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ADAPTIVE WING HIGH-LIFT SYSTEM

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Abstract

The development of effective high-lift airplane wings remains a difficult aerodynamics problem. Take-off and landing are becoming increasingly difficult owing to the increases in the mass and speed of aircraft and the toughening of air safety demands. In this context, improving aspects of the high-lift systems used in future airplanes has tremendous practical value. This problem can be resolved by deflection or bending of the wing tail part. The adaptive high-lift system contains the double-slotted flap and the wing spoiler droop that is deflected on angles up to $\delta_s = 10°$. *Calculations shown increases the lift coefficient by 15% and causes the moving lift force point to shift forward. Experimental researches carried out on the light cargo aircraft model, in the wind tunnel T-102 TsAGI shown increases the lift coefficient by 11–13%. Setting the propeller and set up the load coefficient to B = 1 increases the lift coefficient up to 36%. The application leading edge modifications of the wing expands the operational range of angles of attack and increases the lift coefficient by 10%. Adaptive element application to high-lift devices is an effective means of active control of aerodynamic performance and the problem of longitudinal trimming of the airplane.*

1 Nomenclature

V	Wind tunnel flow speed, m/s
q	Dynamic head, kgf/m2
D	Propeller (model) diameter, m
n, ns	Number of rotates, rpm, rps
P	Thrust, kgf
B	Propeller load coefficient
b_f	flap chords at airfoil chords, %
b_d	deflector chords at airfoil chords, %
δ_f	corner-flap deflection, deg.
δ_s	spoiler droop angle, deg.
Re	Reynold's number
C_L	Lift coefficient
C_D	Drag coefficient

1 Introduction

On a single-slotted flap angle $\delta_f \leq 40°$ are limited. The increment of the lift coefficient is maximum, and the angle cannot be further increased owing to the development of intensive stalls on the flap. This is partly due to the fact that the tail section of the wing's main section is not sufficiently bent. Therefore, air that passes through the slot undergoes a sharp directional change when the flap is significantly deflected, which leads to dramatic separation in the airflow. This problem can be resolved by deflecting or bending the tail section of the wing's main section, ensuring continuous flow through the slotted flap even at large angles of deflection. This modification results in an enhancement of the lift.

Various solutions to the problem associated with increasing the curvature of the main wing's tail section take-off and landing have been proposed: 1) structural deformation of the tail section with the flap moving out during take-off and landing, 2) flexible surfaces operated with a special gear, and 3) hinged devices that deflect the wing's tail downward (spoiler droop).

Significant research activity has been directed toward the wing's «adaptive» elements (spoiler droop). In aerodynamics, this principle of adaptation has been well studied and applied in wind tunnels. Preliminary research was conducted using 2D models [1]. Several studies have considered an actively blown Coanda flap-based high-lift system as an alternative to the state flaps and slats. The features of this system include an adaptive gapless droop with an exceedingly high degree of leading edge morphing [2].

The computational studies of adaptive wings, particularly those of the flexible ones, have been conducted [3]. The results showed that for a rigid wing, the optimal corner-flap deflection corresponded to a lift distribution similar to the chord distribution, whereas for flexible wings, the optimal deflections were dependent on their torsional and bending stiffness.

The most detailed problems with the application of adaptive mechanization arise in research on high-lift systems using circulation-control Coanda-type flaps. The interaction of these high-lift systems with a propeller engine is the subject of the present study. A large and complex wind tunnel model equipped with an active high-lift system and a powered propeller was designed, manufactured and tested. The previously obtained wind tunnel data show the potential for an active high-lift system in 3D wing applications [4]. Note that the present study represents one of the few studies of mechanization with a propeller droop.

Previous research on pneumatic vortex generator jets and fluidic gurneys implemented in a slat less high-lift airfoil (DLR-F15) in a drooped spoiler configuration are reviewed in Ref. [5]. On the one hand, a drooped spoiler could increase the maximum lift; however, on the other hand, it could cause stall on the trailing edge. The vortex generator jets, which are positioned upstream of the spoiler, reduce the flow separation by static or dynamic blowing. The combined blowing by all active flow-control systems, including the vortex generator jets upstream of the spoiler and the fluidic gurneys at the trailing edge of the main wing, results in additional lift [6, 7].

