The integration of cross wind forces into train dynamic calculations

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Abstract

In order to address the issue of train overturning due to cross winds, the study proposes a robust method for the integration of turbulent cross wind forces into train dynamic calculations. The unsteady forces are determined through the concept of aerodynamic weighting function from experimental data of aerodynamic admittance. For constant and sudden winds, the risk of overturning is investigated for a matrix of three mean cross wind and vehicle speeds, and two values of track twist. Limitations on large time scales cause the weighting function to filter out the turbulent fluctuations, making the derailment ratios to be dominated by the transient behaviour of the steady cross wind forces. It is found that a track with cant deficiency presents a higher risk of overturning than one with cant excess. Higher mean wind and vehicle speeds generally increase the risk of overturning. For the derailment mechanism, roll over is more likely to occur than flange climbing, and is also more sensitive to the mean wind speed. The effects of sudden cross winds on derailment are more significant compared with constant cross winds.

1 Introduction

Cross winds can have a number of effects on trains, the most obvious of which is to cause the train to overturn in conditions of high cross winds and there have been a number of such incidents in recent years – see [8] and [12] for examples of recent work in this area. There are also, however, a number of other potential effects – for example turbulent cross winds can, in principle, result in a loss in ride quality if specific vibration modes are excited; the lateral displacement of trains in cross winds can cause the kinematic envelope to be infringed, and can also cause potential dewirement problems with large scale pantograph displacements [13]. A proper consideration of all of these problems requires the integration of the unsteady aerodynamic forces and moments caused by unsteady cross winds with the suspension system of the vehicle and its interaction with the track. Work of this type has already been carried out by a number of researchers [3, 4]. This paper reports the preliminary findings of a study that takes a fundamental approach to this problem, using time-domain simulations of a train’s dynamic response to turbulent cross wind with characteristics of a sudden gust. It is assumed that the train is traveling perpendicular to a cross wind. Section 2 considers the numerical simulation of the natural wind, such that the correct turbulence correlation structure is achieved. It also considers how such unsteady wind time histories are transformed into unsteady aerodynamic force and moment time histories, through the use of the concepts of aerodynamic admittance and aerodynamic weighting functions. Section 3 then considers the incorporation of these force and moment time histories into dynamic models of the train system that fully model the suspension and wheel-rail interaction and make realistic allowance for track roughness and irregularities. Although a large number of parameters, both aerodynamic and mechanical, must be considered, we solely investigate the sensitivity of three factors. This paper presents a parametric study of the problem through investigation of the effects of different mean cross wind speeds, train speed, and track condition for the Class 365 Electrical Multiple Unit (EMU) running over a 2 km track section. An important aim of this work is to establish, if possible, the critical factors that should be taken into account when overturning safety is considered, hopefully establishing some guidelines to be used in norms and standards for train operations. Some brief conclusions and a description of ongoing work are given in Section 4.

2 The aerodynamic model

In order to account for the effects of cross wind forces on train safety during a journey, it is important to generate suitable wind loading histories. This process consists of two steps: 1)
turbulent wind field simulation, and 2) wind force and moment evaluation. We compute the unsteady forces on the leading car of the vehicle since it bears the largest aerodynamic loads.

2.1 Wind time series simulation

The wind velocity simulation consists of an assumed mean value with a superimposed turbulence component. This turbulence, specified by the longitudinal velocity fluctuations at all the spatial points along the track, is considered to be a multivariate stationary stochastic vector process and have been simulated using the method of [14] and further developed in [6]. It is of course possible to prescribe the wind in a different form using for instance a deterministic model such as the Chinese hat profile. The wind velocities are predicted every 20 m with a total of 100 simulation points. Full details of the simulation process can be found in [8]. It is sufficient to note that in all cases the time series are appropriately correlated to one another and have coherence properties as described by Davenport’s coherence form [5]

\[ \text{Coh}_{jm}(\omega) = \exp \left( -C_z \frac{\omega \Delta_{jm}}{2\pi U} \right) \] (1)

where \( \omega \) is the angular frequency, \( C_z \) is a constant decay factor taken as 10, and \( \Delta_{jm} \) is the distance between the simulation points \( j \) and \( m \), \( U \) is the mean wind speed at height \( z = 3 \) m above the ground. Accurate values of the Kaimal’s wind velocity spectrum given in [11] can be reproduced. Kaimal’s longitudinal wind spectrum is given by

\[ S(z, \omega) = \frac{1}{2} \frac{200u_*^2}{2\pi} \frac{z}{U} \frac{1}{1 + 50 \frac{\omega^2}{2\pi U}} \] (2)

