Wheel-Rail Interaction Fundamentals

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Introduction and Objectives

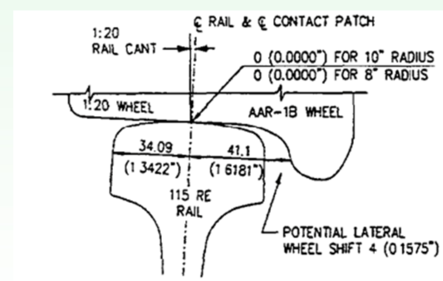
- This two-part session will provide an introduction to several fundamental aspects of vehicle-track interaction at the wheel/rail interface, including:
  - The Wheel / Rail Interface and Key Terminology
  - The Contact Patch and Contact Pressures
  - Creepage and Traction Forces
  - Wheelset Geometry and Effective Conicity
  - Vehicle Steering and Stability
  - Friction, Forces and Wear
  - Shakedown and Rolling Contact Fatigue (RCF)
  - Curving Noise
  - Corrugations
- Participants will emerge with a framework to understand, articulate, quantify and identify key phenomena that affect the practical operation, economics and safety of heavy haul and passenger rail systems.

Overview: Part I

- The Wheel / Rail Interface and Key Terminology
- The Contact Patch and Contact Pressures
- Creepage and Traction Forces
- Wheelset Geometry and Effective Conicity
- Vehicle Steering and Stability

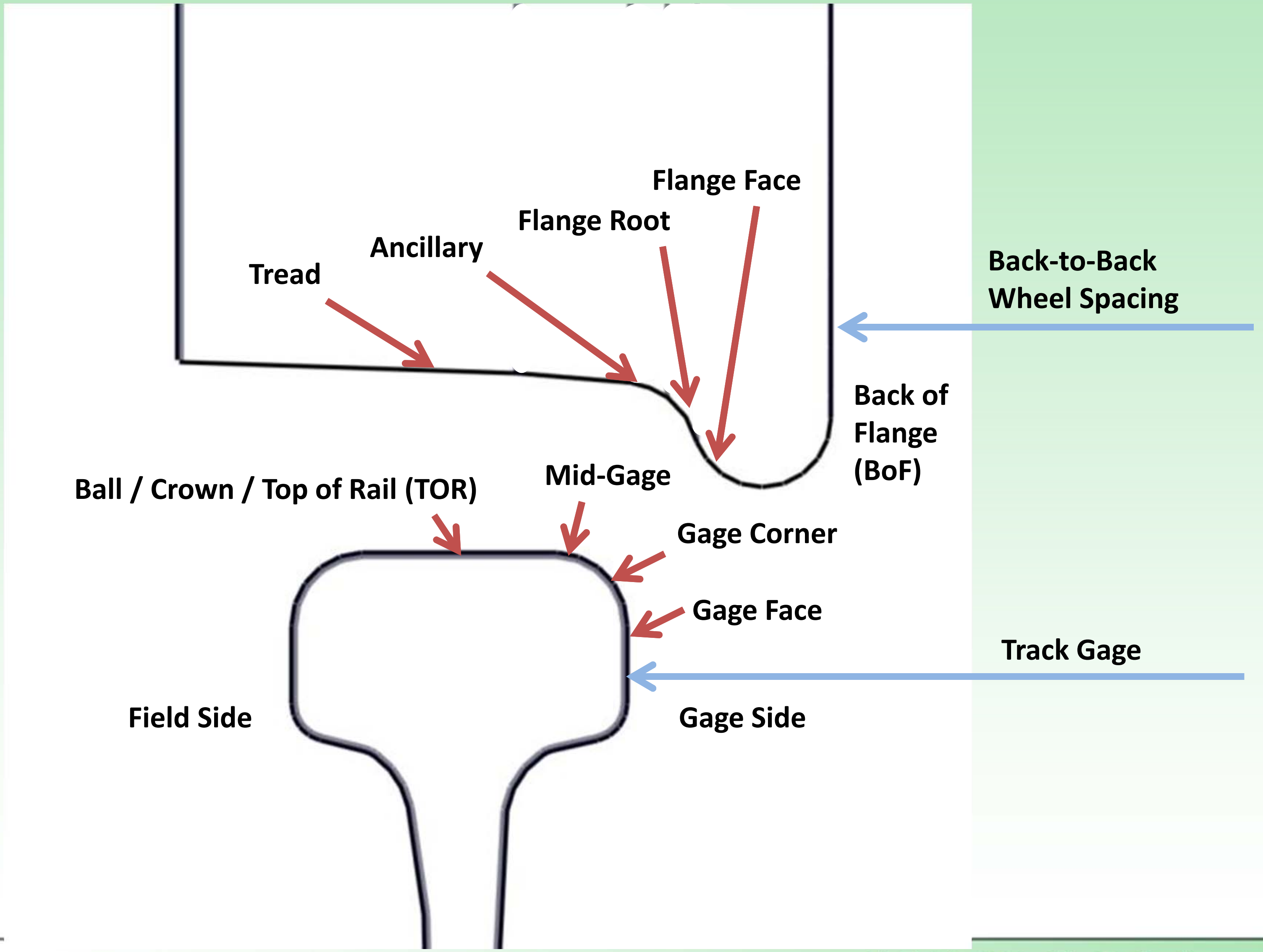
Back to basics…

- Tangent
- Curve
- Spiral
- High Rail
- Low Rail
- Superelevation (aka Cant)
- Rail Cant