2 Configurations

The conducted computational and experimental research have shown the efficiency of the concept in the form of a combination of wing spoiler droop and the sliding slotted flap (Fig. 1) [1, 5].

The mechanization with spoiler droop contains the double-slotted flap deflected on the corners by 20° (take-off position) and 32° (landing position) and the spoiler (with relative size b_{sp} = 21.86%) that is deflected on corners δ_s = 5° and δ_s = 10°. Various versions have been research.

For experimental activities, high level corner-flap deflection of δ_f = 35° and 40° are considered.

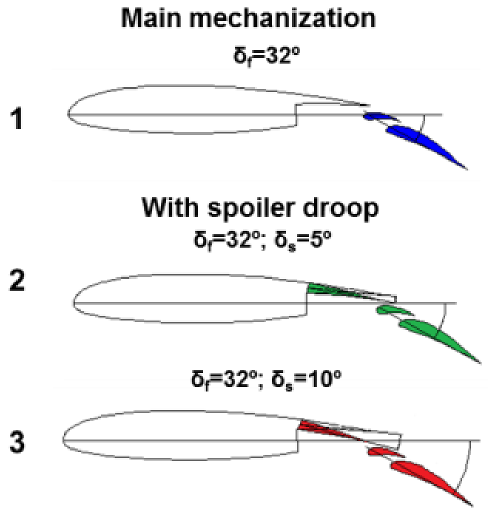


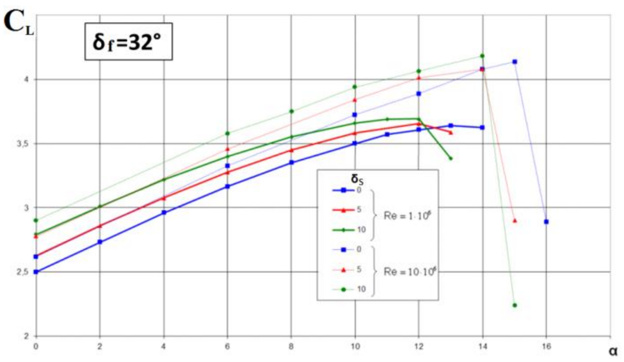
Fig. 1. Airfoil with spoiler droop.

3 Computational Researches

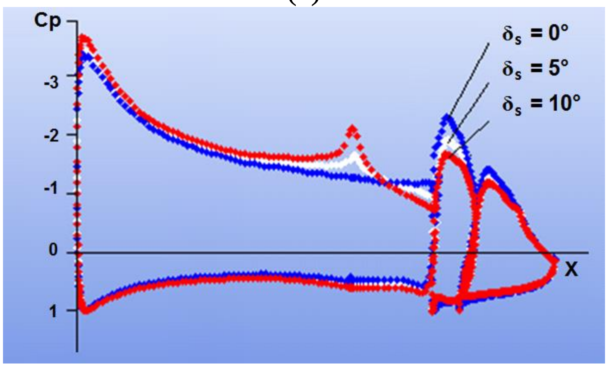
For 2D numerical simulations, the program of Navier-Stokes's equation with SST turbulence model was used. Mesh size about 1 mln. For each configurations with interface modeling and Y+ ~ 1 factor also was used. Flow velocity V = 50 m/s, that corresponds to the Reynold's number value of Re = 0.97 × 10^6.

Calculation results of line pressure profile to an angle of attack α = 0 shown that the spoiler droop creases rarefaction on all leading edge of a airfoil. It is probable because of the increased curvature of its leading edge surface. Thus, in the point of a bending of the spoiler droop the local increase in rarefaction of pressure is observed (Fig. 2b).