\( u_* \) is the shear velocity, \( u_* = KU / \log \left( \frac{z}{z_0} \right) \) which depends on the constant \( K = 0.4 \) and the ground roughness \( z_0 \) (\( z_0 = 0.001 \) m for open country terrain) which measures of the eddy size at the ground. Figure 1 shows good agreement between the target Kaimal’s longitudinal spectrum and that simulated using the current spectral method. A typical velocity simulation is given in Figure 2 for a mean wind speed of 22 m/s. From such simulations the actual wind time series as seen by the moving train is the vector addition of the wind time series and the train velocity.

![Figure 1: Kaimal’s target and simulated spectra of the turbulent velocity (logarithmic scale)](image-url)
2.2 Force and moment time series prediction

The unsteady wind velocity seen by the train having been simulated the next step is to calculate the aerodynamic forces and moments on the train. This is achieved through expressions of the form

\[ F(t) = \bar{F} + F' = 0.5 \rho AC_F \bar{U}_r^2 + \rho AC_F \bar{U}_r \int_0^\infty h_F(\tau)u'(t-\tau)d\tau \]  

(3)

where \( F \) is either the side force or the lift force, \( \bar{U}_r \) is the wind velocity relative to the train \( \left( \bar{U}_r = \sqrt{u^2 + V^2} \right) \), where \( u \) is the absolute wind velocity \( (u = U + u') \), and \( V \) is the vehicle speed. \( \rho \) is the density of air, \( A \) is a reference area, \( C_F \) is a force coefficient and is a function of the yaw angle \( \beta \) (direction relative to the train, defined as \( \beta = \tan^{-1} \left( V / u \right) \)), and \( h_F(\tau) \) is the aerodynamic weighting function of the force being considered. An overbar indicates a mean value, and a \( ' \) represents the fluctuating part. It can thus be seen from Equation (1) that the force time histories can be determined from the velocity time histories if the appropriate force coefficients and weighting functions are known. While the force coefficients have been measured directly in wind tunnel tests on the leading car [2] as shown in Figure 3, it is difficult to measure the weighting function directly. It can be shown, however, that this function, which is real, is the Fourier transform of the frequency domain aerodynamic transfer function, defined as

\[ H(n) = \left| X_F(n) \right|^2 e^{i\phi_F(n)} \]  

(4)

where \( \left| X_F(n) \right|^2 \) is the aerodynamic admittance and \( \phi_F(n) \) is a phase function. It was shown by Baker [14] that the admittance function may be expressed as

\[ \left| X_F(n) \right|^2 = \frac{4S_F(n)}{(\rho AC_F)^2 \bar{U}_r^2 S_U(n)} \]  

(5)

where \( S_F(n) \) and \( S_U(n) \) are the power spectral densities of force and velocity, respectively. The admittance is effectively the ratio of the force power spectrum to the velocity power spectrum and represents a correction to the conventional quasi-steady theory often used in wind engineering. Both \( S_F(n) \) and \( S_U(n) \) can be measured at full scale or model scale, and the admittance calculated, and thus in principle the weighting functions can be found as a function of train geometry, the yaw angle, etc., if \( \phi_F(n) \) is known. However this is not usually the case, as wind velocities and forces are not usually measured sufficiently close together at the same time to enable the phase to be determined. The following approach to determine the weighting functions was adopted. From the wind tunnel experiments [13], the lift and side force admittance functions were estimated. Typical admittance functions are illustrated in Figure 4 for a number of yaw angles.
These admittances were then transformed into the time domain to yield equivalent aerodynamic weighting functions as follows. By fitting curves to data in Figure 4, the aerodynamic admittance function for the Class 365 may be parameterised as

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

(6)

The parameters \( n, n', \xi, \) and \( k \) are constants and have no physical meaning. The time domain equivalent expression for admittance, i.e. the weighting function, is given by

\[ h_f(\tau) = a \sin b \tau \exp^{-c\tau} \]  

