



Chassis systems with chassis laboratory

Introduction

University of Applied Science

2016 - today



Research Professorship
University of Applied Science / Research Center Allgaeu

Vehicle Dynamics
ADAS/Highly Automated Driving
Vehicle Efficiency

AVL List GmbH

2014 - 2016

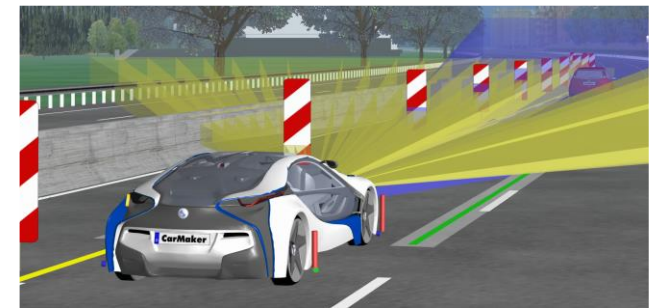


Global Business Unit Manager
Calibration & Virtual Testing
Solutions

Calibration Solution
Test Information Management
Virtual Testing / Model Based Testing

IPG AUTOMOTIVE

2007 - 2013



Managing Director

General Vehicle Dynamics, Integrated
Controls, ADAS, Fuel Efficiency & E-
Mobility

Introduction

TÜV SÜD AUTOMOTIVE

1995 - 2007



General Manager Chassis
Systems

Vehicle Dynamics, Tire & Wheels,
Brakes, Measurement &
Simulation

16 YEARS PRO RACE CAREER

1982 - 1997



250cc, Superbike, Supersport
GP, World, European, German
Championship

Int. German Champion 1996
ProSuperbike Team Champion
1993 / 1994





IFM - Institute for Driver Assistance & Connected Mobility

Welcome

Scope of IFM Research



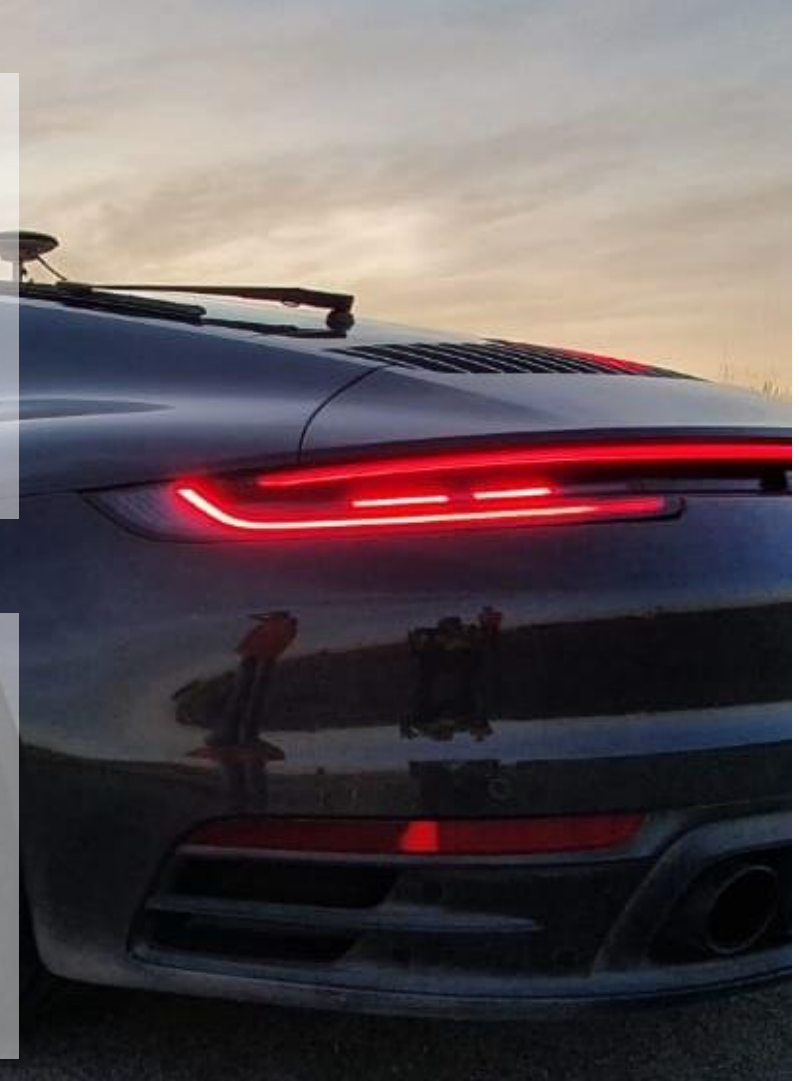
Driver assistance/automated driving

- Consistent development methods and technologies
- Human - Machine Interaction
- Functional Safety
- Environmental sensors and algorithms
- AI – Methods of "Artificial Intelligence"
- Algorithms, IT products and their testing



Tests and Connected Mobility

- Virtual testing of "embedded systems"
- Testing of e-drives on dynamometers
- Positioning, maps, Car2x communication
- Testing and trial of functions & reliability
- Field and fleet tests



Scope of IFM Research



7+2



Professors

Prof. Bernhard Schick, Prof. Dr. Rolf Jung, Prof. Dr. Stefan Schneider, Prof. Dr. Thomas Zeh, Prof. Dr. Andreas Stiegelmeyr, Prof. Dr. Andreas Rupp, Prof. Dr. Ulrich Göhner

Prof. Dr. Werner Mehr, Prof. Dr. Michael Patt

4+2



Research Groups

- IFM: **Adrive**, Safety, Sensor, Connect
- In the IFM building: TTZ, H2

65+35



Staff

- > 65 scientific employees
- > 35 research assistants / interns

10+10



Projects

- >10 publicly funded collaborative projects
- >10 Industry contract research

We are really serious about virtualization, therefore we need ...

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





Hochschule
Kempten

University of Applied Sciences



BA -Vehicle Technology
WS 21/22 Lecture 2

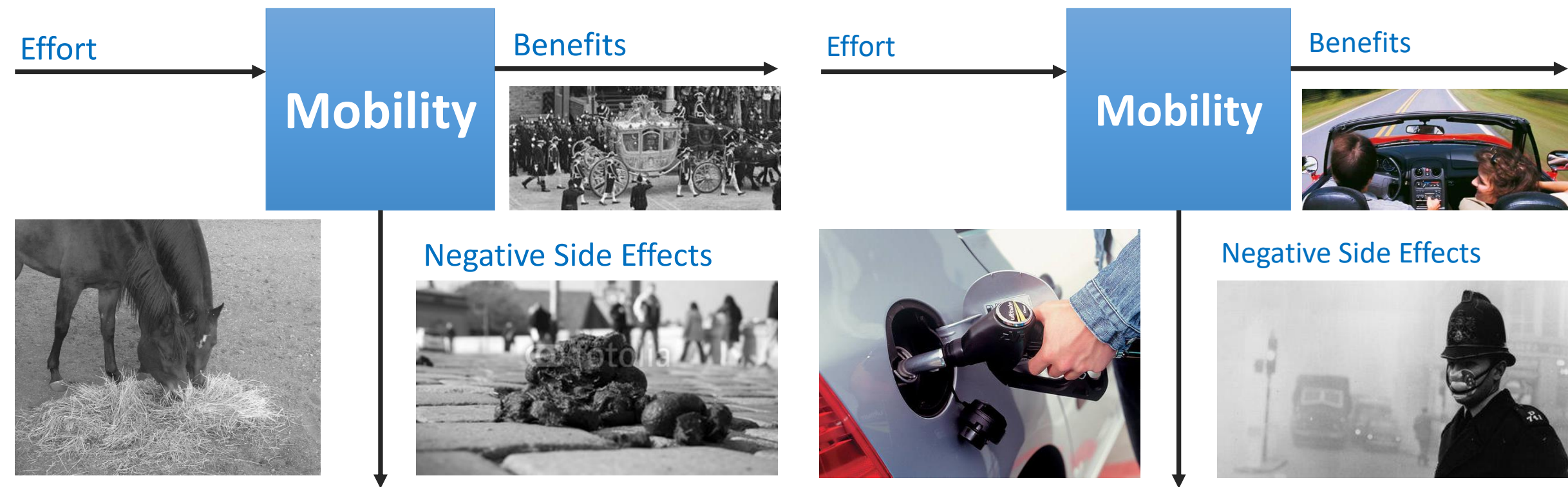
Chassis systems with chassis laboratory

Requirements for vehicles and their global attributes

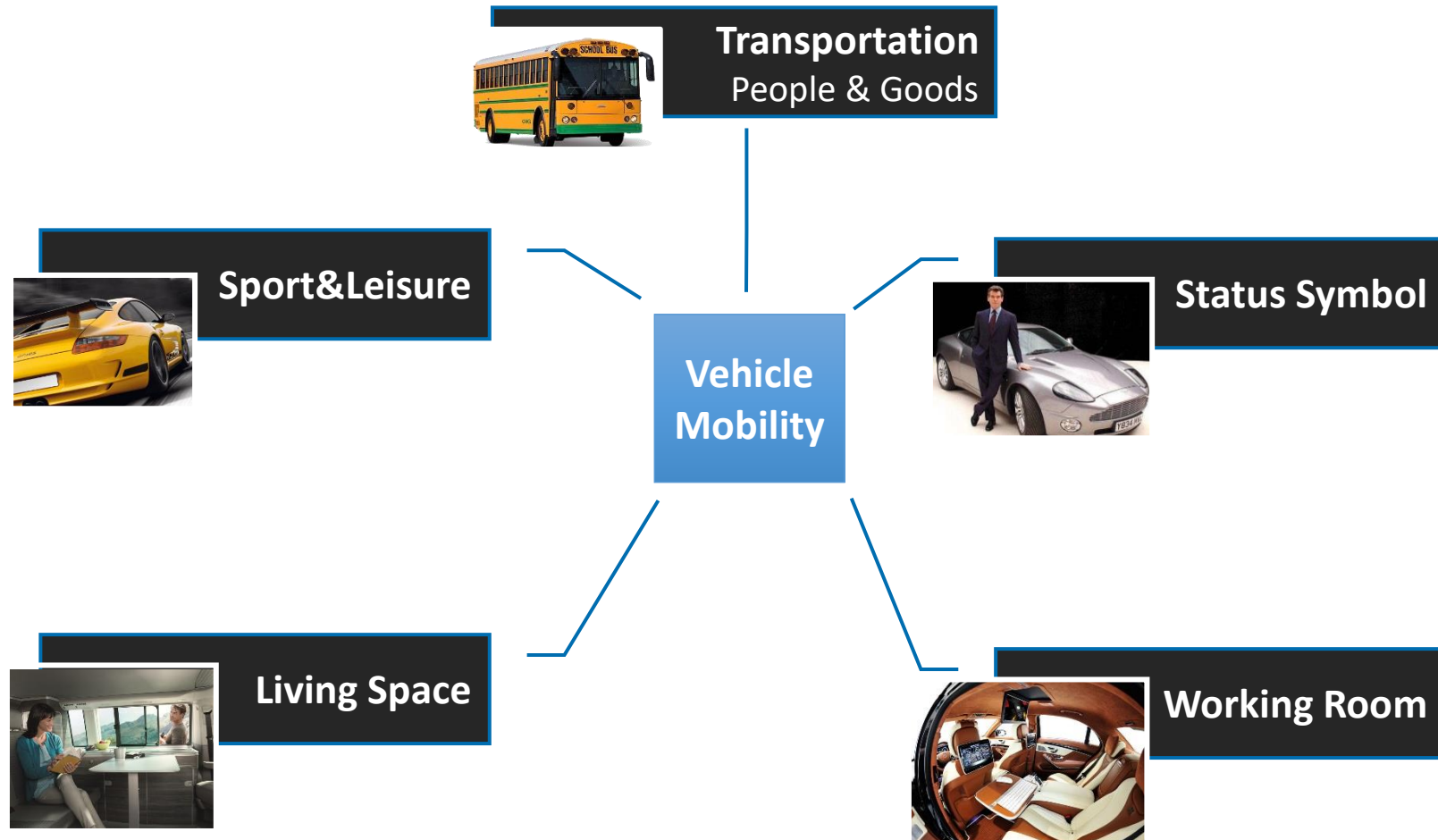
Motor driven mobility changes our live



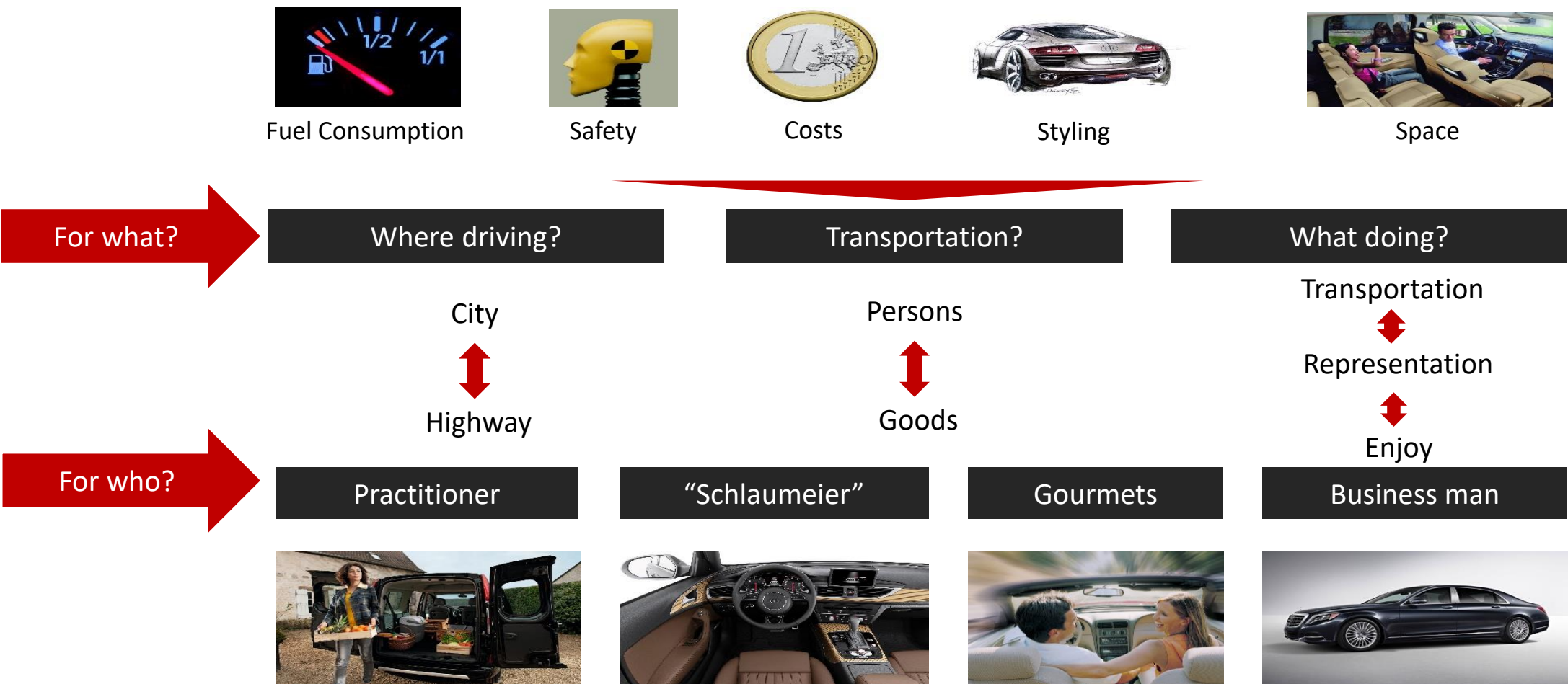
Mobility as a system has efforts and side effects



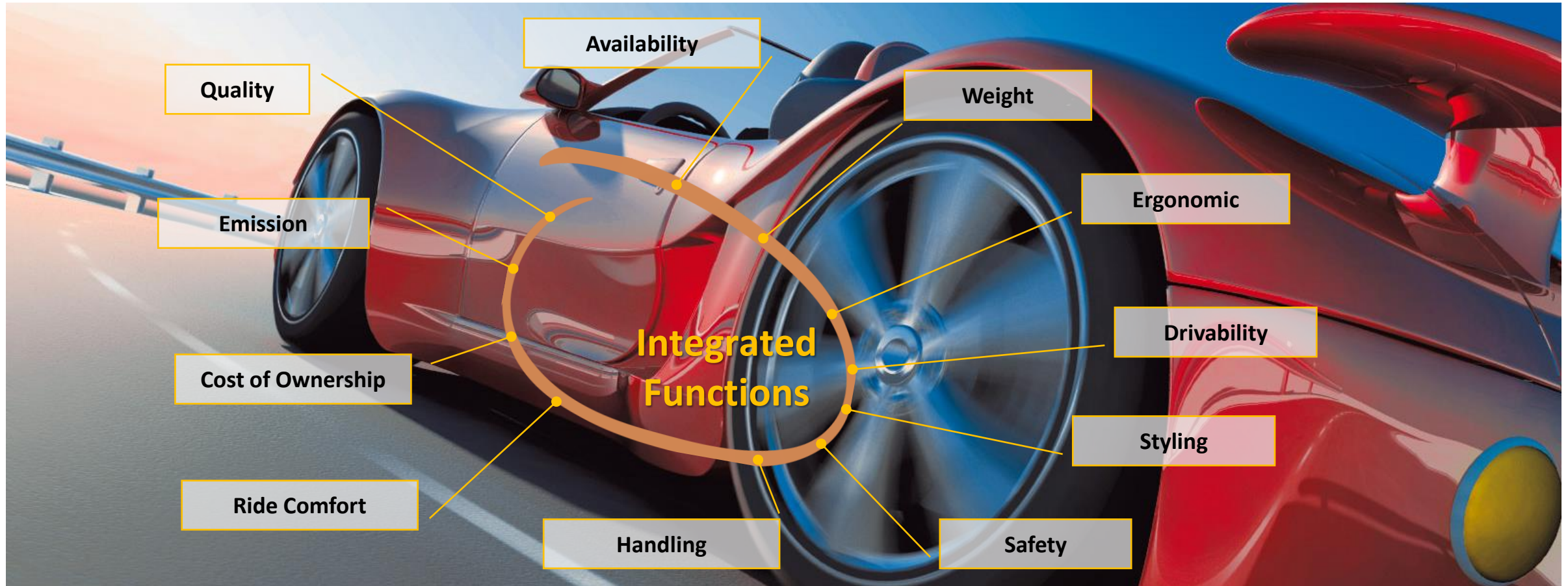
Benefit of the vehicle mobility system.



What motivates humans to buy a vehicle?



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?

[illegible]

Availability

Cost of Ownership

Weight

Quality

Ergonomic

Styling

Safety

Emission

Drivability

Handling

Ride Comfort

1 Evaluation criteria (measurable)

2 Test Method

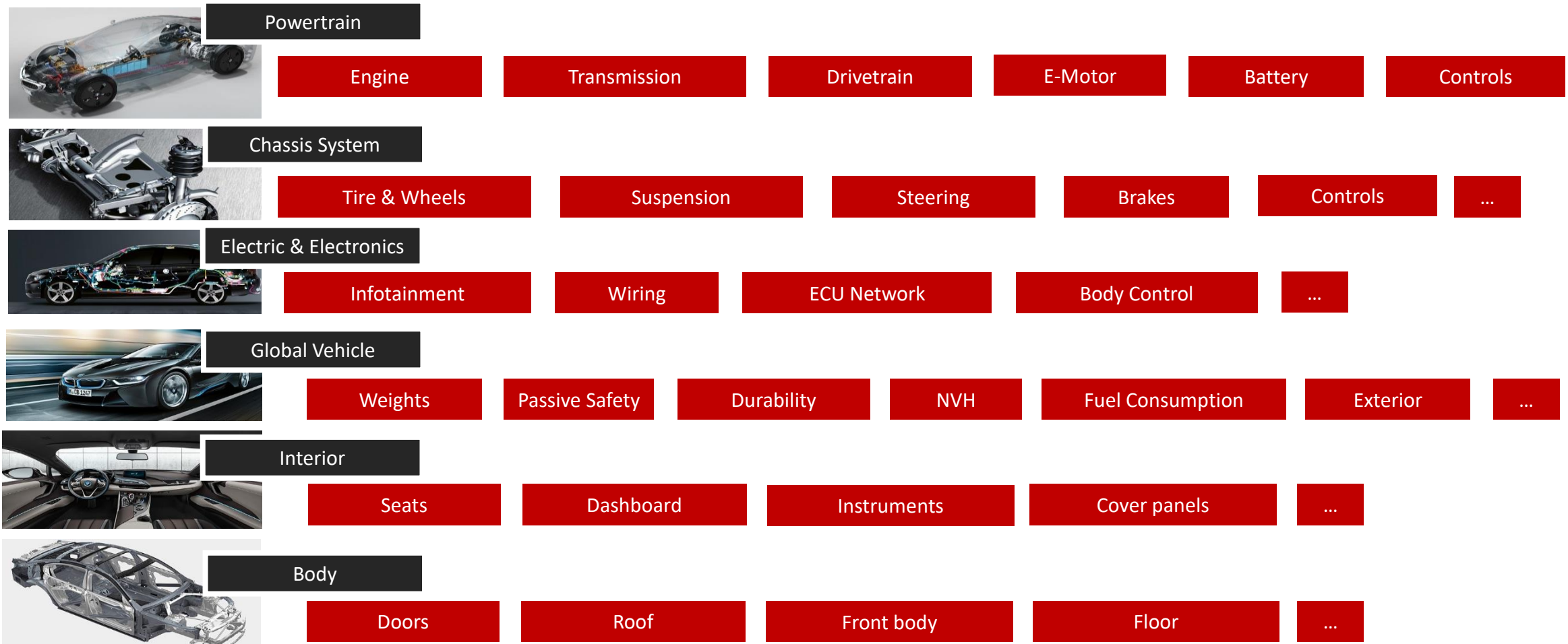
Target

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

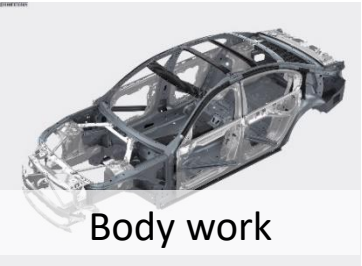
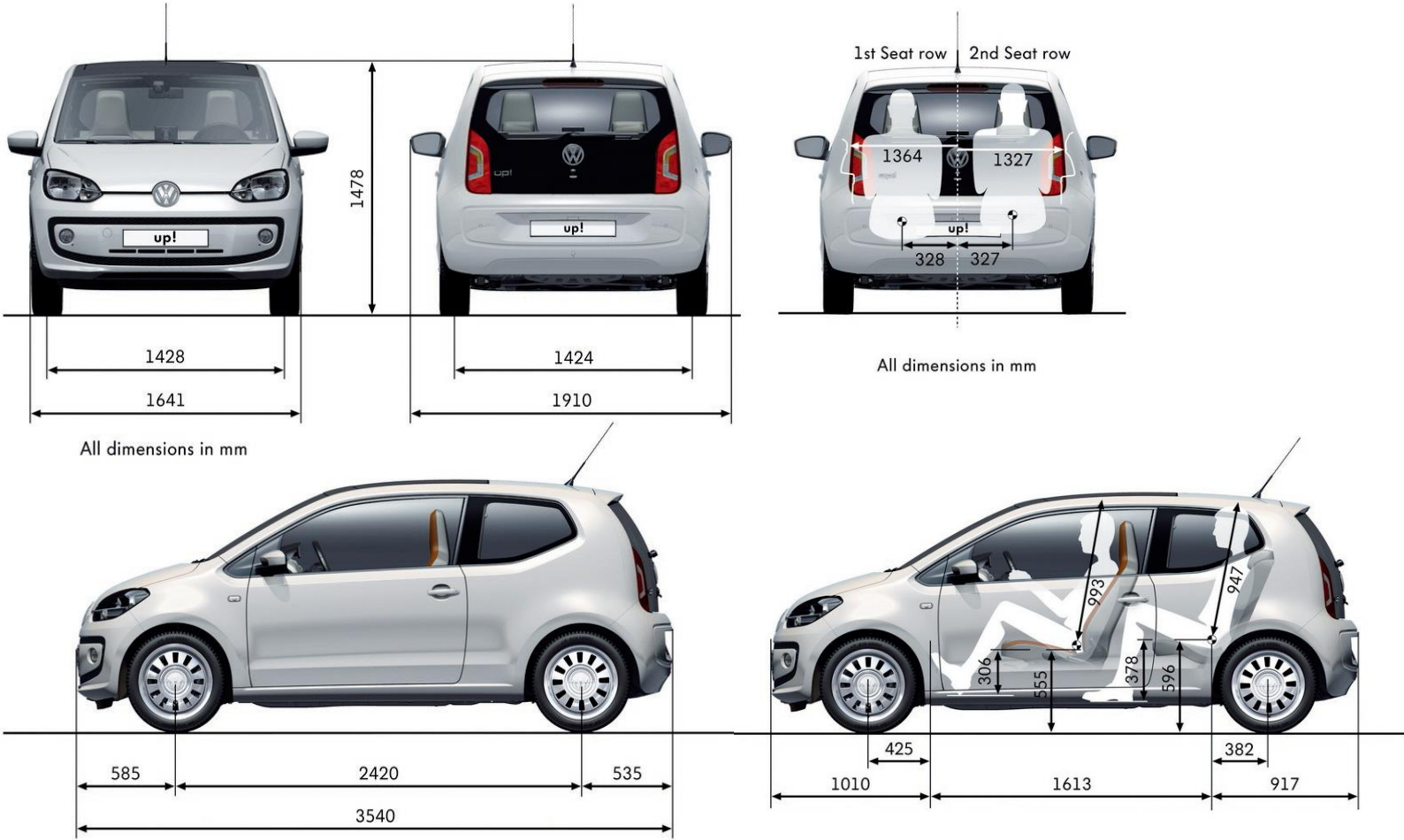
The vehicle and its systems



