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# AERODYNAMIC RESEARCH OF HIGH SPEED TRAINS IN THE SUBSONIC WIND TUNNEL

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**ABSTRACT:**
A review of experimental studies in aerodynamics of trains of great speeds when passing each other on open tracks. This paper describes measurement of the aerodynamic pressures produced by passing trains. The focus for this study is to determine the localized effects such as potential damage to windows.
The paper presents the experimental researches of train models, carried out in wind tunnel in our country. Results of the experiment are compared with the pressures predicted by computational fluid dynamics simulation. Theoretical calculation is based on finite volume discretisation technique, which is used for flow field prediction of two high-speed trains. Speed of the each crossing train has been 250 km/h.
**KEYWORDS:**
Trains of great speeds, high-speed train, aerodynamic, boundary layer wind tunnel

## 1. INTRODUCTION

The moving train shifts the air with it and deforms the moving-through environment. If the train advances with the constant speed on open track, i.e. without presence of other trains or objects to cause interaction with the train being observed, the form of flow is independent of time and the phenomenon are stationary.

When the train moves with non-constant speed or when its immediate environment has been modified by the presence of other passing train or any other obstacle along the railway such as the pedestrian, vehicle, bridge, building, tunnel, etc., the flow of air varies with time and the phenomenon are non-stationary.

Non-stationary aerodynamics studies the effects of the pressure waves occurring when the train moves in the vicinity of single fixed installation, such as wall, bridge or other infrastructure, when passing through the tunnel or passing other train on open track or within the tunnel. In such case, the interaction between the train and its environment shall be determined as well as the safety and comfort limits shall be defined.

The study on non-stationary phenomenon can be derived to stationary studies by dividing the time on sufficiently small intervals $\Delta t$. The phenomenon shall be observed as stationary within single time interval.

## 2. EXPERIMENTAL STUDIES IN AERODYNAMICS OF HIGH-SPEED TRAINS

The aerodynamic resistance becomes ultimate with the increase of the train speed, because it is changed with the speed square. Aerodynamics engineers, engaged with cars, and especially with airplanes, found themselves in an unusual situation. The first reason has been the large length of the vehicle. The length of the car (automobile) is 2.5 to 2.7 times larger than the width. As for the railway cars, the length and width ratio is 6 or 7, whereas with regard to longer trains, it is 50, 100, or more. The aerodynamic resistance coefficient is given based on the cross-section area of the cars or airplanes, which would be unnatural for trains. As for the trains, this coefficient is given based on the length or number of the cars. The trains have to move equally in both directions, which is not required for the airplane, whereas the aerodynamic quality is not required for cars when moving in reverse direction. The conditions are different for the aerodynamics engineers, studying the airplanes, because the train is moving constantly in the presence of the ground, adjacent installation and persons as well as through the tunnels.

One of the significant problems, which emerged with the increase of speed, is non-stationary phenomenon related to the air pressure effect, i.e. pressure waves occurring in passing other trains on open track and when passing through the tunnel, with or without passing by other trains. The pressure alteration in such cases causes fatigue of window and door glass, as well as additional structural loading. Passing trains with each other in the tunnel cause such pressure alterations, which are also conveyed to the passenger's eardrum, causing unpleasant feeling. Special types of the tunnels may reduce the pressure wave power, created by the train, and therefore improve the passenger's comfort. As a result from the initial studies, nose shape replacement and development of the sealed vehicles have occurred, as well as the development of fitting elements providing additional sealing for existing passenger railroad cars. Entrance tunnel portals, adjacent installations and bodies of small dimensions, being in the vicinity of the railway are subject to pressure wave resulting from movement of high-speed trains.

Experimental studies are aimed to explain the aerodynamic phenomenon, occurring in moving high-speed trains and verify its theoretical calculations. The tests are carried out in:

- water cavitation tunnels,
- boundary layer wind tunnels, specially designed for aerodynamics testing of trains,
- wind tunnels for aeronautical testing, and modified and adjusted for testing of non-aeronautical objects, and
- on open track.

Testing in water cavitation tunnels is mostly conducted for visualization around the mock-up of the front and rear train section, in the vicinity of air intake, around pantograph and other projected structural parts.

Testing in aeronautical wind tunnels includes: measurement of the train frontal resistance, resistance of caesuras (joints) between railway cars, pitching and yawing moment, train overturning moment, pressure distribution in vertical and horizontal plane, pressure on railroad car stand, separations on door and window recesses, air supply for cooling and ventilating systems, air discharge of traction electromotor fans, air discharge for cooling of electric brakes, testing of aerodynamic brakes as well as flow visualization with smoke and tufts, adhered to the model surface.

