Department of Automotive Technologies –
Vehicle Mechanics Fundamentals

Gábor Sipos

DEPARTMENT OF AUTOMOTIVE TECHNOLOGIES

Lecture 1

Basic information

Introduction

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Subject

Goal

Participation: Lectures and labs

Tests

Signature

- Midterm exams ~6&14th weeks
- Submitted semester championship documentation
- Based on the result of tests, final mark can be obtained, and no need for exam

Exam

Note

To prepare for exam/tests presentations will be uploaded to Moodle, but the some of the slides aren't – therefore to have the full picture lectures shall be attanded.

Literature

- Milliken and Milliken, 1996 W.F. Milliken, D.L. Milliken Race Car Vehicle Dynamics, Society of Automotive Engineers Inc., Great Britain (1996)
- H. B. Pacejka 2006 Tyre and Vehicle Dynamics Butterworth-Heinemann
- Racecar: Searching for the Limit in Formula SAE Matt Brown Seven Car Publishing 2011

Quiz

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How to convert 1 radian to degree [°]?

A. Multiply 1 rad with $\frac{\pi}{90°}$.

B. Divide 1 by π.

C. Multiply 1 rad with $\frac{180°}{\pi}$.

D. 1 radian and 1 degree [°] marks the same amount of rotation.

Quiz

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Basic information

Week nr.	Date	Lecture (Wednesday)			Lab (Wednesday)		
1	12th Feb	1	General information, Tyre, Driving force		1	Lab	
2	19th Feb	2	Longitudinal and lateral behaviour				
3	26th Feb	3	Concepts and over/understeer		2	Lab	
4	5th Mar	4	Weight transfer				
5	12th Mar	5	Bicycle model		3	Lab	
6	19th Mar	T1	Midterm exam I.				
7	26th Mar	6	Braking and brakes		T1 R	Exam 1 - replacement	
8	2nd Apr	-	Systems of the vehicle				
9	9th Apr	7	Break			Break	
10	16th Apr	8	Quarter vehicle model				
11	23th Apr		Break			Break	
12	30th Apr	T2	Systems of vehicle II. ONLINE				
13	7th May	9	Tyre management		4	Lab	
14	14th May	10	Midterm exam II.				
15	21st May		Racecar engineering		T2 R	Exam 2 - replacement	

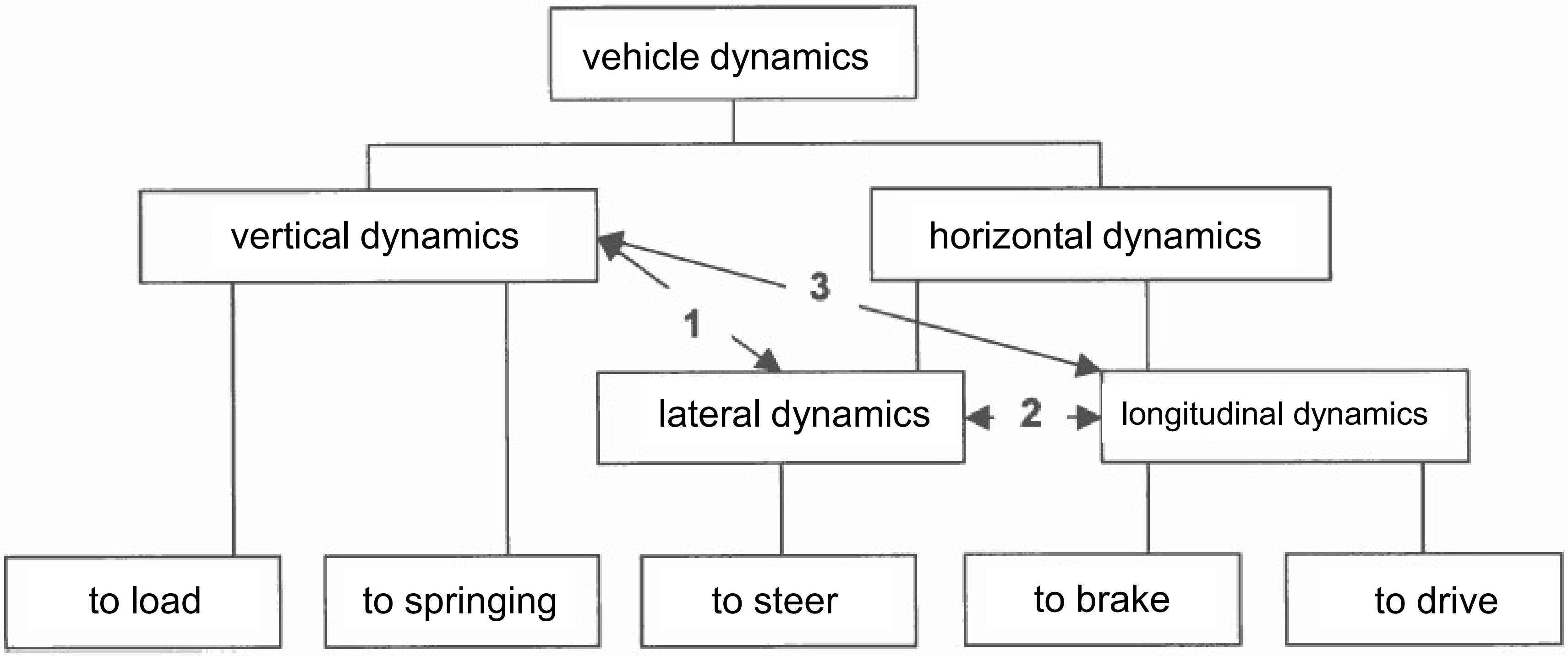
Some mechanical aspects

	Reason of the motion	Inertia	Equation of motion	Dynamics principle
Rectilinear motion	F [N] force	m [kg] mass	$F = m \cdot a$	$\dot{I} = \sum F$ i : Impulse derivative
Circular motion	M [Nm] torque	θ [kg m^2] Moment of inertia	$M = \theta \cdot \varepsilon$	$D_c = \sum M$ D_c: kinetic torque

	Quantities		W Work done by	Work-energy principle
Rectilinear Motion	$I = m \cdot v$ impulse	$E = \frac{1}{2} \cdot m \cdot v^2$ Kinetic energy	$W = F \cdot \Delta s$	$W = \Delta E_{kinetic}$
Rotational motion	$N = \theta \cdot \omega$ Angular moment	$E = \frac{1}{2} \cdot \theta \cdot \omega^2$ Rotational energy	$W = M \cdot \Delta\varphi$	$W = \Delta E_{rotational}$

Some mechanical aspects

Vehicle dynamics blocks



Simple model of VD

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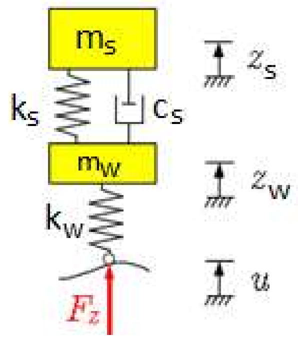
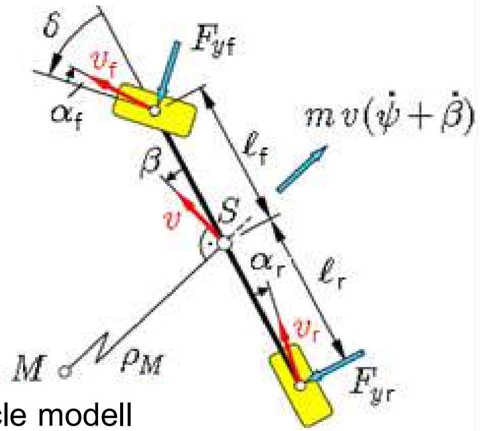
vertical dynamics



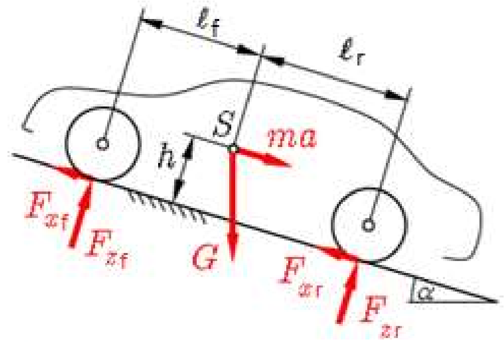
Quarter vehicle modell

lateral dynamics



Bicycle modell

longitudinal dynamics



longitudinal modell

	vertical dynamics	lateral dynamics	longitudinal dynamics
Features	• Vertical vibration • Wheel loads • comfort	• steering • Lateral acceleration • Self aligning torque • Critical speed	• Acceleration and braking • resistances: tyre,air, uphill – power requirement; • Engine characteristics and gears • Braking and driving forces
Parameters	m_s – structural weight m_w – wheel weight k_t – tyre stiffness k_s – spring stiffness c_s – damping u - movement	l – wheelbase l_f – CoG distance m – weight v – vehicle speed α – slip angle δ – steering angle	h – CoG height G – gravity force F_{xf} – front axle driving force F_{zf} – tyre forces at front

Why racecars?

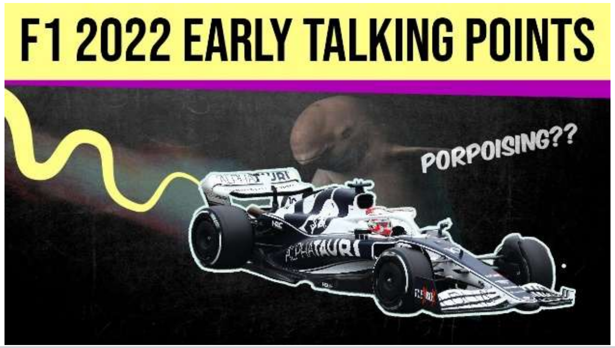
Abstract thinking

What’s the main function of a racecar?

Why racecars?

Interview question of McLaren F1

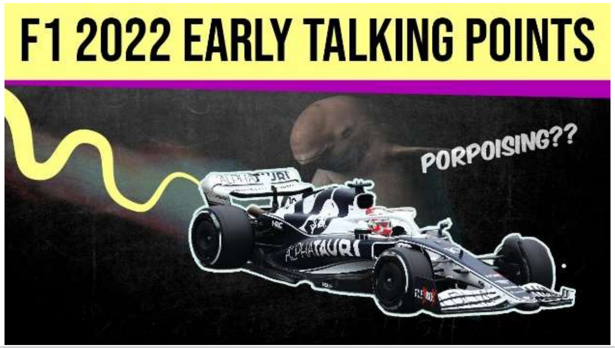
Why porpoising affects more the top teams?



