Numerical Investigation of Airfoil/Jet/Fuselage-Undersurface Flowfields in Ground Effect

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Abstract

THE Euler/Reynolds-averaged compressible Navier-Stokes, continuity, and energy equations are solved in conjunction with a two-equation (K-ϵ) turbulence model for two-dimensional flows related to vertical/short takeoff and landing (V/STOL) aircraft. Beam and Warming's implicit factored central-difference scheme with/without diagonalization is introduced. For the airfoil/jet/ground-interaction flowfields, the inviscid and laminar flows are considered. Different values of parameters (such as width, velocity, and temperature of jet; height of jet above the ground plane; and freestream Reynolds number) are employed to study the physical phenomena and aerodynamic coefficients. Also presented is information about the turbulent impinging jet with curved fuselage-undersurface, pressure distributions on the ground plane and fuselage-undersurface, and distributions of turbulent kinetic energy and velocity component along the centerline.

Contents

The aerodynamic interaction caused by the flow around the airfoil, fuselage-undersurface, and ground in the presence of lift jets is important in V/STOL aircraft design. Based on the solution of three-dimensional thin-layer Navier-Stokes equations, the velocity vectors and suck-down effect of laminar flow around a delta planform wing, equipped with two thrust reverser jets, in ground effect have been studied by Chawla et al.[1] To describe the vortex formulation behind the jet and to include the effect of jet/ground interaction on the flowfield around the airfoil, Agarwal and Deese[2] modified Jameson's Euler code (FLO-53) for computing almost incompressible flow. Agarwal and Bower[3] studied the flow behaviors of the turbulent jet impingement flowfields with curved fuselage-undersurface. The governing equations, including a two-equation model, were expressed in stream function/vorticity forms and formulated by the finite-difference method. In this paper, Beam and Warming's scheme with/without diagonal form[4,5] is introduced to solve the Euler/Reynolds-averaged compressible full Navier-Stokes, continuity, and energy equations in conjunction with a two-equation (K-ϵ) turbulence model.[6] The airfoil/jet/fuselage-undersurface flowfields in ground effect are investigated.

For the airfoil/jet/ground-interaction flowfields, the methods of characteristic, average process, slip/no-slip, and adiabatic-wall conditions are respectively applied to the far-field boundary, trailing edge, wake cut, surface of airfoil, and ground plane. Velocity and temperature about the entering jet are specified, and density is obtained from the values of interior points. With regard to the turbulent impinging jet, the boundary treatments of turbulent kinetic energy (K) and turbulent dissipation (ϵ) are the same as those of Ref. 3. The symmetric condition is imposed on the jet centerline. Along the exit plane, the pressure is specified and conservative variables (ρ, ρu, ρv) are extrapolated. In addition, the boundary treatments of ground plane, fuselage-undersurface, and entering jet are the same as those of airfoil flow in the presence of jet and ground plane.

For low subsonic flow ($M_\infty = 0.0588$, $\alpha = 0$ deg) past a NACA 0018 airfoil in ground effect with a jet issuing from its

Table 1 Lift, drag, and moment coefficients for NACA 0018 airfoil/jet/ground-interaction flowfields

H/C	V_R	D/C	Re_∞	T_R	C_l	C_d	$C_{m_{LE}}$
0.5	2.0	0.02	——	1.0	0.9935	−0.0292	−0.2121
1.0	2.0	0.02	——	1.0	0.9634	−0.0116	−0.2034
∞	2.0	0.02	——	1.0	0.9126	−0.0008	−0.1843
0.5	4.0	0.02	——	1.0	1.2870	−0.3240	−0.1430
0.5	2.0	0.04	——	1.0	1.1793	−0.1556	−0.2059
0.5	2.0	0.02	5000	1.0	0.8222	−0.0145	−0.2615
0.5	2.0	0.02	20,000	1.0	0.9629	−0.0141	−0.3128
0.5	2.0	0.02	5000	1.5	0.6975	−0.0032	−0.2132

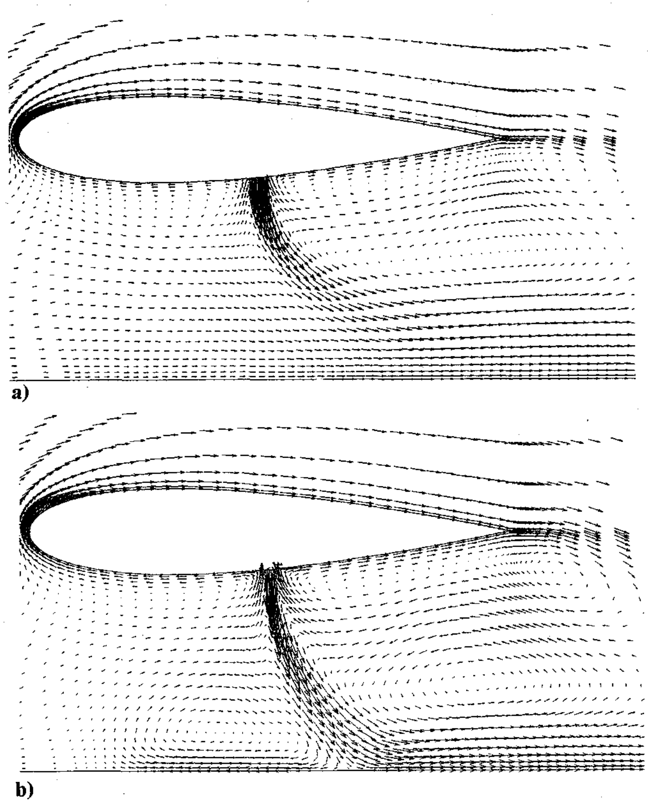

Fig. 1 Velocity vectors for jet issuing from the NACA 0018 airfoil; $M_\infty = 0.0588$, $\alpha = 0$ deg, $H/C = 0.5$, $T_R = 1.0$: a) $V_R = 2.0$, $D/C = 0.04$; b) $V_R = 4.0$, $D/C = 0.02$.

