

Abstract

In the first part of the study, the aerodynamic behavior of airfoils in ground effect is investigated, utilizing Reynolds-Averaged Navier-Stokes (RANS) simulations to analyse the impact of wall proximity on the flow characteristics. A comprehensive validation study is first conducted for a NACA4412 airfoil placed above an impermeable moving wall at chord-based Reynolds numbers of 3×10^5 and angles of attack of 0° and 10° . The simulations demonstrate a good agreement with experimental data for surface pressure distribution, showcasing the effect of decreasing wall distance on lift characteristics. The study further investigates ground effects on airfoils of different camber profiles (NACA0012, NACA4412, and NACA8412) using steady-state RANS simulations at a fixed Reynolds number of 3×10^5 . Results show that at 0° angle of attack, lift coefficients increase for the NACA8412 (higher camber) and decrease for the NACA0012 and NACA4412 airfoils with decreasing wall distance. At 10° angle of attack, all airfoils exhibit increased lift coefficients as the gap ratio decreases, with a more pronounced effect for the NACA8412 airfoil. Additionally, the study explores the effect of airfoil thickness on NACA0012 and NACA0018, at Reynolds numbers of 5×10^4 and 3×10^5 and gap ratios ranging from 0.15 to 1.0. At higher Reynolds numbers, the results show that thicker airfoils experience a more rapid decrease in lift coefficients with decreasing gap ratio at 0° angle of attack, attributed to increased suction on the lower airfoil surface. Conversely, at 10° angle of attack, thinner airfoils exhibit improved lift coefficients as the gap ratio decreases, owing to an increase in positive pressure on the lower surface. At lower Reynolds numbers, flow separation is significantly influenced by the gap ratio and angle of attack.

Subsequently study investigates the sensitivity of flow past a two-element airfoil to changes in the geometry of trailing segment of the main element using Reynolds-Averaged-Navier-Stokes simulations at Reynolds numbers, 5×10^4 and 1.5×10^5 and angles of attack in the range 0 to 7 degrees. Adjoint-based gradient data are used to make systematic changes to the shape in a localized region around the trailing edge of the main element with the objective of maximizing the lift-to-drag ratio. The introduced shape changes tend to modify the converging-diverging flow passage that forms in the overlap region between main element and flap such that separation on the flap suction surface is delayed. Improvements in lift-to-drag ratio of 28% and 10% are obtained at angles of attack 0 and 5 degrees respectively at lower Reynolds number of 5×10^4 , whereas the improvements at higher Reynolds number are comparatively lower. Further, the study extends the investigation to understand the effects of the presence of a wall on the aerodynamics of two-element airfoils at a Reynolds number of 50000, an angle of attack of 5 degrees, and varying flap overlap. The primary geometry of the airfoil features a NACA0012 section as the main element, along with a slotted flap. A second geometry for the main element is obtained by local modifications, in the form of a downward tilt at the trailing edge and shaping of the overlap region. Lift coefficients increase significantly with a reduction in wall distance for both geometries. Geometric modifications at the trailing edge of the main element cause higher pressure due to flow blocking on the lower side, as

well as higher exit speed with flow alignment along the flap surface on the upper side. Improvements in lift coefficients due to geometric changes vary from 7% to 11% when the wall distance decreases from 1 to 0.15 times the chord length of the main element.

Finally, the flow development over the two-element airfoil system with designed tilted trailing edge is studied and compared with that over a single airfoil, using large-eddy simulations at Reynolds number 2.5×10^4 and Mach number 0.2. The single element is considered at incidence of 5° and the two-element airfoil is considered at 3° and at 5° incidence. The objective is to study the surface pressure fluctuations which are known to contribute to far-field noise radiation via scattering at the airfoil surface. Both the amplitude of disturbances and their distribution about the trailing edge influence the noise radiation characteristics of the airfoil.