Department of Automotive Technologies –
Vehicle Mechanics Fundamentals

Gábor Sipos

DEPARTMENT OF AUTOMOTIVE TECHNOLOGIES

Lecture 2

Base 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		
-	23th Apr		Break		Break
11	30th Apr	T2	Systems of vehicle II. ONLINE	4	Lab
12	7th May	9	Tyre management		
13	14th May	10	Midterm exam II.	11	Racecar engineering
14	21st May	T2 R	Exam 2 - replacement		

Schedule change!

Content

Longitudinal and lateral behaviour

- Brush model
- Degressivity of tyre
- Friction coefficient useage
- Lateral dynamics – slip angle
- Tyre behaviours
- Kamm-circle
- Tyres forces and torques
- Cornering stiffness, self-aligning torque

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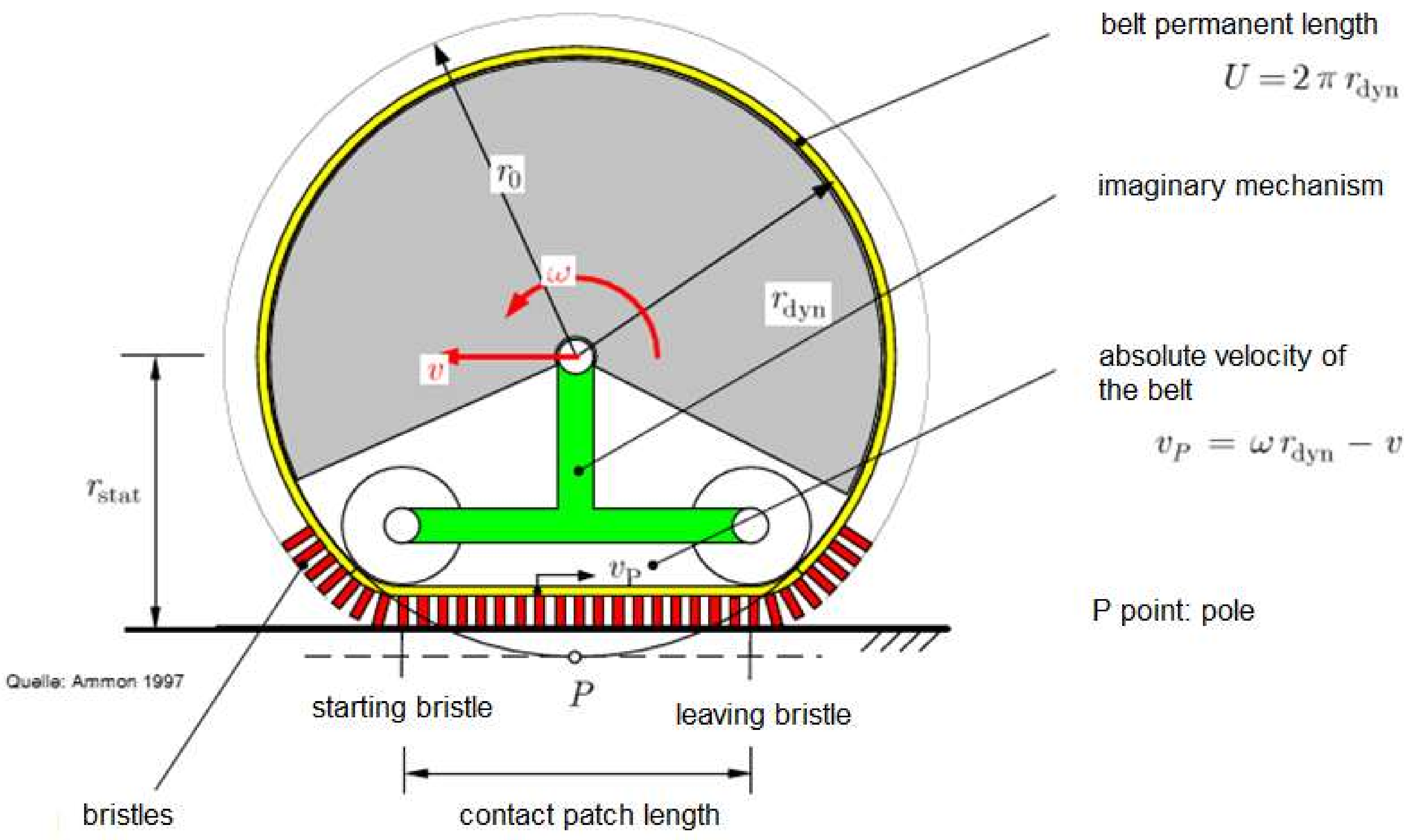
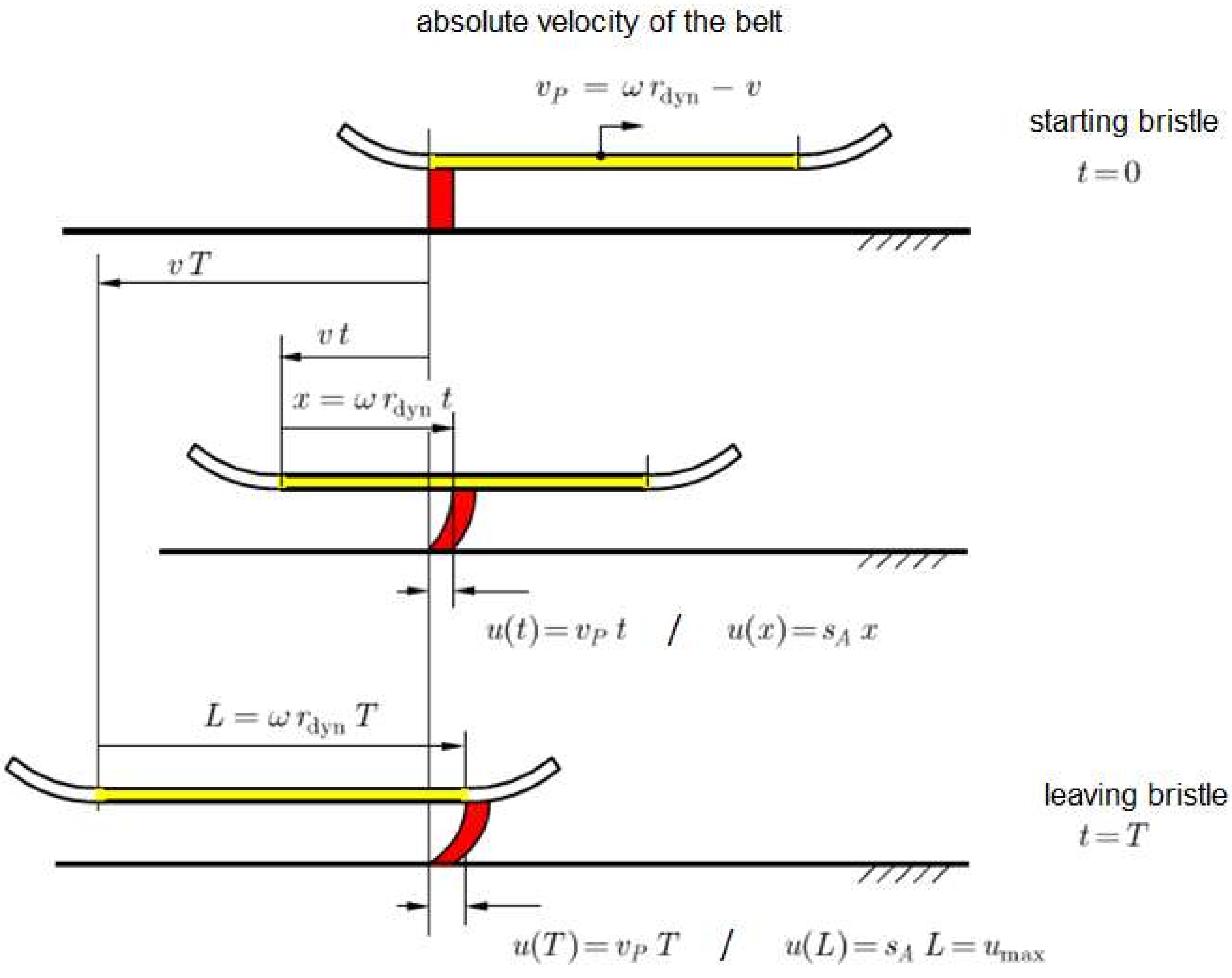
Note

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

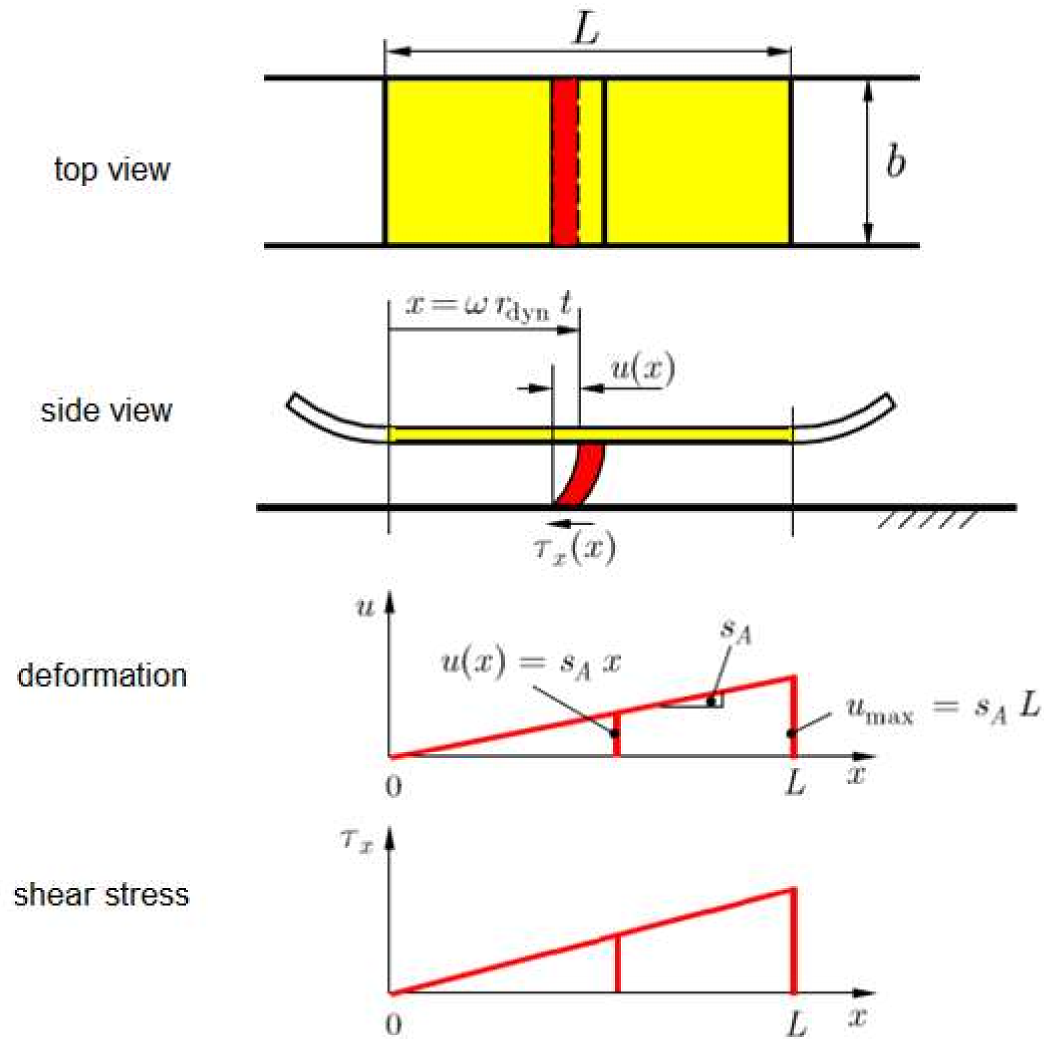

belt permanent length
$U = 2\pi r_{dyn}$
imaginary mechanism
absolute velocity of the belt
$v_P = \omega r_{dyn} - v$
P point: pole
r_0
ω
r_{dyn}
v
r_{stat}
v_P
Quelle: Ammon 1997
starting bristle
P
leaving bristle
bristles
contact patch length

Brush model



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

Brush model



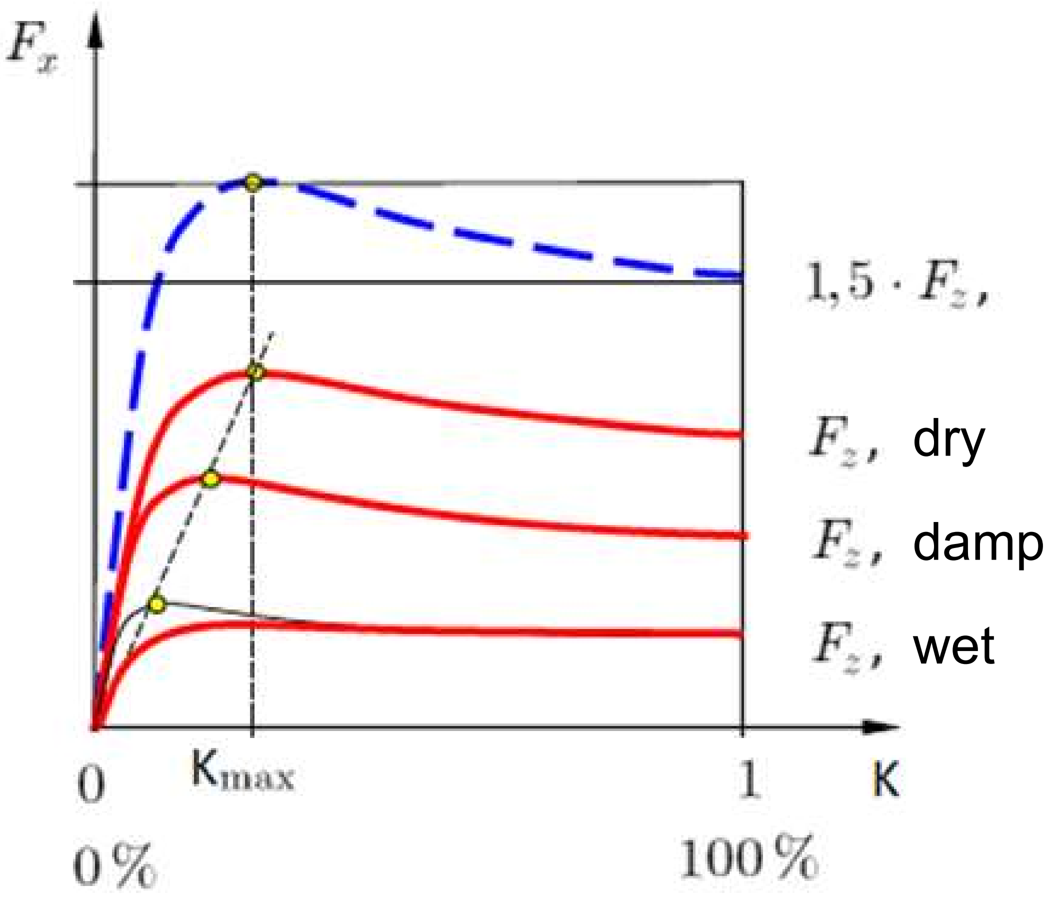
assumption:

contacting on full length of CP

Longitudninal force by bristle

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

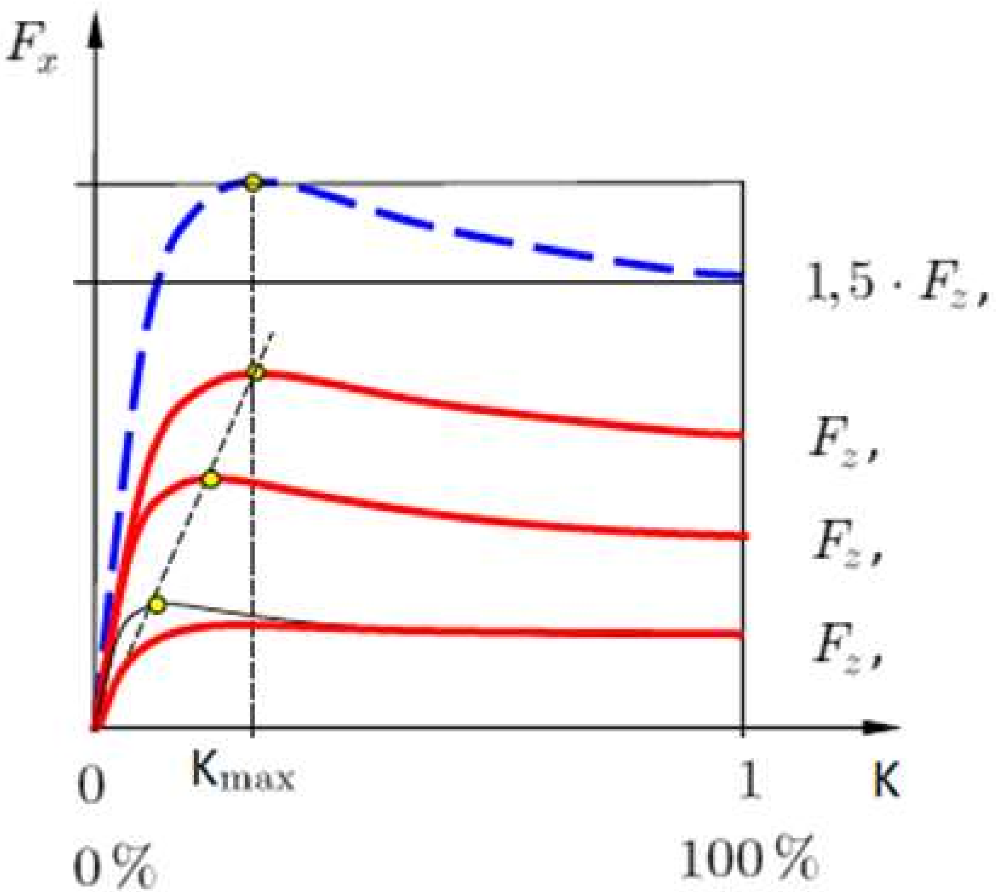
Effect of factors to longitudinal force - SR



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

$$\mathrm{F_x} = \mathrm{m} \cdot a$$

To have the best acceleration

Keep low as possible

Grip limited

$$\mathrm{F_x} = \mathrm{m} \cdot a$$

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

$$= g \cdot \mu_x$$

Buliding tanks or not?

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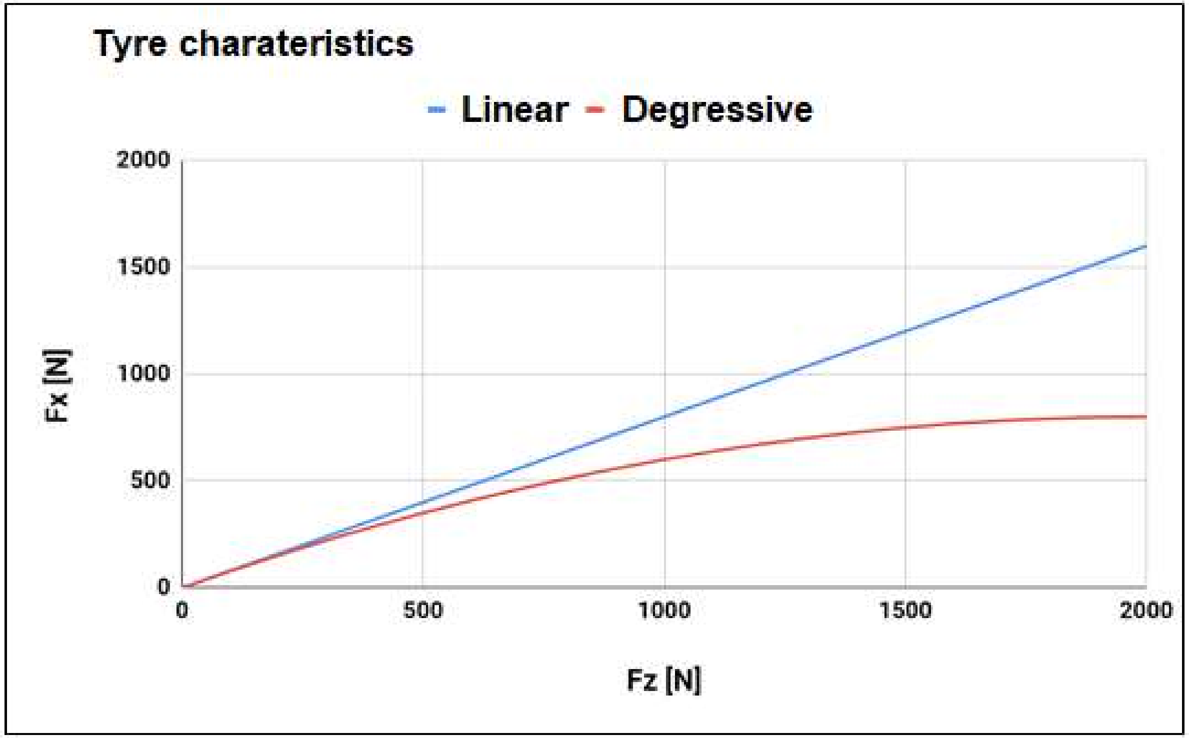
Linear characteristics:

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



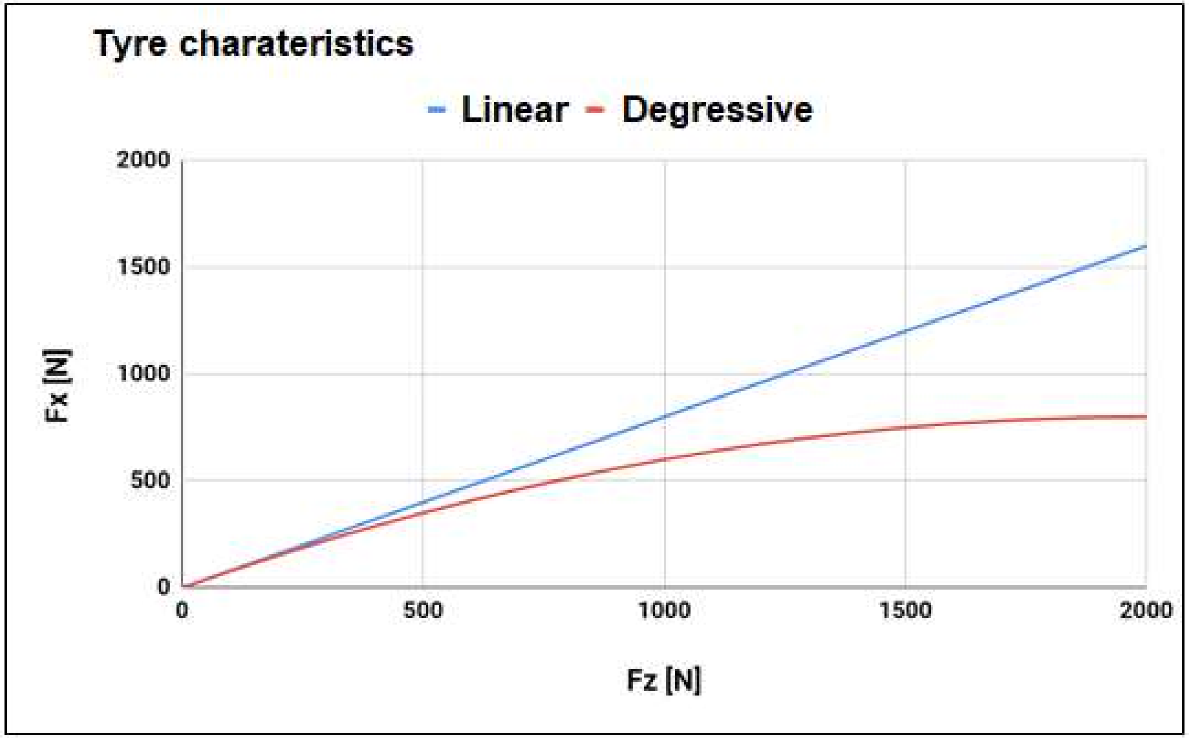
Buliding tanks or not?

Linear characteristics:

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

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!

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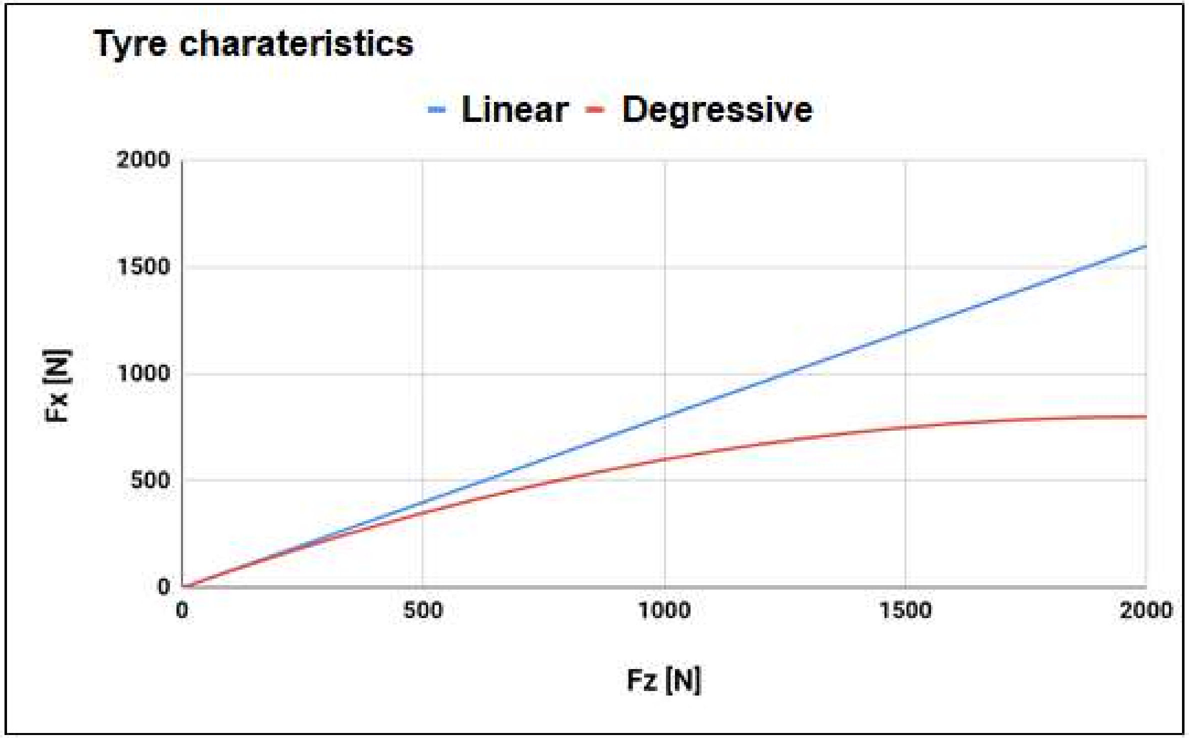
Linear characteristics:

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

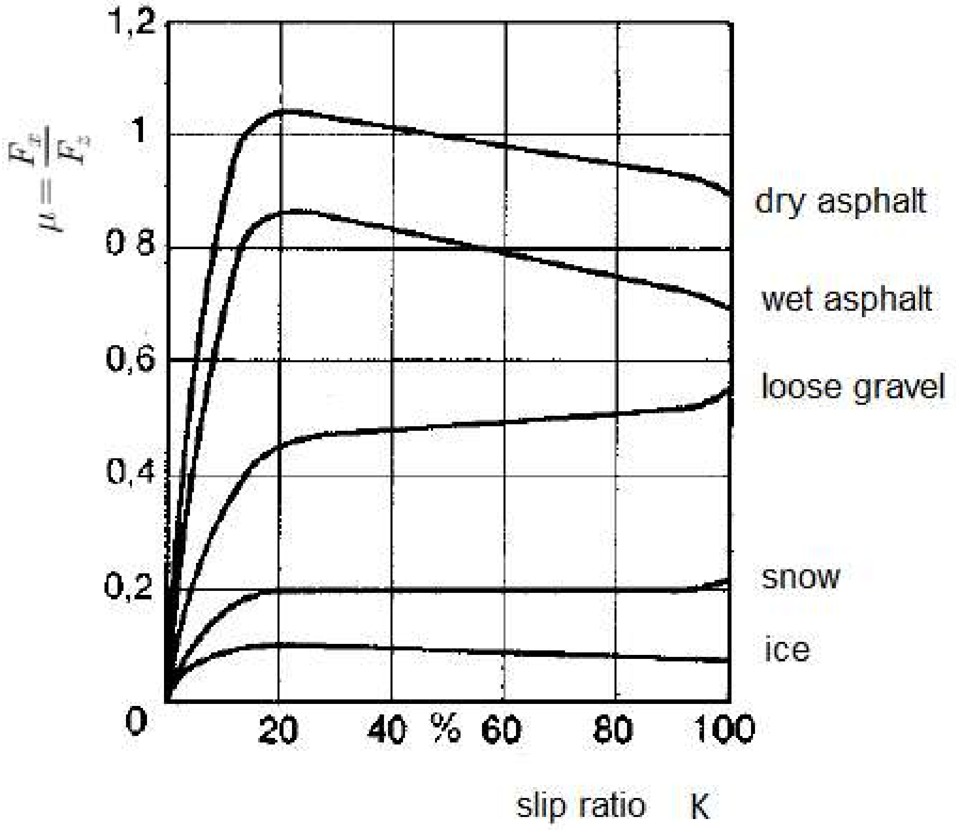


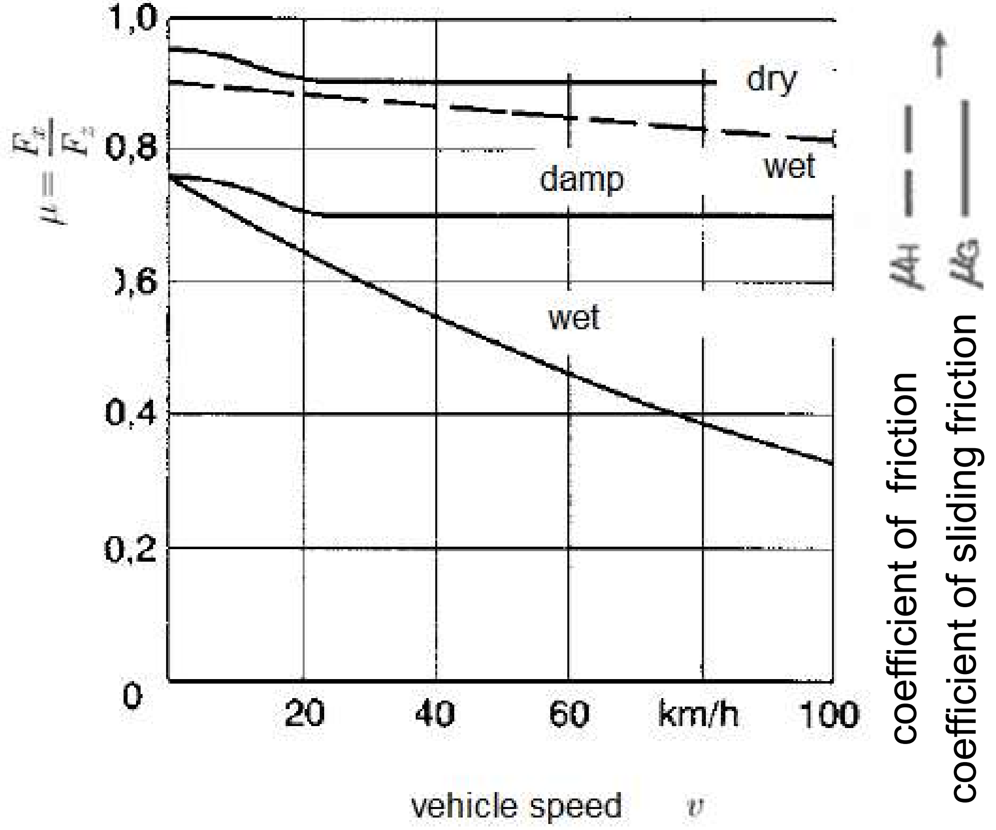
Degressive characteristics:

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

The more vehicle weight results less max. acceleration!

