

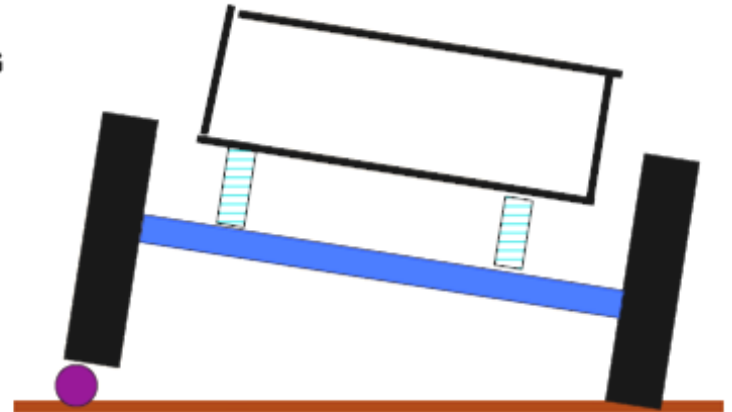
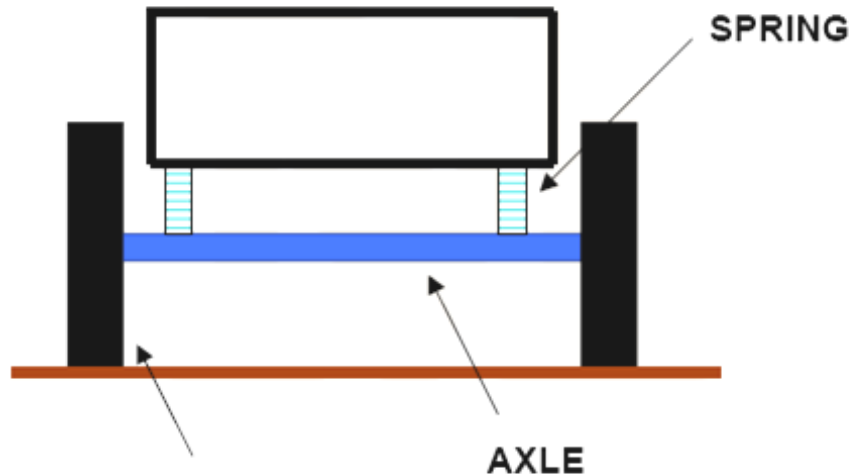
Chapter-10

- Vehicle Suspension System
- Dependent and Independent Suspensions in Vehicles
- Semi Active and Active Suspension Technologies

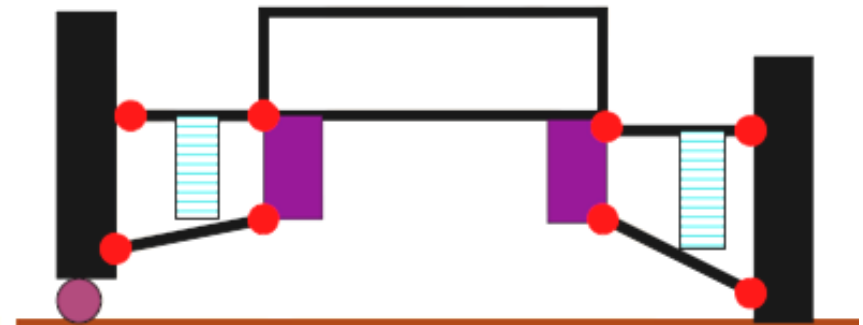
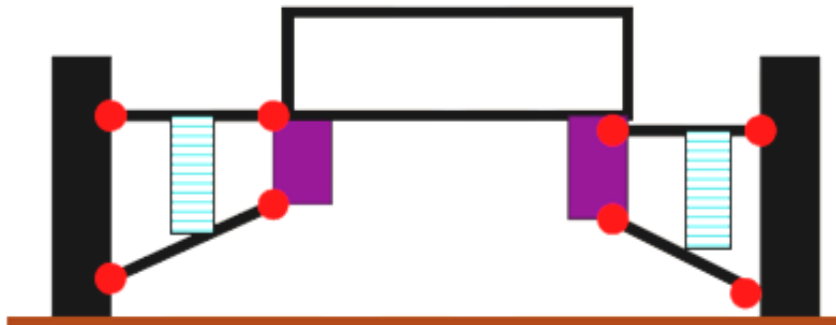
Vehicle Suspension

Suspension refers to the use of front and rear springs to suspend a vehicle's frame, body, engine & power train above the wheels.

Solid Axle or Rigid or Dependent Suspension

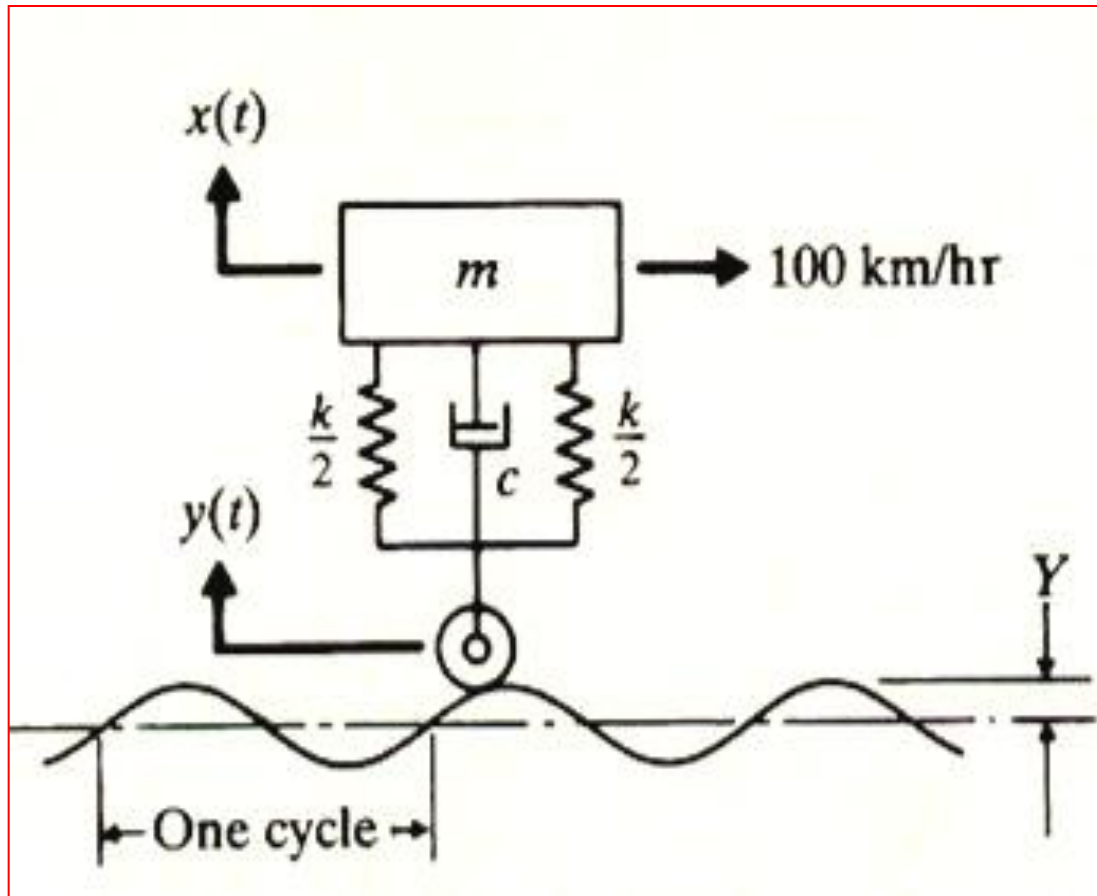


Independent Suspension



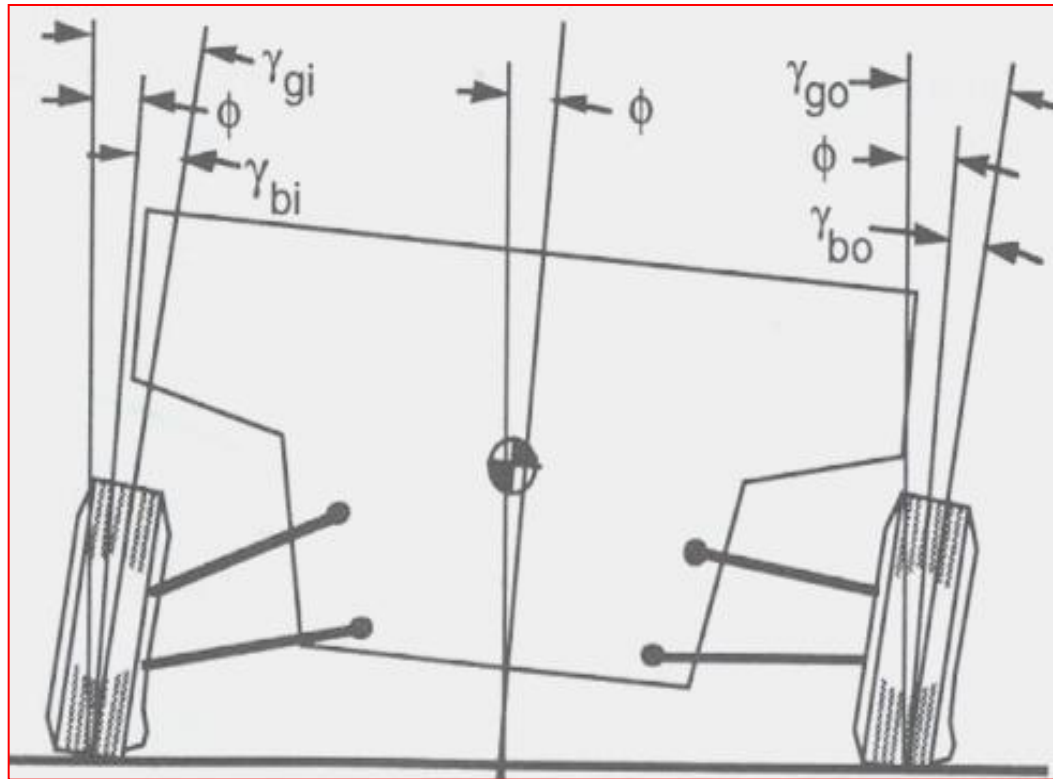
Functions of a Suspension System

- Provide vertical compliance so the wheels can follow the uneven road, isolating the chassis from roughness in the road.



Functions of a Suspension System

- Maintain the wheels in the proper steer and camber attitudes to the road surface.



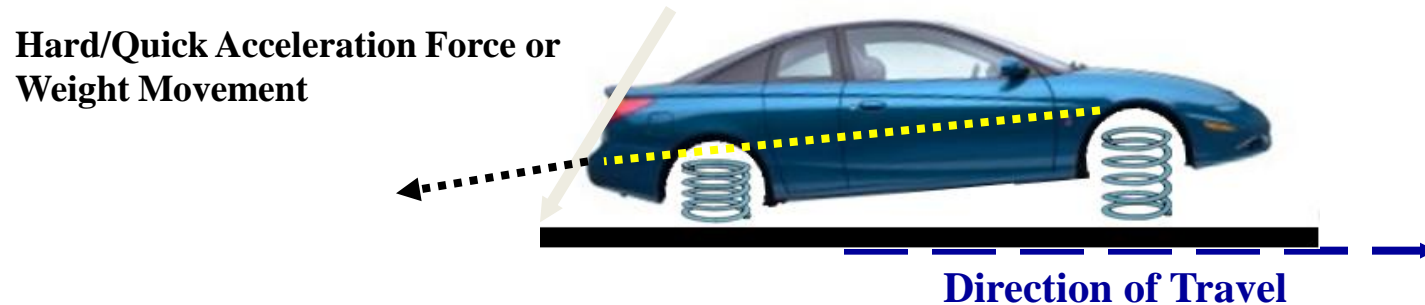
γ_g = Camber angle of the wheel with respect to the ground

γ_b = Camber angle of the wheel with respect to the body

ϕ = Roll angle of the vehicle

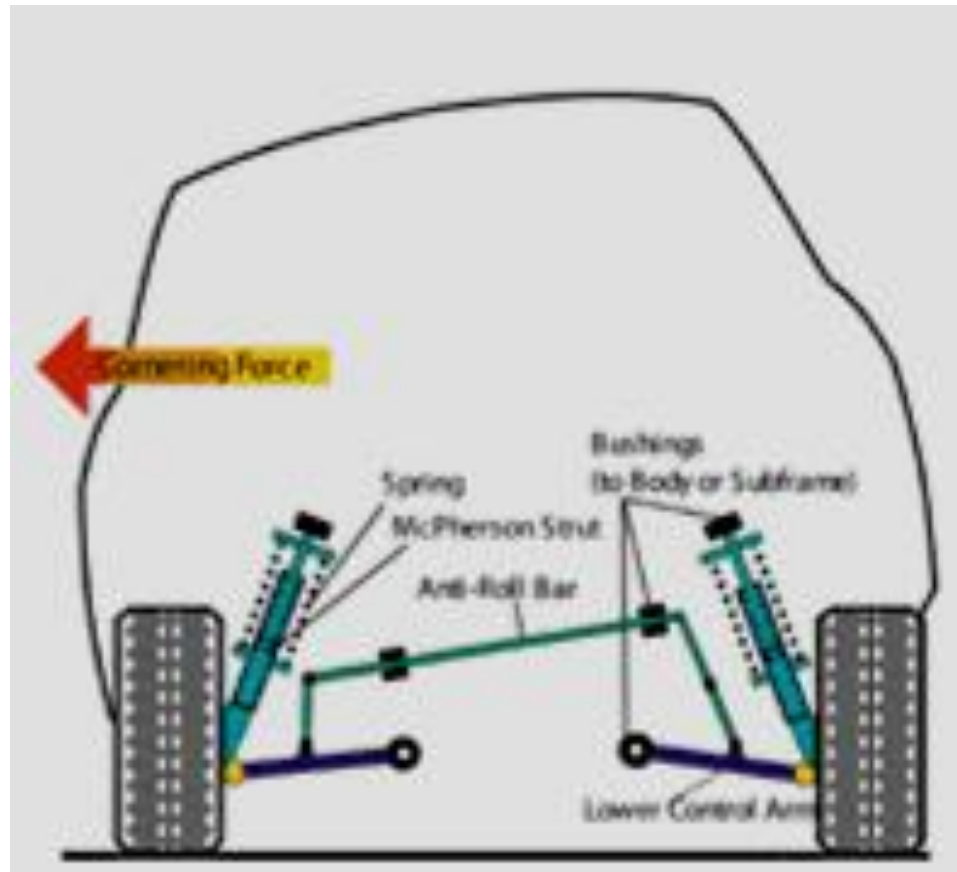
Functions of a Suspension System

- React to the control forces produced by the tires – longitudinal (acceleration and braking) forces, lateral (cornering) forces, and braking and driving torques.

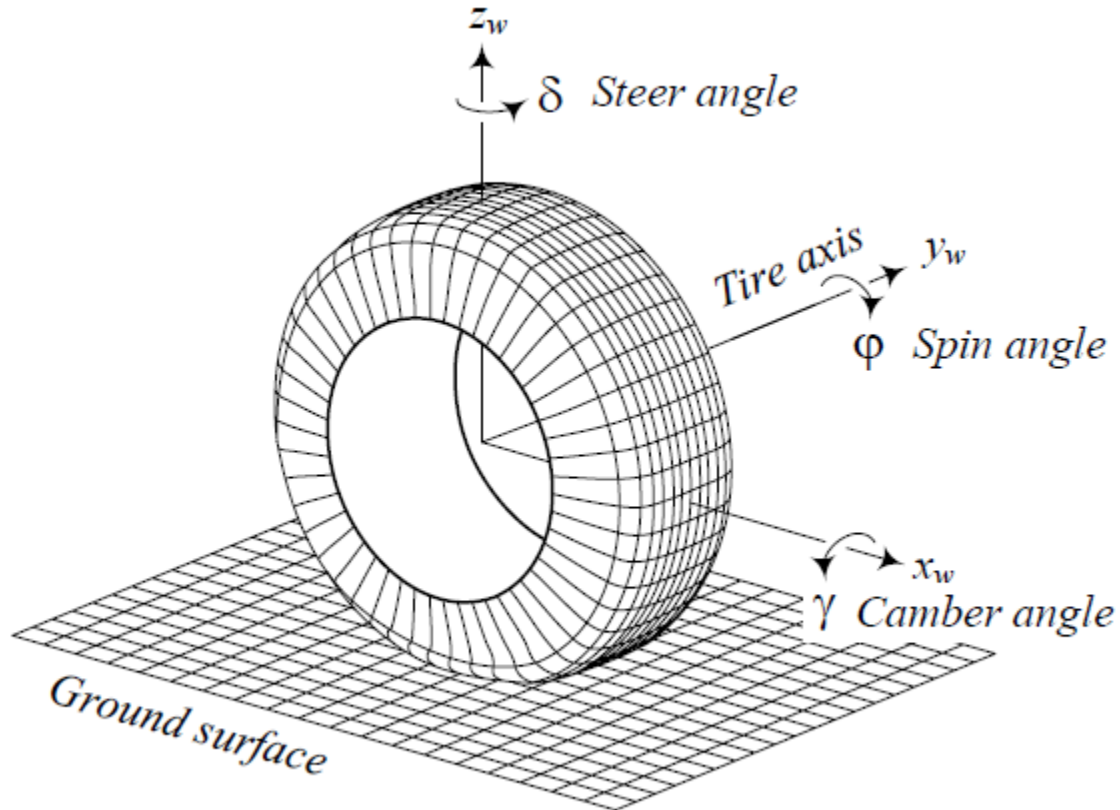


Functions of a Suspension System

- Resist roll of the chassis.



Wheel - Degrees of Freedom



X_w - forward

Y_w - lateral

Z_w - vertical

translations and rotations

Degrees of freedom and Motion Path

- Wheel should move relative to the car body in a single prescribed path
- During the movement of the wheel relative to car body , the wheel must have **camber gain, caster change, toe change as prescribed by the designer**
- The suspension linkages position the wheel (Knuckle) very accurately in all directions but allow the wheel to move up and down against spring and shock
- In front suspension we do have a steer rotation degree of freedom when demanded from the steering system

Degrees of Restraint

- An independent suspension allows only one path of motion of the knuckle relative to the body
- Suspension limits five degrees of restraint (DOR)-limits motion
- Designer strive to determine how to limit motion in five degree of freedom in case of Independent suspension
- **To provide restraint in five degree require five tension and compression links and for 4 DOR, 4 links are required**

Kinematic Linkages

4 D.O.R. Requires 4 Links / 5 D.O.R. Requires 5 Links

Simple Tension - Compression Links



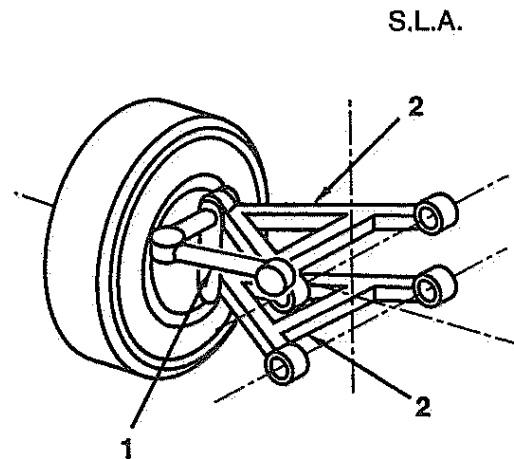
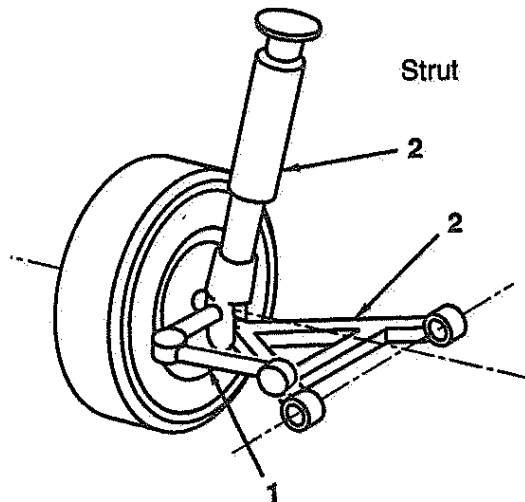
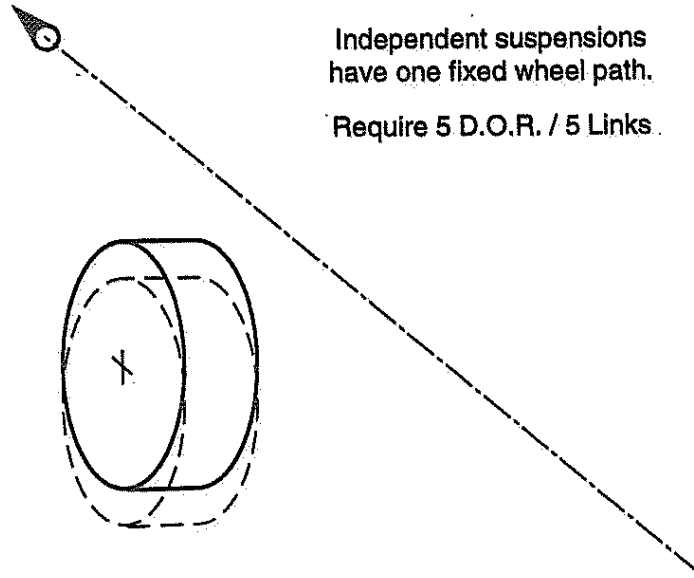
A-Arm = 2 Links



MacPherson Strut = 2 Links;
Slider = A-Arm of Infinite Length

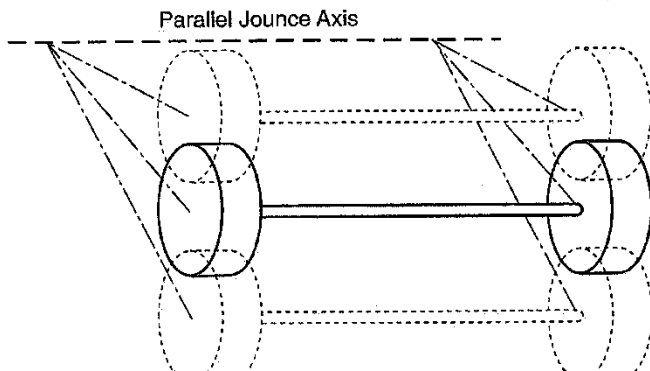


Example- Double Wishbone/Macpherson Suspension



Solid Axle or Dependent Type

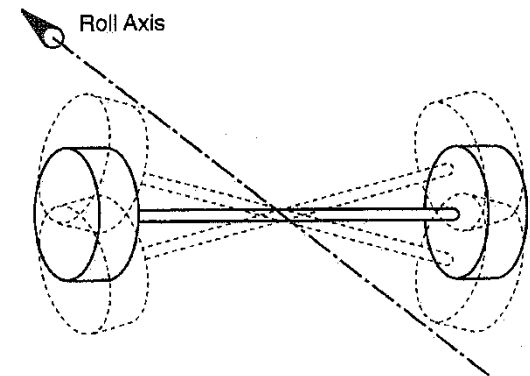
- In solid axle two wheels are tied together
- The wheels can go up or down together-parallel bump motion
- The wheels can go move in opposite directions in roll motion
- Axle has two degrees of freedom, four degrees of freedom must be restrained which can be accomplished using four tension-compression links



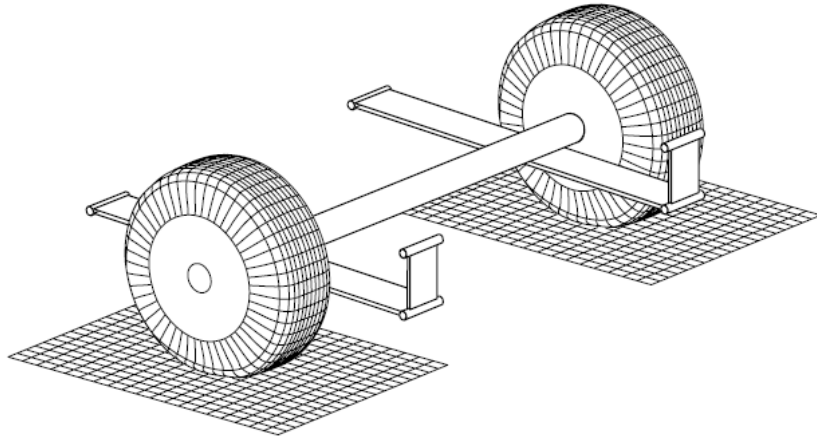
3D Space = 6 D.O.F.

