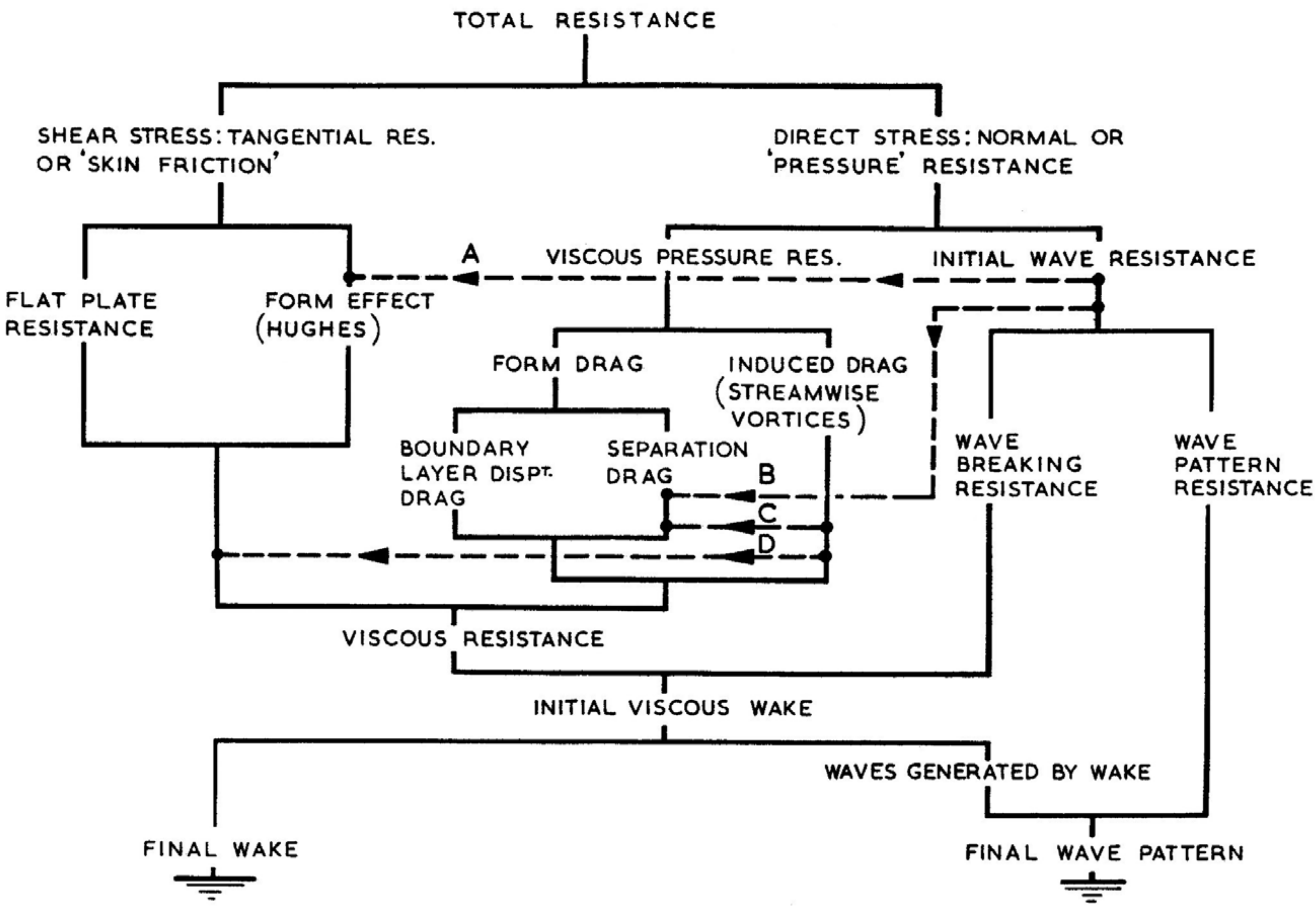
Propulsion & Resistance 1 – lecture 2

Mt 527

1. Similarity laws and scaling
2. Flow models
3. Inviscid flow and wavemaking drag

Decomposition of Resistance

Source: ITTC 1972 Res. Committee



Derivation of Rn and Fn

- Chapter 3 – Similarity

- Navier Stokes eq. for x–direction

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

- Boundary Conditions (bc's)

