Ocean wave patterns & ocean currents

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Overview

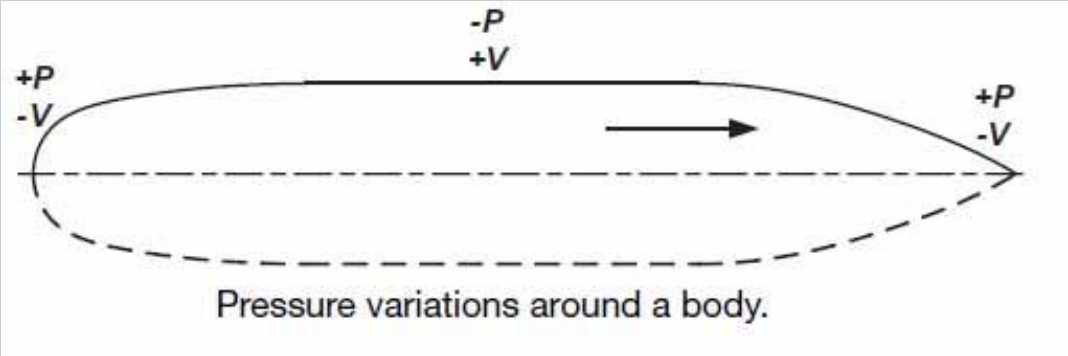
- Kelvin's wave pattern
- Froude's number
- Reynold's number
- Model testing
- Ocean currents & Ekman transport
- Ocean circulation

The appeal of the seas



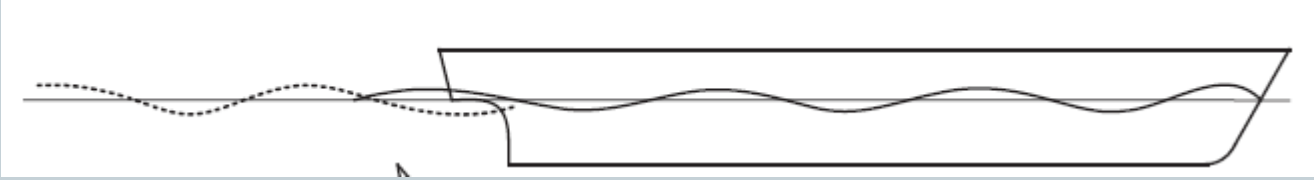
How are waves generated by ships?

- Consider immersed body:



Pressure variations around a body.

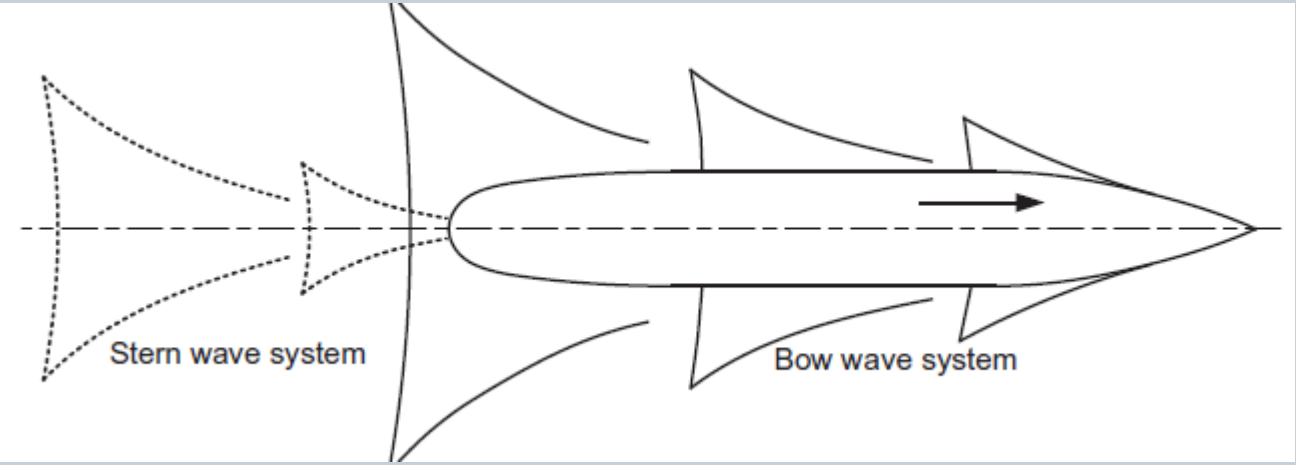
- Now consider a ship at the free surface:



- What form do surface waves assume?

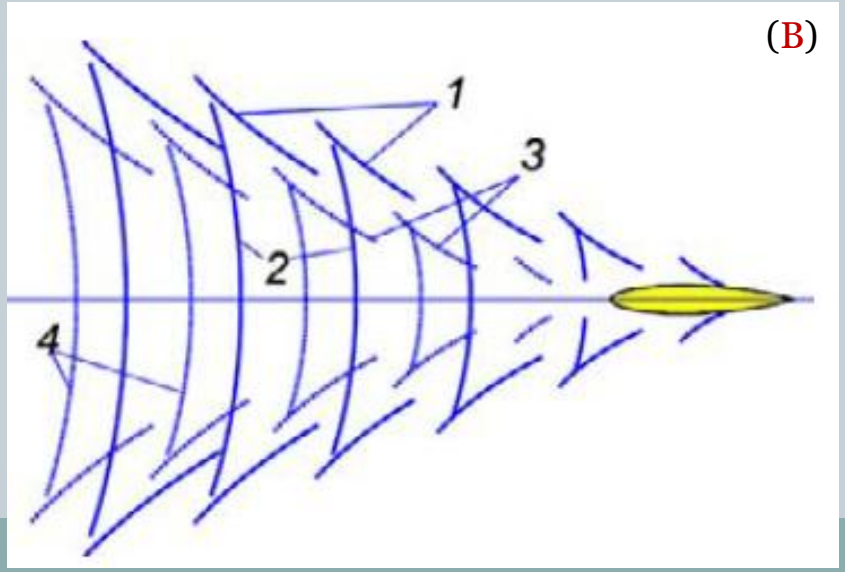
The Kelvin wave pattern

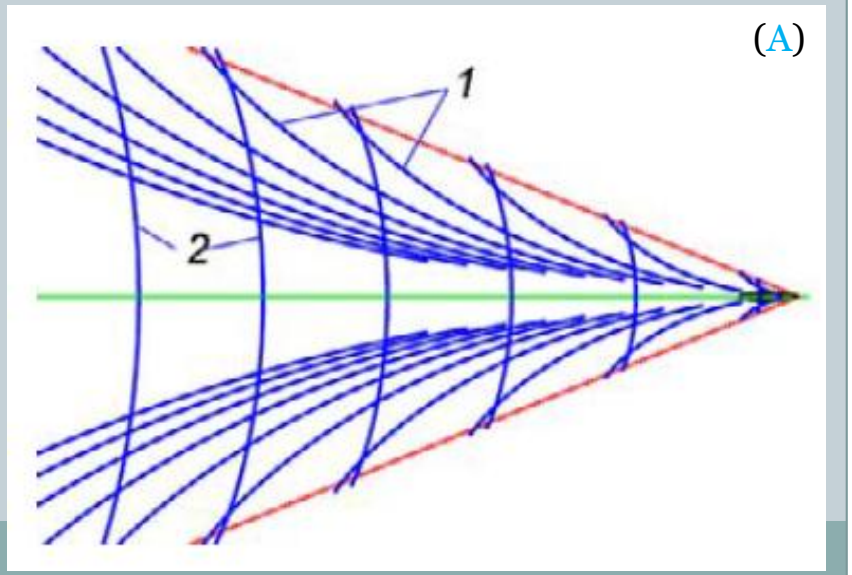
- Kelvin wave pattern is a mathematical form of a wave system
- Wave pattern is created by a pressure point source at the free surface
- Wave system made-up of: a) transverse & b) divergent waves



Bow & stern wave patterns

- (A) Divergent (1) and transverse (2) waves
- (B) Bow divergent (1) & transverse (2) waves &
- (B) Stern 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 are attenuated

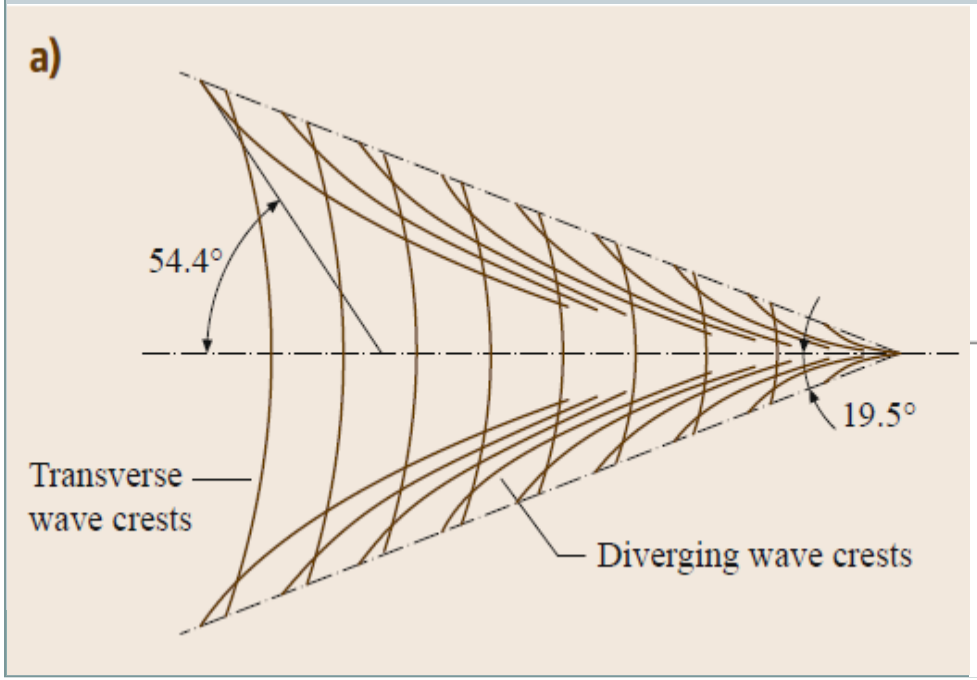


Kelvin wave pattern (2)

