The universities' centre for railway systems research

Rail Research UK

Theme A: Engineering Interfaces

A5: Aerodynamics / Train system Interaction

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Project A5 Review

- **Lighter, high-speed trains face steadily increasing ratio of unsteady aerodynamic loads over inertia forces.**

- **Primarily due to quadratic scaling of aerodynamic loads with train speed.**

- **Not only for energy, but also for safety**

3 Types of aerodynamic forces

1. **Unsteady cross wind forces**
   - **Overturning risk**
   - Vehicle and load displacements
   - Excessive pantograph displacement
   - Contact wire displacement: risk of dewirement

Overturning due to CW forces

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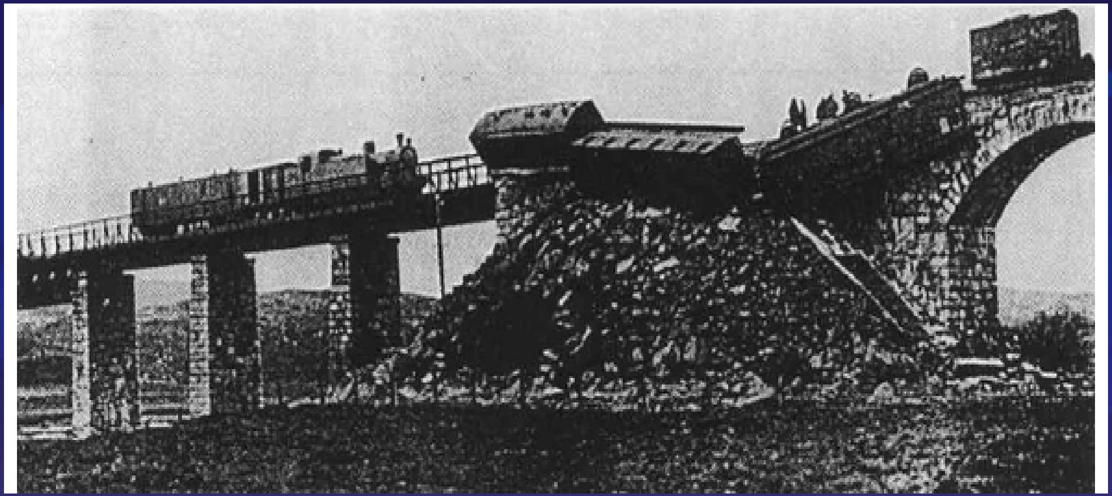

Dozen accidents since 1950 (Japan, Switzerland, Belgium)

Embankment

Open bridge

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2. Transient forces due to passing trains

- Transient loadings on train structural members
- Transient forces on pedestrians at platforms
- Reduced comfort?

Full scale experimental work

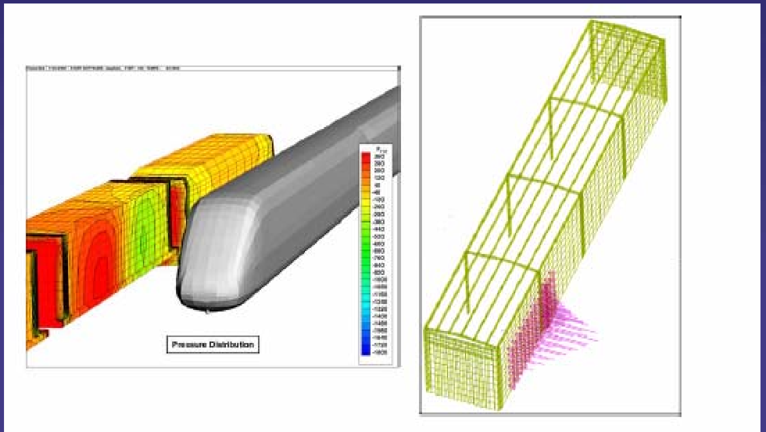

Figure 1: Panel method calculations of a freight train being passed by an ICE 2 (left); Finite element calculations of a pressure pulse passing a swap body (right)

Numerical CFD of passing trains

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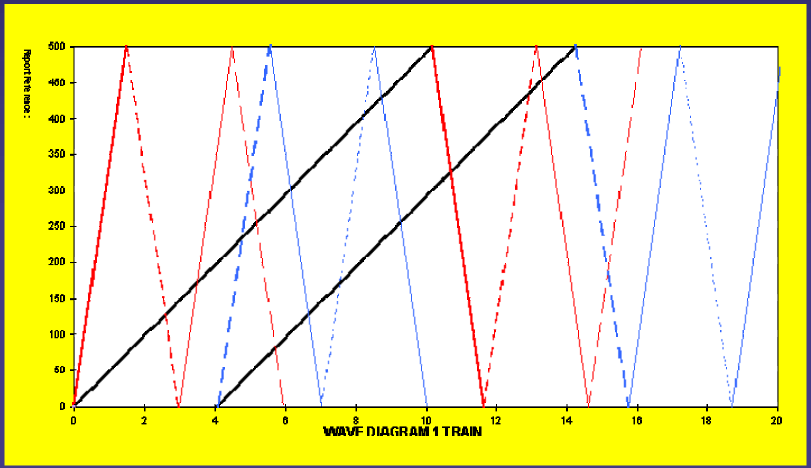
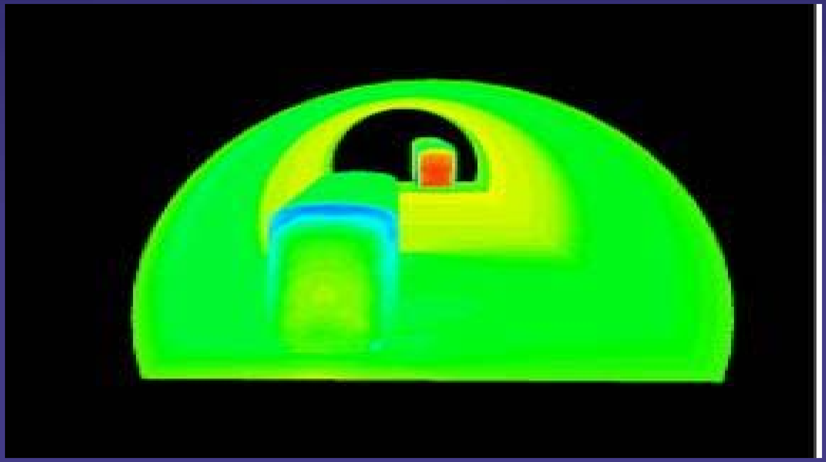
3. Tunnel transient forces

