Challenges in Tire FEM Simulation

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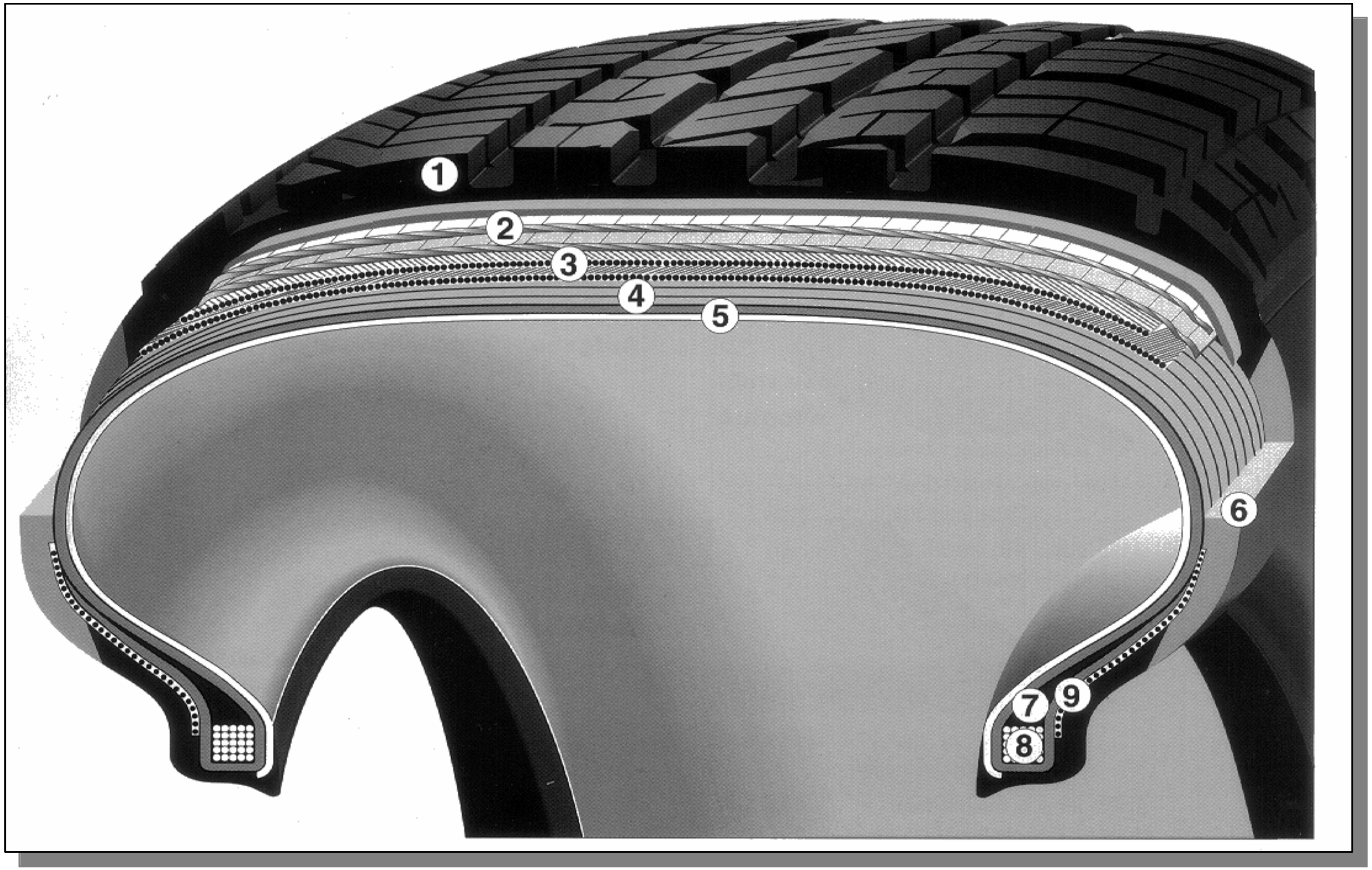
Tire Components

1. Tread
2. Cap ply
3. Belt
4. Carcass ply
5. Inner liner
6. Side wall
7. Apex
8. Bead
9. Bead reinforcement



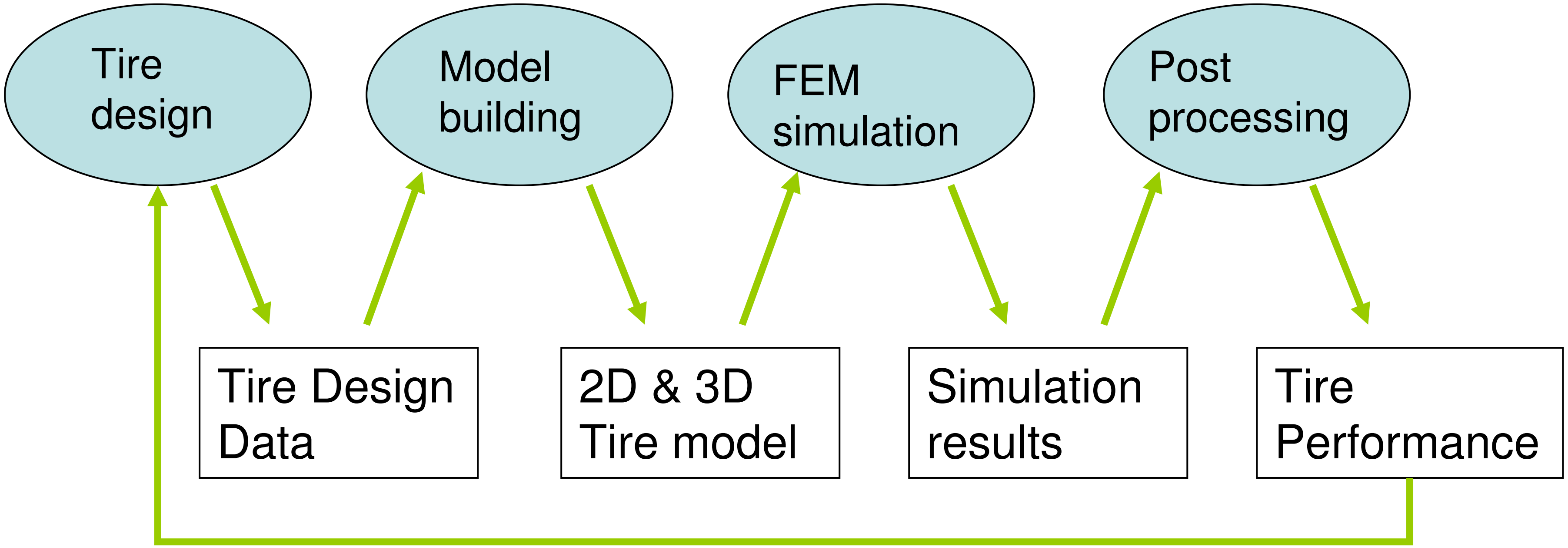
History

- 1970s: FEM tire simulation started at Continental AG
  => 2 dimensional simulation for tire inflation, and tire shape change under high rotational speed.
- 1980s: Static 3d simulation
  => Tire footprint shape can be predicted. Inter-ply shear for tire durability. Tire vibration model.
- 1990s: Rolling tire simulation
  => Tire footprint under rolling condition. Tire force & moment prediction for combining tire in to a vehicle model.
- 2000s: New developments:
  - More accurate material: Viscoelastic parameter.
  - More accurate geometry: Tire model with tread pattern; Tire model combined with rim and air.
  - More accurate load condition: Tire service matrix used in simulation.

