ELECTROKINETIC-PROBE RESPONSE TO VORTEX-STREET FREQUENCY

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The electrokinetic technique has been used to measure the periodic vortex street behind circular cylinders of various sizes in a rectangular open channel water flow at cylinder Reynolds numbers ranging from 50 to 10,000. The result is compared with available data taken with a hot-wire anemometer in air flow. It is proved that the electrokinetic probe is sensitive to the fluctuations of the liquid-flow field.

1. Introduction

The periodic vortex shedding from circular cylinders of various sizes at low Reynolds numbers has been studied extensively for the past half century. The relationship between the vortex shedding frequency and the cylinder Reynolds number has been well established. The relationship for frequency of vortex shedding found by Roshko (1953) with the hot-wire technique in air flow is further supported by Naumann (1958).

The electrokinetic probe suggested by Professor Cermak* and developed by Chuang (1962) has been used to measure the electrokinetic-potential fluctuations produced by turbulence in fully-developed pipe flow with distilled water as the medium. The turbulent intensities and spectral distributions of turbulent energies inferred from the measured electrokinetic-

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potential fluctuations were shown to be in good agreement with the experimental data taken by Laufer (1953) and Sandborn (1955) with the hot-wire technique in an air flow.

The purpose of the present experiment is to obtain further evidence of the probe's sensitivity to the turbulent flow field.

2. Experimental Method

2.1 Apparatus

A "Lucite" open channel (flume) with a cross-section of 8 in. x 8 in. and a length of 30 ft was used as the flow system. The slope of the flume could be adjusted mechanically and the medium was recirculated with a variable speed centrifugal pump. Tap water was used as the medium. It was feasible to vary the mean velocity from 0.09 to 2.0 meters per second. The local mean velocity was measured by means of a Pitot tube.

The electrokinetic probe as shown in figure 1 is made of two varnished, commercial-grade copper wires 0.20 mm in diameter and supported by stainless steel tubing 0.80 mm in diameter. For further details of the probe, reference is made to Chuang (1962) or Chuang and Cermak (1962).

The circular cylinders, brass rods and copper wires used in these experiments varied in diameter from 0.0548 to 0.633 centimeter. The cylinders spanned the 8-inch channel. The probe was located about 5 to 10 diameters downstream and tangent to the cylinder.

2.2 Shedding frequency

The electrokinetic-probe signal was amplified by a low-level differential preamplifier (Tektronix Type 122). It has selective gain and frequency-response ranges which were set at 1000x and from 0.2 to 10,000 cps respectively throughout the measurements. The amplified signal was then fed into the vertical deflection of a cathode-ray oscilloscope. An audiofrequency oscillator (Hewlett-Packard Model 200j) was connected to the horizontal deflection of the oscilloscope so that the frequency of periodic fluctuation could be determined by observing the Lissajous figure.

3. Results

The shedding frequency is expressed in terms of the Strouhal number $S = fd/U_o$ after V. Strouhal who in 1878 measured the relation between the shedding frequency f and the stream velocity U_o . U_o in the present experiment is the local mean velocity at the center of the circular cylinder of diameter d . The Strouhal number S as pointed out by Rayleigh, is a function of the Reynolds number $R = U_o d/\nu$, where ν is the kinematic viscosity of water. Kovasznay (1949) and Roshko (1953) have verified Rayleigh's hypothesis using the hot-wire technique in an air flow past a circular cylinder. The present measurements of the Strouhal number S versus the Reynolds number R of the cylinder are plotted in figures 2 and 3. Even though the water surface and cylinder ends affect the scatter of experimental data, they are in good agreement with those of Kovasznay and Roshko. Roshko's equations for frequency of vortex shedding are also plotted in the figures. The maximum Reynolds number attained in the experiment was 11,200. All measurements were made at Reynolds numbers above Kovasznay's critical Reynolds number. No effort was made to test his equation.

The shedding frequency is also expressed in terms of the dimensionless parameter $F = fd^2/\nu$, as suggested by Roshko. The interrelation among the three dimensionless parameters F , S , and R is given by $F = SR$. The relations between F and R are presented in figures 4 and 5. Roshko's empirical functions of the vortex-shedding frequency law are also plotted. The results are in good agreement with Roshko's empirical relations.

