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[1]**V. M. Sineglazov,**
[2]**A. A. Ziganshin,**
[3]**M. P. Vasylenko**

ALGORITHM OF WIND TURBINE COMBINED ROTOR AERODYNAMICS CALCULATION

Educational and Scientific Institute of Information and Diagnostic Systems, National Aviation University, Kyiv, Ukraine
E-mails: [1]svm@nau.edu.ua, [2]anwarzihan@gmail.com, [3]vasylenkom.89@gmail.com

Abstract—*The paper is devoted to the vertical axis wind turbines with combined rotors aerodynamical modelling. It includes the analysis of existing wind turbine types, their advantages and disadvantages. The article includes reasoning for combined rotor with vertical axis of rotation building and includes new aerodynamic calculation method.*

Index Terms—Combined rotor; wind turbine; vertical axis of rotation; aerodynamics.

I. INTRODUCTION

Increasing of electrical energy consumption and worsening of environmental conditions greatly intensified the search for more ecologically safe methods of energy generation. Laboratories around the world conduct researches devoted to the controlled thermonuclear reaction, direct machineless transformation of internal and chemical energy into electricity. They successfully developed ways to use renewable sources such as solar, wind, geothermal, wave and tidal energy etc.

Modern wind energy is mainly based on the use of wind power plants (WPP) of the two main types – horizontal axis (HA) and vertical axis (VA) of rotation wind turbines.

One of the main elements of the wind turbine is a rotor. The main parameters of rotors classification are: location of rotation axis and used aerodynamic power that causes the rotation. Auxiliary parameters are: the location of the device relative to the oncoming flow, the presence of stream concentrators, way of blades fastening, a way of targeting on the wind or the absence such need, the way of output shaft speed control, constant or variable cross-sectional area of rotor.

II. REVIEW

Analysis of HA and VA turbines structures shows that the greatest efficiency of HA turbines is attainable only if continuous colinearity of propeller axis and wind direction is ensured [1], [4]. The need to focus on airflow direction requires mechanisms and systems for continuous monitoring of wind conditions, search of direction with the highest wind potential, turn the propeller in that direction and keep its position. The presence of such systems in wind turbine construction makes the system sophisticated and reduces its reliability (according to the foreign exploitation experience of such wind turbines up to 13% of total failures falls on the orientation system, especially in small turbines through the twisting power cable or deterioration of current collector). In addition, it is almost impossible to orient the rotor toward the direction of the wind effectively because of the orientation mechanisms delay. For high and medium power wind turbines with propeller diameter greater than 30...40 m effectiveness of its orientation on wind decreases because of noncomplanarity and differences in speed of the wind flow along the blades sweep surface, leading to the inability to install propeller in the best position relative to the wind that decreases power output and economic efficiency of HA wind turbines. The disadvantage of such systems is the fact that the orientation system breaks solid connection between the carriage and the tower [5] that causes the appearance of oscillations and the difference in the frequency characteristics of mobile and motionless parts, that ultimately reduces the reliability and increases servicing costs.

The HA wind turbines also have negative influence on the environment [1], [8] by making infrasound noise during the operation and endangering the birds and bats.

Theoretically proved that the utilization of wind energy of the perfect propeller (rotor) structures is 0.593 [1], [10]. This is because the rotors of wind turbines of both types use the same lift force effect, which occurs when the wind flows around blades profiles. Nowadays wind turbines achieved wind energy utilization coefficient 0.40...0.45 [4].

Moreover, predicted use of vertical-axis wind turbines in developing countries that do not have modern technology [3], [5] – [7]. Constructive simplicity of vertical-axis systems that do not require turning devices and systems is put forward as justification for this prediction is [2], [4], [5].

Vertical axis wind turbines are divided into two classes: Savonius rotors and Darrieus rotors.

