

## Overview of the DLR RailwayDynamics Library

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Knowledge for Tomorrow

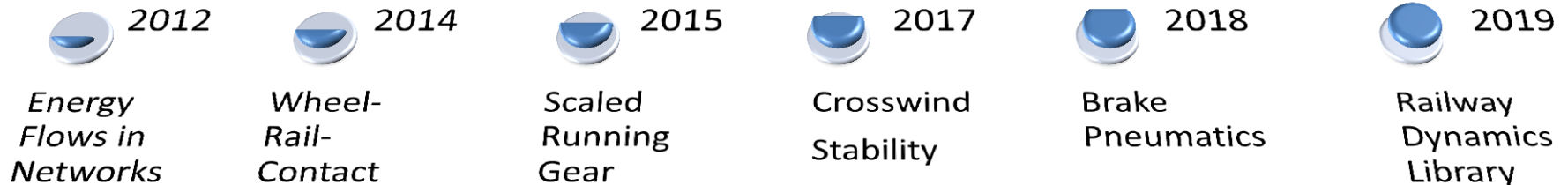
# Contents

- Background and Motivation
- Library, Model and Data Structure
- Railway Modeling Particularities
- Applications
  - Traction
  - Comfort
  - Roller Rig
- Multidomain Modeling
- Conclusions



# Background and Motivation

- DLR's historical background in multibody and railway dynamics
- DLR's Next Generation Train Project
  - Running gear development for an ultra high-speed train in double deck configuration and lightweight design, see [video](#)
- Several precursor papers

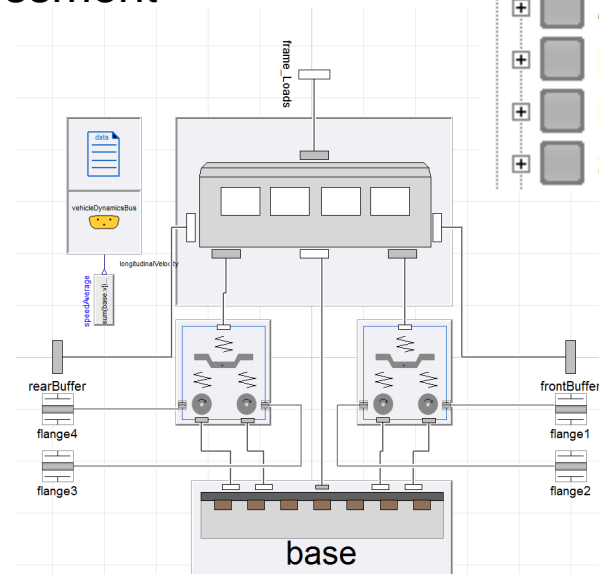
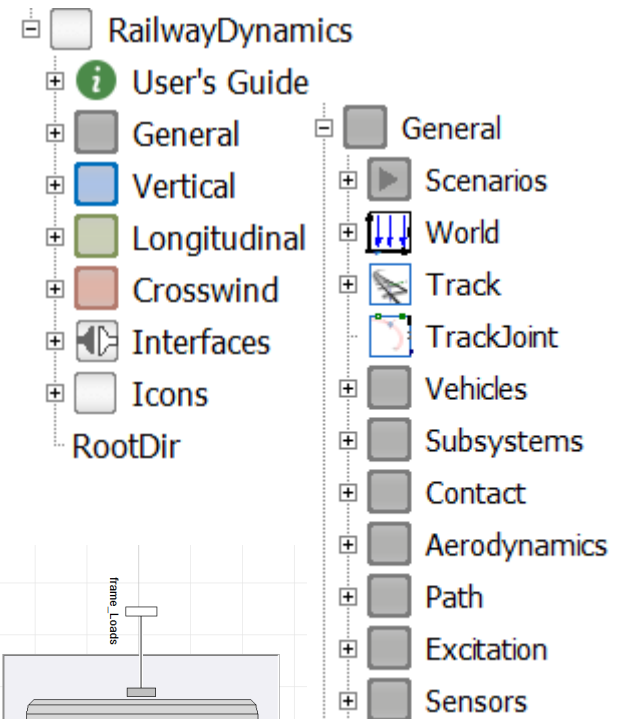
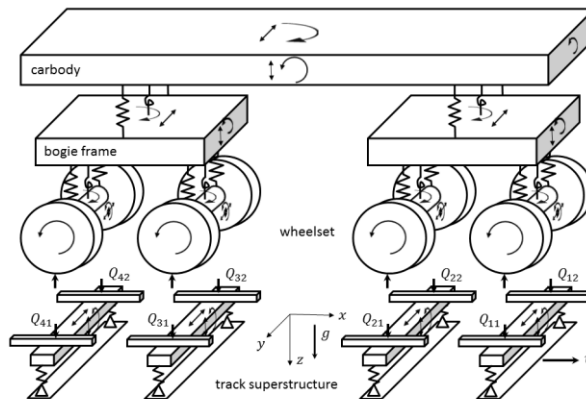


- Objectives
  - Gathering, reorganizing and publishing given models
  - framework for future multidomain engineering tasks



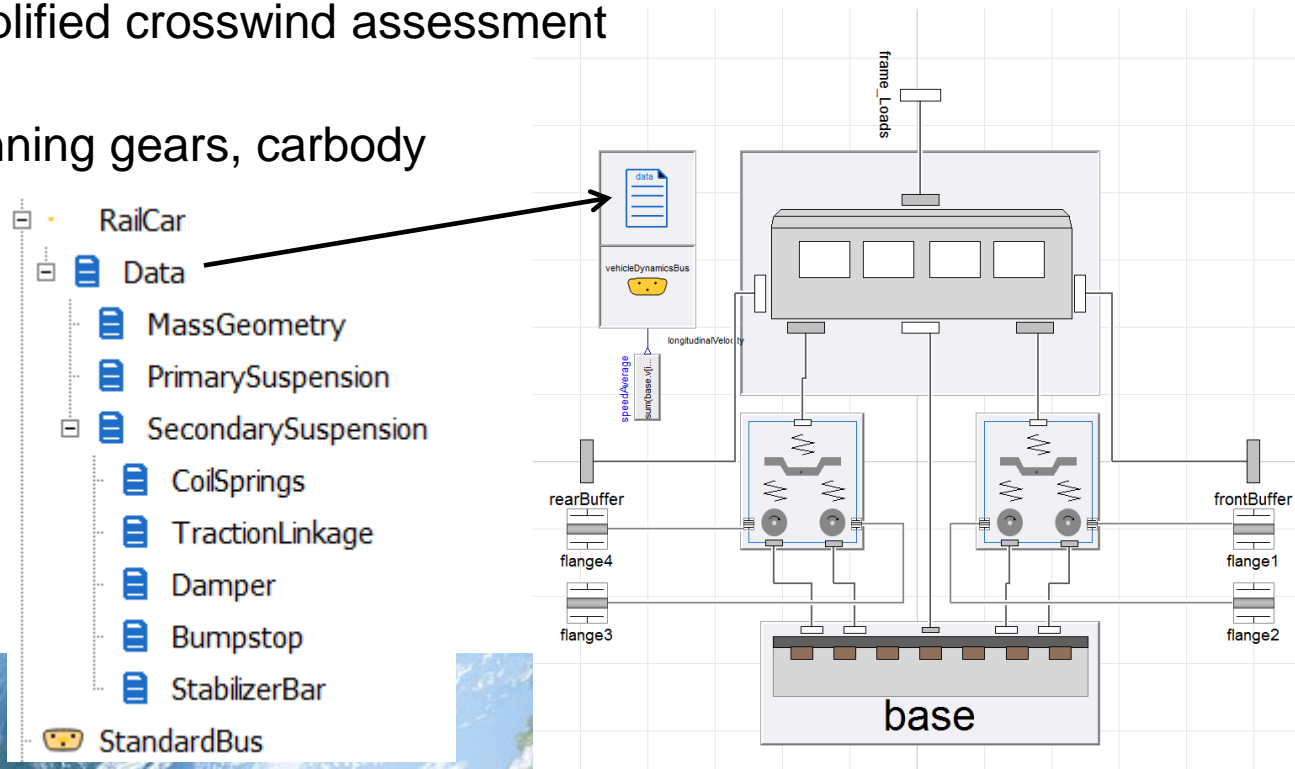
# Library, Model and Data Structure (I)

