DESIGN AND TEST RESULTS OF WIND TUNNEL FOR CAR PROTOTYPES

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ABSTRACT

Several methods are used for conducting aerodynamic tests. The car body belongs to the category of objects that cause difficulty in determining the resistance force of the air acting on it. Even now, car aerodynamic parameters are determined through experimental testing. These tests are performed through virtual and wind tunnels. In the process of designing, a test device for scaled models is one of the best solutions for determining the values of aerodynamic indicators of a car. This article describes the design of an wind tunnel for scaled models and the results of experiments conducted on it. Scale models of a hatchback and a minivan were selected as test models.

Keywords. Wind tunnel, air flow, air resistance, drag coefficient.

INTRODUCTION

It is difficult to determine the force of air resistance on cars using theoretical methods. Therefore, aerodynamic studies are conducted [1]. Various methods are used in the study of car aerodynamics. It is possible to determine the coefficient of air resistance to the car even in road conditions [2]. It is difficult to determine the effect of several factors in this method. One of the most common methods is tests in wind tunnels. The first studies on wind tunnels were performed by Glauert and analyzed flying objects [3]. Wind tunnels generate air flow and how this flow affects the model under test is studied [8]. The device is used in several industries, including aviation, architecture, and automotive. Nowadays, car manufacturers have their own large testing facilities and this is important for them to determine the technical specifications of the car they produce. Aerodynamic properties of cars also significantly affect their fuel consumption. [4] stated that at speeds of 70 km/h and above, the effect of air resistance on fuel consumption is significant. In practice, it is often possible to encounter different performance indicators of different body types of cars with the same engine. Therefore, it is necessary to predict the air resistance of the car at the design stage. This allows to make changes in the body at the first stage. Small wind tunnels play an important role in solving this problem. The aerodynamic characteristics of the manufactured car can be slightly improved with the help of additional elements (spoiler, diffuser, etc.). In sports cars, it is possible to overcome air resistance with the help of these tools [9-14].

2. DESIGNING LOW-SPEED WIND TUNNEL

2.1. Analysis of wind tunnels.

Low-speed wind tunnels have a number of conveniences for conducting experiments with accurate results. Their design is designed differently according to the purpose of use. Accordingly, the elements installed on them are different. Low-speed wind tunnels can be classified according to many criteria. Below are their types.

The tested models are placed in the working parts of the wind tunnel. By type of working part:
a) wind tunnel with an open working part. In this case, the walls of the working part will not exist. Mercker and Wiedemann conducted several studies on open working part studies [5]
b) wind tunnel with a closed working part. In this case, the working part is closed with walls. Cooper conducted research on wind tunnels with a closed working section. [6]
To move the air flow:
Closed return wind tunnel. Air flow moves according to a closed scheme. For this purpose, output and input paths are connected. Most test stands have a single return channel, but test stands with two return paths are also used.
Open return wind tunnel. In such test stands, air is taken from the outside environment and returned to the outside environment again. If the stand is installed inside the room, the size of the room should be large enough to ensure that the air speed inside the room is lower than the air speed inside the pipe. In addition, the test stand can be installed in the open atmosphere, but in this case it is necessary to take into account the presence of wind in the external environment and its influence on the test processes.
In open return wind tunnel, power is wasted due to the loss of kinetic energy of the flow at the outlet [7].

2.2. Design of the working part in the designed wind tunnel.
A test device with an open circuit and a closed working part was designed according to the movement of the air flow. In this device, small models are tested, and the working part has the ability to move the air flow up to 18-20 m/s.
The device has been designed as an air channel and a working part with uniform diameter, circular cross-section and integral connection (tunnel). The part of the tunnel where the air speed is stable was designated as the working part.

