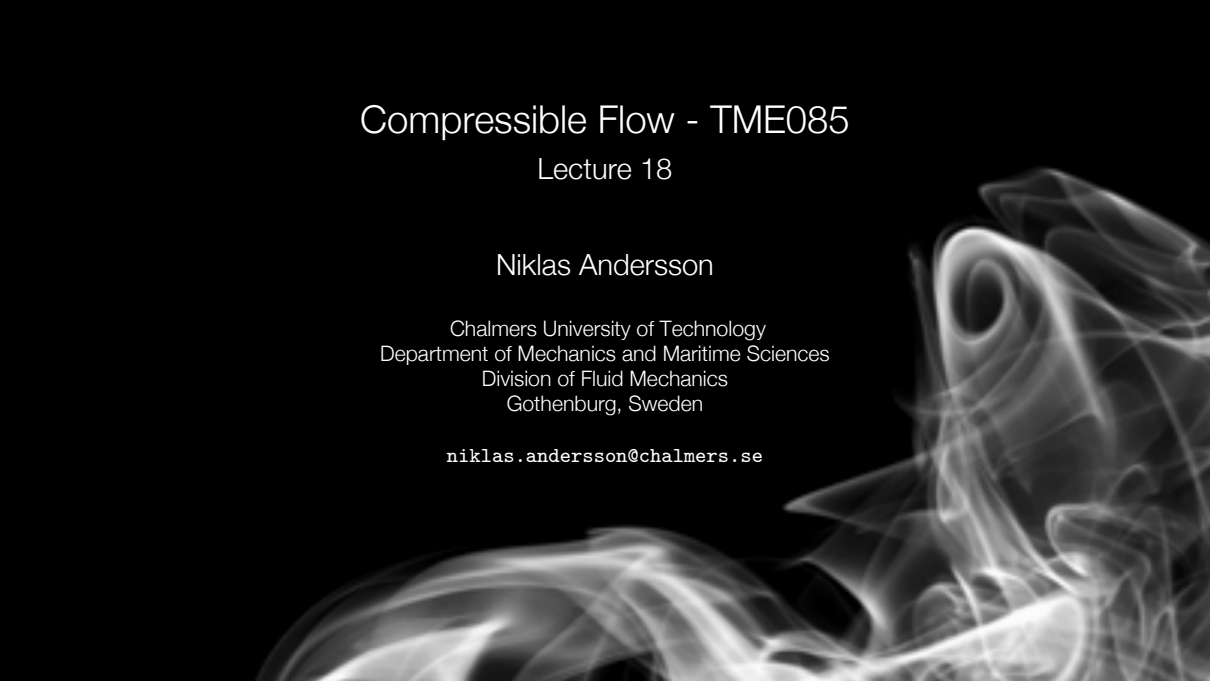
Compressible Flow - TME085

Lecture 18

Niklas Andersson

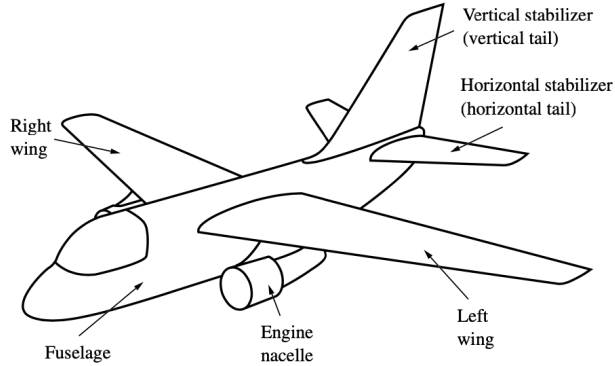
Chalmers University of Technology
Department of Mechanics and Maritime Sciences
Division of Fluid Mechanics
Gothenburg, Sweden

