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Effect of running propellers on flow and hinge moments of trailing edge mechanization of high aspect ratio

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Abstract. This paper presents the results of a numerical study of the flow of an airplane with a mechanized high aspect ratio wing when the wingtips blown by jets of propellers. The layout of the aircraft with a pulling two-bladed propeller, as well as without installed propellers, is investigated. The effect of propeller slipstream on the airplane aerodynamic characteristics and the hinge moments of the flaps and ailerons is shown. It is shown that the external aileron is exposed to the greatest impact of the propeller slipstream. An increase in the underpressure on the upper surface and a strongly increasing pressure on the lower windward side of the aileron leads to a significant increase in the hinge moment of the external aileron when blown by jets of propeller.

Keywords: pulling airscrew, hinge moment, mechanization of the wing, high aspect ratio wing

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Материалы конференции
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Влияние работы воздушных винтов на обтекание и шарнирные моменты механизации задней кромки крыла большого удлинения

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Аннотация. В данной работе представлены результаты численного исследования обтекания самолета с механизированным крылом сверх большого удлинения при обдуве концевых сечений крыла струями воздушных винтов. Исследована компоновка самолета с тянущим двухлопастным воздушным винтом, а также без установленных воздушных винтов. Показано влияние обдува винтом на аэродинамические характеристики самолета и шарнирные моменты закрылков и элеронов.

Ключевые слова: тянущий воздушный винт, шарнирные моменты, механизация крыла, крыло сверхбольшого удлинения

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Introduction

Currently, the task of studying the interaction of a running propeller of an electric power plant installed in the end section of the wing, including on the high aspect ratio wing used in the layout of solar-powered aircraft, is urgent. To ensure the required take-off and landing characteristics of airplanes with the high aspect ratio wing, effective take-off and landing mechanization is required. In addition, there are increased requirements for the efficiency of control surfaces placed on the wing, including the magnitude of the hinge moments that occur on them during deflection, since these characteristics directly affect the power and dimensions of the servo-compensators [1, 2].

This paper presents the results of a numerical study of the flow around an airplane with the high aspect ratio wing with running propellers and deflected the trailing edge mechanization of the wing.

Materials and Methods

The aerodynamic layout of the airplane has the classical scheme with a high-wing (wing aspect ratio of $\lambda = 23.4$), a fuselage with a circular cross section and a single-fin tail with a stabilizer placed on the fuselage (Fig. 1). At the ends of the rectangular wing, engine nacelles with installing pulling two - bladed propellers with a diameter of 0.22 m are placed. The studies were also carried out without installed propellers. The rotation speed of the propellers $N = 15000$ rpm. The rotation direction of the propellers corresponds to the folding of the vortex shroud from the wingtip.

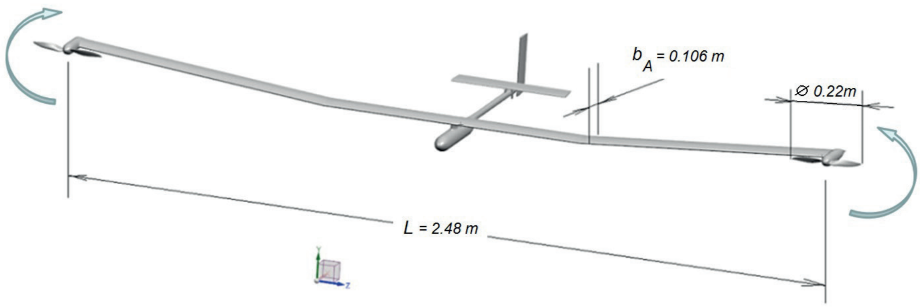

Fig. 1. Airplane main view

The wing is equipped with a plain flap and a two-section aerodynamically-balanced aileron (inner (aileron 1) and outer (aileron 2) sections, Figure 2). The relative chord of the flap and aileron is 15%. The variant of deflection of flaps and ailerons at an angle of +30° is considered. The axis of rotation of the flap and aileron is located at 85% of the wing chord.

