AUTOMOTIVE ENGINEER

TECHNICAL UPDATE 11

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Welcome to the January 2016 issue of the Automotive Engineer Technical update for IMI Certificated Automotive Engineers (CAE) and Advanced Automotive Engineers (AAE)

WOBBLY BITS

- OTHERWISE KNOWN AS SUSPENSION

In this issue, we will look at the only connection between the road wheels and the vehicle structure.

The only connection between the road wheels and the vehicle structure is the suspension system, which has to re-act the drive torque, the braking torque, the forces generated in cornering and the yaw caused by the centre of pressure position relative to the centre of gravity. In addition all the links must not fail, be produced at minimal cost and be able to sustain a high speed road obstacle impact without braking.

The tyre contact patch should remain in full contact with the road surface at all times, which requires a spring / damper system that will allow movement over obstacles but a return to normal ride height as soon as possible. The primary spring / damper system is the tyre, making the suspension spring / damper secondary. The tyre absorbs minor road imperfections by allowing the tread belt to move via the side wall relative to the road wheel, whilst the suspension takes up the major road obstacle displacements along with controlling the sprung vehicle mass dynamics.

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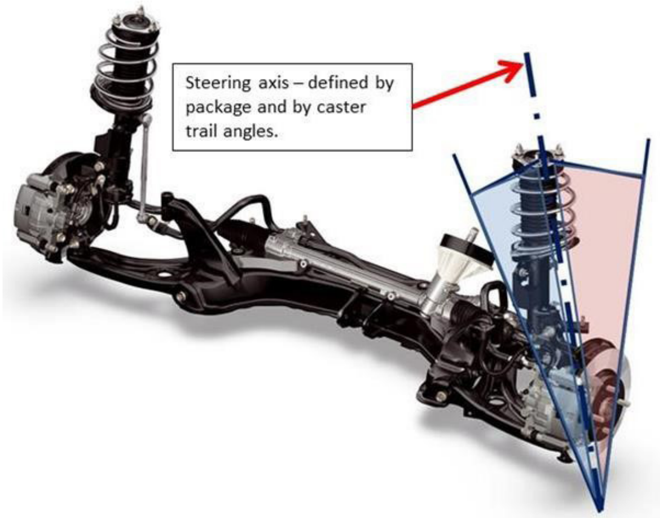
SUSPENSION GEOMETRY

The geometry is carefully developed by Ride & Handling engineers to make the best possible use of the selected tyres – indeed tyre selection can make quite a difference to vehicle dynamics no matter how humble. The original fitment will have tyre compounds which are formulated for the major destination markets so that the operational temperature range and abrasion resistance reflect the regional environment. The engineers use this behaviour to optimise the position of the road wheel relative to the front and rear of the vehicle to deliver the desired handling characteristics, so the alignment data is specific to the model type as well as the allowable tyre choice for that vehicle. Needless to say part of those values will be the pressure inside the tyres when cold, which should be within the manufacturer recommended limits at all times.

Camber: This is the angle the wheel and tyre lean towards or away from the vehicle body, when viewed from in front of the wheel. Most vehicles at normal ride height have wheels that are upright or have slightly negative camber. The idea is that as the wheel moves on the suspension dynamically, it will fall below the ride height position (droop) or rise above the ride height position (bump) but the angular change of the tyre relative to the road is minimised.

Toe: When viewed from above, the leading edge of the wheel could point dead ahead, slightly inwards or slightly outwards. Again, this is developed to ensure the steering system is correctly loaded, and is a function of the Ride & Handling engineers developing vehicle specific calibrations. For example, if the steering rack is moved ahead or behind the front wheel centre line, the appropriate toe angle would not remain constant but would alter to reflect the tensile or compressive forces in the steering arms.

Caster: To produce stability in a straight line the front steering pivot axis is designed to meet the ground ahead of the front tyre contact patch - and where four wheel steering is deployed, the same technique is applied to the rear tyres too. The distance between the point the axis meets the ground and the tyre contact patch means it is following the steering axis, and so will be easier to drive as in a straight line.



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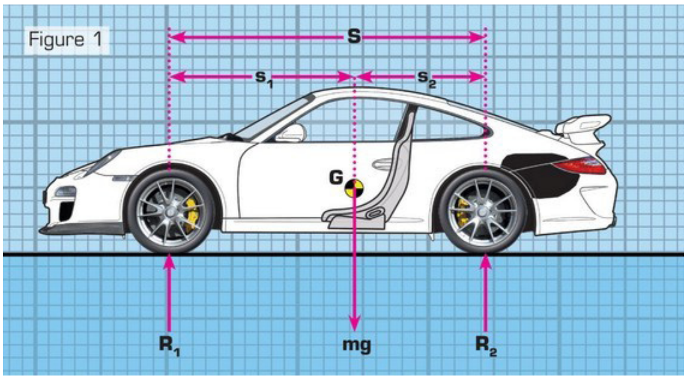
All geometry assumes symmetry either side of the vehicle longitudinal axis and that each axle set is sitting on a line at right angles to the vehicle longitudinal axis. If the vehicle body structure is out of shape, the suspension system will adopt a straight line running 'angle' so that the front and rear wheels are not quite following each other. The 'art' of good geometry is to allow the suspension to move up and down and the steering to move the wheels whilst still maintaining the optimum tyre contact with the road.

