Agenda (1/3)

- **Module 1- Introduction** **(Day 1)**
  - 1-1 General Course Introduction (Day 1 Morning 1)
  - 1-2 Introduction of the Actuation session

- **Module 2 – Introduction to Aircraft Aerodynamics, stability and control** **(Day 1)**
  - **2-1 Aircraft Aerodynamics** (Day 1 Morning 2,3,4)
  - 2-2 Aircraft Stability and Control (Day 1 Afternoon 1,2,3,4)

- **Module 3 - A/C Aircraft configuration for flight controls and high lift** **(Day 2)**
  - 3-1 Arrangement of flight control surfaces and high lift devices (Day 2 Morning 1)
  - 3-2 Cockpit Controls (Day 2 Morning 2)

Objective of the aero session

- What is Aerodynamics
  - In Aviation, the term Aerodynamics is used for subjects arising from flight involving the flow of the air (L. Prandtl)
  - Aerodynamics is the study of air(or other gases) in motion and of the forces acting either on bodies in motion through the air or fixed bodies in an airstream

- It is the objective of this session to get familiar with:
  - Definition of basic aerodynamic quantities (P, T, …) (Part 1)
  - Source of aerodynamic forces (Part2)
  - Definition of lift , drag und momentum coefficient (Part 3)

Fundamental definitions and basic equations of fluid dynamics

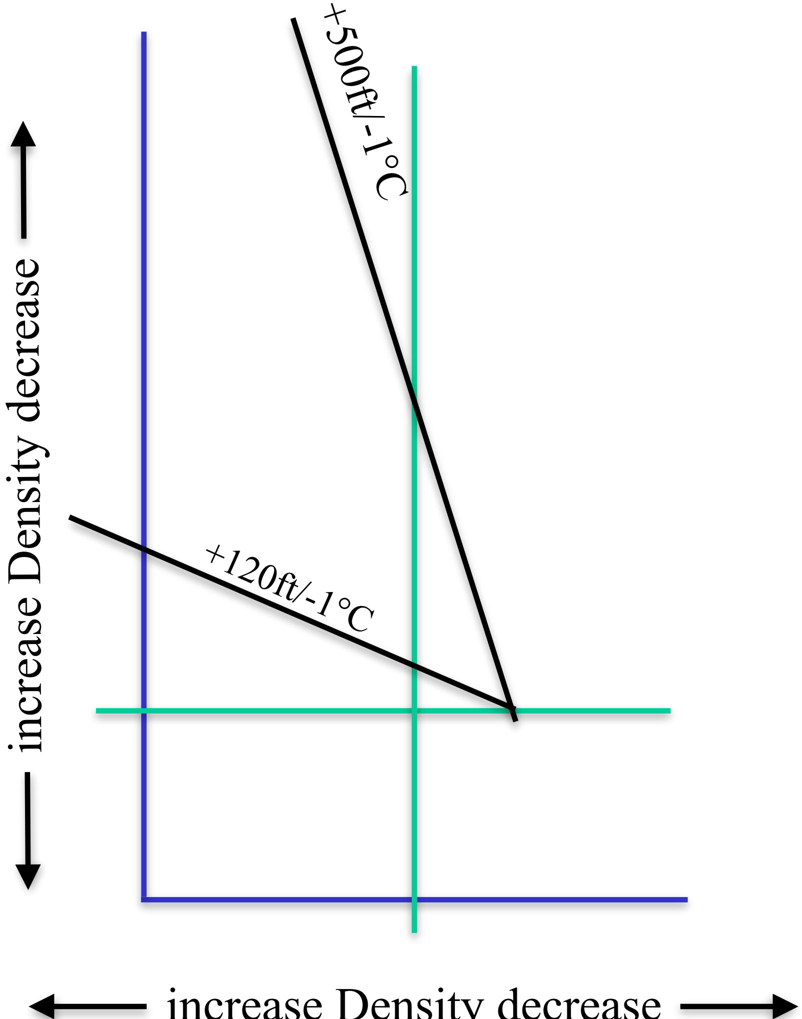
- It is assumed that you are already familiar with the basic definitions of fluid dynamics
  - Properties of the atmosphere .
  - Standard atmosphere
  - -Newton's Three Laws
  - Gas State equation
  - Continuity Equation
  - Momentum Equation
  - Conversation of energy
  - Bernoullis Principal
  - Reynolds Number

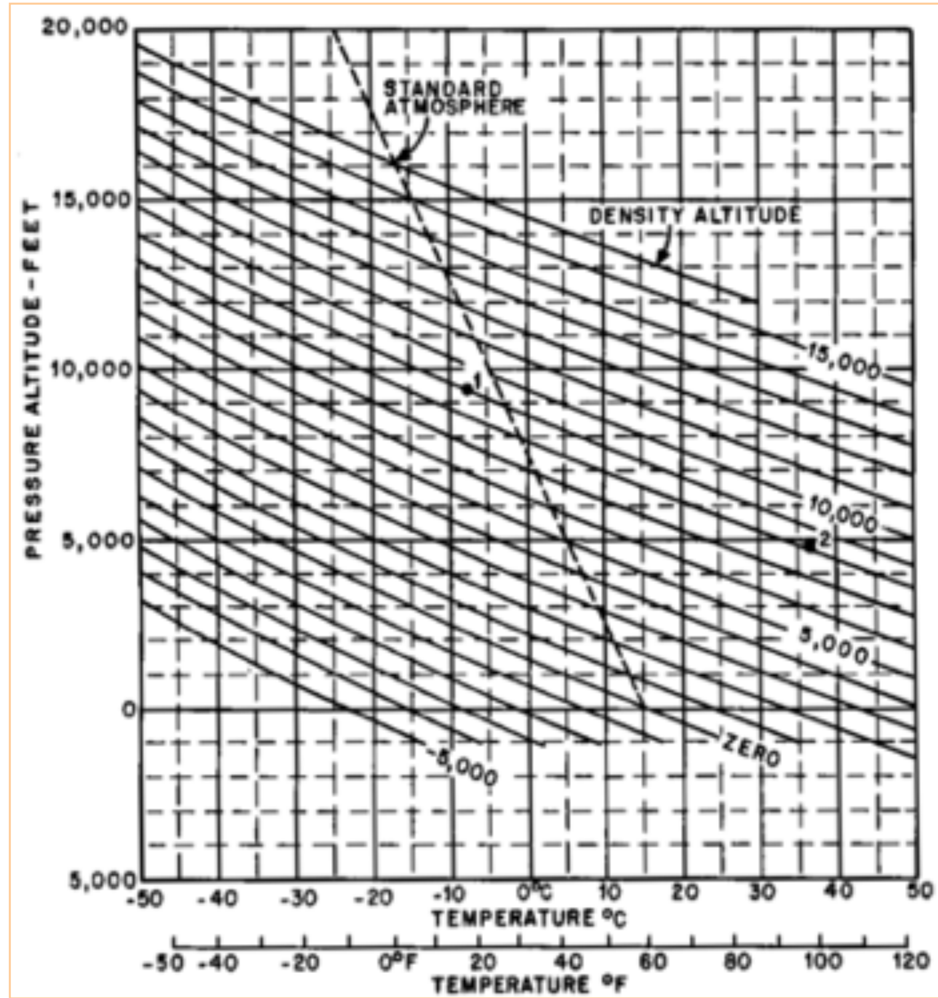
Fundamental definitions and basic equations of fluid dynamics

- It is assumed that you are already familiar with the basic definitions of fluid dynamics
  - Properties of the atmosphere (T,P,ρ,μ,r)
    - Temperature, pressure, density, viscosity, gas const.
  - Standard atmosphere
  - Ideal Gas State equation p*V=R*T , $\frac{P}{rT} = \rho$
  - Continuity Equation (Conservation of mass)
  - Momentum Equation (Conservation of Momentum) (F=m*a)
  - Conversation of energy (no creation, no destroyment) only change of form (kinetic energy, potential energy)
  - Bernoullis Principal $p + \frac{1}{2}\rho v^2 = Const$
  - Reynolds Number (relates Air flow inertia to Viscosity)

$$\mathrm{Re} = \frac{\rho_0 V_0 l}{\mu}$$

Density Altitude





Newton’s Laws

- 1. Law
  - A body at rest remain at rest , a body in motion will continue to move (straight) unless acted by an external force
- 2. Law

  Force equals Mass times Acceleration.

  for aerodynamics: the Force (or thrust) is equal the amount of air expelled per time * velocity of the Gas
- 3. Law
  - For every action there is an equal and opposite reaction

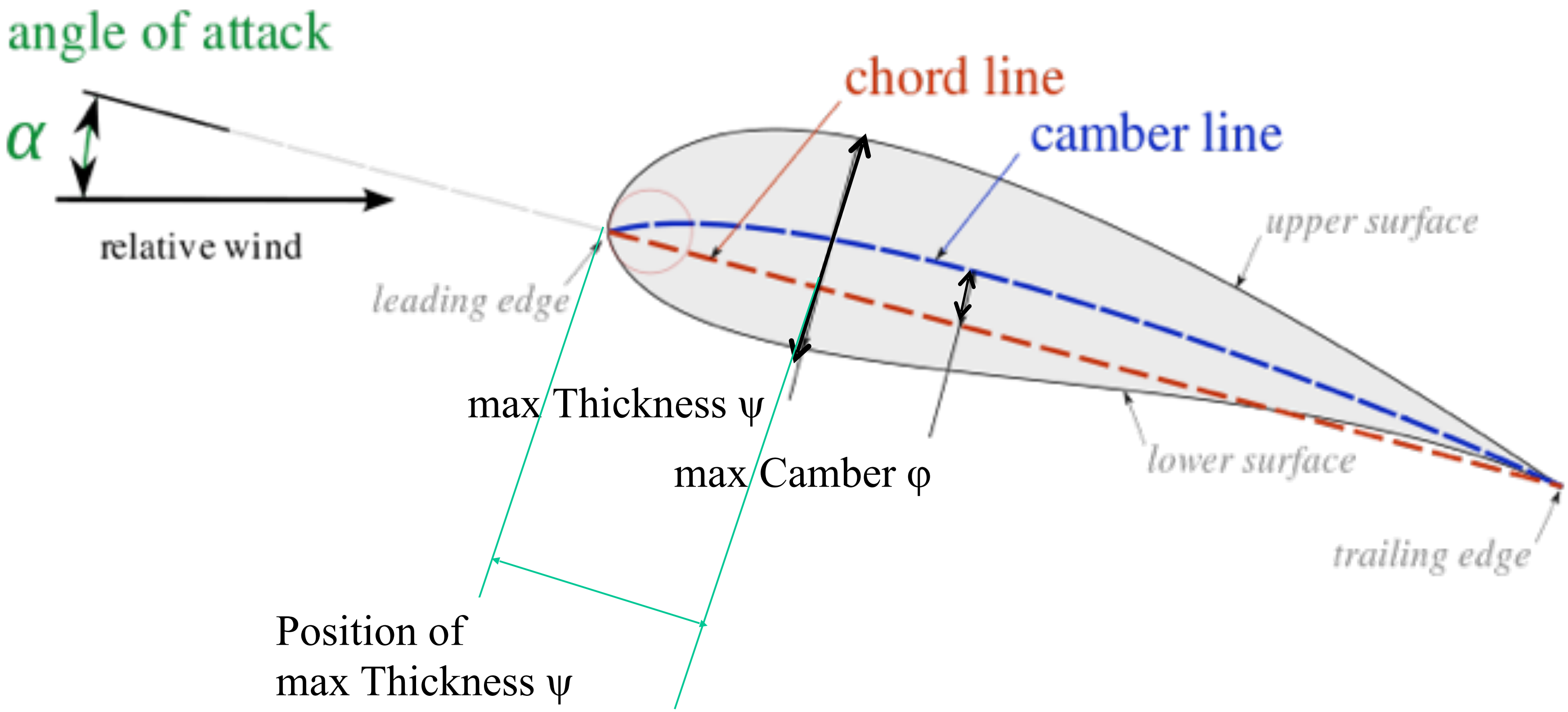
AERODYNAMICS 2

Definitions relating to airfoil and wings

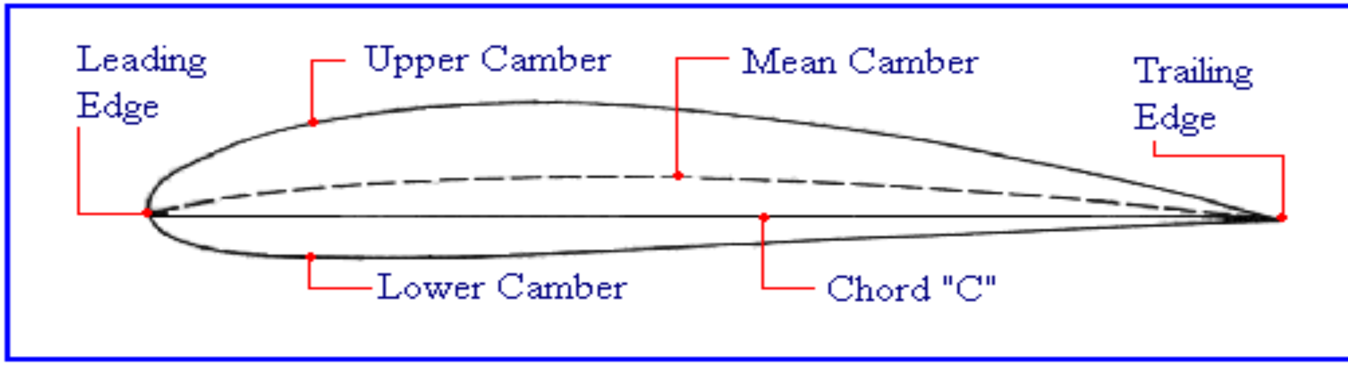
Airfoil geometrical definitions

- The chord, Leading edge and Trailing edge
- Chamber line
- Cord line
- Thickness
- Chamber
- Angle of attack

Airfoil geometrical definitions

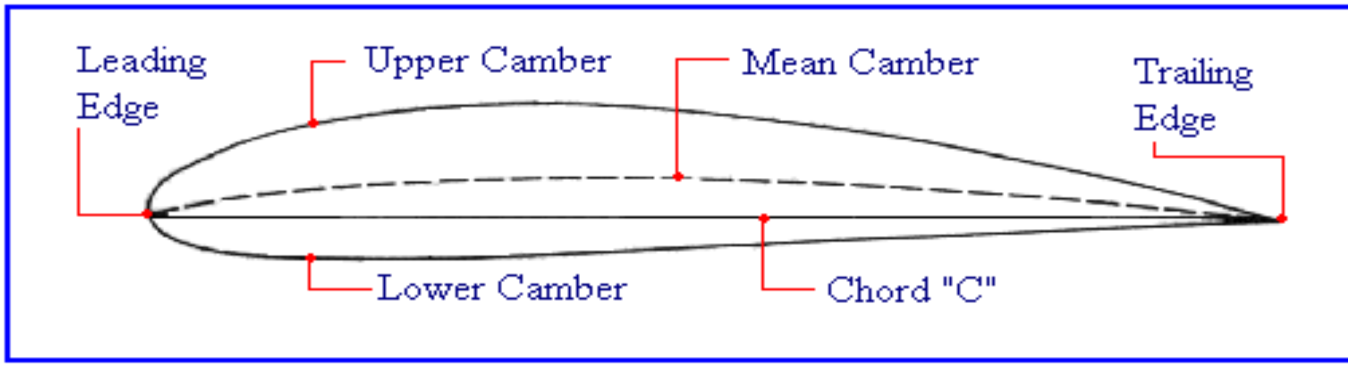


Airfoil geometrical definitions



- The cord line is a straight line between the leading and the trailing edge
- The mean chamber line is the point midway between the the upper and the lower chamber (messured 90° to the cord line)