Scaling dilemma

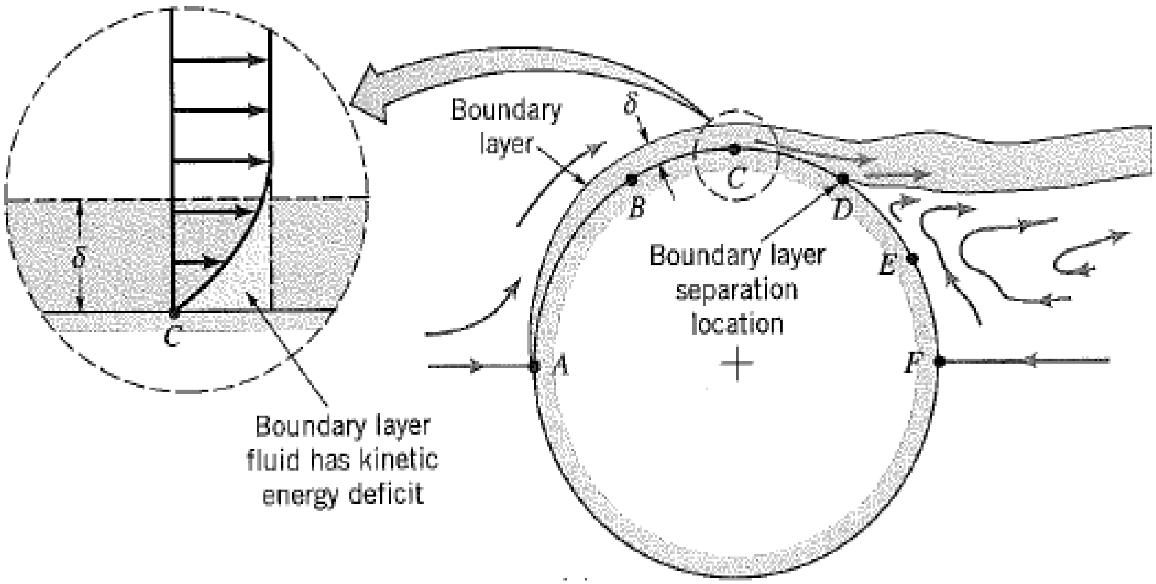
- Obeying Rn and Fn equality is impossible for different scales!
- How do we scale Rm to Rs

Different flow models

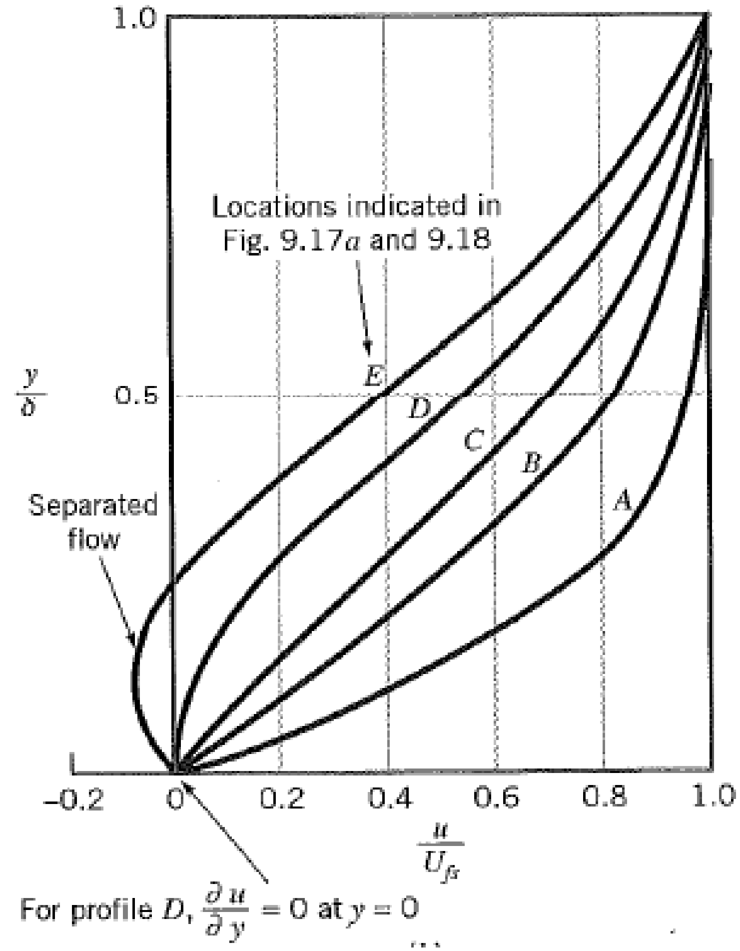
- Euler eq.
- Bernouilly eq.
- Introduction of scalar function velocity potential $\vec{v}(x, y, z) = \nabla \phi$
- Laplace equation $\nabla^2 \phi = 0$

