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Railway applications — Aerodynamics

Part 6: Requirements and test procedures for cross wind assessment

ICS 45.060.01

British Standards

National foreword

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Foreword

This document (EN 14067-6:2010) has been prepared by Technical Committee CEN/TC 256 “Railway Applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2010, and conflicting national standards shall be withdrawn at the latest by July 2010.

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For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

This European Standard is part of the series "Railway applications – Aerodynamics" which consists of the following parts:

— Part 1: Symbols and units

— Part 2: Aerodynamics on open track

— Part 3: Aerodynamics in tunnels

— Part 4: Requirements and test procedures for aerodynamics on open track

— Part 5: Requirements and test procedures for aerodynamics in tunnels

— Part 6: Requirements and test procedures for cross wind assessment

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

Trains running on open track are exposed to cross winds. The cross wind safety of railway operations depends on vehicle and infrastructure characteristics and operational conditions. Important parameters are:

— aerodynamic characteristics of the vehicle;

— vehicle dynamics (e.g. mass, suspension, bump stops);

— track gauge;

— line characteristics (radius and cant of the track, height of embankments and bridges, walls near the track);

— wind exposure of the line;

— operating speed, mode of operation (conventional, tilting, running direction).

1 Scope

This European Standard applies to the cross wind assessment of railways taking into consideration the recommendations given in Annex M on the application of the standard (migration rule). The methods presented have been applied to passenger vehicles with a maximum speed up to 360 km/h and to freight vehicles with a maximum speed up to 160 km/h. This European Standard applies to coaches, multiple units, freight wagons, locomotives and power cars.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 14067-1:2003, *Railway applications — Aerodynamics — Part 1: Symbols and units*

EN 14067-2, *Railway applications — Aerodynamics — Part 2: Aerodynamics on open track*

EN 14363, *Railway applications — Testing for the acceptance of running characteristics of railway vehicles — Testing of running behaviour and stationary tests*

EN 15663, *Railway applications — Definition of vehicle reference masses*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 14067-1:2003 and the following apply.

3.1
lee rail
rail on the lee side of the track

3.2
bias
systematic error affecting an estimate

NOTE In this document, it is expressed as the ratio of a coefficient obtained during benchmark wind tunnel tests to the equivalent coefficient obtained during new wind tunnel tests.

4 Symbols and abbreviations

For the purposes of this document, the symbols given in EN 14067-1:2003 and the following apply.

Table 1 — Symbols

Symbol	Unit	Significance	Explanation or remark
$\widetilde{A}$	-	Normalized gust amplitude	
a_{m}	s/m	Dispersion	Dispersion determined by extreme value analysis of wind tunnel data

Table 1 (*continued*)

Symbol	Unit	Significance	Explanation or remark
a_q	m/s^2	Uncompensated lateral acceleration	
A_{xz}	m^2	Reference side area of the model vehicle	The side area of the model vehicle
A_0	m^2	Reference normalisation area	10 m^2
b_A		Lateral contact spacing	
$b_{A,min}$		Minimum lateral contact spacing	
c_{Fi}	-	Non-dimensional force coefficient based on A_0	$c_{Fi} = \frac{2 \cdot F_i}{\rho \cdot v^2 A_0}$, i = x, y, z
c_{Mi}	-	Non-dimensional moment coefficient based on A_0 and d_0	$c_{Mi} = \frac{2 \cdot M_i}{\rho \cdot v^2 A_0 d_0}$, i = x, y, z
$c_{Mx,lee}$	-	Non-dimensional rolling moment coefficient around leeward rail	
$c_{Mx,lee,bmk}$	-	Benchmark value of rolling moment coefficient around leeward rail	Rolling moment coefficient determined from the benchmark tests
d_0	m	Reference normalisation length	3 m
F	Hz	Frequency	
f_h		Function of the embankment blockage ratio, B_E	
$f_{\Delta Q}$	-	Relative windward wheel unloading factor	0,9
f_m		Method factor	To account for uncertainties in the 3 mass model.
h	m	Vehicle height	
h_{cant}	m	Cant	
h_{VEH}	m	Height of the vehicle from top of rail to roof	
h_{BL}	m	Boundary layer height	
I_i		Turbulence index for the i-wind component	$i = u, v, w$
$I_u(z)$	-	Turbulence intensity	The standard deviation of the wind tunnel velocity at height z divided by the mean velocity at that height
L	m	Vehicle length	
L_{VEH}	m	Length parameter of the vehicle car body	
${}^xL_i$	m	Longitudinal integral length scale of the i-wind velocity component along the x direction	$i = u, v, w$

Table 1 (*continued*)

Symbol	Unit	Significance	Explanation or remark
${}^{y}L_{i}$	m	Lateral integral length scale of the i-wind velocity component along the y direction	$i = u, v, w$
${}^{x}L_{u}$	m	Turbulence length scale	Longitudinal streamwise velocity turbulence length scale in the core stream
${}^{x}L_{u\_FS}$	m	Full scale turbulence length scale	
M_{m}	Nm	Restoring moment due to the vehicles masses	
M_{la}	Nm	Moment due to uncompensated lateral acceleration	
M_{CoG}	Nm	Moment due to the lateral movement of the centre of gravity of suspended masses	
$M_{x,lee}$	Nm	Rolling moment around leeward rail	
m	kg	Vehicle mass (to be considered for cross wind assessment)	Refers to operational mass in working order according to EN 15663
m_{0}	kg	Unsprung masses	Refers to operational mass in working order according to EN 15663
m_{1}	kg	Primary suspended masses	Refers to operational mass in working order according to EN 15663
m_{2}	kg	Secondary suspended masses	Refers to operational mass in working order according to EN 15663
ΔQ	N	Wheel unloading	
Q_{0}	N	Average static wheel load	
$\Delta Q/Q_{0}$	-	Relative wheel unloading	
R_{C}	m	Radius of curve	
Re_{max}		Maximum Reynolds number	The maximum achievable Reynolds number in a wind tunnel test
S_{U}	$m^2/s^2/Hz$	Power spectral density	
S_{t}	-	Model time scale	The ratio of time at model scale to time at full scale
T_{samp}	s	Data acquisition duration	The sampling duration for acquiring data
Tu_{x}		Turbulence level	$Tu_{x} = \left(\overline{u'^2} / \overline{u}^2\right)^{0,5}$

Table 1 *(continued)*

Symbol	**Unit**	**Significance**	**Explanation or remark**
U_{mean}	m/s	Mean wind speed	Refers to the upwind at 4 m height above ground
U	m/s	Wind (tunnel) velocity	
$U(t)$	m/s	Instantaneous wind (tunnel) velocity	
U_{turb}	m/s	Wind velocity turbulent component along the mean wind direction	
v_{a}	m/s	Relative wind velocity	
v_{max}	m/s	Maximum train speed	
v_{W}	m/s	Wind speed	
V_{x}	m/s	Magnitude of wind speed vector	Refers to the upwind at 4 m height above ground
x_{B}	%	Blockage ratio at β = 30°	Total modelled configuration projected side area to the wind tunnel cross section
y_B	m	(Maximum) displacement of the contact point on the wheel in the wheel flange direction	
z	m	Height from the ground	
z_{CoG}	m	Height of the centre of gravity of the total vehicle	
$z_{CoG,0}$	m	Height of the centre of gravity of the unsprung masses	
$z_{CoG,1}$	m	Height of the centre of gravity of the primary suspended masses	
$z_{CoG,2}$	m	Height of the centre of gravity of the secondary suspended masses	
z_0	m	Roughness height	
β	°	Yaw angle	The angle between the vehicle axis and the relative wind acting on the train. In a wind tunnel with stationary train model, it is the angle between the train axis and the wind tunnel axis
$\delta_{99\%}$	m	Boundary layer thickness	z coordinate at which the local velocity equals 99 % of the free stream velocity
ε_{max}		Maximum tolerance target value	
$\varepsilon_{\text{mean}}$		Mean tolerance target value	
ρ_0	kg/m^3	Reference air density	ρ_0 = 1,225 kg/m^3

5 Methods to assess cross wind stability of vehicles

5.1 General

This clause presents various methods to assess the cross wind stability of railway vehicles.

The basic principle is that the cross wind stability of rolling stock is given by values of characteristic wind speeds that the rolling stock can withstand before exceeding some wheel unloading limit values. When these characteristic wind speeds are listed for varying input parameters such as train speeds, uncompensated lateral accelerations or wind angles of attack, the resulting set of characteristic wind speeds is called the characteristic wind curves (CWC).

The cross wind stability of a train is given by the cross wind stability of the most cross wind sensitive vehicle in the train consist.

It has to be noted that the CWC indicate the cross wind stability of the train related to a characteristic state of the wheel vertical forces; the characteristic wind curves do not indicate an overturning threshold.

For a given train running at a range of speeds, the CWC define the maximum natural wind speed that a train can withstand before a characteristic limit for wheel unloading is exceeded. The criterion that defines the CWC is the average value of wheel unloading, ΔQ, of the most critical running gear. The term "average" means that, in case of bogies, wheel unloading is averaged over the wheel sets of the bogie. For the relative assessment of cross wind stability of vehicles the reference air density ρ_0 is fixed at 1,225 kg/m³. Further, the vehicle mass to be considered is defined as the “operational mass in working order” according to EN 15663.

The assessment of cross wind stability of vehicles separates into evaluations of the aerodynamic characteristics (i.e. the aerodynamic coefficients) and the vehicle dynamic characteristics.

Subclause 5.2 states the applicability of the various methods for the purpose of rolling stock assessment.

Subclause 5.3 provides various methods for the determination of aerodynamic coefficients of passenger and freight vehicles and locomotives.

Subclause 5.4 provides various methods for the determination of wheel unloading.

Subclause 5.5 gives information on the required presentation form of CWC of passenger and freight vehicles and locomotives.

5.2 Applicability of cross wind methodologies for rolling stock assessment purposes

Subclauses 5.3 and 5.4 provide various methods for the assessment of the aerodynamic and vehicle dynamic characteristics. In general, these methods divide into simple and complex methods. The simpler methods are easier to apply, but imply an extra uncertainty supplement because they are tuned to be conservative in comparison to the complex ones.

Table 2 specifies which method shall be applied for rolling stock assessment purposes depending on type of rolling stock and its maximum speed v_{max}.

If various methods are permitted, the choice of the method depends on the degree of accuracy necessary for the problem. As a general principle, however, it is logical to start with the simplest appropriate procedures and then to shift to more complex methods if necessary.

All vehicles shall be assessed using any of the methods in Table 2.

In case of a fixed train composition it is sufficient to prove the cross wind stability of only the most cross wind sensitive vehicle in the train consist. In other cases, it is necessary to prove the cross wind stability of each vehicle.

Table 2 — Application of cross wind methodologies for rolling stock assessment

	Passenger rolling stock and locomotives			Freight wagons	
Speed range	v_{max} ≤ 140 km/h	140 km/h < v_{max} ≤ 200 km/h	200 km/h < v_{max} ≤ 360 km/h [a]	v_{max} ≤ 80 km/h	80 km/h < v_{max} ≤ 160 km/h
Simplified proof of cross wind stability	Yes, Regulated by national requirements (see Annex K for more information).	Yes, Subclause 5.3.2 + 5.4.2 or 5.3.3 + 5.4.2 or 5.3.3 + 5.4.3 or 5.3.4 + 5.4.2 Restrictions: 5.3.2 not applicable for trains with active tilting mode 5.4.2 not applicable for articulated trains	Yes, Subclause 5.3.4 + 5.4.2 Restrictions: 5.4.2 not applicable for articulated trains	Yes, Regulated by national requirements (see Annex K for more information).	Yes, Subclause 5.3.2 + 5.4.2 or 5.3.3 + 5.4.2
Full proof of cross wind stability	No	Yes, Subclause 5.3.4 + 5.4.3 or 5.3.4 + 5.4.4	Yes, Subclause 5.3.4 + 5.4.3 or 5.3.4 + 5.4.4	No	Yes, Subclause 5.3.4 + 5.4.2 or 5.3.4 + 5.4.3

[a] Above 360 km/h the methods shall be adapted taking into account also compressibility effects.

Annex A indicates how these approaches are combined for practical cross wind stability analysis in various European countries.

5.3 Determination of aerodynamic coefficients

5.3.1 General

Various methods are available to determine the aerodynamic loading on passenger or freight vehicles. Static wind tunnel test data often serve as a part of the proof that the vehicle fulfils given specifications or requirements for rolling stock assessment. Data obtained from Computation Fluid Dynamics (CFD) simulations are often used for feasibility studies in the early vehicle design process. Data obtained with predictive equations are usually used for a first analysis. The following subclauses describe how these methods are to be applied. Table 2 indicates their applicability for rolling stock assessment purposes.

5.3.2 Predictive equations

The predictive equations can only be used subject to the following restrictions:

— The method may not be valid for vehicles which differ much in their shape from the shape of current vehicles.

— The method is not valid for leading end cars with a length L greater than 28 m or less than 10 m.

— The method is not valid if the car(s) leading the investigated intermediate car have an overall total length of less than 10 m.

— The method is valid only for standard track gauge of 1,435 m.

The equation was chosen to be conservative and therefore should not underestimate the wind loading. The method predicts the wind load on a vehicle using the coefficient for the rolling moment around the lee rail. This is different from the rolling moment definition in EN 14067-1, where the middle of the track is the moment reference centre. The rolling moment coefficient around the lee rail used here is estimated from the main physical dimensions of the vehicle (predictive equations).

The predictive equations allow the wind load to be calculated as follows:

$$c_{M\text{x,lee}}(\beta) = \frac{\left(z_0 + z_1 \cdot \tilde{\beta} + z_2 \cdot \tilde{\beta}^2 + z_3 \cdot \tilde{\beta}^3\right) \cdot h_{\text{VEH}}^2 \cdot L_{\text{VEH}} \cdot f_{\text{L}} \cdot f_{\text{VEH}} \cdot z_4}{A_0 \cdot d_0} \quad (1)$$

with $\tilde{\beta} = \left|\text{arctan}\left[\tan(\beta \cdot z_5)\right]\right|$

when the parameters z_0, z_1, z_2, z_3, z_4, z_5, f_L, and f_{VEH} are given (see Table 3). $c_{M\text{x,lee}}$ is based on A_0 and d_0, this normalization differs from EN 14067-1.

Table 3 — Parameter set for the standard ground configuration (standard gauge)

Parameter	Passenger vehicle (leading endcar) and locomotive	Passenger vehicle (midcar)	Freight vehicle
z_0	0		For 0° ≤ β ≤ 40°: z_0 = 0 For β > 40°: z_0 = 0,55
z_1	$4{,}3 \cdot 10^{-3}$		For 0° ≤ β ≤ 40°: z_1 = 0,01375 For β > 40°: z_1 = 0
z_2	$2{,}2 \cdot 10^{-4}$		0
z_3	$-2{,}1 \cdot 10^{-6}$		0
z_4	1,2		1
z_5	1,2		1
L_{VEH}	Length of the vehicle car body without buffer and inter car gap		Length over buffer
f_L	$f_L = 2 - \frac{L_{\text{VEH}}}{L_0}$ with L_0 = 25 m	1	1
f_{VEH}	1	0,75	1
A_0	10 m^2		
d_0	3 m		
β	Yaw angle in degrees		
h_{VEH}	Height of the vehicle from top of rail to roof according to EN 14067-1		

5.3.3 Simulations by Computational Fluid Dynamics (CFD)

5.3.3.1 General

The chief purpose of applying CFD is to determine the set of aerodynamic loads appropriate for determining the mechanical stability of a critical vehicle. The aerodynamic loads needed for such a study are usually the side and lift forces along with the moments of roll, pitch and yaw according to EN 14067-1. In addition, CFD provides a prediction of the velocity and pressure fields, and easily allows different configurations to be taken into account.

NOTE Those undertaking CFD simulations and analysis of the results should be able to demonstrate competency through a proven record of railway aerodynamic simulations and have knowledge of vehicle aerodynamics.

The approach outlined here is similar to that recommended for reduced-scale wind tunnel measurements, see 5.3.4, in that a stationary train and low turbulence block profile onset flow shall be used.

The flow around the vehicle is usually subjected to the following characteristics; three-dimensionality, high Reynolds number, turbulence, deceleration and acceleration, curved boundaries, separation, possible reattachment, recirculation and swirling properties. The proper solution of this aerodynamic problem can only be determined by DNS (Direct Numerical Simulation) of the Navier-Stokes equations which in practice is strongly limited by computational resources. Approximate solutions may be achieved by turbulence modelling through approaches such as: LES (Large Eddy Simulation), DES (Detached Eddy Simulation), RANS (Reynolds Averaged Navier Stokes).

The flow around a vehicle is inherently unsteady, and varies with the geometry and yaw angle. However, steady methods may be used if the steadiness of the flow is evident. One commonly applied criterion is to confirm that the residuals are reduced by three to four orders of magnitude and the loads of interest have converged with negligible cycling of the solution.

The chief challenge of CFD is the appropriate choice of an adequate combination of computational mesh, computational method and turbulence modelling. One advantage of CFD is that blockage effects can be minimized by using a large enough domain size without compromising the Reynolds number or Mach number.

5.3.3.2 Benchmark tests

In order to demonstrate the appropriateness of the CFD approach, calculations shall be made for at least one specified benchmark vehicle (see 5.3.4.2 and Annex C), in a similar fashion to that described for validating wind tunnel measurements in 5.3.4.2. The results from these calculations shall be compared to the benchmark values derived from wind tunnel measurements. The quality criteria defined in 5.3.4.2 shall be applied.

5.3.3.3 Vehicle model

The representation of the vehicle model shall be according to that for wind tunnel measurements, see 5.3.4.8 and 5.3.4.9, as far as intercar-gaps, vehicles lengths and modelling accuracy are concerned for the test vehicle and adjacent vehicles.

Contact between the wheels and rail or ground may be simplified to avoid numerical singularities in the contact point.

5.3.3.4 Computational domain

The model dimensions may either be at full scale or model scale. The latter may be advantageous from a practical viewpoint if results are compared with wind tunnel measurements at some point.

The domain boundaries shall not interfere with the flow around the vehicle in a physically incorrect way.

The requirements on blockage ratio shall be taken from 5.3.4.7.

The computational domain shall extend in the streamwise direction relative to the vehicle of interest: at least 8 characteristic heights upstream and 16 characteristic heights downstream. The characteristic height is defined by the distance between the top of the train and the ground, e.g. when modelling an embankment this height is the height of the embankment including ballast and rail plus the height of the train.

5.3.3.5 Computational mesh

The mesh shall meet basic requirements concerning wall units adjacent to no-slip walls, appropriate for the selected computational method and turbulence model. Typical values for the dimensionless wall distance $y+$ for the first cell layer for RANS simulations are of the order of 1 for low-Reynolds number turbulence models and typically 30-150 for high-Reynolds number turbulence models.

The mesh should capture regions of high pressure/velocity gradient such as: boundary layers, vortices, stagnation zones, recirculation cells, wakes, flow acceleration.

The design of mesh for different yaw angle calculations should be kept as fixed as possible, in terms of the size and distribution of computational cells. The location and size of regions of relatively high resolution may have to be varied. A sufficient number of mesh nodes between the vehicle and boundaries should be used.

Mesh independency for the vehicle under investigation shall be proven by changing the mesh resolution at least in regions of high gradients with two levels of mesh refinement as a minimum. The mesh resolution shall be different by a factor of 1,5 in each spatial direction in the regions where strong velocity gradients have been found. The results of the three meshes shall show good agreement in both flow topology and force coefficients. The rolling moment coefficient about the lee rail should have an accuracy of 3 % between the three refinements for each yaw angle in the range of interest. The largest of the obtained values at each yaw angle shall be taken as the result.

5.3.3.6 Computational method

The computational method shall be able to model the viscous, turbulent, unsteady, three-dimensional and strongly separated flows. However, steady methods may be used if the steadiness of the flow is evident.

The majority of the methods are based on continuum theory governed by the momentum equations (Navier-Stokes equations) but methods based on kinetic gas theory (Lattice-Boltzmann equations) may be used as well.

5.3.3.7 Turbulence modelling

Turbulence models are engineering assumptions to predict turbulent stresses. These stresses emerge as a result of averaging or filtering of the non-linear convection terms of the governing flow equations. They may be regarded as an extra viscosity that for turbulent flows are sometimes several orders of magnitude larger than the molecular viscosity. However, no universal turbulence model exists.

Calculations shall involve a sensitivity test, using the most appropriate turbulence models. If ambiguous results are obtained, wind tunnel measurements shall be used instead.

Commonly used turbulence models are the k-ε and k-ω models. However, these models are known to produce excessive eddy viscosity which could lead to underestimation of recirculation regions and suppression of flow separation. Therefore, such models should be used with care.

Alternative approaches exist that may require more computational effort and are part of ongoing research activities.

5.3.3.8 Boundary conditions

The onset wind profile at the vehicle of interest shall have a uniform, i.e. block profile, to agree with the specifications in 5.3.4.4 for wind tunnel measurements.

The outlet boundary condition shall be appropriate for the train configuration under consideration e.g. a constant pressure or conservation of mass boundary condition.

The surfaces of the train shall be treated as no-slip walls.

The ground may be either stationary or moving with a relative velocity corresponding to the vehicle speed.

The top and lateral plane boundary conditions shall be appropriate for the train and yaw angle configuration under investigation.

5.3.3.9 Reynolds number

The Reynolds number is based on the flow speed at the onset boundary and with a characteristic length of 3 m (at full scale) and shall be no lower than that specified for the wind tunnel measurements in 5.3.4.5.

5.3.3.10 Test programme requirement

See 5.3.4.11 and 5.3.4.12.

5.3.3.11 Data interpolation

See 5.3.4.13.

5.3.3.12 Documentation

Conformity with all requirements defined in 5.3.3 has to be documented.

5.3.4 Reduced-scale wind tunnel measurements

5.3.4.1 General

The purpose of the wind tunnel tests is to enable the determination of the vehicle aerodynamic force and moment coefficients, including the rolling moment coefficient about the lee rail. This specific coefficient is a non-dimensional form of the full-scale wind induced moment acting around the line of contact between wheels and the lee rail. It is mainly this moment that unloads upwind wheels in strong winds and, at the limit, could cause a vehicle to roll over.

NOTE Those undertaking wind tunnel testing and analysis of the results should be able to demonstrate competency through a proven record of aerodynamic testing in wind tunnels and have knowledge of vehicle aerodynamics.

The type of wind tunnel test that is described here uses static models of the train in a uniform, low turbulence onset flow.

A block profile and low turbulence intensity are usually not present in full scale; nevertheless this is required in the wind tunnel, because it allows a more reliable and repeatable test than more complex flow simulations. A simple block profile, except for the thin boundary layer on the floor, ensures more repeatable conditions between different wind tunnel operators. Various boundary layer techniques are available in wind tunnels e.g. a moving belt, boundary layer suction, wall jet blowing or a splitter plate have proven successful.

This type of wind tunnel test is effectively a simplification of more complex tests that use moving models to simulate the movement of the train over the ground with an atmospheric boundary layer. These more complex tests require further research before they can be considered standard. Requirements for wind tunnel testing with a static model in an atmospheric boundary layer are described in Annex G.

It is permissible to use different types of wind tunnels. Details of the wind tunnel used shall be described according to EN 14067-2.

5.3.4.2 Benchmark test

Wind tunnel tests which are used within the assessment process of rolling stock shall include test results of specified benchmark vehicles. For other wind tunnel tests it is recommended to include tests of specified benchmark vehicles. If wind tunnel benchmark tests are carried out, at least one of the three benchmark vehicle models for ICE 3 endcar, TGV Duplex powercar or ETR 500 powercar (see Annex C) shall be used.

Results of wind tunnel benchmark tests shall be available for basically the same set-up as for the vehicle under investigation. The benchmark test should be conducted using the same techniques, configurations, onset wind conditions, equipment etc. as the tests for the new vehicles. These benchmark tests shall be repeated if there is any change in the wind tunnel set-up (e.g. in wind tunnel, re-number, ground configuration, ground models, balance, boundary layer properties).

The measured test results for the benchmark vehicle $c_{M\text{x,lee,test}}$ shall be compared with the reference values for that benchmark vehicle $c_{M\text{x,lee,bmk}}$ (see Annex C) to determine whether the wind tunnel tests are giving results which are within the required tolerances. They will also show any systematic bias in the coefficients compared with the reference results. Exact agreement is not expected due to differences between different wind tunnels and experimental set-ups. The required tolerances for low turbulence tests are:

$$\max\left(\left|\frac{c_{M\text{x,lee,test}} - c_{M\text{x,lee,bmk}}}{c_{M\text{x lee,bmk}}}\right|\right) < \varepsilon_{\text{max}} \quad (2)$$

$$\text{mean}\left(\left|\frac{c_{M\text{x lee,test}} - c_{M\text{x lee,bmk}}}{c_{M\text{x lee,bmk}}}\right|\right) < \varepsilon_{\text{mean}} \quad (3)$$

Good target tolerance values have been found to be ε_{max} = 0,15 and $\varepsilon_{\text{mean}}$ = 0,1 for the yaw angles relevant for the CWC calculation.

Where the results fall within these tolerances, the test technique is deemed to be an acceptable basis for deriving the required results. If however, any of these tolerances are not respected, modifications should be made to the test arrangements to achieve the target tolerances.

5.3.4.3 Turbulence level

The atmospheric turbulence layer shall not be represented in the wind tunnel tests. It is necessary to ensure that the turbulence level $Tu_{\text{x}} \leq 0{,}025$, where:

$$Tu_{\text{x}} = \left(\overline{u'^2} / \overline{u}^2\right)^{0,5} \quad (4)$$

with u denoting the streamwise velocity component.

5.3.4.4 Boundary layer

The wind tunnel velocity profile shall be a uniform, i.e. block, profile. The flow speed shall be independent of the height above ground, except for a thin boundary layer on the wind tunnel floor. The thickness of the boundary layer, $\delta_{99\%}$, at the axis of rotation of the measured vehicle shall be less than 30 % of the vehicle height. Boundary layer thickness has to be determined without train and without ground model present.

5.3.4.5 Reynolds number

The Reynolds number based on the wind tunnel speed, the characteristic length of 3 m (divided by the model scale) shall be greater than $2{,}5 \times 10^5$ to ensure flow similarity between model and full-scale flows. A check shall be made that the results are nearly Reynolds number independent. As a minimum the results for $c_{M\text{xlee}}$

for at least one configuration for each vehicle tested should be documented over the range [0,6 $Re_{max.}$, $Re_{max.}$].

5.3.4.6 Mach number

In general, the Mach number shall be no higher than 0,3. However, if the real train operates at Mach numbers higher than 0,3, the test Mach number shall not be higher than the Mach number of the real train.

5.3.4.7 Blockage

The blockage ratio x_B is defined at a yaw angle of 30°. It is calculated as the ratio of the total modelled configuration (train model + embankment if present) projected side area to the wind tunnel cross section. The blockage ratio x_B shall be less than 15 %.

For open and partially open test sections (e.g. three quarter open or slotted walls) no blockage correction is needed for blockage ratios smaller than 5 %. Between 5 % and 15 % the blockage corrections described in Annex B may be used. In closed test sections, the coefficients are overestimated, therefore it is conservative not to apply a correction here.

5.3.4.8 Train model setup

All linear dimensions of the model vehicle and ground model are scaled in the same ratio as the model scale so that geometric similarity is achieved.

The ratio of the total length of the train model to the width of the tunnel should not be so large that the presence of the side walls of the tunnel causes any distortions to the flow around the ends of any leading vehicles and should be less than 0,75.

When conducting wind tunnel tests it is essential to cover the realistic worst case train composition.

For all passenger vehicles and locomotives under investigation at least half a down-stream vehicle shall be placed next to the tested model. It is recommended to use a down-stream model of full vehicle length to be placed next to the tested model. If the vehicle under investigation is not a leading vehicle, at least one full vehicle ahead needs to be present to ensure realistic upstream flow conditions. The upstream and downstream model should be of similar cross section to the tested model.

Freight wagons which can possibly run behind an empty flat wagon shall be tested using an empty standard two-axle container trailer model as upstream body. For freight wagons no downstream body shall be used.

The intercar-gap between the vehicles shall be represented with the correct separation between adjacent vehicles. Mechanical contact between the tested model and the passive bodies shall be excluded at all times. Vibration of the tested model or adjacent passive models shall be minimised.

5.3.4.9 Modelling accuracy

The live vehicle should be modelled sufficiently accurately that modelling simplifications do not result in unrealistic flows. Experience shows that relatively minor modelling simplifications have the potential to change the position of flow separation and hence to cause substantial changes in the aerodynamic rolling moment.

The underlying shape of the vehicle body should be modelled to a tolerance of - 0,5 % and + 1 % of a given dimension of the body shape. Smooth curved surfaces should be modelled as such, rather than as polygonal approximations, so as to avoid artificial flow separations. Aerodynamically significant features on the train side and roof should be modelled. The surface of the model should be generally smooth, but where there are localised regions of surface roughness on the vehicle these should be simulated. It is less important to model the under body of the train correctly, however the general shape of the under body and the blockage in the bogie region should be represented. The wheels shall be flattened to prevent contact with the ground. The pantograph should in general not be modelled. If the pantograph is included special care shall be taken to exclude local Reynolds number effects at the pantograph. The accuracy of the modelling of the dummy vehicles is not as critical as the live vehicle, but the general principles for the live vehicle should be followed.

It is recommended to build a symmetrical model, even if the full scale vehicle has slight asymmetries e.g. in the underfloor region or on the roof. The advantage is the chance to judge the quality of the wind tunnel by comparing the left side and right side coefficients, which is very valuable information for the error analysis. To verify the symmetry of the incident flow, check measurements should be performed with both positive and negative yaw angles.

5.3.4.10 Instrumentation requirements

The required moment and force coefficients are derived from measured values of wind speed, moments and forces, and calculated air density. These measured values require anemometers, a force balance, a temperature sensor and a pressure sensor.

Speed measurement

The wind speed shall be measured upstream of the model where the wind speed includes boundary layer treatment effects but is not affected by the vehicle model and its environment. Application of blockage corrections may be considered.

Dynamic pressure measurement devices should have an accuracy of better than 2 % and the resolution should be better than 1 %. Air speed measurement devices should fulfil half the above values.

Force and moment balance

The mean forces and moments should be measured using a force and moment balance. The rolling moment about the lee rail should have an accuracy of 5 % at the lowest yaw angle needed for calculation of the CWC.

The model should be designed so that oscillation of the model mounting system will not affect the analysis. If this is not achieved, modifications to the model and mounting should be undertaken. Demonstration of the system dynamic response should be provided in the test documentation.

Calculation of air density

The air density ρ should be calculated from the average measured temperature, and pressure for each (data acquisition) test using the ideal gas law with an specific gas constant of 287 J/(kg·K).

5.3.4.11 Standard ground configuration single track ballast and rail

A properly scaled simulation of the ballast profile and the rails should be provided, to the following level of detail: the underlying shape should be modelled to ± 5 cm full scale and features with full-scale dimensions greater than 10 cm should be modelled. Any smaller features should be modelled as generalised roughness. Notwithstanding the above, individual ballast stones should not be modelled.

Particular care should be taken with the height of the vehicle relative to the rails so that this is accurate to ± 5 cm full scale. The height should vary by no more than ± 2,5 cm full scale when the vehicle is removed and then replaced during the tests. The distance from the upstream end of the ground model to the leading end of the train model (or upstream body) shall be at least 8 m (in full-scale dimensions). Sketches for the reference configuration of single track ballast are shown in Figure 1 and Figure 2.

