[3]Evans, H. L., *Laminar Boundary-Layer Theory*, Addison-Wesley, London, 1968.
[4]Domb, C. and Sykes, M. E., "On the Susceptibility of a Ferromagnetic Above the Curie Point," *Proceedings of the Royal Society, Ser. A.*, Vol. 240, 1957, pp. 214-228.
[5]Van Dyke, M., "Analysis and Improvement of the Perturbation Series," *Quarterly Journal on Mechanics and Applied Mathematics*, Vol. 27, 1974, pp. 423-450.
[6]Brown, S. N. and Stewartson, K., "Laminar Separation," *Annual Reviews of Fluid Mechanics*, Vol. 1, 1969, p. 50.
[7]Smith, A. M. O., "Improved Solutions of Falkner-Skan Boundary Layer Equations," *Fund Paper, Journal of the Aerospace Sciences*, Sherman M. Fairchild, 1954.
[8]Cebeci, T. and Keller, H. B., "Shooting and Parallel Shooting Methods for Solving Falkner-Skan Equation Boundary Layer Equation," *Journal of Computational Physics*, Vol. 71, 1971, pp. 289-300.

Mean Velocity and Static Pressure Distributions in a Three-Dimensional Turbulent Free Jet

W. R. Quinn*
St. Francis Xavier University, Nova Scotia, Canada
A. Pollard†
Queen's University at Kingston, Ontario, Canada
and
G. F. Marsters‡
Federal Ministry of Transport, Ontario, Canada

Nomenclature

P	= static pressure
t_p	= height of slot, = 12.7 mm
U	= mean streamwise velocity
X, Y, Z	= streamwise, spanwise, and lateral coordinates, respectively
ρ	= density

Subscripts

ATM	= atmospheric value
$\mathbb{C}$	= value on the jet centerline
EXIT	= value of the slot exit plane
LOCAL	= local value anywhere within the jet
STAT	= static value anywhere within the jet

Introduction

SADDLE-backed velocity distributions are known to exist in turbulent free jet flows from rectangular slots of low or moderate aspect ratio in the plane of the major axis of the respective slots.[1-8] Mean streamwise velocity profiles in such flows are characterized by off-center peaks which are apparently more pronounced in flows from sharp-edged slots.[4-6] Mean streamwise velocity off-center peaks are not found in flows from slots that have smooth contracting upstream shaping in both planes of symmetry.[6]

Some attempts have been made to find an explanation for "saddle-backed" velocity distributions using circumferential[1] streamwise[7] vortex hypotheses. "Turbulence-driven secondary flows" have also been suggested as a possible cause.[9] Vortex stretching hypotheses have been postulated to account for mean streamwise velocity off-center peaks in partially bounded turbulent jet flows from low aspect ratio rectangular slots.[10-12]

The static pressure within the jet might play a role in the formation of these mean streamwise off-center velocity peaks. The present Note provides some mean streamwise velocity and near flowfield static pressure data for the fully three-dimensional turbulent jet flow from a sharp-edged rectangular slot of aspect ratio 10.

Experimental Setup and Procedure

Air, drawn from the laboratory by a small commercial fan supported on antivibration neoprene mounts, was fed into a $0.76 \times 0.61 \times 0.61$ m settling chamber which contained six mesh-wire screens, a baffle, and a filter. The 12.7×127 mm rectangular slot was attached to the downstream face of the settling chamber. The downstream face of the settling chamber was flush with a 2.44×2.44 m plywood wall to ensure tangential entrainment at the slot exit plane. A screen cage ($2.44 \times 2.44 \times 3.66$ m) extending from the wall downstream enclosed the top and sides of the jet and helped to minimize the influence of room draughts, thus facilitating far flowfield measurements. A sketch of the settling chamber, plywood wall, and screen cage is given in Fig. 1. Details of the rectangular slot can be found elsewhere.[13]

Single normal wire and X-wire probes were used for the mean flow measurements. The hot-wire probes were operated by linearized constant temperature anemometers and calibrated in situ in the potential core of the test jet. Air temperature variations of no more than 4°C were monitored with a thermocouple and corrections for this effect and that of

