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Flow modelling of slotted slat on spin model

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Abstract. The problem of modelling the airflow through the gap between a main wing part and a slat is investigated. Numerical studies of the aerodynamics of a wing with a slat at beyond stall angles characteristic for a spin are carried out. The features of the flow near the slotted slat of the wing model and full-scale wing are revealed. It is shown that with the observance of the geometric similarity on the spin model, the flow and aerodynamic characteristics are somewhat distorted, respectively. It is proposed to simulate the flow around the gap according to the local jet momentum coefficient of the full-scale aircraft and its model.

Keywords: small-size aircraft model, high angles of attack, spin, similarity theory, low Reynolds numbers, jet momentum coefficient

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Моделирование обтекания щелевого предкрылка на штопорной модели

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Аннотация. Исследована проблема моделирования течения струи воздуха между основной частью крыла и предкрылком. Проведены численные исследования аэродинамики крыла с предкрылком на закритических углах атаки, характерных для штопора. Предложено проводить моделирование обтекания щели по локальному коэффициенту импульса струи натурного летательного аппарата и его модели.

Ключевые слова: малоразмерная модель самолета, большие углы атаки, штопор, теория подобия, малые числа Рейнольдса, коэффициент импульса струи

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Introduction

Experimental studies of a spin on an airplane wing model in a wind tunnel have shown that the parameters of the gap between the wing main part and the slat significantly affect the characteristics of the spin [1, 2]. A feature of the spin models under study are small overall dimensions, which negatively affects the operation of the wing slotted mechanization at low test speeds and corresponding relatively low values of the Reynolds number. At the same time, the thickness of the boundary layer on the surface of the model in a wind tunnel and on an airplane differs significantly. At the same time, the peculiarities of the flow at the spin and the assessment of measures to exit it impose additional requirements to increase the reliability of the results of wind tunnel tests, including when modeling the flow of slotted mechanization [3–5]. In [2], in order to increase the reliability of test results in the design of small-sized models, it was proposed to provide for the possibility of some increase in the size of the gaps in the wing high-lift devices comply with the similarity in the jet momentum coefficient.

In this paper, the issues of modeling the airflow of the slotted slat on a spin wing model using computational fluid dynamics are considered in more detail.

Materials and Methods

The effect of the gap height between the main wing part and the slat was studied on a spin aerodynamic model made on a scale of 1:11, as well as on a full scale. The scheme of the model wing having a positive "V"-shape of 4° is shown in Fig. 1. In the model formulation, two heights of the gap h between the slat tail and the surface of the wing main part were studied: $h = 0.02b$ (direct scaling of the wing) and $h = 0.03b$ (increased height of the gap), where b is the local chord of the wing. The full-scale wing with only the gap $h = 0.02b$ was studied.

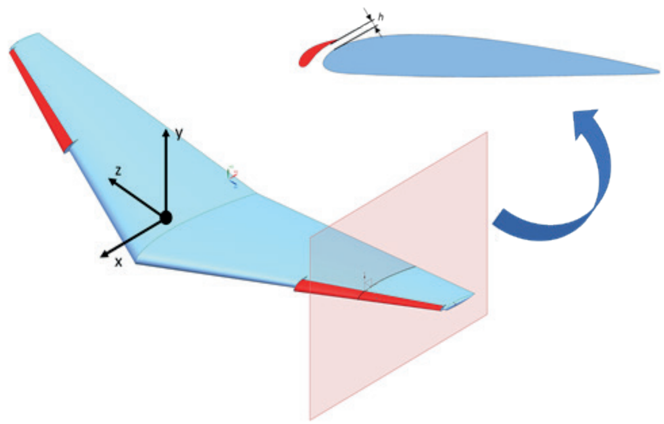

Fig. 1. The scheme of the wing with the slat

Numerical studies of the wing model were carried out on a structured grid (about 20 million cells) according to a program based on solving the Reynolds-averaged Navier-Stokes equations using the k-ε realizable turbulence model, with improved modeling of turbulence parameters near the wall and taking into account the influence of the pressure gradient [6]. Numerical studies were performed at the angle of attack of $\alpha = 60°$ and the flow velocity of $V = 15$ m/s and the Reynolds number $Re = 0.23 \cdot 10^6$ based on the mean aerodynamic chord (MAC) of the wing corresponding to the spin mode of the model of this aircraft. A full-scale wing with a gap height $h = 0.02b$ was calculated in the modes: $\alpha = 60°$, $V = 15$ m/s and 50 m/s at the numbers $Re = 2.48 \cdot 10^6$ and $Re = 8.28 \cdot 10^6$ (based on the MAC), respectively. Thus, at the flow speed of $V = 15$ m/s, the full-scale Reynolds number is almost 10 times higher than the wind tunnel one, and at the speed $V = 50$ m/s it is 36 times higher.

