Department of Automotive Technologies – Vehicle Mechanics Fundamentals

Gábor Sipos

BME
DEPARTMENT OF AUTOMOTIVE TECHNOLOGIES

Lecture 2

Basic informations

Week nr.	Date	Lecture (Monday)		Lab (date+1;Tuesday)	
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	4th Mar	4	Weight transfer		
5	11th Mar	5	Bicycle model	3	Lab
6	18th Mar	T1	Midterm exam I. ONLINE		
7	25th Mar	6	Braking and brakes ONLINE	4	Lab ONLINE
8	1st Apr	-	Break		
9	8th Apr	7	Systems of the vehicle	T1 R	Exam 1 - subsequent
10	15th Apr	8	Quarter vehicle model ONLINE		
11	22th Apr		Break		Break
12	29th Apr	T2	Midterm exam II. ONLINE		
13	6th May	9	Tyre management	T2 R	Exam 2 - subsequent
14	13th May	10	Racecar engineering		

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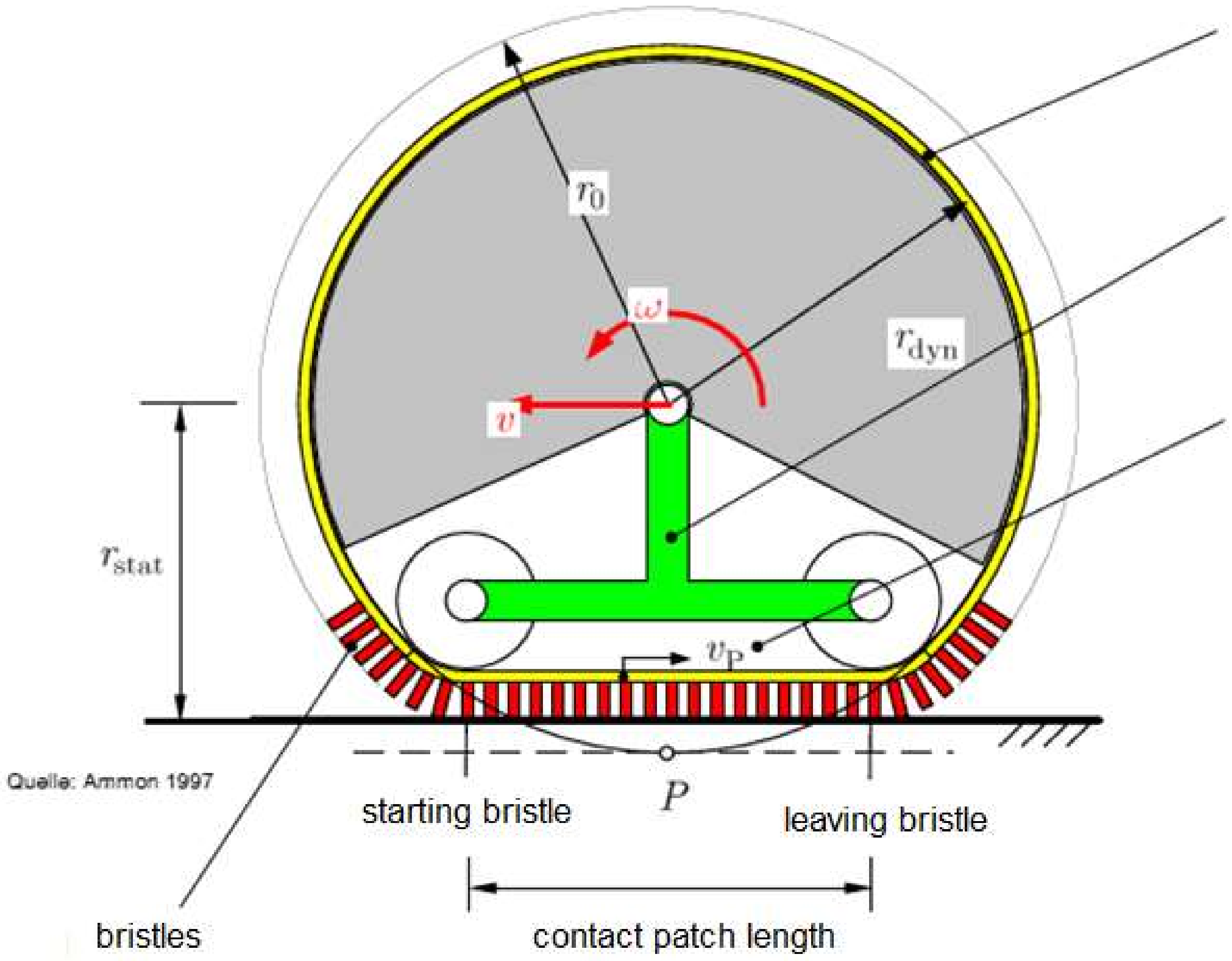
Note

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.

Brush model



belt permanent length

$$U = 2\pi\, r_{\text{dyn}}$$

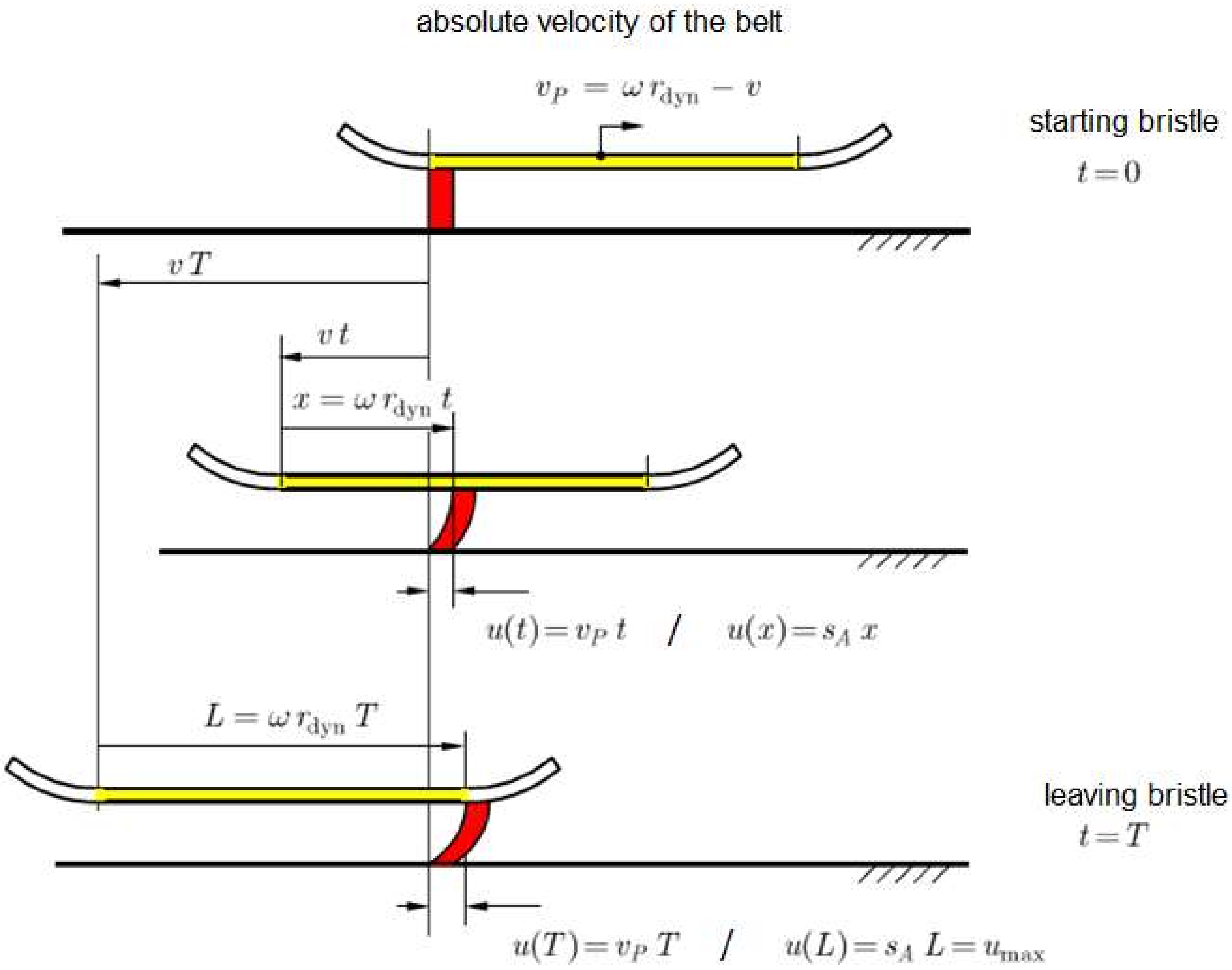
imaginary mechanism

absolute velocity of the belt

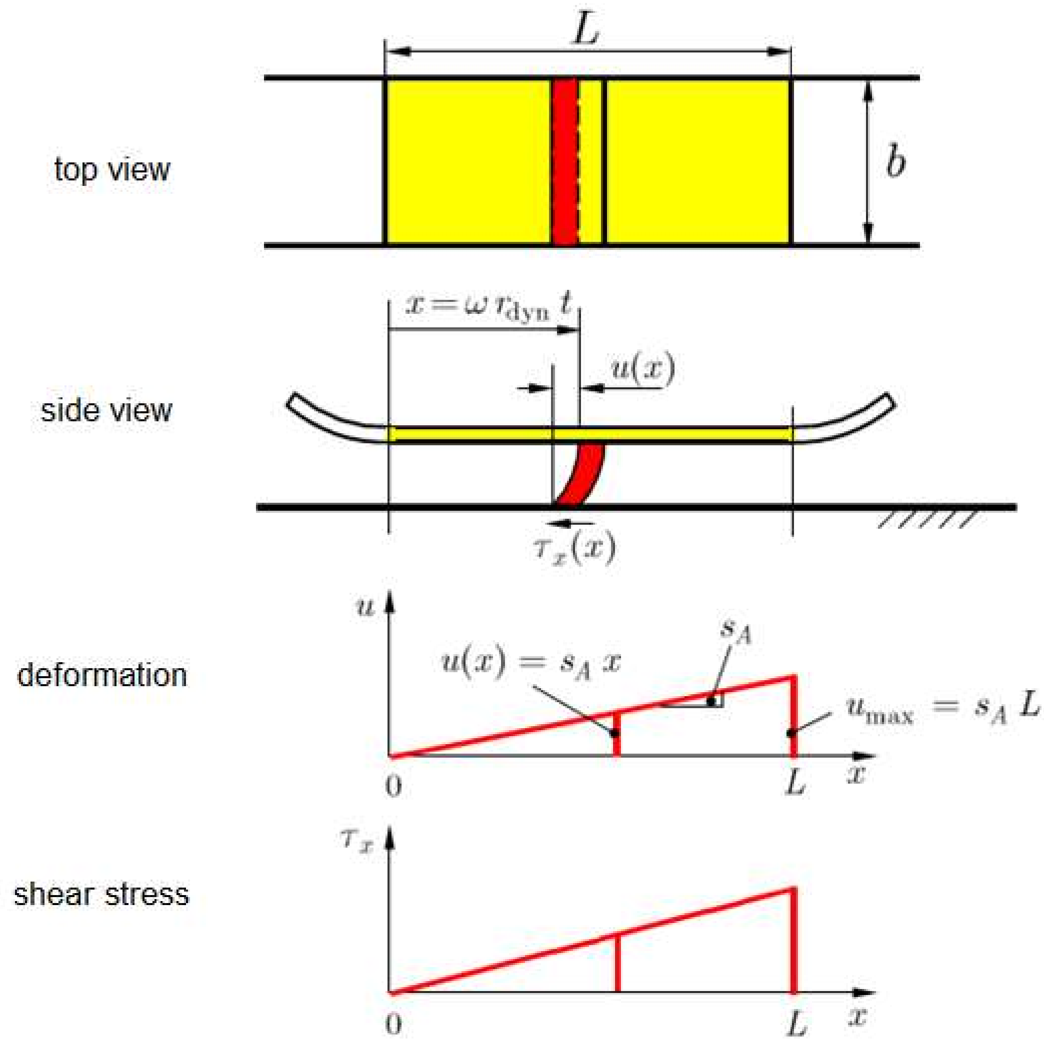
$$v_P = \omega\, r_{\text{dyn}} - v$$

P point: pole

Brush model


absolute velocity of the belt
$v_P = \omega\, r_{\text{dyn}} - v$
starting bristle
$t = 0$
$v\, T$
$v\, t$
$x = \omega\, r_{\text{dyn}}\, t$
$u(t) = v_P\, t \quad / \quad u(x) = s_A\, x$
$L = \omega\, r_{\text{dyn}}\, T$
leaving bristle
$t = T$
$u(T) = v_P\, T \quad / \quad u(L) = s_A\, L = u_{\max}$

