Vehicle systems

Lecture notes

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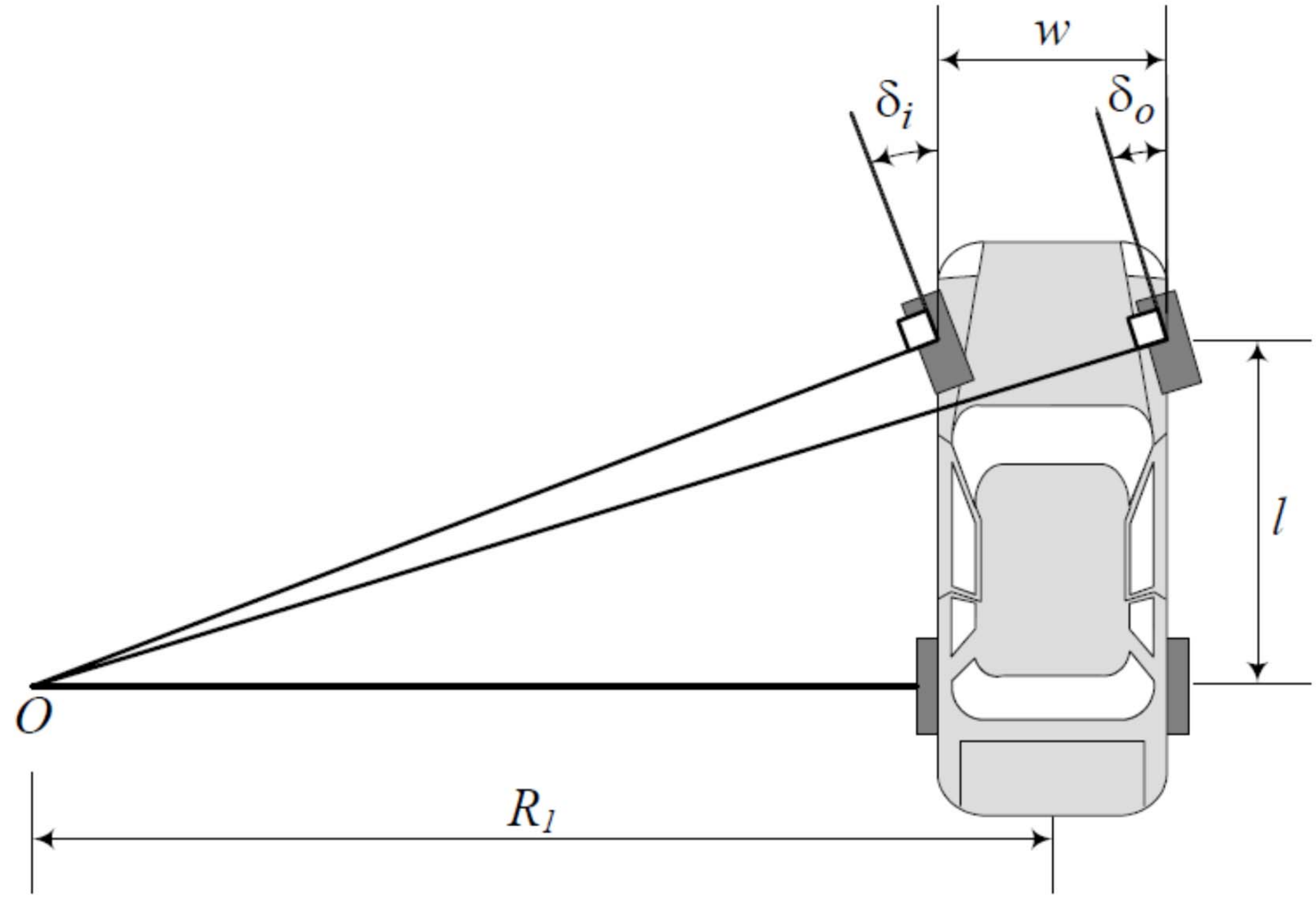
Kinematic Steering

- Consider a front-wheel-steering vehicle that is turning to the left, as shown in Figure When the vehicle is moving very slowly, there is a kinematic condition between the inner and outer wheels that allows them to turn slip-free. The condition is called the Ackerman condition

Kinematic Steering

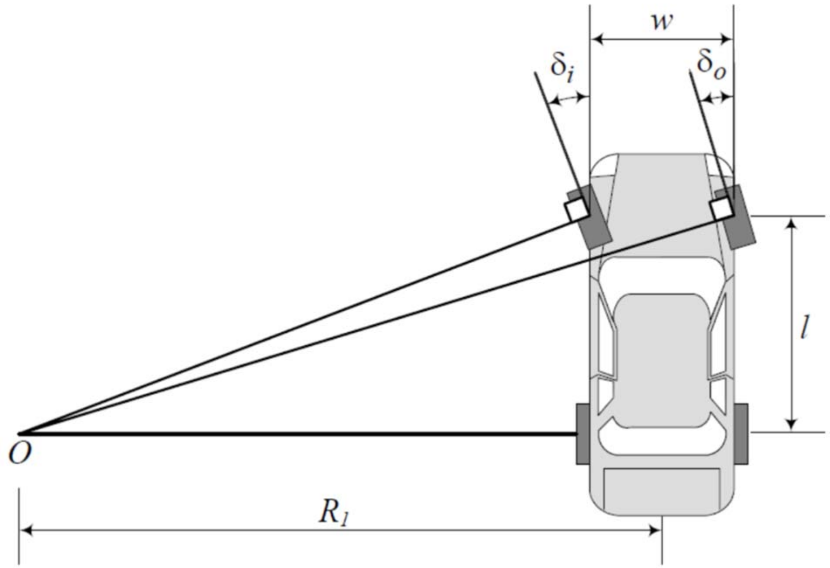


Reza N. Jazar, Vehicle Dynamics Theory and applications, Springer

Kinematic Steering

- Ackerman condition is expressed by,

$$\cot \delta_o - \cot \delta_i = \frac{w}{l}$$



δi: Steer angle of inner wheel

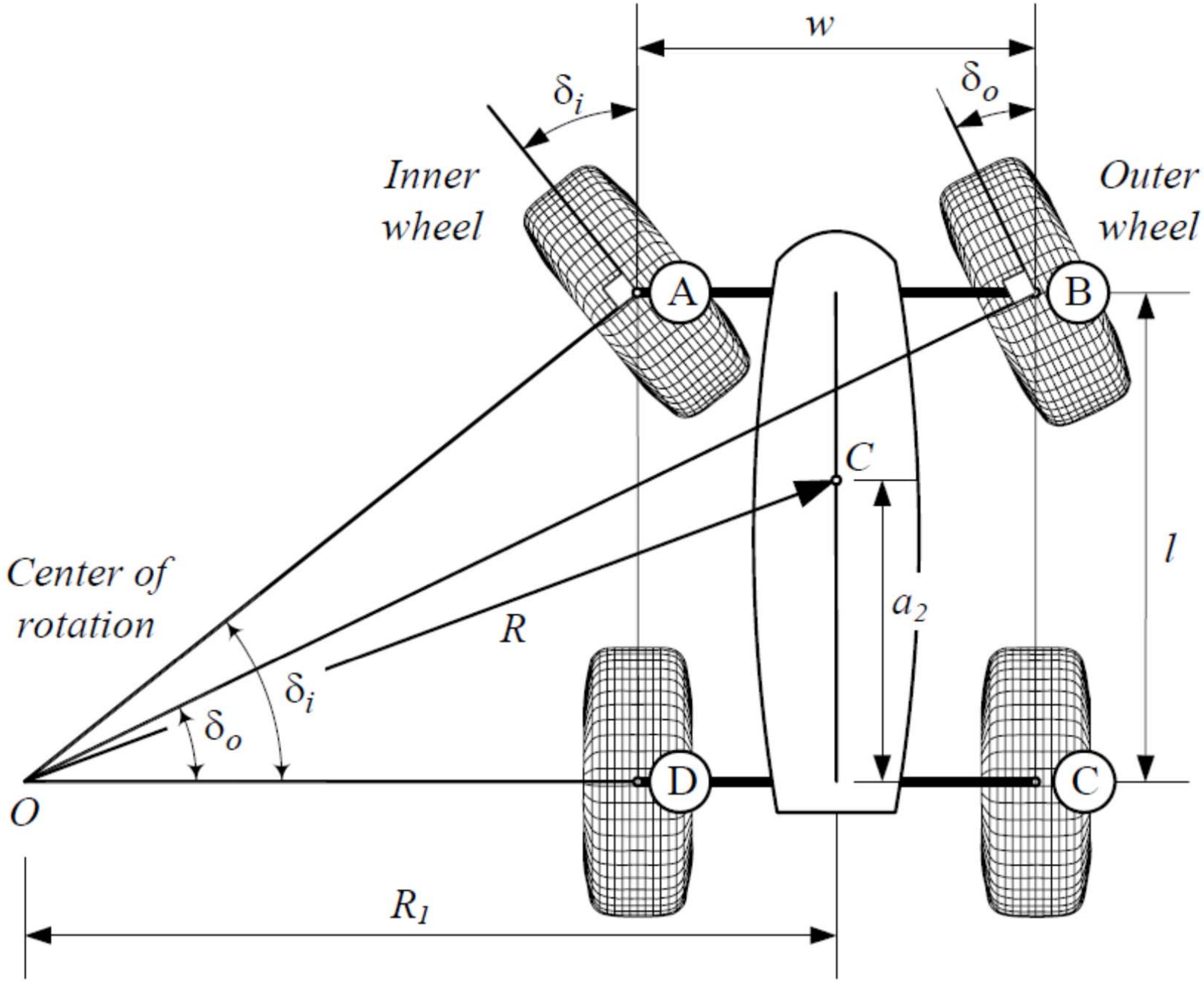
δo: Steer angle of outer wheel

O: Turning center/center of rotation

w: Track-Distance between steer axes of the steerable wheels

l: wheelbase- The distance between the front and rear axles

Kinematic Steering

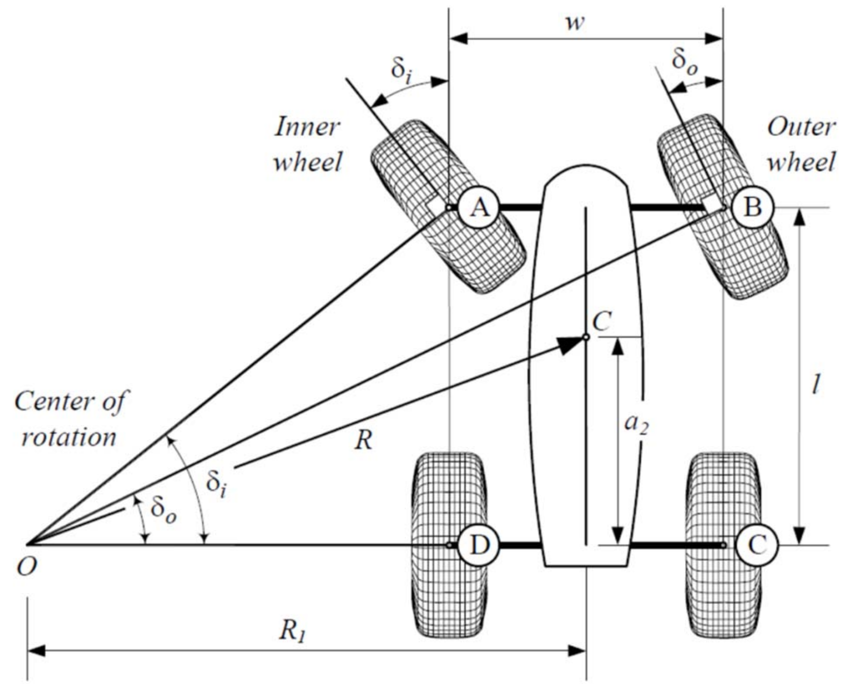


Kinematic Steering

- The mass center of a steered vehicle will turn on a circle with radius R, where δ is the cot-average of the inner and outer steer angles.

$$R = \sqrt{a_2^2 + l^2 \cot^2 \delta}$$

$$\cot \delta = \frac{\cot \delta_o + \cot \delta_i}{2}$$



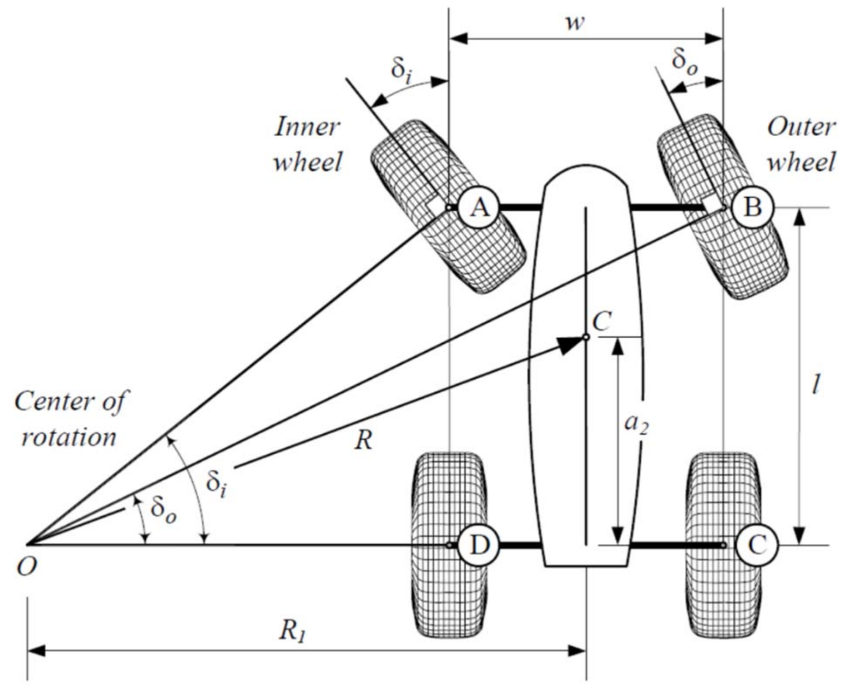
Kinematic Steering

- The inner and outer steer angles δi and δo can be calculated as:

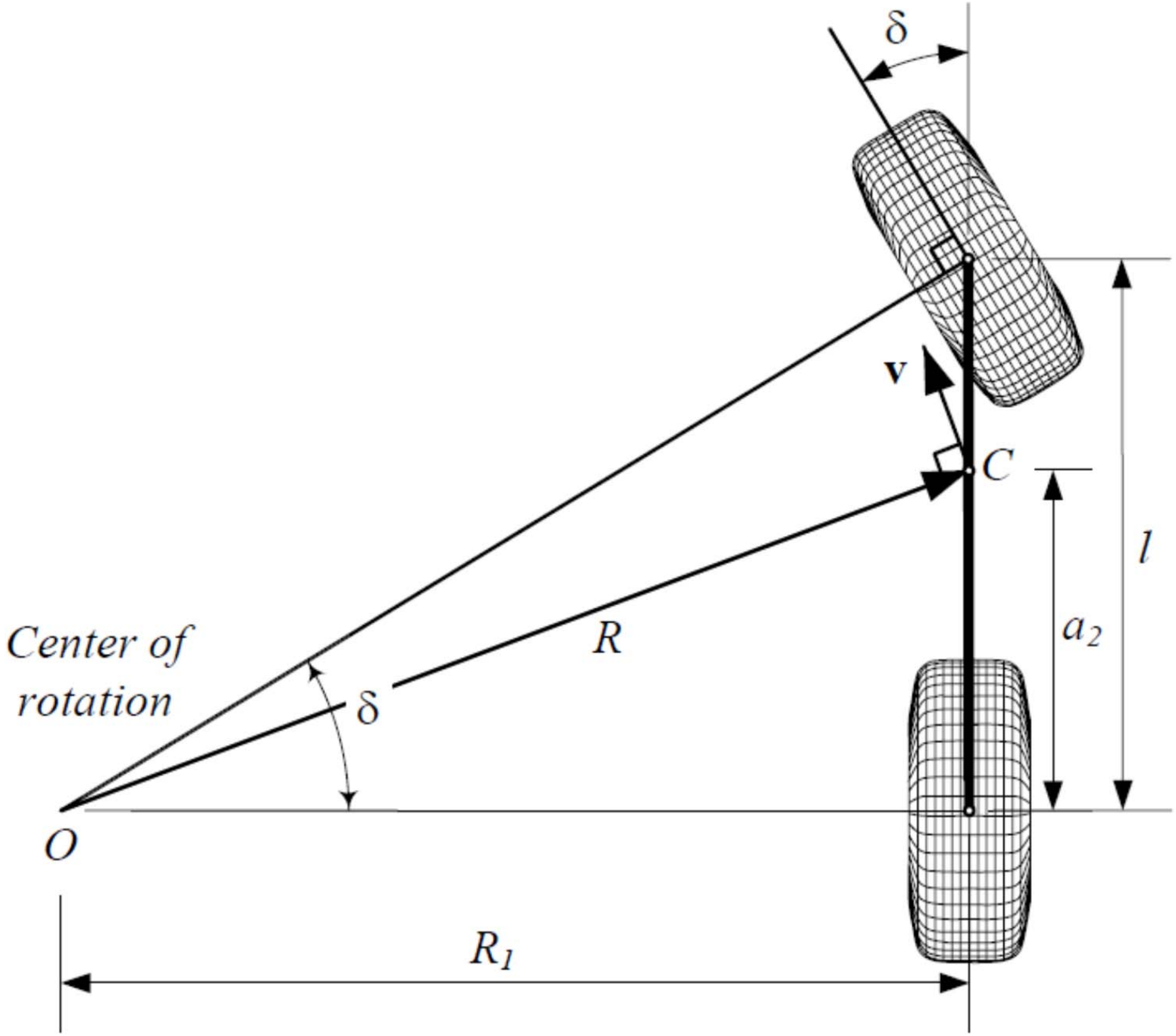
$$\tan\delta_i = \frac{l}{R_1 - \frac{w}{2}}$$

$$\tan\delta_o = \frac{l}{R_1 + \frac{w}{2}}$$

$$\begin{aligned} R_1 &= \frac{1}{2}w + \frac{l}{\tan\delta_i} \\ &= -\frac{1}{2}w + \frac{l}{\tan\delta_o} \end{aligned}$$



Equivalent bicycle model

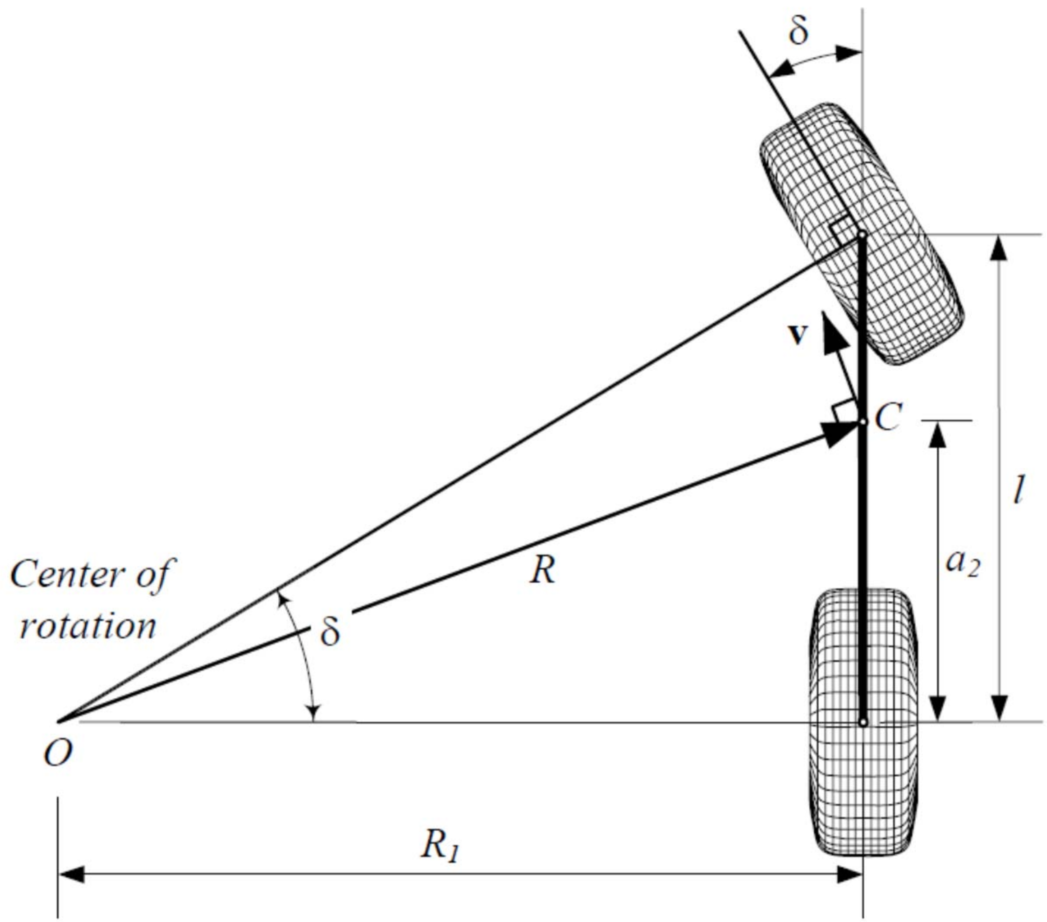


Equivalent bicycle model

- The radius of rotation **R** is perpendicular to the vehicle's velocity vector **v** at the mass center **C**.

$$
\begin{aligned}
R^2 &= a_2^2 + R_1^2 \\
\cot\delta &= \frac{R_1}{l} \\
&= \frac{1}{2}\left(\cot\delta_i + \cot\delta_o\right)
\end{aligned}
$$

$$R = \sqrt{a_2^2 + l^2 \cot^2 \delta}.$$



Kinematic Steering

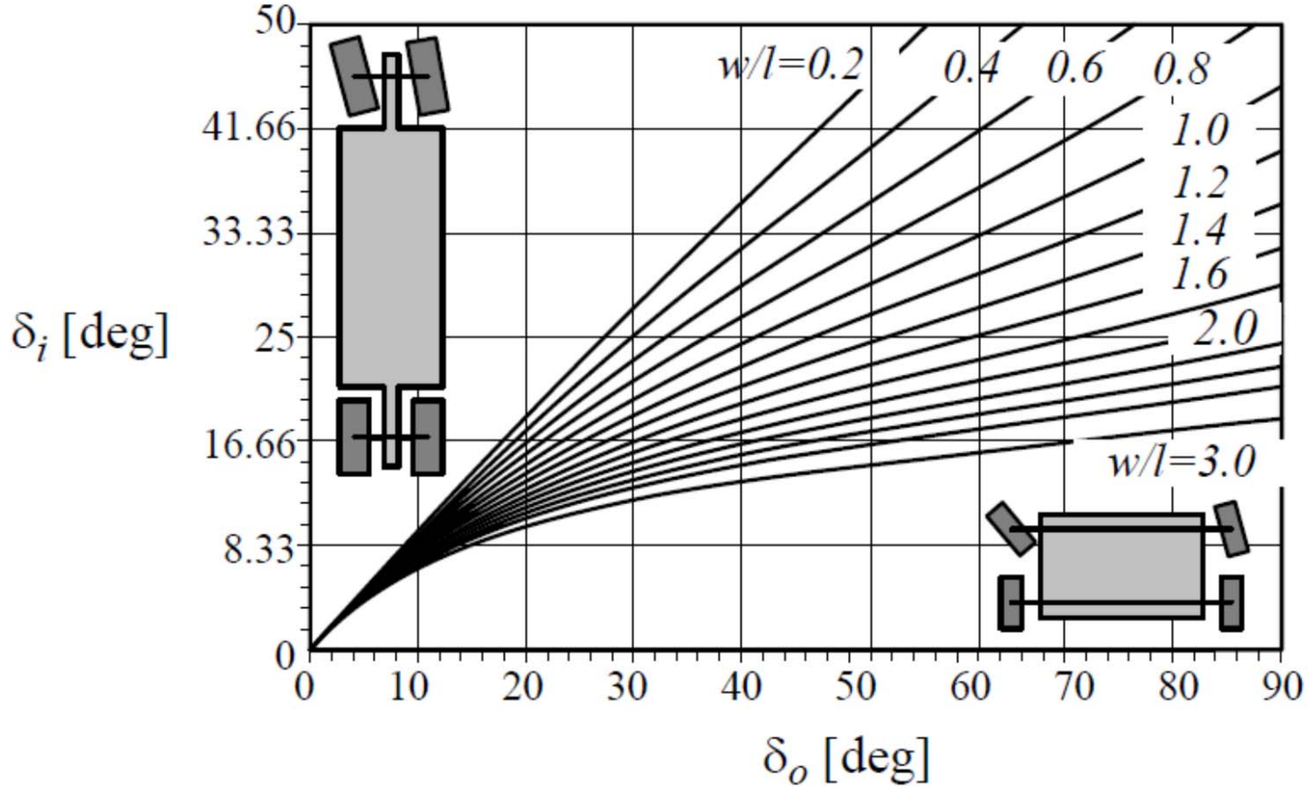
- The Ackerman condition is needed when the speed of the vehicle is too small, and slip angles are zero. There is no lateral force and no centrifugal force to balance each other. The Ackerman steering condition is also called the kinematic steering condition, because it is a static condition at zero velocity.

Kinematic Steering

- A device that provides steering according to the Ackerman condition is called Ackerman steering, Ackerman mechanism, or Ackerman geometry.

