Department of Automotive Technologies –

Vehicle Mechanics Fundamentals

Gábor Sipos

BME
DEPARTMENT OF AUTOMOTIVE TECHNOLOGIES

Lecture 4

Schedule

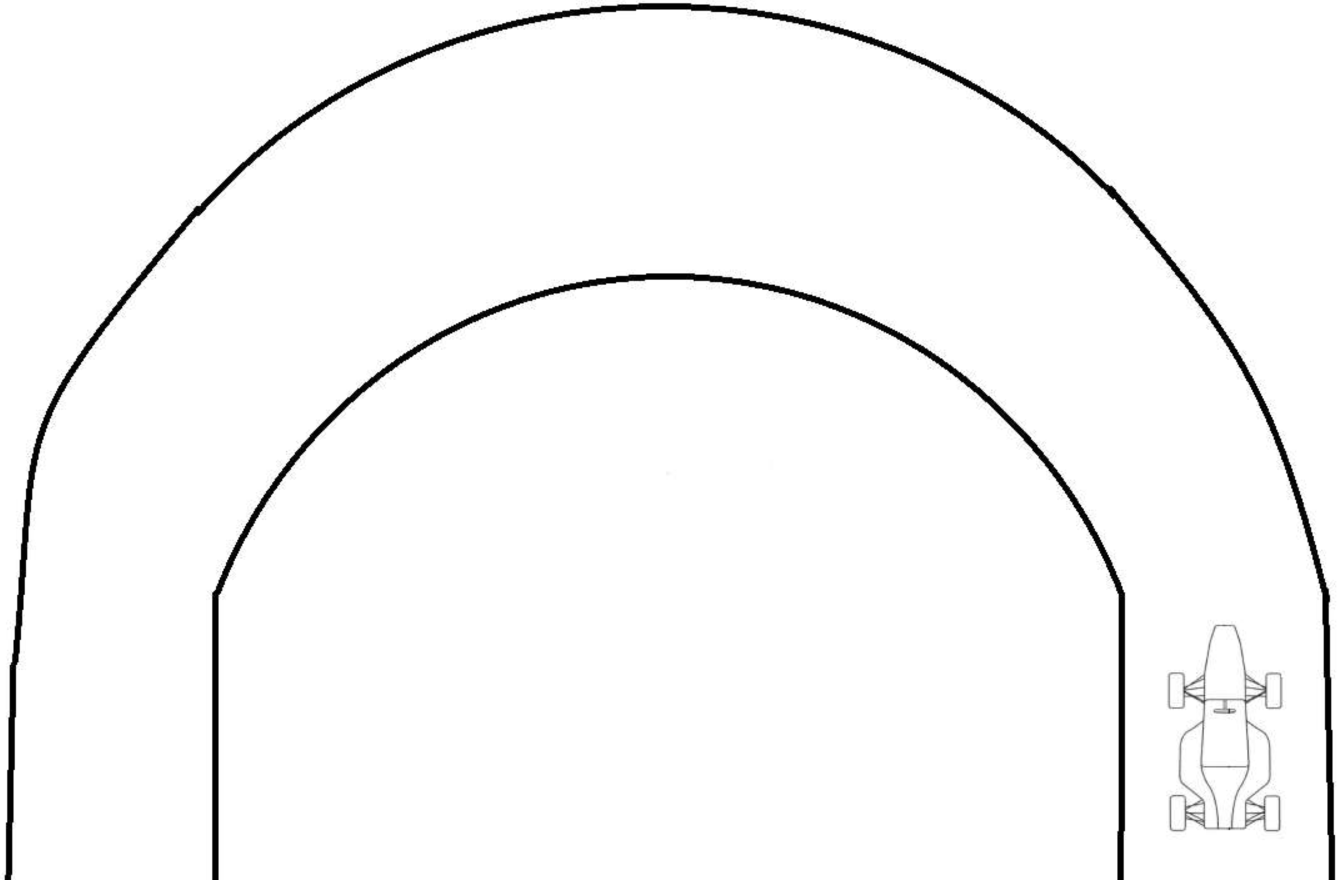
Week nr.	Date	Lecture (Wednesday)			Lab (Wednesday)		
1	12th Feb	1	General information, Tyre, Driving force		1	Lab	
2	19th Feb	2	Longitudinal and lateral behaviour				
3	26th Feb	3	Concepts and over/understeer		2	Lab	
4	5th Mar	4	Weight transfer				
5	12th Mar	5	Bicycle model		3	Lab	
6	19th Mar	T1	Midterm 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				

Content

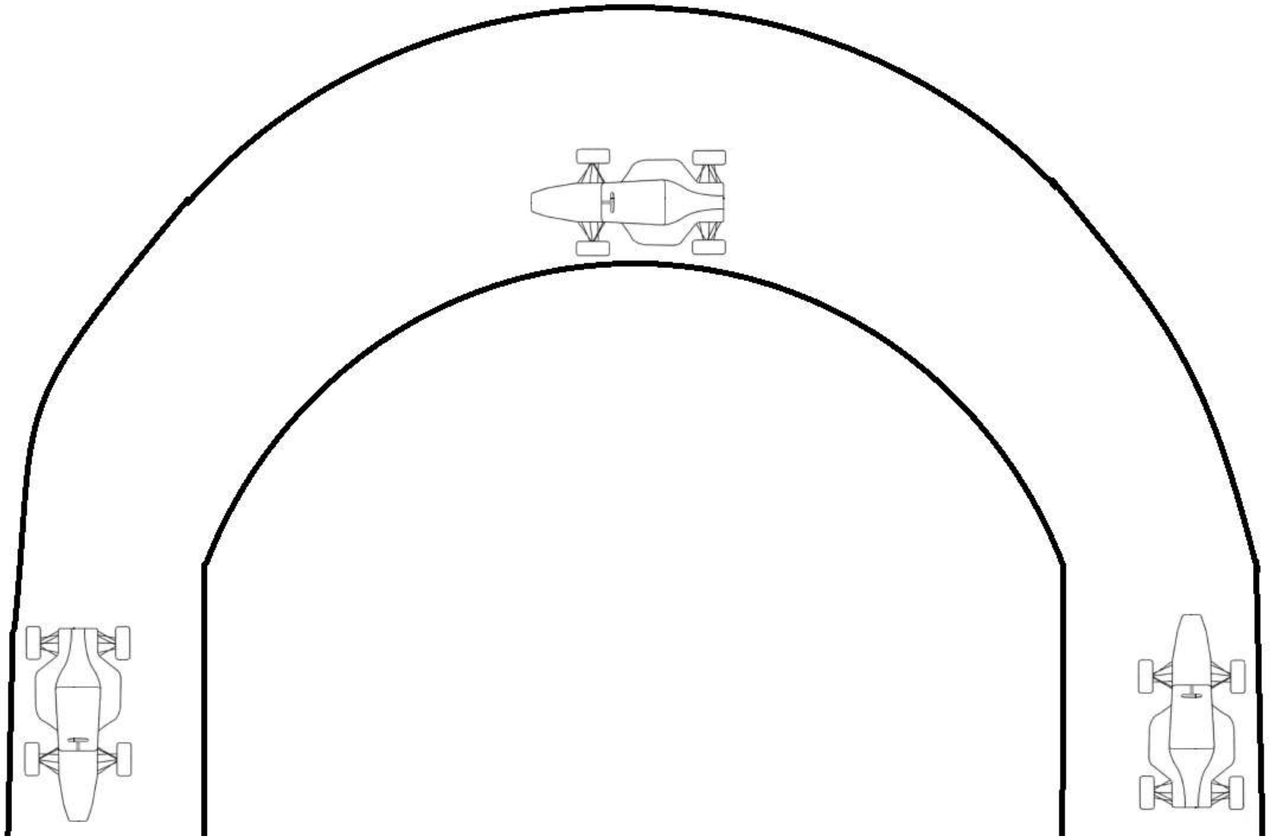
Longitudinal and lateral behaviour

- Cornering with different tyres
- GG diagram
- Vertical load and longitudinal weight transfer
- Lateral weight transfer
- OS/US behaviour

Cornering with different tires



Cornering with different tires



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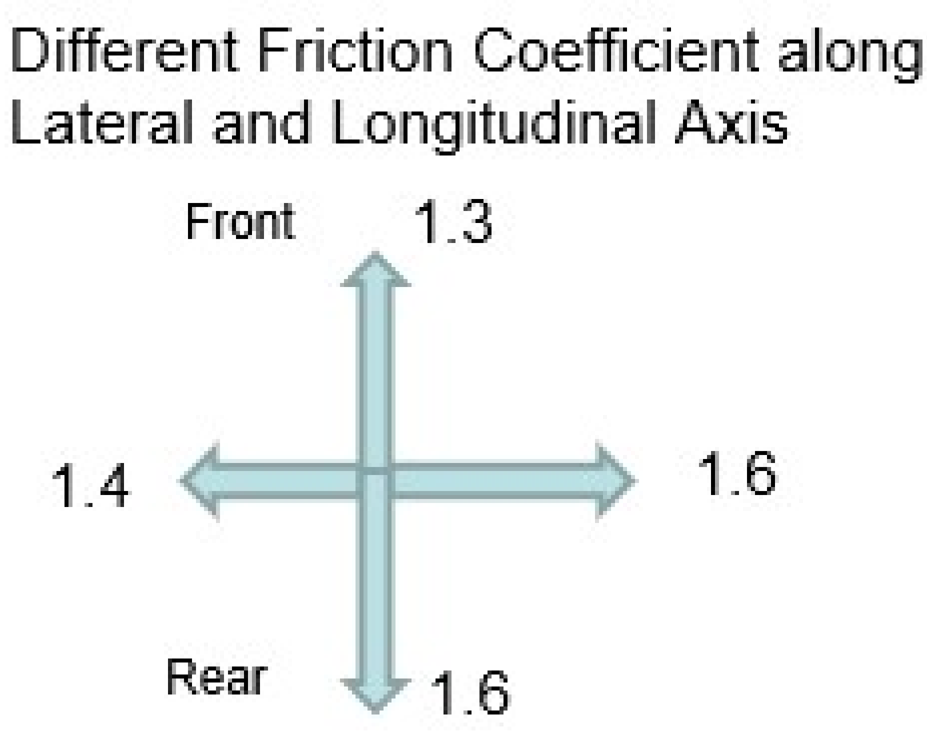