Track testing includes the measurement of pressure distribution, boundary layer thickness around the train, train resistance in isolated drive on open track and within the tunnel, in passing other train on open track and within the tunnel and measurement of train movement-related pressure wave effect to the objects located in the vicinity of the track.

The results of all these tests have indicated that the best aerodynamic shape of the train ends (front and rear), which was found in the water cavitation tunnel, has been also verified in the aeronautical wind tunnel.

The Figure 1 gives the results of the flow visualization around the front train section, manufactured in 1:50 ratio, for the train with speed of 240 km/h. Small air bubbles in water suspension make clearly visible diaphragm, obtaining the flow appearance around the model in various planes. This image of flow can be photographed or recorded with camera.

The existing wind tunnels, designed for the aeronautical needs as well as the needs of automobile industry, do not meet the testing conditions of the mock-ups for longer trains in the desirable ratio. The wind tunnels with longer test sections are designed for the testing needs of the train aerodynamics. The basic reason for existing of these wind tunnels is the measurement of aerodynamic forces on the mock-ups of the trains and railway equipment. The required ratio for the testing model manufacture is 1:20, in order to obtain sufficiently exact reproductions of the vehicles and meet the conditions of Re number. Models can be manufactured from wood, metal and other materials, whereas the selection also depends on the intended use, price and loading to which the model shall be exerted during testing.

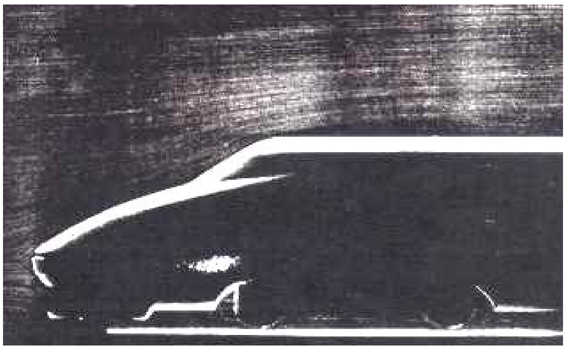


Figure 1: Image of flow around front train section

a) b)

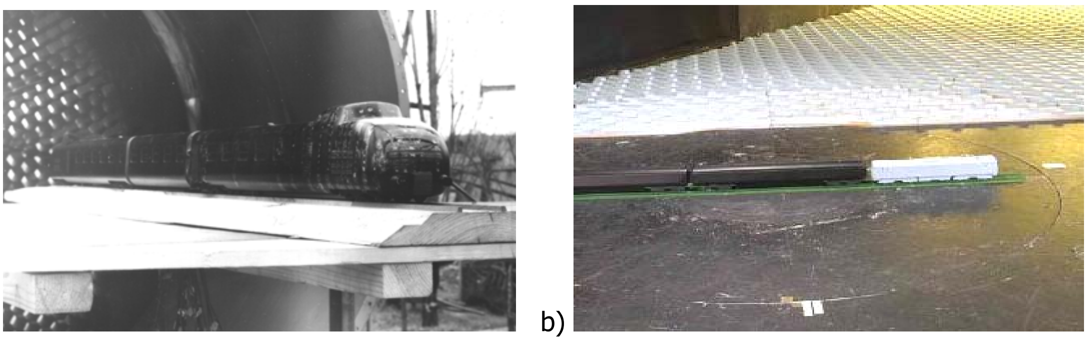


Figure 2: Various train models for testing in wind tunnels

Figure 2 illustrates several train models, positioned on the wind tunnel floor. Tunnel floor roughness has been conducted on the access flow segment. The required access flow turbulence is obtained using wind tunnel floor of the suitable roughness. Figure 2b) illustrates that flat panels with bulges of circular cross-section have been used for wind tunnel floor roughness. Wooden cubes of particular dimensions, positioned according to the previously determined number and arrangement are also used. Figure 2a) illustrates the model positioned on the base, simulating the embankment. There is a table with the drawn mesh of exactly determined dimensions in the model background, used for more precise reading of the flow image with regard to flow visualization.

## 3. ISOLATED DRIVE ON THE OPEN TRACK

The isolated drive on open track belongs to the domain of stationary flow.

The movement of train in air space causes the formation of higher pressure zones in front of the train, turbulent boundary layer along the train due to friction action, appertaining flow on lateral car walls and behind the train.

