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An Experimental Investigation of the Characteristics of an Unsteady Wake

M. R. Hajj
Department of Engineering Science and Mechanics, Virginia Polytechnic Institute and State University
Blacksburg, Virginia, USA

R. W. Miksad*, R. S. Solis and E. J. Powers*
College of Engineering, University of Texas at Austin, Texas, USA

ABSTRACT

An experimental investigation is conducted to determine the effect of low-frequency mean flow unsteadiness on the characteristics of a plane wake. Complex demodulation and bispectral analysis techniques are used to obtain quantitative measurements of the modulation and coupling mechanisms generated by the mean flow unsteadiness. The results show that low-frequency mean flow unsteadiness increases the amplitude and phase modulation levels of the frequency components that correspond to the vortex street. A simple numerical example is presented to show that these modulation effects can be seen as variations in the spacings between the successive elements of the vortex street. The increase in modulation can also be seen as an outcome of an increase in the coupling level among the mode at the unsteadiness frequency, the fundamental frequency component, and its harmonics.

NOMENCLATURE

AM	:	computed amplitude modulation
$a(t)$	:	amplitude modulation
$B(f_i,f_j)$	:	auto-bispectrum
b_0	:	initial half-width of wake
$b^2(f_i,f_j)$	:	auto-bicoherence
$c(t)$	:	complex demodulate
ε	:	amplitude level of mean flow unsteadiness
f_m	:	frequency of mean flow unsteadiness
f_o	:	frequency of fundamental mode
PM	:	computed phase modulation
$p(t)$	:	phase modulation
U_{fs}	:	free stream velocity
U_o	:	mean free-stream velocity
$U(y)$	:	cross-stream shape function
$U(y,t)$	:	local mean velocity
$(u_{rms})_{max}$	:	maximum rms fluctuation
u	:	streamwise velocity fluctuation
v	:	cross-stream velocity fluctuations
X_{fi}	:	Complex Fourier transform with frequency f_i

INTRODUCTION

The spectral energy distribution of slender body wakes is an important factor in determining the magnitude of self-induced vibrations and drag and lift forces acting on the body that generates the wake and on other members placed downstream of that body. The basic dynamics of wakes, and in particular the characteristics of the flow separation and of the downstream vortex street under steady mean flow conditions, are now fairly understood. The vortex street is advected downstream at a frequency that is determined by the length scale of the wake, its half-width, and the free stream mean velocity. Under steady mean flow conditions, the vortex street is ordered and the vertical and horizontal separations between the vortices are fairly constant. In offshore applications, unsteadiness is a natural characteristic of the flow field and the effects of low-frequency mean flow variations on the vortex street have not been studied explicitly.

The objective of this paper is to examine the influence of low-frequency mean flow unsteadiness on an established vortex street. Quantitative measurements of the coupling mechanisms introduced by the unsteady component of the mean flow in both the time and frequency domains are obtained using complex demodulation and bispectral analysis techniques. Experimental measurements of the spectral energy distribution in the wake under steady and unsteady mean flow conditions are presented. In particular, the modulation effects of the mean flow unsteadiness on the vortex street and the coupling characteristics among the vortex street frequency component, its harmonics and the mean flow unsteadiness are discussed. An example is given in which the horizontal and vertical spacings between vortices forming a vortex street are modulated to clarify the modulation and coupling effects of mean flow unsteadiness.

EXPERIMENTAL SETUP AND DATA ANALYSIS

The experiments were conducted in an open return wind tunnel with the mean free-stream velocity, U_0, equal to 8.3 m/s. The wake is formed behind a flat plate that has an aerodynamically rounded leading edge with a tapered trailing edge. The thickness of the trailing edge is 0.050 cm and the chord length is 20 cm. In order to isolate the flow in the test section from pump noise, a sonic throat was installed downstream of the test section. The unsteady mean flow was generated by periodically varying the cross-sectional area of the sonic throat (Fig. 1). The Reynolds number based on U_0 and the initial half-width of the wake, b_0, were equal to 640. Under steady state conditions, the frequency of the dominant wake fluctuation associated with vortex street and usually referred to as fundamental mode, f_0, was 587 Hz. In order to reduce the "natural" variations of the vortex shedding phe-

*ISOPE Member.

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KEY WORDS: Unsteady wakes, wave modulation, bispectral analysis.