Why racecars?

Interview question of McLaren F1

Why porpoising affects more the top teams?
If you are power limited rather than grip-limited, you do not really lose any performance. It mostly happens in high speed corners and straights.



Grip or power limited?

Newton's second law

Keep low as possible

Power limited

$$F_x = m \cdot a$$

Goal: have best acceleration

Grip limited

$$F_x = m \cdot a$$

$$a = \frac{F_x}{m} = \frac{F_z \cdot \mu_x}{m} = \frac{m \cdot g \cdot \mu_x}{m}$$

$$= g \cdot \mu_x$$

Why racecars?

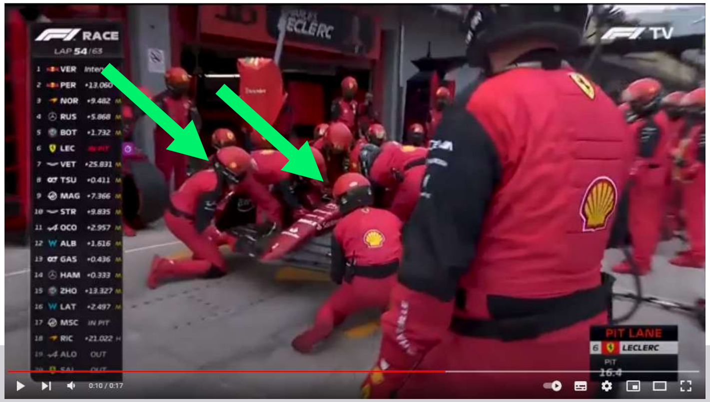
BMW advertisement

Good handling is possible only with perfect weight distribution?

No, WD is one element, it must match with cornering stiffness balance to reach good handling.

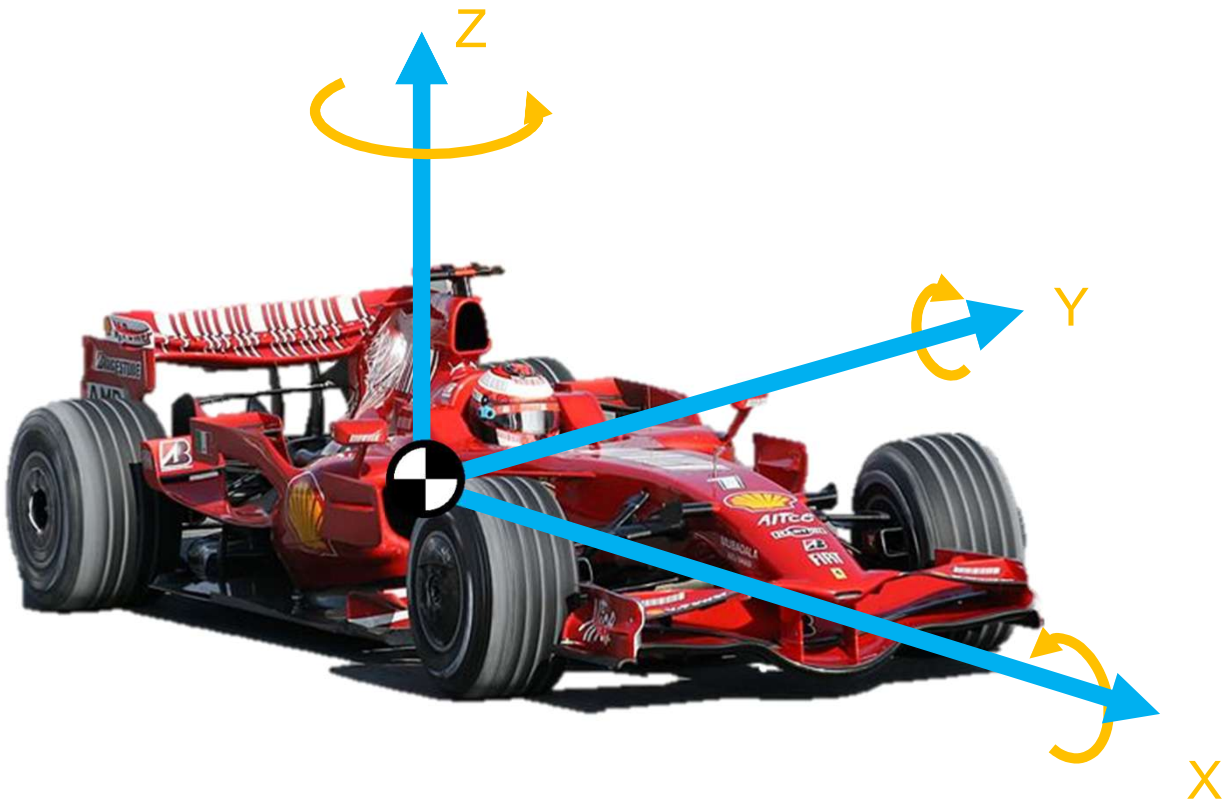
Why racecars?

Front wing change F1

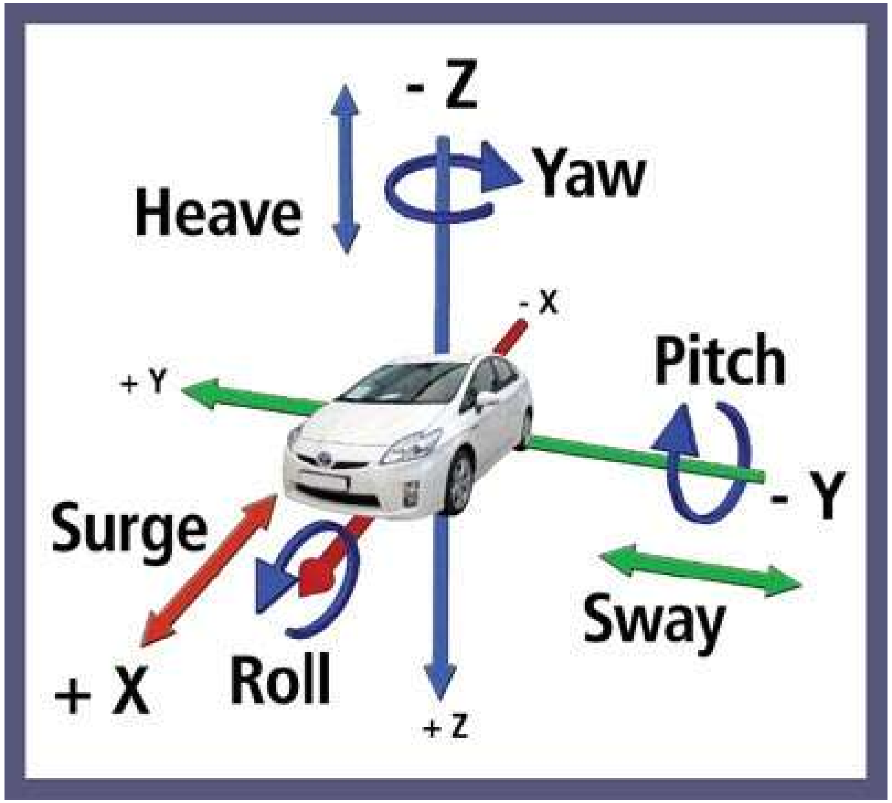


Coordinates in vehicle dynamics

DoF



Coordinates in vehicle dynamics

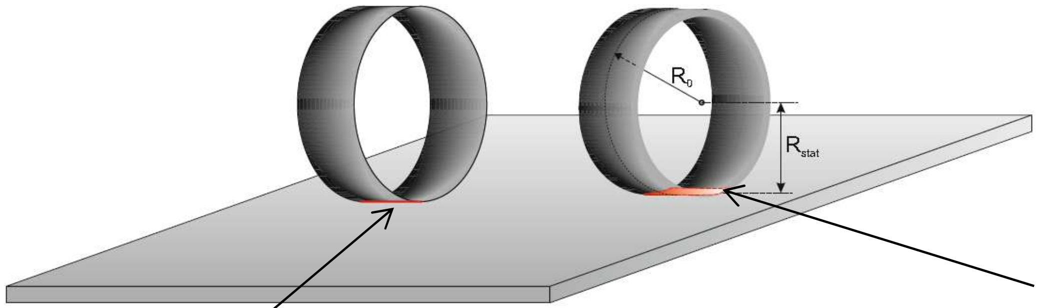


Vehicle dynamics fundamentals

Contact with the ground

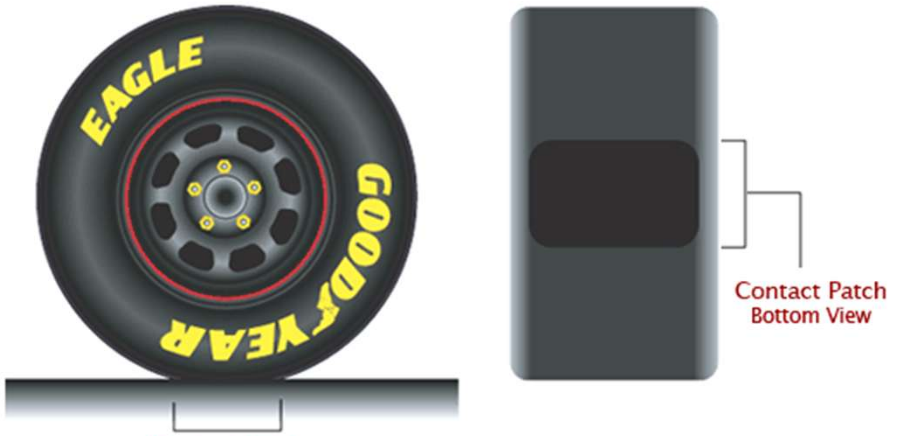
- Tyre
  - the only contact with the ground - ideally
  - The most important part of the car.
- Racing tyre
  - The most important part of the car.
  - The suspension, the areodynamics, the powertrain are areas that try to optimize the tyre performance
  - The main feedback to the driver comes from the tyre
  - Why racecars?

