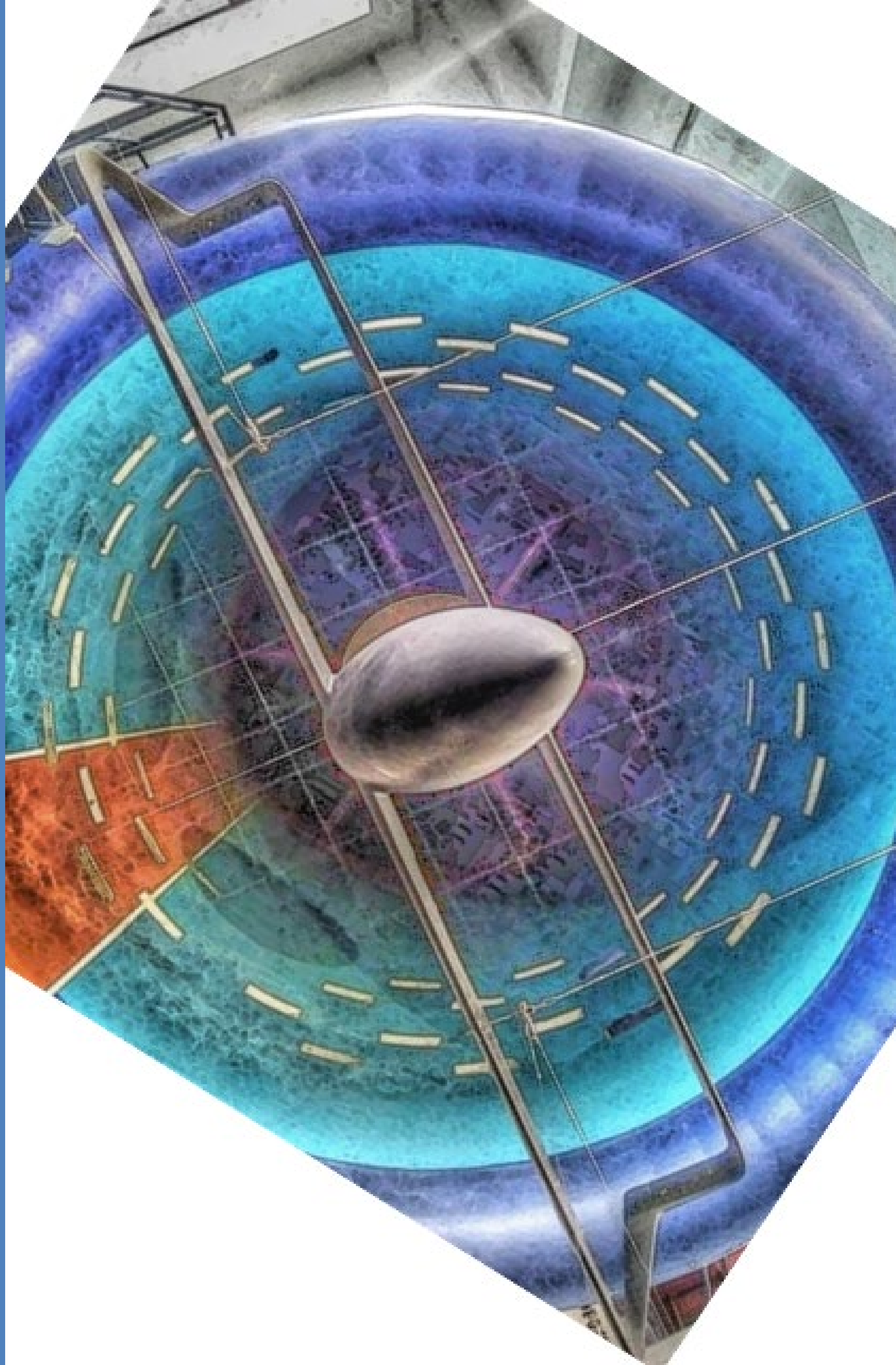
Drag Reduction



Drag Reduction

Drag prediction
Approaches to drag decomposition
Drag model
Drag breakdown in the initial design stages
Drag reduction techniques. Historical note
Skin friction drag reduction
Laminar flow control technology
Lift-induced drag reduction
Drag reduction techniques on the level of aerodynamic design

References:

1. *Stinton Darrol. The design of the airplane. Oxford, BSP Professional books, 1993*
2. *Torenbeek, Egbert. "Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes." (2013).*
3. *Gudmundsson, Snorri. "General Aviation Aircraft Design: Applied Methods and Procedures." (2013)*