Brush model



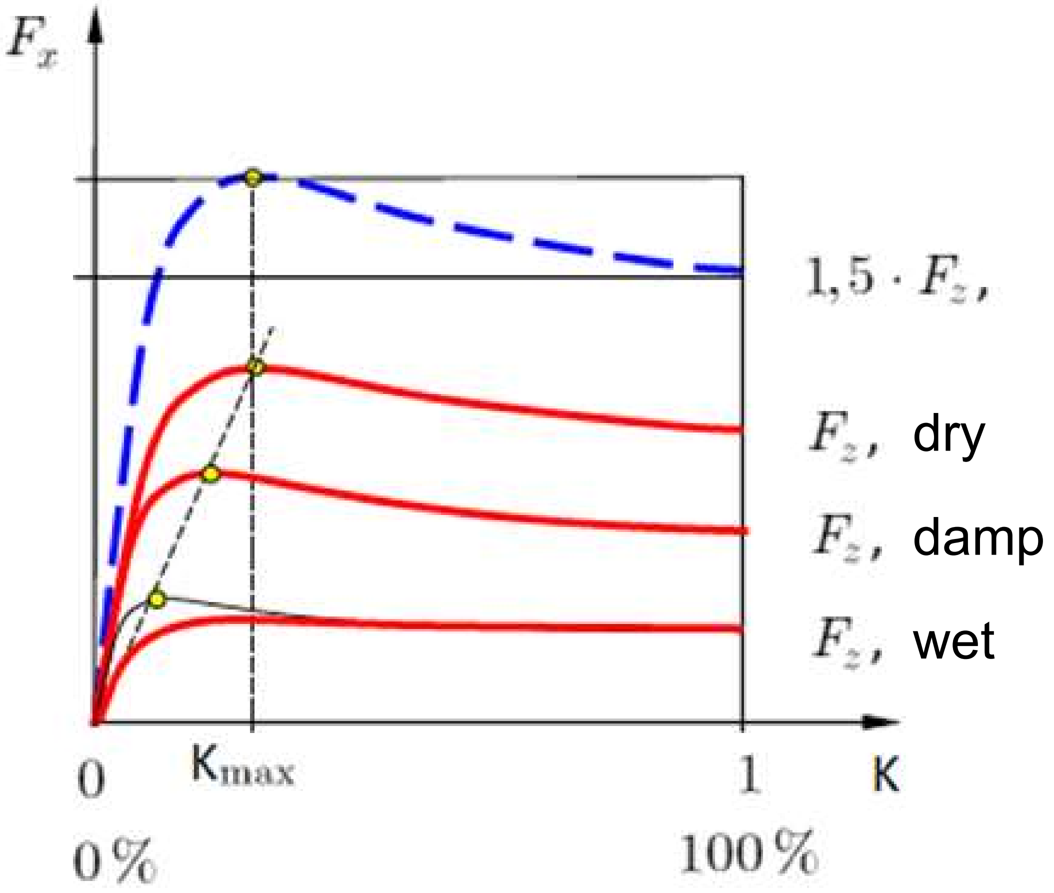
assumption:

contacting on full length of CP

Longitudnal force by bristle

$$\boxed{F_x = \int_A \tau_x(x)\,\mathrm{dA}}$$

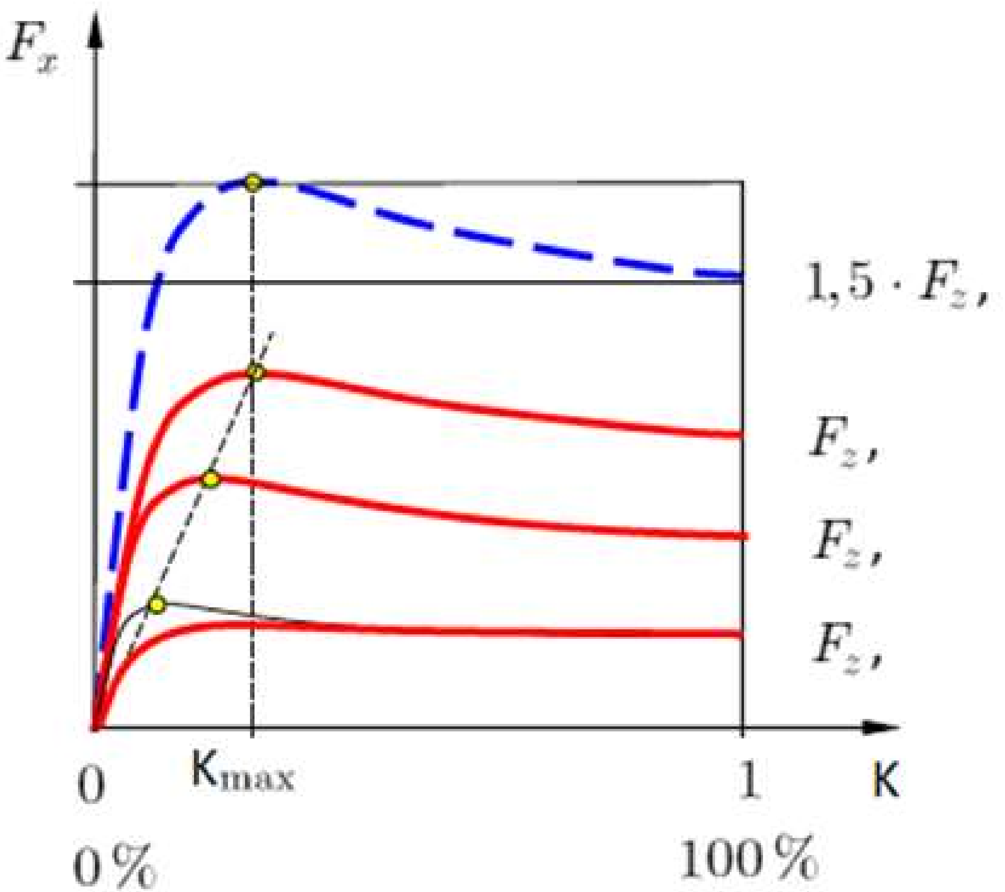
Effect of factors to longitudinal force - SR



effect of different normal force while the friction coefficient is permanent

effect of different friction coefficient while normal force is unchanged

Effect of factors to longitudinal force - SR



effect of different normal force while the friction coefficient is permanent

effect of different friction coefficient while normal force is unchanged

Question: if the more weight effect is as advantageous as it seems here, why don’t we start building tanks?

Grip or power limited?

Newton’s second law

Power limited

$$F_x = m \cdot a$$

To have the best acceleration

Keep low as possible

Grip limited

$$F_x = m \cdot a$$

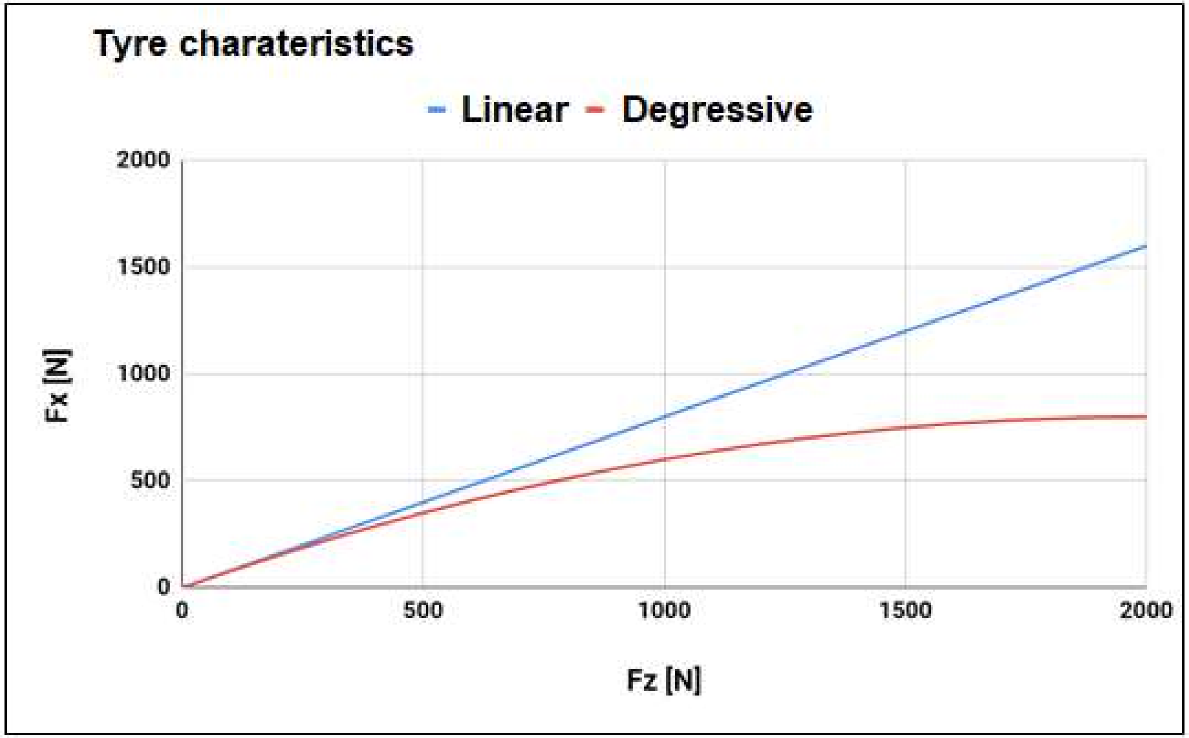
$$a = \frac{F_x}{m} = \frac{F_z \cdot \mu_x}{m} = \frac{m \cdot g \cdot \mu_x}{m}$$

$$= g \cdot \mu_x$$

Buliding tanks or not?

Linear characteristics:

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



Buliding tanks or not?

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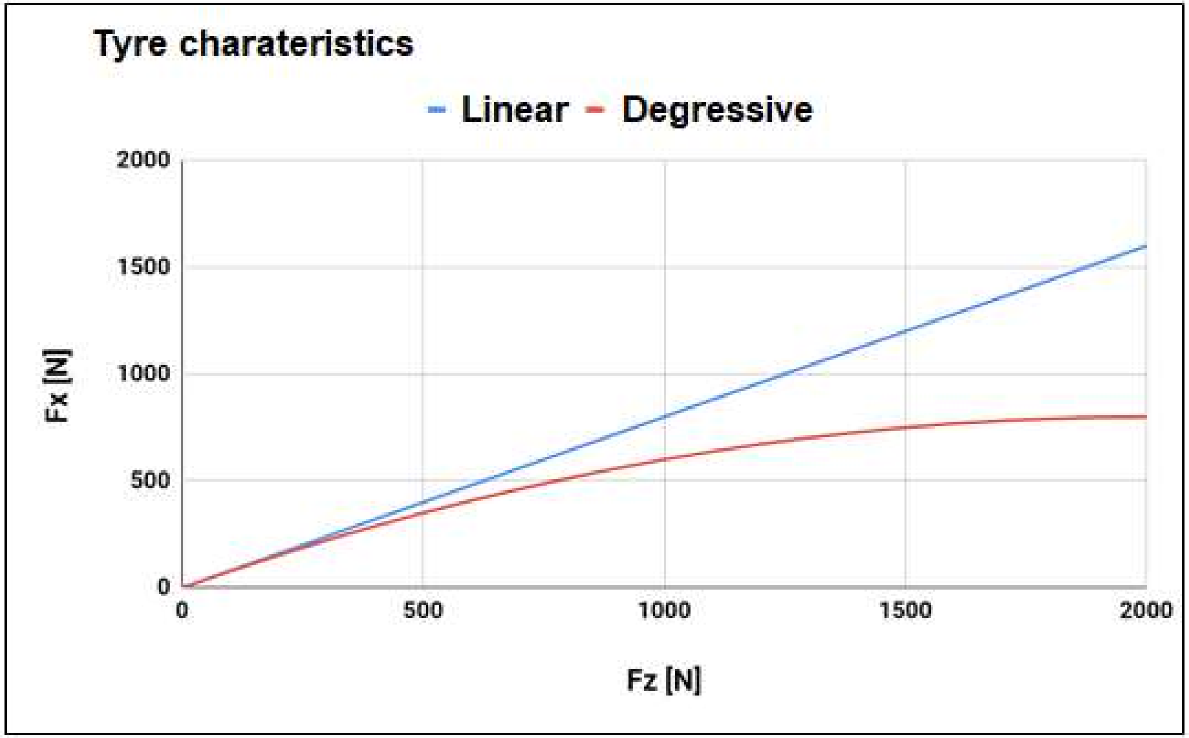
Linear characteristics:

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



Degressive characteristics:

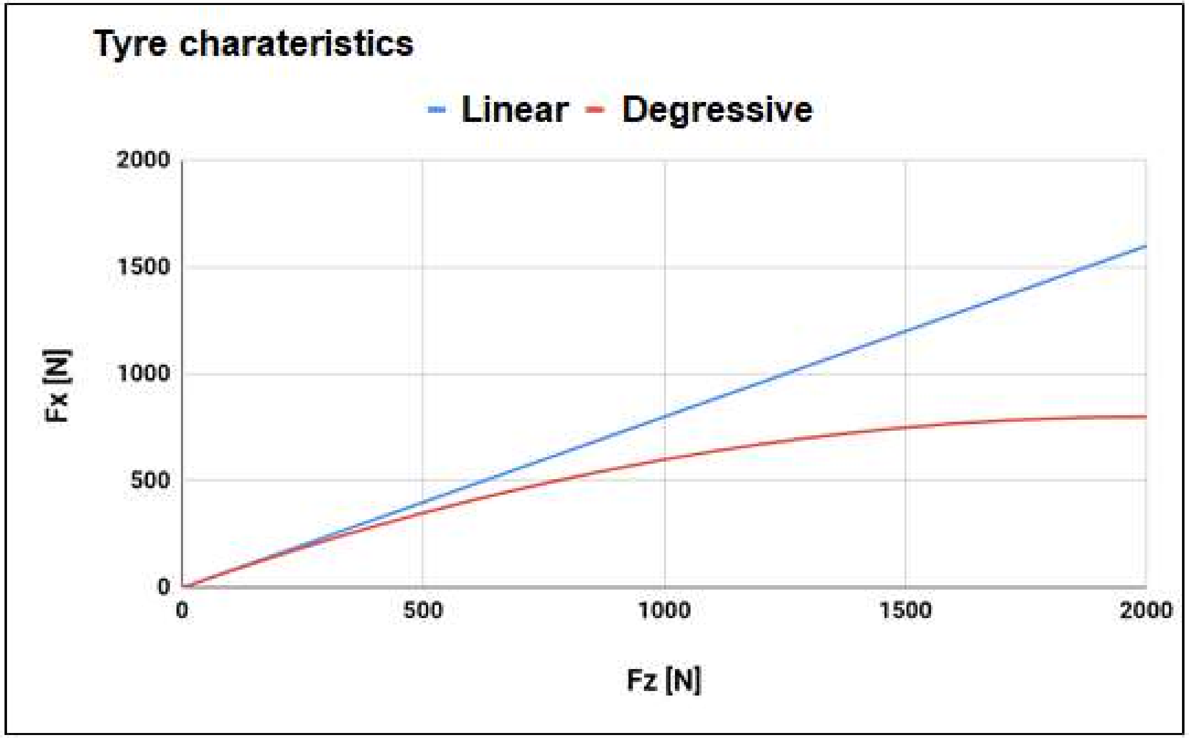
$$a = \frac{F_x}{m} = \frac{F_z \cdot \mu_x - F_z^2 \cdot \mu_{x,2}}{m}$$

Buliding tanks or not?

Tyre characteristics is degressive!

