Vliv rozchodu na bezpečnost proti překlopení kolejového vozidla při působení bočního větru
How the rail gauge affects safety against roll over the rail vehicle caused by crosswind

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Abstrakt

Kolejové vozidlo je při svém provozu vystaveno různým povětrnostním vlivům, na které musí být náležitě připraveno po konstrukční stránce. Jedním z nich je i působení větru na kolejové vozidlo, zejména je-li jeho směr v příčné ose vozidla. V tomto případě hrozí, že jeho následkem může dojít k překlopení vozidla. S narůstající provozní rychlostí roste i účinek bočního větru, proto je tato problematika velice důležitá zejména u vysokorychlostních vozidel. Tento článek se bude zabývat vlivu rozchodu na bezpečnost proti překlopení vozidla a pokusí se stanovit její závislost tak, aby bylo možné při známosti měřením ověřených parametrů již zkonstruovaného vozidla provozovaného na normálním rozchodu teoreticky odvodit chování takového vozidla na jiném rozchodu.

Annotation

Railway vehicle is during its operations exposed to various weather conditions and must be properly designed to safely handle them. One of these condition is the incidence of the crosswind, especially when it is acting in lateral direction of the vehicle. In this case there is a risk of rollover the vehicle. With increasing the operation speed of the railways vehicles the crosswind influence is becoming stronger. Hence this issue is very important for high speed vehicles. This article will deal with the influence of gauge change to the safety of the railway vehicle against the rollover and attempt to determine its dependents so it will be possible to derive the cross wind characteristic from already designed and validated railway vehicle operating on standard gauge to vehicle with the same parameters and properties except for the gauge which will be changed.

Klíčová slova

Rozchod, kolejové vozidlo, boční vítr, překlopení, křivky větru, CWC

Key words

Gauge, railway vehicle, side wind, crosswind, roll over, wind curves, CWC

1. Introduction

Due to the airflow around the vehicle, the aerodynamic forces are acting on it. They can cause the negative influence which we have to consider during the development of the railway vehicle and have to adapt its design to avoid safety risks or to guarantee required properties or characteristics of the railway vehicle. An example could be to guarantee the top speed of the railway vehicle under the action of specific headwind. Strong crosswind may pose a significant risk of the railway vehicle operation safety. One of the most important influence, which we are

considering in, is the safety against rollover the vehicle[1]. We have to avoid in any chance the rollover the vehicle, as it could result in tragic consequences and even the loss of lives.
We can find many studies which are considering to the topic crosswind and safety. Let´s name some of them[2],[3],[4],[5],[6]. However, this article is consider to a slightly different perspective to this topic. Let´s have two identical railway vehicles except for the value of their gauges. We will be particularly interested how the safety against rollover the vehicle is going to change.

2. Aerodynamic force acting on the railway vehicle and force balance

At first, we have to start with interpreting the aerodynamic influence to the vehicle. So at the beginning, let´s mathematically describe them. We are going to applicate the drag equation, which is being used to calculate the forces of drag experiences by an object due to movement through a fully enclosing fluid. We project the aerodynamic force to three directions x,y,z. Axe x is going to represent longitudinal axes of the vehicle, y axe lateral and z vertical direction. Then the aerodynamic forces in each direction can be expressed by equation (1) and the moment by formula (2). $F_{wx,y,z}$ are the aerodynamic forces in relevant direction of the x,y,z-axes, eventually $M_{wx,y,z}$ are the moment, is the mass density of the fluid, v is the flow velocity relative to the vehicle, A is the rail reference area, c_x, c_y, c_z, c_{mx}, c_{my} and c_{mz} are aerodynamics coefficients.

$$F_{wx,y,z} = \frac{1}{2}\rho v^2 c_{x,y,z} A_{x,y,z} \tag{1}$$

$$M_{wx,y,z} = \frac{1}{2}\rho v^2 c_{mx,y,z} A_{x,y,z} L_{x,y,z} \tag{2}$$

Now we applies previous expression to determine the quasi-static force balance of the railway vehicle. For this we adapt formulas (1) and (2) by specific amendments to match standard EN 14067-1[7]. The origin of the coordinate system is going to be in x-direction in half of the distance between pivots, in lateral direction it is on the axe of geometrical symmetry and in vertical direction in the same level as the rail level. New coordinates system with the origin can be seen on figure 1. Next we adjust equations (1) and (2) to standard EN 14067. For practical reasons the area A and length L are the same for all the directions and coefficients are properly recalculated.