Drag prediction

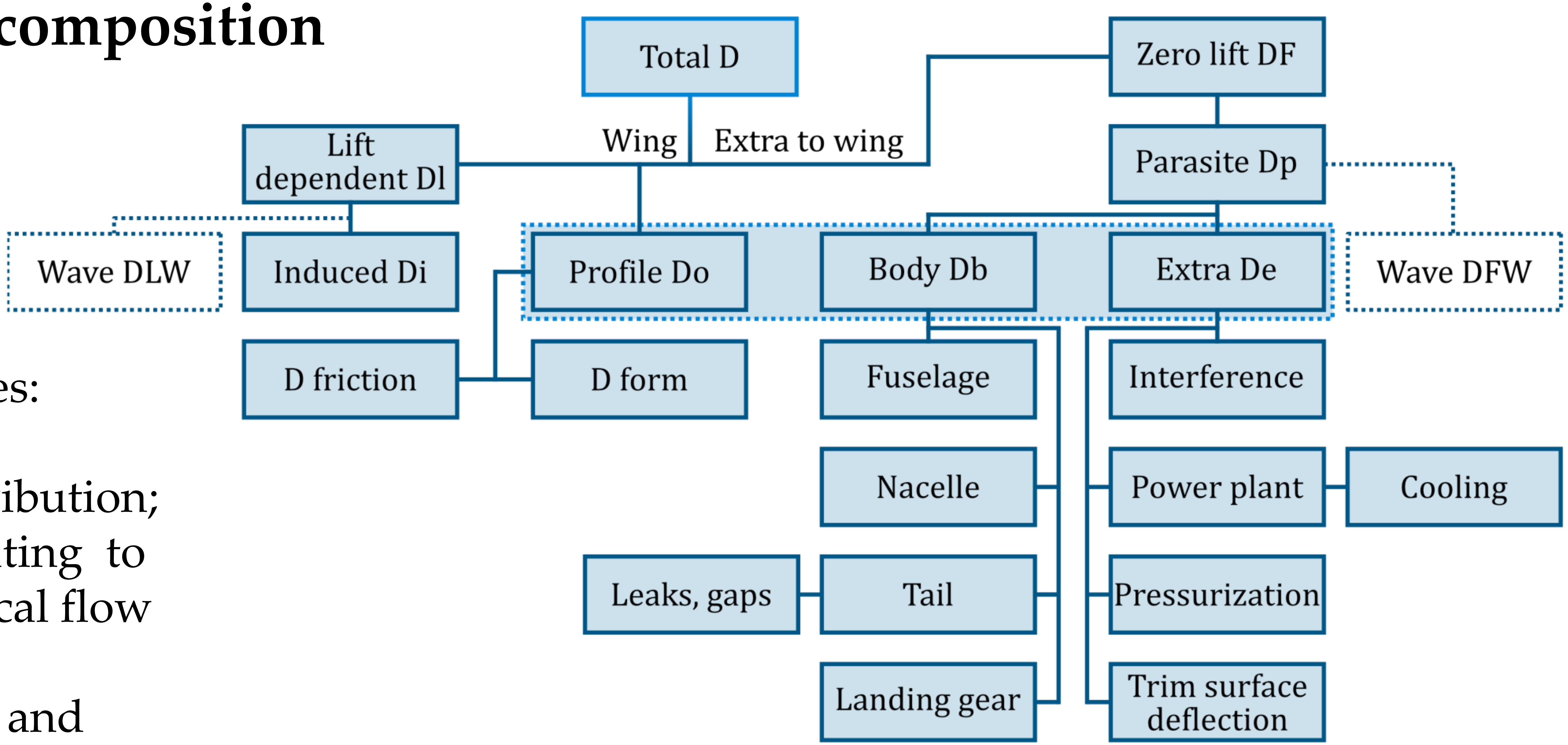
The prediction of drag can be approached in several ways:

- quasianalytically,
- numerically (via CFD), and
- by wind tunnel testing.

Any useful drag estimation method must account for:

- laminar boundary layer,
- turbulent boundary layer,
- location of laminar-to-turbulent transition,
- flow separation regions, and
- compressibility.

Approaches to drag decomposition



The basic decomposition schemes:

- shear stress and pressure distribution;
- physical mechanisms contributing to drag: the viscosity of air, vortical flow and shock waves;
- parasite drag disregarding lift and induced drag caused by lift-generating mechanisms.

Ref.: Torenbeek, Egbert. "Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes." (2013).

