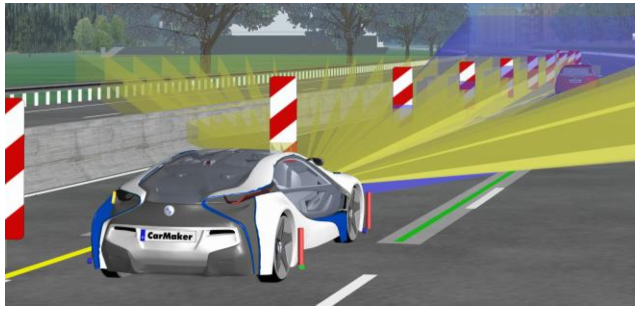
Hochschule Kempten
University of Applied Sciences

Adrive livinglab

BA -Vehicle Technology
WS 20/21 Lecture 2

Chassis systems with chassis labatory

Introduction

University of Applied Science	AVL List GmbH	IPG AUTOMOTIVE
2016 - today	2014 - 2016	2007 - 2013
	 	 
Research Professorship University of Applied Science / Research Center Allgaeu	Global Business Unit Manager Calibration & Virtual Testing Solutions	Managing Director
Vehicle Dynamics ADAS/Highly Automated Driving Vehicle Efficiency	Calibration Solution Test Information Management Virtual Testing / Model Based Testing	General Vehicle Dynamics, Integrated Controls, ADAS, Fuel Efficiency & E-Mobility

Introduction

TÜV SÜD AUTOMOTIVE	16 YEARS PRO RACE CAREER
1995 - 2007	1982 - 1997

General Manager Chassis Systems	250cc, Superbike, Supersport GP, World, European, German Championship
Vehicle Dynamics, Tire & Wheels, Brakes, Measurement & Simulation	Int. German Champion 1996 ProSuperbike Team Champion 1993 / 1994

Research for Automated Driving

Prof. Bernhard Schick, University of Applied Sciences Kempten

Research for Automated Driving

How do people experience the driving of tomorrow and how can human and technology be brought into harmony?

Research for Automated Driving

Research for Automated Driving

Research for Automated Driving

We are really serious about virtualization, therefore we need …

Advanced Driving Simulators to make new systems and functions experienced in a virtualized development process.

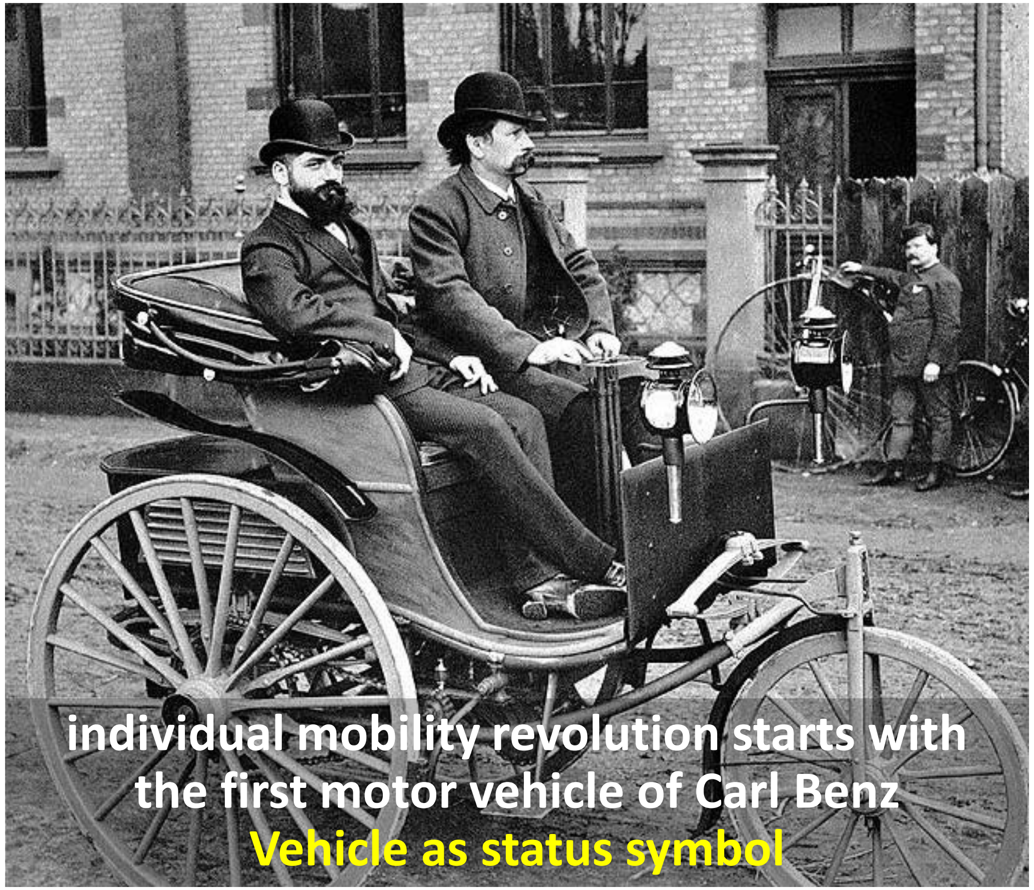
Research for Automated Driving

Hochschule Kempten
University of Applied Sciences

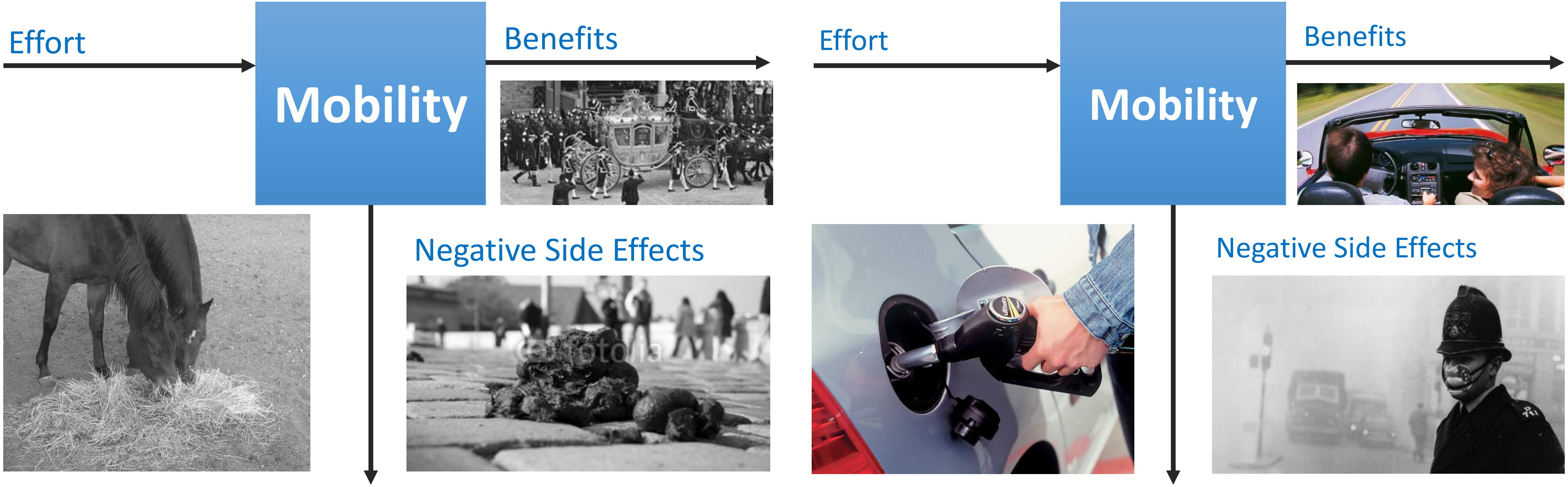
BA -Vehicle Technology
WS 20/21 Lecture 2

Chassis systems with chassis laboratory

Motor driven mobility chances our live

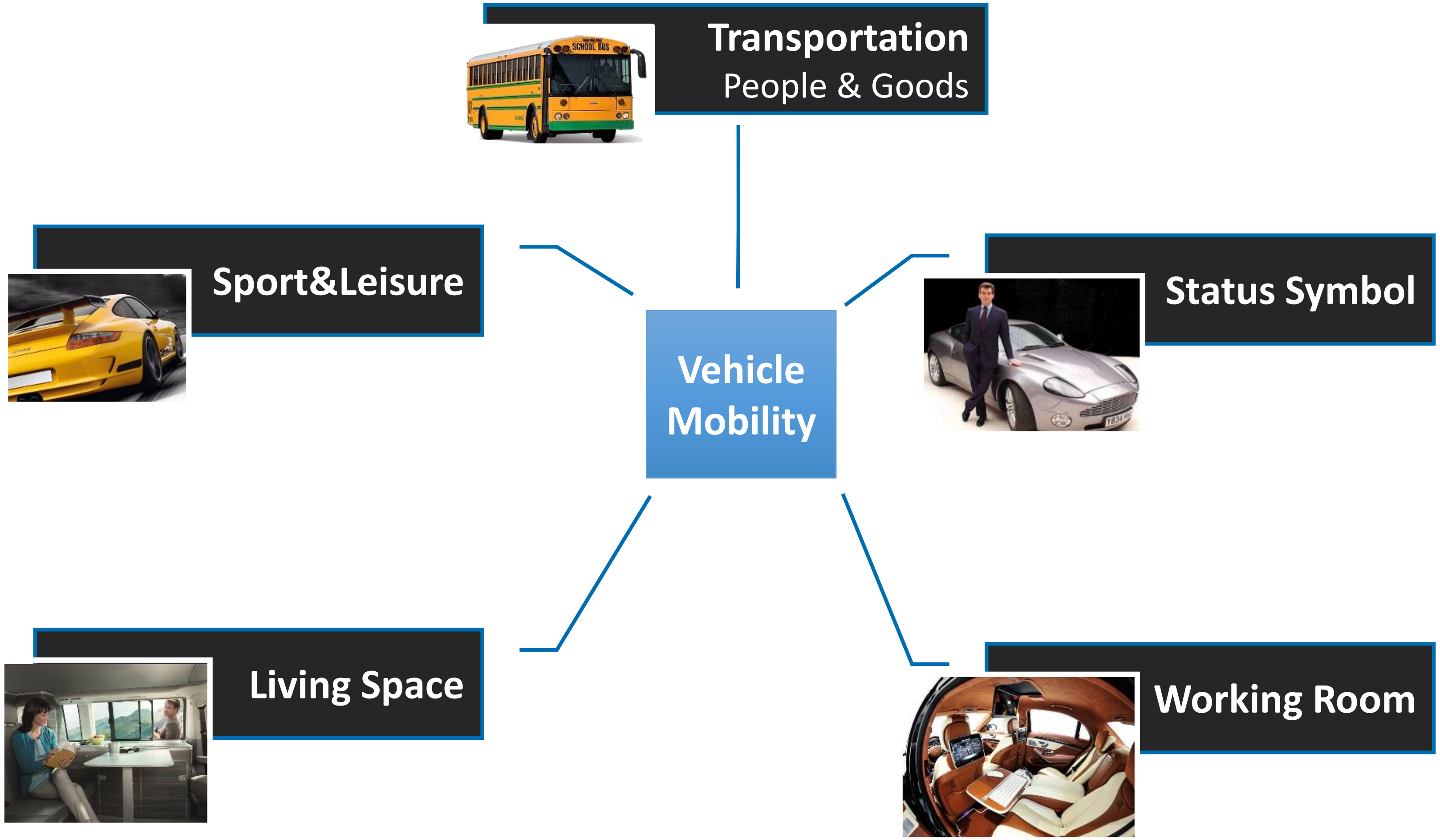


Mobility as a system has efforts and side effects



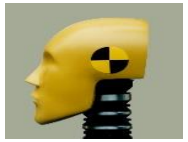
Requirements for vehicles and their global attributes

Benefit of the vehicle mobility system.



What motivates humans to buy a vehicle?

Fuel Consumption



Safety

Costs

Styling

Space

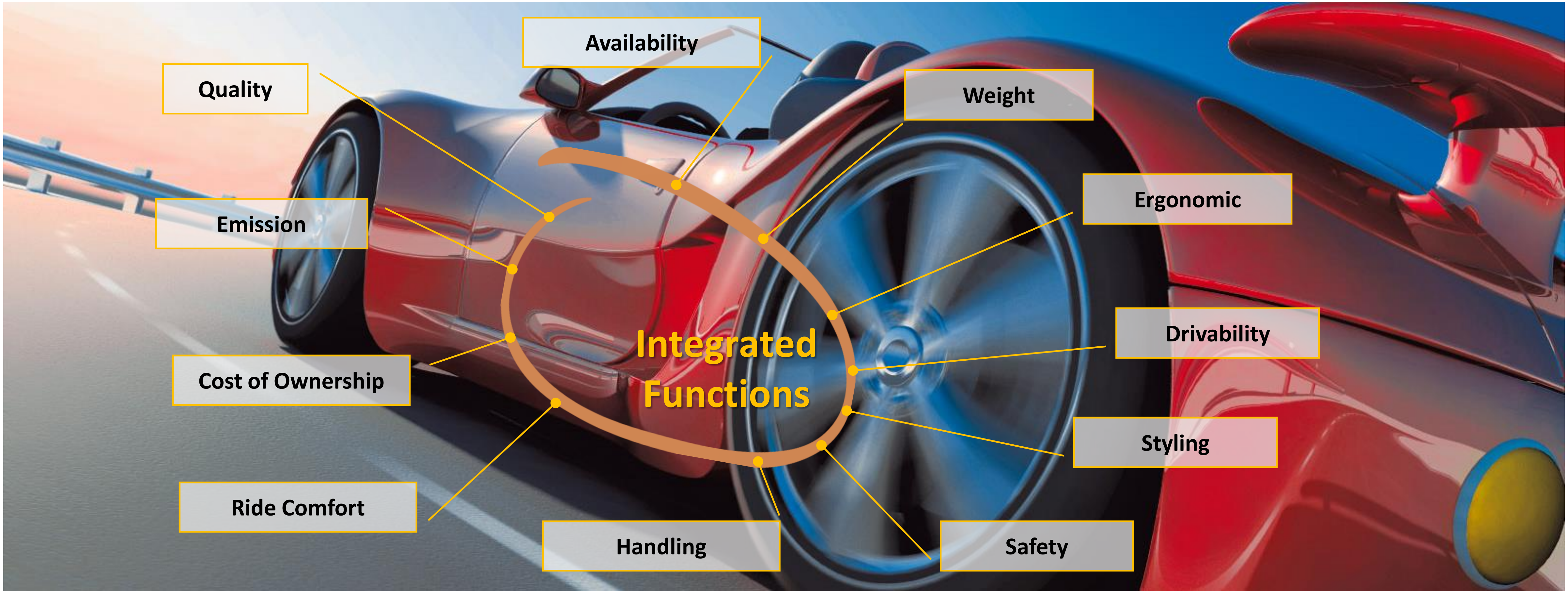
For what?

Where driving?	Transportation?	What doing?
City ⬍ Highway	Persons ⬍ Goods	Transportation ⬍ Representation ⬍ Enjoy

For who?

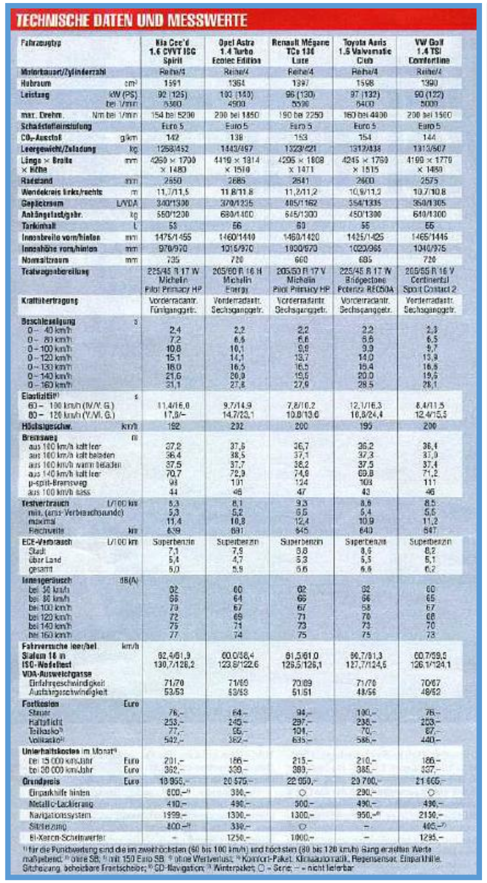
Practitioner	“Schlaumeier”	Gourmets	Business man

Major issue for customer values are the global vehicle attributes



Requirements for vehicles and their global attributes

How can we evaluate the global vehicle attributes?



TECHNISCHE DATEN UND MESSWERTE

Fahrzeugtyp		Kia Cee'd 1.6 CVVT ISG Spirit	Opel Astra 1.4 Turbo Ecotec Edition	Renault Mégane TCe 130 Luxe	Toyota Auris 1.6 Valvematic Club	VW Golf 1.4 TSI Comfortline
Motorbauart/Zylinderzahl		Reihe/4	Reihe/4	Reihe/4	Reihe/4	Reihe/4
Hubraum	cm³	1591	1364	1397	1598	1390
Leistung	kW (PS) bei 1/min	92 (125) 6300	103 (140) 4900	96 (130) 5500	97 (132) 6400	90 (122) 5000
max. Drehm.	Nm bei 1/min	154 bei 5200	200 bei 1850	190 bei 2250	160 bei 4400	200 bei 1500
Schadstoffeinstufung		Euro 5	Euro 5	Euro 5	Euro 5	Euro 5
CO_2-Ausstoß	g/km	142	138	153	154	144
Leergewicht/Zuladung	kg	1258/452	1443/497	1323/421	1312/438	1313/507
Länge × Breite × Höhe	mm	4260 × 1790 × 1480	4419 × 1814 × 1510	4295 × 1808 × 1471	4245 × 1760 × 1515	4199 × 1779 × 1480
Radstand	mm	2650	2685	2641	2600	2575
Wendekreis links/rechts	m	11,7/11,5	11,8/11,8	11,2/11,2	10,9/11,2	10,7/10,8
Gepäckraum	L/VDA	340/1300	370/1235	405/1162	354/1335	350/1305
Anhängelast/gebr.	kg	560/1200	680/1400	645/1300	450/1300	640/1300
Tankinhalt	L	53	56	60	55	55
Innenbreite vorn/hinten	mm	1475/1455	1460/1440	1460/1420	1425/1425	1465/1445
Innenhöhe vorn/hinten	mm	970/970	1015/970	1030/970	1020/965	1040/975
Normsitzraum	mm	735	720	660	695	720
Testwagenbereifung		225/45 R 17 W Michelin Pilot Primacy HP	205/60 R 16 H Michelin Energy	205/50 R 17 V Michelin Pilot Primacy HP	225/45 R 17 W Bridgestone Potenza RE050A	205/55 R 16 V Continental Sport Contact 2
Kraftübertragung		Vorderradantr. Fünfganggetr.	Vorderradantr. Sechsganggetr.	Vorderradantr. Sechsganggetr.	Vorderradantr. Sechsganggetr.	Vorderradantr. Sechsganggetr.
Beschleunigung	s					
0 – 40 km/h		2,4	2,2	2,2	2,2	2,3
0 – 80 km/h		7,2	6,6	6,6	6,6	6,5
0 – 100 km/h		10,8	10,1	9,9	9,9	9,7
0 – 120 km/h		15,1	14,1	13,7	14,0	13,9
0 – 130 km/h		18,0	16,5	16,5	15,4	16,6
0 – 140 km/h		21,6	20,9	19,5	20,0	19,6
0 – 160 km/h		31,1	27,8	27,9	28,5	28,1
Elastizität[1]	s					
60 – 100 km/h (IV./V. G.)		11,4/16,0	9,7/14,9	7,8/10,2	12,1/16,3	8,4/11,5
80 – 120 km/h (V./VI. G.)		17,8/–	14,7/23,1	10,8/13,0	16,8/24,4	12,4/15,5
Höchstgeschw.	km/h	192	202	200	195	200
Bremsweg	m					
aus 100 km/h kalt leer		37,2	37,6	36,7	36,2	36,4
aus 100 km/h kalt beladen		36,4	38,5	37,1	37,3	37,0
aus 100 km/h warm beladen		37,5	37,7	38,2	37,5	37,4
aus 140 km/h kalt leer		70,7	72,9	74,9	69,8	71,2
µ-split-Bremsweg		98	101	124	108	111
aus 100 km/h nass		44	46	47	43	46
Testverbrauch	l/100 km	8,3	8,1	9,3	8,6	8,5
min. (ams-Verbrauchsrunde)		5,3	5,2	6,5	5,4	5,5
maximal		11,4	10,8	12,4	10,9	11,2
Reichweite	km	639	691	645	640	647
ECE-Verbrauch	l/100 km	Superbenzin	Superbenzin	Superbenzin	Superbenzin	Superbenzin
Stadt		7,1	7,9	8,8	8,6	8,2
über Land		5,4	4,7	5,3	5,5	5,1
gesamt		6,0	5,9	6,6	6,6	6,2
Innengeräusch	dB(A)					
bei 50 km/h		62	60	62	62	60
bei 80 km/h		66	64	66	64	65
bei 100 km/h		70	67	67	68	67
bei 120 km/h		72	69	71	70	68
bei 140 km/h		75	71	73	73	70
bei 160 km/h		77	74	75	75	73
Fahrversuche leer/bel.	km/h					
Slalom 18 m		62,4/61,9	60,0/58,4	61,5/61,0	60,7/61,3	60,7/59,5
ISO-Wedeltest		130,7/128,2	123,8/122,6	126,5/126,1	127,7/124,5	126,1/124,1
VDA-Ausweichgasse						
Einfahrgeschwindigkeit		71/70	71/69	70/69	71/70	70/67
Ausfahrgeschwindigkeit		53/53	53/53	51/51	48/56	48/52
Fixkosten	Euro					
Steuer		76,–	64,–	94,–	100,–	76,–
Haftpflicht		253,–	245,–	297,–	238,–	203,–
Teilkasko[2]		77,–	55,–	104,–	70,–	67,–
Vollkasko[3]		542,–	382,–	635,–	586,–	440,–
Unterhaltskosten im Monat[4]						
bei 15 000 km/Jahr	Euro	201,–	186,–	215,–	210,–	186,–
bei 30 000 km/Jahr	Euro	362,–	339,–	389,–	385,–	337,–
Grundpreis	Euro	18 955,–	20 575,–	22 050,–	20 700,–	21 665,–
Einparkhilfe hinten		600,–[5]	380,–	○	290,–	○
Metallic-Lackierung		410,–	490,–	500,–	490,–	490,–
Navigationssystem		1999,–	1300,–	1300,–	950,–[6]	2150,–
Sitzheizung		600,–[5]	330,–	○	–	405,–[7]
Bi-Xenon-Scheinwerfer		–	1250,–	1000,–	–	1295,–

[1] für die Punktwertung sind die im zweithöchsten (60 bis 100 km/h) und höchsten (80 bis 120 km/h) Gang erzielten Werte maßgebend; [2] ohne SB; [3] mit 150 Euro SB; [4] ohne Wertverlust; [5] Komfort-Paket: Klimaautomatik, Regensensor, Einparkhilfe, Sitzheizung, beheizbare Frontscheibe; [6] SD-Navigation; [7] Winterpaket; ○ = Serie; – = nicht lieferbar

- Availability
- Cost of Ownership
- Weight
- Quality
- Ergonomic
- Styling
- Safety
- Emission
- Drivability
- Handling
- Ride Comfort

1 Evaluation criteria (measureable)

2 Test Method

3 Target

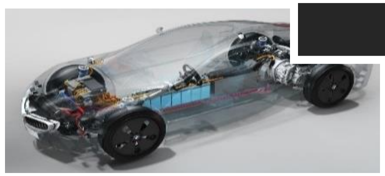
Requirements for vehicles and their global attributes

How can we evaluate the global vehicle attributes?

					Measurable (sample)
Availability	Millage Range	Service Intervals	Times for fuelling	...	Interrupt times
Cost of Ownership	Invest	Fuel	Service	Insurance	Money
Weight	Total weight	System weight	Component weight	..	Weighting
Quality	Service intervals	Clearance (optical)	Defect rates	Breakdown statistics	Statistics
Ergonomic	Seat position	Seat pressure	Accessibility	..	Ergonomic measurement
Styling	Exterior	Interior	..	...	Customer survey
Safety	NCAP Rating	Stability	Controlability	Brake distance	Crash tests
Emission	CO2	HC	NOx	CO	Emission measurement
Drivability	Acceleration performance	Tip In Jerk	Tip In Latency time	Tip Out oscillation	Vehicle measurement
Handling	Cornering behavior	Steering behavior	Braking behavior	Straight running	Vehicle measurement
Ride Comfort	Primary Ride	Secondary Ride	NVH	Noise	Vehicle measurement

Overview of vehicle systems

The vehicle and its systems



Powertrain

- Engine
- Transmission
- Drivetrain
- E-Motor
- Battery
- Controls

Chassis System

- Tire & Wheels
- Suspension
- Steering
- Brakes
- Controls
- ...

Electric & Electronics

- Infotainment
- Wiring
- ECU Network
- Body Control
- ...

Global Vehicle

- Weights
- Passive Safety
- Durability
- NVH
- Fuel Consumption
- Exterior
- ...

Interior

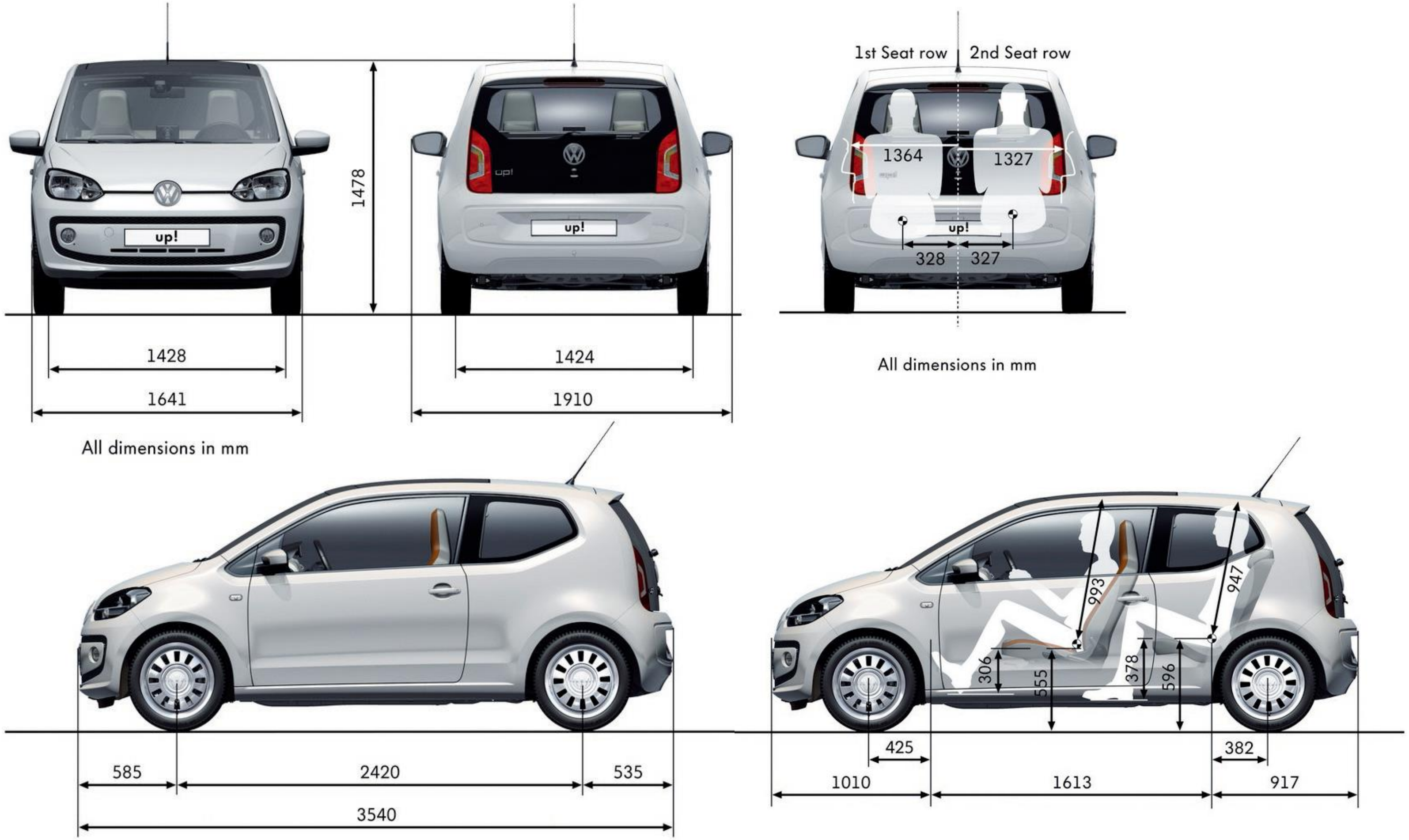
- Seats
- Dashboard
- Instruments
- Cover panels
- ...