4. Conclusions

The electrokinetic probe is shown to be sensitive to the periodic vortex shedding from a circular cylinder in water flow. The probe responds faithfully to the disturbance frequency of the flow. Since the probe is not a heat-transfer device such as the hot-wire anemometer, it will be useful for the study of heat transfer in a liquid.

The author is grateful for the help and advice of Dr. D. B. Simons in making arrangements for this study in the open channel. Financial support provided by the United States Geological Survey for this study and the support given by the New York Research Corporation and the National Science Foundation (Grant 10176) which led to the development of the probe are sincerely acknowledged.

5. References

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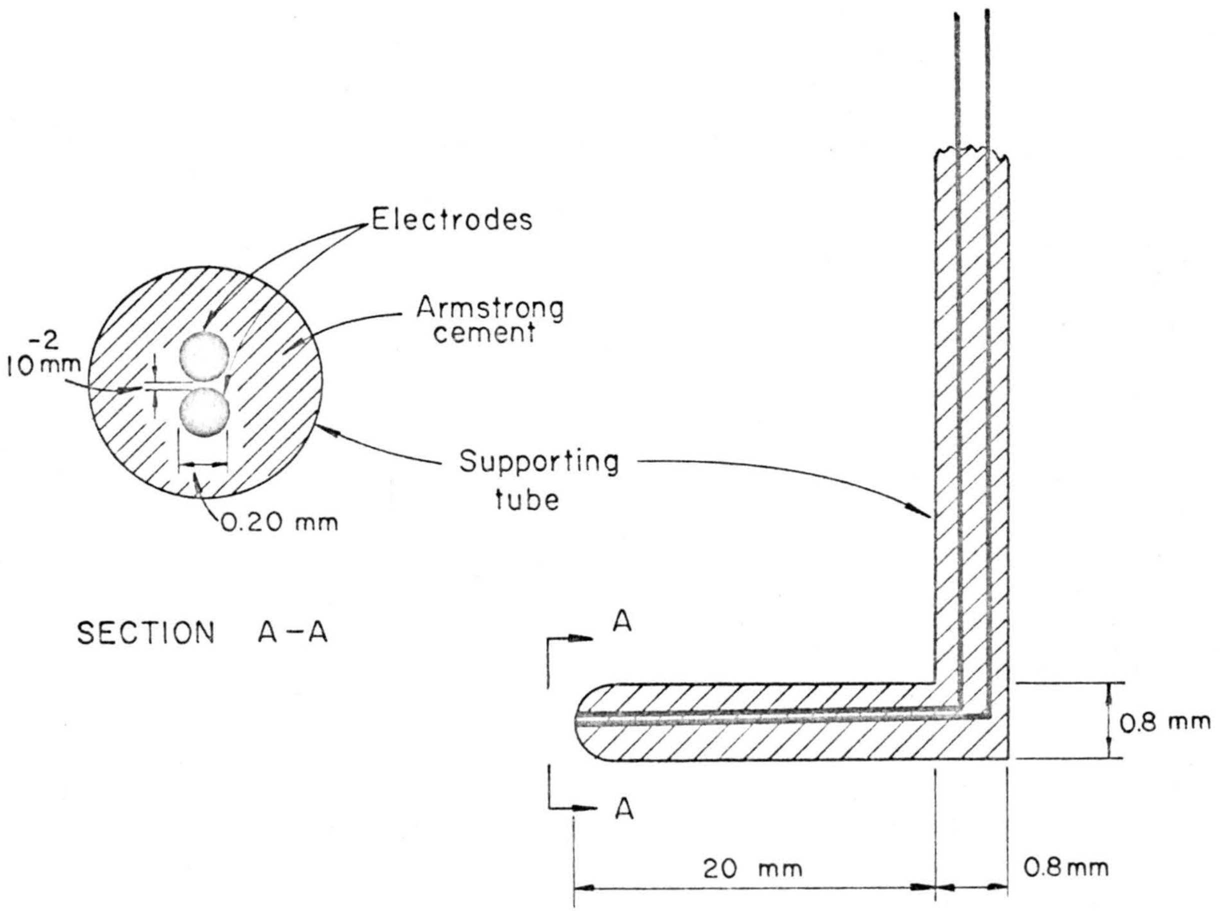

