Ocean wave patterns & ocean currents

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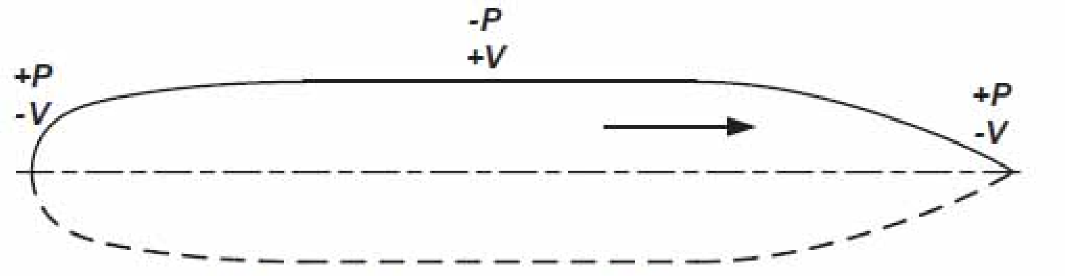
Overview

- Kelvin wave pattern
- Froude's number
- Reynold's number
- Model testing
- Ocean currents & Ekman transport
- Ocean circulation

The allure of the seas

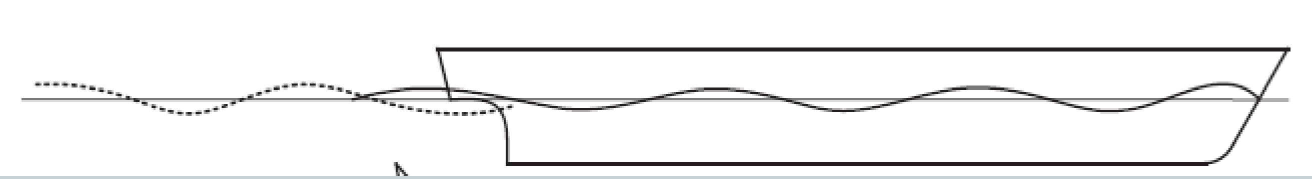
How are waves generated by ships?

- Consider immersed body:



Pressure variations around a body.

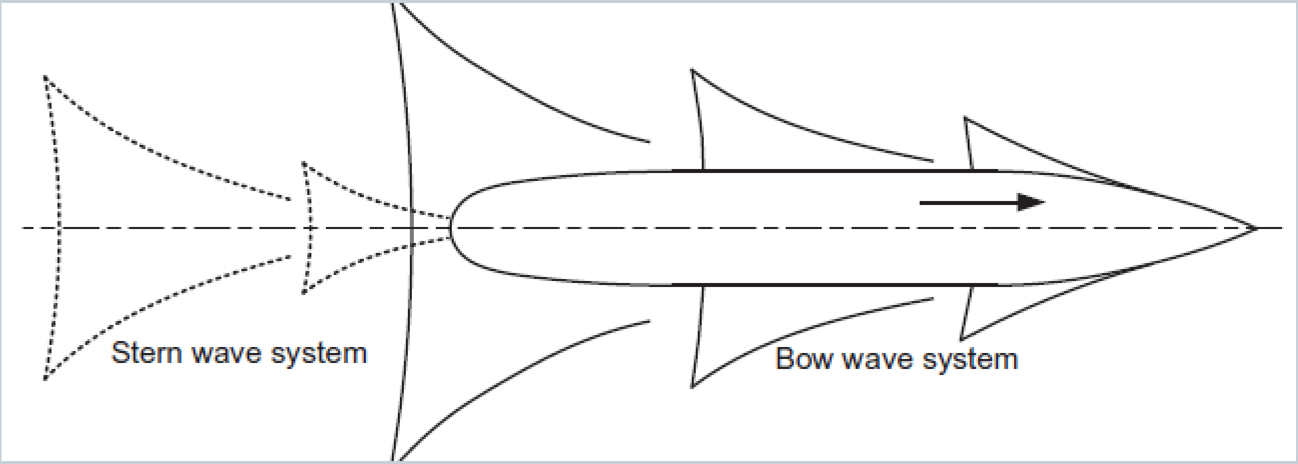
- Now consider a ship at the free surface:



- What form do surface waves assume?

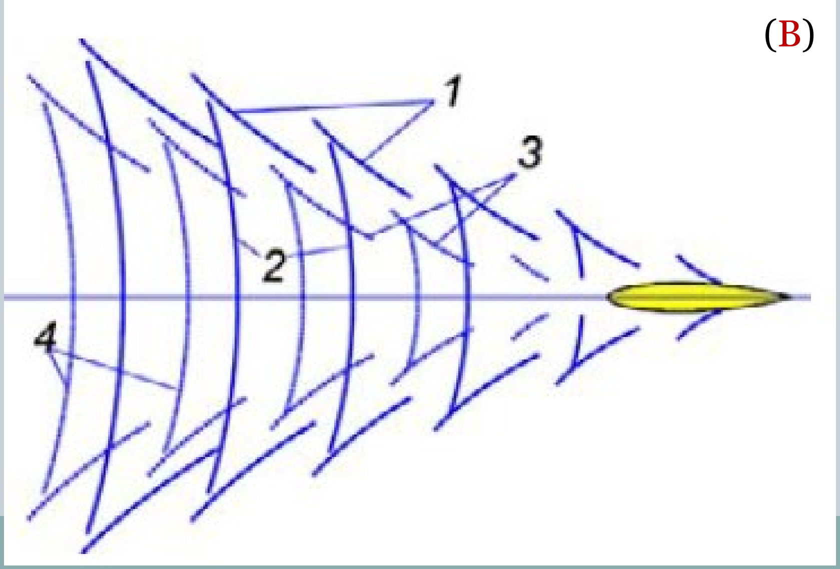
The Kelvin wave pattern

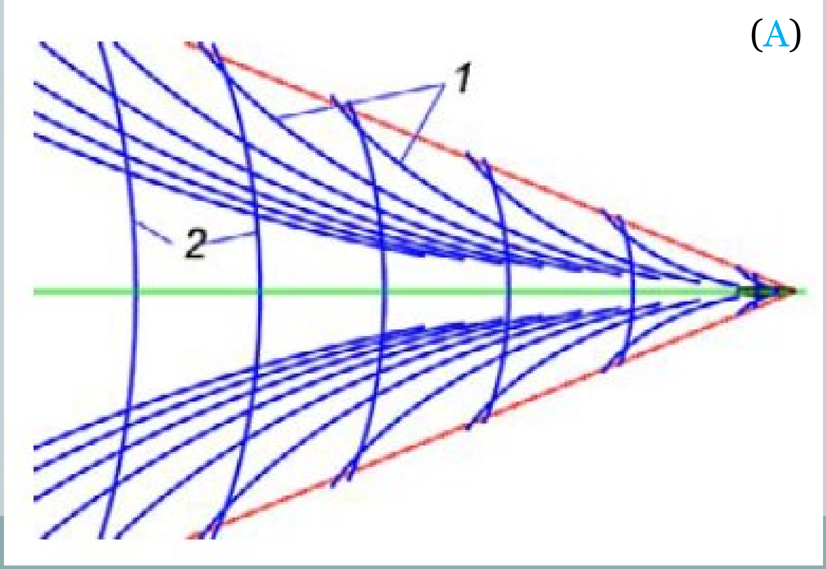
- Kelvin wave pattern is a mathematical form of a wave system
- Wave pattern is created by pressure point source @ free surface
- Wave system made of: a) transverse & b) divergent waves



Bow & stern wave patterns

- (A) Divergent (1) and transverse (2) waves
- (B) Stern divergent (1) & transverse (2) waves &
- (B) Bow divergent (3) & transverse (4) waves