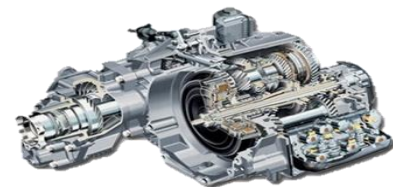
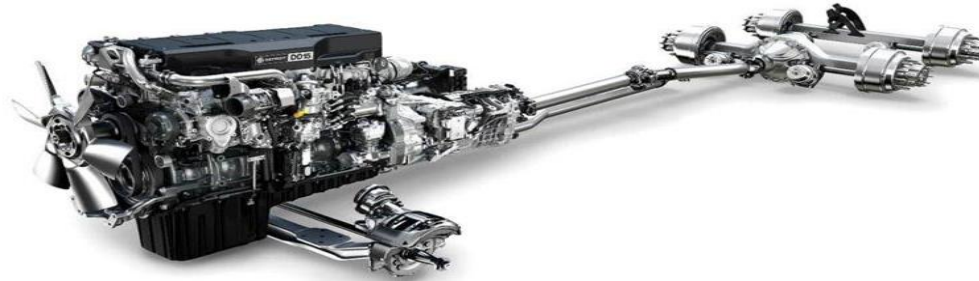
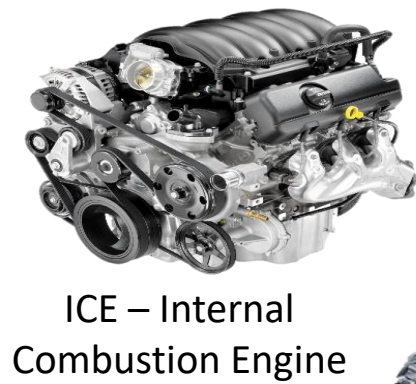
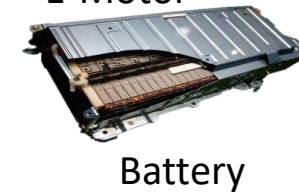
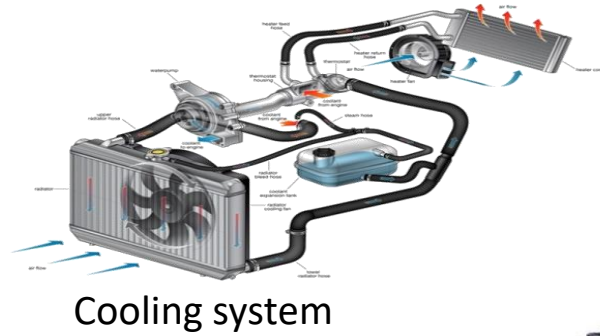
Vehicle body and total vehicle



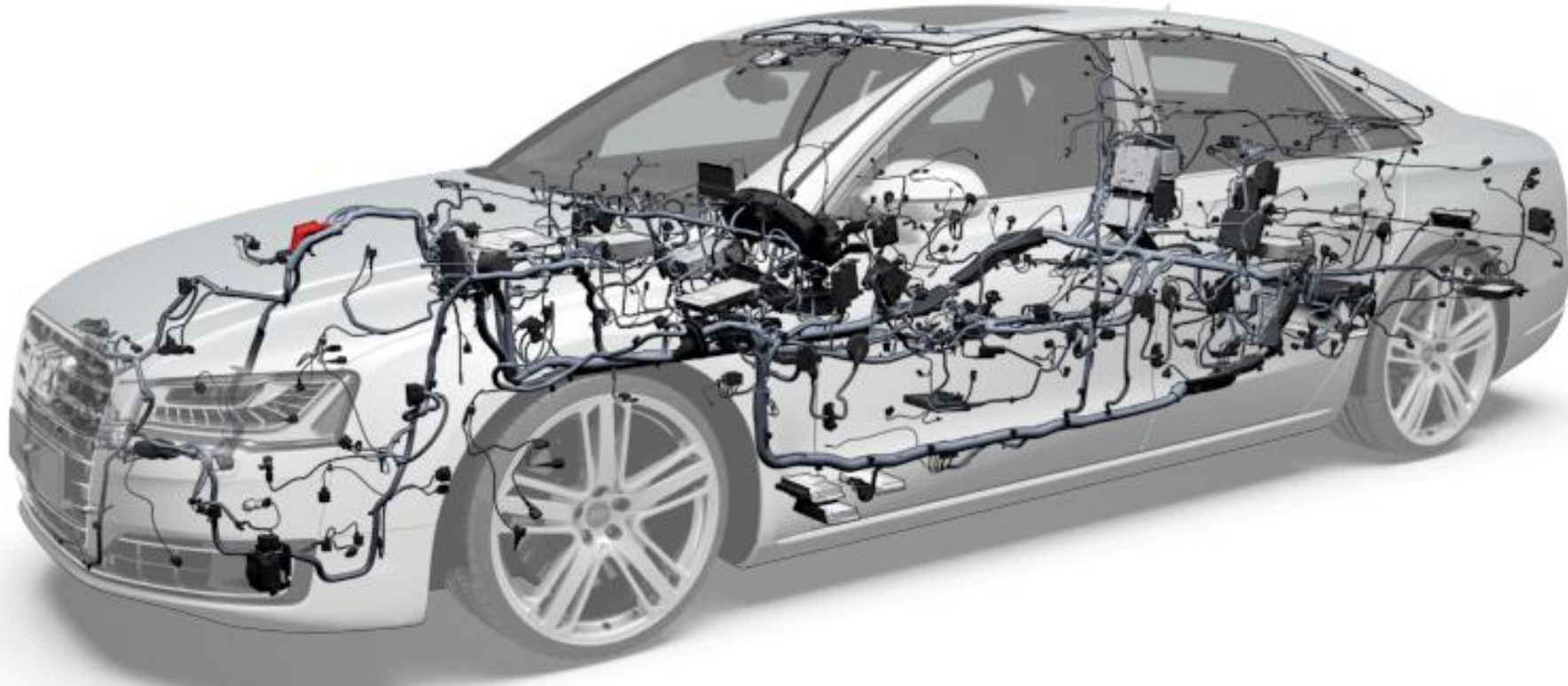
Vehicle body and total vehicle



Powertrain System



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

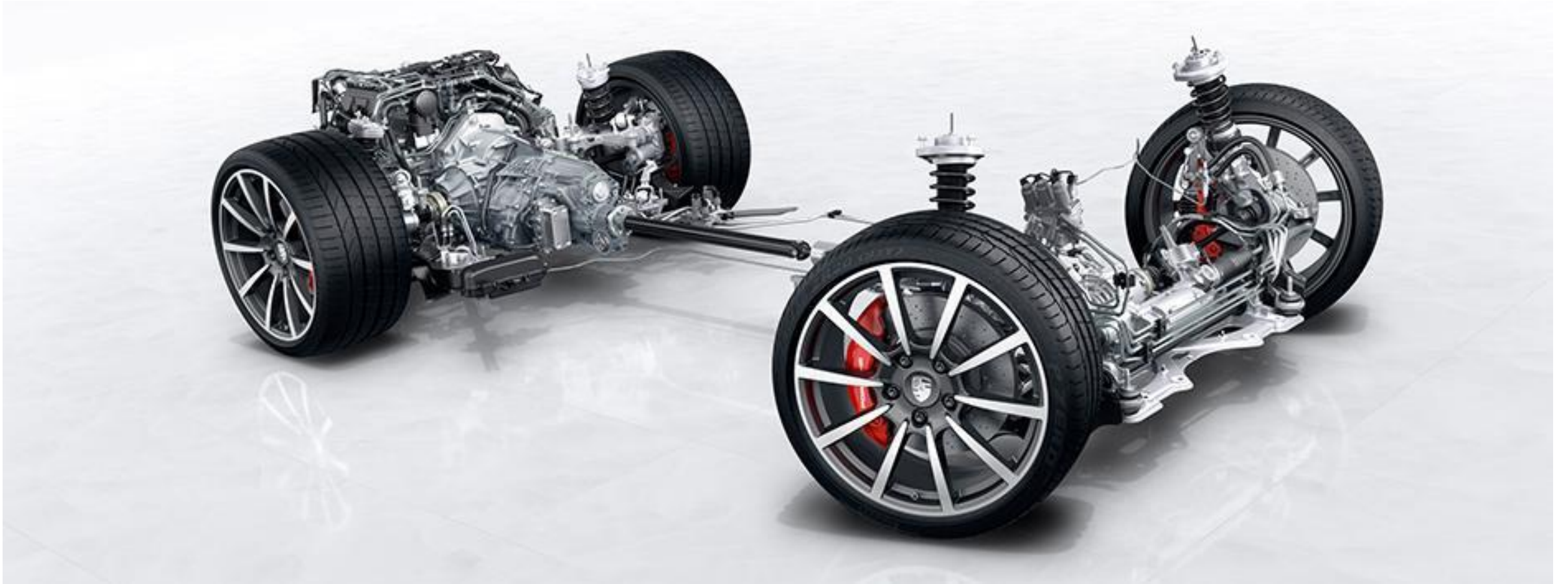
 Audi A3 Sportback - Bedienerlebnis Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi Q3 Sportback – Infotainment, Audi connect, 3D Sound Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi Q3 – Infotainment und 3D Sound Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi A1 Sportback - Infotainment/Connectivity und LED-Schweinwerfer Verfügbare Medien:  Quick View >> Zum Artikel >>	 Vernetzung Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi A3 Sportback - Assistenzfunktionen Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi Q3 Sportback – Fahrerassistenzsysteme Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi A6 allroad quattro – Bergabfahrassistent Verfügbare Medien:  Quick View >> Zum Artikel >>
 Audi A8 – Matrix LED- Leselicht Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi R8 - Innenraum und Bedienung Verfügbare Medien:  Quick View >> Zum Artikel >>	 Neue Bedien- und Anzeigekonzepte Verfügbare Medien:  Quick View >> Zum Artikel >>	 Bedienung und Anzeige Verfügbare Medien:   Quick View >> Zum Artikel >>	 Audi Q3 – Fahrerassistenzsysteme Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi A1 Sportback – Fahrerassistenzsysteme Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi Q8 – Anhängerassistent Verfügbare Medien:  Quick View >> Zum Artikel >>	 Audi A6 Avant – Anhängerassistent Verfügbare Medien:  Quick View >> Zum Artikel >>
 FIS/Multifunktionslenkrad Verfügbare Medien:  	 Head-up-Display Verfügbare Medien: 	 MMI Verfügbare Medien:  	 MMI touch Verfügbare Medien: 	 Audi A6 Limousine – adaptiver Fahrerassistent Verfügbare Medien: 	 Audi A7 Sportback – Prädiktiver Effizienzassistent Verfügbare Medien: 	 Audi A7 Sportback – Audi pre sense 360 Verfügbare Medien: 	 Audi A8 – zentrales Fahrerassistenzsteuergerät (zFAS) Verfügbare Medien: 

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

Aerodynamics



Chassis Systems

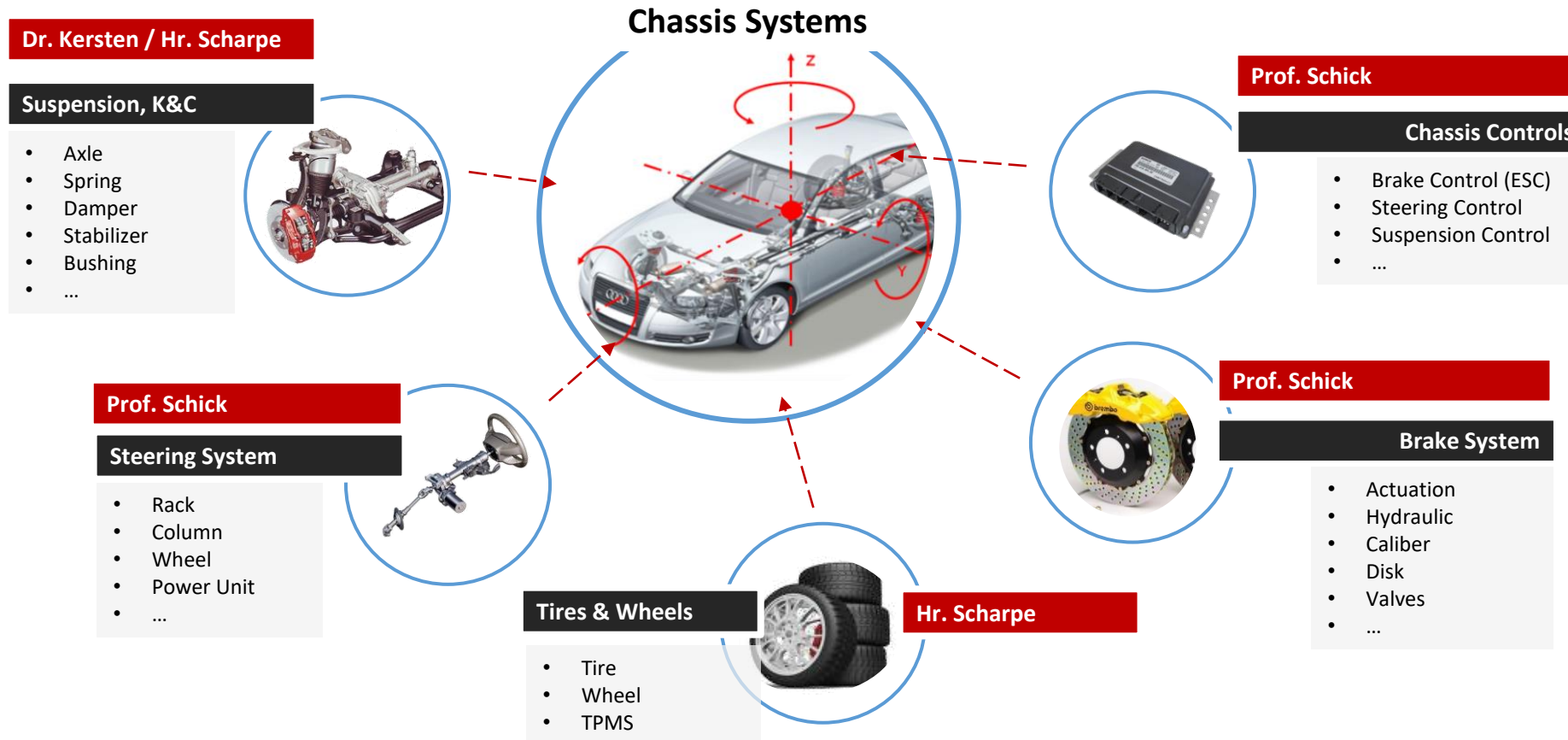


Chassis is responsible for the interconnection between the vehicle and the road including passengers and luggage. Furthermore is responsible to...

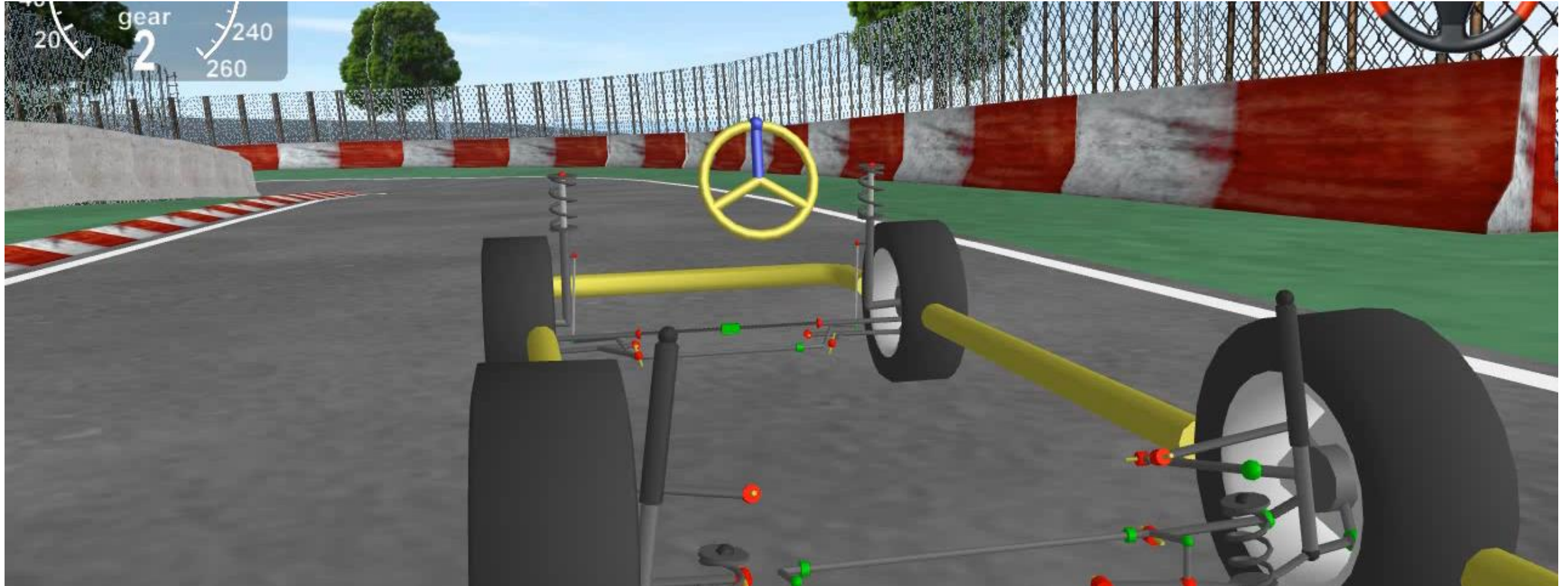


- transfer outer forces and moments via the tires to suspension to vehicle inner forces.
- bring tires into a optimal position for the force and moment transfer.
- control the full body motion for
 - Vehicle dynamics attributes
 - Driving comfort attributes
 - Driving safety attributes

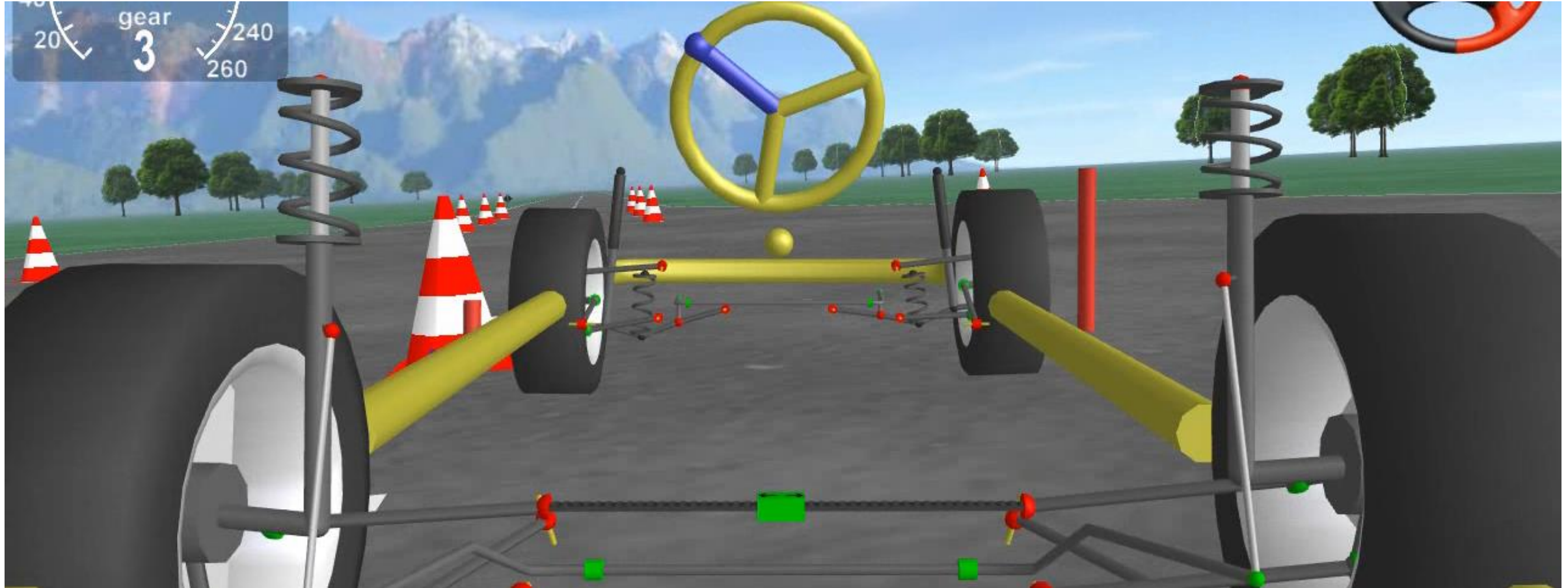
Vehicle dynamics behavior is impact by numerous components



