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Aerodynamic Phenomena Caused by the Passage of a Train. Part 6: Other Influences. Summary of Series

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Summary

This series of articles describes the aerodynamic phenomena caused by the passage of a train, characterising the effects that a train running at high speed has on itself, other trains, trackside objects and people. This impact can be of two types – generated pressure and slipstream. Apart from the literature analysis, the author's research is also taken into account. The sixth part of the series describes mixed aerodynamic impacts on people, as well as other types of impacts, and summarises the entire series.

Keywords: rolling stock, high speed railways, aerodynamic phenomena

1. Introduction

Part one [1] of the series discussed a general classification of aerodynamic phenomena, divided into pressure changes and the slipstream by the type of influence. It also presented changes of pressure in the open air, caused by a train passage, and the influence of pressure on various objects located near the track. Primary normative documents concerning aerodynamic issues were specified as well. It also depicted conclusions on the construction of a high-speed railway vehicle, as well as the durability and location of the structure at high-speed lines.

Part two [2], which continued issues regarding pressure changes, focused on the mutual influence of moving trains on their front and side surfaces. It was concluded that it is the high-speed train that influences the slower train and other objects, not the other way around. The consequence of this is a significant – up to over sixfold – rise in the pressure on the windscreen of an older train with a maximum speed of 120 km/h while passing a train running at 350 km/h, which may entail the risk of damaging the windscreen of the rolling stock with a lower maximum speed.

Part three [3] was devoted to slipstream – the second, and apart from pressure, the main type of aerodynamic influence caused by a train passing at high speed. The characteristic features of the slipstream and its influence on the environment (in the form of forces acting on objects) and railway infrastructure were described. A comparison of the slipstream caused by a standard train (made up of a locomotive and carriages) and high-speed multiple units was presented, making it clear that multiple units create a much smaller slipstream and can run at higher speeds due to this type of influence. Mixed aerodynamic influence (i.e. the combined, simultaneous influence of pressure and slipstream) that can cause the ballast to be picked up by the "suction" of the pressure and the entrainment of the ballast by the slipstream wave are also discussed and illustrated with pictures.

Part four [4] focused on the issue of pressure impact on people – both railway workers and passengers waiting on platforms and standing near open windows or sitting near the window in passing trains.

Part five [5] described the influence of the slipstream on people – both passengers waiting on platforms and railway workers near the track on which a train is passing at high speed. The induced slipstream creates forces whose value and direction change rapidly as the train goes by. This may result in a temporary imbalance or, in extreme cases, cause someone to fall. To better illustrate this, the influence of the slipstream was related to the Beaufort scale, which is commonly used to estimate wind speeds. The high-speed passenger trains operating in Poland were also assessed.

This sixth and final part of the series of articles deals with the mixed aerodynamic influence on passengers and railway workers, as well as other types of influences, summarising the entire series of articles on aerodynamic phenomena caused by train passage.

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2. Mixed Aerodynamic Influences on Passengers and Railway Workers

The final aerodynamic phenomenon to be discussed is the mixed aerodynamic influences on passengers and railway workers. The phenomenon itself is described in more detail in part three [3]. It can cause the ballast under the train to be picked up and pulled in by the slipstream wave (Fig. 1). On the side of the train, it can cause debris lying beside the track to be picked up and dragged along with the slipstream wave. It is possible for small stones (small-sized ballast) to be picked up by the slipstream as well. Fortunately, however, this is quite rare and occurs in very close proximity to a passing train, up to about 0.5 m from the train wall – the author did not observe this phenomenon further away from the train during his research. This phenomenon was also noted in the report [6] and reiterated in another report [7], citing paper [8]: "When a train is passing a station platform at high speeds, the wake effect of the train with its turbulent fluctuations and buffeting in the air, along with any dust and debris that is blown or propelled, is a serious issue regarding the comfort and safety of people on the platform".