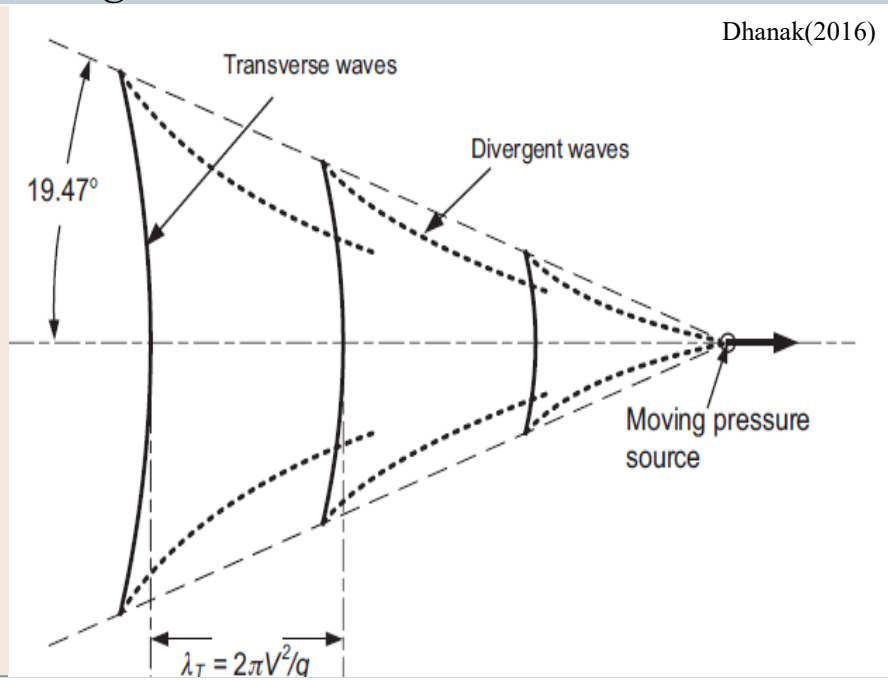


Characteristics of wave patterns

- 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*:

$$Fn = \frac{V}{\sqrt{g\ell}} \tag{3}$$

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.

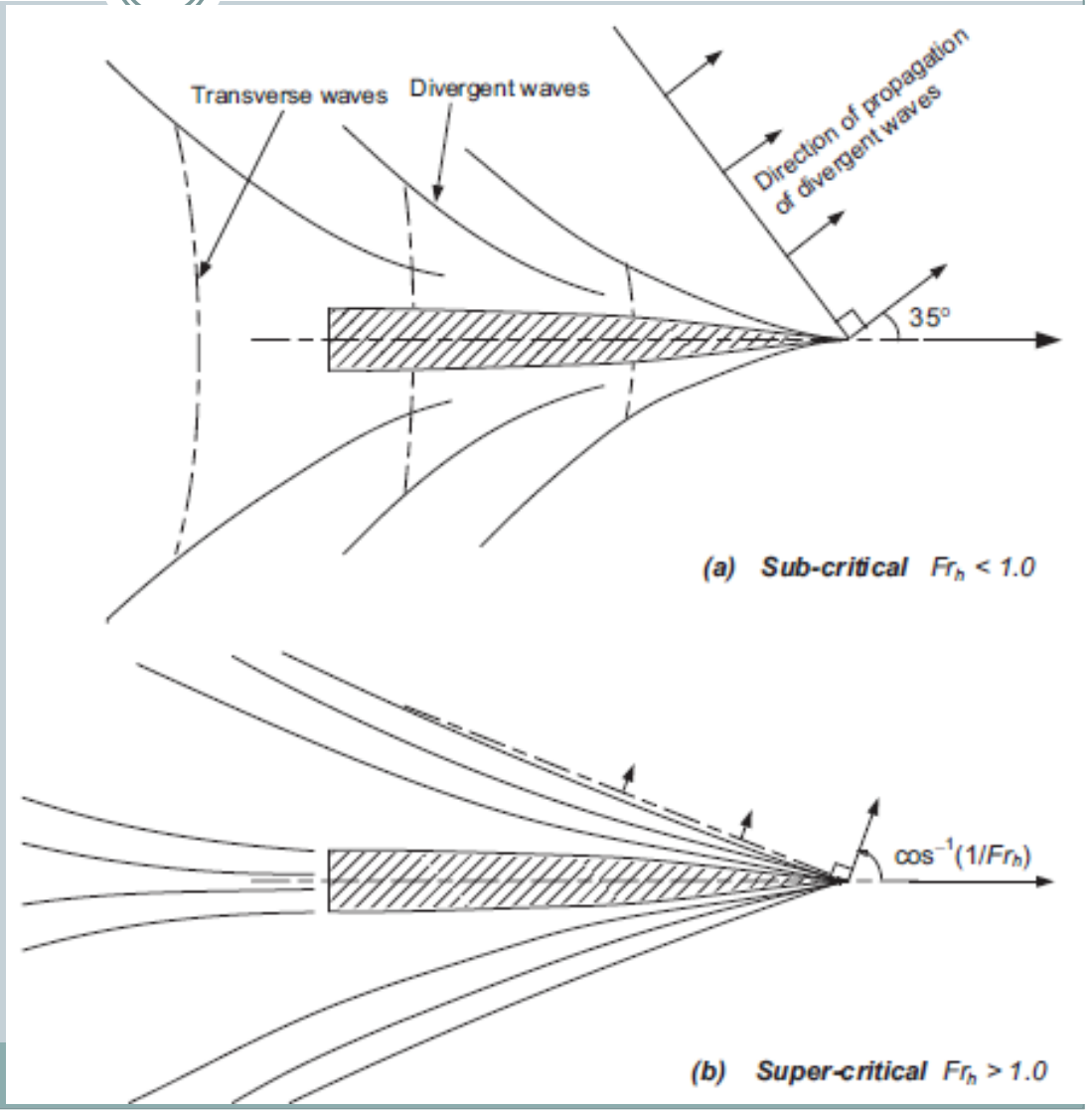
- *Fn* # is used to determine *wave making resistance* (drag) of a ship & allows comparison of different bodies with similar wave patterns.

Shallow water wave patterns

- In shallow water:

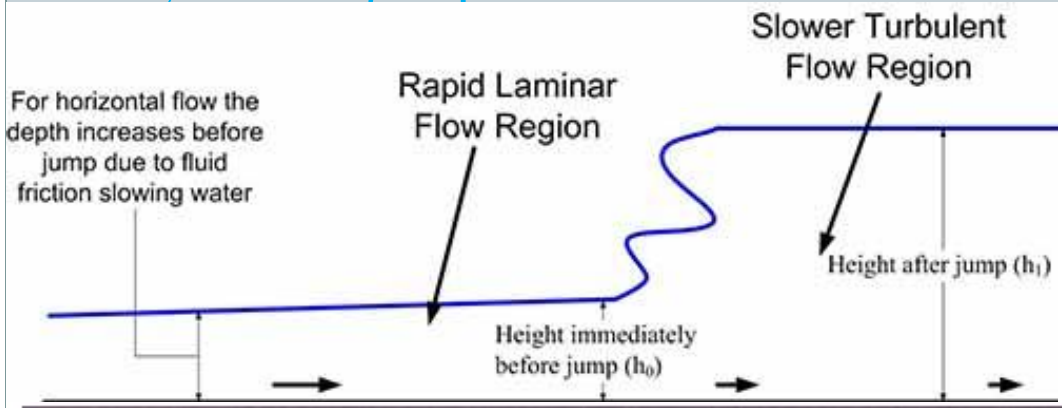
  $c = (gd)^{1/2}$

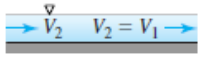
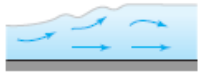
- Deep, $Fn_d = V/(gd)^{1/2}$
- Subcritical speed:
  - Speed < $Fn_d = 1.0$
- Critical speed:
  - Speed = $Fn_d = 1.0$
- Supercritical speed:
  - Speed > $Fn_d = 1.0$

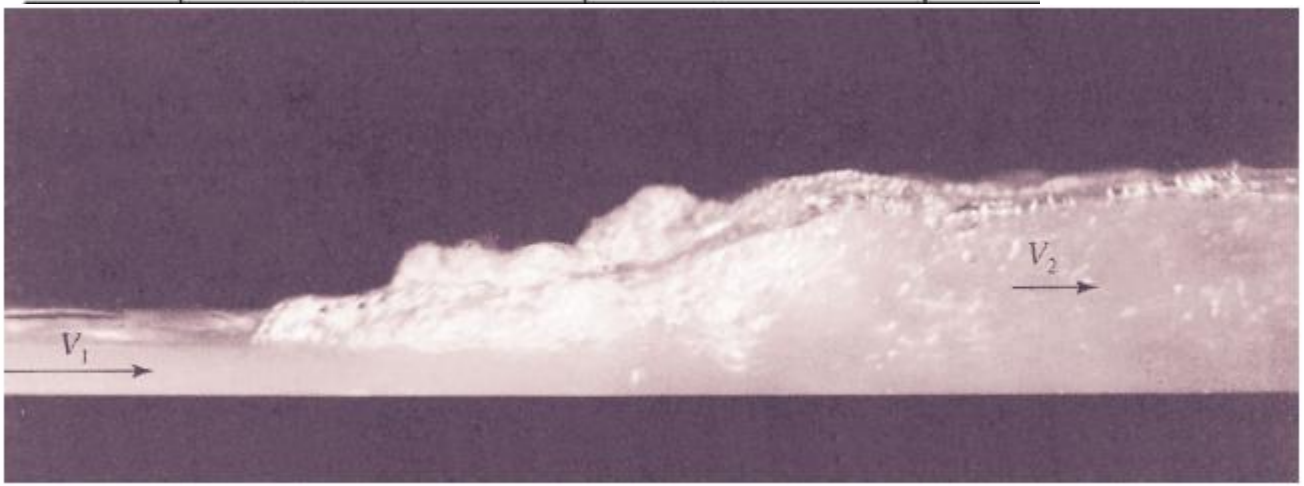


Froude number (2)