Kelvin wave system

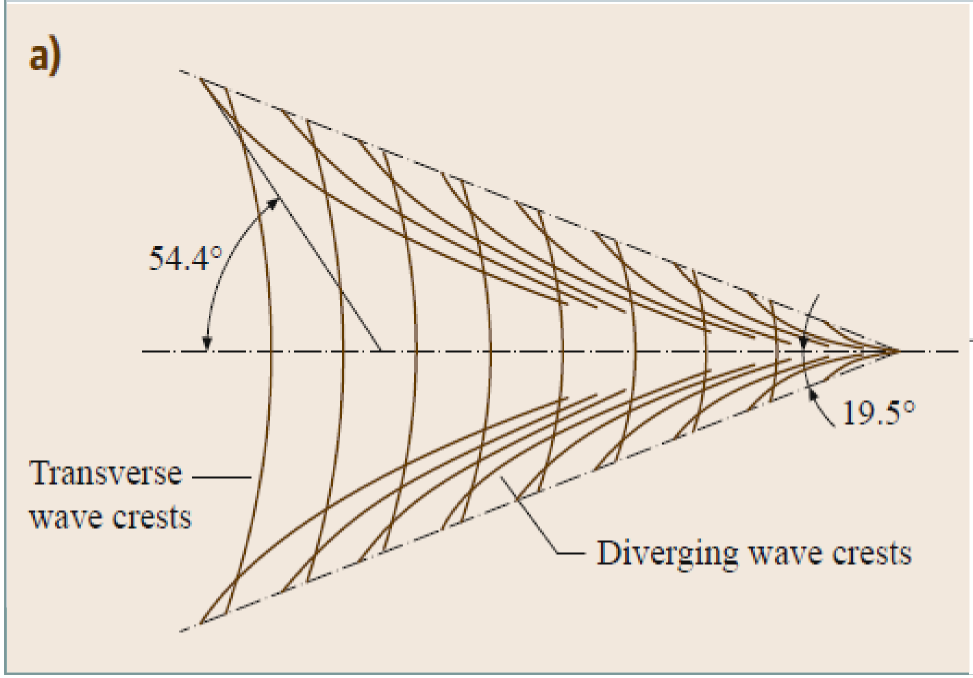
- Interference of wave patterns matters
- When wave crests from bow & stern coincide:
  - They result in larger waves
  - Dissipate more energy
  - Increase vessel's drag

- When bow wave crests coincide with stern troughs then waves become attenuated

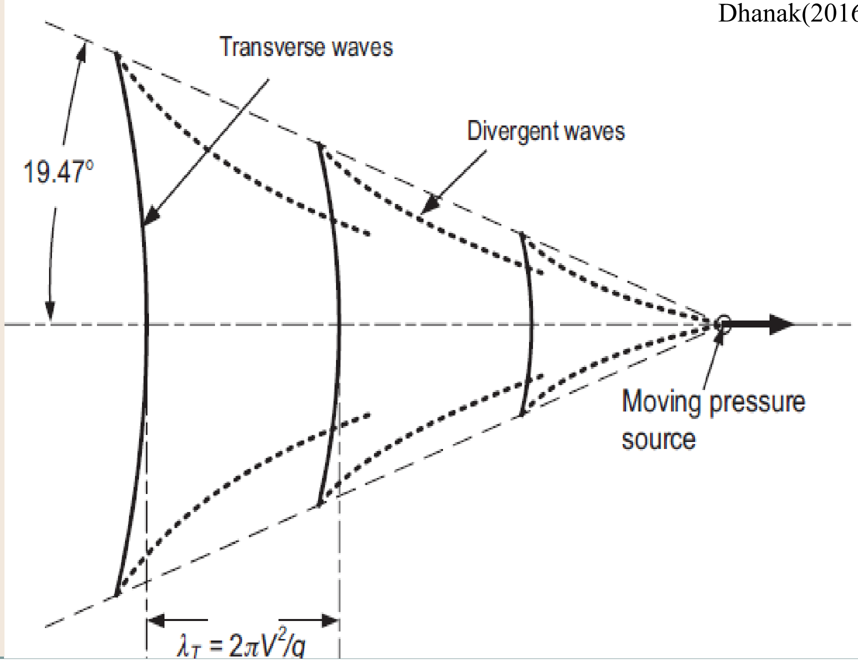
Kelvin wave pattern (2)

Characteristics of wave pattern

- Divergent wave crests diminish slower than divergent cusps (tip)
- Transverse wave system speed is given by: $V = \sqrt{\frac{g\lambda}{2\pi}} = U_{ship}$ (1)
- Wavelength of transverse waves is: $\lambda = \frac{2\pi V^2}{g}$ (2)



Dhanak(2016)



Froude number (Fn)

- Froude # is defined as ratio of *flow inertial* to *gravitational effects*:

$$Fn = \frac{V}{\sqrt{g\ell}} \qquad (3)$$

where V is the characteristic flow velocity & ℓ is a characteristic length. Aka speed-length ratio

- *Fn* # is an index of ratio of force due to acceleration of a fluid particle to the force due to gravity weight

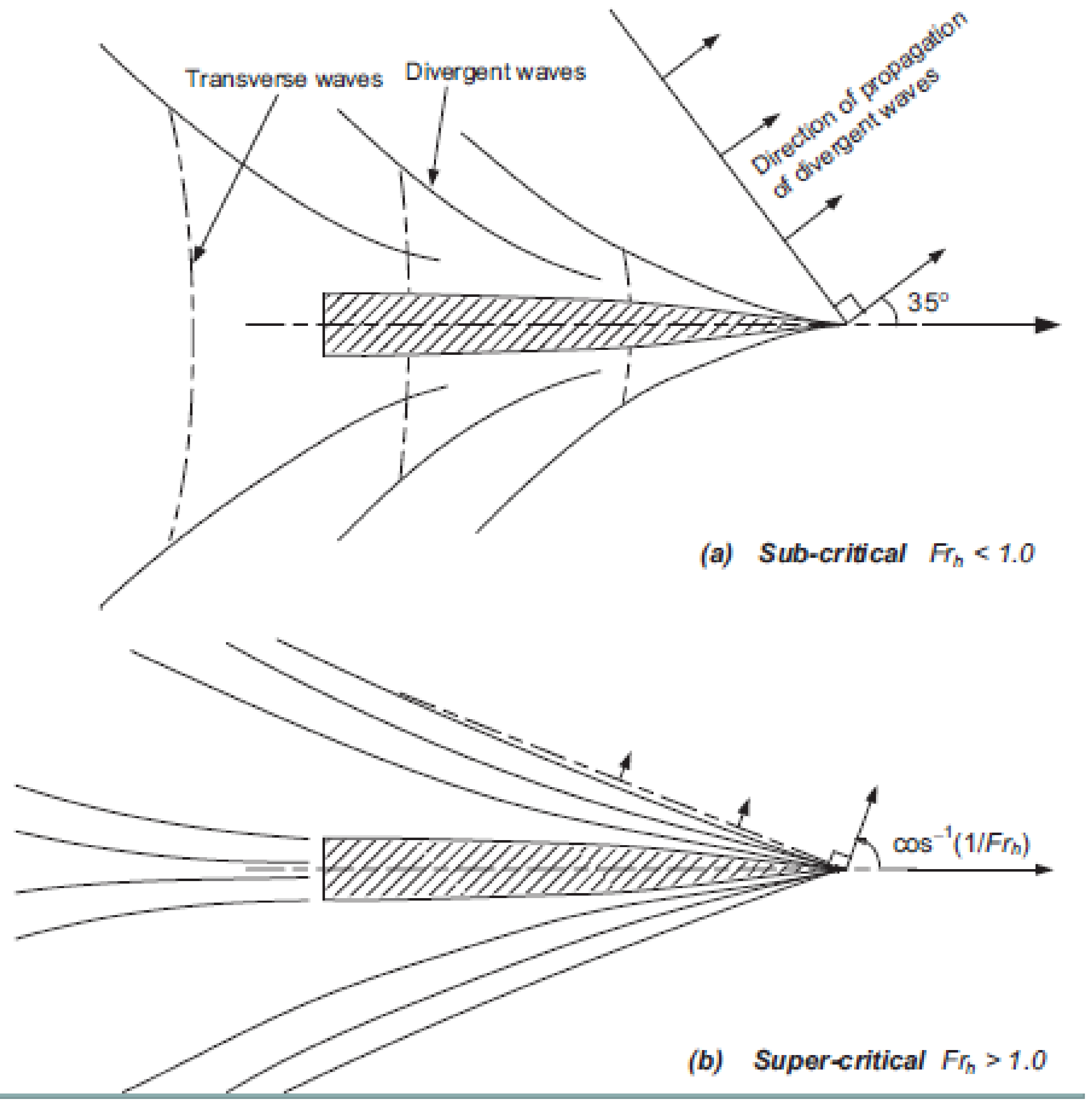
- *Fn* # is used to determine *wave making resistance* (drag) of a ship & allows comparison of different bodies with similar wave patterns

Shallow water wave patterns

- In shallow water:

  $c = (gd)^{1/2}$

- Depth $Fn_d = V/(gd)^{1/2}$
- Subcritical speed:
  - Speed < Fn_d=1.0
- Critical speed:
  - Speed = Fn_d = 1.0
- Supercritical speed:
  - Speed > Fn_d =1.0