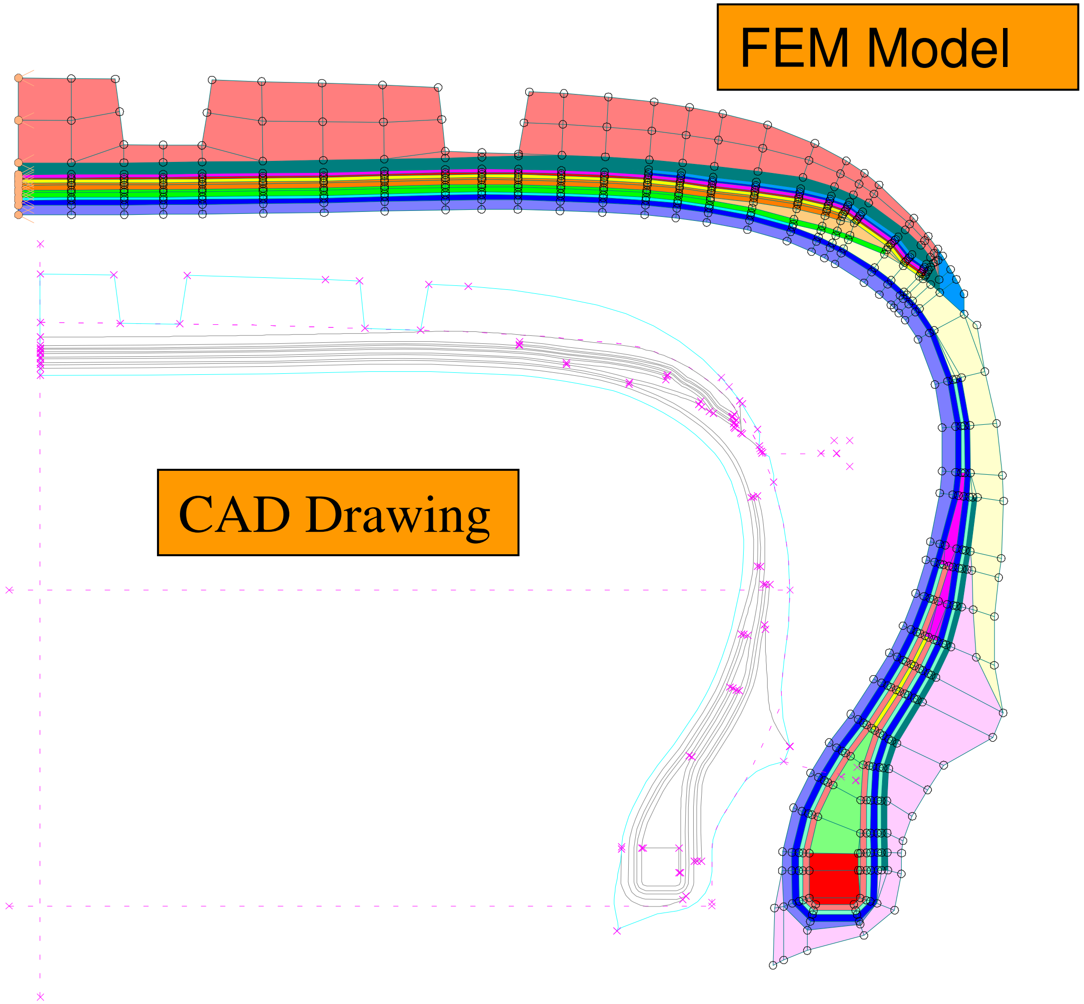
The focus for tire FEM simulation

- Durability
  Ensure tire will not fail during the life of a tire.
- Tread wear
  Tire tread should be worn as even as possible and as long as possible.
- Environmental concerns
  Reduction of tire rolling resistance.
- Vehicle handling
  Tire fitted to vehicle to provide best braking, traction and emergency handling.
- Vehicle comfort
  Tire with optimized Noise, Vibration and Harshness (NVH) performance.

