Hochschule Kempten University of Applied Sciences

ADAS Master WS 20/21
Lecture 7

Vehicle Dynamics in context of Advanced Driver Assistance Systems and Automated Driving.

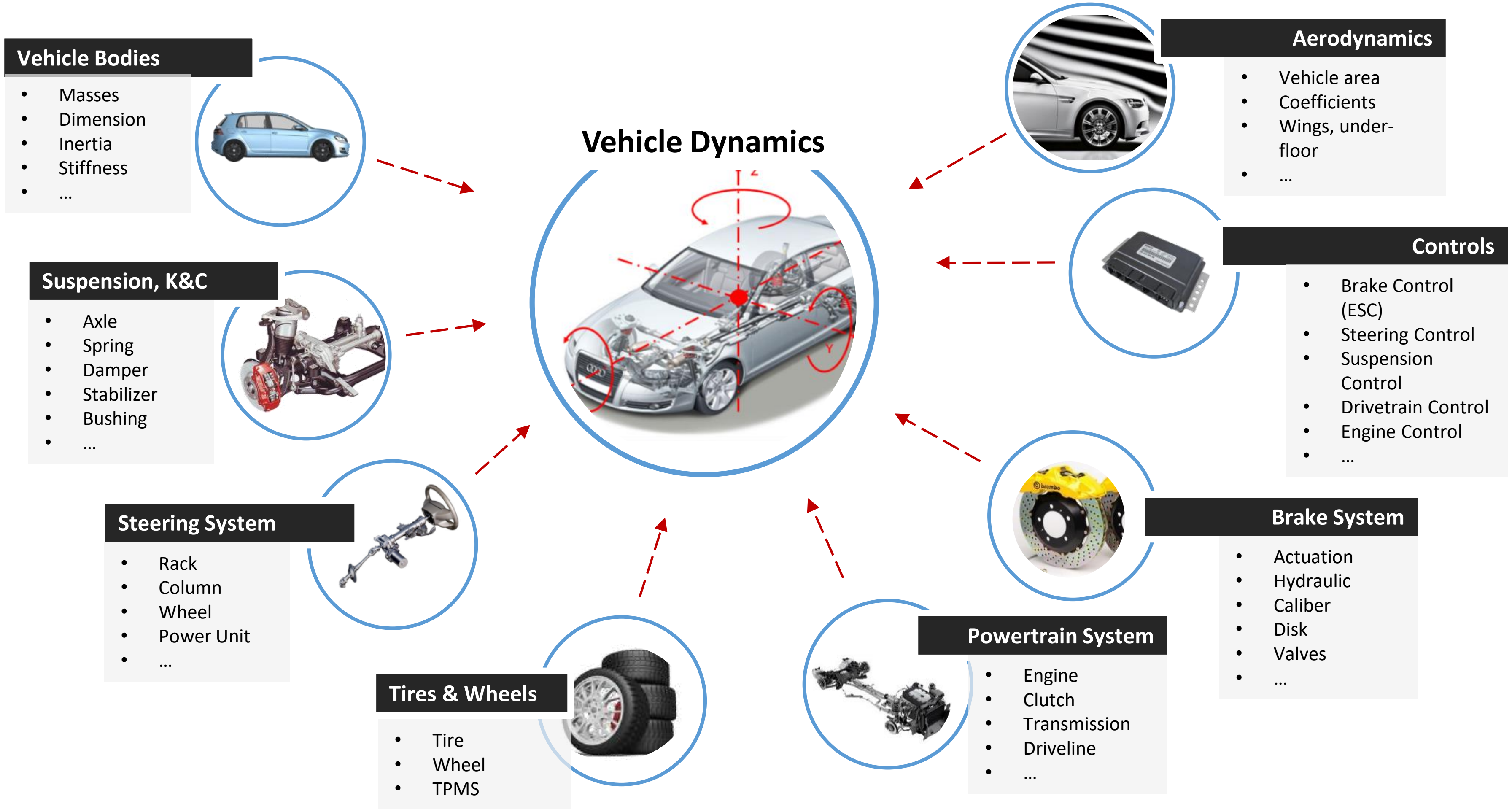
Lecture program

https://moodle2.hs-kempten.de/moodle/course/view.php?id=2914

Nr.	Datum	Inhalt	Ort	Von Wem
1	**01.10.**	**Virtual Test Driving (VTD)** **CarMaker Quick Start Guide**	**T314**	**Self-study**
2	08.10.	Requirements for vehicles and their global attributes	T314 Zoom	Schick
3	15.10.	Vehicle dynamics attributes and their target conflicts	T314 Zoom	Schick
3	22.10.	Test and evaluation methods for vehicle attributes (1) **with practical simulation**	T314 Zoom	Schick
4	29.10.	Test and evaluation methods for vehicle attributes (2) **with practical simulation**	T314 Zoom	Schick
5	**05.11.**	**ADAS DRIVING EVENT** Measurement Tech. Introductions	**Living Lab**	Günther/Riedlmüller/ Schwandke
6	12.11.	Basic vehicle dynamics calculation and vehicle models with exercise	T314 Zoom	Schick
7	**19.11.**	Chassis components and functions (1) Tire & Wheels	T314 Zoom	Schick
8	26.11.	Chassis components and functions (2) Axle & Suspension	T314 Zoom	Schick
9	03.12.	**TEND: ADAS Development for a sports car manufacturer**	T314 Zoom	Manuel Höfer (Porsche)
10	10.12.	Chassis controls and functions (1) Overview & Brakes & Steering	T314 Zoom	Schick
11	17.12.	Chassis controls and functions (2) ESP–Functions & Application & Process	T314 Zoom	Herr Lutz (BOSCH)
12	07.01.	**Chassis controls and functions (3)** **ESP–Application & Hands-On Workshop**	T314 Zoom	Herr Lutz (BOSCH)
13	14.01.	Analysis of international standards and application into the simulation	T314 Zoom	Schick
14	**21.01.**	**Exam preparation**	**T314**	**Schick**

Chassis components and functions – Tire & Wheels

Vehicle dynamics behavior is impact by numerous components



Vehicle Dynamics

Vehicle Bodies

- Masses
- Dimension
- Inertia
- Stiffness
- …

Suspension, K&C

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

Steering System

- Rack
- Column
- Wheel
- Power Unit
- …

Tires & Wheels

- Tire
- Wheel
- TPMS

Powertrain System

- Engine
- Clutch
- Transmission
- Driveline
- …

Brake System

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

Controls

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

Aerodynamics

- Vehicle area
- Coefficients
- Wings, under-floor
- …

Chassis components and functions – Tire & Wheels

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

Chassis components and functions – Tire & Wheels

Tire History

1839: The American chemist Charles Goodyear manufactures rubber-sulfur mixtures and accidentally discovered the vulcanization (patent application 1844).

1888: Scottish veterinarian John Boyd Dunlop building a pneumatic tire for his son's tricycle and reports this to the first bicycle tire for a patent.

1895: The French Industrielen Édouard and André Michelin build the first pneumatic tire for an automobile (L'Eclair - the flash).

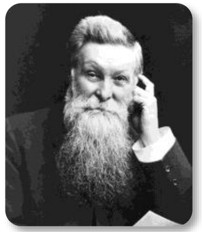
1904: The company Continental (founded in Hanover in 1871) builds the first profile tires for automobiles.

1943: Continental patented the tubeless tire.

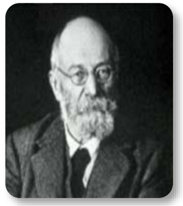
1946: The Michelin brand (founded in 1889 in Clermont-Ferrand) patented the radial tire.

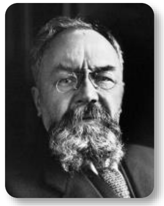
GOODYEAR DUNLOP MICHELIN Continental


Goodyear


Dunlop


L'Eclair


É. Michelin


A. Michelin

Chassis components and functions – Tire & Wheels

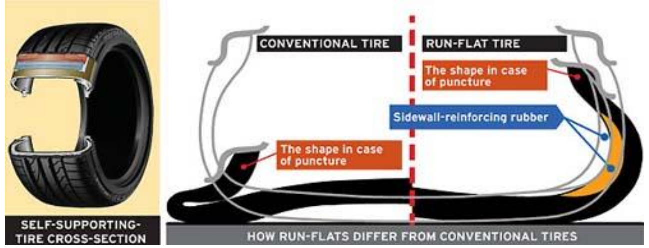
Tire History

1960: Discovery of the aquaplaning effect.

1970’s: Production of the first steel-belted tires.

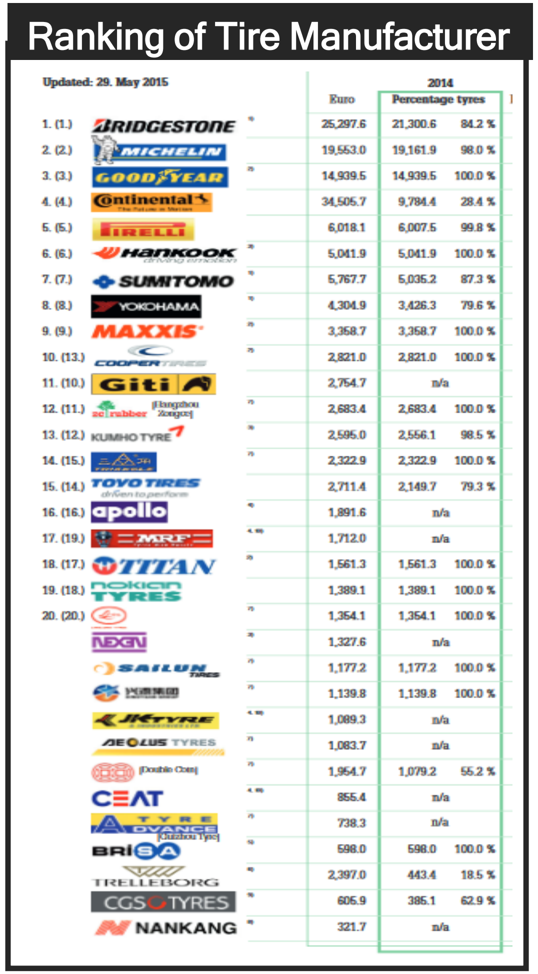
1990’s: **New Materials**

- Silica replaces partially carbon black (enhanced wet performance, rolling resistance is reduced).
- „Run-on-Flat“-Systems.
- Lightweight tires (mass and rolling resistance reduced).



2001: New Materials

- BioTRED technology - Goodyear replaces carbon black and silica partially cornstarch (Reduction of rolling resistance, wear, and weight).



Ranking of Tire Manufacturer

Updated: 29. May 2015

		2014		
		Euro	Percentage tyres	
1. (1.)	BRIDGESTONE	25,297.6	21,300.6	84.2 %
2. (2.)	MICHELIN	19,553.0	19,161.9	98.0 %
3. (3.)	GOODYEAR	14,939.5	14,939.5	100.0 %
4. (4.)	Continental	34,505.7	9,784.4	28.4 %
5. (5.)	PIRELLI	6,018.1	6,007.5	99.8 %
6. (6.)	Hankook	5,041.9	5,041.9	100.0 %
7. (7.)	SUMITOMO	5,767.7	5,035.2	87.3 %
8. (8.)	YOKOHAMA	4,304.9	3,426.3	79.6 %
9. (9.)	MAXXIS	3,358.7	3,358.7	100.0 %
10. (13.)	COOPER TIRES	2,821.0	2,821.0	100.0 %
11. (10.)	Giti	2,754.7	n/a	
12. (11.)	zc rubber [Hangzhou Zongce]	2,683.4	2,683.4	100.0 %
13. (12.)	KUMHO TYRE	2,595.0	2,556.1	98.5 %
14. (15.)		2,322.9	2,322.9	100.0 %
15. (14.)	TOYO TIRES	2,711.4	2,149.7	79.3 %
16. (16.)	apollo	1,891.6	n/a	
17. (19.)	MRF	1,712.0	n/a	
18. (17.)	TITAN	1,561.3	1,561.3	100.0 %
19. (18.)	nokian TYRES	1,389.1	1,389.1	100.0 %
20. (20.)		1,354.1	1,354.1	100.0 %
	NEXEN	1,327.6	n/a	
	SAILUN TIRES	1,177.2	1,177.2	100.0 %
		1,139.8	1,139.8	100.0 %
	JK TYRE	1,089.3	n/a	
	AEOLUS TYRES	1,083.7	n/a	
	[Double Coin]	1,954.7	1,079.2	55.2 %
	CEAT	855.4	n/a	
	TYRE ADVANCE [Guizhou Tyre]	738.3	n/a	
	BRISA	598.0	598.0	100.0 %
	TRELLEBORG	2,397.0	443.4	18.5 %
	CGS TYRES	605.9	385.1	62.9 %
	NANKANG	321.7	n/a	

Chassis components and functions – Tire & Wheels

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

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

Chassis components and functions – Tire & Wheels

Global requirements for tires

Vehicle Dynamics & Safety

- High speed strength
- Durability
- Force transfer
  (dry, wet, snow, ice)
- Straight running, corning stability
- Handling, steering precision
- Mass

Economy

- Roll resistance
- Purchase cost
- Wear
- Mileage

Environmental properties

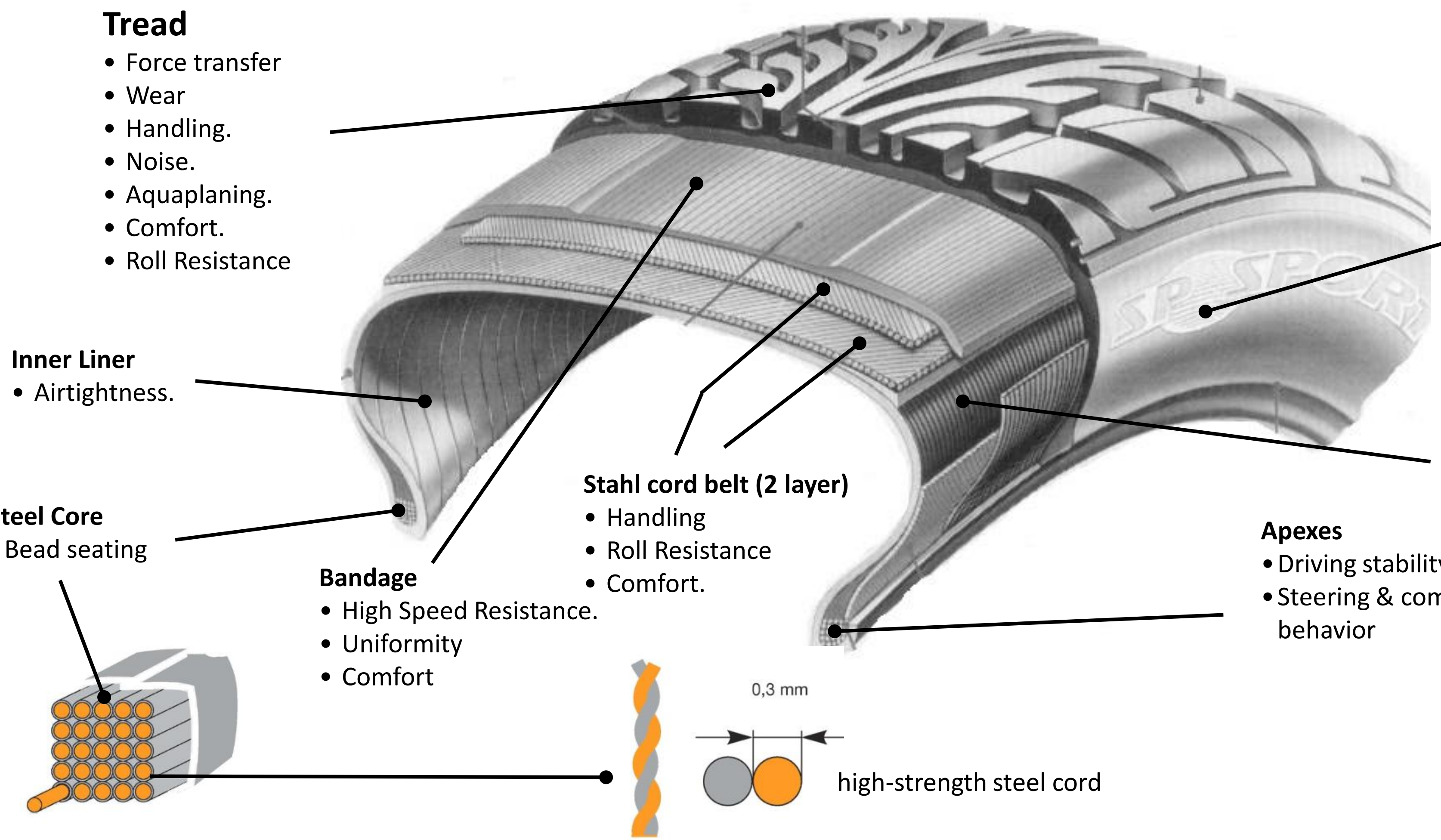
- Partial emission (rubber)
- Energy demand for the production
- Resources saving and protection.
- Recycling

Comfort

- Uniformity (Rundlauf)
- Rolling noise
- Rolling behavior
- Vibration

Chassis components and functions – Tire & Wheels

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.

Steel Core
- Bead seating

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

Apexes
- Driving stability.
- Steering & comfort behavior

Bandage
- High Speed Resistance.
- Uniformity
- Comfort

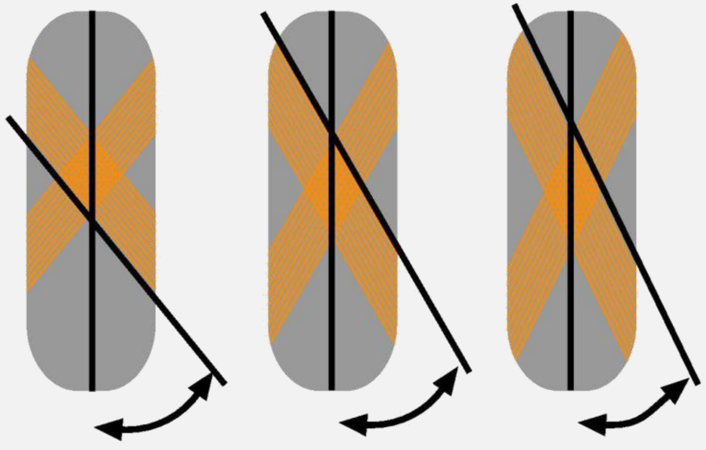
high-strength steel cord

Chassis components and functions – Tire & Wheels

Tire types

Diagonal Tires

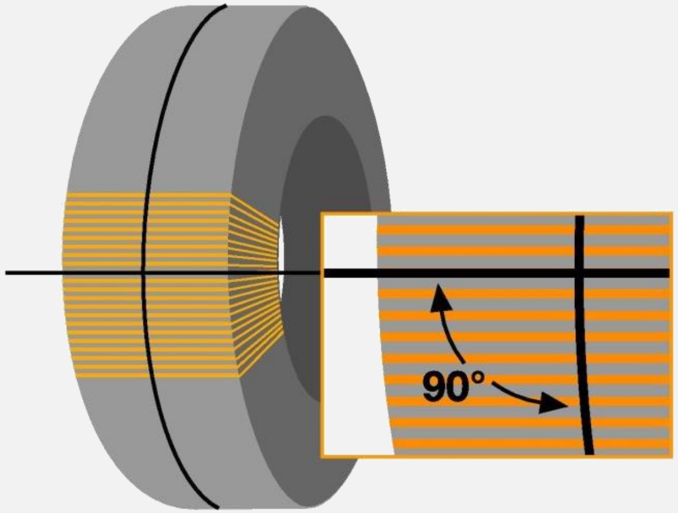
- Cords of each carcass plies are laid each other at an acute angle.
- Advantage: good comfort.
- Disadvantage: worse driving stability, higher role resistance.



