The development of a cloud system for investigation of UAVs aerodynamic characteristics

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Abstract. The paper presents the results of the development of a cloud system for multi-parameter aerodynamic calculations of unmanned aerial vehicles (UAVs). The developed cloud system consists of the following functional parts: web client – provides an access to the computing cloud, allows interactively preparing a task, sending prepared data to a computing cluster, getting and visualizing calculation results; and computing cloud – provides communication with the web client using an open API and manages the computing process. The computing process of the cloud is based on using open technologies of the OpenFOAM software adapted for solving aerodynamics problems. The authors carried out parametric studies of the external flow of UAV at free-stream velocities of 20, 25, 30 m/s with angles of attack from –4 to 12 degrees. It was found that the smallest drag force is observed for 0-3 degrees of the angle of attack of the flying wing, and the best lift to drag ratio is detected for 5 degrees attack angle. For 5 degrees attack angle the lift force is 47 N for an air free-stream velocity 20 m/s, 74 N – 25 m/s, 106 N – 30 m/s.

1. Introduction

Unmanned aviation is one of the fastest growing areas in the aviation industry, as it provides a wide range of opportunities for civilian applications. Aerial photography, objective monitoring of objects in hard-to-reach areas, small-sized cargo delivery, forest fire fighting, and emergency medicine is only a small part of a wide range of applications of unmanned aerial vehicles (UAVs).

In the field of aerodynamic design, the main task is to determine the optimal UAV geometry, delivering a minimum of the UAVs drag, taking into account the numerous limitations of various types and nature on the optimal solution [1-4]. UAV development is divided into a conceptual design phase and a detailed study of the final product [5, 6]. In the case of conceptual design, software systems are usually used that allow for rapid aerodynamic calculations using approximate calculation methods. The most popular at the moment are FwDesign, XFRL5, SailCut, XFOIL, Surfplan, Profili, etc. During the detailed study of the final product, the computational fluid dynamics (CFD) analysis of the three-dimensional model is carried out. At this stage, CFD software are used: Ansys, COMSOL Multiphysics, STAR-CCM+, XFlow, OpenFOAM [7], etc. Carrying out parametric studies using CFD software is a time-consuming task, since it is necessary to vary a large number of parameters: angle of attack, free-stream velocity, turbulence, various UAV configurations, 3D model, etc.

Therefore, the aim of the work is to develop a cloud system for investigation of UAVs aerodynamic characteristics. OpenFOAM is the most suitable of all CFD software for cloud system development. Since it contains a large number of numerical methods, physical and mathematical models, crossplatform, open source, C++, extensible architecture, GNU GPL license, the parallelization, compatibility with various third-party programs and file formats.

2. Cloud system

In figure 1 the topologies of the developed cloud system is shown. The cloud system consists of the following functional parts:

1. Web client – provides access to the computing cloud, and allows you to interactively prepare the task, send the prepared data to the computing cluster, get and visualize the calculations results.
2. Web server – processes client requests, accept three-dimensional models as STL files and parameters for calculations, which stores user data in the database, forms solver cases and queues tasks (Task Manager Server), returns task status and calculation results.
3. Task Manager Server – task scheduler, uses available resources of the computing cluster.
4. Computer Cluster – provides parallel calculations using high-performance computing systems of the SKIF Cyberia Supercomputer [8].