Airfoil geometrical definitions



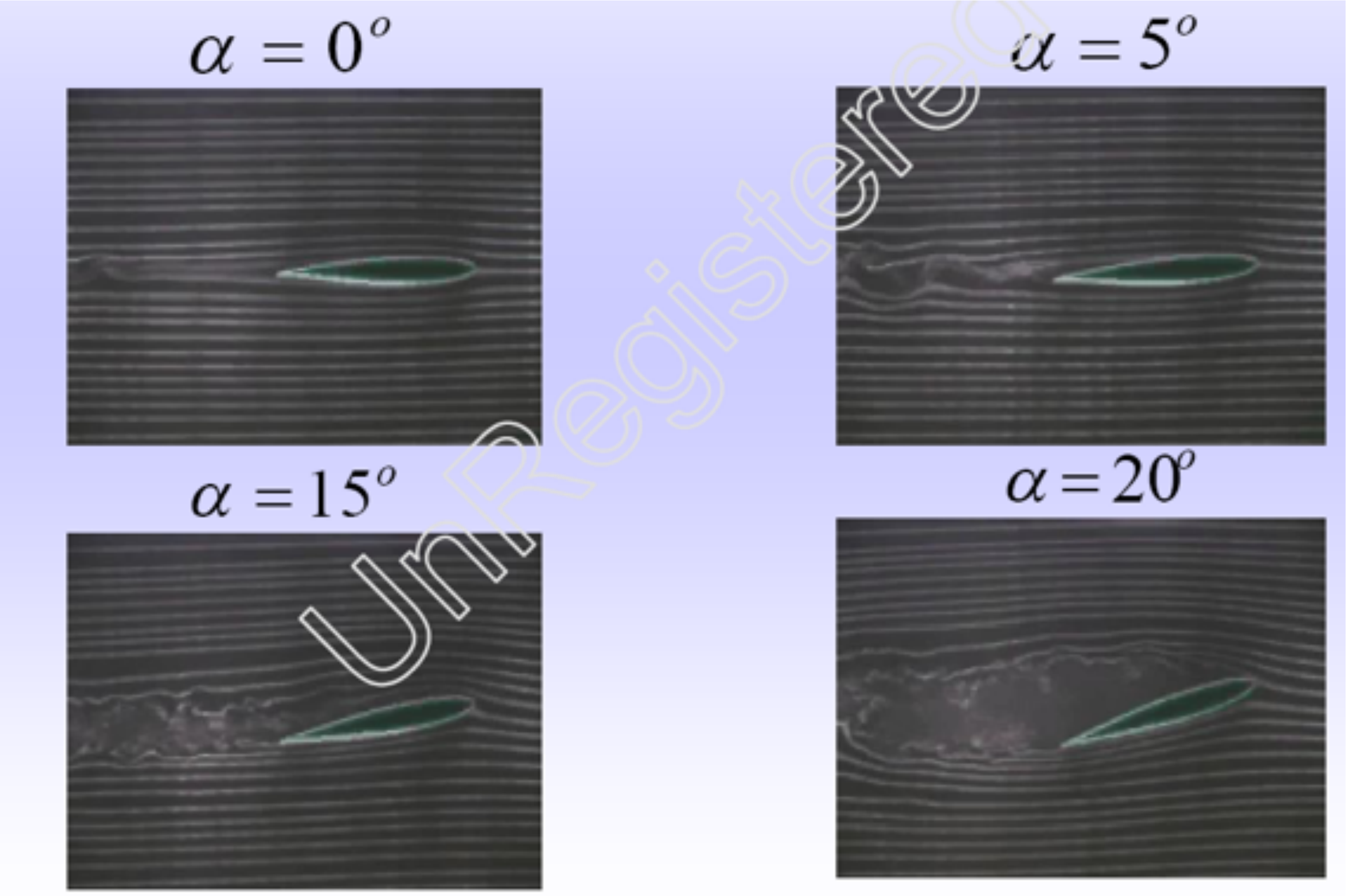
- The maximum distance from the chord line to the camber line is designated as the airfoil camber (f) $f = \frac{\varphi}{C} * 100$
- The maximum distance between the upper and lower surface is the airfoil thickness, (e) $e = \frac{\psi}{C} * 100$
- designate as a percent of chord length

If the mean camber line coincides with the chord line, the airfoil is said to be symmetrical. In symmetrical airfoils, the upper and the lower surfaces have the same shape and are equidistant from the chord line.

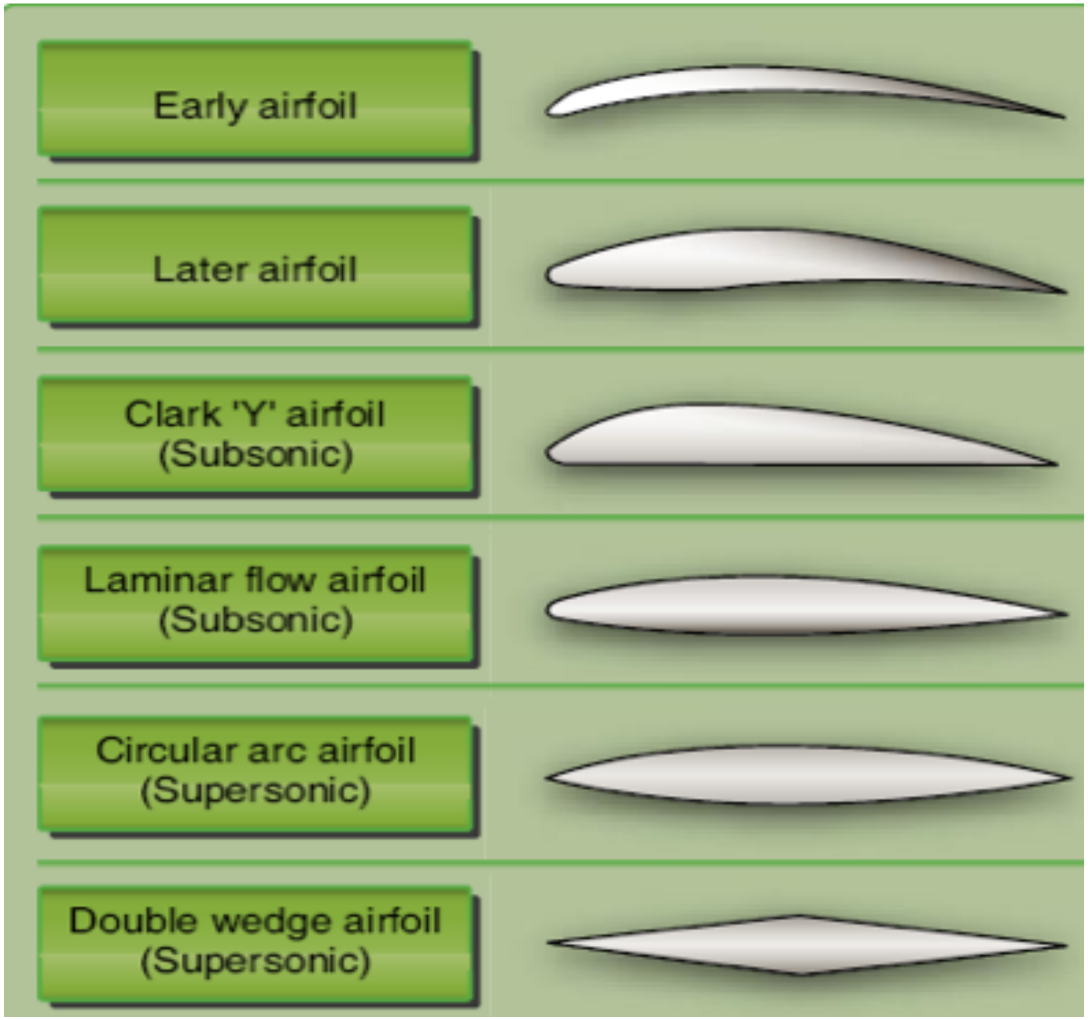
Airfoil

- The Angle of Attack alpha is the angle between relative wind (RW) and the chord.

Typical Airfoil, effect of α to the airflow



Airfoil Designs



Main parameter for **Lift:**
- Surface
- Angle of attack

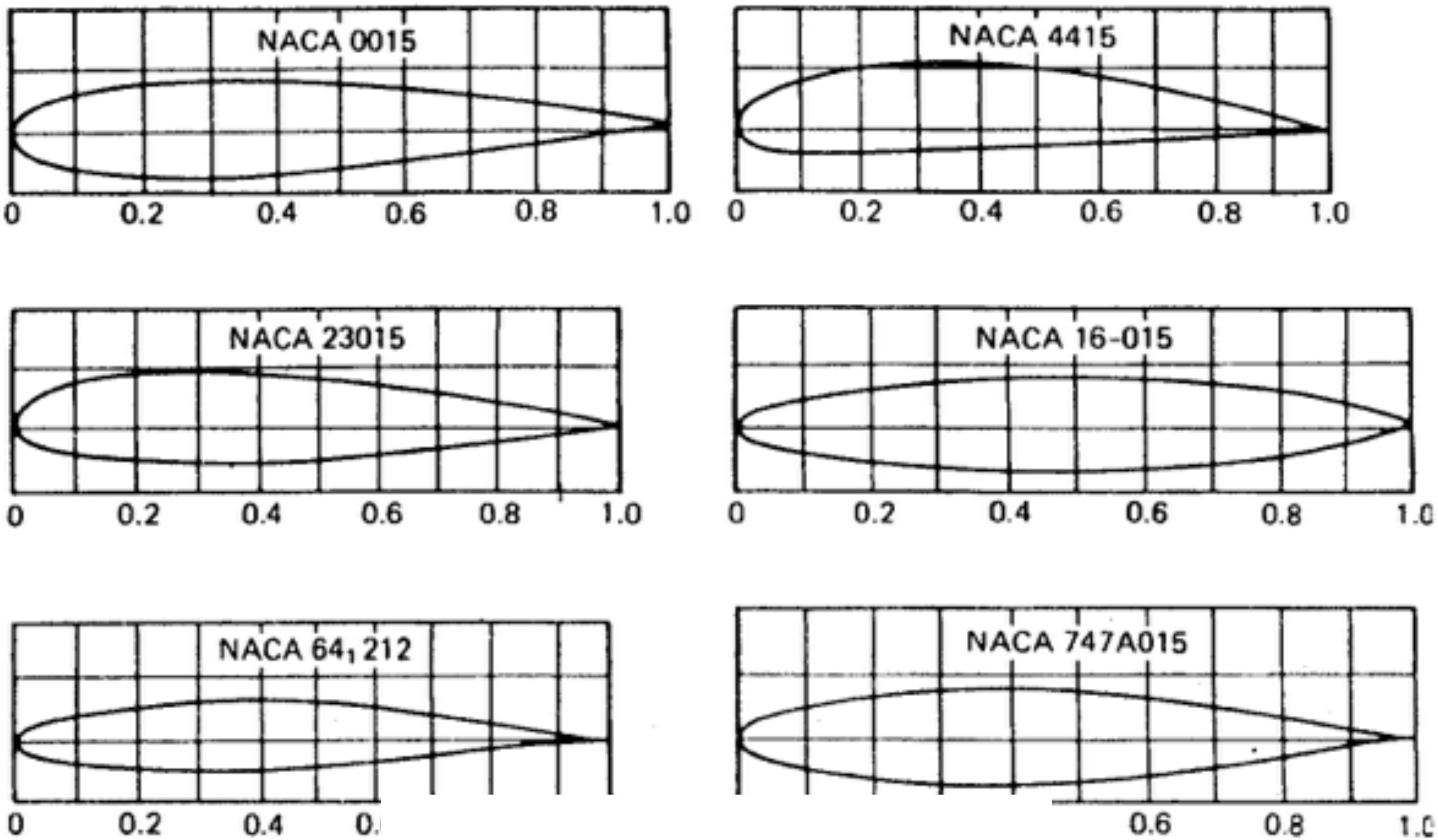
Main parameter for **Drag**:
- Surface
- Airfoil shape

Specific Case:
- Supersonic Speed

Brief History of NACA airfoils

- Early airfoils 4 digit series (low speed)
- 5 digit series for higher speed airfoils with laminar flow
- In the 6th and 7th series airfoils the maximum thickness moves backwards and the leading edge radius reduced (lower drag due to increase of laminar area and higher critical mach number (allows higher speed without compressibility problems))

