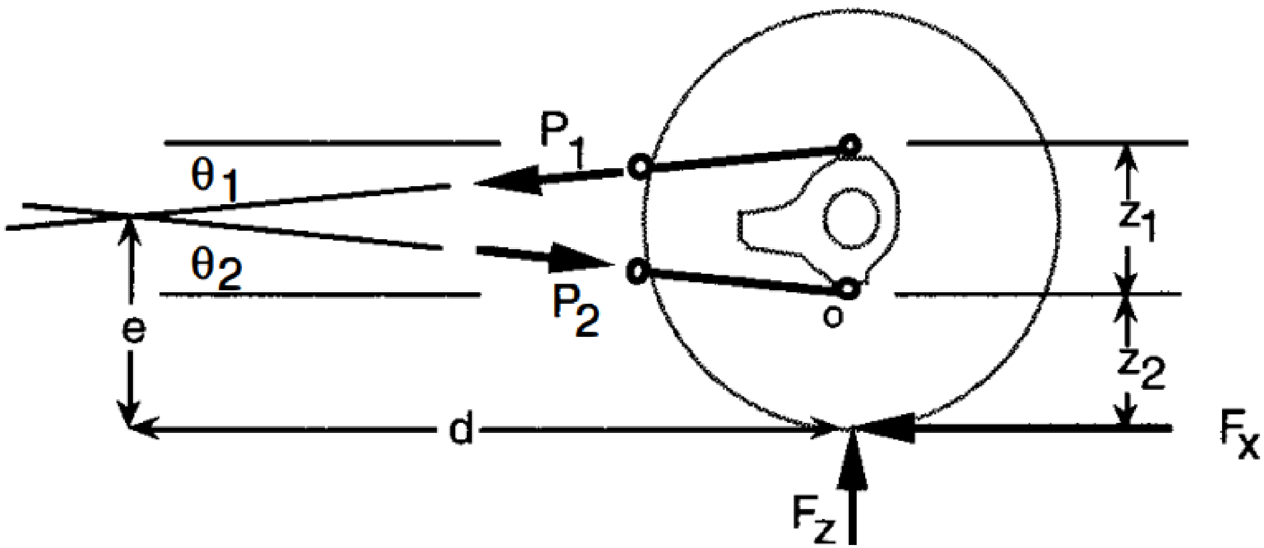
- The load on the rear axle is:

$$W_r = W\left(\frac{b}{L} + \frac{a_x}{g}\frac{h}{L}\right)$$

  - The second term on the right side is the weight transfer effect.
- The weight is transferred to the axle and wheels principally through the suspension. Therefore, there is an implied compression in the rear suspension which, in the case of rear-drive vehicles, has been called "Power Squat.“ Concurrently, there is an associated rebound in the front suspension.
- The combination of rear jounce and front rebound deflections produces vehicle pitch. Suspension systems may be designed to counteract the weight transfer and minimize squat and pitch.

Anti-squat and Anti-pitch Suspension Geometry

- Equivalent Trailing Arm Analysis:
  - Anti-squat forces can be generated on a rear-drive axle by choice of the suspension geometry.
  - All suspensions are functionally equivalent to a trailing arm with regard to the reaction of forces and moments onto the vehicle.
  - Static vertical loads may be neglected in the analysis.



Anti-squat and Anti-pitch Suspension Geometry

- Equivalent Trailing Arm Analysis:
  - Newton's Second Law and moments around the point "O"

$$F_x + P_1 \cos\theta_1 - P_2 \cos\theta_2 = 0$$

$$F_z - P_1 \sin\theta_1 - P_2 \sin\theta_2 = 0$$

$$F_x z_2 - P_1 \cos\theta_1 z_1 = 0 \rightarrow P_1 = \frac{F_x z_2}{z_1 \cos\theta_1}$$

$$\rightarrow P_2 = \frac{F_x (1 + z_2/z_1)}{\cos\theta_2}$$

$$\rightarrow F_z = P_1 \sin\theta_1 + P_2 \sin\theta_2 = F_x \frac{z_2}{z_1} \tan\theta_1 + F_x (1 + \frac{z_2}{z_1}) \tan\theta_2$$

Anti-squat and Anti-pitch Suspension Geometry

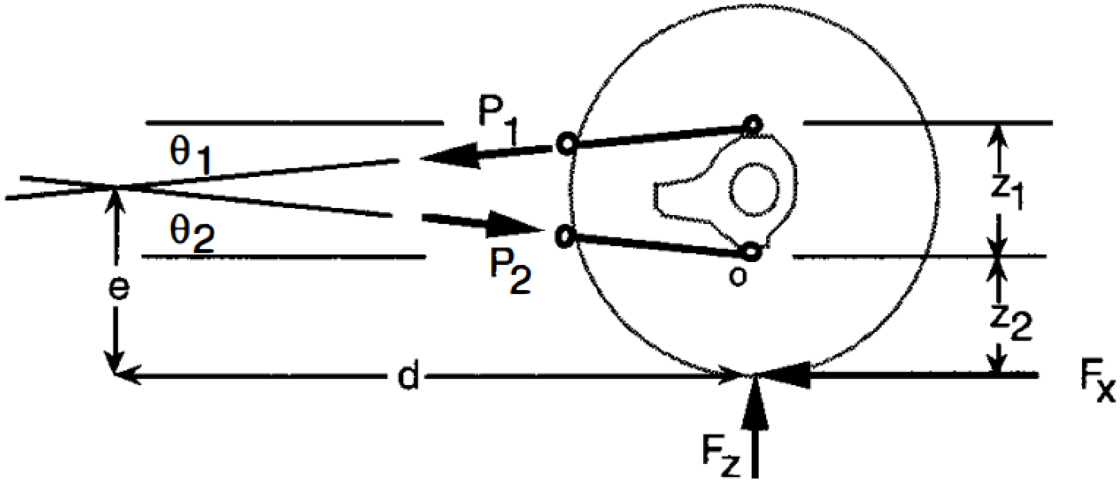
- Equivalent Trailing Arm Analysis:

$$F_z = P_1 \sin\theta_1 + P_2 \sin\theta_2 = F_x \frac{z_2}{z_1} \tan\theta_1 + F_x \left(1 + \frac{z_2}{z_1}\right) \tan\theta_2$$

$$\tan\theta_1 = \frac{z_2 + z_1 - e}{d}$$

$$\tan\theta_2 = \frac{e - z_2}{d}$$

$$\rightarrow \quad \frac{F_z}{F_x} = \frac{e}{d}$$



ANTI-SQUAT AND ANTI-PITCH SUSPENSION GEOMETRY

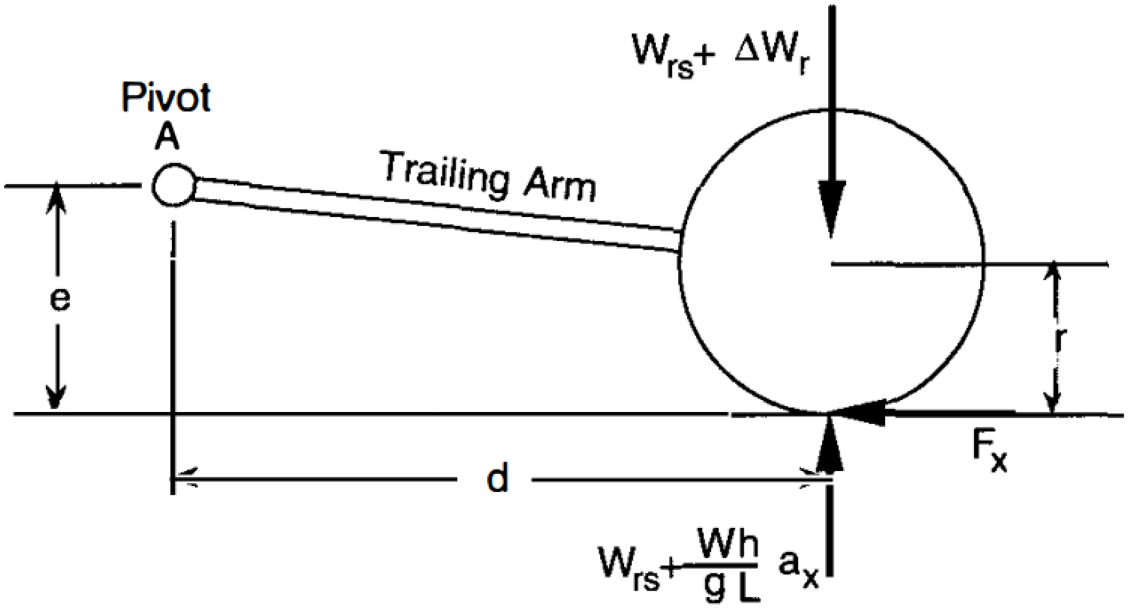
- Equivalent Trailing Arm Analysis: → $\frac{F_z}{F_x} = \frac{e}{d}$

  - The expression is identical to that which would be obtained if the control arms were replaced with a single (trailing) arm pivoting on the body at the projected intersection of the control arm axes.