Beam Axles allow 2 motions,
Vertical & Roll

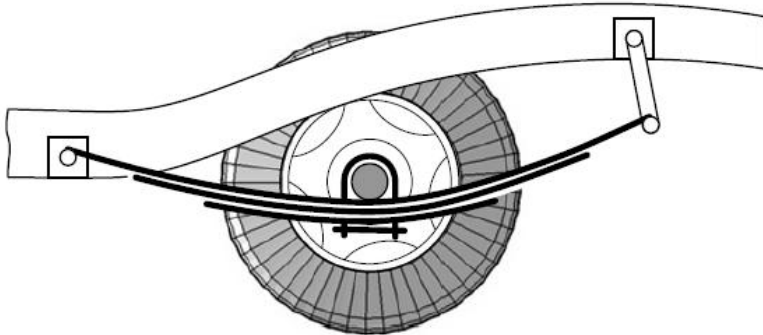
Require 4 D.O.R. / 4 links



Solid Axle Leaf Spring Suspension



- up and down motion in the z-direction
- a roll rotation about the x-axis
- no forward and lateral translation
- no rotation about the axle and the z-axis



Performance can be improved by adding a linkage to guide the axle kinematically and provide dynamic support to carry the non z-direction forces

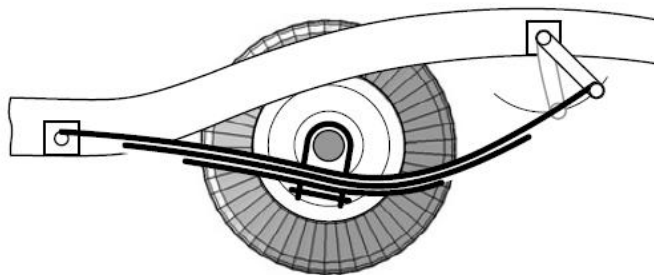
Solid Axle Leaf Spring Suspension

Leaf spring suspension and flexibility problem.

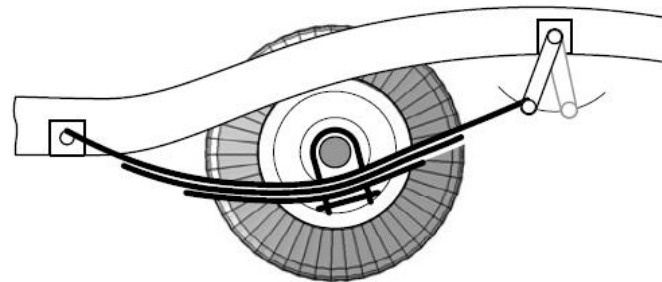
- Springs are supposed to flex under load
- Their flexibility is needed in only one direction

But

- **Nature of leaf springs** to twist and bend laterally and hence, flex also in planes other than the tire plane.
- Leaf springs are not suited for taking up the driving and braking traction forces
- These forces tend to push the springs into an S-shaped profile



(a) Acceleration



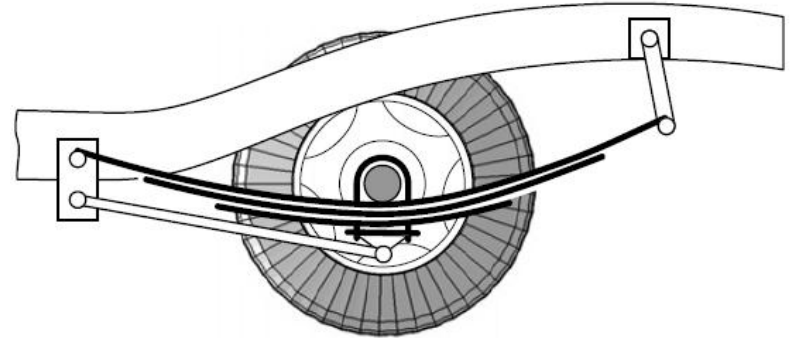
(b) Braking

Solid Axle Leaf Spring Suspension

Leaf spring suspension and flexibility solution

- To reduce the effect of a horizontal force
- S-shaped profile appearance

Adding an anti-tramp bar to guide a solid axle



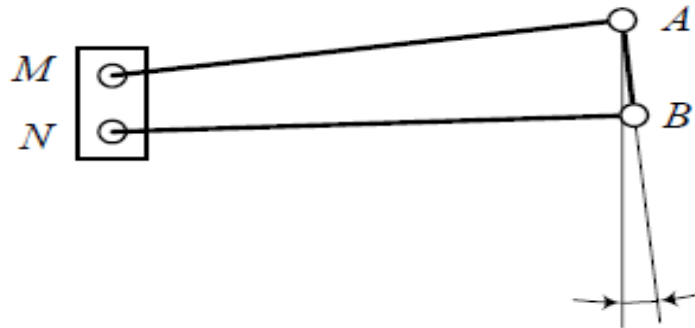
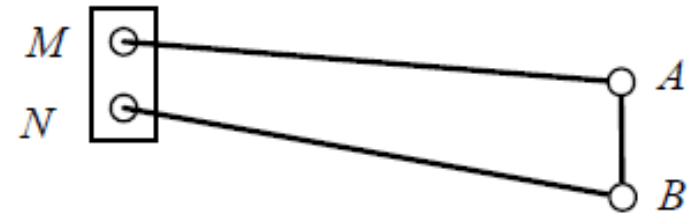
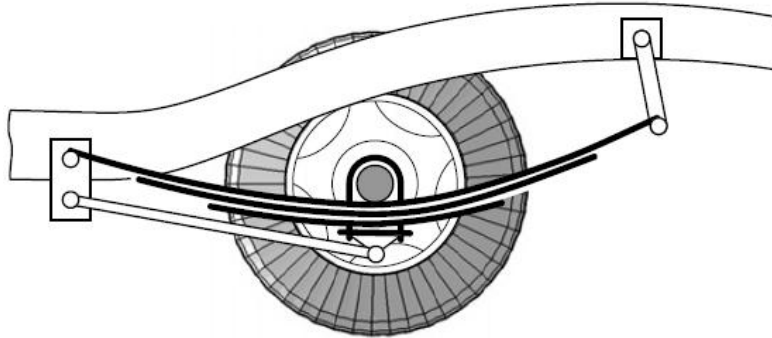
Anti-tramp bar may control the shape of the leaf spring

But

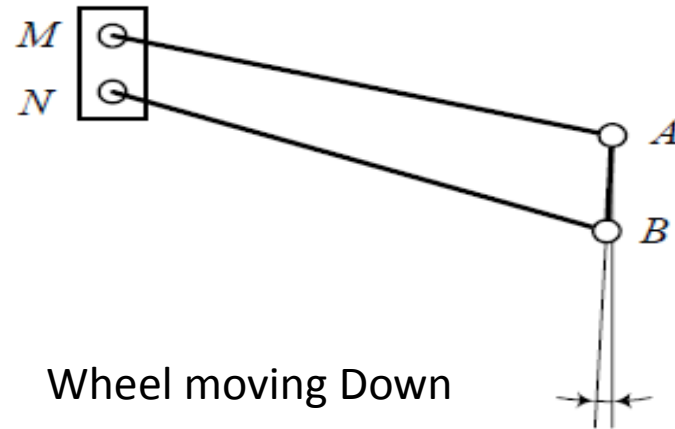
it introduces a twisting angle problem when the axle is moving up and down

Solid Axle Leaf Spring Suspension

Twisting angle problem when the axle is moving up and down



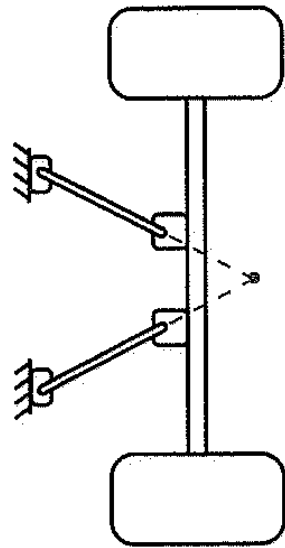
Wheel moving Up



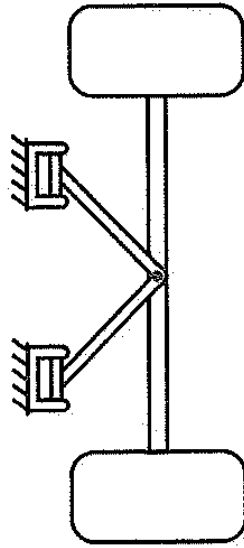
Wheel moving Down

Twisting the axle and the wheel about the axle is called caster

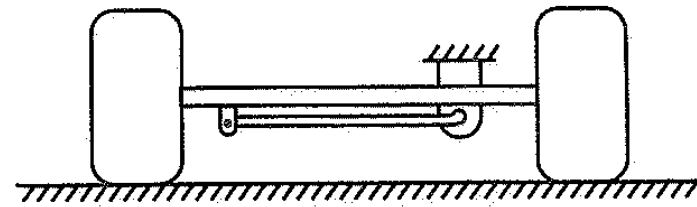
Lateral Restraints



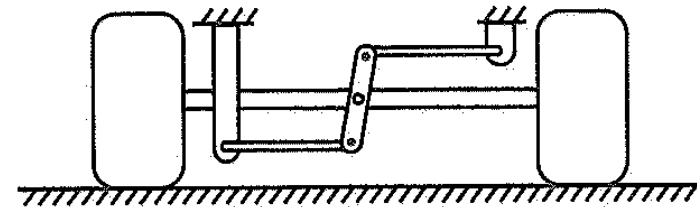
Pair of Arms
(in plan view)



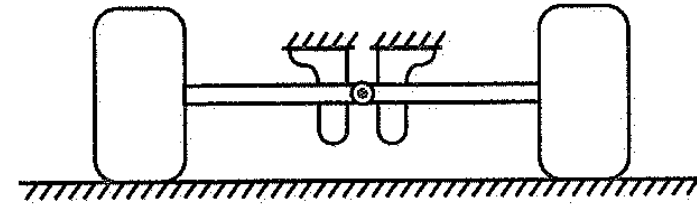
A-Arm
(in plan view)



Panhard Bar



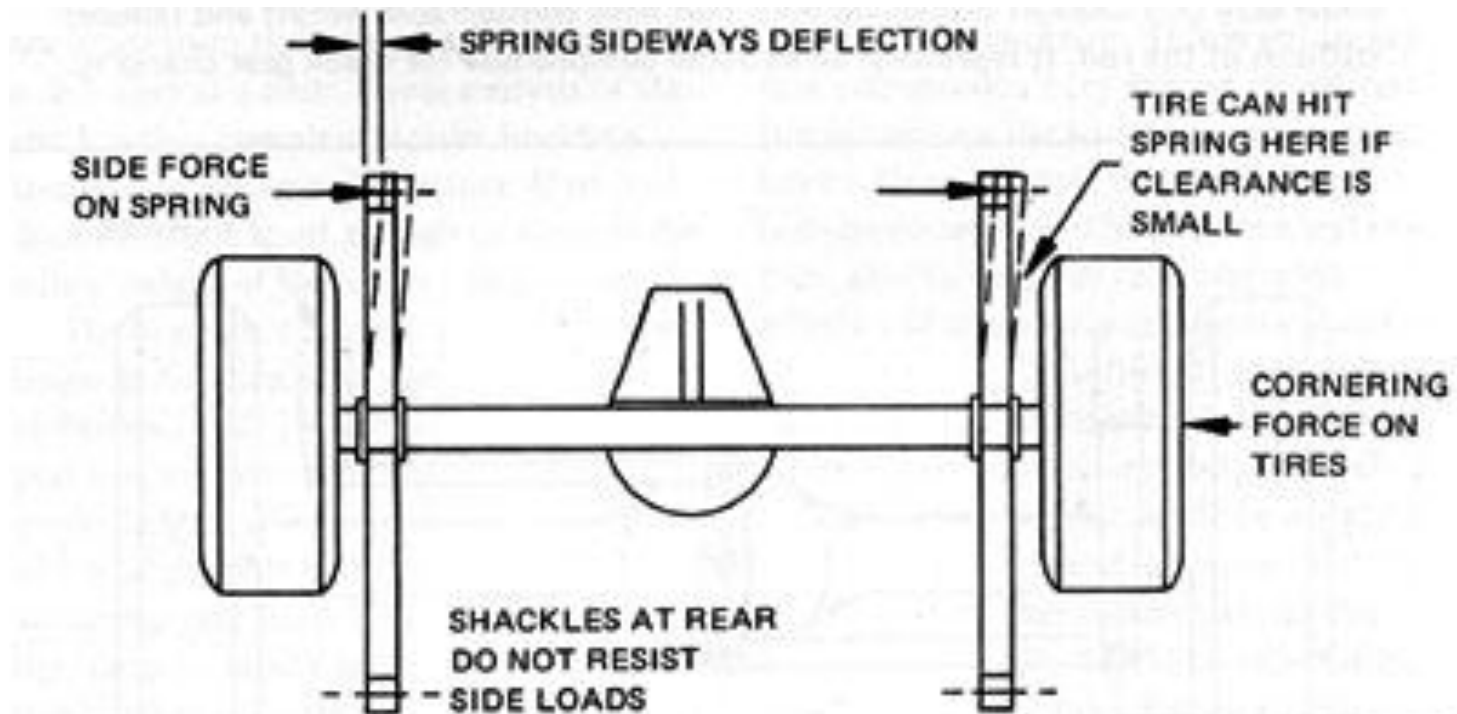
Watt's Linkage



Cam Follower-in-track

As the axle moves up and down relative to the body it is desirable that it move on a straight vertical path. Hence lateral restraints are provided

Lateral Restraints

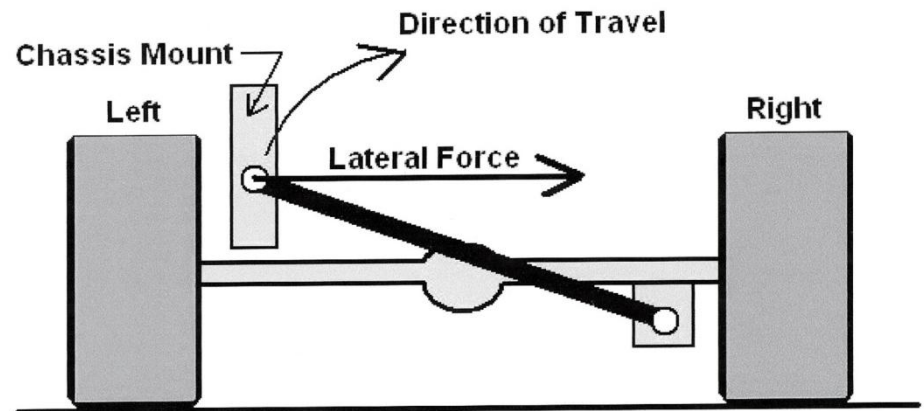


On a conventional leaf-spring rear suspension the side force from the tires is transmitted to the frame through the front of the leaf springs as shown. The springs are not very stiff and they deflect sideways under the loads. This causes the rear of the chassis to feel unstable to the driver. More precise lateral axle location results in better control, plus it gives more clearance for wide tires. Without an extra locating device the tires may hit the springs during hard cornering.

Lateral Restraints

There are two common devices used to control lateral displacement

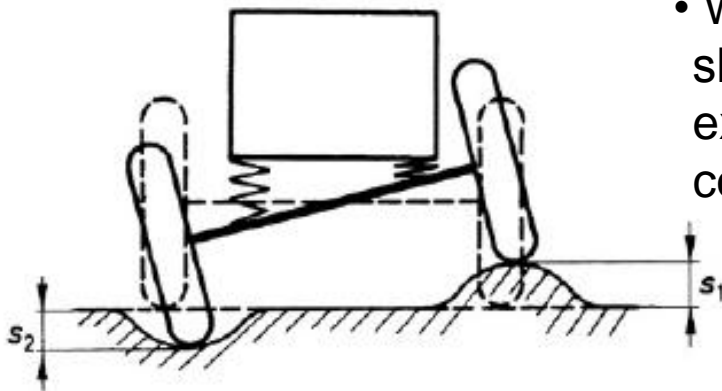
- Watts link
- Panhard bar



Solid Axle Leaf Spring Suspension

Leaf spring location problem

- Front wheels need room to steer left and right
- Leaf springs cannot be attached close to the wheel hubs
- So must be placed closer to the middle of the axle
- gives a narrow spring-base
- small side force can tilt the body relative to the axle through a considerable roll angle due to weight transfer
- IT is uncomfortable for the vehicle passengers, and may also produce unwanted steering



- Mutual influence of the two wheels of a rigid axle
- when travelling along a road with pot-holes, shown as 'mutually opposed springing'. One wheel extends along the path s_2 and the other compresses along the path s_1

Solid axle suspension

- **Unsprung mass problem**

- solid axle is counted as an unsprung member
- The unsprung mass is increased where using solid axle suspension
- Heavy unsprung mass ruins both, the ride and handling of a vehicle
- Lightening the solid axle makes it weaker and increases the most dangerous problem in vehicles
- Rough estimate, 90% of the leaf spring mass may also be counted as unsprung mass, which makes the problem worse
- unsprung mass problem is worse in front, and it is the main reason that they are no longer used in cars
- Front solid axles are still common on trucks and buses
- These are heavy vehicles and solid axle suspension does not reduce the mass ratio $\epsilon = m_s/m_u$ very much
- Live axle can be three to four times heavier than a dead I-beam axle

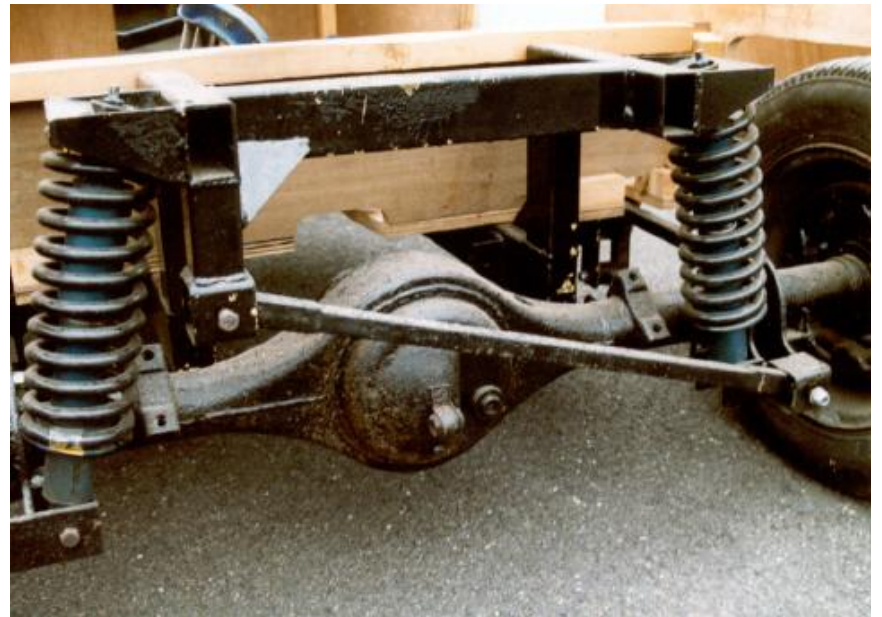
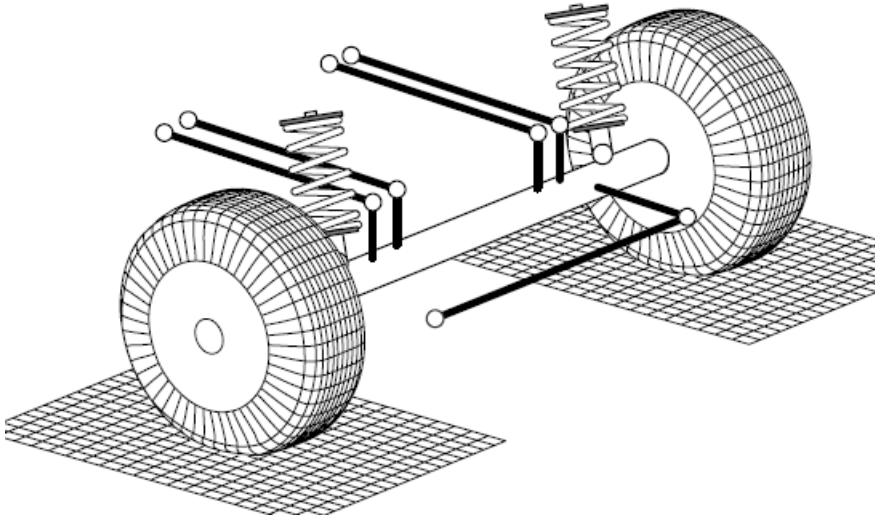
Rear Dependent Suspension- Leaf Spring

