PRESSURE AND VELOCITY MEASUREMENTS IN A THREE-DIMENSIONAL WALL JET*

G. D. Catalano,† J. B. Morton,‡ and R. R. Humpris§

PROBLEM

One of the present designs being investigated for increasing the lifting capabilities of aircraft is termed Upper Surface Blowing. The exhaust gases of the jet engine are directed along the upper surface of the wing and, becoming attached, are turned by the wing's upper surface and trailing-edge flaps. It has been found that a significant increase in lift is realized but the loading that the structure must endure is greatly increased. Hence there exists a need for more information about the flow field for this three-dimensional wall jet.

SCOPE

Several reports (refs. 1, 2) have dealt with the experimental investigation of the near field region of a three-dimensional wall jet (fig. 1). The first report dealt with the one point statistical properties of the flow exiting the nozzle without any confining surfaces present. The vortex shedding model of a turbulent jet was clearly reinforced by the appearance of peaks in the velocity spectra in the potential core region of the flow.

The effects on the flow field of the axisymmetric jet of placing a flat wall surface, referred to as the plate, and a wall surface with large curvature, the flap, adjacent to the lip of the nozzle were the subject of the second report. It was found that the curved wall surface served to break up the potential core region of the jet much more rapidly than was the case for either the unconfined flow or the flow over the flat wall.

In the third paper, emphasis was placed on obtaining space-time correlations in the different turbulent flow fields from which isocorrelation

---

Presented at the AIAA 17th Aerospace Sciences Meeting, January 15-17, 1979, New Orleans, Louisiana.

*Work Supported in part by NASA Grant No. NGR 47-005-219-3 and NSF Grant No. 7522488.

†Aerospace Engineer, Air Force Flight Dynamics Laboratory/FXM, Wright-Patterson Air Force Base, Ohio 45433.

‡Associate Professor, Mechanical and Aeronautical Engineering Department, University of Virginia.

§Senior Scientist, Nuclear Engineering Department, University of Virginia.

contour maps were constructed. The isocorrelation contours for the turbulent flow fields demonstrate the existence of large-scale structures. The shape of the contours was significantly different for each of the three flow configurations in both the longitudinal and horizontal cross-sectional views. The contours depended on whether or not a confining surface was present and whether the wall was flat or curved.

The present paper has two main emphases. First, the effects on the flow fields of varying the ratio of the velocity at the exit plane of the nozzle to the outer tunnel flow are reported. Second, pressure-velocity correlations are taken and some trends are discussed. Emphasis is placed on comparing the coherence between the fluctuating pressure and velocity fields at various locations in the different flow configurations.

The same three flow fields investigated in the second and third reports (ref. 2 and 3) are studied here. The arrangement of the confining surfaces, the flap and the first plate are shown in figure 2(a) and a schematic of the whole facility is shown in figure 2(b).

A two-color laser Doppler velocimeter in conjunction with a phase locked-loop processor is used to make the velocity measurements. The two strongest frequencies of an argon ion laser in the "all lines" mode of operation are selected for use. The two-color LDV system allows the velocity at two different points in the flow fields to be determined with displacement between the probes possible in all three directions. This system is described in more detail in reference 1.

To determine the static and wall surface pressures, the system developed by Schroeder (ref. 4) and Herling (ref. 5) is used. The essential items include a 1/2 in. condenser-type microphone and a tape recorder. When cross-correlations are made between the fluctuating pressure and velocity fields, both signals are filtered (10 Hz to 100 Hz) before being processed to achieve a good signal-to-noise ratio. Figures 3 through 8 show the effects of confining surfaces on the various statistical properties.

SUMMARY

The value of the velocity ratio, λ_j, was found to have a significant influence on the mean velocity field. For the case of the flow over the flap, an increasing value of λ_j decreased the effectiveness of the curved wall surface in diminishing the x-directed momentum. Evidence existed that as λ_j approached infinity, the flow would not remain attached. The parameter λ_j influenced the width of the mean velocity profiles as well, especially in the case of the flow over the flap. An increase in λ_j caused a resultant decrease in the mixing width, y_m.

Pressure velocity correlations using both the static pressure probe and the surface ports yielded strong evidence that as the flow progresses downstream and the flow becomes a fully developed turbulent flow, the relationship between the pressure and velocity field diminishes. For the first several diameters downstream from the exit plane when the pressure and velocity spectra peak at approximately 300 Hz, the coherence between the two fluctuating fields is the strongest.

