Rail & Wheel Profiles: The Nexus of Wheel/Rail Interaction

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Combatting Wear and RCF

1. Wheel and rail profiles
2. Friction management and lubrication
3. Steel metallurgy (hardness, cleanliness)
4. Bogies/trucks (soft vs hard suspension, body steered, self-steering)

- All of them are equally important
- All of them should be used

Looking Back – Rail Profiles

- Softer rail steels – rapid initial wear, plastic flow
- Grinding to remove corrugation, not to attain a specific target profile
- Grinding templates not in use
- No asymmetric profiles = poor steering and high wear
- AREA / AREMA recommended rail profiles

Looking Back – Wheel Profiles

- Worn wheel limits did not include hollowing
- Interchange freight profile was prescribed
- Limited choice for intercity service
- More choice for transit – how to choose?

Looking Back – Friction Management

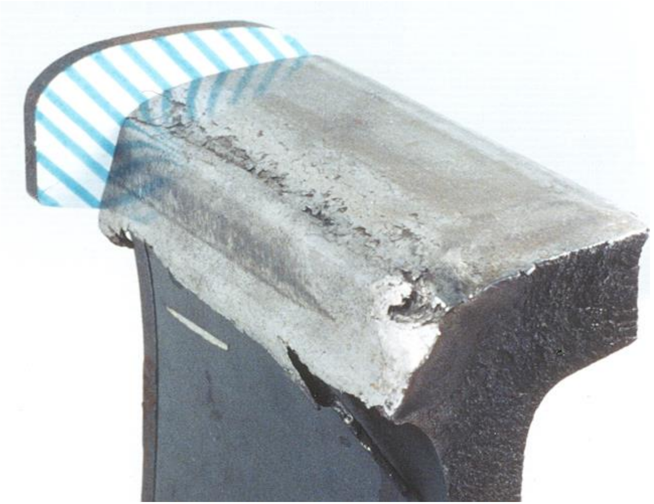
- Gauge face lubrication – spotty
  - Equipment not sophisticated
  - Output not well-controlled
  - Choice of product at the discretion of local people
- TOR-FM – not invented
  - Positive, neutral, negative friction characteristic?

Past, Present and Future

What happens if I choose incompatible profiles?

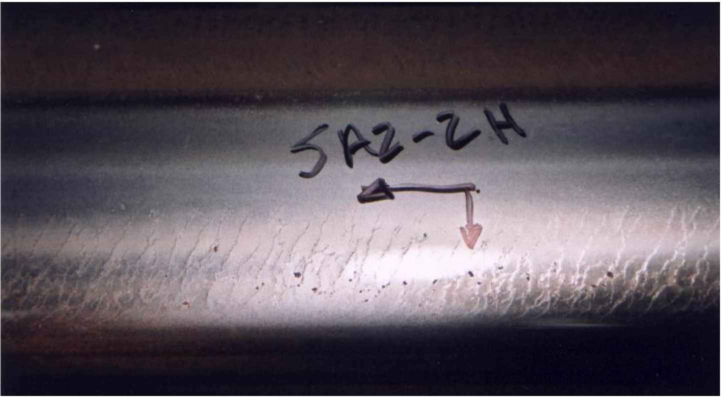
Wrong Profile Combination?

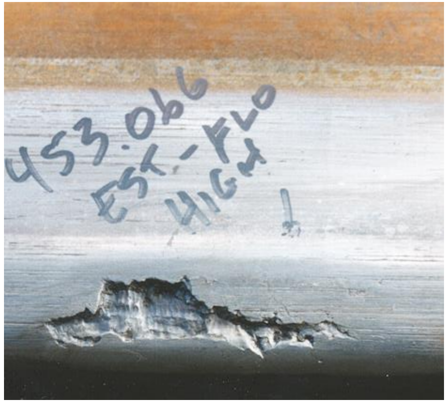
Wrong combination of W/R profiles can lead to high flange and gauge face wear

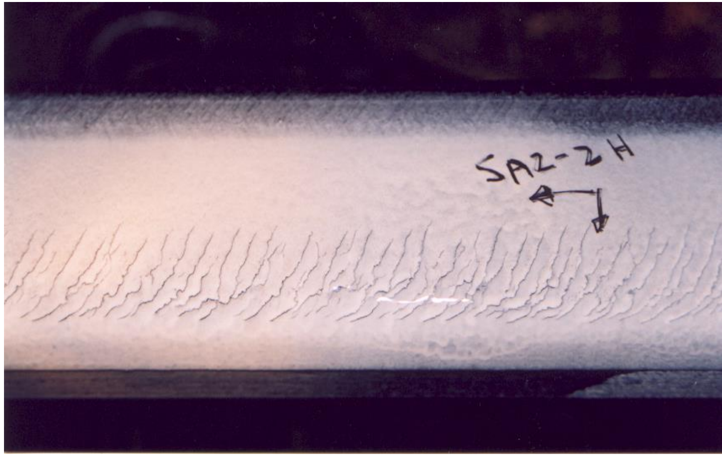


Wrong Profile Combination?

Wrong combination of W/R profiles can lead to rail (sub)surface damage

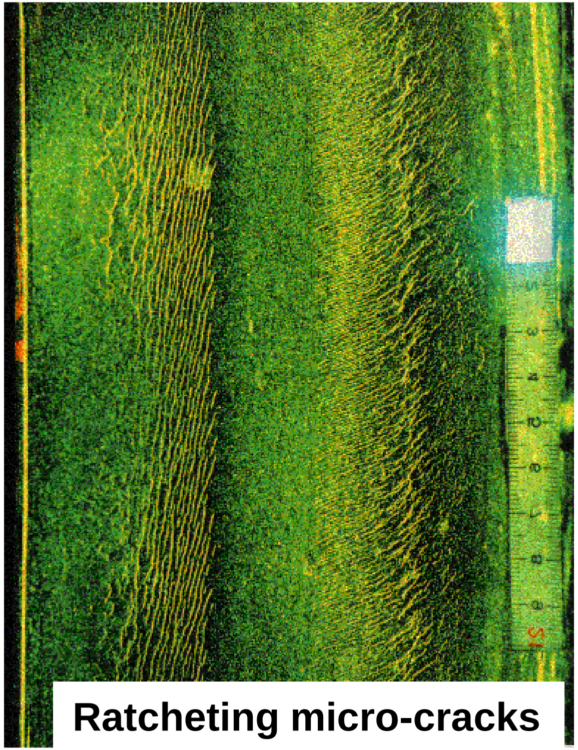






Wrong Profile Combination?