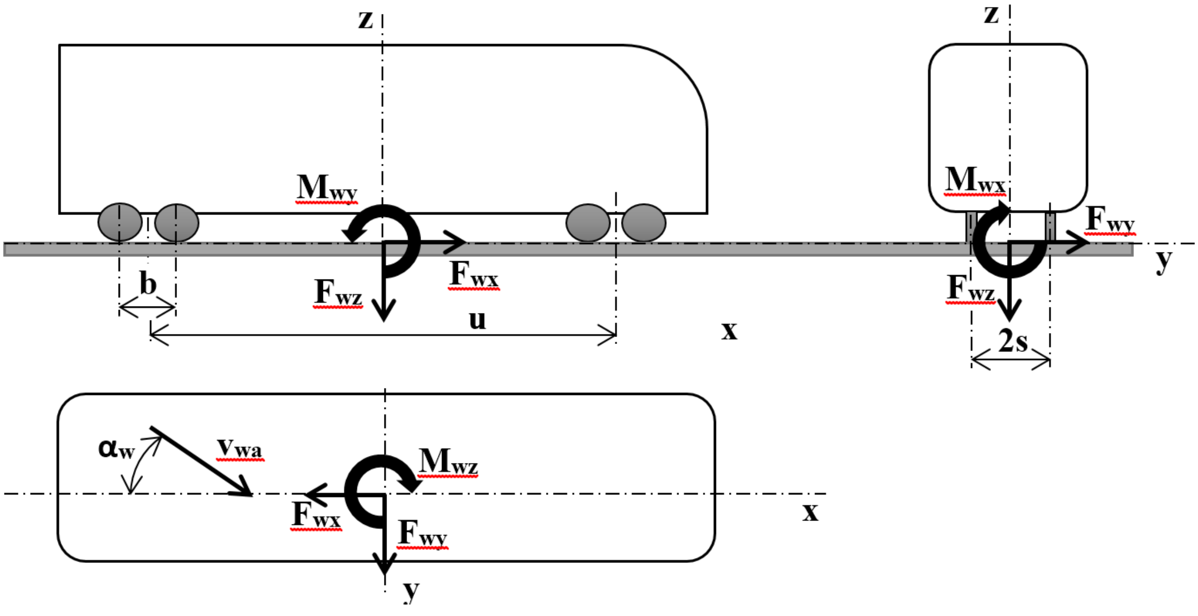

Fig. 1. *This scheme shows aerodynamic forces and moments acting on the railways vehicle, selected basic parameters of the vehicle and wind acting on it and position of all three axes. This conforms to standard EN 14067*

The rollover of the vehicle occurs when wheel load on one side of wheelset (eventually bogie, or even the complete car of train) is going to be totally unloaded. For our case we only consider to the aerodynamic forces and moments that have some influence to i-wheel load ΔQ_i, which is acting in the contact wheel and rail in vertical direction. We obtain just three of them F_z, M_y and M_x, the other three F_x, F_y and M_z do not have any influence. The dependence of the variable ΔQ_i on them can be expressed by the formula (3), where *2s* is the distance between wheel-rail contact points, *u* is wheel base of the bogie ant *t* is the distance between pivots. The rollover is going to happen when just one of the wheels – the critical one – is being totally unloaded. However, in the reality, we can expect there is a linkage between both wheelsets in the same bogies. That why we are going to presume rollover in the case of total unloading of the both wheels on the same side and in the same bogie. So we average forces on the wheels on the one side of the same bogie. Then we can simplify formula to the form (4), because we average distances.

Aerodynamics moments do not load or unload each wheel of the railway vehicle in the same way. For us it is not important to know the position of the critical wheelset, but what does matter is the expression of the critical wheelset´s unload. The force F_{wz} will be same for all wheels, while moments M_{wy} and M_{wx} not. M_{wx} will have the same quantity on all wheels, but one side of the vehicle the wheels will have opposite directing of the force than on the other side, but we can expect unloading by it on windward side. The last moment M_{wy} will cause different reactions, but is the only one which causes different wheel unload on one side of the vehicle. Hence we can assume unload of the critical wheel (the one with the highest unload) is going to be calculated with the absolute value of the moments M_{wy}. We can describe that by equation (5) for single wheel, eventually for our case when we expect wheelset linkage by equation (6).

As we can see, it consists of three main summand, where two of them are independent on rail gauge – the parameter *2s*, and just one is dependent, but all of them depend on the speed qadratically. We reproach the velocity and the rest of summands we substitute by variables k_{w11}, k_{w12} and k_{w2}, where first two of them are representing summands of the moment M_{wy} and force F_{wz} which are independent on the rail gauge and parameter k_{w2} represents all the input of the aerodynamic moment M_{wx} except for the gauge. After substitution we obtain a new form of the equation (8).

$$\Delta Q_{wi} = \frac{\pm \frac{M_{wy}}{u \pm t} \pm \frac{M_{wx}}{2s} - F_{wz}}{4} \tag{3}$$

$$\Delta Q_{wi} = \frac{\left|\frac{M_{wy}}{t}\right| + \frac{M_{wx}}{2s} - F_{wz}}{4} \tag{4}$$

$$\Delta Q_{wi} = \pm \frac{\frac{1}{2}\rho {v_a}^2 c_{my} AL}{t} \pm \frac{\frac{1}{2}\rho {v_a}^2 c_{mx} AL}{2s} - \frac{1}{2}\rho {v_a}^2 c_z A \tag{5}$$

$$\Delta Q_{wmax} = \frac{\left|\frac{\frac{1}{2}\rho {v_a}^2 c_{my} AL}{t}\right| + \frac{\frac{1}{2}\rho {v_a}^2 c_{mx} AL}{2s} - \frac{1}{2}\rho {v_a}^2 c_z A}{4} \tag{6}$$

$$\Delta Q_{wmax} = \frac{\left[\left(\left|\frac{\frac{1}{2}\rho c_{my} AL}{t}\right| - \frac{1}{2}\rho c_z A\right) + \frac{\frac{1}{2}\rho {v_a}^2 c_{mx} AL}{2s}\right]}{4} {v_a}^2 \tag{7}$$

$$\Delta Q_{wmax} = \left[\left(k_{w11(\beta_w)} + \left(k_{w12(\beta_w)}\right)\right) + \left(\frac{k_{w2(\beta_w)}}{2s}\right)\right] {v_a}^2 \tag{8}$$

