Flow Control for an Airfoil with Leading-Edge Rotation: An Experimental Study

Ahmed Z. Al-Garni,* Abdullah M. Al-Garni,† Saad A. Ahmed,‡ and Ahmet Z. Sahin†
King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

An experimental investigation has been conducted on a two-dimensional NACA 0024 airfoil equipped with a leading-edge-rotating cylinder. The airfoil was tested for different values of leading-edge rotations and flap deflection angles. The effects of the angle of attack $\alpha$, the cylinder surface velocity ratio $U_c/U$, and the flap deflection angle $\delta$ on lift and drag coefficients, the size of the separated flow region, and the stall angle of attack are included. The effect of $U_c/U$ on the boundary-layer growth and turbulence intensity are also shown. Experimental results, for example, showed that the leading-edge rotating cylinder increases the lift coefficient of a NACA 0024 airfoil from 0.85 at $U_c/U = 0$ to 1.63 at $U_c/U = 4$ and delays the stall angle of attack by about 160%. Smoke-wire flow visualization results were also used to demonstrate the strong effect of the leading-edge rotating cylinder on the size of the recirculation region.

Nomenclature

$C_D$ = drag coefficient
$C_L$ = lift coefficient
$L/D$ = lift-to-drag ratio
$U$ = freestream mean velocity, m/s
$U_c$ = cylinder tangential velocity, m/s
$U_c/U$ = cylinder surface velocity ratio
$u$ = mean velocity inside the boundary layer at a specific location, m/s
$u'$ = root mean square values of velocity fluctuations along $x$, m/s
$u'/U$ = turbulence intensity
$\alpha$ = angle of attack, deg
$\delta$ = flap deflection angle, deg

Subscripts

$c$ = cylinder
$max$ = maximum
$R$ = required for flow reattachment

Introduction

The problem of boundary-layer control is very important in the field of aerodynamics and hydrodynamics. Boundary-layer control is essential for current wing design technology to increase lift, lift-to-drag ratio, and stall angle of attack. Several methods, such as suction and blowing, have been developed and reported for controlling boundary-layer flow. Although interest in boundary-layer control has increased, little is known about the use of a moving surface to control the boundary layer. Several authors, including Schlichting 1 and Chang, 2 have reviewed a vast body of literature pertaining to boundary-layer control. The effects of a rotating cylinder in a water channel at various cylinder peripheral speeds was investigated by Prandtl and Tietjens. 3

The application of a clockwise rotating cylinder on the upper surface of an airfoil wing was investigated by Alvarez-Calderon and Arnold. 4 Their investigation covers a vertical takeoff and landing configuration. They conducted a numerical and experimental study to investigate the effects of forebody boundary-induced vorticity on the development of the laminar/turbulent boundary layers over modified NACA 0012 and NACA 63-218 airfoils with leading-edge rotation. They utilized an implicit finite difference procedure to solve the two-dimensional compressible full Reynolds-averaged Navier-Stokes equations on a body-fitted curvilinear coordinate system. The study presented the effects of varying the circumferential...