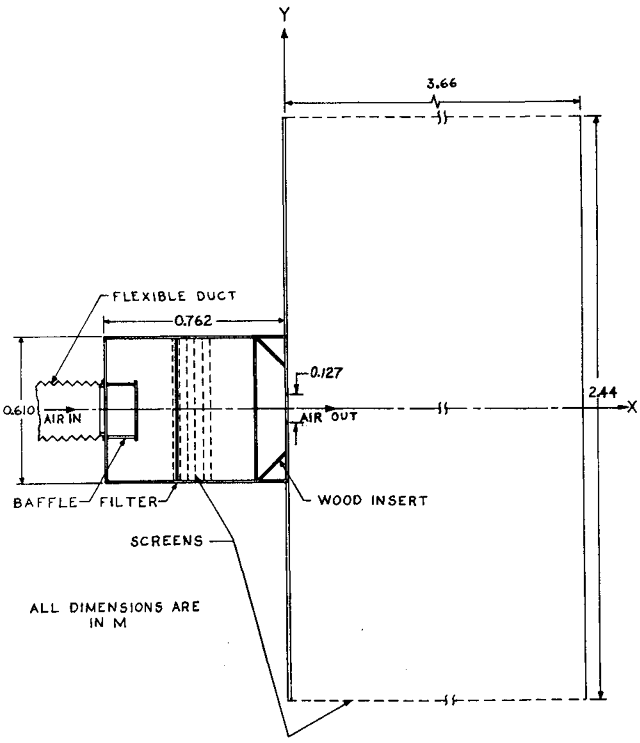


Fig. 1 Top view of settling chamber and screen cage.

Presented as Paper 83-1677 at the AIAA 16th Fluid and Plasma Dynamics Conference, Danvers, Mass., July 12-14, 1983; received Sept. 9, 1983; revision received Aug. 31, 1984.

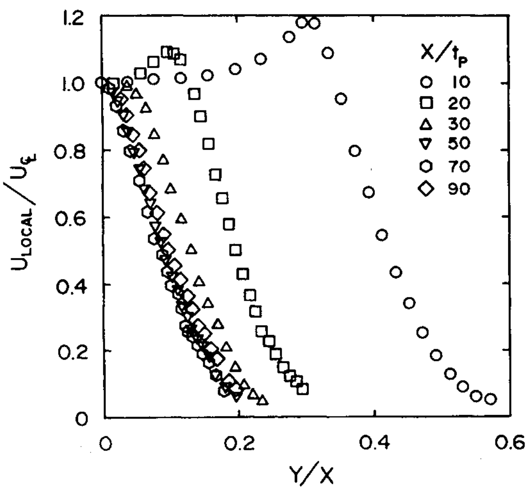
*Assistant Professor, Department of Engineering. Member AIAA.
†Associate Professor, Department of Mechanical Engineering.
‡Director of Airworthiness. Member AIAA.

tangential cooling of the hot-wire sensors were subsequently made in the data reduction. No other corrections were made. The experiments were performed in a 9.02×7.39×3.76 m room which was not air conditioned and to which traffic was controlled. The static pressure measurements were made with a 3.175-mm-diam stainless-steel pitot-static tube in conjunction with a Barocel pressure transducer and a digital voltmeter with variable integrating times. The bilateral symmetry of the flow was utilized in acquiring the data and checks were made to ensure that symmetry did in fact exist.[13] The exit plane velocity profile was flat and the mean streamwise velocity and streamwise turbulence intensity at the center of the slot exit plane were 55 ms^{-1} and 0.7%, respectively. The initial slot wall boundary layer was nominally laminar. The Reynolds number based on the height of the slot was about 4.7×10^4.

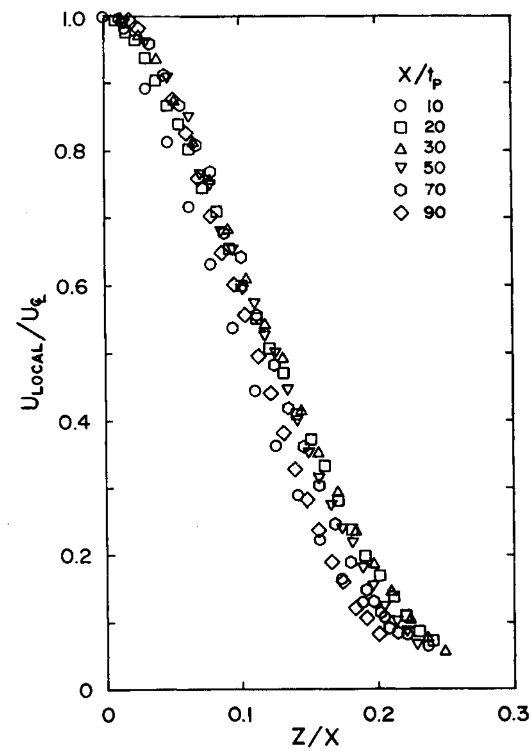
Results and Discussion

Mean Streamwise Velocities

Mean streamwise velocity profiles in the central *X-Y* and *X-Z* planes are shown in Fig. 2. The systematic error in the



a) Central *X-Y* plane.



b) Central *X-Z* plane.

Fig. 2 Mean streamwise velocity profiles.