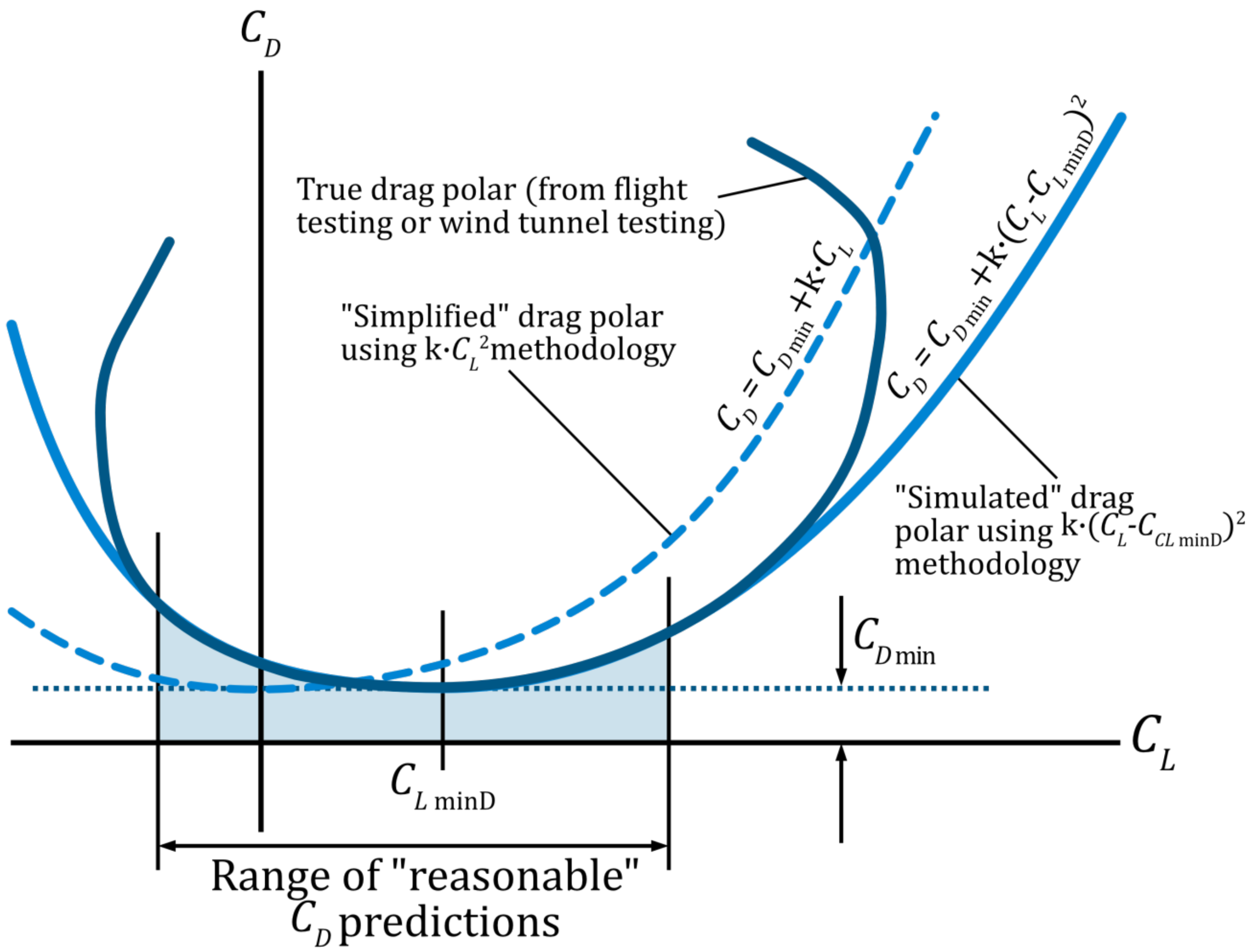
Drag model

Two-term approximation:

$$C_D = C_{D_0} + C_{D_L} = C_{D_0} + K_L C_L^2 = C_{D_0} + \frac{C_L^2}{\pi A R e} \quad (1)$$

Three-term approximation:

$$C_D = C_{D_{min}} + K_L\left(C_L - C_{L_{\min D}}\right)^2 \quad (2)$$

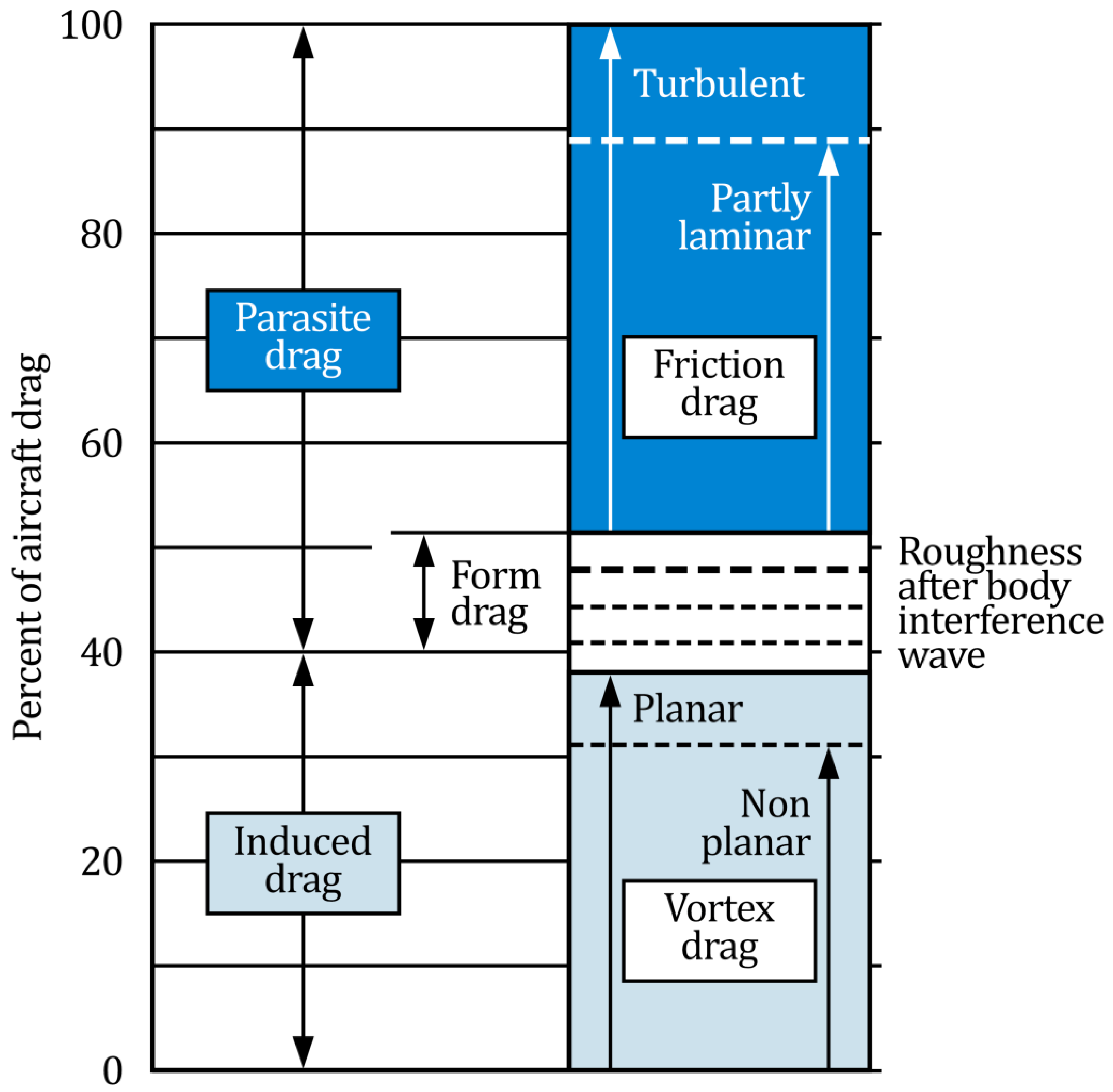


Ref.: Gudmundsson, Snorri. "General Aviation Aircraft Design: Applied Methods and Procedures." (2013)

Drag breakdown in the initial design stages

- Basic pressure drag
- Skin friction drag
- Lift-induced drag
- Wave drag
- Miscellaneous drag
- Trim drag

Example of transport aircraft cruise drag breakdown and drag reduction potential



Drag reduction techniques. Historical note

- Transition delay: favourable pressure gradients and `laminar flow control'
- Turbulent drag reduction: roughness and wetted area reduction
- Induced drag: diffusion of vortices using wingtip devices

