DEVELOPMENT OF COMPUTER SIMULATION METHOD AND ANALYSIS OF PARAMETERS OF THE VERTICAL AIRSTREAM GENERATOR FOR FREE FLIGHT OF HUMAN

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Abstract: It was discussed the problem of computer modelling of aerodynamic system "generator of a vertical airstream" which consists of the inlet device - the air screw - gasdynamic channel - the straightening device. The developed method of modelling allows to compute and optimize aerodynamic parameters of all elements of the generator taking in to account their geometry. Comparison of calculations with results of natural experiments has confirmed their satisfactory concurrence. On the basis of the analysis of results of computer simulation was executed optimization of geometrical and aerodynamic parameters of vertical airstream generator.
KEYWORDS: GENERATOR VERTICAL AIRSTREAM, STRAIGHTENER, AIRSCREW, NAVIER-STOKES EQUATION

1. Introduction

Generator of vertical air stream is one of the main parts of the on ground aerodynamic installations for creation of conditions for free flight of human in a vertical air stream. There are different types of such installations [1], which are used as ground simulators for simulation of long skydiving, as well as sports and entertainment to the public. The installations can be divided into open "Aerodium" type with free vertical air stream and open work area for the flight (similar to the vertical open wind tunnel), and closed type with the closed working zone and reverse channels in which circulates air (similar to a vertical closed loop wind tunnel with a closed working area).

Main structural elements of system for creation of a vertical air stream in open "Aerodium" type installations (Figure 1): are aerodynamic screw (fan) 1 connected to motor 2; channel 3, which forms air stream entering on the screw or fan (in some prototypes doesn't exist); cylindrical lead channel 4, inside of which in general are installed guide vanes and rectifier 5 for eliminating of flow rotation behind the screw (fan) and formation of a uniform vertical air flow at the exit; lower air permeable protective grid 6 from which begins the working area of the free vertical air stream.

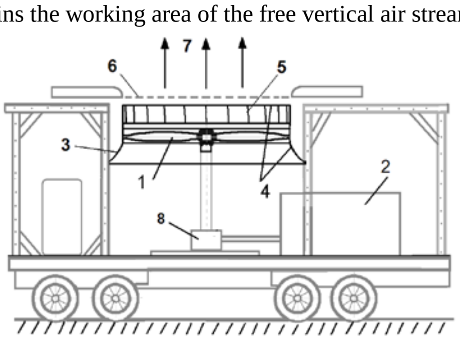


Fig. 1. The concept of mobile "Aerodium" type open device

Disadvantages of known systems of vertical air stream creation in "Aerodium" type installations are inappropriate design of the above mentioned elements and increased operating expenses due to high flow energy losses, both in separate elements, and in the system as a whole with the combination of the elements in a single unit without taking in to acount their aerodynamic interaction on each other.

In this paper is discussed the version of the computer simulation and optimization of vertical air stream generator – a key element of open "Aerodium" type installations. The scope of this work is the development of computer simulation and numerical calculation method of aerodynamic parameters of three-dimensional computer models of air stream installations with optimization purpose (reduction of dimensions while maintaining the air flow quality requirements with a fixed velocity in the working area of the stream).

2. Prerequisites and means for solving the problem

Usual engineering methods for calculation of the considered type wind tunnels, represent a sequential selection of parameters of their individual elements based on hydraulic losses. Various assumptions, as well as the lack of information on the full picture about air flow and mutual influence of the considered zones do not allow to optimize the design of the tunnel and acquire the specified characteristics. In this way estimated parameters are approximate and wind tunnels require fine-tuning during field tests, causing extensive material.

Computer simulation of "Aerodium" type installations using CAD/CAE software packages allow to create 3D geometric models of different modification and to perform virtual blowing of air stream generators ensuring optimal geometric and aerodynamic parameters of developed wind tunnel with low expenses.

Aerodynamic part of the task is described by a system of nonstationary Navier-Stokes equations with additional equations, reflecting turbulent transfer [2,3]. For the numerical solution of the task in the CAE program uses a three-dimensional computer model created in the CAD program. The original mathematical model is discretized in volume of computational domain, and in time as well. For discretization of differential equations and solving of system of algebric equations has been used finite element method, and applied adaptive moving mesh considering rotation of the screw.

