LONG SLENDER CYLINDERS IN AXIAL AND NEAR-AXIAL FLOW.

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ABSTRACT

An experimental investigation of axial and near-axial flow over long slender cylinders, which involved both flow visualisation and hot-wire anemometry, is detailed. The investigation of this type of flow was instigated by the current interest in towed underwater sonar arrays. The need to discriminate between background noise of mechanical origin and the flow-induced noise generated on a moving underwater sound-recording device has produced a requirement for a greater understanding of the larger scale, lower frequency, turbulent flow processes in the wake and the boundary layer of a cylinder in both axial and near-axial flow. Of particular interest are any regular periodic fluid-dynamic processes.

Thick axisymmetric boundary layers with the ratio of outer-layer length scale (the boundary-layer thickness δ) to cylinder radius a in the range $31 \lesssim \delta/a \lesssim 38$ and the corresponding ratio of cylinder radius to the inner-layer length scale (the viscous length ν/U_τ) in the range $22 \lesssim aU_\tau/\nu = a^+ \lesssim 41$ have been investigated. In accord with previous experimental results their mean-flow and turbulence properties are found to be strongly influenced by transverse curvature and to diverge significantly from those of flat-plate boundary layers. A characteristic feature of such thick axisymmetric layers is the occurrence of "spots" of low-speed fluid which are attributed to displacement of inner-layer fluid by large-scale turbulent cross-flows. A front of low-speed fluid which propagates radially across the boundary layer is identified as the primary large-scale, low-frequency, coherent structure within the boundary layer turbulence. A flow mechanism that describes the process by which these fronts are

formed from low-speed spots is formulated on the basis of the experimental evidence obtained.

The stripping of low-speed fluid from the cylinder surface by large-scale cross-flows within the turbulent boundary layer is seen as an additional vorticity- and turbulence-generating mechanism, which cannot occur in a flat-plate layer.

When the cylinder is yawed to the free-stream, an attached boundary layer persists over a small range of yaw angle, before flow separation occurs. In this range the boundary layer becomes extremely asymmetric, even at yaw angles less than 1°. The asymmetry and mean-flow properties of such layers have been investigated for yaw angles of 0.25° and 0.5° at several Reynolds numbers in the range $300 \leq Re_a \leq 600$.

At somewhat larger yaw angles, a new regime of regular vortex-shedding in near-axial flow has been identified. From the experimental results, an empirical relation for the vortex-shedding frequency (in terms of yaw angle, vortex-shedding angle, and a Reynolds number based on the component of free-stream velocity normal to the vortex axes) has been derived as an extension of the Roshko formula for the frequency of vortex shedding from cylinders with their axes normal to the flow.

The results presented advance the current understanding of the fundamental fluid mechanics of cylinders in axial and near-axial flow, and thereby have the potential to contribute to the advancement of the signal-processing techniques applied to towed underwater sonar arrays.

STATEMENT OF ORIGINALITY

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

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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LIST OF COMMONLY USED SYMBOLS

a	cylinder radius	
a^+	non-dimensional radius, $= aU_\tau/\nu$	
d	cylinder diameter	
f	vortex shedding frequency	
r	radial co-ordinate , $= a + y$	
l	cylinder length	
u	longitudinal velocity fluctuation	
u'	rms value of the u fluctuations	
$\langle u \rangle$	ensemble average of u fluctuations	
v	radial velocity fluctuation	
v'	rms value of the v fluctuations	
$\langle v \rangle$	ensemble average of v fluctuations	
x	streamwise coordinate	
y	radial coordinate measured from cylinder surface	
y^+	non-dimensional y, $= yU_\tau/\nu$	
F	frequency parameter	fd^2/ν
F	flatness factor (kurtosis)	
H	boundary layer shape factor	
N	ensemble size (of an ensemble average)	
Re_x	Reynolds Number	U_1x/ν
Re_d	Reynolds Number	U_1d/ν
Re_a	Reynolds Number	U_1a/ν

Re_n	Reynolds Number	$U_1 \sin\beta\, d/\nu$
S	skewness factor	
St	Strouhal Number	fd/U_1
St_n	Strouhal Number	$fd/U_1 \sin\beta$
U_1	free-stream velocity	
U	mean velocity in boundary layer U(y)	
U^+	$= U/U_\tau$	
U_τ	friction velocity $= (\tau_w/\rho)^{1/2}$	
α	shedding angle, between cylinder axis and vortex axis	
β	yaw angle between cylinder axis and flow direction	
δ	boundary layer thickness (=y where $U/U_1 = 0.99$)	
δ^*	boundary layer displacement thickness	
Δ	boundary layer displacement area	
θ	boundary layer momentum thickness	
Θ	boundary layer momentum defect area	
μ	absolute viscosity of fluid	
ρ	density of fluid	
ν	kinematic viscosity of fluid	
τ_w	wall shear stress $= \rho U_\tau^2$	
ϕ	angular coordinate (azimuth)	