RIGA TECHNICAL UNIVERSITY

Natalia SIDENKO

OPTIMIZATION OF PARAMETRES OF THE AERODYNAMIC STAND MEANT FOR FREE FLIGHT THE OF HUMAN IN AIR JET

Summary of Doctoral Thesis

Rīga 2012

RIGA TECHNICAL UNIVERSITY

Faculty of Transport and Mechanical Engineering

Aeronautics institute

Natalia SIDENKO

PhD study programm Transport „ Aviation transport" doctoral candidate

OPTIMIZATION OF PARAMETRES OF THE AERODYNAMIC STAND MEANT FOR FREE FLIGHT THE OF HUMAN IN AIR JET

Summary of Doctoral Thesis

Scientific Supervisor

Dr. habil. sc. ing., profesors

V. USHAKOV

Riga 2012

UDK 533.6.07(043.2)
Si 094-0

Sidenko N. OPTIMIZATION OF PARAMETRES
OF THE AERODYNAMIC STAND MEANT
FOR FREE FLIGHT THE OF HUMAN IN AIR JET
Summary of Doctoral Thesis.- R.:RTU, 2012.-36 lpp.

Printed in accordance with the Board of the AI institute
2012.gada 12.april, protokol Nr.15A00/17-03

Šis darbs izstrādāts ar Eiropas Sociālā fonda atbalstu projektā «Atbalsts RTU doktora studiju īstenošanai».

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

Эта работа выполнена при содействии Европейского социального фонда в рамках проекта «Поддержка развития докторантуры РТУ».

ISBN 978-9934-10-389-6

ROMOTION WORK

IS PRESENTED TO RIGA TECHNICAL UNIVERSITY TO OBTAIN THE SCIENCE DEGREE OF DOCTOR OF SCIENCE IN ENGINEERING

The defence of the promotion works in engeeniring sciences is proposed to obtain the degree of Doctor from Riga Technical University and in accordance with the decision of the Doctarate Board, the public defence shall be held on 28 January 2013 it the TMF Aeronautics institute, 1 Lomonosova str, 1st bld., room 220.

OFFICIAL REVIEWERS

Profesors, Dr.habil.sc.ing. Aleksandr Janushevski
Riga Technikal university (Riga, Latvia)

Profesors, Inženierzinātņu doktors Viktor Gopeenko
ISMA Graduate School (Riga, Latvia)

Profesors, Dr.habil.sc.ing. Vladimir Shestakov
Riga Technikal university (Riga, Latvia)

CONFIRMATION

I confirm that I have independently worked out this promotion work for defence at Riga Technical University for being conferred the degree of Doctor of Sciences in Engeeniring. The promotion works has not been presented to any other university to obtaining the scientific degree.

Natalia Sidenko …………………………….(signature)

Date: ………………………

The promotion works is written in English. It contains introdaction, 3 chapters, conclusion, 96 bibliography, 82 ilustrations, 130 pages.

CONTENTS

1. PROBLEM ACTUALITY

Currently flying in vertical air flow of aerodynamic stand is an integral part of the training process of most skydiving teams.

On ground located aerodynamic stand for human flight in a vertical air jet simulates the feelings what is experiencing the skydiver in free flight. If the time of free flight of the skydiver is about one minute, meanwhile the free flight in the on ground located stand, without taking into account economic considerations, is limited only by the human physical abilities.

Stands of this type are used as:

- Ground stands for simulation of long skydiving (AFF Accelerated Free Fall);
- Training of paratroopers and units of special forces;
- Testing and experimental blowing of equipments and devices;
- New type of sport "Bodyflyght";
- Sport and entertainment of the public.

In the world there is already a large number of aerodynamic stands for free flight of human, which vary in design, dimensions, range of speeds, and ways of creating of a stream.

Known aerodynamic stands have closed (i.e. limited with side panels) or an open work area, and should create a long range vertical stream (altitude can reach 20-25 meters from the outlet section of the tube). In the cross-sections of work area of a jet flow must be sufficiently uniform and without swirling. Average vertical velocity in a work zone is approximately 60 - 70 m/s at standard atmospheric conditions.

Disadvantages of known systems of creation of vertical air jet in open aerodynamic stands are inappropriate design and increased operating costs due to the high losses of flow energy as in separate elements, as well in the system as a whole at the assembly into a single set of elements without taking in to account their reciprocal aerodynamic effects.

Standard engineering methods for calculating of wind tunnels represent a sequential selection of parameters of their individual sections based on hydraulic losses generally without taking into account their mutual influence in a common aerodynamic system. As a result is the consistent composition of individual construction elements of wind tunnels which are not agreed among them as a unique aerodynamic system. Various assumptions, as well as the lack of information about the full picture of currents of flow and mutual influences of the considered sections do not allow optimizing the design of the wind tunnel during the engineering process and getting defined characteristics. In this way calculated parameters are approximate and require fine-tuning during field tests, resulting in extensive material costs.

As a result, many stand (especially open stands with an open work area), have in the working section of the jet significantly uneven speed profile, high flow swirl and as well as large required power supply.

Modern constructions of aerodynamic stands have large dimensions, complex forms, making difficult and expensive implementation of natural or semi-natural experiment, especially if we are talking about an aerodynamic experiment. Therefore, the creation of structures and their optimization is not possible without improving and automating the design, calculation and experiment. Thus the use of modern methods of computer modelling and design of these stands are relevant.

2. PURPOSES AND RESEARCH THE OBJECTIVES

The aim of this work:

Develop a methodology of computer modelling and numerical experiment to optimize geometric and aerodynamic parameters of individual elements of aerodynamic stands, as well as in the whole system: the airscrew (fan) - rectifying apparatus - gas-dynamic channel. The results of numerical calculations, executed through the developed methods require the satisfactorily matching with the results of natural experiment.

To achieve the raised purposes at work the analysis is carried out:

- The general directions of constructions development of simulators (stands) for sport flights in vertical air jet;
- Methods of engineering calculation of elements of aerodynamic stands;
- Existing programs for calculation of gas flow interaction with moving objects in complex gas-dynamic channels.

And resolved following tasks:

- Formulated method of computer simulation and calculation of parameters of the open wind tunnel with vertical air stream of large diameter.
- Developed methodology of computer simulation of geometric and aerodynamic characteristics of individual elements of aerodynamic stands in particular airscrews, inlet devices, rectifying apparatus - gas-dynamic channels.

- Developed methodology of computer simulation and optimization of geometric and aerodynamic parameters of aerodynamic stands of different versions (single airscrew, open type multi-airscrew).
- Experimentally proved the possibility of applicability of the suggested method and its individual parts for the calculation and optimization of aerodynamic parameters aerodynamic stands.

3. THEORETICAL BASIS AND METHODS OF RESEARCH

The theoretical background of the promotion research is based on the basic statements of the fluid and gas mechanics:

- Theory of unsteady movement of liquids and gases;
- Vortex theory of N.Zhukovsky;
- Mathematical model of movement in generally compressible gas, described by nonstationary Navier-Stokes equations and equation of energy (the First Law of Thermodynamics), for turbulent, transitional and laminar flows;
- Numerical methods for solving of tasks of fluid and gas mechanics.

Methods of research:

- Methods of computer simulation, design and calculation using CAD/CAE/CFD programs;
- Solution of nonstationary Navier-Stokes equations by numerical finite-element method using adaptive moving mesh;
- Methods of engineering design and calculation of wind tunnels;
- Methodology and practice of aerodynamic experiment.

Scientific novelty of thesis

- Developed basic method of calculation of parameters of open wind tunnel with a free vertical large-diameter air jet based on set of CAD/CAE software.
- Results of numerical calculation that allow optimizing the characteristics of main elements of aerodynamic stand for free flight.
- Justification of numerical calculations based on the developed methodology by means of resolved verification tasks and individual experiments with satisfactory precision.
- Developed computer models with optimized aerodynamic parameters (single airscrew and multi-screw) of stands for free flight.

- Existing installations of aerodynamic stands designed and manufactured according to results of the numerical calculations.

4. SCIENTIFIC NOVELTY

Development of methods using three-dimensional parametric computer simulation software packages SolidWorks and CFDesign allowing to create different modifications of 3D geometric models of aerodynamic stands and their elements, as well as perform their virtual blowing reaching optimal geometric and aerodynamic parameters of developed constructions of stands.

The developed method allows parametric computer calculations accurately simulating a researched physical phenomenon and allows defining interesting aerodynamic characteristics, satisfactorily matching with the experimental data or known theoretical calculations, confirming the adequacy of the method

The main feature of developed method of the dissertation is the ability to calculate the formation process of by aerodynamic screw submerged jet, which rotates around a fixed vertical axis. Method takes into account the influence of closely located solid or permeable surfaces, as well as the generation of flow zones, induced by the aerodynamic airscrew. Generally flow in the jet is considered as nonstationary and turbulent, and the adjacent zones of the induced flow might be transitional or laminar.

5. PRACTICAL SIGNIFICANCE AND REALIZATION

Developed recommendations for engineering of mobile and fixed stands for free flight of human. Testing of engineering methods of the stands was executed by the Latvian company which developed and manufactured the stands together with foreign companies. In particular the method of computer simulation and numerical calculations was used during development of the aerodynamic stands of different versions (single screw and open type multi-screw) with submerged free vertical air jet. The stands were manufactured and installed by the Latvian company in Latvia and a number of countries in Europe and Asia.

Developed methods were used in scientific projects of Ministry of Education and Science ”Universal computer simulation system for resolution of unsteady tasks of aerogasthermodynamics”; „Aerodynamic calculations of vertical air jet and development of conceptual design of "rectifier of air flow” firma „Aerodium” (Riga, Latvia); scientific project of RTU „Investigation of nonstationary aerohydrodynamic and heat characteristics of relatively to flow moving bodies".

The main results of the research have been published in 6 articles and presented at the 6 international conferences in Latvia, Poland, Bulgaria, and Ukraine, where the author has provided 6 reports related to topics of dissertation. List of articles and reports of conferences listed at the end of the summary of the promotional work.

6. THE WORK STRUCTURE

In the introduction are considered general lines for the development of constructions of stands for sports flights in vertical air jet. Special attention is paid to the modern constructions of aerodynamic stands, which vary in design, size, range of speeds, and ways of creating a stream. Reviewed the principle of operation of the simplest constructions, intended to create a vertical air stream of large diameter. Highlighted main advantages and disadvantages of modern constructions. Performed the analysis of modern engineering methods of calculation of the elements of stands structures. Formulated the relevance of research, aims and objectives of the promotional work.