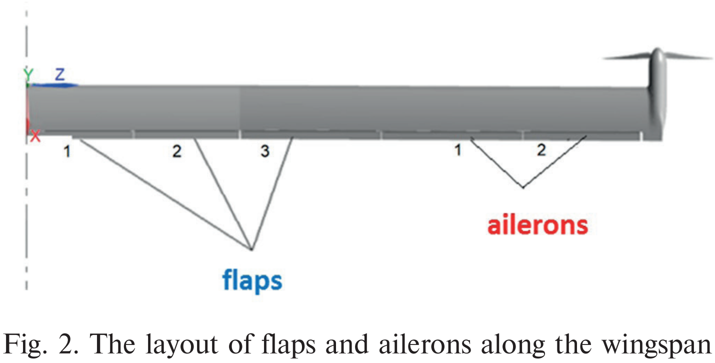

Fig. 2. The layout of flaps and ailerons along the wingspan

Numerical studies on the airplane with and without running propellers was carried out at Mach numbers M = 0.074 and Reynolds numbers Re = $1.78 \cdot 10^6$, which correspond to the take-off mode. The calculations were performed using a program based on solving the Reynolds-averaged Navier-Stokes equations [3–5]. The calculations were performed at a load coefficient value $B = 0.5$. Load coefficient B was determined by the equation (1).

$$B = \frac{P_0}{q_\infty \cdot F}, \tag{1}$$

where P_0 is a propeller thrust, q_∞ is an dynamic pressure in WT, F is a blade swept surface area.

The coefficients of the hinge moments of the ailerons and flaps were determined by the equation (2):

$$C_H = \frac{H}{S \cdot q_\infty \cdot b}, \tag{2}$$

where H is the hinge moment relative to the axis of flap (aileron) rotation, S and b are the area of the flap (aileron) and the chord of the flap (aileron) behind the axis of rotation, respectively, q_∞ is an dynamic pressure.

Results and Discussion

The effect of the propeller mounted at the wingtip on the aerodynamic characteristics of the airplane with the deflected mechanization, depending on the angle of attack, is shown in Fig. 3. The calculation showed that a running propeller mounted at wingtip, with deflected mechanization, leads to a slight increase in the lift coefficient up to an angle of attack of 5°, and at beyond stall angles slightly reduces it. The pitching moment due to propeller slipstream practically does not change. Such a low effect of the propeller slipstream effect on the airplane aerodynamic characteristics is due to the fact that most of the wing mechanization is outside the area of the running propellers. Thus, only the second section of the aileron is mainly located in the slipstream area.

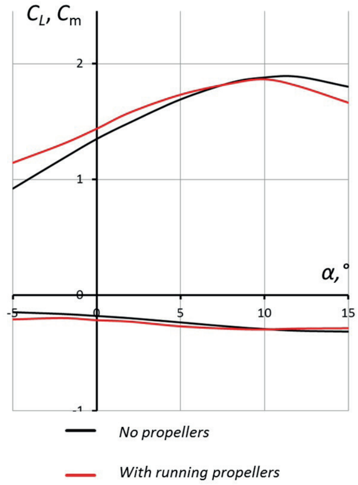

Fig. 3. Lift and pitching moment coefficients versus angle of attack

The values of the hinge moment coefficient of the deflected mechanization by the wingspan at different angles of attack are shown in Fig. 4. The disturbed air flow from the propeller rotating at the wingtips leads to an increase in the hinge moment of the entire deflected wing mechanization (flaps and ailerons) by about 1.5 times, and also increases the derivative of the hinge moment coefficient by the angle of attack. But the aileron 2, located directly behind the propeller, is exposed to the greatest impact of the propeller slipstream. It should be noted that a strong increase in the hinge moment (approximately 3 times) and a sharp increase in the derivative of the hinge moment coefficient of this aileron is observed only in the range of angles of attack from α = -5° to α = +2°, which must be taken into account when controlling the aircraft. A similar effect, but to a much lesser extent, the running propeller has an effect on the hinge moment of the aileron 1.