CENTRE OF GRAVITY AND CENTRE OF PRESSURE

Centre of Gravity (CoG): The centre of gravity lies on the vehicle centre line, and is the balance point of the moments from the front axle weight (R1) and the rear axle weight (R2) relative to the ground contact points, or wheel base (S). For perfect balance the product of R1 x S1 should equal R2 x S2. If the weight bias is towards the rear for example, so the CoG will move rearwards.

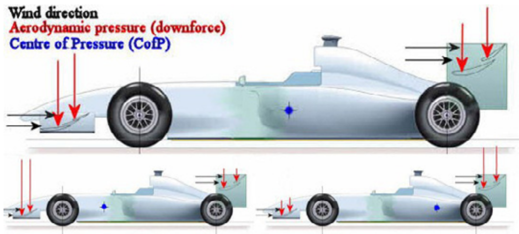


Naturally the CoG moves depending on how the vehicle is loaded, but for passenger cars the payload relative to the kerb weight is usually relatively small. Further, the mass distribution above ground level is critical, since the higher the CoG is above the ground the more readily the vehicle will lean during cornering. For passenger cars most of the mass is concentrated as close to the bottom of the body as possible, but for trucks and buses / coaches the lowest part of the load bearing structure may well be more than 1 m above the ground level.

Centre of Pressure (CoP): Every vehicle has a centre of pressure which occurs along the centre line of the vehicle, assuming it is symmetrical. All vehicles develop aerodynamic forces as the vehicle speed increases, and the objective is to reduce the natural upward force ('lift') with air management which may result in a downward force ('down force'). Typically to reduce lift, engineers seek to minimise the volume of air passing underneath the body and to ensure the maximum attachment of air to the upper surfaces.

The aerodynamic force on each end of the vehicle will have a balance point, where the force multiplied by the distance from the centre of pressure (the moment) is equal. As we can see from the diagram equal forces front and rear will produce a CoP in the middle of the wheel base:

- increase the down force at the front and the CoP will move forwards (bottom left)
- increase the down force at the rear and the CoP will move rearwards (bottom right)



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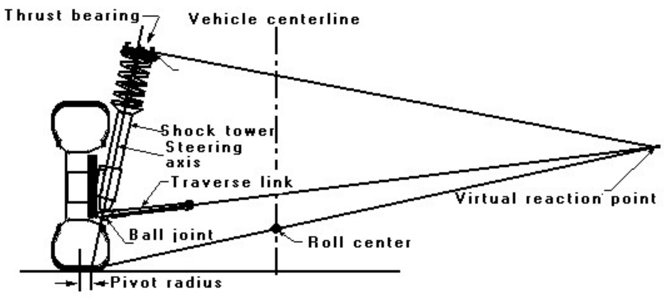
For the best stability in a straight line the CoG needs to be biased towards the front of the vehicle. For zero side wind effects the CoP should be as close to the CoG as possible – the bigger the distance between the CoP and the CoG, the bigger the moment thus the more nervous the vehicle will be in side wind conditions. If the CoP is behind the CoG, the vehicle will turn into the cross wind, which is counter intuitive for the driver. Aerodynamic aids are deployed to ensure the CoP is either close to the CoG or ahead of it, so the vehicle will steer away from the cross wind – leaving the driver to instinctively steer into the cross wind.

ROLL CENTRE

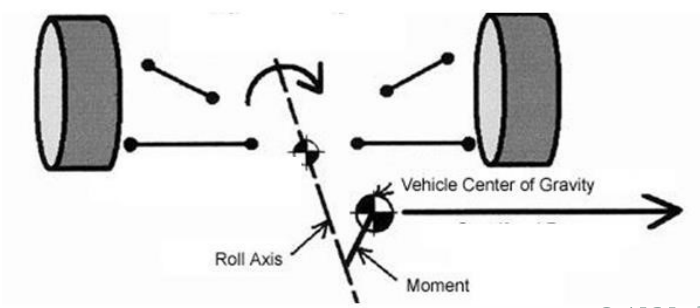
If we draw lines from the pivot / attachment points of the suspension to the body they will converge at a point some way outside the vehicle, as shown below. The line from that convergence point to the centre of the tyre contact patch will cross the vehicle centre line, and that is where the roll centre will occur.

FIGURE 14: MACPHERSON STRUT FRONT SUSPENSION



For vehicles with dead or live axles, the roll centre will pass through the outer spring during cornering. But for independent suspension the roll centre may well move depending on the suspension deflection, although it will always occur on the vehicle centre line. We can see immediately that for a vehicle with independent suspension on one axle angle only the roll centre is much more dynamic than for a vehicle with fully independent suspension.

The roll axis is the line joining the front and rear roll centres, and the height of the CoG as well as the CoP above or below this axis will determine how much the vehicle will roll, as shown below. The ultimate goal is the roll axis will not have a steep inclination, will not move vertically as the suspension is displaced and passes as close as possible to the CoG as well as the CoP. Most competition cars are able to corner at very high speed with little roll due to getting as close to this optimum condition as possible.



