THE RESPONSE OF WAVES TO AN OPPOSING WIND

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ABSTRACT

The results of a laboratory study of the response of waves to an opposing wind are presented. The study was conducted in a special purpose wind-wave flume which allowed mechanically generated waves to propagate in opposition to wind. The mechanically generated waves were created by a wedge wave maker for which an extensive set of measurements were performed to determine its transfer function. A wave follower which could hold pressure and velocity probes a fixed distance above the moving water surface was designed and constructed. Extensive evaluation experiments indicated that the wave follower tracked the water surface with little error in the frequency range of interest. The transfer functions of all intermediate devices in the pressure and velocity recording systems were determined and subsequently used to correct all pressure and velocity records. Measurements of the wave induced pressure at various heights above the waves-indicated that the pressure and water surface were 180° out of phase, consistent with the predictions of potential flow theory. Such a result indicates that there is no air-water energy flux due to normal stresses. Measurements of the velocity field above the waves indicated that the Reynolds stress term $-\rho\ \overline{u''u''}$ can cause waves to decay in an opposing wind. The magnitude of the decay is proportional to the wave slope squared and the term $(1 - U_\infty/C)$ squared. Hence, high frequency waves will decay far more rapidly than low frequency waves. Typical results indicate that low frequency ocean swell is almost uneffected by opposing winds whereas high frequency wind waves will be attenuated very rapidly.

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LIST OF SYMBOLS

Symbol	Definition	Dimension
a	wave amplitude	L
$\bar{A}$	mean of quantity A	-
$\tilde{A}$	wave-induced component of A	-
A'	turbulent component of A	-
A''	fluctuating component of A	-
C	phase speed	LT^{-1}
C_f	friction factor	-
C_g	group velocity	LT^{-1}
C_I	interfacial wave speed	LT^{-1}
d	water depth	L
D_j	coupling coefficient	-
$E(f,\theta)$	variance spectrum	L^2T
Ec	Eckart number	-
E_∞	saturation spectrum	L^2T
f	frequency	T^{-1}
f_N	Nyquist frequency	T^{-1}
$F(\underline{k})$	variance spectrum	L^4
g	gravitational acceleration	LT^{-2}
H	complex transfer function	-
i	complex operator = $\sqrt{-1}$	-
$\underline{k}$	wave number vector	L^{-1}
K	disk probe calibration constant	-
Lr	scale length ratio	-
n	model scale	-
N	complex frequency	radians
p	pressure	$ML^{-1}T^{-2}$
p_D	disk probe pressure	$ML^{-1}T^{-2}$

Symbol	Definition	Dimension
p_s	static pressure	$ML^{-1}T^{-2}$
p_{so}	free stream static pressure	$ML^{-1}T^{-2}$
p_t	total probe pressure	$ML^{-1}T^{-2}$
Pr	Prandtl number	-
Q	source term	L^4T^{-1}
Re	Reynolds number	-
Ri	Richardson number	-
Ro	Rossby number	-
R_s	radiation stress	$ML^{-1}T^{-2}$
$R_x(\tau)$	autocorrelation function	L^2
$R_{xy}(\tau)$	crosscorrelation function	L^2
s	Jeffrey's sheltering coefficient	-
S	source term	L^2
S_A	air-sea interaction source term	L^2
S_D	dissipation source term	L^2
S_N	wave-wave interaction source term	L^2
t	time	T
T	surface tension	$ML^{-1}T^{-2}$
T	temperature	degrees C
Tr	scale time ratio	-
u	instantaneous x velocity	LT^{-1}
u_c	surface drift current velocity	LT^{-1}
u_i	instantaneous velocity in i direction	LT^{-1}
$u_T(t)$	window function	-
u_*	shear velocity	LT^{-1}
U	mean wind velocity	LT^{-1}
U_a	wind velocity at height a	LT^{-1}
U_∞	mean wind velocity outside boundary layer	LT^{-1}

Symbol	Definition	Dimension
v	general velocity	LT^{-1}
V	volume	L^3
Vr	scale velocity ratio	-
w	instantaneous z velocity	LT^{-1}
x	horizontal cartesian coordinate	L
$x(t)$	input time series	-
y	horizontal cartesian coordinate	L
$y(t)$	output time series	-
z	vertical cartesian coordinate	L
z_c	height of critical layer	L
z_g	gradient height	L
z_o	roughness scale length	L
α	angle	degrees
α	power law exponent	-
$\gamma^2(f)$	coherence function	-
δ	boundary layer thickness	L
η	water surface elevation	L
θ	angle	degrees
κ	von Karman's constant	-
μ	coupling coefficient	-
μ	dynamic viscosity	$ML^{-1}T^{-1}$
ν	coupling coefficient	-
$\pi(k,\omega)$	atmospheric pressure spectrum	$M^2L^{-2}T^{-3}$
ρ_a	air density	ML^{-3}
ρ_w	water density	ML^{-3}
σ	normal stress	$ML^{-1}T^{-2}$
τ	shear stress	$ML^{-1}T^{-2}$
ϕ	phase angle	degrees

Symbol	Definition	Dimension
ϕ	velocity potential function	L
χ^2	chi-squared distribution	-
ψ	angle of hot film to fluid flow	degrees
ω	frequency	radians
ω_o	wave frequency in absence of current	radians

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