The increase in the magnitude of the hinge moment of mechanization along the wingspan is caused by a change in aerodynamic forces and depends on the pressure distribution at different angles of attack.

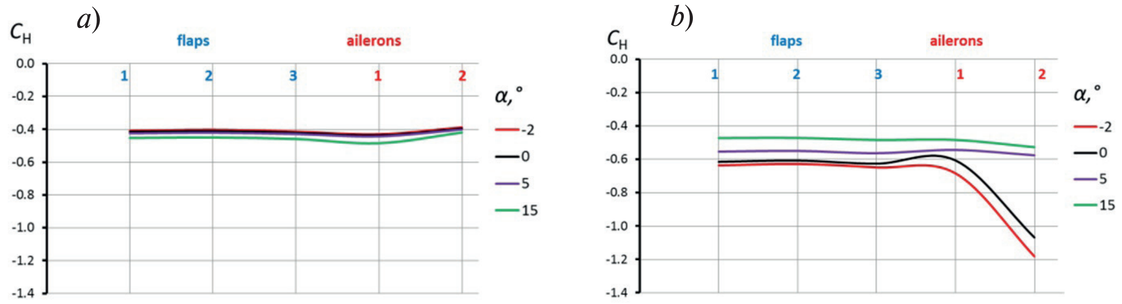

Fig. 4. The magnitude of the hinge moment coefficient of the deflected mechanization along wingspan: no propellers (*a*); with running propellers (*b*)

This is clearly seen in Fig. 5–8, which shows the pressure coefficient distribution over the wing surface, as well as in the section of the aileron 2 at the end of the wing when the propeller is blown at the angles of attack $\alpha = -2°$ and $\alpha = 15°$, which correspond to the maximum and minimum values of the aileron 2 hinge moment coefficient. At the angle of attack $\alpha = -2°$ due to blowing by the propeller, an increase in underpressure is observed on the upper surface of the aileron 2 (Fig. 5, *a* and Fig. 7, *b*), while pressure increases strongly on its lower windward side (Fig. 6, *a* and Fig. 7, *b*). This pressure distribution increases the hinge moment of the deviated aileron by deflecting its back down stream and contributing to its return to its base cruising position. At the lowest value of the hinge moment of the aileron 2, the underpressure its upper surface (Fig. 5, *b* and Fig. 7, *b*) and the pressure on its lower windward side are significantly less (Fig. 6, b and Fig. 7, *b*).

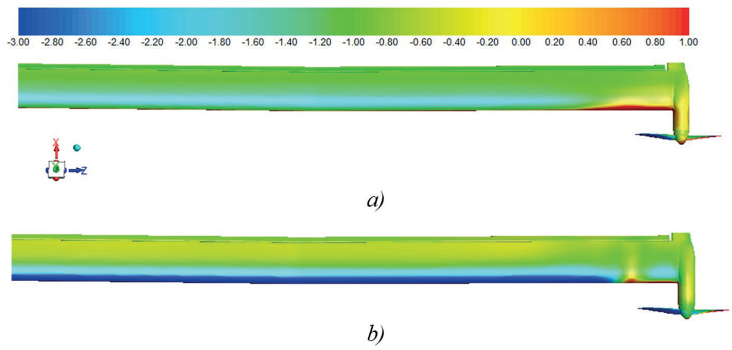

Fig. 5. The propeller slipstream effect on the pressure coefficient distribution of the wing surface with mechanization in the top view: $\alpha = -2°$ (*a*); $\alpha = +15°$ (*b*)

The increment of the pressure coefficient when blown by the propeller slipstream in the middle cross section of the aileron 2 is shown in Fig. 8. Such a change in pressure on the surface of the aileron 2 is associated with a bevel of the flow and a change in the direction of the current lines of the propeller when interacting with the incoming flow V_∞ with a increase in the angle of attack (Fig. 9).

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.