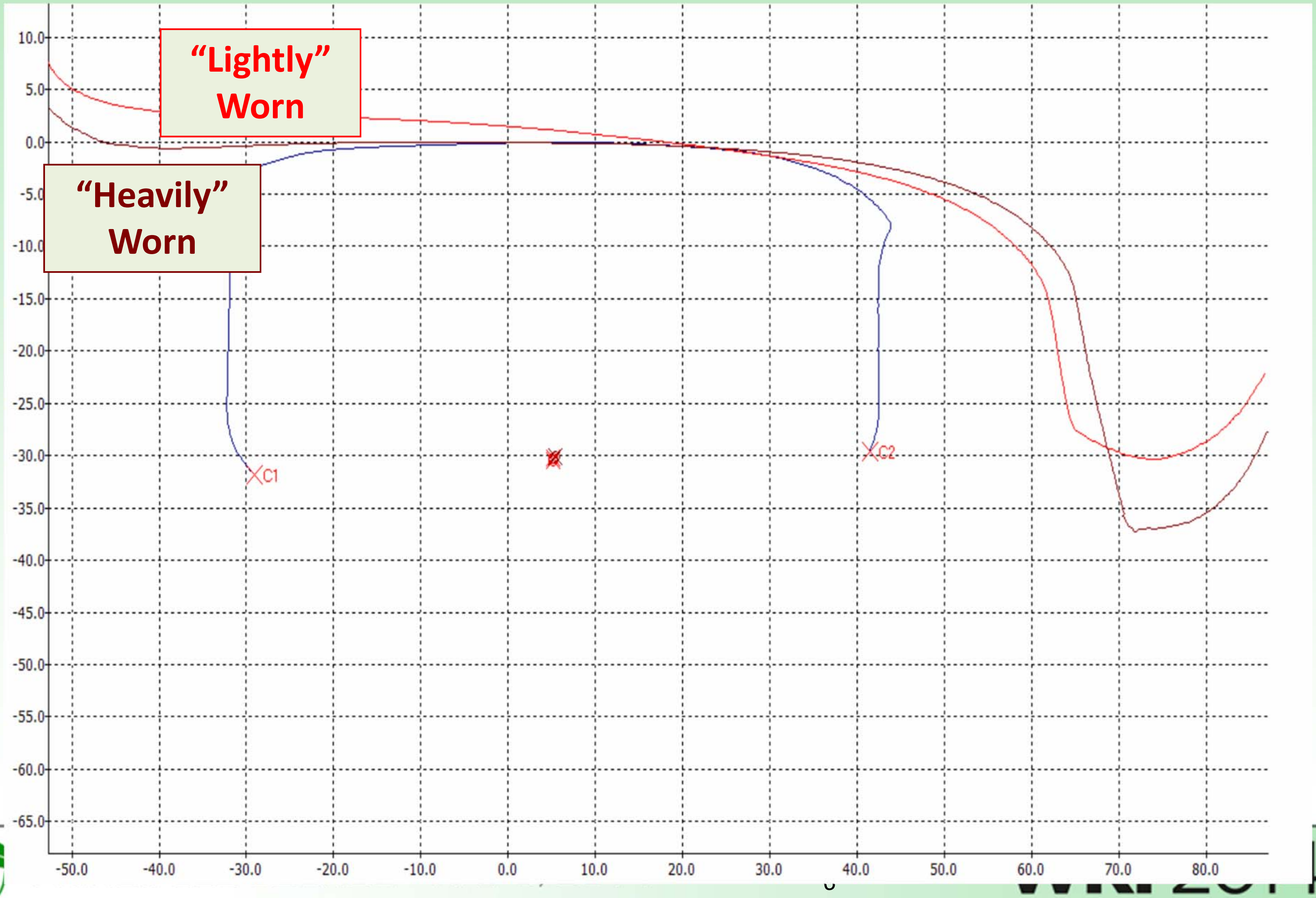


1:20 CANT

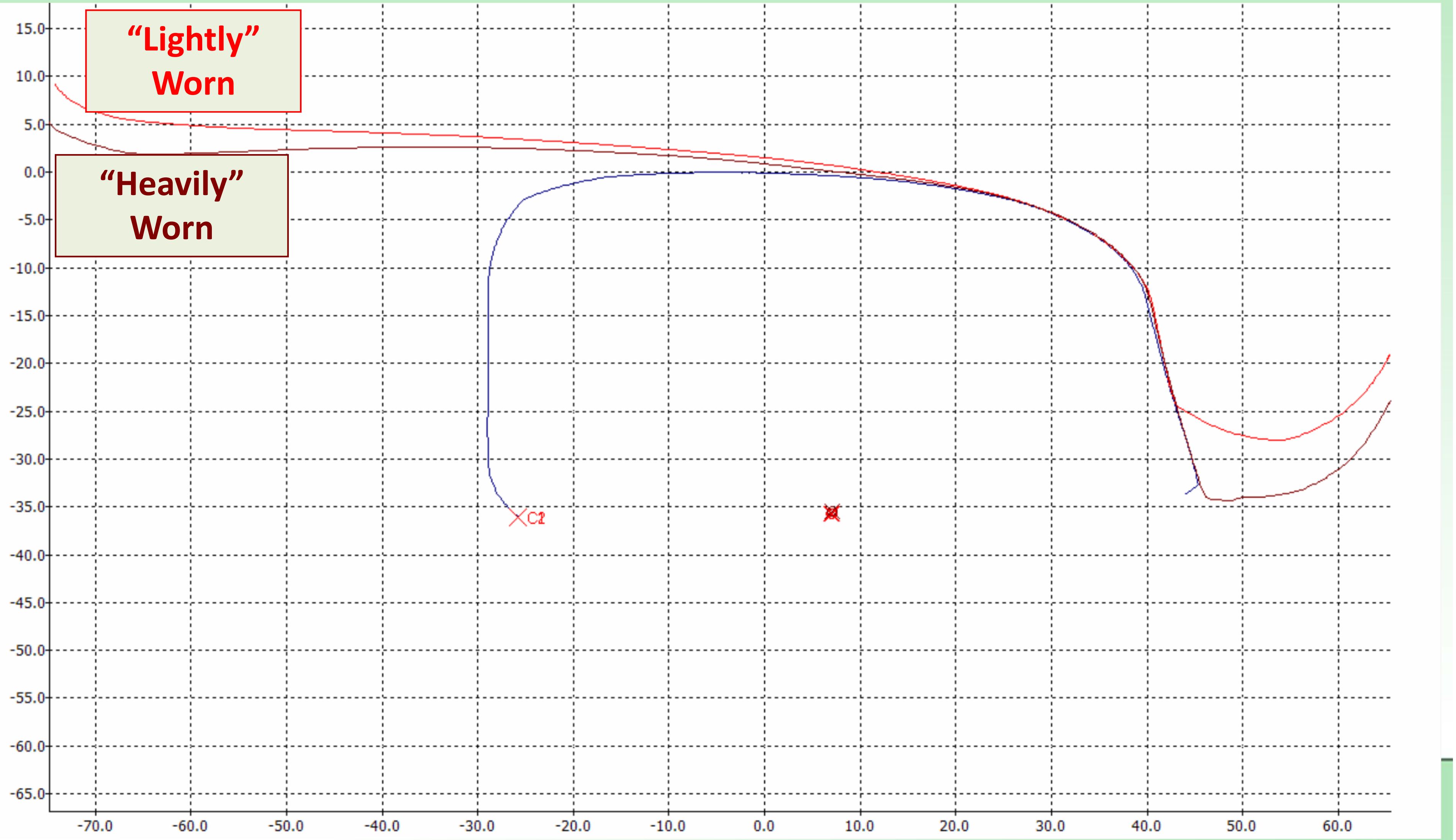
The Wheel / Rail Interface and Key Terminology



The Wheel / Rail Interface and Key Terminology (e.g. Low Rail Contact)

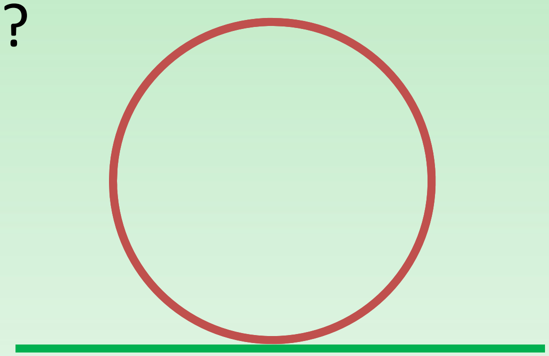


The Wheel / Rail Interface and Key Terminology (e.g. High Rail Contact)



The Contact Patch and Contact Pressures

- Question #1: What is the length (area) of contact between a circle (cylinder) and a tangent line (plane)?

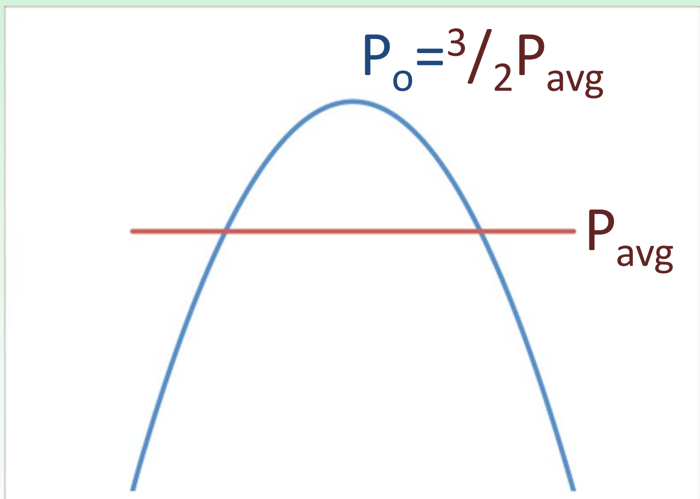


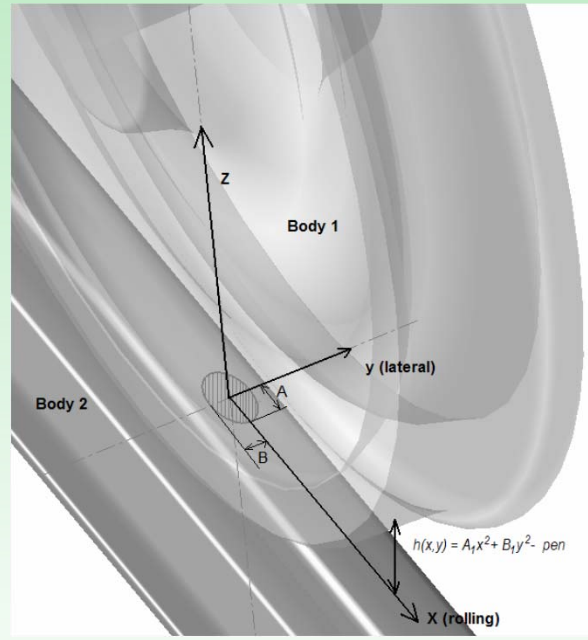
- Question #2: Given Force and Area, how do we calculate pressure?

- Question #3: If a circular body (~wheel) is brought into contact with a linear body (~rail) with a vertical force **F** and zero contact area, what is the resulting calculated pressure?

Hertzian Contact

- Hertzian Contact (1882) describes the pressures, stresses and deformations that occur when curved elastic bodies are brought into contact.
- “Contact Patches” tend to be **elliptical**
- This yields **parabolic** contact pressures