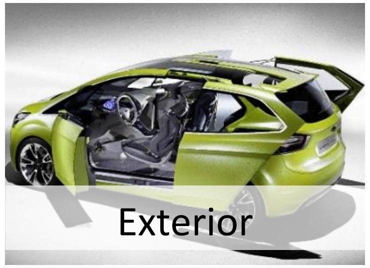
Body

- Doors
- Roof
- Front body
- Floor
- ...

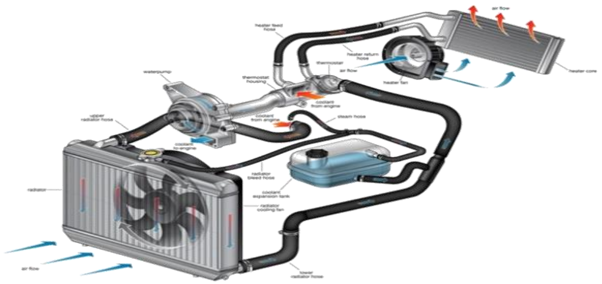
Vehicle body and total vehicle

Vehicle body and total vehicle





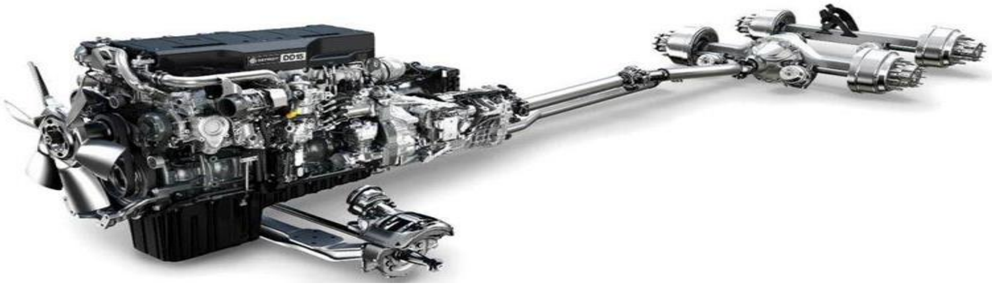
Powertrain System



Cooling system

Exhaust system and after treatment

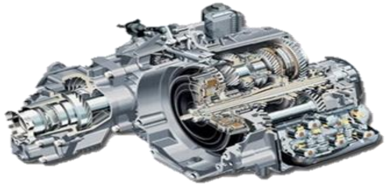
E-Motor



Battery

ICE – Internal Combustion Engine

Differential

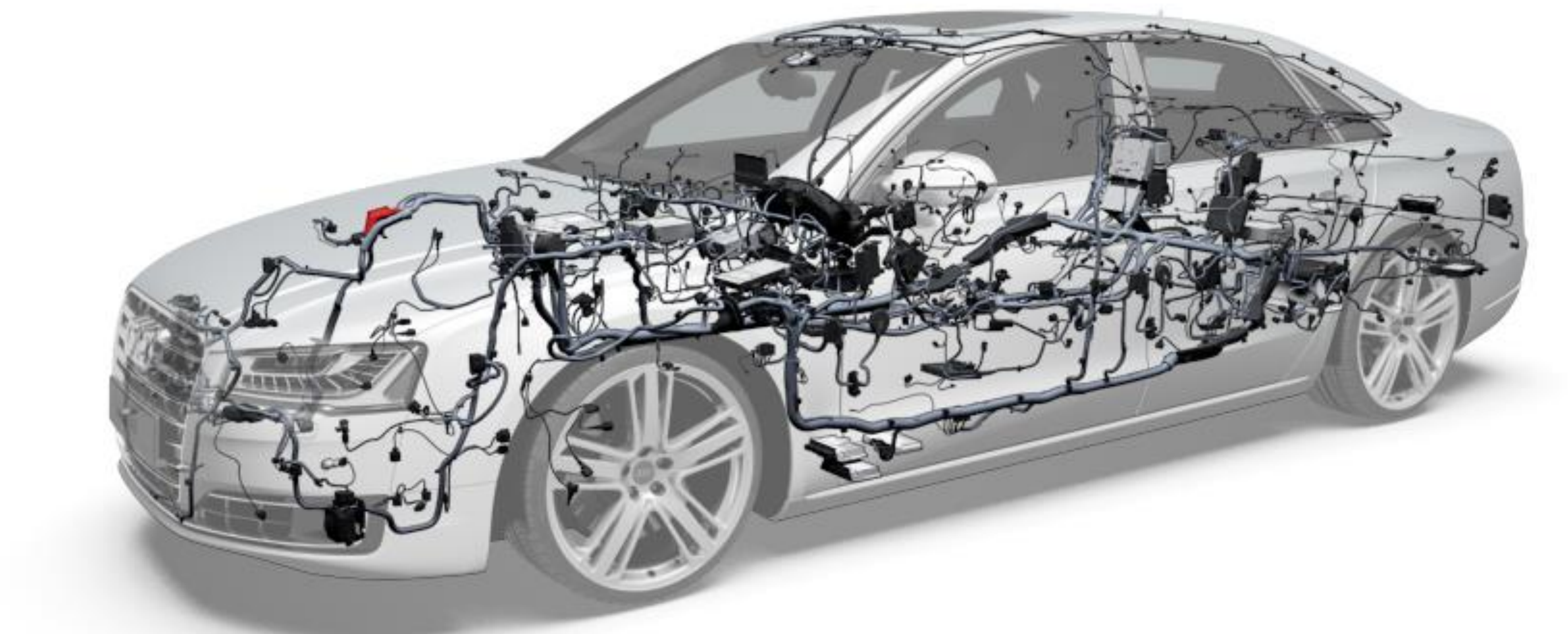


Gear Box / Transmission

Clutch

Shafts

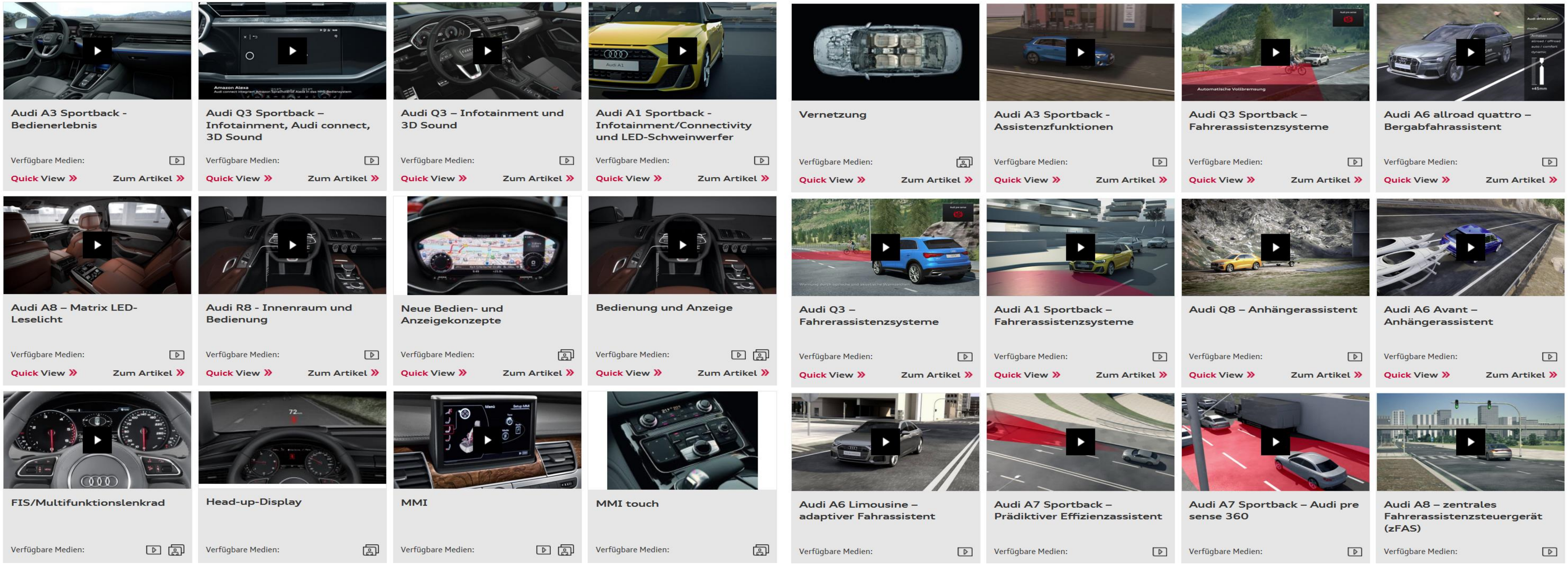
Electric & Electronics



The field of electrics/electronics covers a wide range. It includes electrical operating elements as well as assistance and safety systems, multimedia systems and lighting technology. In all these areas, Audi leads the competition with innovative solutions.

Overview of vehicle systems

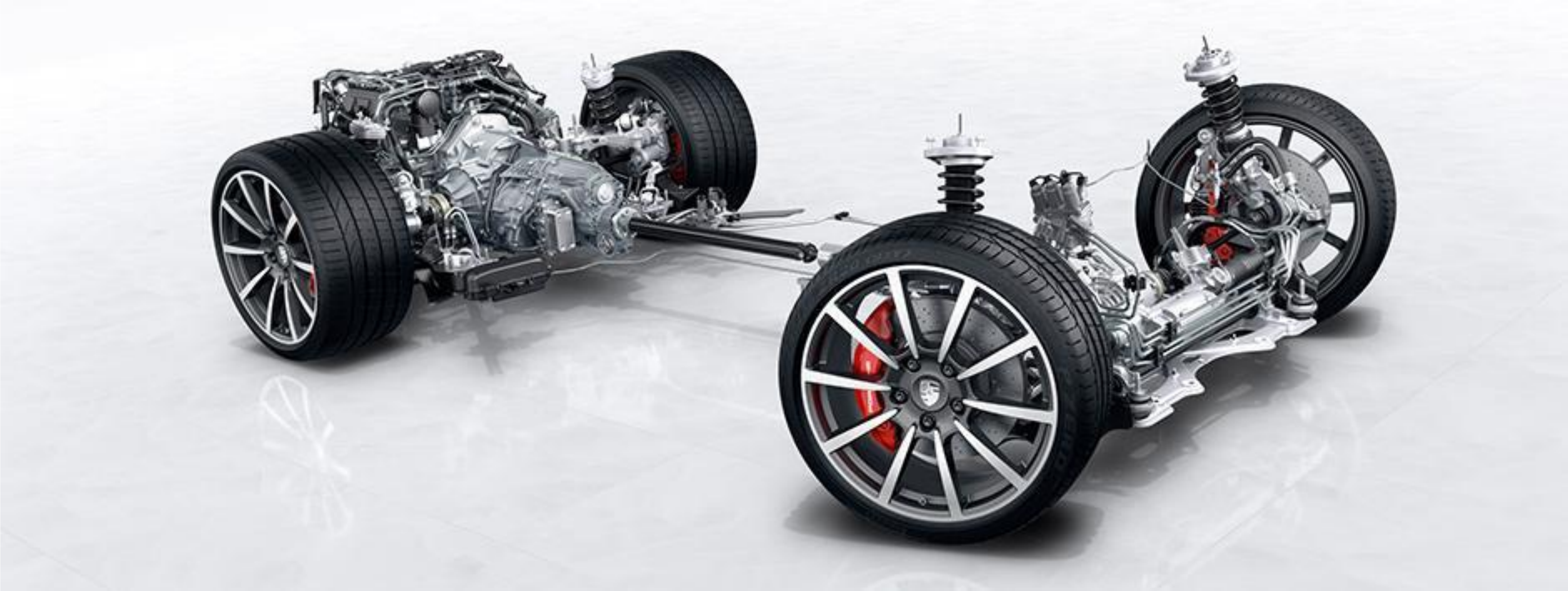
Electric & Electronics



https://www.audi-technology-portal.de/de/

Aerodynamics

Chassis Systems



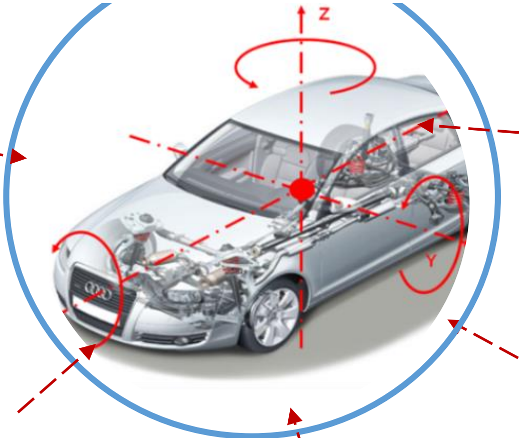
Requirement for chassis systems

Chassis is responsible for the interconnection between the vehicle and the road including passengers and luggage. Furthermore is responsible to…

- transfer outer forces and moments via the tires to suspension to vehicle inner forces.
- bring tires into a optimal position for the force and moment transfer.
- control the full body motion for
  - <u>Vehicle dynamics</u> attributes
  - <u>Driving comfort</u> attributes
  - <u>Driving safety</u> attributes

Vehicle dynamics behavior is impact by numerous components

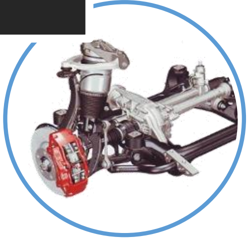
Chassis Systems



Dr. Kersten / Hr. Scharpe

Suspension, K&C

- Axle
- Spring
- Damper
- Stabilizer
- Bushing
- …



Prof. Schick

Chassis Controls

- Brake Control (ESC)
- Steering Control
- Suspension Control
- …

Prof. Schick

Steering System

- Rack
- Column
- Wheel
- Power Unit
- …

Prof. Schick

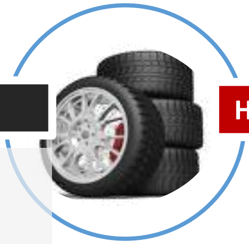
Brake System

- Actuation
- Hydraulic
- Caliber
- Disk
- Valves
- …

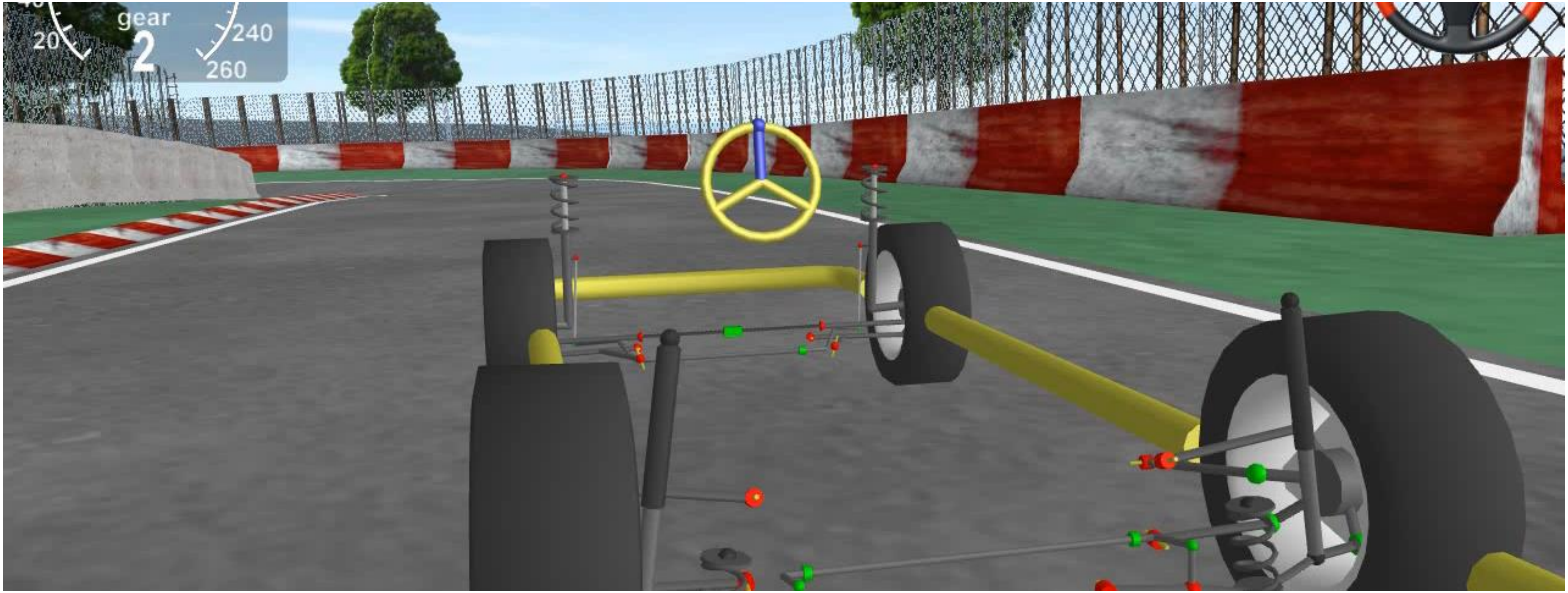
Tires & Wheels

Hr. Scharpe

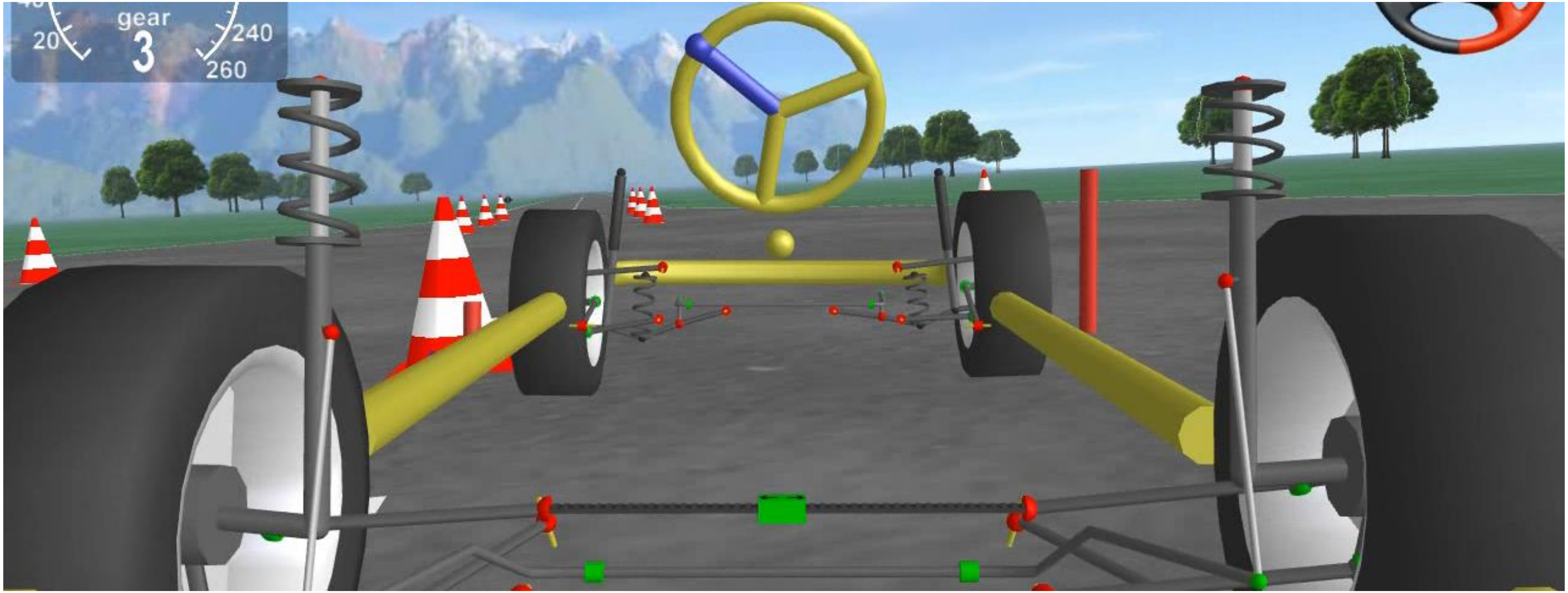
- Tire
- Wheel
- TPMS



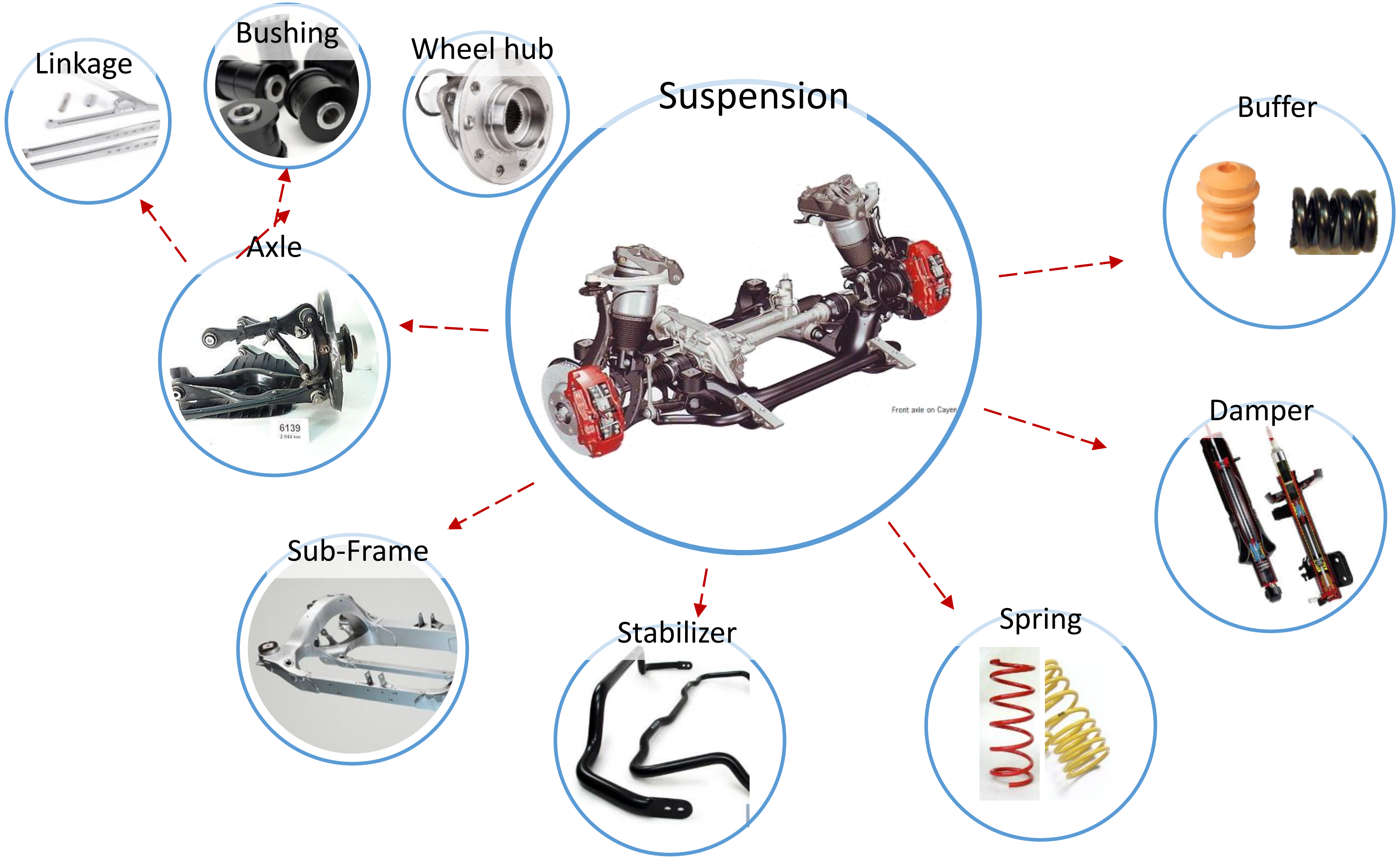
Axle, Suspension, Kinematics&Compliance Characteristics

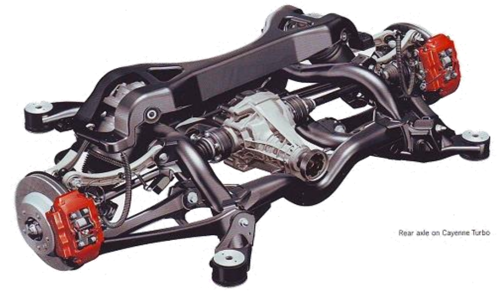


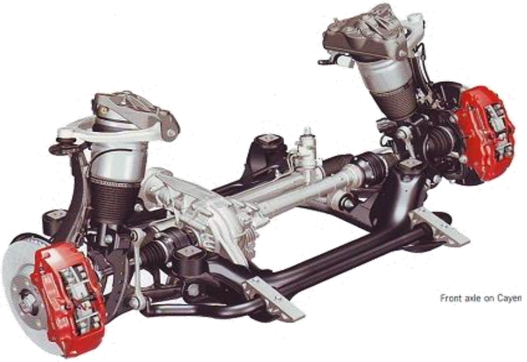
Axle, Suspension, Kinematics&Compliance Characteristics



Suspension components







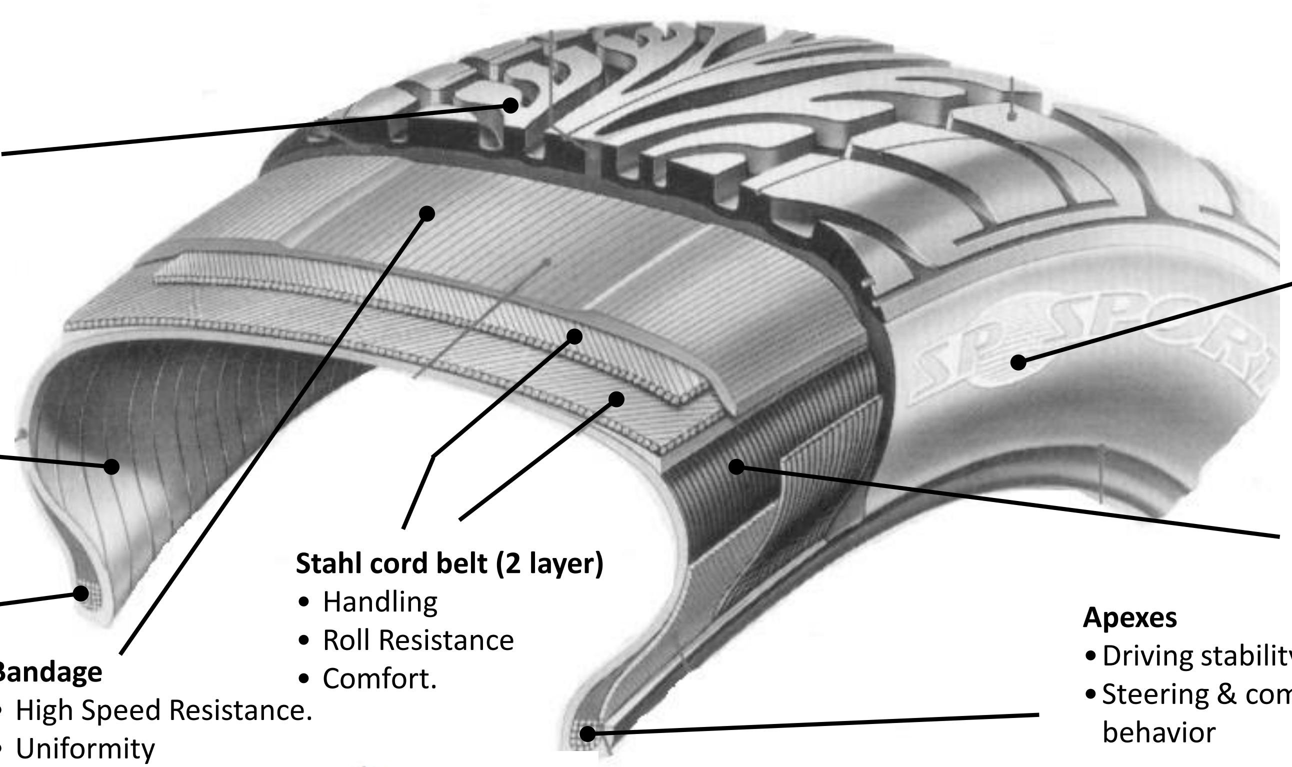
The tire is the “BLACK MAGIC” for transmission of forces between vehicle and track

The tire is the “BLACK MAGIC” – how tire works

https://www.youtube.com/watch?v=BPYxLeW6WjM

Tire construction and component functions

Tread
- Force transfer
- Wear
- Handling.
- Noise.
- Aquaplaning.
- Comfort.
- Roll Resistance



Side wall
- Damage protection.

Inner Liner
- Airtightness.

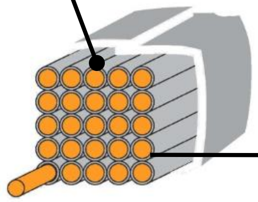
Textile cord Carcass
- Endurance
- Dimensional stability.

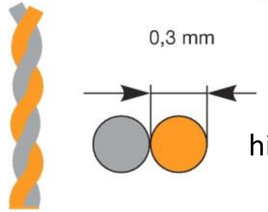
Stahl cord belt (2 layer)
- Handling
- Roll Resistance
- Comfort.

