# Vehicle-Track Interaction & Dynamics

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PRINCIPLES COURSE • JUNE 7

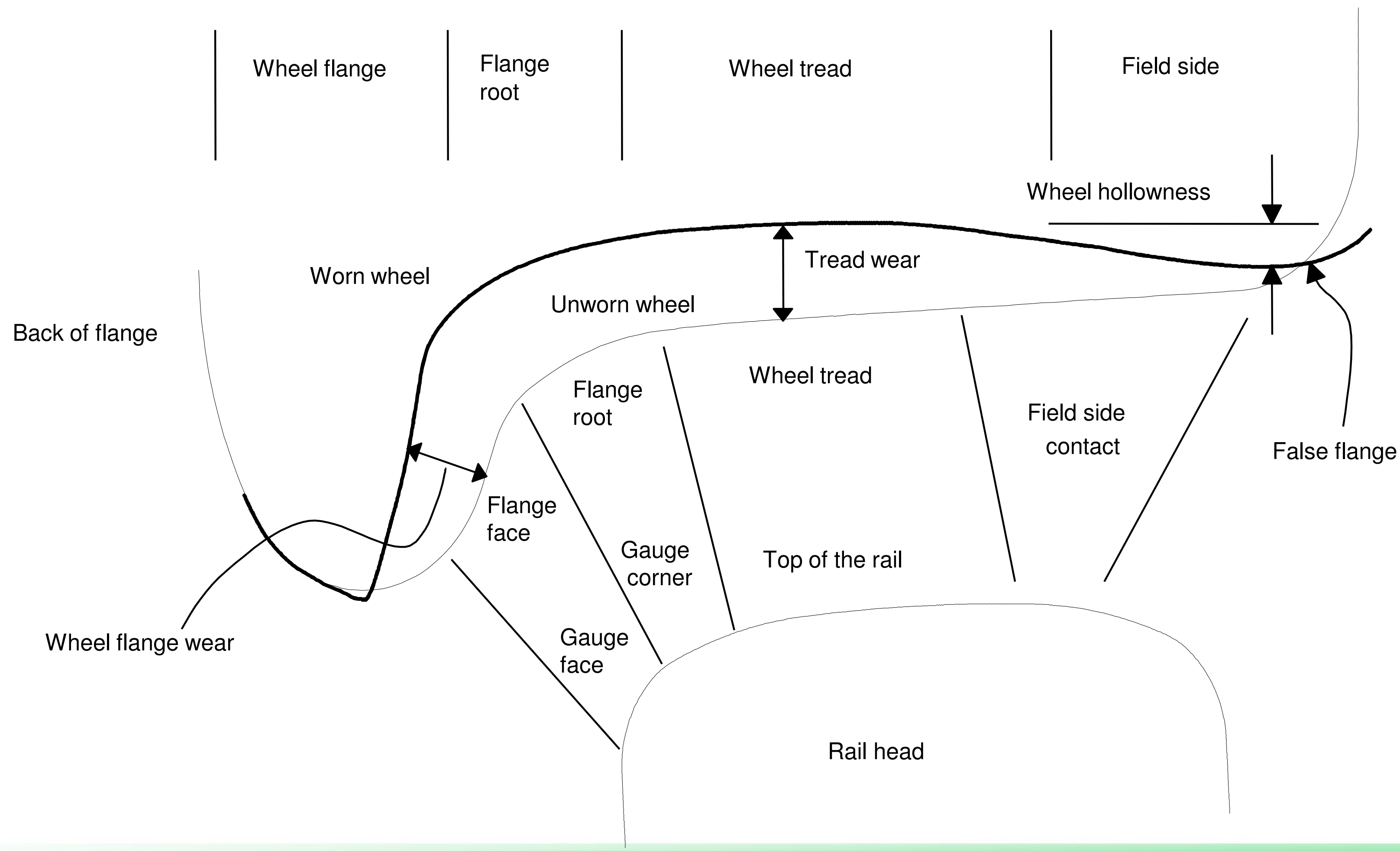
National Research Council Canada

WRI 2023

# Agenda

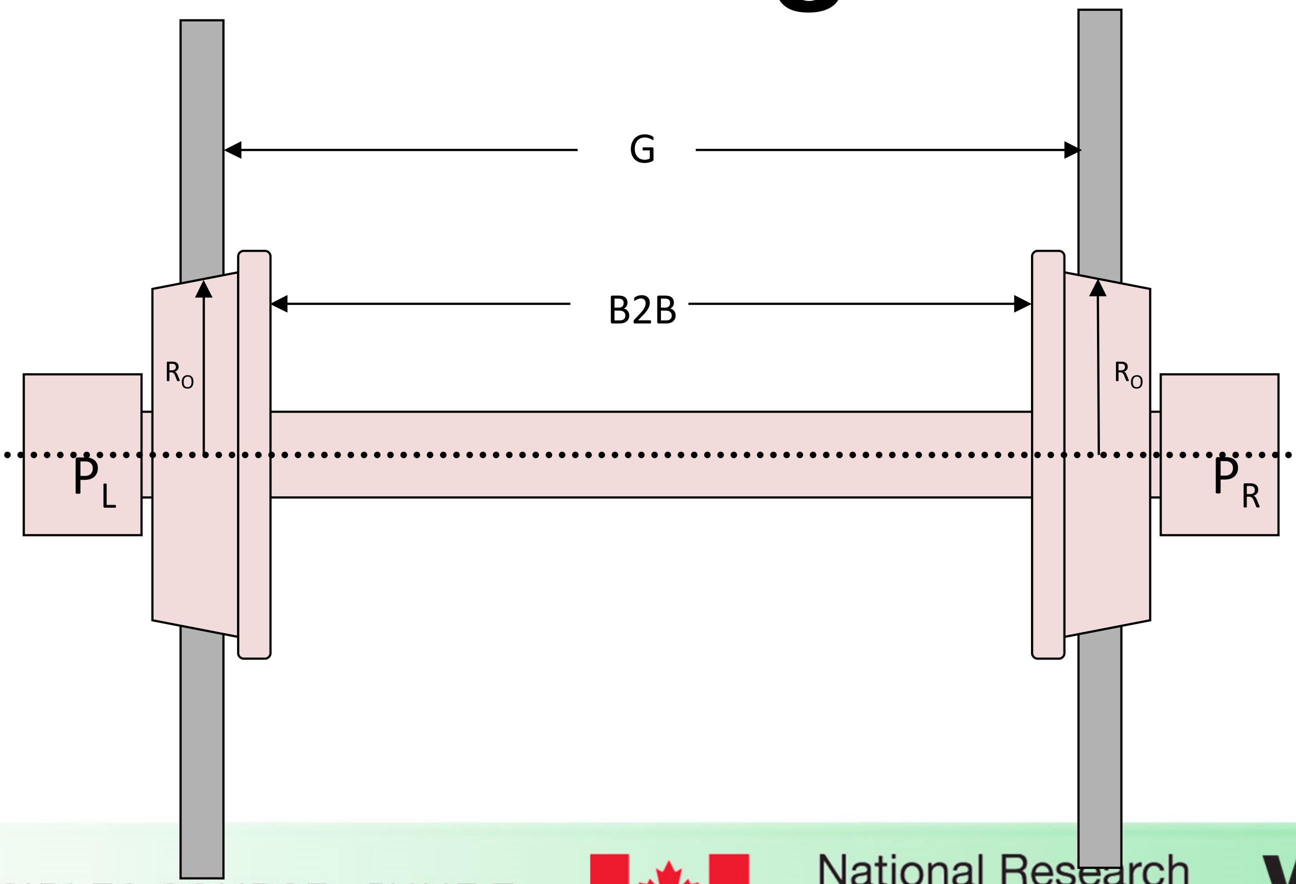
1. Vehicle steering, stability and curving forces
2. Wheel-rail profile design and performance
3. VTI derailment mechanisms and risk assessment

