Unsteady Wake Measurements of an Oscillating Flap at Transonic Speeds

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Abstract

THE steady and unsteady wake profiles of an airfoil with an oscillating flap were measured at nominal free-stream Mach number of 0.8 in the NASA Ames 11×11-ft wind tunnel. The phase averaged wake velocity and pressure profiles at four axial locations are presented up to one chord length from the trailing edge. Both fundamental harmonic frequency and typical time history data are presented to observe the effects of flap angle. The drag coefficient obtained from the wake pressure measurements is compared with that obtained from the airfoil pressure distribution.

Contents

It is important to understand the unsteady aerodynamic behavior of airfoils to solve the problems associated with flutter and buffet. The problems are more complex at transonic speeds due to shock waves and associated separation. Although some systematic results are available on oscillating airfoils having low amplitudes,[1] no reliable data are available at large amplitude separated flows. To fill this gap, a complex experiment was carried out by various groups using Kulite tansducers, LDV, holographic interferometry, and hot-film probes coordinated by Buell and Malcolm.[2] This Synoptic deals with the measurement of steady and unsteady wake velocity and total and static pressure profiles. From the total and static pressure profiles, the drag coefficient is evaluated and compared with the drag coefficient obtained from the surface pressure distribution.

The experiments were conducted in the NASA Ames 11×11-ft transonic wind tunnel. A NACA 64A010 airfoil model with 1.37m (54 in.) span and 50 cm (19.7 in.) chord is held between two splitter plates. All the experiments reported here were conducted at $M = 0.8$ at a pressure corresponding to a Reynolds number of 6 million, based on the chord length. The oscillation frequency of the flap is 30 Hz, corresponding to a reduced frequency of 0.175 based on half chord. The experiments were conducted at two incidence angles, $\alpha = 0$ deg and $+4$ deg. At each incidence angle, the mean flap angle, δ, was set at two values of 0 deg and -4 deg. The flap up position corresponds to negative angle. The amplitude of oscillation was set at ± 2 deg.

A probe consisting of pitot and static tubes and x-array hot-film probe is used to measure the pressures and velocities in the wake. The x-array probe is a DISA 55R51 probe, nickel film deposited on 70-μm diam quartz fiber. Differential Kulite transducers (4.0 psi) of 2.36 mm (0.093 in.) diam are embedded inside 4.75 mm (0.187 in.) pitot and static tubes, as described in Ref. 3. Wake profiles were obtained at four axial locations of $x/C = 0.05$, 0.25, 0.51, and 1.02, where x is the axial distance from the airfoil trailing edge and C is the airfoil chord.

Wake velocity profiles are obtained in two different ways: 1) by measuring the instantaneous static and total pressures, 2) from x-hot-film measurements. An elaborate calibration procedure was followed to obtain the sensitivity coefficients of the hot-film probes at transonic speeds in the NASA Ames 2×2-ft transonic wind tunnel. Data reduction procedures are established to determine the magnitude and direction of the flow at transonic Mach numbers. Typical velocity profiles obtained from hot-film and pressure measurements are compared with LDV and holographic interferometry.[3] The comparison at zero angle of attack and flap angle is reasonable; however, for highly separated flow at higher flap angle, the agreement is poor. It appears that the static holes at the midspan where the transducers are located acts as boundary layer trip at incidence of 4 deg or higher, introducing three-dimensional effects. Only the results at 0 deg airfoil incidence are presented here, the complete experimental data obtained at various conditions are presented in the full back-up paper.

The fluctuating axial velocity u with phase angle are presented in Fig. 1 (u is normalized by the local mean axial velocity U in this figure). The flap motion is also indicated in the same figure, from which the phase of the velocity with respect to the flap motion can be observed. The flap motion is almost a sine wave as there is no difference between the measured points and the fundamental harmonic component. Two locations inside the wake are selected on either side of the center line of the wake for the presentation of time histories. As expected, there is a phase difference of 180 deg at these locations. For unseparated flow at zero incidence and zero mean flap angle the measured points agree well with the first harmonic component. At a mean flap angle of -4 deg and with the airfoil at incidence, higher harmonic components are present. In general, if the flow separates anywhere, higher harmonic components are present.

The mean (oscillating) axial wake velocity profiles, the first harmonic amplitude profiles are presented in Fig. 2. The velocity profiles in Fig. 2a are normalized by a reference velocity at the upper edge of measurment points. The phase angle variation in the wake also is shown in the same figure. From the mean (oscillating) profiles, the time dependent wake profiles can be constructed at any phase angle using the amplitude and phase information. This information is useful for comparison with the predicted results. The mean (oscillating) wake profiles essentially agree with the steady (non-oscillating) profiles for all the tested conditions. The amplitude has two peaks, one above and one below the centerline of the wake. The phase changes gradually close to the center of the wake from both sides. Near the center, the phase changes rapidly almost by 180 deg.