The Darrieus rotor works due to the torque from the lift created by the blades. Therefore, rotor can operate with large enough efficiency compared with rotors that use difference of blades drag. Vector sum of oncoming flow speed and the peripheral speed of blades rotation creates an angle of attack relative to the blade chord. In the Darrieus rotor blades peripheral speed exceeds the speed of oncoming flow. Since the blade must create lift when moving in both directions, so symmetrical shape of profile is selected. According to this this, without rotation of Darrieus rotors torque is not created and therefore such rotors are unable to start on their own. Usually, Darrieus rotor with low values of rapidity has small, and sometimes even negative torque [7], [9]. On the other hand, there is a particular problem with hurricane wind when there is need in a reliable brake to stop the rotor. If the top rotor is not fixed, you can get a big load in a bending moment.

The parameters that characterize work of the turbine and affect the efficiency of its work are the following:

- the number of rotor blades;
- area of the rotor;
- the relative thickness of the blades;
- rapidity;
- filling factor;
- extension of the rotor;
- the angle of the blades.

On the one hand, increasing the number of blades should lead to improved torque uniformity and efficiency of the rotor, but at the same time increasing their mutual influence, which reduces the efficiency of each blade. The growing number of blades may also facilitate the launch at a lower wind speed. Typical Darrieus rotors have 3 or 4 blades.

In Ukraine the highest efficiency of VA wind turbines can be achieved in case of combined rotors use [8]. The example of VA combined rotor is shown in Fig. 1.

III. PROBLEM STATEMENT

The purpose of calculating the wind turbine with vertical rotation axis is to build energy characteristics, such as the dependence of power and torque from the speed factor, and obtaining rotors parameters based on the estimated operating point characteristics and defined as nominal power and speed of air. Calculation of energy performance based on the representation of the forces acting on the rotor toward the air direction can be done by two methods. The first method is based on the theory of ideal pulse windmill with Bernoulli's law for conventional tube current, covering this rotor. The second method is based on the representation of the forces acting on the rotor in the airflow direction as projection in the direction of airflow from the sum of each elementary blade lift and profile drag influence. The coefficients of lift and drag depending on the angle of attack in speed coordinate system specified as final data in accordance with the selected profile type atlases. As a result of the second method the force directed along the flow can be expressed by a double integral on the following variables: the azimuthal angular of elementary blade position relative to the wind stream during rotation and height position *H*. Equating the right sides of expressions obtained from two methods results in equations solved by numerical methods. As a result, we get dependency of power coefficient and torque from rapidity.

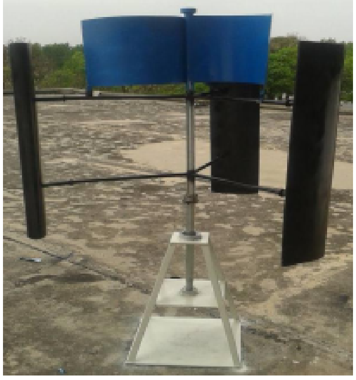

Fig. 1. Combined rotor with three straight Darrieus blades and three straight Savonius blades

In the simulation model used viscous flow of gas with averaging turbulent characteristics (for Reynolds averaged Navier–Stokes equations for incompressible fluid). In compact form they can be written, as:

$$\frac{\partial u_j}{\partial x_j} = 0;$$
$$\frac{\partial u_j}{\partial t} + \frac{\partial (u_j u_i)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu_{\text{eff}}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right], \tag{1}$$

where $x_i, i = 1, 2$ are Cartesian coordinates (*x*, *y*); *t* is time; u_i is the projection (*u*, *v*) of the average speed on the Cartesian coordinate axis; *p* is pressure; ρ is density; $\nu_{\text{eff}} = \nu + \nu_t$ is effective coefficient of kinematic viscosity; ν and ν_t are molecular and turbulent coefficients of kinematic viscosity.

