

Vehicle-Track Interaction & Dynamics

Rob Caldwell

National Research Council Canada

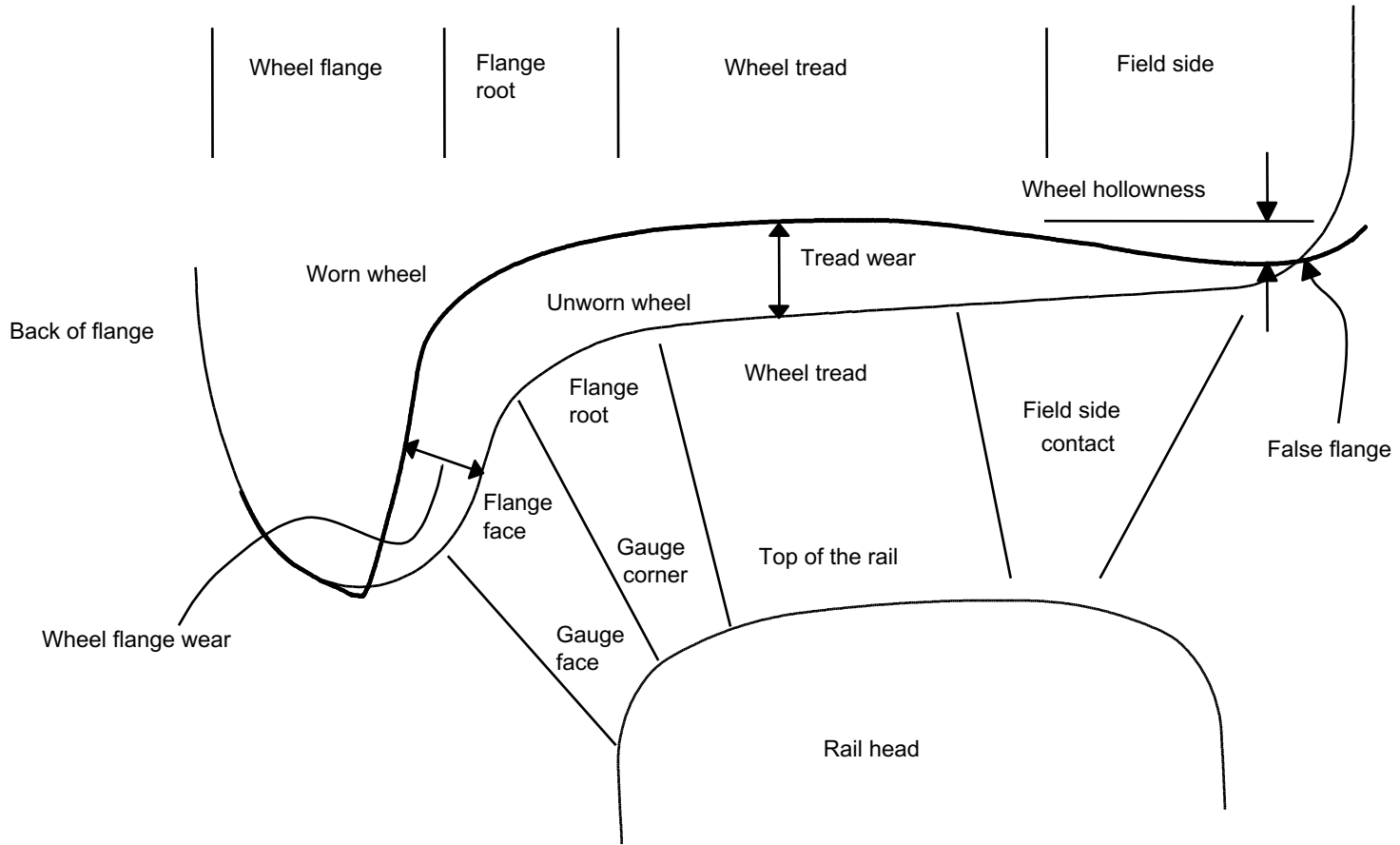


Agenda

1. Vehicle steering, stability and curving forces
2. Wheel-rail profile design and performance
3. VTI derailment mechanisms and risk assessment
4. Impact and dynamic loads



Terminology



WHEELSET & VEHICLE STEERING



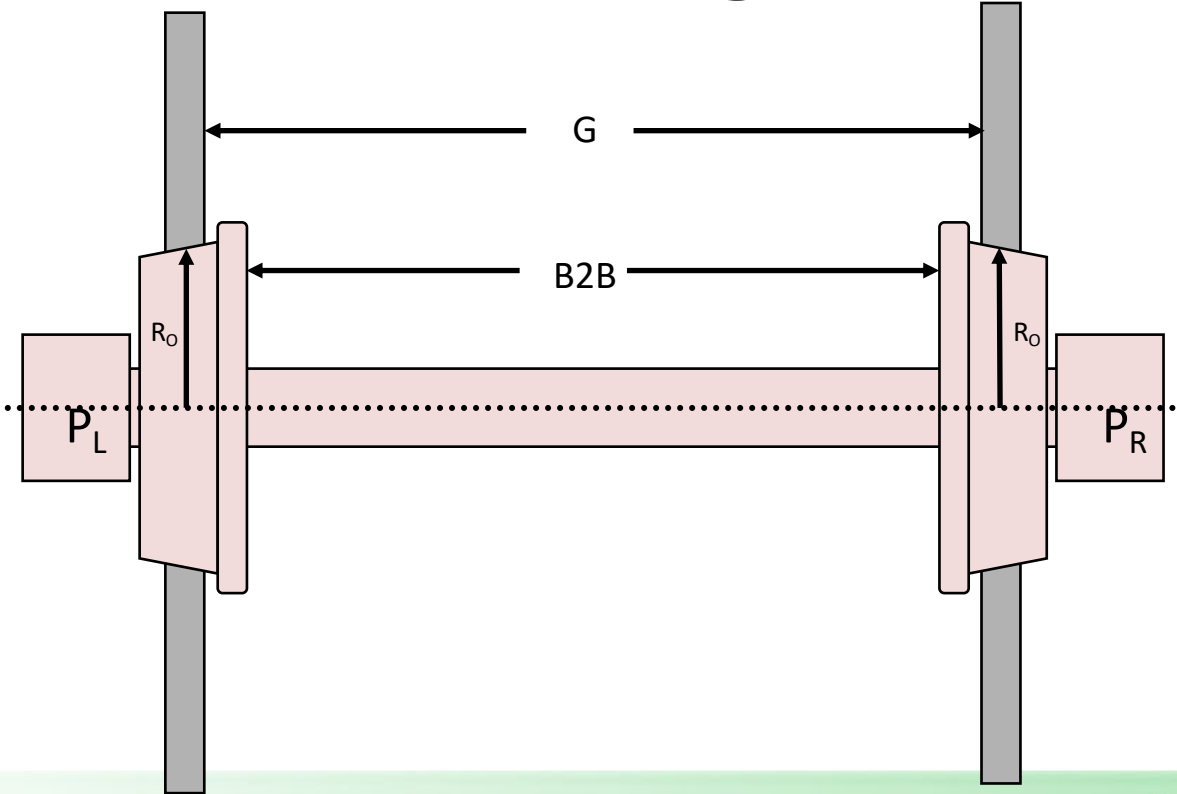
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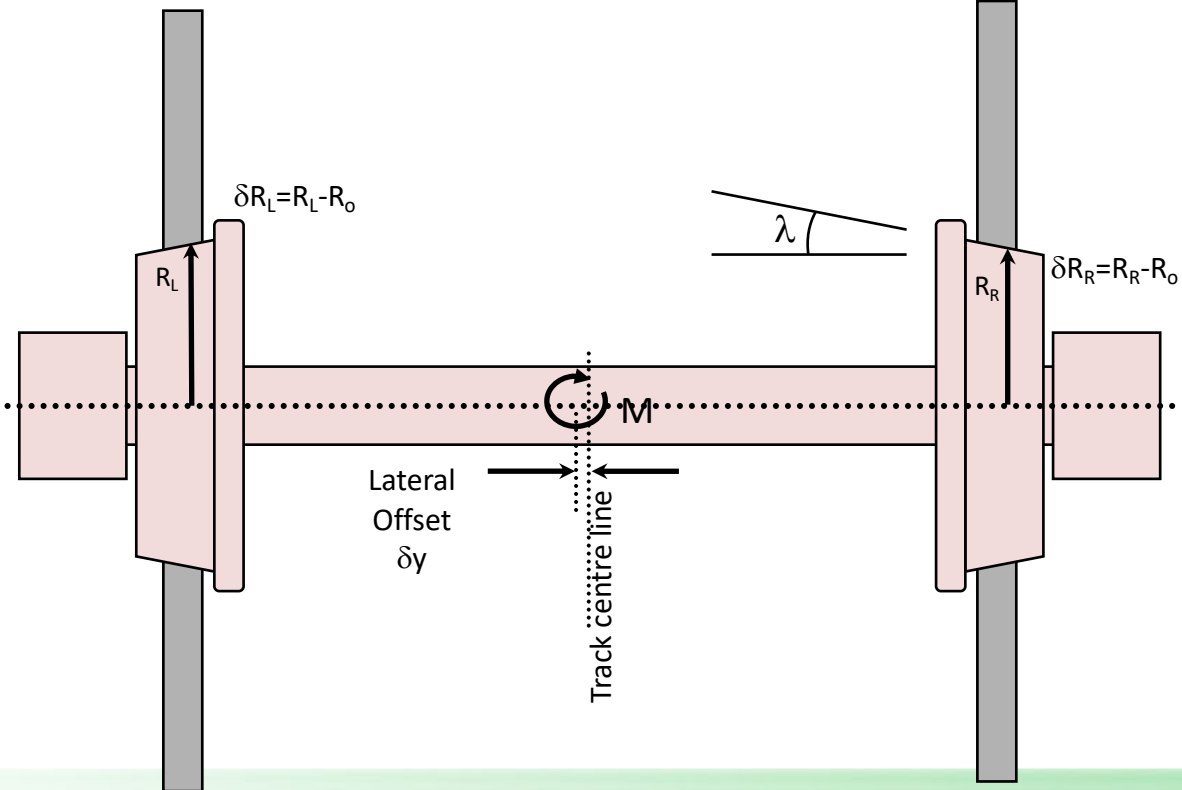
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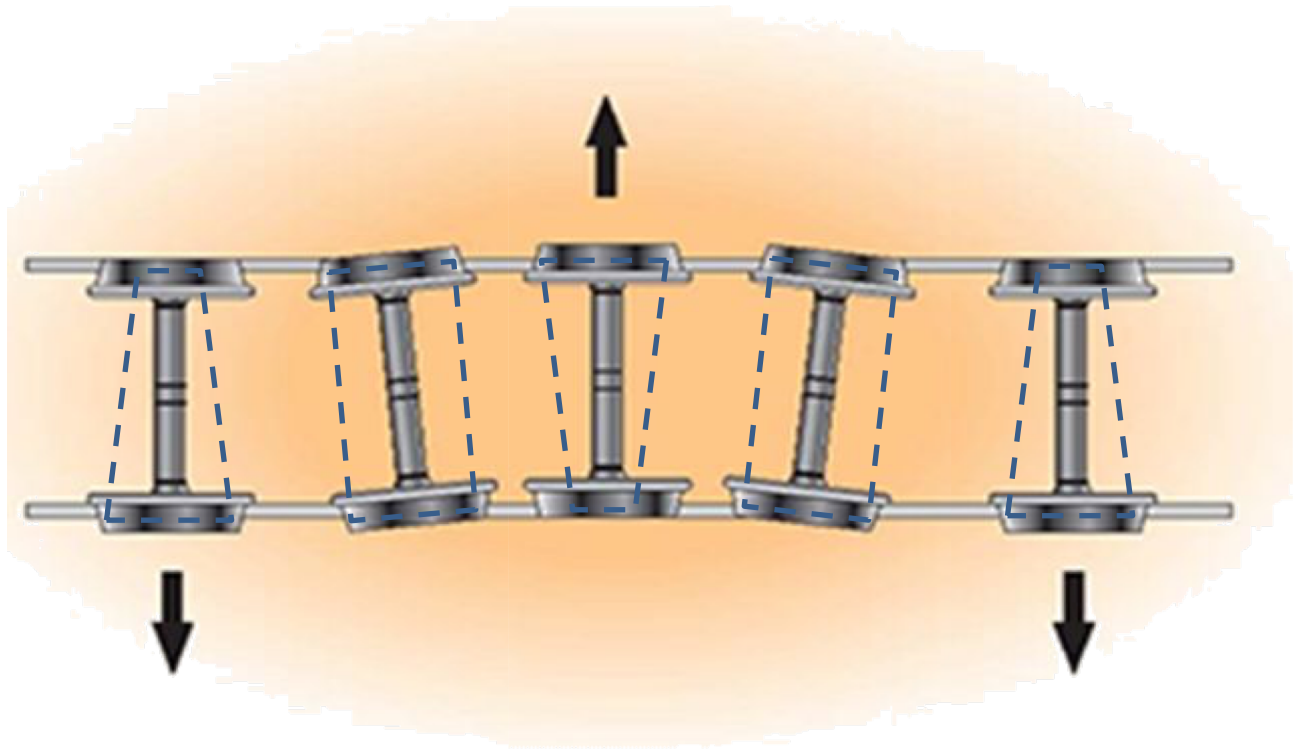
The Free Rolling Wheelset

