Propulsion & Resistance 1 – lecture 1

Mt 527

1. Introduction
2. Governing physics
3. Decomposition of resistance
4. Similarity laws and scaling

Introduction to the course

- Importance of proper power-speed prediction
- Resistance, prop. efficiency, power
- Wake field
- Experimental, empirical or numerical prediction
- Propeller design and cavitation

Study goals

- Understand the *mechanisms for ship resistance and extrapolation* to another scale.
- Understand the *principles of ship propulsion* (actuator disk, ideal efficiency)
- Master a *first propeller design* capability based on systematic series
- Understand *cavitation nuisance* and have a first understanding of the principles.

Historic Perspective

Experimental Prediction
– History

- Earliest model tests

1500 approx. – Leonardo da Vinci
  Tests on 3 different models with variations in fore- aft displacement distribution
1650 approx. Samual Fortrey
  Towing tests with small wooden models in tank
1770 approx. Pieter van Zwijndrecht Pauluszoon
  Towing tests with different waterline models
1871 First purpose built Tow Tank by Froude in Torquay (UK)
1873 Model tests by Bruno Tideman with naval cruiser "Atjeh" at the Rijkswerf in Amsterdam
1932 Opening of the "Nederlandsch Scheepsbouwkundig Proefstation (NSP)" in Wageningen (currently MARIN)

- But how to scale these models and tests?
  - William Froude 1868 – Decomposition of total resistance
  - $R_T = R_F + R_R$?
    - R_F=flat plate frictional resistance
    - R_R=residuary resistance
  - 1883 Notion of Reynolds number and scaling

Computational Techniques – History

1687 – Newton’s “Pilosophiae Naturalis Principia Mathematica”

1752 – d’Alembert published what is now called “D’Alembert’s paradox” in response of a contest organized by the French “Academie des Sciences”

1757 – Euler (Swiss mathematician) published an important equation governing an inviscid flow

1822-1840 Development Navier-Stokes equations

Underlying Principles

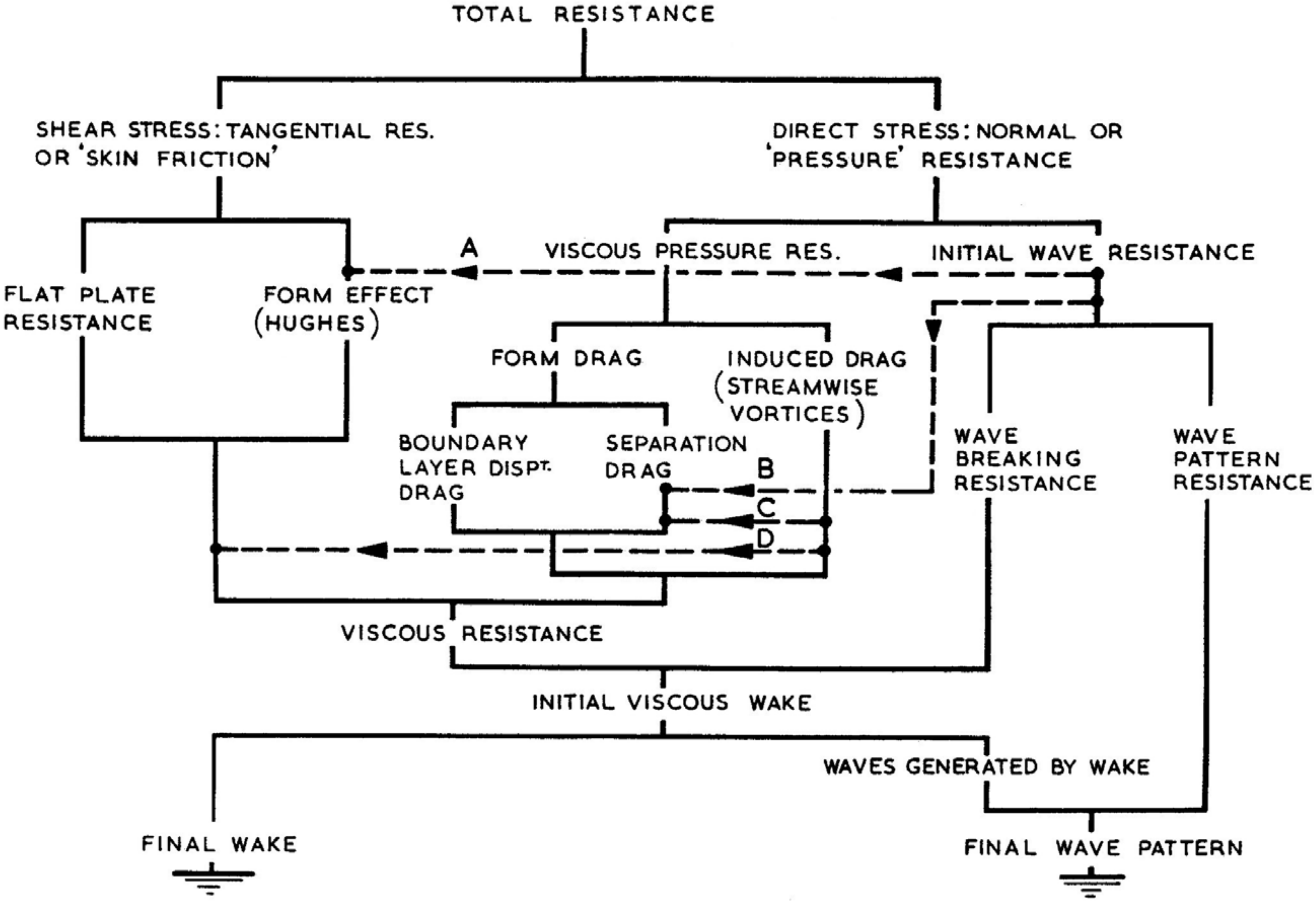
Introduction to continuity, Navier-Stokes and Euler eq's