The material presented in this paper is new and has been excerpted from the author's dissertation. In fact, the information concerning the effects of the value of the velocity ratio has important implications as far as proper testing procedures for a USB design.

The question that immediately comes to mind is the value of testing without the presence of a coflowing secondary stream. In fact, the jet may not stay attached to the airfoil's upper surface.

DATA DESCRIPTION

Documentation of the effects of the value of the velocity ratio, λ_j, on the width and decay of the centerline velocity for the three respective mean flow fields is presented.

Turbulent intensity is the ratio of the rms turbulent velocity fluctuations to a reference mean velocity. In this investigation, turbulence level is nondimensionalized by excess centerline mean velocity at the exit plane of the nozzle. The turbulent intensities are corrected for ambiguity noise using the method of Morton (ref. 6) and shown for various downstream positions.

The longitudinal integral time scale is defined as follows:

$$T_1 = \int_0^{t*} \overline{u(t)u(t + t')dt'}$$

where $t*$ is the time at which the integral first reaches the value of zero (ref. 7).

Additional information concerning the turbulence structure of the various flow fields can be gained from measurements of the pressure fluctuations at both the wall and in the turbulent jet and correlating those signals with fluctuating turbulent velocities in the potential core and in the shearing region.

Pressures are measured either at surface ports located on the flap or plate or by a pressure probe in the flow. In either case, the following space-time correlation are measured:

$$R_{pa}(\vec{x},\vec{\xi},t,\tau) = \frac{P(x,t)u(\vec{x} + \vec{\xi},t + \tau)}{[p(\vec{x},t)^2]^{1/2}\,[u(\vec{x} + \vec{\xi},t + \tau)^2]^{1/2}}$$

where $\vec{\xi}$ is the position of the velocity "probe," measured relative to the pressure probe and p is the static pressure measured at the wall or in the flow field.

The primary focus of this segment of the experimental investigation is to determine the relationship between the pressure and the velocity fields. To show the dependence between the two fields, the coherence is plotted for various pressure and velocity monitoring locations. Coherence, which can be considered a correlation coefficient which varies with frequency, is defined as follows:

$$\delta_{12}^{2} = \frac{|G_{12}|^{2}}{G_{11}G_{22}}$$

where G_{11}, G_{12} are the Fourier Transforms of the individual autocorrelation functions and G_{12} is the Fourier Transform of the cross-correlation function.

REFERENCES

1. Catalano, G. D.; Morton, J. B.; and Humphris, R. R.: Experimental Investigation of an Axisymmetric Jet in a Coflowing Airstream. AIAA J., vol. 14, no. 9, 1976, pp. 1157-1158.

2. Catalano, G. D.; Morton, J. B.; and Humphris, R. R.: An Experimental Investigation of a Three Dimensional Wall Jet. AIAA J., vol. 15, no. 8, 1977, pp. 1146-1151.

3. Morton, J. B.; Catalano, G. D.; and Humphris, R. R.: Some Two-Point Statistical Properties of a Three-Dimensional Wall Jet. AIAA J., vol. 16, no. 7, July 1978.

4. Schroeder, J. C.: Development of Experimental Techniques for Investigation of Unsteady Pressures Behind a Cold Model Jet. Master's Thesis, Univ. of Virginia, 1976.

5. Herling, W. W.: The Development of an Experimental Facility for the Investigation of Scaling Effects. Master's Thesis, Univ. of Virginia, 1976.