# Terminology



# WHEELSET & VEHICLE STEERING

# The Free Rolling Wheelset



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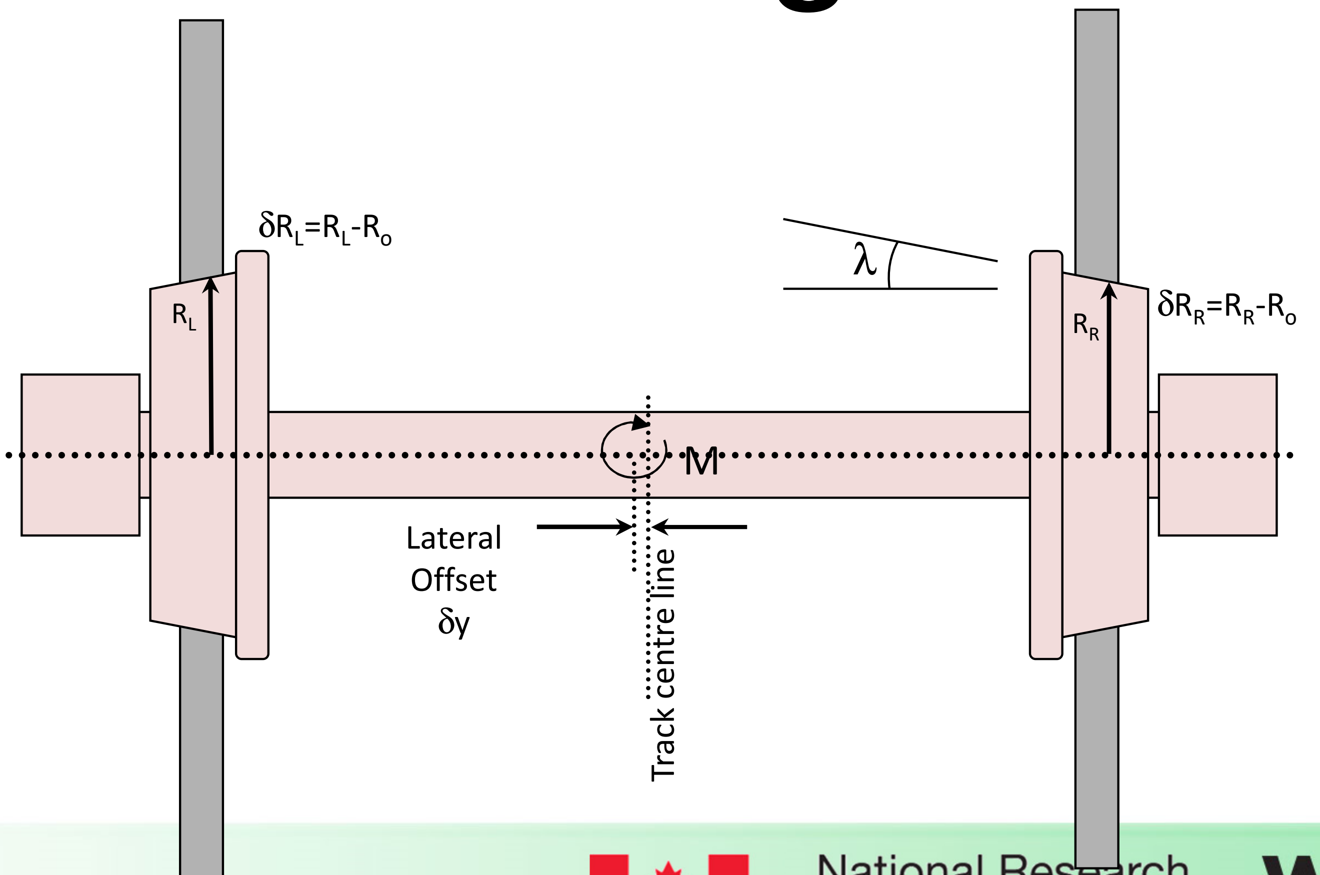
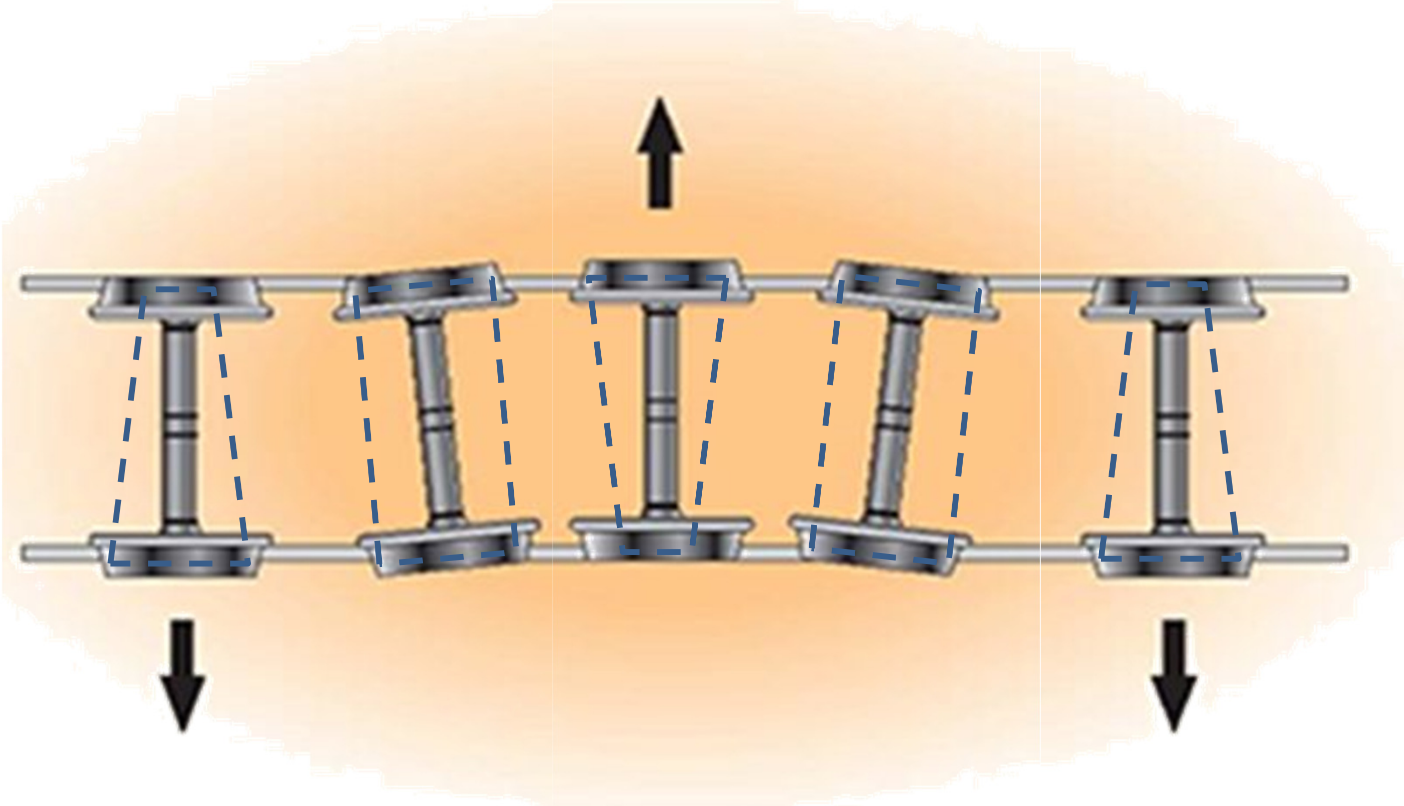
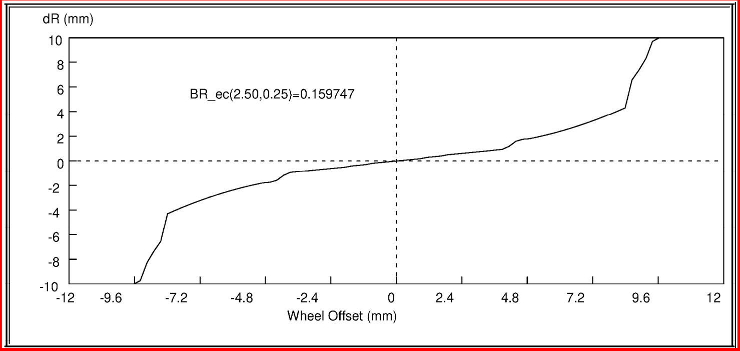
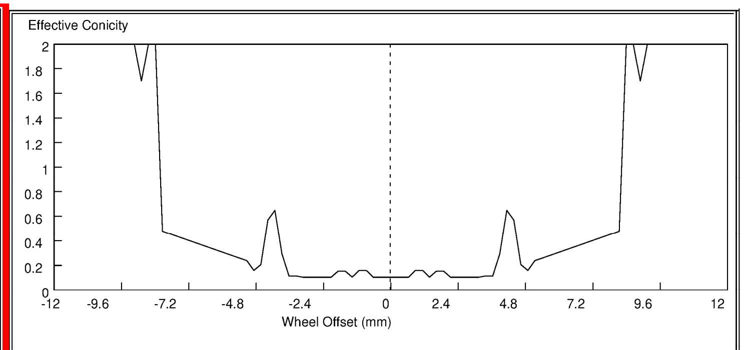