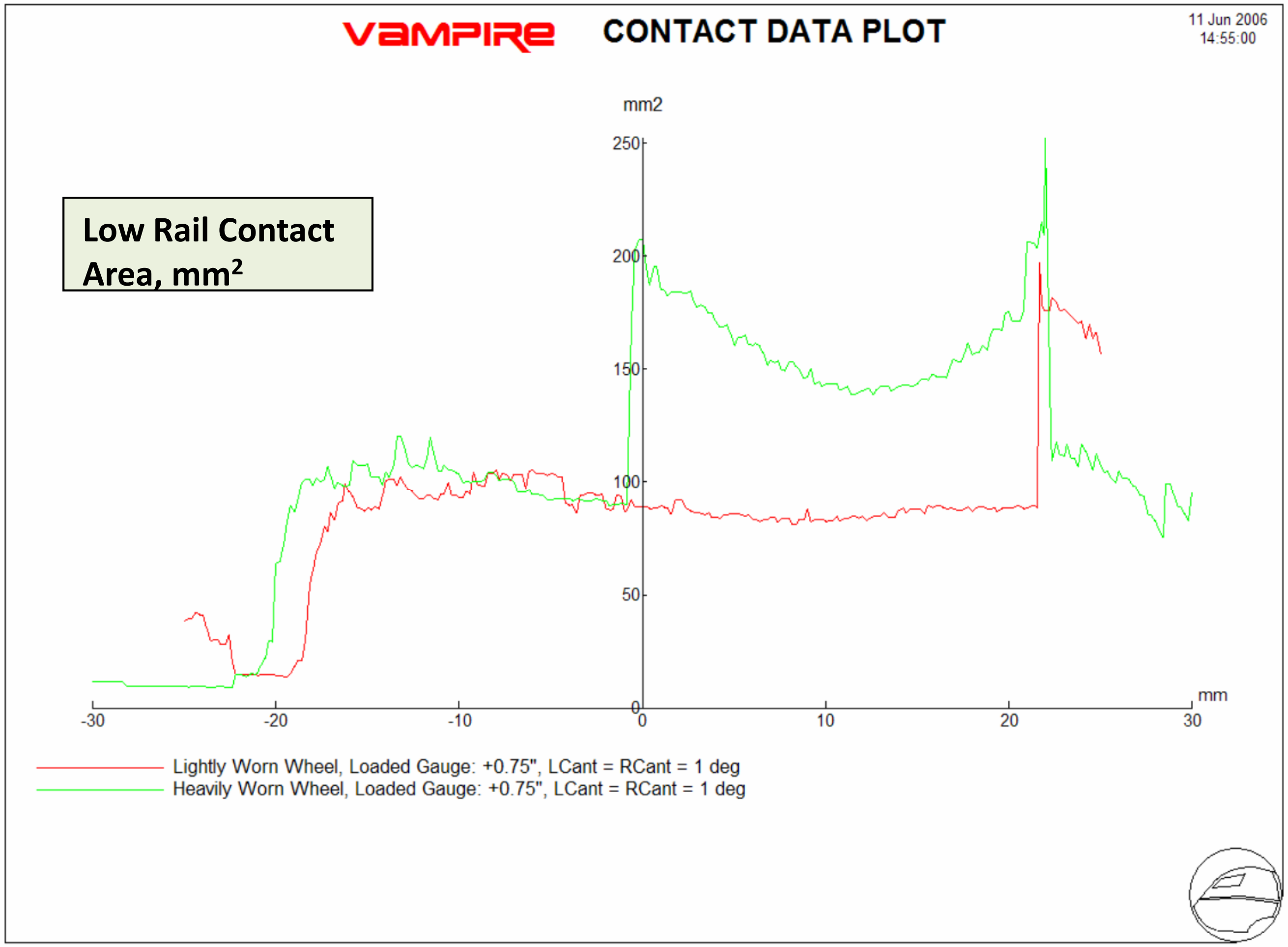




- Contact theory was subsequently broadened to apply to rolling contact (Carter and Fromm) with non-elliptical contact and arbitrary creepage (Kalker; *more on this later…*)

The Contact Patch and Contact Pressures

The Contact Patch and Contact Pressures

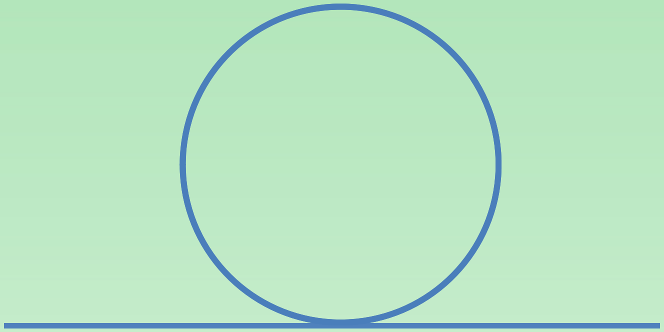


VAMPIRE Plot

Example calculation: Average and Peak Pressure

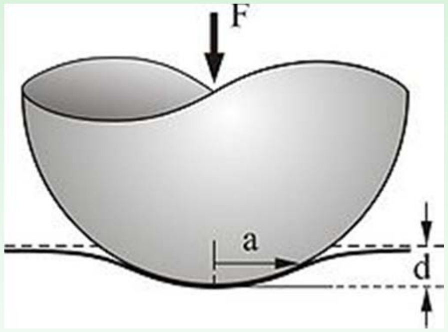
- Let’s assume a circular contact patch, with a radius of **0.4” (10 mm)**
- The contact area is then: **0.49 in^2 (314 mm^2)**
- Assuming a HAL vehicle weight (gross) of 286,000 lbs, we have a nominal wheel load of 35,750 lbs, i.e. **35.75 kips (159 kN)**
- The resulting average contact pressure is then: **73.4 ksi (506 MPa)**
- This gives us a peak contact pressure of: **110 ksi (760 MPa)**

- What is the shear yield strength of rail steel?
- **~58 ksi (~400 MPa)**
- What’s going on?



Cylindrical Contact with Elastic Half-Space (2-D loading)

Tensile Testing (1-D loading)



Spherical Contact with Elastic Half-Space (3-D loading)

(We will see this again later…)

Creepage and Traction Forces

- Longitudinal Creepage
- The Traction-Creepage Curve
- Lateral Creepage
- Spin Creepage

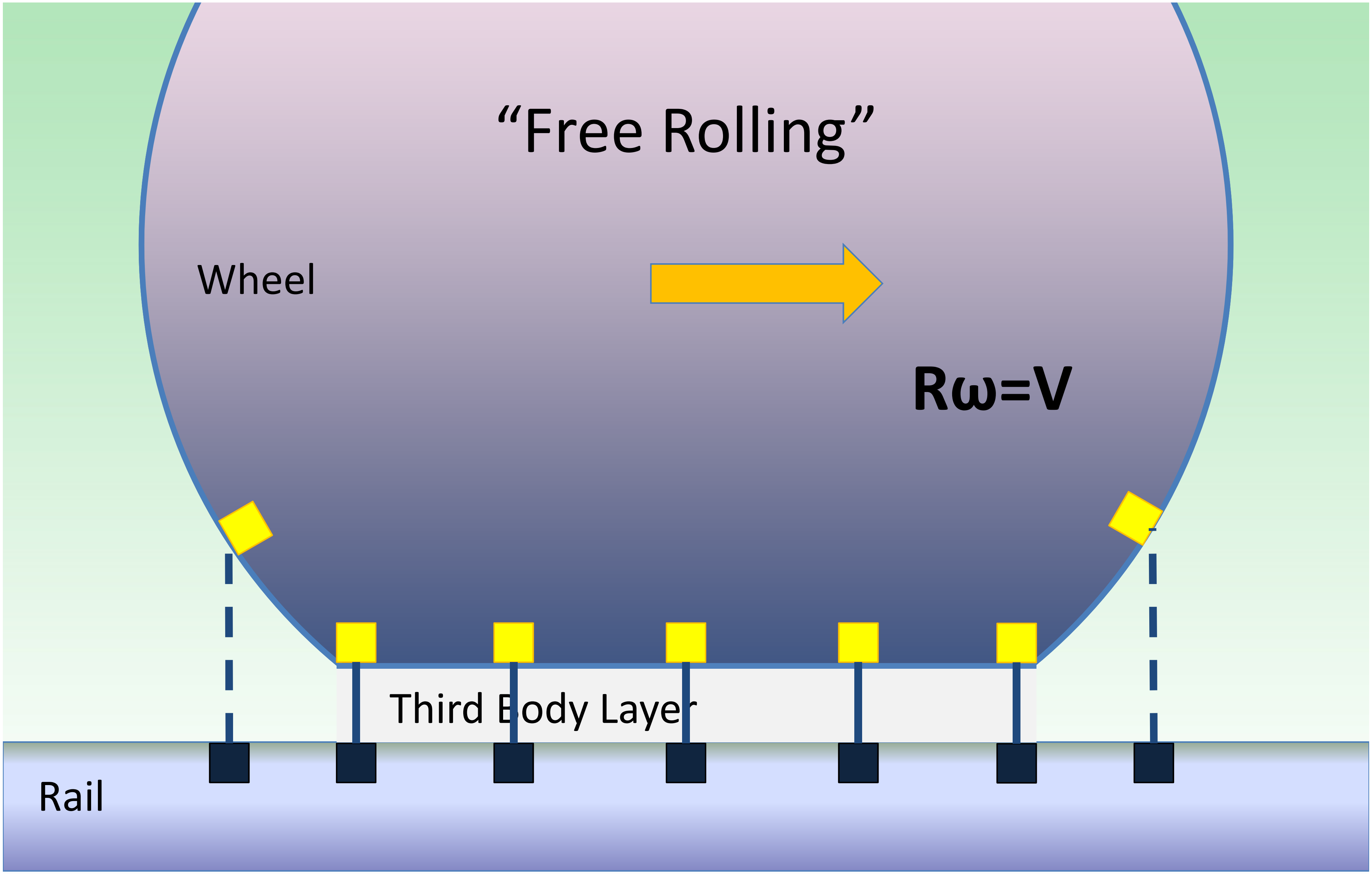
What does Longitudinal Creepage *mean*?...

- The frictional contact problem (Carter and Fromm, 1926) relates frictional forces to velocity differences between bodies in rolling contact.