ROLL CONTROL

This is usually achieved by adding a spring that acts between the opposite sides of the vehicle, to counter the moment caused by the CoG position relative to the roll axis. These are called anti-roll bars, and have one rate – the torsional stiffness of the bar along with the length of the links attaching it to the suspension. For off-road conditions where a vehicle will typically travel at much lower speeds but be much more reliant on axle articulation, there is a device that allows the anti-roll bar to be decoupled.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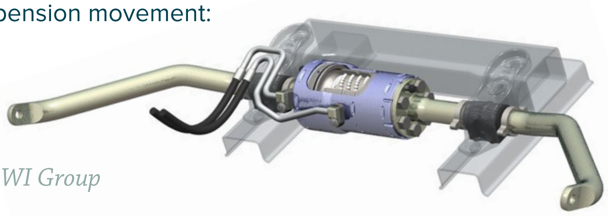
A similar device uses a motor to pre-load two sections of anti-roll bar to produce a greater anti-roll effect for a given suspension movement:


© BWI Group

Another technique is to use adaptive damping to increase the resistance to roll. In some cases if the vehicle has air suspension, to increase the outer air spring pressure to counter roll. In all cases the system needs sensor data to distinguish between hitting a road obstacle, where we need suspension compliance, and the longer duration cornering events. To assist the vehicle systems to decide what is happening the following may be monitored:

- **Engine speed (via the engine management control module)**
- **Vehicle speed (via the ESC system).**
- **Transmission ratio (via the transmission control module, AT and DSG)**
- **Steering angle (via the ESC system).**
- **Yaw angle (via the SRS control module)**
- **Suspension movement**
- **Suspension acceleration**

The latter items are achieved via Hall effect sensors (contactless displacement measurement) usually attached to one link per side of the suspension, and an accelerometer usually mounted on the damper body. These are both features of adaptive damping systems.

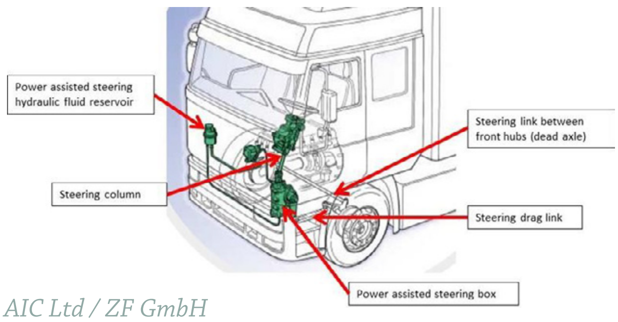
STEERING TYPES

The steering system has to translate the rotary motion of the steering wheel to move the front wheels around the steering pivot axis, either side of straight ahead. Usually the steering system selected relates to the type of suspension arrangement. In addition even the type and power assistance depends on the front axle weight, the size of the tyres, the type of manoeuvre required and the power source.

WORM AND SECTOR

Used mainly by larger panel vans, LTi taxi cabs, trucks and buses as well as off road vehicles with solid front axles. The Ackermann steering linkage is located between the front wheels, but a second lever off one hub is attached to an arm which is worked by the steering box.

- **Advantage:** Easily packaged on just one chassis leg.
- **Disadvantage:** The extended linkage can give quite a lot of play in the system, and the geometry to prevent bump steer (direct feedback of large road undulations back through the steering) is very difficult. For this reason the system tends to be used with full power assistance, where the engine power hydraulics move the steered wheels at the command of the steering wheel.



RACK AND PINION

Can be used without power assistance, the rack has one set of teeth and the pinion is driven by a column from the steering wheel. This is the most common means of steering on passenger cars.

- **Advantage:** Direct actuation of each hub from each end of the rack – better precision.
- **Disadvantage:** Difficult to package in or around engines, difficult to get the steering column drive to it.

HYDRAULIC POWER ASSISTED STEERING WITH RACK AND PINION STEERING RACK:

The system shown below is typical of an engine pump driven hydraulic assistance system. The pump (5) draws fluid from the reservoir (6) and delivers it via the high pressure line (7) to the rack assistance valve body. The valve inside it delivers assistance depending on how the steering wheel moves the rack position via pipes (4). The hot fluid normally will pass through a cooler and then back to the reservoir (3). In this system there is an electronic Control (2) to reduce assistance when the vehicle reaches a certain speed (1).

- **Advantage:** Excellent feedback and if properly developed, unobtrusive assistance.

- **Disadvantage:** The same limitations as for a steering rack with the addition of all the hydraulic pipes, the pump and cooler. In addition the system takes around 1 kW when not working, up to 5 kW when giving maximum assistance.

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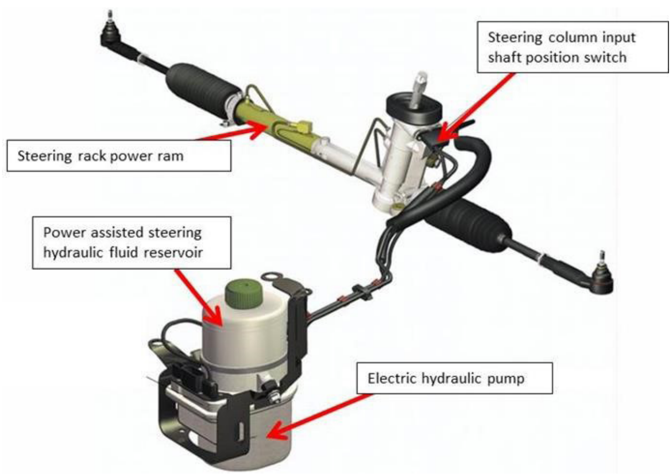
ELECTRO HYDRAULIC POWER ASSISTED STEERING WITH RACK AND PINION STEERING RACK:

As an answer to the constant power required for an engine driven hydraulic system, even when it was not providing any sort of assistance, the on-demand electro-hydraulic system provided power to cope with larger tyres and heavier axle weights, than the first generation electric assistance systems. This technology is now migrating away from cars towards heavy trucks.