Kinematic Steering

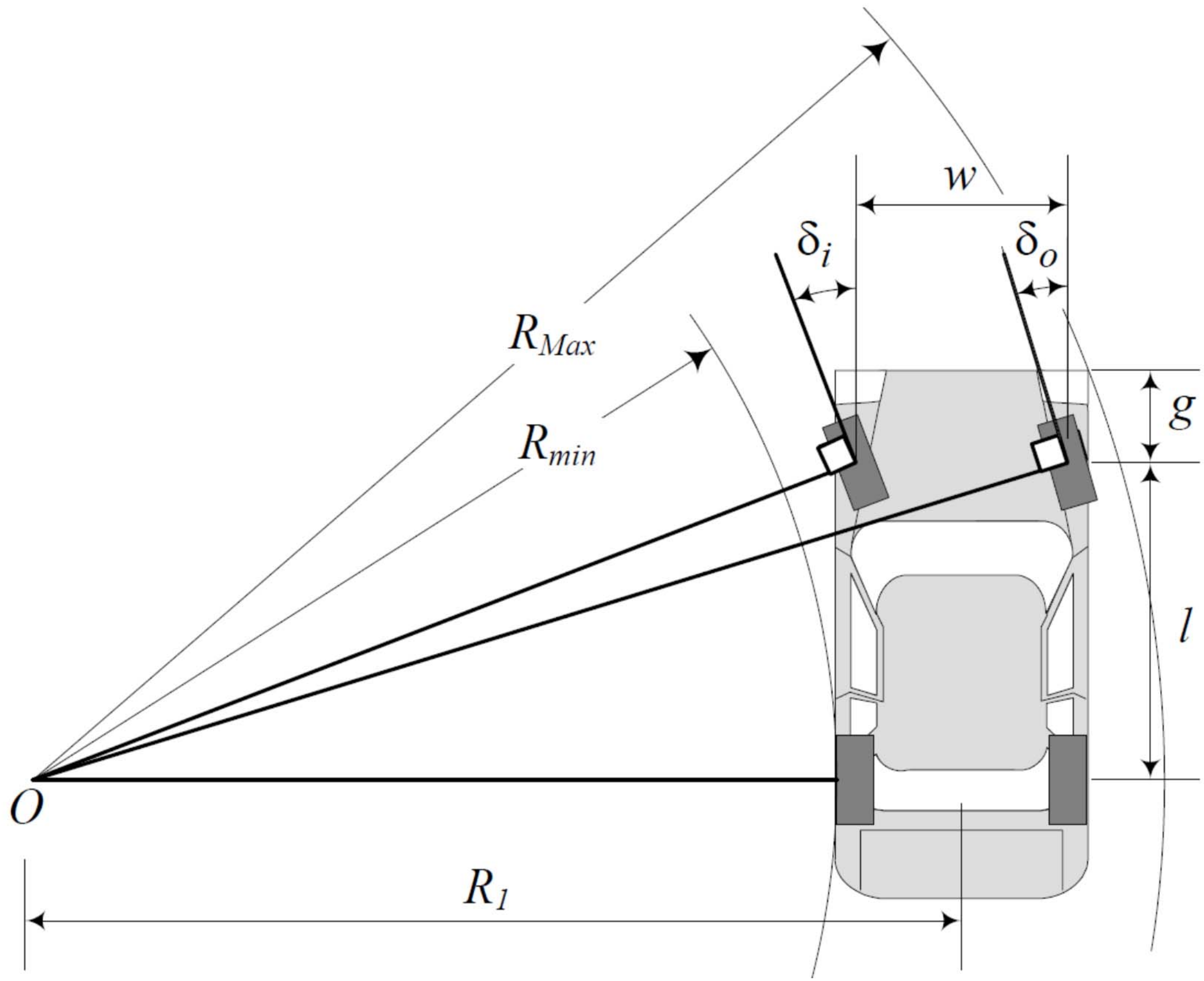
- The inner and outer steer angles get closer to each other by decreasing w/l.



Kinematic Steering

- The kinematic steering condition can be used to calculate the space requirement of a vehicle during a turn.

Kinematic Steering



- The outer point of the front of the vehicle will run on the maximum radius **RMax**, whereas a point on the inner side of the vehicle at the location of the rear axle will run on the minimum radius **Rmin**. The front outer point has an overhang distance **g** from the front axle. The maximum radius RMax is

$$R_{Max} = \sqrt{(R_{min} + w)^2 + (l + g)^2}.$$

The required space for turning is a ring with a width ΔR, which is a function of the vehicle's geometry.

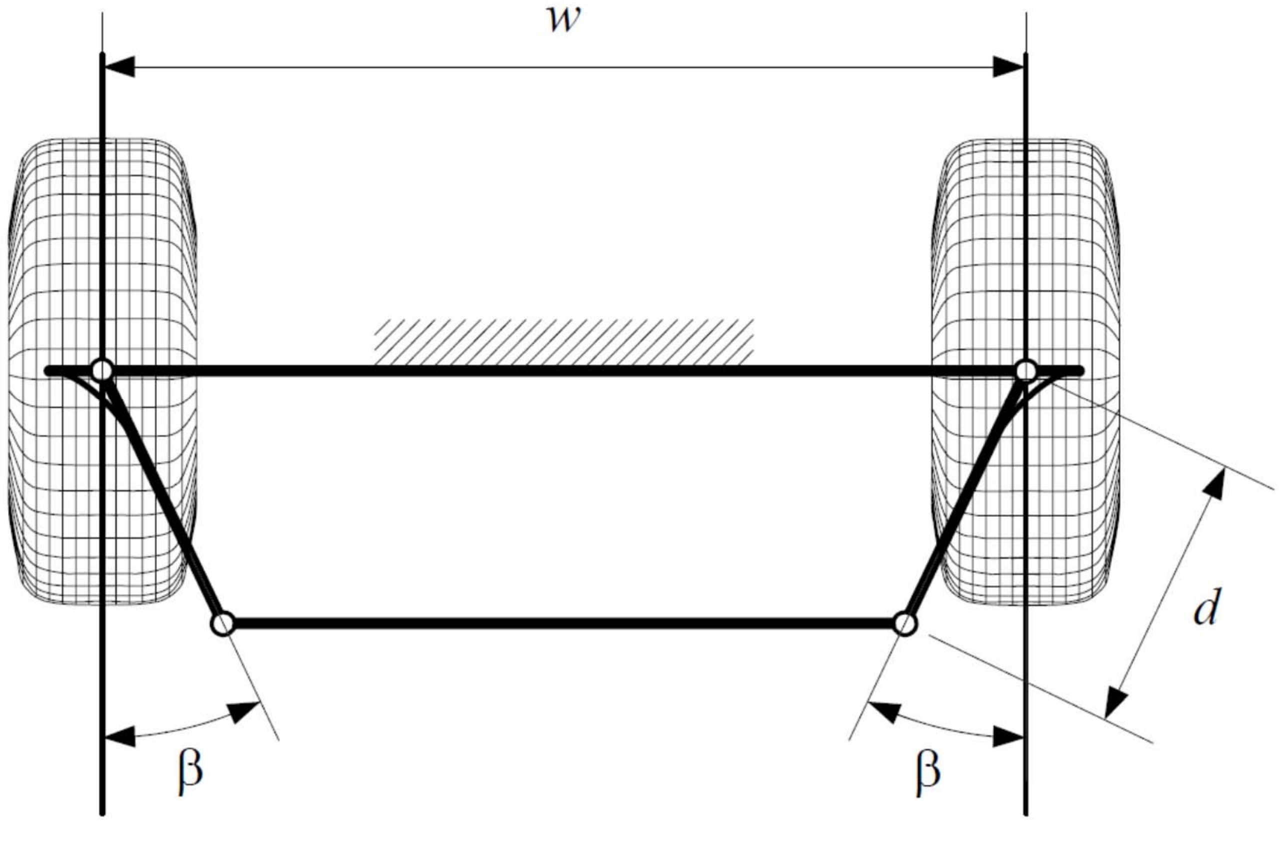
$$\begin{aligned}\triangle R &= R_{Max} - R_{min} \\ &= \sqrt{(R_{min} + w)^2 + (l+g)^2} - R_{min}\end{aligned}$$

$$\begin{aligned}\triangle R &= \sqrt{\left(\frac{l}{\tan\delta_i} + 2w\right)^2 + (l+g)^2} - \frac{l}{\tan\delta_i} \\ &= \sqrt{\left(\frac{l}{\tan\delta_o} + w\right)^2 + (l+g)^2} - \frac{l}{\tan\delta_o} + w.\end{aligned}$$

- In this example the width of the car **wv** and the track w are assumed to be equal. The width of vehicles are always greater than their track.

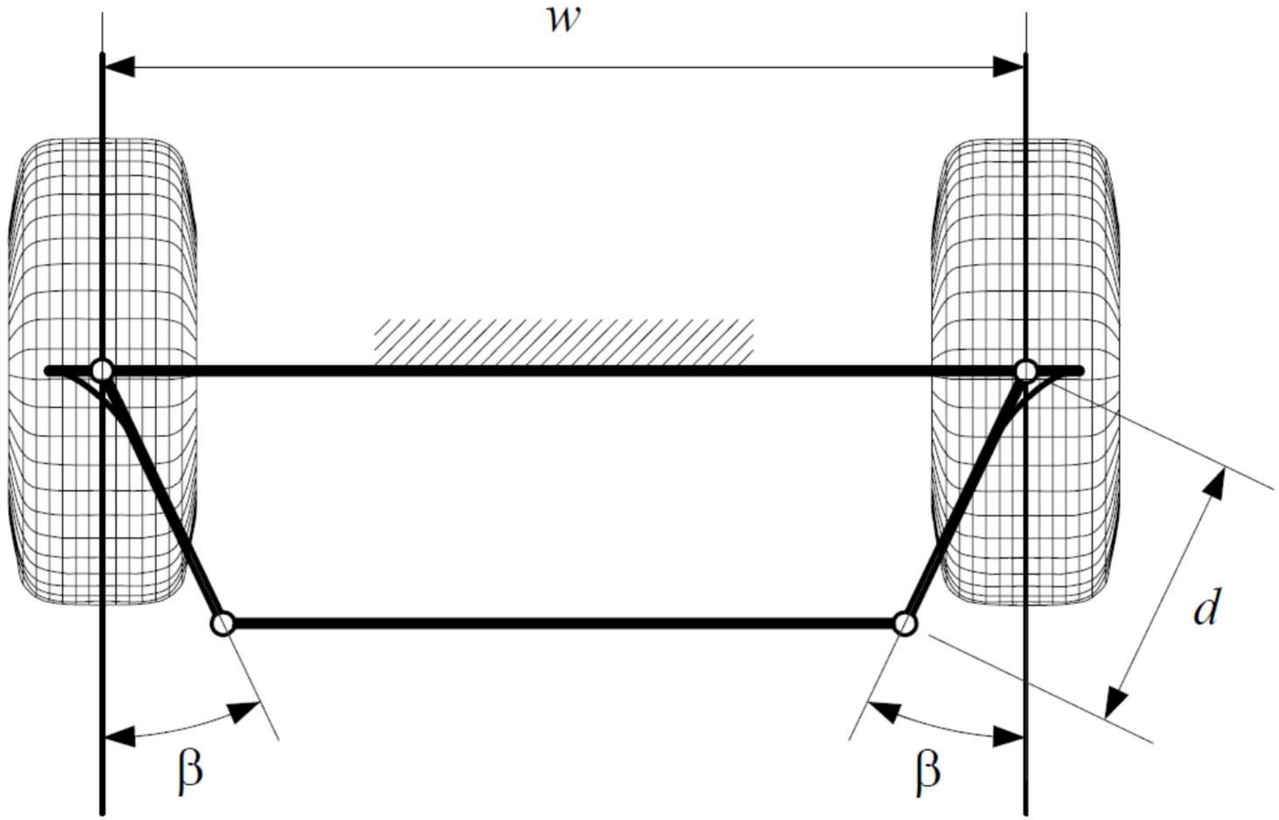
Trapezoidal steering mechanism

A symmetric four-bar linkage, called a trapezoidal steering mechanism.



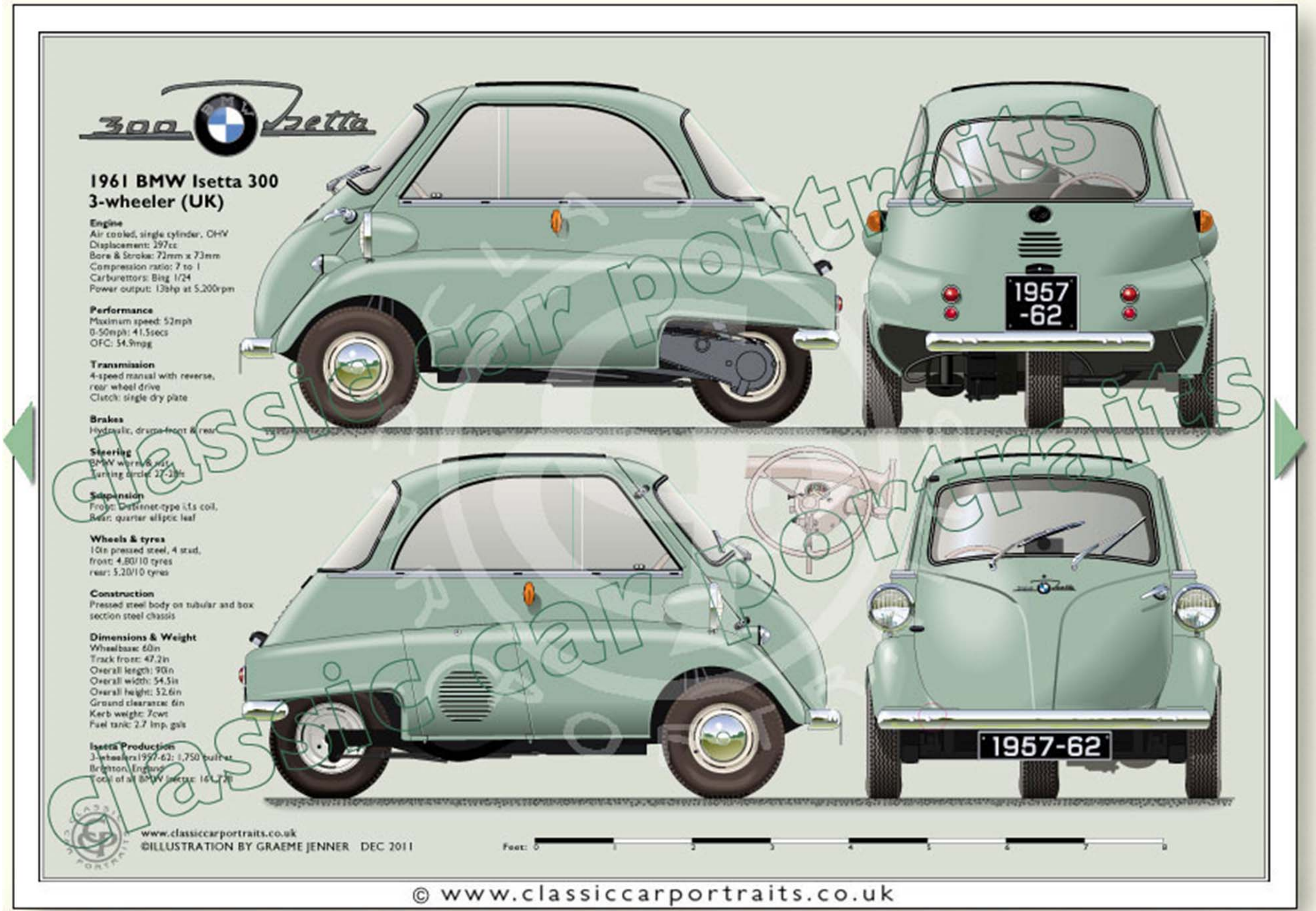
Trapezoidal steering mechanism

- The mechanism has two characteristic parameters: angle β and offset arm length d.