Contact with the ground

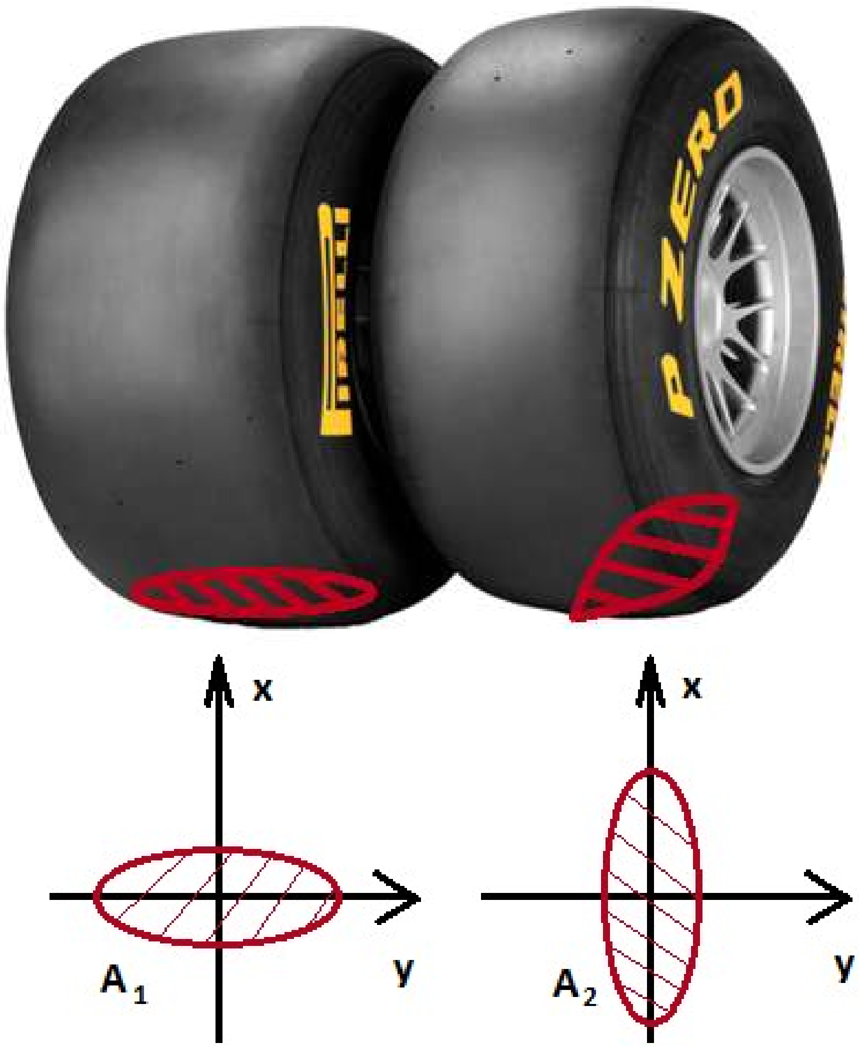


elastic tyre,
contact patch (postcard-sized)

rigid cylinder, linear contacting



Contact with the ground



Contact with the ground

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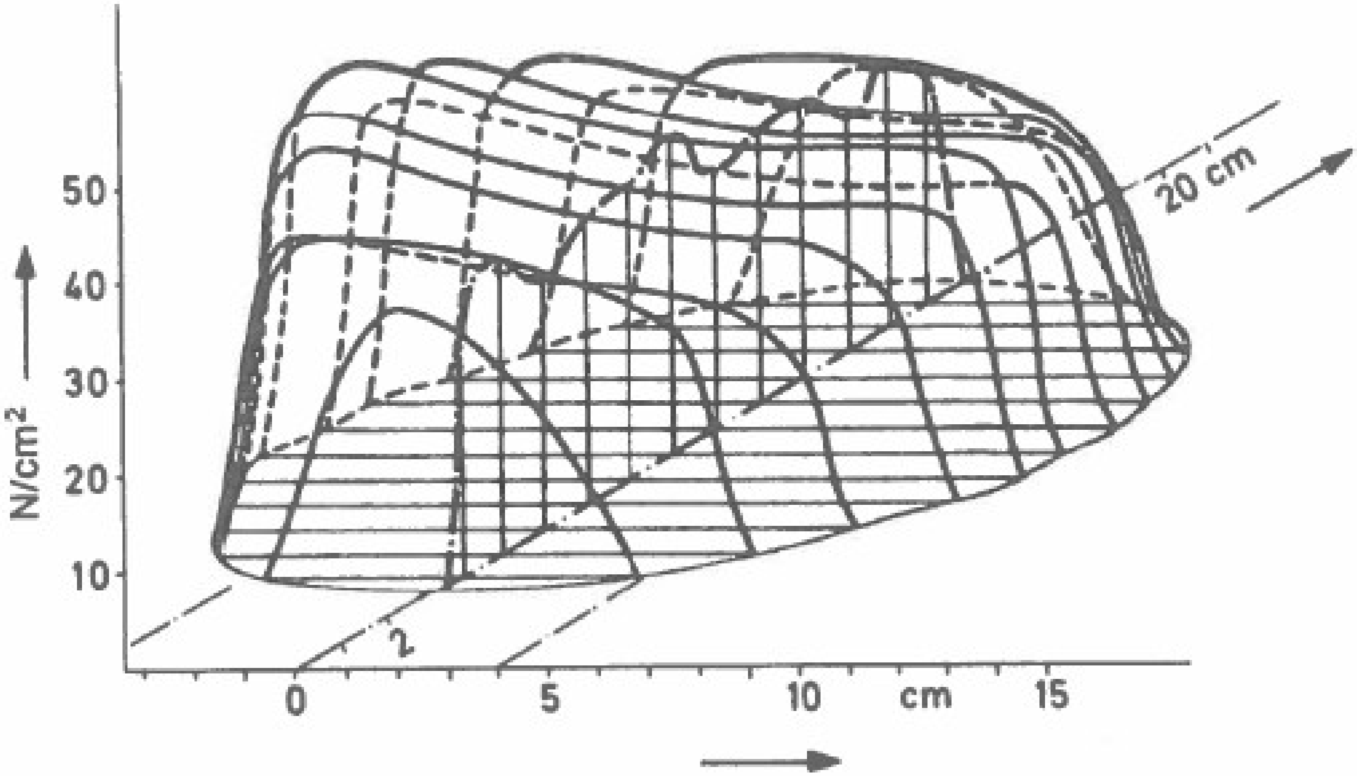
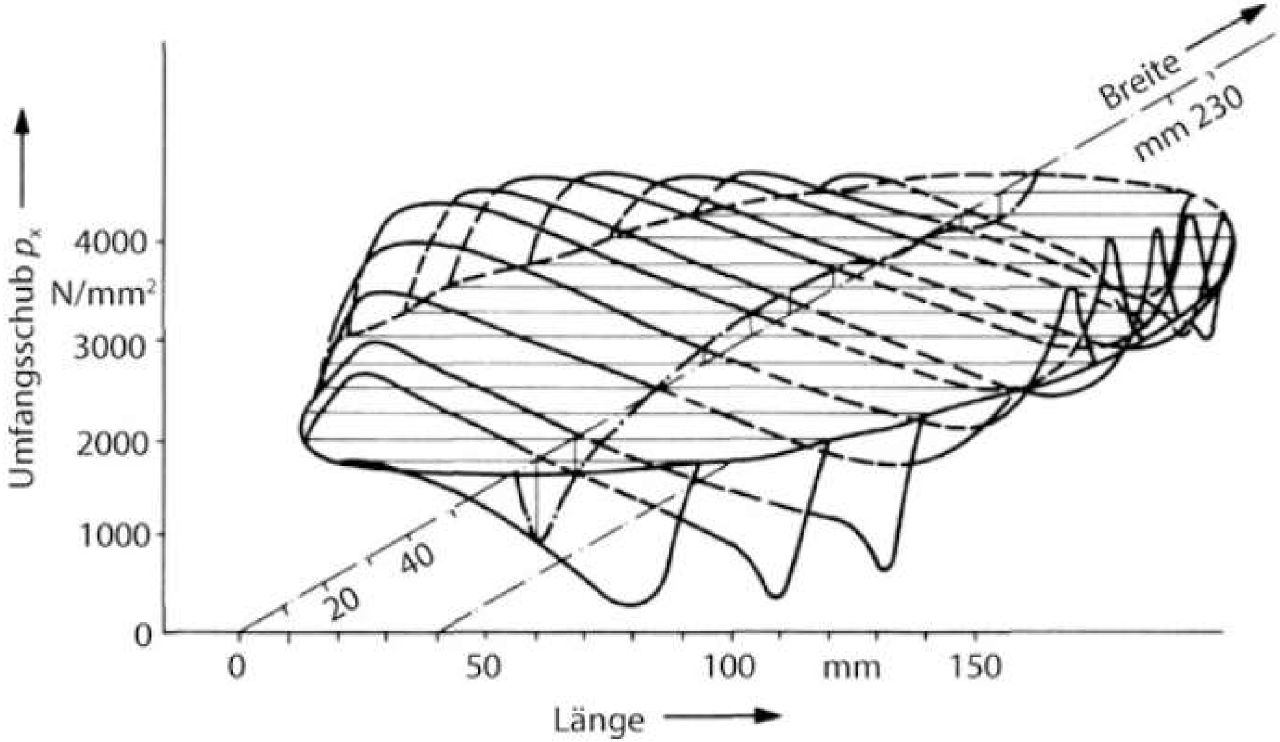


