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On the influence of crosswind on the overturning stability of railway vehicles

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In recent years modern railway vehicle design shows a trend to faster, lighter and more energy efficient railway systems. These developments unfortunately alter the crosswind stability in a negative manner and so the risk of overturning of railway vehicles during operation in strong winds becomes a critical issue. The risk of overturning is quantified by the probability that a railway vehicle capsizes. To improve the crosswind stability it is very important to know the influence of the design and excitation variables on the wheel unloading of the railway car. Sensitivity coefficients of the design and excitation variables with respect to the probability of failure are calculated and the most influential variables are accentuated.

1 Stochastic modeling of the system

The railway vehicle is simulated in the commercial MBS-Code ADAMS/RAIL. The wind induced forces and moments which are acting on the vehicle are modeled as concentrated forces and moments. As shown in figure 2 an artificial gust scenario is

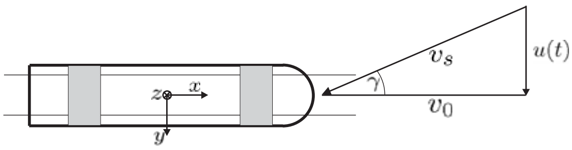

Fig. 1 Sketch of the railway vehicle system.

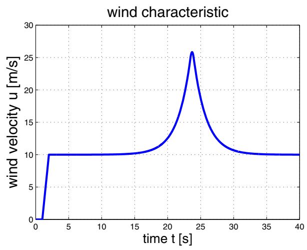

Fig. 2 Characteristic of the crosswind.

designed for the crosswind characteristic [3], in which the amplitude A and the duration T of the exponential gust are modeled as stochastic variables. Not only the amplitude and the duration but also the aerodynamic coefficients $C_{y,z,mx,my,mz}$ of the railway vehicle are uncertain. Altogether there are seven stochastic variables $\underline{z}$ describing the excitation of the system [4].
As the excitation of the nonlinear railway vehicle model is a stochastic process the response of the railway car is also stochastic and so the probability of failure that the railway vehicle turns over can be computed. Failure means, that the wheel unloadings of the windward wheels exceed a certain limit. Carrarini [1] proposed a Probabilistic Characteristic Wind Curve (PCWC) (figure 3) where the failure probability P_f is shown as a function of the mean wind velocity u_0. The probability of failure has been calculated by a FORM and a Line Sampling analysis. Using FORM the probability of failure is approximated by the standard normal cumulative distribution function (CDF)

$$P_f \approx \Phi(-\beta) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\beta} e^{-\frac{1}{2}x^2} dx, \tag{1}$$

where $\beta = \|\underline{z}\|$ is in the space of the stochastic variables the shortest distance from the origin to the limit state function $g(\underline{z}) = 0$, which separates the failure from the safe domain. The point with the shortest distance to the origin lying on the limit state function is the so-called Most Probable failure Point (MPP).

2 Sensitivity calculations

Local sensitivity calculations concerning the 7 stochastic excitation variables $\underline{z}$ and concerning 9 deterministic design parameters $\underline{\theta}$ have been done. At the MPP gradients of the distance β with respect to the excitation variables $\underline{z}$ and gradients with respect to the design parameters $\underline{\theta}$

$$\left.\frac{d\beta}{d\underline{z}}\right|_{z_{\text{MPP}}} = \frac{\underline{z}_{\text{MPP}}}{\|\underline{z}_{\text{MPP}}\|} = -\frac{\nabla g(\underline{z}_{\text{MPP}}, \underline{\theta})}{\|\nabla g(\underline{z}_{\text{MPP}}, \underline{\theta})\|}, \qquad \frac{d\beta}{d\underline{\theta}} = \frac{1}{\|\nabla g(\underline{z}_{\text{MPP}}, \underline{\theta})\|} \frac{\partial g(\underline{z}_{\text{MPP}}, \underline{\theta})}{\partial \underline{\theta}} \tag{2}$$

