• 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?

(a) 2 kg  (b) 1 kg
Which ball is going faster when it reaches the bottom?

(a)  (b)  (c)

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

Pipeline, Hawaii
height = 8 m
Mavericks, California
height = 23 m

**ocean depth and breaker height - empirical**

\[ d_b = 1.28 H_b \]

- \( H_b \) - height of breaker
- \( d_b \) - depth where wave breaks

breaking shallow water waves

- longboard
  - 4.5 ft
  - 10 mph
- fun wave
  - 15 ft
  - 18 mph
- tube wave
  - 24 ft
  - 22 mph
- tow-in wave
  - 60 ft
  - 35 mph
shallow water waves

$$c_s = \sqrt{gd}$$
breaking waves

empirical relation

\[ d_b = 1.28H_b \]

- \( H_b \) - height of breaker
- \( d_b \) - depth where wave breaks
“catching the wave”

\[ c_b = \sqrt{1.28gH_b} \]

- \( H_b \) - height of breaker
- \( d_b \) - depth where wave breaks

paddle speed \( \leq \) wave speed

Breaking shallow water waves

<table>
<thead>
<tr>
<th>Wave Type</th>
<th>Height (ft)</th>
<th>Speed (mph)</th>
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wave height (m) vs. speed (m/s)
“dropping in”

\[
\begin{align*}
KE_{\text{bottom}} &= KE_{\text{top}} + PE \\
\frac{1}{2} mv_d^2 &= \frac{1}{2} mc_b^2 + mgH_b \\
v_d^2 &= c_b^2 + 2gH_b = 3.28gH_b
\end{align*}
\]

- \( g \) - acc. Gravity
- \( c_b \) - wave speed
- \( v_d \) - surfer speed after drop

“dropping in”

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<tr>
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<td>12.7</td>
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<tr>
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<td>16.0</td>
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correction for surfer height

- overhead waves are good
- waist high waves are bad
- short surfers and heavy boards have an advantage in small waves

\[ H' = H_b - \frac{1}{2} H_s \]

effective height = breaker height - 1/2 surfer height
"dropping in"

\[ KE_{\text{bottom}} = KE_{\text{top}} + PE \]

\[ \frac{1}{2} m v_d^2 = \frac{1}{2} m c_b^2 + mg H_b \]

\[ v_d^2 = c_b^2 + 2g H_b = 3.28g H_b \]

- \( g \) - acc. Gravity
- \( c_b \) - wave speed
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“cutting across”

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

\[\theta = \sim 50^\circ\]

This angle is independent of wave height or wave speed!
“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?

$$P\dot{E} = sgc_b$$

How does speed increase with time?

$$v(t)^2 = v_d^2 + \int_{0}^{t} sgc_b \, dt$$

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

- Are the best surf spots in areas of narrow continental margin?

- Are “sets” real? What are the statistical properties of sets? Do “sets” become amplified when they reach shallow water?

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

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

- Need to instrument surfers with intertial sensors.