29th Congress of the International Council of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

COMPUTING SIMULATION FOR FIRE FIGHTING HELICOPTER OPERATION ANALYSIS

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Keywords: *helicopter; liquid tank; computing experiment*

Abstract

The simulation approach of water discharge from helicopter water tank onto external suspension is proposed in this paper. The FlowVision application program is used for numerical experiment. The experiment-calculated procedure for lifting rotor velocity field estimation is suggested. This procedure is based on real lifting rotor experimental data for different helicopter flight speed and known vertical velocity versus radius in lifting rotor plane. Absolute rigidity of water tank and rope is also supposed. The fire is burning around cylinder oil storage tank. The numerical experiment with Ka-32 helicopter presents of this simulation approach. This helicopter moves straight-and-level with flight speed of 38 km/h. This numerical experiment procedure can be used for fire-fighting helicopter design and operation analysis.

Introduction

The need for operational fire control requires creation and improvement of fire-fighting helicopters. Currently, the most widely used extinguishing method is fluid dumped from the water tank onto external suspension (below we use term “helicopter buckets”, HB). The main problem of this fire control method, in addition to flight safety, is optimum use of water received aboard a helicopter. In this regard, the development and improvement of HB and fire-fighting strategies do not stop. At present, the success of the development and application of such systems depends solely on the accumulated experimental data. This greatly increases the value of engineering design errors, as the flight experiment is expensive and does not cover the most extreme situations that may occur in the operation of fire-fighting helicopter. Therefore CFD (Computational Fluid Dynamics) simulation is of interest. There are a few papers on numerical simulation of this problem (example, [1]).

In the present paper we propose a CFD technique for modeling fluid dump from the HB. We take into account the fire, the downwash, HB swing. The following tasks are considered:

- the CFD simulation of the lifting rotor (below we use “rotor”) downwash, fire upflow, the HB swing, liquid jet decay into droplets;
- the CFD simulation of water dumping from Ka-32 helicopter with all the above-mentioned tasks taken into account.

The calculations were performed using the software package FlowVision 2.5.

The different design approach examples are sprinkler VOP-3 by NPK “PANH” design, VSU-5 designed by NII AUS (Feodosiya town), semi-rigid HB Bambi Bucket (Canada).

1 Formulation of the Problem

Consider a physical model of a helicopter with HB for firefighting. The most difficult task is the rotor velocity field simulation.

A commonly used calculation method of rotor stream parameter [2] allows us to determine the average velocity as a function of radius and the distance from the rotor plane. However, scattering and dispersed droplets are determined by instantaneous rather than average velocities near HB [3,4]. Also these velocities define the maximum load on the HB. Another approach is the direct solution of the gas dynamic equations with regard to the spatial position of the rotor blades (example, [5,6]). Theoretically, this approach can be a sufficiently accurate solution, but wants extremely large grids.

Hereupon an experiment-calculated method [7,8] is proposed for determining the rotor flow, using the experimental data at different flight speeds and the known distribution of the rotor vertical velocity function of the radius below the rotor plane. By setting the lower rotor blade side blowing air jets, and on the top - the corresponding air mass runoff, it can fit the gas velocity distribution along the rotor blade radius so that the resulting rotor stream should coincide with the experimentally observed one at different flight speeds. The virtual blade rotation forms an unsteady velocity field around the helicopter. The experimental data obtained by Gromov Test-Flight and Research Institute for Ka-32 helicopter [9].

This approach can significantly reduce the computational time and the demands on the computer. It is cost-effective and takes into account the actual aircraft shape and the rotor blade position.

The second problem is modeling of HB oscillations. In scientific and technical literature there are different difficulty levels to solve this problem (see [10-15]). In the present paper the HB swing problem is solved taking into account the rotor downwash on the assumption of absolute rope and load rigidity.

Atmospheric turbulence must be taken into account when calculating the water droplet trajectories outside the rotor downwash (at high-speed or high altitude flight). The turbulence simulation methodology from the manual "Atmosphere" [16] was used.

