Local nonlinearity modelling requirements for vehicle dynamics simulation

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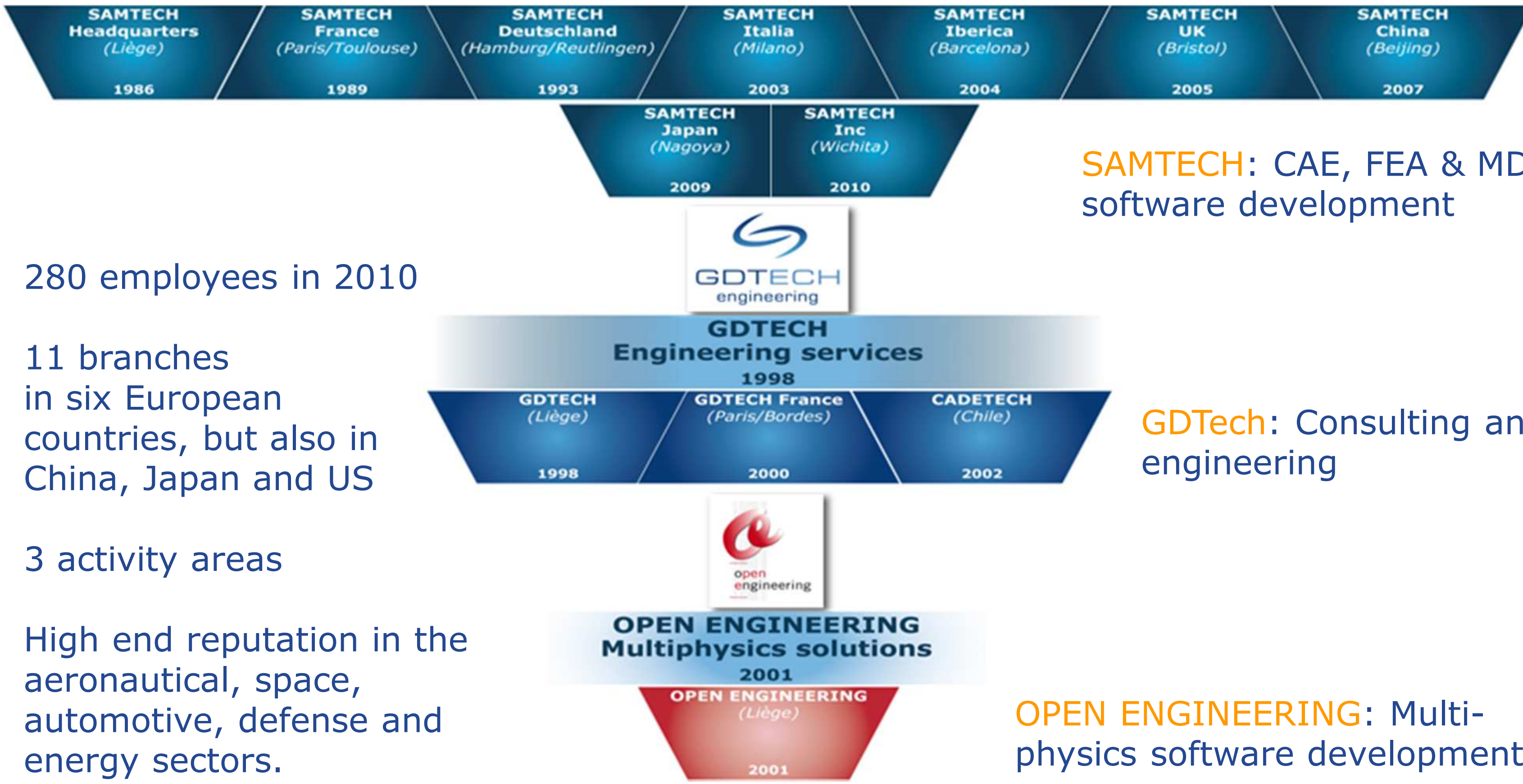
Samtech group

- 280 employees in 2010
- 11 branches in six European countries, but also in China, Japan and US
- 3 activity areas
- High end reputation in the aeronautical, space, automotive, defense and energy sectors.



