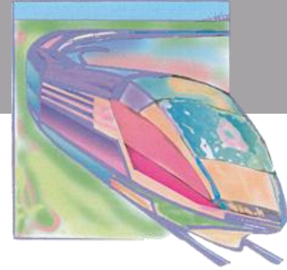

Analysis of vehicle features influencing train derailment processes and consequences

Minimizing disasterous consequences through innovative vehicle design

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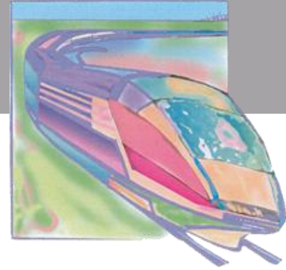

Outline

- **Introduction**
- **Empirical observations and data base**
- **Multi-body simulations**
- **Preventing derailment**
- **Minimizing consequences of derailment**
- **Conclusions**

KTH has been working for >5 years with these issues, in close co-operation with **SJ** (former Swed State Rlys), **Bombardier**, **Banverket** (IM) and **Swed Rly Inspectorate**

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Derailment
(various causes)

Impact
(train to train/object)

Vehicle crashworthiness
(covered in present standards but only in longitudinal direction)

Possible sequence of events after derailment:

- Vehicles start to deviate laterally
- Wheelsets lose vertical support of sleepers
- Switches and crossings aggravate situation
- Larger lateral deviation -> Vehicles **buckle**, **overturn** and/or **collide**

or

- Wheels maintain a **minimal lateral deviation**
- Vehicles remain **in-line**, **upright** and **connected**

Vehicle derailment-worthiness
(no standards, almost no consideration)

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Empirical evidence

Development of an incident/accident database

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- Passenger trains, V > 70 km/h
- Incidents/accidents caused by:
  - -> Running gear failure (axles, wheels, etc.)
  - -> Track defects
  - -> Object on track, etc.

39 events (Nov 2007)

Sweden (13)
North America (10)
UK (8)
France (4)
Germany (3)
Japan (1)

- Based on available information, **the sequence of events** is studied:
  - -> **Incident**: “Why did it not turn into a catastrophe?”
  - -> **Accident**: “How could the events have taken a different course?”

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Empirically based conclusions

- **Mechanical restrictions** between axle and bogie frame may **prevent derailment** after an axle journal failure (Sweden + … ?)
- **Substitute guidance mechanisms** (low-reaching running gear parts) may **prevent** large lateral **deviation** after derailment (Germany, Japan, Sweden…)
- Trains with an **articulated configuration** seem to have favourable properties at high-speed derailments (France)
- Vehicles with a **high centre of gravity** seem to be sensitive to overturning (double-deckers USA)
- **Switches & crossings** may turn a “controlled” derailment into a catastrophe, but on many occasions not!

Means of quantifying **derailment-worthiness features** require a more precise knowledge of **pre/post-derailment vehicle behaviour**

Simulation tools need to be developed!

Pre-derailment methodology

- Simulations performed with “Multi-Body-Systems” (MBS) software GENSYS
  - A typical four-axle conventional vehicle comprises 66 degrees of freedom

- Implemented derailment causes:
  - **Axle journal failure** on the outside of the wheel **->** Removing parts of the primary suspension
  - **‘Wheel flange on rail’** **->** Leading wheelset displaced laterally with a yaw angle
  - **High rail failure** (in a curve) **->** Wheel to high (outer) rail contact removed

- Derailment scenarios:
  - Straight and curved track
  - V = 100 and 200 km/h
  - Cant deficiency = 0 – 245 mm (a_q = 0 – 1.6 m/s^2)

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Post-derailment methodology

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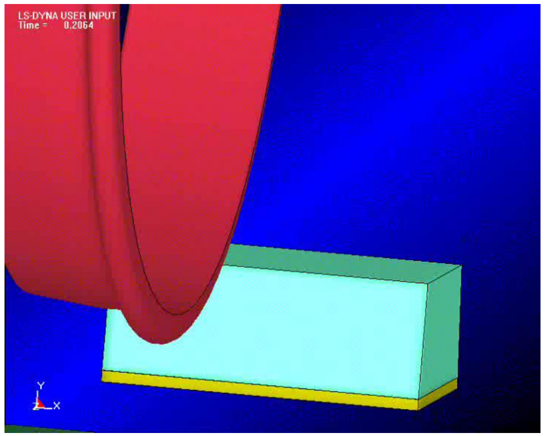
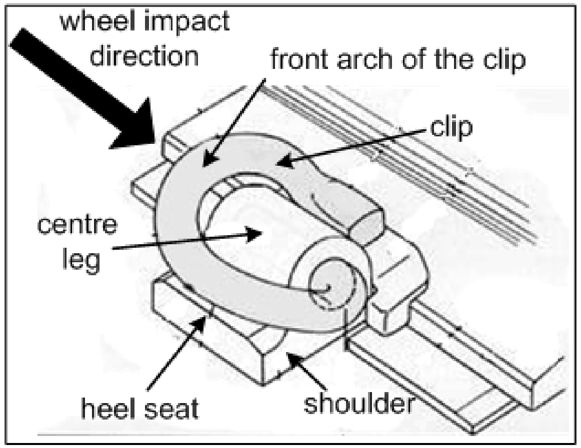
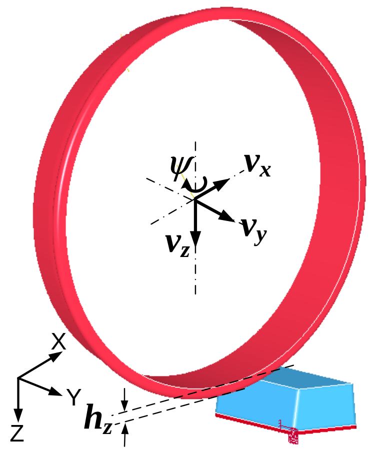
How do we model a wheelset's motion on sleepers?