$$\overrightarrow{v_a} = \overrightarrow{v_{tr}} + \overrightarrow{v_w} \quad (9)$$

$$v_a = \sqrt{{v_v}^2 + {v_w}^2 - 2v_v . v_w . \cos\beta_w} \quad (10)$$

$$v_a = \sqrt{{v_v}^2 + {v_w}^2} \quad (11)$$

The absolute airflow velocity consists of two sub-components which are vehicle speed and wind speed. Both are related to the ground. The absolute velocity (relation between vehicle and wind) can be interpreted as a vector sum (9). Let´s define the variable β_w, which represents the angle of airflow relative to the x-axis. Then we can mathematically calculate absolute velocity from the relative by cosine theorem (10), eventually in the case of crosswind (βw=90°) by Pythagorean theorem (11).

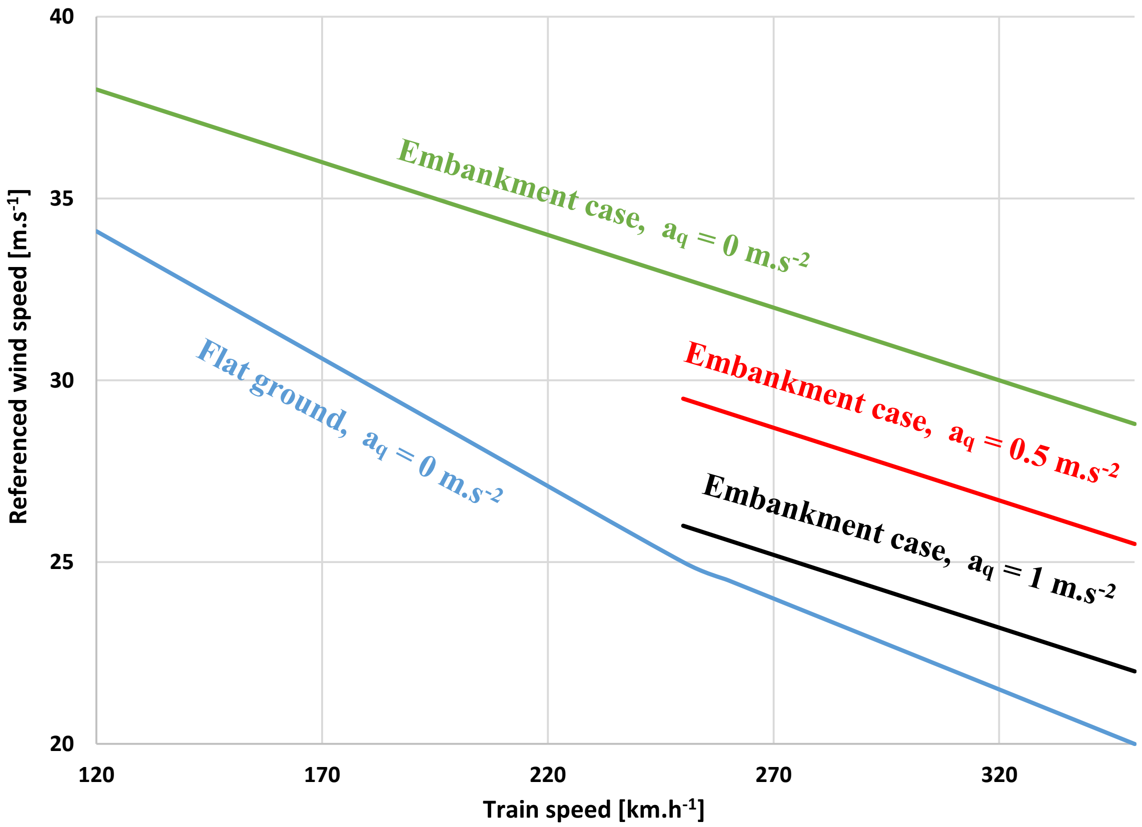

Fig. 2. *Graph of prescribed minimal speed of wind at given train velocity and composed requirement and condition that the train have to safely operate – CRWC – characteristic reference wind curves by HS RST TSI*

3. CWC – Characteristic wind curves

The crosswind design requirements to high speed railway vehicles are specified by European commission decision (2008/232/ES) in HS RST TSI[8] standard, where is said "A train is deemed to meet the crosswind requirements if its characteristic wind curves (CWC: as defined in Annex G) of its most wind sensitive vehicle are superior or at least equivalent to a set of characteristic reference wind curves (CRWC)." At present it is expected that just by multibody simulation with experimental verification the CWC for each vehicle can be evaluated. All the important requirements and methodologies for evaluating CWC for the train are fully provide in above mentioned standard. For our aspiration of evaluation dependency on gauge the most important is to estimate values that are going to be adapted to cape gauge in the next chapter. The summarization of CRWC "minimal requested values" for specific cases are being gathered in table 1 and depicted in the graph on figure 2.