- We all feel changes in air pressure in a tunnel!
- Transient forces on structure from pressure pulses
- Ears pop!
- Reduced comfort



Reflected pressure waves



CFD of two trains inside a tunnel

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A5 Aims and objectives

1. Review & model unsteady/transient aerod. forces for UK rail
2. Develop analytical/numerical formulations of such forces
3. Develop train dynamics model including aerodynamic forces
4. Investigate the effects for a variety of different CW speeds, train speeds, track conditions, etc

A5: Current work

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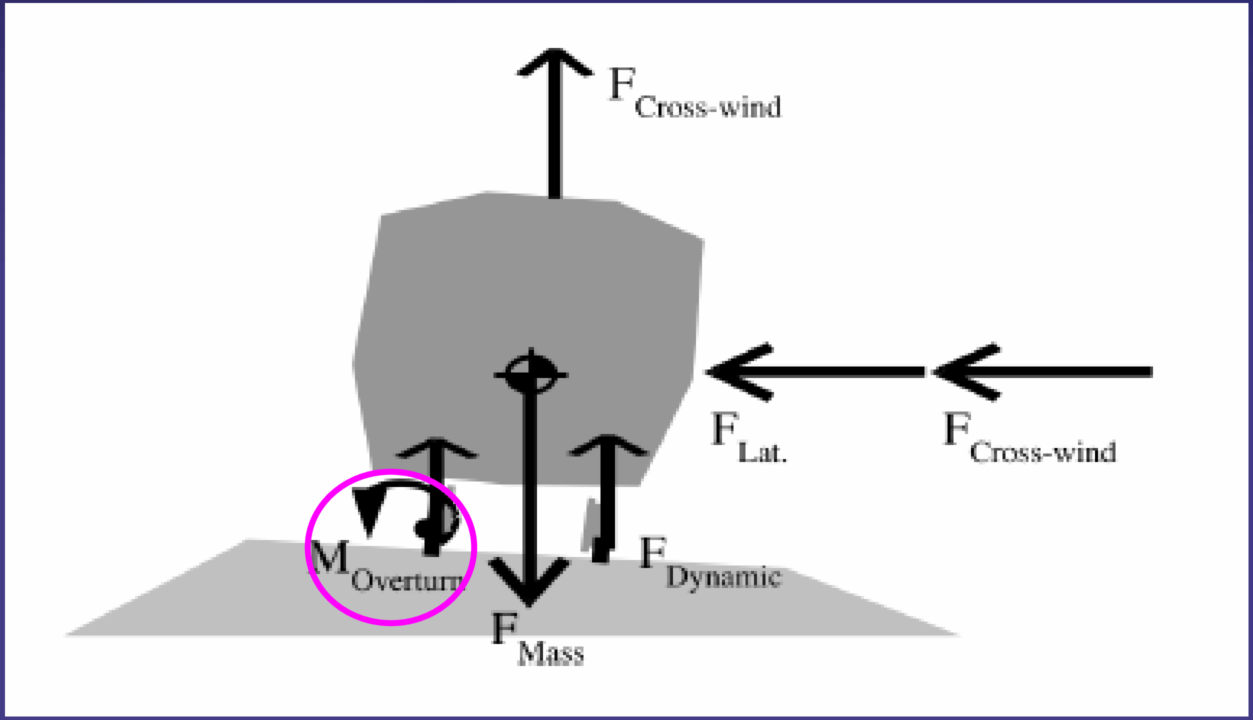
- Model for CW forces/moment on a moving train is developed
- Unsteady forces/moment used in a **VAMPIRE** train model
- **RSSB Pantograph Sway**, with Interfleet Technology, Derby



UoB and MMU (Class 365)