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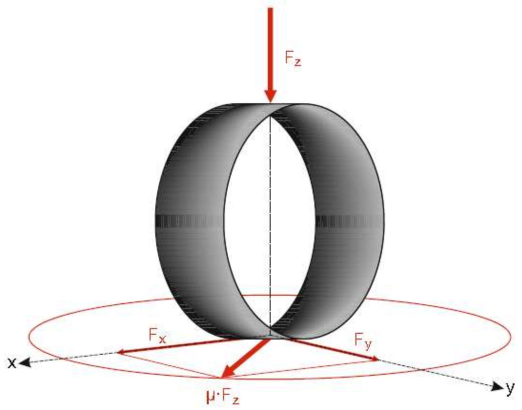
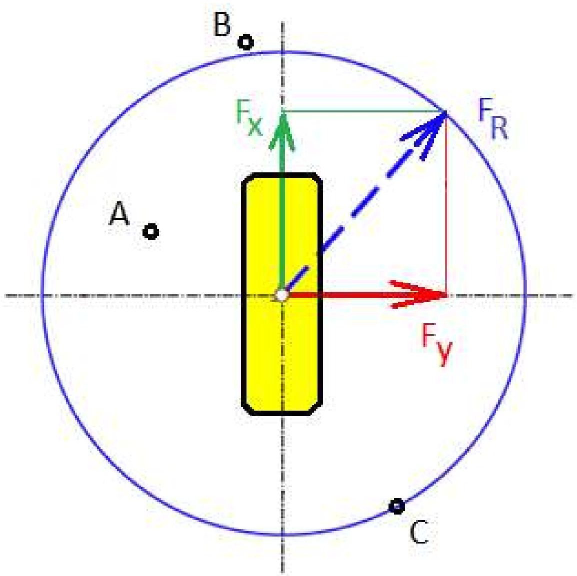
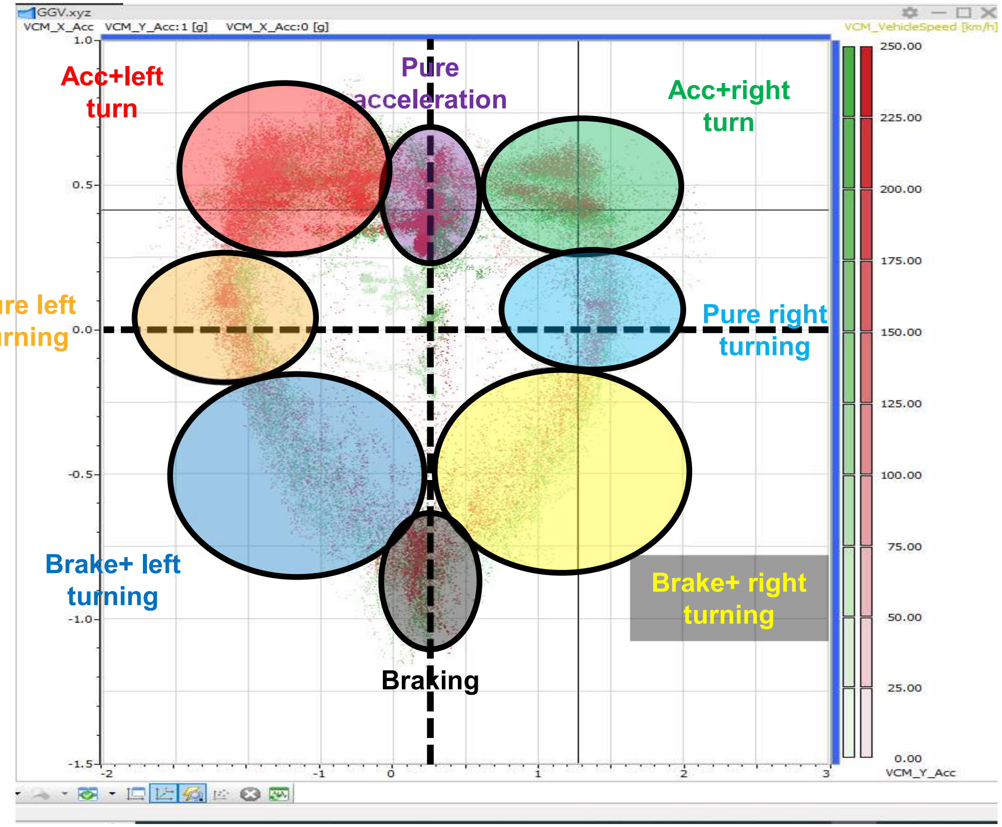




$$F_R = \mu_{max} F_z \geq \sqrt{F_x^2 + F_y^2}$$

- F_x: longitudinal force; F_y: lateral force; F_z: normal force; F_R: resultant horizontal force;
- To which places can resultant horizontal force point?
  - A
  - B
  - C
- The tyre is able to accelerate and corner at the same time. How much of the different components can it use?

GG diagram



** Zero lat axis sensor calibration issue corr*

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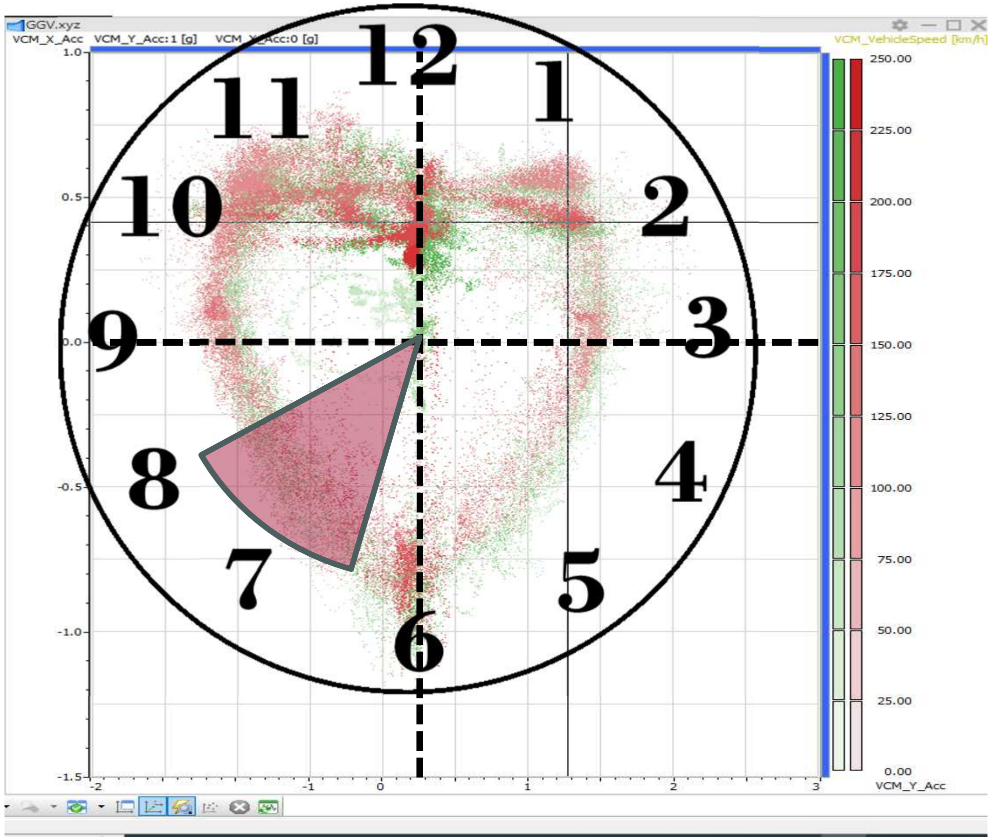
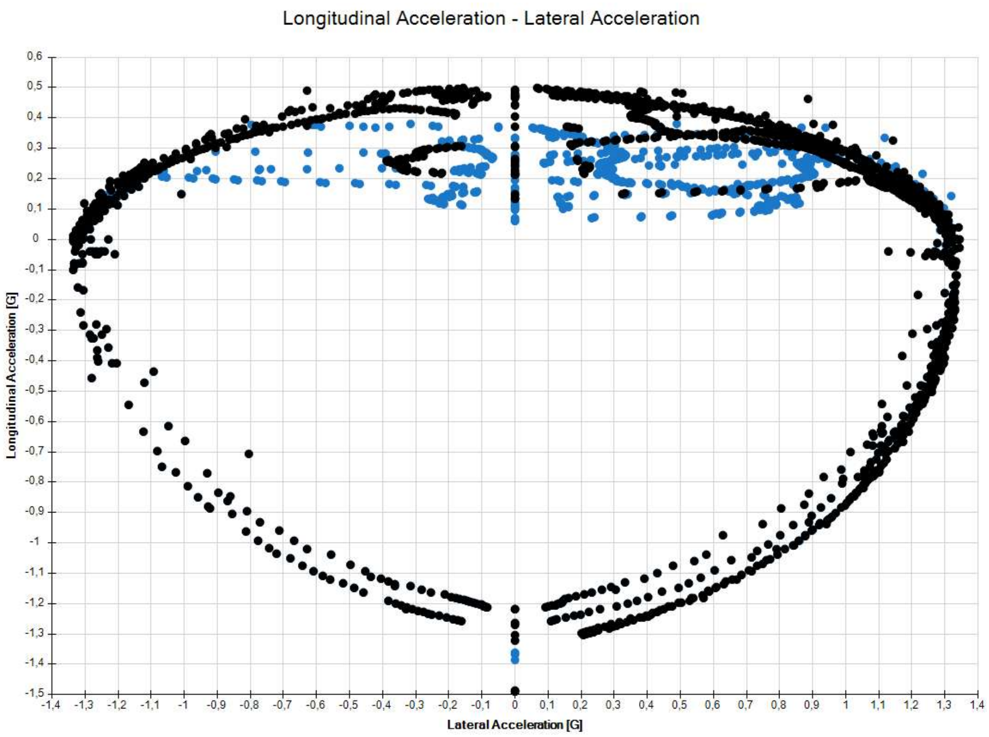


** Zero lat axis sensor calibration issue corr*

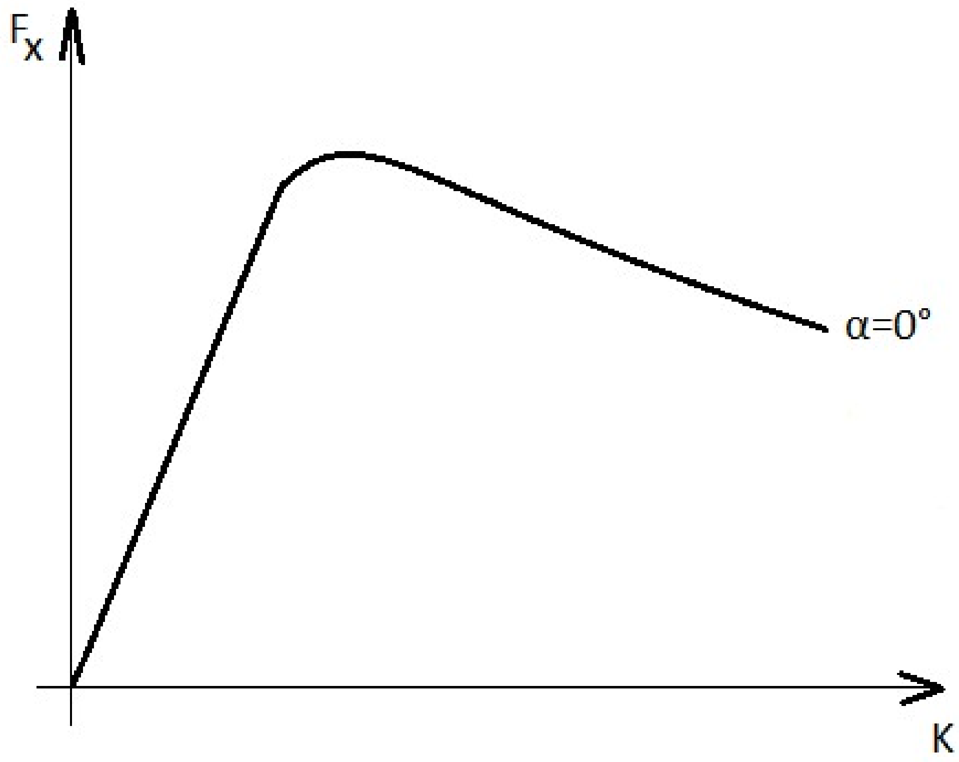
Question

What could be the modification from black (base) to blue electric racecar?

