Effects of Freestream Turbulence on the Performance Characteristics of an Airfoil

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Abstract

THE lift and drag characteristics and associated flowfields over the suction surface of an NACA 0015 airfoil with an aspect ratio of 2.9 were obtained at a Reynolds number of 250,000 for conditions both with and without freestream turbulence (FST). Increasing the FST from 0.25 to 9% resulted in an increase in peak lift coefficient of 30% with no measurable change in the slope of the lift coefficient C_L vs the curve of the angle of attack α; no significant change in drag coefficient C_D at each α occurred. Oil flow visualization results showed an elimination of the laminar separation bubble with FST, corresponding to a disappearance of the hysteresis loop in the performance data; a significant delay in separation was also shown for the case with FST, corresponding to the increase in peak lift coefficient. The results present engineers with information for the design of a wide variety of systems where airfoils experience FST.

Contents

Examples of airfoils that experience FST and/or unsteadiness include wind turbines, the compressor and turbine blades of turbomachines, and the airfoil sections downstream of a canard or a propeller. In nature, birds and fish are observed to navigate in close proximity to one another and in defined patterns. Many of these examples occur at low Reynolds numbers. Although these as well as many other internal and external flows with FST frequently occur in engineering, no information in the literature was found that describes the effects of high levels of FST on the lift and drag characteristics of the flowfields around airfoils.

The purpose of this study is to investigate the effects of near-homogeneous and near-isotropic FST on the performance characteristics of an airfoil. This information will be useful to assess the influence of FST on a wide variety of flows encountered by engineers. The oil flow visualization results and performance characteristics data can be used for comparison of flows modeled using computational fluid dynamics studies. The results also represent a first step in understanding the flowfields around airfoils for the case with FST. At high angles of attack, these flowfields can result in severe buffeting loads on aircraft and turbomachinery blading; the results of this study may suggest solutions to fatigue and stability and control problems.

Airfoil performance characteristics were evaluated in the California Polytechnic 0.88 × 1.18m (test section dimensions) subsonic draw-through wind tunnel.[1] The experimental system used for this study is illustrated in Fig. 1. The NACA 0015 airfoil evalucated has a cord of 15.4 cm and an aspect ratio of 2.9, and was studied at a Reynolds number based on airfoil chord of 250,000. The airfoil is covered with monokote and is mounted by a strut to a sting balance. The strain-gauge-type sting balance, manufactured by Aerolab, has remote control of angle of attack. Voltage outputs of the sting balance are fed into a Hewlett Packard 150 computer and data acquisition system. This system has been programmed to calculate and plot C_L, C_D, and α.

A set of monoplane rods with a mesh size of 6.67 cm and a diameter/mesh size ratio of 0.32 has been used to generate FST.[1] The rods span the entire cross section of the test section and have been positioned at four locations upstream of the airfoil to provide rms longitudinal turbulence intensities (u'/U_∞) between 3 and 12% at the plane perpendicular to the flow at the leading edge of the airfoil. A survey of the velocity and turbulence flowfields downstream of the rod set has shown that essentially homogeneous and isotropic turbulence exists for each test condition.[1]

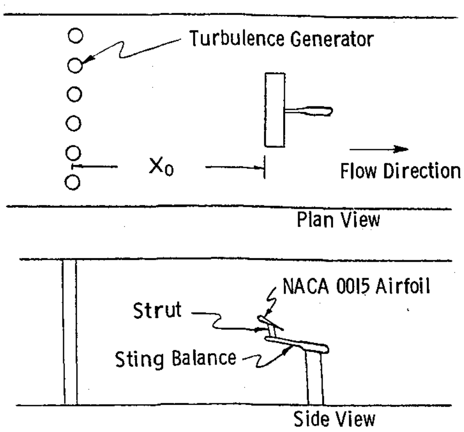

Fig. 1 Experimental system.

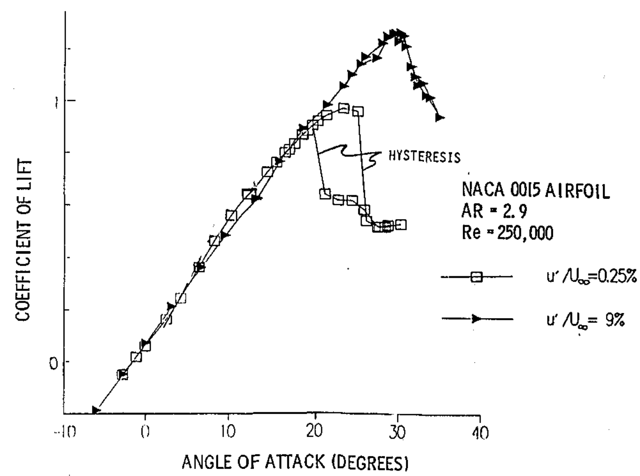

Fig. 2 Coefficient of lift vs angle of attack.