- General subpackage
  - 3D multi-purpose models  
traction, comfort, safety, roller rigs, ...
- 3 specialized subpackages
  - Vertical  $\Rightarrow$  comfort
  - Longitudinal  $\Rightarrow$  traction
  - Crosswind  $\Rightarrow$  simplified crosswind assessment
- Vehicle template
  - Railroad base, running gears, carbody



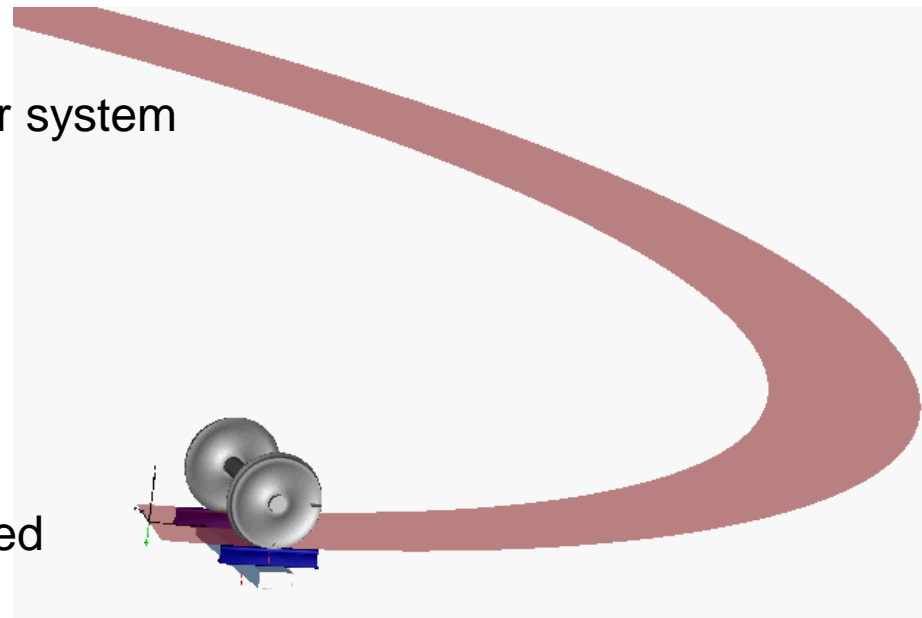
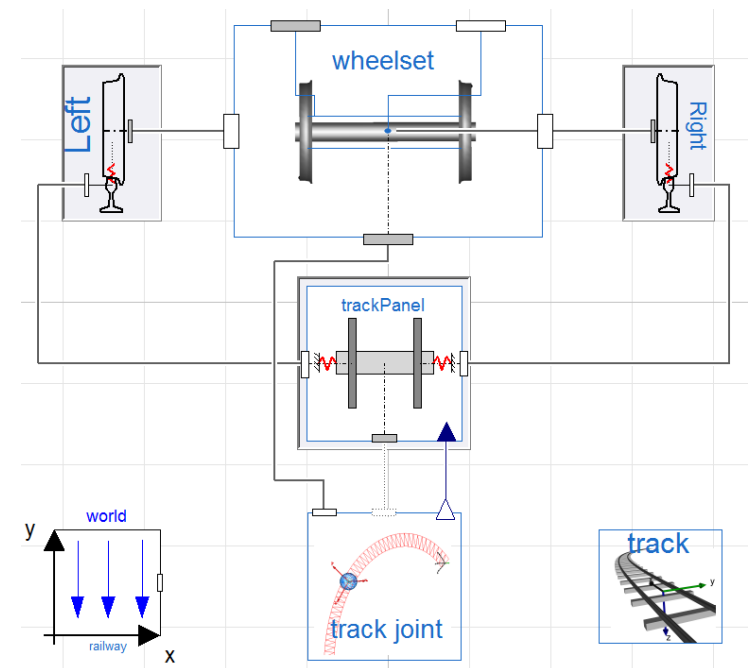
# Library, Model and Data Structure (II)

- General subpackage
  - 3D multi-purpose models  
traction, comfort, safety, roller rigs, ...
- 3 specialized subpackages
  - Vertical  $\Rightarrow$  comfort
  - Longitudinal  $\Rightarrow$  traction
  - Crosswind  $\Rightarrow$  simplified crosswind assessment
- Vehicle template
  - Railroad base, running gears, carbody
- Data Structure
  - Replaceable encapsulated records



# Railway Modeling Particularities Overview

- Track (inner/outer)
  - 3D curve  $\vec{r} = \vec{r}(s)$ , collateral frame
  - rail position and orientation
  - irregularities
- Track joint
  - Longitudinal degree of freedom
  - 2 states:  $s, v$
- Track panel
  - accompanying mass-spring-damper system
  - 2 rail stubs and sleeper
- Wheelset
  - 5 degrees of freedom
  - Inertia properties
- Wheel-Rail contact
  - UIC60 and S 1002 predefined
  - Linear and Polach model predefined



# Railway Modeling Particularities (I)

## Track: some details

track in RailwayDynamics.General.Scenarios.Basic.WheelsetOnSpiralTrack

General | Advanced | Animation | Add modifiers | Attributes

Component

Name

Comment

Model

Path RailwayDynamics.General.Track

Comment definition of global track quantities, such as path, irregularities etc.