Linear characteristics:

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

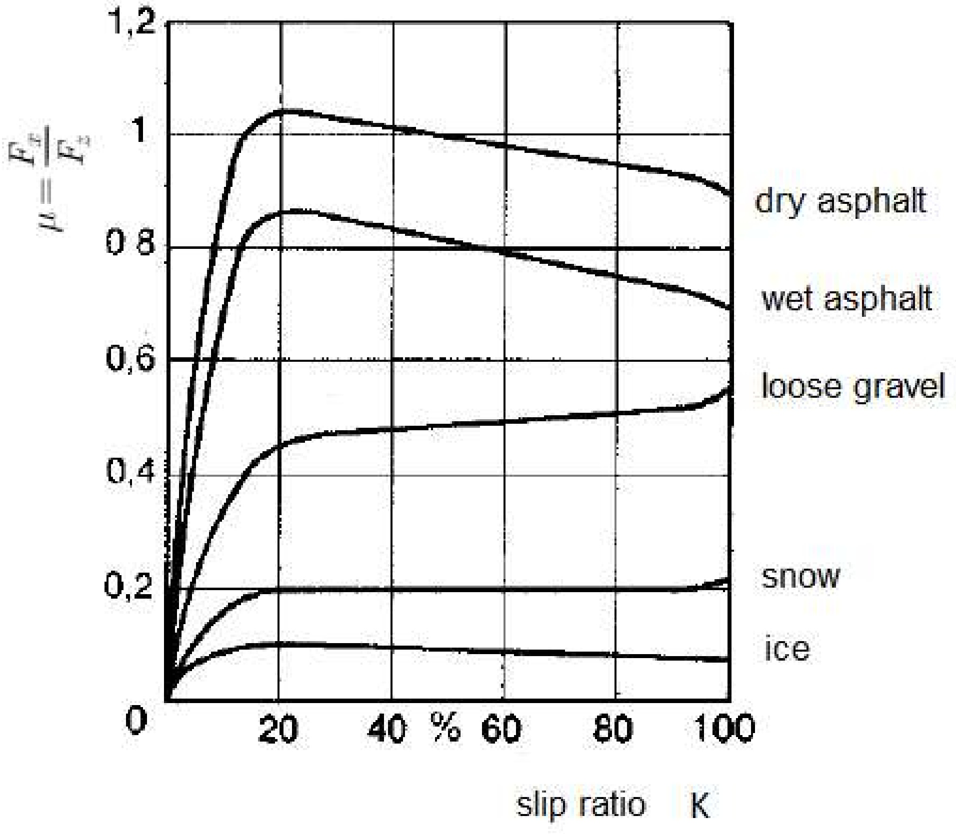


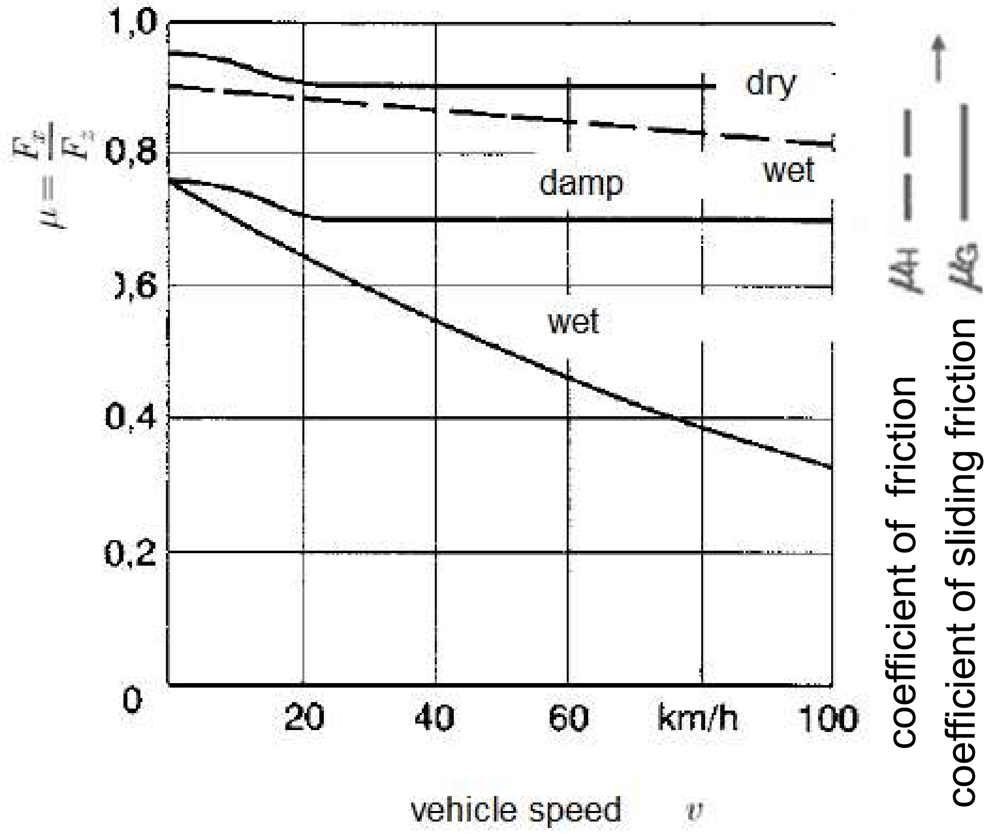
Degressive characteristics:

$$a = \frac{F_x}{m} = \frac{F_z \cdot \mu_x - F_z^2 \cdot \mu_{x,2}}{m} = \frac{m \cdot g \cdot \mu_x - m^2 \cdot g^2 \cdot \mu_{x,2}}{m} = g \cdot \mu_x - m \cdot g^2 \cdot \mu_{x,2}$$

The more vehicle weight results less max. acceleration!

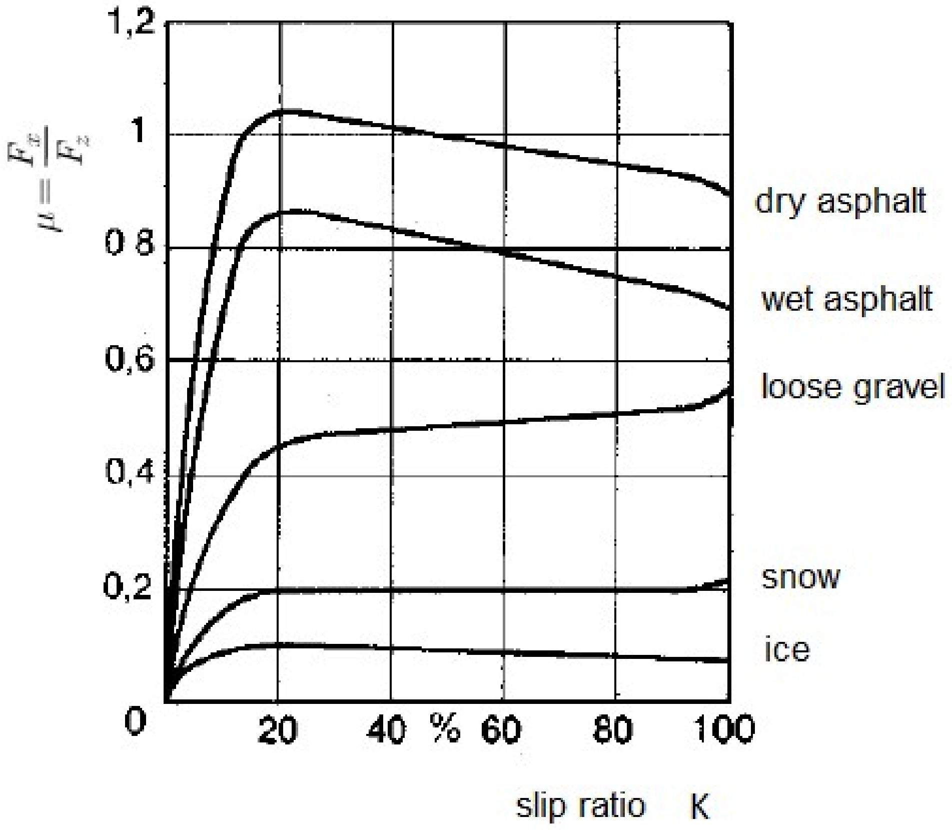
Friction coefficient μ_x





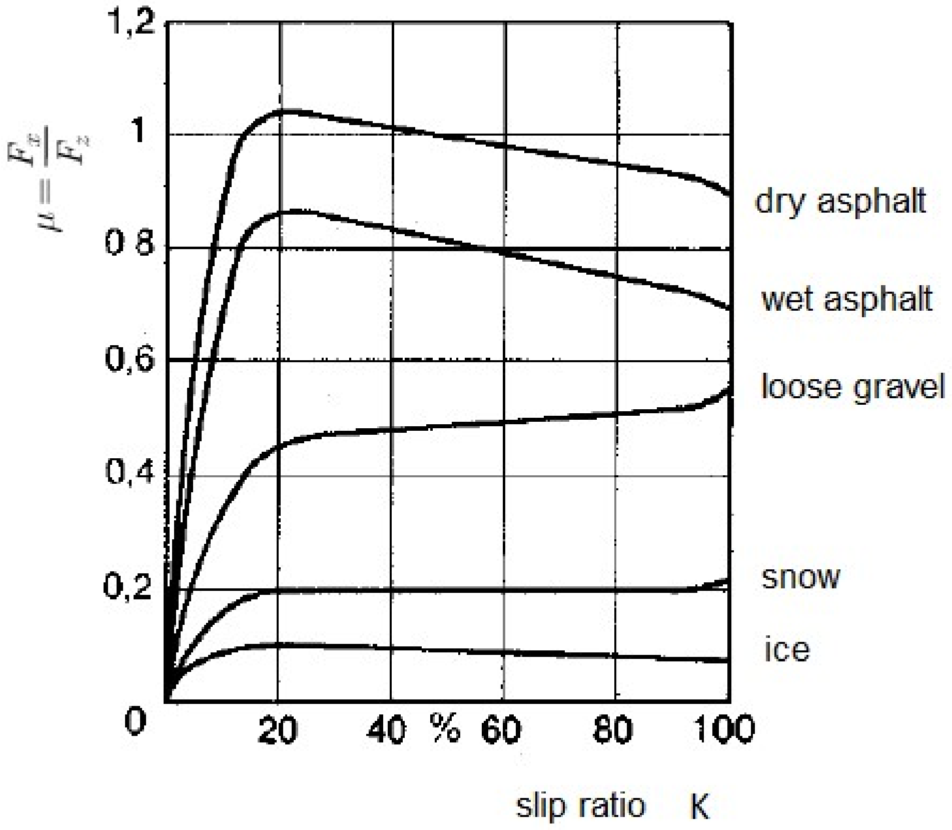
Source: Zomotor Ádám: Gépjármű menetdinamika, 2003

Friction coefficient μ_x



value of μ_x in F1?

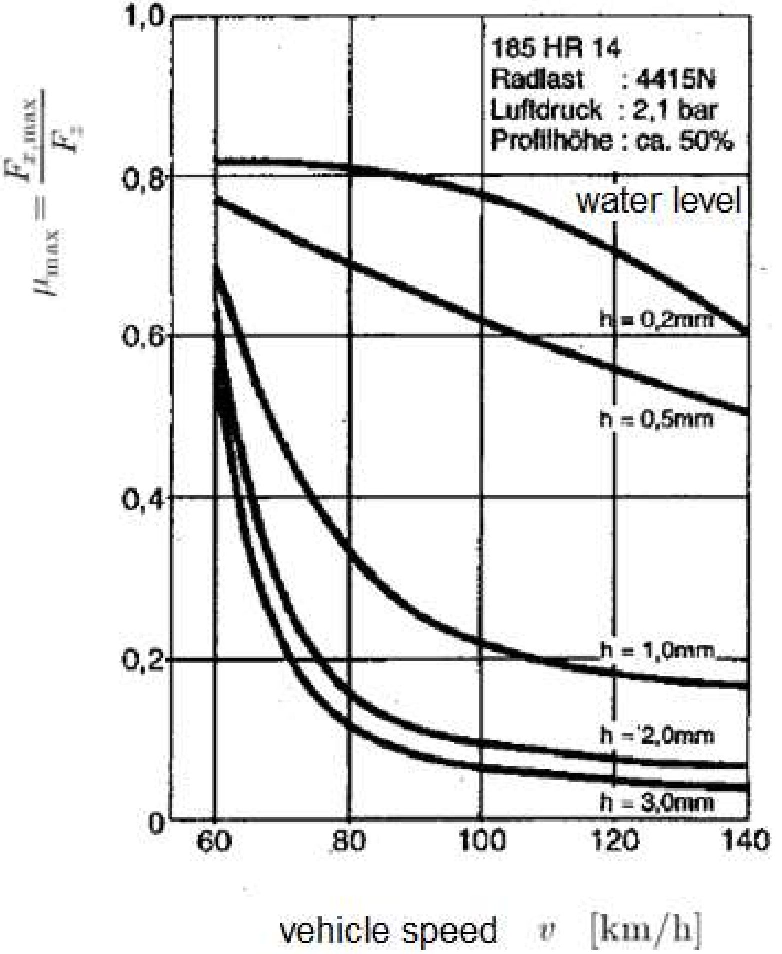
Friction coefficient μ_x

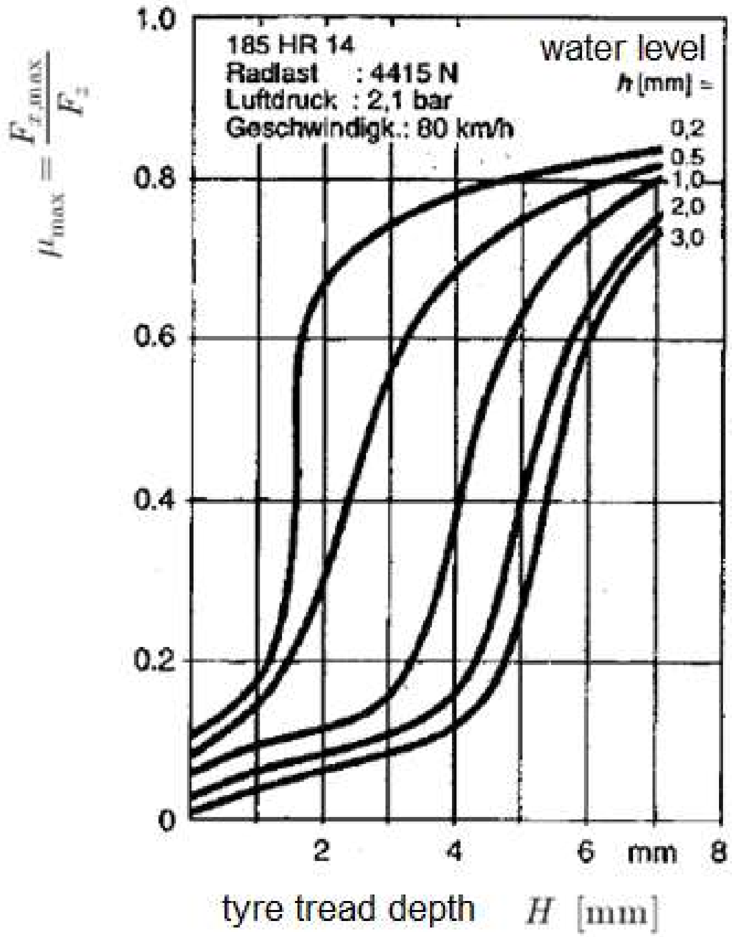


value of μ_x in F1?

