Vortex flow on the wing of aircraft and flow control to improve lift properties

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Abstract. A high-lift configuration of the civil aircraft including body, wing in high-lift configuration, nacelle with pylon and empennage is considered in the present work. Numerical simulations of the flow have been carried out in the framework of Reynolds averaged Navier-Stokes (RANS) equations for low subsonic Mach number. The active flow control method, which is capable to improve maximal lift of the aircraft, has been considered. The influence of jet blowing near wing-body junction on aerodynamic characteristics has been investigated.

1. Introduction

A high-lift configuration of the civil aircraft including body, wing in high-lift configuration, nacelle with pylon and empennage is considered in the present work (figure 1). At low-speed conditions and high angles of attack, which are typical for take-off and landing configurations, separation (and degradation of lift properties of the aircraft) can arise at different places: on the wing-body junction, on the pylon-wing junction or on the outer part of the wing. Landing regime could be realized with lift coefficients $C_L$ which are essentially lower than maximal lift coefficient $C_{L_{\text{max}}}$. In the case of lack of values of aerodynamic characteristics, it is required to undertake special efforts to suppress or reduce separation and to increase $C_{L_{\text{max}}}$.

Flow control method is one of the ways to reduce separation. There are two main types of flow control: passive and active [1, 2]. Aerodynamic strake is one of the effective passive methods to delay separation. Vortex from the strake allows to increase kinetic energy in the region of separation and to delay separation. The intensity and location of this vortex are the characteristics which define effectiveness of the strake. Disadvantage of this method is the additional drag on cruise regime, although this drag is relatively small. In the present time, the usage of the strake on the nacelle is a standard means to increase maximal lift of the modern civil aircraft at high-lift configuration.

Active flow control methods such as pulsed jet blowing were applied near wing-pylon junction in the framework of AFLONEXT FP7 Project [3].

In the present paper, the effect of jet blowing near wing-body junction on the aerodynamic characteristics of the civil aircraft has been investigated numerically.
2. Numerical problem statement
The numerical studies have been carried out on a large-scale half model of the typical transport aircraft. The investigated model, shown in figure 1, includes wing in high-lift configuration with two-section slats and two-section single-slotted flaps, body (fuselage) with wing- fuselage fairing, pylon, flow-through-nacelle, vertical and horizontal tail. The geometry is close to the one investigated in previous stage of the study [4]. The slats are made across the entire wing span with a cut-out along the pylon.

For this work, a multi-block structured grid was used. A topology was developed and a grid with about 130 million cells was built. Far-filed boundaries are located far from the model at more than 20 wing-spans. At the same time, the value Y+ of the first cell near the surface was about 1 in order to resolve the viscous turbulent boundary layer. Figure 2 shows a general view of the grid topology, which contains 4558 blocks. This grid has a C-topology around the wing airfoil, which allows to accurately resolve the flow near the model surface and interference between the elements of the aircraft. Figure 3 shows the grid on the surface of the wing and tail.
To compare aerodynamic performance with jet blowing and without it, the same grid was used, the difference was in changing jet boundary conditions.

To simulate the flow around the model, using the finite-volume approach of the second order, a numerical problem was solved in the framework of RANS approach for compressible ideal gas with a two-parameter SST turbulence model. Free stream parameters: \( M=0.15; Re=1.4 \times 10^6 \) (corresponds to the wind tunnel parameters). Here, the Reynolds number is calculated by the parameters of the free-stream flow and the length of the mean aerodynamic chord (MAC). The boundary layer was considered as turbulent, starting from the leading edges of the model elements. The dependence of laminar viscosity coefficient on the temperature was taken as Sutherland’s law with constant 110.4 K. The laminar conductivity coefficient was calculated so that the Prandtl number remained constant (Pr=0.72). The surface of the model was considered as a no-slip adiabatic wall. The jet was simulated by the input boundary condition set on the surface of the body.

3. Active flow control
In order to suppress or reduce separation near the wing-body junction, the active flow control method on the upper surface of the main element of the wing through slit nozzle was considered (figure 4). This paper compares two cases: the baseline configuration shown above in figure 1 (without flow control) and the same configuration with a jet blowing at the junction of the wing with the fuselage.
The parameters of the jet are the following: jet total pressure $P_{0\text{jet}}=3$ atm, jet total temperature $T_{0\text{jet}}=293$ K, angle of inclination to wing chord $\alpha_{\text{jet}}=45^\circ$. At the same time slot nozzle sizes are equal $\Delta x_{\text{jet}}/c=0.028$ (relative to MAC), $\Delta z_{\text{jet}}/c=0.055$. This method requires additional energy consumption, but it can be used only in the required flight regimes.

Lift curve (dependence of lift coefficient $C_L$ on the angle of attack) is shown in figure 5. The jet is intensive enough to show an increase in the linear part of the curve $C_L(\alpha)$. For the configuration with jet blowing, the maximal lift coefficient $C_{L\text{max}}$ is higher than the one without jet blowing on 0.16 (blue and black curves in figure 5). Also, the critical angle of attack increases by 1 degree, which delays the flow separation.

![Figure 5. Lift curve $C_L(\alpha)$; Re=1.4×10^6; blue curve – baseline configuration without jet blowing; black – jet blowing near wing-body junction.](image)

In figure 6, Mach number fields are presented for the spanwise sections $2z/B=0.12$, $2z/B=0.18$ and $2z/B=0.3$, where $z$ is the coordinate along span, where $B$ is the wing span. The section $2z/B=0.12$ is placed in the location of the jet blowing, the section $2z/B=0.18$ is placed near the body, while the section $2z/B=0.30$ is placed near the pylon. Figure 6 shows the baseline configuration without jet blowing for $\alpha=\alpha_{\text{crit}}+1^\circ$, which is beyond the stall. The section $2z/B=0.18$ shows separation on the main element of the wing which leads to the recirculation zone above the flap. In case of the configuration with jet blowing, figure 6 shows that the recirculation zone above the main element and flap in the section $2z/B=0.18$ is almost eliminated. The flow near the pylon does not change essentially.
The distribution of the pressure coefficient (figure 7) confirms the effect of the jet blowing on the flow near wing-body junction. Comparing the curves for the baseline configuration and the configuration with jet blowing, it can be seen that there are no changes on the lower wing surface for all sections. But there is a change for the upper surface of the wing and flap in section $z/B=0.18$ (figure 7), which means that the separation near the wing-body junction is suppressed. As to the section $z/B=0.4$ near the pylon, there are also a slight changes on the upper surface of the wing, while moving further along the wing span, there is no difference at all.
4. Conclusions
The effect of jet blowing near wing-body junction on the aerodynamic characteristics of the civil aircraft has been investigated numerically. Jet blowing leads to the increase in the linear part of the curve $C_L(\alpha)$, for 0.06 for $Re=1.4 \times 10^6$ and $M=0.15$. The maximal lift coefficient $C_{L_{max}}$ is higher than the one without jet blowing on 0.16. Also, the critical angle of attack increases by 1 degree, which slightly delays the flow separation.

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