Kinematic Steering

Most cars have different tracks in front and rear. The track w in the kinematic condition refers to the front track wf . The rear track has no effect on the kinematic condition of a front-wheel-steering vehicle. The rear track wr of a FWS vehicle can be zero with the same kinematic steering condition.


300 Isetta
1961 BMW Isetta 300
3-wheeler (UK)
Engine
Air cooled, single cylinder, OHV
Displacement: 297cc
Bore & Stroke: 72mm x 73mm
Compression ratio: 7 to 1
Carburettors: Bing 1/24
Power output: 13bhp at 5,200rpm
Performance
Maximum speed: 52mph
0-50mph: 41.5secs
OFC: 54.9mpg
Transmission
4-speed manual with reverse,
rear wheel drive
Clutch: single dry plate
Brakes
Hydraulic, drums front & rear
Steering
Suspension
Rear: quarter elliptic leaf
Wheels & tyres
10in pressed steel, 4 stud,
front: 4.80/10 tyres
rear: 5.20/10 tyres
Construction
Pressed steel body on tubular and box
section steel chassis
Dimensions & Weight
Wheelbase: 60in
Track front: 47.2in
Overall length: 90in
Overall width: 54.5in
Overall height: 52.6in
Ground clearance: 6in
Kerb weight: 7cwt
Fuel tank: 2.7 Imp. gals
Isetta Production
1957 -62
1957-62
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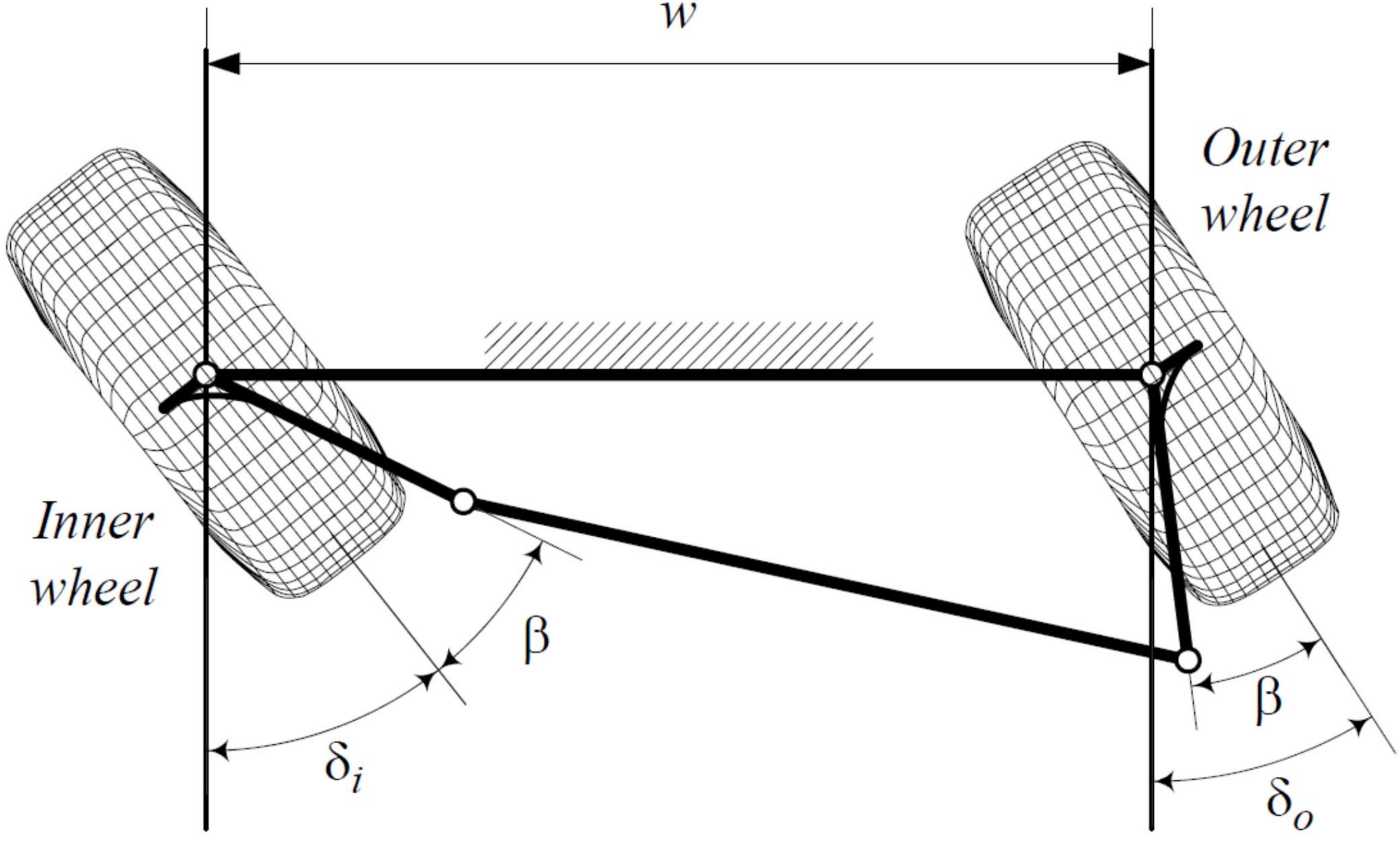
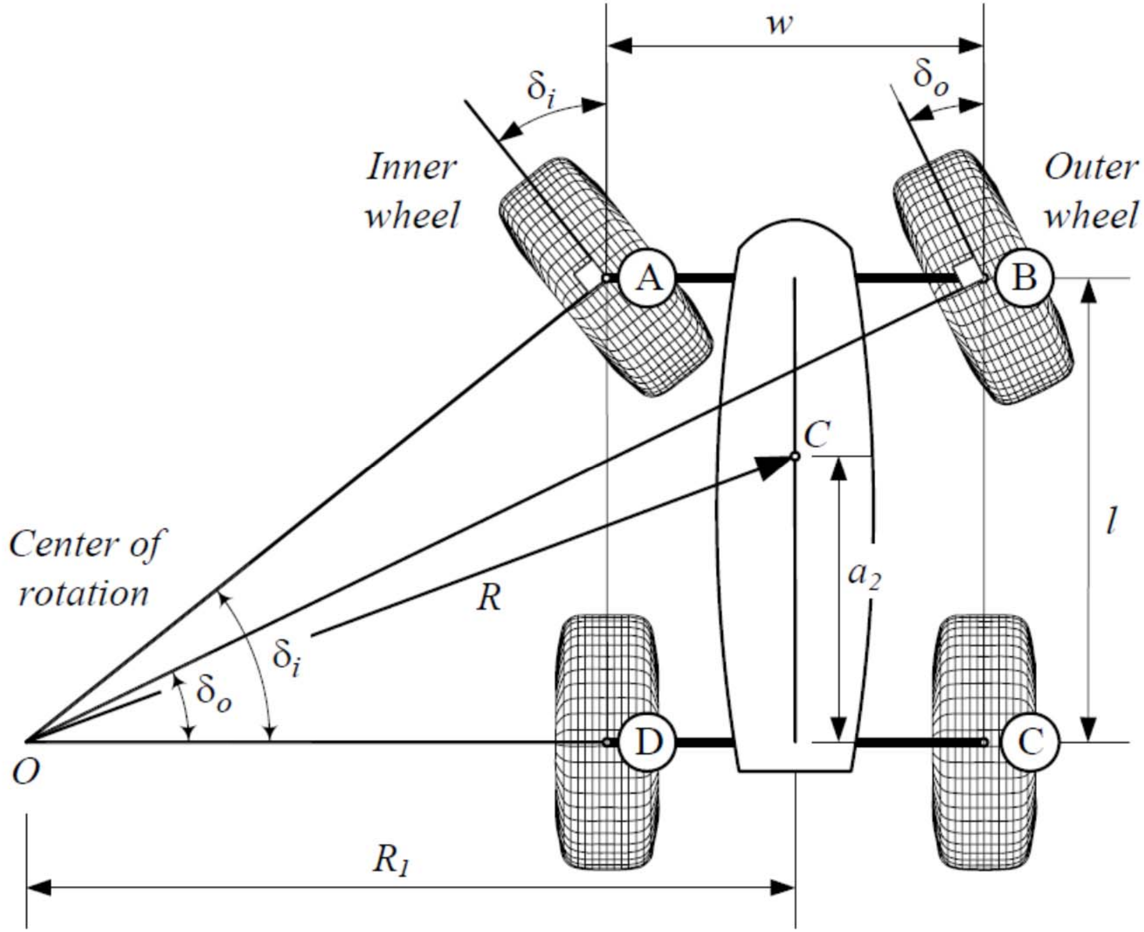
Trapezoidal steering mechanism



r= yaw velocity
Rw= Rear wheel radius
Wri=Angular velocity (inner rear)
Wro=Angular velocity (outer rear)



$$v_{ri} = \left(R_1 - \frac{w}{2}\right) r = R_w \omega_{ri}$$

$$v_{ro} = \left(R_1 + \frac{w}{2}\right) r = R_w \omega_{ro}$$

- If the rear axle is locked

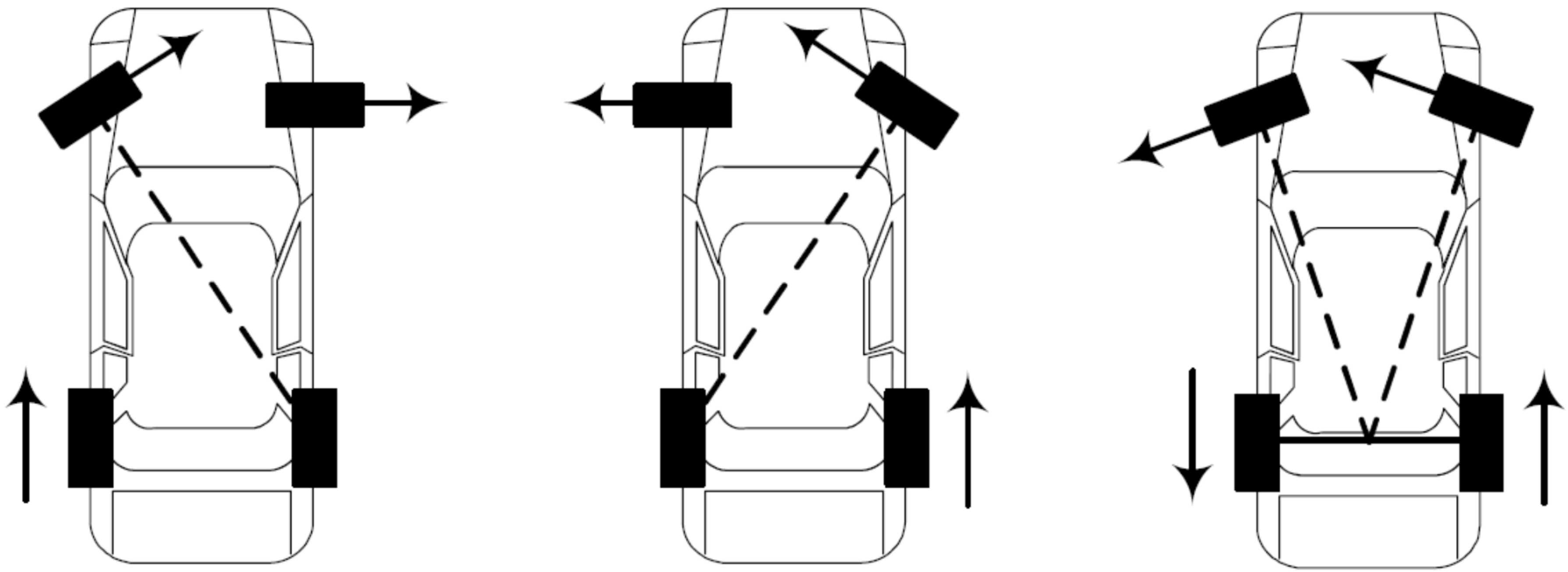
$$\omega_{ri} = \omega_{ro} = \omega$$

$$\left(R_1 - \frac{w}{2}\right) \neq \left(R_1 + \frac{w}{2}\right) \quad ?$$

r=vehicle’s angular velocity about the center of rotation.