A - changed tyre with more lateral performance
B - electric drivetrain changed to a lower power mode
C - electric drivetrain changed to a higher regenerative braking mode
D – suspension adjusted to reach higher lateral acceleration



Cornering with different tires



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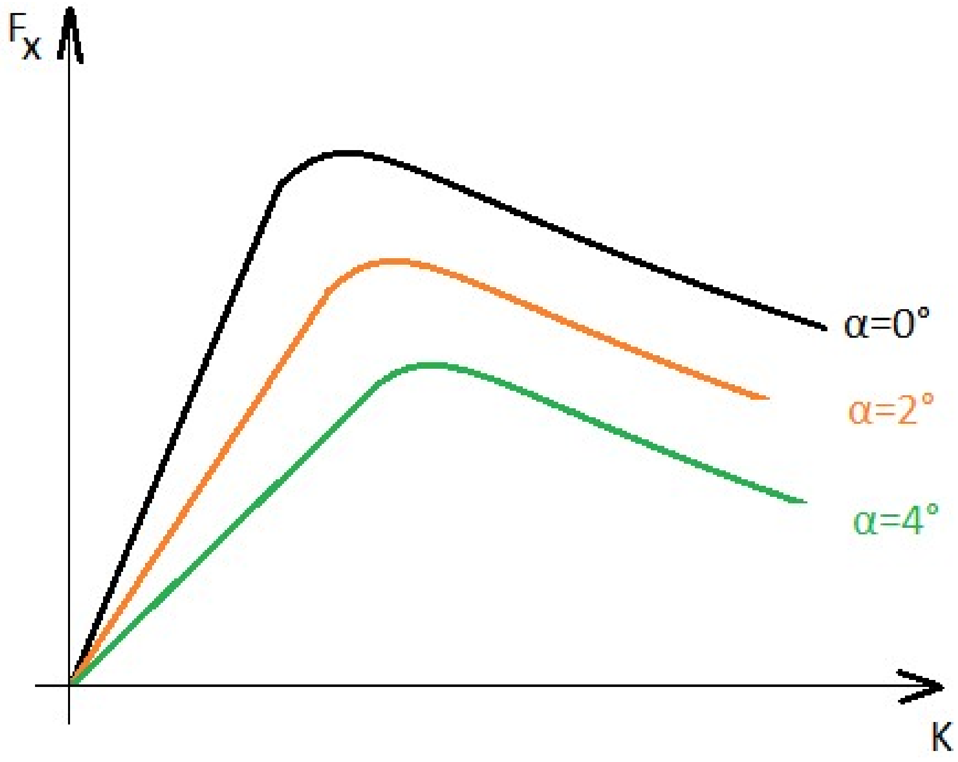

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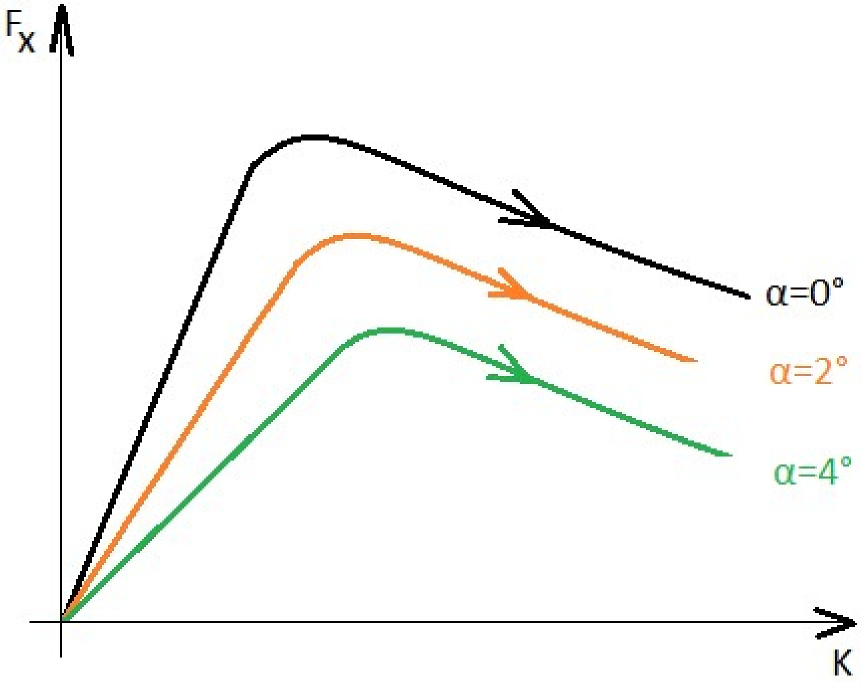

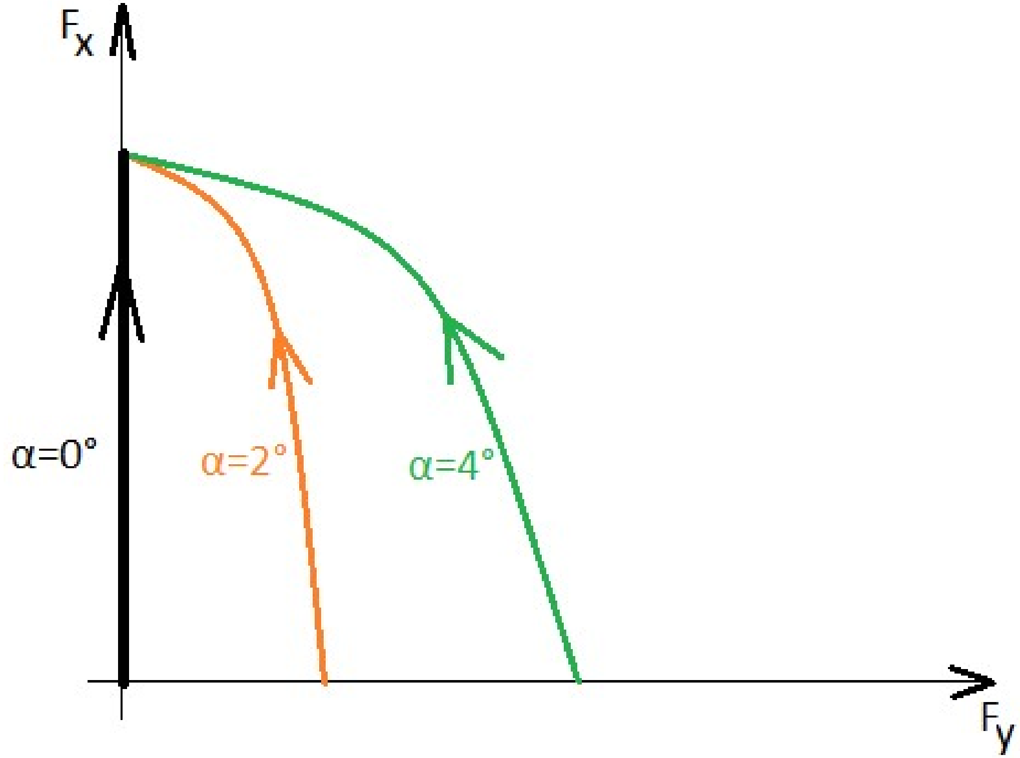

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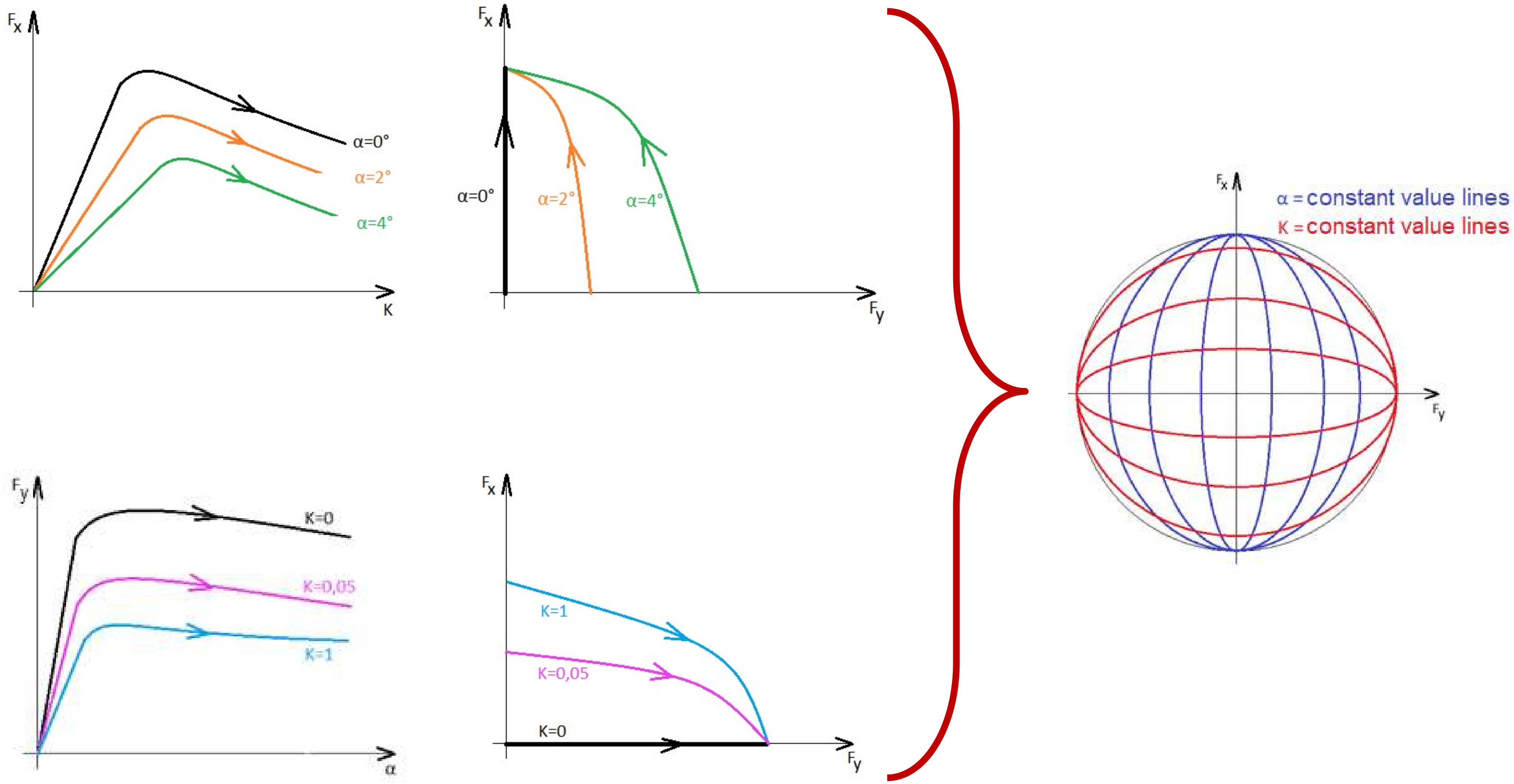