38° - 40°	30° - 35°	26°
Standard Tire	High Speed Tire	Race Tire

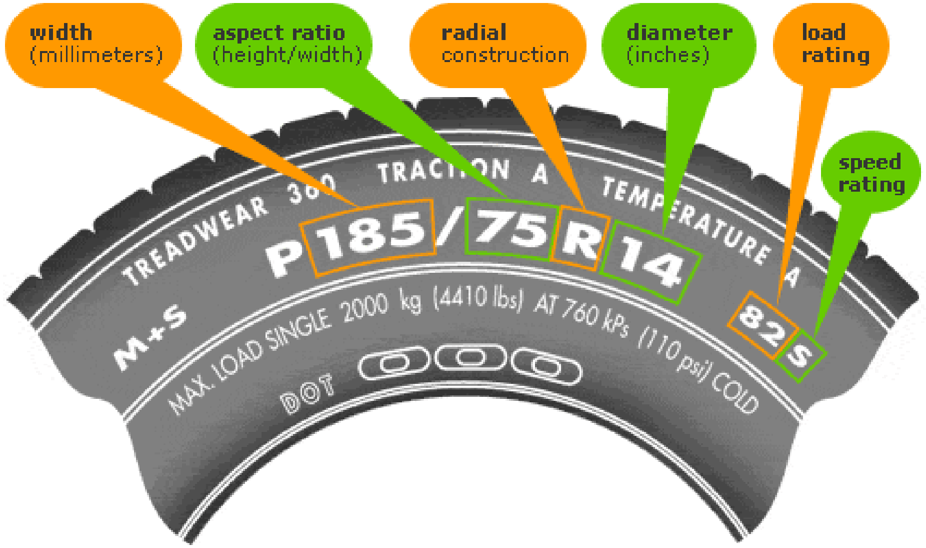
Radial Tires

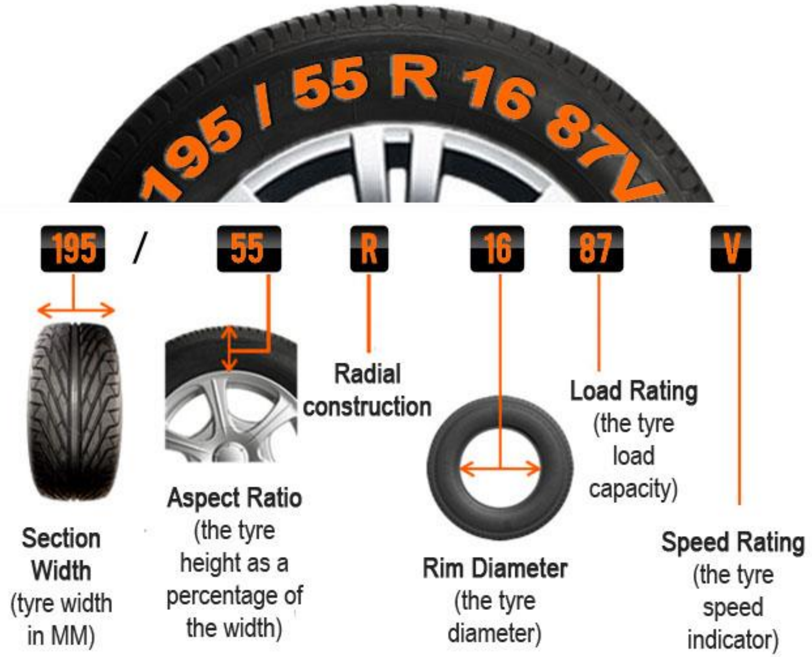
- The carcass cords are laid at an angle of 90 ° to the running direction.
- Advantage: driving stability, better role resistance.
- Disadvantage: comfort.



Chassis components and functions – Tire & Wheels

Tire construction and specification





Chassis components and functions – Tire & Wheels

Tire types

Summer

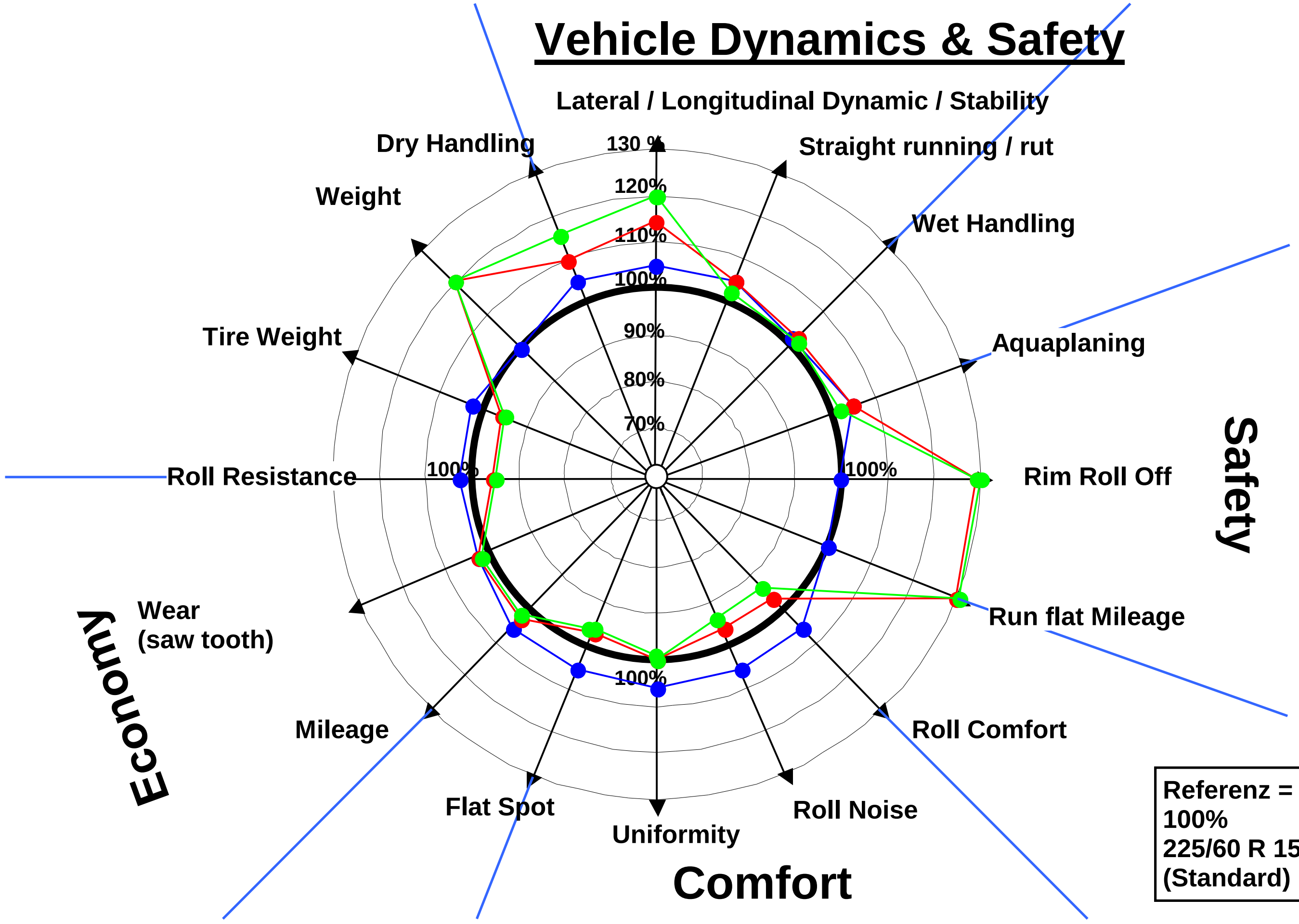
Winter

All Season

All Terrain

Slick Intermediate | **Slick Rain** | **Slick Super Soft** | **Slick Soft** | **Slick Medium** | **Slick Hard**

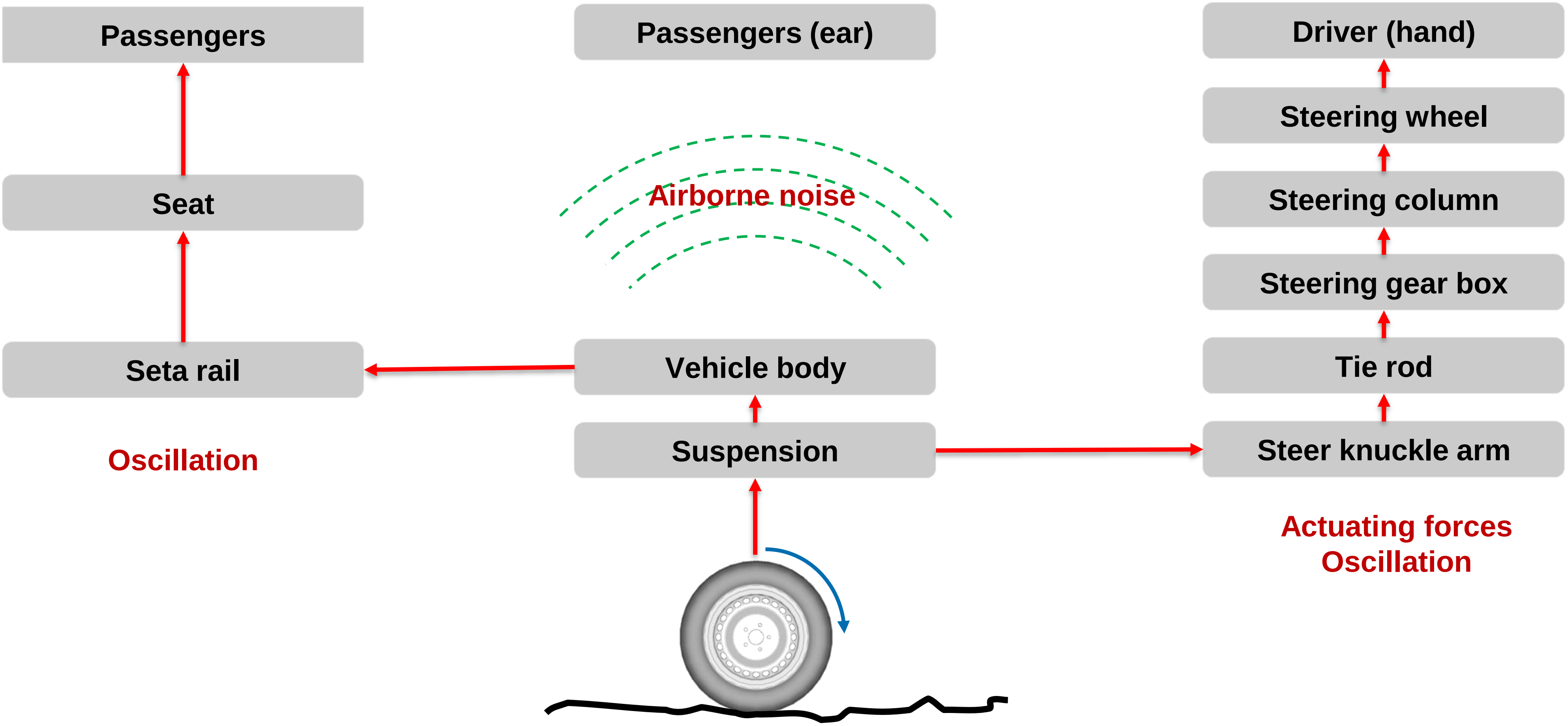
Target conflicts (trade-off) for the development



Referenz =
100%
225/60 R 15 W
(Standard)

Chassis components and functions – Tire & Wheels

Cause and effect chain / transfer path



Passengers

Seat

Seta rail

Oscillation

Passengers (ear)

Airborne noise

Vehicle body

Suspension

Driver (hand)

Steering wheel

Steering column

Steering gear box

Tie rod

Steer knuckle arm

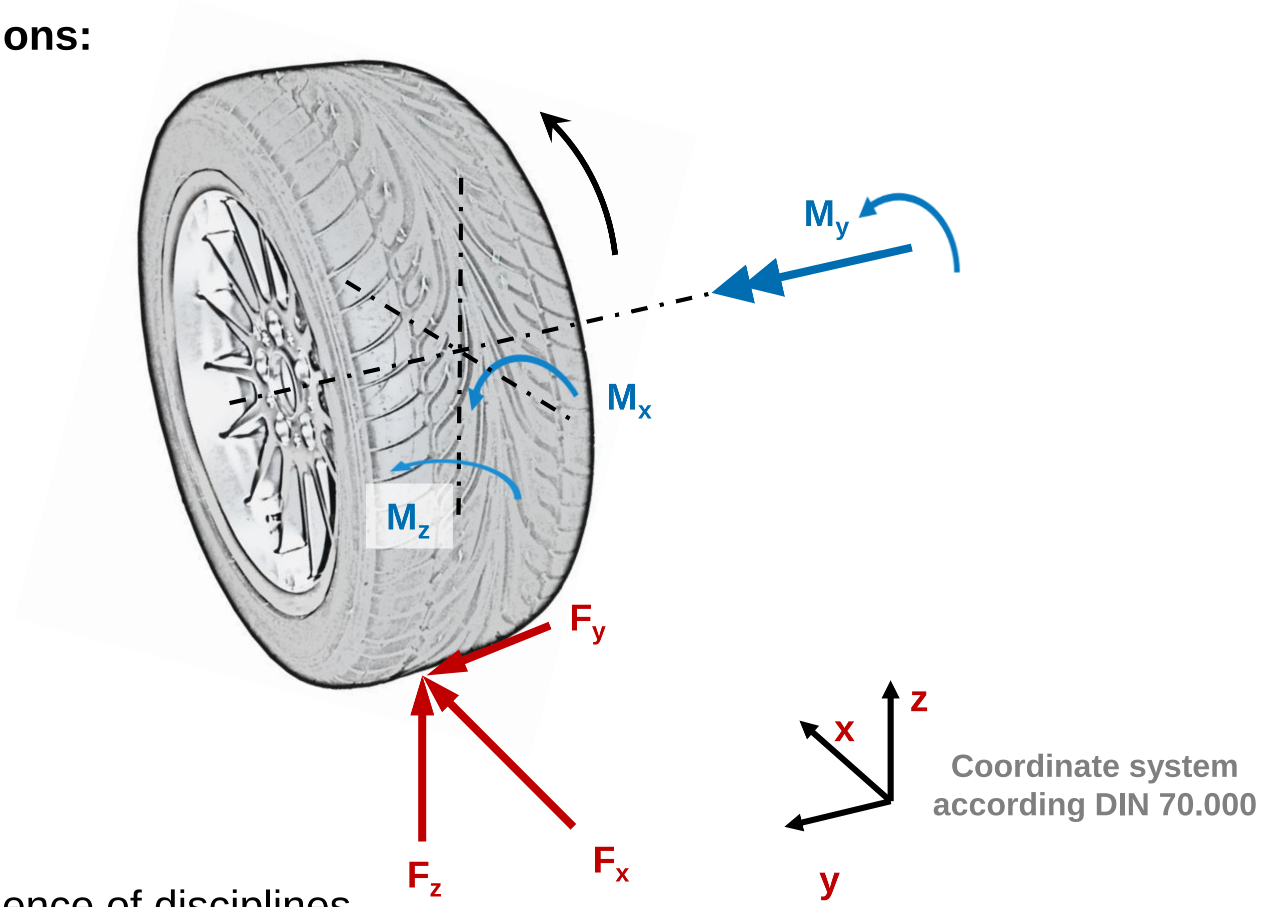
Actuating forces
Oscillation

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



Coordinate system according DIN 70.000

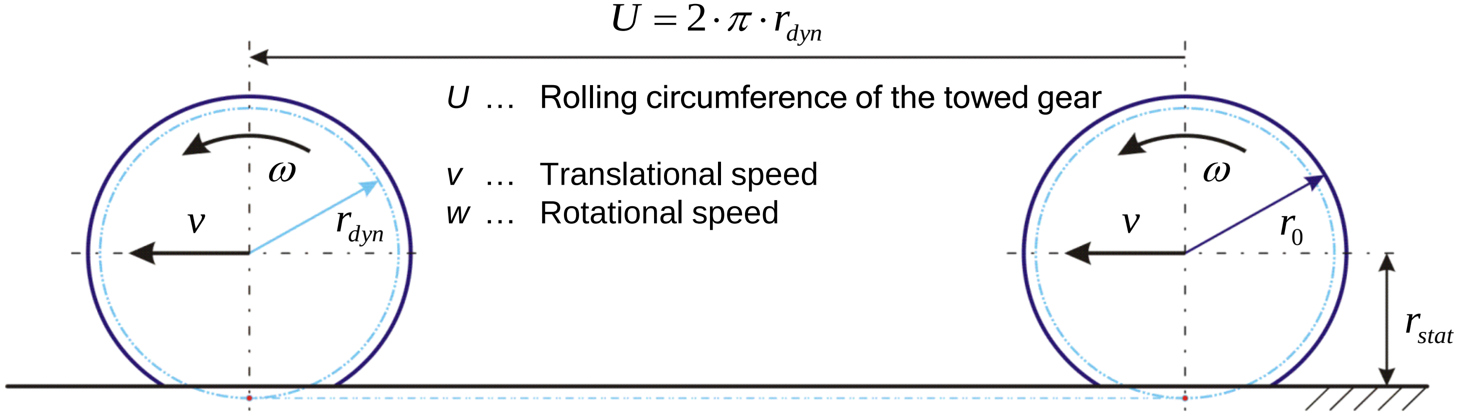
Chassis components and functions – Tire & Wheels

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.