Front Wheel Drive

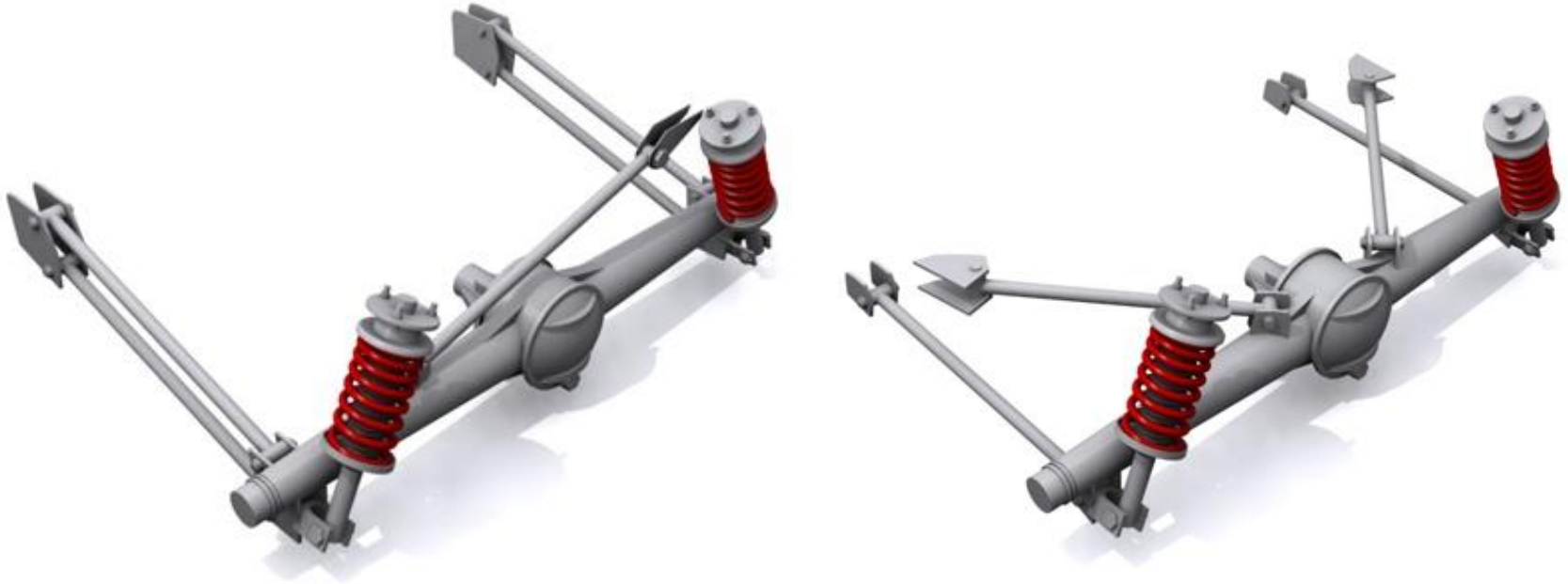
- The advantages of using rear solid axle suspension in front wheel drive are many
- Easy to have higher roll centre at the rear which is desirable
- They are simple and economical to manufacture;
- There are no changes to track width, toe-in and camber on full bump/rebound-travel, thus giving low tyre wear and sure-footed road holding;
- There is no change to wheel camber when the body rolls during cornering, therefore there is constant lateral force transmission of tyres;
- The absorption of lateral force moment by a transverse link, which can be placed at almost any height (e.g. Panhard rod)
- Optimal force transfer due to large spring track width
- The lateral force compliance steering can be tuned towards under- or over-steering

Solid axle suspension with coil springs

To decrease the unsprung mass and increase vertical flexibility of solid axle suspensions



Rear Dependent Suspension



4-bar suspension can be used on the front and rear of vehicles. 4-bar suspension comes in two varieties. Triangulated, shown on the right here, and parallel, shown on the left.

Rear Dependent Suspension

**de Dion suspension, or
the de Dion tube**

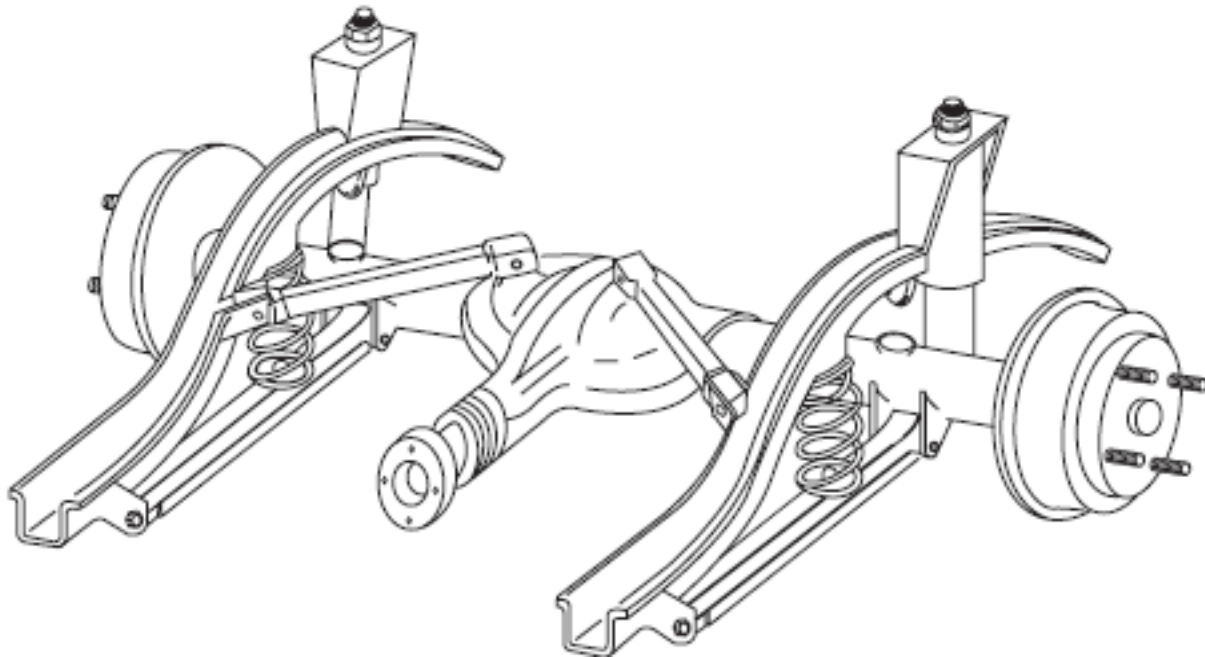


Rear Dependent Suspension



Beam Axle

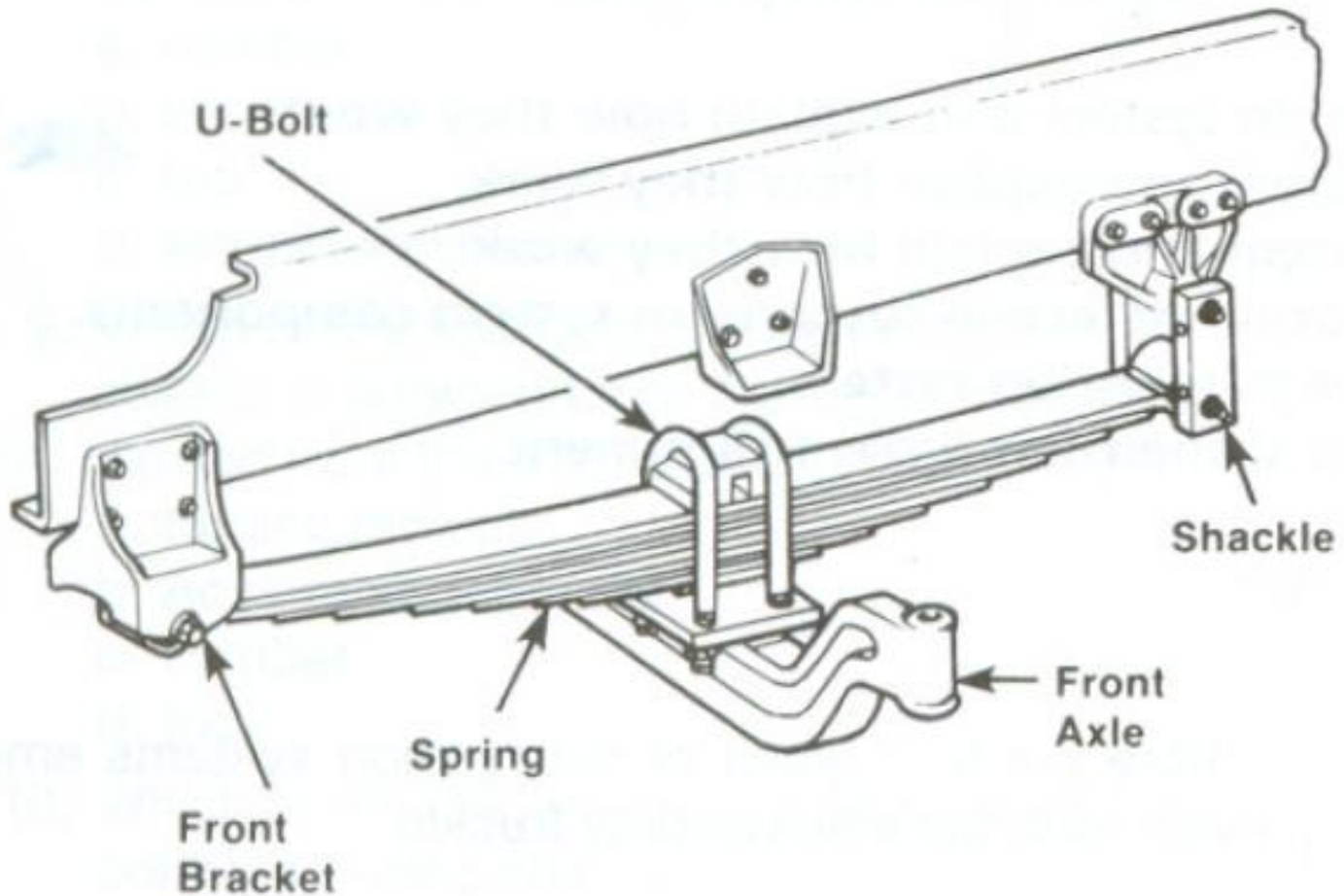
Trailing Arm –Rigid Axle



Advantages: Lateral Constraint, Squat, Roll Center Location, Roll steer

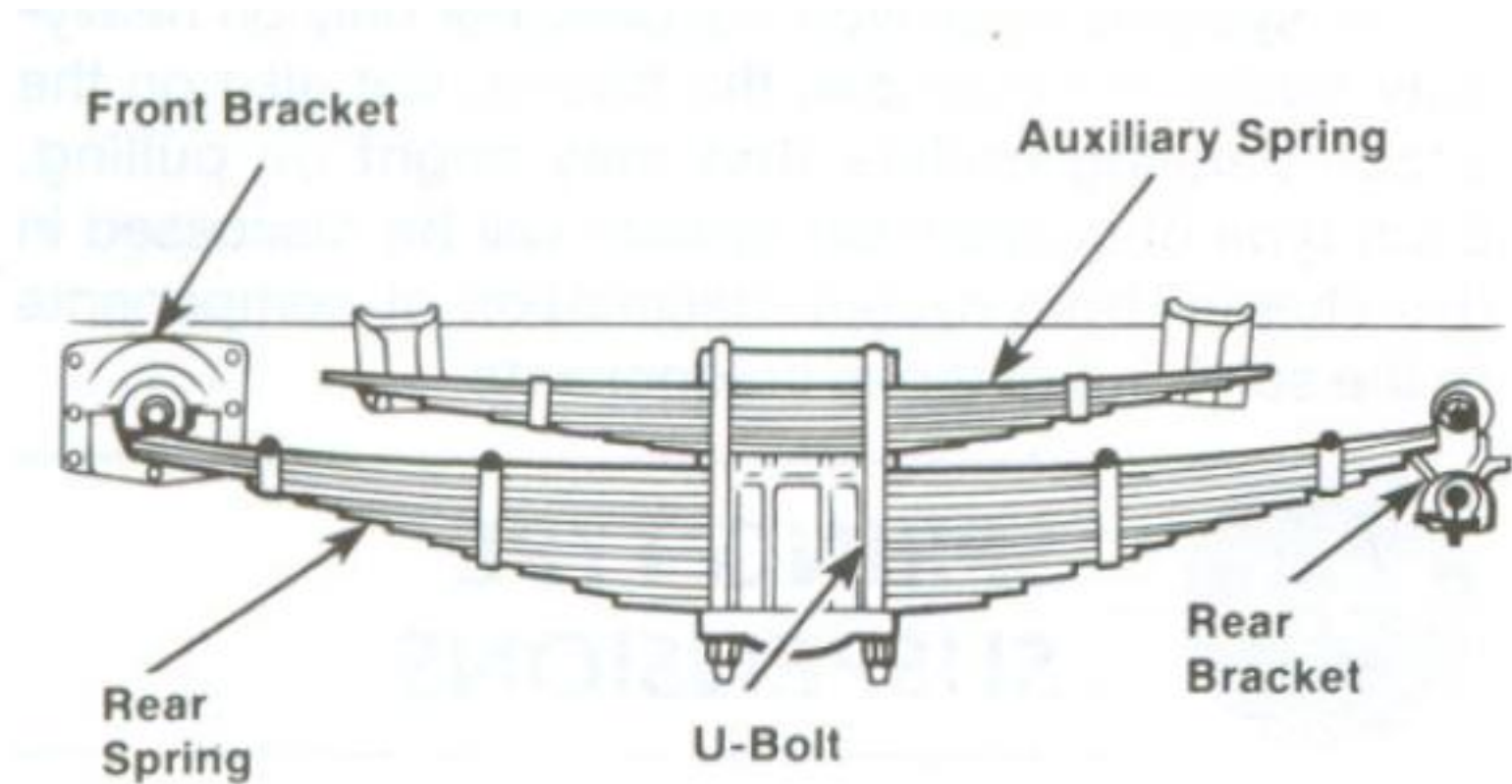
Truck Suspension

Front Axle –Constant Rate- Navistar



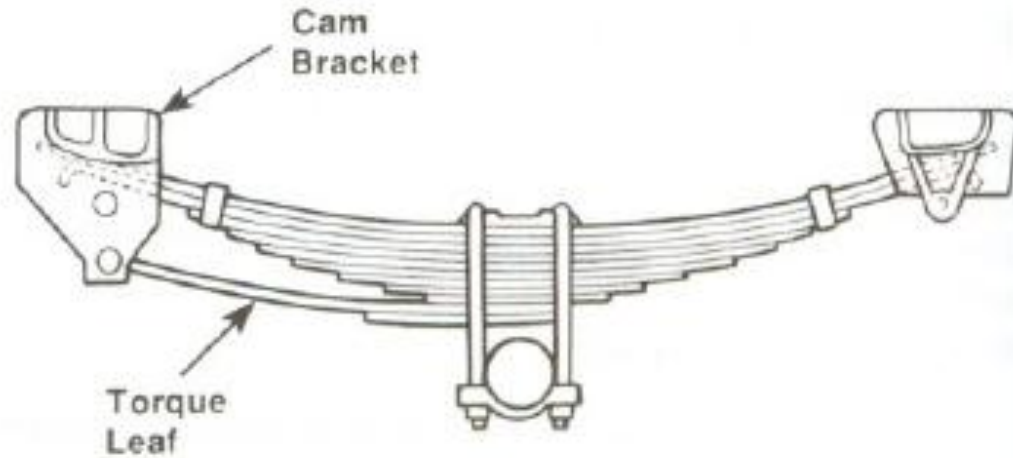
Truck Suspension

Rear Axle –Constant Rate- Navistar

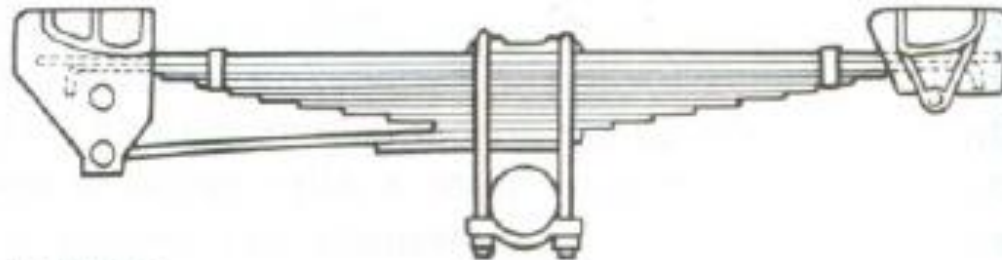


Truck Suspension

Progressive Spring Assembly



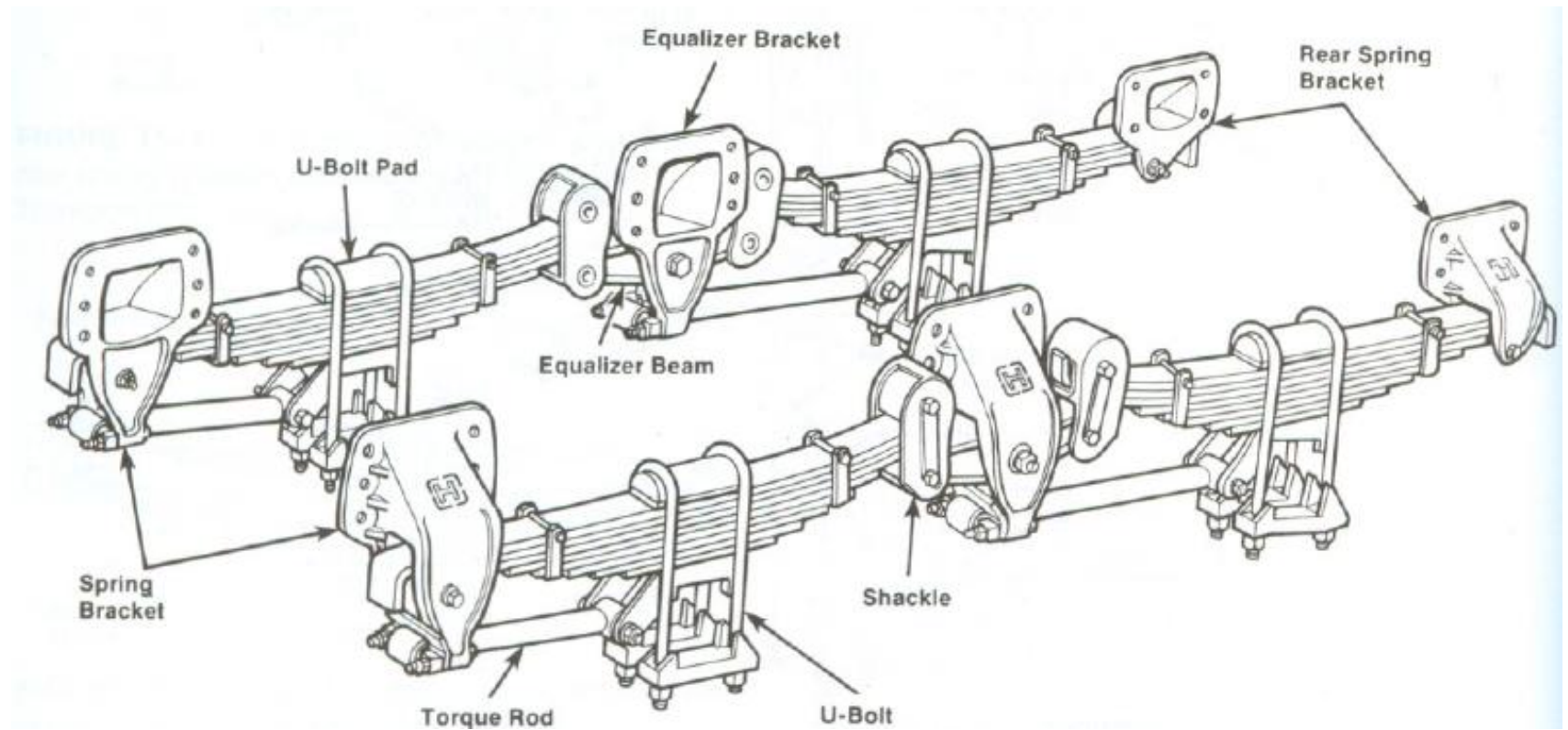
A UNLOADED



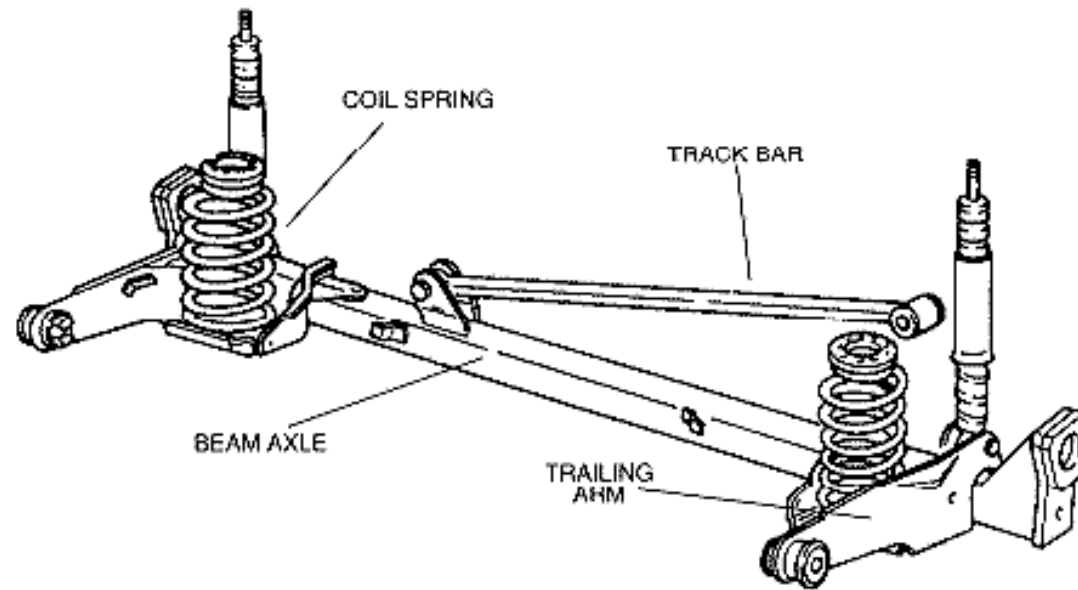
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Truck Suspension

Tandem Axle Suspension

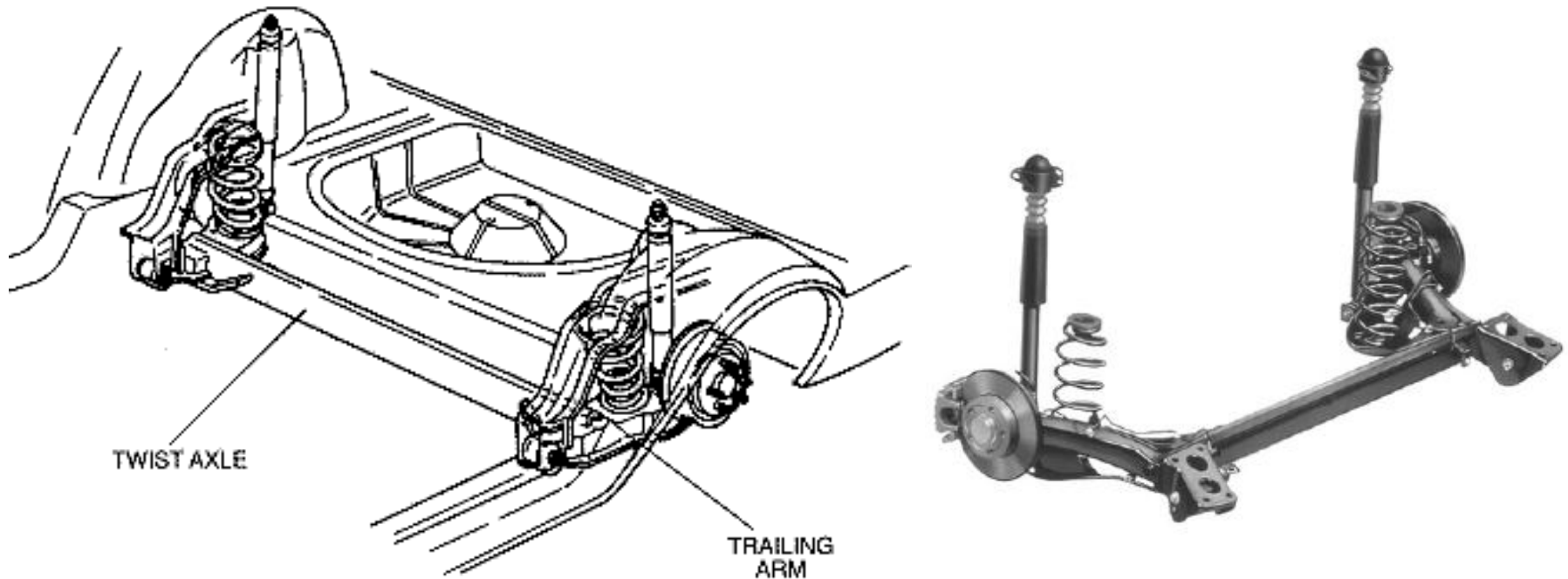


Beam Axle, Front-Wheel Drive



- beam axle a dependent rear suspension,
- used on front-wheel drive vehicles
- lighter than rear suspensions on rear-wheel drive vehicles because it is not a drive axle.
- The stamped beam axle uses coil springs and trailing arms, with a track bar to control side-to-side movement

Twist Axle, Front-Wheel Drive



modified version of the beam axle is a somewhat independent rear suspension called a twist axle.

