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The use of numerical simulation in the analysis of aerodynamic problems in transport

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ABSTRACT The study of the aerodynamic impact of rolling stock on the railway infrastructure is carried out either with experimental methods or with numerical simulation methods. The use of numerical simulation methods allows you to safely and quickly obtain the necessary data. An important task is to determine the factors that affect the aerodynamics of the rolling stock. To study aerodynamic processes in transport it is proposed to use the Frozen Rotor method in combination with the Large Eddy Simulation, which can be implemented using the Solid Works Flow Simulation software package. This method makes it possible to obtain a high-quality picture of the distribution of air flows in the boundary and main layers.

KEYWORDS: finite volume method; numerical simulation; aeroelastic interaction; turbulence; Frozen Rotor method

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Научная статья

Использование численного моделирования при анализе аэродинамических проблем на транспорте

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АННОТАЦИЯ Исследование аэродинамического воздействия подвижного состава (ПС) на железнодорожную инфраструктуру осуществляется с помощью экспериментальных методов или методов численного моделирования. Использование методов численного моделирования позволяет безопасно и быстро получить необходимые данные. Важной задачей является определение факторов, которые влияют на аэродинамику ПС. Для исследования аэродинамических процессов на транспорте предлагается применить метод Frozen Rotor в комбинации с методом крупных вихрей, что можно реализовать с помощью программного комплекса SolidWorks Flow Simulation. Применение данного метода дает возможность получить качественную картину распределения воздушных потоков в пограничном и основном слоях.

КЛЮЧЕВЫЕ СЛОВА: метод конечных объемов; численное моделирование; аэроупругое взаимодействие; турбулентность; метод Frozen Rotor

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INTRODUCTION

To solve problems related to the aerodynamic interaction of rolling stock (RS) with the railway infrastructure, an experimental method (full-scale) or a numerical simulation method using specialized software is used.

The experimental method is often difficult to use. And when analyzing the aeroelastic interaction of rolling stock with tunnel structures, it may be impossible to apply it due to the following factors[1]:

1. High cost and technical complexity of installing air pressure sensors on tunnel walls without interrupting train traffic.

2. Speed measurements are life-threatening because they require being close to a moving train. 3.

3. Insufficient objectivity of research results due to the presence of many limiting factors that do not allow placing the equipment properly.

One of the most realistic experimental methods is blowing a model train in a wind tunnel. But it is not universal because it is costly, numerical results of flow distribution are difficult to interpret.

The use of numerical modelling of aerodynamic processes makes it possible to overcome these difficulties. Modern computer programs, in which the finite element method and solid modelling of infrastructure objects are applied, allow solving a wide range of problems related to the interrelated stationary and non-stationary thermal and aerodynamic fields and processes in tunnel structures during the movement of the train station.

SPECIFICS OF APPLICATION OF NUMERICAL METHODS

Experimental values are required to verify the computer model in any case. With this option, there is no need to investigate many cases; one case is sufficient. If the model proves to be adequate, other cases can be numerically simulated by interpreting the base values using various mathematical methods.

In numerical modelling using the finite volume method, it is important to set the boundary conditions correctly to simulate the interaction of the gas with moving and stationary walls, as well as the effects of the environment. When the air medium interacts with moving surfaces, the surfaces are deformed, which requires the solution of the Navier – Stokes and Laplace equations to account for the stress-strain state of the surfaces [1].

The solution of the problem by the finite volume method in such a formulation requires considerable computational resources. However, in the case of aeroelastic interaction between the rolling stock and artificial structures, the deformations of the surfaces are small; therefore, assumptions are made that there is no change in the shape of the interacting surfaces at all velocities of the rolling stock motion. For wall modeling, the velocity component normal to the surface is assumed to be zero, which means that the solid wall is impermeable. There is no slippage of the medium along the wall. The stationary moving walls of the computational domain are assumed to be smooth. Such assumptions allow us to reduce computational costs and maintain the correctness of the obtained data [2, 3].

Due to the presence of viscous friction forces near the surface of the streamlined body, the flow velocity changes and a boundary layer appears. In this case, at the surface of the body, the flow velocity is equal to the body velocity, and as the body is removed, there is a gradual change in the flow velocity from the body velocity to the velocity of the external flow streamlined around the body.

The flow around the surface of the body of the rolling stock can be divided into two layers: the boundary layer, in which there is a relative movement of air layers, and hence the viscous (friction) forces perceived by the body of the train, and the main flow moving at a constant speed, in the volume of which the forces of viscous friction manifest themselves insignificantly (*Fig. 1*).