6. Morton, J. B.: Experimental Measurements of Ambiguity Noise in a Laser Anemometer. J. Phys. E, vol. 6, no. 4, 1973.

7. Monin, A. S.; and Yaglom, A. M.: Statistical Fluid Mechanics. Vol. 1. MIT Press, 1971.

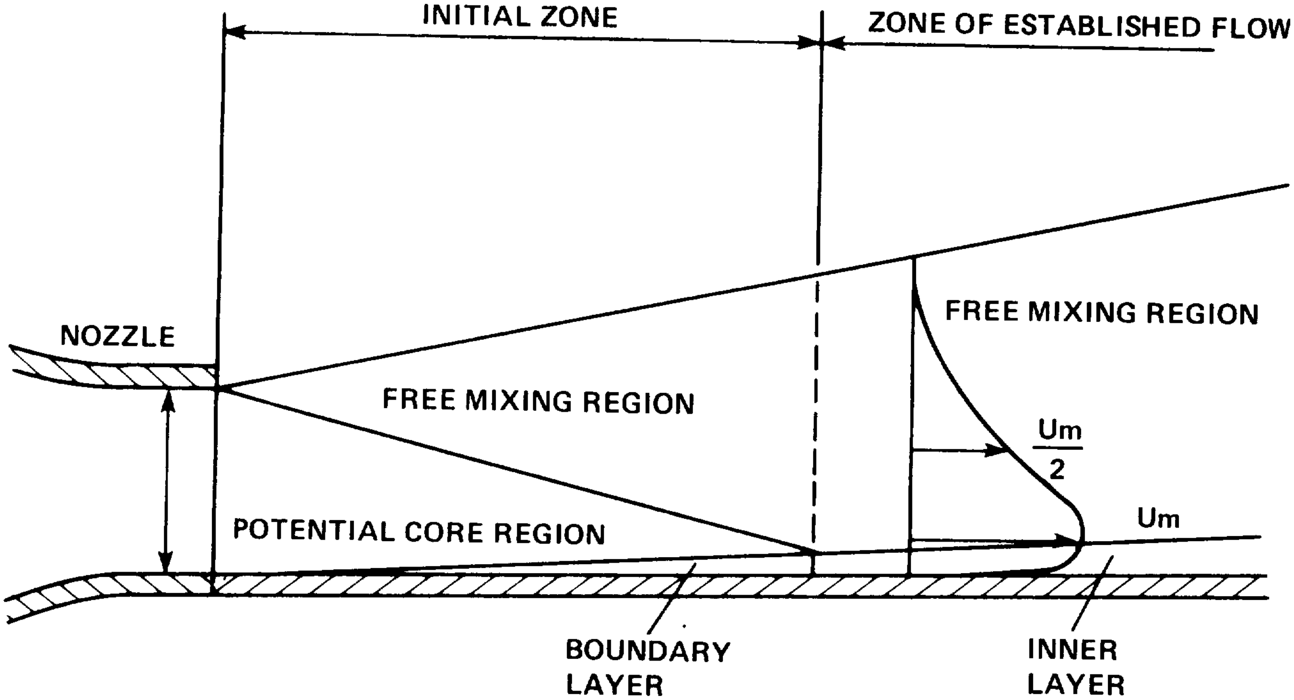
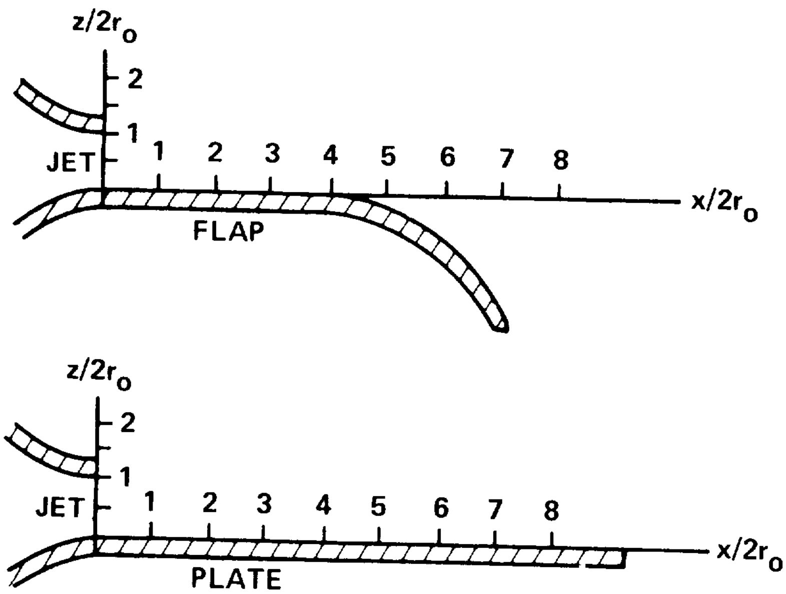
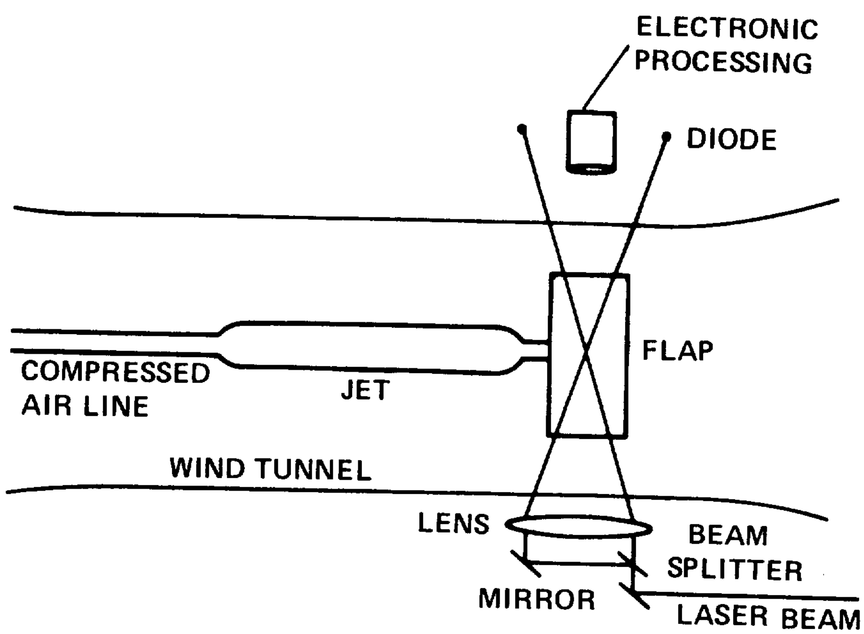