3. Solution of the problem

Main stages of task resolution.

- ✓ The physical phormulation of the problem of study
- ✓ Development of a simplified model of original research object.
- ✓ Creation of an electtronic geometrical model of the object.
- ✓ Mathematical formulation of the task, boundary and initial conditions.
- ✓ Selection of applicable CAD/CAE programs.
- ✓ Creation of discrete calculation model, optimization of computational mesh.
- ✓ Phormulation of the goals of computation and criteria for termination of the computation.
- ✓ Method of calculation control and monitoring process.
- ✓ Method of data visualization and processing of the digital calculation results.
- ✓ Solution of validation tasks, comparison with known data, assessment of the accuracy of solutions.

- ✓ Interpretation of the calculation results to optimize the properties of the investigated object.

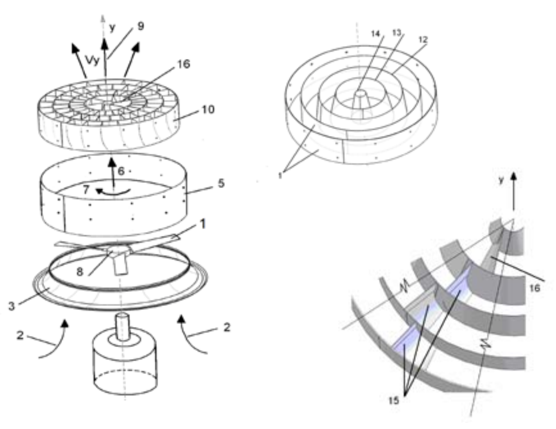


Fig.2. Elements of construction of the vertical air stream generator

Vertical air stream generator works as follows (Fig. 2). Rotating screw 1 in front of itself creates a low-pressure zone and forms an air flow 2, which moves in the inlet device 3 of gasdynamic channel 4 (see Figure 1) from the bottom upwards, and reaches the screw.

Inlet device 3 with curvilinear generating line creates a smooth axisymmetric flow without local vortex separation zones and with small coefficient of energy losses in front of the screw. Aerodynamic screw is located directly after the inlet device in the cylindrical part 5 of gasdynamic channel 4, which is adjacent to the inlet device 3. This arrangement is called "screw in the ring" and is designed to improve the efficiency of the screw and reducing energy losses in the generator.

Flow behind the screw has a high vertical velocity and some variable angular velocity of rotation (flow spin) 7 along the radius respectively of the vertical „Y" axis of the gasdynamic channel. Profile of vertical velocity in the flow cross section 6 usually is significantly uneven due to spinning of the flow by screw, as well as the creation of separation zone behind the sleeve of screw 8 and apperance of the velocity "failure" zone near the axis of the channel. For creation of uniform air stream 9 at the outlet of the gasdynamic channel with satisfactory uniform profile of vertical velocity, behind the rotating screw coaxially installed device 10, which rectifies and smoothens the flow 6.

Rotation of the aerodynamic screws is ensured by means of electric motor or internal combustion engine 2 (Figure 1) which are connected to the shaft of the screw directly or through gearbox 8. In both cases, the engine or gearbox are installed coaxially before or at the inlet to the gasdynamic channel in the zone of small flow velocities.

Method of computer simulation offers preliminary selection of complex of CAD/CAE computer programs. For creation a three-dimensional geometric models it is chosen parametric simulation CAD program SolidWorks. The program allows creating solid and surface models of parts and assemblies. For the calculation of aerodynamic parameters of geometric model it is used CAE program CFDesign which is integrated in the CAD software SolidWorks as an additional module. CFDesign program performs calculations with satisfactory accuracy and Solver is relatively fast. It allows solving tasks with moving solid border (e.g. a rotating screw) and movable finite element mesh, determination the traction and torque on the screw shaft, and investigation of nonstationary flow of weakly compressible gas with variable density as well.

For numerical calculations and creation of finite element mesh in the CAE program CFDesign required to create the domain - space that surrounds the investigated model and area of distribution of air stream. The domain is "transparent" for the air flow is considered as computational region in which is created finite element mesh. Configuration of domain is determined by the shape of the researched model and air stream. Shape of the domain for the considered task is shown in Figure 3.