Axle, Suspension, Kinematics&Compliance Characteristics

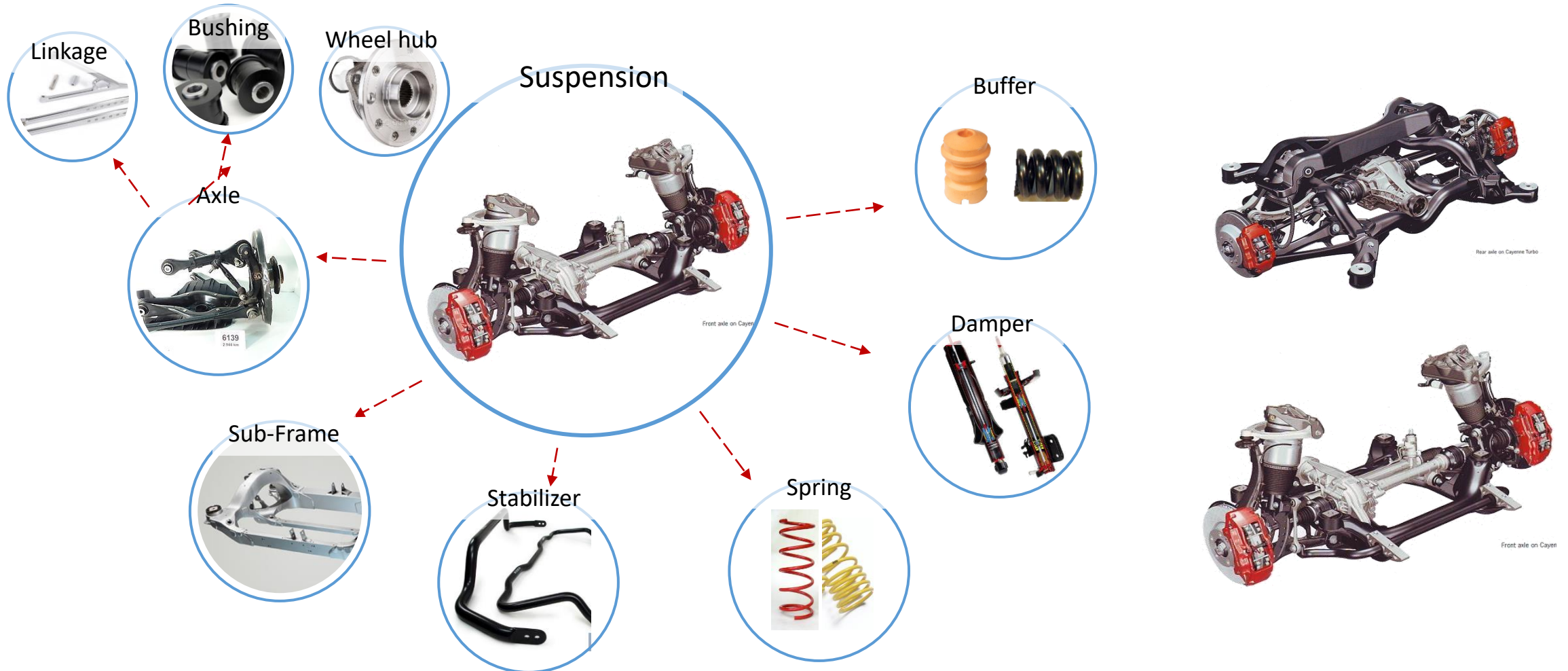


Axle, Suspension, Kinematics&Compliance Characteristics



Chassis systems their function and structure

Suspension components



Chassis systems their function and structure

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

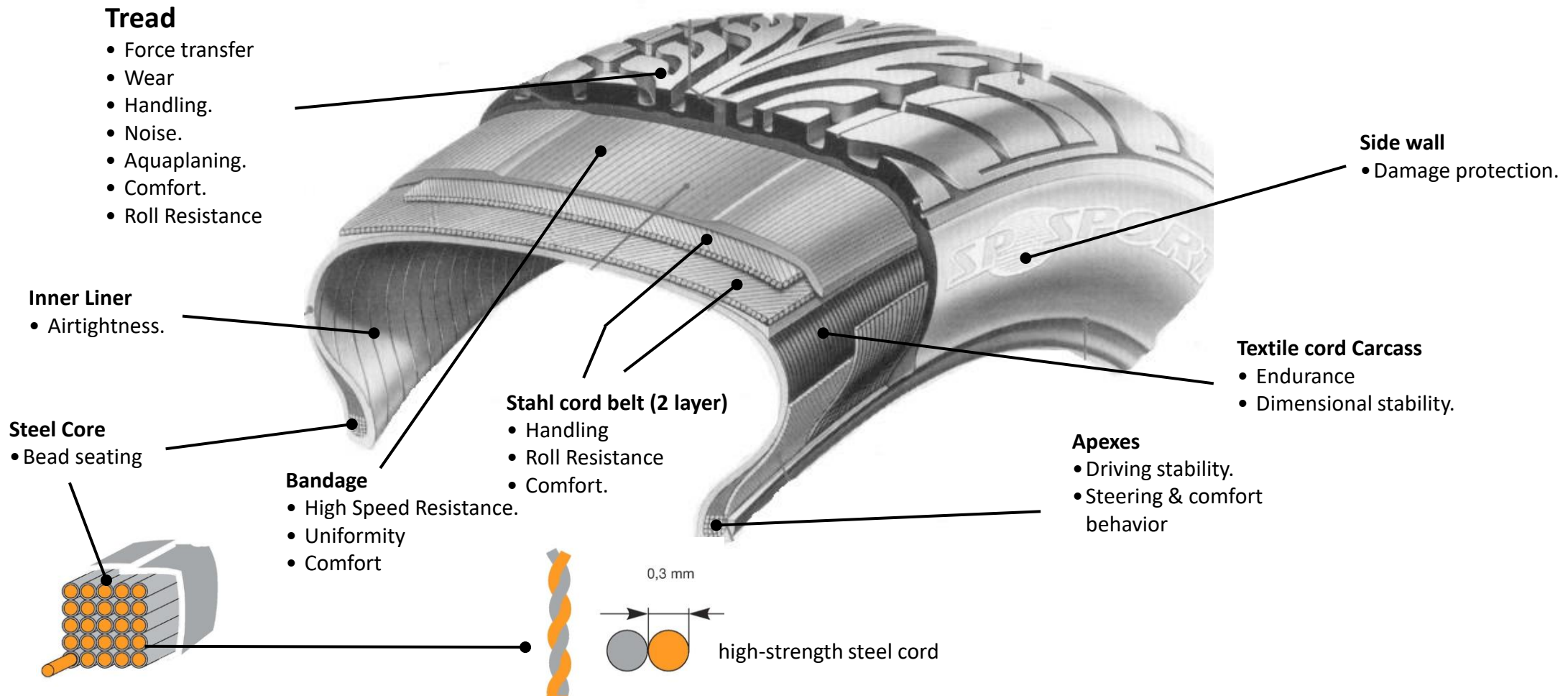


The tire is the “BLACK MAGIC” – how tire works

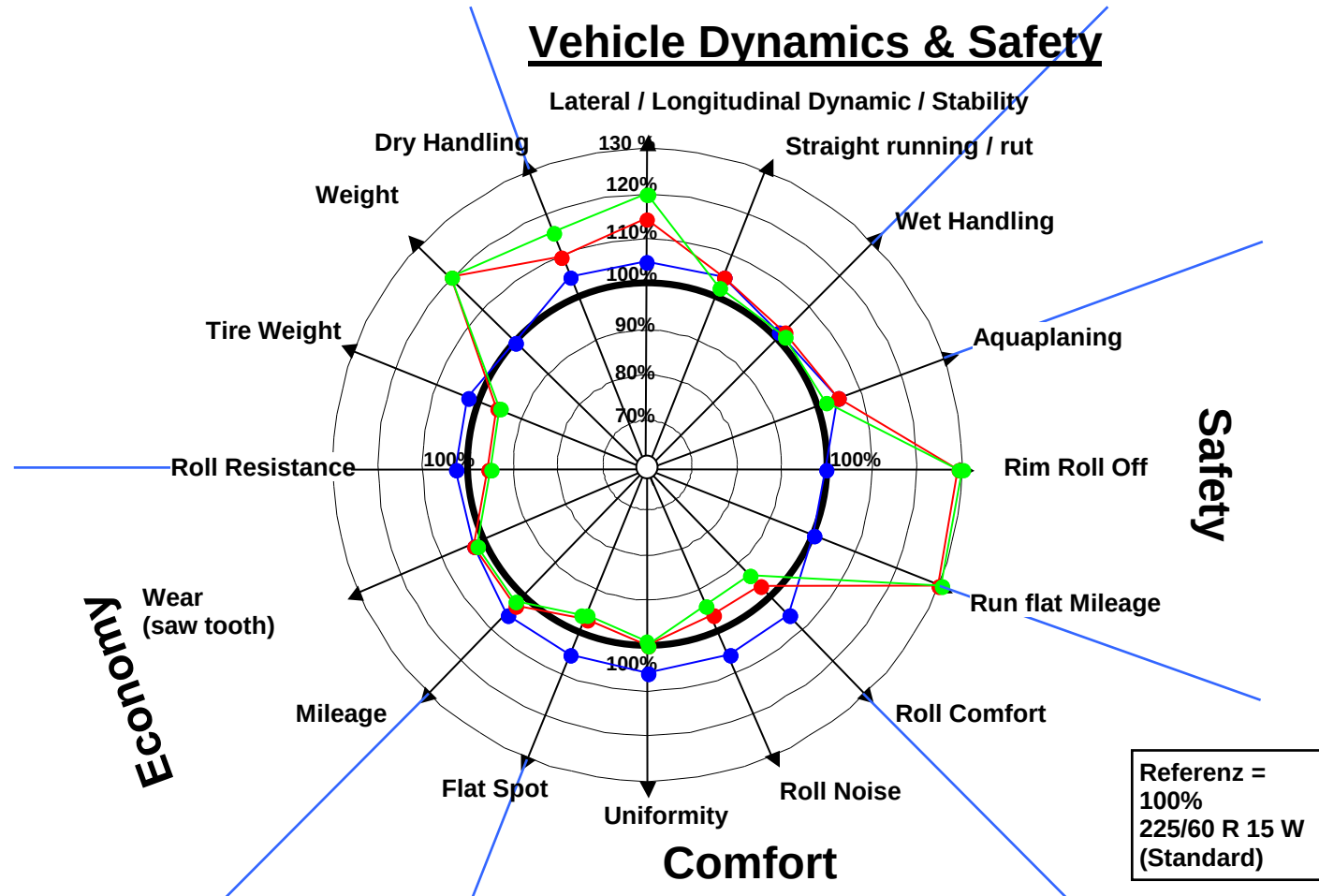


<https://www.youtube.com/watch?v=BPYxLeW6WjM>

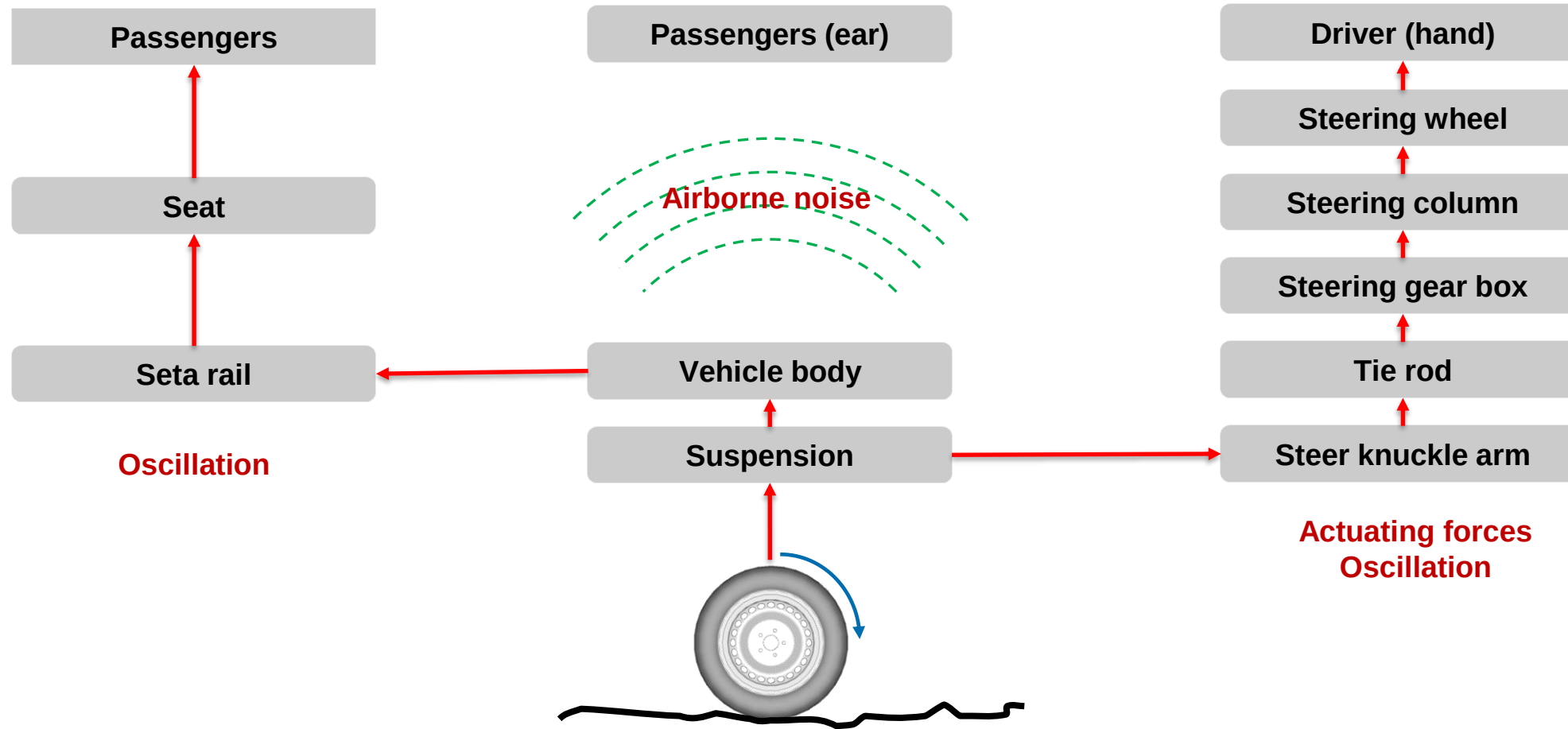
Tire construction and component functions



Target conflicts (trade-off) for the development



Cause and effect chain / transfer path

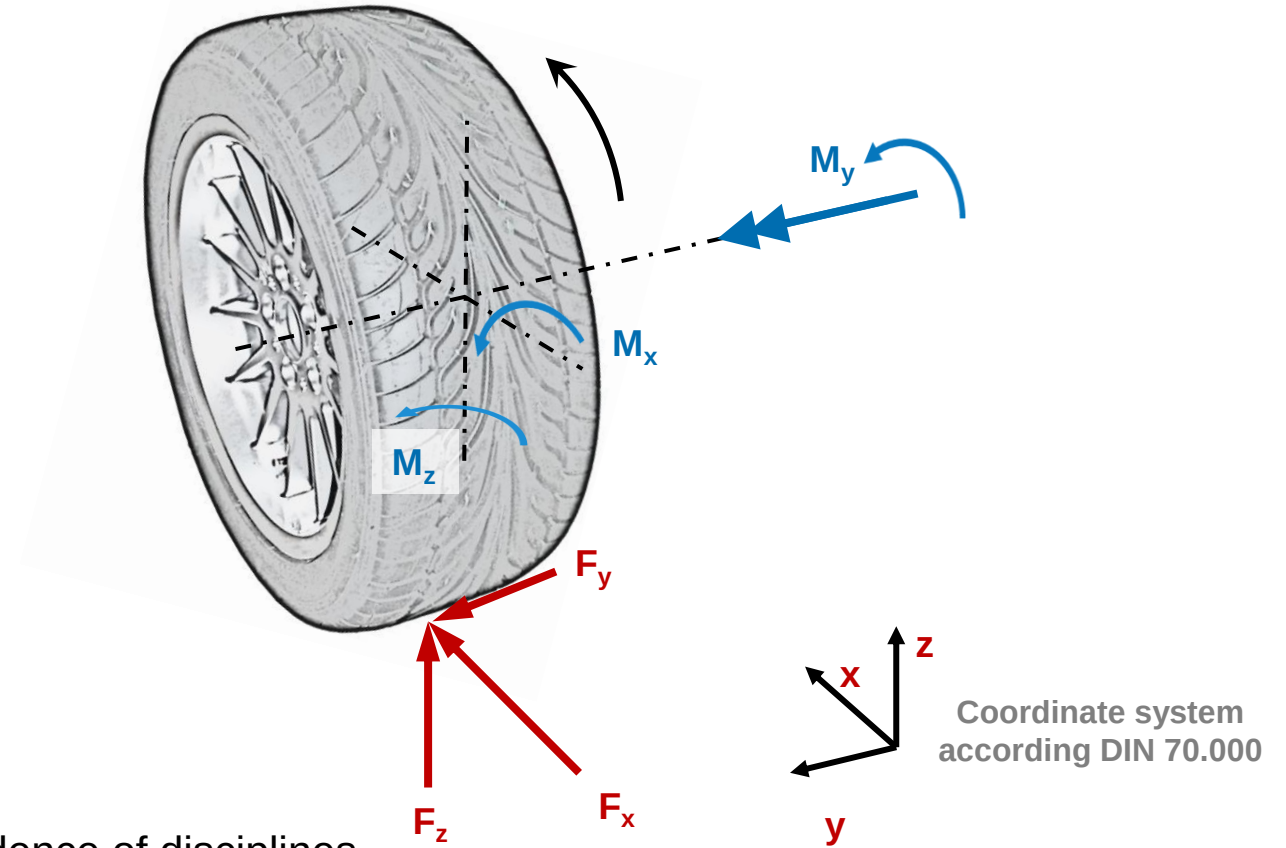


Tires are the interface to the road environment

The behavior of the tire can be subdivided 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

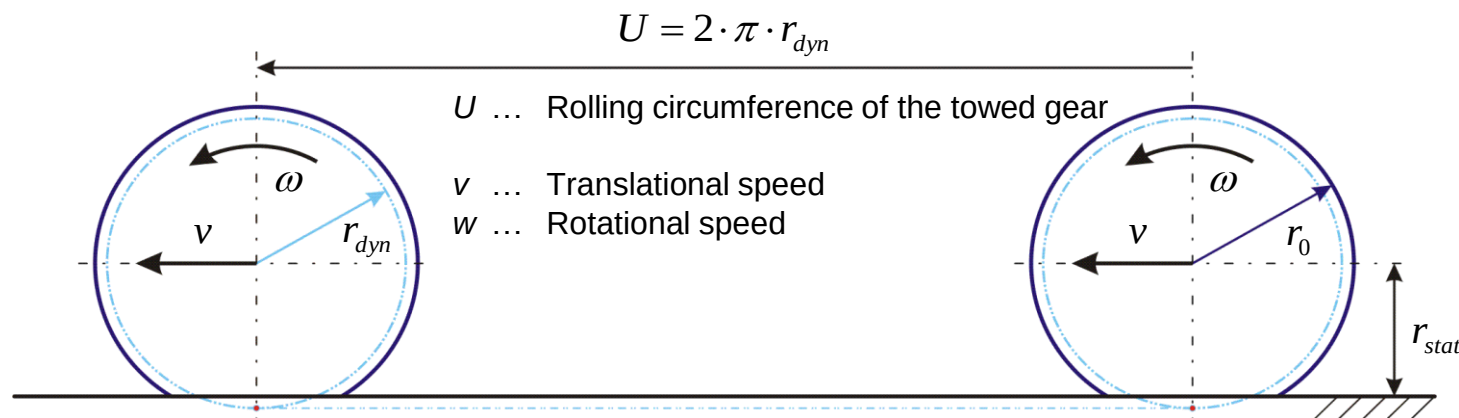


Tires, some fundamentals

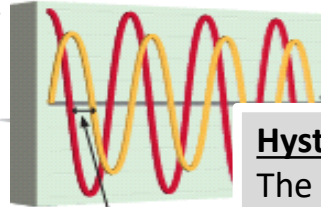
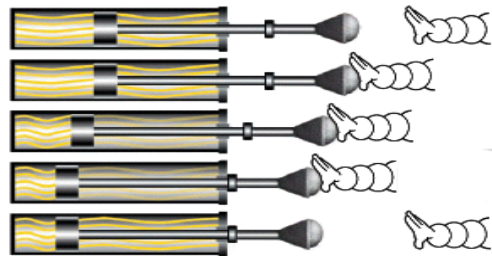
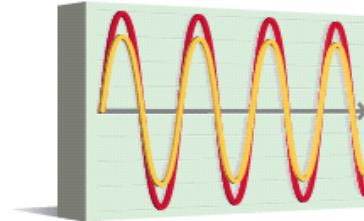
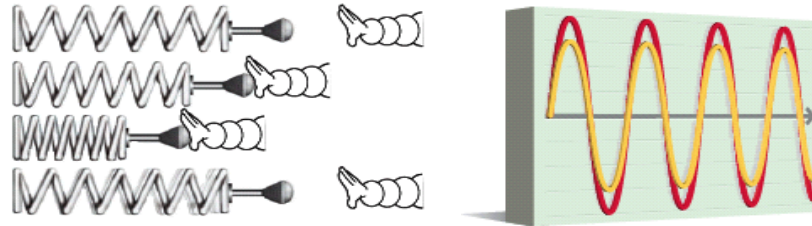
- When considering of forces, torques and speeds at the wheel must be made between different wheel radii:

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.

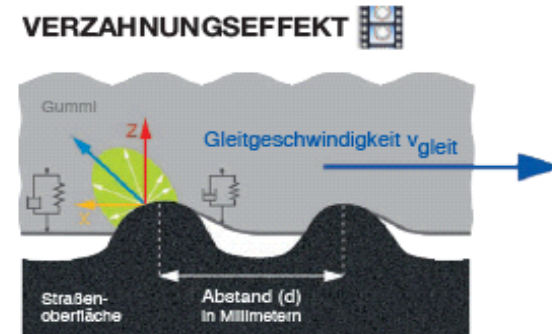
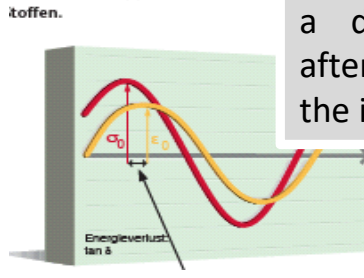
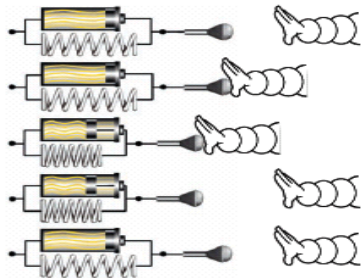


Tires, some fundamentals



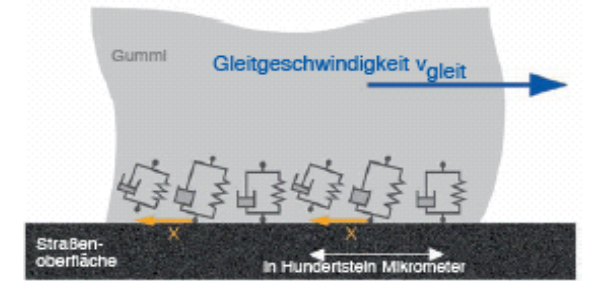
Hysteresis:

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

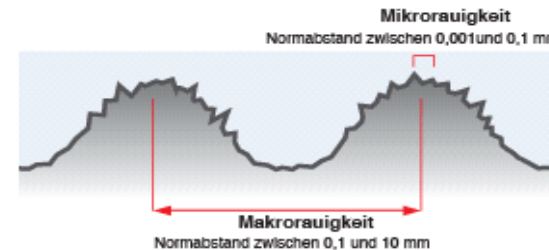


Stößt der Gummiblock gegen eine Erhebung und verformt sich, so kehrt er hystereesebedingt nach der Entlastung nicht sogleich in seine Ausgangslage zurück. Diese asymmetrische Verformung erzeugt ein Kraftfeld, dessen Tangentialkomponente X dem Durchrutschen entgegenwirkt.

MOLEKULARE HAFTUNG

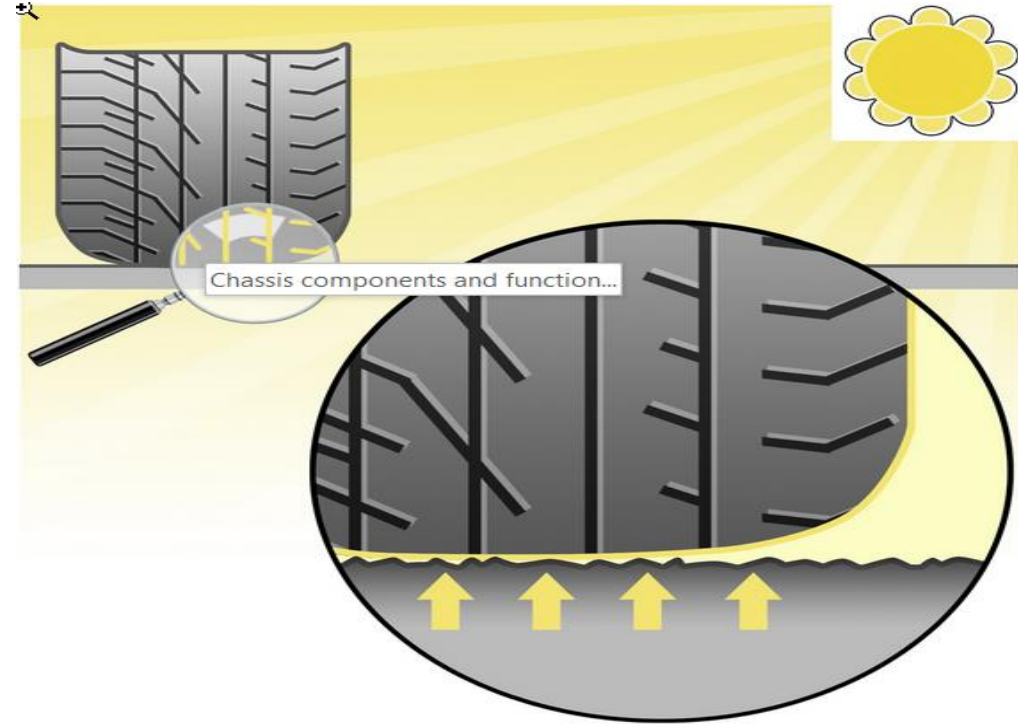


Die Molekülkette wird gedehnt: Aufgrund ihrer viskosen Eigenschaften, symbolisiert durch den Dämpferkolben, widerstehen die Moleküle zunächst der Verformung und erzeugen eine Reibungskraft X, die dem Durchrutschen entgegenwirkt.



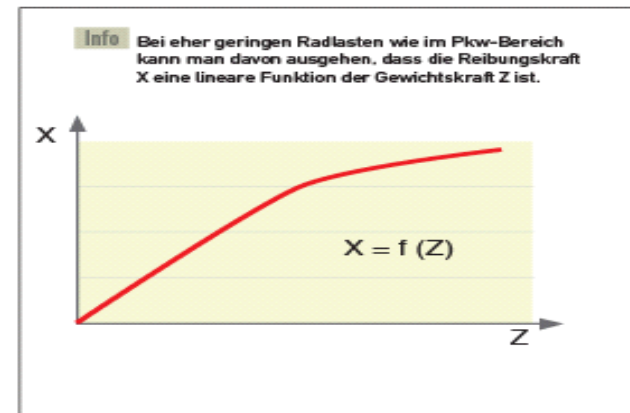
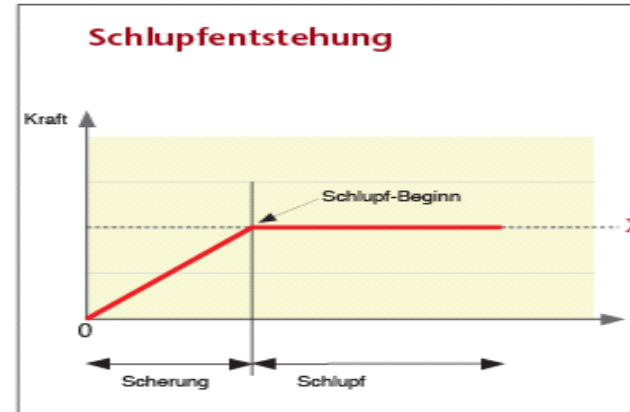
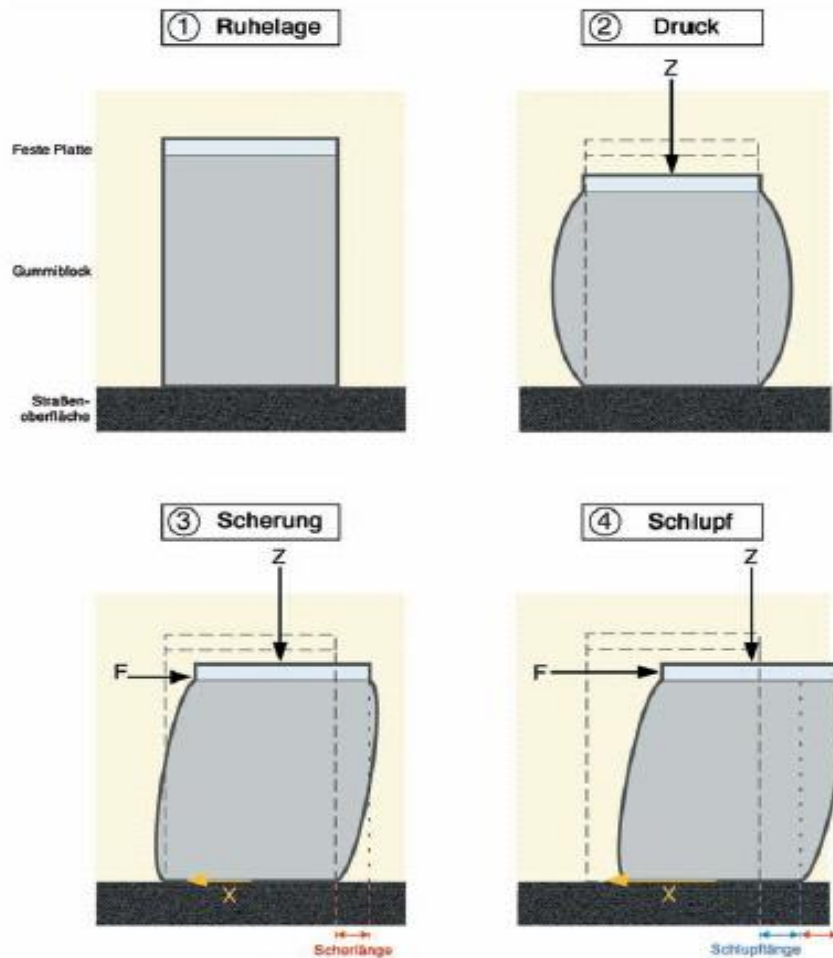
- **Makrorauigkeit.** Dieser Begriff wird gebraucht, wenn der Abstand zwischen zwei "großen" Erhebungen zwischen 100 Mikrometern und 10 Millimetern beträgt. Diese Größe unterstützt den Verzahnungseffekt sowie die Wasserabführung und -einlagerung. Über den Grad der Makrorauigkeit bestimmt das verwendete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

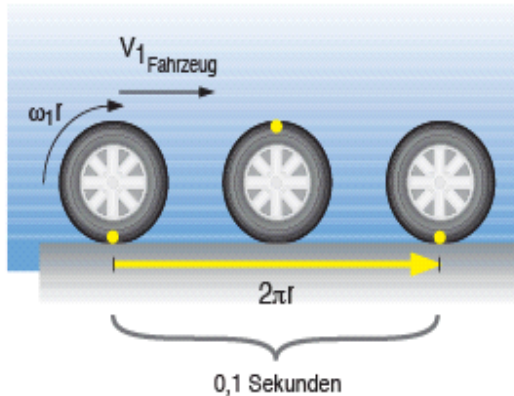
Target conflicts (trade-off) for the development



Tire longitudinal slip behavior

1 VOR BREMSBEGINN

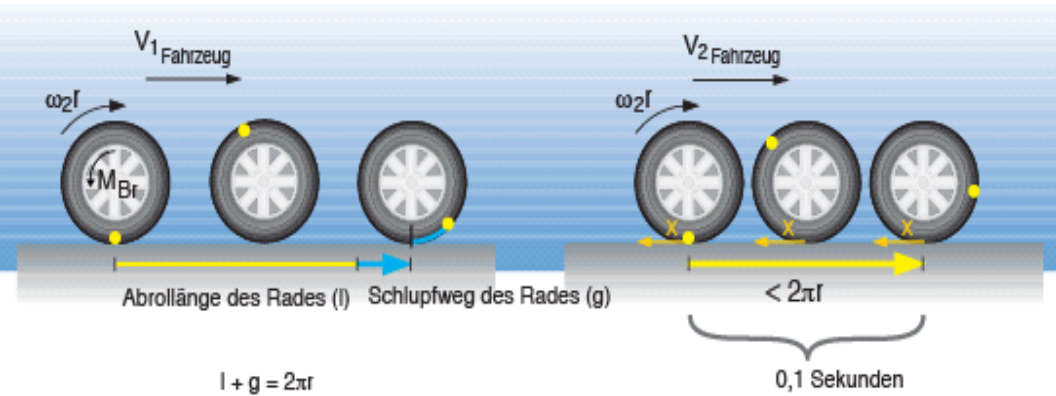
Nehmen wir an, ein Rad lege eine Umdrehung (360°) innerhalb einer Zeit $t = 0,1$ s bei einer Fahrgeschwindigkeit $v = 70$ km/h zurück. Die in dieser Zeit vom rollenden Rad (und gleichzeitig vom Fahrzeug) zurückgelegte Strecke entspricht genau einer abgewickelten Radlänge oder, mathematisch ausgedrückt,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



$$V_1 \text{ Fahrzeug} = V_{\text{Rad}} = \omega_1 \cdot r$$

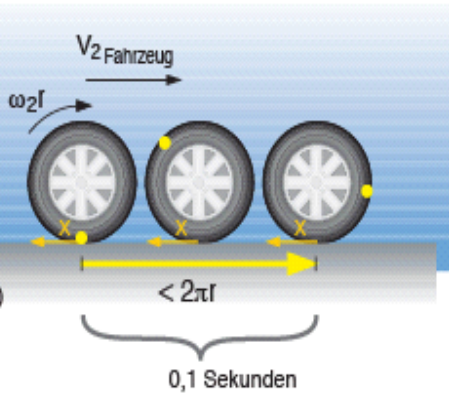
2 WÄHREND DES BREMSVORGANGS

Sobald der Fahrer das Bremspedal niedertritt, fällt die Radumfangsgeschwindigkeit ($\omega \cdot r$) unter den Betrag der Fahrgeschwindigkeit. Von diesem Moment an, wenn das Fahrzeug eine Strecke entsprechend $2\pi \cdot r$ zurücklegt, vollführt das Rad keine vollständige Umdrehung mehr. Um der Vorwärtsbewegung des Fahrzeugs folgen zu können,



$$V_1 \text{ Fahrzeug} > \omega_2 \cdot r$$

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 $2\pi \cdot r$ zurück.