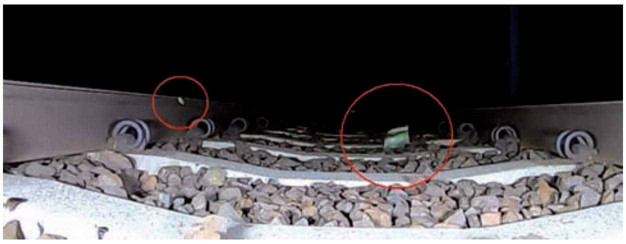

Fig. 1. A small stone (left) and debris (right) dash after the train passage [Photo by A. Zbieć]

Debris would not pose much of a threat on its own, as it is rather small in size and weight. However, it can move at quite high speeds – up to and including the train's speed – which may prove somewhat dangerous to persons when hitting them on the head and especially in the eyes. Among the factors to be considered for reasons of personal safety, the report [7] mentions: "Train-induced airflow in itself is unlikely to be strong enough to propel a solid object such as a rock. However, any particles on the track agitated by the turbulent airflow and its buffeting effect, if struck by the train especially at the underside of a car, can cause the particle to become a fast moving projectile. This would propel it in the direction of the train unless it is deflected outward to the platform. A person on the trackside or low-level platform would be most vulnerable to this hazard".

The same will happen during precipitation, particularly rain. Of course, while rain itself would not be a life-threatening hazard, water droplets lifted by the slipstream can reach speeds close to that of a train (Fig. 2). Should such dashing raindrops fall into the eye, they can cause a very unpleasant sensation of soreness in the eyeball, just as when cycling or skiing in the rain without protective glasses or goggles – even though the speeds while riding are much lower.

Fig. 2. Water droplets lifted by a train [Photo by A. Zbieć]

For the above reasons, workers should not be looking at passing trains. Consideration should be given to equipping workers with safety goggles and providing appropriate training. Protecting passengers on platforms from flying debris seems slightly more problematic. In this case, protection against eye injuries would be ensured by respecting the safety zones mentioned in the previous parts of the series. Announcement of passing trains can be an additional safety measure. Figure 3 shows the barrier separating the train and the safety zone from the rest of the platform at stations where only some Shinkansen trains stop. The rest of the trains pass at a speed reduced to around 150÷180 km/h. Figure 4 shows the barrier separating the train and the safety zone from the rest of the platform at stations where all Shinkansen trains stop. Notably, the barriers feature automatically opening gates, positioned in the same places as the train doors when the train stops. Such a solution requires a uniform type of rolling stock.

Fig. 3. Safety zone at stations where only some trains stop [Photo by A. Zbieć]

Fig. 4. Safety zone at stations all trains stop [Photo by A. Zbieć]

3. Psychological Influence on Passengers and Railway Workers

While the psychological influence does not result directly from aerodynamic factors, it can be linked to them and should be mentioned to complement the overall influences on people. The need to consider psychological factors has been noted in such papers as [7, 9, 10].

The paper [9] states: "A speeding train causes two types of hazards to a human in its vicinity: the psychological and physical influence of the slipstream. At an increased speed, the psychological influence is predominant. (…). The intensity of this feeling depends on the sensitivity of the individual but it is this type of psychological influence that must be reckoned with and taken into account when determining the boundary of the danger zone for humans. This is particularly important at high speeds because, from a psychological standpoint, the danger zone for these speeds extends further than the zone of dangerous physical influences".

The author of paper [10] notes the following: "At speeds increased to 160 km/h, the psychological influence is predominant. This influence is, of course, less dangerous for a person prepared for the train's passage than in cases where one is surprised by it due to inattention. As the train passes through the station, a person standing on the platform feels much like standing on a mountain path near a steep cliff. There is a certain feeling of anxiety. The passing train seems to pull the person towards it. Of course, the intensity of this feeling depends on the sensitivity of the individual but it is precisely this type of psychological impact that must be considered when defining the danger zone for humans, particularly at speeds of up to 160 km/h, because the danger zone at these speeds, from the point of view of psychological influence, extends further than the danger zone of the physical impact of the slipstream on humans. (…) From the point of view of the physical impact of the slipstream with a train speed of 200 km/h, the safe distance from the side wall of the train is 1.0 m and 2.5 m from the track centreline. Due to the psychological influence of a passing train on humans, this distance should be increased to at least 1.5 m from the train's side wall, or 3.0 m from the track centreline, as the psychological influence is still a determining factor. Increasing the train speeds to 250 km/h already requires a slight increase in the danger zone boundary, as this boundary, from the point of view of physical influence, approaches that of the psychological influence danger zone, because the psychological influence itself is due to the proximity of the passing train. It must be noted that there is no established criterion for determining the danger zone boundary from the point of view of psychological influence on humans in the vicinity of passing trains. The proposed assessment of the danger zone is based on direct observation of the reactions of this paper's author".