- What are the principles of the fluid dynamic equations – The conservation laws

The Resistance Breakdown

Decomposition of Resistance

Source: ITTC 1972 Res. Committee



Decomposition of Resistance

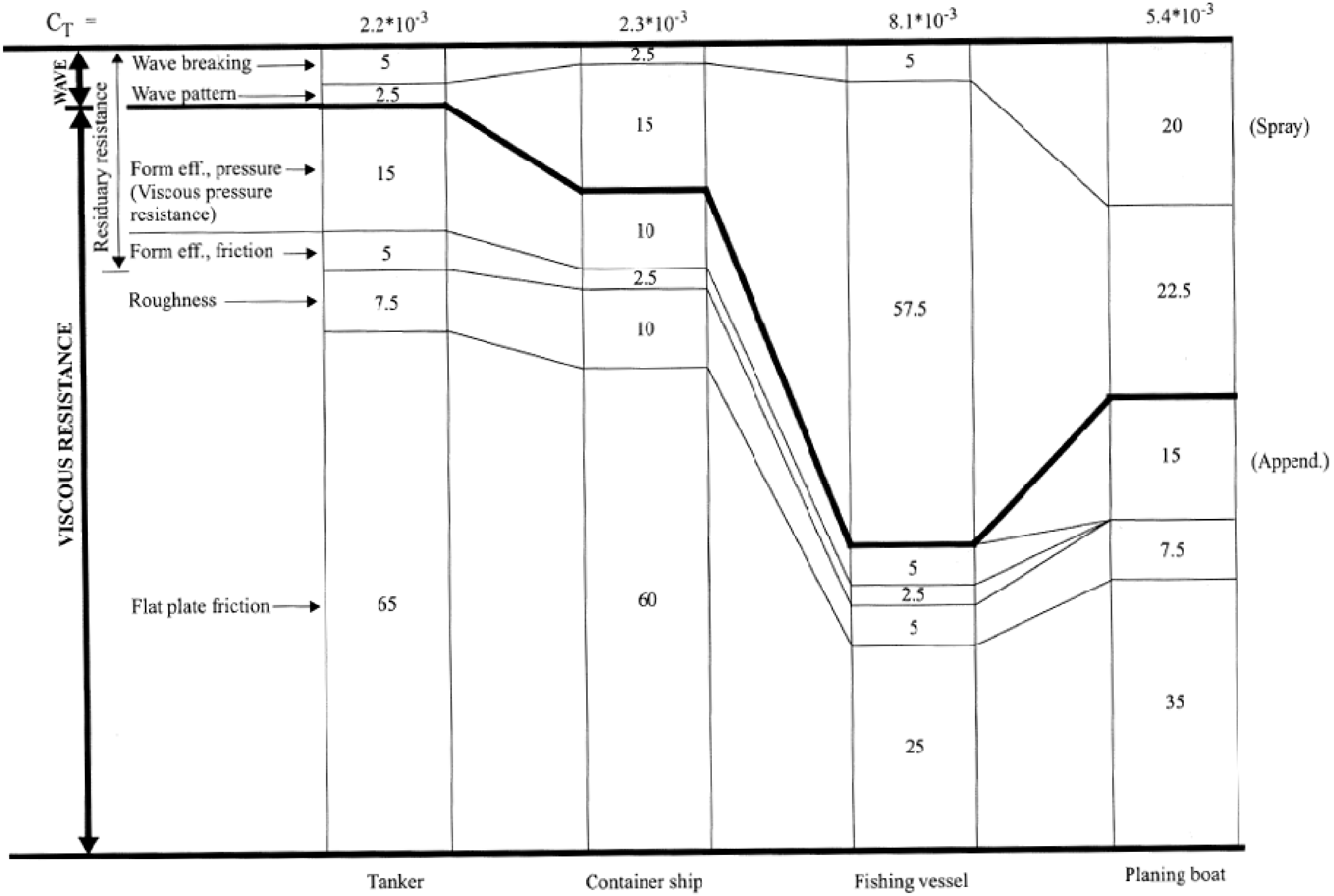


Figure 4.1 Resistance components for four vessels (%).

On flow phenomena

Potential and viscous flow

sheer stress τ [N/m2]:

$$\tau = \mu \frac{\partial u}{\partial y}$$

- velocity U (m/s)
- length scale L (m)
- viscosity μ (Pa s) (kg/ms)
- density ρ (kg/m3)
- kinematic viscosity ν (m2/s)

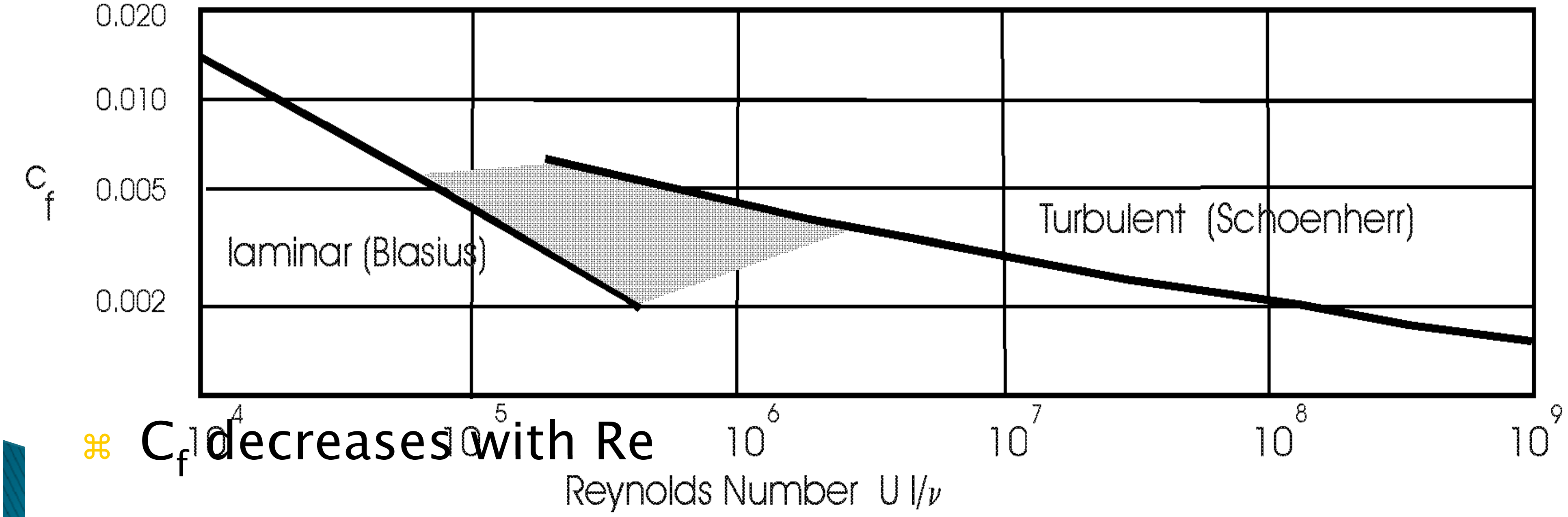
$$\nu = \frac{\mu}{\rho} \qquad \frac{[Pa\sec]}{[kg/m^3]}$$

