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Three-Component Velocity Measurements in an Upper Surface Blowing Configuration

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Introduction

ATTENTION has been focused recently on increasing the lifting capability of aircraft. One of the designs being investigated is termed upper surface blowing (USB). This design utilizes the flow of exhaust gases rearward from the jet engine. The exhaust gases are directed along the upper surface of the wing and, becoming attached, are turned by the wing's curvature. This turning results in a significant increase in lift but severe structural loading problems also occur, specifically at the hinge joint between the wing and flap. Thus the need exists for a better understanding of the turbulent structure of the resultant flowfield.

Several previous reports[1-4] have dealt with the experimental investigation of the near field region of a three-dimensional wall jet. One- and two-point statistical properties such as longitudinal mean velocities, and turbulent intensities, velocity, and concentration autocorrelations and power spectral densities, intermittencies, and space-time velocity, concentration, and pressure cross correlations are measured for flow over a flat plate, a curved flap, and a jet alone. Also, the effects on the flowfields of varying the ratio of the velocity at the exit plane of the nozzle to the outer tunnel flow speed were reported. Isocorrelation contour maps clearly demonstrated the existence of large scale turbulent structures. This Note continues the documentation of the three-dimensional wall jet with special emphasis on the vertical and lateral mean and fluctuating velocities.

Flow System

The flow system consists of a jet and/or wall surfaces mounted inside the test section of a low turbulence level subsonic wind tunnel. The Reynolds number of the jet is 22,600. Two ratios (λ_j) of the jet exit plane velocity to the speed of the outer tunnel are used in the investigation, namely $\lambda_j = 5.1$ and 10.88.

Data Description

To explore the effects of the curvature of the flap for the flow with $\lambda_j = 5.1$, mean velocity components in all three directions are measured. These measurements are obtained for locations over both the flat and the curved segments of the flap. The effectiveness of the flap in turning the flow is shown in Figs. 1 and 2.

Mean velocities in the lateral direction V are measured and presented (Fig. 3). Note that the velocity measurements made in this report are conditionally sampled and thus the V velocities are somewhat larger than might be otherwise expected for unconditional measurements. The mean lateral velocities are determined for the unconfined coflowing jet, the flow over the plate, and the flow over the flap for the same downstream location relative to the exit plane of the nozzle.

A profile of the mean velocity W in the vertical direction z for the downstream location $x/2r_0 = 4$ and $z/2r_0 = 1.85$ is shown (Fig. 3). Comparing this W profile with the one at $z/2r_0 = 0.5$ yields the observation that the jet seems to be rotating or rolling up as it spreads out over the surface of the flap.

Turbulent intensity is the ratio of the root mean square of the turbulent velocity fluctuations to the mean velocity at some reference location. In the investigation, the turbulence level is nondimensionalized by the excess centerline velocity at the exit plane of the nozzle.

Turbulent intensities in the lateral direction, $(\overline{v^2})^{1/2}/(U_0 - U_{FS})$, for the flow over the flap are shown (Fig. 4). A com-

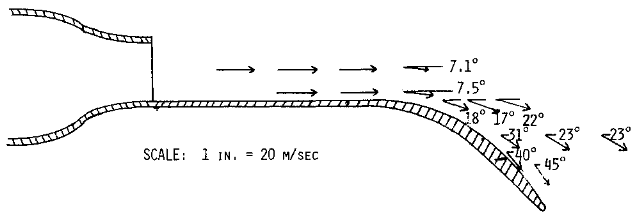

Fig. 1 Vectorial diagram of flow over flap.

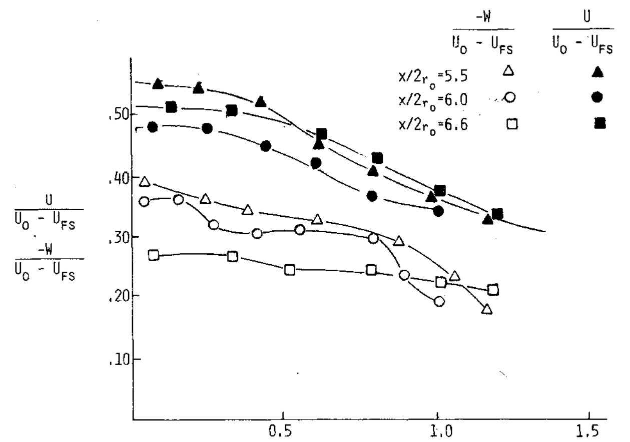

Fig. 2 Longitudinal and vertical mean velocity profiles for flap $z/2r_0 = 0.57$; $\lambda_j = 5.1$.

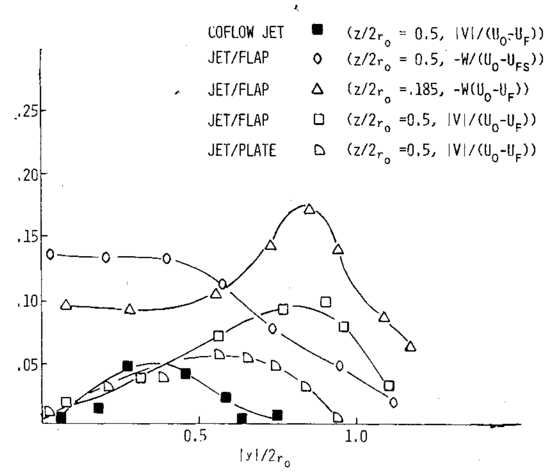

Fig. 3 Vertical and lateral mean velocity profiles for flap $x/2r_0 = 4$; $\lambda_j = 5.1$.