Path

useStandardPath  false  true

path

how to specify path

standard path file

File on which path data is present

Origin of path

Orientation of path: Sequence of rotations

Orientation of path: angles around the axes defined in 'sequence'

lateral distance (inside) between two rails

gauge + gaugeOffset = lateral distance of rail reference frames

inclination

Irregularities.Lateral.Default lateralIrregularity

Irregularities.Vertical.ErrHigh verticalIrregularity

Irregularities.Crosslevel.Default crosslevelIrregularity

Irregularities.Gauge.Default gaugeIrregularity

OK Cancel Info

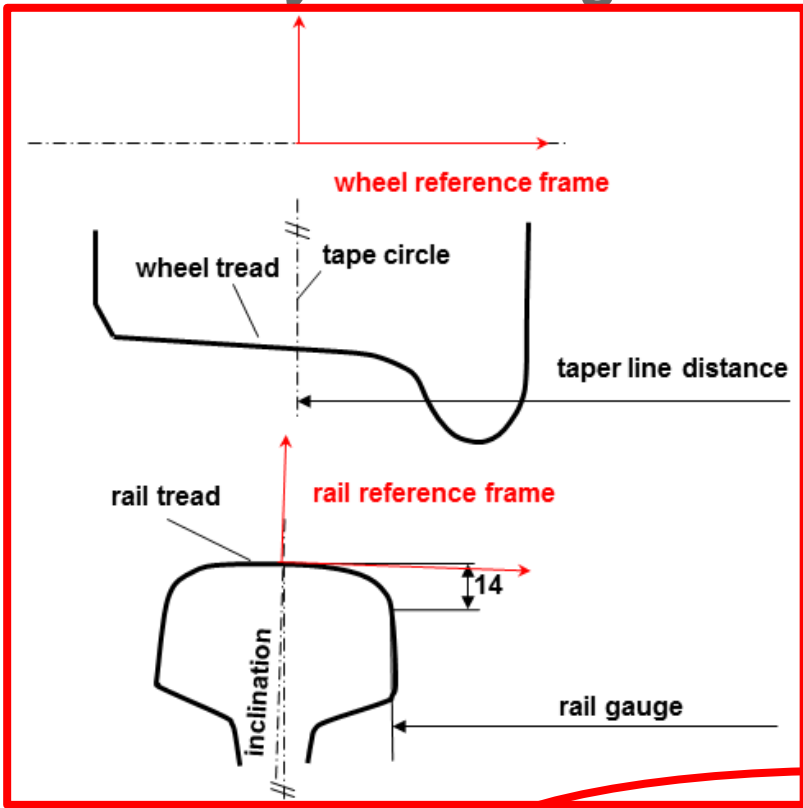
## File format from the early 90's

```

1 header.begin
2 data.type = 3 ! File Format Type: 1/2/3 = s,psis,gams,u/x,y,z,cmb/x,y,z,u
3 data.par(1) = 1.0 ! UnitFactor = x,y,z[User] / x,y,z[SI] ([m])
4 data.par(4) = 1 ! 0/1/2 = Superelevation about center/inner/outer Rail
5 data.par(5) = 1.506 ! Reference Length of Superelevation [m]
6 data.par(7) = 1 ! Increment for Data Reduction
7 header.end
8
9 0.0 0.0 0.0 0.0
10 0.03142633303147171 6.584120135714897E-005 0.0 0.0
11 0.06285225223298509 0.0002633642274198783 0.0 0.0
12 0.09427734377760927 0.000592567344165841 0.0 0.0
13 0.12570119384446826 0.0010534476615704773 0.0 0.0
14 0.1571233886217684 0.0016460011336260443 0.0 0.0
15 0.18854351430982552 0.0023702225583682526 0.0 0.0
16 0.21996115712409248 0.0032261055779105193 0.0 0.0
17 0.2513759032981862 0.00421364267848583 0.0 0.0
18 0.2827873390869147 0.005332825190496208 0.0 0.0

```

# Railway Modeling Particularities (II)



Excitation.Basic.WheelsetOnSpiralTrack

Add modifiers | Attributes

Icon

Tr...

ral.Track  
k quantities, such as path, irregularities etc.

true ▶ how to specify path

"spiralPath.tm" ▶ standard path file

"Resources/Data/Track/" + path ▶ File on which path data is present

{0,0,0} ▶ m Origin of path

{1,2,3} ▶ Orientation of path: Sequence of rotations

{0,0,0} ▶ deg Orientation of path: angles around the axes defined in 'sequence'

gauge 1.435 ▶ m lateral distance (inside) between two rails

gaugeOffset 0.072 ▶ m gauge + gaugeOffset = lateral distance of rail reference frames

incl 1/40 ▶ inclination

Irregularities

lateralIrregularity rededare Excitation.Irregularities.Lateral.Default lateralIrregularity ▶

verticalIrregularity rededare Excitation.Irregularities.Vertical.ErriHigh verticalIrregularity ▶

crosslevelIrregularity rededare Excitation.Irregularities.Crosslevel.Default crosslevelIrregularity ▶

gaugeIrregularity rededare Excitation.Irregularities.Gauge.Default gaugeIrregularity ▶

OK Cancel Info



# Railway Modeling Particularities (III)

## Track:

**redeclare verticalIrregularity in RailwayDynamics.General.Scenarios.Basic.WheelsetOnSpiralTrack**

General | Add modifiers | Attributes

Component

Name: redeclare verticalIrregularity

Comment:

Model

Path: RailwayDynamics.General.Excitation.Irregularities.Vertical.ErriHigh

Comment:

Parameters

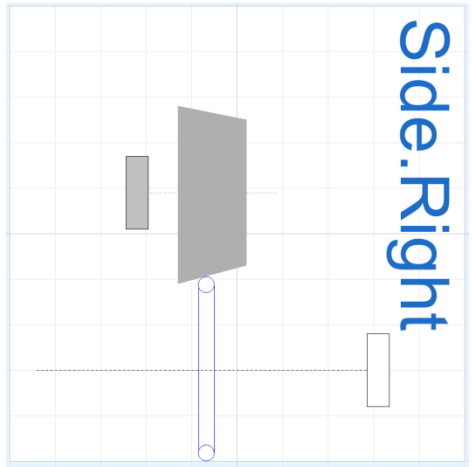
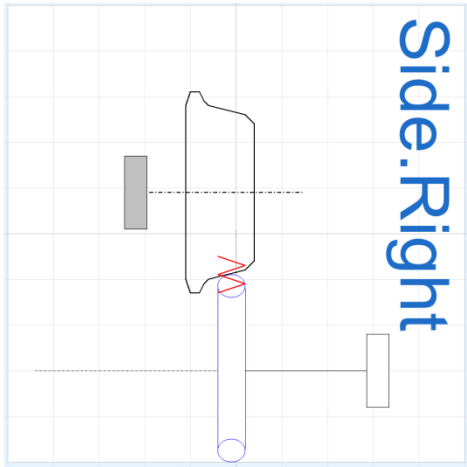
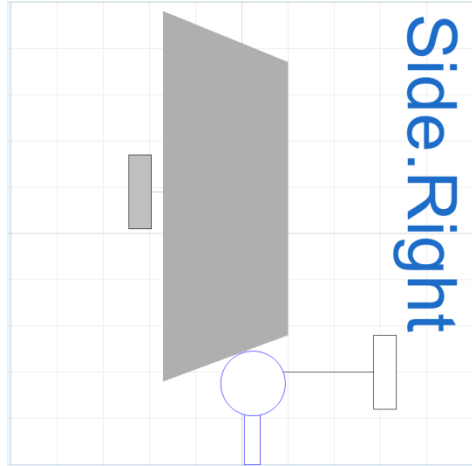
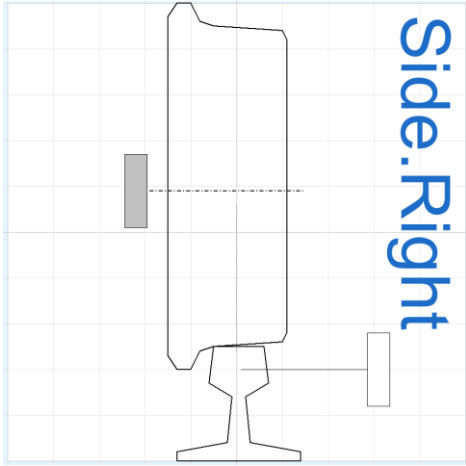
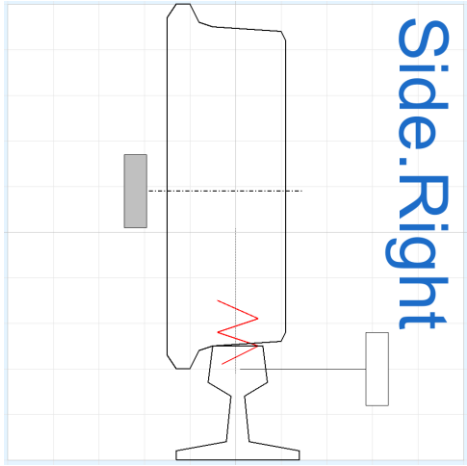
f_min	1e-3	1/m	mininal distance frequency to consider
f_max	10	1/m	maximum distance frequency to consider
n_f	1024		sampling of spectrum w.r.t frequencies
samplingMethod	<input checked="" type="radio"/> linear <input type="radio"/> logarithmic		method of frequency sampling
T	2	s	time constant to smooth onset
onset	<input checked="" type="radio"/> smooth <input type="radio"/> hard		initial onset of excitation
globalSeed	97215		Global seed to initialize random phase generator
localSeed	104976		Local seed to initialize random phase generator
b	{7.343623e-7}		numerator of the poyynomial that specifies PSD
a	{0.00028855,0,0.6803895,0,1}		denominator of the poyynomial that specifies PSD
scale	1		map specification units to SI
angular	true		polynomial specification w.r.t. angular frequency