- Wheel to concrete sleeper impact model is built with LS-DYNA finite element (FE) software -> Material model predicts damage on concrete
- Force resultants are collected into a **look-up table** from large series of FE simulations for various combinations of **initial impact state parameters**
- MBS* post-derailment model detects wheel to concrete sleeper contact and generates force resultants based on the **initial impact state condition**
- MBS* post-derailment model takes into consideration wheel to rail fastener impact



MBS* - Multi Body System





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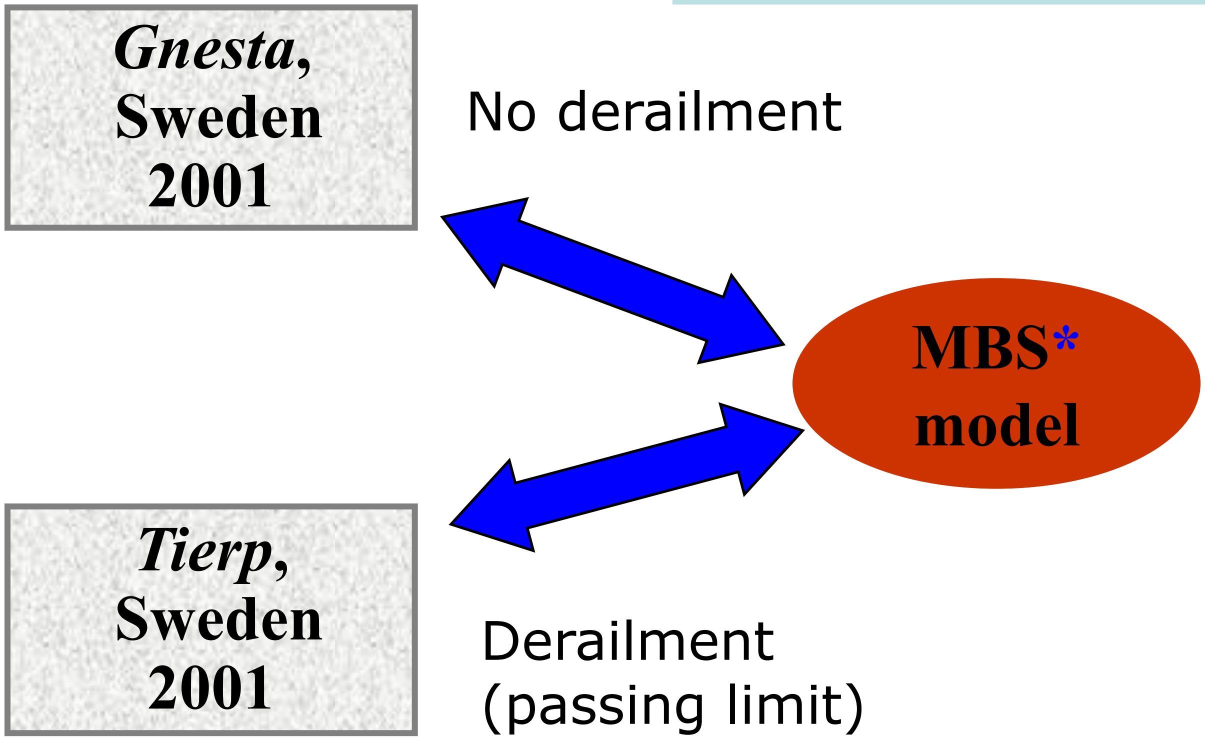
Pre-derailment module validation

Validation:

Axle journal failure model successfully validated against 2 authentic Swedish incidents in terms of vehicle behaviour succeeding failure



MBS* - Multi Body System

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Post-derailment module validation

Upplands Väsby
Sweden
1980

Phase I

FE* model

Phase II

MBS* model

Phase III

Bomansberget
Sweden
2006

Phase III:

Successful agreement of sleeper impact (**indentation**) and **lateral deviation** between MBS-model and an authentic passenger car derailment

FE* - Finite Element ***MBS* - Multi Body System***

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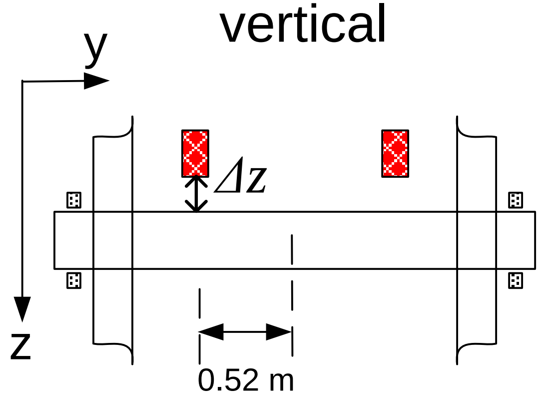
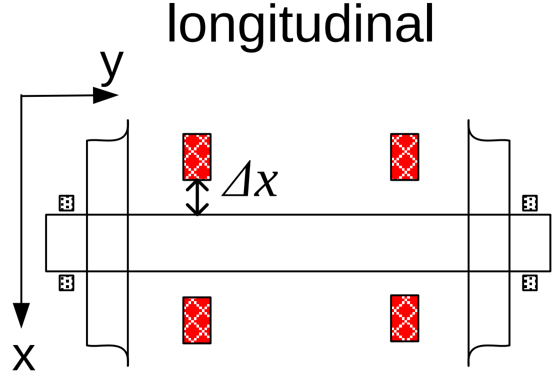
I: Preventing derailment
to occur after axle journal failure: Mechanical restrictions in the bogie

- Axle journal failure occurred on X *2000* power car at 4 occasions
  -> **only 1 derailment** (at Tierp)
- Derailment after an axle journal failure is prevented by inserting **vertical and longitudinal mechanical restrictions** between bogie and axle
- Vehicle design parameters under study:
  - required restrictions play (Δz, Δx) that prevents derailment





Mechanical restrictions attached to bogie frame

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II: Minimizing consequences
after derailment
Overview

Principal vehicle design feature/parameter under investigation

***C* – Conventional train** (four-axle vehicles with centre couplers)
***A* – Articulated train** (one bogie shared by two carbody ends)

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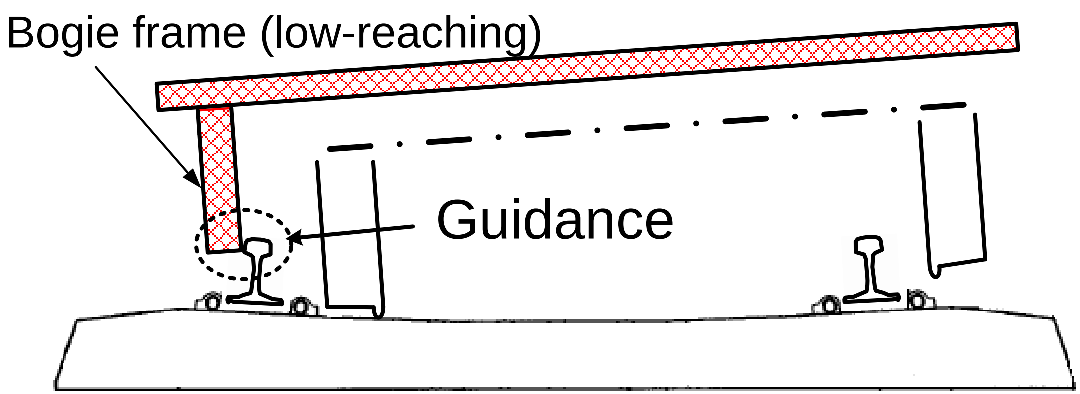
Substitute guidance mechanisms (SGM)