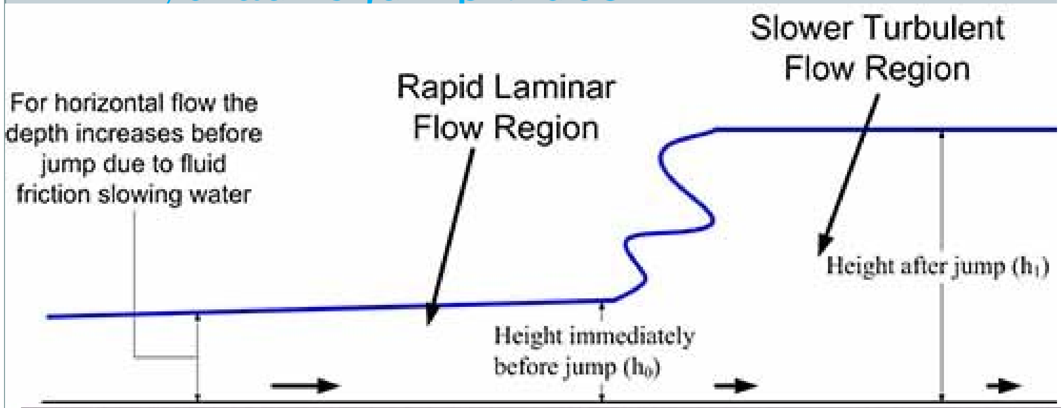


(a) Sub-critical $Fr_h < 1.0$

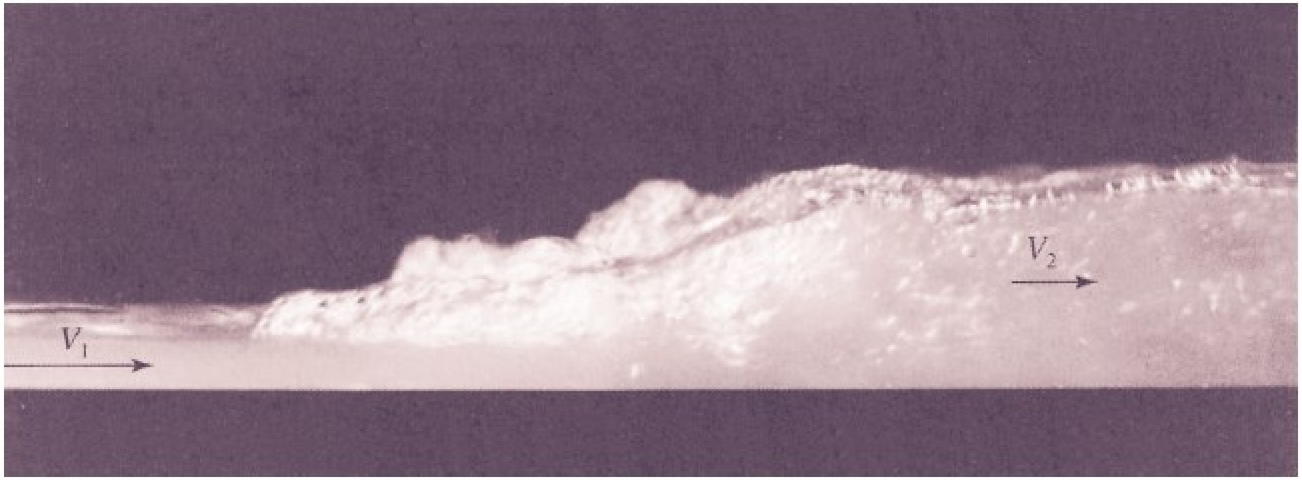
(b) Super-critical $Fr_h > 1.0$

Froude number (2)

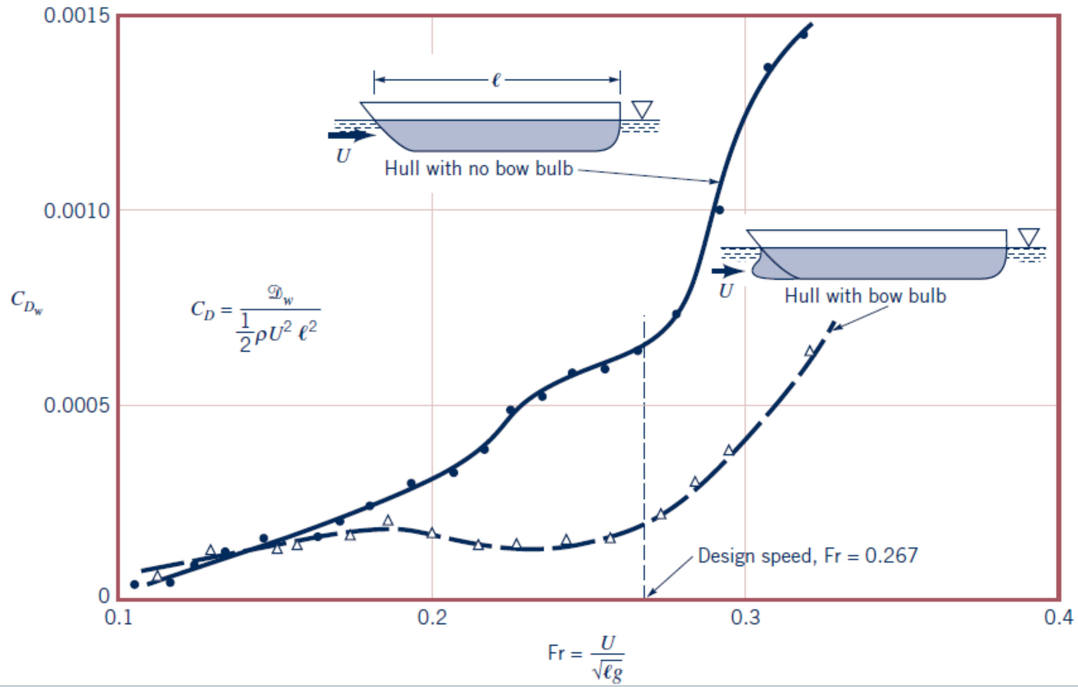
- Utility of *Fn* #: (a) Hydraulic jump, flows in rivers & open conduits, spillway flow of a dam
- Hydraulic jump video

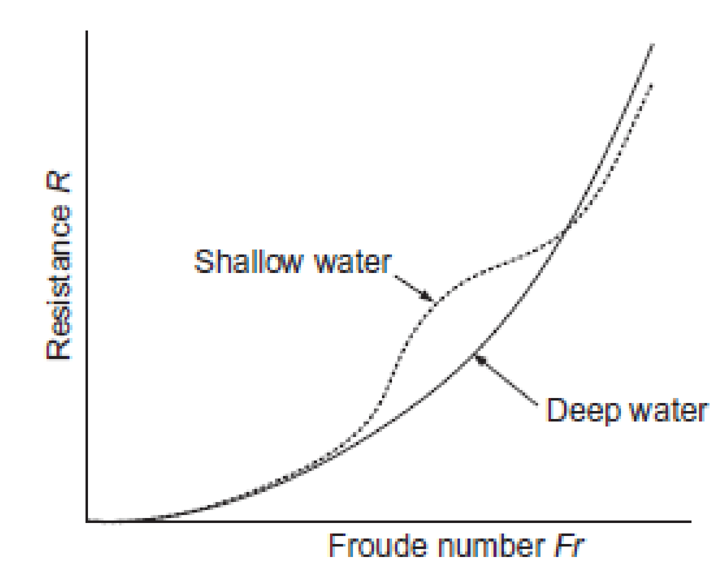


Fr	y_2/y_1	Classification	Sketch
<1	1	Jump impossible	V_2 $V_2 = V_1$
1–1.7	1–2.0	Standing wave or undulant jump	y_1 y_2
1.7–2.5	2.0–3.1	Weak jump	
2.5–4.5	3.1–5.9	Oscillating jump	
4.5–9.0	5.9–12	Stable, well-balanced steady jump; insensitive to downstream conditions	
>9.0	>12	Rough, somewhat intermittent strong jump	



Uses of Froude's number





Reynold's number

- Re # is the ratio of the *inertial* to *viscous* effects:

$$\text{Re} = \frac{Intertial\ force}{Viscous\ force} = \frac{\rho V \ell}{\mu} \qquad \frac{\ell}{\nu} \tag{8}$$