Reynolds: small => viscosity dominated => viscous flow

UL/ν (-) high => inertia dominated => potential flow

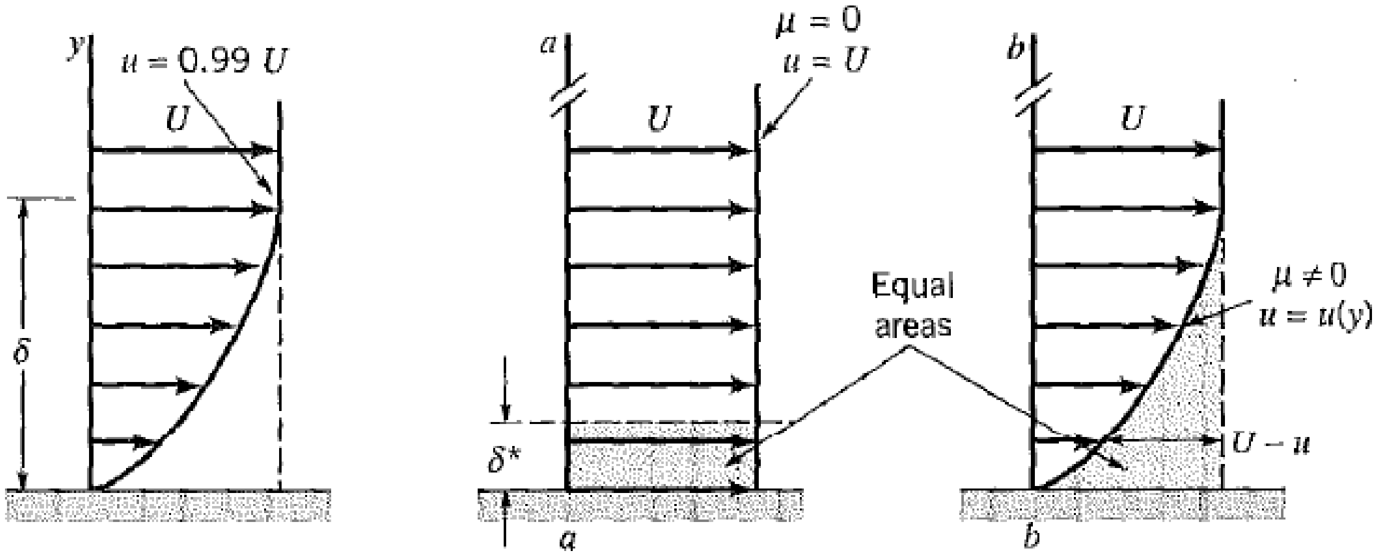
Non dimensional coefficients

- C_f (Re) = Rt / $0.5\rho U^2 S$ is not a constant



- C_f decreases with Re

Boundary layer characterisation

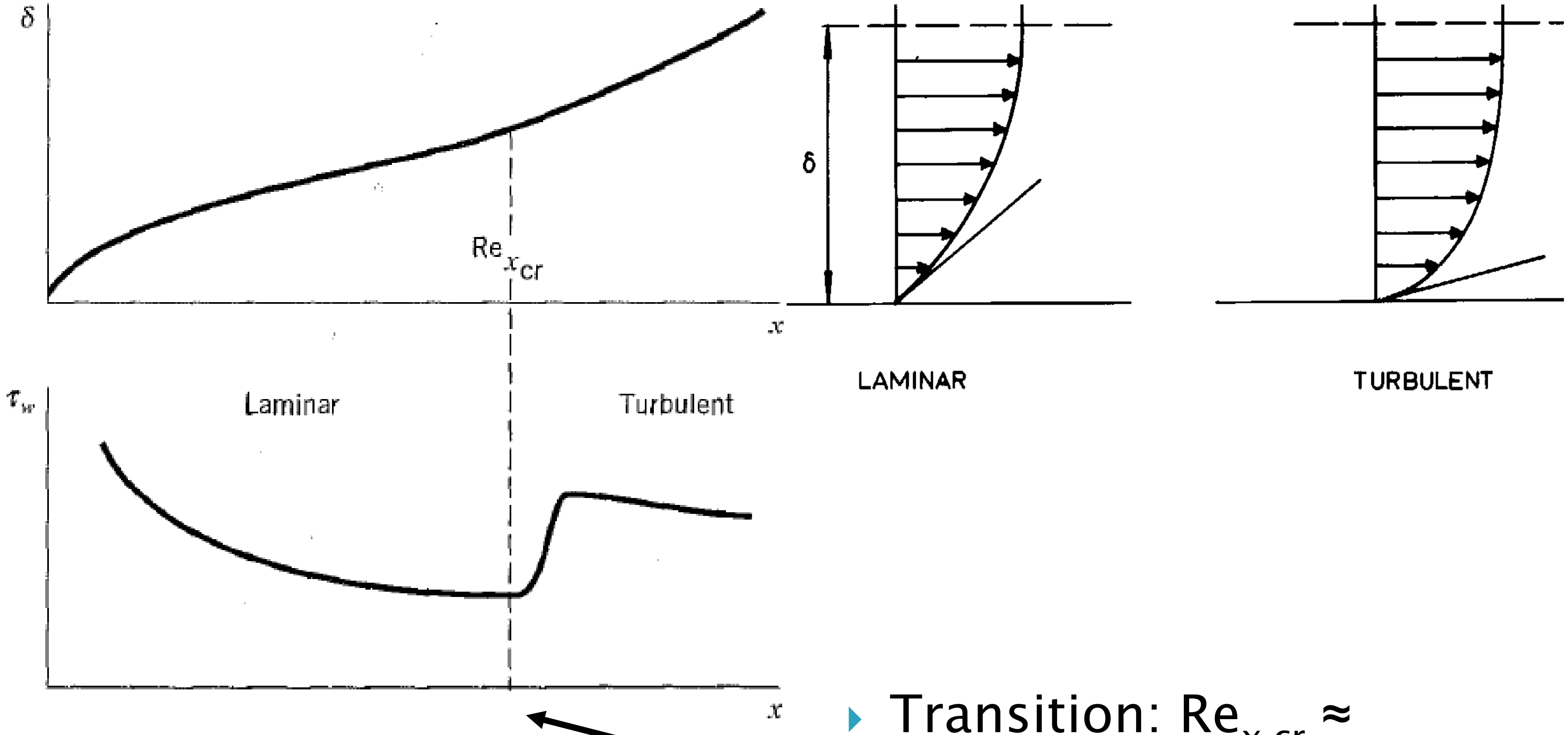