- Longitudinal Creepage can be calculated as: $$\frac{R\omega - V}{V}$$

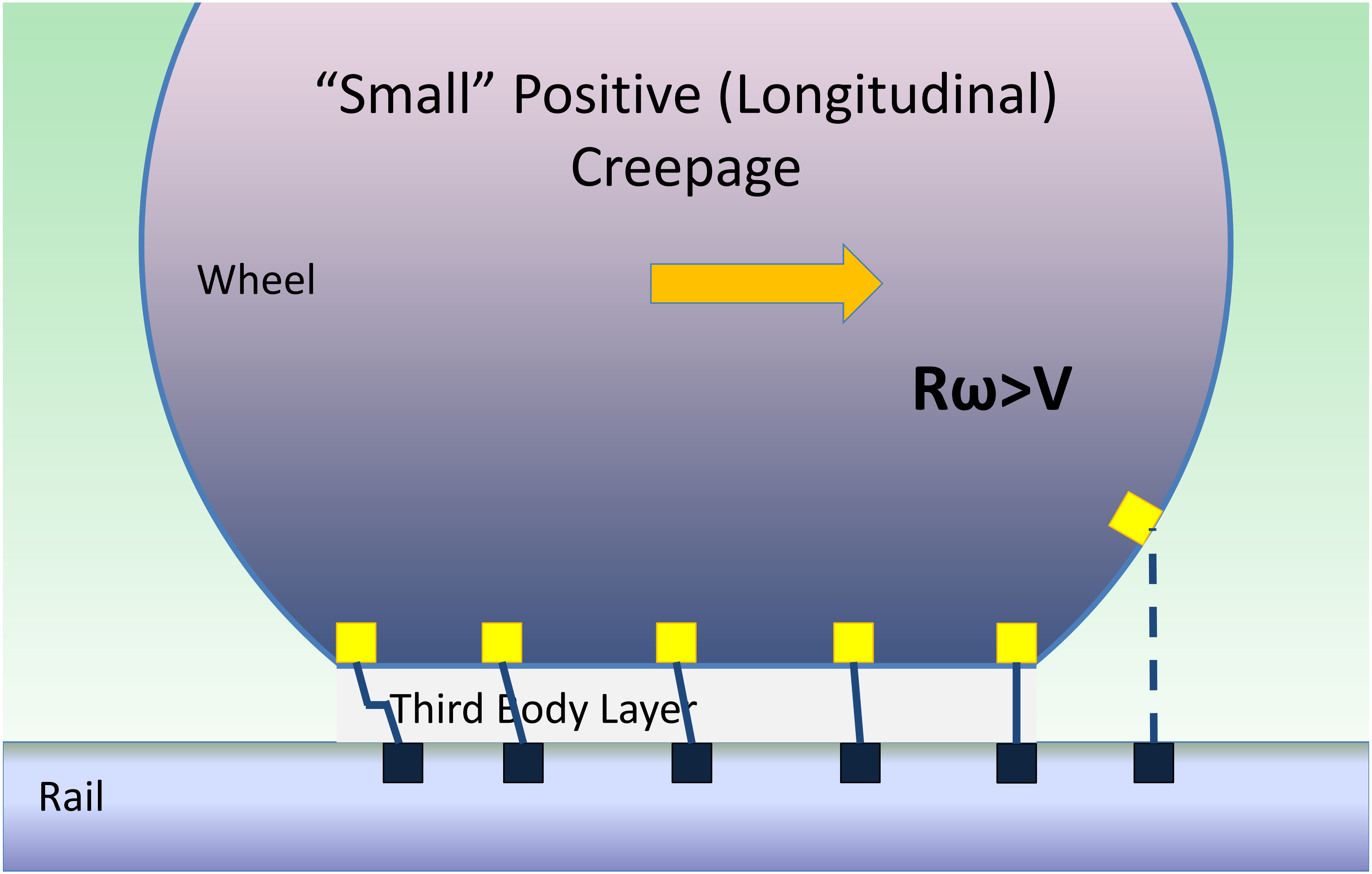
- In adhesion, 1% longitudinal creepage means that a wheel would **turn 101 times while traveling a distance of 100 circumferences**.

- In braking, -1% longitudinal creepage means that a wheel would **turn 99 times while traveling a distance of 100 circumferences.**

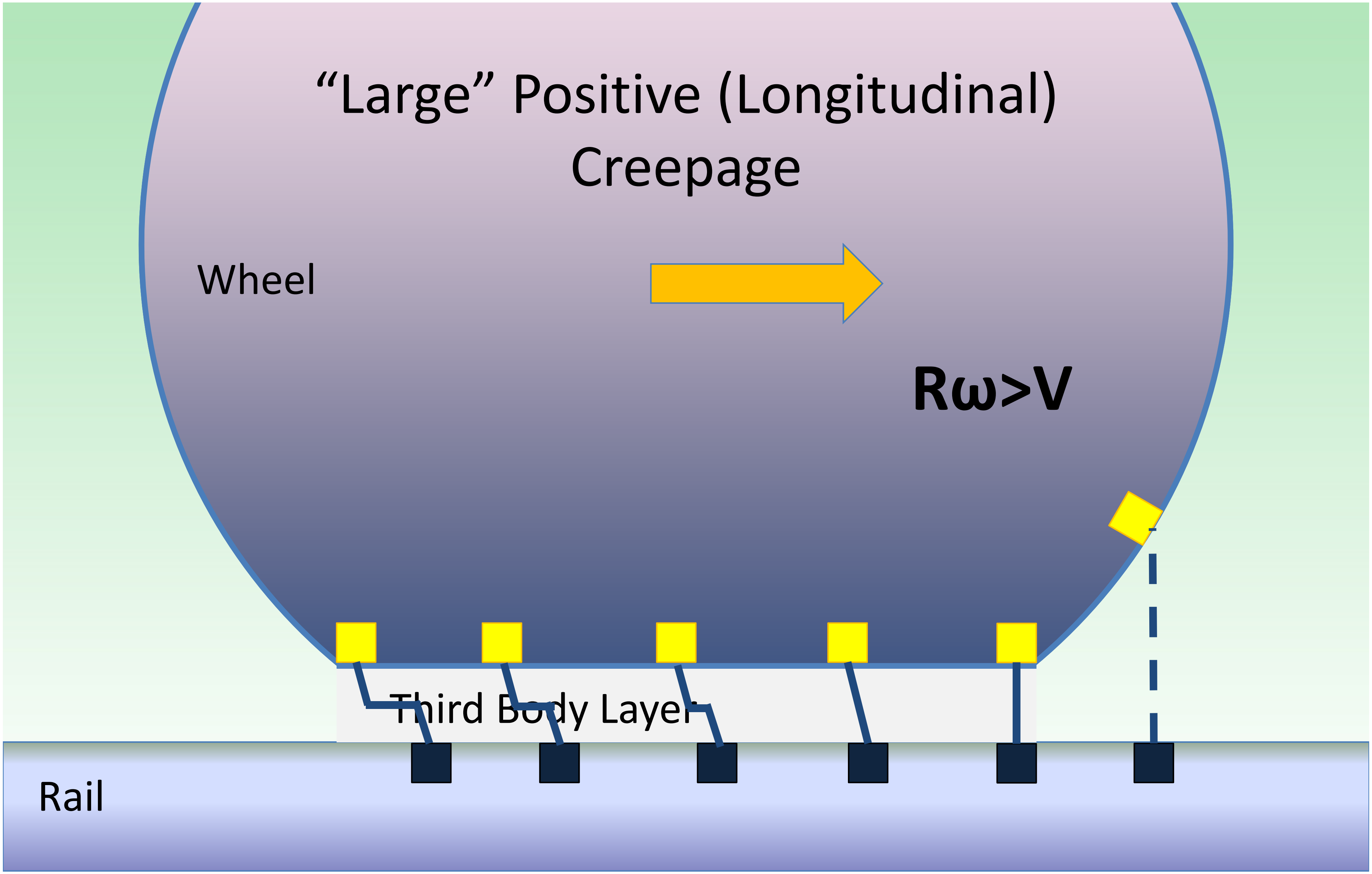


"Free Rolling"
Wheel
Rω=V
Third Body Layer
Rail

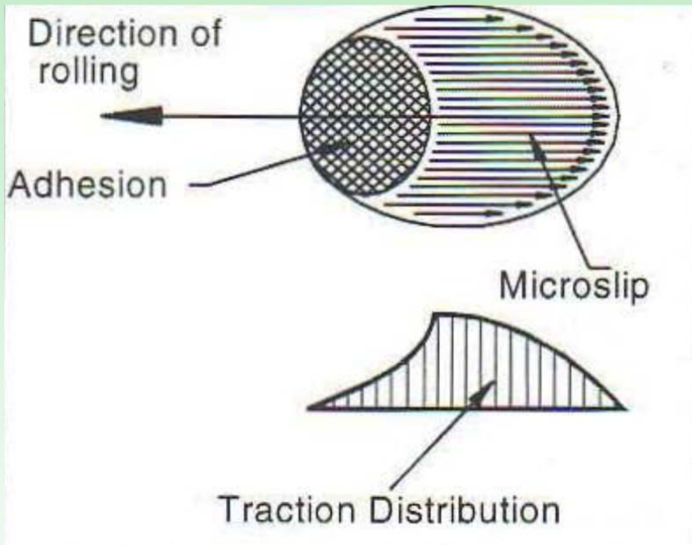
“Small” Positive (Longitudinal) Creepage