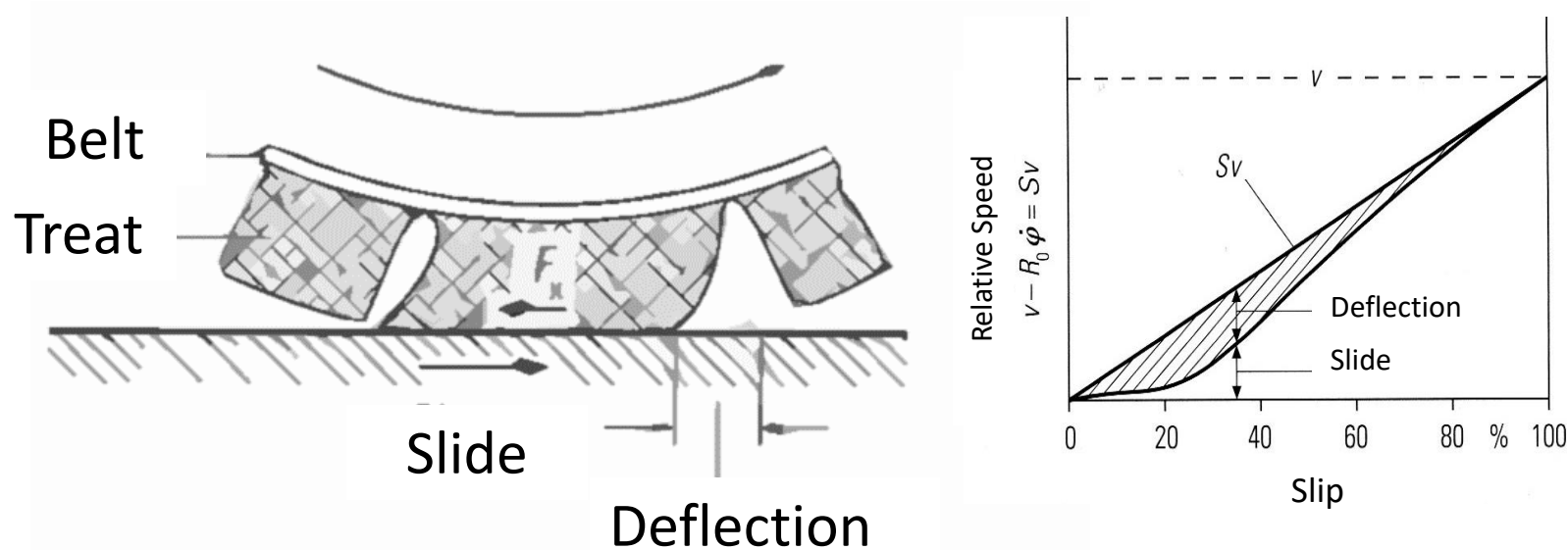
$$V_2 \text{ Fahrzeug} = \omega_2 \cdot r$$

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 Fahrgeschwindigkeit den Wert von $\omega \cdot r$ an: Der Schlupf nimmt ab.

Tire longitudinal characteristics: slip behavior



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).

Slip

$$S = \frac{v_u - v}{v_u} \cdot 100\%$$

Acceleration Slip

$$S_A = \frac{v_u - v}{v_u} \cdot 100\%$$

Brake Slip

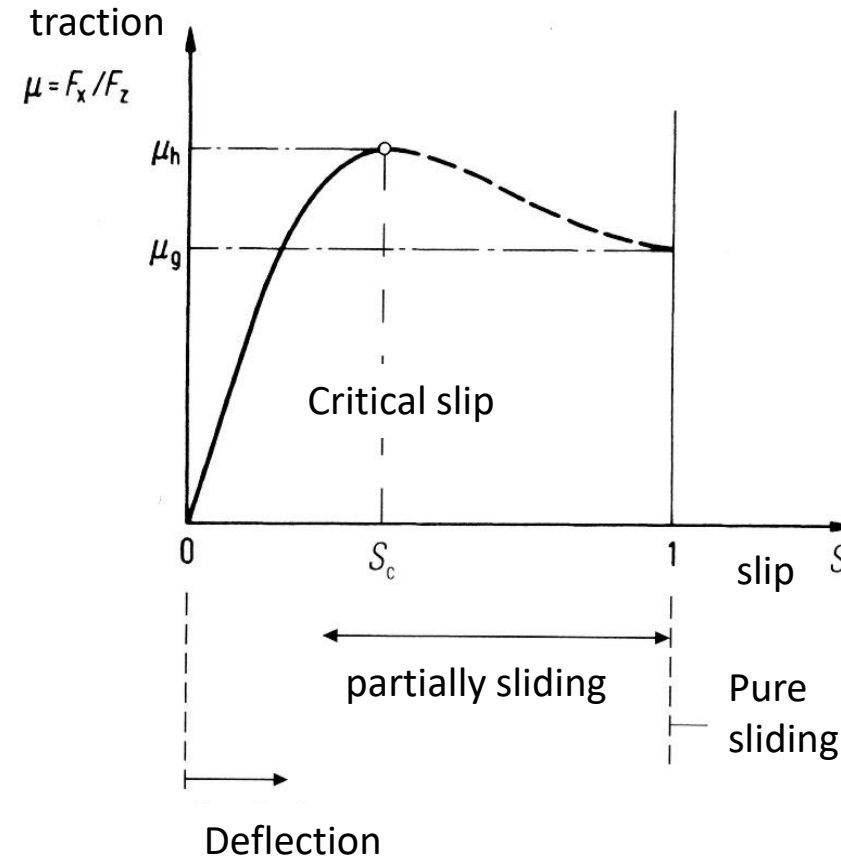
$$S_B = \frac{v - v_u}{v} \cdot 100\%$$

Tire longitudinal characteristics: slip behavior

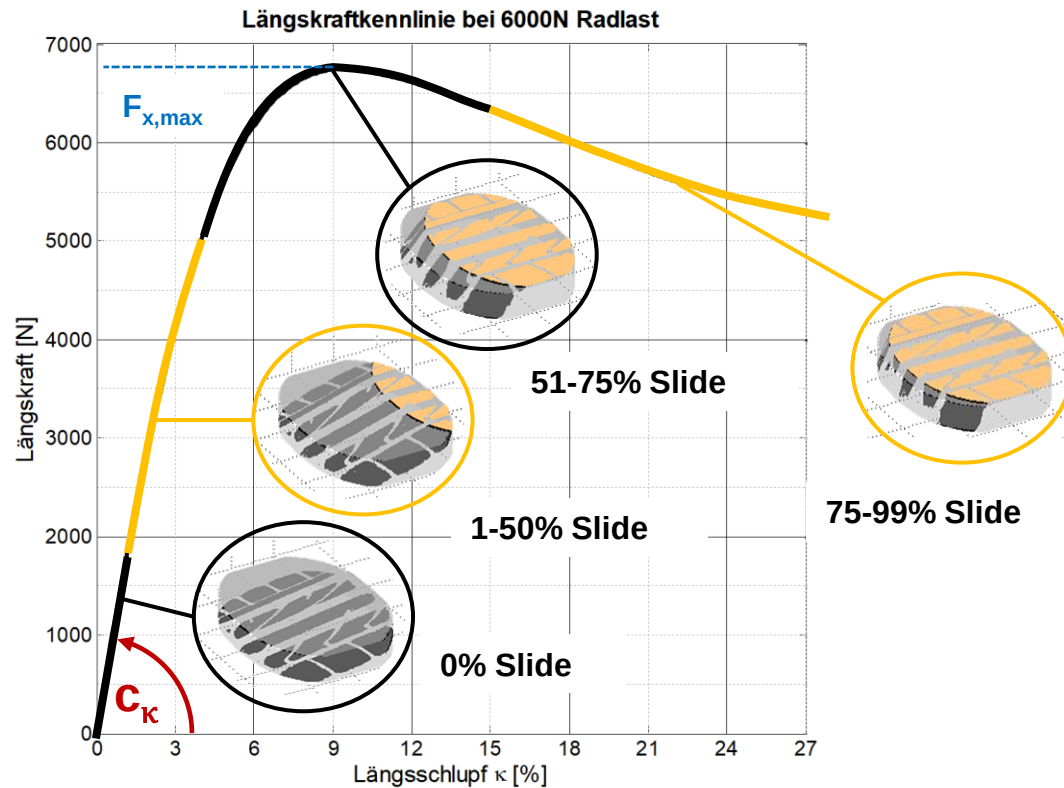
- Transferable force are defined by the adhesion coefficient μ .
- μ is at rubber friction a function of the slip

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

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



Tire longitudinal characteristics: slip behavior



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

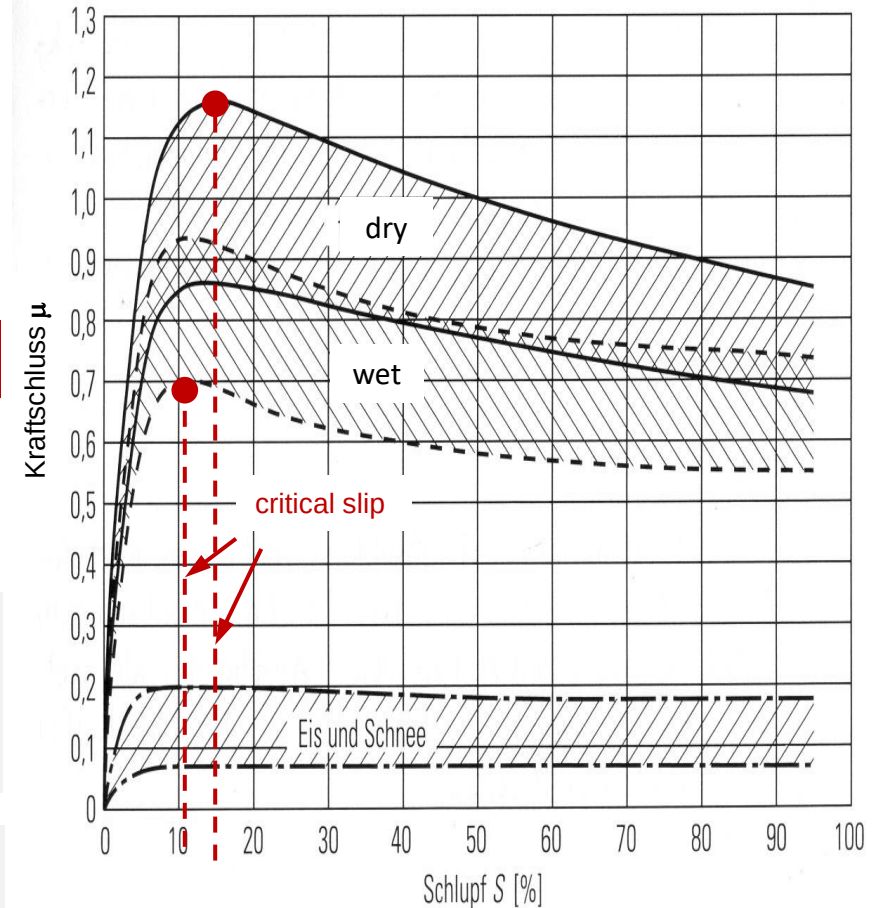
For small longitudinal forces, there is a linear relationship between S and F_x .

c_κ = slip stiffness

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

Influences:

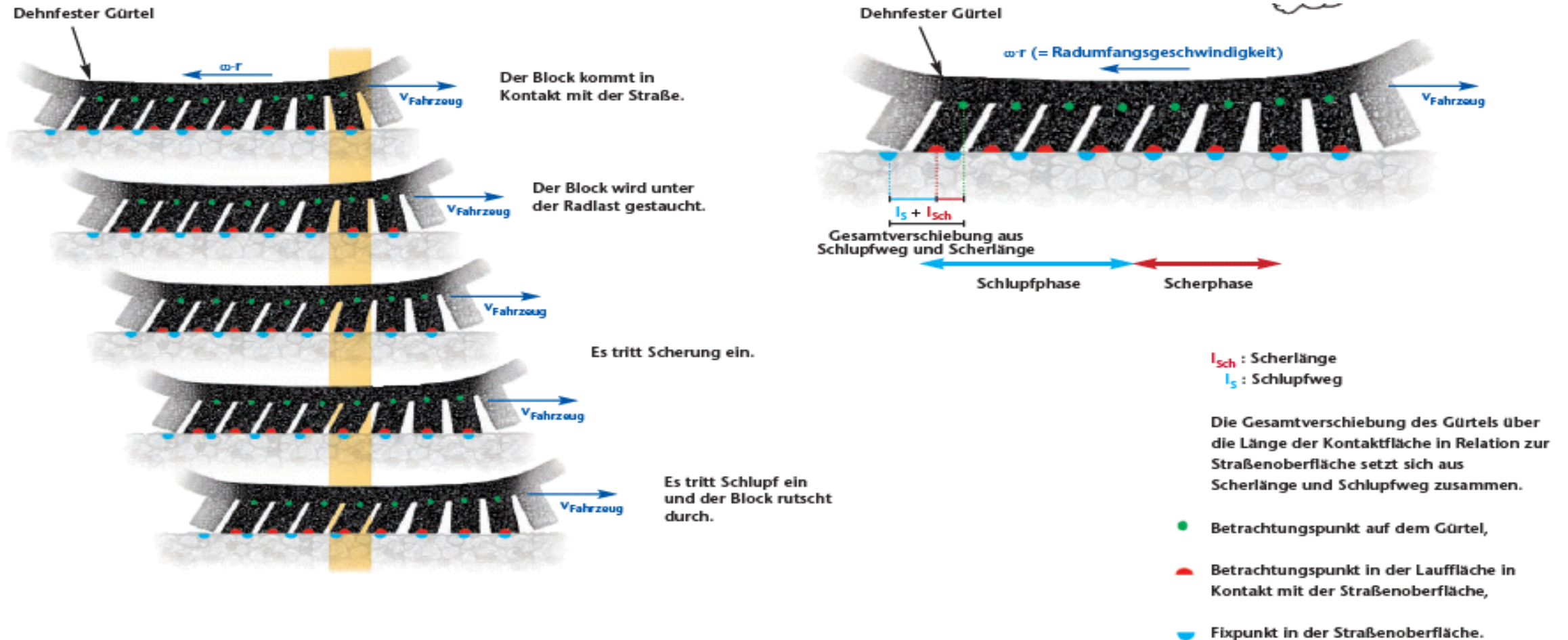
- Tire pressure
- Temperature
- Local friction



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

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

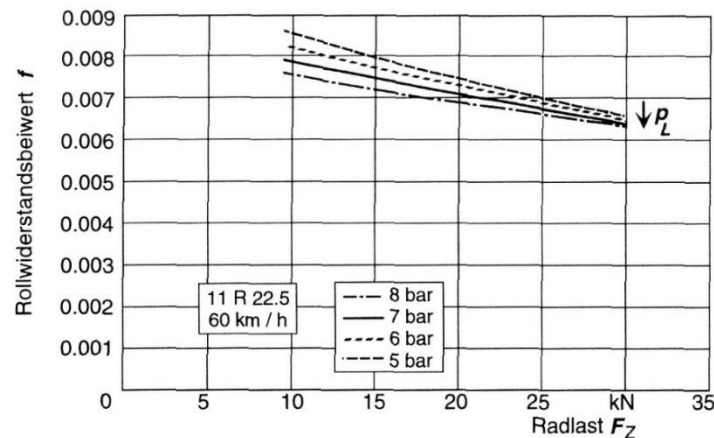
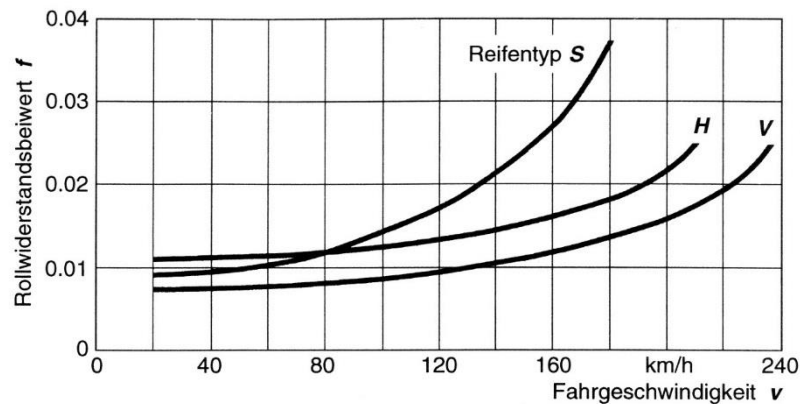
Tire surface and environmental air	Tread of the tire		Side wall and bead area
Air turbulence 	Slip to the ground 	Energy loss dissipation based on deformation Bend - Strain - Shear 	Bend - Shear 
< 15 %	60 up to 70 %		20 up to 30 %

Tire Rolling Resistance (RR) - Sources

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

Roll resistance is depended of:

- wheel load
- tire pressure
- Tire temperature

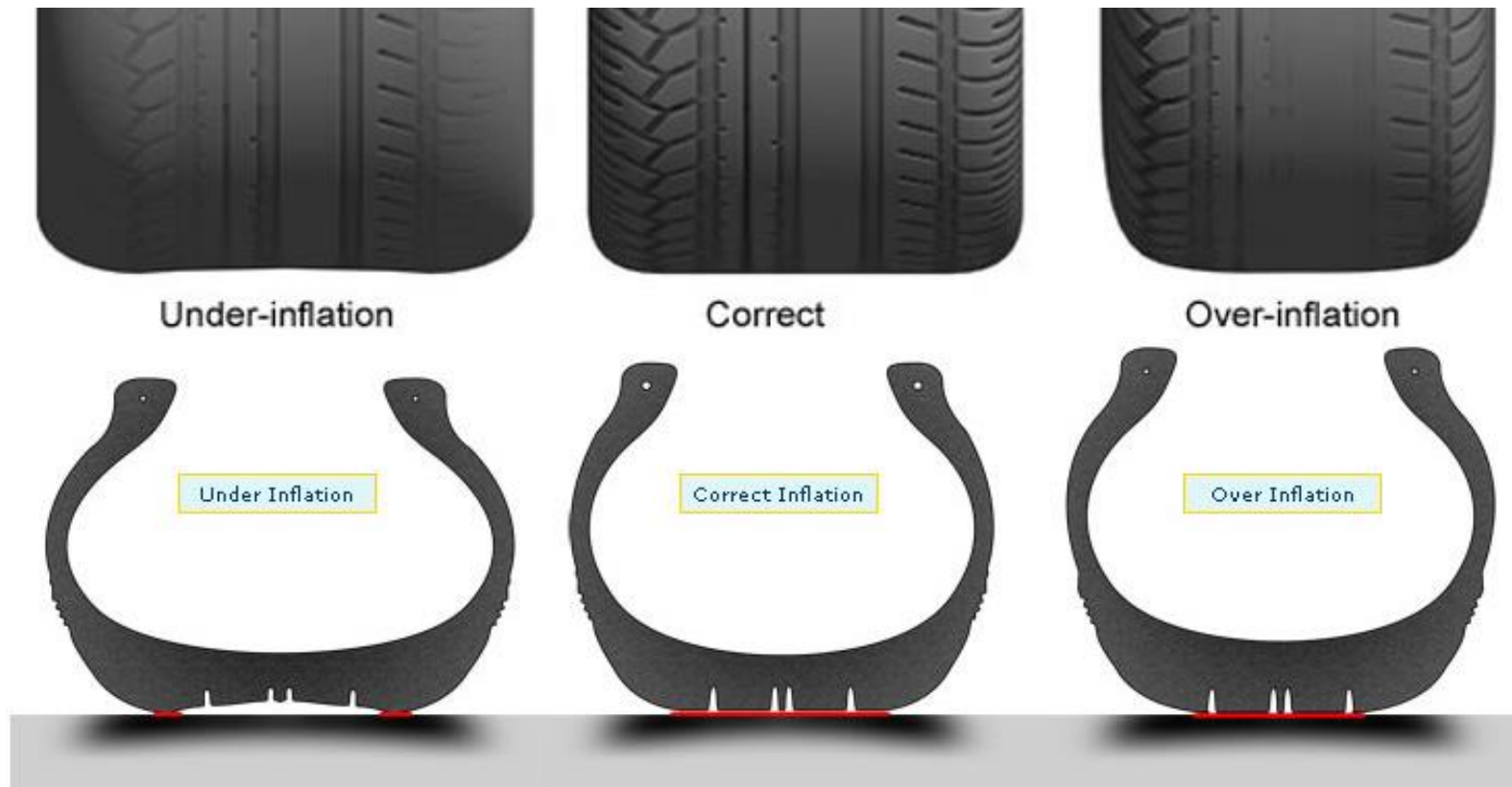


$$f_R = f_{R0} + f_{R1} \cdot \left(\frac{v}{100 \text{ km/h}} \right) + f_{R4} \cdot \left(\frac{v}{100 \text{ km/h}} \right)^4$$

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.

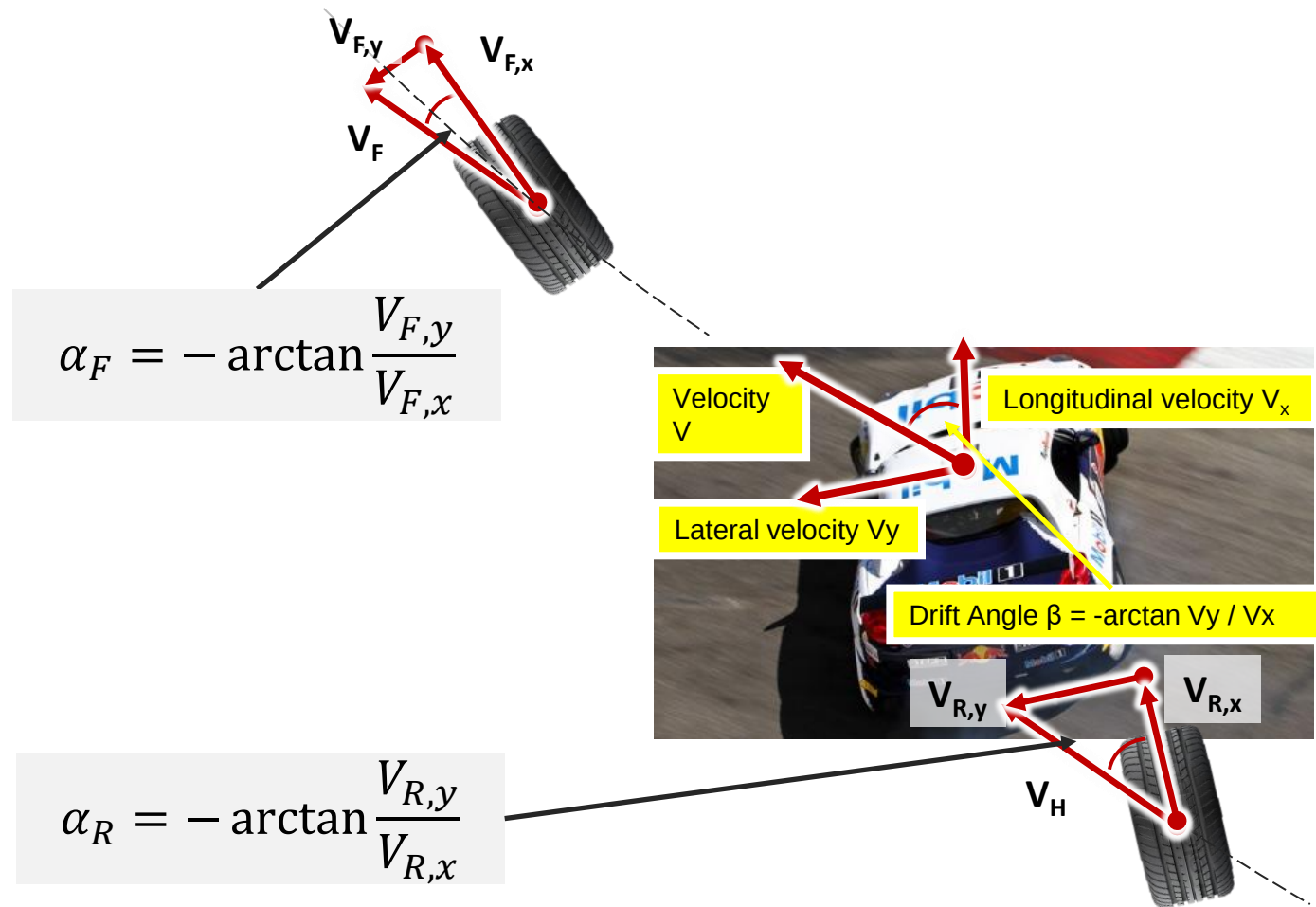
Tire lateral characteristics: side slip behavior



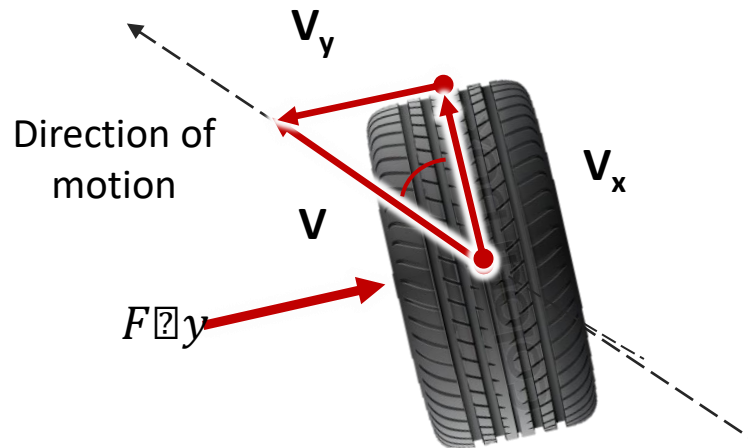
Tire lateral characteristics: side slip behavior



Tire lateral characteristics: side slip behavior



Tire lateral characteristics: side slip behavior



Side slip α :