SAMTECH: CAE, FEA & MDO software development

GDTech: Consulting and engineering

OPEN ENGINEERING: Multi-physics software development

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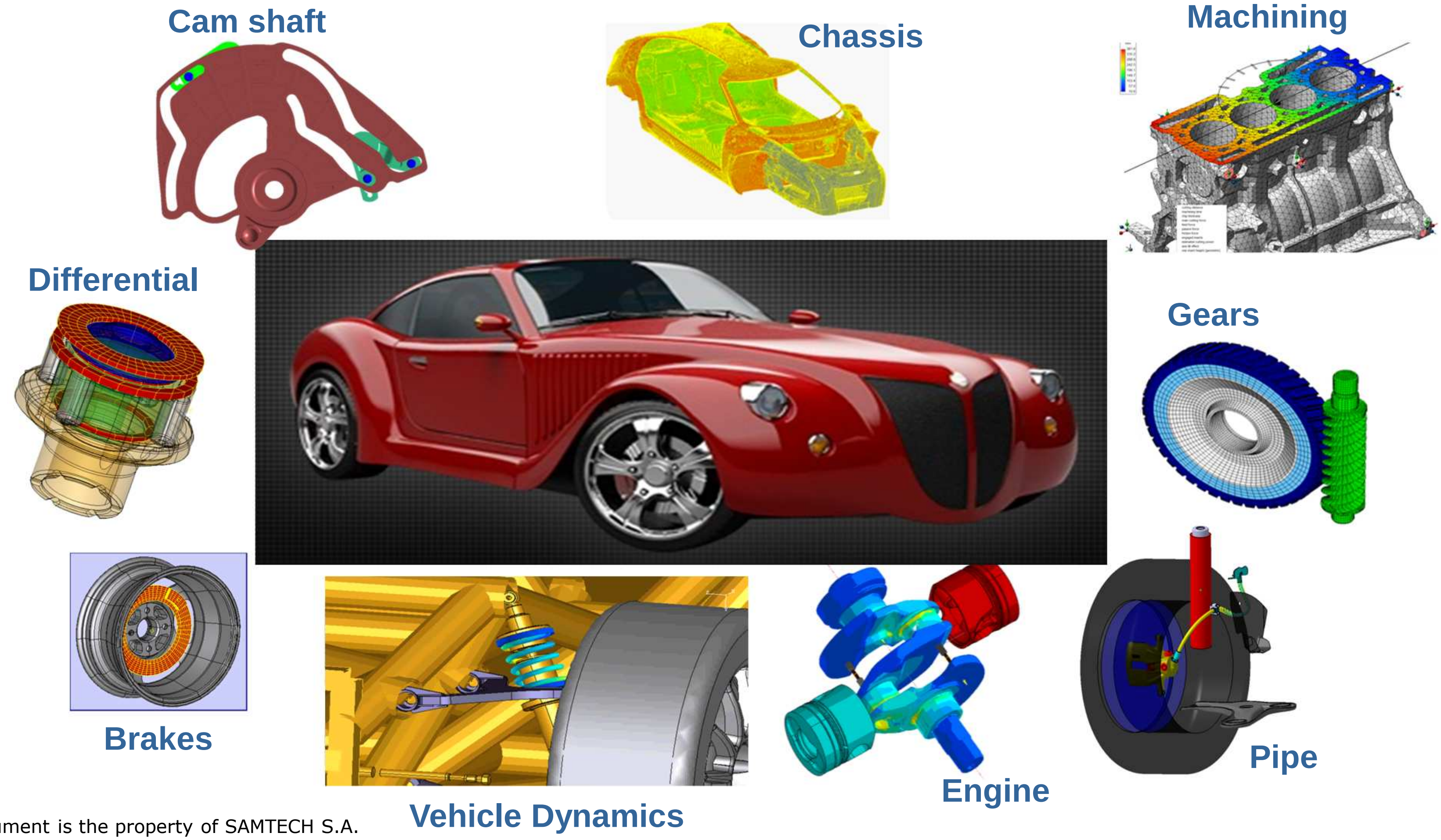
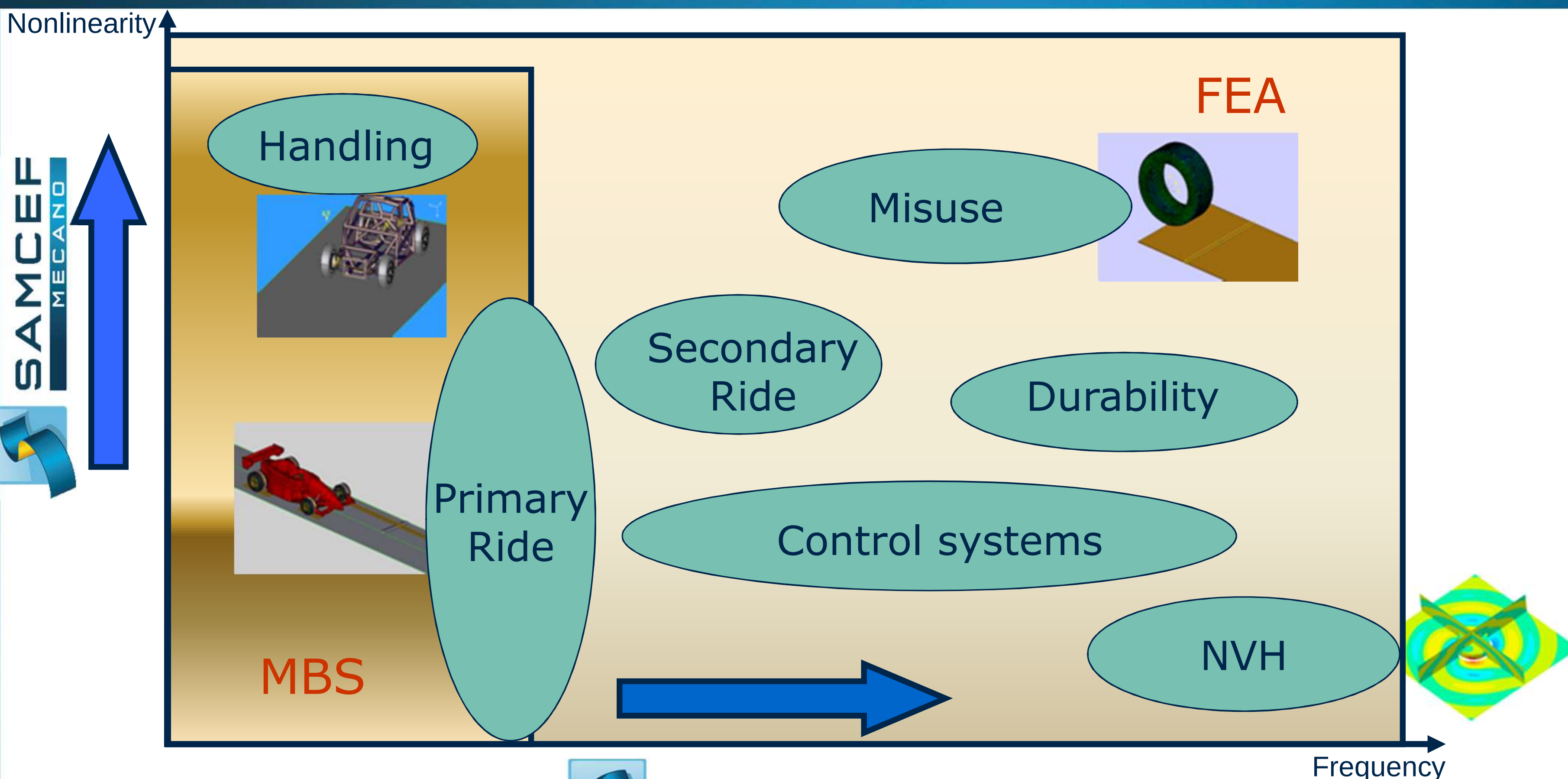
SAMTECH experiences in Automotive



Challenges for vehicle dynamics simulation



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Classical methodology

FEA (local analysis)

CAD data

MBS (Global analysis)

FEA model

Super Elements

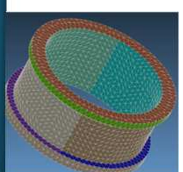
Rigid bodies model

Replace rigid bodies with SE

export

Run simulation

Possibly nonlinear FEA

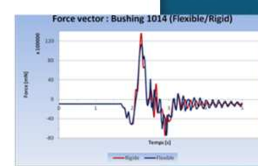


Calculate detailed stress

Optimisation

export

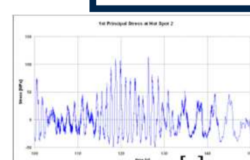
Export node forces time history



...but dynamic load are no longer accurate!!!

Fatigue Prediction?

