Improvement of aerodynamic characteristics of air propellers of wind power plants using jet mechanization of blades

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Abstract. The paper considers the possibility of increasing the efficiency of wind power plants through the use of jet mechanization of propeller blades. The study of jet mechanization of the blade was carried out for the aerodynamic profile of NACA 0012 by numerical simulation in the Flow Vision software. The calculations were carried out by solving the plane problem of a completely compressible fluid or gas flow around the blade profile. The results of numerical simulation confirmed the change in the profile characteristics when additional air is supplied to the profile suction surface. The results obtained have been verified with the results of other authors. The data obtained as a result of modeling can be used both in the creation of new wind stations and in the capital improvement of the existing ones.

1. Introduction
In the 21st century, there has been a steady increase in the generation capacity obtained from renewable energy sources, one of which is wind. The largest wind power stations in China, India and the United States, which have been in operation for more than 5-10 years, require updating and increasing their efficiency [1-3]. According to the Paris Agreement on Climate adopted in 2015 by the UN, it is relevant to ensure markets with energy carriers and raw materials based on the principles of energy saving and energy efficiency [4]. For countries with high potential for the development of wind power, within the framework of this program it is possible to create and develop ways to increase the efficiency of wind power plants (WPP). It will provide the possibility of modernizing existing WPPs, as well as designing new ones.

The task of increasing the efficiency of wind power plants can be solved through the use of jet mechanization of the propeller blade (figure 1). It will improve the efficiency of the plant by increasing the basic properties of the profile [5]. Jet air supply, due to the installation of a slotted nozzle on the leading edge of the blade, allows to increase speed circulation on the profile blades and the effective chord area. This method will improve the efficiency of wind power plants, as well as use them at a reduced wind speed.

The objective of the study is to perform theoretical justification and numerical simulation of jet mechanization of bladed wind power plant by numerical simulation of the aerodynamic profile in the complex of computational fluid dynamics.
2. Methods and materials

Fluidics is a branch of hydraulics and pneumatics that produces devices (elements) in which phenomena arising from the interaction of flows of liquid or gas jets are used to transmit and convert signals (directional deflection of one jet under the action of another, directed at an angle) [6]. The software Flow Vision used for numerical modeling is a software complex for computational aerodynamics and hydrodynamics [7]. The results validation is carried out by assessing the similarity of the results obtained in different studies [8-20].

The study was carried out on the basis of plane problem for the blade element – profile. In order to preserve the identity of the results, the narrow nozzle is replaced with an equivalent “filter”, which made it possible to set the speed of the additionally supplied air (figure 2) without changing the profile geometry. By changing the speed of the supplied air, the intensity of the jet effect on the stream flowing around the investigated profile was adjusted. The impact zone, simulating a narrow nozzle, had the following parameters: the chord distance from the profile nose was 0.2b (b is the profile chord value), the maximum distance from the profile surface was one step of the computational grid (h). The flow velocity vector (V) is directed parallel to the profile chord and has a value twice the incoming flow velocity (Vp). The thickness of the narrow nozzle is commensurate with the size of the computational grid (figure 3). To improve the simulation accuracy, the adjustment of the computational grid in the zone of additional air supply [21] according to the “speed” parameter was used.

![Figure 1](image1.png)

Figure 1. – Elements of a vane-type machine of a wind power plant: 1 – oncoming flow, 2 – blade, 3 – suction surface of the blade, 4 – additional flow, 5 – end edge of the blade, 6 – hub.

![Figure 2](image2.png)

Figure 2. – Geometric dimensions of the narrow profile nozzle for air jet supply on the blade profile.

![Figure 3](image3.png)

Figure 3. – Geometric dimensions of the equivalent “filter” relative to the computational grid for air jet supply on the blade profile.

Among the variety of aerodynamic profiles, the profile NACA 0012 may be highlighted. Its characteristics are well studied, and the research results are publicly available. The test problem for the study of aerodynamic characteristics is present in the Flow Vision software. The simulation was carried
out in a completely compressible environment using the guidance to the study of the operating modes of blade units [22-25]. A number of publications [26-34] devoted to the study of airfoil flow in direct numerical simulation systems confirm the relevance and reliability of the research methods used.

3. Result
At the first stage, a computational study of the NACA 0012 profile in a compressible air flow was carried out for various incident flow angles (α) with constant initial parameters. A series of parameters obtained as a result of the computational study were used as input data for the numerical simulation of the jet impact.

At the next stage, for each angle of the incident flow, using “filter” (figure 3), a computational study of the values characterizing the flow around the airfoil was carried out. The convergence criteria were the values of the residuals displayed by the program.

Figure 4 and figure 5 shows the calculated characteristics of the flow around the airfoil in the Computational Fluid Dynamics (CFD) complex Flow Vision at the different Re.