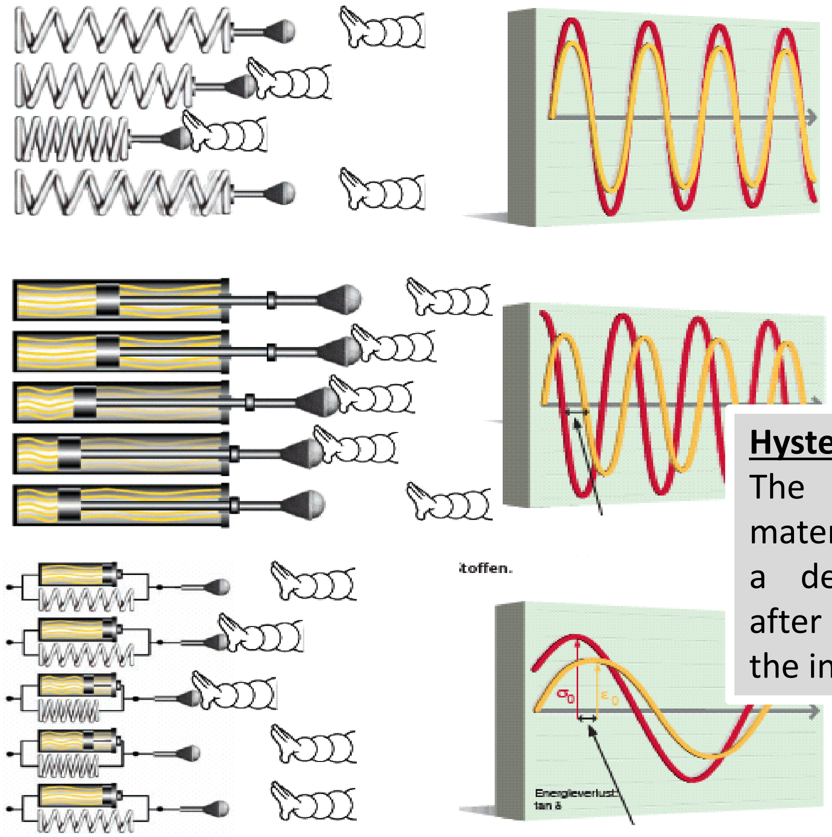


$$U = 2 \cdot \pi \cdot r_{dyn}$$

U … Rolling circumference of the towed gear

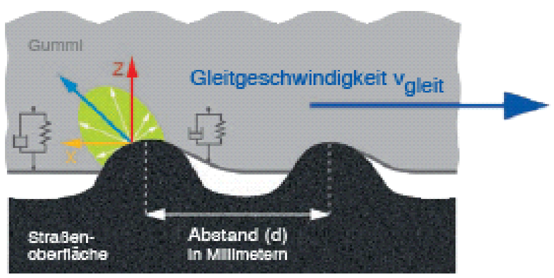
v … Translational speed
w … Rotational speed

Tires, some fundamentals



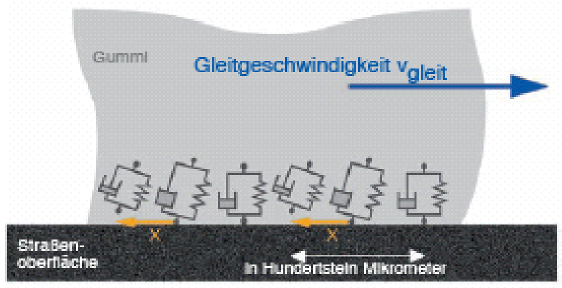
Hysteresis:
The viscous-elastic material returns from a deformation first after a while back to the initial position

VERZAHNUNGSEFFEKT

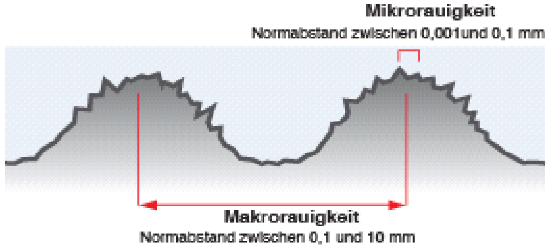


Stößt der Gummiblock gegen eine Erhebung und verformt sich, so kehrt er hysteresebedingt nach der Entlastung nicht sogleich in seine Ausgangslage zurück. Diese asymmetrische Verformung erzeugt ein Kraftfeld, dessen Tangentialkomponente X dem Durchrutschen entgegenwirkt.

MOLEKULARE HAFTUNG



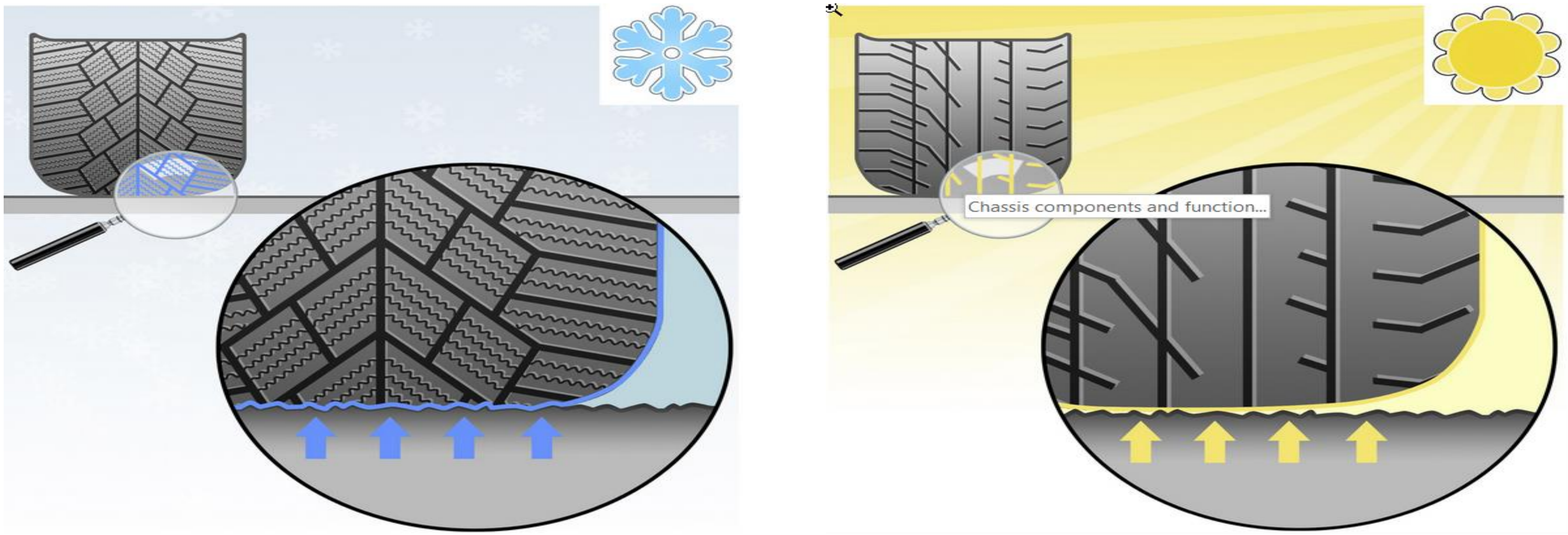
Die Molekülkette wird gedehnt: Aufgrund ihrer viskosen Eigenschaften, symbolisiert durch den Dämpferkolben, widerstehen die Moleküle zunächst der Verformung und erzeugen eine Reibungskraft X, die dem Durchrutschen entgegenwirkt.



- **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.**

Chassis components and functions – Tire & Wheels

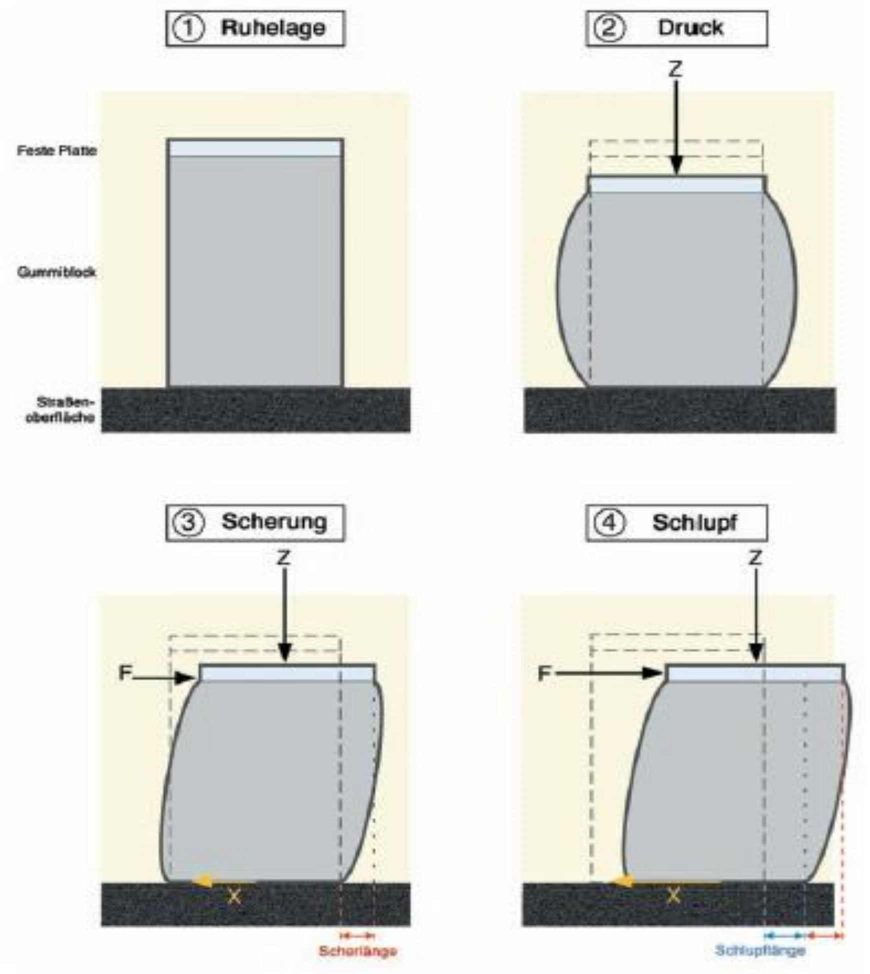
Tire slip mechanisms – shear, slide and slip

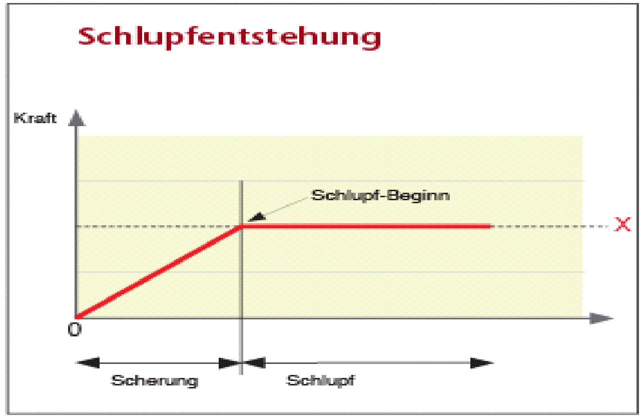


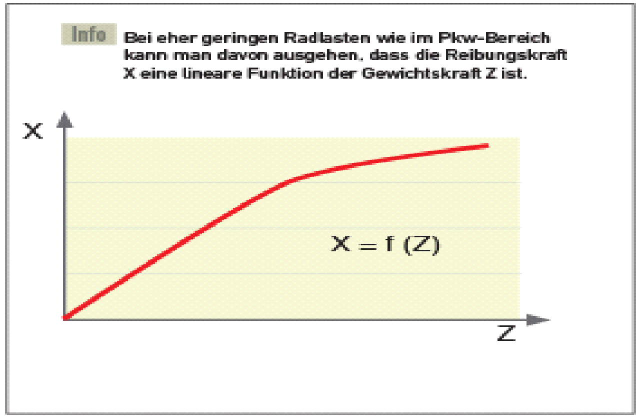
The soft tread compound of winter tires is still flexible even at low temperatures, so that winter tires remain slip-proof and optimally toothing with the road surface.

Chassis components and functions – Tire & Wheels

Target conflicts (trade-off) for the development



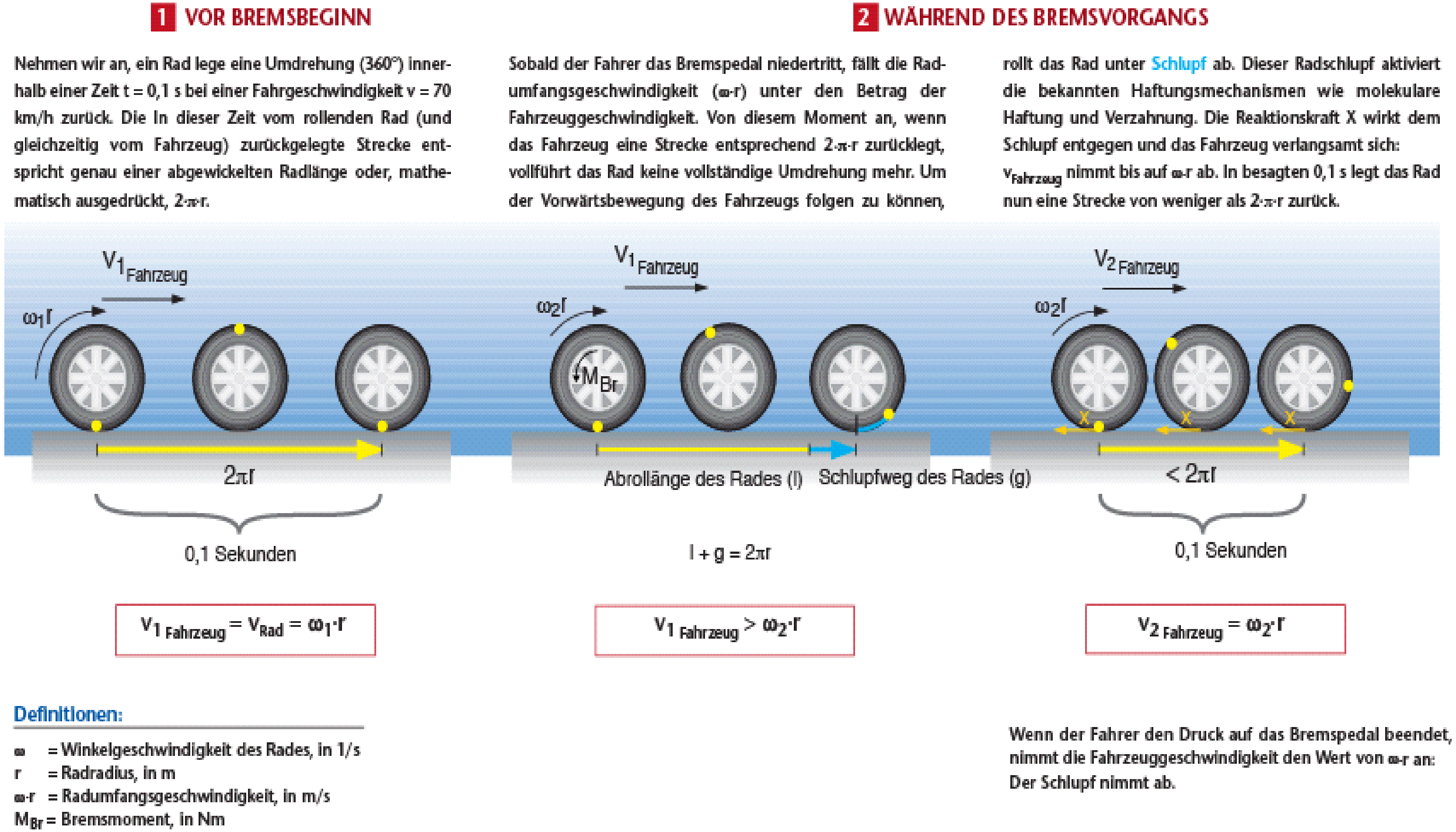




Bei eher geringen Radlasten wie im Pkw-Bereich kann man davon ausgehen, dass die Reibungskraft X eine lineare Funktion der Gewichtskraft Z ist.

Chassis components and functions – Tire & Wheels

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·π·r.

2 WÄHREND DES BREMSVORGANGS

Sobald der Fahrer das Bremspedal niedertritt, fällt die Radumfangsgeschwindigkeit (ω·r) unter den Betrag der Fahrzeuggeschwindigkeit. Von diesem Moment an, wenn das Fahrzeug eine Strecke entsprechend 2·π·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 ω·r ab. In besagten 0,1 s legt das Rad nun eine Strecke von weniger als 2·π·r zurück.

$$V_{1\,Fahrzeug} = V_{Rad} = \omega_1 \cdot r$$

$$V_{1\,Fahrzeug} > \omega_2 \cdot r$$

$$V_{2\,Fahrzeug} = \omega_2 \cdot r$$

Definitionen:

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

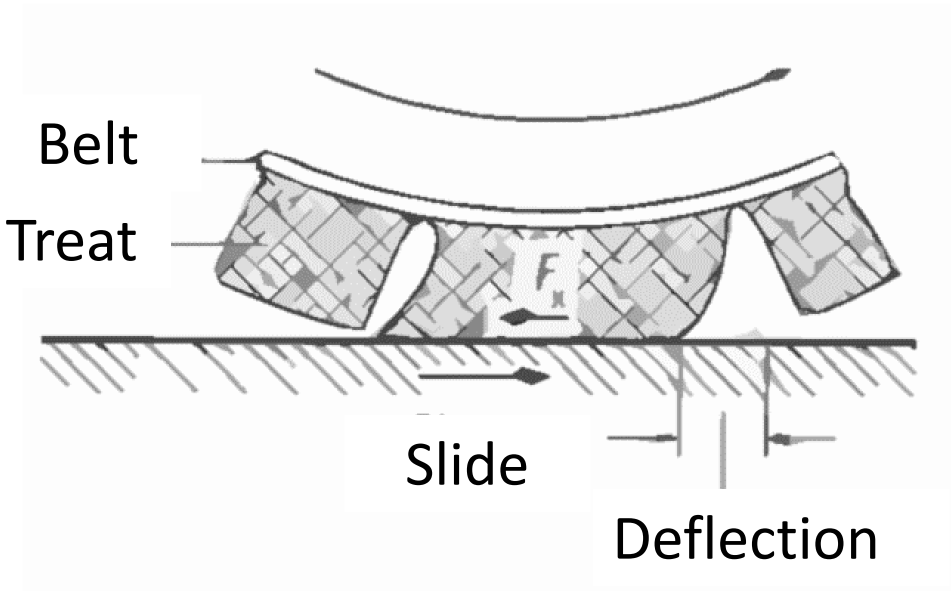
Wenn der Fahrer den Druck auf das Bremspedal beendet, nimmt die Fahrzeuggeschwindigkeit den Wert von ω·r an: Der Schlupf nimmt ab.

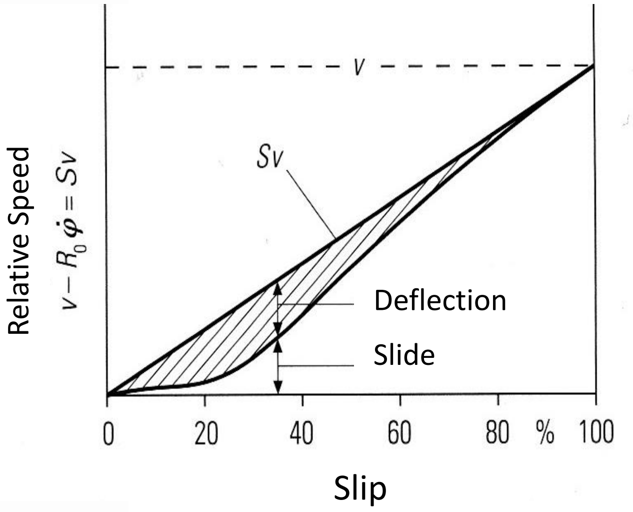
Chassis components and functions – Tire & Wheels

Tire longitudinal characteristics: slip behavior

Chassis components and functions – Tire & Wheels

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).