The main task of fluid drain modeling through the nozzles is the droplet trajectory calculation in order to obtain their distribution on the earth's surface. The droplet volume fraction in the main part of the trajectory fall does not exceed 10^{-3}, so you can expect the movement of each droplet alone, without their influence on each other. The main forces acting on a drop are drag and gravity forces. The movement of a certain number of test particles traced to the surface and their distribution are analyzed in simulation. A test particle is not a single one but present many particles. FlowVision software [17] takes into account the evaporation of particles. This option is used in water drain simulation onto the fire.

A gasoline storage tank in the circular cylinder shape serves as a source of fire. Since the gasoline burn-up rate is known from experiments, the fire, as well as rotor flow, is simulated as a hot gas source with a known flow rate. The adequate air flow runoff is simulated as a ring sink on the upper edge of the tank, since combustion is accompanied by a significant air inflow to the flame (gasoline stoichiometric ratio is about 12).

The mathematical model equations include three-dimensional Navier-Stokes equations for compressible flow and k-ε turbulence model [17].

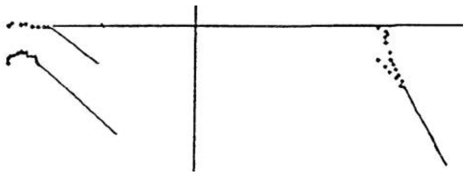
2 Simulation of Different Parts of Complex Problem

2.1 The Rotor Flux and the Velocity Field Simulation around the Helicopter and HB

The calculations were made for the Ka-32 helicopter with VOP-3 and VSU (weight of 3 tons, the distance from the fuselage to the HB upper edge is 11 m) as HB. Some the CFD simulation results are shown in Fig. 1.

From a comparison of the test particle position (they visualize the tip vortices obtained by calculation) and the maximum velocity module range on a side view (Fig. 1-b) with the experimentally obtained tip vortex positions (Fig. 1-a) it is clear that in the simulation the velocity distribution along the rotor radius gives a jet corresponding to an experimental one. Calculated (red) dots scatter on the experimental jet boundaries is due to the fact that after the experiment the data was averaged and the numerical results are given in the "snapshots" form.

For flight speed of 5 km/h to 138 km/h the same velocity distribution along the rotor radius is used. This reduces the number of natural experiments to determine this velocity for other helicopter types to 2 modes (hovering and flying with the maximum permitted speed).



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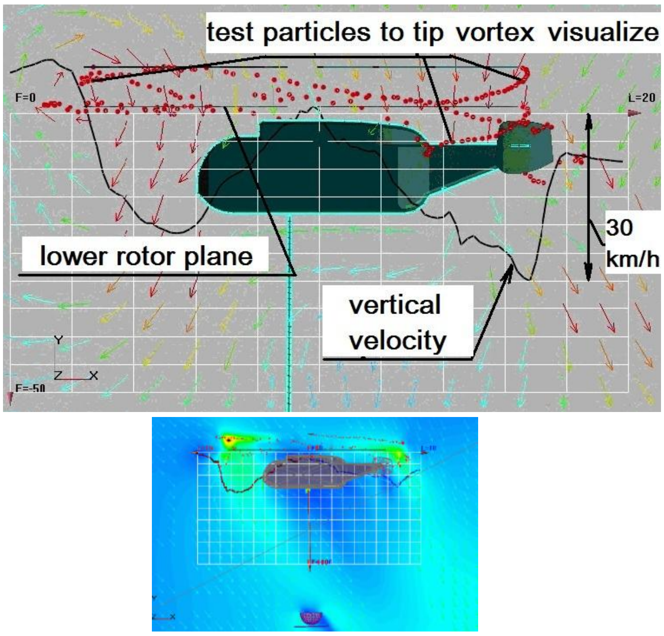


b)

Fig. 1. Flight speed is 38 km/h. Arrows indicate the direction of the velocity in the coordinate system associated with aircraft. Black line is the vertical velocity plot ("instantaneous" snapshot) in the plane between the fuselage and the lower rotor plane. White grid is the velocity plot grid, vertical mesh size corresponds to 5 km/h, horizontal - 2 m. The red dots are test drops, drop diameter is 1 mm and a density of 50 kg/m3, released from the the rotor blade tips.