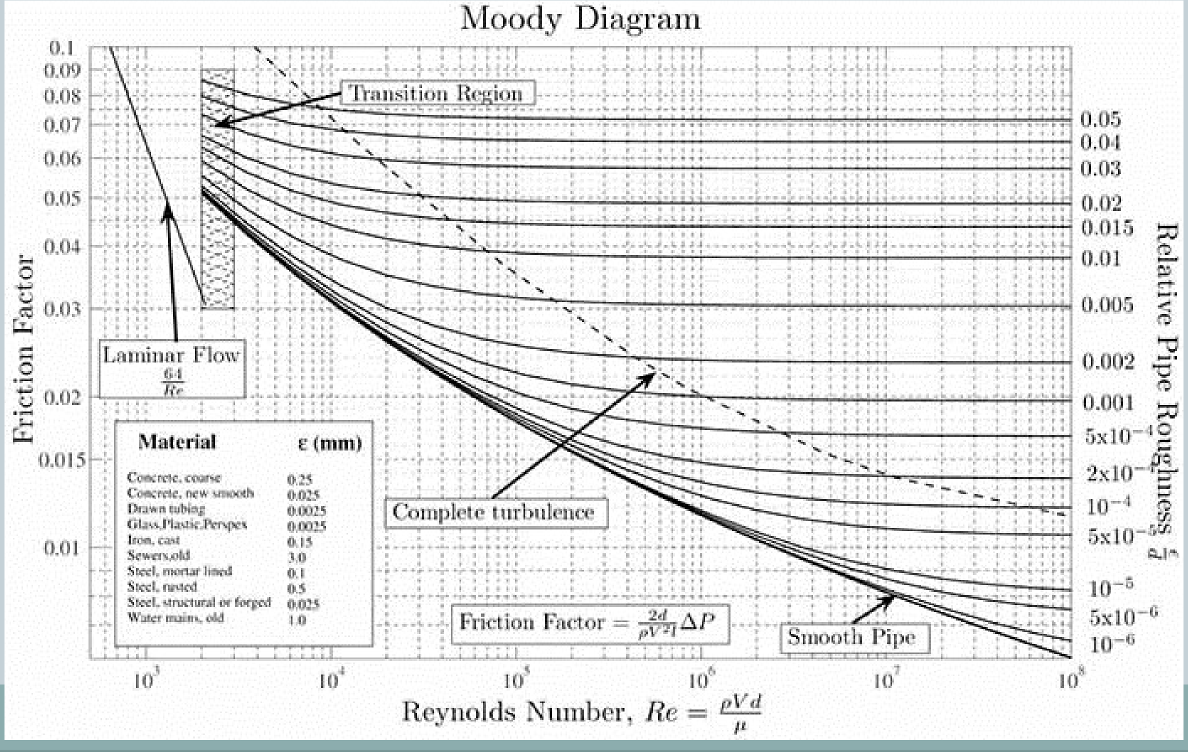
where μ is the dynamic (absolute) viscosity (Pa·s=(N·s)/m² or kg/(s·m)) & ν is kinematic viscosity (ν=μ/ρ, m²/s)

- $Re_m = Re_p$ is a pre-requisite for dynamic similarity of flows when viscous effects are important

- *Re* # is used to predict similar flow patterns in different flow situations

Reynold's number (2)

- Applications of *Re* #:
  - Scaling in fluid dynamics e.g., ships, platforms, aircraft, propeller design, …
  - Characterise flow regimes e.g., laminar, transition, turbulent flow,
  - Pipeline engineering,
  - Aircraft design, etc.

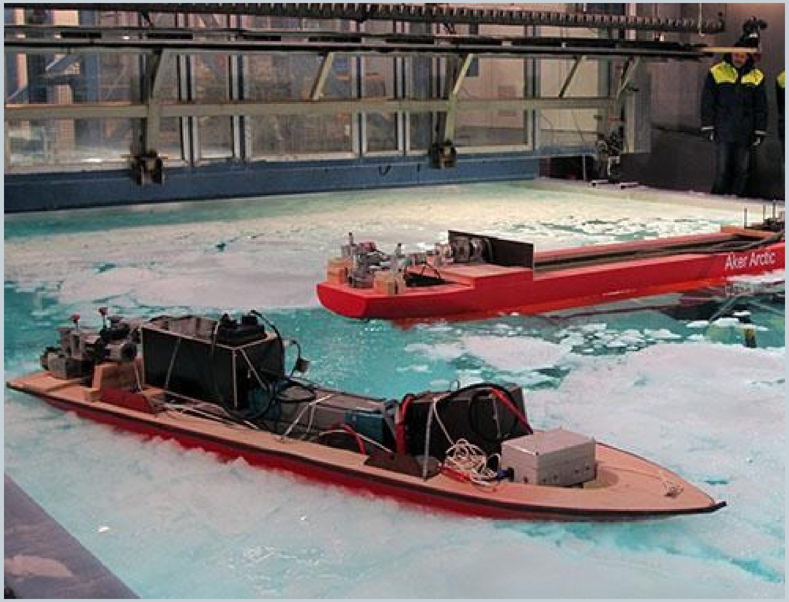


Model testing

- Concept of similarity forms the basis of model testing
- Experimenting with prototypes is costly & time consuming
- Why not use smaller geometrically similar models?
- Models range from aircraft, submarines, vehicles, trucks, harbours, oil & gas platforms, cities, dams, propellers, …

Dynamic similarity

- Between ship and model 3 conditions must be satisfied:
  - 1. Geometric similarity: shape (non-dimensional) parameters α_i of hull must be the same
  - 2. Reynold's #: must be the same
  - 3. Froude's #: must be the same



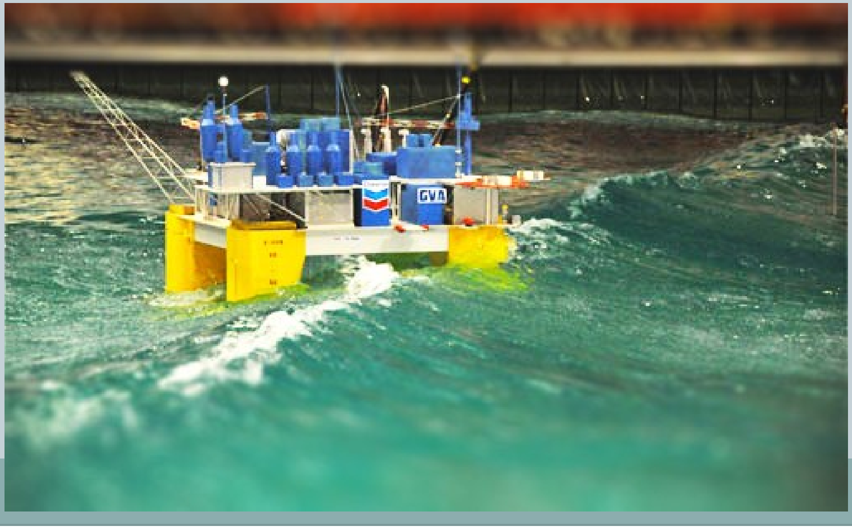
Model testing (2)

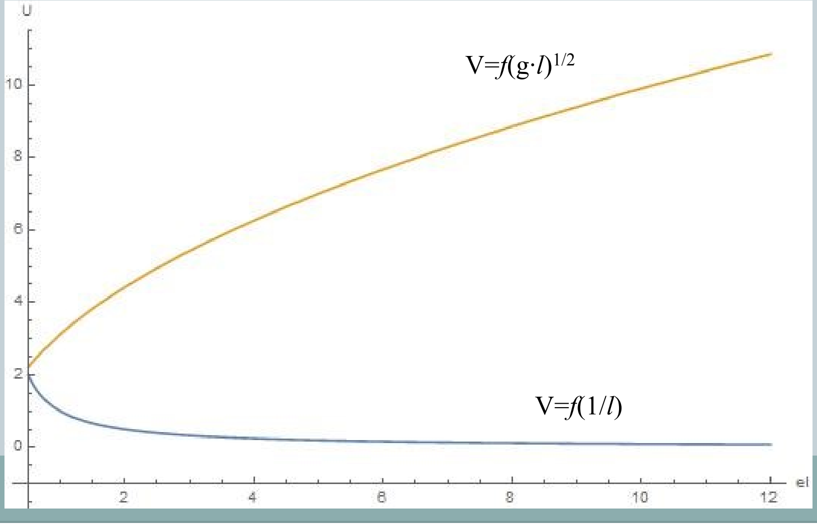
- Both *Re* & *Fn* numbers cannot be satisfied simultaneously since:

$$V \propto (1/l) \text{ and } V \propto (gl)^{1/2}$$

- Decide which d/less group is most important to satisfy

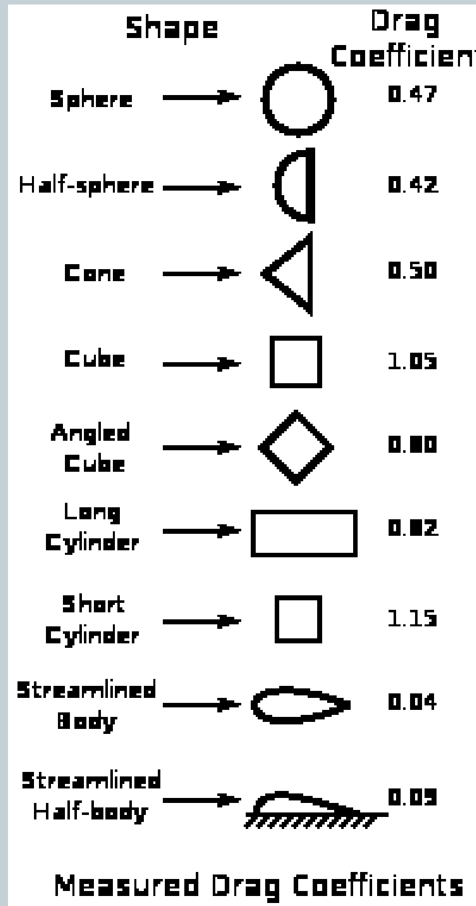
- Distorted models are then corrected





Example #6

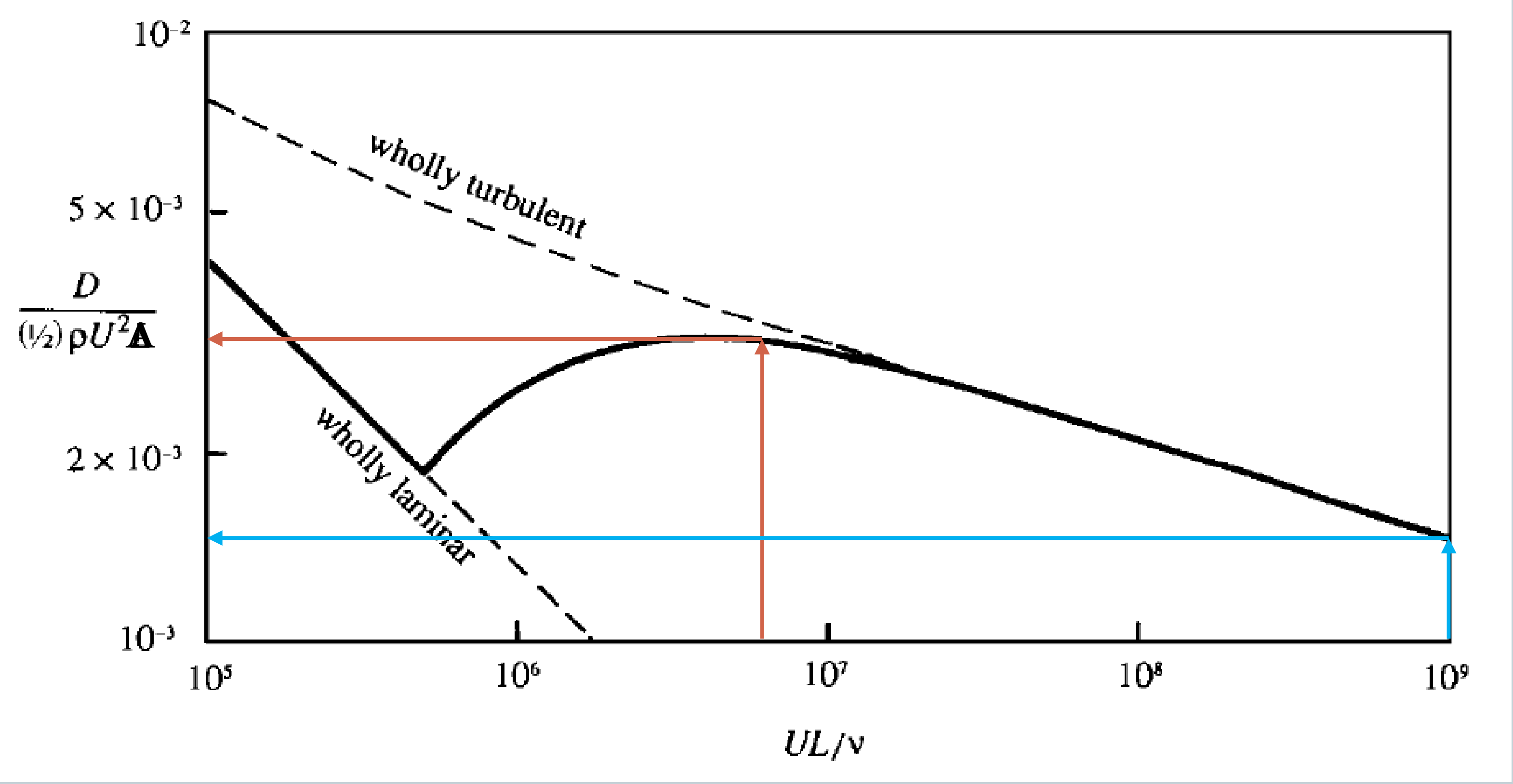
- Drag coefficient in fluids with Re#: ~10^4



Example 6

- Ex#6

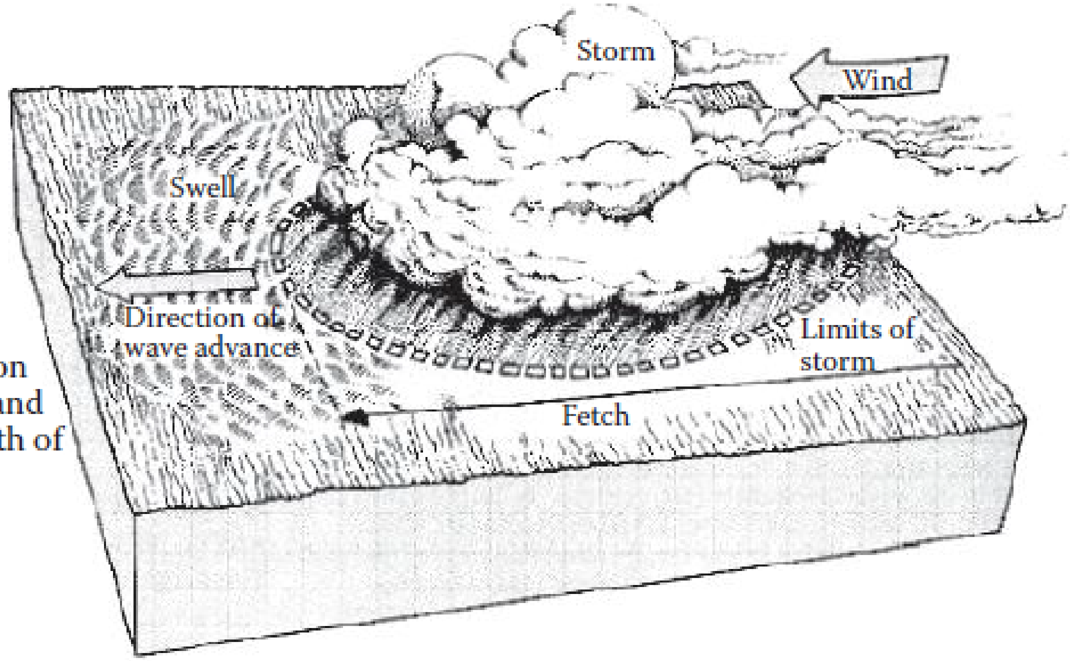
Fig. 1 Drag coefficient v Reynolds number for a boundary layer over a flat surface.
Dotted line depicts partly laminar & partly turbulent flow.

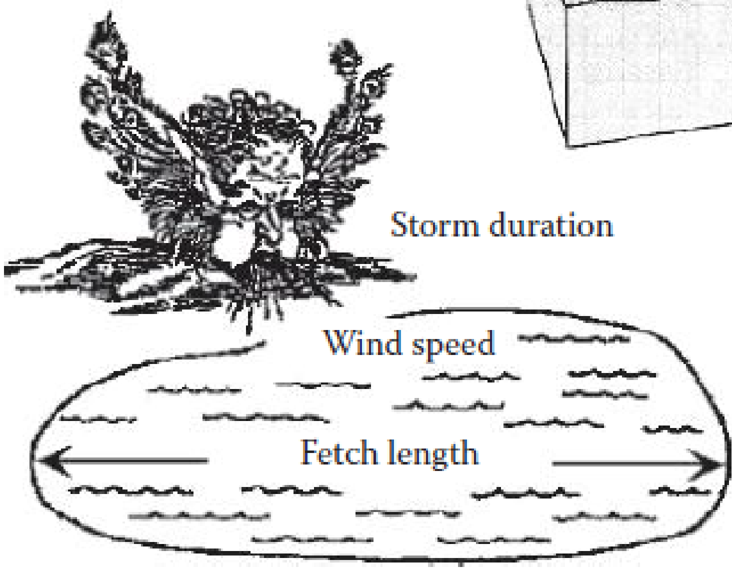


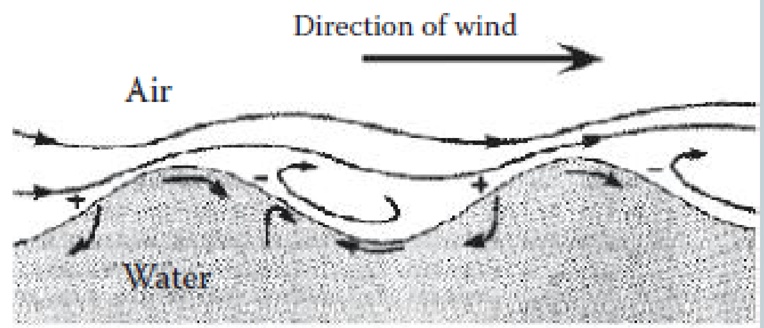
Ocean currents and ocean circulation

Ocean (wind) waves

Waves are formed in a generating area where the wind begins to disturb the water surface, forming ripples and then waves. The size of waves generated is a function of wind speed, duration of coupling between the wind and the water surface, and the length of this coupling.