In the first chapter is formulated basic method of computer simulation and calculation of parameters of large diameter vertical air jet generators (or open wind tunnels generating the air jets). The method includes main steps for this class and contains the main characteristic details inherent in this task. The method enables parametric computer calculations which pretty accurately model researched physical phenomena and allow defining their interesting the practice characteristics. Calculation of developed aerodynamic stands must be done by means of the known engineering CAD/CAE programs that ensure compliance with all the necessary work to be done in a reasonable time period.

In the second chapter developed method of computer simulation and optimization of geometric and aerodynamic characteristics of single elements of aerodynamic stands.

The method allows using 3D parametric computer simulation packages SolidWorks and CFDesign to create different 3D modifications of geometric models and perform their virtual blowing reaching required geometric and aerodynamic parameters of developed stands. Method allows relatively quickly to obtain results, satisfactorily corresponding with the data of natural experiment or known theoretical calculations confirming, the adequacy of the method.

<u>In the third chapter</u> developed the computer simulation and optimization method of geometric and aerodynamic parameters of different modifications of aerodynamic stands (single screw and multi-screw). On the basis of the developed method was created a universal air jet generator designed to create conditions for the free flight of human in the vertical air stream. Universal generator can be used for both mobile and stationary aerodynamic stands. Computer simulation of complex volumetric constructions of wind tunnel with symmetrically placed fans allowed resolution of a number of tasks such as connecting the sections of air channels, taking into account to the necessary narrowing and widening angles, smooth transitions and turns of channels, pairing a several channels, taking into account the restrictions of curvature and rotation of the corners.

Using developed methods have been developed computer models on which base were designed and installed single screw and multi-screw aerodynamic stands.

CHAPTER 1.

METHOD OF CALCULATION OF PARAMETERS OF OPEN WIND TUNNEL WITH LARGE DIAMETER VERTICAL AIR JET ON SIMULATION CAD/CAE SOFTWARE SET

Numerical solution of any particular task requires obligatory preliminary elaboration of a phased approach of its solution. In the case of analysis of a certain class of tasks (in this work is the class of tasks of aerodynamic characteristics of vertical air jets created by ground stands of open type wind tunnels), can be selected the main part of a method which will include steps common for this class of methods. Method of resolution of a particular task will contain only specific parts inherent to this task.

Main stages of the basic methods for resolution of tasks on simulating CAD/CAE programs set used in this paper can be represented as follows:

1. The physical formulation of the problem of study.
2. Development of a simplified model of original research object.
3. Creation of an electronic geometrical model of the object.
4. Mathematical formulation of the task, boundary and initial conditions.
5. Selection of applicable CAD/CAE programs.
6. Creation of discrete calculation model, optimization of computational mesh.
7. Development of strategy for resolution of task:

- Formulation 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.

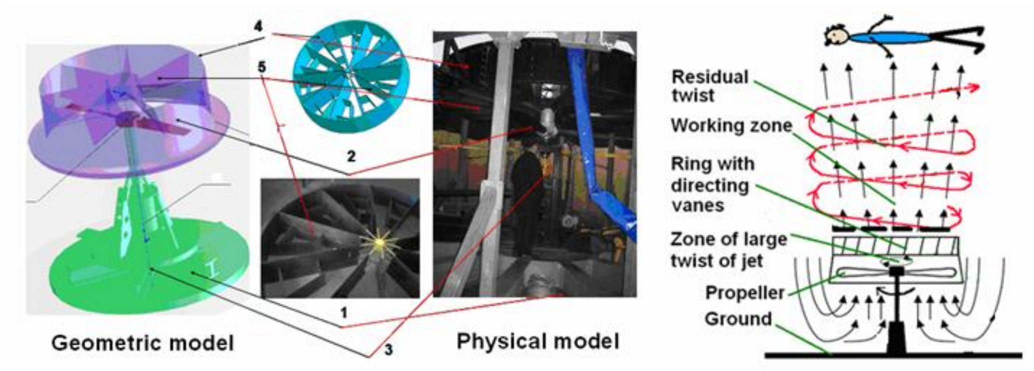
8. Solution of validation tasks, comparison with known data, assessment of the accuracy of solutions.

9. Interpretation of the calculation results to optimize the properties of the investigated object.

In this chapter is formulated basic method of computer simulation and calculation of parameters of generators of large diameter vertical air jet (or open wind tunnels, generating the air jets). The method must enable parametric computer calculations which pretty accurately model researched physical phenomena and allow defining their interesting the practice characteristics. In addition, calculations must satisfactorily match with the experimental data or known theoretical calculations confirming the adequacy of the developed method. Calculation of developed aerodynamic stands must be done by means the known CAD/CAE engineering programs that ensure compliance with all the necessary work to be done in a reasonable time period.

The chapter contains 5 sections that highlight the main steps of the method of resolution of tasks on simulating CAD/CAE programs set unique to specific tasks, considered in the promotional work.

In the first section is considered physical formulation of the task. Computational physical model includes a simplified geometric construction of aerodynamic stand, without the minor parts, faintly influencing its aerodynamic characteristics (for exam. see Fig. 1.1. a).



a) b)

Fig. 1.1. a) Scheme of the simple aerodynamic stand of direct action with open working zone. 1- Ground; 2- Airscrew; 3- Axis of engine; 4-Ring; 5-Directing vanes.

b) Scheme of flow in the aerodynamic stand.

The analyzed physical model can be provided with only a part of properties of real construction. This will simplify the geometric model and mathematical description. How successful chosen physical model of construction, depends laboriousness of calculation and the accuracy of its results.

For the stand, which generates a vertical air jet, the main feature of the task is the necessity to calculate formation process of submerged vertical air jet created by the aerodynamic screw, which rotates around a fixed vertical axis. While necessary to take into account the impact of closely located solid or permeable surfaces, as well as the creation of flow zones, induced by submerged jet and low pressure area before the screw (see flow diagram on Fig. 1.1. b.).

Geometric models of considered open type aerodynamic stands contain the following major structural elements:

- Aerodynamic airscrew (fan) connected to motor;
- Channel, which forms air stream entering on the screw or fan (in some prototypes doesn't exist);
- Cylindrical lead channel, inside of which in general are installed guide vanes and rectifier for elimination of flow rotation behind the screw (fan) and formation of a uniform vertical air flow at the exit of lower air permeable protective grid from which begins the working area of the free vertical air jet.

In the second chapter are given mathematical formulation of problem and boundary conditions. The mathematical model of the task, which makes it possible to consider changes of a temperature and air density, is described by Navier-Stokes equations and by equation of energy. After averaging of initial equation system by Reynolds method for the turbulent, transitional and laminar flows is used *(k - ε)* or *Low Re (k - ε)* models of turbulence (k - turbulent energy, the speed of the dissipation of turbulent energy *Re* - Reynolds number).

Formulated system of differential equations is nonlinear and in this work is solved numerically.

In the third chapter is described the set of programs for calculation of gas flow interaction with moving objects in complex gas-dynamic channels. To create a computer-based geometric models and numerical solution of tasks is used specially selected set of CAD/CAE software SolidWorks/CFdesign. Calculation 3D geometric models of the stand and its elements were created in the CAD program SolidWorks.

Considered features method of creation of numerical geometric model.

As basic examples in this section are described the main features of creation in a CAD program SolidWorks three-dimensional models of aerodynamic screws for two cases of physical constructions of screws: with the known and unknown geometric parameters of cross sections of screws.

Geometric modeling of the surface of the blade by known cross section parameters of the screw can be performed in different ways, for example using Excel and SolidWorks or SolidWorks and Profile programs. In this chapter are discussed the advantages and disadvantages of both techniques and process of direct creation of the surface of the airscrew.

Unknown geometry of sections of existing blade of screw (so-called refurbished blade) nowadays can be relatively easy obtained using scanning devices. In case of unknown geometry of the sections of screw were analyzed the main steps of creation of 3-D geometric computer model of five-blade screw. The screw was intended for installation in a wind tunnel that produces free vertical air jet.

Solid model of the scanned screw blade was divided into sections with step 0.1R (R = radius of the screw). All sections were located in the vertical planes, perpendicular to plane of rotation of the screw. Based on scanned data were identified data about changes in the restored geometrical parameters of blades: relative chord, thickness and twist of the blade. Using the obtained data in SolidWorks program according to known geometry of sections have been created solid model of the blade and a computer model of refurbished five – blade screw with bushing, which were later installed in the model of experimental aerodynamic ground installation.

In continuation of the chapter was justified selection of CAE software for calculation of gas -dynamic parameters of flow. The selected program CFDesign is successfully used for calculation a wide class of problems: streamlining of the cars, flows in the pipes and tubes, in the engineering of ventilation and air conditioning systems, computation of convective heat transfer processes etc. Its main benefits: the ability to work within a wide range of graphical CAD programs, high accuracy of calculations, relatively fast solver, ability to cope with a steady and moving solid boundaries, opportunity of analysis of unsteady gas flows with variable density and heat transfer.

In the fourth chapter were considered the features of formation of the computational mesh and the criteria for the termination of calculation. For the numerical solution of the initial system of Navier-Stokes equations in CFDesign program is used finite element method. It allows successful simulation of both internal and external jets with solid surfaces of arbitrary shape using an adaptive moving mesh with and taking into account visualization of the process, rotation of the screw and compressibility of the media. Because of the rotating elements, for example screw, all tasks are calculated as non-stationary. 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 creating of the computational mesh of finite elements the electronic geometric model of aerodynamic stand was placed into the cylindrical or rectangular computational region (domain). It was performed analysis of features of selection of the form and dimensions of domain, size of computational mesh, setting of the boundary conditions on the solid bodies and domain borders.

Note that to reduce the time of calculation of flows with solid rotating devices (for example, aerodynamic screws, pumps, blowers, turbines and mixers), necessary to create not only the geometric model of a solid body (screw), but also the so called Rotating Region. Rotating region is a closed area, which surrounds the rotating device and rotates together with it relatively to the specified axis with the same speed. Rotating region cannot directly communicate with stationary region (stator). CFdesign program does not allow changing the borders of solid bodies, and also form of the walls of the channel and rotating region in the process of calculation. Angle of rotation of the rotating region within one step at a time is calculated by the formula: $\Delta\theta = 6n_m\Delta t$. Where $\Delta\ \theta$- rotation angle of the body (grad), n_m- number of revolutions per minute (RPM), Δt- time step (s).

For the numerical solution of tasks in addition to definition of all input parameters task, also must be defined the criteria based on which calculation tasks will be completed. Solution of stationary task is defined as a result of the time setting.

Therefore, for stationary tasks the main criterion is the maximum number of iterations to be performed during the computation. It is defined for each task individually and depends on the computational mesh.