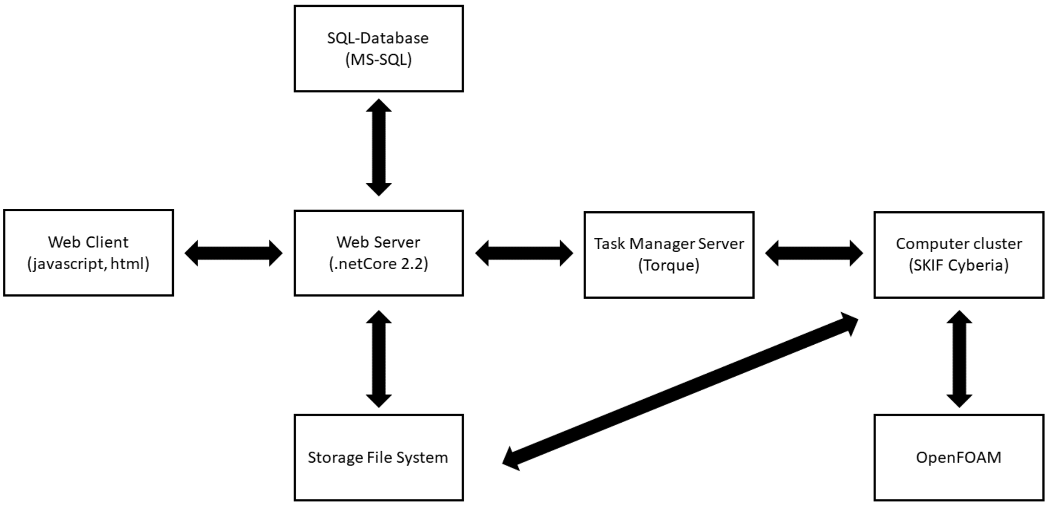

Figure 1. The topologies of cloud system.

3. Physical and mathematical model

The problem of external flow around a flying wing with different angles of attack is considered. In figure 2 the three-dimensional model of the developing flying wing, and in figure 3 the calculation area with boundary conditions are shown. It is estimated that cruising flight speed will be 20-30 m/s, Reynolds number Re=10^6.

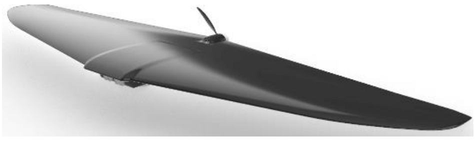

Figure 2. Flying wing.

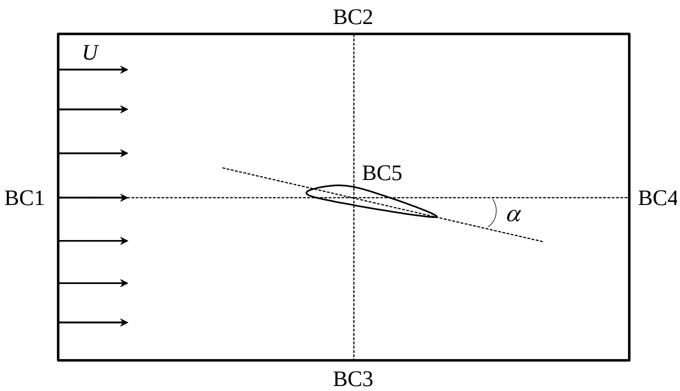

Figure 3. The calculation area with boundary conditions.

For the mathematical description of the problem, the Navier-Stokes equations for an incompressible fluid are used. The system of equations for an incompressible viscous fluid in the Cartesian coordinate system x_1, x_2, x_3 has the following form [9-11]:
The continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0. \tag{1}$$

The momentum equation

$$\rho \frac{\partial u_{ij}}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right) \tag{2}$$

The Reynolds stress tensor is allowed from the assumption of the Boussinesq hypothesis [12]. To close system of equations (1)–(2) Menter's turbulence model are used [13]. In figure 3, the calculation area is shown. Initial conditions for velocity u=0, and pressure p=p0 are set. Boundary conditions (figure 3) BC1: for velocity $u=u_0$, turbulence kinetic energy $k= k_0$, turbulence dissipation $\omega=\omega_0$; BC2, BC3: $\partial/\partial n$ for all parameters; BC4: pressure $p=p_0$; BC5: velocity u=0, turbulence kinetic energy k – wall function (kqWallFunction), turbulence dissipation ω – wall function (omegaWallFunction) are used.

For implementation of the physical and mathematical model and conduct numerical research free software OpenFOAM was used. Numerical method on finite volume method is based. Hexahedral numerical mesh was make automatically using snappyHexMesh utility [14, 15]. For numerical procedure to solve Navier-Stokes equations, SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm was used [16]. System of linear of algebraic equations using the Gauss-Seidel method was solved. The time sampling by Euler method was carried out. The tests of OpenFOAM solvers are done in [17–20], where good agreement with experimental and theoretical data are shown.