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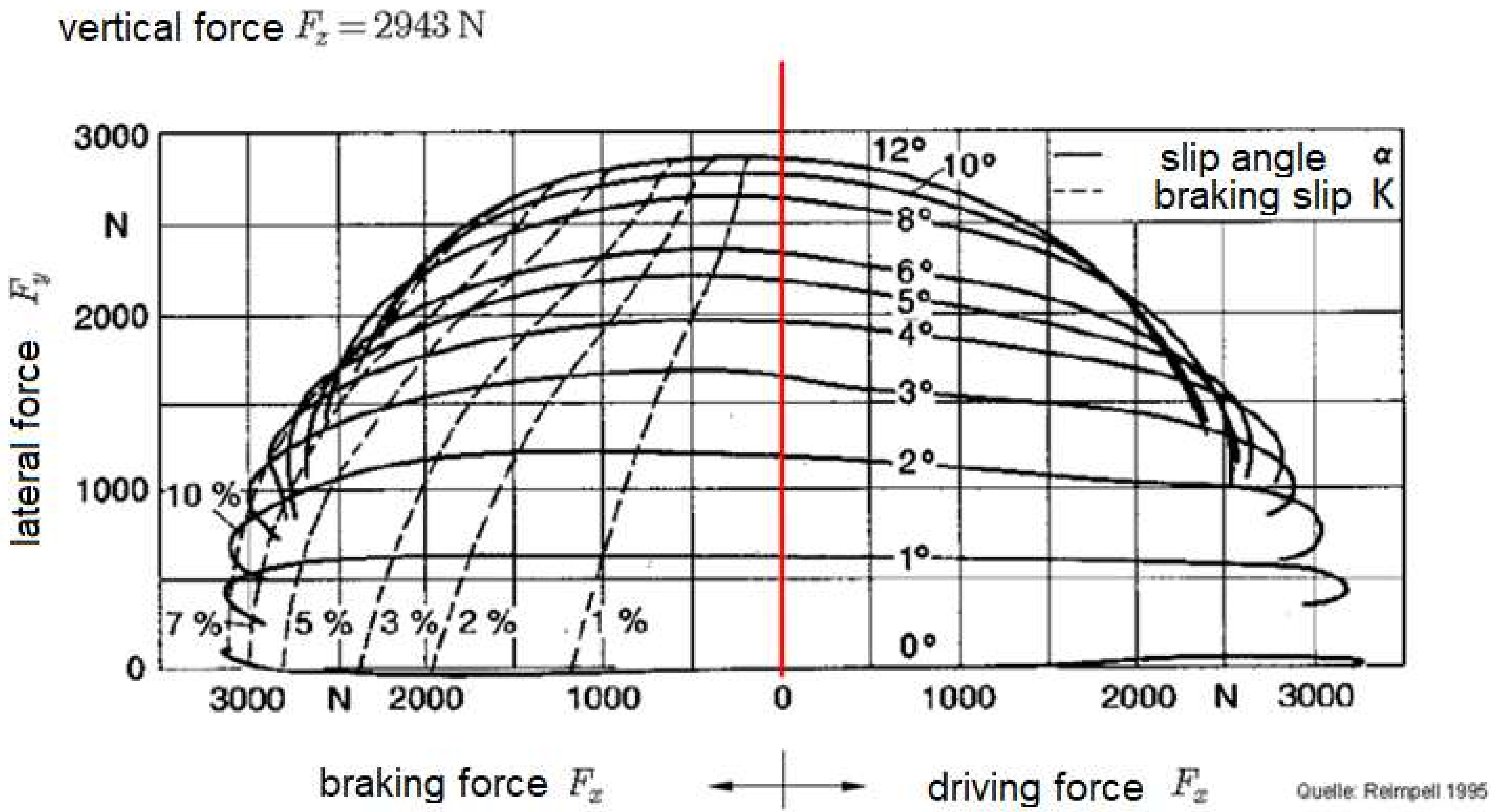
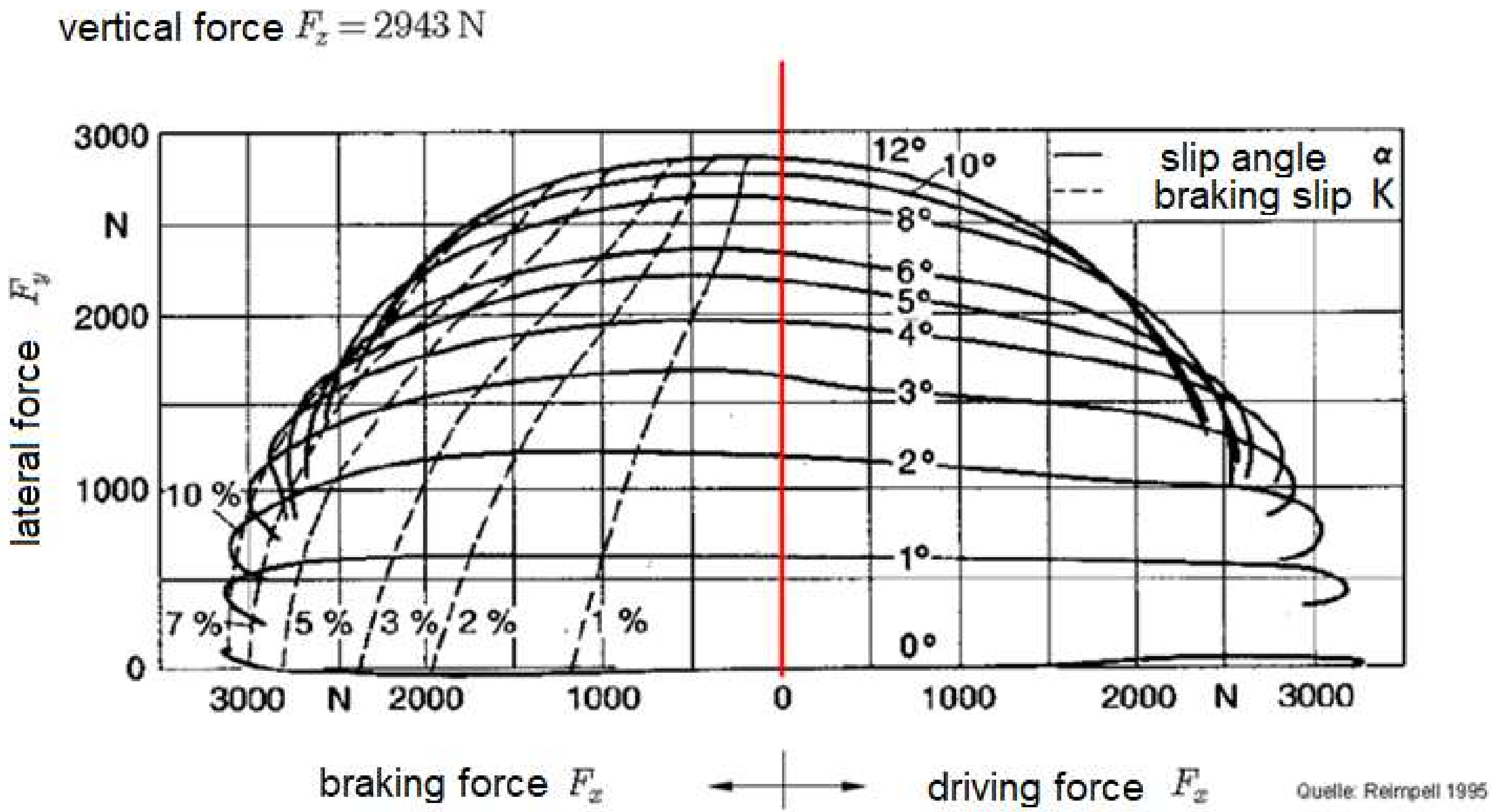


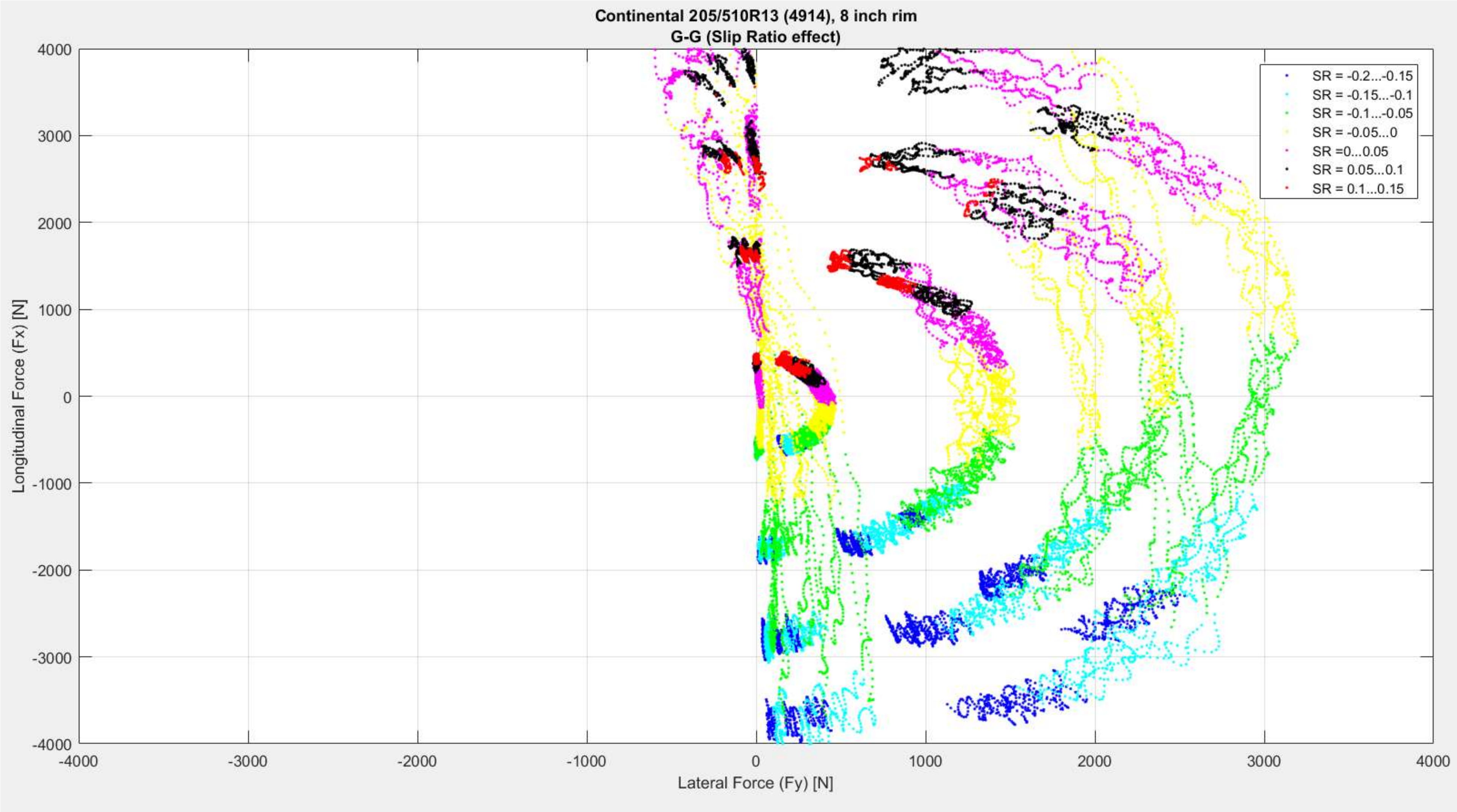
- What is the reason behind the elliptic shape of curves?
- Why the curves are asymmetrical to Fx=0 axis?

Cornering with different tires



- What is the reason behind the elliptic shape of curves?
  Different values of friction coefficients to different directions.
- Why the curves are asymmetrical to Fx=0 axis?
  Tyre behaviour is different in case of accelerating and braking.

Cornering with different tires



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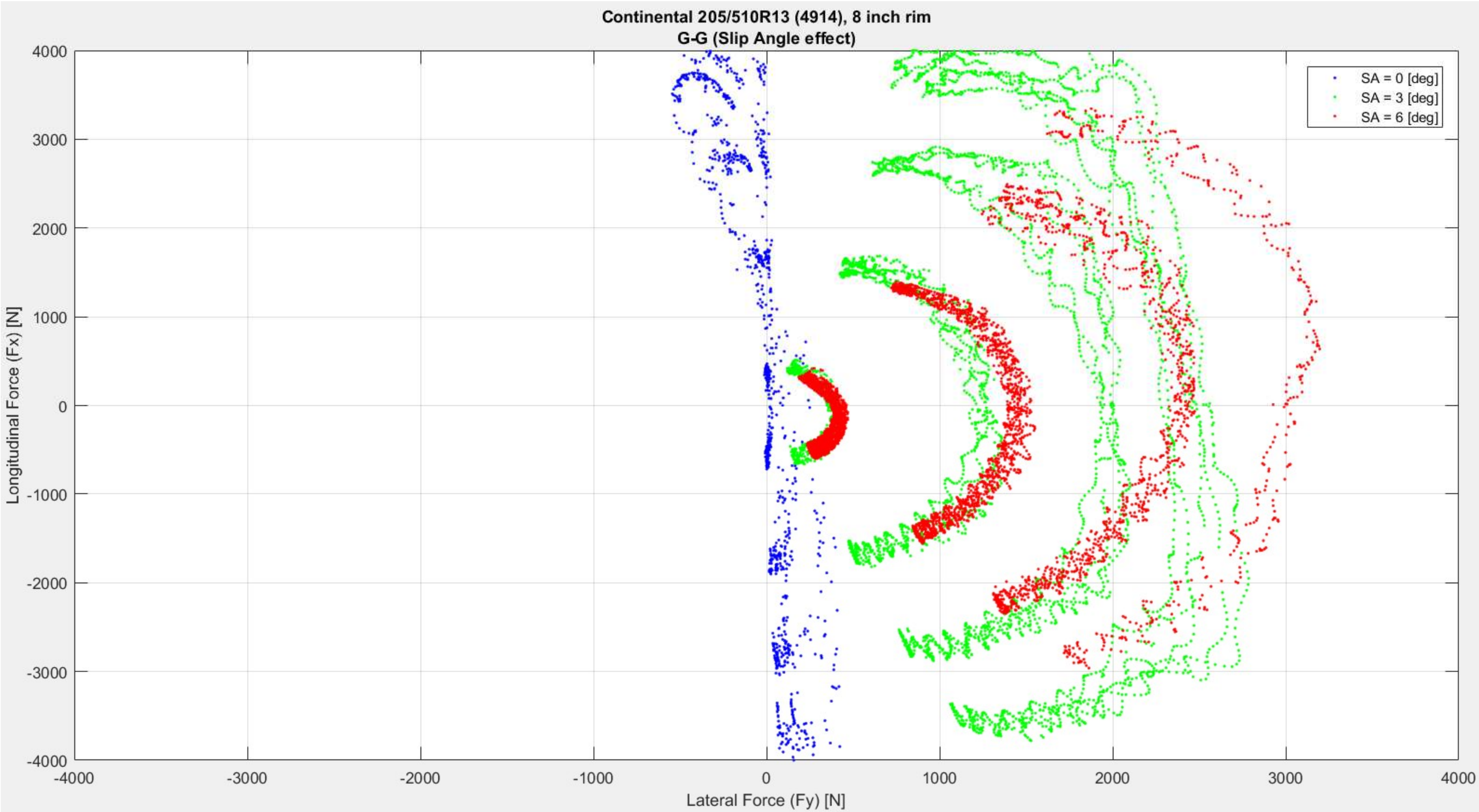
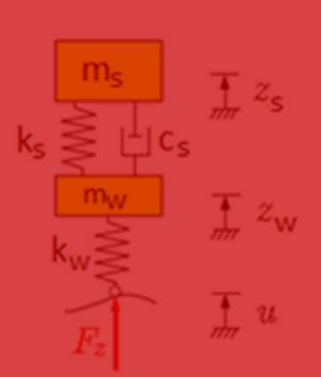