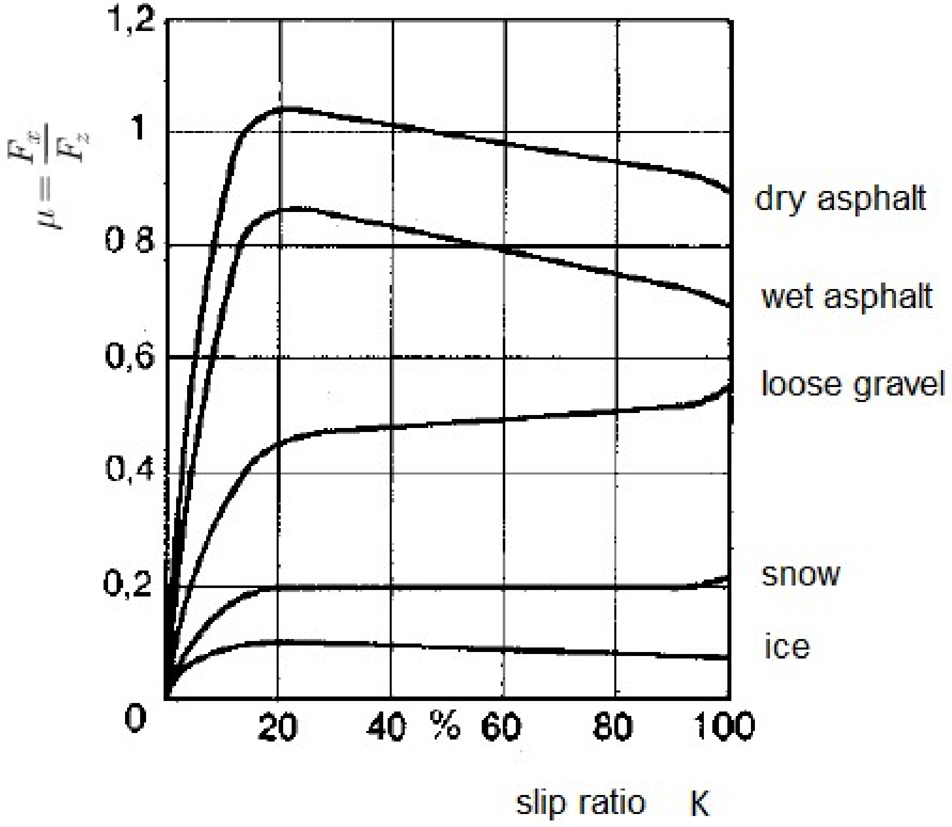
Friction coefficient μ_x





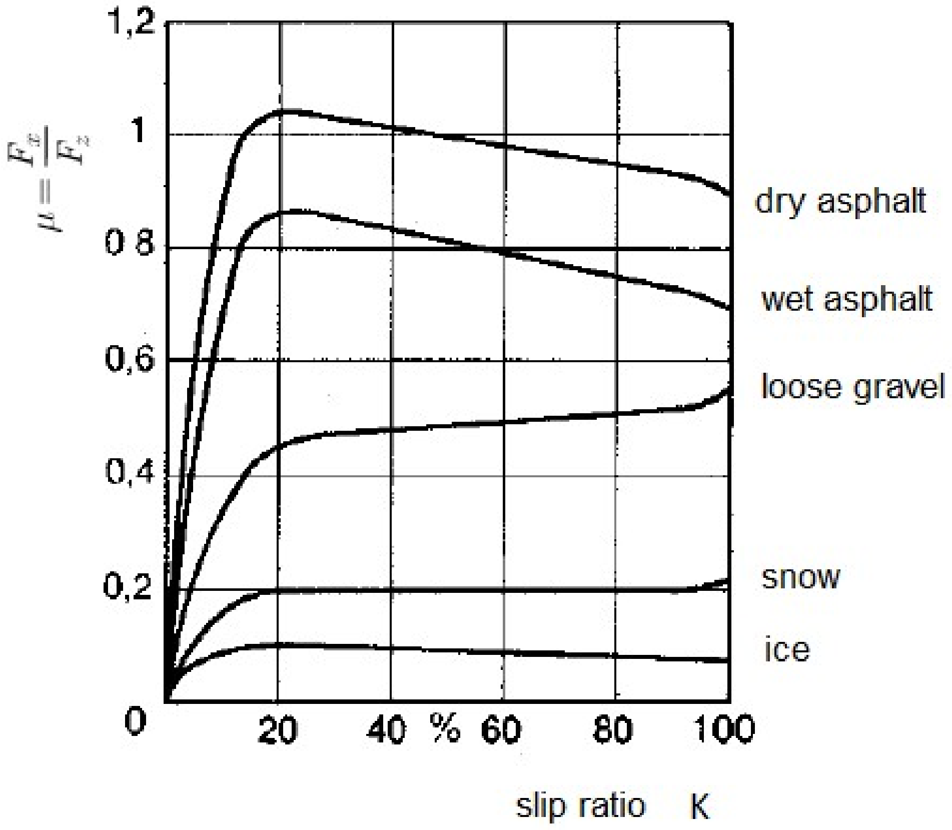
Source: Zomotor Ádám: Gépjármű menetdinamika, 2003

Friction coefficient μ_x



value of μ_x in F1?

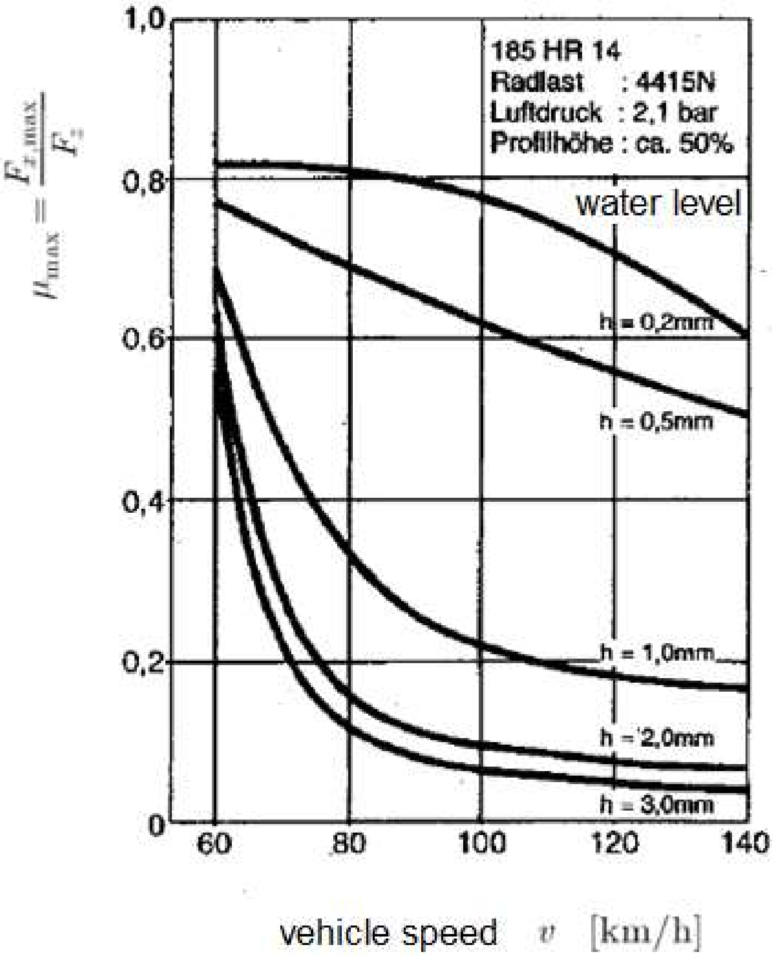
Friction coefficient μ_x

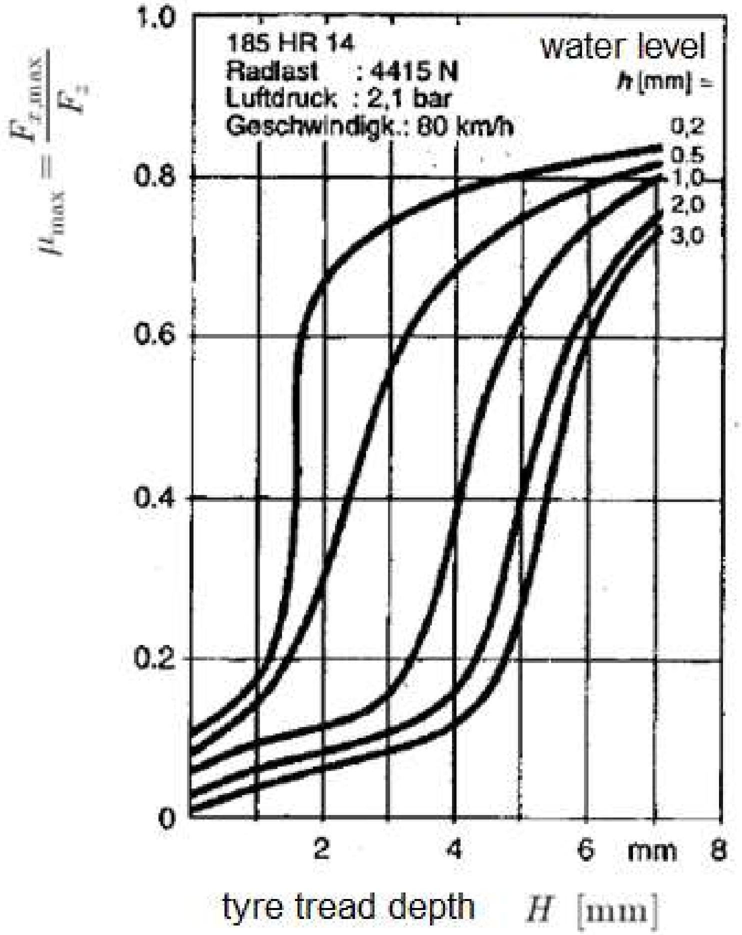


value of μ_x in F1?