Pressure coefficient measured in front of the isolated train at the train speed of 200 km/h is 1.75, but it reaches the value of 2.25 when other train partially blocks the tunnel entrance. Therefore, flow around the train on open track, whether isolated drive or drive in presence of obstacles or passing other train are in question, can be classified as non-compressible flow, which is not the case of the train moving in the tunnel.

## 4. PASSING TRAINS WITH EACH OTHER ON OPEN TRACK

Problem of non-stationary flow is resolved by dividing the time to sufficiently small intervals $\Delta t$, in which the observed phenomenon is treated as stationary. Distribution of flow speeds and pressure coefficient $C_p$ on the train surface or obstacle surface passed by the train, where all stationary and mobile bodies positioned in fluid are considered as obstacle, are observed related to two parameters, which are changed independently. Those are mutual distance and speed ratio of two vehicles. The alteration $C_p$ is incomparably more significant on the passing side, i.e. internal side than on the external side of the trains and it is higher on the slower moving train.

## 5. EXPERIMENTAL RESEARCHES IN AERODYNAMICS OF HIGH-SPEED TRAINS CONDUCTED IN MTI

Testing of train models has been conducted in subsonic wind tunnel T-35. T-35 wind tunnel is of indoor type with test section of octagonal cross-section and area of 11.92 $m^2$. The test section length is 9 meters.

The aim of testing is to determine the pressure distribution on the high-speed train model in the configuration of single drive on open track and the presence of other train.

The testing has been conducted in two stages:

1. Measurement of the pressure distribution on high-speed train model,
2. Measurement of the pressure distribution on high-speed train model in the presence of other train.

### Model description

The train model in 1:20 ratio, illustrated on Figure 3, has been designed and manufactured for conducting this testing. The model has been cast of dural and comprises of two locomotives, mutually back-connected. The total model length is 2.056 m. The cross-section is variable with maximum width of 0.15 m and maximum height of 0.18 m.

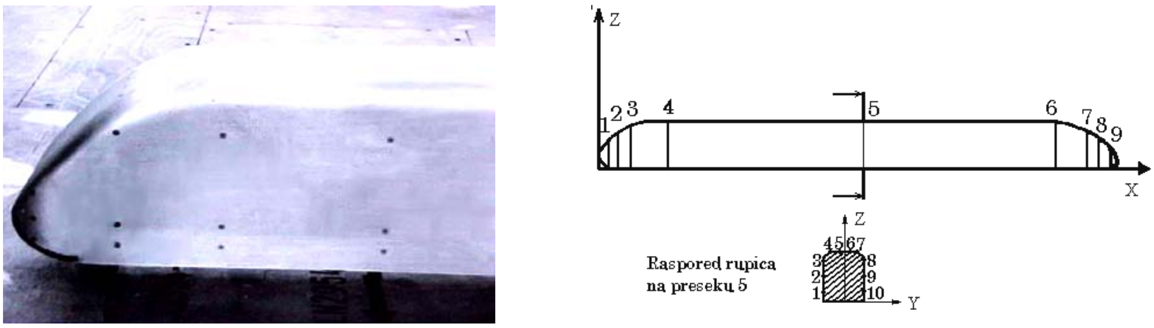
The train model has been positioned on the support, enabling the alteration of slip angle β, i.e. simulation of speed direction alteration, at height of 40 mm from the platform, simulating the train-related ground effect. Two gaps (slots) have been made on the platform, perpendicular to the flow direction, for boundary layer exhaust.

**Testing procedure**

*Stage 1 description:* Measurement of the pressure distribution on the train model has been conducted using two scanivalves, located within the train body. The differential pressure gauges are located within it (of Druck type), measuring the pressure difference from active and reference side. The static pressure from Pitot tube, fitted on the platform, is applied to the reference side, whereas static pressure is applied to the active side from the holes on the model. Scanivalve is connected with the holes on the model using plastic pneumatic tubes. Testing has been conducted for the speeds of 30, 50 and 70 m/s, for angles of deflection $\beta = -10^0$ up to $10^0$ with pitch $\Delta\beta = 2^0$.

*Stage 2 description:* This testing stage included the measurement of the pressure distribution on the train model in the presence of other train, for two speeds of 30 and 50 m/s as well as for five different mutual positions of the trains.