Steel Core
- Bead seating

Apexes
- Driving stability.
- Steering & comfort behavior

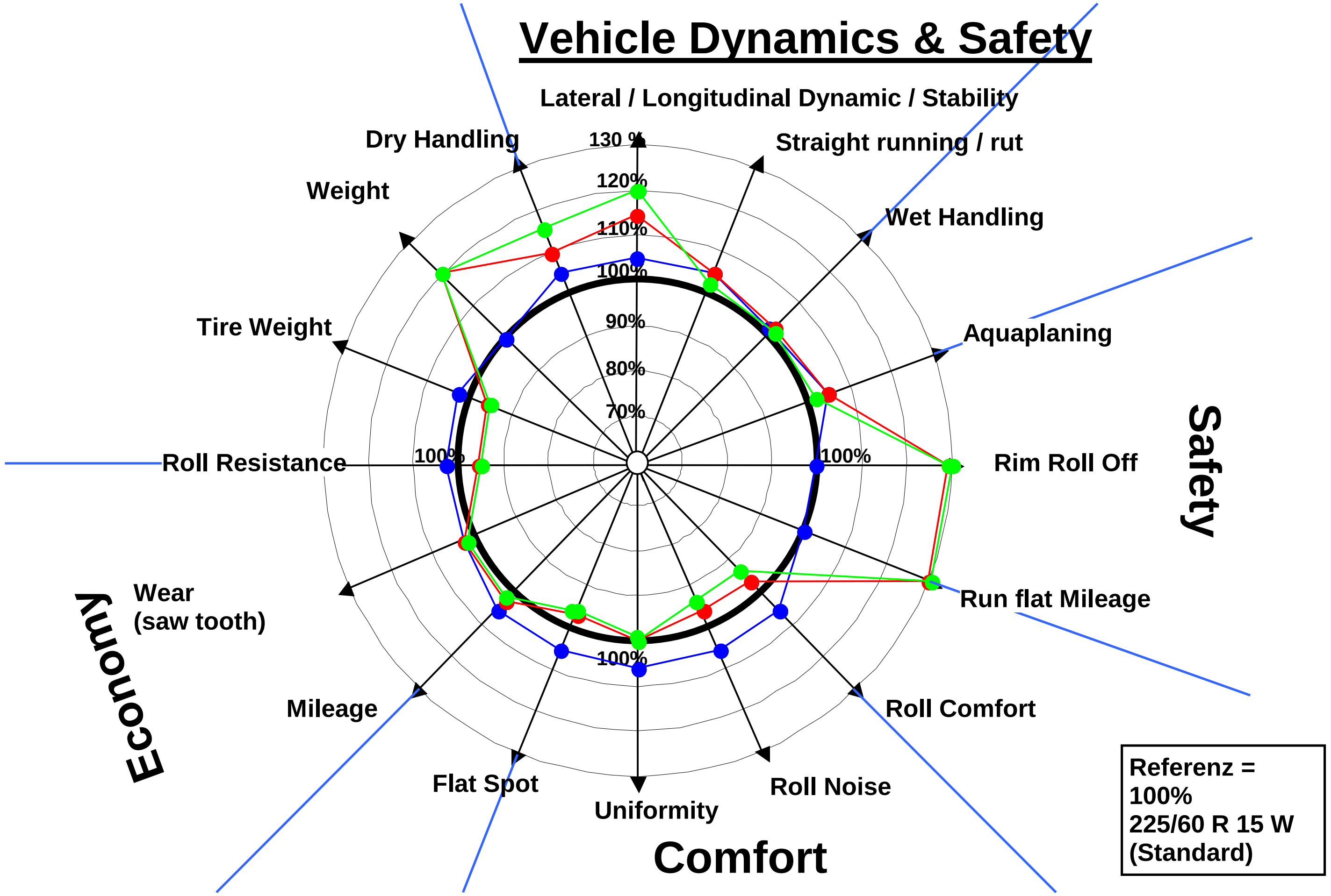
Bandage
- High Speed Resistance.
- Uniformity
- Comfort



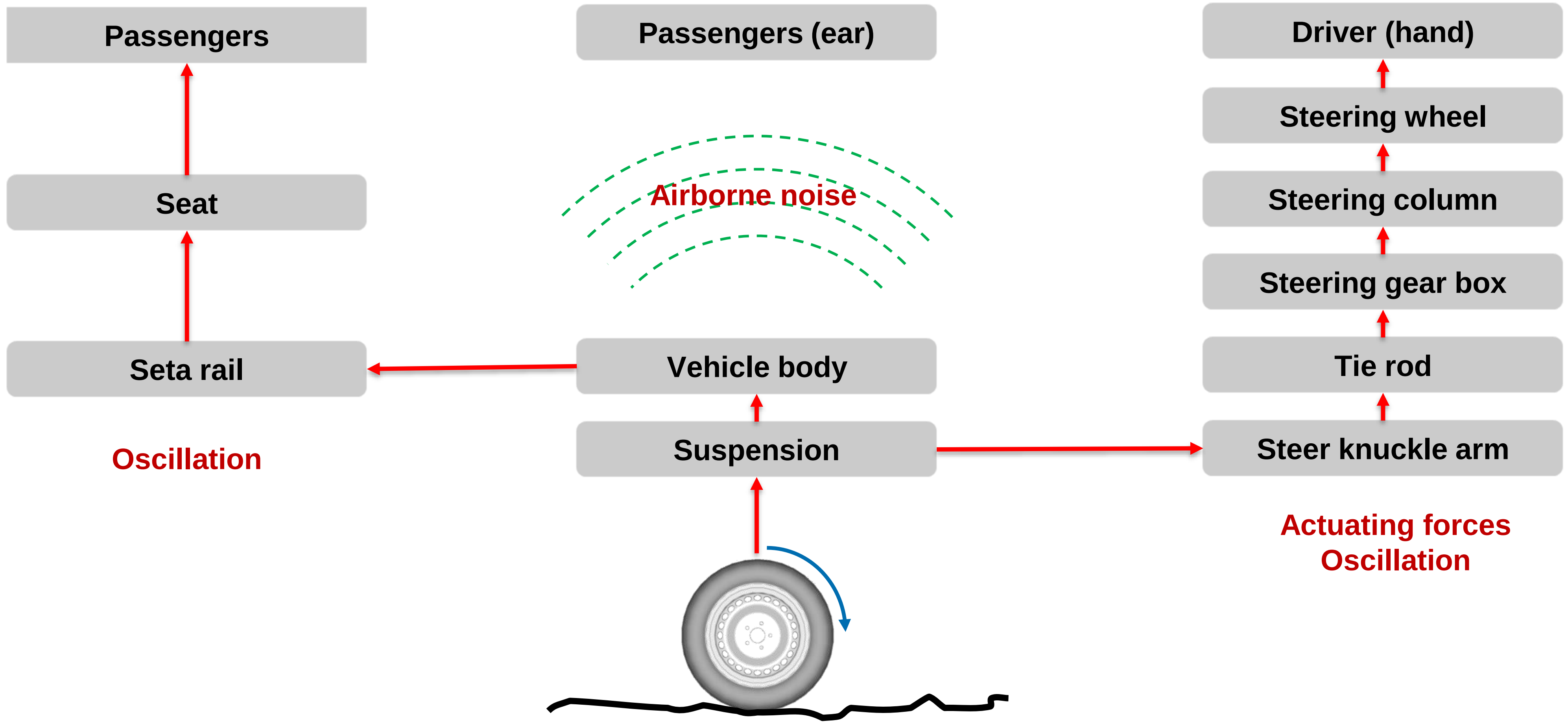


high-strength steel cord

Target conflicts (trade-off) for the development



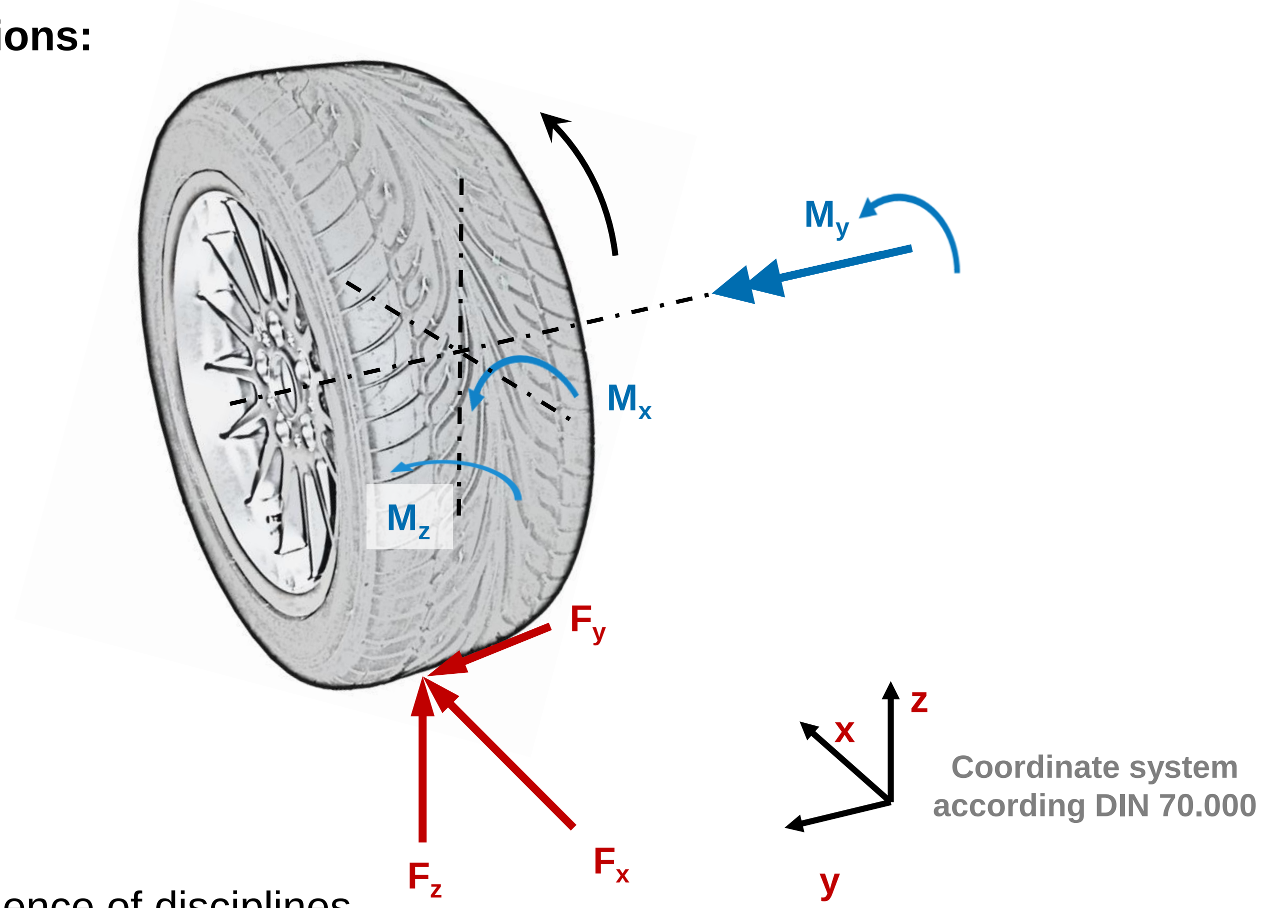
Cause and effect chain / transfer path



Tires are the interface to the road environment

The behavior of the tire can be subdivide into 3 directions:

- Longitudinal Dynamic:
  - F_x = longitudinal force
  - M_y = Acceleration / Brake torque
  - referred as „longitudinal".
- Lateral Dynamics:
  - F_y = lateral force
  - M_x = camber torque
  - M_z = Back alignment /toe torque
  - referred as "lateral"
- Vertical Dynamics:
  - F_z = Wheel load
  - referred as „vertical".



The overall performance is determined by the interdependence of disciplines

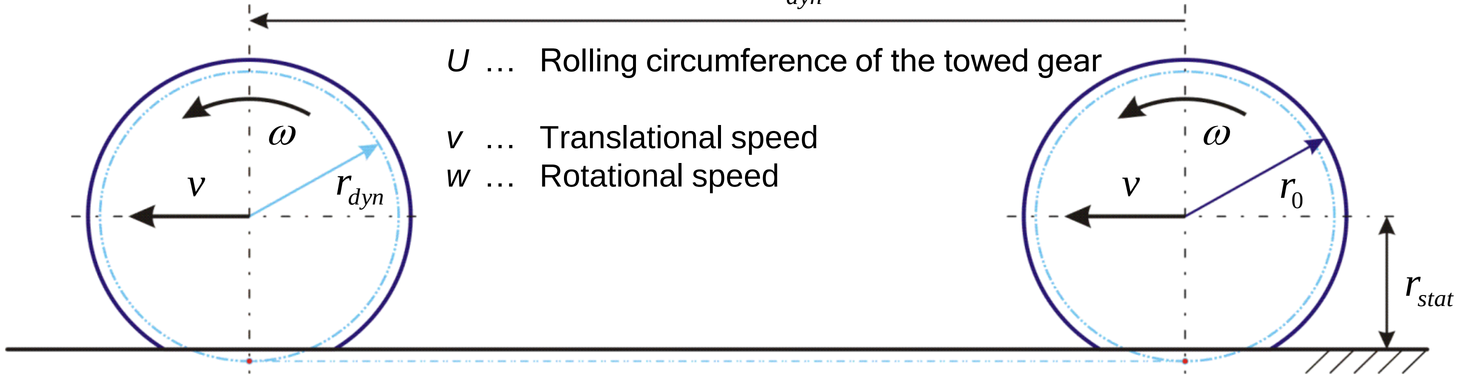
Tires, some fundamentals

- When considering of forces, torques and speeds at the wheel must be made between different wheel radii:

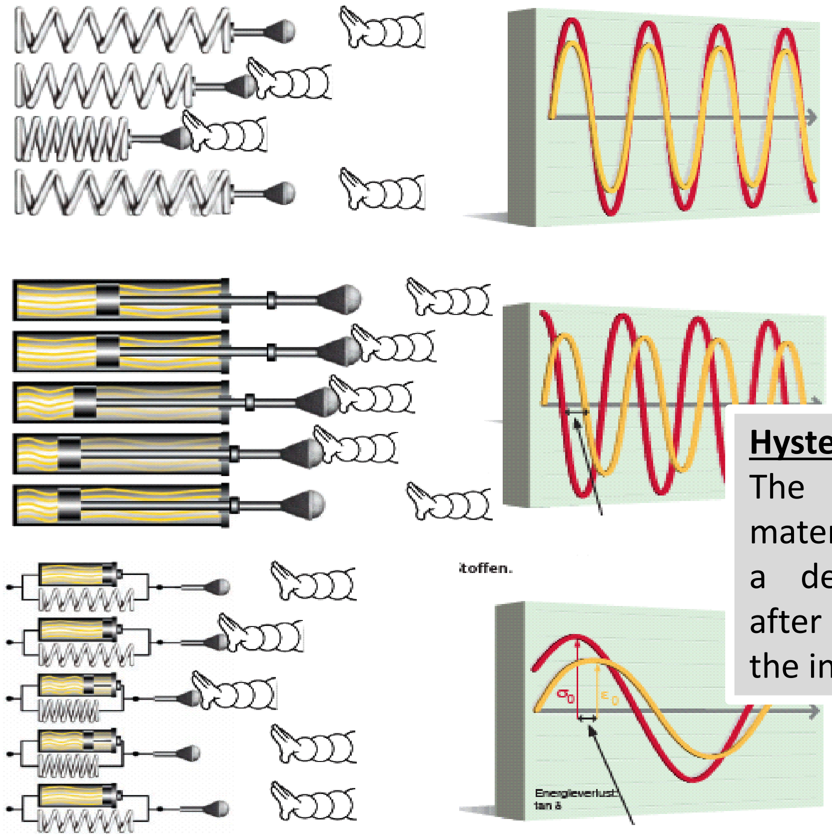
r_0	—	Tire radius of the unloaded wheel (manufacturing radius).
r_{stat}	—	static tire radius (Used in considerations with forces and moments).
r_{dyn}	—	dynamic tire radius (Used for observations with peripheral speeds).

- The static wheel radius is determined on a stationary, loaded wheel.
- The dynamic rolling radius is determined according to DIN 70020 with a towed wheel with a speed of 60 km/h. Predetermined inflation pressure in each case is according the load specification.

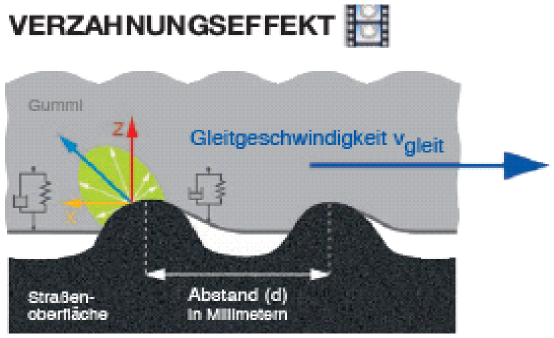
$$U = 2 \cdot \pi \cdot r_{dyn}$$



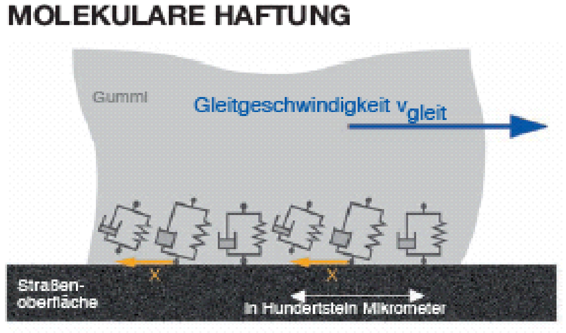
Tires, some fundamentals



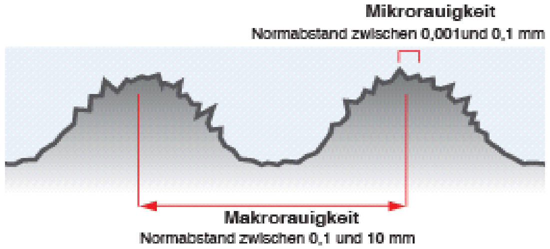
Hysteresis:
The viscous-elastic material returns from a deformation first after a while back to the initial position



Stößt der Gummiblock gegen eine Erhebung und verformt sich, so kehrt er hysteresebedingt nach der Entlastung nicht sogleich in seine Ausgangslage zurück. Diese asymmetrische Verformung erzeugt ein Kraftfeld, dessen Tangentialkomponente X dem Durchrutschen entgegenwirkt.

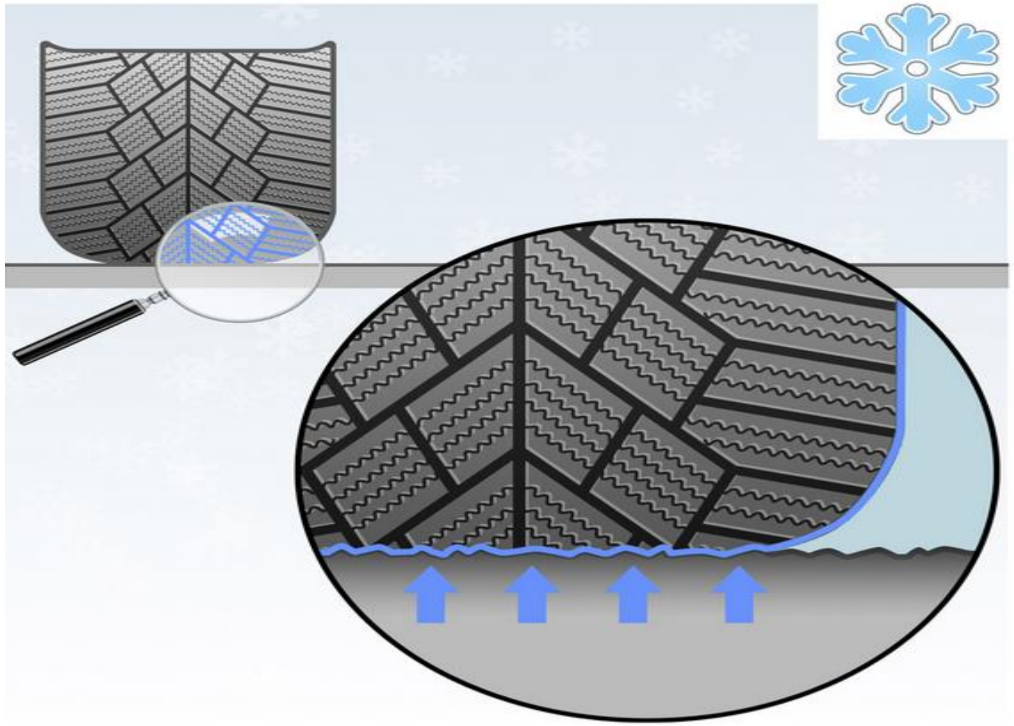


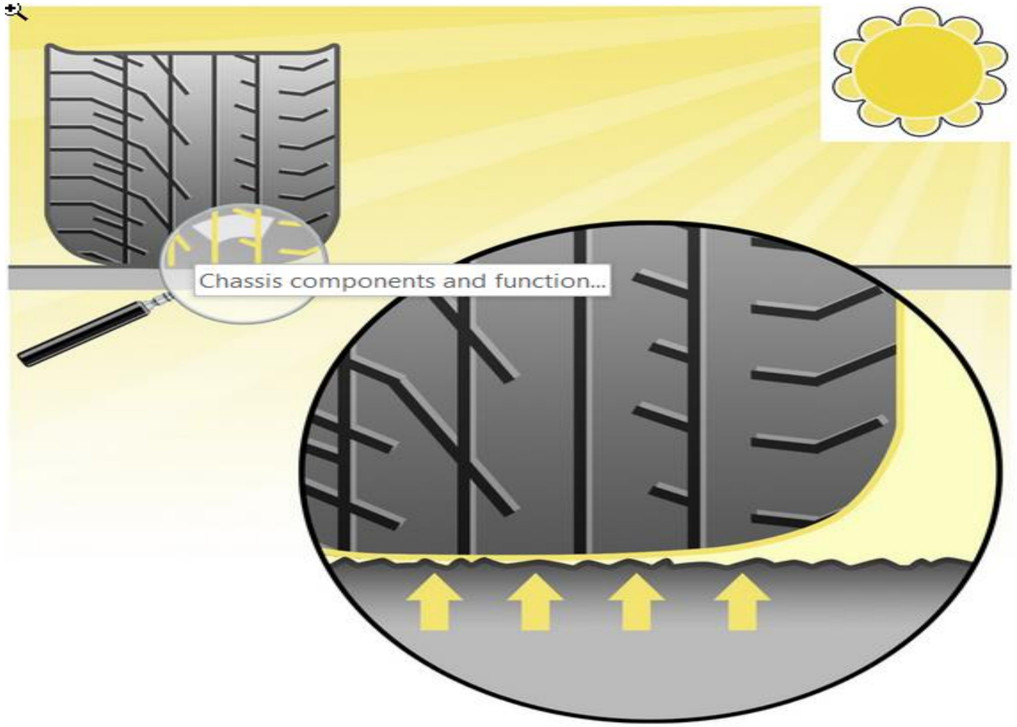
Die Molekülkette wird gedehnt: Aufgrund ihrer viskosen Eigenschaften, symbolisiert durch den Dämpferkolben, widerstehen die Moleküle zunächst der Verformung und erzeugen eine Reibungskraft X, die dem Durchrutschen entgegenwirkt.



- **Makrorauigkeit.** Dieser Begriff wird gebraucht, wenn der Abstand zwischen zwei "großen" Erhebungen zwischen 100 Mikrometern und 10 Millimetern beträgt. Diese Größe unterstützt den Verzahnungseffekt sowie die Wasserabführung und -einlagerung. Über den Grad der Makrorauigkeit bestimmt das verwendete **Asphaltgranulat**.

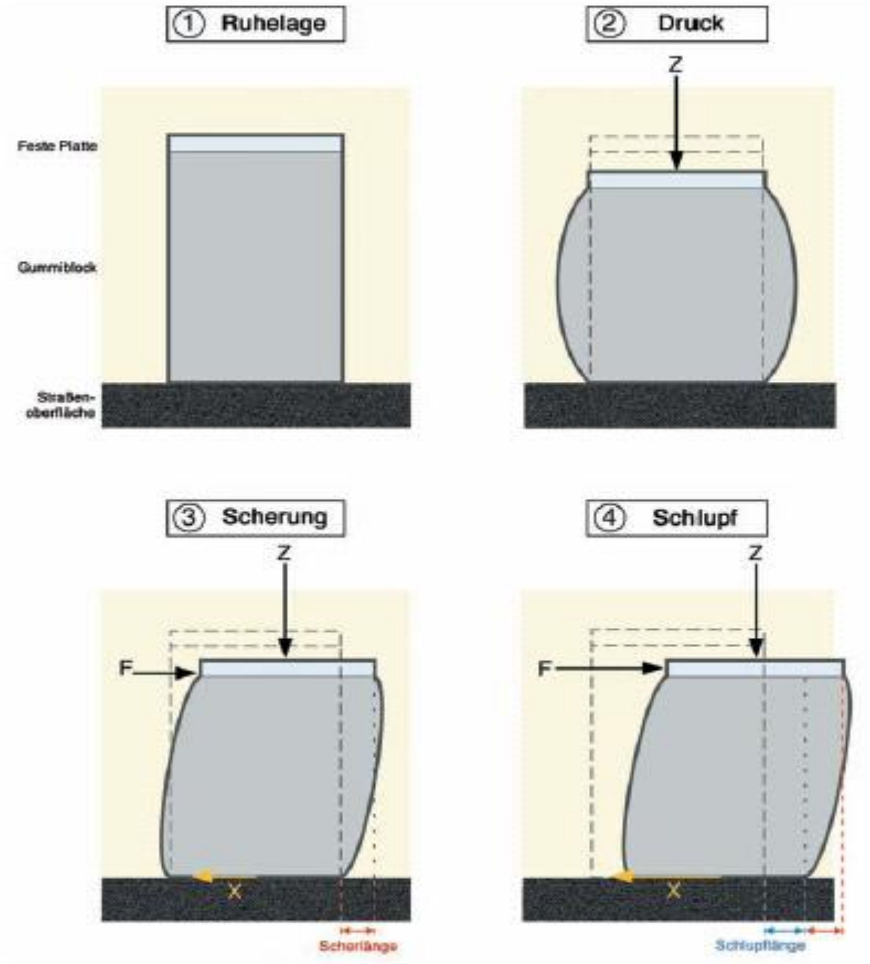
Tire slip mechanisms – shear, slide and slip

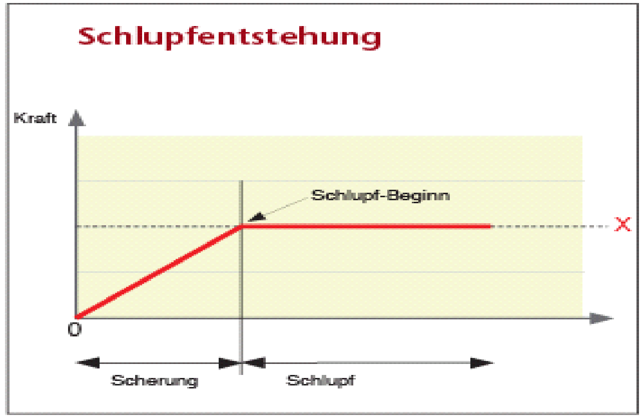


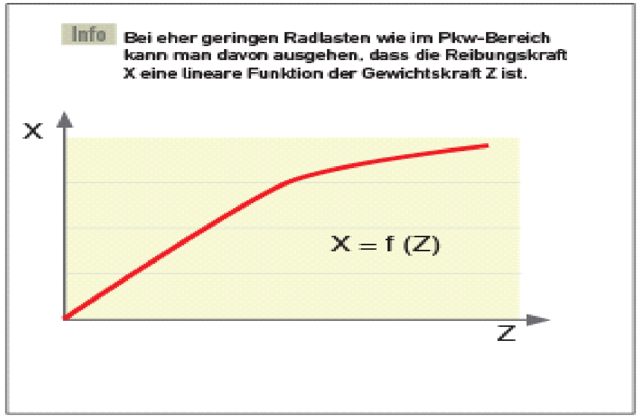


The soft tread compound of winter tires is still flexible even at low temperatures, so that winter tires remain slip-proof and optimally toothing with the road surface.

