Rolling resistance and energy loss in tyres

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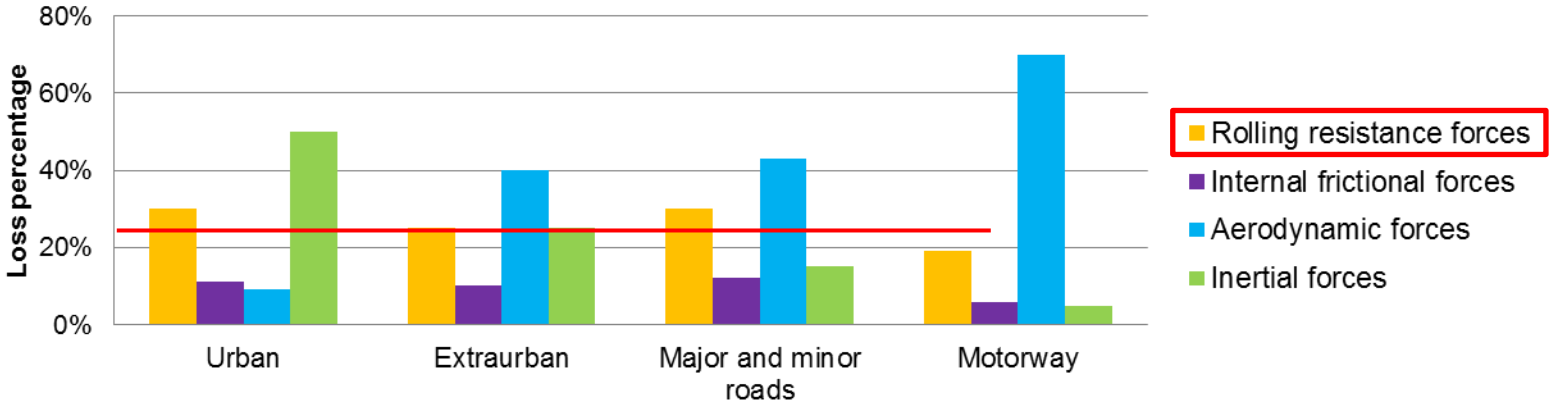
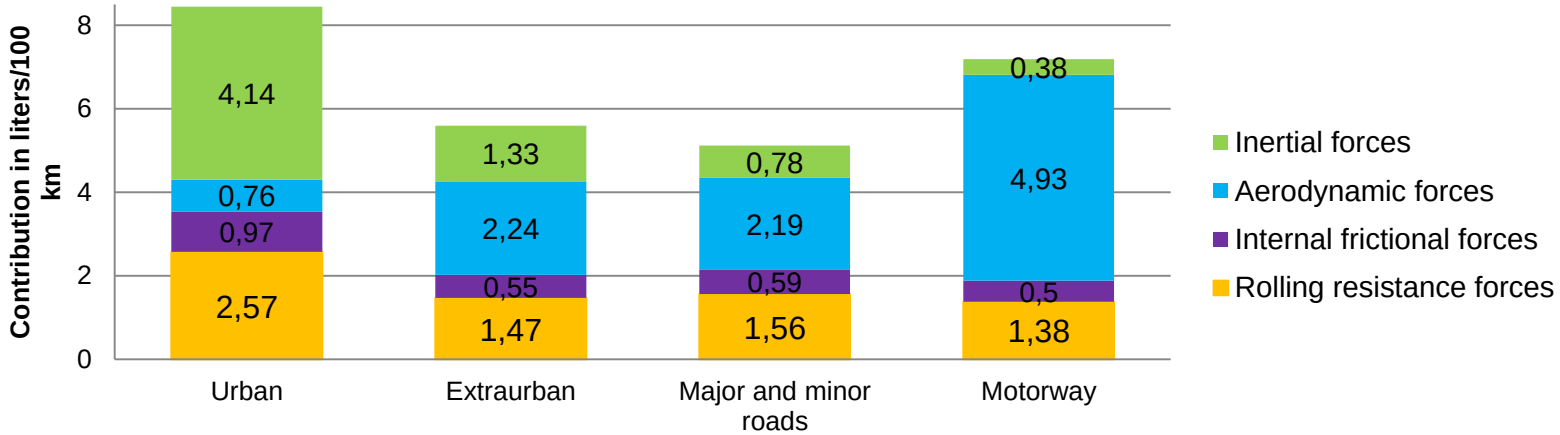
Vehicle energy usage





Every day 2 millions tonnes of fuel burns up to overcome rolling resistance!

Source: Michelin

Reducing rolling resistance and consequently the fuel consumption is a major development goal for vehicle and tyre manufactures.

What does the vehicle industry do?

