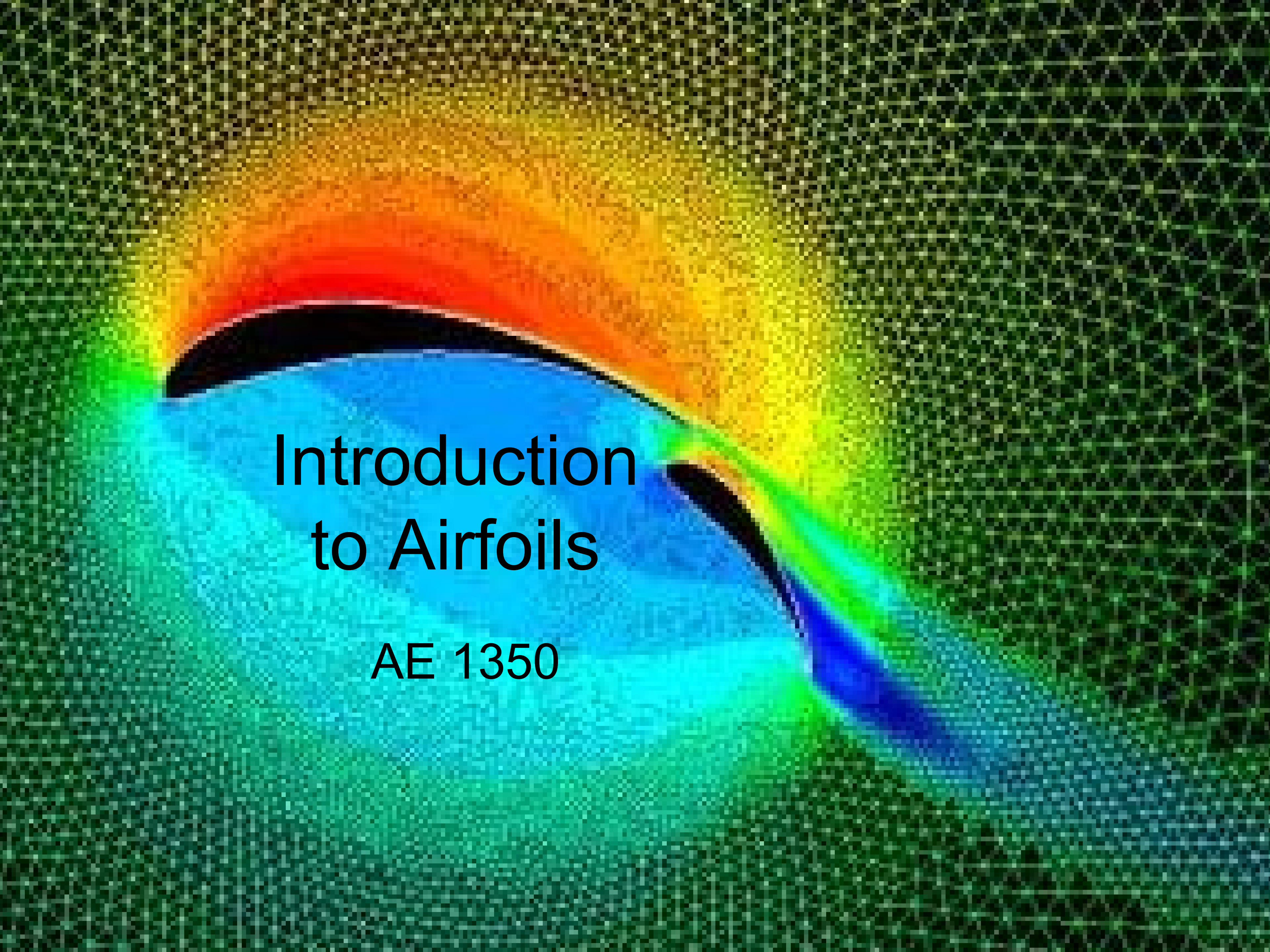


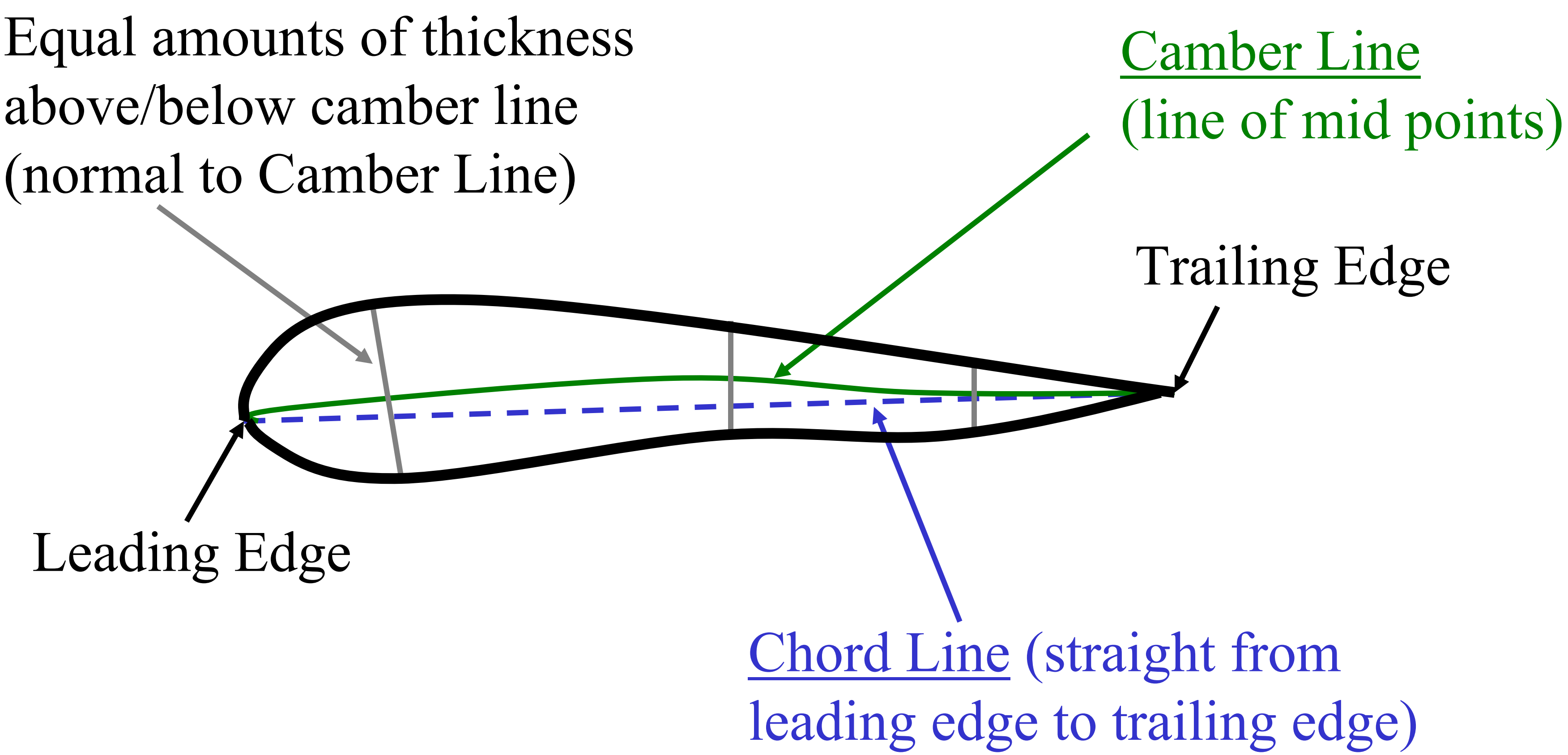
