presented. The present SAG approach uses only the airfoil surface solution to recluster grid points on the airfoil surface. Therefore, the reclustering problem is one dimension smaller than the flowfield calculation problem.

Computed results on solution-adaptive grids indicate significant reductions in the error relative to standard grids using the same number of grid points. Results computed on mesh sequences indicate that both standard grid and SAG calculations approach the same asymptotic values of lift. However, the rate of approach of the SAG sequence is much faster than that of the standard grid sequence.

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Effect of Pulsed Slot Suction on a Turbulent Boundary Layer

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Introduction

As it is now established that turbulence energy production in a boundary layer occurs intermittently in bursts,[1] it would seem logical that turbulence control also need only be intermittent. One may visualize an "ideal" system of boundary-layer control in which the controlling agent operates at just those places and times where a burst is beginning to occur; of course, this would need suitable detectors distributed over the surface on which the flow is to be controlled. As a first step toward this goal, it seemed interesting to find out the response of the boundary layer to pulsed control[2] without any conditioned selection of "favorable" times and locations at which control is to be applied. If control is applied at a point, its effect will be felt over a certain characteristic area. Precise information over the magnitude of this area is not available, but it is clear that the chances of obtaining a beneficial effect due to pulsing are higher if the control is applied at various points rather than over a line, and over a line rather than an area, because of the smaller smearing effect. To enable comparison with available data,[3] this first series of experiments was confined to control along a line, in the form of suction through a flush transverse slot on a flat plate turbulent boundary layer. Although slot suction has certain definite advantages over distributed suction,[3] it has not attracted the detailed study that it deserves. Measurements of mean velocity profiles, longitudinal turbulence intensities, and skin friction coefficients at a single downstream station are reported here for various values of suction rate and frequency of pulsation. The present study supplements investigations of periodic blowing[4] and pressure gradients[5] on boundary layers, and of periodic excitation in shear layers.[6,7]

Experiments

The experiments (of which more details are available in Ref. 8) were conducted in a low-speed open circuit wind tunnel with a 0.3×0.3-m test section; Fig. 1 shows the setup. The test surface was the top wall of the wind tunnel; transition on the surface was fixed by two 30-mm wide strips of coarse sandpaper. A rotameter capable of measuring up to 5 liter/s indicated the suction flow rate through the slot. The suction chamber housed a motor and crank-driven sliding valve which enabled suction at frequencies up to 72 Hz. Mean velocity measurements in the boundary layer were made using a flattened total head probe (size 0.56×2.2 mm). A constant temperature hot-wire anemometer was used to measure longitudinal turbulence intensities ($\hat{u}$) in the boundary layer. The hot wire used was 5-μm-diam, platinum-rhodium Wollaston process wire of length 1-2 mm.

A flush mounted hot-film gage, with a thin platinum film deposited at the center of a 6 mm pyrex rod, was used to measure skin friction. The film was heated to a constant temperature using a setup similar to the one for hot-wire measurements. The steady-state calibration for the gage followed the well-known cube-root law,[9] the constants in the law being determined by calibration in the same wind tunnel against skin friction obtained from the Clauser plot at various tunnel speeds.[8]

All measurements were made 60 mm (about 2½ boundary-layer heights) downstream of the slot, as preliminary runs

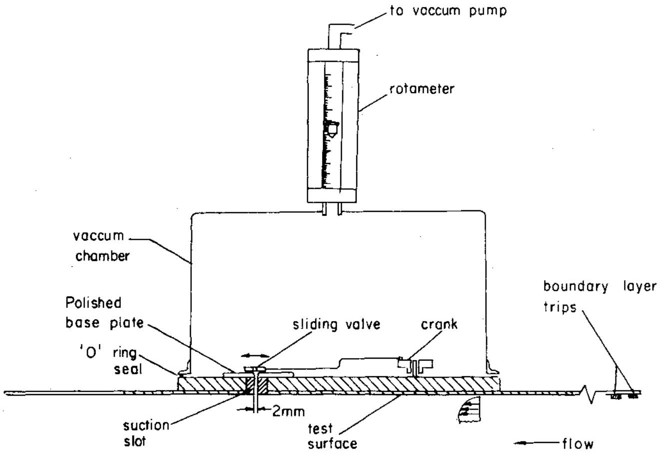

Fig. 1 A schematic sketch of the experimental setup.

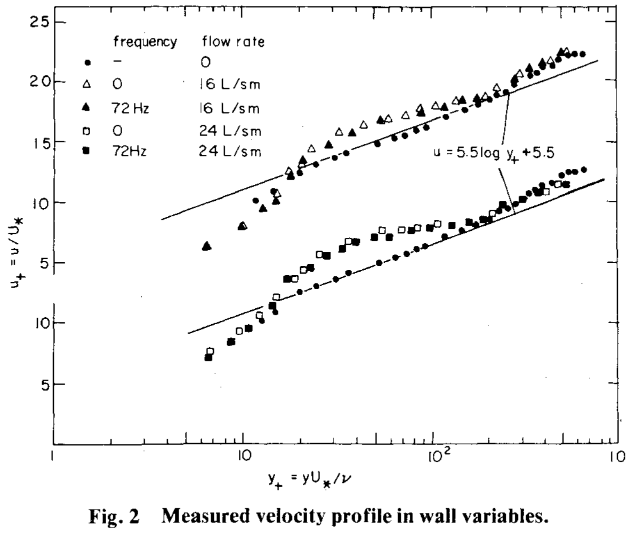

Fig. 2 Measured velocity profile in wall variables.