The similarity of the pressure distribution diagrams of the calculation and the known characteristics observed in figure 5 proves the reliability of the results obtained.

The analysis of the data obtained as a result of numerical simulation shows that the jet air supply to the suction surface of the airfoil allows increasing the basic properties. Thus, it helps to reduce the inverse airfoil quality factor and increase the efficiency of the wind power plant. The ability to regulate the effect by changing the parameters of the supplied air makes it possible to implement a variable effect on the profile depending on the speed and direction of the incoming flow.

Figure 4. – The lift force of the symmetrical airfoil NACA 0012 at the Re=50000: 1 – profile with additional air supply to the leading edge; 2 – profile without additional air supply to the leading edge.  

Figure 5. – The lift force of the symmetrical airfoil NACA 0012 at the Re=400000: 1 – profile with additional air supply to the leading edge; 2 – profile without additional air supply to the leading edge.

Figure 6 shows the results of the computational study of the flow parameters, in comparison with the known characteristics [6], obtained in the study of the profile in the flow of a compressible medium. Figure 7 shows the results of calculation of the inverse quality coefficient of the NACA 0012 airfoil depending on the incident flow angle (α) and the ratio of the supplied jet and incident flow velocities.
Figure 6. – Diagrams of pressure (p) distribution along the profile with jet action along chord (b) at 2° attack angle:
1 – acting surface; 2 – suction surface without a jet; 3 – suction surface with a jet (open sources); 3’ – suction surface with jet (Flow Vision).

Figure 7. – Calculated coefficient of inverse quality of the profile NACA 0012 propeller blades with additional jet air supply to the profile, taking into account the ratio of the profile resistance coefficients (Cx) and the lift coefficient (Cy): dash-dotted line – when air is supplied with the ratio of speeds $V/V_p = 0$; dotted line – when air is supplied with the velocity ratio $V/V_p = 1$; solid line – when air is supplied with a speed ratio $V/V_p = 2$.

Analysis of the results shown in figure 7 confirms the possibility of increasing the aerodynamic qualities of the airfoil by supplying additional air to the suction surface. A significant increase in the aerodynamic characteristics of the airfoil at low speeds of the incident flow will increase useful operation time of wind power plants with minimal additional costs.

4. Conclusion
The data obtained as a result of numerical modeling of the aerodynamic profile of the propeller blade confirm the effectiveness of the use of jet mechanization to improve wind power plants. To prepare a technical justification and develop documents, it is required to carry out a significant amount of numerical modeling, as well as setting up a full-scale experiment on the possibility of operation of a propeller with jet blades. Specific proposals to further improvement of wind power plants with jet mechanization will be relevant not only for the Russian Federation, but for the entire world.