Introduction to Airfoils

AE 1350

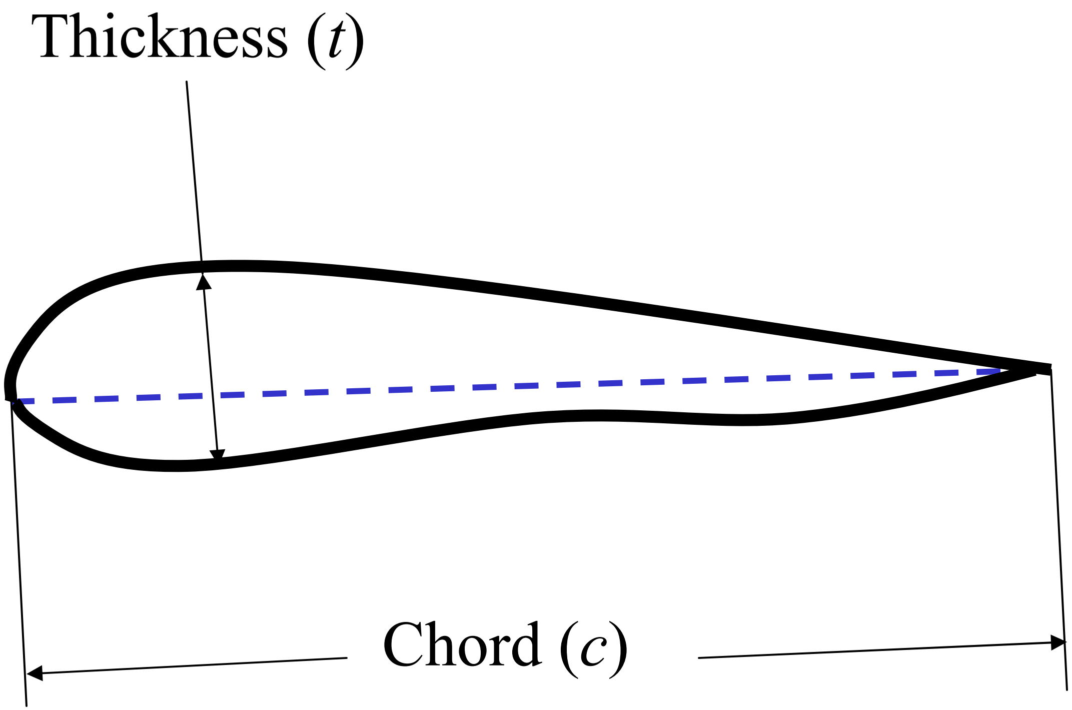
They’re Everywhere!