Load distribution along the contact patch – not driven wheel

Contact with the ground

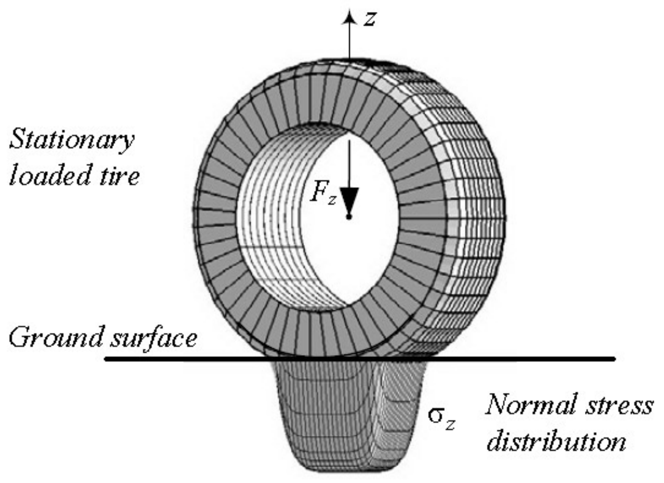
Tangential stress

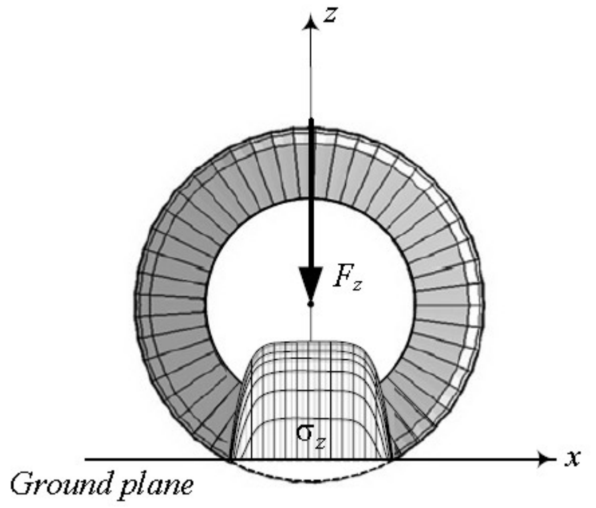


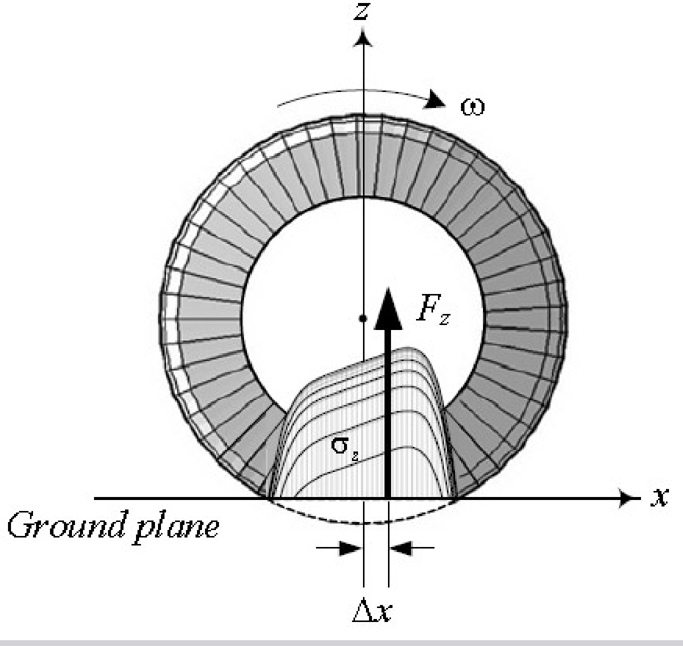
Load distribution along the contact patch – not driven wheel

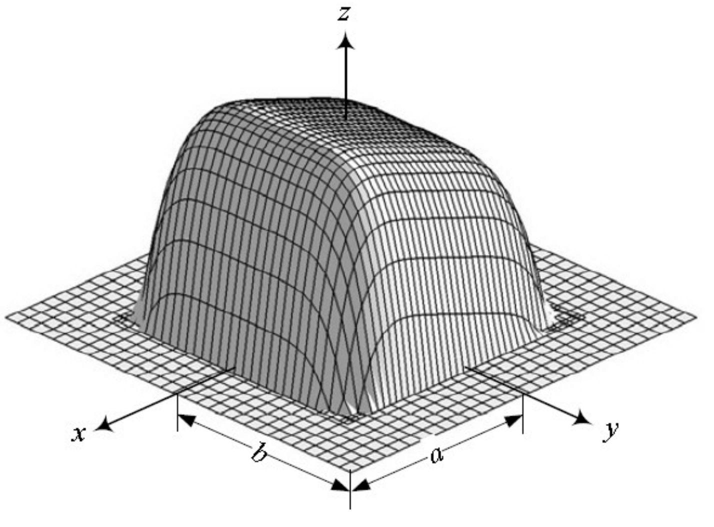
Source: Reimpell, J., Sponagel, P.: Fahrwerktechnik: Reifen und Räder. Vogel-Verlag, Würzburg (1995)

Contact with the ground





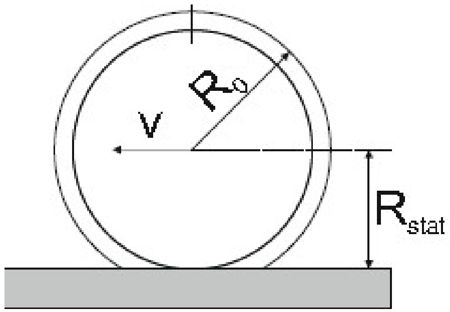




Static radius, R0

R_{stat} – Static radius is the distance measuring from center of the wheel to the supporting surface.

R_0 – Radius of a tyre unloaded, new condition.



Example: FS racecar with different R_0 radiuses caused top speed difference. What are the other effect(s)?

$$\vec{M} = \vec{r} \times \vec{F}$$

Contact with the ground

$$\vec{M} = \vec{r} \times \vec{F}$$

Dynamic radius

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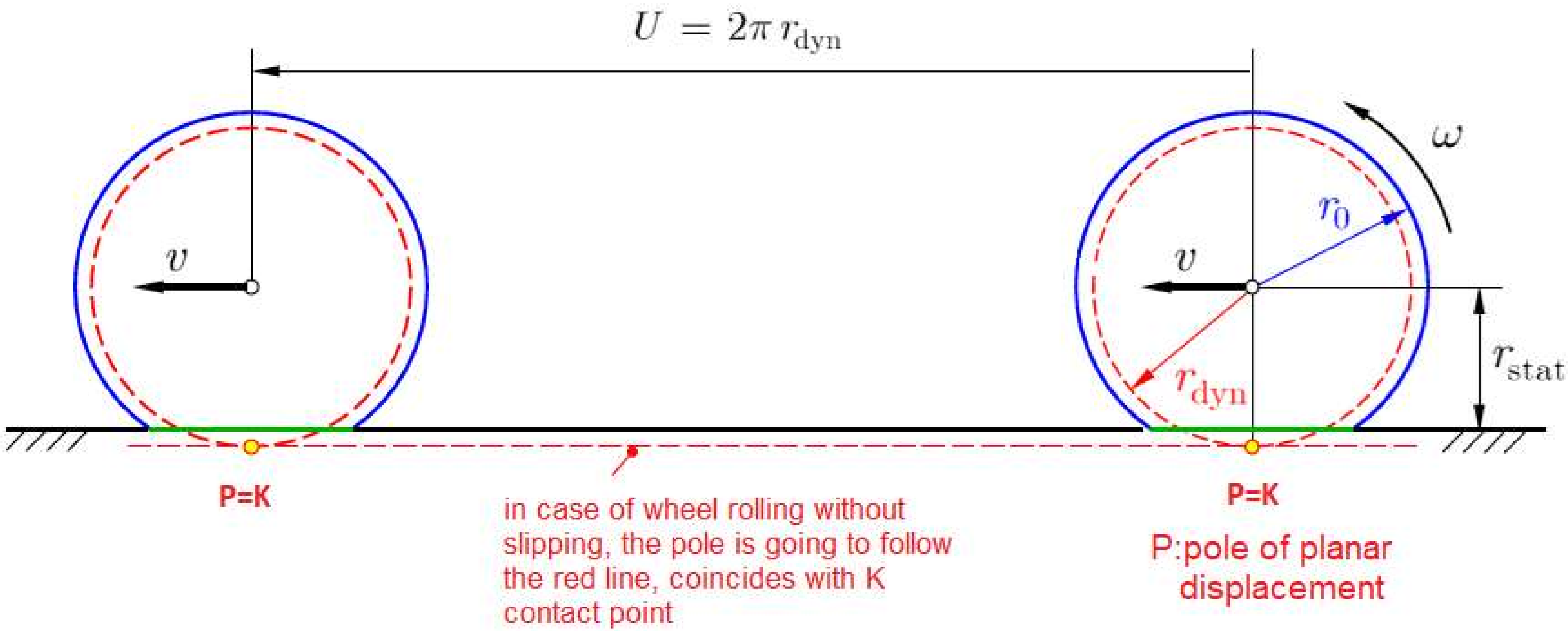

(source: C. Woernle)

Dynamic radius

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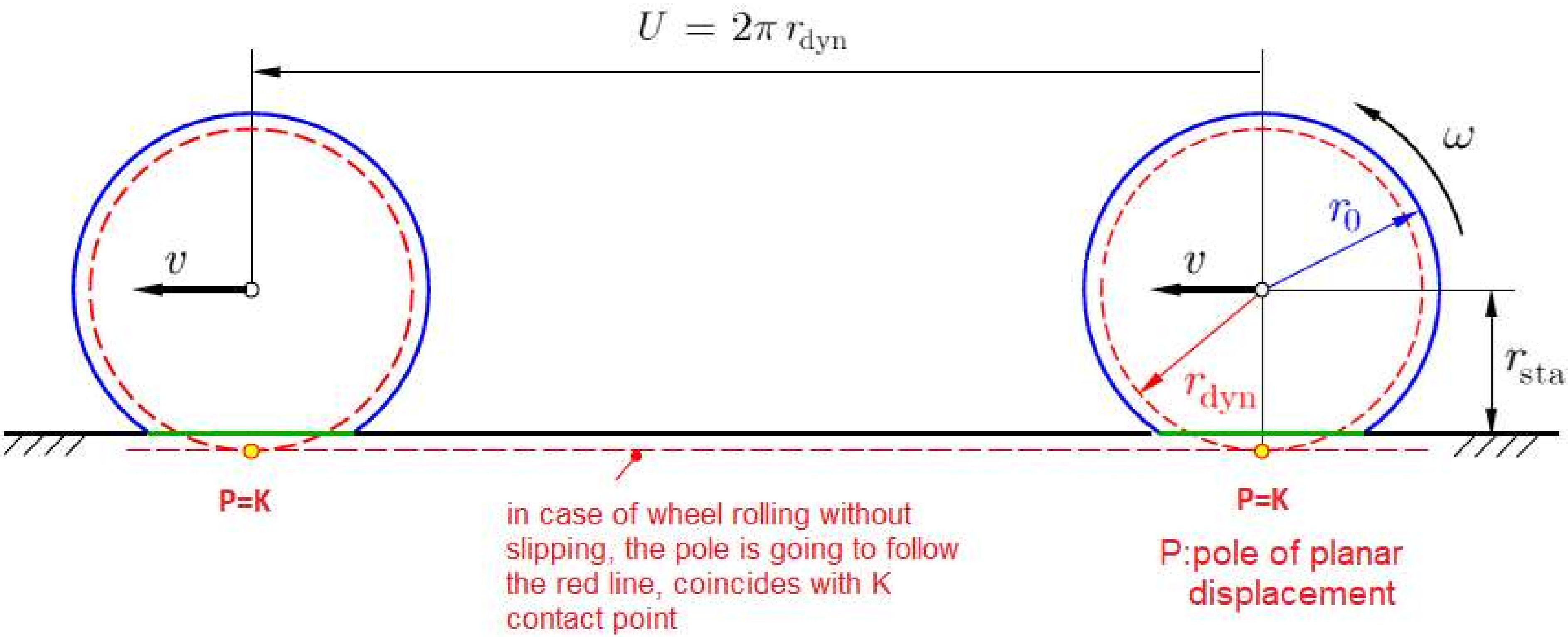
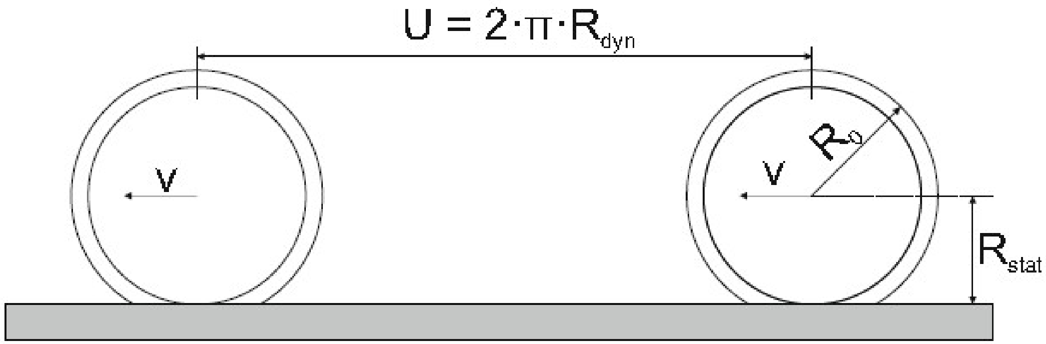


