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Experiments on circular cylinders in crossflow at Reynolds numbers up to 7 million

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Abstract

This paper describes a series of experiments conducted on polished circular cylinders in the Reynolds number range from 100,000 to 7 million. The experiments were conducted in a pressurized wind tunnel wherein Mach number and Reynolds number could be independently varied. Three models were used with aspect ratios of 10, 5 and 2.5. Measurements were also made in two grid-generated turbulent flows with intensities of 5% and 13%. In addition to force balances at each end of the models, 32 pressure taps were embedded in a circumferential ring at mid-span and along the leeward generator. Both time-averaged and unsteady data are discussed. The pressure-tap data provide a detailed understanding of the unsteady flow, including vortex shedding, around the cylinder in different flow regimes. The presence of turbulence can change the flow state and hence the steady and unsteady loads. Compressibility effects are shown to exist above a Mach number of 0.3.

Keywords: Strouhal number; Circular cylinder; Reynolds number; Mach number; Turbulence

1. Introduction

Our understanding of the complex fluid mechanics and steady and unsteady loading on circular cylinders at Reynolds numbers in excess of a few hundred thousand remains incomplete. It is known that the fluid mechanics are influenced by free-stream turbulence, by the surface roughness of the model, and by the ''two-dimensionality'' of the flow. This study was undertaken to expand the knowledge base for smooth cylinders to include the

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effects of compressibility, aspect ratio, and free-stream turbulence. It complements earlier work on roughened cylinders by Zan and Matsuda (2002).

The descriptions of the state of the flow around a circular cylinder are subject to debate, with terms such as "supercritical" and "postcritical" used inconsistently by different authors. To avoid confusion, this paper will adopt the naming convention suggested by Zdravkovitch (1997). Those terms are based on the physical state of the boundary layer, specifically where the transition occurs. In the present context, the relevant regime is transition in the boundary layer, TrBL. For smooth cylinders in low turbulence flow, the TrBL regime has a lower Reynolds number bound of 100K[1] to 200K and an upper bound of 3M to 5M.

The TrBL regime is further sub-divided into the TrBL0 (drag coefficient decreasing and separation moving aft), TrBL1 (laminar bubble on one side of the cylinder), TrBL2 (two laminar bubbles), TrBL3 (spanwise disruption of bubbles) and TrBL4 (elimination of bubbles) regimes, all of which can occur as Reynolds number increases. The Strouhal number and magnitude of steady and unsteady loads are a reflection of the specific flow regime. As will be shown, turbulence can have large effects on the Reynolds number range over which these sub-regimes exist, and can eliminate some completely.

2. Experimental details

2.1. Models and instrumentation

Three aluminum models with the same normalized surface roughness, $k/D = 10^{-6}$, were used in these tests. The diameters were 38, 75 and 150 mm. A model was mounted on a pair of two-component balances located outside the wind tunnel, but within the wind-tunnel plenum (Fig. 1). A boundary-layer suction system on both walls confers higher effective aspect ratios than suggested by the geometry. The model-mounting arrangement and wall-suction system are described in detail in Zan and Matsuda (2002).

In addition to the external balances, the model was instrumented with 24 pressure taps arranged around the circumference of the model at mid-span and with eight pressure taps installed across the leeward generator. The spanwise variation in base pressure is an effective indicator of the flow state in the TrBL regime (Zan and Matsuda, 2002). A hot-film anemometer was also inserted into the wake to record shedding frequencies. It was located 5.2 diameters downstream of each model and 0.4 diameters above each model centerline. All data were acquired at 4.8 kHz per channel.

2.2. The wind tunnel

The tests were carried out in the $0.38\,\text{m} \times 1.5\,\text{m}$ two-dimensional test section of the trisonic blowdown wind tunnel at the Aerodynamics Laboratory (Ohman et al., 1970). The facility is pressurized and was operated at a constant Mach number ($M < 0.4$) and variable pressure for a given run. The total pressure, hence Reynolds number, can vary by an order of magnitude at the same flow speed, with a maximum pressure of 11.5 bar. The floor and ceiling are ventilated, eliminating the requirement for blockage corrections.

[1]Following Zdravkovitch, K is used to denote 10^3 and M to denote 10^6, thus $20\,\text{K} = 20 \times 10^3$.