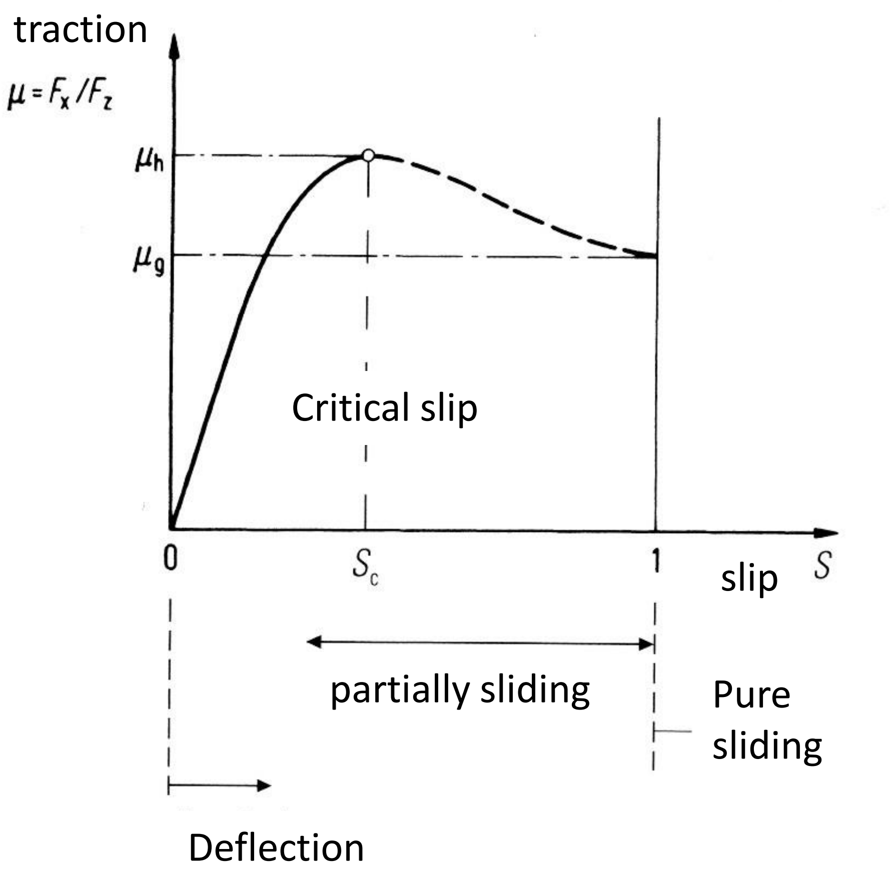
Chassis components and functions – Tire & Wheels

Tire longitudinal characteristics: slip behavior

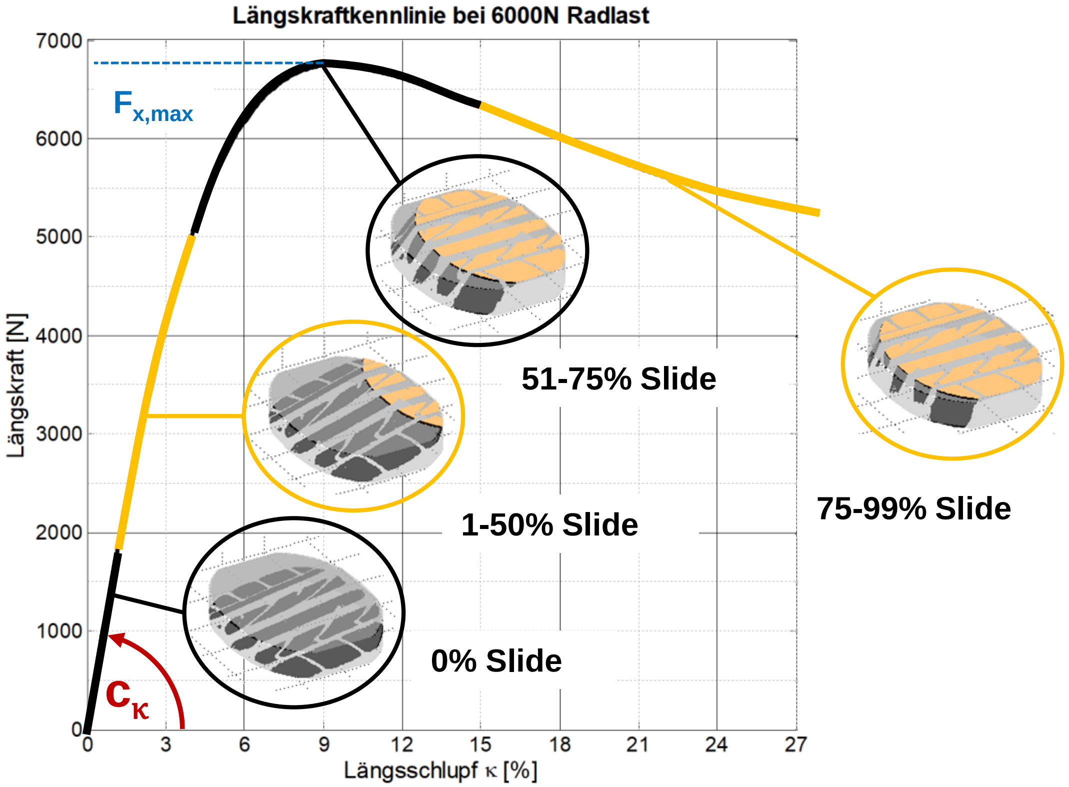
- Transferable force are defined by the adhesion coefficient μ.
- μ is at rubber friction a function of the slip

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

- 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



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

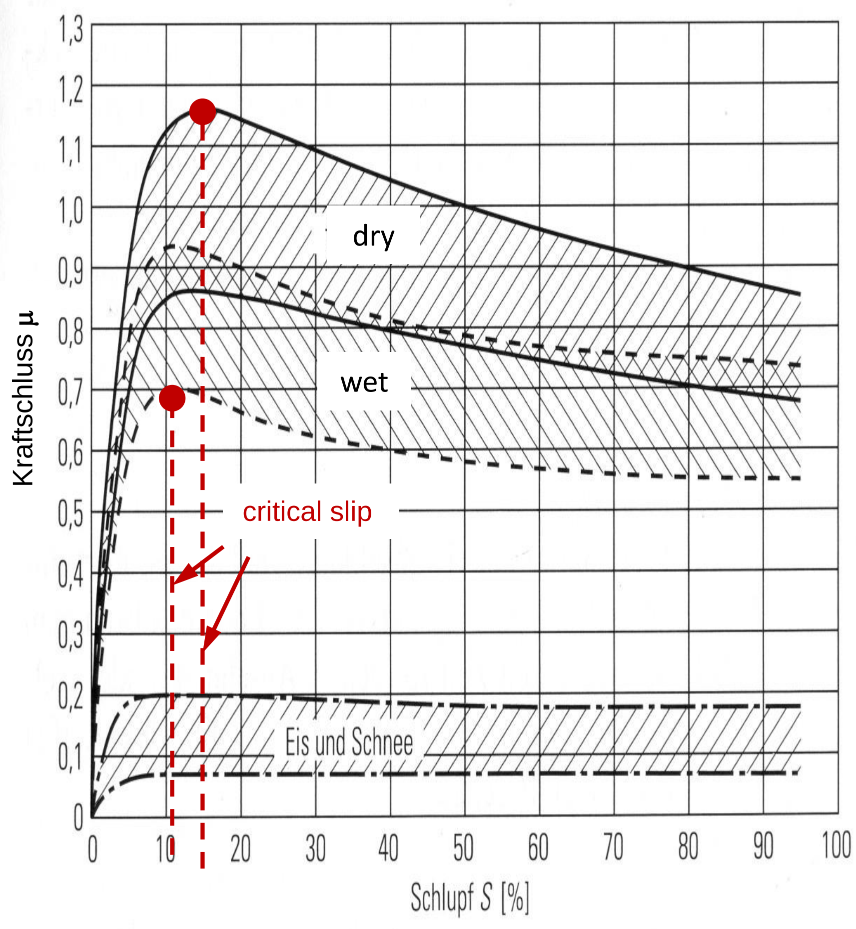
For small longitudinal forces, there is a linear relationship between S and Fx.

c_κ = slip stiffness

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

Influences:

- Tire pressure
- Temperature
- Local friction

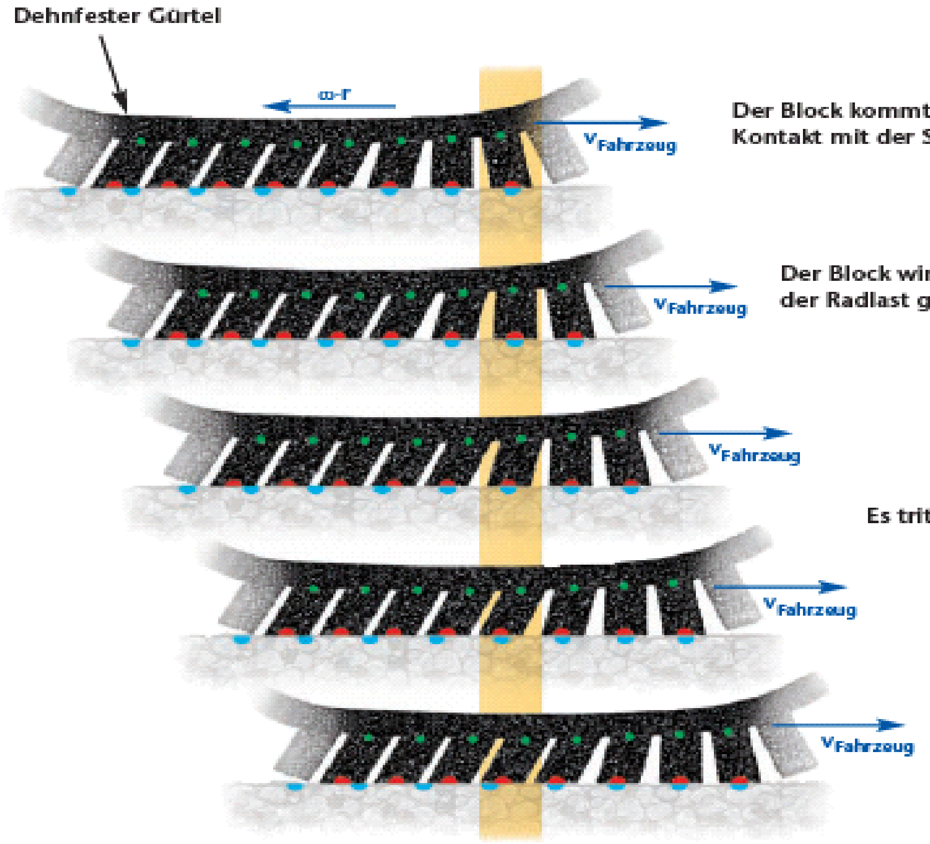


$$F_{x,\max} = \mu_h \cdot F_z$$

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

Chassis components and functions – Tire & Wheels

Tire longitudinal characteristics: slip behavior

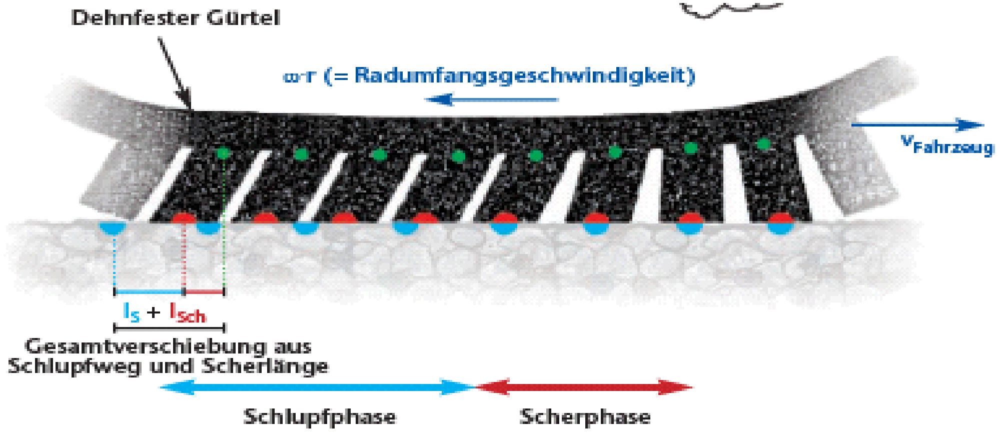


Der Block kommt in Kontakt mit der Straße.

Der Block wird unter der Radlast gestaucht.

Es tritt Scherung ein.

Es tritt Schlupf ein und der Block rutscht durch.



l_{Sch} : Scherlänge
l_S : Schlupfweg

Die Gesamtverschiebung des Gürtels über die Länge der Kontaktfläche in Relation zur Straßenoberfläche setzt sich aus Scherlänge und Schlupfweg zusammen.

● Betrachtungspunkt auf dem Gürtel,

◓ Betrachtungspunkt in der Lauffläche in Kontakt mit der Straßenoberfläche,

◒ Fixpunkt in der Straßenoberfläche.

Chassis components and functions – Tire & Wheels

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 %**

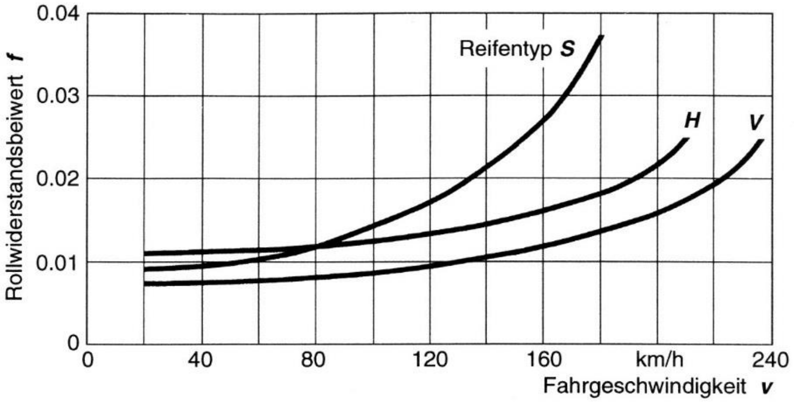
Chassis components and functions – Tire & Wheels

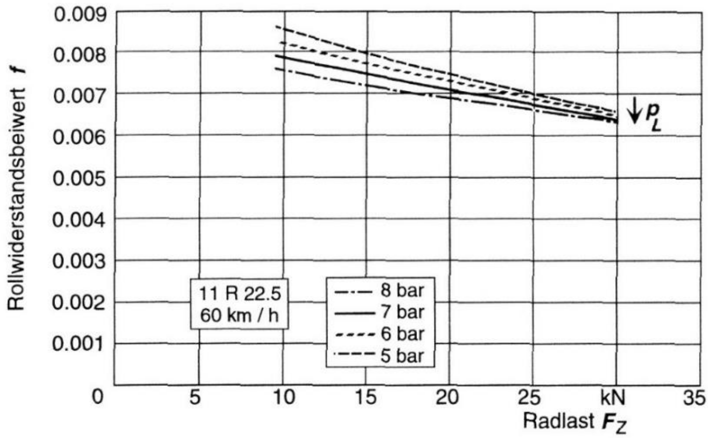
Tire Rolling Resistance (RR) - Sources

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

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:

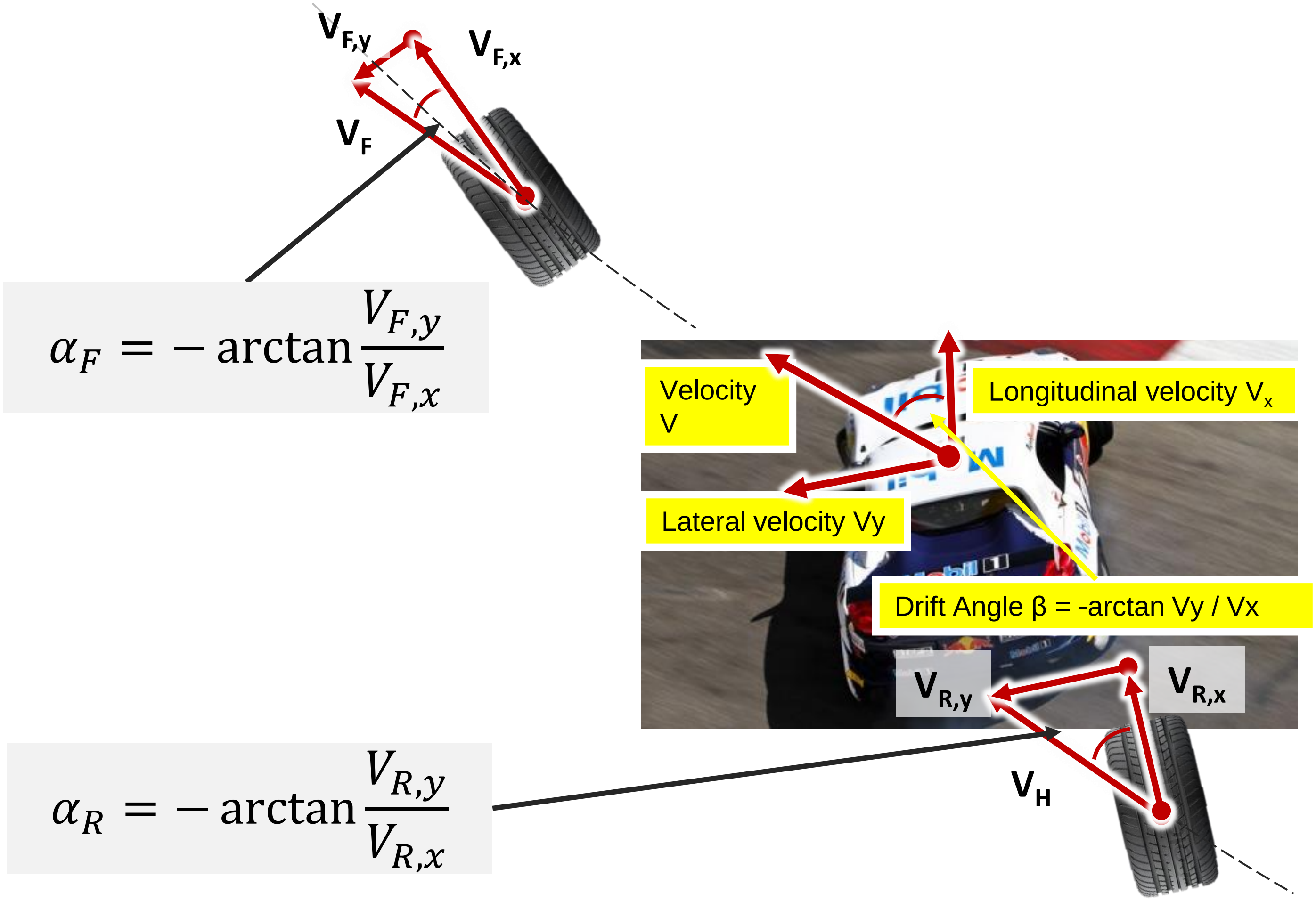
$f_{R0} \approx 0{,}009$
$f_{R1} \approx 2{,}0 \cdot 10^{-3}$
$f_{R4} \approx 0{,}25 \cdot 10^{-3}$

