Aeronautics & Mechanics AENG11301

Lecture 2: Lift!

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Outline for today

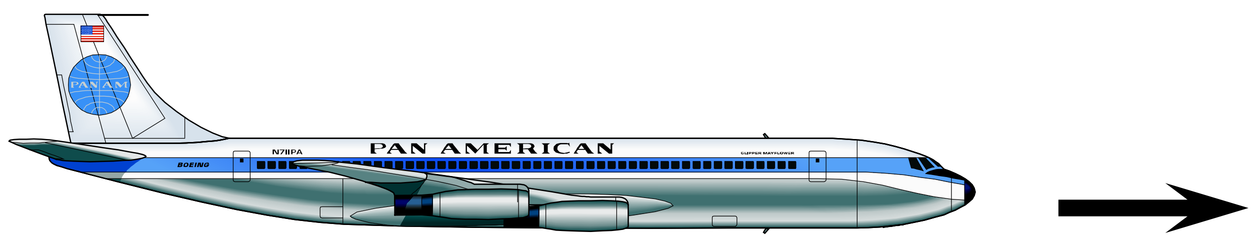
- Definition of lift and drag

- Factors involved in lift

Aims for today

- Be able to define lift and drag
- Get an intuitive understanding of the factors relating to lift

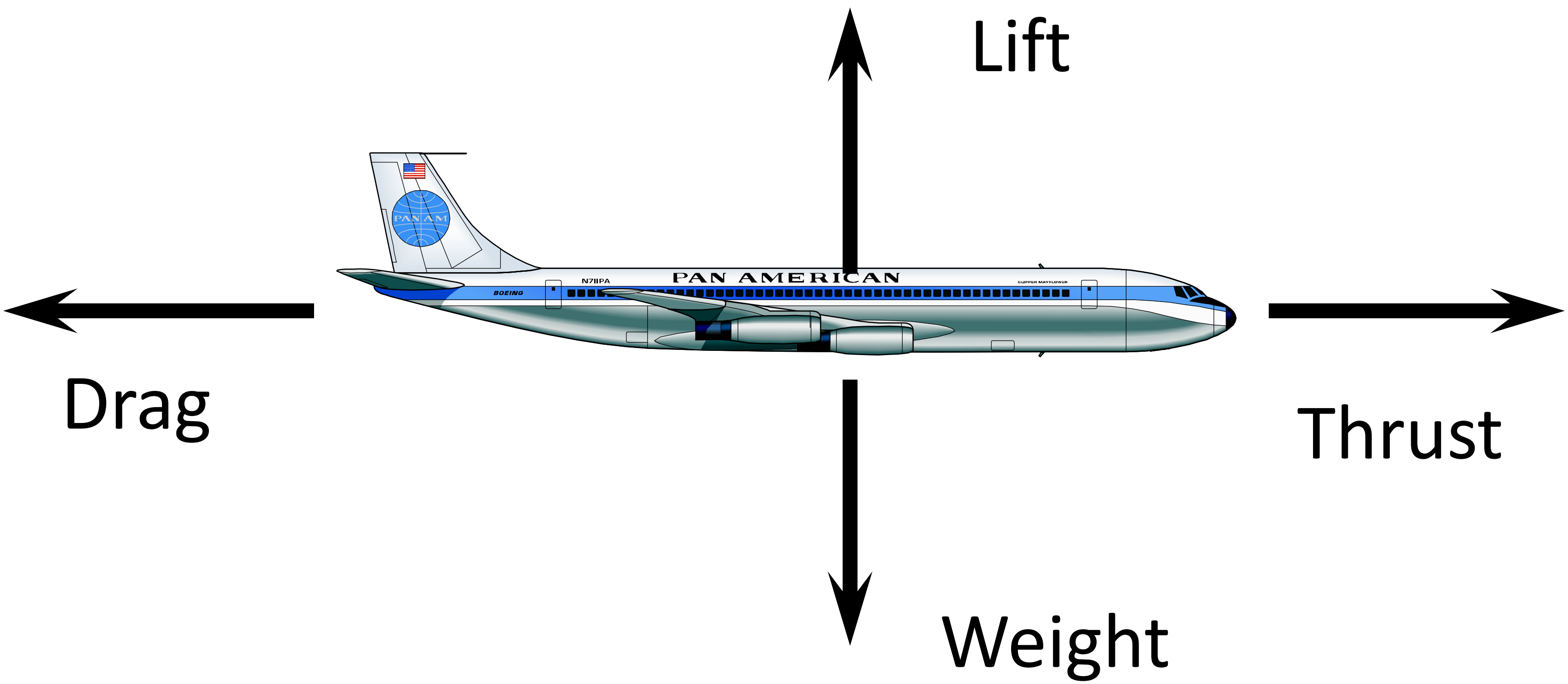
Steady Level Flight



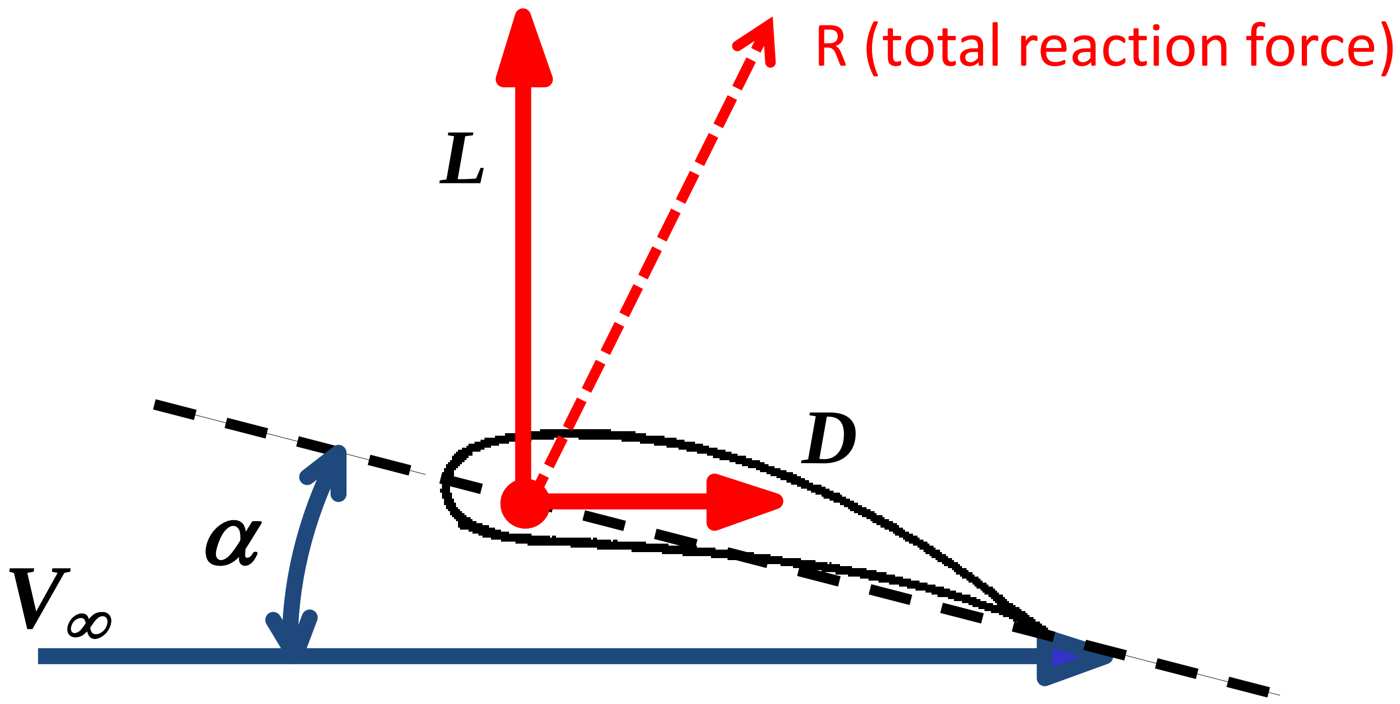
Velocity is constant

$$\text{Lift} = \text{Weight}$$

$$\text{Thrust} = \text{Drag}$$

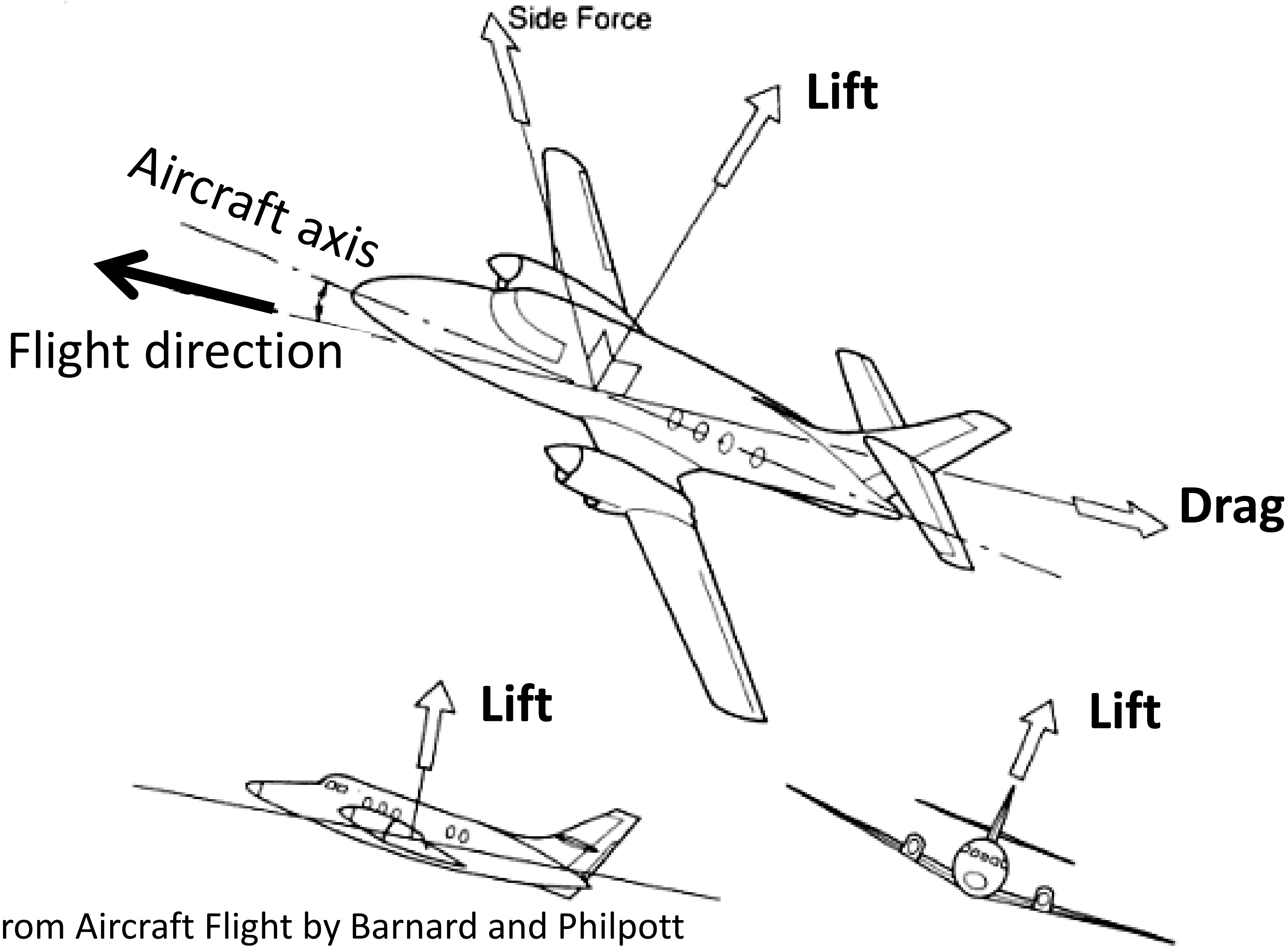


Definition of lift and drag



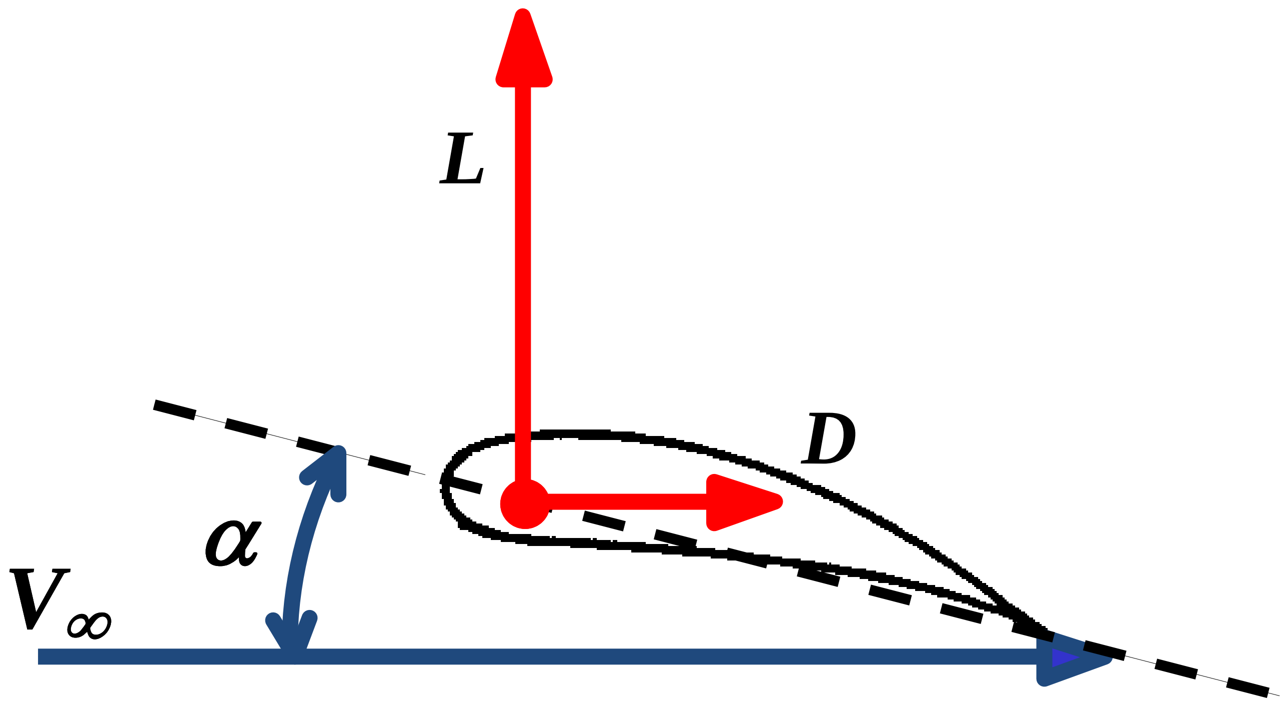