- Superposition of stress
- Cycle counts
- Damage sum



$$E(D) = \sum_i \frac{n_i}{N_i} = \sum_i \frac{E[P]T\,p(S_i)dS}{kS_i^{-b}} < 1.$$

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Classical methodology

☹ Several different models (local, global)

☹ Several different software packages (linear FEA, nonlinear FEA, MBS,…)

☹ Probably several different users/teams

☹ A lot of data transfer and IT management

☹ Hypothesis made: - Flexibility in MBS model

- Local nonlinearity not taken into account in MBS

- Transient loads transformed in static loads for FEA model

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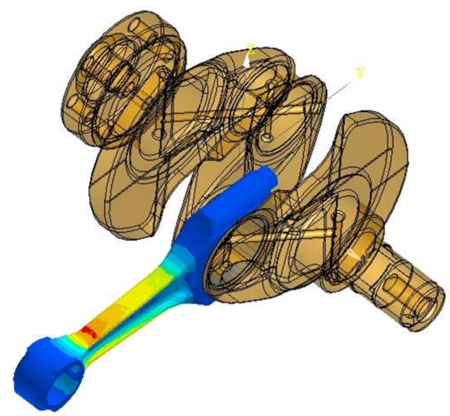
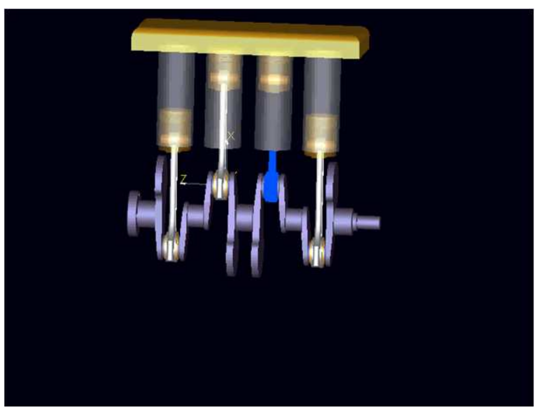
Original methodology of Samcef MECANO

- Finite element approach
- Implicit solver
- Cartesian coordinates (6 dof by nodes)
- Rotation vector theory
- Joints defined by kinematical constraints
- Augmented Lagrangian method





$$\begin{cases} M\ddot{q} + B^T(\overbrace{k\lambda} + \overbrace{p\,\Phi}) = g(q,\dot{q},t) \\ \underbrace{\Phi(q,t)} = 0 \end{cases}$$

Φ: constraint
λ: Lagrangian multiplier
p: penalty factor
k: scaling factor

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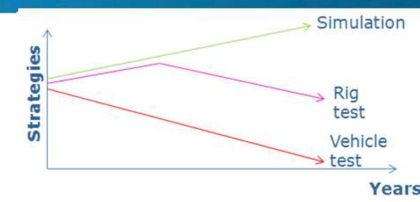
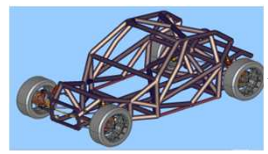
Vehicle dynamics context



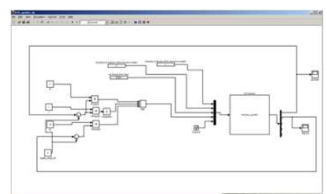
- Nowadays virtual prototyping plays greater role in vehicle design
- Better accuracy needed to predict the vehicle performances based on CAE estimations and results



Virtual

Real

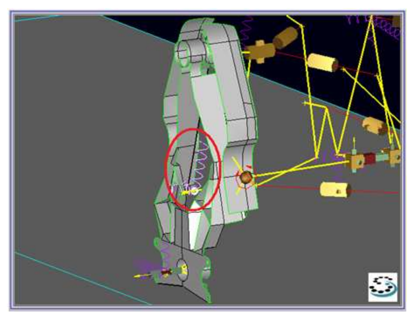
- Challenges faced for vehicle dynamics:
  - Local nonlinearity
  - Frequency domain coverage
  - Multi disciplinary



- Data exchange between platforms
  - MBS
  - FEA
  - Control systems
  - Fatigue program

MATLAB SIMULINK

winLIFE



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Vehicle dynamics applications

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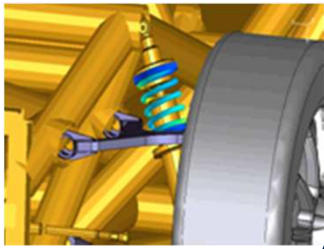
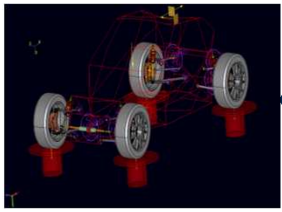
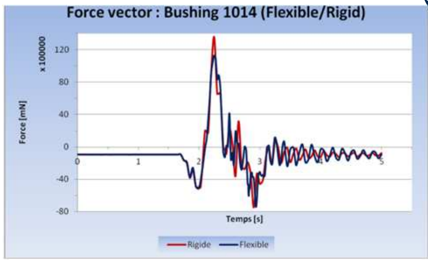