- BL thickness, δ_{99} is difficult to measure => integral measurements
  - displacement thickness
  - momentum thickness

$$\delta^* = \int_0^\infty \left(1 - \frac{u}{U}\right) dy$$

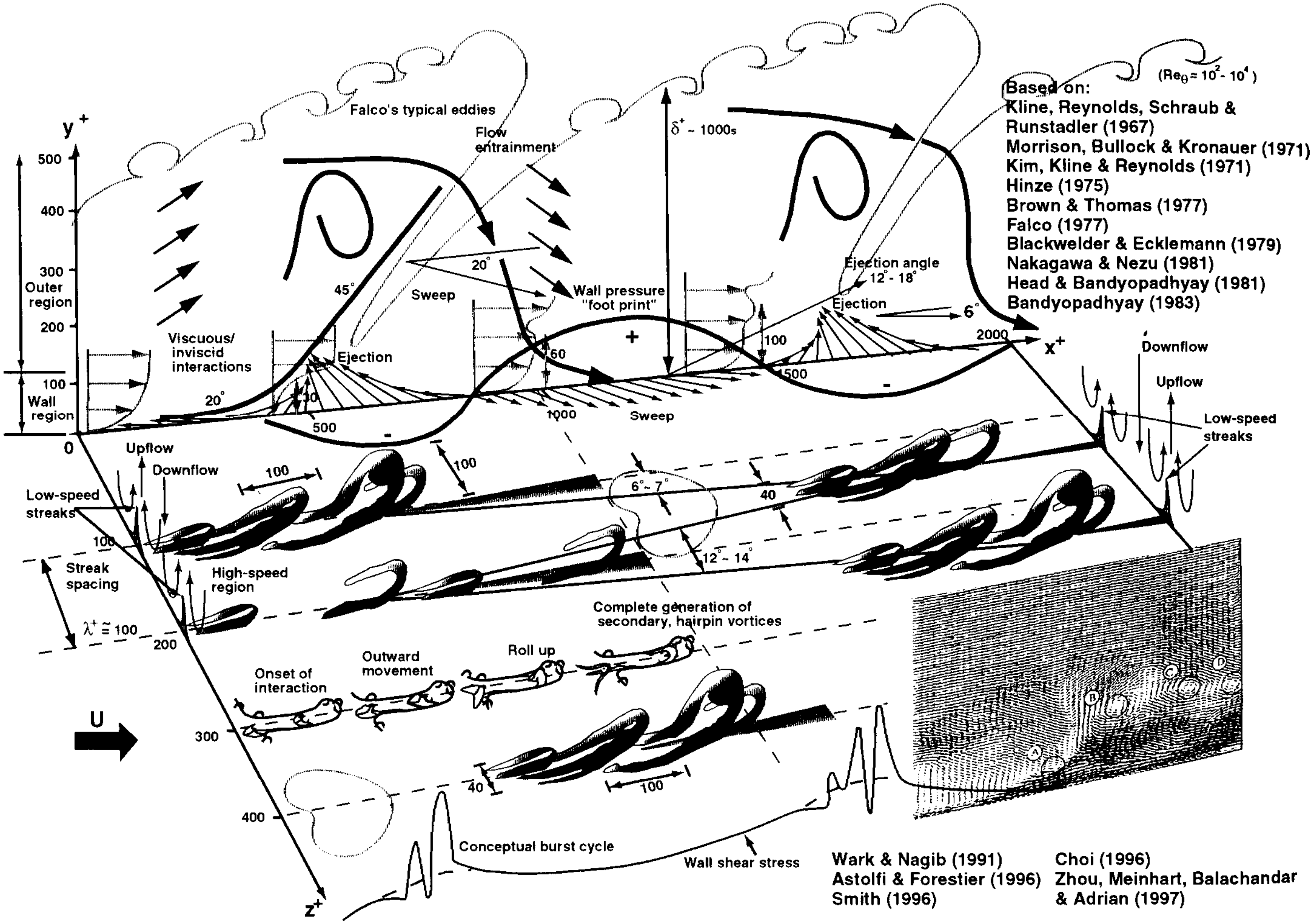
$$\theta(x) \equiv \int_0^\infty \frac{U(y)}{U_0}\left(1 - \frac{U(y)}{U_0}\right) dy$$