1.5-1.7

Friction coefficient μ_x



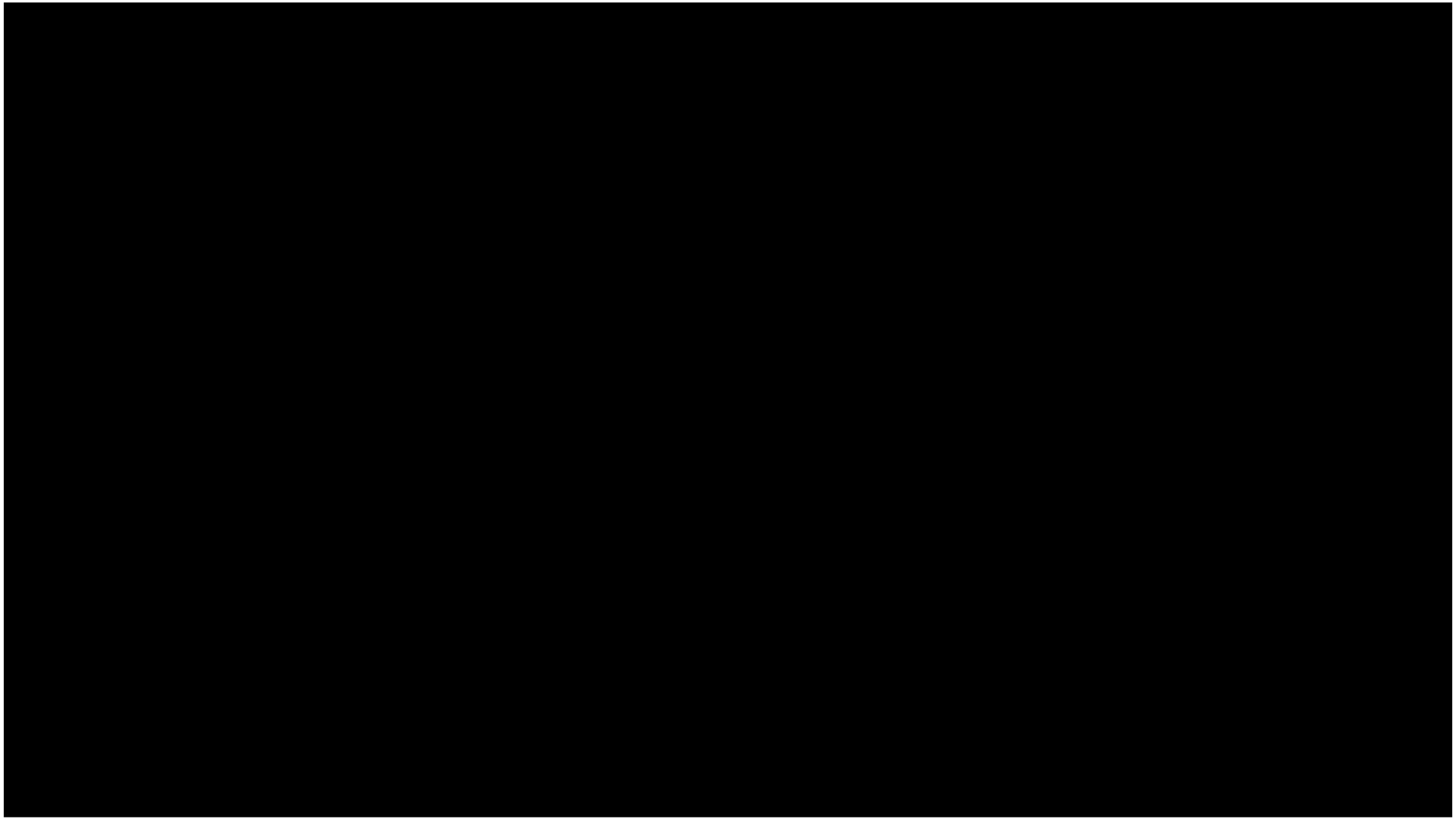


Quelle: Wallentowitz 1997

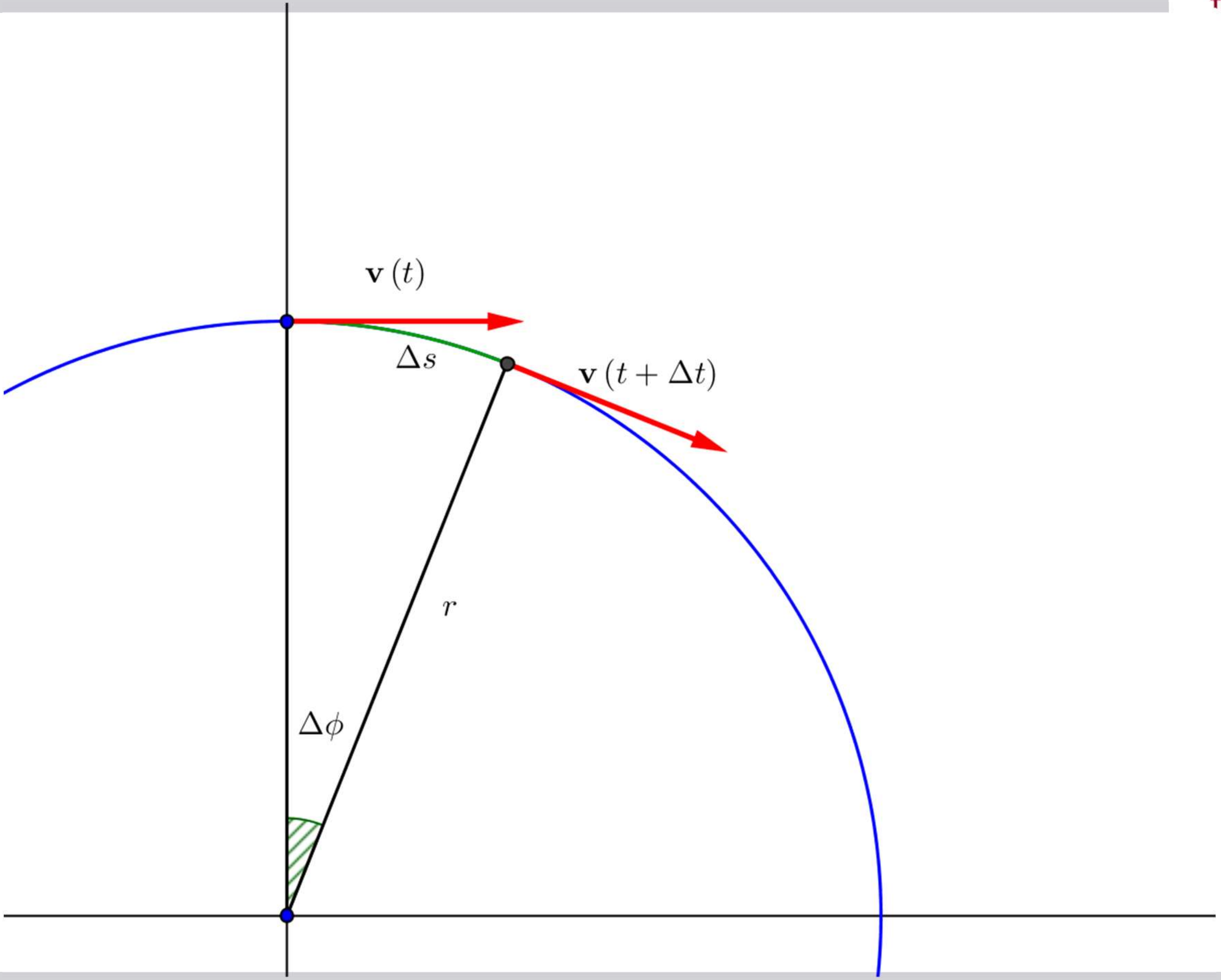
Tread depth


TYRE SAFETY MONTH
Tyre wear affects vehicle performance and safety. The deeper the groove, the more grip and traction your tyre will have.
Make sure you regularly check the tread depth of your tyres and replace them when they are worn.
DAVANTI
LEADING THE WAY
1.6mm
legal minimum tread depth

Day in the office – for tires



Lateral dynamics – steady state condition



Lateral dynamics - steady state condition

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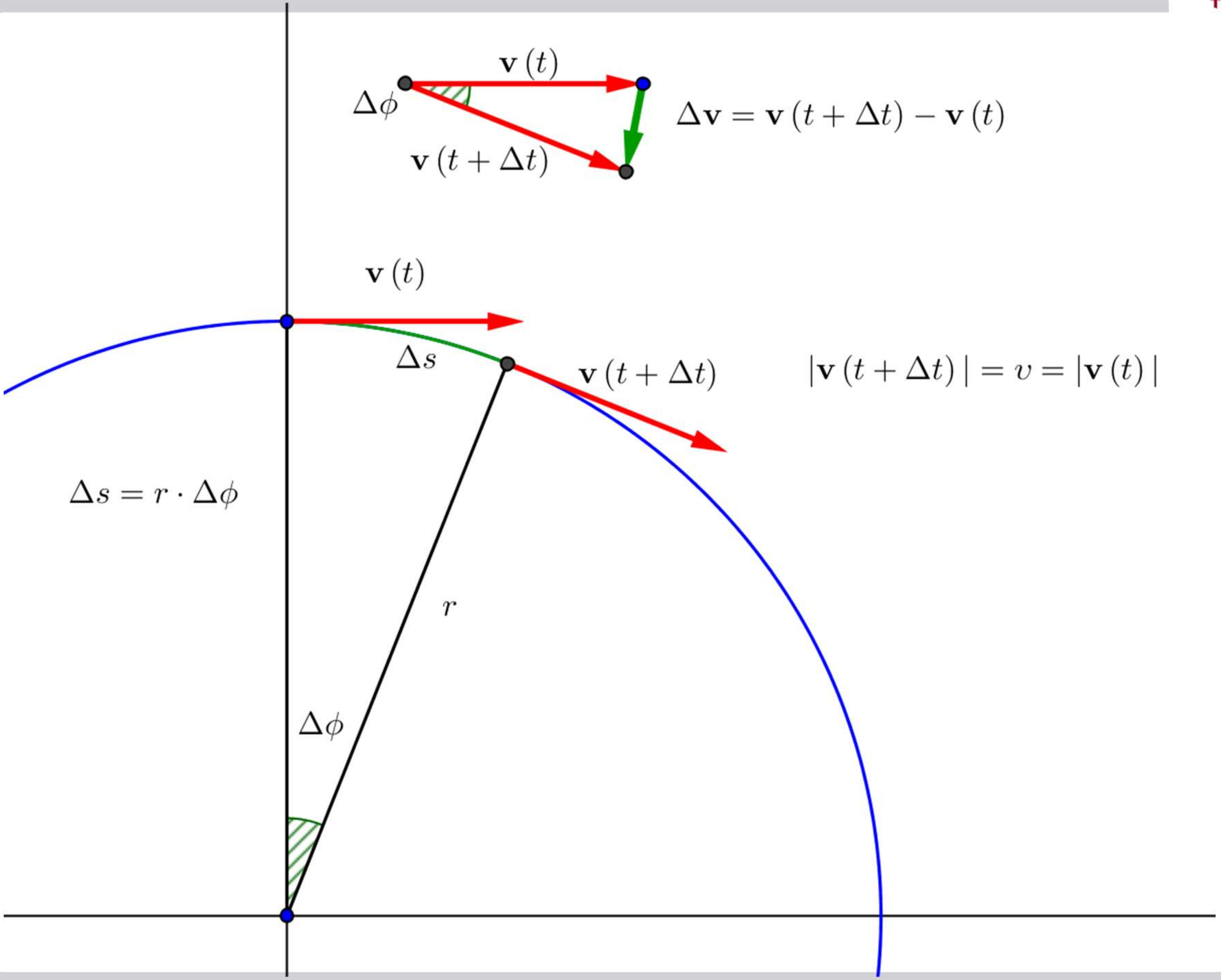
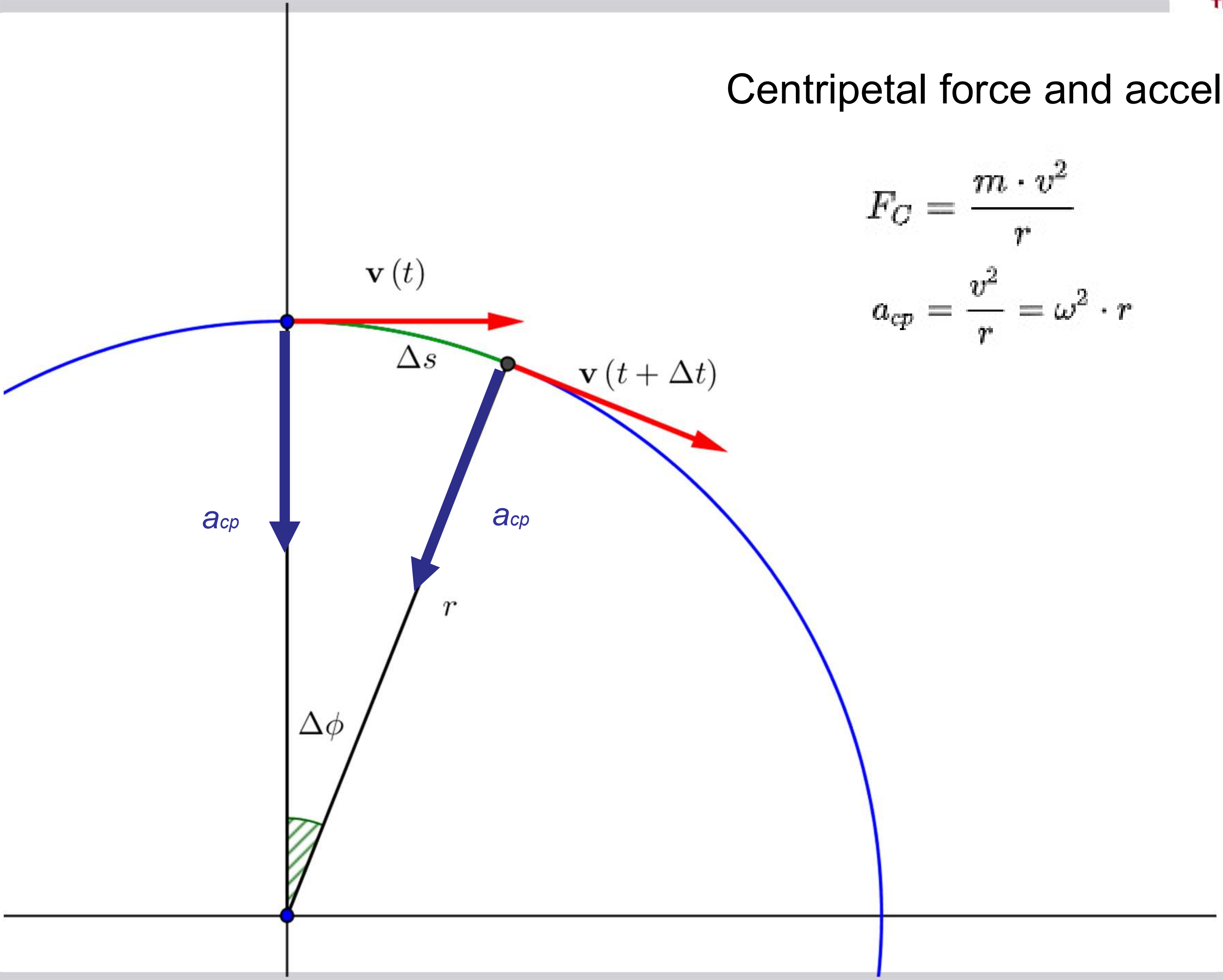