- **Lift** (L) is the component of aerodynamic force *perpendicular* to the relative wind.
- **Drag** (D) is the component of aerodynamic force *parallel* to the relative wind.

Lift: Not always up!



From Aircraft Flight by Barnard and Philpott

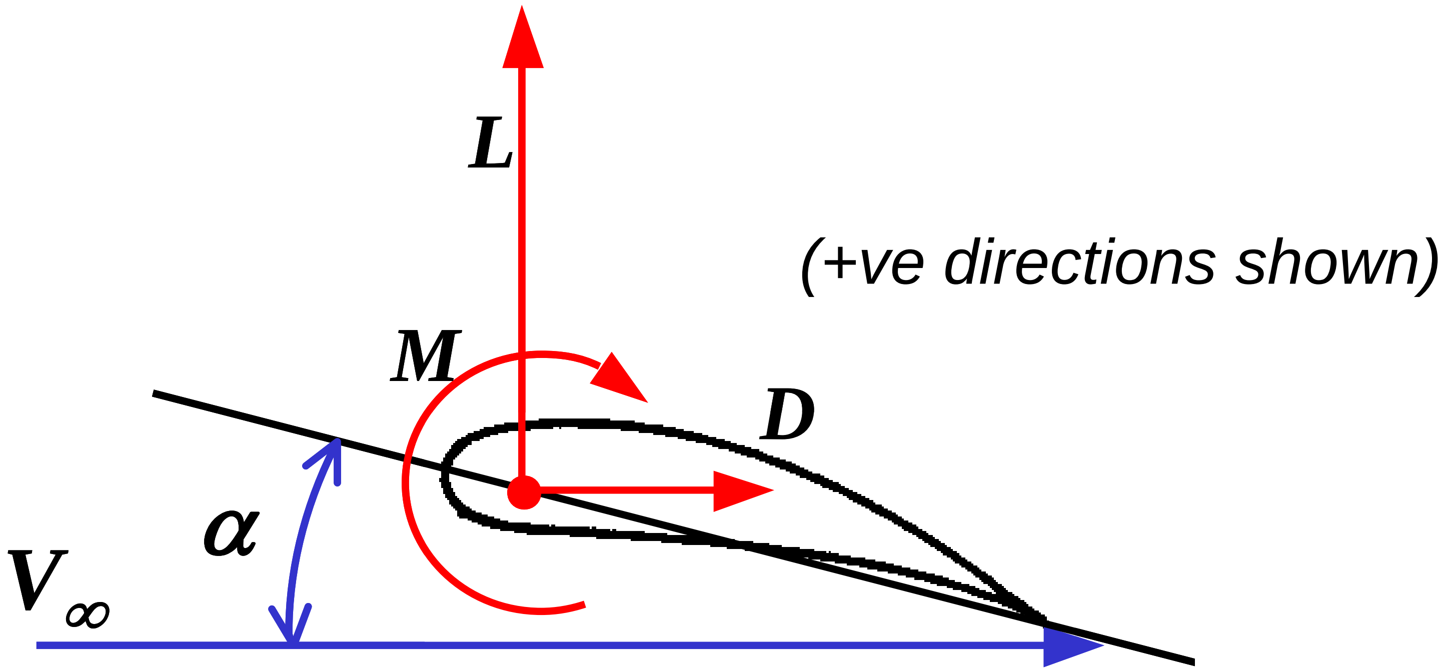
Aerodynamic Forces



Forces related to:

- the **incidence** or **angle of attack** (α), the angle between chord line and flow direction
- the **free stream velocity** (V_∞)
- the shape and size of the body

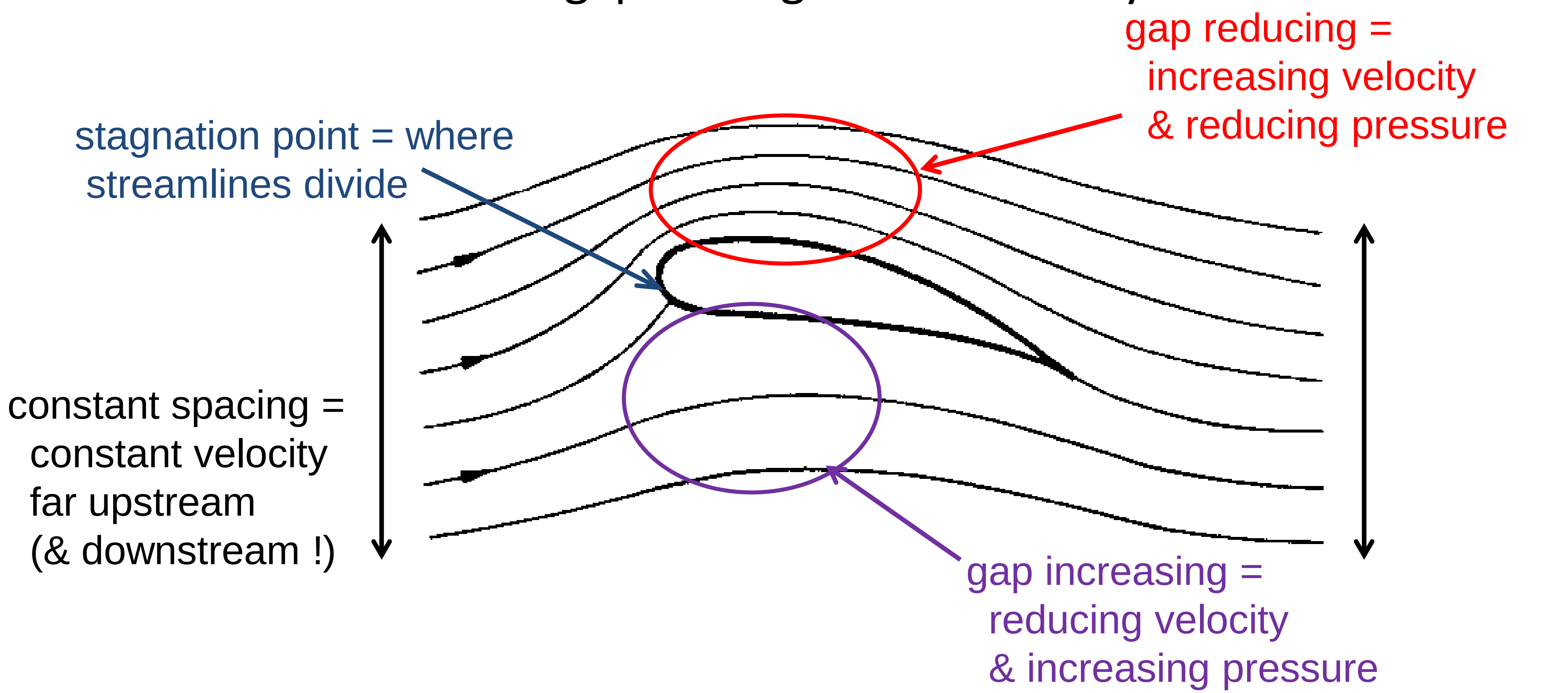
Aerodynamic Moment



There is also a **Pitching Moment** (M) acting about a defined axis usually the leading-edge or the quarter-chord point