__Table 1.__ – CRWC – characteristic reference wind curves by HS RST TSI

Lateral acceleration a_q [m/s^2]	**0**	**0**	**0,5**	**1**
Train speed [km/h]	**Reference characteristic wind speed for the flat ground case (without ballast and rails) in m/s**	**Reference characteristic wind speed for the embankment case in m/s**		
120	34,1	-	-	38,0
160	31,3	-	-	36,4
200	28,5	-	-	34,8
250	25,0	29,5	26,0	32,8
260	24,5	29,1	25,6	32,4
270	24,0	28,7	25,2	32,0
280	23,5	28,3	24,8	31,6
290	23,0	27,9	24,4	31,2
300	22,5	27,5	24,0	30,8
310	22,0	27,1	23,6	30,4
320	21,5	26,7	23,2	30,0
330	21,0	26,3	22,8	29,6
340	20,5	25,9	22,4	29,2
350	20,0	25,5	22,0	28,8
Position on the graph	**1**	**2**	**3**	**4**

4. Dependence of absolute speed to the gauge

TSI standards specifies crosswind requirements for standard gauge only in addition to high speed vehicles at these days. It turns out that these topic were underestimated, so expansion of these standard to other category of railways vehicles (but still with a focus to standard gauge) is being prepared. As trains operating on narrow gauges reaching much lower speeds than the vehicles on standard gauge, aerodynamics and crosswind influence are not appropriately examined. Hence we are going to investigate the effect of gauge resizing to vehicle stability against crosswind to know closer the behavior of high speed vehicles operating on other gauges than the standard one.

$$\frac{\Delta Q}{Q} = \frac{\dfrac{a_{\max n}\, z_{tp}\, m_p}{2s} + \left[\left(k_{w11(\beta_w)} + \left(k_{w12(\beta_w)}\right)\right) + \left(\dfrac{k_{w2(\beta_w)}}{2s}\right)\right] {v_a}^2}{\dfrac{g\, m_p\, (s - y_p)}{2s}} = \tag{12}$$
$$= \frac{a_{\max n}\, z_{tp} + \dfrac{2s}{m_p}\left[\left(k_{w11(\beta_w)} + \left(k_{w12(\beta_w)}\right)\right) + \left(\dfrac{k_{w2(\beta_w)}}{2s}\right)\right] {v_a}^2}{g(s - y_p)} < 0{,}9$$

We are expecting quasi-static force balance. Vehicle do not have center of gravity in axes of symmetry. Vehicle is passing throw curve with no superelevation of the track, so that the centrifugal acceleration a_q acts on the vehicle. Vehicle is empty. At present it is expected that just by multibody simulation with experimental verification the CWC for each vehicle can be evaluated. So we use the validated results for vehicle on standard gauge and recalulcute them to cape gauge. First we are going to neglect small dynamic differences regarding resizing the gauge and small expected changes of velocities. Then we can formulate quasi-static equilibrium of the vehicle by equitation (12). By standard HS RST TSI it is required that ratio between wheel unload and load have to be lower than 0.9. From the equation we isolate variable v_a which represents the absolute speed so we get expression (13). If we are expecting constant angle between the wind direction and longitudinal axe of the railway vehicle (same as we expect the ratio vehicle speed to the wind speed do not change), than we can express the maximal absolute speed by the formulation (14).

$$v_a < \sqrt{\frac{m_p\left[0{,}9g\left(s-y_p\right)-a_{\max n}\, z_{tp}\right]}{2s\left[\left(k_{w11(\beta_w)}+\left(k_{w12(\beta_w)}\right)\right)+\left(\frac{k_{w2(\beta_w)}}{2s}\right)\right]}} \tag{13}$$

$$\frac{v_v}{v_w} = const. \Leftrightarrow\ \beta_w = const. \Rightarrow v_{a\,max} = \sqrt{\sqrt{\frac{m_p\left[0{,}9g\left(1-\frac{y_p}{s}\right)-\frac{a_{\max n}\, z_{tp}}{s}\right]}{\rho AL\left(\left|\frac{c_{my}}{t}\right|+\left|\frac{c_{mx}}{2s}\right|-\frac{c_z}{L}\right)}}} \tag{14}$$

From equation (14) we can see the dependence of absolute velocity on the parameters. If we increase the mass of the vehicle or the gauge is leveled up the absolute velocity is going to rise too. But if we increase the center of mass eccentricity, and does not matter if in lateral or vertical directions, it is going to cause negative influence and the absolute velocity becomes lower. All the remaining parameters that can affect the absolute velocity depend on aerodynamic properties so the last how we can tune the safety against rollover the vehicle is to reform the shape of the vehicle.

Now we have to determine how to recompute absolute velocity of the vehicle operating on standard gauge to the same vehicle on cape gauge. We introduce a new variables k_w and M_w. First one represents the ratio between unload caused by aerodynamic forces and moments that only depends on gauge and unload caused by all the aerodynamic forces and moments. Thanks to that we can divide aerodynamic forces into two new formulation – component, which are going to change when rail gauge resizes and components that are going to be independent on gauge. This is mathematically expressed by equation (16). Second variable M_w is replacing all the aerodynamic forces and moments with an equivalent moment around longitudinal axe.

$$k_w = \frac{\frac{M_{wx}}{2s}}{F_{wz}+\left|\frac{M_{wy}}{u}\right|+\frac{M_{wx}}{2s}} = \frac{\frac{k_{w2}}{2s}}{k_{w11}+k_{w12}+k_{w2}} =$$

$$= \frac{\frac{c_{mx}A\frac{1}{2}\rho {v_a}^2 L}{2s}}{-c_z A\frac{1}{2}\rho {v_a}^2+\left|\frac{c_{my}A\frac{1}{2}\rho {v_a}^2 L}{u}\right|+\frac{c_{mx}A\frac{1}{2}\rho {v_a}^2 L}{2s}} = \frac{\frac{c_{mx}}{2s}}{-\frac{c_z}{L}+\left|\frac{c_{my}}{u}\right|+\frac{c_{mx}}{2s}} \tag{15}$$