Lateral dynamics - steady state condition



Centripetal force and acceleration

$$F_C = \frac{m \cdot v^2}{r}$$

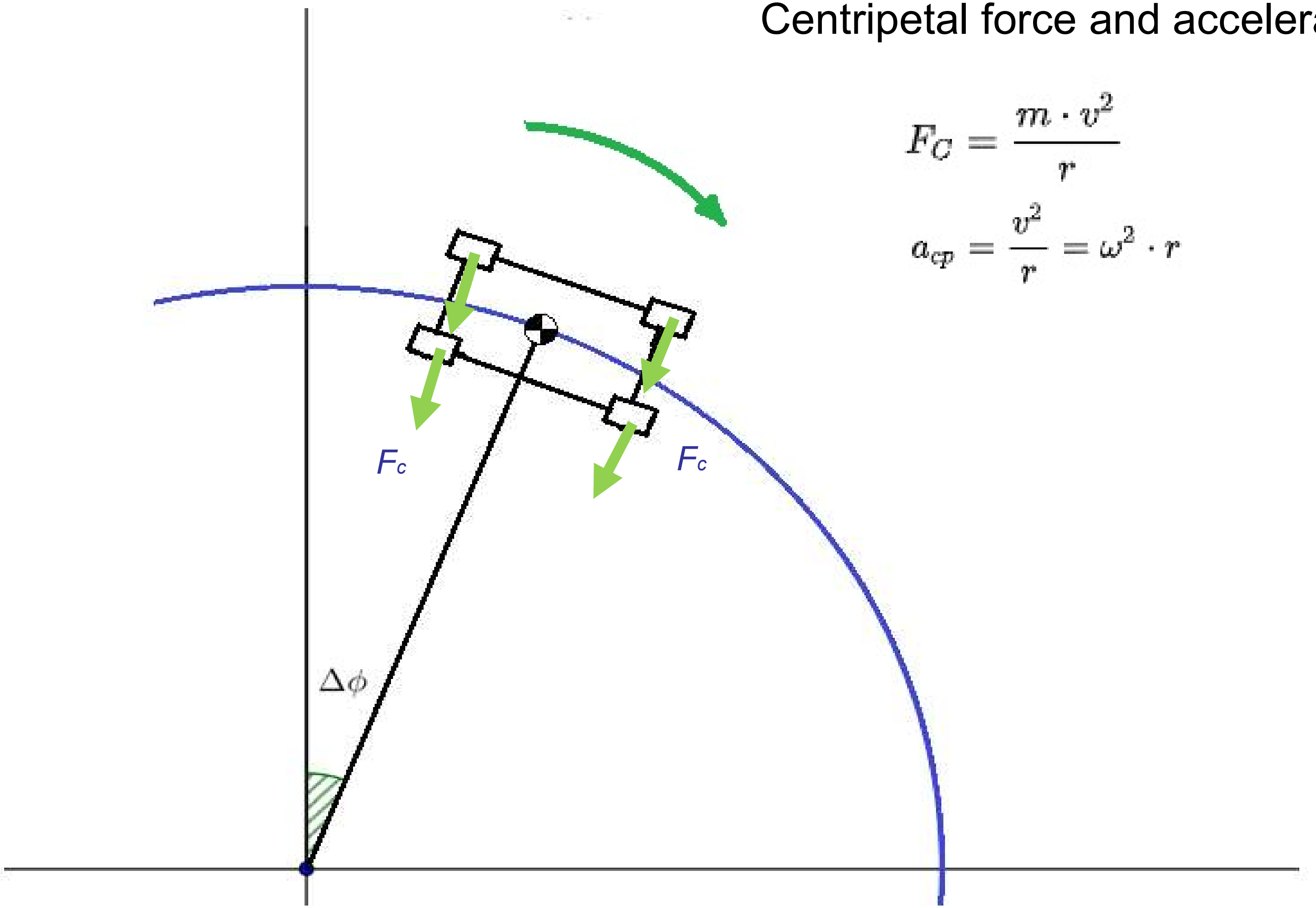
$$a_{cp} = \frac{v^2}{r} = \omega^2 \cdot r$$

Lateral dynamics - steady state condition

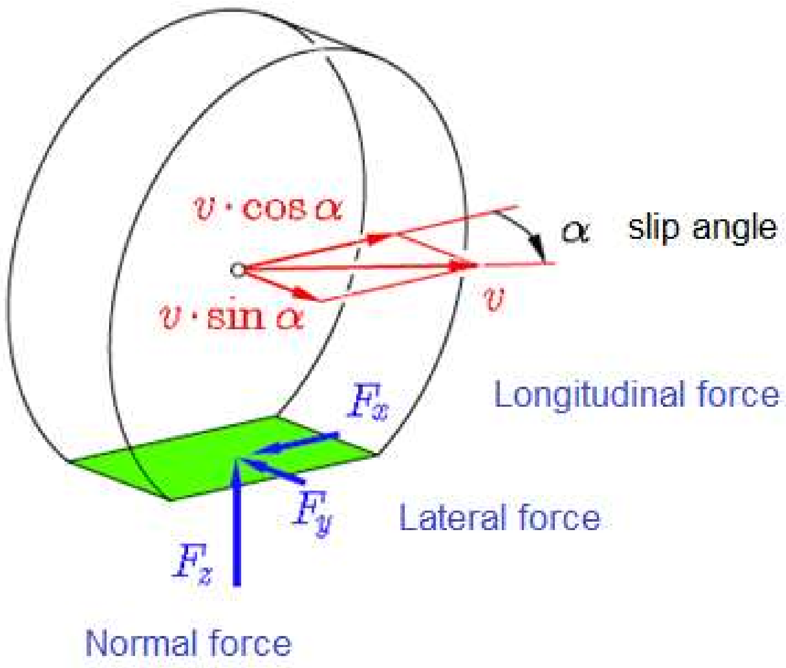
Centripetal force and acceleration

$$F_C = \frac{m \cdot v^2}{r}$$

$$a_{cp} = \frac{v^2}{r} = \omega^2 \cdot r$$

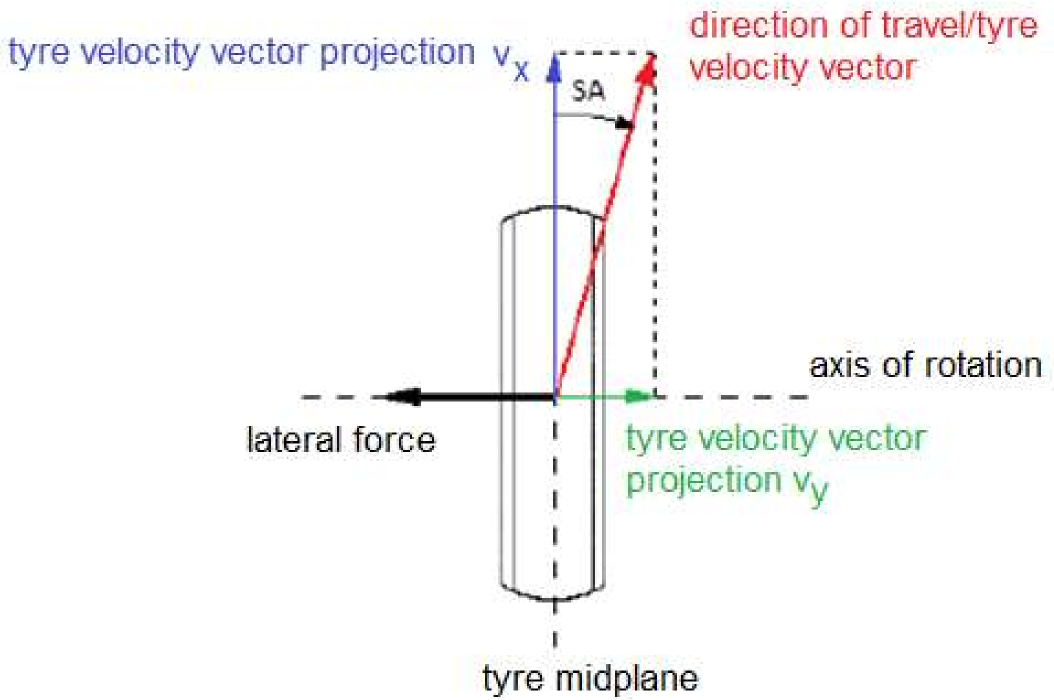


Tyre forces, slip angle



α = SA=slip angle

Slip angle definition



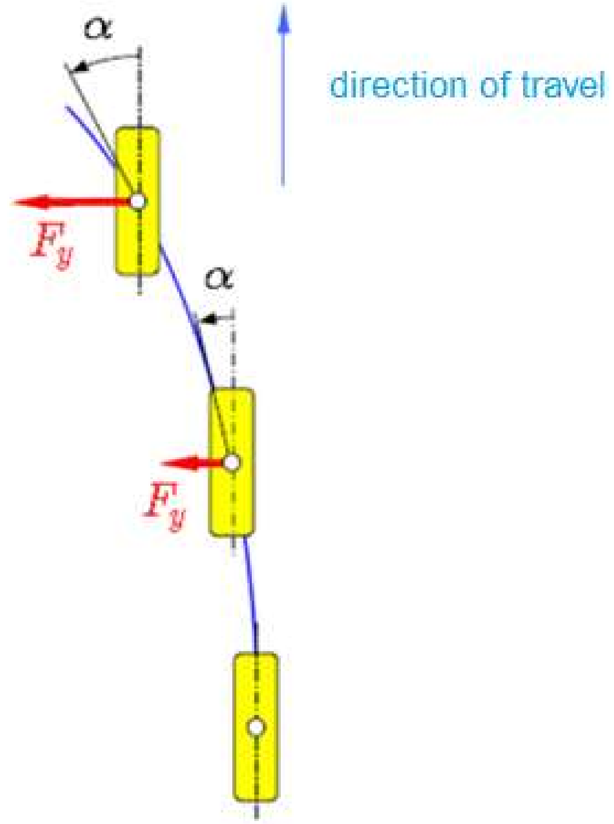
Slip angle defintion:

$$SA = \arctan\left(\frac{v_y}{v_x}\right)$$

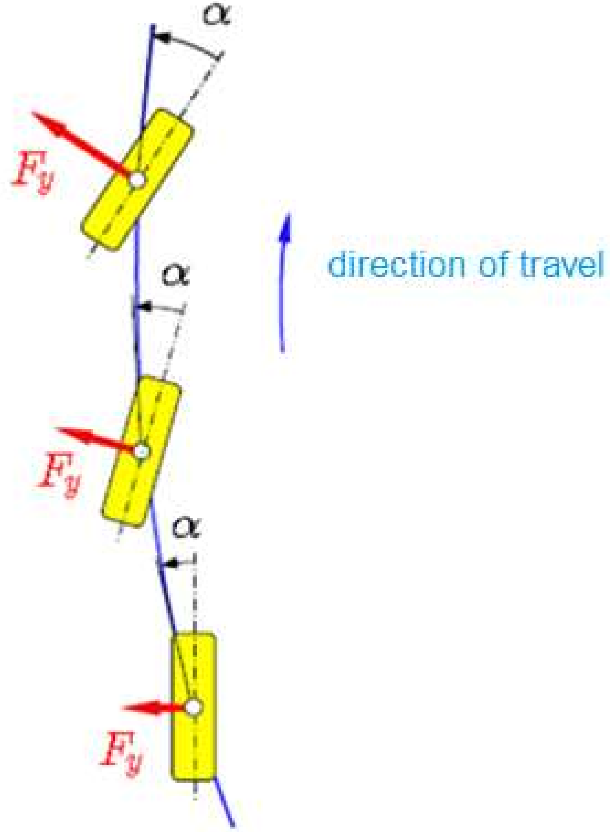
The angle between actual tyre velocity vector and the tyre midplane is the slip angle.

