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Modification of the Karman-Vortex Street in the Freestream

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Nomenclature

c	= chord of thin flat plate
d	= diameter of cylinder
E	= plate eccentricity with respect to cylinder
h	= gap between cylinder and adjacent plate
t	= flat-plate thickness
U	= freestream velocity
$U'_\infty / \bar{U}_\infty$	= freestream turbulence intensity

Introduction

OVER the past 20 years, the observation and study of "coherent structures" in turbulent shear flows (see, for example, Ref. 1) has raised the interesting possibility of turbulence control through alteration of such structures.[2] One method of providing such control is through the use of control vortices produced by embedded fixed bodies.[3] An example of the obvious success of such an approach, which is of particular interest in this Note, is Ref. 4, where a transverse cylinder mounted parallel to the wall and normal to the flow was employed to shed a Karman-vortex street which, in spite of the attendant cylinder momentum deficit, managed to "excite" or "energize" the turbulence and provide separation control/delay. Obviously, multiple as well as single bodies can be used for the production of such "control flows."[5]

The present study arose from three previous observations: 1) most of the fluctuating vorticity in a turbulent boundary layer is biased by and, hence, has the same sign as the mean velocity; 2) the influence of a nearby wall upon the Karman shedding of a circular cylinder is to suppress the portion of the street which emanates from the wall vicinity[6-13]; and 3) a collision of two shear layers of opposite sense forced to come into contact results in "pair annihilation" of the vortical layers.[11-13] The usual effect of the second observation would be to augment the first; i.e., for a transverse cylinder near a wall the shed vorticity has the same sign as the mean vorticity in the boundary layer. If the shed vorticity was of the opposite sense to that of the mean velocity, it could possibly be used as a control to diminish the vorticity within the boundary layer. The reason for producing vorticity of opposite sign is given in Ref. 14: "The only means of decay or loss of vorticity is by cross-diffusion and annihilation of vorticity of opposite signs." The purpose of this Note is to document that such single-signed Karman streets can be produced in the freestream with a relatively small flat plate (as opposed to the extensive surface employed in previous works) combined with a transverse cylinder.

Apparatus and Tunnel Conditions

Experimental work was conducted in the 15-in. Low-Turbulence Wind Tunnel of the Viscous Flow Branch, High-Speed Aerodynamics Division, NASA Langley Research Center. This facility operates in an open-loop mode and is capable of producing a maximum flow velocity of approximately 50 m/s.

The test section of this facility has a total length of 274 cm and a nominal 38.1 cm square cross section. The freestream turbulence intensity level was $U'_\infty / \bar{U}_\infty \simeq 0.03\%$.

The tests consisted of placing a cylinder halfway between the floor and ceiling of the tunnel, across the span of the tunnel, and normal to the incoming flow. A vertical smoke wire was positioned 8 cm upstream of the cylinder. This smoke wire consisted of a very small-diameter metallic wire that could be drawn through an oil reservoir in order to coat it with a number of evenly spaced, very small drops of oil. When a sufficient current is applied to the wire the oil vaporizes and a streakline is produced for each drop of oil (for an in-depth description, see Ref. 15). Instantaneous photographs of the streakline patterns downstream of the cylinder were acquired by use of a high-intensity strobe light/high-speed camera arrangement.

A thin plate was then stretched across the span of the tunnel in the vicinity of the cylinder. In order to minimize resonant vibrations of the thin plate, an aluminum girder framework was constructed around the tunnel to hold the plate in tension. This framework was adjustable so that the angle of attack of the plate could be zeroed, and its relative position with respect to the cylinder could be changed.

Results and Discussion

The geometrical dimensions of the cylinder and adjacent plate were varied over an extensive parameter space (see Fig. 1). The cylinder diameter was varied from 3.175 to 6.350 mm. The adjacent flat plate had a chord length that ranged from 12.7 to 25.4 mm and a thickness ranging from 0.076 to 0.965 mm. The vertical spacing between the cylinder and the adjacent plate was varied from 1.600 to 3.912 mm. The center of the cylinder was traversed ± 4.7625 mm from the center of the flat plate. The optimum configuration shown in Figs. 2b and 3 consisted of a cylinder with a diameter of 4.7625 mm and a 0.254-mm-thick adjacent plate with a chord of 2.54 cm. The vertical spacing between the cylinder and the adjacent plate was 2.39 mm; with the cylinder centered below the plate.