NACA airfoils



THALES AIRBUS GROUP SAFRAN

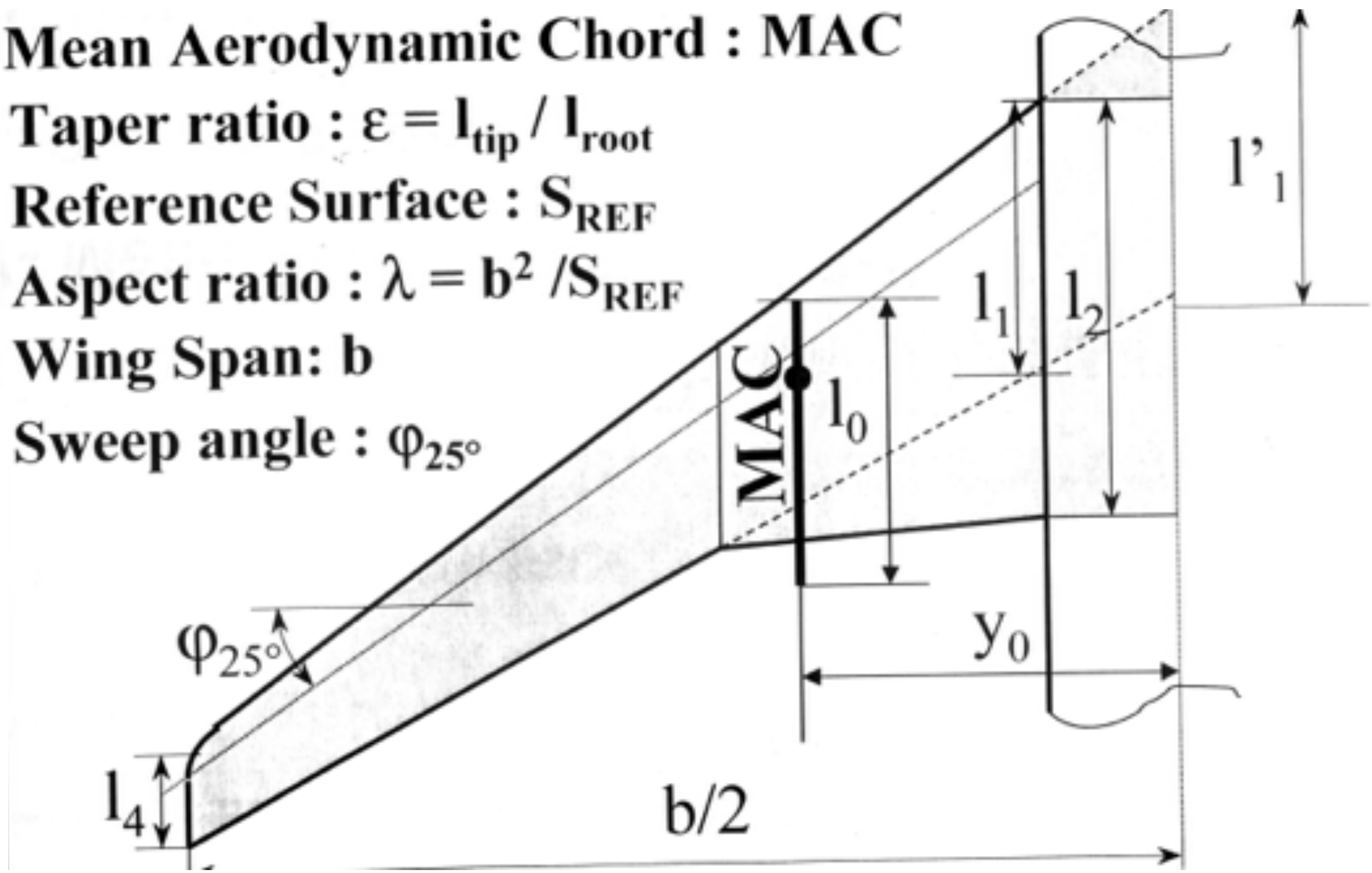
Classification of Airfoils

- NACA 4 digit series (NACA2415)
  - Amount of chamber in % of cord: 2%C
  - Position of max chamber in tenths of cord: 40%C
  - Maximum thickness in % of cord: 15%C
- NACA 6 Digit Series (NACA 64-212)
  - profile of the “6” series
  - Minimum pressure at 40%C
  - Design lift coefficient of .02
  - Thickness of 12%C

Wing geometrical definitions

- Wing planform
- Reference surface
- The aspect ratio
- Mean aerodynamic chord
- Sweep angle
- Dihedral angle

Geometrical definitions

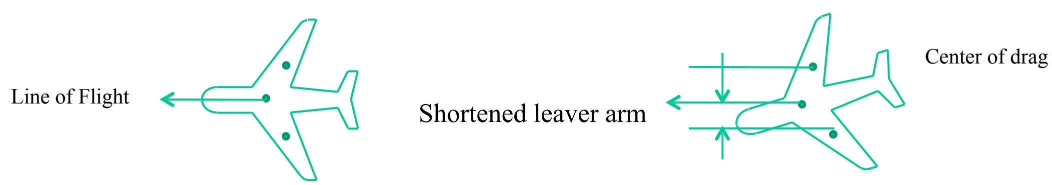


Wing geometrical definitions

- The <u>wing reference surface</u> (Planform) refers to the shape of the wing as seen from directly above. Wings may be rectangular or elliptical or delta shaped.
- The <u>taper ratio</u> of a wing is the ratio of the wing deeps at the tip and the deeps of wing at wing root
- The <u>aspect ratio</u> of a wing is the relationship between the length or span of the wing and its ref Surface.
- The <u>angle of incidence</u> is the angle at which the wing is permanently inclined to the airplanes longitudinal axis. (see next page)

Wing parameter influence

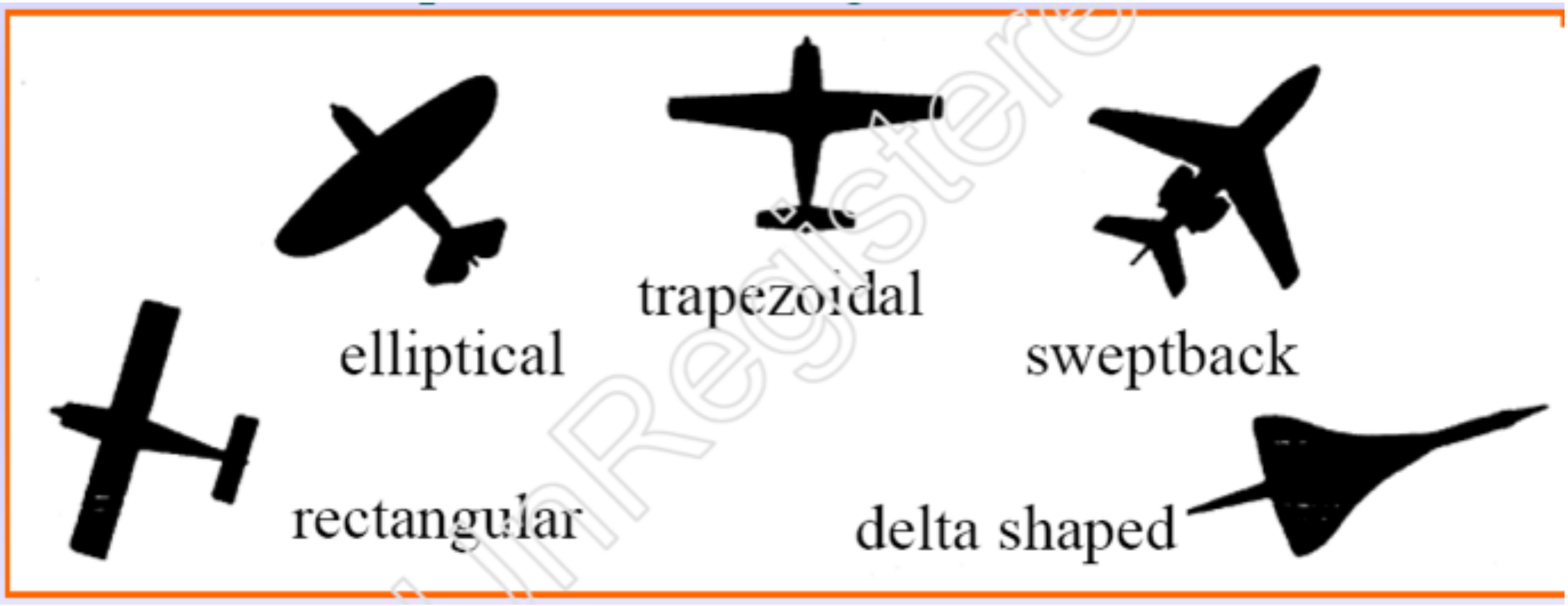
- Wing loading 30N/m2 glider, up to 700N/m2 commercial Jets
  - High wing load for high speed aircraft, (higher Stall speeds, more Turbulence resistance
- High **aspect ratio** wings improve efficiency , less induced drag, more parasitic drag, (with increased cord, wing becomes less efficient to produce lift), but very flexible, and structurally heavy..
- (Small AR wings are lighter , less weight my compensate less lift)
- (Glider: large Span, small Cord, High AR results in 60:1 glide ratio)
- A **Sweep angle** increase will reduce drag at higher speeds, (commercial AC cruise speed is 70 to 90% of M=1)
- Sweep increase improve also lateral stability of the Aircraft



Wing parameter influence

- Large **Wing Taper** (short at the tip, large at the root), high tapered wings have the aerodynamic center closer to the wing root, wing becomes lighter, Span wise distribution of Airflow is best at elliptical wings , but to difficult to build
- **Twist** les angle of attack at the tip, unloads the outer wing, better stall characteristics
- **Dihedral** , stabilise Aircraft in roll and yaw movements
- High wing , low wing, driver for the design are mainly overall practical aspects. (example, long gear legs versus Body mounted fuselage

Various planform of wings



Geometrical influence

λ-aspect ratio
φ-sweep angle

Cruise mach number is the major determinig factor for the wing planform of an aircraft