  - The intersection represents a "virtual reaction point" where the torque reaction of the suspension control arms can be resolved into equivalent longitudinal and vertical forces imposed on the vehicle body.

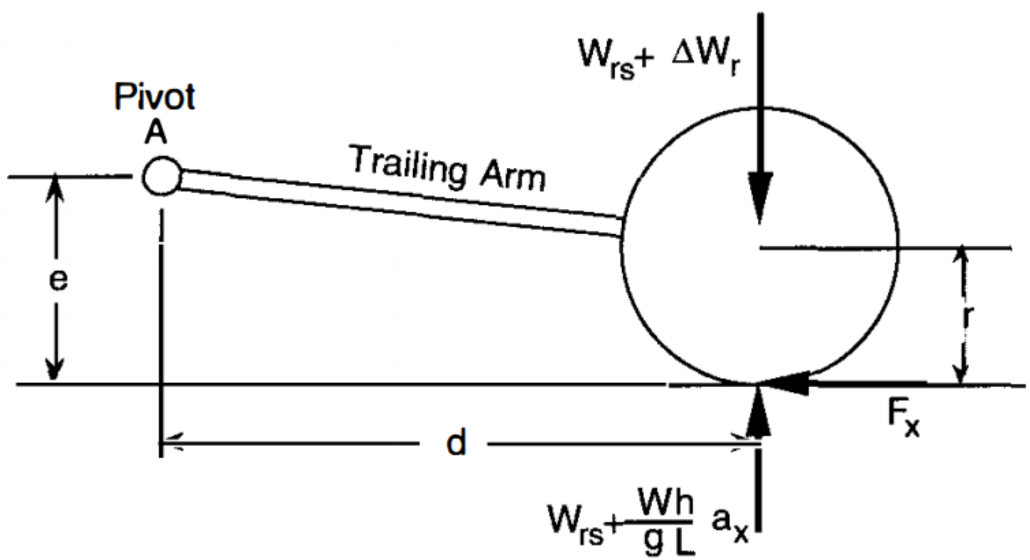
ANTI-SQUAT AND ANTI-PITCH SUSPENSION GEOMETRY

- Equivalent Trailing Arm Analysis:
  - Any suspension is functionally equivalent to a trailing arm
  - The anti-squat performance can be quantified by analyzing the free-body diagram of a rear-drive axle.
  - Point "A" is the imaginary pivot on the vehicle body.



Anti-squat and Anti-pitch Suspension Geometry

- Equivalent Trailing Arm Analysis:
  - Since the arm is rigidly fastened to the axle (resisting axle windup), it has the ability to transmit a vertical force to the sprung mass which can be designed to counteract squat.



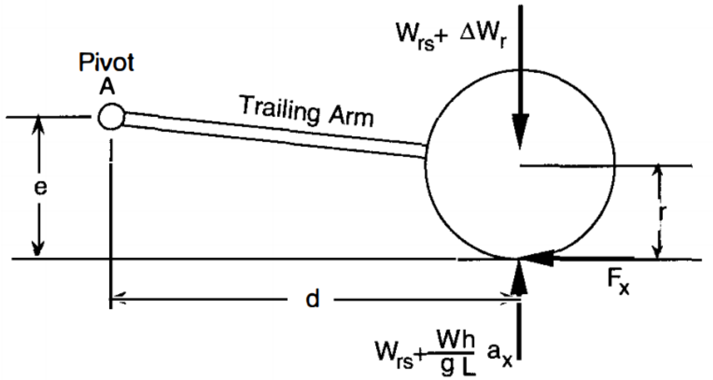
Anti-squat and Anti-pitch Suspension Geometry

- Rear Solid Drive Axle
  - The sum of these torques around the pivot point "A“ must be zero when the system is in equilibrium.
  - For simplicity in the analysis, the rear axle weight will be neglected.

$$\Sigma M_A = W_{rs} d + \frac{W}{g} \frac{h}{L} a_x d - W_{rs} d - \Delta W_r d - F_x e = 0$$

W_{rs} = Static load on the axle = Static load in the suspension

ΔW_r = Change in the suspension load under acceleration



Anti-squat and Anti-pitch Suspension Geometry

- Rear Solid Drive Axle
  - Change in rear suspension load:

$$\Delta W_r = \frac{W}{g}\frac{h}{L}a_x - F_x\frac{e}{d} = K_r\delta_r$$

K_r = Rear suspension spring rate

δ_r = Rear suspension deflection (positive in jounce)

  - The front suspension is undergoing a rebound deflection because of the longitudinal load transfer:

$$\Delta W_f = -\frac{W}{g}\frac{h}{L}a_x = K_f\delta_f$$

Anti-squat and Anti-pitch Suspension Geometry

- Rear Solid Drive Axle
  - The pitch angle of the vehicle during acceleration:

$$\theta_p = \frac{\delta_r - \delta_f}{L} = \frac{1}{L}\frac{W}{g}\frac{h}{L}\frac{a_x}{K_r} - \frac{1}{L}\frac{F_x}{K_r}\frac{e}{d} + \frac{1}{L}\frac{W}{g}\frac{h}{L}\frac{a_x}{K_f}$$

$$= \frac{1}{L}\frac{W}{g}\frac{h}{L}\frac{a_x}{K_r} - \frac{1}{L}\frac{W}{g}\frac{a_x}{K_r}\frac{e}{d} + \frac{1}{L}\frac{W}{g}\frac{h}{L}\frac{a_x}{K_f}$$

$$= \frac{1}{L}\frac{W}{g}a_x\left(\frac{1}{K_r}\frac{h}{L} - \frac{1}{K_r}\frac{e}{d} + \frac{1}{K_f}\frac{h}{L}\right)$$

  - Zero pitch angle is achieved when:

$$\rightarrow \quad \frac{e}{d} = \frac{h}{L} + \frac{h}{L}\frac{K_r}{K_f}$$

Anti-squat and Anti-pitch Suspension Geometry

- Rear Solid Drive Axle

$$\rightarrow \quad \frac{e}{d} = \frac{h}{L} + \frac{h}{L}\frac{K_r}{K_f}$$

- The first term on RHS corresponds to the condition by which anti-squat is achieved on the rear suspension. (If e/d = h/L, the rear suspension will not deflect (Jounce) during acceleration)

- The degree to which this is achieved is described as the percent anti-squat. For example, if e/d = 0.5 h/L, the suspension is said to be 50% anti-squat.

- Since h/L is about 0.2 for most passenger cars, full anti-squat generally requires an effective trailing arm length of 5 times the elevation of “e”

- Normally some degree of squat and pitch is expected during vehicle acceleration, so full compensation is unusual.