- **Advantage:** Supplied pre-assembled and complete with PAS fluid. The on demand electric motor saves energy because it only works when the assistance is demanded – unlike an engine driven PAS system. In addition, there is no need for a PAS oil cooler since the system does not work continuously. The electronic control allows some degree of vehicle self-steer when integrated into the ESC and other safety systems.

- **Disadvantage:** Same disadvantages as a normal rack and pinion system, with the addition of a live power feed to the electric motor (it can draw more than 30A). In addition there was always a slight delay in the PAS assistance starting up, giving the driver the sensation of the steering system suddenly going 'light' as it powered up.



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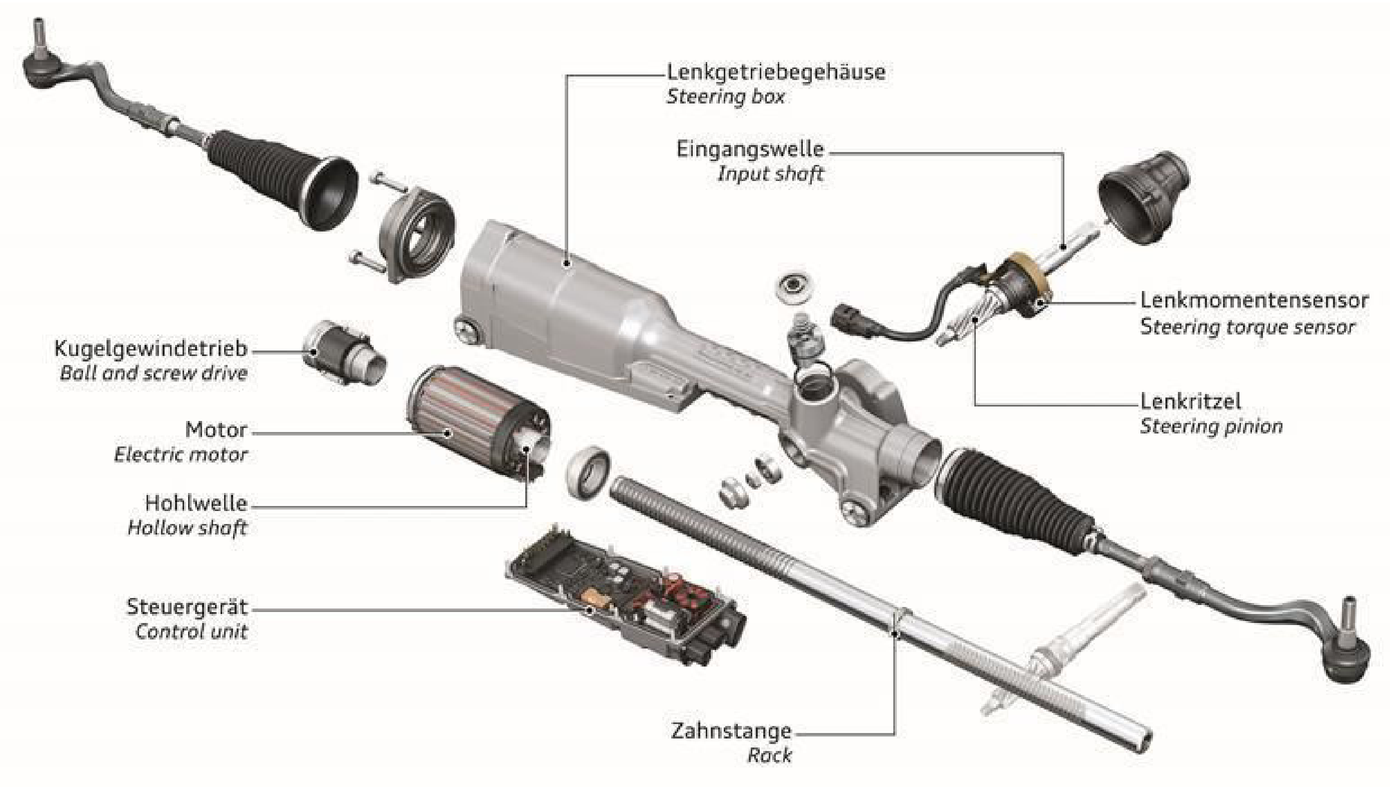
ELECTRIC POWER ASSISTED STEERING WITH RACK AND PINION STEERING RACK

Initially offered in 1989 on the MG F and the Honda NSX Auto, the motor powered system could not cope with axle weights much above 400kg and tyres no wider than 200mm. With the advent of the column mounted systems introduced by Delphi and TRW, cars like the Renault Megane II had the motor pack close to the steering wheel. The column assembly weight however was frequently greater than 20kg, which required a bigger instrument panel carrier beam and issues around airbag calibration. Modern systems package the motor drive by the rack to deliver the best possible assistance, but that too has not been without issues due to heat from the engine just above the rack.