Cruise Mach number M_0 ⟶ Wing planform

Subsonic : $0{,}2<M_0<0{,}4$

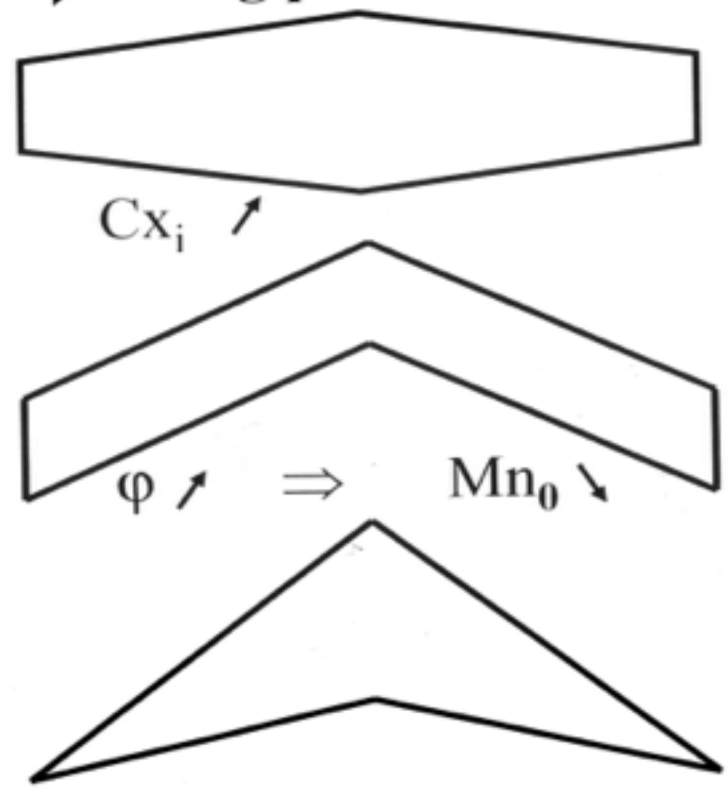
λ high
φ low

low transsonic : $M_0<1$

λ average
φ average

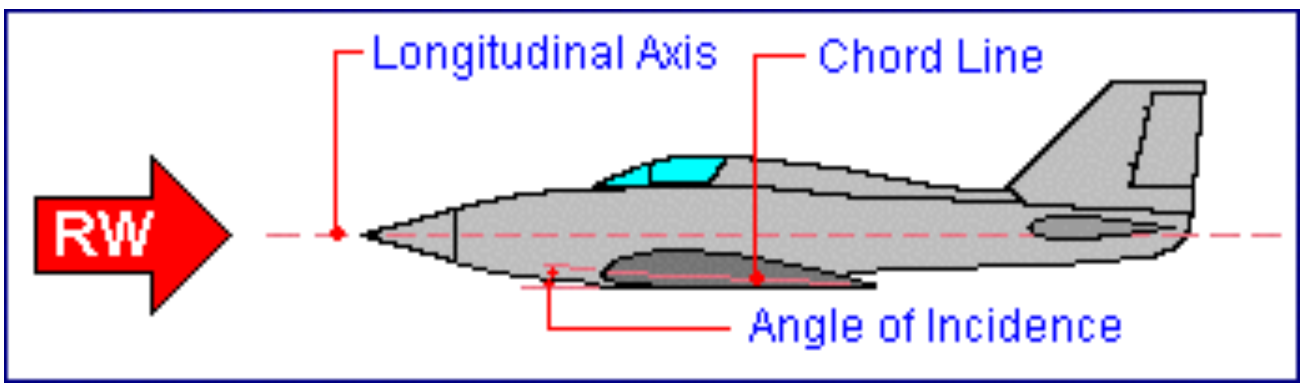
Supersonic : $M_0>1$

λ low
φ high

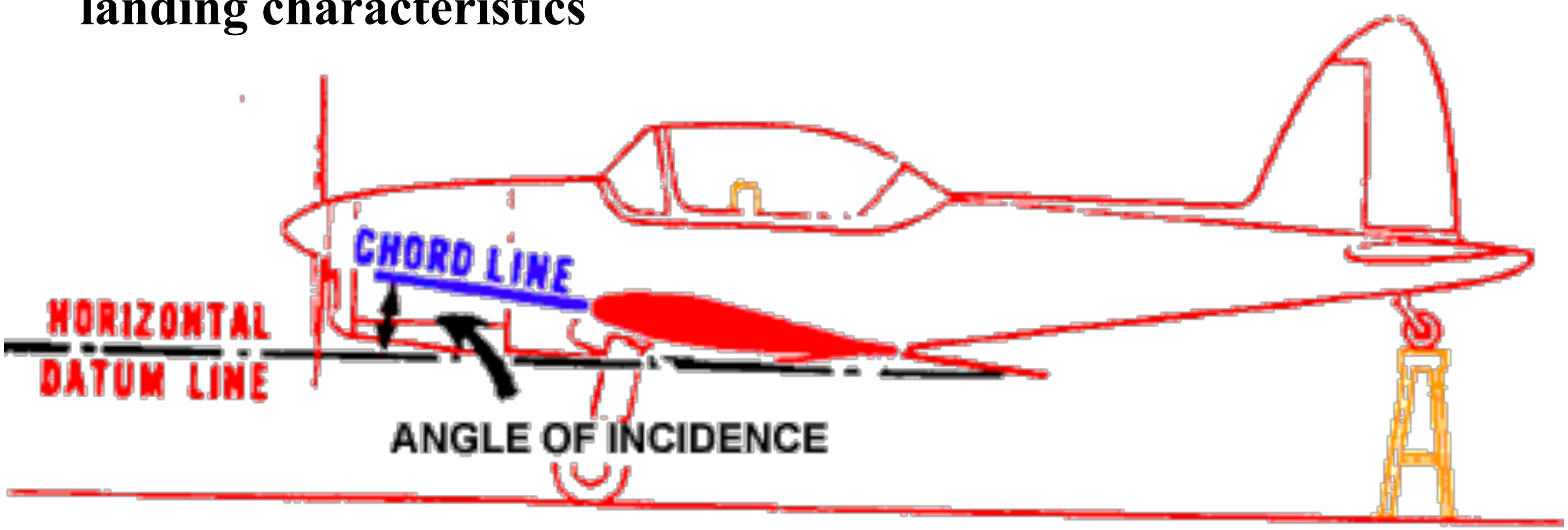


Angle of Incidence

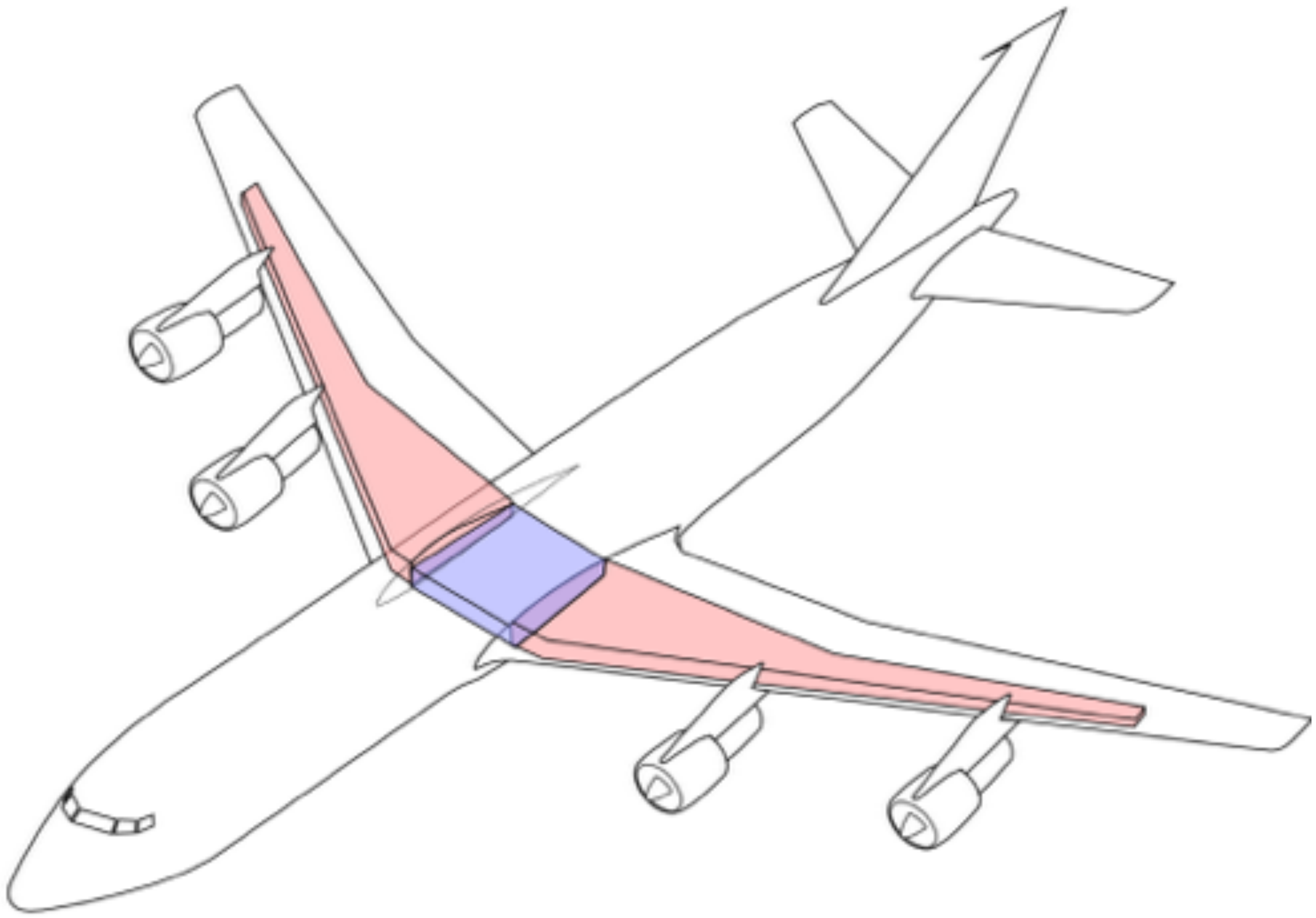
- The angle of incident is the angle between the cord line of the wing and the reference axis of the fuselage.
- The angle of incident has normally a a positive value to minimize the fuselage drag in cruise



The angle of incidennce is the angle between the aircraft horizontal datum line and the wing cord line
Choosing the right angle of incidence optimize drag in level flight. (main parameter for the economy of the aircraft) compromise to be made of achieve sufficient take-off and landing characteristics



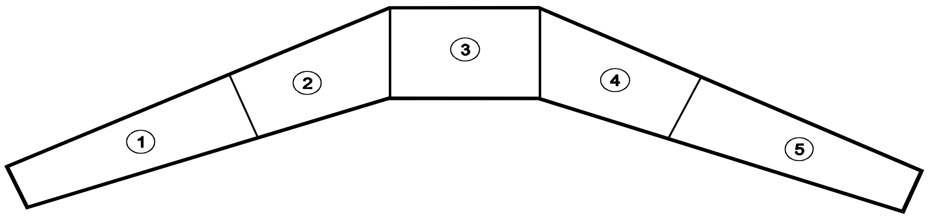
Wing as a fuel tank



The Wing, Fuel tank confiruration and consumption law

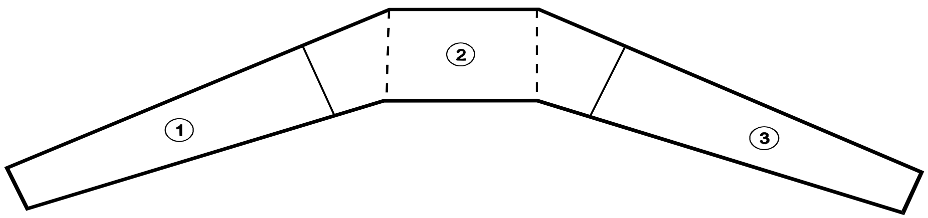
Consumption law

A 300
A 310



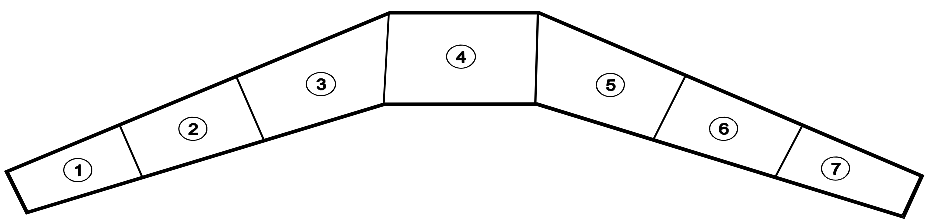
2 + 4 (Take off)
3
2 + 4
1 + 5

A 320



1 + 3 (Take off)
2
1 + 3

B 747

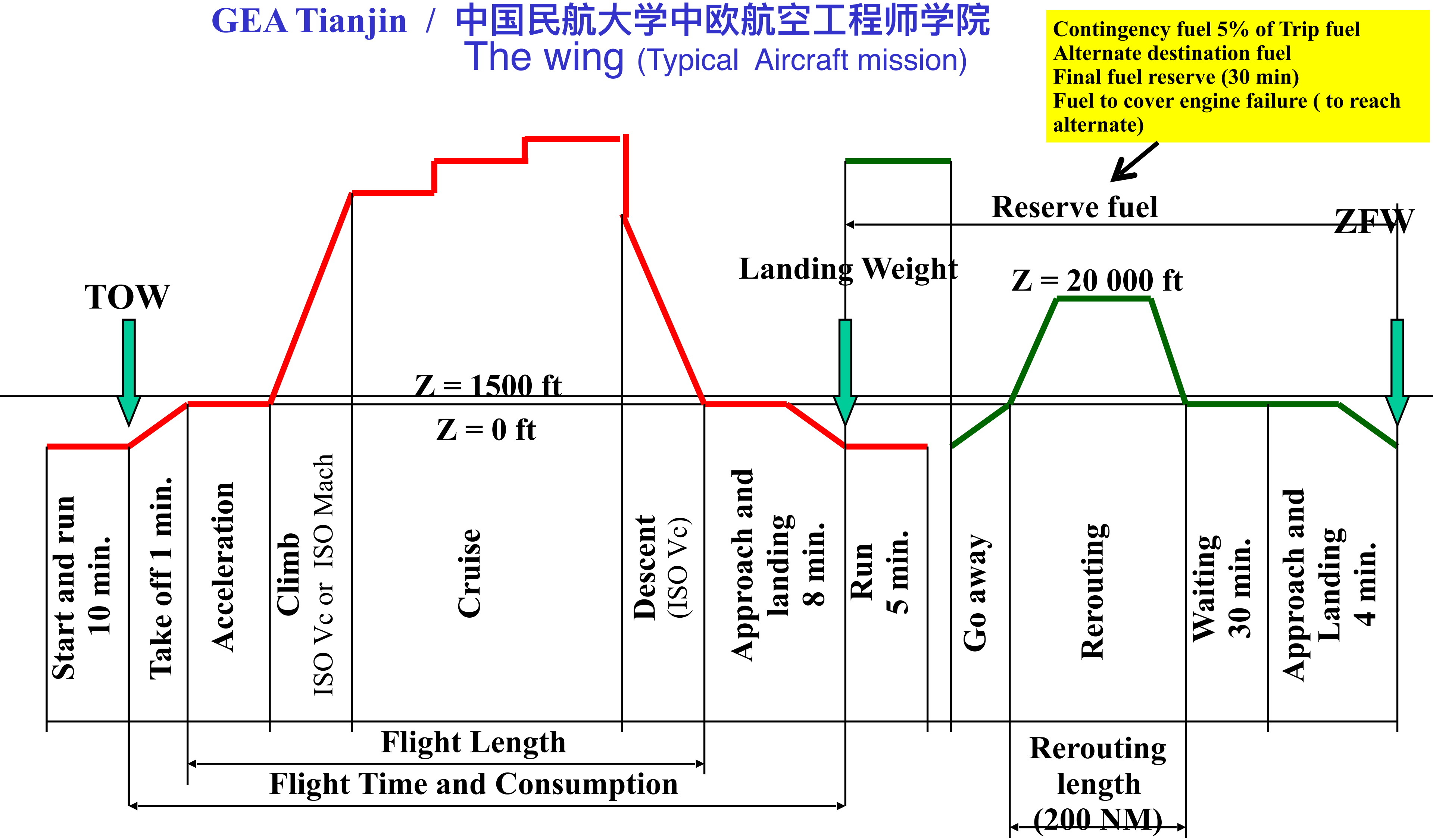


2+3+5+6 (Take off)
4
2 + 3 + 5 + 6
1+7 (non used)

Fuel tank arrangement is a compromise between structural load minimisation and system complexity

GEA Tianjin / 中国民航大学中欧航空工程师学院

The wing (Typical Aircraft mission)



A few wing data from Airbus Aircraft

•

	A380	A320	A330-200	A340-600
Wing span	79.8	34.2	60.3	63.4
Wing area	825	122.6	361.6	439
Wing sweep	33.5	25	30	31.1
AC length	73	37.6	58.8	75.3

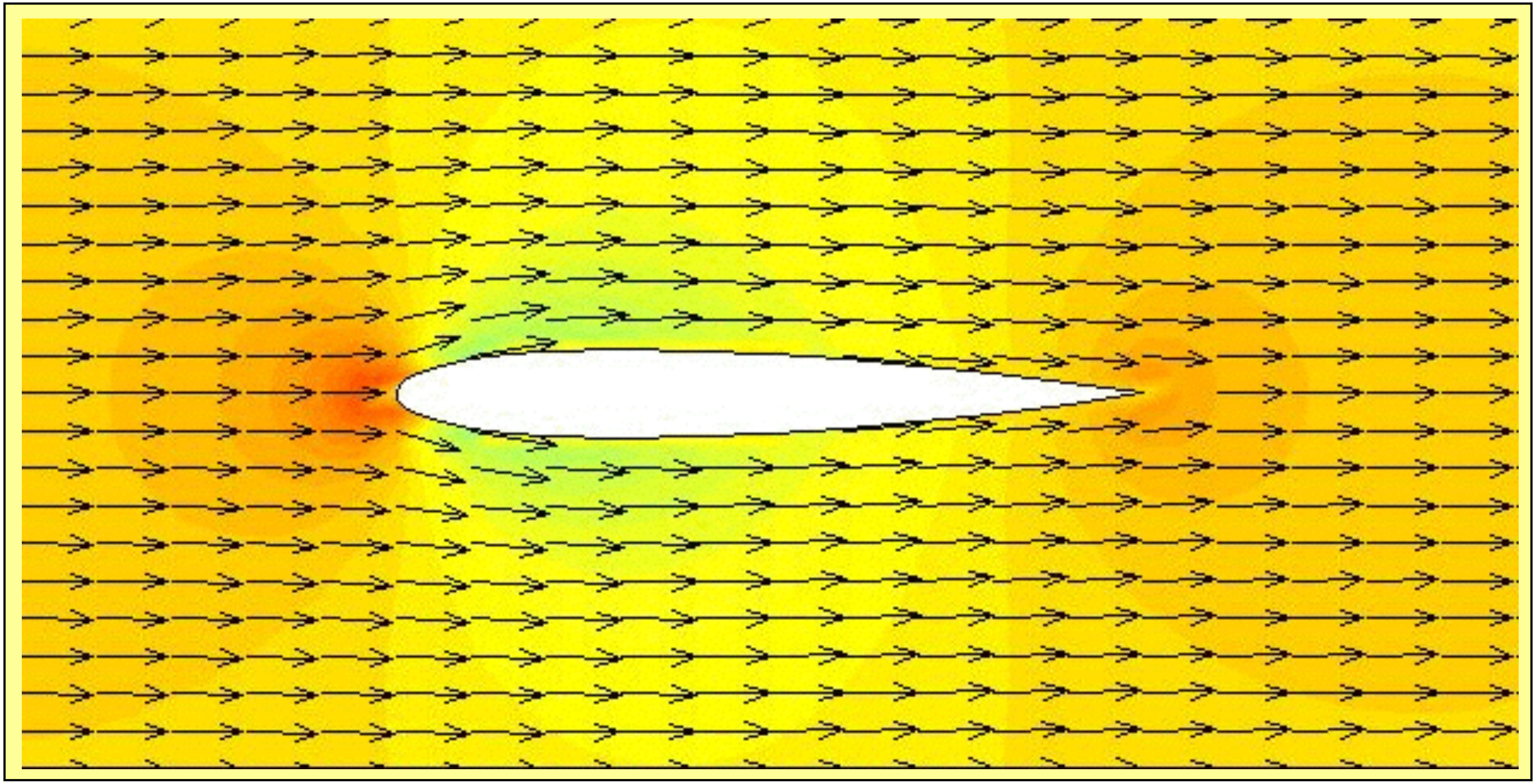
AERODYNAMICS 3

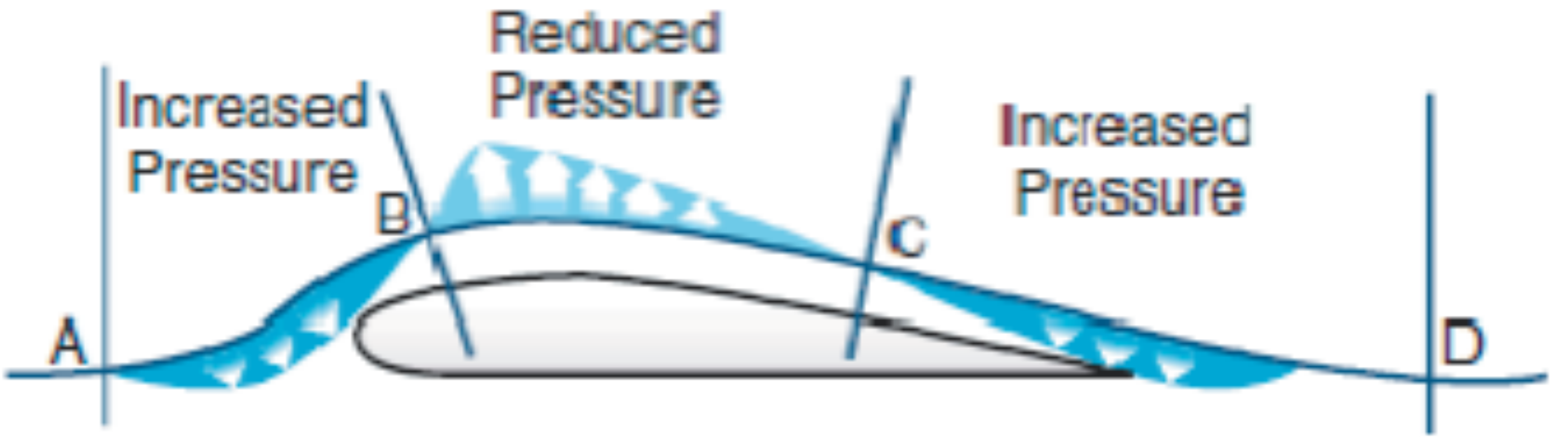
Pressure representation, Pressure coefficients