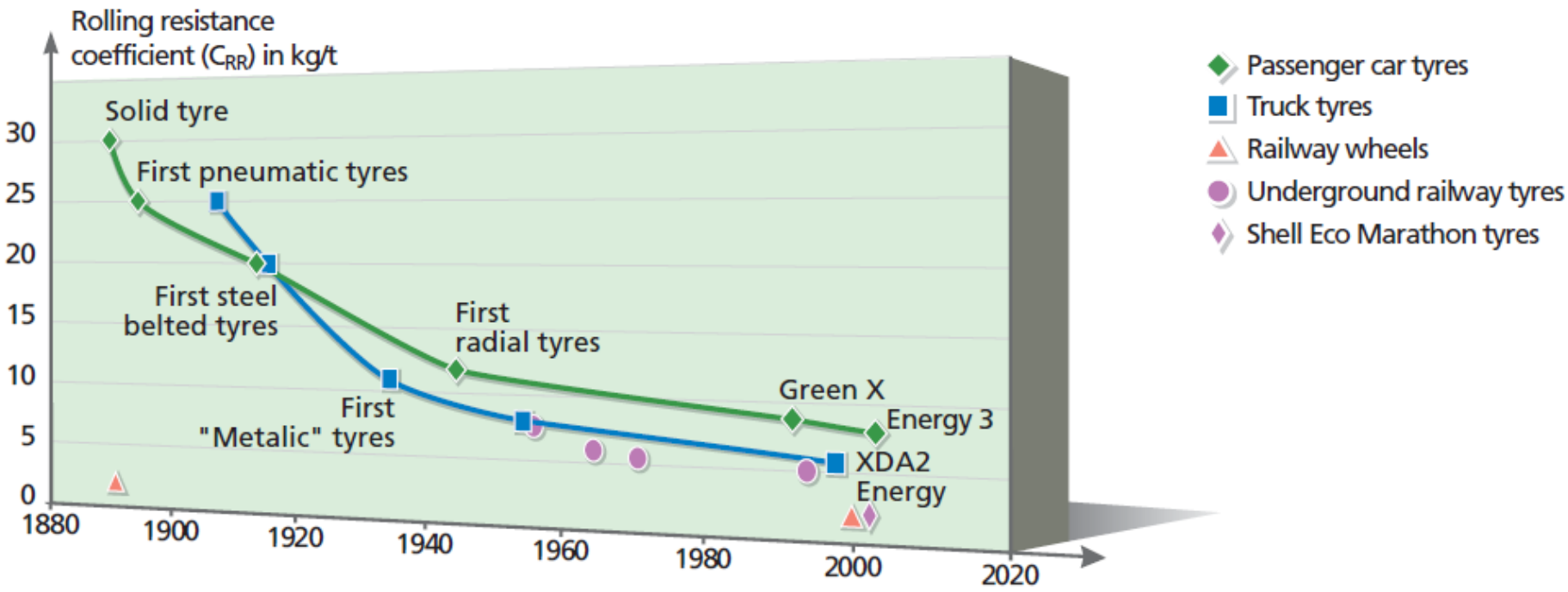
Narrower

Larger

VW XL1: 115/80 R15 Michelin

BMW i3: 155/70 R19 Bridgestone

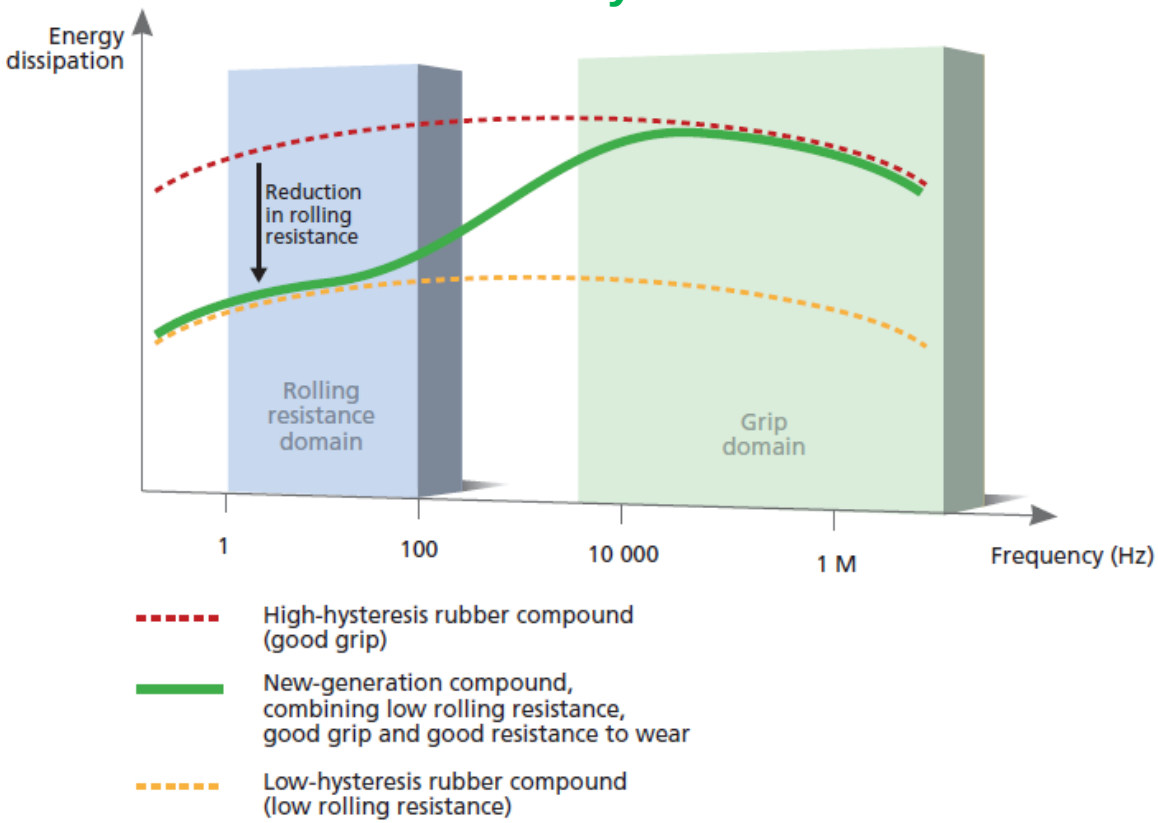
What about the tyre industry?

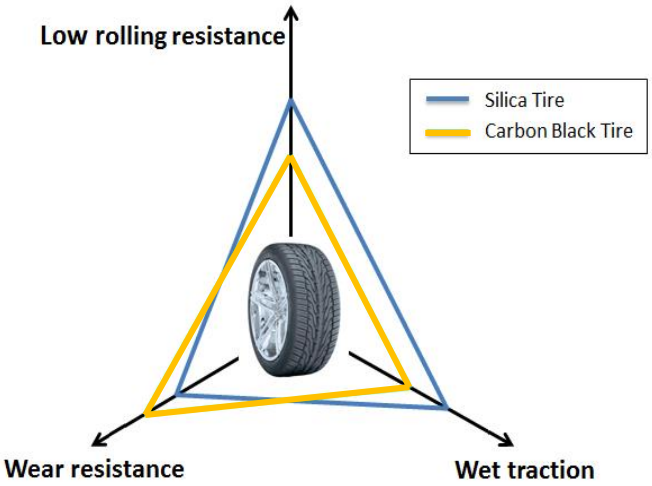


Source: Michelin

…but, there are challenges!

Green tyres





Source: Michelin

What we as vehicle dynamicists can do to affect the rolling resistance?

Research goal…

… presenting an idea, apart from the state-of-the-art methods, to reduce the resistance originated from the tyre.

Research questions

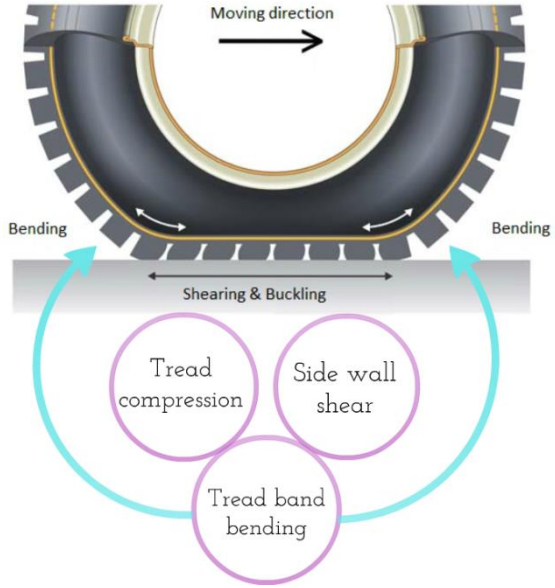
- What is an appropriate model to characterise the **rolling loss** in the tyre during a vehicle manoeuvre?
- Is it reasonable to believe that there is any potential to reduce the **rolling loss** and thereby fuel consumption by using active chassis solutions?

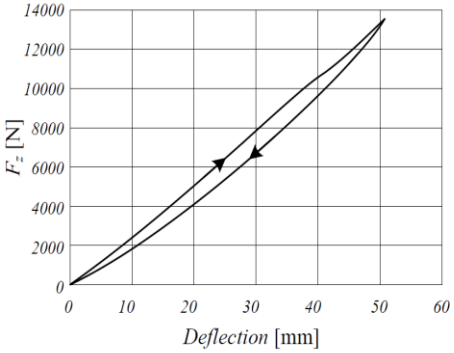
Rolling resistance

Main contributors associated with tyre rolling resistance;

- Hysteretic losses in the sidewall and the tread
- Tyre aerodynamic drag and air circulations
- Tyre-road interaction and surface losses

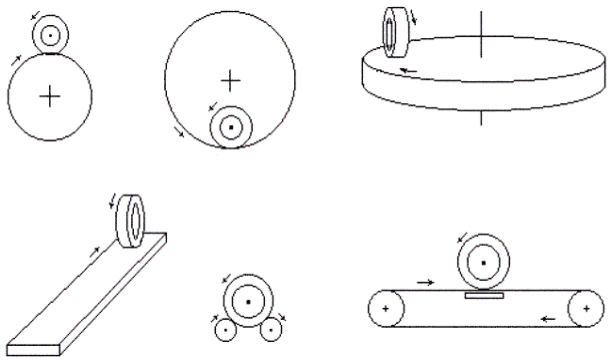
Rubber deformation	80 – 95 %
Aerodynamic resistance	0 – 15 %
Tyre-road interaction	<5 %





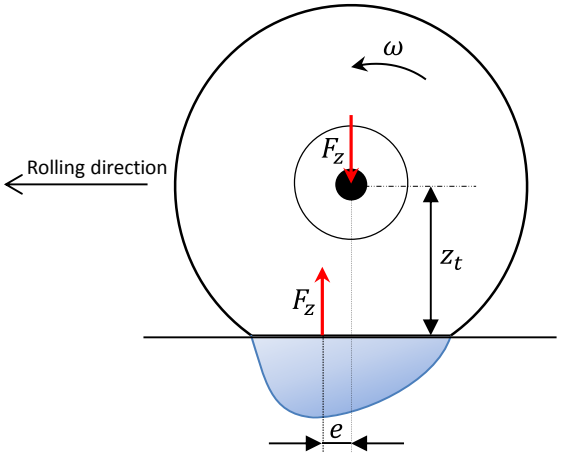
Rolling resistance

In-door measurement



Out-door measurement

[Source: Technical University of Gdansk]



$$M_y = F_z \cdot e \xrightarrow{f_r = \frac{F_r}{F_z}} f_r = \frac{M_y}{F_z \cdot z_t}$$

ISO 18164:2005 measuring rolling resistance, under controlled laboratory conditions (free rolling, straight ahead driving, specific load and speed)

A global definition

Pressure distribution and shape of the contact patch depend on driving conditions and wheel alignments, thus this coefficient will be a variable dependent to other parameters;

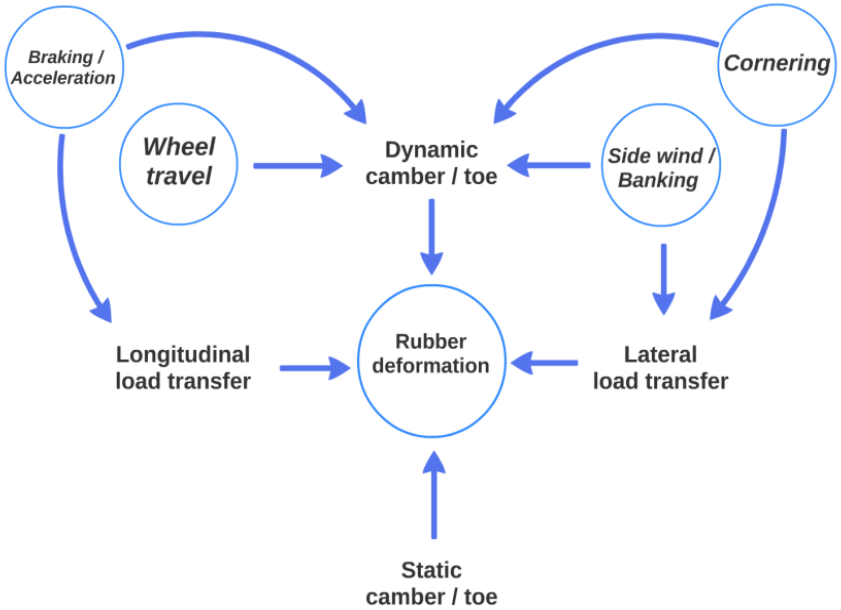
$$Rolling\ resistance\ coefficient = f\begin{pmatrix} side\ slip\ angle \\ camber\ angle \\ slip\ ratio \\ vertical\ load \\ speed \\ temperature \\ material \\ \dots \end{pmatrix}$$

