Aerodynamics of the Airplane

LECTURE 2

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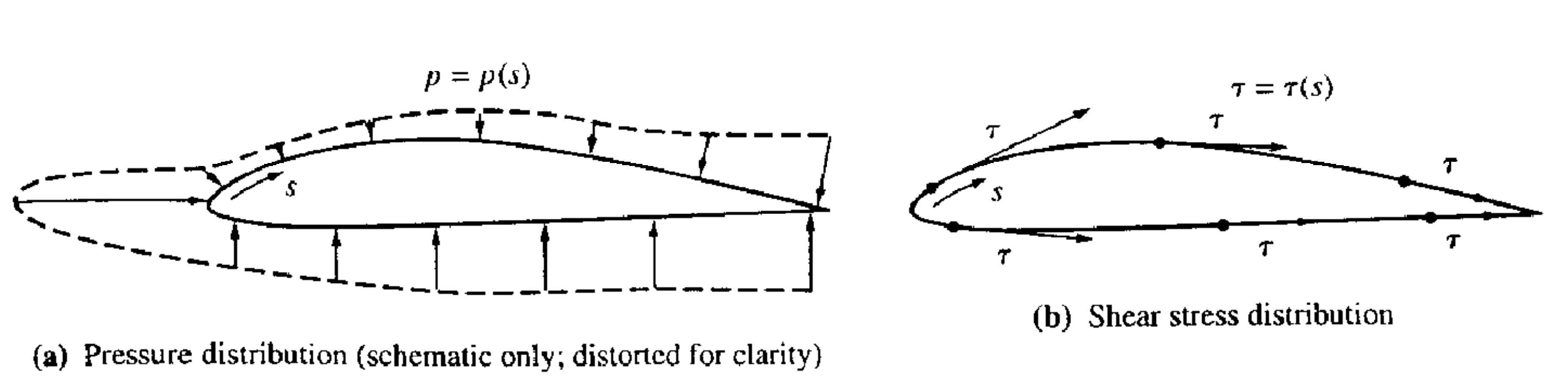
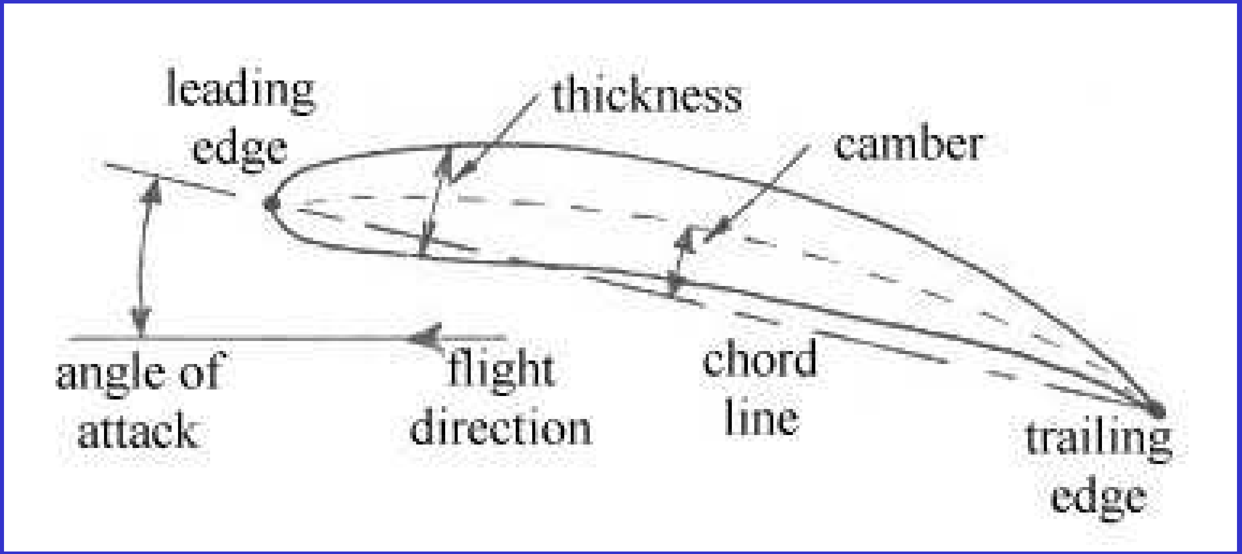
Source of Aerodynamic Force



AIRFOIL

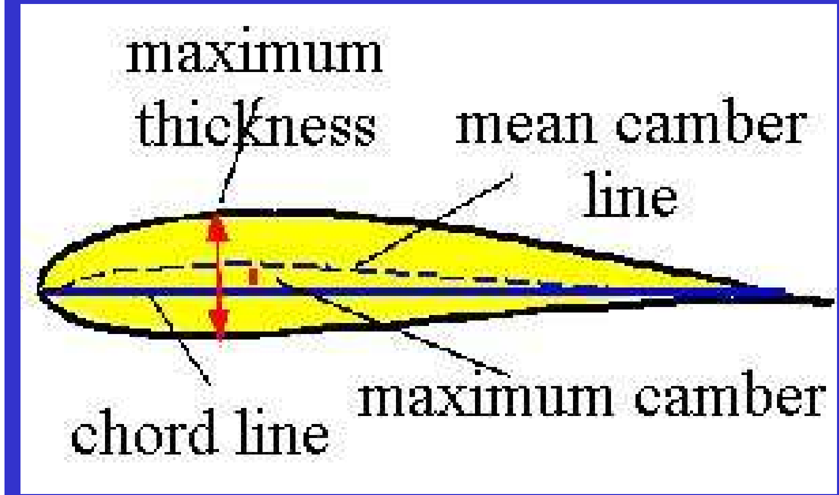
AN AIRFOIL IS A SURFACE DESIGNED TO OBTAIN A DESIRABLE REACTION FROM THE AIR THROUGH WHICH IT MOVES

AIRFOIL GEOMETRY



- CHORD LINE
- MEAN CAMBER LINE
- ANGLE OF ATTACK
- ANGLE OF INCIDENCE

Aerofoils – Geometry & Definitions



- **Chord line**: straight line connecting leading edge (LE) and trailing edge (TE).
- **Chord (c)**: length of chord line.

- **Thickness (t)**: measured perpendicular to chord line as a % of it (subsonic typically 12%).
- **Camber (d)**: curvature of section - perpendicular distance of section mid-points from chord line as a % of it (subsonically typically 3%).

Aerofoil Categories

- Early – based on trial & error.
- NACA 4 digit – 1930's.
- NACA 5-digit – aimed at pushing position of max camber forwards for increased $C_{L,max}$.
- NACA 6-digit – designed for lower drag by increasing region of laminar flow.
- Modern – mainly based upon need for improved aerodynamic characteristics at speeds just below speed of sound.