Inviscid flow and wavemaking drag

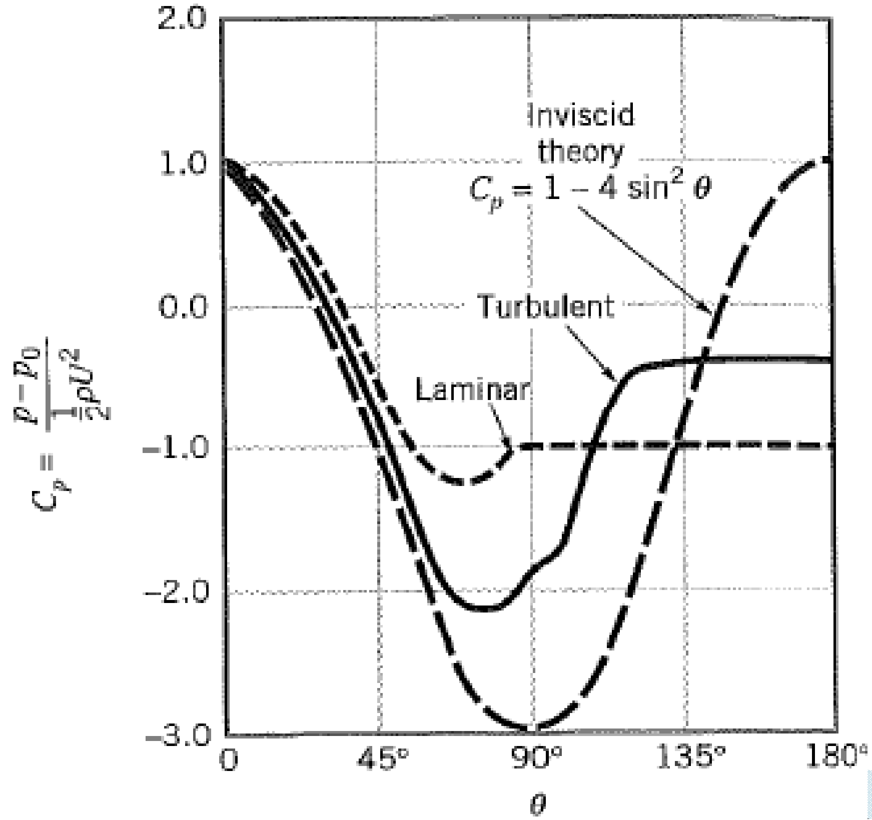
Deeply submerged body



Boundary layer
δ
C
B
D
E
A
F
Boundary layer separation location
Boundary layer fluid has kinetic energy deficit



1.0
0.5
$\frac{y}{\delta}$
Locations indicated in Fig. 9.17a and 9.18
E
D
C
B
A
Separated flow
−0.2
0
0.2
0.4
0.6
0.8
1.0
$\frac{u}{U_{fs}}$
For profile D, $\frac{\partial u}{\partial y} = 0$ at $y = 0$



$C_p = \frac{p - p_0}{\frac{1}{2}\rho U^2}$
2.0
1.0
0.0
−1.0
−2.0
−3.0
Inviscid theory
$C_p = 1 - 4\sin^2\theta$
Turbulent
Laminar
0
45°
90°
135°
180°
θ