- **Advantage:** No PAS fluid, on demand only, initial package problems largely solved with current generation systems. Being fully electronically controlled, the rack can now be fully integrated into the ESC as well as other active safety systems to allow limited vehicle self-steer.

- **Disadvantage:** Apart from the usual rack packaging issues, very few.

This is the integrated electric motor drive for the e-PAS used on the Audi A6 and A7 (C7 platform). Other versions of the same technology use a belt drive between the motor and rack, as well as gear drive.

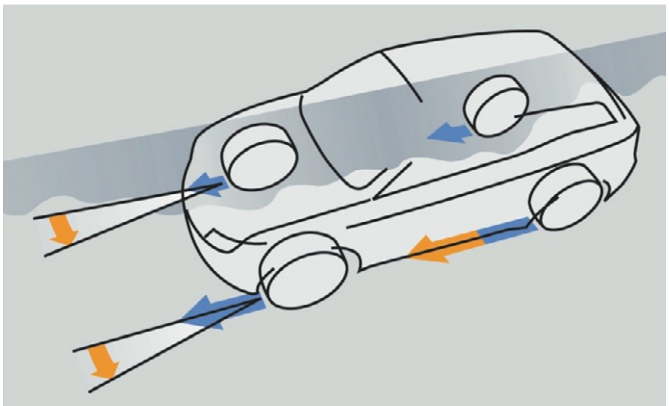


THE WILD CARD...

Steering can be achieved by applying one or more brake during a cornering situation, to the extent the applied torque on the road wheel causes the vehicle to correct the amount of under steer or over steer that would occur without the correction. This is a core technology of Electronic Stability Control (ESC). To assist the vehicle systems to decide what is happening the following may be monitored:

- **Engine speed (via the engine management control module)**
- **Vehicle speed (via the ESC system)**
- **Transmission ratio (via the transmission control module, AT and DSG)**
- **Steering angle (via the ESC system)**
- **Yaw angle (via the SRS control module)**

Another device is active torque vectoring. First introduced on the BMW X6 (E71), unlike the active torque split systems used on four wheel drive vehicles (Nissan GT-R, Mitsubishi Evo) this allows torque to be distributed at will left to right during cornering. The result is a change in vehicle attitude, correcting the level of under steer or over steer that would ordinarily occur.



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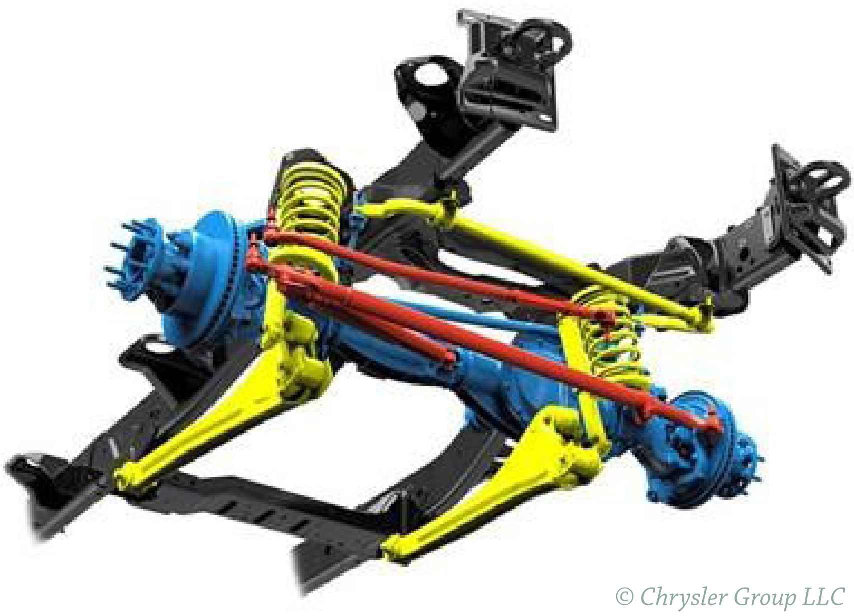
FRONT SUSPENSION

There are three arrangements typically used for the front suspension, since the wheels need to be able to pivot around the steering axis in order to give maximum manoeuvrability, or commonly referred to as steering 'lock'.

SOLID AXLE:

A non-driven solid axle is referred as 'dead' and a driven solid axle called 'live'. The wheels and brakes are built onto the axle, which is then attached to the body via springs, dampers and location struts. The example shown below is from a Dodge Ram 3500 Super Duty 4x4 pickup, with two leading links for longitudinal location and a single Panhard rod for lateral location. The axle is driven, so is referred to as a 'live axle'.

- **Advantage:** Simple layout, relatively low cost, usually excellent steering lock.
- **Disadvantage:** Roll takes place around the outer spring assembly in a corner, so the 'roll axis' moves from side to side depending on which end of the axle is on the outside of the corner. Any deflection of one wheel directly affects the other, and the location is very critical to the overall system accuracy – wear in location rods will directly affect vehicle stability. All components and systems above the axle must be above the maximum bump position, unless connected to the axle itself – this is quite an intrusive packaging constraint. Finally – the steering pivot axis usually ends up quite a way inboard of the wheel, making the king pin inclination angle tricky.