1.5-1.7

Friction coefficient μ_x



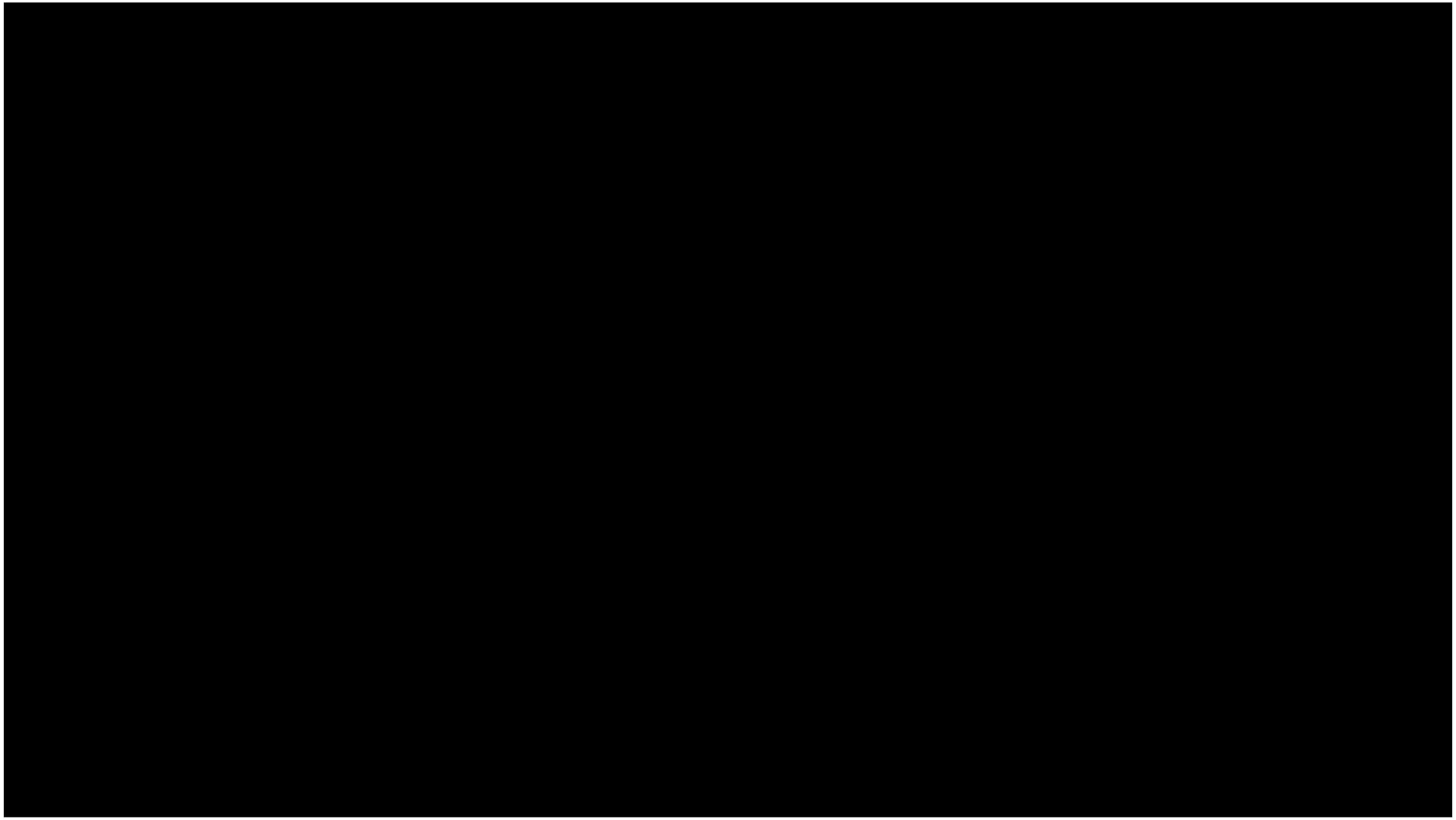


Quelle: Wallentowitz 1997

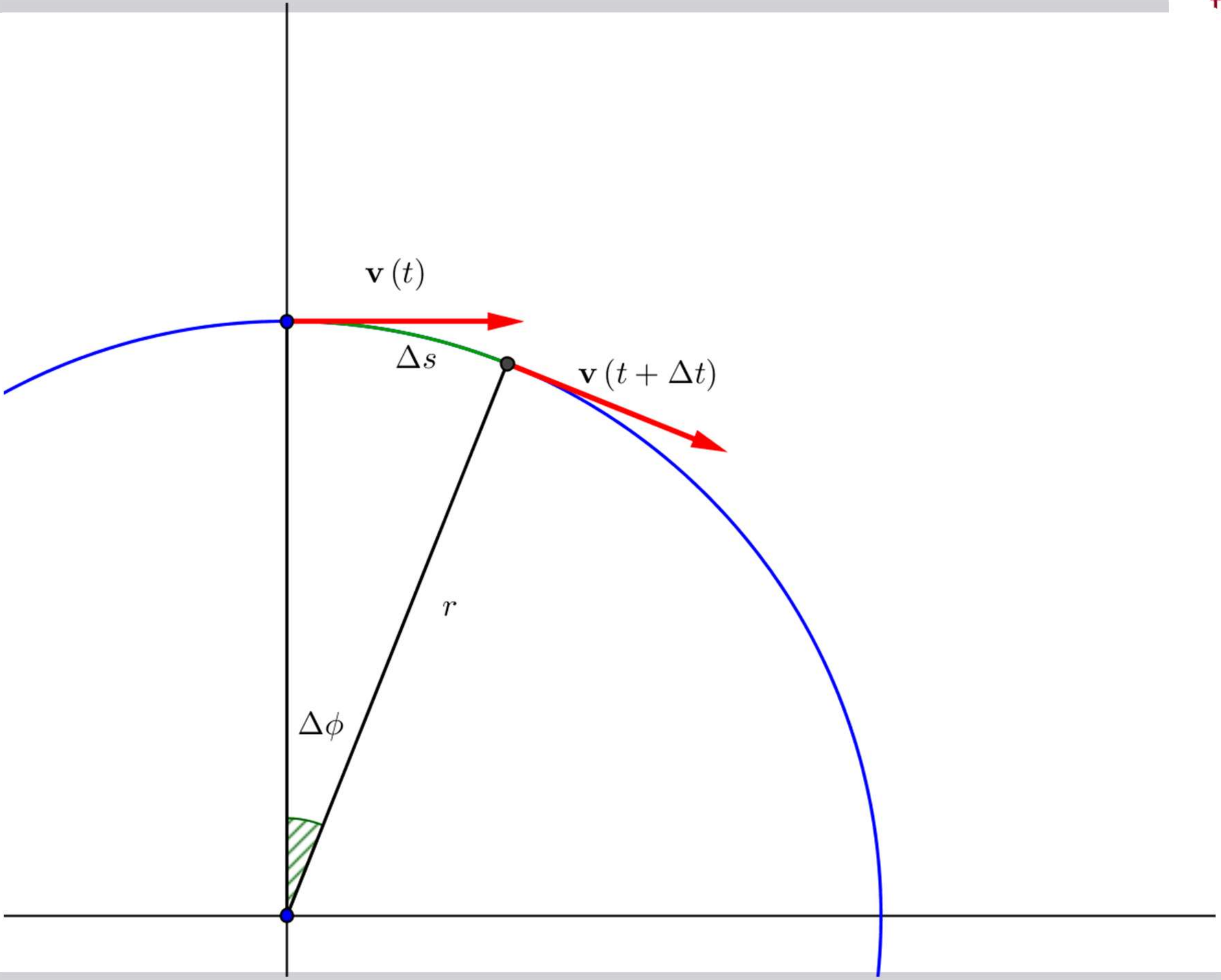
Tread depth

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

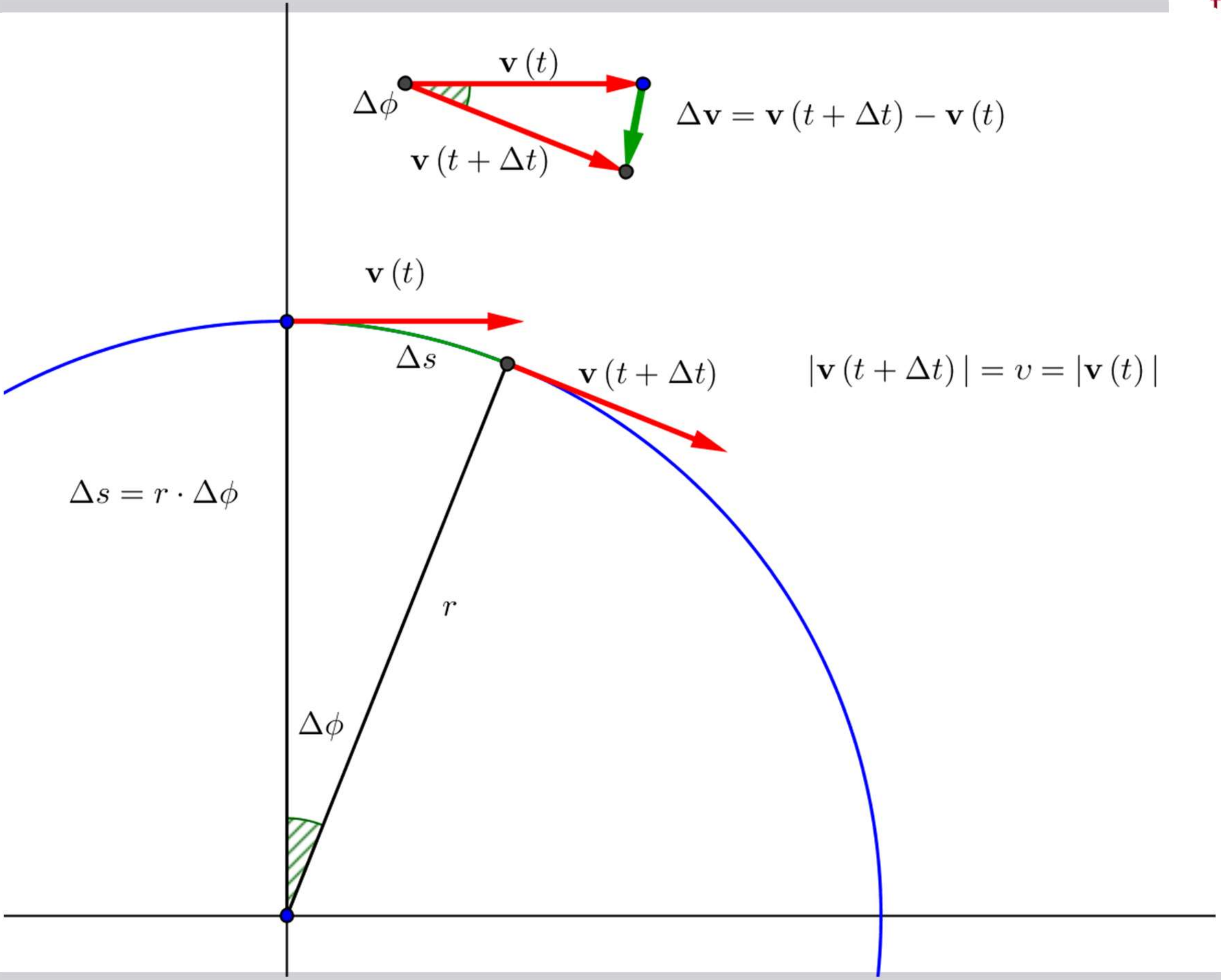
Day in the office – for tires



Lateral dynamics – steady state condition



Lateral dynamics - steady state condition

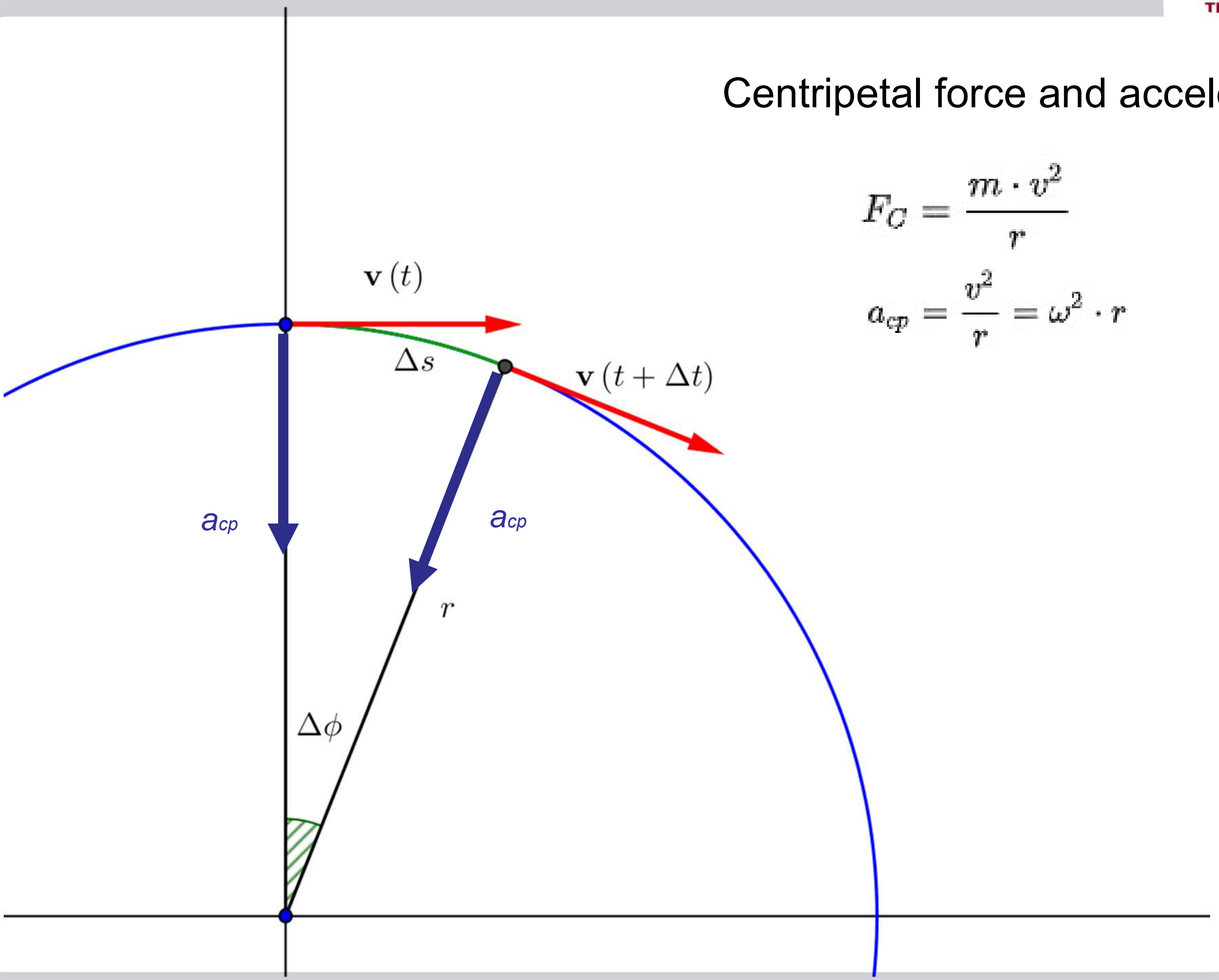


Lateral dynamics - steady state condition

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

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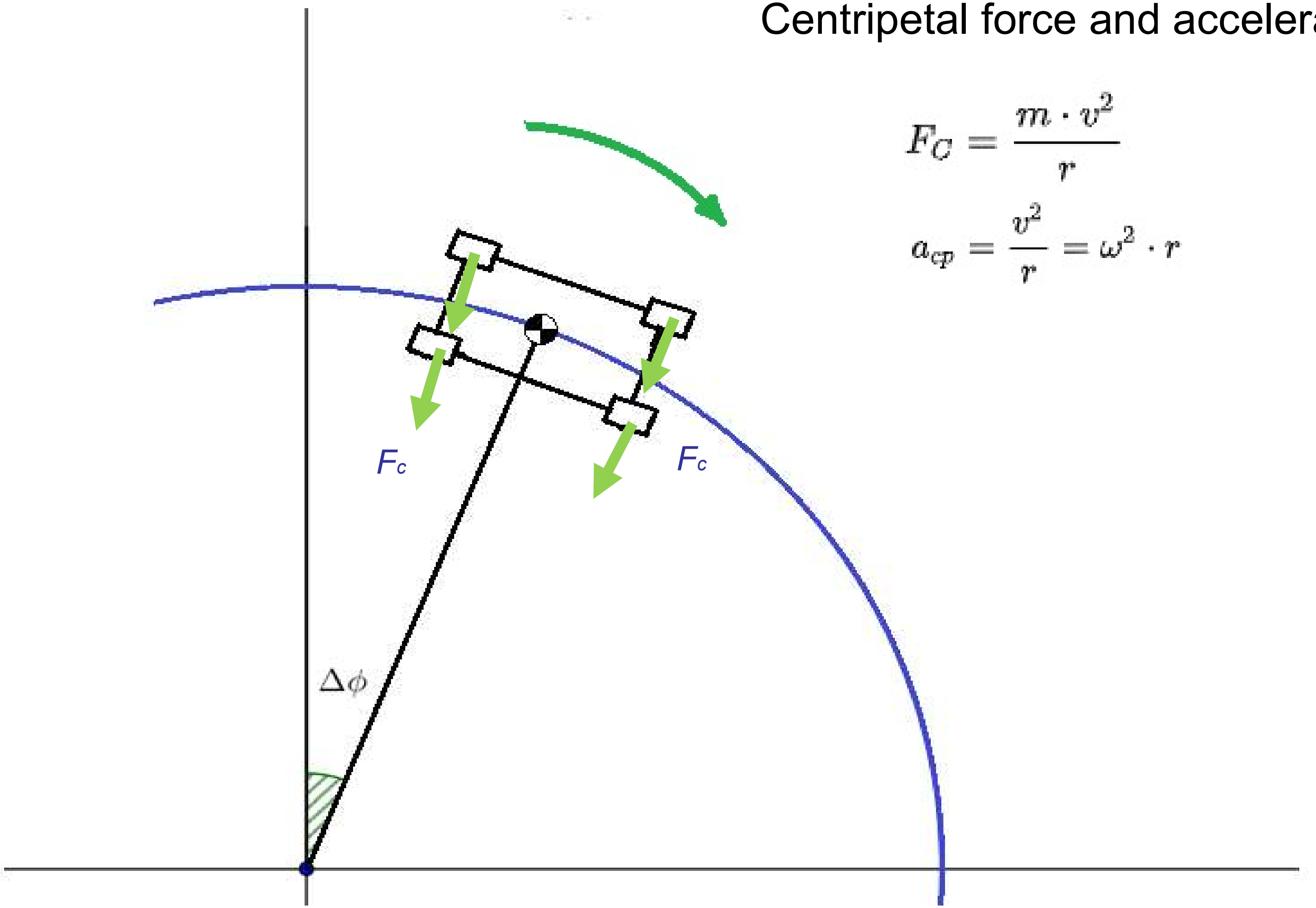
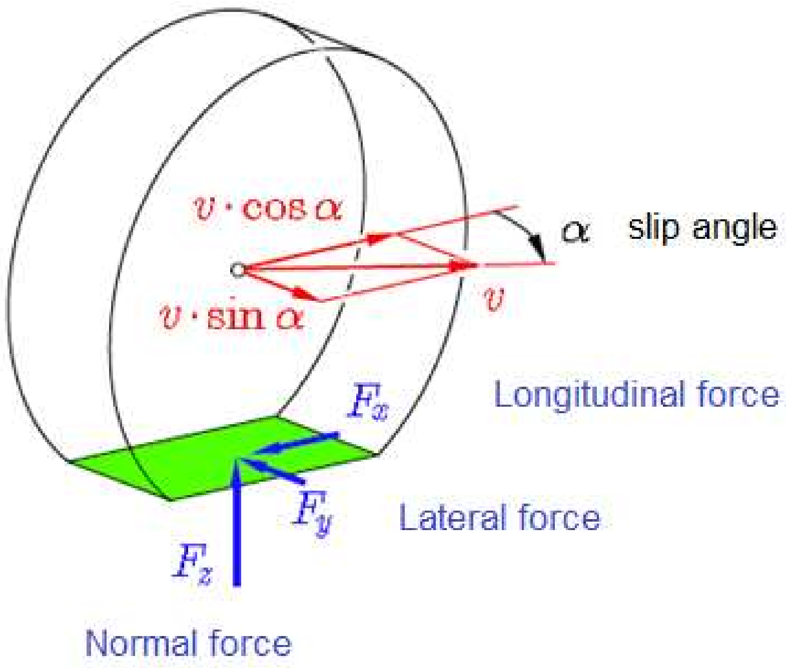