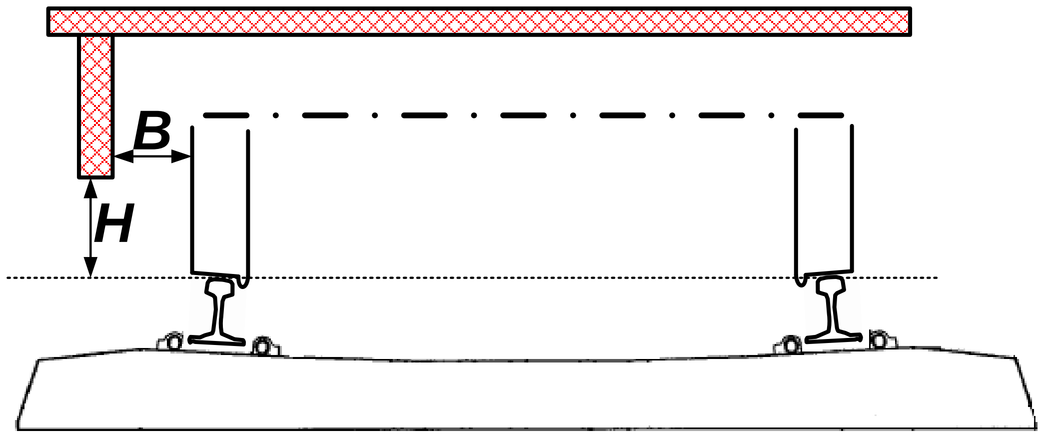
- Minimizing lateral deviation by allowing SGM* to engage laterally with the rail
- Possible SGM* configurations attached onto:

  -> bogie frame (sprung mass)

In a derailed condition



Geometrical feasibility parameters



SGM* - Substitute Guidance Mechanisms

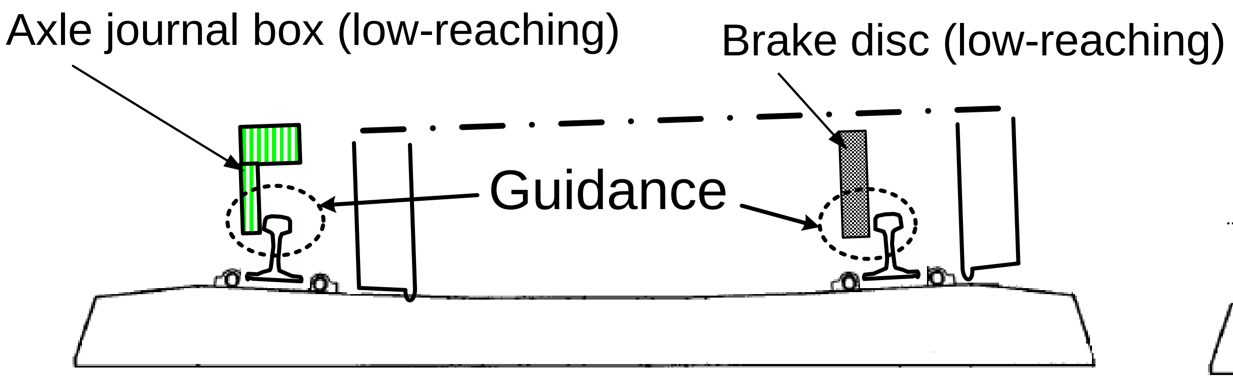
Substitute guidance mechanisms (SGM)

- Minimizing lateral deviation by allowing SGM* to engage laterally with the rail
- Possible SGM* configurations attached onto:

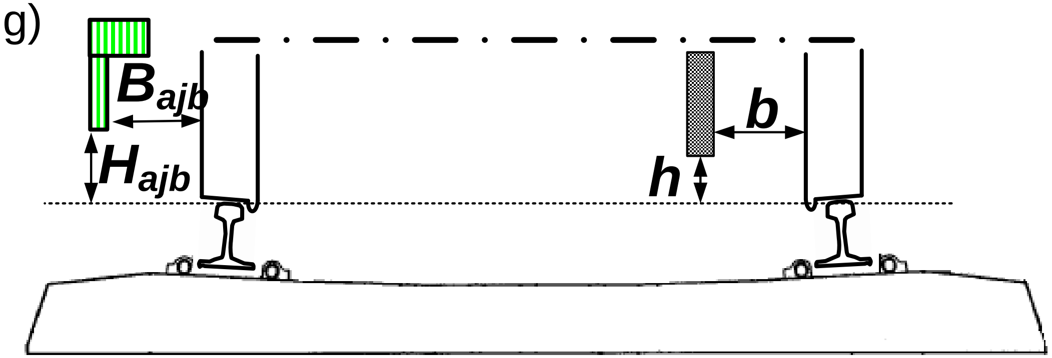
  -> bogie frame (sprung mass)

  -> axle (unsprung mass: journal box, brake disc, etc)

In a derailed condition



Geometrical feasibility parameters



SGM* - Substitute Guidance Mechanisms

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Example: Brake disc

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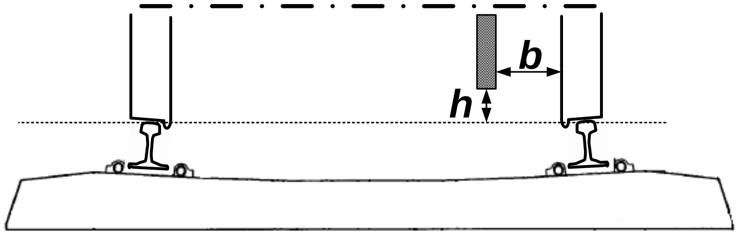
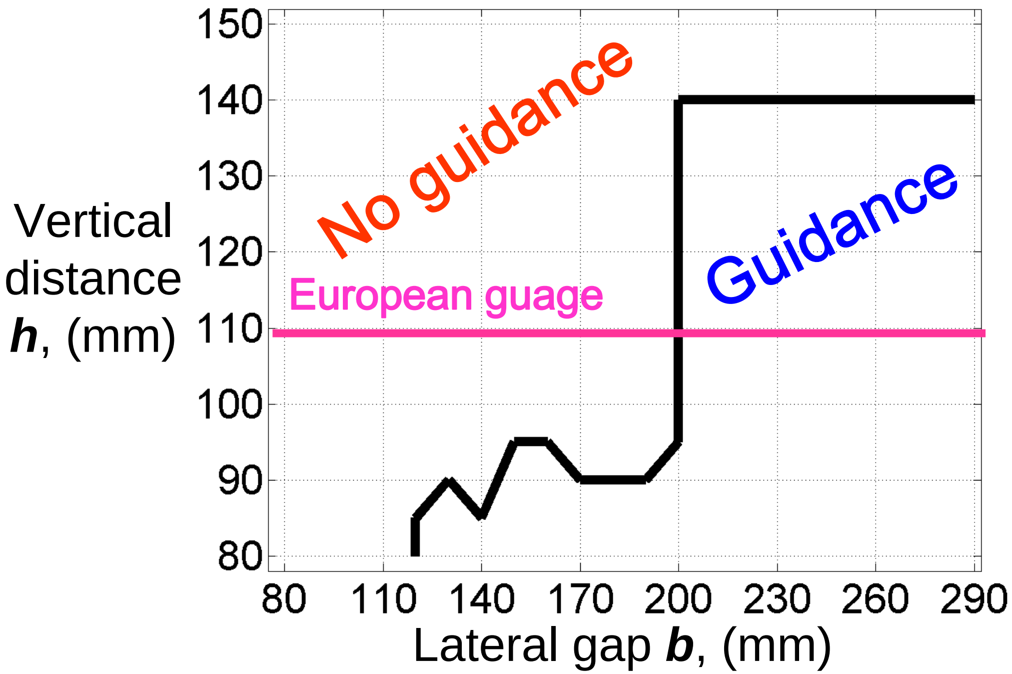