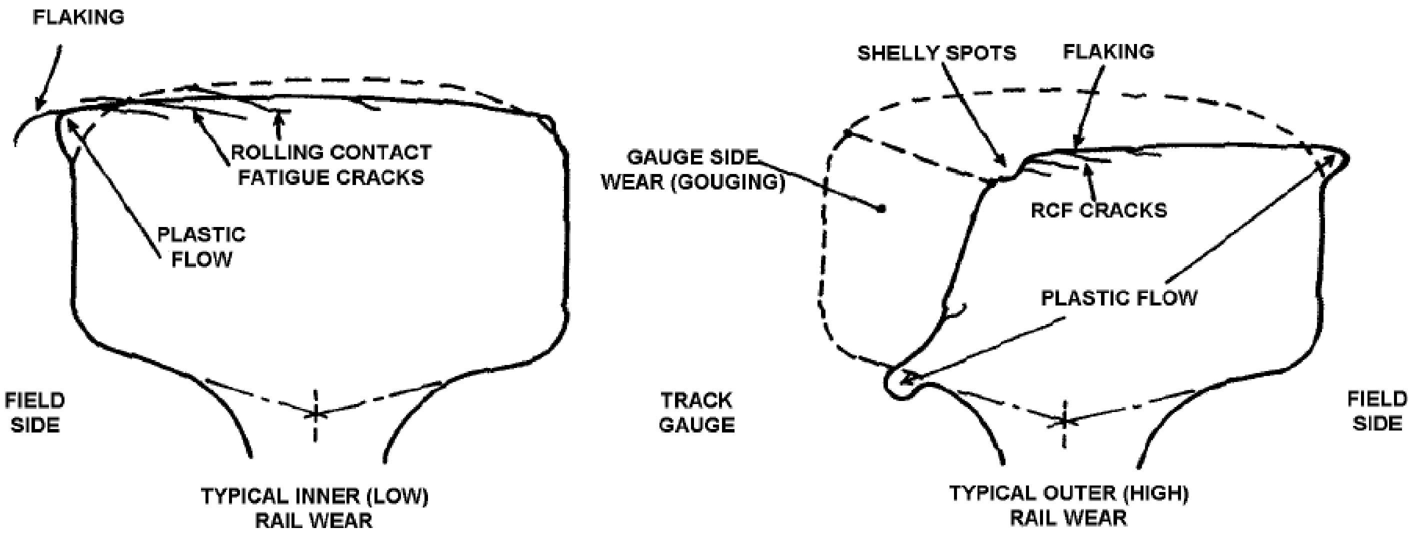
Wrong combination of W/R profiles can lead to wheel surface damage



Ratcheting micro-cracks

Fully shelled wheel

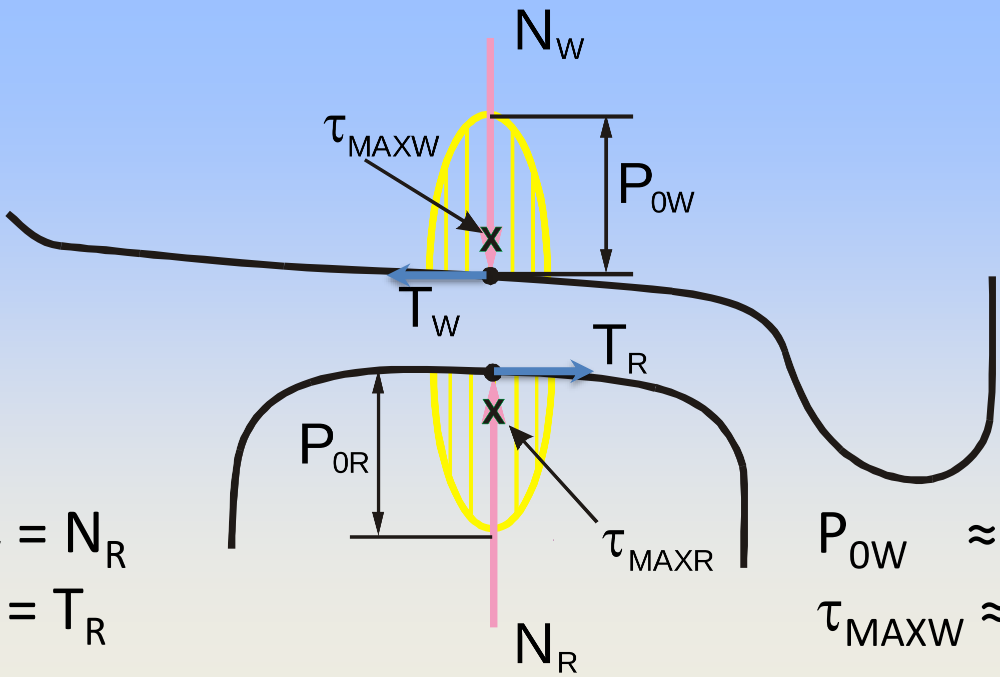
Wear and RCF Damage



Why Manage W/R Profiles?

- Each wheel rail system is unique due to its traffic mix, prevailing bogie suspension and distribution of track curvature – one combination of wheel and rail profiles does not fit all systems
- The choice of available new wheel and rail profiles can reduce or hasten wear, RCF and development of corrugations
- Optimizing and maintaining wheel/rail profiles by periodic re-profiling extends life, reduces vehicle and track maintenance and maintains vehicle stability

W/R Contact Points are Mirror Images



$N_W = N_R$

$T_W = T_R$

$P_{0W} \approx P_{0R}$

$\tau_{MAXW} \approx \tau_{MAXR}$

The Impact of Profiles

- Fatigue (of wheels and rails)
  - rail: 2.2 to 4 million cycles/ 100 MGT
  - wheel: 56 million cycles / 100,000 miles
  - controlled by grinding (rails), truing (wheels), milling (both)
- Wear (of wheels and rails)
  - also lubrication
- Stability

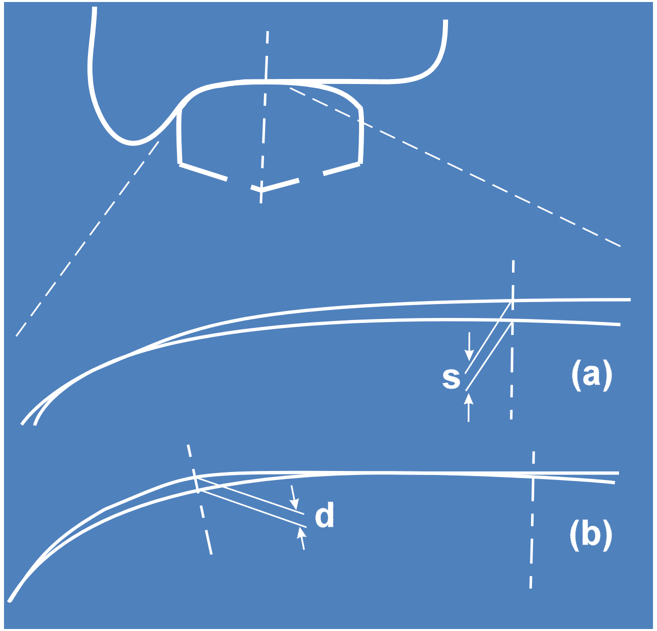
Freight vs High Speed

- Freight trains
  - heavy axle loads (35 kip)
  - slow (30-60 mph)
  - runs under-balance in mixed traffic system
  - relatively flexible bogies
- High Speed
  - light axle loads (25/16 kip)
  - high speed (110 to 150 mph)
  - runs over-balance in mixed traffic operations
  - longer wheelbase, light and stiff bogies