Vertical load in static case

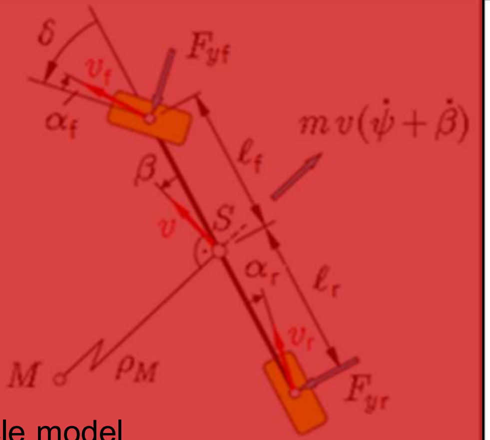
Notation

Vertical load in static case

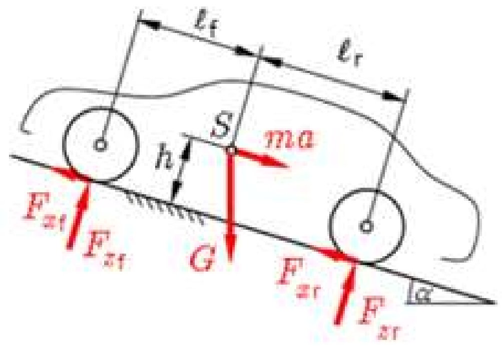
Dynam



Quarter vehicle model



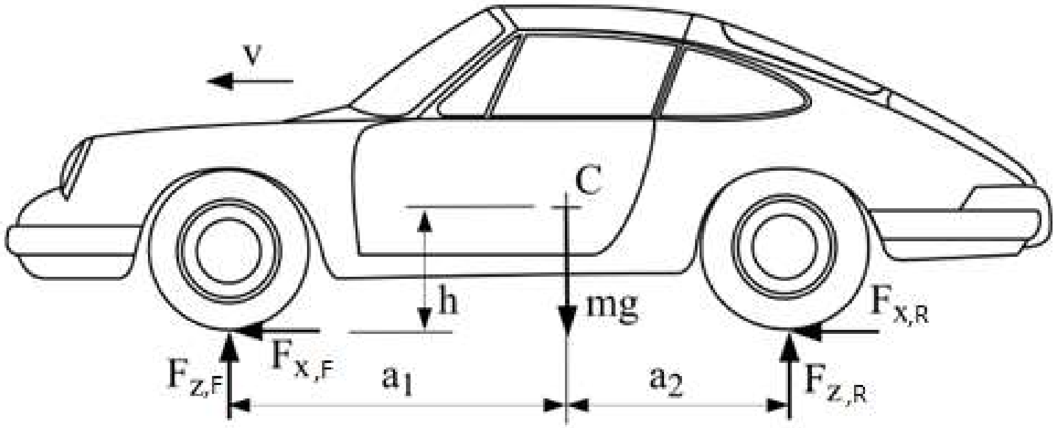
Bicycle model



longitudinal model

	vertical dynamics	lateral dynamics	longitudinal dynamics
	Quarter vehicle model	Bicycle model	longitudinal model
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 k_d – 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

Vertical load in static case



Static load of axles:

$$F_{z,F}^{st} = \mathrm{m} \cdot \mathrm{g} \cdot \frac{\mathrm{a}_2}{\mathrm{w}}$$

$$F_{z,R}^{st} = \mathrm{m} \cdot \mathrm{g} \cdot \frac{\mathrm{a}_1}{\mathrm{w}}$$

static load of tyres:

$$\mathrm{F}_{z,1} = \frac{1}{2} \cdot F_{z,F}$$

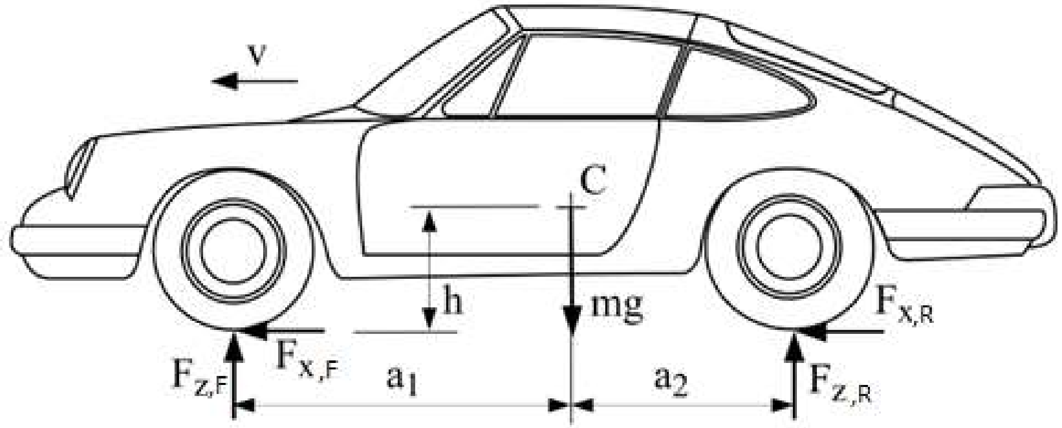
$$\mathrm{F}_{z,3} = \frac{1}{2} \cdot F_{z,R}$$

Longitudinal weight transfer

$\dot{v} \neq 0$

Vertical load in static case

$\dot{v} \neq 0$



Law of motion:

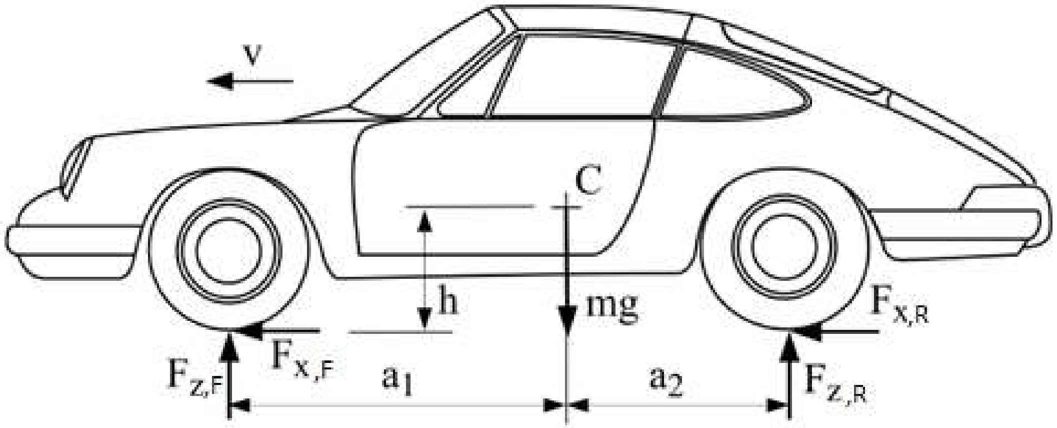
X direction: $m \cdot \dot{v} = F_{x,F} + F_{x,R}$

Z direction: $0 = F_{z,F} + F_{z,R} - m \cdot g$

Moments: $0 = -F_{z,F} \cdot a_1 + F_{z,R} \cdot a_2 - (F_{x,F} + F_{x,R}) \cdot h$

Vertical load in static case

$\dot{v} \neq 0$



Dynamic load of axles:

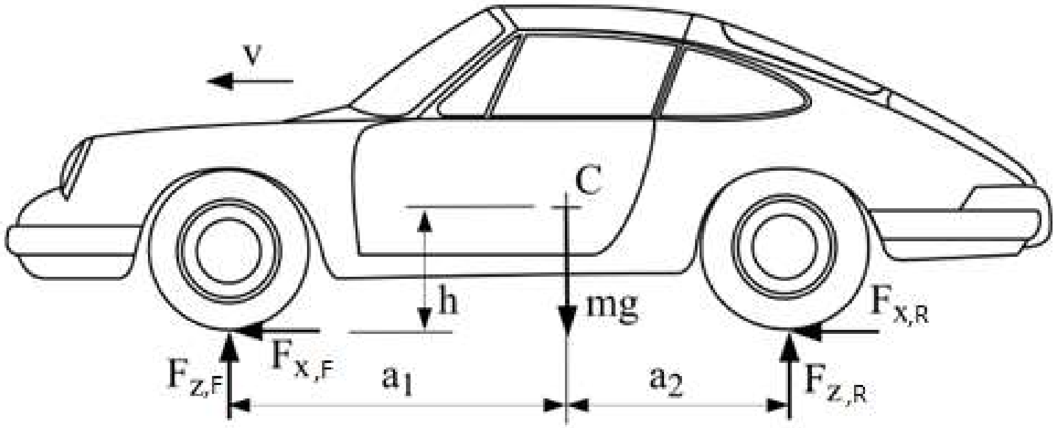
$$F_{z,F} = F_{z,F}^{st} + F_{z,F}^{dyn} \longrightarrow$$

$$F_{z,R} = F_{z,R}^{st} + F_{z,R}^{dyn} \longrightarrow$$

?

Vertical load in static case

$\dot{v} \neq 0$



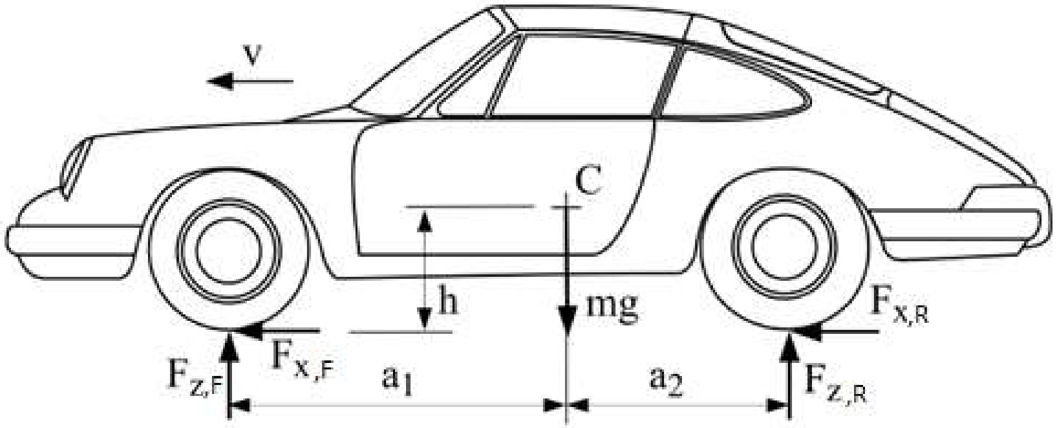
Dynamic load of axles:

$$\mathrm{F_{z,F}} = F_{z,F}^{st} + F_{z,F}^{dyn} \longrightarrow F_{z,F}^{dyn} = -\mathrm{m} \cdot \dot{\mathrm{v}} \cdot \frac{\mathrm{h}}{\mathrm{w}}$$

$$\mathrm{F_{z,R}} = F_{z,R}^{st} + F_{z,R}^{dyn} \longrightarrow F_{z,R}^{dyn} = \mathrm{m} \cdot \dot{\mathrm{v}} \cdot \frac{\mathrm{h}}{\mathrm{w}}$$

Vertical load in static case

$\dot{v} \neq 0$



Dynamic load of axles:

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$$F_{z,R} = F_{z,R}^{st} + F_{z,R}^{dyn} \longrightarrow F_{z,R}^{dyn} = m \cdot \dot{v} \cdot \frac{h}{w}$$