Anti-squat and Anti-pitch Suspension Geometry

- Independent Rear Drive
  - The analysis is changed slightly…

$$\Sigma M_A = W_{rs} d + \frac{W}{g}\frac{h}{L} a_x d - W_{rs} d - \Delta W_r d - F_x (e - r) = 0$$

$$\rightarrow \theta_p = \frac{1}{L}\frac{W}{g} a_x \left(\frac{1}{K_r}\frac{h}{L} - \frac{1}{K_r}\frac{e-r}{d} + \frac{1}{K_f}\frac{h}{L} \right)$$

$$\rightarrow \frac{e-r}{d} = \frac{h}{L} + \frac{h}{L}\frac{K_r}{K_f}$$

- ✓ Similarly, 100% anti-squat in the rear suspension corresponds to $(e-r)/d = h/L$

ANTI-SQUAT AND ANTI-PITCH SUSPENSION GEOMETRY

- Front Solid Drive Axle
  - Performing this type of analysis only results in a change of sign on some of the terms

$$\rightarrow \quad \theta_p = \frac{1}{L}\frac{W}{g} a_x \left(\frac{1}{K_r}\frac{h}{L} + \frac{1}{K_f}\frac{h}{L} + \frac{1}{K_f}\frac{e}{d}\right)$$

$$\rightarrow \quad \frac{e}{d} = -\frac{h}{L} - \frac{h}{L}\frac{K_f}{K_r}$$

✓ The first term on RHS now corresponds to an anti-lift on the front axle, rather than an anti-squat on the rear axle.

ANTI-SQUAT AND ANTI-PITCH SUSPENSION GEOMETRY

- Independent Front-Drive Axle
  - The comparable equations for an independent front-drive axle, as is common on most front-drive cars today:

$$\theta_p = \frac{1}{L}\frac{W}{g}a_x\left(\frac{1}{K_r}\frac{h}{L} + \frac{1}{K_f}\frac{h}{L} + \frac{1}{K_f}\frac{e-r}{d}\right)$$

$$\frac{e-r}{d} = -\frac{h}{L} - \frac{h}{L}\frac{K_f}{K_r}$$

Anti-squat and Anti-pitch Suspension Geometry

- Four-Wheel Drive
  - The performance will depend on how the tractive force is distributed between the front and rear axles.

$$F_{xf} = \xi F_x \quad \text{and} \quad F_{xr} = (1 - \xi) F_x$$

  - Change in load on each axle:

$$\Delta W_r = \frac{W}{g}\frac{h}{L} a_x - (1 - \xi) F_x \frac{e_r - r}{d_r} = K_r \delta_r$$

$$\Delta W_f = \frac{W}{g}\frac{h}{L} a_x + \xi F_x \frac{e_f - r}{d_f} = K_f \delta_f$$

  - The pitch equation:

$$\theta_p = \frac{1}{L}\frac{W}{g} a_x \left(\frac{1}{K_r}\frac{h}{L} - \frac{(1 - \xi)}{K_r}\frac{e_r - r}{d_r} + \frac{1}{K_f}\frac{h}{L} + \frac{\xi}{K_f}\frac{e_f - r}{d_f} \right)$$

Anti-dive Suspension Geometry

- The longitudinal load transfer incidental to braking acts to pitch the vehicle forward producing “brake dive”

- Just as a suspension can be designed to resist acceleration squat, the same principles apply to generation of anti-dive forces during braking.

- Because virtually all brakes are mounted on the suspended wheel, the brake torque acts on the suspension and by proper design can create forces which resist dive.

Anti-dive Suspension Geometry

- Using similar analysis…
- For anti-dive:
  - Front suspension: $$\frac{e_f}{d_f} = \tan\beta_f = -\frac{h}{\xi L}$$
  - Rear suspension: $$\frac{e_r}{d_r} = \tan\beta_r = \frac{h}{(1-\xi)L}$$
    - ✓ Fraction of the brake force developed on the front axle: ξ
  - To obtain 100% anti-dive on the front and 100% anti-lift on the rear, the pivot for the effective trailing arm must fall on the locus of points defined by these ratios.

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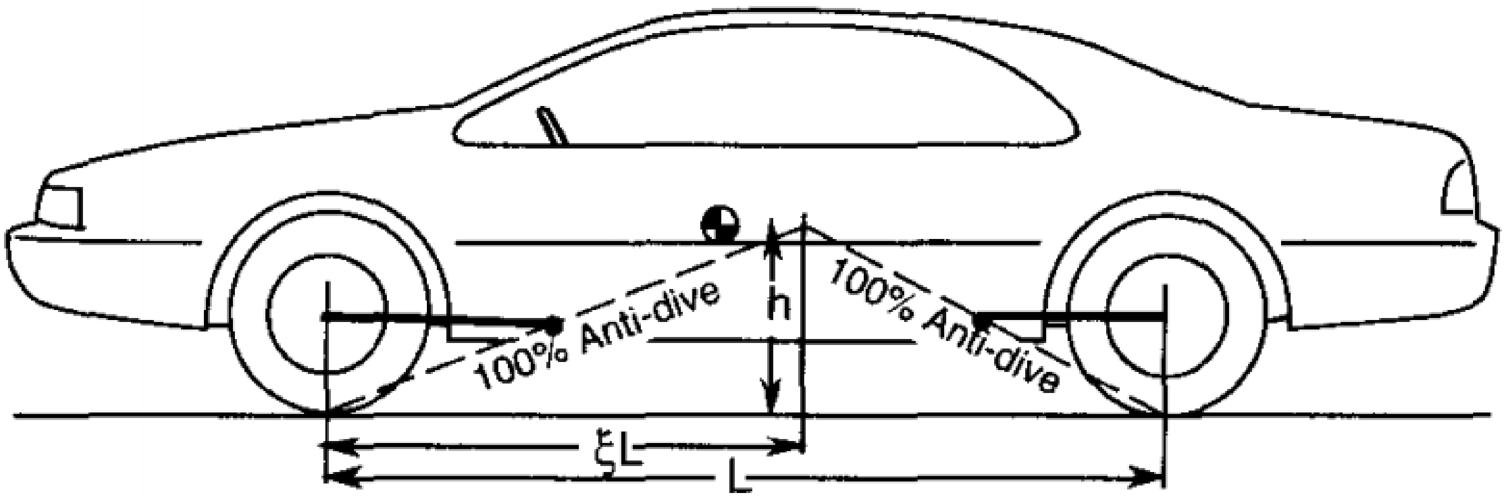
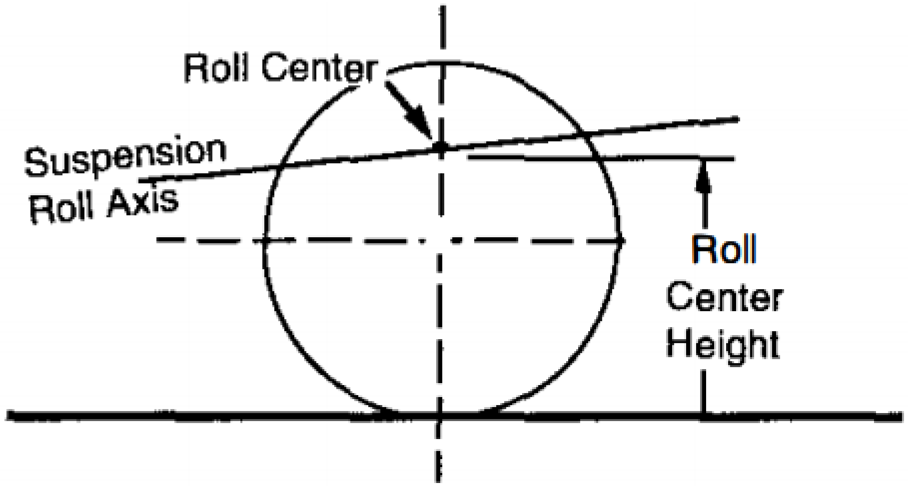
Anti-dive Suspension Geometry

- If the pivots are located below the locus, less than 100% anti-dive will be obtained; if above the locus the front will lift and the rear will squat during braking.
- In practice, 100% anti-dive is rarely used. The maximum anti-dive seldom exceeds 50%.