Irregularities

- lateralIrregularity: redeclare Excitation.Irregularities.Lateral.Default lateralIrregularity
- verticalIrregularity: redeclare Excitation.Irregularities.Vertical.ErriHigh verticalIrregularity
- crosslevelIrregularity: <Remove modifier>
- gaugeIrregularity:
  - ErriHigh
  - ErriLow
  - FrederichBest
  - FrederichAverage
  - FrederichWorst
  - Default

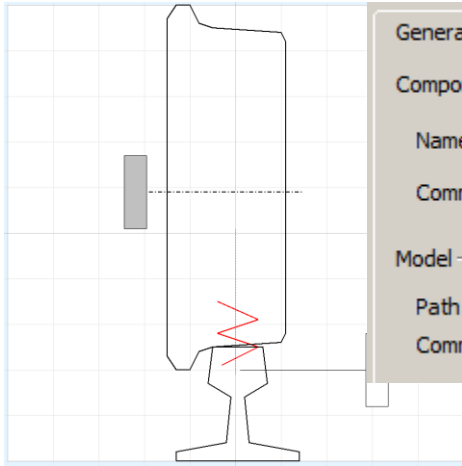
# Railway Modeling Particularities (I)

Contact: some details



# Railway Modeling Particularities (II)

## Contact: some details



General | Tangential Contact | **Normal Contact** | Add modifiers | Attributes

Component

Name:

Comment:

Model

Path: RailwayDynam...

Comment: elastic contact

Icon:

General | Tangential Contact | **Normal Contact** | Add modifiers | Attributes

alpha:  regularization parameter for profile evaluation

d:  N.s/m contact damping (scaled w.r.t. stiffness 2e8 N/m)

p\_0:  m p\_0 > 0: overlap value beyond which force law is regularized

s:

wheelProfile:

railProfile:

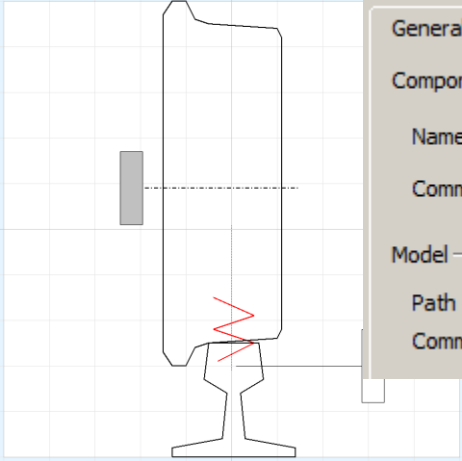
**Profiles**

- S1002
  - extends RailwayDynamics.General.Contact.Profiles.partialProfile
  - evalS1002Profile
- S1002
- UIC60
  - extends RailwayDynamics.General.Contact.Profiles.partialProfile
  - evalUIC60Profile
- UIC60
- partialProfile
  - evalProfile
  - partialEvalProfile



# Railway Modeling Particularities (III)

## Contact: some details



The diagram shows a cross-section of a rail wheel on a rail. A red zigzag line is drawn between the wheel and the rail, representing an elastic contact model. A red arrow points from the 'Tangential Contact' tab in the software interface to this zigzag line.