niklas.andersson@chalmers.se

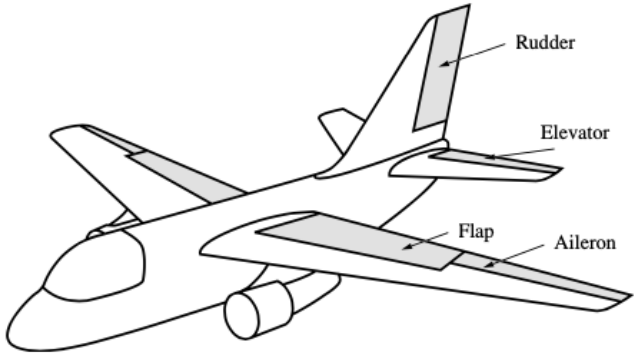


Aircraft Aerodynamics

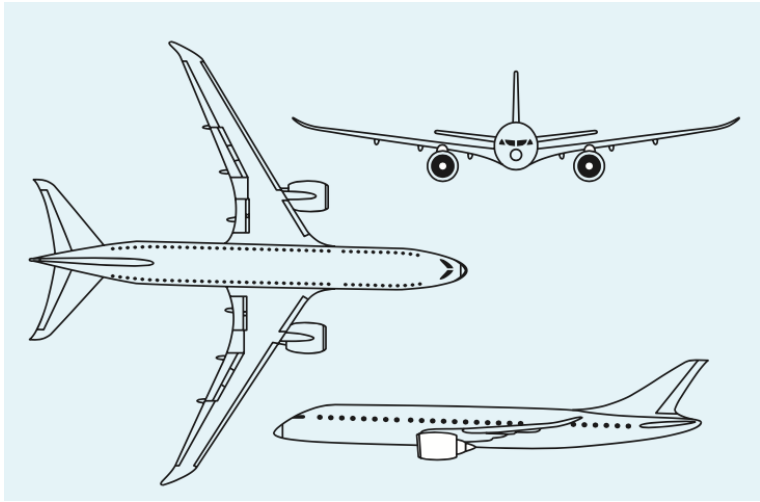
Control Surfaces



Control Surfaces



Control Surfaces

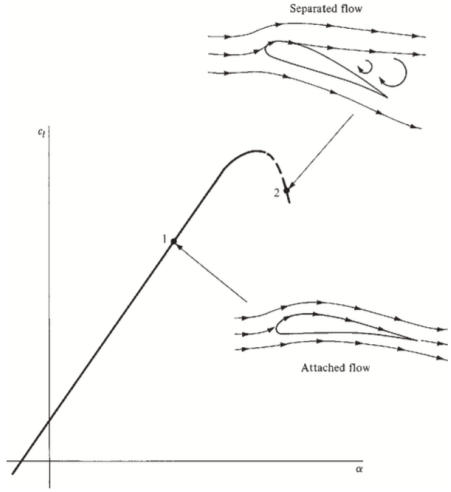


Lift and Drag

$$C_L = \frac{F_L}{\frac{1}{2}\rho U_\infty^2 A_p}$$

$$C_D = \frac{F_D}{\frac{1}{2}\rho U_\infty^2 A_p}$$

where A_p is the planform area



Lift and Drag

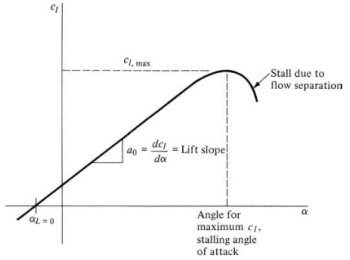
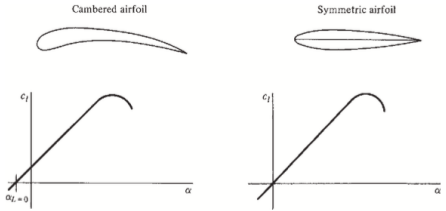
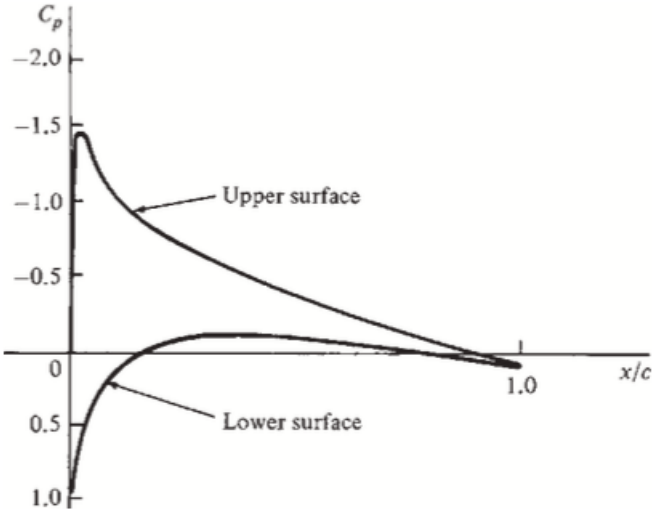


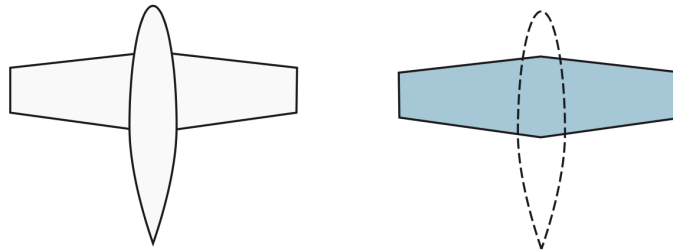
Figure 5.6 Sketch of a typical lift curve.