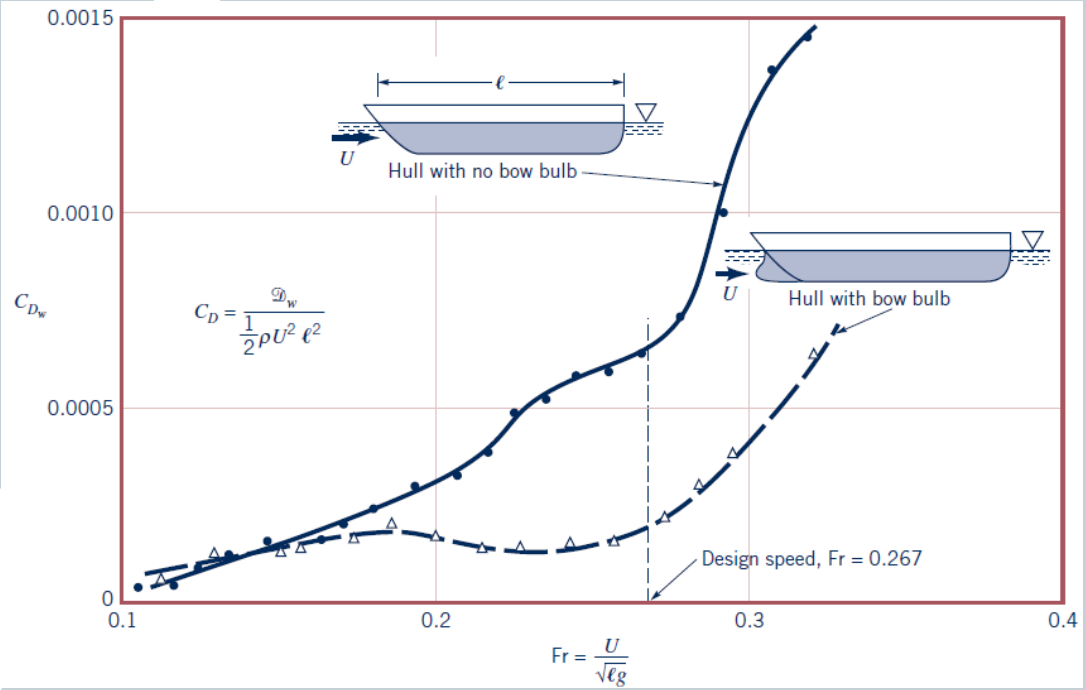
- Utility of *Fn* #: (a) Hydraulic jump, flows in rivers & open conduits, spillway flow of a dam
- Hydraulic jump video

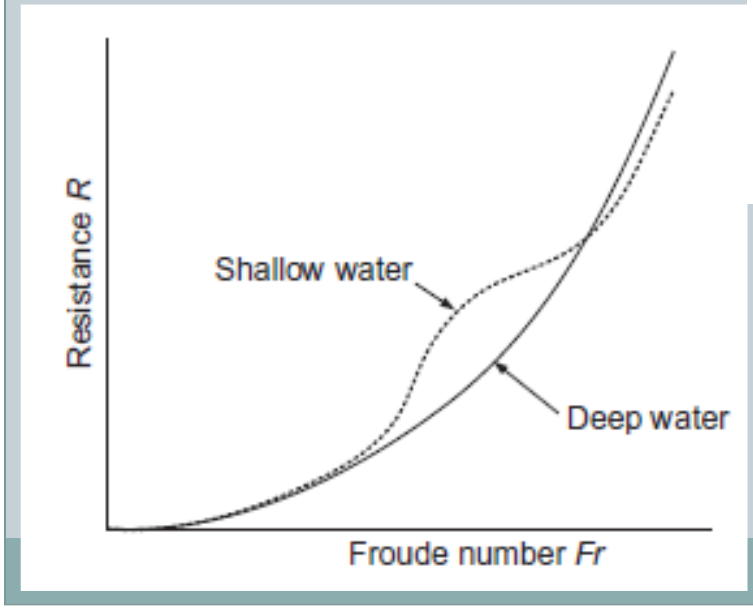


Fr	y_2/y_1	Classification	Sketch
<1	1	Jump impossible	
1–1.7	1–2.0	Standing wave or undulant jump	
1.7–2.5	2.0–3.1	Weak jump	
2.5–4.5	3.1–5.9	Oscillating jump	
4.5–9.0	5.9–12	Stable, well-balanced steady jump; insensitive to downstream conditions	
>9.0	>12	Rough, somewhat intermittent strong jump	



Uses of Froude's number





Reynold's number

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

$$\mathrm{Re}\# = \frac{Intertial\ force}{Viscous\ force} = \frac{\rho V \ell}{\mu} = \frac{V \ell}{\nu} \qquad (8)$$

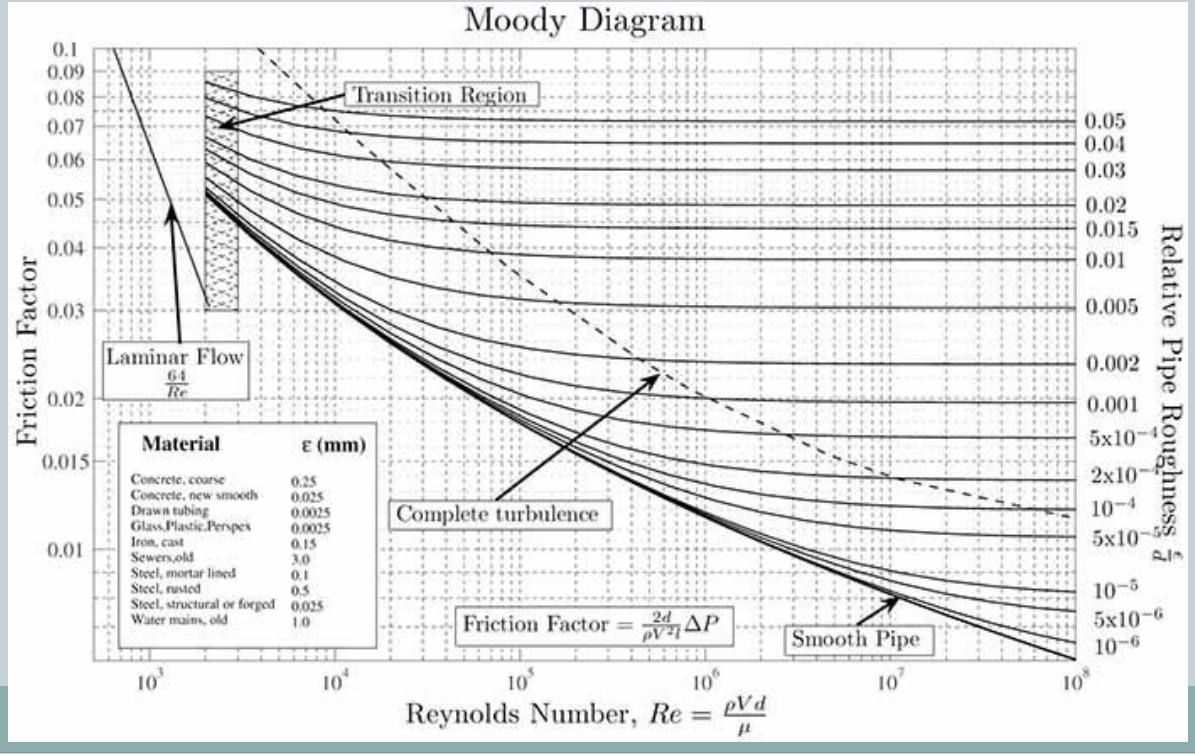
where μ is the dynamic (absolute) viscosity (Pa·s=(N·s)/m² or kg/(m·s)) & ν is kinematic viscosity (ν=μ/ρ, m²/s)

- $Re_m = Re_p$ 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, ocean platforms, aircraft, propeller design, …
  - Characterise flow regimes e.g., laminar, transition, turbulent flow,
  - Pipeline engineering,
  - Aircraft design,
  - Haemodynamics, etc.