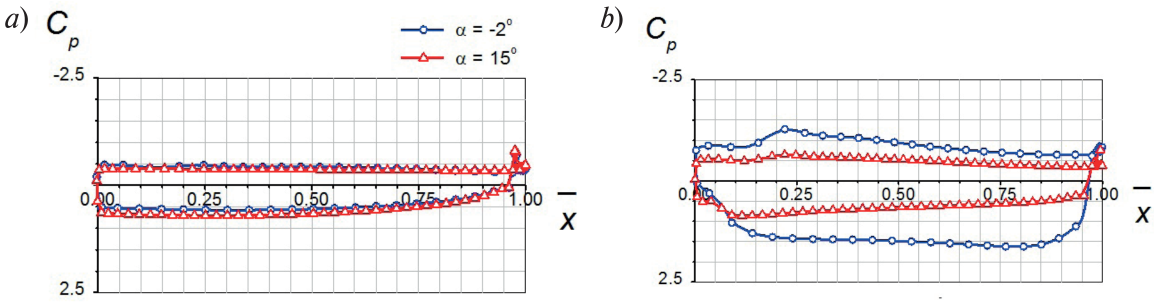

Fig. 7. The pressure coefficient distribution in the middle section of the aileron 2: no propeller (*a*); with running propeller (*b*)

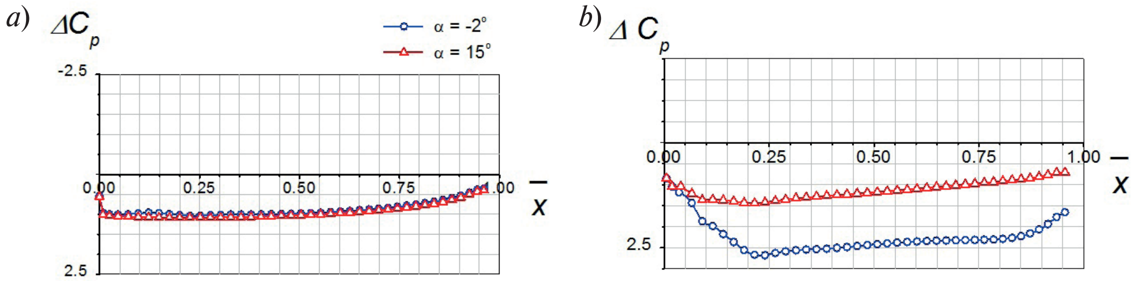

Fig. 8. Increment of the pressure coefficient in the middle section of the aileron 2: no propeller (*a*); with running propeller (*b*)

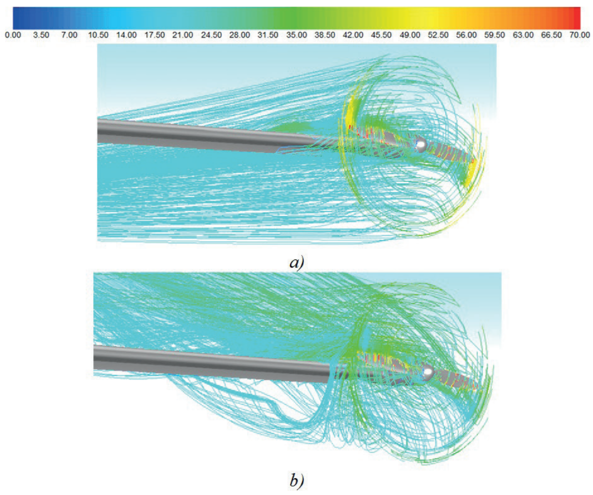

Fig. 9. The current lines behind the propeller: α = -2° (*a*); α = +15° (*b*)

Conclusion

The numerical study of the effect of running propellers on the flow and hinge moments of trailing edge mechanization of the high aspect ratio wing showed that the external aileron located directly behind the propeller is exposed to the greatest slipstream effect. A strong increase in the hinge moment and a sharp increase in the derivative of the hinge moment coefficient of the external aileron are observed only in a certain range of angles of attack from –5° to 2°, which must be taken into account when controlling the aircraft. An increase in the underpressure on the upper surface and a strongly increasing pressure on the lower windward side of the aileron leads to a significant increase in the hinge moment of the outer aileron when blown by an air propeller, when the aerodynamic forces that deflect it back along the flow increase.

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