Lift and Drag - Pressure Coefficient



Lift and Drag - Fuselage Lift



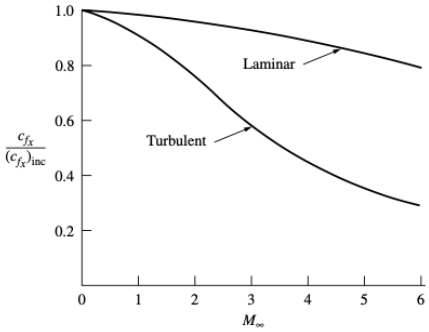
Lift and Drag

$$D = D_{pressure} + D_{friction} + D_{wave}$$

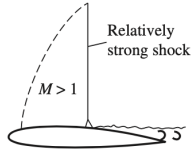
Friction Drag

laminar flow: $C_f = \dfrac{f_1(M_\infty)}{\sqrt{Re_x}}$

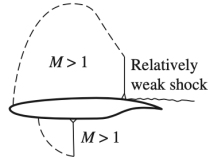
turbulent flow: $C_f = \dfrac{f_2(M_\infty)}{Re_x^{0.2}}$



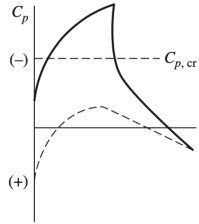
Wave Drag - The Supercritical Airfoil



(a)

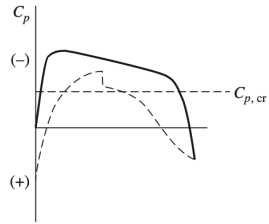


(c)



(b)

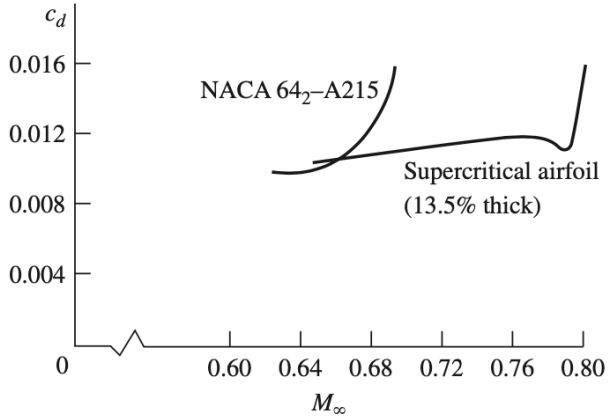
NACA 64_2–A215 airfoil
$M_\infty = 0.69$



(d)

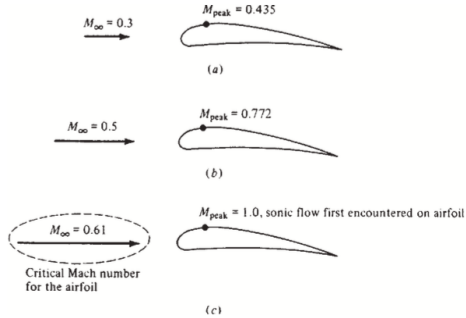
Supercritical airfoil (13.5% thick)
$M_\infty = 0.79$

Wave Drag - The Supercritical Airfoil

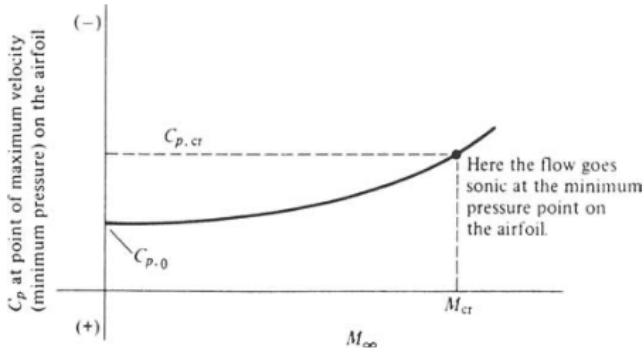


Critical Mach Number

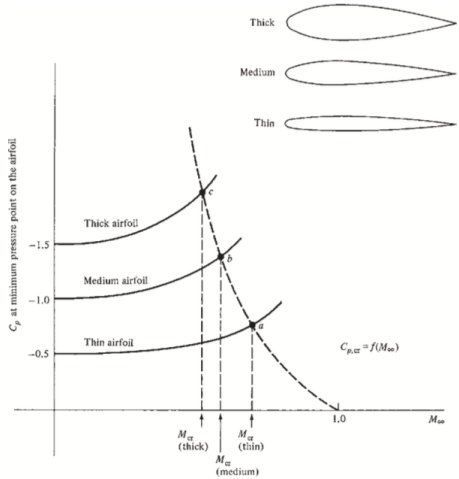
The critical Mach number is the lowest freestream Mach number for which the flow will accelerate to sonic conditions over the wing