At small angles of attack (α < 6°) load redistribution on the main profile (~10 %) while the deflector and the flap "unload" by 15 and 25 %, accordingly (Fig. 2c)



(a)



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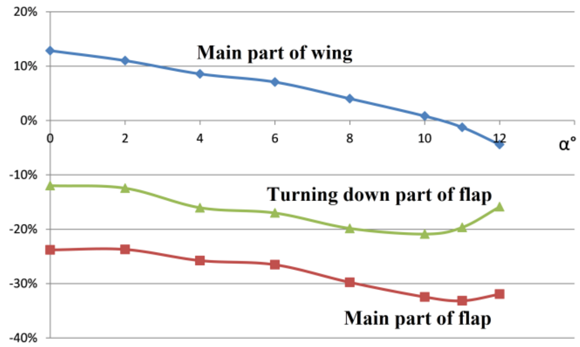
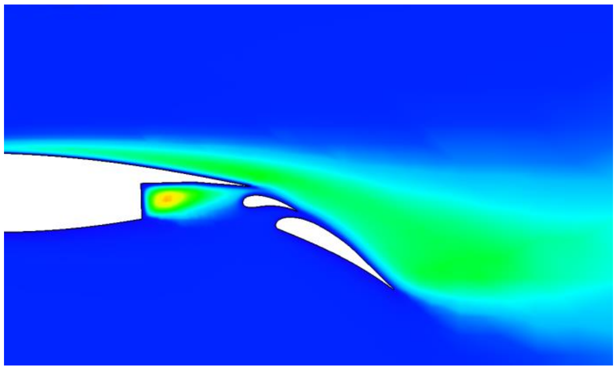


(c)

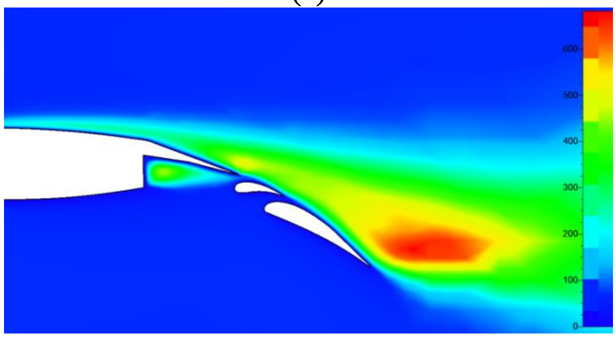
Fig. 2. (a) Relations $C_L(\alpha)$, (b) distribution of pressure coefficient (δ_f = 32º, α =0º), and (c) relative distribution of loads %, results of computational researches.

Figure 2 shows the pressure coefficient distribution along aerofoils chord axis. There is an increase in aerodynamic lift force primarily at the main part of the wing. Flow near the flap elements during the rotation of spoiler is also improved. The pressure coefficient distribution is much improved with the spoiler droop compared to the double-slotted flap (lowering of rarefaction peaks can cause an early stall, Fig. 2b). The reduction of aerodynamic lift force on the flap and it's increase at the spoiler of the aerofoil causes the moving lift force point to shift forward.

A feature of spoiler droop is the reduction of the stall angle of attack in comparison with double-slotted flap (Fig. 2a). Calculations shown that the reason of reaching the stall angle of attack is increase of turbulent viscosity in spoiler area the separation of the flow from an spoiler, which is not present to similar double-slotted corner-flap deflection by δ_f = 32° at α_{max} = 12°. There is a flow separation from aerofoil with spoiler and corresponding aggravation flow of flap in comparison with double-slotted flap (δ_f = 0°, Figs. 3a,b).



(a)



(b)

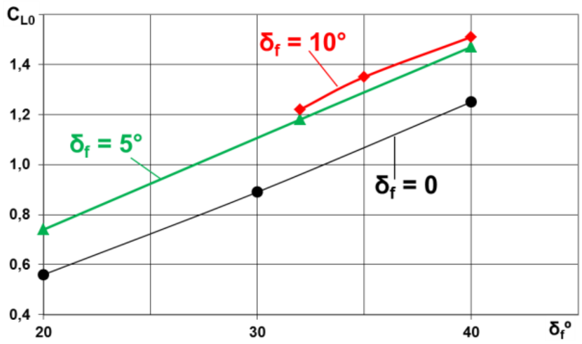
Fig. 3. Flow structure turbulent viscosity at high angles of attack (δ_f = 32º; α = 12º). Results of computational researches: (a) δ_s = 0º, (b) δ_s = 10º.