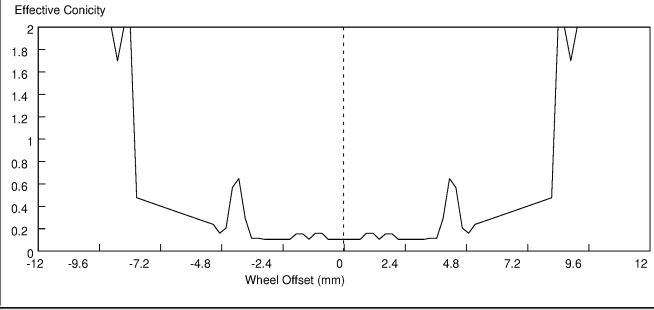
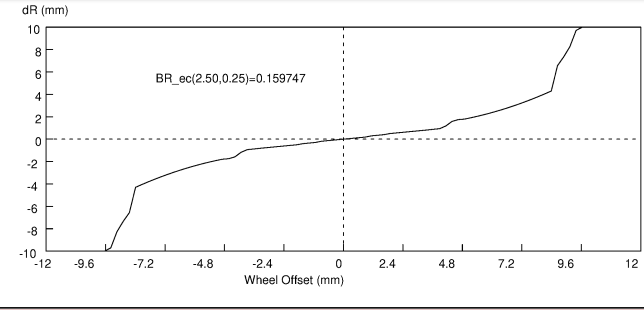


The Free Rolling Wheelset



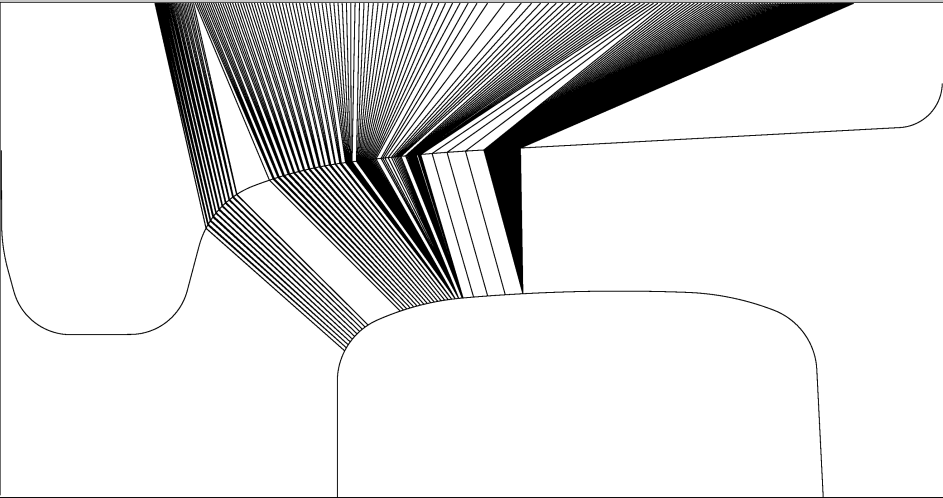
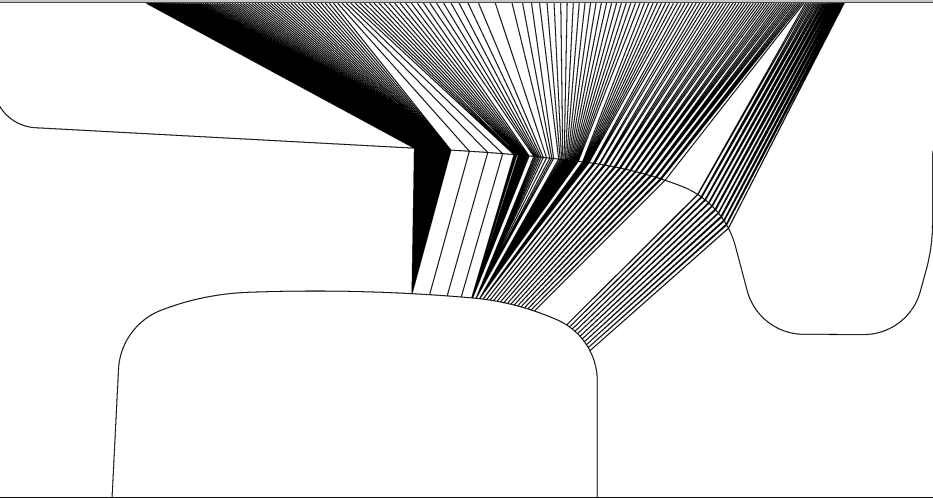
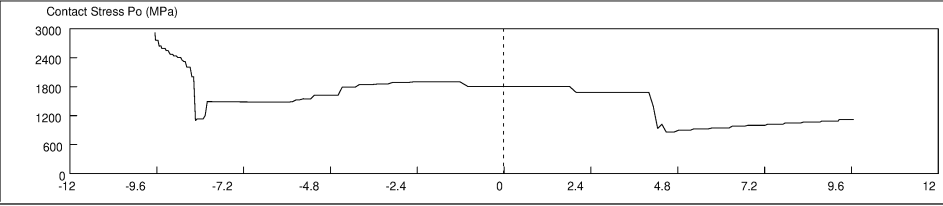
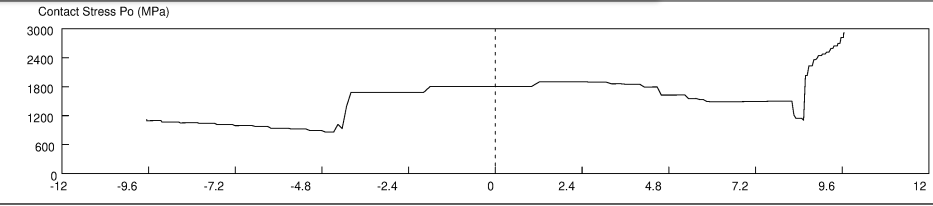
The Free Wheelset - Hunting





