Technical Notes

TECHNICAL NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Criterion for Vortex Periodicity in Cylinder Wakes

Lars E. Ericsson* and J. Peter Reding†
Lockheed Missiles & Space Company, Inc., Sunnyvale, Calif.

The Strouhal number for the vortex shedding from a circular cylinder mounted normal to the freestream is shown in Fig. 1 as a function of Reynolds number. The experimental results[1-9] define a unique Strouhal number (within the data scatter) only for $Re<0.2\times10^6$ and $Re>3.5\times10^6$. Until Roshko showed otherwise,[1] it was generally believed that the periodic von Kármán-type vortex street could not exist at supercritical Reynolds numbers. Roshko showed that the harmonic vortex shedding reappeared at $Re\geq3.5\times10^6$, with a shorter wavelength, higher frequency. These results were confirmed later by Jones et al.,[2] who also found that the harmonic vortex shedding started at $Re\geq3.5\times10^6$. The various nonunique harmonic results in the transcritical region $0.2<Re\times10^{-6}<3.5$ are discussed in Ref. 10, where it is shown that model vibration, measurement in the near wake, misinterpretation of spectral results, and possible effects of cavitation in water-tunnel tests all may serve to explain the measured anomalous Strouhal numbers. Also included in Fig. 1 is the "center frequency" computed by Theisen[9] for the transcritical Reynolds number region using the spectral characteristics measured by Fung.[11] It can be seen that this center-frequency curve provides a smooth transition from subcritical to supercritical Strouhal numbers.

Seeing the results in Fig. 1, one asks, of course, the reason for the disappearance of vortex periodicity in the transcritical region $0.2<Re\times10^{-6}<3.5$. Based on the critical review in Ref. 10 of the available experimental evidence, one concludes that the reason is that at transcritical Reynolds numbers, the separated flow region on a circular cylinder lacks two-dimensionality. Although Reynolds number is a very important parameter, it is not sufficient by itself to determine whether the flow on the cylinder is supercritical or subcritical. Surface roughness can decrease the critical Reynolds number by almost one order of magnitude[12] (Fig. 2), and wind tunnel turbulence has a similarly large effect[13] (Fig. 3). Figure 4 summarizes the effect of roughness on the Reynolds number boundaries of the transcritical region.[14] With the definition of "smooth" used by Schechenyi,[15] i.e., $(\delta/d)_{\rm smooth}=3.5\times10^{-5}$, Fig. 4 indicates that the transcritical region for a smooth cylinder extends from $Re<2.5\times10^5$ to $Re>2\times10^6$, the same Reynolds number range for which definite vortex periodicity is lacking (Fig. 1).

Figure 4 illustrates how sensitive the transcritical Reynolds number boundaries are to roughness. Considering the spanwise variation of model roughness, as well as of wind tunnel turbulence, one cannot, of course, expect the separated flow region to be truly two-dimensional for transcritical Reynolds numbers. This conclusion is supported further by the results of Humphreys[13] showing the boundary-layer transition process on a circular cylinder to be highly three-dimensional with a spanwise wave or cell pattern playing an important role. According to Theisen's theoretical and experimental results,[9] the two-dimensionality needs to extend

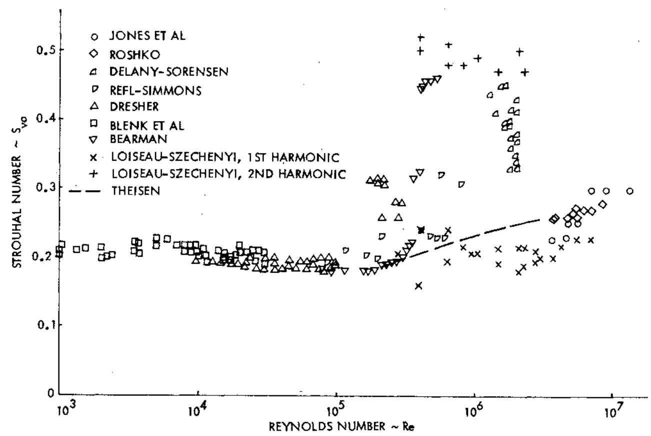

Fig. 1 Strouhal number for vortex shedding off a circular cylinder normal to uniform incompressible flow.