4 Experimental Researches

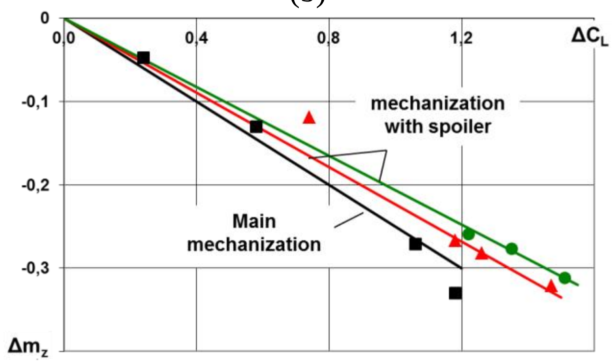
4.1 Tests without propeller

Experimental researches were conducted on a model of a Light Cargo Aircraft (LCA). Tests were executed with various versions of the flaps in a wind tunnel T-102 TsAGI (Fig. 4a) at a flow velocity of V = 50 m/s. This corresponds to the Reynold's number value Re = 0.97 × 10^6 evaluated on a mean aerodynamic chord (MAC) of the wing.

(a)



(b)



(c)

Fig. 4. Results for Light Cargo Aircraft at wind tunnel: (a) research configurations, (b) tested model, (b) lift coefficient at corner-flap deflection, (d) factors of the moments.

A comparison of increments of the lift coefficient at attack α = 0 for various versions of the high-lift devices are shown in fig.4b. An aberration of the tail part of a wing on a corner with deflection by δ_s = 5° increases the model lift coefficient in a take-off configuration by 28% in comparison with the base version. In a landing configuration, this increment is 11% – 13%. It is necessary to mark that absolute values of the increments of the lift coefficient from spoiler droop are slightly diminished with increasing angle of attack in a long range. In addition, the aberration of the spoiler displaces the relationship «X_{F2}» (1), facilitating a problem of a longitudinal trim of the airplane during take-off and landing conditions (Fig. 4c).

$$\bar{X}_{F2} = \bar{X}_T - \frac{\Delta m_z}{\Delta C_L} \qquad (1)$$

4.2 Tests with propeller

Influence of propeller on efficiency of spoiler droop is examined using the model LCA in T-102 TsAGI (Figs. 5-7).

For the trials of airplanes with propellers at TsAGI were developed using the modeling power plant (MPP). The tests were used to determine the influence of streams from propellers (PPs) on the aerodynamic performance of the airplane model, including measurement of forces and the moment factors during the operation of the PP by means of six-component strain gauge scales. For rotation six-blade propeller (diameter D_p = 0.4 m) and two electric engines powered with N = 5 kw and tensometric measuring system were used (Fig.5).

Test are conducted at flow velocities of V = 22–31 m/s corresponding to a Reynold's number value of Re = 0.5-0.75 × 10^6 evaluated on a wing MAC.

The values of load on the area swept by the propeller «B» are evaluated using the equation (2), where: P_0 is thrust of a modelling propeller (in Newtons) at V = 0; q_∞ is velocity factor of air ($\rho \cdot V^2/2$); F_∞ is propeller disk area (in m^2).

$$B = \frac{P_0}{q_\infty \cdot F_\infty} \qquad (2)$$

Range B = 0.5 - 1.5 corresponds to possible values for take-off and landing conditions up to the maximum take-off. Values of rotational speed n = 5000 rpm. The test results are presented in Fig. 6.

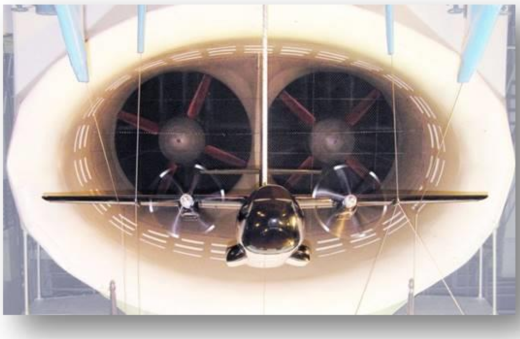


Fig. 5. Tested model for Light Cargo Aircraft with modeling power plant.