Input/Output Values

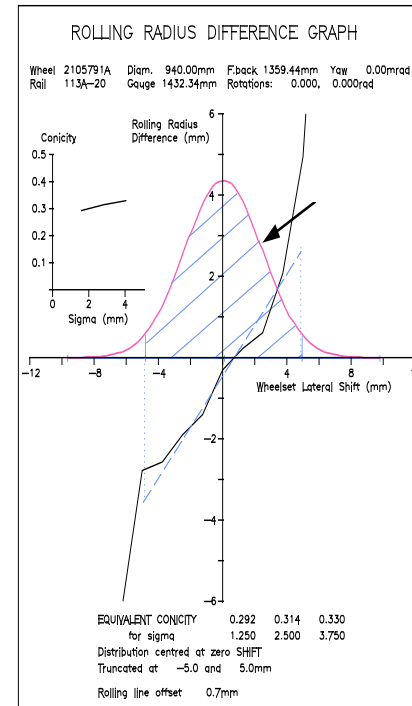
L_load :	5100
R_load :	5100
aca :	0
Rleft :	0.33
Right :	0.33
CurveRadius :	10000
dR :	0.0
Smoment :	0.0
Drag :	0.0



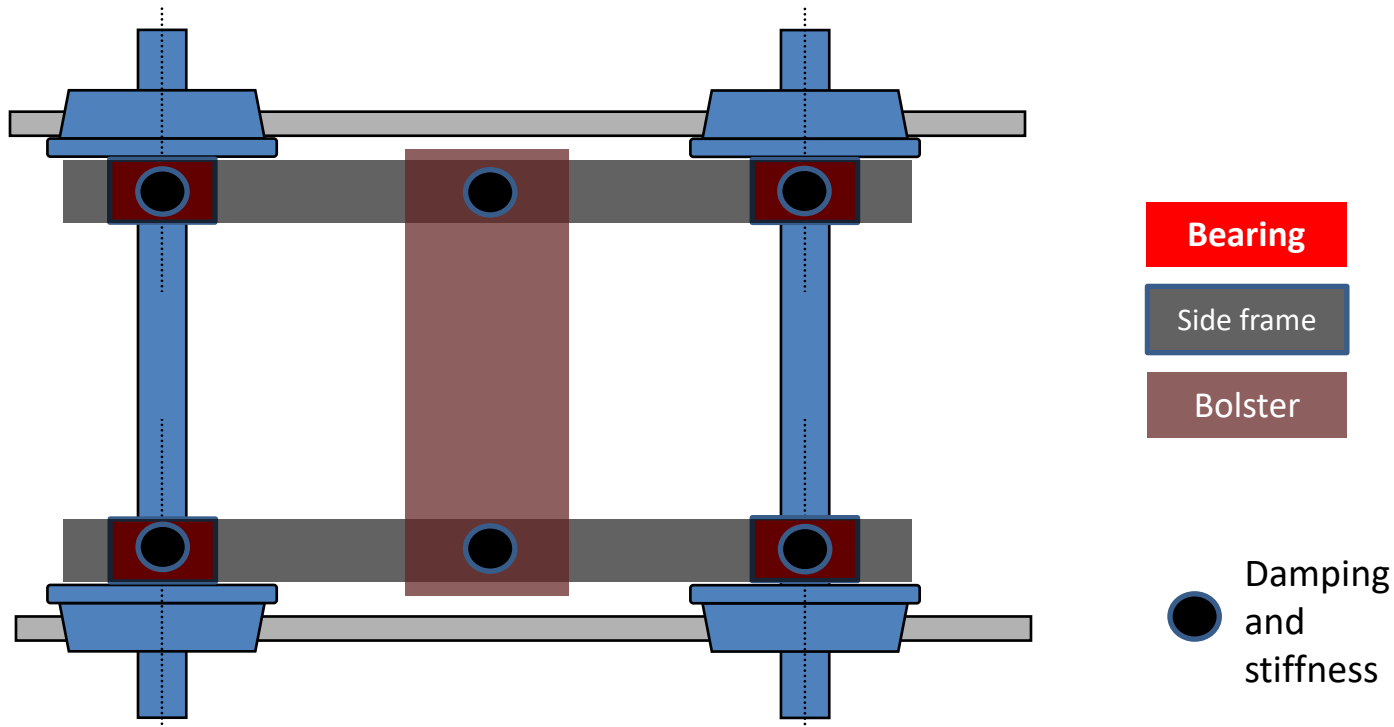
Equivalent Conicity from the ΔR Plot

- British Rail derivation

$$\lambda_e = \frac{1}{2} \int \frac{N(y) (r_R - r_L)}{y} dy$$

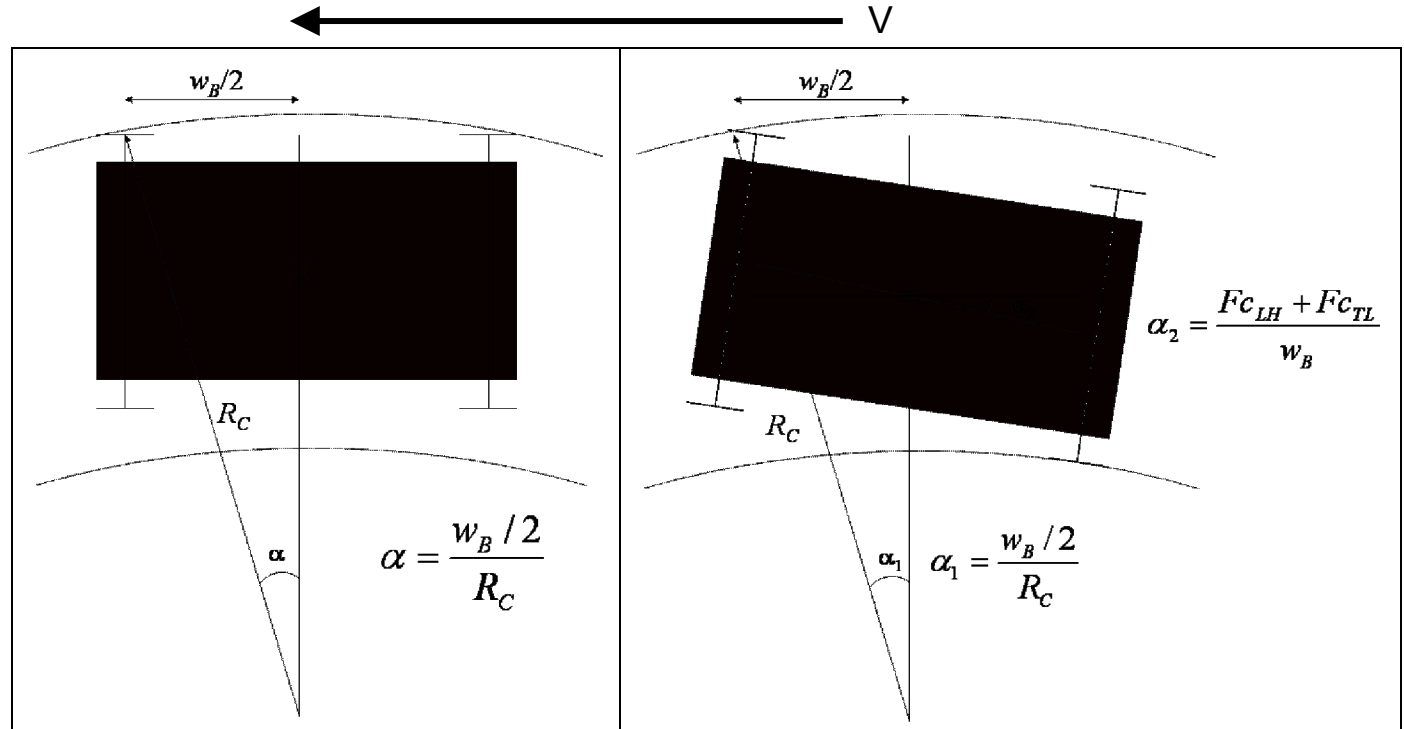


A Truck can Provide Stability



Leading Wheelset - Yaw Angle

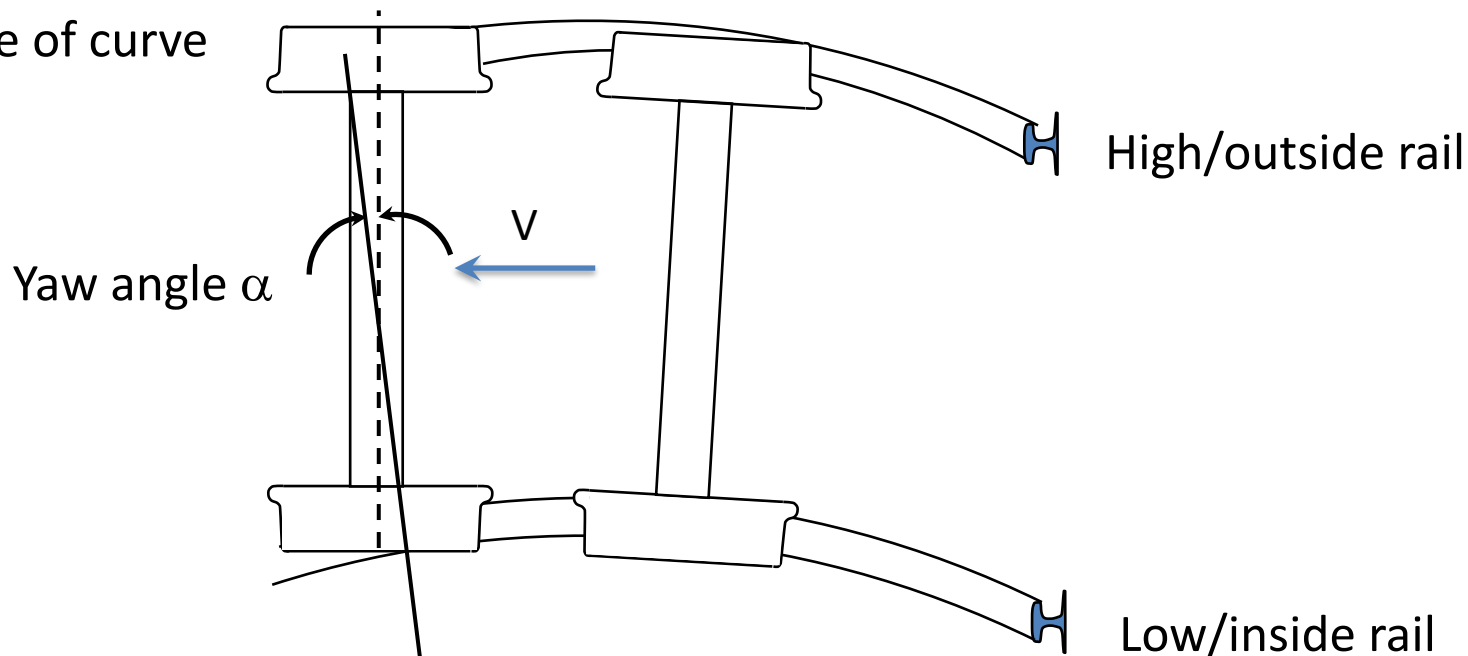
- Rigid truck
- Self-steering (flexible)
- Steered



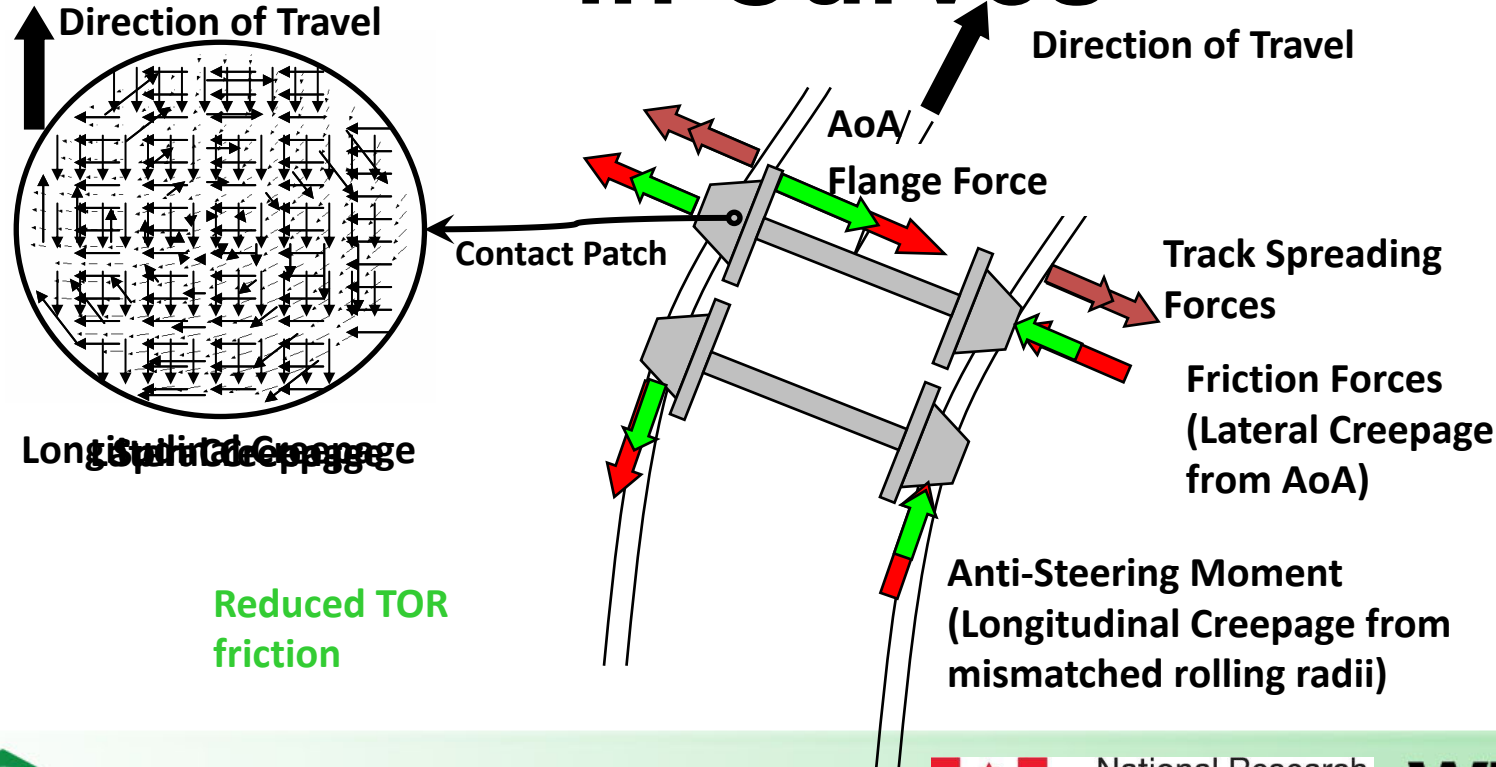
Also, yaw angle due to deflection of suspension (bending and shear)

The Wheelsets (in a curve)

(Leading) wheelset shifts
to outside of curve



Lateral Forces (Creep) in Curves



WHEEL-RAIL PROFILE DESIGN AND PERFORMANCE



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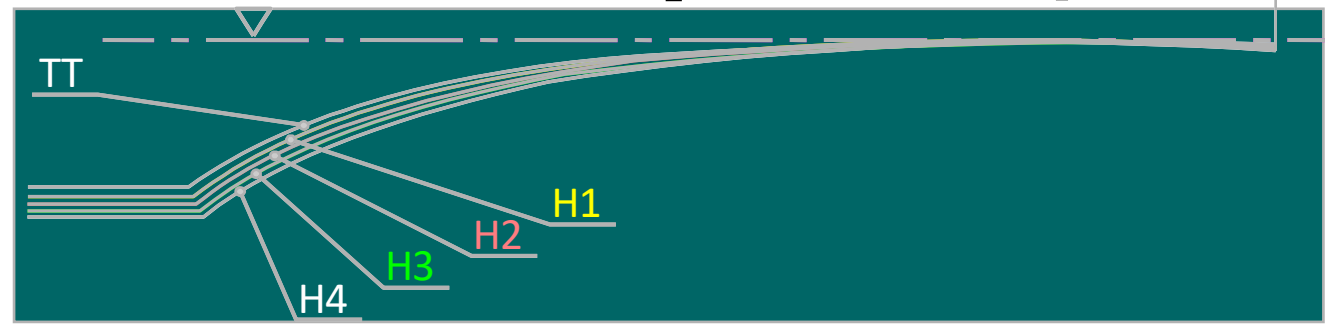