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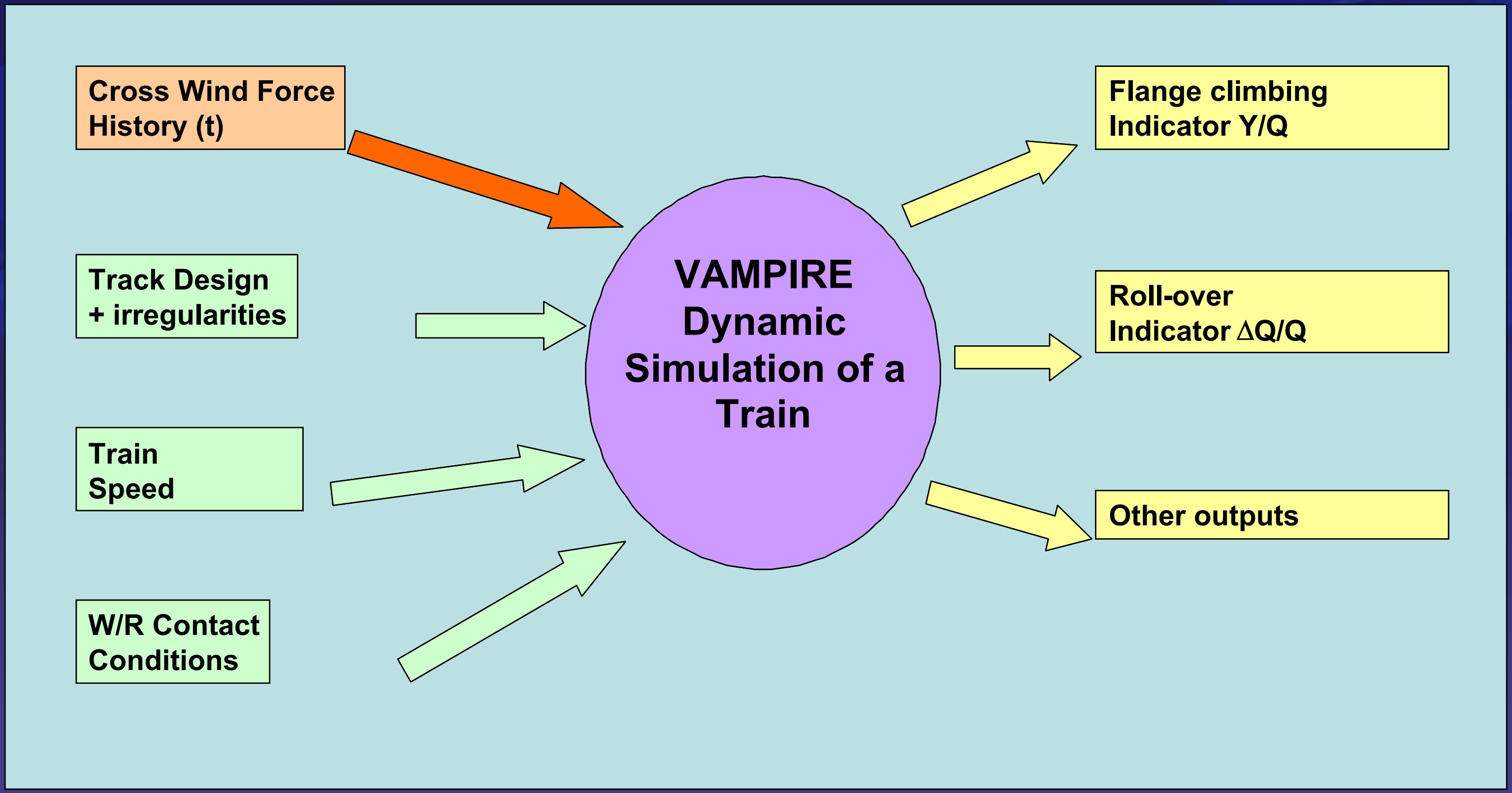

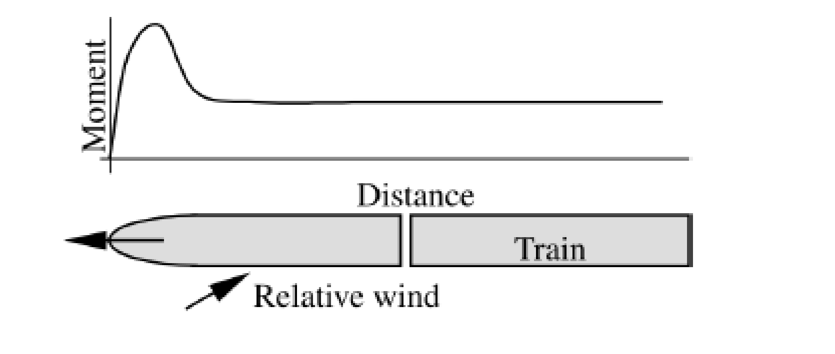

Leading car is most affected by CW

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Steps in building model for CW forces/moments

Turbulent cross wind simulation

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Wind tunnel test for a static scaled model

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Aerodynamic admittance functions

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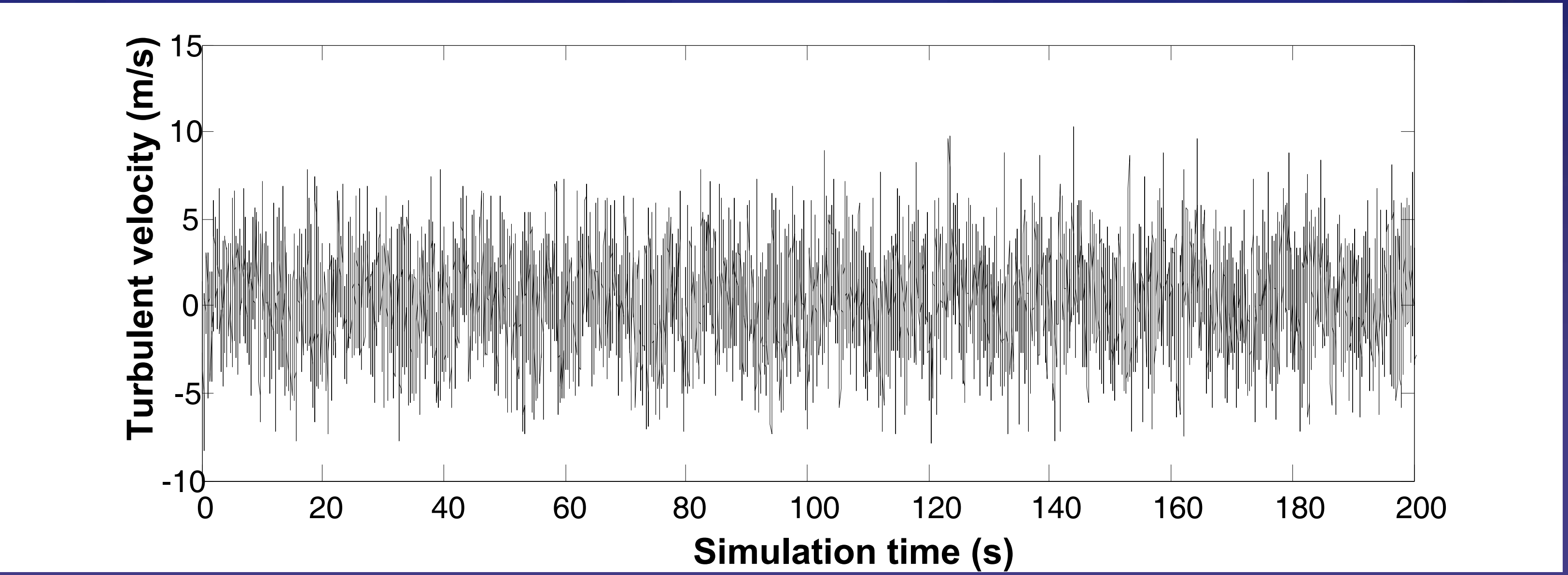
Unsteady forces and moment