In it the wheels are supported by individual trailing arms that are connected to one another by a V-, U-, or I-shaped axle beam

Advantages

- From an installation point of view:
 - the whole axle is easy to assemble and dismantle;
 - it needs little space;
 - a spring damper unit or the shock absorber and springs are easy to fit;
 - no need for any control arms and rods; and thus only few components to handle

Advantages

- From a suspension point of view:
 - there is a favourable wheel to spring damper ratio;
 - there are only two bearing points O_l and O_{rs} , which hardly affect the springing
 - low weight of the unsprung masses; and
 - the cross-member can also function as an anti-roll bar.

Advantages

- **From a kinematic point of view:**
 - there is negligible toe-in and track width change on reciprocal and parallel springing;
 - there is a low change of camber under lateral forces;
 - there is low load-dependent body roll understeering of the whole axle; and
 - good radius-arm axis locations O_l and O_{rs} which reduce tail-lift during braking.

Dis -advantages

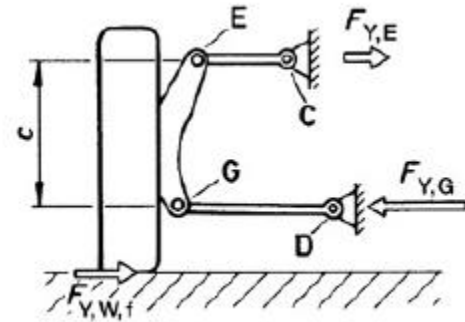
- The disadvantages are:
 - a tendency to lateral force oversteer due to control arm deformation;
 - torsion and shear stress in the cross-member;
 - high stress in the weld seams; which means the permissible rear axle load is limited in terms of strength;
 - the limited kinematic and elastokinematic opportunities for determining the wheel position;
 - the establishment of the position of the instantaneous centre by means of the axle kinematics and rigidity of the twist-beam axle;
 - the mutual effect on the wheel;
 - the difficult decoupling of the vibration and noise caused by the road surface; and the considerable need for stability of the bodywork in
 - the region of those points on the front bearings at which complex, superposed forces have to be transmitted.

Independent Suspension-Advantages

- little space requirement
 - a kinematic and/or elastokinematic toe-in change,
 - tending towards understeering is possible;
 - easier steerability with existing drive;
 - low weight;
 - no mutual wheel influence
- The last two characteristics are important for good roadholding, especially on bends with an uneven road surface.

Independent Suspension

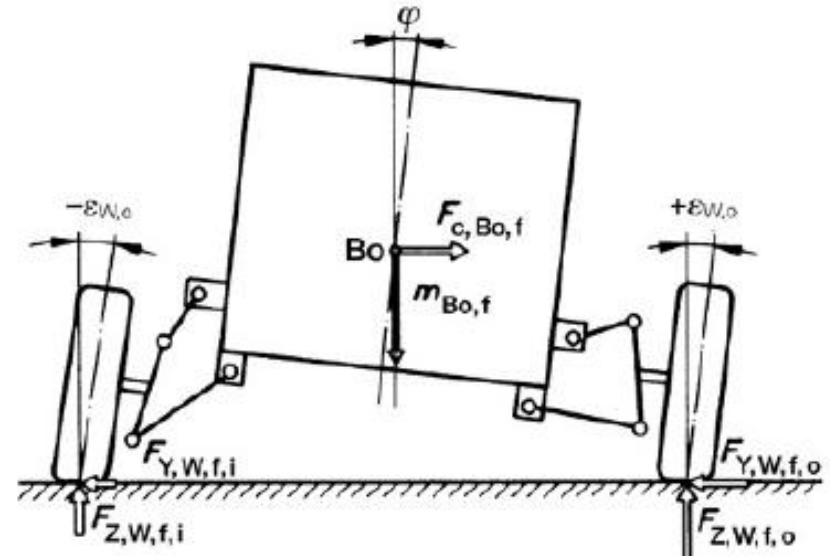
- Transverse arms and trailing arms ensure the desired kinematic behaviour of the rebounding and jouncing wheels and also transfer the wheel loadings to the body
- Lateral forces also generate a moment which, with unfavourable link arrangement, has the disadvantage of reinforcing the roll of the body during cornering.
- The suspension control arms require bushes that yield under load and can also influence the springing.



On front independent wheel suspensions, the lateral cornering force $F_{Y,W,f}$ causes the reaction forces $F_{Y,E}$ and $F_{Y,G}$ in the links joining the axle with the body. Moments are generated on both the outside and the inside of the bend and these adversely affect the roll pitch of the body. The effective distance c between points E and G on a double wishbone suspension should be as large as possible to achieve small forces in the body and link bearings and to limit the deformation of the rubber elements fitted.

Independent Suspension

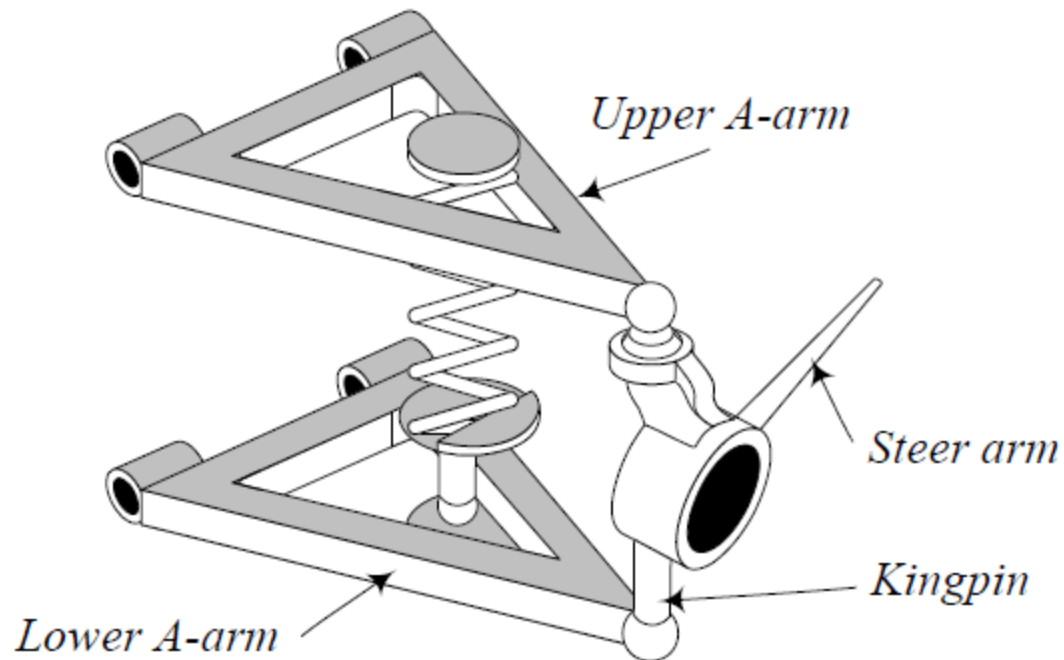
- The wheels incline with the body
- The wheel on the outside of the bend, which has to absorb most of the lateral force, goes into a positive camber and the inner wheel into a negative camber, which reduces the lateral grip of the tyres.
- To avoid this, the kinematic change of camber needs to be adjusted to take account of this behaviour and the body roll in the bend should be kept as small as possible.
- This can be achieved with harder springs, additional anti-roll bars or a body roll centre located high up in the vehicle.



If the body inclines by the angle ϕ during cornering, the outer independently suspended wheel takes on a positive camber $\epsilon_{W, o}$ and the inner wheel takes on a negative camber $\epsilon_{W, i}$. The ability of the tyres to transfer the lateral forces $F_{Y, W, f, o}$ or $F_{Y, W, f, i}$ decreases causing a greater required slip angle

Double Wishbone Suspension

Equal Length A-Arms



Advantages

Improved Independent Advantages

The double A-arm design offered even further improvement in ride quality and road holding than other designs. Most quality car manufacturers now use this system.

Rigid Links

The double A-arm uses solid, rigid control arms to mount the knuckle to the chassis. These arms prevent deflections during cornering which ensures that the steering and wheel alignment remain consistent.

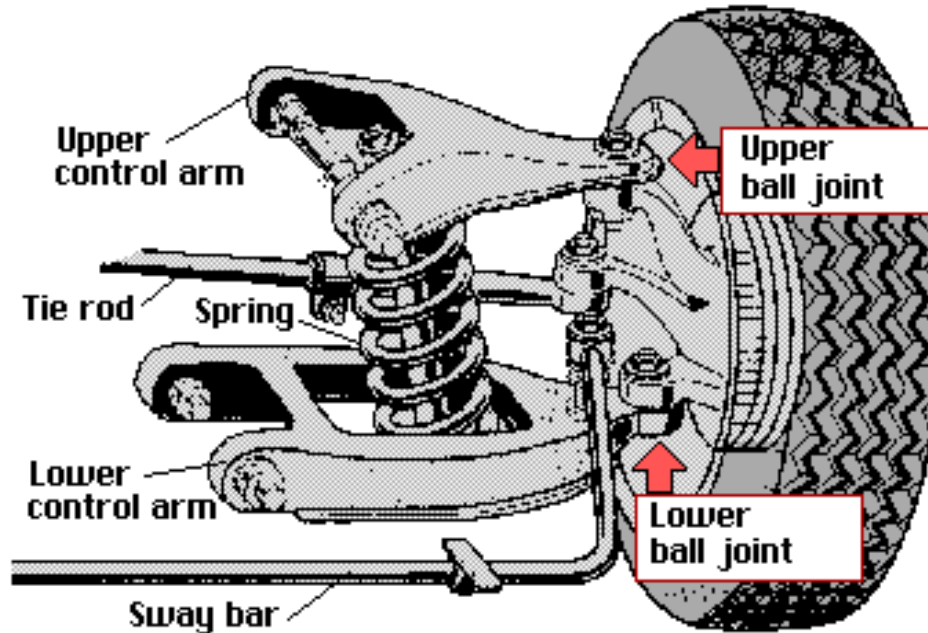
Disadvantages

Lack of Camber Gain

Even though the double A-arm suspension provided a vast improvement in ride and cornering stability. With equal length upper and lower arms, there is no negative camber generated as the wheel moves into bump.

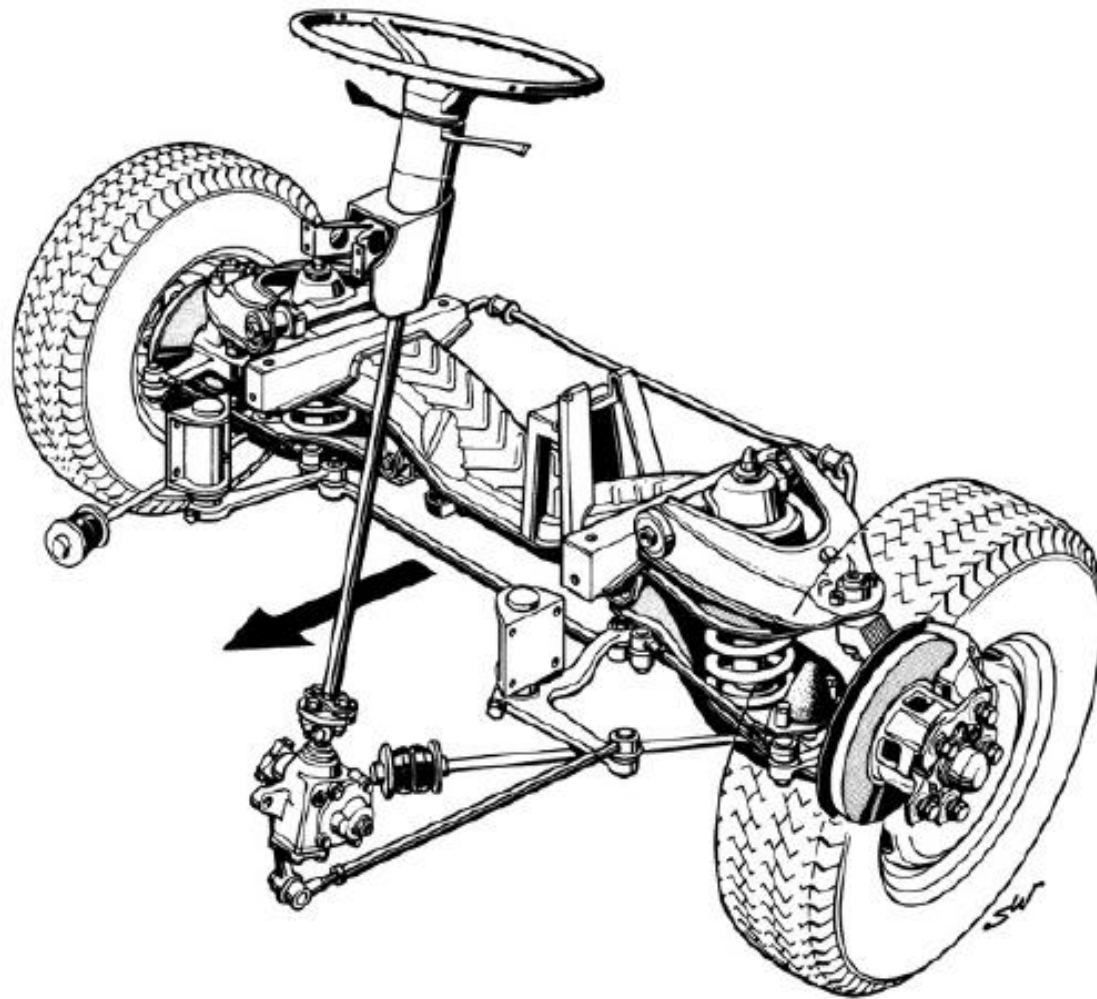
The result is that as the car rolls, the wheel gains positive camber and loses traction just as the MacPherson strut suspension does.

Unequal A Arm (SLA)



By using an upper control arm that is shorter than the lower one, as the wheel travels up it tips in, gaining negative camber. This is because the upper arm swings through a shorter arc than the lower and pulls in the top of the tire as the wheel travels upwards. The advantage in this negative camber gain is that as the chassis rolls against the wheels, the increasing negative camber on the outside wheel helps keep the wheel upright against the road surface and allows the tire to generate the maximum possible cornering force. By adjusting the length of the arms and their respective angles to the ground, there are infinite possibilities in the design of a vehicle's roll center height and swing arm length.

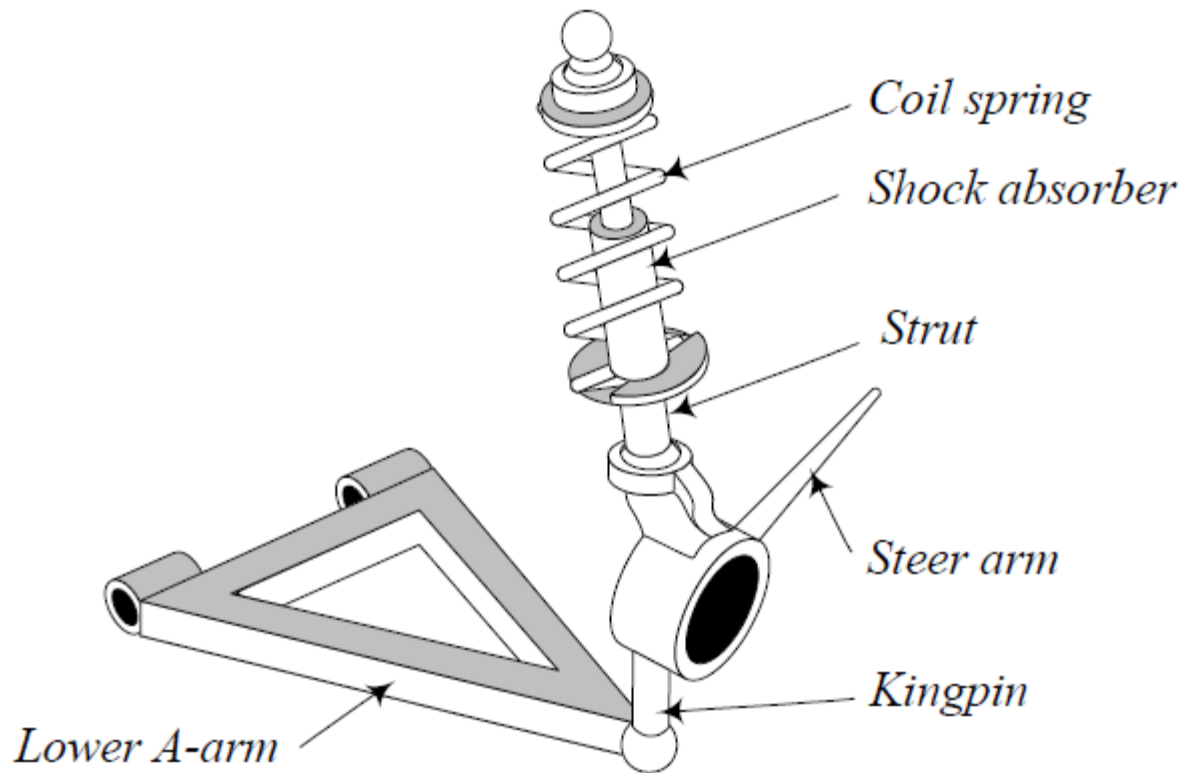
Double Wishbone



Macpherson- Strut



McPherson Strut



Advantages

Standard Independent Advantages

The MacPherson design offered all of the improvements in ride quality and road holding that an independent front suspension can.

Size

The MacPherson suspension is extremely compact and allows for smaller overall chassis dimensions. This is perfect for small cars.

Suited for Front Wheel Drive

Because the MacPherson design uses the strut as the upper suspension link, there is nothing located directly behind the steering knuckle/front hub. This provides the clearance necessary for driveshafts on a front wheel drive vehicle.