For non-stationary tasks the main criteria is the estimated time to computation (duration of calculation according to physical time), which depends on the properties of the fluid and the time period within flow a crosses computational domain. If, at some point of time, resolution of non-stationary task is steady state, i.e. becomes stationary or periodic for the selected criteria, then it can be stated that the solution was reached. As criterion can be selected one or several interesting physical parameters that in the form of graphs are displayed in the corresponding window of program. If the value of a physical parameter varies by less than 5% over the last 20% of the total number of time steps, then this is a good sign of convergence.

In the fifth chapter are discussed methods of data visualization, processing and verification of results of computer experiments.

Unlike a physical experiment, in which you can receive only the values of physical parameters measured at certain points by means of special sensors, the computer experiment has a much greater capacity. In a computer experiment can simultaneously receive not only numerical values of investigated parameters, but also visualize them in the form of 2D and 3D graphs or colored pictures, as well as flow lines, trajectories of motion, etc. This information may be obtained from any of the points, lines, surfaces, or volumes available in the current domain. Visualization of flow parameters in some cases allows to identify characteristic physical features of the flow (form of separation zones, zones of intense vortexes, etc.) that are difficult to identify in the physical experiment.

Therefore, in a computer experiment for successful analysis of obtained results of calculation should be formulated method of visualization of calculation data, taking into account the characteristics of the considered class of tasks. In the chapter is considered and analyzed different ways of presentation and interpretation of the results used in carrying out specific tasks.

In the final chapter are formulated criteria's de reliability and validation (verification) of solution obtained using computational method that comprise from two evaluations:

- Evaluation of the accuracy of solution of mathematical task, corresponding to the used mathematical model of physical phenomena;
- Evaluation of the accuracy of the modelling of physical process used in the computational method of mathematical model.

Accuracy of solution of mathematical task is determined by mathematical methods, regardless of the adequacy of mathematical model against to analyzed physical phenomenon. This assessment is based on an analysis of the accuracy of mesh convergence of task solution on the basis of the decisions obtained on the different meshes.

Evaluation of the accuracy of the simulation of the physical process is performed using the computational method of mathematical model. For that compares the obtained solutions with existing experimental data (taking into account to their errors, consisting from the measurement error and error of the purity of the experiment, i.e. the absence of parasitic influences). Due to limited experimental data for this validation is desirable to select them as much as possible close to an engineering task. In some cases, in addition to the task, must be resolved some test task for which there are experimental data, and with what can compare the obtained data. This increases the reliability of evaluation of the accuracy of numerical solutions of engineering tasks.

CHAPTER 2.

NUMERICAL CALCULATION AND OPTIMIZATION OF CHARACTERISTICS OF THE MAIN ELEMENTS OF AN AERODYNAMIC STAND FOR FREE FLIGHT.

This chapter is devoted to development of methods of computer simulation and optimization of geometric and aerodynamic parameters of main elements of aerodynamic stands. These methods by means of SolidWorks and CFDesign software packages allow creating different modifications of 3D geometric models and performing their virtual blowing ensuring optimal geometric and aerodynamic parameters of developed stands. Methods must permit to obtain relatively quickly results satisfactorily matching with the data of natural experiment.

Aerodynamic screw is a main element of generators of large diameter free vertical jets. Computer simulation method, including creation of a numerical geometric model of the screw and calculation process of its aerodynamic characteristics significantly depends on the geometric parameters of elements of the stand and its composition scheme. In this chapter are discussed several versions of methods of calculation of individual main elements separated in individual sections, which can be composed and analyzed the characteristics of different types of aerodynamic stands.

- Method of calculation and numerical validation of the aerodynamic parameters of the screw with the known geometry;
- Method of simplified computer simulation of aerodynamic parameters of the refurbished screw;
- Methods of computer simulation of system: inlet device - screw - gasdynamic channel. Comparison of the results of numerical calculations with the results of field measurements.
- Computer simulation of aerodynamic parameters of rectifier.

For justification of the proposed in chapter 1.3 method of the creation of surface of the screw with the known geometry and the ability to calculate its aerodynamic characteristics by means SolidWorks and CFdesign was selected a Clark Y type three-blade screw with known geometry and experimental aerodynamic parameters.

Physical experiment (described in the works Barnes W. Mc Cormick, Aerodinamic, Aeronautics and Flight mechanics, John Wiley & Sons.inc., 1995, and Кравец А.С. „Характеристики воздушных винтов.” Гос. Изд. оборонной промышленности., Москва - 1941.) was performed in wind tunnel with diameter 6,1m at flow velocities v=0-44,4m/s. In an experimental installation screw was mounted on the nacelle, fixed on the wing compartment which geometry is not specified in the work.

In computer experiment in SolidWorks based on the known geometrical data was created the 3D geometric model of the screw with Clark Y type profiles, Fig. 2.1.a., screw diameter D = 2.0 m, diameter bushing - 0.24 m installation angle of the screw φ = 30° to relative radius of r = 0.75. In a computer experiment advance ratio of the screw $\lambda = \frac{V}{n_s \cdot D}$ (n_s- second speed of screw) was selected in the range of V = 0-22 m/s, n_s = 10-11 RPS. Unlike physical experimental installation, in the calculation model of airscrew was missing nacelle.

In Fig. 2.1.b. for screw D = 2.0 m in a wind tunnel is shown an example of a domain in the form of a cylinder with a diameter of 6.1 m and a height of 8 m. To improve the accuracy of calculation in a jet behind the screw inside the main domain is located cylindrical internal domain with diameter 2.05m. The size of computational mesh in the internal domain is significantly less than in the external. This makes it possible to significantly reduce the total number of computational cells, the time of computation and the required operational memory of computer.

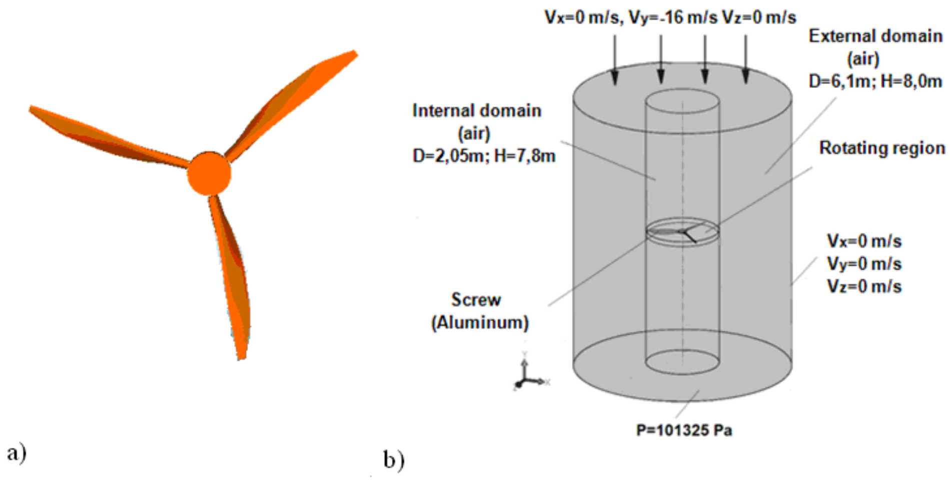


Fig. 2.1. Models of three-bladed screw: a) Geometric computer model of screw;
b) Computational model of screw model in a wind tunnel.

At the entrance and exit from the domain are set boundary conditions respectively for the velocity and pressure. On side walls of domain (wind tunnel) automatically assigns the adhesion conditions of viscous liquid (Vx = Vy = Vz = 0).

Screw and bushing of the screw are modelled as solid material (due to the lack of heat exchange physical properties of the material are not important). Everything else inside the domain – poorly compressed air. Screw is placed in the Rotating Region of the form of a closed cylindrical region, whose axis coincides with the axis of rotation of the screw. CFdesign calculation program makes it possible to determine the aerodynamic characteristics of the screw, detailed picture of the streamlining, as well as traction force and torque on the shaft of the screw, based on which respectively are calculated the relative coefficients of traction α, power β and efficiency η.

As described in Chapter 1, for discretization of non-stationary differential Navier-Stokes equations and resolution of system of algebraic equations in the CFdesign program is used finite element method. Depending on the type of task for satisfactory accuracy of results in this work were required about 800000-1200000 liquid and solid elements. All tasks were calculated in two CPU computers with RAM ≥ 3.5 GB.

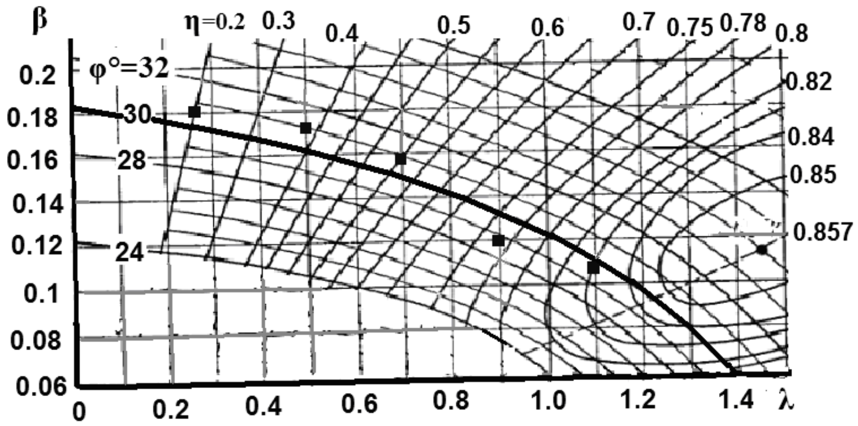
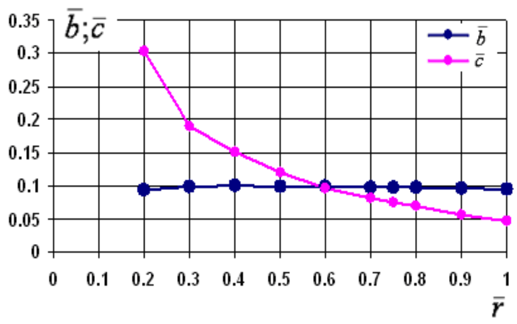


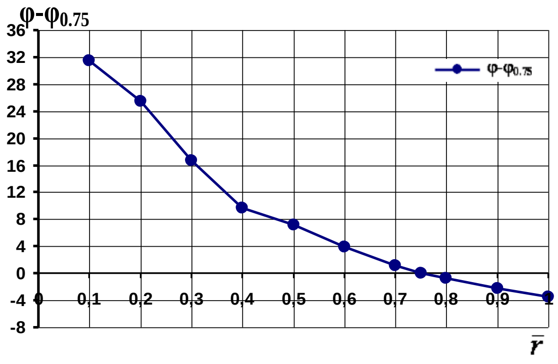
Fig.2.2. Dependences of β (λ) and η (λ) at installation angle φ = 30° for three-bladed screw (points- calculation, line - experiment).

