Wind-Effect on Wave Shape

Thomas Zdyrski [1] Falk Feddersen [2]

[1]Department of Physics
UC San Diego

[2]Scripps Institute of Oceanography
UC San Diego

18 Nov. 2018

Onshore (Meisenheimer 2016)

Offshore (Johnson n.d.)

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UC San Diego

- Growth rates found by Miles and Phillips
- Numerical simulations reveal air field
- Simulations often use static wave shape
- Phase-averaged quantities
- How does wind affect wave shape?

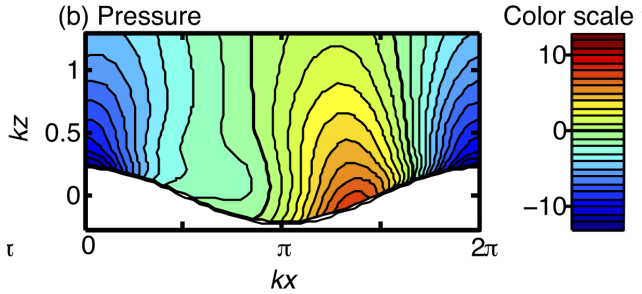


Figure 1: LES simulation of pressure above a wave (Hara and Sullivan 2015).

- Experimental measurements of wave shape
  - Leykin et al. (1995)
  - Feddersen and Veron (2005)
- Effects of wave shape:
  - beach morphodynamics
  - microwave backscatter wave measurements
- Phase angle β and amplitude A_2 (deep water):

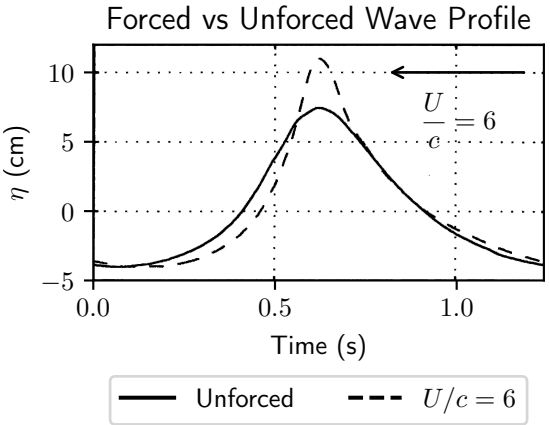


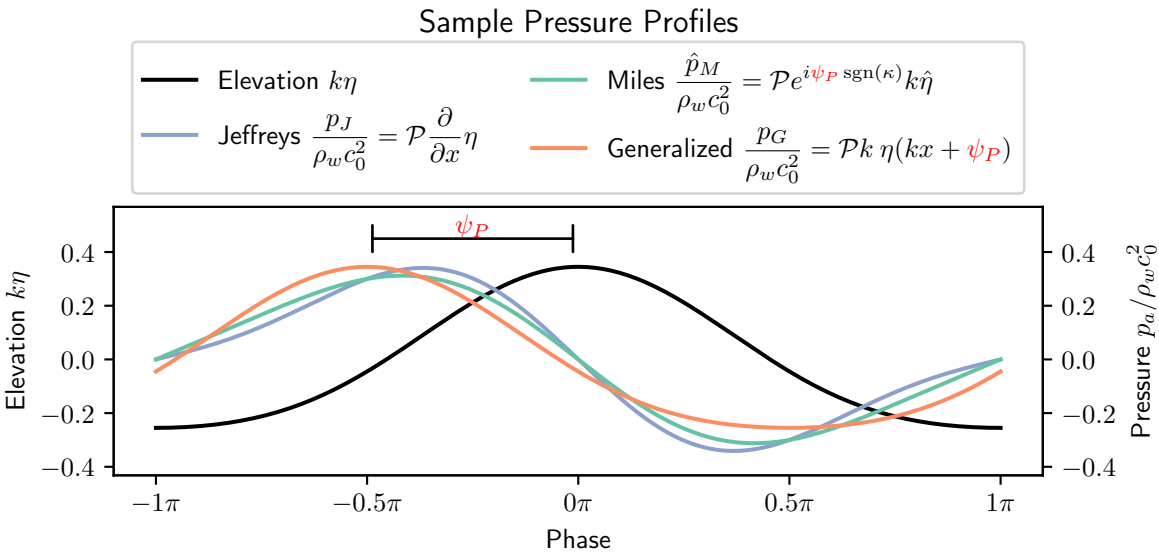
Figure 2: $kh = 0.85$, $ak = 0.21$. Reproduced from Feddersen and Veron (2005).

$$\eta k = (ak)\sin k(x - ct) + \frac{1}{2}(ak)^2 A_2 \sin[2k(x - ct) + \beta]$$

- Incompressible, irrotational, inviscid, 2D flow
- $\eta(x,t)$ and $\boldsymbol{\nabla}\phi(x,t,z) = \vec{u}$
- Pressure enters Bernoulli equation

$$0 = g\eta + \left.\frac{\partial \phi}{\partial t}\right|_{z=\eta} + \frac{1}{2}\left.\left(\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial z}\right)^2\right)\right|_{z=\eta} + \left.\frac{p_a}{\rho_w}\right|_{z=\eta}$$

