Physics of Surfing
Energetics of a Surfer

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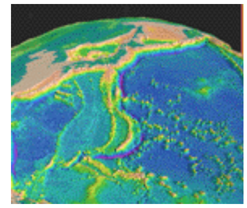
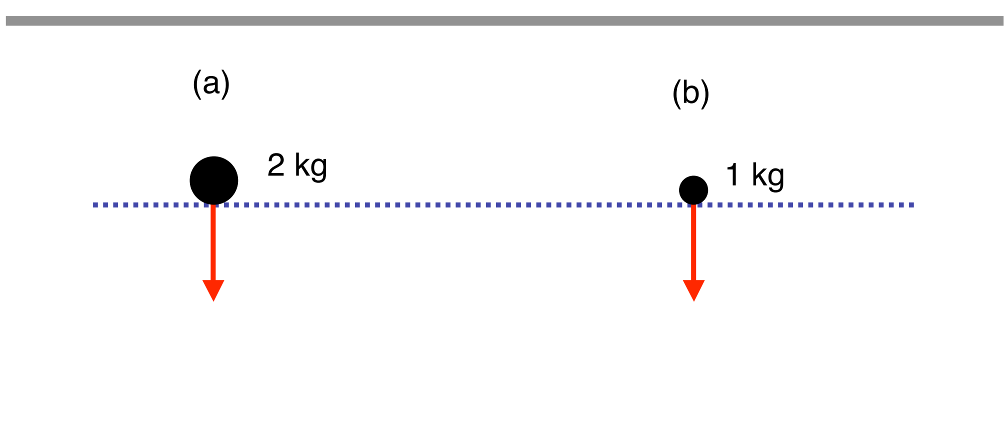
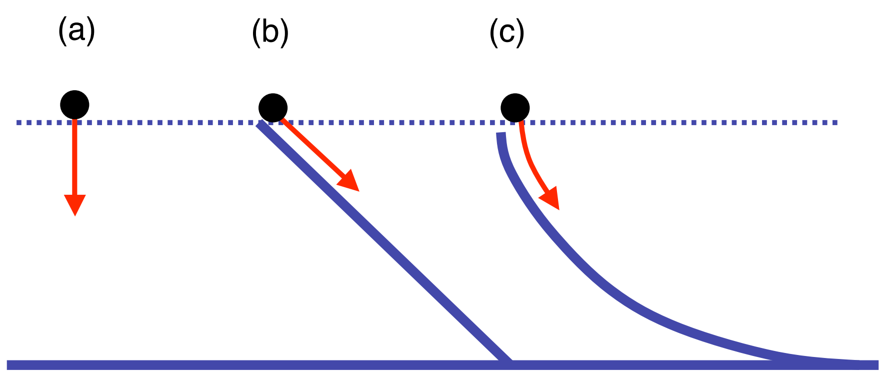


- Four styles of surfing
- Waves
  - Big swell coming? (storms)
  - What makes "sets"? (dispersion)
  - Why is Blacks Beach good for surfing? (refraction)
- Riding waves
  - "catching" the wave (speed)
  - "dropping-in" (energy conservation)
  - "tube riding" (tapping wave energy)
  - "need more speed" (surfboard drag)

Which ball is going faster when it reaches the bottom?



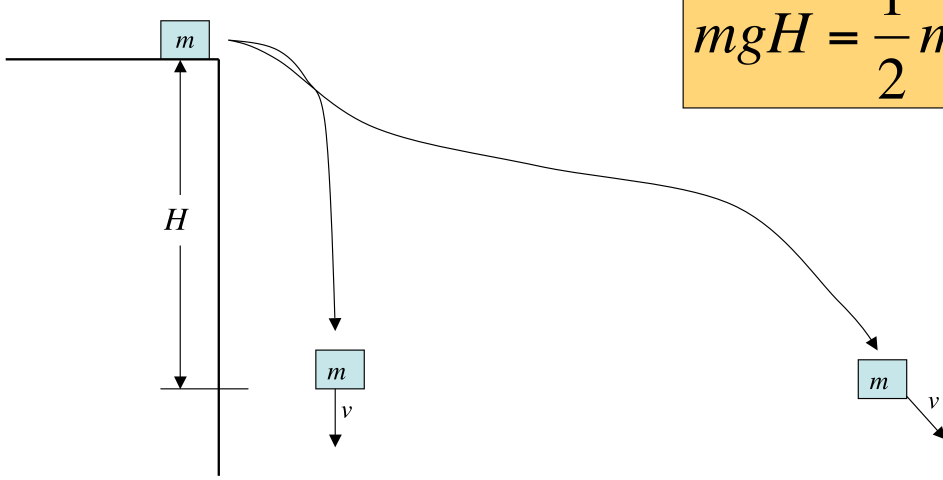
Which ball is going faster when it reaches the bottom?