Friction forces in the boundary layer create frontal resistance of the rolling stock. Due to the complex configuration of the train body (presence of protruding

[1] Technical Regulations of the Customs Union “On the Safety of High-Speed Rail Transport” dated 15.07.2011 with amendments as of 09.12.2011 (TR CU 002/2011). URL: http://docs.cntd.ru/document/902293437

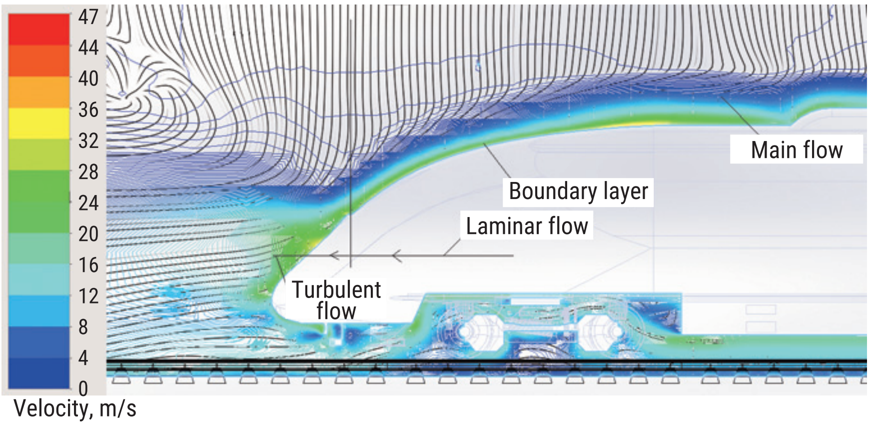

Fig. 1. Types of flows when a train is streamlined by air flow

parts, inter-car gaps, niches, etc.), turbulent flows arise. At the end of the train a rarefaction and vortex trace are formed. All these are the reasons for the increase in the forces of resistance to motion [4–7].

To analyze the aeroelastic interaction between the rolling stock and tunnel structures, one needs to use software packages that allow to realize the mathematical description of moving surfaces and volumes in a stationary air medium. The accuracy of the calculation is largely determined by how correctly the boundary layer modeling is performed.

An important point in modeling aerodynamic processes is the choice of the method of numerical modeling of turbulence. There are several main methods: Direct Numerical Simulation (DNS), Large Eddy Simulation (LES), as well as models based on Reynolds-averaged Navier – Stokes (RANS) and hybrid Shear Stress Transport (SST, shear stress transport).

Since the SST model is the most universal of these models and functions effectively for a wide class of complex gradient flows, it is used for modeling aeroelastic interaction using the program tools SolidWorks Flow Simulation [8, 9].

NUMERICAL METHOD FROZEN ROTOR

The need to reduce the calculation time without loss of accuracy on the one hand and at relatively low computational power consumption on the other made it necessary to use the Frozen Rotor method in this work. Its use allows us calculating the distribution of velocities and pressures depending on the position of an object moving along a circle. The radius of the circle along which the motion occurs is set large enough. The calculation error (primarily for rectilinear motion) will be determined, among other things, by the value of this radius due to the presence of the tangential component of velocity (*Fig. 2*).

The essence of the Frozen Rotor method is generally reduced to the selection of such an angular velocity of rotation of the coordinate system that the resulting ve-

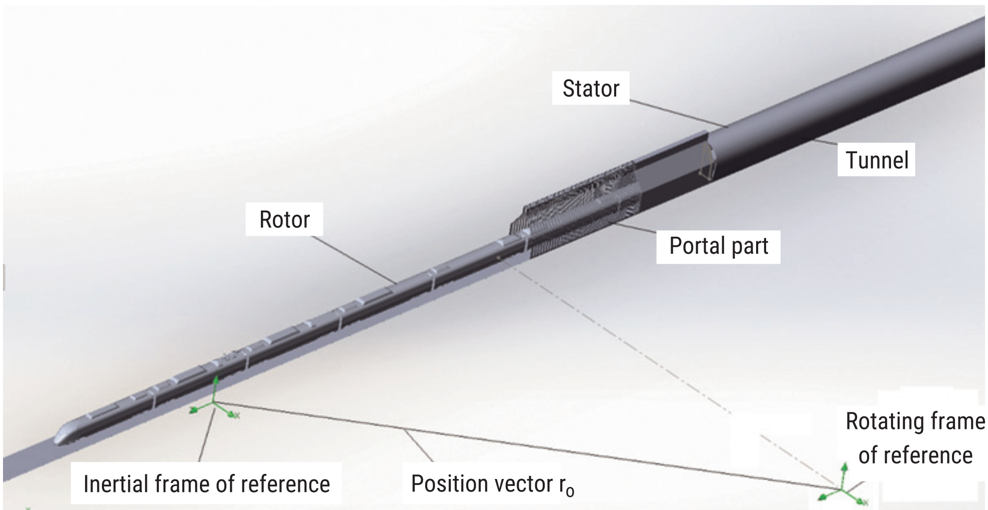

Fig. 2. Stationary and rotating frames of reference

locity of the body relative to the stationary walls of the tunnel becomes equal to zero, which will make it possible to reduce the calculation to a stationary process. When performing the transformation, the conditions of conservation of mass, momentum, and energy have to be satisfied. Centrifugal forces are applied to the air particles of the stationary region.

A serious advantage of this method is the reduction of computational time and resources consumed. This method allows us estimating the distribution of aerodynamic characteristics at different points.

CONCLUSION

The Frozen Rotor method used in combination with the large eddy method is the most promising and optimal in terms of performance and computational power consumption. It is characterized by low costs of numerical experiments compared to in-situ experiments, versatility, high speed and the possibility of performing studies at the design stage. Practically, it can be realized with the help of SolidWorks Flow Simulation software package tools.

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