$$r = \frac{R_w \omega_o}{R_1 + \frac{w}{2}} = \frac{R_w \omega_i}{R_1 - \frac{w}{2}}$$

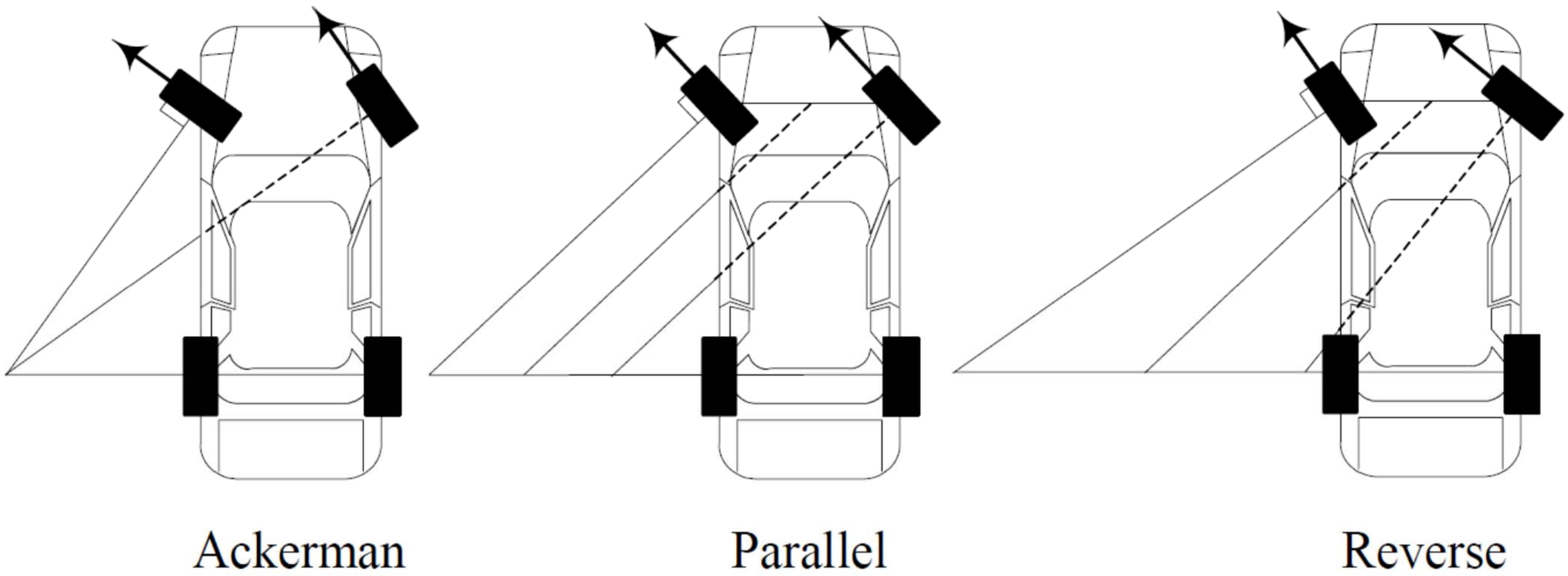
For some special-purpose vehicles, such as moon rovers and autonomous mobile robots, we may attach each drive wheel to an independently controlled motor to apply any desired angular velocity. Furthermore, the steerable wheels of such vehicles are able to turn more than 90 deg to the left and right. Such a vehicle is highly maneuverable at a low speed.



- The Ackerman or kinematic steering is a correct condition when the turning speed of the vehicle is slow. When the vehicle turns fast, significant lateral acceleration is needed, and therefore, the wheels operate at high slip angles. Furthermore, the loads on the inner wheels will be much lower than the outer wheels. Tire performance curves show that by increasing the wheel load, less slip angle is required to reach the peak of the lateral force. Under these conditions the inner front wheel of a kinematic steering vehicle would be at a higher slip angle than required for maximum lateral force.

- Therefore, the inner wheel of a vehicle in a high speed turn must operate at a lower steer angle than kinematic steering. Reducing the steer angle of the inner wheel reduces the difference between steer angles of the inner and outer wheels.

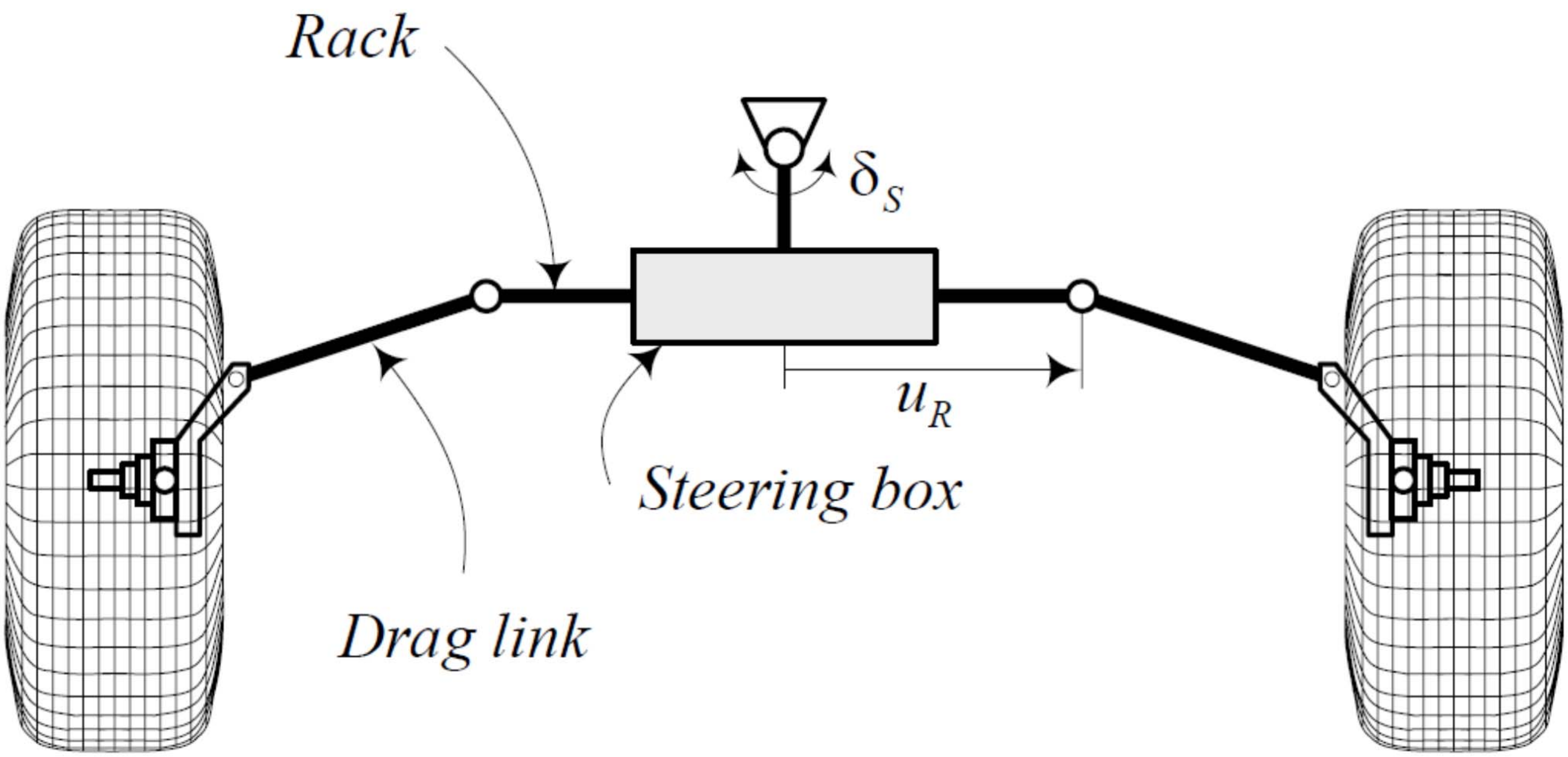
For race cars, it is common to use parallel or reverse steering. The correct steer angle is a function of the instant wheel load, road condition, speed, and tire characteristics. Furthermore, the vehicle must also be able to turn at a low speed under an Ackerman steering condition. Hence, there is no ideal steering mechanism unless we control the steer angle of each steerable wheel independently using a smart system.



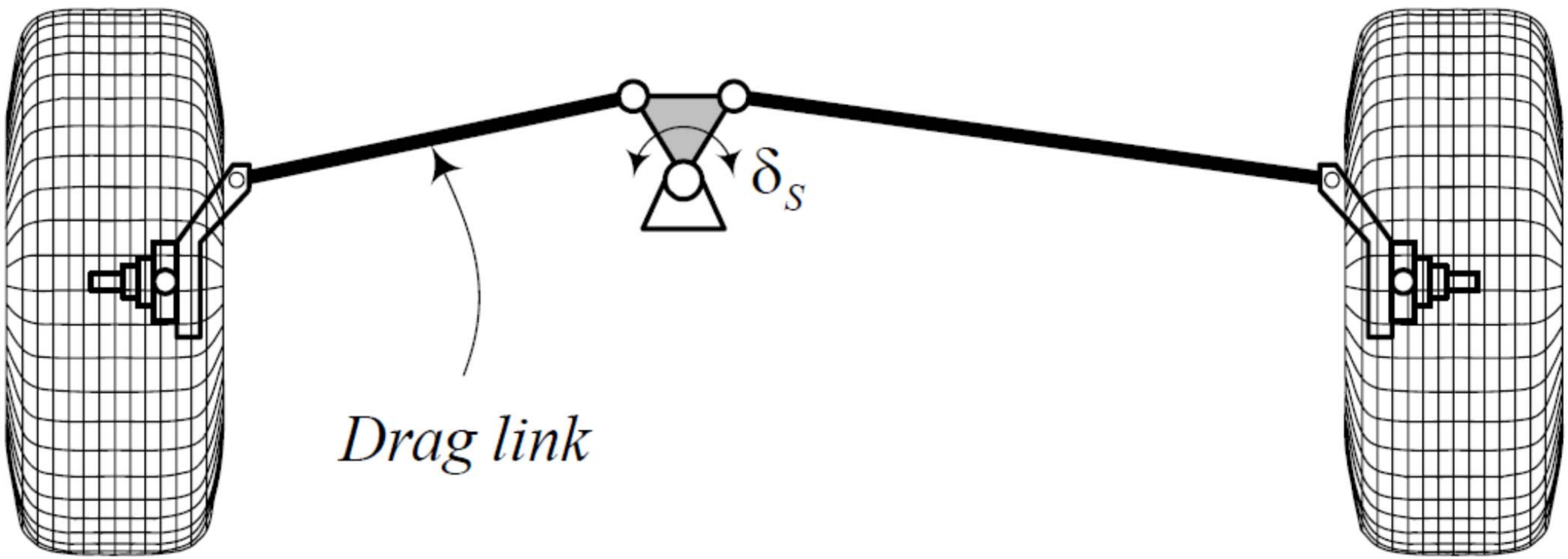
Speed dependent steering system

- There is a speed adjustment idea that says it is better to have a harder steering system at high speeds. This idea can be applied in power steering systems to make them speed dependent, such that the steering be heavily assisted at low speeds and lightly assisted at high speeds. The idea is supported by this fact that the drivers might need large steering for parking, and small steering when traveling at high speeds.