- 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

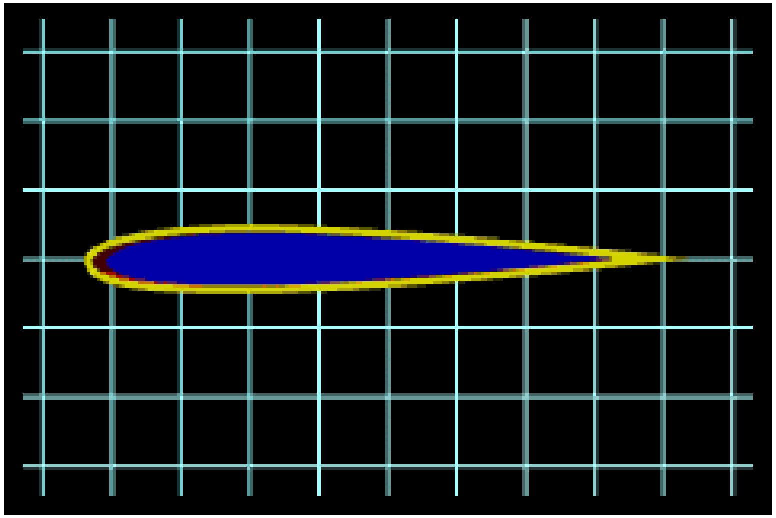


Anatomy of an Airfoil

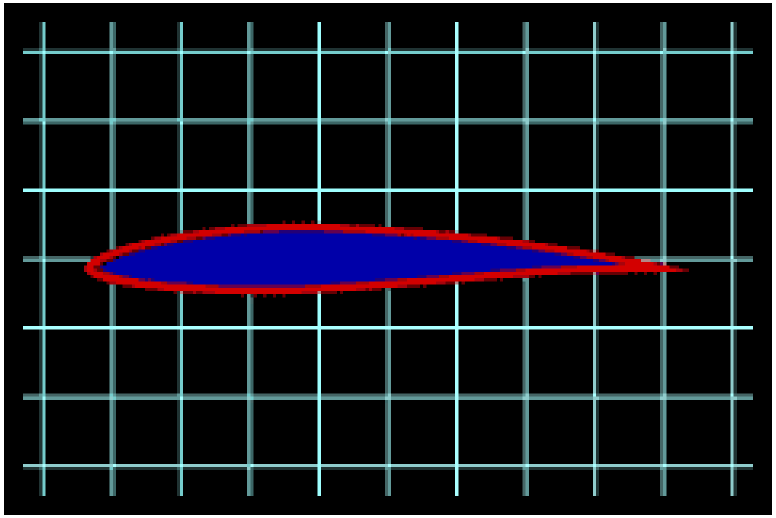


Specifying an Airfoil

