References

[1]Vollmers, H. and Rotta, J. C., "Similar Solutions of Mean Velocity, Turbulent Energy and Length Scale Equation," *AIAA Journal*, Vol. 15, May 1977, pp. 714-720.

[2]Hanjalic, K. and Launder, B. E., "A Reynolds Stress Model of Turbulence and Its Application to Thin Shear Flow," *Journal of Fluid Mechanics*, Vol. 52, 1972, pp. 609-638.

[3]Launder, B. E. and Morse, A., "Numerical Prediction of Axisymmetric Free Shear Flows with a Reynolds Stress/Closure," *Turbulent Shear Flows I*, edited by F. Durst et al., Springer-Verlag, Berlin, 1979, pp. 279-294.

[4]Riberio, M. M. and Whitelaw, J. H., "Coaxial Jets with and without Swirl," *Journal of Fluid Mechanics*, Vol. 95, 1980, pp. 769-795.

[5]Townsend, A. A., *The Structure of Turbulent Shear Flow*, Cambridge University Press, Cambridge, England, 1956.

[6]Bradshaw, P., Ferriss, D. H., and Atwell, N. P., "Calculations of Boundary-Layer Development Using the Turbulent Energy Equation," *Journal of Fluid Mechanics*, Vol. 28, 1967, pp. 593-616.

[7]Biringen, S., "Calculation of Axisymmetric Jets and Wakes with a Three-Equation Model of Turbulence," *Journal of Fluid Mechanics*, Vol. 86, 1978, pp. 745-759.

[8]Biringen, S. and Levy J., "Calculation of Two Dimensional Turbulent Boundary Layers," *AIAA Journal*, Vol. 16, Sept. 1978, pp. 1016-1019.

[9]Adbol-Hamid, K. S. and Biringen, S., "Self-Similar Solution of Turbulent Jets Using Second-Order Closure Models," Mechanical Engineering Dept., Univ. of New Hampshire, Durham, Tech. Rept. ME-TFA-84011, 1984.

[10]Wygnanski, I. and Fiedler, H., "Some Measurements in the Self-Preserving Jet," *Journal of Fluid Mechanics*, Vol. 38, 1969, pp. 874-912.

[11]Bradbury, L. J. S., "The Structure of a Self-Preserving Turbulent Plane Jet," *Journal of Fluid Mechanics*, Vol. 23, 1965, pp. 31-64.

Reduction of Background Noise Induced by Wind Tunnel Jet Exit Vanes

Ruth M. Martin,* Thomas F. Brooks† and Danny R. Hoad‡

NASA Langley Research Center, Hampton, Virginia

THE NASA Langley 4×7 m wind tunnel, when operating in the open-throat mode, exhibits a phenomenon typical of many open-jet tunnels—development of low-frequency flow pulsations at certain velocity ranges. This pulsation, sometimes called "wind tunnel pumping," is thought to be created by the interaction of the unstable shear layer formed at the jet exit and acoustic waves radiated from the region of impingement of the shear layer on the flow collector. Vortices formed in the shear layer at the jet exit travel downstream and strike the collector, causing a pressure fluctuation that then travels back upstream, interacting with the jet shear layer and causing additional vortex shedding at the jet exit. When this shedding occurs at critical frequencies related to path lengths in the tunnel circuit, resonances can occur that enhance the phenomenon. Such pulsations are of serious concern because they affect the aerodynamic quality of the flow and thus the quality of the resulting data. In the NASA Langley 4×7 m tunnel, the open-throat pulsation problem occurs at three distinct ranges of tunnel dynamic pressure as shown in Fig. 1. In order to conduct a test in a smooth flow environment, the test speed must be within the limited ranges where the pulsation is at a minimum. For most tests, this is impractical due to the operational requirements and aims of the test program.

