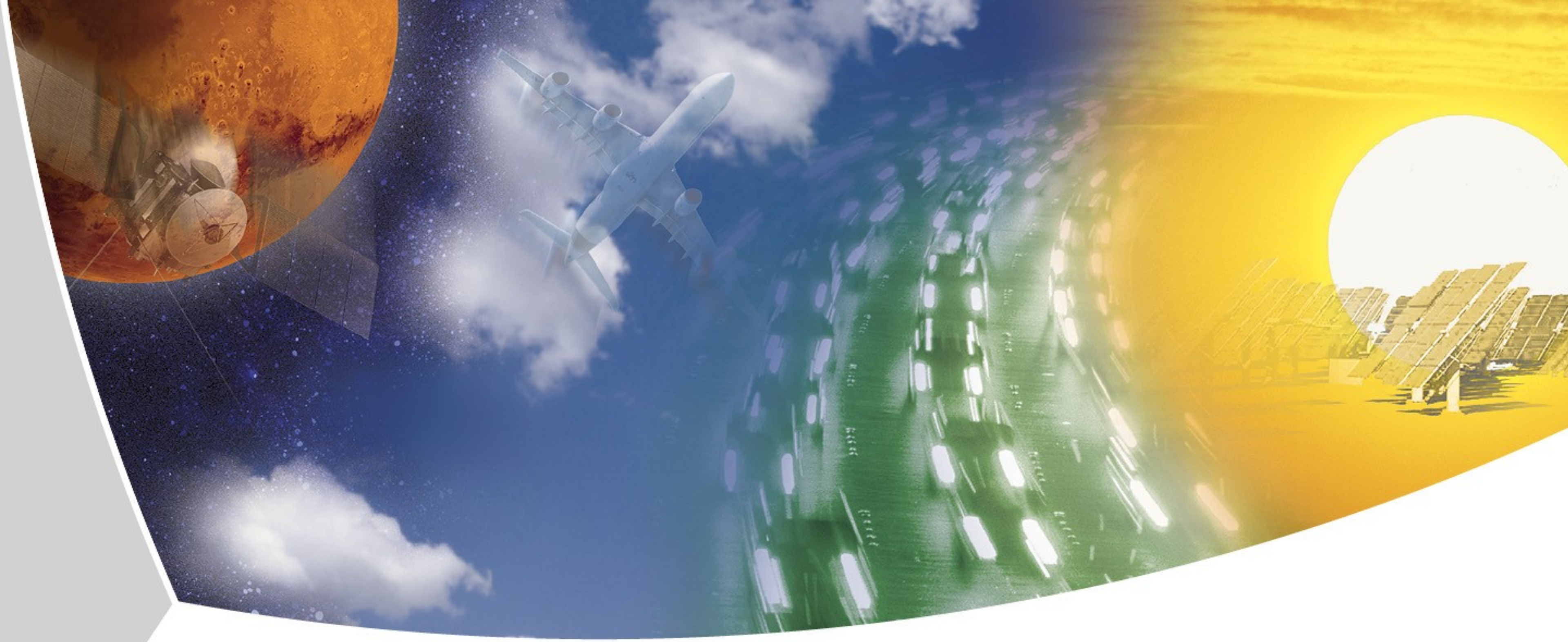

Reliability based analysis of the crosswind stability of railway vehicles

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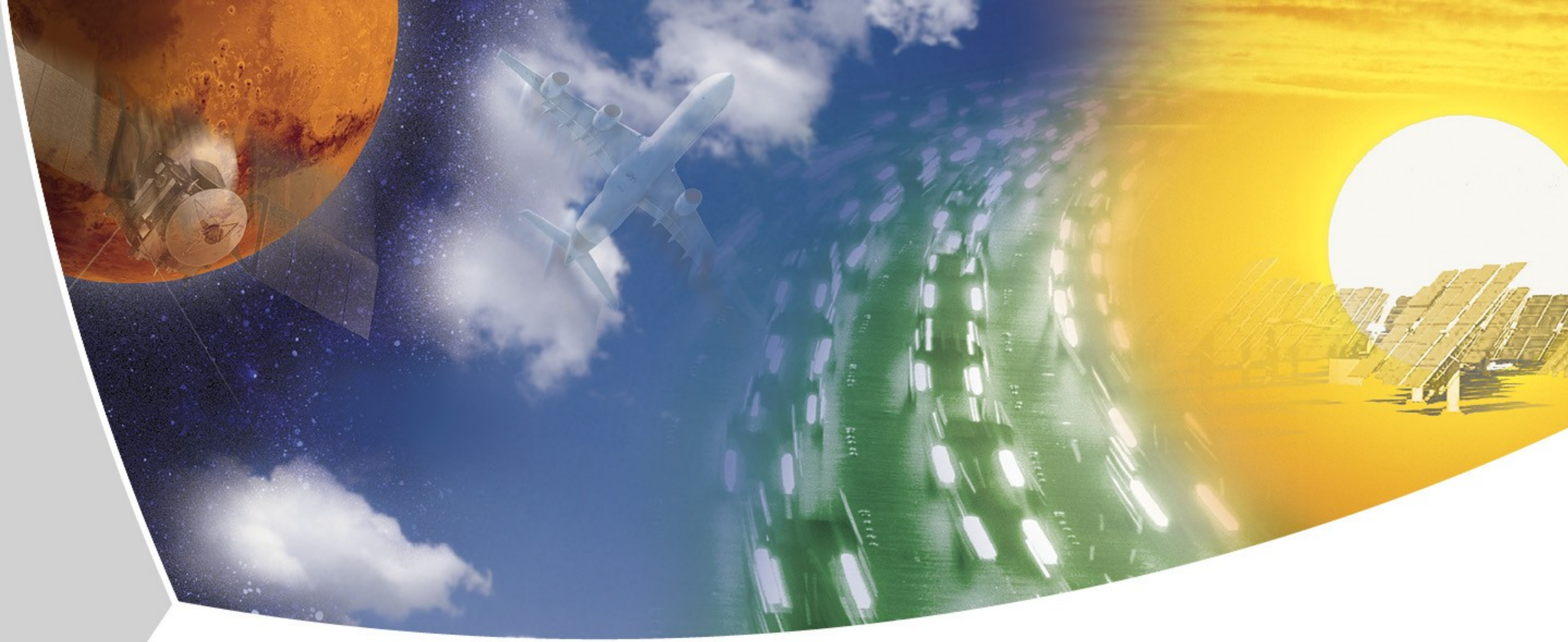


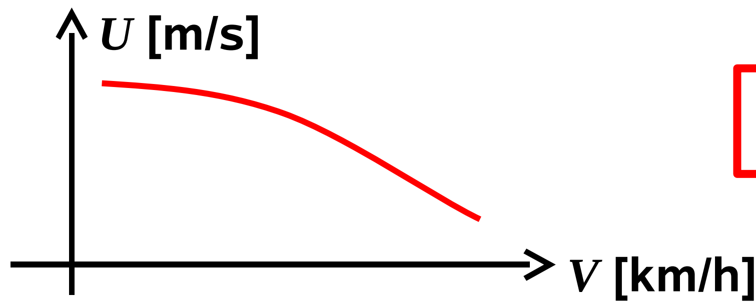
Outline

- Introduction of the crosswind stability problem
- Simulation, parametric uncertainty
- Probabilistic Characteristic Wind Curve
- Reliability analysis
- Application and results

Crosswind Stability

- Safe-life approach
  (based on returning period)
- Passive safety
- Countermeasures (always) needed:
  ballasting, fencing, etc.
- In Germany:
  - No anemometers
  - Many high speed driving trailers/motor coaches (e.g. ICE2, ICE3)
  - No accidents to date (but some in Austria)
  - Few storms but Föhn