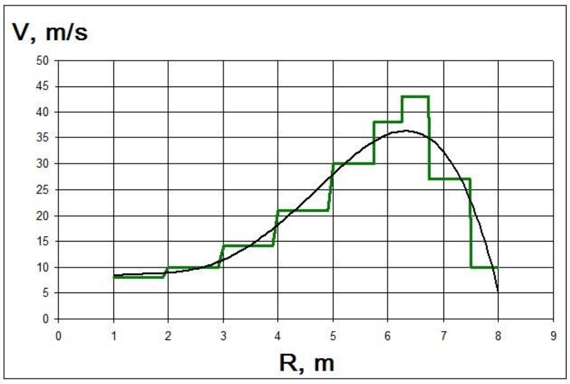


Fig.2. Velocity distribution along rotor blade for simulation.

The numerical experiments showed (Fig.3) that VOP-3 exits from rotor jet when flight speed is greater than 40 km/h, and noticeable (over 10^{o}) downwash induced by the jet keeps near VOP-3 up to flight speed about 100 km/h. Therefore, we can assume that at low velocities the rotor jet exerts the main influence on the droplet scattering rather than quiet atmosphere turbulence.

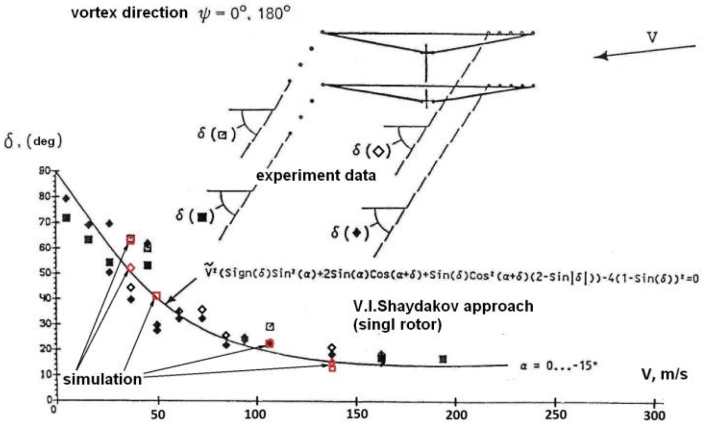
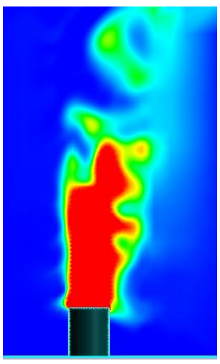


Fig. 3. Comparison of experimental and simulated (middle) angles of trailing vortex trajectory as function of the flight speed V.

2.2 Fire Upflow Simulation

Fire upflow simulation should be carried out for correct account changes in the mass and trajectory of droplets due to evaporation and variable velocity field. Some results are shown in Figure 4. Boundary conditions corresponds the decrease in pressure with height by the isothermal atmosphere law. Upflow, as expected (example [18]), is a subsonic axisymmetric jet, the maximum flow velocity not near the fire, but with some increase in height.



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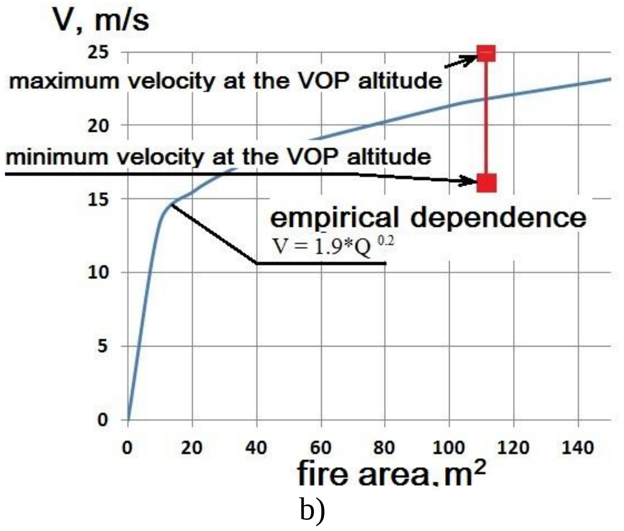


Fig. 4. Fire upflow parameters (burning oil storage tanks with a diameter of 12 m). a) - color shows the temperature field (blue corresponds to a temperature of 0 C, red is 100 C); b) – red squares are the simulation results, the VSU above the fire at 20 m. Shown is the plot of maximum upflow velocity (empirical dependence).