Aerofoils – NACA 4 Digit

- Rarely used today except for in simple symmetrical tailplane and fin sections.
  - 1st digit: maximum camber (as % of chord).
  - 2nd digit (x10): location of maximum camber (as % of chord from leading edge (LE)).
  - 3rd & 4th digits: maximum section thickness (as % of chord).
- Thus NACA 2412 has 2% camber at 40% chord from LE & is 12% thick (max).

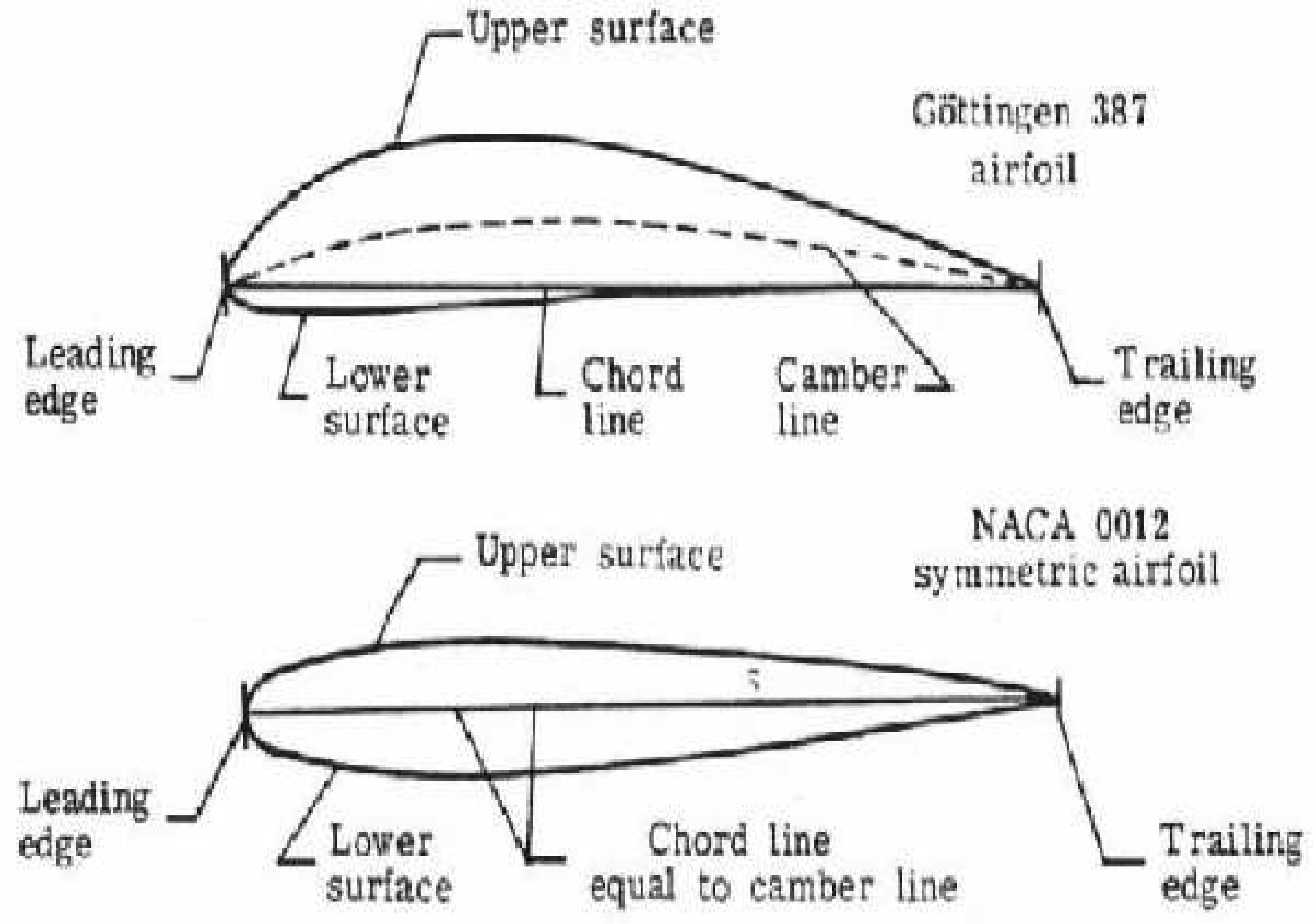
Aerofoils – NACA 5 Digit

- Much better low-speed characteristics than 4 digit series.
  - 1^{st} digit (x0.15): design lift coefficient.
  - 2^{nd} & 3^{rd} digits (x0.5): location of maximum camber (as % of chord from LE).
  - 4^{th} & 5^{th} digits: maximum section thickness (as % of chord).
- Thus NACA 23012 has C_L of 0.3 with max camber at 15% chord from LE & is 12% thick (max).

