



Introduction to Airfoils

AE 1350

They're Everywhere!

- Wings
- Tail Surfaces (Vertical Fin & Horizontal Stabilizer)
- Propellers and Turbofans
- Helicopter Rotors
- Compressors and Turbines
- Wind Turbines
- Hydrofoils
(wing-like devices which can lift up a boat above waterline)

Anatomy of an Airfoil

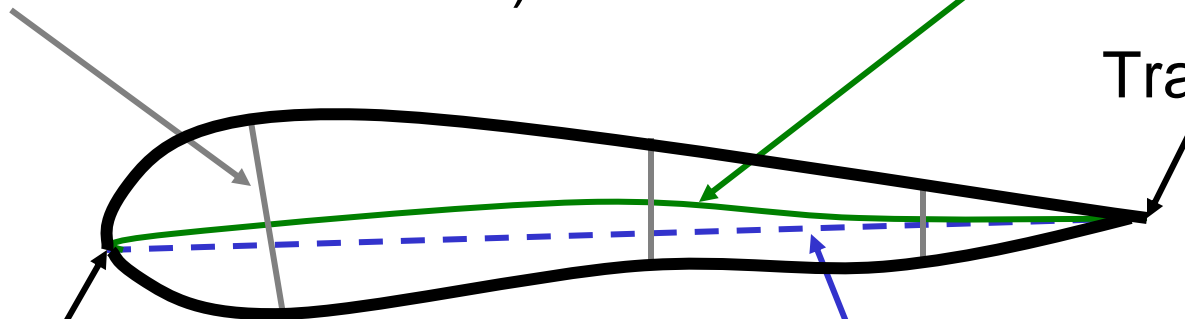
Equal amounts of thickness
above/below camber line
(normal to Camber Line)

Camber Line
(line of mid points)

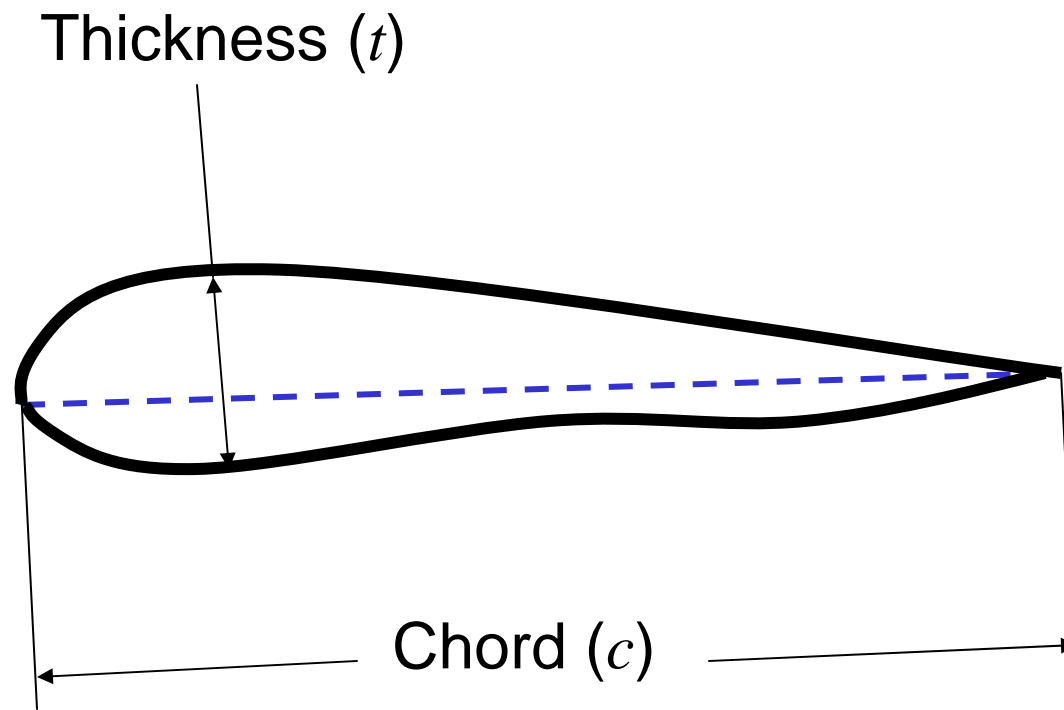
Trailing Edge

Leading Edge

Chord Line (straight from
leading edge to trailing
edge)