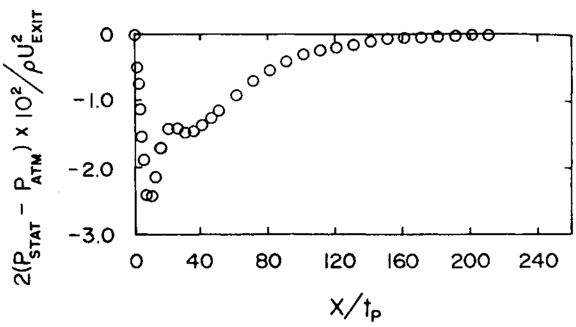
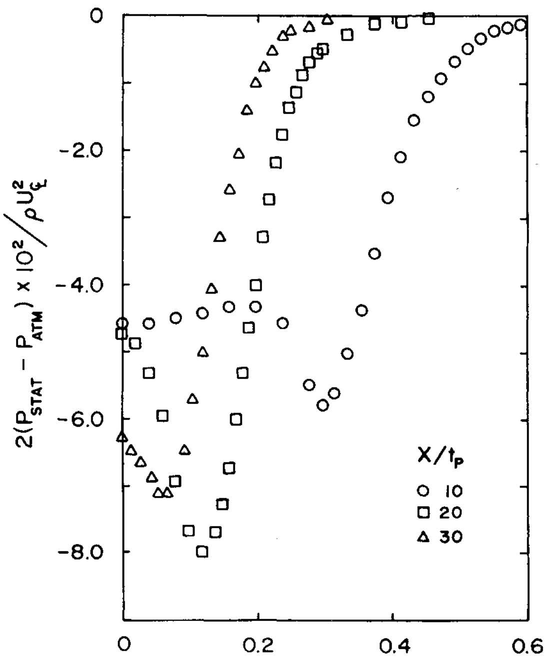
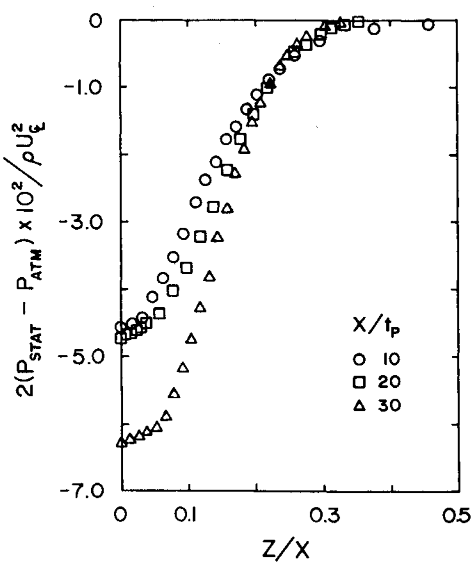


Fig. 3 Static pressure distribution on the jet centerline.



a) Central *X-Y* plane.



b) Central *X-Z* plane.

Fig. 4 Static pressure profiles.

mean streamwise velocity data is about 2%. Mean streamwise velocity off-center peaks are clearly evident at $X/t_p = 10$ and 20 in the X-Y plane (Fig. 2a). These mean streamwise velocity off-center peaks, which do not occur in the potential core region ($X/t_p \leq 3$, not shown) or in the X-Z plane, appear to move toward the jet centerline with downstream distance and seem to disappear after the shear layers growing in the X-Y plane merge on the jet centerline at about $X/t_p = 30$. The profiles in the X-Z plane seem to be geometrically similar after about $X/t_p = 10$ and those in the X-Y plane appear to be geometrically similar beyond $X/t_p = 30$. These observations are in accord with those made by other investigators.[2-8]

Static Pressure Distribution

The static pressure distribution on the jet centerline is presented in Fig. 3. Steep streamwise static pressure gradients are clearly evident.

Static pressure profiles in the central X-Y and X-Z planes are presented in Fig. 4 for the flow region ($X/t_p = 10$ to 30) where mean streamwise velocity off-center peaks are found. The static pressure profiles at $X/t_p = 10$ and 20 in the central X-Y plane (Fig. 4a) indicate that the static pressure drops significantly before it starts to recover to the atmospheric value at the edge of the jet. It is, indeed, interesting to note that the locations of the static pressure "valleys" at $X/t_p = 10$ and 20 in Fig. 4a correspond to those of the mean streamwise velocity off-center peaks at the same stations in Fig. 2a. The static pressure profile at $X/t_p = 30$ (Fig. 4a) exhibits a behavior similar to those at $X/t_p = 10$ and 20, but the drop in static pressure is not as significant as that at $X/t_p = 10$ and 20. It should be recalled that there is no mean streamwise velocity off-center peak at $X/t_p = 30$ (Fig. 2a). However, in view of the static pressure profile at $X/t_p = 30$ (Fig. 4a), it is possible that a mean streamwise velocity off-center peak indeed exists at $X/t_p = 30$ in the central X-Y plane, but that it is of such small magnitude, that the instrumentation used was incapable of resolving it. The central X-Z plane static pressure profiles (Fig. 4b) are characterized by monotonic recovery to the atmospheric value at the edge of the jet from low values on the jet centerline.