Comparation of the results of numerical calculations with experimental data
Dependence β (λ) and η (λ) at an angle of installation
φ = 30 ° for three-bladed screw (points - calculation, lines - experiment)

In Fig. 2.2. are presented results of numerical calculation of dependence of power factor β from advance ratio λ at the installation angle φ = 30°. There are also presented natural experimental data for β and η. From the presented graphs is clear that in case not taking in to account in the calculation the influence of nacelle and wing compartment, computational results are satisfactory matching with the experimental data with an accuracy of ~ 5-10%. The obtained results confirm the possibility to use SolidWorks and CFdesign for numerical calculation of aerodynamic characteristics of aircraft screws with known geometry.

The following calculation method was developed for the case when there are no available data about the aerodynamic characteristics of aerodynamic screw, as well as the detailed geometric characteristics of the blade. This occurs in case you need to restore the damaged screw or to create a approximate analogue of known screw. For physically existing blade modern technology allows fast enough by 3D scanning methods to obtain required number of blade section profiles comfortable to create a three-dimensional computer model of the screw. Method of creation of solid geometrical model of known geometry blade of the screw in SolidWorks based on known geometry of section was considered in Chapter 1. p.1.3. Geometry parameters of the blades of refurbished screw are shown in Fig. 2.3. airscrew (D = 1.8 m and D of screw hub 0,228m) is intended for installation in natural open wind tunnel that creates a free vertical air jet. Created computer model of the five - blade airscrew with D=1.8m and D of screw hub 0,228m Fig. 2.4.a allows to calculate its aerodynamic characteristics.



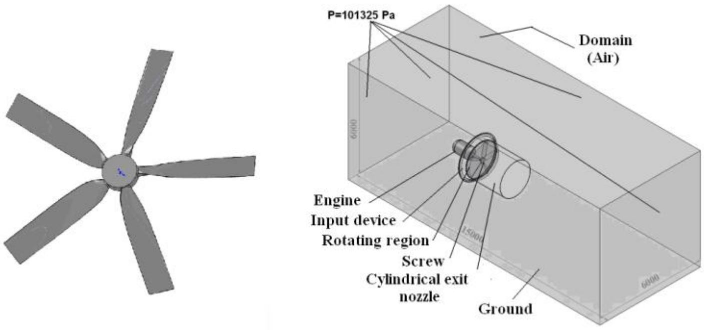


a) b)

Fig. 2.3. Geometrical characteristics of the blade of refurbished screw. a) Relative chord and relative thickness; b) Twist of blade.

In this chapter is discussed the process of simulation of aerodynamic properties of the screw by means of simplified disc model of the aerodynamic screw or fan.

To justify the possibility of replacing of the screw by disk model previously were investigated features of formation of jets behind the screw with inlet device and a short cylindrical exit nozzle located in the immovable air. Calculation model of this intermediate task is shown in Fig. 2.4.b. Model of engine, screw, and inlet device, cylindrical exit nozzle, modelled as solids are placed in rectangular domain (domain dimensions 15x6x6 m). Inside the domain is defined generally poorly compressed air, but on the side walls and at the inlet to and exit from the domain - atmospheric pressure P = 101325Pa. At the bottom of the domain (land) is set the condition of adherence of viscous fluid (Vx = Vy = Vz = 0). Screw is placed in rotating region which rotates along with the screw with speed ω = 2180 RPM. Angle of installation and angular velocity of rotation of the screw were approximately the same as the corresponding values in natural experiment, described below.



a) b)

Fig. 2.4. a) Geometrical model of five - blade screw; b) Screw in a short channel with inlet device and cylindrical exit nozzle.

Aim of this task is to determine the flow rate of air flowing through the plane of refurbished screw, as well as to evaluate the estimate the twist of flow behind the screw. These data will allow approximately replace the screw in the calculation model of experimental installation with simplified model of internal fan (disk model fan).

Disk model looks like air-permeable rotating disc, which creates a stream with the specified flow rate and can rotate with a constant speed which generally is equal to zero or not exceeding the screw rotation speed. Parameters of simplified internal fan model depend on the accuracy of the restored geometry, installation angle of the blade, screw speed and accuracy of calculation of aerodynamic characteristics of a screw.

As a result of the replacement of screw model by internal fan, the calculation of aerodynamic parameters of flow in gas-dynamic channel behind the screw will contain mainly the slow in time and large-scale in space processes, so the time of calculation would be significantly reduced.

Below are shown the results of calculation of axial and linear circular components of speed behind the screw needed for approximate determination of parameters of model of internal fan: volumetric air flow Q m^3/s and number of revolutions of flow behind the screw thread n_b RPM.

High-quality picture of currents in the area behind the screw (horizontal plane of section) and twist of flow near the plane of rotation of the screw (vertical plane) is shown in Fig. 2.5.

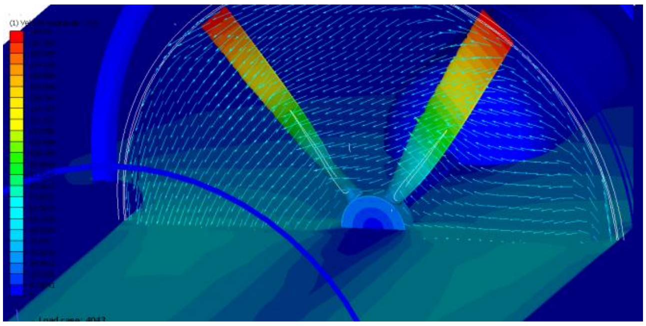
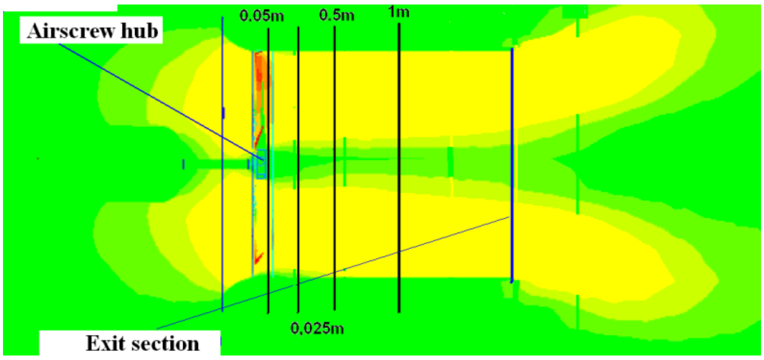
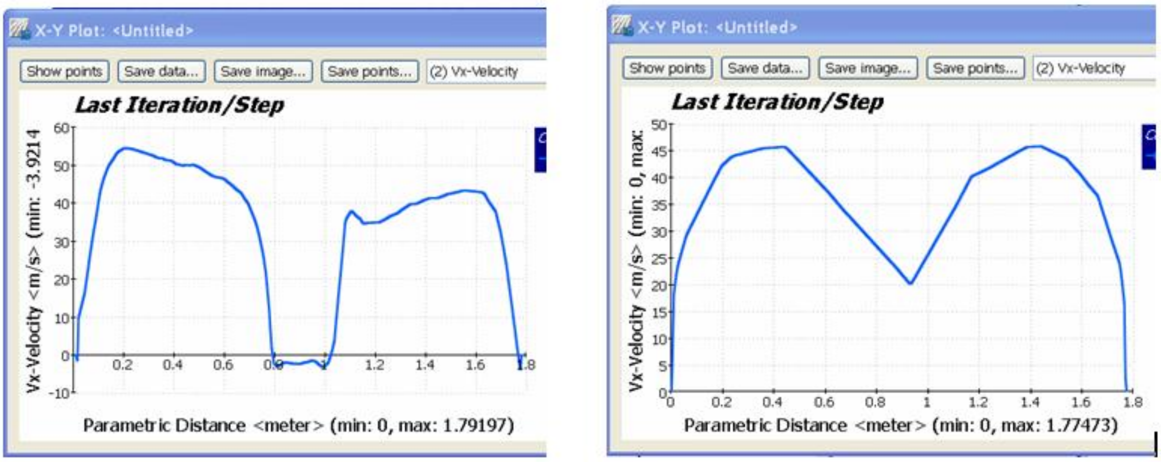


Fig. 2.5. The flow pattern in the area behind the screw (in horizontal plane of section) and twist the flow near the plane of rotation of the screw (in vertical plane).

You can see that the cylindrical sleeve airscrew formed area of return currents, which quickly cut down the stream. Already at distances of x > 0.125 D of bushings profile longitudinal velocity Vx has only a "failure" of speed near the screw axis, indicating a lack of return currents in this section the flow (Fig. 2.6).

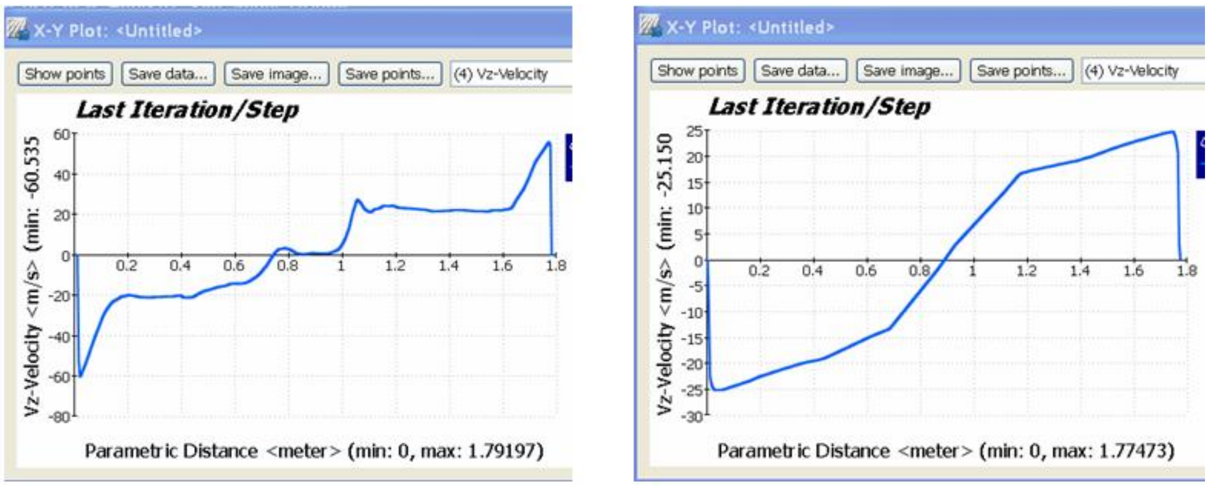




a) b)

Fig. 2.6. Dependence of the longitudinal velocity Vx (y) in the section of the jet:
a) - x = 0.05m ≈ 0.025D, b)- x = 1m ≈ 0.5D.