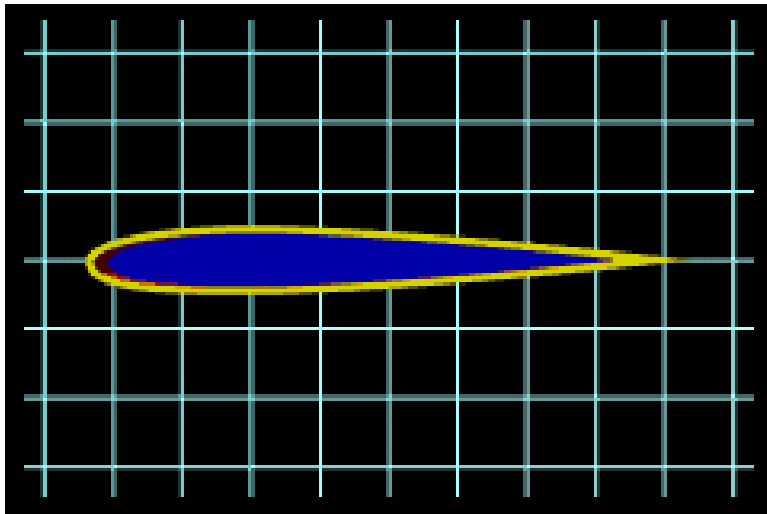


Anatomy of an Airfoil

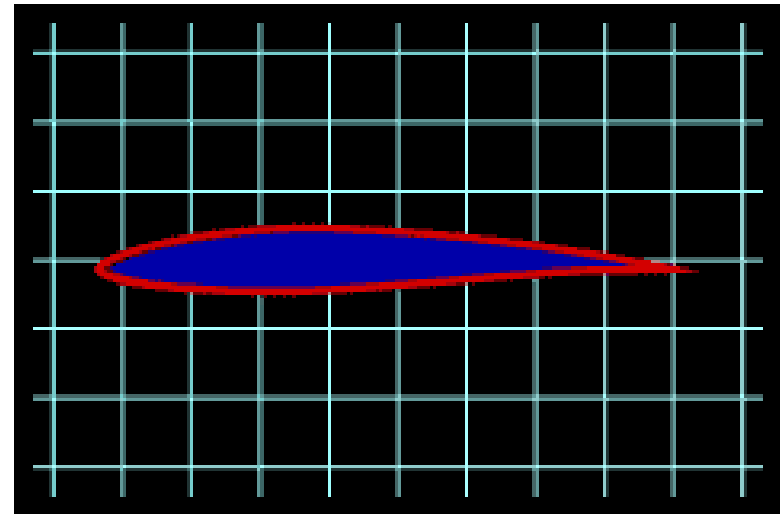


Specifying an Airfoil

- First: Camber line drawn with respect to the chord line
 - Note: Symmetric airfoils have no camber
- Second: Thickness Distribution which is added to the camber line, normal to the camber line