FIG. 1 ELECTROKINETIC PROBE

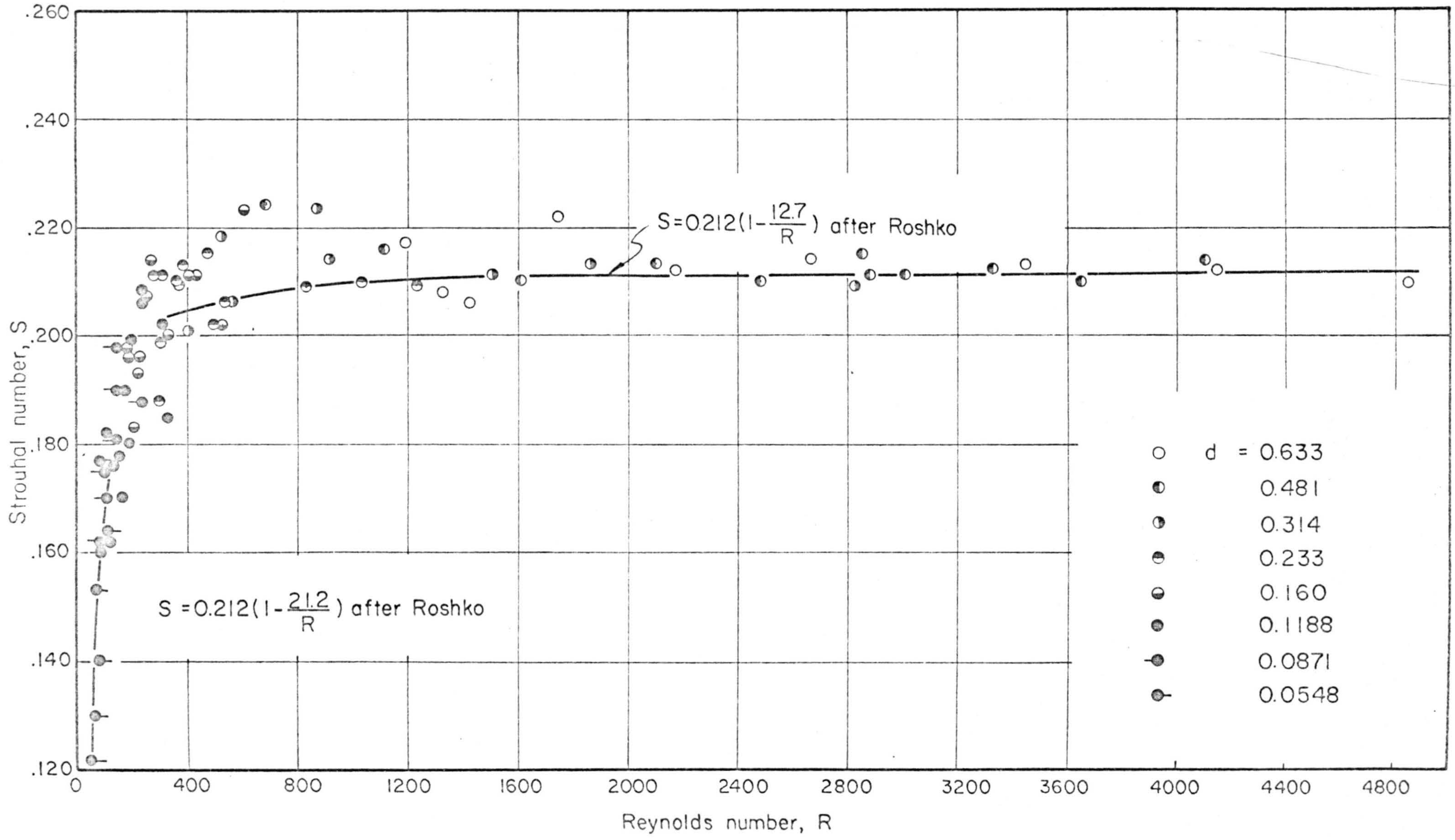

FIG. 2 STROUHAL NUMBER VS. REYNOLDS NUMBER FOR A CIRCULAR CYLINDER