- R_{dyn} – dynamic radius is characteristic that can be calculated from the distanced travelled in case of rolling wheel without slipping

Dynamic radius



Beispiel:

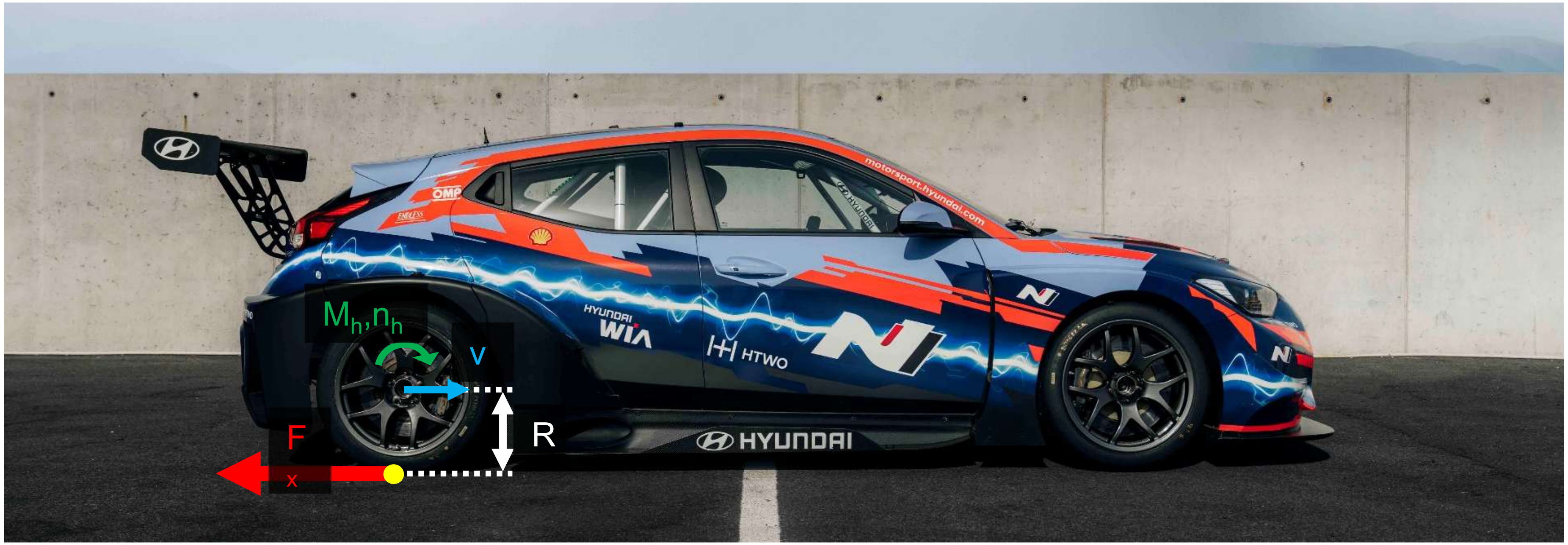
Reifen	r_0 [mm]	r_{stat} [mm]	U [mm]	r_{dyn}
185/65 R 15	311	284	1895	302
195/65 R 15	318	290	1935	308
205/65 R 15	324	294	1975	314

Quelle: Reimpell 1995

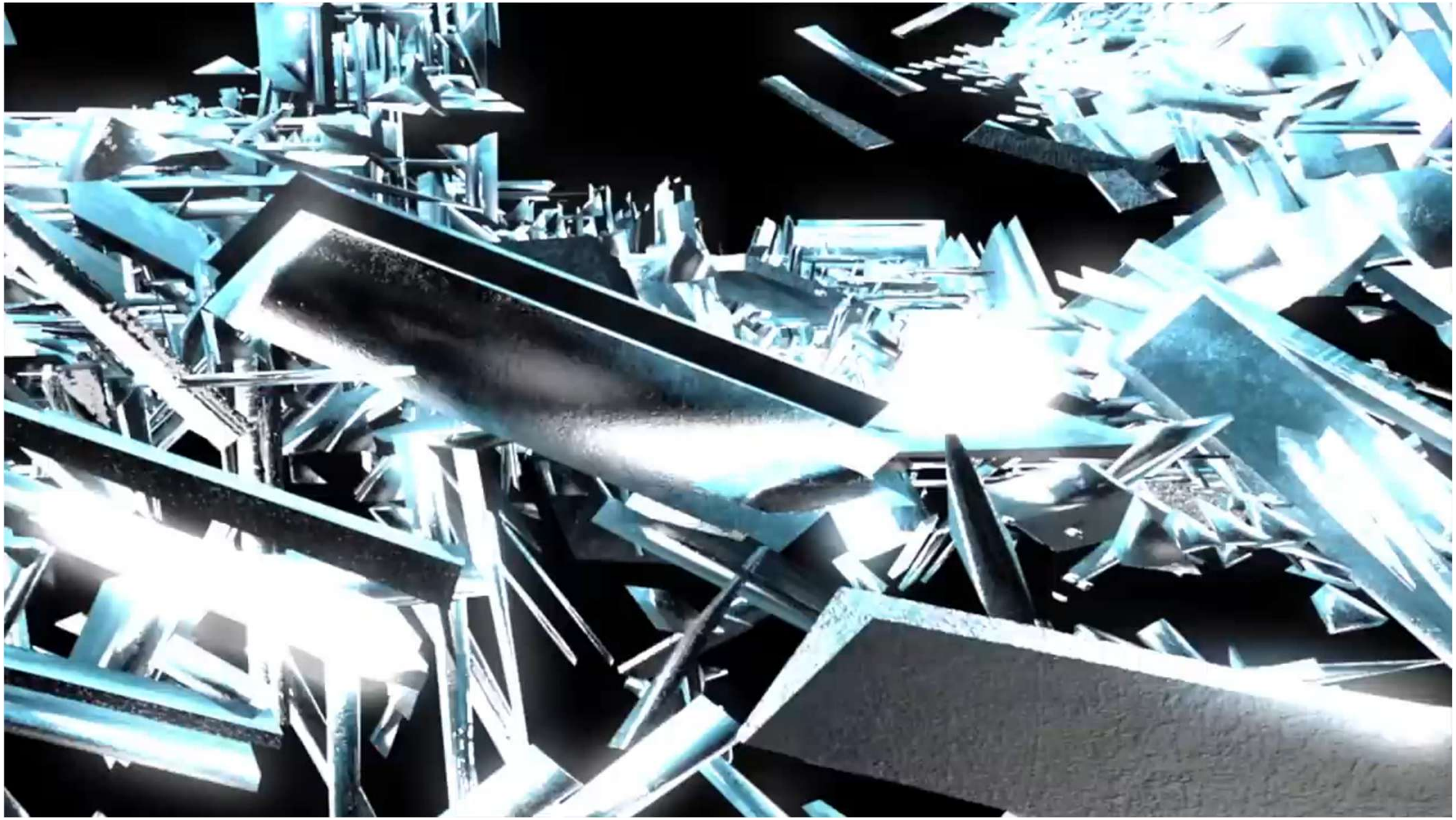
- The typical value of R_{dyn} is between R_0 and R stat.
- If we mark as ‚f' bumping the difference between R_0 and R_{stat}, then we can say $R_{dyn} = R_{stat}+2/3f$