Target conflicts (trade-off) for the development







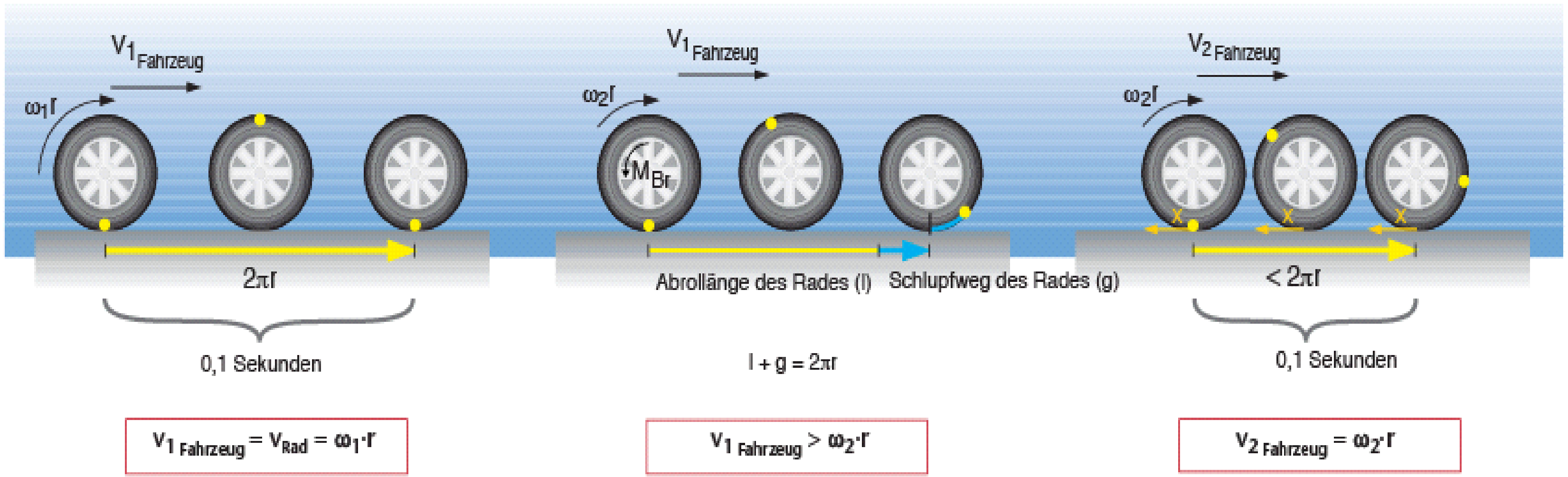
Tire longitudinal slip behavior

1 VOR BREMSBEGINN

Nehmen wir an, ein Rad lege eine Umdrehung (360°) innerhalb einer Zeit t = 0,1 s bei einer Fahrgeschwindigkeit v = 70 km/h zurück. Die in dieser Zeit vom rollenden Rad (und gleichzeitig vom Fahrzeug) zurückgelegte Strecke entspricht genau einer abgewickelten Radlänge oder, mathematisch ausgedrückt, $2 \cdot \pi \cdot r$.

2 WÄHREND DES BREMSVORGANGS

Sobald der Fahrer das Bremspedal niedertritt, fällt die Radumfangsgeschwindigkeit ($\omega \cdot r$) unter den Betrag der Fahrzeuggeschwindigkeit. Von diesem Moment an, wenn das Fahrzeug eine Strecke entsprechend $2 \cdot \pi \cdot r$ zurücklegt, vollführt das Rad keine vollständige Umdrehung mehr. Um der Vorwärtsbewegung des Fahrzeugs folgen zu können, rollt das Rad unter Schlupf ab. Dieser Radschlupf aktiviert die bekannten Haftungsmechanismen wie molekulare Haftung und Verzahnung. Die Reaktionskraft X wirkt dem Schlupf entgegen und das Fahrzeug verlangsamt sich: $v_{Fahrzeug}$ nimmt bis auf $\omega \cdot r$ ab. In besagten 0,1 s legt das Rad nun eine Strecke von weniger als $2 \cdot \pi \cdot r$ zurück.

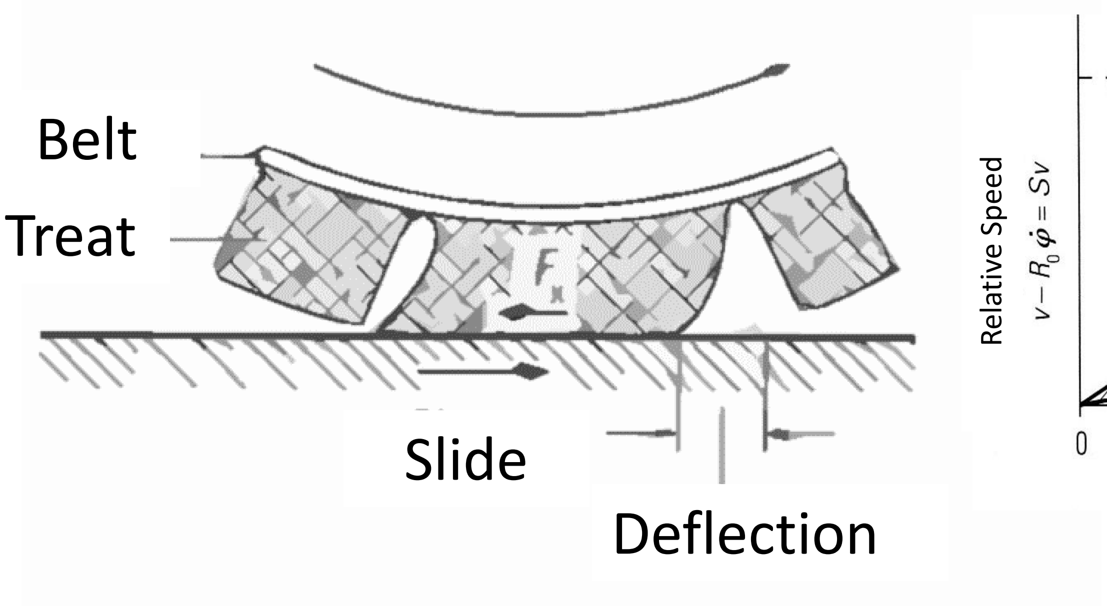


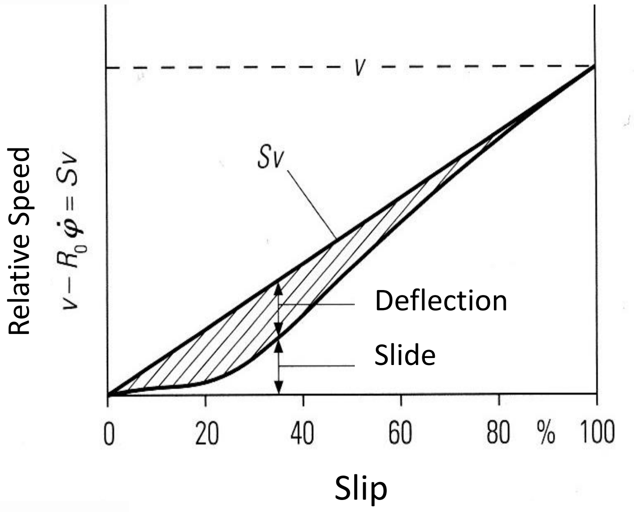
Definitionen:

ω = Winkelgeschwindigkeit des Rades, in 1/s
r = Radradius, in m
$\omega \cdot r$ = Radumfangsgeschwindigkeit, in m/s
M_{Br} = Bremsmoment, in Nm

Wenn der Fahrer den Druck auf das Bremspedal beendet, nimmt die Fahrzeuggeschwindigkeit den Wert von $\omega \cdot r$ an: Der Schlupf nimmt ab.

Tire longitudinal characteristics: slip behavior





Slip	Acceleration Slip	Brake Slip
$S = \frac{v_u - v}{v_u} \cdot 100\%$	$S_A = \frac{v_u - v}{v_u} \cdot 100\%$	$S_B = \frac{v - v_u}{v} \cdot 100\%$

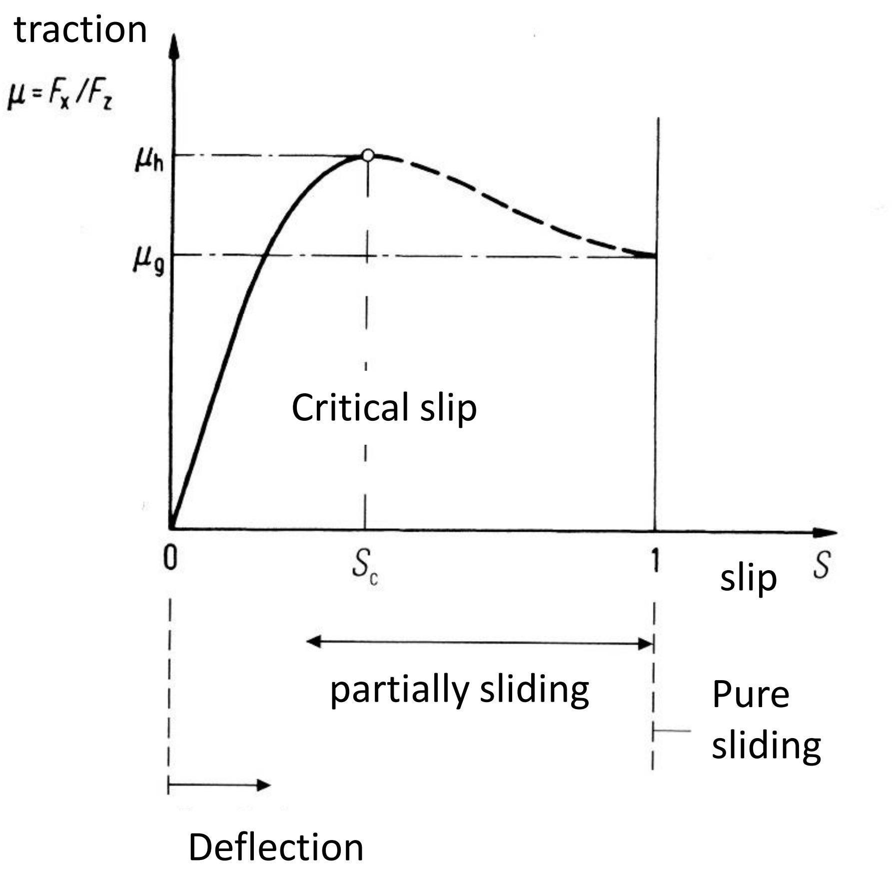
The longitudinal force F_x causes a shear deformation of the tire tread. When transferring this circumferential force between tire and road a slip (S or κ) occurs. The overall slip is put together as a deformation portion (deformation slip) and a sliding portion (sliding slip).

Tire longitudinal characteristics: slip behavior

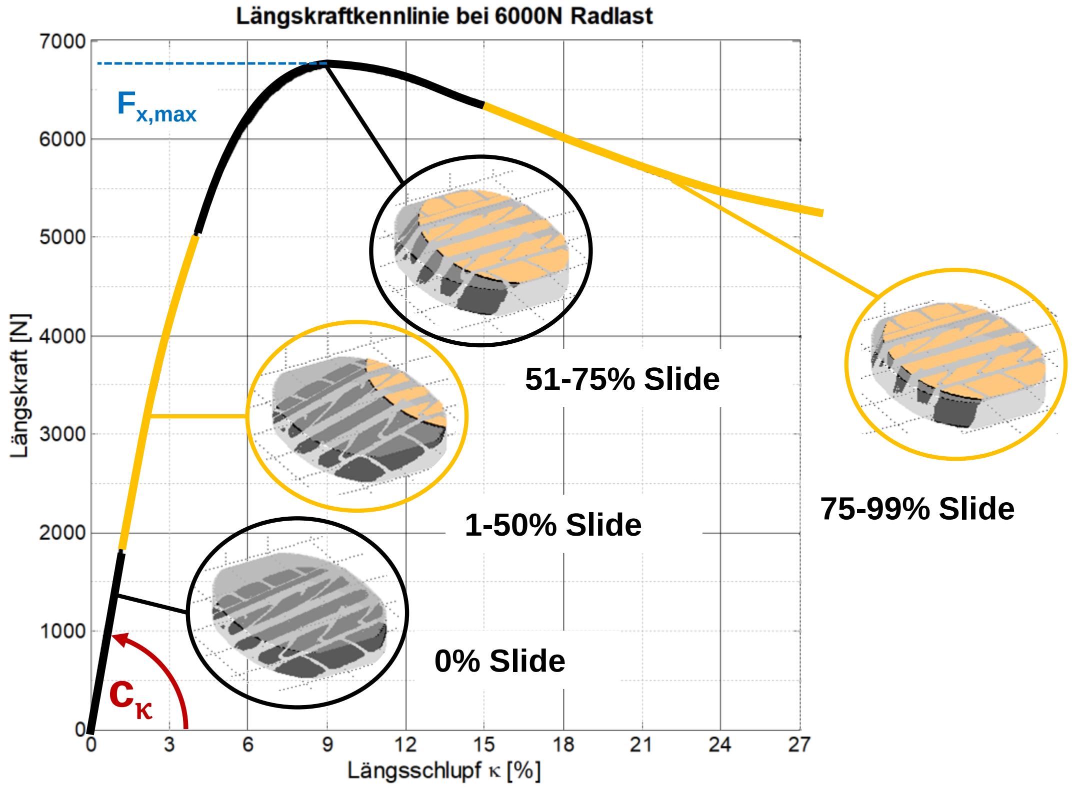
- Transferable force are defined by the adhesion coefficient μ.
- μ is at rubber friction a function of the slip

$$\mu = \frac{F_x}{F_z}$$

- μ_h defines the maximum traction, defined al friction coefficient.
- The corresponding slip is defined as “critical slip” S_c and ~10%.
- At 100% slip the traction is decreased to the sliding frication μ_g.



Tire longitudinal characteristics: slip behavior



$$F_x = c_\kappa \cdot S$$

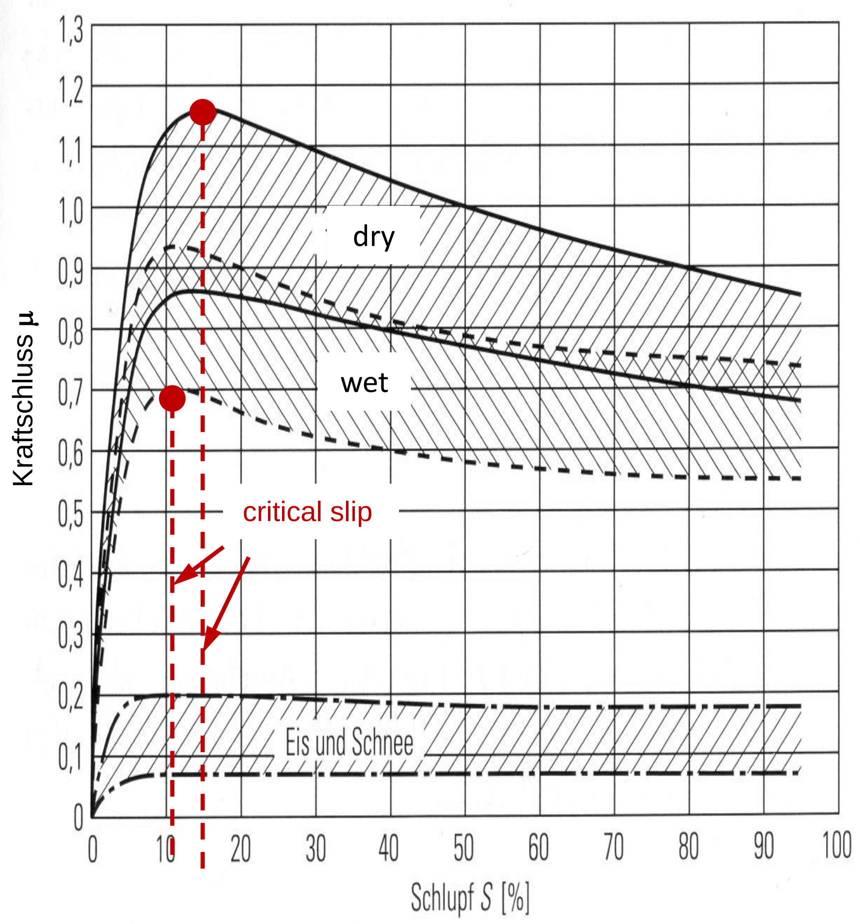
For small longitudinal forces, there is a linear relationship between S and Fx.

c_κ = slip stiffness

$$c_\kappa = \frac{dF_x}{dS} = f\left(F_z\right)$$

Influences:

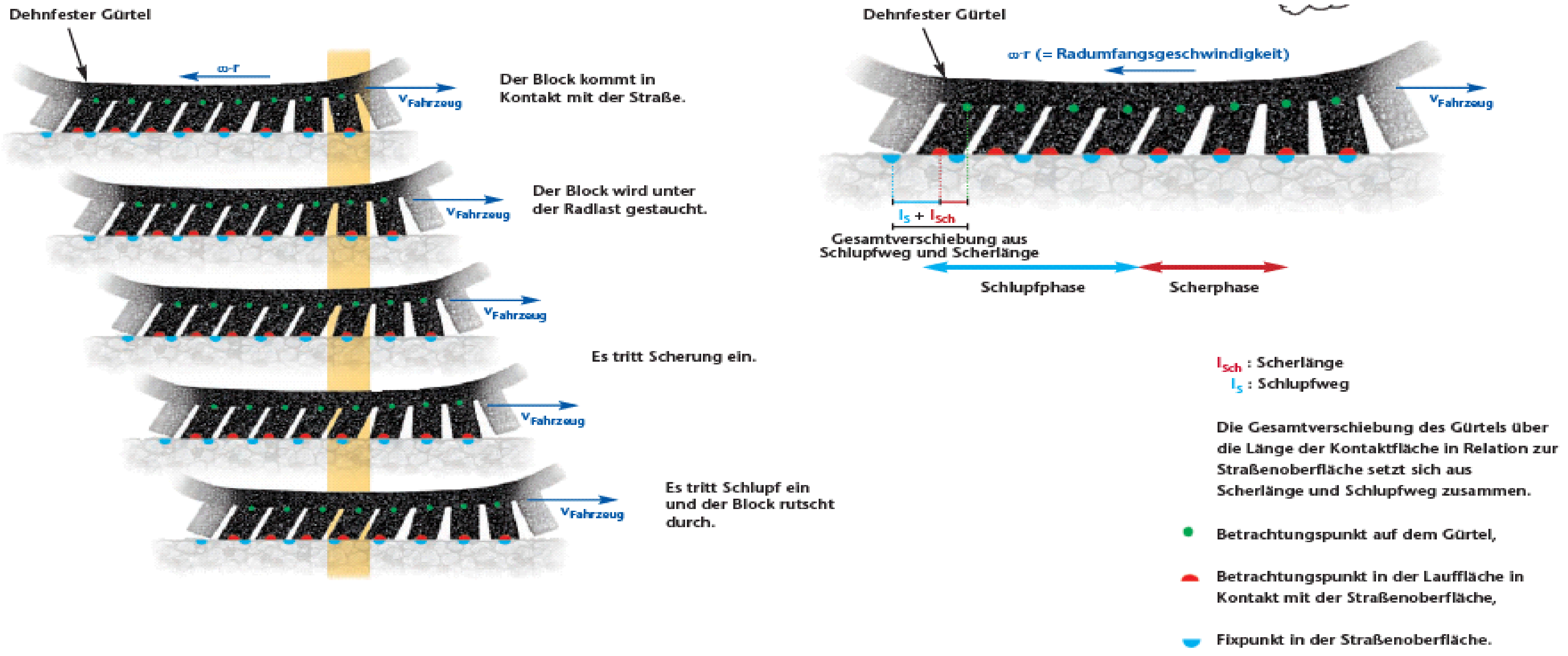
- Tire pressure
- Temperature
- Local friction



$$F_{x,\max} = \mu_h \cdot F_z$$

The maximal longitudinal force is depended on the friction (e.g. $\mu_h \approx 1{,}1$)

Tire longitudinal characteristics: slip behavior



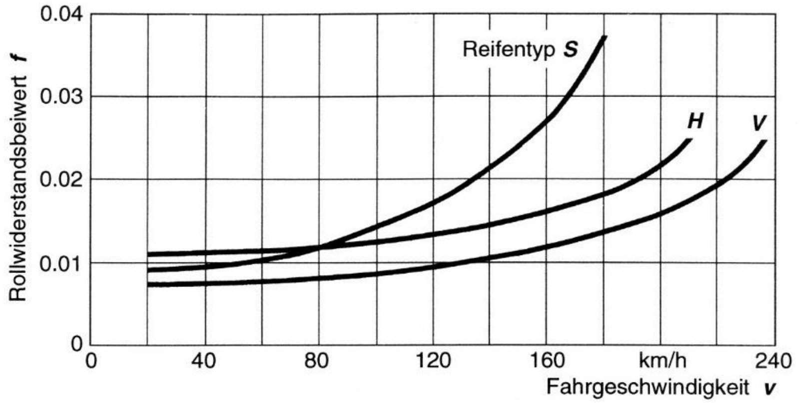
Tire Rolling Resistance (RR) - Sources

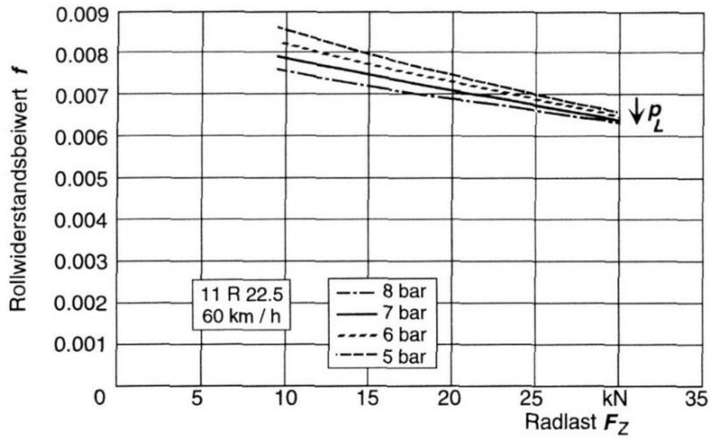
Tire surface and environmental air	Tread of the tire		Side wall and bead area
Air turbulence	Slip to the ground	Energy loss dissipation based on deformation	
		Bend - Strain - Sheer	Bend - Sheer
			
< 15 %		60 up to 70 %	20 up to 30 %

Tire Rolling Resistance (RR) - Sources

$$F_{R,roll} = f_R \cdot F_z$$

Roll resistance is depended of:
- wheel load
- tire pressure
- Tire temperature





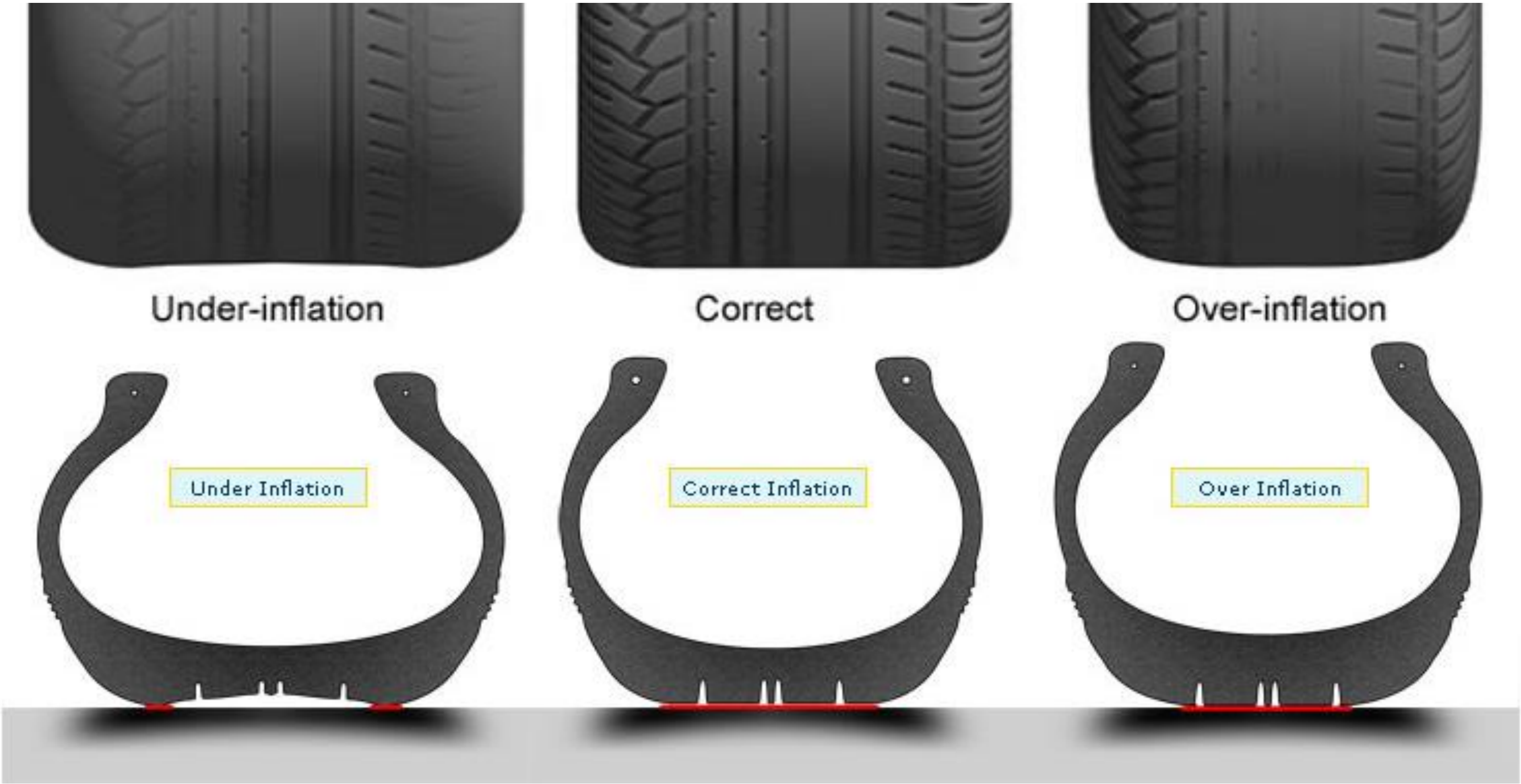
$$f_R = f_{R0} + f_{R1} \cdot \left(\frac{v}{100\,{}^{km}\!/_{h}} \right) + f_{R4} \cdot \left(\frac{v}{100\,{}^{km}\!/_{h}} \right)^4$$

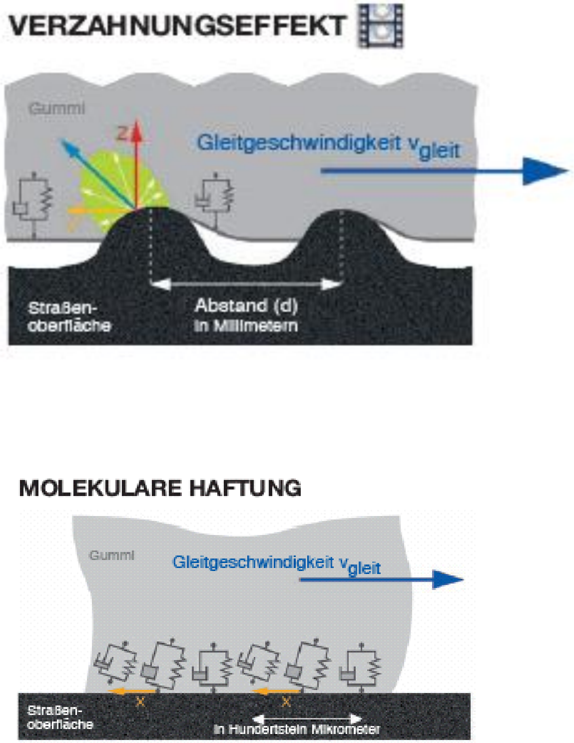
for HR-tires:

$f_{R0} \approx 0{,}009$
$f_{R1} \approx 2{,}0 \cdot 10^{-3}$
$f_{R4} \approx 0{,}25 \cdot 10^{-3}$

F_R is often assumed to be constant and at a value of 0,01.

Correct inflation pressure for a good foot print



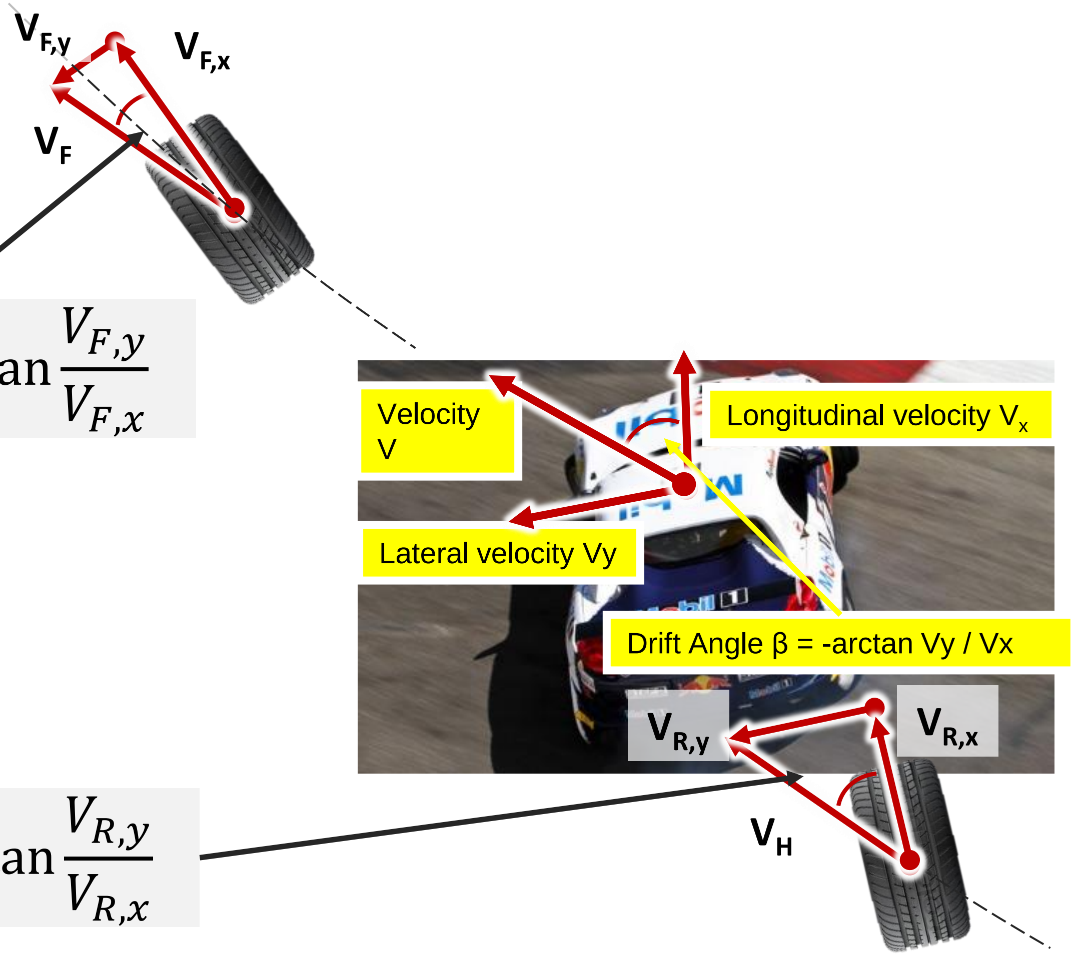


Influence to the brush, tooth and molecular adhesion effect is obvious.