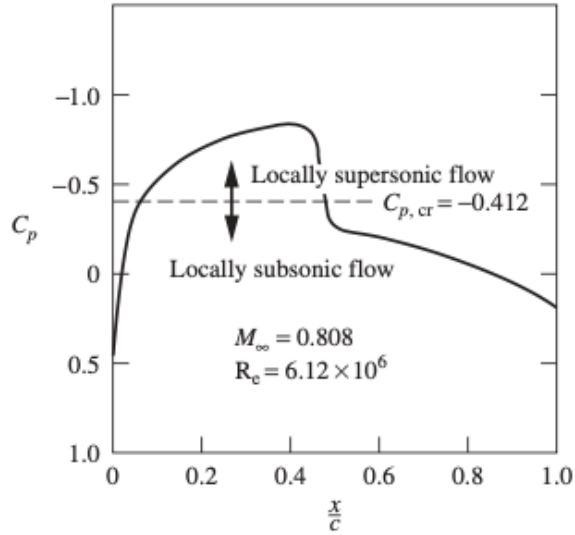
Critical Pressure Coefficient



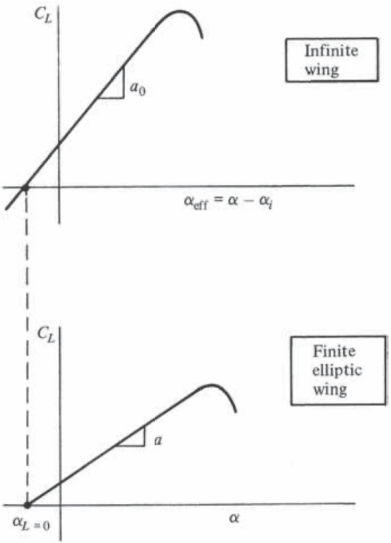
Critical Pressure Coefficient



Critical Pressure Coefficient



Finite Wing Span

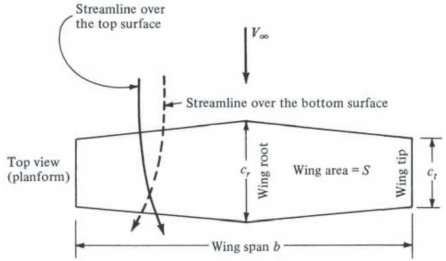


Induced Drag

The higher pressure on the lower side of the wing leads to a flow leakage over the wing tip

The flow below the wing has a velocity component towards the wing tip

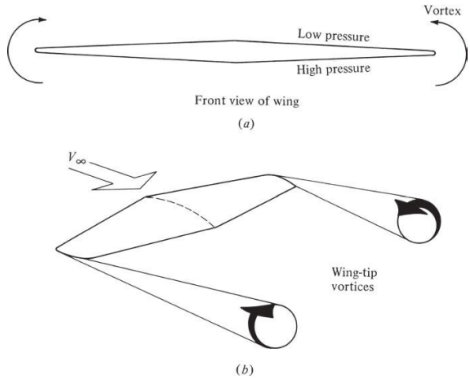
The flow over the wing has a velocity component towards the fuselage



Induced Drag

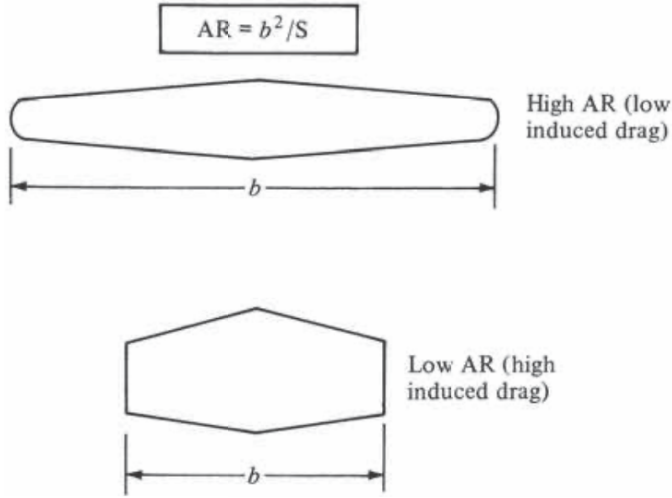
The flow from high pressure regions to low pressure regions forms a vortex at the wing tip