Derailment scenario:

- Axle journal failure
- V = 200 km/h
- Cant deficiency = 245 mm (a_q = 1.6 m/s^2)

Maximum allowed **vertical distance** (**h**) for different **lateral gap** (**b**) for a low-reaching brake disc, in order to limit lateral deviation



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Example: Brake disc

Derailment scenario:

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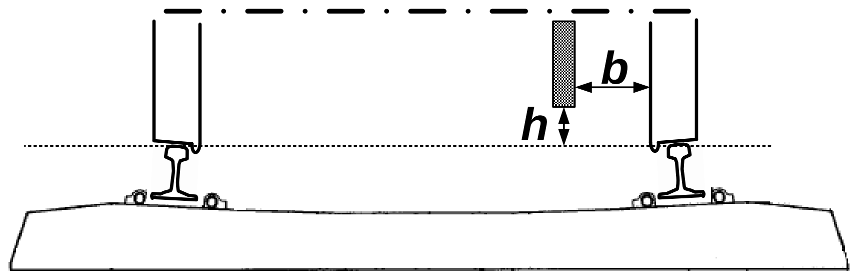

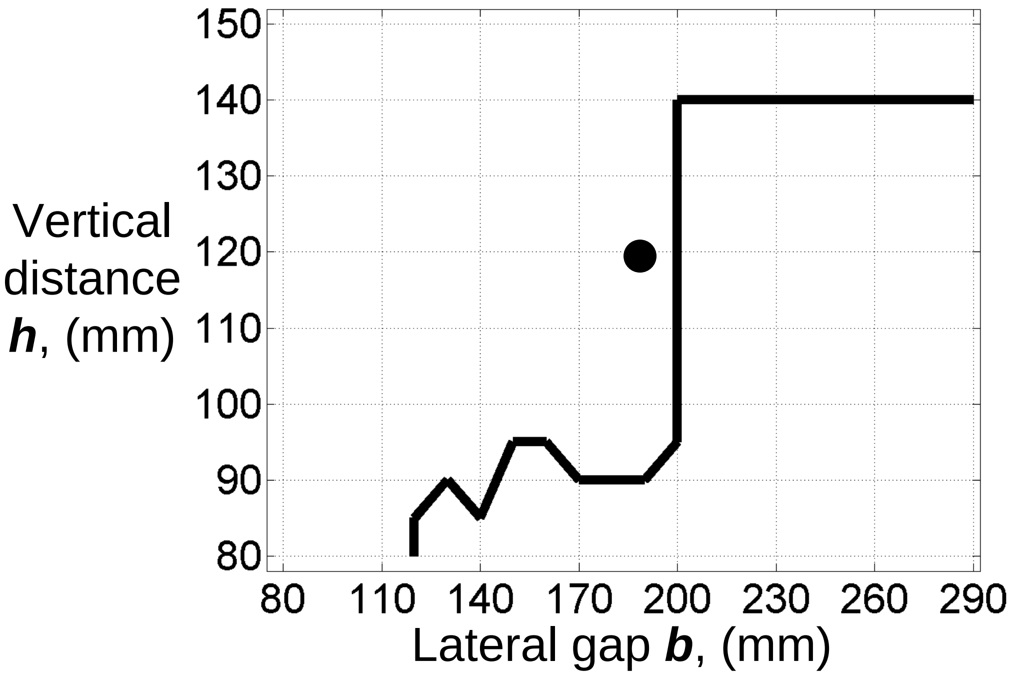

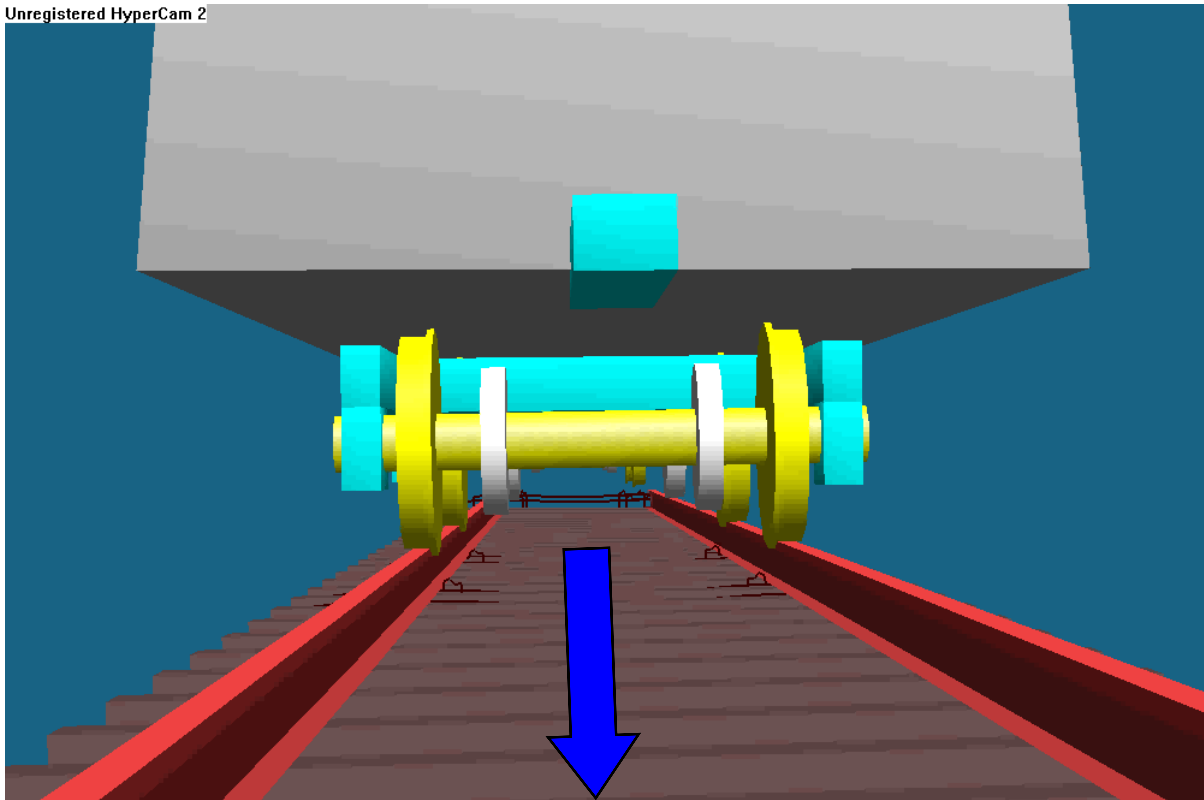

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Example: Brake disc

Derailment scenario:

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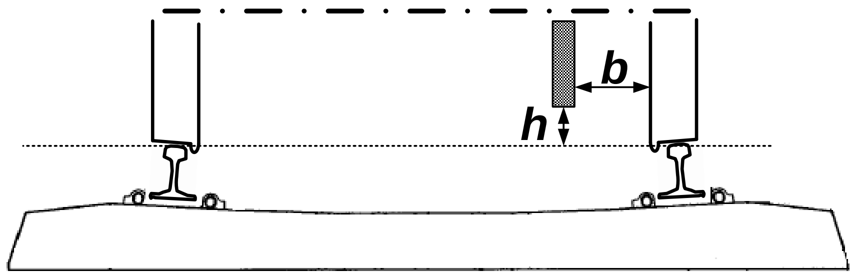

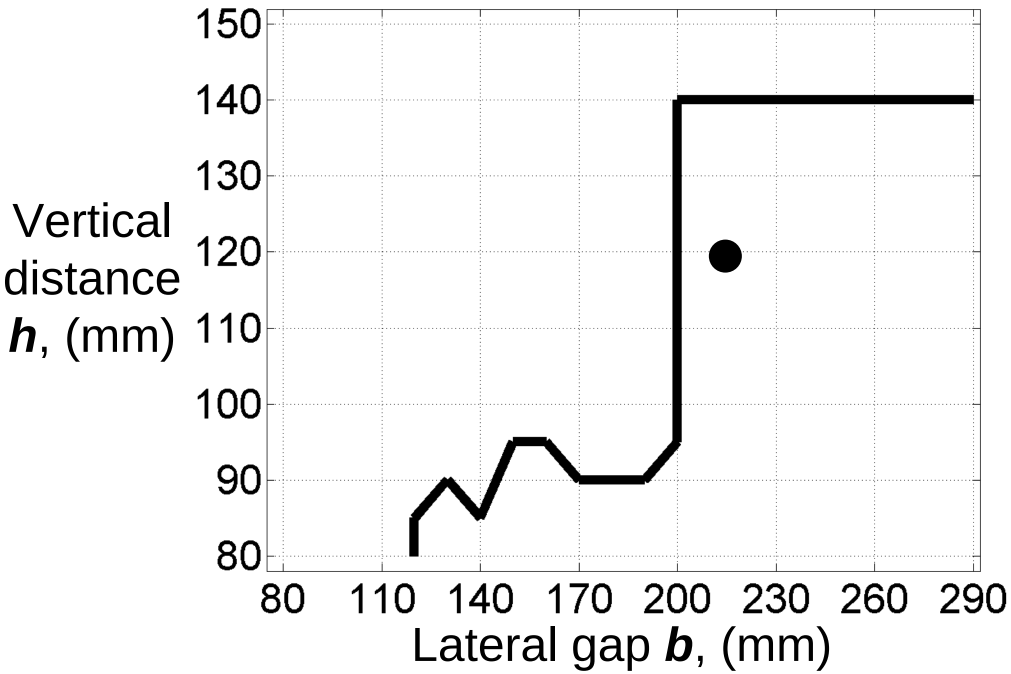

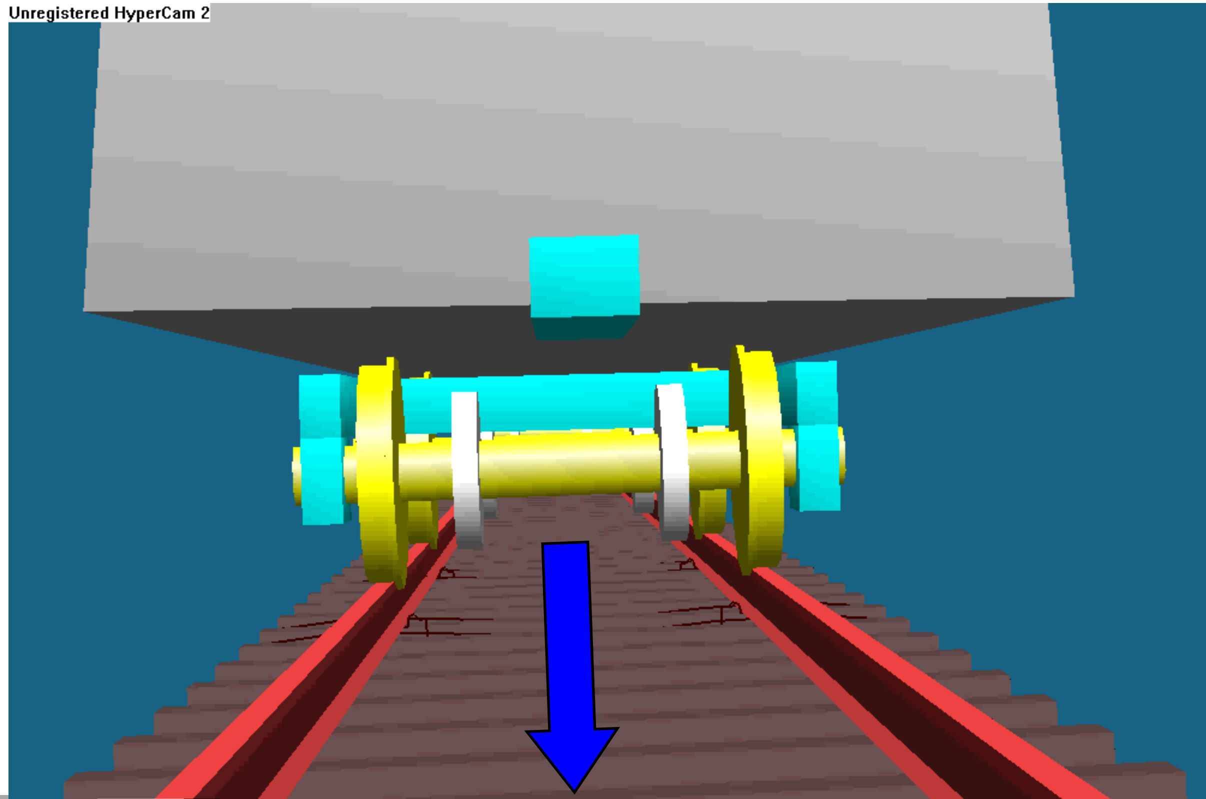

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Carbody height of centre of gravity and other features