Design of Engineered Rail Profiles

Rail design considers:

- Track curvature
 - Worn wheel shapes
 - Types of vehicle and speed (hunting)
 - Dynamic rail rotation
 - Rail hardness
 - Grinding interval (profile deterioration between intervals)
 - Static gage
- control contact stress
 - inhibit hunting
 - minimize wear



The NRC Family of Heavy Haul Rail Templates (1990s)



Rail Profile Design Criteria

Goals are to reduce/control:

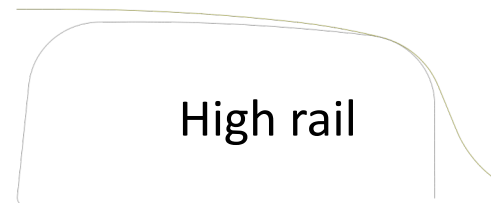
- Gauge face and TOR wear
- Rolling contact fatigue (RCF)
- Dynamic instability (hunting)
- Corrugation formation
- Wheel hollowing

And are easily or practically implemented by grinding



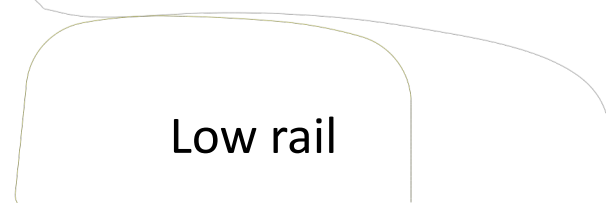
Wheel-Rail Contact Stresses

- Stress and damage depend on:
 - wheel radius
 - wheel load
 - friction coefficient
 - wheel/rail profiles
(contact geometry)