In General, the flow behind the screw has a variable twist, which nature was a changes along the radius of the blade is shown in Fig. 2.7. It should be noted that close to the axis of the screw at a distance of 0<r<0.2R tangential flow velocity V_z increases along the radius of the blade approximately according to the law of solid body, then it is approximately constant 0.2R < r <0.7R and at r > 0.7R practically linearly increases at approaching of the cylindrical wall of the nozzle (Fig. 2.7.a). At the distance from the rotation plane of the screw more than x > 0.5D character of rotation of flow is close to the rotation of a solid body (Fig.. 2.7. b.).



a) b)

Fig. 2.7. Nature of changes of linear rotation velocity of of the flow along the radius of the airscrew. a) x = 0.05m ≈ 0.025D, b) x = 1m ≈ 0.5D.

Taking into account of the given data and to reduce the time of numerical calculation of gas-dynamic parameters of experimental installation (Fig. 2.8. b.) with a cross-section of exit 2.03 m^2 in order to obtain the specified average air outlet velocity $V_y \approx 60$ m/s, five-blade screw with diameter D = 1.8 can be replaced with approximation model of internal fan with diameter D = 1.8 with volumetric flow rate Q = 120 m3/s. This model is a disk whose diameter is equal to the diameter of the screw and which generates the flow with the specified volumetric flow rate and with twist of flow in plane of model of fan as well.

Analysis of results of the systematic calculations showed that the twist of the flow has little effect on the average velocity in the exit section. Therefore, to compare the results of numerical calculations and experiments was selected fixed number of screw revolutions (n_b = 900 rpm), which corresponds to sliding of the screw s ≈ 0.36 - 0.4 for the range of numbers of screw revolutions of the experimental device n=2180- 450 rpm (s - ratio of the angular velocity of the flow to the angular velocity of the screw).

High value of sliding s was chosen with a purpose of confirmation of its weak impact on the average main parameters of investigated installation. Note that this condition does not occur in case if close to the screw for elimination of twist is installed rectifier, on whose blades within noncomputational regime might appear flow separation that will reduce flow velocity.

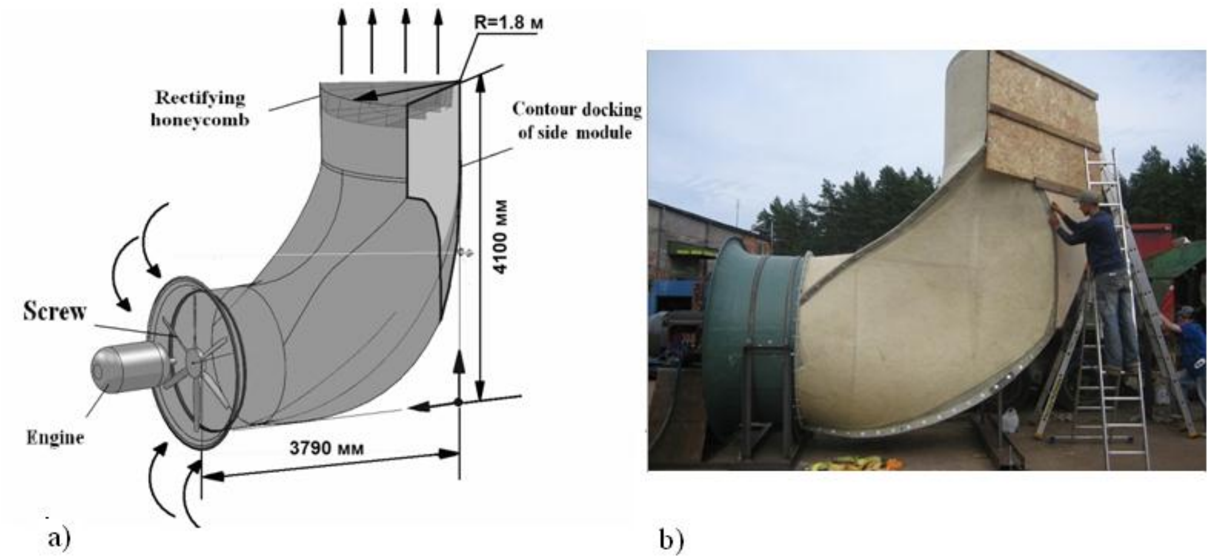


Fig. 2.8. Natural module of wind tunnel with a fan and motor, a) Computer model, b) Natural tunnel

The following chapter discusses the methods of computer simulation of symmetric element of real aerodynamic stand with disk model of aerodynamic screw. Aerodynamic facility is an open wind tunnel foe creation of a free large diameter vertical air jet. Tunnel consists of five identical adjacent to each other modules, in each of which as fan is used above described five-blade screw. General view of such a module with the dimensions is shown in Fig. 2.8.a.

Before the screw is located inlet device, followed by complex form air channel, turning the flow by 90°. Electric motor installed in front of an inlet device rotates the screw at 2180 RPM. Vertical velocity of the jet coming out from the installation is 50-60 m/s.

Feature of numerical solution the of task about creation a of the air flow in the considered installation consists in the following. Close to the rapidly rotating five - blade screw computational time step must be equal to one-hundredth fractions of the rotation period of the screw (i.e. thousandth fractions of seconds), and the characteristic size of finite elements mesh– around one millimetre. The process of forming an air flow in the channel and in a free jet - much more slowly and more large-scaled in space, therefore, the desired time step - tenths of a second or more, and the size of finite elements mesh - decimetres and meters.

It should be noted that detailed picture of the flow near the screw in comparison with the integral characteristics of screw - flow rate and pressure behind the screw, has a weak influence on the parameters of the free jet.

Taking into account the mentioned characteristics, the average time of calculation of task about the formation of jet behind the screw, motion of flow in the channel and the escape of the free vertical jet might be very large and reach up to several days (with RAM ≥ 3.5 Gb).

Aim of this phase of the work is to compare the results of numerical calculation of gas-dynamic parameters of experimental installation with disk model of screw, with the results of the measurements of distribution of vertical velocity of escape in outlet section of the installation. The module contains five-blade screw with refurbished geometrical and aerodynamic parameters of screw. Measurements were performed using the metering rod with a length 2 m, on which with the gap 0,2m were installed 8 receivers of air pressure. The rod was mounted along the radius in the symmetry plane of the sector of outlet section.

In numerical calculation was used disk model of screw. Diameter of screw and model are equal. Disk model generates a stream with the specified volumetric flow rate, which is determined by the distribution along the radius normal to the plane of the disk velocity of the flow V_y, as well by the twist in the plane of model. The nature of the changes of vertical flow velocity V_y and linear velocity of the rotation V_z along the radius of screw (twist of the flow) for analyzed tasks is shown in Fig. 2.9.

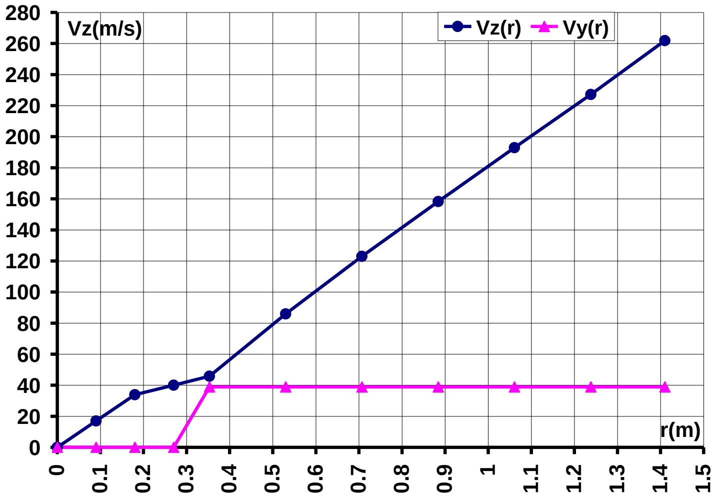


Fig. 2.9. Character of the changes of vertical velocity Vy (-▲-) and the linear rotation velocity Vz (-•-) of the flow along the radius of the airscrew.

Note that the picture of flow and distribution of velocity Vy(r) generally in installation and, in particular, in the outlet section is not symmetric (see Fig. 2.10.a). Therefore the average vertical velocity in the plane of symmetry of the outlet section in Fig. 2.11. is equal to 47 MPS. At the same time, the average vertical velocity in the whole outlet section equals ≈ 60 m/s, what is confirmed by the results of the calculation in Cfdesign program, taking into account uneven distribution of V_y (r) in the section (see Fig. 2.10.b.).

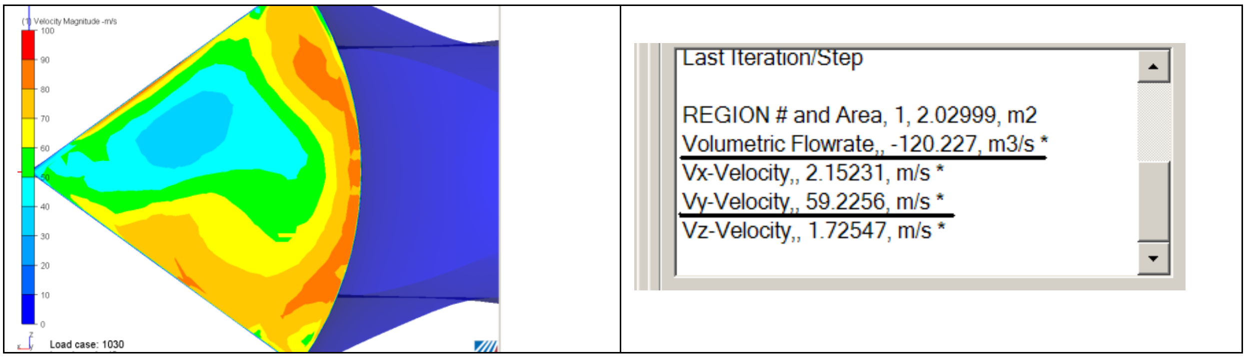


Figure 2.10. a) Picture of distribution of velocity Vy (r) in the outlet section of computer model of the experimental device; b) The results of calculation in the program CFdesign of the parameters averaged in cross-section.

The results of the calculations and measurements are presented in Figure 2.11., what confirms that 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.

