Aerodynamics of airfoil moving along a circular trajectory

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Abstract. An experimental and computational study of the NACA0016 airfoil has been carried out for two cases: a stationary airfoil in an incoming flow on an aerodynamic stand and an airfoil moving along a circular trajectory in a stationary flow in a hydrodynamic stand. The Reynolds number for both cases was 60000. A qualitative comparison of the velocity fields for the cases with smooth airflow and boundary layer separation was carried out. It is shown that the used calculation methods describe the task under study with sufficient quality.

1. Introduction

Unlike fixed aircraft wings, the blades of vertical-axial wind and hydroelectric power plants, as well as cycloidal propellers of ships and aircraft, move along circular trajectories. As the studies of research groups show [1-3], the aerodynamics of fixed blades and blades running along a circle has some differences. This is due to the occurrence of flow circulation inside the rotor, as well as due to the blade hitting the track formed by the forward-moving blades, and the location of the upper and lower surfaces of the airfoil at a different radius from the axis of rotation, which leads to the fact that the linear velocity of their movement is different.

In the present paper, experimental studies of the fixed airfoil NACA0016 (chord 75 mm, length 150 mm) were carried out on an aerodynamic stand, using a strain gauge platform. The dependences of lift and drag on the angle of attack were determined. The profile flow was visualized using the PIV (Particle Image Velocity) method. The transition zone from a smooth airflow to a separated boundary layer was determined. CFD models were adapted based on experimental data, and numerical simulation of the problem was carried out. The Reynolds number in the experiments was 60000.

2. Investigation and results

To study the profile moving along a circular trajectory, a hydrodynamic stand was created. It consists of an optically transparent water tank, a controlled servo drive that rotates the rotor with the airfoil, an optical flow research system PIV (consisting of Pegasus high-speed pulsed laser, PCO1200hs dual-frame camera, POLIS synchronizing device, and spatial positioning system) (figure 1).
Based on the inductance sensor, a system for synchronizing the PIV measuring system and the rotating blade has been developed. A 12 teeth gear was installed on the shaft of the servomotor that rotates the studied airfoil. A TTL signal is formed, during the passage of one of the gear teeth close to the inductance sensor. According to the TTL signal, the PIV system is triggered. For one revolution of the airfoil, 12 phase-averaged flow patterns are obtained. In 3 of 12 images, the studied airfoil falls into the field of view of the camera. The airfoil rotation speed was 1 rpm, which corresponded to Re = 60000 as in the studies on aerodynamic set-up. The statistics were 300 images in one phase for each case.

With this formulation of the experiment, in the obtained pictures of velocity fields, the flow does not run over the airfoil, unlike studies on an aerodynamic stand, but is carried away following the moving profile. The difference lies in the fact that in this case, the profile moves relative to both the flow and PIV camera of the system, while on an aerodynamic stand, the camera and the airfoil are stationary relative to each other. A data processing method, which consisted in transformation of the PIV data from a rotating coordinate system to a laboratory one by subtracting the numerically simulated rotation field of the coordinate system from the experimental data was used for comparison with the results of the study of a fixed airfoil with a rotating one.

During the experiment carried out in a wide range of angles of attack, data for an airfoil with the formation of smooth and detached flow regimes were obtained. Figure 2 shows a comparison of PIV and CFD flow patterns of a stationary airfoil in an aerodynamic installation and a rotating airfoil in a hydrodynamic tank.
Figure 2. PIV and CFD flow patterns of stationary (a, b) and rotating (c, d) airfoil profiles, angle of attack is 22°.

As can be seen from the velocity distribution fields, in contrast to the flow around a stationary airfoil, a linear velocity gradient is observed for a rotating profile with an increase in the distance from the airfoil rotation center.

A good qualitative agreement can be noted between experimental and numerical simulation results, confirming the feasibility of the selected CFD models used. Comparison of integral parameters, such as drag and lift for a stationary blade also gives a good agreement of the calculated and experimental data.

To perform numerical simulation of a rotating blade, a computational unstructured mesh with more than 500,000 cells was build. The calculation was performed in the Ansys Fluent using the unsteady RANS approach. Based on the results of previous computational studies the k-ω SST turbulence model was chosen.

Figures 3 and 4 show a comparison of the results of PIV and numerical simulation of the NACA0016 airfoil with an angle of attack of 15° (smooth flow mode) and 22° (flow with separation). As can be seen, the results of numerical simulation qualitatively coincide with the results of the experiment. The profiles of the X and Y components of the velocity in different sections of the airfoil profile were compared, which also showed a good agreement between the calculation and the experiment.
Figure 3. Smooth flow, angle of attack is 15 degrees.

Figure 4. Boundary layer separation, angle of attack is 22 degrees.
Conclusions
An experimental and computational study of the NACA0016 airfoil has been carried out for two cases: a stationary airfoil in an incoming flow on an aerodynamic stand and an airfoil moving along the circular trajectory in a stationary flow in a hydrodynamic stand. It is shown that the main difference between the aerodynamics of a stationary airfoil and the airfoil moving along a circular trajectory is associated with the incoming flow profile. In the case of a stationary airfoil, the velocity profile is uniform, while in the case of a rotating airfoil, there is a velocity gradient directed towards the rotation center. This fact can affect the lift-to-drag ratio of the airfoil. A qualitative comparison of the velocity fields for the cases with smooth airflow and boundary layer separation was carried out. Good agreement between the calculated and experimental data was obtained.

Acknowledgments
The study was carried out under state contract with IT SB RAS.

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