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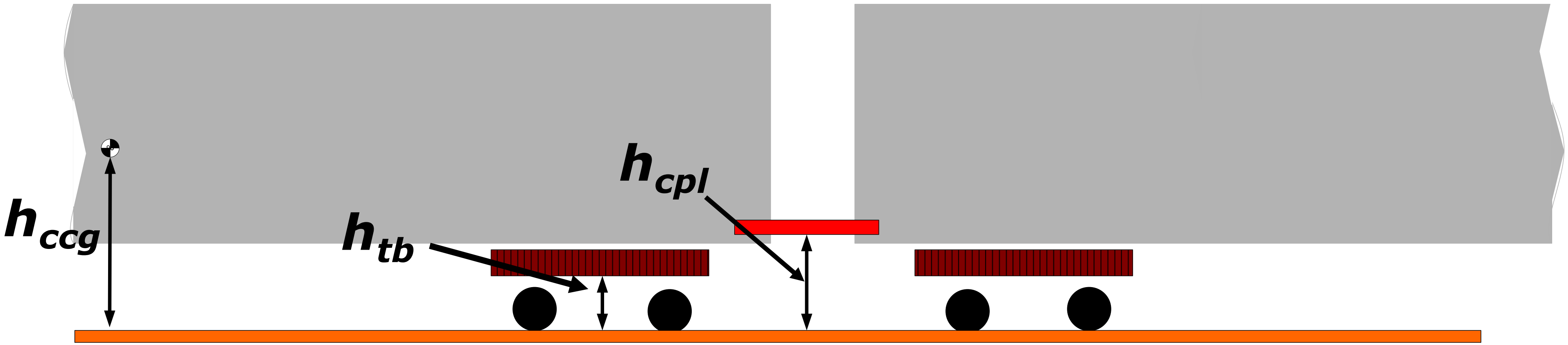
- Vehicle overturning tendency after derailment on straight and curved track
- Vehicle design parameters under study:
  - -> Carbody height of centre of gravity, h_{ccg} = 1.61 m (std), +20, +40%
  - -> Vehicle coupler height, h_{cpl} = 1.025 m (std), ±10, ±20%
  - -> Bogie transversal beam height, h_{tb}



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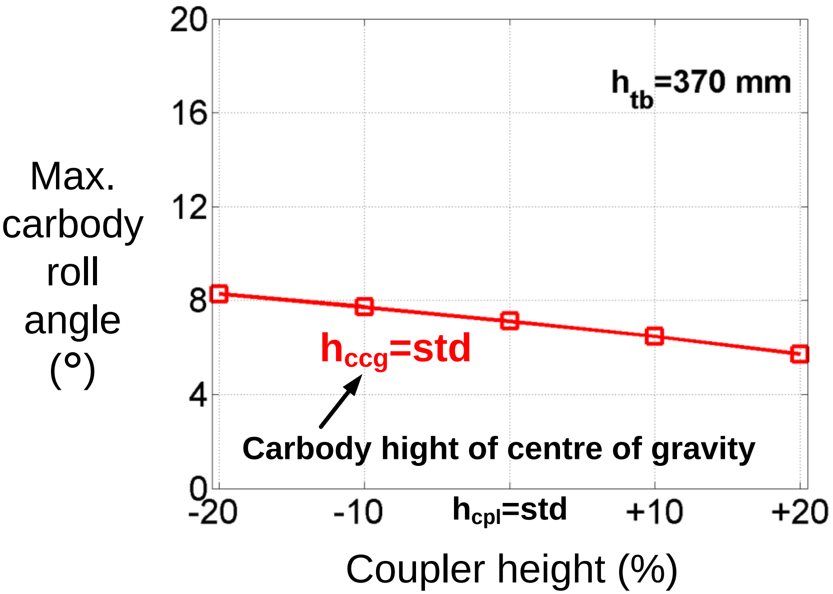
Example: Overturning tendency

- Train configuration: 3 intermediate passenger cars with centre couplers
- Derailment scenario: 'Wheel flange on rail', tangent track, V = 200 km/h, sleeper length = 2.53 m



Example: Overturning tendency

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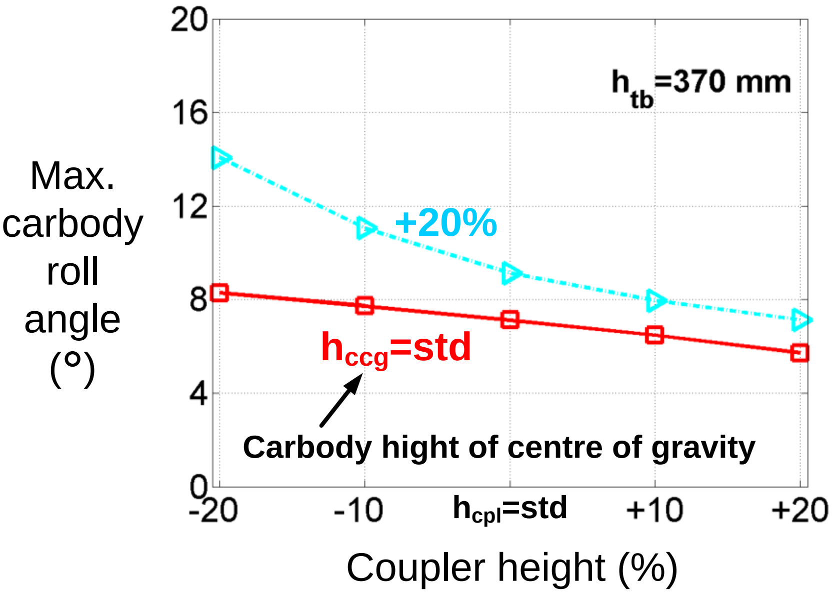
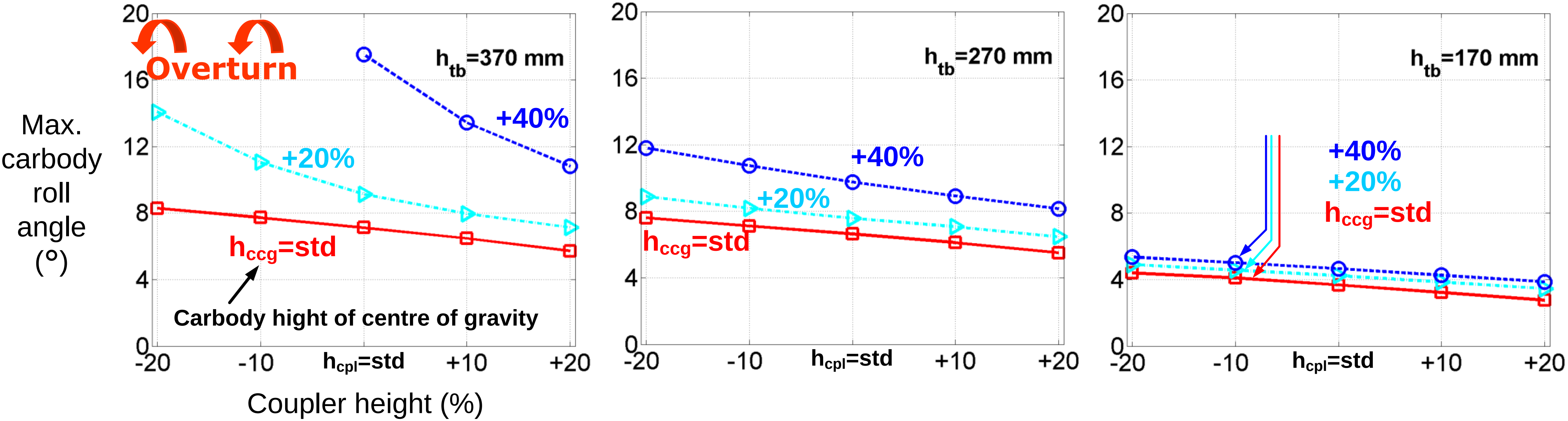