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

Chassis components and functions – Tire & Wheels

Tire lateral characteristics: side slip behavior

Tire lateral characteristics: side slip behavior

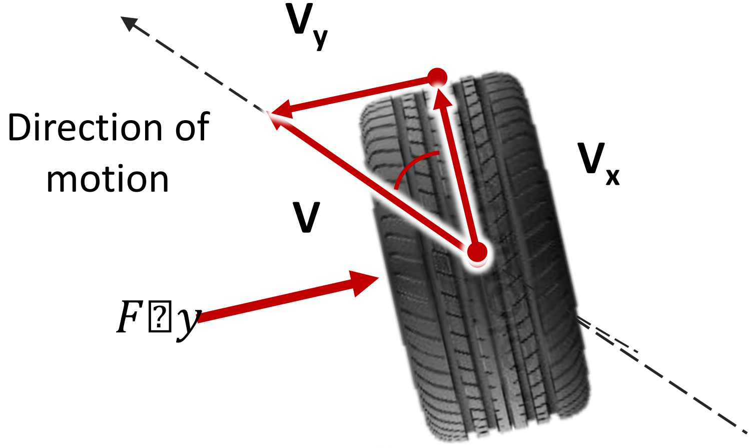


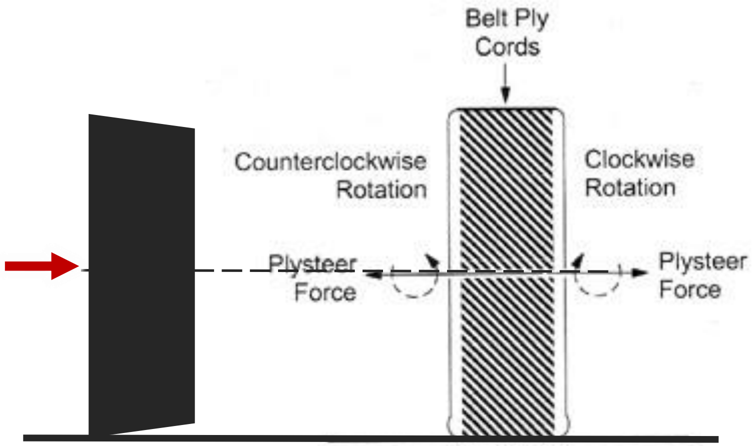
$$\alpha_F = -\arctan\frac{V_{F,y}}{V_{F,x}}$$

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

Chassis components and functions – Tire & Wheels

Tire lateral characteristics: side slip behavior





Conicity

Ply steer

Side slip α:

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

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

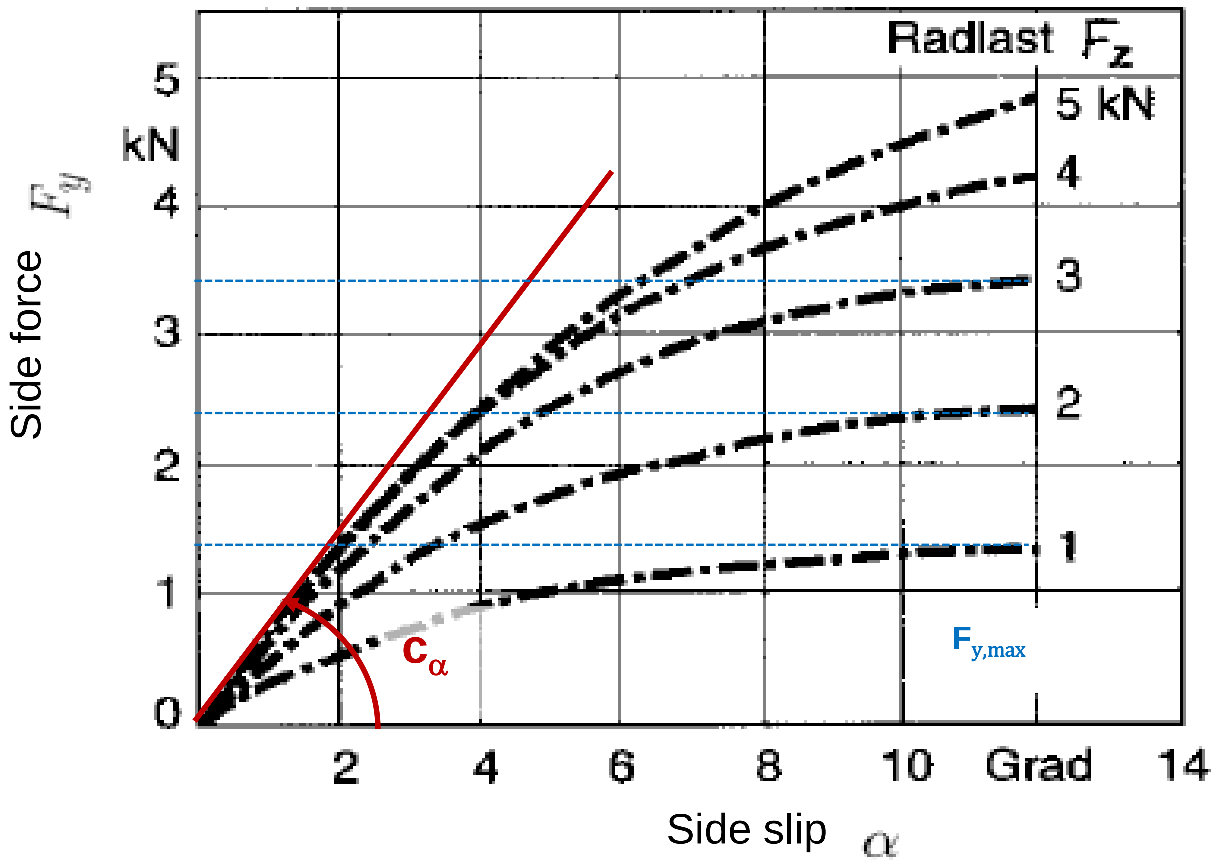
Tire side force generated by:

- 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.

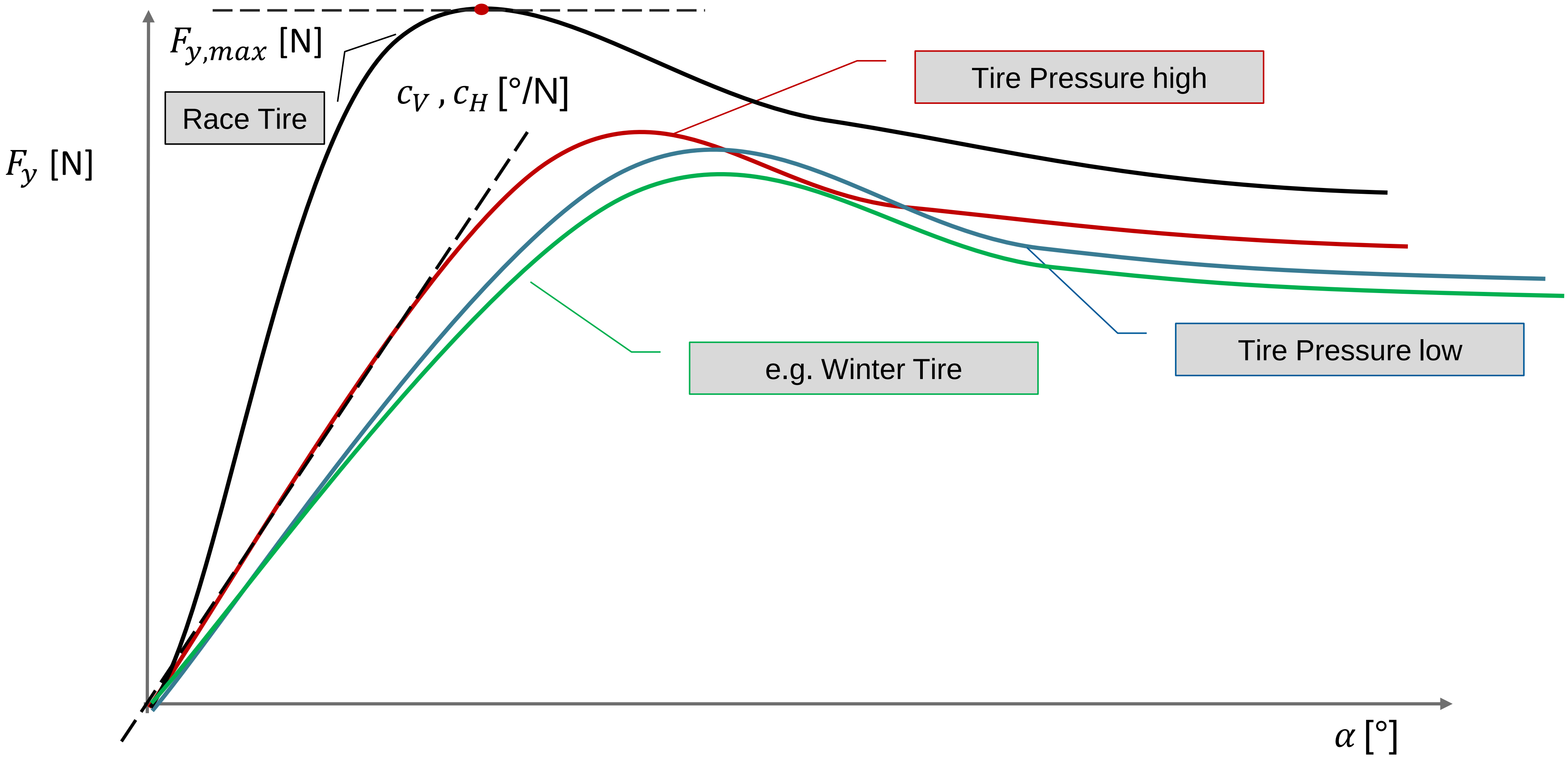
$$c_\alpha = \frac{dF_y}{d\alpha} = f(F_z)$$

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

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

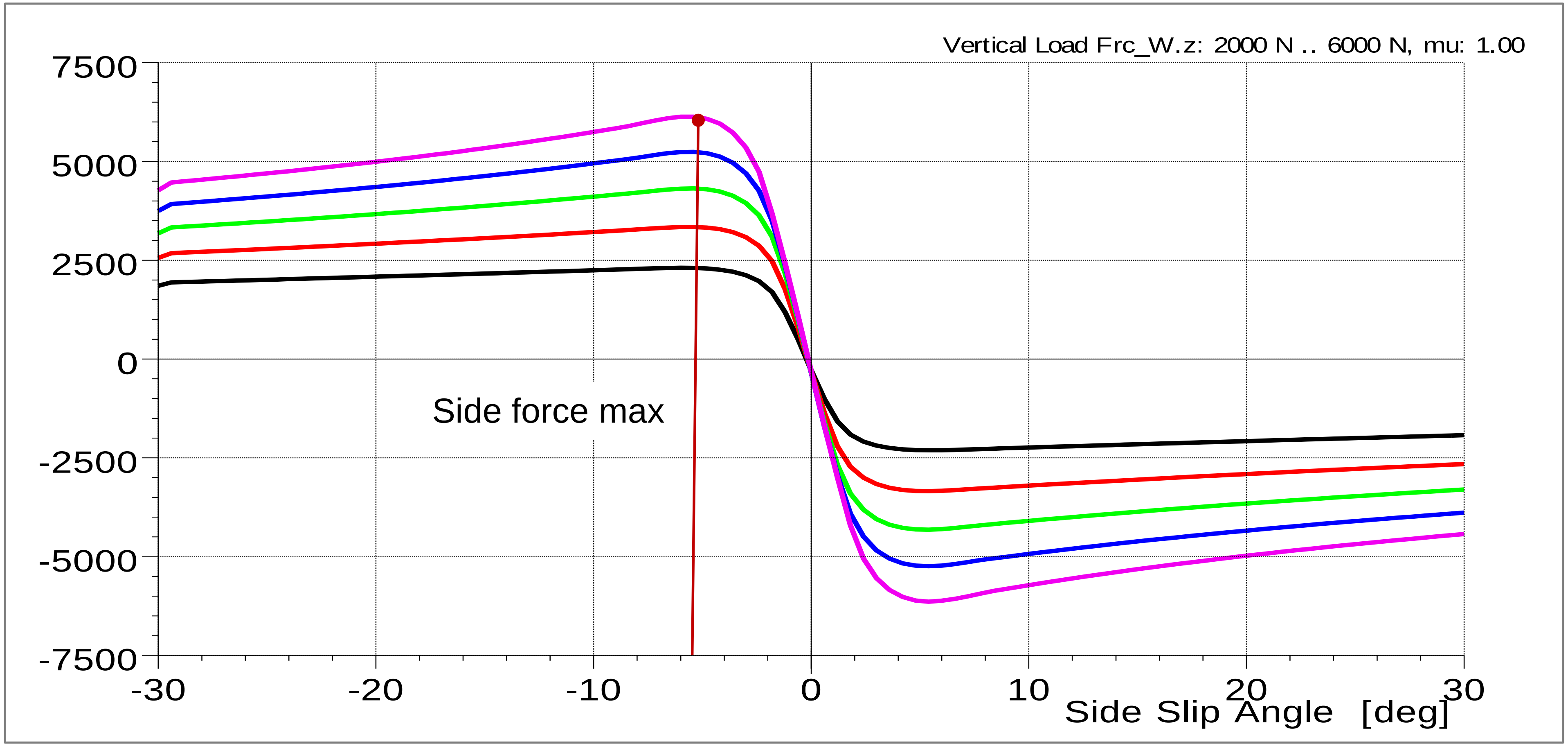
- The maximum transferable lateral forces are dependent on maximum adhesion in lateral direction.

Tire characteristics for understeer behavior (qualitative)



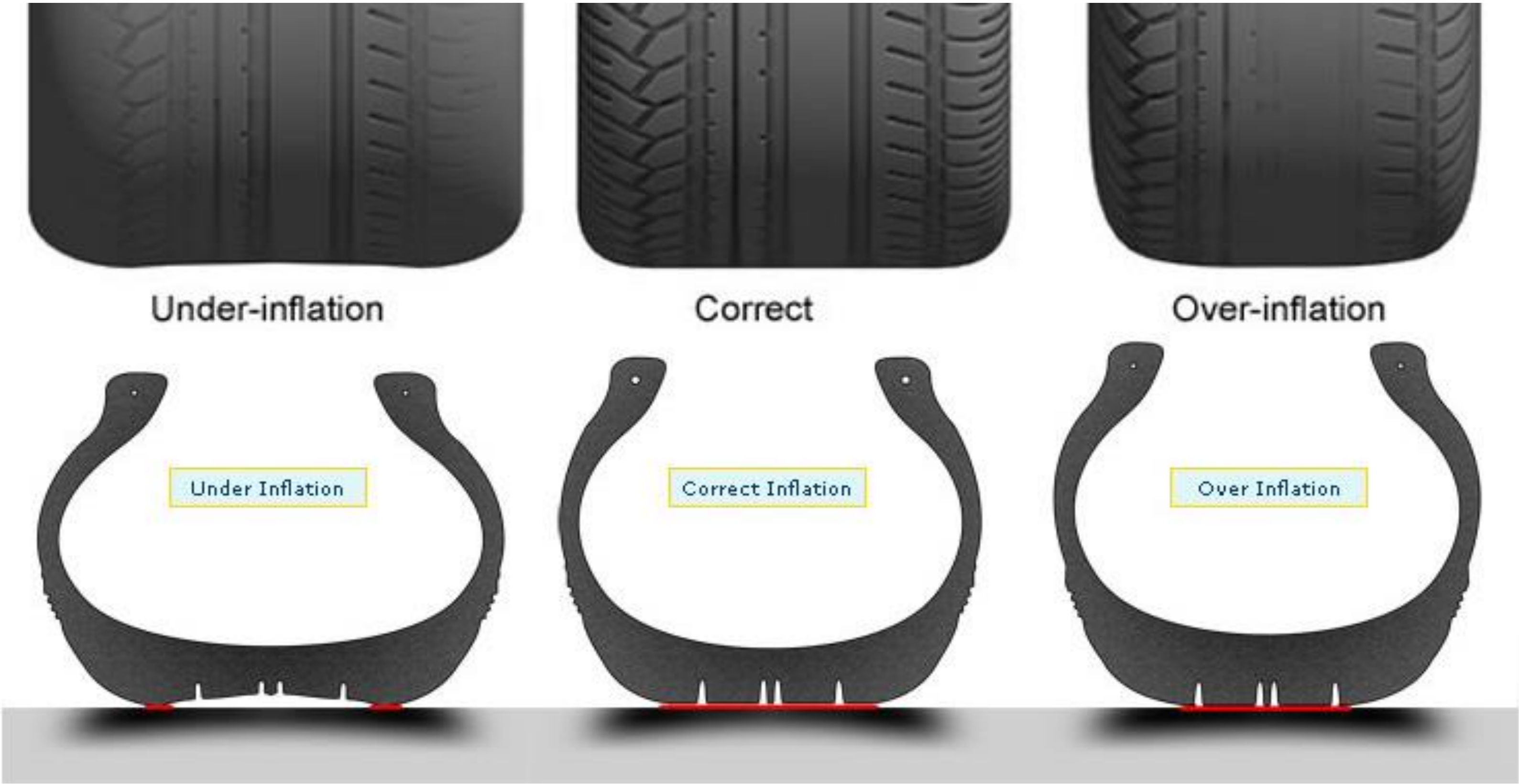
Chassis components and functions – Tire & Wheels

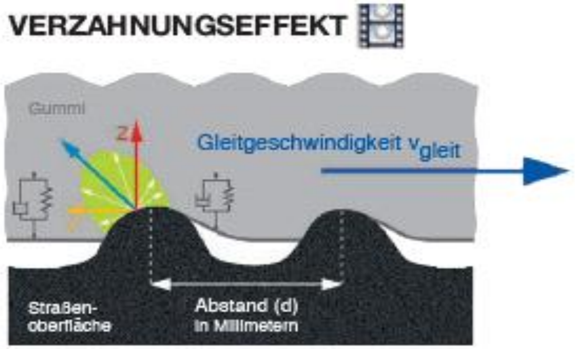
Tire lateral characteristics: side slip behavior