Dynamic load of tyres:

$$F_{z,1} = \frac{1}{2} \cdot F_{z,F}$$

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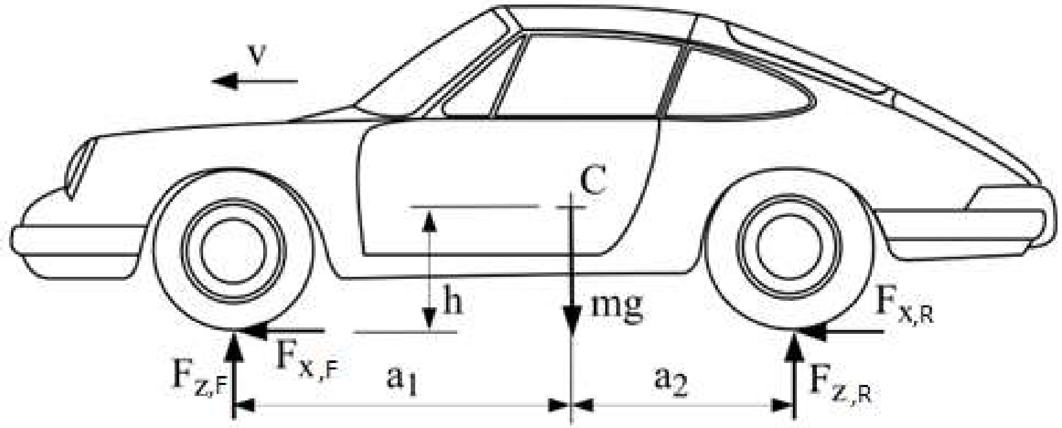
Vertical load in static case



Dynamic load of axles:

$$F_{z,F} = m \cdot g \cdot \frac{a_2}{w} - \frac{h}{w} \cdot m \cdot \dot{v}$$

$$F_{z,R} = m \cdot g \cdot \frac{a_1}{w} + \frac{h}{w} \cdot m \cdot \dot{v}$$

Dynamic load of tyres:

$$F_{z,1} = \frac{1}{2} \cdot F_{z,F}$$

$$F_{z,3} = \frac{1}{2} \cdot F_{z,R}$$

Longitudinal weight transfer

What does weight transfer depend on?

- CoG height
- weight of car
- amount and direction of acceleration
- wheelbase

$$F_{z,R}^{dyn} = \mathrm{m} \cdot \dot{\mathrm{v}} \cdot \frac{\mathrm{h}}{\mathrm{w}}$$

nothing else!

Longitudinal weight transfer

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$$F_{z,R}^{dyn} = \mathrm{m} \cdot \dot{\mathrm{v}} \cdot \frac{\mathrm{h}}{\mathrm{w}}$$

nothing else!

With increased wheelbase, the longitudinal weight transfer will be ….

Longitudinal weight transfer

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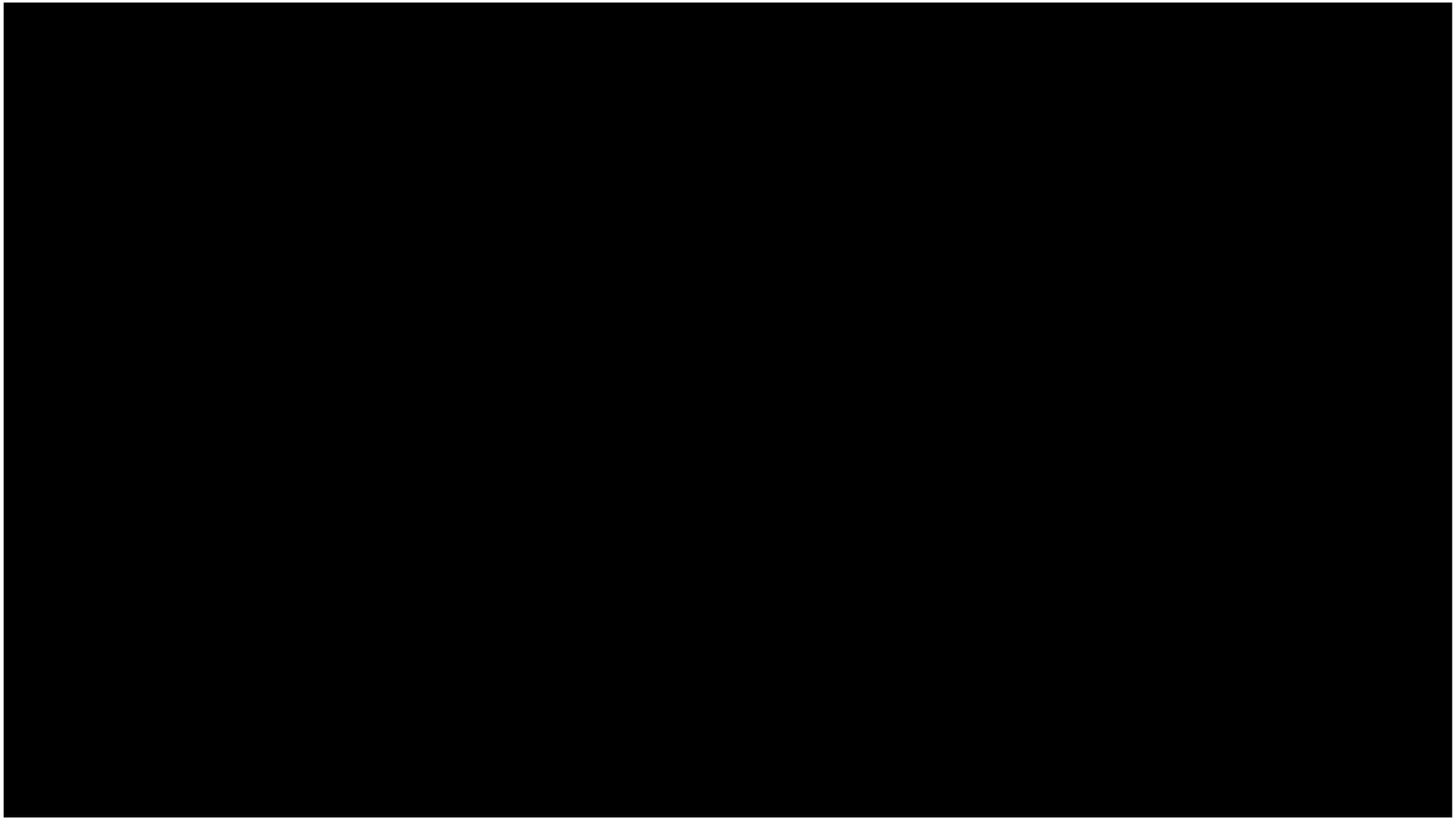
nothing else!

With increased wheelbase, the longitudinal weight transfer will be ….

less

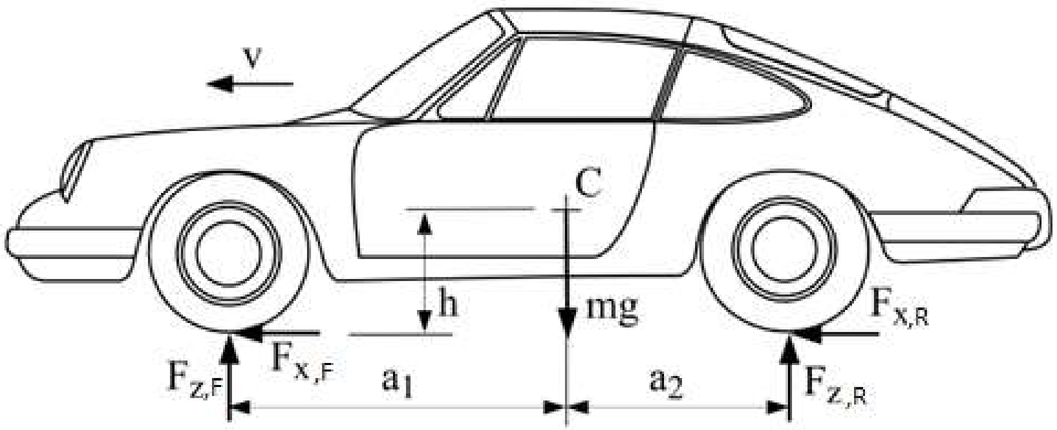
Longitudinal weight transfer

dynamic loads (and forces)



Longitudinal weight transfer

help me!

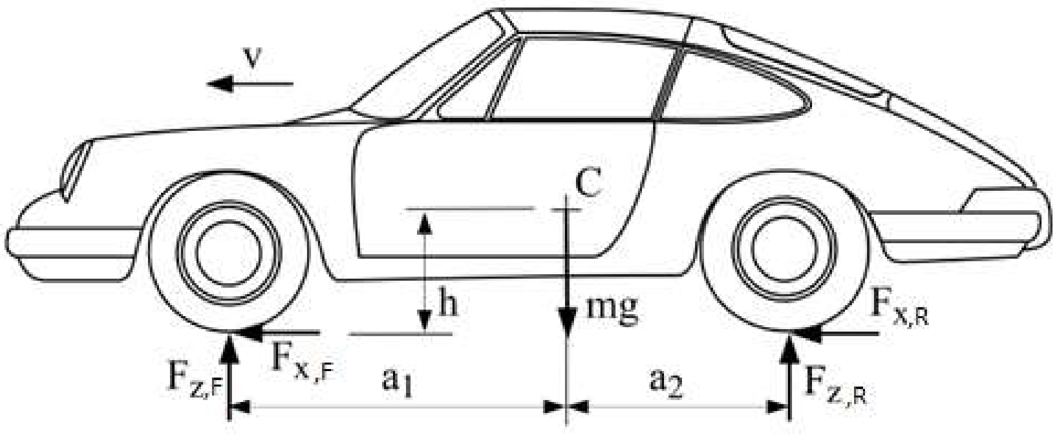


I’m going on a motorway with my own car, Waze warns of a pothole but it’s too late, inevitable to go through, what should I choose?

A. $\dot{v}$ should be 0, go through with constant speed
B. $\dot{v}$ should be negative, braking
C. $\dot{v}$ should be positive, accelerating
D. none of the soultions above helps, damage will be the same

Longitudinal weight transfer

help me!



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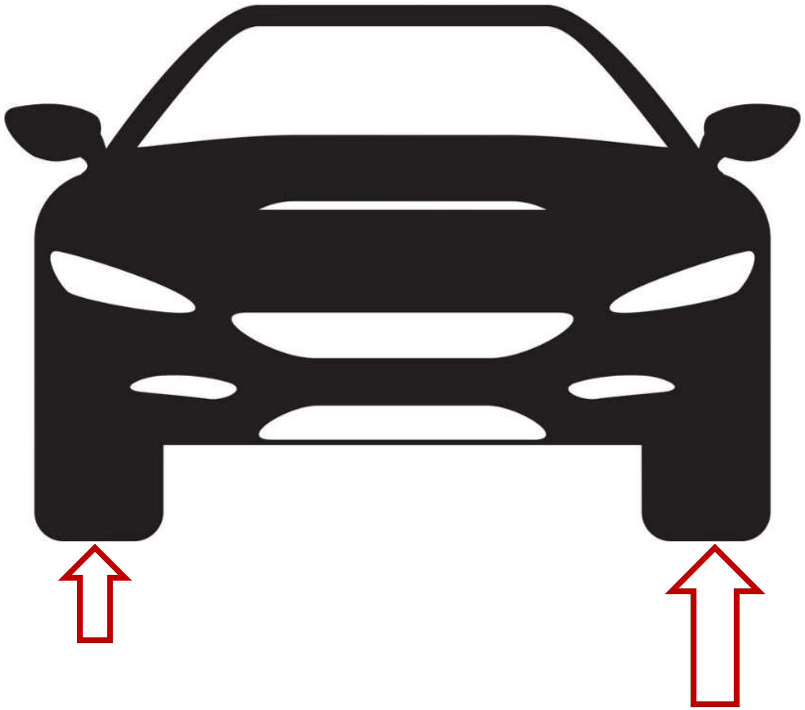
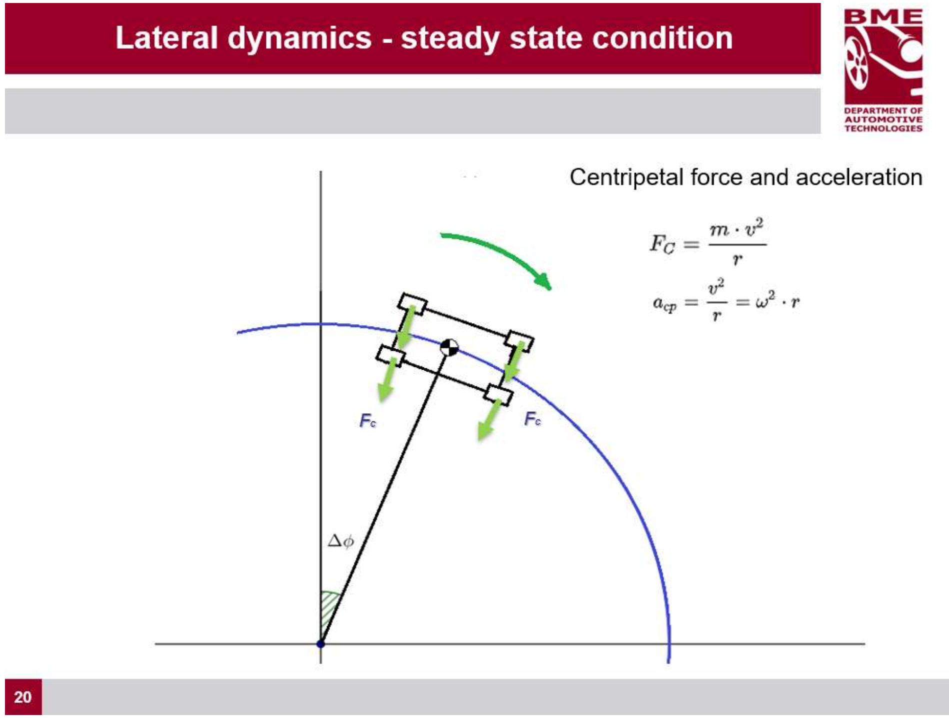
Lateral weight transfer