General | **Tangential Contact** | Normal Contact | Add modifiers | Attributes

Component


Name

Comment

Model

Path RailwayDynamics

Comment elastic contact

Icon 

General | Tangential Contact | Normal Contact | Add modifiers | Attributes

nonLinearTangentialContact  false  true ▶

mue\_0  ▶ 1 maximum friction coefficient at zero slip velocity

A  ▶ ratio of friction coefficient

B  ▶ s/m coefficient of exponential friction decrease

k\_A  ▶ friction reduction in adhesion area

k\_S  ▶ friction reduction in slip area

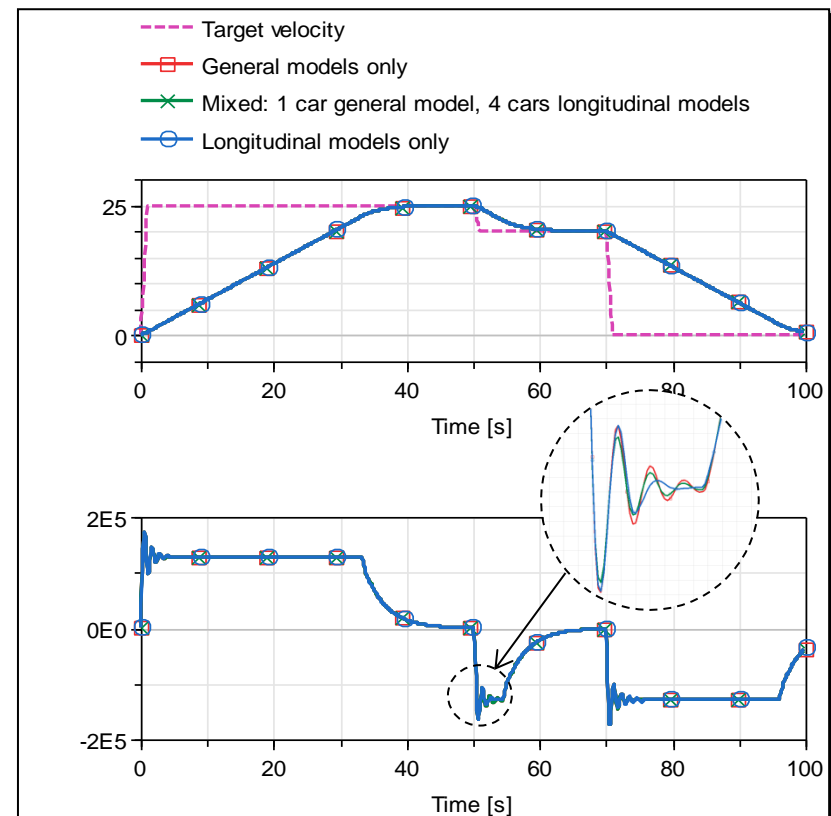
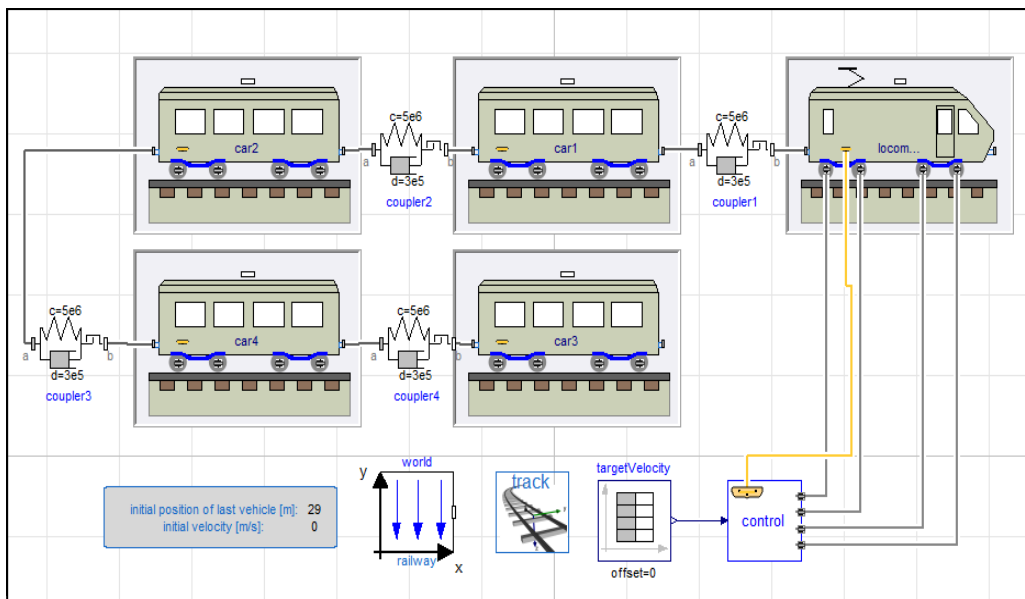
eval\_NonLinearTangentialContact  ▶



# Applications: Traction

- Estimate longitudinal forces & oscillations during braking and accelerating
- Use reduced models: simulate large systems (e.g. freight train with 50 cars)

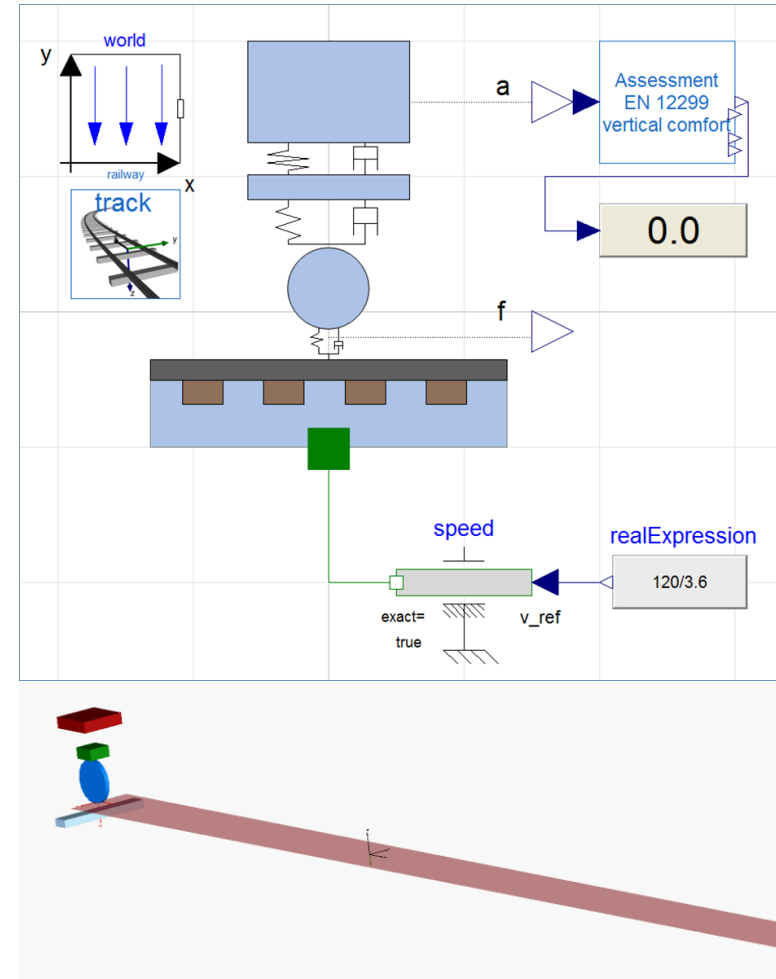
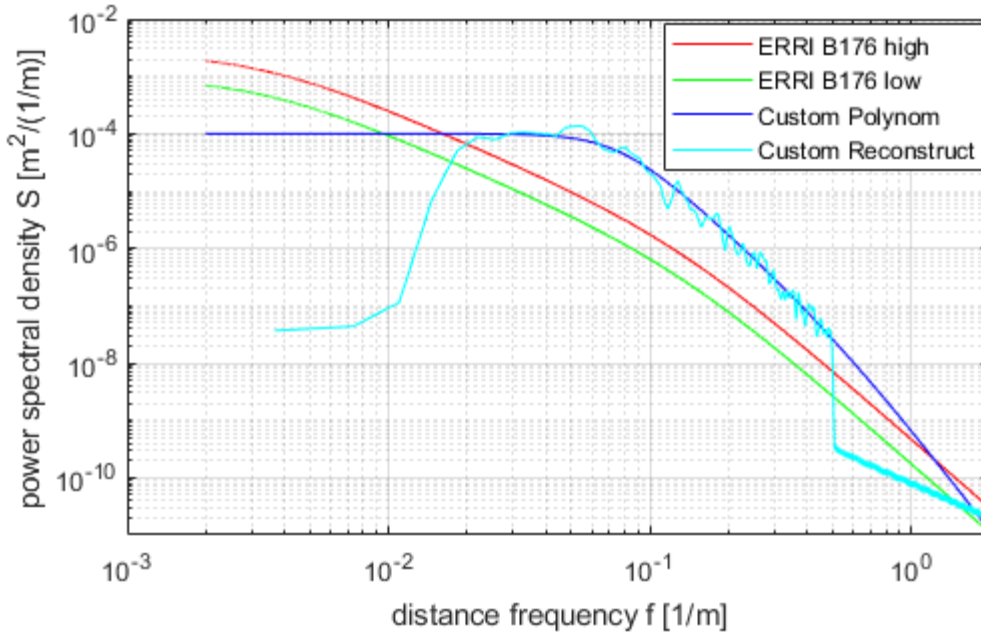
Example: Train with 5 cars	CPU-s/s	Number of states
General models only	69.5	605
Mixed: 1 car 3D + 4 cars 1D	6.65	157
Longitudinal models only	0.08	51



- Peaks of coupler forces occur at beginning of brake and acceleration phases
- Simulation results of different models coincide