Tire lateral characteristics: side slip behavior

Tire lateral characteristics: side slip behavior

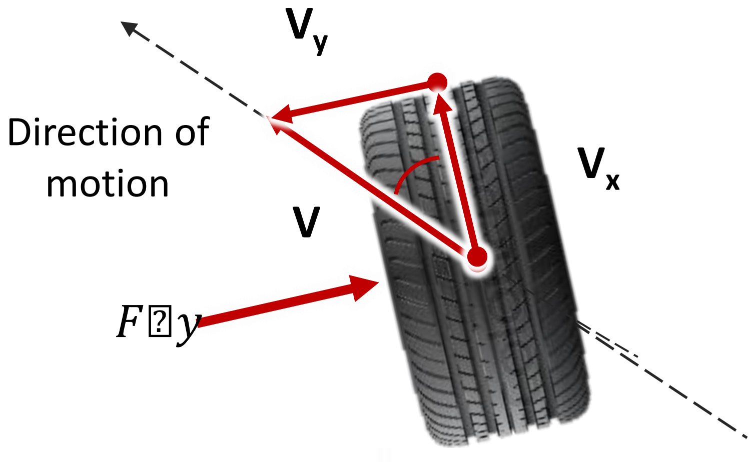
Tire lateral characteristics: side slip behavior

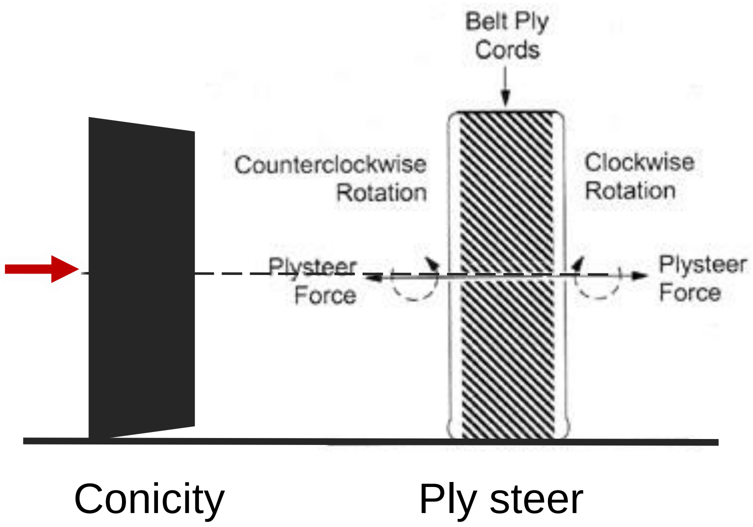


$$\alpha_F = -\arctan\frac{V_{F,y}}{V_{F,x}}$$

$$\alpha_R = -\arctan\frac{V_{R,y}}{V_{R,x}}$$

Tire lateral characteristics: side slip behavior





Side slip α:

- Angle between direction of motion and direction of wheel plane.

$$\alpha = -\arctan\frac{V_y}{V_x}$$

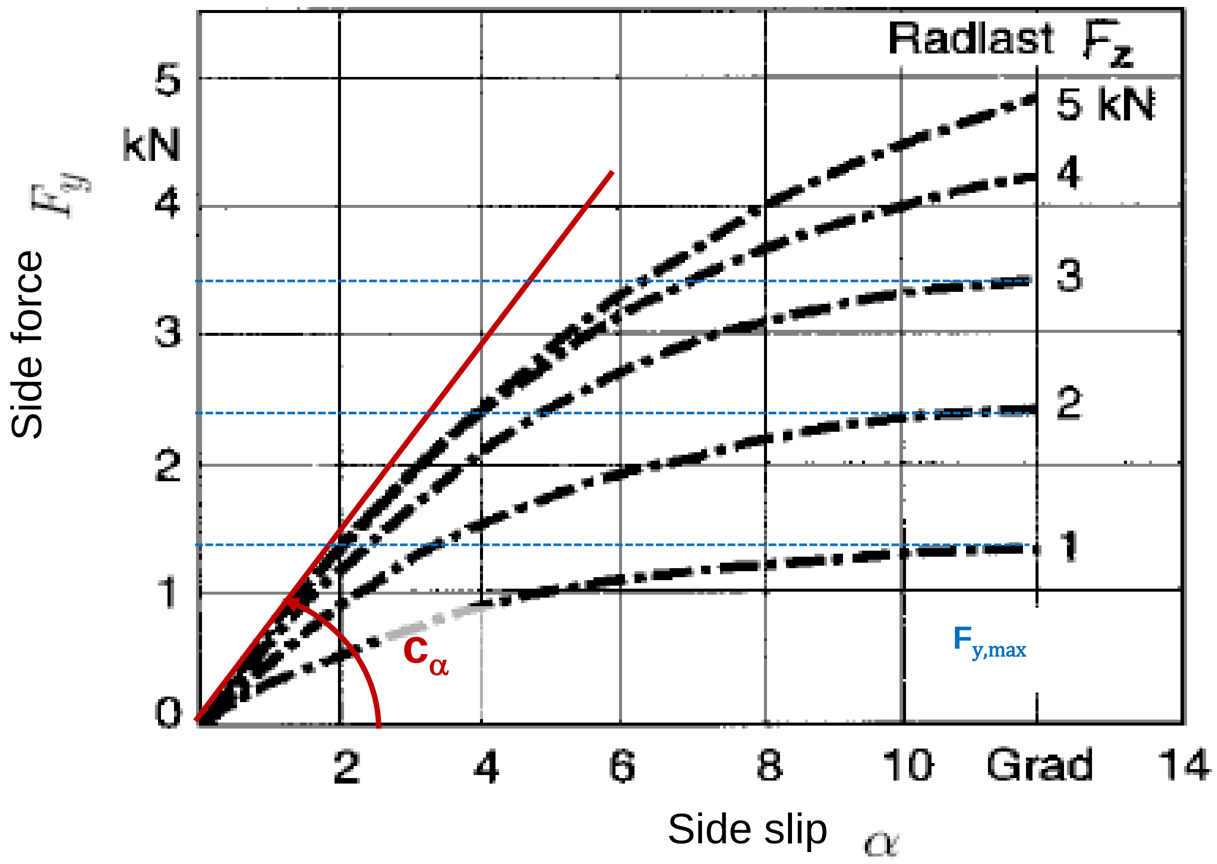
Tire side force generated by:

- Rolling diagonal to the direction of motion (side slip angle **α**).
- Inclination of the tire from its vertical position to the road (camber γ).
- Tire conicity (geometrical)
- Ply steer (tread/belt construction)

Side force as result of side slip angle:

- Wind, centrifugal or gravity forces requested tire forces.
- The vehicle must apply side slip.

Tire lateral characteristics: side slip behavior



$$F_y = c_\alpha \cdot \alpha$$

- For side slip angle to approximately 4°, there is a linear relationship between **α** and Fy.
- c_α is called side slip stiffness.

$$c_\alpha = \frac{dF_y}{d\alpha} = f\left(F_z\right)$$

- **Influences to c_α:**
  - Tire pressure.
  - Temperature.
  - Local friction
  - Wheel load

$$F_{y,\max} = \mu_{y,\max} \cdot F_z$$

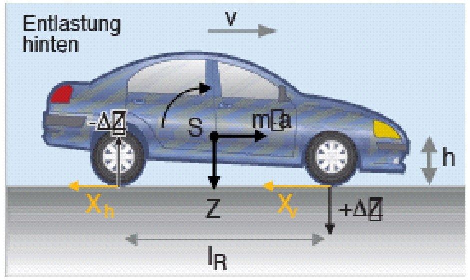
- The maximum transferable lateral forces are dependent on maximum adhesion in lateral direction.

Combined tire characteristics: dynamic load distribution

GEWICHTSVERLAGERUNG IN LÄNGSRICHTUNG

Nehmen wir an, die Schwerpunkthöhe eines Fahrzeugs ist bekannt und die Reibungskraft X greift beim Bremsen an der Schnittstelle Reifen/Straße an.
Das entstehende Bremsmoment verursacht eine hohe **dynamische Achslastverschiebung** von hinten nach vorn, so dass kurzfristig vorne eine Überlast (+ΔZ), hinten eine Unterlast (-ΔZ) entsteht. So scheint die Vorderachse schwerer, die Hinterachse leichter als im ungebremsten Fall. Ohne ABS kann dies dazu führen, dass die entlasteten Hinterräder vor den Vorderrädern blockieren, was sich in punkto Fahrstabilität sehr ungünstig auswirken und zum Schleudern führen kann.

Bremskraftregler verhindern dieses instabile Überbremsen der Hinterräder und erfüllen so das Fahrstabilitätskriterium.

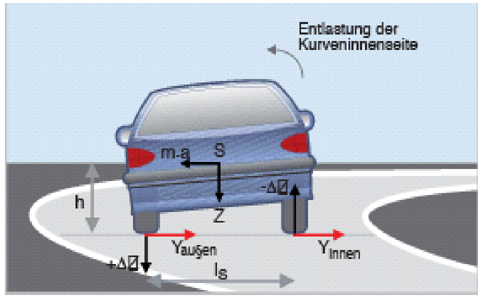


X = Längsreibungskraft vorne (X_v) und hinten (X_h), in N
S = Schwerpunkt des Fahrzeugs,
m = Masse des Fahrzeugs, in kg
a = Beschleunigung in Längsrichtung, in m/s²
Z = Gewichtskraft (= Summe der 4 Radlasten), in N
h = Schwerpunkthöhe über der Straße, in m
l_R = Radstand des Fahrzeugs, in m

GEWICHTSVERLAGERUNG ZUR SEITE

Nehmen wir an, die Schwerpunkthöhe eines Fahrzeugs ist bekannt und die seitliche Reibungskraft Y greift in der Kurve an den Schnittstellen Reifen/Straße an. Das entstehende **Rollmoment** verursacht eine **dynamische Achslastverschiebung** von der Kurvenaußen- auf die -innenseite, so dass fliehkraftbedingt innenseitig eine Überlast (+ΔZ), an der Außenseite eine Unterlast (-ΔZ) entsteht. Die Summe der unterschiedlichen vier Seitenkräfte fällt geringer aus als für den hypothetischen Fall gleichmäßiger Kraftverteilung.
Seitliche Gewichtsverlagerung führt somit zur Abnahme des Querhaftungspotenzials.

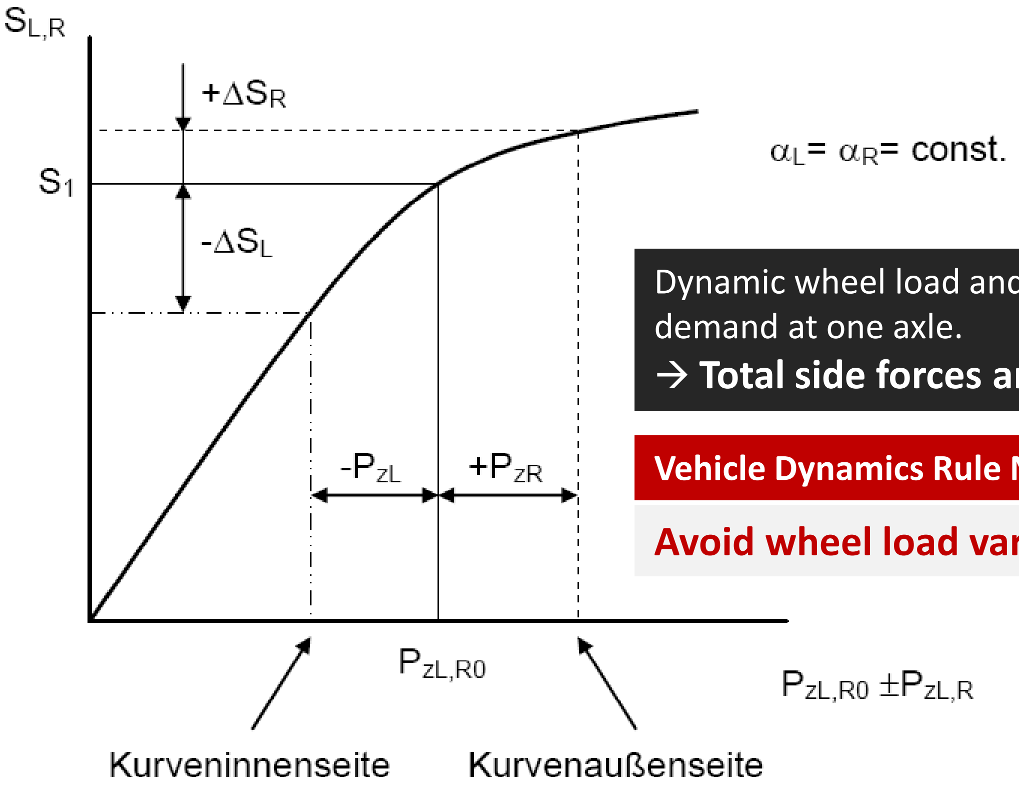
Um diesen unerwünschten Effekt zu reduzieren, kann der Konstrukteur z.B. die Spur verbreitern oder die Schwerpunkthöhe verringern.



Y = Quer-Reibungskraft vorne (Y_v) und hinten (Y_h), in N
S = Schwerpunkt des Fahrzeugs,
m = Masse des Fahrzeugs, in kg
a = Beschleunigung in Querrichtung, in m/s²
Z = Gewichtskraft (= Summe der 4 Radlasten), in N
h = Schwerpunkthöhe über der Straße, in m
l_S = Spurweite des Fahrzeugs, in m.

$$F_R \leq \mu \; * \; F_N$$

Coulombsche Friction Rule, **but μ for tire & road are strongly non-linear**



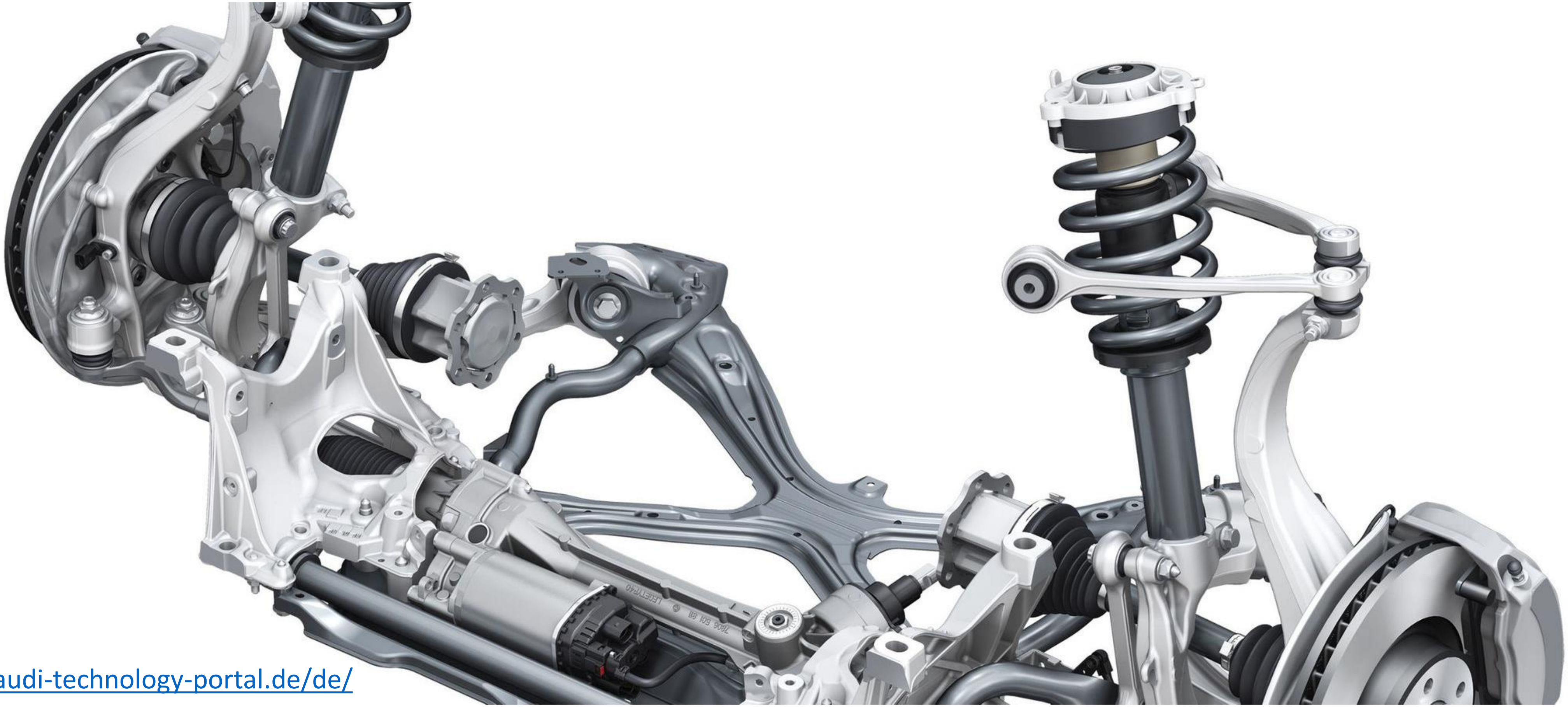
Dynamic wheel load and side force demand at one axle.
→ **Total side forces are reduced**

Vehicle Dynamics Rule No. 1:

Avoid wheel load variation

Chassis systems their function and structure

https://www.audi-mediacenter.com/de/technik-lexikon-7180/fahrwerk-7185



https://www.audi-technology-portal.de/de/

Hydraulik Brake system and brake control systems

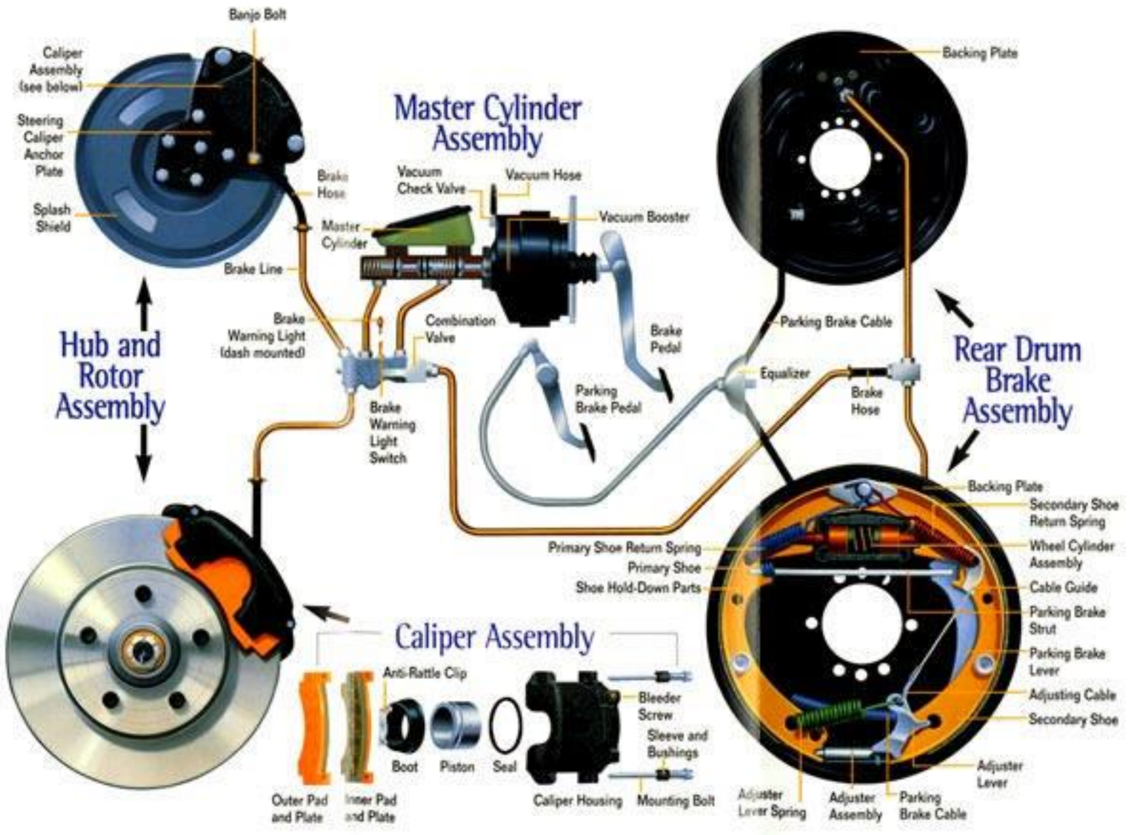
Classification of braking systems

- **Service brake system (BBA - Betriebsbremsanlage)**
  The service brake system must be operated in steps can and usually consists of two brake circuits.

- **Auxiliary braking system (HBA-Hilfsbremsanlage)**
  The deceleration achievable with the secondary braking system must be at least half the size of the BBA.

- **Parking brake system (FBA-Feststellbremsanlage)**
  The parking brake system must be able tocan maintain a slope of 20%.

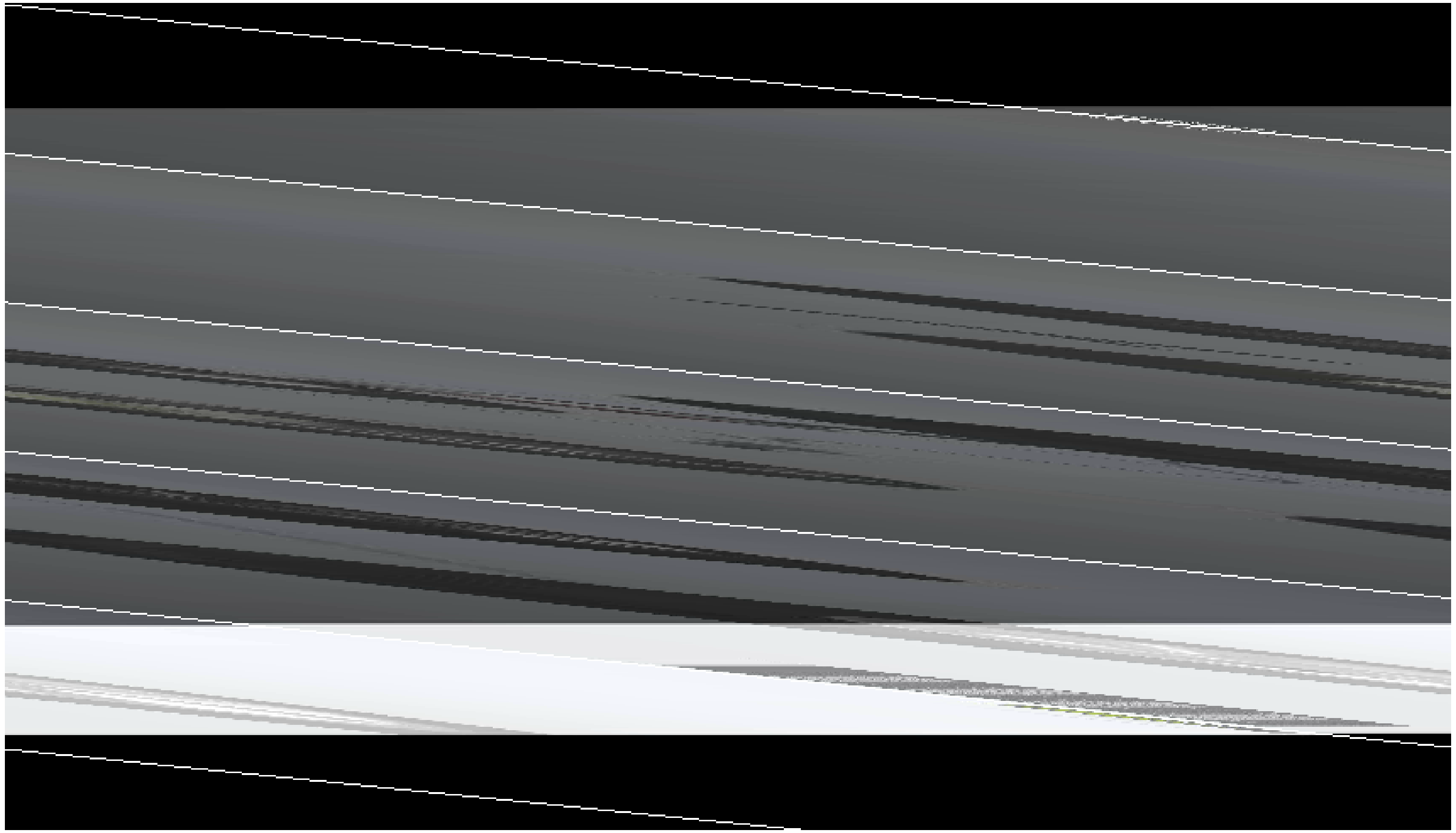
- **Continuous braking system (DBA -Dauerbremsanlage)**
  Continuous braking systems are wear-free brakes for longer steady-state braking of commercial vehicles and buses.



https://www.youtube.com/watch?v=ugtrRmyPSfE

Chassis systems their function and structure

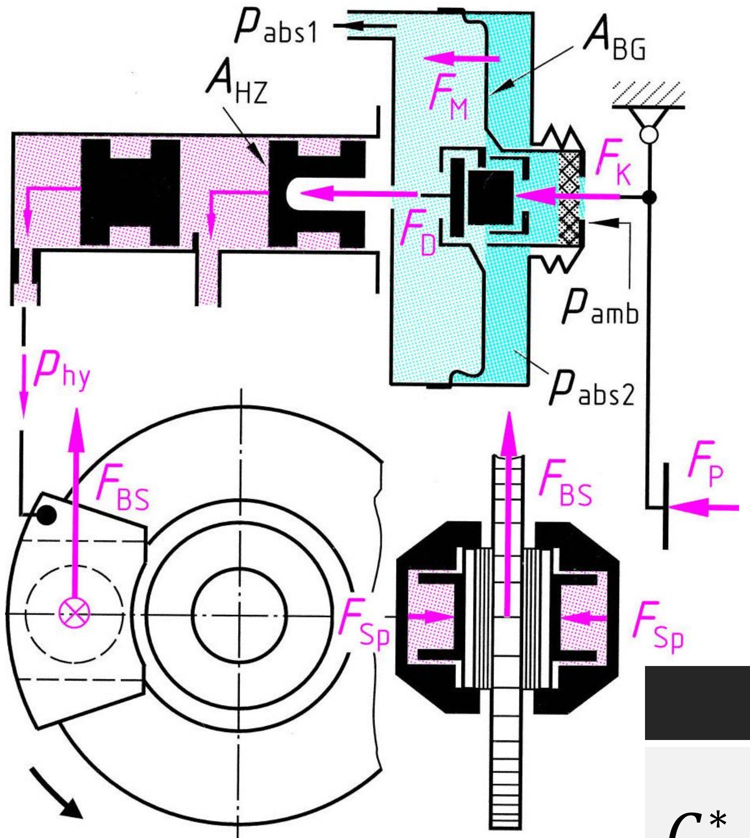
Hydraulik Brake system and brake control systems



https://www.youtube.com/watch?v=GHt0u_7abvs

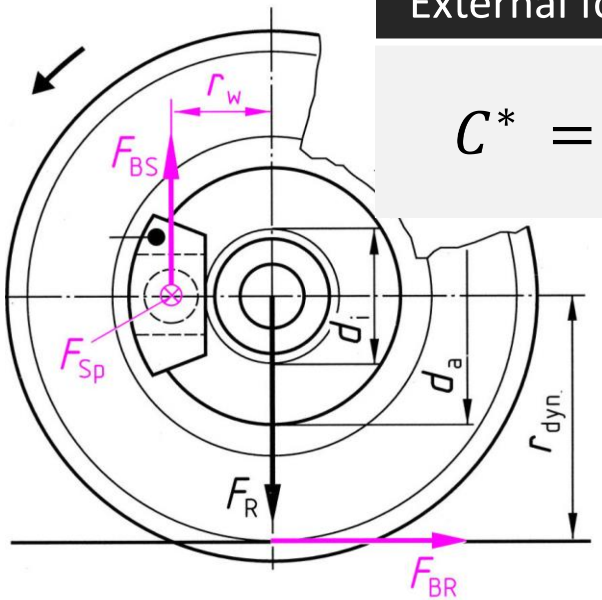
https://www.youtube.com/watch?v=CzEBVdZeyQs