Boundary layer development



- Transition: $Re_{x,cr} \approx 10^5$

Development of boundary layer

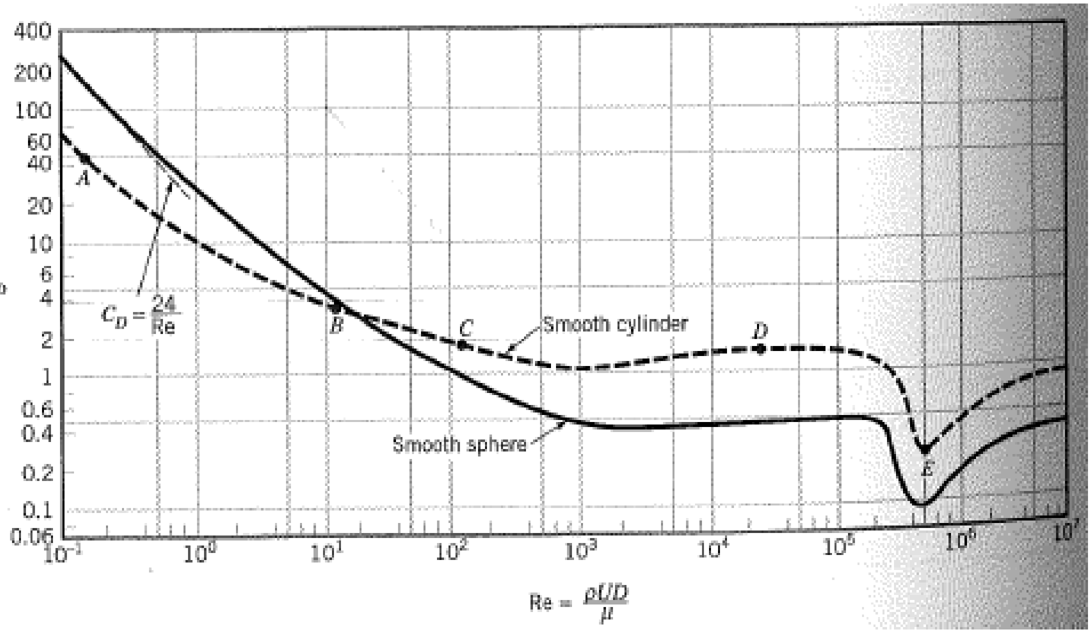


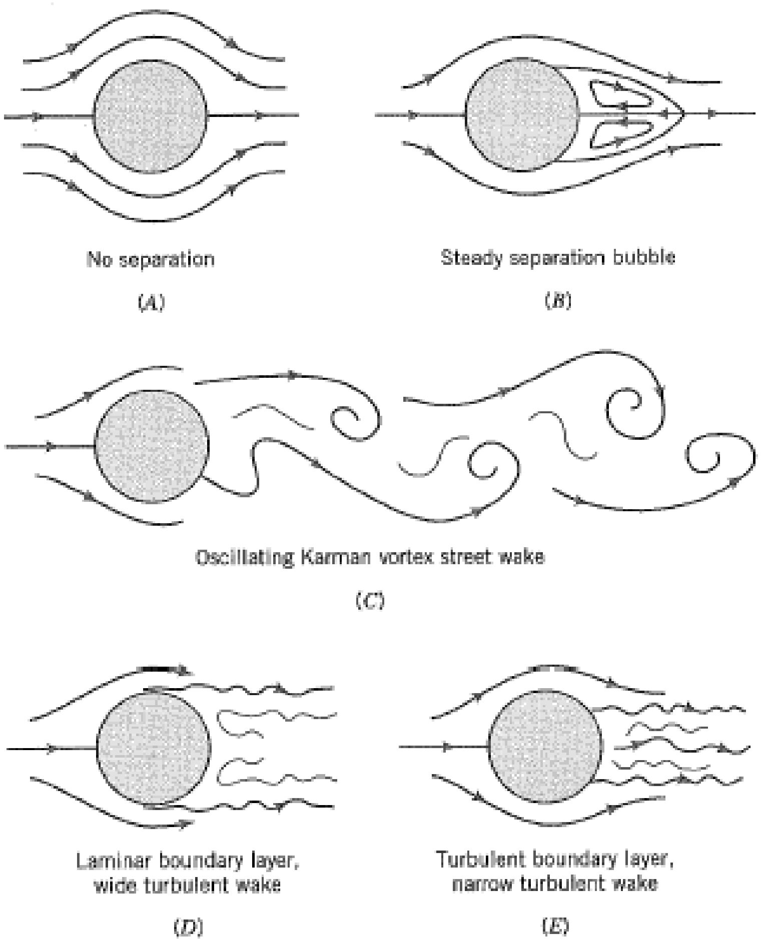
Based on:
Kline, Reynolds, Schraub & Runstadler (1967)
Morrison, Bullock & Kronauer (1971)
Kim, Kline & Reynolds (1971)
Hinze (1975)
Brown & Thomas (1977)
Falco (1977)
Blackwelder & Ecklemann (1979)
Nakagawa & Nezu (1981)
Head & Bandyopadhyay (1981)
Bandyopadhyay (1983)

Wark & Nagib (1991)
Astolfi & Forestier (1996)
Smith (1996)

Choi (1996)
Zhou, Meinhart, Balachandar & Adrian (1997)

Flow pattern around a cylinder




No separation
(A)

Steady separation bubble
(B)

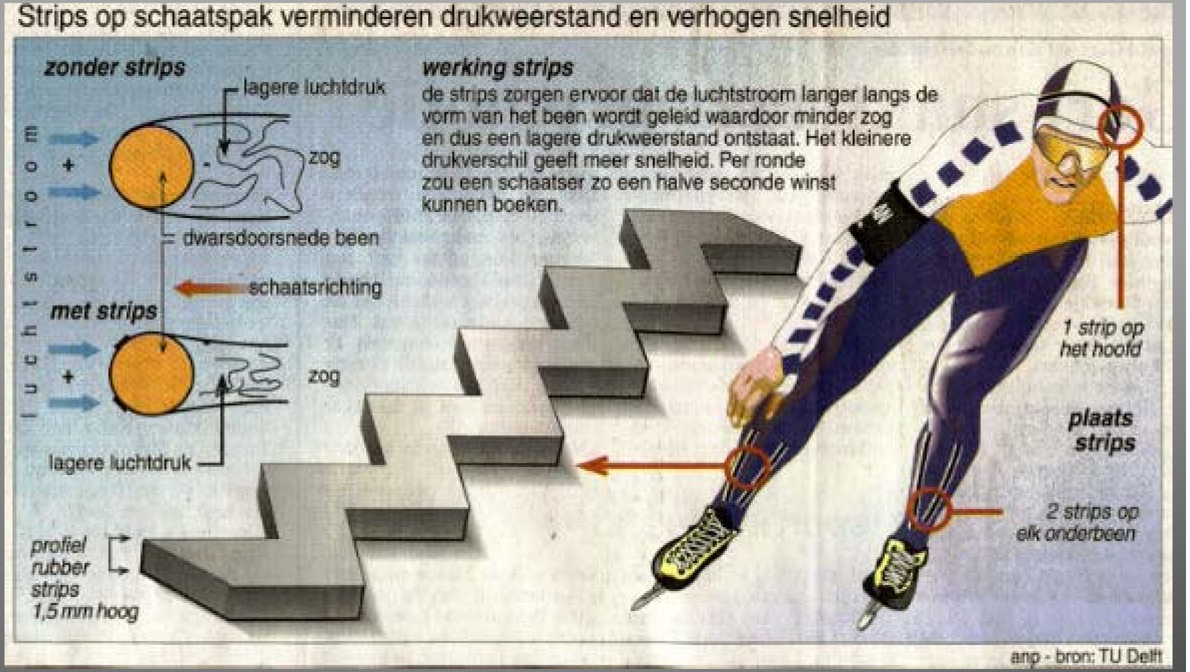
Oscillating Karman vortex street wake
(C)