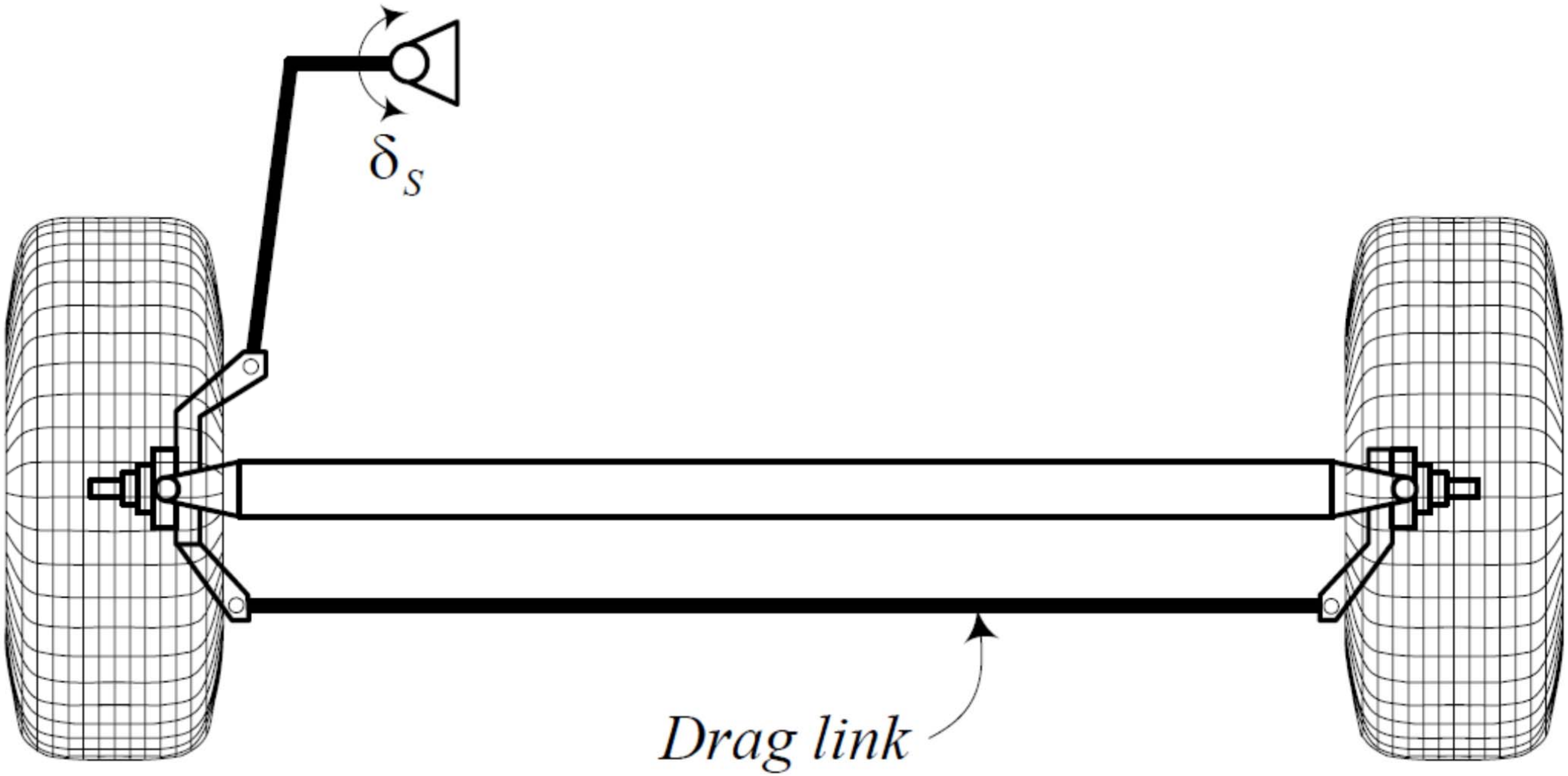
Rack-and-pinion steering



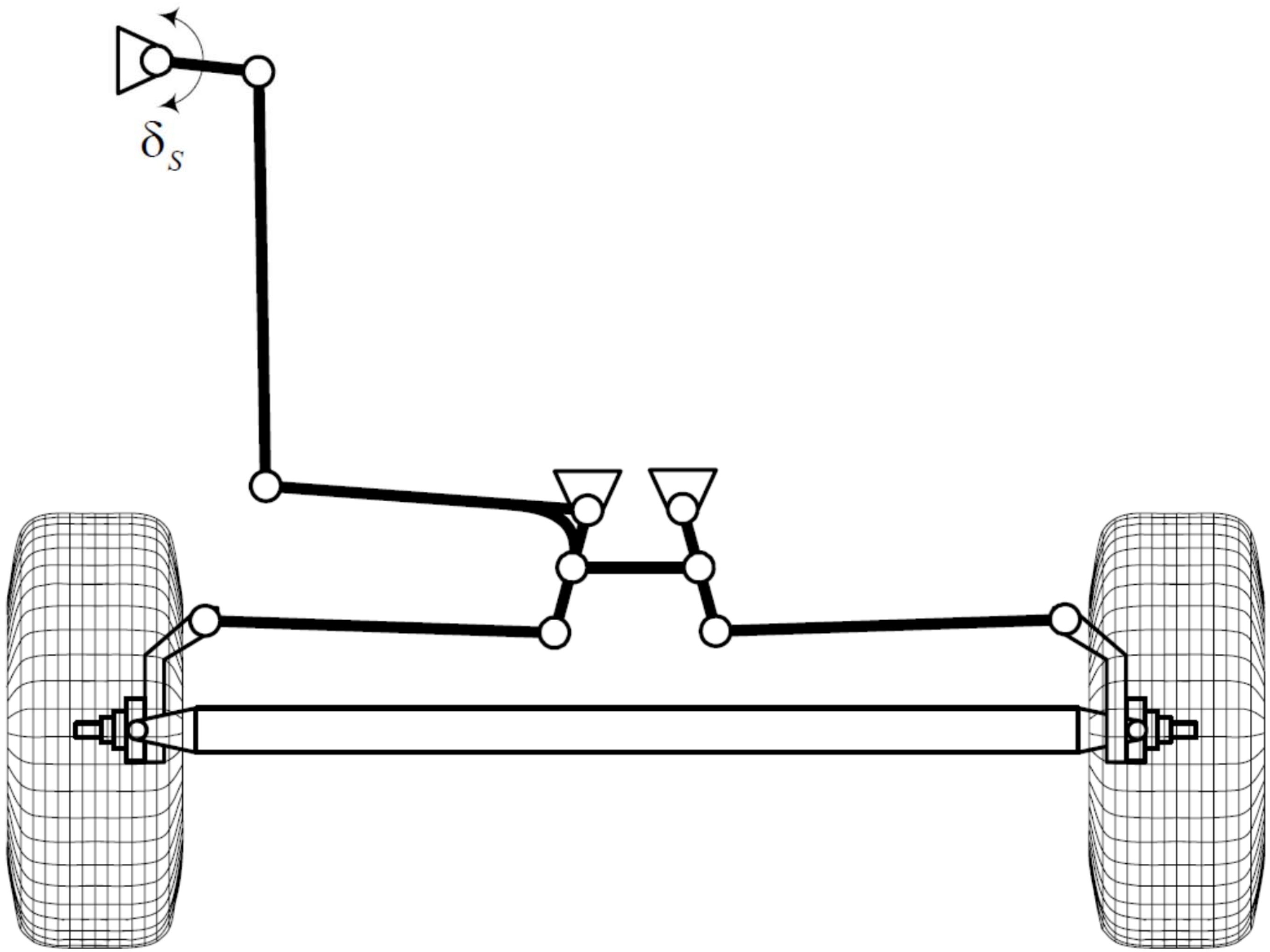
Lever arm steering system



Drag link steering system



Multi-link steering mechanism



STEERING SYSTEMS

Steering systems requirements

- The steering system must also allow the driver to have some road feel (feedback through the steering wheel about road surface conditions).
- The steering system must help maintain proper tire-to-road contact.
- For maximum tire life, the steering system should maintain the proper angle between the tires both during turns and straight-ahead driving.
- The driver should be able to turn the vehicle with little effort, but not so easily that it is hard to control.

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Steering wheels

- The only part of the steering system the average driver is familiar with is the steering wheel. Older wheels are made of hard plastic, are larger in diameter, and are relatively thin when compared to modern steering wheels.

- The modern steering wheel is generally padded. Most steering wheels have two or three spokes or a large center section that connects the wheel portion to the hub. To prevent slippage, the steering wheel hub has internal splines, which match external splines on the steering shaft. Some shafts and steering wheels have a master spline, which is larger than the others. The master spline prevents the installation of the wheel in the wrong position. A large nut holds the hub to the steering shaft.

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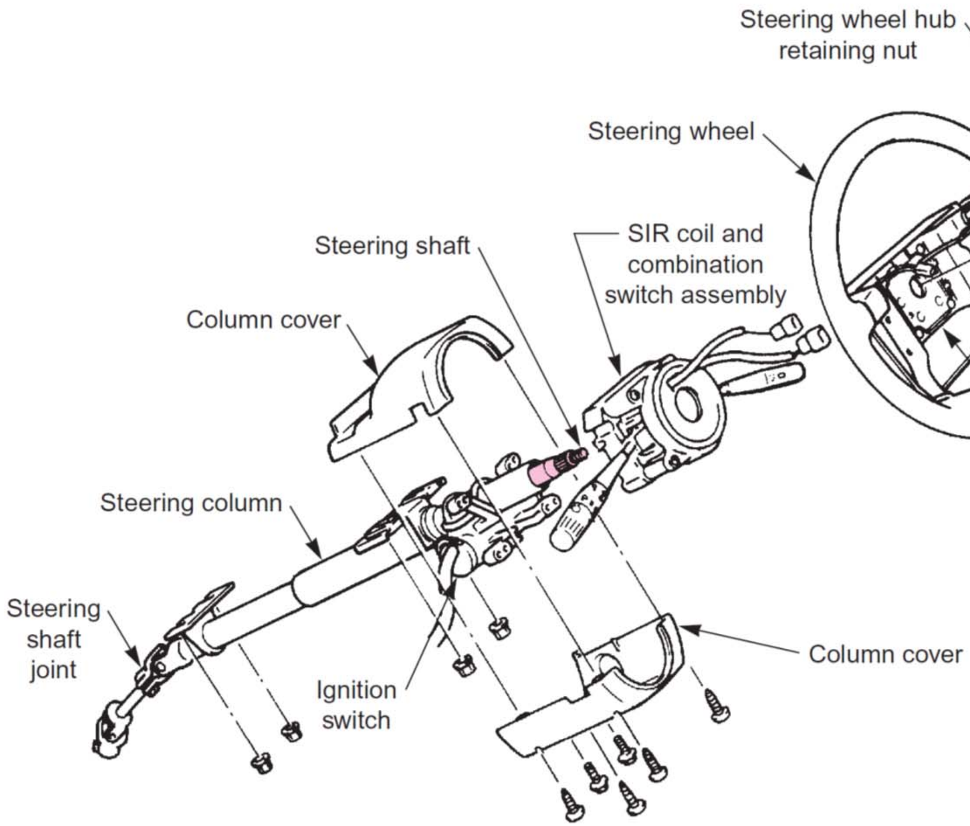
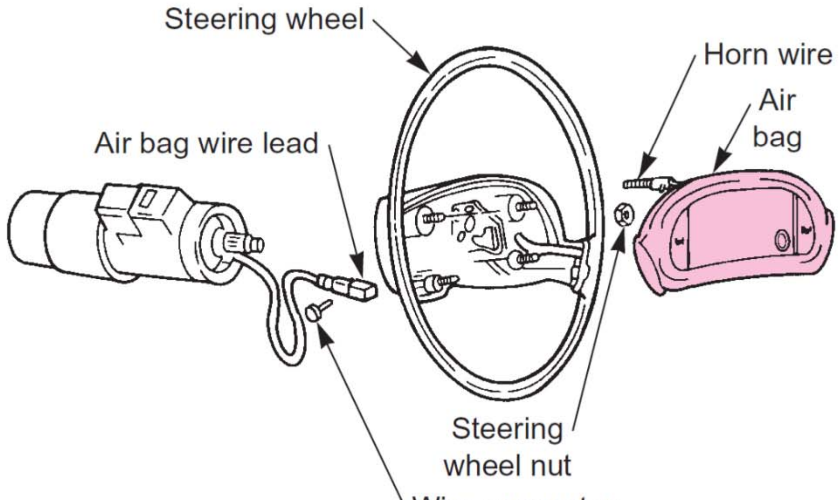
Steering wheels





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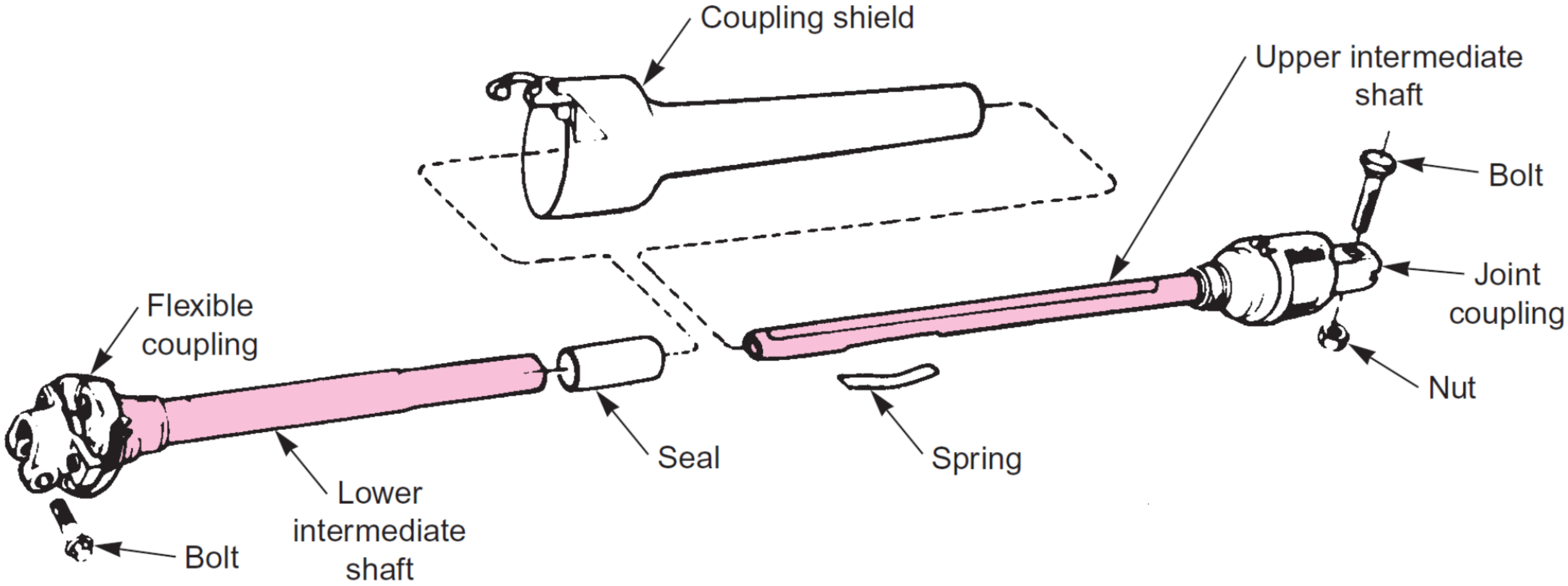
Steering columns and shafts



- The steering shaft is installed in the steering column. Bearings are generally used to hold the shaft in position. The shaft and column assembly is usually removed and replaced as a unit. However, individual parts are often replaced without removing the shaft or column.
- Modern steering shafts are made of two sections of steel rod. One section is hollow and the other is solid. The solid section slides into the hollow section.