Dynamic radius

$$M_h = R \cdot F_x \qquad v = R \cdot \omega = R \cdot 2\pi \cdot n_h$$

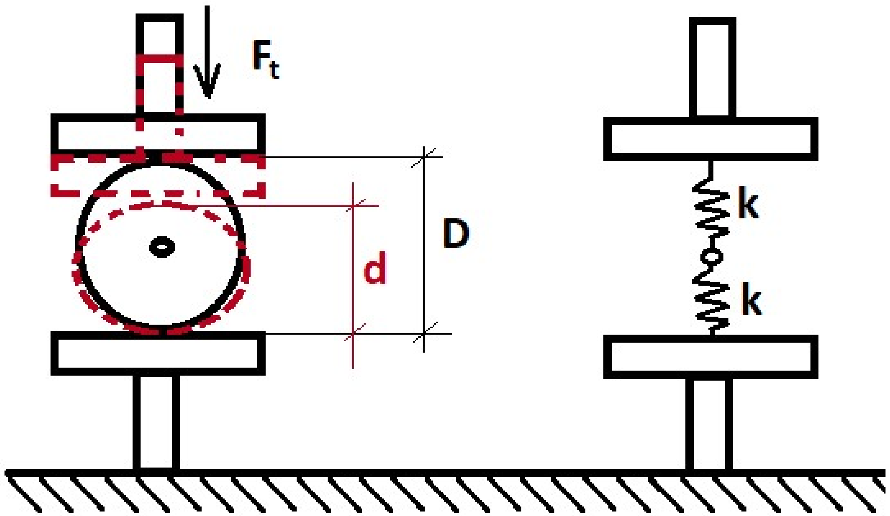


Different radiuses



Tyre vertical stiffness

Tyre vertical stiffness



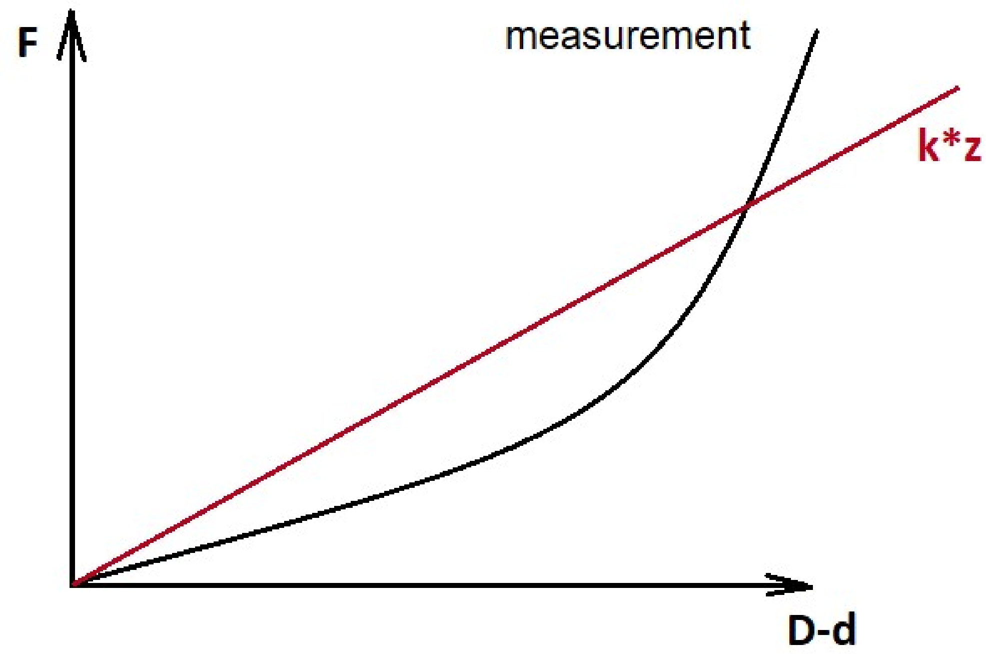
$$k = \frac{F_t}{\left(\frac{D-d}{2}\right)}\ \left[\frac{N}{m}\right]$$

$$F_z = \frac{m \cdot g \cdot \%_F}{2}\ [\mathrm{N}]$$

$$R_{stat} = R_0 - \frac{F_Z}{k}\ [\mathrm{mm}]$$

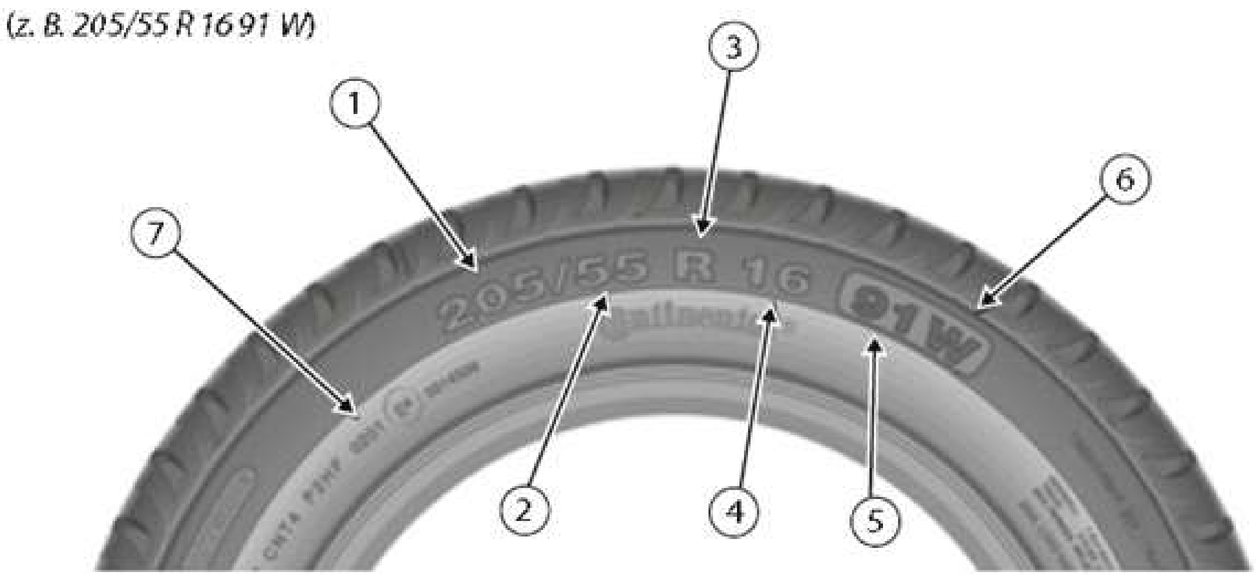
- k: spring stiffness; F_z: normal force ; $\%_F$: first axle load; m: vehicle weight

Tyre vertical stiffness



- Progressivity
  - effect of air
  - tyre effect
    - sidewall structure
    - sidewall size
- Curve fitting
  - approximation of stiffness
    - k*z

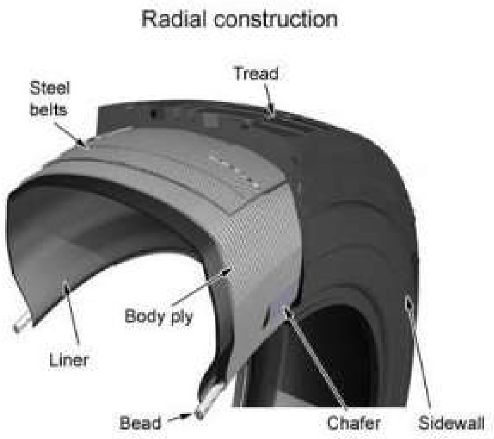
Tyre nomenclature



- 205 –tyre width [mm]
- 55 – ratio between tyre height and width [%]
- R – structure (R/D)
- 16 – rim diameter – inches
- 91 – load capacity index
- W – speed limit (W=270 km/h)

Tyre structures

Radial



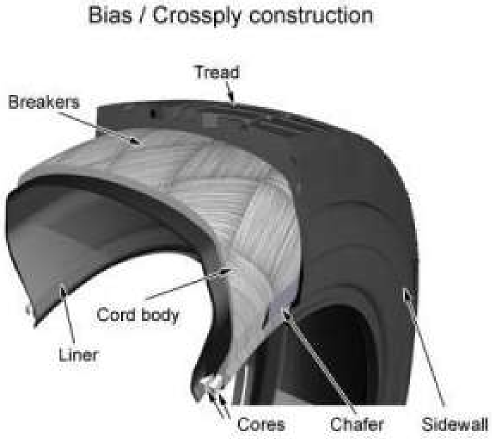
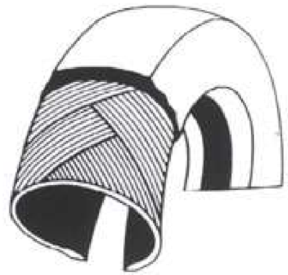


Image source: recstuff.com/radialvsbiasplytrailertires.aspx

Diagonal



- **Radial strings +belts**
- **Advantage**
  - better roadability
  - less sensitivity to pot-holes
- **Disadvantage**
  - bigger driving noise
  - higher costs

- **Crossplies**
- **Advantages**
  - less vulnerable
  - easier to manufacture
- **Disadvantages**
  - lower spring-comfort
  - poor manoeuvrability
  - worse grip-warming-tyre wearing

Driving force

Longitudinal slip – slip ratio

$$\mathrm{SR} = \kappa = \frac{R_{dyn} \cdot \omega - v}{v} \; [-] \qquad \kappa \epsilon[-1;\infty]$$

⊖ braking

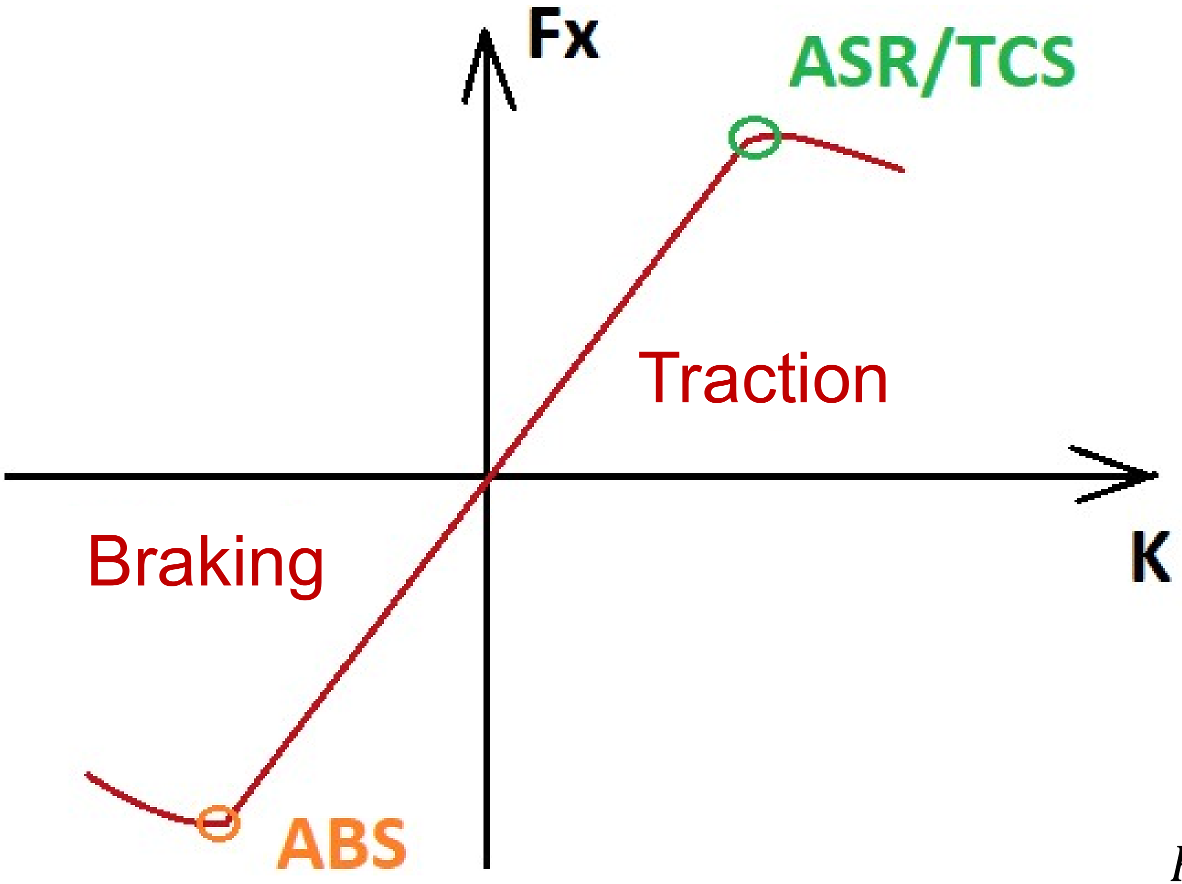
0 rolling

⊕ drive

v – vehicle speed [m/s]; ω – angular velocity [1/s]