2.3 The Drain Water Stream Simulation

Before carrying out a comprehensive numerical experiment it is necessary to clarify the need to incorporate a solid reach of the liquid stream. Here's the problem - to define the dispersiveness of droplet flow. However, the conditions of HB use allow to simplify the task to a certain degree. Since the main mechanism of the liquid stream decomposition is the aerodynamic effect, it is possible to determine the droplet mass fraction and dispersiveness by approximations for aerodynamic droplet (not stream) crashing in a drifting air stream as described in the review [19]. The solid liquid stream decomposition was simulated, with surface tension forces taken into account to assess the validity of this approach. Figure 5 shows that the solid reach of the liquid stream is practically absent, therefore, to reduce the simulation time we can ignore this section assuming that the known diameter droplets leave immediately the drain hole. The droplet size was determined by the critical Weber number $We_{critical}$ by formula

$$D_p = We_{critical} \cdot \sigma / (\rho_g \cdot |\mathbf{W}_g - \mathbf{W}_p|^2),$$

where σ - the surface tension of drop substance (for water σ = 0.075 N/m), and $We_{critical}$ was assumed to be 12 (for maximum velocity near VOP-3 droplet diameter is 44 mm).

The drain water stream simulation with different divergence angle of droplet flow (Fig. 6) showed that the control of this angle allows to adjust a sprayed zone width in a very wide range.

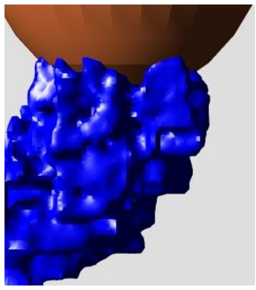


Fig. 5. The surface of the liquid stream (shown in blue) during VSU drain at 38 km/h flight speed (side view).

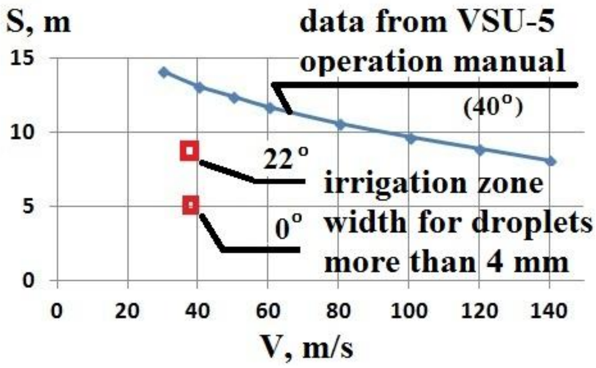


Fig. 6. The water stream dump with different divergence angle of droplet flow. Comparison of simulation data of sprayed zone width (red squares) and data from VSU-5 Operation Manual (“PANH ” NPK).

3 The simulation of helicopter operation

3.1 The simulation of VOP-3 spray device operation for Ka-32 helicopter

In the first stage (excluding fire) to verify the proposed approach the VOP-3 operation on Ka-32 helicopter was simulated at a flight speed of 38 km/h with the use of the spray device [21]. There is an experimental data for this case.

A rectangular adaptive computational grid was used (Fig. 7, the red dots visualize the drop flow). Comparison with the results obtained on a finer grid showed that the used grid is sufficient to determine the particle landing points with an accuracy of 20 cm.

Fig. 8, 9 show the simulation results at a certain moment of time ("instantaneous" snapshot). It is evident that some portion of the spray device comes into the so-called "shadow", with strong transverse fluctuations of air velocity, so droplets from this zone will be scattered maximum.

The lifting rotor jet turn significantly affects the droplet trajectory at a low (up to 3 m) height, dramatically increasing transverse deviation of drop landing points from the helicopter symmetry plane. Therefore, the sprayed strip width will somewhat reduce with flight speed increase. It is shown from Fig. 9 that the width of wet range is 12±1 m where is major part of water, which is consistent with the experimental NPK "PANH" data.