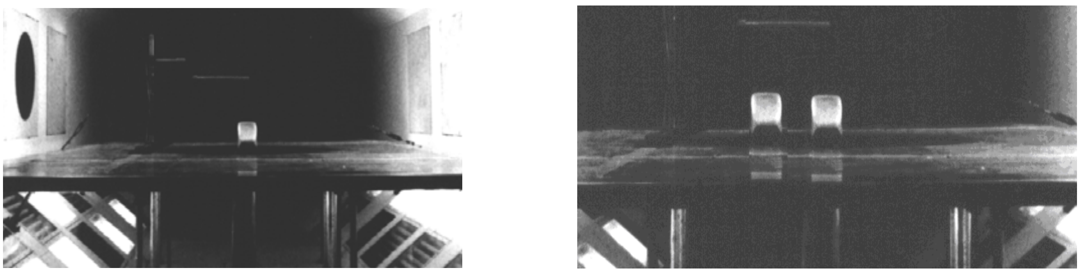
The measurement mode and measuring devices used are the same as in the stage 1.




a) b)

Figure 3: Model with holes for measuring pressure distribution a), coordinate system, position of measuring sections and measuring points on the train model b)

The mutual position of trains is given on the Figure 5. The testing has included the measurement of pressure distribution on the train model in the presence of other train. The measurement has been made for 5 different mutual positions of the trains and two speeds of air flow.



a) b)

Figure 4: Position of train model on the platform for ground simulation a) simulation of single drive on open track, b) simulation of passing other train on open track

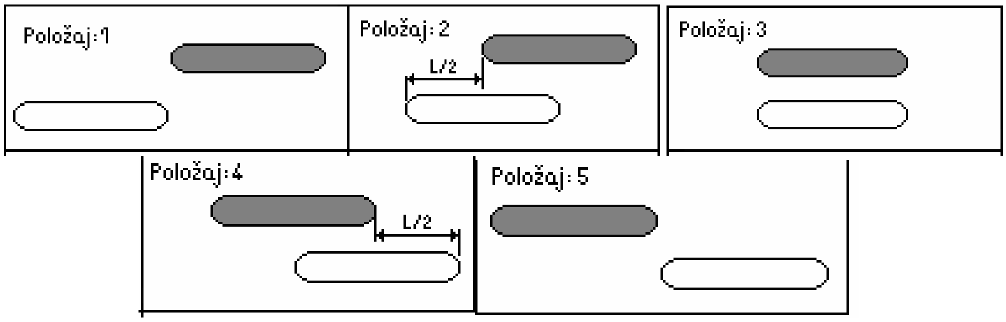



Figure 5: Mutual position of the train for testing in stage 2

**Measuring results of pressure distribution by the train model for stage 1**

Figures 6 and 7 give the pressure distribution along cross-section of the train for cross-section 1, speed of 50 m/s and pressure distribution in the train's plane of symmetry for the speed of 50 m/s. As it can be seen from the obtained results, pressure distribution on the train cross-section is symmetric related to the train's plane of symmetry by slip angle of β=0°.

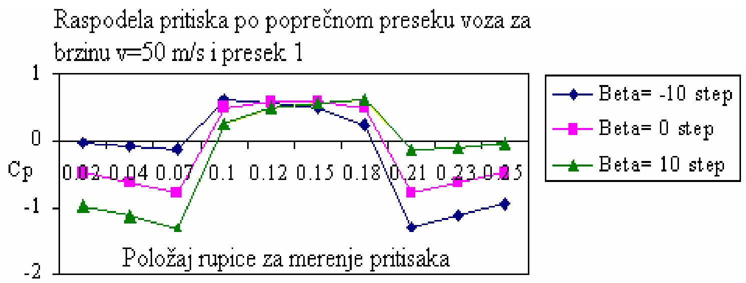



Figure 6: Pressure distribution along train's cross-section

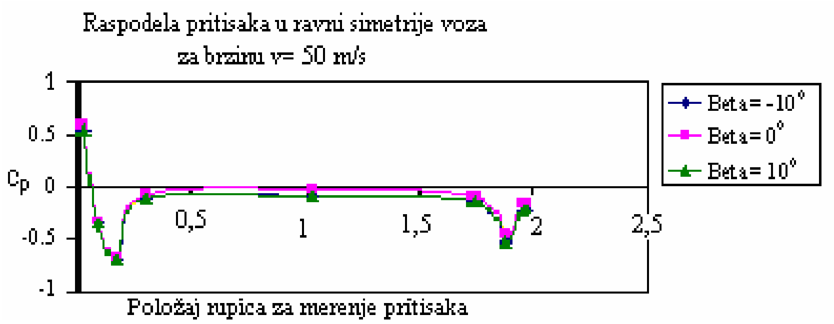



Figure 7: Pressure distribution in the train's plane of symmetry

Figure 7 represents the pressure distribution for the points of the front train section and top, in the train's plane of symmetry and slip angles of β= -10°, 0° and 10°. The figures illustrate that the stagnation point in the plane of symmetry is on the spot where Cp has maximum positive value. Flow separation occurs in the spots where the curve moves away from abscissa. The figure illustrates that this is behind the stagnation point and behind the section 6.