# The Free Wheelset - Hunting

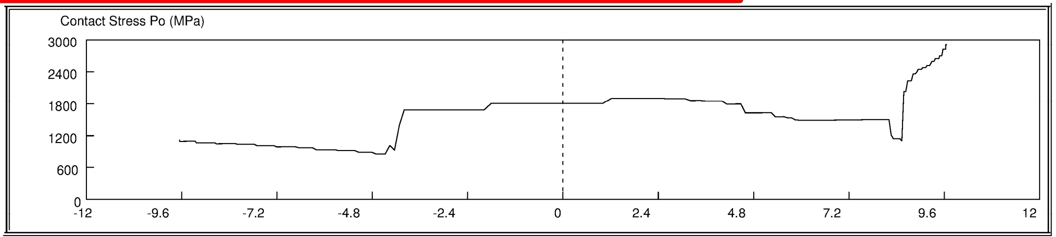


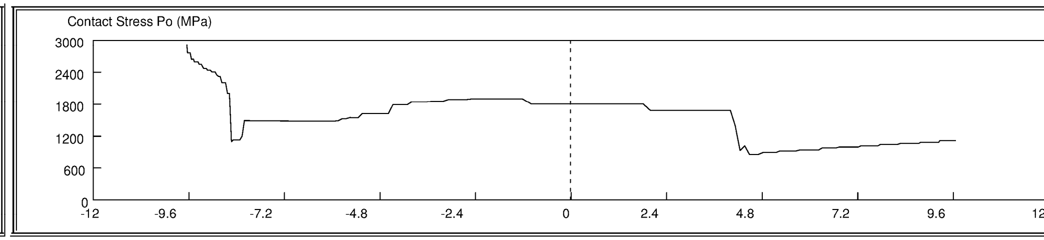


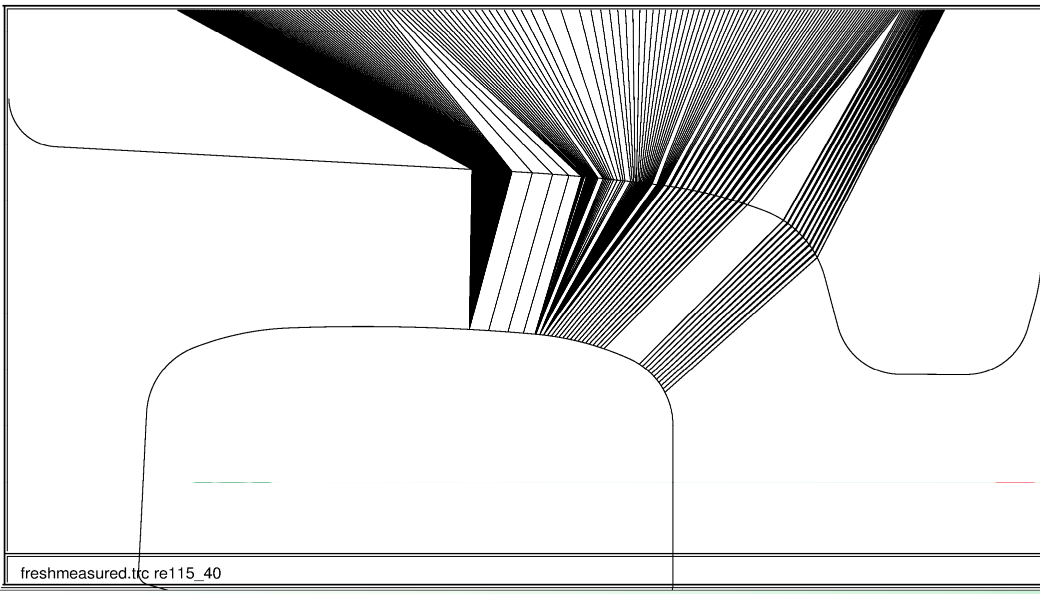



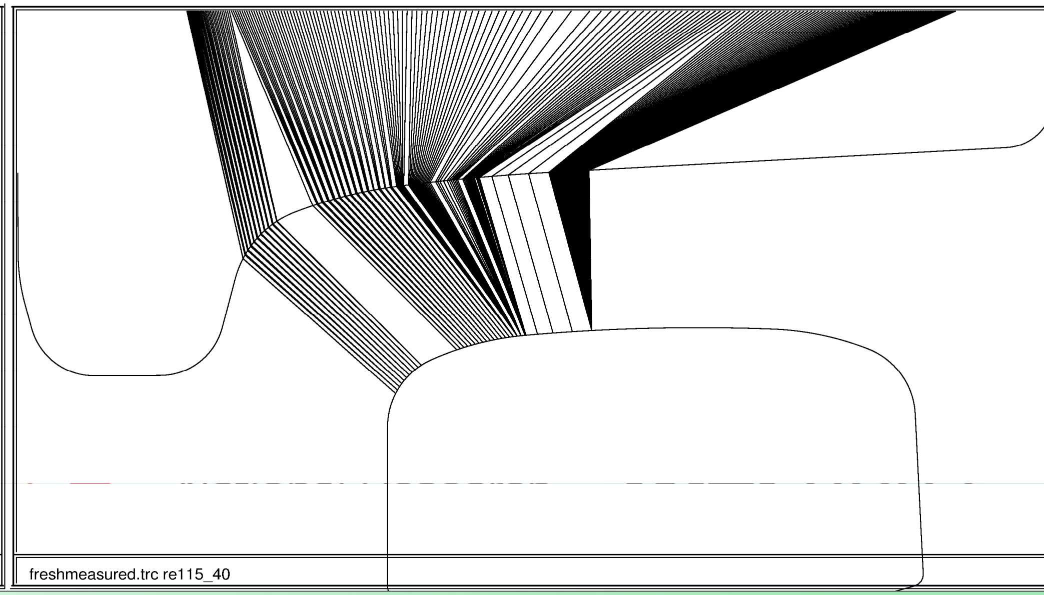

Input/Output Values

| | |
|---|---|
| L_load : | 5100 |
| R_load : | 5100 |
| aoa : | 0 |
| Rleft : | 0.33 |
| Rright : | 0.33 |
| CurveRadius : | 10000 |
| dR : | 0.0 |
| Smoment : | 0.0 |
| Drag : | 0.0 |