conservation of energy

(assume no friction)

kinetic energy + potential energy = constant

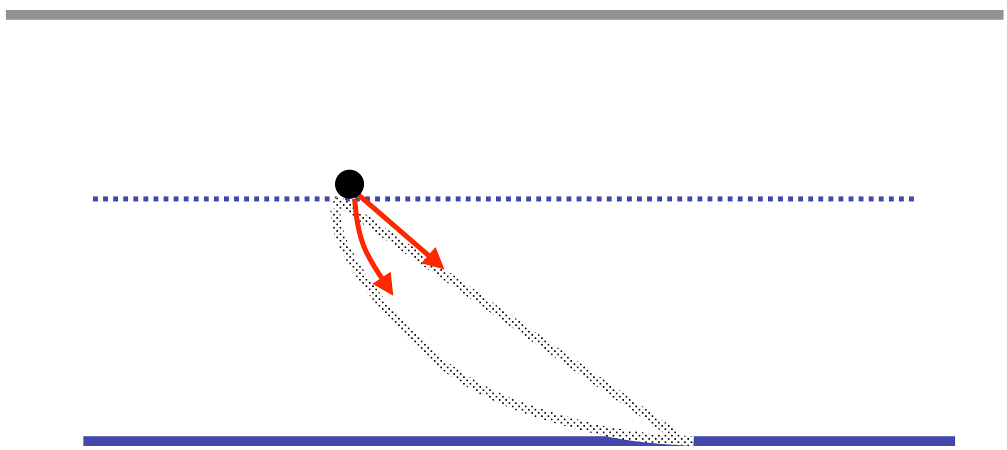


$$mgH = \frac{1}{2}mv^2$$

optimal skateboard ramp

(The brachistochrone problem)

What is the best ramp shape for the minimum time down?