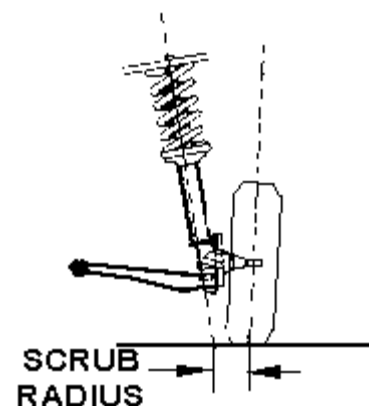
Disadvantages

Scrub Radius Issues

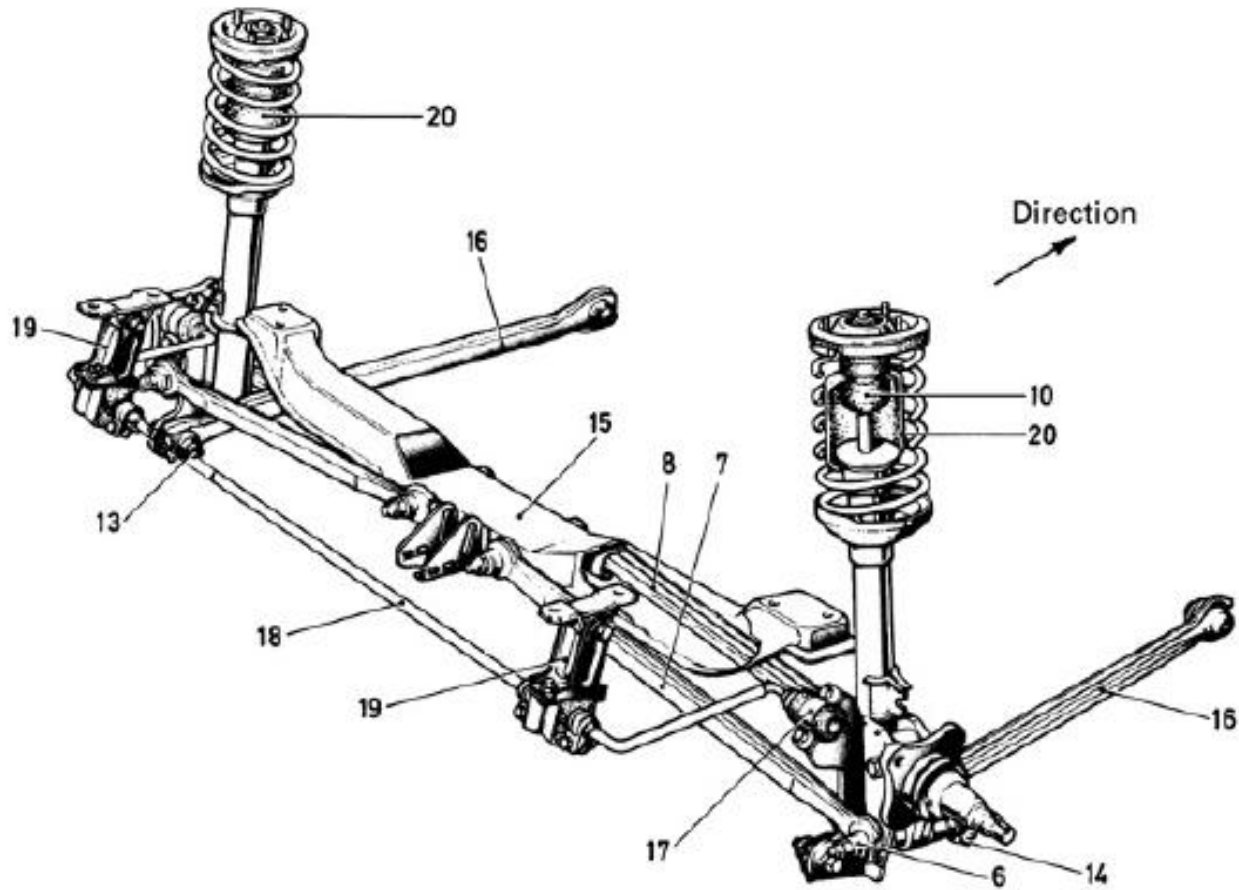
With a MacPherson setup, it is very difficult to increase the tire width on the car. The only way to do this is to increase the scrub radius of the tire as it moves through the range of suspension travel. This is not desirable as it increases side loading on the suspension and bends components.

Lack of Camber Gain

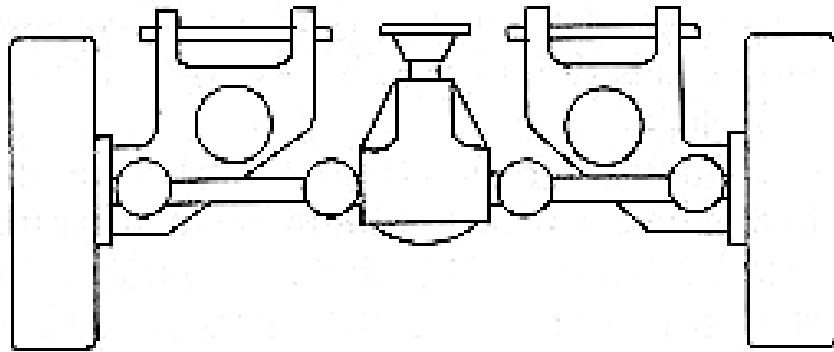
Due to the design of a strut suspension, there is very little if any camber gain as the wheel moves up in bump. The result is that as the chassis rolls on the suspension, the tire will roll into positive camber and reduce the overall cornering power of the tire.



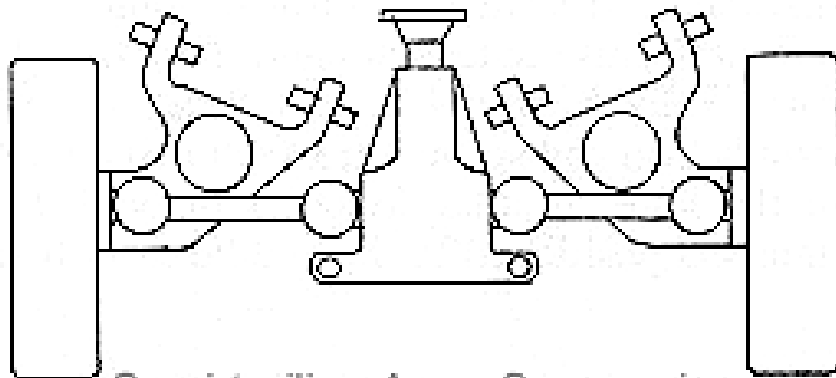
McPherson Rear Axle



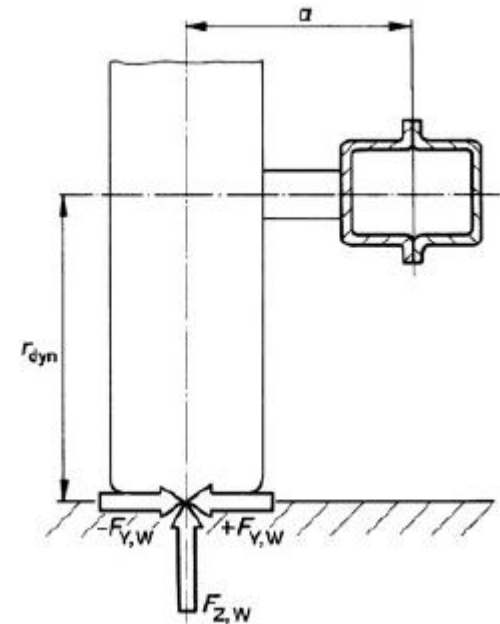
Rear Independent Trailing Arm Suspension



Trailing Arms Suspension



Semi-trailing Arms Suspension



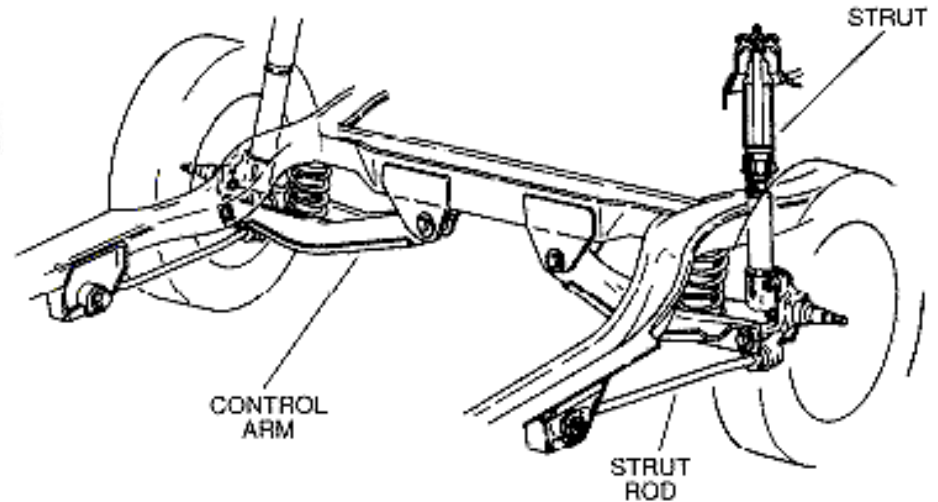
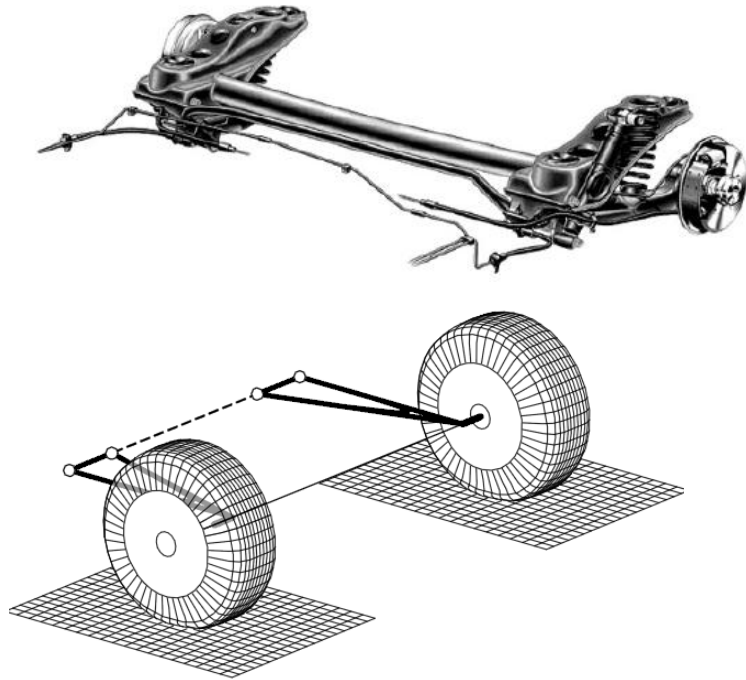
On rear axle trailing-link suspensions, the vertical force $F_{Z,W}$ together with the lateral forces $F_{Y,W}$ cause bending and torsional stress, making a corresponding (hollow) profile, e.g. a closed box profile necessary. A force from inside causes the largest torsional moment:

$$T = F_{Z,W} \times a + F_{Y,W} \times r_{dyn}$$

Trailing Arm Suspension

- The trailing-arm axle is relatively simple and is popular on front-wheel drive vehicles.
- It offers the advantage that the car body floor pan can be flat and the fuel tank and/or spare wheel can be positioned between the suspension control arms.
- If the pivot axes lie parallel to the floor, the bump and rebound-travel wheels undergo no track width, camber or toe-in change, and the wheel base simply shortens slightly.
- If torsion springs are applied, the length of the control arm can be used to influence the progressivity of the springing to achieve better vibration behaviour under load.
- The control arm pivots also provide the radius-arm axis O; i.e. during braking the tail end is drawn down at this point.
- The tendency to oversteer as a result of the deformation of the link (arm) when subject to a lateral force, the roll centre at floor level the extremely small possibility of a kinematic and elastokinematic effect on the position of the wheels and the inclination of the wheels during cornering consistent with the inclination of the body outwards (unwanted positive camber) are disadvantages.

Trailing Arm Suspension

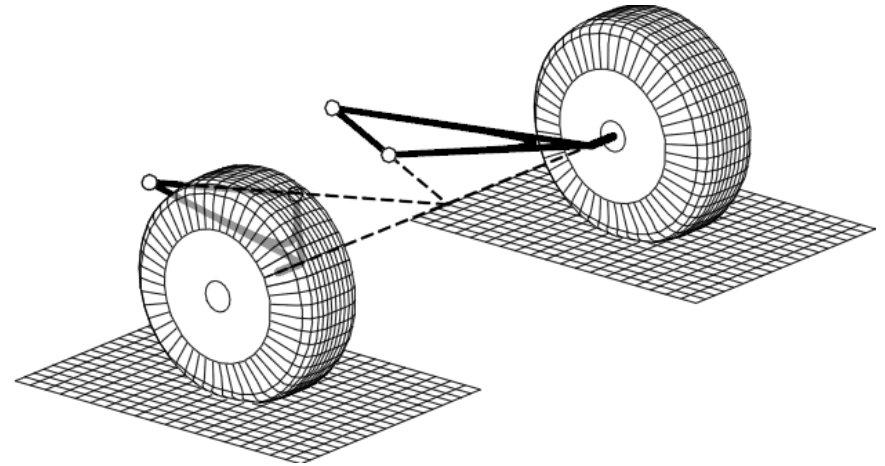
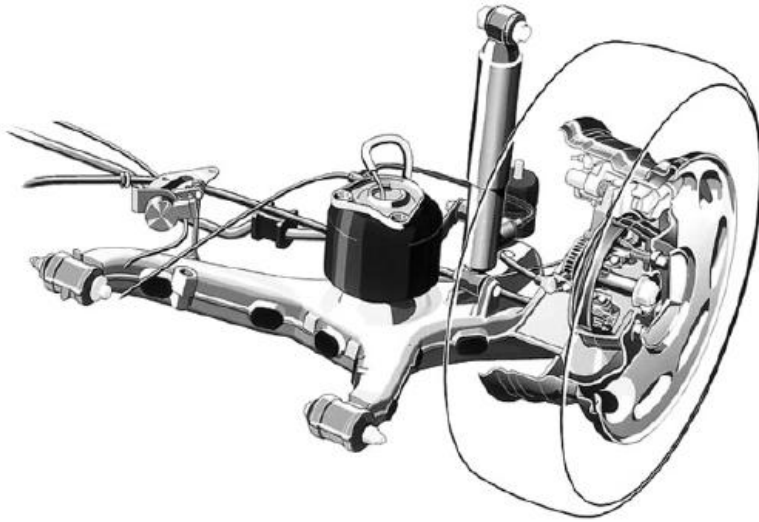


- Trailing arm suspension that is a longitudinal arm with a lateral axis of rotation
- The camber angle of the wheel, supported by a trailing arm, will not change during the up and down motion
- Trailing arm suspension has been successfully using in a variety of front wheel-drive vehicles, to suspend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

Trailing Arm Suspension



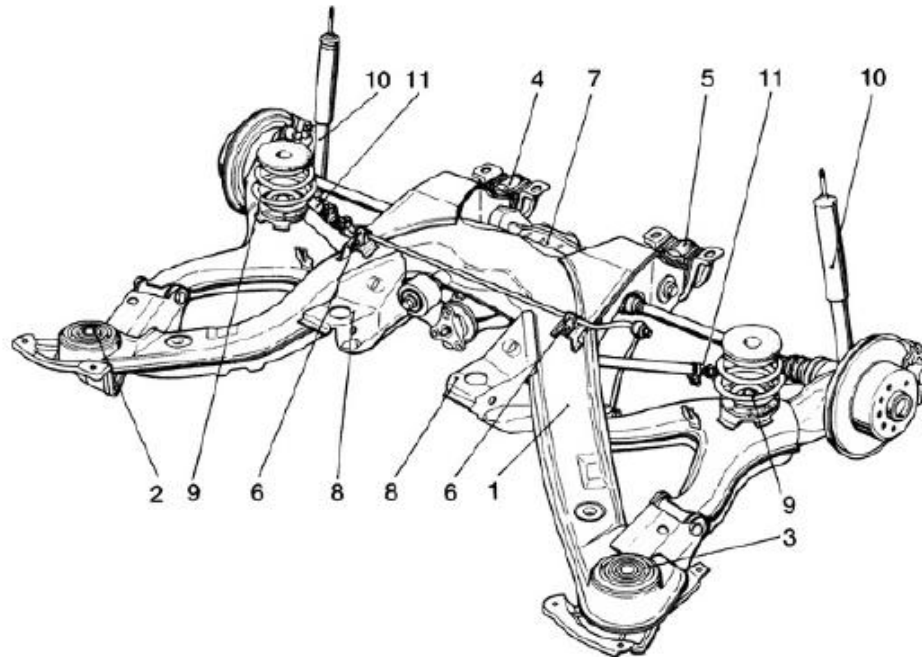
Semi Trailing



- Semi-trailing arm suspension is a compromise between the swing arm and trailing arm suspensions
- suspensions have acceptable camber angle change, while they can handle both, the lateral and longitudinal forces
- Semi-trailing design has successfully applied to a series of rear-wheel-drive cars

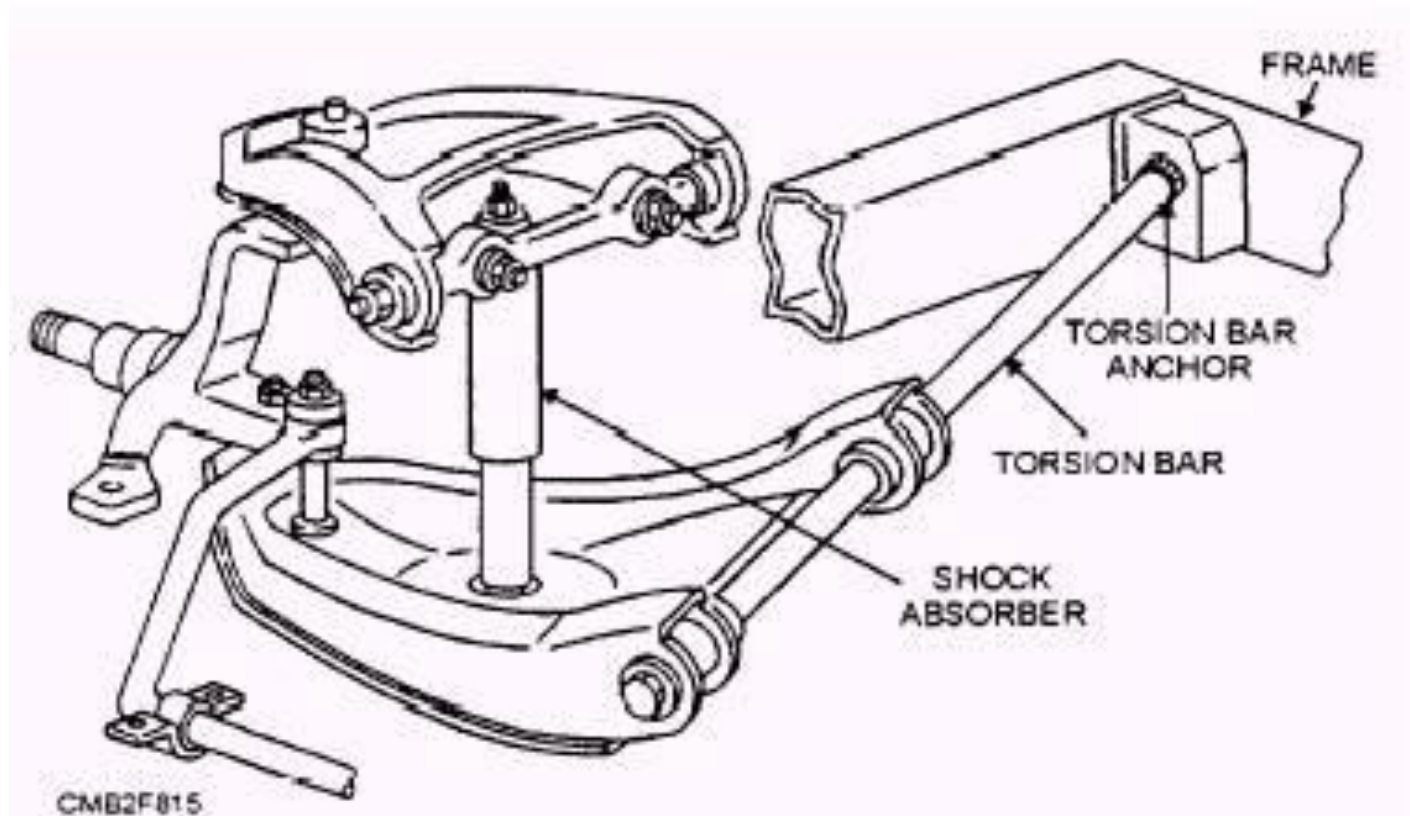
Semi Trailing

semi-trailing axles have an elastokinematic tendency to oversteering.

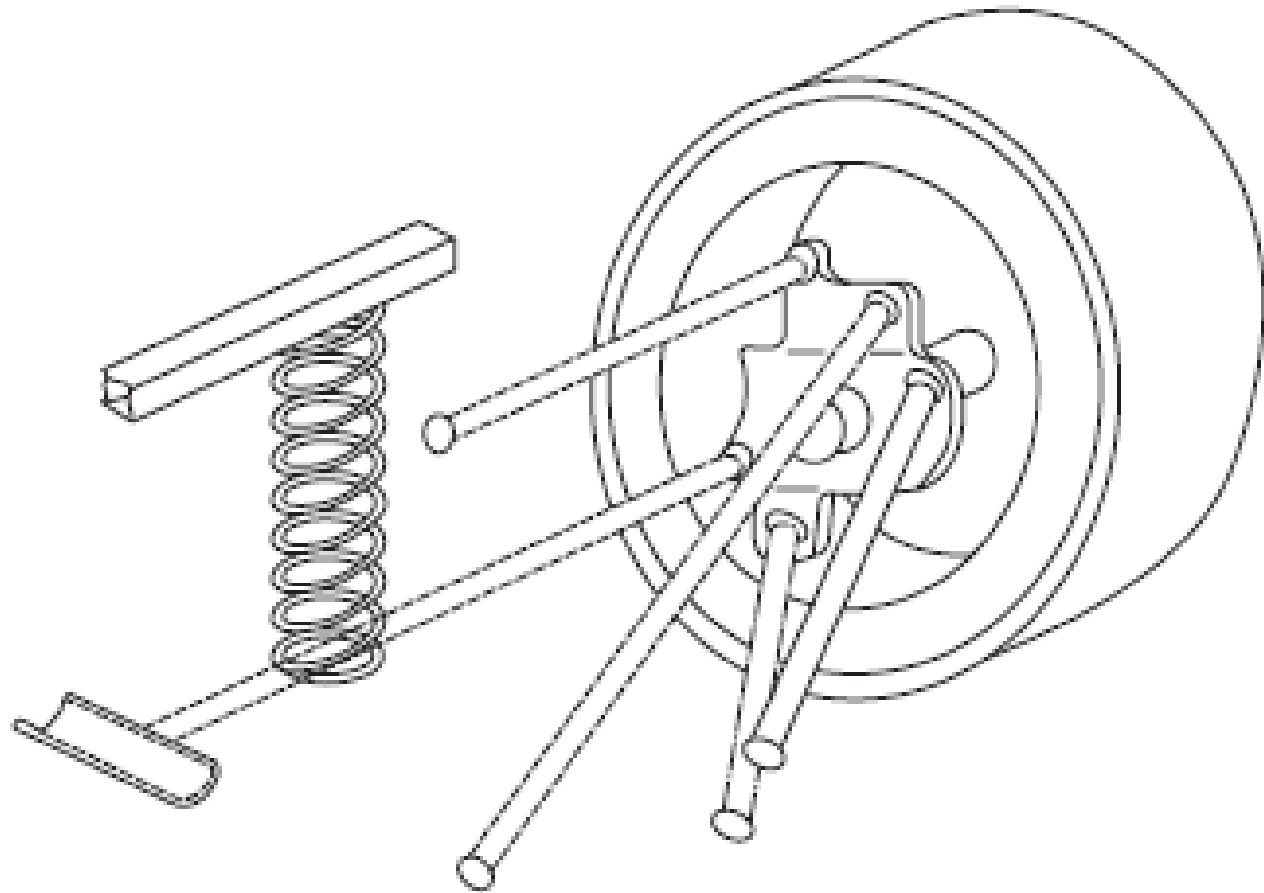


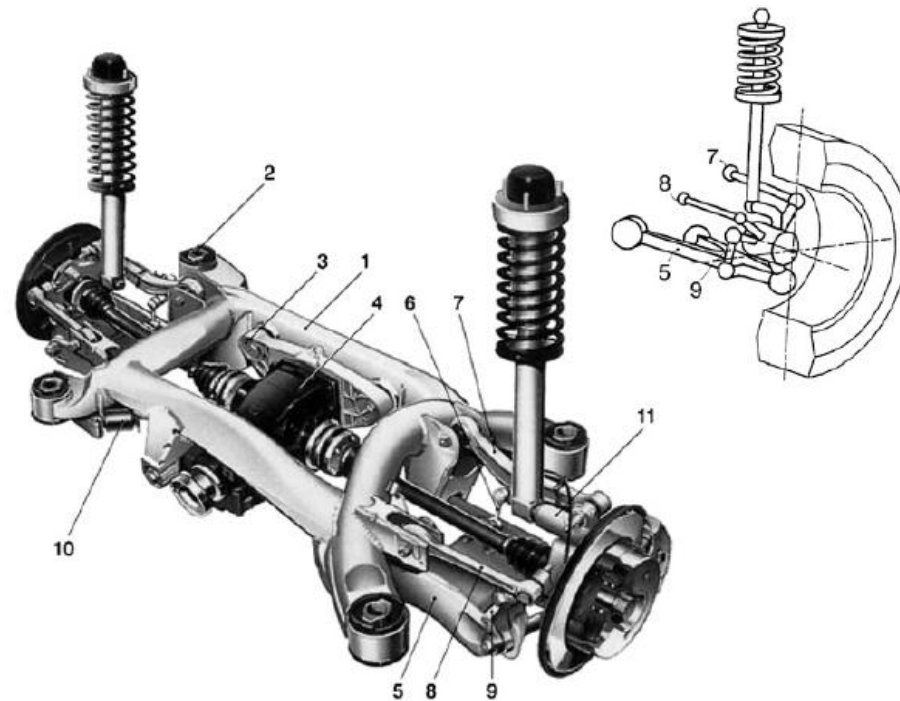
The angle of sweep of the tilted shafts amounts to $\alpha = 10^\circ$ and the Dachwinkel, assume roof or top angle $\beta = 1^\circ 35'$. Both of these angles change dynamically under the influence of the additional tilted shaft (11). These support the sideforces, coming from the wheel carriers directly against the subframe (1). They raise the lateral stability of the vehicle, and provide an absolute neutral elastic steering under side-forces and also, that in driving mode, favourable toe-in alterations appear during spring deflection, and also under load.

