Wall Boundary Effects of Wire-Wrapped Cylinders at High Reynolds Number

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Introduction

THERE have been extensive studies on the effects of end conditions on the shedding frequency and spanwise coherency of smooth circular cylinders at low Reynolds numbers. These studies[1–4] have shown that the discontinuity in the Strouhal–Reynolds number curve of a finite aspect ratio cylinder has been attributed to end conditions, cylinder vibration, or nonparallel vortex shedding. In the absence of nonuniformity in the approaching flow and cylinder vibration, two-dimensional shedding can be obtained with minimizing the wall boundary effect. The end plates and a novel method proposed by Hammache and Gharib[5] are among methods used to control the wall boundary effects.

If the aspect ratio is higher than 300, experiments have shown that the discontinuity in the Strouhal–Reynolds number curve is mostly the result of nonparallel vortex shedding. Williamson[6] has shown that the curve can be made completely continuous if the Strouhal number is divided by $\cos\theta$, where θ is the oblique shedding angle. Further studies by Williamson[7,8] have shown the direct influence of the end conditions on the shedding frequency even for cylinders with large aspect ratios.

At high Reynolds numbers, studies by Szepessy and Bearman[9] have shown that, except for an aspect ratio of unity, the shedding across the span of a cylinder is not in phase.

The problem of oblique shedding of circular cylinders with finite aspect ratios and the effects of end conditions as they relate to dislocations and cellular shedding are not fully explored. The present investigation is focused on whether the wire-wrapping approach can be used to control the end wall boundary effect for cylinders with low aspect ratio, to promote parallel vortex shedding from these cylinders.

Experimental Procedure and Techniques

All experiments were performed in the open-circuit blower wind tunnel of the Mechanical and Aerospace Engineering Department at California State University, Long Beach. The wind tunnel is

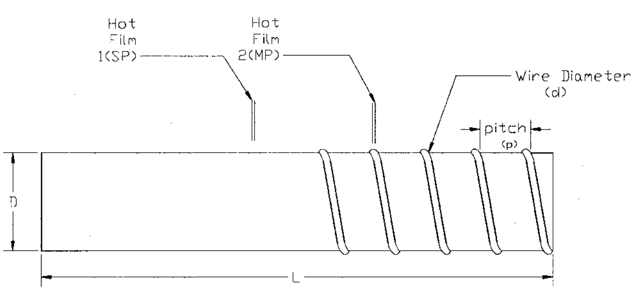

Fig. 1 Wire-wrapped cylinder.

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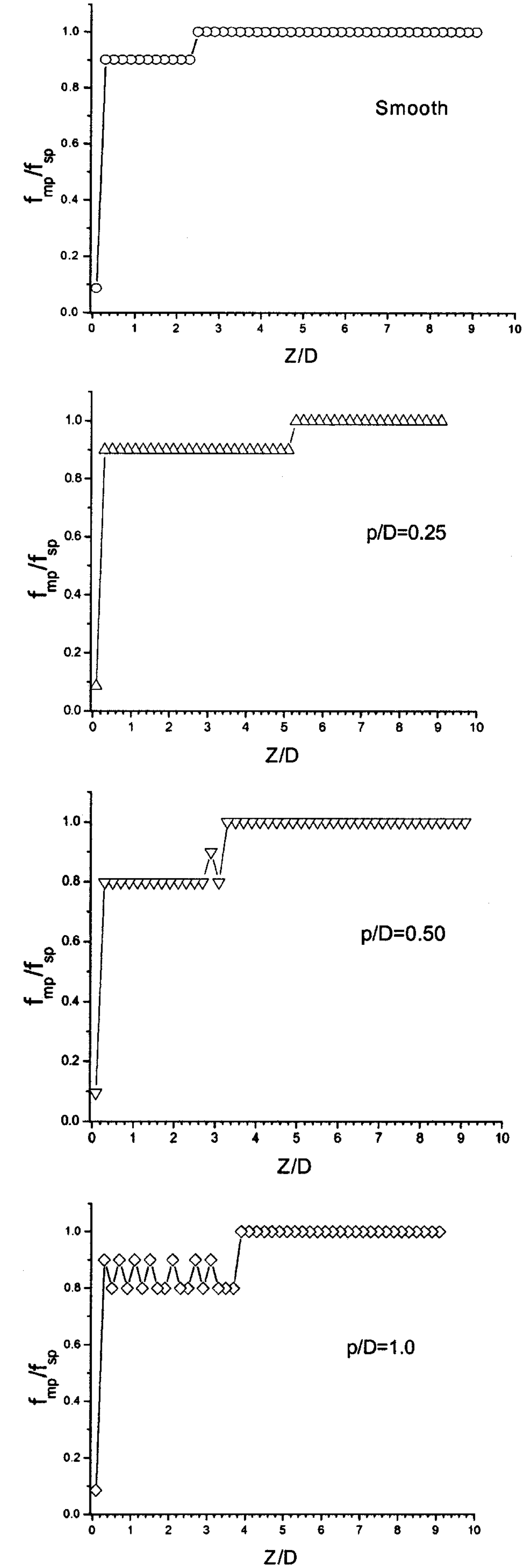