Skin friction drag reduction

- Laminar flow control (LFC) (pressure gradient, suction)

- Techniques to alter the average flow/drag directly such as
  wetted area minimization,
  reduced roughness,
  use of a "Stratford closure" (adverse pressure gradient),
  mass injection, and
  bubbles to reduce the average near-wall density in water

- Turbulent boundary layer management:
  riblets,
  LEBU,
  vortex generators

Skin friction drag reduction

- Active control
- Passive control
- Interactive control

Laminar flow control technology

- NLF concept (Reynolds numbers of less than 20×10^6 and leading edge sweep angles of less than 20 degrees)

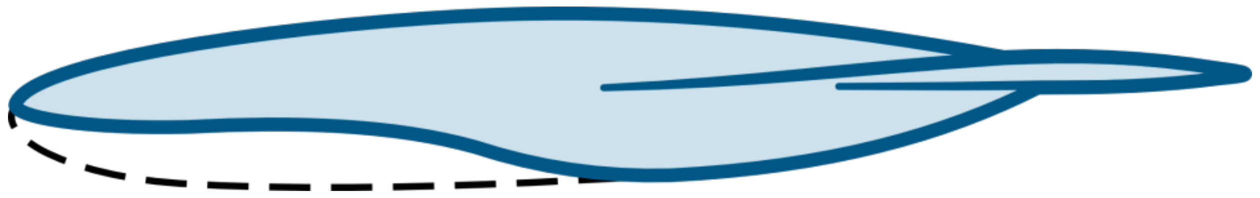
- Suction (high Reynolds number and high sweep)

- Hybrid Laminar Flow concept

Lift-induced drag reduction

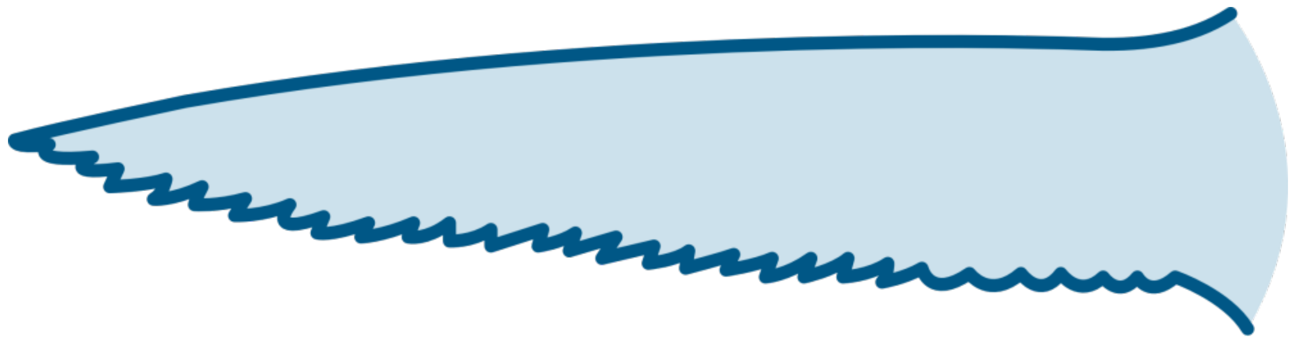
- Non-planar lifting systems
- Energy/thrust extraction from the tip vortex
- Mass addition at/ near the tip

Lift-induced drag reduction
Increasing effective wingspan (vortex diffusion)

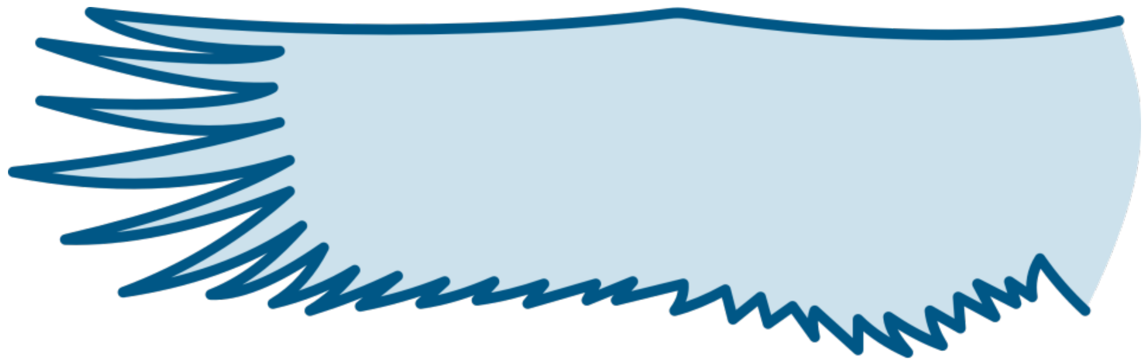


Emarginated feather

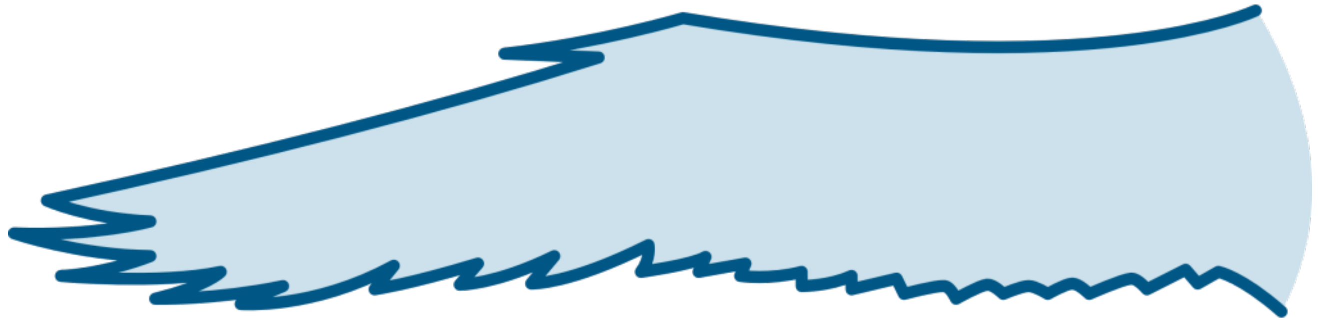
Wings of seabirds (a and b) with aspect ratios around 12; and soaring land birds (c and d) with aspect ratios around 10, but with slots formed by emarginated pinion feathers (not to scale)