For one concrete railway vehicle the aerodynamic coefficients are depending on the angle β_w only and all the other parameters are constant. Hence parameter k_w is going to be dependent on this angle only too. Table shows the value of this parameter for specific sizes of angle β_w. In a range β_w = 15–70°, which fully covers the entire spectrum in which the values can be in reality found, we can say that the coefficient k_w is approximately equals 0.55. So we can substitute this value and obtain simplified equation (17). For our purpose of investigation is this operation sufficiently accurate. Anyway, in the case of request a higher accuracy we have to substitute exact value calculated based on the given size of the angle.

__Table 2.__ – Values of the variable k_w for specific angle β_w and its percentage difference from the value 0.55, which is being used for approximation.

β_w [°]	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
k_w [-]	0.143	0.645	0.579	0.554	0.539	0.538	0.541	0.544	0.538	0.520
Difference [%]	-285.6	14.7	5.0	0.8	-2.0	-2.2	-1.6	-1.0	-2.3	-5.8
β_w [°]	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	
k_w [-]	0.528	0.531	0.550	0.556	0.567	0.579	0.586	0.586	0.622	
Difference [%]	-4.1	-3.7	0.0	1.2	3.0	5.0	6.1	6.2	11.5	

Previous mathematical operations led to a new form of equation (17), in which we are going to substitute numerical values based on railway vehicle properties for each variable except for the equivalent moment which we calculate. After that we change the size of the gauge to the cape gauge and input again to the equation, but this time we skip substitution for absolute velocity and instead we insert previously calculated value of the equivalent moment. Finally we obtain equivalent absolute speed for the same vehicle operating on cape gauge. At the end we have to determine both components of this absolute velocity. As the angle β_w have to be constant the vehicle speed can be computed using cosine theorem respectively wind speed with sine theorem.

$$\frac{\Delta Q}{Q}=\frac{\dfrac{a_{\max n}\, z_{tp}\, m_p+k_w.M_w.v^2}{2s}+\dfrac{(1-k_w)M_w.v^2}{2s_n}}{\dfrac{g\, m_p\,(s-y_p)}{2s}}=\frac{a_{\max n}\, z_{tp}\, m_p+\frac{1}{2}\rho v^2 c_s A y_w}{g\, m_p\,(s-y_t)}=\frac{a_{\max n}\, z_{tp}\, m_p+k_w v^2 y_w}{g\, m_p\,(s-y_p)} \tag{16}$$

$$\frac{\Delta Q}{Q}=\frac{\dfrac{a_{\max n}\, z_{tp}\, m_p+0{,}55.M_w}{2s}+\dfrac{0{,}45M_w}{2s_n}}{\dfrac{g\, m_p\,(s-y_p)}{2s}} \tag{17}$$

***Fig. 3.** Graph of prescribed safety speed of the wind at given train velocity and specific centrifugal acceleration a_q. Lines with circle shaped points represents real vehicle operating on standard gauge (SG), while lines with square shaped point represents values that belongs to the same vehicle on cape gauge (CG)*

5. Adaption CWC to cape gauge

For the adaptation, measured and validated parameters of real railway high speed vehicle including characteristic wind curves determine by European standards are taken as an input. For specific cases from each vehicle speed and its relevant wind speed the absolute velocity is calculated. Then each absolute velocity is transformed to the same railway vehicle, which are operating on the cape gauge by process mentioned in previous chapter. So we obtain recalculated wind speed and vehicle speed. The results of this process are shown on graph in figure 3.

As it was previously derived from equation the wind speed that can train safely reach is decreasing if we reduce the gauge. The resizing is not negligible. This causes that the vehicles which is operating on narrower gauges are going to be more sensitive to the wind influence and it is very important to deal with this phenomena. If we compare how much has been the speed changed for specific vehicle speed, we are getting that the difference is between 5 and 8 m.s^{-1} for a train velocity above 120 km.h^{-1}. At lower speed the difference rises up to 12 m.s^{-1}. So with the increasing the vehicle speed, the difference slightly decreases. The centrifugal acceleration has a slightly influence too – higher centrifugal acceleration leads to a little greater difference between velocities.