(7)

where \( a, b, \) and \( c \) are constants related to \( n, n', \xi, \) and \( k, \) and \( \tau \) is the weighting function time lag. Note that the Fourier transform of Equation (7) can be obtained analytically and thus the optimization of the parameters through a curve fit to the measured admittance is relatively straightforward. Experience shows that the variation of the parameters \( a, b, \) and \( c \) with yaw angle is simple and amenable to parameterisation. It is shown in [15] that Equation (7) can be simplified to give the following expression for the dimensional weighting function

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

(8)

where \( \bar{n}' = n' \frac{L}{U}, \) \( L \) is the vehicle's length (20 m). The values of \( \bar{n}' \) (either for lift or side force) were determined experimentally as a function of yaw angle based on the formulation in Equation (6). The weighting functions are thus found from the measured admittance functions. As noted in [1], since the rolling moment is effectively the product of the side force
and a moment arm about the c.g. (assumed constant), the aerodynamic admittance and weighting functions for the rolling moment will be similar to those for the side force. Now that the weighting functions are computed, the unsteady forces are obtained as a sum of averaged and fluctuating values as defined in Equation (3). The fluctuating part \( F'(t) \) can be computed either in the time domain by expressing the integral as a convolution \( h_P(\tau) \ast u'(t) \) (since the system is causal), or in the frequency domain by taking a Fourier transform for \( F'(t) \), which transforms the integral to a product of the Fourier transforms of \( h_P(\tau) \) and \( u'(t) \), and then taking an inverse Fourier transform of the result. A sample set of simulated force and moment time histories is shown in Figure 5, corresponding to the velocity history of Figure 2. Typical forms of the weighting functions of lift \( h(L) \) and side force \( h(s) \) are shown in Figure 6. It is clear that even at the highest vehicle speed of 100 mph and mean wind speed the weighting function’s characteristic time scale is only 0.6 s, thus according to Equation (3) the effects of turbulence are filtered out after this time, so that the aerodynamic force calculation beyond this point is effectively quasi-steady.

![Figure 5: Sample time histories of simulated forces and moment (U = 22 m/s, V = 100 mph)](image1)

![Figure 6: Sample form of the weighting functions h (L) and h(s) (U = 22 m/s, V = 100 mph).](image2)

2.3 Effects of mean wind speed and train speed on the forces

Figures 7 shows typical calculated side force time histories with increasing train speed while the effects of increasing the mean wind speed on the forces is shown in Figure 8. From Equation (3), if the mean wind velocity is constant, the aerodynamic load increases due to increased relative velocity, but decreases due to decreased force coefficient since the yaw angle is reduced. It is clear, however, that force amplification due to increased vehicle speed exceeds the reduction due to the decreased yaw angle. From Figure 8, when the vehicle speed is constant, increasing the mean speed increases both the relative velocity and yaw angle, and so the loading is increased. In terms of overturning risk to the vehicle, increasing either the mean wind speed or the vehicle driving speed leads to higher risk of overturning.
Designers of railway vehicles use a number of methods to ensure the safe operation of railway vehicles in all possible conditions. Prediction of the derailment ratio is a key aspect in this process. On track measurements can be made but require the use of expensive instrumented wheelsets and it is often difficult to capture the worst possible loading case in a test. Dynamic simulation techniques are often employed in these investigations. Although simulations can include a wide range of values for key variables such as wheel and rail profiles, suspension characteristics, track condition etc [10] it is not usual to include wind loading effects in vehicle dynamics calculations. In this work these effects are included in a vehicle dynamics model using the VAMPIRE software tool. The objective is to identify the running conditions that involve the highest risk of derailment under the effect of cross winds of different intensity and type. Although the likelihood of derailment is affected by the vehicle suspension as well as the track condition, assessment of derailment potential in this work only considers the effects of track variability. The general process undertaken to complete the
work involves first, identification of running cases that could potentially involve derailment risk under cross winds, and second, using VAMPIRE simulations of the selected cases and assessment of the derailment risk.