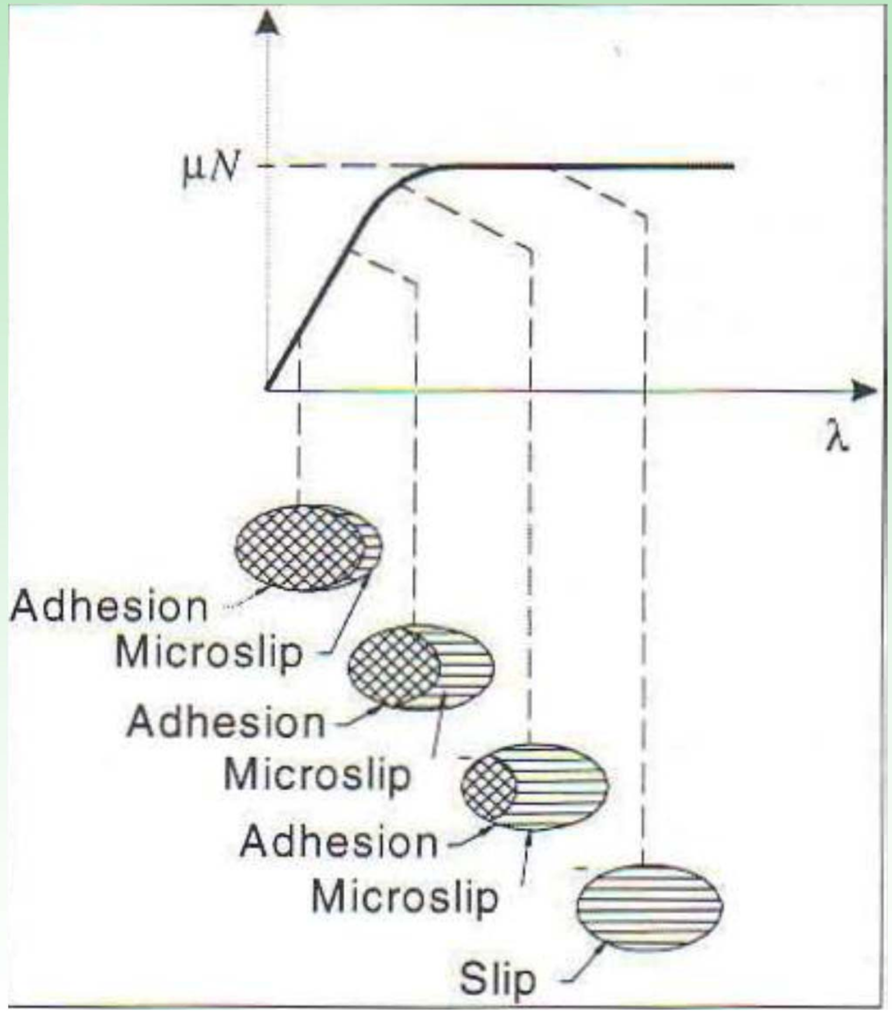


“Large” Positive (Longitudinal) Creepage



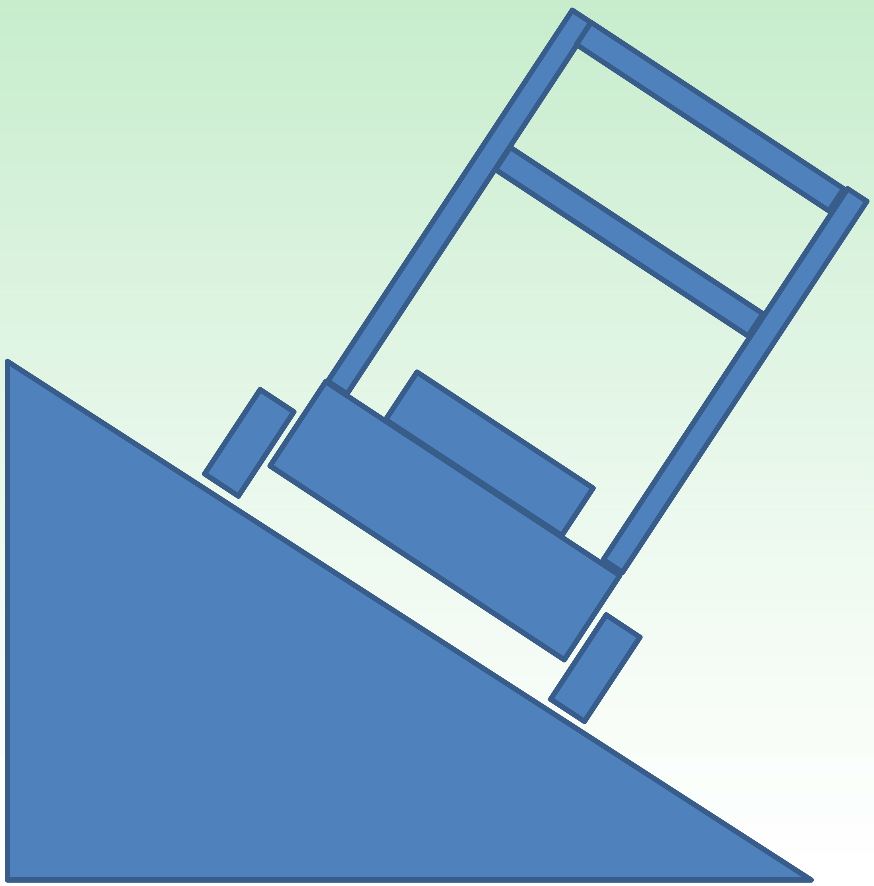
The Traction-Creepage Curve

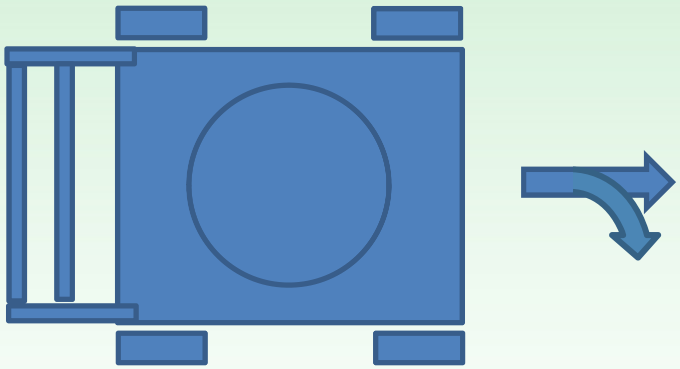




Lateral creepage

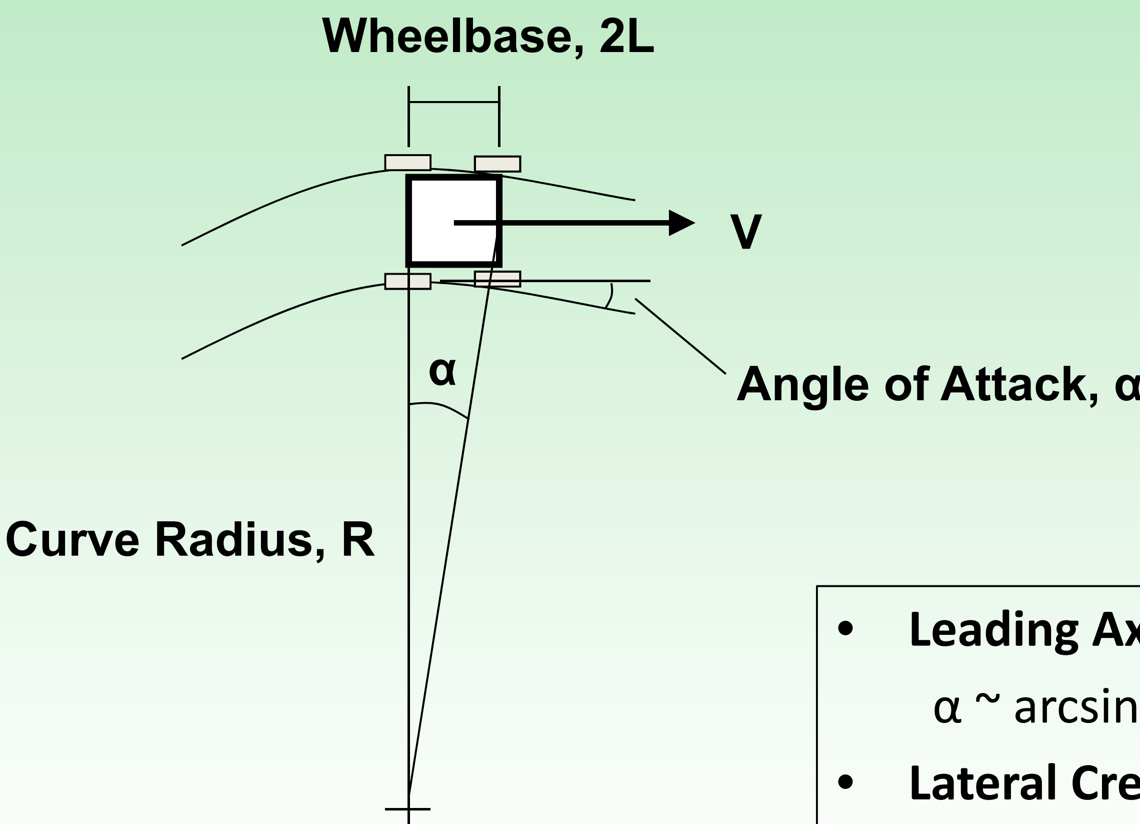
Imagine pushing a lawnmower across a steep slope…





OK, but when does this occur at the WRI?...