We write Navier–Stokes equations (1) in partial derivatives in divergence form:

$$\frac{\partial U_x}{\partial t}+\frac{\partial (U_x)^2}{\partial x}+\frac{\partial (U_xU_y)}{\partial y}=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[\nu_{eff}\left(2\frac{\partial U_x}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[\nu_{eff}\left(\frac{\partial U_x}{\partial y}+\frac{\partial U_y}{\partial x}\right)\right],$$

$$\frac{\partial U_y}{\partial t}+\frac{\partial (U_yU_x)}{\partial x}+\frac{\partial (U_y)^2}{\partial y}=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left[\nu_{eff}\left(\frac{\partial U_y}{\partial x}+\frac{\partial U_x}{\partial y}\right)\right]+\frac{\partial}{\partial y}\left[\nu_{eff}\left(2\frac{\partial U_y}{\partial y}\right)\right], \qquad (2)$$

$$\frac{\partial U_x}{\partial y}+\frac{\partial U_y}{\partial x}=0,$$

where U_x, U_y are airflow speeds in x and y directions.

According to accepted parameters (U_∞, p_∞) initial conditions of undisturbed flow for the entire calculation area:

$$U_{0x}=U_\infty;\ U_{0y}=0;\ p_0=p_\infty. \qquad (3)$$

To record boundary conditions (BC) consider a box in which combined rotor is placed. Then BC can be represented as follows.

For the side surface of blade BC can be determined by expression:

$$\vec{U}_{x,\,y\,\in\,G}=\vec{\omega}\times\vec{r};\quad \left(\frac{\partial p}{\partial n}\right)_{x,\,y\,\in\,G}=0, \qquad (4)$$

where $\vec{r}=\{x,\,y\}$ is radius vector of point on the blade surface; n is normal to the blade.

Conditions for the input boundary of the box BC can be written, as:

$$U_x=U_\infty;\ U_y=0;\ p=p_\infty. \qquad (5)$$

For the output boundary of the box the Neumann conditions are fulfilled:

$$\frac{\partial U_x}{\partial x}=0;\ \frac{\partial U_y}{\partial y}=0;\ \frac{\partial p}{\partial x}=0;\ \frac{\partial p}{\partial y}=0. \qquad (6)$$

For the lateral boundaries of the box the conditions of reflection are fulfilled:

$$\frac{\partial U_x}{\partial n}=0;\ \frac{\partial U_y}{\partial n}=0;\ \frac{\partial p}{\partial n}=0, \qquad (7)$$

where n is normal to the boundary.

IV. CALCULATION ALGORITHM

A numerical solution of the Navier–Stokes equations for combined rotor is rather complicated computational procedure. That is the reason to create the iterative procedure of aerodynamic calculations for Savonius and Darrieus rotors which are the components of combined rotor.

The task of wind turbine combined rotor (Fig. 2) aerodynamic calculation is divided into two interrelated subtasks on calculations and Savonius and Darrieus rotors, which schematically divided among the sections I-I and II-II. Parameters of the stream in these sections simultaneously include mutual influence between the rotors and serve as the boundary conditions for calculations. Thus, the problem reduces to the iterative sequence of individual subtasks to calculate aerodynamic of Savonius and Darrieus rotors and considering the mutual influence between them.

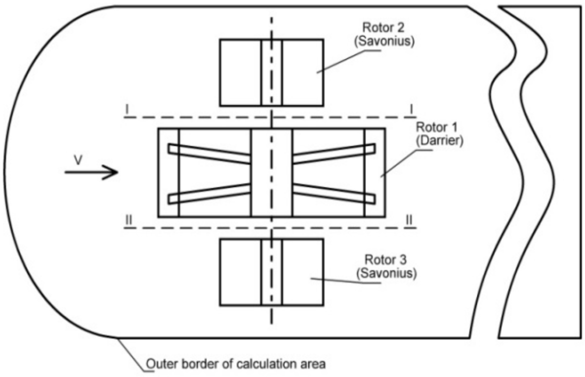

Fig. 2. Aerodynamic scheme of combined rotor in the settlement area

The proposed algorithm for calculating the aerodynamic flow around the combined rotor includes the following steps.

1) Solving Navier–Stokes equations (2) for the isolated Darrieus rotor (1 in Fig. 2) with initial conditions (3) and BC (4) – (7) on the external borders of the box. As a result, we find the distribution of velocity and pressure throughout the settlement area.

2) Solving Navier–Stokes equations (2) for the Savonius rotor (2 in Fig. 2) of the BC (4–7) on the external borders and by section I-I.