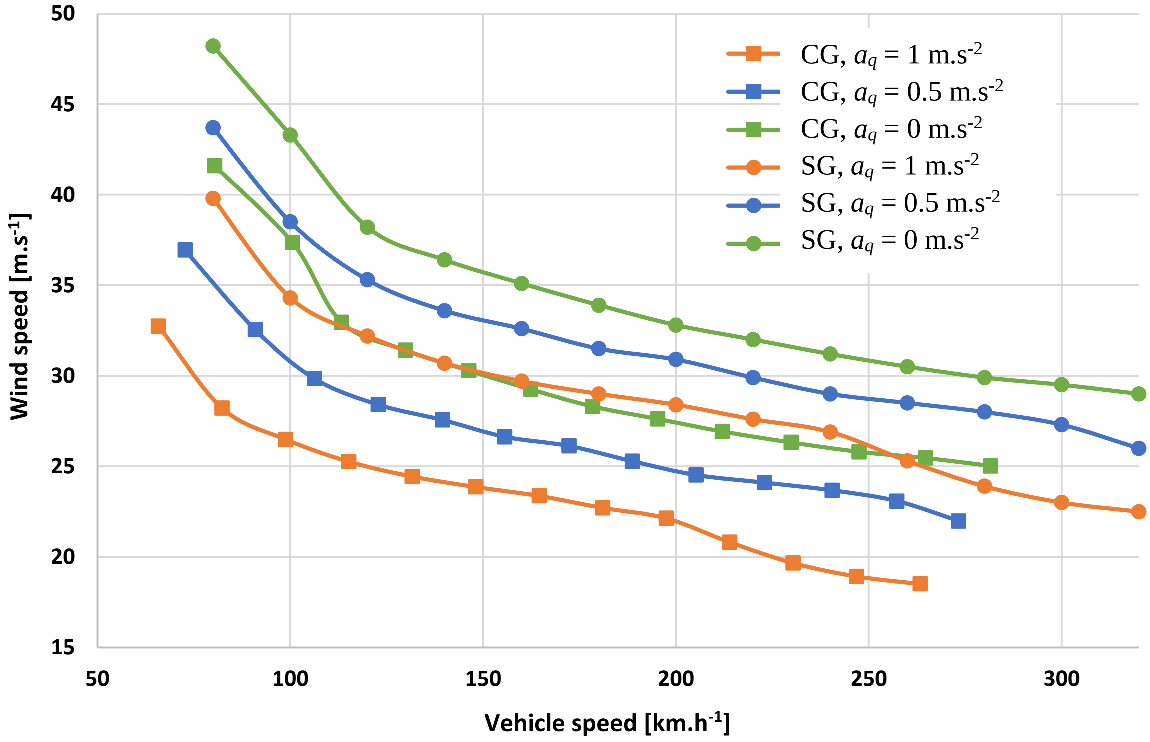

Fig. 3. *Graph of prescribed safety speed of the wind at given train velocity and specific centrifugal acceleration a_q. Lines with circle shaped points represents real vehicle operating on standard gauge (SG), while lines with square shaped point represents values that belongs to the same vehicle on cape gauge (CG)*

6. Probability of reaching a given wind speed

From previous part we know the influence of the gauge to safety against the rollover the vehicle. But question is what that really means in reality. For a help with interpretation we are going to express the frequency of wind speed. This can be nicely mathematically interpreted by formulation of probability. The log-normal distribution was chosen as it is the credible accepted method used by meteorologist.

In probability theory, it is defined as a continuous probability distribution of a random variable whose logarithm is distributed normally. We skip detailed characteristic, etc. and have a look directly to its mathematical interpretation. Probability density function of a log-normal distribution is represented by equation (18). The random variable is x, μ is mean value and parameter σ is standard deviation. Log-normal distribution has a cumulative distribution function (19), where *erf* is error function determine by equation (20), *erfc* is the complementary error function and can be calculated by formula (21). Φ is the standard normal cumulative distribution function.

$$f_X(x;\mu,\sigma) = \frac{1}{x.\sigma\sqrt{2\pi}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}, x > 0 \tag{18}$$

$$F_X(x;\mu,\sigma) = \frac{1}{2}\left[1 + erf\left(\frac{\ln x - \mu}{\sigma\sqrt{2}}\right)\right] = \frac{1}{2} erfc\left(-\frac{\ln x - \mu}{\sigma\sqrt{2}}\right) = \Phi\left(\frac{\ln x - \mu}{\sigma}\right) \quad (19)$$

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}\,dt \quad (20)$$

$$\mathrm{erfc}(x) = 1 - \mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}\,dt \quad (21)$$

Long term collected data from measuring in meteorological station Ruzyně in Prague[9] has been taken. From this data we determine the parameters μ, σ and then fully define log-normal distribution. The mean become equal $\mu = 2.56116$ and the standard deviation is $\sigma = 0.31224$. Probability density function will have following form (22) and cumulative distribution function this form (23). Now by those we are going to calculate the probability that the wind reaches the given speed. The results that express the pure probability, probability of how many times per year this phenomena occurs or per how many years we have to wait for reaching the specified wind speed can be found in the table 3. The results are also graphically depicted in the graph of figure 4.

$$f_X(x;\mu,\sigma) = \frac{1}{x.0.31224\sqrt{2\pi}} e^{-\frac{(\ln x - 2.56116)^2}{2(0.31224)^2}}, x > 0 \quad (22)$$

$$F_X(x;\mu,\sigma) = \frac{1}{2} erfc\left(-\frac{\ln x - 2.56116}{0.31224.\sqrt{2}}\right) = \Phi\left(\frac{\ln x - 2.56116}{0.31224}\right) \quad (23)$$

Table 3. *– Probability that the wind reaches specified speed in location Ruzyně in Prague. First column of probability represents its exact value, second one probability how many days per a year the wind reaches given speed and the last column indicates in how many years it is probable that this velocity occurs*