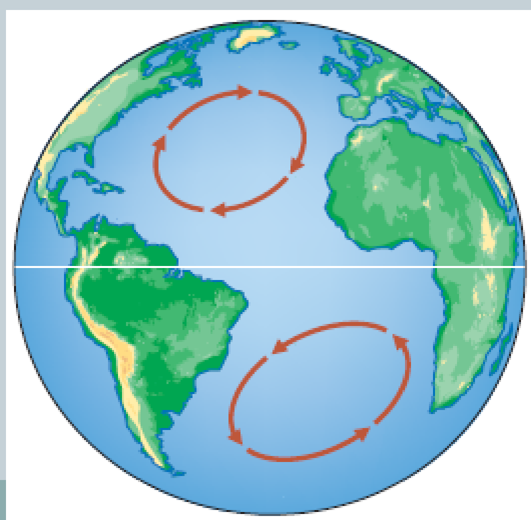


Waves are formed by frictional drag of the wind across the water surface. Growth of the wave is from the sheltering effect of the wave crest.

Source: http://geology.uprm.edu/Morelock/waves.htm

Ocean currents

- Ocean surface currents are water masses in motion
- Currents transfer heat from warmer to cooler areas
- Currents are tied to movement of nutrients in the oceans
- Affect transport of pollution substances



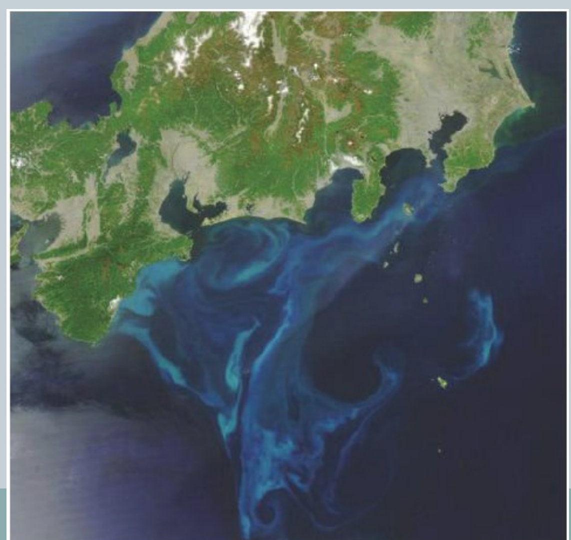
1. Surface winds
2. Sun heat
3. Coriolis effect
4. Gravity

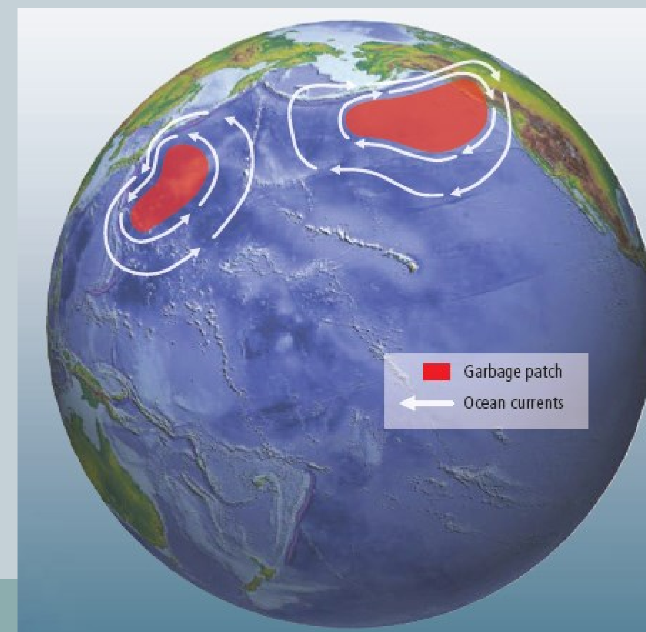
North Atlantic gyre

Importance of ocean currents

- Currents impose drag forces on fixed or floating platforms
- Ocean currents transport sea ice & marine debris at sea
- Cause deposition of ocean bottom material
- Influence corrosion rates of various materials

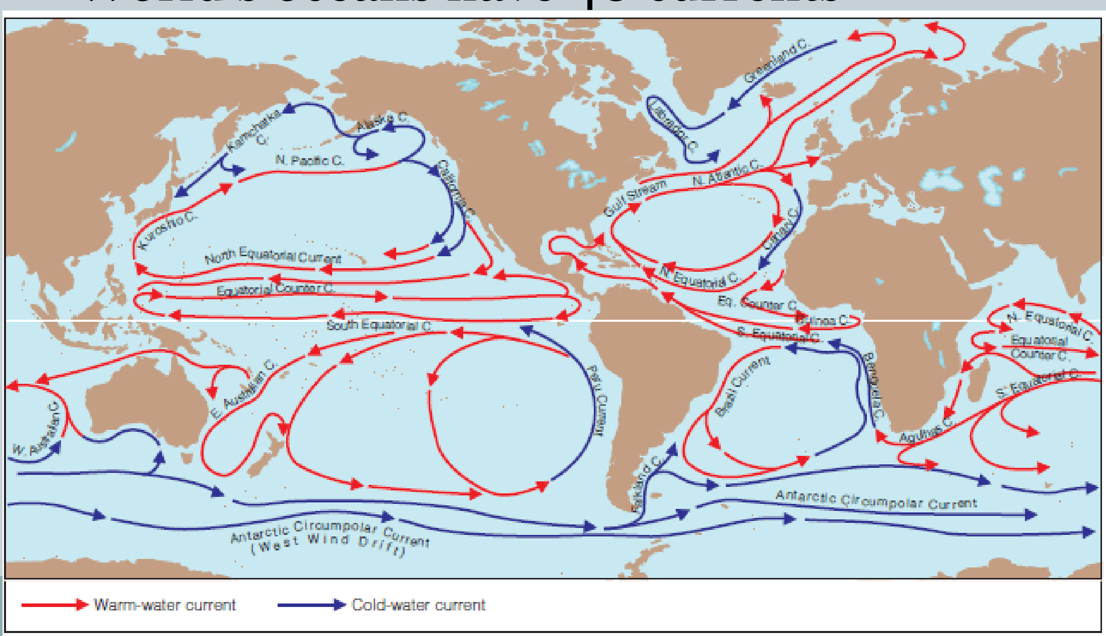
Phytoplankton transport, Honshu, Japan

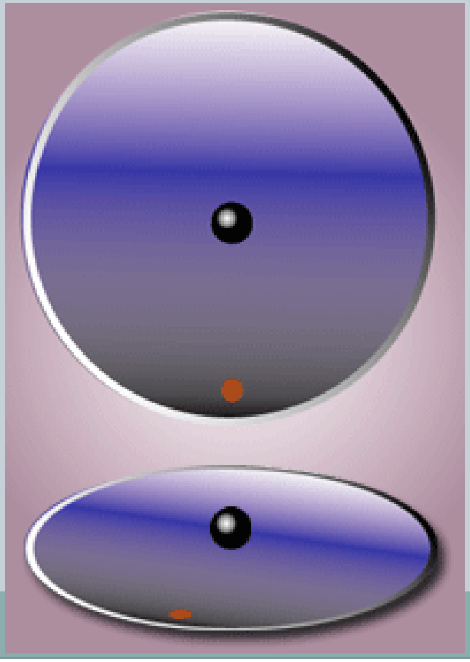




Ocean currents

- Winds blowing on sea surface generate frictional & pressure forces
- Wind generates both ocean waves & surface currents
- Currents affected by Coriolis effect, land masses & continental shelves
- World's oceans have 40 currents

