Numerical studies of reducing the influence of adverse meteorological conditions on the aerodynamic characteristics of the wing profile

© I.Yu. Belousov,[1] O.V. Pavlenko,[1,2] A.V. Fevralskih,[3] S.B. Kinsa,[2] Ye Htun[2]

[1] Zhukovsky Central Aerohydrodynamic Institute,
140180 Zhukovsky Central Aerohydrodynamic Institute
[2] Moscow Institute of Physics and Technology,
141701 Dolgoprudny, Moscow oblast, Russia
[3] Moscow Aviation Institute,
125993 Moscow, Russia
e-mail: ivan.belousov@phystech.edu, olga.v.pavlenko@yandex.ru, a.fevralskih@gmail.com, kindysandos01@gmail.com, yetun53@gmail.com

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The results of a numerical study of the effect of temperature changes on ice formation on a straight wing with an asymmetric profile are presented. The results of calculating the effect of ice on the aerodynamic characteristics of the wing show that ice formed at the angle of attack 2° practically does not affect the lift and pitch moment, but has a negative effect on the drag and aerodynamic quality of the wing. An analysis of the results of calculating the weight of the growing ice showed that for an aircraft wing, depending on its aerodynamic profile, there is an optimal angle of attack — from the point of view of the minimum weight of ice build-up and the optimal angle of attack of ice build-up, the shape of which has a minimal effect on its aerodynamic characteristics.

Keywords: aerodynamic characteristics, icing straight wing, icing temperature, digital modeling, CFD method.

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Icing of bearing surfaces is one of the most dangerous natural effects on an aircraft. Sticking of ice to the bearing surfaces distorts their outlines and worsens aerodynamic characteristics of the aircraft.

It is known that the temperature of air in the atmosphere is heterogeneous and depends on an altitude. The most intense icing is observed in conditions when the surface temperature of the aircraft is close to the water freezing temperature and air contains a lot of supercooled water drops, for example, when flying in clouds. It is known that the aircraft are most often iced at the temperatures from 0 °C to −15 °C [1–3].

The effect of temperature changes on ice formation is numerically studied on a straight wing with an asymmetric profile Clark Y+, of the relative thickness of 12 %, wherein the maximum profile thickness is at 33 % of the profile chord from a nose part of the wing. Relative elongation of the wing is $\lambda = 5$, the wind chord is constant over the entire wingspan $b = 0.64$ m and an area of projection to the plane is XOZ $S = 2.048\,\mathrm{m}^2$.

The ICEM CFD software was used for calculation and a structured grid containing 10 million cells was constructed. A value of the parameter y^+ in the first near-wall node is $y^+ \leq 0.734$.

The wing circumvention was digitally modelled in the software ANSYS Fluent at the angle of attack $AoA = 2^\circ$ and the oncoming flux velocity $V = 80$ m/s within the temperature range from 0 °C to −14 °C. The finite volume method was used to solve Reynolds equations closed by the SST turbulence model, which is the most common one for

Calculation conditions

Dynamic viscosity, μ, [kg/(m·s)]	Density, ρ, [kg/m^3]	Temperature, K	Temperature, °C	Reynolds number, Re·10^6	Mach number, M
$1.715 \cdot 10^{-05}$	1.16256	273	0	3.47	0.242
$1.705 \cdot 10^{-05}$	1.17114	271	−2	3.52	0.243
$1.695 \cdot 10^{-05}$	1.17985	269	−4	3.56	0.244
$1.685 \cdot 10^{-05}$	1.18869	267	−6	3.61	0.245
$1.665 \cdot 10^{-05}$	1.20677	263	−10	3.71	0.246
$1.645 \cdot 10^{-05}$	1.22540	259	−14	3.81	0.248

modeling flows of this type. Dynamic viscosity of air was pre-defined based on a Sutherland law kinetic theory using a method of three coefficients:

$$\mu = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \frac{T_0 + S}{T + S},$$

where μ is viscosity, [kg/(m · s)], T is a static temperature, [K], μ_0 is an initial value of viscosity, [kg/(m · s)], T_0 is an initial value of the static temperature, [K], S is a value of the effective temperature, [K] (the Sutherland constant). For air at the moderate temperature and pressure, $\mu_0 = 1.716 \cdot 10^{-5}\,\mathrm{kg/(m \cdot s)}$, $T_0 = 273.11$ K and $S = 110.56$ K.