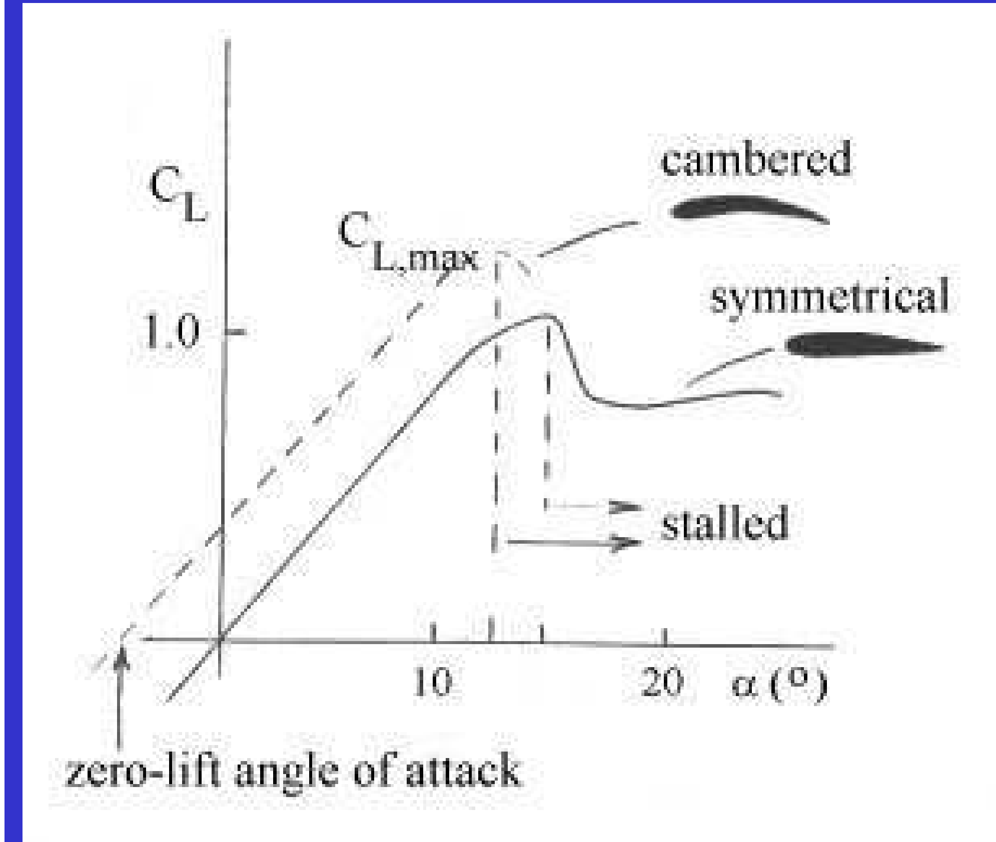
Aerofoils – NACA 6 Digit

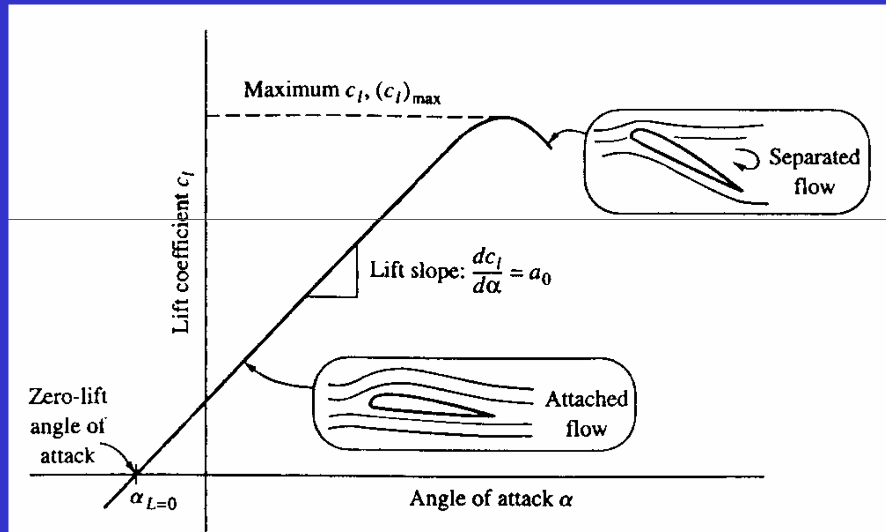
- Still represents good basis for some subsonic & high-speed applications (e.g. Mach 2 F-15 uses 64A series).
  - 1st digit: identifies series type.
  - 2nd digit (x10): location of minimum pressure (as % of chord from leading edge (LE)).
  - 3rd digit: indicates acceptable range of C_L above/below design value for satisfactory low drag performance (as tenths of C_L).
  - 4th digit (x0.1): design C_L.
  - 5th & 6th digits: maximum section thickness (%c)
- Thus NACA 632-315 is 6-series with minimum pressure 30% of chord back from LE, design C_L of 0.3 ± 0.2 & is 15% thick (max).