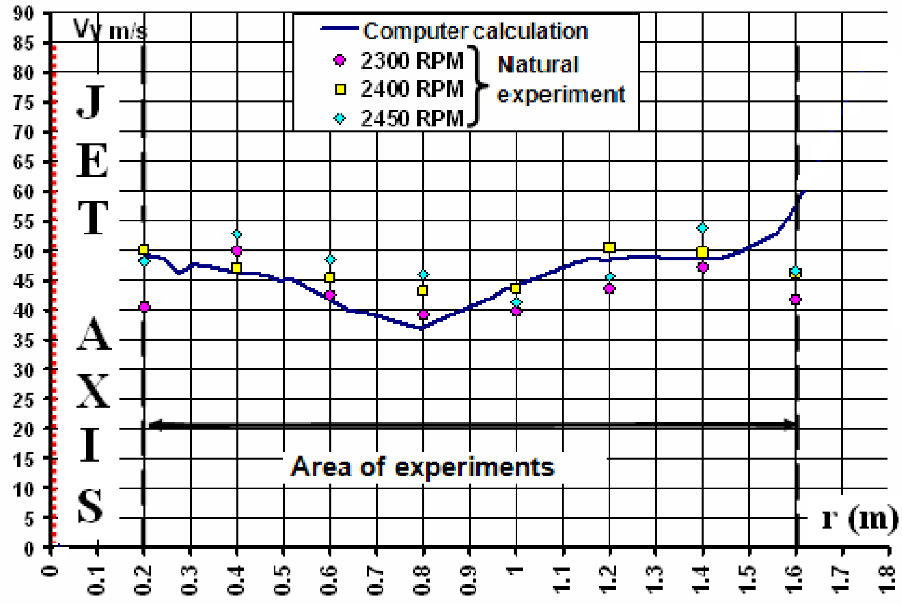


Figure 2.11. Comparison of results of numerical calculations and experiments of determination of vertical velocity Vy (r) in jet in the exit of the module of the experimental device.

CHAPTER 3.

COMPUTER SIMULATION AND OPTIMIZATION OF PARAMETERS OF AERODYNAMIC STANDS FOR THE FREE OF HUMAN

In this chapter are presented results of developing of computer simulation and numerical calculation methods of the aerodynamic parameters of three-dimensional computer models of different modifications of installations with the purpose of their optimization (decrease of dimensions and required power keeping the requirements of the air flow quality with the given speed in the working area of the jet).

Main tasks of this chapter:

- Development of method of computer simulation and numerical calculation of the aerodynamic parameters of three-dimensional computer models of installations with the generator of air jet for the purpose of their optimization.
- Optimization of one of the designs of aerodynamic stand for creation of large diameter vertical air jet presented by company;
- Development of method of computer simulation and analysis of the geometric and aerodynamic parameters of the complex aerodynamic installations, which generally contain

the system of fans (or aerodynamic screws), gas-dynamic channels and rectifiers for the formation of large diameter free vertical jet with the defined parameters.

In the first part of this chapter is considered the version of computer simulation and optimization of the generator of vertical air jet - the main element of open type installations for creation of conditions of free manned flight in the vertical air flow. The generator of air jet must be sufficiently universal so that it it would be possible to use it as separate module in the stationary, sectional and mobile open aerodynamic stands for the manned flight in the vertical air flow.

As disadvantages of many known systems of creation of vertical air jet in open type installations are the irrational construction of the above-indicated elements and the increased operational expenses because of high flow energy losses in the separate elements and in the system as a whole at the junction (combination) of elements into the common complex without taking into account their mutual aerodynamic effect on each other.

The computer simulation of open type installations by means of CAD/CAE programs allows to create different modifications of three-dimensional geometric models and to carry out the virtual blowing of the generators of air jet, thus obtaining the optimal geometric and aerodynamic parameters of the developed tunnels with the low material expenses.

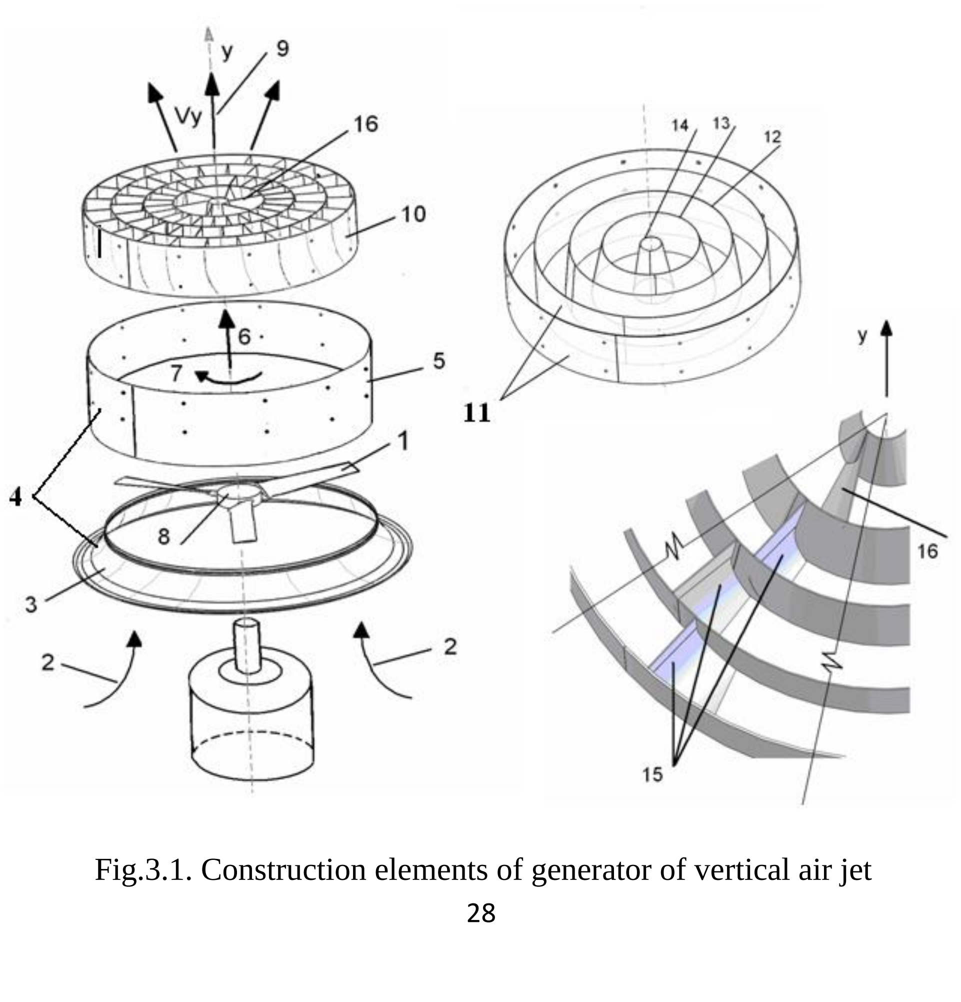


Fig.3.1. Construction elements of generator of vertical air jet

The generator of vertical air jet includes all above mentioned main elements of open type installations and it works as follows (Fig.3.1.). Rotating screw 1 creates before itself the zone of the reduced pressure, forming airflow 2, which moves in the inlet device 3 of gas-dynamic channel 4, cylindrical of part 5 of which adjoins to the inlet device 3. Curvilinear generatrix of device 3 forms smooth axisymmetric flow without the formation of the local flow separation zones and with the low energy loss factor before the screw. Aerodynamic screw is placed directly after the inlet device in the cylindrical part 5 of gas-dynamic channel 4. This composition usually is called “screw in the ring” and is intended for increasing the effectiveness of screw and decrease of energy loss in the generator.

Rotation of aerodynamic screw is realized by means of electric motor or internal combustion engine, which are connected with the screw shaft directly or through speed reducer. In both cases the engine or its speed reducer are coaxially installed before or in the entrance into the gas-dynamic channel in the zone of the low velocity of flow.

Configuration of the domain for the numerical calculations and creation of final elements mesh determined by the form of the model being investigated and by the air jet for the considered task is shown in Fig. 3.2.

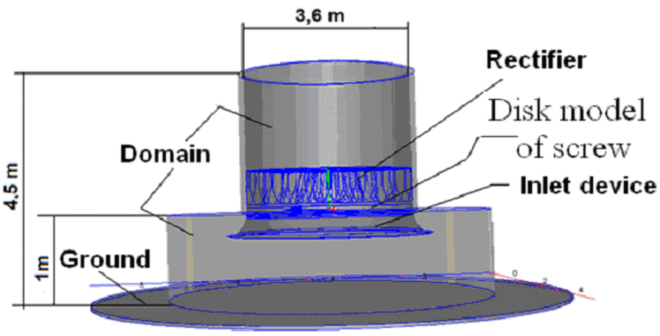


Fig.3.2. The computational diagram of the generator of air jet with the domain

In this part for the purpose of shortening of calculation time, instead of the screw, was considered disk model of the screw (fan).

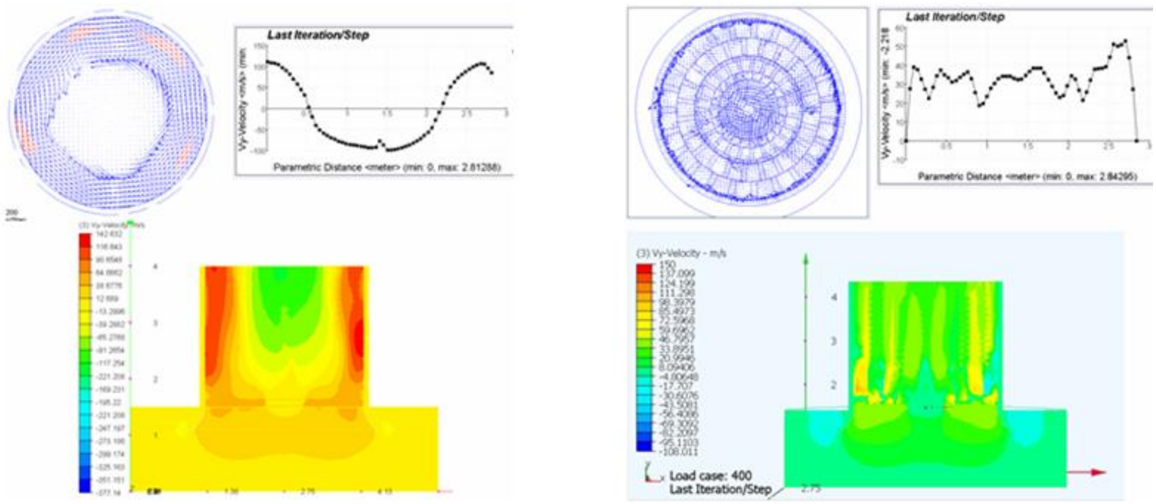
Below presented recommendations regarding the construction of air jet generators are the generalization of the results of numerical calculations of different models of open type vertical air jet generators. Main purpose of calculations consisted in creation of model of the generator of minimum height with the fixed diameter of jet at the outlet from the generator and the retention of requirements for the air flow quality with the given velocity in the working area of the jet. The proposed construction of the generator of air jet is universal and can be used as separate module in open type stationary, sectional and mobile installations for the manned flight in the vertical air flow.