Figure 1.- Schematic of a wall jet.

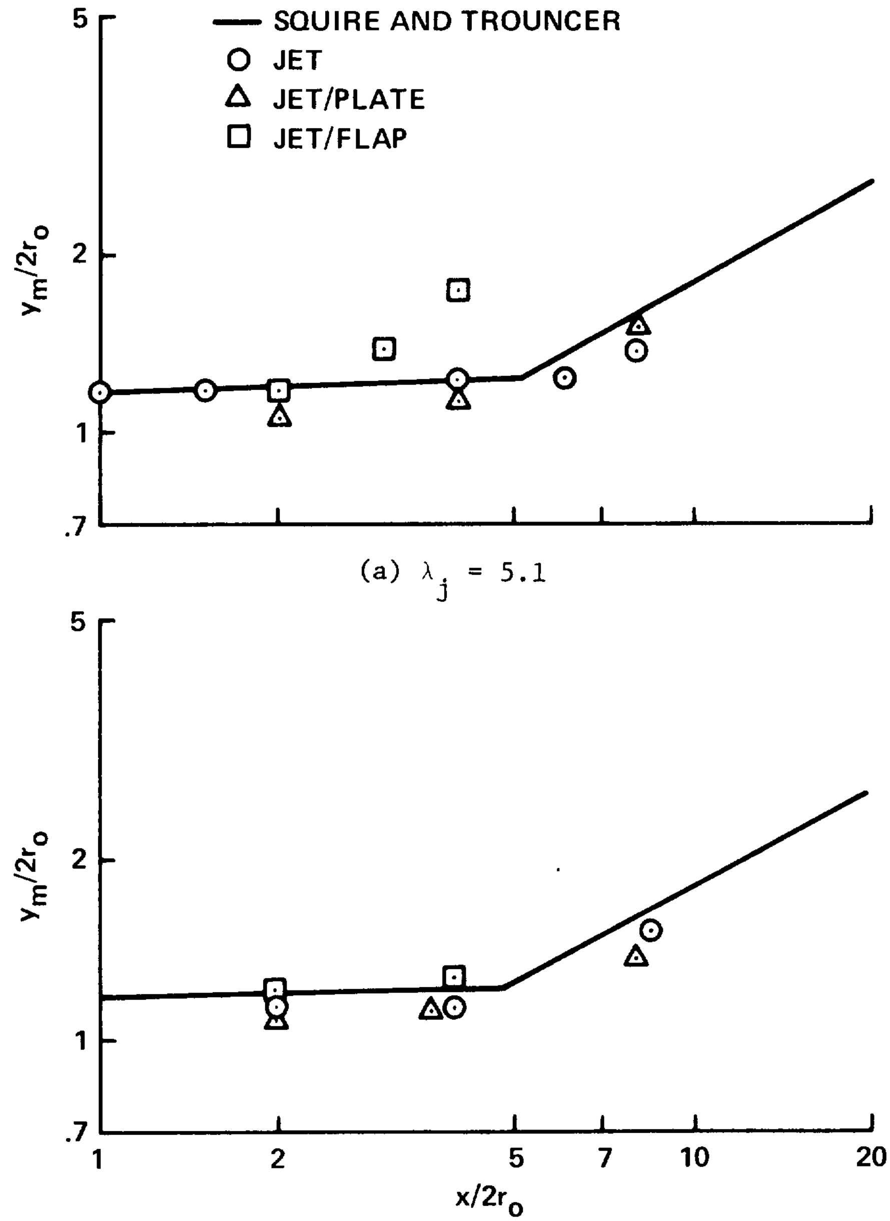


(a) Flow configurations.



(b) Schematic of laboratory setup.

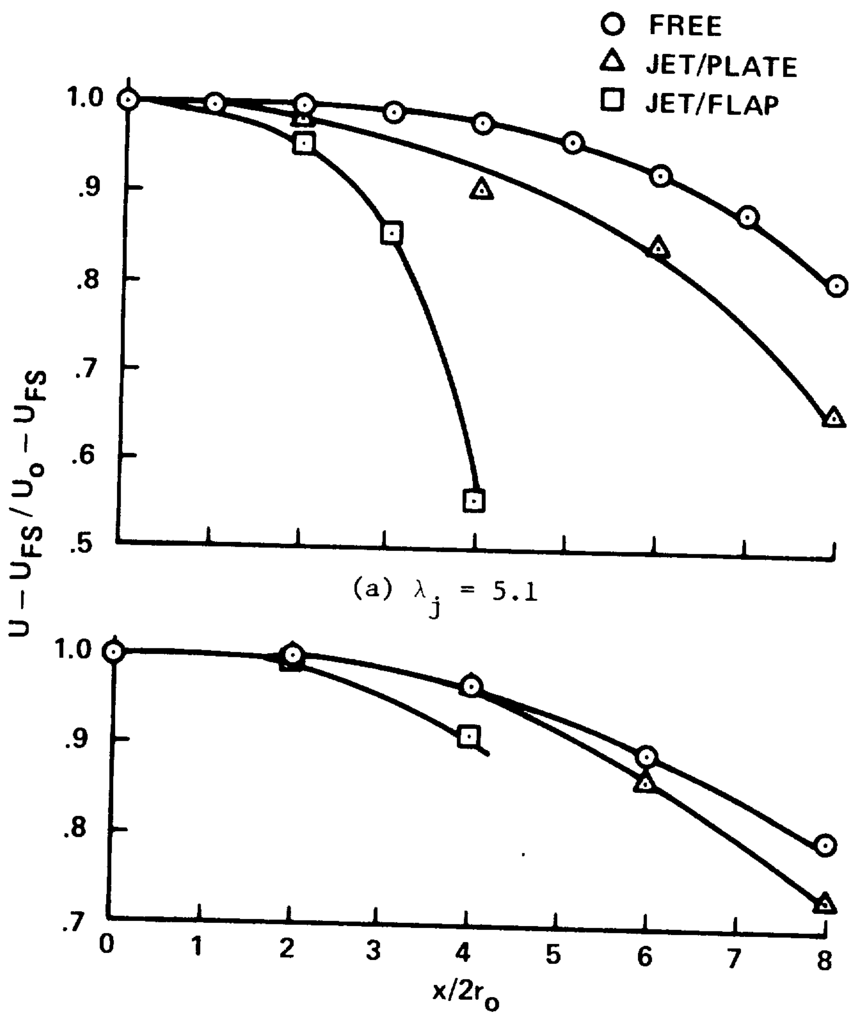
Figure 2.- Text configurations.



(a) $\lambda_j = 5.1$

(b) $\lambda_j = 10.88$

Figure 3.- Growth of mixing width.



(b) λ_j = 10.88

Figure 4.- Decay of centerline mean velocity, $z/2r_o$ = 0.5.

