LIFT ON AN OSCILLATING CYLINDER IN SMOOTH AND TURBULENT FLOWS

A thesis submitted by
Hugh Maurice Blackburn
B Eng (Mech)

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Department of Mechanical Engineering
Monash University

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Contents

ABSTRACT

Wind tunnel investigation of sectional lift forces acting on a circular cylinder in cross flows of varying turbulence intensity was carried out with the aim of extending the knowledge of lift at high Reynolds numbers and turbulence intensities. Reynolds numbers in the range 1.1×10^5 to 5×10^5 were employed in conjunction with grid-generated turbulence with longitudinal intensities up to 18% and integral length scales up to half the cylinder diameter. The cylinder had an aspect ratio of 4.5:1, a tunnel blockage of 10%, and mounted six sectional lift force transducers at axial spacings of 0.75 diameter. It could be held fixed or be forced to oscillate cross flow at amplitudes up to $\pm 3\%$ of diameter and frequencies from 10 Hz to 50 Hz, providing a range of reduced velocities between 3 and 6, independent of changes in Reynolds number.

Results indicated that addition of progressively higher intensity turbulence first brought about early transition to supercritical flow, followed by transcritical flow, with definite but broad Strouhal peaks in the lift spectra centred at $St \simeq 0.23$, and increased spanwise correlation of lift. Comparison with full scale results obtained at higher Reynolds numbers and similar turbulence intensities but greater turbulence length scale to diameter ratios showed that the wind tunnel results had higher standard deviations of sectional coefficients of lift, implying that turbulence length scale ratio is an important parameter in addition to intensity.

Imposition of cylinder motion produced additional lift which could be correlated with motion. In smooth subcritical flow, the variation of motion-correlated forces with reduced velocity was similar to previous experimental observations. Investigation of spanwise correlation of lift indicated that the observed increases in spanwise correlation above that for the fixed cylinder could be accounted for by motion-correlated forces, well correlated along the span. In turbulent transcritical flow, motion-correlated forces were comparatively much smaller and the variation with reduced velocity was dissimilar to the subcritical results.

STATEMENT OF ORIGINALITY

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text.

Hugh M. Blackburn

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NOMENCLATURE

Symbol	Quantity
B	Spectral bandwidth parameter
c	Damping force per unit length
C_a	Coefficient of added mass
C_d	Coefficient of drag
C_l	Coefficient of lift
C_{la}	Coefficient of lift correlated with cross flow acceleration
C_{li}	Coefficient of lift induced by buffeting
C_{lr}	Coefficient of residual lift
C_{lv}	Coefficient of lift correlated with cross flow velocity
C_p	Pressure coefficient
C_{pb}	Base pressure coefficient
D	Diameter
$E[\,]$	Expected value
f	Frequency
f_n	Natural frequency $\frac{1}{2\pi}\sqrt{k/m}$
f_r	Reduced frequency fD/U
g	Peak factor
$\Im$	Imaginary part
I_u	Longitudinal turbulence intensity σ_u/U
I_v	Transverse turbulence intensity σ_v/U
j	$\sqrt{-1}$
k	Stiffness per unit length
$\mathcal{K}_j$	Modal stiffness for jth vibration mode
K_a	Aerodynamic damping parameter
K_{a0}	Aerodynamic damping parameter in the limit $\alpha \to 0$
K_s	Mass-damping parameter $\zeta m/\rho D^2$
l	Lift force per unit length
L	Cylinder length
ΔL	Spanwise length of transducer
L_u^x	Longitudinal integral scale of turbulence
m	Mass per unit length
m_e	Equivalent mass per unit length
Ma	Mach number
$P(k)$	Timeseries of process P
p	Pressure
$\Re$	Real part
Re	Reynolds number UD/ν
$S_x(\,)$	One-sided autospectral density of quantity x
$S_{xy}(\,)$	One-sided cross-spectral density of quantities x and y

St	Strouhal number (value of f_r at a spectral peak)
Ta	Taylor parameter $I_u\,(L_u^x/D)^{-1/5}$
T	Sampling period of data collection
t	Time
U	Mean airspeed
U	Reduced velocity $U/\omega D$
V_r	Reduced velocity U/fD
u, v, w	Instantaneous fluctuating fluid velocities in the x, y and z directions
x	Along flow displacement
y	Cross flow displacement
$\dot{y}$	Cross flow velocity
$\ddot{y}$	Cross flow acceleration
z	Spanwise displacement
α	Dimensionless oscillation amplitude y/D
ϵ	Surface roughness length scale
ζ	Damping as a fraction of critical
Λ	Dimensionless correlation length $\Lambda = \int_0^\infty \rho_\lambda \, d\lambda$
Λ_L	Correlation length as a fraction of span $D\Lambda/L$
λ	Dimensionless spacing $\lvert z_1 - z_2 \rvert / D$
μ_x	Mean value of quantity x
ν	Kinematic viscosity
ρ	Density
ρ_{xy}	Correlation coefficient of quantities x and y
ρ_λ	Spanwise correlation function
σ_x^2	Variance of quantity x
τ	Time
Υ	Inverse wavelength of turbulence
ϕ	Phase angle
Ψ	Mode shape
ω	Angular frequency $2\pi f$

Abbreviations

AR	Aspect ratio
DFT	Discrete Fourier transform
FFT	Fast Fourier transform
FIR	Finite impulse response
FRF	Frequency response function
IIR	Infinite impulse response
IRF	Impulse response function
LSR	Length scale ratio L_u^x/D
PDF	Probability density function
PSD	Power spectral density
RMS	Root mean square
TR	Transmissibility