Based on the executed calculations it was found that for the purpose of simplification of construction Fig 3.1., improvement of the operational aerodynamic properties of jet and reduction of the operational expenses all elements of generator, which create air jet, must be compactly placed inside one short vertical axisymmetrical gas-dynamic channel 4 (average minimum height of channel is approximately equal to a radius of screw). It is useful to perform the inlet device 3 as thin-walled axisymmetrical channel with the smooth curvilinear generating line of the type of Bernoulli's lemniscate. Aerodynamic screw should be placed in the adjacent to the inlet device cylindrical part of the gas-dynamic channel directly behind the inlet device in the initial section of cylindrical channel or at a certain distance from it < 0.5 of diameter of the screw. To increase the speed of flow created by screw, the clearance between the ends of screw blades and the internal surface of cylindrical part must be not more than (2.0-2.5) % of the screw diameter.

It is desirable to install the fixed rectifier 10 with the height $(0.1 \div 0.4)$ of screw diameter in the small distance from it (not less than on 30-50 mm from the elements of the construction of screw and not more than 0.5 of screw diameter). The height of rectifier depends on the diameter of the screw hub and limitations to the height of gas-dynamic channel 4 (generally for the mobile installations). 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 (Fig. 3.1.). 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 hub of the screw 8 and reducing of velocity "failure" near the axis of vertical jet, in the centre of the rectifier in front of hub 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 V_y in a vertical plane of generator section, and as well the velocity profile V_y in cross-section of stream at distance of 1 m from outlet section of the generator without rectifier the device are shown in Fig. 3.3.a.



a) b)

Fig.3.3. a) Distribution pattern of flow swirling and vertical velocity component (V_y) in absence of air flow rectifying device. b) Distribution pattern of flow swirling and vertical velocity component (V_y) of air flow after installation of the rectifying device.

A similar picture of distribution of vertical velocity (V_y) for generator with rectifier is shown in Fig. 3.3.b. 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.

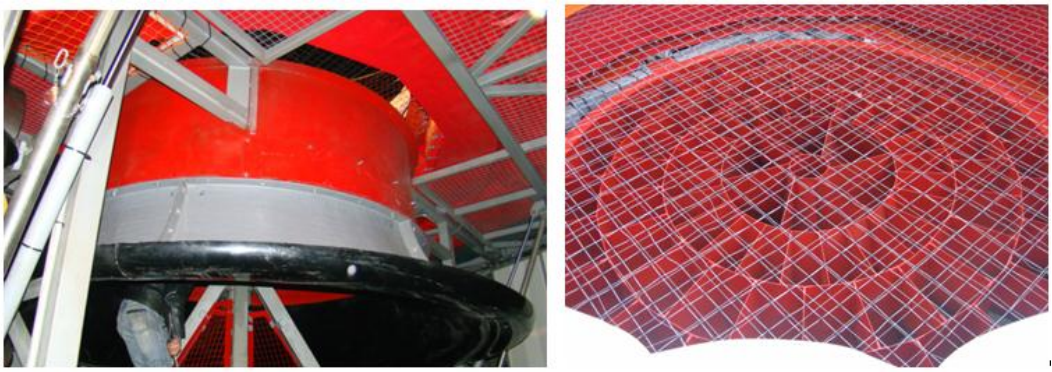
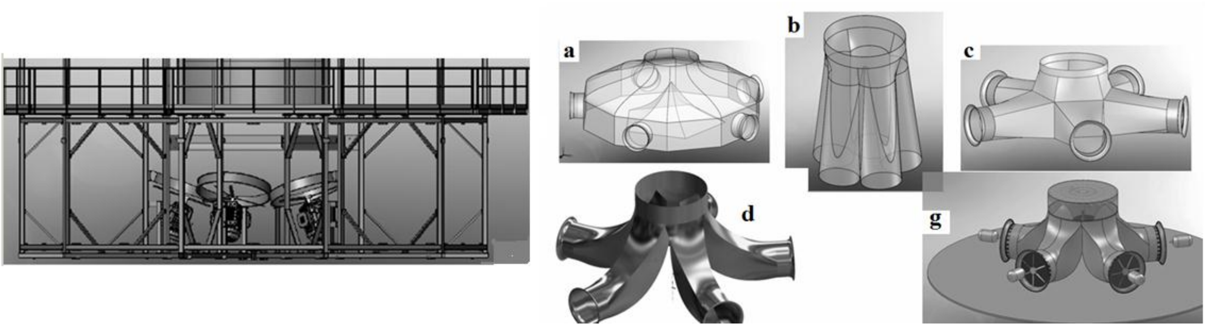


Fig. 3.4. Construction air jet generator.

Proposed construction with optimized geometric parameters of the generator of vertical air jet was used as separate module in the mobile open aerodynamic stends for the free manned flight. Installation was designed and manufactured in Latvia Fig 3.4..

In the next part of this chapter are presented the results of computer optimization of one of the real designs of aerodynamic stand for creating the large diameter vertical air jet. Initial aerodynamic stand (Fig.3.5.a) consisted of five symmetrically established propellers by the diameter of 1.8m, located inside the short cylindrical channels, whose axes were directed at the angle of ~80° toward the vertical axis of jet. Fans create five free collided jets, which according to the intention of designers had to create the required large diameter vertical jet. Trial natural experiments showed that the required parameters of vertical air jet do not realize.

In the process of computer optimization were examined several versions of constructions (see Fig. 3.5.b) a- g) of open type aerodynamic stand. One of main conditions of the optimized design was required use of the already existing aerodynamic screws, electric motors and electrical equipment. The analysis of geometry and results of numerical calculations of output aerodynamic parameters showed that best of the developed versions, which are presented in Fig.3.5.b) a-g is the version, shown in Fig.3.5.b) g.



a) b)

Fig. 3.5. a) Initial aerodynamic stand; b) Examinated options of stand structures.

In the designed and investigated computer model of aerodynamic stand (Fig.3.5.b) g.) vertical air jet creates five serial five-blade screws with the diameter 1.8m, whose horizontal axes are symmetrically located in the circle along its radii. Each screw is installed into the profiled ring, which behind the screw passes into the three-dimensional channel of complex L - shaped form for the smooth and the nonseparable turning of flow at 90˚ in parallel to the vertical axis of installation. After the completion of the turning of all five channels they are junked into one axisymmetrical nozzle with the diameter ~3.6m, which forms free jet. The finite-element computational model of the optimized full-scale tunnel with vertical jet is shown in Fig.3.6. The results of the computer calculations of the symmetrical 1/5 part of this installation, and also their comparison with the results of physical experiment are presented in chapter 2, section 2.4.

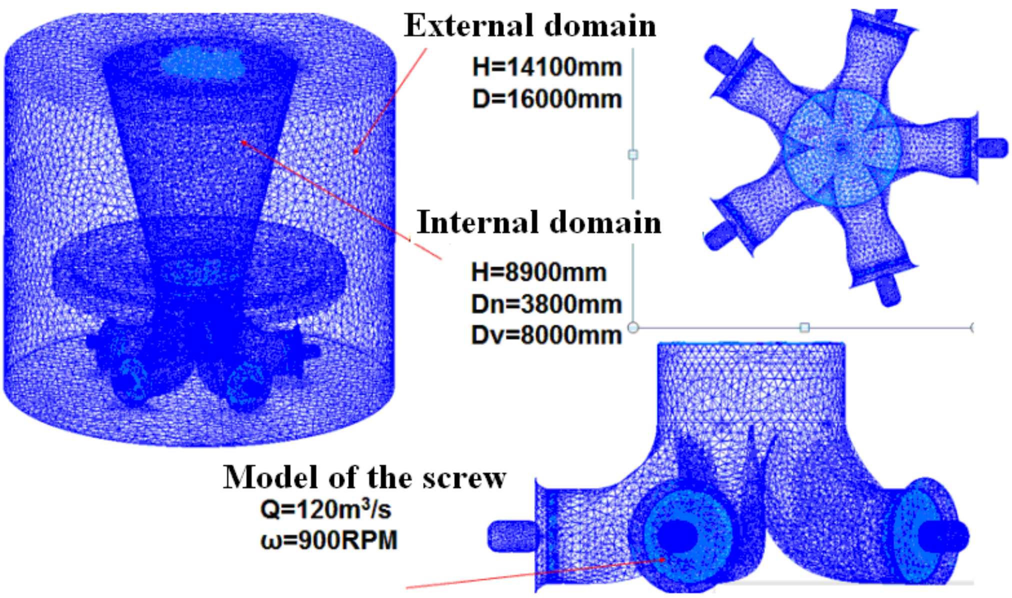


Fig. 3.6. Finite element computational model of optimized tunnel with natural dimensions

Main advantages of the proposed version: the lowest hydraulic losses in the gas-dynamic circuit; the shaped channels and the absence of the mixing chamber made it possible to avoid energy losses due to the collision of the jets, created by screws, which as a result increased the efficiency of tunnel; the use of a system screw in the shaped ring, increased flow rate and velocity of flow behind the screw; construction made it possible to obtain the maximum speed (~60-70 MPS) in the initial cross-section area of vertical jet at the outlet from the gas-dynamic channel with the defined geometry of screw and power of electric motors, and also the maximum uniformity of flow in working area of jet. The special feature of proposed construction of aerodynamic stand is absence of special rectifiers behind the screws, since the macro-vortices, which are formed after them considerably destroy each other because of the identical direction of rotation of all screws. Calculations showed that for smoothening and elimination of residual twist of the flow in the form of five zones it is sufficient to install on the outlet nozzle circular honeycomb with the low energy loss factor. The results of calculations, presented in Fig .3.7., confirm this conclusion.