Ice formation in the calculation corresponded to the conditions when water drops freeze partially under impact

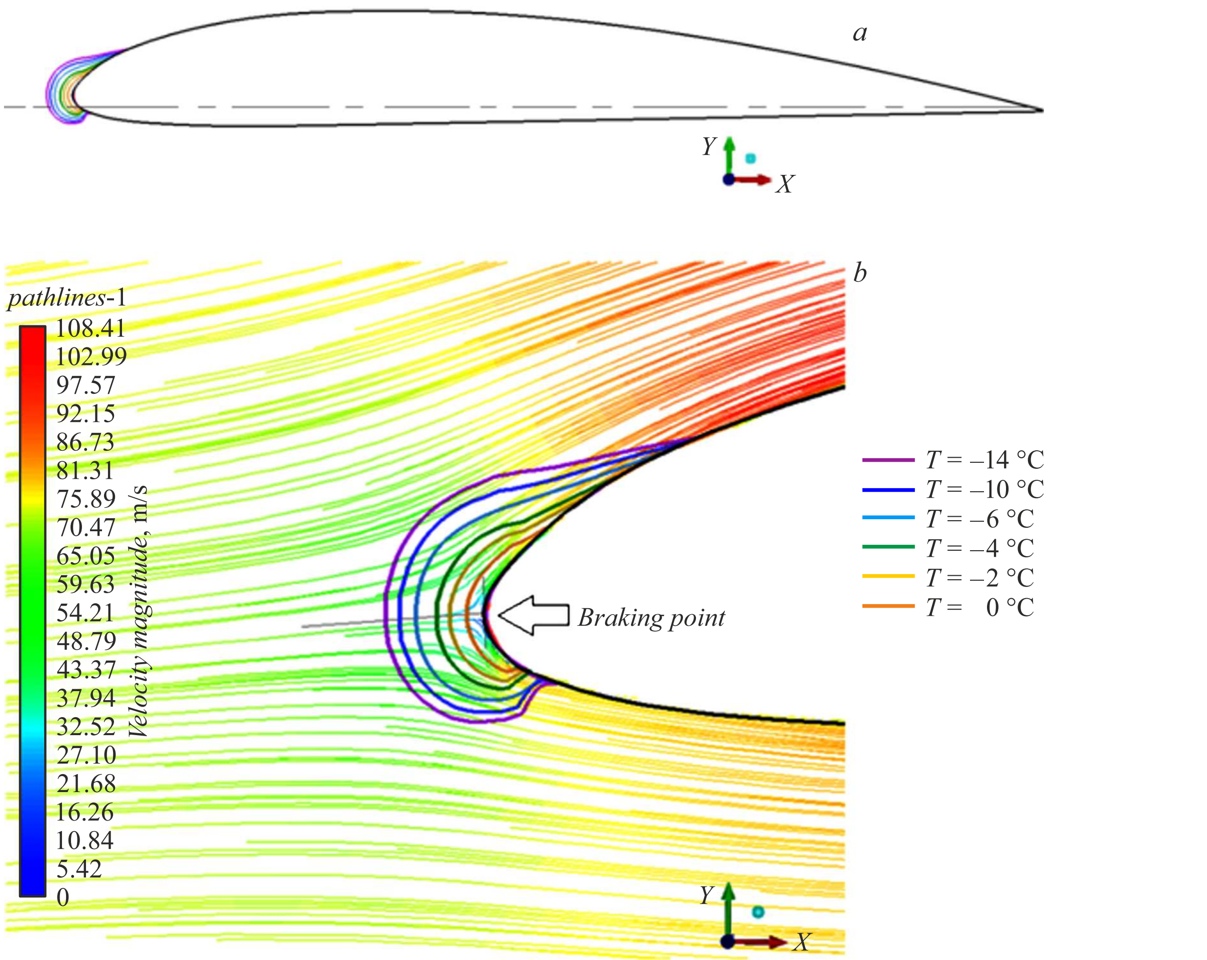

Figure 1. Ice forms in the average section of the wing: *a* — the ice forms depending on the temperature; *b* — flow lines along the velocity scale (m/s) when ice builds up at the forward edge of the profile and the flux braking point.

and spread partially. A drop size was assumed to be the same to be $20\,\mu$m, so was a content of a water liquid phase in air LWC $= 0.005\,\mathrm{kg/m^3}$. The drop freezing temperature varied from $0\,^\circ$C to $-14\,^\circ$C. Viscosity of the medium was calculated in a dependence on variation of the temperature. The calculation conditions are given in Table. Ice build-up on the wind was modeled using the software program FENSAP-ICE [4], into which we imported a grid model of the flow area, which was constructed in the software ICEM CFD, and a field of physical characteristics of the flow (pressure, velocity and temperature), which was obtained by the software program ANSYS Fluent. Ice build-up time is $t = 10$ min.