A net downwash flow is induced leading to a reduction of lift



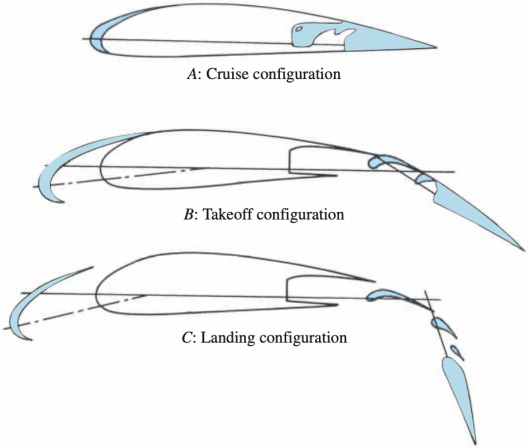
Induced Drag - Downwash

Induced Drag

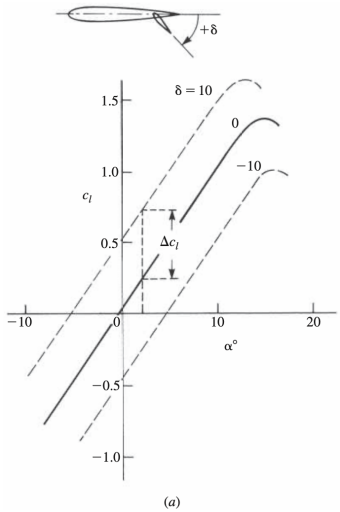


Induced Drag - Winglets

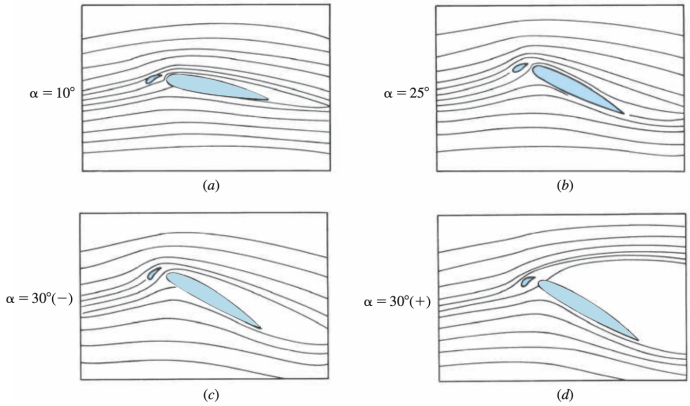
High-Lift Devices



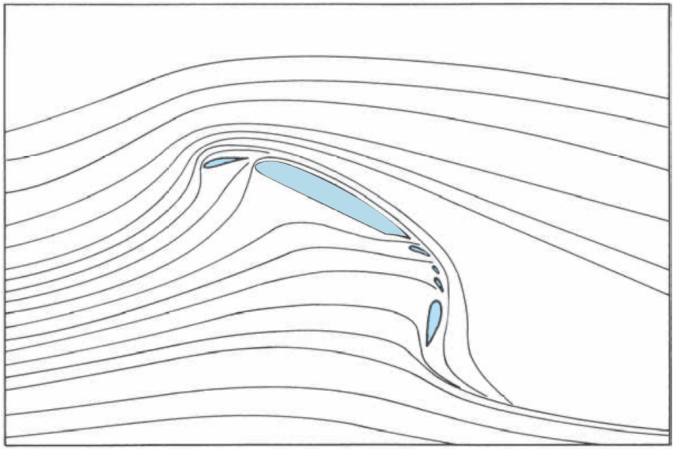
High-Lift Devices - Flaps



High-Lift Devices - Slats



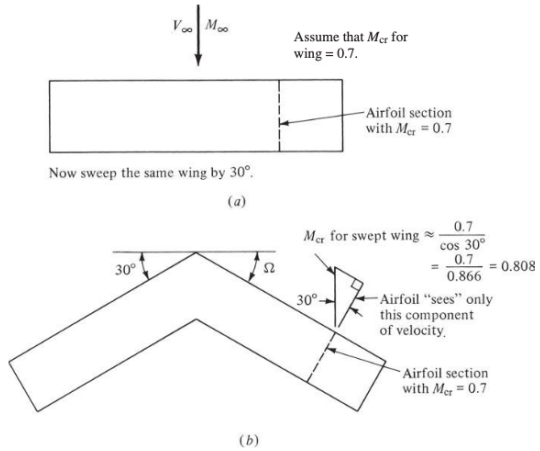
High-Lift Devices



$\alpha = 25°$

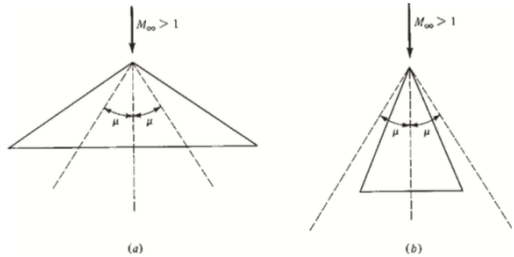
Swept Wings - Subsonic Aircraft

- The wing profile ”sees” a flow with the Mach number normal to the leading edge