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

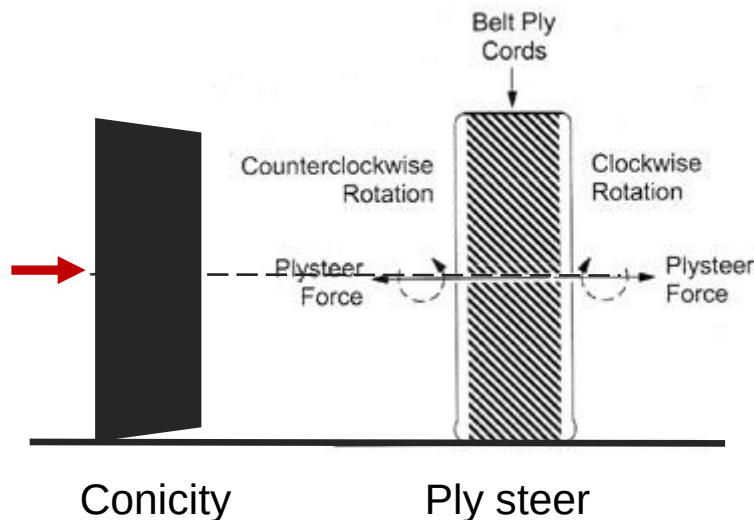
$$\alpha = -\arctan \frac{V_y}{V_x}$$

Tire side force generated by:

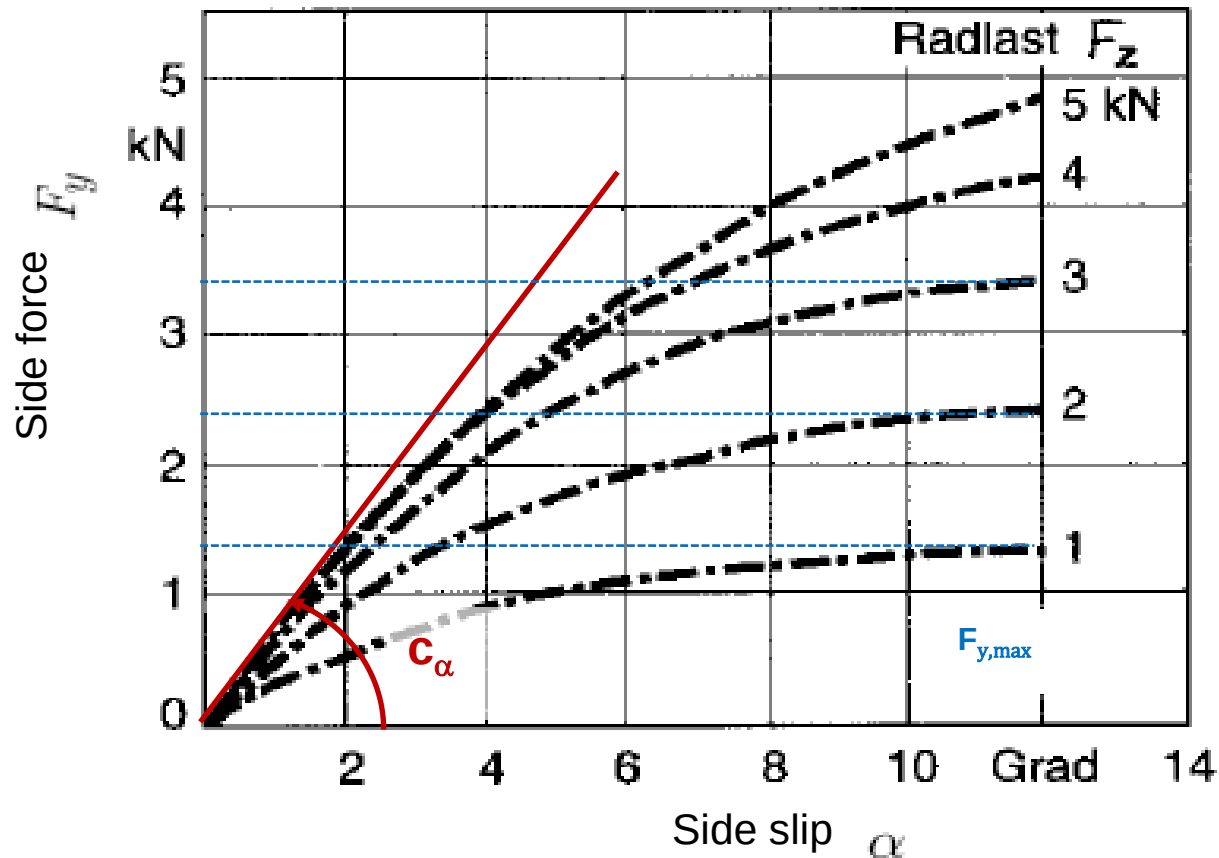
- Rolling diagonal to the direction of motion (side slip angle α).
- Inclination of the tire from its vertical position to the road (camber γ).
- Tire conicity (geometrical)
- Ply steer (tread/belt construction)

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 F_y .
- c_α is called side slip stiffness.

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

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

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

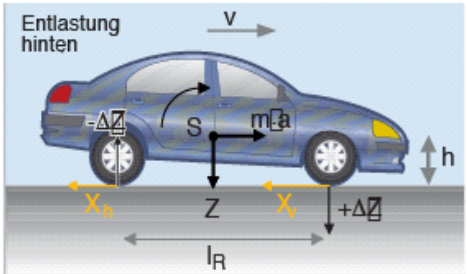
- The maximum transferable lateral forces are dependent on maximum adhesion in lateral direction.

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 unbremsten 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.

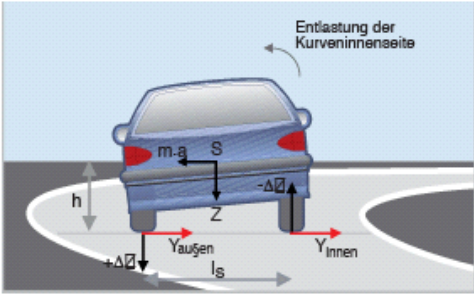


X = Längsreibungskraft vorne (X_v) und hinten (X_h), in N
 S = Schwerpunkt des Fahrzeugs,
 m = Masse des Fahrzeugs, in kg
 a = Beschleunigung in Längsrichtung, in m/s^2
 Z = Gewichtskraft (= Summe der 4 Radlasten), in N
 h = Schwerpunkthöhe über der Straße, in m
 l_R = Radstand des Fahrzeugs, in m

■ GEWICHTSVERLAGERUNG ZUR SEITE

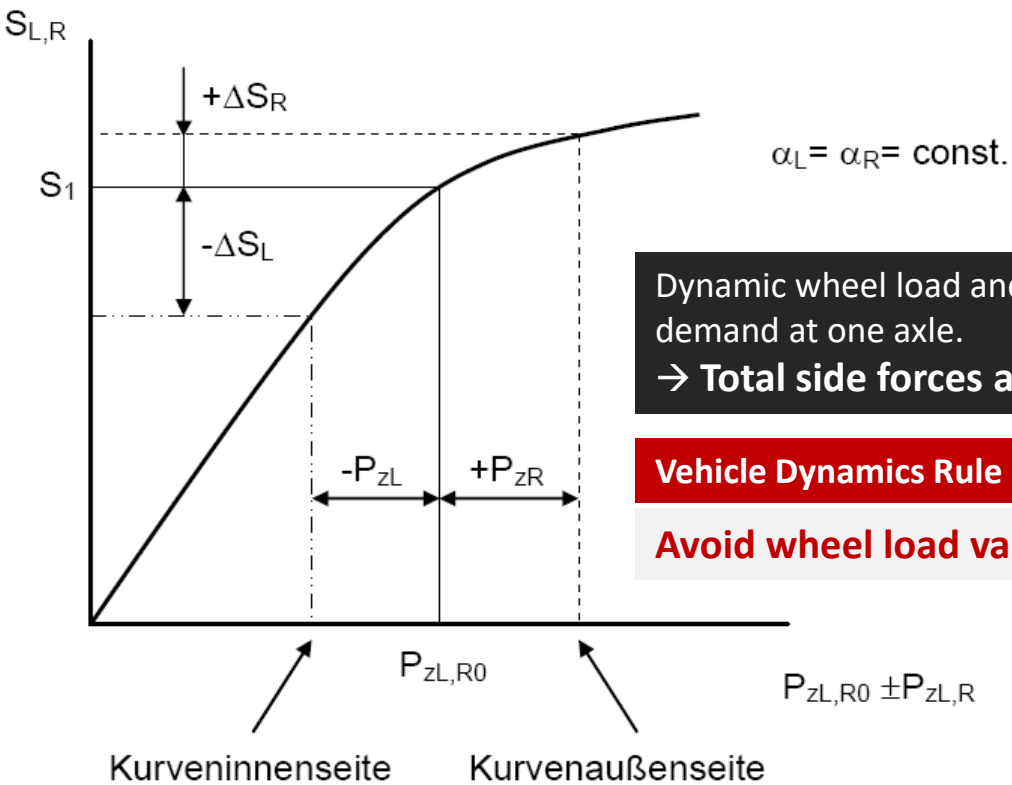
Nehmen wir an, die Schwerpunkthöhe eines Fahrzeugs ist bekannt und die seitliche Reibungskraft Y greift in der Kurve an den Schnittstellen Reifen/Straße an. Das entstehende Rollmoment verursacht eine **dynamische Achslastverschiebung** von der Kurvenaußen- auf die -innenseite, so dass fliehkraftbedingt 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/s^2
 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

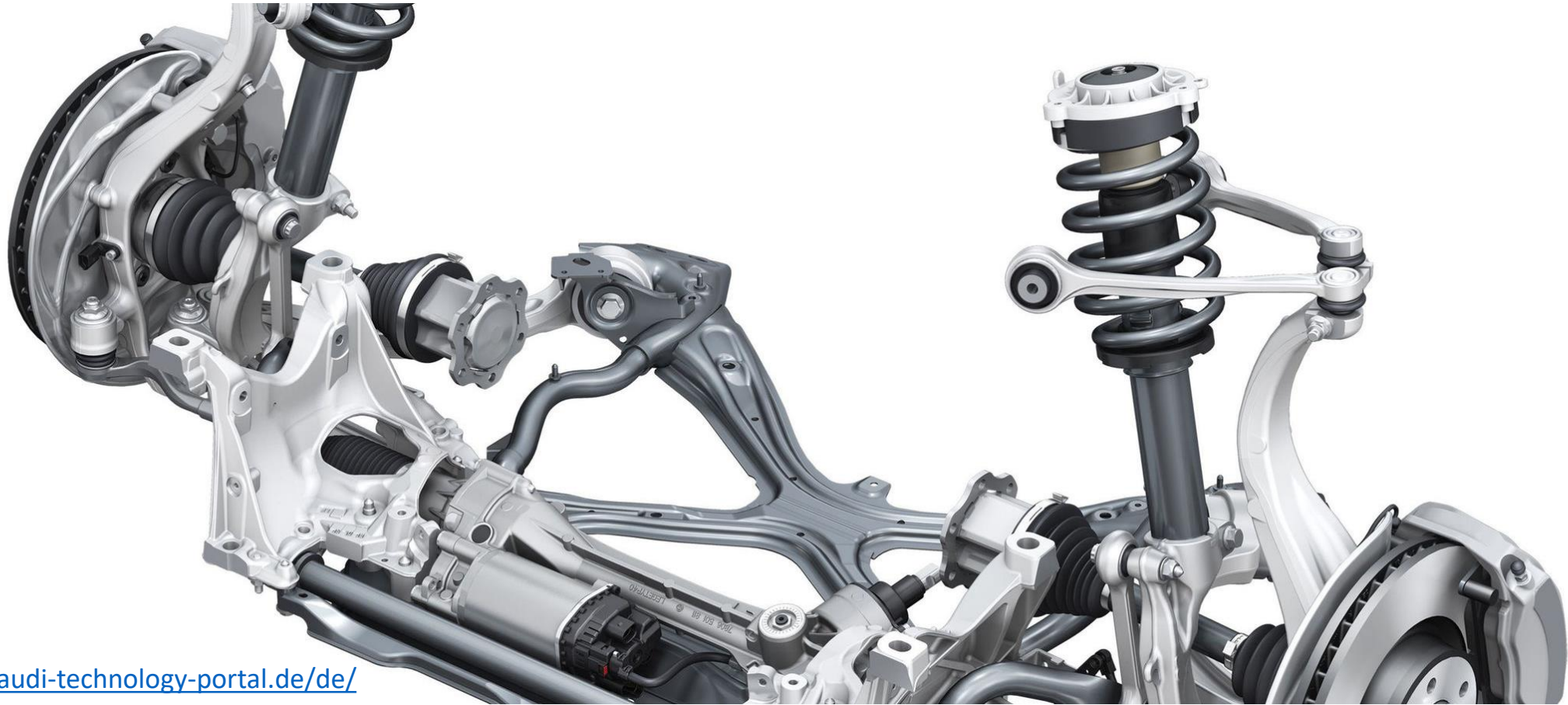


Dynamic wheel load and side force demand at one axle.
→ Total side forces are reduced

Vehicle Dynamics Rule No. 1:
Avoid wheel load variation

Chassis systems their function and structure

<https://www.audi-mediacycenter.com/de/technik-lexikon-7180/fahrwerk-7185>

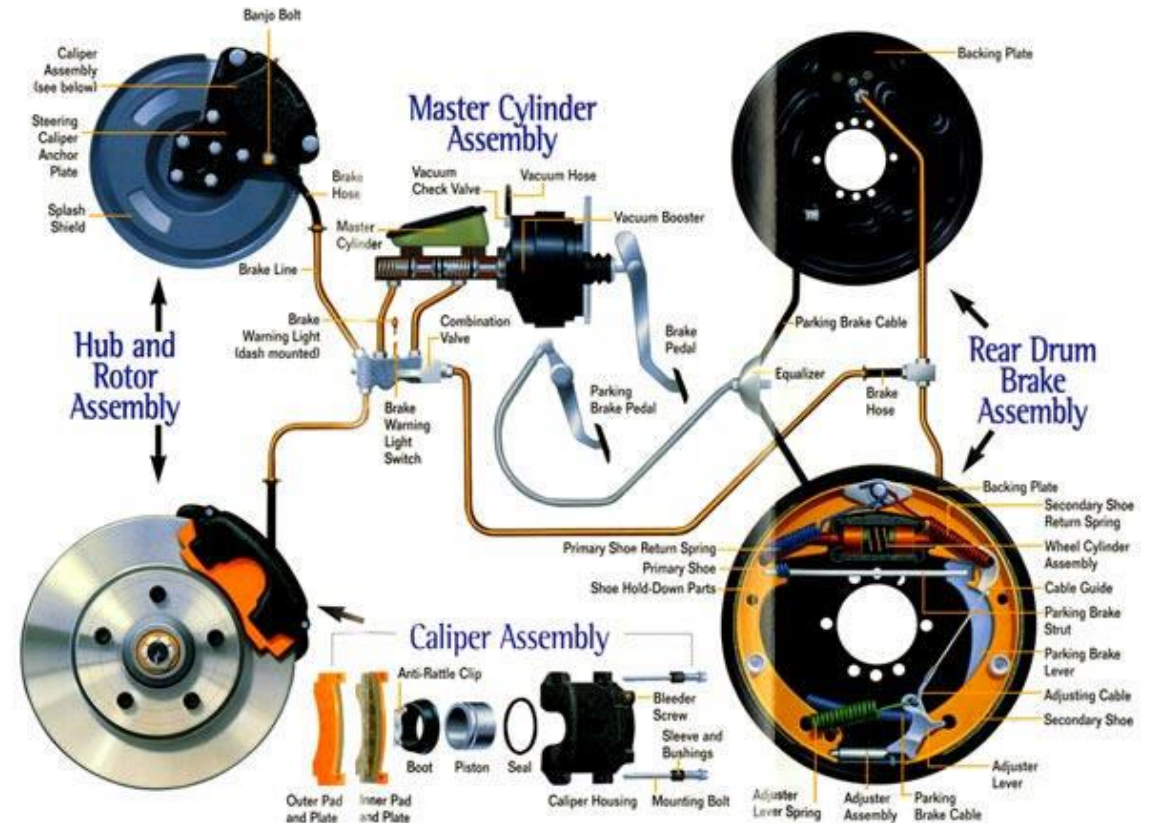


<https://www.audi-technology-portal.de/de/>

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 to 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.

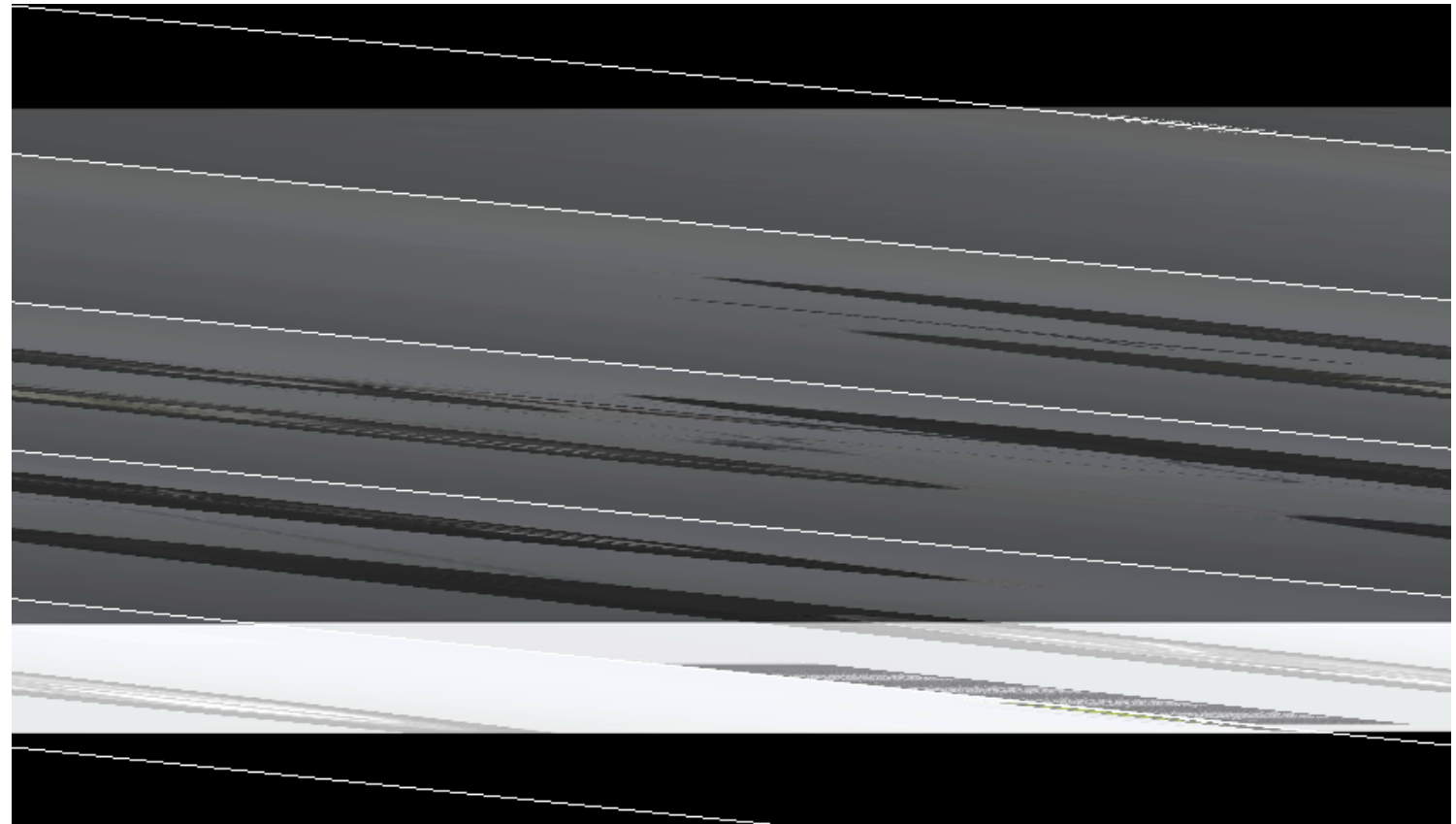


<https://www.youtube.com/watch?v=ugtrRmyPSfE>

Hydraulik Brake system and brake control systems

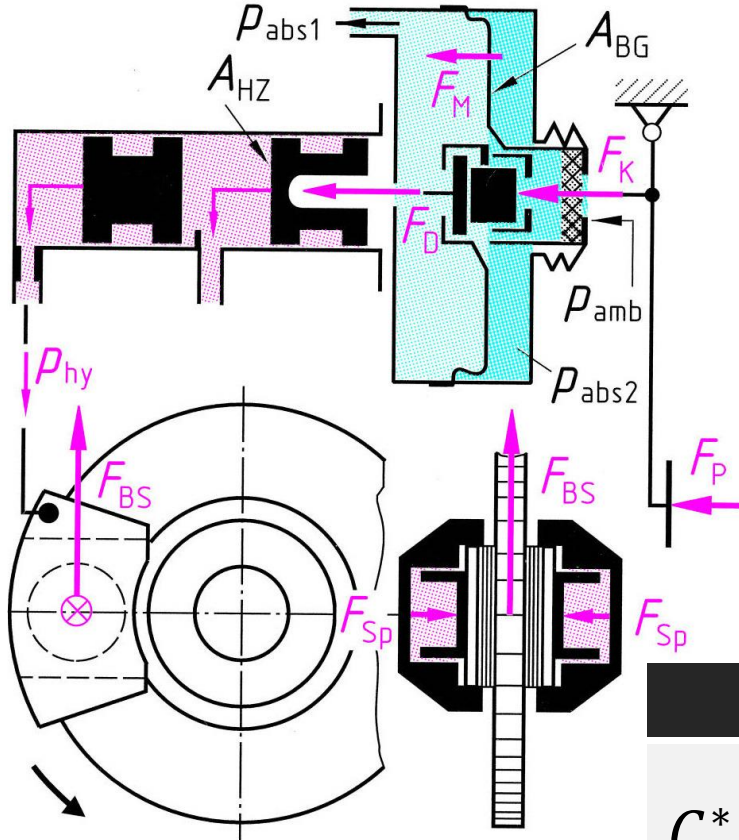


https://www.youtube.com/watch?v=GHT0u_7abvs



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

External and internal force ratio of a brake system

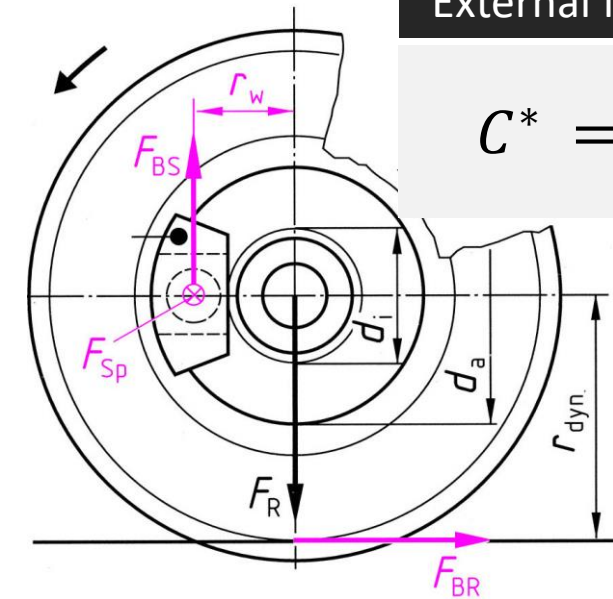


External force ratio

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

Brake disk characteristics

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



External force ratio

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

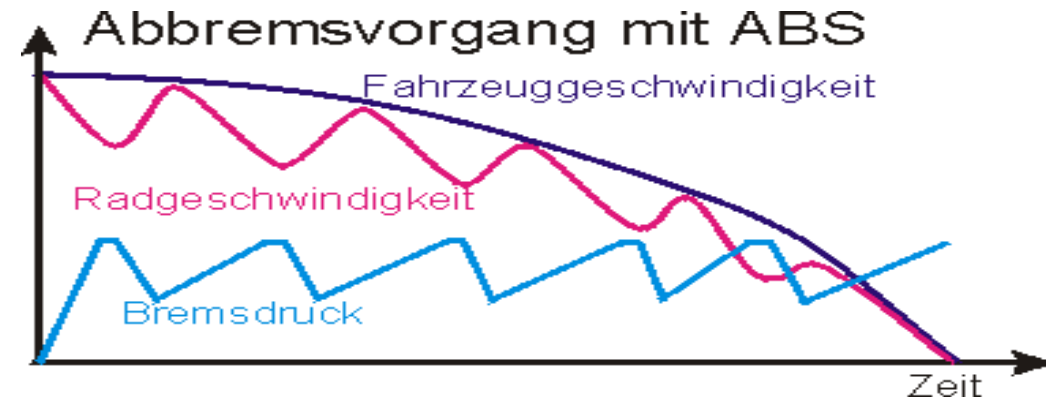
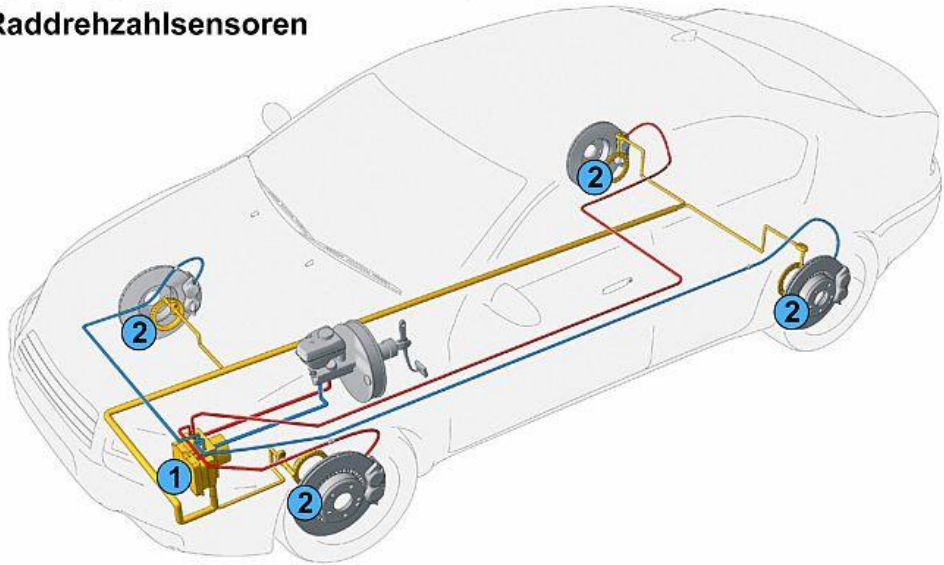
Wheel brake force