Example: Overturning tendency

- Train configuration: 3 intermediate passenger cars with centre couplers
- Derailment scenario: 'Wheel flange on rail', tangent track, V = 200 km/h

Conclusions on favourable features:

- Low centre of gravity
- Transversal beam in bogie



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Inter-carbody longitudinal dampers

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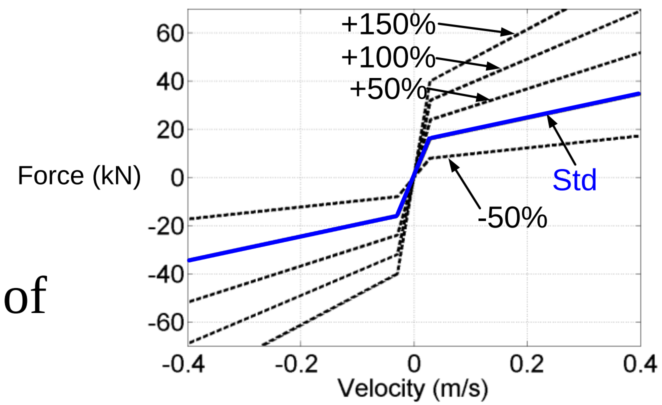
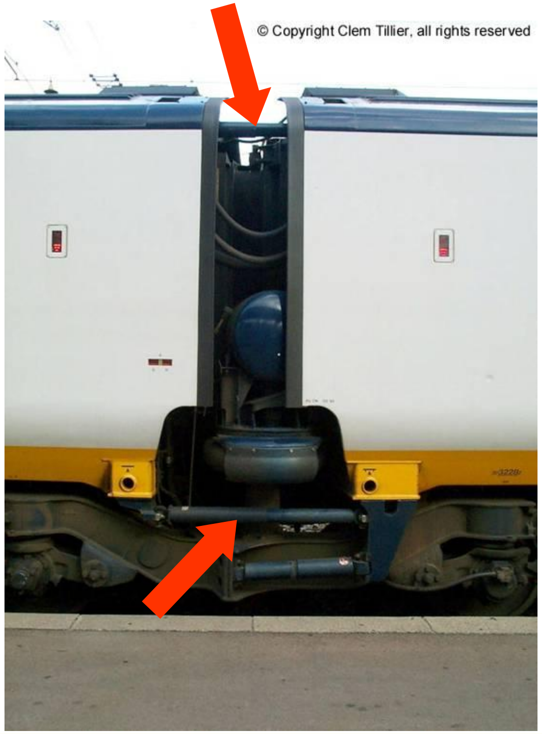
- Articulated train configuration
- Vehicle lateral deviation and overturning tendency after derailment on straight and curved track
- Vehicle design parameters under study:
  - -> Inter-carbody longitudinal damper characteristics
  - -> Bogie transversal beam height

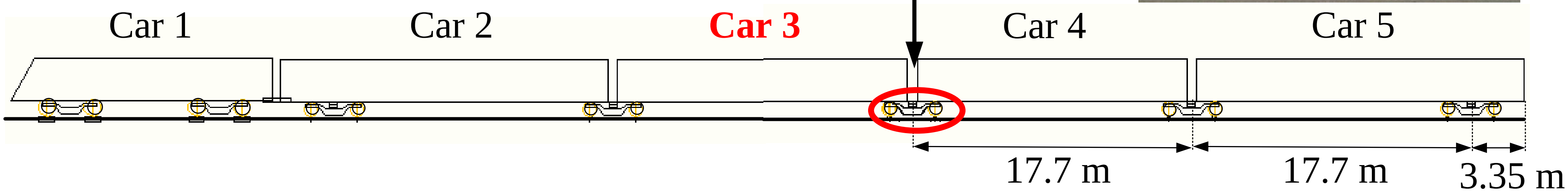
Tested inter-vehicle dampers characteristics