- Increases the critical freestream Mach number
- Possible to operate at higher Mach number with lower drag
- Comes with the price of lower lift

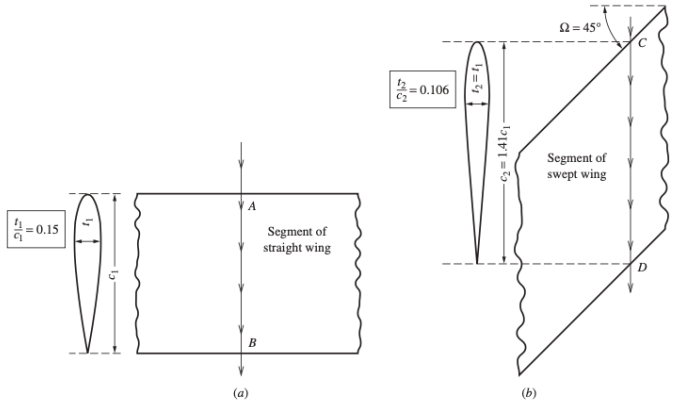


Swept Wings - Supersonic Aircraft

- If the wing is within the Mach angle cone, the trailing-edge-normal flow is subsonic

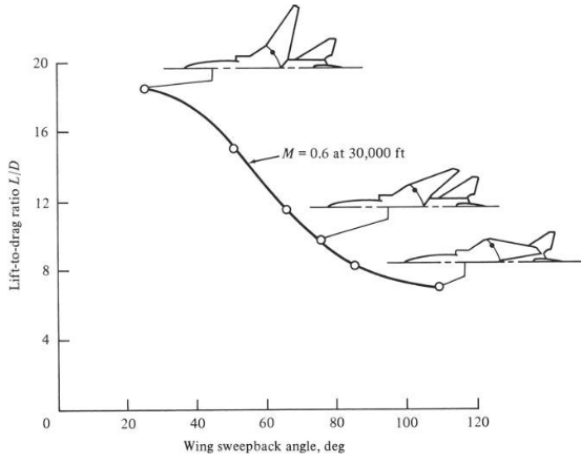


Swept Wings

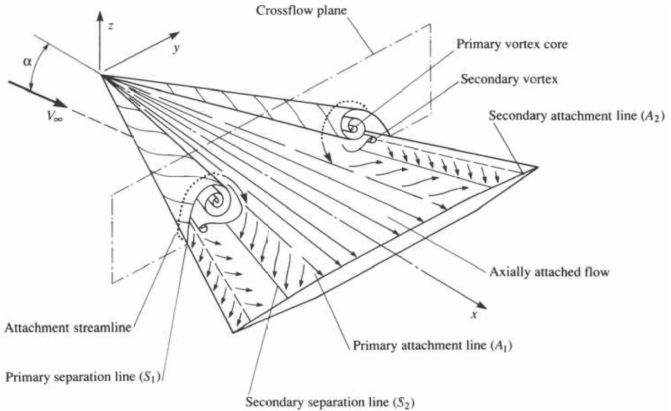

$\frac{t_1}{c_1} = 0.15$
t_1
c_1
A
Segment of straight wing
B
(a)
$\Omega = 45°$
C
$\frac{t_2}{c_2} = 0.106$
$t_2 = t_1$
$c_2 = 1.41c_1$
Segment of swept wing
D
(b)