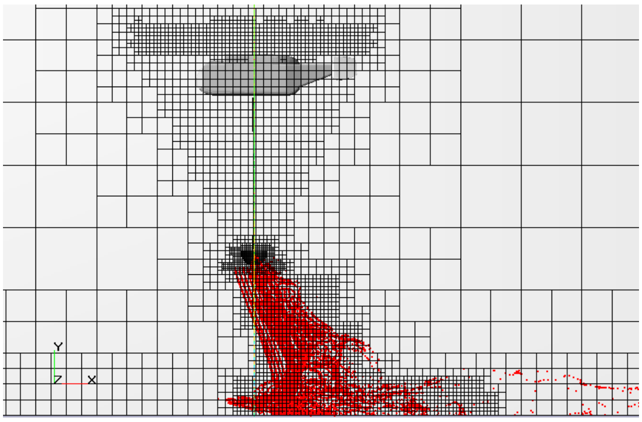
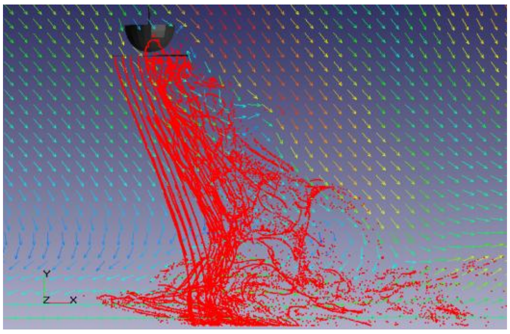


Fig. 7. Computational grid (side view). The red dots visualize the drop flow.



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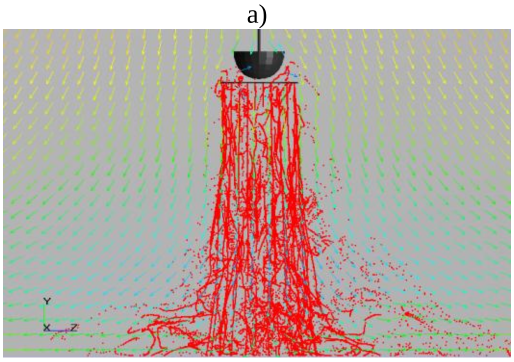
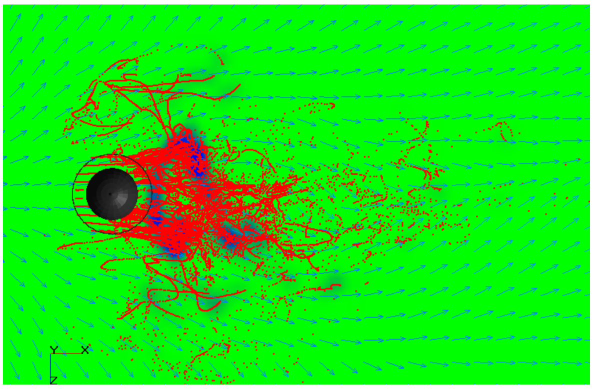


b)

Fig. 8. The water stream drain during VOP-3 drain of 38 km/h Ka-32 helicopter flight ("instantaneous" snapshot). a) – side view; b) - front view. The red dots visualize the water drop flow.



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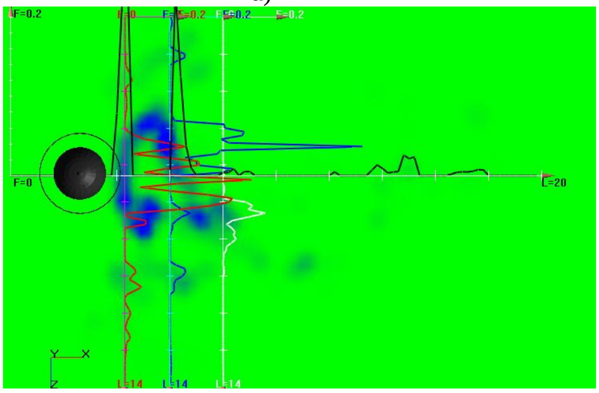

b)

Fig. 9. The water stream drain during VOP-3 drain of 38 km/h Ka-32 helicopter flight ("instantaneous" snapshot, plan view). The blue color corresponds to the water concentration on the earth of more than 200 g/m^2. Diameter VOP-3 (black circle) is equal to 3 m. a) – the red dots visualize the water drop flow; b) - distribution of the water concentration collected on the ground at a time (fill color and a few plots). F = 0.2 corresponds to 0.2 kg/m^2.