Characteristic Wind Curve



$$U_{overt} = U_{overt}(V)$$

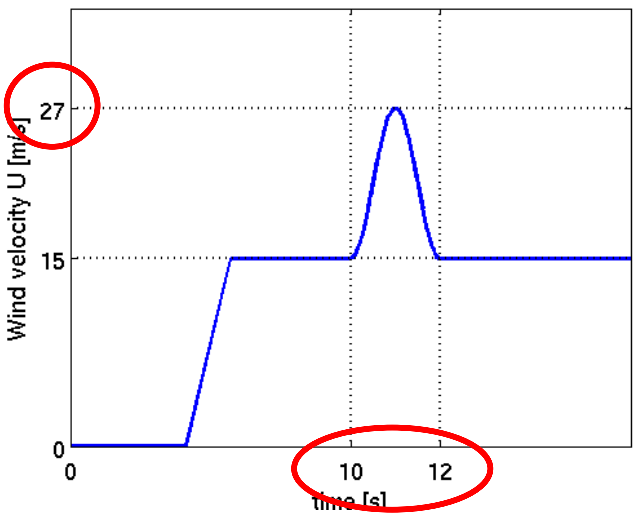
- U is the mean wind velocity
- Overturning is checked by wheel unloading on the wind side:

$$Q_{lim} = 0.1\ Q_0$$

- The CWC is computed by series of multibody simulations (fully virtual homologation)

Simulation

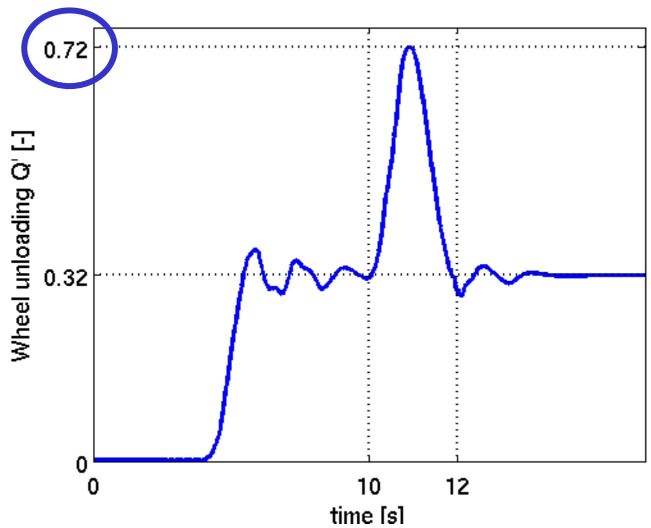
Unsteady wind



Vehicle (MBS)

$$F(\theta, t) = \frac{1}{2} \rho\, C(\theta)\, (U(t))^2$$

Wheel unloading



Gust factor / duration ?

Aerodynamic coefficients ?

Probabilistic Characteristic Wind Curve

Uncertain/Variable Parameters → Stochastic Variables X

The wheel unaloading $Q = Q(U, V, X)$ is also a stochastic variable

~~$Q < Q_{lim}$~~

$$\Pr_X\{Q < Q_{lim}\} \doteq p_F(U, V)$$

$$U_{overt} = U_{overt}(p_F, V)$$

Probabilistic Characteristic Wind Curve (**P**CWC)