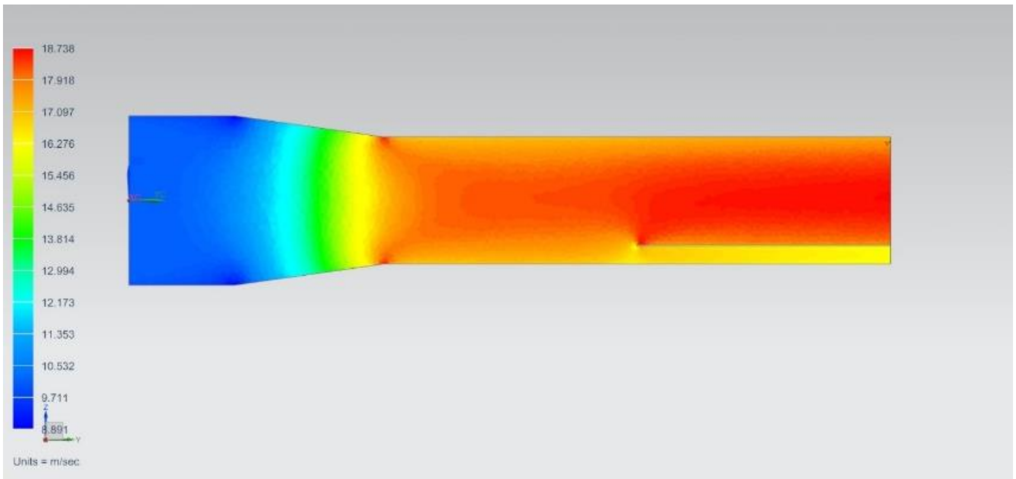


Figure 1. Airflow velocity in the wind tunnel

2.3. Working parts of the wind tunnel
Working part. The test model is placed on the working part. The working part is the narrowest part of the wind tunnel, where the flow rate reaches its maximum value. Below are the advantages and disadvantages of open and closed working parts.

An important parameter of the working part is the air tightness of the tested model. Usually, this parameter depends on the relationship between the characteristic size of the tested model and the cross-sectional size of the working part. If the tested model occupies more of the cross-sectional surface of the working part, the impact of air flow on the walls of the working part has a great impact on the results of the experiment. In stands with an open working part, this indicator of influence is much less compared to those with a closed working part. Therefore, it is possible to test relatively large models in wind tunnels with an open working part.
Depending on the purpose of using the wind tunnel, the type of working part is selected, if it is necessary to conduct many tests on different models, it should be equipped for easy placement of the model on the working part. Or it is advisable to use a device with an open working part. However, it is necessary to take into account the influence of the external environment in wind tunnel with an open working part.
Ensuring turbulence in the open working part causes difficulties. If small values of flow turbulence are important, it is necessary to choose a closed working part.
The length of the open working part can usually be 1.5-2 times larger than the transverse size. It is not possible to test long models in wind tunnel with an open working part. Closed working parts make it possible to do this.
In pipes with a closed working part, special measures are taken to ensure that the static pressure does not change along the working part. Frictions on the walls and the surface of the test model lead to a decrease in flow pressure.
In order to avoid changes in static pressure, it is necessary to extend the lower part of the cross section of the working part. In general, the distance to be extended is different for different models. For the working part without a model or with a small model, the distance expansion is chosen equal to the shear thickness of the boundary layer. To calculate this value, the logarithmic velocity profile on a smooth plate in a fully turbulent boundary layer is used.
The shape of the cross-section of the working part depends on the type of models to be checked. For example, wind tunnels designed for testing airplane models often have an elliptical cross-section. The projection of the plane is well suited to this section. The wings are located along the major semi-axis of the ellipse.
Many wind tunnels intended for testing cars and construction models have a rectangular or polygonal cross-section.
The working part of the designed aerodynamic pipe is 650 mm, and its cross section is circular. A control window is installed to monitor the test progress. The surface on which the car model is mounted is made of flat material. Equipment for measuring air speed and loads falling on the model was placed in the working part.

2.3.1. Nozzle

When using the first wind tunnel, it became clear that special devices should be used to obtain the same air flow. The main device for obtaining a uniform flow is the nozzle. The nozzle is located in front of the working part and represents a channel that narrows the air flow.
In addition to creating a uniform flow, the nozzle has another function. The nozzle performs the task of moving from the widest part of the pipe at low speeds to the narrowest part at high speeds.