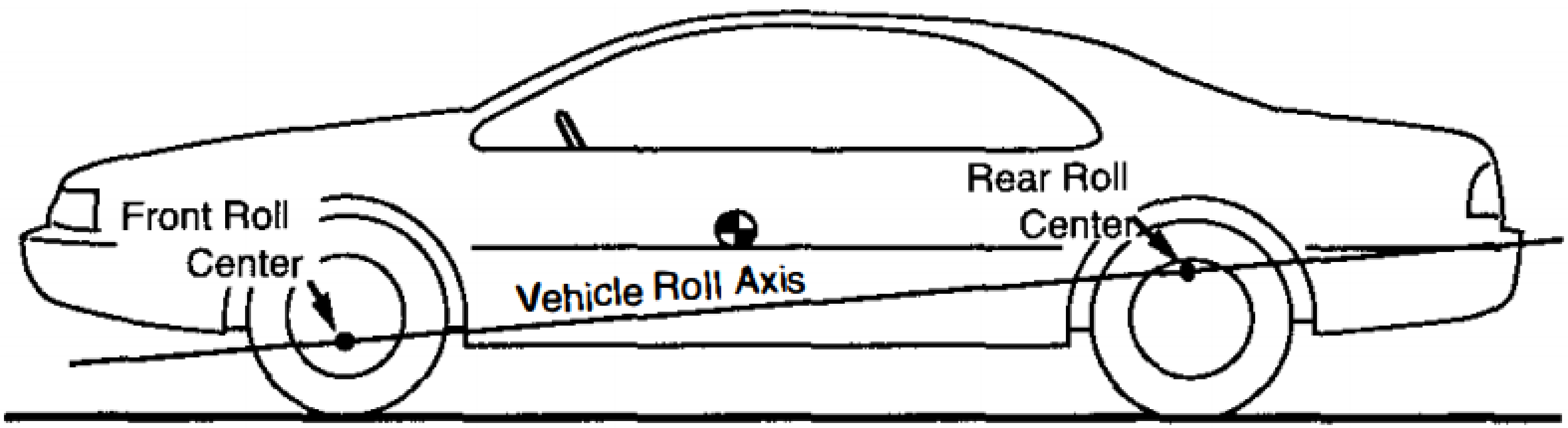
Roll Center Analysis

- Roll center:
  - The location at which lateral forces developed by the wheels are transmitted to the sprung mass.
  - The roll center affects the behavior of both the sprung and unsprung masses, and thus directly influences cornering.
  - The roll center is the intersection of the suspension roll axis with the vertical plane through the centers of the two wheels.



Roll Center Analysis

- Once the front and rear suspension roll centers are located, the vehicle roll axis is defined by the line connecting the centers.
- This axis is the instantaneous axis about which the total vehicle rolls with respect to the ground.

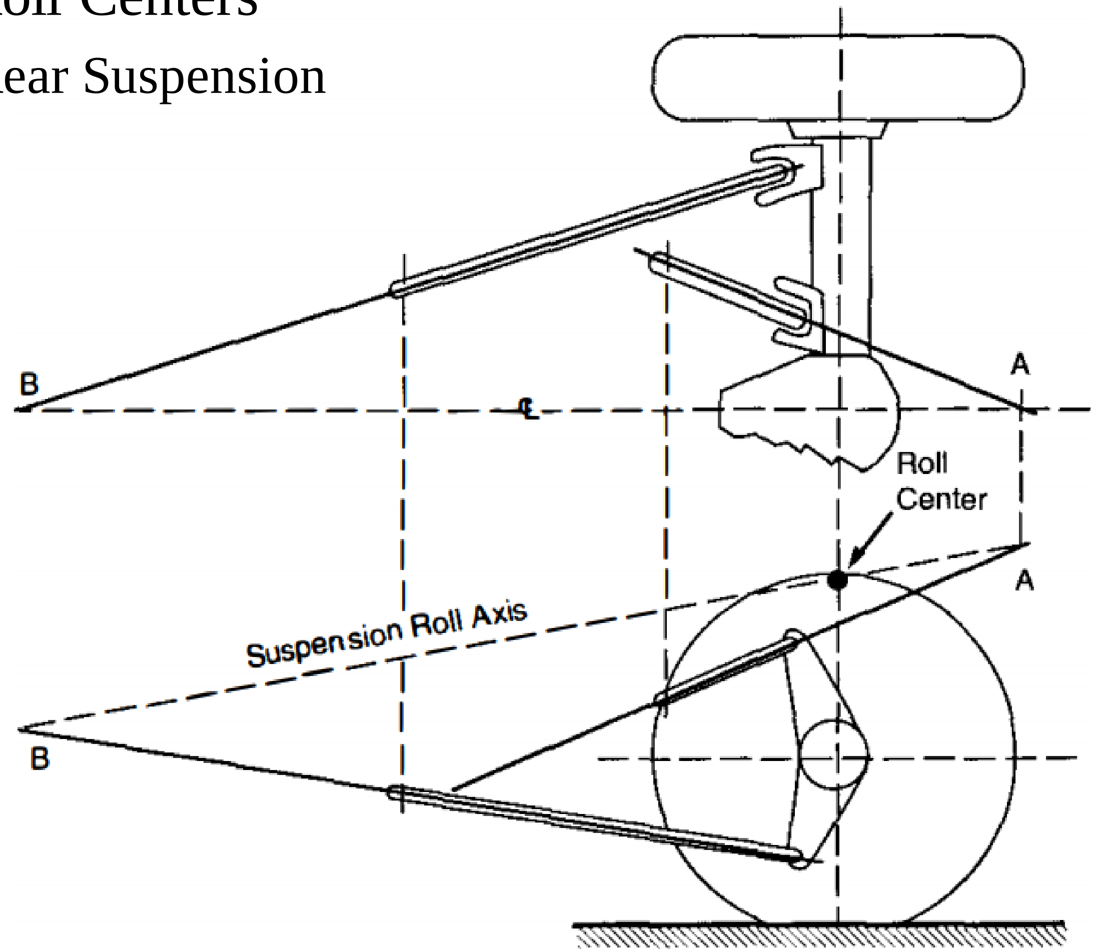


Roll Center Analysis

- Solid Axle Roll Centers
  - The suspension roll axis and roll center can be determined from the layouts of the suspension geometry in the plan and elevation views.
  - For the analysis we draw again on the concept of a "virtual reaction point." (instant center)
  - Physically, the virtual reaction point is the intersection of the axes of any pair of suspension control arms.