References
[1] Zhang S, Wei J, Chen X and Zhao Y 2020 China in global wind power development: Role, status and impact Renewable and Sustainable Energy Reviews 127 109881
[2] Pryor S, Barthelmie R and Shepherd T 2020 20% of US electricity from wind will have limited impacts on system efficiency and regional climate Scientific reports 10(1) 1-14
[3] Lu T, Sherman P, Chen X, Chen S, Lu X and McElroy M 2020 India’s potential for integrating solar and on-and offshore wind power into its energy system Nature communications 11(1) 1-10
[4] Gills B and Morgan J 2020 Global Climate Emergency: after COP24, climate science, urgency, and the threat to humanity Globalizations 17:6 885-902
[5] Osovskii D, Sharatov A, Gorbenko A, Klimenko N, Sharatova N and Bidenko S 2020 CfD modeling and study of additional medium jet impact on the blade of the propeller Procedia Computer Science International Conference on Computational Intelligence and Data Science ICCDIS 2019 1096-101
[6] Gad-el-Hak M 2007 Flow control: passive, active, and reactive flow management
[7] Aksenov A 2017 FlowVision: Industrial computational fluid dynamics Computer Research and Modeling 9 5-20
[8] Prospathopoulos J, Riziotis V, Schwarz E, Barlas T, Aparicio-Sanchez M, Papadakis G and Lutz T 2020 Simulation of oscillating trailing edge flaps on wind turbine blades using ranging fidelity tools Wind Energy 1–22
[9] Debnath M, Santoni C, Leonardi S and Iungo G 2017 Towards reduced order modelling for predicting the dynamics of coherent vorticity structures within wind turbine wakes Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 375(2091) 20160108
[10] Moshfeghi M and Hur N 2015 Effects of SJA boundary conditions on predicting the aerodynamic behavior of NACA 0015 airfoil in separated condition Journal of Mechanical Science and Technology 29(5) 1829-1836
[11] Beyhaghi S and Amano R 2018 A parametric study on leading-edge slots used on wind turbine airfoils at various angles of attack Journal of Wind Engineering and Industrial Aerodynamics 175 43-52
[12] Ullah T, Javed A, Abdullah A, Ali M and Uddin E 2020 Computational evaluation of an optimum leading-edge slat deflection angle for dynamic stall control in a novel urban-scale vertical axis wind turbine for low wind speed operation Sustainable Energy Technologies and Assessments 40 100748
[13] Nafar-Sefiddashti M, Nili-Ahmadabadi M, Saeedi-Rizi B and Pourhoseini J 2019 Visualization of flow over a thick airfoil with circular cross-sectional riblets at low Reynolds numbers Journal of Visualization 22(5) 877-88
[14] Xu H, Qiao C and Ye Z 2016 Dynamic stall control on the wind turbine airfoil via a co-flow jet Energies 9(6) 429
[15] Zhu H, Hao W, Li C, Ding Q and Wu B 2019 Application of flow control strategy of blowing, synthetic and plasma jet actuators in vertical axis wind turbines Aerospace Science and Technology 88 468-80
[16] Acarer S 2020 Peak lift-to-drag ratio enhancement of the NACA 2412 airfoil by passive flow control and its impact on horizontal and vertical axis wind turbines Energy 201 117659
[17] Moshfeghi M and Hur N 2020 Power generation enhancement in a horizontal axis wind turbine blade using split blades Journal of Wind Engineering and Industrial Aerodynamics 206 104352
[18] Zhu H, Hao W, Li C and Ding Q 2020 Effect of flow-deflecting-gap blade on aerodynamic characteristic of vertical axis wind turbines Renewable Energy 158 370-87
[19] Sun J, Sun X and Huang D 2020 Aerodynamics of vertical-axis wind turbine with boundary layer suction–Effects of suction momentum Energy 209 118446
[20] Rezaeia A, Montazeri H and Blocken B 2019 Active flow control for power enhancement of vertical axis wind turbines: Leading-edge slot suction Energy 189 116131
[21] Gao L, Zhang H, Liu Y and Han S 2015 Effects of vortex generators on a blunt trailing-edge airfoil for wind turbines Renewable Energy 76 303-11
[22] Shin K and Andersen P 2015 CFD analysis of cloud cavitation on three tip-modified propellers with systematically varied tip geometry In Journal of Physics: Conference Series 656(1) 012139
[23] Ajirlo K, Tari P, Gharali K and Zandi M Development of a wind turbine simulator to design and test micro HAWTs Sustainable Energy Technologies and Assessments 43 100900
[24] Macias M, Mendes R, Oliveira T and Brasil A 2020 On the upscaling approach to wind tunnel experiments of horizontal axis hydrokinetic turbines Journal of the Brazilian Society of Mechanical Sciences and Engineering 42(10) 1-14
[25] Rosemeier M, Gebauer T and Antoniou A 2020 A practical approach for the peel stress prediction in the trailing-edge adhesive joint of wind turbine blades IOP Conference Series: Materials Science and Engineering 942 N1 012026
[26] Mühle F, Bartl J, Hansen T, Adaramola M and Sætran L 2020 An experimental study on the effects of winglets on the tip vortex interaction in the near wake of a model wind turbine Wind Energy 23(5) 1286-300

[27] Bossanyi E 2003 Individual Blade Pitch Control for Load Reduction Wind Energ 6 119-128

[28] Amano R 2020 Aerodynamic Behavior of Rear-Tubercle Horizontal Axis Wind Turbine Blade In Sustainable Development for Energy, Power, and Propulsion 545-562

[29] Amini S, Golzarian M, Mahmoudi E, Jeromin A and Abbaspour-Fard M Numerical simulation of the Mexico wind turbine using the actuator disk model along with the 3D correction of aerodynamic coefficients in OpenFOAM Renewable Energy 163 2029-2036

[30] Erkan O, Özkan M, Karakoç T, Garrett S and Thomas P 2020 Investigation of aerodynamic performance characteristics of a wind-turbine-blade profile using the finite-volume method Renewable Energy, 161 1359-67

[31] Mohamed O, Ibrahim A, Etman A, Abdelfatah A and Elbaz A 2020 Numerical investigation of Darrieus wind turbine with slotted airfoil blades Energy Conversion and Management: X 5 100026

[32] Ni Z, Dhanak M and Su T 2019 Performance of a slotted hydrofoil operating close to a free surface over a range of angles of attack Ocean Engineering 188 106296

[33] Shehata A, Xiao Q, Kotb M, Selim M, Elbatran A and Alexander D 2018 Effect of passive flow control on the aerodynamic performance, entropy generation and aeroacoustic noise of axial turbines for wave energy extractor Ocean Engineering 157 262-300

[34] Ou M, Yan L, Huang W, Li S and Li L 2018 Detailed parametric investigations on drag and heat flux reduction induced by a combinational spike and opposing jet concept in hypersonic flows International Journal of Heat and Mass Transfer 126 10-31