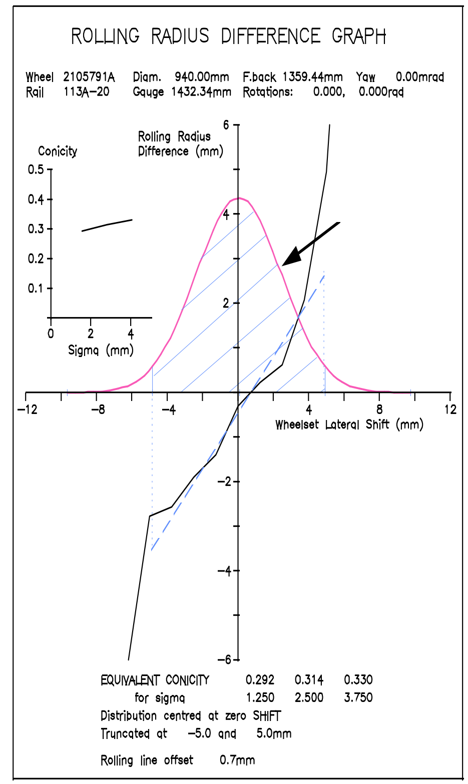



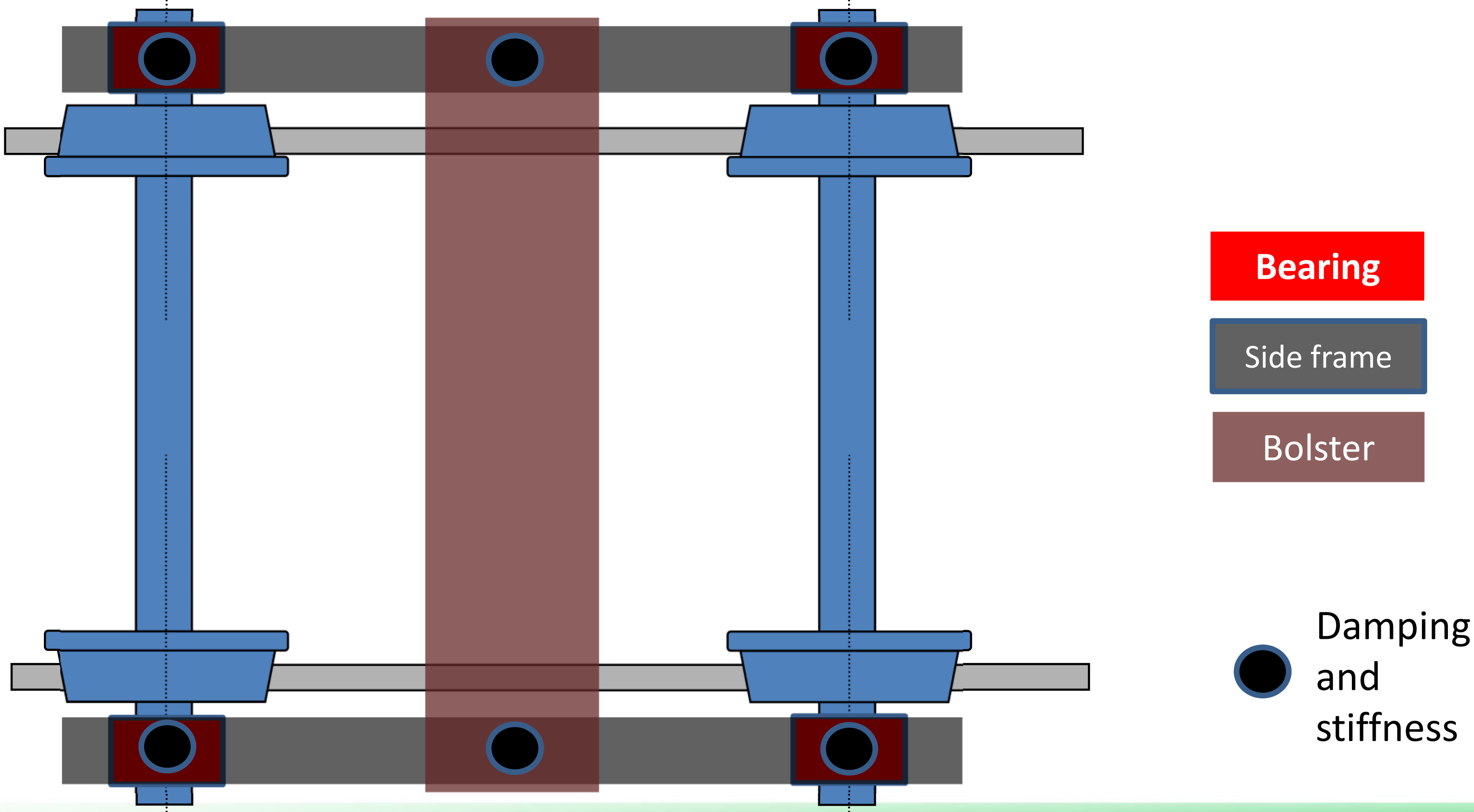
# Equivalent Conicity from the ΔR Plot

- British Rail derivation

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

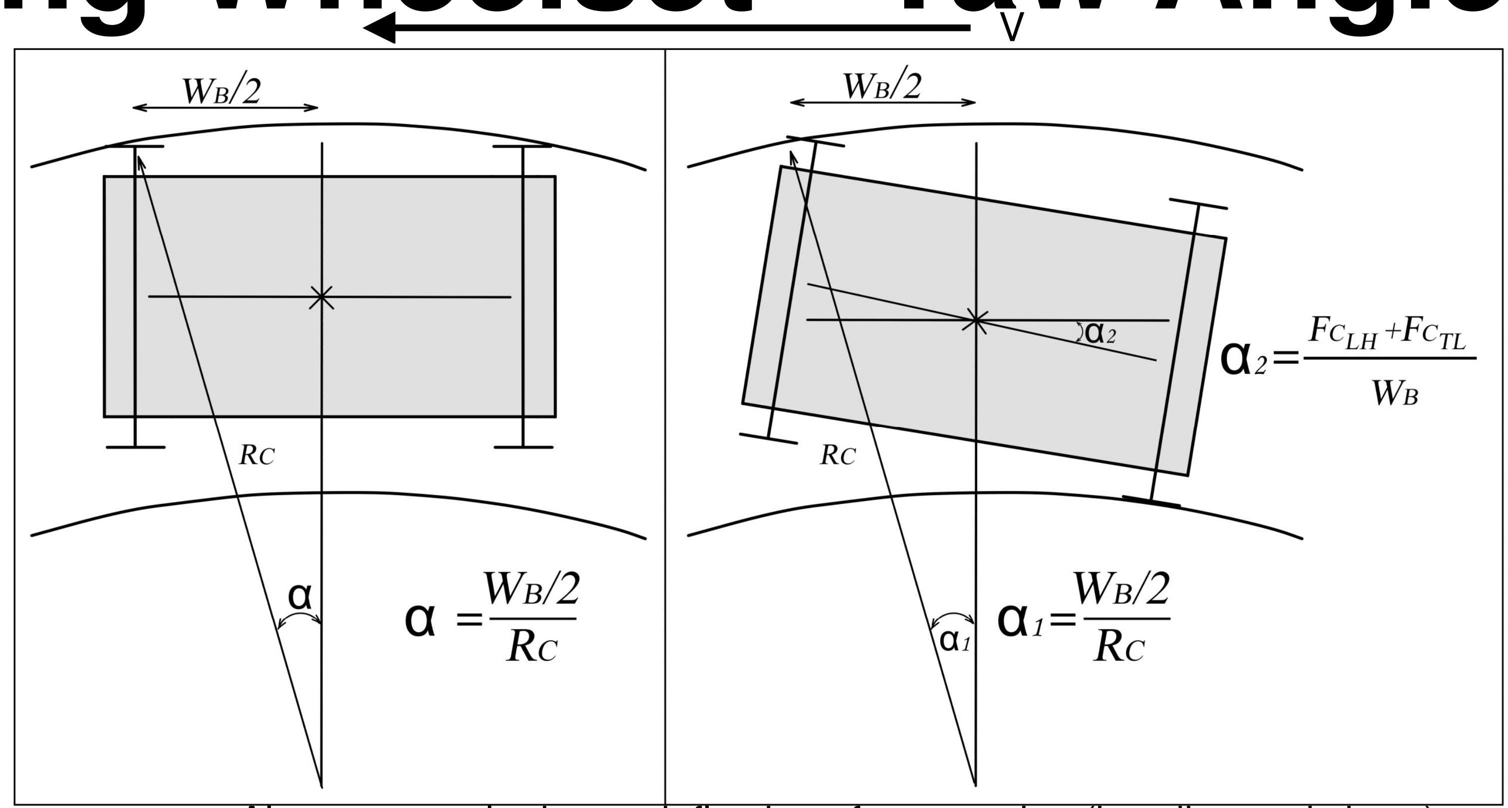


# A Truck can Provide Stability



# Leading Wheelset - Yaw Angle

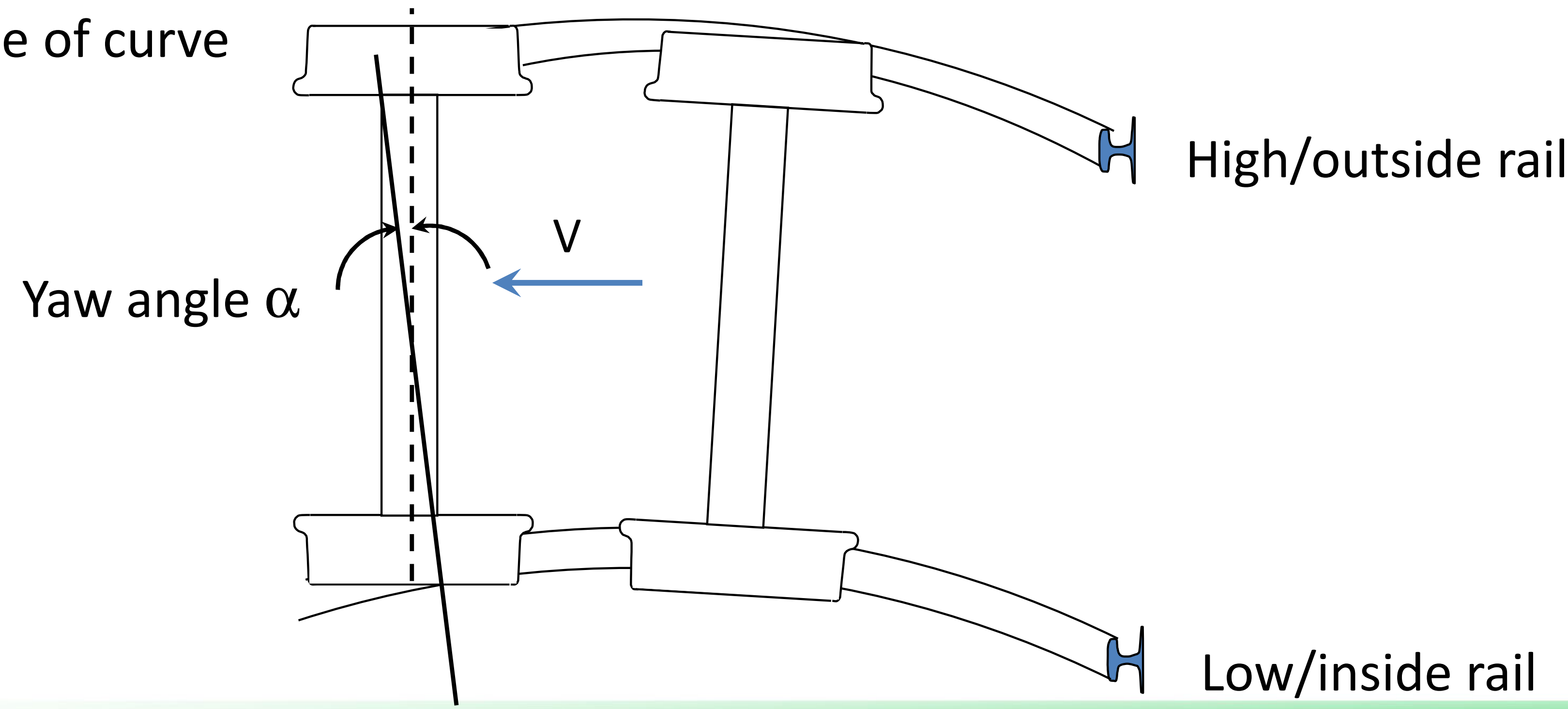
- Rigid truck
- Self-steering (flexible)
- Steered



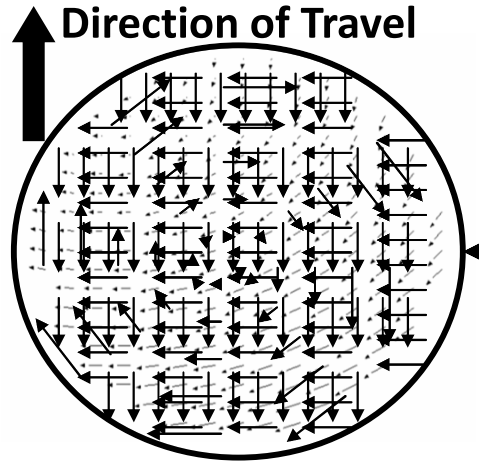

Also, yaw angle due to deflection of suspension (bending and shear)

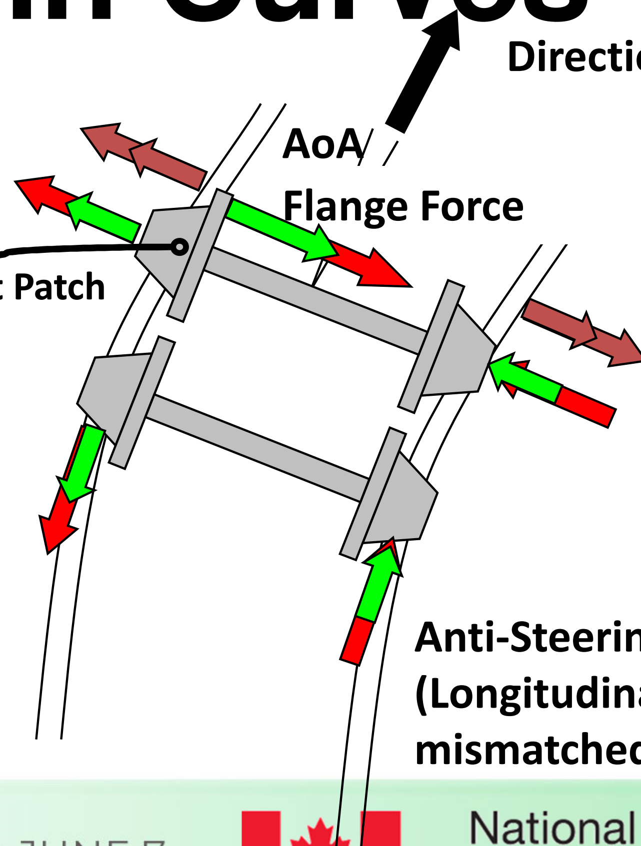
# The Wheelsets (in a curve)

(Leading) wheelset shifts to outside of curve



# Lateral Forces (Creep) in Curves




Reduced TOR friction

# WHEEL-RAIL PROFILE DESIGN AND PERFORMANCE

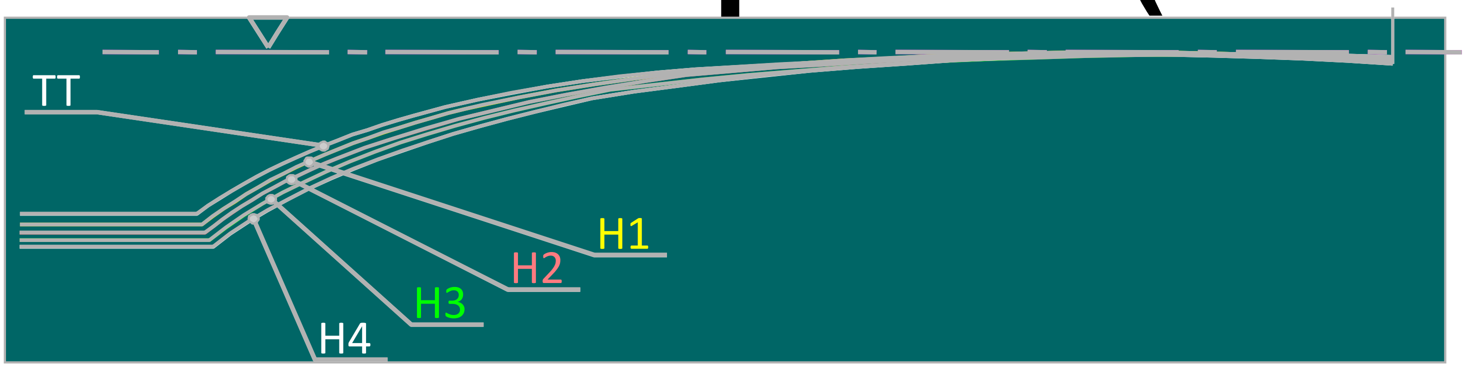
# Design of Engineered Rail Profiles

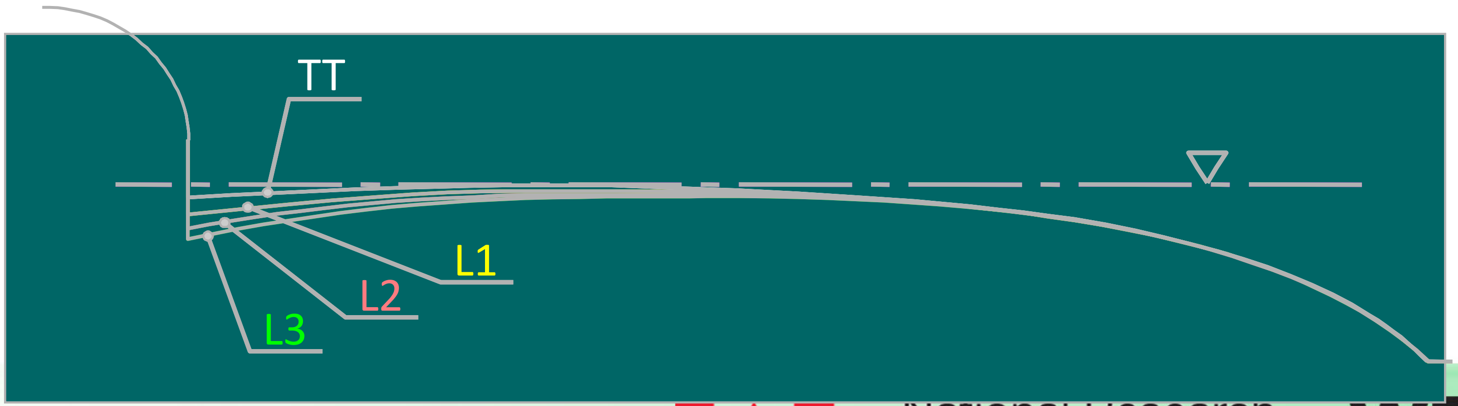
Rail design considers:

- **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

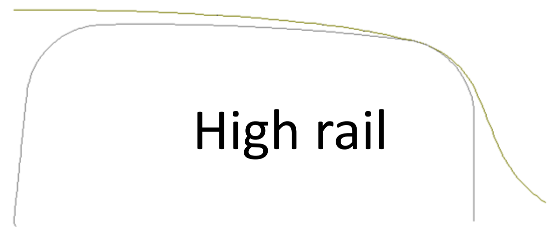
Goals are to reduce/control:

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

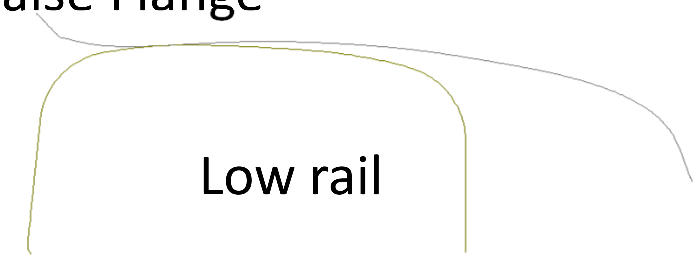
And are easily or practically implemented by grinding

# Wheel-Rail Contact Stresses

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

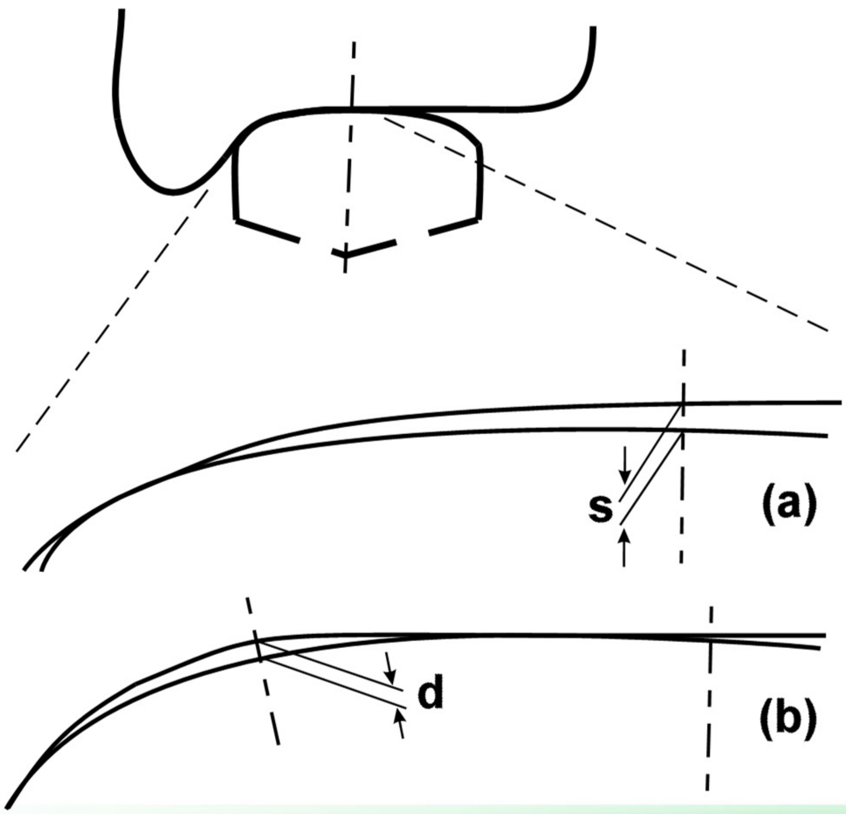



**Severe gauge-corner contact**




**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)

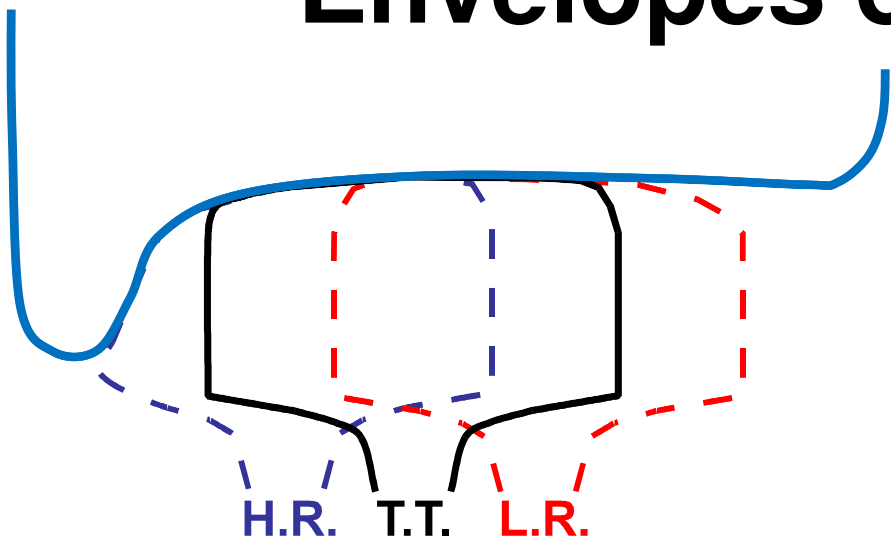
## Non-conformal profiles

High stress state W/R interface

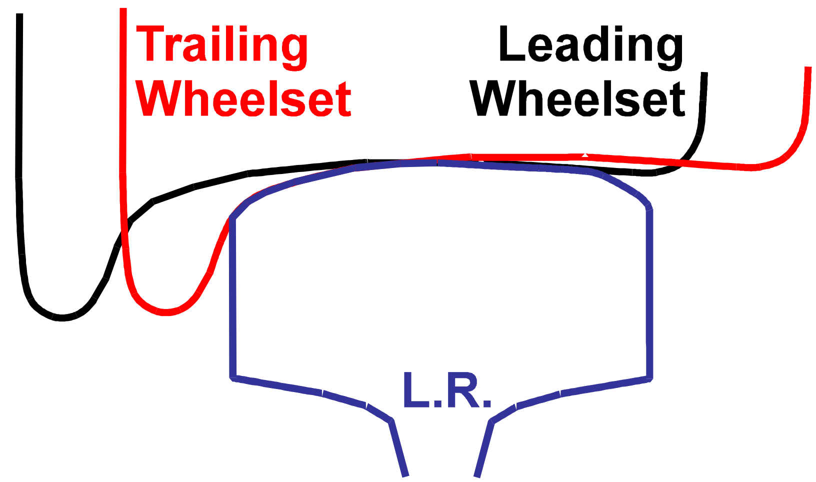
1PT: cracks (RCF) at GC of HR and FS of LR

2PT: high gauge face wear in curves

# Worn Wheel and Rail Profiles are Envelopes of Each Other




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

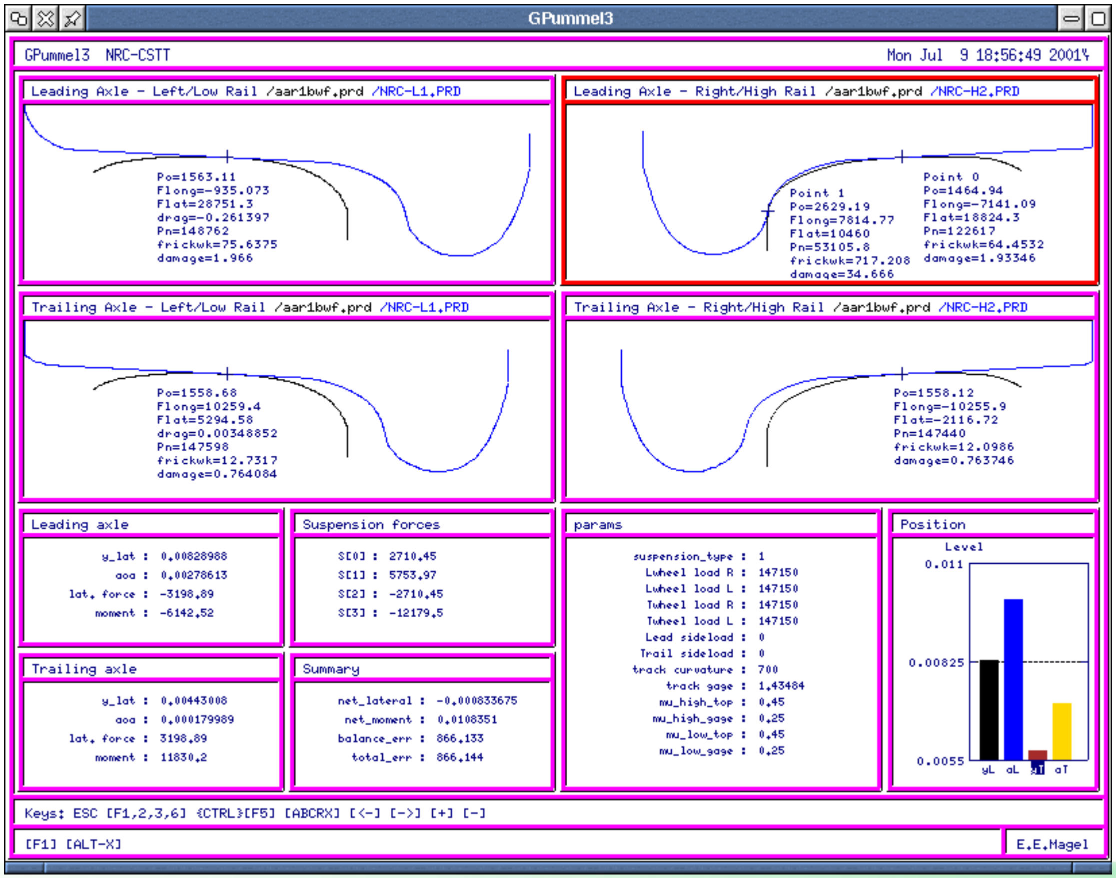


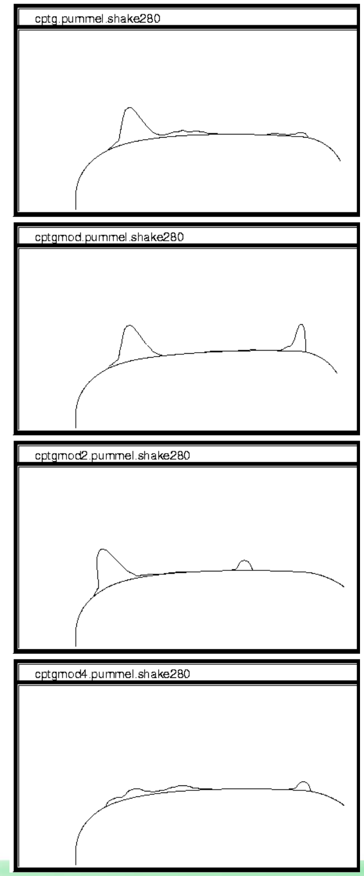

- Worn wheel is an envelope of all rail profiles it encounters on a particular route