The stagnation point is moved from the train's plane of symmetry to the windy lateral side, whereas the flow speed of front top edge and front lateral edge on the windy side is increased. The curve distance from abscissa in the zone of points 4, 5 and 6 is increased by increasing the slip angle β. That dimension represents the pressure fall on the top surface. The flow separation occurs near point 7, resulting in repeated flow approached after that.

### Measuring results of pressure distribution by the train model for stage 2

Pressure distribution in the train's plane of symmetry for speed of 50 m/s is illustrated on Figure 8. Pressure distribution for points of train front section and top in the plane of symmetry of the train and $\beta=0^0$ indicate that the stagnation point in the train's plane of symmetry is on the spot where $C_p$ has maximum positive value. Flow separation occurred on the spots where the curve moves away from abscissa. The figures indicate that it is behind the stagnation point and section 6.

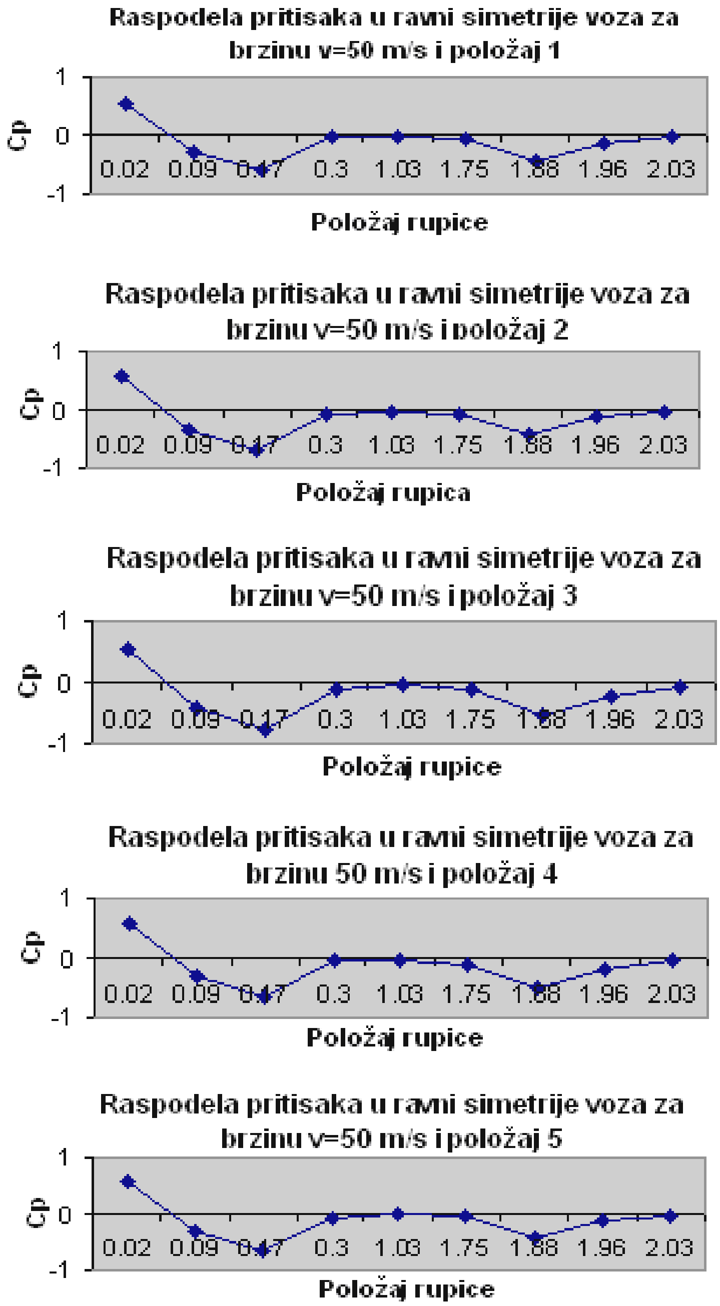



Figure 8: Pressure distribution in train's plane of symmetry for 5 mutual positions of trains

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