# Applications: Comfort

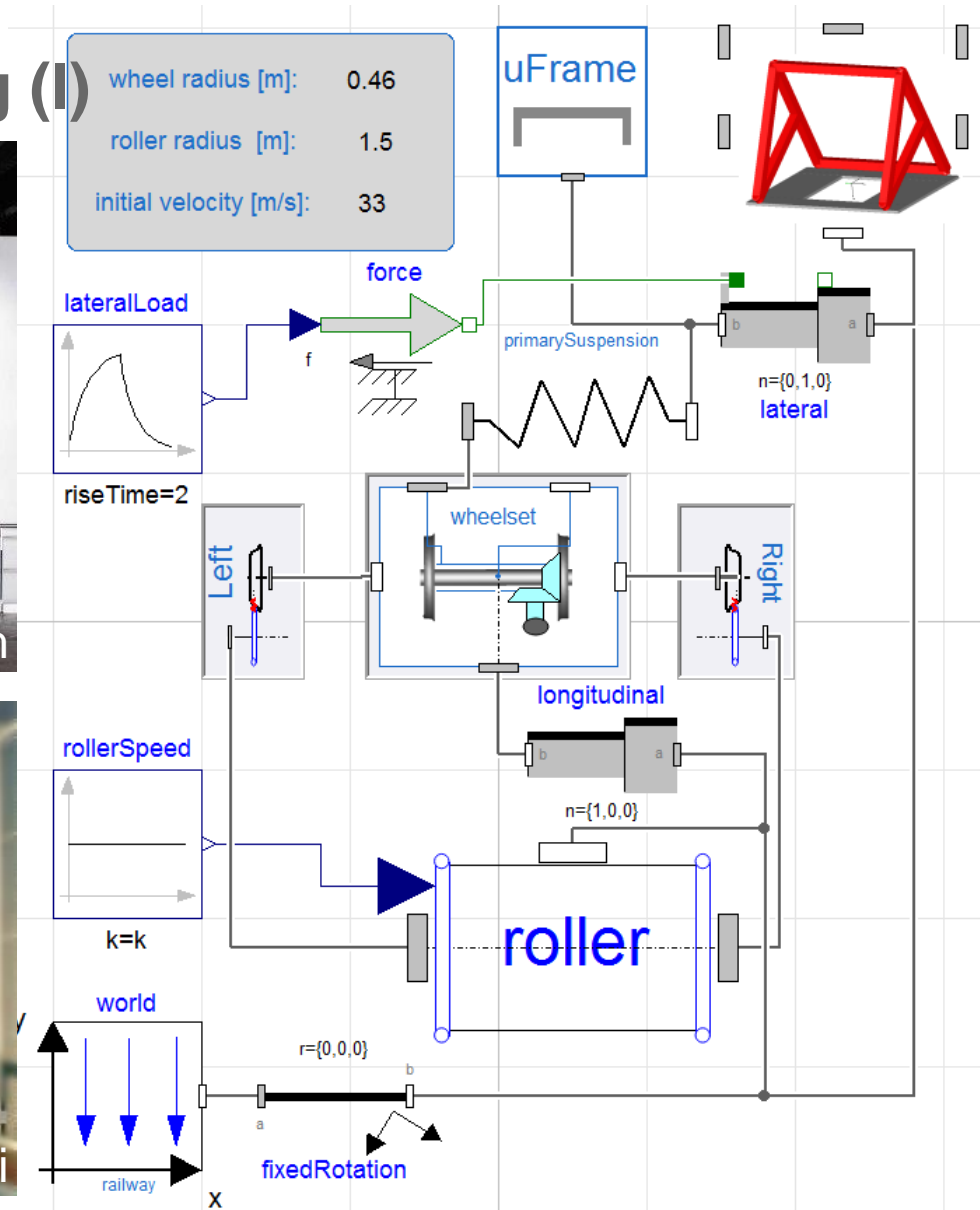
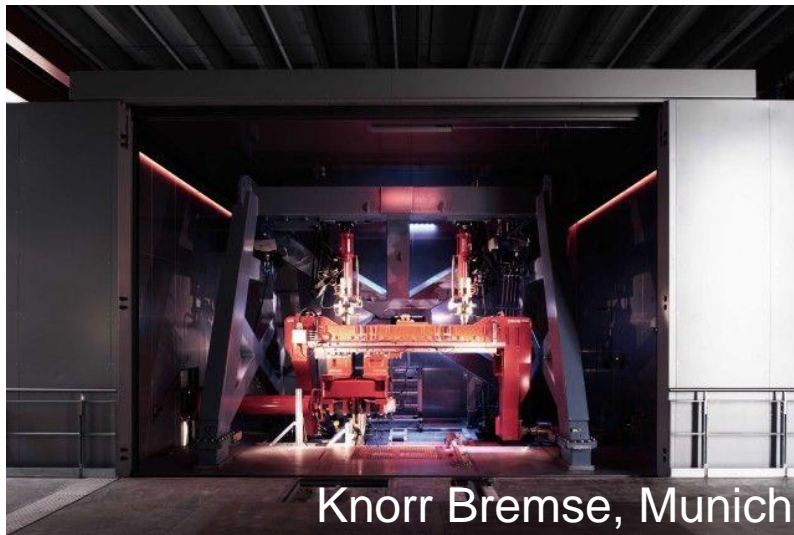
$$S(\Omega) = \frac{b_0 + b_1\Omega^2}{a_0 + a_2\Omega^2 + a_4\Omega^4 + a_6\Omega^6} \quad f = \frac{\Omega}{2\pi} \left[ \frac{1}{m} \right]$$