Severe gauge-corner contact

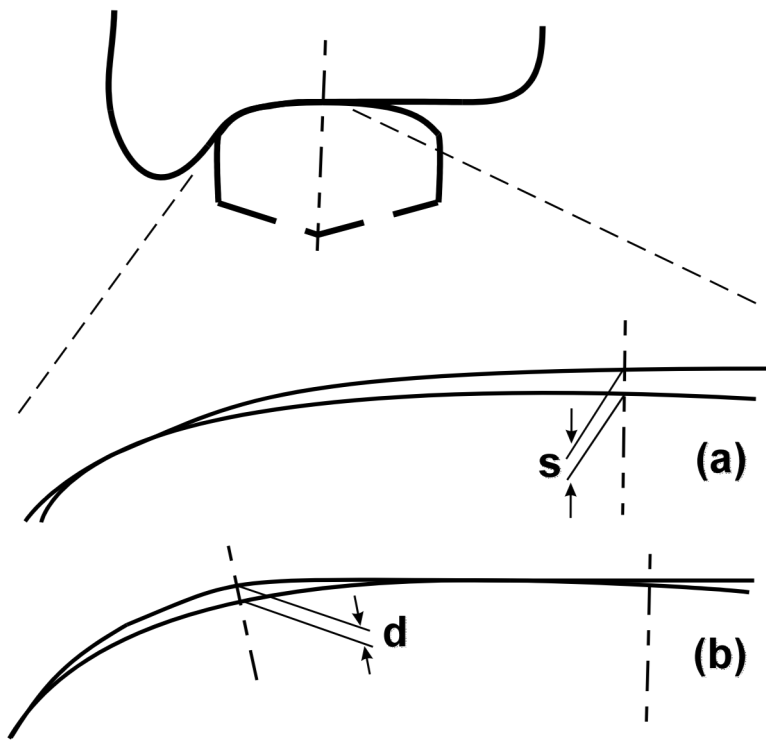
False Flange



Hollow wheels



Wheel / Rail Conformality



- closely conformal
0.1 mm (0.004") or less
- conformal
0.1 mm to 0.4mm
(0.004" to 0.016")
- non-conformal
0.4 mm (0.016") or larger



Some Typical Issues Associated with Wheel/Rail Conformality

Closely conformal profiles

Dynamic instability (hunting)

Corrugation formation by spin creepage

Conformal profiles

Low stress state W/R interface

Used for mass transit and high speed lines = 1PT conformal

(good for steering)

Heavy haul = 2PT conformal (balance contact stress steering and wear)

Non-conformal profiles

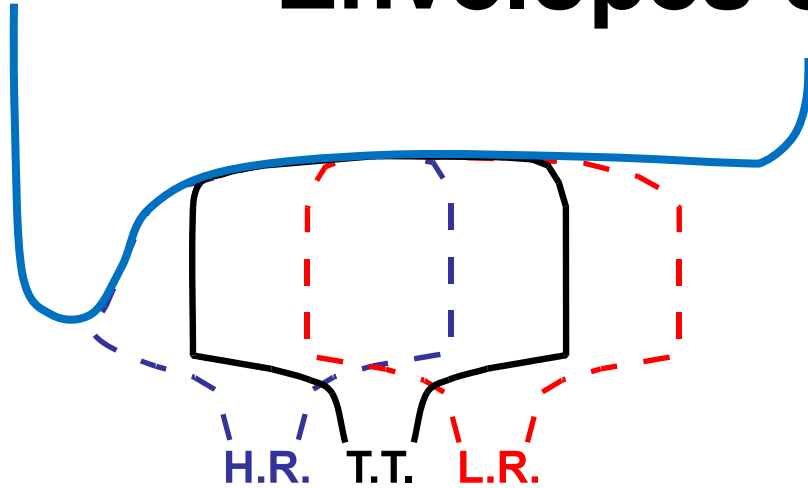
High stress state W/R interface

1PT: cracks (RCF) at GC of HR and FS of LR

2PT: high gauge face wear in curves

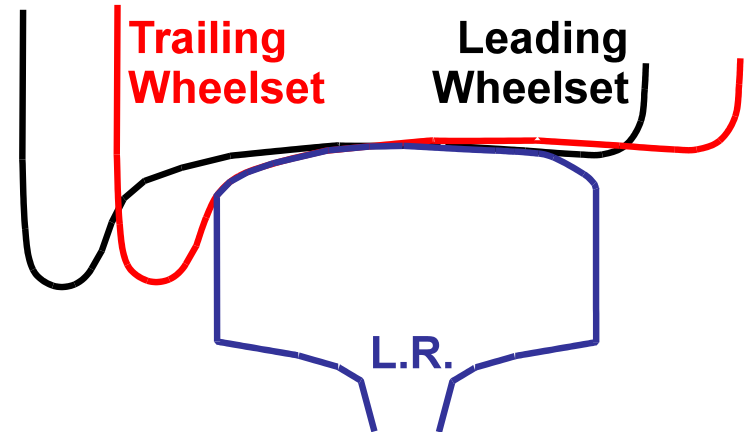


Worn Wheel and Rail Profiles are Envelopes of Each Other



- Worn wheel is an envelope of all rail profiles it encounters on a particular route

- Worn rail is an envelope of all wheel profiles that pass over it

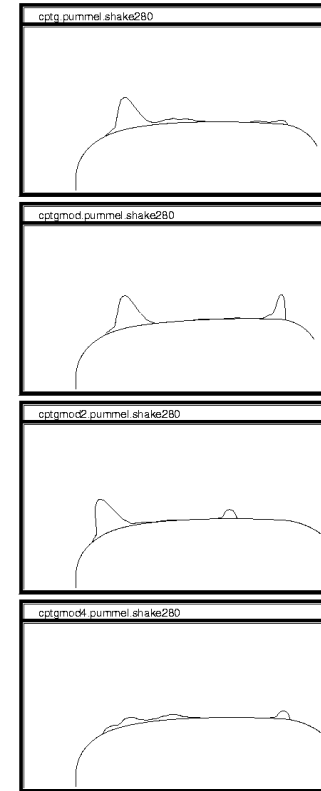
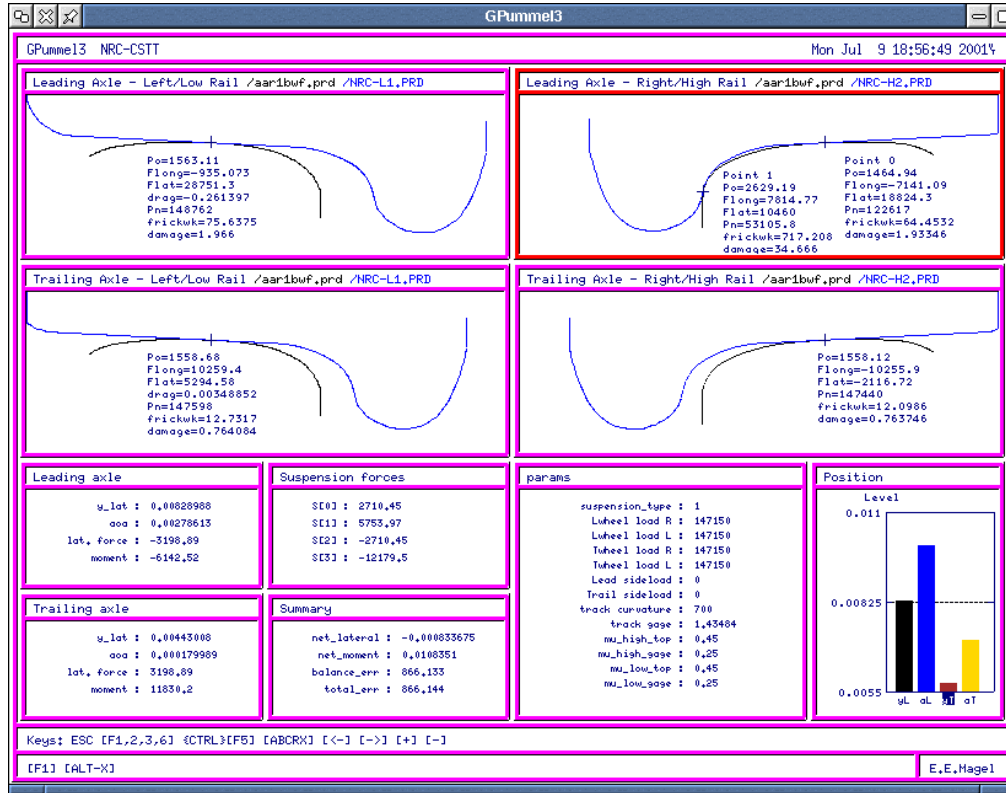