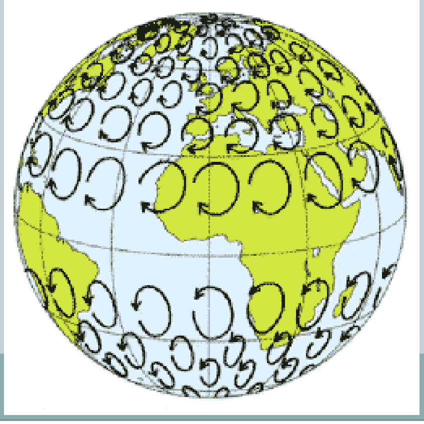




Ocean currents

- Ocean currents are either *wind driven* or *density triggered*

- Causes of sea currents comprise:
  1) Tidal motion;
  2) Global circulation due to temp. differences & Coriolis effect;
  3) Wind forces;
  4) River discharge (hydraulic currents);
  5) Internal waves (density changes);
  6) Eddies
  7) Self-edge currents caused by ΔTs



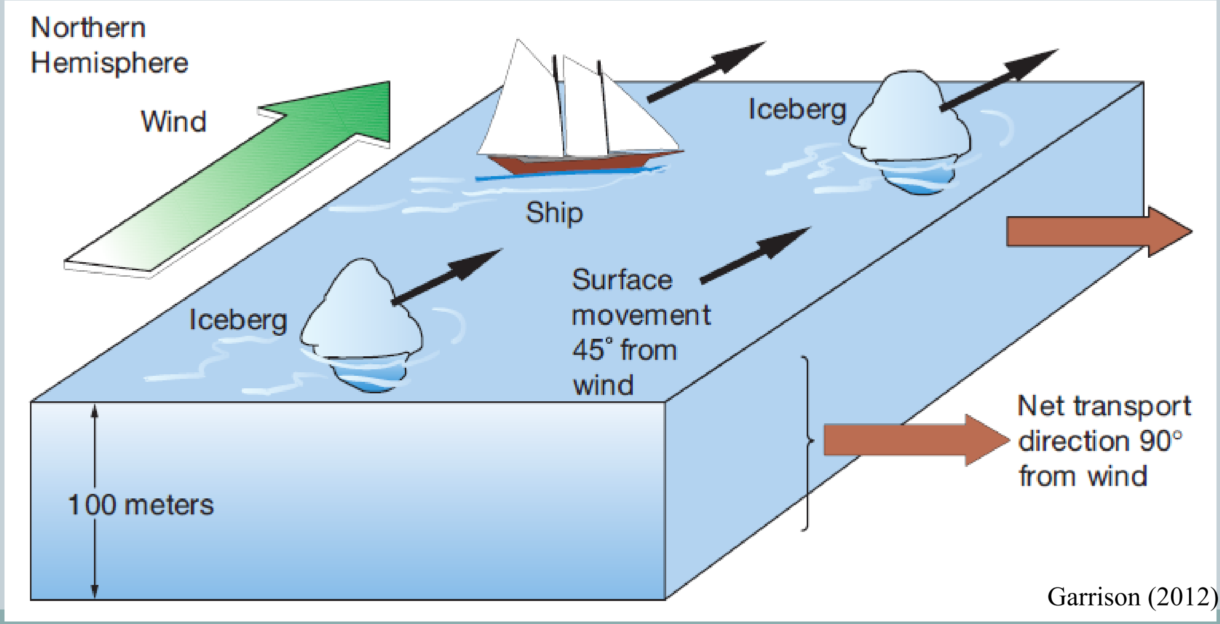
Garrison (2012)

Shoes & bathtub toys as drifters

- 30,910 shoes
- 01/1992: 29,000 floating toys
- 6 months
- 2,400km

Ekman transport

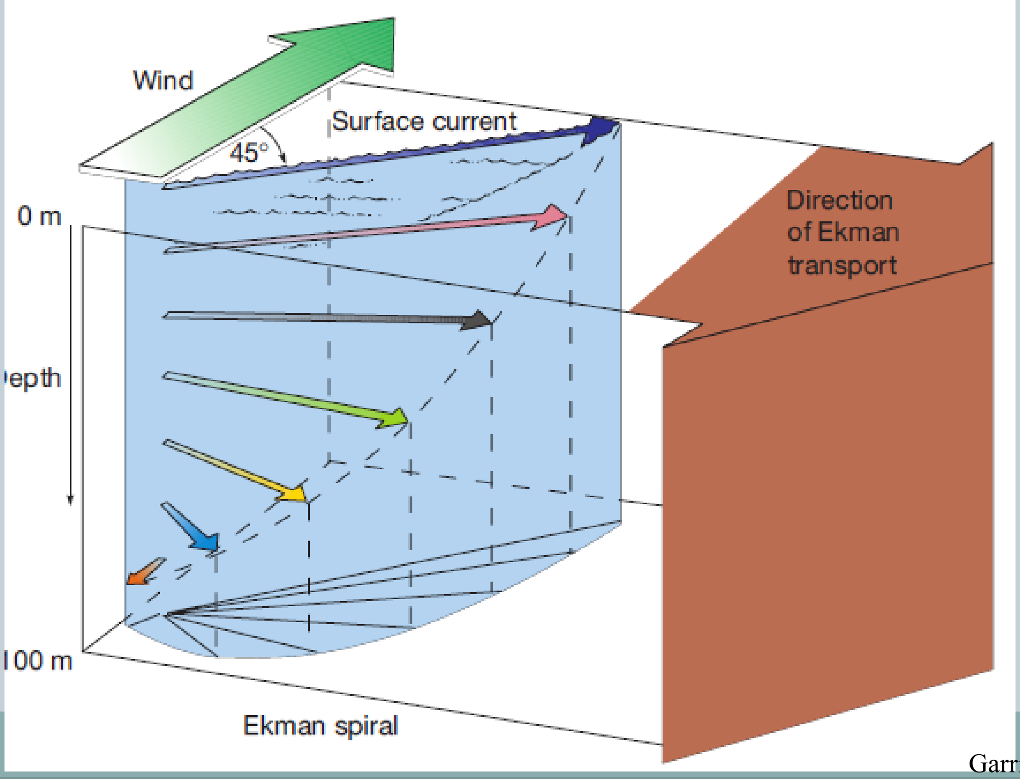
- Why does water, icebergs & vessels move 90° to wind currents?
- Why do ocean currents rotate CLW in N. hemisphere & ACLW in S. hemisphere?
- Attributed to balance btw *frictional effects* & *Coriolis force*

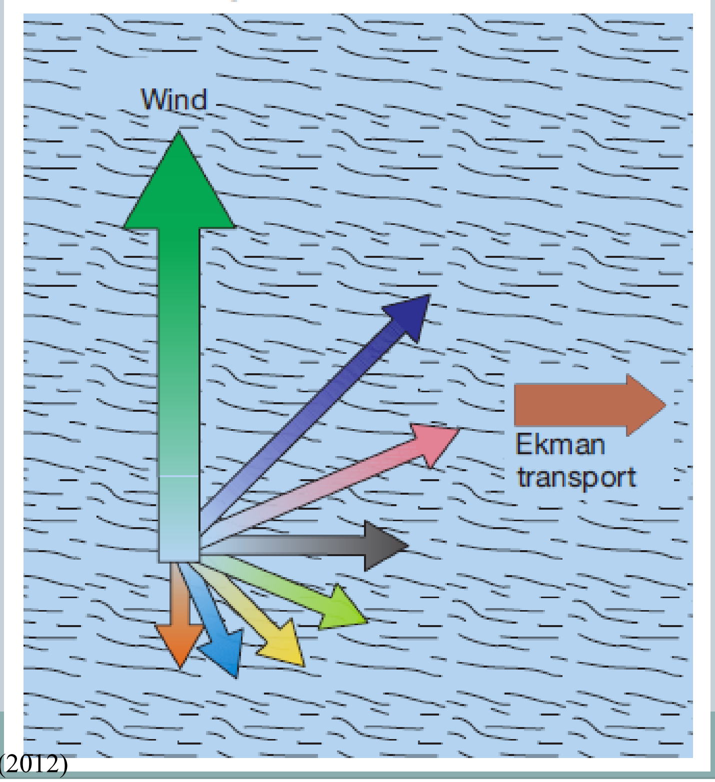


Garrison (2012)

Ekman's "spiral" (1)

- Coriolis effect transports water molecules at 45°
- Energy's imparted at lower water layers
- Spiral extends btw –100m to –200m
- *Surface currents* manifest at 45° & *net Ekman transport* at 70°