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Steering columns and shafts

- This design allows the steering shaft to collapse when the vehicle is in a collision. For this reason it is called a collapsible shaft. Collapsible shafts are often referred to as telescoping shafts, since the shaft length is reduced as one section of the shaft slides into the other in the same way a portable telescope is collapsed.
- During normal driving, the two halves of the steering shaft are held in position by shear pins. Shear pins are purposely made of a relatively weak material, usually plastic. Their purpose is to break when sufficient pressure is placed on them, preventing injury to the driver. If a collision occurs that is severe enough to cause the driver to strike the steering wheel, the shear pins break, allowing the shaft to collapse.

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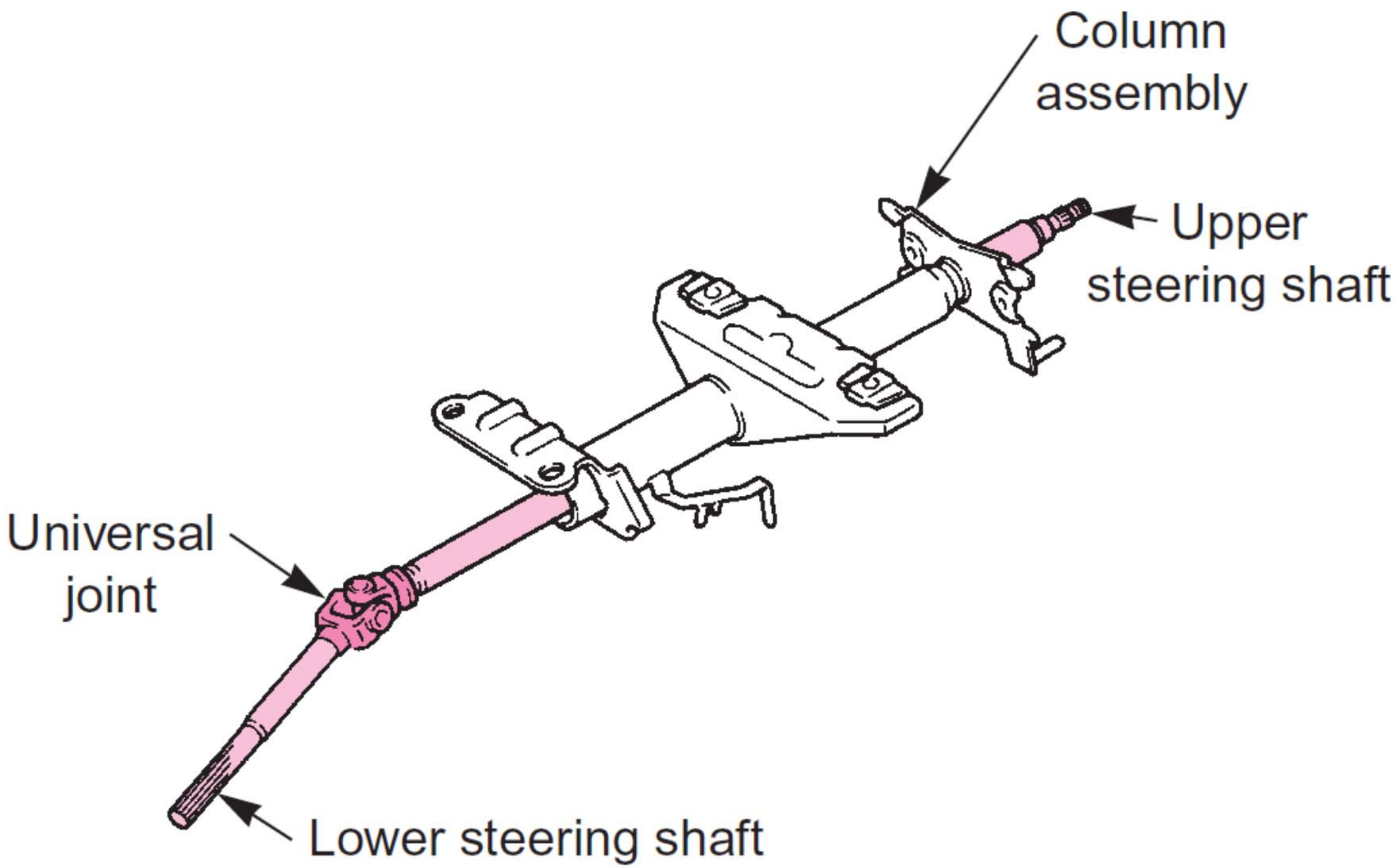
Universal joints



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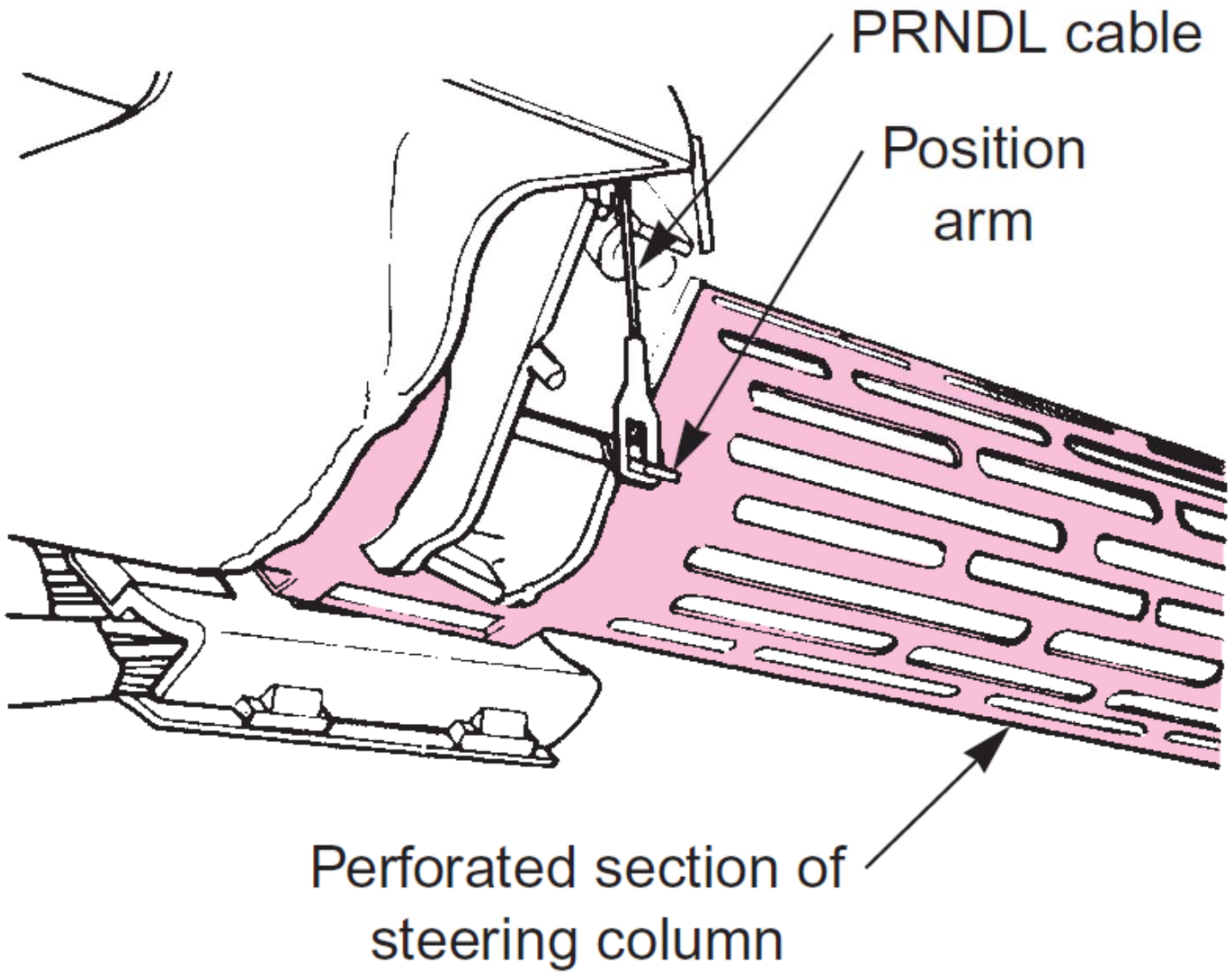
Steering column

- The steering column is collapsible, although its design is somewhat different from that of the steering shaft. The lower section of the steering column is perforated and resembles a heavy screen.
- If the driver hits the steering wheel during an accident, the perforated area will bend, allowing the column to collapse.



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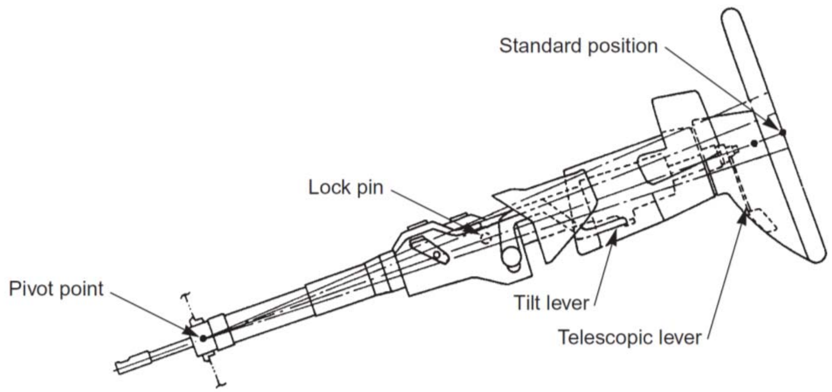
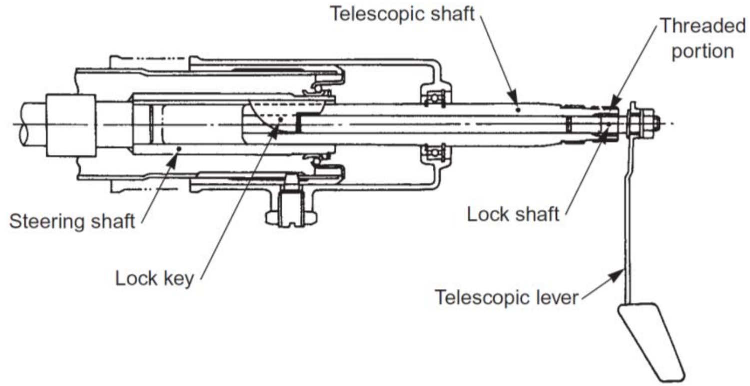
Adjustable Steering Columns

Telescoping steering columns are designed so that the steering wheel can be moved either toward or away from the driver. The telescoping parts of a steering column include a solid steering shaft section inside a hollow shaft section. This assembly is called a telescopic shaft. During normal driving, a locking mechanism holds the telescopic shaft in position. Moving a lever on the steering column allows the driver to release the lock and move the steering wheel.





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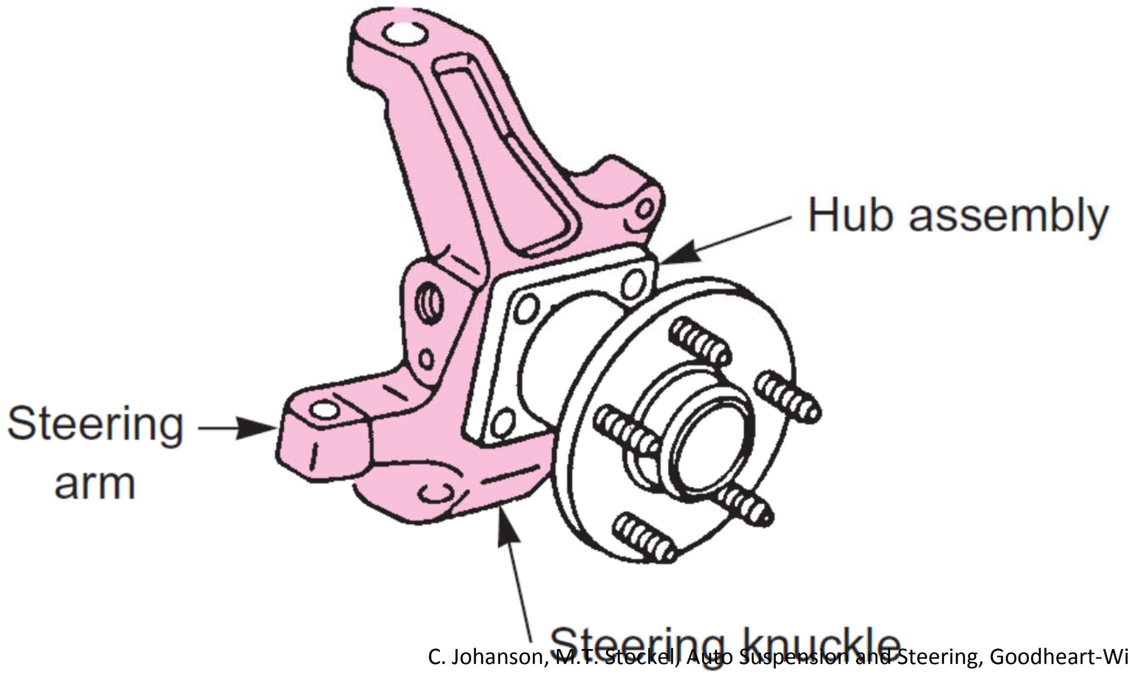
Steering arms

- The ***steering arm*** converts the linear (back-and-forth) motion of the steering linkage to the rotating motion of the steering knuckle.



