Features of the influence of air wetness on aerodynamic characteristics of mechanizations wing during takeoff

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The results of numerical studies were carried out on two-components ambient: in dry and wet air. The influence of the volumetric content of water vapor in the air on maximum lift, drag and critical angle of attack was studied. Numerical studies were carried out using the numerical code for the Reynolds-averaged Navier–Stokes equations.

Keywords: aerodynamic characteristics, take-off characteristics, thermodynamic properties of the environment, CFD- methods.

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The molecular and thermodynamic properties of a medium have a direct effect on the airflow around the aircraft. It is known that humidity, the effect of which on air density is negligible at low temperatures and noticeable at high temperatures, contributes to lower air density compared to the density of dry air. It is accepted that the values of the atmospheric parameters in height are calculated using the formulas obtained for the standard atmosphere [1], assuming that the air is completely dry. In real life, air always contains a certain amount of water vapor, and its parameters differ from the standard values. The effect of fog on the aerodynamic characteristics of aircraft is still not well-known. Problems associated with fog impact on aircraft equipment during takeoff or landing are usually associated with limited visibility below acceptable limits, without taking into account the impact of environmental changes [2–4]. The peculiarity of such impact is that a noticeable effect is observed only in separated flow modes, which is a new result. This study was carried out in order to identify the facts and mechanisms of fog impact on the aerodynamic characteristics of the wing profile.

In this paper, a numerical study of air humidity effect on the aerodynamic characteristics of a wing profile with a deflected flap in takeoff mode is carried out. The cross-section of CLARC Y+ profile of relative thickness $\bar{c} = 12\%$, with chord $b = 0.64$ m and deflected flap at $\delta_{flap} = 20^\circ$ is considered [5]. The flap chord is equal 1/3 of the wing profile chord. The nose of the flap profile is made in the form of a circular arc inscribed in the upper surface of the profile. The width of the gap between the major profile and flap is equal 1.5% of the profile chord (Fig. 1).

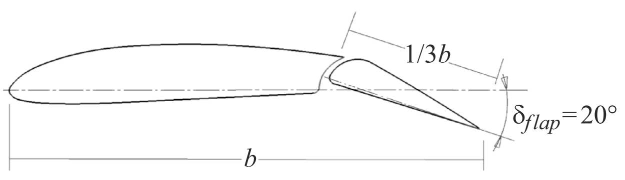

Figure 1. Computational model of the wing-flap profile .

Numerical studies were carried out in a stationary formulation according to a program based on solving Reynolds averaged Navier–Stokes equations on a structured computational grid containing about 1 million cells, 150 of which are located along the wing chord. To resolve the boundary layer, a special *o-grid*, constructed along the normal to the surface and containing 20 cells in height, was created. When modelling in the boundary layer region, the height of the first grid cell near the wing surface was chosen such that the boundary layer could accommodate a sufficient number of cells to calculate the near-wall function. Parameter $y+$ in the first near-wall point was $y+ \leq 0.365$. In computation we used *k-ε-realizable* turbulence model [6] with improved modelling of turbulence parameters near the wall. A one-parameter turbulence model adapted to the near-boundary flows was used in the wall region [7]. A simplified model of the medium was used to calculate the stationary flow over the wing-flap profile by a stream of humid air„Mixture“. In this model, we use continuity equation $\nabla(\rho_m \mathbf{V}_m) = 0$, where $\mathbf{V}_m = \Big(\sum_{k=1}^{n} \alpha_k \rho_k \mathbf{V}_k\Big)/\rho_m$ — mass average velocity, and $\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k$ — mixture density, n — number of mixture components; in the studied case$n = 2$.

The momentum equation for this model of the medium is obtained by summing the corresponding equations for each component:

$$\nabla(\rho_m \mathbf{V}_m \mathbf{V}_m) = -\nabla p + \nabla\big[(\nabla \mathbf{V}_m + \nabla \mathbf{V}_m^T)\big] - \nabla\Big(\sum_{k=1}^{n} \alpha_k \rho_k \mathbf{V}_{dr,k} \mathbf{V}_{dr,k}\Big),$$

Computation procedure

Volume percentage of vapor in air $\eta, \%$	Density mixture ρ, kg/m^3	Dynamic mixture density $\mu \cdot 10^5$, Pa·s	Number Reynolds $\mathrm{Re} \cdot 10^{-6}$
0	1.2250	1.79	3.46
8	1.1713	1.75	3.42
16	1.1177	1.72	3.33
25	1.0573	1.68	3.23

where $\mu_m = \sum_{k=1}^{n} \alpha_k \mu_k$ — mixture viscosity, and $\mathbf{V}_{dr,k} = \mathbf{V}_k - \mathbf{V}_m$ — relative velocity of the mixture components.

The energy equation for this model of gases mixture has the following form:

$$\nabla \sum_{k=1}^{n} \left(\alpha_k \mathbf{V}_k (\rho_k E_k + p)\right) = \nabla (k_{eff} \nabla T),$$

where k_{eff} — efficient thermal conductivity factor, $k_{eff} = \sum_{k=1}^{n} \alpha_k (k_k + k_t)$; k_k — molecular thermal conductivity factor of k-th component of mixture; k_t — turbulent thermal conductivity factor defined complying with the used turbulence model; $E_k = h_k - p/\rho_k + V_k^2/2$ — for compressed component, and $E_k = h_k$ — for non-compressed model, whereh_k — enthalpy of k-th mixture component.