Results and Discussion

Numerical studies of the aerodynamic characteristics of the wing have shown that with the gap height of $h = 0.02b$ reduces its lift along the entire wingspan and increasing the gap to $h = 0.03b$

gives closer results to the full-scale wing (Fig. 2). The strongest differences are observed in the area of the root section of the slat. Thus, when modelling the stream flowing through the gap between the wing main part and the slat, a simple geometric similarity is not enough. The general view of the flow around the full-scale wing and its separation area is shown in Fig. 3.

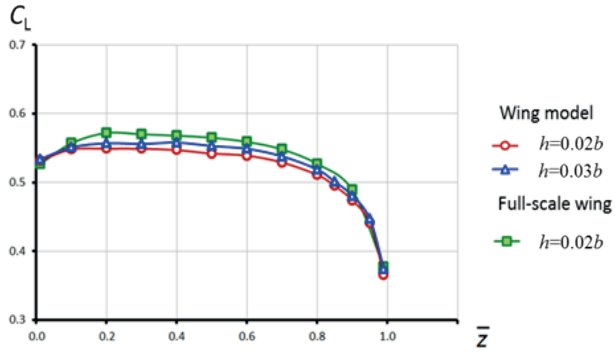

Fig. 2. Distribution of the lift coefficient along the wingspan, V = 15 m/s

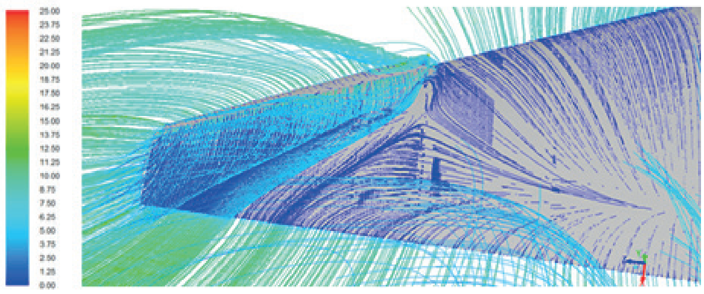

Fig. 3. Distribution of the lift coefficient along the wingspan, V = 15 m/s

The velocities distribution in cross sections along the span of the slat (Fig. 4, 5) shows that a slight increase in the gap height leads to an increase in the velocity of air flowing through it and a more correct modelling of the flow on the wing after the air jet comes out of the slot. A comparison of the velocity distribution along the span of the slat in the sections of the wing model with the gap height of h = 0.03b and the full-scale wing with the gap height of h = 0.02b showed their qualitative agreement (Fig. 5). Numerical research showed that in the gap between the main part of the model wing and the slat at h = 0.02b, especially in the end sections, where the gap height h is very small and is 1.56 mm, there is a significant deceleration of the air flow (Fig. 4) and, as a consequence, the decrease in the underpressure on the nose of the wing airfoil (Fig. 6).

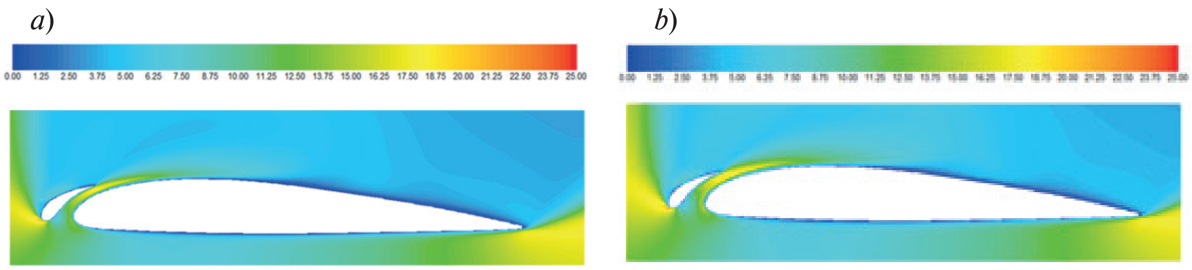

Fig. 4. Velocity distribution in the middle cross-section of the slat on the wing model at the flow velocity V = 15 m/s: (a) h = 0.02b; (b) h= 0.03b

Based on numerical studies of the velocity fields of the flow coming out of the gap between the slat and the wing main part, the distribution of local jet momentum coefficients [2] along the wingspan was determined. The local jet momentum coefficient was defined as the ratio of the amount of movement of the entire impulse flow passing through the gap segment along the span per unit of time to the amount of movement of the undisturbed flow passing through this section of the gap per unit of time.