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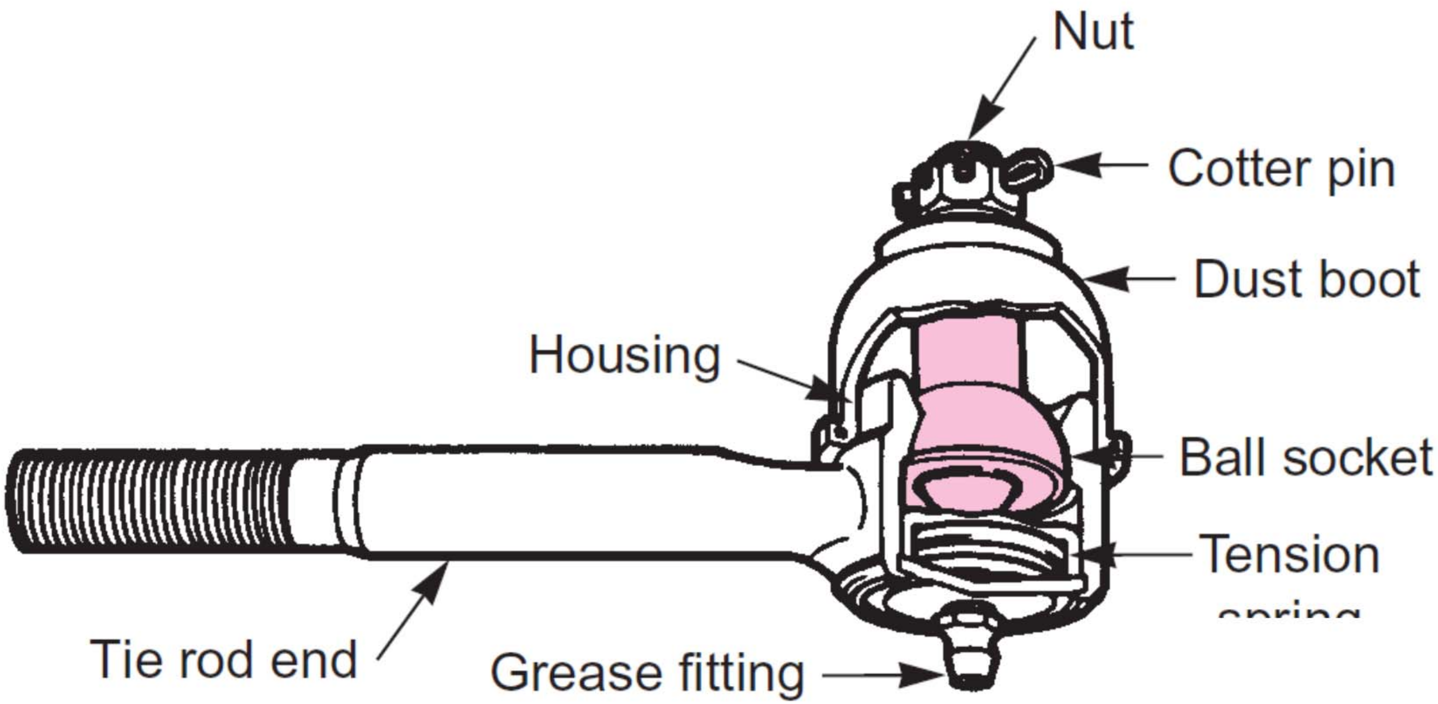
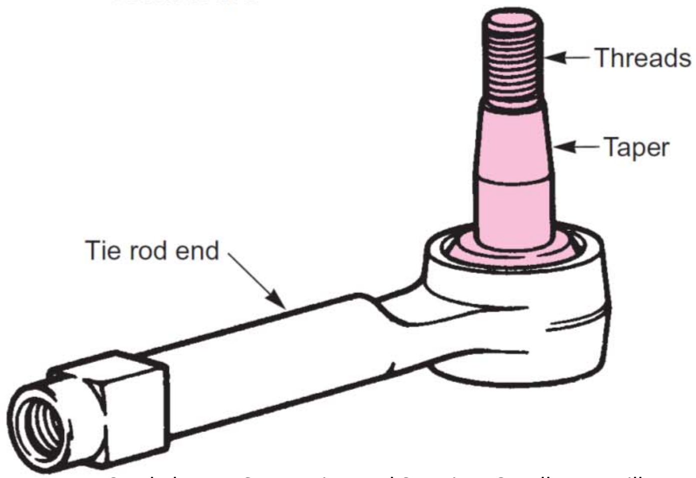
Ball sockets





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Steering ratio

- Steering ratio is the relative number of turns of the steering wheel compared to the movement of the wheels. If the steering wheel must be turned one revolution to turn the front wheels one sixteenth of a turn, the steering ratio is 1 to 1/16. Reversing the numbers gives a ratio of 16 to 1, or 16:1. Although the steering ratio is not as critical on modern vehicles with power steering, it must be carefully selected as a compromise between handling and steering effort. The average steering ratio on modern vehicles ranges from 12:1 to 24:1. A heavy vehicle will have a higher ratio than a lighter vehicle. If the vehicle has power steering, the ratio will be lower

- A relatively high steering ratio also helps to absorb shocks from the road. If for instance the steering ratio is 16:1, road shocks are transmitted to the steering wheel at 1/16 of their original intensity.

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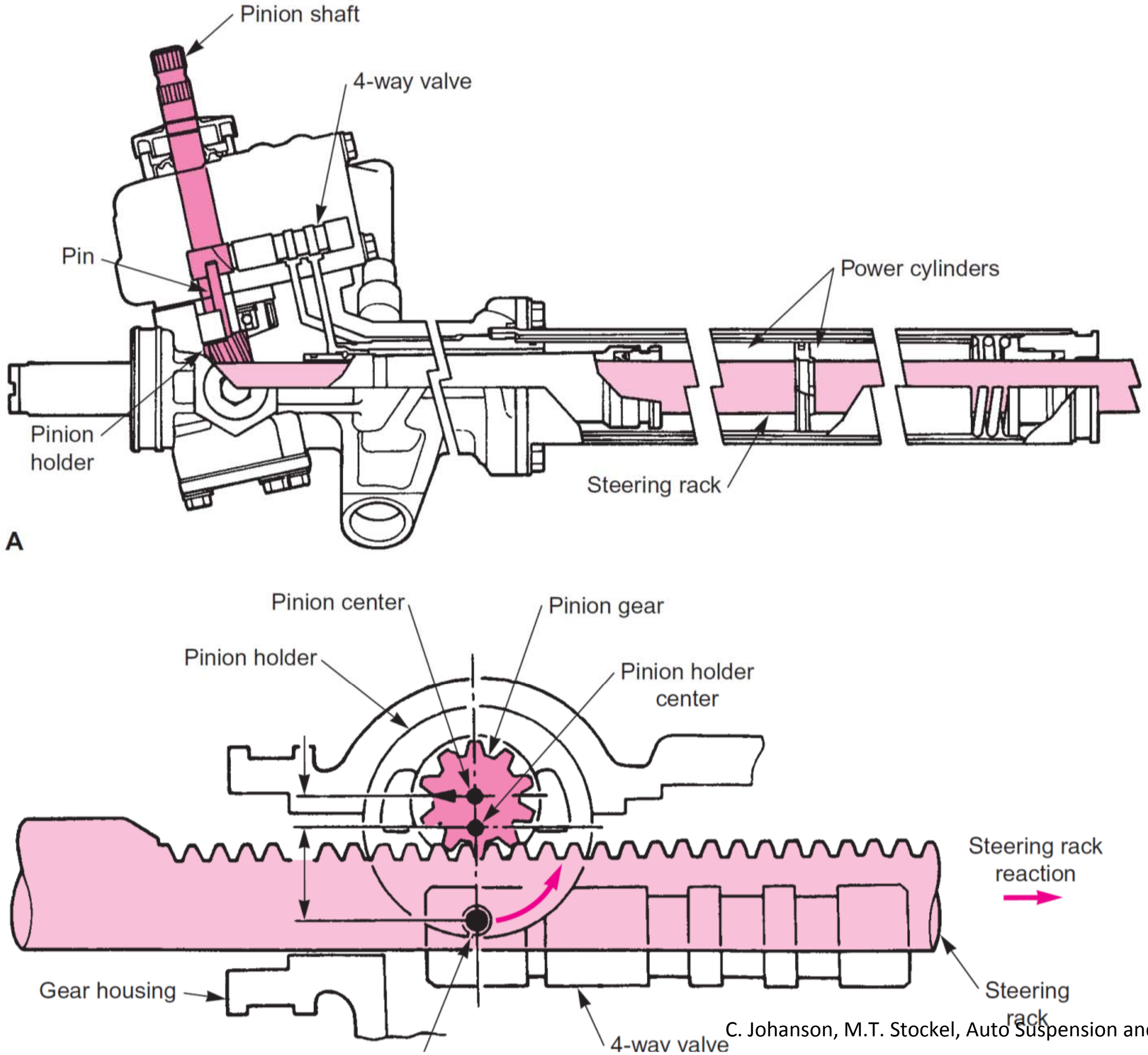
Rack and pinion steering



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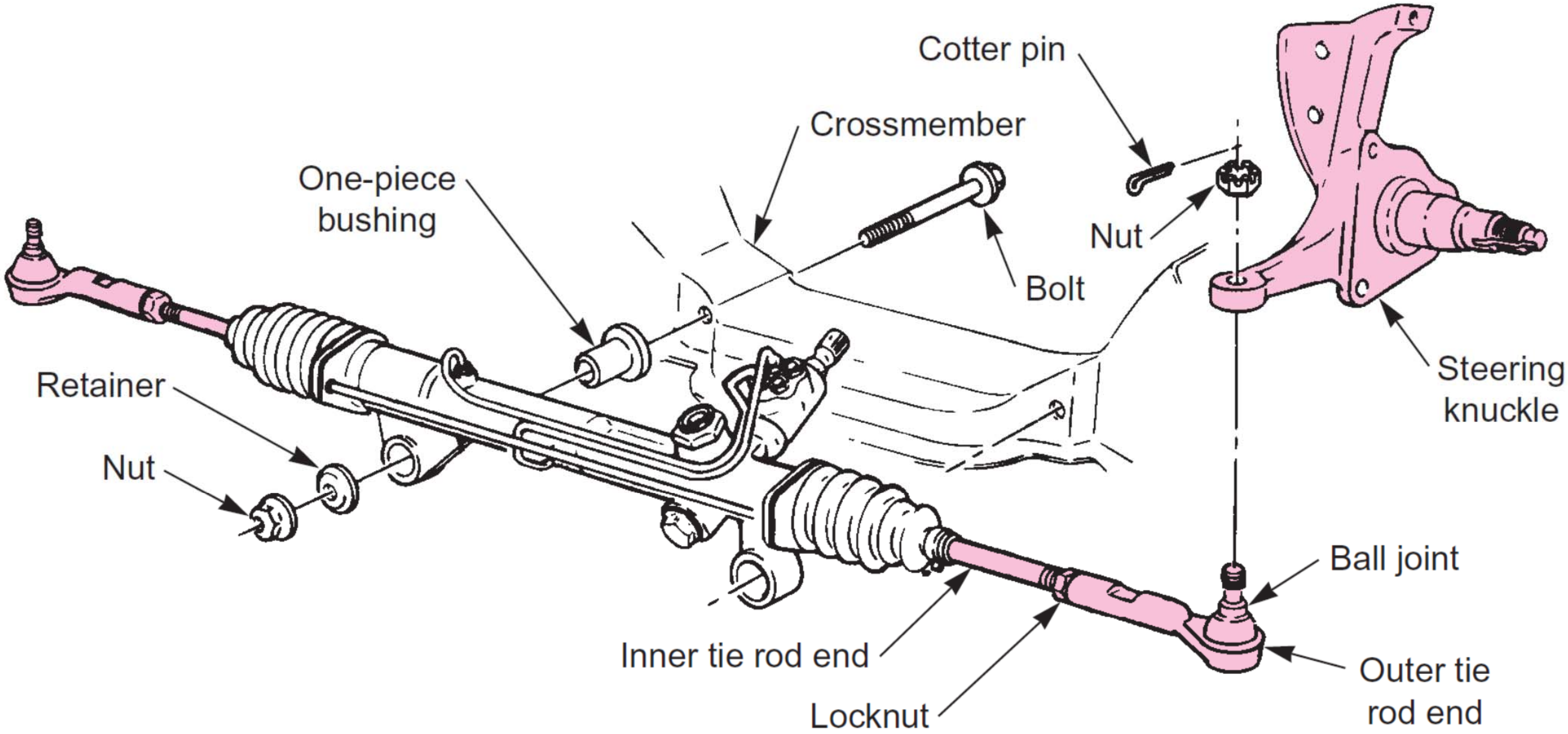
Rack and pinion steering



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Your vehicle's suspension and steering system endures much abuse from pot-holes and speed-bumps.
Did you know the force from hitting a pot-hole or speed-bump can exceed several tons?