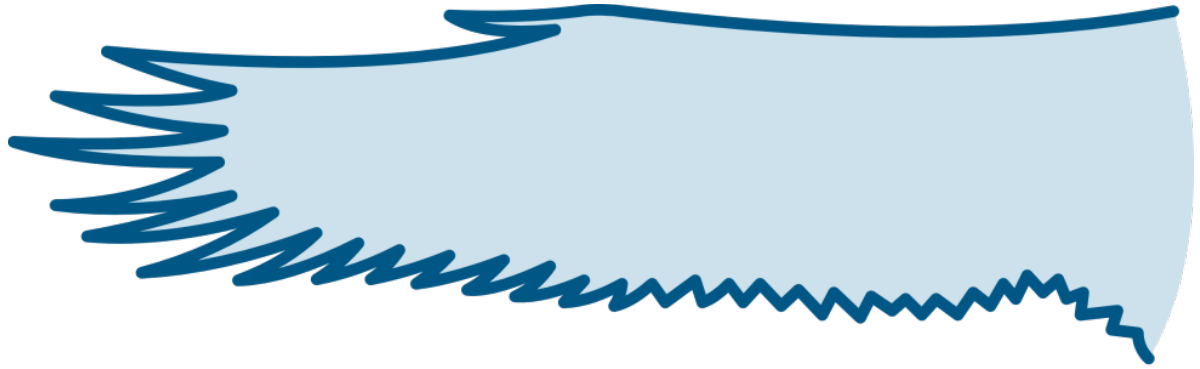
a. Fulmar petrel (Fulmarus glacialis)



c. Nubian vulture (Aegypius tracheliotus)



b. Gannet (Morus bassanus)



d. White pelican (Pelecanus onocrotalus)

Ref.: Stinton Darrol. The design of the airplane. Oxford, BSP Professional books, 1993

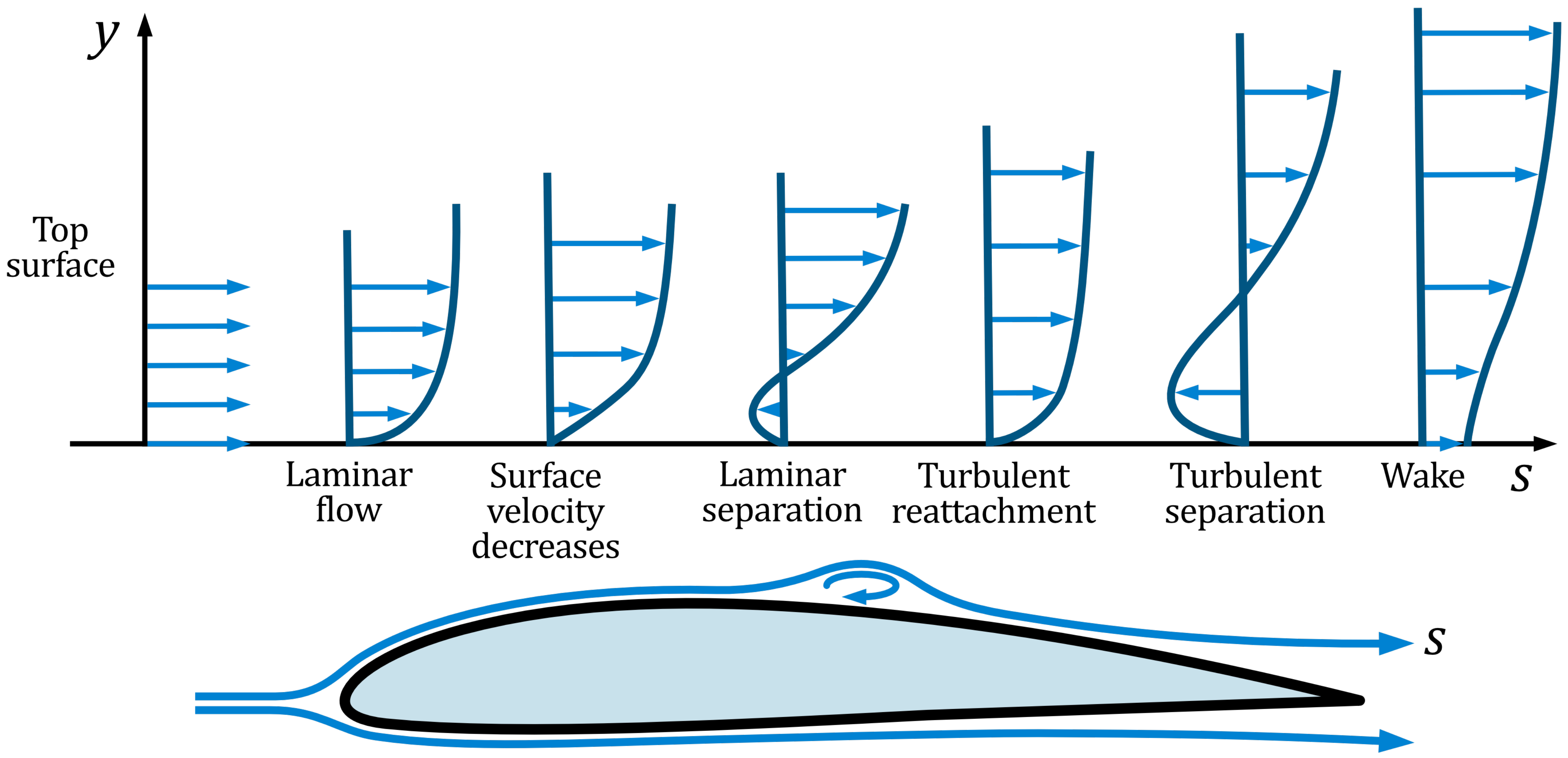
Drag prediction

- The use of riblets reduces turbulent skin friction drag by about 1-2%
- The hybrid laminar flow technology: about 10%
- The innovative wing-tip devices: about 2%
- The shock control and trailing edge devices (variation of the lift coefficient or of the Mach number): about 1%