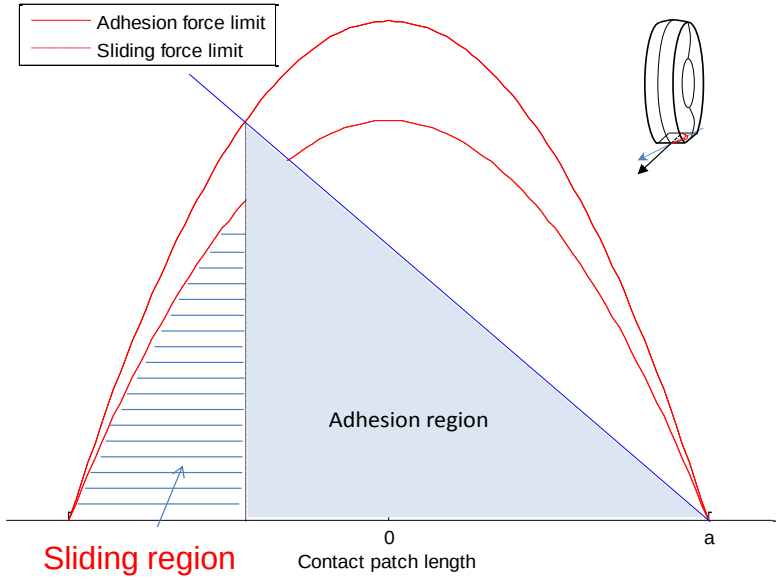
Therefore, for free-rolling, straight ahead driving and neutral wheel alignment **in-plane rolling resistance coefficient (f_r)** will be used instead and in general the term **rolling resistance coefficient (f_R)**.

Rolling loss

“Rolling loss" refers to the energy dissipation in the tyre due to deflections as well the losses in the sliding region.

Dissipation sources

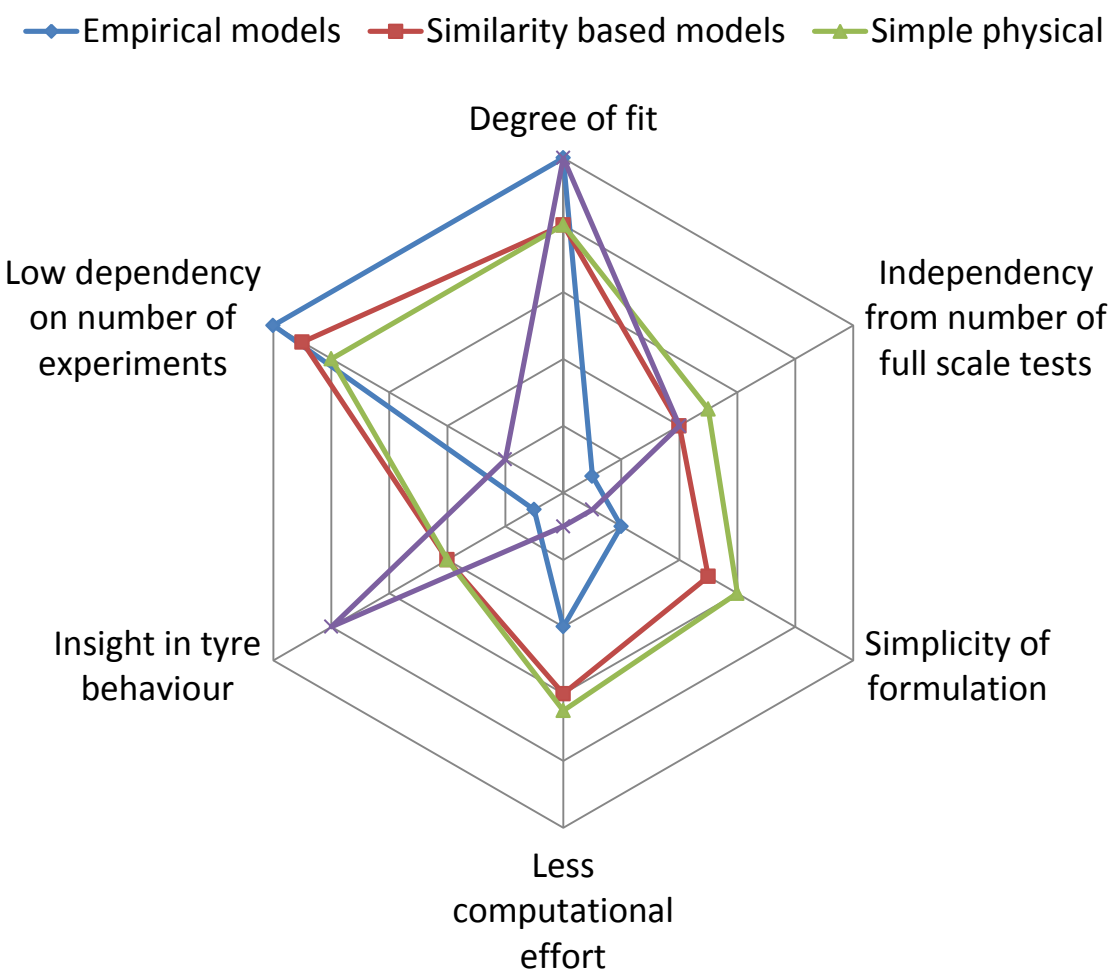


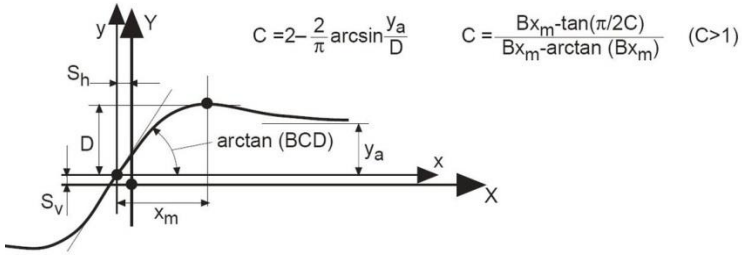


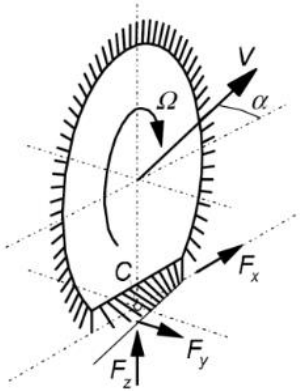
Internal losses

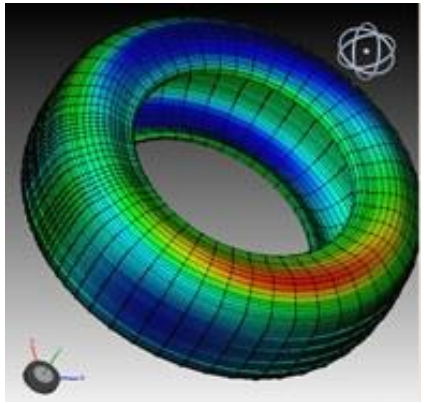
External losses

Tyre models


Empirical models
Similarity based models
Simple physical models
Complex physical models
Degree of fit
Independency from number of full scale tests
Simplicity of formulation
Less computational effort
Insight in tyre behaviour
Low dependency on number of experiments

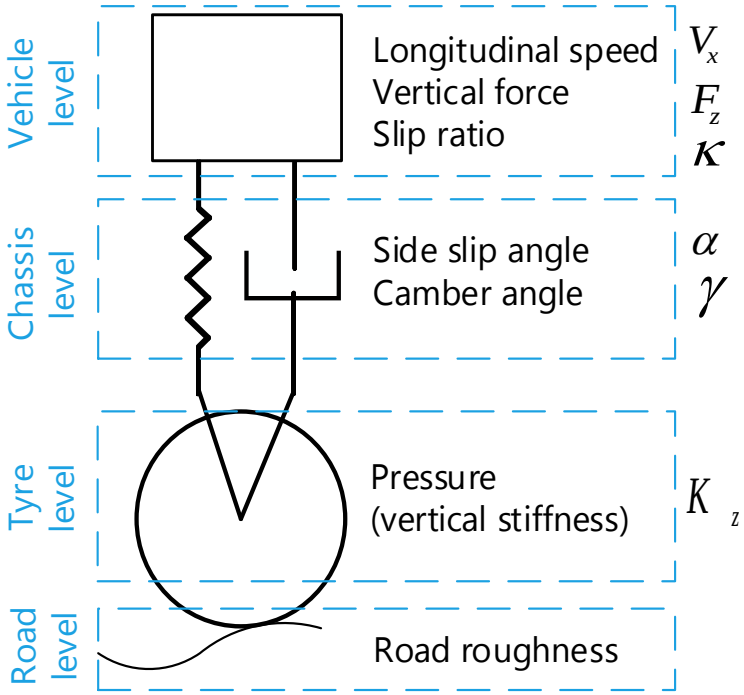

$C = 2 - \frac{2}{\pi} \arcsin \frac{y_a}{D}$
$C = \frac{Bx_m - \tan(\pi/2C)}{Bx_m - \arctan(Bx_m)}$ (C>1)
arctan (BCD)



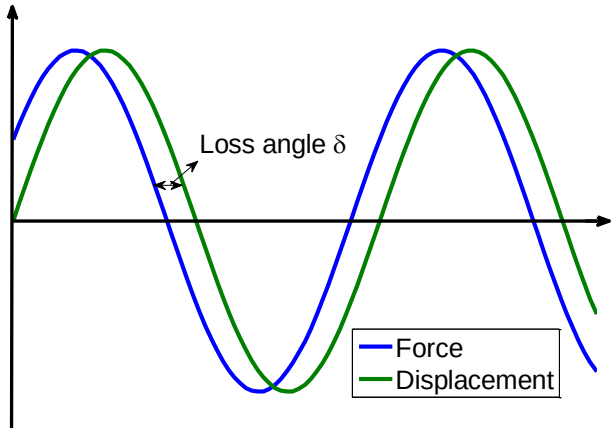


Expectations from the model...