Aerodynamic on an airfoil

- Pressure coefficient
- Lift
- Drag polar and lift to drag ratio
- Pitching moment and aerodynamic center

Pressure Field





The distribution of pressure over the airfoil can be expressed in terms of the Pressure coefficient

Aerodynamic coefficients

- Aerodynamic coefficients are used to Model all the complex dependencies of overall dimensions,shape, inclination, flow conditions … on aerodynamic forces
- Coefficients expressing the ratio of Aerodynamic forces in relation to the dynamic pressure and a reference dimension (length, Area, momentum)
- Coefficients are the result of wind tunnel testing. Effects of air viscosity (Mach number match) and compressibility (Reynolds number match) are included
- Aerodynamic forces(i.e; Lift) can be determined by using the the related Equation (lift equation)

Pressure coefficient

$$k_p = \frac{p - p_0}{\frac{1}{2}\rho_0 v^2}$$

Kp is the difference between the local static pressure and the free-stream static pressure non-dimensionaliezed by the free-stream dynamic pressure

Bernoulli

$$k_p = \frac{p - p_0}{\frac{1}{2}\rho_0 v^2} = 1 - \left(\frac{v}{v_0}\right)^2 = \frac{p - p_0}{p_T - p_0}$$

Aerodynamic Coefficients

$$X = -\frac{1}{2}\rho_0 V_0^2 S C_X$$

$$L = -\frac{1}{2}\rho_0 V_0^2 S l C_l$$

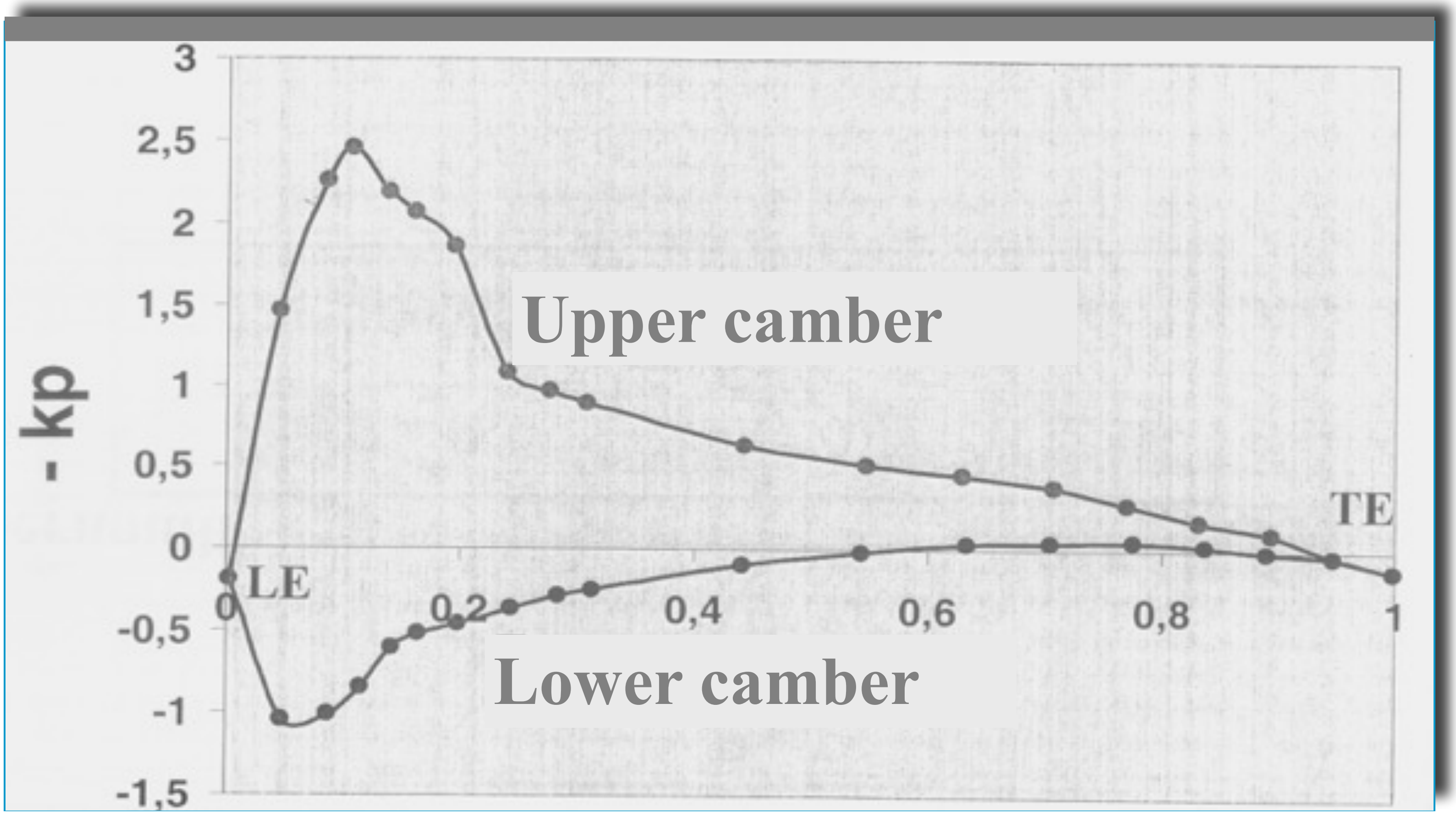
$$Y = -\frac{1}{2}\rho_0 V_0^2 S C_Y$$

$$M = -\frac{1}{2}\rho_0 V_0^2 S l C_m$$

$$Z = -\frac{1}{2}\rho_0 V_0^2 S C_Z$$

$$N = -\frac{1}{2}\rho_0 V_0^2 S l C_n$$

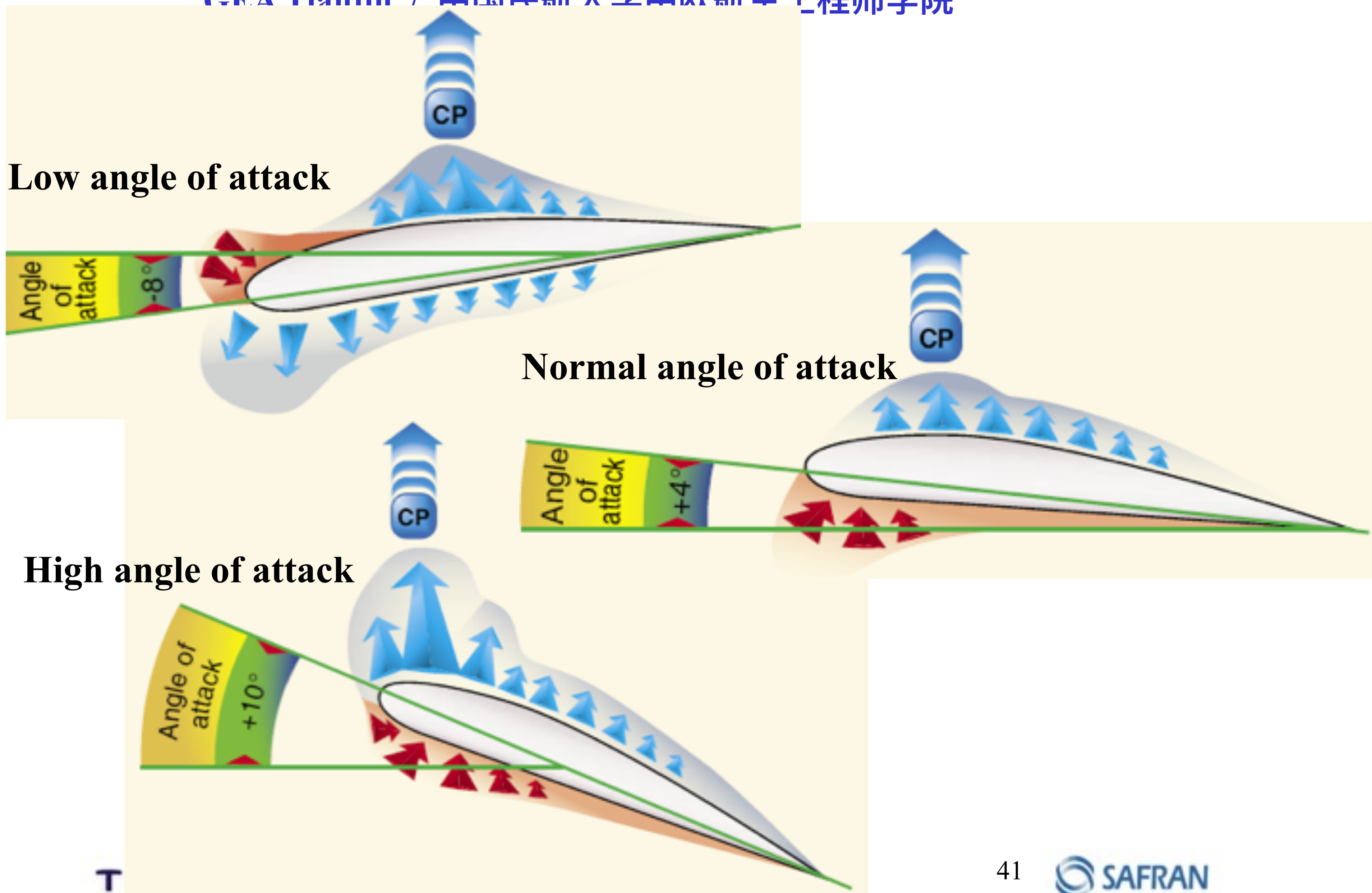
Pressure coefficient



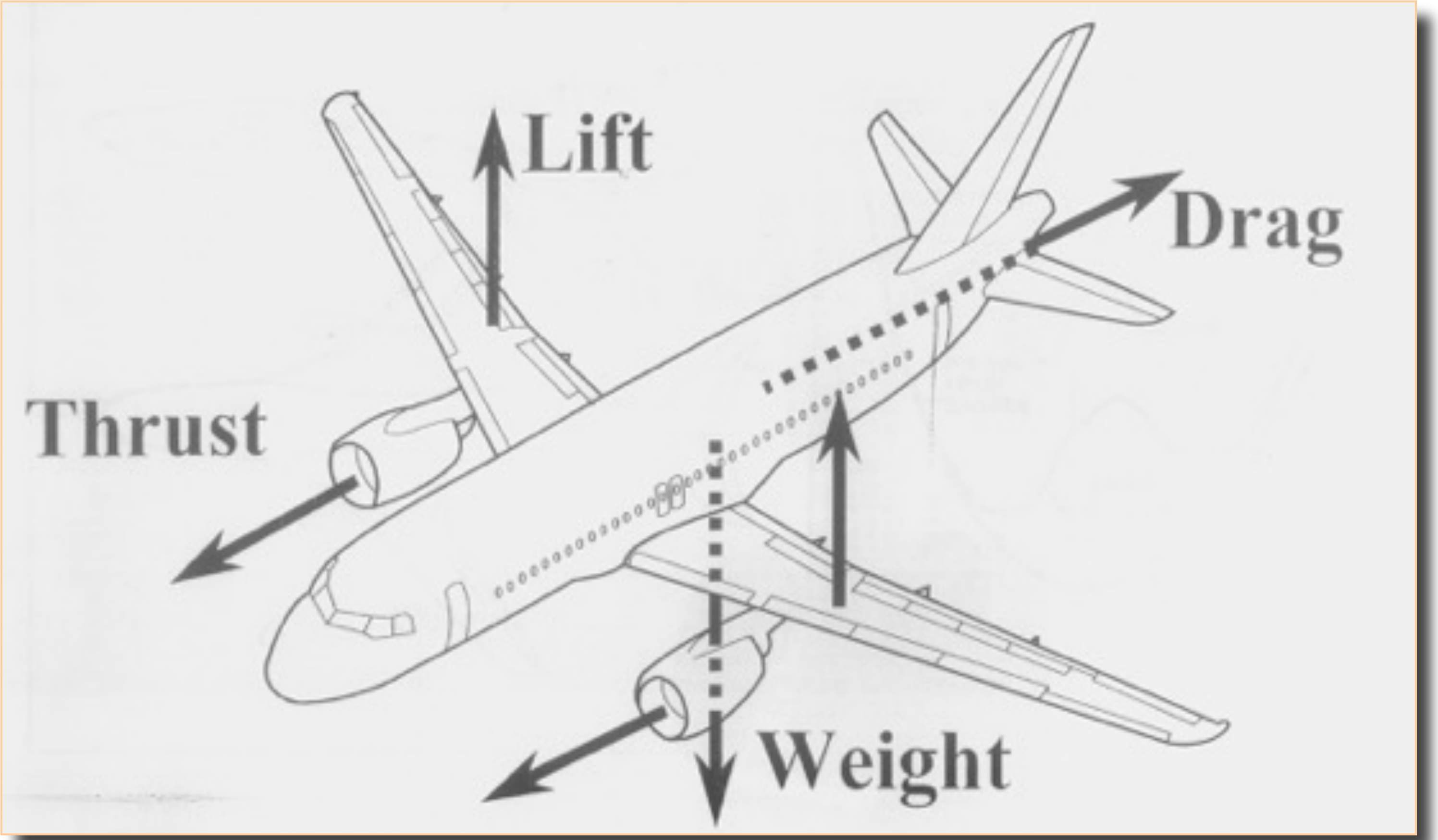
Pressure Distribution

The average of the pressure variation for any given angle of attack is referred to as the center of pressure (CP). Aerodynamic force acts through this CP

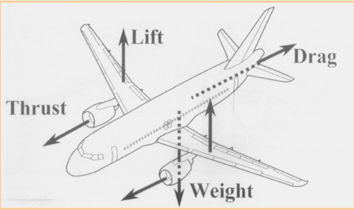
The position of CP depends mainly on the angle of attack. It is aft with low angle and moves forward with higher angle of attack


CP
Low angle of attack
Angle of attack
-8°
CP
Normal angle of attack
Angle of attack
+4°
CP
High angle of attack
Angle of attack
+10°

The four forces



The four forces



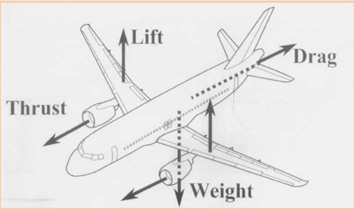
1. **WEIGHT.** The downward force due to the weight(gravity) of the airplane and its load, directly opposed to lift

2. **LIFT.** The upward force created by the wings moving through the air, which sustains the airplane in flight.