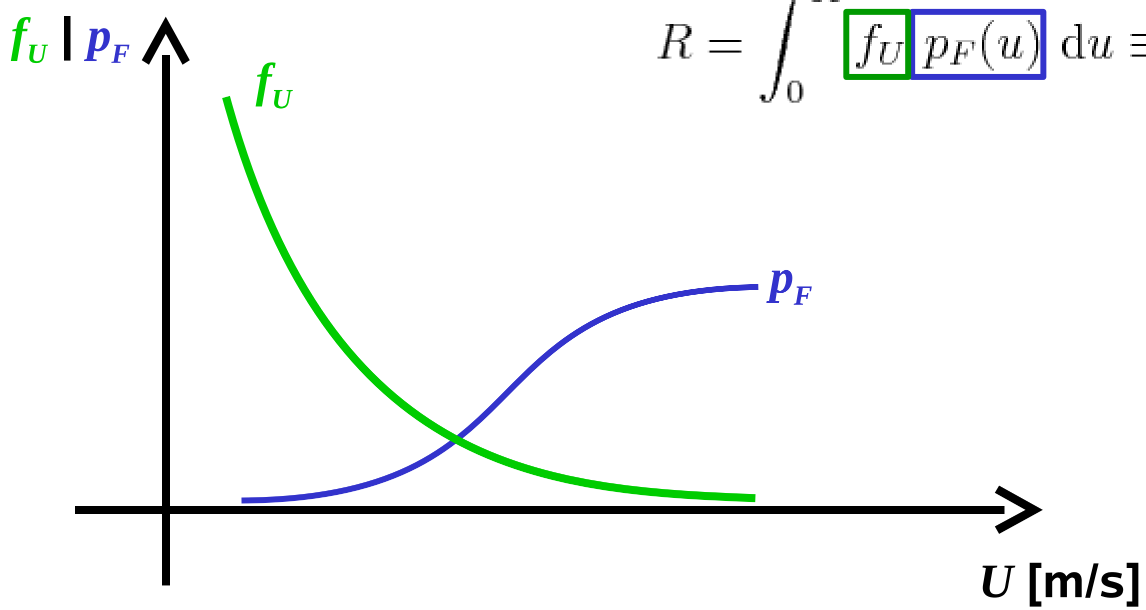
$$U_{overt} = U_{overt}(V)$$

Characteristic Wind Curve (CWC)

Risk evaluation

Consider the driving velocity V fixed :

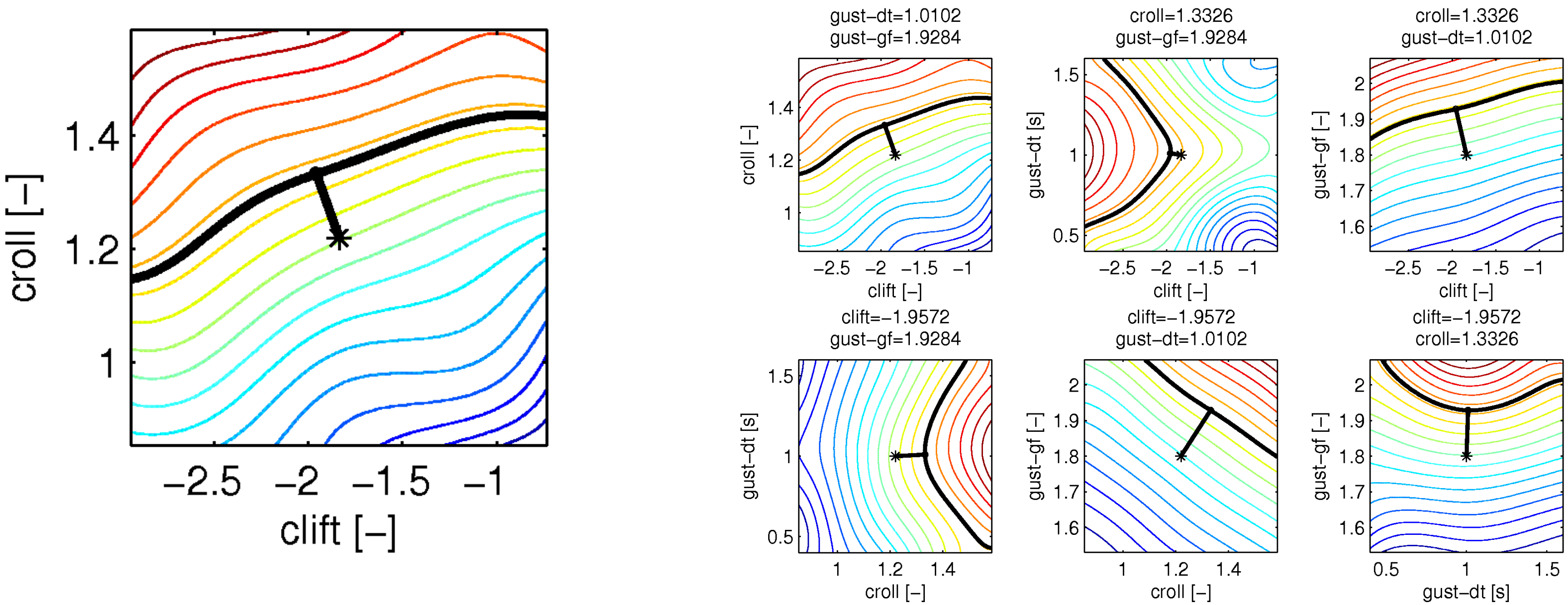
- p_F is given by the PCWC
- f_U (wind recurrence) is given by the weather service



$$R = \int_0^\infty f_U \, p_F(u) \, \mathrm{d}u \equiv E[p_F]$$

How to evaluate $\Pr_X\{Q < Q_{lim}\} \doteq p_F(U,V)$
Semianalytical techniques

- Well established methods form <u>structural mechanics</u>
- Basic idea: $Q = Q(U,V,X)$ is approximated (e.g. <u>linearised</u> → MPP)
- For non-gaussian and/or correlated X_i , further <u>approximations</u> are required
- Computationally a <u>minimization</u> task must be solved