Tire simulation steps



Model Generation



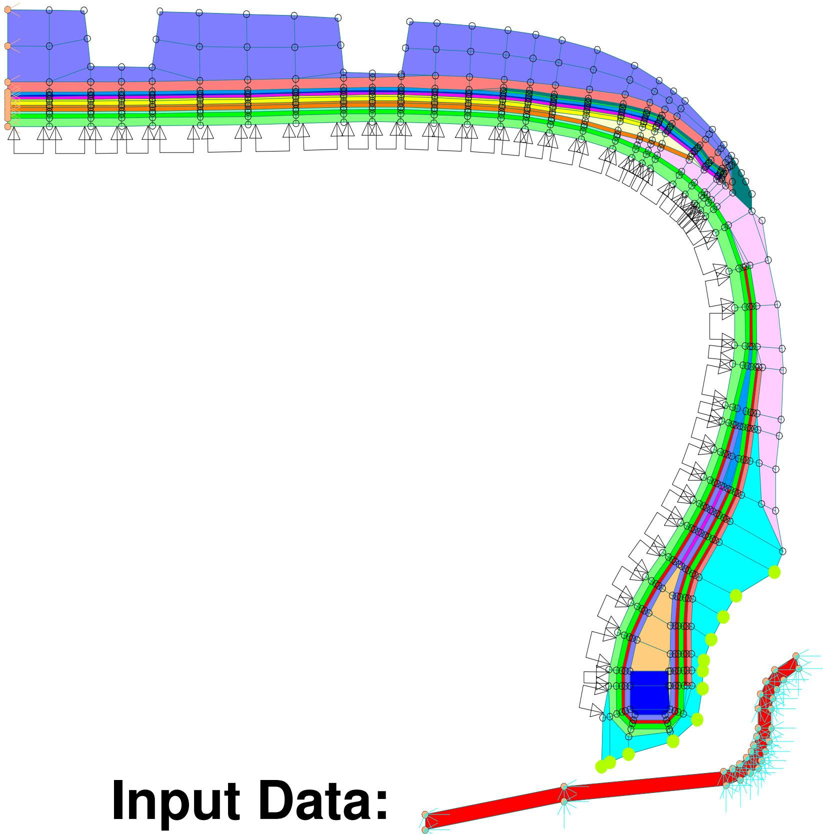
Rubber compounds

- Tread
- Inner liner
- Side wall
- Apex
- Coating of cord

Cord material

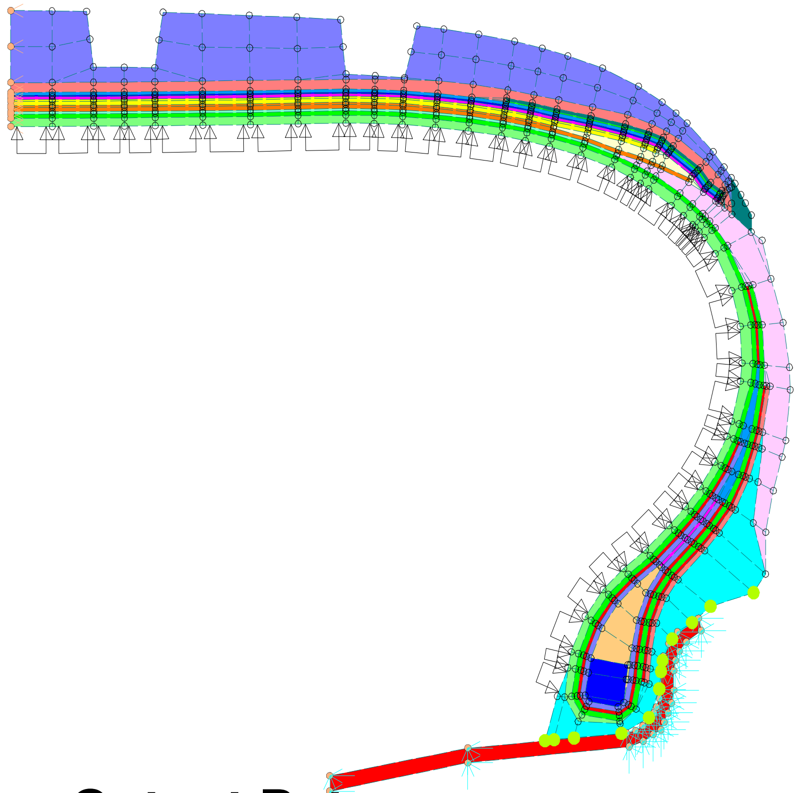
- Carcass
- Belt
- Cap ply
- Bead
- Bead reinforcement

2D simulation



Input Data:

- Rim contact
- Inner pressure
- Centrifugal loading



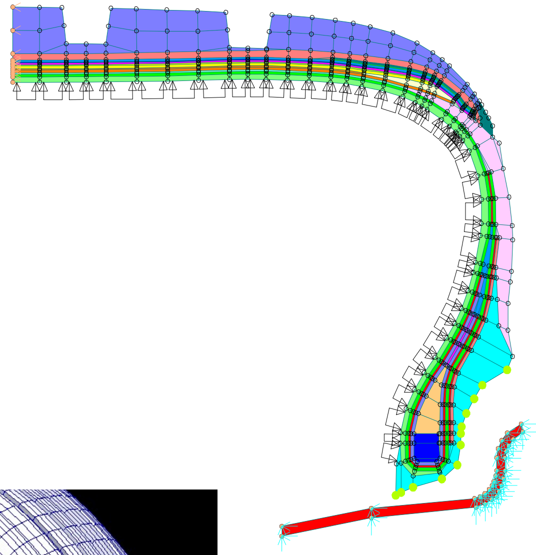
Output Data

- Resulting geometry
- Dynamic contour
- Force on rim

Tire Simulation

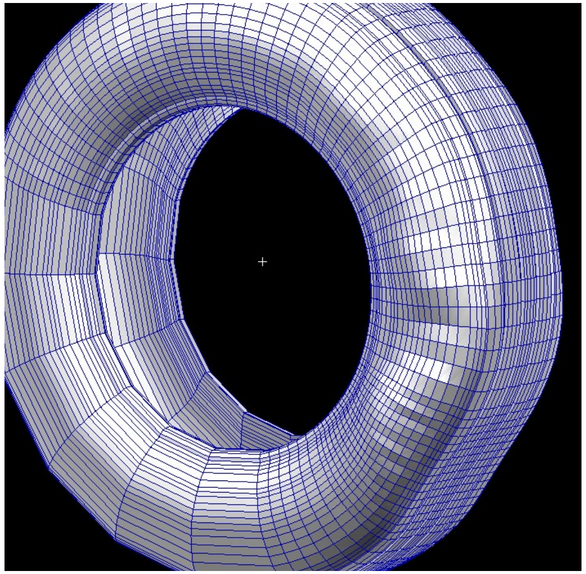
FEM features:

- Incompressible non-linear material
- Composite material
- Contact between tire/rim and tire/road
- Large deformation
- Rolling dynamic

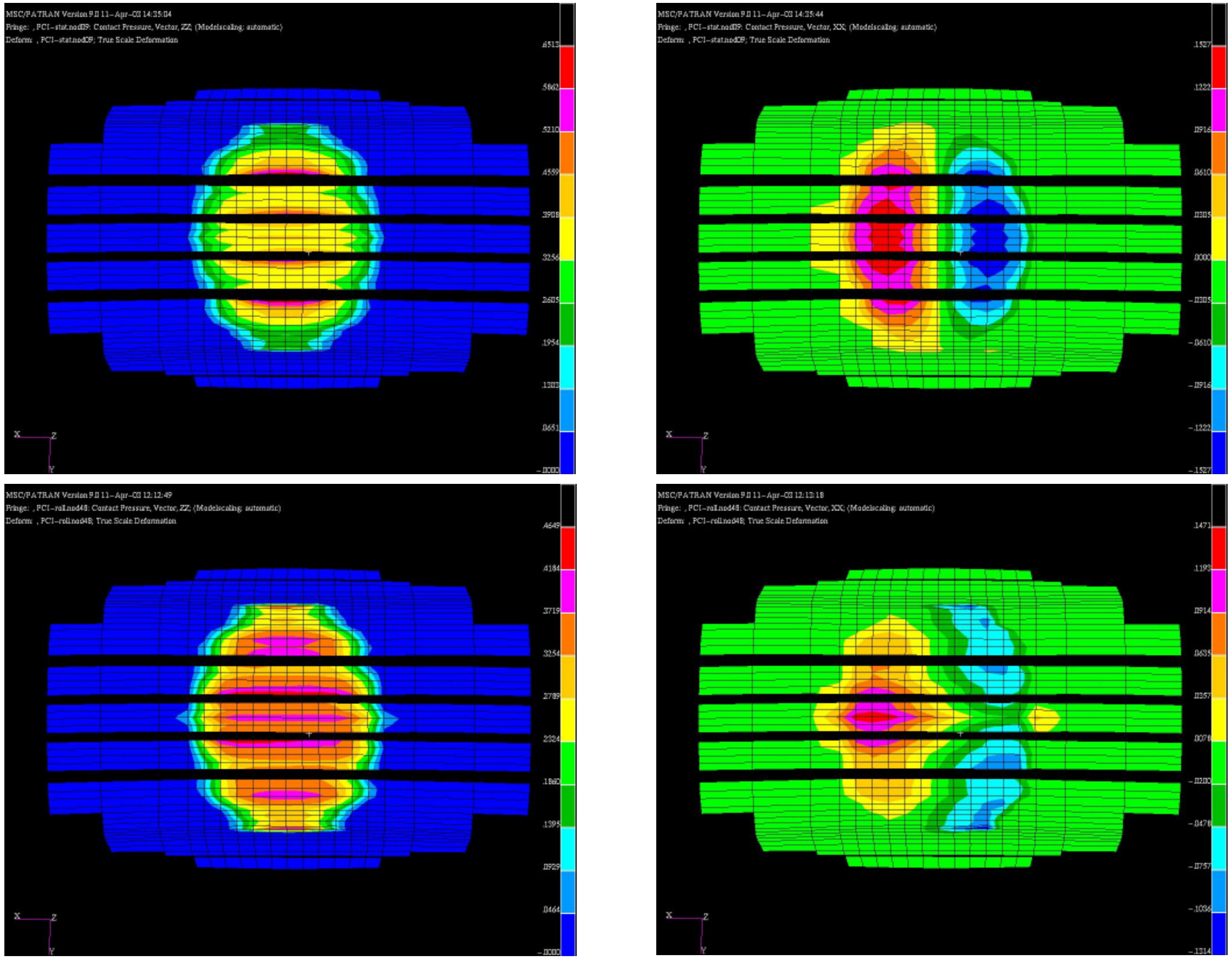


Investigation parameters:

- Tire construction
- Material parameters
- Inner pressure
- Tire speed and load
- Tire camber and slip angles



Tire footprint results



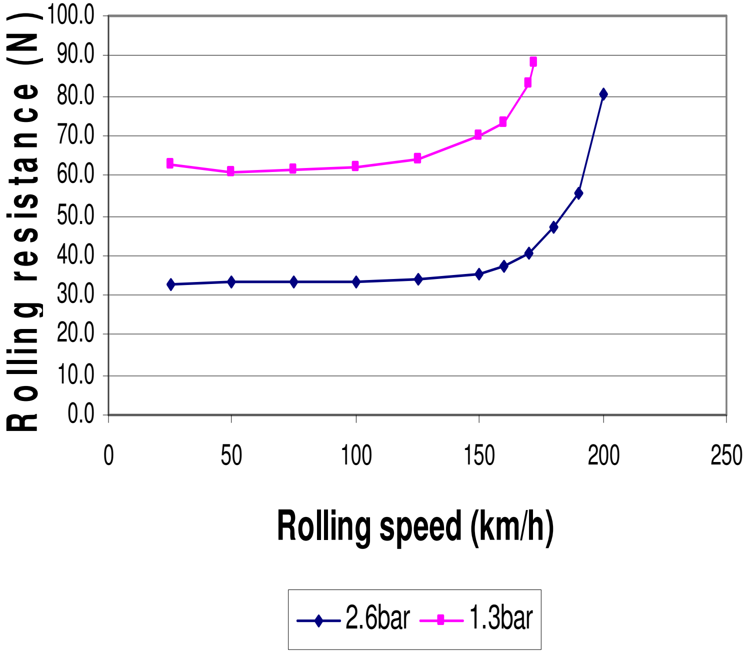
Static Simulation

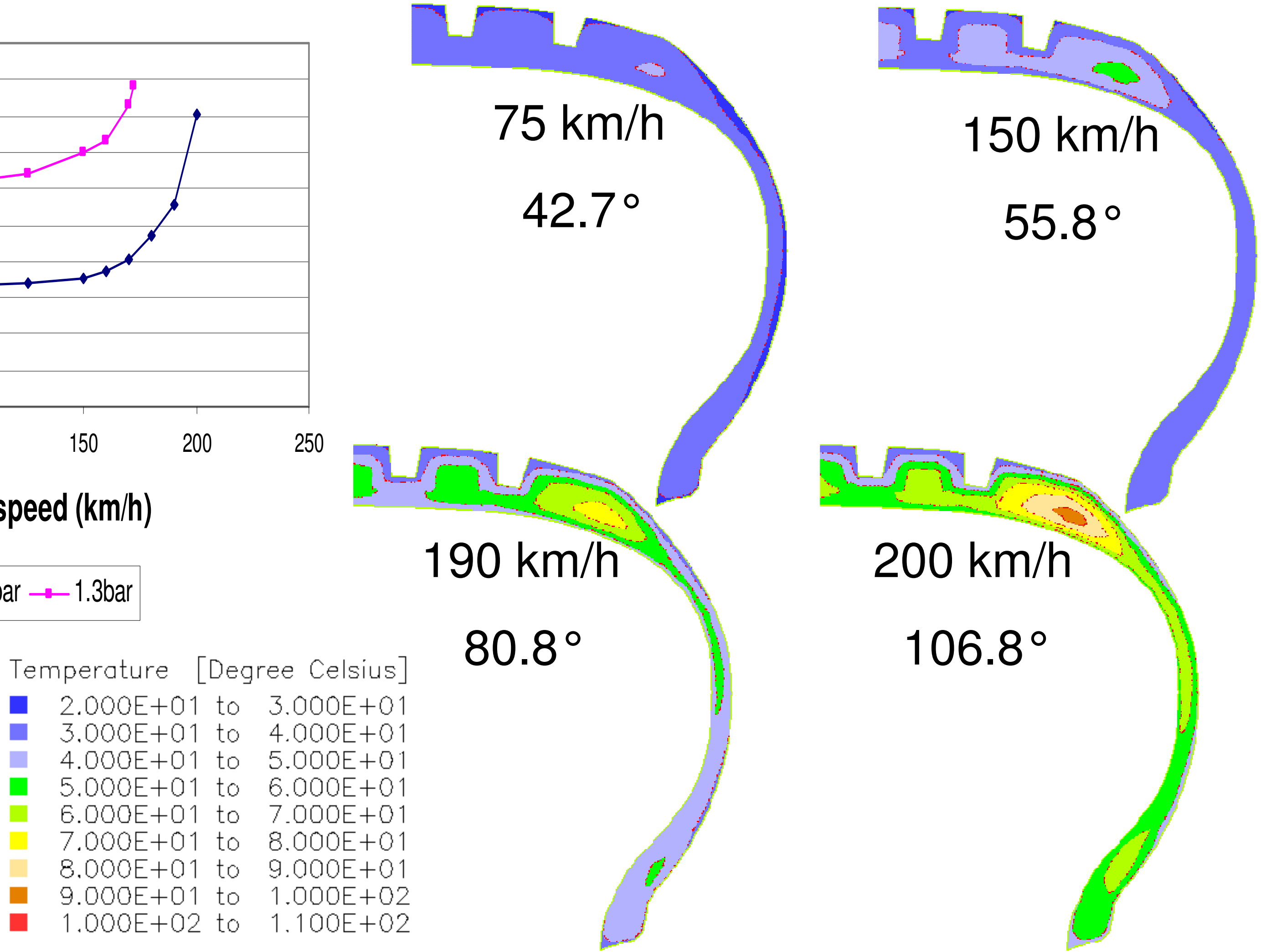
Rolling Simulation

Contact Pressure

Longitudinal frictional Stress

Temperature inside a tire due to energy dissipation

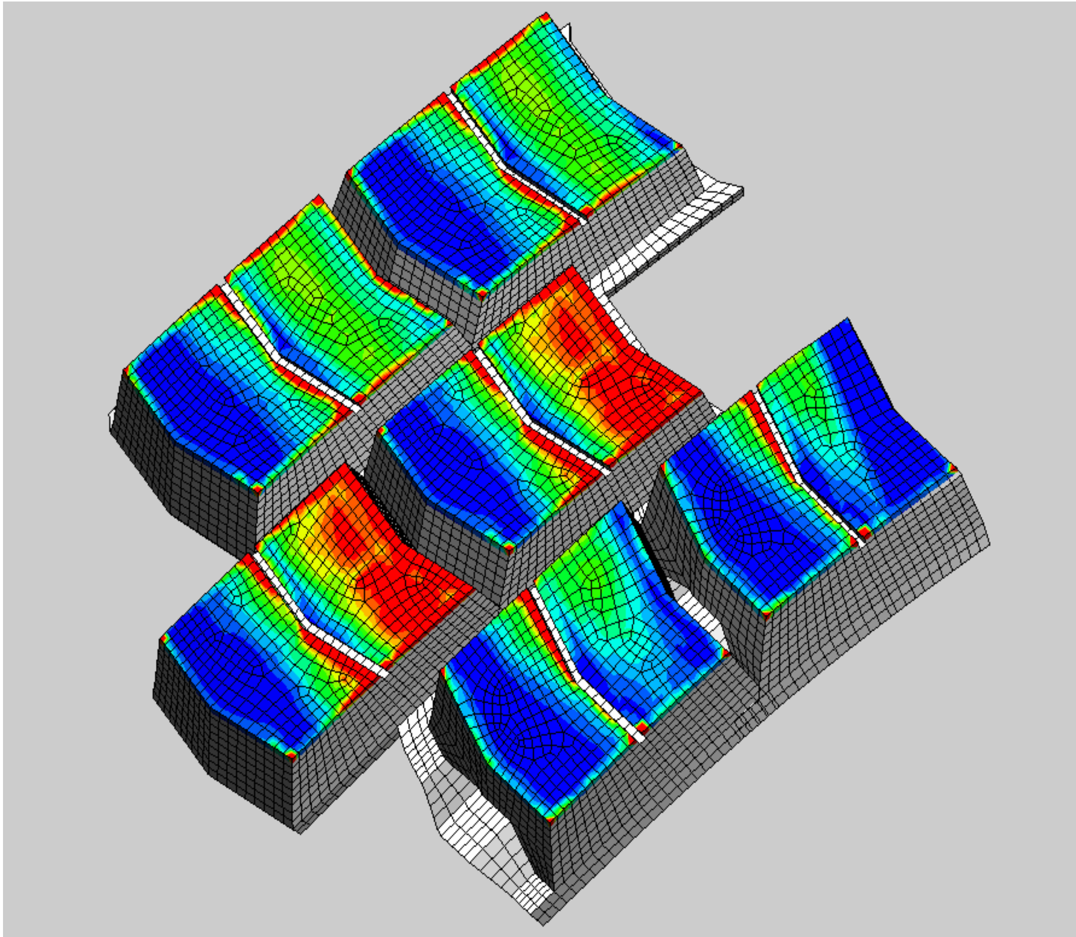