Dimensions in millimetres

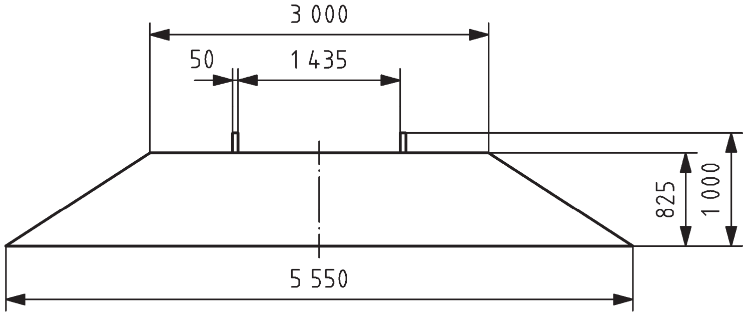
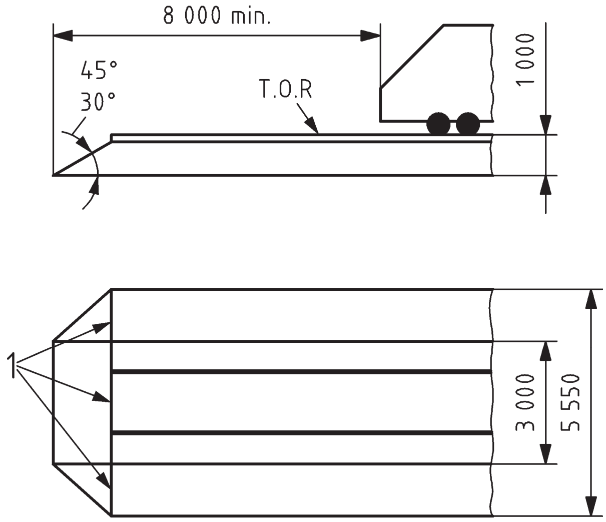


Figure 1 — Sketch of the wind tunnel configuration single track ballast (front view, 1:1 scale)

Dimensions in millimetres



Key

1 edge rounding R = 300

Figure 2 — Sketch of the wind tunnel configuration single track ballast (side and top view, 1:1 scale)

5.3.4.12 Test program requirements

The effect of strong wind on rail vehicles varies not only with train design, but also whether the train is on flat ground or embankments, whether the train is canted or tilted as well as the angle of the wind to the track. It is not possible to test for all these variables and so tests are reduced to the following standard test programme:

— The ground configuration shall be according to 5.3.4.11.

— The measurements relevant for the CWC calculation should be made at a sufficient yaw angle resolution. Additionally, where practical, measurements should also be made at β = 90°.

— For vehicles without an active tilting system, the aerodynamic coefficients shall be measured for the vehicle at a tilting angle of 0° (no tilting). For vehicles with an active tilting system, the aerodynamic coefficients shall be measured for the vehicle at a tilting angle of 0°, at the maximum tilting angle and the minimum tilting angle.

For high speed trains with $v_{max} \geq 250$ km/h, current (and additional) interoperability requirements are set out in Annex A. An overview of test requirements for other approaches is also given in Annex A.

5.3.4.13 Data interpolation

The discrete values of mean force and moment coefficients should be interpolated to obtain continuous representations of these coefficients. The interpolation method should be documented.

5.3.4.14 Documentation

Conformity with all requirements defined in 5.3.4 has to be documented.

5.4 Determination of wheel unloading

5.4.1 General

Various methods are available to determine the wheel unloading on passenger or freight vehicles due to cross wind. Time-dependent multi-body simulation and an advanced quasi-static approach often serve as a part of the proof that the vehicle fulfils given specifications or requirements for rolling stock assessment. Data obtained from a simple method (quasi-static three mass model) are considered to be less precise but conservative because of built-in margins.

5.4.2 Simple method using a two-dimensional vehicle model (three mass model)

5.4.2.1 Application range and restrictions

The simple assessment method is subject to the following restrictions:

— The method is suitable only for vehicles with two sets of running gear or two single axles. Articulated trains, vehicles with Jacobs bogies or similar solutions with transmission of roll moments between car bodies shall not be evaluated with this method.

— The method may be used for tilting trains, but the effects of tilt shall be included in the mass distribution, the suspension characteristics and the body centre of gravity movements due to the added effect of tilt. This modelling shall be appropriate and conservative.

5.4.2.2 General approach

For the calculation of the characteristic wind speed the moment of equilibrium towards the leeward rail is calculated. The procedure relies on four fundamental quantities:

— the restoring moment M_{m} due to the vehicle masses;

— the moment M_{la} due to the uncompensated lateral acceleration;

— the moment M_{CoG} due to the lateral movement of the centre of gravity of suspended masses (due to sway and lateral displacement);

— the aerodynamic moment $M_{x,lee}$ due to the wind load;

The vehicle is considered to consist of three principal masses: the unsprung mass m_0, the primary sprung mass m_1 and the secondary sprung mass m_2.

5.4.2.3 Computation of the characteristic wind speed

Using the coordinate system defined in EN 14067-1 with the exception of the wind from the right in the direction of travel (see Figure 3) the moment of equilibrium towards the leeward (left) rail is given by:

$$\Sigma M = f_{\Delta Q} \cdot \frac{1}{f_{\mathrm{m}}} \cdot M_{\mathrm{m}} + M_{\mathrm{CoG}} + M_{\mathrm{la}} - M_{\mathrm{x,lee}} = 0 \qquad (5)$$

The factor $f_{\Delta Q}$ describes the relative wheel unloading and is fixed to 0,9. The factor f_{m} is a method factor which considers uncertainties in the method. It is larger than 1,0 and for UIC standard gauge (1 435 mm) it shall be chosen according to Table 4.

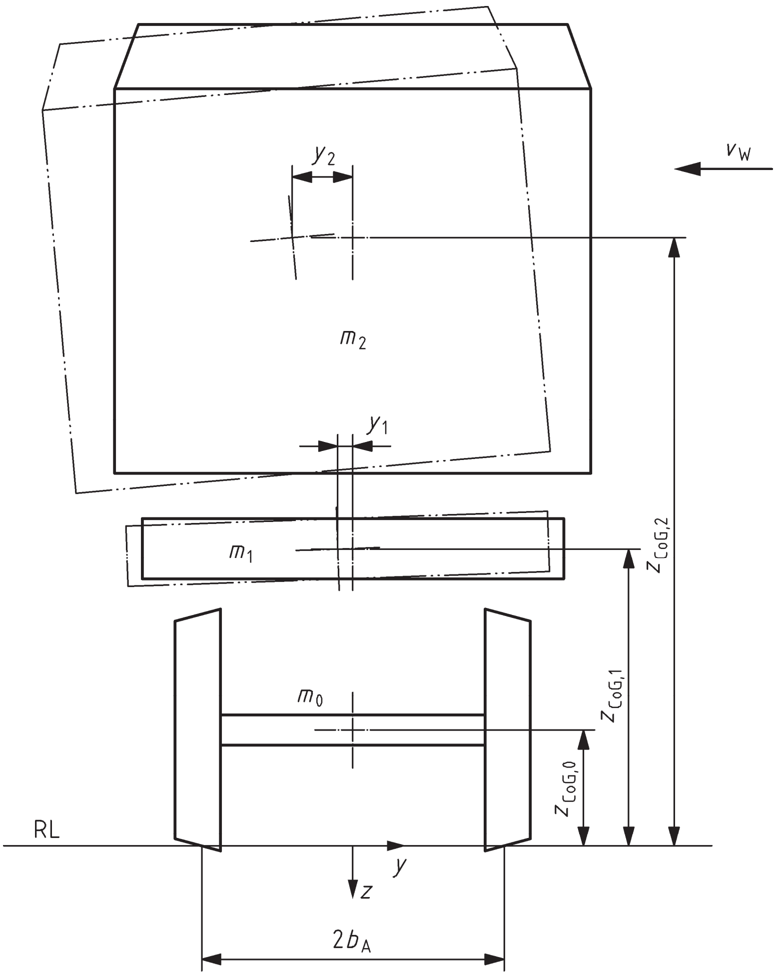


Figure 3 — Illustration of three mass model

Table 4 — Method factor f_{m} for UIC standard gauge (1 435 mm) for various vehicle types

	Passenger vehicles	Freight wagons	Locomotives
Method factor f_{m}	1,20	1,15	1,20

The moments in Equation (5) are calculated according to Equations (6) to (11).

$$M_{\mathrm{m}} = m \cdot g \cdot b_{\mathrm{A}} \quad (6)$$

$$M_{\mathrm{CoG}} = (m_1 \cdot y_1 + m_2 \cdot y_2) \cdot g \quad (7)$$

$$M_{\mathrm{la}} = m \cdot a_{\mathrm{q}} \cdot z_{\mathrm{CoG}} \quad (8)$$

with

- negative values for y_1 or y_2 for movements of the CoG to the left;
- negative values for z_{CoG};
- unsprung masses m_0;
- primary suspended masses m_1:
- secondary suspended masses m_2;
- the total vehicle mass $m = m_0 + m_1 + m_2$;
- the lateral contact spacing (for UIC standard gauge) $2b_{\mathrm{A}}$ = 1,5 m;
- the uncompensated lateral acceleration a_{q}; for a particular curve of radius R_{c} [m] with cant h [m]; $a_{\mathrm{q}} = \frac{v_{\mathrm{tr}}^2}{R_{\mathrm{c}}} - \frac{gh}{2b_{\mathrm{A}}}$
  (R_{c} positive for curve to the right, positive value for h results in rotation of track in direction of x);
- the height of the centre of gravity of the unsprung masses $z_{\mathrm{CoG},0}$ (usually the wheel radius);
- the height of the centre of gravity of the primary sprung masses $z_{\mathrm{CoG},1}$;
- the height of the centre of gravity of the secondary suspended masses $z_{\mathrm{CoG},2}$;
- the height of the centre of gravity of the total vehicle $z_{\mathrm{CoG}} = \left(\frac{m_0 \cdot z_{\mathrm{CoG},0} + m_1 \cdot z_{\mathrm{CoG},1} + m_2 \cdot z_{\mathrm{CoG},2}}{m} \right)$.

NOTE Data (such as height of roll centre, maximum lateral displacement distances, flexibility coefficient (suspension coefficient) needed for the calculation of y_1 and y_2 may be obtained from the assumptions given in the gauge calculation of the vehicle according to EN 15273-2:2009.

The aerodynamic moment induced by the wind is:

$$M_{\mathrm{x,lee}} = \frac{1}{2} \cdot \rho_0 \cdot v_{\mathrm{a}}^2 \cdot A_0 \cdot d_0 \cdot c_{M\mathrm{x,lee}}(\beta) \quad (9)$$

The lee rail rolling moment coefficient $c_{M\mathrm{x,lee}}(\beta)$ shall be made available from wind tunnel tests, from CFD simulations or from calculations using predictive equations (see 5.3).

The relative wind speed and the yaw angle β can be calculated as follows:

$$v_a^2 = (v_w \cdot \cos\beta_w + v_{tr})^2 + v_w^2 \cdot \sin^2\beta_w \qquad (10)$$

$$\beta = \arctan\left(\frac{v_w \cdot \sin\beta_w}{v_{tr} + v_w \cdot \cos\beta_w}\right) \qquad (11)$$

Equations (5) to (11) have to be solved to obtain values for the characteristic wind speed v_W (v_{tr}, a_q, β_W). This may be done by iterative methods.

5.4.3 Advanced quasi-static method

5.4.3.1 General

This clause describes a quasi-static method which considers kinematics of the main bodies of a vehicle. Dynamic effects, e.g. from dampers, are excluded. It has been shown that this method leads to characteristic wind speeds no higher than the method utilising time-dependent multi-body simulation (MBS) presented in 5.4.4. This method is therefore conservative.

The underlying principle is to divide the vehicle into the relevant concentrated masses which are connected with coupling elements. The mechanical system results in a set of equations which can be determined using MBS codes or by explicit formulation of the equations.

5.4.3.2 Computation method

In this method, a quasi-static approach is used for the calculation of characteristic wind curves (CWC) with the main effects and influencing factors on the vehicles' side wind stability being considered.

The following input parameters (bracketed) are required:

— unsprung masses, such as wheel sets (masses, positions of the centres of gravity);

— primary suspended masses, such as bogies, mounted parts (masses, positions of the centres of gravity);

— secondary suspended masses such as car body, tilting technology (masses, positions of the centres of gravity);

— primary and secondary suspension elements (linear or non-linear stiffnesses, positions);

— anti-roll bars (rotational stiffnesses);

— primary and secondary stops in the lateral and vertical directions (position and characteristics);

— wind loads (aerodynamic coefficients);

— influence of tilting technology and/or active transverse centring;

— forces between adjacent cars due to coupling elements.

A model of the system is used for deriving the mathematical formulation which is used for the calculation of the characteristic wind curves (CWC). A simple model (five mass model) is suitable for many vehicles. A simplified vehicle-specific MBS model can be set up for those vehicles for which the simple model is not adequate. Verification shall be carried out for each vehicle model.

The decision on the appropriateness of a five mass model depends on the structure of the vehicle and on the coupling elements to adjacent cars. The five mass model described below is suitable for the CWC calculation for vehicles with the following characteristics:

— vehicle with two sets of running gear;

— no coupling elements to adjacent vehicles or running gear, where major static lateral and vertical forces as well as rolling moments are transferred;

— vehicles with active transverse centring or tilting technology. The influence of the active components on the displacement of the centre of gravity shall be included, with the following aspects being considered:

  — If the active components effect a displacement of the car body's centre of gravity towards the interior of the curve, the displacement of the centre of gravity may be considered and included.

  — If the active components effect a displacement of the car body's centre of gravity towards the exterior of the curve, the displacement of the centre of gravity shall be considered and included.

An example derivation of the mathematical system of equations of a simple five mass model is given in Annex H. The subsequent CWC calculation can be carried out by using suitable software packages.

5.4.3.3 Vehicle model verification

A verification of the vehicle model used should prove that the main vehicle characteristics affecting the side wind stability are represented with sufficient accuracy. The verification of the vehicle model shall be carried out by comparison of the calculation with measured results based on the following values:

— The sums of the axle loads of each bogie are to be compared with the measurements (e.g. by weighing). The deviation from the measurements shall not exceed ± 1 %. If there are several values measured, the mean value should be used.

— The maximum bump stop distance shall be modelled according to the nominal design data.

— The model flexibility coefficient (suspension coefficient) should be compared with that from full-scale tests. The definition of the flexibility coefficient (suspension coefficient) s shall comply with the definition used for kinematic gauge calculation. If more than one value for s is available from the test, the average should be taken. If better model verification methods are available (e.g. static or dynamic measurements of the Q-forces), these may be used instead. The results of the simulation shall lie within the tolerances of the measured values.

— If the verification of the vehicle model calculations are unsatisfactory, the simplified MBS model has to be modified. Modifications of the simplified MBS model will need to be verified according to the above.

5.4.3.4 Calculation of CWC

For the CWC calculation, the equilibrium position of the vehicle shall be determined depending on the external forces acting on the vehicle. The following forces and moments have to be considered:

— mass forces due to the acceleration due to gravity (g) and the uncompensated lateral acceleration (a_q);

— spring forces and bump stop forces due to the suspension and due to anti-roll bars;

— wind forces acting on the car body using the full set of aerodynamic coefficients, neglecting the drag coefficient c_{Fx}.

The stiffness of metallic bump stops has to be considered. A recommended minimum value for the stiffness of the metallic bump stop between car body and bogie is 10^8 N/m.

Depending on the vehicle and wind speed, the following applies to the wind forces and moments:

$$F_i = \frac{1}{2} \cdot A_0 \cdot \rho \cdot v_a{}^2 \cdot c_{Fi}(\beta),\ i = y, z \qquad (12)$$

$$M_i = \frac{1}{2} \cdot d_0 \cdot A_0 \cdot \rho \cdot v_a{}^2 \cdot c_{Mi}(\beta),\ i = x, y, z \qquad (13)$$

The relative airflow velocity is calculated from the wind speed, the train speed and the angle between the wind and track direction according to EN 14067-1.

The relative flow velocity and the yaw angle are calculated as follows (see also EN 14067-1):

$$v_a{}^2 = (v_{tr} + v_W \cos \beta_W)^2 + (v_W \sin \beta_W)^2 \qquad (14)$$

$$\beta = \arctan\left(\frac{v_w \cdot \sin(\beta_w)}{v_{tr} + v_w \cdot \cos(\beta_w)}\right) \qquad (15)$$

When calculating the wheel-rail forces (Q-forces), the displacement of the contact point in the wheel flange direction shall be considered (see Figure 4).

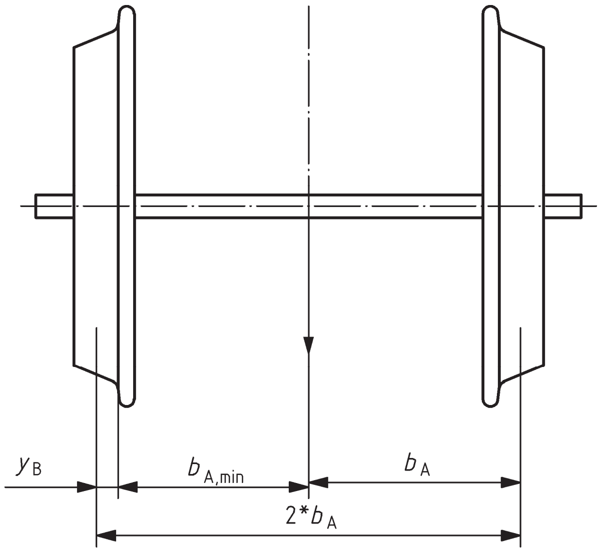


Figure 4 — Illustration of contact point

The value $b_{A,min}$ results from the width between the supports

$2b_A$ = 1,5 m (for nominal track gauge 1 435 mm) (16)

and the maximum displacement of the contact point on the wheel in the wheel flange direction

y_B = 0,028 m (for nominal track gauge 1 435 mm) (17)

so

$$b_{A,min} = b_A - y_B \qquad (18)$$

For the calculation of the characteristic wind curves, the equilibrium position has to be calculated for different wind speeds. The definition of the characteristic wind speed is that wind speed which leads to 90 % wheel unloading (i.e. a residual load of 10 % of Q_0).

5.4.3.5 Process verification

The implementation has to be proven by a process verification.

If the typical five mass model is used, each CWC calculation for a vehicle should include the CWC calculations for the two example vehicles specified in Annex H. The process is proved when the calculated CWC of the vehicles at β_W = 90° deviate by a maximum of ± 0,5 m/s from the CWC of the example vehicles.

5.4.4 Time-dependent MBS method using a Chinese hat wind scenario

5.4.4.1 General

An MBS program shall be used along with a gust scenario. Modelling shall consider the most critical vehicle of the train and that this vehicle is empty (operational mass in working order according to EN 15663). A check shall be made that an even distribution of passengers is not more critical than an empty vehicle (for instance due to centre of gravity shifts), e.g. by using a simplified check with a fully static approach.

If there is no roll restraint at the coupling, only the critical vehicle needs to be modelled, otherwise adjacent vehicles shall be modelled too.

Track irregularities shall not be considered.

For the assessment of interoperable rolling stock, the calculation shall be carried out with standard gauge, rail profile 60E2, new wheel profile and 1/20 and 1/40 rail inclinations. The worst case will be used for assessment against the limits. For the assessment of other rolling stock, the calculation shall be done with the gauge used.

The criterion that defines the CWC is the average value of wheel unloading, ΔQ, of the most critical running gear (bogie or single axle in case of single axle running gear). This unloading shall not exceed 90 % of the average static wheel loads, Q_0, of the running gear as given in the following equation:

$$\frac{\Delta Q}{Q_0} < 0{,}9 \,. \tag{19}$$

The CWC obtained refer to the peak wind of the time-dependent gust.

5.4.4.2 Chinese hat gust scenario

This subclause gives a short description of the gust model. The equations given here refer to a wind direction normal to the track. The full mathematical description for this gust model for all wind directions is given in Annex I.

The gust generated for the method has a fixed amplitude (corresponding to a probability level of amplitude ~ 99 %) and a probability level of exceedance of 50 % for the gust duration (the mode of the distribution). Furthermore, the chosen approach has the following characteristics:

— The gust time-space model (bi-exponential) corresponds to an approximation of the average of a random process in the vicinity of a local maximum (see Figure 5).

— The mean wind is assumed to be horizontal; only the along wind component U is used. This component represents the prominent part of wind fluctuations and is the projection of the instantaneous wind vector in the mean wind direction.

— Variations of wind direction in the period of the gust are not taken into account.

— Temporal variations are neglected in favour of spatial variations, i.e. the gust is not convected with the mean wind speed.

The input data for the scenario are:

v_{tr} train speed,

U_{max} maximum wind speed,

β_W wind direction with respect to the line.

The following parameters are fixed:

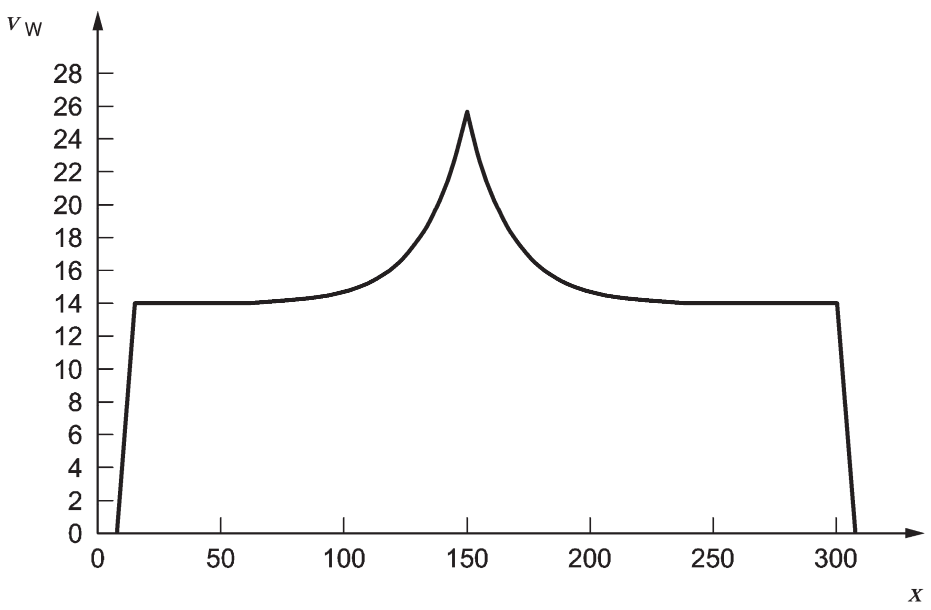
z = 4 m reference height,

$\widetilde{A}$ = 2,84 normalized gust amplitude $\widetilde{A} = (U_{max} - U)/\sigma_u$ with mean wind speed U,

z_0 = 0,07 m roughness height of sites representative of interoperable lines,

$Pr(T)$ = 0,5 probability of a gust of duration T for a given amplitude.

For the calculation of the characteristic wind curves (CWC), the spatial distribution of the wind is described with a mathematical model, with the shape plotted in Figure 5.



Key

x space, in m

v_W wind speed, in m/s

Figure 5 — Example of the spatial distribution of the wind using a Chinese hat gust model

The wind gust is fixed in space. It is assumed that the train velocity is constant, thus the temporal distribution can be evaluated from the spatial one by transformation.

The mean wind speed is calculated from the maximum wind speed:

$$U_{\text{mean}} = \frac{U_{\text{max}}}{1{,}6946} \tag{20}$$

The power spectral density is calculated from:

$$S_{\text{u}}(n) = \frac{22{,}9839\ \text{m} \cdot U_{\text{mean}}}{\left(1 + 652107\,\text{m}^2 \cdot \left(\frac{n}{U_{\text{mean}}}\right)^2\right)^{\frac{5}{6}}} \tag{21}$$

where the frequency range is limited to n = [1/300 Hz,1 Hz].

The characteristic frequency f for of the gust is the integral:

$$f = 0{,}239091 \cdot \left[\frac{\int_{1/300}^{1} n^2 \cdot S_{\text{u}}(n)dn}{\int_{1/300}^{1} S_{\text{u}}(n)dn}\right]^{0{,}5} \tag{22}$$

which can be solved numerically (see Annex I, I.1). e.g. by performing a trapezoidal numerical integration using a resolution of at least Δn = 1/300 Hz

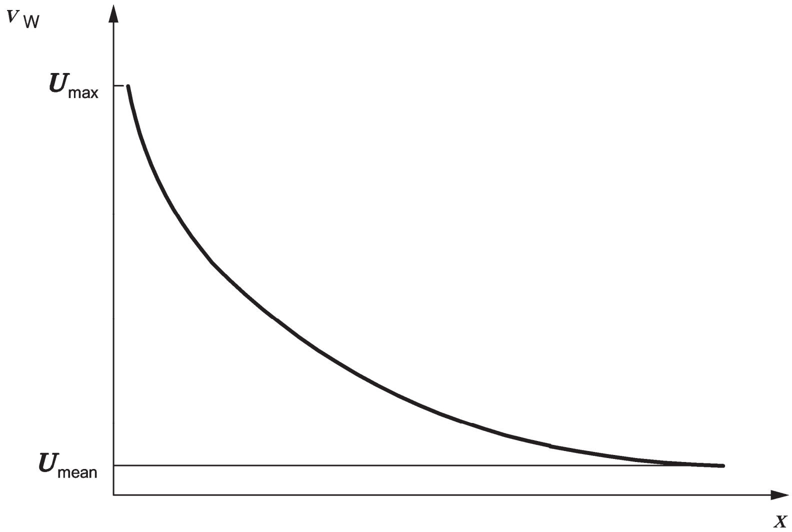
The wind speed normal to the vehicle along the track can be calculated from:

$$v_{W-90} = U_{\text{mean}} \cdot \left(1 + 0{,}6946 \cdot C_{90}\right) \tag{23}$$

where $C_{90} = e^{\frac{-16 \cdot f \cdot \tilde{x}}{U_{\text{mean}}}}$ (24)

and $\tilde{x}$ represents the spatial distance towards the position of the maximum amplitude of the gust.

The mathematical description only refers to the second half of the Chinese hat where the wind decays from U_{max} to U_{mean} Since the exponential decay does not reach the level of the mean wind speed U_{mean} at any instant, the Chinese hat shall be confined to an appropriate region (see Figure 6):



Key

x space

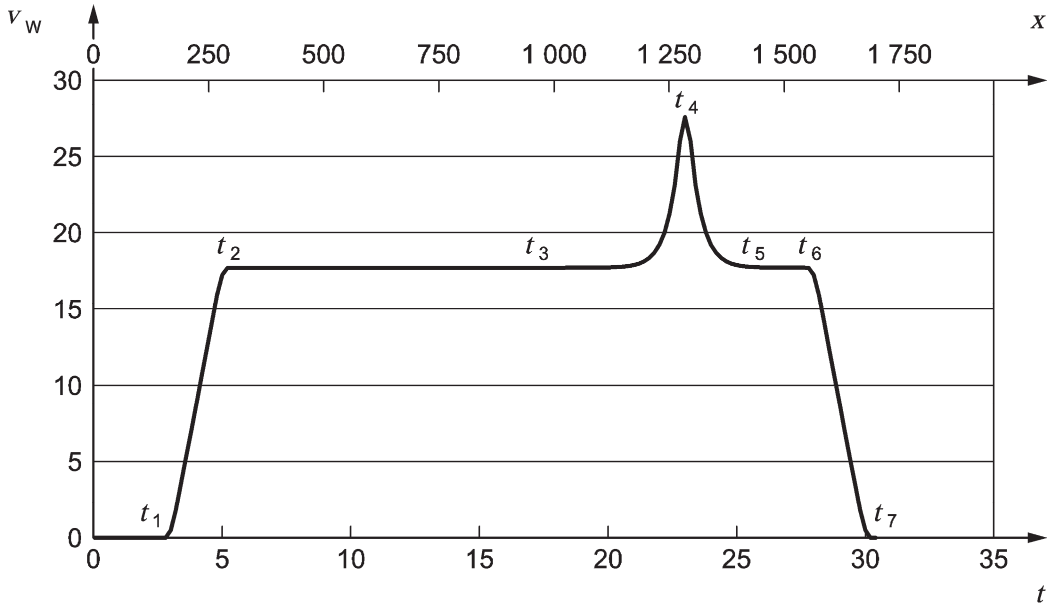
v_W wind speed

Figure 6 — Illustration of wind decay within Chinese hat gust model

For practical implementation, the exponential decay is assumed to have reached the lower limit if there is less than 1 % deviation between U_{mean} and the calculated wind speed. For the complete representation of the Chinese hat, mirroring is necessary in the y axis.

The wind gust shall be low-pass filtered using a moving spatial average based on a window size equal to the vehicle length and a step size smaller than 0,5 m.

The scenario consists of a base level wind speed, followed by the rising wind speed part of the Chinese hat. This is then followed by the decaying part and then the base level wind speed once again. In order to get repeatable results in the time-dependent MBS simulations, the vehicle has to be in a steady wind load state. For this reason the scenario consists of the following in terms of temporal distribution (see Figure 7, example as in Annex I, I.2):



Key

x, in m

v_W, in m/s

t, in s

Figure 7 — Application of Chinese hat wind scenario: Example of temporal wind distribution for v_{tr} = 200 km/h, v_W = 30 m/s, vehicle length = 24 m

Up to t_1 there is no wind. From t_1 to t_2 there is a linear rise until the base level U_{mean} is reached. The vehicle has to be in a steady wind loading state between t_2 and t_3, before the second rise of the wind speed begins. For this either the constant value of the base level may be applied or the mirrored Chinese hat scenario with a deviation between U_{mean} and the calculated wind speed of less than 1 % may be used. After t_3 the rise follows the mirrored Chinese hat up to the maximum at t_4. After the maximum, the wind decays according to the Chinese hat function to t_5. Time t_6 can be chosen equal to t_5. In case t_6 is chosen $t_6 \neq t_5$, the wind stays at the base level once again from t_5 to t_6. From t_6 on there is a linear fall, until at t_7 the wind scenario is finished. The wind scenario in the different intervals is described by the functions given in Table 5:

Table 5 — Functions for the Chinese hat gust model

Interval	Function
$[t_0:t_1]$	$u(t) = 0$
$[t_1:t_2]$	$u(t) = \frac{U_{mean}}{t_2 - t_1} \cdot (t - t_1)$
$[t_2:t_3]$	$u(t) = U_{mean}$
$[t_3:t_4]$	$u(t)$ = mirrored Chinese hat; t_3: deviation between U_{mean} and the calculated wind speed of less than 1 %
$[t_4:t_5]$	$u(t)$ = Chinese hat; t_5: deviation between U_{mean} and the calculated wind speed of less than 1 %
$[t_5:t_6]$	$u(t) = U_{mean}$
$[t_6:t_7]$	$u(t) = \frac{U_{mean}}{t_7 - t_6} \cdot (t_7 - t)$

For articulated trains, vehicles with Jacobs bogies or similar solutions with transmission of roll moments between car bodies, one single gust is considered and each car body will be submitted to either the mean wind or the gust. As the gust is being fixed in space there will be a time delay between the application of the forces and the moments resulting from the gust acting on each vehicle. This time delay depends on the distance between two adjacent car bodies and the train speed. This distance is defined as the distance of the geometrical centres (considered longitudinally) of two adjacent car bodies.

Filtering of the gust has to be done separately for each car body considering the length of this car body.

The specific scenario for articulated train set can be defined on the basis of the one presented in Figure 5. Up to t_1 there is no wind applying onto the train, from t_1 to t_2 there is a linear rise until the base level U_{mean} is reached. All the vehicles of the train have to be in the steady wind loading state between t_2 and t_3, before the second rise of the wind speed begins. After t_3, the rise follows the mirrored Chinese hat until t_4. After the maximum, the wind decays according to the Chinese hat function to t_5. Time t_6 is reached when the rear of the last vehicle of the train is again fully submitted to the mean wind.

5.4.4.3 Vehicle model setup

The modelling of the vehicle shall be adequate for the investigation of cross wind characteristics. The dynamic model of the vehicle shall be 3D and shall incorporate at least the following features:

- Car body, bogies and wheel sets and other relevant parts of the vehicle (masses, inertias, position of centres of gravity);
- Suspensions (stiffness of the springs in the vertical, lateral and longitudinal directions, non-linearity in stiffness, damping characteristics in the vertical and lateral directions, damping non-linearity, position);
- Bump stops which could come into play;
- Wheel/rail contact, contact forces calculated featuring nonlinear contact geometry and creep force/creep relation. Any special further device in the suspension system which might have an effect on the overturning mechanism.

5.4.4.4 Vehicle model verification

A verification of the vehicle model used should prove that the main vehicle characteristics affecting the side wind stability are represented with sufficient accuracy. The verification of the vehicle model shall be carried out by comparison of the calculation with measured results based on the following values:

— The sums of the axle loads of each bogie are to be compared with the measurements (e.g. by weighing). The deviation from the measurements shall not exceed ± 1 %. If there are several values measured, the mean value should be used.

— The maximum bump stop distance shall be modelled according to the nominal design data.

— The model flexibility coefficient (suspension coefficient) should be compared with that from full-scale tests. The definition of the flexibility coefficient (suspension coefficient) s shall comply with the definition used for kinematic gauge calculation. If more than one value for s is available from the test, the average should be taken. If better model verification methods are available (e.g. static or dynamic measurements of the Q-forces), these may be used instead. The results of the simulation shall lie within the tolerances of the measured values.