External and internal force ratio of a brake system



External force ratio

$$i_{ext} = \frac{F_{SP}}{F_P}$$



External force ratio

$$C^* = \frac{F_{BS}}{F_{SP}}$$

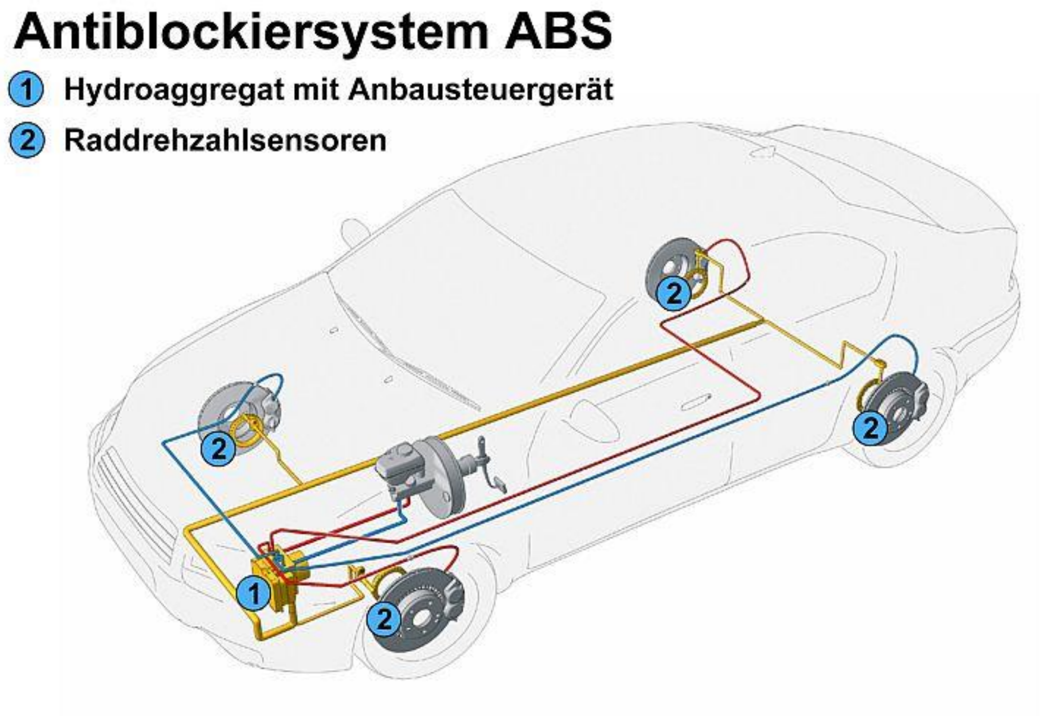
Brake disk characteristics

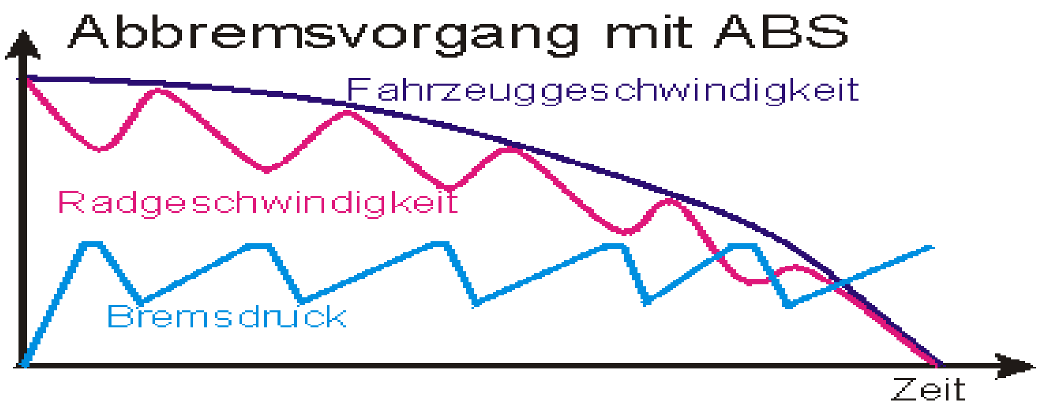
$$C^* = \frac{F_{BS}}{F_{SP}} = \frac{2\mu * F_{SP}}{F_{SP}} = 2\mu$$

Wheel brake force

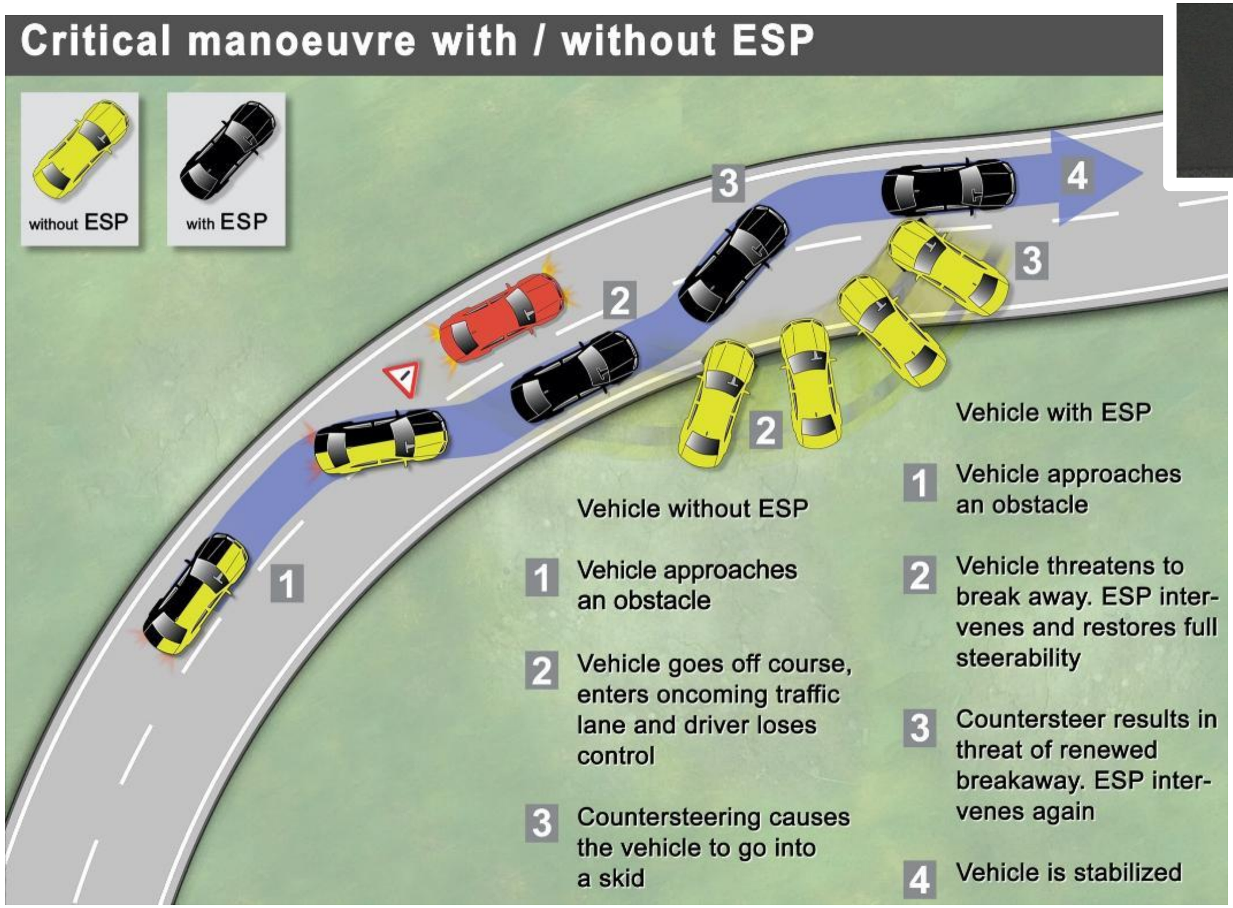
$$F_{BR} = F_P * i_{ext} * C^* \frac{r_w}{r_{dyn}}$$

ABS – Antiblockiersystem (Antilocking System)

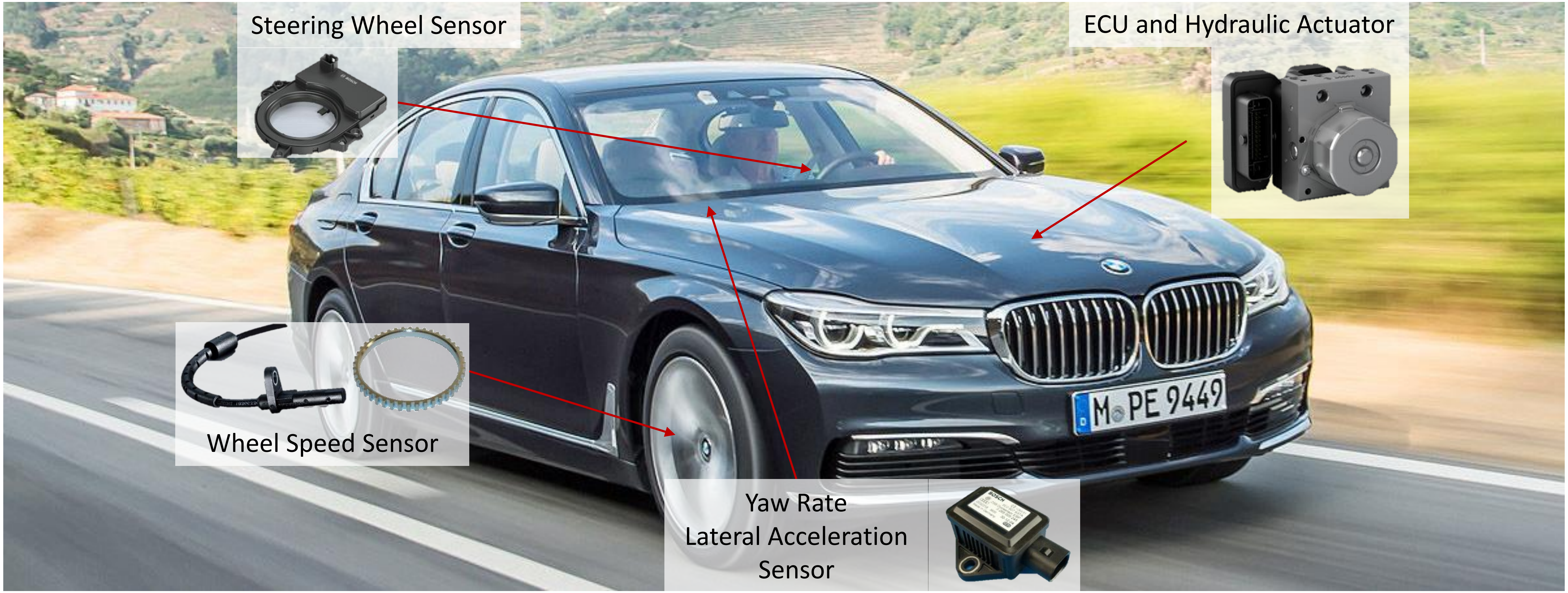




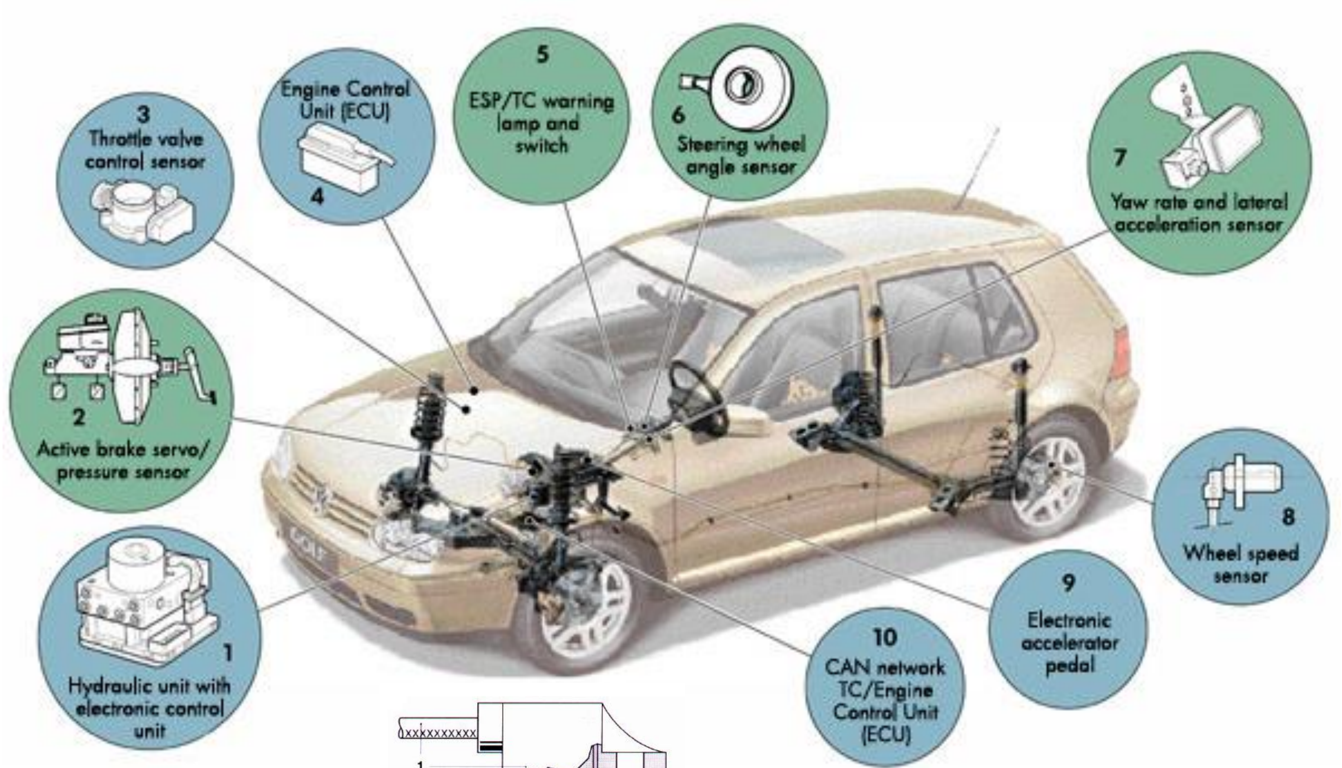
Electronic Stability Program (ESP)

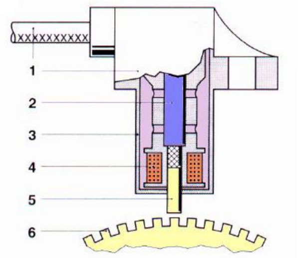


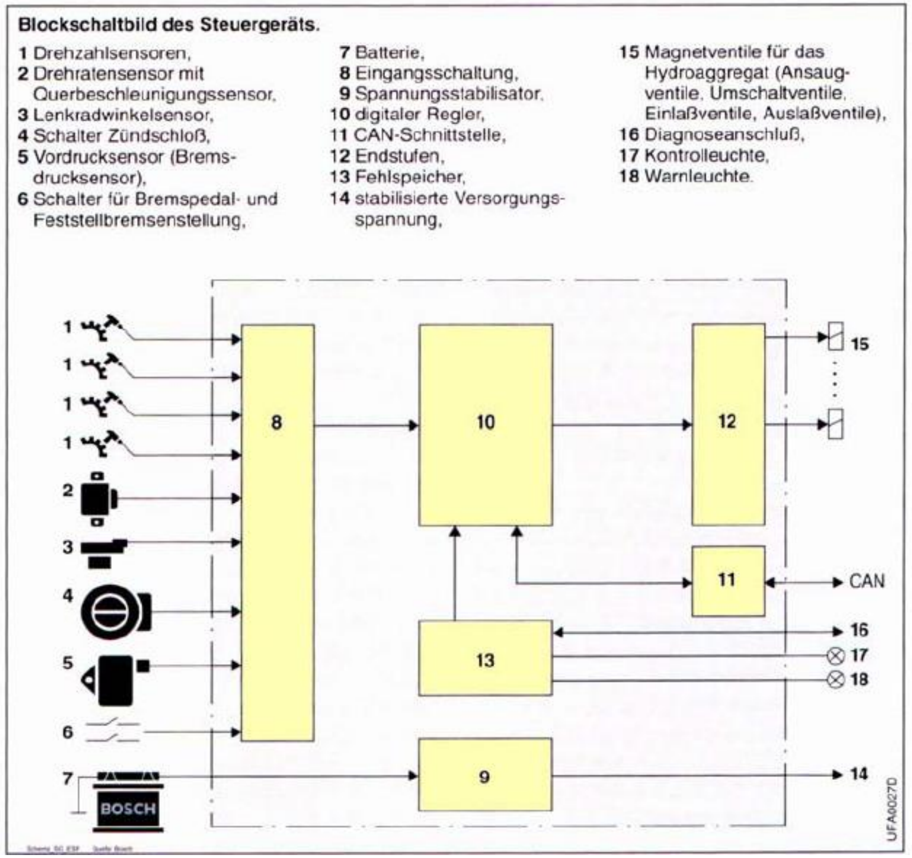
Electronic Stability Program (ESP)



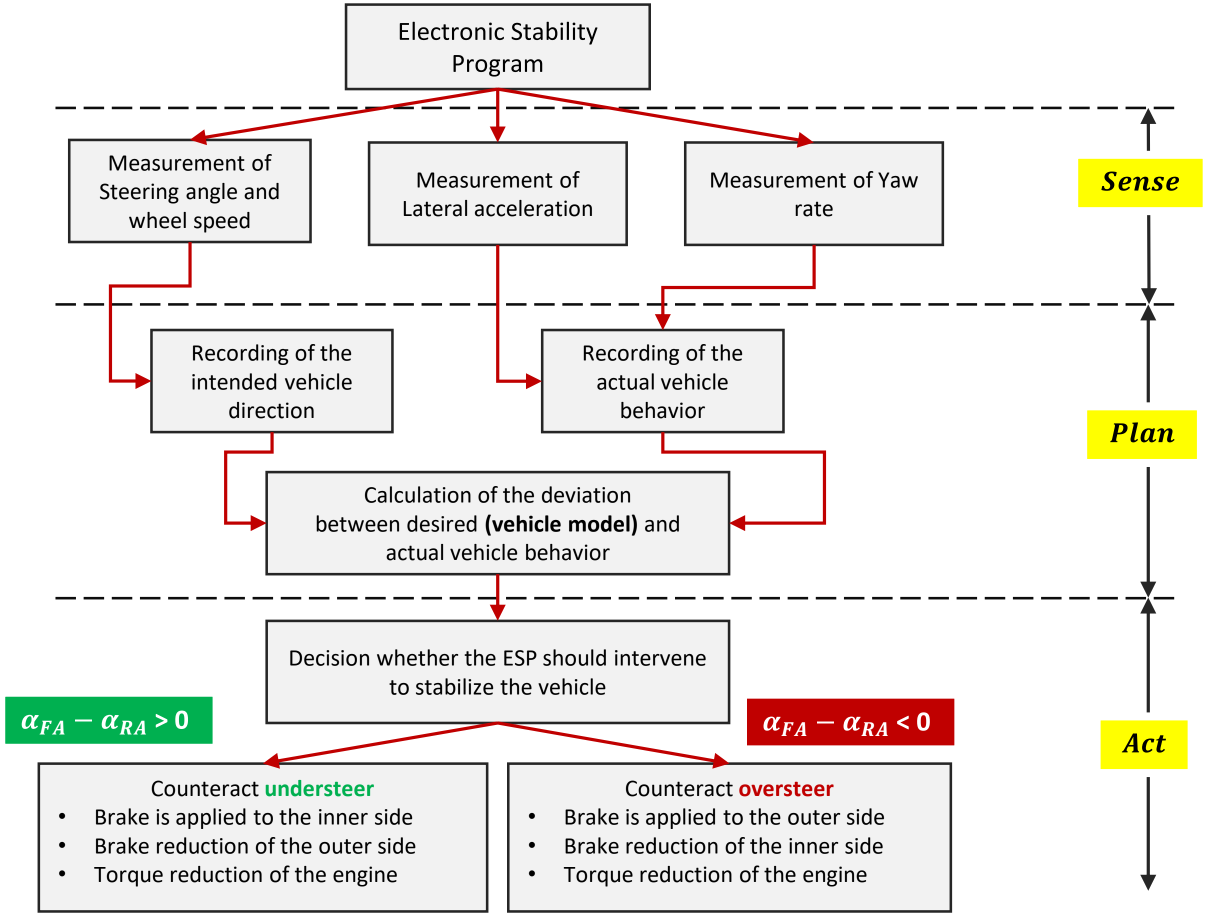
Electronic Stability Program (ESP)

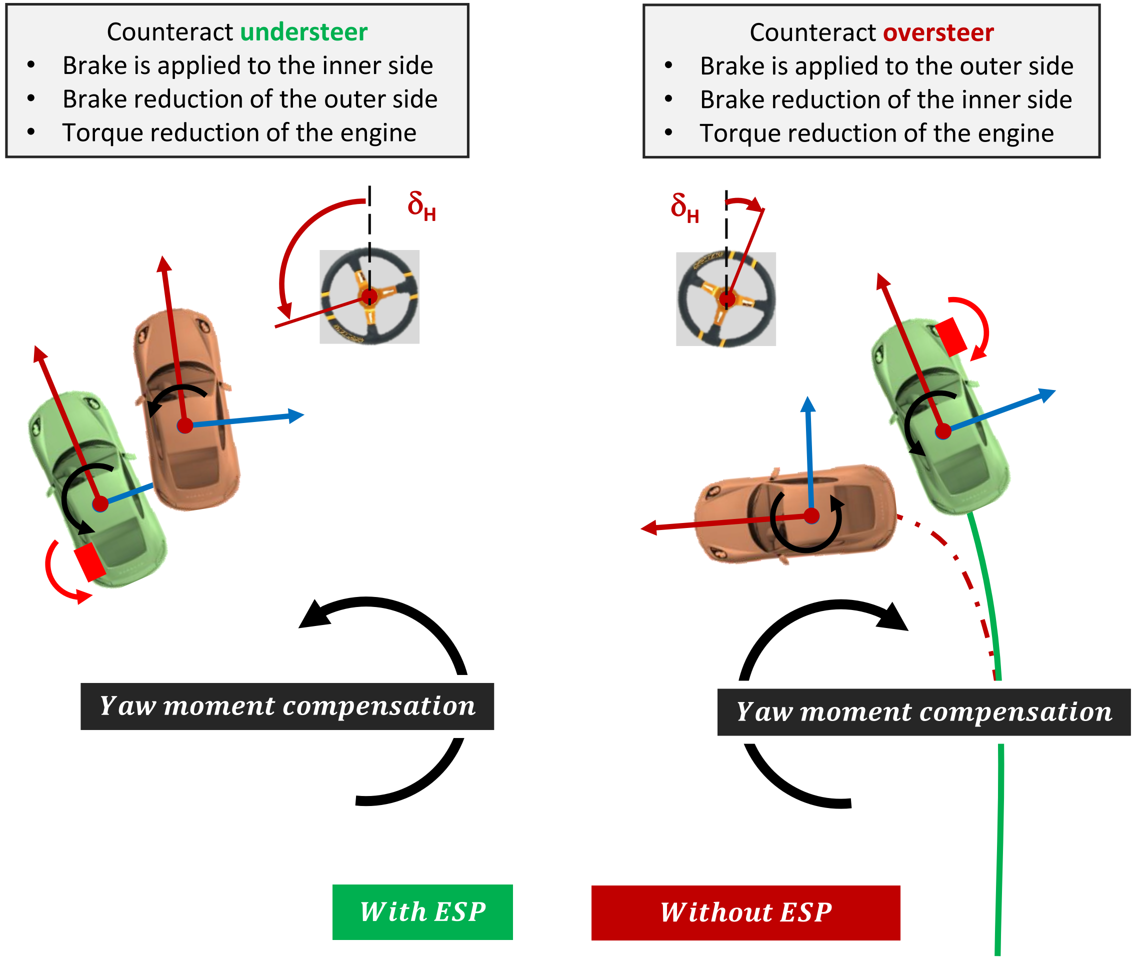






Electronic Stability Program (ESP)



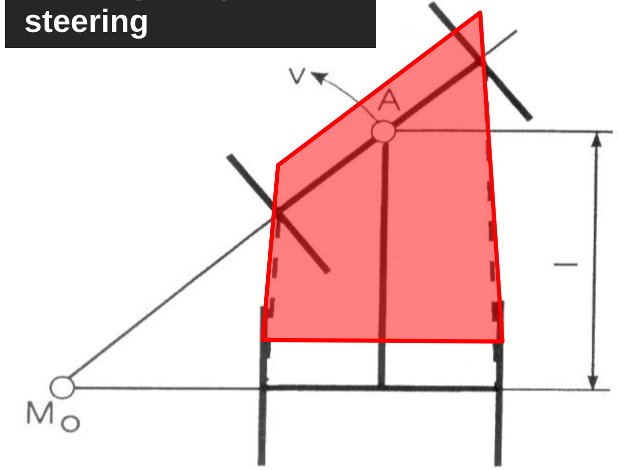


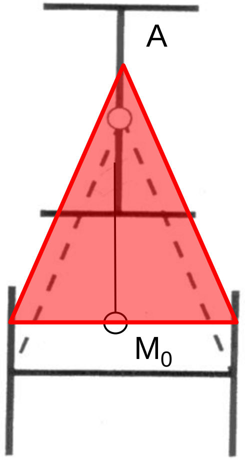
Audi Talk – Chassis technologie from rigid axle to intelligent chassis

Steering System

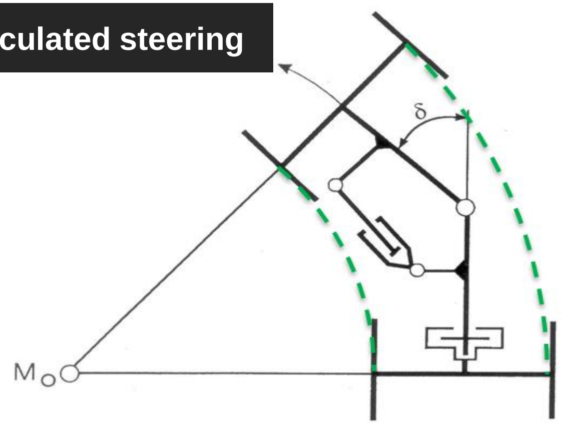
Steering System

Center pivot plate steering



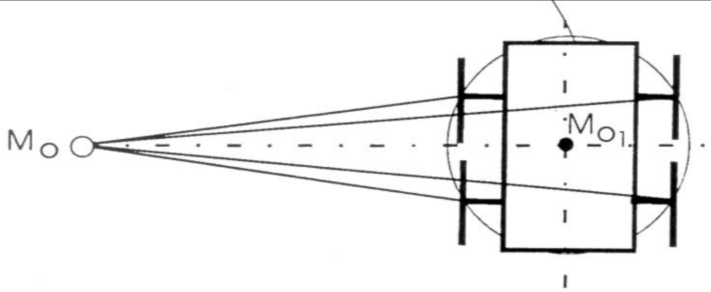


articulated steering

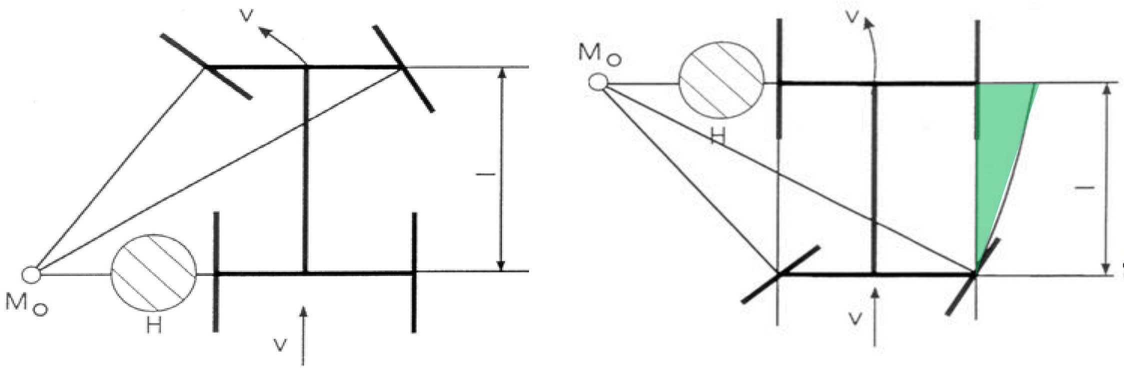


Steering System

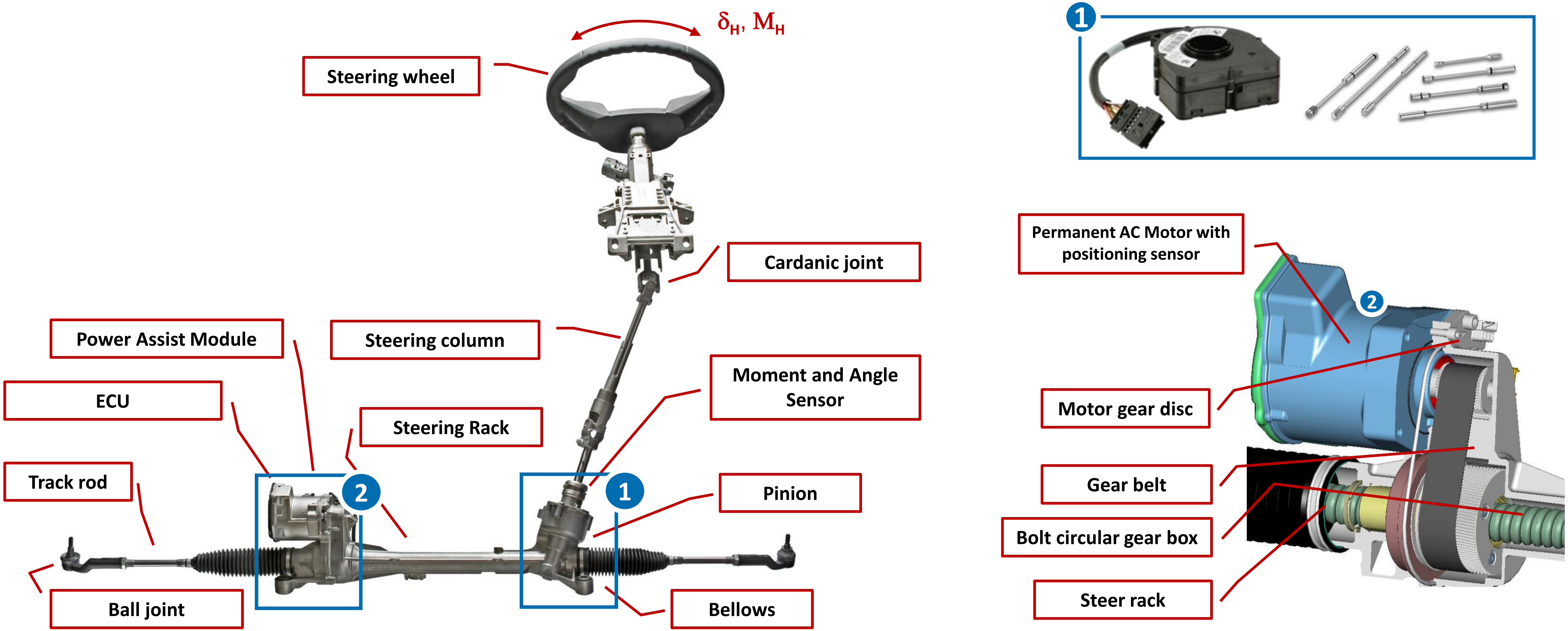
Wheel Side Steer thru different wheel speed