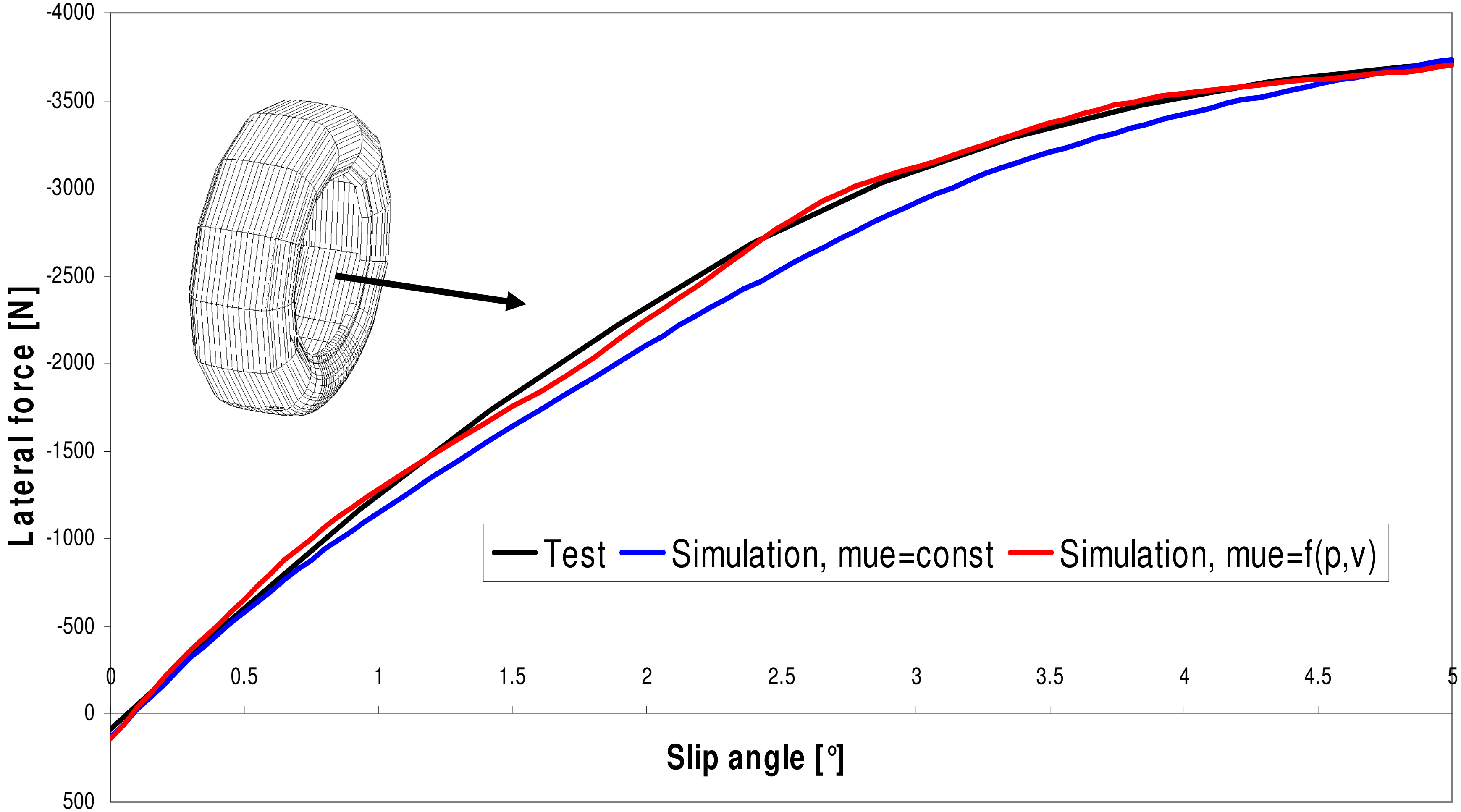
Tread pattern irregular wear

We are able to predict frictional energy of block patterns

➔ Prognosis for heel & toe wear (Sägezahnabrieb)



Tire lateral force vs. slip angle

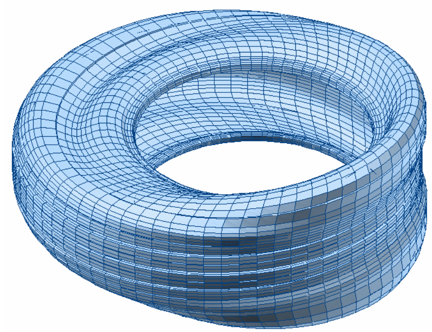


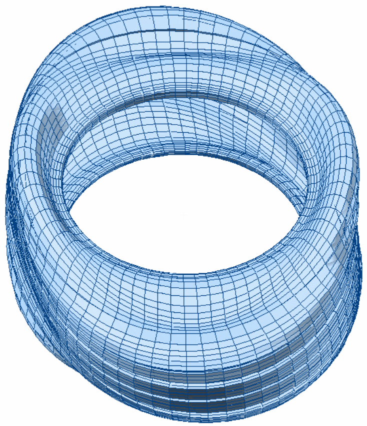
Tire Vibration – modal analysis

Tire noise and vehicle comfort is affected by tire construction.