# 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

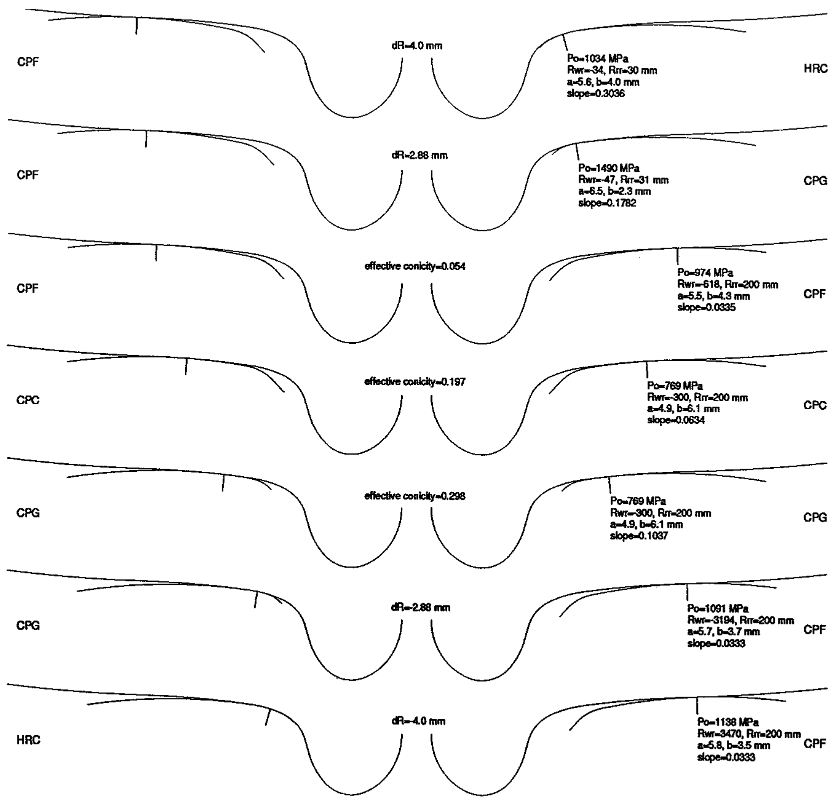
# Pummelling: Design/Analysis Tool 



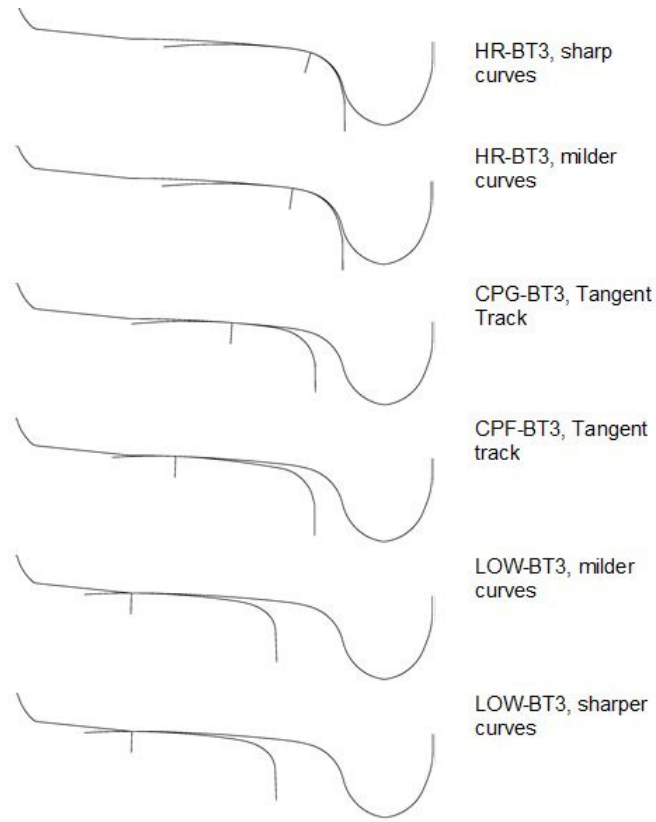



# Families of Rail Profiles

Los Angeles




San Francisco



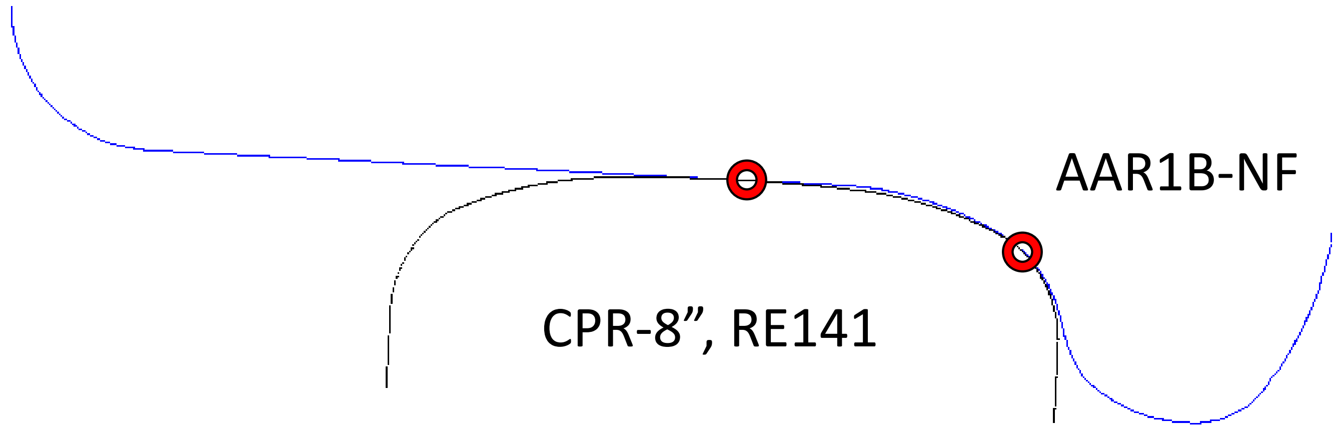
# VTI DERAILMENT MECHANISMS AND RISK ASSESSMENT