3.1 Assessment of the risk of derailment

Based on the British Railway Group Standard GM/RT2141 issue 2, the main derailment mechanisms are flange climbing and vehicle roll over. For flange climbing, the lateral to vertical load ratio on the wheel ($Y/Q$) must not exceed 1.2. Derailment of railway vehicles due to flange climb can also occur during low-speed running on sharply curved and twisted tracks [9]. Roll-over starts when the unloading ratio of the wheel $\Delta Q/Q$ exceeds 1 (complete unloading for the wheel). In practice, if flange climbing or roll over occurs over a very short time, derailment may not occur straightaway, though the risk level is unacceptable.

3.2 Factors in the selection of simulation cases involving derailment risk

For higher vehicle speeds on curved tracks, the effect of centrifugal acceleration is not compensated by the cant of the track, while for lower vehicle speeds the effect of the cant exceeds that of the centrifugal acceleration, resulting in two possibilities: cant deficiency and cant excess. The presence of cross winds can exacerbate these effects. The correct combinations of curve radius and cant are determined as shown in Table 1. For a higher curvature, the angle of attack is generally higher, leading to an increased lateral force $Y$ and thus a higher flange contact. For a lower curvature, higher vehicle speeds are required for the same cant deficiency, resulting in higher dynamic effects due to track irregularities.

<table>
<thead>
<tr>
<th>Cant deficiency 150 mm</th>
<th>Cant excess 100 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve $R = 1000 m$</td>
<td>100 mph</td>
</tr>
<tr>
<td>Curve $R = 500 m$</td>
<td>70 mph</td>
</tr>
</tbody>
</table>

Table 1: Required curve track and cant for three vehicle speeds

For track irregularities, only the effects of positive/negative track twist are considered since these are the dominant factor for both flange climbing and roll over. Two values of twist are used along a 3 meter track section: ±1:126 (for 14 day intervention limit) and ±1:91 (for 36 hour intervention limit).

3.3 Case studies

3.3.1 Constant cross wind

Four constant mean wind speeds are simulated for each case: $U = 0, 10, 15,$ and $22 \, m/s$. Later, the situation of sudden wind will be investigated. Along the 2 km track, the wind forces are smoothly introduced from 250 $m$ onwards. While the train is subjected to turbulent winds, positive twist is introduced at about 600 $m$, and a negative twist at about 1000 $m$. The relative influence of these cases will be compared with the base case where no wind or twist is used. The implicit implication of the force calculation approach is that the vehicle’s length is smaller compared with the distance over which the cross wind velocity changes [1]. For wind gusts over shorter distances, however, this assumption is not valid, and so a correction for vehicle length is introduced. While the aerodynamic forces have been computed every 20 $m$, interpolation is used in VAMPIRE to apply the aerodynamic forces every 2 $m$. The use of the 2 $m$ force interval was originally designed to match the vehicle suspension frequencies that could be excited at such range.

3.3.2 Constant cross wind: simulation results and analysis

In order to measure the influence of increasing the mean wind speed, the time histories of $\Delta Q/Q$ and $Y/Q$ along the track are plotted in figures 9 and 10, respectively, for a train speed of 100 $mph$ and similar twist. The increase in $Y/Q$ and $\Delta Q/Q$ on the curve with increasing wind
speeds is very significant. The trends in Figure 9 illustrate that the occurrence of a 22 m/s wind raises the value of $\Delta Q/Q$ across the curve from less than 0.2 to around 0.7. This is crucial in terms of safety, as this increase is sustained for a relatively long time, which increases the probability of occurrence of an additional factor that may lead to vehicle rollover. When the effect of the track twist is added, $\Delta Q/Q$ reached its maximum value allowed, but only for a very short time. Figure 10 shows a similar pattern for $Y/Q$. In this case, however, the maximum value is considerably below the safety limits.

Figure 9: Effect of increasing $U$ on $\Delta Q/Q$ ($V = 100$ mph, -1:126 twist at 600 m and +1:126 at 1000 m).

Figure 10: Effect of increasing $U$ on $Y/Q$ ($V = 100$ mph, -1:126 twists at 600 m and +1:126 at 1000 m).