- Stokes waves $p_a = 0$; we need $p_a \neq 0$
- Need to specify pressure distribution


Sample Pressure Profiles
Elevation $k\eta$
Jeffreys $\frac{p_J}{\rho_w c_0^2} = \mathcal{P}\frac{\partial}{\partial x}\eta$
Miles $\frac{\hat{p}_M}{\rho_w c_0^2} = \mathcal{P}e^{i\psi_P \operatorname{sgn}(\kappa)}k\hat{\eta}$
Generalized $\frac{p_G}{\rho_w c_0^2} = \mathcal{P}k\,\eta(kx + \psi_P)$
ψ_P
Elevation $k\eta$
Pressure $p_a/\rho_w c_0^2$
0.4
0.2
0.0
−0.2
−0.4
-1π
-0.5π
0π
0.5π
1π
Phase

- Four free, nondimensional parameters:
  - ak (amplitude)
  - kh (depth)
  - $\mathcal{P} \propto \gamma/f$ (pressure magnitude)
  - ψ_P (wind phase)

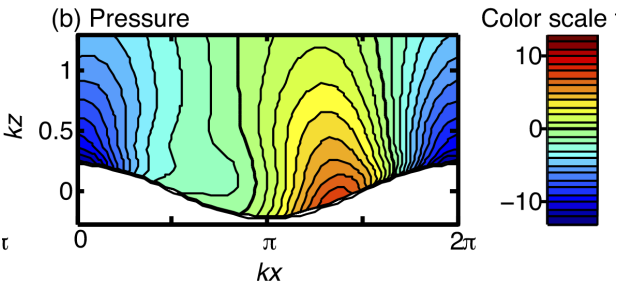


Figure 3: Hara and Sullivan (2015).

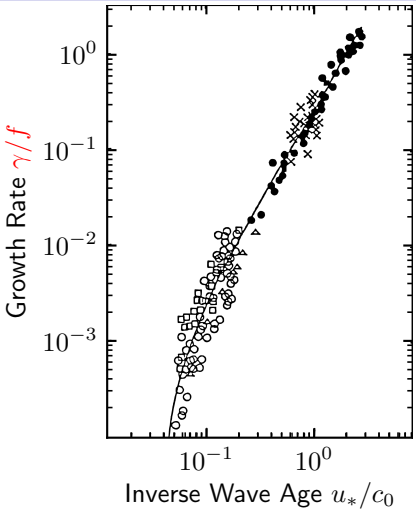
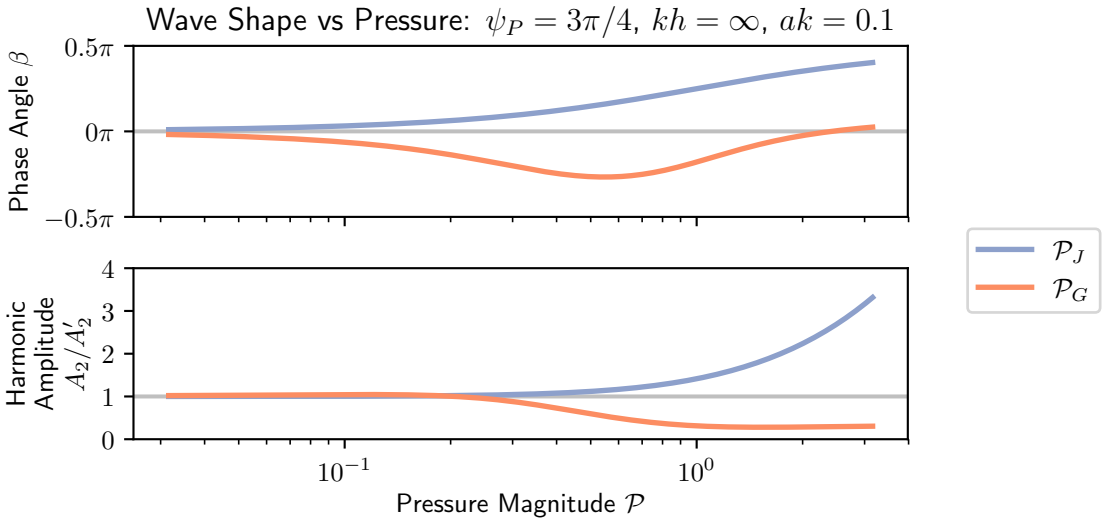
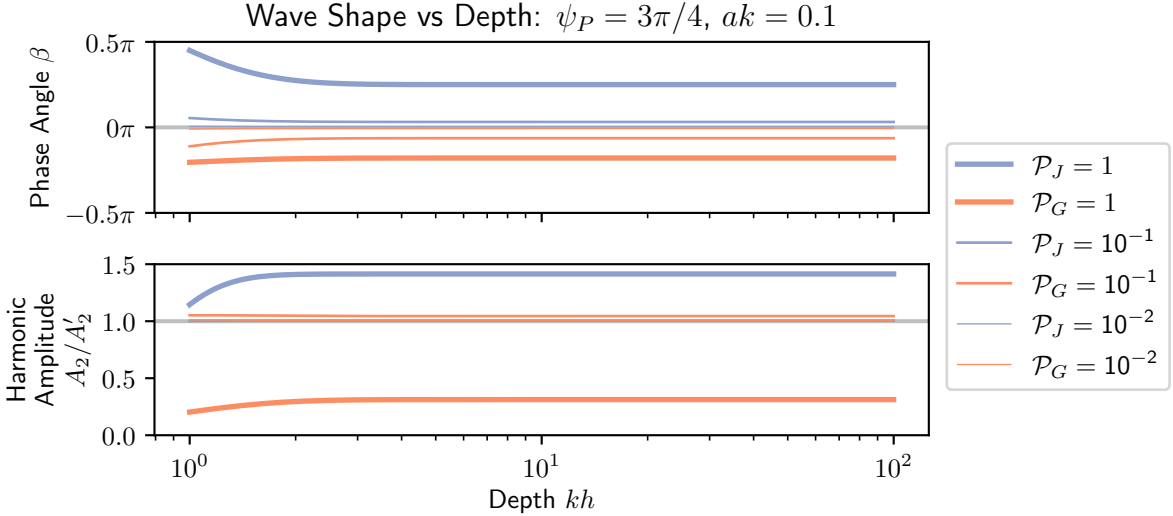