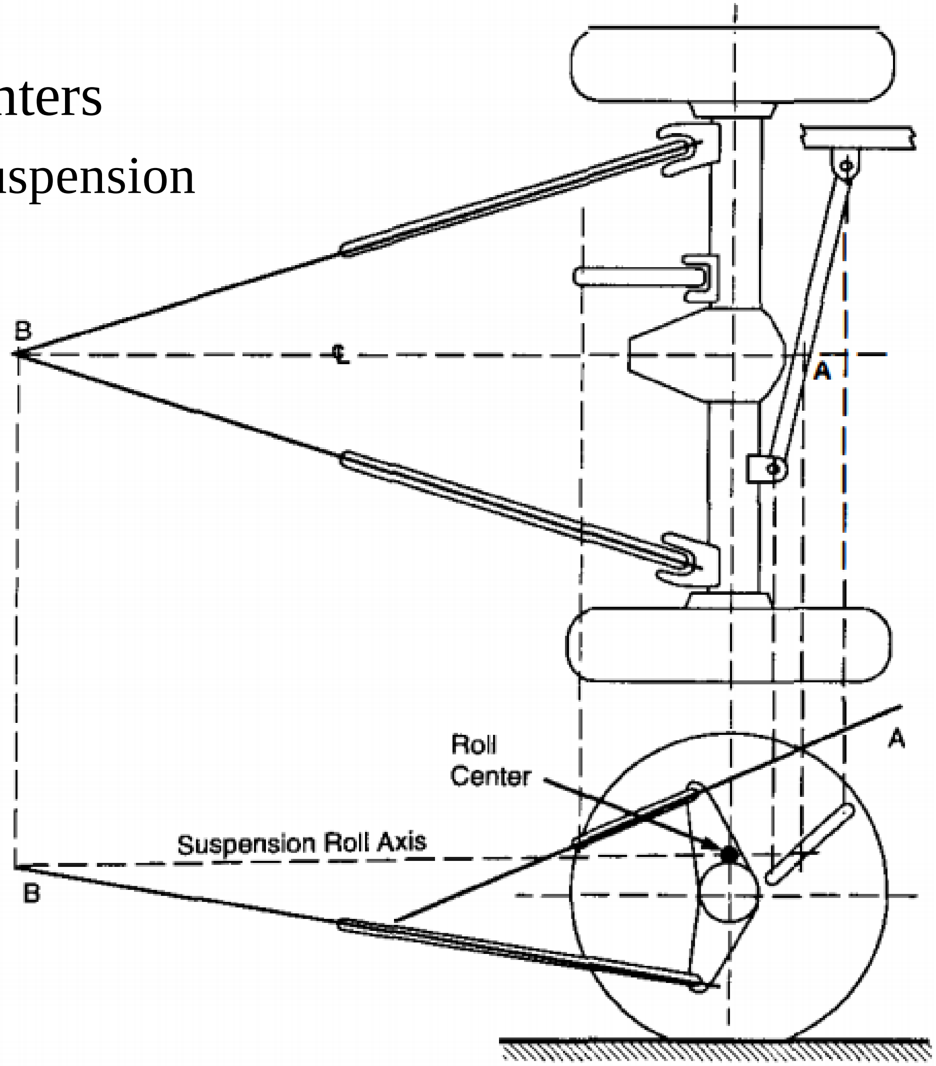
Roll Center Analysis

- Solid Axle Roll Centers
  - Four-Link Rear Suspension



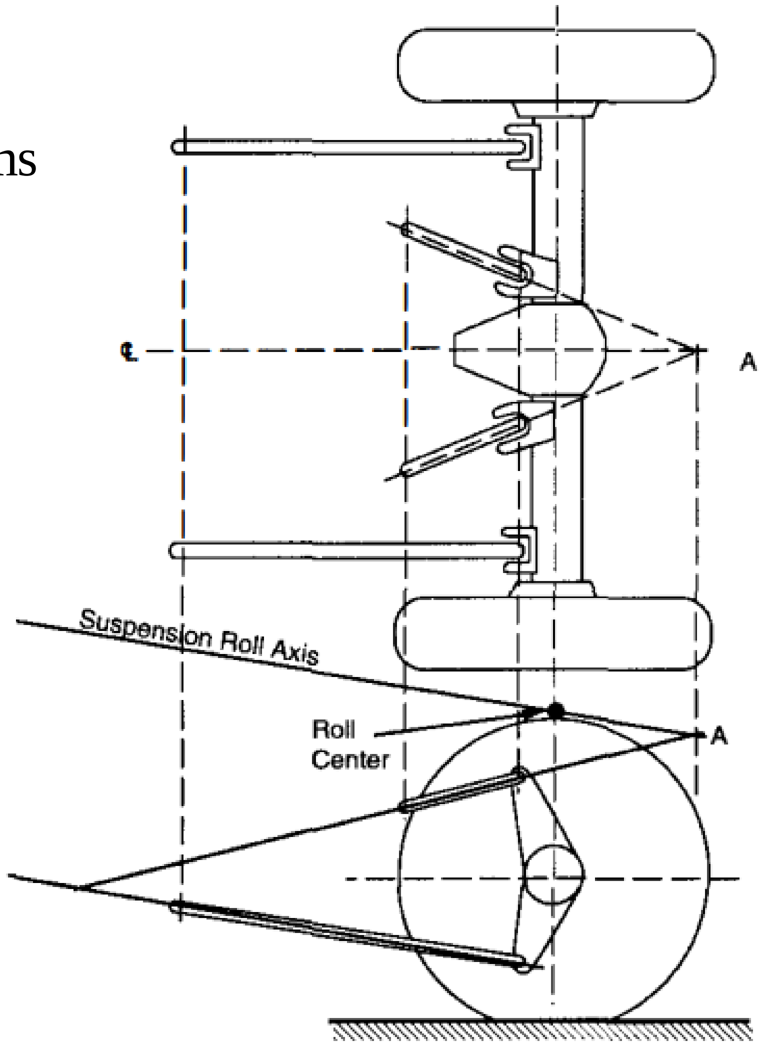
Roll Center Analysis

- Solid Axle Roll Centers
  - Three-Link Rear Suspension



Roll Center Analysis

- Solid Axle Roll Centers
  - Four-Link with Parallel Arms



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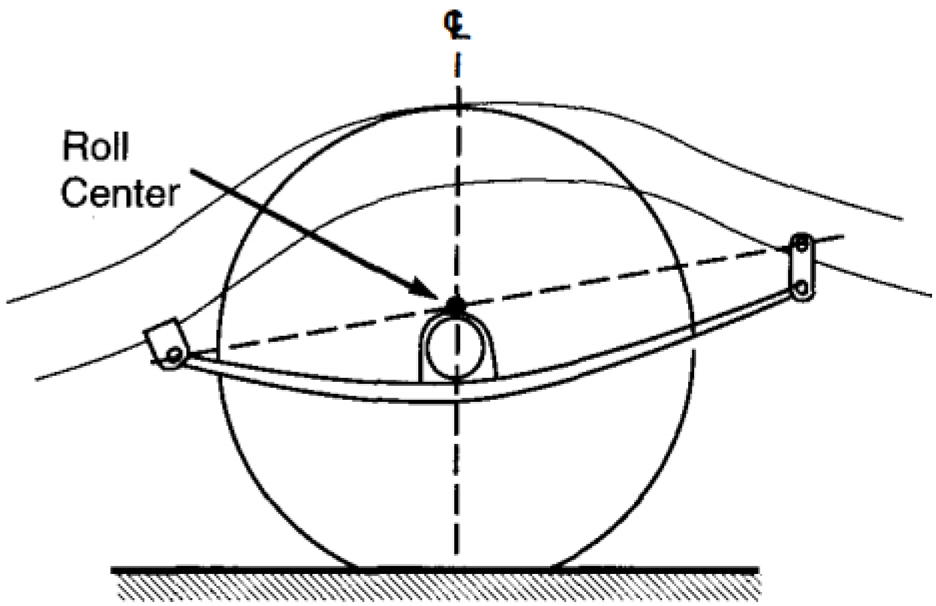
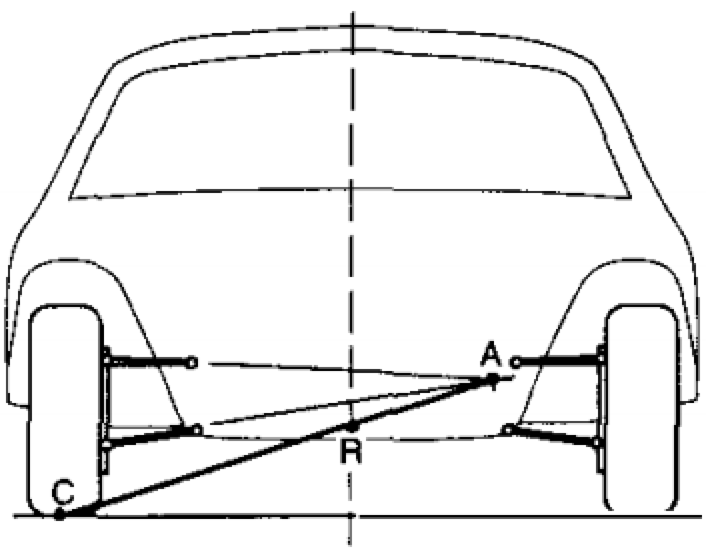
Roll Center Analysis