The report [7] states: "The effects of people exposed to the aerodynamic force from a passing train were based on a person's physical ability to maintain stability. Human response is also influenced by psychological factors that can compromise safety. (…) Further study should include the role that psychological factors play for people on station platforms."

The same report [7], presents an interesting Swedish sociological study [11]. The study examined the sensations of travellers staying on platforms, with trains passing by at up to 200 km/h without stopping. Around 800 travellers, aged up to 65 years, were interviewed while waiting on platforms at ten different stations. The platforms had yellow zigzag lines to warn against approaching the edge. They varied in type (island and side platforms), size and structure. The speed of passing trains varied as well. Further, some platforms were equipped with electronic warning signs (i.e. capable of displaying graphic and/or text messages) or with audible warning systems to warn of any approaching trains that do not stop at the station. The interviewees included both frequent (experienced) and infrequent (inexperienced) rail users. Discomfort with passing trains was expressed by 40÷70% of respondents. Table 1 shows the six most frequently mentioned sources of discomfort, presented in order of frequency of occurrence.

The main cause of discomfort associated with a fast-moving train appears to be psychological factors. The author of study [11] commented: "It may seem somewhat surprising that the most common reason for discomfort has nothing to do with the wind forces generated by passing trains. Rather, the speed of the passing train seems to be the primary source of discomfort, or as one of the interviewees phrased it, 'the unpleasant feeling that something large and heavy is coming straight towards you at high speed". Opinions on the electronic and audible warning systems used to warn of an approaching train were mixed. Though there were positive responses, some also found these measures insufficient. The audible warning system was considered unreliable and elicited a less positive reaction. About half of those interviewed at stations with no train approach warning systems said such systems should be provided.

Table 1

Causes of discomfort associated with passing trains [7, 11]

Common source of discomfort	Frequency of occurrence	
	Quantity	Percentage
High train speed	140	37
Air turbulence	108	29
Noise	61	16
Being surprised	30	8
Concern for the safety of others (mainly children)	27	7
Swirling snow	11	3
Total	**377**	**100**

A similar interview was conducted with the SNCF research team who ran a study on the impact of the slipstream on travellers in Mansfield, Massachusetts, using dummies imitating human silhouettes. Unfortunately, these observations are not comparable, as the study location, weather circumstances, platform type (high and low), sample size and, most importantly, interviewees (ordinary travellers in Sweden vs an SNCF research team, i.e. railway employees, in the USA) are all different. Nevertheless, it is worth mentioning the results of this study. Safety at Mansfield railway station was ensured by an electronic system that monitored the approach of trains and generated audible messages, as well as warning signs and a yellow strip along the platform edge. Table 2 lists the test participants' observations related to trains passing by, in order of frequency.

Despite the differences between these studies, there is great similarity in the results. The psychological influence has a significant impact on an individual's response: a large, fast-moving object causes natural anxiety in anyone nearby.

One curious observation at Mansfield was that when the warning system was triggered, travellers waiting on the platform moved towards the platform edge, expecting the commuter train they were waiting for to arrive and paying no attention to the type of train or its speed. Meanwhile, oncoming was a high-speed train that did not stop at the station. As a result, the warning system was generating an unintended hazard. The test team suggested that the warning system should indicate the type of approaching train.

Table 2

Test participant observations [7]

Sources of concern or discomfort	Frequency of occurrence	
	Quantity	Percentage
Train size	4	22
Concern for the safety of others (mainly children)	4	22
High train speed	3	17
Noise	2	11
Debris	2	11
Experienced instability*	2	11
Being surprised	1	6
Total	**18**	**100**

* The sense of instability was not expressed as a source of discomfort or concern, but was in specific response to the perception of force from a passing train.

There are, of course, no strict guidelines for defining the psychological danger zone; however, with a forecast increase in train speeds to 300÷350 km/h, the new safety zones, expanded due to the physical impact of aerodynamic phenomena, should also consider this aspect of worker and passenger protection.

4. Environmental Impact

Aerodynamic considerations aside, it should be noted that the aerodynamic shape of the vehicle (nose shape, body and undercarriage continuity and smoothness, pantograph design), in addition to the intensity of the aerodynamic phenomena induced, has a direct bearing on the noise generated, as well as on the driving resistance on which energy consumption depends, thereby affecting issues that are inextricably linked with the environmental issues that are so much in focus today. Designers of high-speed vehicles are constantly working to increase driving speed and comfort and reduce noise. While doing all this, they are simultaneously trying to lower electricity consumption. To that end, each successive design uses the latest technology available at that stage of technological development.