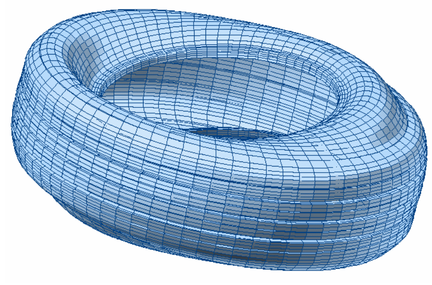
Vibrations can be predicted by FEM.

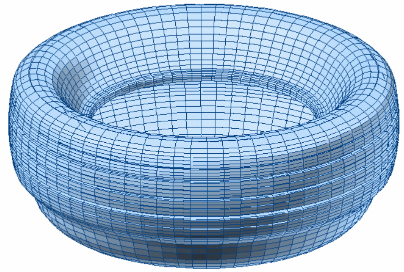
Radial Modes

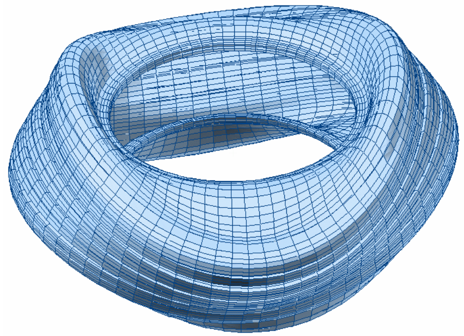




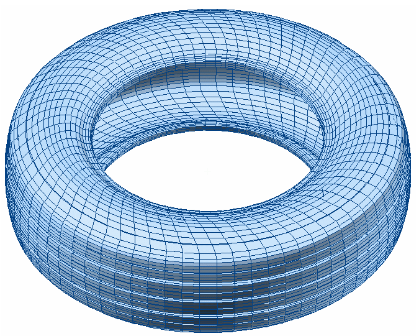
Bending modes







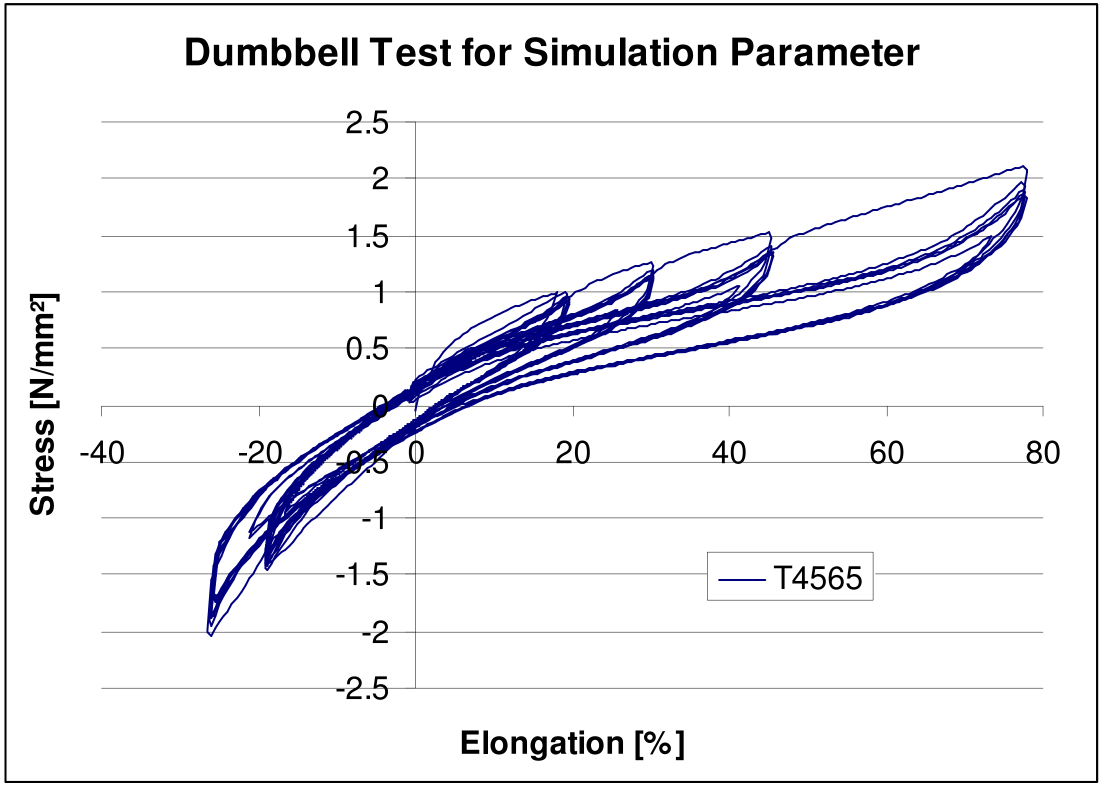
Torsion mode



Challenge: Better Rubber Material model

Rubber Characteristics:

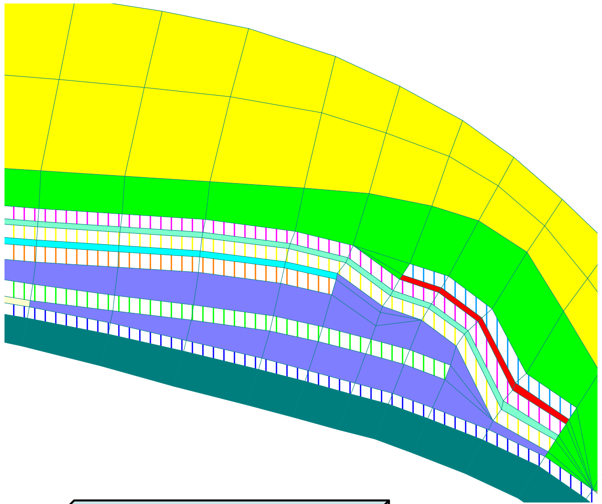
- Incompressible
- Non-linear
- Viscoelasticity
- Loading history dependency
- Ageing

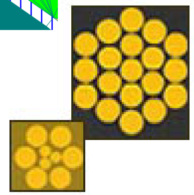


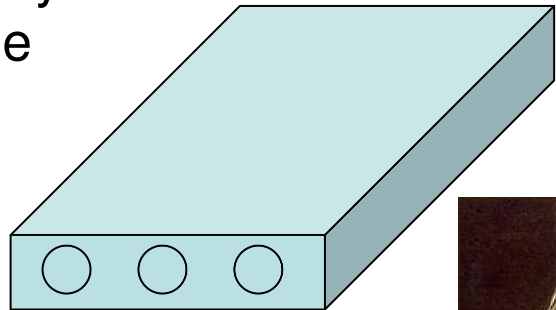
Can we find a material model to represent behavior of rubber?

Challenge: Modeling of belt and cord

- Tire belt and ply is made of tire cord embedded in rubber matrix specific end count.
- The cord is made of two or more steel or polymer cord twisted according to specific design.
- How to model the belt so we not only how the average stress but also the true stress between cord?
- How to model the cord, especially when it is under compression?