SYMMETRIC AND UNSYMMETRIC AIRFOIL



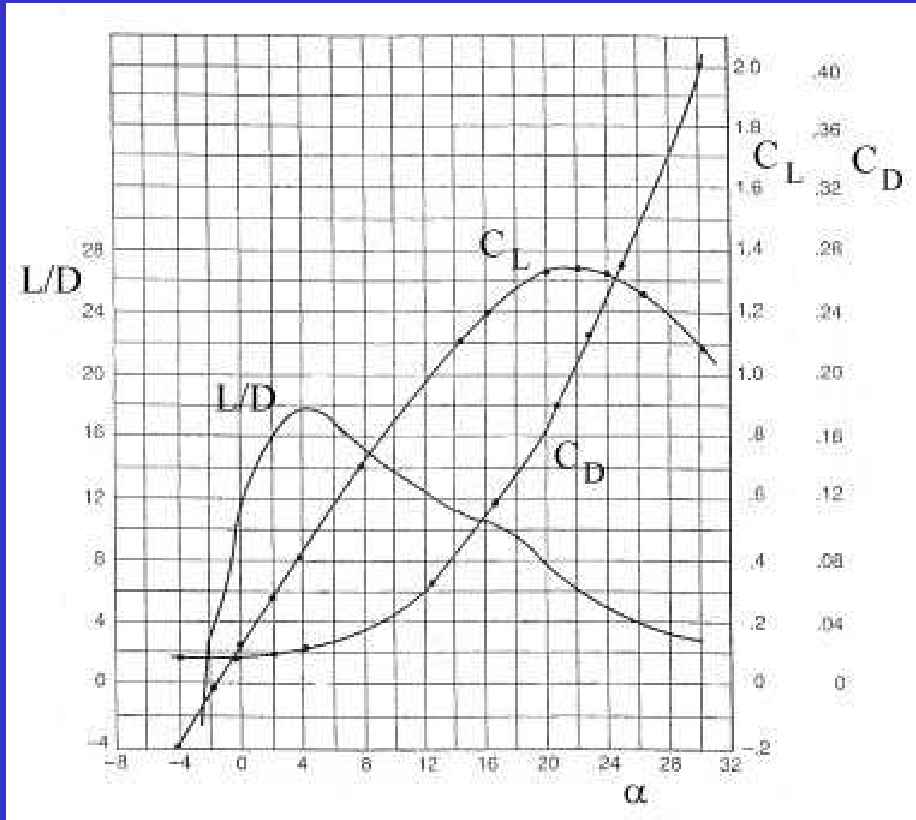
C_L VS ANGLE OF ATTACK CURVE



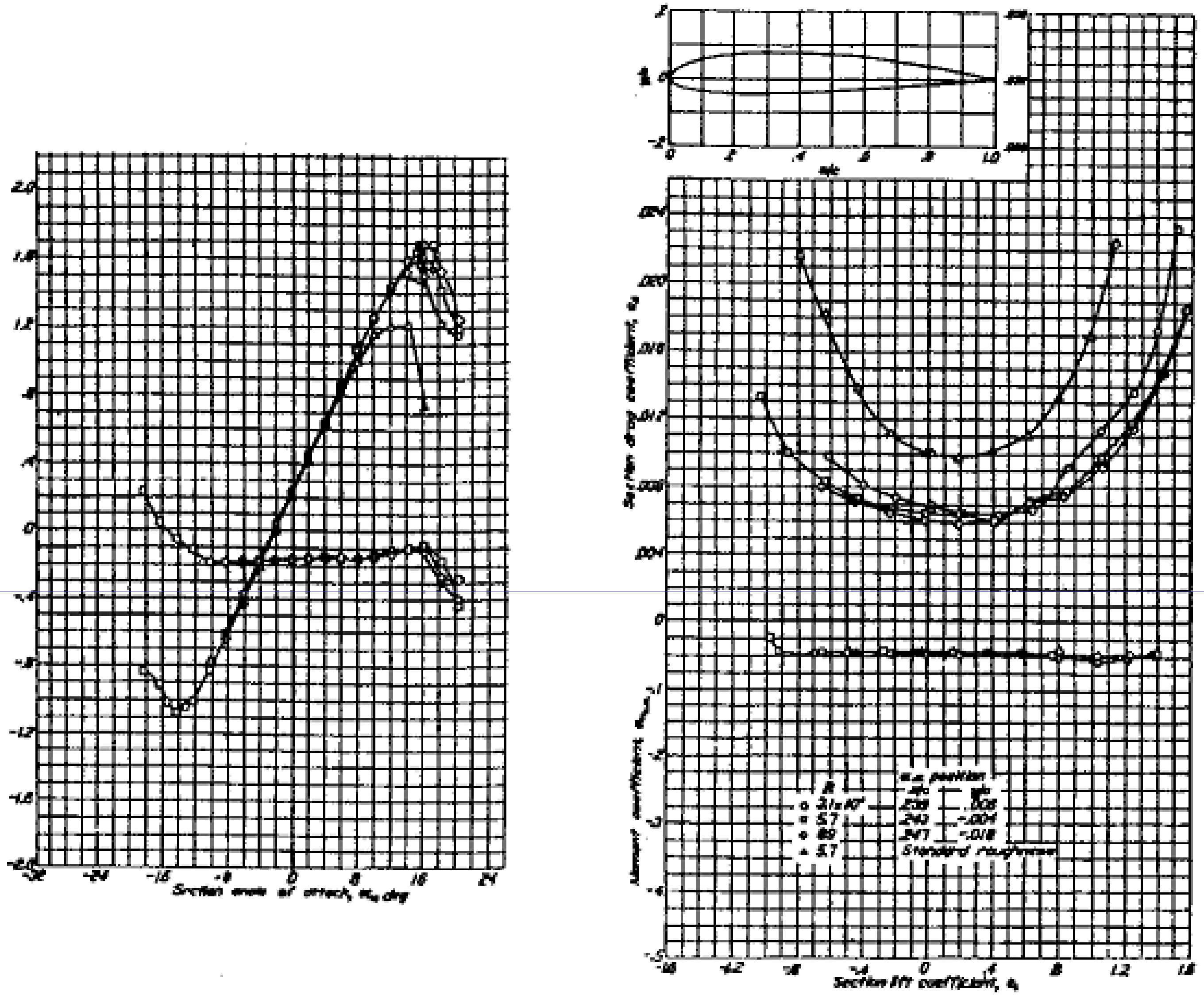


Characteristic Curves

- Available for all classes of standard aerofoils.
- Include plots of C_D, C_L, L/D,



Example – NACA 2421



(a) (b)

Data for the NACA 2412 airfoil. (**a**) Lift coefficient and moment coefficient about the quarter-chord versus angle of attack. (**b**) Drag coefficient and moment coefficient about the aerodynamic center as a function of the lift coefficient. (From Abbott and von Doenhoff, Ref. 19.)

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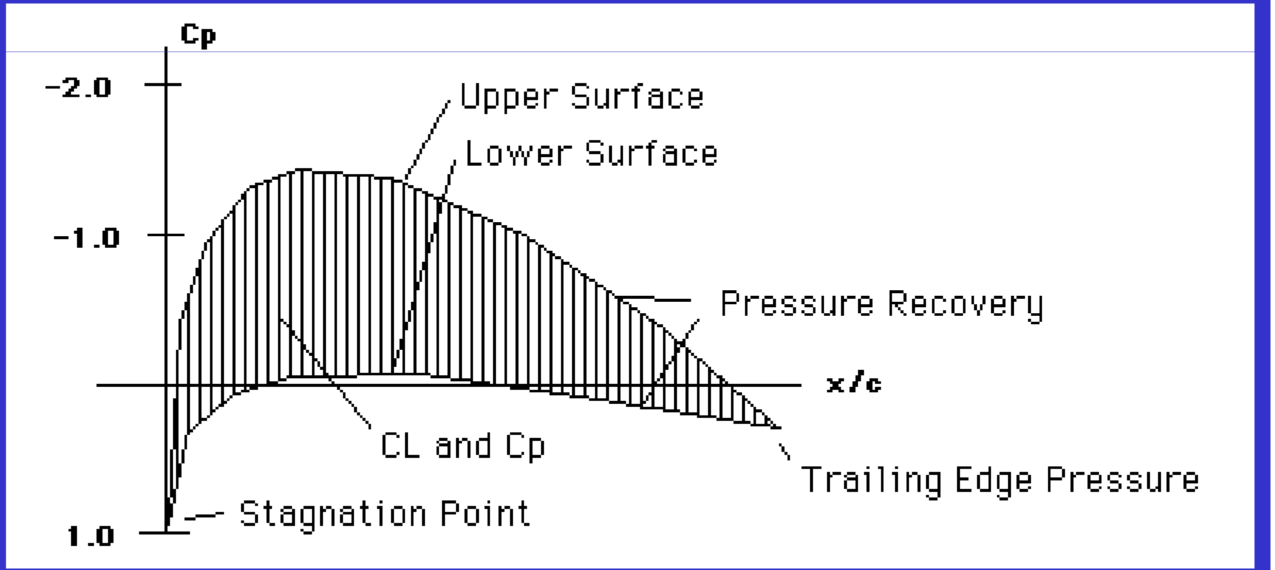
PRESSURE DISTRIBUTION ON A AIRFOIL