Turbulent CW velocity simulation

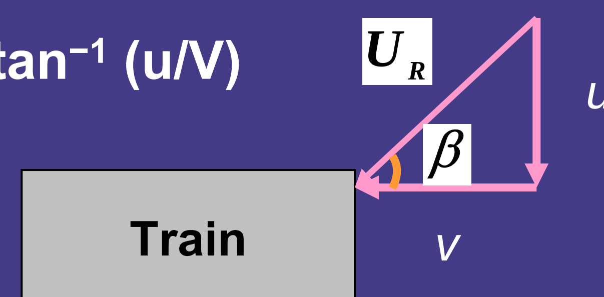
- Turbulent CW velocity field simulated via a spectral approach



Wind tunnel tests on a scaled model

Class 365 EMU 30th scale model. Forces measured at several yaw angles

β = $\tan^{-1}$ (u/V)



$$U_R = \sqrt{u^2 + V^2}$$

$$\boldsymbol{u = U + u'(t)}$$

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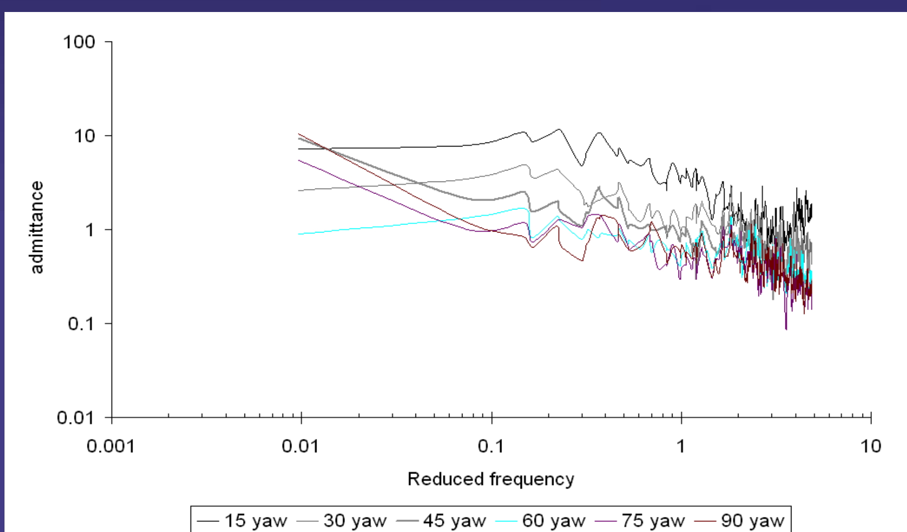
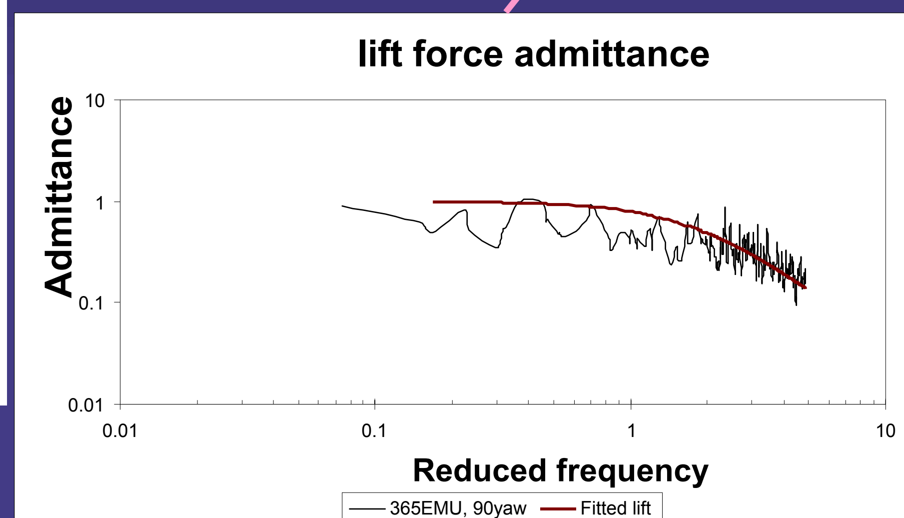
Aerodynamic admittance function

$$|X_F(n)|^2 = \frac{4S_F(n)}{(\rho A C_F)^2 \bar{U}^2 S_U(n)}$$

$$|X_F(n)|^2 = \frac{1/k}{\left\{\left[1-\left(\frac{\bar{n}}{\bar{n}'}\right)^2\right]^2 + \left[2\xi\frac{\bar{n}}{\bar{n}'}\right]^2\right\}^{1/2}}$$