Passive devices to inhibit the development of such pulsation problems have been applied in various facilities in the past. The devices generally attempt to introduce random turbulence, thereby delaminarizing and destroying the shear layer vortex structure. Vanes, tabs, or teeth that protrude into the airstream around the jet exit have been shown to effectively reduce the magnitude of these flow pulsations.[1-4]

Six configurations of jet exit passive devices were tested and evaluated in the 4×7 m tunnel.[5] The most promising configuration, shown in Fig. 2 as installed in the tunnel, was utilized for the present acoustic study. The structure consists of triangular vanes with a span of 0.6 m (23.6 in.) and a chord of 14.5 cm (5.7 in.), bent to form a 45 deg flap (see Fig. 3). These vanes were attached to the trailing edge of flat steel rails mounted 10 cm (4 in.) from the inside of the jet exit walls. The vanes were installed 0.6 m (23.6 in.) from each other on the rails, pointing alternately into and out of the flow. This vane configuration was aerodynamically effective in substantially reducing the pulsations. As shown in Fig. 1, only the flow pulsations existing at very low dynamic pressure remained. However, the vanes were a serious source of flow noise and, therefore, of concern for acoustic testing. The purpose of this Note is to present the results of an attempt to reduce the inherent noise of the vanes while retaining their pulsation reduction features.

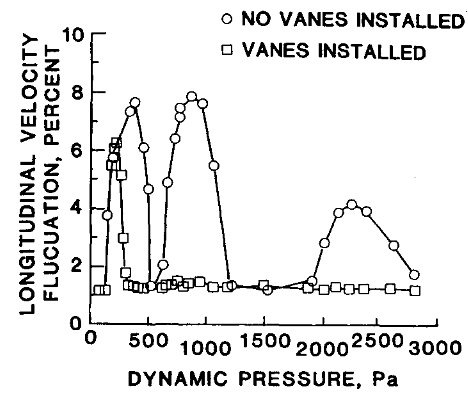

Fig. 1 Longitudinal velocity fluctuation in NASA Langley 4×7 m wind tunnel open-throat test section, with and without jet exit vanes installed (data from Ref. 5).

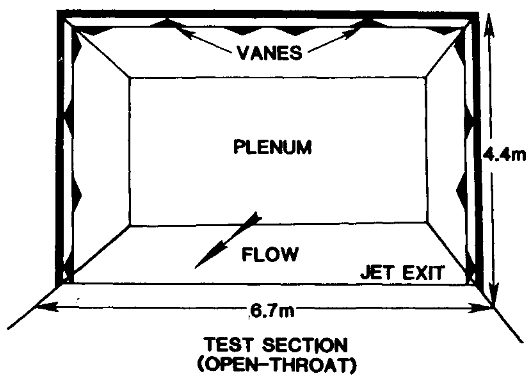

Fig. 2 Pulsation reduction vanes installed in jet exit.

Received Sept. 7, 1984; revision received Dec. 10, 1984.

*Aerospace Engineer, Aeroacoustics Branch, Acoustics Division. Associate Member AIAA.

†Aerospace Engineer, Aeroacoustics Branch, Acoustics Division.

‡Aerospace Engineer, Rotorcraft Aerodynamics Office, Aerostructures Directorate, USAARTA (AVSCOM).

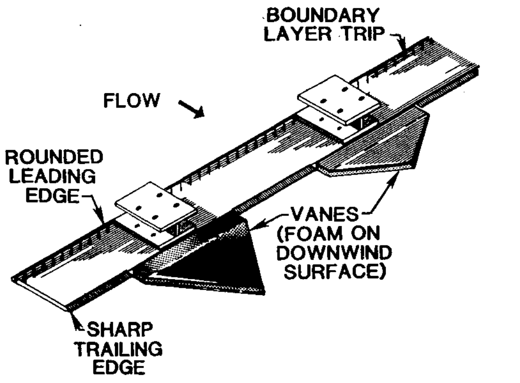

Fig. 3 Vane structure with noise reduction modifications.

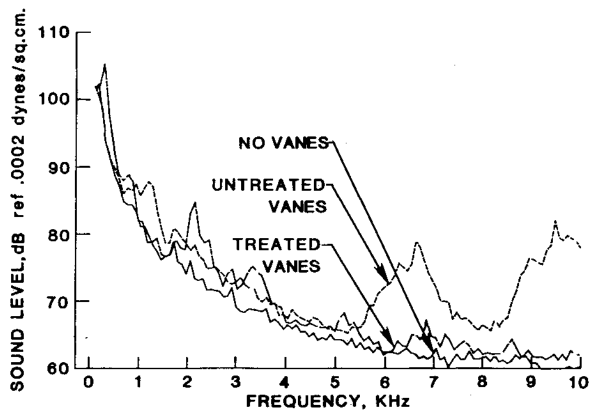

Fig. 4 Background noise spectra for an in-flow microphone with no vanes, untreated vanes, and treated vanes installed [dynamic pressure 2278 Pa (47.6 psf)].

