

Drag Reduction and Vibration Control of a Spar-Type Cylindrical Structure Through Boundary-Layer Control

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Abstract

At present, the oil and energy industry is actively considering alternative structural concepts such as spar type of floating oil platform for deep water oil exploration and production. A spar platform consists of a long, hollow circular cylinder and it is prone to vortex induced vibrations under the combined actions of ocean currents and waves. The present study focuses at a fundamental level on the use of Moving Surface Boundary-layer Control (MSBC) as applied to a spar type of cylindrical structure for drag reduction and suppression of vortex induced vibrations. Two small rotating elements are used to inject the momentum into the boundary-layer. Extensive wind tunnel tests yielded information regarding the surface pressure distribution, drag coefficient, Strouhal number and pressure fluctuations in the wake as affected by the rate of momentum injection, location of the rotating elements as well as symmetric and asymmetric momentum injection. The results clearly suggest that the vortex shedding frequency is increased (up to 22%) and the pressure fluctuations associated with the vortex shedding are diminished by as much as 60% in presence of the momentum injection. The drag coefficient is reduced by more than 80%. The investigation was complemented by a comprehensive flow visualization study which clearly demonstrated effectiveness of the momentum injection in disrupting the vortex shedding as well as narrowing of the wake.

LIST OF SYMBOLS

ACR	autocorrelation strength
C_D	drag coefficient, $F_D/(1/2)\rho U^2 D$
C_P	mean pressure coefficient, $(p_m - p_\infty)/(1/2)\rho U^2$
C_{PB}	mean pressure coefficient measured at the base of the cylinder (i.e. at $\theta = 180^\circ$)
F_D	mean drag force
D	diameter of the circular cylinder model
D/d	cylinder to rotating element diameter ratio
N	cylinder rotational speed, rpm
PSD	power spectral density
Re	Reynolds number, UD/ν
St	Strouhal number, $f_V D/U$
T	sampling interval

U	freestream wind speed
U_C	rotating cylinder surface speed, $\pi DN/60$
U_C/U	momentum injection parameter
d	rotating element diameter
f_V	frequency of vortex shedding
f_N	structure natural frequency
$p(t)$	pressure at any point in the flow, $p(t) = p_m + p'(t)$
p_m	mean pressure at any point in the flow, $p_m = \frac{1}{T} \int_0^T p(t) dt$
$p'(t)$	fluctuating component of the pressure at any point in the flow
p_∞	free stream pressure of air
t	time
x_m	streamwise location downstream from the base of the cylinder
β	angular location of the rotating element
θ	angular location of a pressure tap on the surface of the model
θ_{sep}	angle at which the flow separates from the surface of the model
ρ	density of air
ν	kinematic viscosity of air
λ_m/D	maximum wake width nondimensionalized with respect to the cylinder diameter
τ	time delay parameter for autocorrelation analysis

INTRODUCTION

Flow past bluff structures have direct engineering significance. Bluff body wakes are complex; they involve the interaction of three shear layers in the same problem, namely a boundary-layer, a separating shear layer, and a wake (Williamson, 1996). A wide variety of structures encountered in wind and ocean engineering practice are fluid dynamically bluff. At present the oil and energy industry is actively considering alternative structural concepts, such as spar type of floating oil platform.

Spar Type Cylindrical Structures

A spar platform consists of a hollow vertical cylinder which provides buoyancy to support facilities above the ocean surface. It possesses a high degree of stability, as the center of gravity is