longboard wave

SIO Pier, La Jolla,
height = 1.5 m

fun wave

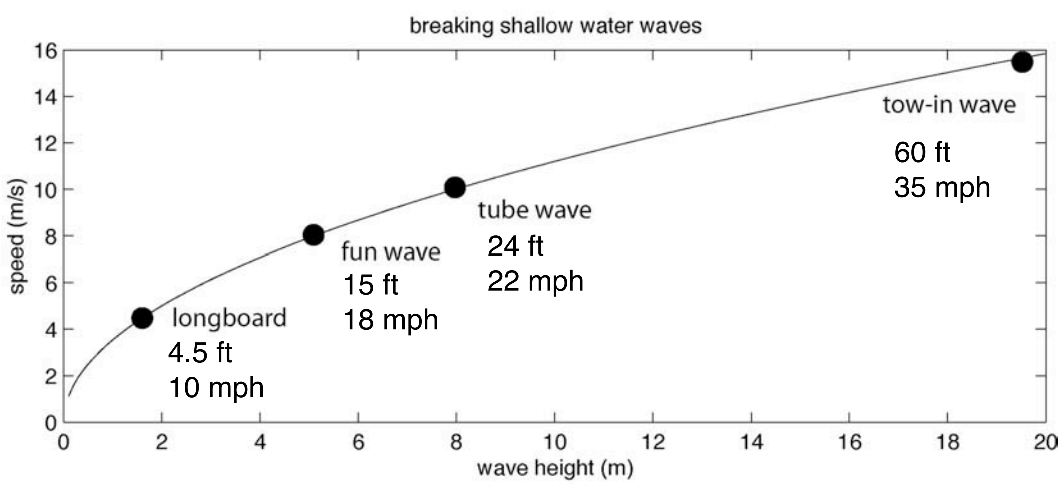
Blacks, La Jolla,
height = 5 m

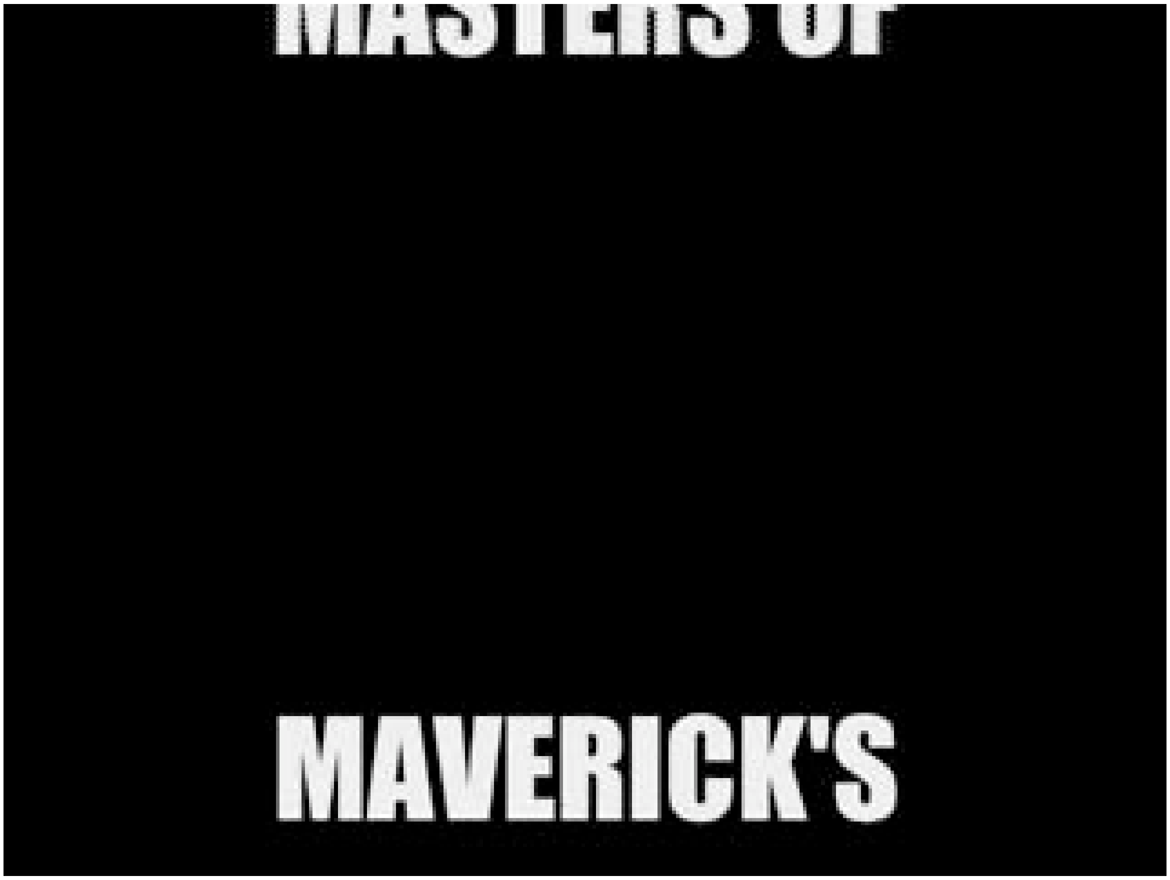
tube wave

Pipeline, Hawaii
height = 8 m

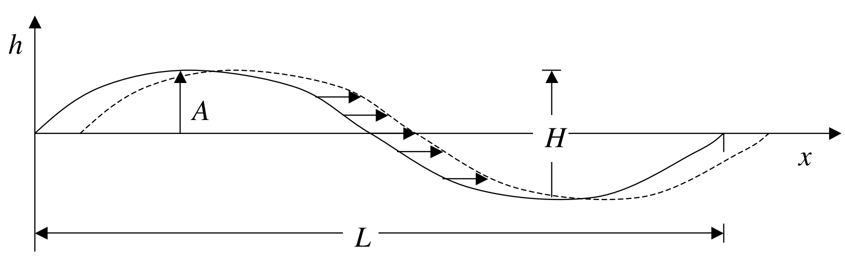
tow-in wave

Mavericks, California
height = 23 m





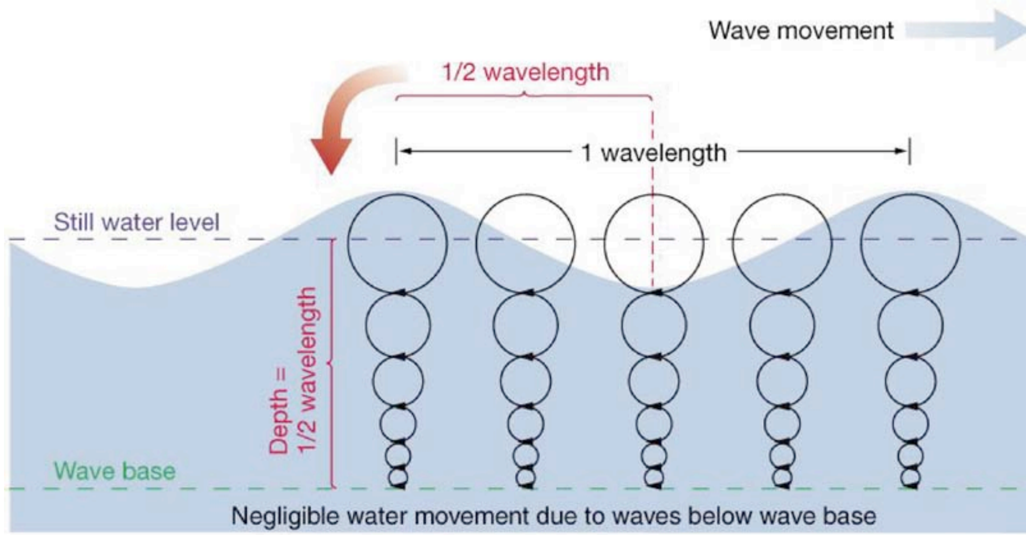