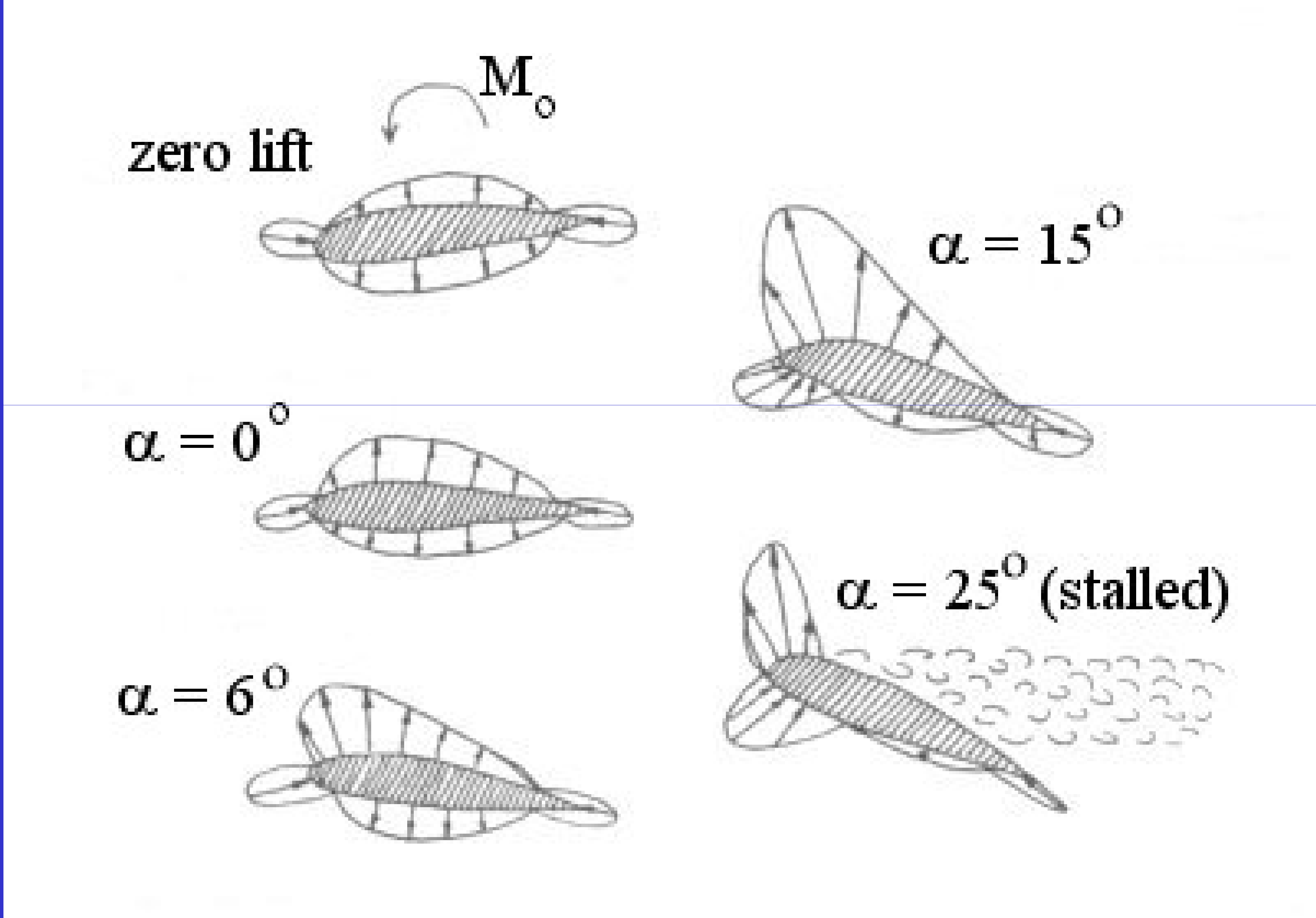
THE AERODYNAMIC PERFORMANCE OF AIRFOIL SECTIONS CAN BE STUDIED MOST EASILY BY REFERENCE TO THE DISTRIBUTION OF PRESSURE OVER THE AIRFOIL. THIS DISTRIBUTION IS USUALLY EXPRESSED IN TERMS OF THE PRESSURE COEFFICIENT:

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho U_\infty^2}$$

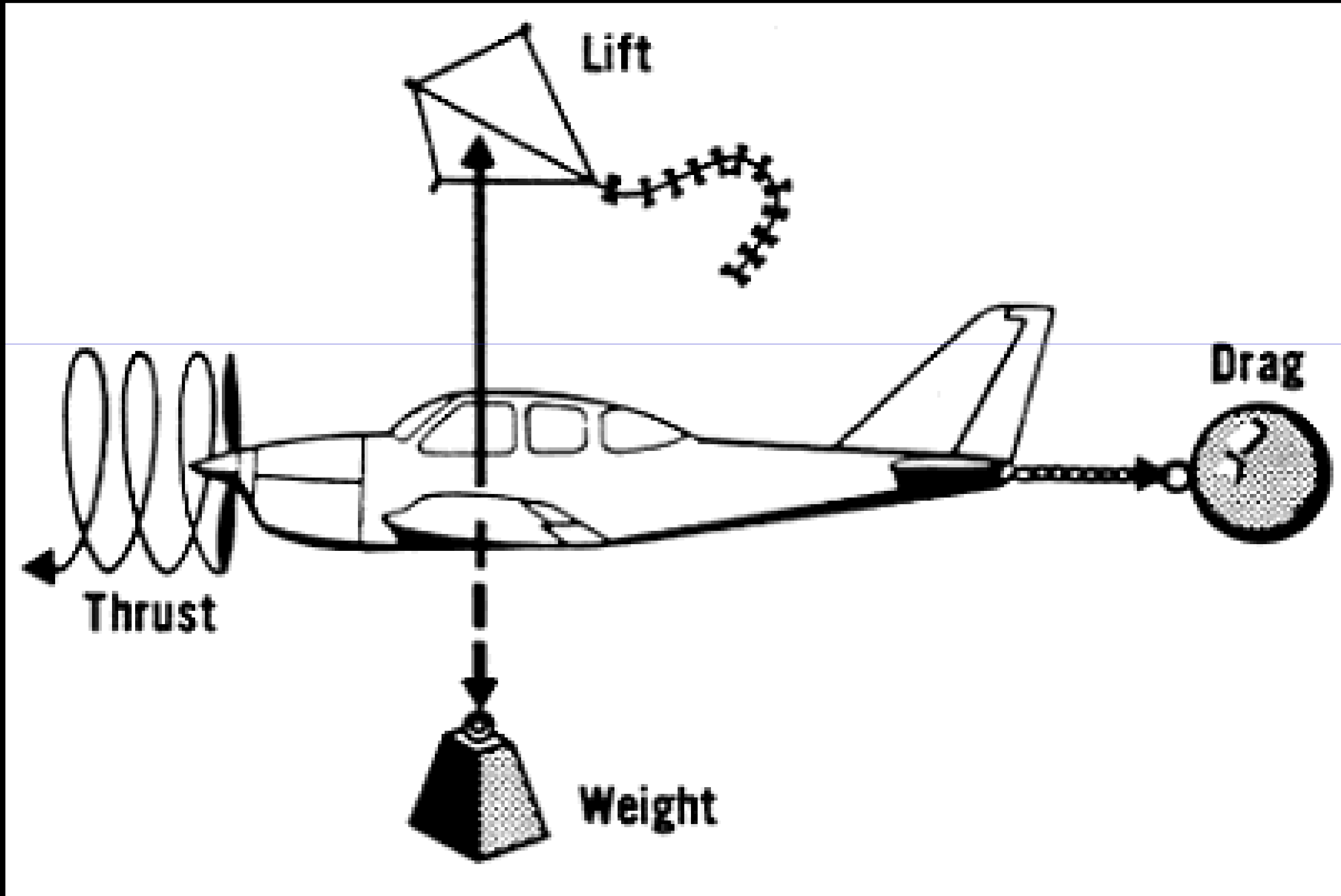


The section lift coefficient is related to the Cp by: Cl = int (Cpl - Cpu) dx/c

PRESSURE COEFFICIENT VARIATION WITH α



FOUR FORCES OF FLIGHT



FOUR FORCES OF FLIGHT

During flight the four forces acting on the airplane are:

- **Lift** is the upward force created by the effect of airflow as it passes over and under the wings. It supports the airplane in flight.
- **Weight** is a downward force caused by the pull of gravity. It opposes lift.
- **Thrust** is the forward force generated by the propeller and engine which propels the airplane through the air.
- **Drag** is the rearward force that limits the speed of the airplane.