Durability

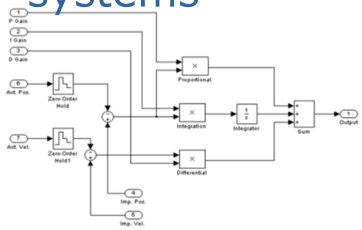


Kinematics



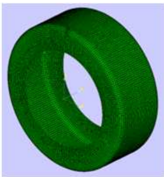
Handling

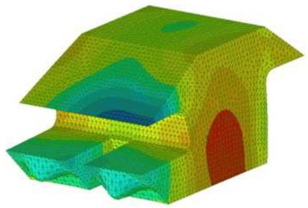
Control systems



Ride and comfort

Misuse





NVH

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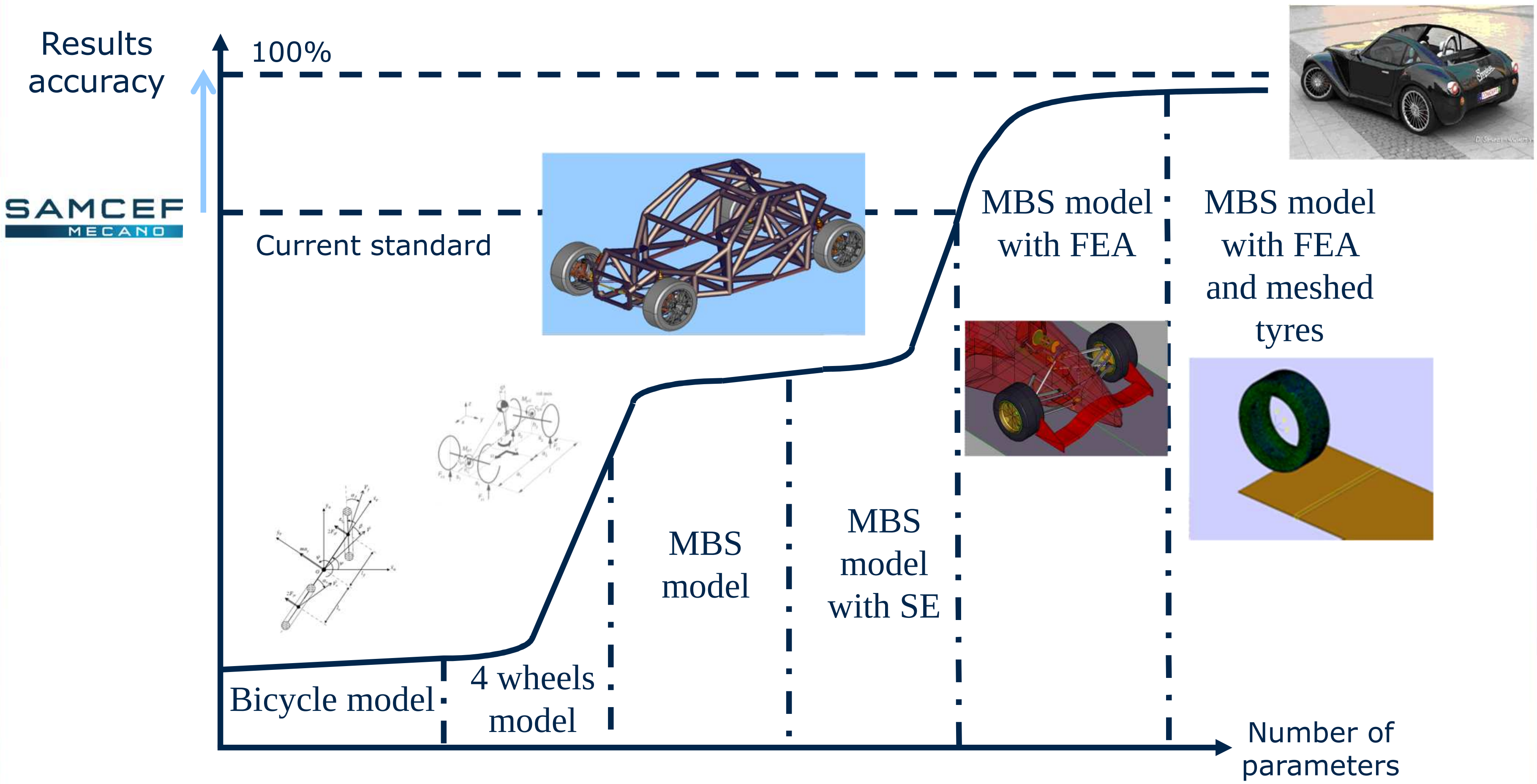
Model complexity



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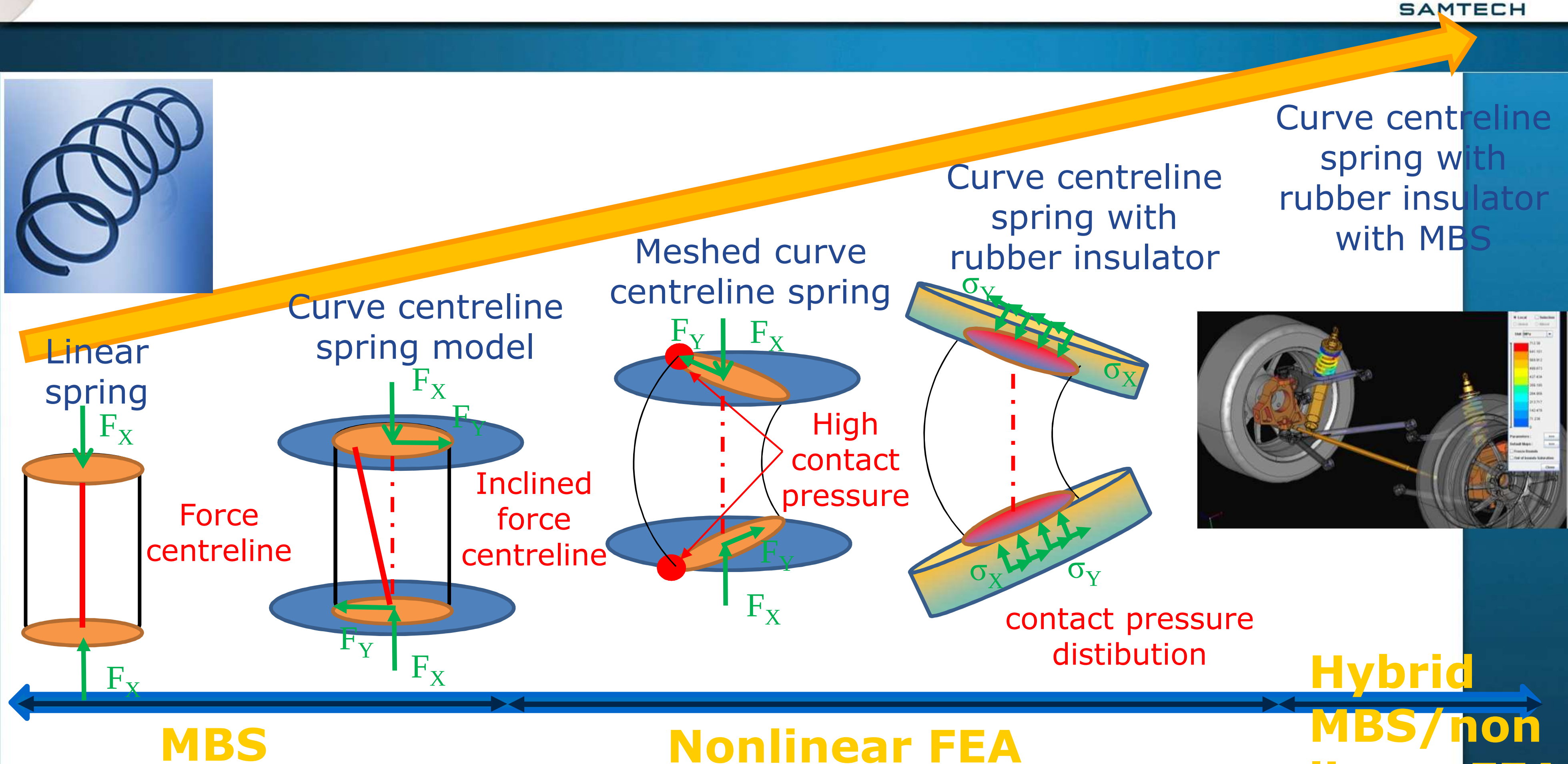
Nonlinearity: the coil spring