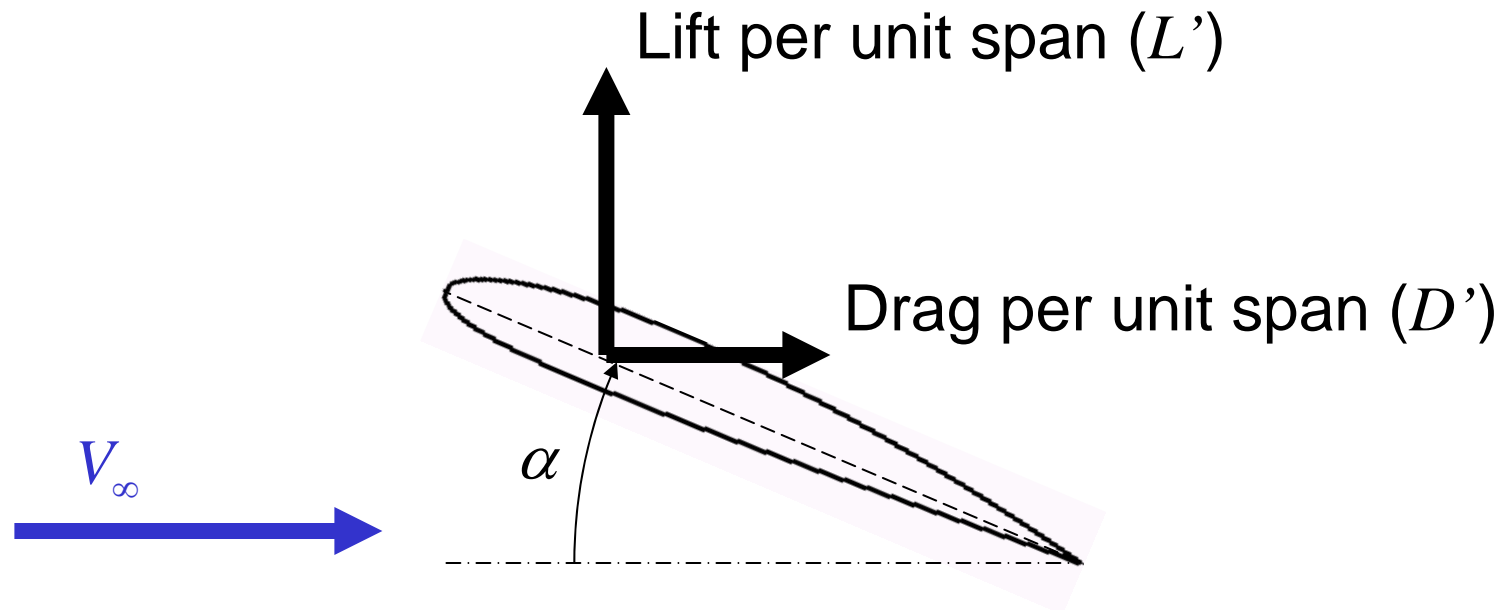


Symmetric



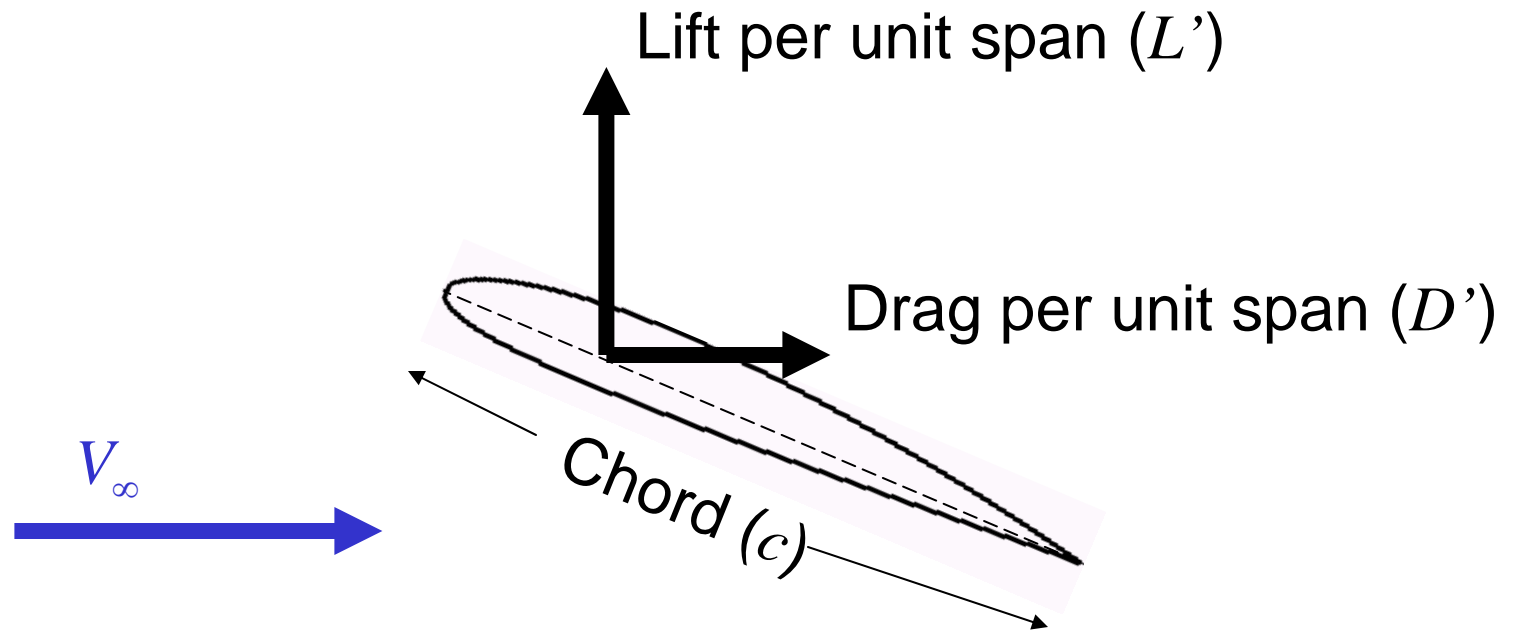
Cambered

Airfoil at Angle of Attack (α)



- Angle of attack is defined as the angle between the freestream and the chord line, given the symbol α
- The component of aerodynamic forces per unit of span (e.g. per foot of wing span) normal to the freestream, is called the sectional lift force, and is given the symbol L'
- The component along the freestream (per unit of span) is called the sectional drag force, and is given the symbol D'

Airfoil at Angle of Attack (α)