Torsion Bar Suspension



Multi Link Suspension

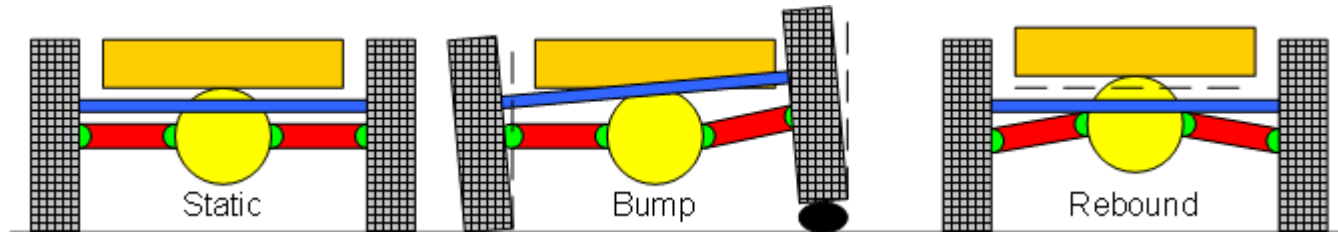
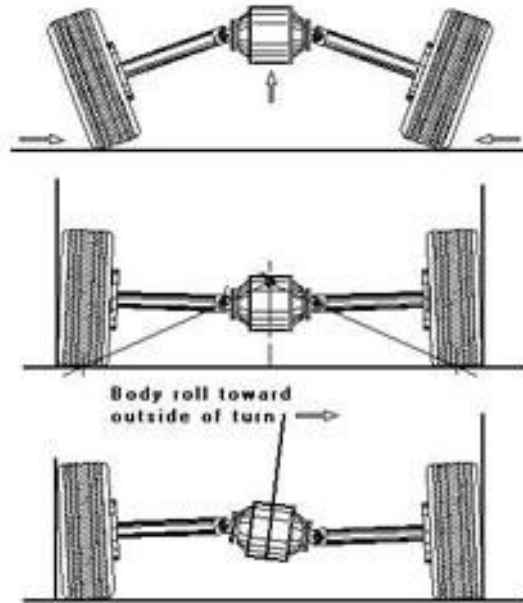




Multi-link rear suspension of the BMW 5 series (E39, 1996). For the first time in large-scale car production, mainly aluminium is used for the suspension system derived from the geometry of the BMW 7 series.

The subframe (rear-axle support) (1), produced from welded aluminium tubes, is attached to the bodywork by means of four large rubber mounts (2). These are soft in a longitudinal direction for the purposes of riding comfort and noise insulation and rigid in a transverse direction to achieve accurate wheel control. The differential gear also has compliant mounts (3). The wheel carrier is mounted on a U-shaped arm (5) at the bottom and on the transverse link (7) and inclined guide link (8) at the top. As a result of this inclined position, an instantaneous centre is produced between the transverse link and guide link outside the vehicle which leads to the desired brake understeer during cornering and the elastokinematic compensation of deformation of the rubber bearings and components. The driving and braking torque of the wheel carrier (11) is borne by the 'integral' link (9) on the swinging arm (5), which is subject to additional torsional stress as a result. This design makes it possible to ensure longitudinally elastic control of the swinging arm on the guide bearing (10) for reasons of comfort, without braking or driving torque twisting the guide bearings as would be the case with torque borne by pairs of longitudinal links. The stabilizer behind presses on the swinging arm (5) by means of the stabilizer link (6), whereas the twin-tube gas-pressure shock absorber, whose outer tube is also made of aluminium, and the suspension springs provide a favourably large spring base attached directly to the wheel carrier (11). For reasons of weight, the wheel discs are also made of aluminium plate. The wheel carrier is made of shell cast aluminium. The rear axle of the station wagon BMW Tourer is largely similar in design. However, the shock absorber extends from the U-shaped swinging arm in order to allow for a wide and low loading area.

Independent Suspension-Swing Axle



De- Dion

Advantages

Simple

While a little more complex than a solid axle this design is still far simpler than an SLA setup

Less Wheel Movement

Because this is an independent setup, forces from one wheel are not transmitted directly to the other. This dramatically improves the stability of the car over rough terrain and through corners.

Ride Quality

Again, by de-coupling the front wheels and not mounting the chassis on a solid beam, there is better ride isolation between the sprung and unsprung masses providing improved ride characteristics and more predictable suspension response

Steering Provisions

An independent suspension provides more leeway in steering geometry. As a result, bump steer could be more controlled, further improving the handling of the vehicle when the suspension is in bump.

Disadvantages

Handling Problems from Jacking

While the swing axle is satisfactory for some applications on vehicles that can create larger cornering forces, a swing axle exhibits a phenomenon known as jacking. Where forces act through the wheel and axle to raise the car. When this happens, the car lifts, the axle drops and there is a severe loss in negative camber. This causes a loss in cornering power right when it is needed most. The most prominent example of this can be found in the early Corvairs with a swing axle. When the car would raise, the back end would lose traction causing the vehicle to lose control.

This type of suspension was considered better than the more typical live axle for two reasons:

- It reduced unsprung weight since the differential is mounted to the chassis
- It eliminates sympathetic camber changes on opposite wheels

Shortcomings

- However, there are a number of shortcomings to this arrangement:
- A great amount of single-wheel camber change is experienced, since the wheel is always perpendicular to the driveshaft
- "Jacking" on suspension unloading (or rebound) causes positive camber changes on both sides, which (In extreme cases) can overturn the car.
- Reduction in cornering forces due to change in camber can lead to oversteer — a dynamically unstable condition where a vehicle can lose control and spin — and in extreme cases lift-off oversteer.
- These problems were evident on the Mercedes-Benz 190SL and 300SL, the early versions of the Porsche 356, the Triumph Herald, Vitesse and Spitfire, Tatra T603, Renault Dauphine, Volkswagen Beetle (until rear suspension modifications, c. 1967) and others.
- 1964 Corvair swing-axle rear suspension with transverse leaf spring

Solutions

- A number of engineering options could ameliorate swing axle handling:
- Anti-roll bar: As a design option, engineers can include a front anti-roll bar which can ameliorate the swing axle car's handling – shifting weight transfer to the front outboard tire, considerably reducing rear slip angles—thereby avoiding potential oversteer.
- Single-pivot point: Mercedes-Benz addressed the handling issues by producing swing axles with a single-pivot point located under the differential, and thus well below the axle. This configuration markedly reduced the tendency to "jack-up" and the later low pivot swing-axle equipped cars were praised in contemporary publications for their handling. The low-pivot swing-axle remained in production with Mercedes-Benz W108 280SE and 300SEL until 1972. It was fitted to the 300SEL 6.3, which was during the early 70s the world's fastest production sedan. AMG-modified 6.3s were also raced with the stock swing axle
- Tire pressure differential: The Renault Dauphine, Volkswagen Beetle and first generation Chevrolet Corvair (1960–1964) used a *tire pressure differential* strategy to eliminate oversteer characteristics of their swing axle suspensions — specifically low front and high rear tire pressure — which induced understeer. Nonetheless, the *tire pressure differential* strategy offered a *significant* disadvantage: owners and mechanics could inadvertently but easily re-introduce oversteer characteristics by over-inflating the front tires (e.g., to typical pressures for other cars with other suspension systems).

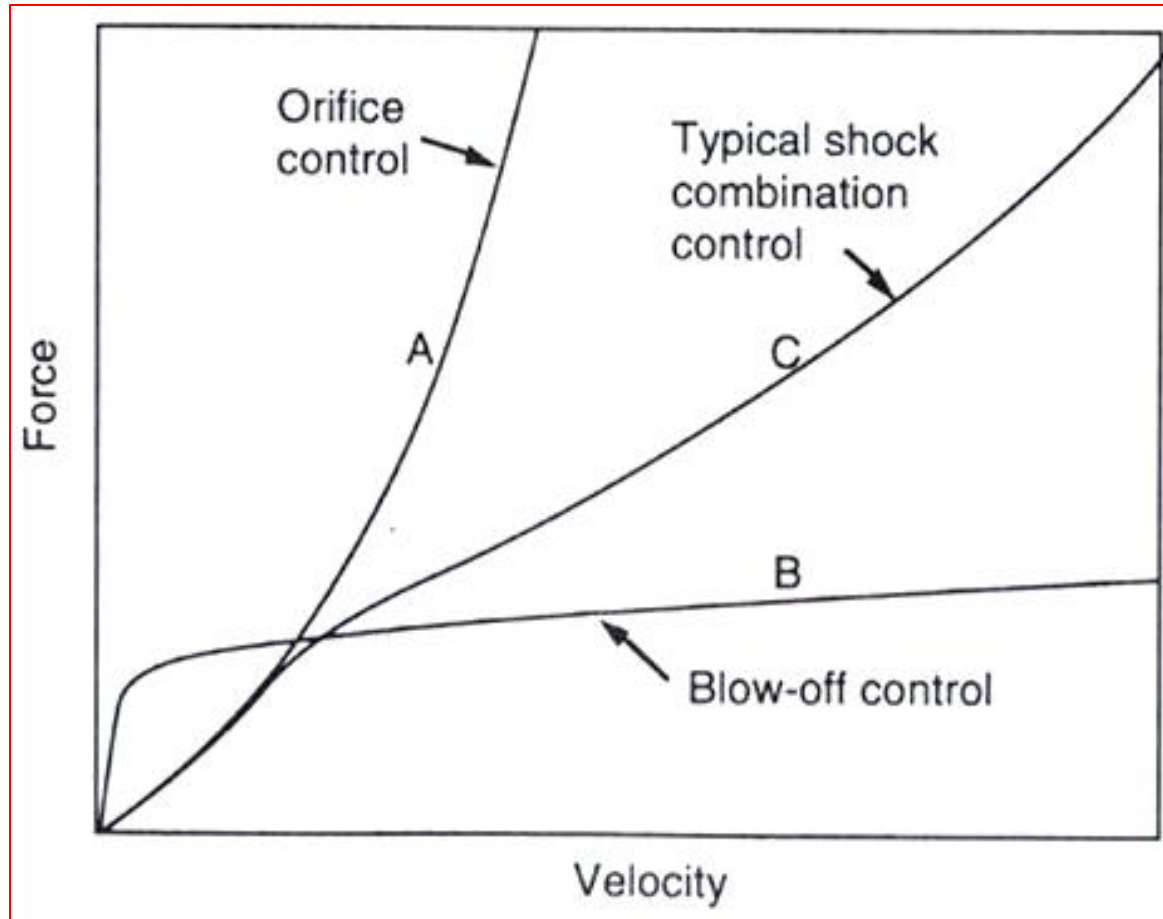
Passive Suspension

- Passive Suspension - Suspension characteristics cannot be changed at will
 - Suspension Spring Stiffness Coefficient
 - Suspension Damping Coefficient

Passive System Limitations

- Damping in suspension jounce (compression) and rebound (extension) directions is not equal
- Damping in the jounce direction must be low
- Damping in the rebound direction is desirable to dissipate the energy stored in the spring from the encounter with the bump
- For good ride the suspension damping ratio on modern passenger cars usually falls between 0.2 and 0.4.
- Shock absorbers must be tailored not only to achieve the desired ride characteristics, but also play a key role in keeping good tire-to-road contact essential for handling and safety

- Damping behaviour of a typical dual rate damper is



- Among these vehicle parameters, the suspension designer is only free to select the stiffness and damping values. The influence of these parameters is displayed in [Fig: 10.5](#), where the rms vertical acceleration is plotted against the rms suspension travel with different values of stiffness and damping.

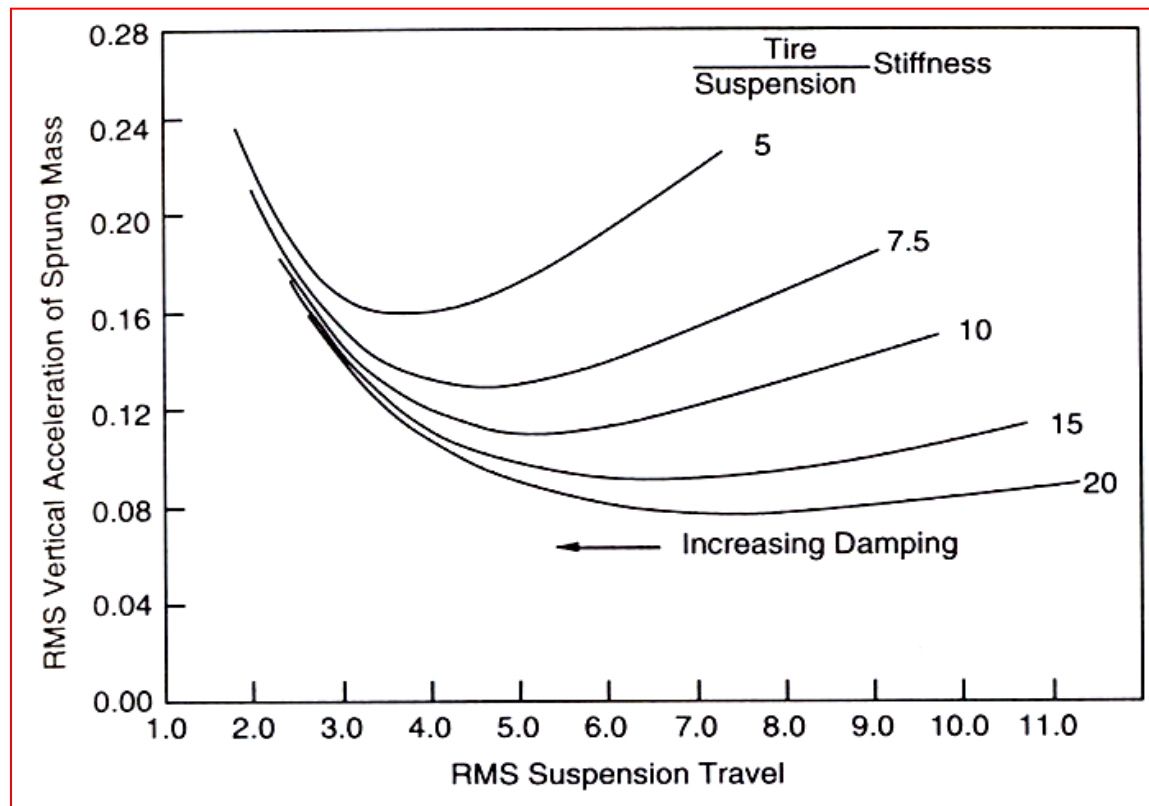


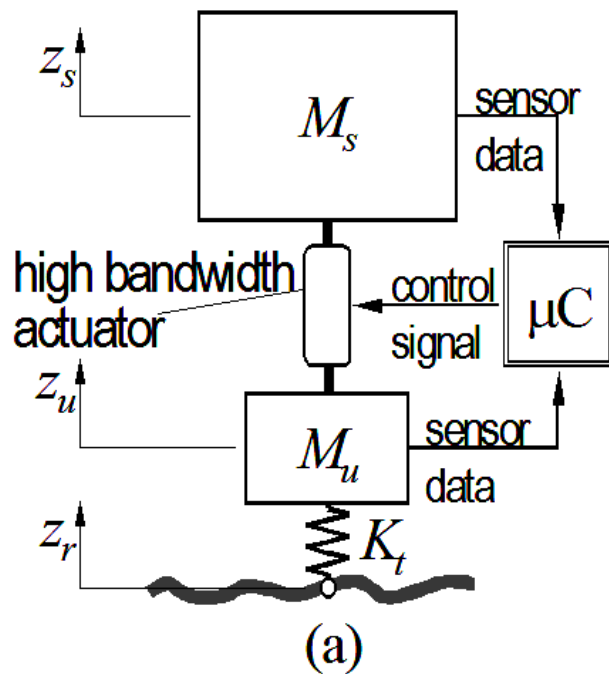
Fig: 10.5 Acceleration versus suspension travel for a passive suspension ($X=0.15$)

Summary of Requirements

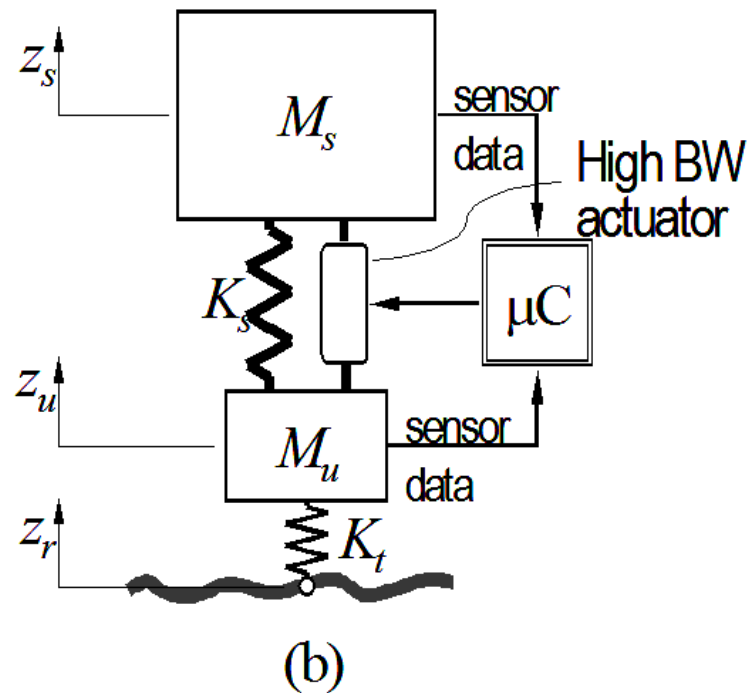
Control objectives		Damping force <u>Front</u> <u>Rear</u>
Roll	Roll reduction for quick steering operation	<u>Hard</u> <u>Hard</u>
Pitch	Reduction of nose diving by braking	<u>Hard</u> <u>Hard</u>
	Reduction of pitching when accelerating and decelerating	<u>Medium</u> <u>Medium</u>
Bouncing	Reduction of light, bouncy vibrations in bottoming	<u>Medium</u> <u>Medium</u>
	Reduction of light, bouncy vibrations in bouncing on a heaving road	<u>Medium</u> <u>Medium</u>
Road holding performance	Road holding performance improvement when running on rough roads	<u>Medium</u> <u>Medium</u>
Others	Stability improvement at high speed	<u>Medium</u> <u>Soft</u>
	Prevention of shaking when stopping and rocking when passengers exit or enter	<u>Hard</u> <u>Hard</u>