— If the verification of the vehicle model calculations are unsatisfactory, the MBS model has to be modified. Modifications of the MBS model will need to be verified according to the above.

5.4.4.5 Input of aerodynamic forces and moments

Calculations of the vehicle responses to gusts defined by their maximum speed U_{max} shall be computed for increasing values of U_{max} until the criterion of unloading is met. The corresponding plots of U_{max} values, which just cause maximum unloading criterion to be met, against the vehicle speed and/or wind angle are called characteristic wind curves (CWC). The presentation of CWC is described in detail in 5.5.

The simulation of the vehicle response to a gust shall be performed using the gust scenario described in 5.4.4.2.

The five components of forces and moments (F_y, F_z, M_x, M_y and M_z) shall be calculated using the following equations:

$$\left.\begin{aligned} F_{\mathrm{i}}(t) &= \frac{1}{2}\rho\, A_0\, c_{Fi}(\beta(t))\, v_{\mathrm{a}}^2(t) \\ M_{\mathrm{i}}(t) &= \frac{1}{2}\rho\, A_0\, d_0\, c_{Mi}(\beta(t))\, v_{\mathrm{a}}^2(t) \end{aligned}\right\},\ i \in \{x, y, z\} \qquad (25)$$

$$\left.\begin{aligned} v_{\mathrm{a}}(t) &= \sqrt{\left(v_{\mathrm{tr}} + v_{\mathrm{w}}(t)\cos\beta_{\mathrm{w}}\right)^2 + \left(v_{\mathrm{w}}(t)\sin\beta_{\mathrm{w}}\right)^2} \\ \beta(t) &= \arctan\left(\frac{v_{\mathrm{w}}(t)\sin\beta_{\mathrm{w}}}{v_{\mathrm{tr}} + v_{\mathrm{w}}(t)\cos\beta_{\mathrm{w}}}\right) \end{aligned}\right\} \qquad (26)$$

It shall be proven that the integration method calculates an integration step at the maximum wind peak. The output step size of the calculation shall be lower than 1/30 s.

5.4.4.6 Calculation of CWC

5.4.4.6.1 Evaluation of the criterion

From each simulation run of the parameter variation time data of the Q-forces for each wheel are obtained.

The following calculation steps are needed:

— Calculation of the $\Delta Q/Q_0$ values by the time-data of Q-forces:

$$\frac{\Delta Q}{Q_0} = 1 - \frac{Q_{i1} + Q_{j1}}{2 \cdot Q_0} \quad (27)$$

— Low-pass filtering of $\Delta Q/Q_0$ with a 2 Hz 4th order Butterworth filter, or another filter shown to be equivalent.

— Identification of the maximum $\Delta Q/Q_0$ value over the running gear.

Herein Q_0 are the Q-forces for the empty (unloaded) vehicle without any excitation, Q_{i1} are the Q-forces of the unloaded wheel of the first wheel set in the bogie and Q_{j1} are the Q-forces of the unloaded wheel of the second wheel set in the bogie.

5.4.4.6.2 Calculation of the effect of curves

For curved track the centrifugal force is assumed to act in addition to the crosswind on the vehicle.

The calculation shall be performed using MBS on straight track, canted according to a_q values.

5.4.4.6.3 Relative wind-angle decomposition method

For trains that do not show strong vehicle dynamic dependence with train speed, the computed characteristic wind velocities can be transferred to other combinations of train speeds and angles.

Usually the characteristic wind velocity is given for a wind angle of 90° to the track. To obtain the CWC for other wind angles, train speeds and wind speeds, a geometric decomposition/addition of the velocity vectors has to be carried out first (see Figure 8).

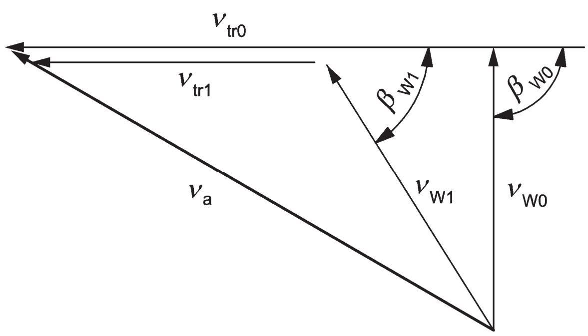
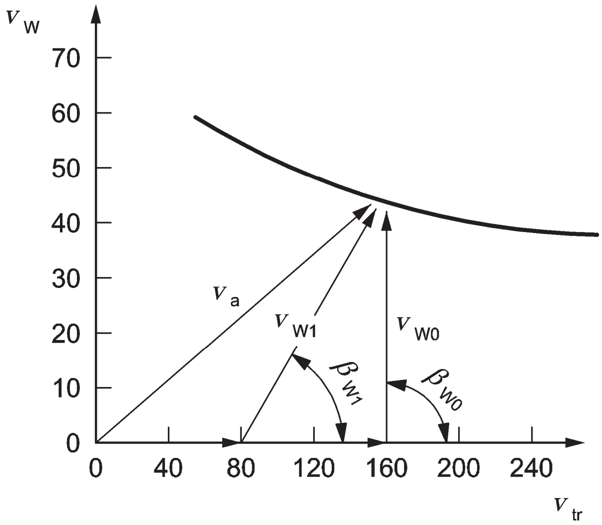


Figure 8 — Illustration of geometric approach considering the angle of attack

Here, v_a is the resultant wind acting on the vehicle. A decomposition of v_a into a component coming from the train speed (v_{tr0} and v_{tr1}) and a component coming from the wind speed (v_{W0} and v_{W1}) can be made in various ways. For the vector chain v_{W0} and v_{tr0} the wind angle is β_{W0}, and for the vector chain v_{W1} and v_{tr1} the wind angle is β_{W1}. For straight track, the wind velocity for different angles of attack can be directly drawn out in a diagram. An example is illustrated in Figure 9. Here β_{W1} = 60° and β_{W0} = 90°.



Key

v_{tr} vehicle speed v_{tr}, in km/h

v_W wind speed, in m/s

Figure 9 — Illustration of geometric approach considering the angle of attack of CWC on straight track

5.5 Presentation form of characteristic wind curves (CWC)

5.5.1 General

The CWC of a train is needed to help a railway operator to evaluate whether the train's operation on a line is safe. For this purpose, train builders shall give the CWC that their train has to withstand. Subclause 5.5.2 presents the requirements for vehicles other than freight wagons, subclause 5.5.3 presents the requirements for freight wagons.

5.5.2 CWC presentation form for passenger vehicles and locomotives

The CWC presentation form shall include the following information:

— vehicle type and main dimensions,

— whether vehicle is in active tilting or non-tilting mode,

— method used to determine the aerodynamic coefficients (prediction formula, CFD, wind tunnel tests),

— vehicle dynamic method used to compute the CWC (simple quasi-static method, advanced quasi-static method, time-dependent multi-body simulation),

— track configuration (standard gauge or alternative) and rail inclination.

For passenger vehicles and locomotives in non-tilting mode, the CWC table shall be put in the form given in Table 6:

Table 6 — Form for CWC table for passenger vehicles and locomotives in non-tilting mode

Train speed (in km/h)	**CWC (in m/s) for angle β_W**								
	90°	**80°**	**70°**	**60°**	**50°**	**40°**	**30°**	**20°**	**10°**
80									
90									
100									
110									
120									
130									
… (minimum Δv_{tr} = 20 km/h)									
Maximum train speed									
The tables shall be provided for a_q = 0 m/s², a_q = 0,5 m/s² and a_q = 1 m/s² The values shall be given to one significant decimal.									

For trains that may be operated in active-tilting mode, the additional CWC table shall be put in the form given in Table 7:

Table 7 — Form for CWC table for trains in active tilting mode

Train speed (in km/h)	**Max. active tilting angle:**								
	Wind direction / curve								
	CWC (in m/s) for angle β_W								
	90°	**80°**	**70°**	**60°**	**50°**	**40°**	**30°**	**20°**	**10°**
80									
90									
100									
110									
… (minimum Δv_{tr} = 20 m/s)									
Maximum train speed									
The tables shall be provided for a_q = 1,0 m/s².... $a_{q\text{-}max}$ (Δa_q = 0,5 m/s²). These tables shall be provided for the following two wind directions: from inside the curve and from outside the curve. The values shall be given to one significant decimal.									

In Table 6 and Table 7, the grey cells shall be completed. It is also desirable to complete the white cells and to provide additional tables for a_q values different from those stated above. White cells may be completed by using the method described in 5.4.4.6.3 for additional train speeds and wind angle cases. The characteristic wind velocities corresponding to other uncompensated accelerations may also be obtained by linear interpolation; in the case of negative a_q, they may be obtained by inference from the positive a_q values and a_q = 0 m/s^2.

When time-dependent MBS methods are applied, the characteristic wind velocities corresponding to the other train speeds, from 80 km/h to $v_{tr,max}$ for the 90° wind angle case, may be obtained by linear interpolation using the MBS-calculated results above.

5.5.3 CWC presentation form for freight wagons

The CWC presentation form shall include the following information:

- vehicle type and main dimensions,
- method used to determine the aerodynamic coefficients (prediction formula, CFD, wind tunnel tests),
- vehicle dynamic method used to compute the CWC (simple quasi-static method, advanced quasi-static method),
- track configuration (standard gauge or alternative) and rail inclination.

For freight wagons the CWC table shall be put in the form given in Table 8:

Table 8 — Form for CWC table for freight wagons

Train speed (in km/h)	CWC (in m/s) for angle β_W								
	90°	80°	70°	60°	50°	40°	30°	20°	10°
80									
90									
100									
110									
… (minimum Δv_{tr} = 20 km/h)									
Maximum train speed									
The tables shall be provided for a_q = 0 m/s^2 , a_q = 0,4 m/s^2 and $a_{q\text{-}max}$ = 0,85 m/s^2 according to EN 14363. The values shall be given to one significant decimal.									

The grey cells shall be completed. It is also desirable to complete the white cells and to provide additional tables for a_q values different from those stated above. White cells may be completed by using the method described in 5.4.4.6.3 for additional train speeds and wind angle cases.

The characteristic wind velocities corresponding to other uncompensated accelerations may also be obtained by linear interpolation; in the case of negative a_q, they may be obtained by inference from the positive a_q values and a_q = 0 m/s².

6 Method to acquire the needed railway line data

6.1 General

A universal railway database format is necessary to ensure that a risk analysis can be undertaken from the geographic configuration and the associated CWC.

6.2 Presentation form of railway line data

6.2.1 General

The train is considered driving in the forward direction if the line kilometres increase. The return driving direction will be called “backward direction”. The handedness (left or right) is designated in the direction of increasing kilometres. The orientation of the line, defined in the forward direction and in a clockwise system, is expressed relative to the geographic north, e.g. 90° corresponds to east.

The following subclauses give all relevant information which is needed to describe the line according to the cross wind issues. In order to simplify the work for the line database construction, each subclause is focused on a limited set of parameters. In 6.2.7, a concatenation of all the previous parameters into only one database is given. The minimum requirement on line data in terms of accuracy and uncertainty is given in 6.2.8.

6.2.2 Plan profile

The plan profile has to be documented as follows. Homogeneous route elements are defined as a straight line, a transition curve or a curve. The length of each homogeneous element has to be documented as well as the start radius and cant. For curves, transition curves and alignments, the radius and cant at the end of the section has to be entered in Table 9 as well. In Table 9, index 1 indicates the information for the beginning of an element that has to be documented, while index 2 stands for the end of an element. With this information, a transition curve can be approximated by linear interpolation of radius and cant. The sign of the radius defines the orientation of the curve in the forward direction: a right-orientated curve has a positive radius and left-orientated curve has a negative radius. The alignment shall be identified by an infinite radius and a zero cant. The orientation of each element has to be given, for curves the orientation at the beginning of the element has to be stated.

The coordinate system used (e.g. Gauß-Krüger) and all useful information of this coordinate system (e.g. the origin) have to be stated.

The following information at the starting point of the line shall be given:

— starting kilometre;

— coordinates in x and y;

— orientation related to the geographic north.

For double track lines it is usually sufficient to consider the track geometry (radius, cant, coordinates and line orientation) only for one track (lines running parallel with significant large curve radii). It should be indicated which track is referred to. In case of tracks with a separation larger than 20 m, a second sheet with all necessary information shall be provided.

All information relevant for the line plan profile description shall be documented by completing Table 9.

Table 9 — Layout for plan profile parameters

<table>
<tr><th>Connection</th><th>Line section</th><th>Line-No.</th><th>Start-km</th><th>End-km</th><th>Total Length</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="3">Coordinate system used</td><td colspan="3">At the starting line kilometre</td></tr>
<tr><td>x coordinate</td><td>y coordinate</td><td>Orientation/north</td></tr>
<tr><td>[m]</td><td>[m]</td><td>[°]</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Line-km</td><td>Element length</td><td>Radius 1</td><td>Radius 2[a]</td><td>Cant 1</td><td>Cant 2[a]</td><td>Orientation/north</td></tr>
<tr><td>[km]</td><td>[km]</td><td>[m]</td><td>[m]</td><td>[mm]</td><td>[mm]</td><td>[°]</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">[a] To be completed only in case of transitions.</td></tr>
</table>

6.2.3 Vertical profile

Homogeneous route elements are defined by the element type:

— level ground;

— embankments;

— cuttings;

— tunnels;

— viaducts.

In order to simplify the database, homogeneous route elements should be defined by track height category. For each homogeneous route elements, its starting line kilometre and its length and the ground surrounding height (altitude) have to be documented. The height of the ballast bed shall not be taken into account when determining the track height. For a longitudinal resolution of a homogeneous part of the line (same kind of line, same roughness), the mean of the different heights is the representative one.

Minimum resolutions and accuracies are given in 6.2.8.

To obtain the position of cuttings, embankments, tunnels and viaducts construction drawings can be used.

Embankment and viaduct heights (respectively cutting depths measured from top of rail) are quoted with positive (respectively negative) sign in metres for both sides of the line.

Track heights in homogeneous sections consisting of tunnels are not needed.

All information relevant for the line vertical profile description shall be documented by completing Table 10.

Table 10 — Layout for vertical profile parameters

Connection	**Line section**	**Line-No.**	**Start-km**	**End-km**	**Total Length**

Line-km	Element length	x coordinate of line km	y coordinate of line km	Track height category		Track type [a]		Altitude above sea level
				Resolution				
				Left	Right	Left	Right	
[km]	[km]	[m]	[m]	[m]	[m]			[m]

[a] **Possible track type:**

E1: embankment with a 2/3 slope

E2: embankment with 1/2 slope

C: cutting

V : viaduct

L: level track

6.2.4 Track design speed

The track design speeds have to be listed. Homogeneous route elements are defined by elements for which the track design speed is constant. Track design speed shall be given for both running directions. For each homogeneous route element, its starting line kilometre and its length have to be documented. For lines built for tilting train operation, the design speed for both normal trains and tilting trains has to be stated.

All information relevant for the track design speed shall be documented by completing Table 11.

Table 11 — Layout for track design speed

Connection	**Line section**	**Line-No.**	**Start-km**	**End-km**	**Total Length**
Train operation mode (normal, active tilting):					
Forward direction			Backward direction		
Line-km	Element length	Design speed	Line-km	Element length	Design speed
[km]	[km]	[km/h]	[km]	[km]	[km/h]

6.2.5 Walls

Walls can be neglected unless they are necessary side wind protection measures (or if an investigation is needed to derive future reference values for crosswind safety). Walls are vertical surfaces or fences with a porosity of 0 %. If walls have a different porosity, this has to be stated in the column “remark on wall design” as well as the wall design type and the influence of this particular design on the wind distribution. The position of the wall on the left-hand and/or the right-hand side of the track, its starting line kilometre, its length, its distance and its height has to be stated.

Minimum resolutions and accuracies are given in 6.2.8.

All information relevant to the description of protective walls shall be documented by completing Table 12.

Table 12 — Layout for wall

Connection	**Line section**	**Line-No.**	**Start-km**	**End-km**	**Total Length**

Line-km	Element length	Wall distance from furthest track centre line		Wall height above top of rail		Remark on wall design
		Left	Right	Left	Right	
[km]	[km]	[m]	[m]	[m]	[m]	

6.2.6 Meteorological input data for line description

The geographical and topographic data of the region surrounding the line shall be collected. These data are relief data and terrain roughness. The situation of the studied line (zone of strong relief or not, zone of strong wind exposure or not) can have a big influence on the meteorological analysis.

The terrain roughness class shall be documented for predefined sectors. The number of sectors is dependent on the resolution along the line. A categorisation in two sectors (left and right hand side of the line) is permitted. A higher resolution into e.g. 90° sectors or 30° sectors is recommended. The classification name of the roughness should be given according to EN 1991-1-4. If additionally other roughness classifications are used, a definition of this classification shall be provided.

All information relevant for the meteorological description shall be documented by completing Table 13.

Table 13 — Layout for line database: meteorological part

<table>
<tr><th>Connection</th><th>Line section</th><th>Line-No.</th><th colspan="2">Start-km</th><th>End-km</th><th colspan="2">Total Length</th></tr>
<tr><td></td><td></td><td></td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Reference of the map</td><td rowspan="3">Coordinate system used</td><td colspan="6">At the starting line kilometre</td></tr>
<tr><td colspan="2">x coordinate</td><td colspan="2">y coordinate</td><td colspan="2">Orientation/north</td></tr>
<tr><td colspan="2">[m]</td><td colspan="2">[m]</td><td colspan="2">[°]</td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="2">Line-km
[km]</td><td colspan="6">Name of classification
Roughness (class)</td></tr>
<tr><td colspan="3">left of track</td><td colspan="3">right of track</td></tr>
<tr><td colspan="2"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="2"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="2"></td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

6.2.7 Integrated line database

The integrated line database format is the concatenation of the five previous databases. The guiding principle to build this final database is to redefine homogeneous sections via the superposition of those given in the previous subclauses.

To build this integrated database, it is recommended to:

1) copy all the different homogeneous elements of the previous tables with respect to the proposed layout for the integrated database,

2) sort out the information with respect to the line kilometre at the start of the homogeneous elements and erase their length,

3) copy unchanged data for all new homogeneous element beginning at the starting kilometre of the line,

4) calculate the new homogeneous element length.

The layout for the integrated line database is given in Table 14.

Table 14 — Layout for integrated line database

Connection	Line section	Line-No.	Start-km	End-km	Total length

Train operation mode (normal or active tilting)	Coordinate system used	At the starting line kilometre		
		x-coordinate	y-coordinate	Orientation/north
Reference of the map		[m]	[m]	[°]

				Radius		Cant			Track height category: resolution [m]		Track type			Design speed		Wall distance from furthest track centre line		Wall height above top of rail		Remarks on wall design		Roughness (class) Name of classification	
Line-km	Element length	x coordinate	y coordinate	Radius 1	Radius 2	Cant 1	Cant 2	Orientation to north	Left	Right	Left	Right	Altitude above sea level	Forward direction	Backward direction	Left	Right	Left	Right	Left	Right	Left of track	Right of track
[km]	[km]	[m]	[m]	[m]	[m]	[mm]	[mm]	[°]	[m]	[m]			[m]	[km/h]	[km/h]	[m]	[m]	[m]	[m]				

6.2.8 Required minimum resolution/accuracy

The minimum resolution/accuracy of various parameters of railway line data is given in Table 15.

If data with higher resolution and accuracy is available, it should be used and stated.

Table 15 — Required minimum resolution/accuracy

Item	Value [m]
Resolution of track height relative to ground [a]	2
Accuracy of track height	± 1
Track altitude	100
Longitudinal resolution	50
Minimum length of topographical features	50
Minimum length of presence of tunnels, embankments, cuttings, viaduct	50
Accuracy of longitudinal position (starting kilometre and total length) of topographic features, embankments, cuttings	± 50
Accuracy of longitudinal position of viaducts, tunnels, walls	25
Resolution of wall height above top of rail	0,5
Accuracy of wall height	± 0,25
Minimum length of wall	50
Resolution of distance from the wall to the furthest track centreline [b]	10
Resolution of terrain roughness zone in longitudinal track direction	250
Lateral extension of area next to line investigated for classification of terrain roughness zone	200
[a] Cuttings deeper than 10 m may be considered to be tunnels.	
[b] Walls further away than 20 m from the furthest track centreline may be neglected.	

7 Methods to assess the wind exposure of a railway line

Although there are several national approaches established, there is not yet a European-wide agreed method. General information on the subject is given in Annex L (see also [11]).

8 Methods to analyse and assess the cross wind risk

Although there are several national approaches established, there is not yet a European-wide agreed method (see also [11]).

9 Required documentation

9.1 General

The determination and assessment of the CWC require detailed documentation, which indicates and explains the underlying parameters, the assumptions made and the conclusions drawn.

9.2 Assessment of cross wind stability of passenger vehicles and locomotives

The required documentation has to contain at least the following:

- documentation about the identification of the most sensitive vehicle wagon within the train set;
- description of the vehicle, including the vehicle type identification;
- description of the permissible a_q range of that vehicle;
- the aerodynamic coefficients and the lee rolling moment coefficient versus yaw angle;
- vehicle height and length, including source references if the aerodynamic coefficient for the lee rail moment have been obtained by means of predictive formulae (5.3.2);
- a report according to 5.3.3.12, if the aerodynamic coefficients have been obtained by means of CFD;
- a report according to 5.3.4.14, if the aerodynamic coefficients have been obtained by means of wind tunnel measurements;
- a documentation of the determination of wheel unloading and the source of the basic vehicle model parameters used;
- a documentation of the vehicle model verification and the vehicle mass determination (e.g. the report on the vehicle dynamic model and the test report of running tests according to EN 14363), if an advanced quasi-static method or a time-dependent multi-body simulation is used;
- CWC in the presentation form as defined in 5.5.2.

9.3 Assessment of cross wind stability of freight vehicles

The required documentation has to contain at least the following:

- documentation about the identification of the most sensitive vehicle wagon within the train set;
- description of the vehicle, including the vehicle type identification;
- description of the permissible a_q range of that vehicle;
- the aerodynamic coefficients and the lee rolling moment coefficient versus yaw angle;
- vehicle height and length, including source references if the aerodynamic coefficient for the lee rail moment have been obtained by means of predictive formulae (5.3.2);
- a report according to 5.3.3.12, if the aerodynamic coefficients have been obtained by means of CFD;
- a report according to 5.3.4.14, if the aerodynamic coefficients have been obtained by means of wind tunnel measurements;

- a documentation of the determination of wheel unloading and the source of the basic vehicle model parameters used;

- CWC in the presentation form as defined in 5.5.3.

9.4 Acquisition of railway line data

The railway line data shall be documented with the help of the tables provided in 6.2. The source of the infrastructure data including the date should be documented.

Annex A
(informative)

Application of methods to assess cross wind stability of vehicles within Europe

Annex A provides information on how the various methodological elements with respect to cross wind stability of vehicles presented in this European Standard are currently applied in Europe to carry out cross wind studies. Table A.1 and Table A.2 display the cross wind study approaches according to:

— the Technical Specification for Interoperability of high speed rolling stock (TSI HS RST, issue 2008);

— the DB guideline Ril 80704 [1], which is required by the German railway authority EBA for German rolling stock assessment;

— the RSSB standard GM/RC2542 [2]. Railway Group Standard GM/RT2142 [3] "Resistance of Railway Vehicles to Roll-over in Gales" mandates safety criteria for railway vehicles to ensure safe operation when operating under gale conditions on Network Rail controlled infrastructure. The Rail and Safety Standards Board standard GM/RC2542 gives recommended methods for wind tunnel testing railway vehicles in order to meet the requirements of GM/RT2142.

Table A.1 — Application of methodological elements for rolling stock assessment purpose within Europe (aerodynamic assessment)

	TSI HS RST	DB Ril 80704	RSSB standard GM/RC2542	
Application range	High speed trains with speed $v_{tr} \geq 250$ km/h (class 1 vehicle)	All passenger trains with speed $v_{tr} > 140$ km/h (trains at standard cant deficiency and trains at greater than standard cant deficiency)	Trains at standard cant deficiency	Trains at greater than standard cant deficiency
			All passenger and freight trains	Tilting trains
CWC requirement	CWC using: Flat ground with 235 mm gap (see D.1) 6 m standard embankment configuration (see D.3, or transformation from 1 m ballast and rail CWC in D.2)	CWC using flat ground with 235 mm gap (see D.1)	Not mentioned	Not mentioned
Wind tunnel benchmark test	Mentioned	Not mentioned	Mentioned	Mentioned
Assessment of aerodynamic coefficients	Stationary coefficients from wind tunnel tests according to 5.3.4 if not indicated differently	Stationary coefficients from wind tunnel tests according to 5.3.4 if not indicated differently	Stationary coefficients from wind tunnel tests according to 5.3.4 if not indicated differently	Stationary coefficients from wind tunnel tests according to Annex G if not indicated differently
Blockage	Shall be < 10 %	< 5 % (<15% with correction for blockage in open test sections)	Shall be < 15%, blockage correction applied	Shall be < 3% for ballast and rail case, blockage correction applied Shall be < 23% with embankment model (if included), blockage correction applied

Table A.1 *(continued)*

	TSI HS RST	DB Ril 80704	RSSB standard GM/RC2542	
Turbulence level	≤ 2,5 %	≤ 2,5 %	≤ 2,0 %	Turbulence profiles prescribed in lower boundary layer
Wind tunnel block profile flow	Block profile; the boundary layer shall be small compared to the vehicle height	Block profile; the boundary layer shall be small compared to the vehicle height	Block profile; the boundary layer shall be minimised	Atmospheric boundary layer
Reynolds number	No criterion	> 600 000	> 250 000 (Re based on vehicle height)	> 200 000 (Re based on vehicle height)
Reynolds number independency check	Force and moment coefficients shall not change significantly with increasing Reynolds number	Comparison of lift and rolling moment coefficient (e.g. at 20°, 30° and 40° yaw angle) for three different Reynolds numbers: 0,5 Re_{max}, 0,75 Re_{max}, and Re_{max}.	Lee rail rolling moment coefficient to vary by less than ± 5 % over range [0,9 Re_{max} ; Re_{max}]	Not mentioned as benchmarking method is used
Mach number	< 0,3 or smaller than the Mach number of the real train.	< 0,3 or smaller than the Mach number of the real train.	< 0,25 or smaller than the Mach number of the real train	< 0,25 or smaller than the Mach number of the real train
Wind tunnel ground simulation	Flat ground with 235 mm gap (see D.1)	Flat ground with 235 mm gap (see D.1)	Ballast and rail (see D.2)	Ballast and rail (see D.2)
Wind tunnel embankment simulation	6 m standard embankment (see D.3)	Not applied	Not applied	4 m, 8 m and 12 m standard embankments of given slope and 8 m top width
Modelling accuracy	± 10 mm (with respect to full scale dimensions)	± 10 mm (with respect to full scale dimensions)	± 20 mm tolerance (with respect to full scale dimensions)	± 20 mm tolerance (with respect to full scale dimensions)
Allowed model simplifications	The pantograph shall not be modelled. Strong simplification of the running gear is allowed.	The pantograph shall not be modelled. Strong simplification of the running gear is allowed.	The pantograph shall not be modelled. Accurate modelling of the running gear is required.	The pantograph shall not be modelled. Accurate modelling of the running gear is required.
Model symmetry	A symmetrical model is required. In case the real train is not symmetric, the symmetric model shall represent the case which is associated with the larger wind loads.	A symmetrical model is required. In case the real train is not symmetric, the symmetric model shall represent the case which is associated with the larger wind loads.	Not applied	Not applied
Symmetry check	Needed, no criterion is given	At yaw angles of 0°, ± 20°, ± 30° and ± 40°, the differences in C_{Fy}, C_{Fz} and C_{Mx} shall be smaller than 5 % or 0,1.	None	None

Table A.1 *(continued)*

	TSI HS RST	DB Ril 80704	RSSB standard GM/RC2542	
After body and forebody length requirement	If the measured vehicle is a leading endcar, the after body shall have least half of the length of the endcar. The true cross section shall be represented at least for the first third of the length. If the measured vehicle is not a leading car, the length of the body in front of the vehicle shall be at least one vehicle length.	If the measured vehicle is a leading endcar, the after body shall have least half of the length of the endcar. The true cross section shall be represented at least for the first third of the length. If the measured vehicle is not a leading car, the length of the body in front of the vehicle shall be at least one vehicle length.	A leading or intermediate vehicle to be tested must have at least one adjacent downstream vehicle. Additionally an intermediate vehicle to be tested must have up to three upstream vehicles, depending on the position of the vehicle in the train and the wind tunnel size.	A leading or intermediate vehicle to be tested must have at least one adjacent downstream vehicle. Additionally an intermediate vehicle to be tested must have up to three upstream vehicles, depending on the position of the vehicle in the train and the wind tunnel size.
Accuracy at lee rail for C_{M}x	No criterion given	< 5 % (Gaussian error at 40° yaw angle)	<2,5 %	<2,5 % Benchmark tests are required. The maximum deviation of the mean rolling moment coefficient shall be less than 15 %. The mean deviation of the mean rolling moment coefficient shall be less than 5 %. The maximum deviation of the peak rolling moment coefficient shall be less than 10 % at a yaw angle of 90°. Bias corrections are applied.
Yaw angle range and increment	0° to 70° in steps of 5°.	0° to 50° in steps of 5° and 50° to 90° in steps of 10°.	50° as a minimum. Recommended to measure at other yaw angles, such as 15° to 60° in steps of 15°.	15° to 90° in steps of 15° for mean coefficients. 90° for peak coefficients.
Interpolation between coefficient	Linear or higher order	Linear	Not mentioned	6th order polynomial

Table A.2 — Application of methodological elements for rolling stock assessment purpose within Europe (vehicle dynamic assessment)

	TSI HS RST	DB Ril 80704	RSSB standard GM/RC2542	
Criterion for the evaluation of characteristic wind speed (CWC)	Unloading of the most critical running gear $\|\Delta Q/Q_0\|$=90% (low-pass filtered at 2 Hz, 4th order Butterworth)	Unloading of the most critical running gear $\|\Delta Q/Q_0\|$=90% (low-pass filtered at 2 Hz, 4th order Butterworth)	Not mentioned	Not mentioned
Modelling of dynamics	Time-dependent multibody simulation (MBS) accor-ding to 5.4.4	Time-dependent multibody simulation (MBS) accor-ding to 5.4.4 or advanced quasi-static approach according to 5.4.3 and Annex H	Not mentioned	Not mentioned

Table A.2 (*continued*)

	TSI HS RST	DB Ril 80704	RSSB standard GM/RC2542	
Underlying gust model	Chinese Hat according to 5.4.4.2 and Annex I.	Chinese Hat according to 5.4.4.2 and Annex I or steady wind	Not mentioned	Not mentioned
Rail inclination	Worst case of 1/20 and 1/40	Not mentioned	Not mentioned	Not mentioned
Vehicle model verification	Comparison of the mass, the flexibility coefficient (suspension coefficient), the bump stops and the centre of gravity. The difference of the vehicle masses between model and train shall be < ± 1 %. The flexibility coefficient (suspension coefficient) shall not differ by more than 10 %. A comparison with transient record of Q-forces is required if this data is available.	The difference of the vehicle masses between model and train shall be < ± 1 %. The bump stops shall be modelled at an accuracy which is better than 1 mm. A comparison with transient record of Q-forces is required if this data is available.	Not mentioned	Not mentioned

Annex B
(informative)

Blockage correction

B.1 Dynamic pressure method

The following method can be applied to closed test sections:

— measure the dynamic pressure in the potential core of the flow without the models (e.g. fences, train, embankment);

— measure for each yaw angle, the dynamic pressure in the core of the flow above the models with the models being present (e.g. fences, train, embankment);

— multiply the coefficient by the ratio of the pressure without the models to that with the models.

B.2 German method

This clause describes the blockage correction for tests according to 5.3.4.11, D.1, D.2 or D.3 in open or ¾-open test sections (see DB standard Ril 807.0432 [1]).

The blockage ratio x_B is defined at a yaw angle of 30° in %. In closed test sections no blockage correction is needed.

NOTE The coefficients are overestimated in closed test sections, therefore it is conservative not to apply a correction here.

For open test sections no blockage correction is needed for blockage ratios smaller than 5 %. Between 5 % and 15 % the following blockage correction should be used.

The correction only applies to the rolling moment coefficient, the other coefficients remain unchanged.

The correction factor is calculated by:

$$f_{BL} = 0{,}0003 x_B^2 + 0{,}0002 x_B + 1 \quad (B.1)$$

EXAMPLE The mockup, including down-stream body, is at 15th scale. It has a projected side area of 0,6 m^2 at the yaw angle of 30°. An open wind tunnel with a test section of 10 m² is used. The blockage corresponds to 0,6 / 10 = 6 %. The rolling moment coefficient has to be corrected at all yaw angles using a correction factor of: f_{BL}=0,0003 · 6^2 + 0,0002 · 6 + 1 = 1,012.