The computations were performed at the critical angle of attack $\alpha_{\text{cr}} = 12°$ at the incoming flow velocity of $V = 80$ m/s, atmospheric pressure of $p = 101325$ Pa, ambient temperature $t = 15°$ with both, dry and humid air consisting of air and water vapor in various proportions (see table). The water drops in the fog are known to have a radius of 1 to 60 μm, at that, most of the drops have a radius of 5–15 μm at positive air temperature and 2–5 μm at air temperatures below zero. Therefore, in the present calculation, at an air temperature above zero, the size of vapor particles was assumed to be 10 μm. The particles imitating water vapor (water–vapor) were evenly distributed over the calculated volume.

Numerical analysis has shown that with increasing humidity, the maximum lifting force rises (Fig. 2). At that the critical incidence angle also goes up. Thus, in case of air

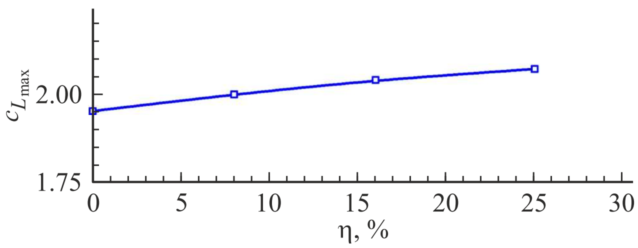

Figure 2. Maximal lift coefficient of the flap profile versus percentage of water vapor in the air.

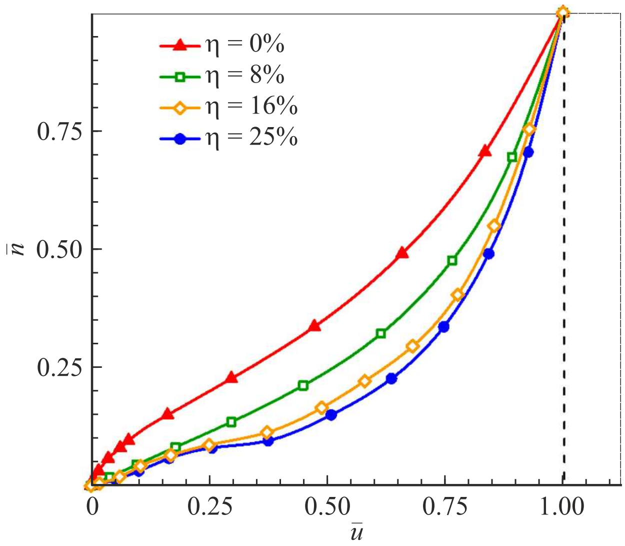

Figure 3. Velocities distribution in the boundary layer in the point on the flap upper surface $x = 0.92b$

blowing over the wind in dry air $\alpha_{\text{cr}} = 8°$, and in humid air at $\eta = 25\%$ it increases to $\alpha_{\text{cr}} = 12°$. This phenomenon is explained by the fact that with an increase in air humidity, the position of the separation point of the boundary layer on the flap shifts to its trailing edge.

Boundary layer velocities profile for a deflected flap at various concentrations of water vapor $\eta\%$ are shown in Fig. 3. In this figure, the velocity is related to the velocity at the exterior of the boundary layer, $\bar{u} = u/u_e$, and the distance normal to the flap surface is related to the thickness of the boundary layer, $\bar{n} = n/\delta$. According to calculations, in dry air, the point of separation is located at a distance of $\bar{x} = x/b = 0.92$ from the tip of the flap. In this point the dependence $\bar{u} = \bar{u}(n)$ at $\eta = 0\%$ has a zero friction velocity profile, $\tau_\omega \sim (\partial \bar{u}/\partial \bar{n})_\omega \approx 0$ (Fig. 3); in the range of $\bar{x} = x/b = 0.92$ a reverse flow is observed, $\tau_\omega < 0$. As humidity increases, the tangential stress τ_ω on the flap surface goes up. At $\eta = 25\%$, the separation point is displaced to the trailing edge of the flap, and at $\bar{x} = 0.92$, the tangential stress becomes positive, $\tau_\omega > 0$.

It is shown that in special weather conditions, such as fog, humidity should be taken into account during aircraft takeoff and landing, as it affects the aerodynamic forces. Even in a small values $\text{Re} = 3.23 \cdot 10^6 - 3.46 \cdot 10^6$, with a decrease in air humidity, the maximum lift coefficient can decrease by 6%, and the critical incidence angle by $\Delta\alpha_{\text{cr}} = 4^\circ$. This phenomenon can be dangerous for aircraft if there is fog on the runway.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] V.V. Minyaev. Vestnik MGTU named after N.E. Bauman. Ser. Estestv. Nauki, No.2, 106 (2004) (in Russian).
[2] A.L. Rybalkina, A.S. Spirin, E.N. Trusova. Nauchny Vestnik MGTU GA, **21** (03), 101 (2018) (in Russian).
[3] D.V. Diachkov, O.V. Zolotarev. International conference „Physico-technical informatics — CPT 2020". ANO „Scientific and Research Center of Physico-technical informatics" 2020. p. 289–320.
[4] V.A. Pozdnyakova. *Prakticheskaya aviatsionnaya metrologia*, training guidelines for flight staff and dispatchers (Ekaterinburg, 2010), p. 113.
[5] M.A. Brutyan, Ye Khtun, O.V. Pavlenko. Trudi MFTI Mekhanika **16** (1), 112 (2024) (in Russian).
[6] T.H. Shih, W.W. Liou, A. Shabbir, J.A. Zhu. Computers Fluids, **24** (3), 227 (1995).
[7] M. Wolfshtein. Intern. J. Heat and Mass Transfer, **12** (3), 301 (1969).

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