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On the Fluid Dynamics of Elliptic Cylinders

V.J. Modi,* E. Wiland† and A.K. Dikshit†
Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada
and
T. Yokomizo
Department of Mechanical Engineering, Kanto Gakuin University, Yokohama, Japan

ABSTRACT

The aerodynamics of a set of two-dimensional stationary cylinders with eccentricity (e) in the range of 0.44 - 0.98 is studied experimentally during the organized wake condition. Extensive results are presented on static pressure distribution, Strouhal number and near-wake geometry as functions of the angle of attack with the Reynolds number in the range of 3×10^4 - 10^5. The mean location of the separating shear layers is also obtained using the analytical Görtler series solution approach. Results suggest that the pressure loading as well as the wake characteristics are significantly affected by the cylinder eccentricity and attitude. In general, basing the Strouhal number on the projected width of the model appears to reduce its dependence on the angle of attack. An extensive scanning of the pressure field provides fundamental information concerning the vortex formation region, longitudinal and lateral spacing between the vortices, the classical wake geometry ratio, and vortex velocity. Extensive flow visualization study complements the wind tunnel test-program. The information should prove useful in the design of a variety of offshore structures, including oil-drilling platforms, energy conversion systems such as OTEC, marine risers, and submarine detection systems.

NOMENCLATURE

C_d : drag coefficient, pressure drag / (1/2) $\rho V_\infty^2 2ac$
C_ℓ : lift coefficient, lift/(1/2) $\rho V_\infty^2 2ac$
C_m : pitching moment coefficient, moment / (1/2) $\rho V_\infty^2 4a^2 c$
C_p : pressure coefficient, $(p - p_\infty)/(1/2)\ \rho V_\infty^2$
L : longitudinal spacing between vortices
N_r, R : Reynolds number, $\rho V_\infty 2a / \nu$
N_s : Strouhal number, $f h / V_\infty$ or $f 2b/V_\infty$
S : percentage circumference, measured clockwise from tap o
V_∞ : freestream velocity
W : lateral spacing between vortices
a : semimajor axis of model
b : semiminor axis of model
c : length of model
e : eccentricity, $(1 - b^2 / a^2)^{1/2}$
f : frequency of vortex formation, Strouhal frequency
h : projected height of model, $2(a^2 \sin^2\alpha + b^2 \cos^2 \alpha)^{1/2}$
p : mean static pressure
x, y : lateral and streamwise coordinates, respectively
w : transverse distance from centre of model
α : angle of attack
ρ : density of fluid
ν : fluid kinematic viscosity

*ISOPE Charter Member.

† Graduate research assistant.

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KEY WORDS: Pressure loading, Strouhal number, near-wake geometry, elliptic cylinders.

INTRODUCTION

The oscillations of aerodynamically bluff bodies, when exposed to a fluid stream, have been a subject of considerable investigation. Ever since the pioneering contribution by Strouhal (1878), who correlated the periodicity of the vortex shedding with the diameter of the circular cylinder and velocity of the fluid stream, there has been a continuous flow of important contributions resulting in a vast body of literature. This has been reviewed rather adequately by Rosenhead (1953), Willie (1960), Marris (1964), Morkovin (1964), Parkinson (1971), Cermak (1975), Welt (1988) and others. In general, the nature of the wind loading, vortex shedding frequency and wake geometry form three important parameters in an aeroelastic instability study. Determination of the corresponding information associated with a set of elliptic cylinders forms the subject of this paper.

Historically, in investigations aimed at fluid mechanics of bluff bodies, circular cylinder and flat plate geometries have served as two basic elements. The significance of elliptic geometry in such a study becomes apparent when one recognizes the fact that a circular cylinder, in yawed condition, presents an elliptic cross-section to the relative fluidstream. Furthermore, an elliptic section represents a more general configuration permitting realization of a wide range of geometrical shapes, from circular cylinder (e = 0) to flat plate (e = ∞), by a systematic variation of eccentricity. Thus an organized investigation of the elliptic geometry can yield not only useful information concerning wake-body interactions but also provide the fundamental fluid dynamic information pertaining to transition from boundary layer type to fixed separation condition. Interestingly, the elliptic geometry appears to be ideally suited for generating a family of axisymmetric bodies approaching symmetric control surfaces for hydrofoils and submersibles.

With this as background, the paper studies the aerodynamics of a family of two-dimensional, stationary elliptic cylinders (e = 0.44, 0.6, 0.8, 0.92, and 0.98) in the subcritical Reynolds number range of 3 x 10^4 - 10^5. The comprehensive project has four phases :

(a) Detailed study of the mean static pressure distribution and Strouhal number as affected by the cylinder eccentricity and angle