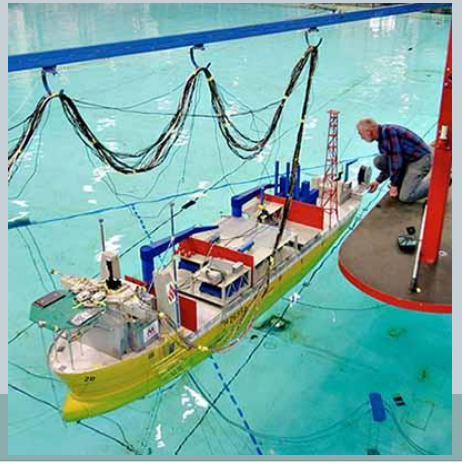


Model testing

- 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, artificial hearts, pumps, …

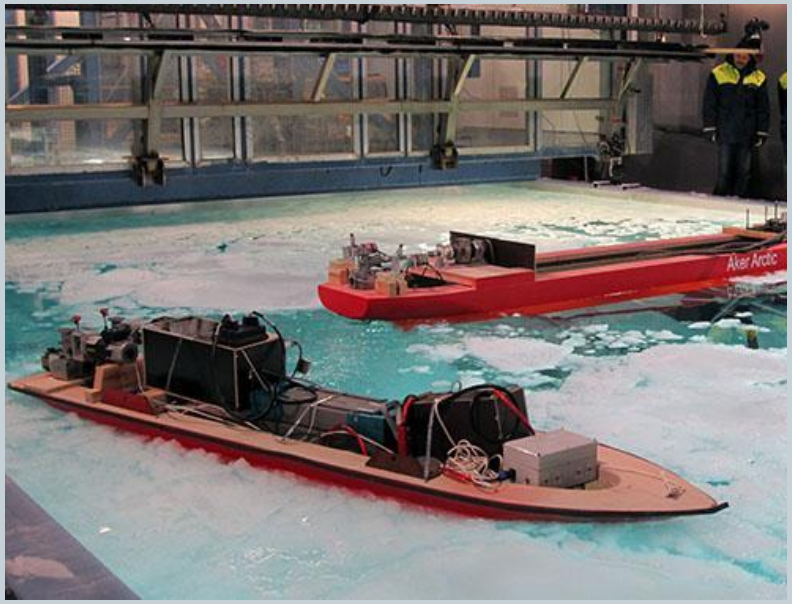






Dynamic similarity

- 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





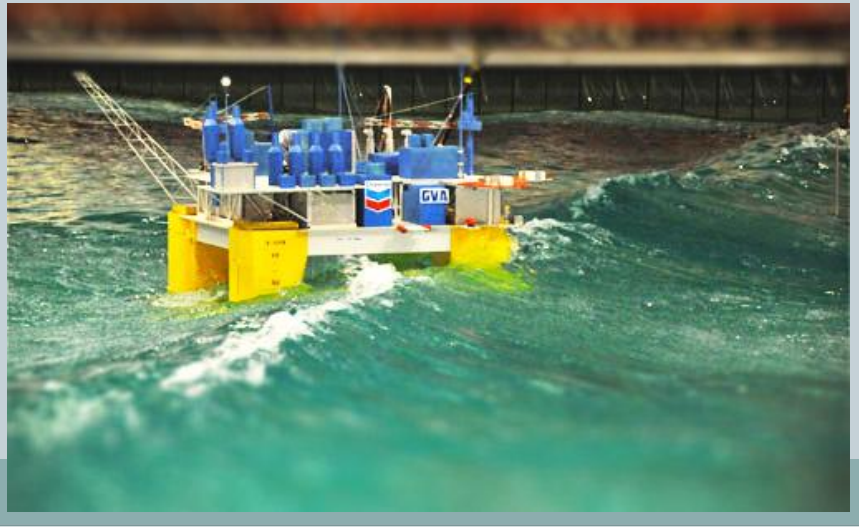
Model testing (2)

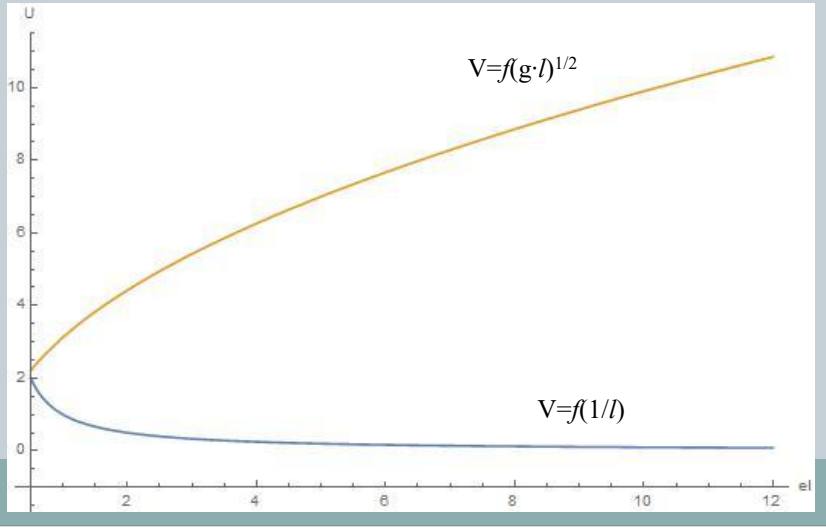
- Both *Re* & *Fn* numbers cannot be satisfied simultaneously since:

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

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

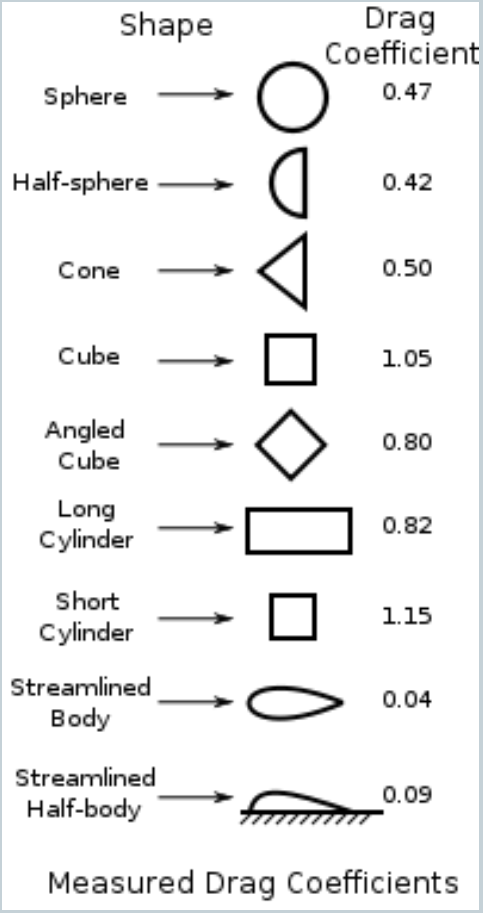
- Distorted models are then corrected





Example #6

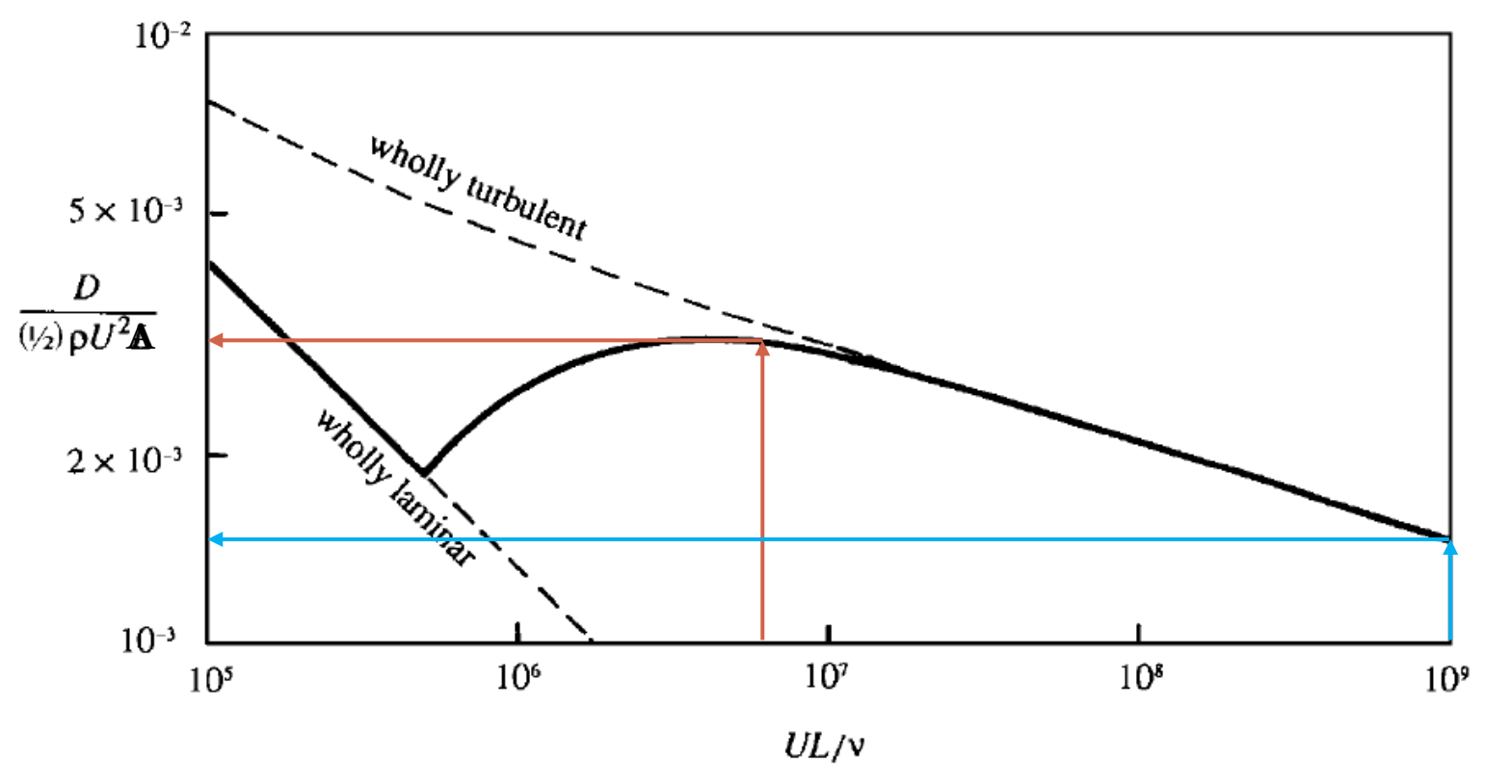
- Drag coefficient in fluids with Re#: ~10^4



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.