AERODYNAMIC FORCE COEFFICIENTS

Aerodynamic force is proportional to *dynamic pressure* and a *reference area*.

$$C_F = \frac{Force}{(\frac{1}{2}\rho V_\infty{}^2)S}$$

force coefficient

ambient dynamic pressure (q)

reference area

In aerodynamics: S = gross wing planform area

In ballistics: S = maximum front sectional area

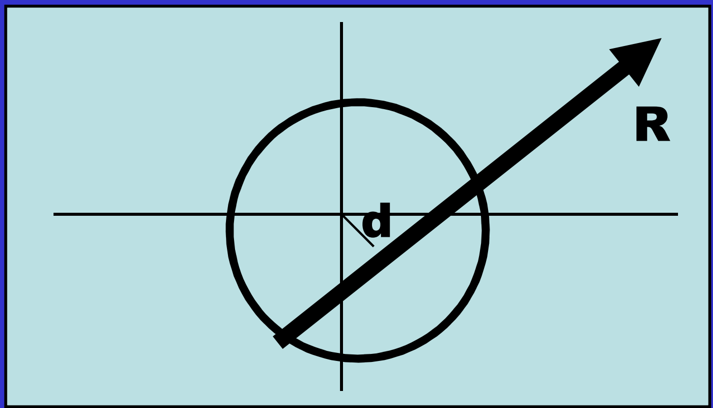
Lift Coefficient: $C_L = \frac{Lift}{qS}$

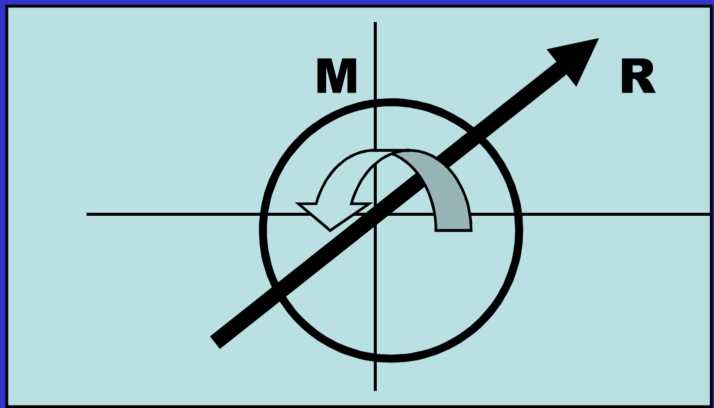
Drag Coefficient: $C_D = \frac{Drag}{qS}$

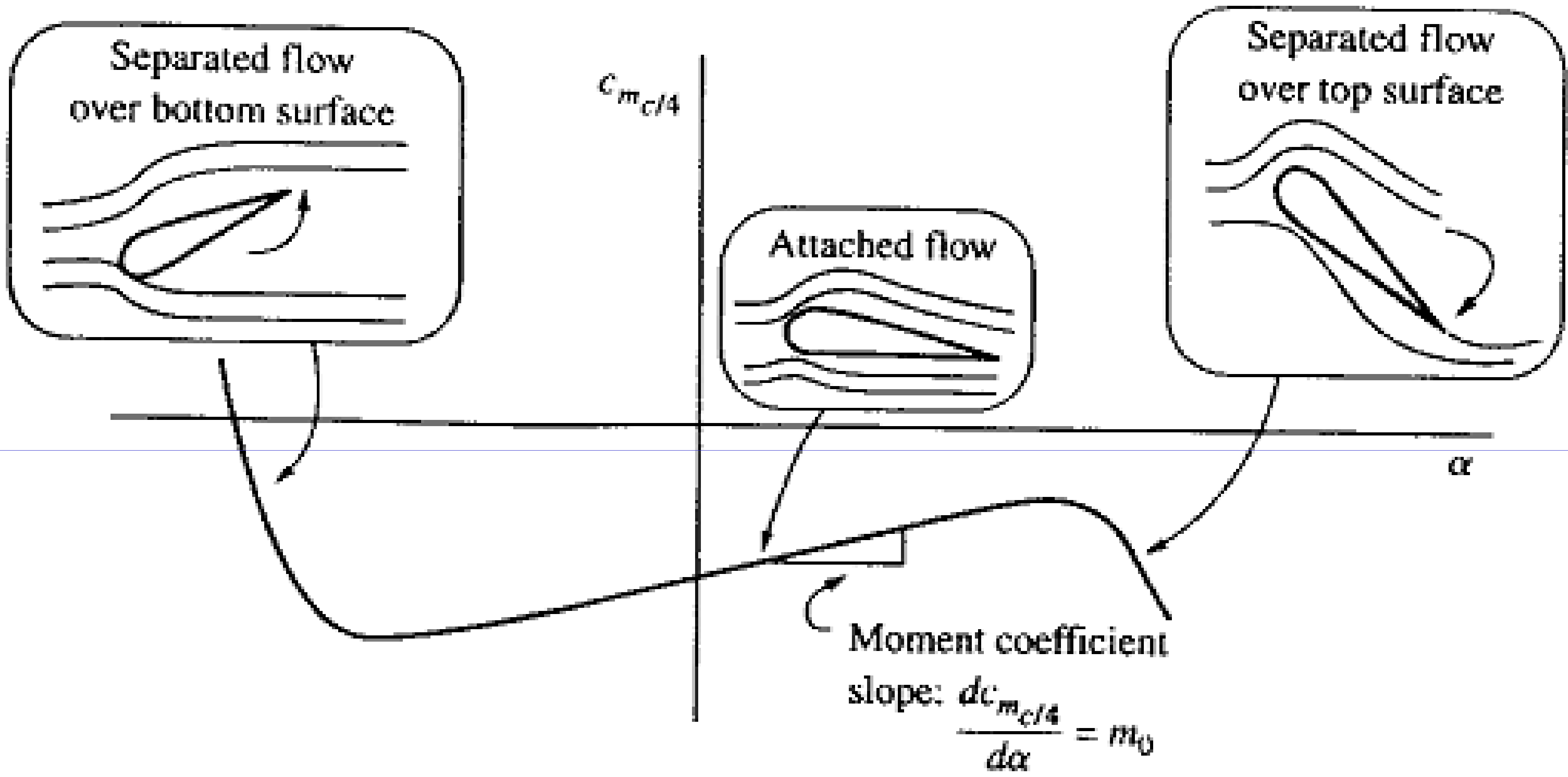
PITCHING MOMENT

THIS IS THE MOMENT ACTING IN THE VERTICAL PLAN WHICH CARRIES LIFT AND DRAG. THE PITCHING MOMENT IS POSITIVE WHEN IT TENDS TO PUSH THE NOSE UP AND NEGATIVE WHEN IT TENDS TO PUSH THE NOSE DOWN