Pummelling Analysis

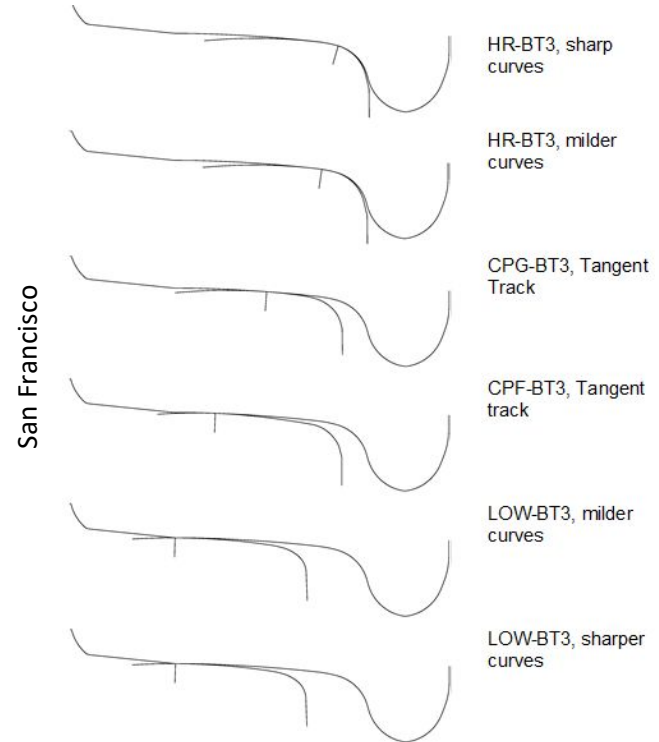
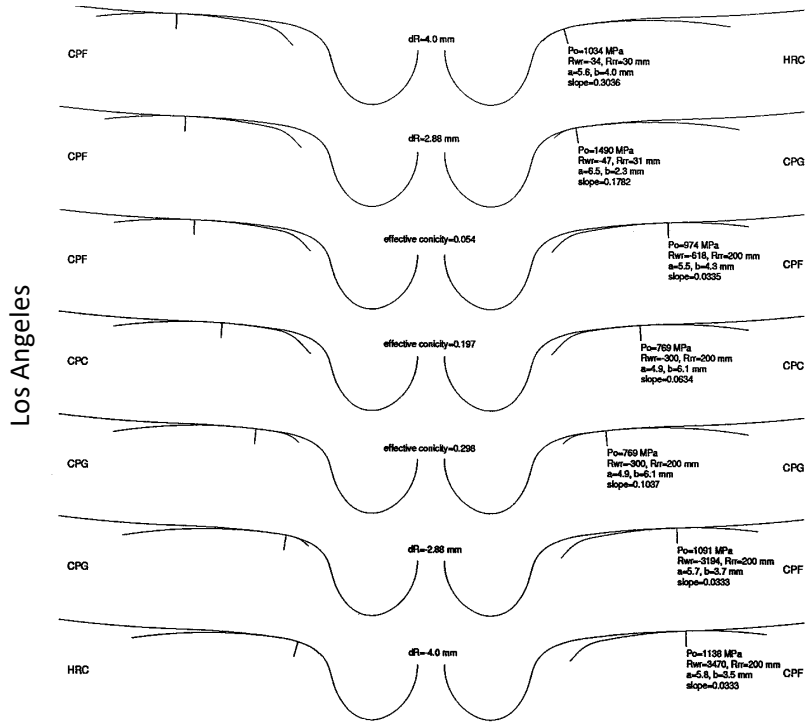
- Simulation
 - measured wheel profiles
 - vehicle characteristics (stiffness, wheelbase etc.)
 - rail hardness (for damage evaluation)
 - rail curvature, super-elevation, dynamic rail rotation etc.
- Evaluate distributions of
 - contact stress
 - steering moments
 - effective conicity



Pummelling: design/analysis tool



Families of Rail Profiles



VTI DERAILMENT MECHANISMS AND RISK ASSESSMENT

Wheel climb

Low rail rollover

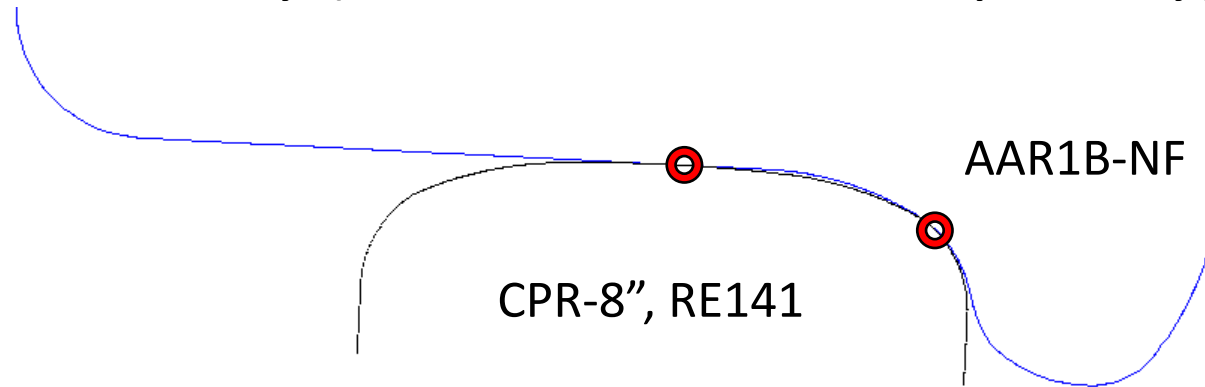


WHEEL CLIMB

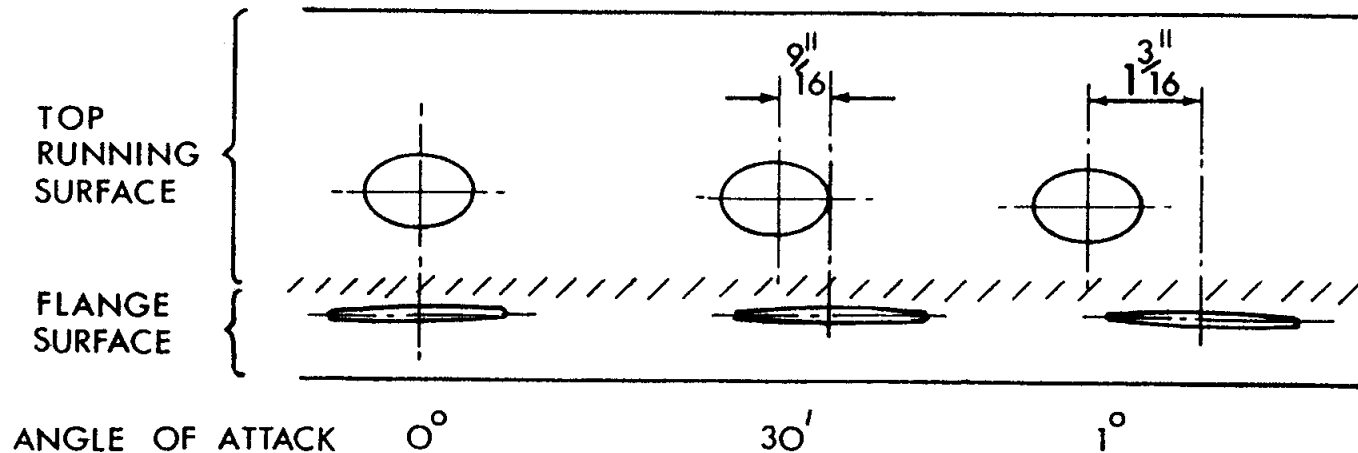


Wheel/Rail Contact

- W/R contact often takes place at two points simultaneously (some new wheels especially)



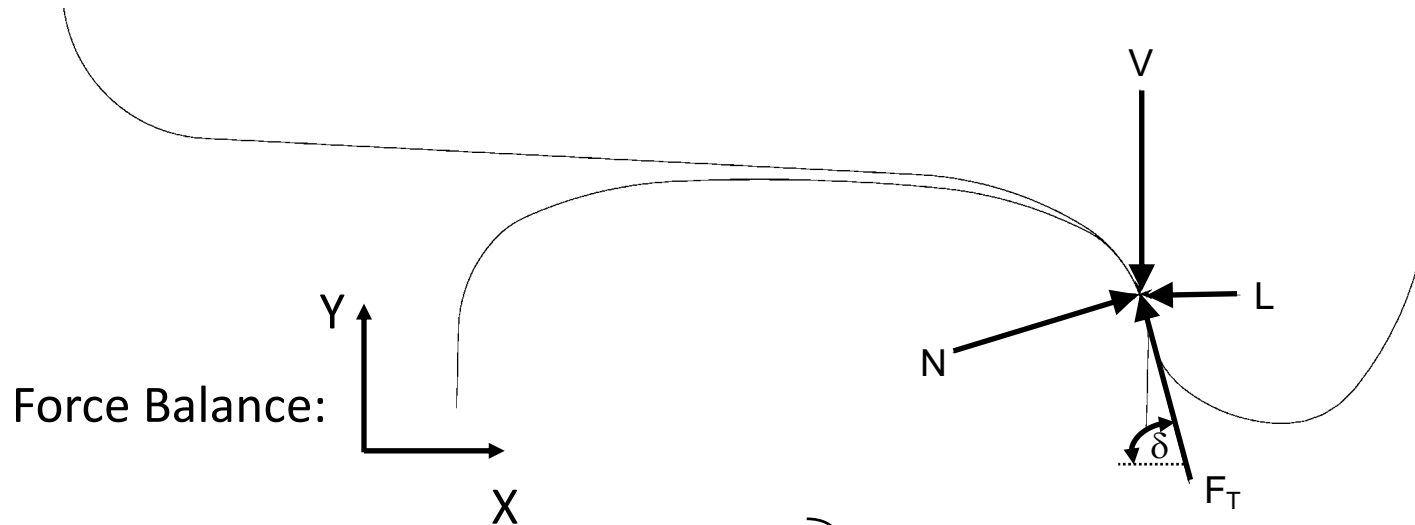
Wheel/Rail Contact (cont'd)