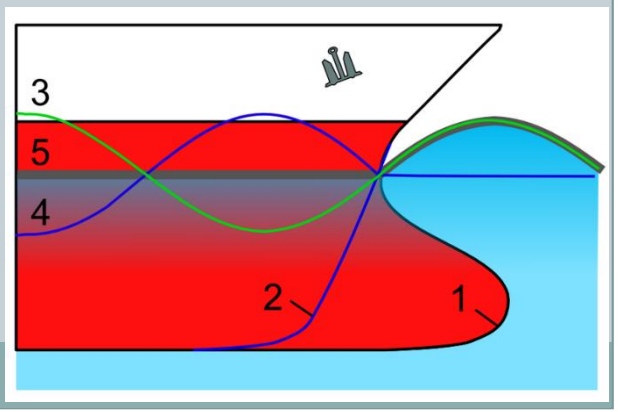


Bulbous bow

- Bulbous bow is a protruding bulb at the ship's bow below the waterline
- Modifies wave making resistance (drag), boosts speed, range, …
- Bulbous bow also lowers fuel efficiency by 12-15% vs no bulbous bow
- Enhances buoyancy, stability and lowers vessel's pitching
- Conditions:
  - Waterline: >15m
  - Bulbous bow optimised for vessel service speed
- Ships <4,000 dwt & speed <12knots, suffer from eddies
- Adds to wetted surface area, construction & maintenance costs







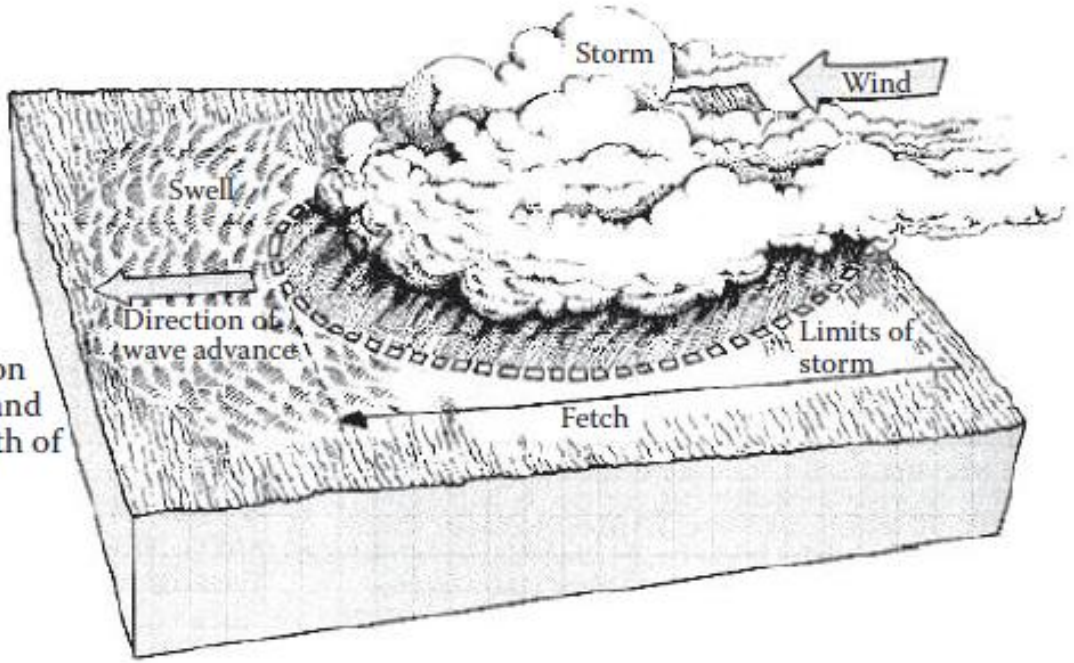
Bulk Carriers

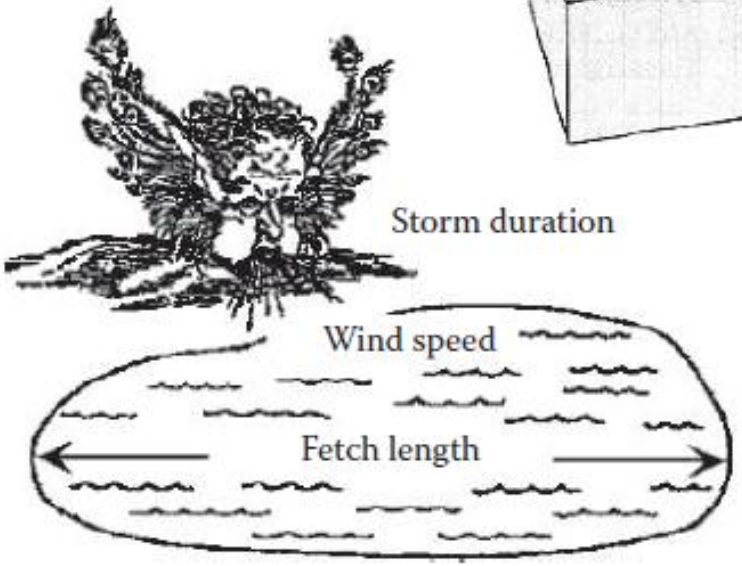


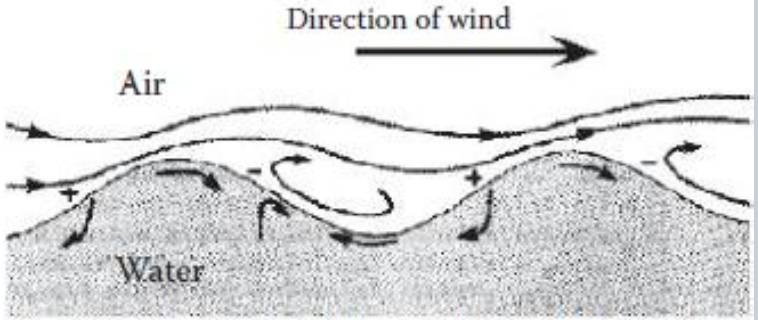
Ocean currents and ocean circulation

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 (& momentum) 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

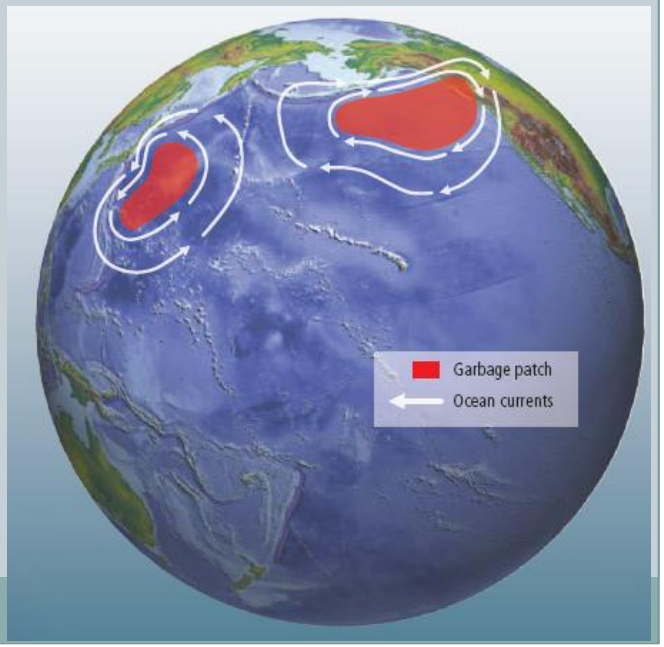


Importance of ocean currents

- 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

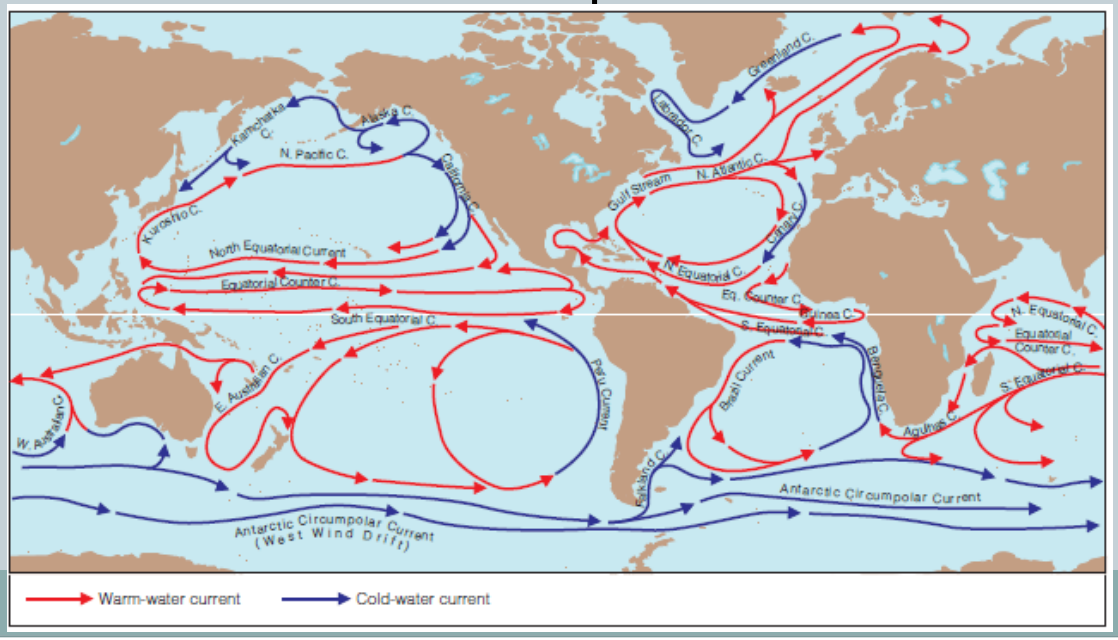
Phytoplankton transport, Honshu, Japan

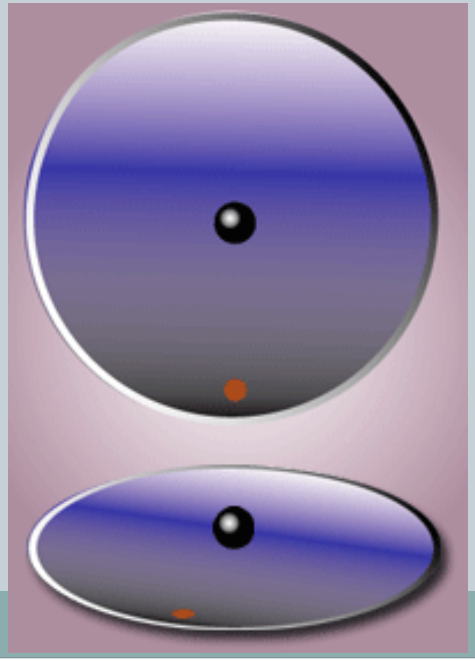




Ocean currents

- 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

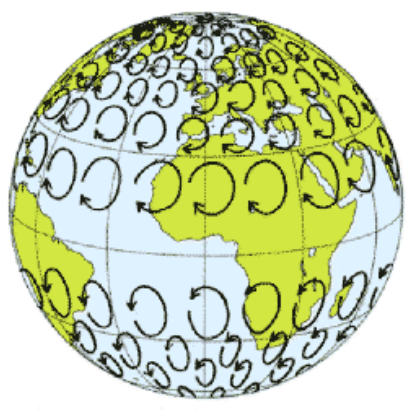




Ocean currents

- 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, and
  7) Self-edge currents caused by ΔTs