$$M = C_M \frac{1}{2} \rho V^2 S \overline{C}$$



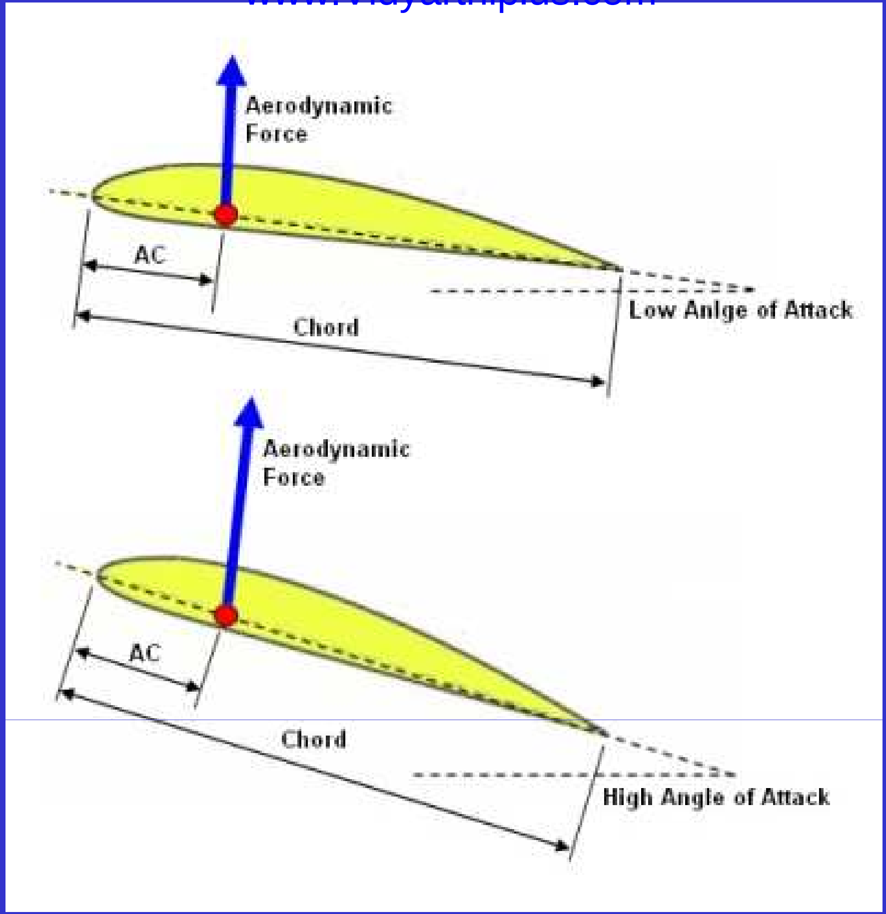




Sketch of a generic moment curve.

AERODYNAMIC CENTRE

IF THE PITCHING MOMENT AT EACH POINT IS CALCULATED FOR EACH VALUES OF C_L, ONE SPECIAL POINT IS FOUND FOR WHICH THE C_M IS CONSTANT INDEPENDENT OF THE LIFT COEFFICIENT. THIS POINT IS CALLED AERODYNAMIC CENTRE. AT SUBSONIC SPEED THE A.C IS ¼ OF THE CHORD FROM THE L.E

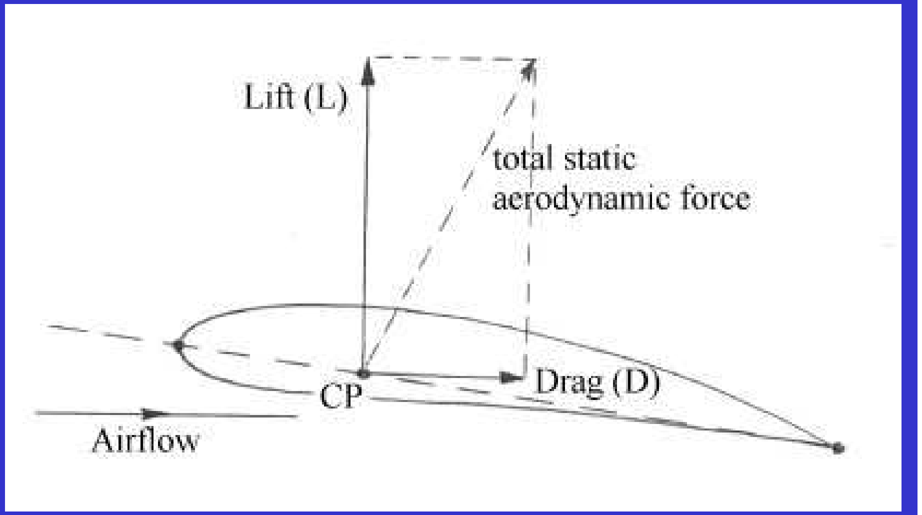


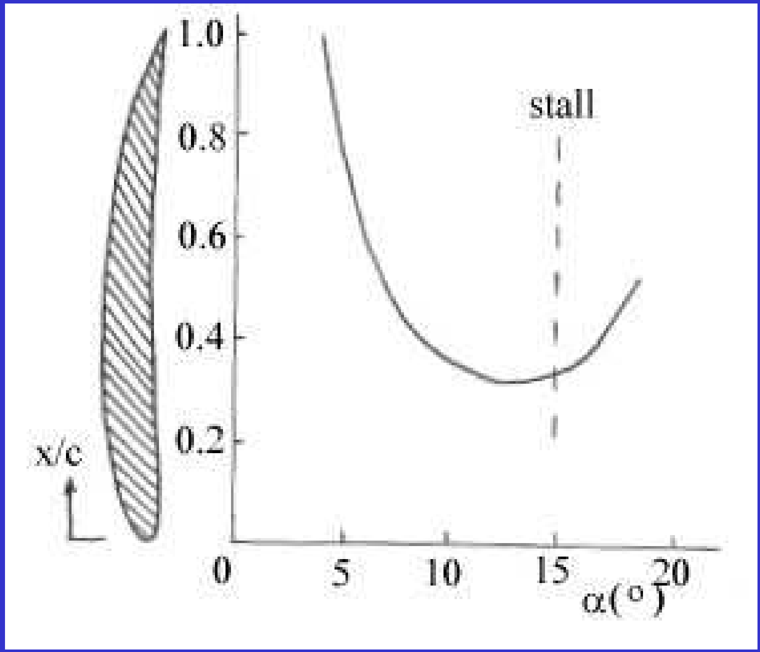
Aerodynamic Center (AC) is an imaginary point on the aircraft wing. When the aircraft wing move through the air, the position of the aerodynamic center remain at the same point regardless of change in angle of attack.