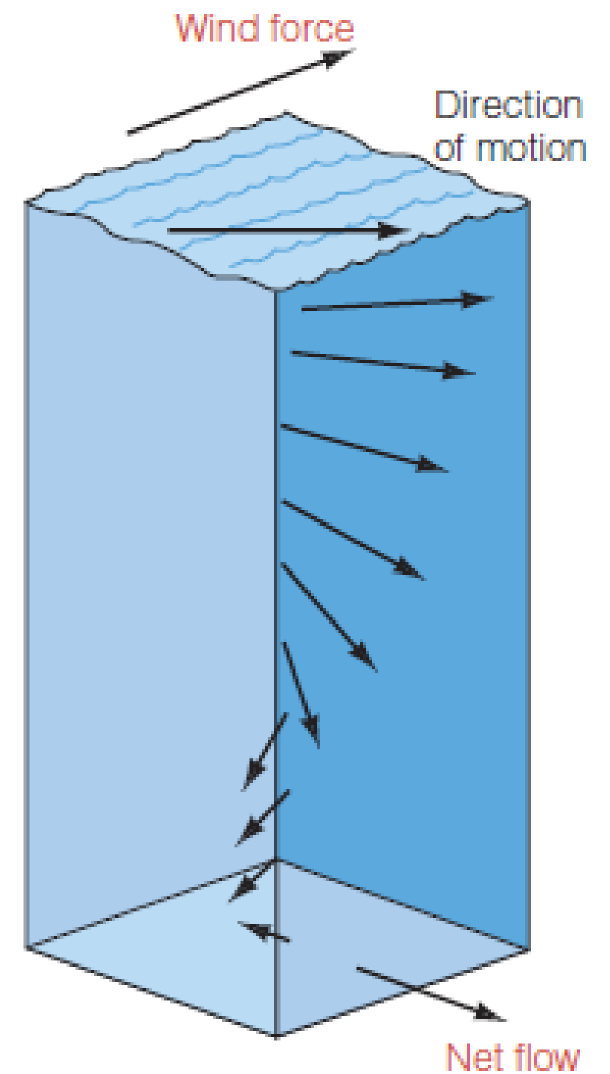




Garrison (2012)

Ekman "spiral" (2)

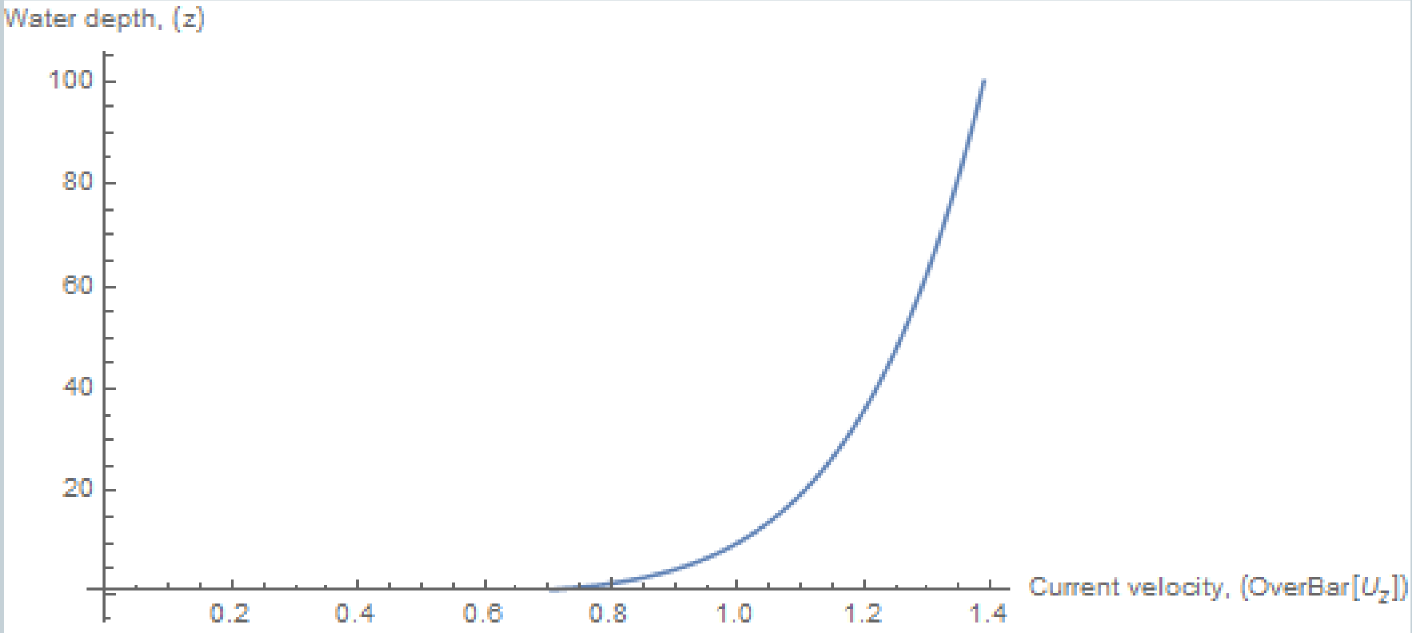
- Ekman transport in gyres <90°
- Actual water deflection is ≈45°
- Due to interaction btw Coriolis effect & pressure gradient



Garrison (2012)

Ocean currents

- Theory



Exercise #7

- Ex#7

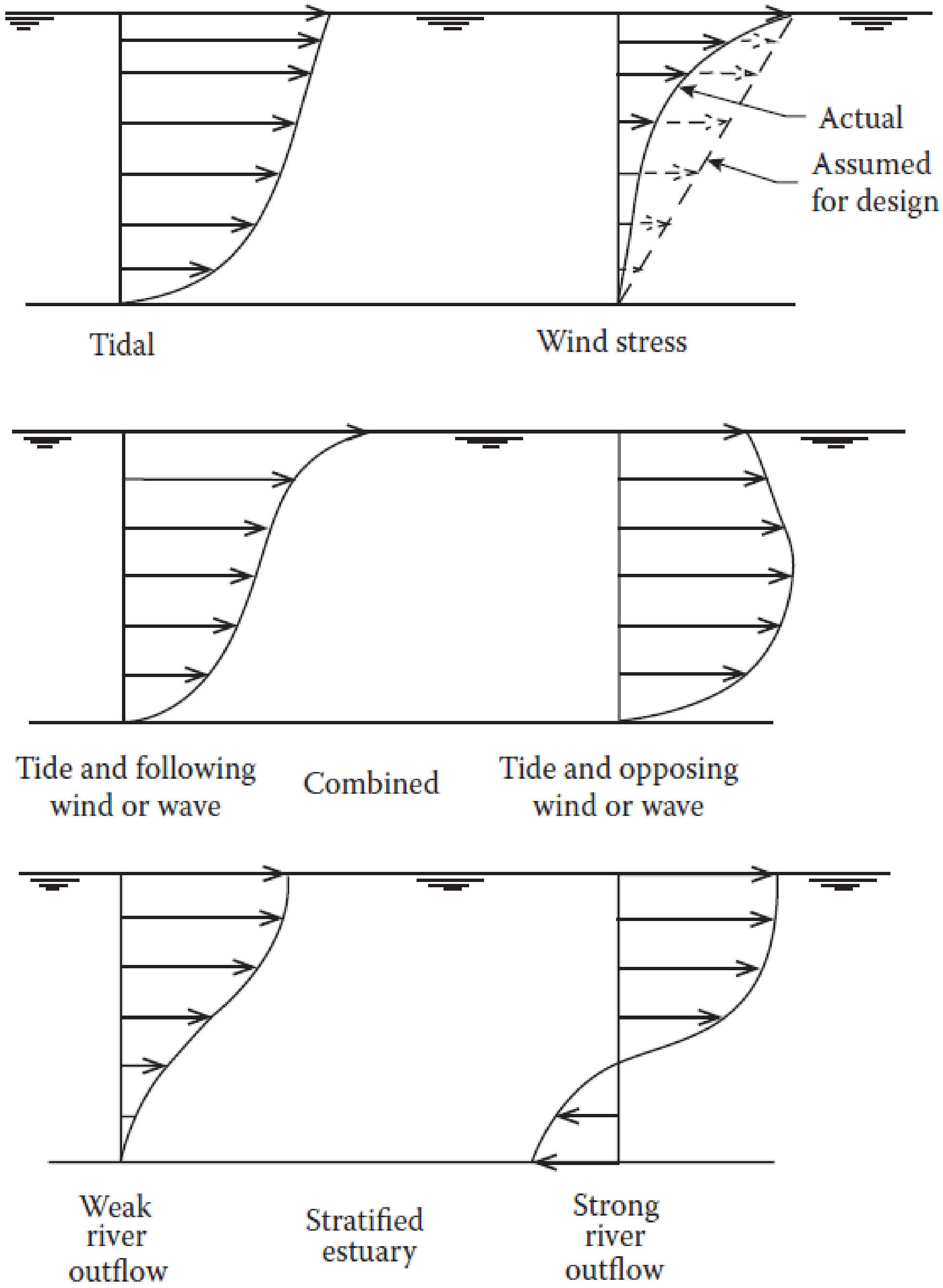


Fig. 2 Various ocean current velocity profiles

Thanks for your attention!