Wheel/Rail Profile Design (the 5 C's)

- Conformality
- Contact Stress
- Conicity
- Curving
- Creepage

1. Conformality



closely conformal

0.1 mm (0.004”) or less

conformal

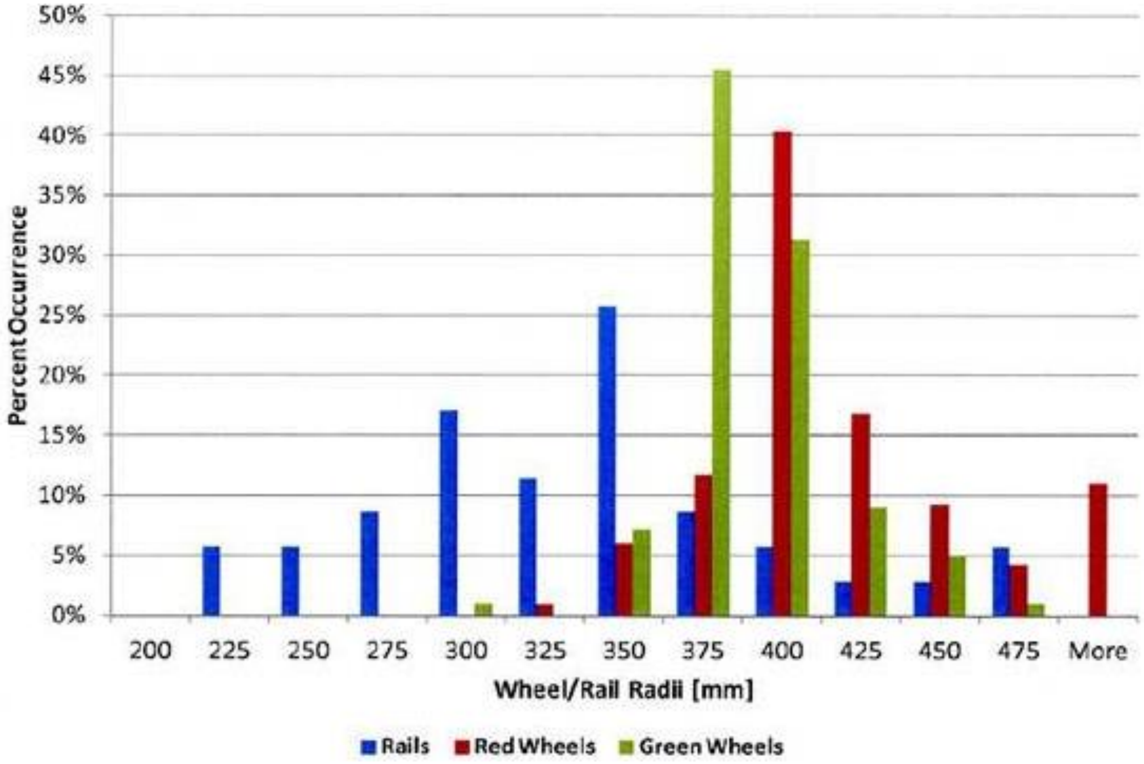
0.1 mm to 0.4mm

(0.004” to 0.016”)

non-conformal

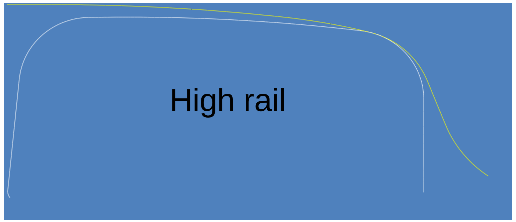
0.4 mm (0.016”) or larger

Conformality on Tangents

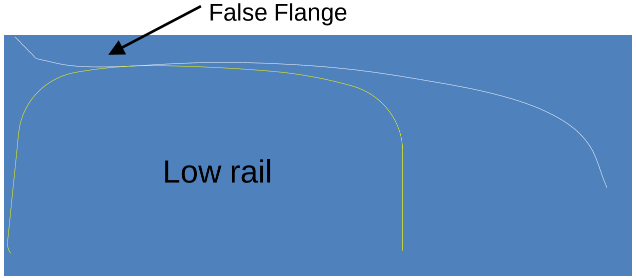


2. Contact Stress

- Depends on
  - wheel radius
  - wheel load
  - wheel/rail profile
  - friction coefficient