wave characteristics



$$h(x,t) = A\sin\left(\frac{2\pi x}{L} - \frac{2\pi t}{T}\right)$$

L - wavelength
A - amplitude
H - height
T - period (5 - 18 s)

$$c = \frac{L}{T}$$ phase velocity



Airy solution

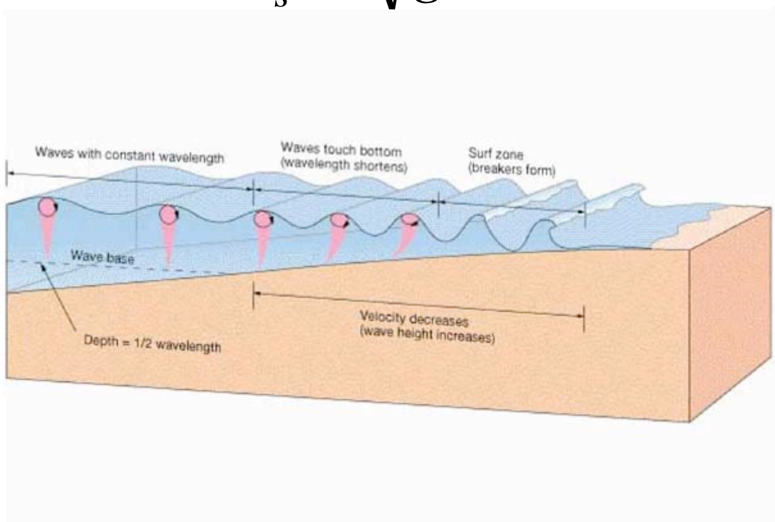
$$c(d) = \left[\frac{gL}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)\right]^{1/2}$$