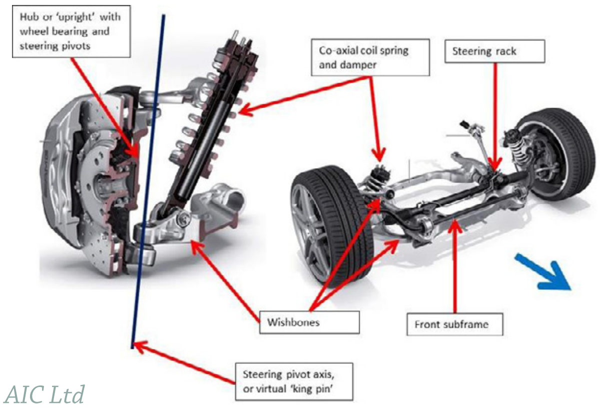


DOUBLE TRANSVERSE LINKS / DOUBLE 'WISHBONE':

The classic solution to providing wheel control so that as one wheel is moving over a bump, the other remains unaffected.

- **Advantage:** Relative freedom to pace the steering pivot axis in the best possible position without too much influence on the hub / wheel bearing / brake package. Excellent wheel location in longitudinal and transverse directions along with lower powertrain installation height.

- **Disadvantage:** Cost – two sets of links per wheel and the associated body pick up points.



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MACPHERSON STRUT:

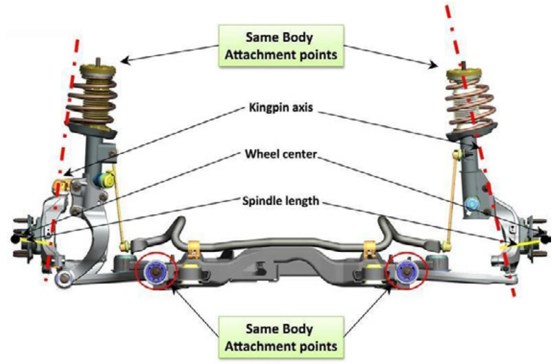
Invented by a Ford engineer and first appeared on the Ford Anglia 105E. This arrangement has been used in all types of vehicle – it integrates the spring / damper unit as part of the steering pivot axis location as well as providing location for the wheel along with a single lower transverse member.

- **Advantage:** Just two body inputs - one for the spring / damper unit, and one for the lower transverse link. Thus lower cost than the double wishbone arrangement. Excellent wheel location both in longitudinal and transverse directions, along with the advantages seen in the double wishbone arrangement.

- **Disadvantage:** The package of the spring / damper unit relative to the tyre dictates the steering pivot axis position. On smaller vehicles this is less of a problem, but as tyres size and transmitted power increases (for front wheel drive) the steering pivot axis offset at ground level increases, so causing more torque steer.

The latter point was solved on higher performance front wheel drive cars by using a hub within a hub. This solution has been used for:

- **PSA - Peugeot 406, Peugeot 407, Peugeot 607, Peugeot 508, Citroën C5, Citroën C6**
- **Renault - Megane II RS / III RS, Renault Clio III RS / IV RS**
- **Ford Focus 2 RS**
- **Vauxhall - Insignia VXR, Astra 'J' GTC, Astra 'J' VXR, Cascada**



© Adam Opel AG

On the right is a conventional MacPherson strut, whilst on the left is the double hub pivot assembly which creates another – optimised – steering pivot axis, free from the tyre to spring / damper package constraints. Crucially reduction of the 'spindle length' reduces the moment of the tyre contact patch relative to the steering pivot axis, and so reduced torque steer force.

Torque steer afflicts front wheel drive cars. As the lock is applied, if the engine power is then increased the steering may try to apply more lock. When accelerating in a straight line, slight variations in traction between the two front tyres may also induce a steering effect. The result is the driver never knows which way the vehicle is going to steer during acceleration. How can torque steer be reduced without using the solution shown above?

- By increasing the level of power steering assistance, so the driver gets less torque feedback though the steering wheel.

- By limiting the power transmitted to the front wheels – typically less than 250 bhp. Above this level either four wheel drive or rear wheel drive should be used.

REAR SUSPENSION

There are many variations in design, depending on if the rear wheels are driven or not. Some common layouts include:

SOLID AXLE:

A non-driven solid axle is referred as 'dead' and a driven solid axle called 'live'. The wheels and brakes are built onto the axle, which is then attached to the body via springs, dampers and location struts.

- **Advantage:** Simple layout, relatively low cost.

- **Disadvantage:** Roll takes place around the outer spring assembly in a corner, so the 'roll axis' moves from side to side depending on which end of the axle is on the outside of the corner. Any deflection of one wheel directly affects the other, and the location is very critical to the overall system accuracy – wear in location rods will directly affect vehicle stability. All components and systems above the axle must be above the maximum bump position, unless connected to the axle itself – this is quite an intrusive packaging constraint.

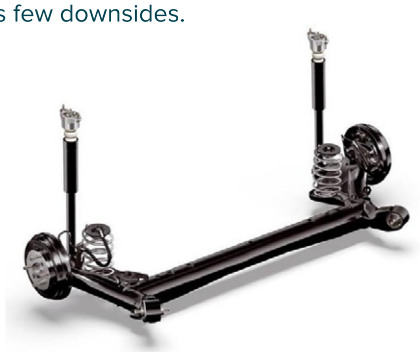
TORSION BEAM:

Usually not driven, the torsion beam refers to the section welded between two trailing arms. It has been widely adopted because it is relatively light and has six attachment points – two for the dampers, two for the road springs (usually coil springs) and two primary locations for all the longitudinal as well as transverse loads.