Garrison (2012)



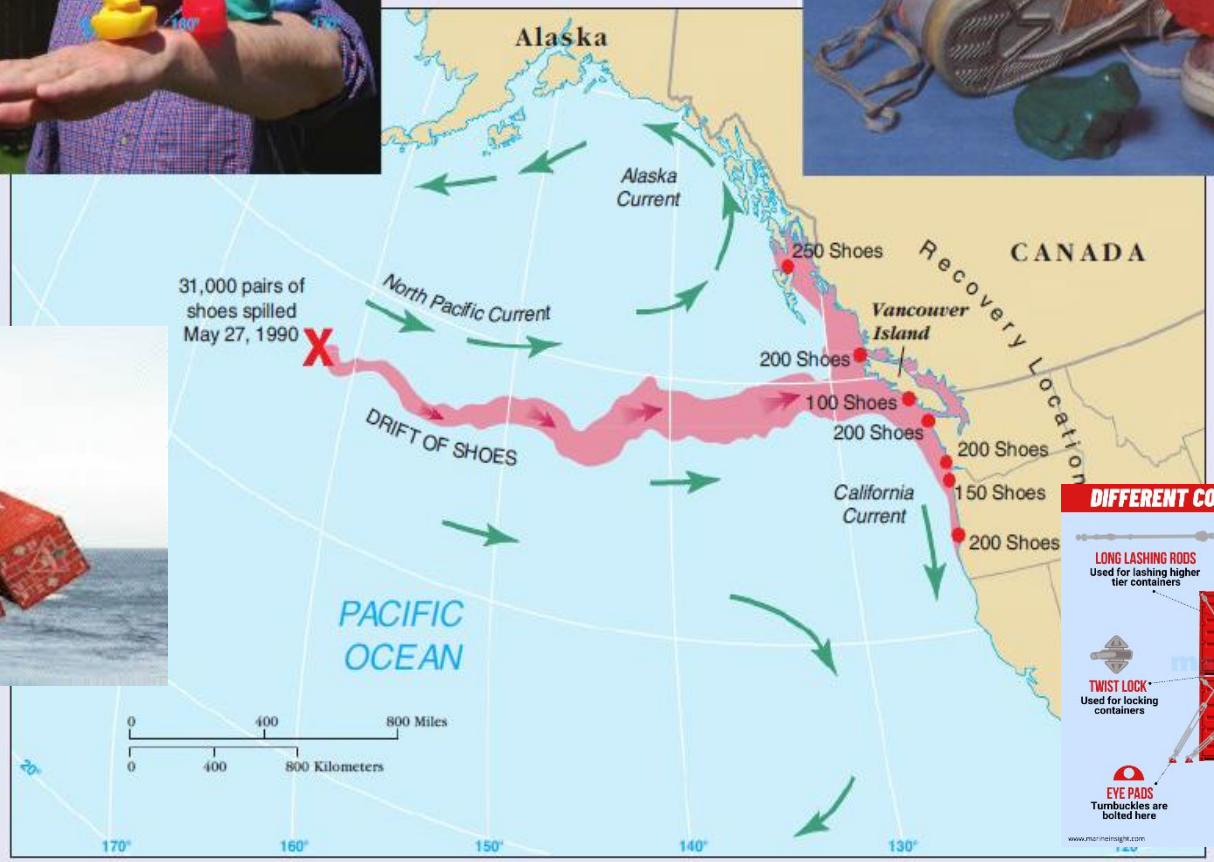
Shoes & bathtub toys as drifters

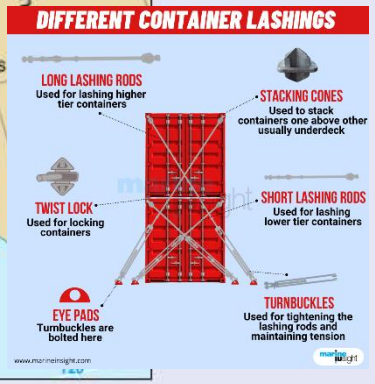
- 30,910 shoes
- 01/1992: 29,000 floating toys
- 6 months
- 2,400km





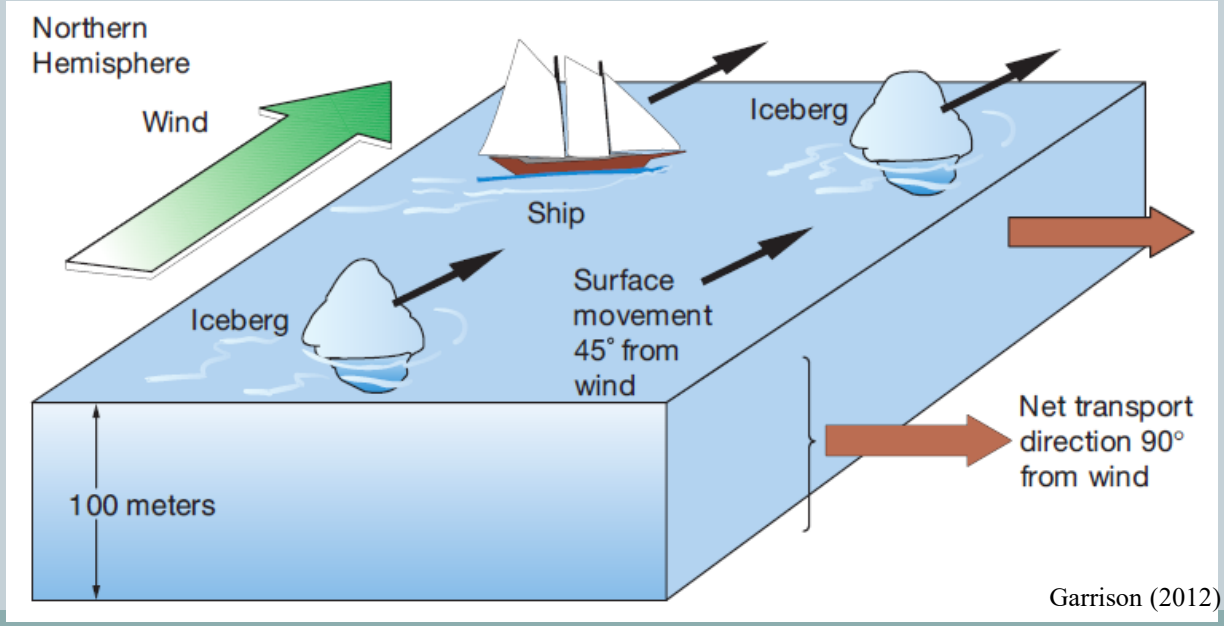






Ekman transport

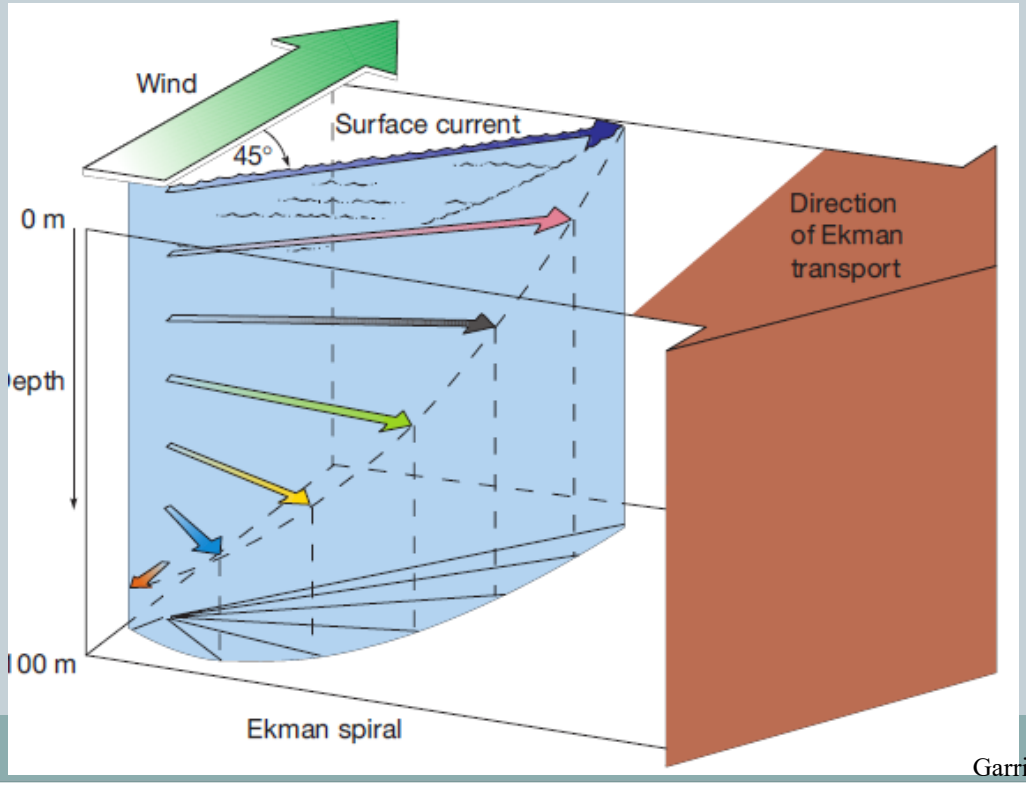
- Why does water, icebergs & vessels move 90° to wind currents?
- Why do ocean currents rotate CLW in N. hemisphere & ACLW in S. hemisphere?
- Attributed to balance btw *frictional effects* & *Coriolis force*