Front Steer ⟷ **Rear Steer**

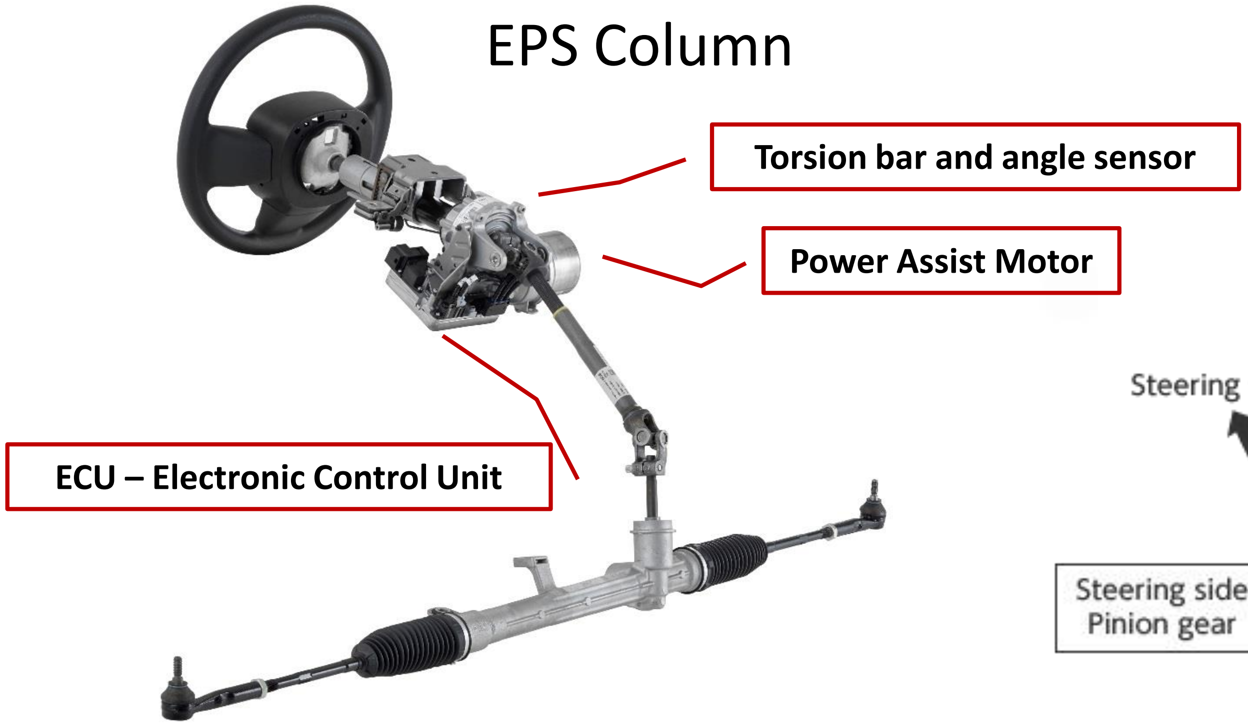


Steering system – Electrical Power Steer (EPS) EPS apa (axle parallel)

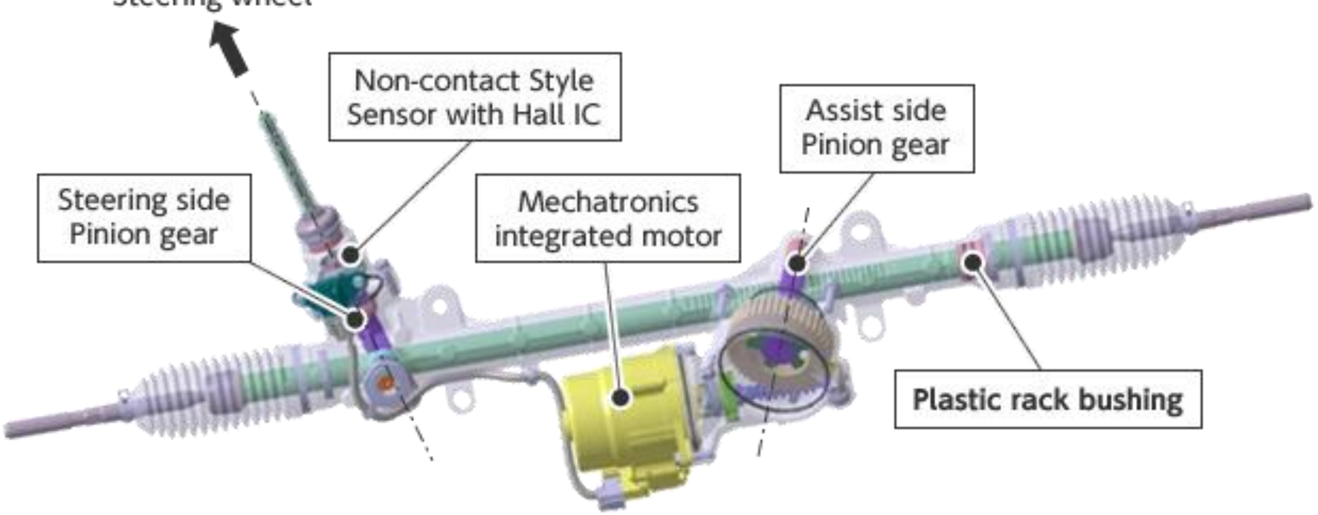


Steering system – Electrical Power Steer (EPS)

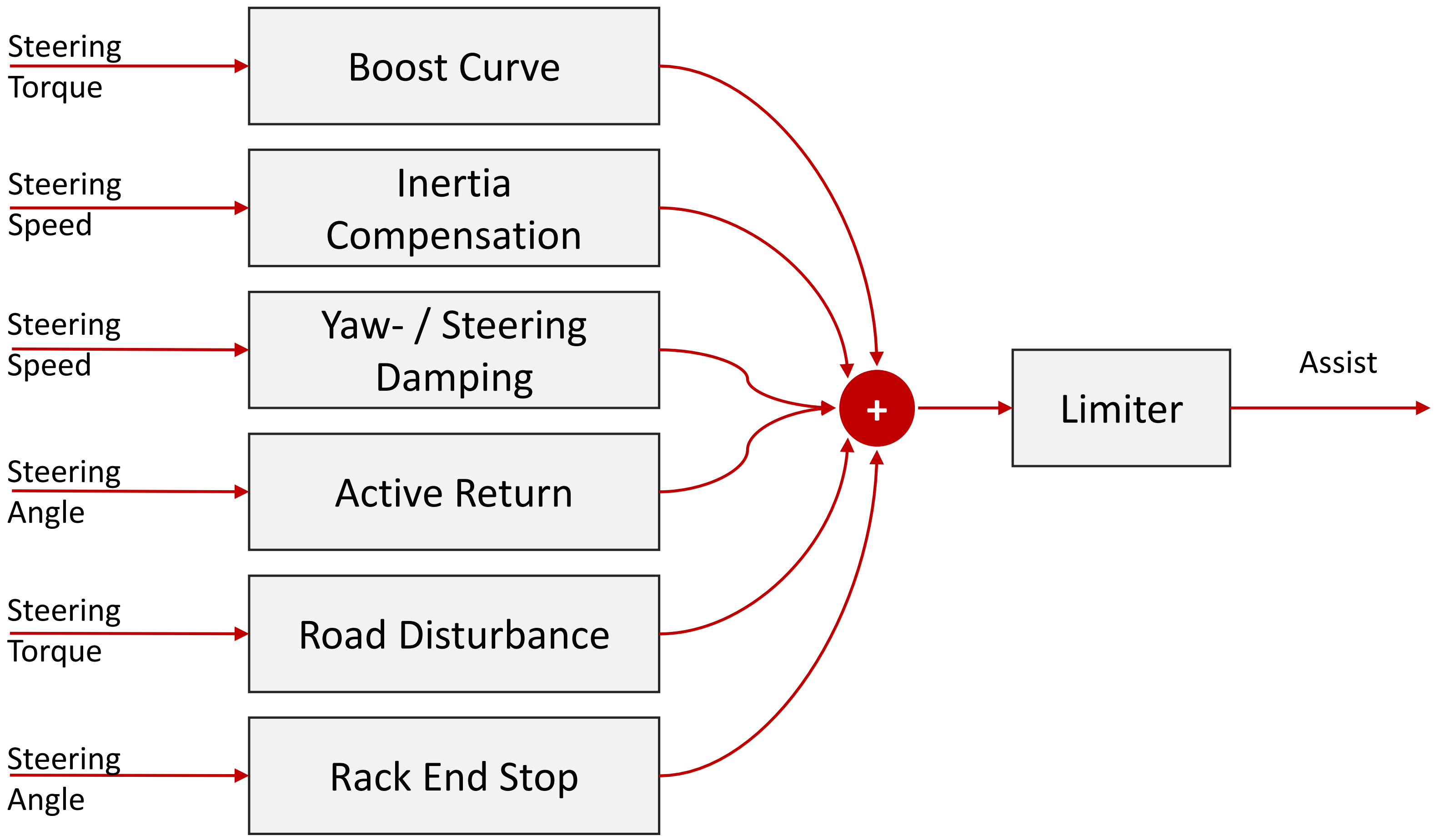
EPS Column



EPS Dual Pinion



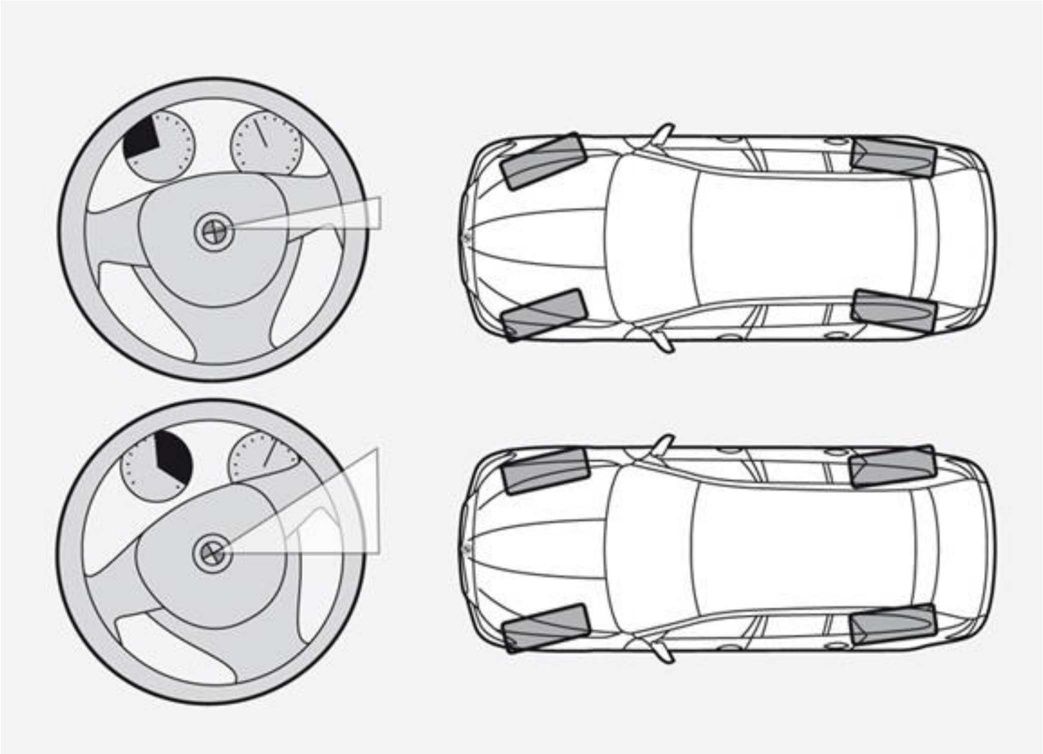
EPS Basic Functions



Rack an pinion steering system

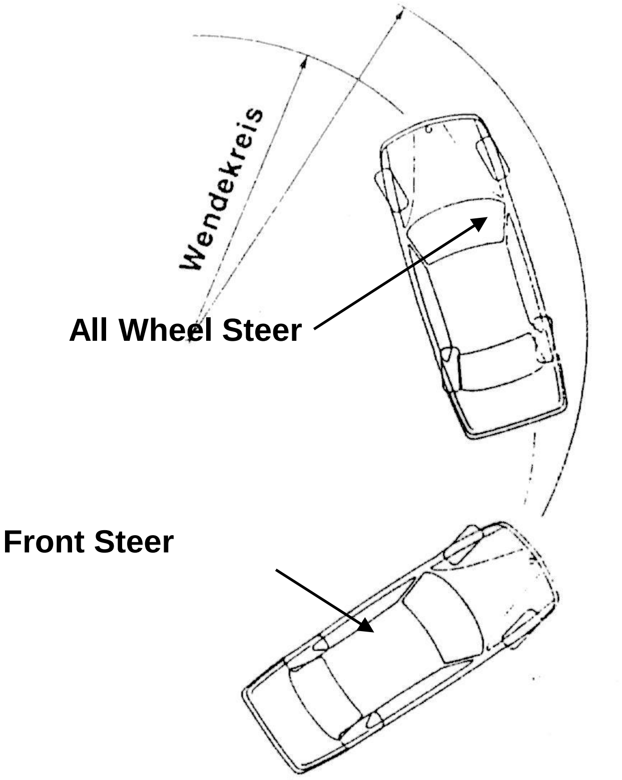
https://www.youtube.com/watch?v=DC6Opx_3EUo

All Wheel Steering System

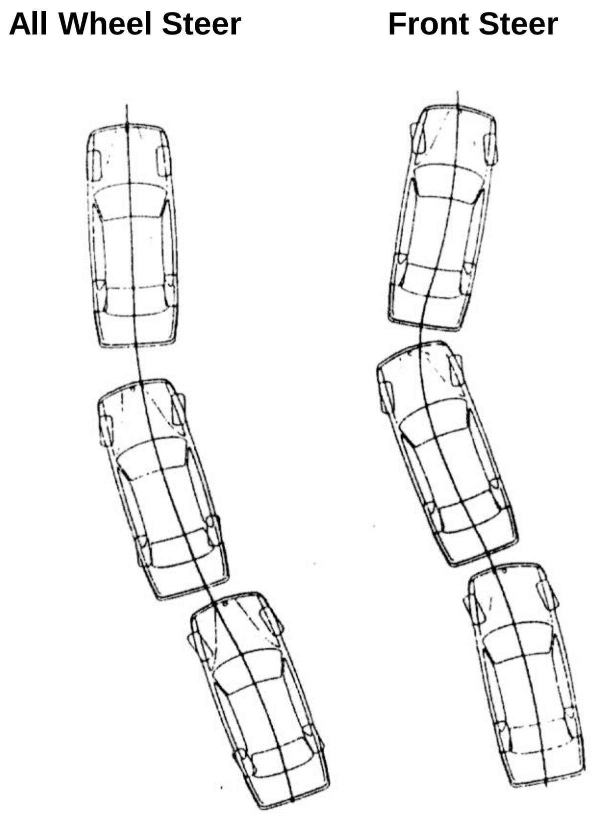


All Wheel Steering System

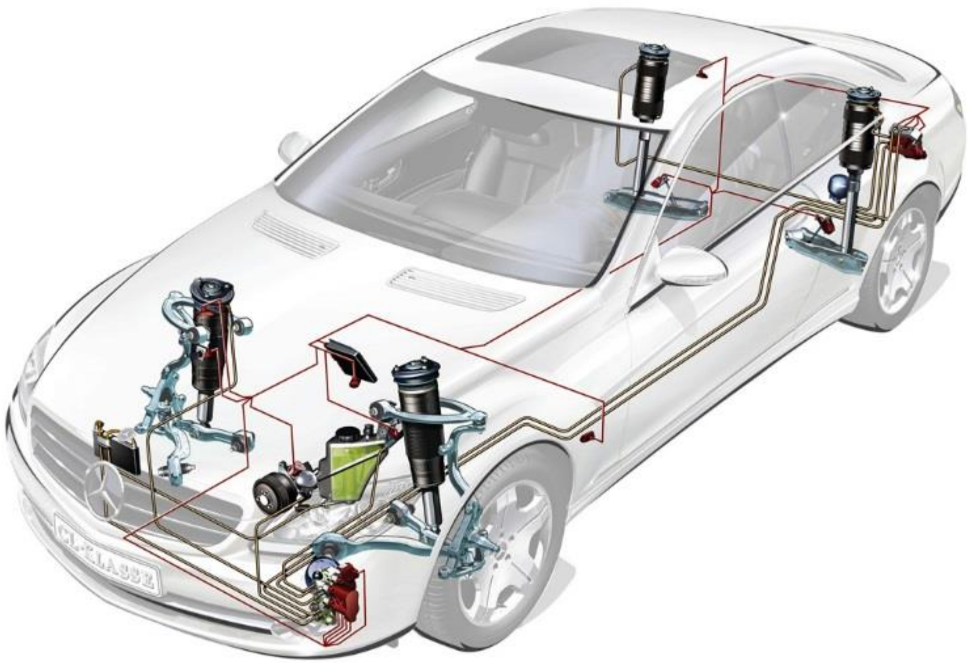
Steering in the opposite direction of rear wheels to achiev a small turning circle

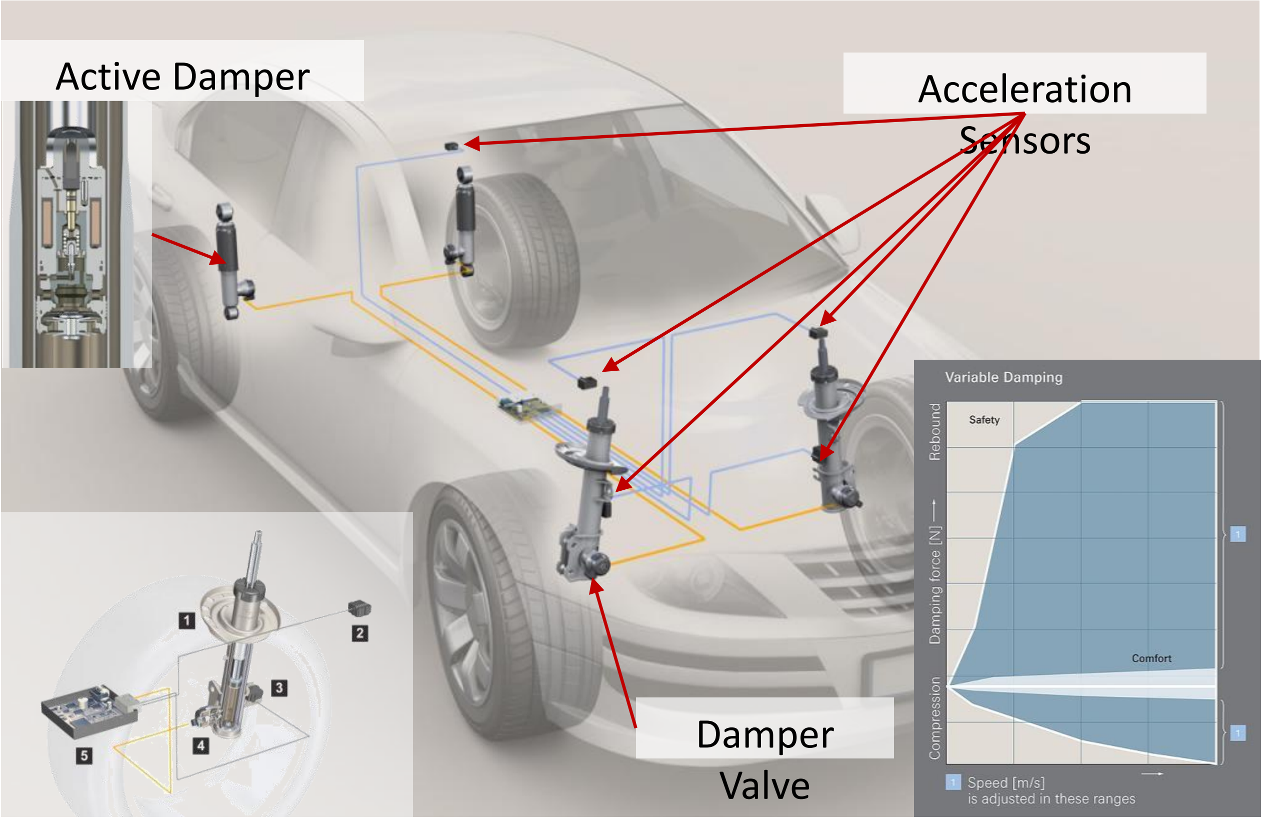


Steering in the same direction of rear wheels to achiev stability

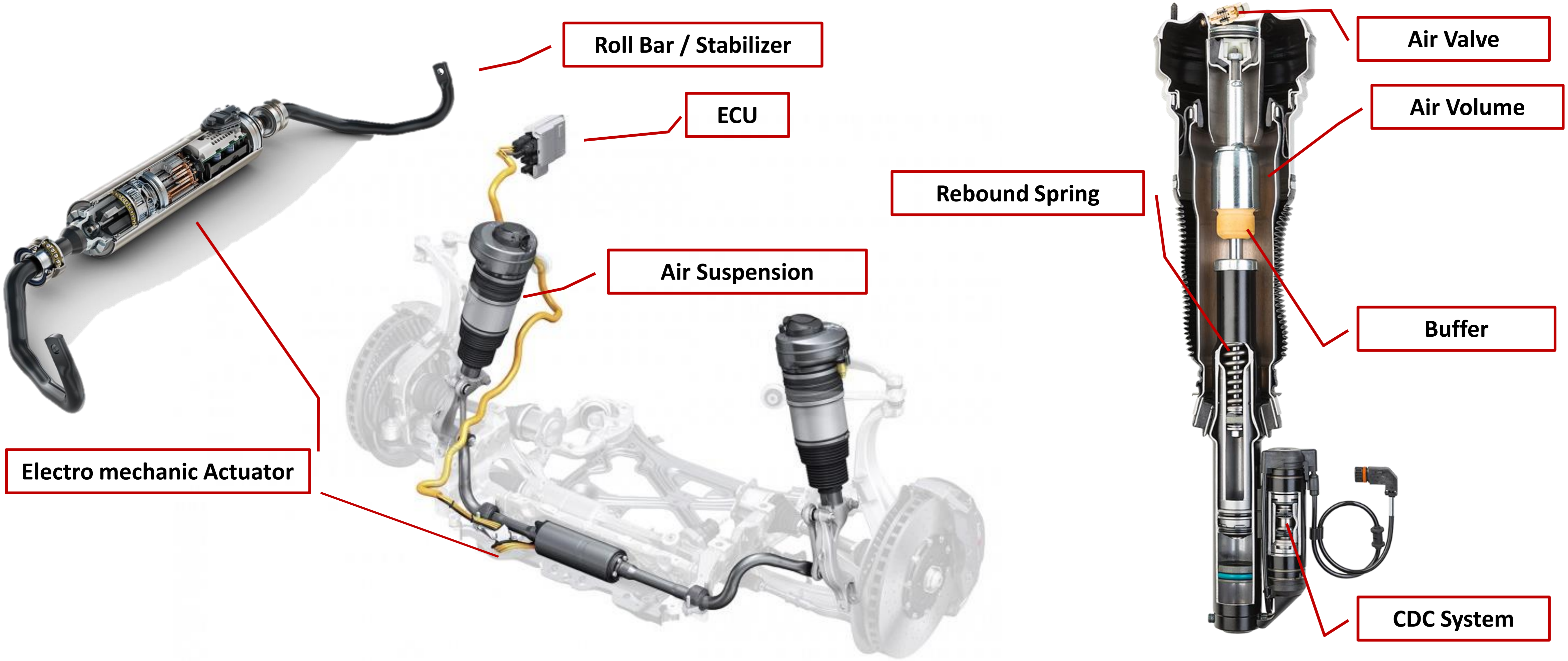


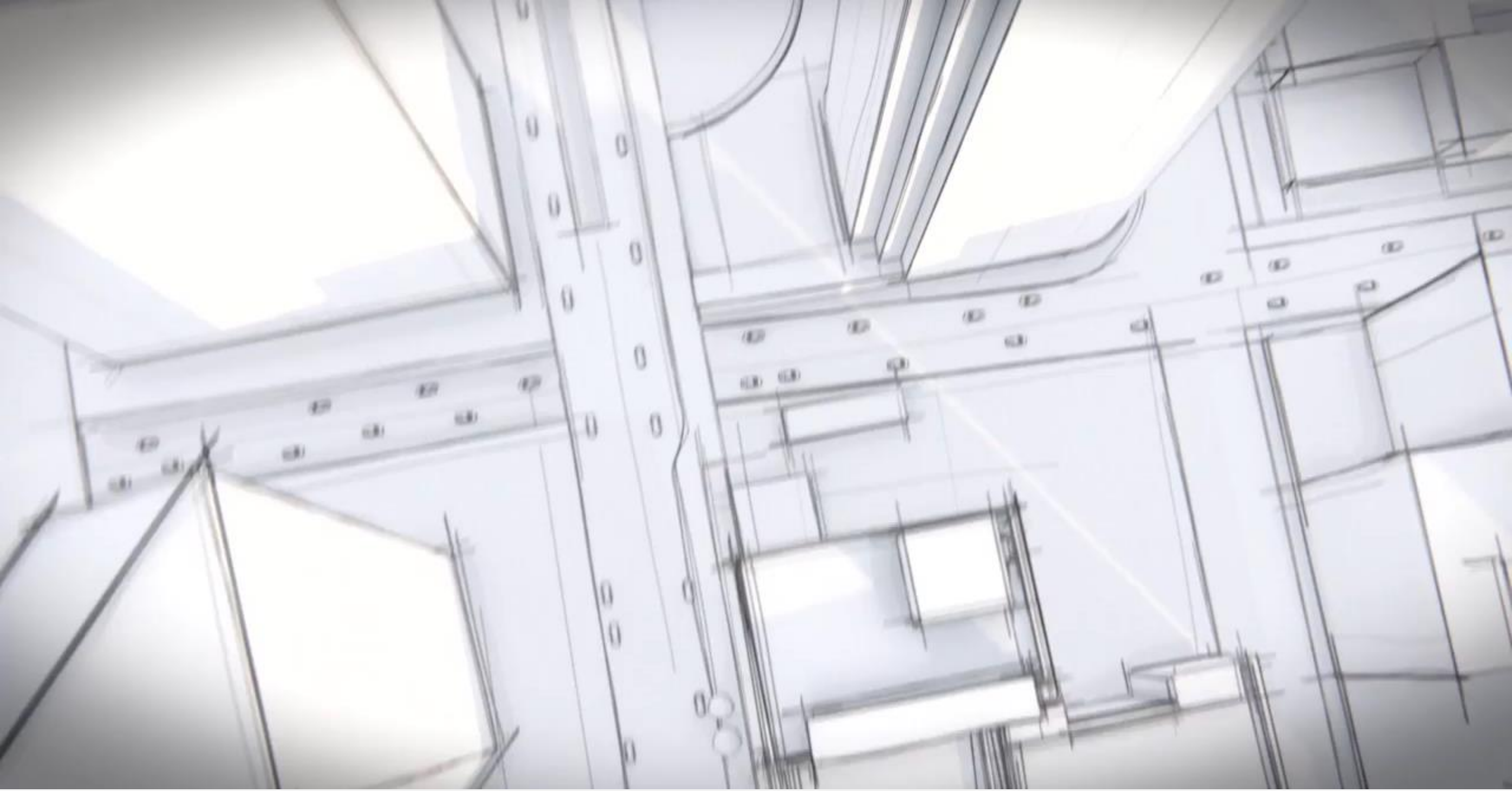
Active suspension control with CDC – Continuous Damping Control





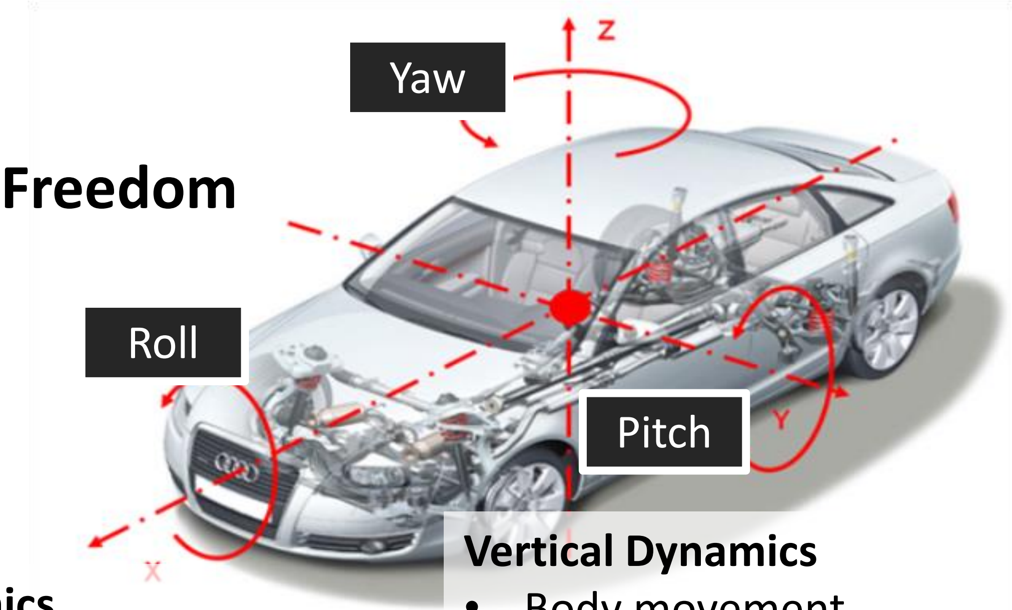
Active suspension control with CDC – Continuous Damping Control





What is vehicle dynamics? It describes the full vehicle motion dynamics.