- Wheel climb
- Low rail rollover

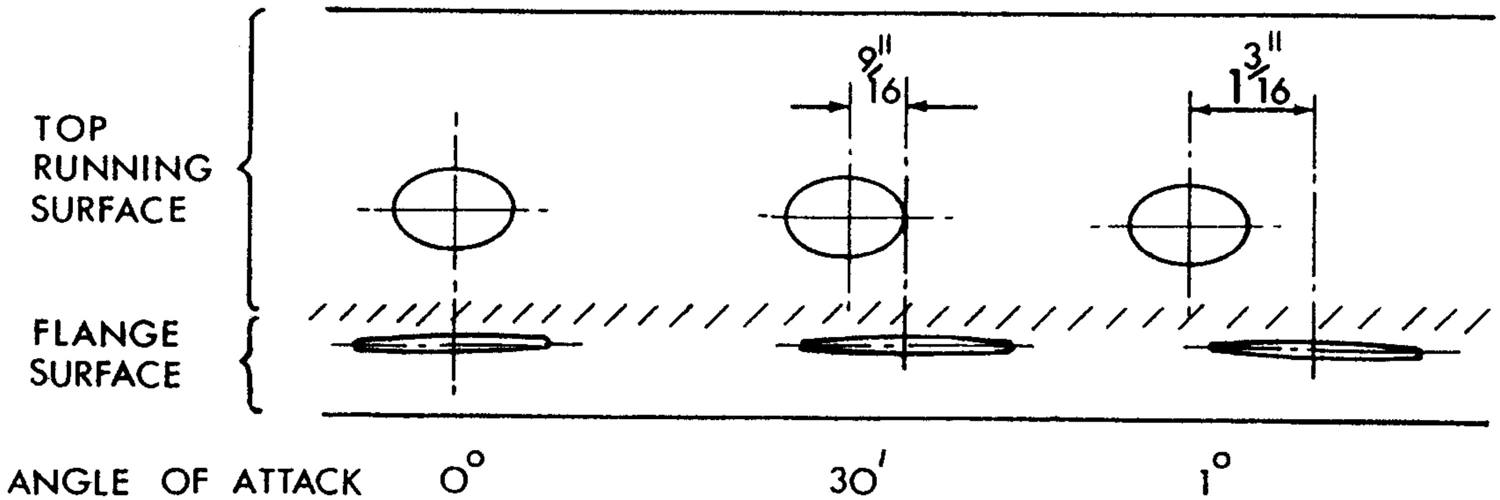
# WHEEL CLIMB

# Wheel/Rail Contact

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



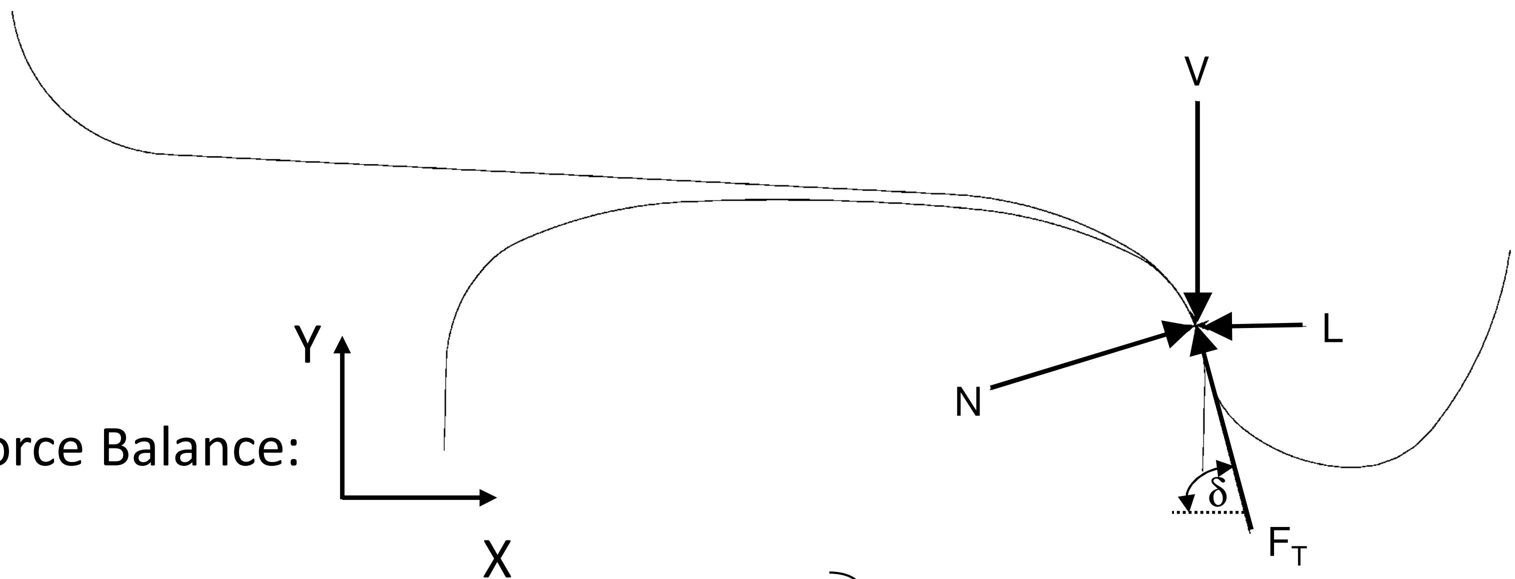
# Wheel/Rail Contact (cont'd)




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

# Deriving Nadal

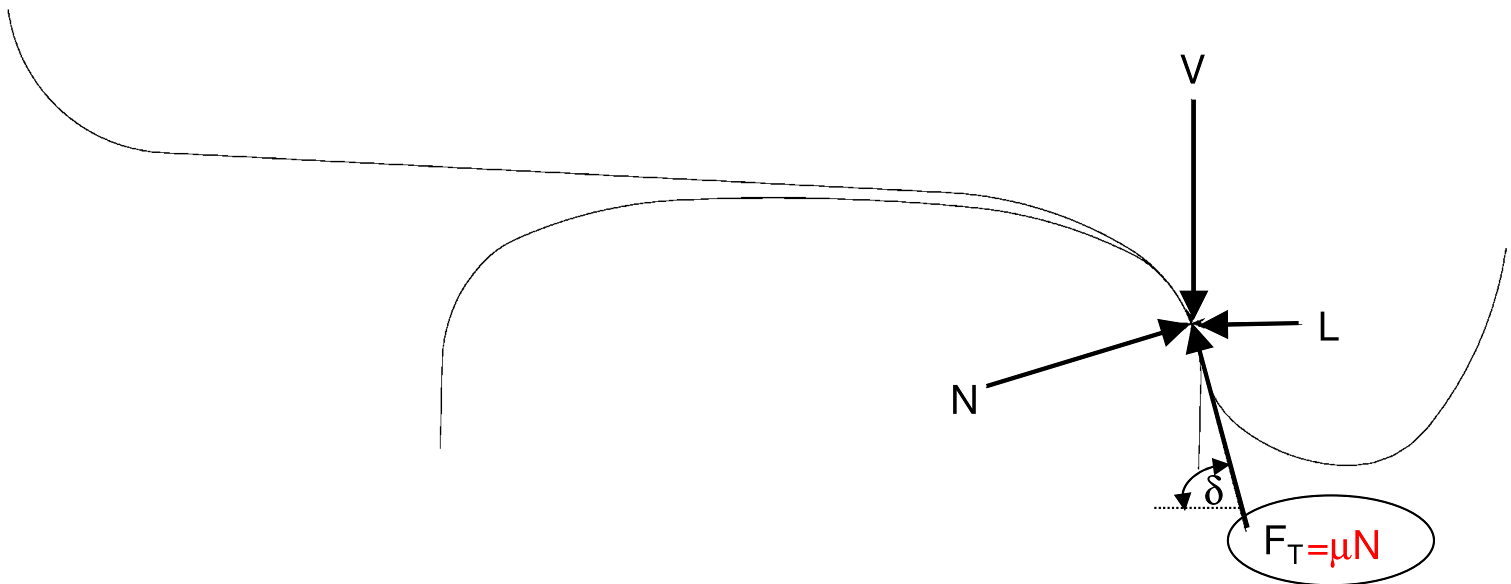
Force Balance:




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

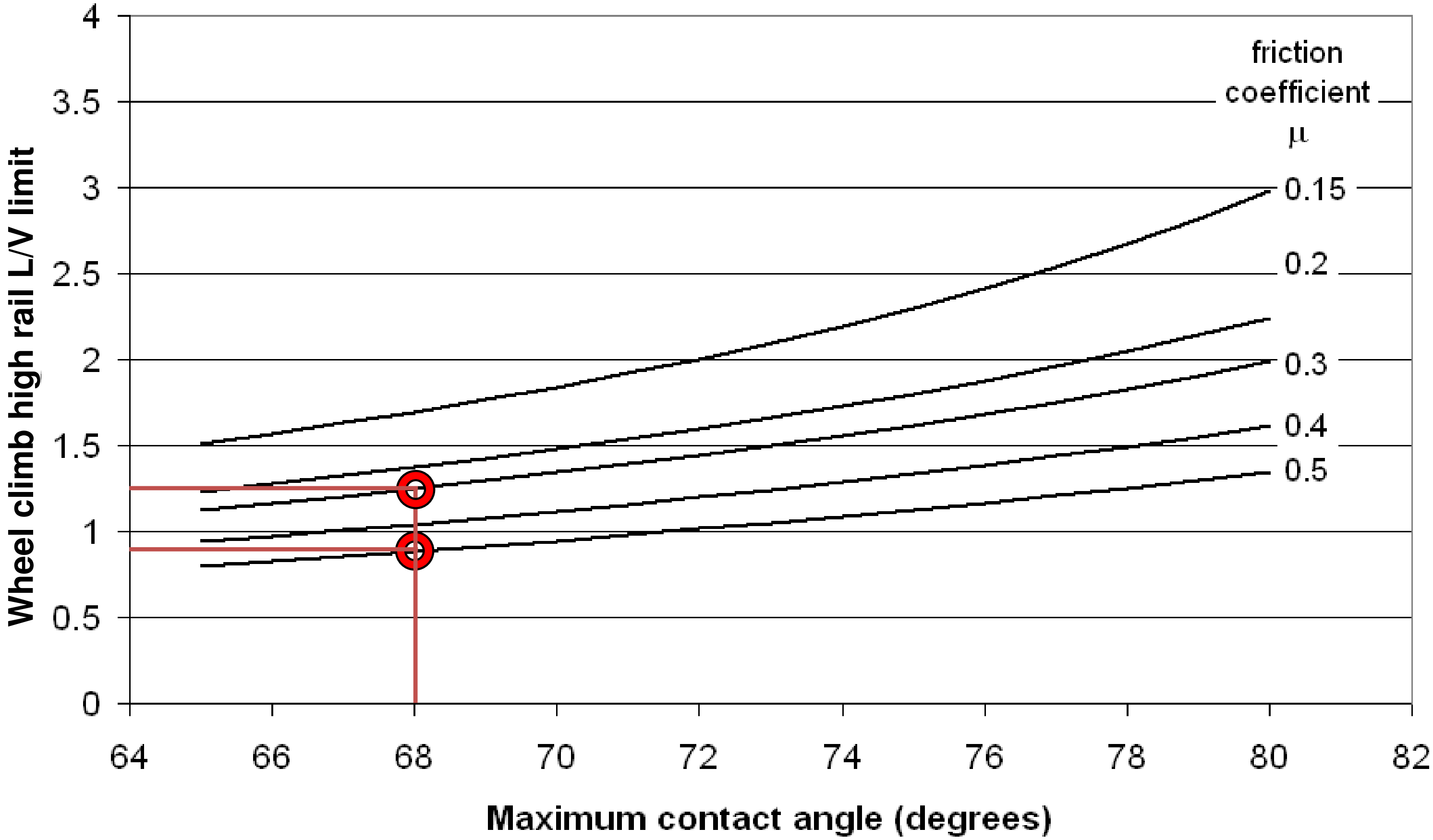
$$\frac{L}{V} = \frac{\tan\delta - F_T / N}{1 + F_T\tan\delta / N}$$