3. **DRAG.** The resistance of the airplane to forward motion directly opposed to thrust.

4. **THRUST.** The force exerted by the engine and its propeller(s), which pushes air backward with the object of causing a reaction, or thrust, of the airplane in the forward direction.

The four forces

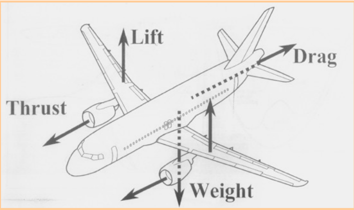


LIFT.

The easiest way to understand lift is to use Newton's three laws of motion; the first law states:

A body at rest will remain at rest , and a body in motion will continue straight line movement unless acted by an external force

Regarding the lift , if a flow of air bends (over a wing surface) there must be a force acting on it. This force is expressed by the difference in pressure



The four forces

Newton's third law states:

For every action there is a an equal and opposite reaction

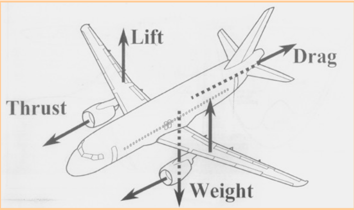
The bending of the air over a wing (down) requires a force;, by this law the air must be putting an equal force (up) to the element which is bending it , the wing

Newton's Second law states

*force equels mass times acceleration, (F=m*a),_*

The wing produce lift by diverting the air down

The four forces



LIFT.

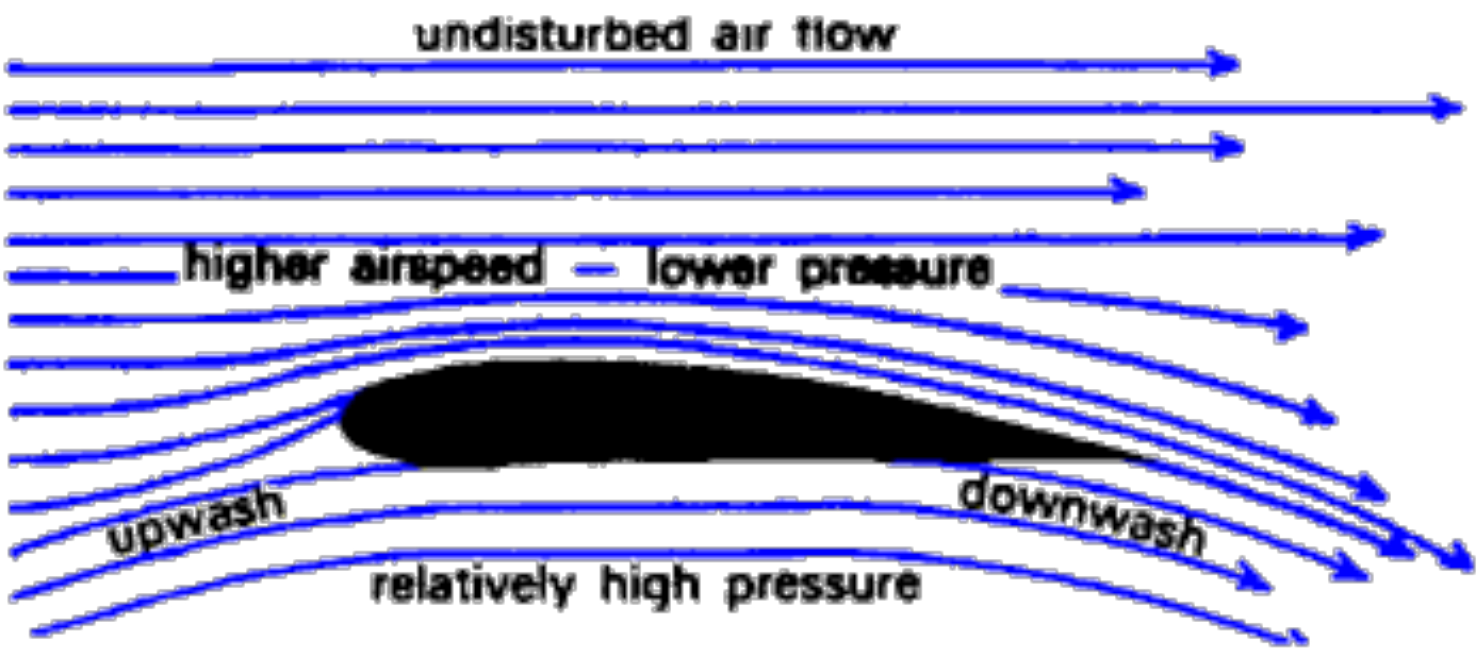
The lift of the wing is proportional to the amount of air diverted per times the vertical velocity of the Air

The amount of Air diverted by the wing is proportional to the speed of the wing and the density of the air

The vertical velocity of the downwash is proportional to the angle of attack and the speed of the wing

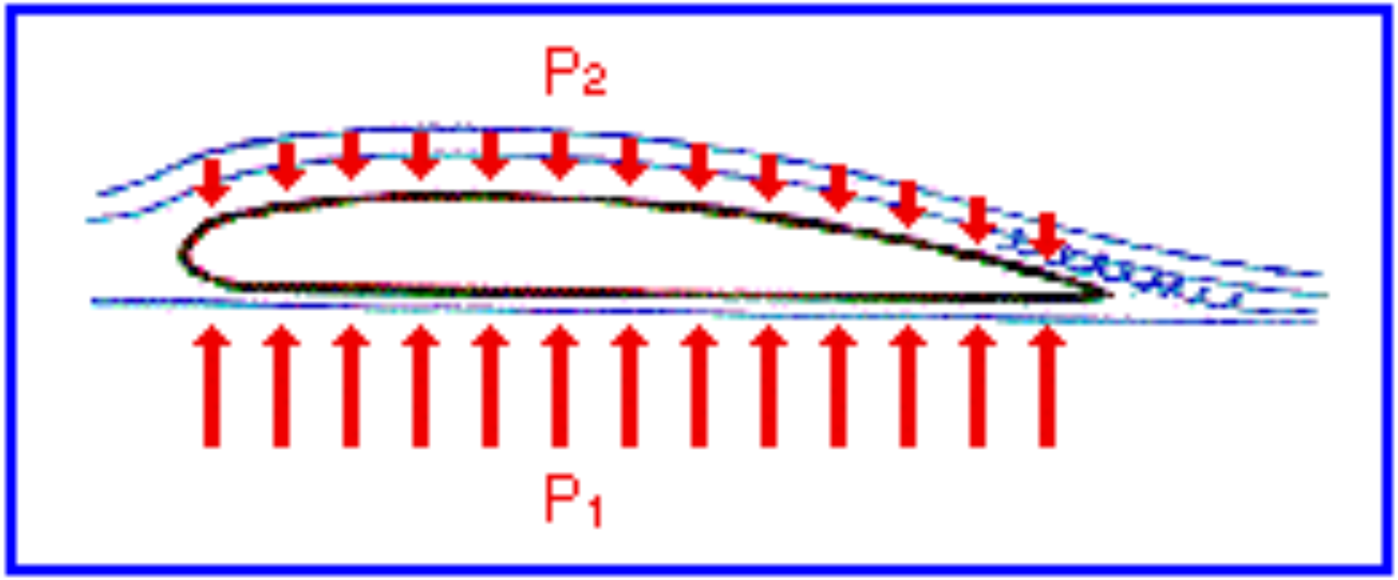
How Is Lift Created

Angle of attack: Newton's Third Law



Airflow over an Airfoil.

Angle of attack create LIFT, Camber optimize it.



LIFT FORCE Z

Lift Force(Z): Pressure effect on the airfoil

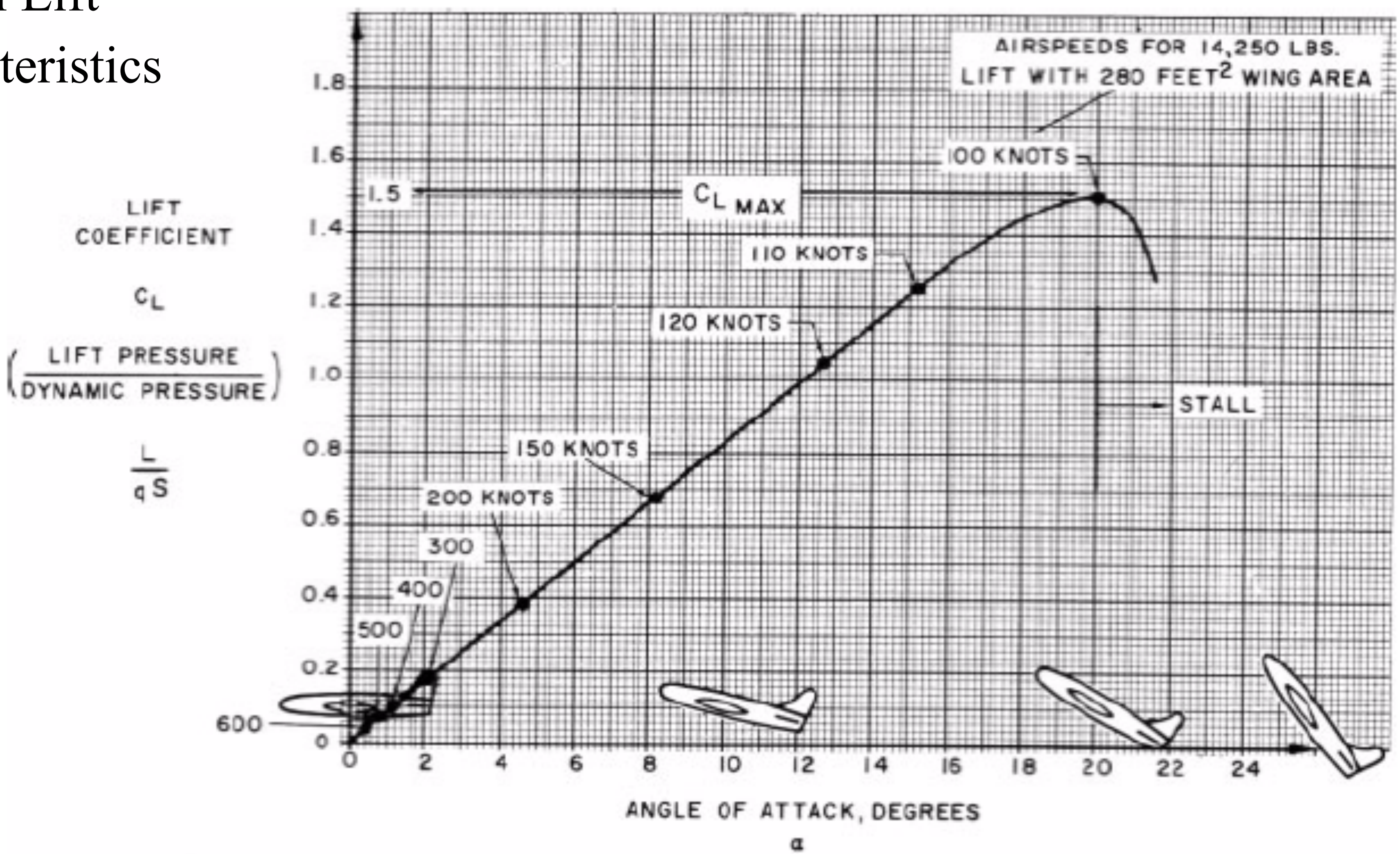
Lift equation:

$$\boxed{Z = \frac{1}{2}\rho_0 V_0{}^2 S_{ref} C_Z}$$

Factors which effect the lift and drag

- Airstream velocity V (knots)
- Airstream density ratio σ (dimensionless)
- Planform area S (ft^2)
- Profile shape of the airfoil
- Viscosity of the air
- Compressibility effects
- **Angle of attack α** (degrees)

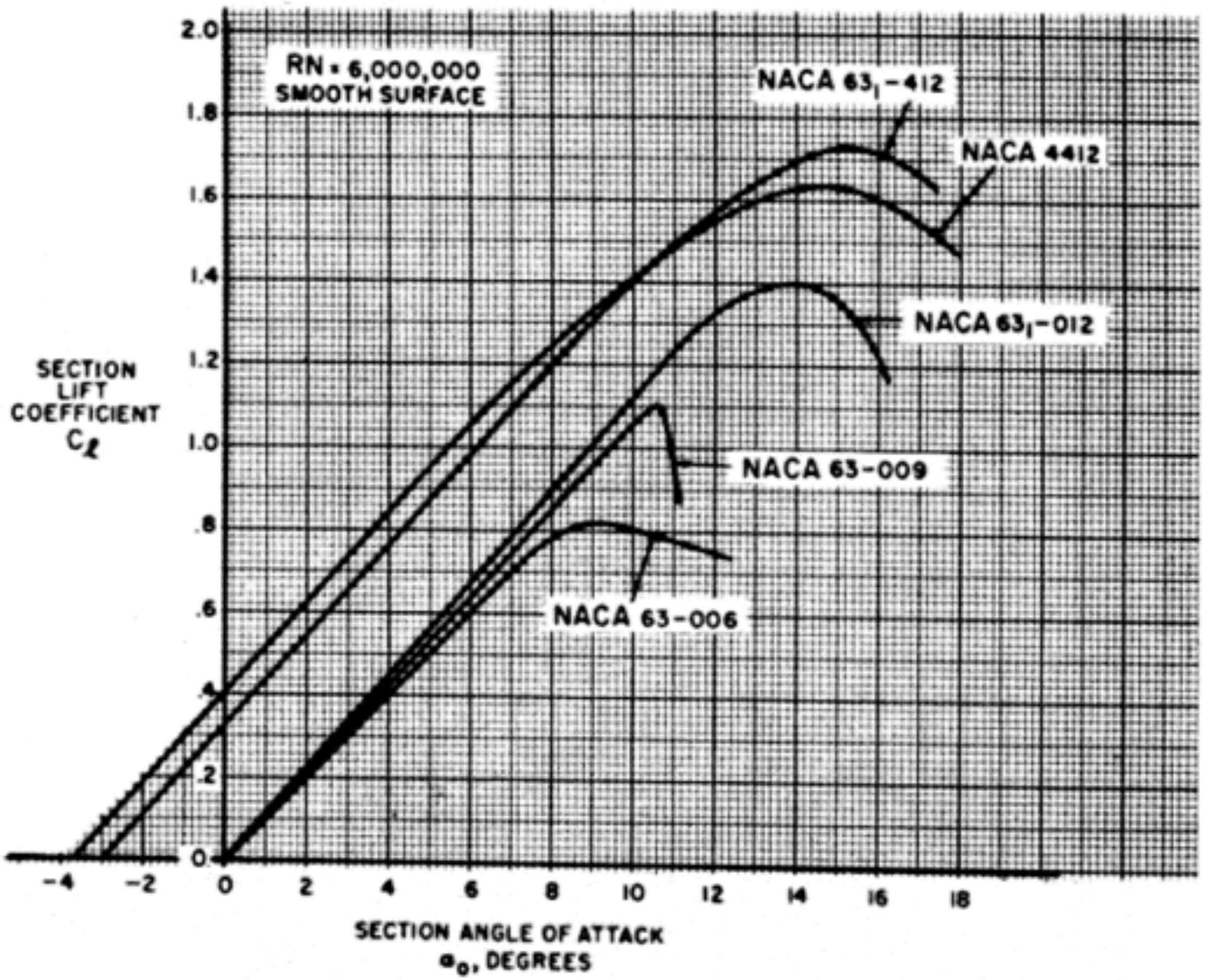
Typical Lift Characteristics



Stall

- Stall is airflow separation of the boundary layer from a lifting surface, it is characterized by reduction in lift and a rapid increase in drag.
- Slow-speed, high-AOA separation: occurs during the takeoff and landing phases of flight and is dangerous, it starts at the trailing edge of a wing and progresses forward.
- The accelerated stall occurs with a sudden rapid increase in AOA. Sharp leading edges occurs. Don’t make sudden nose-up movements of the control stick.