Weighting functions

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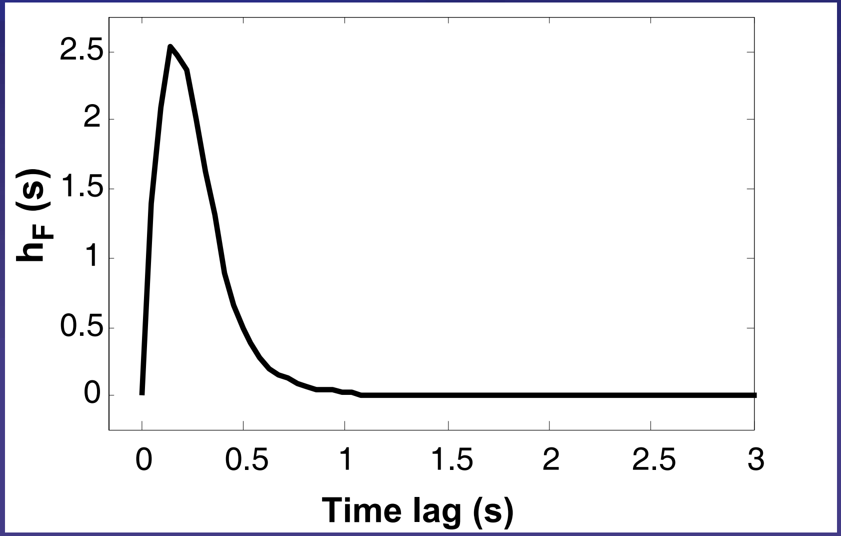
$$h_F(\tau) = \left(2\pi \bar{n}'\right)^2 \left(\frac{U_R}{L}\right)^2 \tau \left[\exp^{\left(-2\pi \bar{n}' \frac{U}{L}\right)\tau}\right]$$

Time domain

$$\left|X_F(n)\right|^2 = \frac{1/k}{\left\{\left[1-\left(\frac{\bar{n}}{n'}\right)^2\right]^2 + \left[2\xi \frac{\bar{n}}{n'}\right]^2\right\}^{1/2}}$$

Frequency domain



$$F(t) = \bar{F} + F'(t) = 0.5\rho A C_F \bar{U}_R^{\,2} + \rho A C_F \bar{U}_R \int_0^\infty h_F(\tau)\, u'(t-\tau)\, d\tau$$

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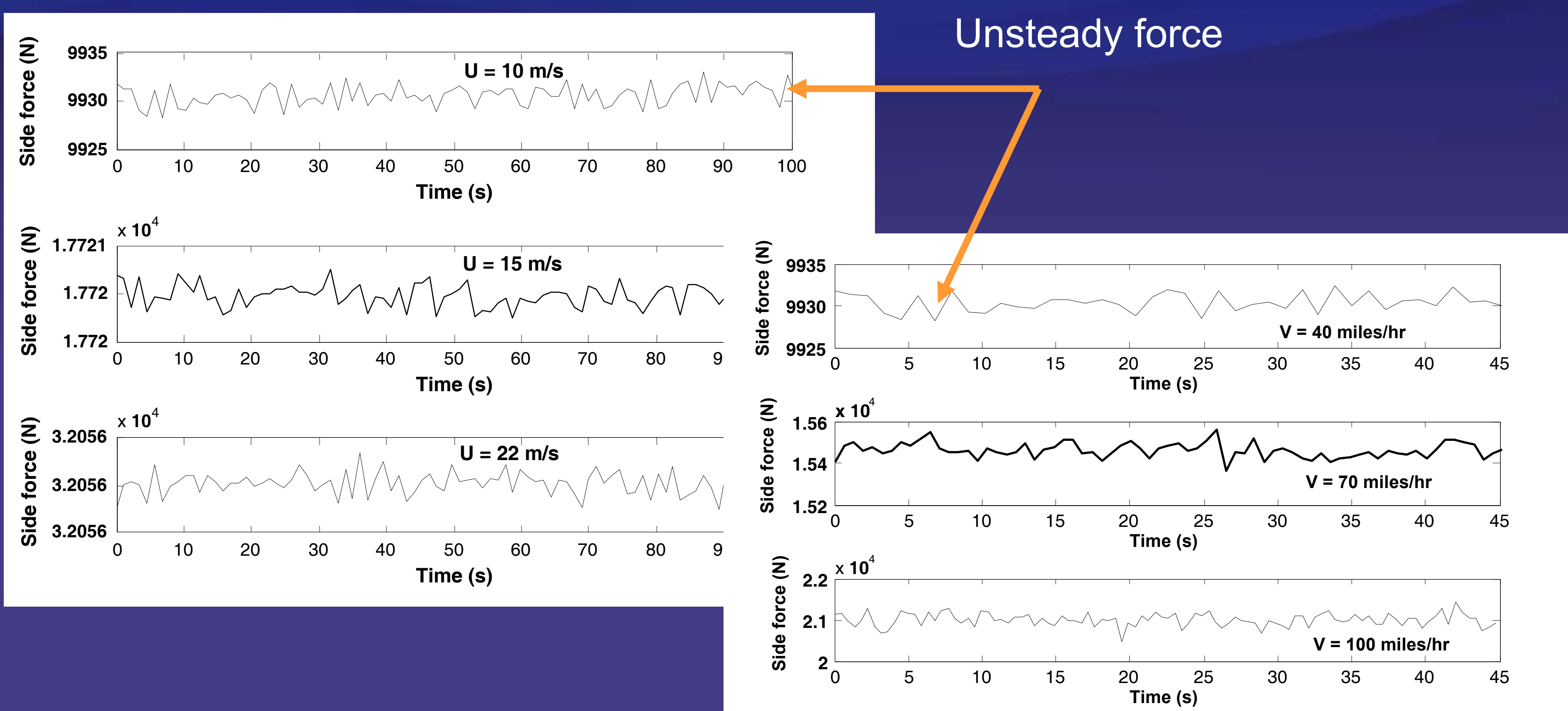
Effect of mean CW/train speeds

$$F(t) = \overline{F} + F'(t) = 0.5\rho A C_F \overline{U}_R^{\,2} + \rho A C_F \overline{U}_R \int_0^{\infty} h_F(\tau) u'(t-\tau)\, d\tau$$



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Pantograph sway (with Interfleet)

- Objectives:

1. Compute **pantograph sway:** different CW
2. Compare with current regulations/standards
3. Offer recommendations when necessary

Pan displacement due to CW

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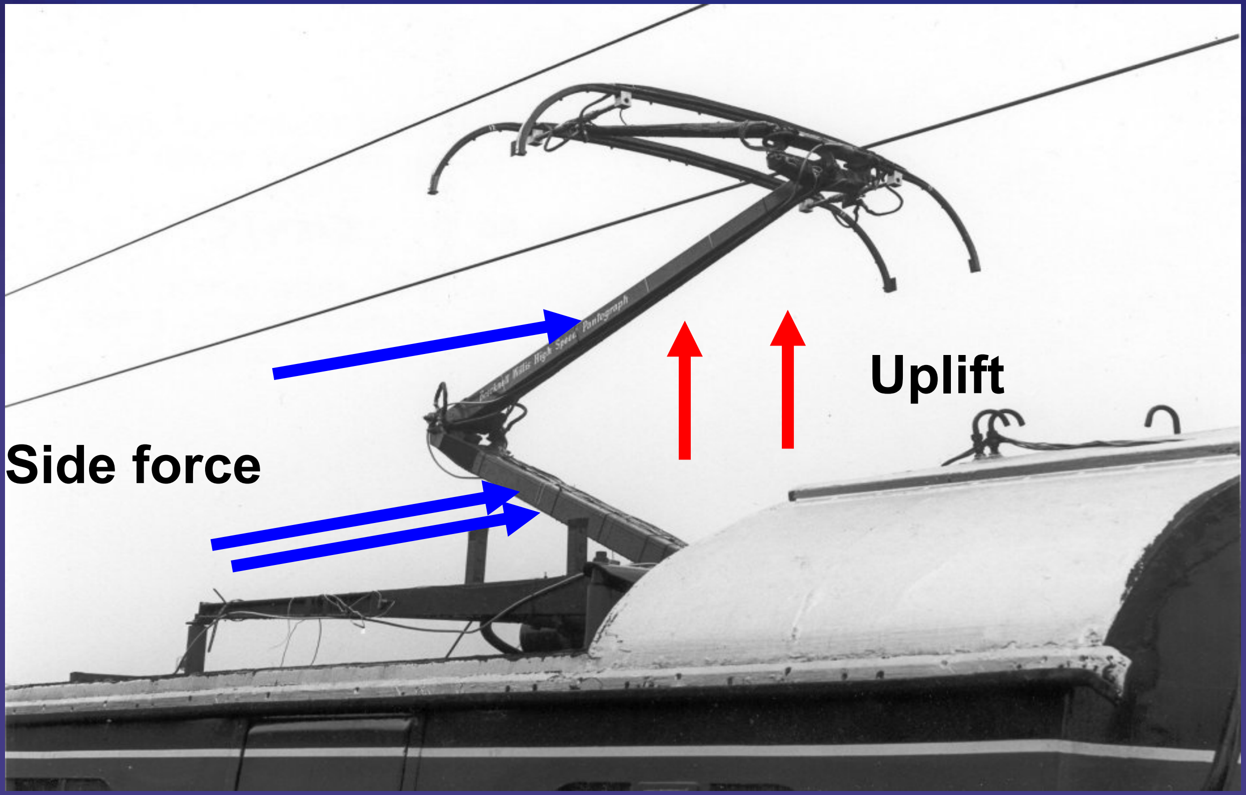
- Excessive pan displacements can cause dewirement
- Excitations of the pan's suspension modes due to CW?



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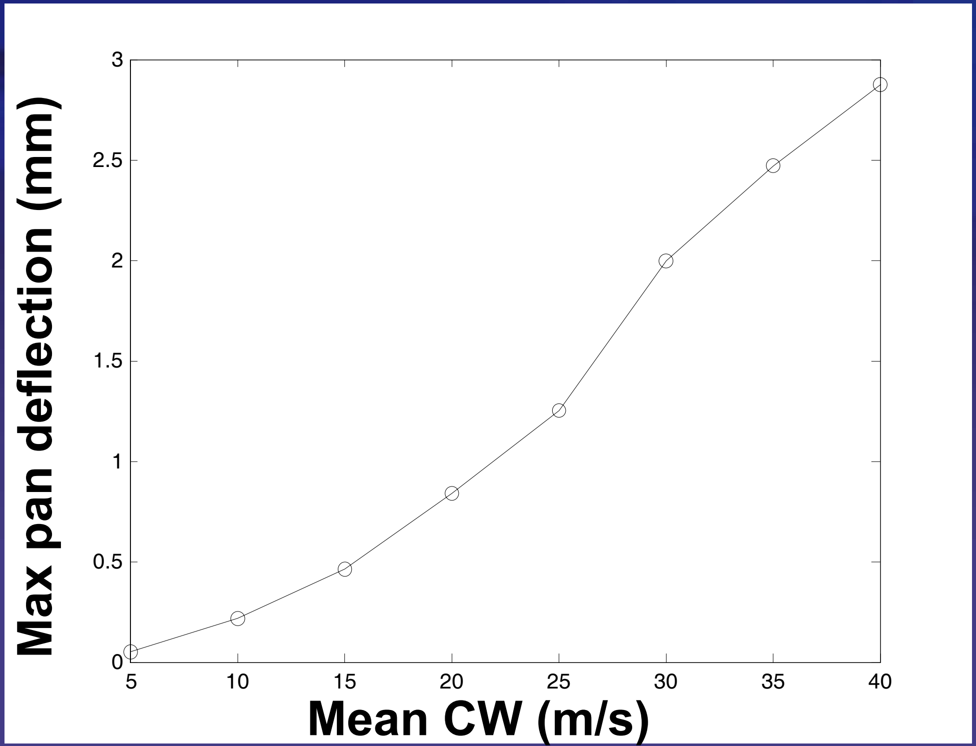
Pan maximum static deflection history