Boundary conditions in section I-I taken from the calculation on step 1:

$$U_x=(U_x)_{\text{I-I}};\ U_y=(U_y)_{\text{I-I}};\ p=p_{\text{I-I}};$$

$$\frac{\partial U_x}{\partial x}=\left(\frac{\partial U_x}{\partial x}\right)_{\text{I-I}};\ \frac{\partial U_y}{\partial x}=\left(\frac{\partial U_y}{\partial x}\right)_{\text{I-I}};\ \frac{\partial p}{\partial x}=\left(\frac{\partial p}{\partial x}\right)_{\text{I-I}}; \qquad (8)$$

$$\frac{\partial U_x}{\partial y}=\left(\frac{\partial U_x}{\partial y}\right)_{\text{I-I}};\ \frac{\partial U_y}{\partial y}=\left(\frac{\partial U_y}{\partial y}\right)_{\text{I-I}};\ \frac{\partial p}{\partial y}=\left(\frac{\partial p}{\partial y}\right)_{\text{I-I}},$$

Savonius rotor flow calculation (3 in Fig. 2) performed similarly Savonius rotor (2 in Fig. 2) of the BC (4) – (7) and by BC section II-II:

$$U_x = \left(U_x\right)_{\text{II-II}};\ U_y = \left(U_y\right)_{\text{I-II}};\ p = p_{\text{I-II}};$$

$$\frac{\partial U_x}{\partial x} = \left(\frac{\partial U_x}{\partial x}\right)_{\text{II-II}};\ \frac{\partial U_y}{\partial x} = \left(\frac{\partial U_y}{\partial x}\right)_{\text{II-II}};\ \frac{\partial p}{\partial x} = \left(\frac{\partial p}{\partial x}\right)_{\text{II-II}};$$

$$\frac{\partial U_x}{\partial y} = \left(\frac{\partial U_x}{\partial y}\right)_{\text{II-II}};\ \frac{\partial U_y}{\partial y} = \left(\frac{\partial U_y}{\partial y}\right)_{\text{II-II}};\ \frac{\partial p}{\partial y} = \left(\frac{\partial p}{\partial y}\right)_{\text{II-II}}. \tag{9}$$

3) Re solving NS (2) for the Darrieus rotor (Fig. 3) of the BC (4–7) and BC in sections I-I (8) and II-II (9) obtained in step 2.

4) Calculations on steps 2–3 repeated until the entire settlement area is not reached the necessary convergence between the results of iterations.

As noted above, the Darrieus rotor creates the torque by blades lift. As the number of blades of the rotor is changed from three to four, their mutual influence and minimal aerodynamic calculation instead of solving Navier–Stokes equations (2) can be found with sufficient accuracy using airfoil flow data. The theory of profile flow (flow theory for wing of infinite span) can be used for wings with lengthening greater than 4, which takes place in this case. These profiles data are the dependencies between the lift coefficient and the angle of attack $C_y = f(\alpha)$ and drag coefficient $C_x = f(\alpha)$. Dependsng on the angular position the blades are flown around with the angles of attack ranging from negative to positive values, it is advisable to apply symmetric profiles.