In the absence of streams from the PPs (B = 0, without propeller) and the corner-flap deflection at take-off position δ_f = 20°, the lift coefficient increases to C_{L0} = 0.5 and C_{Lmax} = 1.8. The stall angle of attack is also reduced to $\Delta\alpha_{max}$ = 2.5° in comparison with cruiser configuration (Fig. 6a). The application of an spoiler droop with the deflection by δ_s = 5º, increases lift coefficient at a zero angle of attack of $\Delta C_{L0}(5)$ = 0.6 with the insignificant lowering of the maximum lift factor $\Delta C_{Lmax}(5)$ and stall attack angle by $\Delta\alpha_{max}(5)$ = 3.5°. The application of both kinds of the mechanization gives same C_{D0}.

The propellers with corner-flap deflection in the take-off position increases lift coefficients to C_{L0} = 0.9, C_{Lmax} = 2.7 and $\Delta\alpha_{max}$ = 1.5°, in comparison to the cruiser configuration. The deflection of the spoiler to δ_s = 5º increases ΔC_{L0} by 2.8 and ΔC_{Lmax} by 2.75 while retaining an αmax comparable to the double-slotted flap configuration (Fig. 6a).

For corner-flap deflection at landing position δ_f = 32°, the lift coefficients are C_{L0} = 1 and C_{Lmax} = 2.2, and the stall angle of attack is reduced to $\Delta\alpha_{max}$ = 3° in comparison with cruiser configuration (Fig. 6b). The deflection of the spoiler to δ_s = 10º increases the lift coefficient at zero angle of attack by C_{L0} = 1.2 and does not reduce ΔC_{Lmax} at some convergence of the stall angle of attack ($\Delta\alpha_{max}$ = 2°), in comparison to the simple double-slotted flap configuration. The application of both kinds of mechanization leads to drag increase on ΔC_{D0}.

The propellers and corner-flap deflection at a landing position δ_f = 32° increases the lift coefficients to C_{L0} = 1.35 and C_{Lmax} = 3.3 and lowers the stall angle of attack by $\Delta\alpha_{max}$ = 2.5° in comparison with cruiser configuration. The aberration of the spoiler droop deflection δ_s = 5° increases C_{L0} = 1.5 and C_{Lmax} = 3.4 while preserving αmax in comparison with the simple double-slotted flap. The aberration of the spoiler with an angle δ_s = 10° leads to an increase in C_{L0} = 1.6 and C_{Lmax} = 3.45 while reducing $\Delta\alpha_{max}$ = 2° in comparison with the simple double-slotted flap (Fig. 6b).