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

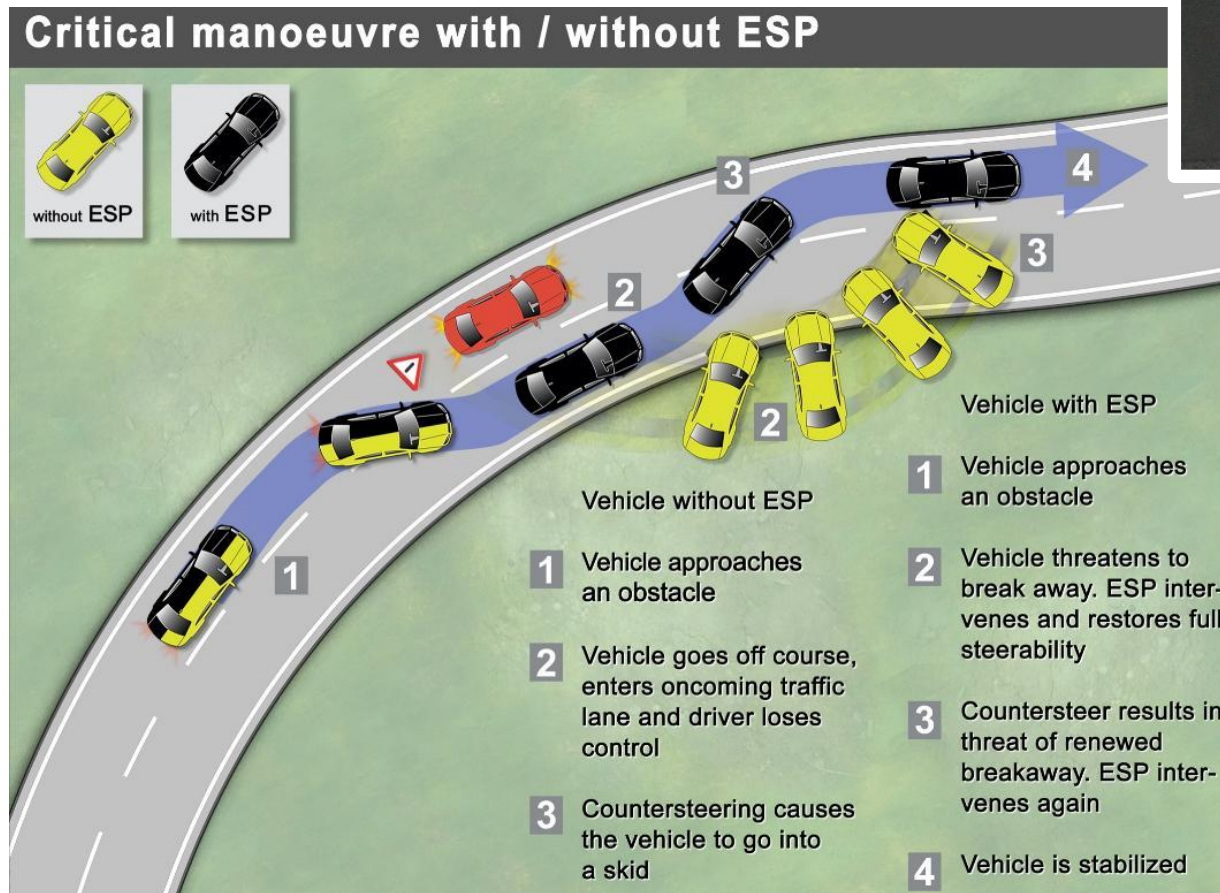
ABS – Antiblockiersystem (Antilocking System)

Antiblockiersystem ABS

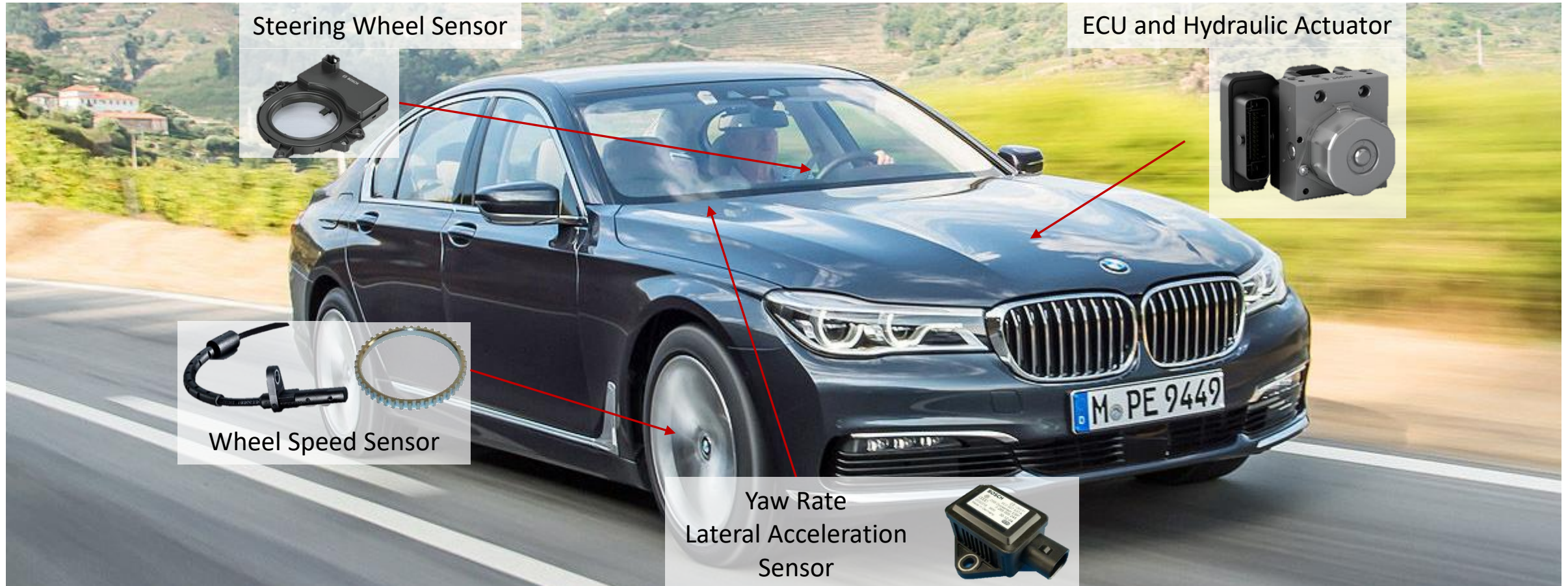
- ① Hydroaggregat mit Anbausteuergerät
- ② Raddrehzahlsensoren



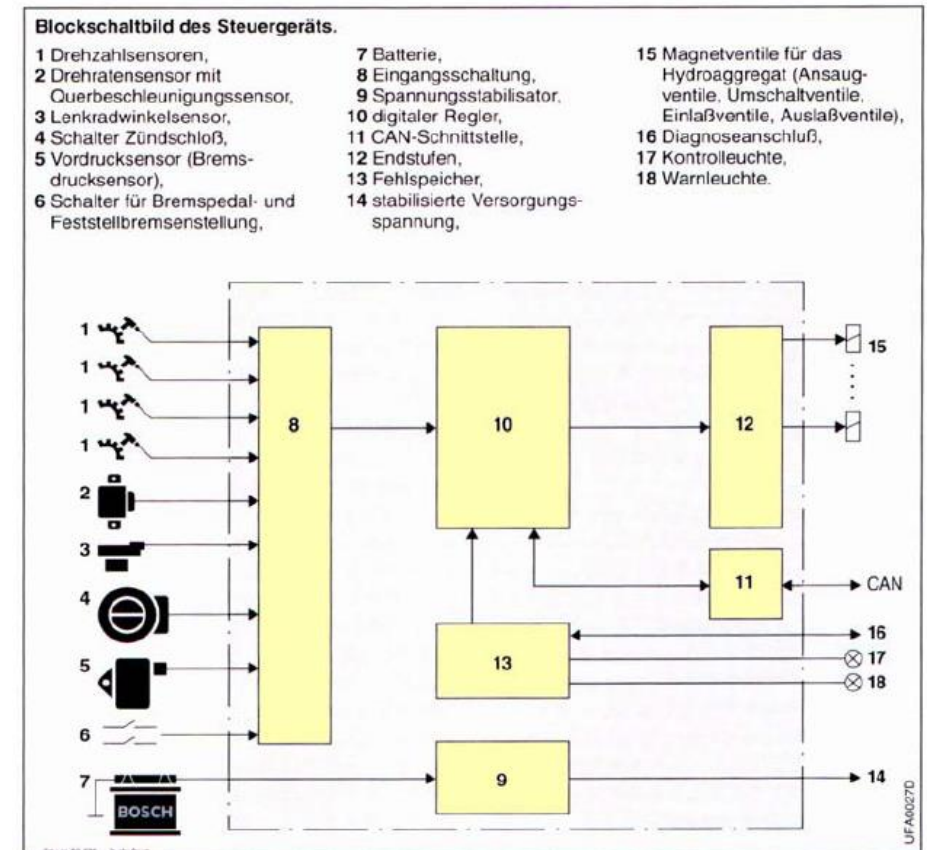
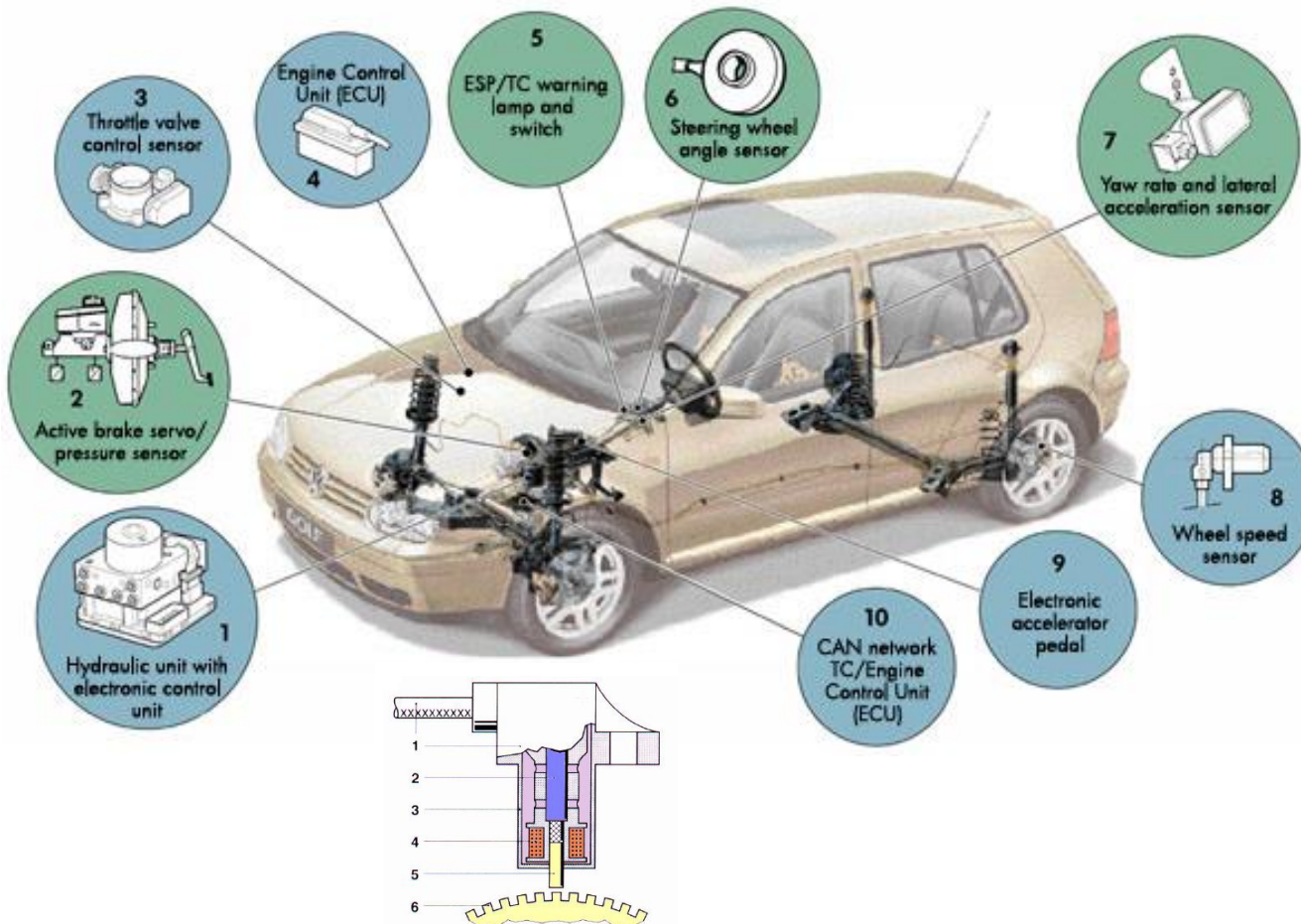
Electronic Stability Program (ESP)



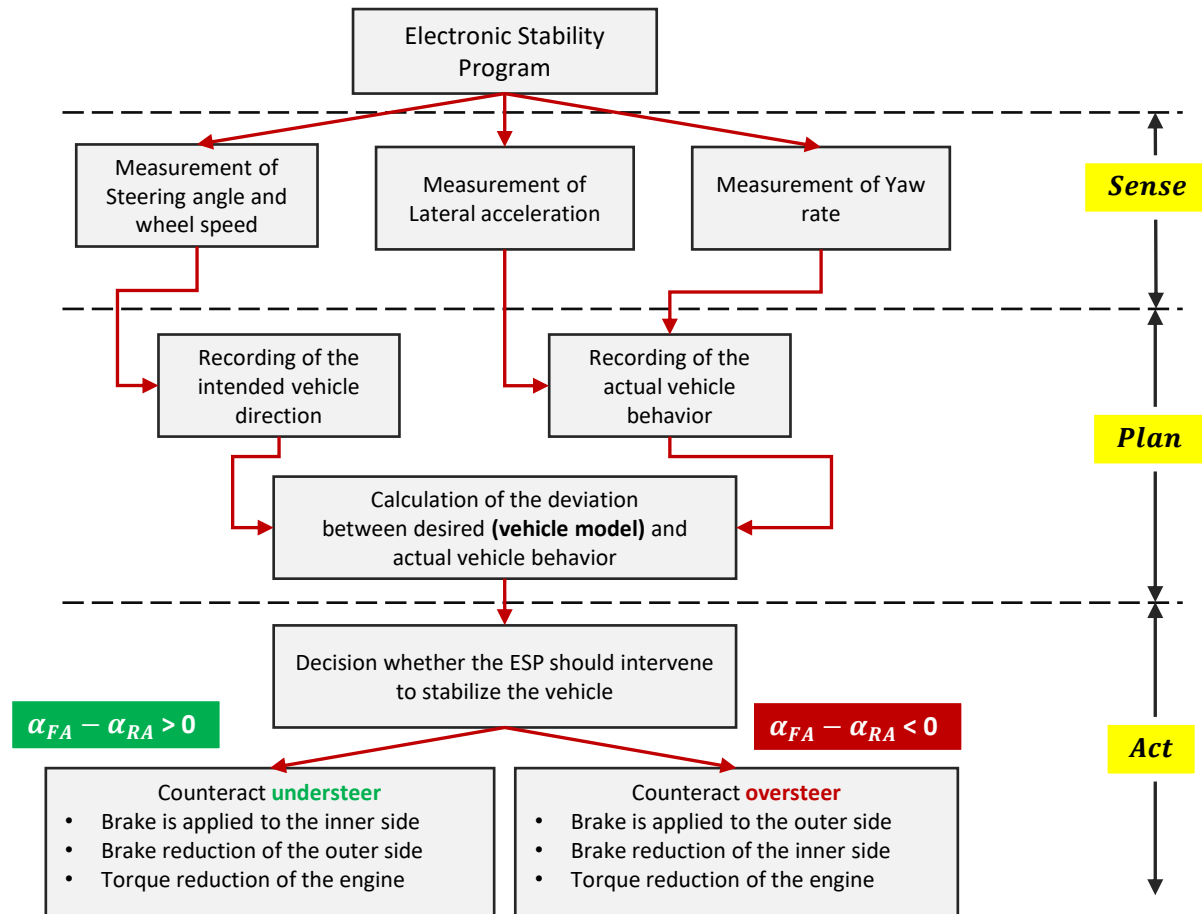
Electronic Stability Program (ESP)



Electronic Stability Program (ESP)

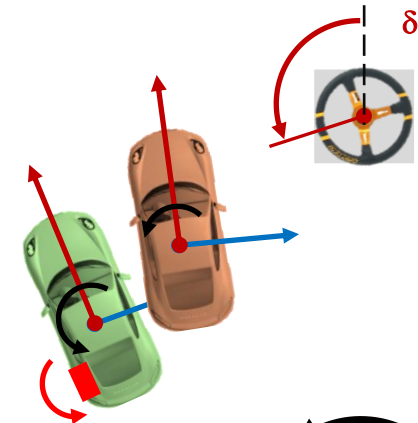


Electronic Stability Program (ESP)



Counteract **understeer**

- Brake is applied to the inner side
- Brake reduction of the outer side
- Torque reduction of the engine

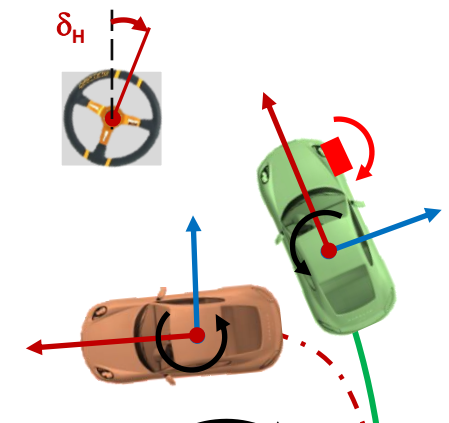


Yaw moment compensation

With ESP

Counteract **oversteer**

- Brake is applied to the outer side
- Brake reduction of the inner side
- Torque reduction of the engine



Yaw moment compensation

Without ESP

Audi Talk – Chassis technologie from rigid axle to intelligent chassis



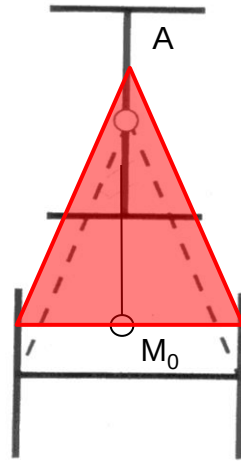
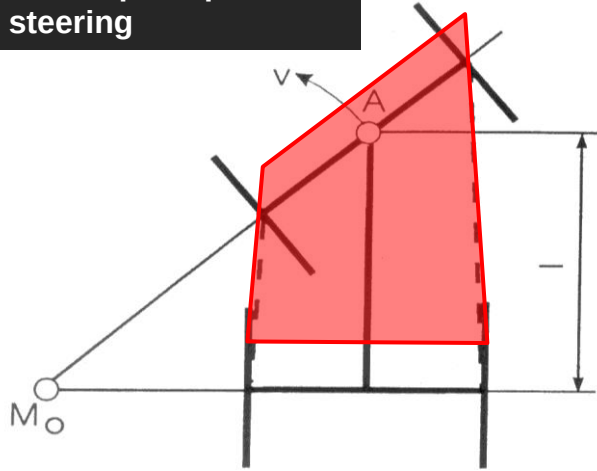
Steering System



Chassis systems their function and structure

Steering System

Center pivot plate steering



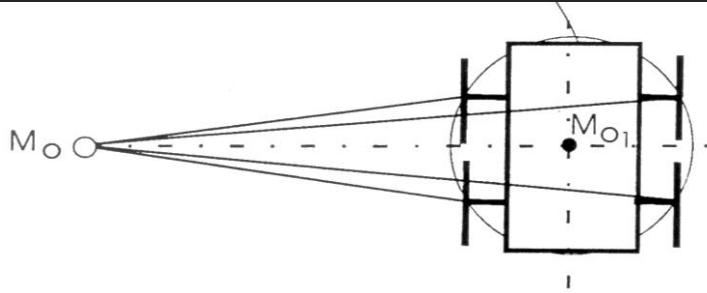
articulated steering



Chassis systems their function and structure

Steering System

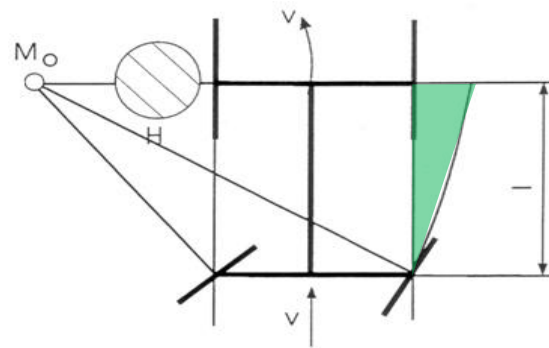
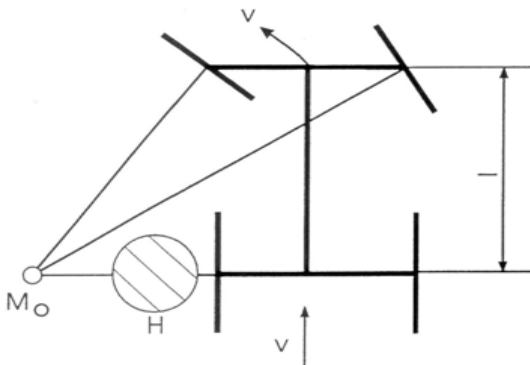
Wheel Side Steer thru different wheel speed



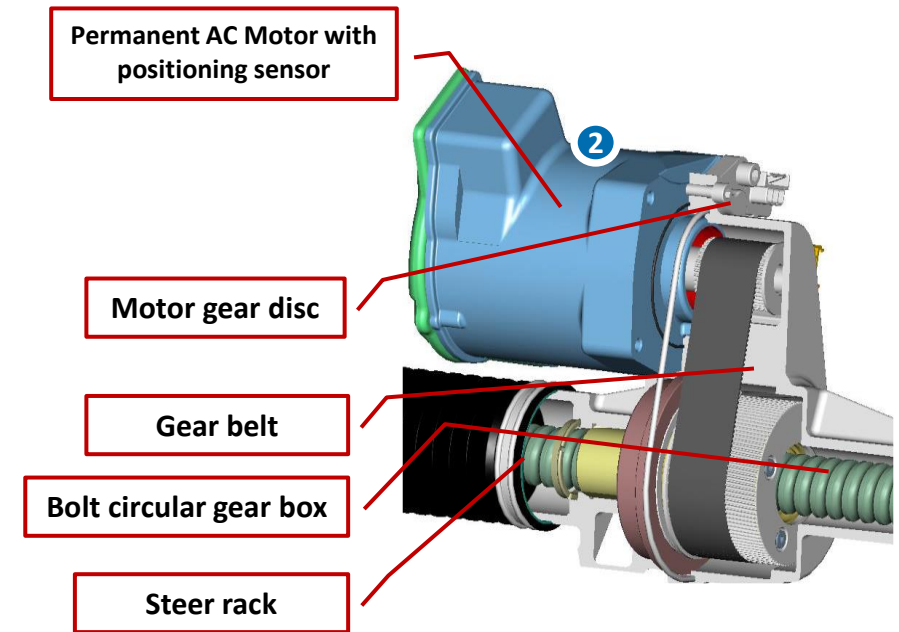
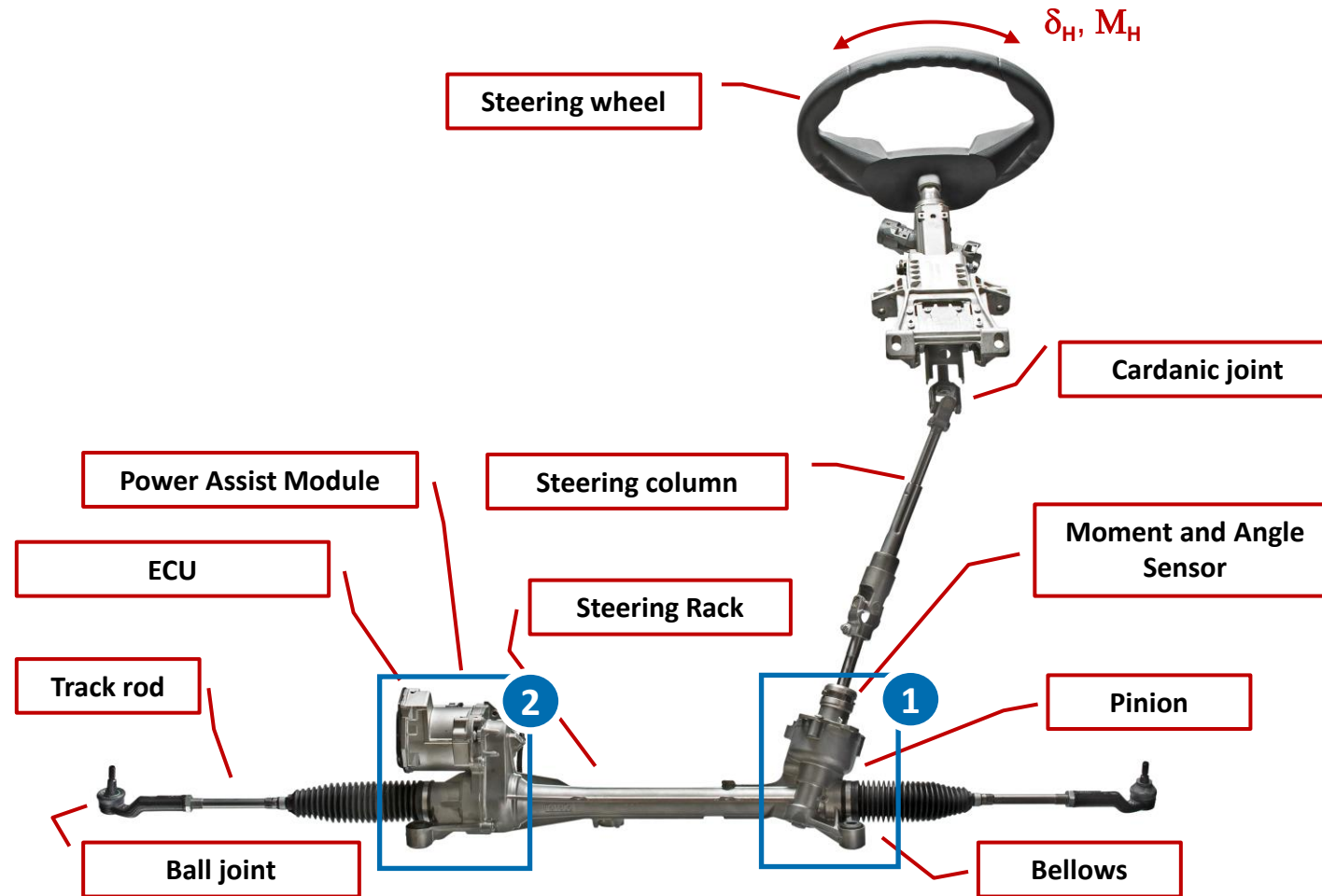
Front Steer