Laminar boundary layer, wide turbulent wake
(D)

Turbulent boundary layer, narrow turbulent wake
(E)

- <u>Exception</u> where turbulence reduces the drag !!
- => golf ball
- => suits for ice skaters

Examples



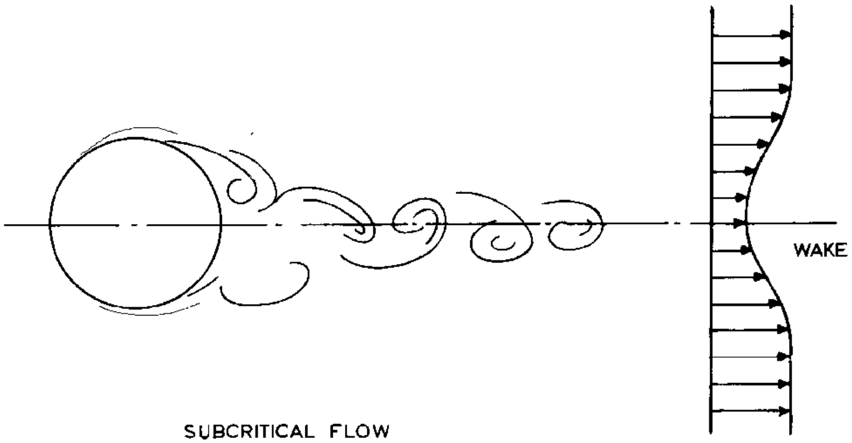
Strips op schaatspak verminderen drukweerstand en verhogen snelheid

werking strips

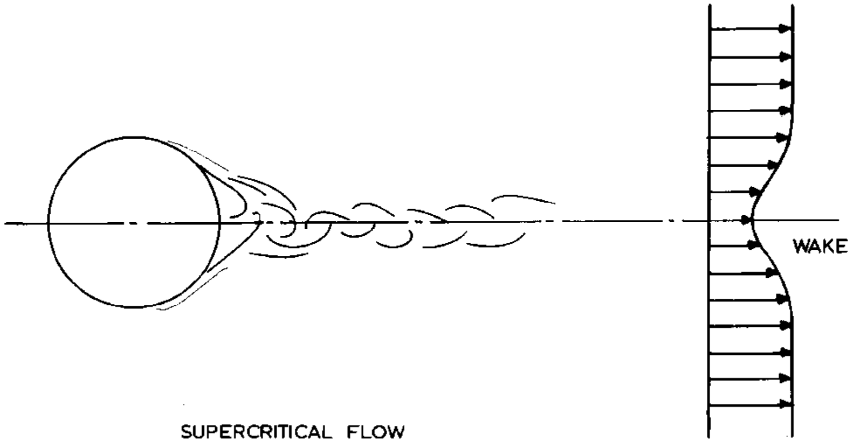
de strips zorgen ervoor dat de luchtstroom langer langs de vorm van het been wordt geleid waardoor minder zog en dus een lagere drukweerstand ontstaat. Het kleinere drukverschil geeft meer snelheid. Per ronde zou een schaatser zo een halve seconde winst kunnen boeken.