The numerical studies resulted in detecting a dependence of ice extension on the temperature over the wind profile (Fig. 1) and its weight, Fig. 2 and 3, respectively. The ice weight P_{ice} is expressed in percentage to wing lift with ice $F_{y\,ice}$, which is obtained in the calculation at this temperature: $P = P_{ice} \cdot 100\,\%/F_{y\,ice}$ at the angle of attack $\alpha = 2^\circ$. An increase of the ice weight in the dependence on the temperature decrease is linear.

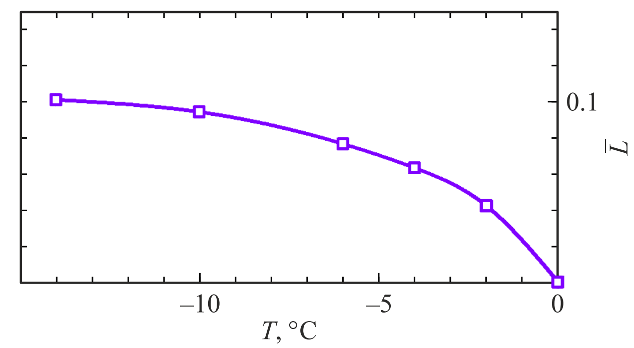

Figure 2. Ice extension dependence on the temperature over the wing profile.

The results of calculating the ice effect on the aerodynamic characteristics of the wing show that ice formed at the angle of attack $AoA = 2^\circ$ practically does not affect the lift and pitching moment, but has a negative effect on the drag and aerodynamic quality of the wing. It should be noted that the maximum increase of wind drag due to icing is observed

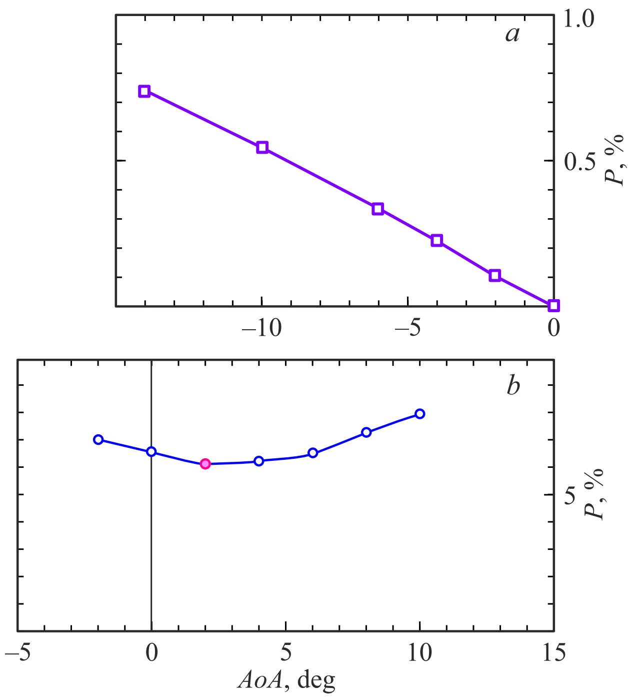

Figure 3. Dependences of the ice specific weight on the temperature at the angle of attack 2° (*a*) and on the angle of attack at the temperature of 268 K (*b*).

at the temperature below −4 °C. Thus, for example, at the temperature $T = -6\,^\circ$C ice formed on the wing increases wing drag in 1.3. times.

The results of calculating the weight of building-up ice at the various angles of attack and the temperature of 268 K (Fig. 3, *b*) were analyzed to show that for the aircraft wing, in a dependence on its aerodynamic profile there a certain angle of attack — in terms of weight-minimal build-up of ice — and an angle of attack of ice build-up, whose shape minimally affects it aerodynamic characteristics. Thus, detecting an allowable range of the angles of attack in the icing conditions for the various wing profiles will provide a safer flight.

Conflict of interest

The authors declare that they have no conflict of interest.

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