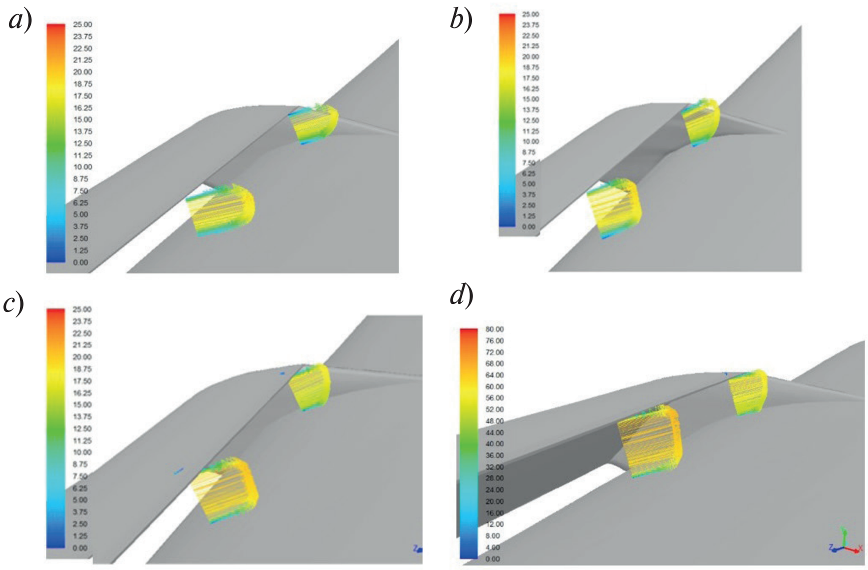

Fig. 5. Velocity distribution (m/s) in the slat slot sections: wing model with $h = 0.02b$ at $V = 15$ m/s (*a*); wing model with $h = 0.03b$ at $V = 15$ m/s (*b*); full-scale wing $h = 0.02b$ at $V = 15$ m/s (*c*); full-scale wing $h = 0.02b$ at $V = 50$ m/s (*d*)

Fig. 7 shows that the distribution along the slat of the local jet momentum coefficients of $C\mu$ for the model with an enlarged gap ($h = 0.03b$) is close to the corresponding distribution for a full-scale aircraft. The presented results of calculations and experimental studies indicate a more adequate modeling of the flow of a full-scale aircraft with an increased size of the gap in the model between the slat and the wing main part.

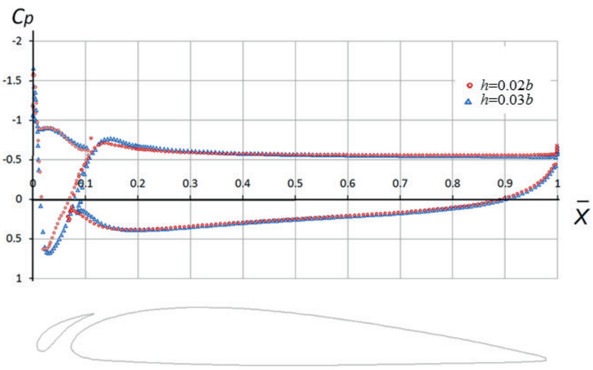

Fig. 6. The distribution of the pressure coefficient in the middle cross section of the slat wing model at $V = 15$ m/s

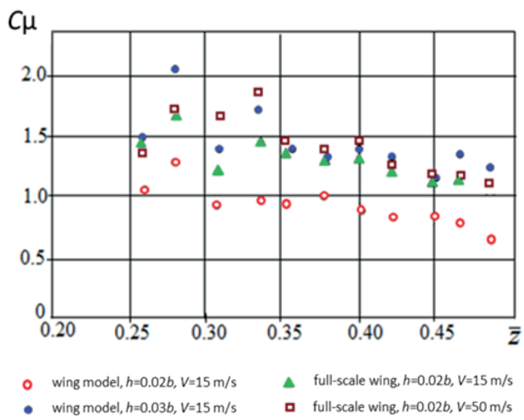

Fig. 7. Distribution of local jet momentum coefficients along the slat span

Conclusion

Numerical studies carried out on the wing with the slat at beyond stall angle of $\alpha = 60°$ have shown that with the observance of the geometric similarity on the spin model including the gap height of the slat, the flow and aerodynamic characteristics are somewhat distorted, respectively. This circumstance leads to the closing of the air flow in the slot of a small experimental model. In this case, the gap, depending on the scale, can be completely immersed in the boundary layer. The solution to this problem, as calculated studies have shown, may be a slight increase in the gap height between the wing main part and the slat, taking into account the similarity in the jet momentum coefficient.

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