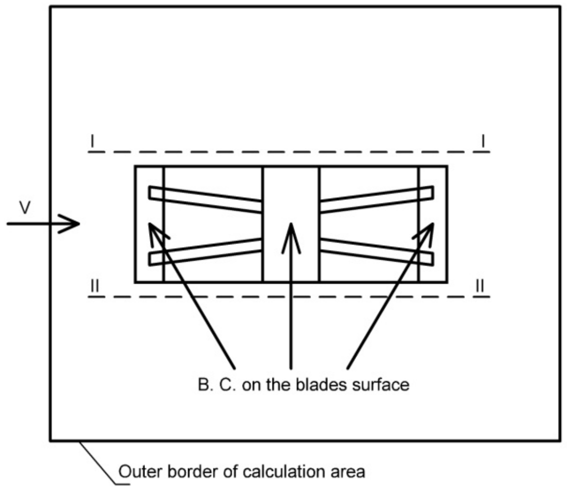

Fig. 3. Aerodynamical schematic of Darrieus rotor in the settlement area

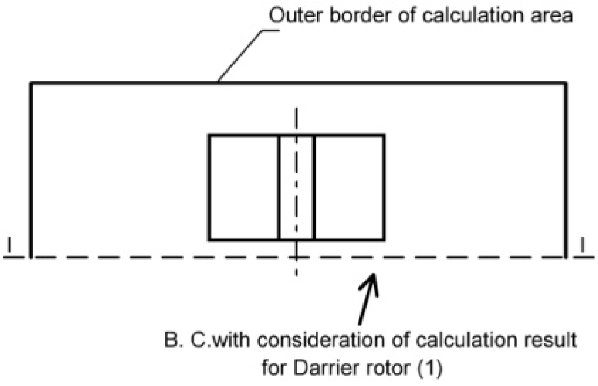

Fig. 4. Savonius rotor aerodynamic scheme in the settlement area

A significant nonlinearity of Navier–Stokes equation, solving the problem of aerodynamics can be obtained only numerically. As a method of numerical solution, finite volume method was selected because of it's:

- relative mathematical simplicity;
- relatively easy programming;
- to calculate the tear-off flows;
- irregular grid able to use all forms;
- describes the curved boundary.

Because of these advantages, most commercial software developed numerical solution of problems of hydrodynamics using the finite volume method.

Finite volume method requires to solve the following equations of aerodynamics model:

$$\begin{aligned}
&\frac{d}{dx}AU_{j,k} + 0{,}25(U_{j,k-1} + U_{j,k})(V_{j,k-1} + V_{j,k})(x_B - x_A) + k\frac{U_{j,k-1} - U_{j,k}}{y_k - y_{k-1}}(x_B - x_A) \\
&\quad - 0.5k(V_{j,k-1} + V_{j,k}) + 0.25(U_{j+1,k} + U_{j,k})^2(y_c - y_B) + 0.5(p_{j+1,k} + p_{j,k})(y_c - y_B) \\
&\quad + 2k\frac{U_{j+1,k} - U_{j,k}}{x_{j+1} - x_j}(y_c - y_B) - 0.5k(V_{j+1,k} + V_{j,k}) + 0.25(U_{j,k+1} + U_{j,k}) \\
&\quad \cdot (V_{j,k+1} + V_{j,k})(x_C - x_D) + k\frac{U_{j-1,k+1} - U_{j-1,k}}{y_{k+1} - y_k}(x_C - x_D) - 0.5k(V_{j,k+1} + V_{j,k})
\end{aligned}$$

$$+0.25(U_{j-1,k}+U_{j,k})^2(y_D-y_A)+0.5(p_{j-1,k}+p_{j,k})(y_D-y_A)+2k\frac{U_{j-1,k-1}-U_{j-1,k}}{x_j-x_{j-1}}(y_D-y_A)$$
$$-0.5k(V_{j-1,k}+V_{j,k})=0. \tag{10}$$

Equation (3) transforms into:

$$\frac{d}{dx}AV_{j,k}+0.25(V_{j,k-1}+V_{j,k})^2(x_B-x_A)+0.5(p_{j,k-1}-p_{j,k})(x_B-x_A)$$
$$+2k\frac{V_{j,k-1}-V_{j,k}}{y_k-y_{k-1}}(x_B-x_A)-0.5k(U_{j,k-1}+U_{j,k})+0.25(V_{j+1,k}+V_{j,k})(U_{j+1,k}+U_{j,k})$$
$$+(y_c-y_B)-k\frac{V_{j+1,k}-V_{j,k}}{x_{j+1}-x_j}(y_c-y_B)-0.5k(V_{j+1,k}+V_{j,k})+0.25(V_{j,k+1}+V_{j,k})^2(x_C-x_D)$$
$$+0.5(p_{j,k+1}+p_{j,k})(x_C-x_D)+2k\frac{V_{j-1,k+1}-V_{j-1,k}}{y_{k+1}-y_k}(x_C-x_D)-0.5k(U_{j,k+1}+U_{j,k}) \tag{11}$$
$$+0.25(V_{j-1,k}+V_{j,k})(U_{j-1,k}+U_{j,k})(y_D-y_A)+k\frac{V_{j-1}-V_{j,k}}{x_j-x_{j-1}}(y_D-y_A)$$
$$-0.5k(U_{j-1,k}+U_{j,k})=0.$$