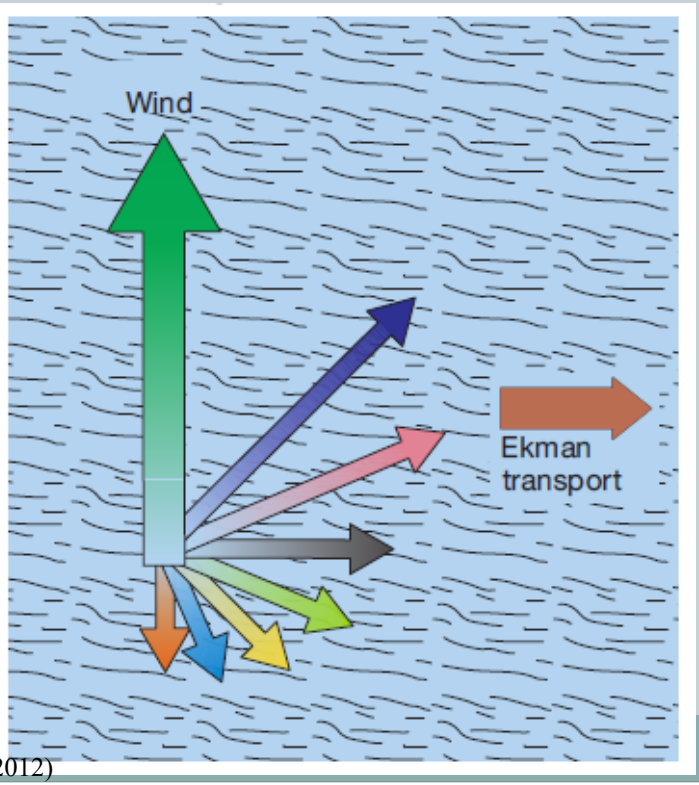


Garrison (2012)

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°

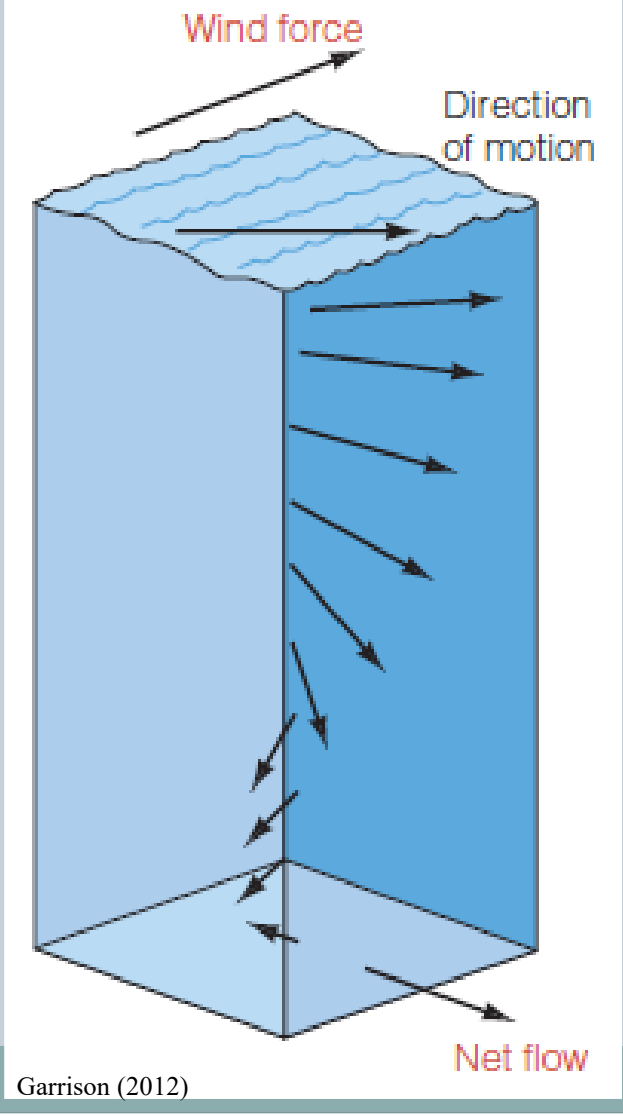




Garrison (2012)

Ekman "spiral" (2)

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



Garrison (2012)

Measuring wind and current speed

- Wind speed measured using:
  - Cup anemometer
  - Vane anemometer
  - 3D ultrasonic anemometer





Vane anemometer



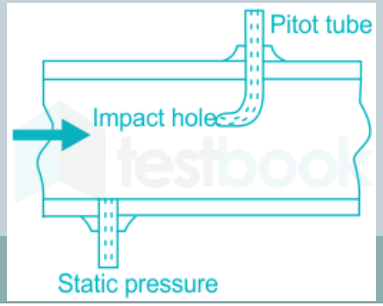
3D ultrasonic anemometer



- Water current velocity measured by:
  - Acoustic Doppler current profiler
  - Pilot tubes
  - Water flow probe

Acoustic Doppler current profiler





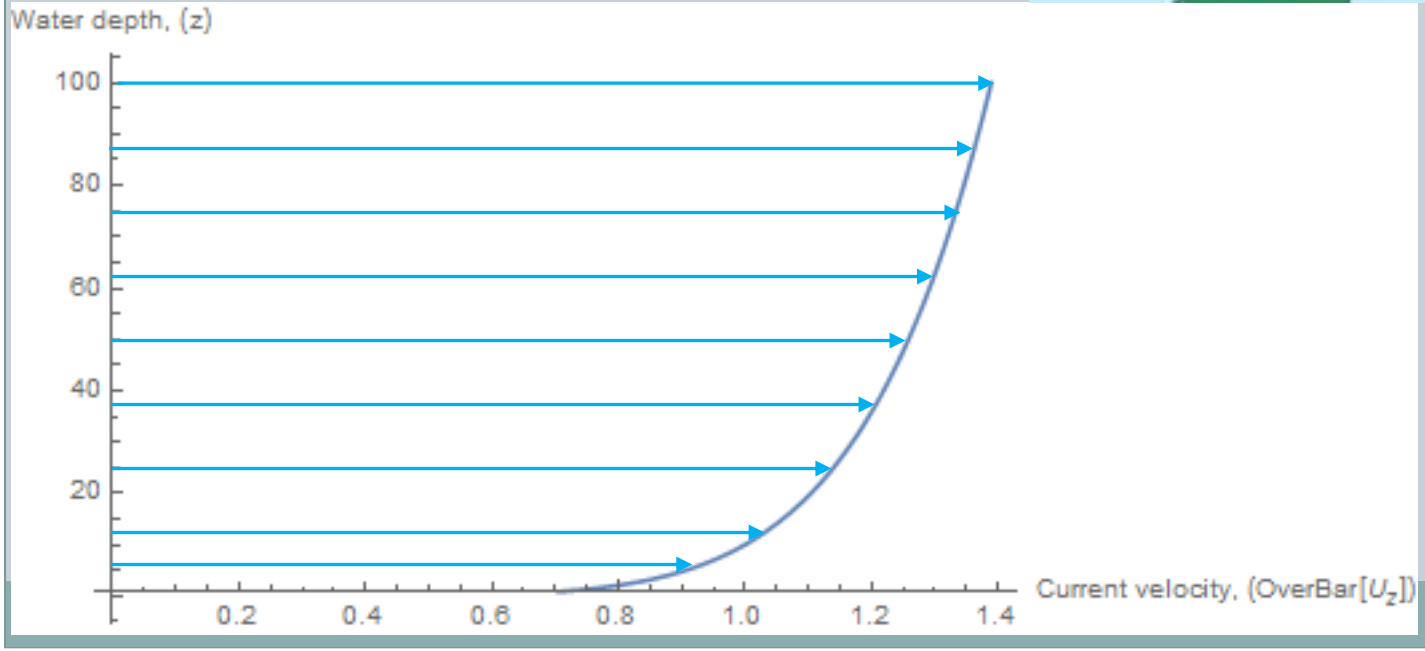
Water flow probe



Ocean currents

- Theory
- Gulf Stream: 100km wide by 800–1,200m deep
- Max velocity at surface: 2.5m/s