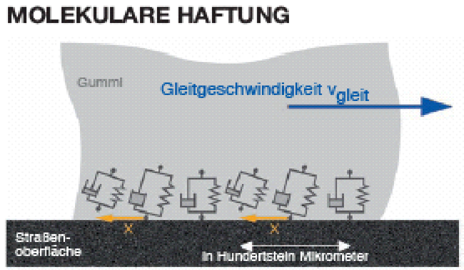


Chassis components and functions – Tire & Wheels

Correct inflation pressure for a good foot print



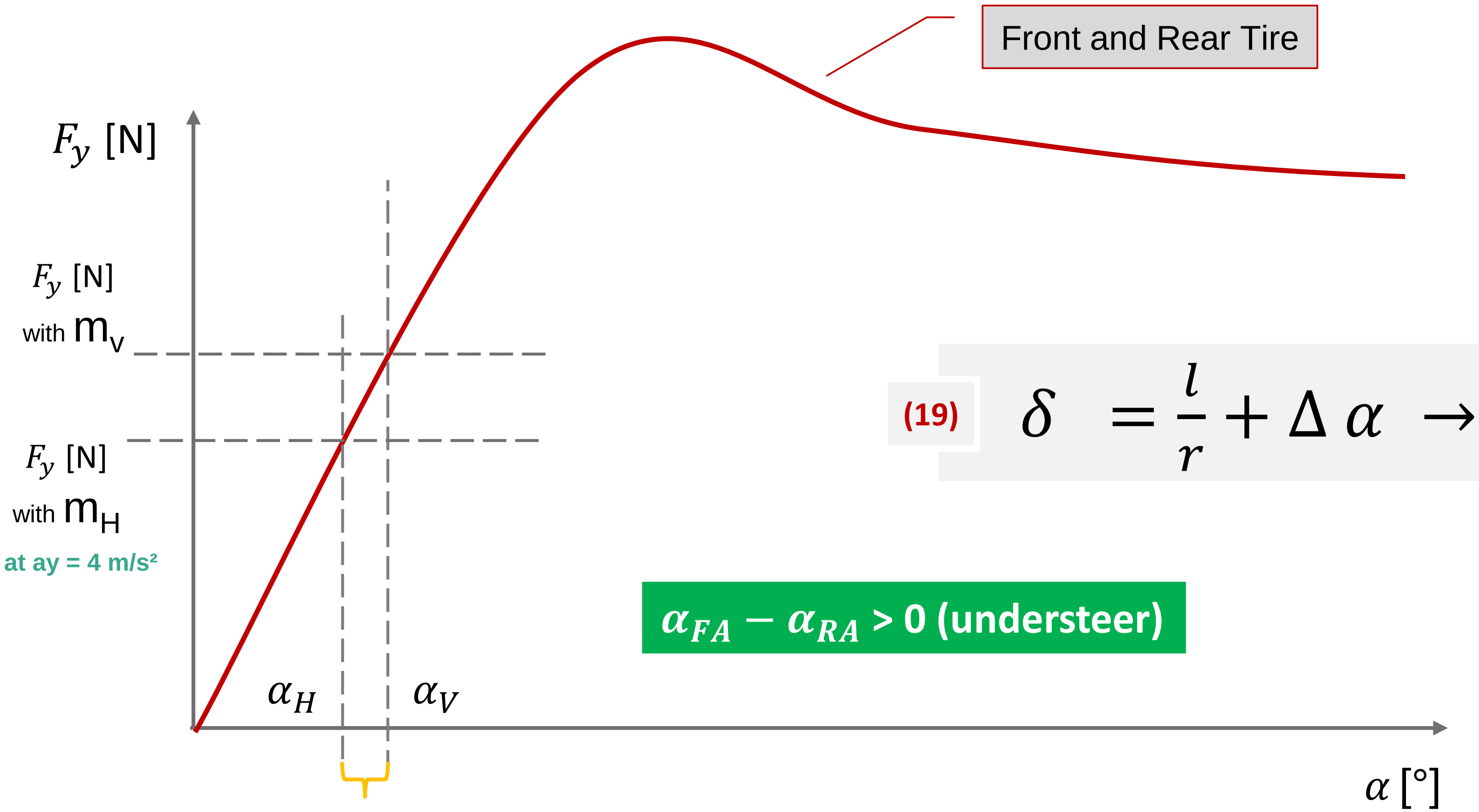




Influence to the brush, tooth and molecular adhesion effect is obvious.

Chassis components and functions – Tire & Wheels

Case 1: Understeer behavior with wheel load distribution



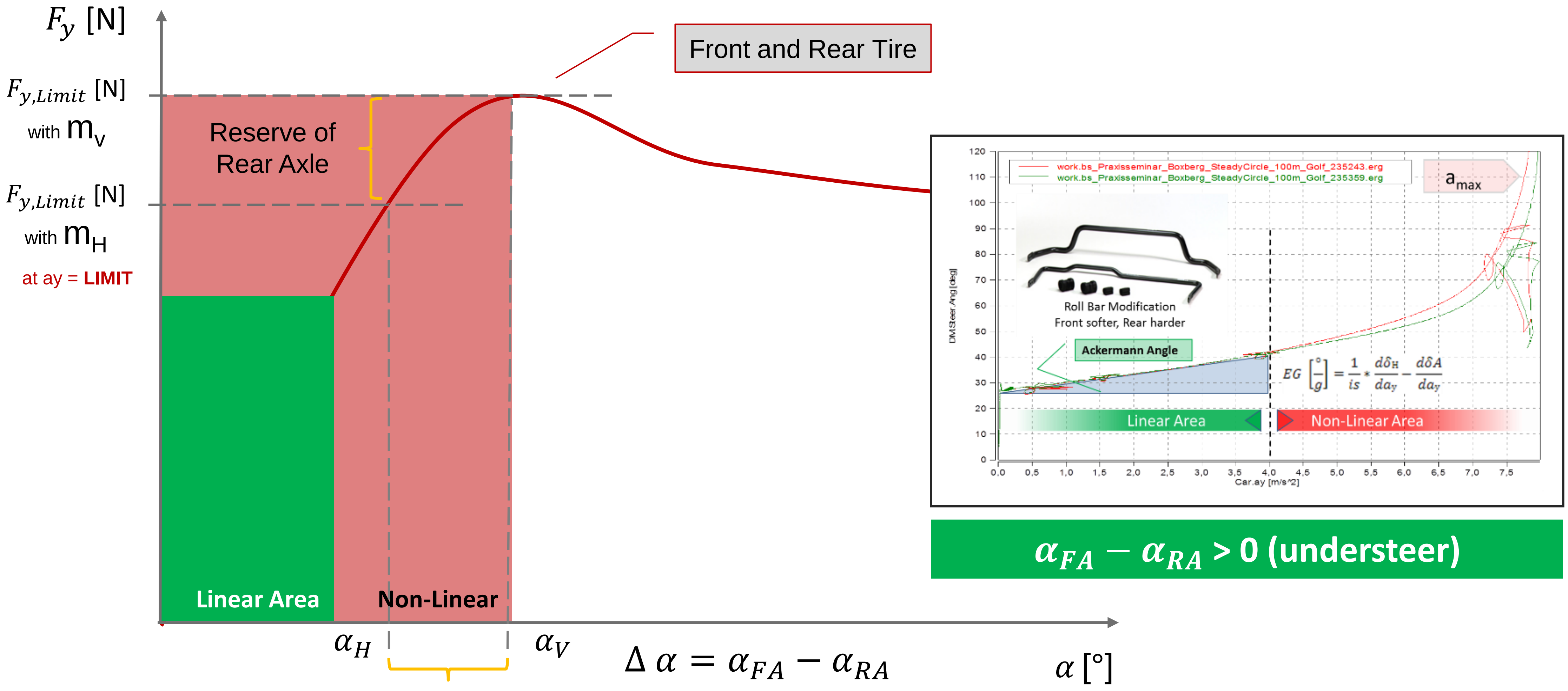
$$\Delta\,\alpha = \alpha_{FA} - \alpha_{RA}$$

(19) $$\delta \;= \frac{l}{r} + \Delta\,\alpha \;\rightarrow [\alpha_{FA} - \alpha_{RA}]$$

$\alpha_{FA} - \alpha_{RA}$ > 0 (understeer)

Chassis components and functions – Tire & Wheels

Case 1: Understeer behavior with wheel load distribution

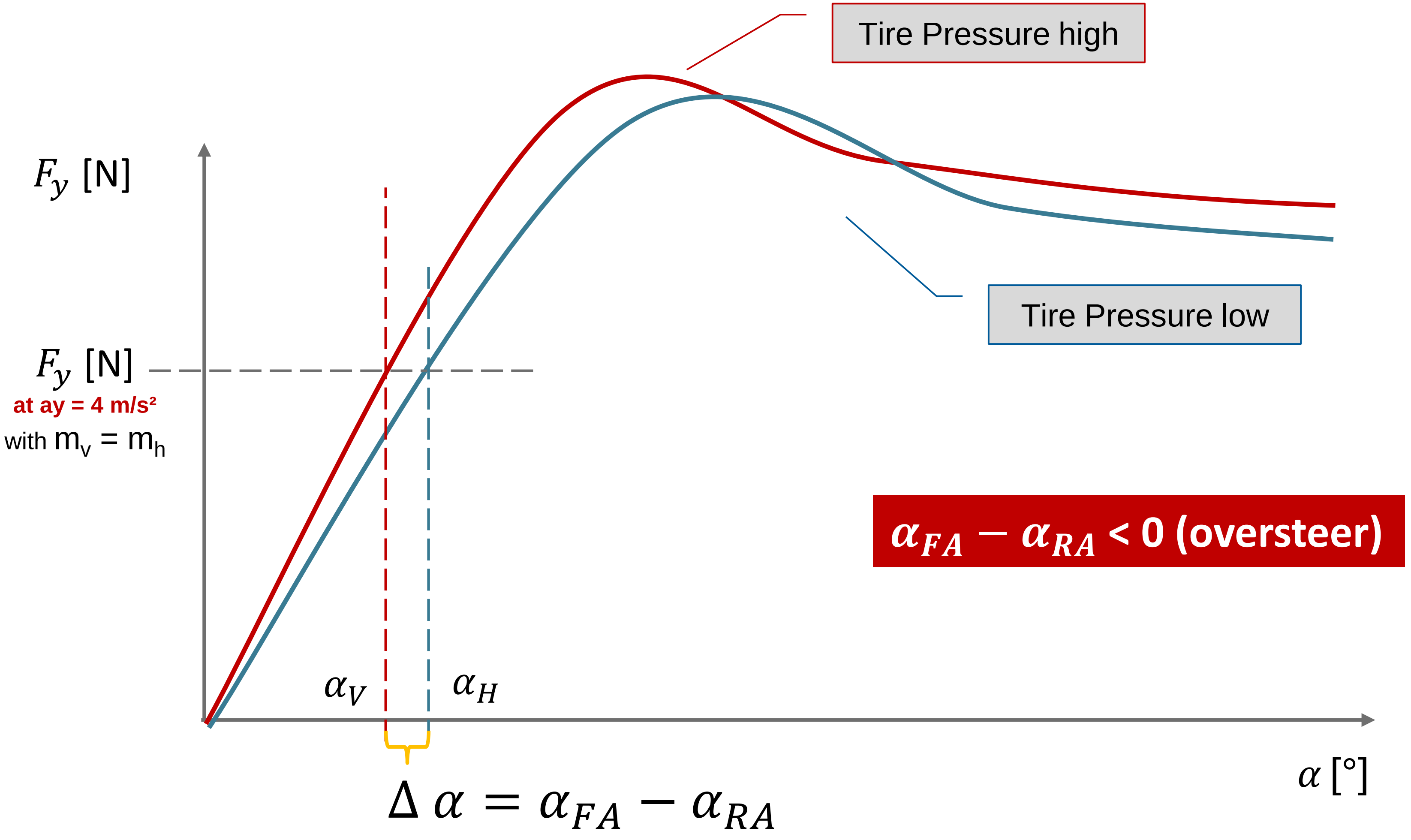


$$EG\left[\frac{°}{g}\right] = \frac{1}{is} * \frac{d\delta_H}{da_y} - \frac{d\delta A}{da_y}$$

$$\Delta\,\alpha = \alpha_{FA} - \alpha_{RA}$$

$\alpha_{FA} - \alpha_{RA}$ **> 0 (understeer)**

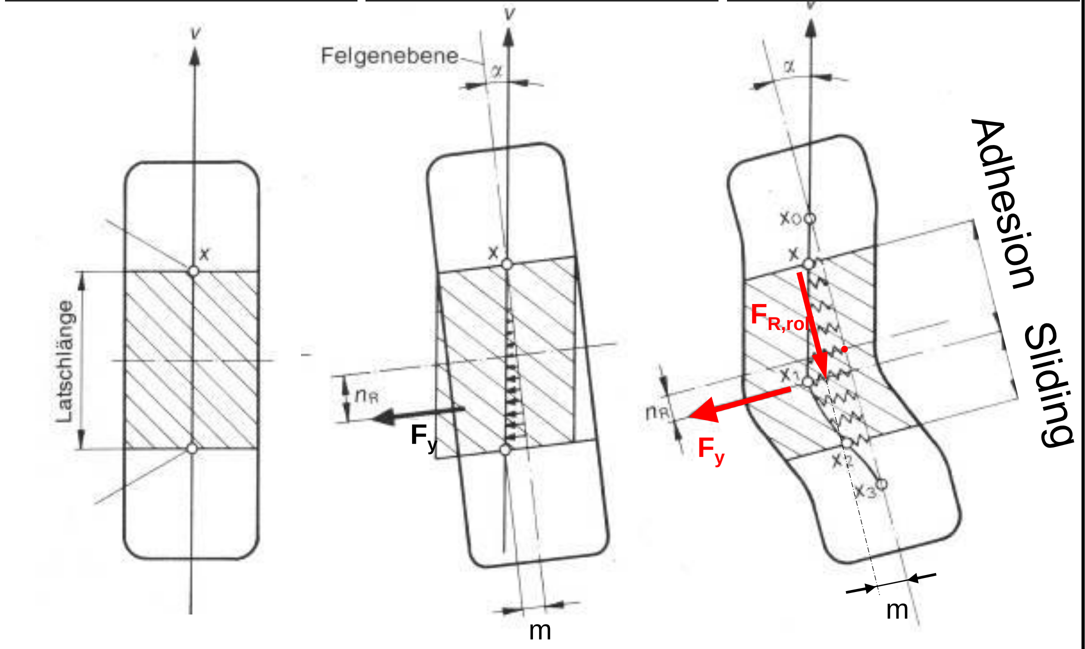
Case 2: Oversteer behavior with tire pressure difference



Chassis components and functions – Tire & Wheels

Tire lateral characteristics: side slip behavior

Straight running	Driving with small side slip angle	Driving with big side slip angle



Definition

- The lateral force Fy and the rolling resistance F_R, effect to the CoG of the deformation area.
- The x-distance from the center of foot print is called pneumatic trail.
- The y-distance to the rim plane is denoted by m.

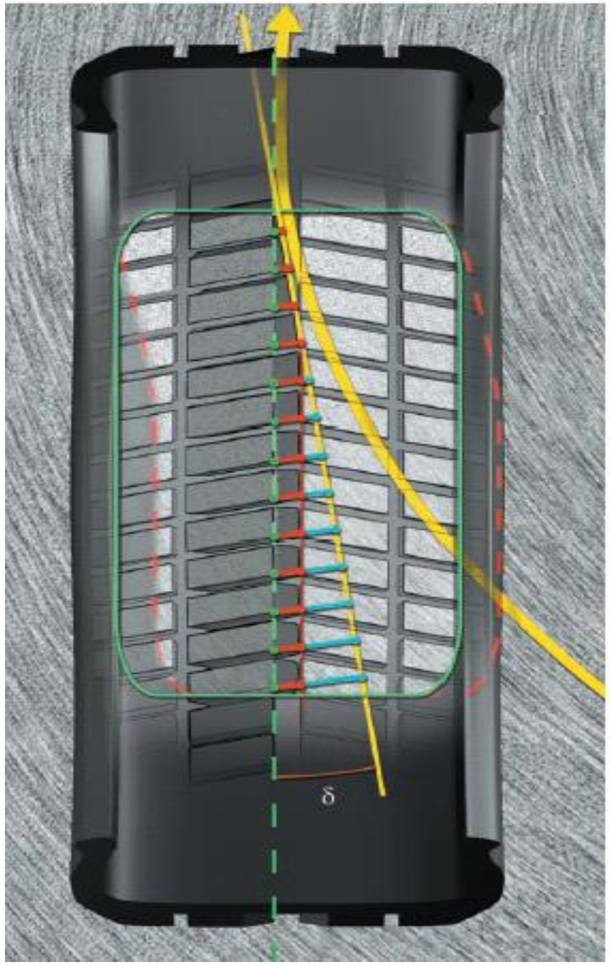
Back alignment torque:

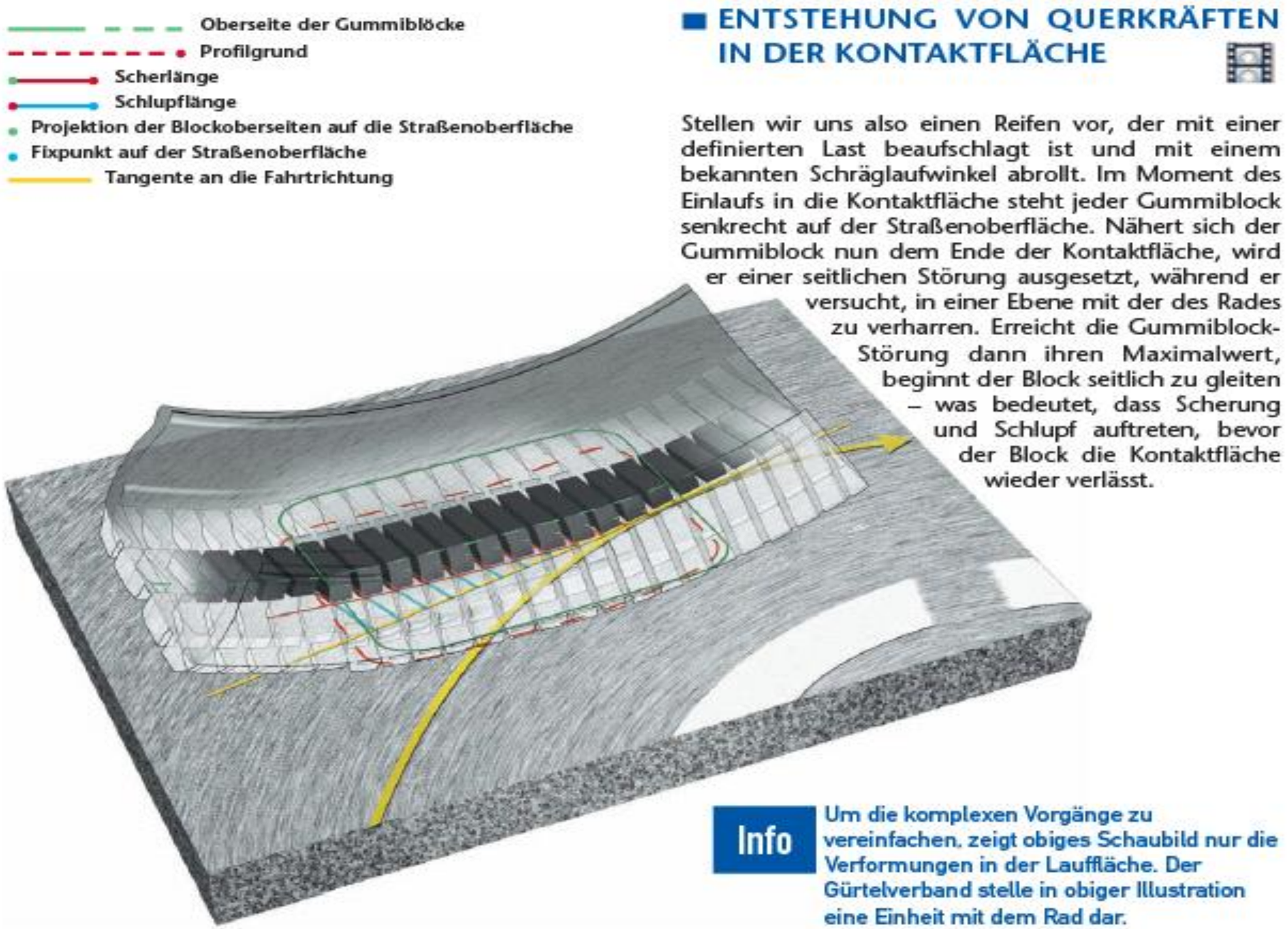
$$M_z = F_y \cdot n_R - F_{R,roll} \cdot m \quad (37)$$