Centripetal force and acceleration

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

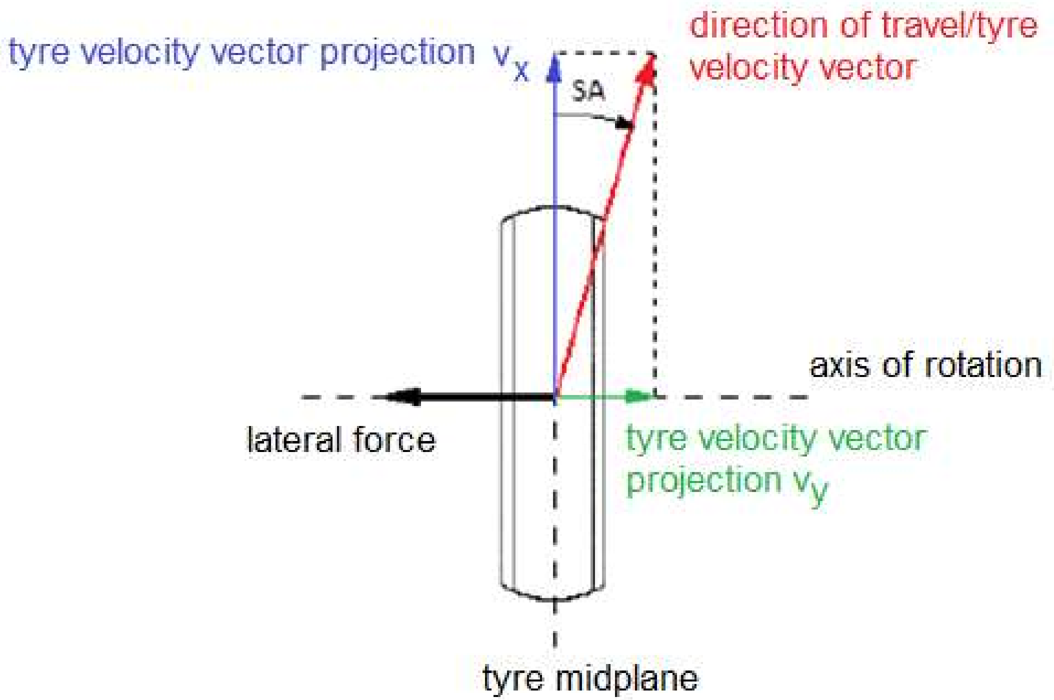
$$a_{cp} = \frac{v^2}{r} = \omega^2 \cdot r$$

Tyre forces, slip angle



α = SA=slip angle

Slip angle definition



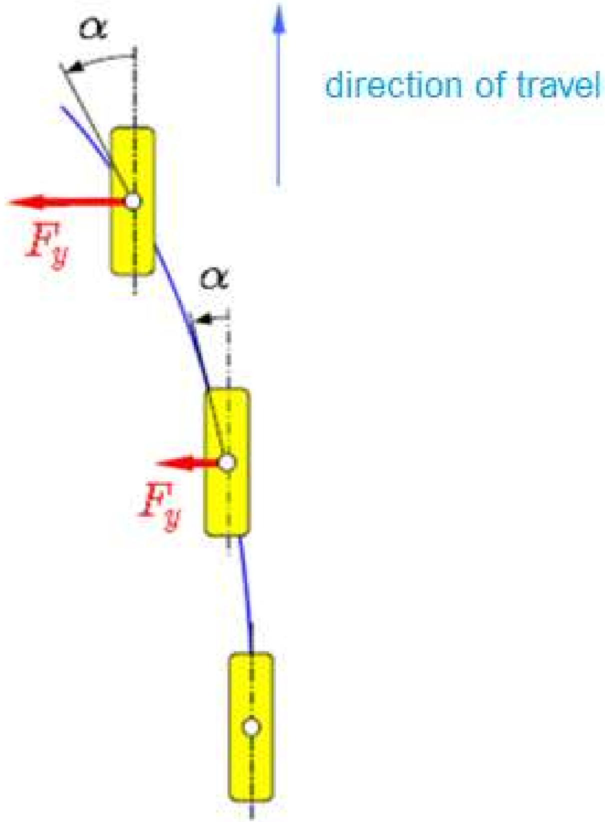
Slip angle defintion:

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

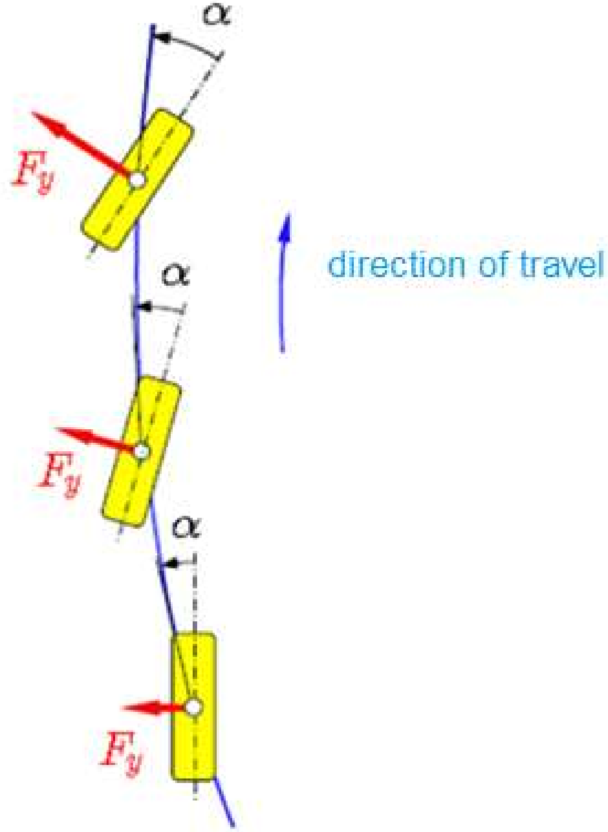
The angle between actual tyre velocity vector and the tyre midplane is the slip angle.

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

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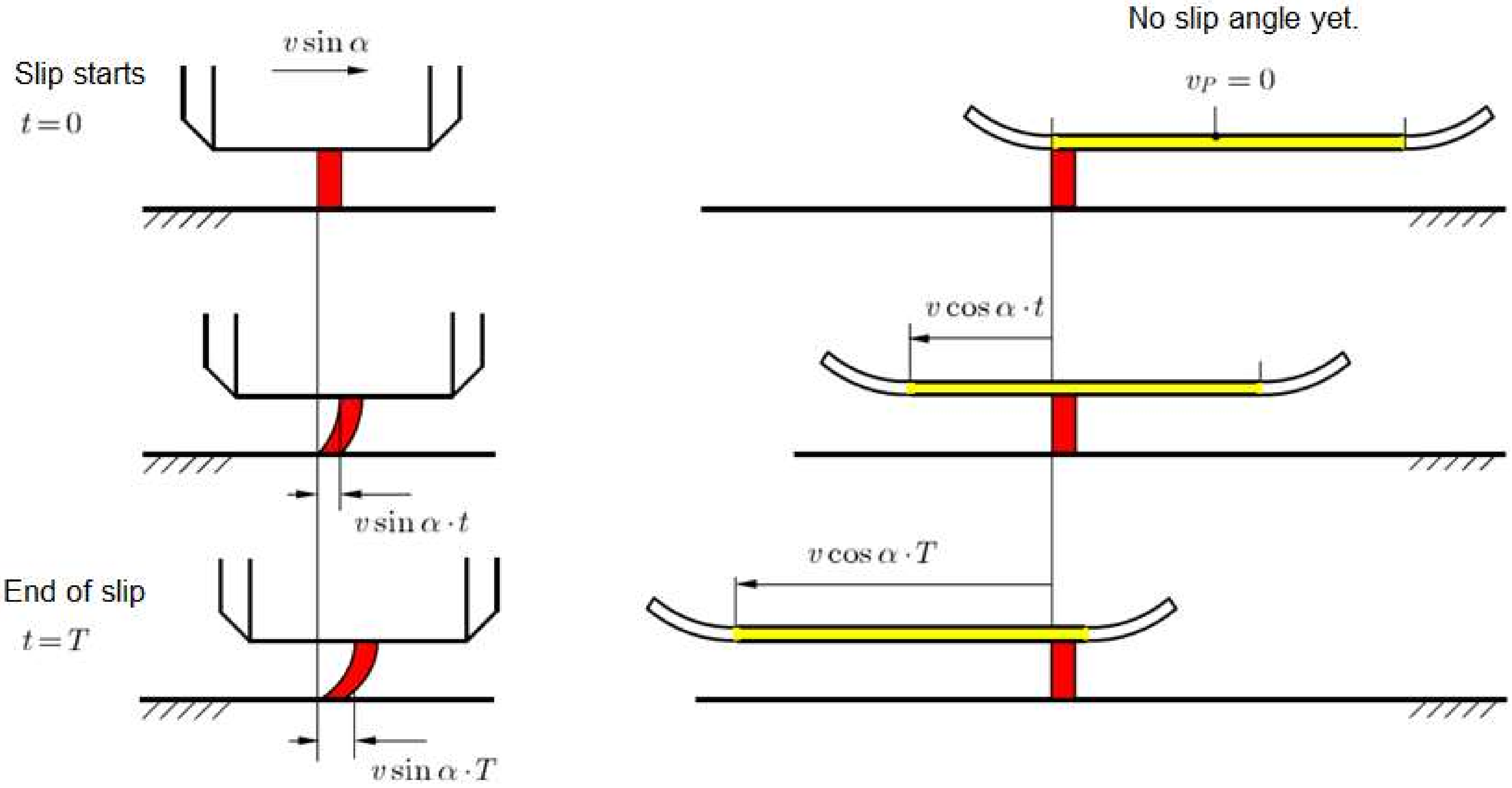
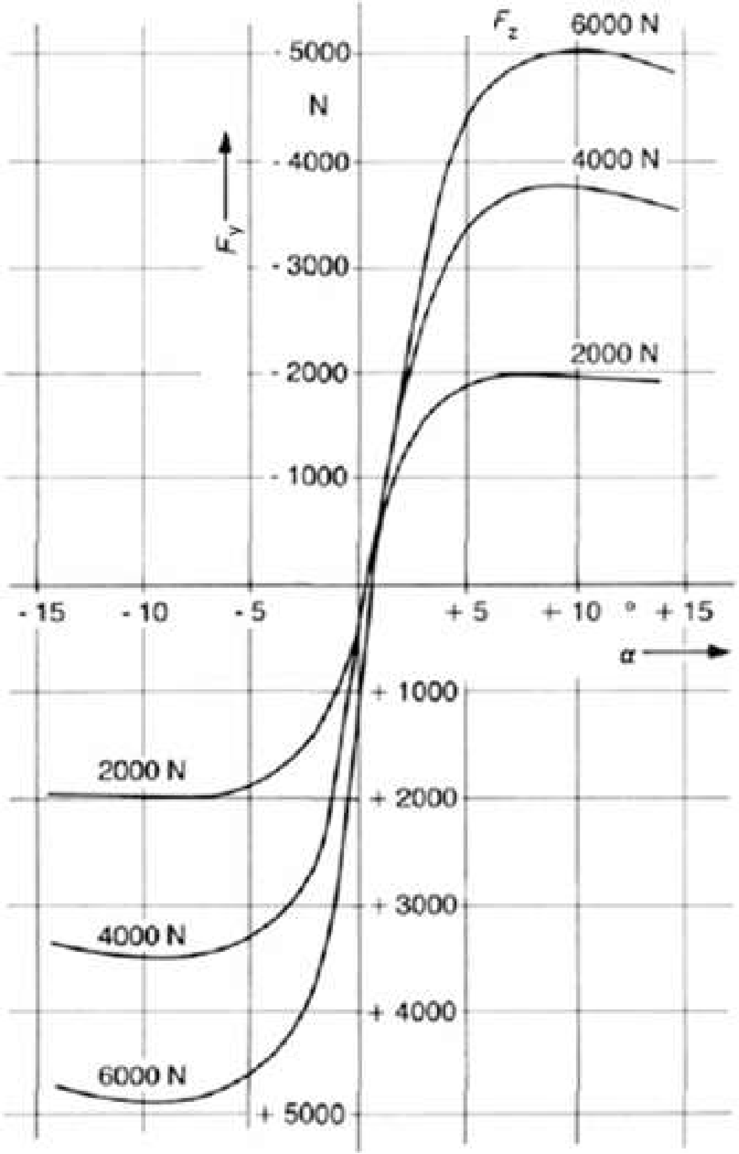


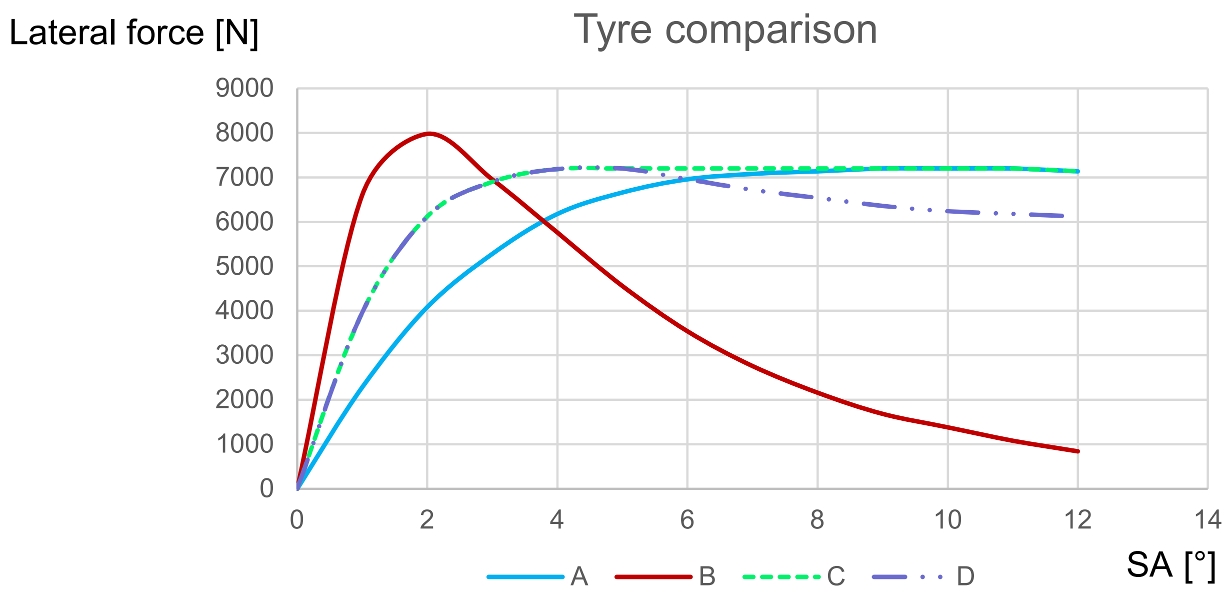
The deformation of one bristle.