- Plan view of contact ellipses on high rail for different angles of attack



Deriving Nadal



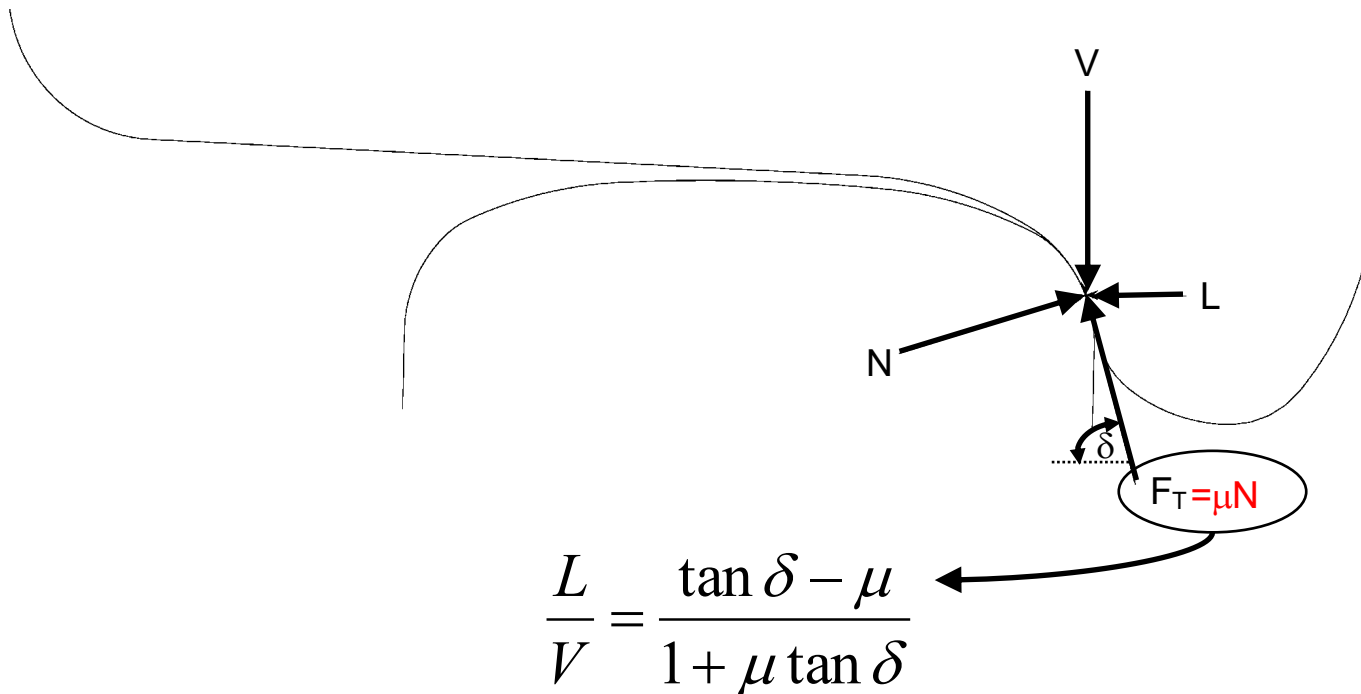
$$\sum F_x = 0 \Rightarrow N \sin(\delta) - F_T \cos(\delta) - L = 0$$

$$\sum F_y = 0 \Rightarrow F_T \sin(\delta) + N \cos(\delta) - V = 0$$

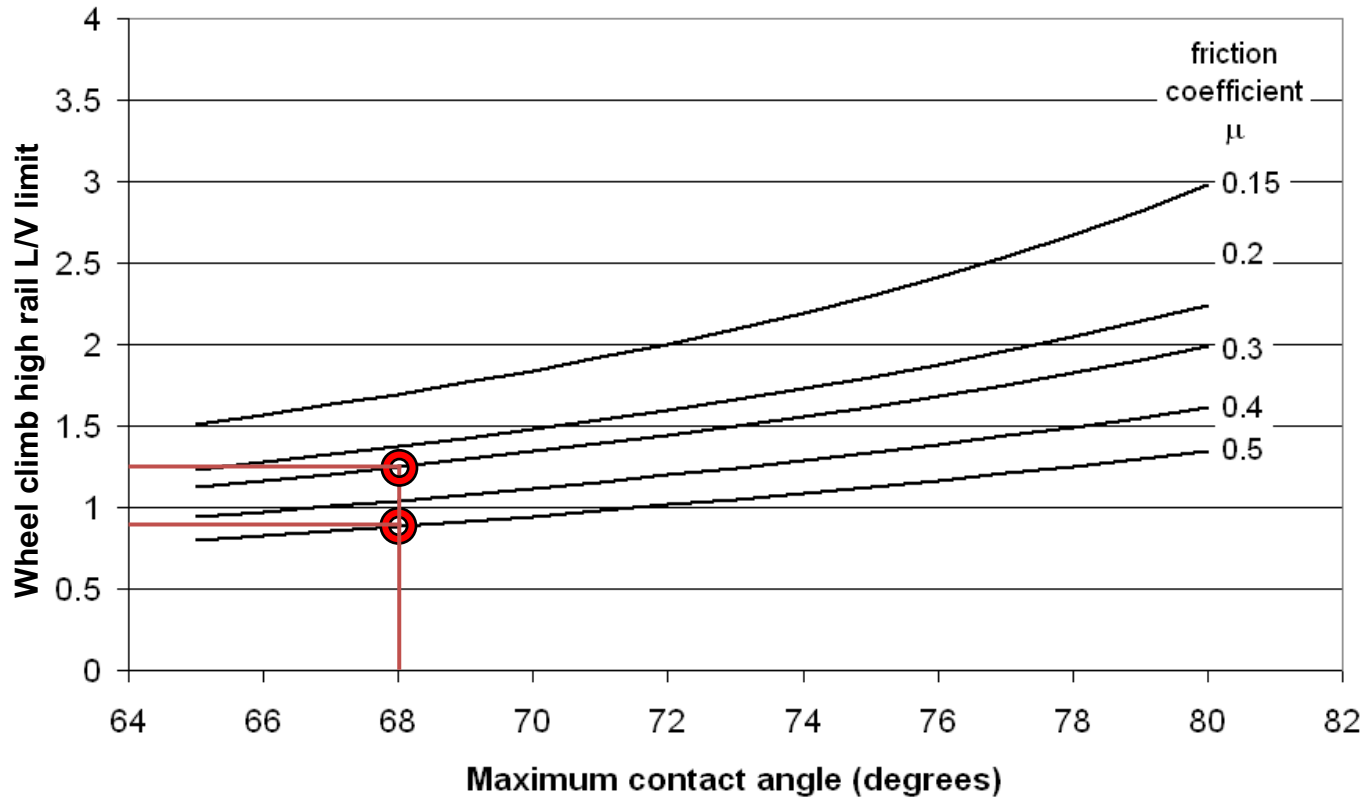
$$\frac{L}{V} = \frac{\tan \delta - F_T / N}{1 + F_T \tan \delta / N}$$



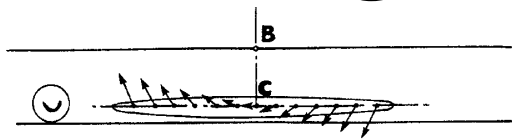
Nadal's Relationship



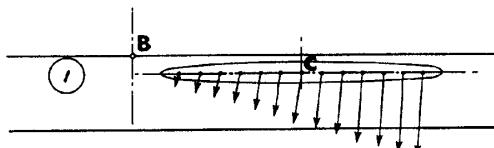
Nadal Index (1908)