3.2 The simulation of the water dump from the large hole of VSU-5 on Ka-32 helicopter suspension onto the fire

Simulation of water dump from the VSU-5 by Ka-32 helicopter onto the fire was performed using early proven methods for rotor flow and fire upflow simulation (Fig. 10). The rotor flow substantially alters the velocity field in the fire zone (Fig. 10). The calculation results show that the droplets should be larger than 1.5 mm, and for this it is necessary to change the flight speed, so that the VSU-5 has not been in the area of the rotor maximal velocity.

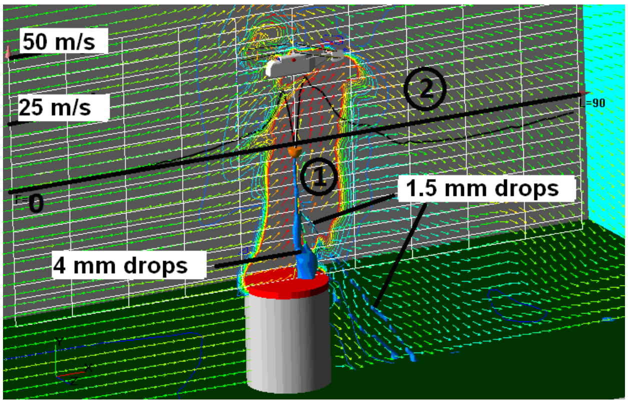

Fig.10. Water dump from the VSU-5 onto the fire, flow rate 800 l/s, flight speed 38 km/h. 1 - zone with a temperature of over 100 °C (limited by red contours); 2 – rotor downward flow. Black thin line is the vertical velocity plot along the coordinate axis (thick black straight line). Simulation is performed in the coordinate system associated with the helicopter.

Conclusion

The CFD simulation analysis shows that the proposed method takes into account the complex factors that influence the helicopter operating efficiency to extinguish, to assess the drop settling zone and drop concentration with reasonable accuracy. Also modeling technique gives a guaranteed maximum estimate, it is possible to predict the area where all the particles of a specified size fall out.

Totally justified is the proposed approach to the modeling of the velocity field near helicopter based on experimental data for a particular helicopter type. The well-defined helicopter types are used for fire fighting in a narrow range of flight configuration, so the receipt of necessary experimental data is a feasible problem.

The obtained results make it possible to use the proposed simulation technology for testing HB versions and tactics of their application without test flights.

It is shown that atmospheric turbulence and HB oscillations under the influence of aerodynamic forces are not significant factors influencing the HB efficiency.

We can make the following recommendations to improve the efficiency of the fire suppression using HB:

- HB use, creating a droplet stream with a diameter of not less than 1.5 mm;
- flight speed should ensure the dripping into the fire before the rotor jet (it is more than 38 km/h on the minimum allowed by the safety altitude requirements for Ka-32 and VSU-5) to extinguish the fire "on the move"
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Also, to narrow a strip sprayed over, you can use the following methods:

- it is necessary to increase the flight speed of the more than 38 km/h for HB not to be in the zone of maximum rotor velocity;
- increase the fluid flow rate (droplet density and velocity), but it is important that the droplets reach the fire before interaction with the rotor jet;
- to improve the HB outlet, using device regulating the divergence angle of droplet flow, or change the nozzle length.flight speed should ensure the dripping into the fire before the rotor jet (it is more than 38 km/h on the minimum allowed by the safety altitude requirements for Ka-32 and VSU-5) to extinguish the fire "on the move".

The authors are grateful to Parshentsev Sergey (NPK "PANH”) for the cooperation in the course of the work.

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