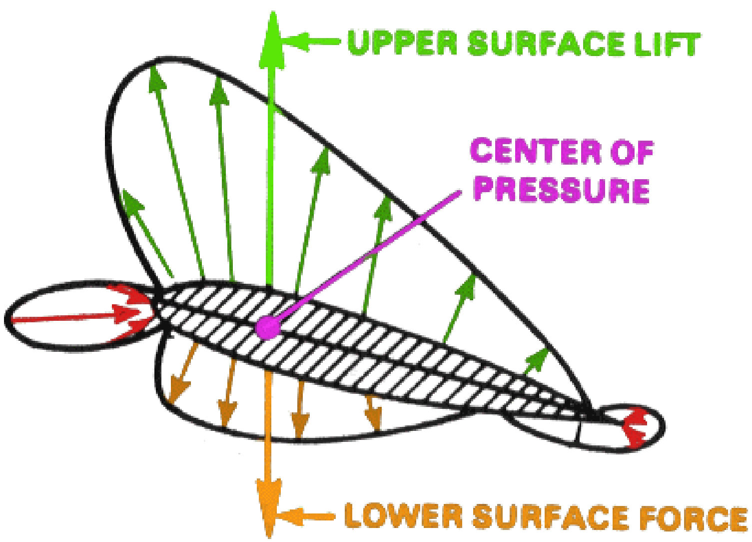
Streamlines

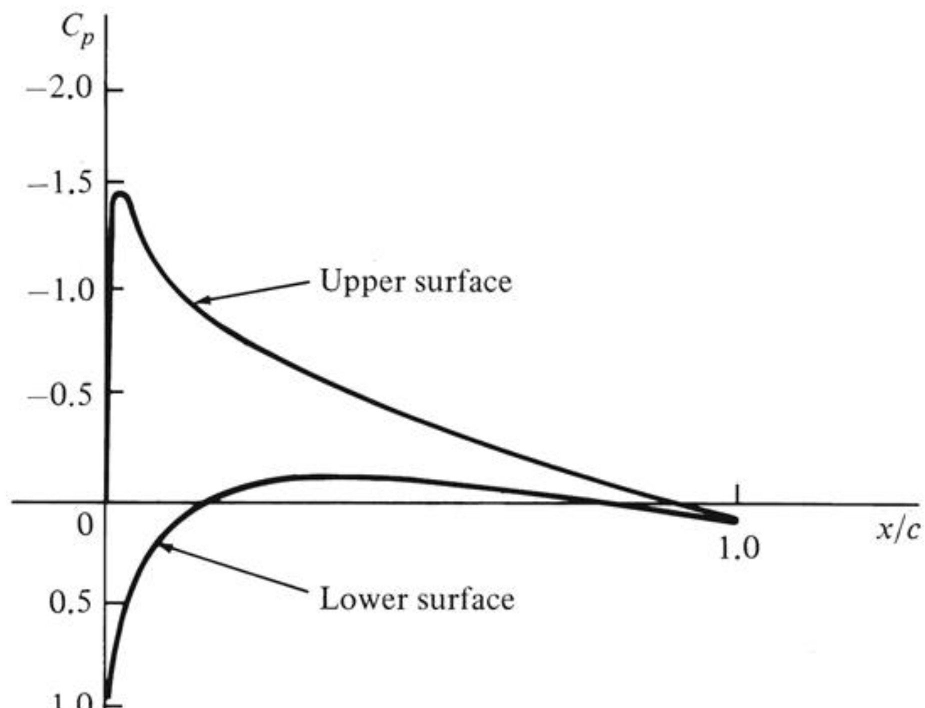
- flowfield represented graphically using **streamlines**
- streamlines indicate local flow direction
- spacing between streamlines indicates magnitude of local flow velocity
  - think of flow constrained between two walls
  - the narrower the gap the higher the velocity



Pressure Distribution

- variation in pressure acting on surface
  = aerodynamic forces & moments acting on the wing
- pressure distributions shown graphically
  - non-dimensionalised using **pressure coefficient** (C_p)
  - vector plot or simpler C_p vs x/c graph
  - conventional to plot *–ve* pressure coefficient upwards!





Explaining lift

As we've seen:

- Fluid forces arise from the distribution of pressure and shear stresses over an object
- Lift on an aerofoil mainly due to the imbalance of pressure distributions over the top and bottom surfaces

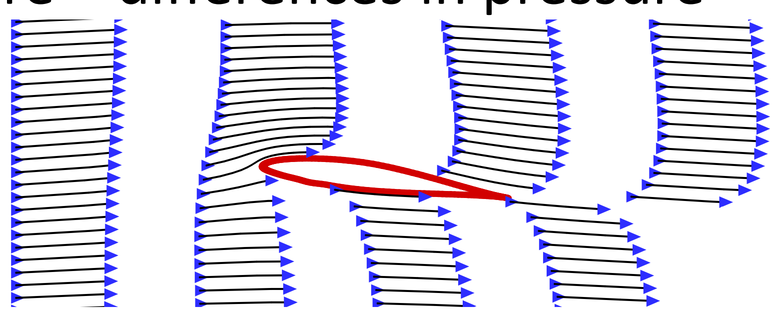
But what creates this distribution of pressure and sheer stress?

Where does lift actually come from?

Where does lift actually come from?
Not a trivial question!

There are no fewer than **3 different** answers to this question…

- The intuitive "flow redirection" answer:
  - **Newton's Laws** – 2nd and 3rd – What we'll learn today
- The mathematical answer:
  - **Circulation** – Lift comes from "rotation" of the air – useful as a mathematically rigorous definition – underlies classical analysis methods – you will see this in your Fluids classes
- The popular, but **wrong** answer!
  - Bernoulli's equation – **equal transit time** forces differences in velocity, and therefore pressure – differences in pressure create lift
  - Equal transit time is a myth!
  - Flat plates create lift!



But don’t take my word for it…

Doug McLean – retired Boeing Technical Fellow
“Common Misconceptions in Aerodynamics”

https://www.youtube.com/watch?v=QKCK4lJLQHU

(50 minutes of mildly interesting discussion by some old dude)

Newton’s Third Law

“To every Action there is an
equal and opposite Reaction”

Therefore for a wing to generate lift
it must force air down

Can help to think of Lift as a reaction force

Cessna Citation flying over fog (Photo By Paul Bowen)

A Rotating Wing also Pushes Air Down

Also true for sharkopters.

Note the helicopter’s downwash is visibly pushing down on water

Does this picture show an airfoil generating lift?

No! the air must experience a net change in direction:

Wing diverts air down -- Downwash

Newton's Second Law

"Force is proportional to the rate of change of momentum"

The thrust of a rocket is equal to the velocity of the exhaust times the amount of mass ejected per second

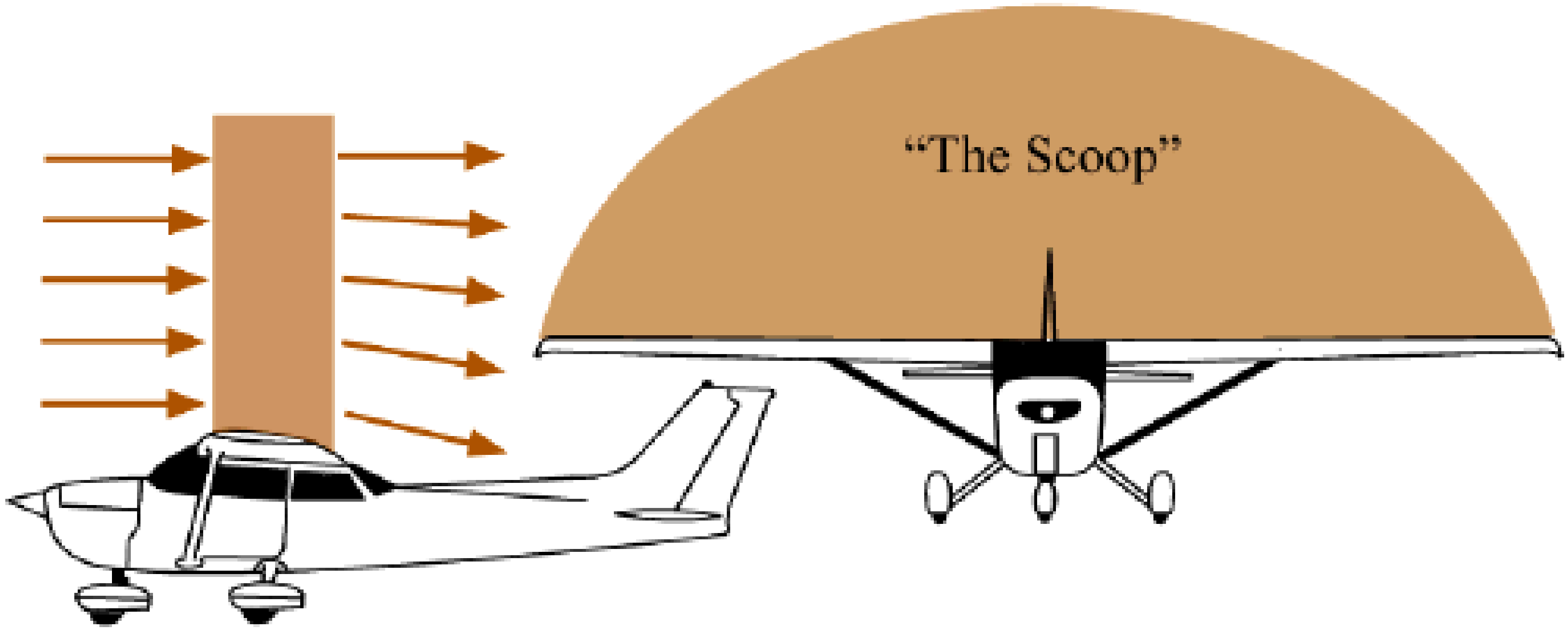
The lift on a wing is proportional to the amount of air diverted per second times the vertical velocity of the air