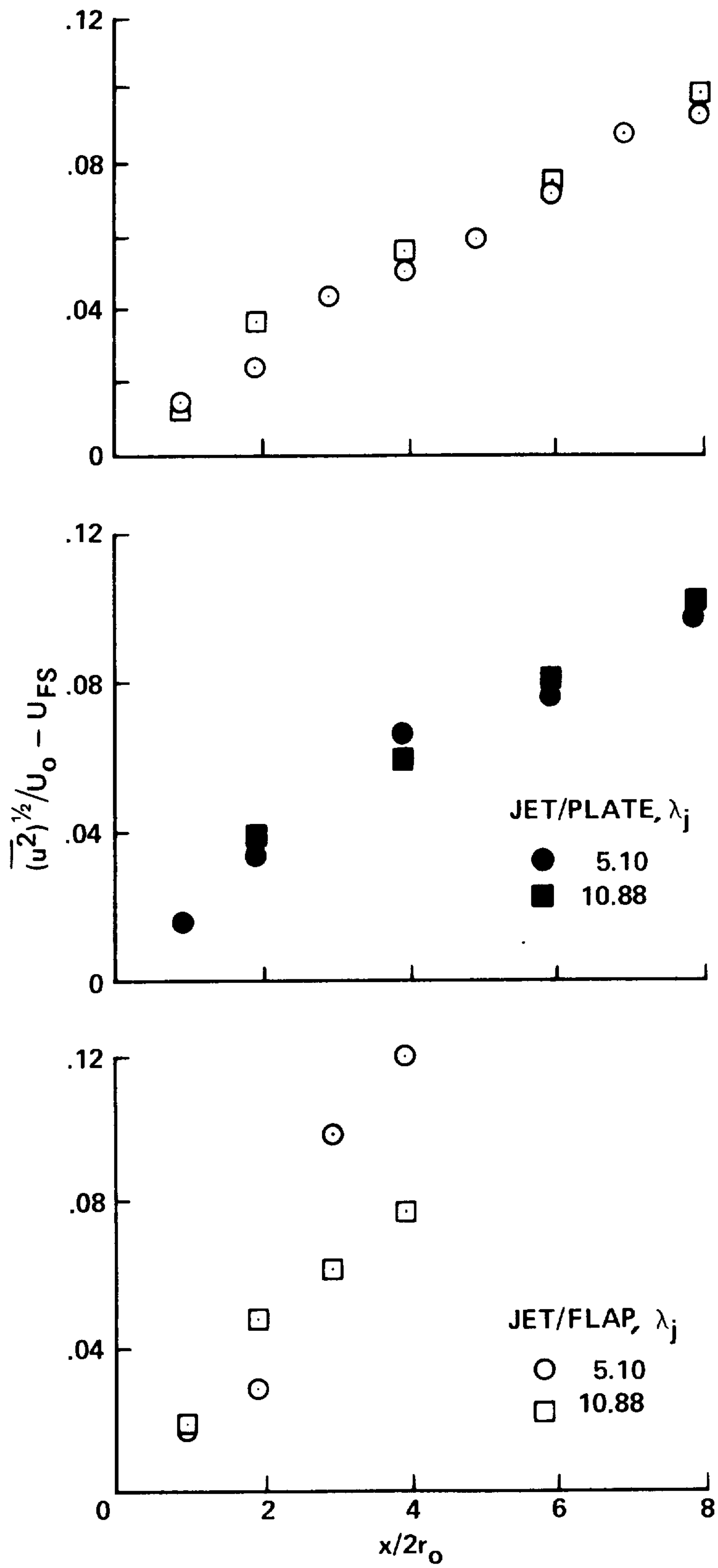