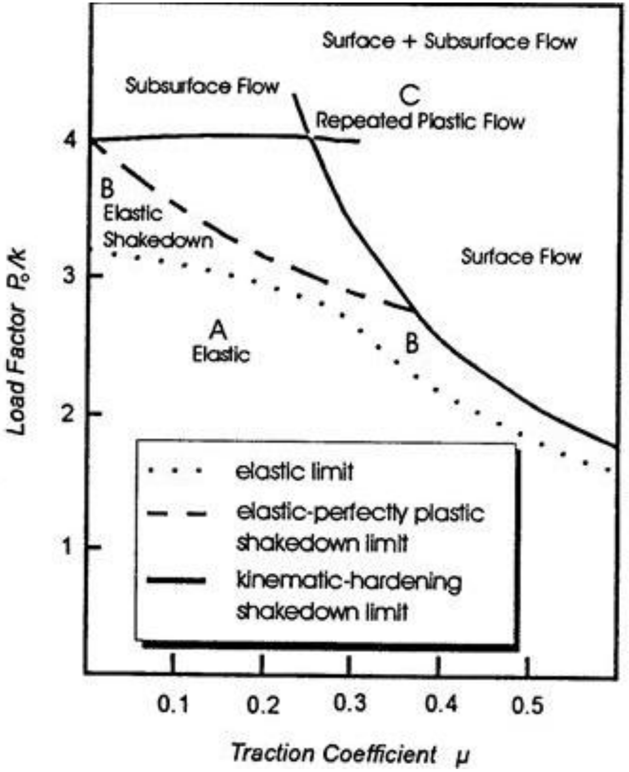


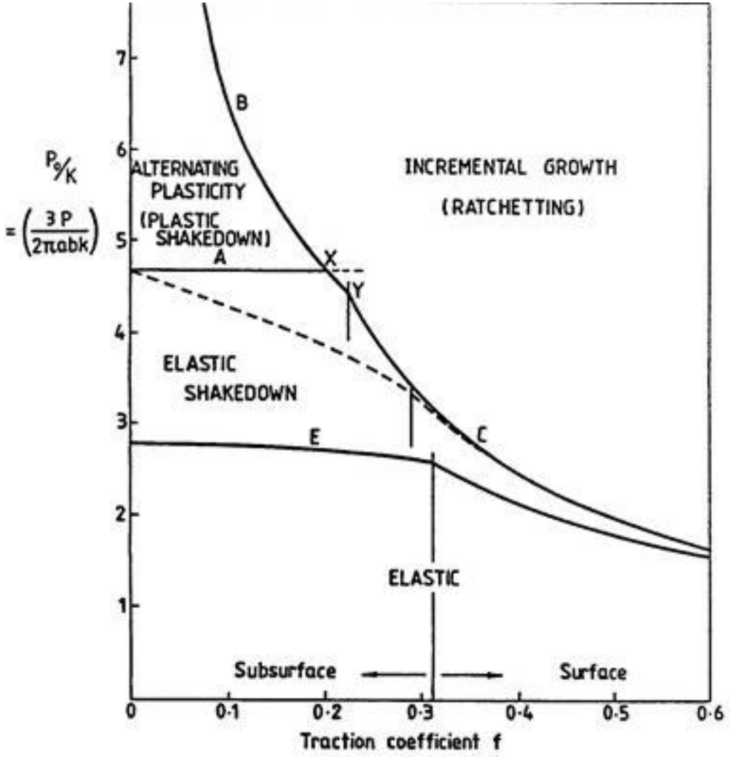
Non-conformal contact



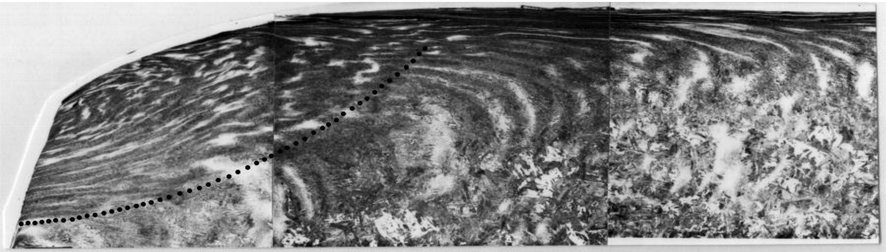
Hollow wheels

Shakedown


Surface + Subsurface Flow
Subsurface Flow
C
Repeated Plastic Flow
B
Elastic
Shakedown
Surface Flow
A
Elastic
B
elastic limit
elastic-perfectly plastic
shakedown limit
kinematic-hardening
shakedown limit
Load Factor P_o/k
Traction Coefficient μ
0.1
0.2
0.3
0.4
0.5
1
2
3
4

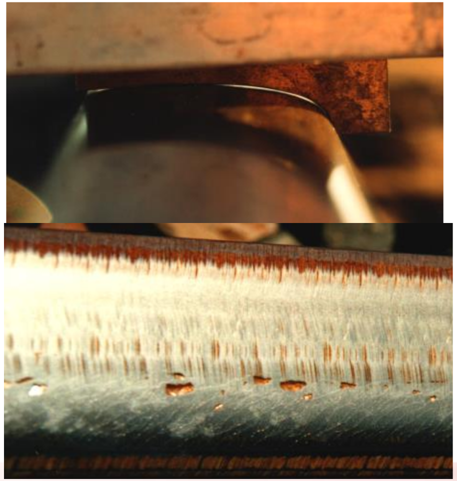

P_o/K
$= \left(\frac{3P}{2\pi abk}\right)$
B
ALTERNATING
PLASTICITY
(PLASTIC
SHAKEDOWN)
A
X
Y
INCREMENTAL GROWTH
(RATCHETTING)
ELASTIC
SHAKEDOWN
E
C
ELASTIC
Subsurface
Surface
Traction coefficient f
0
0·1
0·2
0·3
0·4
0·5
0·6

