Detailed Measurements on a Circular Cylinder in Cross Flow

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Abstract

A SERIES of wind tunnel tests covering a range of Mach numbers and Reynolds numbers in subsonic and transonic flows was conducted on a circular cylinder placed normal to the flow. Form drag coefficients were determined from surface pressure measurements and displayed as a function of Mach number to show the transonic drag rise phenomenon. Buried wire gages arranged on the model surface were used to measure skin friction distributions and vortex shedding frequencies at different flow conditions. It was found that detectable periodic shedding ceases above $M=0.9$. The measured skin friction distributions indicate the positions of mean separation points clearly; these values are documented for different flow conditions.

Contents

Flow past circular cylinders is of interest because of its relevance to various problem areas such as aerodynamics of aircraft and missiles at high angles of attack,[1,2] wind effects on tall chimney structures, flow past tube banks of heat exchangers, hydrodynamics of towing and mooring cables for undersea applications, etc. Recently, there has been some interest in developing numerical methods for solving flow past circular cylinders so that predictions can be made for flow regimes that cannot be easily attained in test facilities. Success in such attempts depends heavily on extended flow documentation, especially on boundary-layer development. At present, only very limited data exist in this regard.

The present investigation was concerned with three main features of flow past cylinders: skin friction distribution, form drag coefficients, and vortex shedding frequencies. All tests were conducted in the 2- × 2-ft (61 × 61-cm) transonic wind tunnel at NASA Ames Research Center. Perforated walls in the test section allowed good control of Mach number through the transonic range. Different values of Reynolds numbers were achieved by altering the pressure level in the tunnel.

The model selected for these tests was a fully tunnel-spanning 2.54-cm-diam hollow circular cylinder (used by other investigators in a different test series[2]). This model (Fig. 1) has nine surface pressure ports arranged at equal angular intervals around the periphery near midspan. Pressures were measured through a scanning valve device and recorded on the conventional data acquisition system of the tunnel.

Vortex shedding frequencies and skin friction distributions were determined by operating two sets of specially developed buried wire gages installed in slots separated by about 35 deg on the surface near midspan. It is perhaps appropriate here to briefly describe the buried wire gage technique, which had its origin long ago but did not gain popularity as a part of wind tunnel instrumentation until recently.[3]

The buried wire gage has a sensor in the form of a thin wire extending across flush embedded electrical leads on a substrate of low thermal conductivity and remaining well attached to it over the entire span. A variation of this technique is a thin film gage, more popularly known as the thin film resistance thermometer, in which a narrow thin film takes the place of the wire. For all practical purposes, buried wire gages and thin film gages behave identically. However, buried wire gages are preferable because they are relatively easy to arrange on wind tunnel models and their small streamwise extent renders them virtually insensitive to local pressure gradients in skin friction measurements. These gages are operated in a constant temperature mode from an anemometer system and may be calibrated by two simple measurements: one in the absence of any flow, and the other in a flow with known skin friction.

In the present test series, the known flow for purpose of calibration was taken to be an $M=0.4$, $Re_D=0.083\times10^6$ freestream flow, which assures laminar boundary layer over the front of the cylinder and hence allows skin friction distribution to be predicted accurately by feeding the measured pressure distribution to the boundary-layer code developed by Murphy and Davis.[4] The calibration constants

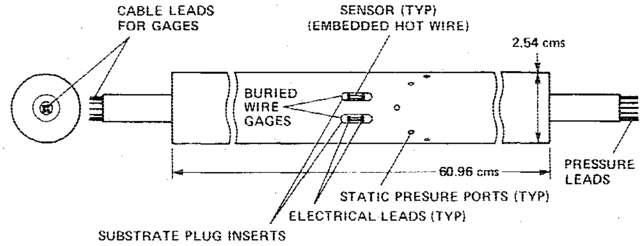

Fig. 1 Schematic of 2.54-cm-diam cylinder model.

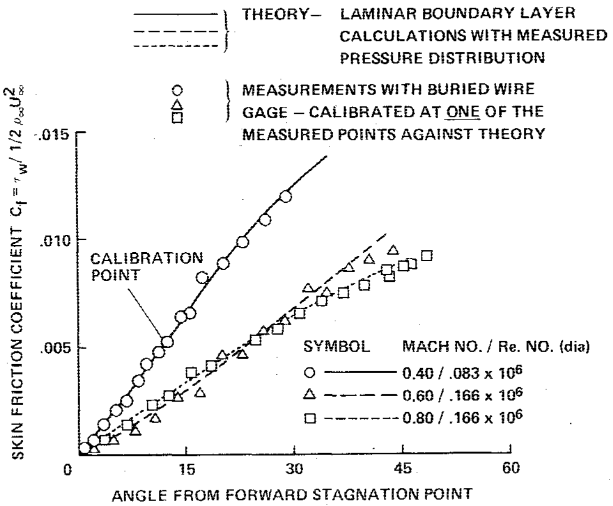

Fig. 2 Calibration characteristics of buried wire gages.

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Index categories: Transonic flow; Aerodynamics; Boundary Layers and Convective Heat Transfer—Turbulent.

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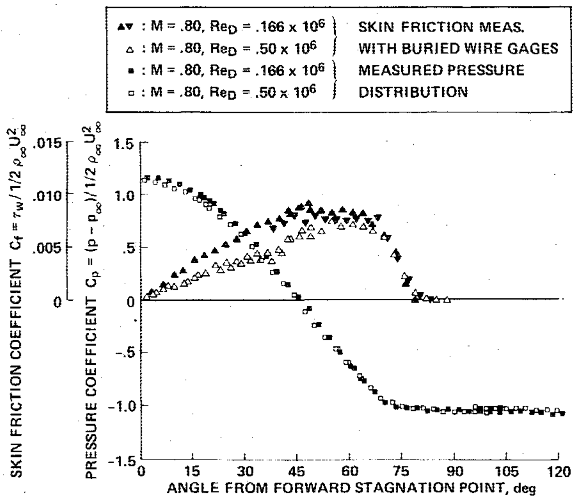

Fig. 3 Skin friction and pressure distributions on circular cylinder in cross flow.