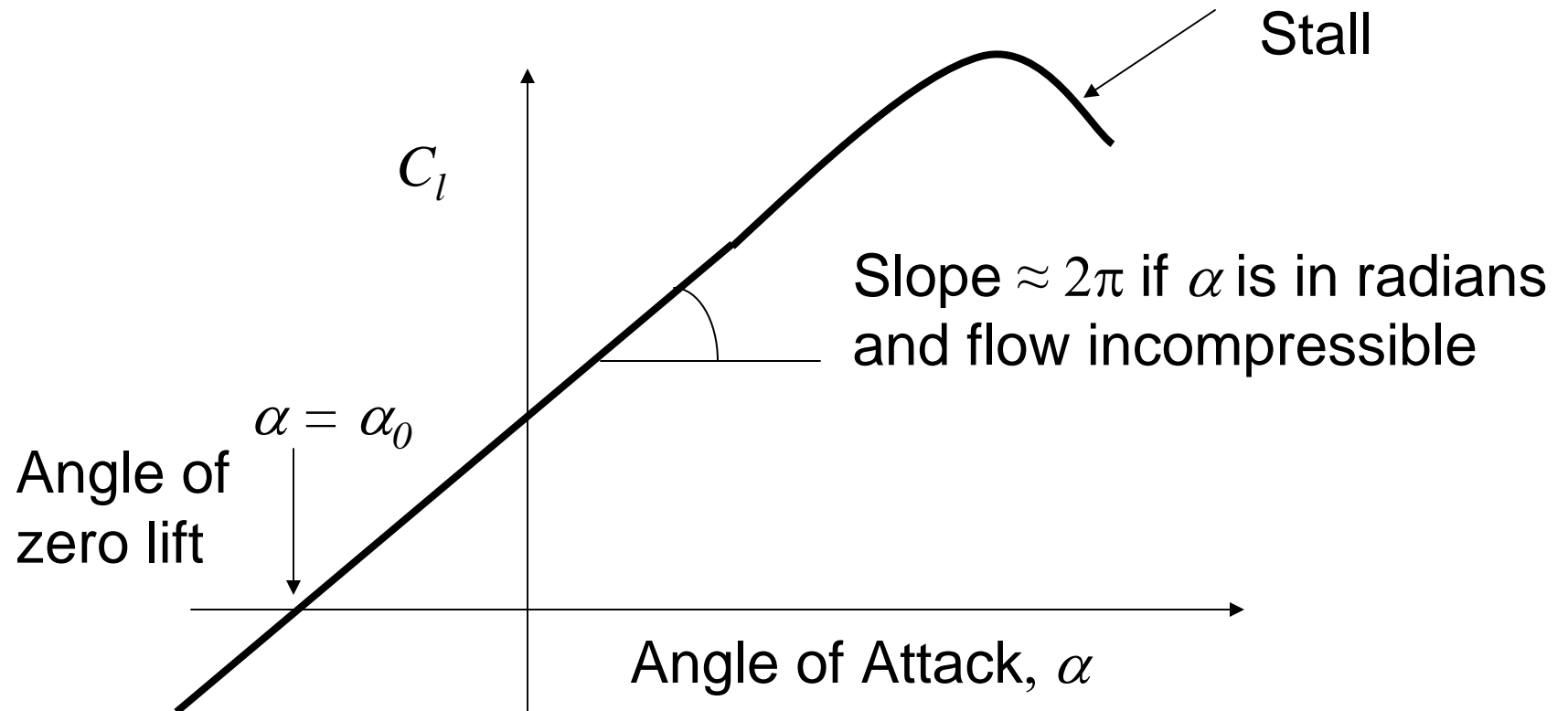


- The sectional lift and drag coefficients are defined by:

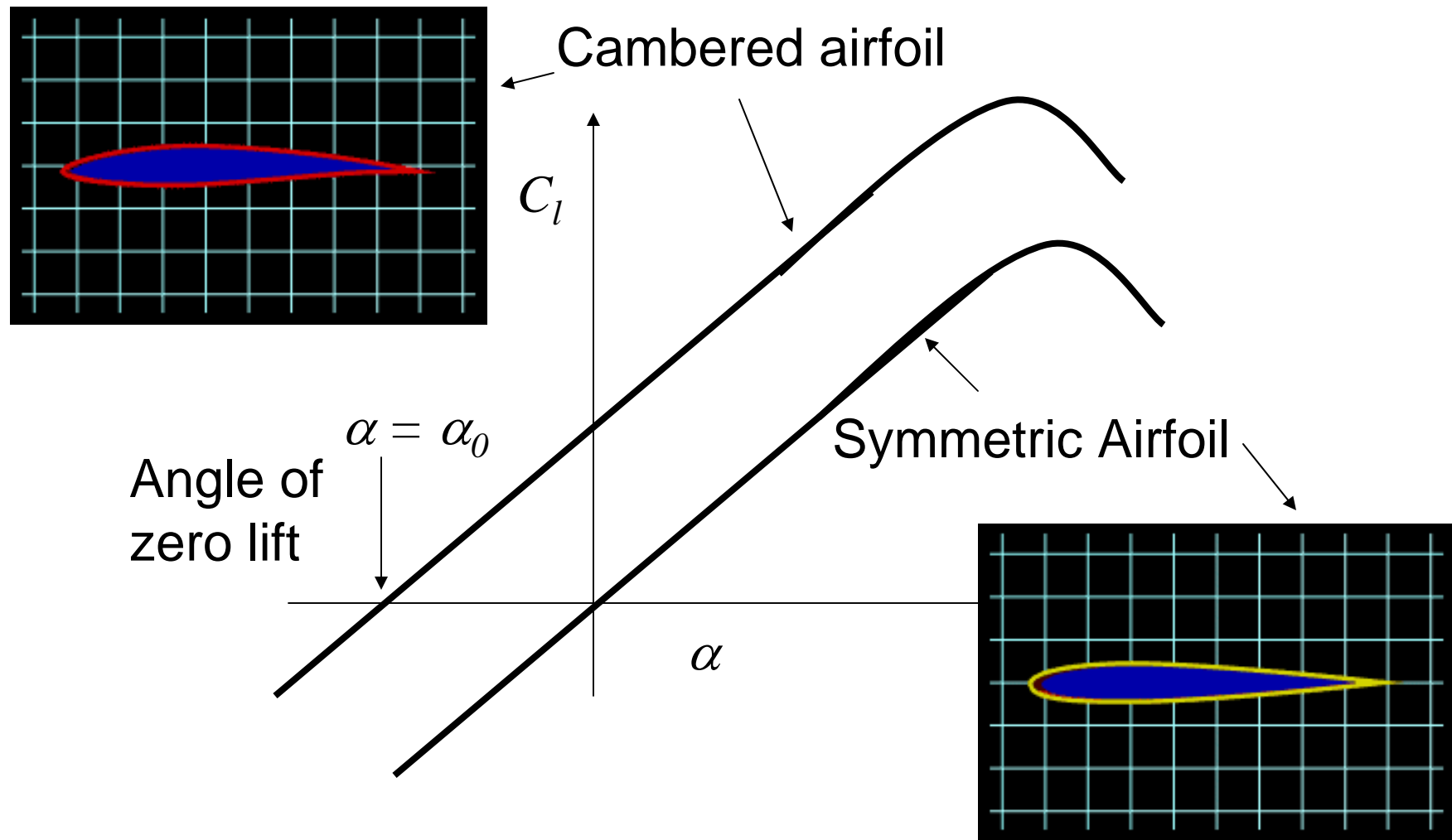
$$C_l = \frac{L'}{\frac{1}{2} \rho V_\infty^2 c} \quad C_d = \frac{D'}{\frac{1}{2} \rho V_\infty^2 c}$$

- Where c is the airfoil chord

Characteristics of C_l vs. α



Angle of Zero Lift Depends on Camber



Model for C_l at Low α (No Stall)

Incompressible Flow: $C_l = 2\pi(\alpha - \alpha_0)$

Compressible Flow: $C_l = \frac{2\pi}{\sqrt{1 - M_\infty^2}}(\alpha - \alpha_0) = \frac{C_{l,incompressible}}{\sqrt{1 - M_\infty^2}}$

- If we know how an airfoil behaves in low speed, incompressible flow, we can easily estimate how the lift will be altered in high speed flight
- This relation works until the Mach number over the airfoil exceeds 1 somewhere, and shocks form on the airfoil