Excessive Contact Stress



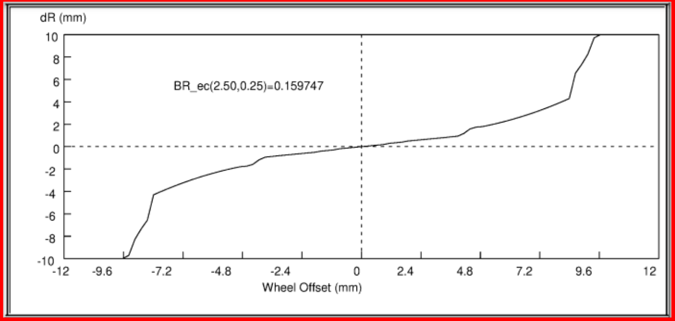
Gage corner collapse

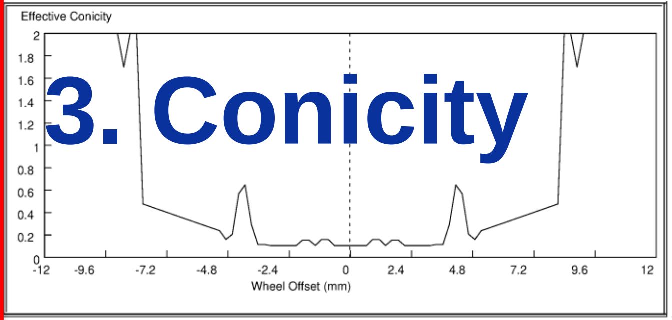
Cracked high rail



Concave low rail

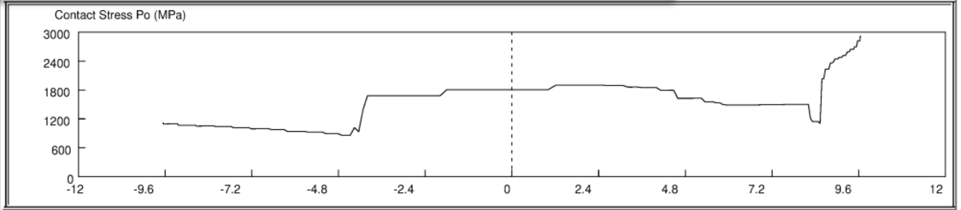
3. Conicity

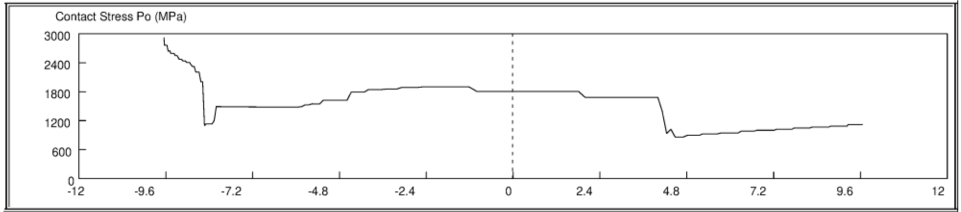


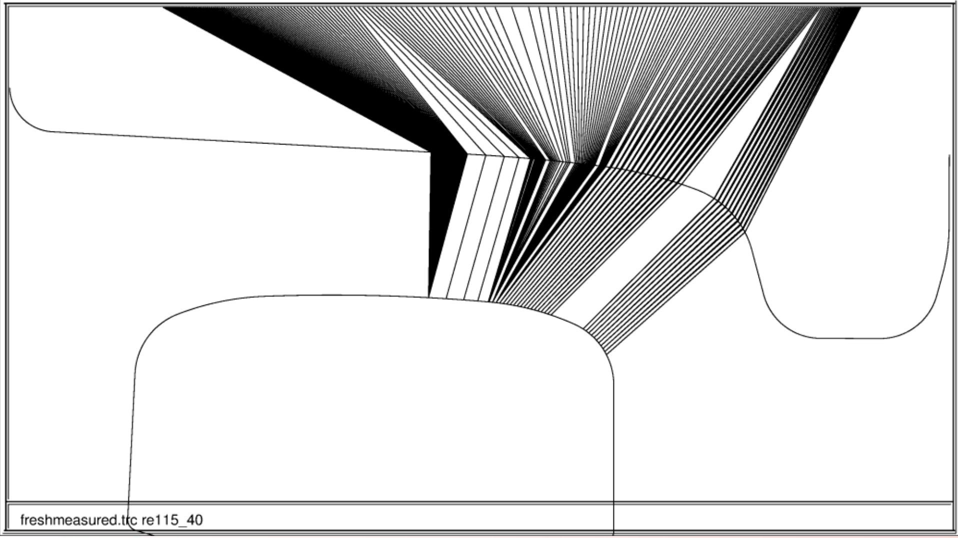


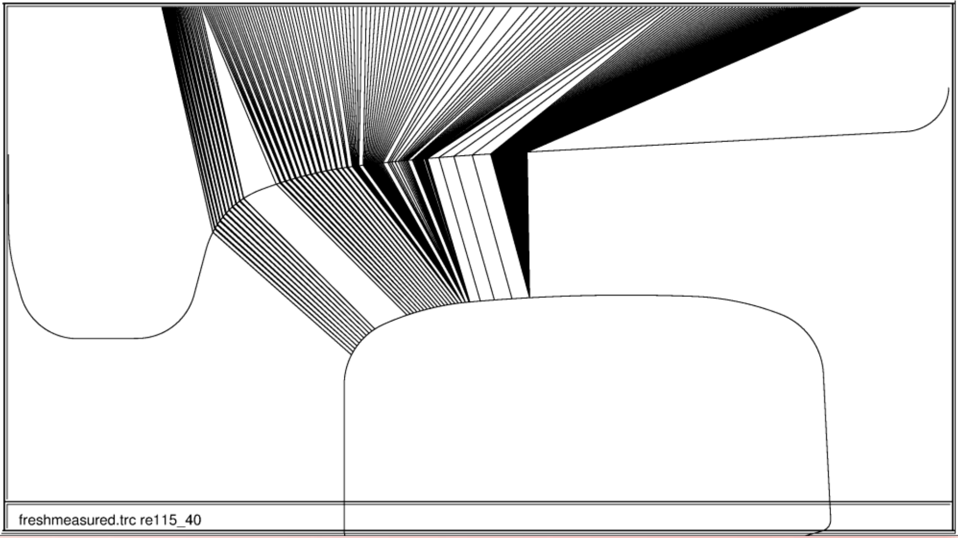
Input/Output Values

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





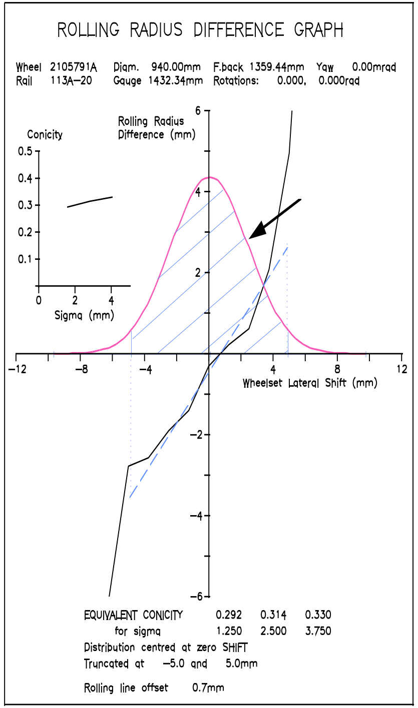




Conicity – the general case

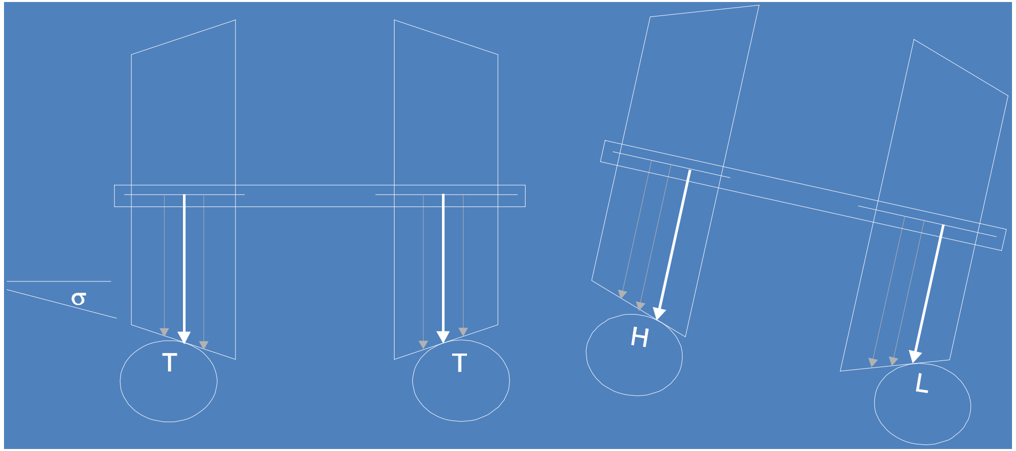
- British Rail derivation

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



4. Wheelset Curving

Rolling radius difference achieved by conical wheels in curves
Also by using asymmetric rail profiles