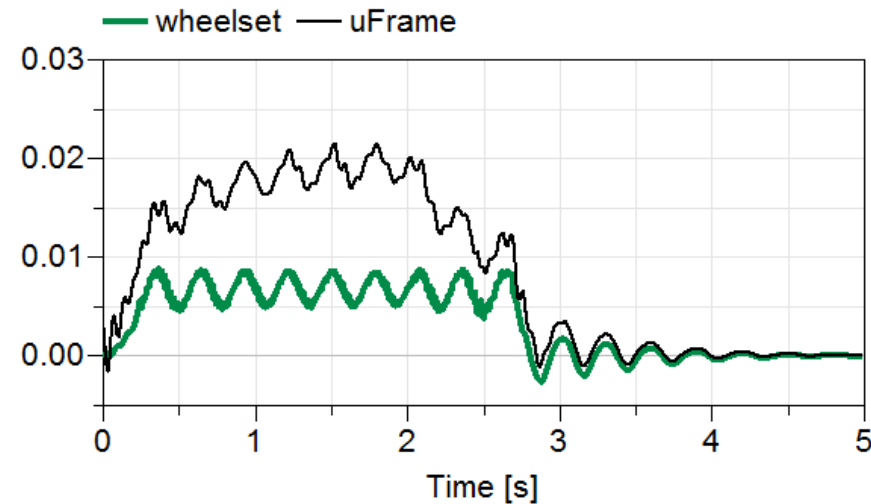
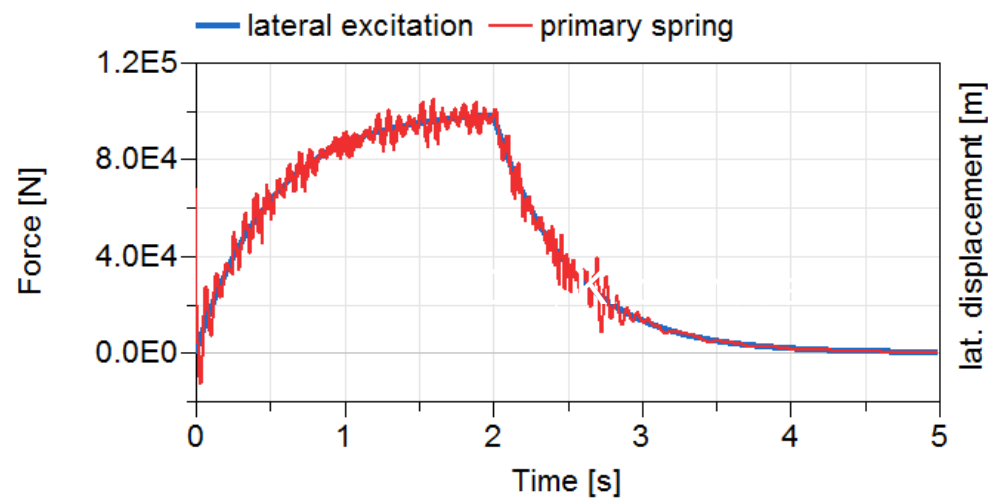
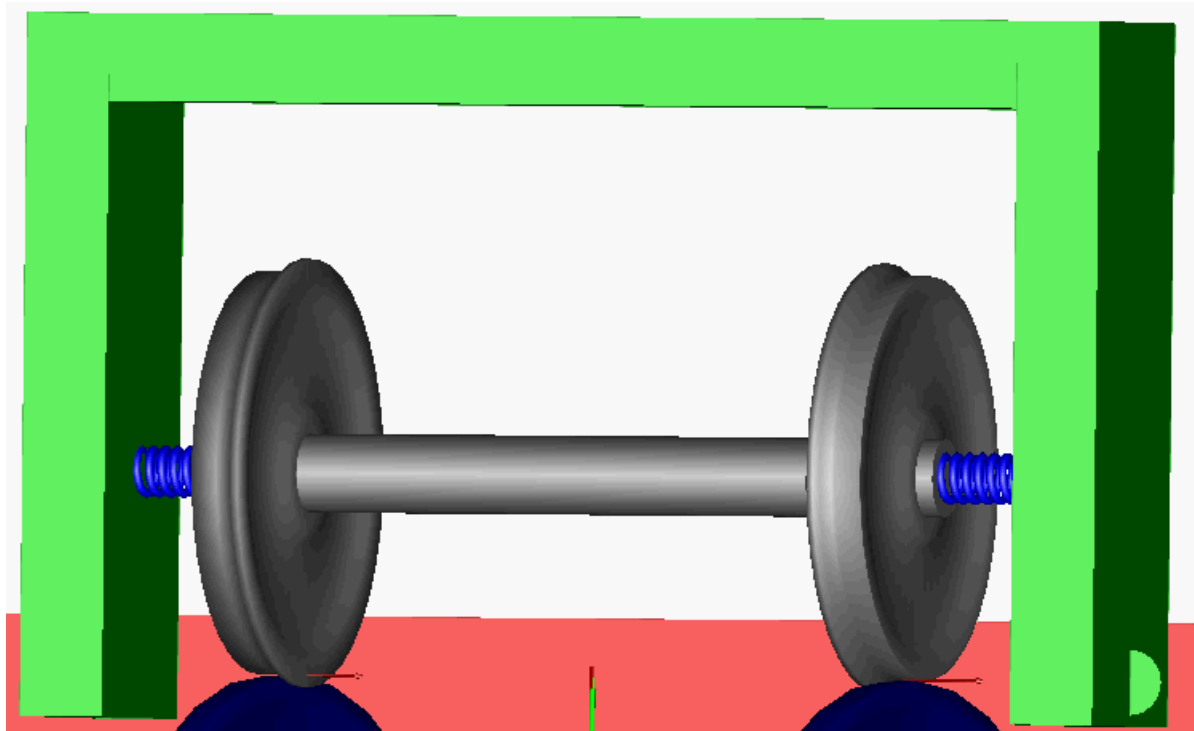
	CPU-s/s	$N_{MVZ}$
Quarter vehicle	1.58	0.63
Full vehicle	9.08	0.43 ... 0.83



# Applications: Roller Rig (I)



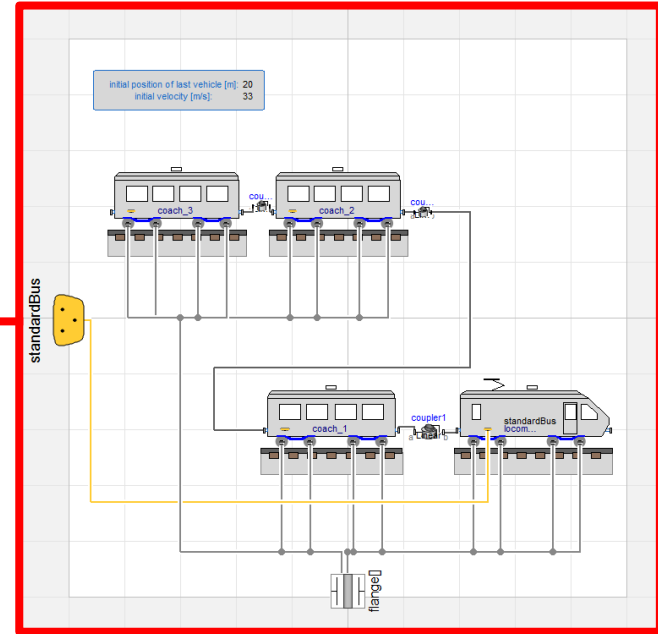
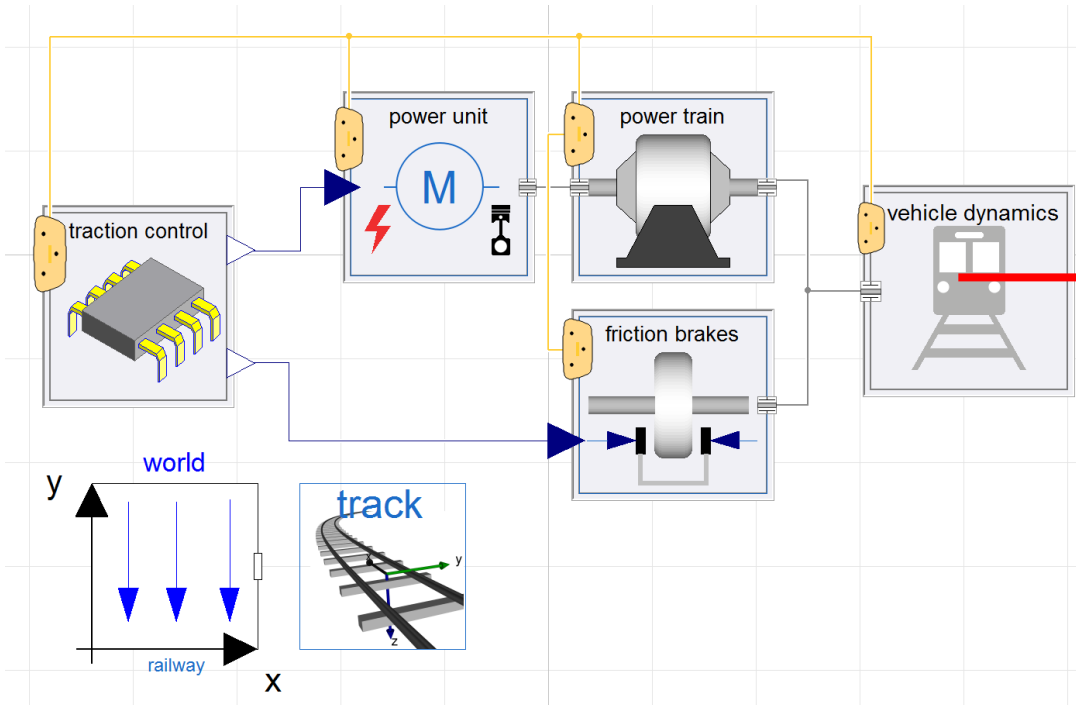
# Applications: Roller Rig (II)