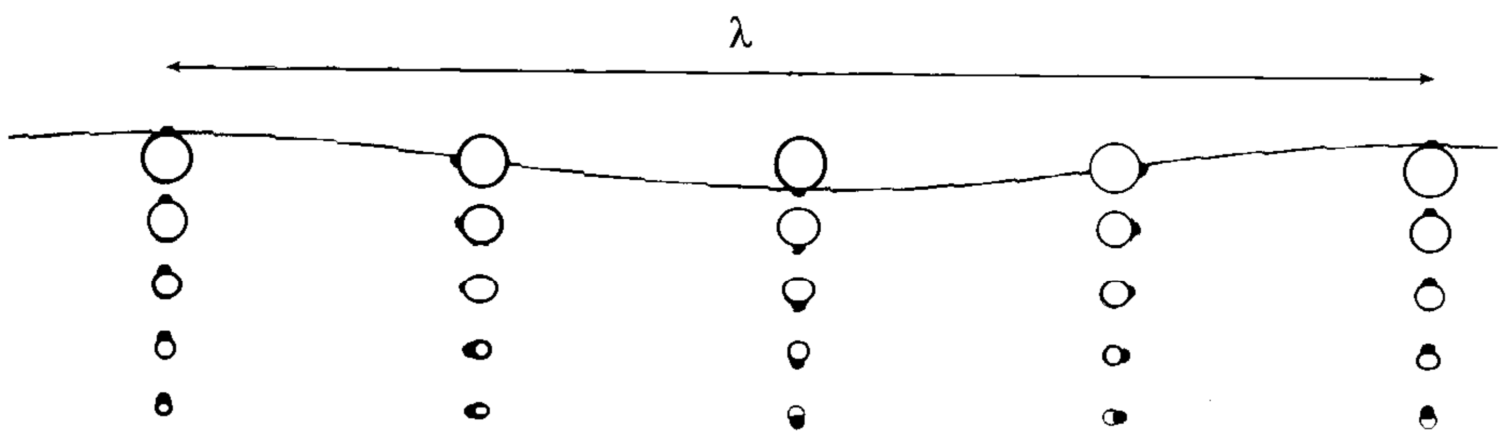
But,.....
most of the ships operate at the free surface

Questions

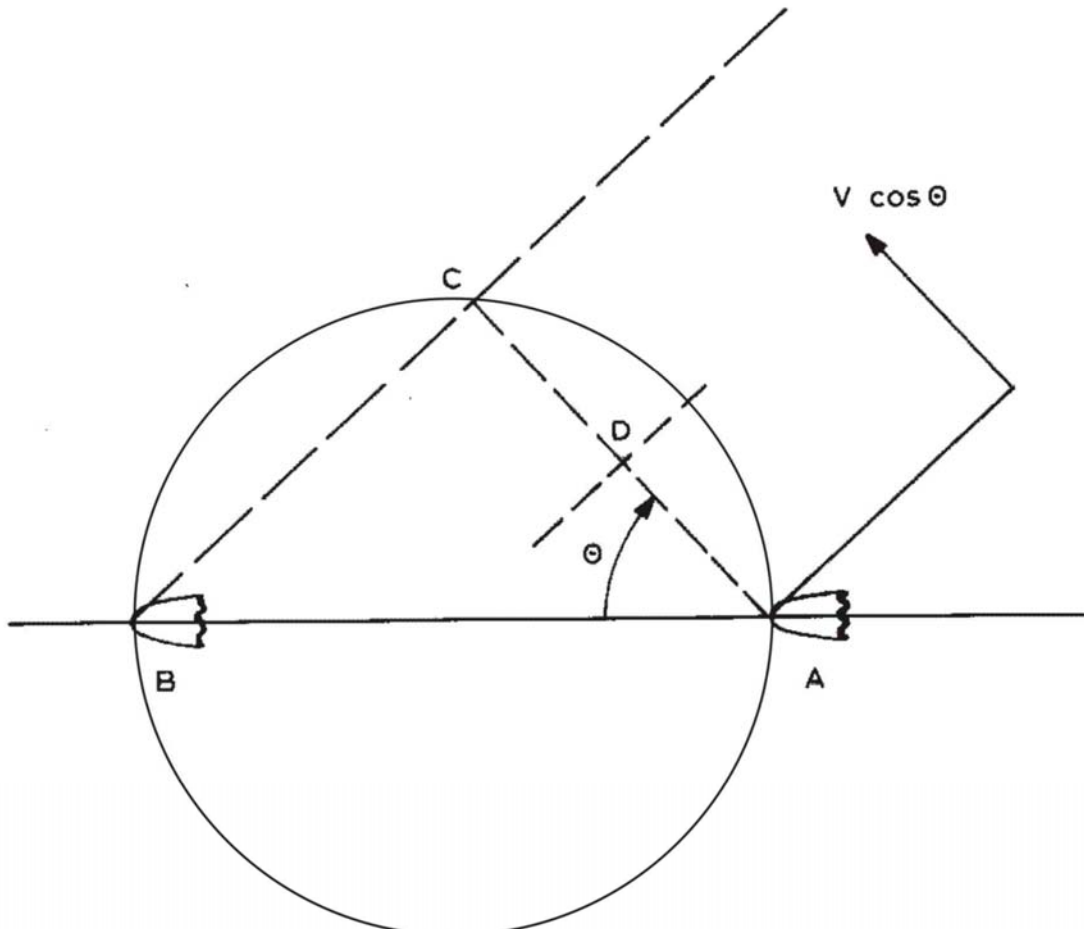
- How much energy is lost in wave system
- How can we compute or measure it
- How can we improve it