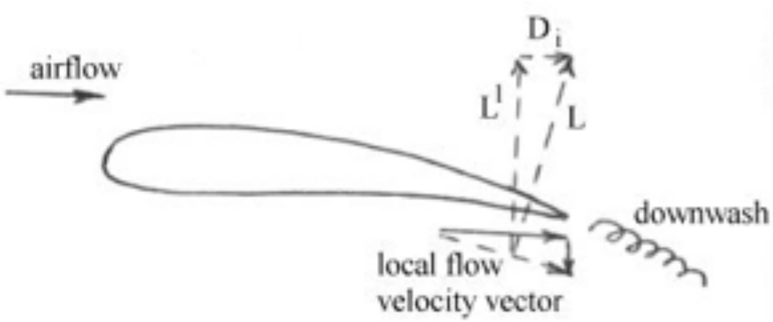
(DATA FROM NACA REPORT NO. 824)

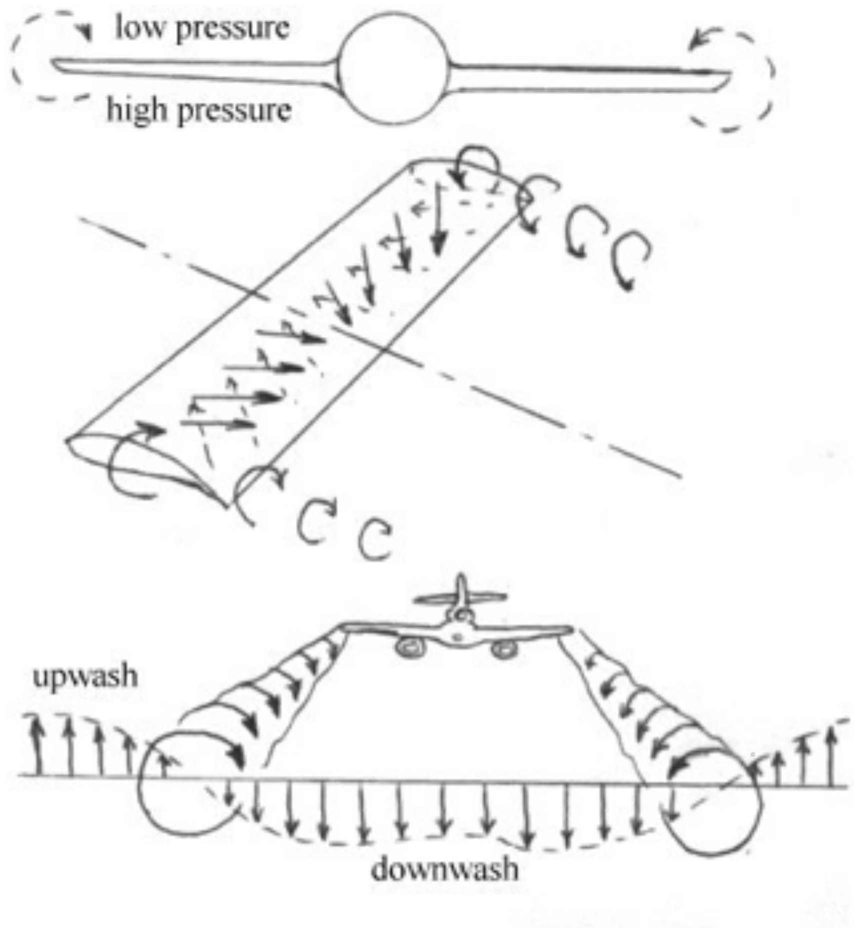


Definition of DRAG

- Drag can be defined as the force which opposes thrust, it is the force which opposes all motion through the atmosphere and is parallel to the direction of the relative wind.
- Drag is made up of a number of components of the aircraft.
- The total drag can be divided into two main parts,
  - **Induced drag** and
  - **Parasitic drag,**
    - Pressure drag (form drag) and
    - frictional drag (viscous drag)
    - Interference drag
    - Leakage drag

Induced drag





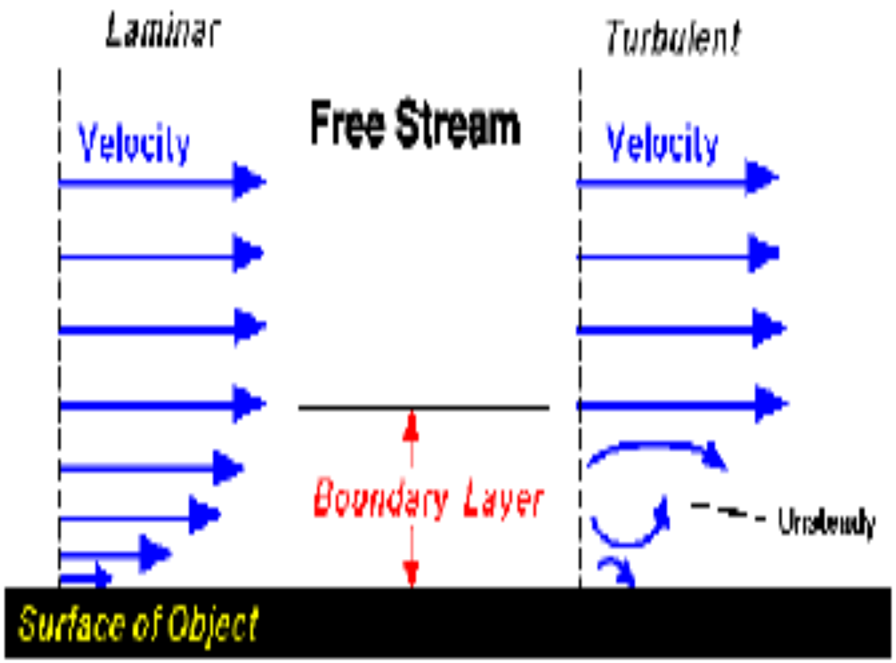
- Induced drag is the unavoidable by-product of lift and increases as the angle of attack increases.

PARASITE DRAG

- Parasite drag is associated with the energy lost due to collisions with the air . It increase with aircraft speed (varies with V squared)
- These are:
  - Skin-friction drag
  - Pressure drag (form drag)
  - Interference drag
  - Leakage drag

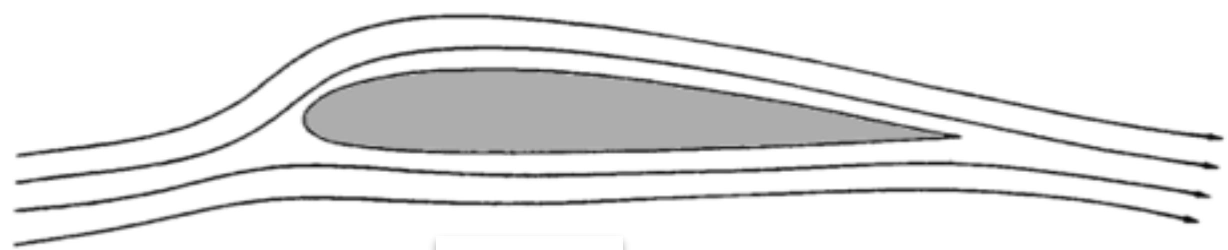
Skin-friction drag

Skin-friction drag is caused by the friction between outer surfaces of the aircraft and the air through which it moves. It will be found on all surfaces of the aircraft: wing, tail, engine, landing gear, and fuselage.



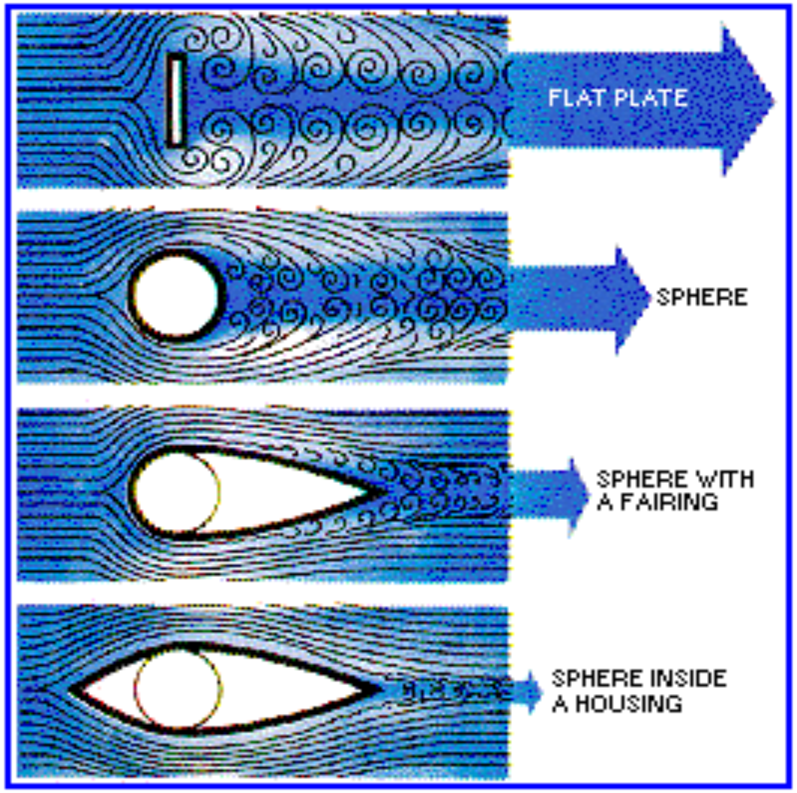
Velocity is zero at the surface (no-slip)

Skin-friction drag



Pressure drag (Form drag)

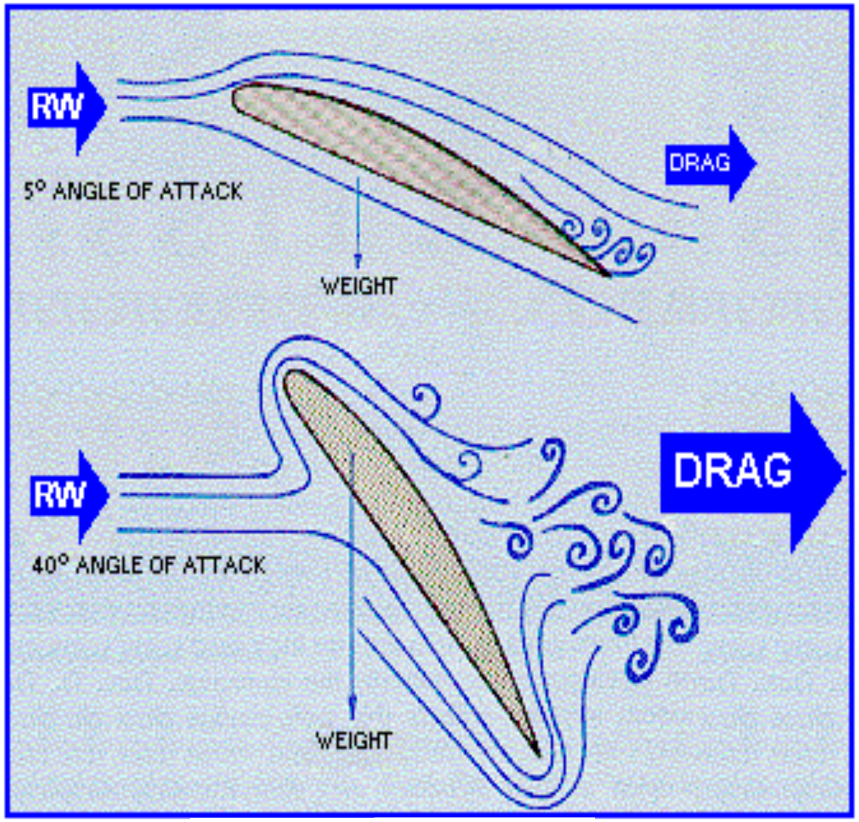
- Form drag is also a resistance to the smooth flow of air.
- The shape of something may create low-pressure areas and turbulence which retard the forward movement of the aircraft.



No lift created!