T: tangent   H: high rail   L: low rail

Rolling Radius Difference

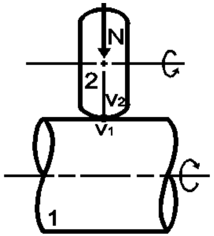
- not enough (insufficient):
  - poor steering, flanging, wear, noise
  - e.g. new wheel on worn high rail
- just enough:
  - perfect steering, free rolling
  - e.g. asymmetric grinding + steered bogies
- too much (excessive):
  - mild curves - to overcome suspension resistance
  - yields longitudinal creep forces

Rolling Radius Difference (ΔR)

Curve R [m]	Curve R [ft]	Curvature (degree)	dR [mm]
1750	5741	1	0.36
875	2871	2	0.73
580	1903	3	1.10
440	1444	4	1.45
350	1148	5	1.82
290	951	6	2.20
250	820	7	2.55
220	722	8	2.90
195	640	9	3.27
175	574	10	3.64
150	492	12	4.25

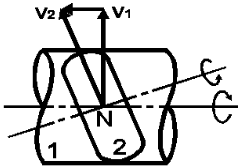
Wheel radius = 14.5” (0.3683 m)
Gauge = (1680+50)mm = 68-1/8”

5. Creepage (slip)



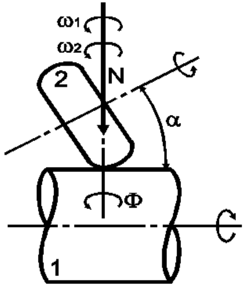
$$\Psi_x = \frac{V_1 - V_2}{\frac{1}{2}(V_1 + V_2)}$$