A good example of these efforts is the efforts of the designers of the Shinkansen, a Japanese high-speed vehicle described in the paper [12]. Among other things, they are constantly working on improving the shape of the train's nose and all kinds of covers for the spaces between the multiple unit's cars, the undercarriage and the running gear. Recuperative (regenerative) braking is used to reduce energy consumption. Further, a tilting body system allows the vehicle to travel at higher speeds in curves, resulting in less braking and re-acceleration after exiting them. Offering excellent aerodynamic performance, the nose shape of the N700-series trains, as seen in Figure 5, was developed using the latest analytical techniques – genetic algorithms used in the design of aircraft wings. The attachment and shape of all covers, pantographs and window panels are tested in a wind tunnel. For comparison, Figure 6 shows the nose shape of the ED250 (Pendolino) vehicle.

Fig. 5. The long nose of the Japanese Shinkansen N700-series high-speed vehicle [Photo by A. Zbieć]

Fig. 6. The nose of the ED250 (Pendolino) electric multiple unit [Photo by A. Zbieć]

Commissioned in 2007, the N700-series Shinkansen is 49% more energy efficient than the 0-series (the first Shinkansen series of trains, commissioned in 1964, in service until 2008) at a speed of 220 km/h (the maximum speed of the 0-series). At 270 km/h, the N700-series consumes 32% less energy than the 0-series. Continuous work on improving the aerodynamic shape and energy consumption has yielded tangible results during the introduction of successive vehicle series, as shown in Figure 7. Despite a 30% increase in the power of the traction equipment to enable higher speeds, the N700-series vehicles are 19% more fuel-efficient than their 700-series predecessors.

5. Summary of Series

The design of a new high-speed rail vehicle must take into account its future aerodynamic shape and, in particular, the shape of the nose, which has a decisive impact on the amount of pressure change generated in the surroundings, the slipstream and the resistance to movement and associated energy consumption. Of course, due to the regulations in force and the need for the vehicle to fit into the gauge (including in track curves), the distance of the terminal axle from the vehicle's end cannot be arbitrarily large. However, under the current regulations, the nose can have a different shape, even in the case of vehicles travelling at similar speeds. This can be seen clearly in Figures 5 and 6. Figure 5 shows the nose of the Japanese N700-series Shinkansen, with a maximum operating speed of 300 km/h while Figure 6 shows the nose of the ED250 (Pendolino) vehicle operating in Poland, with a top speed of 250 km/h. The Shinkansen's nose is about 3 m longer (extending all the way past the passenger door) than the Pendolino's nose and, unlike the Pendolino, has a covered bogie.

Another element contributing to the factors mentioned is the continuous body structure and the well-shielded undercarriage. The analysis of rolling stock

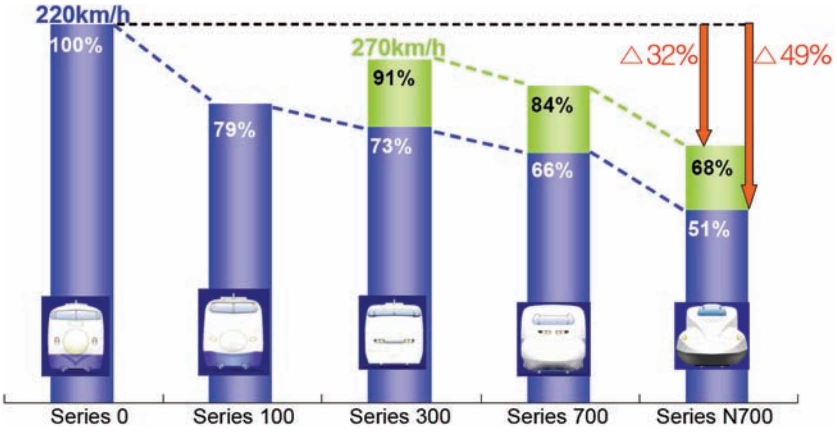

Fig. 7. Energy consumption of successive series of Shinkansen vehicles compared to the 0 series [12]

in parts three [3] and five [5] (both in Poland and the USA) shows that trains with a uniform and continuous structure, such as multiple units, have better aerodynamic properties than conventional trains comprising a locomotive and attached cars, which are characterised by producing a stronger and more uneven slipstream.