Noise Reduction Approach

The high-frequency flow noise produced by the vane structure is due to the generation and shedding of vorticity from the hard vane structure. Such self-noise mechanisms are explained in detail in Refs. 6 and 7. The noise reduction modifications to the vane structure are shown in Fig. 3. A thin layer of open-cell polyurethane foam was glued to the downwind surface of each vane. The foam was shaped to have a smooth junction with the structure near the leading edge and to be approximately 2.5 cm (1.0 in.) thick at the trailing edge. This foam served to inhibit vortex generation, as well as to change the vane surface impedance, thus reducing the noise radiation without altering the vanes' desired pulsation suppression characteristics. To make the structure more aerodynamically streamlined, sections of wood dowel were attached to the blunt leading edge of the support rails to create a rounded leading edge. Slender triangular lengths of wood were also attached to the rail trailing edge. All bolt holes, protruding hardware, and sharp corners or steps were filled or covered with clay to avoid cavity noise or "whistles." A boundary-layer trip was applied near the leading edge of the steel rail to prevent the occurrence of the coherent vortex shedding noise attributed to laminar boundary layers.[7]

Results

The results of these noise reduction modifications are shown in Fig. 4. A comparison of the measured background noise spectra for a microphone located within the flow of the tunnel test section is presented. The spectrum created by the untreated vane structure exhibits two large amplitude humps near 6 and 10 kHz. The result of the vane treatment is to reduce this high-frequency background noise (by as much as 20 dB) to levels comparable to those measured with no vanes installed. Similar noise reduction results were measured at several other in-flow microphone locations and over a range of tunnel speeds, although the largest noise reduction occurred at the higher tunnel speeds [dynamic pressure of 1200-2400 Pa (25-50 psf)]. On-line observations of the velocity fluctuations confirmed that the pulsation problem was still favorably reduced. Thus, the modifications to the vane structure were verified as an effective, economical, and easily implemented technique to reduce the additional noise induced by the vanes.

References

[1]Jacobs, E. N., "Investigation of Air Flow in Open-Throat Tunnels," NACA Rept. 322, 1929.

[2]Seiferth, R., "Pre-Calculation and Removal of Oscillations in Free-jet Wind Tunnels," *A VA Monographs on German Aeronautical Research Carried Out Since 1939*, Vol. D4.4, Ministry of Aircraft Production, Volkenrode, Rept. and Trans. 947, Aug. 1947.

[3]Rogers, O.R., "Wind Tunnel Pulsations," AAF Tech. Rept. 5513, 1946.

[4]Brodski, Z., "Stream Control for Low Speed Range in Wind Tunnels," FTD-TT-62-1476/1+2, March 1985 (unedited rough draft translation).

[5]Sellers, W.L. III, Applin, Z.T. Molloy J.K., and Gentry G.L., "The Effect of Jet Exit Vanes on Flow Pulsations in an Open Jet Wind Tunnel," NASA TM-86299, 1984.

[6]Brooks, T.F. and Schlinker, R.H., "Progress in Rotor Broadband Noise Research," *Vertica*, Vol. 7, 1983, pp. 287-307.

[7]Brooks, T.F. and Marcolini, M.A. "Airfoil Self Noise—Effect of Scale," AIAA Paper 83-0785, 1983.

Speed Measurement of Flat Flame in a Tube Using Ion Probes

Masao Maekawa*
Ehime University, Matsuyama, Japan

Introduction

THE difficulties of measuring flame speed using various types of tubes have been described elsewhere.[1] The difficulties are due to problems in generating a flat flame. In trying to solve this problem, Coward and Hartwell[2] introduced a tube technique that Garstein et al.[3] improved by adding a nozzle to smooth the flow. However, the flame surfaces were semiellipsoids of revolution. Fuller et al.[4] measured the fundamental flame speed of propane-air mixtures by means of multiple-exposure photographs using a modified Garstein tube. Our model is also a modified Garstein tube, but it has ion probes mounted on the tube to measure the flame speeds. The present study was, in fact, undertaken to develop a means of measuring flame speeds directly using ion probes. In this experiment, measurements of the flame speeds made by the ion probes were compared with those made by multiple-exposure photographs of the flame moving down the tube. Using the ion probe method, accurate measurements were easily taken and the results were in agreement with other studies. Therefore, it is thought that the ion probe method of measuring flame speeds can be a useful experimental tool.

Received May 7, 1984; revision received Oct. 25, 1984.

*Department of Mechanical Engineering.