The increase in derailment ratio due to increasing wind speeds can be clearly seen, though the jump occurs with benign oscillations. Track twist irregularity, however, causes large initial
transients at 600 m and 1000 m, with the derailment ratios settling down to the same constant value for winds, a few hundred metres into the section. This suggests that for the wind cases considered, the effects of wind turbulence on the derailment ratio is quite small, and the derailment ratio is determined by the mean wind speed. This is not surprising, however, knowing that the large time steps used for the weighting function meant that most of the turbulent fluctuations were being filtered out. It can be expected, therefore, that if the method for computing the aerodynamic forces through the concept of weighting function uses much lower time steps the effects of turbulence on derailment would be seen more clearly.

Tables 2 and 3 summarise the maximum filtered values of $\Delta Q/Q$ and $Y/Q$ for all simulated cases. The time histories of the ratios $\Delta Q/Q$ and $Y/Q$ are filtered by a 2 m moving average.

### Table 2: Peak $\Delta Q/Q$ values for the mean wind/vehicle speed matrix and two track twists

<table>
<thead>
<tr>
<th>Mean wind Speed (m/s)</th>
<th>R = 1000 m, 150 mm cant deficiency ($V_i = 100$ mph)</th>
<th>R = 500 m, 150 mm cant deficiency ($V_i = 70$ mph)</th>
<th>R = 1000 m, 100 mm cant excess ($V_i = 40$ mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist 1:126</td>
<td>Twist 1:126</td>
<td>Twist 1:126</td>
<td>Twist 1:126</td>
</tr>
<tr>
<td>0</td>
<td>0.513 0.689 0.524 0.662</td>
<td>0.423 0.545</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.747 0.870 0.676 0.849</td>
<td>0.477 0.601</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.839 1 (1 m) 0.785 0.933</td>
<td>0.516 0.639</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>1 (2 m) 0.998 1 (2 m)</td>
<td>0.585 0.712</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Peak $Y/Q$ values for the mean wind/vehicle speed matrix and two track twists

<table>
<thead>
<tr>
<th>Mean wind Speed (m/s)</th>
<th>R = 1000 m, 150 mm cant deficiency ($V_i = 100$ mph)</th>
<th>R = 500 m, 150 mm cant deficiency ($V_i = 70$ mph)</th>
<th>R = 1000 m, 100 mm cant excess ($V_i = 40$ mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist 1:126</td>
<td>Twist 1:126</td>
<td>Twist 1:126</td>
<td>Twist 1:126</td>
</tr>
<tr>
<td>0</td>
<td>0.461 0.618 0.525 0.666</td>
<td>0.284 0.458</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.490 0.609 0.513 0.641</td>
<td>0.296 0.487</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.493 0.625 0.509 0.630</td>
<td>0.298 0.508</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.592 0.677 0.532 0.632</td>
<td>0.314 0.590</td>
<td></td>
</tr>
</tbody>
</table>

It is clear that increasing the mean wind speed generally increases the peak values for both $Y/Q$ and $\Delta Q/Q$, though increases in the latter are more significant. For stronger winds, complete unloading of the wheels ($\Delta Q/Q = 1.0$) occurred on four occasions, but the train did not derail since the unloading lasted over very short distances as indicated in brackets. For $Y/Q$ history, despite the observed increments due to increased mean wind speed, this ratio was always far from 1.2 for all wind and train speeds.

While the unloading ratio $\Delta Q/Q$ increases with increasing train speed, the opposite is true for the ratio $Y/Q$. The risk of flange climbing is therefore more important at lower vehicle speeds, as expected. Both derailment ratios $Y/Q$ and $\Delta Q/Q$ are clearly lower in cant excess compared with cant deficiency. The derailment ratios are sensitive to the wind speed, but the correlation is weaker compared with cant deficiency. A possible explanation is that since the wind speeds relative to the vehicle are lower due to lower vehicle speed, the dynamic effects from track irregularities are also reduced. For any combination of train speed and mean wind speeds, the track twist 1:126 gives lower derailment ratios compared with the 1:91 track twist.