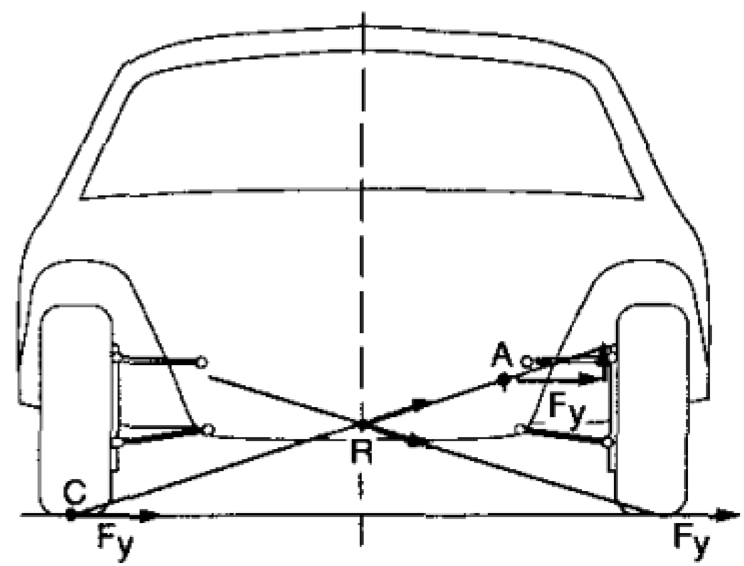
- Solid Axle Roll Centers
  - Hotchkiss Suspension
    - ✓ The design of this suspension is quite differenty, but the general rules for determining the roll axis and center still apply.



Roll Center Analysis

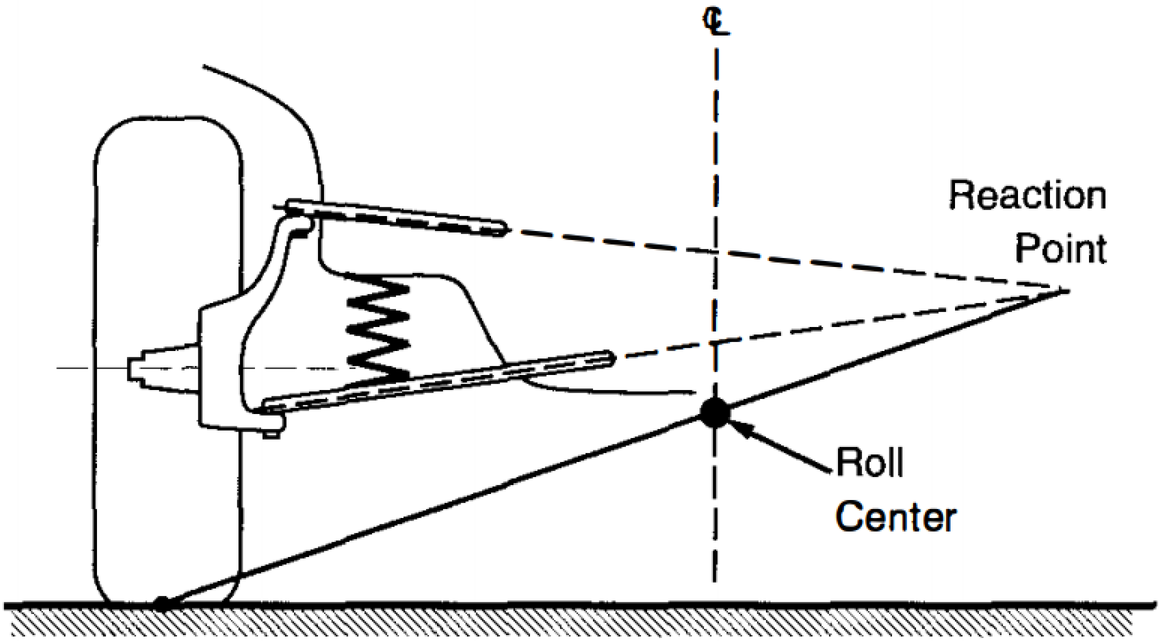
- Independent Suspension Roll Centers
  - Determining the roll center of an independent suspension requires a slightly different application of the virtual reaction point concept…