B.3 UK method

This clause describes the blockage correction for tests according to D.2 and D.5 in closed test sections (according to [3]).

The measured values of mean wind tunnel velocity ($\overline{U}_{raw}$) have to be corrected for blockage effects. Two corrections are applied: the first relates to the embankment blockage, the second to the vehicle blockage. These corrections are applied as:

$$\overline{U} = \overline{k}_{\mathrm{e}} \cdot k_{\mathrm{v}} \cdot \overline{U}_{\mathrm{raw}} \quad \text{(B.2)}$$

The embankment blockage factor $\overline{k}_{\mathrm{e}}$ compensates for the speed up effect of the constraint of the wind tunnel roof on the deflection of the flow over the embankment.

$$\overline{k}_{\mathrm{e}} = 1 + f_{\mathrm{h}}\left(1 - \frac{1}{\overline{U}_{\mathrm{e\_raw}} / \overline{U}_{\mathrm{raw}}}\right) \quad \text{(B.3)}$$

where

$\overline{U}_{\mathrm{e\_raw}}$ is the measured wind tunnel velocity above the embankment and

$f_{\mathrm{h}} = 1{,}25\sqrt{B_{\mathrm{E}}} - 0{,}25$, for B_{E} > 0,04; (B.4)

$f_{\mathrm{h}} = 0$ otherwise and B_{E} is the embankment blockage ratio. (B.5)

The vehicle blockage factor k_{v} compensates for the effect of the constraints of the tunnel walls on the local flow over the vehicle:

$k_{\mathrm{v}} = \sqrt{1 + B_{\mathrm{v}}}$ where B_{V} is the vehicle blockage. (B.6)

B.4 Slotted walls

Wind tunnels with slotted walls can be used without blockage correction if reference measurements of a similar model setup and scale have been shown to be within the accuracy range specified in 5.3.4.2.

Annex C
(normative)

Wind tunnel benchmark test data for standard ground configuration

C.1 General

This annex contains wind tunnel test reference data for three wind tunnel benchmark vehicle models ICE 3 endcar, TGV Duplex powercar and ETR 500 powercar. Beside the wind tunnel model contour geometry (CAD data), the aerodynamic coefficients obtained are presented. The geometry of the downstream body which is also provided is only informative while the intercar gap dimension is normative.

All aerodynamic coefficients refer to a reference normalisation length of d_0 = 3 m and a reference normalisation area A_0 = 10 m^2 and to the coordinate system defined in EN 14067-1. The 3D CAD data is available in electronic form at the TC 256 Secretariat held by DIN FSF.

NOTE The files will contain the models of ETR 500 powercar, ICE endcar and TGV Duplex powercar and their respective downstream bodies and bogies.

C.2 ICE 3 endcar wind tunnel model

Figure C.1 illustrates the contour of an ICE 3 endcar wind tunnel model.

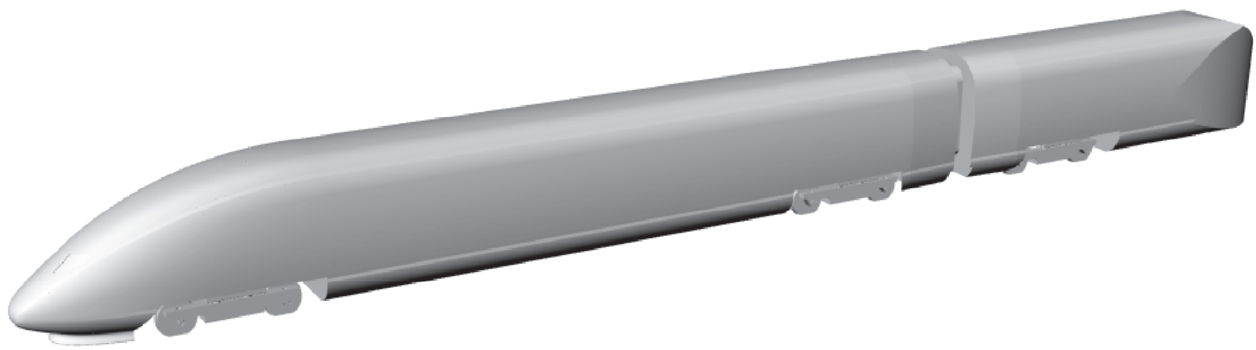


Figure C.1 — Contour of a wind tunnel model of the ICE 3 endcar

Table C.1 shows the reference data for aerodynamic coefficients of the ICE 3 endcar model on the ground configuration "single track with ballast and rail" according to 5.3.4.11. These reference data are based on a single data set measured in a wind tunnel test campaign and are confirmed by data from three further campaigns in three other separate wind tunnels.

Table C.1 — Reference data for aerodynamic coefficients of the ICE 3 endcar model for the ground configuration "single track with ballast and rail" according to 5.3.4.11

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}	$c_{Mx,lee}$
0	-0,162	-0,026	0,037	-0,015	-0,332	-0,051	-0,024
5	-0,203	0,496	-0,151	0,264	-0,402	1,205	0,302
10	-0,232	1,072	-0,775	0,582	-0,505	2,278	0,776
15	-0,261	1,736	-1,662	0,952	-0,316	3,084	1,368
20	-0,257	2,543	-2,631	1,396	0,463	3,590	2,053
25	-0,189	3,432	-3,700	1,885	1,386	4,152	2,810
30	-0,101	4,455	-4,702	2,457	2,384	4,385	3,632
35	0,025	5,616	-5,638	3,115	3,109	4,533	4,524
40	0,200	6,806	-6,368	3,773	3,443	4,840	5,365
45	0,580	8,085	-6,979	4,480	4,099	5,460	6,225
50	0,954	8,655	-7,158	4,783	5,165	6,392	6,572
55	0,976	8,802	-6,543	4,873	5,899	5,538	6,508
60	1,041	8,511	-5,900	4,682	4,508	4,555	6,156
65	0,815	7,629	-5,270	4,157	1,756	2,276	5,474
70	0,600	7,346	-5,057	4,067	0,132	0,432	5,331
75	0,576	7,214	-5,008	4,014	-1,106	0,055	5,266
80	0,542	7,011	-4,685	3,895	-1,270	-0,754	5,066
85	0,470	6,869	-3,799	3,799	-0,201	-1,395	4,749
90	0,399	6,687	-3,794	3,695	-0,036	-2,281	4,643

C.3 TGV Duplex powercar wind tunnel model

Figure C.2 illustrates the contour of a TGV Duplex powercar wind tunnel model.

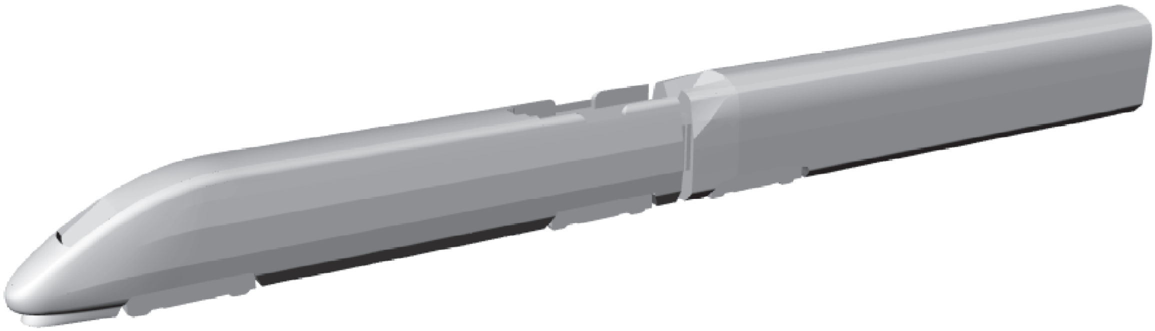


Figure C.2 — Contour of a wind tunnel model of the TGV Duplex powercar

Table C.2 shows reference data for the aerodynamic coefficients of the TGV Duplex powercar model on the ground configuration "single track with ballast and rail" according to 5.3.4.11. These reference data are based on a single data set measured in a wind tunnel test campaign.

Table C.2 — Reference data for aerodynamic coefficients of the TGV Duplex powercar model for the ground configuration "single track with ballast and rail" according to 5.3.4.11

β	c_{x}	c_{y}	c_{z}	c_{Mx}	c_{My}	c_{Mz}	$c_{Mx,lee}$
0	-0,147	0,000	-0,117	0,000	-0,005	0,000	0,000
5	-0,157	0,484	-0,294	0,317	-0,119	1,013	0,394
10	-0,132	1,196	-0,813	0,790	-0,327	1,964	0,992
15	-0,105	2,011	-1,543	1,289	-0,243	2,866	1,675
20	-0,102	2,982	-2,259	1,853	0,126	3,695	2,417
25	-0,090	4,054	-3,001	2,420	0,367	4,352	3,170
30	-0,021	5,093	-3,778	2,972	0,410	4,922	3,917
35	0,126	6,387	-4,605	3,738	0,714	5,095	4,890
40	0,307	8,076	-5,297	4,777	1,487	4,410	6,101
45	0,625	9,573	-6,000	5,753	2,339	3,900	7,253
50	1,030	10,024	-6,205	6,018	3,176	4,396	7,569
55	1,286	10,010	-6,087	5,902	4,134	4,772	7,424
60	1,119	9,111	-5,389	5,275	4,109	3,337	6,622
65	0,653	7,290	-4,785	4,247	2,936	-0,103	5,443
70	0,590	7,066	-4,494	4,230	3,022	-1,327	5,354
75	0,601	7,275	-3,808	4,420	2,809	-1,855	5,372
80	0,587	7,175	-3,581	4,376	2,486	-2,146	5,271
85	0,573	6,876	-3,474	4,195	2,194	-2,268	5,064
90	0,580	6,523	-3,180	3,988	1,984	-2,276	4,783

C.4 ETR 500 powercar wind tunnel model

Figure C.3 illustrates the contour of an ETR 500 powercar wind tunnel model.

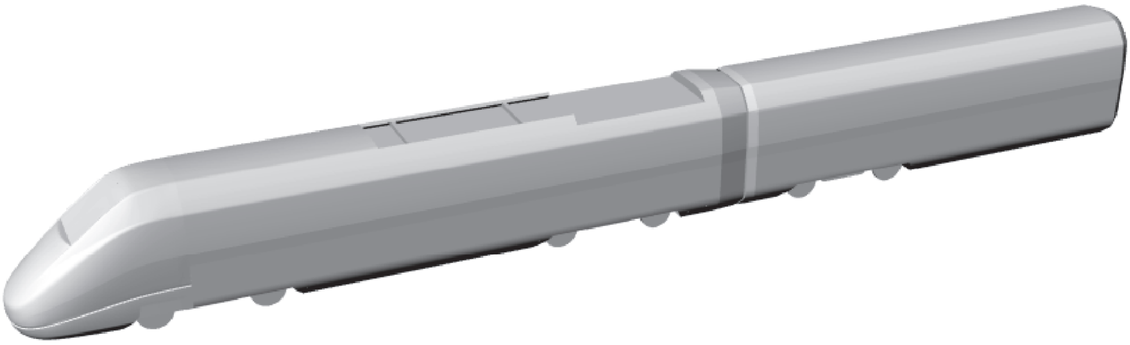


Figure C.3 — Contour of a wind tunnel model of the ETR 500 powercar

Table C.3 shows reference data for the aerodynamic coefficients of the ETR 500 powercar model on the ground configuration "single track with ballast and rail" according to 5.3.4.11. These reference data are based on a single data set measured in a wind tunnel test campaign.

Table C.3 — Reference data for aerodynamic coefficients of the ETR 500 powercar model for the ground configuration "single track with ballast and rail" according to 5.3.4.11

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}	$c_{Mx,lee}$
0	-0,225	-0,036	-0,001	-0,027	-0,223	-0,107	-0,027
5	-0,265	0,468	-0,143	0,304	-0,206	0,909	0,339
10	-0,253	1,117	-0,625	0,739	-0,182	1,883	0,895
15	-0,259	1,958	-1,454	1,294	-0,103	2,812	1,658
20	-0,163	2,837	-2,403	1,839	0,258	3,481	2,440
25	-0,084	3,935	-3,200	2,510	0,842	3,806	3,310
30	0,016	5,385	-3,844	3,432	1,478	3,865	4,393
35	0,223	7,264	-4,485	4,664	1,720	3,980	5,785
40	0,521	8,995	-5,256	5,821	1,860	4,542	7,135
45	0,769	10,120	-5,612	6,552	2,323	5,710	7,955
50	0,931	10,387	-5,259	6,652	2,522	6,044	7,967
60	0,857	9,693	-3,814	6,222	0,873	3,426	7,175
70	0,702	8,800	-3,456	5,697	-0,062	0,732	6,561
80	0,802	8,284	-3,277	5,393	-0,298	0,093	6,213
90	0,723	7,580	-3,010	4,964	-0,474	-1,256	5,716

Annex D
(informative)

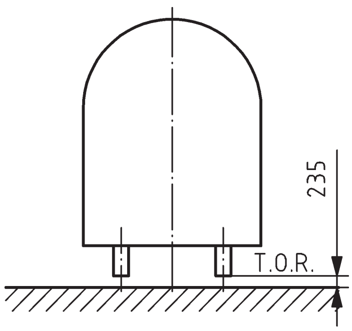
Other ground configurations for wind tunnel testing

D.1 Flat ground with gap (TSI HS RST)

For this flat ground configuration, a representation of the ballast and rails is omitted. In this case, the clearance between the height of the position of the top of the rail (T.O.R) and the wind tunnel floor shall be 235 mm full scale equivalent.

Particular care should be taken with the height of the vehicle relative to the rails so that this is accurate to ± 5 cm full scale. The height should vary by no more than ± 2,5 cm full scale when the vehicle is removed and then replaced during the tests.

Dimensions in millimetres



Key

T.O.R top of rail

Figure D.1 — Sketch of the wind tunnel configuration flat ground with 235 mm gap

D.2 Double track ballast and rails (TSI HS RST)

A properly scaled simulation of the ballast profile and the rails should be provided, to the following level of detail: the underlying shape should be modelled to ± 5 cm full scale and features with full-scale dimensions greater than 10 cm modelled. Any smaller features should be modelled as generalised roughness. Notwithstanding the above, individual ballast stones should not be modelled.

Particular care should be taken with the height of the vehicle relative to the rails so that this is accurate to ± 5 cm full scale. The height should vary by no more than ± 2,5 cm full scale when the vehicle is removed and then replaced during the tests. The track bed system may be modelled with cants at specified angles and should include ballast profiles. The geometry and spacing for uncanted track is shown in Figure D.2.

Dimensions in millimetres

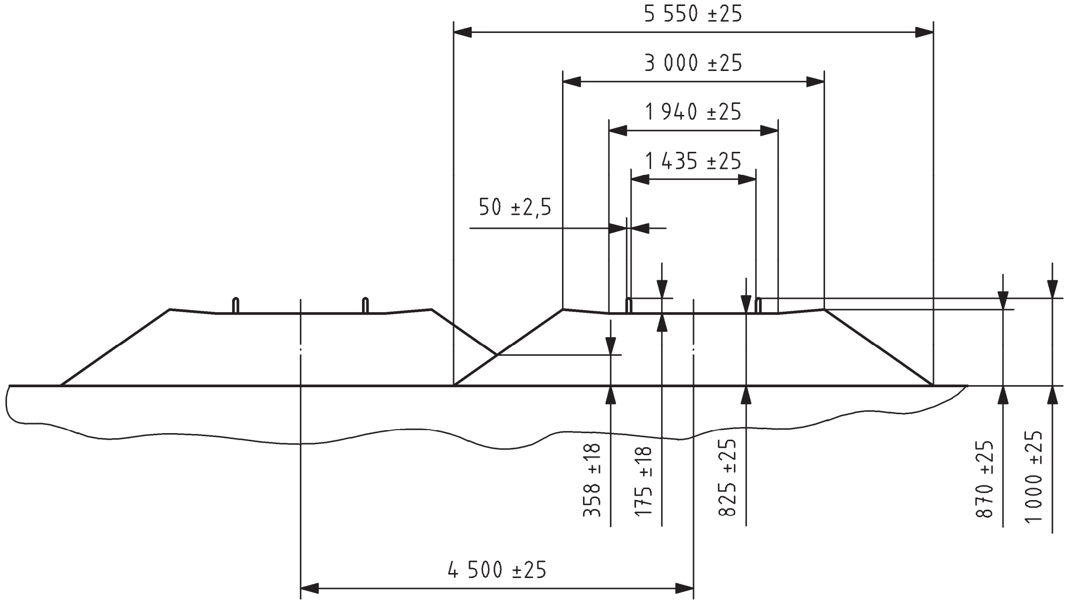


Figure D.2 — Sketch of ballast geometry

D.3 Standard embankment of 6 m height (TSI HS RST)

The 6 m standard embankments shall be modelled as having a slope of arctangent (2/3) with track placement and dimensions as shown in Figure D.3.

For train speeds below 200 km/h (and angles β above 40°) tests shall be carried out for the windward and leeward configurations. For train speeds of 200 km/h and higher only the windward configurations have to be considered. Thus, in this speed range, a single track embankment with reduced base width is allowed. The embankment shall have streamlined ends. Endplates at the embankment ends can be useful.

Dimensions in millimetres

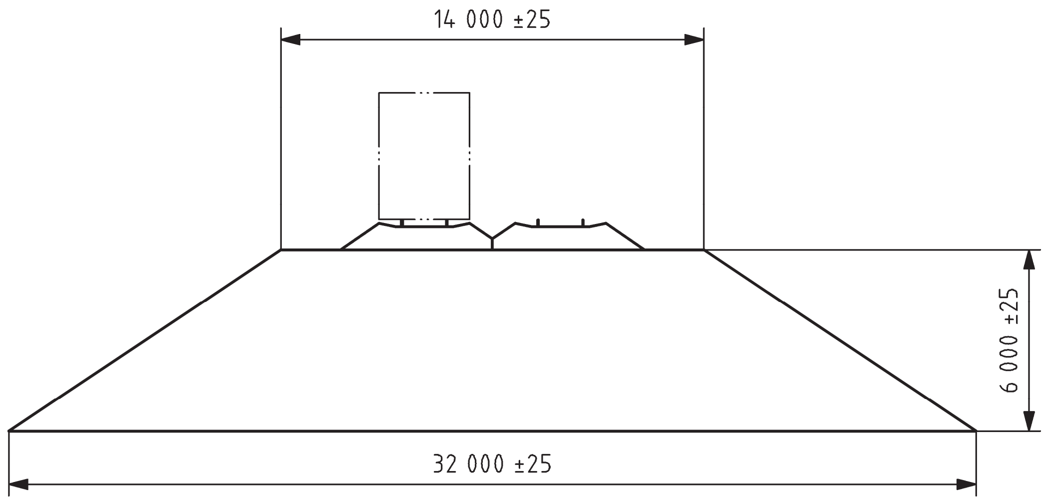
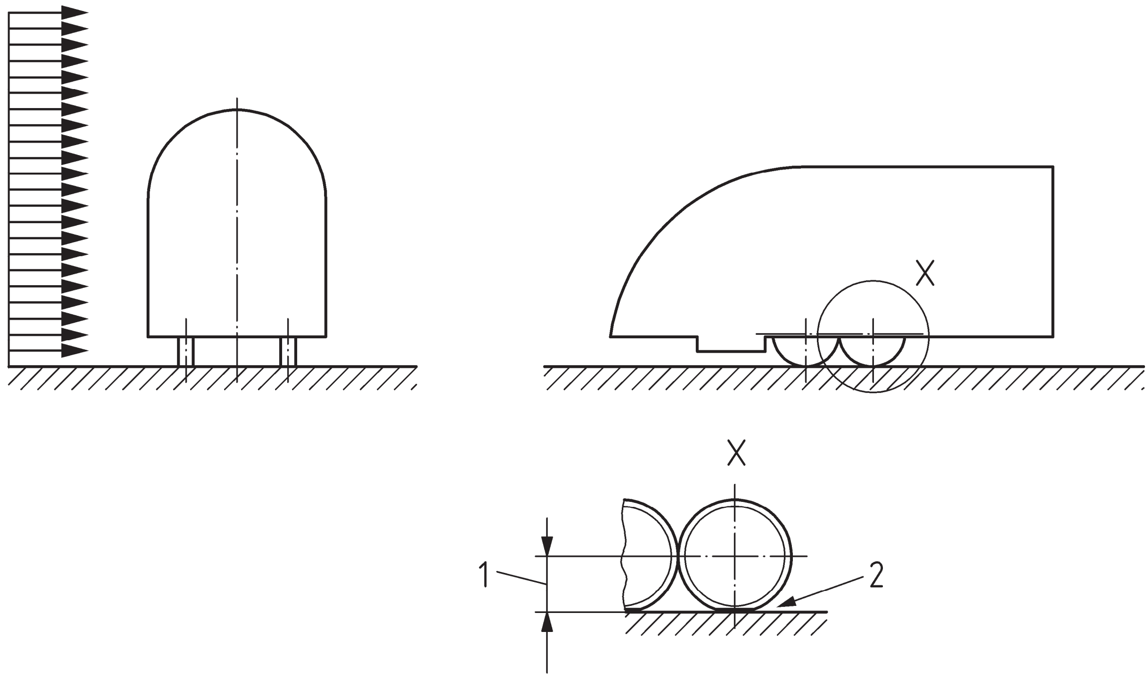


Figure D.3 — Sketch of the embankment geometry

D.4 Flat ground without gap (Finnish method)

The ground level of the wind tunnel is at the level of the top of the rail as presented in Figure D.4. The ballast and rails are not modelled in the test configuration.

In this configuration there should be a cutting on the lower edge of the wheels to avoid contact between the floor and the wheel.



Key

1 wheel radius

2 gap between ground and flattened wheel to avoid contact

Figure D.4 — Sketch of the wind tunnel configuration flat ground without gap

D.5 Double track ballast and rails (UK method)

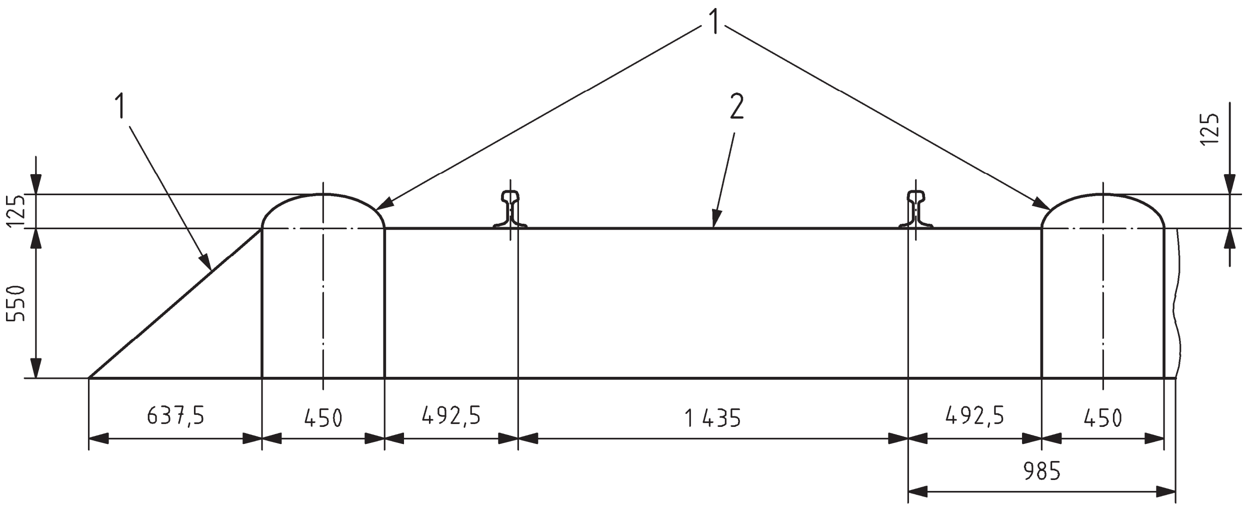
A properly scaled simulation of the ballast profile and the rails should be provided, to the following level of detail: the underlying shape should be modelled to ± 5 cm full scale and features with full-scale dimensions greater than 10 cm modelled. Any smaller features should be modelled as generalised roughness. Notwithstanding the above, individual ballast stones should not be modelled.

Particular care should be taken with the height of the vehicle relative to the rails so that this is accurate to ± 5 cm full scale. The height should vary by no more than ± 2,5 cm full scale when the vehicle is removed and then replaced during the tests. The track bed system may be modelled with cants at specified angles and should include ballast profiles.

Embankments should be modelled as having a slope of arctangent (4/7) from horizontal and a top width of 8 m full scale. These characteristics are representative of most embankments in the UK. The track bed system should be modelled at cants of 0° and 6° and should include ballast profiles with the track centre lines symmetrically placed either side of the embankment centre line. The vehicle models should be mounted on the windward track. The model embankments should span the wind tunnel at all yaw angles that are used, in order to eliminate end effects.

Figure D.5 shows half the geometry of uncanted track bed in Great Britain.

Dimensions in millimetres



Key

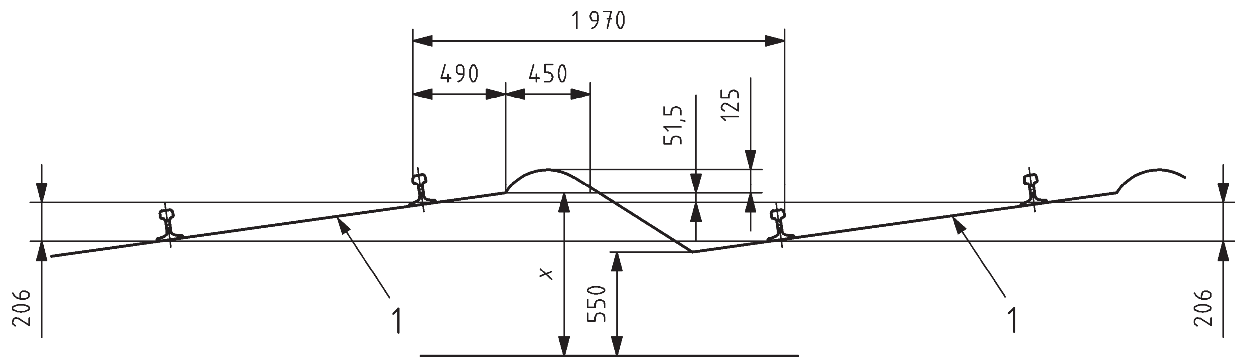
1 ballast

2 sleeper

Figure D.5 — Ballast and rail configuration for uncanted track in Great Britain

Figure D.6 shows the geometry of the ballast and rail on a 6° canted track bed in Great Britain.

Dimensions in millimetres



Key

1 sleeper

Figure D.6 — Saw tooth canted ballast and rail in Great Britain

Annex E
(informative)

Wind tunnel benchmark test data for other ground configurations

E.1 General

This annex contains wind tunnel test reference data for three benchmark vehicle models. The aerodynamic coefficients presented had partly been the basis to derive the interoperability requirements (reference CWC) for high speed rolling stock. All aerodynamic coefficients refer to a reference normalisation length of d_0 = 3 m and a reference normalisation area A_0 = 10 m^2 and to the coordinate system defined in EN 14067-1.

E.2 ICE 3 endcar wind tunnel model

For all wind tunnel measurements given in this subclause, an appropriate downstream body was used. Details of the way that theses results have been obtained can be found in [4].

Table E.1 shows benchmark data for the aerodynamic coefficients of the ICE 3 endcar on flat ground with gap (see D.1) measured on a 7^{th} scale model at 80 m/s in a wind tunnel.

Table E.1 — Benchmark data for aerodynamic coefficients of ICE 3 endcar on flat ground with gap, measured by DB AG on a 1:7-scale model at 80 m/s in DNW wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	-0,12	-0,01	0,02	0,02	-0,32	0,03
5	-0,13	0,39	-0,11	0,24	-0,51	1,07
10	-0,12	0,91	-0,50	0,53	-0,74	2,03
15	-0,11	1,56	-1,06	0,91	-0,91	2,70
20	-0,11	2,33	-1,76	1,35	-0,62	3,25
25	-0,08	3,19	-2,35	1,83	0,35	3,72
30	0,01	4,17	-2,79	2,39	1,54	3,84
35	0,10	5,27	-3,17	3,02	2,68	3,62
40	0,24	6,40	-3,56	3,68	3,48	3,59
45	0,41	7,51	-3,95	4,36	4,23	3,81
50	0,52	8,47	-4,30	4,92	5,14	4,26
60	0,80	9,74	-5,35	5,67	7,06	5,80
75	0,94	7,33	-6,59	3,71	2,15	3,33
90	0,38	6,57	-5,49	3,35	2,11	-2,58

Table E.2 and E.3 show benchmark data for the aerodynamic coefficients of the ICE 3 endcar on the ground configuration for double-track ballast and rail (see D.2) measured on a 15th scale model at 50 m/s in a wind tunnel.

Table E.2 — Benchmark data for aerodynamic coefficients of ICE 3 endcar on the windward side on the double track ballast and rail, measured by CSTB on a 1:15-scale model at 50 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0,00	0,00	0,00	0,00	0,00	0,00	0,00
5,00	-0,05	0,40	-0,27	0,26	-0,29	1,09
10,00	-0,09	0,91	-0,77	0,51	-0,28	1,81
15,00	-0,12	1,58	-1,46	0,83	-0,03	2,33
20,00	-0,12	2,43	-2,28	1,23	0,38	2,77
25,00	-0,09	3,41	-3,19	1,72	0,90	3,20
30,00	-0,02	4,48	-4,14	2,28	1,45	3,66
35,00	0,09	5,56	-5,08	2,84	1,99	4,15
40,00	0,23	6,57	-5,96	3,37	2,48	4,66
45,00	0,39	7,41	-6,75	3,80	2,86	5,15
50,00	0,57	8,02	-7,41	4,09	3,11	5,56
55,00	0,76	8,41	-7,93	4,22	3,35	6,05
60,00	0,89	8,23	-8,23	4,07	2,86	5,71
65,00	0,88	7,80	-8,10	3,82	2,31	4,56
70,00	0,79	7,31	-7,78	3,58	1,72	3,17
75,00	0,71	6,83	-7,47	3,34	1,12	1,78
80,00	0,63	6,34	-7,16	3,09	0,53	0,40
85,00	0,55	5,85	-6,84	2,85	-0,07	-0,99
90,00	0,47	5,37	-6,53	2,61	-0,67	-2,38

Table E.3 — Benchmark data for aerodynamic coefficients of ICE 3 endcar on the leeward side on the double track ballast and rail, measured by CSTB on a 1:15-scale model at 50 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,05	0,44	-0,44	0,21	-0,54	1,04
10	-0,09	0,92	-0,86	0,48	-0,44	1,85
15	-0,11	1,54	-1,38	0,83	-0,01	2,49
20	-0,11	2,35	-2,09	1,28	0,51	3,00
25	-0,07	3,35	-2,98	1,80	1,00	3,45
30	0,00	4,47	-4,05	2,36	1,37	3,88
35	0,12	5,63	-5,22	2,91	1,63	4,34
40	0,26	6,73	-6,42	3,40	1,80	4,85
45	0,44	7,66	-7,57	3,78	1,92	5,41
50	0,64	8,33	-8,55	4,00	2,07	6,00
55	0,90	8,71	-9,30	4,08	2,29	7,10
60	1,00	8,47	-9,52	3,90	2,53	6,70
65	0,97	7,92	-9,32	3,60	2,63	5,49
70	0,88	7,36	-8,93	3,35	2,48	3,95
75	0,80	6,80	-8,54	3,10	2,34	2,40
80	0,71	6,24	-8,15	2,85	2,19	0,85
85	0,62	5,68	-7,76	2,60	2,04	-0,70
90	0,53	5,12	-7,37	2,35	1,90	-2,24

Table E.4 shows benchmark data for the aerodynamic coefficients of the ICE 3 endcar on the windward side of the standard embankment (see D.3) measured on a 15th scale model at 50 m/s in a wind tunnel.