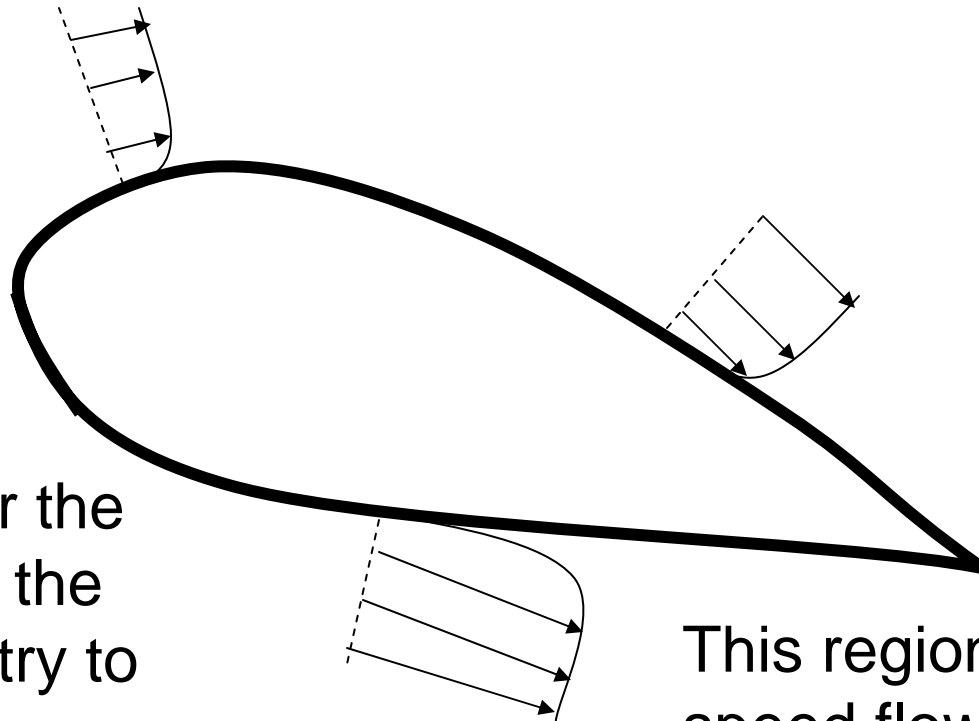
Drag is caused by

- Skin Friction - The air molecules try to drag the airfoil with them (due to viscosity)
- Form Drag - The flow separates near the trailing edge, due to the shape of the body; This causes low pressures near the trailing edge, pulling the object back
- Wave Drag - Shock waves form over the airfoil, converting energy of the flow into heat, causing drag
- ...and one more we need to be in 3 dimensions to talk about...

Skin Friction and the Boundary Layer

Particles away from the airfoil move unhindered

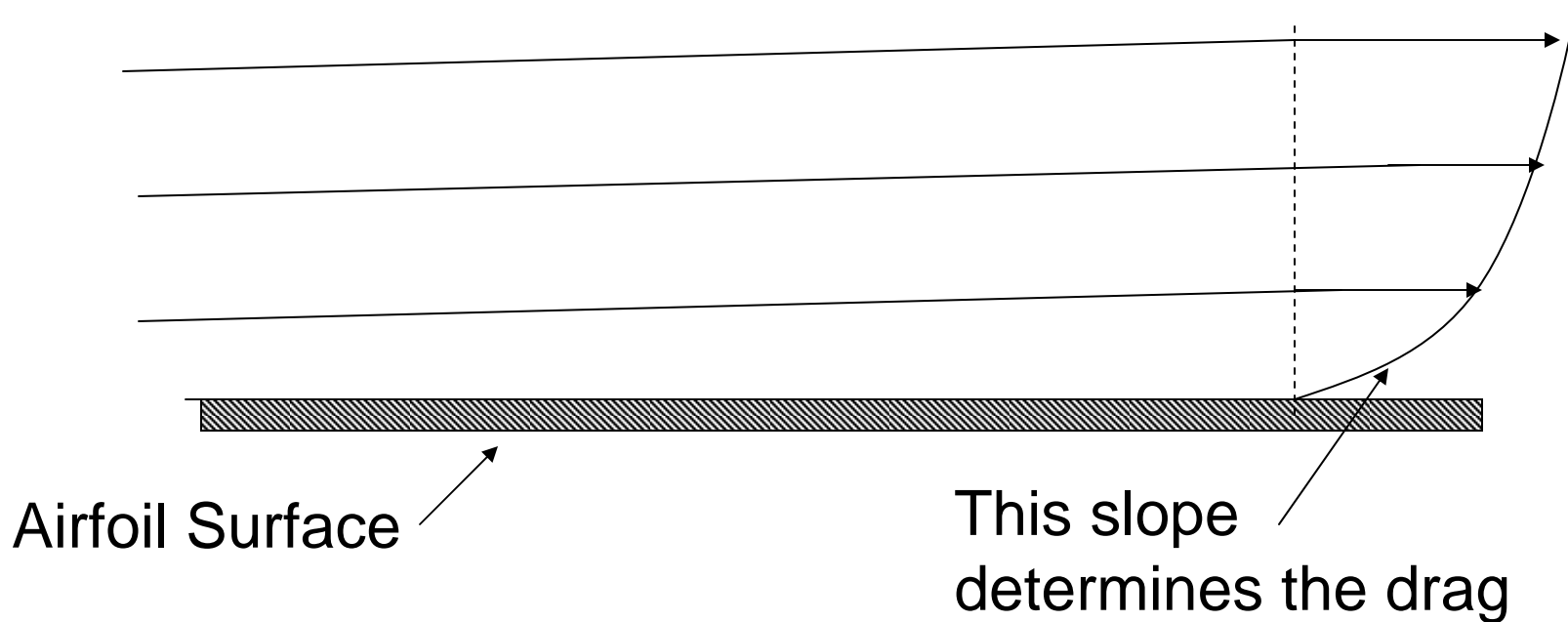
Particles near the airfoil stick to the surface, and try to slow down the nearby particles