L - wavelength
g - acc. gravity
d - ocean depth

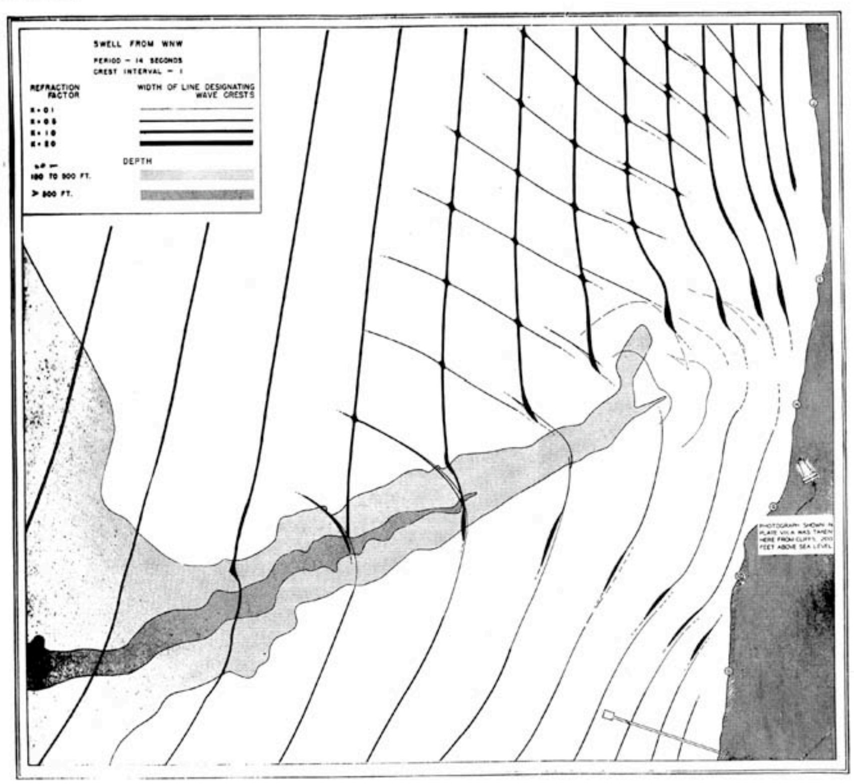
deep water waves	shallow water waves
$d >> L/2$	$d << L/2$
$c_d = \sqrt{\frac{gL}{2\pi}}$	$c_s = \sqrt{gd}$

shallow water waves

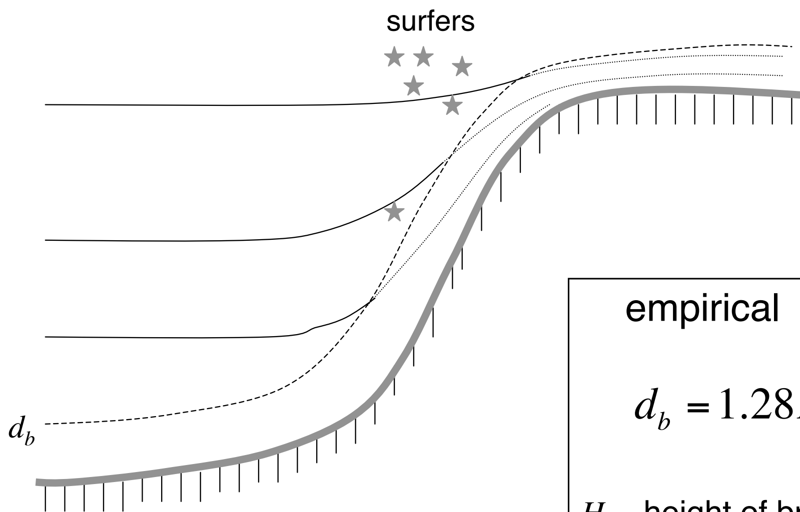
$$c_s = \sqrt{gd}$$



Munk, W. H. and M. A. Traylor, Refraction of Ocean Waves, J. Geology, v. LV, No. 1, 1947