Example: Estimating Lateral Creepage in Sharp Curves



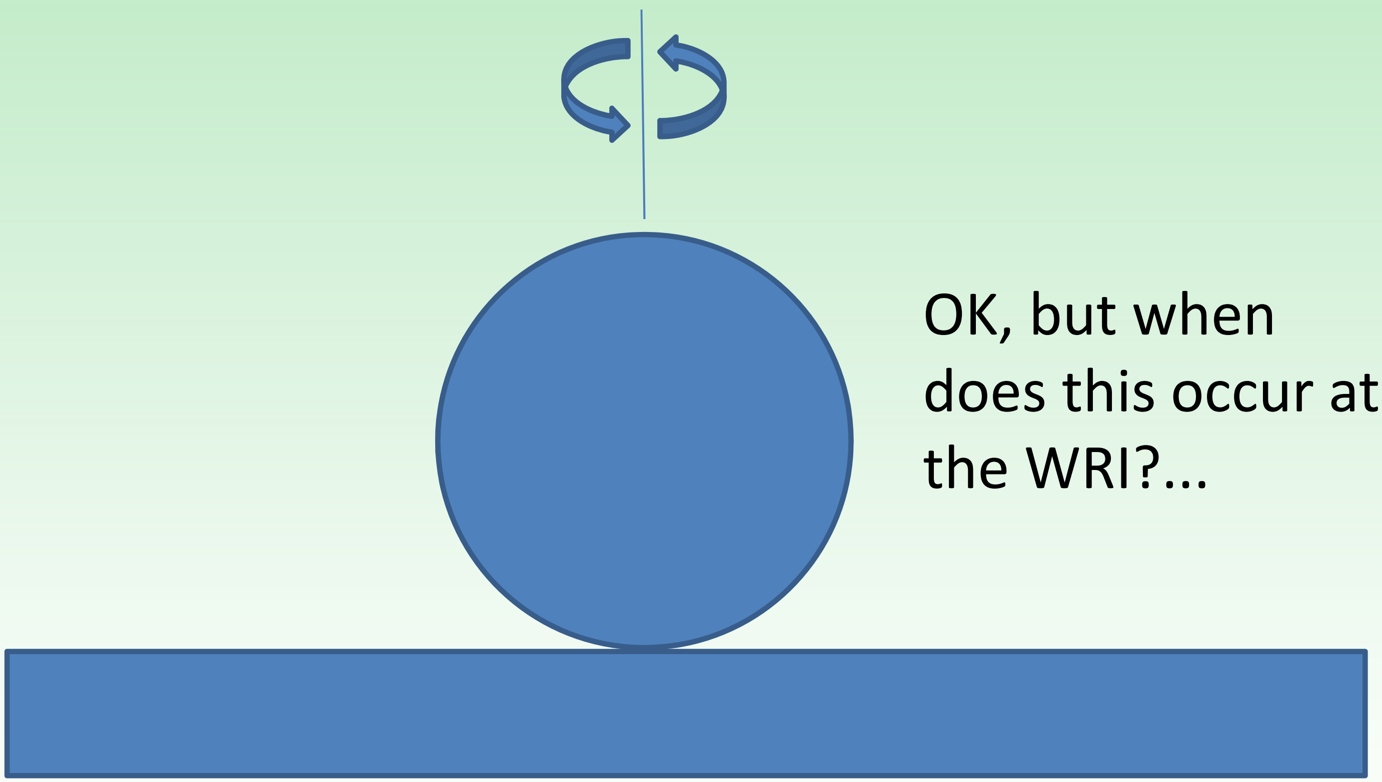
- **Leading Axle angle of attack:**

  $\alpha \sim \arcsin(2L/R) \sim 2L/R$

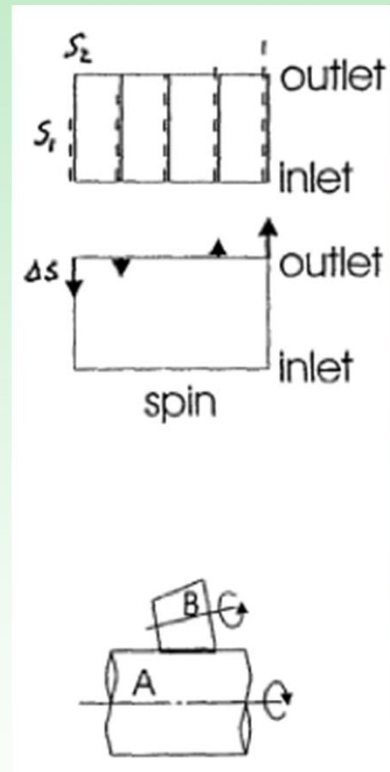
- **Lateral Creepage at TOR contact:**

  $V_{lat}/V \sim 2L/R \sim \alpha$

Spin Creepage
Think of spinning a coin on a tabletop….

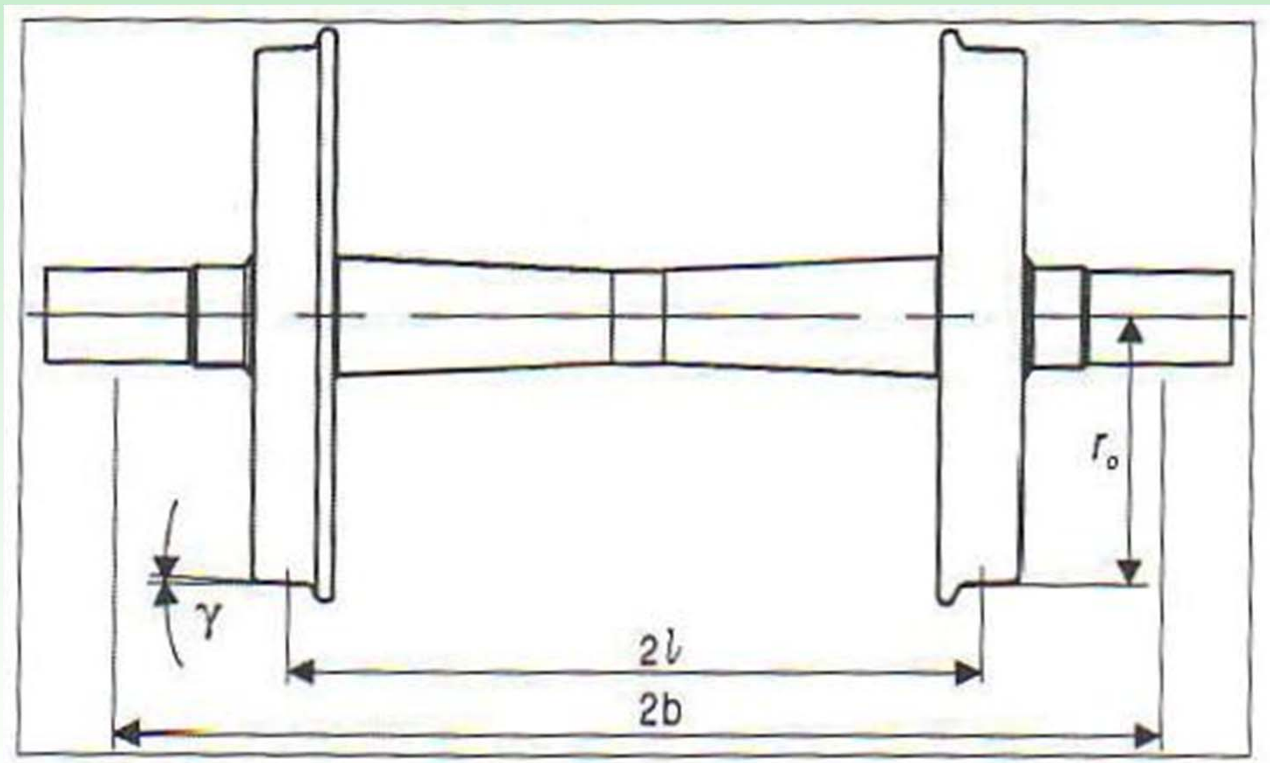


OK, but when does this occur at the WRI?...