Lateral weight transfer

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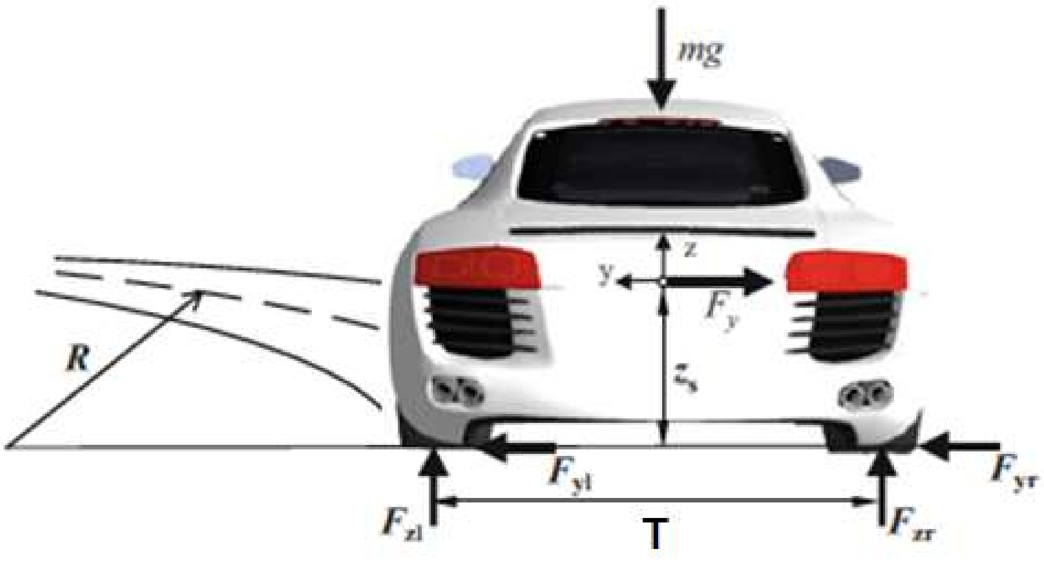
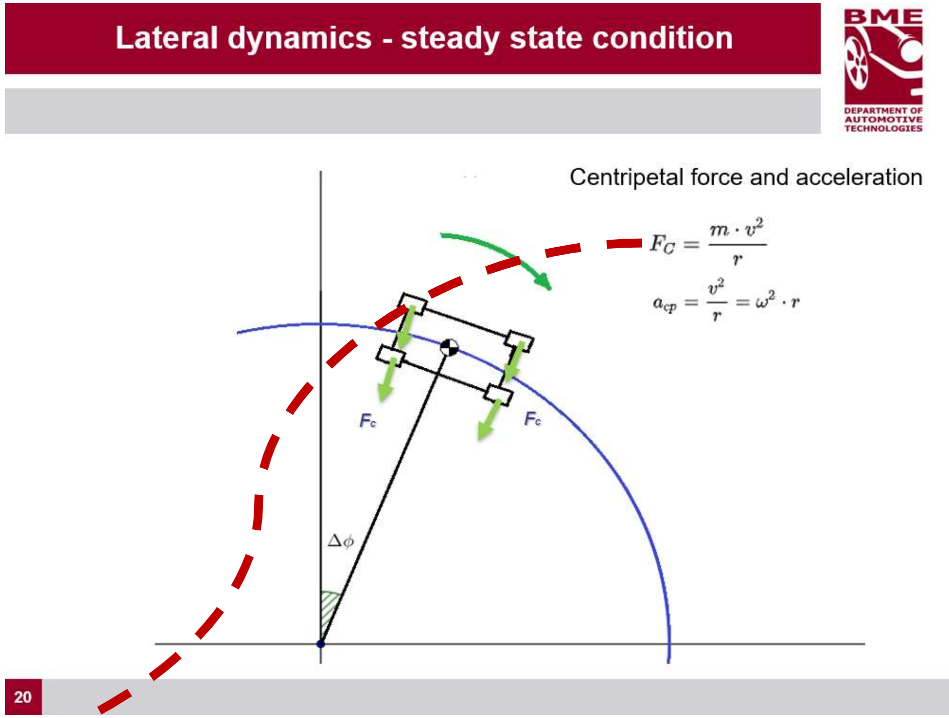
Steady state case





$$F_{cp} = \mathrm{m} \cdot a_y = m \cdot \frac{v^2}{R}$$

Lateral weight transfer

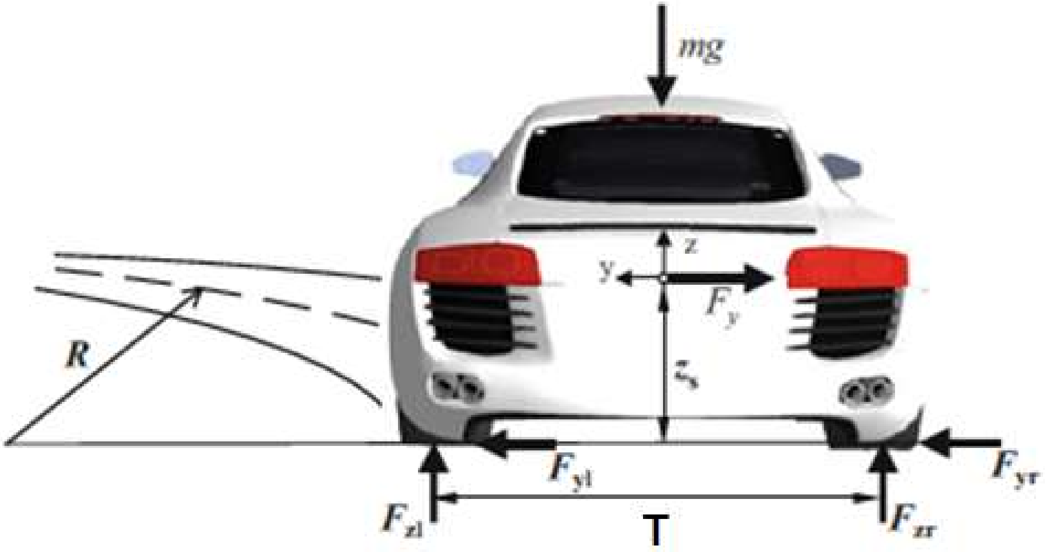
Steady state case

$$F_{z,1} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_2}{w} - F_{cp} \cdot \frac{h}{T} \cdot \frac{a_2}{w}$$

$$F_{z,2} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_2}{w} + F_{cp} \cdot \frac{h}{T} \cdot \frac{a_2}{w}$$

$$F_{z,3} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_1}{w} - F_{cp} \cdot \frac{h}{T} \cdot \frac{a_1}{w}$$

$$F_{z,4} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_1}{w} + F_{cp} \cdot \frac{h}{T} \cdot \frac{a_1}{w}$$



Lateral weight transfer

Steady state case

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$$F_{z,4} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_1}{w} + F_{cp} \cdot \frac{h}{T} \cdot \frac{a_1}{w}$$

Contradiction pointed out by a student:

„Here is the formula needed to calculate lateral weight transfer. If I understand correctly, the increase/decrease in normal force is inversely proportional to the track width. However, at the end of the online class, the professor said that widening the front track does not reduce understeer. I don't understand why—if I increase the front track width, the weight transfer decreases, and grip increases, right? What am I thinking incorrectly?"

Lateral weight transfer

Steady state case

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Answer from me:

Your point is flawless, and based on the presented material, the contradiction has understandably emerged. The course places greater emphasis on the longitudinal vehicle dynamics model and its calculations (in practice) because this aligns with its introductory nature.
If we were to establish a model that derives the relationship between lateral load transfer and balance (OS/US), we would have to go beyond the scope of this course.
In short: the equations on the slide you sent treat the vehicle as if it were constructed without a quasi-rigid chassis, with four independent wheels, and only consider steady-state conditions. The easiest way to see how unrealistic this is would be to compare two cases that differ only in front axle track width—according to the model, the rear WT remains the same in both cases. This does not reflect reality. In practice, any change in track width affects the WT on both axles, and it is the change in **the ratio of WT** that determines balance.

Lateral weight transfer

Steady state case

The contradiction:

•**The video (online class) statement:** The wider the track, the greater the **percentage** of WT on the front axle. This contradicts the claim in the video embedded in the presentation ("widening the front track helps understeery behavior"). From a practical perspective, when examining the vehicle as a whole, the class statement is correct.

•**The equations on the slide:** The wider the track, the lower the WT on that specific axle (when looking at that axle alone). However, as I mentioned, this model assumes the WT on the unchanged axle remains constant, which is incorrect.

To see the full picture, we need to account for the chassis (which connects the axles), its torsional stiffness and the corresponding equations to properly derive on-track balance behavior.

Lateral weight transfer

What does weight transfer depend on?

- CoG height
- CoG distance from front/rear axle
- weight of car
- amount and direction of acceleration
- wheelbase
- track

$$F_{z,4} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_1}{w} + F_{cp} \cdot \frac{h}{T} \cdot \frac{a_1}{w}$$

$$F_{cp} = \mathrm{m} \cdot a_y$$

nothing else!