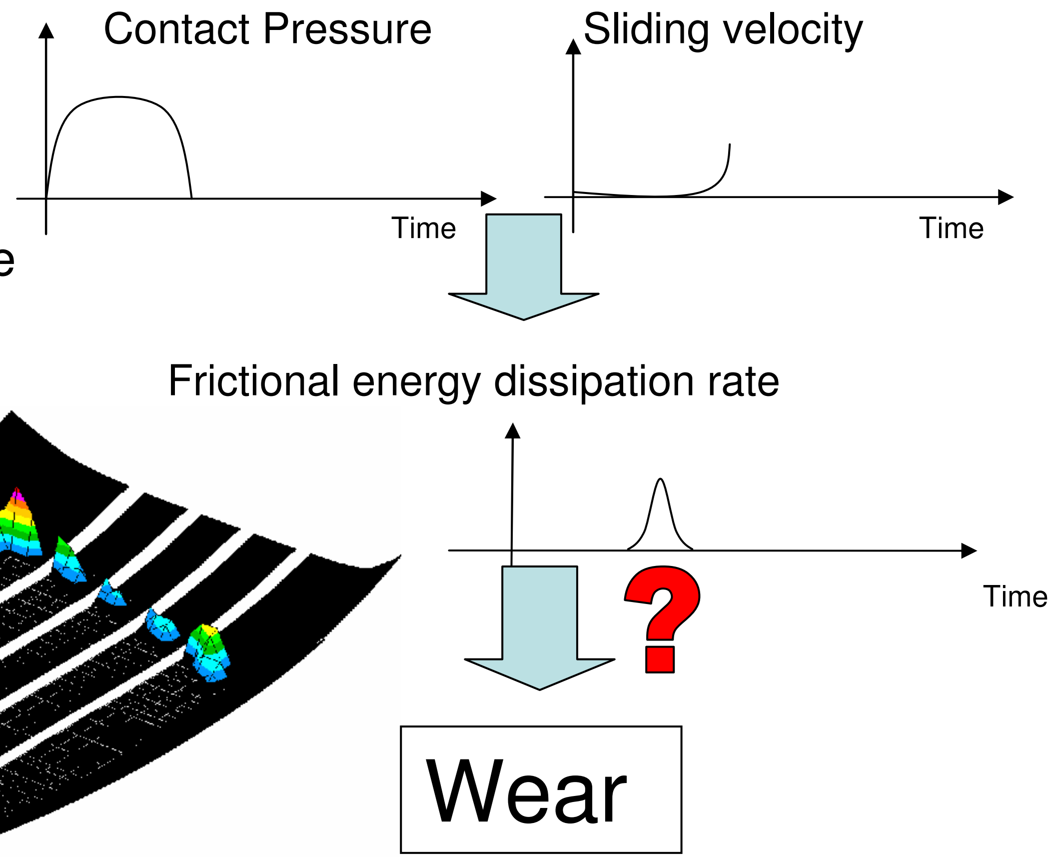


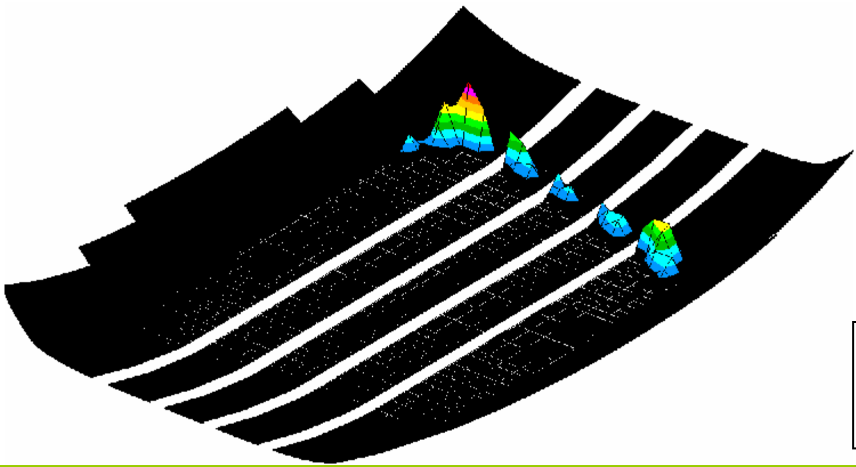


Can multi-scale simulation help?

Challenge: Rubber abrasion model

- Abrasion rate dependent on contact pressure, sliding velocity, temperature, etc.
- Rubber slide for a very short time for each tire revolution where none of above parameters are easily determined by measurement.



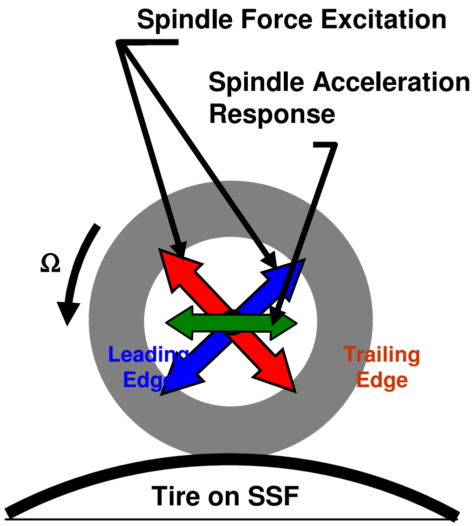


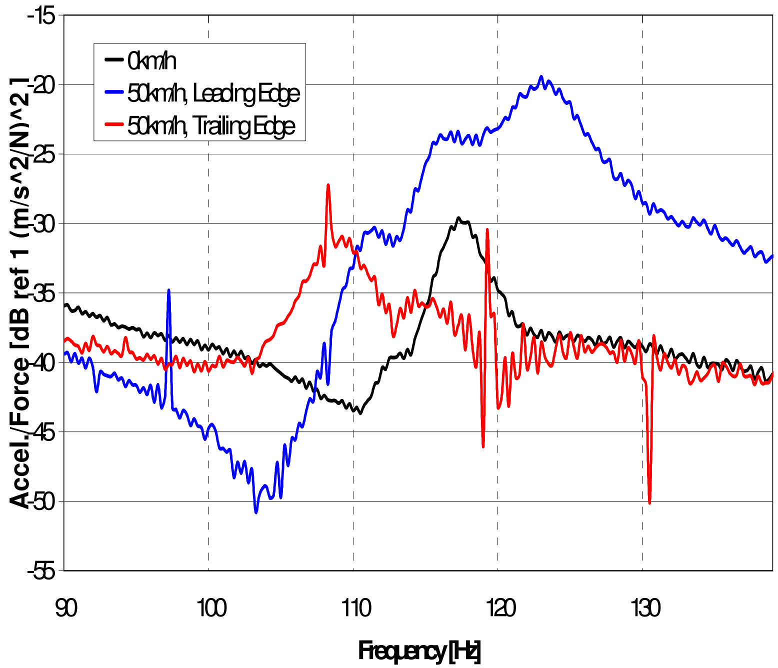
Can we find an abrasion model and define test method to measure its parameters?

Challenge: Rolling tire vibration

- Rolling tire and standing tire show clearly difference in vibration.
- Gyroscopic effect for rolling tire cannot be represented in standing tire model.
- How to model the boundary condition on the contact area?