Simplified:

$$M_z = F_y \cdot n_R \quad (38)$$

Tire lateral characteristics: side slip behavior





Oberseite der Gummiblöcke
Profilgrund
Scherlänge
Schlupflänge
Projektion der Blockoberseiten auf die Straßenoberfläche
Fixpunkt auf der Straßenoberfläche
Tangente an die Fahrtrichtung

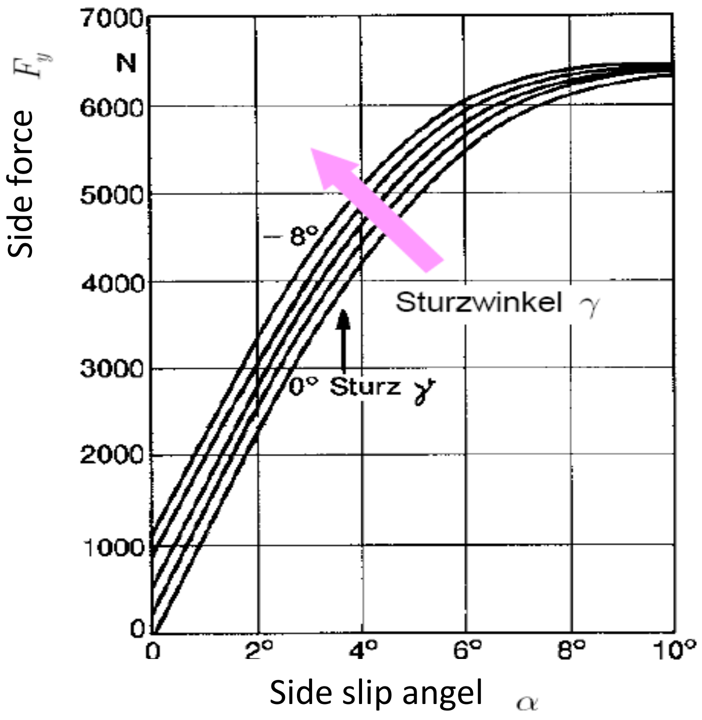
ENTSTEHUNG VON QUERKRÄFTEN IN DER KONTAKTFLÄCHE

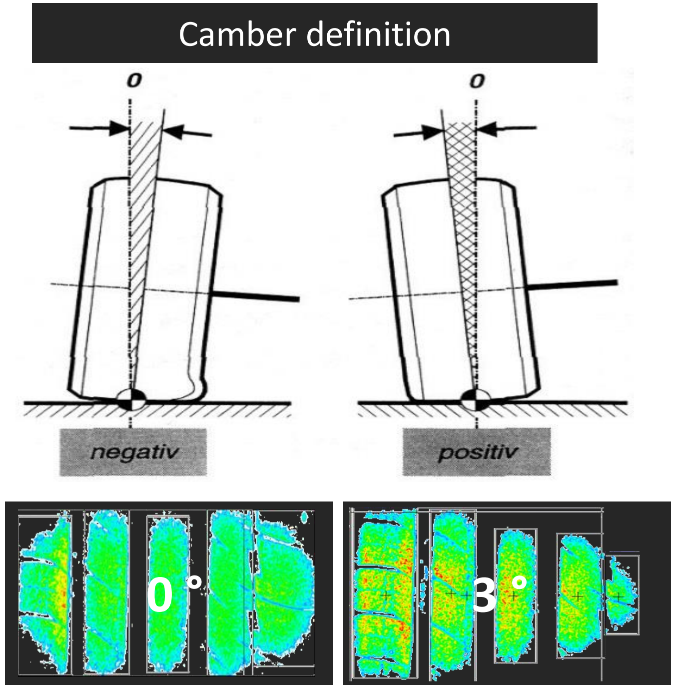
Stellen wir uns also einen Reifen vor, der mit einer definierten Last beaufschlagt ist und mit einem bekannten Schräglaufwinkel abrollt. Im Moment des Einlaufs in die Kontaktfläche steht jeder Gummiblock senkrecht auf der Straßenoberfläche. Nähert sich der Gummiblock nun dem Ende der Kontaktfläche, wird er einer seitlichen Störung ausgesetzt, während er versucht, in einer Ebene mit der des Rades zu verharren. Erreicht die Gummiblock-Störung dann ihren Maximalwert, beginnt der Block seitlich zu gleiten – was bedeutet, dass Scherung und Schlupf auftreten, bevor der Block die Kontaktfläche wieder verlässt.

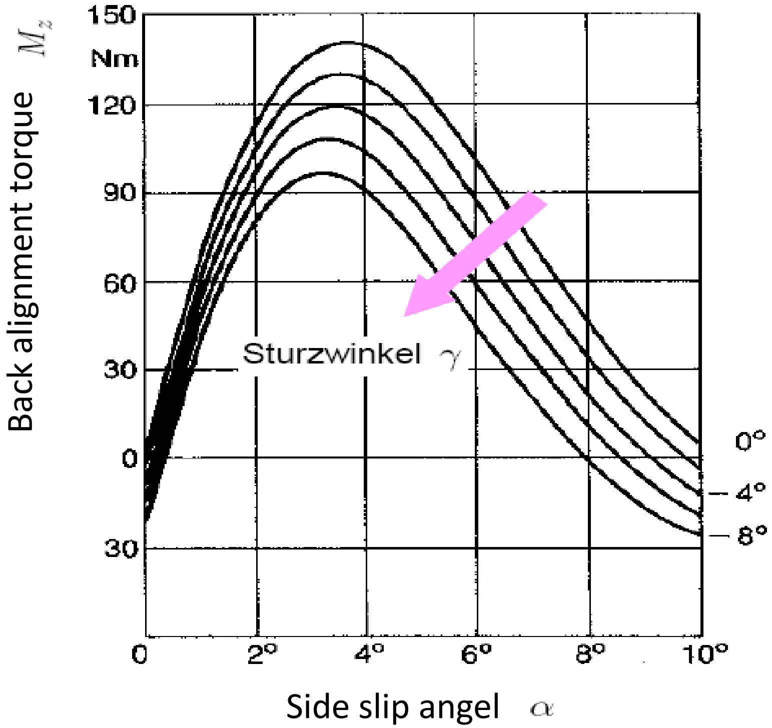
Info Um die komplexen Vorgänge zu vereinfachen, zeigt obiges Schaubild nur die Verformungen in der Lauffläche. Der Gürtelverband stelle in obiger Illustration eine Einheit mit dem Rad dar.

Chassis components and functions – Tire & Wheels

Tire lateral characteristics: side slip behavior

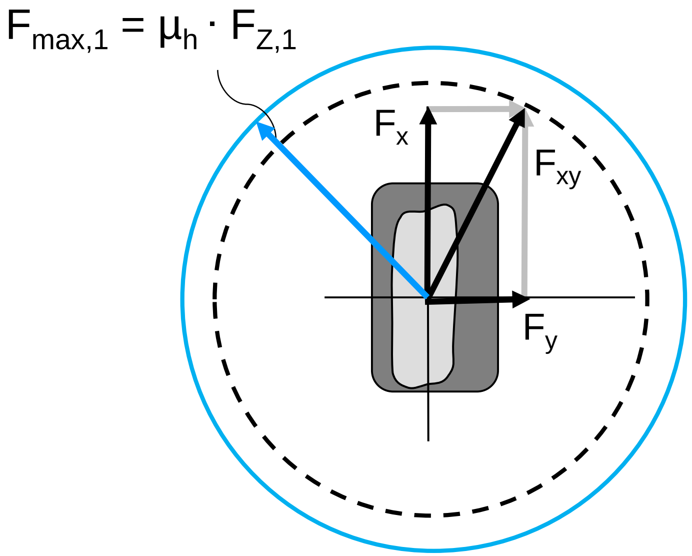






A negative camber angle allows for the same side slip angle slightly greater lateral forces.

XY combined tire characteristics: Kam’sche Cycle



$$F_{xy}^2 = F_x^2 + F_y^2 \quad (39)$$

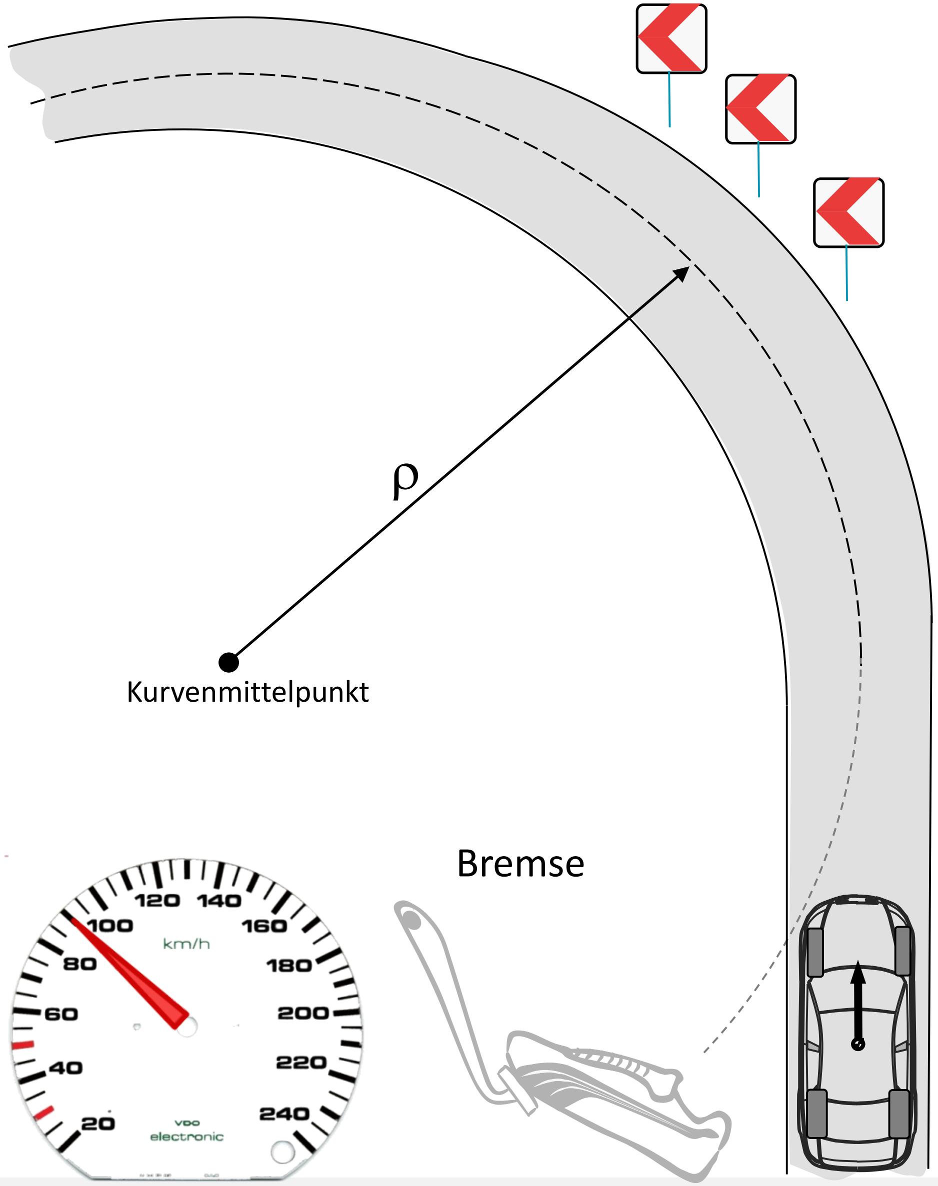
$$F_{xy} \le F_{max} = \mu_h \cdot F_z \quad (40)$$

The sum of these forces is at most as large as the maximum transferable force between tire and road, which is the product of coefficient of adhesion and wheel load.

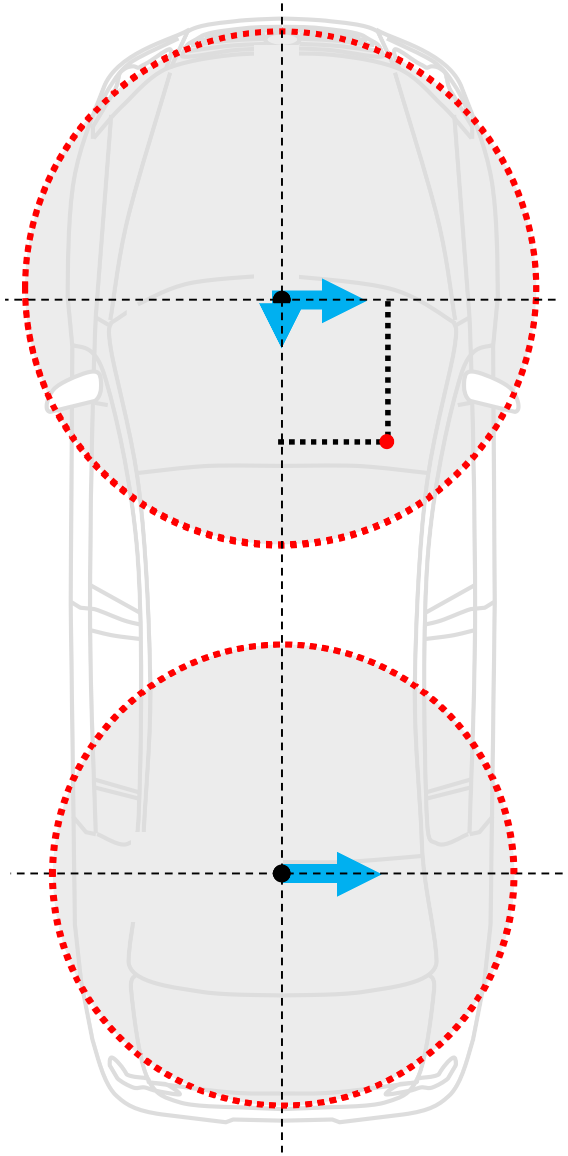
So that the vehicle in the longitudinal and lateral direction can be performed stably, i.e. the wheel moves without high sliding, the limit of adhesion between the wheel and the road must not be exceeded.