Semi Active and Active Suspension

Fully-active suspensions



Actuator provides total suspension force



Static load supported by passive spring

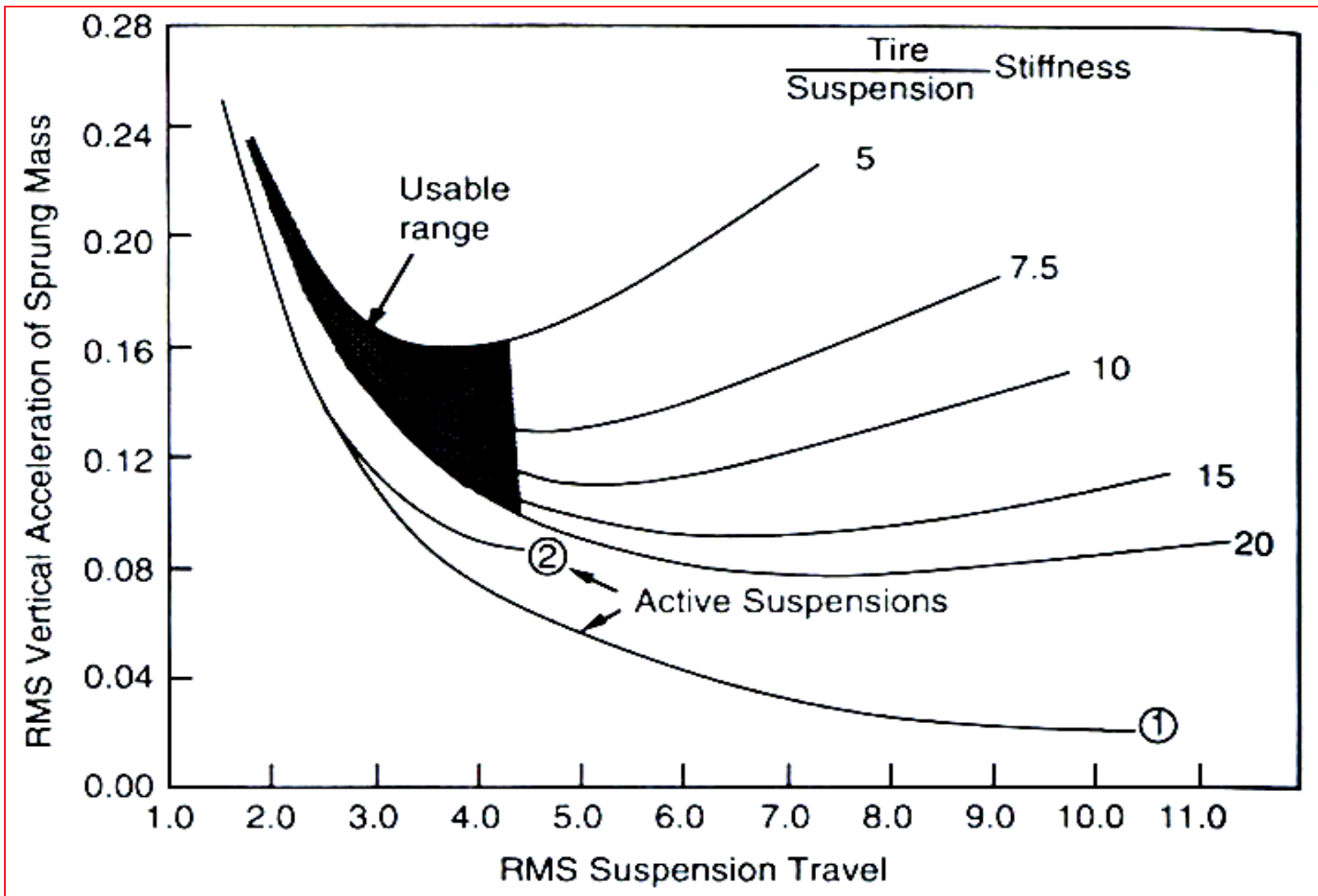
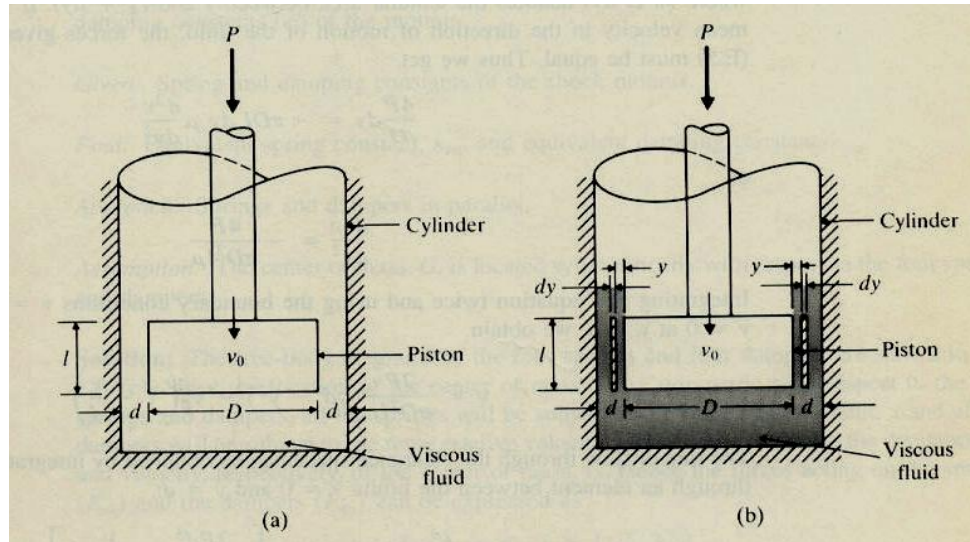


Fig: 10.6 Acceleration versus suspension travel for an active suspension

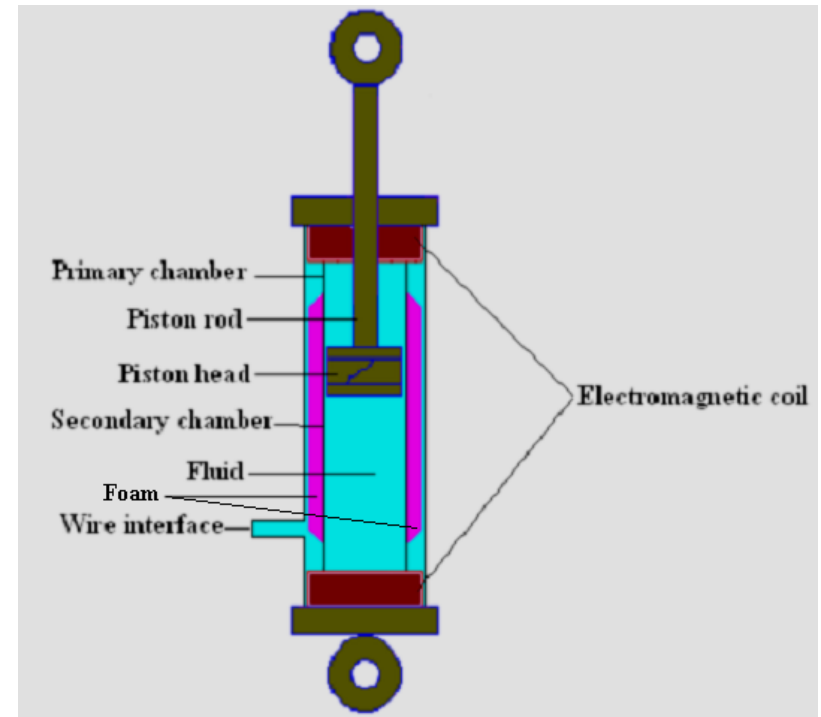
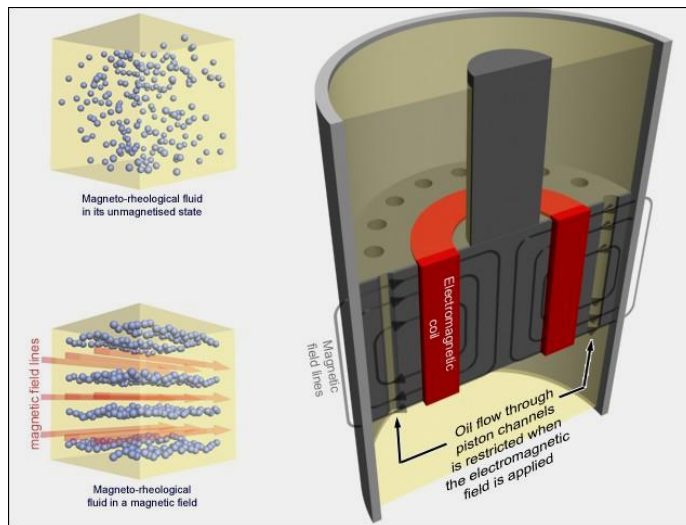
Damping Control Principle

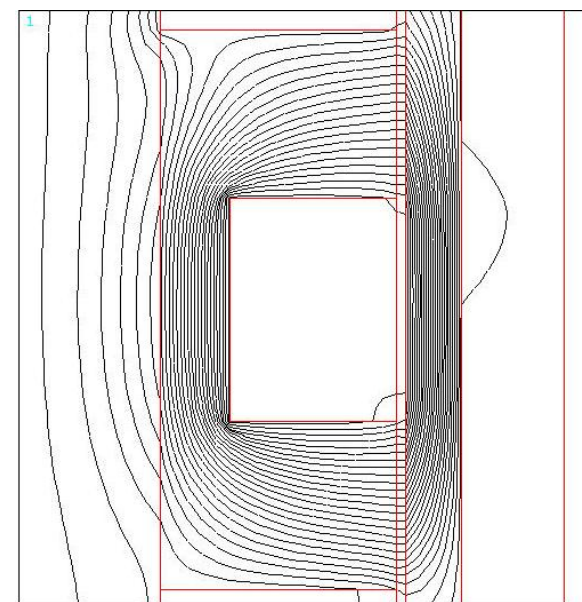
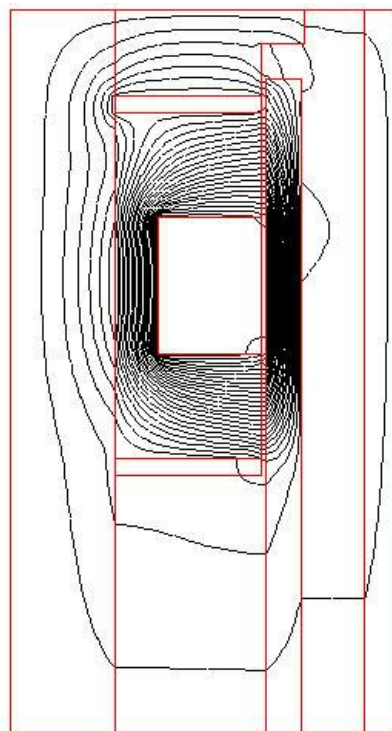
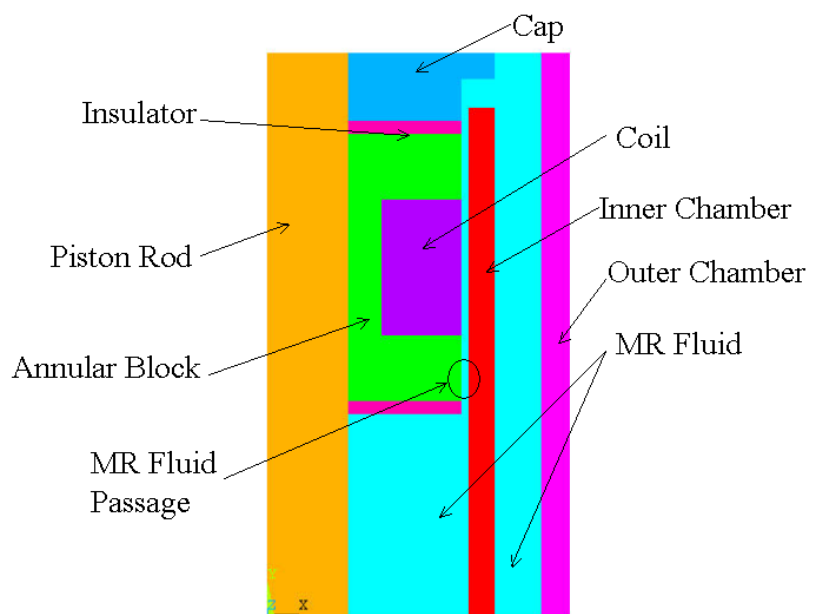


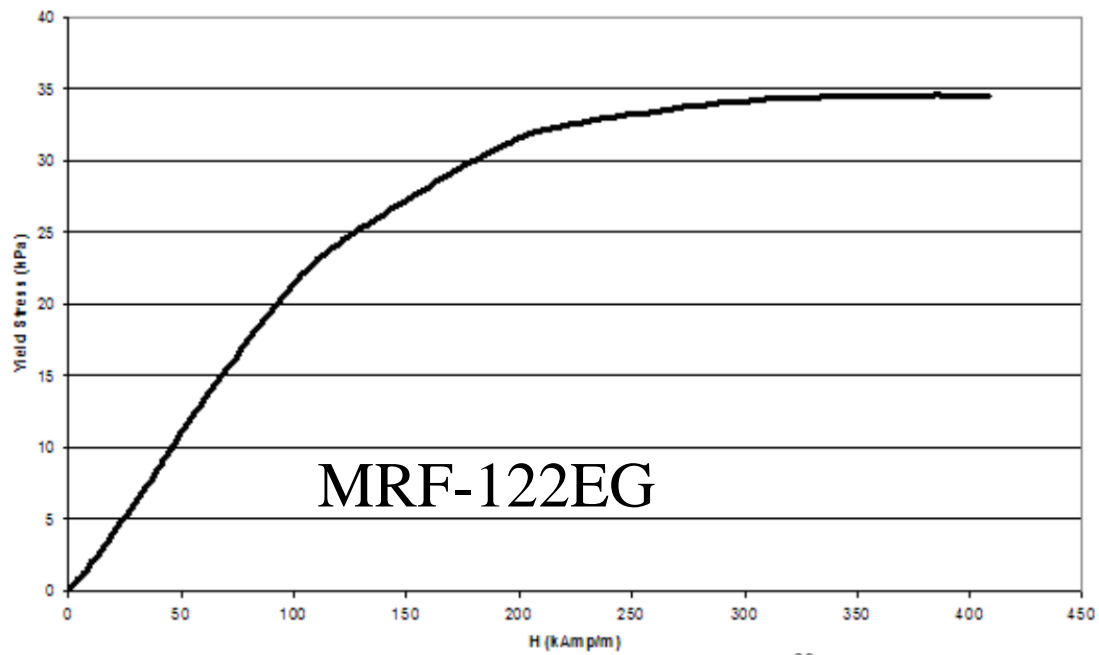
$$c = \mu \left[\frac{3\pi D^3 l}{4d^3} \left(1 + \frac{2d}{D} \right) \right]$$