- Be applicable within vehicle dynamics simulations.
- Considering the rolling loss in tyre from a holistic approch.
- Be able to simulate the internal and external losses.



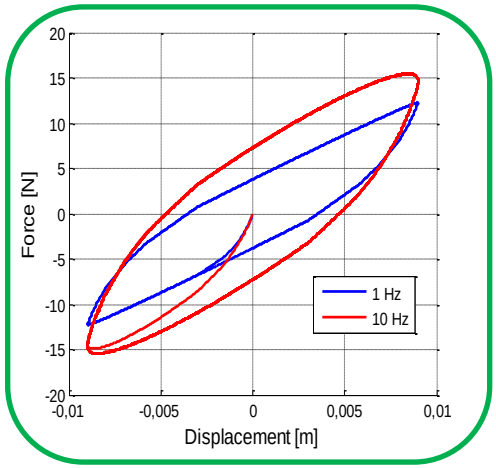
Modelling process: Dissipation modelling

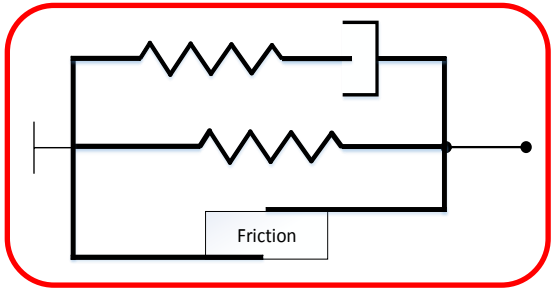


Phase

Viscoelastic modules → Rate dependent

Friction modules → Rate independent



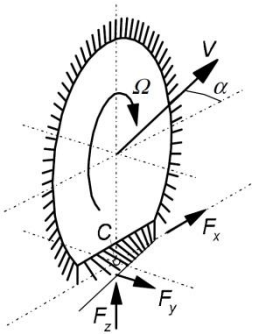


Rubber model

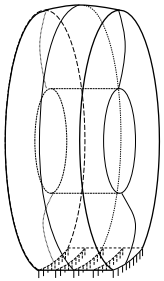
Modelling process: Tyre modelling

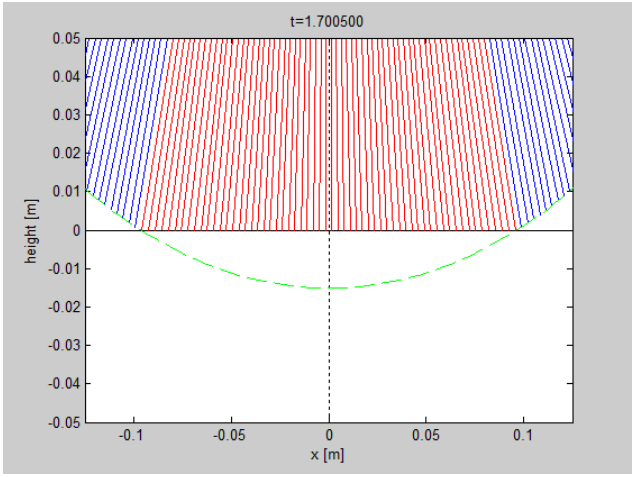
Extended Brush tyre Model (EBM)

Brush tyre theory

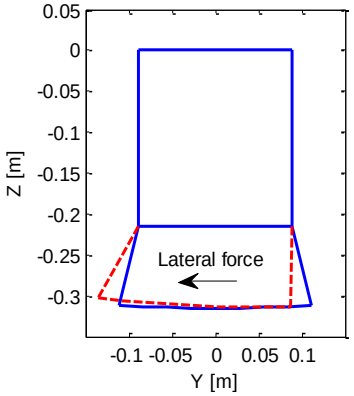


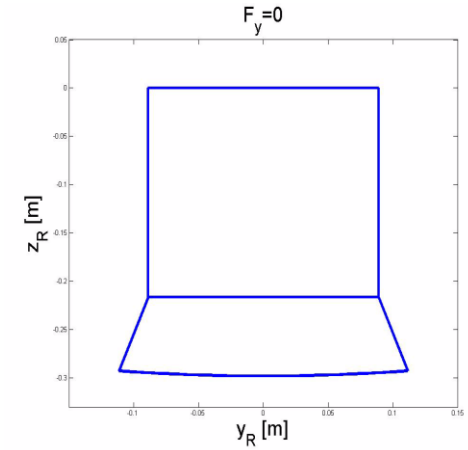
Finite number of lines and bristles





Flexible carcass

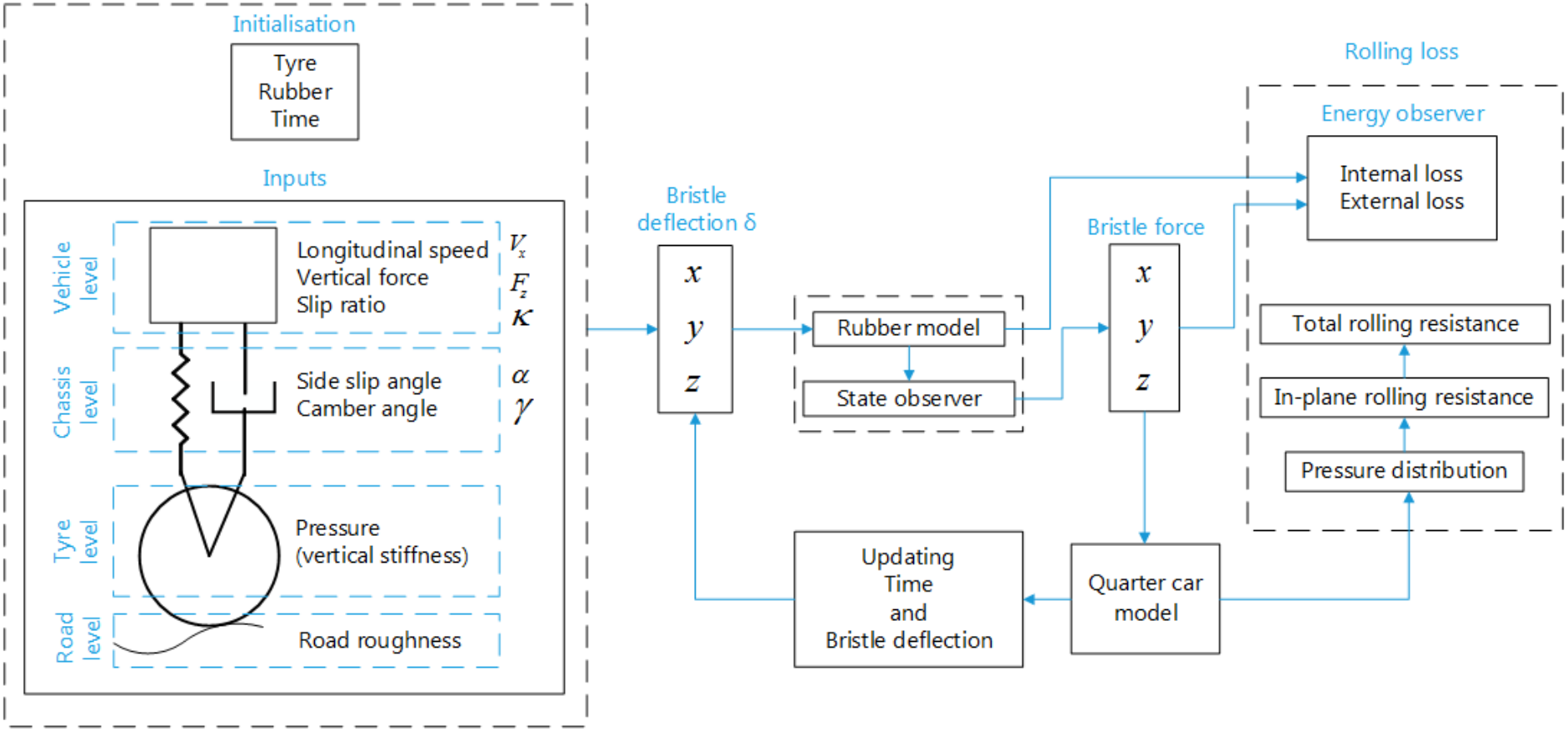




State observer

- Friction ellipse
- Maximum Dissipation Rate Mode (MDRM)