Wind speed		**Probability that wind reaches given speed**		
[m.s^{-1}]	**[km.h^{-1}]**	**[-]**	**[days per year]**	**[once per *x* years]**
18	**64.8**	0.1458565	53.2	0.0
20	**72.0**	0.0819899	29.9	0.0
22	**79.2**	0.0448425	16.4	0.1
24	**86.4**	0.0240924	8.8	0.1
26	**93.6**	0.0128046	4.7	0.2
28	**100.8**	0.0067663	2.5	0.4
30	**108.0**	0.0035683	1.3	0.8
32	**115.2**	0.0018832	0.7	1.5
34	**122.4**	0.0009965	0.4	2.7
36	**129.6**	0.0005296	0.2	5.2
38	**136.8**	0.0002829	0.1	9.7
40	**144.0**	0.0001521	0.1	18.0
42	**151.2**	0.0000823	0.0	33.3
44	**158.4**	0.0000448	0.0	61.1
46	**165.6**	0.0000246	0.0	111.4
48	**172.8**	0.0000136	0.0	201.4
50	**180.0**	0.0000076	0.0	361.6

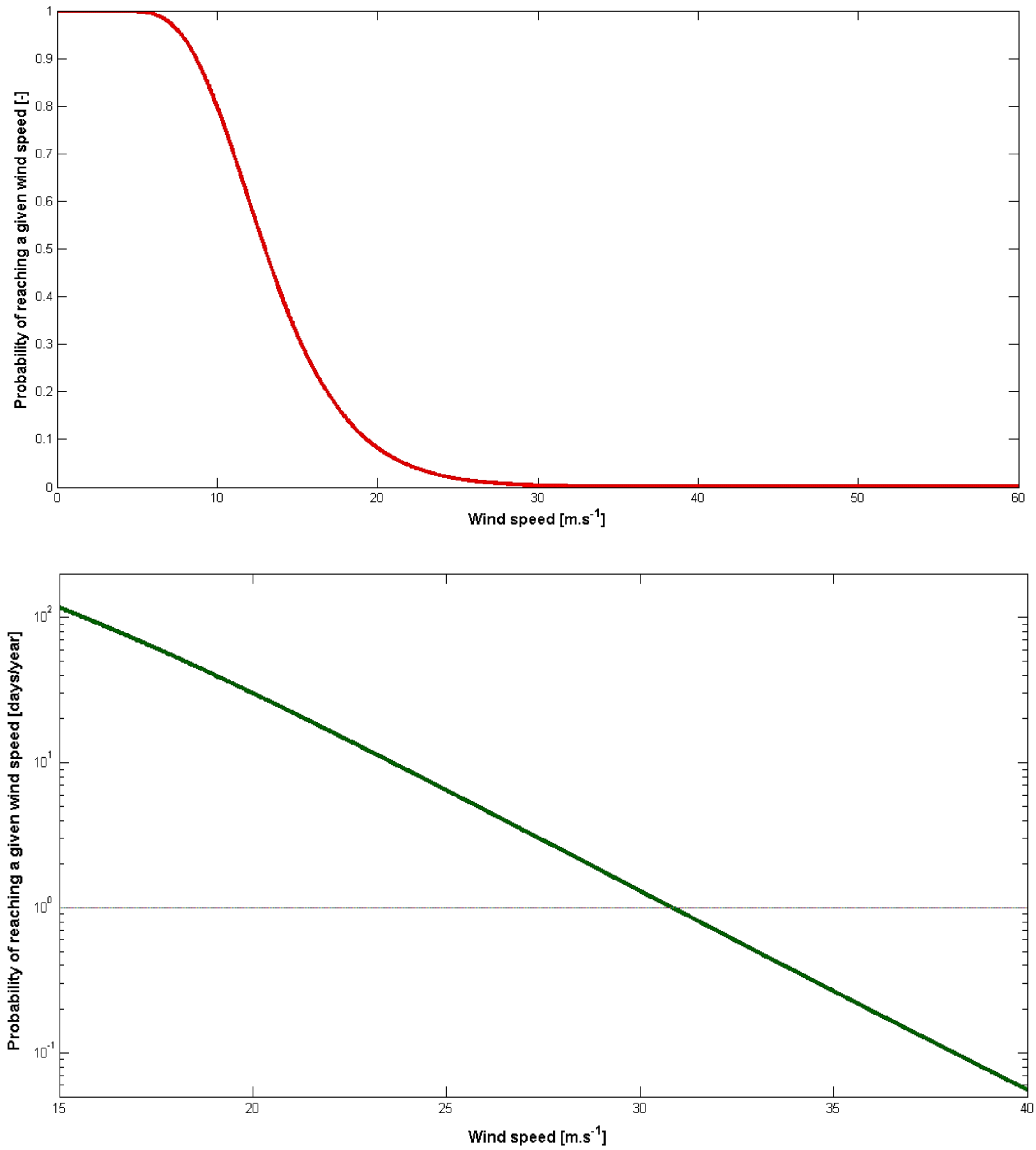

Fig. 4. *Graphs representing probability that the wind reaches given speed. Above is shown whole the spectrum and bellow zoomed area with modified units on the y-axes, which changes to probability of how many days in a year.*

Unsurprisingly, probability that wind reaches given speed decrease when the given speed is increased. As it can be visible in the table 3, if we increase the wind speed by 2 m.s^{-1}, the probability to reach it decrease by about half. Interesting is that this is valid in the whole investigation spectrum of the speed, which fully cover the results of CWC. For minimal velocity change caused by gauge resizing, we obtain 4 times higher probability that the wind exceeds the safety vehicle limits. This is more dramatic for maximal difference where the probability is even 40 times higher! As an example of combination CWC with wind speed probability we show that investigated vehicle passing the curve with centrifugal acceleration 1 m.s^{-2} at the speed 250km.h^{-1} probably exceeds the safety limits against rollover approximately 53 days per a year on a cape gauge, but only less than 5 days per year in the case it is designed for standard gauge.