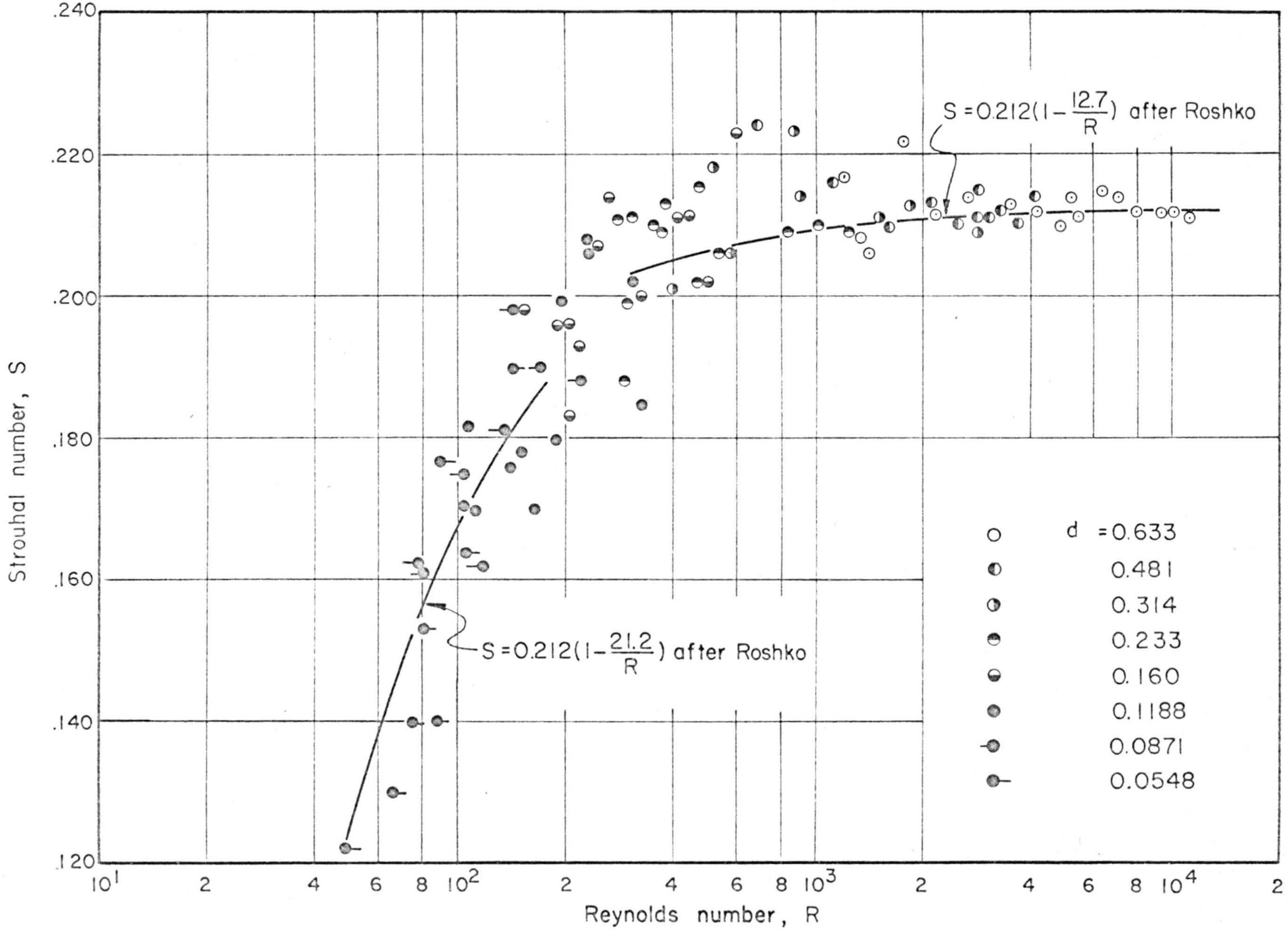

FIG. 3 STROUHAL NUMBER VS. REYNOLDS NUMBER FOR A CIRCULAR CYLINDER