Table E.4 — Benchmark data for aerodynamic coefficients of ICE 3 endcar on the windward side of standard embankment of 6 m height, measured by CSTB on a 1:15-scale model at 50 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,03	0,79	-0,81	0,41	0,29	1,20
10	-0,06	1,75	-1,70	0,92	0,56	2,43
15	-0,06	2,81	-2,64	1,49	0,95	3,51
20	-0,01	3,92	-3,59	2,08	1,53	4,34
25	0,09	5,02	-4,49	2,66	2,24	4,84
30	0,23	6,03	-5,30	3,19	3,02	4,97
35	0,40	6,89	-5,95	3,63	3,75	4,99
40	0,58	8,22	-6,72	4,24	4,97	4,94
45	0,74	8,56	-7,20	4,42	5,35	3,90
50	0,86	7,63	-7,02	3,83	4,91	1,54
55	0,87	7,14	-5,96	3,59	3,50	0,66
60	0,60	6,59	-5,00	3,53	2,18	-0,41
65	0,51	6,55	-4,70	3,38	0,60	-1,12
70	0,41	6,50	-4,73	3,37	-0,98	-1,82
75	0,31	6,45	-4,77	3,36	-2,15	-2,53
80	0,31	6,25	-4,62	3,27	-2,74	-2,56
85	0,32	6,04	-4,48	3,17	-2,92	-2,59
90	0,32	5,84	-4,33	3,07	-3,10	-2,62

Table E.5 shows benchmark data for the aerodynamic coefficients of the ICE 3 endcar on the leeward side of the standard embankment (see D.3) measured on a 15th scale model at 50 m/s in a wind tunnel.

Table E.5 — Benchmark data for aerodynamic coefficients of ICE 3 endcar on the leeward side of the standard embankment of 6 m height, measured by CSTB on a 1:15-scale model at 50 m/s in CSTB wind tunnel

β	c_{x}	c_{y}	c_{z}	$c_{M\text{x}}$	$c_{M\text{y}}$	$c_{M\text{z}}$
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,04	0,73	-0,60	0,40	0,14	1,15
10	-0,10	1,49	-1,26	0,83	0,40	2,14
15	-0,13	2,40	-2,00	1,34	0,82	3,14
20	-0,11	3,48	-2,82	1,95	1,40	4,19
25	-0,03	4,70	-3,68	2,63	2,09	5,28
30	0,11	5,97	-4,54	3,34	2,82	6,35
35	0,29	7,18	-5,34	4,01	3,50	7,28
40	0,38	8,20	-6,00	4,63	4,04	8,19
45	0,71	9,47	-6,64	5,19	4,90	9,01
50	0,83	9,69	-7,01	5,35	4,38	8,98
55	1,08	8,97	-7,00	4,96	3,73	8,04
60	1,09	7,53	-6,65	4,07	3,06	5,56
65	0,86	6,60	-6,28	3,57	2,10	3,47
70	0,63	5,68	-5,90	3,08	1,14	1,37
75	0,39	4,75	-5,53	2,59	0,61	-0,41
80	0,37	4,51	-5,12	2,44	0,12	-0,93
85	0,34	4,28	-4,70	2,30	0,05	-1,14
90	0,32	4,04	-4,29	2,15	-0,02	-1,35

E.3 TGV Duplex powercar wind tunnel model

For all wind tunnel measurements given in this subclause, an appropriate downstream body was used. Details of the way that theses results have been obtained can be found in [4].

Table E.6 shows benchmark data for the aerodynamic coefficients of the TGV Duplex powercar on flat ground with gap (see D.1) measured on a 7^{th} scale model at 80 m/s in a wind tunnel.

Table E.6 — Benchmark data for aerodynamic coefficients of TGV Duplex powercar on flat ground with gap, measured by DB AG on a 1:7-scale model at 80 m/s in DNW wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	-0,12	0,00	0,04	0,01	0,06	0,01
5	-0,14	0,52	-0,05	0,34	-0,10	0,80
10	-0,14	1,19	-0,42	0,77	-0,32	1,60
15	-0,12	1,97	-1,01	1,27	-0,44	2,41
20	-0,03	2,80	-1,64	1,77	-0,54	3,22
25	-0,08	3,63	-2,28	2,21	-0,31	4,15
30	-0,08	4,62	-2,74	2,76	0,26	4,67
35	-0,02	5,85	-3,03	3,46	1,19	4,68
40	0,10	7,23	-3,39	4,29	2,16	4,38
45	0,28	8,54	-3,66	5,06	2,86	4,41
50	0,53	9,59	-3,90	5,68	3,78	4,75
60	0,95	10,15	-4,82	5,94	4,34	5,81
75	0,84	7,54	-4,69	4,09	3,58	0,33
90	0,26	7,59	-3,30	4,26	1,96	-1,35

Table E.7 and Table E.8 show benchmark data for the aerodynamic coefficients of the TGV Duplex powercar on the ground configuration for double-track ballast and rail (see D.2) measured on a 15th scale model at 25 m/s in a wind tunnel.

Table E.7 — Benchmark data for aerodynamic coefficients of TGV Duplex powercar on the windward side on the double track ballast and rail, measured by CSTB on a 1:15-scale model at 25 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,10	0,44	-0,22	0,31	0,00	0,63
10	-0,27	0,98	-0,69	0,67	-0,01	1,21
15	-0,38	1,69	-1,29	1,12	0,05	1,87
20	-0,39	2,59	-1,94	1,66	0,22	2,63
25	-0,26	3,64	-2,56	2,28	0,49	3,46
30	-0,03	4,78	-3,13	2,93	0,86	4,27
35	0,27	5,93	-3,63	3,57	1,29	4,94
40	0,57	6,98	-4,15	4,12	1,74	5,34
45	0,81	7,85	-4,50	4,58	2,15	5,35
50	0,95	8,44	-4,80	4,88	2,47	4,91
55	0,71	8,61	-5,04	4,99	2,49	3,85
60	0,74	8,45	-4,91	4,90	2,53	2,83
65	0,75	7,99	-4,57	4,67	2,48	1,48
70	0,76	7,53	-4,24	4,44	2,43	0,14
75	0,72	7,24	-3,96	4,28	2,11	-0,45
80	0,66	7,08	-3,71	4,18	1,60	-0,54
85	0,60	6,91	-3,47	4,07	1,09	-0,63
90	0,53	6,74	-3,22	3,96	0,58	-0,71

Table E.8 — Benchmark data for aerodynamic coefficients of TGV Duplex powercar on the leeward side on the double track ballast and rail, measured by CSTB on a 1:15-scale model at 25 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,10	0,91	-0,44	0,64	-0,07	1,40
10	-0,16	1,47	-0,86	1,04	-0,09	2,24
15	-0,18	2,00	-1,32	1,39	-0,07	2,79
20	-0,15	2,68	-1,83	1,83	0,00	3,23
25	-0,08	3,58	-2,41	2,41	0,11	3,64
30	0,03	4,70	-3,02	3,11	0,26	4,05
35	0,17	5,96	-3,62	3,90	0,44	4,42
40	0,31	7,23	-4,18	4,70	0,66	4,68
45	0,46	8,68	-4,84	5,74	0,90	4,75
50	0,59	9,44	-4,96	6,06	1,17	4,55
55	0,75	9,25	-4,76	5,97	1,76	4,41
60	0,79	8,84	-4,60	5,70	1,86	2,97
65	0,78	8,36	-4,47	5,38	1,92	1,51
70	0,69	7,76	-4,37	5,01	1,89	0,00
75	0,61	7,17	-4,27	4,63	1,87	-1,51
80	0,56	6,69	-4,15	4,33	1,76	-2,48
85	0,57	6,40	-4,01	4,13	1,50	-2,63
90	0,57	6,10	-3,86	3,93	1,25	-2,78

Table E.9 shows benchmark data for the aerodynamic coefficients of the TGV Duplex powercar on the windward side of the standard embankment (see D.3) measured on a 25th scale model at 40 m/s in a wind tunnel.

Table E.9 — Benchmark data for aerodynamic coefficients of TGV Duplex powercar on the windward side of the standard embankment of 6 m height, measured by CSTB on a 1:25-scale model at 40 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,14	1,09	-0,69	0,60	0,30	1,59
10	-0,12	2,03	-1,38	1,11	0,40	2,59
15	-0,10	2,97	-2,06	1,61	0,51	3,59
20	-0,04	4,17	-2,80	2,25	0,80	4,15
25	0,06	5,55	-3,58	2,99	1,20	4,42
30	0,16	6,92	-4,36	3,72	1,61	4,69
35	0,34	8,22	-5,04	4,45	2,18	4,98
40	0,63	9,71	-5,62	5,32	2,85	5,35
45	0,96	11,06	-5,96	6,17	3,26	5,61
50	1,19	11,59	-5,63	6,62	3,19	5,26
55	0,95	10,82	-3,99	6,43	1,75	3,48
60	0,65	9,96	-2,73	6,09	0,57	2,08
65	0,53	9,55	-2,36	5,87	0,24	1,30
70	0,43	9,22	-2,14	5,69	-0,01	0,44
75	0,33	8,89	-1,92	5,52	-0,25	-0,41
80	0,28	8,54	-1,75	5,31	-0,37	-0,86
85	0,27	8,17	-1,62	5,08	-0,41	-1,04
90	0,27	7,81	-1,48	4,86	-0,45	-1,22

Table E.10 shows benchmark data for the aerodynamic coefficients of the TGV Duplex powercar on the leeward side of the standard embankment (see D.3) measured on a 25th scale model at 40 m/s in a wind tunnel.

Table E.10 — Benchmark data for aerodynamic coefficients of TGV Duplex powercar on the leeward side of the standard embankment of 6 m height, measured by CSTB on a 1:25-scale model at 40 m/s in CSTB wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	0,00	0,00	0,00	0,00	0,00	0,00
5	-0,06	0,79	-0,52	0,53	0,20	1,06
10	-0,12	1,59	-1,03	1,05	0,41	2,12
15	-0,14	2,51	-1,65	1,64	0,63	3,09
20	-0,10	3,62	-2,45	2,32	0,87	3,95
25	-0,06	4,73	-3,24	3,00	1,12	4,81
30	0,01	5,96	-4,02	3,76	1,43	5,43
35	0,14	7,35	-4,80	4,60	1,89	5,72
40	0,32	8,55	-5,46	5,31	2,39	6,11
45	0,55	9,36	-5,80	5,77	2,87	6,69
50	0,85	9,82	-5,90	5,99	3,38	7,34
55	1,14	9,76	-5,68	5,95	3,63	7,38
60	1,13	8,95	-5,16	5,49	3,31	5,82
65	0,91	7,99	-4,63	4,97	2,64	3,39
70	0,68	7,02	-4,11	4,45	1,97	0,96
75	0,52	6,40	-3,74	4,12	1,46	-0,67
80	0,47	6,28	-3,61	4,06	1,20	-1,07
85	0,41	6,16	-3,48	4,00	0,93	-1,48
90	0,35	6,04	-3,35	3,95	0,67	-1,88

E.4 ETR 500 powercar wind tunnel model

Table E.11 shows benchmark data for the aerodynamic coefficients of the ETR 500 powercar on flat ground without ballast and rail (see D.1) measured on a 10th scale model at 12 m/s in a wind tunnel.

Table E.11 — Benchmark data for aerodynamic coefficients of ETR 500 powercar on flat ground with gap, measured by Politecnico di Milano on a 1:10 -scale model at 12 m/s in MPWT wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	-0,24	0,14	0,03	0,10	-0,32	-0,07
5	-0,29	0,59	-0,03	0,40	-0,43	0,68
10	-0,28	1,22	-0,29	0,80	-0,67	1,39
15	-0,25	1,92	-0,89	1,27	-1,01	2,14
20	-0,22	2,68	-1,55	1,78	-1,19	2,60
25	-0,17	3,55	-2,30	2,37	-1,08	2,94
30	-0,13	4,66	-2,83	3,13	-0,41	2,98
35	-0,03	5,96	-3,26	4,07	0,81	3,11
40	0,12	7,21	-3,55	4,96	2,09	3,11
45	0,30	8,43	-3,62	5,82	3,46	2,92
50	0,50	9,52	-3,20	6,58	4,39	3,33
55	0,71	9,99	-3,23	6,89	4,68	3,73
60	0,96	9,99	-2,96	6,84	3,59	4,17
65	0,76	8,77	-1,18	5,93	-0,07	2,49
70	0,54	8,10	-1,06	5,48	-0,34	0,58
80	0,59	7,75	-0,91	5,32	-0,47	-1,05
90	0,68	7,35	-0,70	5,07	0,07	-2,19

Table E.12 shows benchmark data for the aerodynamic coefficients of the ETR 500 powercar on the windward side of the standard embankment (see D.3) measured on a 10 th scale model at 12 m/s in a wind tunnel.

Table E.12 — Benchmark data for aerodynamic coefficients of ETR 500 powercar on the windward side of the standard embankment of 6 m height, measured by Politecnico di Milano on a 1:10-scale model at 12 m/s in MPWT wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
5	-0,20	0,59	-0,20	0,36	-0,08	0,76
10	-0,18	1,33	-0,76	0,81	-0,20	1,77
15	-0,14	2,27	-1,58	1,34	-0,06	2,57
20	-0,03	3,32	-2,38	1,97	0,52	2,94
25	0,12	4,87	-2,91	2,91	1,33	3,02
30	0,38	6,58	-3,39	3,97	1,46	3,40
35	0,64	8,00	-3,76	4,82	1,42	4,27
40	0,88	8,99	-3,83	5,39	1,93	4,63
45	1,02	9,52	-3,54	5,66	1,93	3,94
50	0,84	8,89	-3,01	5,32	0,56	1,19
55	0,99	8,76	-3,09	5,25	0,84	0,99
60	1,04	8,63	-2,96	5,14	1,50	0,36
65	0,99	8,04	-2,67	4,79	1,31	-0,56
70	0,97	7,85	-2,42	4,69	0,87	-1,44
80	0,80	7,93	-2,27	4,73	0,07	-2,68
90	0,64	7,74	-2,05	4,60	-0,46	-3,07

Table E.13 shows benchmark data for the aerodynamic coefficients of the ETR 500 powercar on the leeward side of the standard embankment (see D.3) measured on a 10th scale model at 12 m/s in a wind tunnel.

Table E.13 — Benchmark data for aerodynamic coefficients of ETR 500 powercar on the leeward side of the standard embankment of 6 m height, measured by Politecnico di Milano on a 1:10 -scale model at 12 m/s in MPWT wind tunnel

β	c_x	c_y	c_z	c_{Mx}	c_{My}	c_{Mz}
0	-0,16	-0,07	-0,08	-0,05	-0,06	-0,06
5	-0,18	0,48	-0,15	0,30	-0,14	0,74
10	-0,19	1,28	-0,60	0,80	-0,31	1,81
15	-0,16	2,33	-1,40	1,47	-0,23	2,66
20	-0,08	3,41	-2,24	2,15	0,29	3,22
25	0,06	4,70	-2,81	2,94	1,02	3,78
30	0,29	6,44	-3,12	4,01	1,26	3,95
35	0,54	8,08	-3,50	5,00	0,90	4,42
40	0,87	9,15	-3,69	5,63	1,22	5,49
45	0,99	9,32	-3,32	5,77	1,43	5,72
50	1,08	8,92	-2,98	5,57	1,83	5,89
55	1,13	8,54	-2,41	5,37	0,99	5,52
60	0,92	7,62	-2,40	4,88	0,81	3,57
65	0,89	6,84	-2,18	4,47	0,73	2,34
70	0,79	6,40	-1,71	4,21	0,09	1,72
80	0,77	5,63	-1,86	3,83	0,12	-0,67
90	0,62	4,99	-1,49	3,48	0,73	-3,79

Annex F
(informative)

Embankment overspeed effect

For the embankment configuration, the so-called "Baker's hypothesis" describes the acceleration of wind when crossing an embankment. According to this approach, only the component normal to the embankment is accelerated over the embankment. This hypothesis is based on work done by Jackson [6] and confirmed by Baker [7]. The resulting wind velocity is given by Equation (F.1):

$$\left.\begin{aligned} V_{\mathrm{emb}} &= \sqrt{(v_{\mathrm{tr}} + U\cos\beta_{\mathrm{w}})^2 + f_{\mathrm{emb}}{}^2\,(U\sin\beta_{\mathrm{w}})^2} \\ \beta &= \arctan\left(\frac{f_{\mathrm{emb}}\,U\sin\beta_{\mathrm{w}}}{v_{\mathrm{tr}} + U\cos\beta_{\mathrm{w}}}\right) \end{aligned}\right\} \qquad \text{(F.1)}$$

Where β_{w} is the direction of the wind relative to the track and f_{emb} is the over-speeding coefficient.

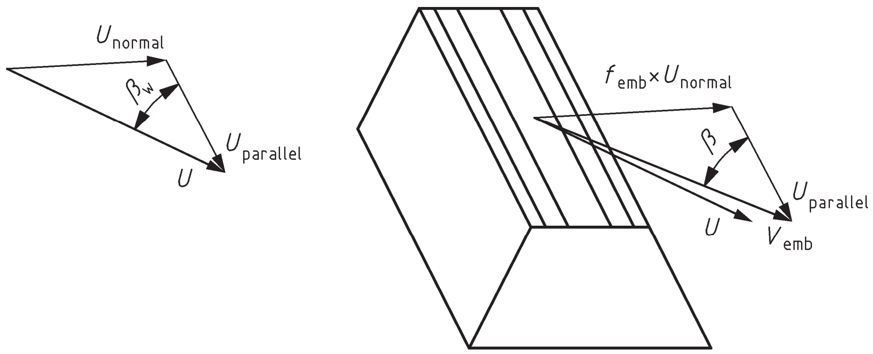


Figure F.1 — Illustration of embankment overspeed effect

In order to determine the aerodynamic forces and moments for both the flat ground and the embankment configurations based on single track ballast and rail measurements, the five components of forces and moments (F_{y}, F_{z}, M_{x}, M_{y} and M_{z}) are calculated using the following equations:

$$\left.\begin{aligned} F_{\mathrm{i}} &= \frac{1}{2}\rho\,A_0\,c_{Fi}(\beta)V_{\mathrm{emb}}^2 \\ M_{\mathrm{i}} &= \frac{1}{2}\rho\,A_0\,d_0\,c_{Mi}(\beta)V_{\mathrm{emb}}^2 \end{aligned}\right\}, i \in \{x, y, z\}, \qquad \text{(F.2)}$$

For calculation from the standard 1 m ballast and rail data to an embankment scenario, coefficients f_{emb} should be taken from an adequate source, e.g. EN 1991-1-4.

Annex G
(informative)

Atmospheric boundary layer wind tunnel testing

G.1 General

This type of wind tunnel test uses static models of the train in a large environmental wind tunnel in which the atmospheric turbulence and shear has been simulated accurately.

The aerodynamic coefficients obtained may be used subsequently in an analysis of the stability of the vehicle when moving through strong winds. This stability analysis requires a coefficient that relates the peak rolling moment about the lee rail occurring due to a gust of wind ($\hat{c}_{M\text{x,lee}}$). This differs from the mean coefficient $\tilde{c}_{M\text{x,lee}}$ due to the effects of atmospheric simulation.

Low turbulence tests, (see 5.3.4), are principally used to obtain a measurement of the mean vehicle aerodynamic rolling moment coefficient about the lee rail $\tilde{c}_{M\text{x,lee}}$. Use of this mean coefficient together with a gust wind speed is likely to give a conservative (high) estimate of the peak moment that could be expected due to the gust wind speed. The use of an atmospheric boundary layer test, therefore, offers the possibility of reducing the conservatism in the final coefficients, but at the added cost of test complexity and increased analysis of the results.

$\hat{c}_{M\text{x,lee}}$ is determined directly for yaw angles of 90° but is determined indirectly from $\tilde{c}_{M\text{x,lee}}$ at lower yaw angles. This indirect procedure removes the biasing effect of taking peak coefficients derived on a stationary train, (where load maxima arise because of fluctuations in both wind speed and direction), as estimates for loads on a moving train (where the dominant cause of load maxima is the fluctuations in relative wind speed). For this reason, both types of coefficient are required for this method.

For the competency of those undertaking wind tunnel tests, see 5.3.4.1.

G.2 Benchmark tests

The atmospheric boundary layer wind tunnel tests might include tests of specified benchmark vehicles. The requirements for benchmark tests are given in 5.3.4.2. Good tolerance values, defined in Equations (2) and (3), for atmospheric boundary layer tests are ε_{max} = 0,15 and $\varepsilon_{\text{mean}}$ = 0,05 for the tested yaw angles.

The remaining bias, following any improvements to the test techniques and arrangements, should be expressed as ratios, which should be used as correction factors during data processing.

$$\bar{k}_{M\text{x,bias}} = \text{mean}\left(\frac{\tilde{c}_{M\text{x,lee,bmk}}}{\tilde{c}_{M\text{x,lee,m}}}\right) \quad \text{(G.1)}$$

and

$$\hat{k}_{M\text{x,bias}} = \left(\frac{\hat{c}_{M\text{x,lee,bmk}}}{\hat{c}_{M\text{x,lee,m}}}\right) \quad \text{(G.2)}$$

where $\hat{k}_{M\text{x,bias}}$ is determined using the values for the case of yaw angle, β = 90°.

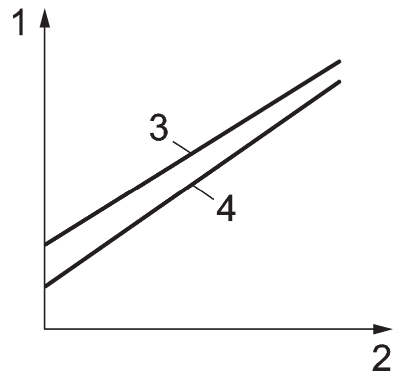
G.3 Wind simulation

G.3.1 Boundary layer profiles

The measured mean velocity profiles in the bottom 20 m (equivalent full scale) of the wind simulation should fall between the expected velocity profiles for two target representative full-scale ground roughness heights, e.g. 0,01 m and 0,05 m. The flow profiles for these examples are given by the following expressions and are illustrated in Figure G.1.

$$\frac{\tilde{U}_{\mathrm{m,z}}}{\tilde{U}_{\mathrm{m,3}}} = 0{,}403 \log_{10}(100z) \text{ and} \tag{G.3}$$

$$\frac{\tilde{U}_{\mathrm{m,z}}}{\tilde{U}_{\mathrm{m,3}}} = 0{,}562 \log_{10}(20z) \tag{G.4}$$



Key

1 $\mathrm{Log}_{10}(z)$ logarithm of height z

2 $\frac{\tilde{U}_{\mathrm{m,z}}}{\tilde{U}_{\mathrm{m,3}}}$ ratio of mean wind tunnel velocity to mean value at 3 m full scale equivalent reference height[1)]

3 upper limit, Equation (G.4)

4 lower limit, Equation (G.3)

Figure G.1 — Upper and lower limits for mean velocity profiles

G.3.2 Turbulence intensities

The measured values of turbulence intensity in the bottom 20 m (equivalent full scale) of the wind simulation should fall between the two expected turbulence intensity profiles corresponding to the target full-scale ground roughness heights used for the flow profiles. For example, these are given by the following expressions for the full-scale roughness heights of 0,01 m and 0,05 m.

$$I_{\mathrm{u}}(z) = \frac{0{,}434}{\log_{10}(100z)} \text{ and} \tag{G.5}$$

$$I_{\mathrm{u}}(z) = \frac{0{,}434}{\log_{10}(20z)} \tag{G.6}$$

[1)] The reference height of 3 m is used in the UK, 4 m is also used as an alternative.

G.3.3 Turbulence integral length scale

The turbulence length scale L_X, (i.e. the longitudinal streamwise velocity turbulence length scale at 3 m equivalent height in the wind tunnel), is a measure of the size of the turbulence gusts. Full-scale values of this parameter close to the ground in rural terrain are uncertain, variable and difficult to achieve in atmospheric wind tunnels. Provided that the calculated value is 15 m or greater, (equivalent full scale), the simulation can be regarded as adequate.

The length scale should be calculated from the calculation of the area under the velocity autocorrelation curve, for a velocity time series measured at 3 m full scale equivalent reference height.

G.4 Model scale and blockage requirements

The Reynolds number is based on a reference mean wind speed, measured at a full scale height of 3 m above the wind tunnel floor and 20 m upstream of the upwind rail under the vehicle being tested or the base of any embankment in place, and a characteristic length of 3 m. (All dimensions are equivalent full scale). The Reynolds' number should be greater than $1,8 \times 10^5$ to ensure flow similarity between the model and full-scale flows.

For Mach number requirements, see 5.3.4.6.

The ratio of the total train model side area to the cross-sectional area of the tunnel section should be less than 0,03.

The ratio of the height of the maximum model embankment to be tested to the height of the wind tunnel should be less than 0,2.

The residual effects of blockage should be accounted for by applying appropriate blockage corrections, see Annex B.

A reference wind tunnel velocity should be chosen and all tests should be made at similar wind tunnel velocities within a 5 % tolerance of this value so that $0{,}95 < \overline{U}_{\text{test}} / \overline{U}_{\text{ref}} < 1{,}05$.

The ratio of the total length of the train model to the width of the tunnel should not be so large that the presence of the side walls of the tunnel cause any distortions to the flow around the ends of any leading vehicles when these are perpendicular to the tunnel and should be less than 0,75.

G.5 Modelling accuracy

See 5.3.4.9.

G.6 Instrumentation requirements

G.6.1 General

See 5.3.4.10.

G.6.2 Speed measurement

The wind speed should be measured with a device suitable for data acquisition at the specified data acquisition frequency. The device should have an accuracy of better than 0,2 m/s and a resolution of better than 0,04 m/s.

The reference mean wind speed should be measured for all tests. In addition, for any embankment configurations, the wind tunnel velocity should be measured at 3 m (full scale equivalent) above the leading edge of the top of the embankment with no vehicle in place for the specific configuration of 90° yaw. This measurement is required to determine the speed up of the wind over the embankment used to determine the embankment blockage corrections.

G.6.3 Force and moment balance

See 5.3.4.10 in conjunction with the following additional requirements. The calculated or measured moment coefficient about the lee rail should have an accuracy of 2,5 % and a resolution of 1 %.

When checking that the oscillation of the model mounting system does not affect the analysis, it should be verified that any residual modes of oscillation below the sampling frequency are sufficiently small that the resulting error in the peak rolling moment coefficient would be less than 2 %. If this is not achieved, modifications to the model and mounting should be undertaken. Where the modification cannot reduce the resulting error sufficiently, the signal should be filtered.

G.7 Data acquisition requirements

G.7.1 General

This section establishes the data acquisition frequency and the minimum quantity of measured data that should be acquired for each test configuration. All data should be acquired concurrently.

G.7.2 Time scale, sampling frequency and acquisition duration

A first requirement is to establish the time scale. All times, and reciprocals of frequency, should be scaled by the time scale ratio, S_t. The time scale is calculated as:

$$S_t = \frac{\widetilde{U}_{\mathrm{FS}}}{\widetilde{U}_{\mathrm{ref}}} \times \frac{L_{\mathrm{X}}}{L_{\mathrm{X,FS}}} \tag{G.7}$$

The turbulence length scale at full scale $L_{\mathrm{X,FS}}$ should be taken as 30 m.

Data from the force and moment balance and anemometer should be acquired at a frequency that corresponds to at least 10 Hz full scale. Therefore, the corresponding data acquisition frequency f_{samp} is

$$f_{\mathrm{samp}} > \frac{10\ \mathrm{Hz}}{S_t} \tag{G.8}$$

Data from temperature and pressure measurement should be sampled at a frequency of at least 1 Hz.

Data is required to permit derivation of the required peak and mean force and moment coefficients as follows:

a) For the cross wind case (i.e. when β = 90°), 12 blocks of data each of 10 min full scale equivalent duration are required to permit extreme value analysis. This is 7 200 s full-scale duration. Hence the data acquisition duration T_{samp} for each cross wind test configuration is given as:

$$T_{\mathrm{samp}} > S_t 7200\ \mathrm{s} \tag{G.9}$$

b) For all other cases at least 30 min of full-scale equivalent duration are required to allow mean values to be determined. Hence the data acquisition period for all other test configurations is given as:

$$T_{\mathrm{samp}} > S_t 1800\ \mathrm{s} \tag{G.10}$$

G.7.3 Measurement of temperature and atmospheric pressure

The temperature of the air within the wind tunnel should be measured throughout the experiments by a sensor with an accuracy of 0,5° C and a resolution of 0,1° C.

The absolute pressure of the air within the wind tunnel should be measured throughout the experiments by a sensor with an accuracy of 1 kPa and a resolution of 200 Pa.

G.8 Calculation of mean values

The mean values of the measured air velocities, the forces and moments, the atmospheric pressure and the temperature should be determined for all data within the data acquisition period, T_{samp}. For example, for the wind tunnel velocity $\widetilde{U}_{\text{rm}}$:

$$\widetilde{U}_m = \frac{1}{T_{\text{samp}}} \int_0^{T_{\text{samp}}} U(t')dt' \qquad \text{(G.11)}$$

G.9 Calculation of peak values

The peak values of wind tunnel speed and lee rail rolling moment, $\hat{U}$ and $\hat{M}_{\text{x,lee}}$, are determined by an extreme value analysis technique. This is explained in this clause taking $\hat{U}$ as an example. The analysis for $\hat{M}_{\text{x,lee}}$ is identical.

The raw signal is processed to give the running one second average $\widetilde{U}_{\text{1\_s}}(t) = \frac{1}{\Delta t}\int_{\text{t}-\Delta\text{t}}^{\text{t}} U(t')dt'$ where Δt is the equivalent of 1 s of time at full scale. The maximum value is determined for each of the 12 blocks of ten minutes data and these are ranked in ascending order as values $\hat{U}_{\text{m}}$ (for m = 1,…12). The cumulative probability of each is then given as:

$$P(\hat{U}_{\text{m}}) = m/13 \qquad \text{(G.12)}$$

A Lieblein method should then be used to find the best linear data fit of the form $\hat{U}_{\text{m}} \approx u - \frac{1}{a}\ln\left(-\ln\left(P(\hat{U}_{\text{m}})\right)\right)$ where u is the mode and $1/a$ is the dispersion. The best estimate of the maximum value with the required probability of exceedance is determined as:

$$\hat{U}_{\text{m}} = u + \frac{1,4}{a} \qquad \text{(G.13)}$$

G.10 Correction of wind tunnel velocity for vehicle and embankment blockages

The raw values of mean and peak wind tunnel velocity have to be corrected for blockage effects. Two corrections are applied: the first relates to the embankment blockage, the second to the vehicle blockage. For corrections to the mean wind tunnel velocity see B.3. The correction for the peak velocity is:

$$\hat{U} = \hat{k}_{\text{e}} \times k_{\text{v}} \times \hat{U}_{\text{m}} \qquad \text{(G.14)}$$

Peak values of the coefficients at yaw angles other than 90° can then be formed by assuming that the ratio of peak to mean coefficients is constant across the yaw angle range and can thus be obtained from the mean value at any particular angle and the peak/mean ratio at an angle of 90°,

$$\hat{c}_{Mx,\text{lee}}(\beta) = \frac{\hat{c}_{Mx,\text{lee}}(90°)}{\bar{c}_{Mx,\text{lee}}(90°)} \times \bar{c}_{Mx,\text{lee}}(\beta), \tag{G.15}$$

The embankment blockage factor $\hat{k}_e$ compensates the peak velocity for the speed up effect of the constraint of the wind tunnel roof on the deflection of the flow over the embankment.

$$\hat{k}_e = 1 + f_h \left(1 - \frac{1}{\hat{U}_{e,m} / \hat{U}_m} \right) \tag{G.16}$$

where

$f_h = 1{,}25\sqrt{B_E} - 0{,}25$, for B_E > 0,04; and (G.17)

$f_h = 0$ otherwise. (G.18)

The vehicle blockage factor k_v is described in B.3.

G.11 Calculation of air density

See 5.3.4.10.

G.12 Calculation of the uncorrected rolling moment coefficient

The raw coefficients are determined as:

$$\tilde{c}_{Mx,\text{lee,m}} = \frac{\tilde{M}_{x,\text{lee}}}{\frac{1}{2}\rho A_{xz} h \tilde{U}^2} \text{ and} \tag{G.19}$$

$$\hat{c}_{Mx,\text{lee,m}} = \frac{\hat{M}_{x,\text{lee}}}{\frac{1}{2}\rho A_{xz} h \hat{U}^2} \tag{G.20}$$

NOTE The latter peak coefficient is only derived for the 90° yaw case.

G.13 Determination of the lee rail roll moment coefficient

The bias ratios determined previously are allowed for by applying a correction factor to the raw moment coefficients:

$$\tilde{c}_{Mx,\text{lee}} = \bar{k}_{Mx,\text{bias}} \times \tilde{c}_{Mx,\text{lee,m}} \text{ and} \tag{G.21}$$

$$\hat{c}_{Mx,\text{lee}} = \hat{k}_{Mx,\text{bias}} \times \hat{c}_{Mx,\text{lee,m}} \tag{G.22}$$

NOTE The latter peak coefficient is only derived for the 90° yaw case.

