Comparison of experimental and theoretical results of airflow around two rough surfaces at different speeds

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Abstract. The aim of the work is to determine the effect of a rough surface on the airflow flowing around it, depending on the degree of roughness of this surface. Experimental visualization of the flow of air around samples with various rough surfaces is carried out. The experimental results are compared with the theoretical results obtained as a result of modeling this process based on the RANS system of equations.

1. Introduction
The PIV method is currently widely used in various technical fields, such as automotive and aircraft engineering, energy and mechanical engineering. PIV has also found application in various scientific fields: for the study of environmental and meteorological phenomena. For example, PIV is used to model the process of pollution of marine coastal areas by wastewater discharge systems, to measure the parameters of airflow on mixed surfaces [1], as well as to study the flow characteristics in the jet nozzles of gas turbine engines [2].

Particle image velocimetry (PIV) allows us to solve a wide range of problems: from the study of slow directional motion in capillaries and living cells to the remote measurement of the velocity of airflow turbulence in supersonic pipes and wind in the atmosphere, measured from several m/s to several km/s [3, 4].

The purpose of this study was to determine the effect of surface roughness on the airflow flowing around the surface. As a result of the conducted research, it is possible to detect the dependence of the change in the flow that occurs when flowing around surfaces with different degrees of roughness, depending on the characteristic size of the surface irregularities.

2. Experimental setup
To study the airflow around rough surfaces, an experimental setup was created, which made it possible to implement anemometry methods based on particle images for aerodynamic research.

As samples of surfaces with different degrees of roughness, fragments of rectangular sandpaper with different grain sizes were used. The choice of sandpaper for use as rough surface samples is due to the fact that the dimensions of the surface irregularities are set in accordance with the standards [5–7], so no additional research is required to determine the parameters of the surface roughness. The parameters of the sandpaper of various roughness classes that were used to create the samples are shown in figure 1, and its main characteristics are shown in table 1.
Figure 1. Sandpapers of various roughness classes: a – P150, b – P280.

Table 1. Parameters of sandpaper of different roughness classes.

| Marking the grit of sandpaper | Characteristic (average) dimensions of surface irregularities, µm |
|-------------------------------|------------------------------------------------------------------|
| P150                          | 90.5±15.5                                                        |
| P280                          | 52.2±2.0                                                         |

Photo of the created experimental setup is shown in figure 2. With this experimental setup, the particle image velocimetry (PIV) method can be used to study the flow around the surface. The surface sample is placed in a plexiglass cube filled with aerosol generated by the generator. The laser plane is formed from laser radiation using a special optical system that illuminates the particles in the desired cross-section. The airflow is generated by an construction dryer. The flow flows around the surface in the direction of the laser plane. The image of the particle flow is captured by a digital camera. The resulting images are transmitted to a computer, where they are processed. As a result of processing, a vector field of flow velocities can be obtained.

Figure 2. Experimental setup diagram: 1 – laser, 2 – optical system for forming a laser plane, 3 – surface sample, 4 – digital video camera, 5 – aerosol generator, 6 – synchronization unit.
The obtained images were subjected to cross-correlation processing, which consists of the search for correlation maxima [8]. The main processing parameters that affect the visualization result are the size and shape of the survey window, as well as the percentage of overlap of the studied areas. As a result, the vector velocity fields of the particles of the observed flow were obtained and the profiles of the average velocity in the selected plane were calculated.

3. Results of experimental studies
As a result of cross-correlation processing of the experimental images, vector fields with a flow velocity in the considered cross-section of the plane perpendicular to the sample surface were obtained. The processing was performed with the following parameters: the standard cross-correlation algorithm, the size of the survey area was 64×64 pixels, and the overlap was 50%.

Then, for each group of measurements, the obtained vector fields were averaged, i.e., the value and direction of the resulting vector were averaged for each survey area. This led to turbulence in the flow of the construction dryer.

The averaged vector fields of the flow velocity for a rough surface sample, which is a fragment of sandpaper P150 and P280, at different values of the flow velocity as an example of experimental results and results of modeling (RANS-The Reynolds-averaged Navier-Stokes equations) are presented in figures 3 and 4 and at a flow velocity of 0.735 m/s. Why are such low velocities chosen in the experiment and simulation (about 1 m/s). Because an industrial hair dryer is used to obtain the flow rate. In a construction dryer, there are five flow rates and the highest level is 1.45 m/s.

![Graph](image1)

**Figure 3.** Flow patterns of sandpaper P150: a – experimental results (PIV), b – results of modeling (RANS) at a flow rate of 0.735 m/s.

Graphs of the dependence of the flow velocity on the longitudinal coordinate over a rough surface obtained using simulations, for different values of the velocity are shown in figure 5. Direct comparison of the vector fields of the flow velocities obtained by the experimental method with the distributions of the flow velocities obtained as a result of modeling can be carried out mainly visually. Such a comparison is of an exclusively qualitative nature, therefore, additional processing of the obtained data is necessary for the transition from qualitative to quantitative analysis.
Figure 4. Flow patterns of sandpaper P280: a – experimental results (PIV), b – results of modeling (RANS) at a flow rate of 0.735 m/s.

Figure 5. Dependence of the flow velocity on the coordinate along the surface: a – P150, b – P 280.
4. Comparison of experimental and theoretical results

For comparison, all the experimentally obtained graphs and the simulated ones were transferred in pairs to the same coordinate system. At the same time, the resulting graphs were approximated, which significantly reduced the impact of random outliers in the data sets on the resulting graph representation. Comparative diagrams of the rough surface of samples P150 and P280 at different flow rates are shown in figures 6 and 7.

![Graphs](image)

**Figure 6.** Dependence of the flow velocity over the surface of the sample P150 of the longitudinal coordinate: the flow velocities: a – 0.735 m/s, b – 0.945 m/s, c – 1.1 m/s, d – 1.02 m/s, e – 1.45 m/s.

In this case, the theoretical results were obtained by simulating the flow around a rough surface with some simplifications. First, the surface model in the original version was given in a much-simplified form, in which it had obvious structural differences from the real sample of a rough surface made of sandpaper. Secondly, only a part of the airflow was taken into account to simplify and, consequently, speed up the modeling process, while the samples used in the experiments did not have
a certain thickness, which also affected the results. This demonstrated the need to improve the parameters of the surface and airflow models used in modeling this process.

![Figure 7](image)

**Figure 7.** Dependence of the flow velocity over the surface of the sample P280 on the longitudinal coordinate at flow velocities: a – 0.735 m/s, b – 0.945 m/s, c – 1.1 m/s, d – 1.02 m/s, e – 1.45 m/s.

5. **Conclusion**

The results of the experimental part of this study consist of obtaining a vector field of the flow rate of two rough surfaces having different roughness, at different values of the velocity of the gas flow flowing around these samples.

The result of this simulation is the spatial distribution of the velocity obtained experimentally, for the purpose of visual comparison. When modeling rough surfaces, a problem has arisen that requires a lot of computing power, since when creating a model of rough surfaces, their parameters are similar to the real sample used in experimental studies, the amount of calculations required depends on this...
difficulty, which consists in the fact that when the surface roughness decreases, the average size of the surface roughness attribute becomes smaller, and when creating a sufficiently realistic model of a rough surface, this situation inevitably leads to a significant increase in the calculation time.

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