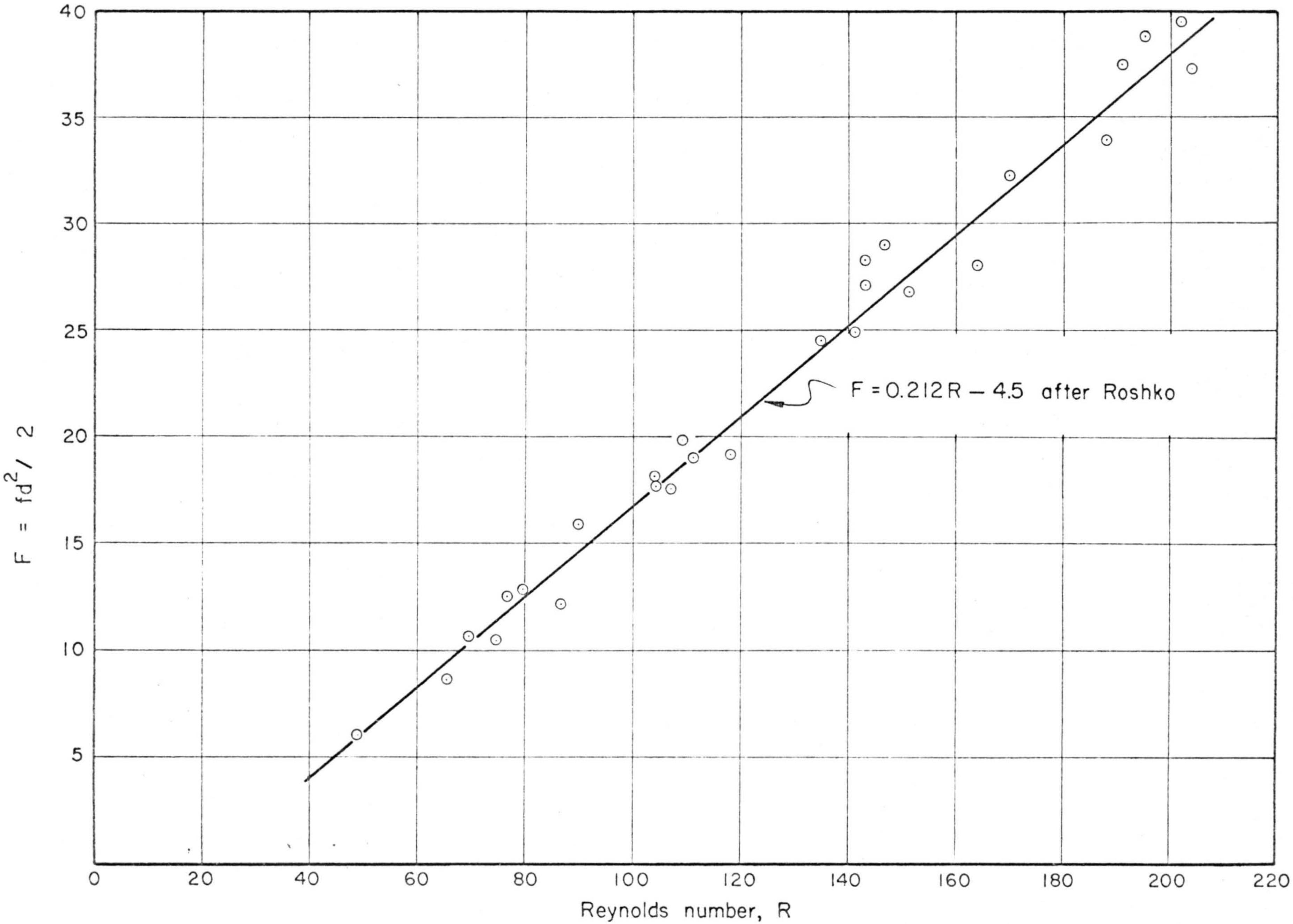

FIG. 4 DIMENSIONLESS FREQUENCY PARAMETER VS. REYNOLDS NUMBER FOR A CIRCULAR CYLINDER