Swept Wings

Wing sweep reduces drag but there is also a significant reduction of lift

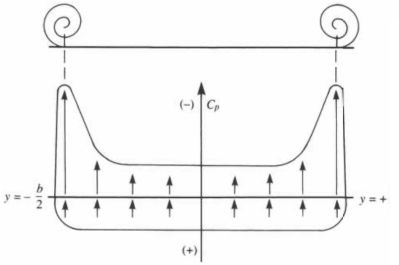


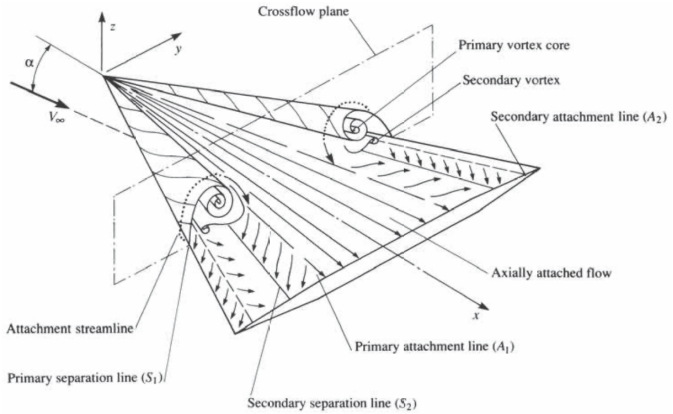
The Delta Wing



leakage of flow from high-pressure regions to low-pressure regions leads to the formation of vortices on the upper side of the wing

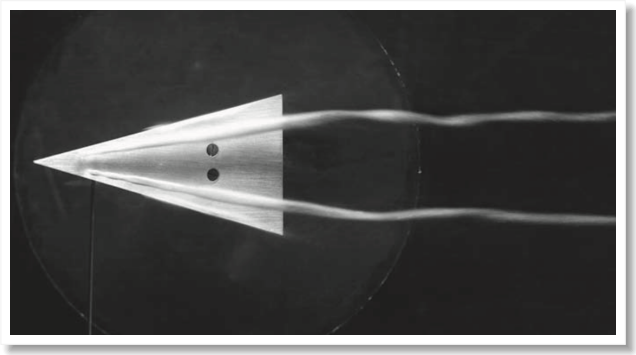
The Delta Wing





The vortical structures on the upper side of the wing reduces the pressure and increases lift

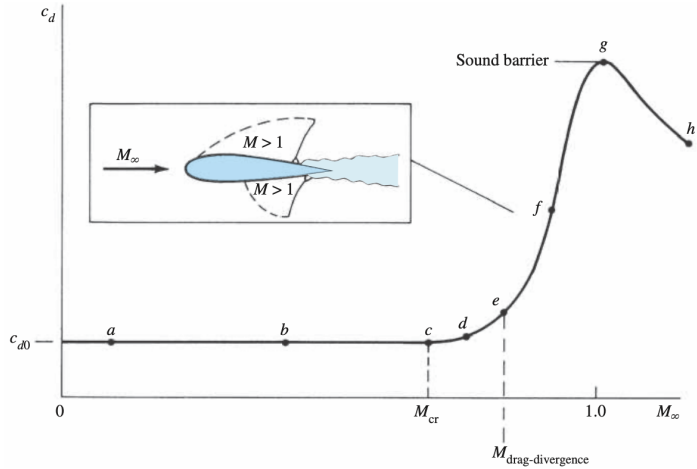
The Delta Wing



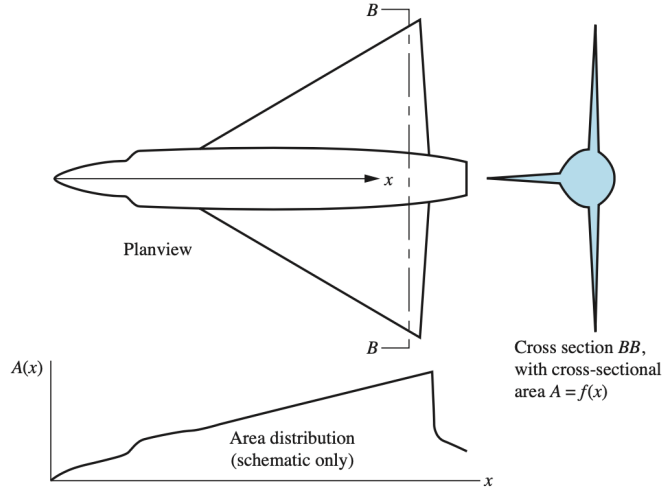
Visualization of vortex structures over a delta wing in a water tunnel experiment