Driving force

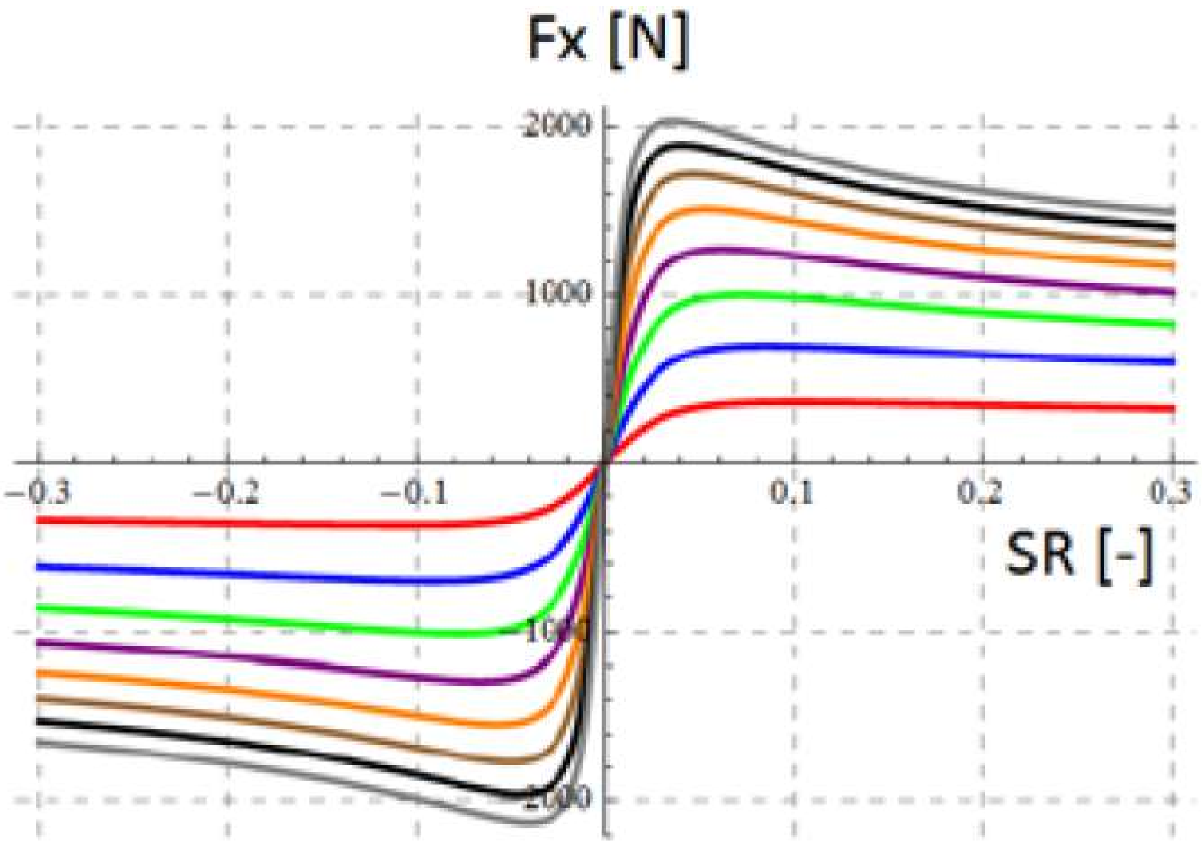
Characteristics depends on tyre!



$$SR = \kappa = \frac{R_{dyn} \cdot \omega - v}{v} \; [-]$$

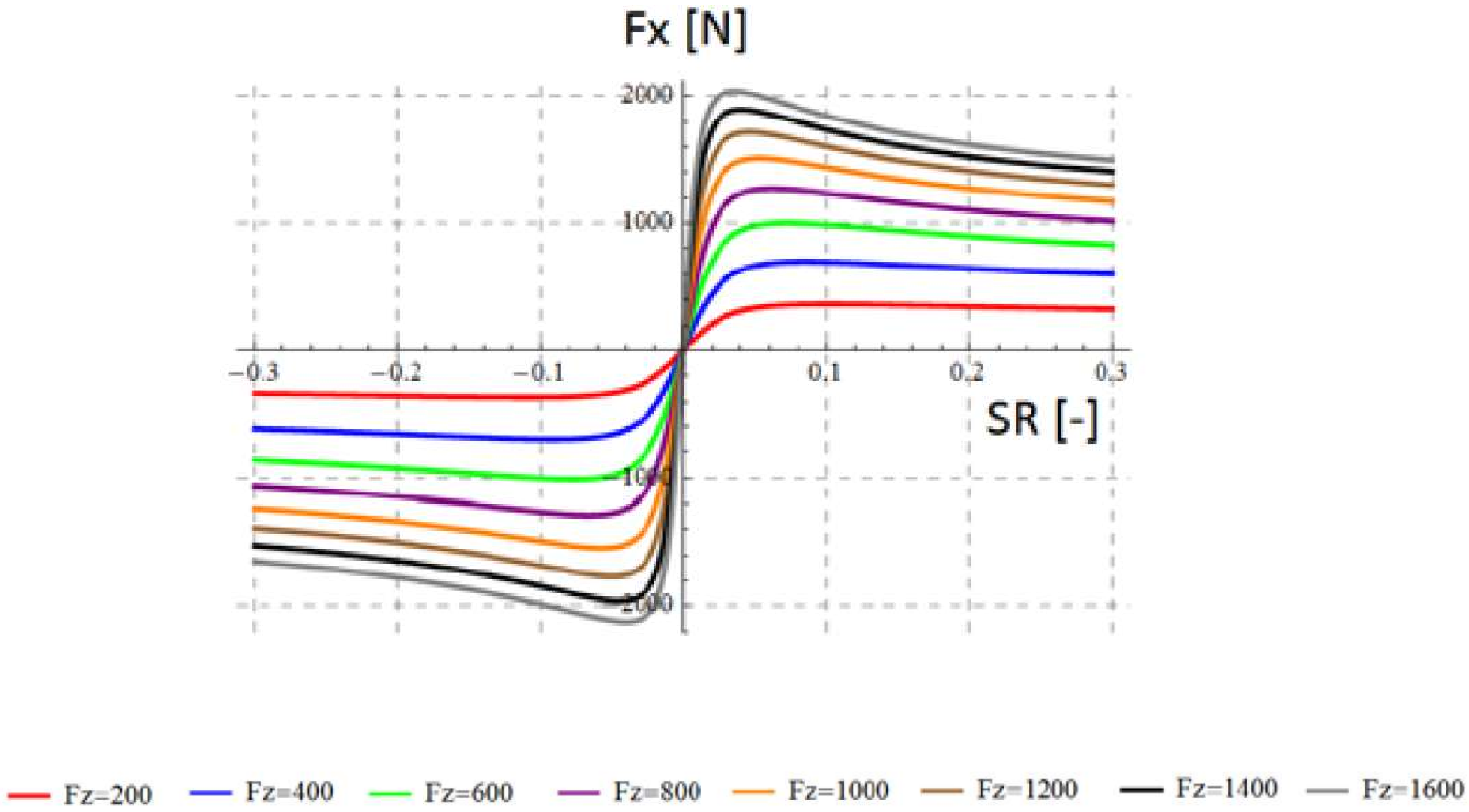
Driving force

What could the colours mean?



Driving force

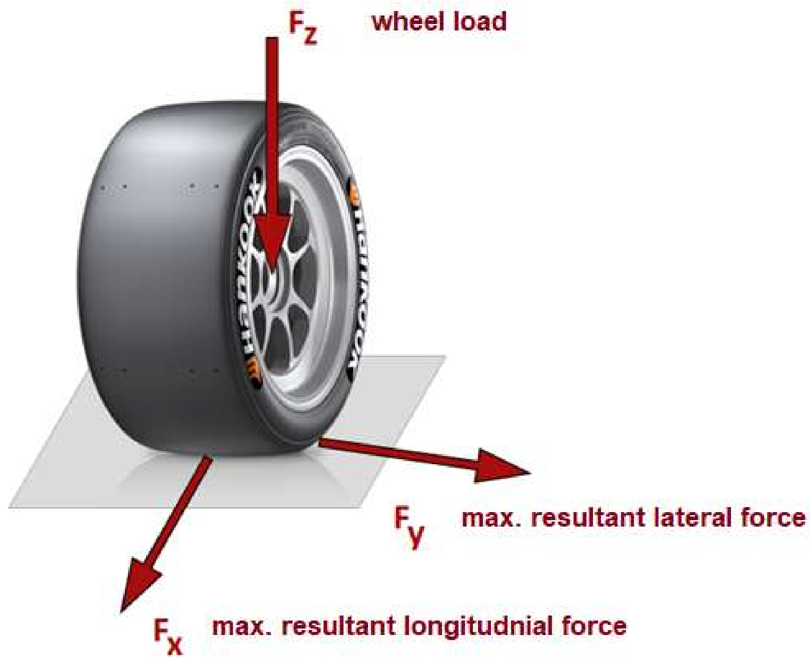
What could the colours mean?