Fig. 2 Axial variation of the normalized shedding frequency for the smooth and wire-wrapped cylinders.

composed of a centrifugal fan, a wide-angle diffuser, a settling chamber containing the flow conditioners, a three-dimensional 6:1 contraction, and a working area. The working area has a cross-sectional dimension of 38.1 × 14.5 cm and is 213 cm long. The freestream mean velocity can be changed from 0.5 to 30 m/s, and the variation in the freestream mean velocity between 1 and 30 m/s is less than 0.2%.

Four smooth stainless-steel cylinders of 2.54 cm diameter and 38.1 cm in length were used in the experiments. Three of the cylinders were wire wrapped with a 0.127-cm-diam stainless-steel wire. The wire wrapping was performed over 15-cm length from the end of each cylinder (Fig. 1). The ratio of wire diameter to the cylinder diameter d/D was 0.05, and the ratios of wire pitch spacing to the cylinder diameter p/D were 0.25, 0.5, and 1.0.

Each cylinder is spanned the width of the test section at the midsection of the working area. The blockage and aspect ratio were 17 and 15%, respectively. Results were not corrected for the blockage effect.

Experiments were performed for the freestream mean velocity of 30 m/s, which corresponds to an approximate Reynolds number of 4.35×10^4, based on the smooth cylinder diameter.

Measurements of the shedding frequencies were obtained using two TSI hot-film sensors Model 1201-20. The hot-film sensors were connected to two channels of TSI IFA 100 intelligent flow analyzers.