In the same way equation (4) transforms into:

$$\frac{U_{j+1,k}-U_{j-1,k}}{2\Delta x}+\frac{V_{j,k+1}-V_{j,k-1}}{2\Delta y}=0. \tag{12}$$

If we take equations (10) – (12) for each finite volume of calculation grid, we will obtain the system of linear algebraic equations:

$$\mathbf{b}U+\mathbf{n}V+\mathbf{m}\,p=\mathbf{G}. \tag{13}$$

where **b,n,m** are matrixes of coefficients of the variables *U, V, p*; **G** is vector of the right side of the equations, defined by the.

Obtained block-matrix system of algebraic equations is solved by the Gauss–Seidl iteration method by the following algorithm.

To solve the non-stationary task for each moment of time it is necessary to:

1. Find the field of speeds *U, V*, considering the known field of pressure p.
2. Clarify the pressure field.
3. Repeat steps 1 and 2 until the needed accuracy is reached.

For the step 1 the most effective is to determine the speed field separately for each coordinate:

1) solve the equation system, considering the speeds along the y axis constant (V = const);
2) solve the equation system, considering the speeds along the x axis constant (V = const);

On the basis outlined in the previous section calculation task of combined rotor flow (see Fig. 2) splits into two independent tasks.

1. Physical model of Darrieus rotor is given in the form of polyplan. Determination of aerodynamic characteristics of each blade is based on techniques for isolated wing of a large scale. For each angular position of the blade, depending on the speed of air flow and velocity, defined:

– the true speed of the incoming flow and the true angle of attack;

– the characteristics of the profile: according to the true angles of attack find the lift coefficient $C_y = f(\alpha)$ and resistance factor $C_x = f(\alpha)$;

– torque and power rotor.

2. Solving Navier–Stokes equations (2) for isolated Savonius rotors (Fig. 4) with BC (3) – (7).

The following method can be used as the subsystem of computer-aided design system for vertical axis wind turbines with combined rotor. Structure of such subsystem is shown in Fig. 5.

Such subsystem allows to obtain the optimal aerodynamic parameters for designed wind turbine.

V. CONCLUSIONS

Reasoned two mathematical models rotor aerodynamics combined with a separate calculation Savonius and Darrieus rotors. The structure of the subsystem aerodynamic calculation of rotor turbines.

Based on the analysis of numerical methods for solutions of Navier–Stokes equations the choice of method of finite volumes. The results of the simulation. An optimal choice of blade profile.