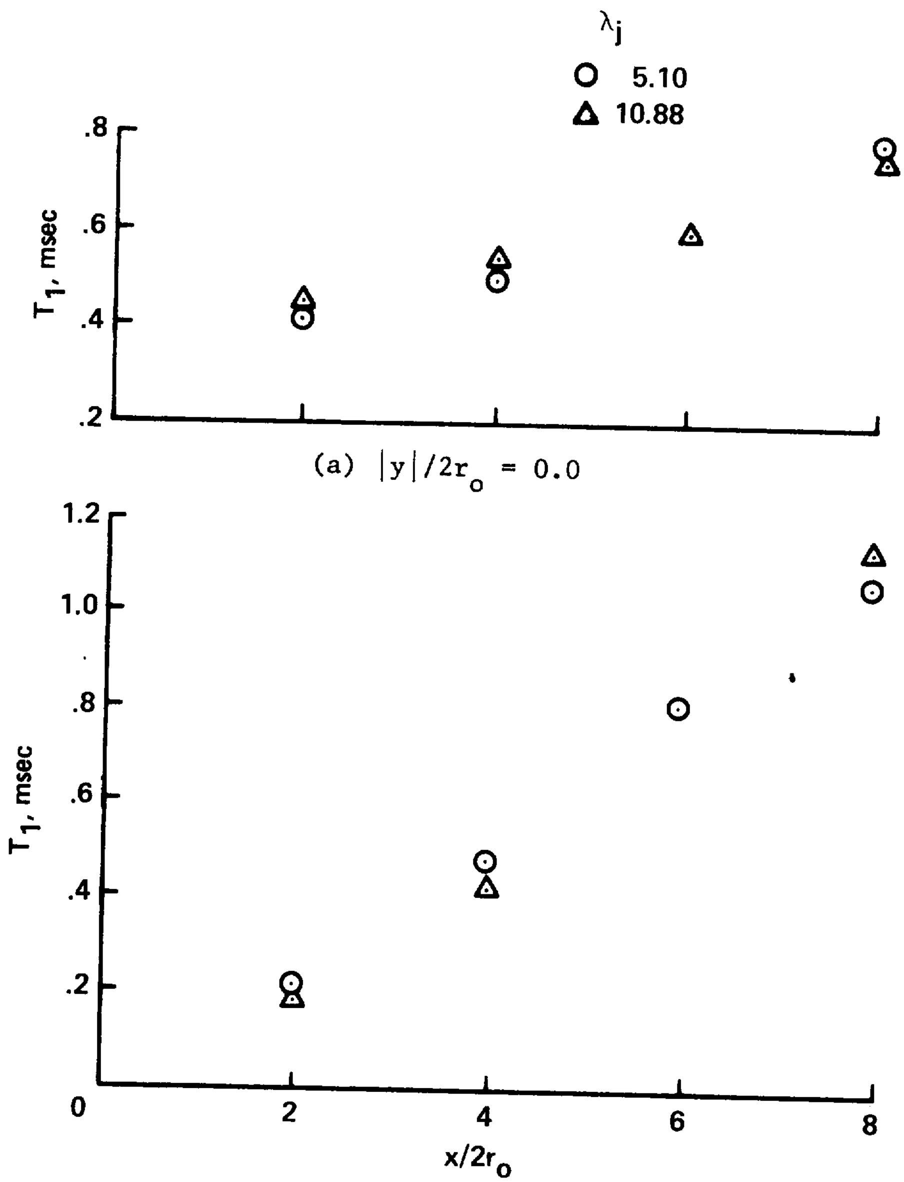