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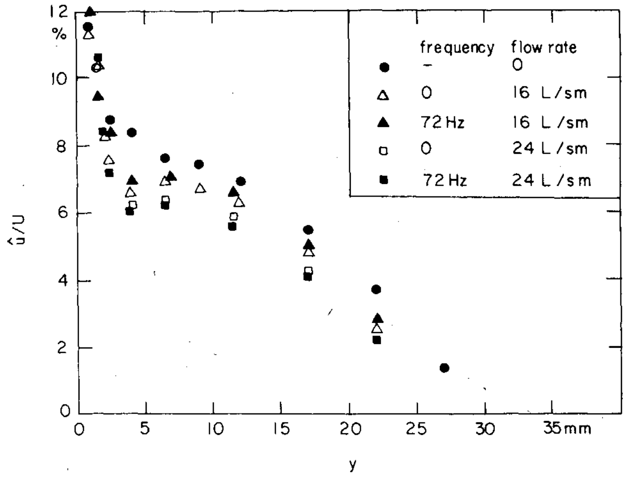

Fig. 3 Longitudinal turbulence intensity.

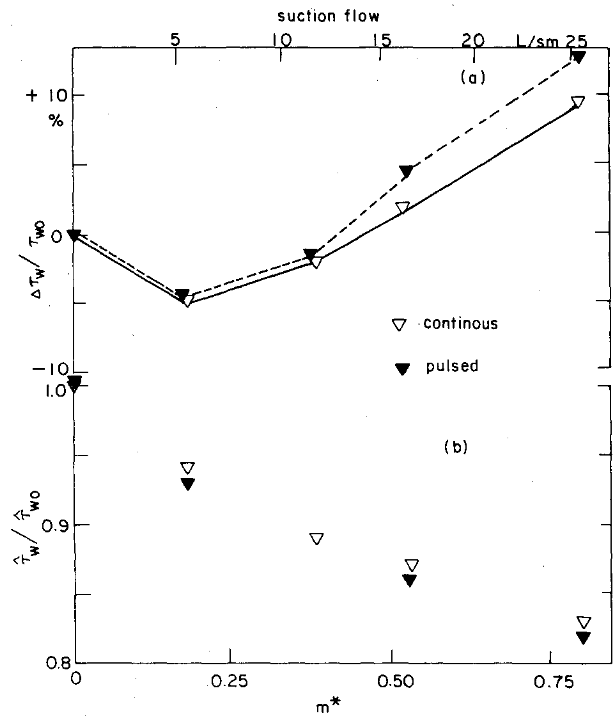

Fig. 4 Change in mean and rms wall stress due to suction.

indicated that the effects here were still noticeable without being dominated by the vertical suction velocity at the slot. The freestream velocity was kept at 7.5 m/s. Corresponding to this speed the unsucked boundary layer had a thickness $\delta_0 = 26$ mm at the measurement station. The mean bursting frequency, estimated[10] as $U/5\,\delta$, is about 60 Hz in this flow.

Owing to the limited capacity of the vacuum pump the highest flow rate of 24 liter/s-m could be obtained only by closing 125 mm of the slot (5/12 of its total width). Measurements were made chiefly along the centerline of the open portion of the slot.

Results and Discussion

Mean velocity profiles for the various suction conditions are shown in inner variables in Fig. 2. Data for no suction were in good agreement with standard profiles at the corresponding Reynolds numbers.

Distributions of the longitudinal turbulence intensity $\hat{u}$ across the boundary layer for all the experiments are plotted in Fig. 3.

The change in the mean wall stress $\Delta\tau_w = \tau_w - \tau_{w0}$, expressed as a percentage of the value τ_{w0} in the standard unsucked boundary layer, is shown in Fig. 4, as well as the rms value of the fluctuating component of the stress $\hat{\tau}_w$. Each value of τ_w is the mean of about 20 samples; the 95% confidence band is also shown in Fig. 4.

As a measure of the suction applied we use the convenient nondimensional parameter $m^* = m/U\delta_0^*$, where δ_0^* is the displacement thickness of the unsucked boundary layer at the slot; m^* measures the suction flow relative to the boundary-layer volumetric flux defect.

As is clear from the data, suction (continuous or pulsed) does produce significant changes, especially in the mean velocity profile and turbulence intensity levels, but these changes seem to depend only on the suction flow rate and not on the frequency of pulsing, in the range of values covered in the present experiments.

The mean velocity profiles are affected most in the log region. Evidently, at $x = 60$ mm the slowly reacting wake has not yet felt the effects of suction. No departures in the region close to the wall ($y^+ < 10$) are noticeable.

The $\hat{u}/u$ distributions again show a remarkable drop in the log region, but the sublayer and the outer region indicate only marginal changes.

As the suction flow rate is increased, the mean skin friction first drops to a minimum, and then increases continuously, whether the suction is continuous or pulsed. The minimum occurs at the nondimensional suction flow rate $m^* \doteq 0.16$. Skin friction fluctuations, however, decrease monotonically with increasing flow rate (Fig. 4).

We conclude that unconditioned pulsed control offers no special advantages at frequencies comparable to and below burst frequencies. The negative effect reported[5] for pulsed pressure gradients over an area is not modified by adopting line control. Either higher frequencies, or more favorable spatial and/or temporal selection of control sites, is required. The stronger effects found in shear layers,[6,7] therefore, must be attributed to the considerably simpler turbulent structure of these flows.

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