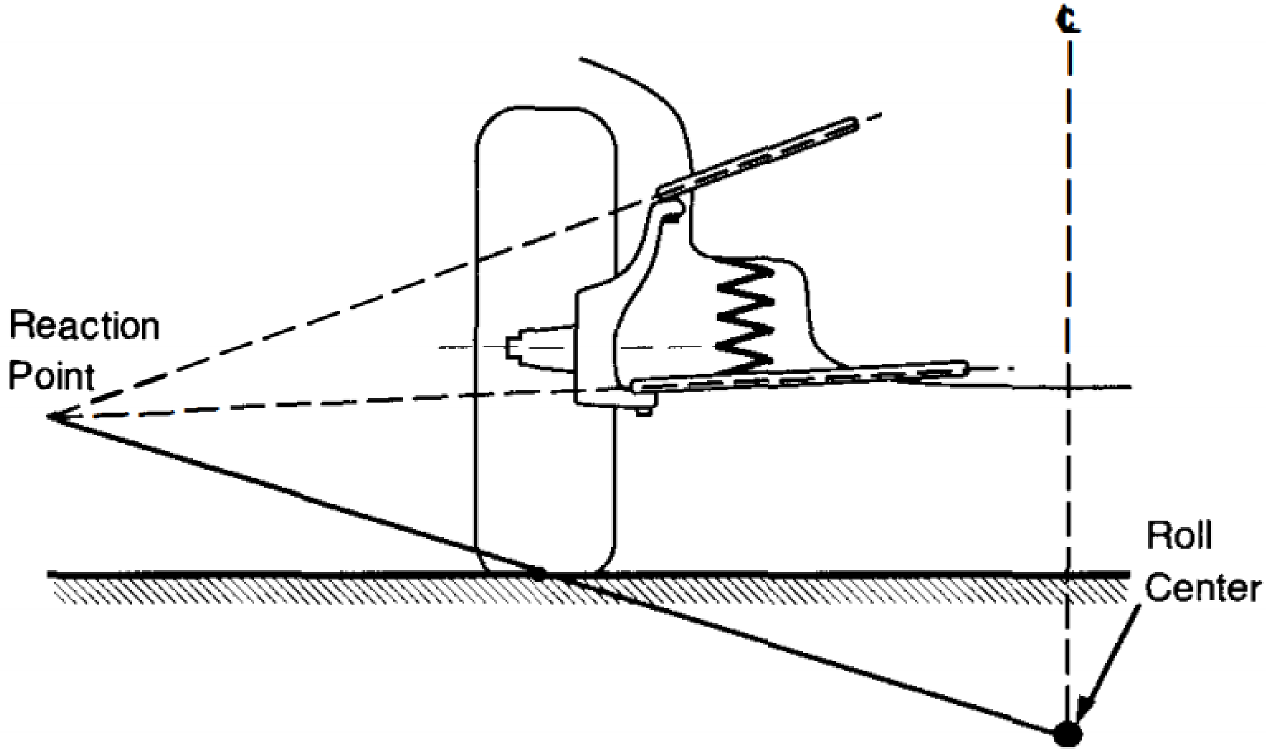
Roll Center Analysis

- Independent Suspension Roll Centers
  - Positive Swing Arm Geometry



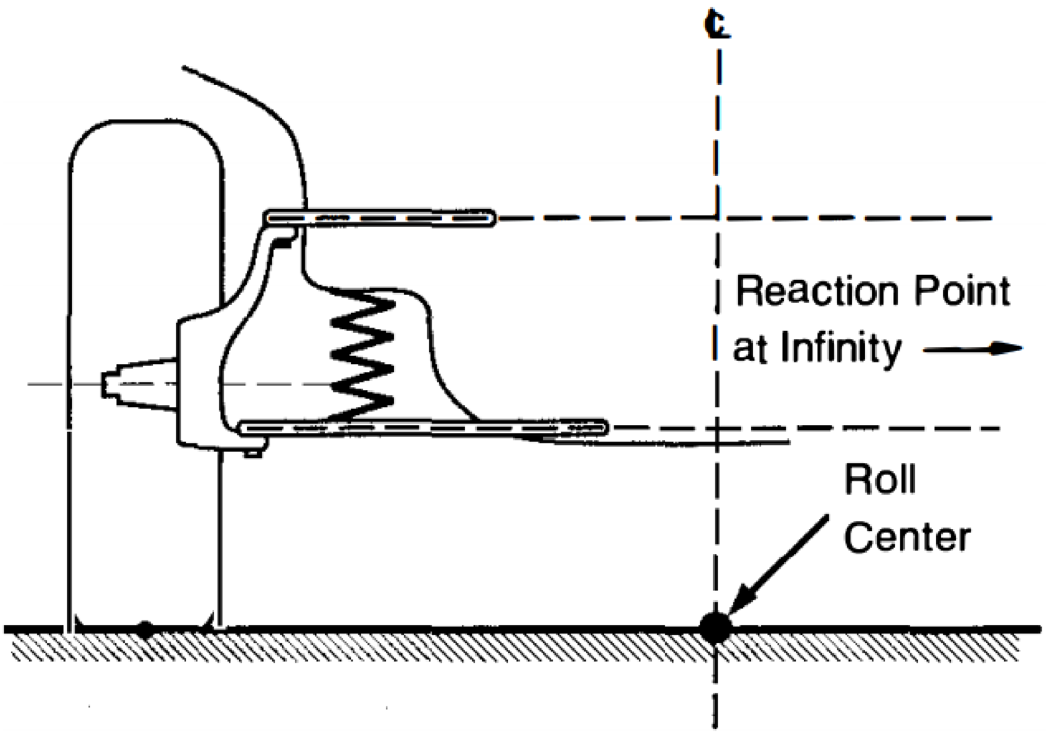
Roll Center Analysis

- Independent Suspension Roll Centers
  - Negative Swing Arm Geometry



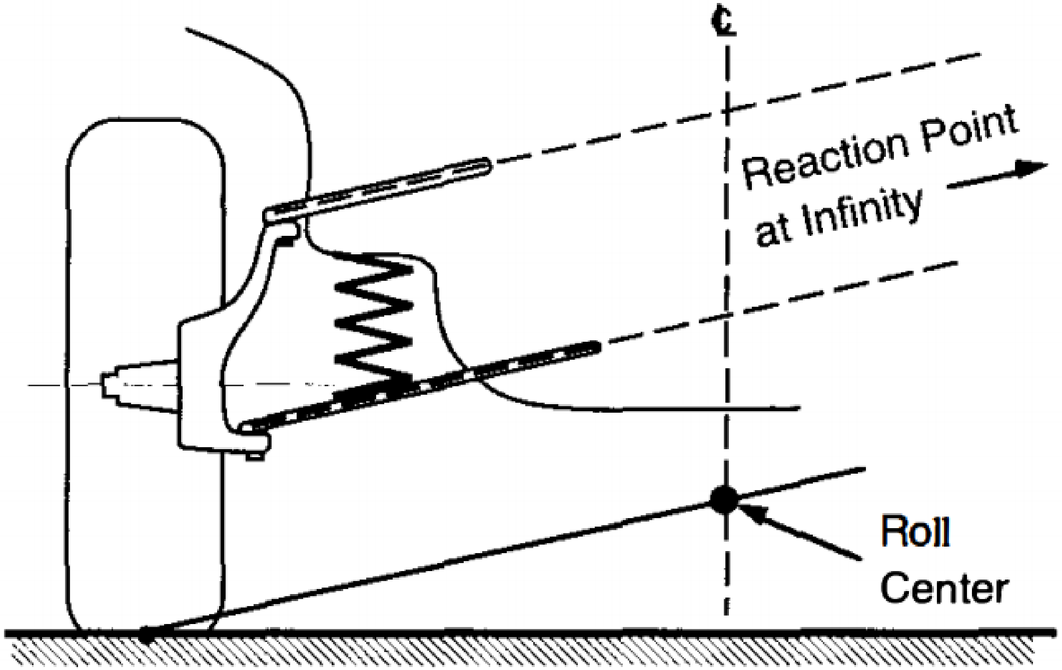
Roll Center Analysis

- Independent Suspension Roll Centers
  - Parallel Horizontal Links



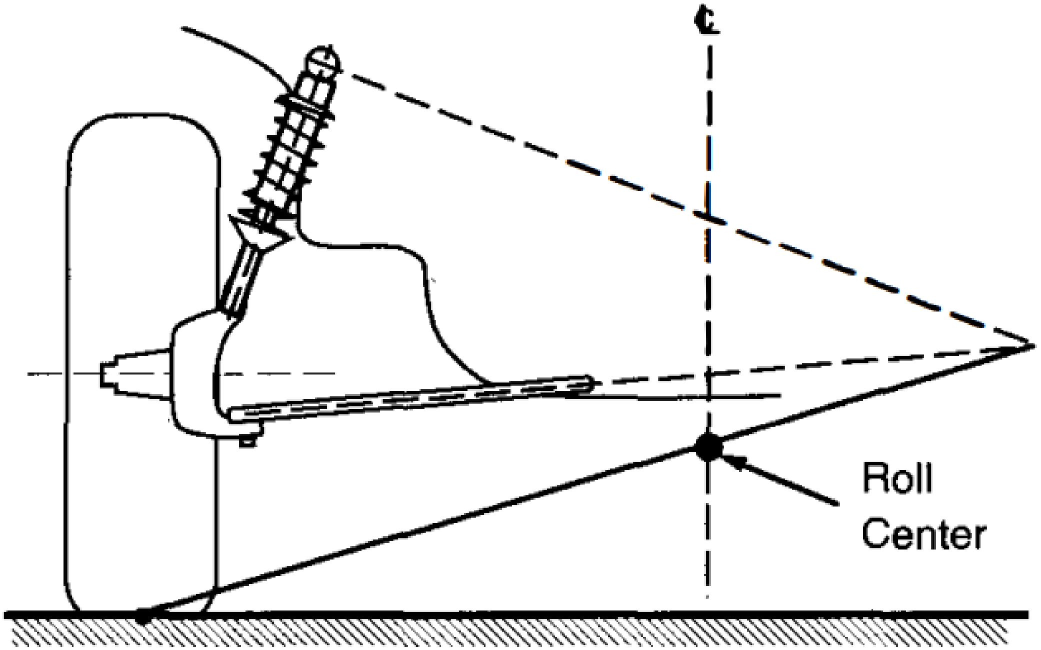
Roll Center Analysis

- Independent Suspension Roll Centers
  - Inclined Parallel Links



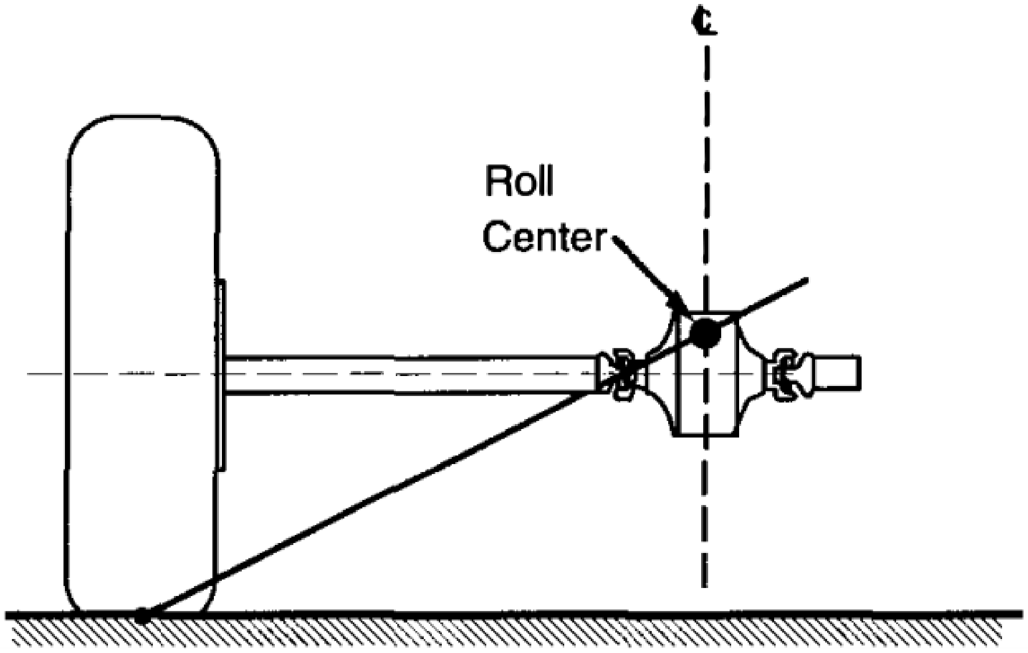
Roll Center Analysis

- Independent Suspension Roll Centers
  - MacPherson Strut



Roll Center Analysis

- Independent Suspension Roll Centers
  - Swing Axle



ACTIVE SUSPENSIONS

- In the interest of improving the overall performance of automotive vehicles in recent years, suspensions incorporating active components have been developed.

- Suspension Categories:
  - Passive suspensions
  - Self-leveling suspensions
  - Semi-active suspensions
  - Full-Active suspensions

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Active Suspensions

- Suspension Categories:
  - Passive suspensions
    - ✓ Consist of conventional components with spring and damping (shock absorber) properties which are time-invariant.
    - ✓ Passive elements can only store energy for some portion of a suspension cycle (springs) or dissipate energy (shock absorbers).
    - ✓ No external energy is directly supplied to this type of suspension.

Active Suspensions

- Suspension Categories:
  - Self-leveling suspensions
    - ✓ The primary lift component (usually air springs) can adjust for changes in load
    - ✓ Air suspensions, which are self-leveling, are used on many heavy trucks and on a few luxury passenger cars.
    - ✓ A height control valve monitors the suspension deflection, and when its mean position has varied from normal ride height for a designated period of time (typically more than 5 seconds), the air pressure in the spring is adjusted to bring the deflection within the desired range.
    - ✓ The most notable feature of an air suspension is that as the pressure changes with load, the spring stiffness changes correspondingly causing the natural frequency of the suspension to remain constant.