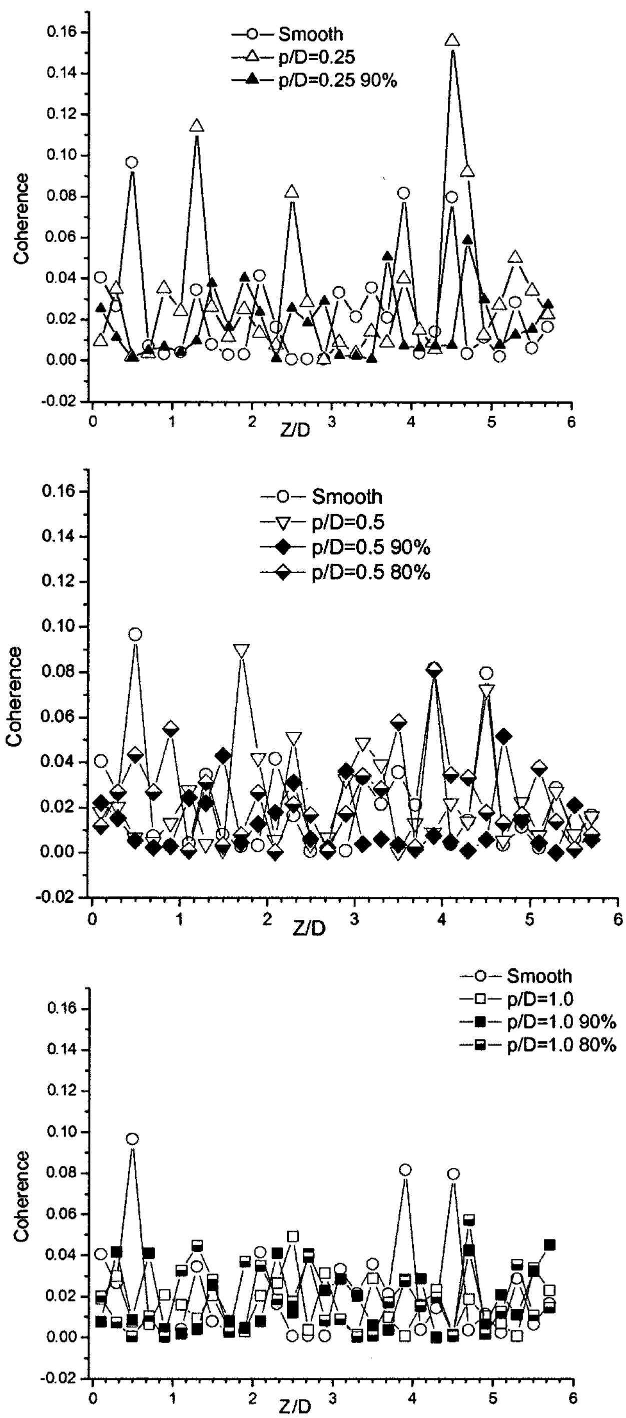

Fig. 3 Axial variation of the coherence of the smooth and wire-wrapped cylinders.

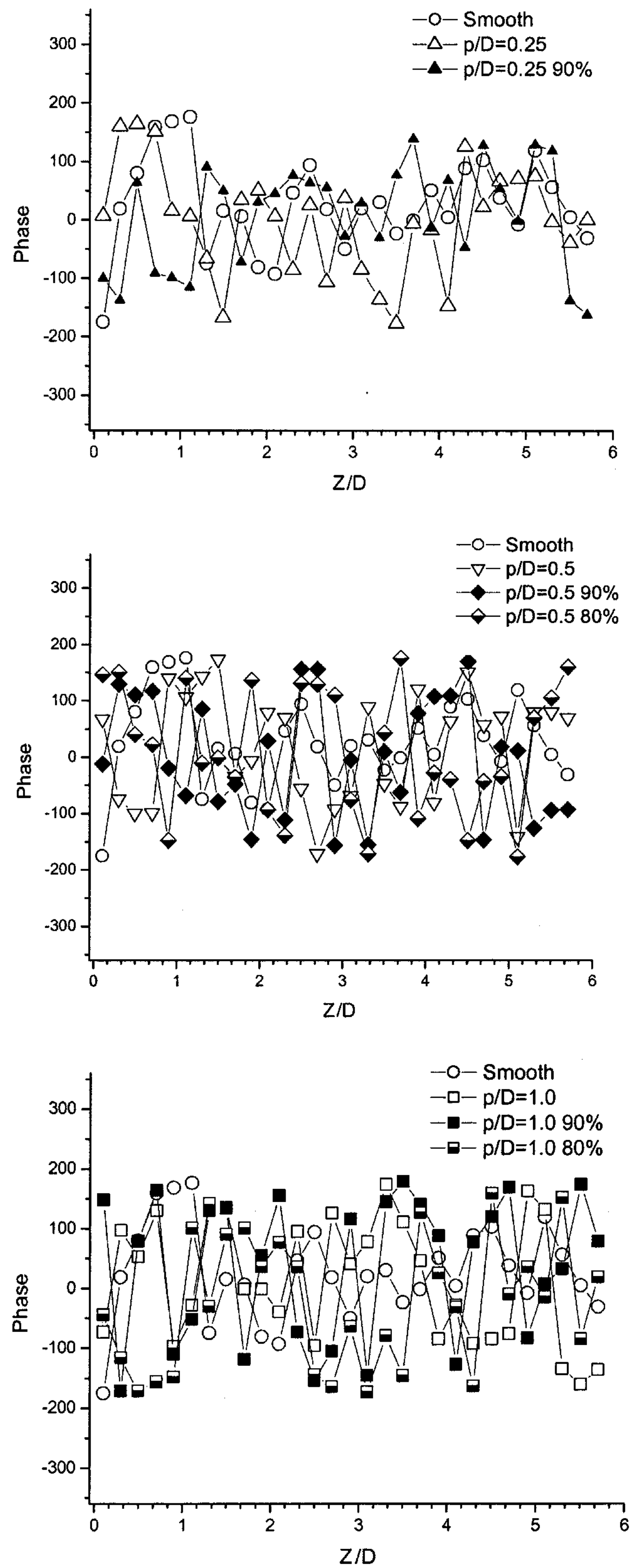

Fig. 4 Axial variation of the phase angle of the smooth and wire-wrapped cylinders.

The hot films were placed at approximately three cylinder diameters downstream and one cylinder diameter above its centerline in a horizontal plane. The position of the first hot film [stationary probe (SP)] was near the midsection of the cylinders and remained stationary, whereas the second sensor [moving probe (MP)] was moved in the spanwise direction toward the wind-tunnel wall in increments of 0.51 cm.