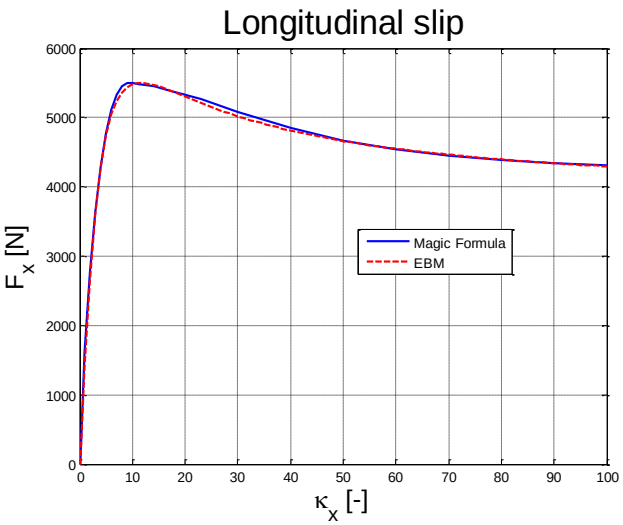
Model algorithm

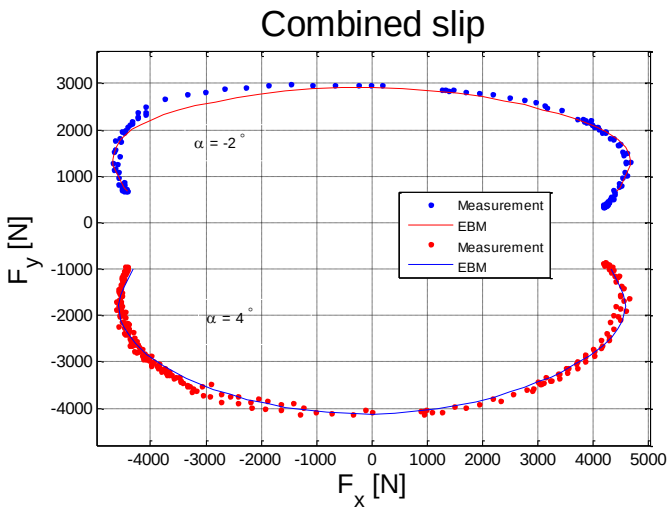


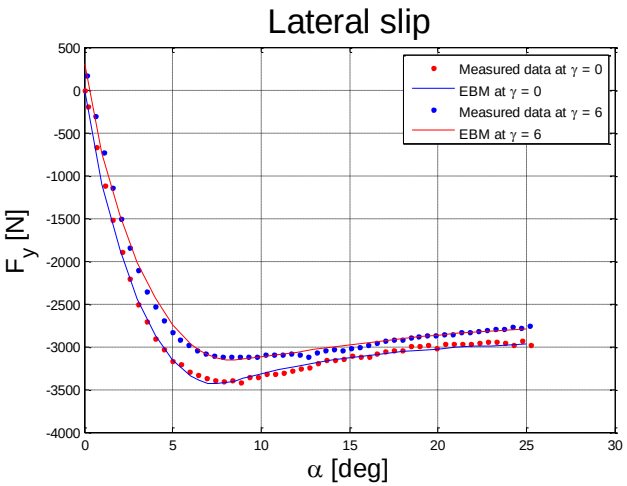
Results

Global forces

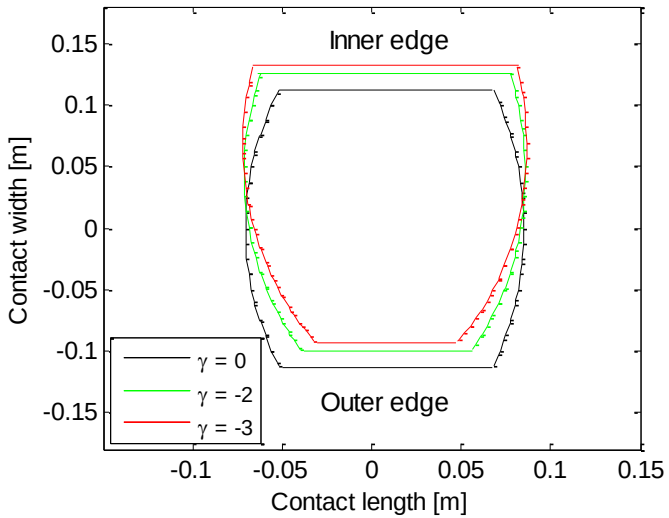
The structural behaviour of the tyre model represented by the global forces shows good fit with measured data and Magic Formula.