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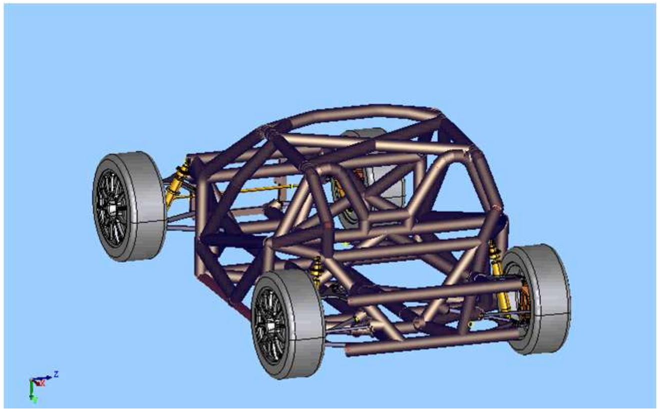
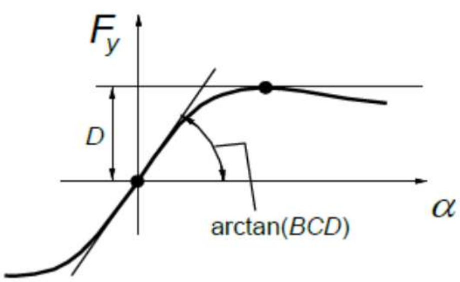
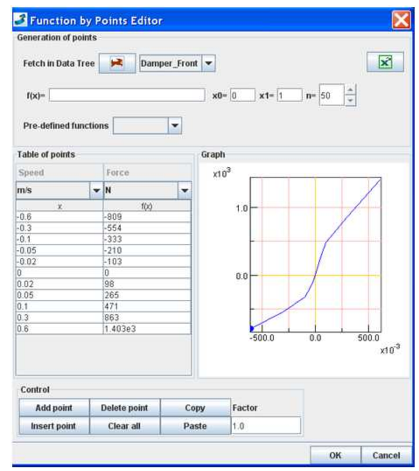
Linear spring: classical MBS





MBS approach:

- Front and rear double wishbone suspensions
- Front and rear antiroll bar
- Joints:
  - hinges
  - bushing
  - nonlinear springs
  - nonlinear dampers
- Nonlinear tyre model (Pacejka Magic Formula)



Rigid Multi Body Simulation allows:
- Short calculation time
- Investigation of an important number of designs covering several input variables and their full range of interest

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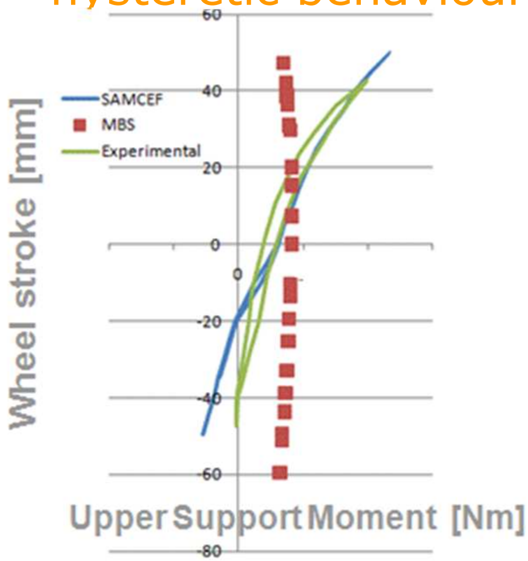
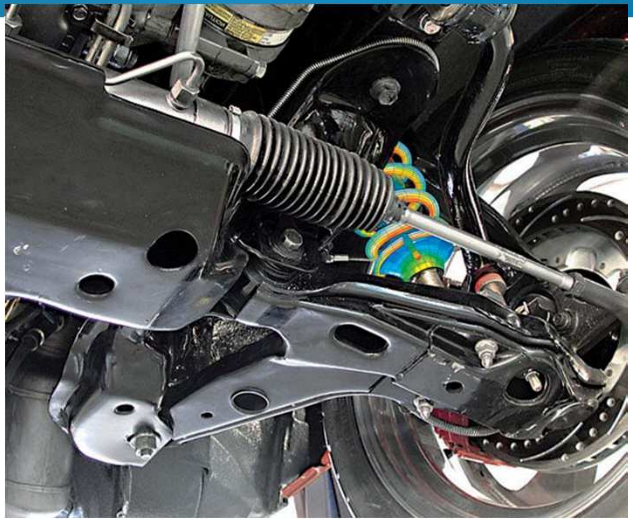
Nonlinear coil spring

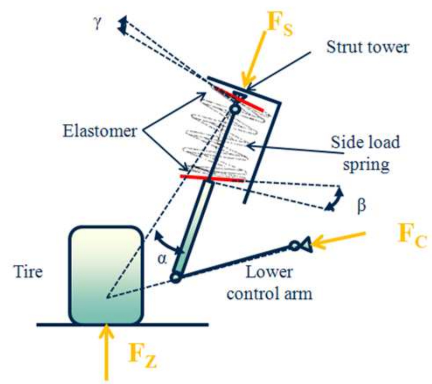
- Coil springs have a nonlinear behaviour due to large displacements

- Transmitted forces display an hysteretic behaviour





- A classical “MBS like” spring element cannot represent this bending effect resulting in an additional moment



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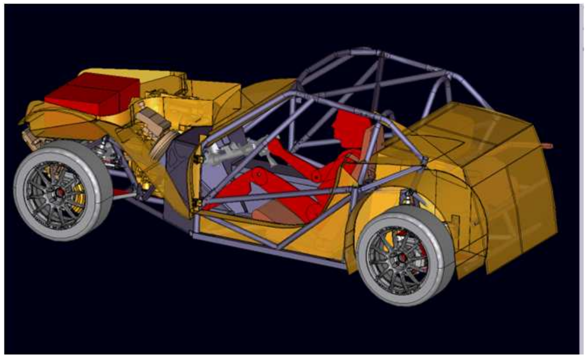
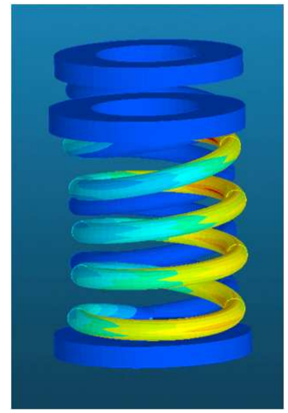
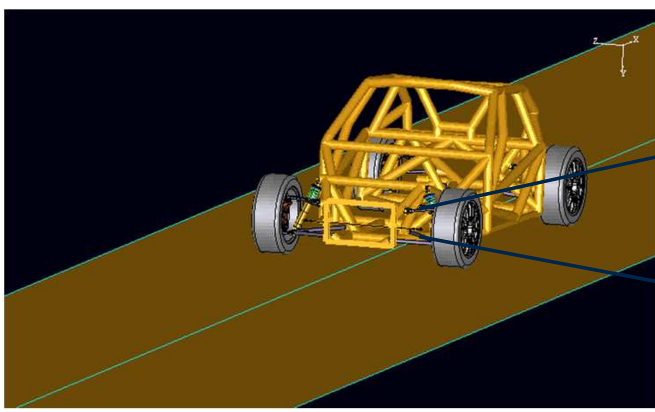
Nonlinear coil spring: innovative methodology