4. Numerical results

Parametric calculations for UAVs 3D model (figure 2) are done. The computational grid was generated by snappyHexMesh utility, the number of computational cells are 1.5 million. Air free-stream velocities of 20, 25, and 30 m/s with angles of attack from –4 to 12 degrees are considered.

In figures 4 and 5, numerical results are shown. Figure 4(a) shows the change in lift force depending on the attack angle. The lifting force varies linearly, it can be seen that for velocity of 30 m/s at negative angles of attack the lifting force is less and at positive angles it is more in comparison to a variant for velocity of 20 m/s. In figure 4(b) drag forces are shown. With an increase in the velocity of an air free-stream from 20 m/s to 30 m/s, the drag force increases twice. The lowest drag force is in the range of 0-3 degrees of attack angle.

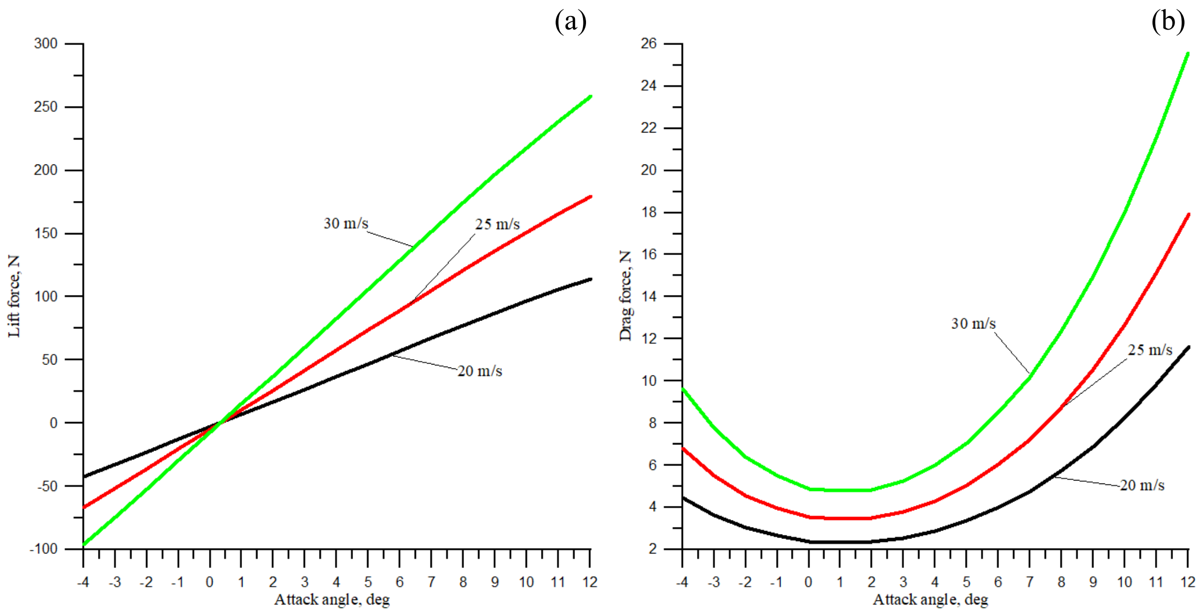

Figure 4. Lift force (a), drag force (b)

In figure 5, lift to drag (L/D) ratio for flying wing is shown. On the graph for all considered velocities the curves of lift/drag ratio of the wing qualitatively coincide. The maximum lift to drag ratio of the wing is observed for 5 degrees attack angle and is 12-14, the worst at negative attack angles. After 5 degrees attack angle there is a decline in L/D ratio to 10. Based on the best L/D ratio the lift force at 5 degrees attack angle is 47 N for air free-stream velocity 20 m/s, 74 N – 25 m/s, 106 N – 30 m/s.