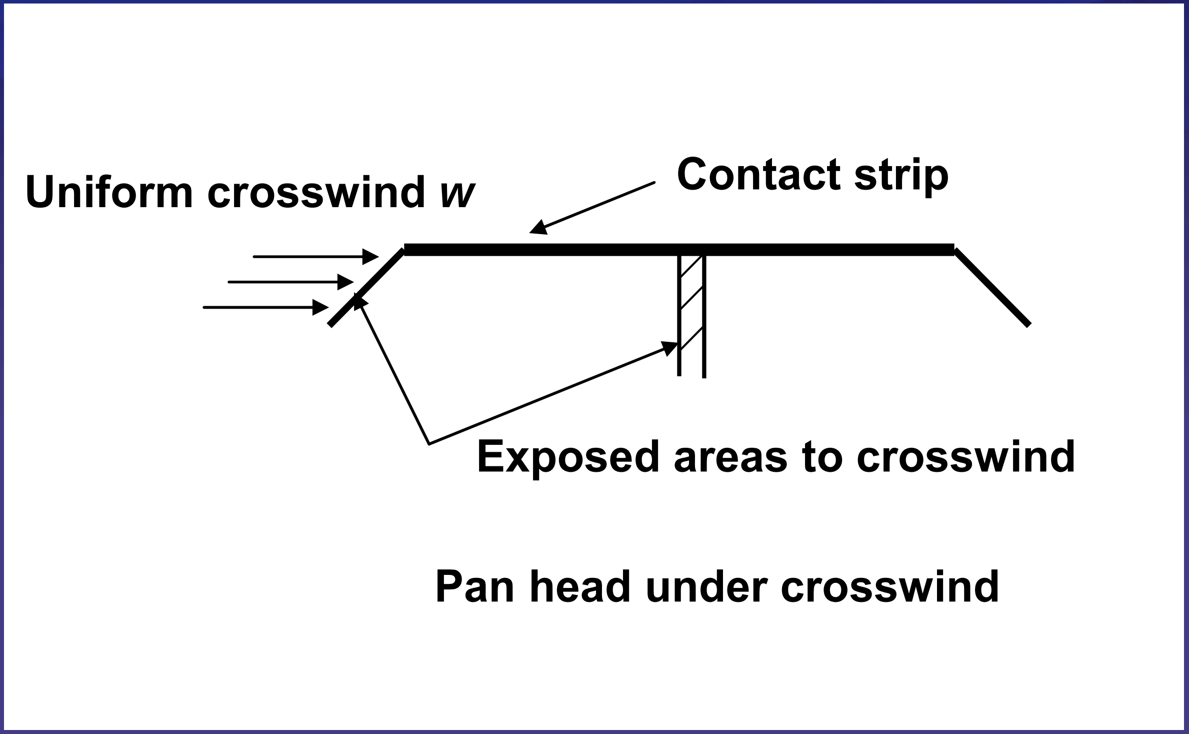


- **Pantograph deflection increases with CW speed.**
- **Deflections negligible**