7. Conclusion

Rail gauge size has considerable influence to the safety against rollover the railways vehicle which may be caused by crosswind. Train operating on standard gauge exhibits higher resistance, while the same railway vehicle operating on cape gauge safely resists crosswind that has 5 to 8 m.s^{-1} lower speed. If we are expecting that the vehicle have to lower his speed if the wind exceeds the maximal allowed one and we are taking into account the probability based on measured data from real meteorological station, then we predict that the probability of slowing down the speed of the vehicle is 4 times up to 10 times higher.

It is necessary to mention that the possible mass change, which can also be caused by gauge changeover was not taken into account. Hence the reality could be even worse for the trains operating on narrower gauges. Concrete mass influence based on the gauge, however, is beyond the scope of this article. Anyway we can recommend, that empty head vehicle have to be heavy as much as possible and have center of gravity low in vertical axes and close to the axes of symmetry in lateral direction as much as possible. This shows that conception of the trainset with two head power cars on both sides and both without the passengers (like ICE1 or TGV Atlantigue) that are nearly reaching maximal axle load will be the best choice and will help to increase the safety.

Symbols

$F_{wx,y,z}$	aerodynamic forces in x,y,z-direction of the vehicle	(N)
$M_{wx,y,z}$	aerodynamic moments in x,y,z-direction of the vehicle	(N·m)
$c_{x,y,z}$	aerodynamic forces coefficients in x,y,z-direction of the vehicle	(1)
$c_{mx,y,z}$	aerodynamic moments coefficients in x,y,z-direction of the vehicle	(1)
A	reference area	(m^2)
L	reference length	(m)
ρ	air density	(kg·m^{-3})
ΔQ_i	unload of i-wheel	(N)
u	wheel base	(m)
t	distance between pivots	(m)
$2s$	distance between nominal running circles (distance between contact points)	(m)
v_a	absolute speed (wind-vehicle)	(m·s^{-1})
β_w	angle between the longitudinal axe of the vehicle and wind direction	(°)
k_{w11}	coefficient	(1)
k_{w12}	coefficient	(1)
k_{w2}	coefficient	(1)
k_w	coefficient	(1)
v_v	vehicle speed	(m·s^{-1})
v_w	wind speed	(m·s^{-1})
a_q	centrifugal acceleration	(m·s^{-2})
g	gravitational constant	(m·s^{-2})
z_{tp}	eccentricity of the center of gravity in vertical direction	(m)
y_p	eccentricity of the center of gravity in lateral direction	(m)
m_p	mass of empty vehicle	(kg)
ΔQ	unload	(N)
Q	load	(N)
x	random variable	(1)
μ	mean	(1)
σ	standard deviation	(1)

Bibliography

[1] **Simes, T.** *A Blow to Train Operations, Can strong winds cause derailment? intlrailsafety.com.* [Online] [Visited: 14. Prosinec 2014.] http://www.intlrailsafety.com/Melbourne/Papers/SIMES%20-%207.3%20A%20blow%20to%20train%20operations%20can%20strong%20winds%20cause%20derailment.pdf.

[2] **Yu, Meng-Ge.** *Study on the operational safety of high-speed trains exposed to stochastic winds.* Singapore:Acta Mechanica Sinica, 2014. 0567-7718.

[3] **Gerd, Matschke.** *COMPUTATIONAL SIMULATION OF AERODYNAMIC FORCES AND SIDE WIND BEHAVIOUR OF RAILWAY VEHICLES.* Barcelona : European Congress on Computational Methods in Applied Sciences and Engineering ECCOMAS 2000, 2000.

[4] **Biadgo, Asress, Mulugeta.** *Aerodynamic Characteristics of High Speed Train under Turbulent Cross Winds: a Numerical Investigation using Unsteady-RANS Method.* Place unknown : FME Transactions, 2014.

[5] **Schober, Martin.** *WIND TUNNEL INVESTIGATION OF AN ICE 3 ENDCAR ON THREE STANDARD GROUND SCENARIOS.* Milano : BBAA VI International Colloquium on: Bluff Bodies Aerodynamics & Applications, 2008.

[6] **Naumann, Rudolf, Höppe, Clemens a Grab, Martin.** *Calculation of characteristic wind curves for cross wind investigation.* Montreal : WCRR 2006, 2006

[7] ČSN EN 14067-1 (281901). *Železniční aplikace - Aerodynamika - Část 1: Značky a jednotky.* Praha: Úřad pro technickou normalizaci, metrologii a státní zkušebnictví, 2003. Třídící znak 281901.

[8] HS-RST-TSI 2008/232/EC. *Commission Decision of 21 February 2008 concerning the technical specification for interoperability relating to the rolling stock subsystem of the trans-European high-speed rail systém referred to in Article 6(1) of Directive 96/48/EC.*

[9] **Návorka, Michal a Tůmová, Olga.** *Vybrané statistické metody pro tvorbu pravděpodobnostních map. csq.cz.* [Online] 17. březen 2011. [Visited: 10. únor 2015.] http://www.csq.cz/fileadmin/user_upload/Spolkova_cinnost/Odborne_skupiny/Statisticke_metody/sborniky/2011/03_Metody_pro_tvorbu__pravdepodobnostnich_map.pdf.