Active Suspensions

- Suspension Categories:
  - Semi-active suspensions
    - ✓ Contain spring and damping elements, the properties of which can be changed by an external control. A signal or external power is supplied to these systems for purposes of changing the properties.
    - ✓ There are several sub-categories of semi-active systems:
      - **1) Slow-active:**
        - Can be switched between several discrete levels in response to changes in driving conditions. Slow-active systems may also be called "adaptive" suspensions.
      - **2) Low-bandwidth:**
        - Modulated continuously in response to low-frequency sprung mass motions (1-3 Hz)
      - **3) High-bandwidth:**
        - Modulated continuously in response to both low-frequency sprung mass motions (1-3 Hz) and high-frequency axle motions (10-15 Hz).

Active Suspensions

- Suspension Categories:
  - Full-Active suspensions
    - ✓ Incorporate actuators to generate the desired forces in the suspension.
    - ✓ The actuators are normally hydraulic cylinders.
    - ✓ External power is required to operate the system.
    - ✓ Full active systems may be classified as low-bandwidth or high-bandwidth according to the definitions given above.

ACTIVE SUSPENSIONS

- Functions
  - The modes of performance that can be improved by active control:
    - ✓ Ride Control
    - ✓ Height Control
    - ✓ Roll Control
    - ✓ Dive Control
    - ✓ Squat Control
    - ✓ Road Holding

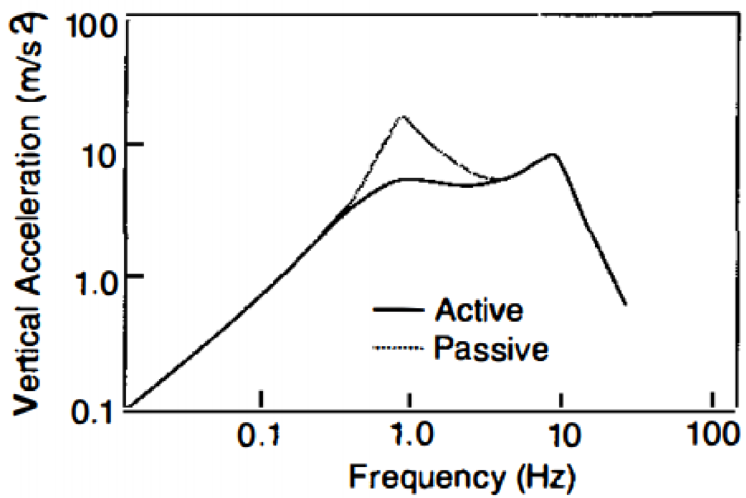
Active Suspensions

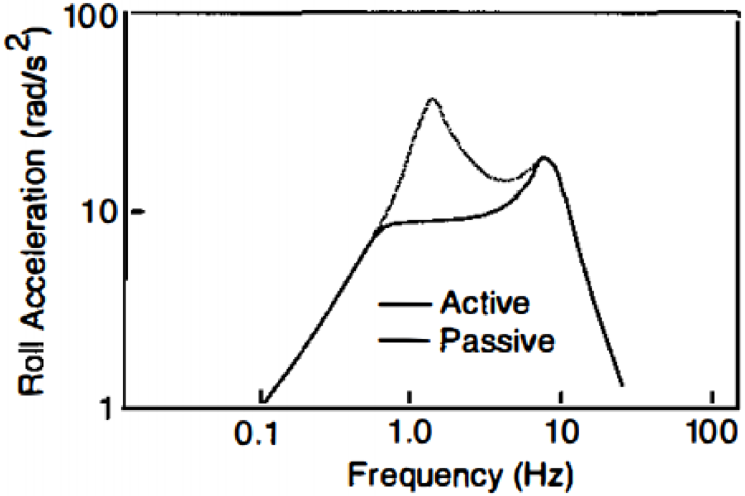
- Performance
  - In general, the semi-active and full-active suspension systems have the greatest capability to achieve optimum performance in the different modes, but at a penalty in weight, cost, complexity and reliability.
  - Performance Potential of Various Types of Suspension Systems

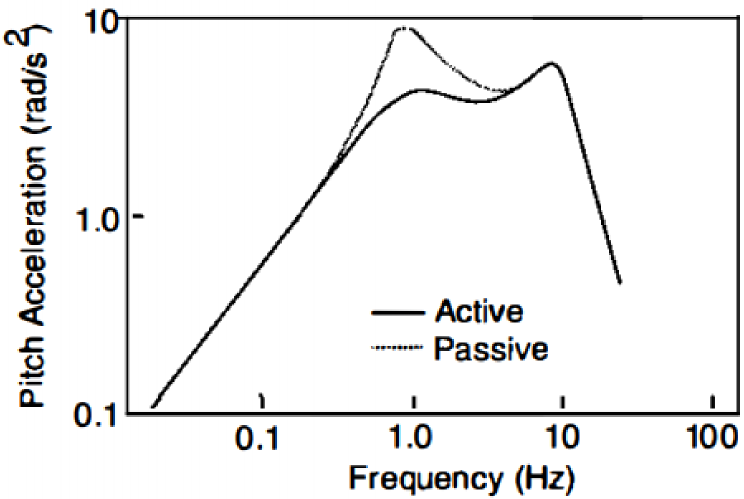
	Performance Mode					
Suspension Type	Ride	Height	Roll	Dive	Squat	Road-holding
Passive	Performance is a compromise between all modes					
Self-leveling	High	High	NA	NA	NA	NA
Semi-active	Medium	NA	Low	Low	Low	Medium
Full-active	High	High	High	High	High	High

Active Suspensions

- Performance
  - Comparison of responses







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