The systematic error in the static pressure data is about 3% but it should be noted that static pressure data in turbulent flows are, because of the unknown effects of turbulence, of uncertain quantitative value.[14] However, the qualitative trends shown by the static pressure data presented above are real.

Acknowledgment

The work reported herein was supported by Grant A4310 from the Natural Sciences and Engineering Research Council of Canada.

References

[1]Van der Hegge Zijnen, B. G., "Measurements of the Velocity Distribution in a Plane Turbulent Jet of Air," *Applied Scientific Research*, Section A, Vol. 7, 1958, pp. 256-276.

[2]Sforza, P. M., Steiger, M. H., and Trentacoste, N., "Studies on Three-Dimensional Viscous Jets," *AIAA Journal*, Vol. 4, May 1966, pp. 800-806.

[3]Trentacoste, N. and Sforza, P. M., "Further Experimental Results for Three-Dimensional Free Jets," *AIAA Journal*, Vol. 5, May 1967, pp. 885-891.

[4]Sfeir, A. A., "The Velocity and Temperature Fields of Rectangular Jets," *International Journal on Heat and Mass Transfer*, Vol. 19, 1976, pp. 1289-1297.

[5]Sfeir, A. A., "Investigation of Three-Dimensional Turbulent Rectangular Jets," *AIAA Journal*, Vol. 17, Oct. 1979, pp. 1055-1060.

[6]Marsters, F. G., "The Effects of Upstream Nozzle Shaping on Incompressible Turbulent Flows from Rectangular Nozzles," *Transactions of CSME*, Vol. 4, 1978/79, pp. 197-203.

[7]Marsters, G. F., "An Experimental Investigation of Spanwise Velocity Distributions in Jets from Rectangular Slots," AIAA Paper 80-0202, Jan. 1980.

[8]Krothapalli, A., Baganoff, D., and Karamcheti, K., "On the Mixing of a Rectangular Jet," *Journal of Fluid Mechanics*, Vol. 107, 1981, pp. 201-220.

[9]McGuirk, J. J. and Rodi, W., "The Calculation of Three-Dimensional Turbulent Free Jets," *First Symposium on Turbulent Shear Flows*, University of Pennsylvania, University Park, Pa., Vol. 1, April 1977, pp. 1.29-1.36.

[10]Foss, J F., and Jones, J. B., "Secondary Flow Effects in a Bounded Rectangular Jet," *Journal of Basic Engineering, Transactions of ASME,* Vol. 90, June 1968, pp. 241-248.

[11]Holdeman, J. D. and Foss, J. F., "The Initiation, Development and Decay of the Secondary Flow in a Bounded Jet," *Journal of Fluids Engineering, Transactions of ASME*, Vol. 97, Sept. 1975, pp. 342-352.

[12]Rockwell, D. O., "Vortex Stretching Due to Shear Layer Instability," *Journal of Fluids Engineering, Transactions of ASME*, Vol. 99, March 1977, pp. 240-244.

[13]Quinn, W. R., "Turbulent Free Jet Flow from a Sharp-Edged Rectangular Slot," Ph.D. Thesis, Queen's University at Kingston, Canada, 1984.

[14]Hinze, J. O., *Turbulence*, 2nd ed., McGraw-Hill Book Co., Toronto, 1975, pp. 164-165.

Velocity Biasing of Two-Component LDV Data in Low-Turbulence Flows

R. R. Craig* and A. S. Nejad*
U.S. Air Force Wright Aeronautical Laboratories
Wright-Patterson Air Force Base, Ohio

THE velocity biasing of data obtained by laser Doppler velocimetry (LDV) in highly turbulent flows has been investigated for 11 years since it was originally identified by McLaughlin and Tiederman.[1] The constant time interval sampling approach developed and verified by Stevenson et al.[2-4] is the most reliable approach for eliminating this biasing. Improvements in technique and seeding detailed in Ref. 5 make this a viable approach in all flows of interest.

The purpose of this Note is to alert researchers using two-component LDV systems to a velocity biasing problem we have encountered in low-turbulence flows where it is generally assumed that velocity biasing is not a problem.

In general, it has been assumed that, when using LDV systems in flows with turbulence intensities below 10-15%, a correction for velocity biasing is not required. When measuring only the mean and fluctuating component of the directed flow, that assumption is true. However, when measuring a second or third component of velocity where the mean value of the other components is near zero and the turbulence is nearly isotropic, problems arise. Even though the turbulence level relative to the mean directed flow may be low (1-2%) the turbulence intensity relative to the near-zero mean secondary velocity component is extremely high.

Received May 7, 1984; revision recieved June 4, 1984.

*Aerospace Engineer, Ramjet Technology Branch, Aero Propulsion Laboratory.