Figure 4: Reproduced from Banner and Song (2002)

- Finite depth $kh \geq 1$
- Method of Multiple Scales
  - $\eta = (ak)\eta_1 + (ak)^2\eta_2 + \ldots$
  - $t_0 = t$, $t_1 = (ak)t$, $t_2 = (ak)^2 t$, $\ldots$
- Miles gives $\beta = 0$ and $A_2 = 1$
- Inconsistent with experiment (Leykin et al. 1995)


Wave Shape vs Pressure: $\psi_P = 3\pi/4$, $kh = \infty$, $ak = 0.1$
Phase Angle β
0.5π
0π
-0.5π
Harmonic Amplitude A_2/A_2'
4
3
2
1
0
10^{-1}
10^{0}
Pressure Magnitude $\mathcal{P}$
$\mathcal{P}_J$
$\mathcal{P}_G$


Wave Shape vs Depth: $\psi_P = 3\pi/4$, $ak = 0.1$
Phase Angle β
0.5π
0π
-0.5π
Harmonic Amplitude A_2/A_2'
1.5
1.0
0.5
0.0
10^0
10^1
10^2
Depth kh
$\mathcal{P}_J = 1$
$\mathcal{P}_G = 1$
$\mathcal{P}_J = 10^{-1}$
$\mathcal{P}_G = 10^{-1}$
$\mathcal{P}_J = 10^{-2}$
$\mathcal{P}_G = 10^{-2}$

- Used Method of Multiple Scales to couple surface pressure to Stokes wave
- Wind can change wave shape: β and A_2
- Different pressure types yield different β and A_2
  - Miles-type gives $\beta = 0$
  - Experiments show $\beta \neq 0$

Future Work:

- Shallow water $kh \ll 1$
- Consider more complex pressure forcings

Acknowledgements

Special Thanks To:

- Feddersen Team
- Giddings Team

Banner, Michael L and Jin-Bao Song (2002). "On determining the onset and strength of breaking for deep water waves. Part II: Influence of wind forcing and surface shear". In: *Journal of physical oceanography* 32.9, pp. 2559–2570.

Feddersen, Falk and Fabrice Veron (2005). "Wind effects on shoaling wave shape". In: *Journal of physical oceanography* 35.7, pp. 1223–1228.

Hara, Tetsu and Peter P Sullivan (2015). "Wave boundary layer turbulence over surface waves in a strongly forced condition". In: *Journal of Physical Oceanography* 45.3, pp. 868–883.

Johnson, Mark A (n.d.). *Offshore wind and breaking wave, Hawaii*. Mark A Johnson Photographer.

Leykin, IA et al. (1995). "Asymmetry of wind waves studied in a laboratory tank". In: *Nonlinear Processes in Geophysics* 2.3/4, pp. 280–289.

Meisenheimer, Aaron (Nov. 26, 2016). *Jax Pier Surf Report - THANKSGIVING AM*. Void Magazine.

Miles, John W (1957). "On the generation of surface waves by shear flows". In: *Journal of Fluid Mechanics* 3.2, pp. 185–204.