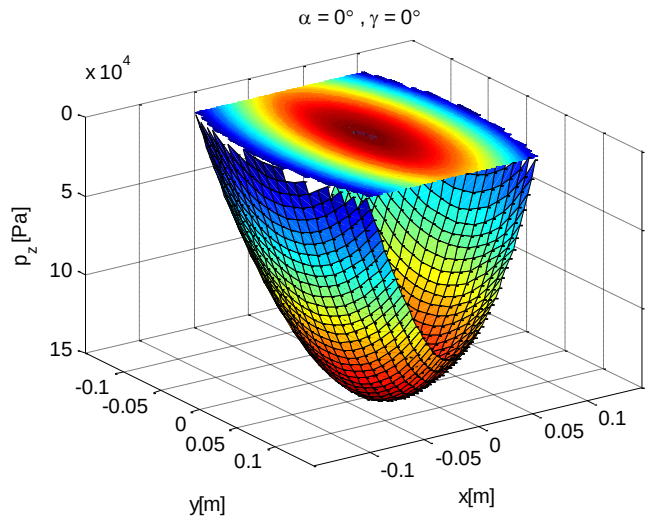


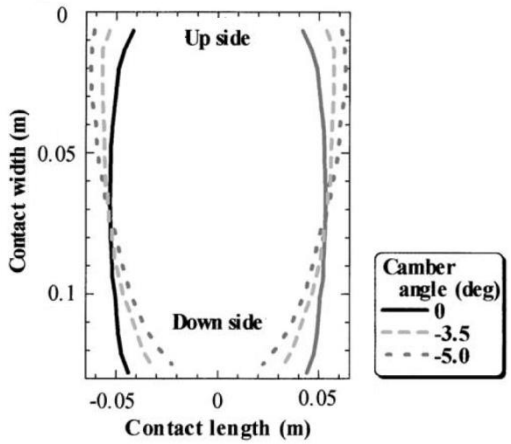


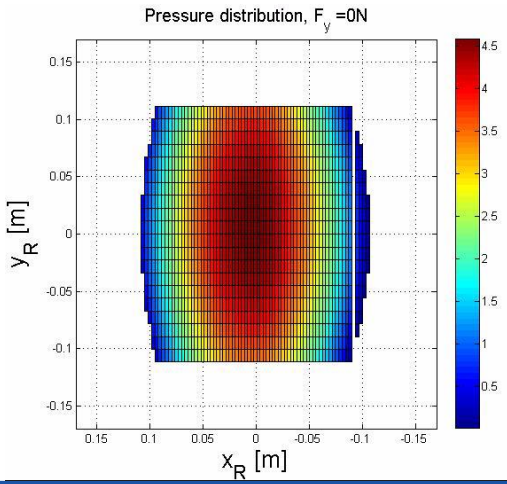


Detailed study of contact patch

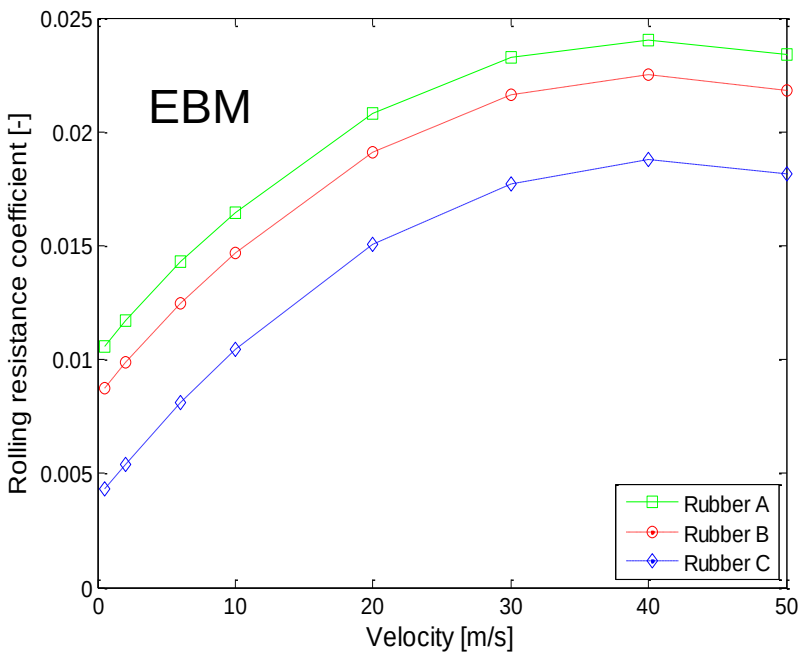


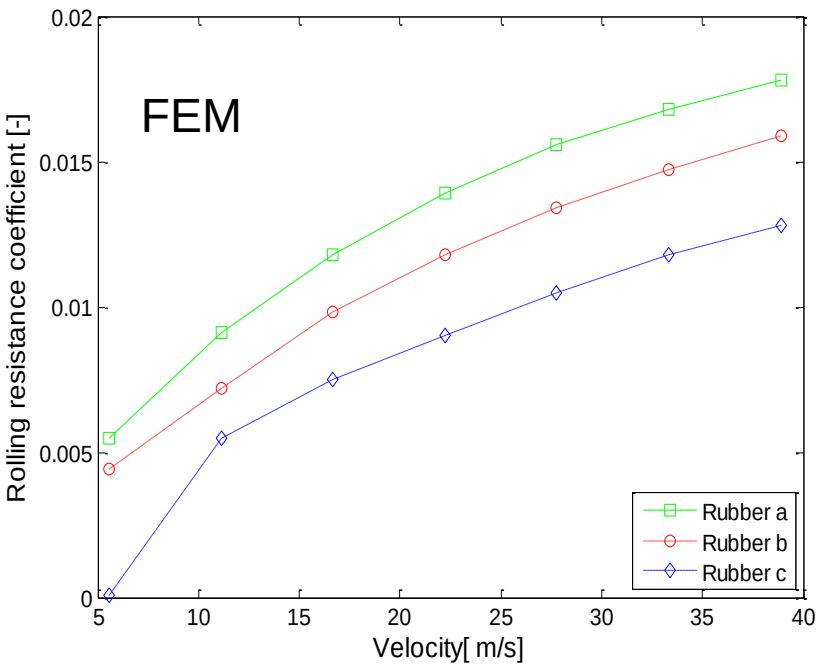




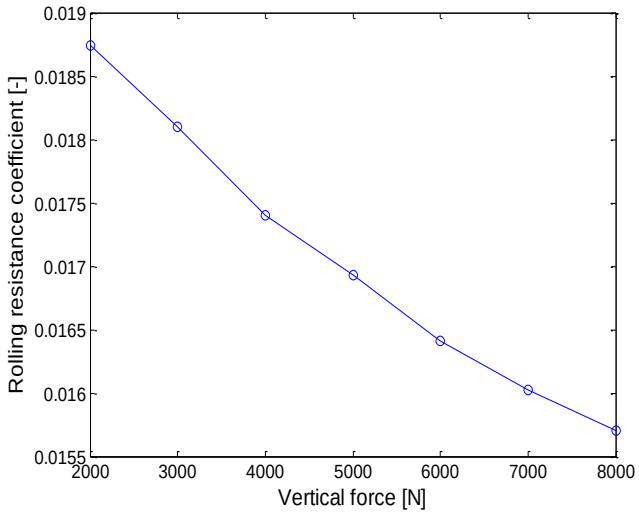


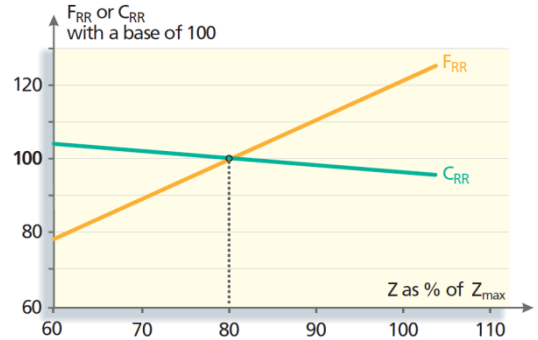
Influence of vehicle level parameters: speed