Slip angle video

Slip angle and lateral force

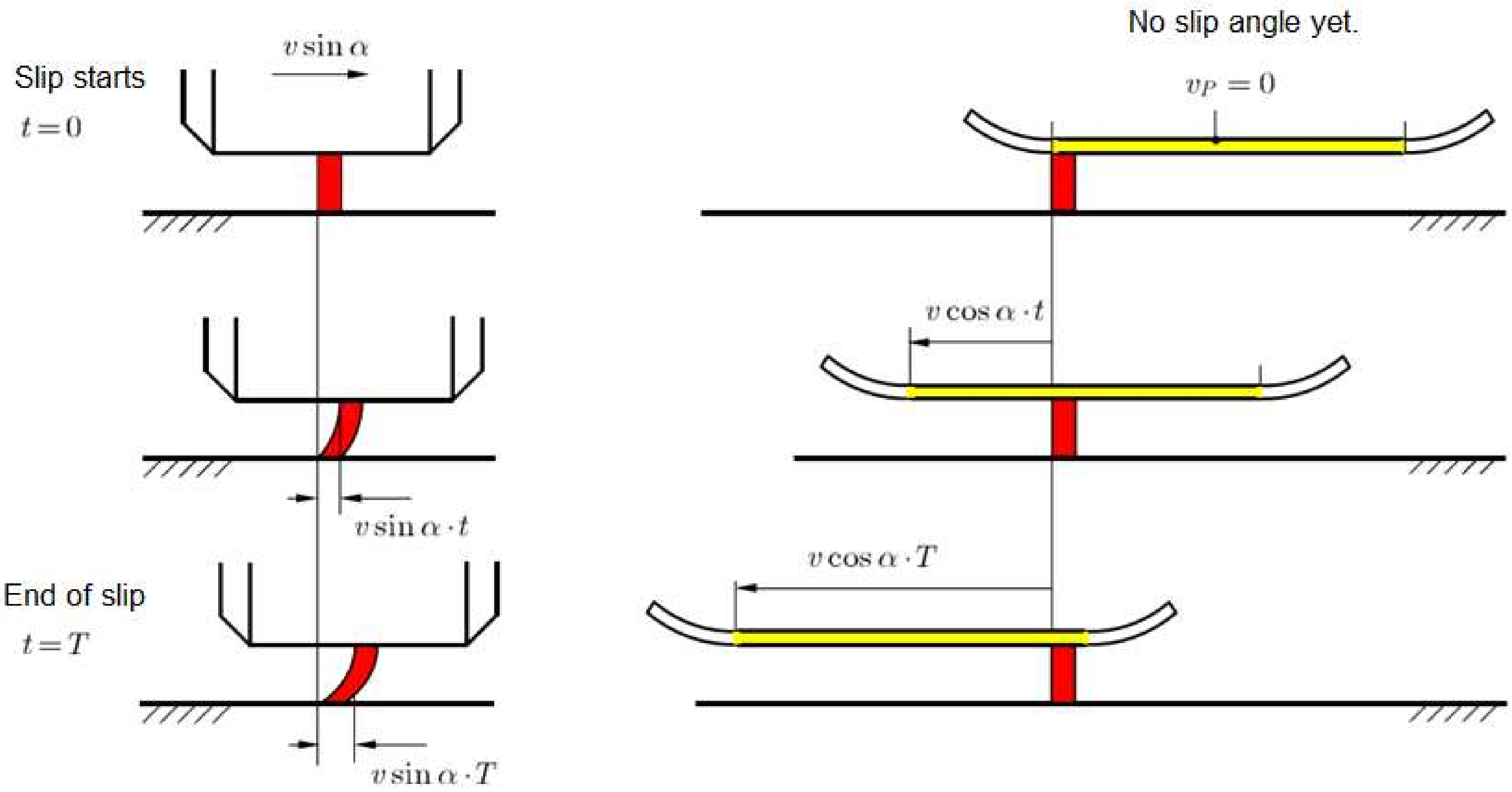


by increasing lateral force -> SA will be increasing



by increasing SA -> lateral force will be increasing

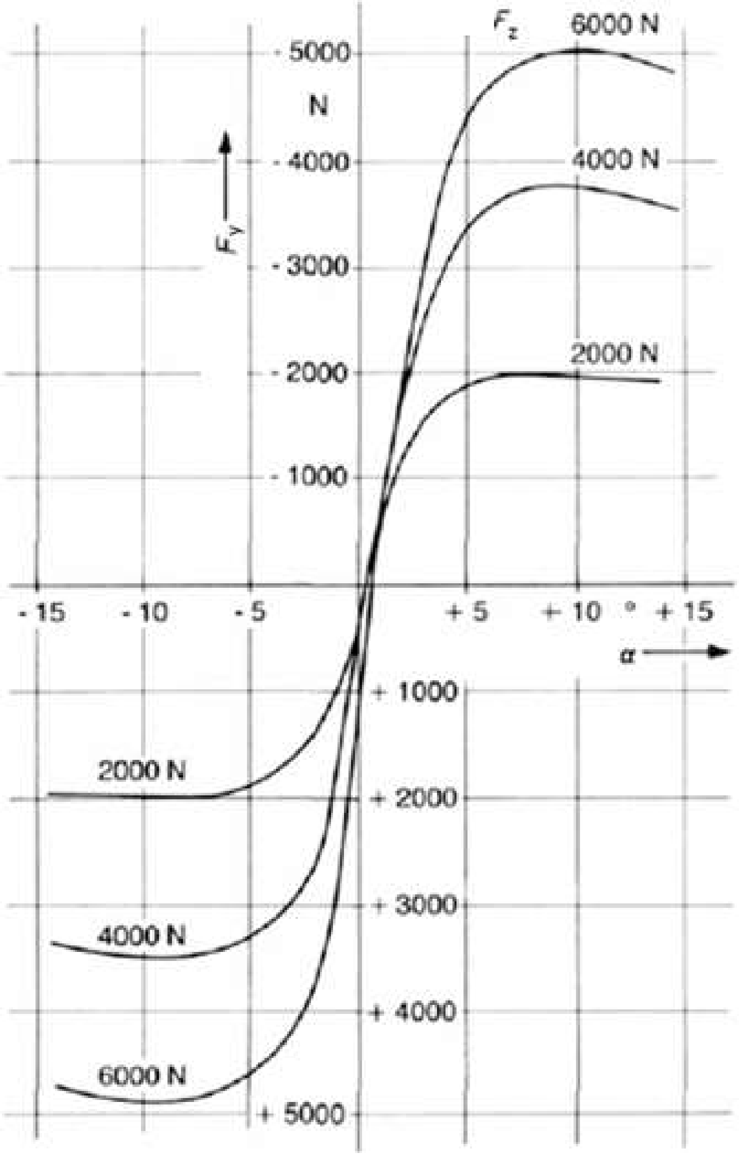
Brush model for lateral behaviour



The deformation of one bristle.

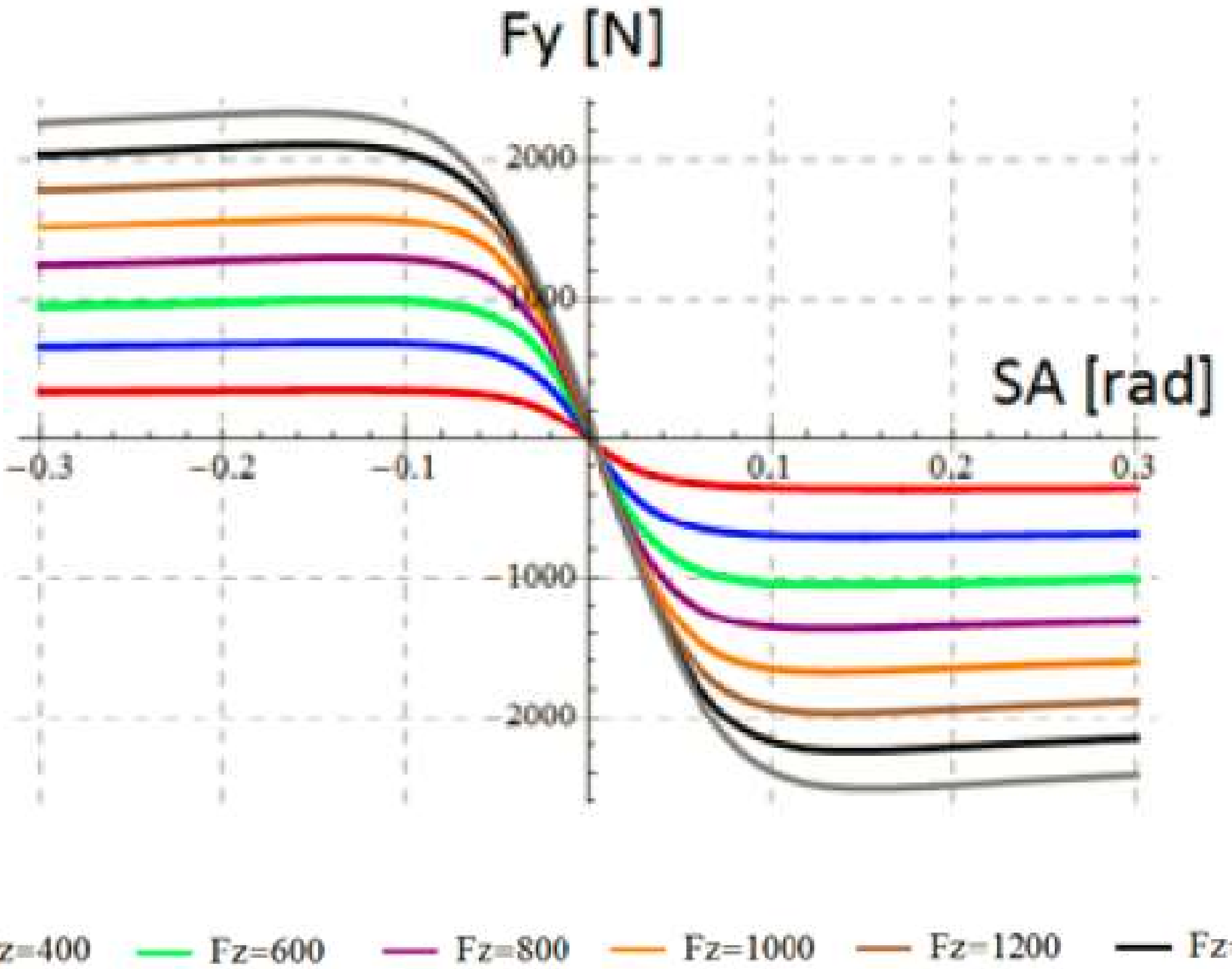
Source: C. Woernle

Correlation of a tyre lateral force – SA



Lateral force

What could the colours mean?