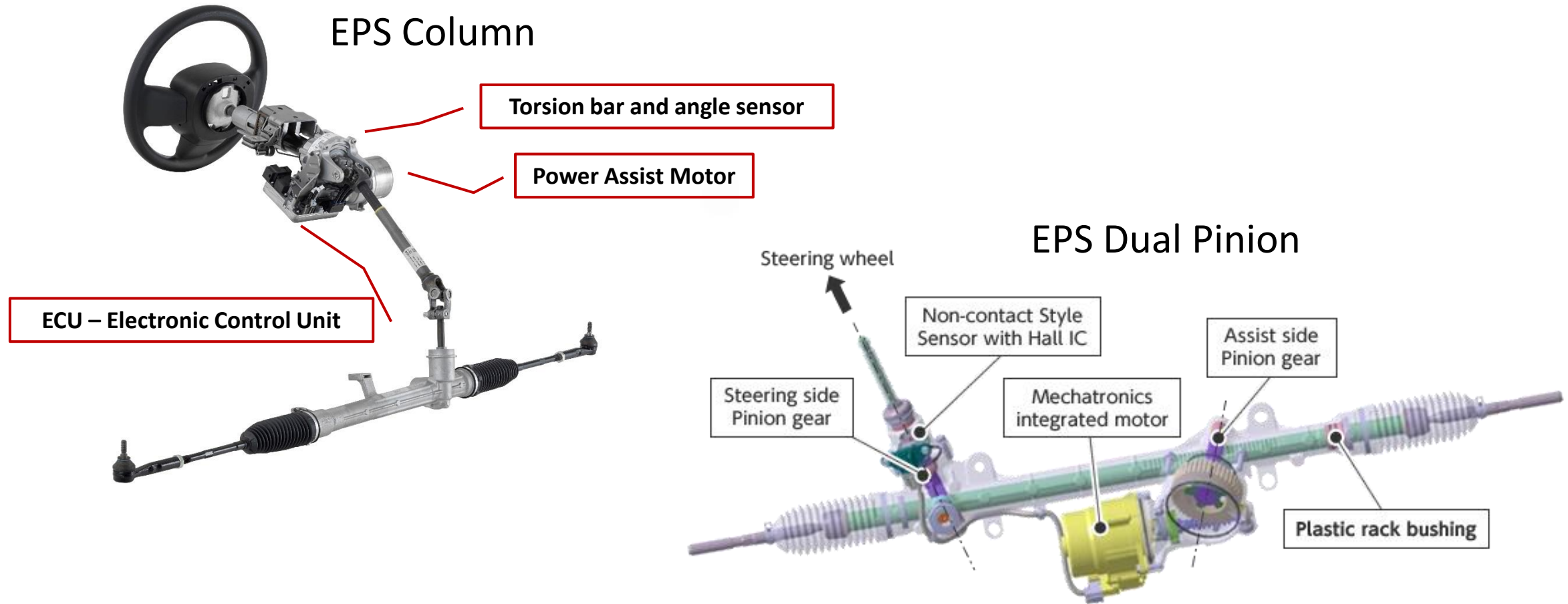
Rear Steer



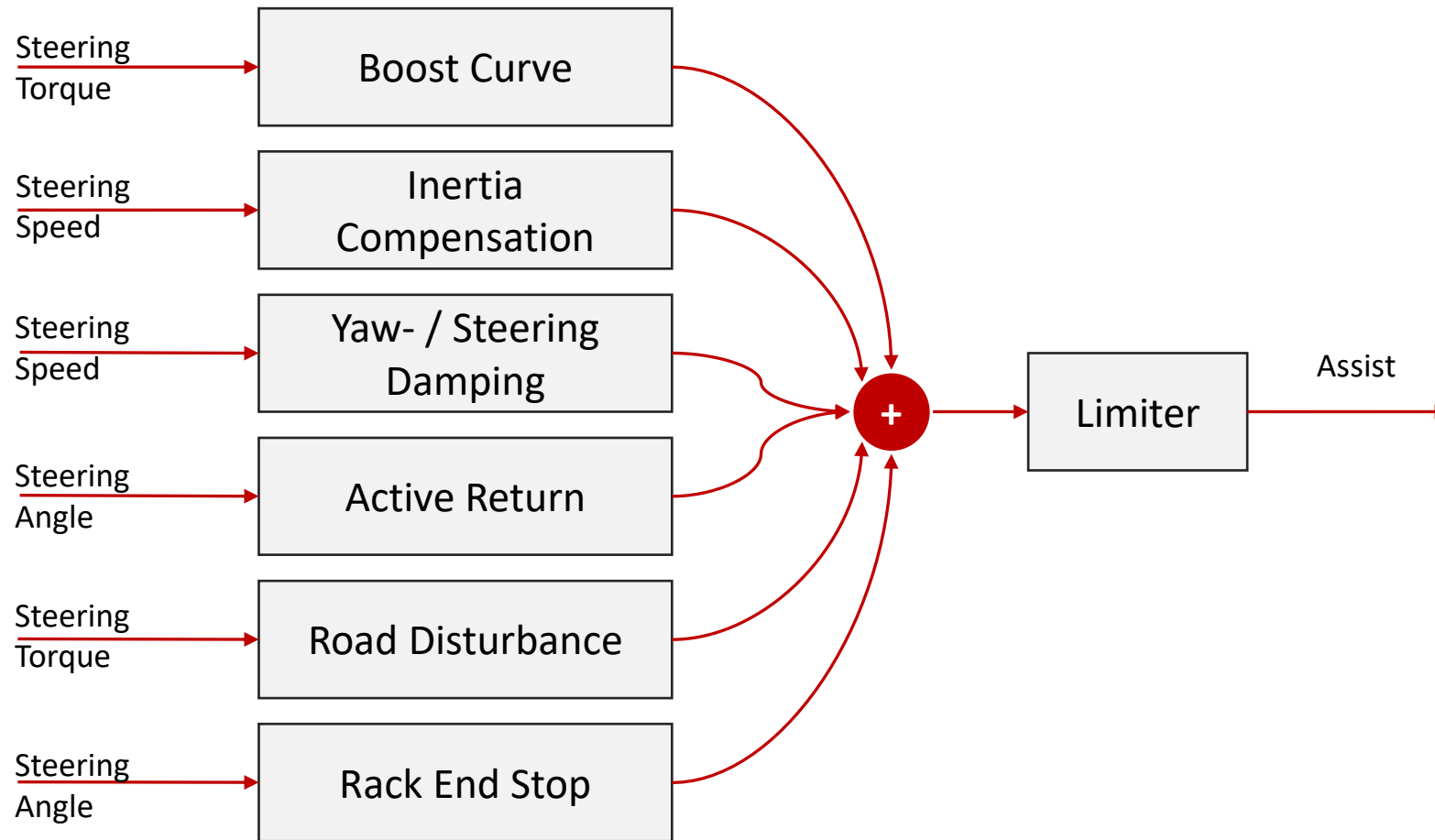
Steering system – Electrical Power Steer (EPS) EPS apa (axle parallel)



Steering system – Electrical Power Steer (EPS)



EPS Basic Functions



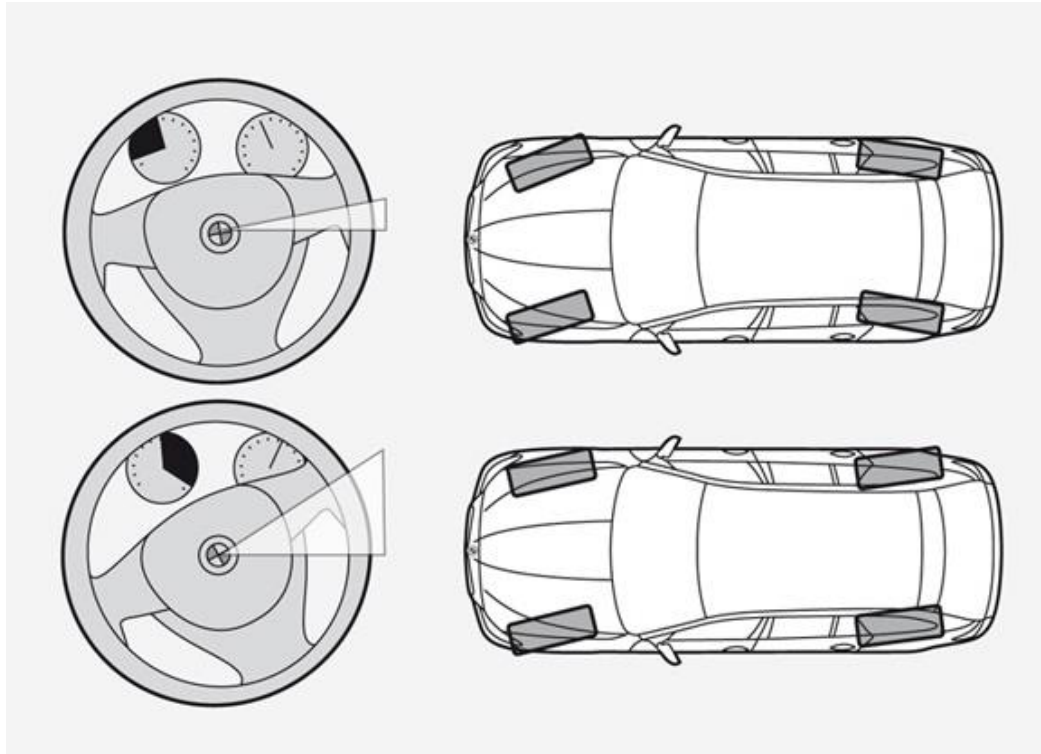
Chassis systems their function and structure

Rack and pinion steering system



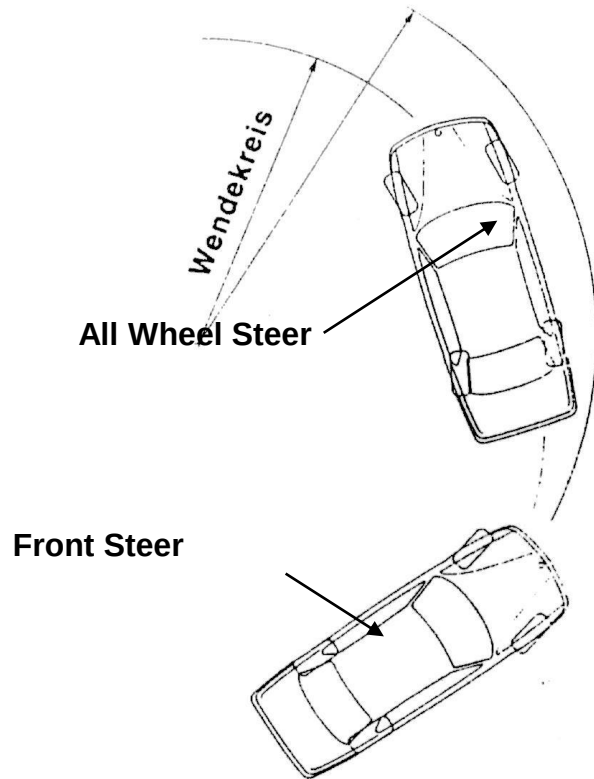
https://www.youtube.com/watch?v=DC6Opx_3EUo

All Wheel Steering System



All Wheel Steering System

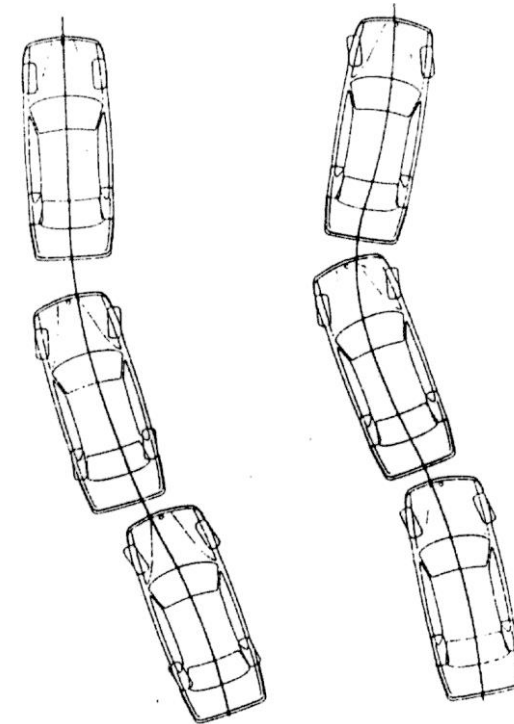
Steering in the opposite direction of rear wheels to achieve a small turning circle



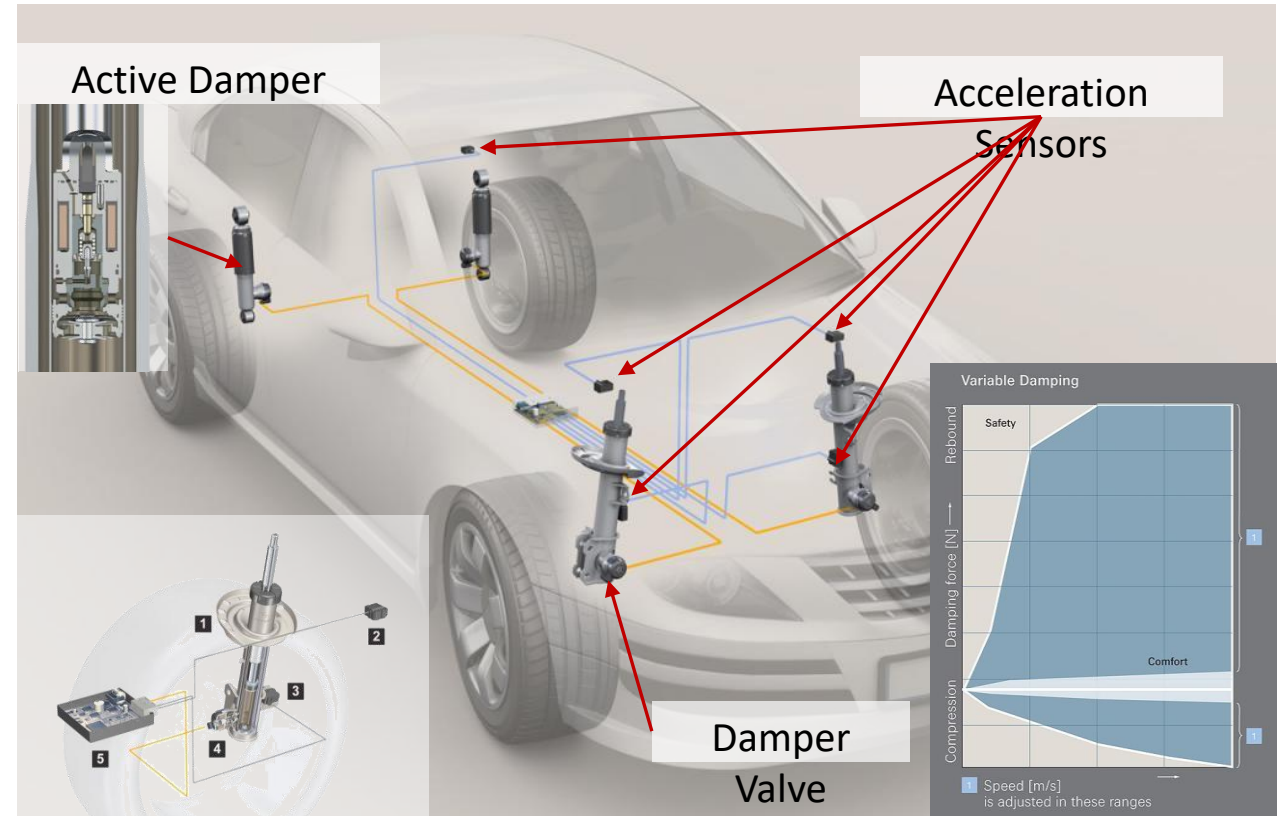
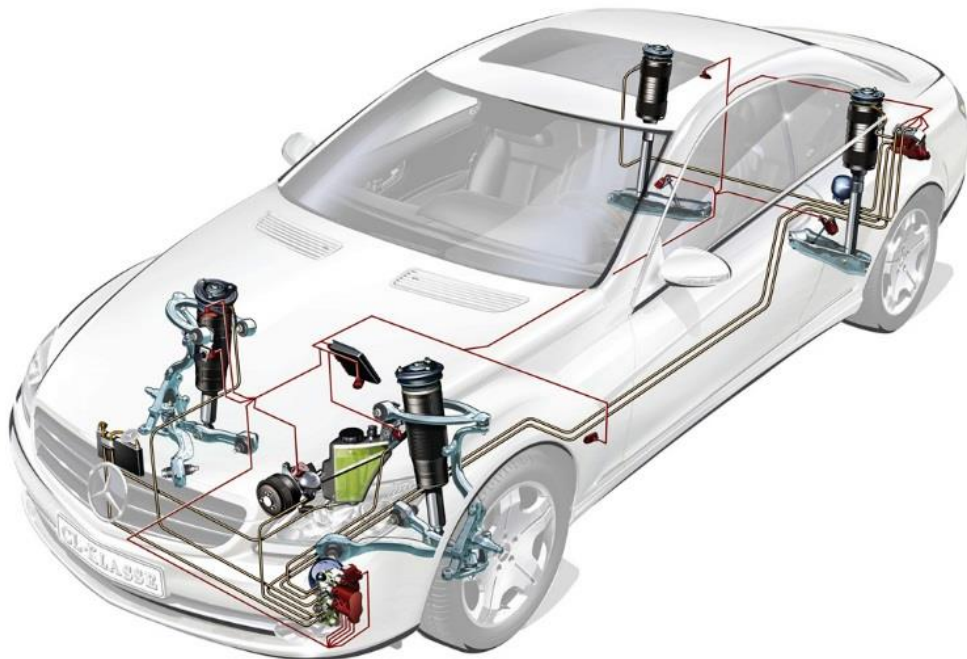
Steering in the same direction of rear wheels to achieve stability

All Wheel Steer

Front Steer

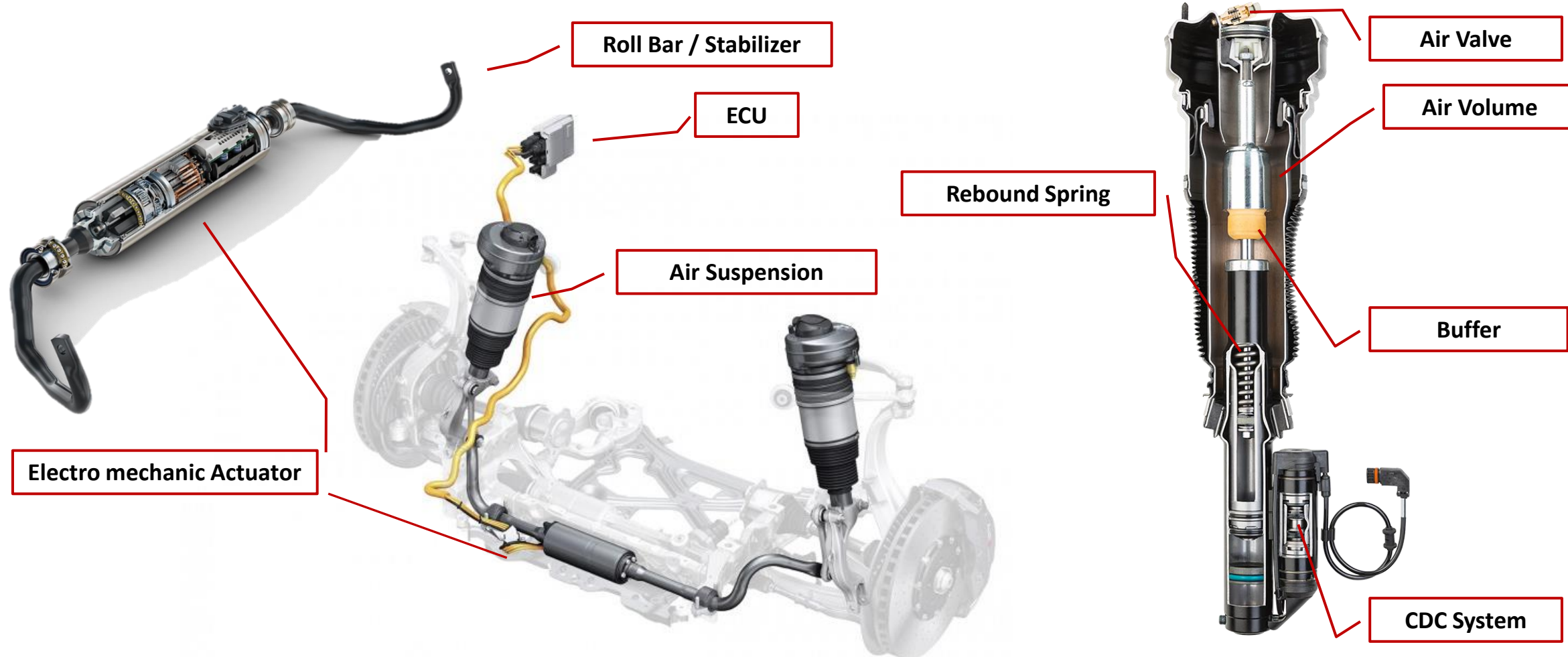


Active suspension control with CDC – Continuous Damping Control

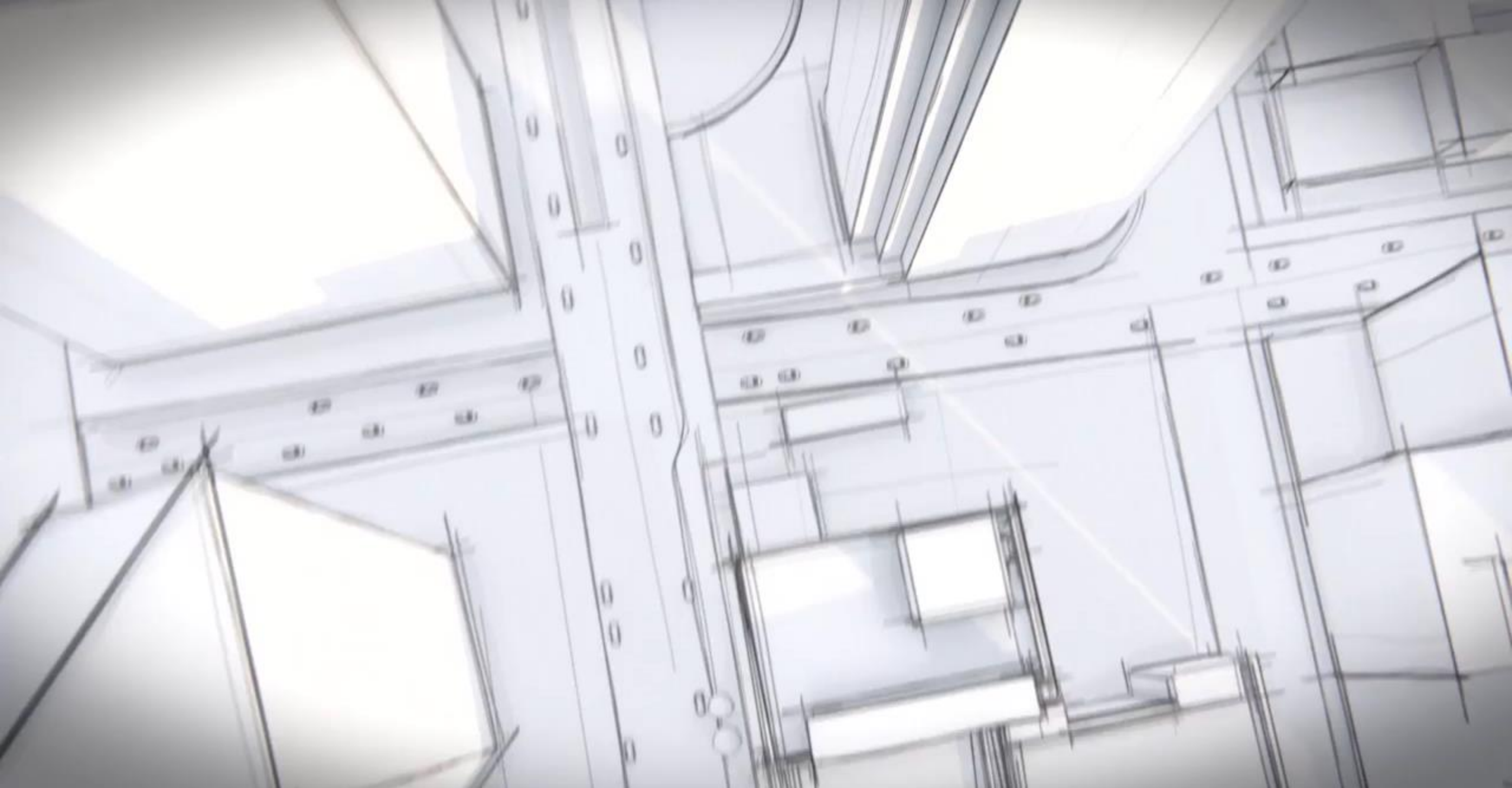




Active suspension control with CDC – Continuous Damping Control

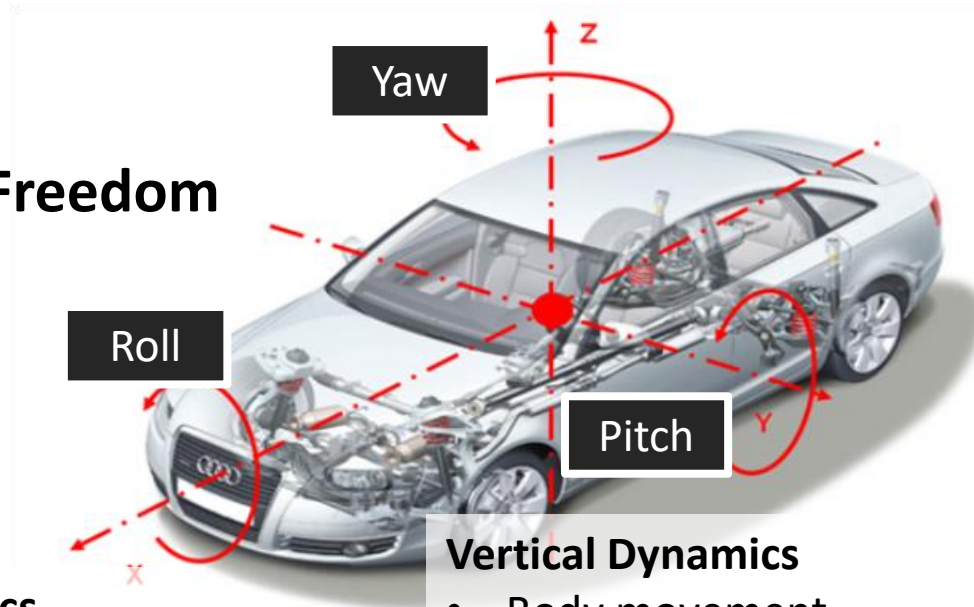






What is vehicle dynamics? It describes the full vehicle motion dynamics.