Figure 5.- Growth of turbulent intensity, $(\overline{u^2})^{1/2}$, at centerline.



(a) $|y|/2r_o = 0.0$

(b) $|y|/2r_o = 0.5$

Figure 6.- Development of integral time scale for jet, $z/2r_o = 0.5$.

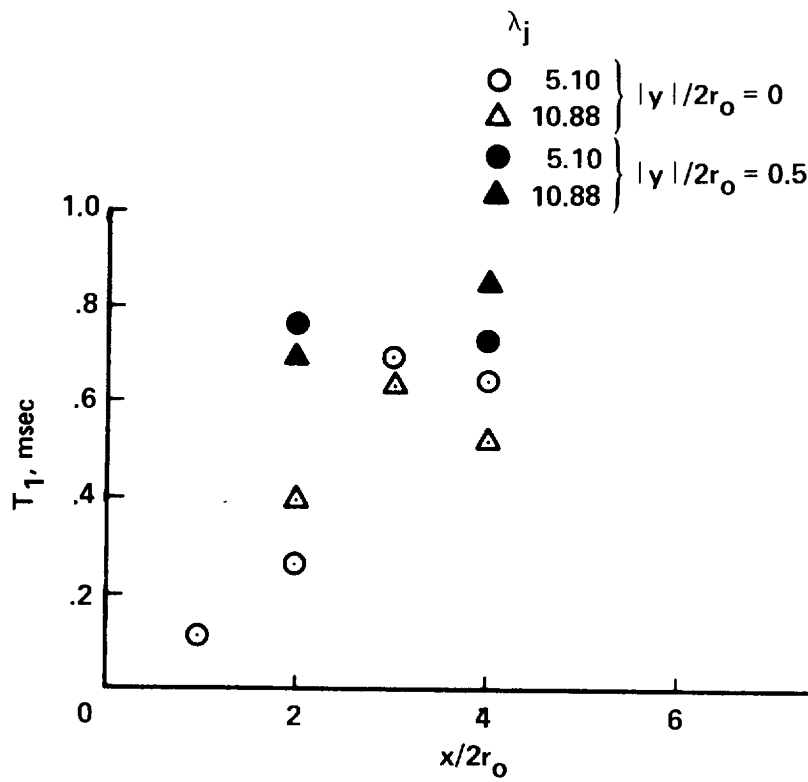
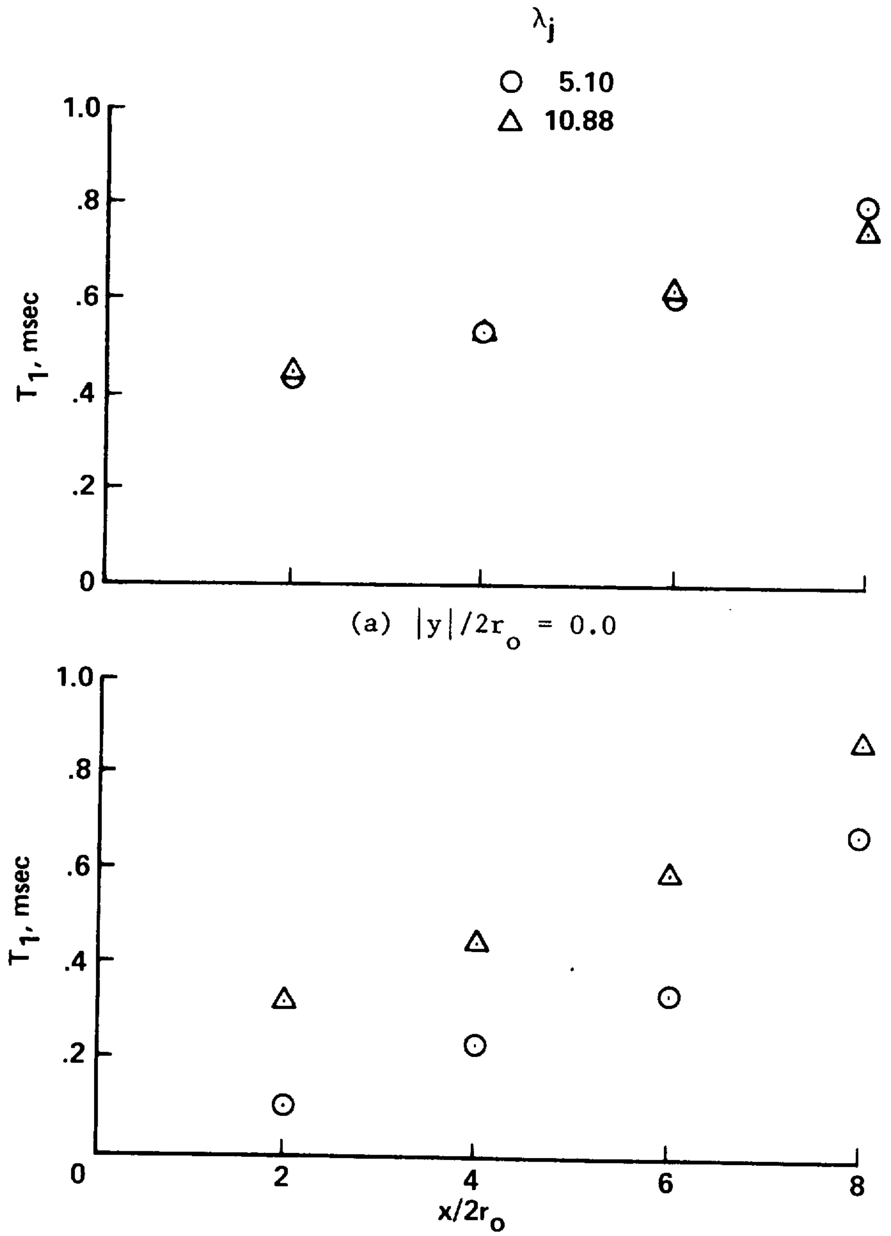


Figure 7.- Development of integral time scale for jet/flap, $z/2r_o = 0.5$.



(b) $|y|/2r_o = 0.5$

Figure 8.- Development of integral scale for jet/plane, $z/2r_o = 0.5$.