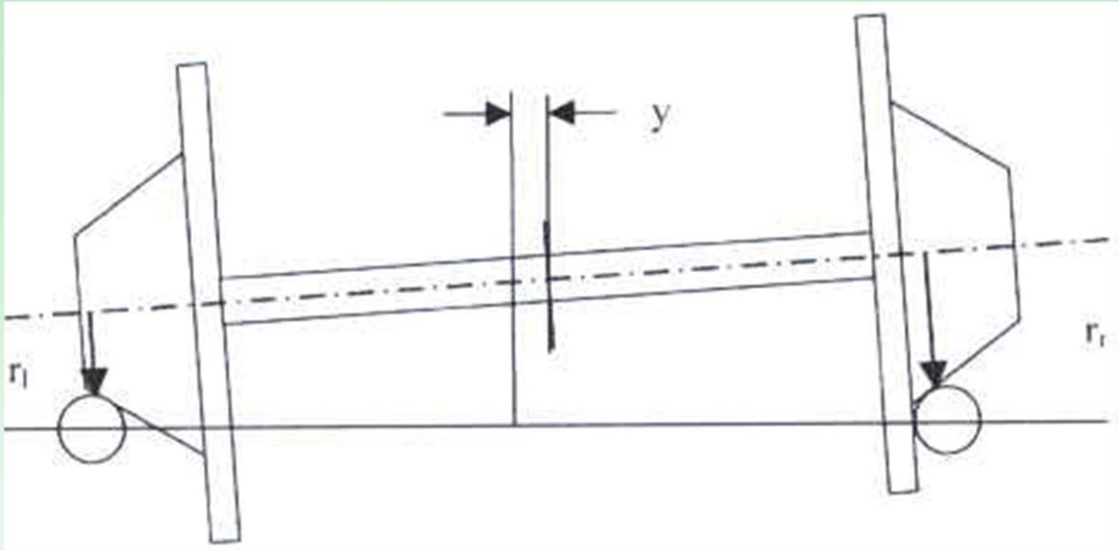


Vehicle Curving and Steering

- The wheel set



Displaced wheel set



λ = effective conicity

r_0 = wheel radius of undisplaced wheelset

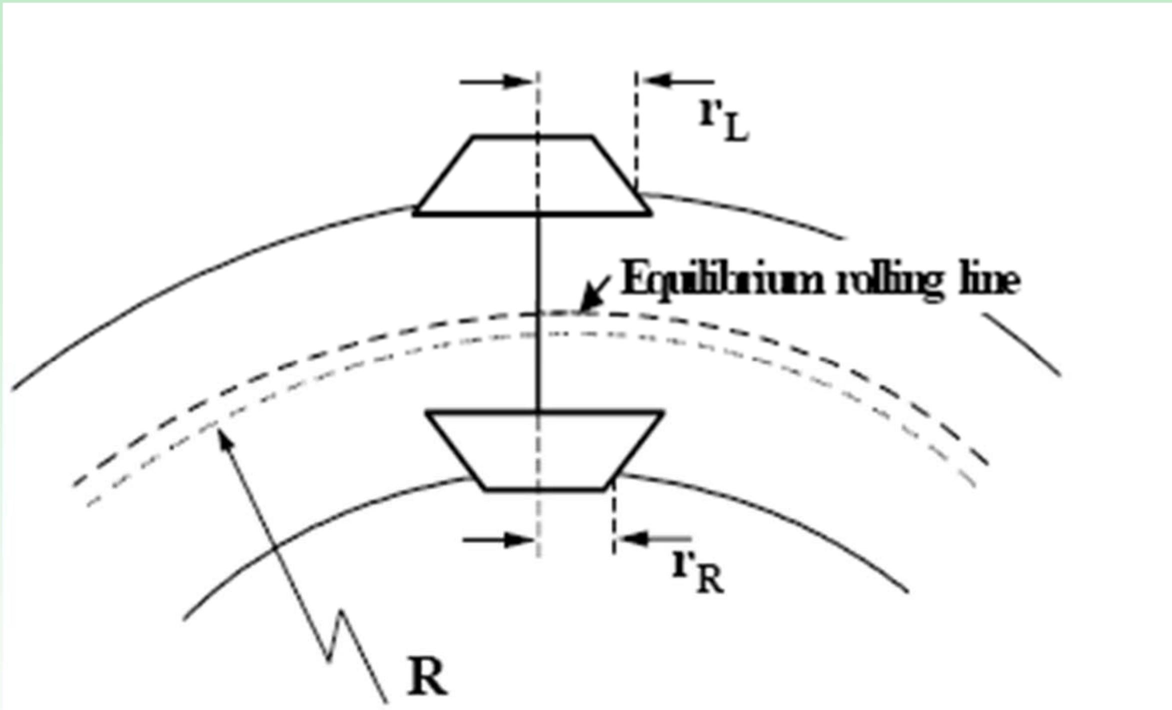
R = curve radius

L_0 = half gauge

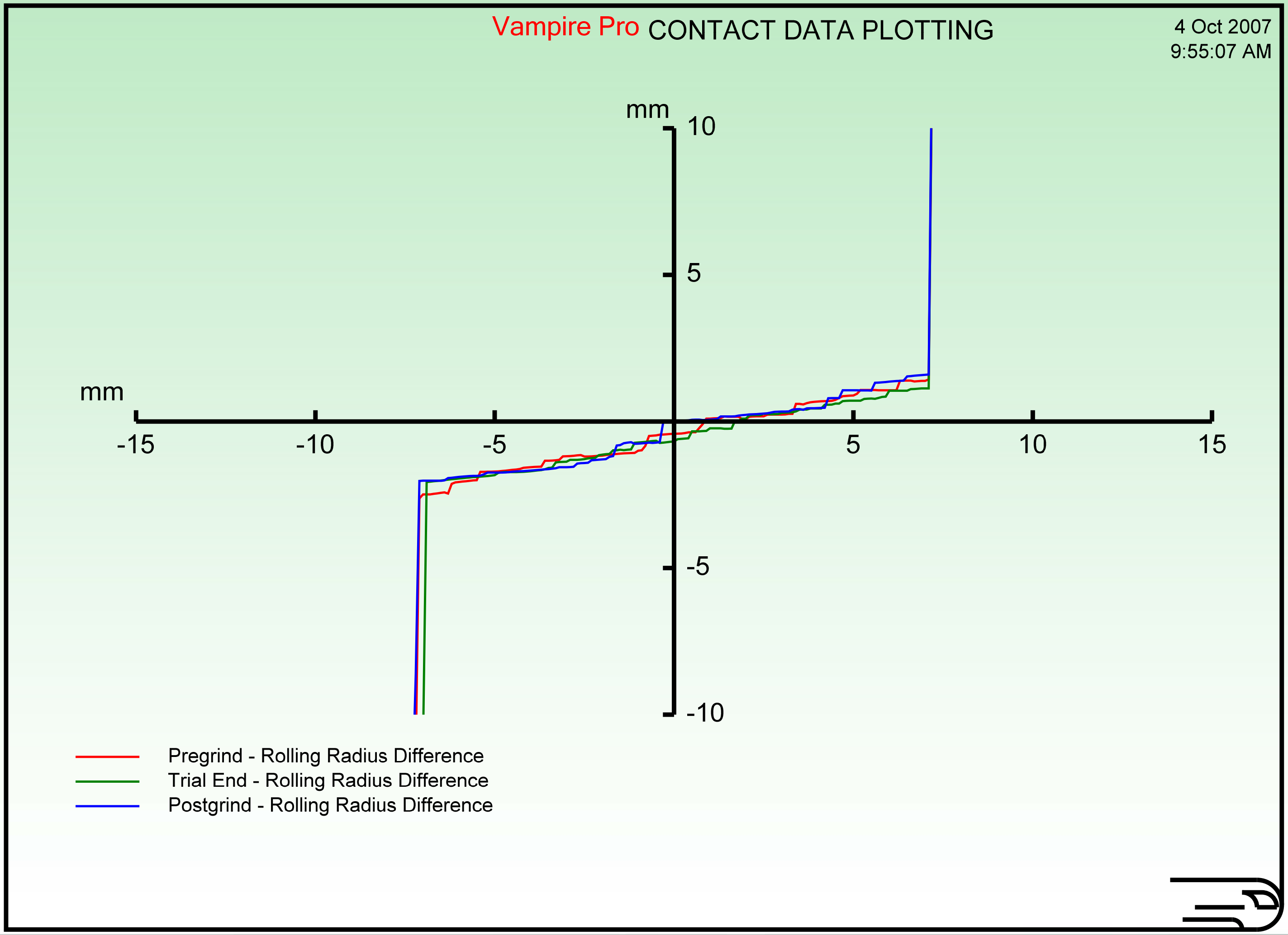
$$\boxed{\frac{r_0 - \lambda y}{r_0 + \lambda y} = \frac{R - l_0}{R + l_0},}$$