before looking for answers, we look for fundamental understanding

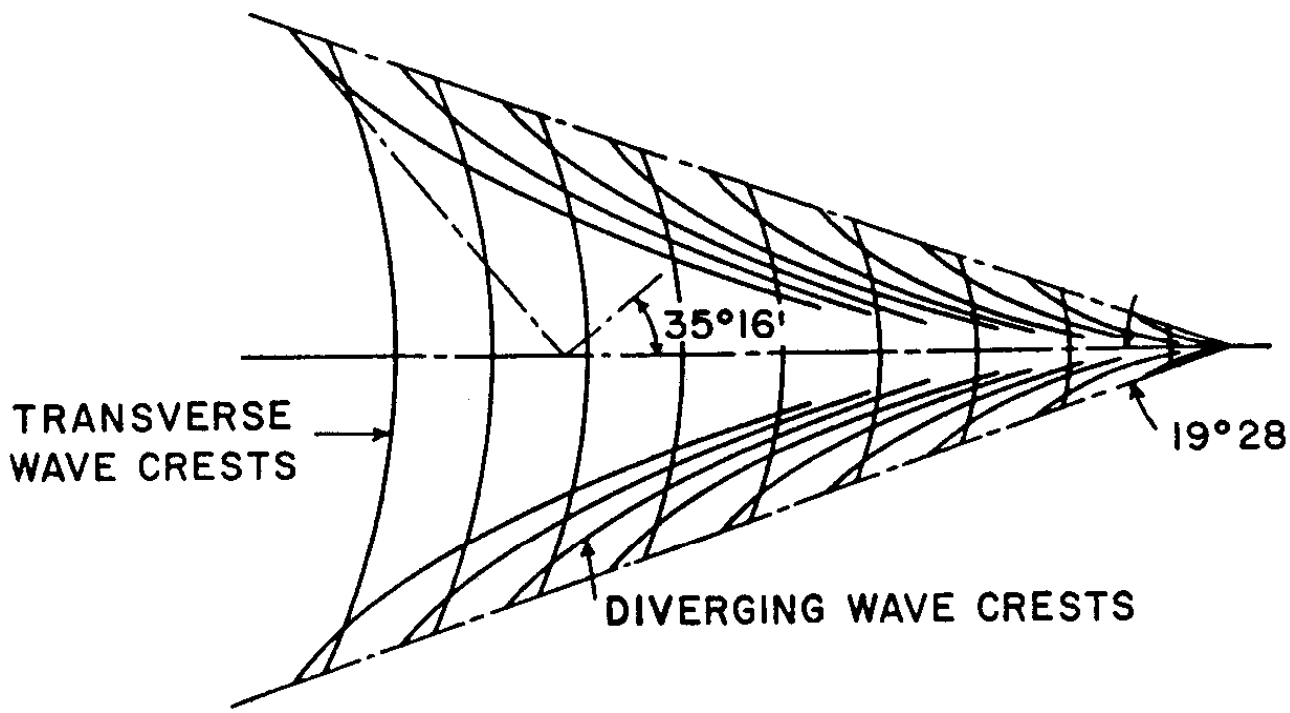
Motions of fluid particles in waves



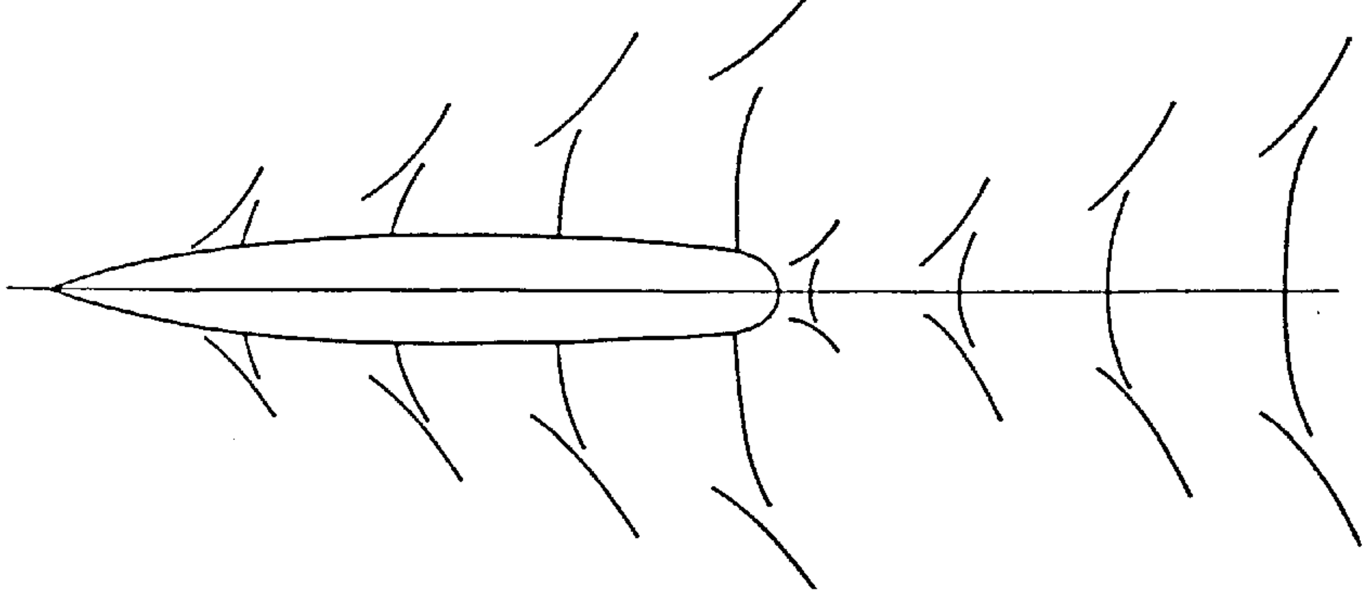
Wave propagation from a Kelvin Source



Wave system by a traveling pressure point – The Kelvin wave system



Wave system from a ship



Analysis of ship wave patterns --- general approach

- A ship wave pattern will be considered as consisting of separate sinusoidal wave components
- These components originate from different points, have different directions and lengths
- Wave lengths and wave directions are connected via the dispersion relation
- To improve a ship, reduce amplitudes of wave components, and improve their interference.

points to be clarified:

- may we superimpose wave components?
- are sinusoidal waves a good approximation?
- wave length / wave direction related how?

is it permitted to consider wave components separately, and superimpose them?

justification 1:

- look at intersecting wave patterns of different ships (or ducks). they seem to sum up without affecting each other.

justification 2:

- waves are governed by field equation and the free-surface boundary conditions.
- we have to demonstrate that for both we may apply superposition.
- for field equation: transition to potential flow.
- for free-surface boundary conditions, linearity for small wave amplitudes.

Superposition of wave components

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Analysis of ship wave patterns --- justification 2 (I)

- Ship wavemaking can be approximated as an inviscid process: Navier-Stokes equations → Euler equations
- Irrotational flow: Euler equations → Bernoulli equation
- Irrotational flow: velocity vector is gradient of potential
- Continuity equation → Laplace equation
- Laplace is a linear and homogeneous equation: superposition of solutions is permitted.

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Analysis of ship wave patterns --- justification 2 (II)

- Free-surface flows have to satisfy free-surface boundary conditions:
- dynamic condition: pressure at water surface is atmospheric
- kinematic condition: wave surface moves with the flow
- For small wave amplitudes: linearisation permitted → Kelvin condition
- This is a linear and homogeneous condition: superposition of solutions is permitted.

Conclusions so far

points to be clarified:

- may we superimpose wave components?

  YES, if:
  - Viscous effects negligible
  - Small wave amplitudes
- are sinusoidal waves a good approximation?
- wave length / wave direction related how?