longitudinal



$$\Psi_y = \frac{V_1 - V_2}{\frac{1}{2}(V_1 + V_2)}$$

lateral



$$\Phi = \frac{\omega_1 - \omega_2}{\frac{1}{2}(V_1 + V_2)}$$

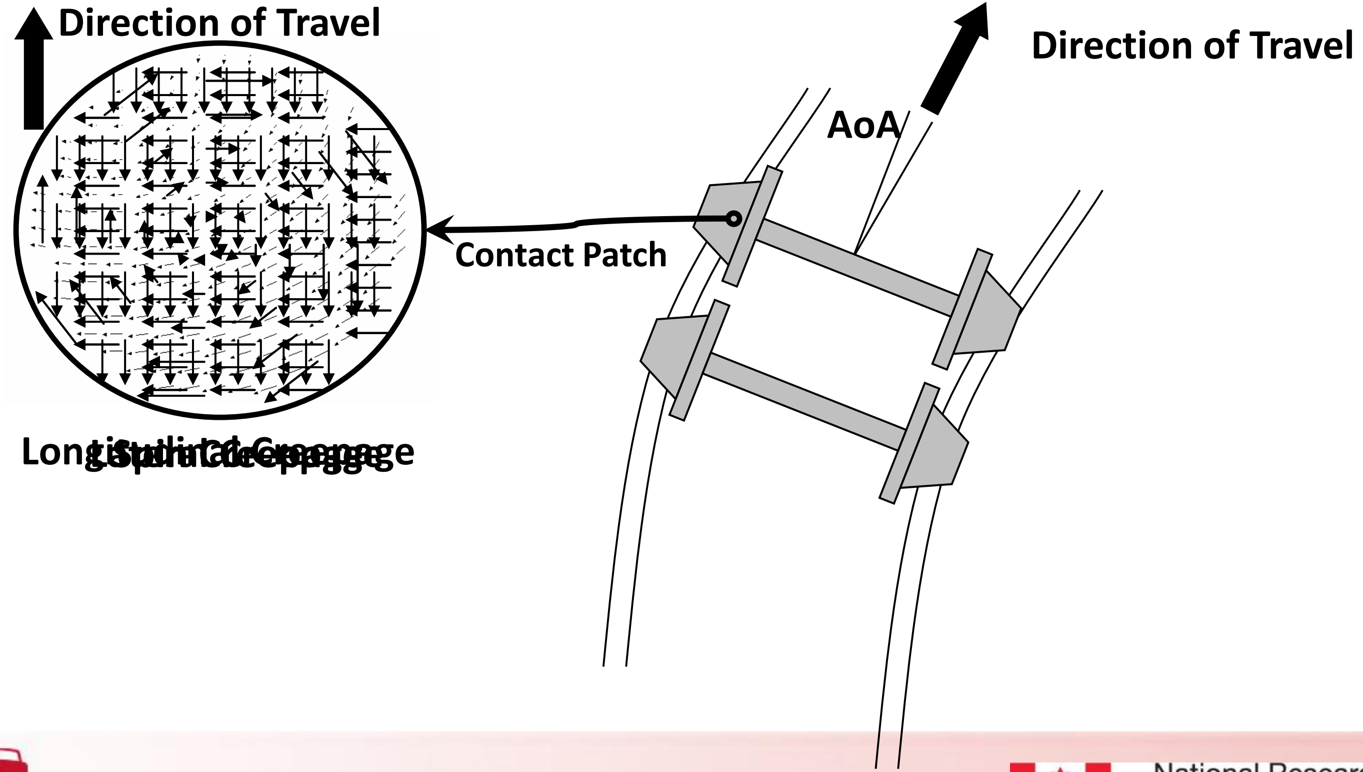
$$\omega_1 = 0$$

$$\omega_2 = \frac{V_2}{r} \cos\alpha$$

spin

Creepage: impacts:
- wear
- fatigue
- L/V forces
- traction/adhesion

Lateral Forces (Creep) in Curves

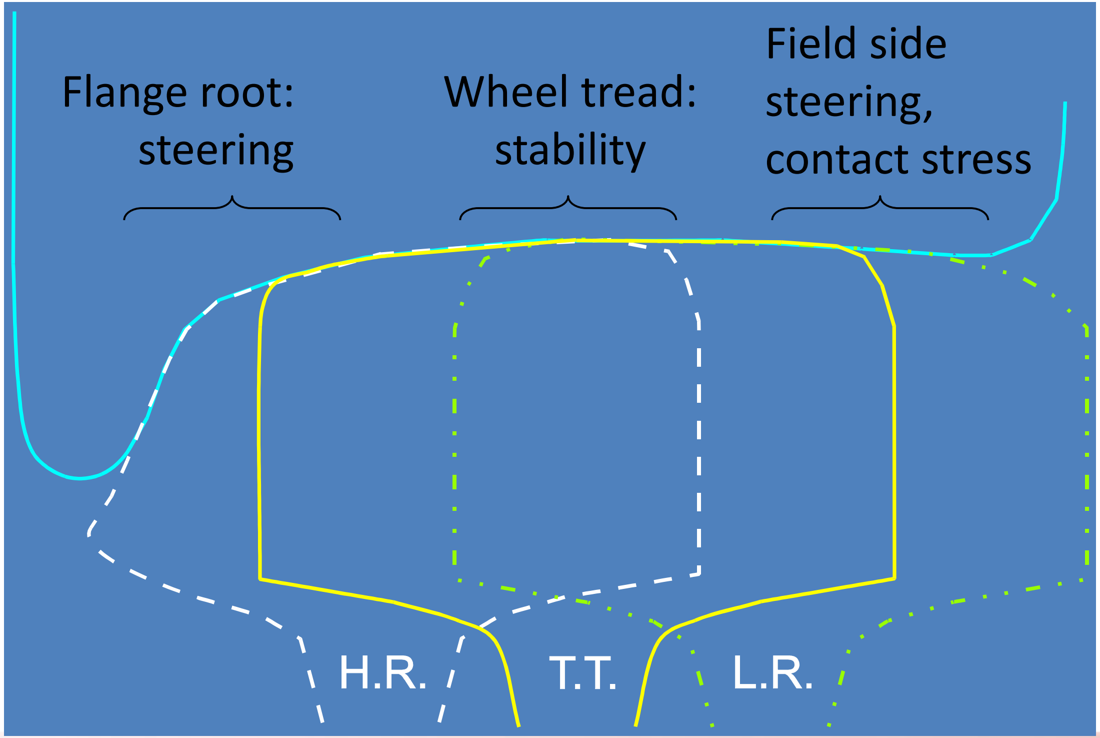


Design Objectives

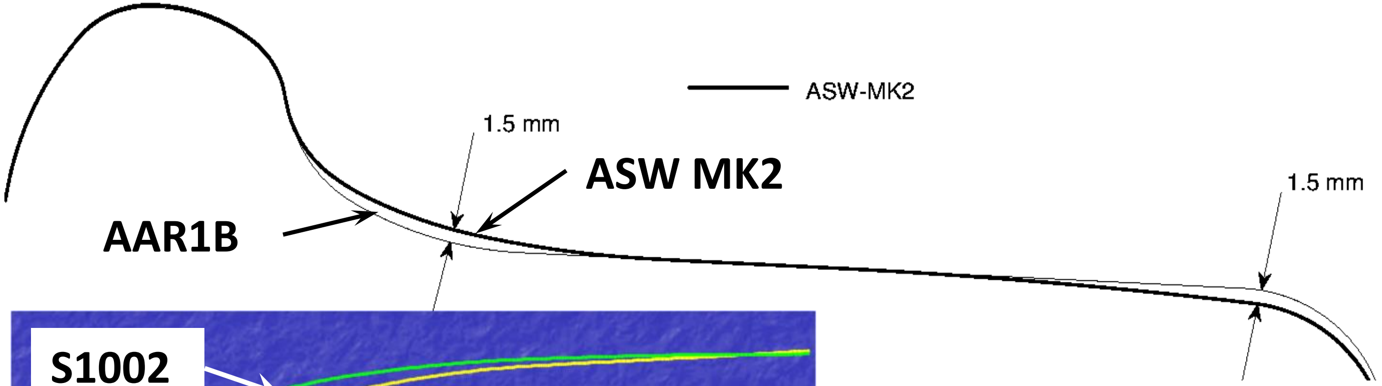
- High Speed
  - stability
  - noise
  - wear
  - corrugation
  - fatigue
- Heavy Haul
  - contact fatigue
  - (curve) wear
  - stability
  - corrugation
  - noise