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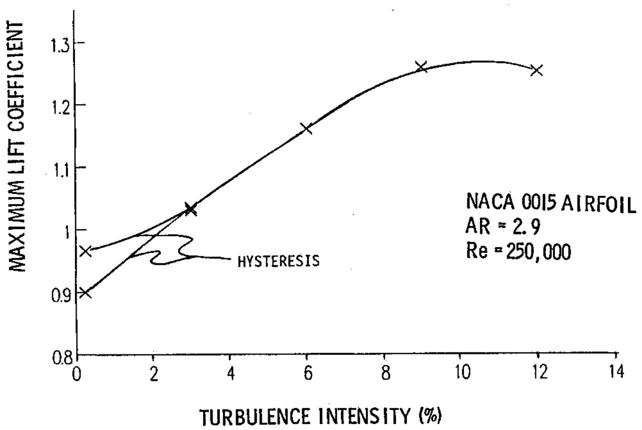

Fig. 3 Maximum coefficient of lift vs freestream turbulence intensity.

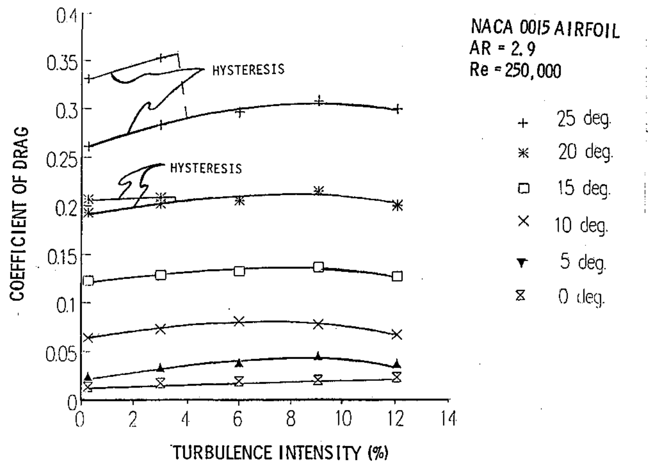

Fig. 4 Coefficient of drag vs freestream turbulence intensity.

Curves of C_L vs α for the NACA 0015 airfoil are presented in Fig. 2. The curve for low FST shows a significant hysteresis loop with a span of about 5.5 deg. Airfoil performance characteristics were also obtained with FST intensities of 3, 6, 9, and 12%. With a 3% FST, the span of the hysteresis loop decreased to about 1 deg, and did not exist for larger FST intensities. The slope of the C_L vs α curve did not change with increasing FST and, as shown in Fig. 3, the peak C_L increased 30% as the FST intensity increased from 0.25 to 9%. Saturation of the maximum C_L vs u'/U_∞ curve presented in Fig. 3 occurs at $u'/U_\infty \simeq 9\%$.

Curves of C_D vs u'/U_∞ at various values of α are presented in Fig. 4 and appear to peak generally at a $u'/U_\infty = 9\%$.

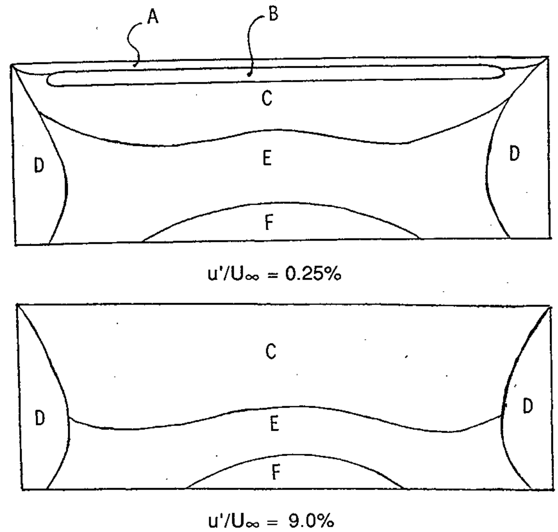

Fig. 5 Oil flow visualization results at $\alpha = 17$ deg. Regions: A = laminar boundary layer, B = laminar separation bubble, C = attached turbulent boundary layer, D = wing tip vortices, E = separation, and F = upstream velocities.

Changes in C_D are a result of skin friction, which increases as u'/U_∞ increases (due to earlier transition, delayed separation, and higher skin-friction coefficients), and are a result of losses due to flow distortion, which decrease with increasing u'/U_∞. The changes in C_D due to increases in u'/U_∞ at each α are small, and the additional skin-friction losses that occur with increasing U'/U_∞ are approximately equal to the gains obtained as a result of delayed separation and improved flow distortion.

The oil flow technique was used to visualize the flow patterns on the suction surface of the airfoil at different FST intensities[1]; the results are presented in Fig. 5. At an angle of attack of 17 deg with low onset FST (before peak C_L), regions of the laminar separation bubble, turbulent boundary layer, wing tip vortices, separation and upstream flow were observed and are similar to those observed by Winkelmann.[2] At an angle of attack of 17 deg with 9% onset FST, the laminar separation bubble has disappeared, which agrees with the elimination of the hysteresis loop on the performance data. Separation is significantly delayed relative to the low FST condition.

References

[1]Hoffmann, J. A., "Effects of Onset Freestream Turbulence on the Performance Characteristics of an Airfoil," AIAA Paper 90-3025, Aug. 1990.

[2]Winkelmann, A. W., "Separated Flow on a Wing at Low Reynolds Numbers," AIAA Paper 88-3548, July 1988.