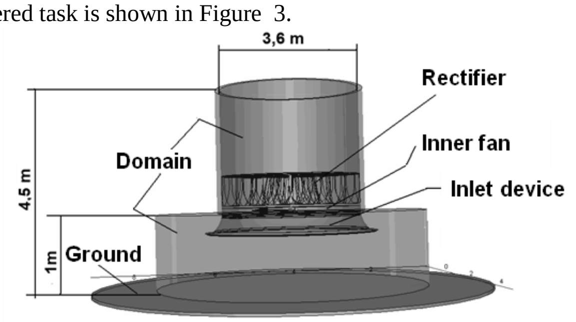


Fig..3. Computational arrangement of air stream generator with domain

For the numerical solution of the original system of Navier-Stokes equations in CFDesign programm is used finite element method [4], which allows successfull simulation of both internal and external flows with solid surfaces of arbitrary shape. Finite element mesh is usually uneven and is fined in the areas of alleged large gradients of each of the dependent variables, or in areas of significant change in the curvature of the surface of a solid body. For resolution of considered tasks it was required around 800 000 – 1 200 000 liquid and solid elements. RAM of the computer must be above 3.5 GB.

On all solid walls of model, including the Earth's surface, the program automatically sets the boundary conditions of adhesion (air velocity is equal to zero). On all exterior walls of the domain it was set atmospheric pressure.

In this work with an aim to reduce the time of calculation instead of the screw, it was considered a model of the internal fan [4]. This model is a disk whose diameter is the diameter of the screw and which generates the flow with the specified volume flow rate (or with the distributed vertical and radial velocities), and with twist of flow in plane of model of fan as well. The nature of the changes in flow vertical velocity and linear velocity of the rotation (spin) along the radius of screw for analyzed tasks is shown in Figure 4.

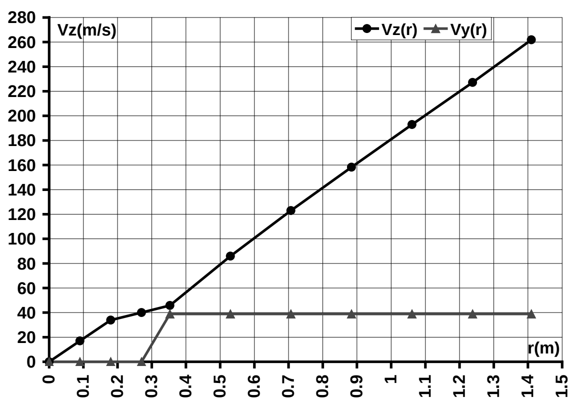
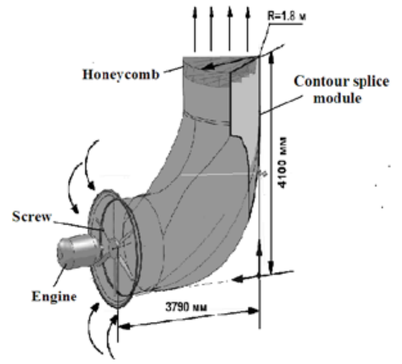


Fig.4. Character of the changes of vertical velocity Vy (-▲-) and the linear rotation velocity Vz (-•-) of the flow along the radius of the screw

It has been performed validation computer calculation of aerodynamic characteristics of three bladed screw with a diameter of 2.8 m with the specified geometry of blades, located in the working zone of wind tunnel, and obtained results were compared with experimental data [5]. Results coincided with deviation 5-10%.

The results of the comparison of the numerical calculation of vertical velocity V_Y (line) with the disk model five bladed screw with a diameter of 1.8 m and experimental measurements (points) in the outlet section of the natural "Aerodium" installation with curved channel without honeycomb are shown in Figure 5a-5b. It is visible that calculated data satisfactory coincide with the results of the natural experiment. This confirms the opportunity to use this method of calculation and numerical simulation, and chosen approximated disk model of the screw as well.



a)

b)