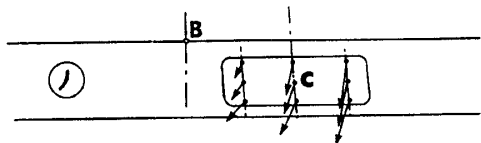
Slip Vectors at the Gage Face Contact



$$\delta > \beta, \alpha = 0$$



$$\delta < \beta, \text{large } \alpha$$



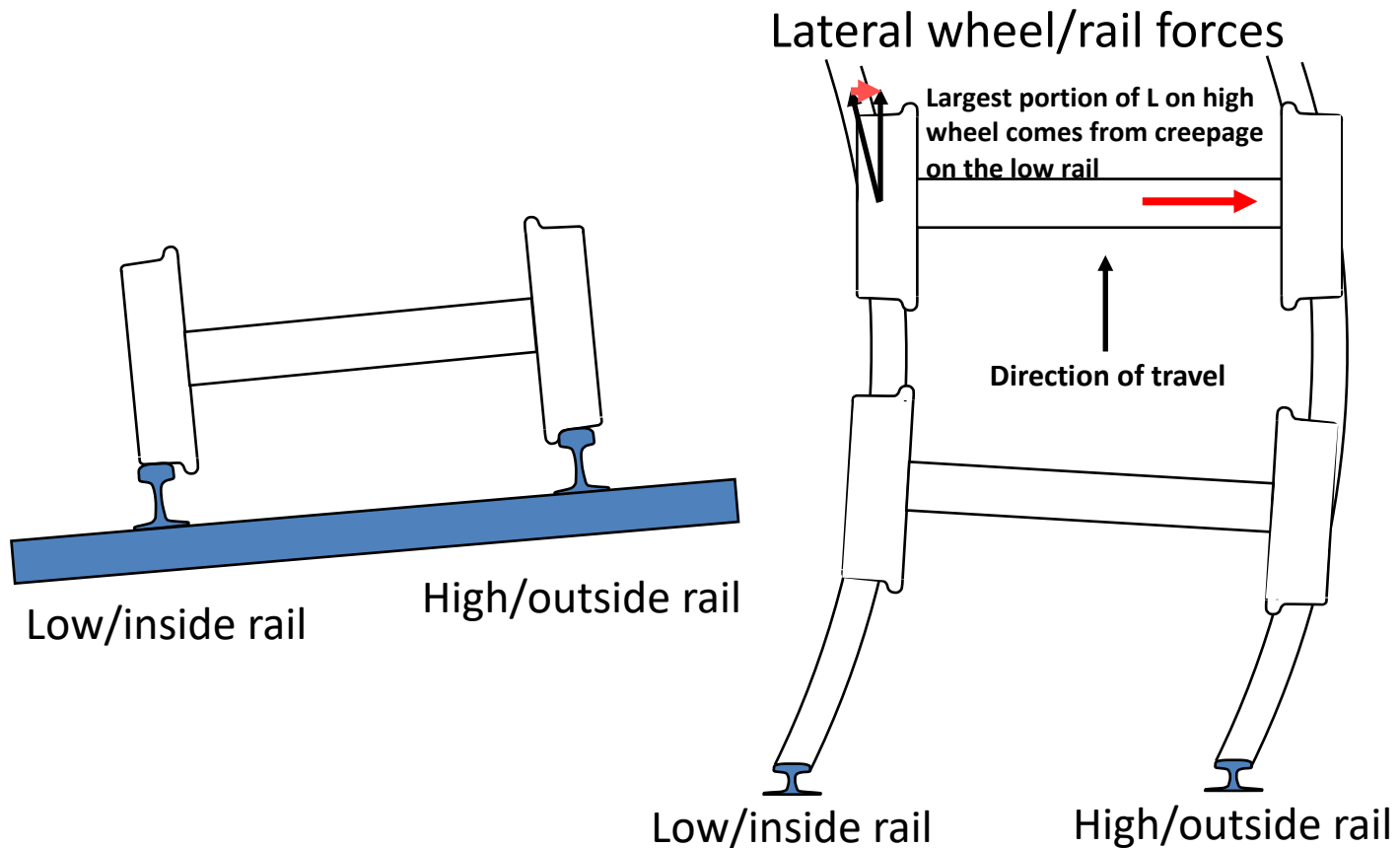
$$\delta = \beta, \text{moderate } \alpha$$

α = angle of attack

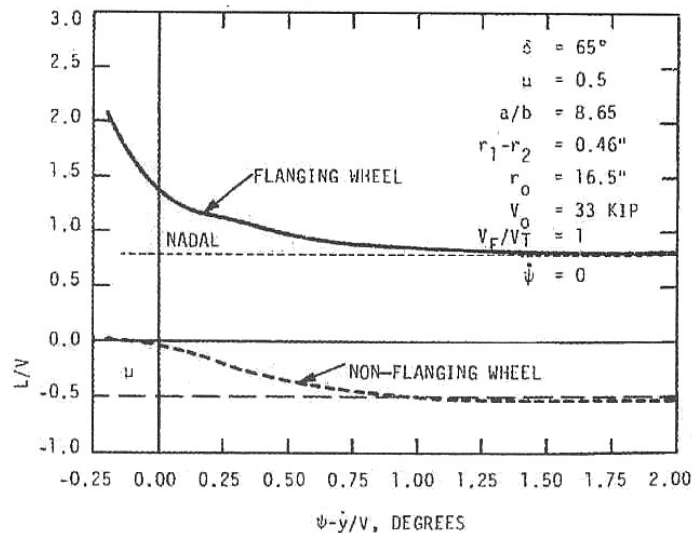
δ = wheel flange angle

β = gage face angle





Weinstock Derailment Criterion



$$|L/V|_{\text{flanging}} + |L/V|_{\text{non-flanging}} > (L/V_{\text{NADAL}} + m)$$

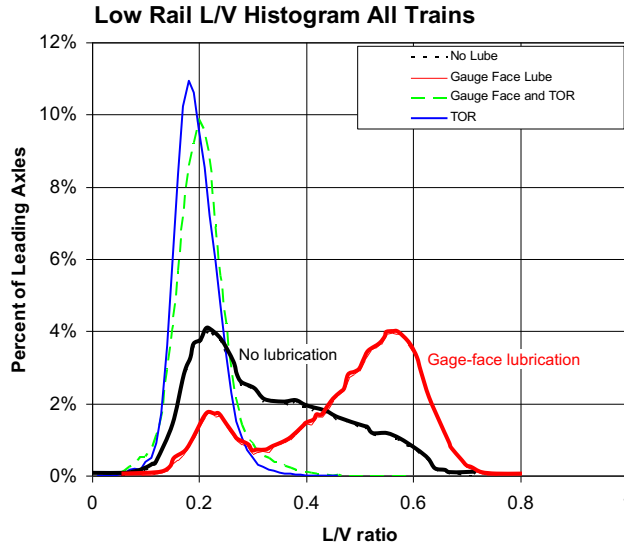
- Holds for all positive angles of attack,
- Less accurate for +ve cant deficiency

- At incipient wheel climb, the L/V values on the flanging and non-flanging wheels are, for positive angles of attack, separated by a roughly constant value equal to the Nadal limit plus the coefficient of friction on the top of the low rail

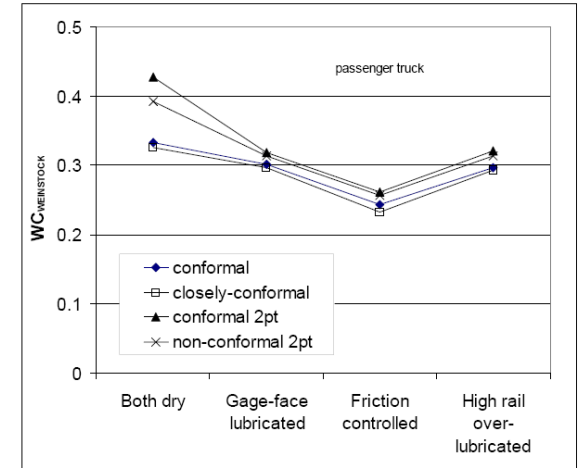


An Example

- Is lubrication a good thing?



L/V goes up, but Weinstock limit also.



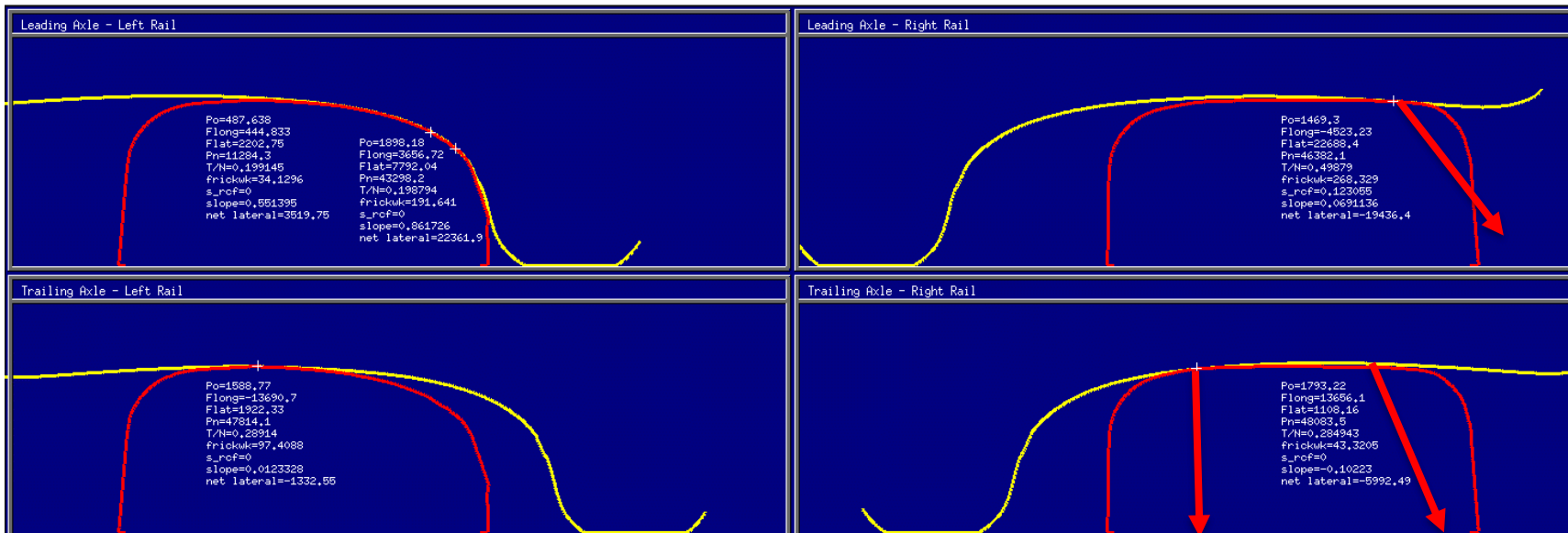
Wheel climb - conclusions

- Nadal – provides a relationship between contact angle and friction coefficient
- Is based upon simplified view of the slip conditions
- Wheel climb threshold matches Nadal at most practical angles of attack, but not for low aoa.
- Weinstock rectifies that (for positive angles of attack) and includes explicitly the effect of friction on top of low rail.
- A safe L/V is some fraction of the (Nadal or Weinstock) threshold value, say 60-80%.
- These are static and quasi-static derivations.



Low rail rollover

- Wide gauge, hollow wheels, poor restraint, underbalanced running, high friction



Conclusions

- Matching of wheel/rail profiles
 - Rolling radius difference: stability and curving
 - Strong impact on stress, curving forces, stability, surface damage, safety/derailment (with friction conditions, truck suspensions, track geometry etc.)
 - Must consider both new and worn shapes (pummeling)
- Nadal formula is adequate for most wheel climb analyses