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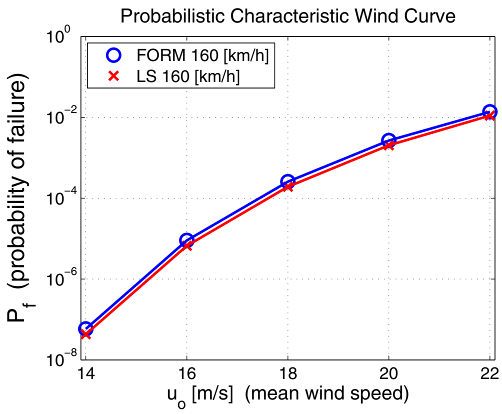

Fig. 3 Probabilistic Characteristic Wind Curve.

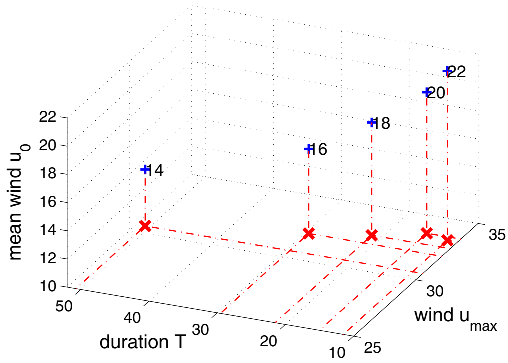

Fig. 4 Maximum wind speeds and gust durations at the MPP.

have been computed. These gradients were determined at the MPP by a numerical finite differences procedure [5]. The distance β is a good measure to investigate the sensitivity of system parameters [2] because if the distance β is increasing the probability of failure is decreasing ($\beta\uparrow \implies P_f\downarrow$), which is wanted, and if the distance β is decreasing the probability of failure is increasing ($\beta\downarrow \implies P_f\uparrow$), which is not wanted. As can be seen from figure 5 the excitation variables with the

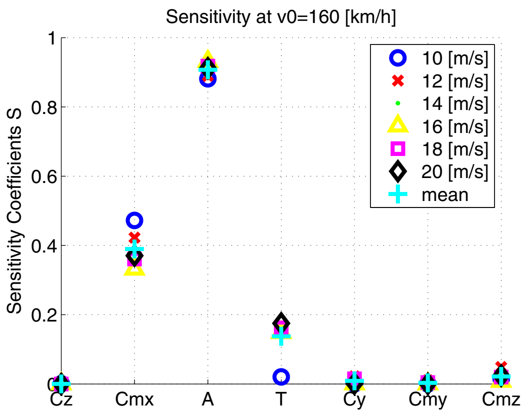

Fig. 5 Sensitivity coefficients for the stochastic excitation variables.

Table 1 Sensitivity coefficients for the design parameters.

design parameters	sensitivity coefficients
mass of the carbody	$+0.4524$
center of mass-z	$+0.0025$
center of mass-y	-0.0053
moment of inertia-x	-0.0046
spring coef. SS-z	$+0.0394$
damper coef. SS	-0.0029
spring coef. PS-z	-0.0034
spring coef. anti-roll-bar	$+0.0034$

highest impact on the crosswind stability are the gust amplitude A, the aerodynamic roll moment coefficient C_{mx} and the gust duration T. The other aerodynamic coefficients have almost no contribution and can be neglected which is a computational advantage as the FORM analysis is based on a numerical demanding nonlinear optimization routine. The most influential design parameters are shown in table 1. The parameters, which can be changed during the engineering process are the spring coefficient of the secondary suspension in z-direction and the spring coefficient of the anti-roll bar. The mass of the carbody, the moment of inertia about the x-axis and the center of mass are stochastic variables as they vary irregularly with passenger load and so they are not considered here. All the presented investigations have been carried out assuming an empty train. The sensitivity coefficients for the deterministic design variables can be used to optimize the railway vehicle, but as there are also other important criterion e.g.comfort a stochastic multi criterion optimization should be done.

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