breaking waves

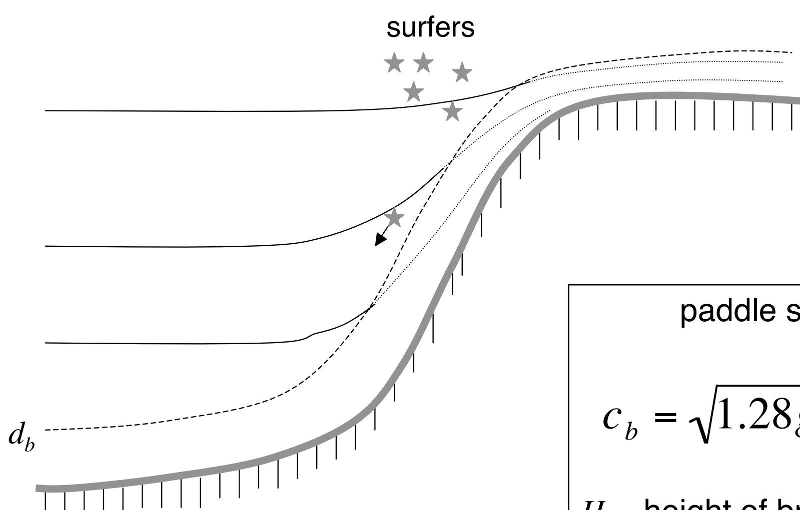


empirical relation

$$d_b = 1.28 H_b$$

H_b - height of breaker
d_b - depth where wave breaks

“catching the wave”

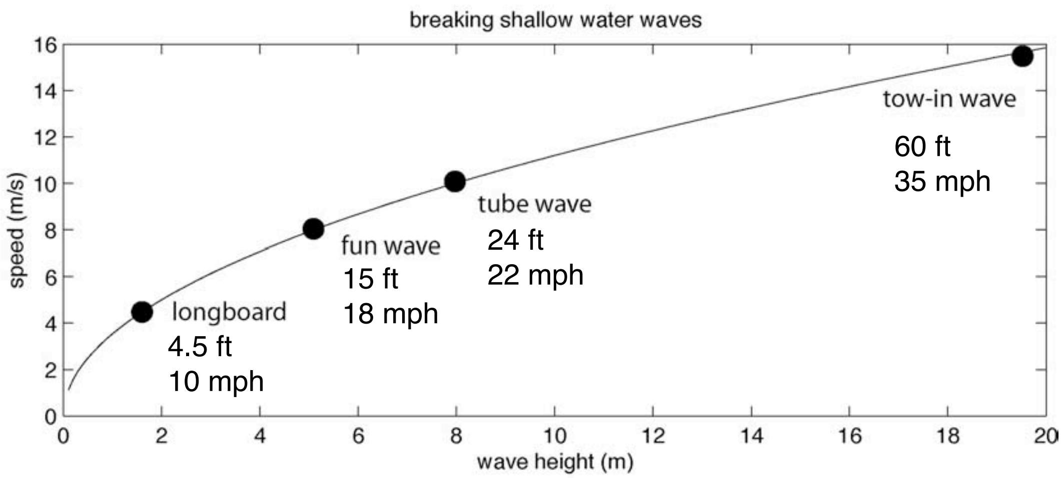


paddle speed

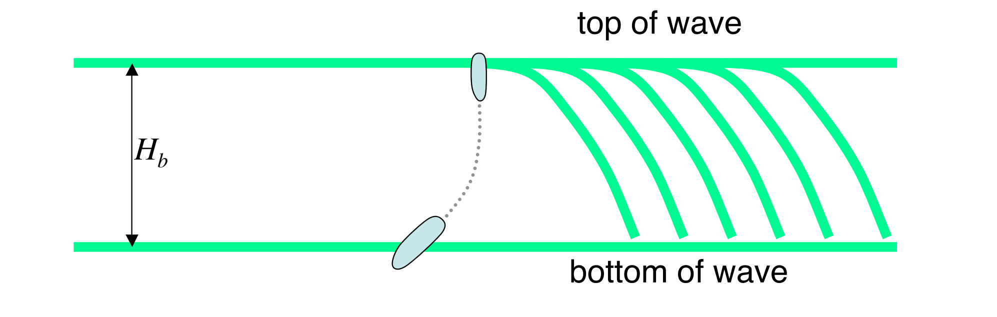
$$c_b = \sqrt{1.28 g H_b}$$

H_b - height of breaker
d_b - depth where wave breaks

paddle speed = wave speed



"dropping in"