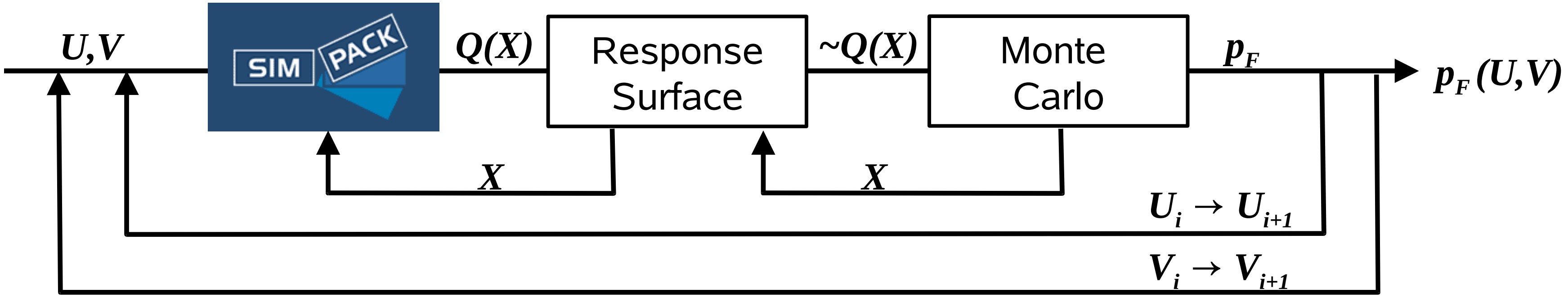


Isolines of $Q(X)$ with U,V fixed. The thick line is $Q=Q_{lim}$.