The profile drag is calculated from the total and static pressure distributions in the wake as described in Ref. 4. Results are presented in Fig. 3 and Table 1. The form drag also is evaluated and presented in the same figure. The drag is calculated for the steady as well as mean (oscillating)

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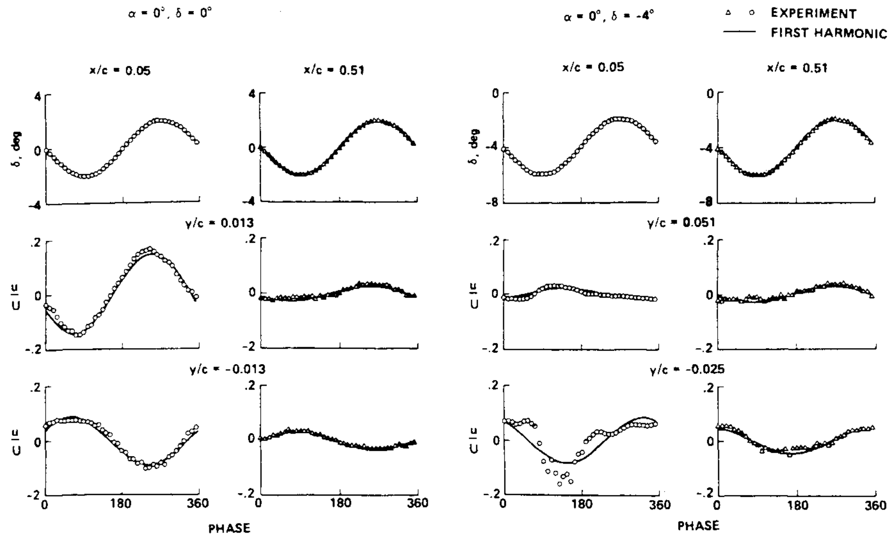

Fig. 1 Fourier components of axial velocity at typical locations in the wake.

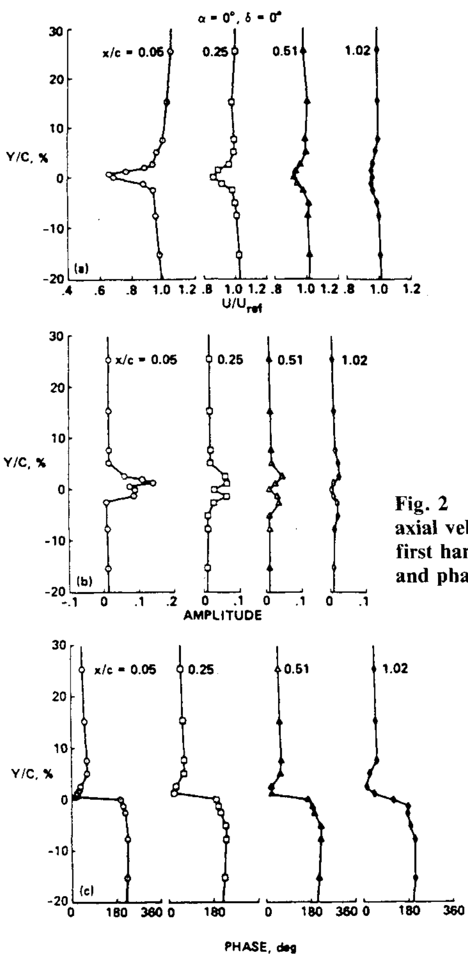

Fig. 2 Mean (oscillating) axial velocity profiles, first harmonic amplitude, and phase in the wake.

pressure distribution. It can be seen from Table 1 that the difference between the steady (non-oscillating) and mean (oscillating) drag coefficient is very small and may not be distinguished from the errors involved. As expected, the form drag coefficient calculated from the pressure distribution is less than the profile drag calculated from the wake pressure measurements. The difference can be attributed to the skin friction drag. Note that the instrumentation required to evaluate the drag from the pressure distribution is inadequate, particularly near the leading edge.

The instantaneous form drag is evaluated from the phase averaged model C_p distribution for the four tested cases and presented in Fig. 3. Unsteady effects can be clearly observed.

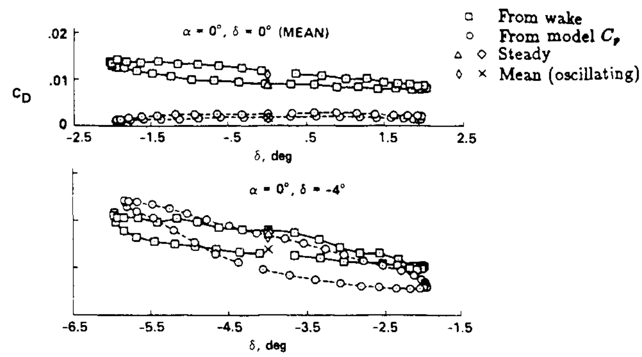

Fig. 3 Comparison of drag coefficient based on wake pressure measurements and model C_p distribution.

Table 1 Mean drag coefficient

	Steady		Oscillating mean	
Condition	From C_p	From wake	From C_p	From wake
$\alpha=0$ deg, $\delta=$ 0 deg	0.0010	0.0085	0.0013	0.0010
$\alpha=0$ deg, $\delta=-4$ deg	0.0174	0.0171	0.0137	0.0163

Drag due to skin friction is not included in this value. From phase averaged static and total wake pressure profiles, the "instantaneous drag coefficient indicator" is evaluated using the same steady state expressions and presented in the same figure. This so-called "drag indicator" can be better described as the instantaneous momentum defect in the wake rather than the drag experienced by the airfoil, since the wake drag expressions are only good for steady flow. However, a comparison with the form drag shows similar unsteady effects.

Acknowledgments

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