- **Advantage:** Simple layout, relatively low cost. The anti-roll bar function is included in the beam, but some assemblies have an anti-roll bar too.

- **Disadvantage:** There is some transfer of wheel movement from side to side, so is frequently called 'semi-independent'. For on-road applications the arrangement offers few downsides.

© Mazda Motor Co.



DOUBLE TRANSVERSE LINKS / DOUBLE 'WISHBONE':

The classic solution to providing wheel control so that as one wheel is moving over a bump, the other emains unaffected.

- **Advantage:** Excellent wheel location both in longitudinal as well as transverse direction.

- **Disadvantage:** Cost – two sets of links per wheel – and intrusion into the body. In addition double wishbones can be used alone but usually require a trailing arm to react traction forces whilst still providing generous longitudinal compliance for ride quality.

MACPHERSON STRUT:

Often called the 'Chapman strut' after the founder of Lotus, Colin Chapman. It is identical to the front end application except the wheel is fully located so that there is no steering pivot axis.

- **Advantage:** Just two body inputs - one for the spring / damper unit, and one for the lower transverse link, so cheaper than the double wishbone arrangement. Excellent wheel location both in longitudinal and transverse directions.

- **Disadvantage:** The package of the spring / damper unit leads to quite a tall intrusion into the rear body space, and the geometry is not well suited to long travel suspension.

MULTI-LINK:

This is a hybrid double wishbone and trailing link arrangement, where it typically has four to five links. First seen on the Mercedes-Benz 190 (W201) the arrangement allows specific isolation bush tuning for the load carrying (spring / damper), torque reaction (drive and braking), lateral location, longitudinal location and control of toe / camber. The assembly from the Mercedes-Benz ML (W166) is shown below.

- **Advantage:** Ability to tune the suspension to deliver excellent wheel control along with excellent refinement.

- **Disadvantage:** Cost, as well as the intrusion into the rear underbody.

© Daimler AG

SPRINGS, DAMPERS AND ADAPTIVE DAMPERS

There are three types of road spring in widespread use:

LEAF SPRING:

Called 'semi-elliptic' leaf springs, these were originally used on horse drawn carriages as a pair of springs. Each unit is made up of strips of spring steel held together at the axle attachment point, and the outer ends are attached to the body. Variations of this technology include variable depth leaves ('taper leaf springs') as well as springs made from either glass reinforced plastic or even carbon fibre reinforced plastic. The latter application has been used as part of a double wishbone linkage on the Chevrolet Corvette since 1964.

- **Advantage:** Typically used with dead or live solid axles, it offers complete axle location.

- **Disadvantage:** The complete axle location is a complete myth, in that the lateral loads cause the leaf springs to twist. Most systems have at least additional transverse location with a Panhard rod or Watt linkage.

COIL SPRING:

A single bar of tempered steel wound into a helix. It is effectively a compact torsion bar spring. Usually made from steel, has been made with thick wall tubes, and also made from Titanium.

- **Advantage:** Pure spring energy, cheap to make.

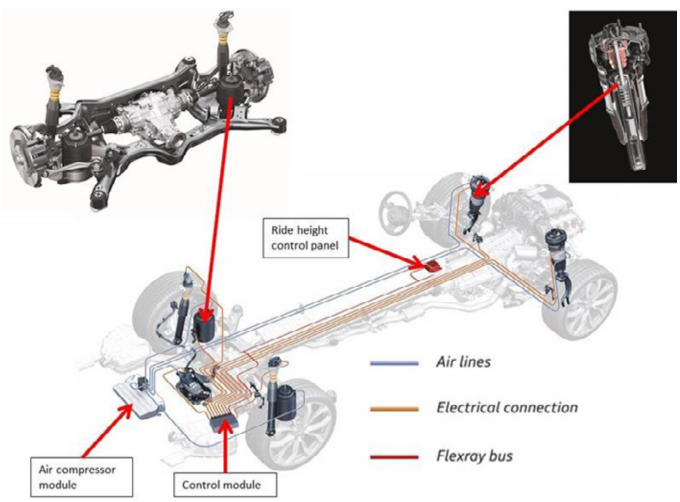
- **Disadvantage:** Requires the suspension to provide all the wheel location – nothing is provided by the coil spring. Seating of the coil spring is critical to longevity, and failure is usually caused by a break down in the spring corrosion protection.

AIR SPRING:

Using compressed air, the rubber envelop replaces the (usually) steel spring. Below is the system used for the Audi A6 and A7 (A7 platform), with the front strut including the damper as well as the ride height sensor.

- **Advantage:** Pure spring energy, relatively cheap to make. Also provides the opportunity to vary ride height or maintain ride height regardless of load on board.

- **Disadvantage:** Requires the suspension to provide all the wheel location – nothing is provided by the air spring. Additionally the system requires an air compressor, ride height sensors and a control module.