Exercise #7

- Ex#7

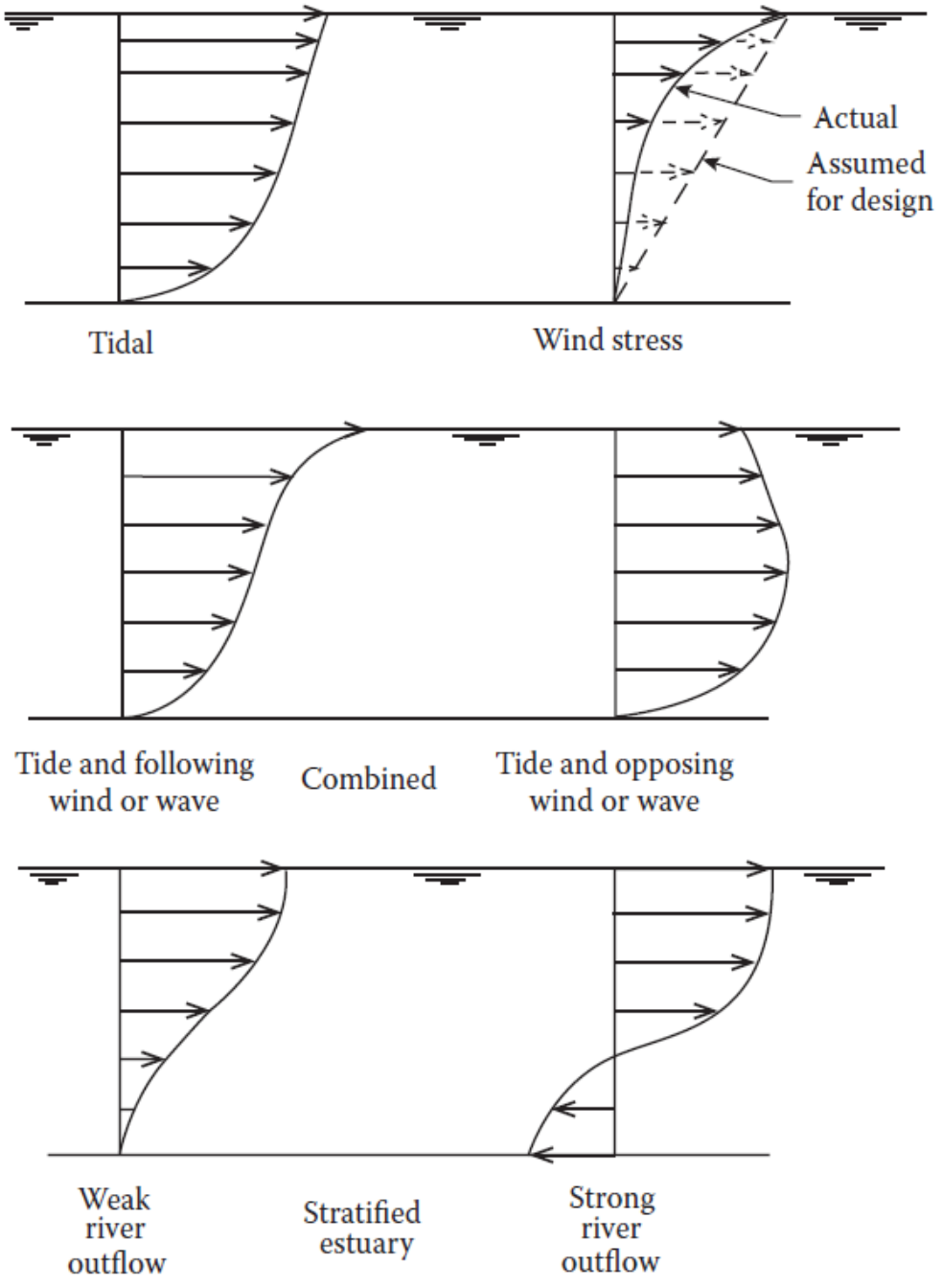
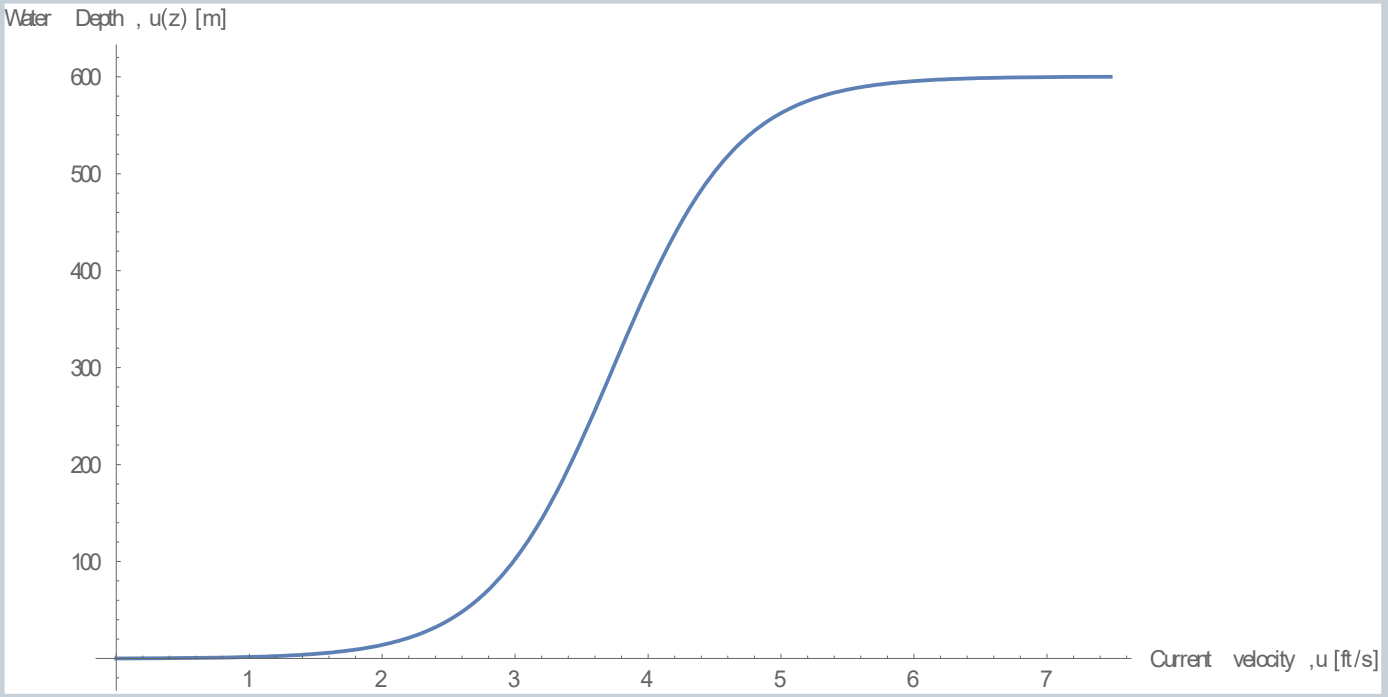


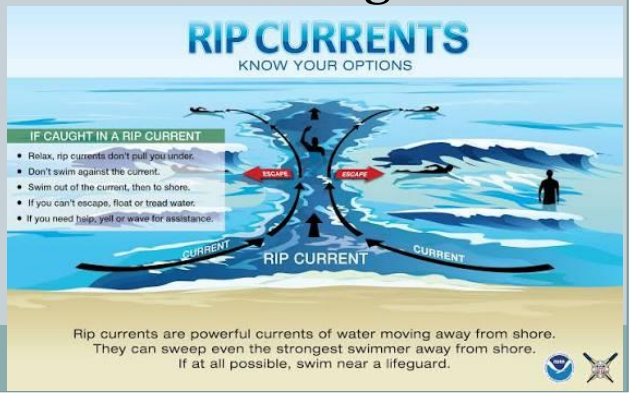
Fig. 2 Various ocean current velocity profiles

Ex.#7


Water Depth , u(z) [m]
600
500
400
300
200
100
1
2
3
4
5
6
7
Current velocity ,u [ft/s]

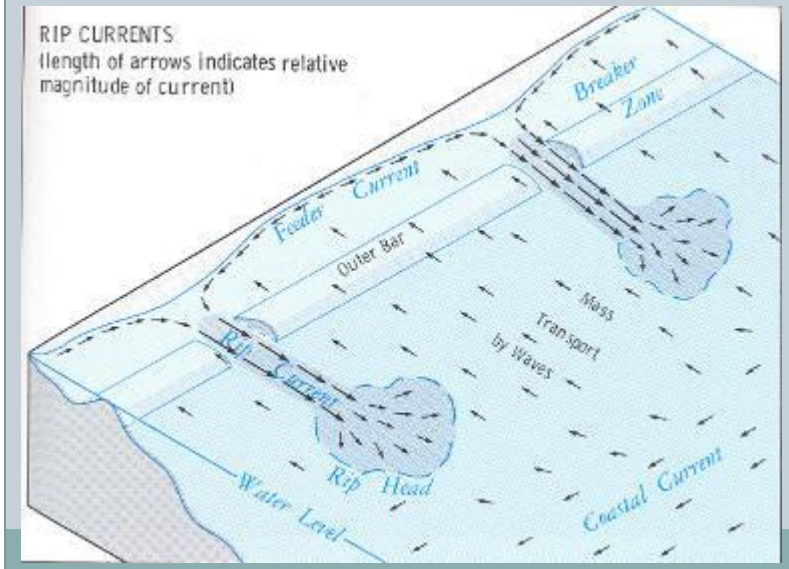
Rip currents

- Rip currents are narrow, fast-moving channels of water that flow from the shoreline back out to sea through the surf zone.
- They form when waves & accumulated water near the beach seek the easiest path offshore, often through gaps in sandbars.
- Rip currents can reach speeds of up to 2m/s (4.5 mph) or more, making them stronger than many swimmers.
- They do not pull people underwater, but they can rapidly carry swimmers away from the shore, creating a drowning hazard.
- If caught in a rip current, stay calm, float, and swim parallel to the shoreline until free of the current, then return to shore at an angle.
- www.youtube.com/watch?v=PuAlDTC_gIQ
- www.youtube.com/shorts/PL9kGg2Anbk



Rip currents (2)

- Rip currents manifest above deeper sea channels
- Pose a trap as water in rip currents is calm
- Rip currents will pull you in the sea
- Advice: do not swim against the current
- Remain afloat, go with the flow and escape their loop
- Some of course, induce vortices. Seeking help is the best approach.





Thanks for your attention!