Lift = mass/sec * vertical velocity

Lift = "diverted air" * vertical velocity

$$units = \frac{kg}{s}\frac{m}{s} = \frac{kg\ m}{s^2}$$ = Newtons!

The wing as a “virtual” scoop



Diverted Air

The amount of air diverted is proportional to:

- The <u>speed</u>
- The air <u>density</u>

$$\frac{m}{t} \propto V_{\infty}, \rho$$

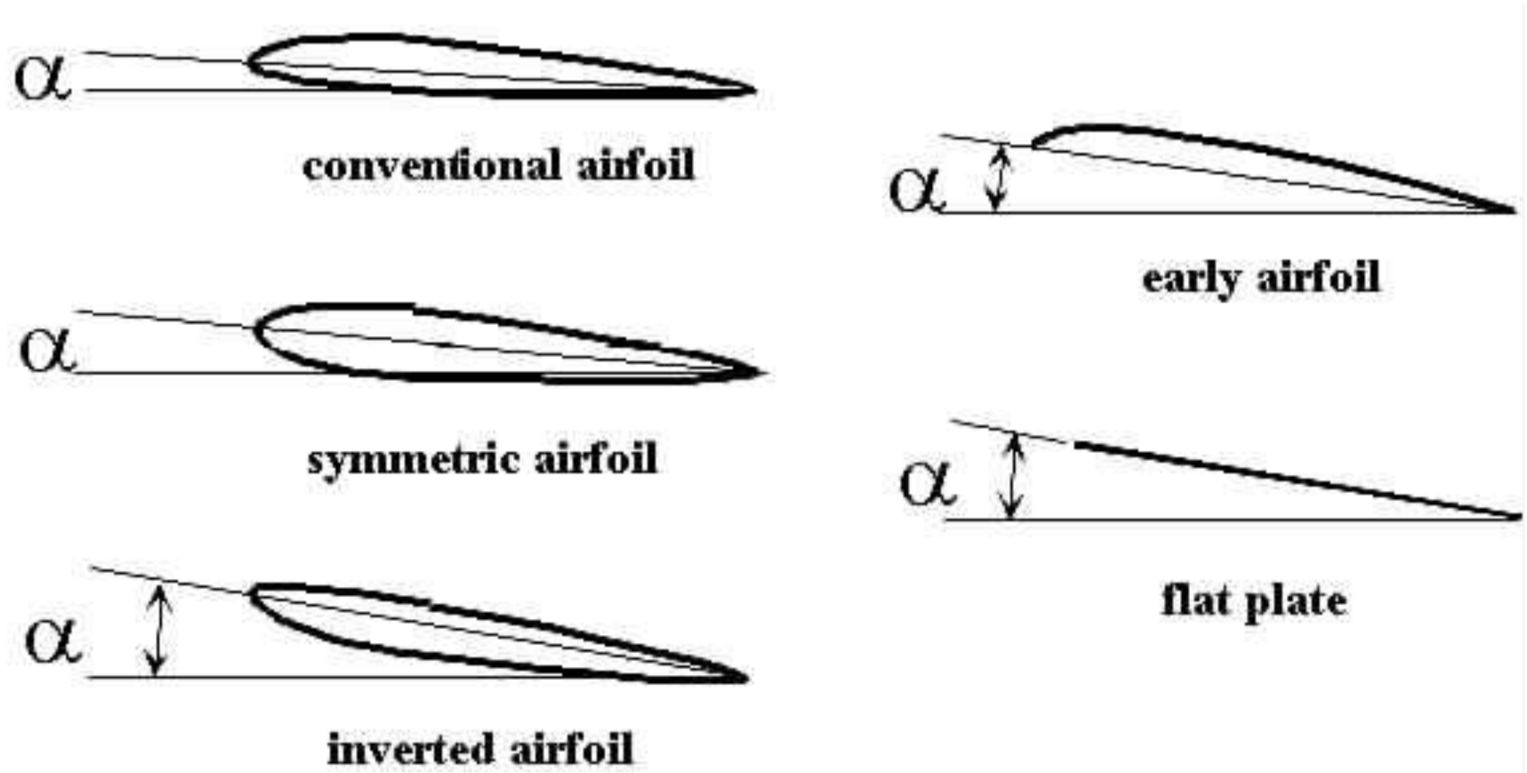
Vertical Velocity

The vertical velocity is proportional to:

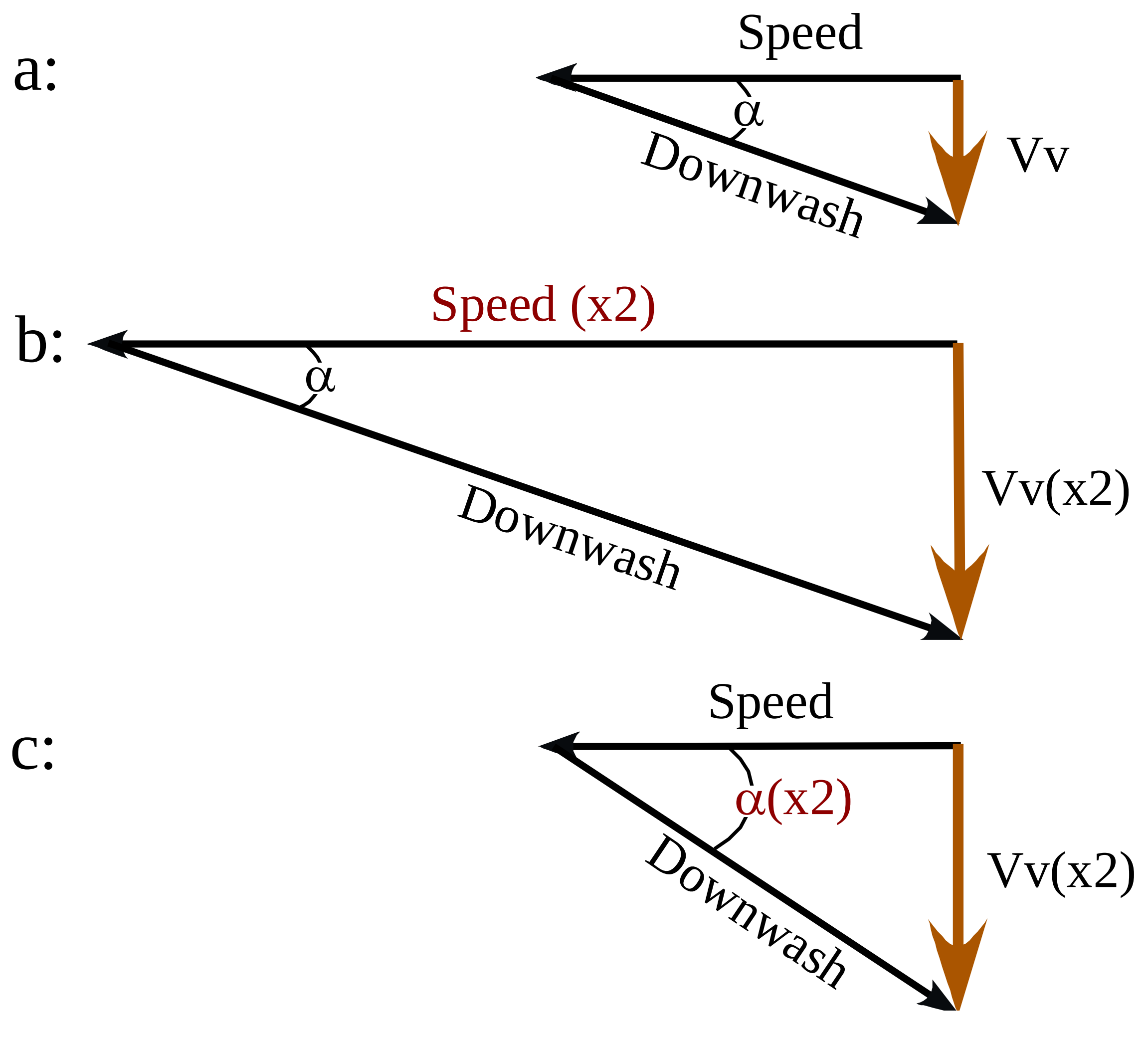
- The <u>speed</u>
- The <u>angle of attack</u>

$$V_v \propto V_\infty, \alpha$$

Angle of Attack

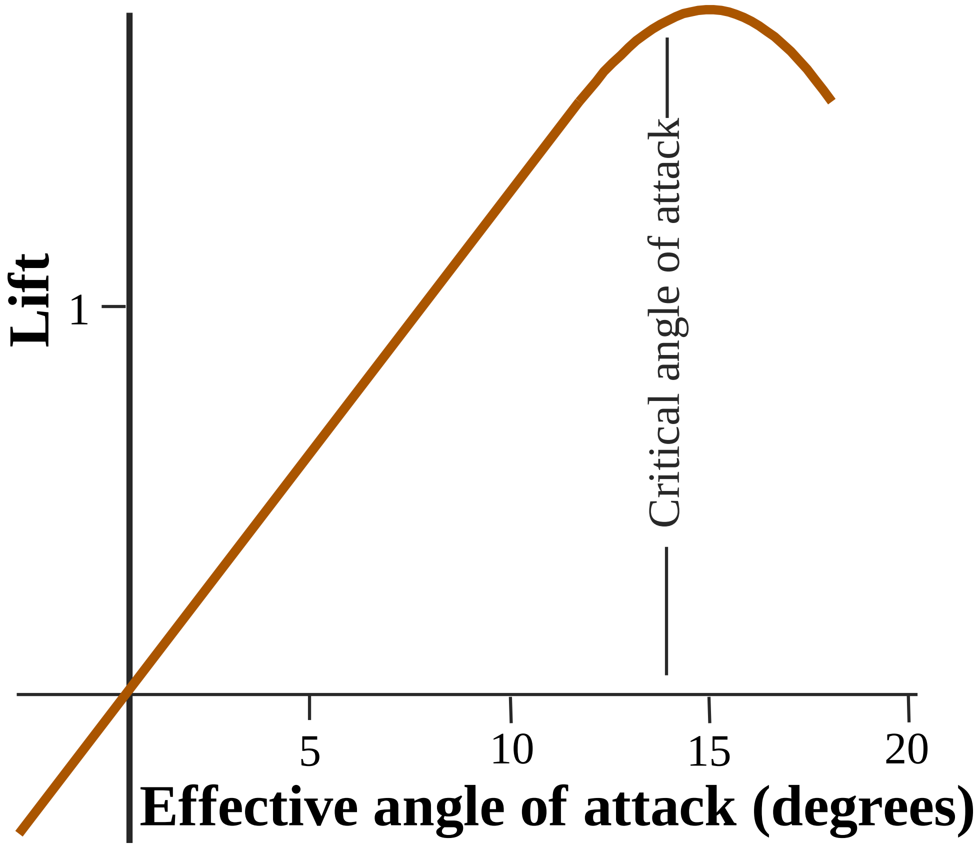


Vertical Velocity



<u>Pilot</u> controls <u>airspeed</u> and <u>angle of attack</u>

Lift is a Function of Angle of Attack



(at constant density and speed)

Implications

At twice the speed:

- **Twice** the mass of air is diverted per second, and given **twice** the vertical velocity, meaning that lift increases by a **factor of four**.