G.14 Data interpolation

See 5.3.4.13.

Annex H
(informative)

Five mass model

H.1 General

Hereunder the model for a typical vehicle with two sets of running gear is described. An example for the derivation of the system of equations for this vehicle model is given in H.3. In what follows, the coordinate system defined in EN 14067-1 is used.

The model (see Figure H.1) consists of five masses, the car body (CB), the front and the rear bogie (BG_1 and BG_2) and the two bodies for the front and the rear wheel set of a bogie (WS_1 and WS_2). The following are to be considered in the operating condition: all unsprung masses for the wheel set bodies, all primary suspended masses for the bogies and all secondary suspended masses for the car body.

The car body has five degrees of freedom, translatory in the y and z directions, y_{CB}, z_{CB}, and rotational degrees of freedom around all axes, Ψ_{CB}, Θ_{CB}, Φ_{CB}. The bodies of the bogies BG_i have three degrees of freedom, y_{BGi}, z_{BGi} and Ψ_{BGi}. The wheel set bodies WS_i have 0 degrees of freedom. Consequently, the system has a total of 11 degrees of freedom.

The spring elements of the secondary and primary suspension (c_s and c_p) are located between the bodies. They are modelled as compact elements with stiffnesses in the y and z directions, with the spring elements of a spring stage being combined to a spring-stiffness. The stiffnesses may be represented by a non-linear characteristic.

If the vehicle is equipped with an anti-roll bar, this has to be considered. The anti-roll bars (ARB_1, ARB_2) with rotational stiffnesses around the x axis are usually located between the car body and the bogie frame.

The bump stops in the lateral and vertical directions of the primary and secondary suspension are critical for the calculation of the characteristic wind curves. They can be modelled at the same point as the primary and secondary springs. The stops can be represented by a non-linear characteristic.

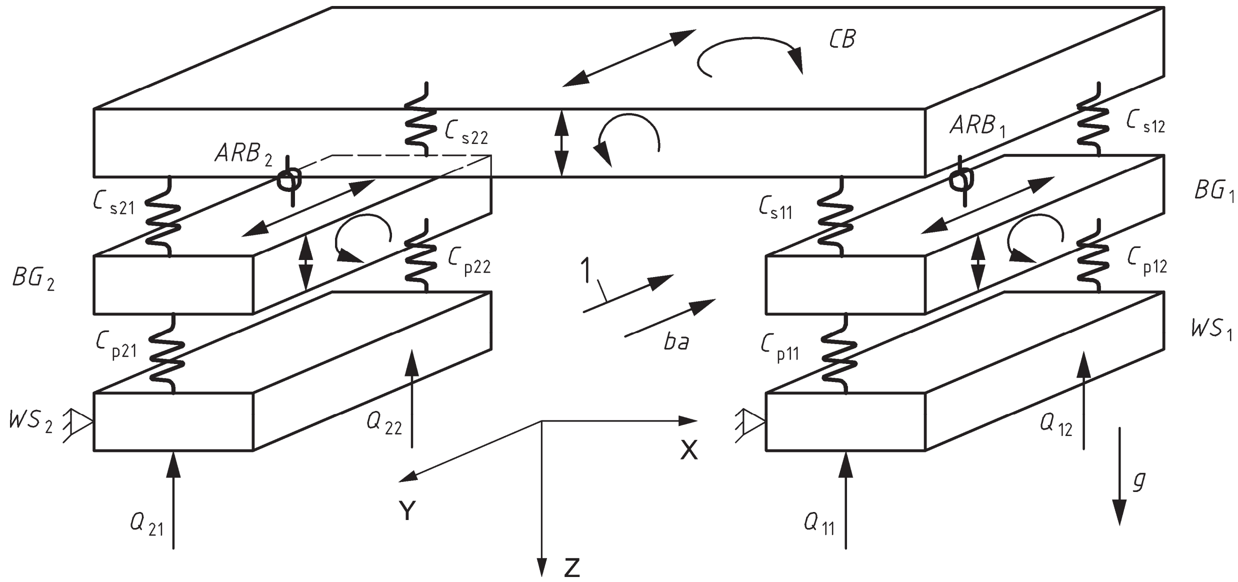


Figure H.1 — Illustration of five mass model

The model described above requires the following input data to solve the system of equations:

— Geometrical data:

— bogie spacing a,

— wheel radius.

— Masses:

— secondary suspended masses, (service weight of the car body), with the centre of gravity position in the x, y, and z directions,

— primary suspended masses (bogie masses) with the centre of gravity position in the y and z directions,

— unsprung masses (wheel set masses) with the centre of gravity position in the y and z directions (running radius).

— Secondary suspension:

— secondary spring lateral spacing y,

— height z of the secondary suspension,

— secondary spring stiffnesses y (force-distance characteristic),

— secondary spring stiffnesses z (force-distance characteristic).

— Primary suspension:

— primary spring lateral spacing y,

— height z of the primary suspension,

- primary spring stiffnesses y (force-distance characteristic),
- primary spring stiffnesses z (force-distance characteristic).

The spring elements are combined so that the stiffnesses of one bogie side are to be used.

- Anti-roll bar:
  - front rotational stiffnesses,
  - rear rotational stiffnesses.
- Stops of the primary suspension:
  - maximum movement in compression (downwards),
  - minimum movement in extension (upwards),
  - maximum lateral movement, right/left symmetrically.
- Stops of the secondary suspension:
  - maximum movement in compression (downwards),
  - minimum movement in extension (upwards),
  - maximum lateral movement, right/left symmetrically.
- Aerodynamic coefficients:
  - $c_{F\mathrm{y}}$, $c_{F\mathrm{z}}$, $c_{M\mathrm{x}}$, $c_{M\mathrm{y}}$, $c_{M\mathrm{z}}$ as a function of the yaw angle β,
  - reference length d_0,
  - reference area A_0,
  - air density ρ = 1,225 kg/m³.

H.2 demonstrates the derivation of a system of equations for the five mass model.

H.2 Derivation of equations

This clause describes the derivation of a mathematical system of equations for a five mass model on the basis of the model described in H.1.

The position of a body B_i is described by its position vector:

$$\underline{x}_\mathrm{Bi} = \left[x_\mathrm{Bi}, y_\mathrm{Bi}, z_\mathrm{Bi}, \Psi_\mathrm{Bi}, \Theta_\mathrm{Bi}, \Phi_\mathrm{Bi}\right]^\mathrm{T} \quad \text{(H.1)}$$

The system has a total of 11 degrees of freedom combined in the position vector of the system

$$\underline{x} = \left[y_\mathrm{CB}, z_\mathrm{CB}, \Psi_\mathrm{CB}, \Theta_\mathrm{CB}, \Phi_\mathrm{CB}, y_\mathrm{BG1}, z_\mathrm{BG1}, \Psi_\mathrm{BG1}, y_\mathrm{BG2}, z_\mathrm{BG2}, \Psi_\mathrm{BG2}\right]^\mathrm{T} \quad \text{(H.2)}$$

The use of half of the distance between the centres of the sets of running gear leads to the following position vectors for the individual bodies:

$$\underline{x}_{CB} = [0, y_{CB}, z_{CB}, \Psi_{CB}, \Theta_{CB}, \Phi_{CB}]^{T} \quad (H.3)$$

$$\underline{x}_{BG1} = [a, y_{BG1}, z_{BG1}, \Psi_{BG1}, 0, 0]^{T} \quad (H.4)$$

$$\underline{x}_{BG2} = [-a, y_{BG2}, z_{BG2}, \Psi_{BG2}, 0, 0]^{T} \quad (H.5)$$

$$\underline{x}_{WS1} = [a, 0, 0, 0, 0, 0]^{T} \quad (H.6)$$

$$\underline{x}_{WS2} = [-a, 0, 0, 0, 0, 0]^{T} \quad (H.7)$$

The following rotation matrices based on the Kardan-angles are used for the transformation of vectors in the different reference systems. Defining:

$$c\Psi = \cos(\Psi_{Bi}); c\Theta = \cos(\Theta_{Bi}); c\Phi = \cos(\Phi_{Bi}) \quad (H.8)$$

$$s\Psi = \sin(\Psi_{Bi}); s\Theta = \sin(\Theta_{Bi}); s\Phi = \sin(\Phi_{Bi}) \quad (H.9)$$

the rotation matrix of the body B_i into the stationary global reference system I is defined as follows:

$$\underline{A}_{IBi} = \begin{bmatrix} c\Theta \cdot c\Phi & -c\Theta \cdot s\Phi & s\Theta \\ c\Psi \cdot s\Phi + s\Psi \cdot s\Theta \cdot c\Phi & c\Psi \cdot c\Phi - s\Psi \cdot s\Theta \cdot s\Phi & -s\Psi \cdot c\Theta \\ s\Psi \cdot s\Phi - c\Psi \cdot s\Theta \cdot c\Phi & s\Psi \cdot c\psi + c\Psi \cdot s\Theta \cdot s\Phi & c\Psi \cdot c\Theta \end{bmatrix} \quad (H.10)$$

Thus, the following applies to the rotation matrix from B_j to B_i:

$$\underline{A}_{BiBj} = \underline{A}_{IBi}{}^{T} \cdot \underline{A}_{IBj} \text{ with} \quad (H.11)$$

$$\underline{A}_{IBi}{}^{-1} = \underline{A}_{IBi}{}^{T} \quad (H.12)$$

Each body B_i has a local body-fixed reference system. In the starting position, the local body-fixed reference system has the same orientation as the global reference system.

The coordinates for the cross points of the elements are each described in the local body-fixed coordinate system B_i. The position of the centre of gravity on the body B_i is described by the vector $\underline{r}_{CBi,Bi}$.

$$\underline{r}_{CCB,CB} = [c_{x,CB}, c_{y,CB}, c_{z,CB}]^{T} \quad (H.13)$$

$$\underline{r}_{CBGi,BGi} = [0, c_{y,BGi}, c_{z,BGi}]^{T} \quad (H.14)$$

$$\underline{r}_{CWSi,WSi} = [0, 0, r_0]^{T} \quad (H.15)$$

The position of the primary suspension on the wheelset WS_i is described by the following vectors:

$$\underline{r}_{cp1,WSi} = [0, b_1, -r_0]^{T} \text{ right primary spring,} \quad (H.16)$$

$$\underline{r}_{cp2,WSi} = [0, -b_1, -r_0]^{T} \text{ left primary spring.} \quad (H.17)$$

The position of the primary suspension on the bogie BG_i is described by the following vectors:

$$\underline{r}_{cp1,BGi} = [0, b_1, -r_0]^T \text{ right primary spring,} \quad (H.18)$$

$$\underline{r}_{cp2,BGi} = [0, -b_1, -r_0]^T \text{ left primary spring.} \quad (H.19)$$

The position of the secondary suspension on the bogie BG_i is described by the following vectors:

$$\underline{r}_{cs1,BGi} = [0, b_2, h_2]^T \text{ right secondary spring,} \quad (H.20)$$

$$\underline{r}_{cs2,BGi} = [0, -b_2, h_2]^T \text{ left secondary spring.} \quad (H.21)$$

The position of the secondary suspension on the car body is described by the following vectors:

$$\underline{r}_{cs1,BG1,CB} = [a, b_2, h_2]^T \text{ right secondary spring, } BG_1, \quad (H.22)$$

$$\underline{r}_{cs2,BG1,CB} = [a, -b_2, h_2]^T \text{ left secondary spring, } BG_1, \quad (H.23)$$

$$\underline{r}_{cs1,BG2,CB} = [-a, b_2, h_2]^T \text{ right secondary spring, } BG_2, \quad (H.24)$$

$$\underline{r}_{cs2,BG2,CB} = [-a, -b_2, h_2]^T \text{ left secondary spring, } BG_2. \quad (H.25)$$

The stops have the same position as the spring elements.

The calculation of the deflection of the force-element is necessary for determining the spring forces. The y and z components of the forces are determined by evaluating the force-characteristics for the given deflection. The force-characteristics take into account the stiffnesses in the primary and secondary suspension and the bump stops. The stiffness of metallic stops shall be fixed at $1 \cdot 10^8$ N/m. For numerical stability, the transition is modelled using a parabolic curve for a distance of 0,5 mm before the stop.

The deflections of the right/left primary springs are determined by means of the following equation, with the deflections being measured in the reference system of WS_i:

$$\underline{dr}_{cp1/2,i} = \underline{A}_{IWSi}^T \cdot (\underline{x}_{BGi}(1:3) - \underline{x}_{WSi}(1:3)) - \underline{r}_{cp1/2,WSi} + \underline{A}_{WSiBGi} \cdot \underline{r}_{cp1/2,BGi} \quad (H.26)$$

Analogously, the following applies to the secondary springs, with the deflections being measured in the reference system of BG_i:

$$\underline{dr}_{cs1/2,i} = \underline{A}_{IBGi}^T \cdot (\underline{x}_{CB}(1:3) - \underline{x}_{BGi}(1:3)) - \underline{r}_{cs1/2,BGi} + \underline{A}_{BGiCB} \cdot \underline{r}_{cs1/2,BGi,CB} \quad (H.27)$$

The twisting angle $d\varphi_{cs,i}$ of the BG_1 and BG_2 anti-roll bars is calculated by inverse transforming the rotary matrices $\underline{A}_{BGiCB}$.

The total sum of the forces is composed of spring forces, wind forces and mass forces.

The spring forces of the primary and secondary spring are calculated from the deflections $\underline{dr}$.

$$\underline{f}_{ci} = [f_{ci,x}, f_{ci,y}, f_{ci,z}]^T = \underline{f}(\underline{dr}_{ci}) = [f_{ci,x}(\underline{dr}_{ci}(1)), f_{ci,y}(\underline{dr}_{ci}(2)), f_{ci,z}(\underline{dr}_{ci}(3))]^T \quad (H.28)$$

As relative motions in the x direction are not considered, the following applies to the longitudinal forces

$$f_{\mathrm{ci,x}} = 0 \tag{H.29}$$

A linear interpolation is carried out between the points in a force-distance characteristic. In the vertical direction a parameter $f_{\mathrm{ci,nom}}$ for the nominal forces in the starting condition is implemented for each spring element.

The following applies to the moment of the anti-roll bar:

$$\underline{t}_{\mathrm{cs,i}} = \left[c_{\mathrm{s}\varphi,\mathrm{i}} \cdot d\varphi_{\mathrm{cs,i}}, 0, 0\right]^{\mathrm{T}} \tag{H.30}$$

The wind forces are calculated as described in 5.4.3.4.

The following applies to the mass forces on the body B_{i}:

$$\underline{f}_{\mathrm{m,Bi}} = m_{\mathrm{Bi}} \cdot \left[0, a_{\mathrm{q}}, g\right]^{\mathrm{T}} \tag{H.31}$$

$$\underline{t}_{\mathrm{m,Bi}} = \underline{r}_{\mathrm{CBi,I}} \times \underline{f}_{\mathrm{m,Bi}} \text{ with} \tag{H.32}$$

$$\underline{r}_{\mathrm{CBi,I}} = \underline{A}_{\mathrm{IBi}} \cdot \underline{r}_{\mathrm{CBi,Bi}} \tag{H.33}$$

The calculation of the sum of forces and moments is necessary for setting up the complete system of equations:

Spring forces on the car body CB:

$$\underline{f}_{\mathrm{f,CB}} = \underline{A}_{\mathrm{ICB}} \sum_{\mathrm{i}=1}^{2} \underline{A}_{\mathrm{BGiCB}}{}^{\mathrm{T}} \left(-\underline{f}_{\mathrm{cs1,i}} - \underline{f}_{\mathrm{cs2,i}}\right) \tag{H.34}$$

$$\underline{t}_{\mathrm{f,CB}} = \underline{A}_{\mathrm{ICB}} \cdot \sum_{\mathrm{i}=1}^{2} \begin{pmatrix} \underline{r}_{\mathrm{cs1,BGi,CB}} \times \left(\underline{A}_{\mathrm{BGiCB}}{}^{\mathrm{T}} \cdot \left(-\underline{f}_{\mathrm{cs1,i}}\right)\right) + \underline{r}_{\mathrm{cs2,BGi,CB}} \times \left(\underline{A}_{\mathrm{BGiCB}}{}^{\mathrm{T}} \cdot \left(-\underline{f}_{\mathrm{cs2,i}}\right)\right) \\ + \underline{A}_{\mathrm{BGiCB}}{}^{\mathrm{T}} \cdot \left(-\underline{t}_{\mathrm{cs,i}}\right) \end{pmatrix} \tag{H.35}$$

Spring forces on the bogies BG_{i}:

$$f_{\mathrm{f,BGi}} = \underline{A}_{\mathrm{IBGi}} \cdot \left(\underline{A}_{\mathrm{WSiBGi}}{}^{\mathrm{T}} \cdot \left(-\underline{f}_{\mathrm{cp1,i}} - \underline{f}_{\mathrm{cp2,i}}\right) + \underline{f}_{\mathrm{cs1,i}} + \underline{f}_{\mathrm{cs2,i}}\right) \tag{H.36}$$

$$\underline{t}_{\mathrm{f,BGi}} = \underline{A}_{\mathrm{IBGi}} \cdot \begin{pmatrix} \underline{r}_{\mathrm{cp1,BGi}} \times \left(\underline{A}_{\mathrm{WSiBGi}}{}^{\mathrm{T}} \cdot \left(-\underline{f}_{\mathrm{cp1,i}}\right)\right) + \underline{r}_{\mathrm{cp2,BGi}} \times \left(\underline{A}_{\mathrm{WSiBGi}}{}^{\mathrm{T}} \cdot \left(-\underline{f}_{\mathrm{cp2,i}}\right)\right) \\ + \underline{r}_{\mathrm{cs1,BGi}} \times \underline{f}_{\mathrm{cs1,i}} + \underline{r}_{\mathrm{cs2,BGi}} \times \underline{f}_{\mathrm{cs2,i}} + \underline{dr}_{\mathrm{cs1,i}} \times \underline{f}_{\mathrm{cs1,i}} + \underline{dr}_{\mathrm{cs2,i}} \times \underline{f}_{\mathrm{cs2,i}} + \underline{t}_{\mathrm{cs,i}} \end{pmatrix} \tag{H.37}$$

Spring forces on the wheel sets WS_{i}:

$$\underline{f}_{\mathrm{f,WSi}} = \underline{A}_{\mathrm{IWSi}} \cdot \left(\underline{f}_{\mathrm{cp1,i}} + \underline{f}_{\mathrm{cp2,i}}\right) \tag{H.38}$$

$$\underline{t}_{\mathrm{f,WSi}} = \underline{A}_{\mathrm{IWSi}} \cdot \left(\underline{r}_{\mathrm{cp1,WSi}} \times \underline{f}_{\mathrm{cp1,i}} + \underline{r}_{\mathrm{cp2,WSi}} \times \underline{f}_{\mathrm{cp2,i}} + \underline{dr}_{\mathrm{cp1,i}} \times \underline{f}_{\mathrm{cp1,i}} + \underline{dr}_{\mathrm{cp2,i}} \times \underline{f}_{\mathrm{cp2,i}}\right) \tag{H.39}$$

This results in the following sum of forces on the body B_i (applied to the bogies)

$$\underline{f}_{total,Bi} = \underline{f}_{m,Bi} + \underline{f}_{f,Bi} \quad (H.40)$$

$$\underline{t}_{total,Bi} = \underline{t}_{m,CB} + \underline{t}_{f,CB} \quad (H.41)$$

In addition, the following wind forces act on the car body:

$$\underline{f}_{total,CB} = \underline{f}_{m,CB} + \underline{f}_{f,CB} + \underline{f}_{Wi,CB} \quad (H.42)$$

$$\underline{t}_{total,Bi} = \underline{t}_{m,CB} + \underline{t}_{f,CB} + \underline{t}_{Wi,CB} \quad (H.43)$$

Only those directions of forces or moments are relevant for the system of equations to be set up in which the corresponding body also has a degree of freedom. This results in the following total system for the car body and the bogies (degrees of freedom of the wheel sets are zero):

$$F = F(\underline{x}) = \begin{bmatrix} \underline{f}_{total,CB}(2:3) \\ \underline{t}_{total,CB}(1:3) \\ \underline{f}_{total,BG1}(2:3) \\ \underline{t}_{total,BG1}(1) \\ \underline{f}_{total,BG2}(2:3) \\ \underline{t}_{total,BG2}(1) \end{bmatrix} = \underline{0} \quad (H.44)$$

The system of equations can be solved by a suitable non-linear solution algorithm. The result will be the equilibrium position of the vehicle.

The wheel-rail-forces as well as the sum of Y-forces can then be calculated:

$$Q_{1,WSi} = -\frac{\left(\underline{t}_{total,WSi}(4) + \underline{f}_{total,WSi}(3) \cdot b_{min}\right)}{4 \cdot b_{min}} \quad (H.45)$$

$$Q_{2,WSi} = -\frac{\underline{f}_{total,WSi}(3)}{2} - Q_{1,WSi} \quad (H.46)$$

$$SY_{WSi} = -\frac{1}{2}\underline{f}_{total,WSi}(2) \quad (H.47)$$

For the calculation of the CWC, the equilibrium position of the system has to be determined for different wind speeds. The definition of the CWC is described in 5.4.3.4. The following procedure is suggested for calculating the characteristic wind values:

— nominal forces: determination of the parameters $f_{ci,nom}$ so that $\underline{x} = \underline{0}$ solves the system of equations. Running speed, wind speed and lateral acceleration are each to be set to zero;

— calculation of the static wheel loads Q_0 for the starting position $\underline{x} = \underline{0}$ mm, $Q_{target} = 0{,}1 \cdot Q_0$;

— outer loop v_{tr};

— inner loop a_q;

— starting value for v_W = 30 m/s;

— calculation of the equilibrium position of the system (solution of the system of equations), determination of the wheel-rail-forces Q in the equilibrium position;

— when accuracy is achieved for Q, v_W is correct, otherwise interpolation of $v_{W\text{-new}}$ from former wind and Q-values.

H.3 Example calculations

H.3.1 General

This clause contains the input data and results for two example vehicles calculated with the quasi-static method.

H.3.2 Example vehicle 1

Example vehicle 1 has a maximum speed v_{max} = 160 km/h. The input data given in Table H.1 to Table H.5 shall be used for the five mass model.

The body parameters are given in Table H.1.

Table H.1 — Body parameters

	Mass [kg]	Position of centre of gravity [m] in		
		x	y	z
CB	22 904	0,0	0,0	-1,769
BG_1	2 598	–	0,0	-0,77
BG_2	2 598	–	0,0	-0,77
WS_1	2 200	–	–	-0,475
WS_2	2 200	–	–	-0,475

The secondary suspension parameters are given in Table H.2.

Table H.2 — Secondary suspension parameters

Half secondary spring lateral spacing y	1,0 m
Height z of the secondary suspension	-0,744 m
Maximum movement in compression (z downwards)	0,08 m
Minimum movement in extension (z upwards)	-0,08 m
Maximum lateral movement (y)	0,06 m
Secondary spring stiffness (z) for each bogie side	$0{,}278 \cdot 10^6$ N/m
Lateral stiffness y for each bogie side	$0{,}156 \cdot 10^6$ N/m
Rotational stiffness of ARB_1	0,0 Nm/rad
Rotational stiffness of ARB_2	0,0 Nm/rad

The primary suspension parameters are given in Table H.3.

Table H.3 — Primary suspension parameters

Half primary spring lateral spacing y	1,0 m
Height z of the primary suspension	-0,475 m
Maximum movement in compression (z downwards)	0,045 m
Minimum movement in extension (z upwards)	-0,045 m
Maximum lateral movement (y)	0,01 m
Primary spring stiffnesses z for each bogie side	$2{,}0 \cdot 10^6$ N/m
Lateral spring stiffnesses y for each bogie side	$14{,}0 \cdot 10^6$ N/m

General parameters are given in Table H.4.

Table H.4 — General parameters

Wheel radius	0,475 m
Bogie spacing	19,0 m

For the calculation of the wind forces, the aerodynamic coefficients given in Table H.5 shall be used. The coordinate system defined in EN 14067-1 is used. Reference values are A = 10 m^2 and d = 3 m.

Table H.5 — Aerodynamic coefficients

β [°]	c_{Fx}	c_{Fy}	c_{Fz}	c_{Mx}	c_{My}	c_{Mz}
0	-0,36	0,01	-0,19	-0,04	-0,36	0,08
5	-0,37	0,41	-0,33	0,19	-0,38	1,13
10	-0,40	0,92	-0,71	0,47	-0,45	2,26
15	-0,41	1,56	-1,30	0,88	-0,28	3,22
20	-0,42	2,25	-2,09	1,31	0,14	4,11
25	-0,42	3,06	-2,76	1,80	1,12	4,84
30	-0,55	4,13	-2,58	2,32	1,63	5,31
40	-0,61	5,90	-3,58	3,14	1,85	5,48
50	-0,54	6,93	-4,68	3,63	0,82	6,08
60	-0,20	7,95	-4,27	4,11	1,51	5,04
70	0,11	8,22	-3,55	4,17	1,02	3,80
80	0,23	7,64	-2,59	3,71	0,57	1,01
90	0,26	7,35	-2,61	3,51	-0,10	1,47

At a yaw angle of β_W = 90°, these input data result in the characteristic wind curves given in Table H.6.

Values given in bold letters are calculated. All other values are the result of the interpolation.

Table H.6 — Resulting CWC for example vehicle 1: v_{CWC} in [m/s] depending on the vehicle speed and the unbalanced lateral acceleration a_q at a yaw angle of β_W = 90°

v_{tr} [km/h] / a_q [m/s²]	80	90	100	110	120	130	140	150	160
-1,0	41,0	40,0	38,9	37,3	35,7	34,6	33,6	32,5	31,3
-0,9	40,3	39,2	38,1	36,6	35,1	34,0	33,0	31,9	30,8
-0,8	39,6	38,5	37,4	35,9	34,4	33,4	32,3	31,3	30,3
-0,7	38,9	37,8	36,7	35,2	33,8	32,7	31,7	30,7	29,7
-0,6	38,2	37,1	36,0	34,6	33,2	32,1	31,1	30,1	29,1
-0,5	37,6	36,4	35,3	33,9	32,6	31,5	30,5	29,5	28,5
-0,4	36,9	35,8	34,6	33,3	32,0	30,9	29,9	28,9	28,0
-0,3	36,3	35,1	34,0	32,7	31,4	30,3	29,3	28,3	27,4
-0,2	35,7	34,5	33,3	32,1	30,8	29,8	28,7	27,8	26,8
-0,1	35,0	33,9	32,7	31,4	30,2	29,1	28,1	27,2	26,3
0	**34,4**	33,3	**32,1**	30,8	**29,5**	28,5	**27,6**	26,7	**25,8**
0,1	33,8	32,7	31,5	30,1	28,8	27,9	27,0	26,1	25,2
0,2	**33,2**	32,0	**30,9**	29,5	**28,1**	27,3	**26,4**	25,6	**24,7**
0,3	32,6	31,4	30,2	28,9	27,6	26,7	25,8	25,0	24,1
0,4	**32,0**	30,8	**29,6**	28,3	**27,0**	26,1	**25,3**	24,4	**23,6**
0,5	31,3	30,1	28,9	27,6	26,4	25,5	24,7	23,8	23,0
0,6	**30,7**	29,4	**28,2**	27,0	**25,8**	24,9	**24,1**	23,2	**22,4**
0,7	30,0	28,7	27,5	26,3	25,2	24,3	23,4	22,6	21,8
0,8	**29,3**	28,0	**26,8**	25,7	**24,6**	23,7	**22,8**	22,0	**21,3**
0,9	28,6	27,3	26,0	25,0	23,9	23,0	22,2	21,4	20,7
1,0	**27,8**	26,6	**25,3**	24,3	**23,3**	22,4	**21,5**	20,9	**20,2**

With v_{max} = 160 km/h, the different yaw angles β_w result in the CWCs given in Table H.7.

Values given in bold letters are calculated. All other values are the result of the interpolation.

Table H.7 — Resulting CWC for example vehicle 1: v_{CWC} in [m/s] depending on yaw angle β_W and the unbalanced lateral acceleration a_q at v_{max} = 160 km/h

β_W [°] / a_q [m/s²]	80	70	60	50	40	30	20	10
-1,0	29,8	29,7	31,6	35,1	40,4	50,2	68,6	116,6
-0,9	29,3	29,2	31,1	34,6	39,7	49,4	67,6	114,8
-0,8	28,8	28,8	30,5	34,0	39,1	48,6	66,6	113,1
-0,7	28,4	28,3	30,0	33,5	38,5	47,9	65,6	111,3
-0,6	27,9	27,9	29,6	32,9	37,9	47,1	64,6	109,6
-0,5	27,5	27,4	29,1	32,4	37,3	46,4	63,7	108,0
-0,4	27,1	27,0	28,7	31,9	36,7	45,6	62,7	106,3
-0,3	26,5	26,5	28,2	31,4	36,2	44,9	61,8	104,7
-0,2	26,0	26,1	27,8	30,8	35,6	44,2	60,9	103,1
-0,1	25,5	25,7	27,3	30,3	35,0	43,5	60,0	101,5
0,0	**25,0**	**25,3**	**26,9**	**29,8**	**34,5**	**42,8**	**59,1**	**99,9**
0,1	24,4	24,8	26,4	29,3	33,9	42,1	58,1	98,4
0,2	**23,9**	**24,4**	**26,0**	**28,8**	**33,3**	**41,4**	**57,2**	**96,8**
0,3	23,4	24,0	25,6	28,3	32,7	40,7	56,3	95,2
0,4	**22,9**	**23,5**	**25,1**	**27,8**	**32,2**	**39,9**	**55,4**	**93,6**
0,5	22,4	23,1	24,7	27,2	31,6	39,2	54,4	91,9
0,6	**22,0**	**22,6**	**24,2**	**26,7**	**31,0**	**38,5**	**53,5**	**90,2**
0,7	21,5	22,2	23,7	26,2	30,4	37,7	52,5	88,5
0,8	**21,1**	**21,7**	**23,2**	**25,6**	**29,8**	**36,9**	**51,5**	**86,8**
0,9	20,6	21,3	22,7	25,1	29,2	36,2	50,5	85,0
1,0	**20,2**	**20,8**	**22,2**	**24,5**	**28,6**	**35,4**	**49,5**	**83,2**

H.3.3 Example vehicle 2

Example vehicle 2 has a maximum speed v_{max} = 200 km/h. The input data given in Table H.8 to Table H.12 shall be used for the five mass model.

The body parameters are given in Table H.8.

Table H.8 — Body parameters

	Mass [kg]	Position of centre of gravity [m] in		
		x	y	z
CB	36 635	0,468	0,0	-2,074
BG_1	4 260	–	0,0	-0,54
BG_2	4 190	–	0,0	-0,54
WS_1	3 672	–	0,0	-0,46
WS_2	3 672	–	0,0	-0,46

The secondary suspension parameters are given in Table H.9.

Table H.9 — Secondary suspension parameters

Half secondary spring lateral spacing *y*	0,9 m
Height *z* of the secondary suspension	-0,889 m
Maximum movement in compression (*z* downwards)	0,04 m
Minimum movement in extension (*z* upwards)	-0,04 m
Maximum lateral movement (*y*)	0,05 m
Secondary spring stiffness (*z*) for each bogie side	$0,62 \cdot 10^6$ N/m
Lateral stiffness *y* for each bogie side	$0,56 \cdot 10^6$ N/m
Rotational stiffness of ARB_1	$5,832 \cdot 10^6$ Nm/rad
Rotational stiffness of ARB_2	$5,832 \cdot 10^6$ Nm/rad

The primary suspension parameters are given in Table H.10.

Table H.10 — Primary suspension parameters

Half primary spring lateral spacing y	1,0 m
Height z of the primary suspension	-0,46 m
Maximum movement in compression (z downwards)	no stop
Minimum movement in extension (z upwards)	no stop
Maximum lateral movement (y)	no stop
Primary spring stiffnesses z for each bogie side	$2{,}636 \cdot 10^6$ N/m
Lateral spring stiffnesses y for each bogie side	$21{,}8 \cdot 10^6$ N/m

General parameters are given in Table H.11.

Table H.11 — General parameters

Wheel radius	0,46 m
Bogie spacing	20,0 m

For the calculation of the wind forces, the aerodynamic coefficients given in Table H.12 shall be used. The coordinate system defined in EN 14067-1 is used. Reference values are A = 10 m^2 and d = 3 m.

