Instantaneous Turbulence Profiles in the Wake of an Oscillating Airfoil

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Abstract

THE actual spectacular development of computational methods in fluid dynamics has reached a stage where two-dimensional, time-averaged Navier-Stokes equations can be solved within reasonable cost and storage requirements, for both steady and unsteady situations. The comparison of calculated Navier-Stokes solutions and experimental data, however, is still limited, mainly by a lack of detailed information about the turbulence input to the equations; and the question of the influence of the unsteadiness on the turbulence structure is still unanswered.

Experimental data in this field were recently compiled by Carr.[1] From this review it appears that in the case of a pitching airfoil little or no detailed information about velocity and turbulence profiles is to be found at the present time, although for the corresponding steady-state case, such information is available but not profuse.[2,3]

In the present investigation, detailed experimental profiles for the velocity and non-zero Reynolds stresses are presented at different downstream positions in the wake of a sinusoidally pitching NACA 0012 airfoil. Several frequencies, mean incidences, and oscillation amplitudes are considered. Instantaneous incidences vary from zero to just above the static stall limit. The chord Reynolds number is 300,000, the airfoil aspect ratio is 1.6, and a tripping wire is mounted at 10% chord distance from the leading edge. Trailing-edge stall was observed as the static incidence reaches 14 deg. Instantaneous velocity and turbulence profiles are available at five downstream positions in the near wake of the airfoil at 48 times during one oscillation period. The data are available from NASA AMES.

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A single slanted rotating hot wire measurement technique is used for the measurements of velocities and all four non-zero Reynolds stresses. Details of this technique can be found in Ref. 4. Velocities can be considered as accurate within a few percent, except near stall and recirculation areas. The technique is subject to a "small turbulence" assumption. Turbulence levels can be considered as accurate within 5% for most experiments, but are less reliable at high turbulence levels owing to this assumption. Since the mean flow is two-dimensional, two Reynolds stresses can be neglected, and no significant differences were found when neglecting these stresses when processing the data. Mean flow reversal has been detected from the continuity in flow angle profiles. This was made possible by the high density of data within one instantaneous profile. The technique does not allow the observation of random flow recirculations such as vortex shedding.

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Instantaneous profiles are reconstructed from the time signal of a hot wire probe which is translated very slowly across the swept wake using conditional and periodic sampling techniques.

Results are available at a low and at a high frequency ($\omega c/2Q_\infty = 0.36$ and 1), at a small and high amplitude (3.4 and 10 deg peak to peak), and at mean incidences of 0, 5, 9, and 10 deg. Steady-state data are available at 0, 5, 10, and 13 deg incidence.

Some representative results are shown on Figs. 1-3. Figure 1 shows steady-state data. The upper/lower part of Fig. 1 represent respectively the chordwise mean velocity and the rms of mainstream velocity fluctuations. Both variables are dimensionless and are referred to the external velocity Q_∞. The five profiles correspond to distances from the trailing

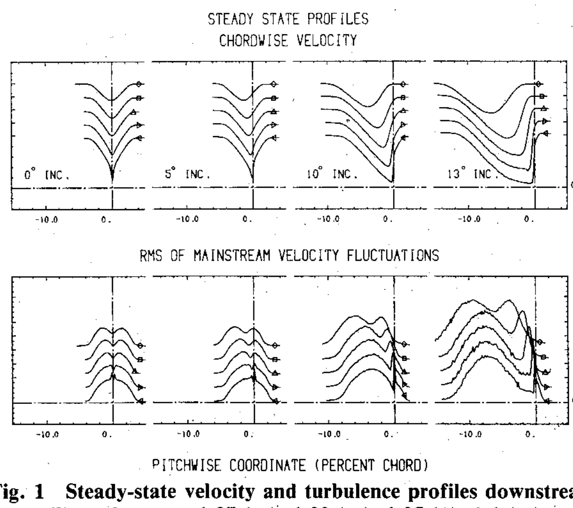

Fig. 1 Steady-state velocity and turbulence profiles downstream of the trailing edge $x/c = 1.07$ (◁), 1.02 (▷), 1.05 (Δ), 1.1 (□), and 1.2 (◇).