$KE_{bottom} = KE_{top} + PE$

$$\frac{1}{2} m v_d^2 = \frac{1}{2} m c_b^2 + m g H_b$$

$$v_d^2 = c_b^2 + 2gH_b = 3.28 g H_b$$

g - acc. Gravity

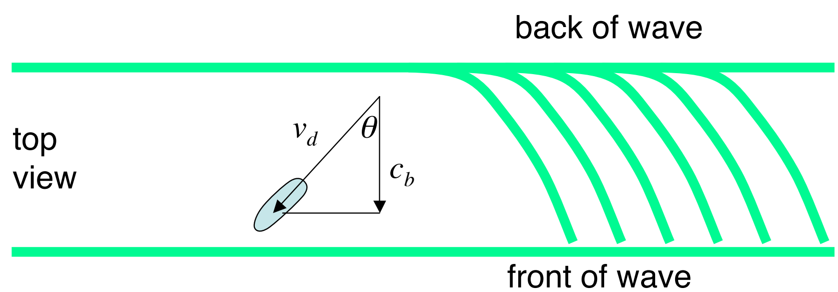
c_b - wave speed

v_d - surfer speed after drop

“dropping in”

style	H_b (m)	c_b (m/s)	v_d (m/s)	v_d (mph)
longboard	1.5	4.3	6.9	15.2
fun	5	7.9	12.7	27.9
tube	8	10.0	16.0	35.2
tow-in	23	17.0	27.2	59.8

"cutting across"



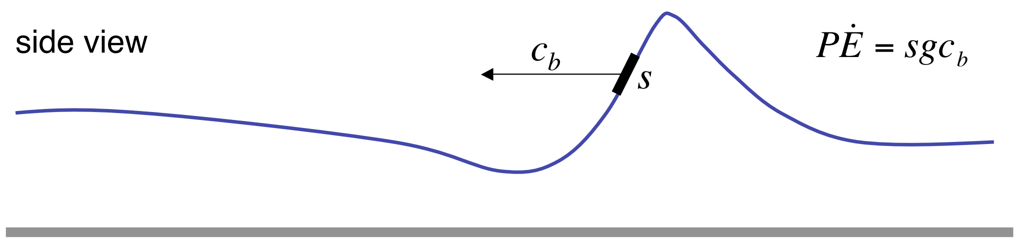
$$\frac{c_b^2}{v_d^2} = \frac{1.28}{3.28} = \cos^2\theta$$

This angle is independent of wave height or wave speed!

$$\theta = \sim 50^\circ$$

"riding the wave"

Suppose the surfer remains on the steepest part of the wave having a slope s. What is the rate of potential energy increase supplied to the surfer?

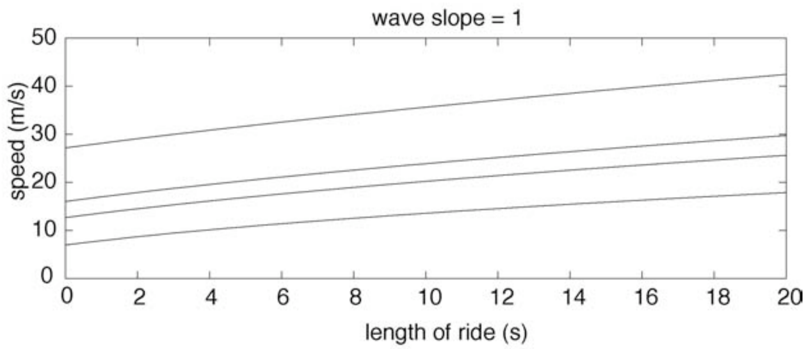


How does speed increase with time?

$$v(t)^2 = v_d^2 + \int_o^t sgc_b dt$$

$$v(t)^2 = 3.28gH_b + tsg\sqrt{1.28gH_b}$$

“the drag”



$$v(t)^2 = 3.28gH_b + 1.13g^{3/2} \; s \; H_b^{1/2} \; t - drag$$

total velocity = paddle drop in + slope of “the curl” breaker height duration of ride - energy dissipation

Future Research

– How does the shape of the bottom translate into the “perfect wave”?

– What is the terminal velocity for a given breaker height? (Can establish the magnitude of the drag term.)

– Need to instrument surfers with intertial sensors.

– How does surfboard shape effect terminal velocity for each style of surfing?

Experiment - April 23, 2005

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