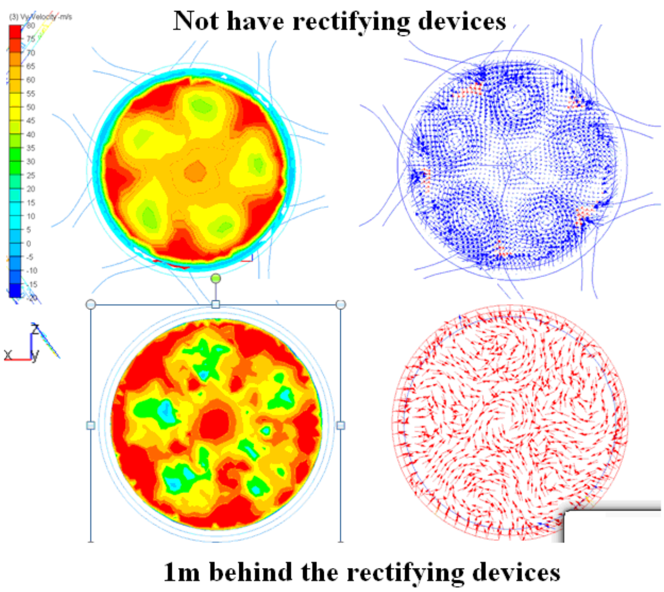


Fig.3.7. Distribution pattern of vertical velocity and swirling zones in the jet.

It must be noted that in the optimized design the computer simulation made it possible to solve the complex geometric problems of connection of air ducts sections with the observance of limitations to the narrowing and extension angles, the smoothness of transitions and turnings of channels, junction of several channels.

For determination of the optimal angle of installation screw blade of aerodynamic stand and estimation of power expenses of aerodynamic stand was performed a series of natural experiments. Experiments were conducted on 1/5 part of the installation, considered in the second chapter, for the different numbers of revolutions in the range 2000-2450 RPM and with the angles of screw blade 11°-16°. By means of pressure sensors were determined full and static pressure, and then was calculated flow velocity. These data were used in the computer calculations considered in the second chapter.

Fig. 3.8. shows full-scale installation which was designed, manufactured and installed in Jelgava (Latvia), in accordance with optimized computer model.

Fig. 3.8. Full-scale plant in Jelgava (Latvia).

MAIN CONCLUSIONS

1. Based on modern engineering CAD/CAE programs was formulated the method of computer simulation and calculation of the parameters of on ground located aerodynamic stands (or open wind tunnels), who are creating the large diameter vertical air jet of. Indicated stands are intended for the free manned flight in the vertical air flow.

2. Developed methods of computer simulation and numerical calculation of aerodynamic characteristics of refurbished aviation screws, allowing to obtain results of the calculations, which with accuracy of 5 - 10% coincide with known experimental data.

3. For the five-blade screw with the restored geometry, which was installed in the designed and manufactured module of experimental aerodynamic installation, results of executed natural experiments confirmed the satisfactory matching of the calculated and experimental data of the value of the vertical velocity of air jet in the outlet section of module.

4. Developed methods of computer simulation of aerodynamic characteristics submerged vertical air jet generated by system “the rotating aerodynamic screw in a ring (shrouded propeller) – rectifying device with profiled blades”. The given method provides possibility of change of frequency of rotation of the screw, the registration of influence of

geometry of the screw on the form of blades of the rectifying degree of an air flow in a working zone of jet.

5. Based on a series of calculations performed to optimize the geometry of the aerodynamic stands for generation of vertical air jet proposed universal design of air jet generator, which can be used as a separate module in stationary, sectional and mobile open type wind tunnels for the free flight of human in a vertical air jet.

6. Developed the method of computer simulation and analysis of the geometric and aerodynamic parameters of the complex aerodynamic installations, which generally contain the system of aerodynamic screws (or fans), gas-dynamic channels and rectifiers for the formation of large diameter free vertical jet with defined parameters.

7. Based on method (point 5) was designed, calculated and optimized aerodynamic stand with five symmetrically located five-blade screws, which create the submerged large diameter vertical air jet. Stand was manufactured, installed and experimentally tested in Jelgava (Latvia). Physical experiments satisfactorily confirmed the results of numerical calculations performed according to developed procedure.

LIST OF PUBLICATIONS

1. *V.Ušakovs, N.Sidenko.* Žāvējamās mašīnas nestacionāras skaitliskās analīzes metodika// Mašinzinātne un transports, Intelektuālais Transporta sistēmas 18. sējums, 2004.g. 11-13. oktobri, Latvija, Rīga.- Rīga: Izd. “RTU“ 2005.g.,- 102-112. lpp.

2. *V. Ushakov, N.Sidenko.* Aerodynamic characteristics of the vertical air jet behind the directing vanes of the aerodynamic propeller, installed on the ground// The Third World Congress “Aviation in the XXI-st Centery’’- Safety in Aviation and Space Technology 22-24 September 2008.g. Ukraine, Kiev – Kiev: Izd. “National Academy of Sciences of Ukraine National Aviation University” 2008.g.- 15.85-15.92p.

3. *V. Ushakov, N.Sidenko.* Численный анализ аэродинамических характеристик восстанавливаемого винта// 4 th International Conference on the Scientific Aspects of Unmanned AerialVehicles-2010, Poland, Kielce 5-7 May 2010, Izd. Kielce university of technology Faculty of Mechatronics and Machine Building Chair of Information Technology and Armament Al. Tysiąclecia P.P. 7, 25-314. Kielce, Poland, 590-601 p. ISBN 978-83-88592-70-6.

4. ***V. Ushakov, N. Sidenko, G. Filipsons.*** Computer simulation and optimization of parameters of device, which creates a large diameter vertical air jet by means of symmetric system of

fans// 2-nd International Specialized Symposium "Space & Global Security of Humanity" (SGS 2010). 5-9 July 2010.g., Riga, Latvia.- Riga: Izd. "Transport and Telecommunication Institute, 2010.g.", 96p., ISBN 978-9984-818-29-0. viperson.ru, http://spacesystems.tsi.lv.

5. *V. Ushakov, N.Sidenko.* Оптимизация аэродинамического иенератора вертикальной воздушной струи для свободного полета человека// IX International Scientific and Technical Conference «The Improvement of The Quality, Reliability and Long Usage of Technical Systems and Technological Processes»**.** Conference Dedicated 80 Years CIAM, december 12-19, 2010 Sharm El Sheikh (Egypt). 81-85 p. ISBN 978-966-330-106-8.

6. *Ushakov V., Sidenko N.* Development of computer simulation method and analysis of parameters of the vertical airstream generator for free flight of human// The 19TH International Scientific and Technical Conference on Transport, Road-Building, Agricultural, Hoisting & Hauling and Military Technics and Technologies. Jule 1-4, 2011 Bulgaria ISBN 1310-3946, http://elibrary.ru

7. *Ushakov V., Sidenko N., Filipsons G.* Computer Analysis of the Aerodynamics and Heat Exchange of a Cylinder in a Viscous Oscillating Flow // Automatic Control and Computer Sciences, Vol.45, Nr.6, pp. 346-360, Allerton press, inc a Division of Pleiades Publishing, Inc. ISSN 0132-4160, DOI: 10.3103/S0146411611060083. http://elibrary.ru - Springer, SpringerLink, Secaucus, New Jersey, USA, - Ulrich's International Periodicals Directory, New Providence, USA. - VINITI (Россия)

8. *Ushakov V., Sidenko N., Filipsons G.* Численный анализ особенностей аэродинамики и теплообмена цилиндра в вязком осциллирующем потоке // Научно-теоретический журнал Nr.6, 2011.g. „Автоматика и Вычислительная Техника", Изд. - Институт электроники и вычислительной техники Латвийского университета, 58.-76. с.

9. *Sidenko N., Filipsons G.* Система компьютерного моделирования нестационарных задач аэрогазотермодинамики с неподвижными и движущимися границами// The 20TH International Scientific and Technical Conference on Transport, Road-Building, Agricultural, Hoisting & Hauling and Military Technics and Technologies. June 27-29, 2012 Bulgaria ISBN 1310-3946, 71-74 p.

PATENTA CO-AUTORS

1. Nr. P-09-105 „Vertikālas gaisa strūklas ģenerators cilvēka brīvajam lidojumam", Rīga, Latvija V.Ušakovs, N.Sidenko, G.Filipsons.

LIST OF CONFERENCES

1. *V.Ušakovs, N.Sidenko.* Žāvējamās mašīnas nestacionāras skaitliskās analīzes metodika// Mašinzinātne un transports, Intelektuālais Transporta sistēmas 2004.g. 11-13. oktobri, Latvija, Rīga.
2. *V. Ushakov, N.Sidenko.* Aerodynamic characteristics of the vertical air jet behind the directing vanes of the aerodynamic propeller, installed on the ground// The Third World Congress "Aviation in the XXI-st Centery''- Safety in Aviation and Space Technology 22-24 September 2008.g. Ukraine, Kiev
3. *V. Ushakov, N.Sidenko.* Численный анализ аэродинамических характеристик восстанавливаемого винта// 4 th International Conference on the Scientific Aspects of Unmanned AerialVehicles-2010, Poland, Kielce 5-7 May 2010.
4. *V. Ushakov, N. Sidenko, G. Filipsons*. Computer simulation and optimization of parameters of device, which creates a large diameter vertical air jet by means of symmetric system of fans// 2-nd International Specialized Symposium "Space & Global Security of Humanity" (SGS 2010). 5-9 July 2010.g., Riga, Latvia.
5. *V. Ushakov, N.Sidenko.* Оптимизация аэродинамического генератора вертикальной воздушной струи для свободного полета человека// IX International Scientific and Technical Conference «The Improvement of The Quality, Reliability and Long Usage of Technical Systems and Technological Processes». Conference Dedicated 80 Years CIAM, december 12-19, 2010 Sharm El Sheikh (Egypt).
6. *Ushakov V., Sidenko N.* Development of computer simulation method and analysis of parameters of the vertical airstream generator for free flight of human// The 19TH International Scientific and Technical Conference on Transport, Road-Building, Agricultural, Hoisting & Hauling and Military Technics and Technologies. Jule 1-4, 2011 Varna, Bulgaria.
7. *Sidenko N., Filipsons G.* Система компьютерного моделирования нестационарных задач аэрогазотермодинамики с неподвижными и движущимися границами// The 20TH International Scientific and Technical Conference on Transport, Road-Building, Agricultural, Hoisting & Hauling and Military Technics and Technologies. June 27-29, 2012 Varna, Bulgaria

LIST OF PROJECT

1. Vertikālās gaisa strūklas aerodinamiskie aprēķini un „gaisa plūsmas taisnotāja" skiču projekta izstrāde. SIA „AERODIUM" (Rīga, Latvija). 2007. g.
2. Nr. R7320 Universālas datormodelēšanas sistēmas nestacionāru aerogāztermodinamisku uzdevumu risināšanai. IZM projekts RTU TMF AI. 2007. g.
3. Nr. R7330 Attiecībā pret plūsmu kustīgu ķermeņu nestacionāras aerohidrodinamikas un siltumapmaiņas īpatnību izpēte. RTU projekts TMF AI. 2008. g.