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Effect of Steady Spanwise Blowing on the Aerodynamic Coefficients of a Maneuverable Aircraft Wing Model

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ABSTRACT: In this study, the effect of steady spanwise blowing on the aerodynamic coefficients of a maneuverable aircraft wing model has been simulated three dimensionally applying the fluent software. The simulations have been performed at the Mach number of 0.4 and different angles of attack, using unstructured grid and the (k–ω SST) turbulence model. Numerical simulation results showed that the spanwise blowing along the wing leading edge caused a flow along the axis of leading edge vortex and delayed the vortex breakdown until the high angles of attack. As a result, the lift coefficient increases at higher angles of attack, which is directly related to the jet momentum coefficient. By apply blowing, due to the vortex breakdown on the wing surface, drag coefficient is greater in comparison to the no blowing condition until the angle of attack 24 degrees and after this angle, the drag coefficient decreases. Also, drag coefficient decrease is lower at greater jet momentum coefficients. By injecting the flow over the wing, the vortex increases in different longitudinal sections and causes a greater pressure drop on the upper surface of the wing. Also, the greatest amount of pressure in the inner span of the wing and near the edge of the wing attack is observed.

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1- Introduction

Initial studies on the use of steady spanwise blowing carried out by Dixon [1] in 1969. This concept means ejecting high momentum air directly out of the fuselage in a spanwise direction over the low pressure surface of a wing. It was found that for a flat plate, with blowing at the position of 25% chord (when the angle of attack is less than 4 degrees), there is no evidence of vortex shedding. Using the same model Dixon and Cornish [2] showed the flow, reattach by blowing after completely separated from a flat plate with a sharp leading edge and could be made to unstall. Clarke [3] performed some experiments of steady spanwise blowing on a wing with a moderately swept angle and it was found that when the nozzle is placed at 20% of the root chord, the lift force decreases. In 1974, Bradley and Wray [4] noted four advantages of using a steady spanwise blowing over highly swept wings. These advantages are increased vortex lift, delayed vortex breakdown, improved directional stability, and increased effective aspect ratio. In this study, the effect of spanwise blowing on the wing of a maneuverable aircraft is numerically investigated using fluent software. In this study, we can provide good information on the flow control mechanism using the blowing method on the aerodynamic forces on the existing aircraft and determine the effectiveness of this method.

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1. Methodology

1- 1- Geometry

Three different views of (3-D) model of aircraft investigated in this study are shown in Fig. 1.

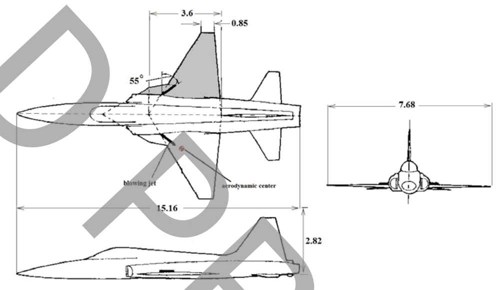

Fig. 1. Three aspects of aircraft (dimensions in meters)

The operating conditions and the details of the aircraft can be found at Table 1 and Table 2.

Table 1. Aircraft details

Parameter	Description
$b = 7.68$ m	wing span
$C_{root} = 3.6$ m	wing root chord
$C_{tip} = 0.85$ m	wing tip chord
$C_{tip}/C_{root} = 0.24$	taper ratio
$\Lambda_{Le} = 32^{o}$	leading edge sweep angle

Table 2. Operating conditions

Parameter	Description
h = 9000 m	flight height
P∞ = 30800 Pa	freestrean pressure
T = -43.42 °C	Temperature
$\rho_\infty = 0.4671\ kg/m^3$	freestream density
$\mu = 1.493 \times 10^{-5}\ N.s/m^2$	dynamic viscosity

1- 2- Numerical simulation

Considering that the Mach number in this simulation is 0.4, the flow is compressible and the density is calculated using the ideal gas law according to Eq. (1).

$$\rho = \frac{P + P_\infty}{\frac{R}{M_\omega} T} \tag{1}$$

Where $R = 8.314\ (J.K^{-1}.mol^{-1})$ and M_ω is the molecular weight. In this study, the flow is assumed to be steady, incompressible and three-dimensional. So continuity, momentum and energy equations become:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{2}$$

$$\frac{\partial}{\partial x_k}\left(\overline{\rho u_i u_k}\right) = -\frac{\partial \overline{P}}{\partial x_i} + \frac{\partial \overline{\tau_{ik}}}{\partial x_k} - \frac{\partial}{\partial x_k}\left(\overline{\rho u_i' u_k'}\right) \tag{3}$$

$$\frac{\partial}{\partial x_k}\left[\overline{\rho u_k}\left(\overline{h} + \frac{\overline{u_i u_k}}{2}\right) + 0.5\,\overline{u_k}\,\overline{\rho u_i' u_k'}\right] = \frac{\partial}{\partial x_k}\left(-\overline{\rho u_i' h'} + \overline{u_i}\left(\overline{\tau_{ik}} - \overline{\rho u_i' u_k'}\right) + \overline{\tau_{ki} u_i'} - 0.5\,\overline{\rho u_k' u_i' u_i'}\right) \tag{4}$$

The Menter's shear stress transport turbulence model (k−ω SST) was used to solve turbulence Eqs. (5) and (6).