Source: C. Woernle

Correlation of a tyre lateral force – SA



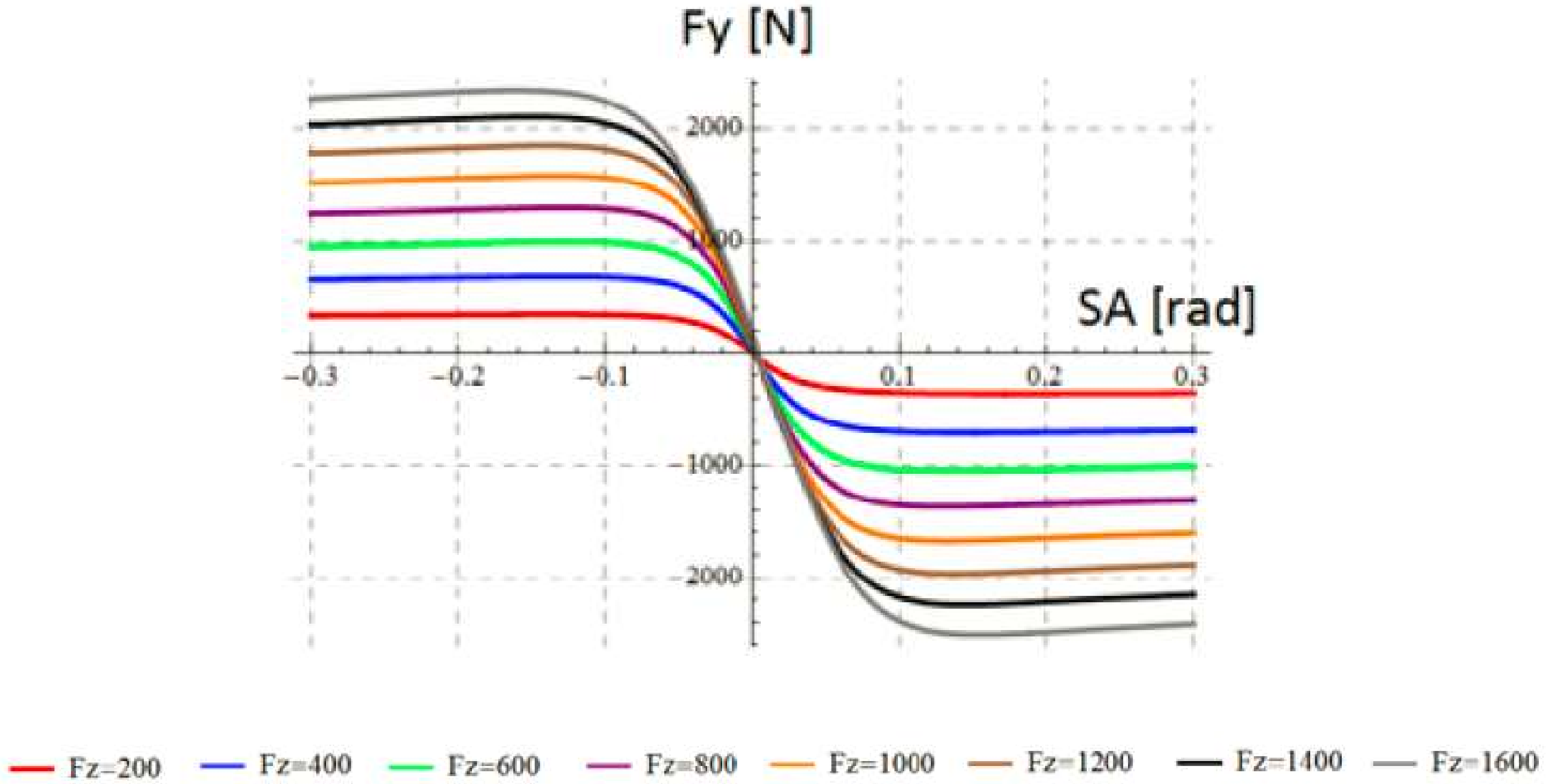
Different tyre charateristics – Fy - SA



	A	B *In theory the fastest*	C	D
reaction	slow	required good driver	difficult to drive	quick
feedback	good	best	minimum	less
energy loss	high	minimum	highest	less

Lateral force

What could the colours mean?