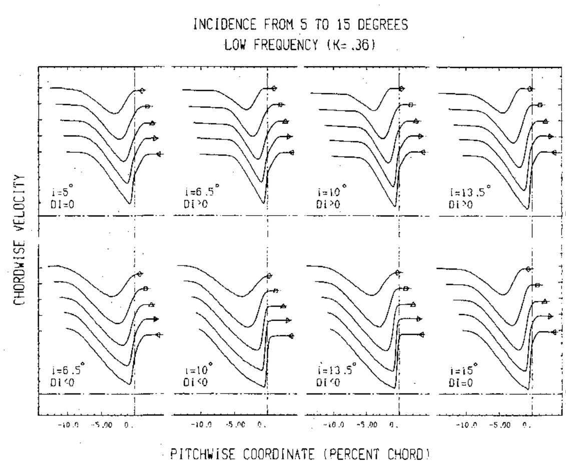

Fig. 2 Instantaneous chordwise velocity profiles downstream of the trailing edge (testcase WLA5). $x/c = 1.07$ (◁), 1.02 (▷), 1.05 (Δ), 1.1 (□), and 1.2 (◇).

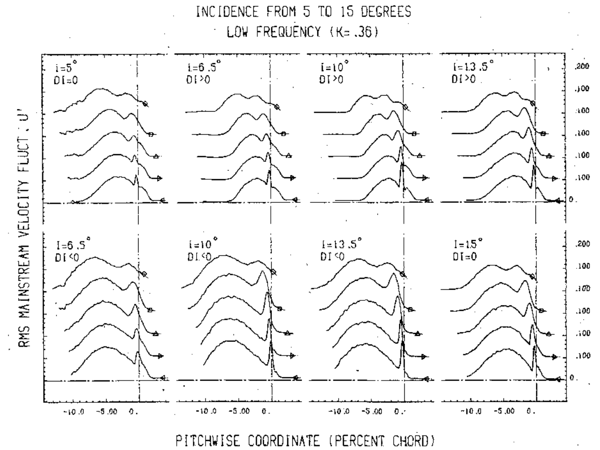

Fig. 3 Instantaneous mainstream turbulence profiles downstream of the trailing edge (testcase WLA5). $x/c = 1.07$ **(◁), 1.02 (▷), 1.05 (Δ), 1.1 (□), and 1.2 (◇).**

edge of 0.7, 2, 5, 10, and 20% chord distance. These results were obtained without smoothing of the raw hot wire data and are comparable with previous experiments performed at higher Reynolds number.[2] Details close to the trailing edge are, however, better observed in the present investigation when compared with previous data.[2,3] The peaks close to the trailing edge are comparable to calculated data of Baker[5] and probably indicate small trailing edge separation.

Figures 2 and 3 represent similar profiles at low reduced frequency for incidences varying from 5 to 15 deg, which is just above the static stall limit. These profiles are shown at every 45-deg phase angle. The upper part of the figures correspond to increasing incidences and the lower part to decreasing incidences. An important hysteresis is observed between increasing and decreasing incidences. The maximum wake thickness and turbulence levels are smaller than in the corresponding static case at the same incidence. Narrow turbulence peaks are observed close to the trailing edge at the pressure side of the wake; however, no flow reversal is detected at this frequency. At high frequency, however (reduced frequency equal to 1.), a small recirculation area is observed up to a distance at 2% chord downstream from the trailing edge (not shown).

The following qualitative conclusions can be mentioned:

At high amplitude, the influence of the oscillations is important. A phase lead in shape factor and a phase lag in wake thickness are found which increase with the oscillation frequency.

Strong effects on the turbulence structure in the near vicinity of the trailing edge are observed and lead to an overall increase in turbulence farther downstream of the trailing edge.

When the static stall limit is lightly exceeded (1 deg), the wake does not appear to be stalled either at low or high frequency.

The present investigations are extended to deeper stall cases and to measurements of the airfoil boundary layers using a sensor mounted on the airfoil.

Acknowledgments

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