$$\frac{\partial}{\partial x_i}(\rho U_i k) = \frac{\partial}{\partial x_i}\left[(\mu + \sigma_k \mu_t)\frac{\partial k}{\partial x_i}\right] + \widetilde{P}_k - \beta^* \rho k \omega \tag{5}$$

$$\frac{\partial}{\partial x_i}(\rho U_i \omega) = \frac{\partial}{\partial x_i}\left[(\mu + \sigma_\omega \mu_t)\frac{\partial \omega}{\partial x_i}\right] - \beta \rho \omega^2 + \alpha \rho S^2 + 2(1 - F_1)\rho \sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i} \tag{6}$$

In the Eqs. (4) and (5), F1 is blending function, S is the invariant measure of the strain rate, β^* is 0.09 and σ_{w2} is 0.856. The inlet of the flow domain and the fair field must be sufficiently far away from the airplane so that disturbances at the inlet and far field are not noticeable at the aircraft. Generating a good quality mesh is a key step in obtaining a correct solution. For this study, the tetra element is used because it is very universal and can be used for difficult geometries without much user input. The steady blowing jet can be explained by its position along the chord wing, the height of the nozzle and the nozzle size. The blowing jet is 4 cm in diameter, located 8 m at the tip of the aircraft, at 55° angle, as shown in Fig. 1. The jet momentum coefficient of blowing used in this study is presented in the form of an Eq. (7):

$$C_\mu = \frac{\dot{m} V_j}{q S_{ref}} \tag{7}$$

Where $\dot{m}$ is mass flow rate, V_j jet velocity, q is freestream dynamic pressure and S is the reference wing area.

2- Results and Discussion

The effect of spanwise blowing on the variation of lift coefficient for three jet momentum coefficients ($C_\mu = 0.02, 0.04, 0.06$) in terms of the angle of attack for the bare wing illustrated in Fig. 2. It is observed that by increasing the angle of attack, vortex shedding has become more powerful on the upper surface of the wing. With increasing blowing rate, lift increases, particularly at higher angles of attack. In addition, blowing delays wing stall to slightly higher angles of attack. The significant point to note is that the spanwise blowing is quite effective on the F-5E wing, which has a relatively low leading-edge sweep angle of 32 deg.

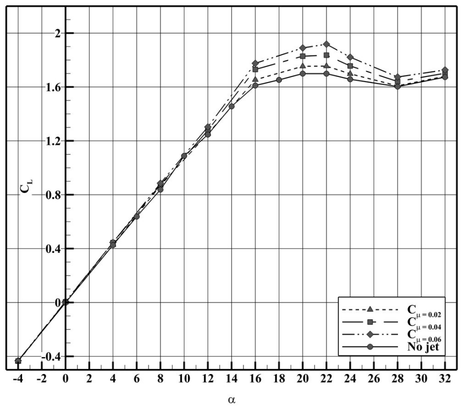

Fig. 2. The effect of blowing on the lift coefficient versus angle of attack for the bare wing at Mach No=0.4

Table 3 shows the lift coefficient for wing with and without blowing jet at various angles of attack. The table shows that the wing with a blowing jet has a higher stall angle compared to the wing without the blowing jet. Therefore, the flow can remain stable in a wider range of flight conditions and Mach numbers on the wing surface.

Table 3. The lift coefficient of the aircraft with and without blowing a jet

α	Without jet	$C_\mu = 0.02$	$C_\mu = 0.04$	$C_\mu = 0.06$
16	1.6108	1.6534	1.7299	1.7755
20	1.6992	1.7533	1.8286	1.8897
22	1.6987	1.7550	1.8362	1.9175
24	1.6571	1.6974	1.7562	1.8211

In Fig. 3, the pressure distribution on the upper surface of the wing is shown for wing with and without blowing jet at the desired cross-section at an angle of attack 16°. The spanwise blowing influences the pressure field on the upper surface of the wing, but has no significant effect on the lower surface of the plane, so only the upper surface of the plane is shown. As shown in Fig. 3, the lowest pressure value is for the primary parts of the wing edge. By applying the spanwise blowing, the pressure on the wing's upper surface is reduced rather than no blowing jet mode, thereby increasing the lift force. The effects of the spanwise blowing at the higher angles of attack are higher and are related to the separated flow field on the surface of the wing, which occurs in a no blowing state.

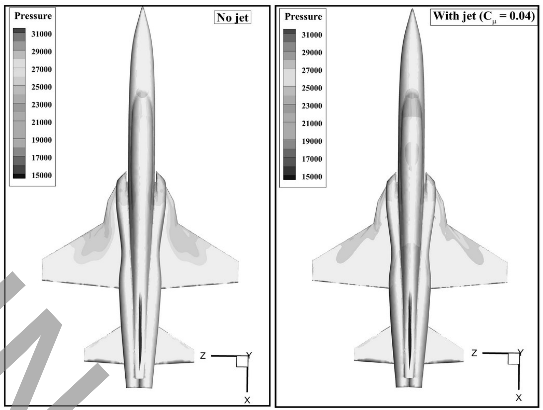

Fig. 3. Static pressure contours on the upper surface of the wing at α=16°

3- Conclusions

The results of this study are as follows:

1. The amount of the lift coefficient has a direct relationship with the jet momentum coefficient and increasing at the high angles of attack. In addition, its tail results in an increase in the angle of exhaustion compared with its tail.
2. The spanwise blowing has a significant effect in the pressure field on the upper surface of the wing at high angles of attack. A higher pressure drop occurs in the inner span of the wing and near the leading edge of the wing.
3. At low angles of attack, the spanwise blowing does not affect the pitching moment.

4- References

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