This region of low speed flow is called the boundary layer

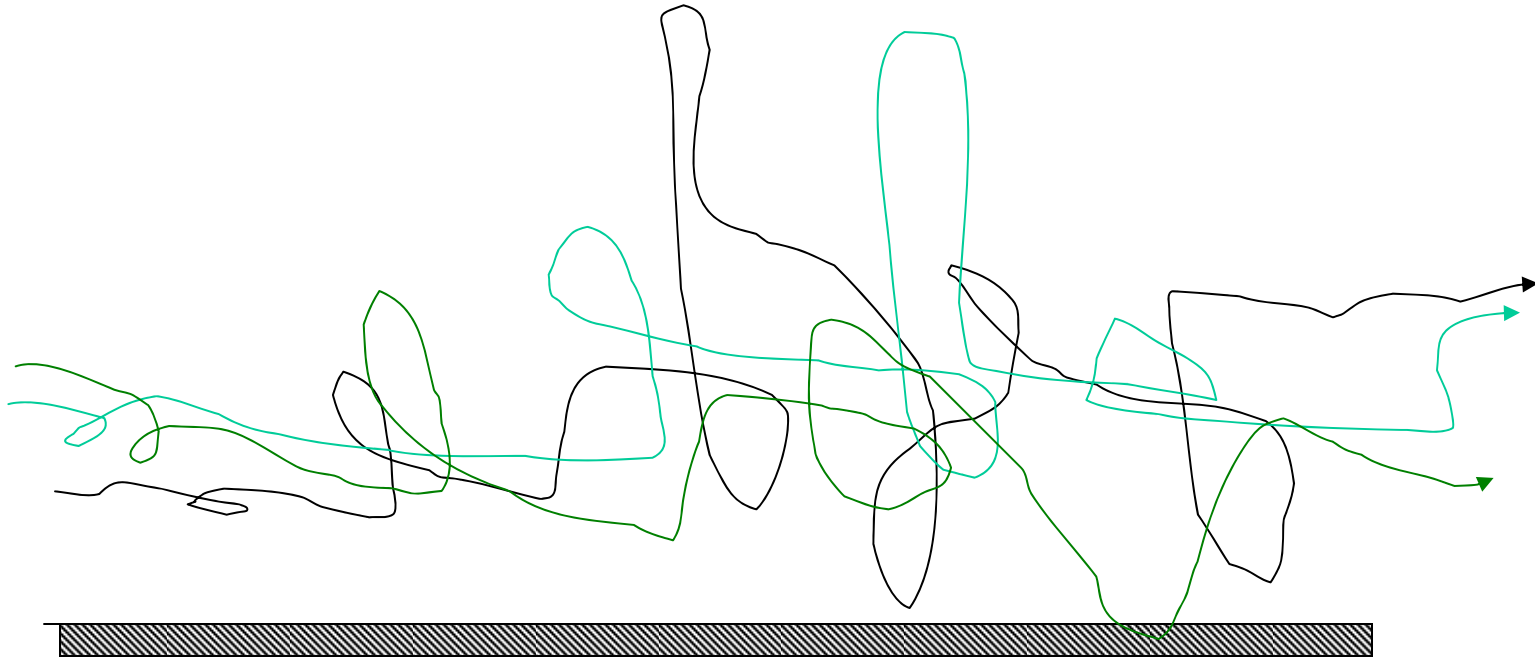
A tug of war results - airfoil is dragged back with the flow