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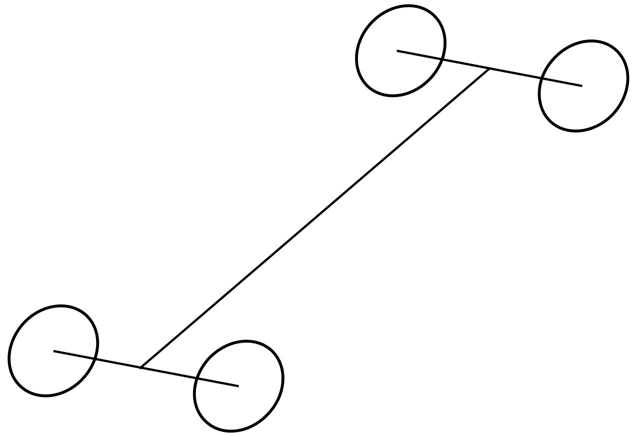

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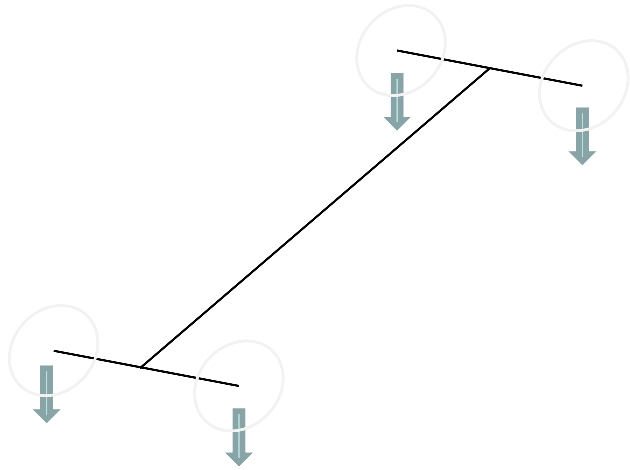

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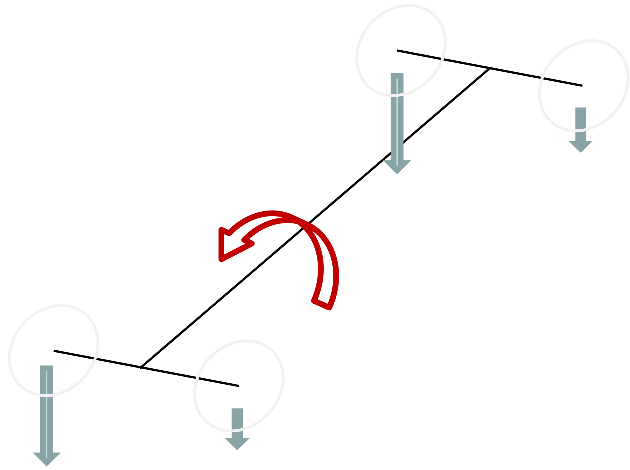

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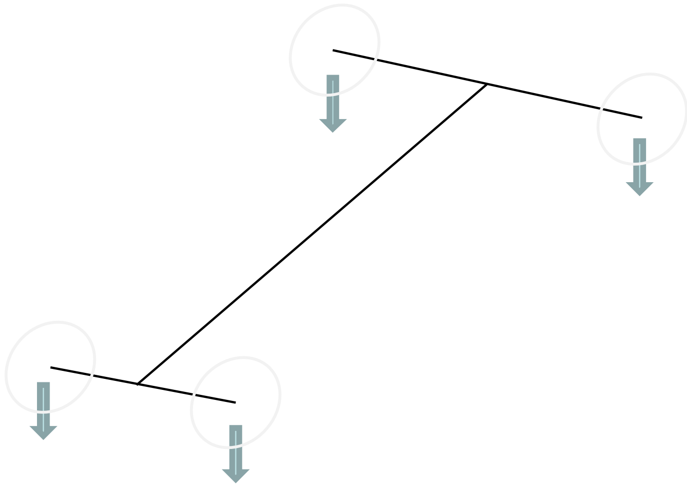

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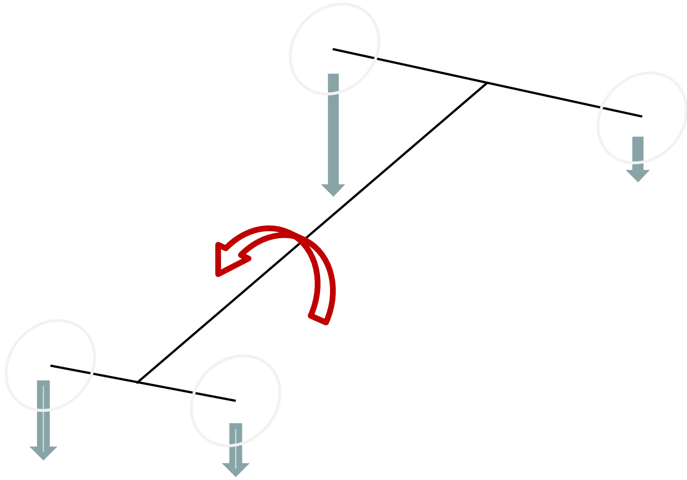
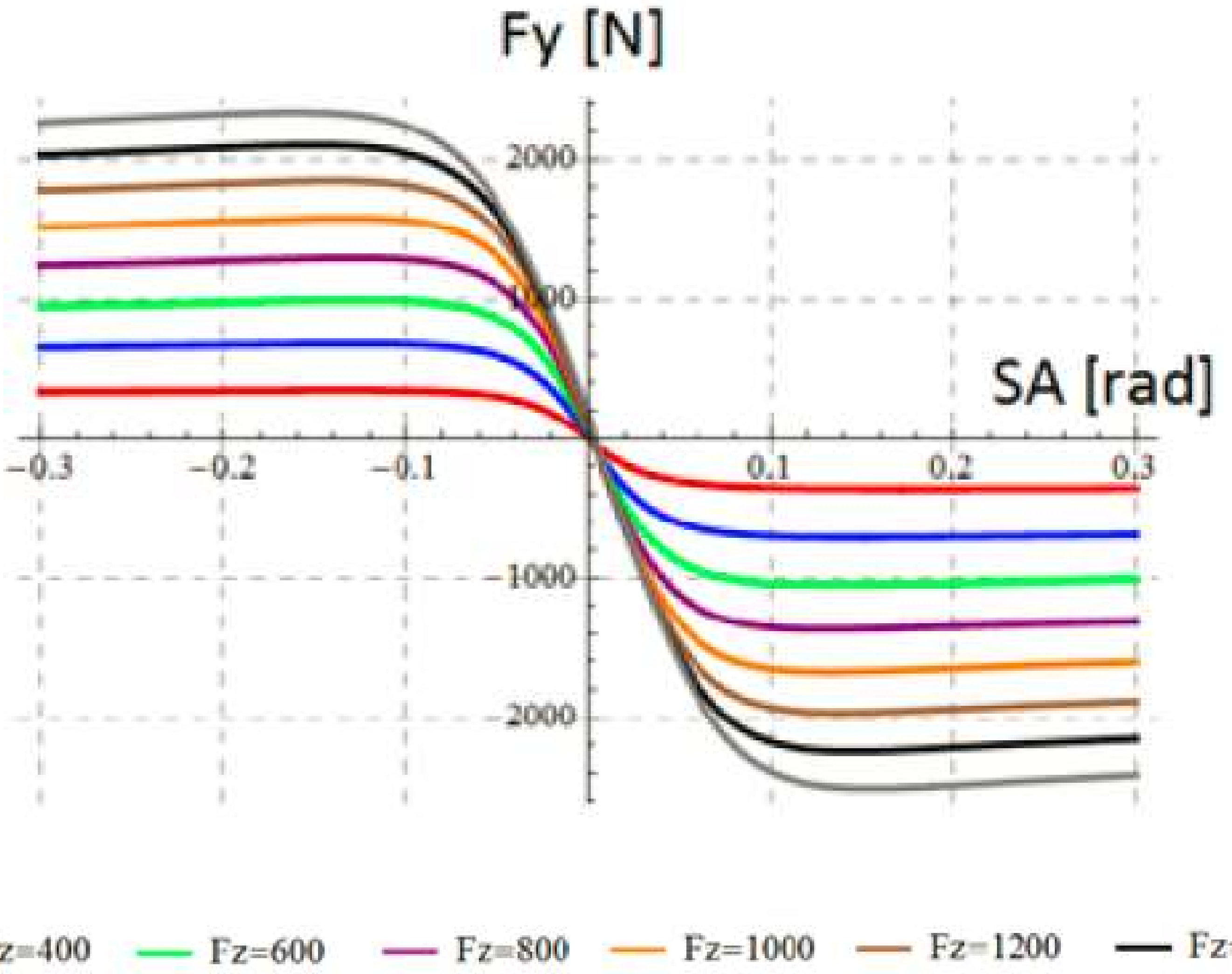
- wheelbase
- track



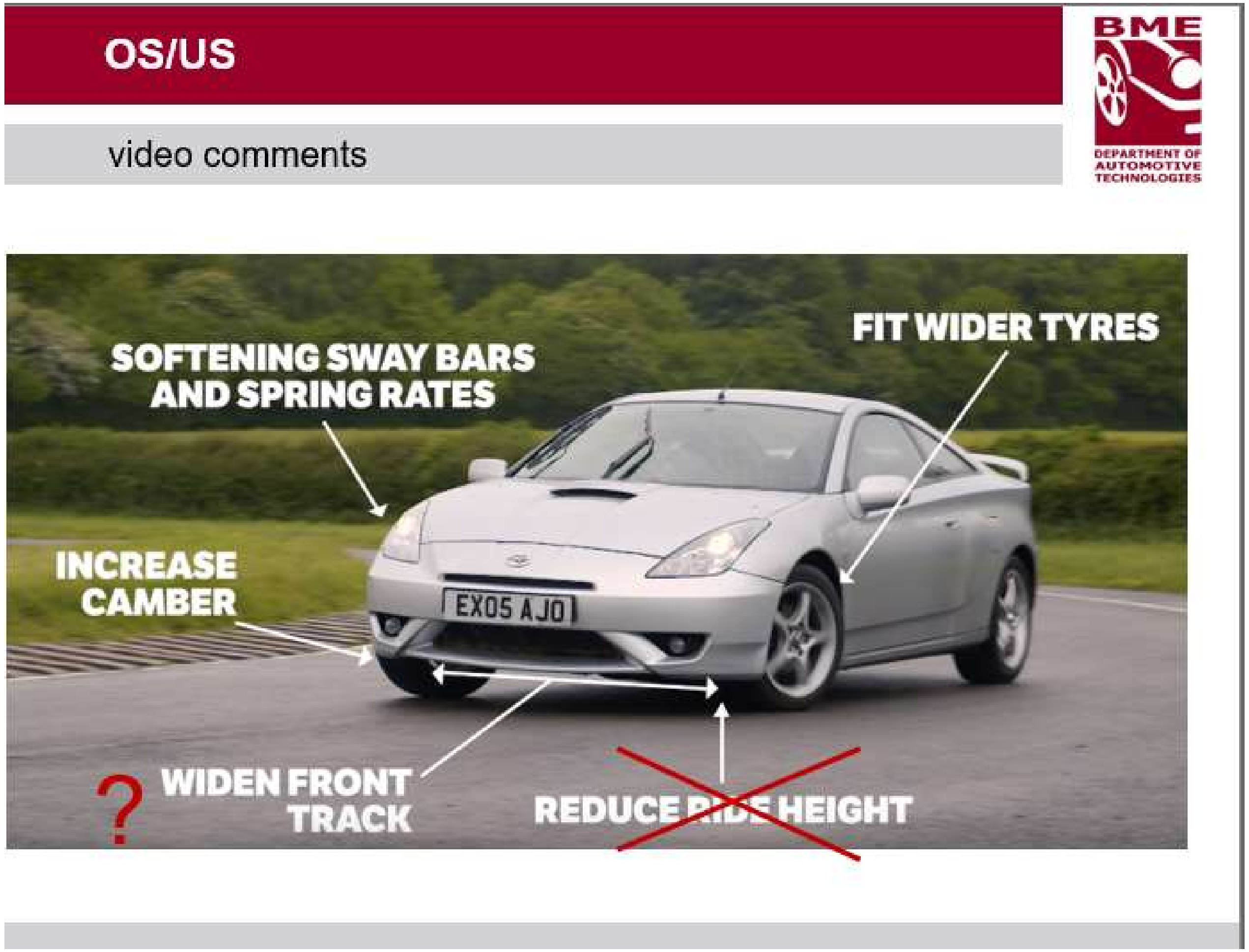
Effect of weight transfer…

…with tyre degressivity



from previous lecture…

video comments



Lateral weight transfer

https://www.facebook.com/photo?fbid=956716504863645&set=gm.1347862322229703

Midterm tests and exams

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1

- know concepts and definitions – you are able to give definitions of :
  - different type of tyre radius
  - contact patch
  - tyre structures
  - slip ratio
  - slip angle
  - aware of the different characteristics of tyre behaviour and able to distinguish one from other
  - friction coefficient
  - brush tyre model and explanation of tyre force
  - able to orientate in the coordinate system of a vehicle
  - cornering stiffnes of a tyre
  - self aligning torque
  - pneumatic trail
  - friction ‚cirle'
  - steady state basics equations
  - transient basics equation
  - characteristics of transient basics diagrams

Midterm tests and exams

2

- assymetric tyre behaviour to acceleration and braking
- static vertical tyre loads
- longitudinal weight transfer with the help of longitudinal model
- lateral weight transfer in steady state cornering
- understanding the effect of tyre degressivity and weight transfer

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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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Thank you for your attention!

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