anp - bron: TU Delft

Flow pattern around cylinder



SUBCRITICAL FLOW

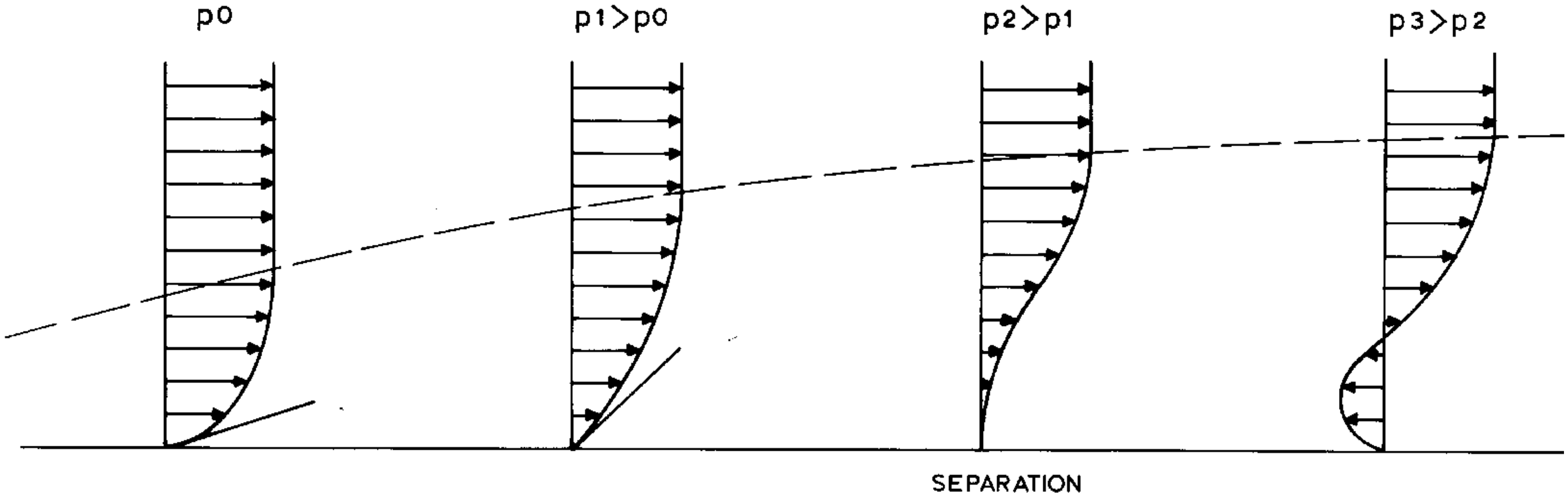


SUPERCRITICAL FLOW

- Reduction of the wake
  - => lower momentum loss
  - => lower resistance

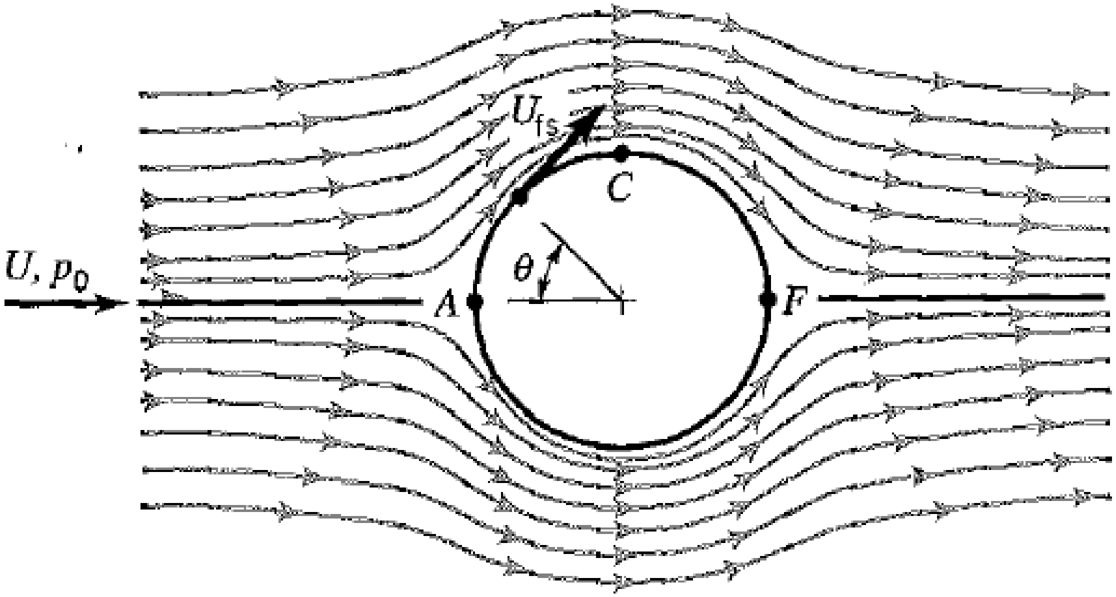
Velocity profiles in BL around separation

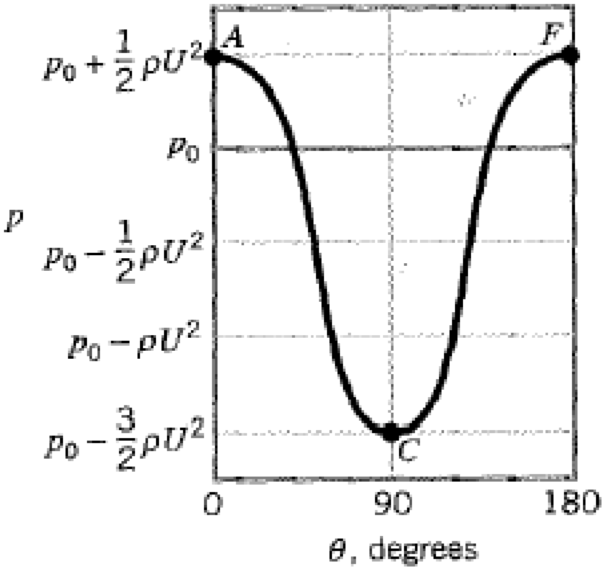
- dP/dx > 0: favourable pressure gradient (bow)
  - Stabilises BL
- dP/dx < 0; adverse pressure gradient (stern)
  - destabilises BL