The signals from the hot films were digitized by a Metra-Byte DAS-20 analog-to-digital converter, connected to a Pentium-based microcomputer. At each location, 50 records per channel of data, where each record consists of 2048 samples, are digitized at a sample rate of 6000 samples/s and then analyzed using standard software.

Results and Discussion

Figure 2 shows spanwise variation of the normalized shedding frequency. The shedding frequencies are obtained from the spectra of axial turbulent velocity. The normalized shedding frequency is obtained by dividing the shedding frequency from the MP at each position by the shedding frequency of the SP.

For the smooth cylinder, the shedding frequency of MP drops to 90% of the shedding frequency of SP at $Z/D = 2.4$ and stays constant until at $Z/D = 0.2$, where it reduces to a near zero value near the wall. The decrease in the shedding frequency is due to the end wall effect.

For the wire-wrapped cylinder with $p/D = 0.25$, the drop in shedding frequency from the MP is the same as the corresponding drop for the smooth cylinder, except that it starts at $Z/D = 5$ and approaches zero near the end wall. When it is considered that the wire wrapping starts at $Z/D = 4.5$, the effect of wire wrapping is seen as increased oblique angle as compared to the smooth middle portion of the cylinder, and in this case, the oblique angle seems to be the same as the one caused by the end wall on the smooth cylinder.

For the wire-wrapped cylinders with $p/D = 0.5$ and 1.0, the shedding frequency from MP initially decreases to 80% of the shedding frequency from SP, at $Z/D = 3$ and 4, respectively. This is followed by a zigzag behavior, fluctuating between 80 and 90% values, until they approach zero near the wall. Here it seems that the wire wrapping divides the flow along the span of the cylinders into cells of different frequencies. Those affected by the wire wrapping have a higher oblique angle and, thus, a lower frequency, and those in between, which are not affected, have a lower oblique angle, and thus, a higher frequency.

Figures 3 and 4 show spanwise variations of coherence and phase angle between the two probes. For all cases, coherency is low at almost all of the spanwise locations, except for a few locations where there are slight increases in the coherency.

The phase angle changes along the span for all cylinders and the maximum shifts in the phase angles are from -180 to 150 deg.

Conclusions

The present limited experimental studies indicate that, for a finite aspect ratio cylinder, similar to the observation of Szepessy and Bearman,[9] there is phase angle variation along the span of the cylinder, and in our case, the end wall effect is observed at $Z/D \leq 2.4$. The effects of wire wrapping is seen as controlling the shedding angle, reducing the shedding frequency with increasing oblique angle. The oblique angle can be changed with changes in the pitch spacing. Different pitch spacings have different helix angles; thus, it can be concluded that an imposed helix angle maybe a viable option in controlling the flow angle along a cylinder.

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Oscillating Flows in a Model Pulse Detonation Engine Inlet

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Introduction

MULTITUBE detonation devices connected to a common inlet provide a promising configuration for a pulse detonation engines (PDE) as a design that allows for the generation of continuous thrust by initiating the detonation and recharging of the detonation ducts at controlled frequencies.[1–4] However, such configurations raise the issues of inlet-combustion chamber interactions resulting in unsteady inlet flowfields. The exit plane of the inlet experiences nonuniform pressure fields arising from the operation of the intake valves on the PDE detonation tubes. Backpressure induced by cyclic operation of the detonation tubes might affect the inlet operation including the potential of hammershock and inlet-unstart. A single inlet acting as a plenum for multiple detonation tubes reduces the effect of backpressure on the inlet flowfield allowing for flow transfer from the blocked channels to the open ones.

The unsteady interactions between the combustion chamber and supercritical inlets have been studied mainly on ramjets' inlets, and, in most cases, the exit plane pressure has been simulated by spatially uniform pressures oscillating only in time.[5] Previous theoretical studies[6] indicated that during the transient flow at the inlet exit produced by the valving system of a stack of detonation tubes the time available for the transfer of air between adjacent tubes is $\mathcal{O}(10\ \mu s)$, which is significantly shorter than the time required to form the hammershock, $\mathcal{O}(10\ ms)$. Thus, the concept of a plenum inlet supplying air to multiple tubes has the potential to become a practical solution for the inlet of a PDE. Analyses of diffuser flows displaying self-excited fluctuations have shown that the bulk of the

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