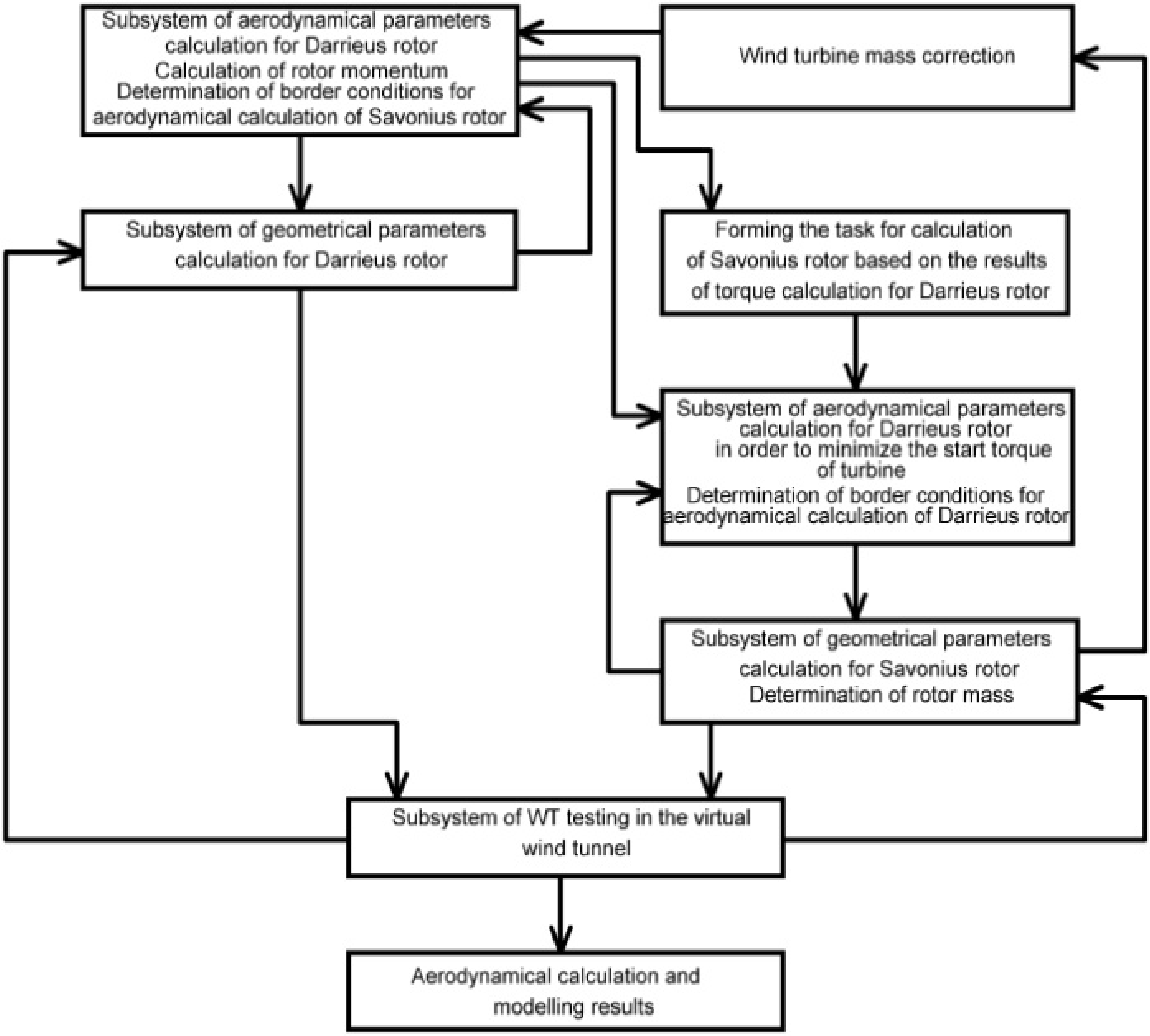

Fig. 5. Structure of the aerodynamic calculation subsystem

REFERENCES

[1] B. A. Alekseev, “Electrical powerstations.” *International wind energy conference*, vol. 2, 1992. (in Russian)

[2] “Carvas” wind generators http://www.karvas.hl6.ru/, 2008

[3] M. I. Volchenkov, “Wind energy today” *“Pinions” studio* http://www.4ygeca.com/poyas.html, 2003–2007 (in Russian)

[4] D. N. Gorelov and Yu. N. Kuzmenko, “Experimental estimation of maximum power for vertical axis wind turbine, *Heat physics and air mechanics,* vol. 8, pp. 329–334, 2001. (in Russian)

[5] I. V. Kragelskiy, M. N. Dobychin and V. S. Kombalov, *Deterioration and friction calculations*, Moscow: Mashinostroenie, 1977, 526 p. (in Russian)

[6] A. V. Kulbaka, “Computer aided design of wind power systems with vertical axis of rotation, *XI International conference Avia-2013,* vol. 4, 2014, pp. 17–21.