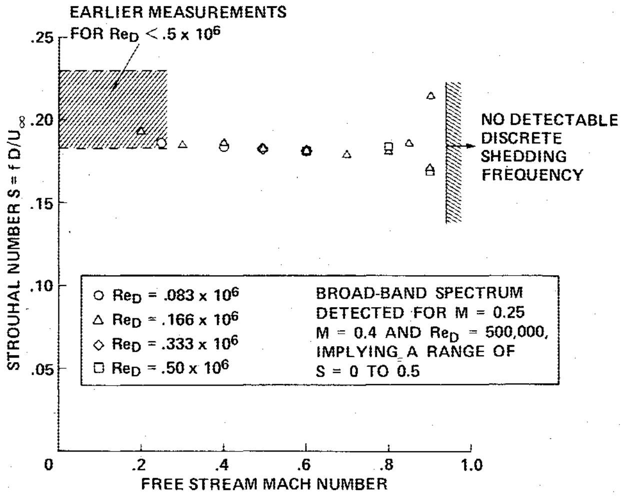

Fig. 5 Strouhal number and vortex shedding frquency.

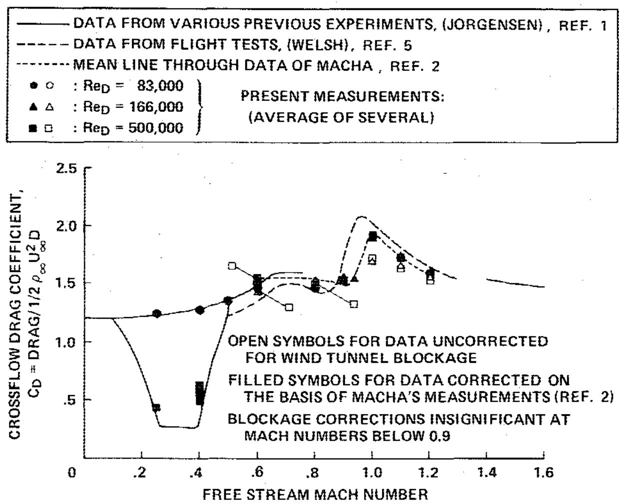

Fig. 4 Cross flow drag coefficient of circular cylinder.

thus obtained were used to measure the skin friction distributions at other flow conditions that assured laminar boundary layer on the front of the cylinder. These measurements agree (Fig. 2) with the results of theoretical calculations[4] over the wide range of angles and Mach numbers and demonstrate that the measurement technique is well justified.

Having thus established the technique and calibration of the gages, additional measurements were performed in the Mach number range of 0.25 to 1.2 and three values of Reynolds numbers (based on cylinder diameter) of 0.03×10^6, 0.166×10^6 and 0.50×10^6. Both pressures and skin friction were measured at approximately every 3 deg of angular positions by rotating the cylinder in 3 deg steps until the pressure measurements overlapped or until the desired range of angles were swept by the buried wire gages.

Figure 3 presents the results of measurements made for freestream conditions of $M = 0.8$, $Re_D = 0.166 \times 10^6$ and $M = 0.8$, $Re_D = 0.50 \times 10^6$. The separation points are very clearly identified by the measured skin friction distribution. Measurements of this kind have been made for several other flow conditions and are reported in the full paper.

Measured pressure distributions were integrated to obtain the pressure drag coefficients as a function of Mach number; the result is seen plotted in Fig. 4 along with other published data. The contribution of skin friction to the total drag is very small and hence the pressure drag could be regarded as the total drag itself. The present data were corrected for wind tunnel blockage effects on the basis of Macha's findings.[2] Corrections are insignificant for Mach numbers below 0.9 and maximum for Mach numbers close to unity. Figure 4 shows that the present measurements agree well with other published data.

The buried wire gages were capable of responding to an upper frequency limit of about 30 kHz and therefore were used to determine the vortex shedding frequencies. The gage signals were analyzed for their frequency content and the dominant frequencies were read as the shedding frequencies. These shedding frequency measurements are summarized in Fig. 5 in terms of Strouhal number as a function of Mach number. They generally agree, at low Mach numbers, with the data reported in existing literature. The Strouhal number does not seem to be a strong function of Mach number over the entire Mach number range which exhibits discrete shedding frequencies.

References

[1] Jorgenson, L. H., "Prediction of Static Aerodynamic Characteristics for Space Shuttle Like and Other Bodies at Angles of Attack from 0 to 180," NASA TN D-6996, Jan. 1973.

[2] Macha, J. M., "A Wind Tunnel Investigation of Circular and Straked Cylinders in Transonic Cross Flow," Texas A/M Research Foundation, College Station, Texas, TAMU Rept. 3319-76-01, Nov. 1976.

[3] Rubesin, M. W., Okuno, A. F., Mateer, G. G., and Brosh, A., "A Hot Wire Surface Gage for Skin Friction and Separation Detection Measurements," NASA TM X-62,465, July 1975.

[4] Murphy, J. D. and Davis, C. B., "User's Guide—Ames Inlet Boundary Layer Program MK I," NASA TM X-62,211, Jan. 1973.

[5] Welsh, C. J., "The Drag of Finite Length Cylinders Determined from Flight Tests at High Reynolds Numbers for a Mach Number Range from 0.5 to 1.3," NACA TN 2941, June 1953.