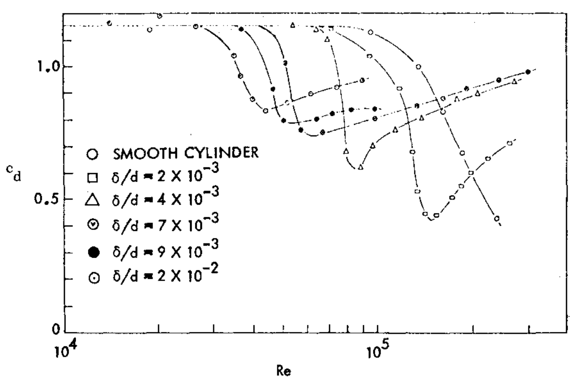

Fig. 2 Effect of roughness on cylinder drag (Ref. 12).

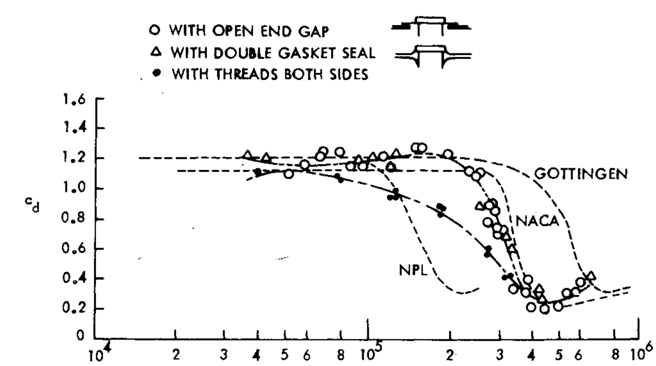

Fig. 3 Drag coefficient vs Reynolds number in different ground facilities (Ref. 13).

Received March 5, 1979; revision received April 20, 1979.

Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interations; Nonsteady Aerodynamics.

*Consulting Engineer. Associate Fellow AIAA.

†Research Specialist. Member AIAA.

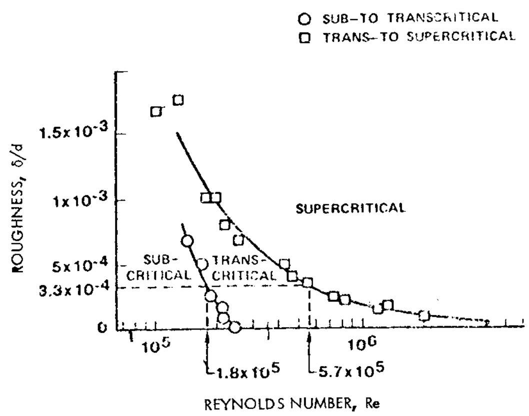

Fig. 4 Limits of flow regimes for different relative roughness sizes (Ref. 14).

over four cylinder diameters before von Kármán-type vortex shedding is established.

In summary, then, it appears that a necessary condition for the establishment of vortex periodicity in cylinder wakes is the existence of a well-defined, two-dimensional separated flow region. Consequently, one would expect that the periodic vortex shedding with the associated problems of self-excited oscillations could be eliminated by introducing three-dimensional flow disturbances that prevent the formation of a well-defined, two-dimensional flow separation geometry.

References

[1] Roshko, A., "Experiments on the Flow Past a Circular Cylinder at Very High Reynolds Numbers," *Journal of Fluid Mechanics*, Vol. 10, 1960, pp. 345-356.

[2] Jones, Jr., G.W., Cincotta, J.C., and Walker, R.W., "Aerodynamic Forces on a Stationary and Oscillating Circular Cylinder at High Reynolds Numbers," NASA TR R-300, Feb. 1969.

[3] Delany, N.K. and Sorenson, N.E., "Low-Speed Drag of Cylinders of Various Shapes," NACA TN-3038, Nov. 1953.

[4] Relf, E.F. and Simmons, L.G.F., "The Frequency Generated by the Motion of Circular Cylinders Through a Fluid," ARC R&M No. 917, Aircraft Research Council, Great Britain, 1924.

[5] Drescher, H., "Messung der auf querangeströmte Zylinder ausgeubten Zeitlich veränderten Drucke," *Zeitschrift für Flügwissenschafen*, Vol. 4, Heft 112, 1956, pp. 17-21.

[6] Blenk, H.F., Fuchs, D., and Liebers, F., "Über Messungen von Wirbelfrequenzen," Luftahrtforschung 12, 1935, pp. 38-41.

[7] Bearman, P.W., "On Vortex Shedding from a Circular Cylinder in the Critical Reynolds Number Regime," *Journal of Fluid Mechanics*, Vol. 37, Part 3, 1969, pp. 577-585.