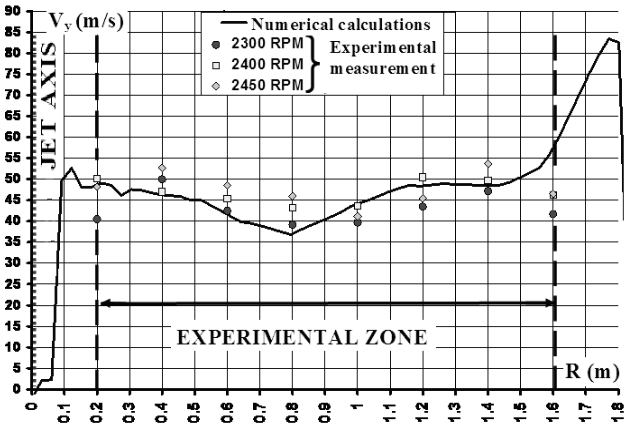


Fig.5. a) - natural "Aerodium" installation with curvilinear channel; b) numerical calculations (line) and experimental measurement (points) a vertical velocity Vy in outlett section of the installation without honeycomb.

4.Results and discussion

Results in this section are a summary of the numerical calculations of various models of open type vertical air stream generators. The main purpose of the calculations was to create a model of generator with minimum height at fixed diameter of the stream at the outlet of generator, and keeping the quality requirements of the air flow with a fixed velocity in the working zone of the stream. Air stream generator should be sufficiently generic to be used as a separate module in the stationary, sectional and mobile open "Aerodium" type installations for manned flight in vertical air stream.

On the basis of calculation it was found that in order to simplify the design, improve the performance of aerodynamic properties of stream and reduce operating costs, all items of the generator that are creating air stream, shall be compactly placed inside a vertical short coaxial gasdynamic channel 4 (average minimum height of the channel approximately equal to the radius of the screw). It is useful to perform inlet device 3 as thinwalled symmetric channel with smooth curvilinear generatrix line as lemniscate of Bernoulli. The aerodynamic screw should be placed in a cylindrical part adjoining the entrance device gasdynamic channel at once behind the entrance device in initial section of the cylindrical channel or on some distance from it <0.5 diameters of the screw.

To increase the velocity of flow which is created by screw, gap between the ends of the blades and the inner surface of the cylindrical part must should not exceed 2,0-2,5% of the diameter of the screw.

Immovable rectifier 10 with a height 0,1 to 0,4 diameters of the screw recommendable to install at small distance from it (not less than 30-50 mm from the construction elements of the screw and not more than 0.5 diameter screw). The height of the rectifier depends on diameter of the screw sleeves and restrictions on the height of the gasdynamic channel 4. Based on analysis of effectiveness of different designs it was selected rectifier composed of the same height co-axial rings 11, truncated cones 12-14 and radial curved blades 15 made from sheet material and coaxially fixed in the cylindrical channel (Figure 2). Blades 15 have constant or variable geometrical twist along the radius. To reduce energy losses during flow attack against the blade, at areas adjacent to their front edges profiles of the blades are performed curvilinear while maintaining linear remaining parts of profiles. Blade 15 eliminates the spin 7 of air flow 6 behind the screw 1 and partially smoothen the "failure zone" of vertical velocity near the axis of the stream. They are installed between the rings 11 and cones 12,13 along the sections of the radiuses, displaced at some angle to each other in such a way that are generally located in the rectifier in chessboard order. To reduce excessive blocking of free space, in central part of the rectifier number of installed blades is less than at periphery. This kind of arrangement makes the assembly of rectifier blades easier, and promotes aligning of velocity profile in the stream of generator 9, where don't penetrate macrovortexes which are created by the screw, because they are shredded into smaller vortexes in channels formed by blades and rings or cones.

For fixing of flow separation zone behind sleeve of the screw 8 and reducing of velocity "failure" near the axis of vertical stream, in the centre of the rectifier in front of sleeve of the screw 8 are coaxially installed two downstream narrowing truncated thin cones 13, 14. Between walls of the cones are fixed several short blades 16 with geometric twist for flow spinning between cones in the direction opposite to rotation of the screw.

Diameters of large bases of the cones 14 and 13 respectively should be slightly larger than diameter of sleeve 8 of the screw 1, and diameter of the nonworking zone of blades adjacent to the sleeve. Maximum opening angle of the cones of rectifier 10 is selected depending from conditions of lack of separation flow inside the formed circular cone channels.