At twice the angle of attack:

- The **same mass** of air is diverted per second, but is given **twice** the vertical velocity, meaning that lift increases by a **factor of two**.

Therefore a pilot can change the amount of lift produced by changing the airspeed or changing the angle of attack

How much air is pushed down?

A Cessna 172 diverts approximately
5 times its own weight per second!

Summary of Lift

- Lift is proportional to:

  Amount of air diverted per second

  Downwash velocity of that air
- Amount of air diverted per second is proportional

  to: Speed of wing

  Density of air
- Downwash velocity of air is proportional to:

  Angle of attack

  Speed of wing
- Therefore Lift is proportional to speed squared, density, and angle of attack

Summary

- **Lift** is the component of aerodynamic force *perpendicular* to the relative wind.
- **Drag** is the component of aerodynamic force *parallel* to the relative wind – More to come on this!
- Lift on an aerofoil mainly due to the imbalance of pressure distributions over the top and bottom surfaces
- Lift is proportional to speed squared (V^2), density (ρ,) and angle of attack (α)

Follow-up materials

To help with exam:

- Introduction to Flight – 5.1-5.2

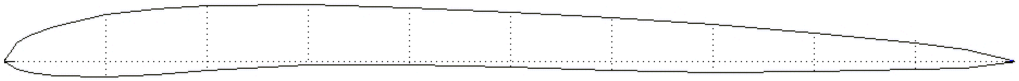
To aid in understanding:

- Aircraft Flight – Barnard & Philpott – Chapter 1 (3 copies in library)
- Understanding flight – Chapter 1

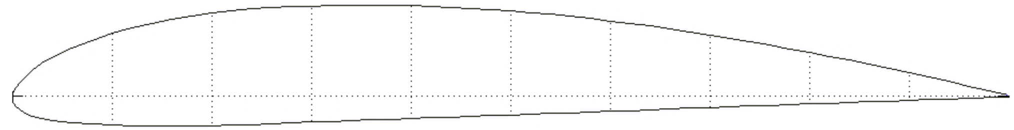
For interest:

- Introduction to Flight – 5.19 (explanation of lift)

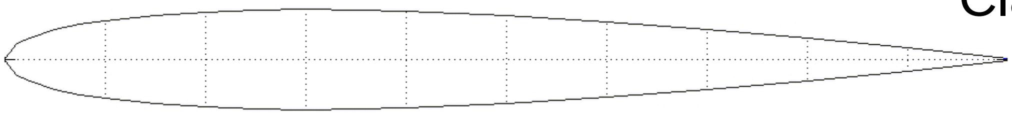
Some Typical Aerofoil Sections



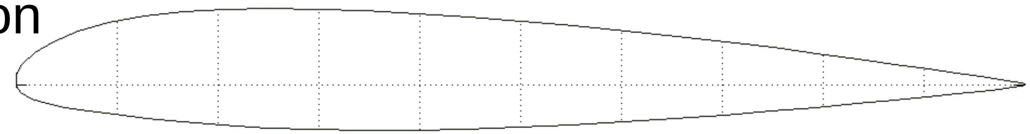
RAF-15 – WWI biplane



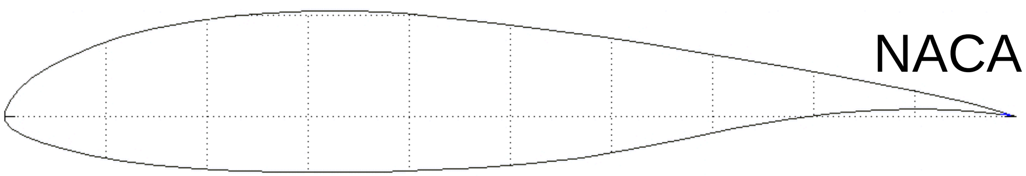
Clark Y – early ‘flat-bottomed’ section



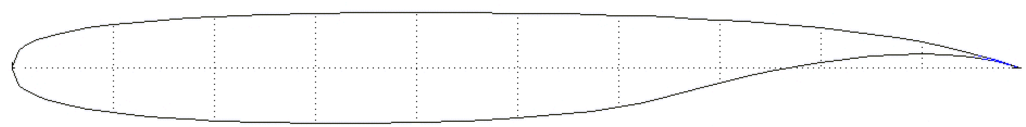
NACA 0010 – basic symmetric section



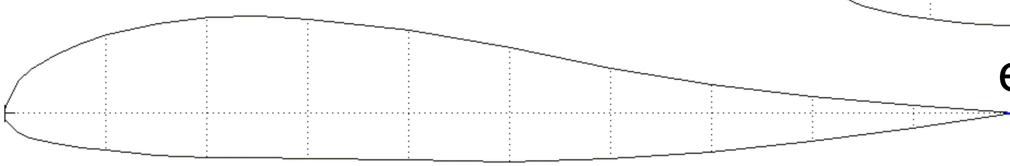
NACA 23012 – common post-war section



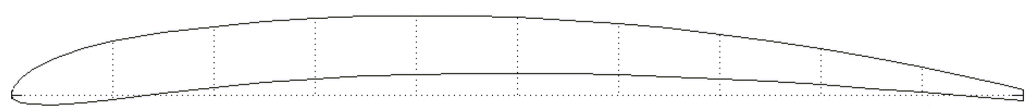
typical laminar flow section



early ‘supercritical’ transonic section



‘reflex’ camber for flying wing



high-speed propeller section