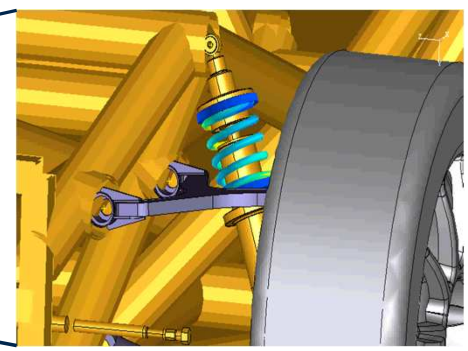
MBS



Nonlinear FEA



zoom



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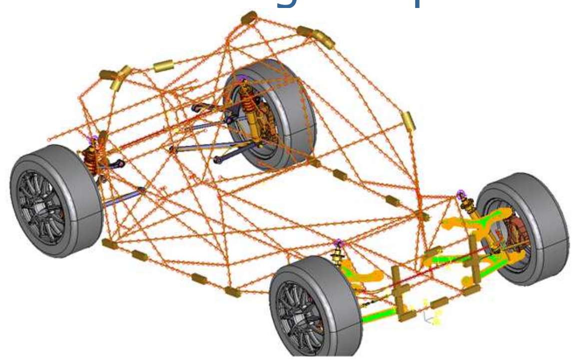
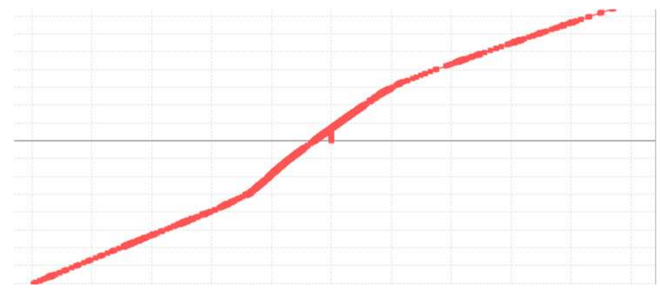
Kinematics and compliance with meshed springs

- Coil springs have a nonlinear behaviour due to large displacements

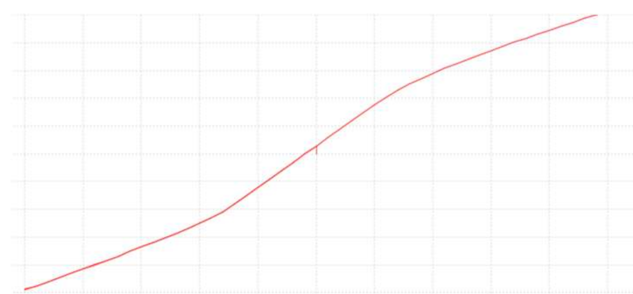


Camber/Fx compliance



Camber vs wheel displacement

Camber/Fy compliance



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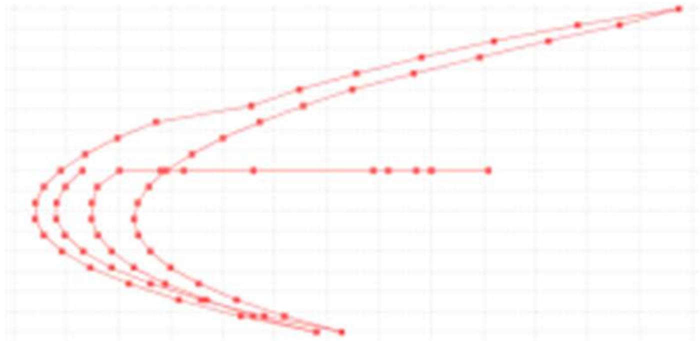
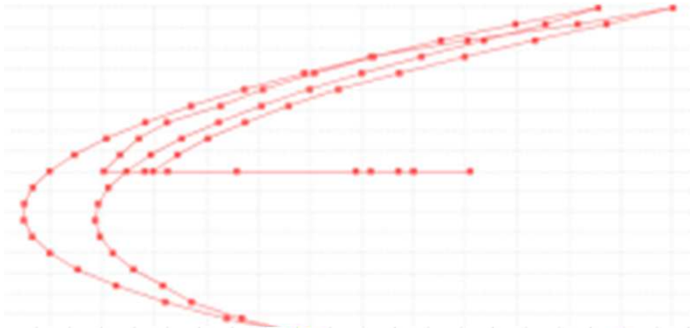
Kinematics and compliance with elastomer

- Elastomer introduce nonlinearity and hysteric behaviour
- Camber change

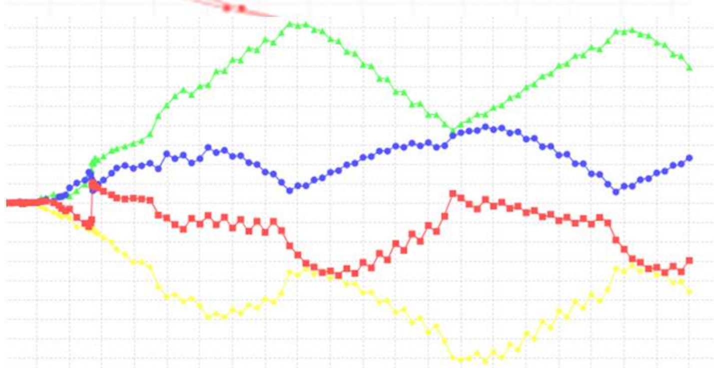
Initial downwards motion



Initial upwards motion



- Same results available for toe
- Lateral force at the upper spring mount



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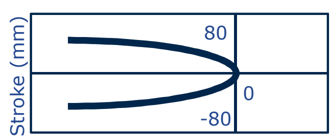
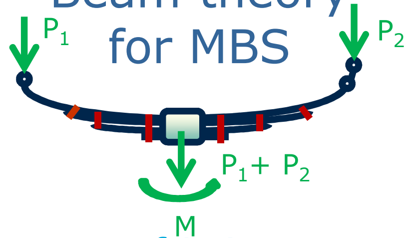
Leaf spring suspension