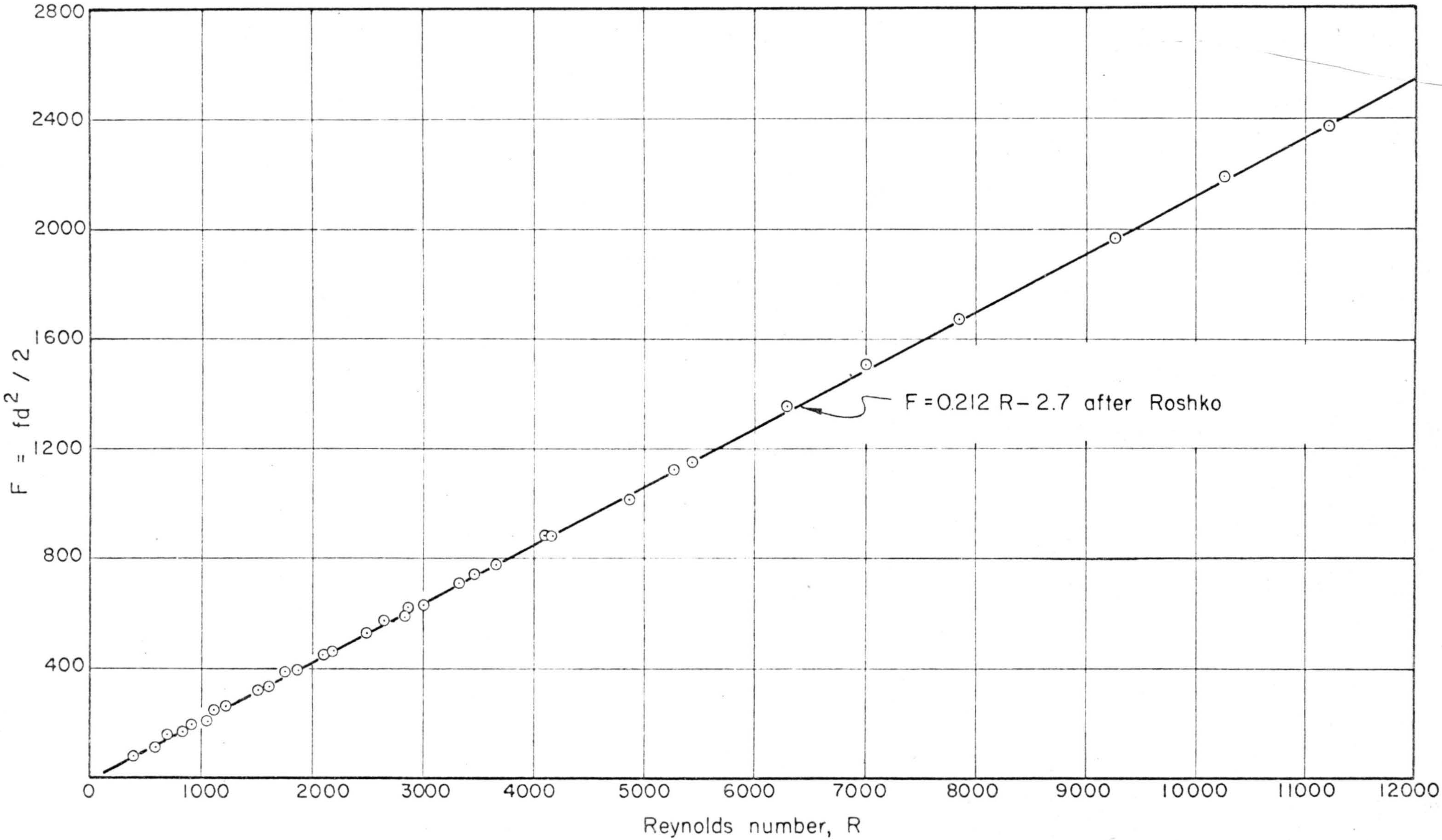

FIG. 5 DIMENSIONLESS FREQUENCY PARAMETER VS. REYNOLDS NUMBER FOR A CIRCULAR CYLINDER