[8] Loiseau, H. and Szechenui, E., "Analyse Experimentale des Portances sur un Cylindre Immobile Soumis a un Ecoulement Perpendiculaire a son Axe a des Nombres de Reynolds Elevés," *La Recherche Aérospatiale*, Sept.-Oct. 1972, pp. 279-291.

[9] Theisen, J.G., "Vortex Periodicity in Wakes," AIAA Paper 67-34, Jan. 1964.

[10] Ericsson, L.E. and Reding, J.P., "Vortex-Induced Asymmetric Loads on Slender Vehicles," Rept. LMSC-D630807, Contract N60921-77C-0234, Lockheed Missiles & Space Co., Inc., Sunnyvale, Calif., Jan. 1979.

[11] Fung, Y.C., "Fluctuating Lift and Drag Acting on a Cylinder in a Flow at Supercritical Reynolds Numbers," *Journal of the Aeronautical Sciences*, Vol. 27, Nov. 1960, pp. 801-814.

[12] Fage, A. and Warsap, "The Effects of Turbulence and Surface Roughness on the Drag of a Circular Cylinder," ARC R&M No. 1283, 1930.

[13] Humphreys, J.S., "On a Circular Cylinder in a Steady Wind at Transition Reynolds Number," *Journal of Fluid Mechanics*, Vol. 9, Part 4, 1960, pp. 603-612.

[14] Schlinker, R.H., Fink, M.R., and Amiet, R.K., "Vortex Noise from Non-Rotating Cylinder and Airfoils," AIAA Paper 76-81, Jan. 1976.

[15] Schechenyi, E., "Supercritical Reynolds Number Simulation for Two-Dimensional Flow Over Circular Cylinders," *Journal of Fluid Mechanics*, Vol. 70, Part 3, 1975, pp. 529-542.

On-Axis Velocity Component Measurement with Laser Velocimeters

Sudhakar Neti* and Wayne Clark†

NASA Ames Research Center, Moffett Field, Calif.

Introduction

MEASUREMENT of fluid velocities with Doppler-shifted laser light was demonstrated almost two decades ago; since then, laser velocimetry has developed into a powerful method for measuring fluid and other velocities. While it has been relatively easy to measure the two velocity components normal to the optical axis of the system, measuring the on-axis velocity component has not been as simple. Methods used for measuring the on-axis component include both reference-beam (local oscillator) and dual-beam (fringe mode) techniques. Some of the methods used in the past are discussed herein.

Fridman et al.,[1] Bossel et al.,[2] and Dubnistchev and Vasilenko[3] used three-component, reference-beam systems with forward scattering. In these geometries, the point of measurement is illuminated by focused laser light of single color, and the light scattered by the particles in the fluid is detected by three photodetectors. The position of the photodetectors determines the velocity components measured, which are not necessarily the preferred components. The three measured velocity components are then resolved to yield the Cartesian velocity components of interest.

Fridman et al.[1] installed their detectors in front of the laser and the test section. In their system, unscattered light was focused to and heterodyned on the detectors to sense the Doppler shift. The scheme proposed by Bossel et al.[2] used Wollaston prisms to combine and heterodyne forward scattered light from two different directions on the photodetector. By properly choosing polarizations and Wollaston prism orientations, they devised a scheme for measuring three arbitrary velocity components. The heterodyning of light in the system of Dubnistchev and Vasilenko[3] was achieved with the use of light reflected from a reflector in front of the system.

Orloff and Logan[4] devised an optical geometry to measure a velocity component close to the on-axis component. Their arrangement uses backscattered light from one of the beams of a dual-beam velocimeter with a crossing angle of θ. The reference beam is obtained as a spurious reflection from a splitter cube and aligned with scattered radiation onto the photomultiplier tube. The measured velocity component is $\theta/4$ off the axis of the velocimeter, and for small θ, this is close to the desired on-axis component. Farmer et al.[5] also used a similar system to measure the on-axis component in addition to two normal components. The reference-beam backscatter method generally yields large values of Doppler shifts, and thus may not be suitable for many applications.

The direct measurement of the on-axis component is also difficult with dual-beam (fringe mode) methods. One of the schemes for such a direct measurement involves crossing the forward and backward (reflected) beams, thus forming fringes perpendicular to the optical axis of the velocimeter. Because of physical and geometrical constraints, the angle between the crossing beams and hence the Doppler shift in this

Received March 27, 1979. This paper is declared a work of the U.S. Government and therefore is in the public domain.

Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; Research Facilities and Instrumentation.

*NASA-ASEE Summer Fellow: Assistant Professor, Department of Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, Pa.

†Research Physicist, Electronic Instrument Development Branch.