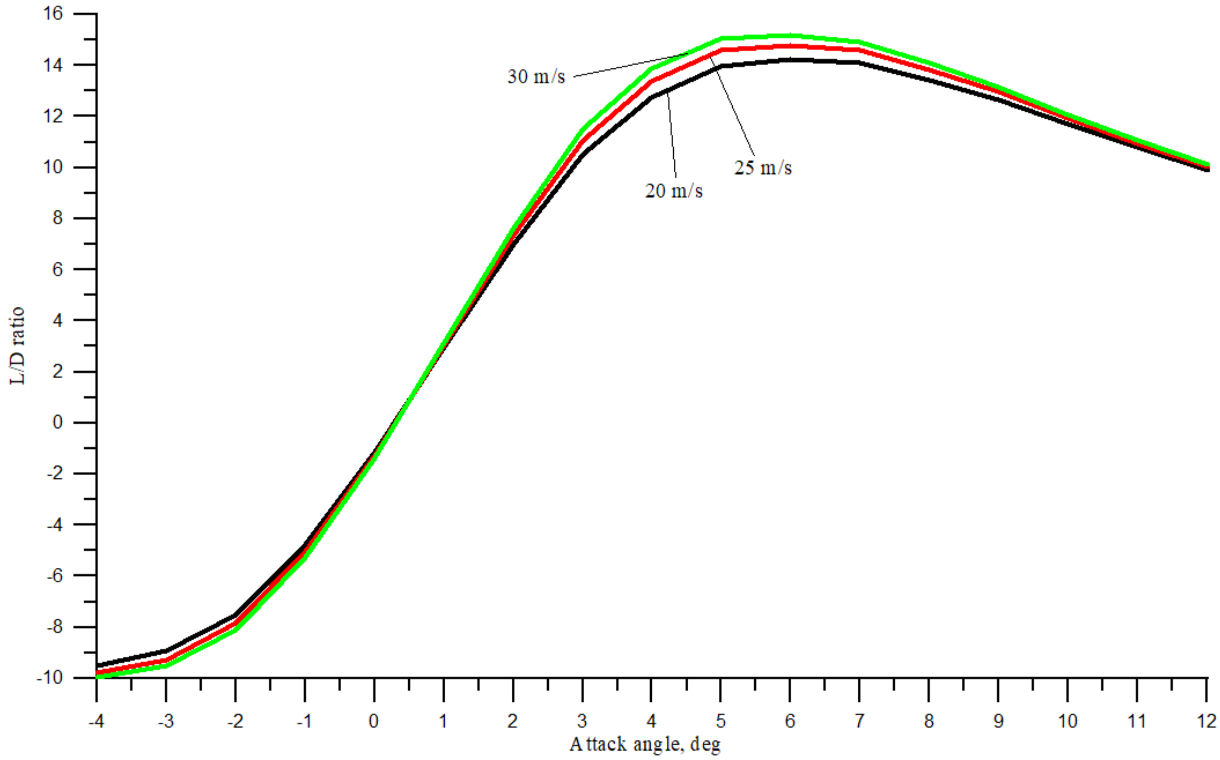

Figure 5. The calculation lift to drag ratio

5. Conclusion

A cloud system for conducting multi-parameter aerodynamic calculations of UAVs was developed. The computing process of the cloud is based on the OpenFOAM software, which was adapted for solving aerodynamic problems. The developed cloud system can be used for a wide range of tasks in addition to aerodynamic calculations. It is enough to configure or create a new solver in OpenFOAM for the required physical and mathematical model by determining the generation parameters of the computational mesh. This system is an analog of such as Simscale, HELYX-OS, Visual-CFD, etc. Authors' cloud allows isolating user from the technical details of the computing process and provides the opportunity to conduct computational experiments without the need to install specialized hardware and software at the workplace.

Parametric studies of the external flow around the UAV at free-stream velocities of 20, 25, 30 m/s with angles of attack from –4 to 12 degrees were carried out. The values of the lifting force and the force of the external aerodynamic drag was calculated. The lowest drag force for 0-3 degrees attack angle of the flying wing was obtained. The lift force for a free-stream velocity of 30 m/s compared to 20 m/s was doubled. The highest lift to drag ratio of the wing at 5 degrees attack angle was observed.

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