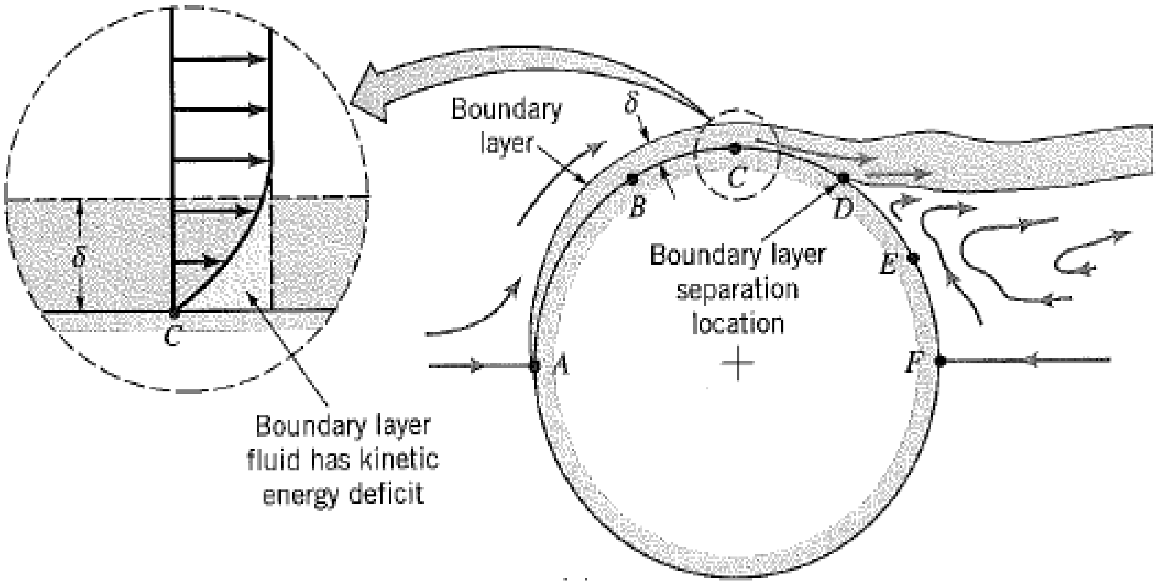


Cylinder: Potential flow solution

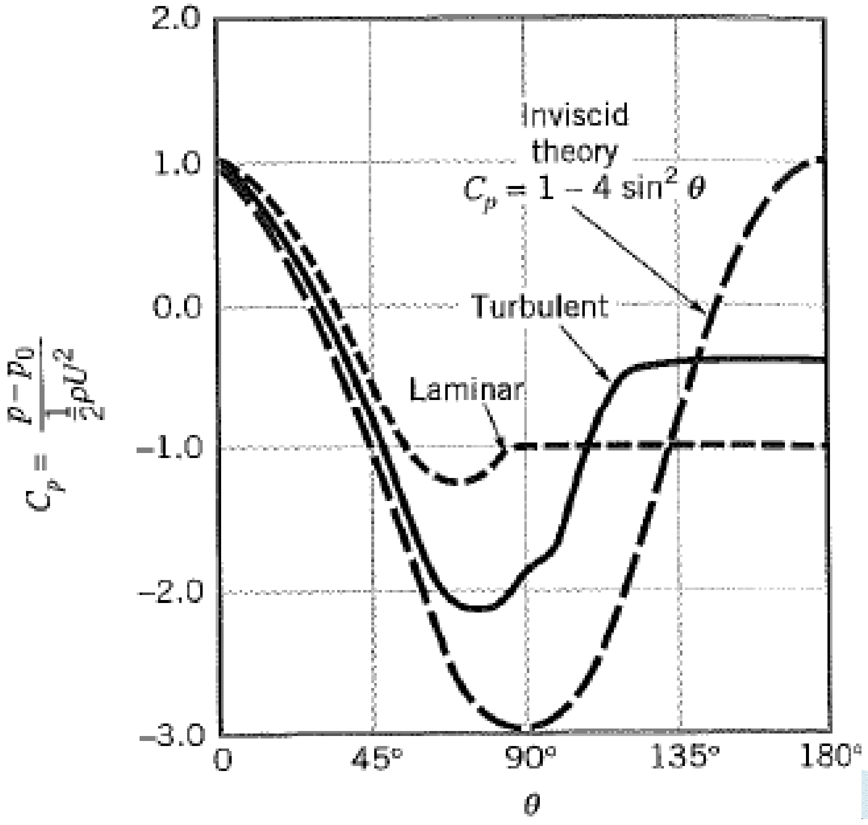
- Potential flow; no friction, no pressure gradient => No drag
- High Re; limit $\mu \to 0$; no friction??
- Experiments: always finite drag => **D'Alembert paradox**



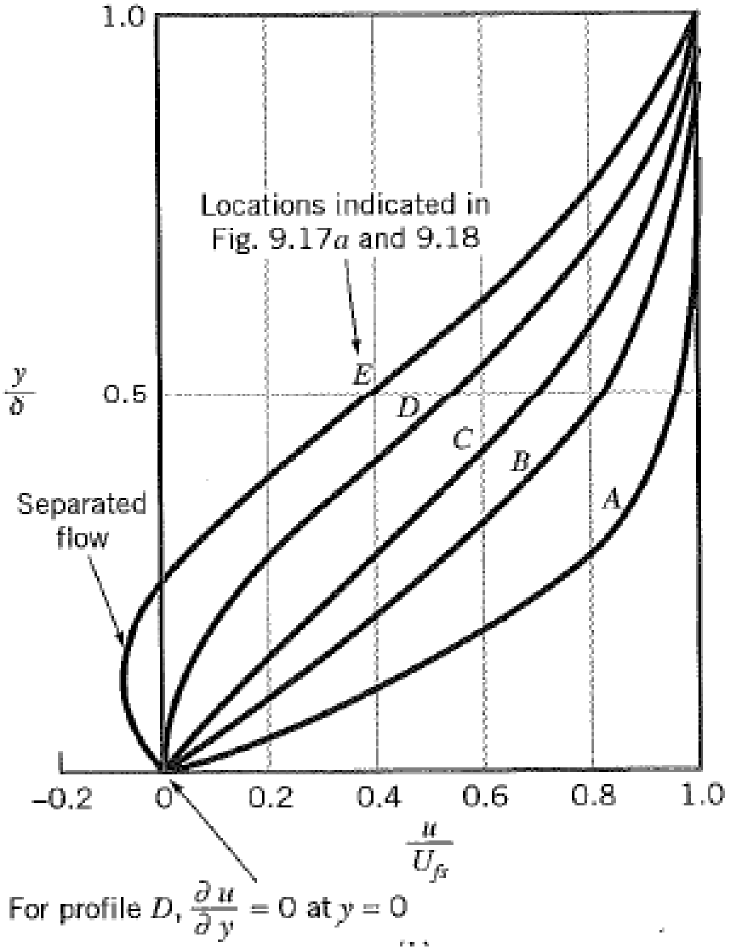




δ
C
Boundary layer fluid has kinetic energy deficit
Boundary layer
δ
B
C
D
E
A
F
Boundary layer separation location



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



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 $y = 0$

Coupling form drag and friction drag

- From flow over plate and cylinder:
  - pressure => BL growth => friction
  - friction => separation => pressure

- Froude hypothesis:
  - *For streamlined bodies (small dP/dx) without flow separation assume that pressure (form) drag and friction drag are independent*
- *=> Application on ship design:*
  - *Form factor and flat plate resistance*

Study guidelines

- 1. Introduction – *read*
- 2. Governing equations
  - 2.1–2.3: *understand*, need not be reproduced
  - 2.4–2.5: BCs: Be able to *reproduce physical origin of* bc's
- 3. Similarity
  - *reproduce* similarity numbers if N-S eq. is given
  - *reproduce* consequences of similarity requirements
- 4. Decomposition of resistance
  - Reproduce
  - Understand appendix from BB "Notes on Resistance Breakdown" – ITTC/Paffett 1972

Laws of similarity

- Derivation of Rn, En, Fn, Wn from N-S eq. and bc’s
- Rn-Fn dilemma