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Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; Nozzle and Channel Flow; Boundary Layers and Convective Heat Transfer—Turbulent.

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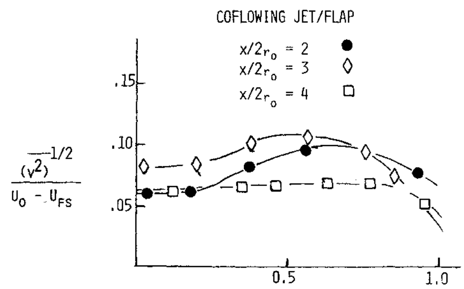

Fig. 4 Development of lateral turbulent intensity profiles for flow over flap, $z/2r_0 = 0.5$, $\lambda_j = 5.1$.

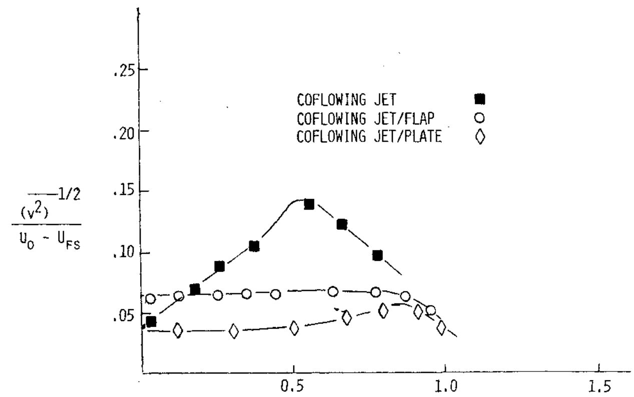

Fig. 5 Lateral turbulent intensity comparison $x/2r_0 = 4$, $z/2r_0 = 0.5$; $\lambda_j = 5.1$.

parison of the intensities for the different flow configurations at the same downstream location is also presented (Fig. 5).

Conclusion

The presence of the confining surfaces was found to be of importance in the resultant effects on both the mean and fluctuating parts of the turbulent velocity field of the jet.

The confining surfaces caused a more rapid increase in the turbulent intensities in the x-direction at the jet axis. Here, the value of λ_j was also found to be important. At the large value of λ_j, the turbulent intensities for the flow over the flap increased at a significantly less rapid pace than was the case for λ_j equal to 5.1. An indication that the flap and the plate serve to break up the potential core more rapidly was also noted and discussed.

Turbulent intensities in the lateral (y) direction for the three flow configurations were also measured. The turbulent intensity was found to be much greater in the shearing layer of the unconfined jet than in either of the other two configurations. Some evidence thus exists which indicates a damping of the turbulence in the y direction.

Acknowledgments

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Vortex Shedding from Square Plates Perpendicular to a Ground Plane

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Introduction

THE original motivation for this study developed out of an investigation of wind effects on central receiver solar collectors.[1] This particular configuration utilized large arrays of tracking mirrors (heliostats) which can be approximated as square plates near a ground plane. The work presented herein gives experimental results for the vortex shedding frequency behind square plates placed normal to a uniform flow over a ground plane as a function of Reynolds number and distance from the ground plane.

While a number of experimental as well as analytical studies have been performed concerning vortex shedding from different kinds of two-dimensional bluff bodies, a relatively few have been performed on three-dimensional bodies. Notable among those experiments performed on bluff bodies with aspect ratios equal to one are those for spheres,[2] circular disks,[3] inclined circular disks,[4] and inclined square plates.[4,5] However, no experimental studies have been reported to date which consider square plates in the presence of a ground plane.

Experimental Setup

These tests were conducted in the Texas Tech University low-speed wind tunnel, which has a 0.914 m × 1.219 m test section. For this particular experiment the facility was operated in an open-jet configuration to reduce blockage effects caused by insertion of the 10-cm square plate. The plate was placed above a horizontal ground plane with its bottom edge at various distances from the wall. The flow upstream of the plate was a uniform flow with a turbulence intensity of less than 0.005. The upstream ground plane boundary layer was thin, with its displacement thickness being less than 1% of the plate height.

Determination of the dominant vortex shedding frequency was accomplished by use of a DISA hot wire anemometer and a Honeywell SAI-48 correlator. A single hot wire was placed in the wake region of the plate. The output signal from the hot wire anemometer was autocorrelated to separate the dominant vortex shedding frequency from background turbulence present in the wake. In order to check this methodology, a test was conducted on a two-dimensional flat plate normal to the flow in which shedding frequencies were obtained for several Reynolds numbers near 1×10^4. These results compared well with data taken by Roshko[6] close to the same Reynolds number.

Vortex Shedding Frequencies

The Strouhal number for the square plate was obtained as a function of distance above the ground plane and as a function of Reynolds number as shown in Fig. 1. It should be noted that these results represent a special case in which the upstream boundary layer is thin with respect to the plate height.

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