Driving force

Longitudnial friction coefficient

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

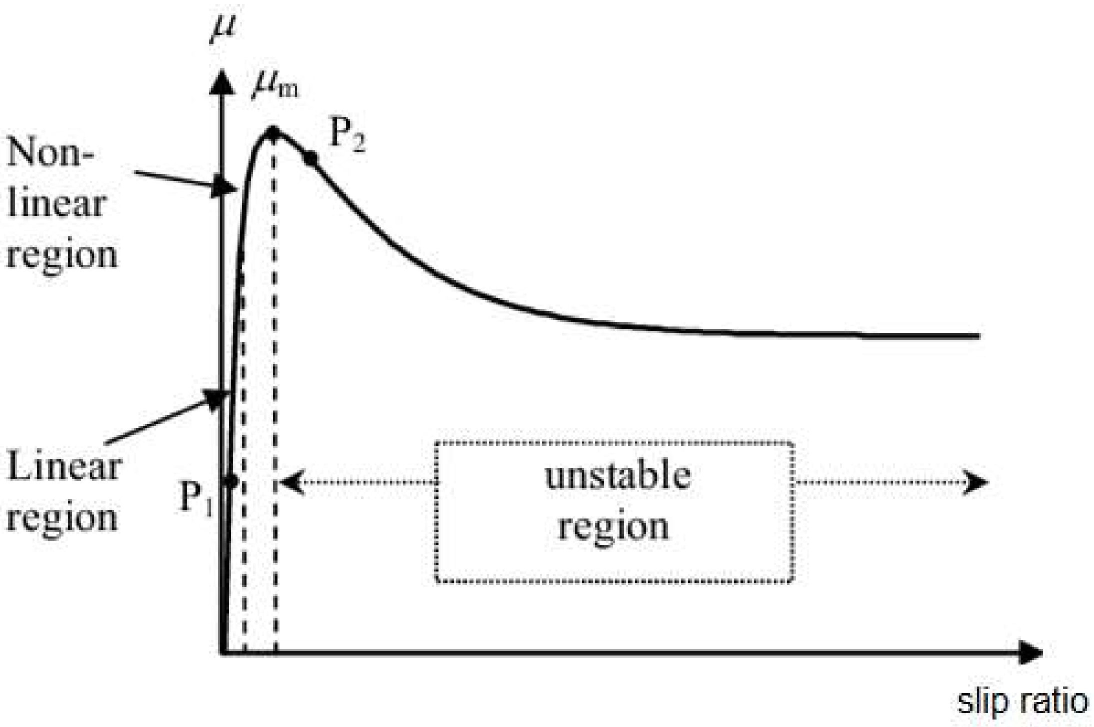


μ_x:

- longitudinal friction coefficient
- friction coef.

Driving force

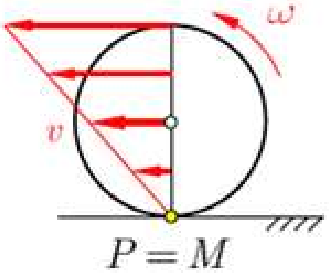
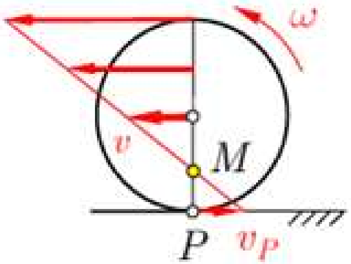
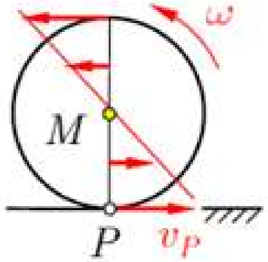
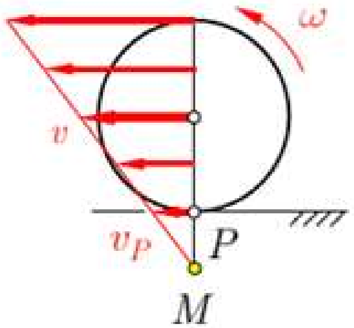
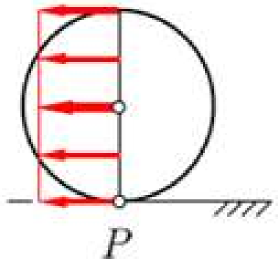
Typical μ_x-slip ratio curve



Fx belongs to maximum grip

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

Phases of slip ratio

$v = \omega R_{dyn}$	$v < \omega R_{dyn}$		$v > \omega R_{dyn}$	
rolling wheel	driven wheel	spinning wheel	braking	wheel blocked
 kontaktpont : P sebességpólus : M				
no slip	driving slip		braking slip	
K = 0	$\kappa = \dfrac{R_{dyn} \cdot \omega - v}{v}$	$\kappa = \infty$	$\kappa = \dfrac{R_{dyn} \cdot \omega - v}{v}$	$\kappa = -1$

Quelle: Popp, Schiehlen 1993

Driving force

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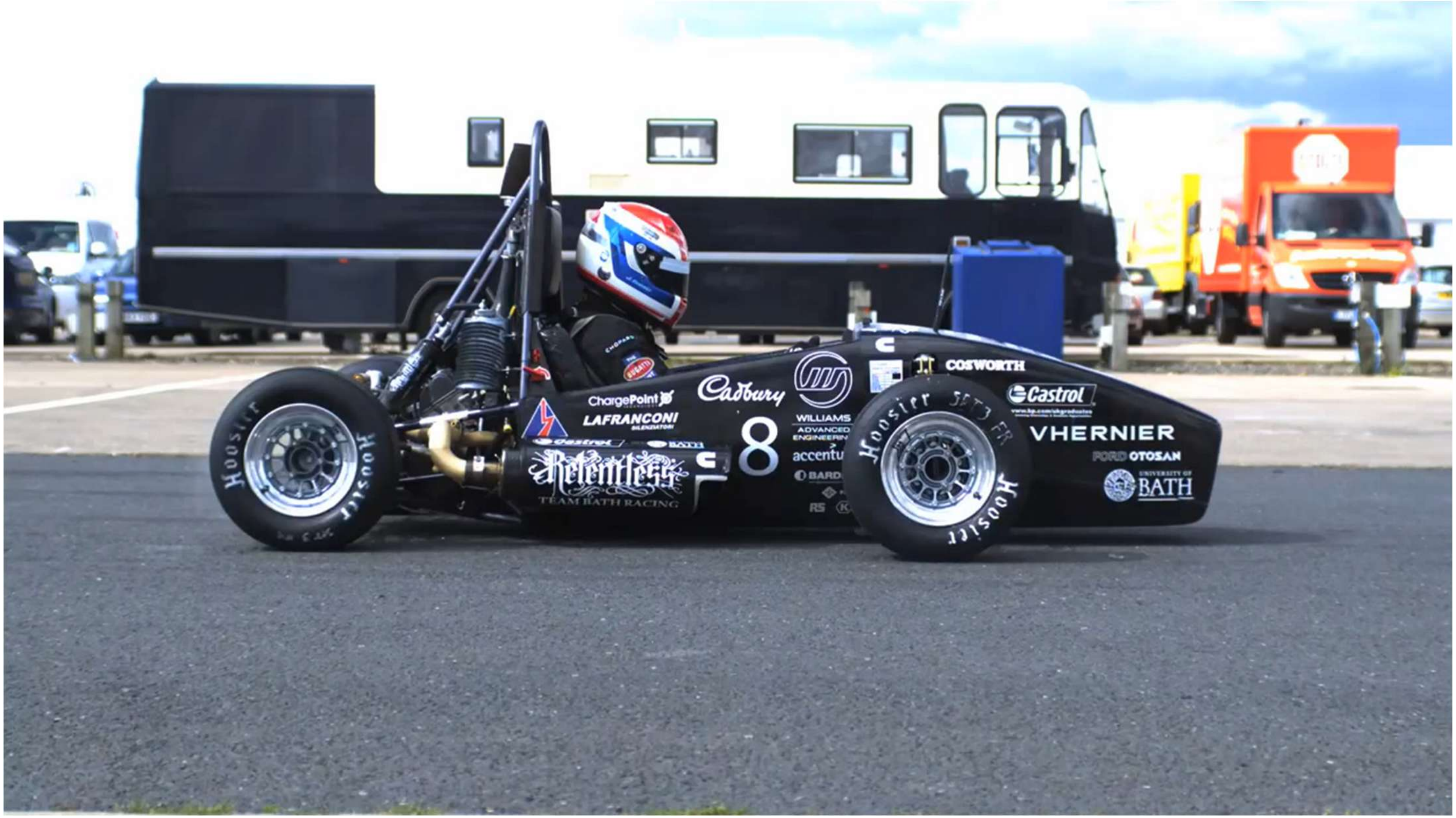

Driving force

Tab. 3.6: Gegenüberstellung unterschiedlicher Schlupfdefinitionen am Beispiel des Längsschlupfes für ein in der Vertikalebene rollendes Rad

Schlupf für (Antreiben / Bremsen)	$\frac{v_C - \omega r_e}{v_C}$	$\frac{\omega r_e - v_C}{v_C}$	$\frac{\omega r_e - v_C}{\omega r_e}$	Antreiben: $\frac{\omega r_e - v_C}{\omega r_e}$ / Bremsen: $\frac{v_C - \omega r_e}{v_C}$
Quelle	wir	[3.18]	[3.19]	[3.20]
Schlupfwert für durchdrehendes Rad $\omega \to \infty$	$-\infty$	∞	1	1
Schlupfwert für blockiertes Rad $\omega = 0$	1	-1	$-\infty$	1
Schlupfwert für frei rollendes Rad $v_C = \omega r_e$	0	0	0	0

v_C Translationsgeschwindigkeit des Radschwerpunktes in Richtung der Radebene
ω Winkelgeschwindigkeit des Rades um die Radachse
r_e effektiver Rollradius

Bibliography

- https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.wired.com%2F2008%2F05%2Fff-formulaone%2F&psig=AOvVaw1Jpc66dH0FE0zK_Le6ev-D&ust=1612202433180000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCNDU7Z_gxu4CFQAAAAAdAAAAABAD
- https://www.google.com/url?sa=i&url=https%3A%2F%2Fthecuriousastronomer.wordpress.com%2Ftag%2Fangular-velocity%2F&psig=AOvVaw0VWIzbfG2-A6w7ca5mULVB&ust=1612208234344000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCJjTkuv1xu4CFQAAAAAdAAAAABAY
- https://www.google.com/imgres?imgurl=https%3A%2F%2Fi0.wp.com%2Fotrwheel.com%2Fwp-content%2Fuploads%2F2016%2F08%2FradialvsbiasplyFINAL.jpg%3Fresize%3D630%252C301&imgrefurl=https%3A%2F%2Fotrwheel.com%2Fotr-blog%2Fradial-vs-bias-need-know%2F&tbnid=y0Ea_MrsrdG3gM&vet=12ahUKEwi4sPLjvM7uAhUjqnEKHTx0AewQMygFegUIARCiAQ..i&docid=0Oz8itZjkydoIM&w=630&h=301&q=tyre%20%20bias%20ply%20radial&ved=2ahUKEwi4sPLjvM7uAhUjqnEKHTx0AewQMygFegUIARCiAQ

Thank you for your attention!

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