Bellow as example are shown results of the calculations of vertical stream generated by the generator with the disk model of three blade screw with a diameter 2,8 m for two cases: with rectifier and without it. The main parameters of rectifier: 24 staggered blades; geometrical twist is constant and is equal to 17°; height of rectifier is 0.6 m. Rectifier has 3 cones with disclosure angles of large cone 12°, middle 24° c and small central 18°. Height of generator is 1,4 m. Pictures of the distribution of flow spin, vertical flow velocity Vy in a vertical plane of generator section, and as well the velocity profile Vy in cross-section of stream at distance of 1 m from outlet section of the generator without rectifier the device are shown in Figure 6.

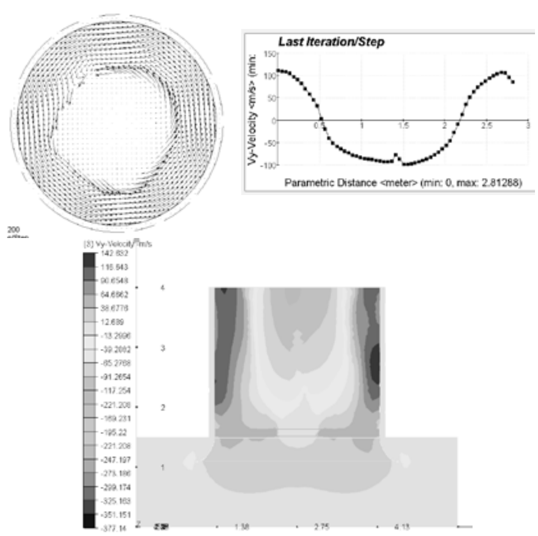


Fig.6. Picture of flow twist and vertical speed (Vy) distribution of air flow in the absence of a rectifier.

A similar picture of distribution of vertical velocity (Vy) for generator with rectifier is shown in Figure 7. It is obvious that in case of absence of rectifier in a significant part of the cross-section of the stream is present "failure", that is not acceptable for on ground simulators, simulating long skydiving or sport and entertaining attractions, using free manned flight. Installation of the developed rectifier significantly improves uniformity of flow in cross-section of the stream already at small distances from outlet section of the generator. With the increase of the location height of the cross sections, distribution of vertical velocity becomes more even while reducing the maximum vertical velocity on the axis of the wind tunnel.

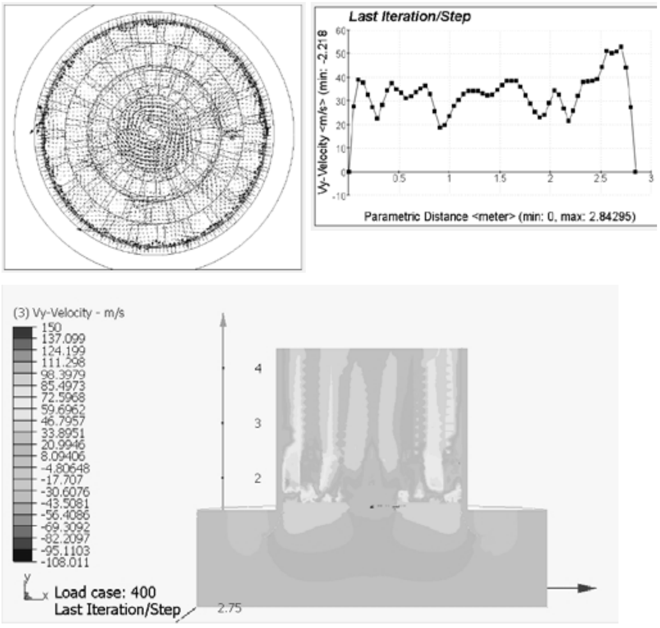


Fig.7. Picture of flow twist and vertical speed (Vy) distribution of air flow after installatin of the rectifier.

5. Conclusions

1. Developed method of computer simulation of complex aerodynamic systems including inlet device – screw - gasdynamic channel - rectifier.
2. Physical experiments satisfactorily confirmed the results of numerical calculations performed by the developed method.
3. On the basis of calculation were optimized parameters of vertical air stream generator.
4. Proposed universal design of air stream generator, which can be used as a separate module in the stationary, sectional and mobile open "Aerodium" type installations for manned free flight in vertical air stream.

6. Literature

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