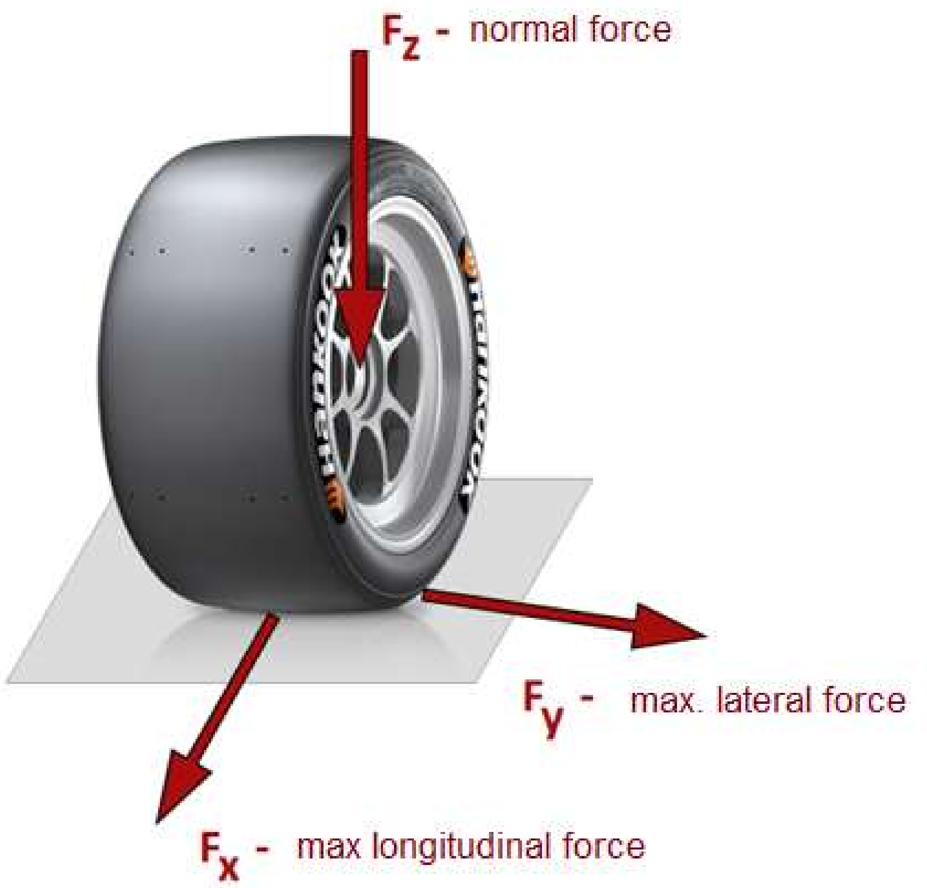


Friction coefficient μ_y

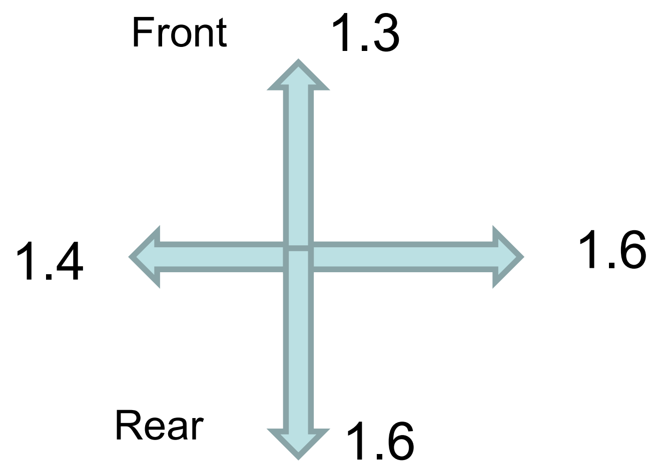
Friction coefficient definitions

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

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

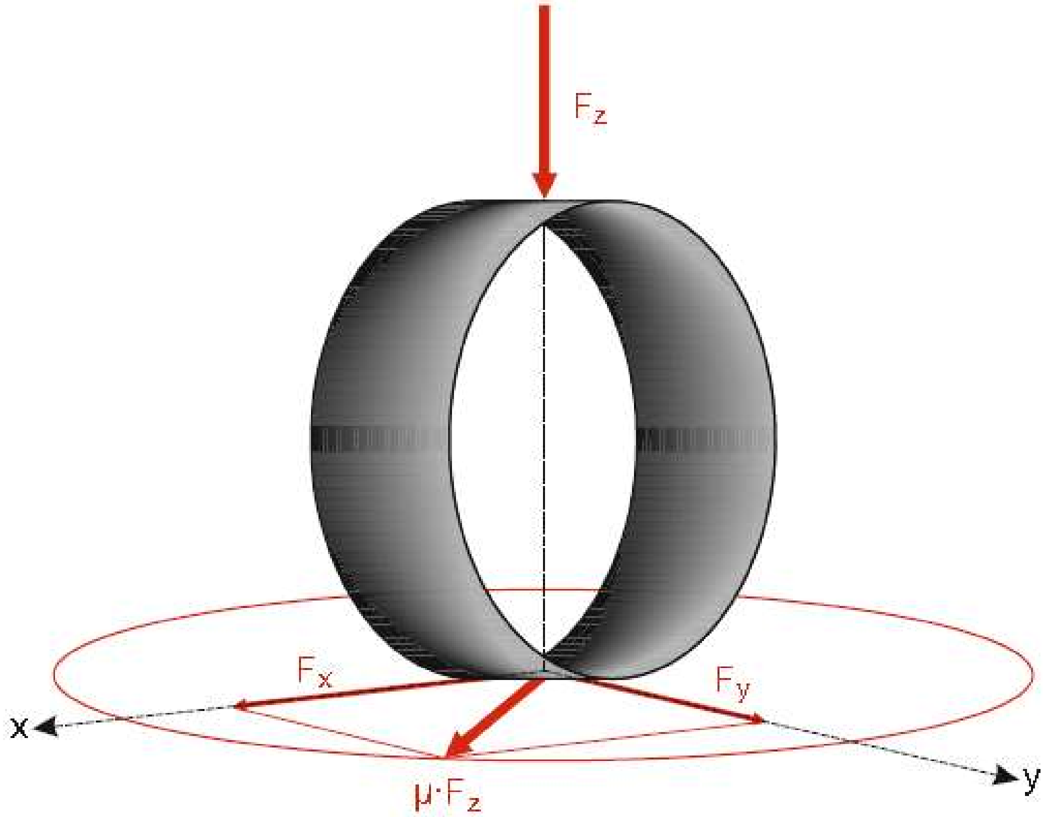


Different Friction Coefficient along Lateral and Longitudinal Axis



Kamm circle

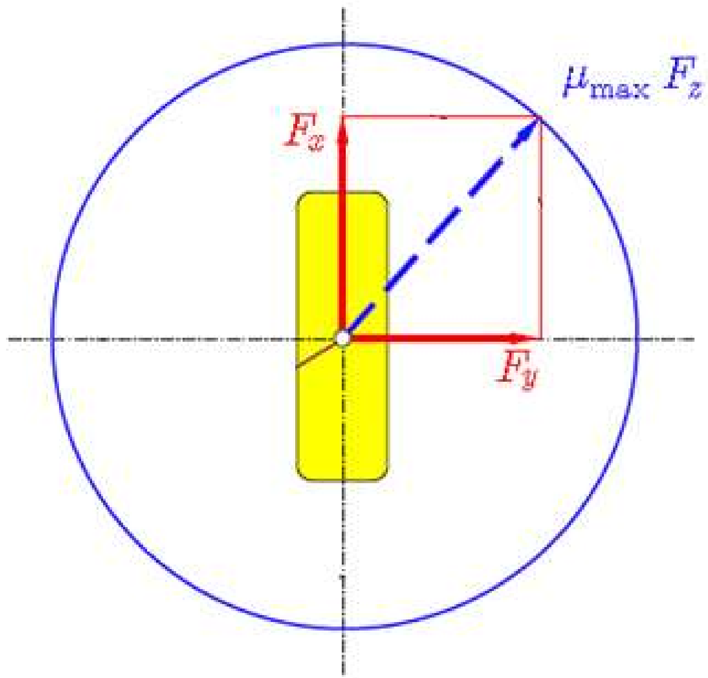
Circle of friction



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

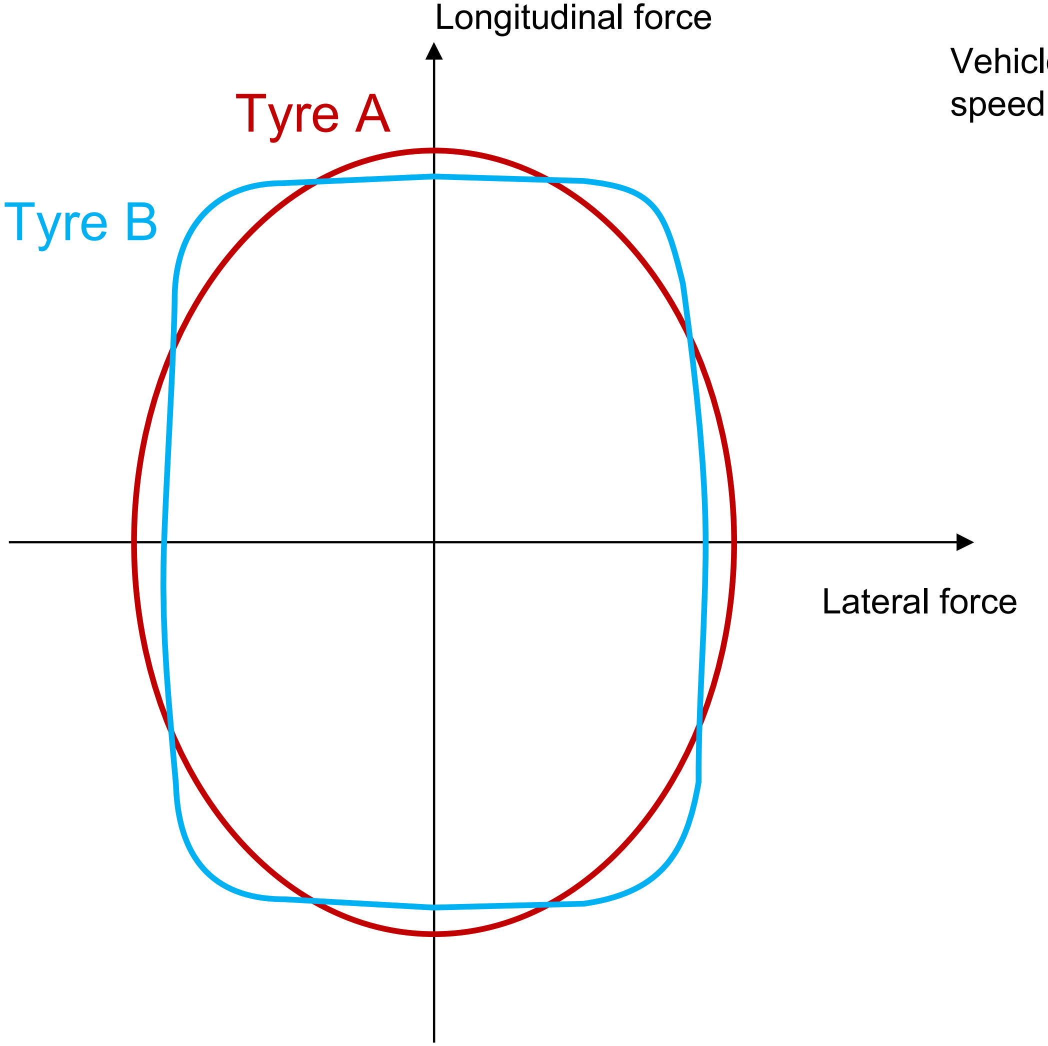
Kamm circle

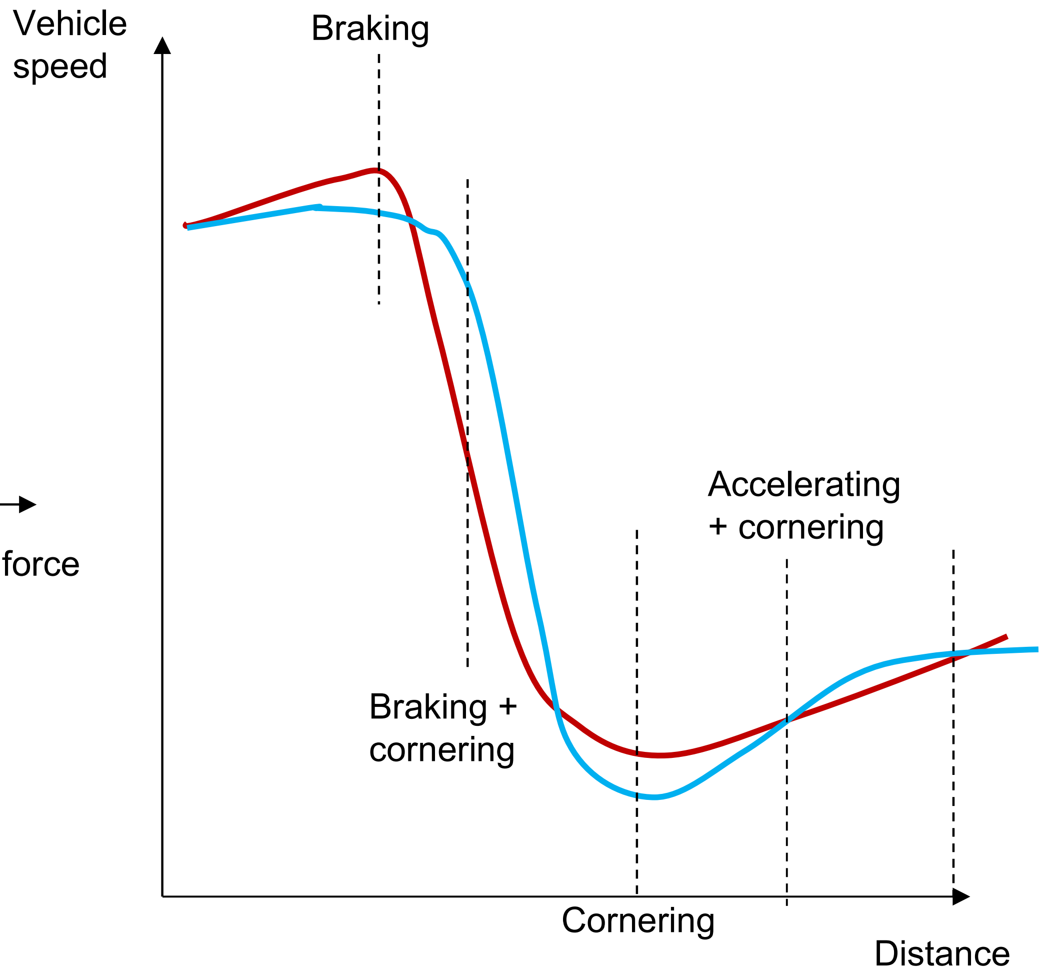
Circle of friction



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

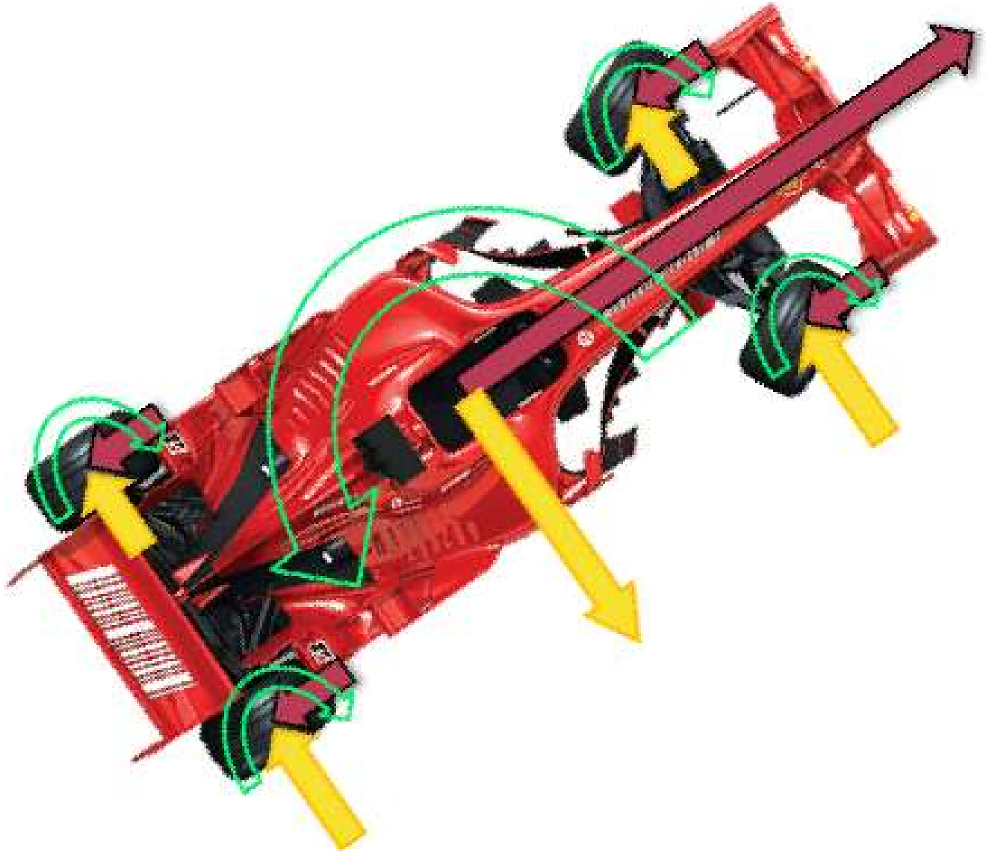
Different tires





Tyre forces

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

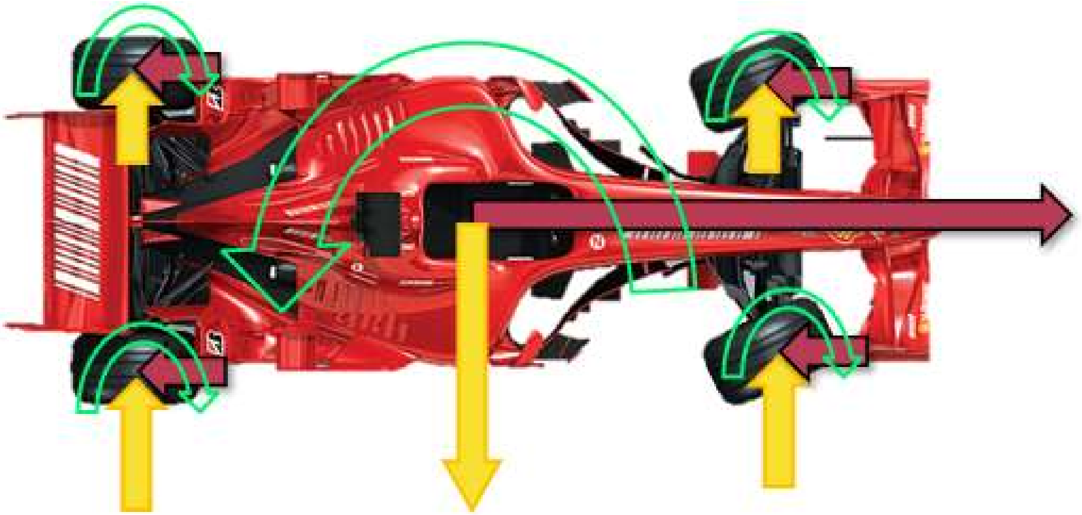


Tyre moments

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

Tyre forces and moments

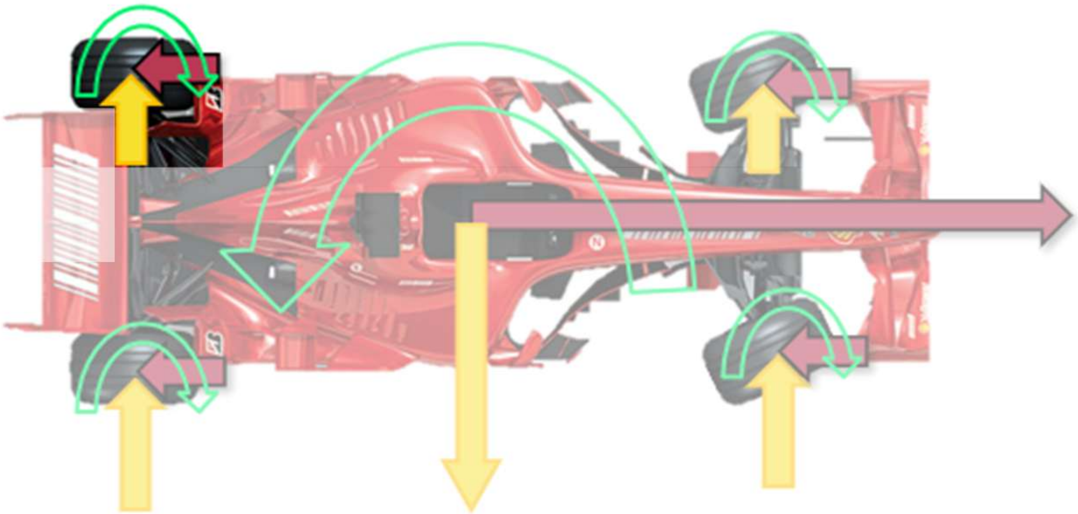
- Tyre forces and moments are function of tyre compound and structure, ground and …



- slip angle
- slip ratio
- vertical load
- inclination angle
- speed
- pressure
- temperature
- rim design
- tyre wear…

Source of yaw moment

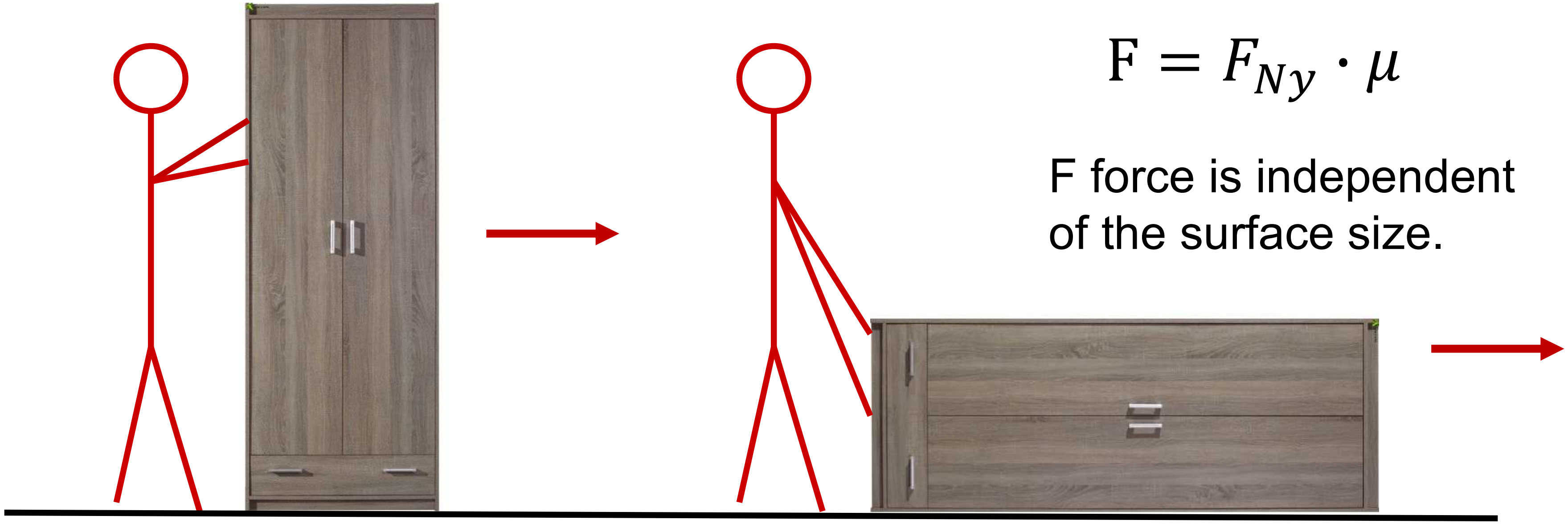
- F_x, F_y and M_z



Why slick?

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

F force is independent of the surface size.



?

Lateral force and cornering stiffness

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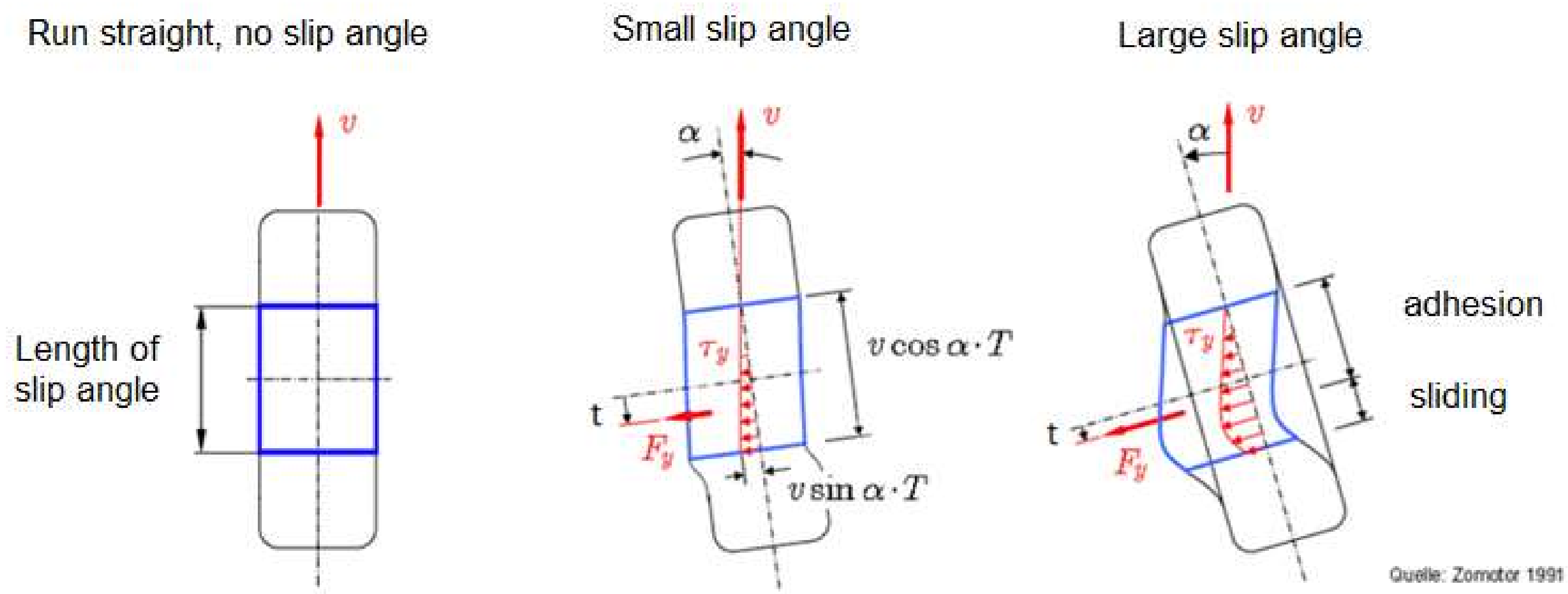
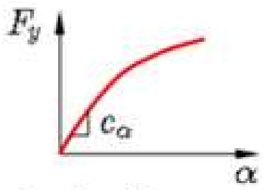