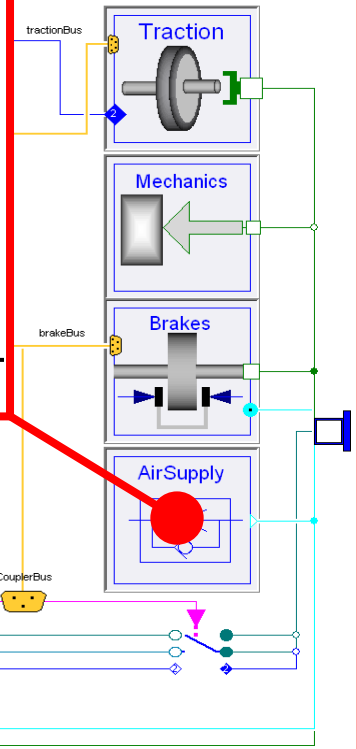
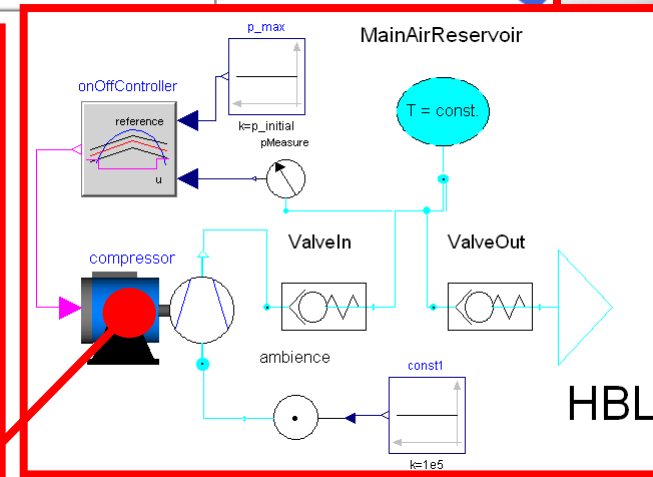
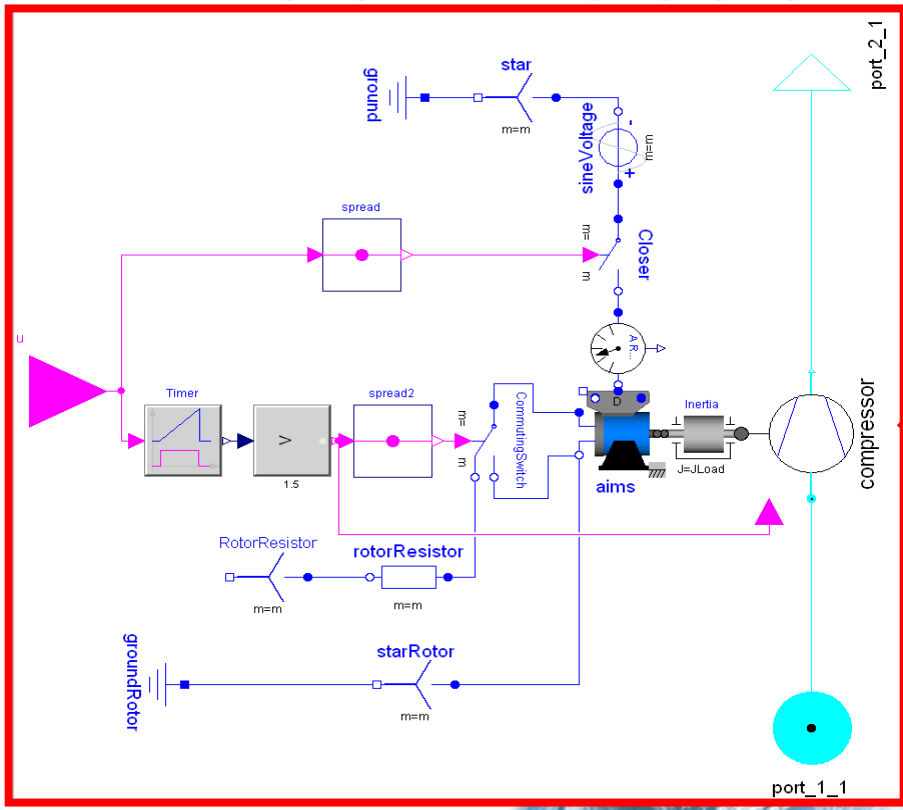
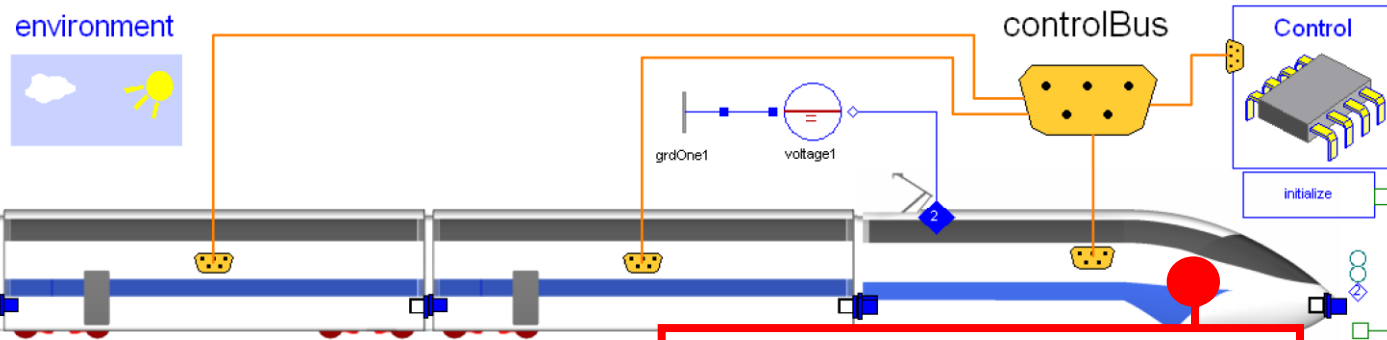


# Multidomain Modeling

## VehicleInterfaces Library reloaded



# Multidomain Modeling Alternative Proposal



# Conclusions

- The DLR RailwayDynamics Library covers railway dynamics.
- Different levels of details up to realtime capability: SiL, HiL
- Synthesis of advanced observer and controller lay-outs
- Multidomain modeling in one consistent environment
  - Pneumatics: brakes, air suspensions
  - Power trains: electric, Diesel-hydraulic, Diesel-electric
  - Regeneration of electric energy
  - Adhesion and interaction of traction and power-train
  - Auxiliary systems
  - .....