Aerodynamic center is located around 25% of the chord from the leading edge for low speed airfoils. For subsonic flow, it located approximately 50% chord from the leading edge of an aerofoil.

Centre of Pressure

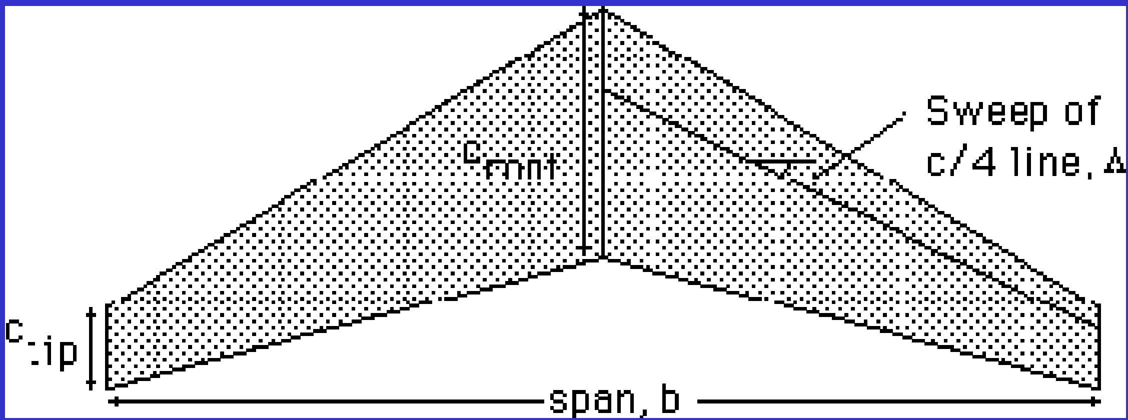
- Lift acts through the *centre of pressure* - on a cambered aerofoil this point moves as the angle of attack changes due to pressure distribution variations.
- It moves forwards until *stall* is reached, after which it moves back again.





Movement with α

WING PARAMETER



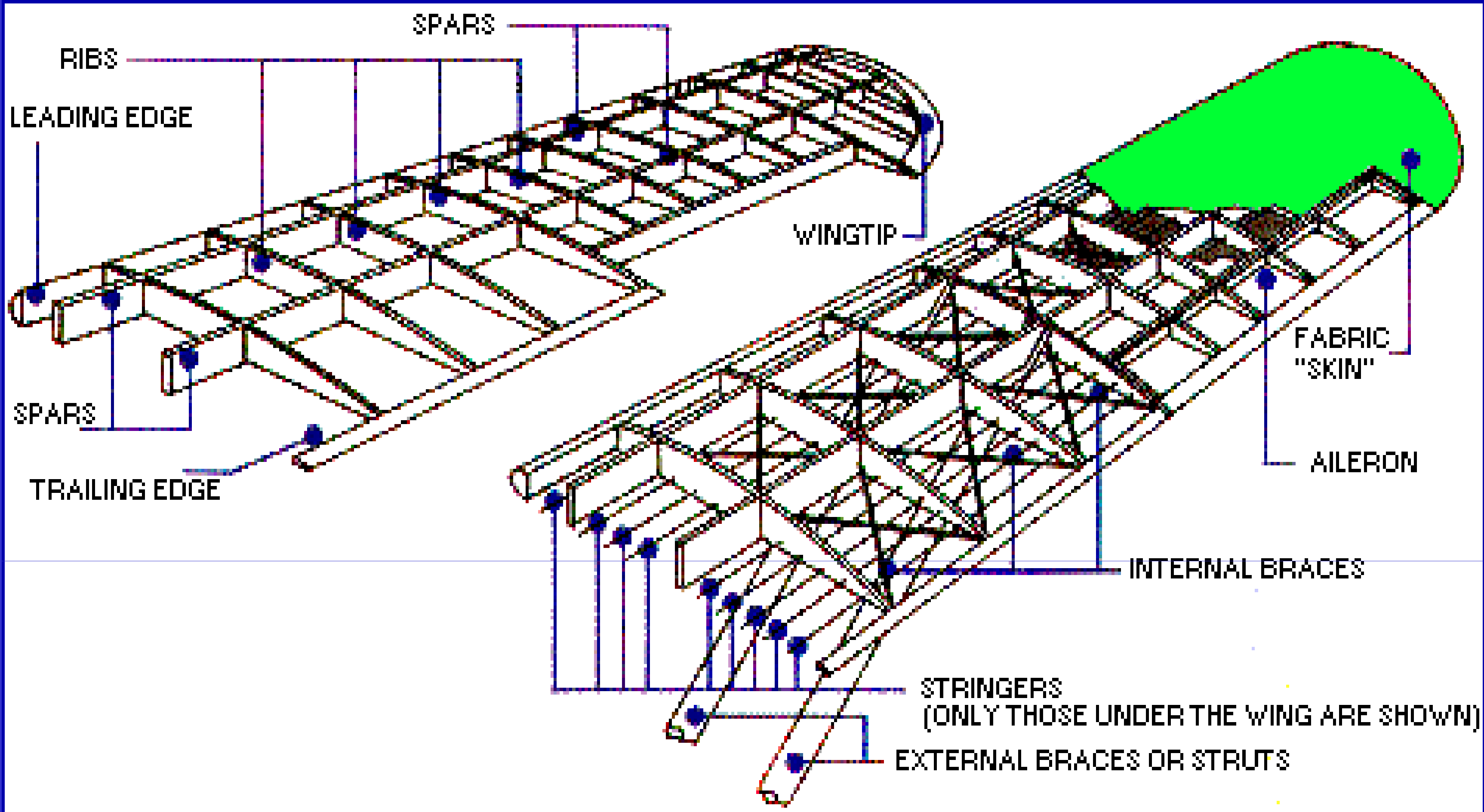
S = wing area

AR = aspect ratio = $\dfrac{b^2}{S} = \dfrac{b}{\bar{c}}$

λ = taper ratio = $\dfrac{c_{tip}}{c_{root}}$

Λ = sweep of c/4 line

θ = wing twist angle



$$a = \frac{a_0}{1 + \frac{57.3 a_0}{\pi e AR}}$$

THANK YOU