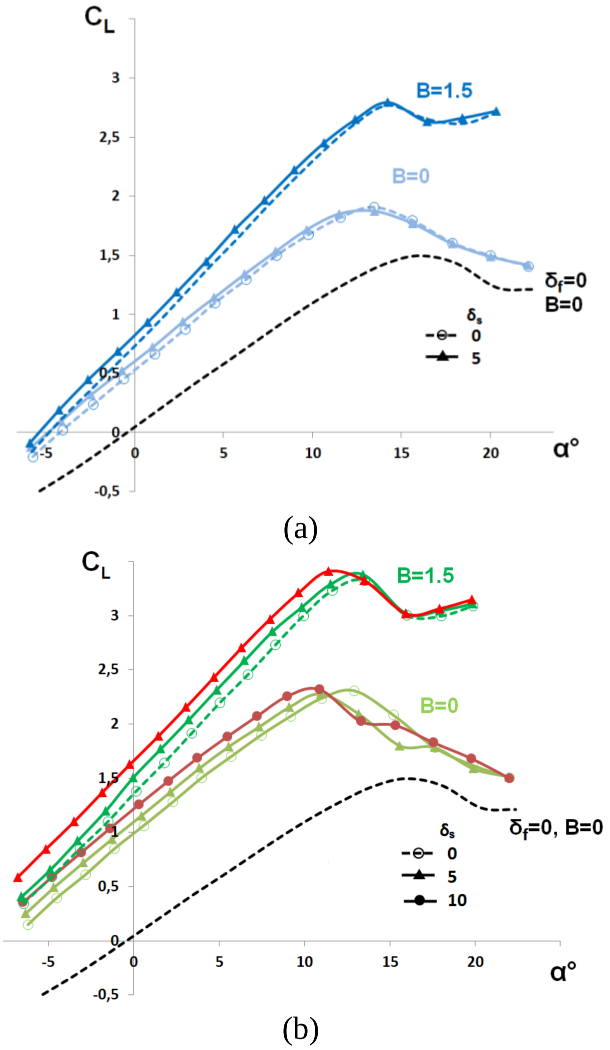


Fig. 6. Results for Light Cargo Aircraft at wind tunnel, lift coefficient to angle of attack for (a) δ_f = 20º and (b) δ_f = 32º configuration.

4.2 Tests wing leading edge modification with propeller

For improving the wing flow, an spoiler droop is tested with large angles of attack modification on the nose leading edge of a wing (Fig. 7a). According to calculations, local changes in the wing airfoil have not practically aggravated the cruising performance of an airplane; however, it has considerably diminished the gradients of pressure and has weakened the development of flow separation on the upper wing surface at high angles of attack. The factors of the moments are evaluated based on the conditional center of mass disposed on 25% of the MAC.

Leading edge modification of a wing profile has weaken intensity of separation and at $\delta_s = 0$ to increase factor of the maximum lift on $\Delta C_{Lmax} \approx 0.2$ and critical angle of attack $\Delta\alpha_{max} = 3^o - 4^o$ (Fig.7b). At the wing with the flaps rejected in a take-off position on $\delta_f = 20^o$ leading edge modified value $\Delta C_{Lmax} \approx 2.05$ also is increase at $\alpha_{max} = 17^o$ (Fig.7c). More essential increase of aerodynamics parameter is reached at use of modeling power plant. At a landing flap position ($\delta_f = 35^o$) the deviation of a wing spoiler droop on $\delta s = 10^o$ increases a lift coefficient on a linear piece function $C_L = f(\alpha)$ on $\Delta C_L \sim 0.1 - 0.15$, without essential increase α_{max} and C_{Lmax} of LCA model. Modification of a nose profile at a propellers air stream has allowed to receive a significant increment α_{max} and C_{Lmax} in comparison with main double-slotted flap.

Wing leading edge modification covered with streams from PPs has increased the maximum lift by $\Delta C_{Lmax} \approx 0.3$ with a stall angle of attack by $\alpha_{max} \approx 2.5°$ (Fig. 8a). As a whole, the application of «adaptive» high-lift devices in a combination with wing leading edge modification expands the operation range of airplane angles of attack and lift coefficient values $\Delta C_{Lmax} \approx 3.3$ in a landing configuration ($\delta_f = 35°$ and $\delta_s = 10°$) with ventilation covered with streams at a small intensity (B = 0.5). Thus wing leading edge modification has not influenced other key aerodynamic performance metrics, such as the drag coefficient C_D and the pitching moment factor Δm_z (Fig. 8b).