6 DOF - Degree of Freedom



Longitudinal Dynamics

- Driving Resistance
- Acceleration behavior
- Braking behavior

Vertical Dynamics

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

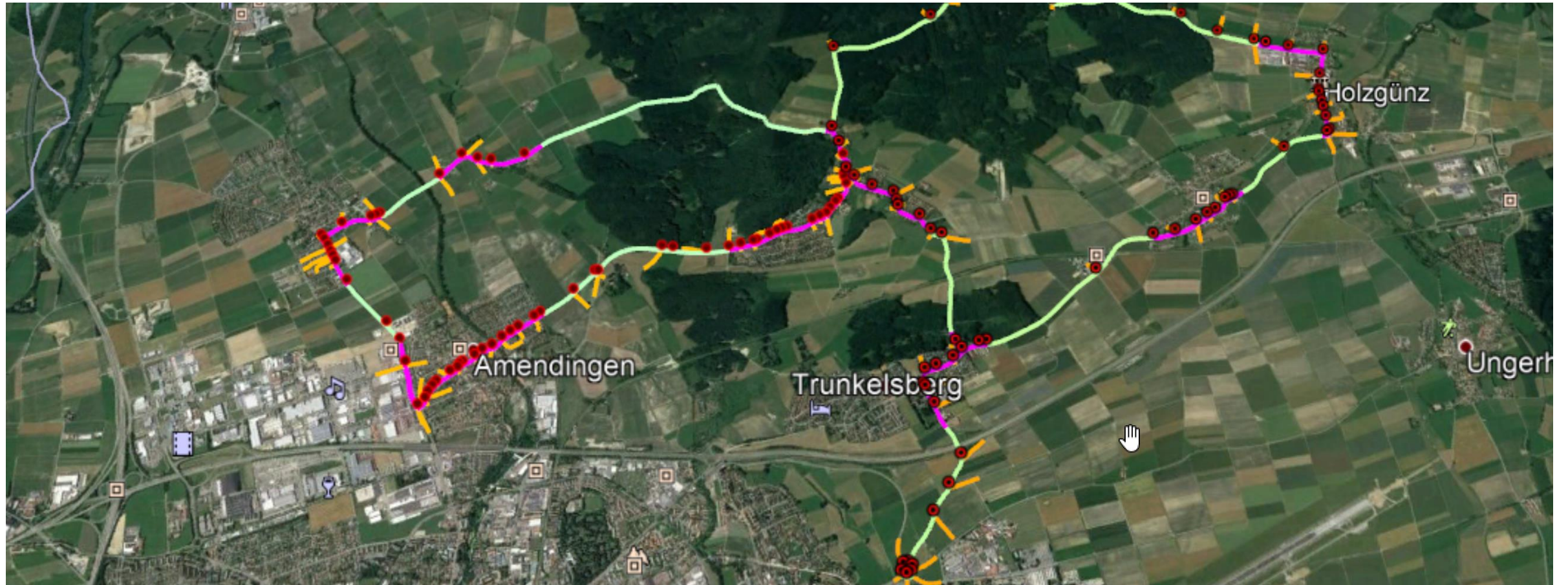
Lateral Dynamics

- Stationary behavior
- Transient behavior
- Steering behavior



Student Driving Event

Handling and comfort routes around measured as digital twin



Student Driving Event

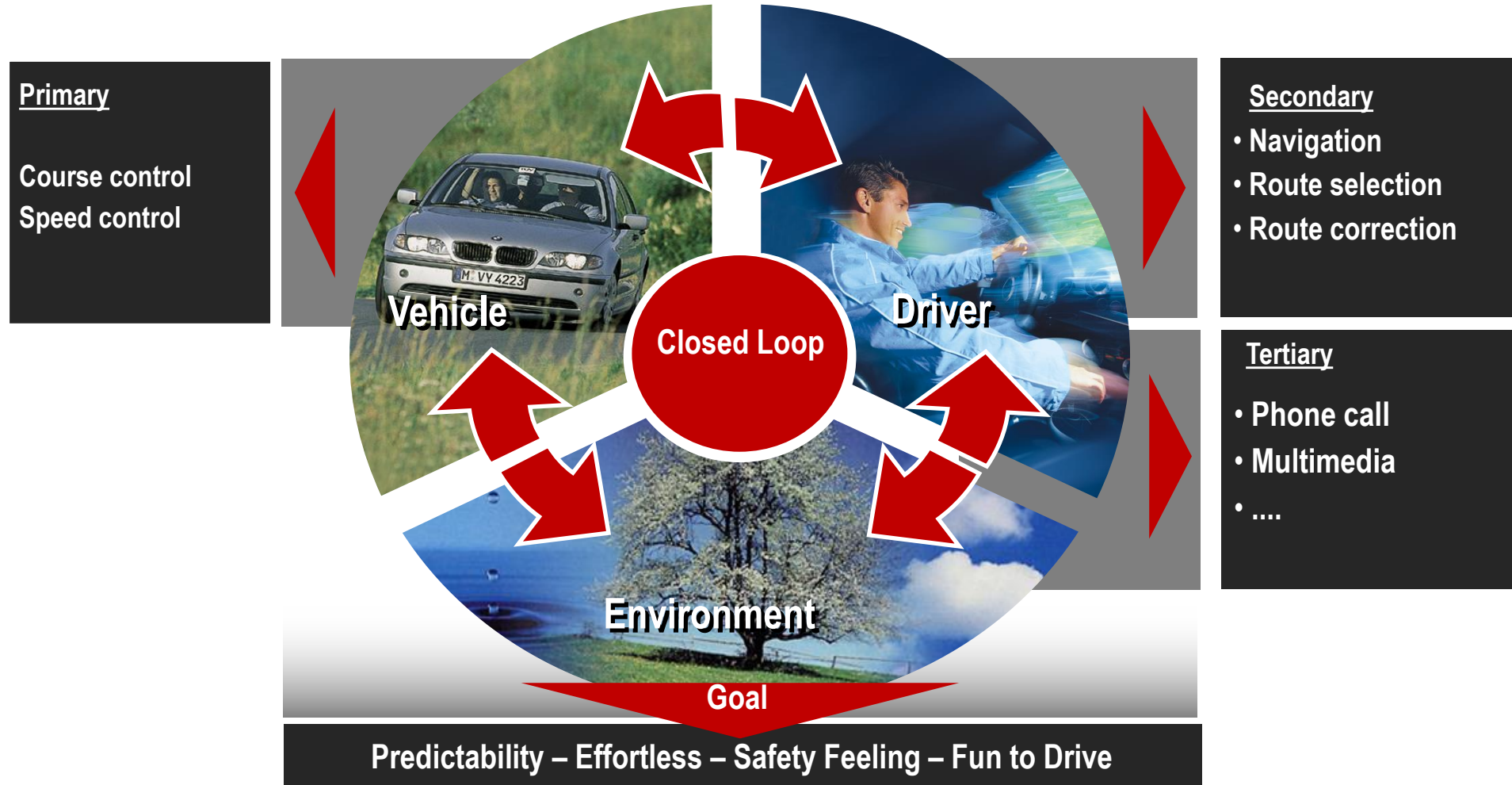


Influence of chassis systems on the driving characteristics

“Driver – Vehicle – Environment” – a closed loop!



“Driver – Vehicle – Environment” – a closed loop!



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

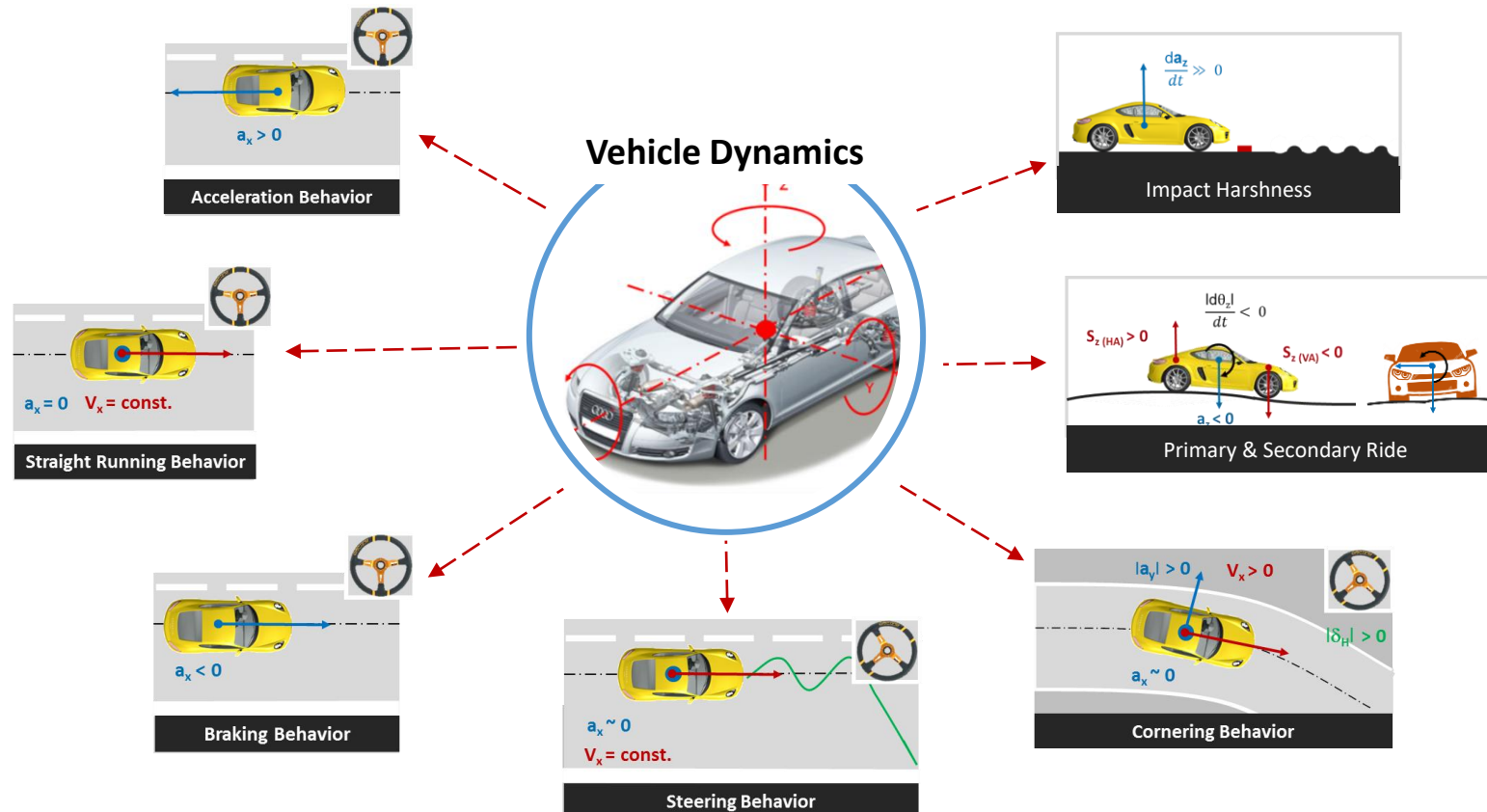
Descriptions of the way vehicles perform transverse to their direction of motion, particularly during cornering and swerving. It also includes their stability when moving in steady state as well as in transient conditions. Vehicle dynamics are one major component of a vehicle's "active" safety.



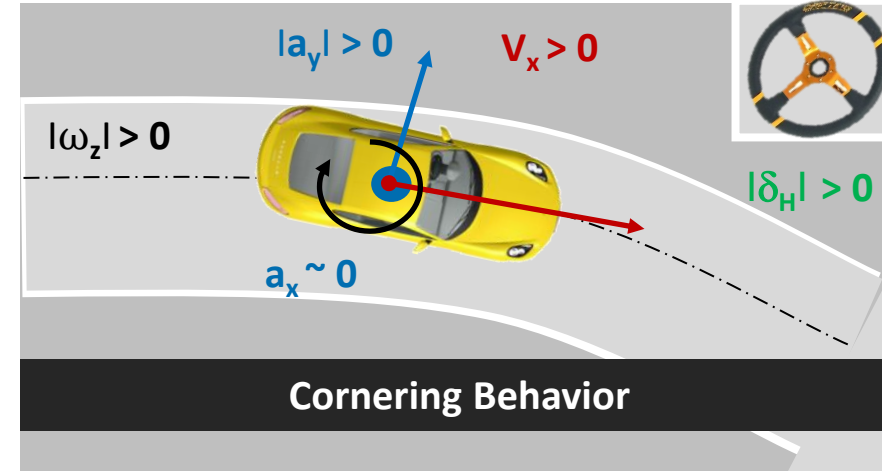
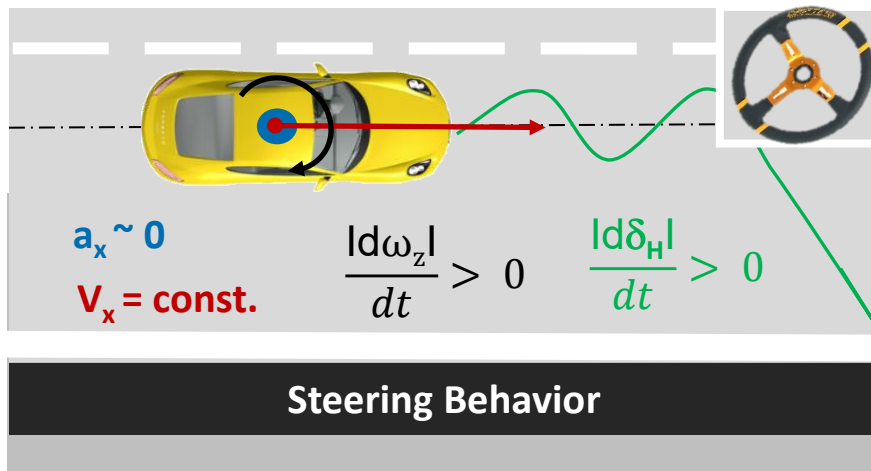
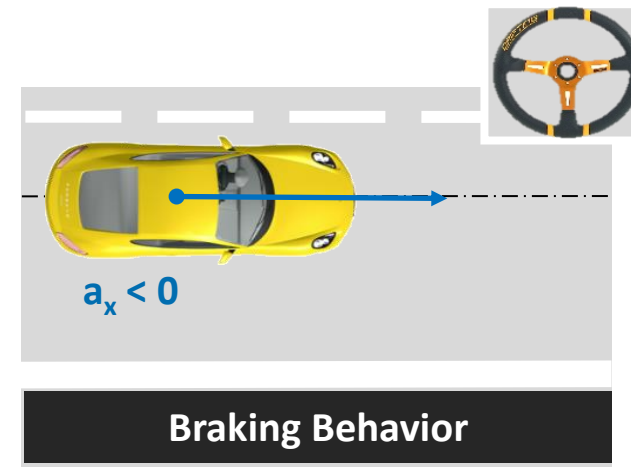
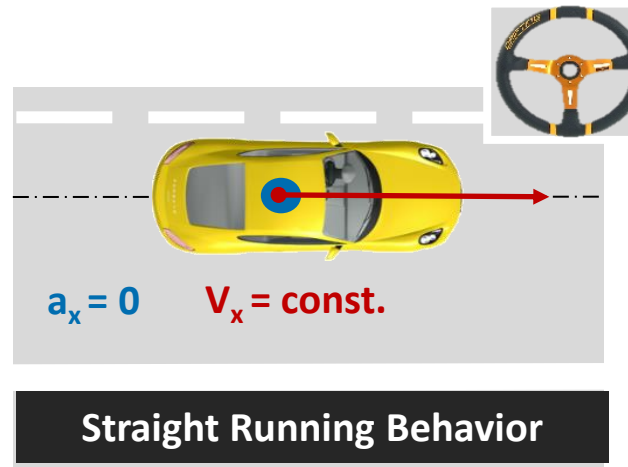
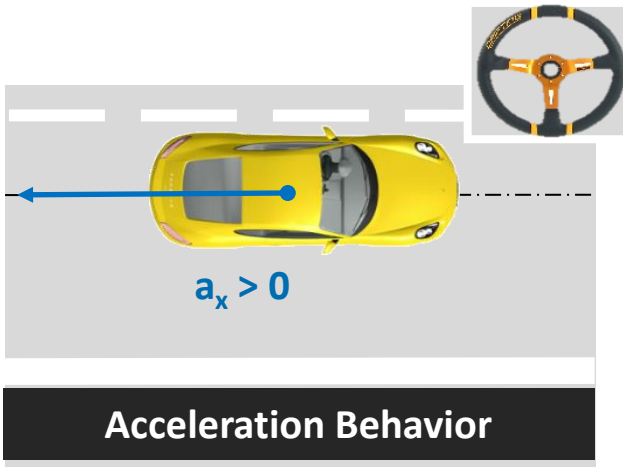
Vertical Dynamics: Ride & Comfort Behavior

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.

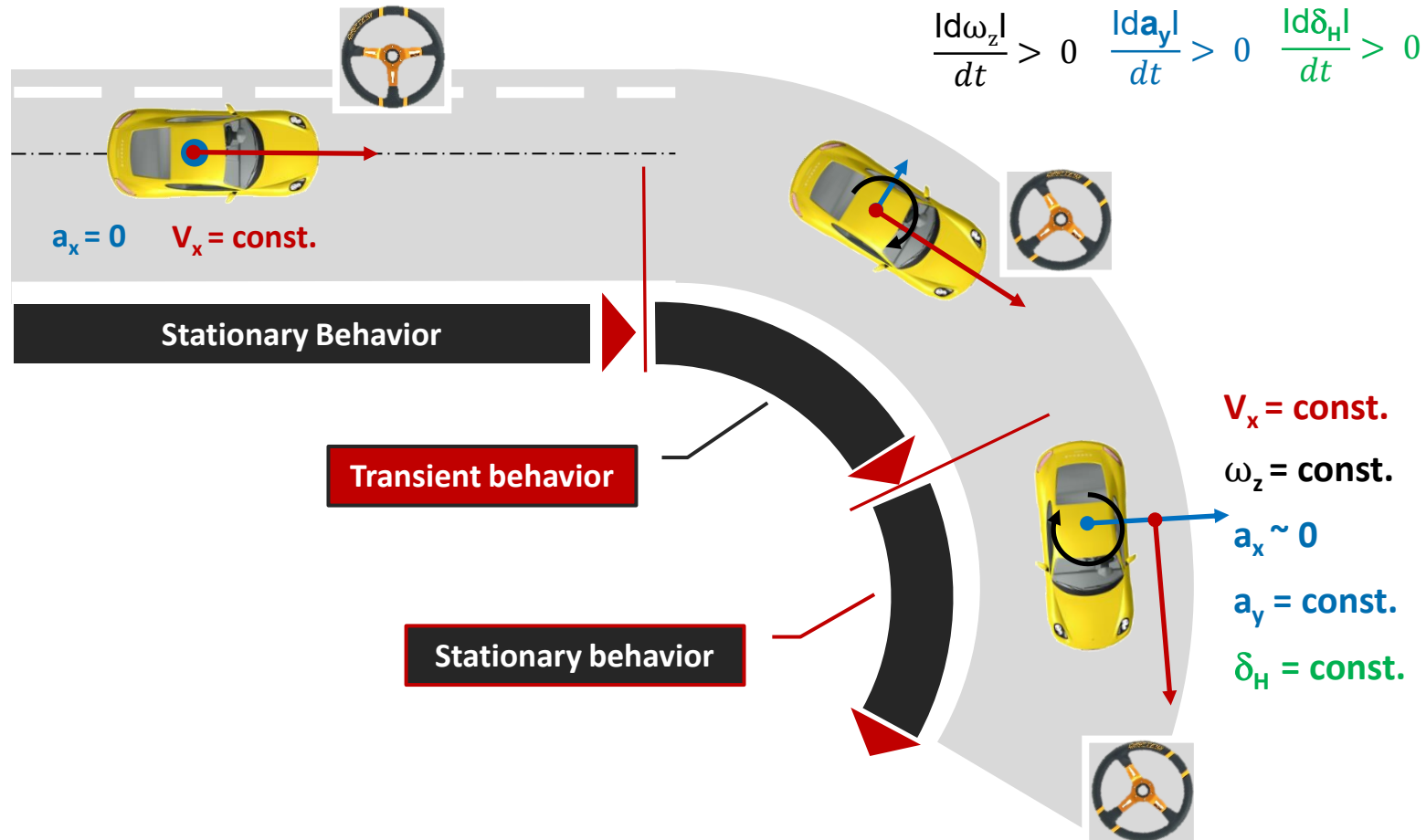
Different groups of ride & handling behavior



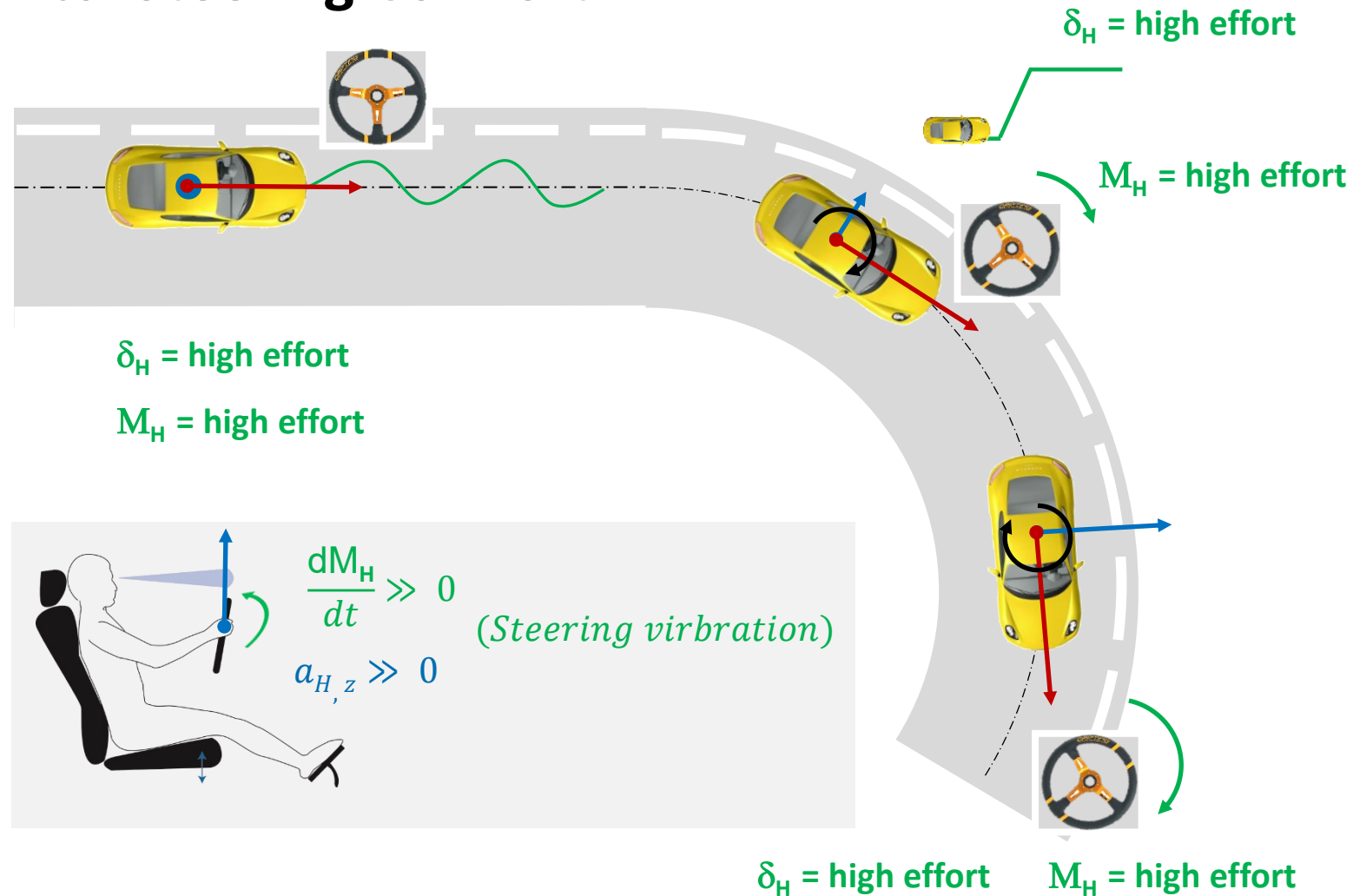
Lateral Dynamics: Handling and Agility Behavior



Lateral Dynamics: Stationary and transient behavior

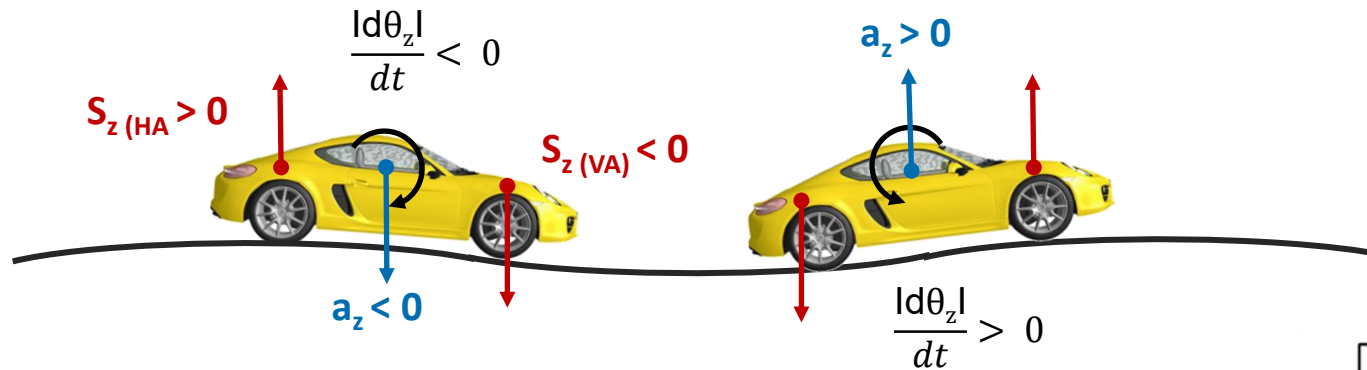


Lateral Dynamics: Steering Comfort

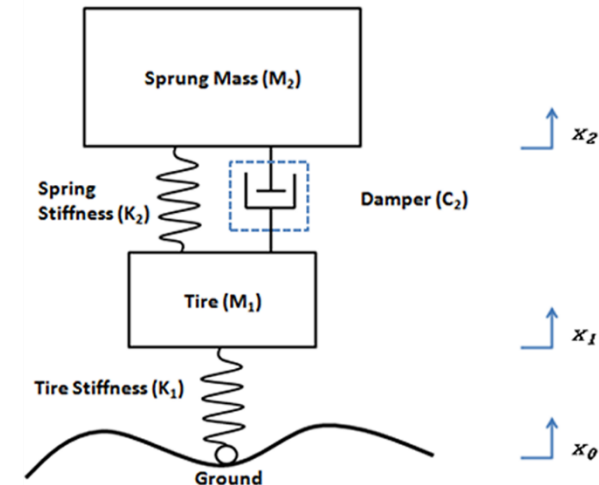
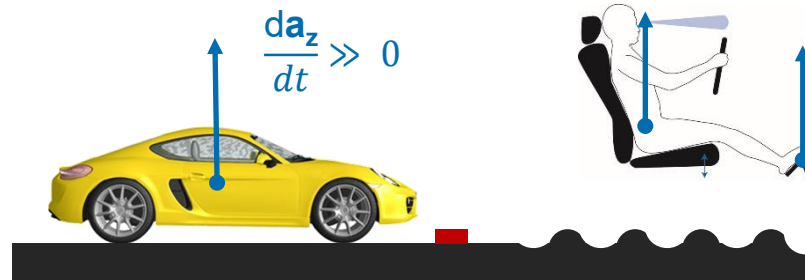


Vertical Dynamics: Ride & Comfort Behavior

Body Movement (Primary & Secondary Ride)



Body acceleration (Harshness, Vibration)



Influence of chassis systems on the driving characteristics



Subjective and objective evaluation language



KPI and target matrix within a consistent development process

Driving Maneuver	Objective Evaluation Criteria	Benchmark Result			Target
		Veh 1	Veh 2	...	
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.



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.

Customer key requirements to vehicle dynamics