$$\boxed{y = \frac{r_0 l_0}{R\lambda}.}$$

Theoretical Equilibrium

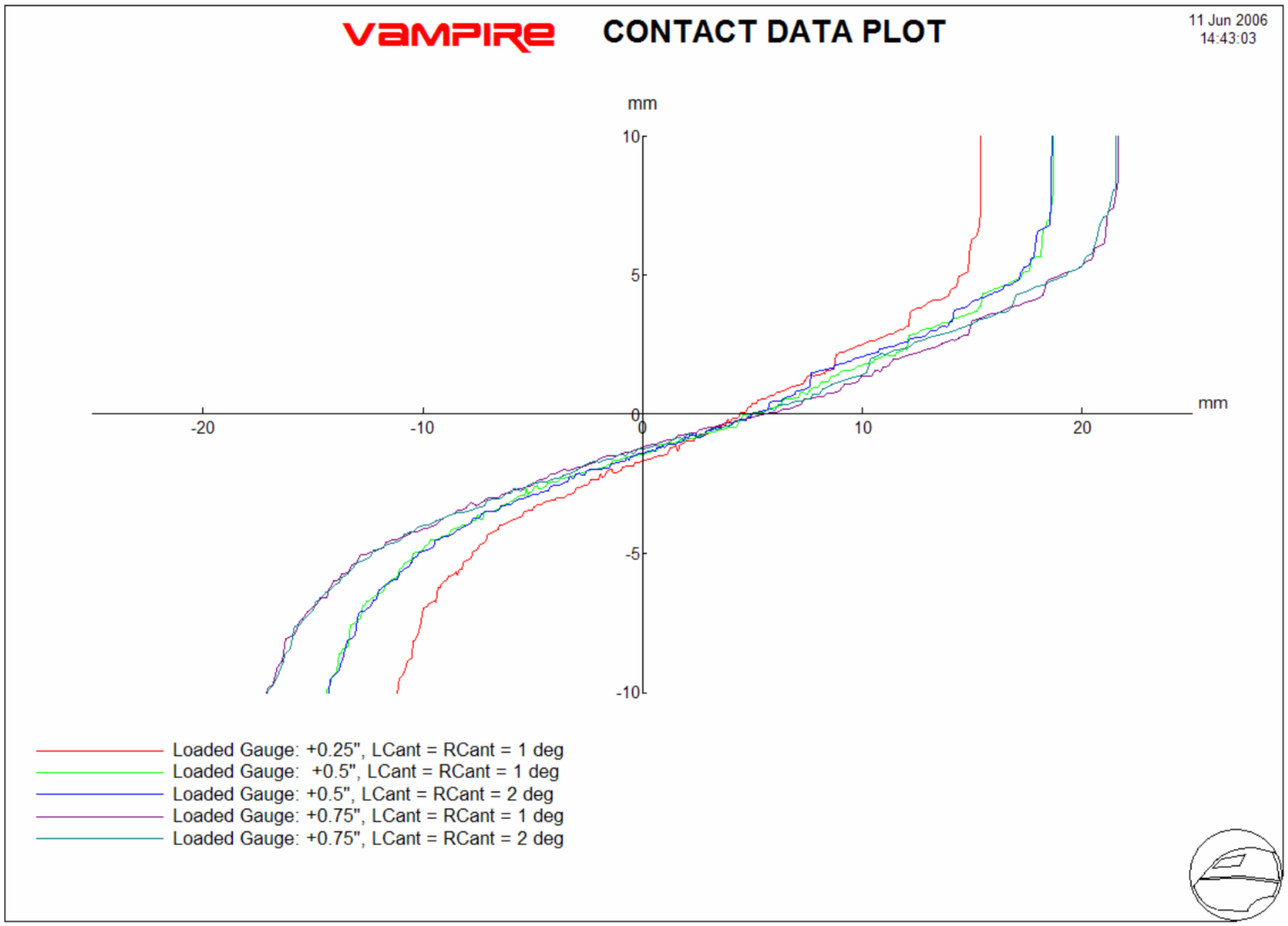


Effective Conicity



Rolling Radius Difference

Effective Conicity (Worn Wheels)



VAMPIRE Plot

Effect of rolling radius difference on steering moment

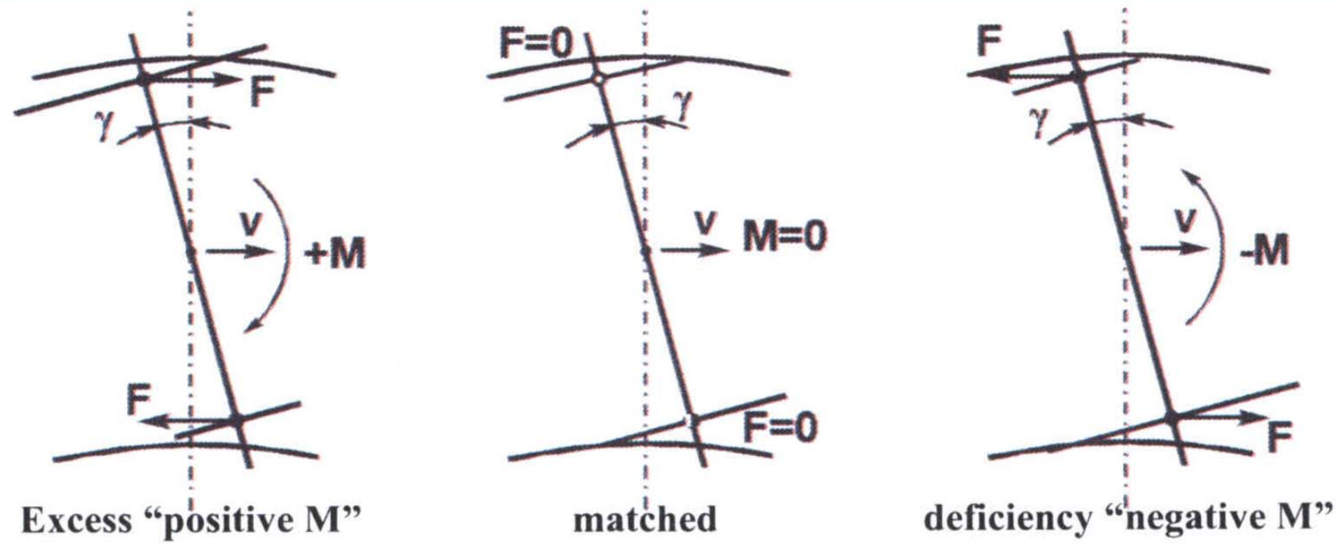
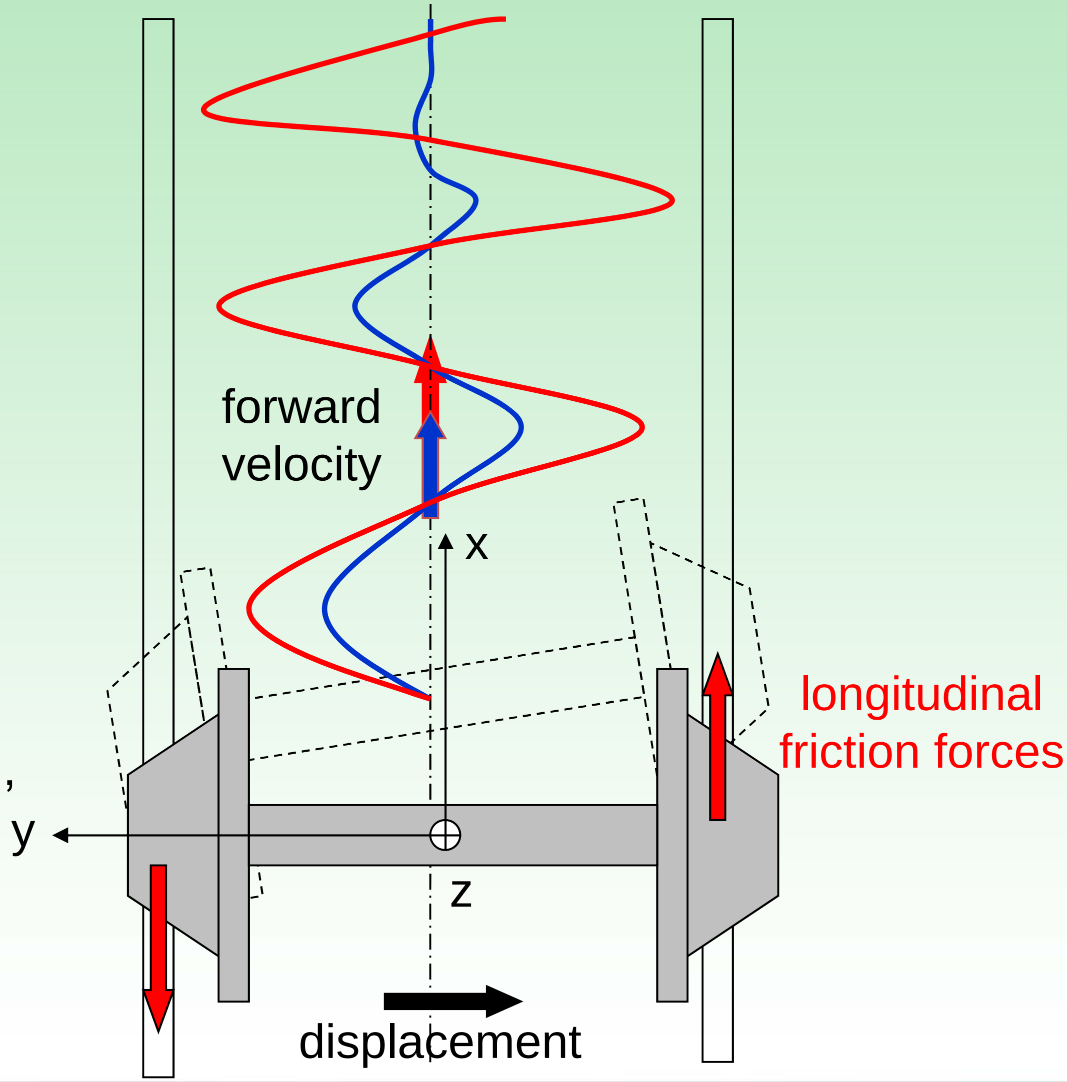


Figure 2: effect of rolling radius difference on longitudinal component of creepage force

Tangent Running and Stability

- Lateral displacement
  → ΔR mismatch
  → friction forces
  → steering moment
- Wheelset passes through central position with lateral velocity.
- At low speeds, oscillations decay.
- Above critical hunting speed, oscillations persist.



Questions & Discussion