Often, as an example of the theoretical formula of the nozzle contour, the Vitoshinsky formula [1] obtained using the ideal fluid model for a nozzle with a circular cross-sectional shape is given. However, this formula may not always be used in practice. There are also wind tunnel with different inlet and outlet parts of the nozzle. For example, the AT-12 aerodynamic pipe nozzle has a square inlet and a circular outlet.

When designing the nozzle shape, conflicting requirements are taken into account. On the one hand, the length of the nozzle should be minimal, so that the installation takes up less space. On the other hand, a short nozzle does not provide a uniform flow. The contour of the nozzle at the exit greatly affects the quality of the flow. A good result is achieved by the shape of the nozzle contour approaching the shape of a cubic parabola.

An important feature of the nozzle is its narrowing and is determined by the ratio of the inlet cross-sectional area A_1 to the outlet cross-sectional area A_2.

$$n=A_1/A_2$$

We will see that the air flow passing through the nozzle contour is not the same. We put 1 on the index of the values in the inlet part of the nozzle and 2 on the index of the exiting values.

Using Bernoulli's equation, the input and output values for any flow are related as follows:

$$P_1 + \rho v_1^2/2 = P_2 + \rho v_2^2/2 \quad (1)$$

Here, P - is pressure, ρ is density, and v - is air velocity

We change the equation (1) on the cross section by putting the average values of the quantities drawn on top:

$$\bar{P}_1 + \rho \bar{v}_1^2/2 = \bar{P}_2 + \rho \bar{v}_2^2/2 \quad (2)$$

Subtract equation (2) from equation (1), and since the values of pressures P_1 and P_2 are equal to their average values, we get the following result:

$$v_1^2 - \bar{v}_2^2 = v_2^2 - \bar{v}_2^2 \quad (3)$$

According to the law of conservation of mass for incompressible gases:

$$\bar{v}_1 A_1 = \bar{v}_2 A_2 \quad (4)$$

We express the change of speed pressure as follows:

$$K = \frac{v^2 - \bar{v}^2}{\bar{v}^2}$$

Using this expression, we derive the following relation of equations (3) and (4):

$$K_2 = \frac{K_1 A_2^2}{A_1^2} = \frac{K_1}{n^2}$$

It can be seen that the velocity pressure at the exit from the nozzle decreases n^2 times [7].

2.3.2. Fan

Usually, the fan is installed after the diffuser or after the flow diversion channel, before the flow return channel, in the wind tunnel with closed coils. To create air flow, you can use direct flow fans or centrifugal fans. In large devices, fans with direct flow are used, and the radius of the fan in them reaches several meters. In order to reduce the sound output, a limit can be set on the rotation frequency of the fan. The maximum rotation speed is selected not more than 180-200 m/s. An increase in speed leads to a decrease in the efficiency of the fan and an increase in noise. The flow rate is controlled by changing the rotation frequency of the fan. Two or more ventilators are installed next to each other in the form of an ellipse cross section.

A direct flow fan was selected for the designed device.

2.3.3. Anemometer

Anemometers are used to measure the speed of the current moving in the working part. Nowadays, digital anemometers are common. Sensors for measuring air temperature are added to modern anemometers. This provides an opportunity to obtain information about the flow rate and temperature at the same time.

Description of the digital anemometer used in the device:

The range of temperature measurement is -10 .... +50^{0}C,

measurement error - ±50C,

measurement frequency is 0.5 sec.

Speed measurement range 0.4... 20 m/s,

the measurement error is 0.2 m/s.

2.3.4. Dynamometer

It is advisable to use tensometric type dynamometers for accurate test results. In addition, electromagnetic load measuring devices are also used. Results are obtained by magnetic flux between the model under test and the dynamometer. But preparing the test model from magnetic material and the test area from non-reflective materials creates some difficulties.

Tensometric type dynamometers have a number of advantages. Firstly, it is small in size, and secondly, it has high accuracy. These dynamometers are used by many researchers for their ease of use and simplicity. Tensometric type dynamometers are used in aerodynamic studies [15].

Tensometric sensor is deformed as a result of the force applied to the support, and its current resistance changes. With the help of a sensitive circuit, the resistance value is determined and integrated into the voltage value accordingly.