The Delta Wing

The Sound Barrier

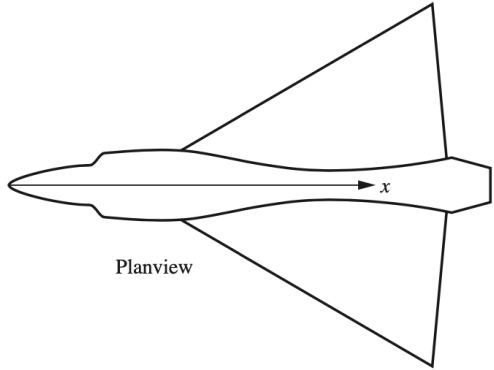


Area Rule

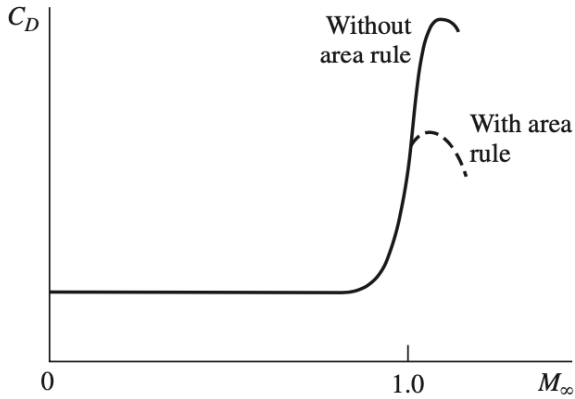

B
x
Planview
B
Cross section BB,
with cross-sectional
area A = f(x)
A(x)
Area distribution
(schematic only)
x

Area Rule

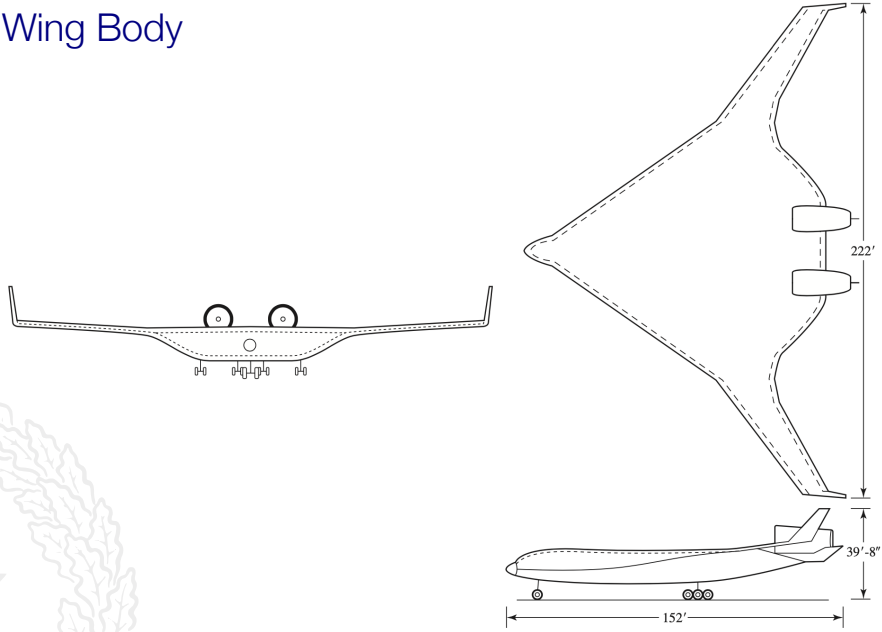
Designing the whole aircraft such that the variation in cross-section area is smooth reduces the peak in drag near Mach 1



Area Rule

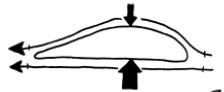


Blended Wing Body



Blended Wing Body

HANDLING A STUDENT WHO CHALLENGES YOUR EXPERTISE WITH AN INSIGHTFUL QUESTION:



SO, KIDS, THE AIR ABOVE THE WING TRAVELS A LONGER DISTANCE, SO IT HAS TO GO FASTER TO KEEP UP. FASTER AIR EXERTS LESS PRESSURE, SO THE WING IS LIFTED UPWARD.

BUT THEN WHY CAN PLANES FLY UPSIDE DOWN?

RIGHT:

WOW, GOOD QUESTION! MAYBE THIS PICTURE IS SIMPLIFIED—OR WRONG! WE SHOULD LEARN MORE.

WRONG:

IT'S... COMPLICATED.

AND WE NEED TO MOVE ON.

VERY WRONG:

SANTA CLAUS IS YOUR PARENTS.