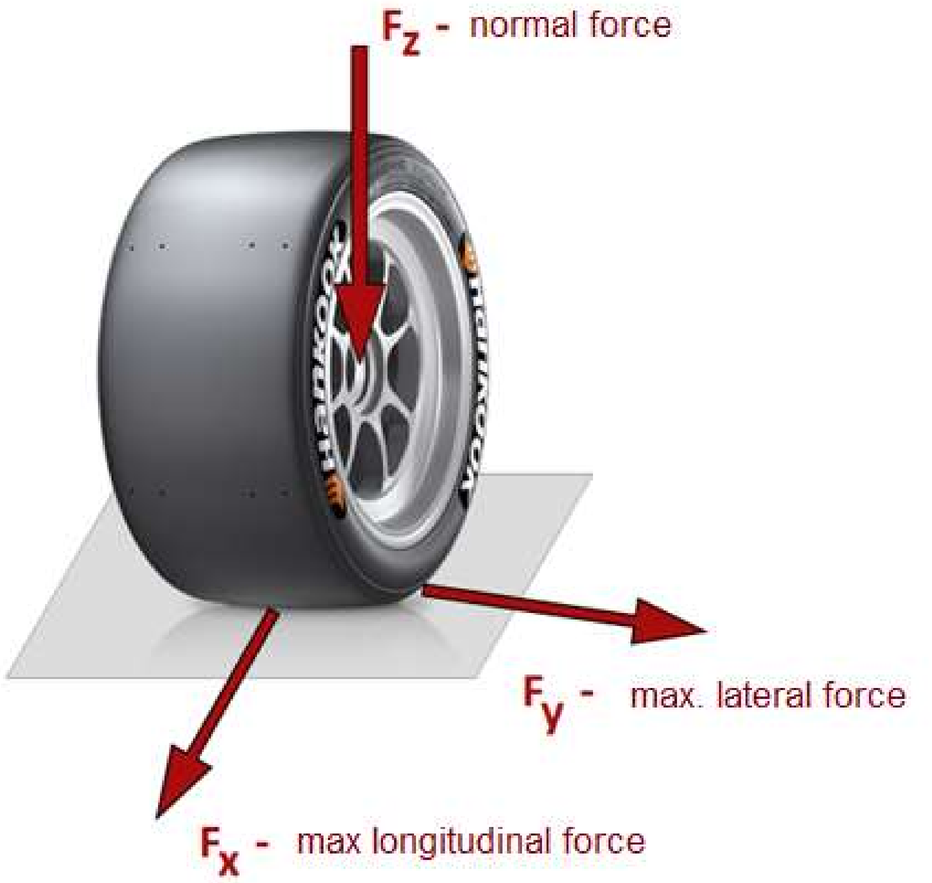


Friction coefficient μ_y

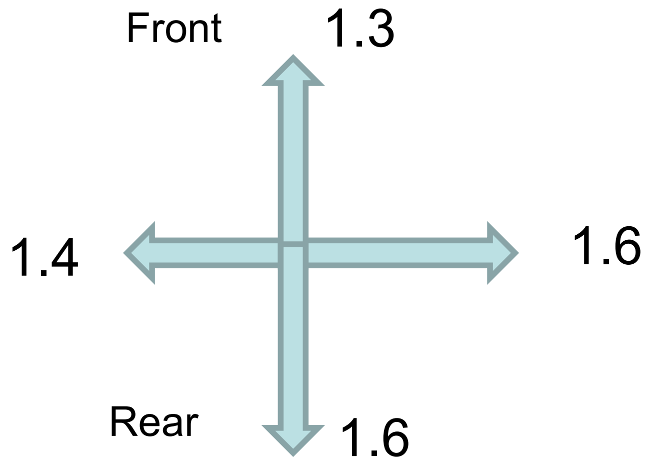
Friction coefficient definitions

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

$$\boldsymbol{\mu_y} = \frac{\mathbf{F_y}}{\mathbf{F_z}}$$

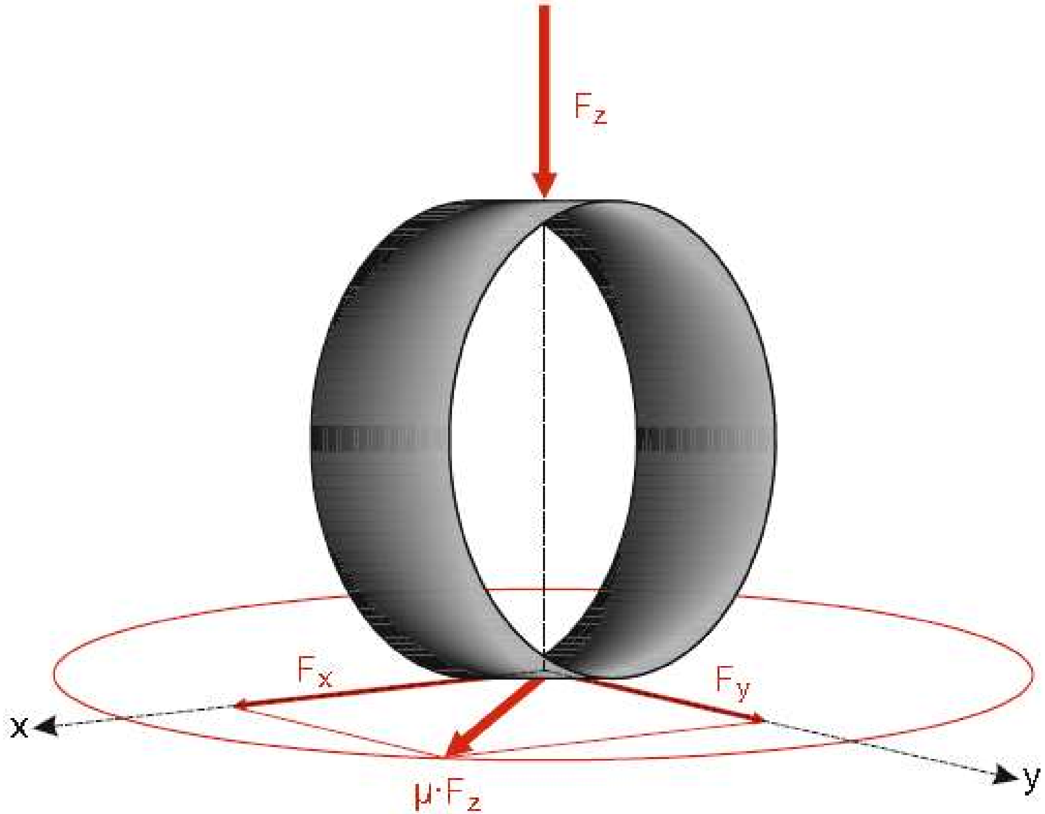


Different Friction Coefficient along Lateral and Longitudinal Axis



Kamm circle

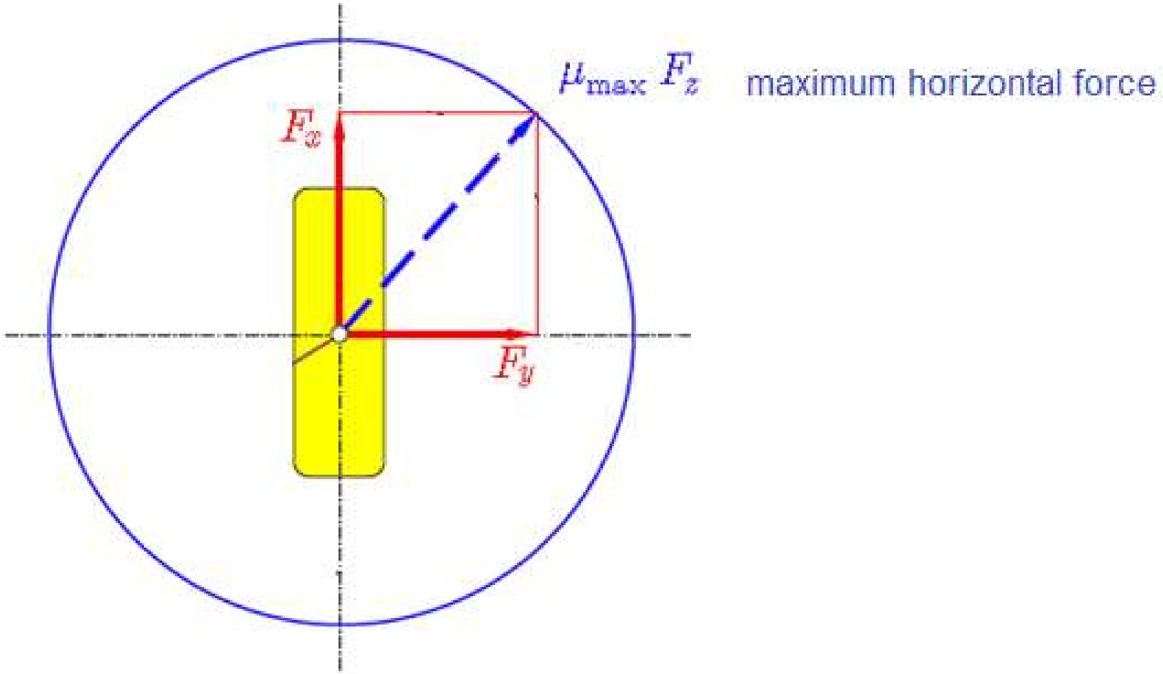
Circle of friction



$$\mu_{max} F_z \geq \sqrt{F_x^2 + F_y^2}$$

Kamm circle

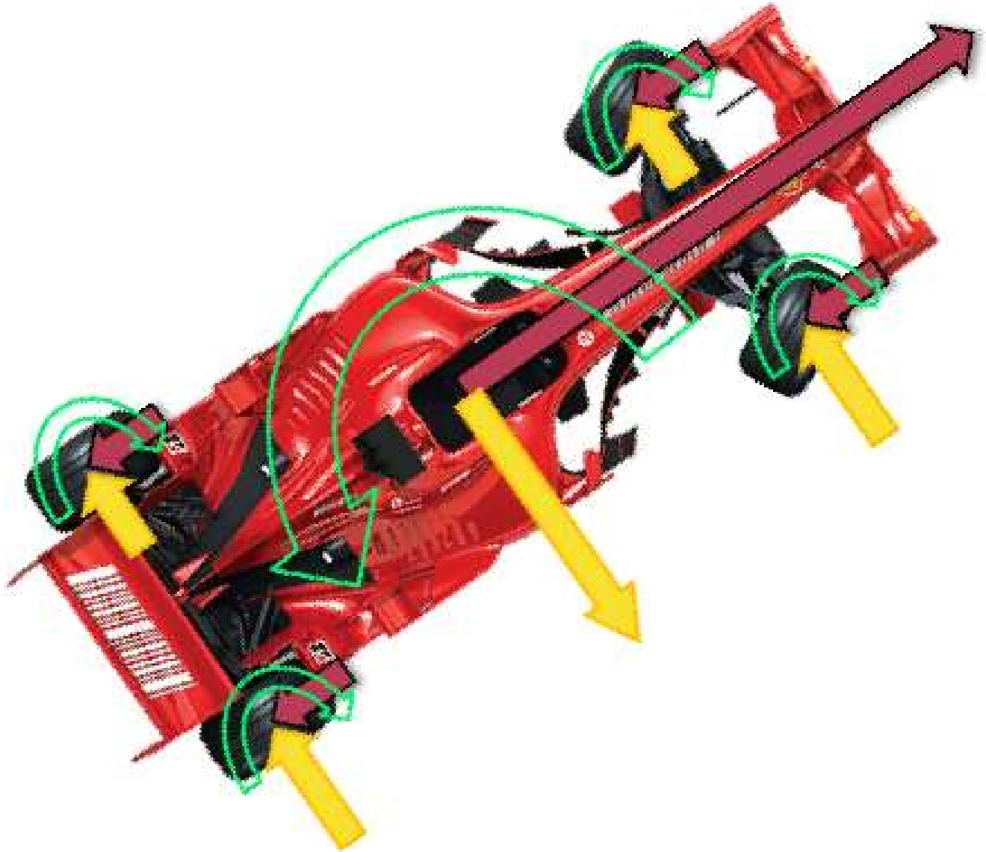
Circle of friction



$$\sqrt{F_x^2 + F_y^2} \leq \mu_{\max} F_z$$

Tyre forces

- weight of the car
- lateral G
- longitudinal G
- vertical aero
- longitudinal aero
- lateral aero

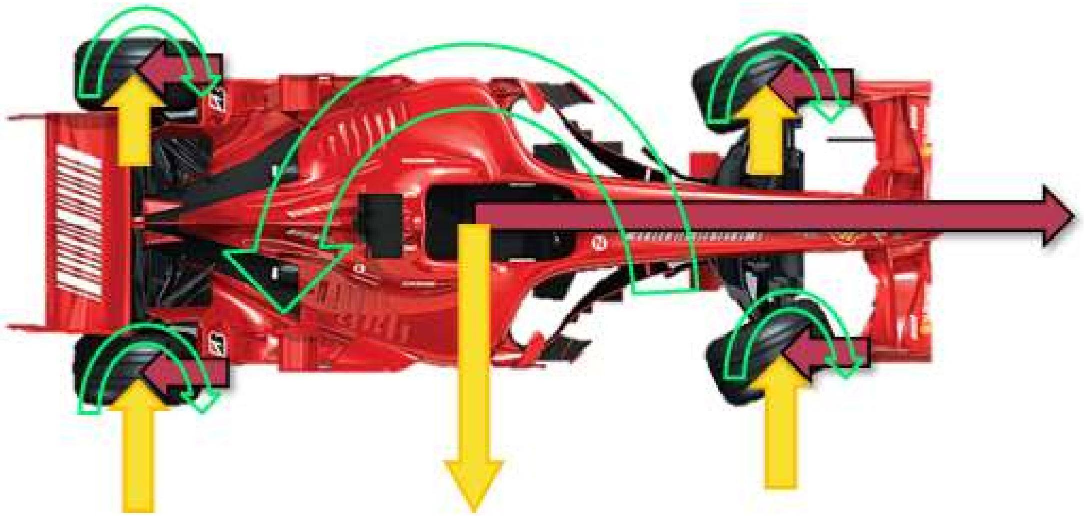


Tyre moments

- Overturning moment M_x
- Rolling resistance M_y
- Aligning torque M_z

Tyre forces and moments

- Tyre forces and moments are function of tyre compound and structure, ground and …

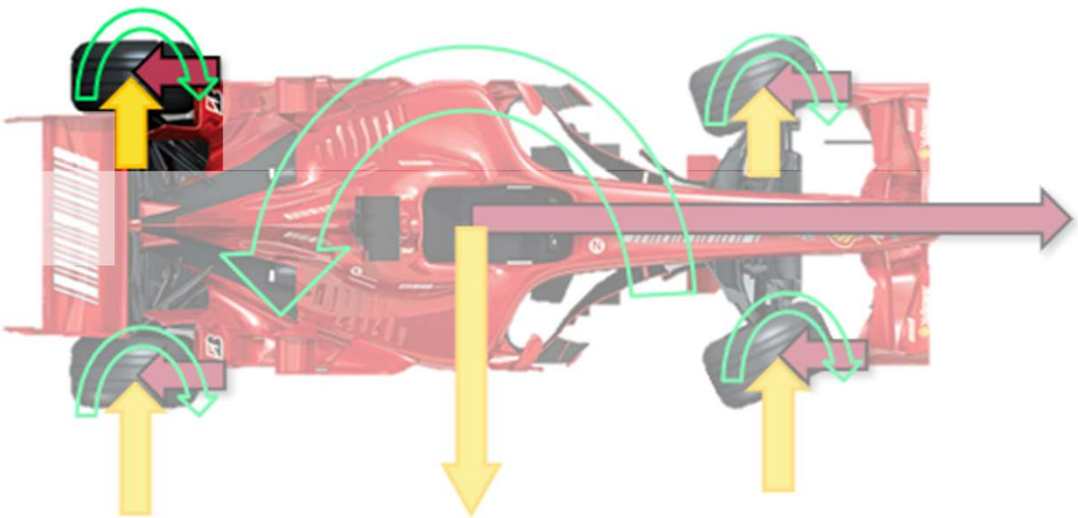


- slip angle
- slip ratio
- vertical load
- inclination angle
- speed

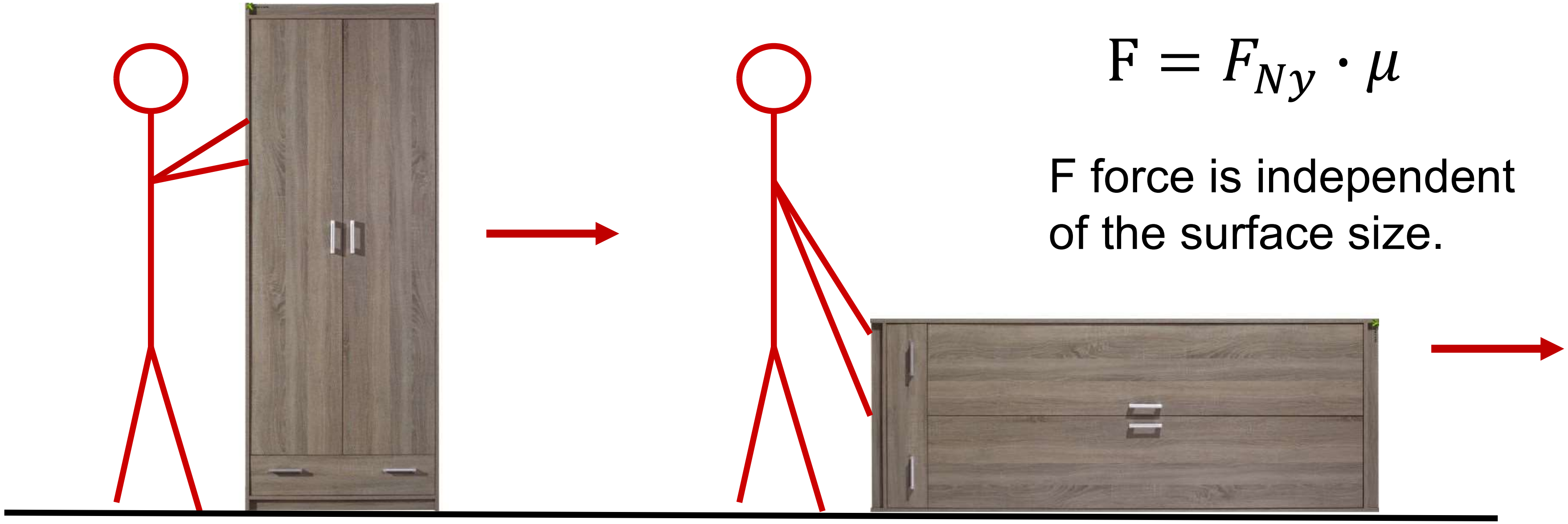
- pressure
- temperature
- rim design
- tyre wear…

Source of yaw moment

- F_x, F_y and M_z



Why slick?



$$\mathrm{F} = F_{Ny} \cdot \mu$$

F force is independent of the surface size.

?

Lateral force and cornering stiffness

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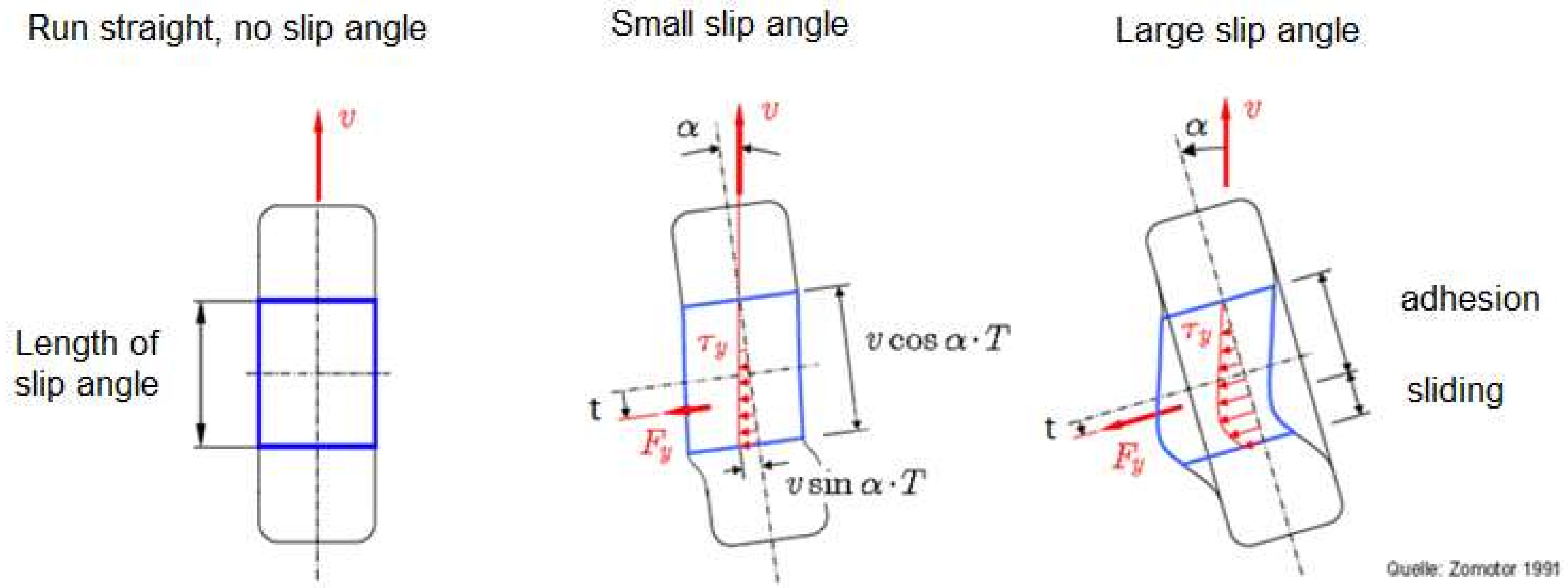
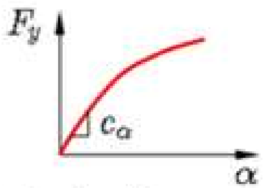