Lookup tables after measurements

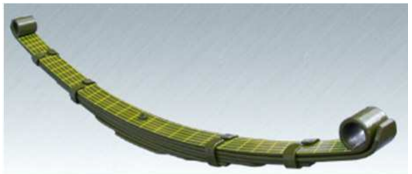


Beam theory for MBS



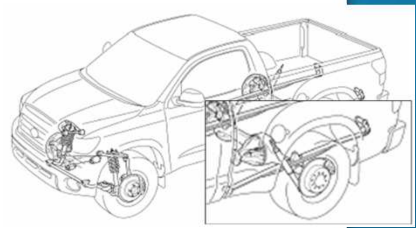
- No friction
- No contacts
- No hysteresis
- Similar curvatures
- No prestress
- …

Nonlinear FEA to take into account contacts and friction



- prestress
- Contact pressure between the leafs
- Hysteresis: more realistic damping
- fatigue

Meshed leafspring with MBS



MBS

Nonlinear FEA

Hybrid MBS/non linear FEA

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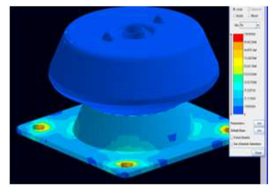
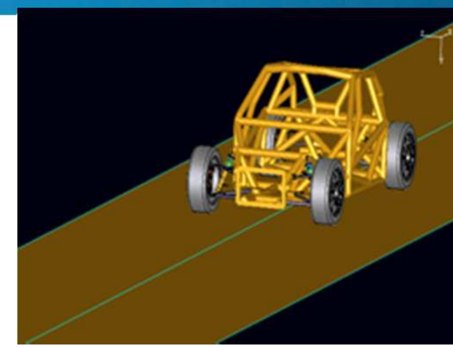
Motion in FEA – Rigid vs Flexible vehicle with MECANO

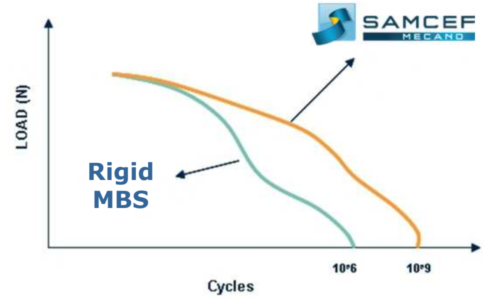
Flexible approach



- Physical suspension compliance definitions:
  - FEA parts
  - nonlinear 3D bushings
  - elastomer



- Greater details improve the accuracy of the results:
  - Higher frequency contents
  - Higher number of cycles for fatigue performance assessment



- No need to re-measure the suspension if
  - geometry changes (attachment point)
  - part redesigned (new FEA model)
  - fatigue can be integrated early in the design process

Better modularity

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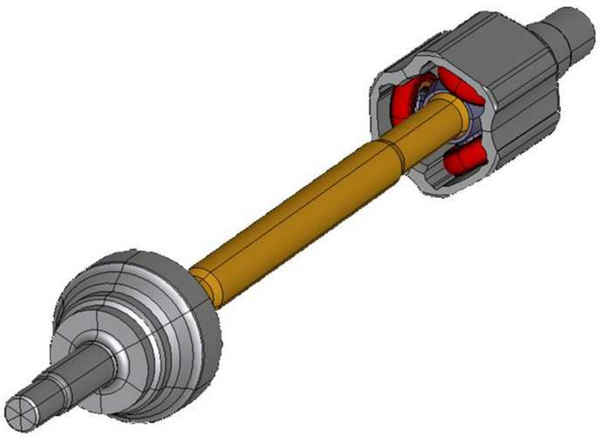
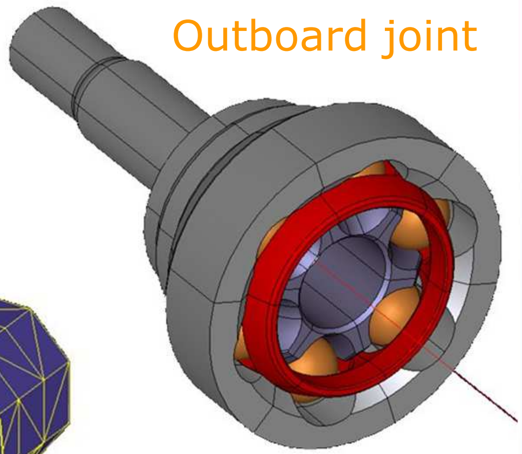
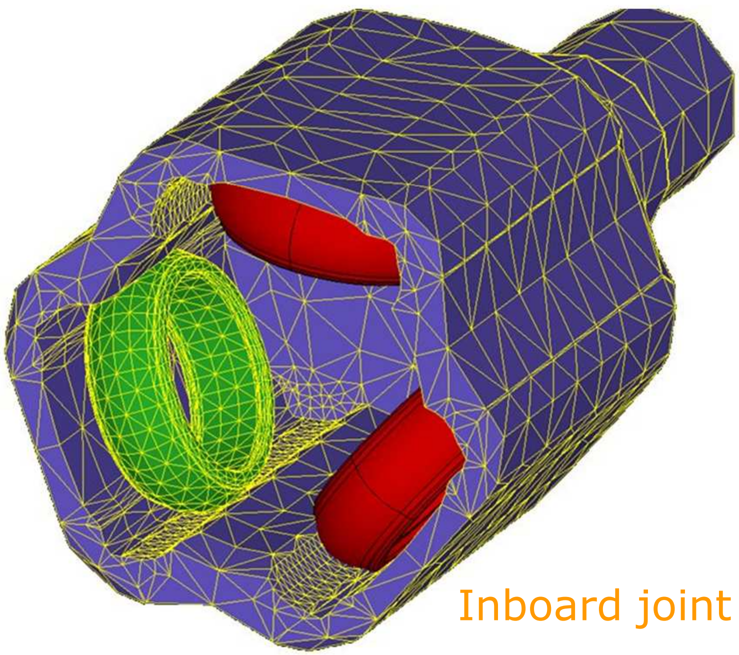
Driveshaft





- No Hertzian contact theory
- Use of flexible-flexible and flexible-rigid contacts algorithms available in Mecano