### 3.4 Sudden cross wind

This part of the work is concerned with recreating the running conditions when the train goes from a part of the track which is protected from the wind to one which is totally exposed. The
transient effects for the sudden application of the aerodynamic forces need to be introduced. The transient moments also appear when the vehicle is partially covered because the forces are applied out of the centre of the vehicle. The synchronisation between the location of application of the wind and the location of the track twist was a particularly difficult problem to overcome. An intuitive solution was to locate the track twist so that the front wheelset sees it just when the total surface of the vehicle becomes uncovered (in the case of the Class 365 vehicle the twist needs to be located around 20 m ahead of the location where the protection to the wind ends). Table 4 summarises the maximum $Y/Q$ and $\Delta Q/Q$ ratios in the case $R = 1000$ m, 150 mm cant deficiency ($V = 100$ mph), with 1:126 track twist, and for all mean wind speeds.

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>Max $Y/Q$</th>
<th>Max $\Delta Q/Q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No wind, 0</td>
<td>0.461</td>
<td>0.513</td>
</tr>
<tr>
<td>10</td>
<td>0.527</td>
<td>0.794</td>
</tr>
<tr>
<td>15</td>
<td>0.576</td>
<td>0.980</td>
</tr>
<tr>
<td>22</td>
<td>0.665</td>
<td>1 (4.4 m)</td>
</tr>
</tbody>
</table>

Table 4: Filtered peak $Y/Q$ and $\Delta Q/Q$ values for the Class 365 with a sudden wind application

It is noted that the maximum $Y/Q$ occurs for a sudden wind synchronised with negative value of the twist, while the maximum $\Delta Q/Q$ is encountered for a sudden wind synchronised with a positive value of the twist.

By comparing sudden wind with constant wind condition, the increase in $Y/Q$ in a sudden wind is modest but visible, especially for the highest values of wind speeds. Still, the total values of $Y/Q$ are far from the 1.2 limit. For $\Delta Q/Q$, however, the increase due to a sudden wind is more noticeable especially at higher wind speeds. For instance, at 15 m/s the increase due to sudden wind is about 17%. At 22 m/s, there is complete wheel unloading in both cases, but in the sudden wind case the unloading lasts for 4 m, while it lasts 2 m in the constant wind case.

4 Conclusions and possible future work

From the previous sections it can be seen that a robust method for the integration of cross wind forces into train dynamic calculations has been developed. In particular, a method has been proposed for the determination of the aerodynamic weighting function from experimental values of aerodynamic admittance. For the case presented, the filtering effect of the admittance function at high frequencies can be clearly seen, although in this case the calculated derailment ratio is dominated by the transient behaviour and the forces due to steady cross winds. The cant deficiency case shows much higher risk than the cant excess case. For the same cant deficiency, the lower curvature but higher speed case seems to be slightly worse than the higher curvature but lower speed one. In general, the dynamic effects coming from higher vehicle speeds seems to have an effect. Regarding the derailment mechanism, roll over clearly shows more derailment danger than flange climbing, and it is more sensitive to the wind speed. Effects of sudden cross winds on derailment are more significant compared with constant cross winds.

There are many avenues that could be explored in the future to extend the current findings. There is a need to consider the effects of curved tracks as the force distribution will be different around the train. Since the loads depend on the gust, it is important to investigate the overturning risk when predetermined wind scenarios such as the Chinese hat, and the 1-cos ideal gust, are used as opposed to a sudden gust. Another possibility would be to base the wind on available Characteristic Wind Curves (CWC). In addition, the complete turbulent field should be simulated including the $y$ and $z$ components. A main drawback of the current approach is that the aerodynamic admittance may only be obtained from expensive experiments, but if one has the data, the overturning risk is clearly more accurate as data is based on physical experiments. The aerodynamic admittances that have been used from experiments do not involve the effects of moving ground between the track and vehicle. Such
effect is known to modify the flow around the lower part of moving vehicles (Ref.*) and thus the force loading from the wheels. Since trains will be running at increasingly higher speeds, their effects on overturning must be determined. It would be worthwhile investigating the influence of different train aerodynamic parameters (i.e. different aerodynamic force coefficients and aerodynamic admittance functions), although these depend on availability of wind tunnel or full scale data. As a train moves through different terrains, the ground roughness, and thus turbulent intensity vary. This in turn affects the values of turbulent velocity, and so its potential influence on overturning risk must be appreciated. Other track and train suspension conditions could be investigated to measure their relative importance in train overturning. Other modes of derailment are possible such as wheel lift, and gauge spreading, while excitation of train natural suspension modes could exacerbate the effects of dynamic forces.

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References