

Abstract

A detailed study of aerodynamics of generic multi-element airfoil configurations is presented at moderate values of Reynolds number (in the range $5 \times 10^4 - 1.5 \times 10^5$) and Mach numbers in the range < 0.4 . Several studies are reported on aerodynamics of high-lift systems at high-Reynolds number but the areas of low and moderate Reynolds number flow regimes have gained interest recently due to their applications in the design of unmanned aerial vehicles (UAV) and micro-aerial vehicles (MAV). Parametric studies of flows past single, two- and three-element airfoils are conducted using Reynolds-Averaged-Navier-Stokes simulations with single equation Spalart-Allmaras turbulence model, to study dependencies on several geometric parameters that appear in the problem. Unsteady compressible flow effects, including the generation of noise at the trailing edge, are also studied using numerical solutions of two-dimensional Navier Stokes equations.

A two-element airfoil is systematically developed using NACA0012 and NACA23012 airfoils for the main element and flap, respectively. A detailed study of effects of flap geometric parameters (overlap, gap-width and deflection angle) on flow is conducted at Reynolds number of 5×10^4 and a configuration of maximum lift is identified. The trailing edge of the main element is subsequently modified to a cusped shape to increase the range of flap overlap and influencing the pressure distribution on flap to prevent early flow separation. With the application of active flow control in the form of steady blowing/suction, a 9 – 13% increase in values of lift coefficients to a maximum value of approximately 1.5 is achieved when the free-stream angle of attack is 5° . The influence of viscous effects such as a laminar separation bubble, boundary layer formation in the slot

region between the flap and the main element are examined in detail. In the next step, a slat is positioned upstream of the two-element airfoil. Two angles of attack of 5° and 13° at Reynolds number of 1.5×10^5 are considered to analyse the effects of slat geometric camber and deflection angle for a fixed value of slat gap and overlap. Aerodynamic performance of the three-element airfoil is sensitive to the boundary layer that evolves on the slat surface. Both the geometric parameters are found to have a significant effect on the merging of the slat wake and the boundary layer on the suction surface of the main element. Implementation of suction/blowing based active flow control at the slat surface is found to yield a thinner slat wake and delay wake-boundary layer confluence to aft positions on the main element. With adjustments in slat deflection and application of active flow control, the maximum lift coefficient is found to increase to 2.5 at angle of attack of 13° for the three-element airfoil up from a value of 1.6 for the two-element airfoil at angle of attack of 7° .

The occurrence of trailing edge noise radiation from a single and two-element airfoil is studied using numerical solutions of two-dimensional compressible Navier Stokes equations at Reynolds number of 5×10^4 and angle of attack of zero degrees. Several verification and validation tests of the in-house computer program used for research are presented. In the case of single airfoil, vortex shedding and the scattering of pressure fluctuations at the trailing edge is found to result in tonal noise radiation. In the case of two-element airfoil, merging of the wake of the main element with the shear layer that separates off the flap results in rapid development of flow unsteadiness and mixing due to appearance of small scales, away from the trailing edges of main element and flap. The noise radiated from the two-element airfoil is consequently lower in amplitude compared to that from the single airfoil.