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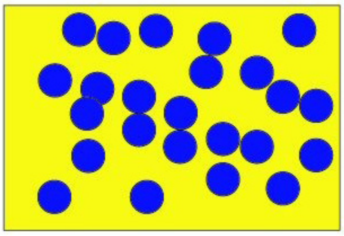
DAMPERS:

These control the motion of the spring as the suspension absorbs road surface inputs – if these were not fitted the spring would continue to vibrate at its natural frequency long after the initial road surface input. For live axles they also provide a useful torque reaction function, which is why they can by inclined in opposite directions. The dampers also form a wheel location function when used in a MacPherson or Chapman strut.

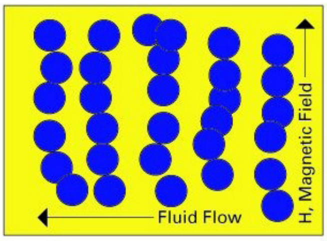
Where length of the damper is difficult to package, the twin tube damper is used. The piston slides inside a tube which has valves between the inner and outer tubes in addition to the piston damper. In the case of a co-axial spring a spring seat pan is welded to the outer damper body, and in the case of a MacPherson strut the lower damper body will have attachment straps for the hub.

ADAPTIVE DAMPERS:

Most dampers are configured to cope with a range of vehicle weight conditions, but are not fully optimised for any single condition. Adaptive dampers allow the electronically controlled suspension to detect if load is being carried, the effect of vehicle attitude, and to alter the damper characteristic accordingly. Some systems use a stepper motor to control different damper piston rod valves, and hence can alter damper stiffness in real time. Another technology is to use a special fluid which can have its viscosity altered by application of a magnetic field around the damper body (the 'Magneride' system), as shown below.



System 'off' – normal damping



System 'on' – increased fluid viscosity

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To assist the vehicle systems to decide what is happening the following may be monitored:

- **Engine speed (via the engine management control module)**
- **Vehicle speed (via the ESC system).**
- **Transmission ratio (via the transmission control module, AT and DSG)**
- **Steering angle (via the ESC system).**
- **Yaw angle (via the SRS control module)**
- **Suspension movement**
- **Suspension acceleration**

The latter items are achieved via Hall effect sensors (contactless displacement measurement) usually attached to one link per side of the suspension, and an accelerometer usually mounted on the damper body. These are both features of active roll control systems.

PUTTING IT ALL TOGETHER

All suspension systems are re-active, managing the effect of passing over an obstacle or the effect of physics during cornering. Active suspension places each road wheel relative to the road surface, allowing all sorts of party tricks.

Lotus Engineering together with TRW and Moog devised the very first automotive active suspension systems staring in the late 1970s, using sets of sensors to determine the impending acceleration and movement demand for each road wheel. The wheel was moved into position via a powered hydraulic system – the road springs were present only to take the static weight of the vehicle. The system was relatively bulky, noisy (the hydraulic pump was driven by a continuously variable speed transmission from the Harrier) and relatively expensive.

Mercedes-Benz used the introduction of the S class Coupe C217 to integrate active roll control with active safety forward scanning devices (RADAR, LIDAR) to produce what they called 'curve tilting function'. This allows the vehicle to lean into a corner much as a motor bike would rather than let physics take over and roll outwards. Whilst this system uses a combination of adaptive damping, variable rate air springs and active roll control, it is not an active system in the sense of the Lotus vision.

However, the dream is not dead yet. As cars get lighter the payload will become more significant, which already causes great challenges when developing a suspension system. Additionally larger vehicles with much higher axle weights (HGVs, buses, coaches) need much better wheel control to reduce the effect of compounded road damage – effectively there is a real need for active suspension that can take into account all payload scenarios.

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WHAT'S IN THIS FOR US?

The state of the road system across the UK will ensure a steady stream of tyre, wheel and suspension damage repair for many years to come. The suspension and steering links are designed to deform in the event of severe impact, which may mean the customer notices the vehicle is pulling to one side after hitting a severe road imperfection.

Four wheel alignment is the start of the process, to scope the extent of the damage. Once complete, an inspection of each link is required, taking into account the possibility of isolator bush wear. When the apparent damage has been fixed, a four wheel alignment check is required to ensure the combination of camber, castor and toe as specified by the OEM Ride & Handling engineers is achieved. Finally, before the vehicle is released, the tyre condition and pressure whilst cold need to be checked – the pressures should be adjusted in line with the OEM recommended data.

There are exciting developments with active ride systems, glass fibre reinforced coil springs, carbon fibre wheels, active anti-roll bars and active torque vectoring that will ensure plenty of opportunities to support vehicles in later life, aside from routine repairs.

QUESTIONS

01 What are the three key geometry measurement types called?
02 What does a damper do?
03 What is adaptive damping?
04 What is a MacPherson strut?
05 How is the ground offset on a MacPherson strut reduced for more powerful front wheel drive cars?
06 What is a double wishbone layout?
07 What is E-PAS?
08 Where is a dead axle, a live axle or a torsion beam typically used on a car?
09 Which component provides the vehicle primary suspension?
10 Should the plan include the financial aspects of equipment, building, training and new staff?

FURTHER READING

There is an excellent suite of online and offline courses available from the IMI which go into all kinds of engineering in greater depth. You can access these by visiting the **Professional Development (CPD) section** on the IMI website.

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Written by: Andrew Marsh
Auto Industry Consulting Ltd
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