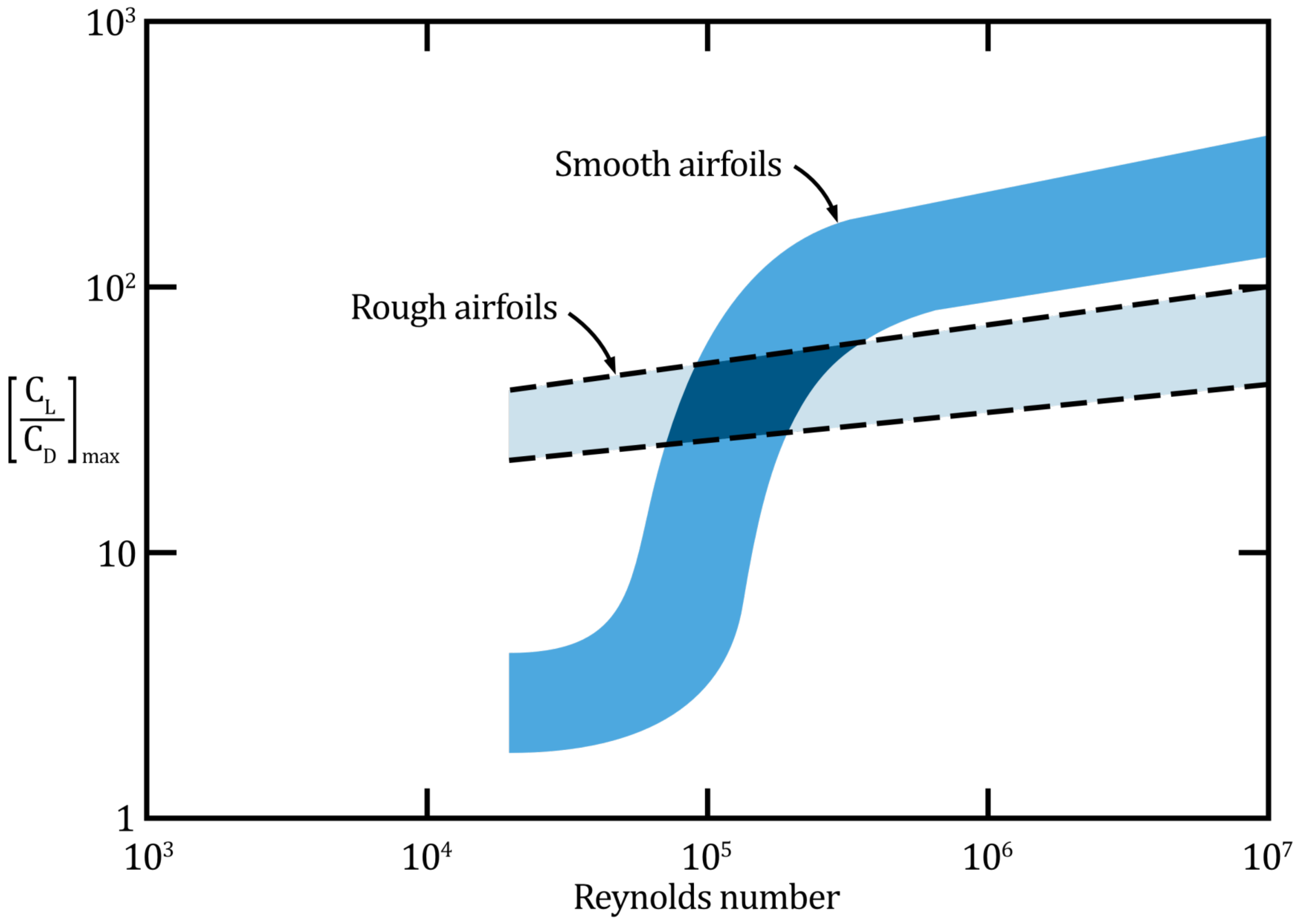
Drag reduction techniques on the level of aerodynamic design

- **Friction drag**: small surface areas, smooth finish, active controls (low stability).
- **Form drag, wave drag**: small volume, correct distribution of volume along length, favorable shape and slope of surfaces.
- **Induced drag**: lift distribution as near elliptical as possible, long span, washout, tip shape.
- **Interference drag**: fairing to avoid rapid local changes of airspeed, spacing of struts, pylons, nacelles.
- **Leaks**: good sealing between airfoil top and bottom surfaces, doors, hatches.
- **Trim drag**: low C_m, static stability.