6 DOF - Degree of Freedom



Lateral Dynamics
- Stationary behavior
- Transient behavior
- Steering behavior

Vertical Dynamics
- Body movement
  - Primary Ride
  - Secondary Ride
- Body acceleration
  - Harshness
  - Vibration
- Wheel Load Oscillation

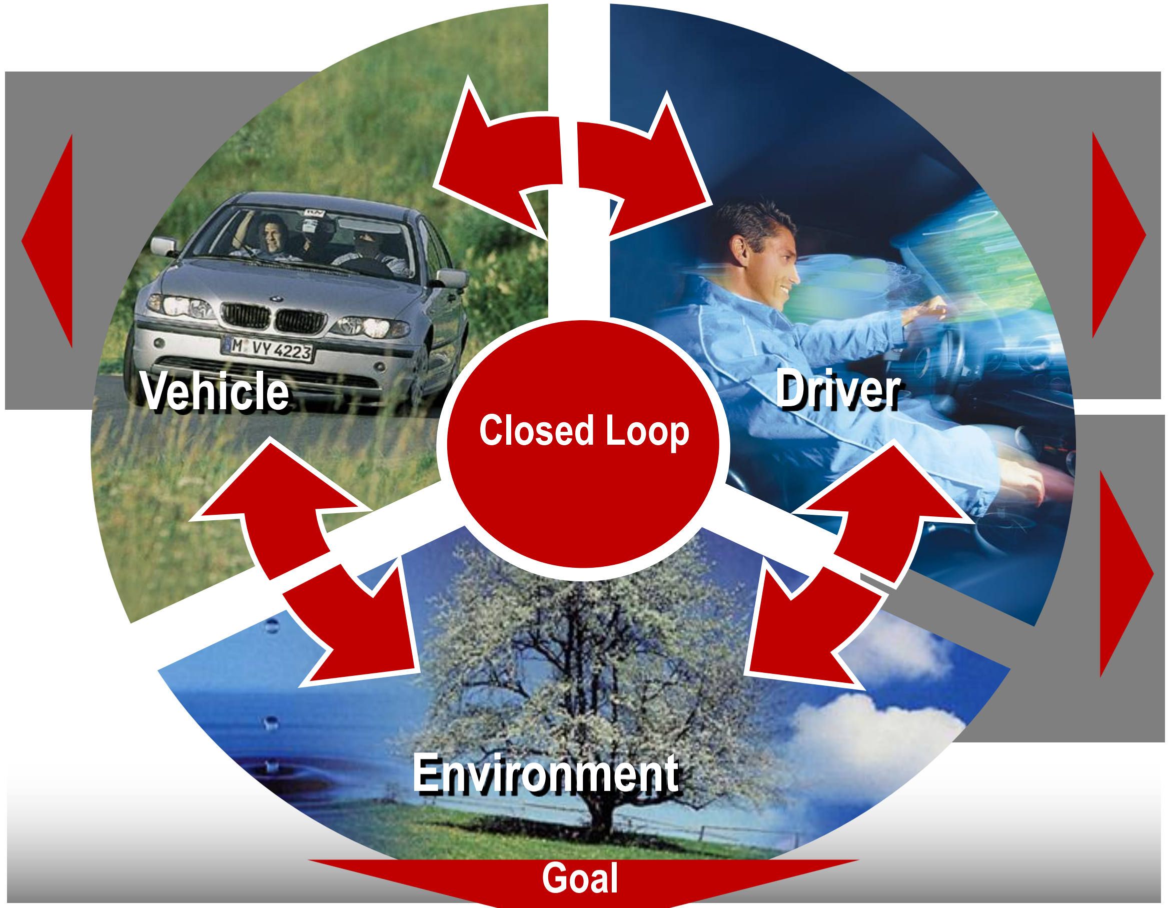
Longitudinal Dynamics
- Driving Resistance
- Acceleration behavior
- Braking behavior

"Driver – Vehicle – Environment" – a closed loop!

"Driver – Vehicle – Environment" – a closed loop!

Primary

Course control
Speed control



Secondary
- Navigation
- Route selection
- Route correction

Tertiary
- Phone call
- Multimedia
- ....

Predictability – Effortless – Safety Feeling – Fun to Drive

Influence of chassis systems on the driving characteristics

Main vehicle characteristics behavior

Longitudinal Dynamics: Drivability Behavior

Descriptions the longitudinal vehicle behavior and performance which results due to driver control input of acceleration, speed and shifting.

Lateral Dynamics: Handling and Agility Behavior

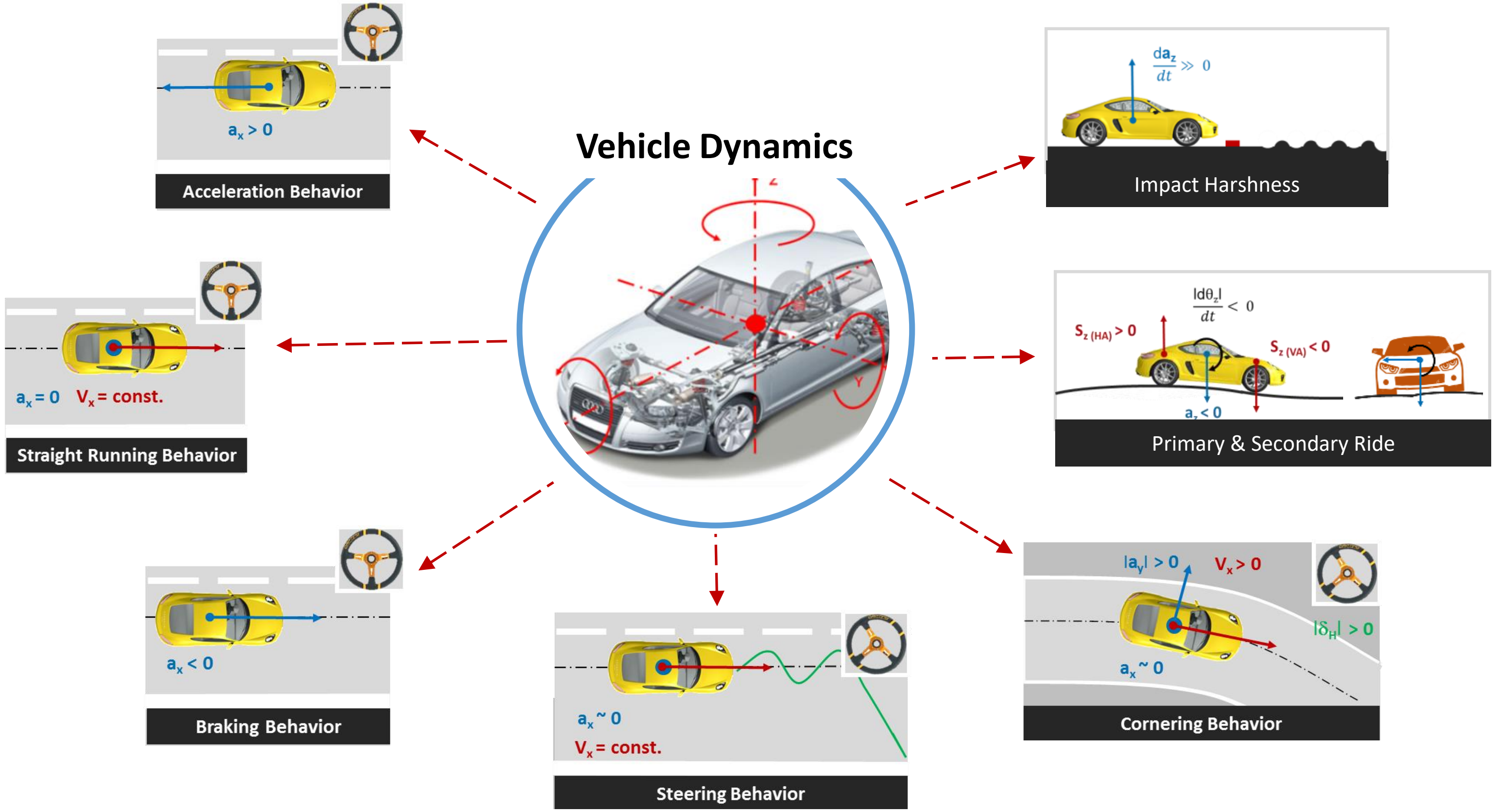
Descriptions of the way vehicles perform transverse to their direction of motion, particularly during cornering and swerving. It also includes their stability when moving in steady state as well as in transient conditions. Vehicle dynamics are one major component of a vehicle's "active" safety.

Vertical Dynamics: Ride & Comfort Behavior

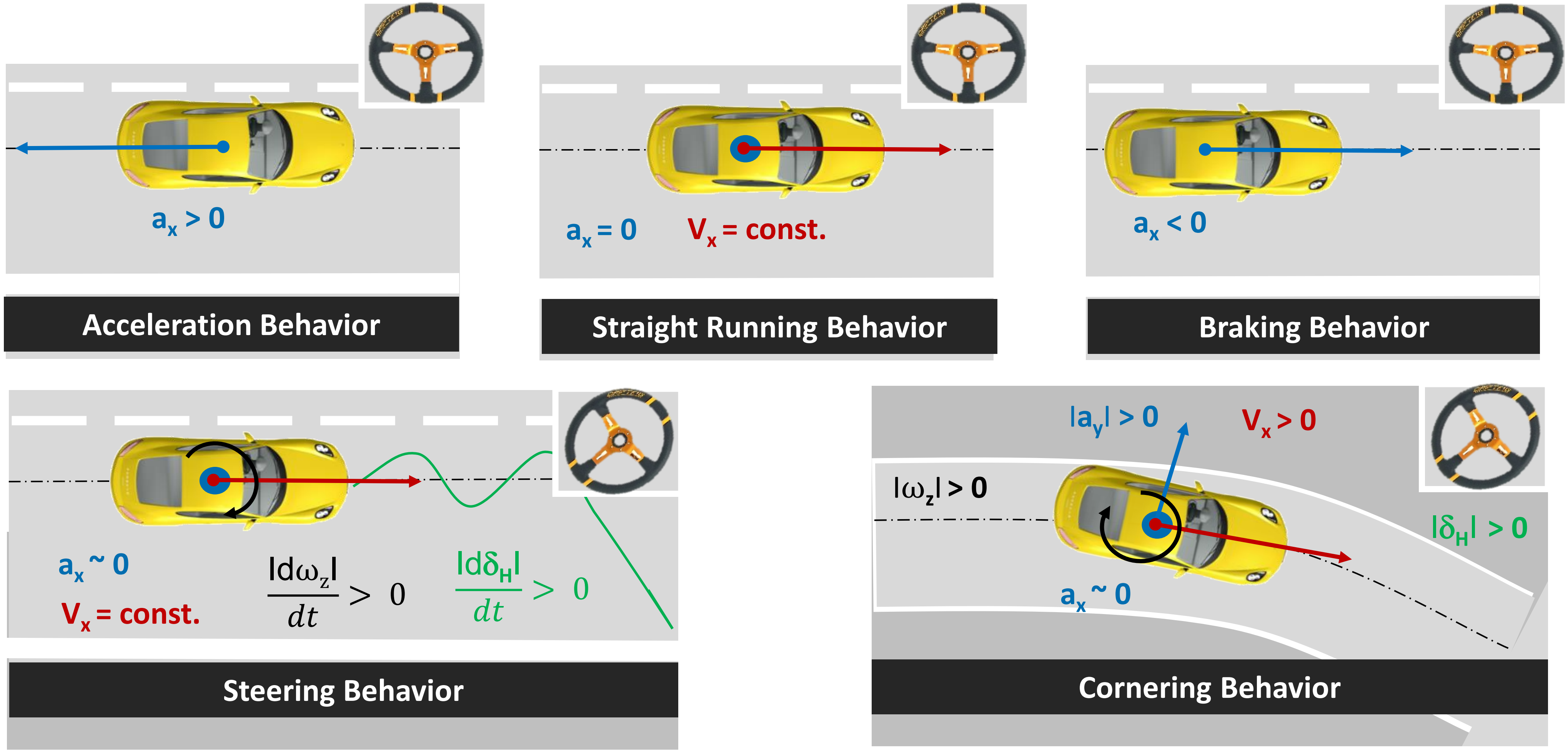
Descriptions annoying driver or passenger impact dynamic due to driver effort, road excitation and vehicle vibrations, which negative influence the work load, effort, comfort feeling and healthiness.

Influence of chassis systems on the driving characteristics

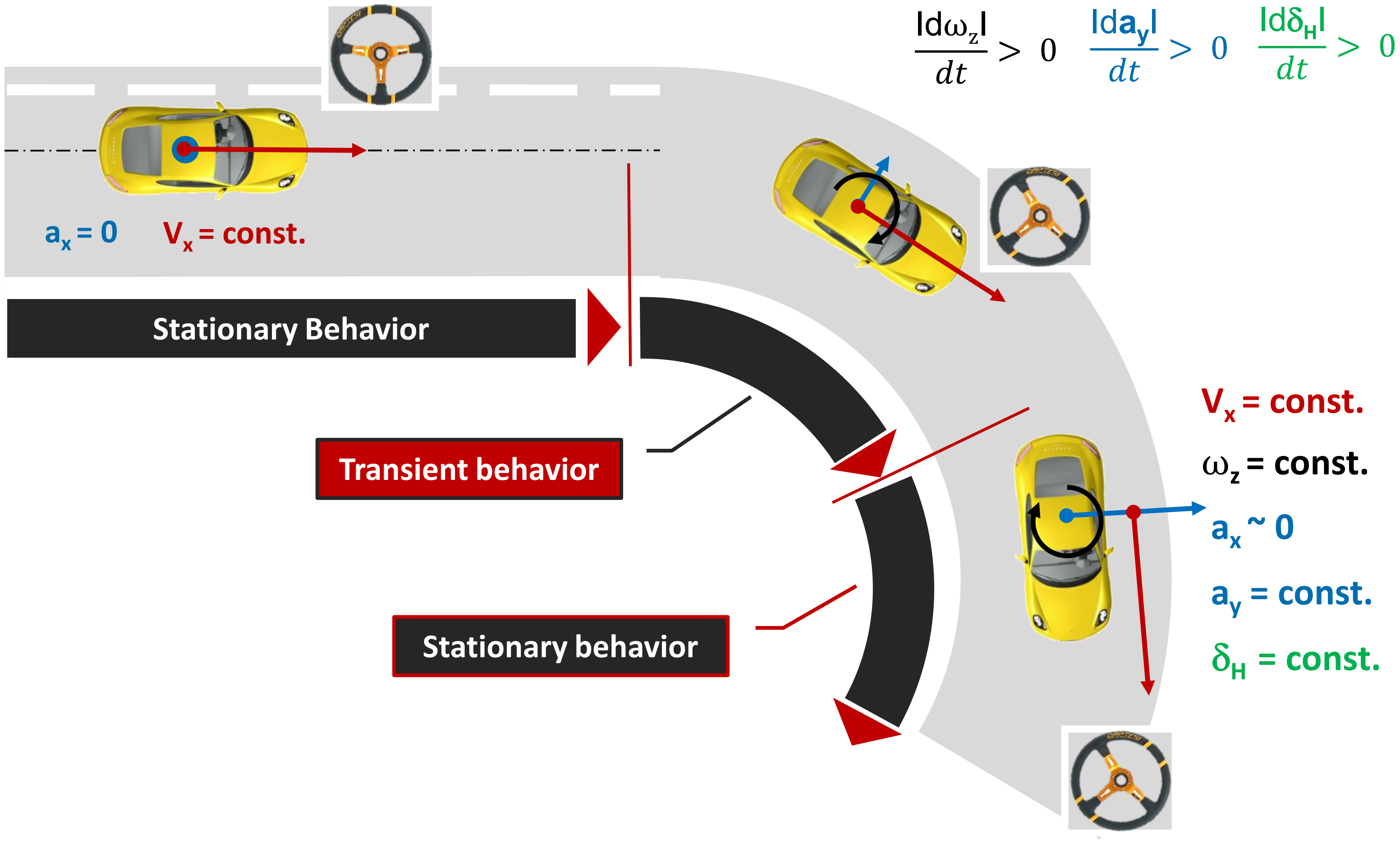
Different groups of ride & handling behavior



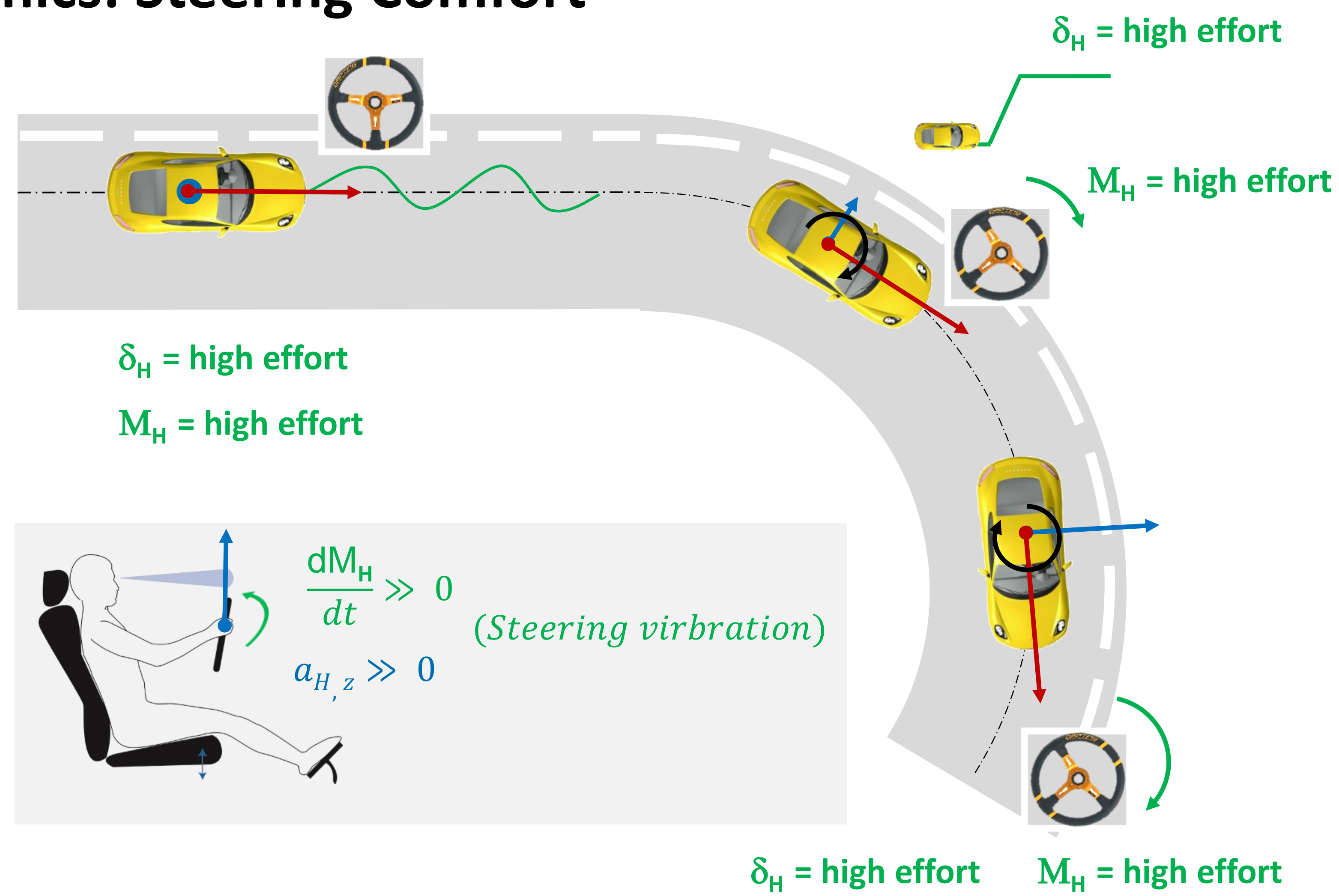
Lateral Dynamics: Handling and Agility Behavior



Lateral Dynamics: Stationary and transient behavior

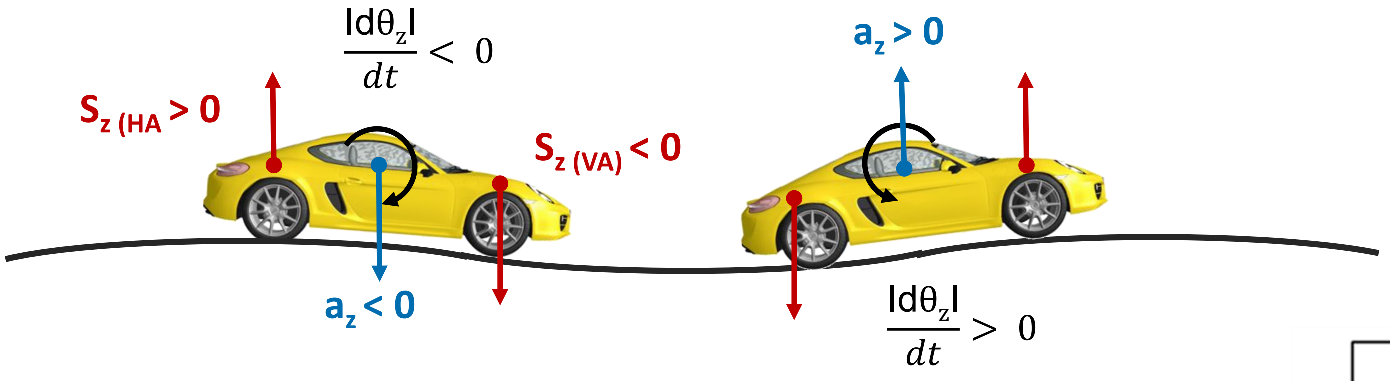


Lateral Dynamics: Steering Comfort

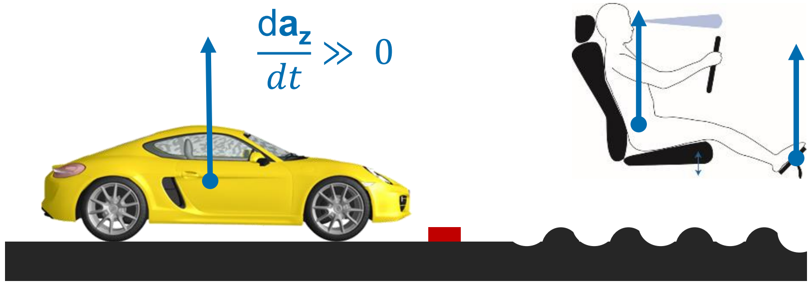


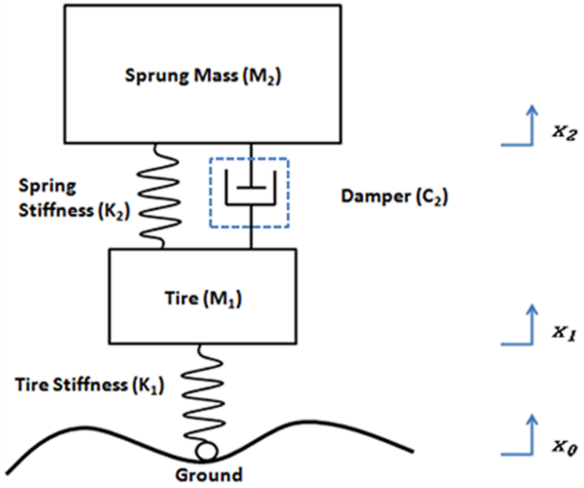
Vertical Dynamics: Ride & Comfort Behavior

Body Movement (Primary & Secondary Ride)



Body acceleration (Harshness, Vibration)





Influence of chassis systems on the driving characteristics

Subjective and objective evaluation language

Customer Wishes

Subjective Language

Subjective evaluation

Subjective evaluation criteria in a rating system

- Center Point Feeling
- Force Feedback
- Road Surface Contact
- Roll Behaviour
- Spring / Damper Balance
- Steering Effort
- ....

Objective Language

Objective measurement data

Characteristic values for vehicle behavior

- Yaw Gain
- Understeer Gradient
- Roll Stiffness
- Frequency Response
- Maximum Force
- Linearity
- ....

Correlation and linkage between both languages are important

Influence of chassis systems on the driving characteristics

KPI and target matrix within a consistent development process

Driving Maneuver	Objective Evaluation Criteria	Benchmark Result Veh 1	Veh 2	...	Target
Steady Circular Driving	Ackermann Angle(SWA)	28	25	..	**25**
Power Off	Understeer Gradient	2,6	0.8	..	**> 2 < 2,2**
Sine Steer	$a_{y,max}$	8,5	8,9	..	**> 9**
...	Yaw Gain Max	13,5	14,5	..	**> 14,5**
	Roll Stiffness	4,2	4,6	..	**> 3,6 > 4,0**
	SWT max	4,5	5,2	..	**> 4,8 > 5,2**
	Ay rel at SWT	70	85	..	**> 80 < 90**
	Side Slip Max	1,8	2,1	..	**< 1,8**
	...	...	...	..	**..**

Brand specific

Influence of chassis systems on the driving characteristics



Performance	The accomplishment of a given task measured against preset known standards of accuracy, completeness, costs, acceleration and speed.
Agility	Agility is the ability to change the direction of the vehicle based on drivers steering input.
Stability	The vehicle ability of being enduring on the driver given path and free from non-desirable change or variation.
Comfort	Descriptions annoying driver or passenger impact dynamic due to driver effort, road excitation and vehicle vibrations, which negative influence the work load, driver effort, comfort feeling and healthiness.
Safety	Safety is the condition of being protected against physical, social, spiritual, financial, political, emotional, occupational, psychological, educational or other types or consequences of failure, damage, error, accidents, harm or any other event which could be considered non-desirable.

Influence of chassis systems on the driving characteristics

Customer key requirements to vehicle dynamics

Driving at the performance limit

Longitudinal Performance and Stability
High acceleration and short brake distance – controllable and predictable

Lateral Dynamics Performance and Stability

Controllable driving behavior at the physical limit.

Sporty Driving

Normal Driving

Steering Comfort

- Low steering forces
- Low steering angle
- Small turning cycles

Agility

Corner driving pleasure

Dynamics and agility

Low roll perception

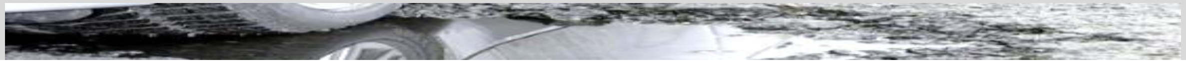
Driving Stability /Safety

Safety feeling

Low driving work load

Straight driving precision

Driving Comfort at uneven roads with low passenger movement and acceleration



City | Cross Country | Autobahn