Table H.12 — Aerodynamic coefficients

β [°]	c_{Fx}	c_{Fy}	c_{Fz}	c_{Mx}	c_{My}	c_{Mz}
0	-0,24	0,01	0,16	0,12	-0,74	0,14
5	-0,29	0,55	0,03	0,39	-1,01	1,17
10	-0,34	1,24	-0,35	0,82	-1,34	2,29
15	-0,37	2,18	-1,01	1,42	-1,68	3,18
20	-0,36	3,34	-1,86	2,20	-1,57	3,59
25	-0,37	4,66	-2,21	3,04	-0,65	3,93
30	-0,37	6,20	-2,33	3,96	1,12	4,13
40	-0,16	9,45	-1,98	5,90	2,85	4,48
50	0,22	11,09	-2,39	6,62	2,06	5,16
60	0,21	9,82	-2,77	5,36	0,84	2,11
70	0,68	9,68	-3,43	4,99	0,50	0,89
80	0,72	9,21	-3,26	4,56	-0,07	-1,24
90	0,31	9,07	-3,28	4,37	-0,89	-3,79

At a yaw angle of β_W = 90°, these input data result in the characteristic wind curves given in Table H.13.

Values given in bold letters are calculated. All other values are the result of the interpolation.

Table H.13 — Resulting CWC for example vehicle 2: v_{CWC} in [m/s] depending on the vehicle speed and the unbalanced lateral acceleration a_q at a yaw angle of β_W = 90°

v_{tr} [km/h] / a_q [m/s^2]	80	90	100	110	120	130	140	150	160	170	180	190	200
-1,0	57,3	54,9	52,5	47,2	41,7	39,6	37,3	36,8	36,3	35,6	34,8	34,5	34,1
-0,9	56,1	53,9	51,7	46,4	41,0	38,9	36,7	36,2	35,7	35,0	34,2	33,9	33,5
-0,8	54,9	52,9	50,9	45,7	40,4	38,3	36,1	35,6	35,1	34,4	33,6	33,3	32,9
-0,7	53,9	52,0	50,1	44,9	39,6	37,6	35,5	35,0	34,5	33,8	33,0	32,7	32,3
-0,6	53,0	51,1	49,3	44,1	38,8	36,9	34,9	34,4	33,9	33,3	32,5	32,2	31,8
-0,5	52,0	50,0	48,1	43,1	38,0	36,2	34,3	33,8	33,3	32,7	32,0	31,7	31,2
-0,4	51,1	49,0	46,9	42,1	37,2	35,5	33,7	33,2	32,8	32,2	31,5	31,2	30,7
-0,3	50,1	47,7	45,3	40,9	36,4	34,8	33,1	32,6	32,2	31,6	30,9	30,6	30,2
-0,2	49,2	46,5	43,8	39,8	35,7	34,2	32,6	32,1	31,6	31,1	30,4	30,1	29,7
-0,1	48,3	45,3	42,3	38,7	34,9	33,5	32,0	31,5	31,0	30,5	29,9	29,6	29,2
0,0	**47,5**	44,2	**40,9**	37,6	**34,2**	32,9	**31,5**	31,0	**30,5**	30,0	**29,4**	29,1	**28,7**
0,1	46,7	43,1	39,5	36,5	33,5	32,3	31,0	30,5	30,0	29,5	28,9	28,6	28,2
0,2	**45,8**	41,9	**38,0**	35,4	**32,7**	31,6	**30,4**	29,9	**29,4**	28,9	**28,4**	28,1	**27,7**
0,3	44,9	40,7	36,5	34,3	32,0	31,0	29,9	29,4	28,8	28,4	27,9	27,6	27,2
0,4	**43,9**	39,4	**34,9**	33,1	**31,2**	30,3	**29,3**	28,8	**28,2**	27,8	**27,3**	27,0	**26,7**
0,5	43,0	38,4	33,7	32,1	30,4	29,6	28,7	28,2	27,7	27,3	26,8	26,5	26,2
0,6	**42,0**	37,3	**32,5**	31,1	**29,6**	28,9	**28,1**	27,6	**27,1**	26,7	**26,3**	26,0	**25,6**
0,7	41,1	36,4	31,7	30,3	28,8	28,2	27,5	27,0	26,5	26,2	25,8	25,5	25,1
0,8	**40,1**	35,5	**30,9**	29,5	**28,0**	27,5	**26,9**	26,4	**25,9**	25,6	**25,2**	24,9	**24,5**
0,9	38,9	34,5	30,1	28,8	27,4	26,9	26,3	25,8	25,3	25,0	24,6	24,3	23,9
1,0	**37,7**	33,5	**29,3**	28,0	**26,7**	26,2	**25,7**	25,2	**24,7**	24,4	**24,0**	23,7	**23,3**

With v_{max} = 200 km/h, the different yaw angles β_W result in the CWCs given in Table H.14.

Values given in bold letters are calculated. All other values are the result of the interpolation.

Table H.14 — Resulting CWC for example vehicle 2: v_{CWC} in [m/s] depending on the yaw angle β_W and the unbalanced lateral acceleration a_q at v_{max} = 200 km/h

β_W [°] / a_q [m/s^2]	80	70	60	50	40	30	20	10
-1,0	33,8	34,5	36,7	40,4	47,1	59,1	80,4	134,7
-0,9	33,2	33,9	36,1	39,8	46,3	58,2	79,2	132,6
-0,8	32,7	33,4	35,6	39,2	45,6	57,3	78,1	130,6
-0,7	32,1	32,8	35,0	38,6	44,9	56,3	76,9	128,6
-0,6	31,6	32,3	34,4	38,0	44,2	55,4	75,7	126,7
-0,5	31,0	31,8	33,8	37,3	43,5	54,5	74,5	124,7
-0,4	30,5	31,3	33,3	36,7	42,9	53,6	73,4	122,7
-0,3	30,0	30,7	32,7	36,1	42,2	52,7	72,2	120,7
-0,2	29,5	30,2	32,2	35,6	41,5	51,8	71,1	118,8
-0,1	29,0	29,7	31,6	35,0	40,8	50,9	69,9	116,9
0,0	**28,5**	**29,2**	**31,1**	**34,4**	**40,2**	**50,1**	**68,8**	**115,0**
0,1	28,0	28,7	30,6	33,8	39,6	49,3	67,7	113,1
0,2	**27,5**	**28,2**	**30**	**33,2**	**38,9**	**48,4**	**66,5**	**111,2**
0,3	27,0	27,7	29,5	32,7	38,2	47,5	65,4	109,3
0,4	**26,5**	**27,1**	**28,9**	**32,1**	**37,5**	**46,6**	**64,2**	**107,3**
0,5	26,0	26,6	28,4	31,5	36,9	45,7	63,1	105,3
0,6	**25,4**	**26,1**	**27,8**	**30,8**	**36,2**	**44,8**	**61,9**	**103,3**
0,7	24,9	25,6	27,2	30,2	35,5	43,9	60,7	101,4
0,8	**24,3**	**25**	**26,6**	**29,6**	**34,8**	**42,9**	**59,5**	**99,4**
0,9	23,8	24,5	26,1	29,0	34,1	42,0	58,4	97,4
1,0	**23,2**	**23,9**	**25,5**	**28,4**	**33,3**	**41,1**	**57,2**	**95,3**

Annex I
(normative)

Mathematical model for the Chinese hat

I.1 Mathematical model for Chinese hat

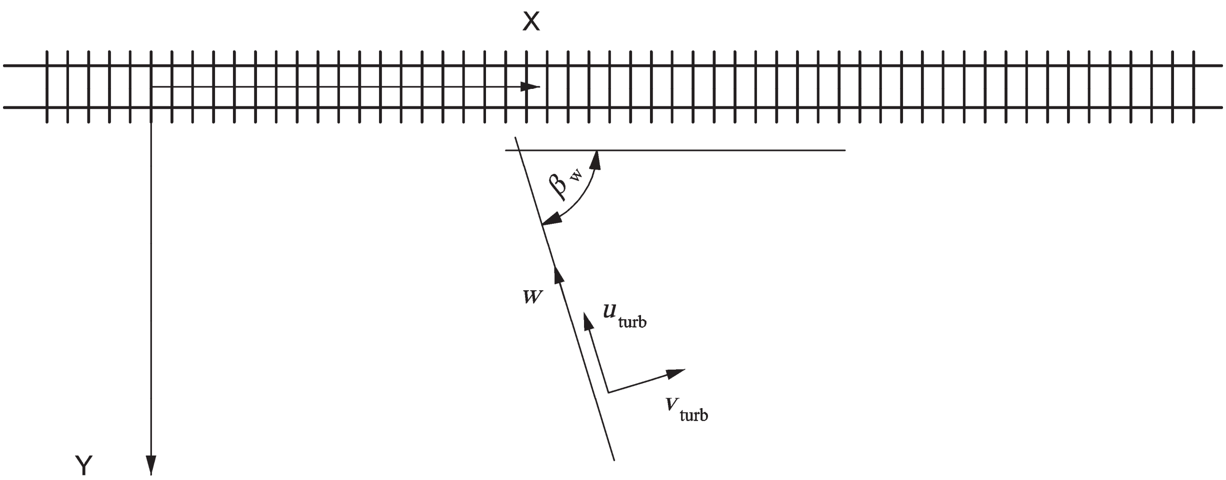
The basis of the mathematical model for the temporal distribution of the wind is a description of a statistically typical gust. The gust model has been obtained by meteorological measurements. The wind model is needed as an input to the vehicle dynamics simulation and has the shape plotted in Figure 5 in 5.4.4.2.

Distance is plotted on the x axis and the wind speed is plotted on the y axis. During the simulation the vehicle is assumed to have a constant speed when it is hit by the gust.

The wind gust is fixed in space. This means the spatial distribution is described, not the temporal one. Since the train velocity is constant, the temporal distribution can be evaluated from the spatial one by transformation.

In what follows, the calculation of the wind speed as a function of distance is described. It can be derived by using a gust factor and a time constant.

In Figure I.1 the coordinate system is shown which is used for the derivation of the wind model. The main wind direction w is defined in the coordinate system x, y. Turbulence produces disturbances to the amplitude and the direction of the wind. These deviations from the main flow direction are described by the components u_{turb} and v_{turb} parallel and perpendicular respectively to the main flow direction.



Key

X, Y inertial coordinate system for the definition of the main flow direction w

β_W angle between wind and track

u_{turb} turbulent disturbances parallel to the main flow direction w

v_{turb} turbulent disturbances perpendicular to the main flow direction w

Figure I.1 — Coordinate system

The angle between the main flow direction and the track accords with the angle β_w defined in EN 14067-1. For β_w = 90°, the main flow direction w and the component u_{turb} are parallel to the y direction, whilst the component v_{turb} is parallel to the x direction.

To calculate the wind scenario, the mean wind speed is first calculated from the gust factor and the maximum wind speed:

$$U_{mean} = \frac{U_{max}}{G} \tag{I.1}$$

The gust factor G is equal to 1,6946. For the calculation of the wind speed function, the standard deviation which depends on the mean wind speed is necessary:

$$\sigma_u = 0{,}2446 \cdot U_{mean} \tag{I.2}$$

The calculation of the temporal distribution of the wind scenario then requires the following steps.

First a time constant has to be calculated. This can be calculated from the power spectral density (PSD) of the longitudinal component u.

Then the characteristic length (the spatial wavelength of the gust) in the w direction is:

L_u^y = 96,0395 m (based in accordance with the TSI on a reference height of z = 4 m and roughness height z_0 = 0,07 m) (I.3)

The normalized frequency using the characteristic length is:

$$f_u = \frac{n \cdot L_u^y}{U_{mean}} \tag{I.4}$$

The frequency range of calculated or measured data is limited between n = [n_1, n_2]. It is assumed that the lower frequency limit n_1 is 1/300 Hz and the upper frequency limit n_2 is 1 Hz.

The power spectral density can be calculated by:

$$S_u(n) = \frac{4 \cdot f_u \cdot \sigma_u^2}{\left(1 + 70{,}7 \cdot f_u^2\right)^{\frac{5}{6}}} \cdot \frac{1}{n} \tag{I.5}$$

The mean time constant of the gust is given by the integral expression:

$$\overline{T} = \frac{1}{2} \cdot \left[\frac{\int_{n_1}^{n_2} n^2 \cdot S_u(n) dn}{\int_{n_1}^{n_2} S_u(n) dn} \right]^{-0{,}5} \tag{I.6}$$

which can be solved numerically, e.g. by performing a trapezoidal numerical integration using a suitable resolution of the frequency range. The mean time constant is a function only dependent on the mean wind speed. An analytical solution of the equation can be derived, however it is not practical for implementation.

The time constant T of the gust is given by:

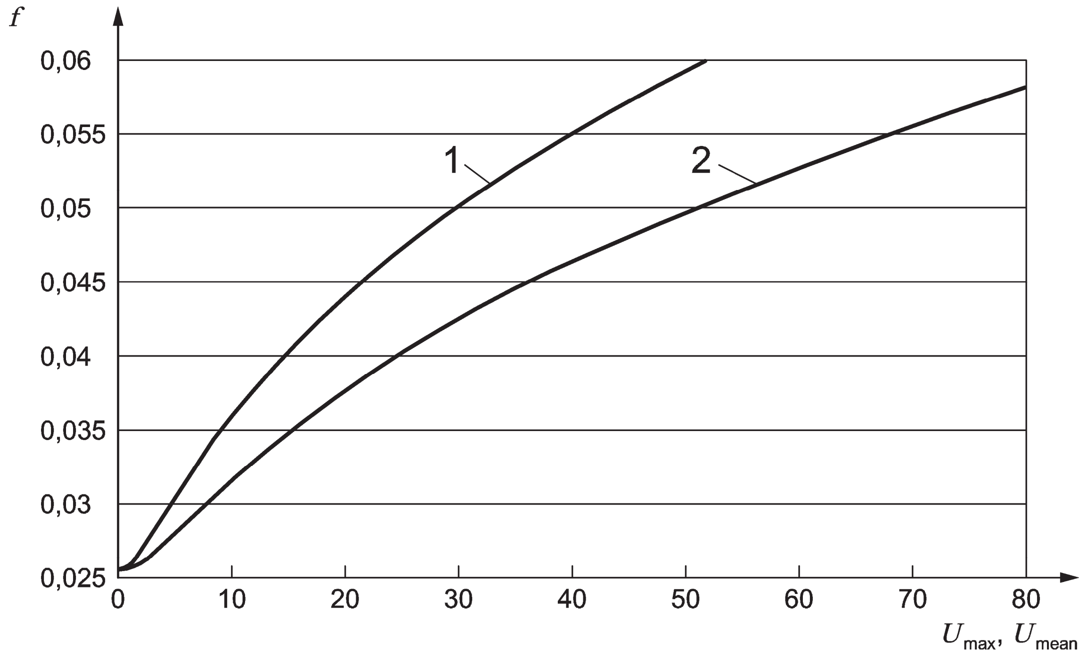
$$T = \overline{T} \cdot 4{,}1825 \quad \text{(I.7)}$$

By using the time constant and the wind angle relative to the track, the wind speed in the longitudinal and lateral directions relative to the track can be determined.

The factor f [s^{-1}] is calculated from the time constant:

$$f = \frac{1}{2 \cdot T} \quad \text{(I.8)}$$

For better comprehensibility the following Figure I.2 shows the dependency of factor f on the wind velocity.



Key

f, in s^{-1}

U_{max} , U_{mean}, in m/s

1 U_{mean}

2 U_{max}

Figure I.2 — Dependency of f on U_{mean} and U_{max}

With this factor the wind velocity of the u-component along and across the track are:

$$u_x(\tilde{x}) = f \cdot \tilde{x} \cdot \cos(\beta_w) \cdot \frac{1}{U_{mean}} \quad \text{(I.9)}$$

$$u_y(\tilde{x}) = f \cdot \tilde{x} \cdot \sin(\beta_w) \cdot \frac{1}{U_{mean}} \quad \text{(I.10)}$$

where $\tilde{x}$ [m] represents the distance along the track towards the position of the maximum amplitude of the gust.

The coherence function for the resulting wind speed can then be determined via linear interpolation from:

$$C = e^{-\sqrt{25 \cdot u_x^2 + 256 \cdot u_y^2}} \quad (I.11)$$

The wind speed along the track and normal to the vehicle can then be calculated by:

$$v_w = U_{mean} + 2{,}84 \cdot \sigma_u \cdot C \quad (I.12)$$

For β_w=90°, the longitudinal component u_x = 0 and the calculation of the correlation is simplified to:

$$C_{90} = e^{-16 \cdot u_y} \quad (I.13)$$

The wind speed normal to the vehicle along the track can be calculated by:

$$v_{w-90} = U_{mean} + 2{,}84 \cdot \sigma_u \cdot C_{90} \quad (I.14)$$

For practical implementation, the exponential decay is assumed to achieve the lower limit U_{mean} after reaching a maximum deviation of 1 % between those two values. The mathematical description only refers to the second half of the Chinese hat where the wind decays from U_{max} to U_{mean} (see Figure 6 in 5.4.4.2).

This model for spatial distribution can be used to derive the temporal distribution of a gust by accounting the time that the vehicle needs in order to travel this distance. The maximum wind speed (U_{max}) is the value attributed in the calculation of the CWC (rather than the peak wind speed after spatial averaging).

I.2 Example calculation for Chinese hat

In 5.4.4.2 (Chinese hat gust scenario) an example for the temporal distribution of the wind speed is given in Figure 7. The gust wind scenario is described mathematically as a spatial distribution as given in Equations (I.1) to (I.14). For the example calculation a wind scenario with U_{max} = 30,0 m/s is assumed. This results in a mean wind speed of U_{mean} = 17,7033 m/s. The temporal distribution of the gust is derived for a train with constant train speed v_{tr} = 200 km/h. From the given wind speed a characteristic frequency of f = 0,04252359 Hz results.

Table I.1 gives the calculated wind speed for time intervals of 0,2 s. The maximum wind speed occurs at t = 23 s. Up to t_1 = 3,0 s there is no wind. From t_1 to t_2 = 5,0 s there is a linear rise until the base level U_{mean} is reached. At t_3 = 16 s the deviation between the mirrored Chinese hat and U_{mean} is 0,00002 % << 1 %. After t_3 = 16 s the rise follows the mirrored Chinese hat up to the maximum at t_4 = 23 s. The vehicle has to be in a steady wind loading state between t_2 and t_3, before the second rise of the wind speed begins. After the maximum, the wind decays according to the Chinese hat function to t_5 = 28 s, where the deviation between the Chinese hat and U_{mean} is 0,0016 % << 1 %. The time t_6 is chosen in this example calculation to be equal to t_5. From t_6 on, then there is a linear fall until at t_7 = 30 s the wind scenario is finished.

The temporal distribution of the wind scenario is low-pass filtered on the basis of a centred moving average with a window size equal to the assumed vehicle length of 24 m and a step size smaller than 0,5 m. Due to this filtering, both Figure 7 in 5.4.4.2 and Table I.1 show a maximum wind speed of 27,55 m/s which is smaller than the assumed value of U_{max} as this assumed value relates to the spatial wind distribution.

Table I.1 — Calculation example for Chinese hat gust scenario with U_{max} = 30,0 m/s, v_{tr} = 200 km/h, vehicle length = 24 m

Time interval t [s]	Wind speed v_W [m/s]	Moving average [m/s]	Time interval t [s]	Wind speed v_W [m/s]	Moving average [m/s]
0,0	0,0000	0,0000	6,6	17,7033	17,7033
0,2	0,0000	0,0000	6,8	17,7033	17,7033
0,4	0,0000	0,0000	7,0	17,7033	17,7033
0,6	0,0000	0,0000	7,2	17,7033	17,7033
0,8	0,0000	0,0000	7,4	17,7033	17,7033
1,0	0,0000	0,0000	7,6	17,7033	17,7033
1,2	0,0000	0,0000	7,8	17,7033	17,7033
1,4	0,0000	0,0000	8,0	17,7033	17,7033
1,6	0,0000	0,0000	8,2	17,7033	17,7033
1,8	0,0000	0,0000	8,4	17,7033	17,7033
2,0	0,0000	0,0000	8,6	17,7033	17,7033
2,2	0,0000	0,0000	8,8	17,7033	17,7033
2,4	0,0000	0,0000	9,0	17,7033	17,7033
2,6	0,0000	0,0000	9,2	17,7033	17,7033
2,8	0,0000	0,0026	9,4	17,7033	17,7033
3,0	0,0000	0,4780	9,6	17,7033	17,7033
3,2	1,7703	1,7703	9,8	17,7033	17,7033
3,4	3,5407	3,5407	10,0	17,7033	17,7033
3,6	5,3110	5,3110	10,2	17,7033	17,7033
3,8	7,0813	7,0813	10,4	17,7033	17,7033
4,0	8,8516	8,8516	10,6	17,7033	17,7033
4,2	10,6220	10,6220	10,8	17,7033	17,7033
4,4	12,3923	12,3923	11,0	17,7033	17,7033
4,6	14,1626	14,1626	11,2	17,7033	17,7033
4,8	15,9330	15,9303	11,4	17,7033	17,7033
5,0	17,7033	17,2253	11,6	17,7033	17,7033
5,2	17,7033	17,7007	11,8	17,7033	17,7033
5,4	17,7033	17,7033	12,0	17,7033	17,7033
5,6	17,7033	17,7033	12,2	17,7033	17,7033
5,8	17,7033	17,7033	12,4	17,7033	17,7033
6,0	17,7033	17,7033	12,6	17,7033	17,7033
6,2	17,7033	17,7033	12,8	17,7033	17,7033
6,4	17,7033	17,7033	13,0	17,7033	17,7033

Table I.1 (*continued*)

Time interval t [s]	Wind speed v_W [m/s]	Moving average [m/s]	Time interval t [s]	Wind speed v_W [m/s]	Moving average [m/s]
13,2	17,7033	17,7033	19,8	17,7166	17,7170
13,4	17,7033	17,7033	20,0	17,7236	17,7243
13,6	17,7033	17,7033	20,2	17,7344	17,7356
13,8	17,7033	17,7033	20,4	17,7510	17,7527
14,0	17,7033	17,7033	20,6	17,7765	17,7791
14,2	17,7033	17,7033	20,8	17,8154	17,8195
14,4	17,7033	17,7033	21,0	17,8752	17,8813
14,6	17,7033	17,7033	21,2	17,9667	17,9762
14,8	17,7033	17,7033	21,4	18,1071	18,1215
15,0	17,7033	17,7033	21,6	18,3222	18,3443
15,2	17,7033	17,7033	21,8	18,6518	18,6858
15,4	17,7033	17,7033	22,0	19,1571	19,2092
15,6	17,7033	17,7033	22,2	19,9316	20,0114
15,8	17,7033	17,7033	22,4	21,1186	21,2409
16,0	17,7033	17,7033	22,6	22,9378	23,1254
16,2	17,7033	17,7033	22,8	25,7262	25,9981
16,4	17,7033	17,7033	23,0	30,0000	27,5544
16,6	17,7033	17,7033	23,2	25,7262	25,9981
16,8	17,7033	17,7033	23,4	22,9378	23,1254
17,0	17,7033	17,7033	23,6	21,1186	21,2409
17,2	17,7033	17,7033	23,8	19,9316	20,0114
17,4	17,7034	17,7034	24,0	19,1571	19,2092
17,6	17,7034	17,7034	24,2	18,6518	18,6858
17,8	17,7035	17,7035	24,4	18,3222	18,3443
18,0	17,7036	17,7036	24,6	18,1071	18,1215
18,2	17,7037	17,7037	24,8	17,9667	17,9762
18,4	17,7040	17,7040	25,0	17,8752	17,8813
18,6	17,7043	17,7044	25,2	17,8154	17,8195
18,8	17,7049	17,7049	25,4	17,7765	17,7791
19,0	17,7057	17,7058	25,6	17,7510	17,7527
19,2	17,7070	17,7071	25,8	17,7344	17,7356
19,4	17,7089	17,7091	26,0	17,7236	17,7243
19,6	17,7119	17,7123	26,2	17,7166	17,7170

Table I.1 (*continued*)

Time interval t [s]	Wind speed v_W [m/s]	Moving average [m/s]
26,4	17,7119	17,7123
26,6	17,7089	17,7091
26,8	17,7070	17,7071
27,0	17,7057	17,7058
27,2	17,7049	17,7049
27,4	17,7043	17,7044
27,6	17,7040	17,7040
27,8	17,7037	17,7011
28,0	17,7036	17,2255
28,2	15,9330	15,9304
28,4	14,1626	14,1626
28,8	10,6220	10,6220
29,0	8,8516	8,8516
29,2	7,0813	7,0813
29,4	5,3110	5,3110
29,6	3,5407	3,5407
29,8	1,7703	1,7703
30,0	0,0000	0,4780
30,2	0,0000	0,0026
30,4	0,0000	0,0000
30,6	0,0000	0,0000

Annex J
(informative)

Stochastic wind model

J.1 General

The statistical methodology aims to reproduce the statistical interaction between the train dynamics and the aerodynamic forces. The methodology computes a spatial-time distribution of the wind speed that allows the physical stochastic characteristics of the phenomenon to be reproduced. As a stationary random process, the spatial-time distribution should be representative of the statistical properties of the atmospheric boundary layer depending on the wind speed power spectral densities S_{ii}, the coherence functions γ_{ii} and the roughness height z_0.

Using the wind speed distribution, the corresponding aerodynamic forces and moments are introduced as input to a multi-body model that simulates the vehicle dynamics. During the dynamic simulation, the railway vehicle is subjected to an aerodynamic force time history and not only to a single impulsive input (gust) as with the Chinese hat approach.

The MBS requirements are the same as those described in 5.4.4.

The computation of the train response to turbulent wind is repeated for different spatial-time distributions of wind speed corresponding to a probabilistic set of possible real operating conditions. Results are analysed by a statistical approach. It is necessary that the probabilistic convergence of the results is achieved.

The method is in the process of being developed and has been applied in Italy only.

J.2 Assumptions

The stochastic methodology is based on the following assumptions:

— The mean wind is assumed to be horizontal; only the along wind component U is used. This component represents the prominent part of wind fluctuations and is the projection of the instantaneous wind vector in the mean wind direction. The mean value of v (lateral) component of wind is considered equal to 0.

— Dynamic variations of the mean wind direction are not taken into account.

J.3 Application range

The stochastic method can be used:

— in turbulent wind conditions defined by a unique z_0 roughness height or on particular site characterised by different z_0 values at different positions;

— with different scenarios (subject to evaluation of aerodynamic coefficients by wind tunnel tests);

J.4 General Approach

J.4.1 General

Figure J.1 shows the flow chart of the overall procedure. It follows different steps:

— evaluation of the static aerodynamic coefficients (see 5.3);

— calculation, by a numerical model (based on the Cooper theory), of the turbulent wind speed time-history experienced by a point moving with the vehicle;

— evaluation, by a numerical algorithm based on the aerodynamic admittance function, of the aerodynamic forces acting on a vehicle subjected to real turbulent wind;

— simulation of the dynamic behaviour of rail vehicles subjected to real turbulent wind by a multi body model;

— computation of the $\Delta Q/Q_0$ index time history, starting from the output of the numerical simulation, and evaluation of the corresponding characteristic wind curves.

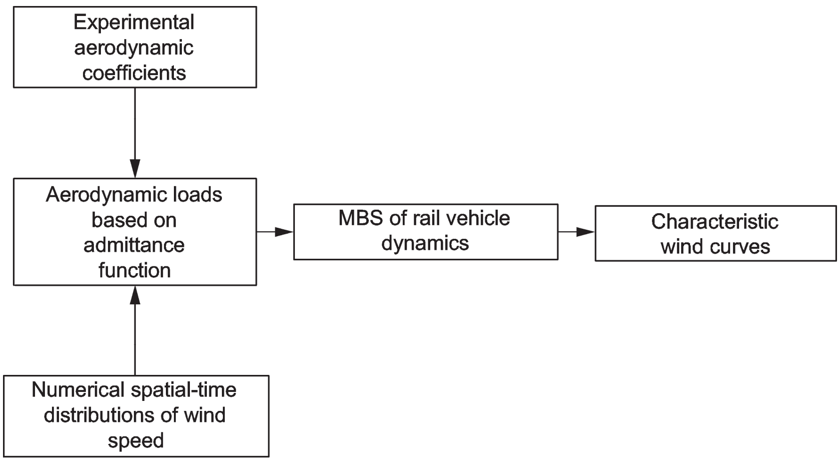


Figure J.1 — Flow chart of the methodology

J.4.2 First step: wind tunnel tests (aerodynamic properties determination)

The aerodynamic coefficients are evaluated by wind tunnel tests following one of the methodologies described in the paragraphs related to wind tunnel tests (see 5.3.4).

J.4.3 Second step: calculation of turbulent wind speed

The second step can be divided into three tasks according to the following paragraphs:

J.4.3.1 Input data definition

The input data for the calculation of turbulent wind speed are:

v_{tr} train speed,

U_{mean} mean wind speed,

β	wind direction with respect to the line
z_0	roughness height
h_{BL}	boundary layer height

A reference height is assumed z = 4 m. The statistical properties of boundary layer necessary to the stochastic methodology for the evaluation of the time-space wind speed distribution are:

— standard deviation of the along-wind turbulence component u, v;

— longitudinal integral length scales: ${}^{x}L_u$.

Wind experimental data or empirical laws may be used to define the statistical properties for the specific site. Starting from the roughness height z_0 (which identifies the terrain category), it is possible to evaluate by empirical expression both the standard deviations and the integral length scales.

The standard deviation $\sigma_u(z)$ up to a height of about 100 m to 200 m above homogeneous terrain, for flat terrain, is approximately given by:

$$\sigma_u = \frac{A\kappa}{\ln(z/z_0)} U_{mean} \tag{J.1}$$

where κ is von Karman's constant (κ = 0,4) and the constant $A^* \approx 2{,}5$ if z_0 = 0,05 m and $A^* \approx 1{,}8$ if z_0 = 0,3 m.

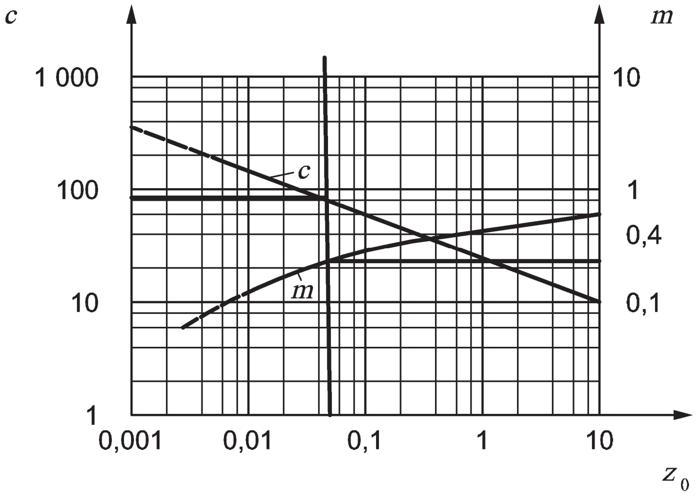
The standard deviation σ_v can be computed as:

$$\sigma_v = \sigma_u \left(1 - 0{,}22\cos^2\left(\frac{\pi}{2}\frac{z}{h_{BL}}\right)\right) \tag{J.2}$$

The longitudinal integral length scale can be evaluated by the purely empirical expression proposed by Counihan (see [12]):

$${}^{x}L_u = Cz^{m} \tag{J.3}$$

where C and m depend on roughness height z_0, as shown in Figure J.2. Figure J.2 shows C and m constant as a function of the roughness height z_0 for the longitudinal integral length scale calculation.