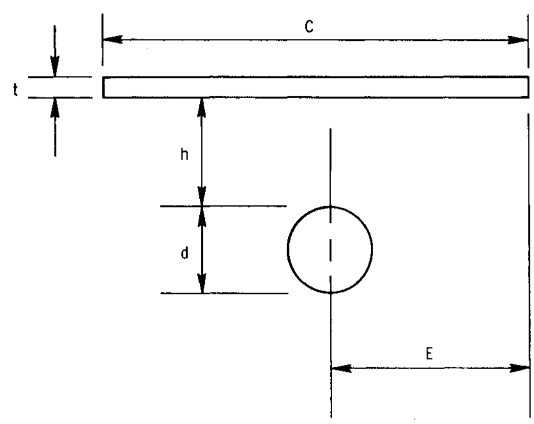

Fig. 1 Device geometry.

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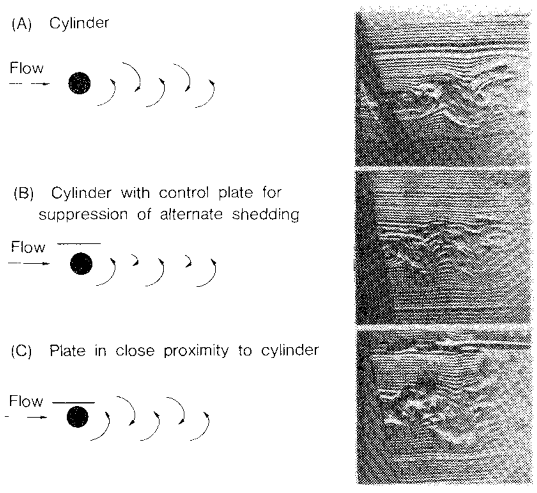

Fig. 2 Qualification of vortex suppression in freestream.

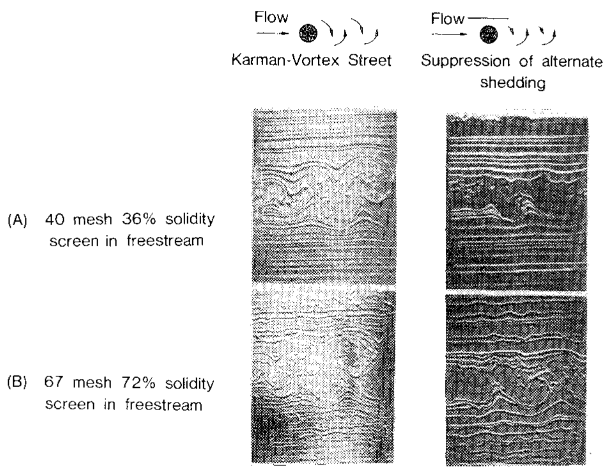

Fig. 3 Qualification of vortex suppression in a turbulent flowfield.

Figure 2 shows the results of the study in the freestream. The left side of the figure shows sketches of the proposed flow downstream of the device, and on the right side are the corresponding streakline patterns photographed in the tunnel. The cylinder alone produced the expected Karman-Vortex street. The cylinder/flat plate arrangement produced different patterns depending on the relative displacement between them. With the spacing of the optimum configuration there was evidence of suppression of alternate shedding of vorticity. When the components were too close, the streakline pattern corresponded to a single body. Not shown is the case where the components were too far apart—this simply produced separate patterns for each piece.

To answer the question of what happens to the suppression when the cylinder and adjacent plate are placed in a more turbulent flowfield (initial $U'_\infty / \bar{U} \simeq 0.03\%$), screens of varying mesh and percent solidity were placed 25.4 cm upstream of the cylinder. The entire process of photographing the vortex patterns downstream of various configurations was then repeated. Figure 3 shows typical results for two different screens: screen A was 40 mesh and had a solidity of 35%, screen B was 57 mesh and had a solidity of 72%. In all cases, the turbulence from the screens had little, if any, effect on the suppression mechanism of the cylinder/adjacent plate configuration.

Conclusions

The placement of a relatively short-chord, flow-aligned plate in the proximity of a cylinder allows the production of nearly "one-sided" or "one-signed" oscillatory transverse control vortices. The turbulence level of the incoming freestream has little effect on the suppression of the shed vorticity within the range considered in this study.

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Influence of Trailing-Edge Meshes on Skin Friction in Navier-Stokes Calculations

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Introduction

FROM recent investigations concerning numerical solutions of the Navier-Stokes equations for transonic turbulent flows over airfoils one can easily conclude that accurate

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