Pressure drag (Form Drag)

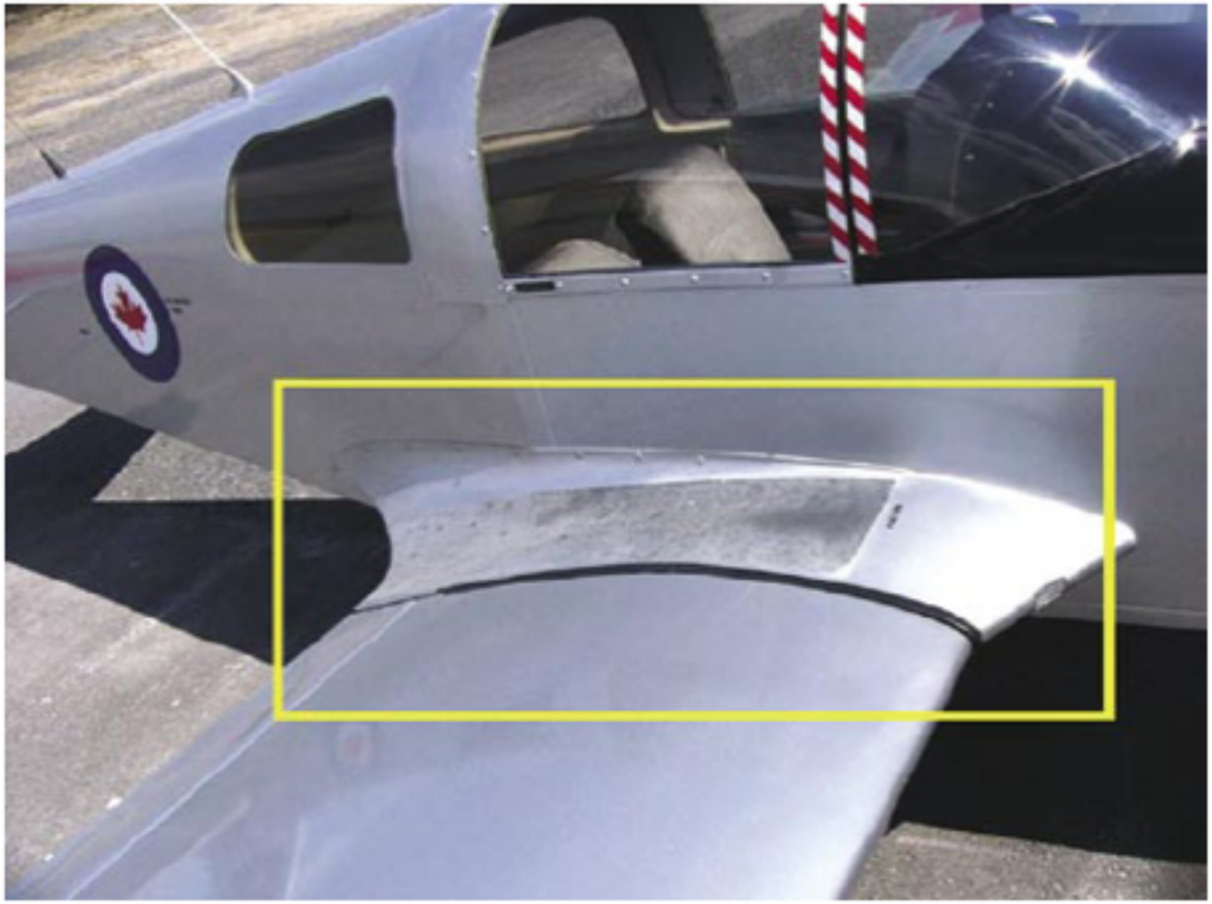
Depending on the angle of attack, there will be a force backward.



Lift is created!

Interference drag

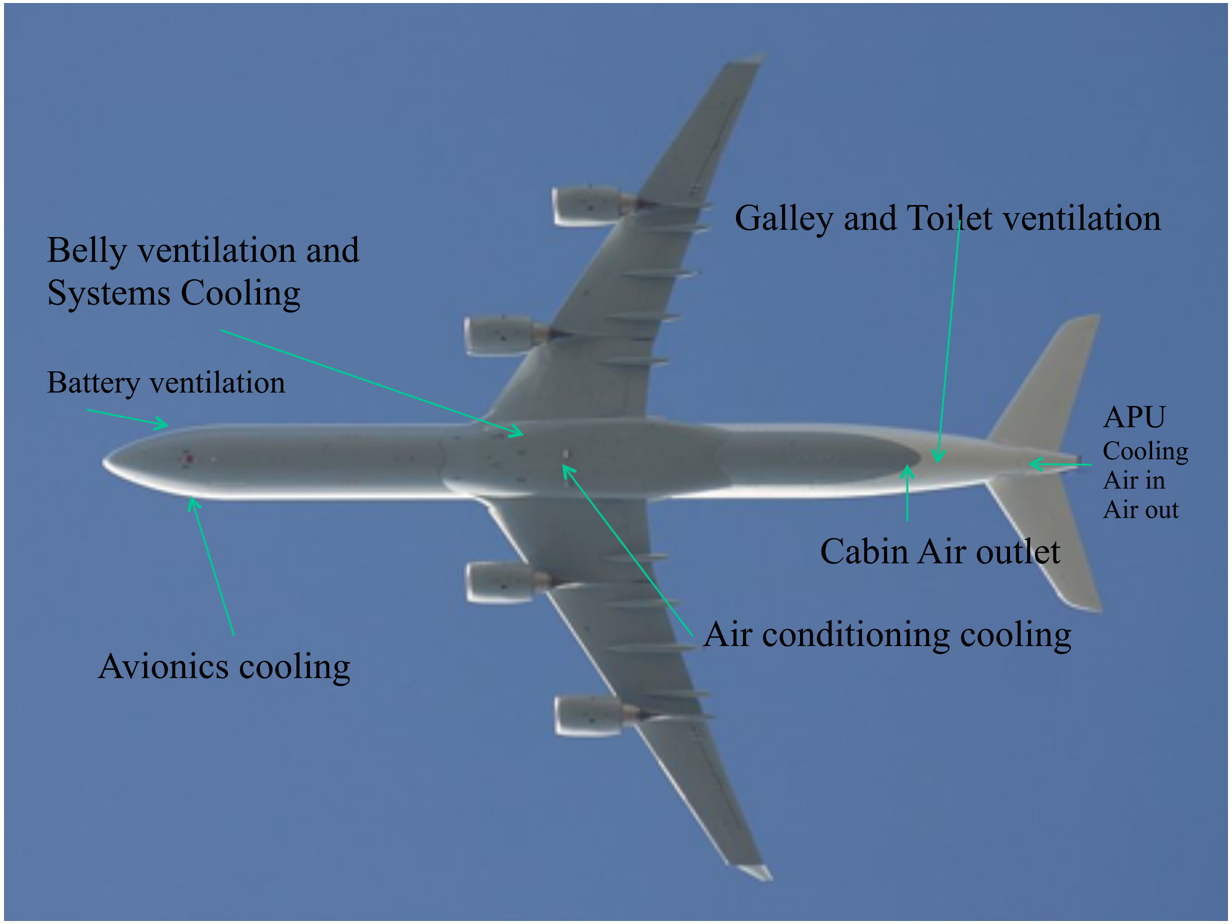
- Is caused by the interference of boundary layers from different parts of the airplane.



Leakage drag/ cooling drag

- Is caused by differential pressure inside and outside the aircraft.
- Air flowing from a higher pressure inside the fuselage through a crack or door seal will create an airstream that impinges on the airflow around the aircraft and creates drag.
- Doors and windows sills are sealed with masking tape before an air race to lessen this drag.

Leakage drag/ cooling drag



Parasitic DRAG

Drag Force(X):

$$\boxed{X = \frac{1}{2}\rho_0 V_0^{\,2} S_{ref} C_X}$$

X= Drag force (in the direction of flow)

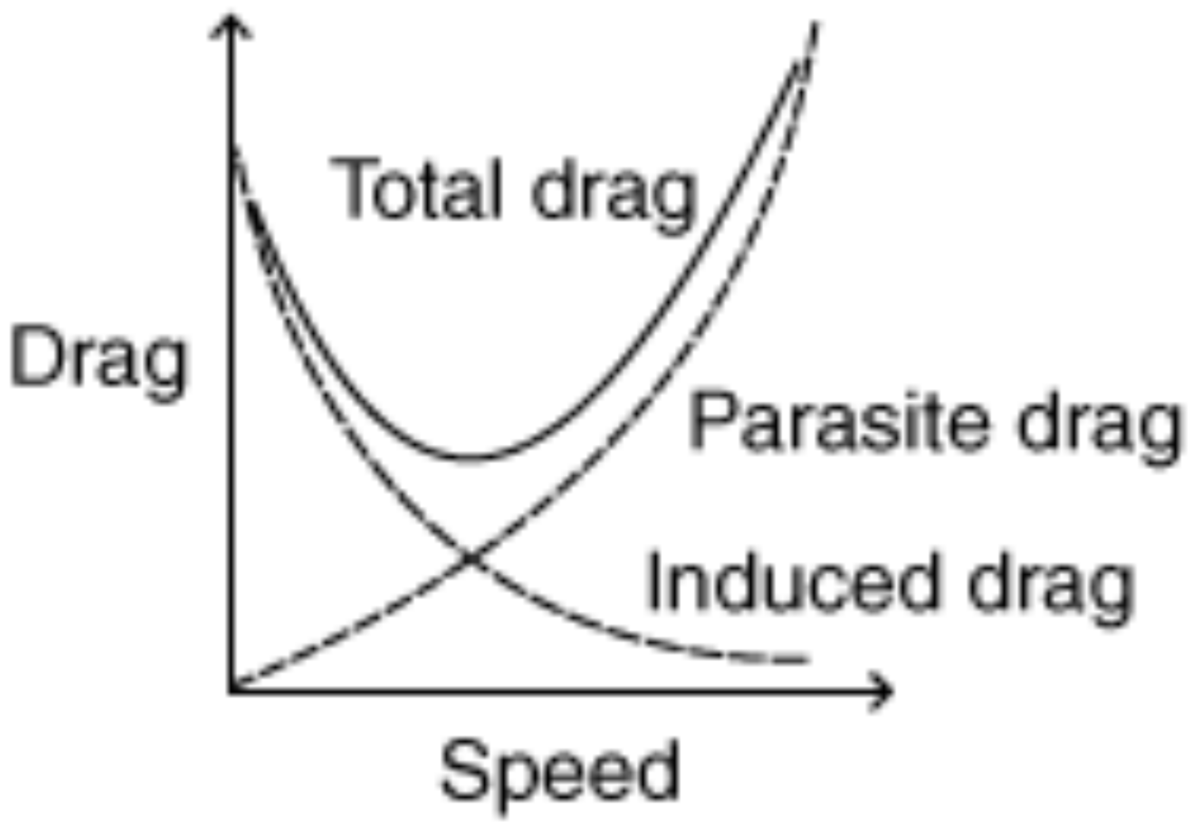
ρ = density of Air

V= Air speed

S= referens area

$\frac{1}{2}\rho V^2$ Dynamic pressure

Drag Summary



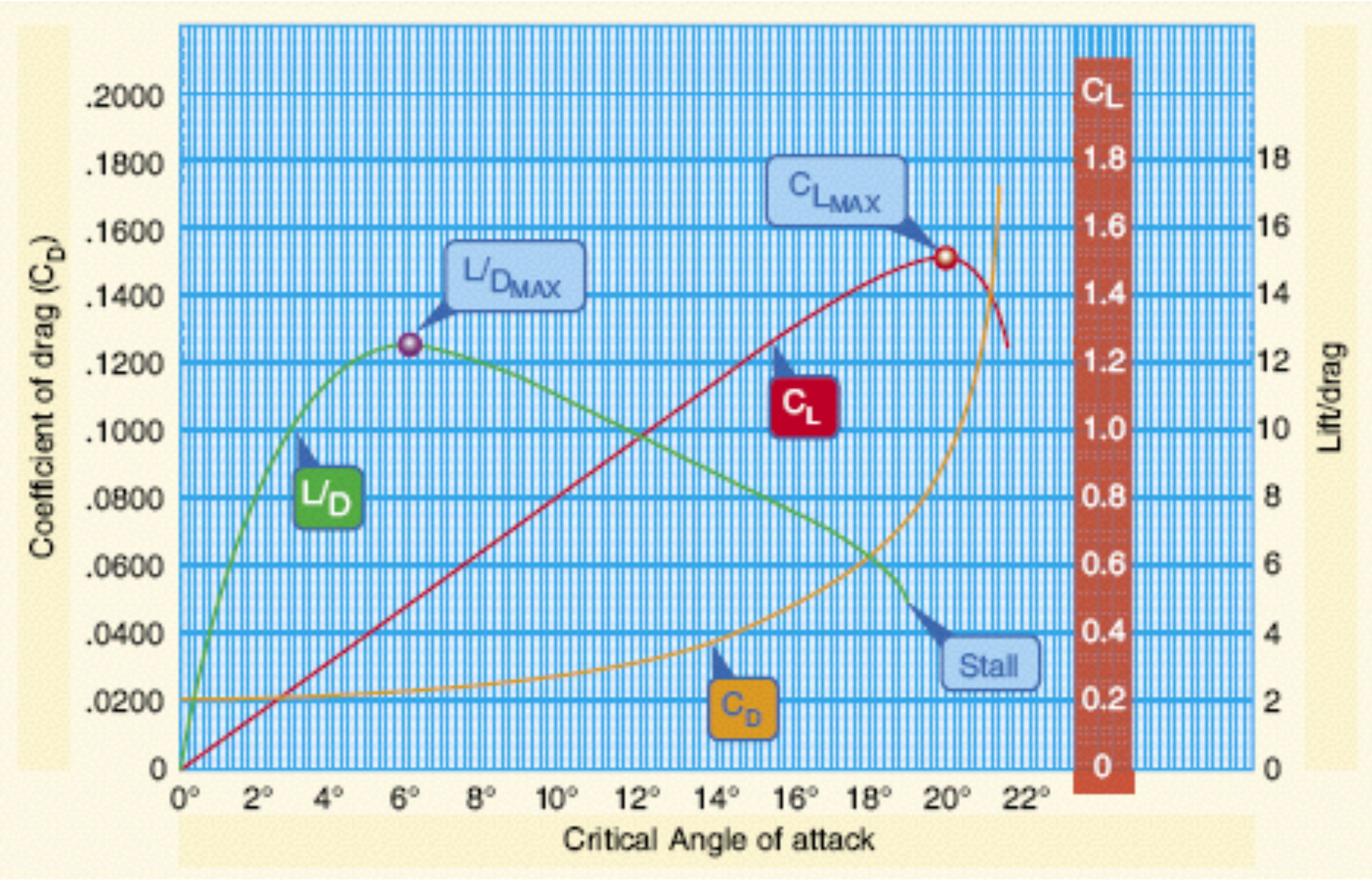
Parasitic drag is proportional to speed 2

Induced drag is proportional by 1/ speed 2

Lift to Drag Ratio

$$\boxed{f = \frac{C_Z}{C_X} = \frac{Z}{X} = \tan\theta}$$

- Civil transport aircraft : ～12 to 20
- Supersonic Jet : ～5 to 10
- Glider : >55



Coefficient of drag (C_D)
.2000
.1800
.1600
.1400
.1200
.1000
.0800
.0600
.0400
.0200
0
0° 2° 4° 6° 8° 10° 12° 14° 16° 18° 20° 22°
Critical Angle of attack
C_L
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
18
16
14
12
10
8
6
4
2
0
Lift/drag
$C_{L_{MAX}}$
L/D_{MAX}
C_L
L/D
Stall
C_D

End of aero session

- It was the target of this lecture to deliver a reminder (remember lecture AE11), on basic features of aerodynamics and to provide an entry point for the lectures this week.
- Thank you