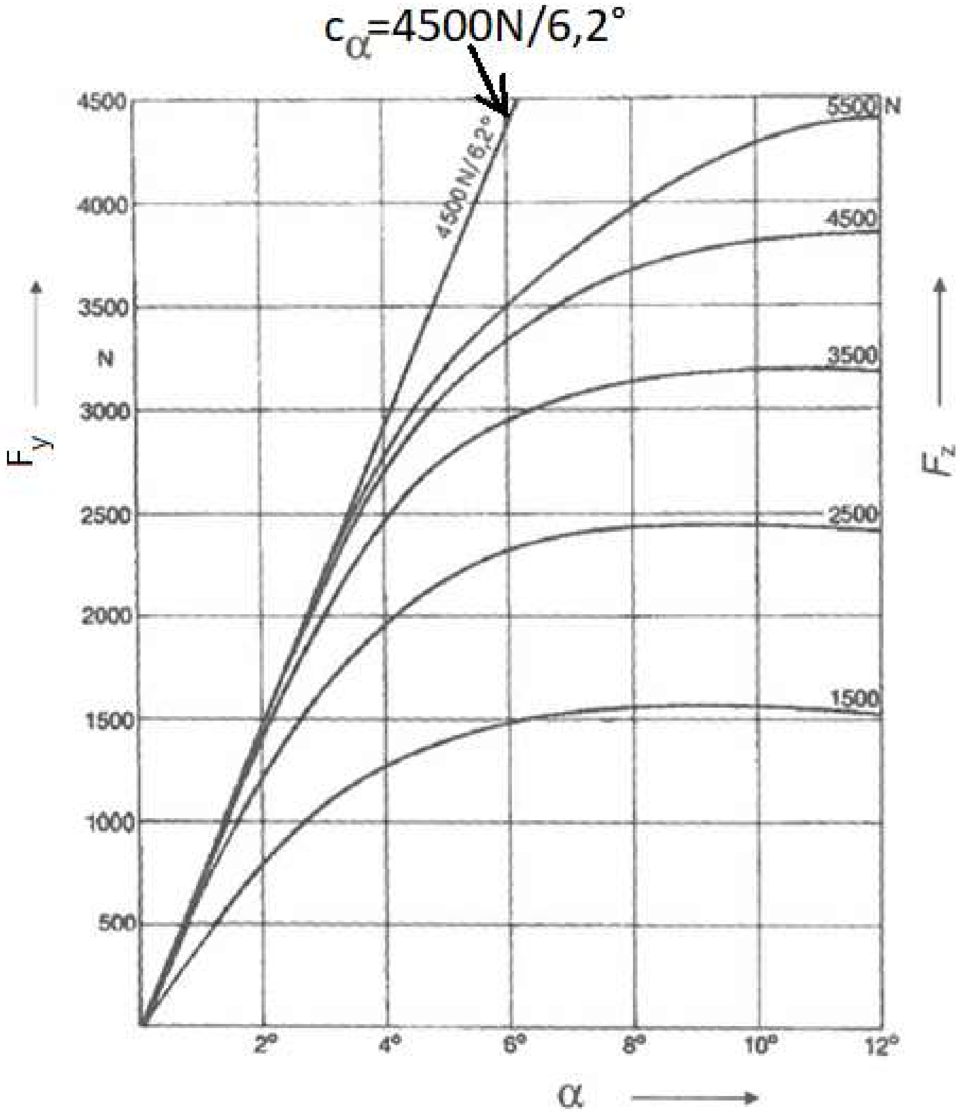
lateral force ~ area below the $\tau_y(x)$ curve

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



cornering stiffness c_α [N/rad]

Lateral force and cornering stiffness



Tyre: 175 HR 14

pressue: 2.3 bar

cornering stiffness: $C_\alpha = 41586\ \mathrm{N/rad}$

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

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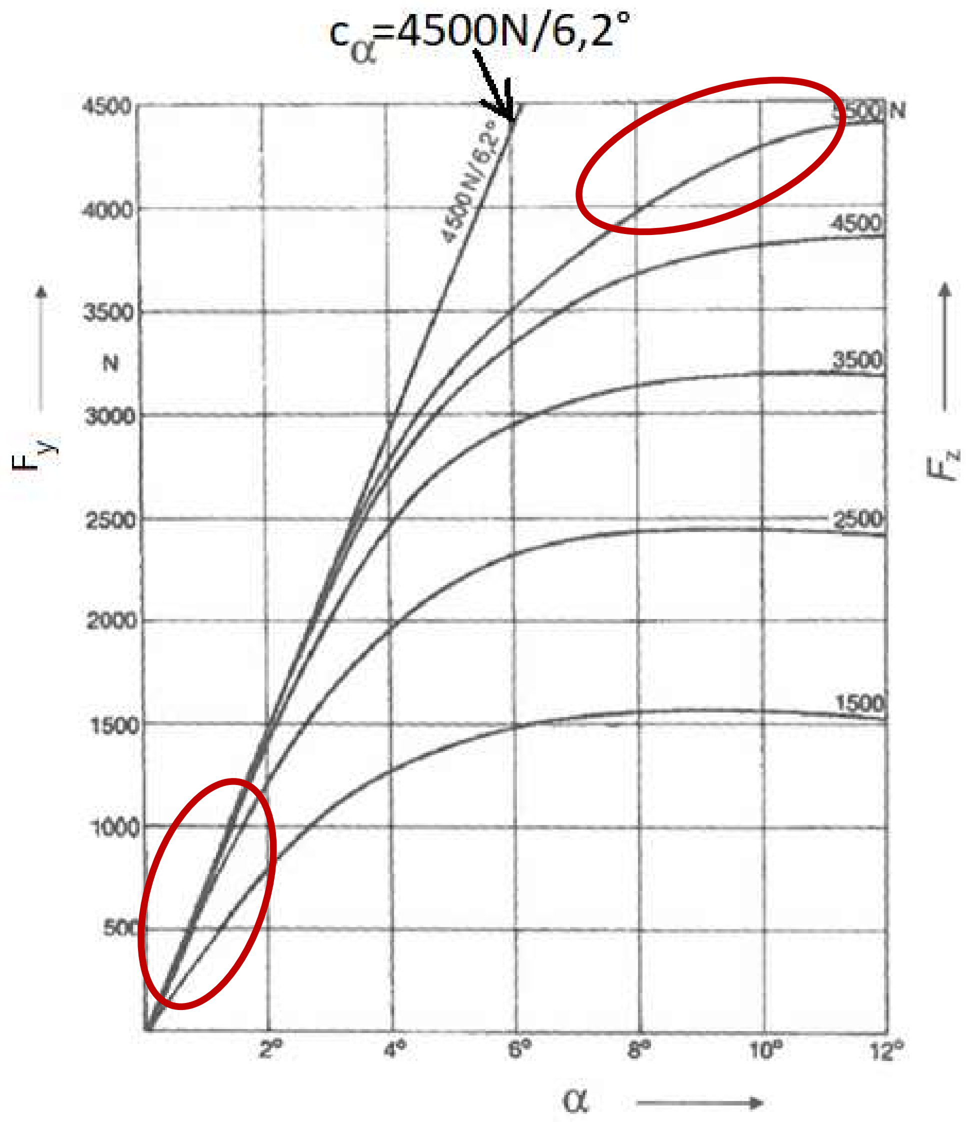
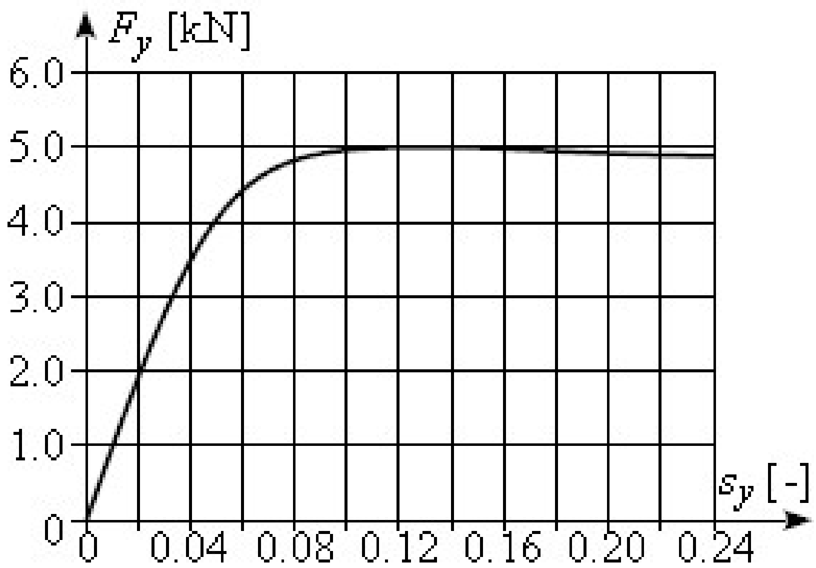


$$m \cdot a_y = F_{y,F}(\alpha) + F_{y,R}(\alpha)$$

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

- 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

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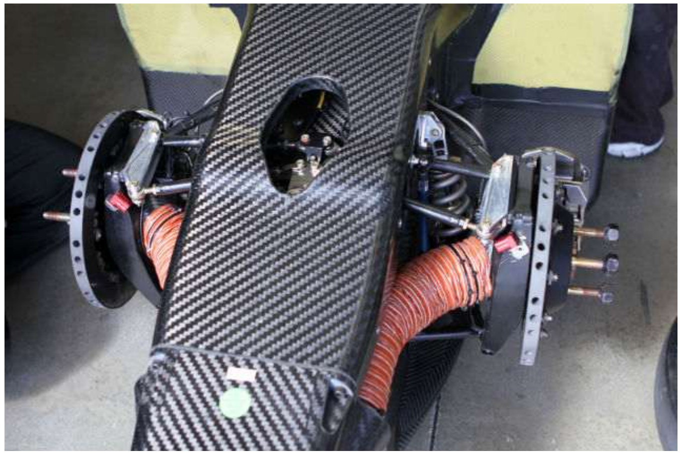
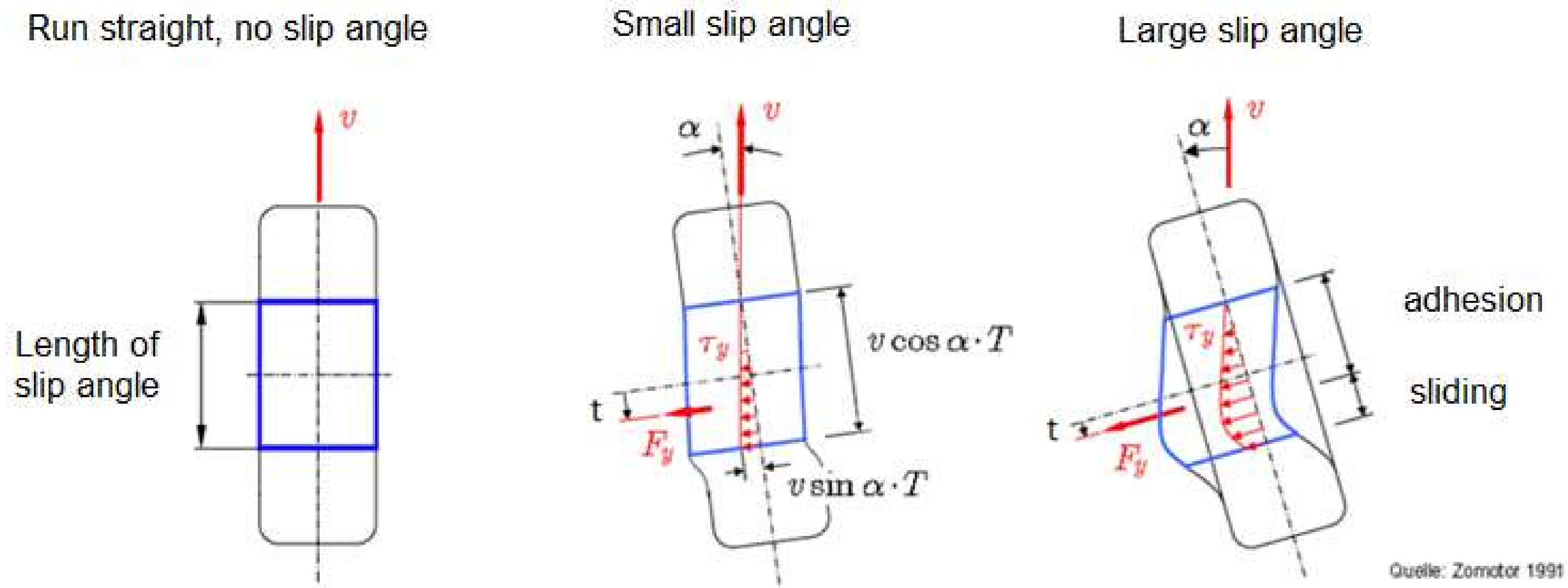
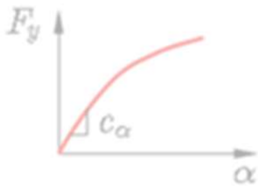
- Cornering stiffness scales roughly linearly with tyre width
- Guessing WD of a particular car if you look at the relative tyre width front to rear
- Good example: Deltawing sportscar
  - 4 inch wide front tyres
  - If far enough from CoG, reasonable yaw moment if can be generated





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

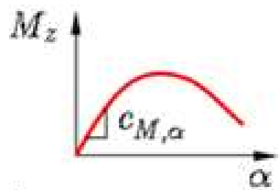
$$F_y = c_\alpha \sin\alpha \cdot \cos\alpha \approx c_\alpha\, \alpha$$



cornering stiffness c_α [N/rad]

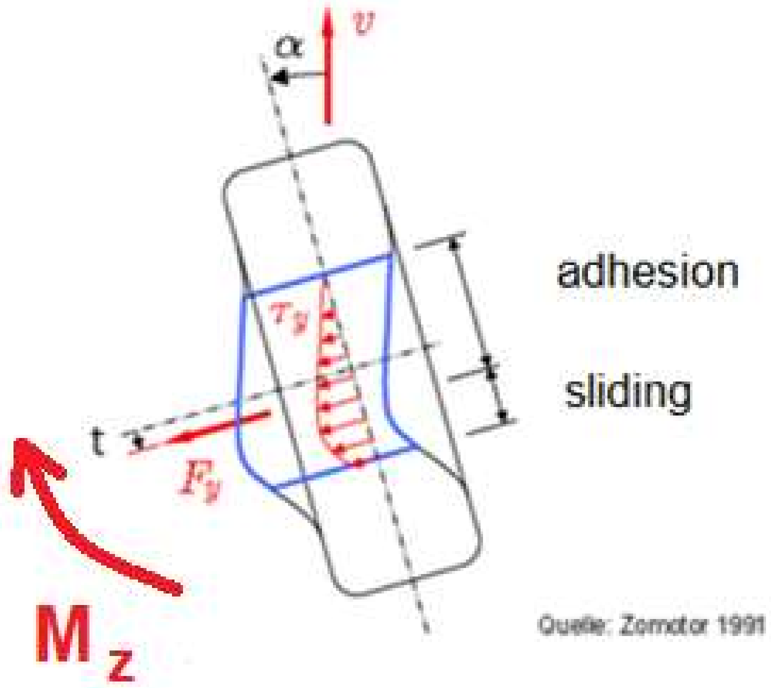
self aligning torque

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



pneumatic trail t [m]

Self aligning torque



Q & A

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- Main objective?
- Starting point - ending point?
- Complex parts?
- Less relevant part(s), could be omitted part(s)?
- Most useful part(s)?
- How could today’s material have contributed to your professional goals?

Bibliography

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- 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
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Thank you for your attention!

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