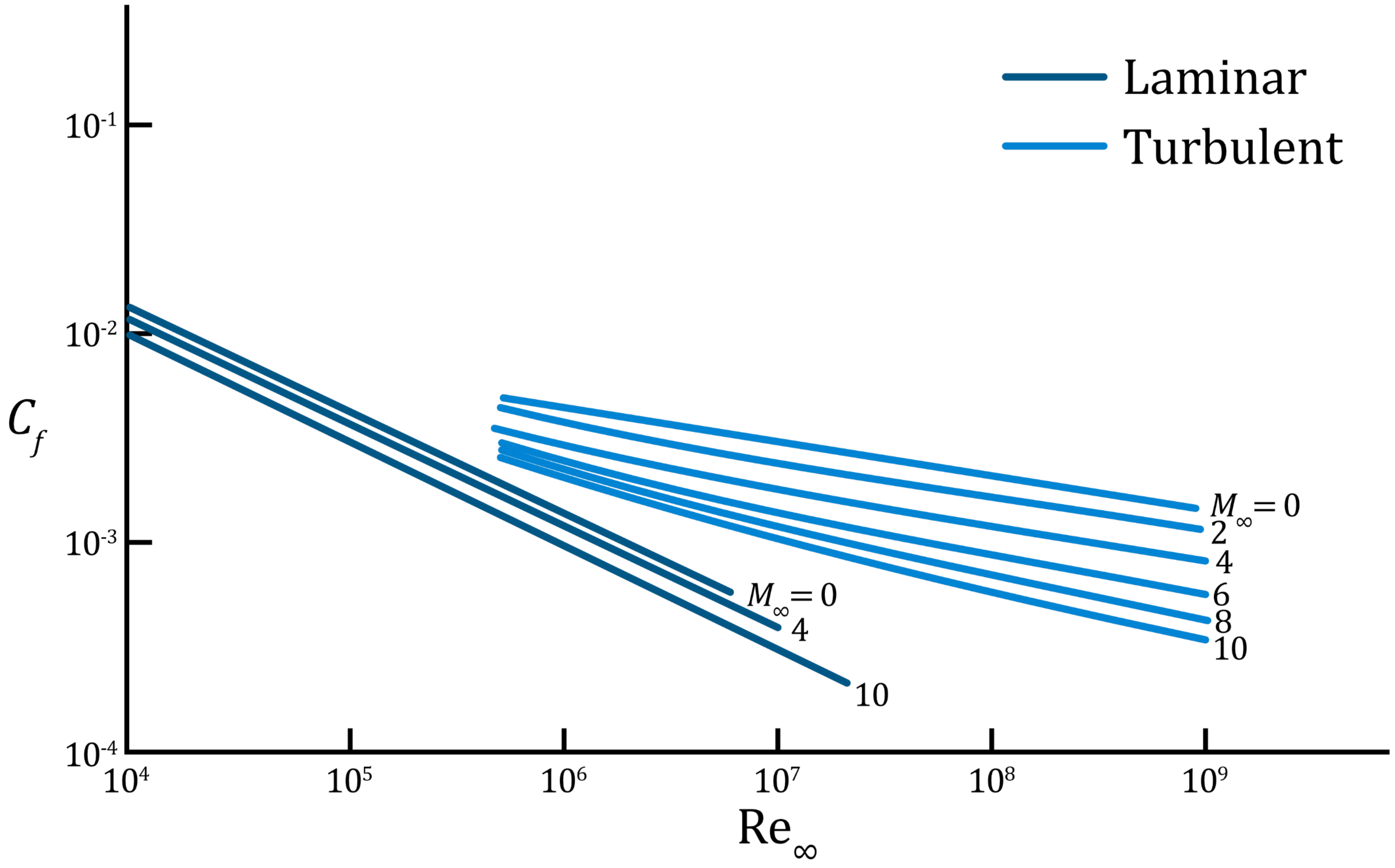
Boundary layer velocity profiles along the chord of an airfoil



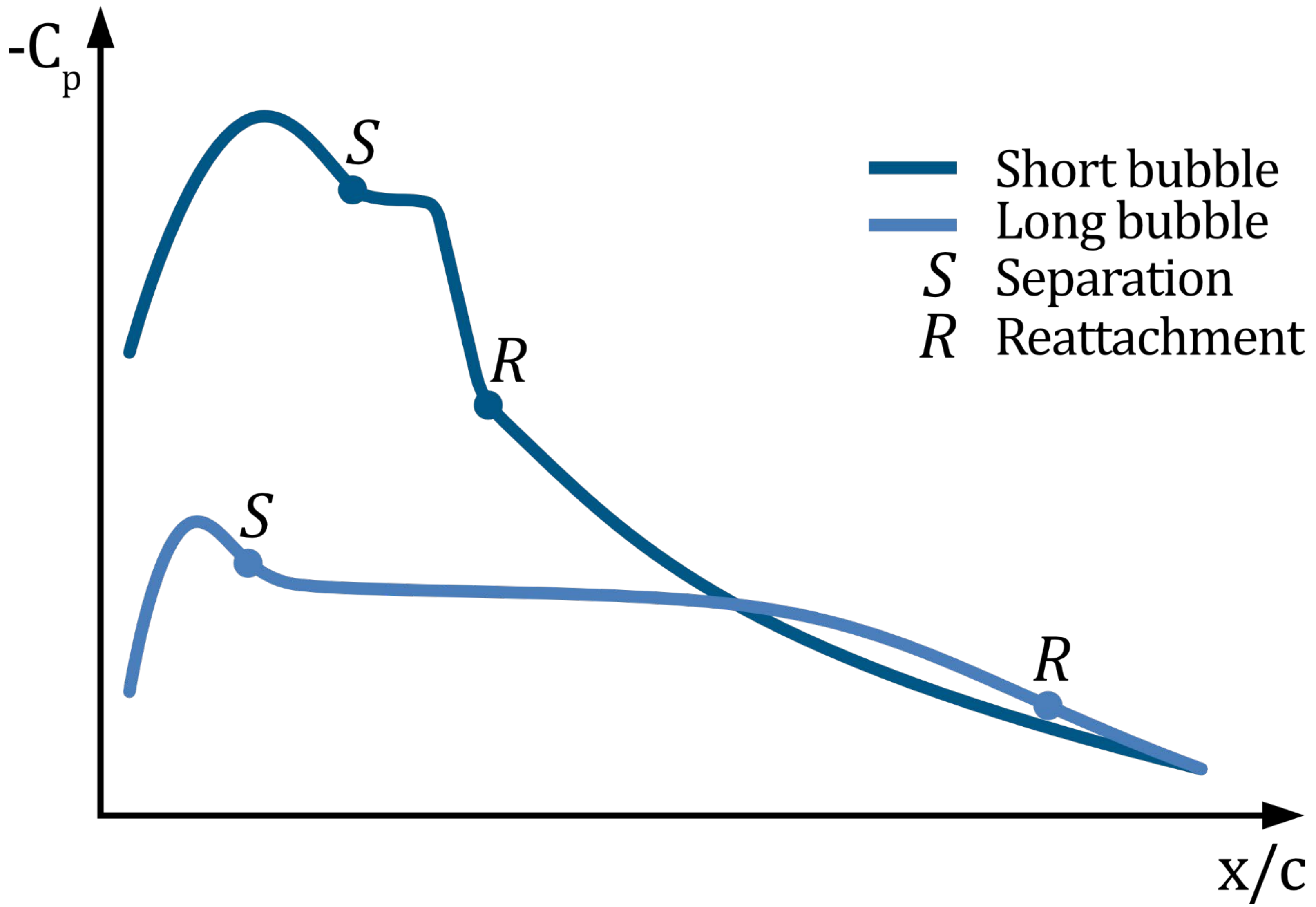
The effectiveness of rough and smooth airfoil as a function of Reynolds number



