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Interactions of boundary shear stress, secondary currents and velocity

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Abstract

This paper deals with the interaction of boundary shear stress, velocity distribution and secondary currents in open channel flows. A method for computing boundary shear stress and velocity distribution in steady, uniform and fully developed turbulent flows is developed by applying an order-of-magnitude analysis to the Reynolds equations. A simplified relationship between the wall-tangential and wall-normal terms in the Reynolds equation is hypothesized, then the Reynolds equations become solvable. This analysis suggests that the energy from the main flow is transported towards the nearest boundary to be dissipated through a minimum relative distance or normal distance of the boundary. The equations governing the boundary shear stress and Reynolds shear stress distributions are obtained, and the influence of wall-normal velocity on the streamwise velocity is assessed. It is found that the classical log-law is valid only when the wall-normal velocity is zero, the non-zero wall-normal velocity results in the derivation of measured streamwise velocity from the classical log-law. The derived equations are in good agreement with existing experimental data available in the literature.

Keywords: Boundary shear stress; Turbulent flows; Reynolds shear stress; Velocity profiles; Dip-phenomenon; Secondary currents

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Nomenclature

A	constant
A_b and A_w	area of bed and sidewall sub-region
b	width of channel bed
b_1	coefficient
c	constant
c_1	integration constant
D	characteristic length representing energy dissipation of boundary
g	gravitational acceleration
h	water depth
l_n	the normal distance to the boundary
l_b/D_b and l_w/D_w	relative distance to the bed and the sidewall
m	coefficient
n	empirical coefficients
p	coefficient
p_w and p_b	sidewall and bed perimeter
S	energy slope
u, v and w	mean velocities in x, y and z directions
u', v', z'	fluctuating velocity components
$\overline{u}_{*b}$ and $\overline{u}_{*w}$	mean bed and sidewall shear velocities
u_*	shear velocity
u_{*1}	global shear velocity [$=(gRS)^{0.5}$]
x	streamwise direction
y	wall-normal direction
y_o	parameter of boundary characteristics
y_{max}	location maximum velocity
z	wall-tangential direction
μ	dynamic viscosity
τ_{xy}	$\mu\partial u/\partial y - \rho\overline{u'v'}$
τ_{xz}	$\mu\partial u/\partial z - \rho\overline{u'w'}$
$\bar{\tau}_b$, $\bar{\tau}_w$	mean bed and sidewall shear stresses
$\bar{\tau}_b$	$\rho\overline{u}_{*b}^2$
$\bar{\tau}_w$	$\rho\overline{u}_{*w}^2$
Δ	typical boundary roughness height
α	coefficient
θ	angle of channel wall
κ	Karman constant (≈ 0.4)
v	kinematic viscosity
ξ	y/h
ρ	fluid density
τ_b	local boundary shear stress