How to evaluate $\Pr_X\{Q < Q_{lim}\} \doteq p_F(U,V)$

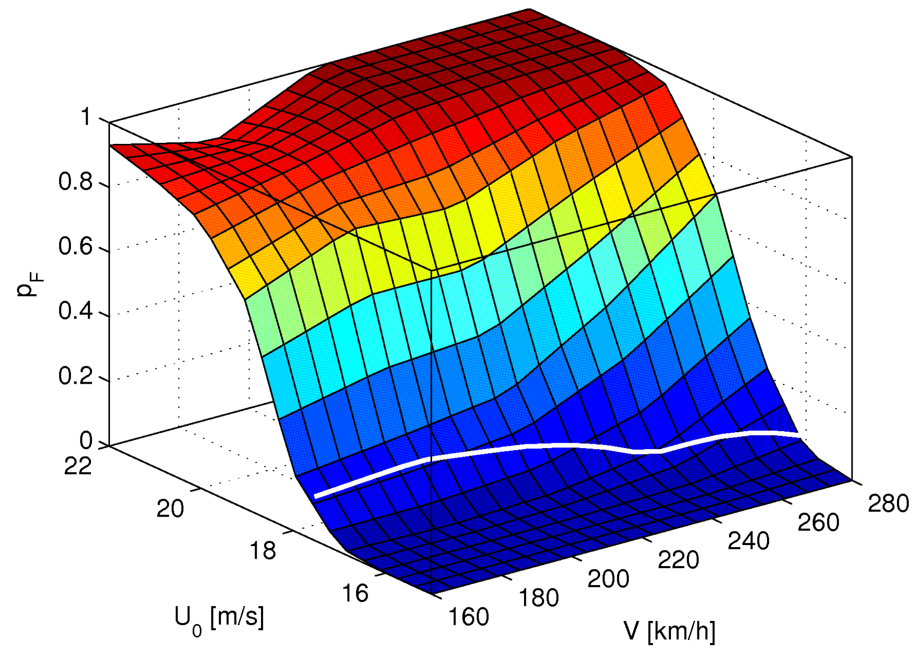
Sampling based techniques

- p_F can be also expressed (with U, V fixed) as $p_F = \int_{\Omega_F} f_{\mathbf{X}}(\mathbf{x})\,\mathrm{d}\mathbf{x}$ where: $\Omega_F = \{\mathbf{x} \in \mathbb{R}^n : Q(\mathbf{x}) > Q_L\}$
- But Ω_F is only known implicitly by MBS …
- "Hit or Miss" Monte Carlo + MBS can be used ☺
- But $p_F << 1$ $\rightarrow$ a huege amount of samples is required ☹
- Importance Sampling etc. can be used 😐
- Anyway: $Q=Q(X)$ has to be approximated by Response Surfaces



Finally: the PCWC ($\Pr_X\{Q < Q_{lim}\} \doteq p_F(U,V)$)

- Many curves are needed: straight track, curved track with different cant deficiencies, embankment, bridge, etc.
- The PCWC is computed only once (the risk has to be evaluated for each track)
- Filtering of the Q time histories can have large influence on the results
- Less conservative results are obtained (if compared to the safety factor approach)



The white line is the conventional CWC

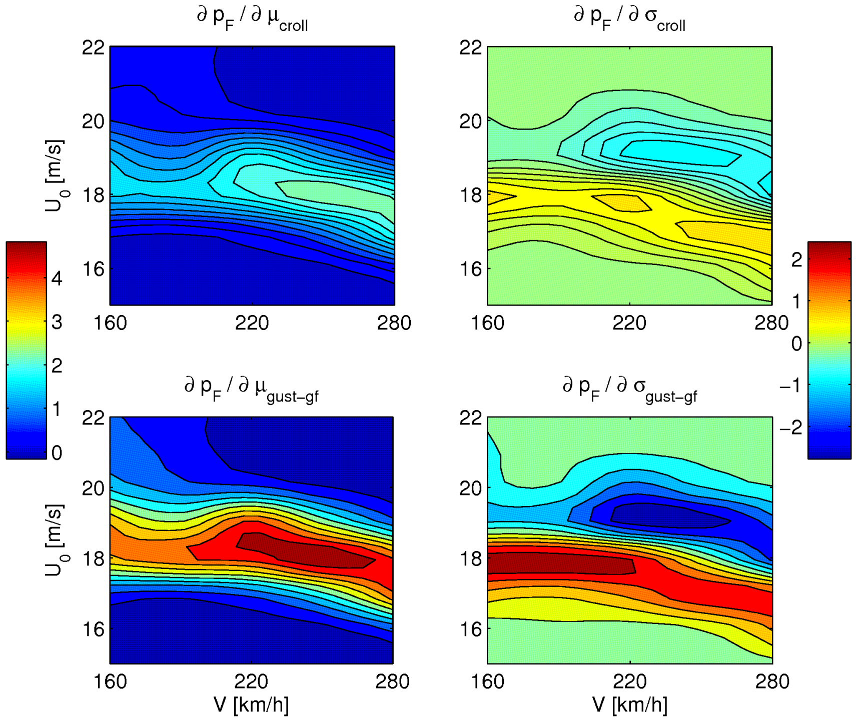
Further topics

- Sensitivity : if U , V are fixed, p_F is a function of the statistical properties of the parameters X , thus:

$$\partial p_F / \partial \mu \ , \ \partial p_F / \partial \sigma$$

- Optimization : constrains can / has to be expressed as a function of p_F

- Linearization :SIMPACK can compute a linear model from the original MBS one. Real wind samples instead of ideal gust can be used (linear system analysis).



Sensitivities w.r.t. the aerodynamic roll moment coeff. and the gust factor

Summary and Outlook

- The risk analysis for the crosswind stability of railway vehicles can be enhanced considering parametric uncertainties
- A framework based on the coupling of SIMPACK with reliability analysis techniques has been presented
- The computational effort is large and much statistical input is required but they can be suited to the desired accuracy

- The statistical models must be improved (e.g. statistical dependency between gust parameters and wind recurrence f_U)
- Time dependent reliability analysis (upcrossing frequency etc.) based on real wind samples and linearized MBS system could be used