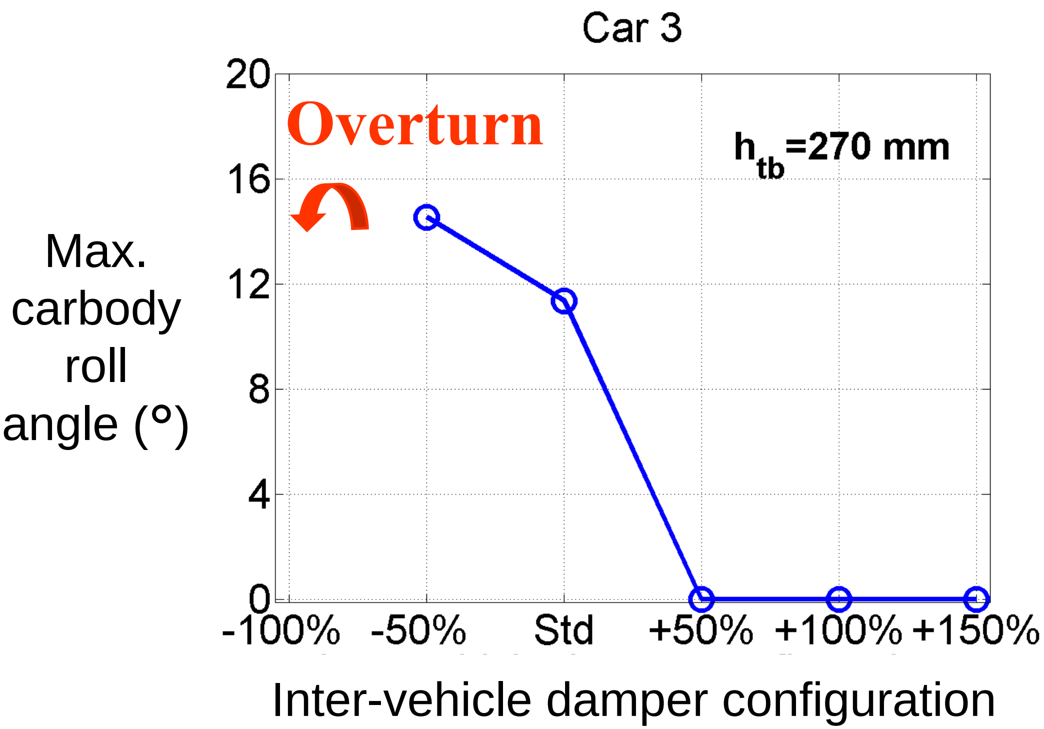
Derailing bogie

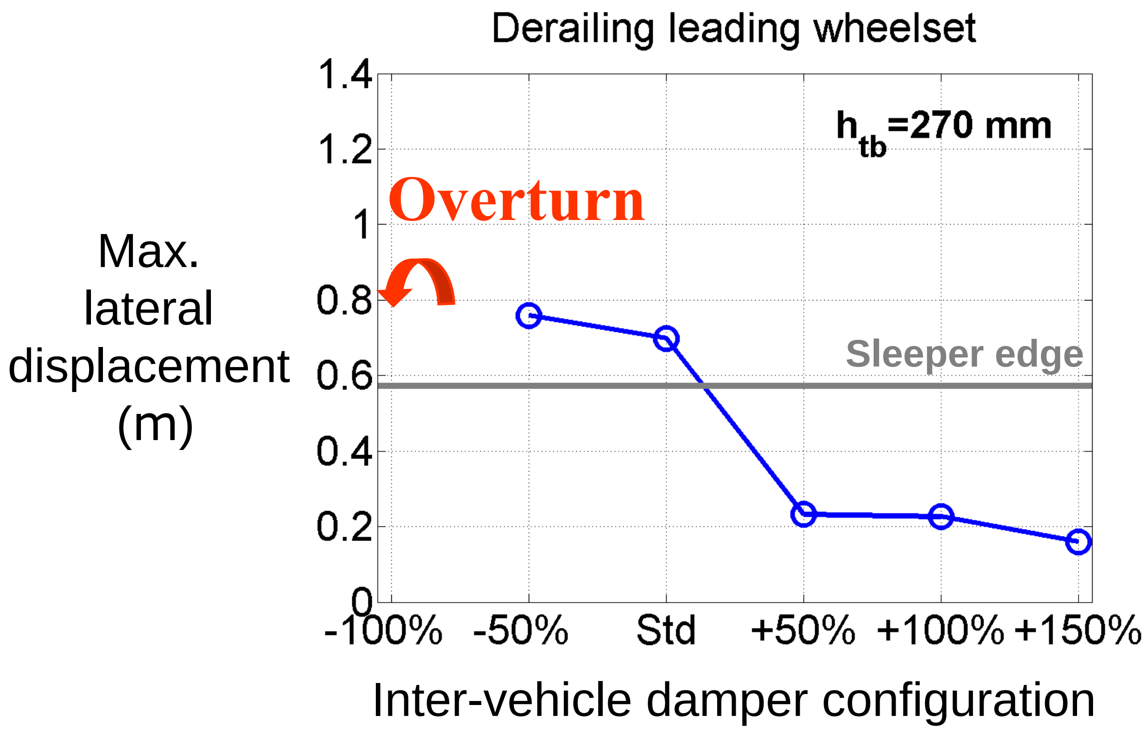
Direction of travel



Example: Lateral deviation and overturning tendency

- Derailment scenario: ‘Wheel flange on rail’, straight track, V = 200 km/h
- Conclusions:
  - Longitudinal dampers are highly efficient to prevent lateral deviation
  - The articulation alone does not prevent





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Conclusions on methodology

- A data base of **incidents and accidents** has been set up on which basis several vehicle features and train design parameters are identified as able to limit the consequences after train derailment – or prevent derailment - at higher speed.
- Vehicle derailment-worthiness studies are enabled by the development of a novel **post-derailment simulation module** to account for impact between wheel and sleepers/fasteners.
- The simulation module has been **validated successfully** in several stages with authentic passenger vehicle derailments.

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Conclusions on **vehicle features** found to ultimately increase **derailment-worthiness**

- ✓ **Mechanical restrictions** that limit the wheelset’s longitudinal and vertical movements relative to the bogie frame
- ✓ Low-reaching **lateral guidance mechanisms** attached onto bogie frames or axles (axle box, brake discs etc)
- ✓ Low-reaching **vertical support mechanisms** (transversal beam in bogie)
- ✓ No too high carbody **height of centre of gravity** in relation to coupler pivot centre height
- ✓ Small centre **coupler yaw angle** relative to the carbody for the conventional train configuration
- ✓ Powerful **inter-vehicle longitudinal dampers** for the articulated train configuration

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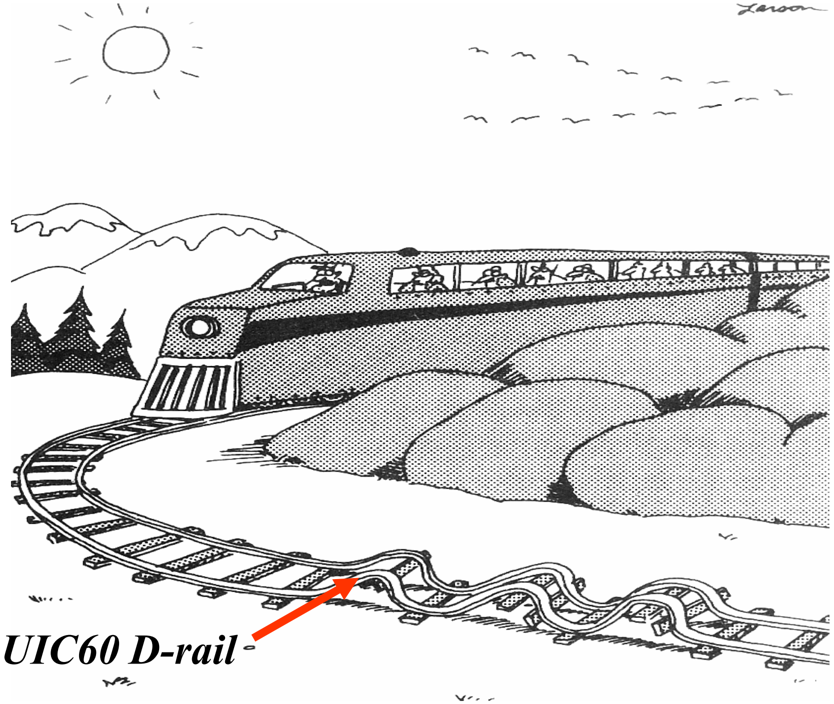

Thank you for your attention !!!

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