# Nadal's Relationship



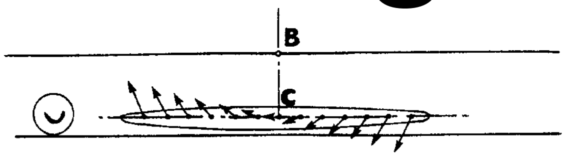

$$\frac{L}{V} = \frac{\tan\delta - \mu}{1 + \mu\tan\delta}$$

# Nadal Index (1908)

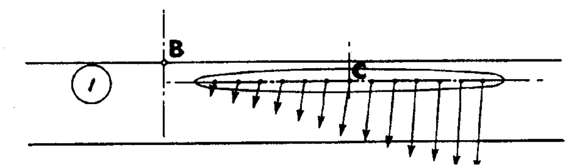



2023

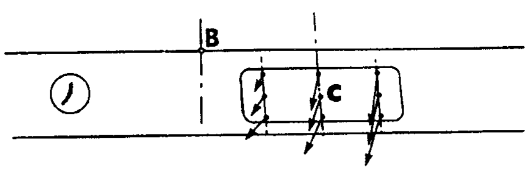
# Slip Vectors at the Gage Face Contact




δ>β, α=0




δ<β, large α



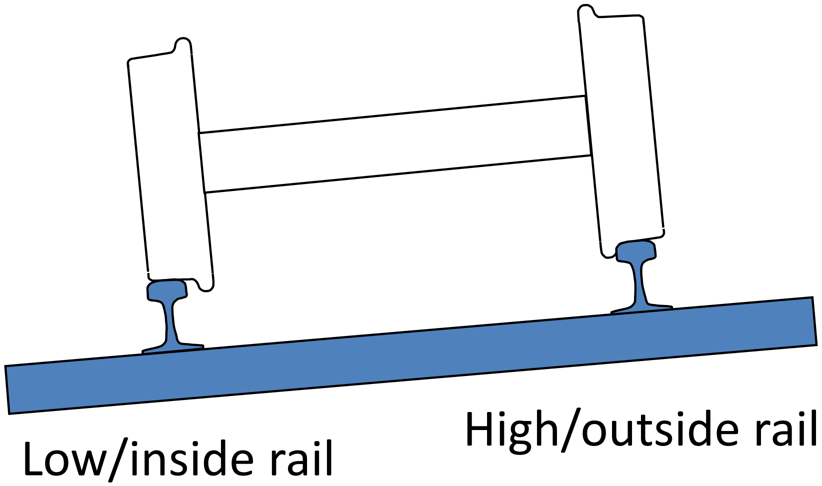

δ=β, moderate α

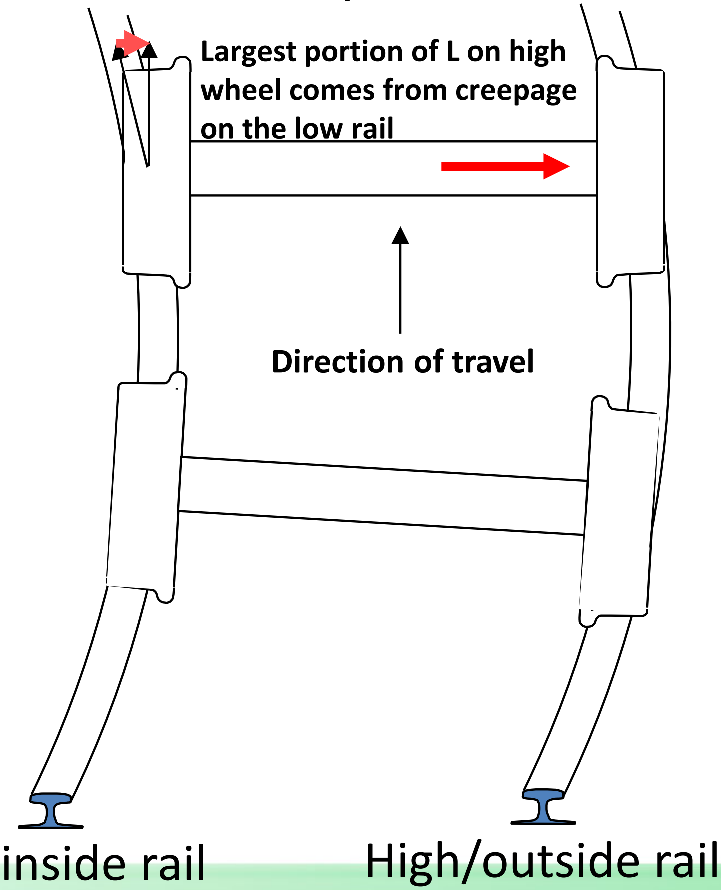
α = angle of attack

δ = wheel flange angle

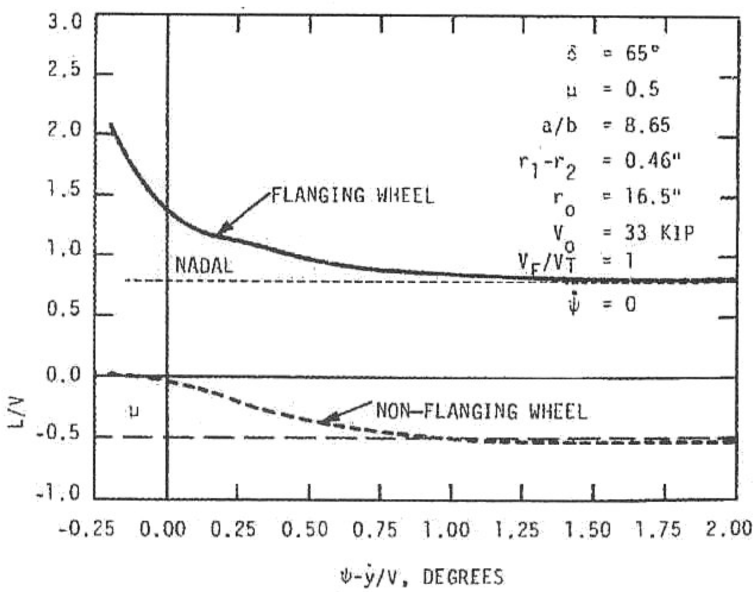
β = gage face angle

# Lateral wheel/rail forces



# Weinstock Derailment Criterion



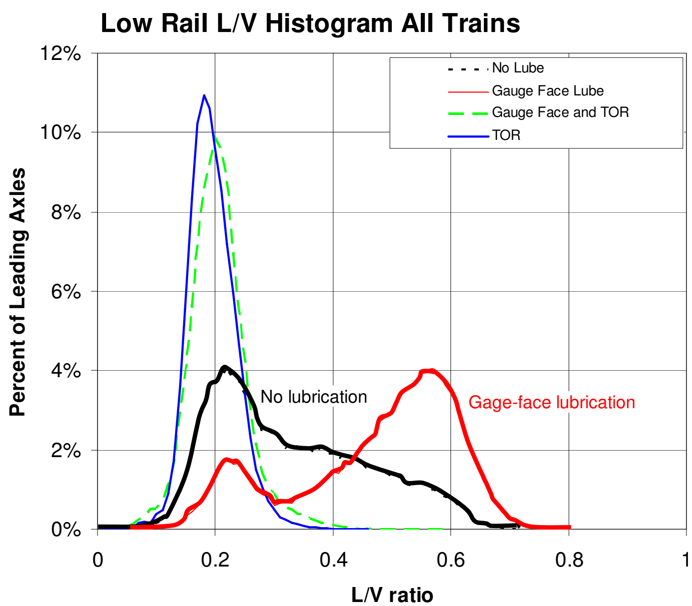

$$|L/V|_{flanging} + |L/V|_{non\_flanging} > (L/V_{NADAL} + m)$$

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

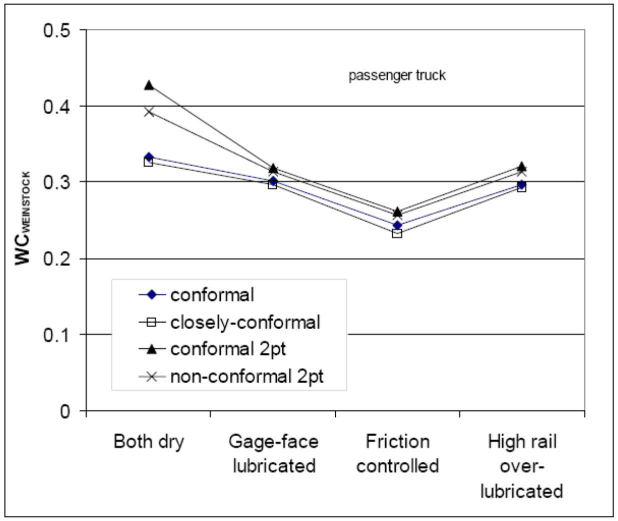
- At incipient wheel climb, the L/V values on the flanging and non-flanging wheels are, for positive angles of attack, separated by a roughly constant value equal to the Nadal limit plus the coefficient of friction on the top of the low rail

# An Example

- Is lubrication a good thing?








L/V goes up, but Weinstock limit also.

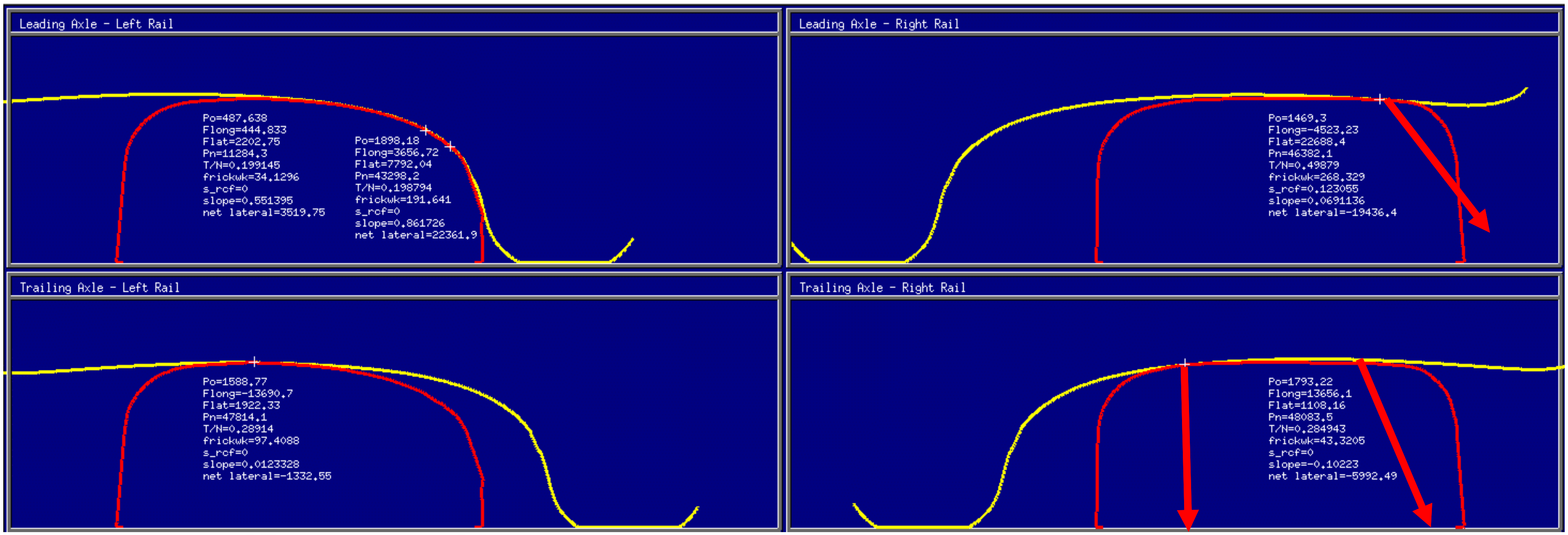
# Wheel Climb - Conclusions

- 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

# 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