As shown in part three [3], it is also preferable to use a train of homogeneous design (multiple unit train) than a conventional train (locomotive + carriages) which, at the same running speed, has a greater effect on ballast lifting. Attention must be paid to the design of the railway surface on which high-speed trains are to travel. Apart from the performance of the track itself, the ballast must be laid correctly (including the correct grain size and height) so that it is not lifted, which can endanger people and the rolling stock itself. Consideration could be given to using ballastless tracks or stabilising the ballast subgrade using a bonding resin (ballast bonding).

Regarding the design of trackside structures on high-speed lines, either on the side of the track or at a certain height above the track, e.g:

- acoustic screens,
- bridges and footbridges,
- overhead contact line guards,
- platform canopies,
- waiting rooms and other structures,
- enclosed structures surrounding tracks,

part one [1] indicated that the pressure values affecting these structures, which would be higher than the value of the characteristic wind speed pressure for the territory of Poland based on the EN 1991-1-4 construction standard [13], should be taken into account. An alternative to increasing a structure's strength is placing it further away from the track centreline.

As regards the strength of the windows, it was shown in part two [2] that the side windows of passenger cars and multiple units should have sufficient strength to withstand pressure changes when passing a high-speed train. If necessary, their fixing should be inspected to avoid them being torn out entirely, e.g. due to corrosion at the fixing points. In contrast, there is a real danger of damage to the windscreens of older rolling stock (including multiple units, on track machines (OTMs), gang-cars and other rolling stock), particularly with maximum speeds of up to 120 km/h, due to a significant increase in windscreen pressure, ranging from almost 3 times to as much as over 6 times. Until the safe operation of this type of rolling stock has been confirmed through experiments, it should not be allowed to run on the same lines as high-speed rolling stock.

Due to the pressure effects on the human hearing system in the vicinity of fixed vertical buildings (shelters, waiting areas, noise barriers, etc.), part four [4] proposed a safety zone of about 5.2 m from the track centreline (about 3.6 m from the edge of the platform), in which people should not be present during the passage of a 350 km/h train. For train speeds of 250 km/h and 300 km/h, this zone should be 3.5 m and 4.3 m, respectively. In the absence of normative regulations, the zone's size was calculated based on the now repealed version of the regulation on harmful factors in the working environment [14], taking a value of 145 dB (≈ 355 Pa) as the criterion for the peak uncorrected sound pressure level. Due to the possible impact of pressure on the hearing systems of passengers travelling on conventional trains that may pass high-speed trains, modern air-conditioned cars with non-opening windows should be used on such routes.

As far as the influence of the slipstream on people is concerned, as described in part five [5], it is advisable to reduce it by at least 1÷2 Beaufort degrees (to a value of 5÷6 B) for passengers and by 2÷3 Beaufort degrees (to a value of 6÷7 B) for employees in relation to the value given in EN 14067-4 [15]. The author's research has confirmed that this condition is met in the case of high-speed passenger trains running in Poland.

Countermeasures to protect passengers and railway workers from excessive pressure changes, as well as from excessive slipstreams and the hazards associated with these influences, and also to protect other rolling stock from damage, should not include reducing the speed of high-speed trains when passing platforms on which these trains do not stop, or older trains with top speeds of up to 120 km/h or trains with top speeds of up to 160 km/h, but with opening windows. This would contradict their very purpose. One does not work to increase train speeds only to have trains slow down every couple of minutes. Further, repeatedly bringing a high-speed train up to its top speed would involve increased energy consumption. Other measures should be used, such as providing a sufficiently extensive area inaccessible to staff, as well as providing staff with protective equipment and appropriate training. Passengers should also be provided with a sufficiently wide zone separating them from the high-speed train, preferably by constructing platforms next to the auxiliary main tracks (separating passengers by an additional track from passing trains), and either by fencing them off with special barriers that only open when the train is stopped, or as a minimum, clearly marking the platform with information boards and lines on the platform, preferably in combination with a warning system to indicate an approaching train and whether the train is stopping at the station. This would also provide an effective safeguard against the psychological influence of high-speed trains, which to date has not been framed in any way that can be described by mathematical formulas.

Due to the impact of the slipstreams of high-speed trains currently running in Poland, a safety zone of

3 m from the track centreline (1.325 m from the platform edge) is sufficient. Any new trains with operating speeds of 250÷350 km/h should be subjected to slipstream tests, and until such tests are carried out, passengers and staff should be provided with at least a 5 m safety zone from the track centreline.

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