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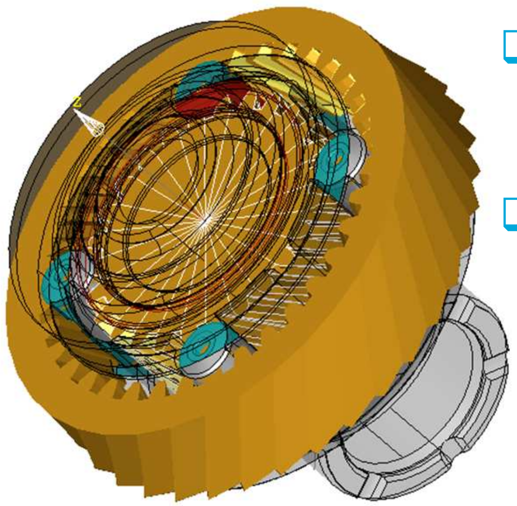
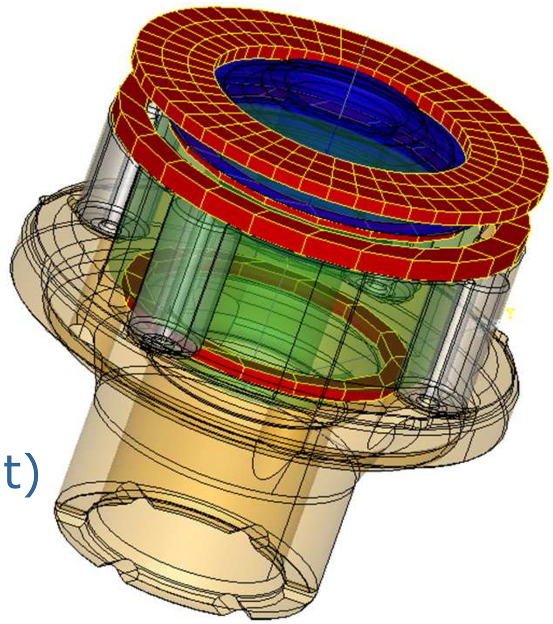
Torsen differential (1/2)

- Assumptions:
  - Joints between Planet gears and housing modelled as hinges
  - Planet gears and one thrust washer locked axially
  - Contact SG/washer 3 and CPL/washer 4 neglected



- 15 bodies (10 rigid, 5 flexible washers)
- Constraints :
  - 8 gear elements
  - 5 contact relations (4 hinges, 1 screw joint)



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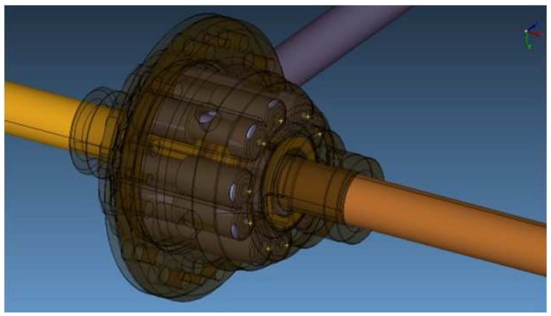
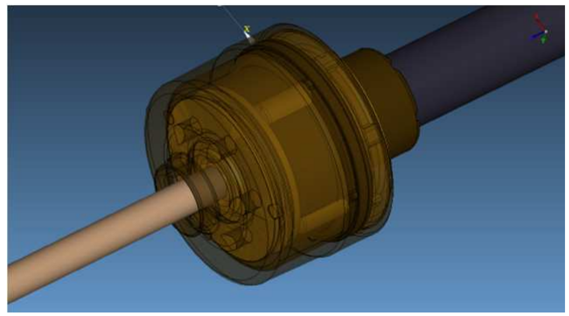
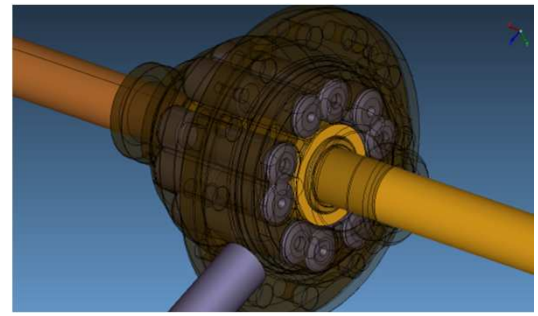
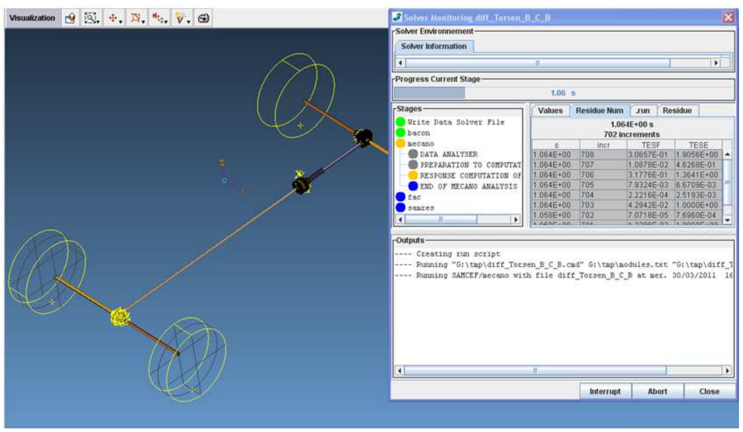
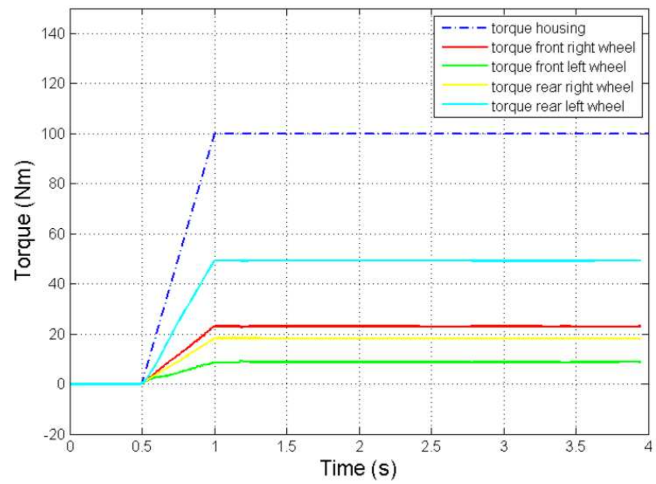
Torsen differential (2/2)











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SAMCEF MECANO: optimising the whole system

- From design/optimisation of each part separately…
- … to the design/optimisation of the subsystem parts
- … to the optimisation of the global system
- Thanks to:
  - Increase of nonlinearity range
  - Increase of frequency range

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