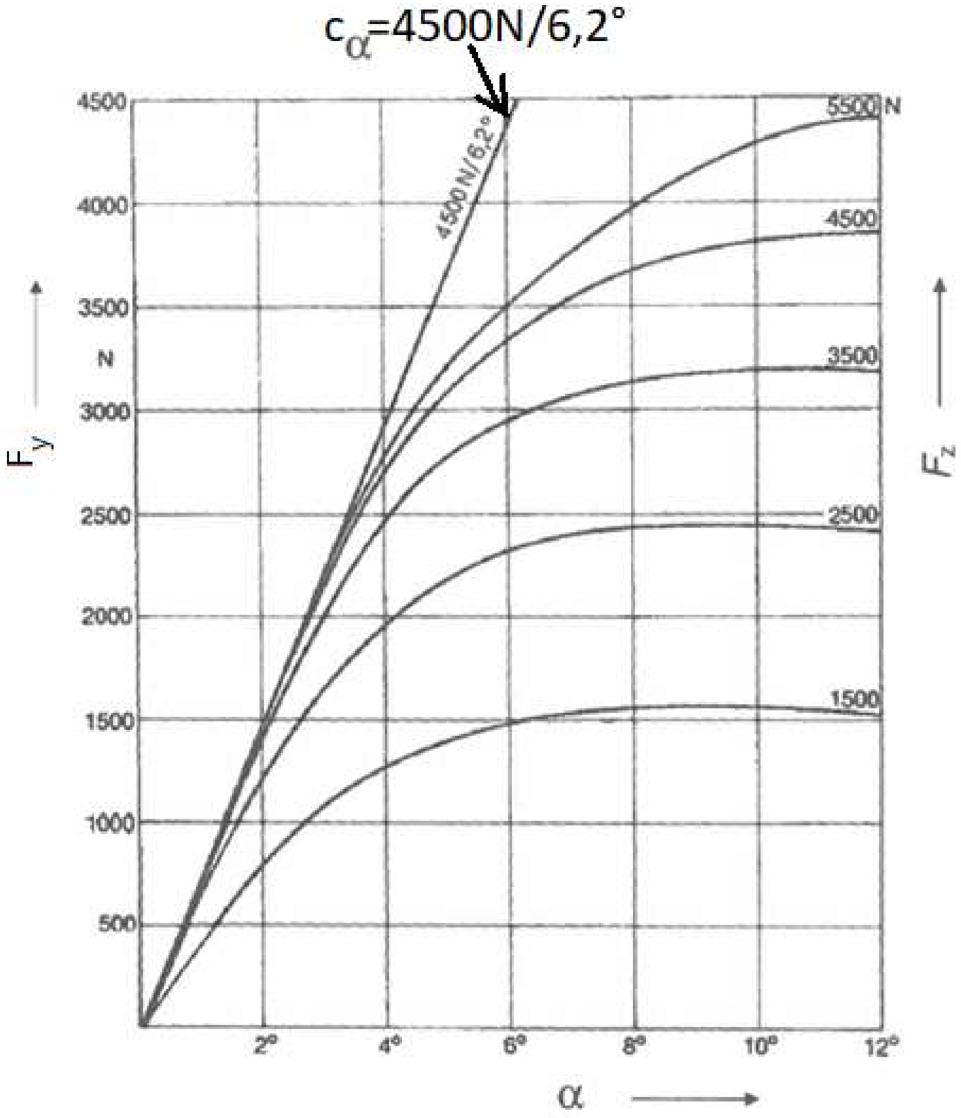
lateral force ~ area below the $\tau_y(x)$ curve

$$F_y = c_\alpha \sin\alpha \cdot \cos\alpha \approx c_\alpha\, \alpha$$



cornering stiffness c_α [N/rad]

Lateral force and cornering stiffness



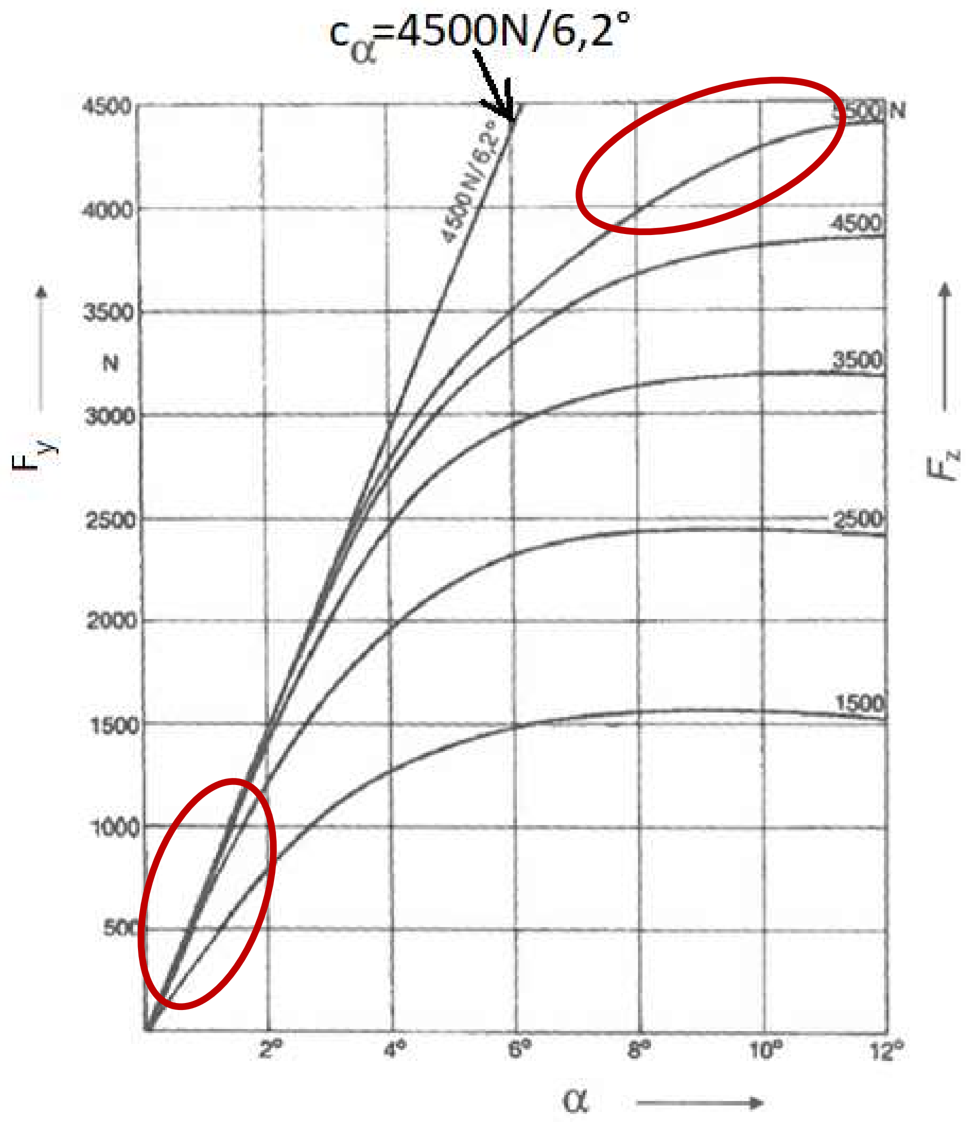
Tyre: 175 HR 14

pressue: 2.3 bar

cornering stiffness: C_α =41586 N/rad

The same tyre has different behaviour on different vehicles, therefore the value of C_α will be different as well.

Lateral force and cornering stiffness

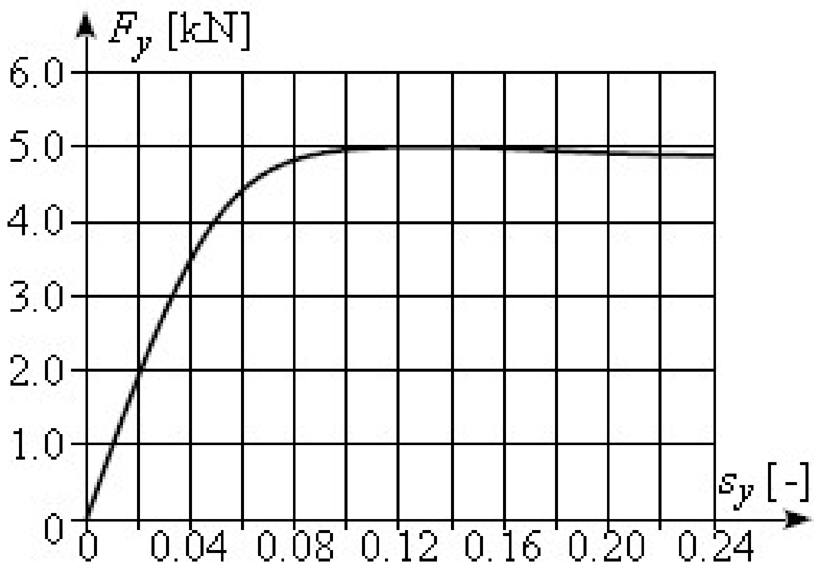


$$m \cdot a_y = F_{y,F}(\alpha) + F_{y,R}(\alpha)$$

$$\alpha = \alpha(v, \omega, \dots)$$

- calculation is easier – reason to linearize
- the value of slip angle in that range where we use tyre is low, so we are allowed to linearize

Test example



Tyre test bench measurement data can be seen on diagram.

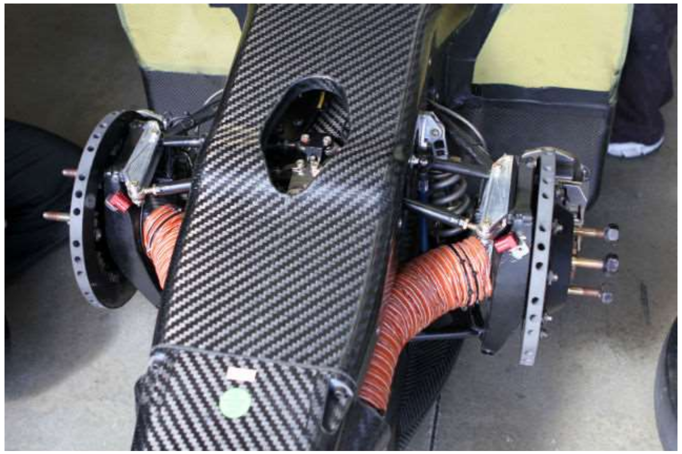
a) What value is the cornering stiffness?

b) Draw an approximately correct graph with the same tyre as it is marked in wet conditions! The nature of the curve should be correct!

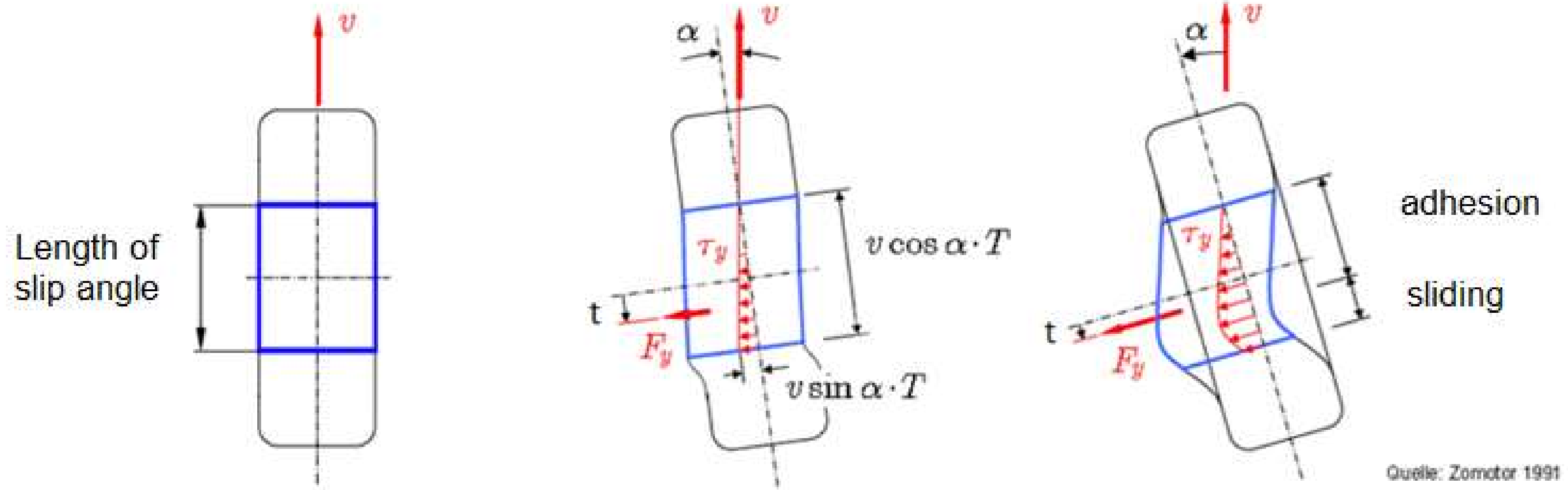
Cornering stiffness distribution

Nissan Deltawing racecar

- Cornering stiffness scales roughly linearly with tyre width
- Guessing WD of a particular car if you look at the relative tyre width front to rear
- Good example: Deltawing sportscar
  - 4 inch wide front tyres
  - If far enough from CoG, reasonable yaw moment if can be generated

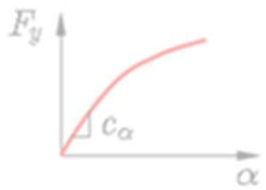


Run straight, no slip angle | Small slip angle | Large slip angle



lateral force ~ area below the $\tau_y(x)$ curve

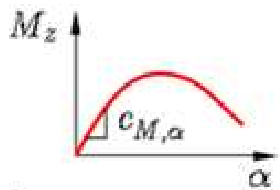
$$F_y = c_\alpha \sin\alpha \cdot \cos\alpha \approx c_\alpha\, \alpha$$



cornering stiffness c_α [N/rad]

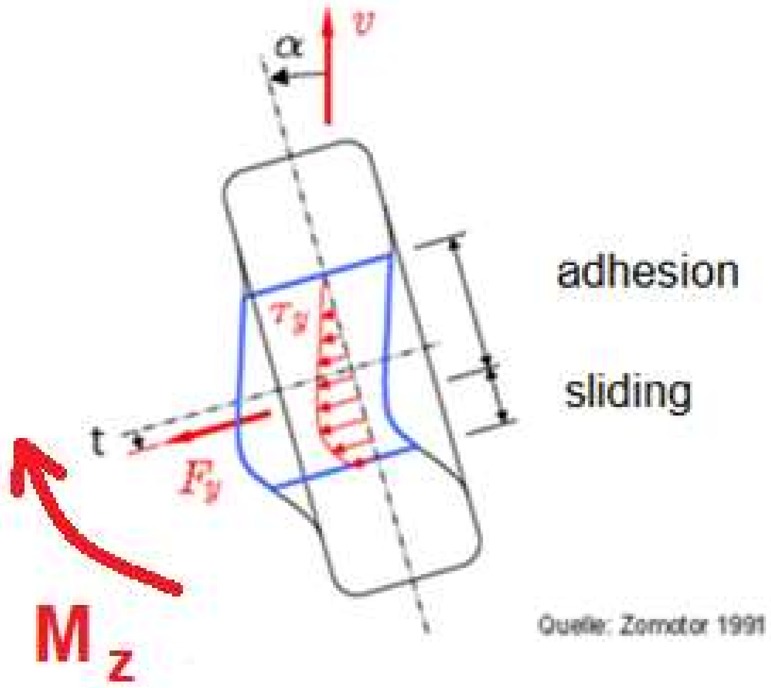
self aligning torque

$$M_z = t\, F_y \approx \underbrace{t\; c_\alpha}_{c_{M,\alpha}}\, \alpha$$



pneumatic trail t [m]

Self aligning torque



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!