2.4. The principle of operation of the wind tunnel.

The wind tunnel with a closed working part and an open return is connected to the power source. The required voltage is 200-220V. Changing the value of the current on the test stand is achieved by changing the voltage supplied to the fan.

The test model is mounted on the working part. It should be ensured that the longitudinal axis of the model is parallel to the flow direction.

The dynamometer and the anemometer are lowered into the working position, and then the air flow is created. That is, voltage is supplied to the ventilator. At first, in low ranges, it is gradually increased to higher ranges. Air speed and load values are recorded at each stage.

3. TEST RESULTS

3.1. Models for testing

The experiment was conducted on car model of hatchback body types The front surfaces of the model S_1=10127mm^2.

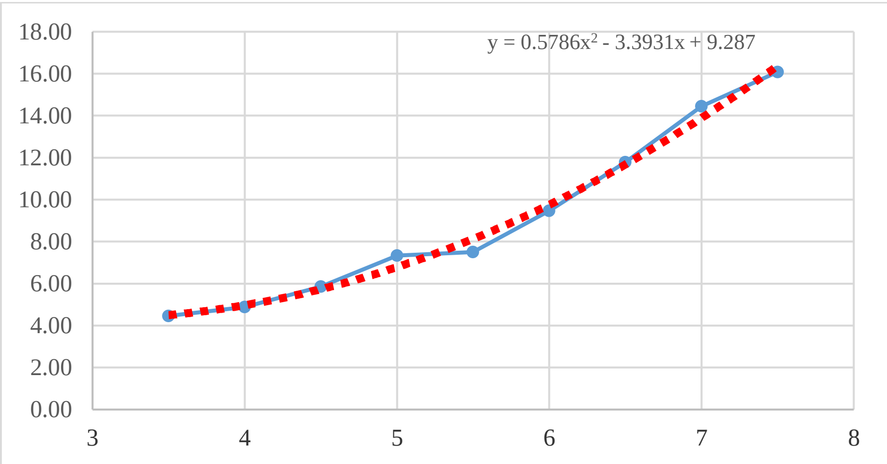
The model was placed on the working part in the order indicated above. Starting from a speed of 3.5m/s, the test process was started and the results at every 0.5m/s interval were recorded in the table below. To increase the accuracy of the test results, the results were magnified 100 times.

Table 1. The results of the experiment on the hatchback type model

Airflow speed	Air resistance force acting on the test model, 10^{-2} N							Average value
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	
3,5	3,73	3,73	4,93	4,83	4,68	4,59	4,74	4,46
4	4,55	4,99	4,86	4,99	4,91	4,93	4,95	4,88
4,5	5,84	5,77	5,91	5,86	5,82	5,98	5,85	5,86
5	7,76	7,6	7,53	7,69	7,73	7,3	5,75	7,34
5,5	7,55	7,47	7,59	7,11	7,18	7,63	7,99	7,50
6	9,39	9,42	9,49	9,45	9,39	9,72	9,39	9,46
6,5	11,98	11,73	11,54	11,57	12,03	12,18	11,47	11,79
7	14,15	14,23	13,87	14,37	14,74	14,83	14,9	14,44
7,5	16,93	15,86	15,96	16,08	16,43	16,14	15,18	16,08

Putting the air flow speed on the X-axis and the air resistance values on the Y-axis, we get the following diagram:

Diagram 1. Air resistance to a hatchback model



We determine the graph of the function corresponding to the resulting graph, which allows us to determine the force of air resistance at other speeds y=(0.5786x2-3.3931x+9.287) . But it should be noted that this function is used only for one model.

4. CONCLUSION

Wind tunnel test stand was created, which allows to determine the aerodynamic resistance of the air, the coefficient of drag in car prototypes.

Tests were conducted on prototypes of two types of cars with different bodies in the aerodynamic pipe.

At the first stage of testing, the front surface of the car prototypes, the sail center were determined.

The results of the test were processed using the distribution laws of mathematical statistics, and the approximations of the obtained analytical results with the experimental values was determined using the Pearson compatibility criteria.

The change function of the amount of loading affecting the car prototypes in the flat acceleration values of the air speed was determined.

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