[7] A. I. Yakovlev and M. A. Zatuchnaya, *Calculation of wind power systemswith vertical axis of rotation*, Educational guidance, Kharkiv aviation institute, 2002, 61 p. (in Russian)

[8] Anthony L. Rogers, *Wind Turbine Acoustic Noise*, Renewable Energy Research Laboratory, Department of Mechanical and Industrial Engineering, University of Massachusetts, 2002, 3 p.

[9] K. K. Sharma, A. Biswas, and R. Gupta, “Perfomance Measurement of a Three-Bladed Combined Darrieus-Savonius Rotor,” *International Journal of Renewable Energy Research*,vol. 3, no. 4, 2013.

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Sineglazov Viktor. Doctor of Engineering. Professor.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kiev Polytechnic Institute. Kiev, Ukraine (1973).
Research interests: Air Navigation, Air Traffic Control, Identification of Complex Systems, Wind/solar power plant.
Publications: more than 600 papers.
E-mail: svm@nau.edu.ua

Ziganshin Anwar. Assistant.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kazan Aviation Institute. Kazan, Russia (1978).
Research interests: computer aided design systems, numerical methods of aerodynamics, renewable sources of energy.
Publications: 8.
E-mail: anwarzihan@gmail.com

Vasylenko Mykola. Candidate of Engineering.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kyiv National University of Technologies and Design, Kyiv, Ukraine (2012).
Research interests: renewable energy sources, thermal noise based estimation of materials properties.
Publications: more than 20 papers.
E-mail: vasylenkom.89@gmail.com

В. М. Синєглазов, А. А. Зіганшин, М. П. Василенко. Алгоритм розрахунку аеродинаміки комбінованого ротора вітроенергетичної установки

Розглянуто вітроенергетичні установки з вертикальною віссю обертання. Проаналізовано типи вітроенергетичних установок, їх переваги та недоліки. Обґрунтовано необхідність та доцільність побудови вітроенергетичних установок з комбінованим ротором та наведено новий алгоритм аеродинамічного розрахунку.

Ключові слова: комбінований ротор; вітроенергетична установка; вертикальна вісь обертання; аеродинаміка.

Синєглазов Віктор Михайлович. Доктор технічних наук. Професор.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Київський політехнічний інститут. Київ, Україна (1973).
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E-mail: svm@nau.edu.ua

Зіганшин Анвар Абдуллович. Асистент.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
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Кількість публікацій: 8.
E-mail: anwarzihan@gmail.com

Василенко Микола Павлович Кандидат технічних наук.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Київський національний університет технологій та дизайну, Київ, Україна (2012).
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E-mail: vasylenkom.89@gmail.com

В. М. Синеглазов, А. А. Зиганшин, Н. П. Василенко. Алгоритм расчета аэродинамики комбинированного ротора ветроэнергетической установки

Рассмотрены ветроэнергетические установки с вертикальной осью вращения. Проанализированы типы ветроэнергетических установок, их преимущества и недостатки. Обоснована необходимость и целесообразность построения ветроэнергетических установок с комбинированным ротором и приведен новый алгоритм аэродинамического расчета.

Ключевые слова: комбинированный ротор; ветроэнергетическая установка; вертикальная ось вращения; аэродинамика.

Синеглазов Виктор Михайлович. Доктор технических наук. Профессор.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Киевский политехнический институт. Киев, Украина (1973).
Направление научной деятельности: аэронавигация, управление воздушным движением, идентификация сложных систем, ветроэнергетические установки.
Количество публикаций: больше 600 научных робот.
E-mail: svm@nau.edu.ua

Зиганшин Анвар Абдуллович. Ассистент.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Казанский авиационный институт. Казань, Россия (1978).
Направление научной деятельности: системы автоматизированного проектирования, численные методы в аэродинамике, возобновляемые источники энергии.
Количество публикаций: 8.
E-mail: anwarzihan@gmail.com

Василенко Николай Павлович. Кандидат технических наук.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Киевский национальный университет технологий и дизайна, Киев, Украина (2012).
Направления научной деятельности: возобновляемые источники энергии, оценка свойств веществ и материалов по их собственным электромагнитным излучениям.
Количество публикаций: больше 20 научных робот.
E-mail: vasylenkom.89@gmail.com