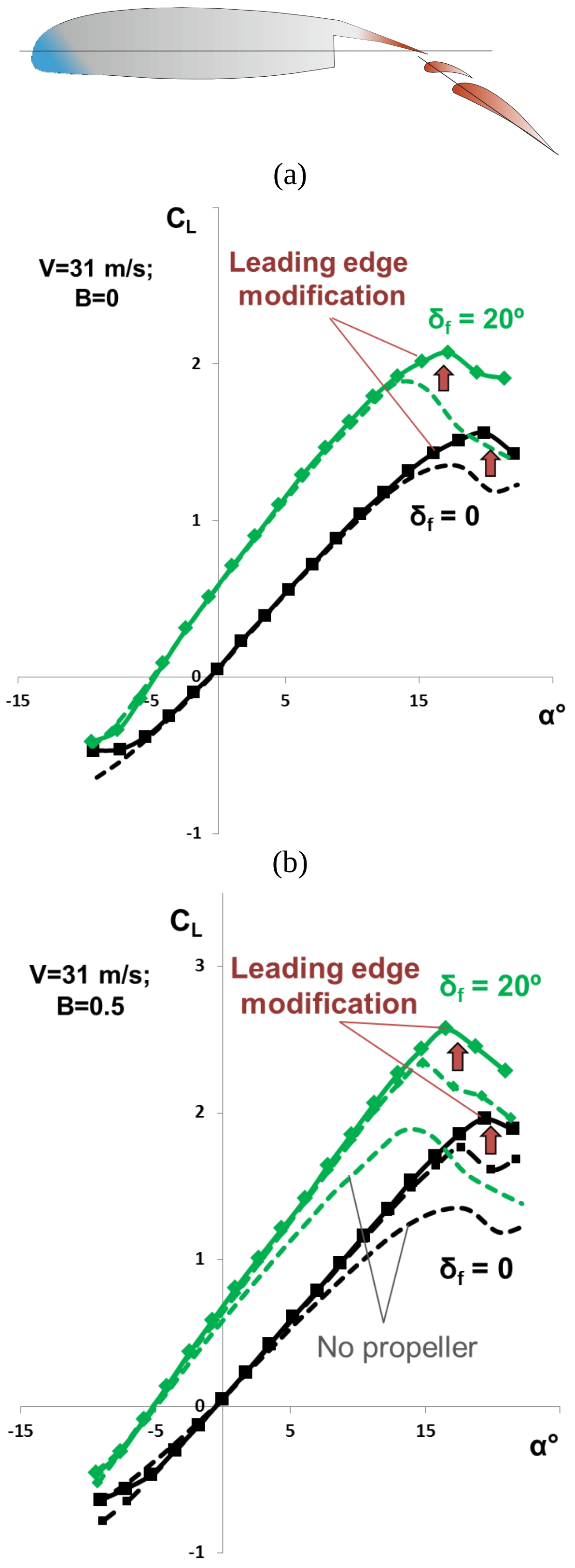


Fig. 7. Results for Light Cargo Aircraft at wind tunnel: (a) research configurations, (b) lift coefficient at angle of attack without propeller, (c) lift coefficient at angle of attack with propeller.

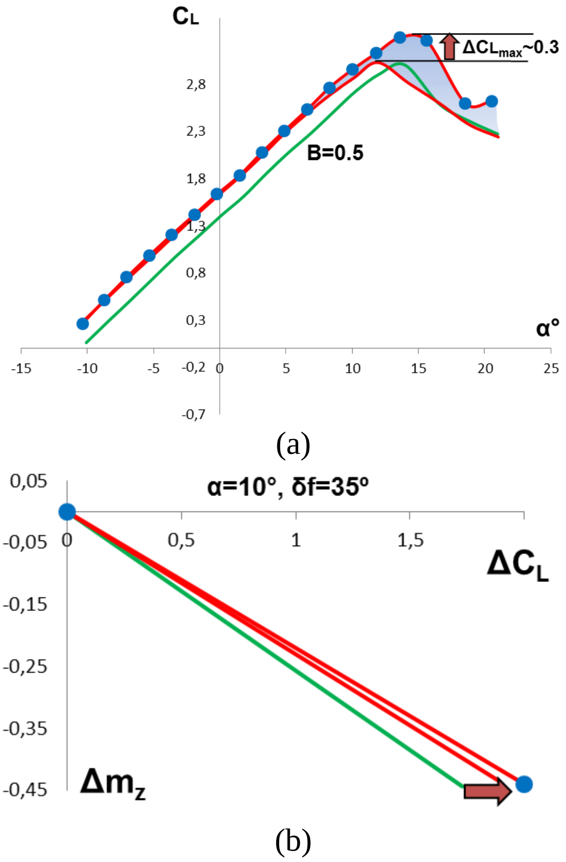


Fig. 8. Results for Light Cargo Aircraft at wind tunnel: (a) lift coefficient at angle of attack $\delta_f = 35°$, (b) factors of the moments.

5 Conclusion

The results obtained here demonstrate that using a spoiler droop in the form of a deflected wing tail in high-lift devices is an effective means of actively controlling the aerodynamic performance of an airplane. At an aberration of this element on the positive corners together with flaps, there is increase in the lift of a wing at the take-off and landing conditions with favorable reduction in the values of the pitching moment factor in a dive in comparison with the simple double-slotted flap configuration.

5 Conclusion

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