Important relations

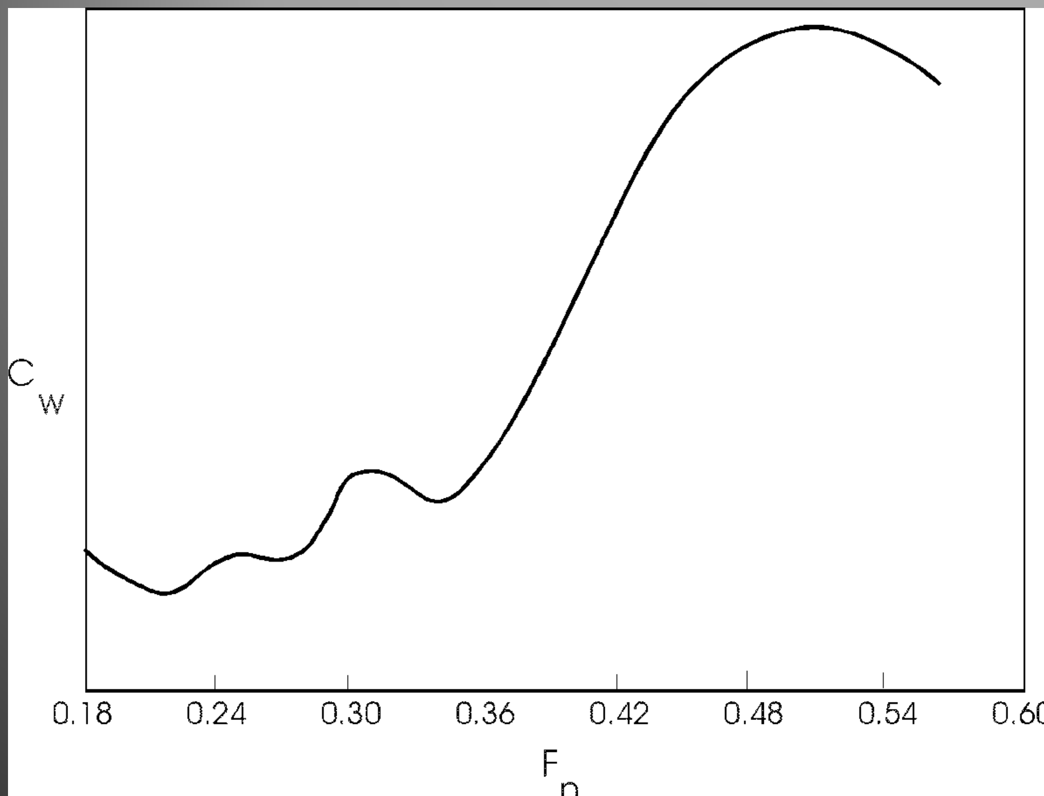
- Dispersion relation for wave of "phase" velocity $v_w = \sqrt{\dfrac{g\lambda}{2\pi}}$
- Wave group velocity $v_g = \tfrac{1}{2} v_w$
- Wave crest velocity: $v_c = \tfrac{1}{2} v_w \cos\theta$

- Energy in a plane wave per unit area: $E_w = \tfrac{1}{8}\rho g h_w^2$
- Wave resistance of a traveling Kelvin pressure source

$$R = \tfrac{1}{8}\pi\rho V^2 \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \left[h_w(\theta)\right]^2 \cos^3\theta \, d\theta$$

Example of wave resistance coefficient

showing characteristic humps and hollows



$$L_{SS}\left(economical\right) = k\frac{2\pi V^2}{g}$$

Hull speed

Questions

- How much energy is lost in wave system
- How can we compute or measure it
- How can we improve it

Study guidelines

5.1 reproduce

5.2 Inviscid flow around a body – reproduce but equations need not be reproduced, with the exception of potential function definition (5.5), Bernouilly (5.3 & 5.8) and Laplace (5.11)

5.3 Free surface waves

5.3.1 Derivation of sinusoidal waves – read

5.3.2 Properties of sinusoidal waves – read but reproduce Linearity, Dispersion relation (5.25), Group velocity (5.27)

5.4 Ship waves – read

5.4.1-5.4.2 – understand

5.4.3 Kelvin pattern – understand

5.4.4 Ship wave patterns – understand

Study guidelines – 2

5.5 Wave resistance – Read

Understand and reproduce interference of wave systems leading to humps and hollows

5.6–5.12 is allowed to skip

Exercise

- Tentamen W&W mt527 – 17 Jan. 2011
  - Vraag 1a t/m d
- Zie BB: mt527 – course information – exam material