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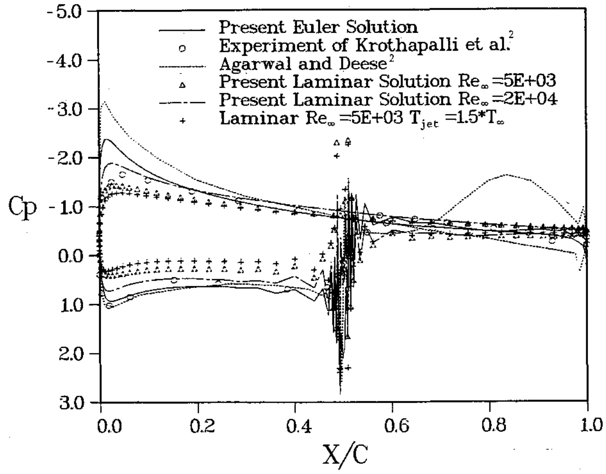

Fig. 2 Pressures distributions for jet issuing from the NACA 0018 airfoil; $M_\infty = 0.0588$, $\alpha = 0$ deg, $H/C = 0.5$, $V_R = 2.0$, $D/C = 0.02$.

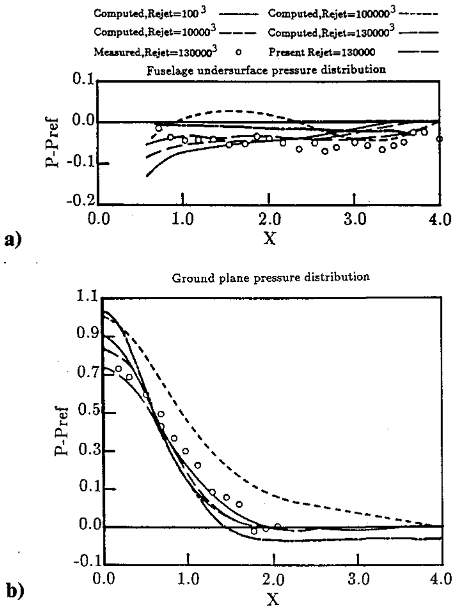

Fig. 3 Fuselage-undersurface (a) and ground plane (b) pressure distributions for two-dimensional impinging jet; $H = 2.0$, $W = 3.68$.

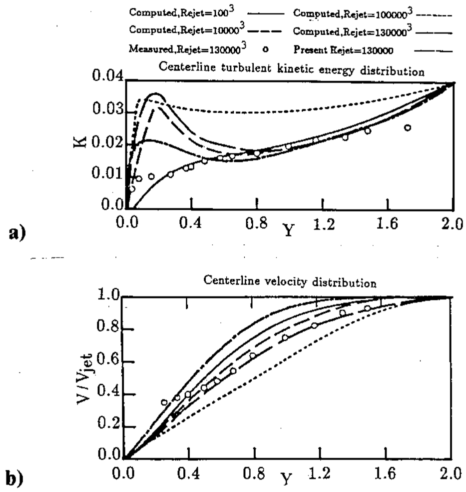

Fig. 4 Centerline turbulent kinetic energy (a) and centerline velocity (b) distributions for two-dimensional impinging jet; $H = 2.0$, $W = 3.68$.

undersurface,[2] several parameters, such as jet conditions [velocity ratio ($V_R = V_{\text{jet}}/V_\infty$), temperature ratio ($T_R = T_{\text{jet}}/T_\infty$), location ($x_{\text{jet}}/C$), width ($D/C$)], height of jet above the ground (H/C), and freestream Reynolds number (Re_∞), can influence the flow phenomena. In this paper, different values of H/C, V_R, D/C, Re_∞, and T_R are introduced to study the flow structure and aerodynamic coefficients. Jet discharging normally into the crossflow is located at the middle of the chord. As shown in Fig. 1a, a small vortex and three recirculation zones appear near the trailing edge and in the wind and lee sides of jet. If the jet momentum is enhanced, the strong blockage effect will divide the flowfield into two major regions between the ground and the lower surface of the airfoil. As shown in Fig. 1b, five vortices are formulated. From the pressure coefficients plotted in Fig. 2, the present numerical results for the inviscid and viscous flows are reliable. The numerical values of lift, drag, and moment coefficients for different parameters are given in Table 1, where nose-up moment is defined as positive. As expected, the computed value of lift is higher at $H/C = 0.5$ than $H/C = 1.0$.

With regard to a single planar jet emanating from curved fuselage-undersurface, the experimental and numerical data presented by Agarwal and Bower[3] are used to compare the present solutions. The numerical data in Ref. 3 were obtained by solving the incompressible stream function/vorticity equations without considering the energy equation. In this paper, the Mach number and temperature at the center of the entering jet are assumed to be 0.1 and 293 K, respectively, and the total temperature along the plane of entering jet is kept constant. Because no temperature distributions along fuselage-undersurface and ground plane were given in Ref. 3, the adiabatic wall condition is assumed. The pressure distributions on the fuselage-undersurface and ground plane and the distributions of turbulent kinetic energy and velocity component along the centerline are presented in Figs. 3 and 4. Even though the pressure and velocity distributions (Fig. 3 and 4b) do not show better agreement with experimental data than the computed results of Ref. 3, the centerline turbulent kinetic energy distribution is closer to the experimental data.

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