Chassis components and functions – Tire & Wheels

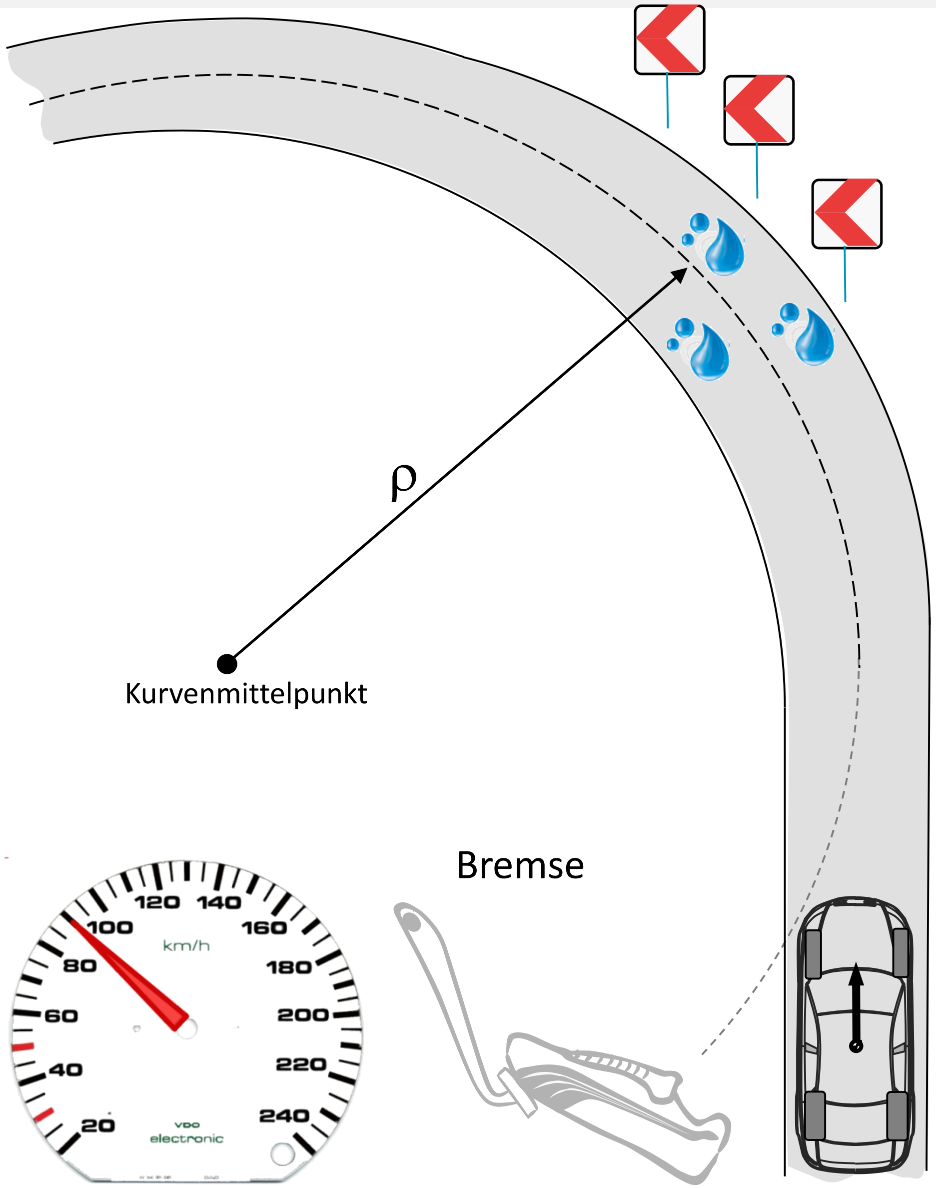
①



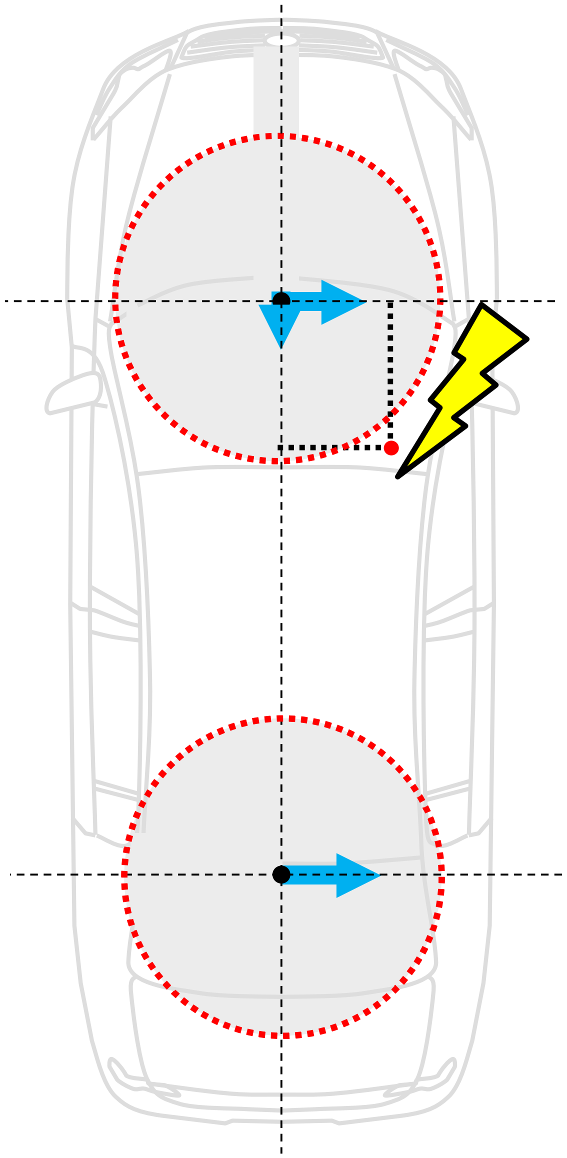
$\mu_h \approx 1{,}0$



Chassis components and functions – Tire & Wheels



$\mu_h \approx 0{,}5$



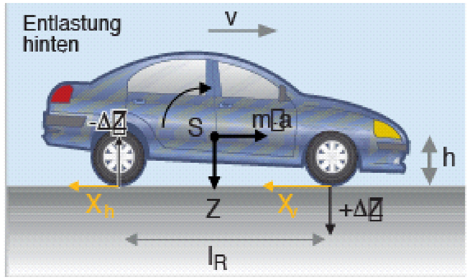
Chassis components and functions – Tire & Wheels

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.



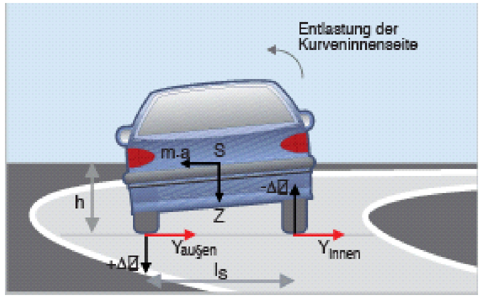
X = Längsreibungskraft vorne (X_v) und hinten (X_h), in N
S = Schwerpunkt des Fahrzeugs,
m = Masse des Fahrzeugs, in kg
a = Beschleunigung in Längsrichtung, in m/s²
Z = Gewichtskraft (= Summe der 4 Radlasten), in N
h = Schwerpunkthöhe über der Straße, in m
l_R = Radstand des Fahrzeugs, in m

Druckfehler
Innen: - ΔZ
Außen: + ΔZ

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.

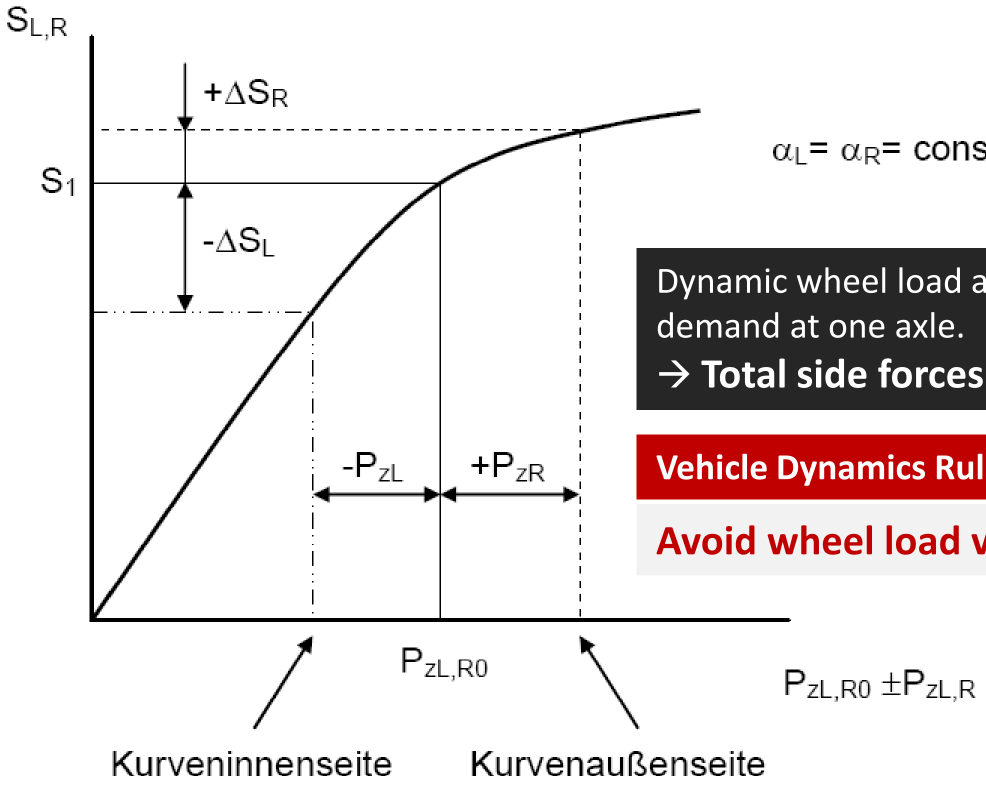
Um diesen unerwünschten Effekt zu reduzieren, kann der Konstrukteur z.B. die Spur verbreitern oder die Schwerpunkthöhe verringern.



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**



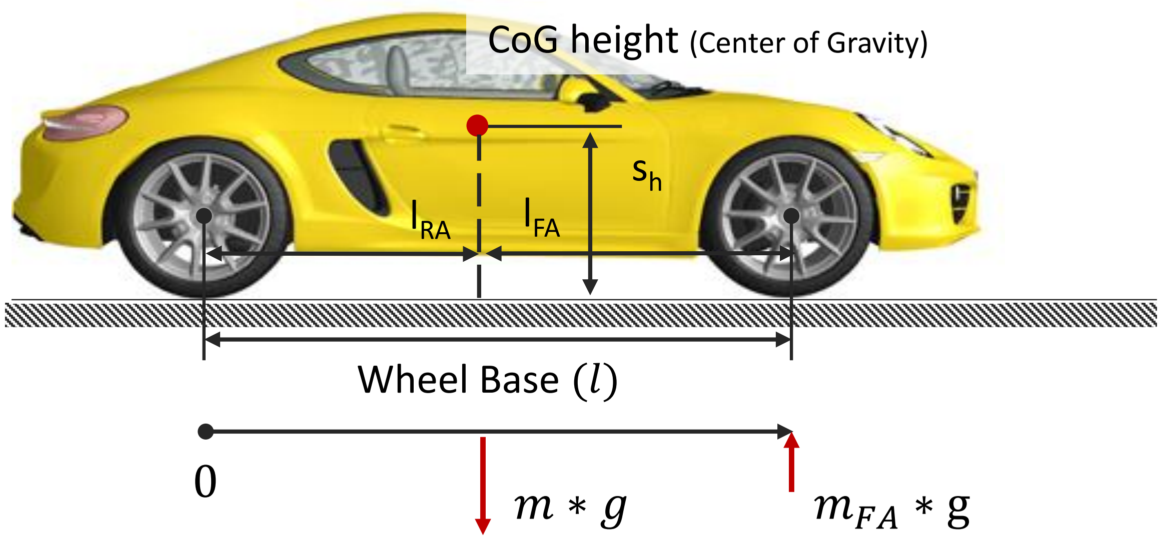
Dynamic wheel load and side force demand at one axle.
→ **Total side forces are reduced**

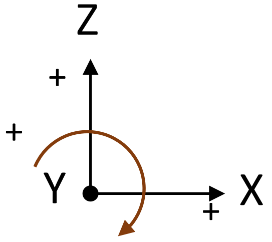
Vehicle Dynamics Rule No. 1:

Avoid wheel load variation

Chassis components and functions – Tire & Wheels

Calculation of CoG – Center of Gravity





$$\sum F_z = 0$$

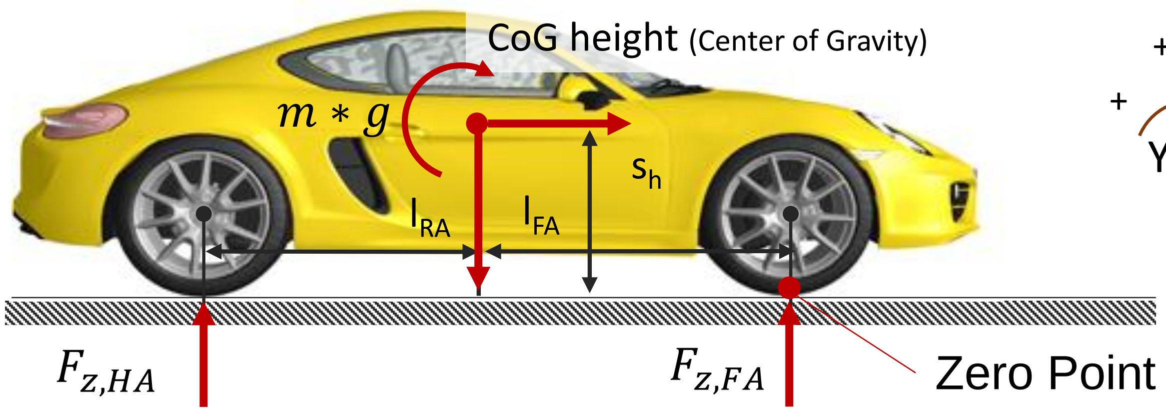
$$m * g * l_{RA} = m_{FA} * g * l$$

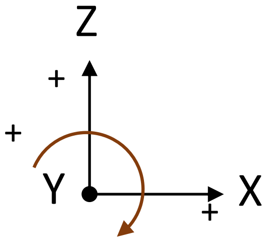
$$l_{FA} = l - l_{RA}$$

Vehicle weight (with driver)	= 1.970 kg
m_{FA} (front axle)	= 1100 kg
m_{RA} (rear axle)	= 870 kg
Wheel base	= 2.807 mm,
Center of gravity	= 0,65 m

Chassis components and functions – Tire & Wheels

Dynamic Wheel Load Calculation





$$\sum F_z = 0 \qquad 0 = m * g - (F_{z,FA} + F_{z,HA})$$

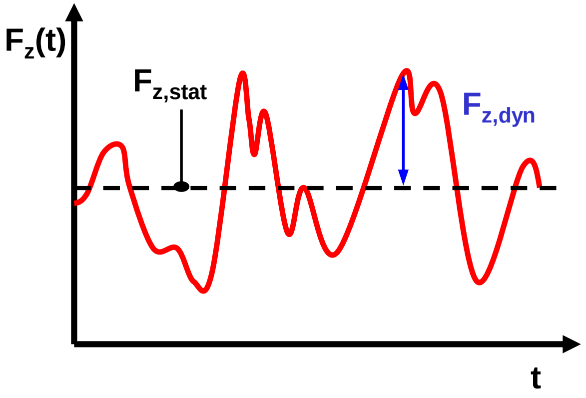
$$\sum M_y = 0 \qquad 0 = m * a_x * s_h - m \ * g * l_{FA} + F_{z,HA} + l$$

$$F_{z,HA} = \frac{m * g * \ l_{FA} - m * a_x * s_h}{l}$$

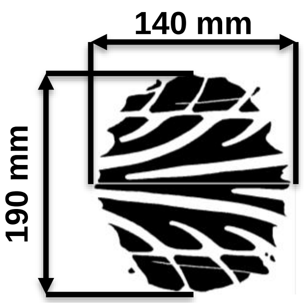
$$F_{z,VA} = m * g - F_{z,HA}$$

Chassis components and functions – Tire & Wheels

Tire vertical characteristics: dynamic wheel load



Sample:
245/40 R18, 2,2 bar, F_z = 4.700 N



- Brutto foot print ≈ 230 cm²
- Netto foot print ≈ 150 cm²

The acting vertical tire force (wheel load) shall be composed of:

- **Static wheel load** $F_{z,stat}$ = constant (Gravity and vehicle mass).
- **Dynamical wheel load** $F_{z,dyn}$ = f(t) (Relative motion of the body related to the ground).

Due to the elasticity of the rubber and the air in the tire, it comes to vertical defection. This leads to the formation of a contact area A between the road and tread - the tire contact area (foot print). About this all forces must to be transferred.

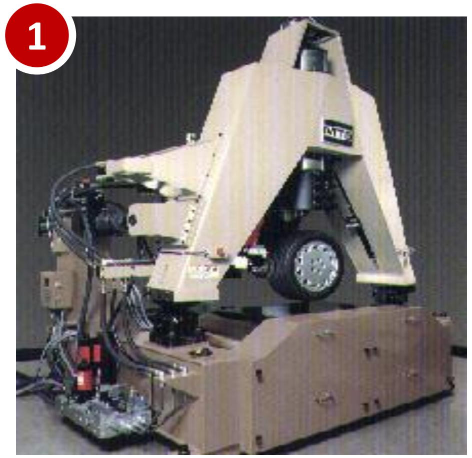
Influences to the effective foot print:

- Wheel load.
- Tire inflation pressure
- Tire construction.
- Tire dimension.
- Profile.

Chassis components and functions – Tire & Wheels

Tire characteristics measurement

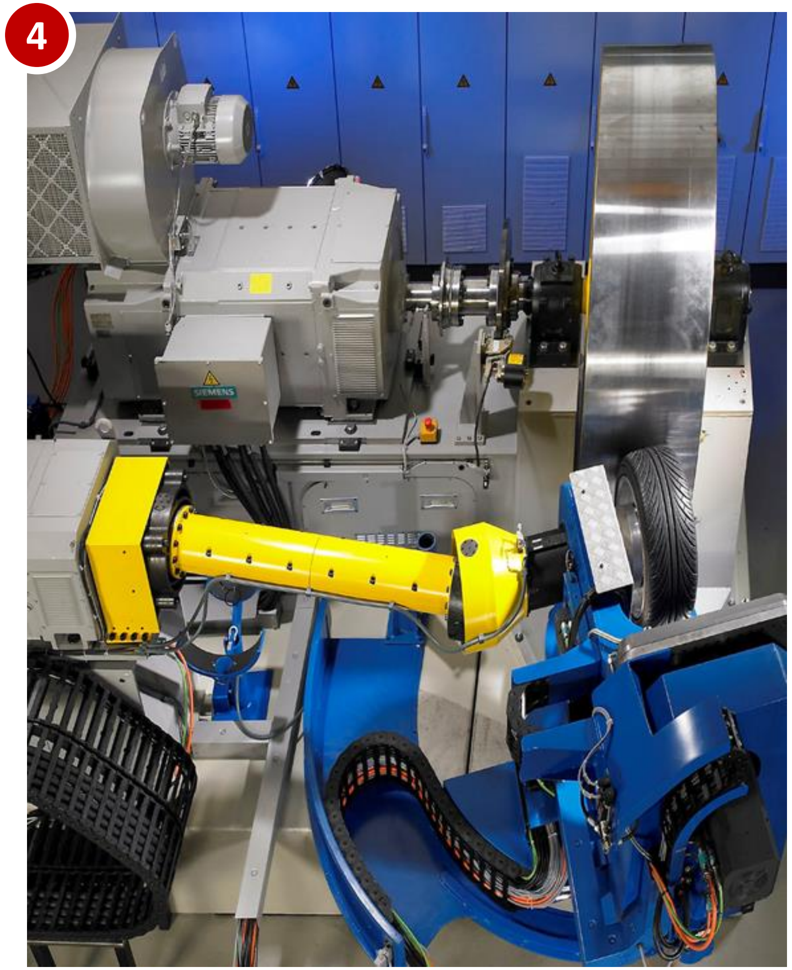
1



2

3

4

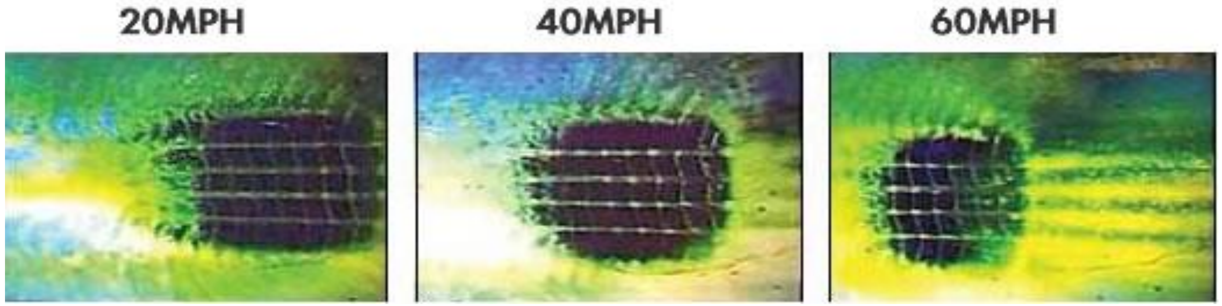


1. Flat Belt Test Rig
2. Measurement Vehicle
3. Inner Drum Test Rig
4. Roller Drum Test Rig

Chassis components and functions – Tire & Wheels

Chassis components and functions – Tire & Wheels

Aquaplaning effect



Chassis components and functions – Tire & Wheels

Chassis components and functions – Tire & Wheels

Chassis components and functions – Tire & Wheels