Laminar Flow



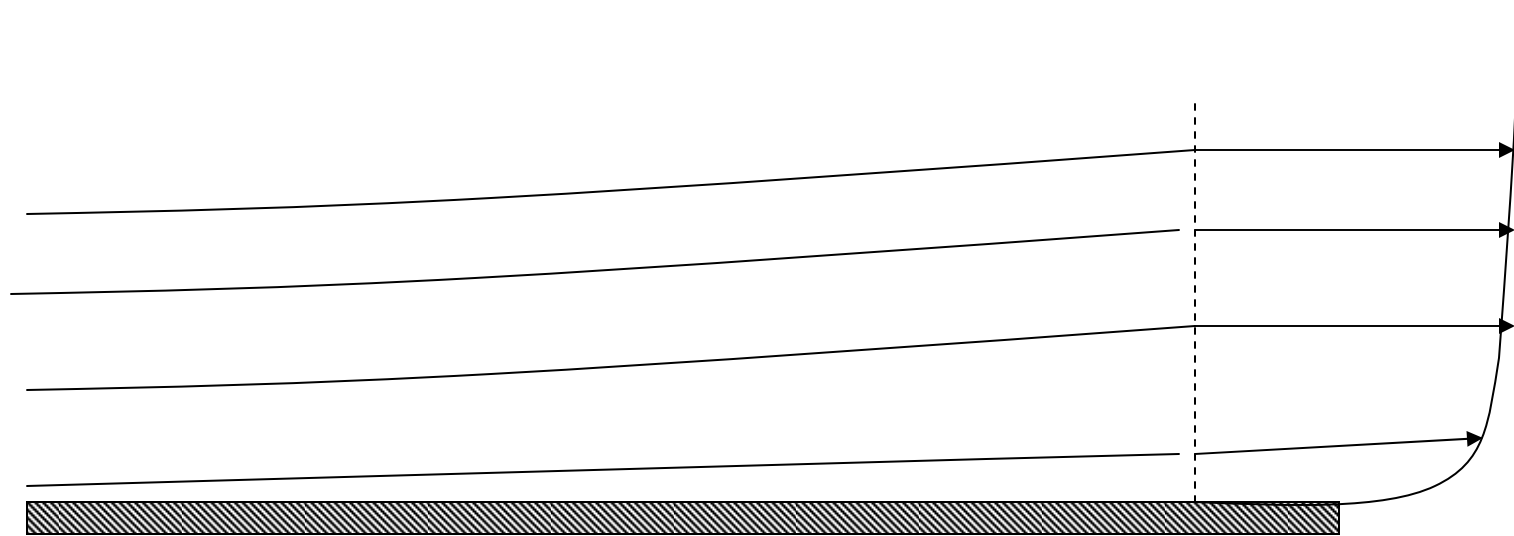
- For laminar flow:
 - Streamlines move in an orderly fashion - layer by layer
 - The mixing between layers is due to molecular motion, and is very slow
 - Drag per unit area is proportional to the slope of the velocity profile at the wall
 - Drag is small

Turbulent Flow



- For turbulent flow:
 - highly unsteady, three-dimensional, and chaotic
 - It can still be viewed in a time-averaged manner
 - For example, at each point in the flow, we can measure velocities once every millisecond to collect 1000 samples and average

“Time-Averaged” Turbulent Flow

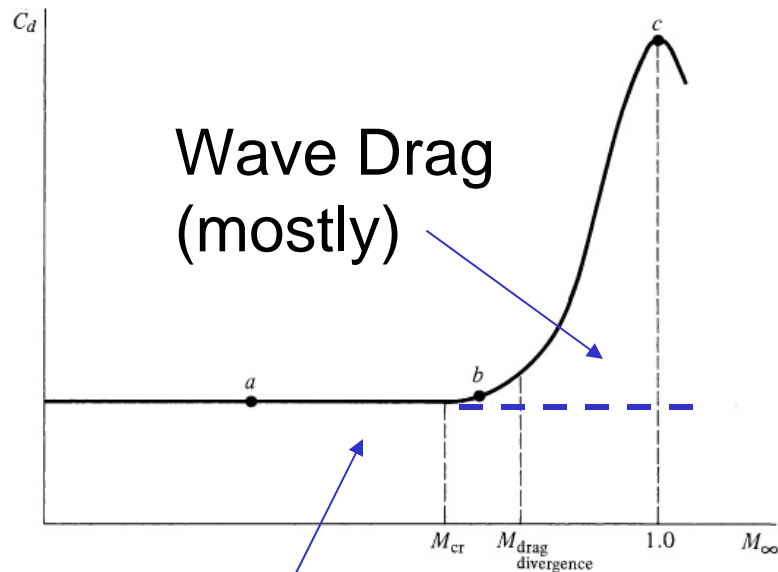


- Velocity varies rapidly near the wall due to increased mixing
- The slope is higher, so skin friction is higher
- Because separation properties or different, form drag could actually be lower and max lift higher...

Will it be Laminar or Turbulent?

- Reynolds number
 - Surface roughness
 - State of flow
(if its already turbulent, it's not going to become laminar)
 - Pressure gradient
 - ...and other factors...
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- On a typical wing, flow is laminar near the leading edge, but eventually trips to turbulent for (typically) most of the surface

Drag vs. Mach (Compressibility)



Skin Friction