Compromise design via pummelling

Wheel Profile Design



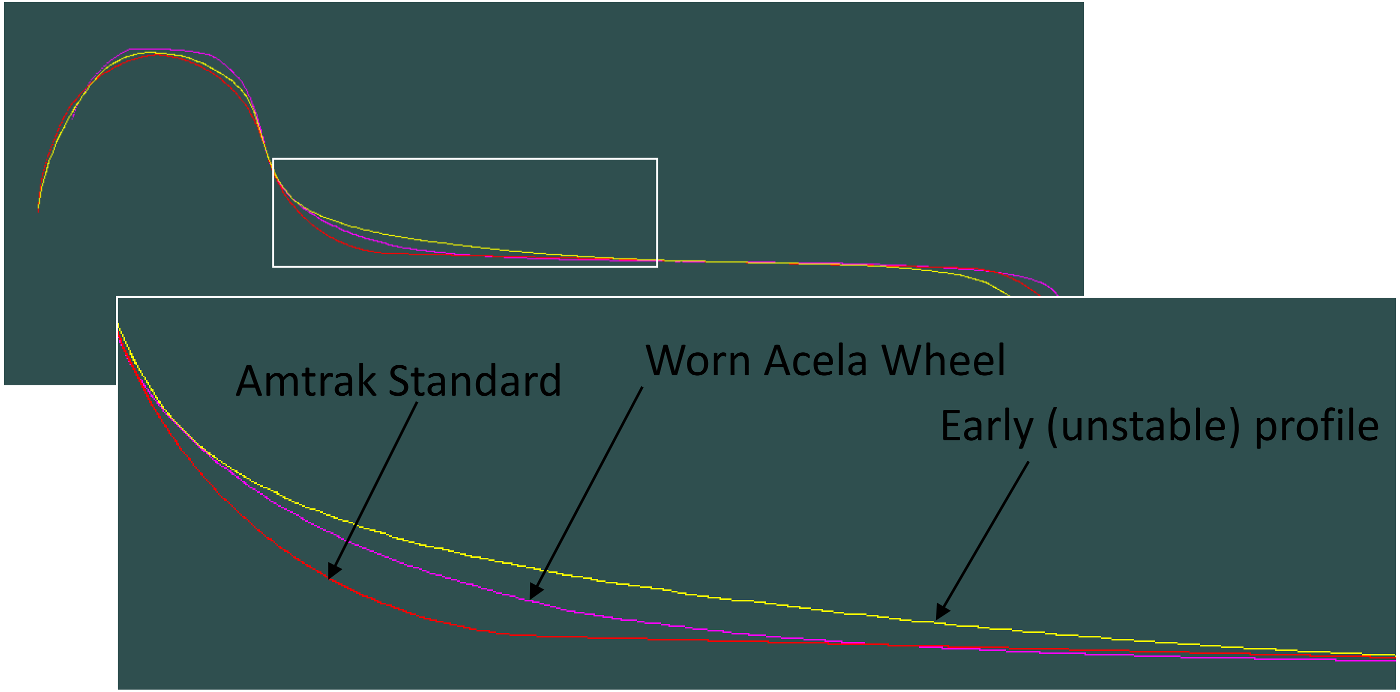
Example: ASW Profile Designs



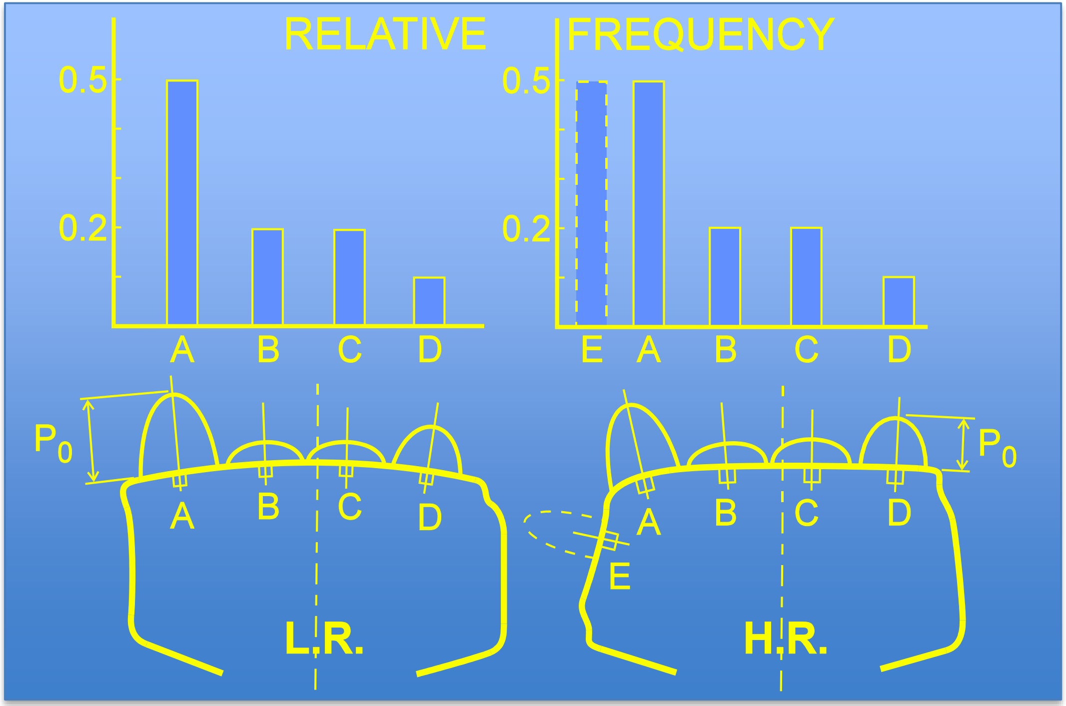
NRC-ASW wheel profile

"High conicity" Anti-Shelling Wheel (ASW) profile designs reduced RCF shelling by 18 – 60% on various railroads

Example: Acela Wheel Profile



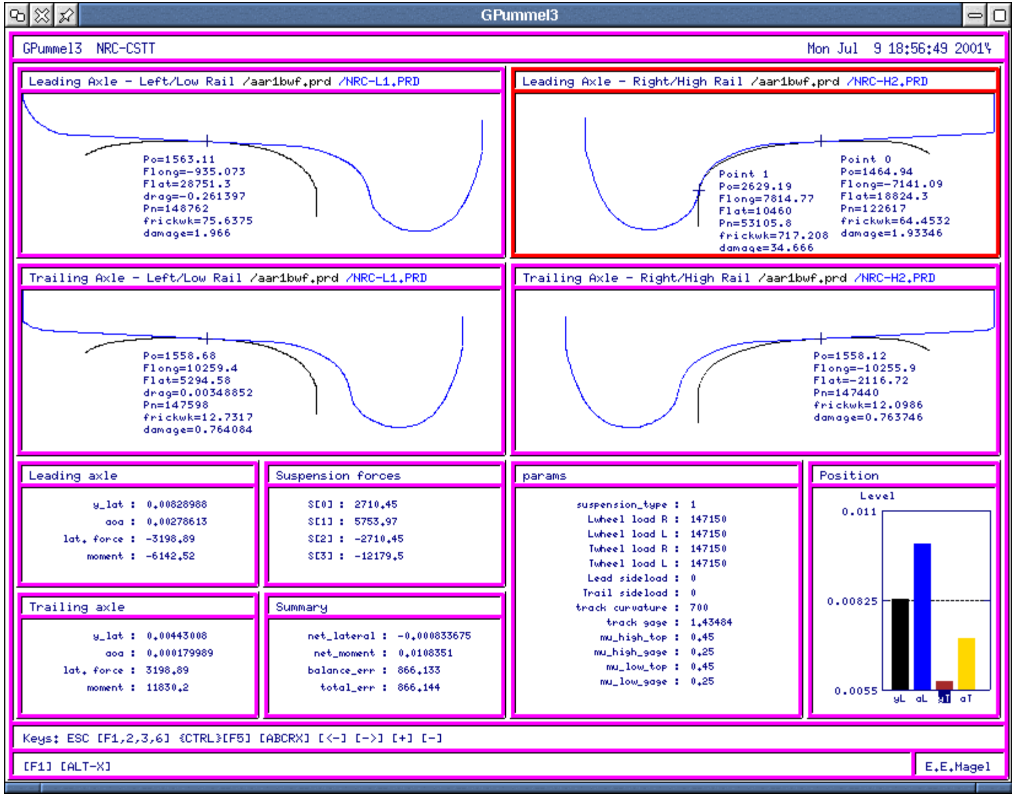
Rail Profile Design - Pummelling

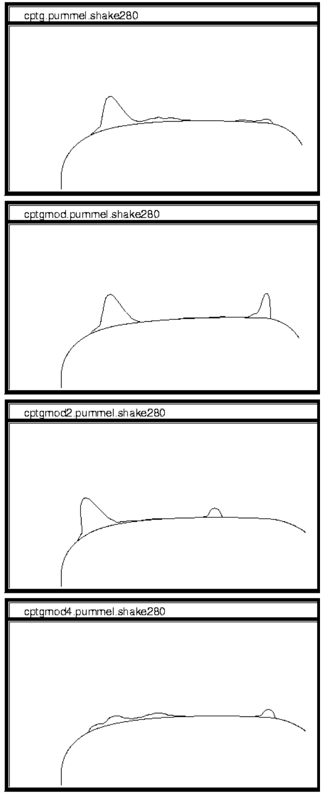


Pummelling Analysis

- 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 Tool





Looking Ahead…

- Smarter profile design tools
  - Define an objective function, tolerance, number of iterations permitted
  - Genetic algorithms
- Steels with increased damage/wear resistance
- Increased use of
  - flexible (yaw) trucks on freight
  - Steered trucks on transit
- Widespread use of friction management
- Route-specific rail profiles

Questions?