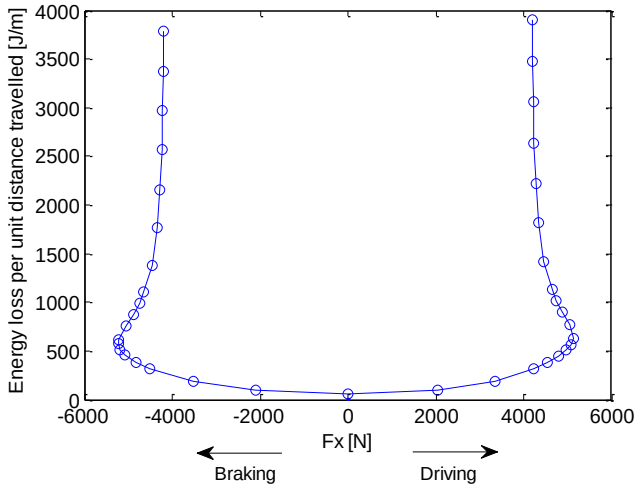


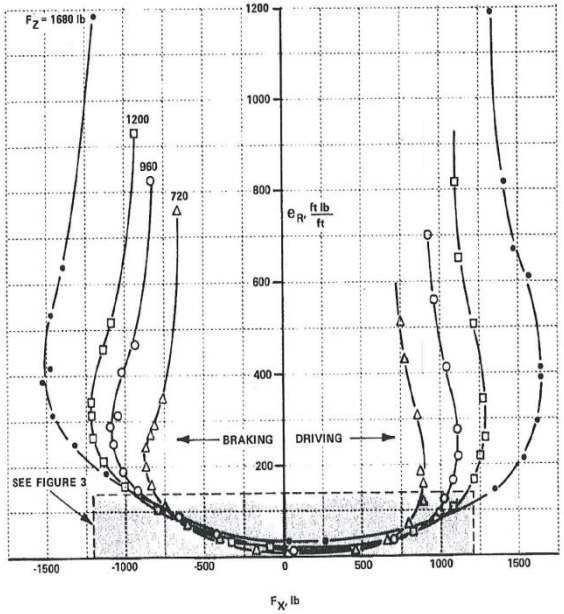


Influence of vehicle level parameters: load and torque

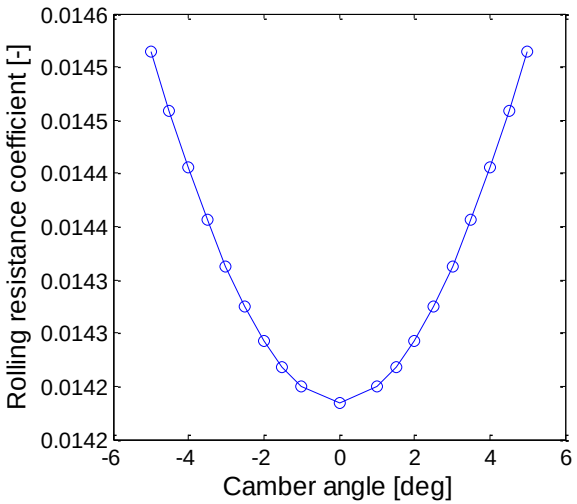


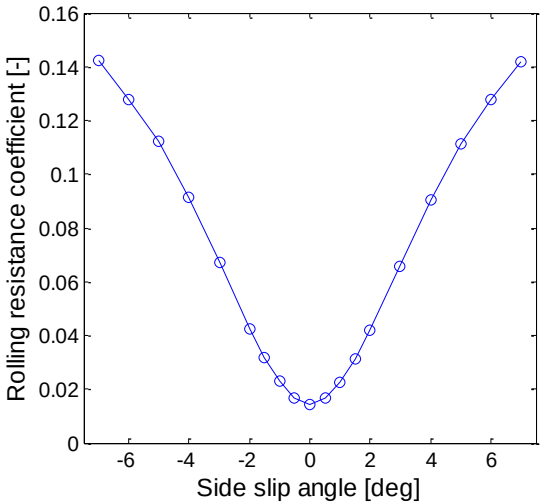


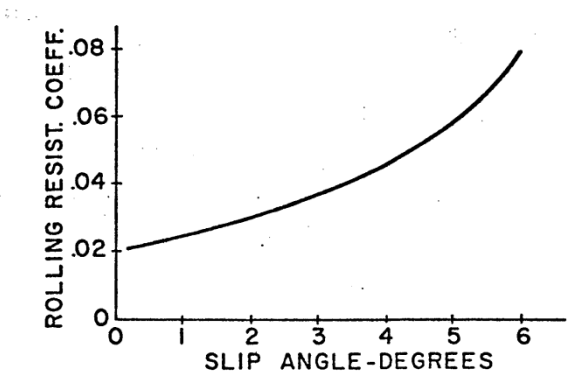


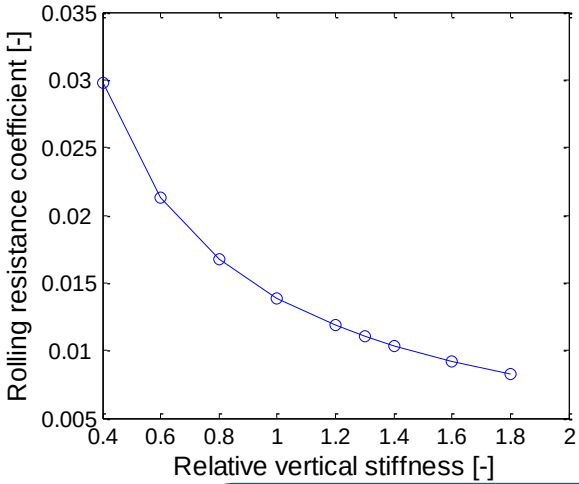


Influence of chassis and tyre level parameters



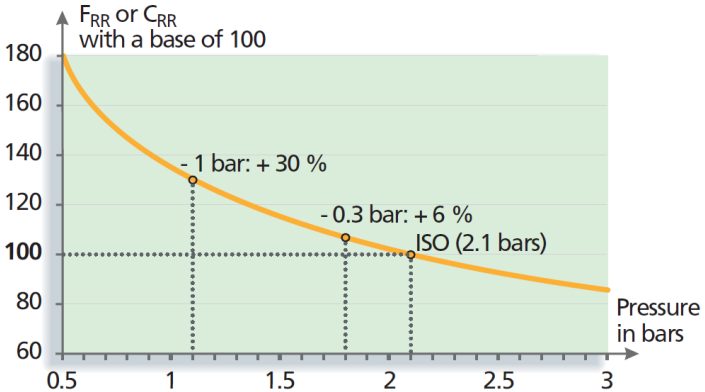




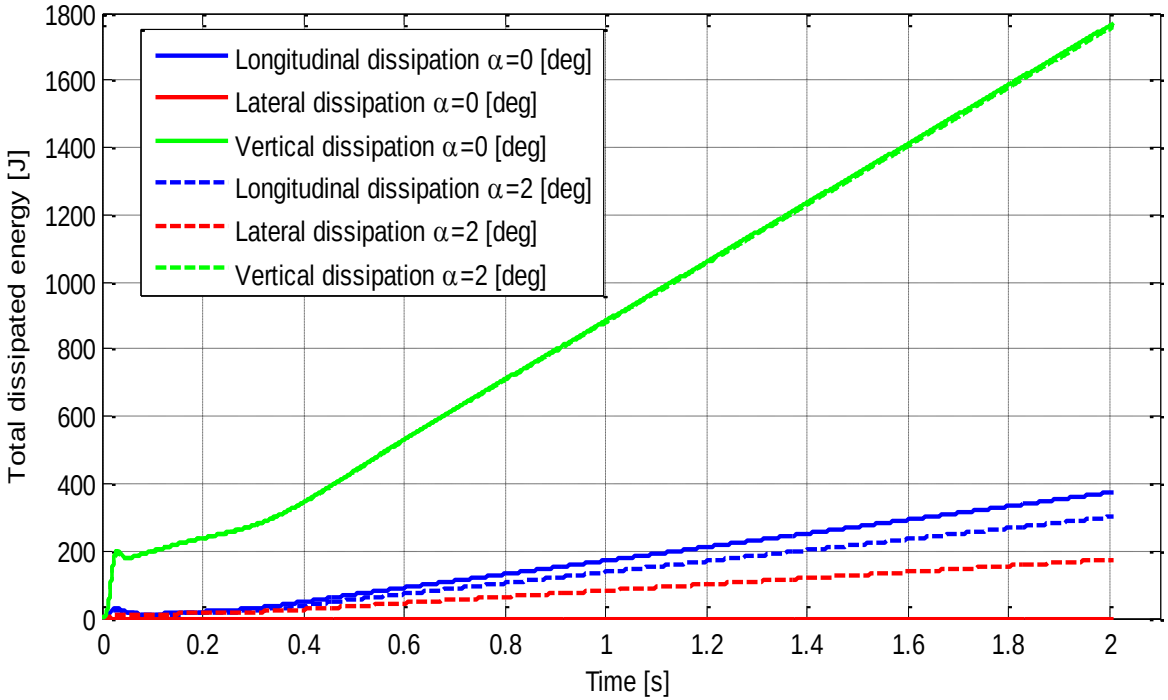


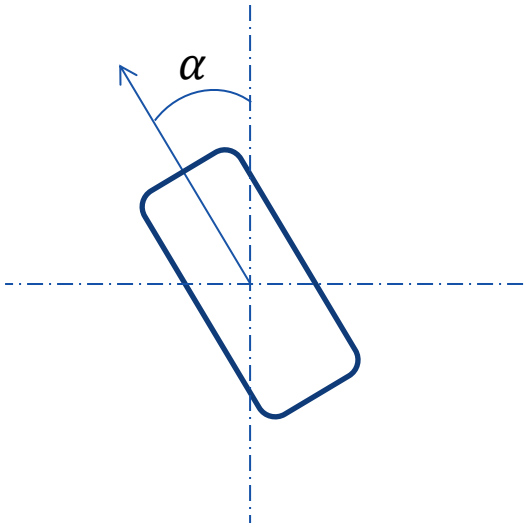
Tyre pressure and vertical stiffness are linearly dependent