Semi Active Suspension Technologies

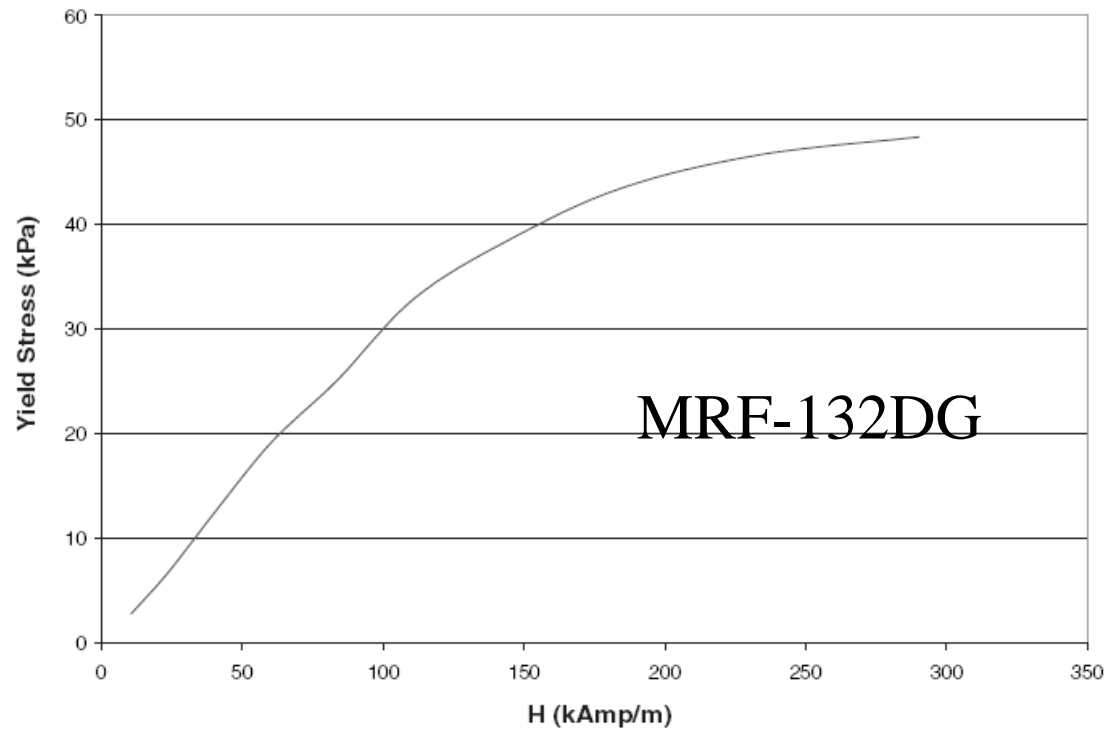
- Magneto Rheological Damper



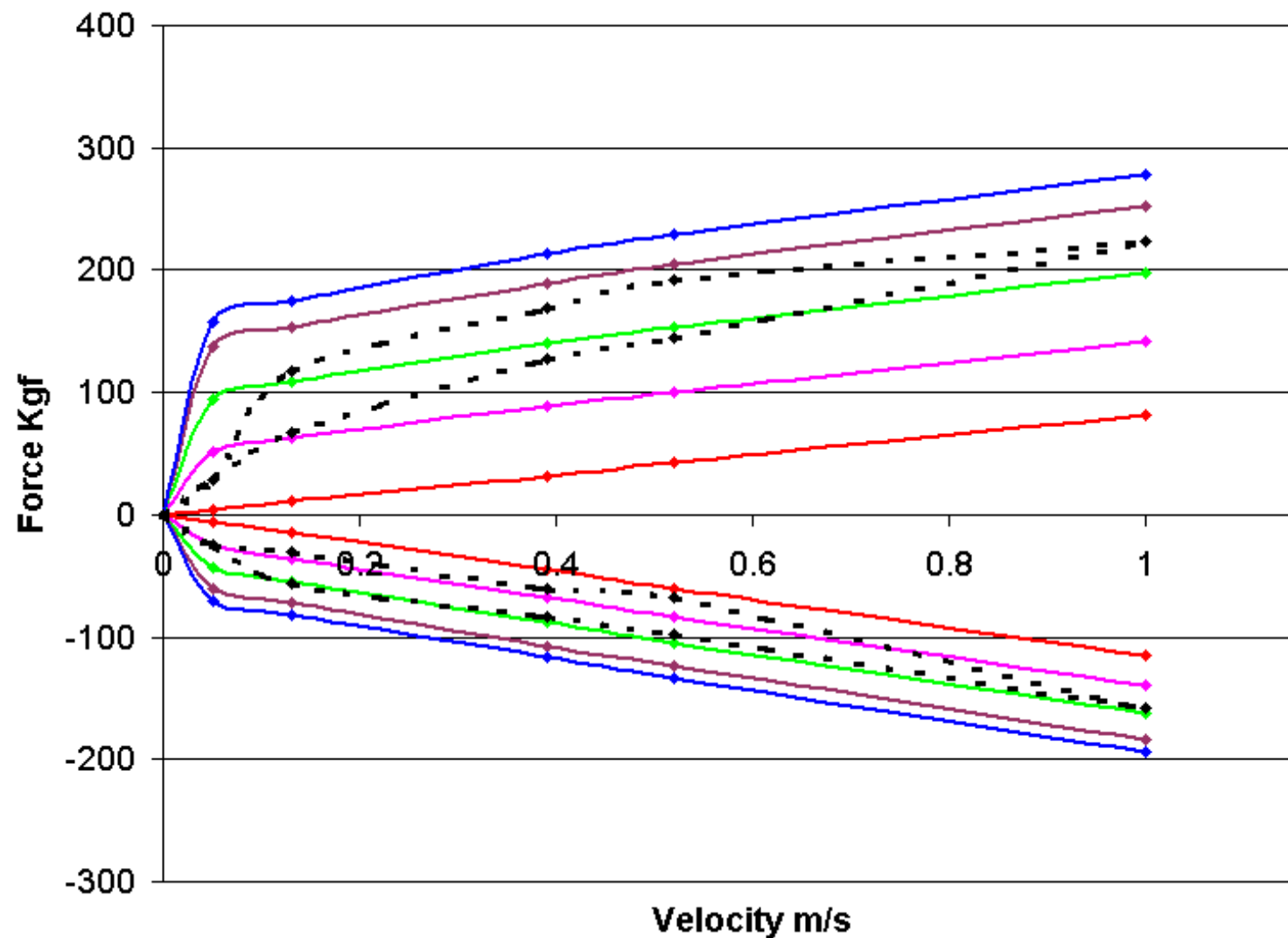




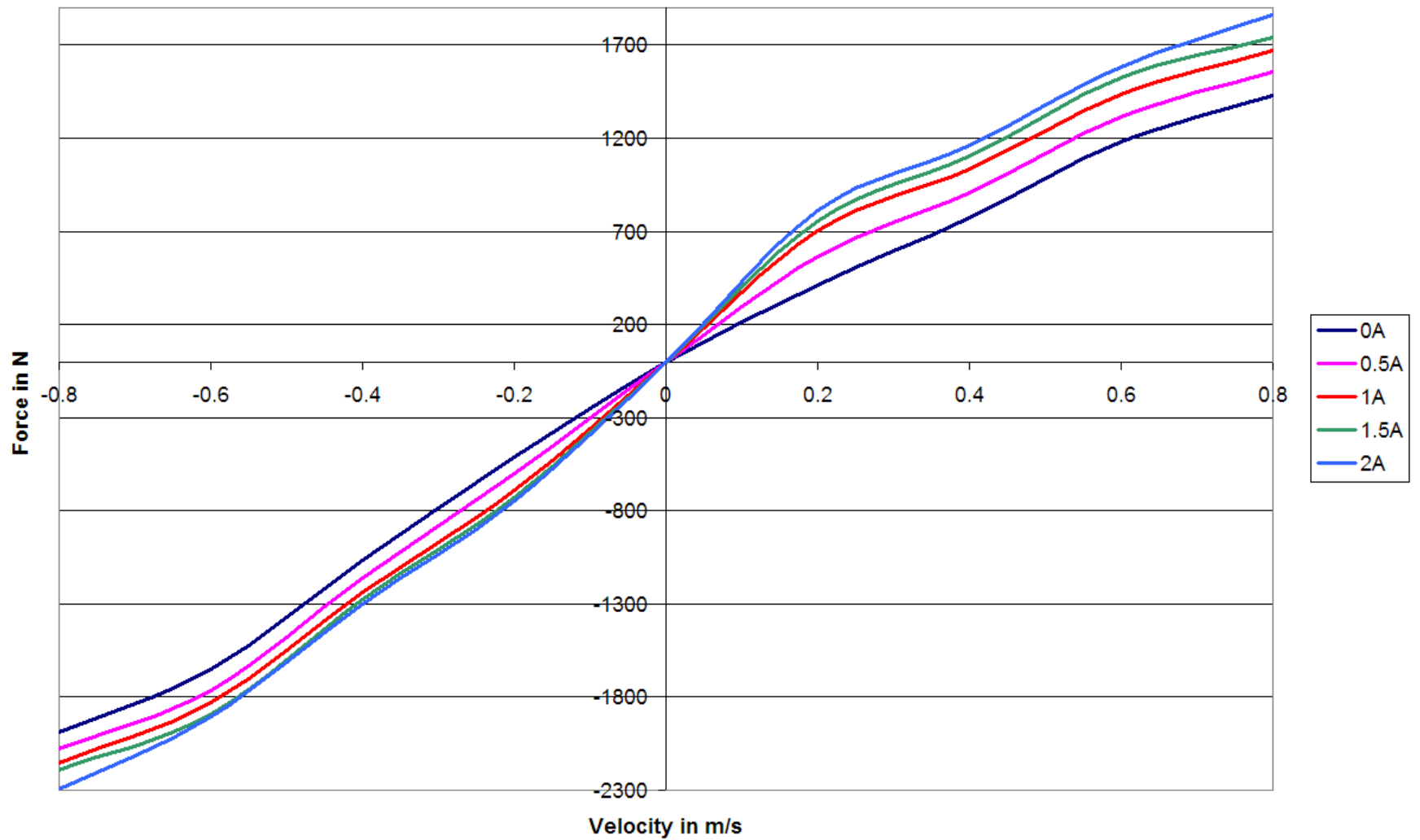
Yield Stress vs Field Intensity



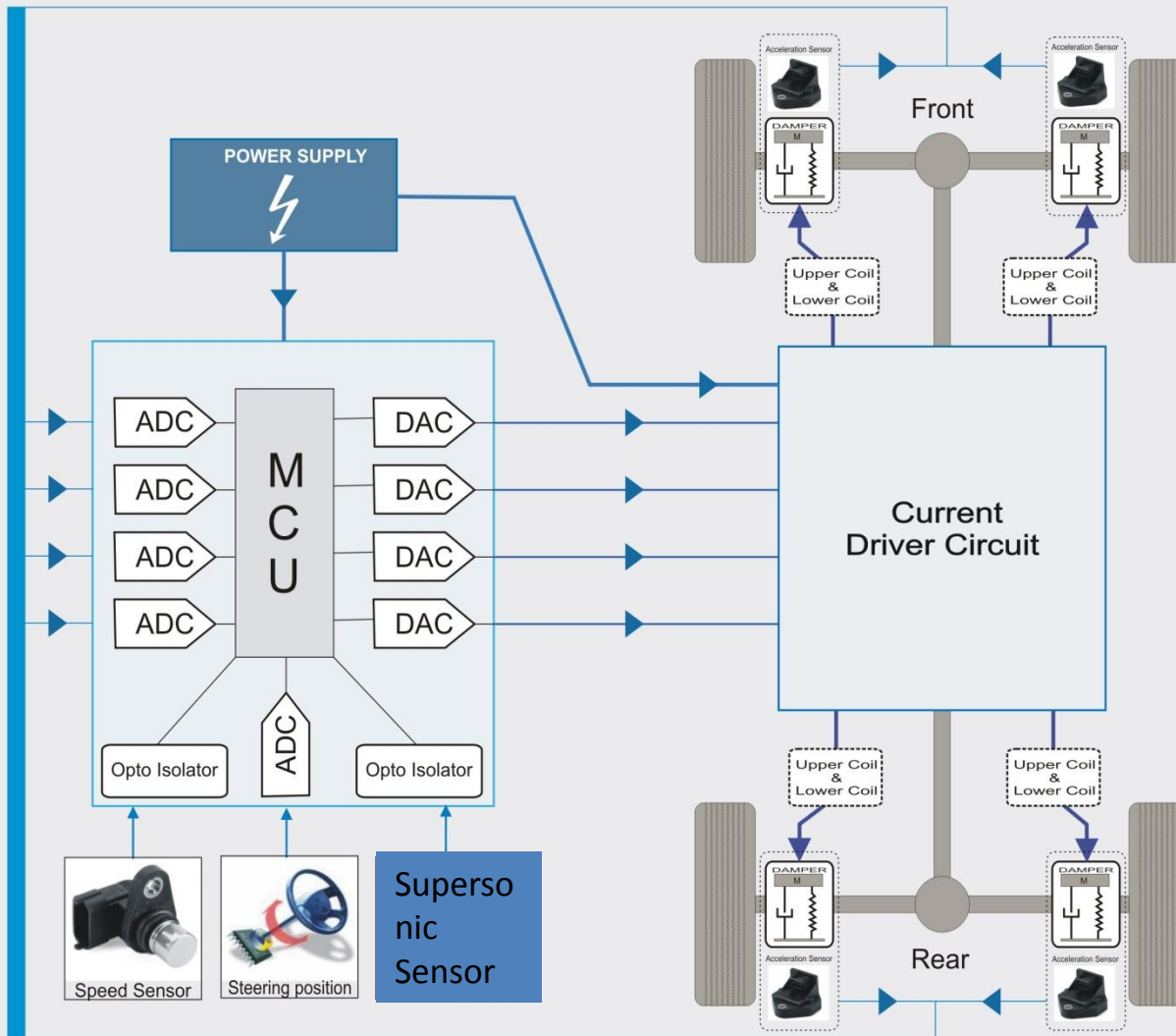
Force vs velocity (Viscosity-0.042 Pa s)



Force vs Velocity

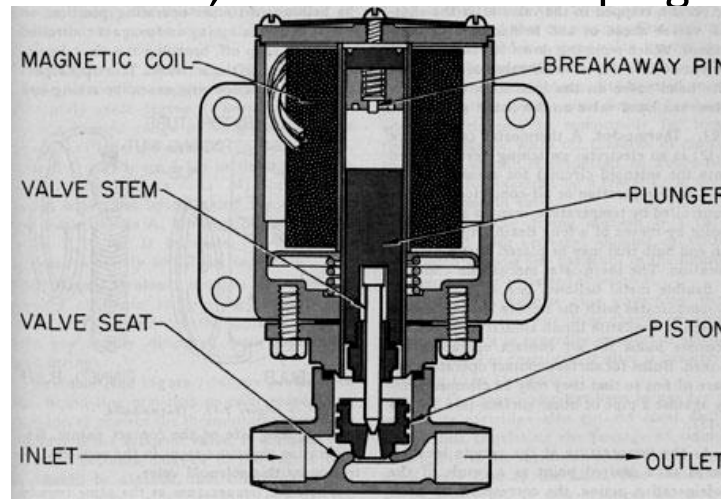


Electronic system block diagram for 4- Semi Active MR Dampers



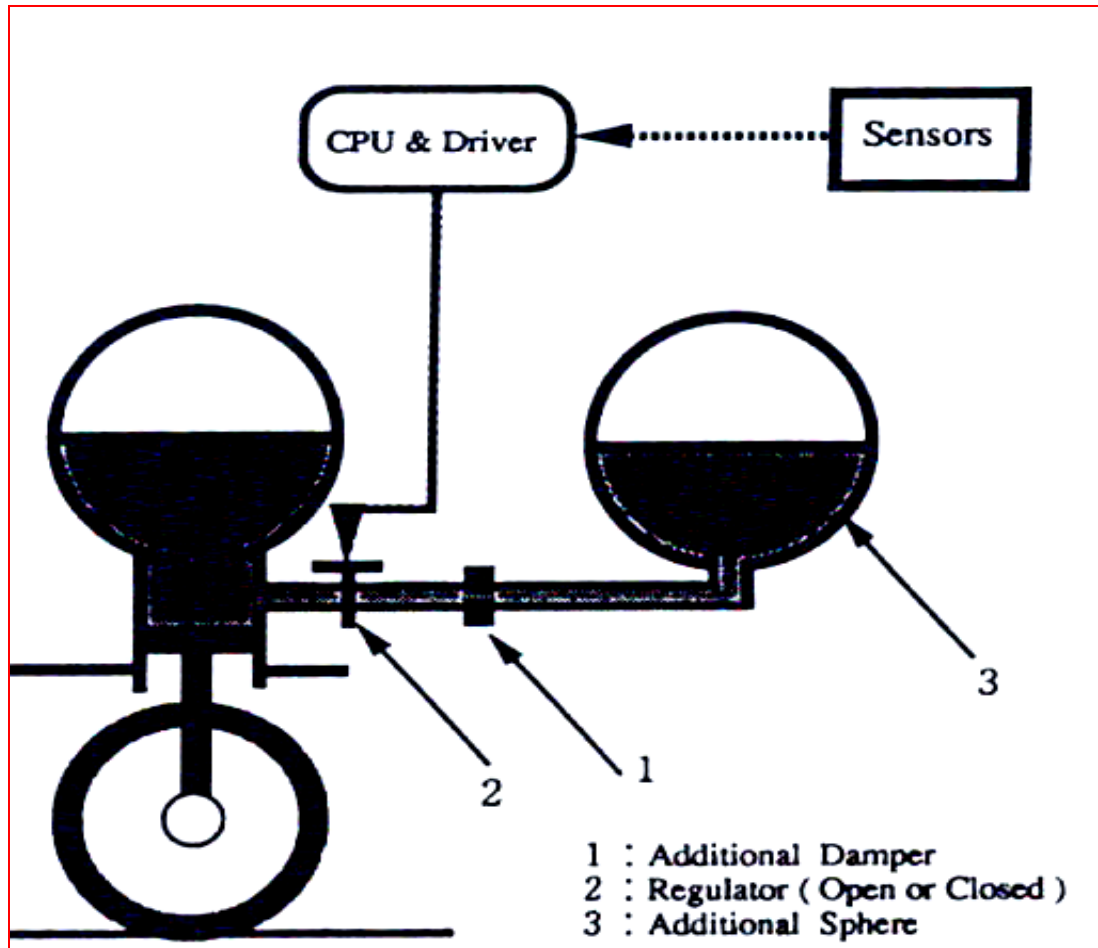
Semi Active Suspension Technologies

- Solenoid Valve Semi Active Suspension
 - This type is the most economic and basic type of semi-active suspensions
 - They consist of a solenoid valve which alters the flow of the hydraulic medium inside the shock absorber, therefore changing the dampening characteristics of the suspension setup. The solenoids are wired to the controlling computer, which sends them commands depending on the control algorithm
 - Varying the orifice size, it varies the damping coefficient



Active Suspension Technologies

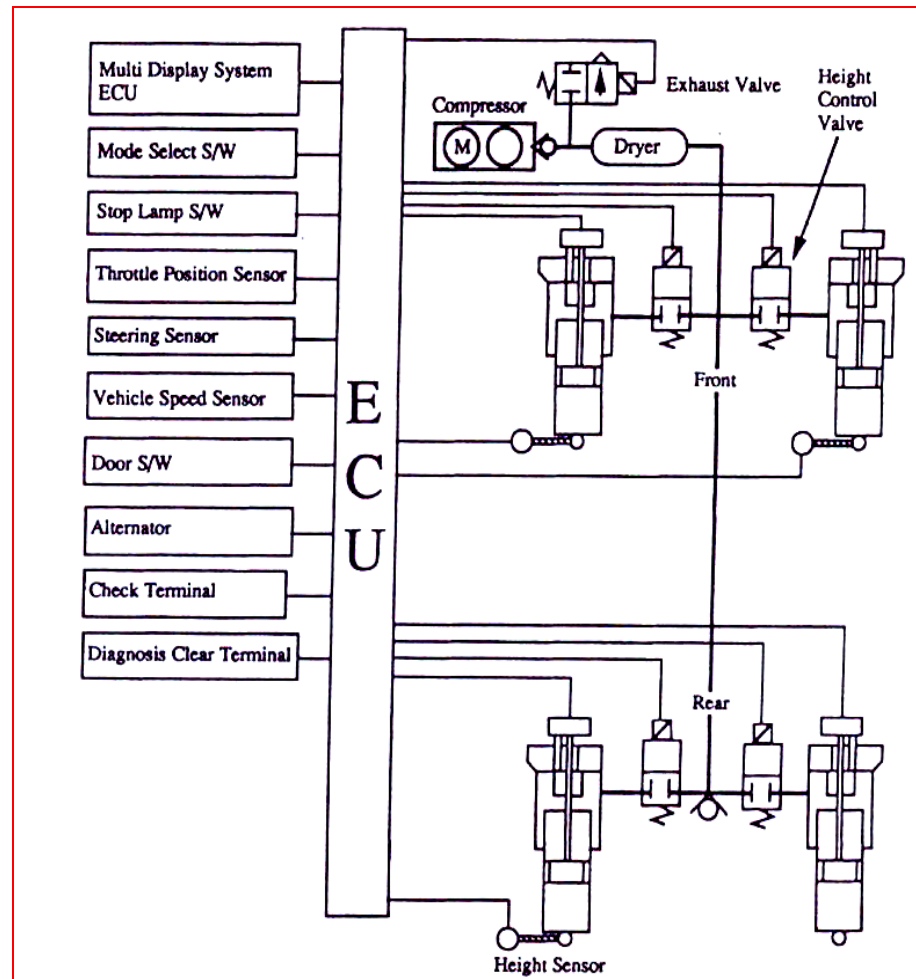
- Hydropneumatic



Slow Response

Active Suspension Technologies

- Air Suspension Control



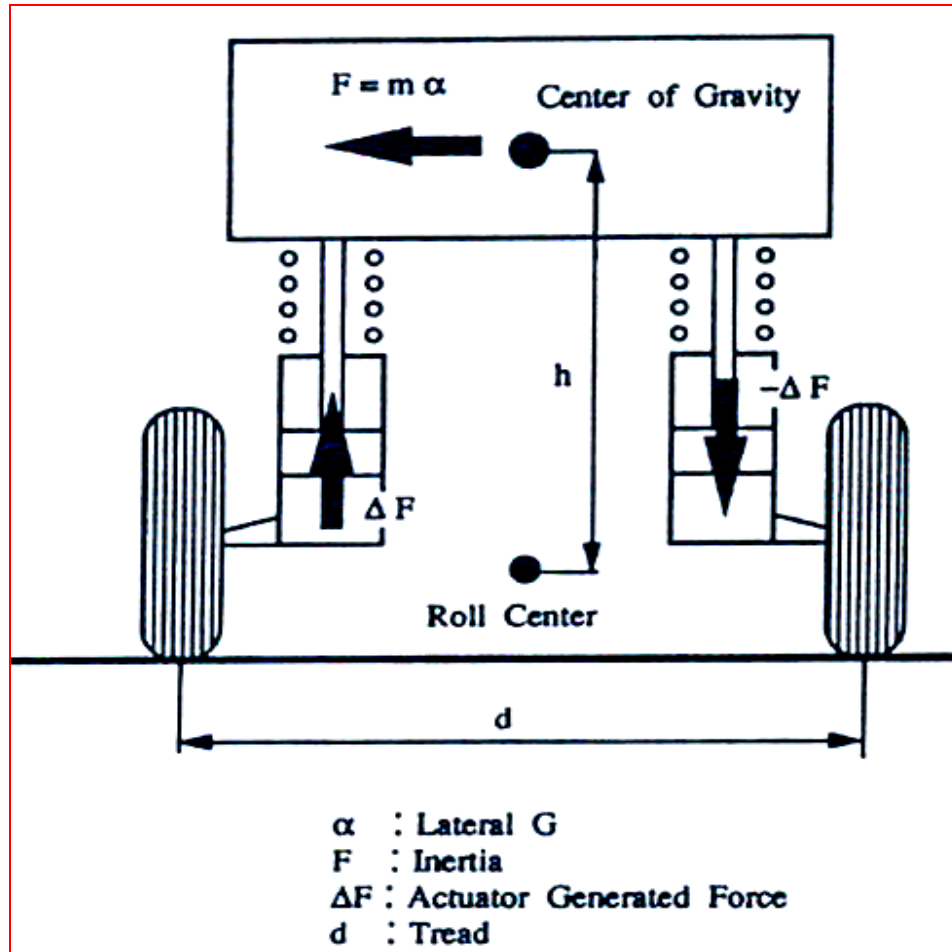
Active Suspension Technologies

- Electromagnetic recuperative



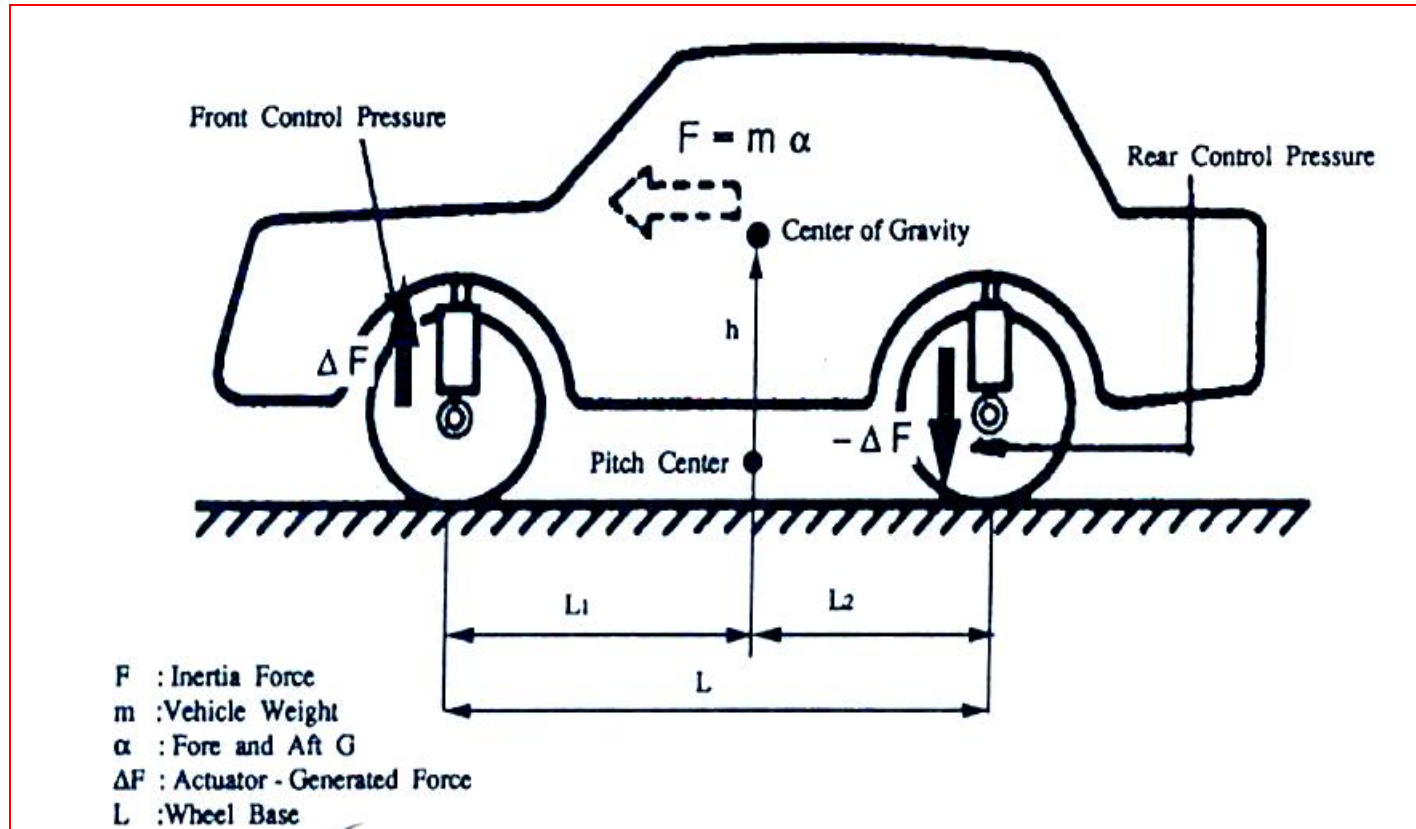
Faster Response

Control Action



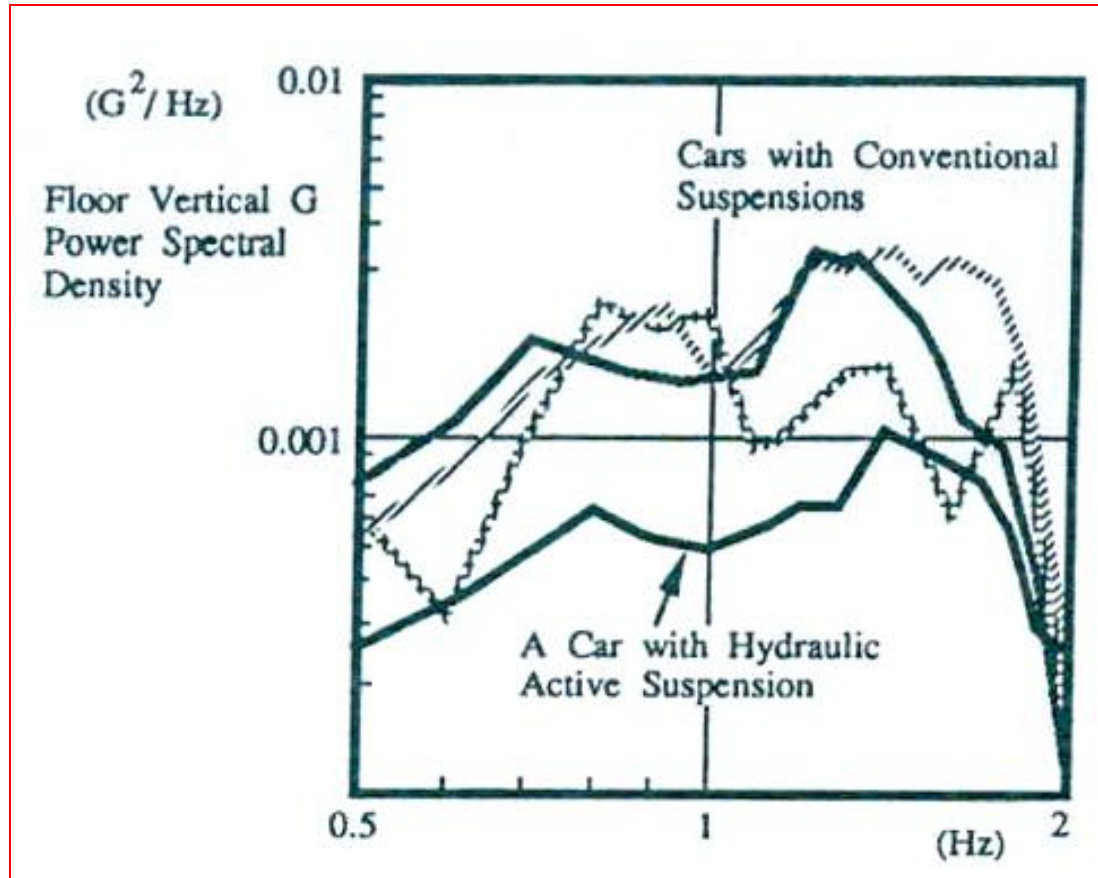
Roll Control

Control Action



Pitch Control

Control Action



Bounce Control

Active Suspension and Roll