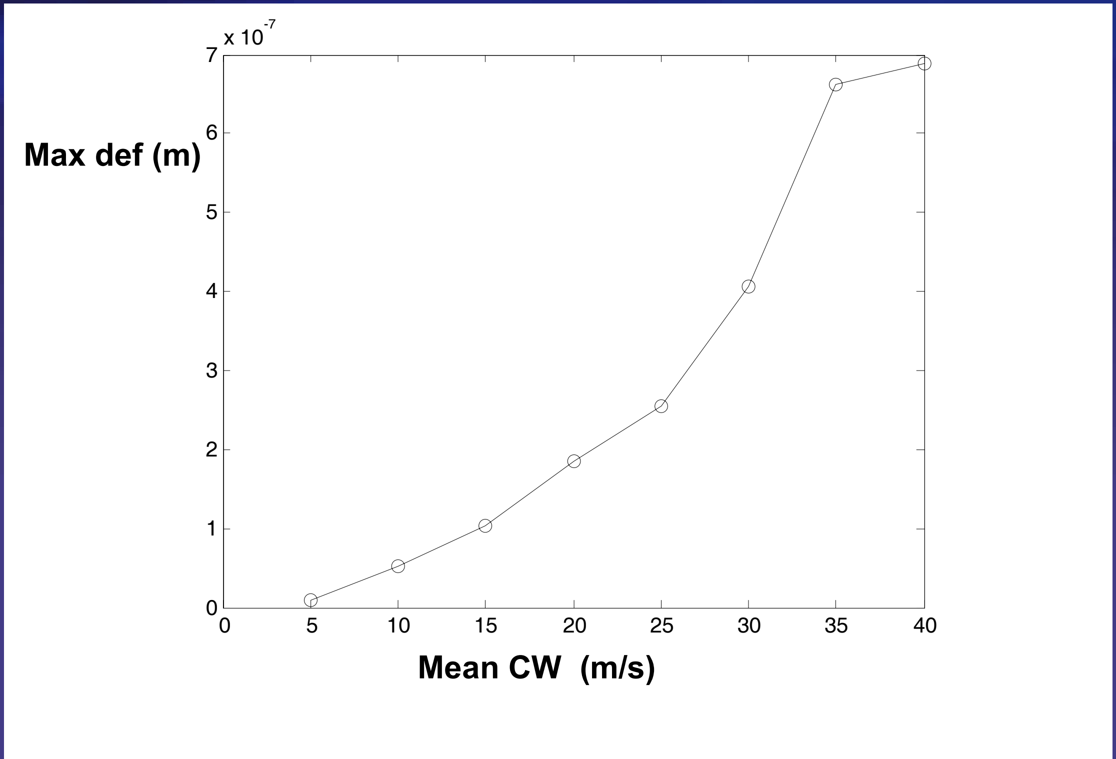
Static pan-head deflection

Model the curved section as cantilever beams under external uniform loading

$$y_{max} = \frac{wl^4}{8EI}$$



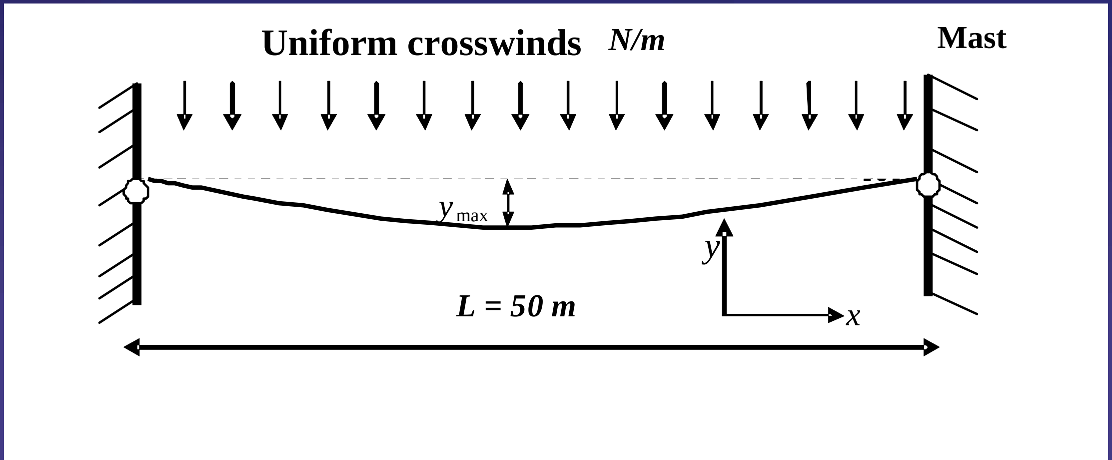
Max pan-head deflection due to CW



Pan-head deflection due to cross wind is **practically zero** even at highest U

Contact wire displacement due to CW

- **Contact wire moves** with cross winds
- The wire reacts to turbulent length scales of ~20m so wire deflections are only due to mean wind speeds, no turbulent effects included



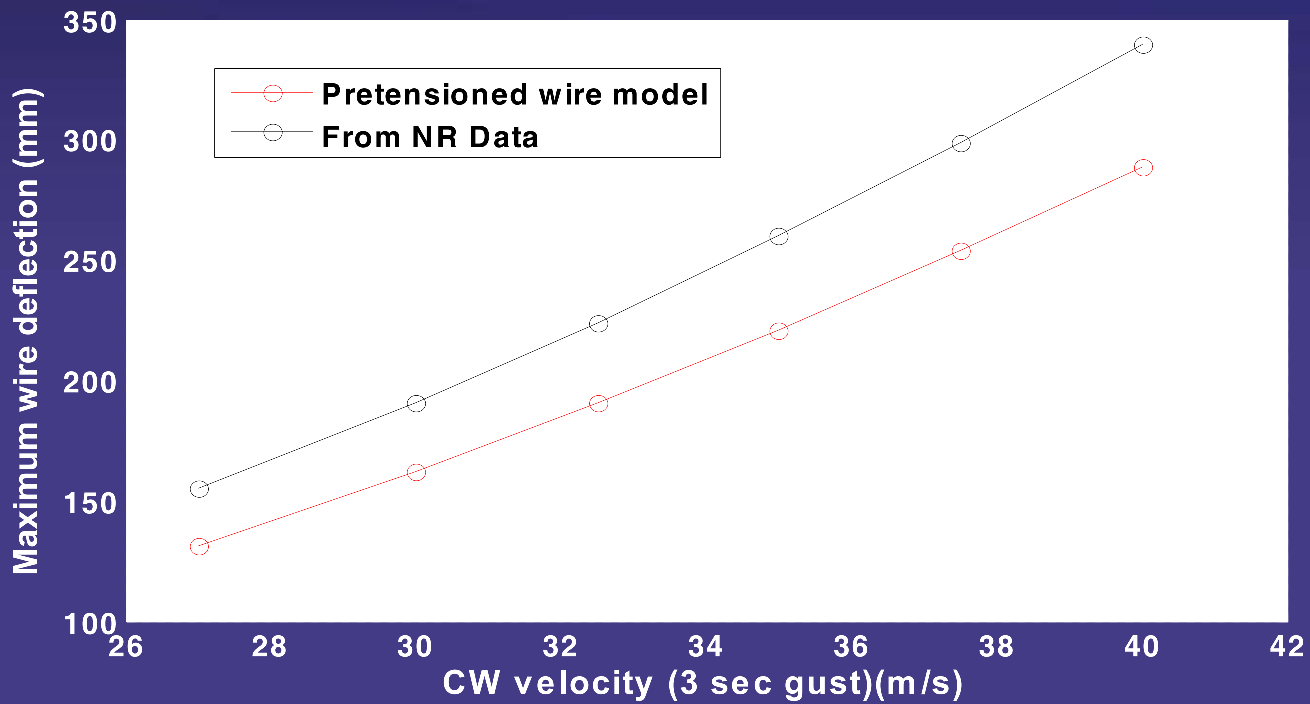
$$y_{max} = L\left(\frac{3Lw}{64EA}\right)^{\frac{1}{3}}$$

Maximum deflection a strong function of wire length

Maximum deflection of contact wire due to CW

Wire movements (<u>150-350 mm</u>) compared to the pan (1~6 mm)

No stiffening effects of droppers, the catenary wire on the contact wire



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Future work/prospects

- Improve wind simulation (more velocity components)
- Unsteady forces on Pendolino and Class 91 loco
- How overturning risk relates to train shape?
- Review & understand transient effects of passing trains and trains in tunnels; supply time histories to MMU
- In the long term, we need to study parameters like topography, infrastructure, train operation, meteorology (comprehensive view)