$P \propto k_z$

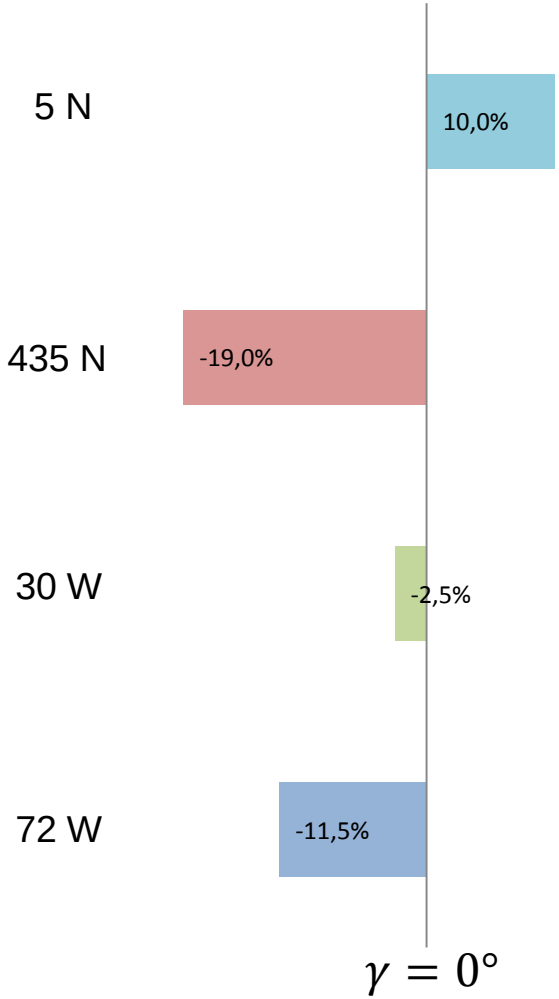


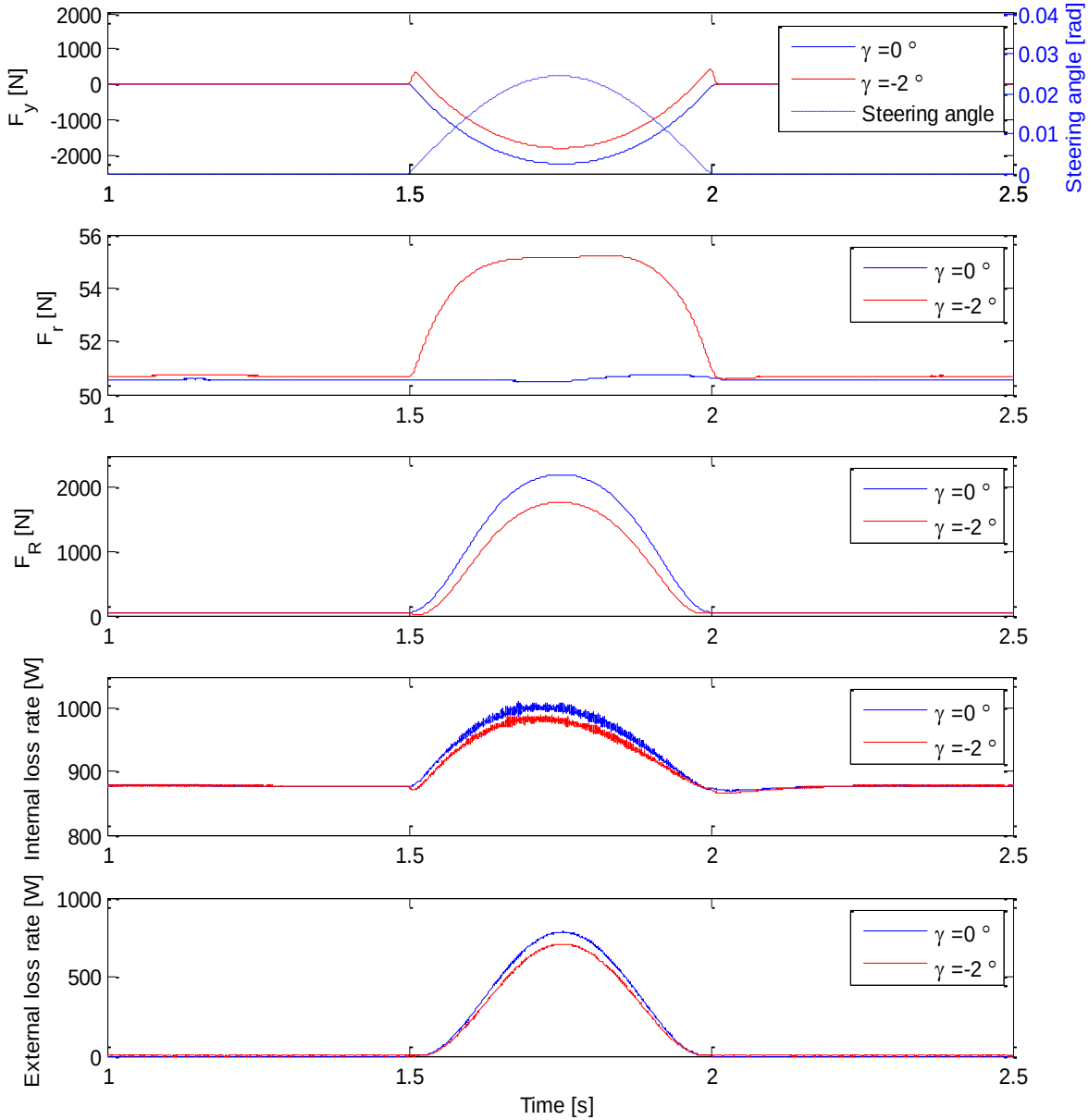
Energy studies

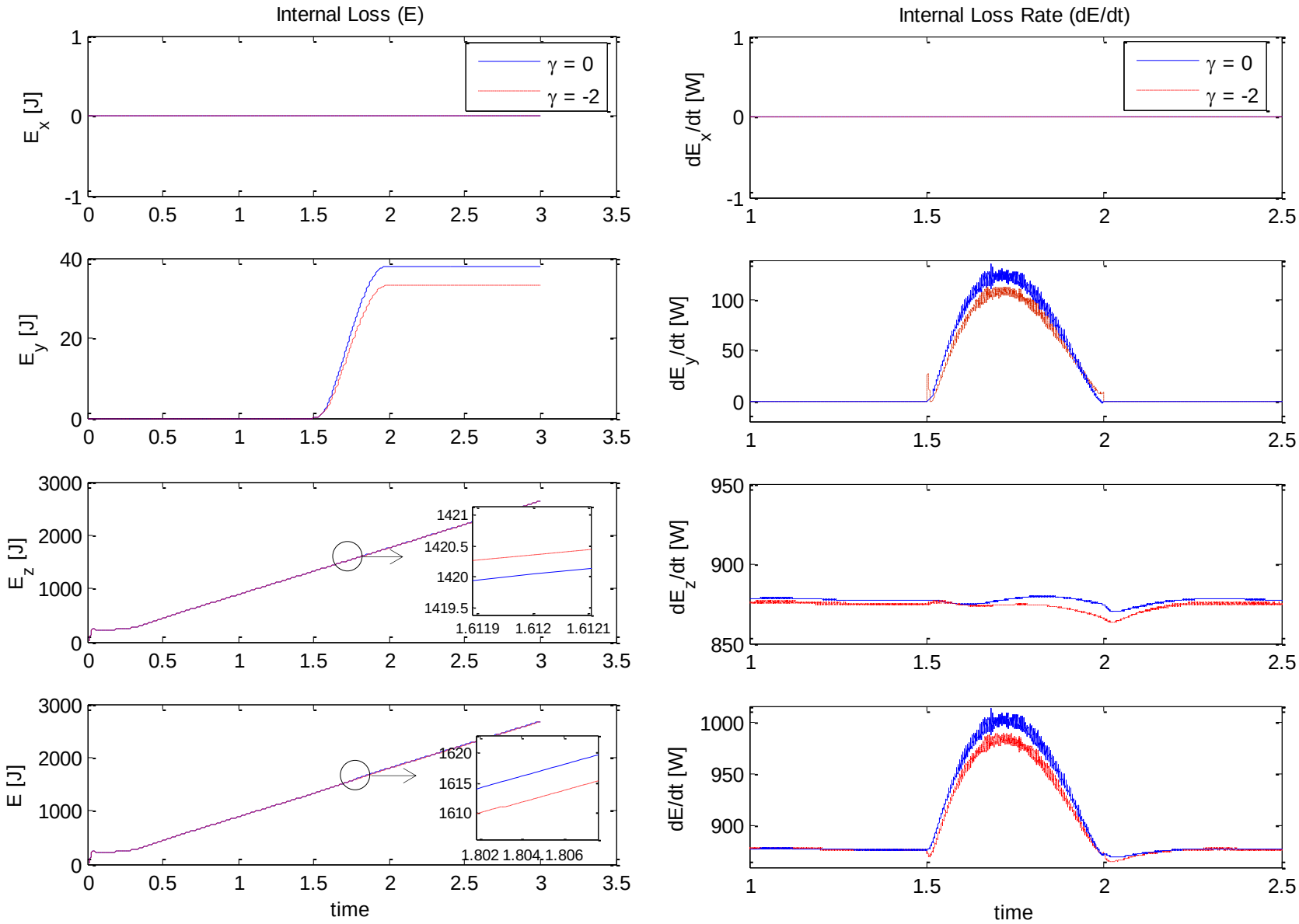




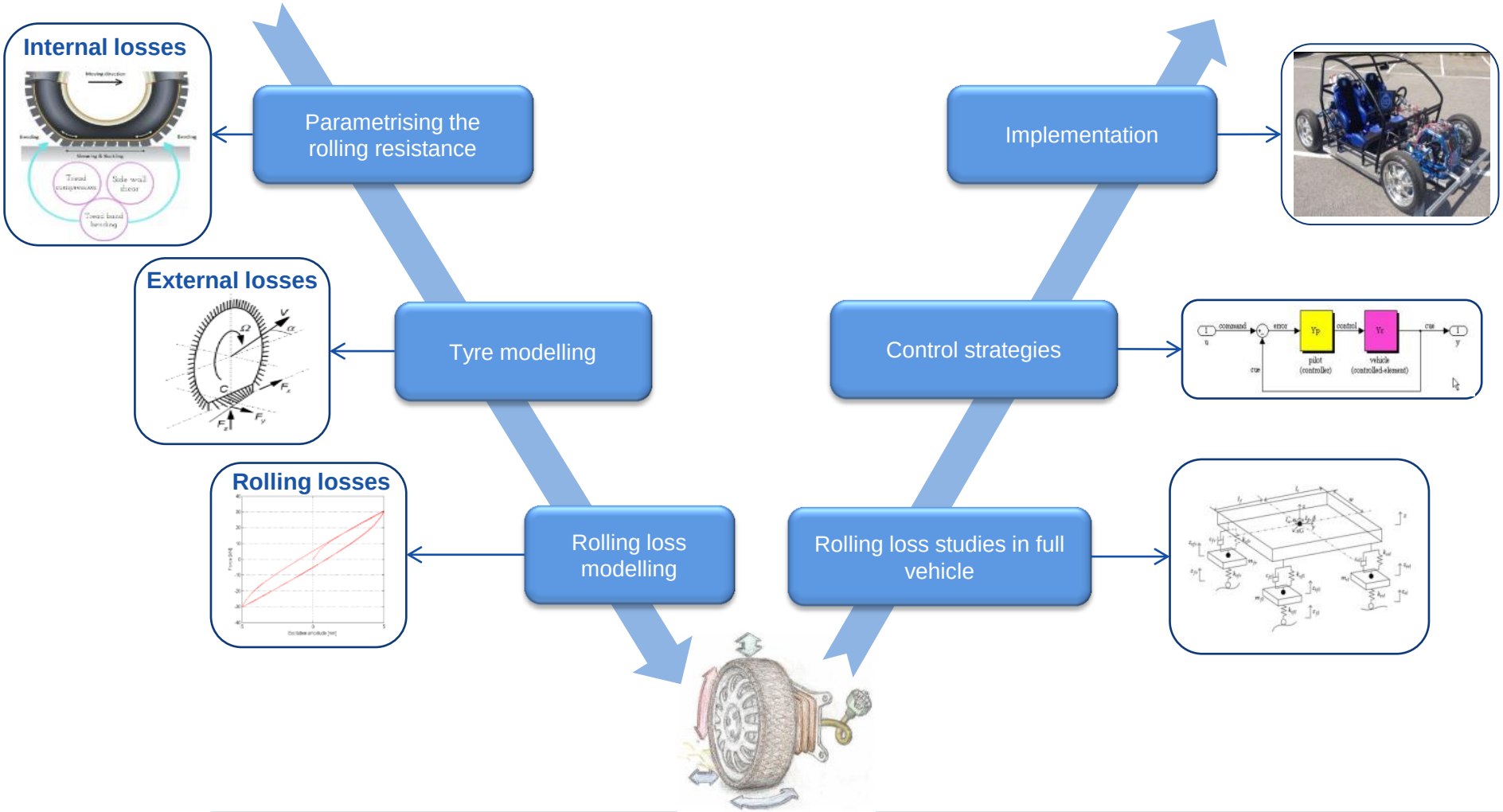
Dynamic maneouvres






Internal Loss (E)
Internal Loss Rate (dE/dt)
γ = 0
γ = -2
E_x [J]
E_y [J]
E_z [J]
E [J]
dE_x/dt [W]
dE_y/dt [W]
dE_z/dt [W]
dE/dt [W]
time
time

Summary and future work



Conclusion

- A tyre model to investigate the rolling loss is presented.
- The presented model kept simple but is still applicable to analyse the tyre behavior, in terms of global forces and moments.
- The model provides a detail understanding of rolling loss under different driving conditions.
- Dependency of the in-plane rolling resistance on vehicle inputs, wheel alignment and tyre parameters is investigated.
- The model can be used for a detailed study of contact patch.
- A holistic approach to study the tyre rolling loss is presented.
- A platform for investigating the effect of road roughness on rolling loss.
- Facilitating the tyre wear studies using the presented model.

Thank you for your attention!

... research where ECOlogy & ECOnomy meet

www.eco2vehicledesign.kth.se