Lissaman, P. B. S. (1983). Low-Reynolds-Number-Airfoils. Annual Review of Fluid Mechanics, 15, 223–239. https://doi.org/10.1146/annurev.fl.15.010183.001255

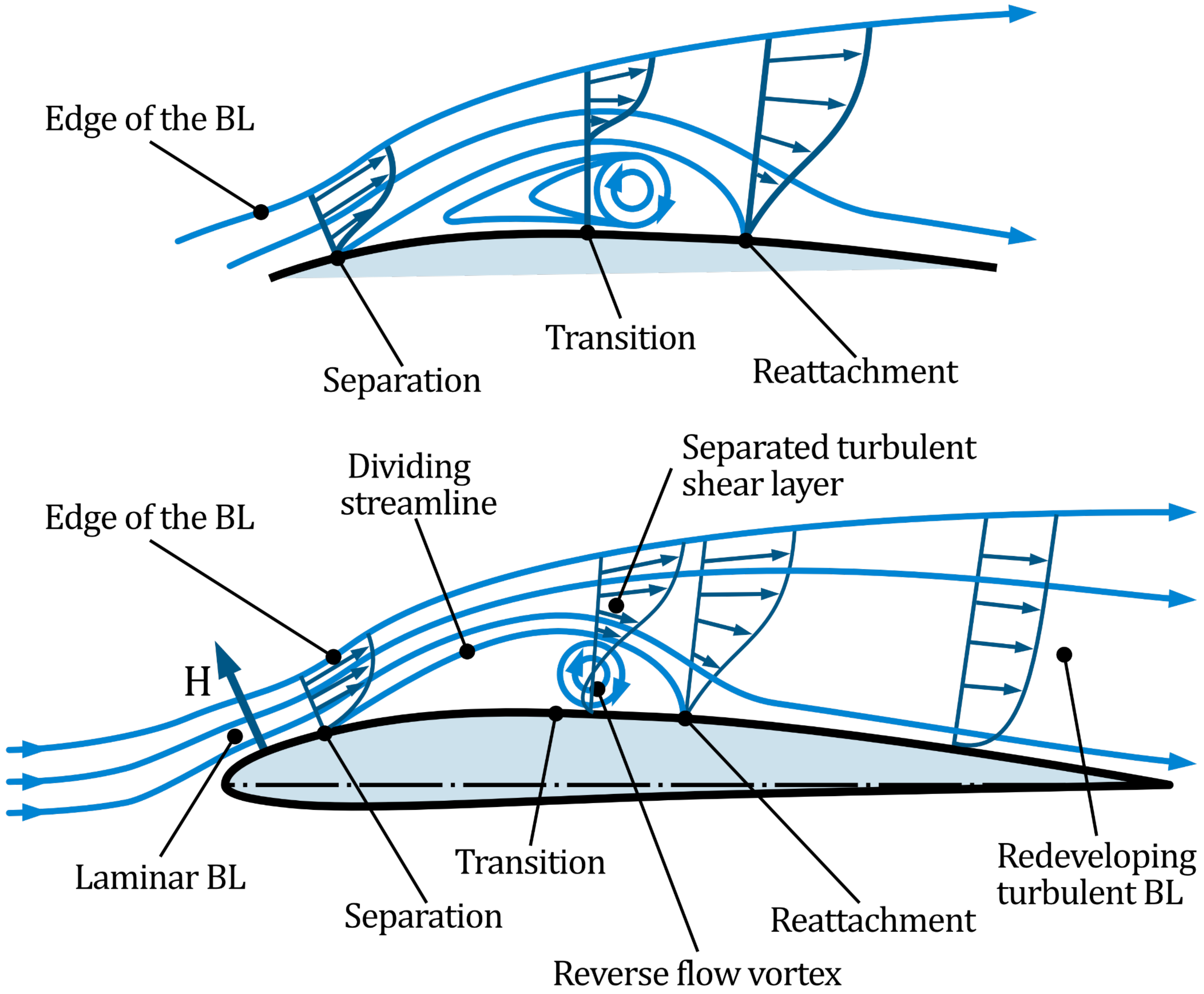

Laminar
Turbulent
C_f
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
Re_∞
$M_\infty = 0$
4
10
$M_\infty = 0$
2
4
6
8
10

Thin vs thick laminar bubble



Ref.: Horton, H. P., 1968. *Laminar Separation Bubbles in Two and Three Dimensional Incompressible Flow.* London: s.n.

Features of a laminar bubble



Ref.: Horton, H. P., 1968. *Laminar Separation Bubbles in Two and Three Dimensional Incompressible Flow.* London: s.n.

Boundary layer properties vs Reynolds number