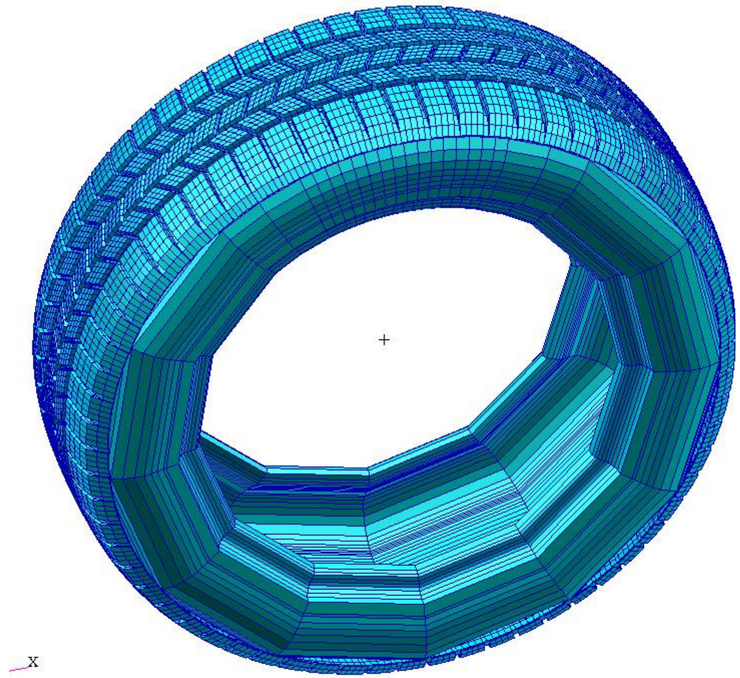
$$\left(\mathbf{K}+\mathbf{K}_i+\mathbf{K}_d+\mathbf{K}_f\right)\delta\mathbf{u}+\left(\mathbf{C}+\mathbf{C}_i+\mathbf{C}_f\right)\delta\dot{\mathbf{u}}+\mathbf{M}\delta\ddot{\mathbf{u}}=\Delta F$$





Challenge: Modeling of Tread Pattern

- Tire tread pattern is important for many tire performances such as traction, wear, hydroplaning, noise and vibration.
- Tire tread pattern has strong interaction with the road, and water, snow, mud, etc on the road.
- Full transient dynamic simulation coupled with water/snow/mud will be economically impossible to do.

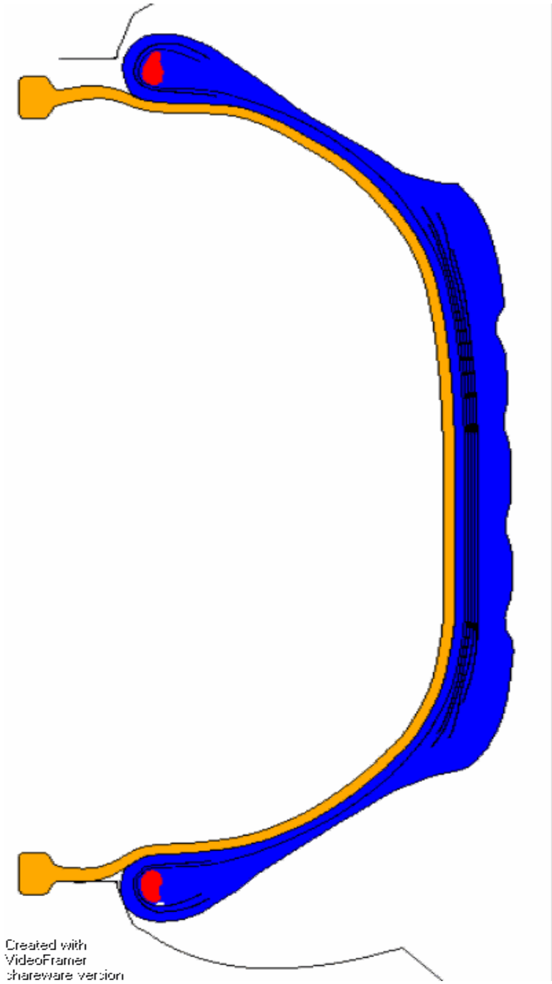


How to simplify the model/simulation procedure to save time yet still produce meaningful results?

Challenge: What is really inside a tire

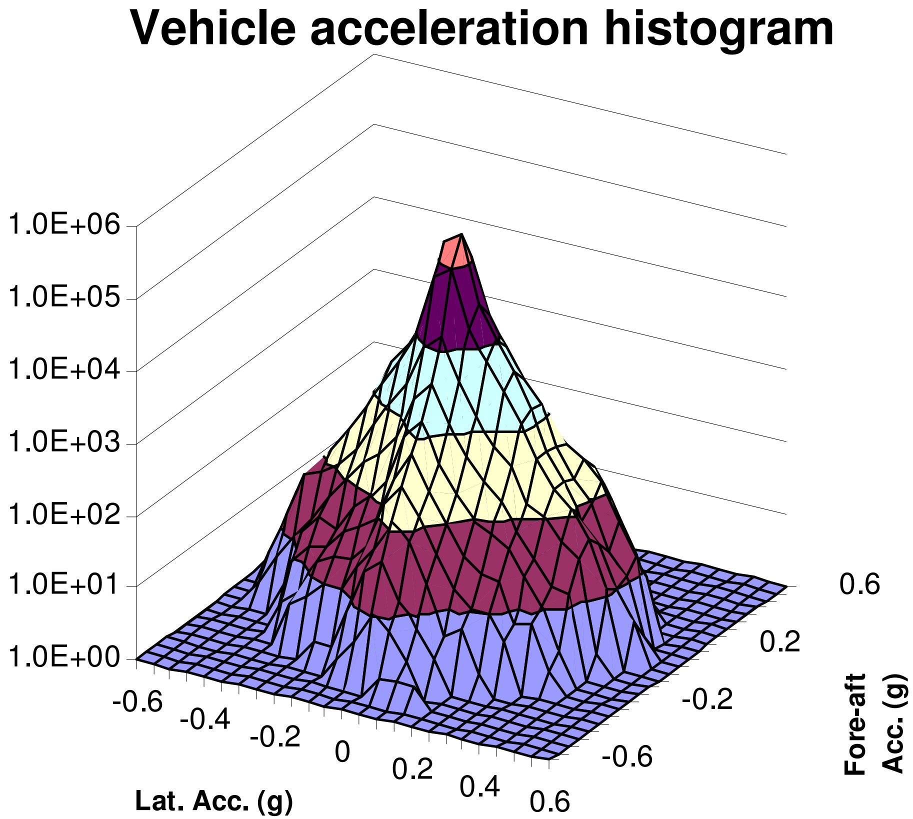
- Rubber curing state differs from location to location. Rubber property depends on curing state.
- Pre-strain exists inside tire due to tire building, lifting of belt, and curing. The pre-strain influences the tire performance.

- Will simulation of tire building/curing help?
- How rubber property changes from uncured to cured?
- What about the chemical reaction during tire curing?



Challenge: Prediction of real life performance

- Vehicle runs at cruise condition for around 95% of time.
- However, tire load is much higher when vehicle accelerates, brakes, or turns.
- The combined effects are needed to predict tire performances, such as durability, tread wear, in the real usage.



Tire responses for all type of loading has to be predicted.
Can we develop a model to combine the effect from different loading together?

Summary

- Continental AG has a long history of tire FEM simulation and is actively improving and expanding the simulation
- The simulation is helping Continental on all key areas of tire performance including:
  - Tire durability
  - Tread wear
  - Rolling resistance
  - Vehicle handling
  - NVH
- Many challenges remain for us to overcome.