Key

z_0 roughness height, in m

Figure J.2 — Parameters C and m as a function of z_0 for the calculation of ${}^{x}L_u$ (Couninhan expression)

Alternatively, the roughness height and the relative parameter can be assumed as fixed by the methodology. For example, as proposed in the TSI, it is possible to assume:

$$z_0 = 0{,}07 \text{ m} \tag{J.4}$$

$$I_u = 24{,}5\ \% \tag{J.5}$$

$${}^{x}L_u = 50 \times \frac{z^{0{,}35}}{z_0^{0{,}063}} = 96{,}0395 \text{ m} \tag{J.6}$$

From ${}^{x}L_u$ it is possible to evaluate the other integral length scales from the ESDU standard (see [13]):

$${}^{y}L_u = 0{,}42\,{}^{x}L_u \tag{J.7}$$

$${}^{x}L_v = 0{,}5\,{}^{x}L_u\left(\frac{\sigma_v}{\sigma_u}\right)^3 \tag{J.8}$$

$${}^{y}L_v = 2\,{}^{y}L_u\left(\frac{\sigma_v}{\sigma_u}\right)^3 \tag{J.9}$$

J.4.3.2 Power spectral density of absolute wind speed on moving point: Cooper theory

The Cooper theory (see [14]), starting from the Von Karman PSD expression, defines the non dimensional power spectral density functions for the u-component and v-component at a moving point:

$$\tilde{S}_{uTuT}\left(\tilde{f}_u\right) = \left[4 * \tilde{L}_u\left(1 + 70{,}8\,\hat{f}_u^2\right)^{5/6}\right]\left[c_u + \left(1 - c_u\right)\left(0{,}5 + 94{,}4\,\hat{f}_u^2\right)/\left(1 + 70{,}8\,\hat{f}_u^2\right)\right] \tag{J.10}$$

where

$$\tilde{S}_{uTuT}\left(\tilde{f}_u\right) = v_{rel}\tilde{S}_{uTuT}(f)/{}^{x}L_u\sigma_u^2 \tag{J.11}$$

$$\tilde{f}_{\text{u}} = f\,{}^{\text{x}}L_{\text{u}} / v_{\text{rel}} \quad \text{(J.12)}$$

$$\hat{f}_{\text{u}} = f\,L_{\text{u}} / v_{\text{rel}} \quad \text{(J.13)}$$

$$c_{\text{u}} = \left[\left(v_{\text{tr}} / v_{\text{rel}} \right) \cos\Phi + \left(U_{\text{mean}} v_{\text{rel}} \right) \right]^2 \quad \text{(J.14)}$$

$$\tilde{L}_{\text{u}} = L_{\text{u}} / {}^{\text{x}}L_{\text{u}} \quad \text{(J.15)}$$

L_{u} is defined as $L_{\text{u}} = {}^{\text{x}}L_{\text{u}} \left[c_{\text{u}} + \left(2\,{}^{\text{y}}L_{\text{u}} / {}^{\text{x}}L_{\text{u}} \right)^2 \left(1 - c_{\text{u}} \right) \right]^{\frac{1}{2}}$ (J.16)

$$\tilde{S}_{\text{vTvT}}\left(\tilde{f}_{\text{v}}\right) = \left[4 * \tilde{L}_{\text{v}} \left(1 + 70{,}8\,\hat{f}_{\text{v}}^2 \right)^{5/6} \right] \left[c_{\text{v}} + \left(1 - c_{\text{v}} \right) \left(0{,}5 + 94{,}4\,\hat{f}_{\text{v}}^2 \right) / \left(1 + 70{,}8\,\hat{f}_{\text{v}}^2 \right) \right] \quad \text{(J.17)}$$

where

$$\tilde{S}_{\text{vTvT}}\left(\tilde{f}_{\text{v}}\right) = v_{\text{rel}} S_{\text{vTvT}}(f) / {}^{\text{y}}L_{\text{v}} \sigma_{\text{v}}^2 \quad \text{(J.18)}$$

$$\tilde{f}_{\text{v}} = f\,{}^{\text{x}}L_{\text{u}} / v_{\text{rel}} \quad \text{(J.19)}$$

$$\hat{f}_{\text{v}} = f\,L_{\text{v}} / v_{\text{rel}} \quad \text{(J.20)}$$

$$c_{\text{v}} = \left[\left(v_{\text{tr}} / v_{\text{rel}} \right) \sin\beta \right]^2 \quad \text{(J.21)}$$

$$\tilde{L}_{\text{v}} = L_{\text{v}} / {}^{\text{x}}L_{\text{u}} \quad \text{(J.22)}$$

L_{v} is defined as $L_{\text{v}} = {}^{\text{y}}L_{\text{v}} \left[c_{\text{v}} + \left(2\,{}^{\text{x}}L_{\text{v}} / {}^{\text{y}}L_{\text{v}} \right)^2 \left(1 - c_{\text{v}} \right) \right]^{\frac{1}{2}}$ (J.23)

J.4.3.3 Admittance function

The aeroadmittance function for the lateral force and for the rolling moment are defined as:

$$H^2(f) = \frac{4 \int_0^h \int_0^L (L - y)(h - z)\, \gamma_{\text{uu}}(\Delta \underline{r}, f)\, dy\, dz}{L^2 h^2} \quad \text{(J.24)}$$

where

— L and h are the length and the height of the vehicle;

— $\gamma_{\text{uu}}(\Delta \underline{r}, f)$ is the square-root coherence function:

$$\gamma_{\text{uu}}(\Delta \underline{r}) = \exp\left(-1{,}15\,\eta_1^{1{,}5} \right) \quad \text{(J.25)}$$

$$\eta_1 = \left[\left(0{,}747\,\tilde{r}_{\text{g}} \right)^2 + \left(c\,2\pi n \Delta r / \overline{U} \right)^2 \right]^{\frac{1}{2}} \quad \text{(J.26)}$$

$$c = \min\left\{\frac{1{,}6\tilde{r}_g^{0{,}13}}{\eta^b}, 1.0\right\} \quad \text{(J.27)}$$

$$\eta = \left[\left(0{,}747\tilde{r}_{\mathrm{g}}\right)^2 + \left(2\pi n \Delta r / \overline{U}\right)^2\right]^{\frac{1}{2}} \quad \text{(J.28)}$$

$$b = 0{,}3\tilde{r}_{\mathrm{g}}^{0{,}2} \quad \text{(J.29)}$$

$$\tilde{r}_{\mathrm{g}} = \Delta r / \left(2\,{}^{\mathrm{r}}L_{\mathrm{u}}\right) \quad \text{(J.30)}$$

where ${}^{\mathrm{r}}L_{\mathrm{u}}$ is evaluated as:

$${}^{\mathrm{r}}L_{\mathrm{u}} = \frac{\left[\left({}^{\mathrm{y}}L_{\mathrm{u}}\Delta y\right)^2 + \left({}^{\mathrm{z}}L_{\mathrm{u}}\Delta z\right)^2\right]^{\frac{1}{2}}}{\Delta r} \quad \text{(J.31)}$$

$$\Delta r = \left(\Delta y^2 + \Delta z^2\right)^{1/2} \quad \text{(J.32)}$$

For the other components (vertical and longitudinal force and pitch and yaw moment) the admittance function $H^2(f) = 1$.

J.4.4 Third step: evaluation of aerodynamic forces

A single wind velocity point is seen by the vehicle, this approximation may be justified by the use of an admittance function. However, this method can be applied for more than a vehicle, if the admittance function is known for each vehicle.

According to the corrected quasi-steady theory, in condition of turbulent wind, the aerodynamic force is evaluated by the following equation:

$$F(t) = \frac{1}{2}\rho A C\left(\beta_{\mathrm{rel}}(t)\right) v_{\mathrm{rel\_TC}}^2(t) \quad \text{(J.33)}$$

where

— the relative wind-train speed is:

$$v_{\mathrm{rel\_TC}}^2(t) = \left(v_{\mathrm{tr}} + v_{\mathrm{T}}(t)\right)^2 + U_{\mathrm{T}}^2(t) \quad \text{(J.34)}$$

— the angle of attack is defined as:

$$\beta_{\mathrm{rel}}(t) = \alpha \tan\left(\frac{U_{\mathrm{T}}(t)}{\left(v_{\mathrm{tr}} + v_{\mathrm{T}}(t)\right)}\right) \quad \text{(J.35)}$$

The transverse component of the corrected absolute wind speed, U_{TC} is:

$$U_{\mathrm{TC}}(t) = \sum_{n=0}^{n_{\max}} U_{\mathrm{TC}}(f_{\mathrm{n}}) \cos\left(n\omega_{\mathrm{o}} t \varphi_{\mathrm{n}}\right) = \sum_{n=0}^{n_{\max}} U_{\mathrm{TC}}(f_{\mathrm{n}}) \cos\left(2\pi f_{\mathrm{n}}\, t + \varphi_{\mathrm{n}}\right) \quad \text{(J.36)}$$

and

$$U_{TC}^{2}(f_n) = H(f_n)^2 U_T^2(f_n) \tag{J.37}$$

where

— $H(f_n)$ is the admittance function defined in Equation (J.24);

— $U_T(f_n)$ is the generic harmonic of the spectrum of the wind speed, obtained by starting from the power spectral density S_{uTuT} at a moving point with the following expression:

$$U_T(f_n) = \sqrt{2\omega_o S_{uTuT}}\ ; \tag{J.38}$$

— n is the generic harmonic component of the wind speed spectrum;

— n_{max} is the number of harmonics considered in the series, e.g. n_{max} = 4 096;

— $\omega_0 = \dfrac{2\pi}{T_0}$ stands as fundamental frequency (evaluated from the chosen time period, e.g. T_0 = 300 s);

— $f_n = \dfrac{\omega_n}{2\pi} = \dfrac{n\omega_0}{2\pi}$ is the n-frequency;

— φ_n is random phase between 0-2π that can be chosen arbitrarily for each reproduction of time-space distribution of wind speed.

The longitudinal component of the corrected absolute wind speed, v_T is:

$$v_T(t) = \sum_{n=0}^{n_{max}} v_T(f_n)\cos(n\omega_o t + j_n) = \sum_{n=0}^{n_{max}} v_T(f_n)\cos(2\pi f_n t + j_n) \tag{J.39}$$

where

— $v_T(f_n)$ is the generic harmonic of the spectrum of the wind speed, obtained by starting from the power spectral density S_{uTuT} at a moving point with the following expression:

$$v_T(f_n) = \sqrt{2\omega_o S_{vTvT}} \tag{J.40}$$

J.4.5 Fourth step: simulation of vehicle dynamics

Multi-body simulations (MBS) shall be used to determine the vehicle dynamic behaviour under strong wind (see 5.4.4).

J.4.6 Fifth step: evaluation of characteristic wind speed

For the definition of the $\Delta Q/Q_0$ index and the corresponding CWC see 5.4.4.6.

Starting from the numerical simulation results, it is possible to evaluate the $\Delta Q/Q_0$ indexes of the vehicle and, as a consequence, the characteristic wind curves that represent the combination of train speed v (or cant deficiency) and limit wind speed which leads to the exceedance of the $\Delta Q/Q_0$ limit. In particular, the $\Delta Q/Q_0$ index, defined as:

$$\frac{\Delta Q}{Q_0} = 1 - \frac{\sum_{k=1}^{2} Q_{\text{unloaded}}^{\text{k}}}{2 \cdot Q_0} \leq 0{,}9 \qquad \text{(J.41)}$$

where $\sum_{k=1}^{2} Q_{\text{unloaded}}^{\text{k}}$ is the sum of the dynamic vertical loads on the unloaded wheels of the first and of the second wheel set of the bogie. The time history of the index is filtered through a 2 Hz low-pass filter.

The evaluation of the admittance function shall be repeated $\overline{N}$ times, using different choices of random phase φ_{n}, in order to define statistically the mean CWC and the spread range. The mean CWC is defined as:

$$CWC = \frac{\sum CWC_{\text{i}}}{\overline{N}} \quad \text{(see [15])} \qquad \text{(J.42)}$$

The spread band is equal to 2σ where σ is the standard deviation. In case of a Gaussian distribution 2σ corresponds to 95,45 %.

Special considerations are necessary for the calculation of the CWC using stochastic wind on an embankment.

Annex K
(informative)

Stability of passenger vehicles and locomotives against overturning at standstill according to national guidelines

K.1 General

According to 5.2, a basic cross wind stability of vehicles with small maximum speed can be assumed due to (other) general regulations.

K.2 According to DB Guideline 80704 (Germany)

The following section describes a method for determining the stability against overturning of passenger and traction vehicles at standstill according to the DB Guideline 80704 [1]. According to that guideline, stability against overturning at standstill has to be proven in principle for any vehicles. However, stability against overturning at standstill is taken for granted if the cross wind stability of the vehicle has been proven by dedicated methods.

The basic concept of this method consists of calculating the characteristic wind speed that allows for a sufficient reliability against overturning. The determination of stability against overturning is based on a quasi-static approach. The displacement of the centre of gravity due to cant deficiency and due to wind load acting on the vehicle body is considered to be the primal effect. The following effects are taken into account on determining the stability against overturning at standstill:

— uncompensated acceleration in the plane of the bogies due to cant deficiency;

— possible transmission of rolling moments between adjacent car bodies (coupling);

— lateral displacement of the centre of gravity of the car body;

— wind direction perpendicular to the vehicle.

The determination of stability against overturning at standstill has to be carried out for each unit of a vehicle which is stiff against rolling. A 'unit which is stiff against rolling' means single car bodies of a vehicle or of a train set or of corresponding elements of groups of car bodies which are coupled in such a way that they act together stiffly against rolling. An explanation for any such chosen unit has to be given.

For the calculation of stability against overturning at standstill, the following vehicle data is required as a minimum:

— vehicle mass in tare load condition;

— primary suspended masses;

— secondary suspended masses (includes for example the mass of the car body);

— position of centre of gravity of secondary suspended masses (includes for example the centre of gravity of the car body);

— height of primary and secondary suspension elements (height of roll centre);

— flexibility coefficient (suspension coefficient) (possibly for verification);

— lateral displacement of primary suspension to the bump stop, possibly lateral stiffness;

— lateral displacement of secondary suspension to the bump stop, possibly lateral stiffness;

— vehicle height from top of rail to roof top;

— car body length without buffers and inter car gap.

The computation of lateral displacement of the gravity centre of the car body shall reproduce the characteristics of vehicle rolling. This may be done with simplified rules for clearance gauge calculation. For the simplest case, both suspension elements are set to lateral stop as a conservative approach. If data is available, the lateral displacement may be calculated from lateral forces and lateral stiffness. The suspension angle of the car body may be derived from the sum of moments of the lateral forces and the flexibility coefficient (suspension coefficient). More complex methods for calculation, e.g. use of MBS models, are permitted.

The cant deficiency is fixed to 165 mm.

In terms of wind load, a force F_y acting in the height $H/2$ in the centre of area is assumed:

1. F_y is based on the dynamic pressure and is derived from the height h and length L of the car body:

$$F_y = \frac{\rho}{2} w_{standstill}^2 \cdot H \cdot L \tag{K.1}$$

   The rolling moment M_x due to the wind load F_y acting in the height $H/2$ is given by:

$$M_x = \frac{H}{2} \cdot F_y \tag{K.2}$$

   Both the wind load F_y and the rolling moment M_x act on the car body at the height of top of rail and in the middle of the car body, the point of application in longitudinal direction with respect to the lateral surface is equal to $L/2$.

2. Alternatively, it is permitted to use wind tunnel tests results at a yaw angle of β = 90° for c_{Mx}, c_y and c_z.

The wheel sets of one bogie may be considered as being one.

For articulated trains and vehicles with inter-car bogies or similar constructions which facilitate a transmission of rolling moment, this coupling has to be accounted for.

The wheel loads due to the displacement of the centre of gravity have to be calculated. For standard UIC track gauge, the wheel-rail forces (Q-forces) are based on the lateral contact spacing 2 b_A = 1,5 m.

The characteristic wind speed $w_{standstill}$ has to be determined for the case when the residual averaged wheel load for the unit stiff against rolling is equal to 10 % of the nominal wheel load (i.e. 10 % of Q_0).

A dimensionless parameter $k_{standstill}$ can be derived from this characteristic wind speed $w_{standstill}$ by dividing the speed by 29,5 m/s.

The proof of stability against overturning at standstill is made if the parameter $k_{standstill}$ assumes a value of $k_{standstill} \geq 1{,}0$.

K.3 According to Railway Group Standard GM/RT 2141 (Great Britain)

This subclause describes the minimum requirements applied in Great Britain for railway vehicles to ensure they have an acceptable resistance to overturning induced by overspeeding (see [8], [9]). Indirectly, this requirement covers the resistance to cross wind as well. The requirements apply to both tilting and non-tilting vehicles.

Vehicles have to be designed in terms of mass distribution and suspension characteristics to ensure their capability to run around smooth curves at constant speed at:

— Not less than 16,5° cant deficiency for freight vehicles designed to operate at speeds no greater than 120 km/h,

— Not less than 21° cant deficiency for all other vehicles.

In all cases the curve is assumed to be smooth, such that quasi-static effects are taken into account, but not the effects of transitions; track irregularities or cross wind.

Normal design cant deficiency is 150 mm (approximately 6°) for non-tilting, non-freight trains travelling at maximum track speeds. There is therefore at worst, a margin of 15° cant deficiency for such trains and the limiting cant deficiency at which overturning will occur. Experience in Great Britain shows this margin is sufficient to ensure that the risk of overturning is tolerable.

In practice, a train travelling at nominal design cant deficiency may experience a significantly higher equivalent cant deficiency, reducing the margin before overturning occurs. The additional equivalent cant deficiency arises from:

— track irregularities;

— possible overspeeding;

— cross wind.

No budget cant deficiency is allocated to the above effects.

A tilting train may have a maximum design service cant deficiency up to 12°, as it can travel at higher cant deficiencies through curves than non-tilting trains. In this case there is a margin at worst, of only 9° cant deficiency to overturning, which is a considerable reduction in the margin to overturning. Additional controls therefore are required to ensure the safety of the train from overturning.

For both tilting and non-tilting trains the effect of strong winds has to be assessed separately (see [3], [10]), in addition to the requirements above.

Demonstration of compliance with the above minimum cant deficiency requirements can be either by full-scale static testing or using a quasi-static dynamics program. In both methods the maximum angle to which the vehicle can be canted before wheel unloading occurs is determined.

Annex L
(informative)

Information on methods to assess the wind exposure of a railway line

L.1 General

The determination of the cross wind safety of railway operations involves both a description and understanding of the vehicles, the infrastructure on which the operations are planned and the wind exposure of the line containing the infrastructure. Combining all this information allows the cross wind risk to be determined.

In Clauses 5 and 6, methods have been presented for assessing the susceptibility of the railway vehicles to cross-winds and how to detail the relevant characteristics of the infrastructure.

Two methods of determining the wind exposure of a line are described.

The first utilises wind maps for the country of operation, which show in zones the extreme wind speeds which may be expected to occur rarely in any given year. These wind speeds can be modified by various factors, depending on local terrain features e.g. relief, roughness. They are used to determine the local gust wind environment along the line, i.e. the wind exposure.

In the second method, data from appropriate meteorological stations near the line is used with the aid of numerical modelling to determine the extreme gust winds along the line.

The first method is significantly simpler to apply than the second and is appropriate for lines having relatively simple topography. If the line runs through complex topography e.g. mountainous regions requiring many high viaducts, the second method will usually provide more detailed information and may support the implementation of a wind alert system.

Both methods give the wind exceedance probability of the line which may be used for further safety analysis.

L.2 Wind map approaches

The basic principle of this approach is to use reference wind data from wind maps or wind tables based on long-term wind statistics, which is defined within national standards. The wind map or wind table gives the general velocity distribution of a reference wind, such as a mean wind, for a region. Combining this information with additional correction factors accounting for effects such as orography, roughness and direction by using a few simple calculations, the wind exposure at any point of the railway line can be derived. The accuracy of this derivation depends on the choice of effects included.

These methods are based on the following actions:

— Step 1: Collection of geographical and infrastructure input data:

  The railway line data and terrain data are collected according to Clause 6. In addition, auxiliary data to enable subsequent determination of e.g. directional correction factors are collected.

— Step 2: Choice of reference wind data

The reference wind velocity for a region is obtained from a suitable wind map (e.g. from national or European standards) based on measurements taken over a long time period. The reference wind velocity is given either as a function of direction or alternatively, a directional factor is introduced.

— Step 3: Adjustment of reference wind data

  If the wind map data do not include gust data, the gust peak values can be calculated e.g. by modelling and applying a gust factor.

— Step 4: Transfer to line

  The results of step 3 are transformed to each site of the line by corrections made using the data of step 1 in order to account for the effects of line orientation, orography, roughness, elevation, embankments, viaducts and so on. The output data of this transfer process is the extreme wind velocity distribution for all directions at each site of the line. With these peak values a probabilistic distribution of occurrence and exceedance of pre-defined wind speed thresholds can be deduced by using an adequate statistical distribution function.

— Step 5: Required documentation

  In Step 5 the integrated line database is extended by the probabilities of exceedance of pre-defined wind speeds for all directions obtained by the wind map approach.

The probability of exceedance of the wind velocity with respect to the vehicle CWCs may be calculated for safety analysis.

L.3 Transfer approaches

Transfer methods used to assess the wind exposure of a railway line are based on long-term wind databases from meteorological stations close to the line, transferred to the line by a numerical modelling of the atmospheric flow.

These methods are based on the following actions:

— Step 1: Collection of geographical and infrastructure input data

  The railway line data and terrain data are collected according to Clause 6.

— Step 2: Collection and treatment of meteorological input data

  Long-term wind databases at meteorological stations: data of all meteorological stations of the region surrounding the line are analysed; only the meteorological stations meeting specific criteria of both data quantity and quality are used.

— Step 3: Numerical modelling of the atmospheric flow

  The objective of the modelling is to obtain either the transfer coefficients required for a risk analysis, or the mean wind distribution at specified points of the line for wind exceedance probabilities.

  This modelling is done according to the available data and the situation of the line studied. At the present time, no specific numerical method of modelling is imposed.

— Step 4: Gust modelling

  The aim is the determination of gust coefficients at every point of line selected, to derive the gust wind from the mean wind.

— Step 5: Collection of output data

  The gust wind distribution at each site of the line is documented. Additionally, further data can be collected:

  — Transfer coefficients of the mean wind between the meteorological stations and the sites on the line,

  — Gust coefficients at sites on the line,

  — The gust wind distribution at the meteorological stations.

The probability of exceedance of the wind velocity with respect to the vehicle CWCs may be calculated for safety analysis and to implement a wind alert system.

Annex M
(informative)

Migration rule for this European Standard

The obligation to apply a standard can be stated by law, a regulation or a private contract, but cannot be stated in the standard itself. However, the stakeholders who are represented in the CEN Technical Committee responsible for the standard are of the opinion that the standard should be applied as follows.

Unless specifically called for by a European regulation or TSI, the standard, for which CEN received a mandate by the EC under the interoperability directives, should NOT be used for rolling stock assessment and certification or authorisation for putting into service purposes of rolling stock, when such rolling stock falls under one of the following exemption categories:

— rolling stock that is purchased under a contract already signed or was at the final phase of the tendering procedure at the date of publication of this European Standard;

— renewed or upgraded rolling stock where the work that would be necessary to achieve compliance requires alterations that would necessitate re-validation of the cross wind stability.

Also exempt during a transitional period are:

— rolling stock that are purchased under options of contracts already signed, or at the final phase of a tendering procedure, at the date of publication of this European Standard;

— rolling stock built in accordance with an existing design approval, having received a rolling stock assessment, certification or an authorisation for putting into service within the European Union before the date of publication (dop) of this European Standard, which is purchased under contracts signed during this transitional period.

The proposed transitional period of 4 years should start from the date of publication.

These exemptions should continue to apply during the whole operational life of the rolling stock concerned, and would also include parts for maintenance and repair, as long as this rolling stock is neither renewed nor upgraded.

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2008/57/EC

This European Standard has been prepared under mandates given to CEN/CENELEC/ETSI by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the Directive 2008/57/EC[2].

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the clauses of this standard given in Tables ZA.1 and ZA.2 for High Speed Rail and Tables ZA.3, ZA.4 and ZA.5 for Conventional Rail confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

Table ZA.1 – Correspondence between this European standard, the HS TSI RST, published in the Official Journal on 26 March 2008, and Directive 2008/57/EC

Clause(s)/ sub-clause(s) of this European Standard	Chapter/ § of the TSI	Essential Requirements of Directive 2008/57/EC	Comments
Clause 5.3.4 Reduced-scale wind tunnel measurements (except 5.3.4.11, see comment) **Clause 5.4.4** Time-dependent MBS method using a Chinese hat wind scenario **Clause 5.5** Presentation form of characteristic wind curves (CWC) **Clause 9** Required documentation **Annex D** Other ground configurations for wind tunnel testing	**4** Characteristics of the subsystem **4.2.6.3** Crosswind **Annex G** Effect of crosswinds	1. General requirements 1.1. Safety Clause 1.1.1. 1.5. Technical compatibility 2. Requirements specific to each subsystems 2.3. Control-command and signalling 2.3.1. Safety 2.4 Rolling stock 2.4.3. Technical compatibility §3	For class 1 trains, as the current TSI requires wind tunnel tests, assessment using simulation code (CFD) as specified in subclause 5.3.3 of the standard is not allowed by the current TSI. For the current TSI, the ground configurations for wind tunnel testing defined in the informative Annex D shall be used instead of those of the normative subclause

[2] The Directive 2008/57/EC adopted on 17th June 2008 is a recast of the previous Directive 96/48/EC ‘Interoperability of the trans-European high-speed rail system’ and 2001/16/EC ‘Interoperability of the trans-European conventional rail system’ and their revision by Directive 2004/50/EC of the European Parliament and of the Council of 29 April 2004 amending Council Directive 96/48/EC on the interoperability of the trans-European high-speed rail system and Directive 2001/16/EC of the European Parliament and of the Council on the interoperability of the trans-European conventional rail system

Table ZA.1 *(continued)*

Annex E Wind tunnel benchmark test data for other ground configurations **Annex I** Mathematical model for the Chinese hat			5.3.4.11. Some TSI parameter values shall be used instead of EN values (subclauses 5.3.4.4, 5.3.4.7, 5.3.4.9). For Class 1 tilting trains and Class 2 vehicles limiting values and corresponding methods are an open issue.

Table ZA.2 – Correspondence between this European standard, the HS TSI INS, published in the Official Journal on 19 March 2008, and Directive 2008/57/EC

Clause(s)/ sub-clause(s) of this European Standard	Chapter/ § of the TSI	Essential Requirements of Directive 2008/57/EC	Comments
5.4.4. Time-dependent MBS method using a Chinese hat wind scenario - General **6** Method to acquire the needed railway line data **9** Required documentation	**4.2** Functional and technical specifications of the domain **4.2.17** Effect of crosswinds	1. General requirements 1.5. Technical compatibility	The HS TSI INF doesn't define the ballast configuration, nor the embankment geometry

Table ZA.3 – Correspondence between this European Standard, the CR TSI RST Freight Wagon dated July 2006 and its intermediate revision approved by the Railway Interoperability and Safety Committee on 26 November 2008 and Directive 2008/57/EC

Clause(s)/ sub-clause(s) of this European Standard	Chapter/ § of the TSI	Essential Requirements of Directive 2008/57/EC	Comments
5 Methods to assess cross wind stability of vehicles **9** Required documentation **Annex C** Wind tunnel benchmark for standard ground configuration **Annex I** Mathematical model for the Chinese hat	**4** Characterisation of the subsystem **4.2.6.3** Functional and technical specifications of the sub system, Environmental conditions, Cross winds **6** Assessment of conformity and/or suitability for use of the constituents and verification of the subsystem **6.2.3.4.3** Subsystem conventional rail rolling stock freight wagons, Specifications for assessment of the subsystem, Environmental conditions, Cross winds	1. General requirements 1.1. Safety Clause 1.1.1 1.5. Technical compatibility 2. Requirements specific to each subsystem 2.3. Control-command and signalling 2.3.1. Safety 2.4. Rolling stock 2.4.3.Technical compatibility §3	In the 2006 publication of the TSI clauses 4.2.6.3 and 6.2.3.4.3 are open points to be specified at the next revision of the TSI. In the intermediate revision of the TSI the open point identified in sections 4.2.6.3 and 6.2.3.4.3 of the TSI is closed without any mandatory provision concerning wagon design. Some operational measures could apply.

Table ZA.4 – Correspondence between this European standard, the CR TSI INF (Final draft Version 3.0 dated 2008.12.12), and Directive 2008/57/EC

Clause(s)/ sub-clause(s) of this European Standard	Chapter/ § of the TSI	Essential Requirements of Directive 2008/57/EC	Comments
5.4.4. Time-dependent MBS method using a Chinese hat wind scenario - General **6** Method to acquire the needed railway line data **9** Required documentation	**4.2**. Functional and technical specifications of subsystem **4.2.11.6**. Effect of crosswinds	1. General requirements 1.5. Technical compatibility	Subclauses 4.2.11.6 remains an open point in the TSI The CR TSI INF doesn't define the ballast configuration, nor the embankment geometry The CR TSI INF is still a draft subject to change without notice

Table ZA.5 – Correspondence between this European standard, the CR TSI Locomotive and Passenger Rolling Stocks (Preliminary draft Rve 2.0 dated 14 November 2008) and Directive 2008/57/EC

Clause(s)/ sub-clause(s) of this European Standard	Chapter/ § of the TSI	Essential Requirements of Directive 2008/57/EC	Comments
5 Methods to assess cross wind stability of vehicles **9** Required documentation **Annex C** Wind tunnel benchmark for standard ground configuration **Annex I** Mathematical model for the Chinese hat	**4.**Characteristics of the subsystem **4.2.6.2.5** Cross wind	1. General requirements 1.2. Safety Clause 1.1.1 1.5. Technical compatibility 2. Requirements specific to each subsystem 2.3. Control-command and signalling 2.3.1. Safety 2.4. Rolling stock 2.4.3.Technical compatibility §3	Subclauses 4.2.6.2.5 remains an open point in the TSI The CR TSI Locomotives and Passenger RST is still a draft subject to change without notice

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

Bibliography

[1] Ril 80704 Bautechnik, Leit-, Signal- und Telekommunikationstechnik: Ausgewählte Maßnahmen und Anforderungen an das Gesamtsystem Fahrweg/Fahrzeug – Aerodynamik / Seitenwind. Internal standard of DB Netz AG adopted by German Railway Authority (EBA) as the basis for vehicle rolling stock assessment with respect to cross wind characteristics. Version in force from April 30th, 2006 on.3)

[2] GM/RC2542 *Recommendations for Determination of Aerodynamic Rolling Moment Coefficient*. Railway Group Standard 4)

[3] GM/RT2142 *Resistance of Railway Vehicles to Roll-over in Gales*. Railway Group Standard4)

[4] *Common DEUFRAKO Research on Cross Wind Effects on High Speed Railway Operation 2001-2004.* Final Report of DEUFRAKO SIDE WIND project. Edited by Thorsten Tielkes (Deutsche Bahn AG, DB Systemtechnik, Department of Aerodynamics and Air Conditioning, Voelckerstr. 5, D-80939 Munich) and Pierre-Etienne Gautier (SNCF, Direction de l'Innovation et de la Recherche, Physics of Railway System Unit, 45 Rue de Londres, F-75379 Paris), 2005.

[5] UIC 505-1 *Railway Transport Stock – Rolling Stock Construction Gauge*

[6] *The influence of local terrain features on the site selection for wind energy generating system*, P-S. JACKSON, rep. BLWT-1-1979, University of Western Ontario, 1981

[7] *The determination of topographical exposure factors for railway embankments*, C-J. BAKER, Journal of Wind Engineering and Industrial Aerodynamics, 21 (1985) 89-99

[8] GM/RT2141, *Resistance of Railway Vehicles to Derailment and Roll-Over.* Railway Group Standard

[9] GC/RT5021, *Track System Requirements.* Railway Group Standard

[10] GE/RT8012, *Controlling the Speed of Tilting Trains through Curves.* Railway Group Standard

[11] *DEUFRAKO Project Aerodynamics in Open Air (AOA) WP 2 Cross wind issues. Final WP 2 Report of DEUFRAKO AOA project*. Edited by Elisa Masson (SNCF, Direction de l'Innovation et de la Recherche, Physics of Railway System Unit, 45 Rue de Londres, F-75379 Paris), 2008.

[12] Dyrbye C., Hansen S. O. (1996) *Wind loads on structures*, John Wiley & Sons, Chinchester, England

[13] ESDU 86010 *Characteristics of atmospheric turbulence near the ground Part III: variations in space and time for strong winds (neutral atmosphere)*

[14] Cooper R. (1984), *Atmospheric Turbulence with respect to moving ground vehicles*, Journal of wind engineering and industrial aerodynamics, vol. 17, 215-238

[15] Cheli F., Corradi R., Diana G., Tomasini G. (2004) *A Numerical-Experimental Approach to Evaluate the Aerodynamic Effects on Rail Vehicle Dynamics*. Vehicle System Dynamics Supplement Vol. 41, pp707-716

[16] EN 1991-1-4, *Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions*

3) Available at: DB Kommunikationstechnik GmbH, Kriegsstraße 1, 76133 Karlsruhe, Tel.: +49 0721 938-5965, Fax:-5509

4) To be obtained free of charge from RSSB website (www.rssb.co.uk)

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