- 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

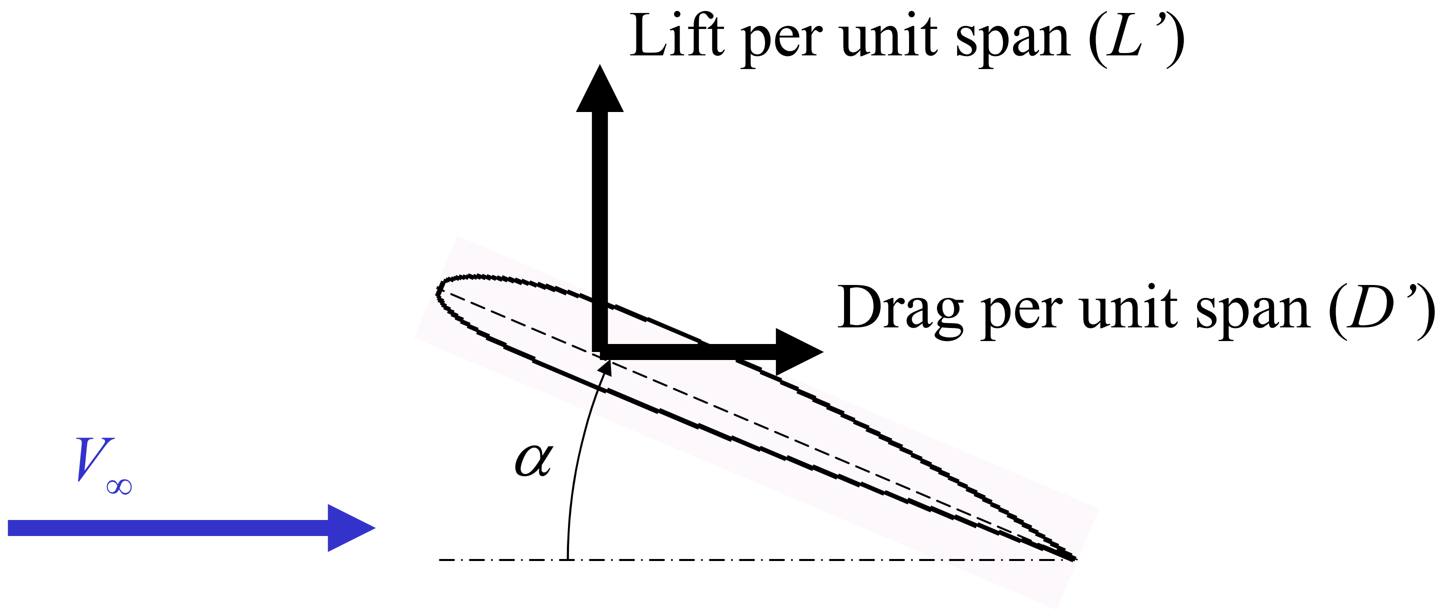


Symmetric



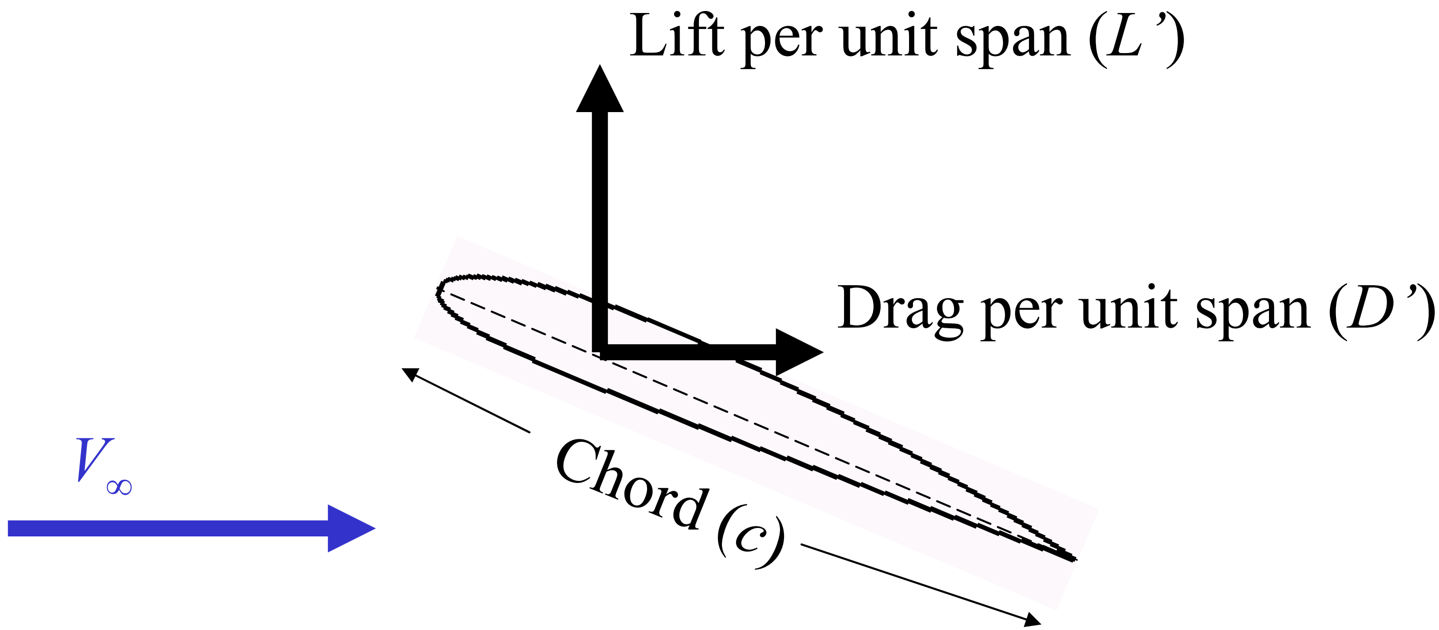
Cambered

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)

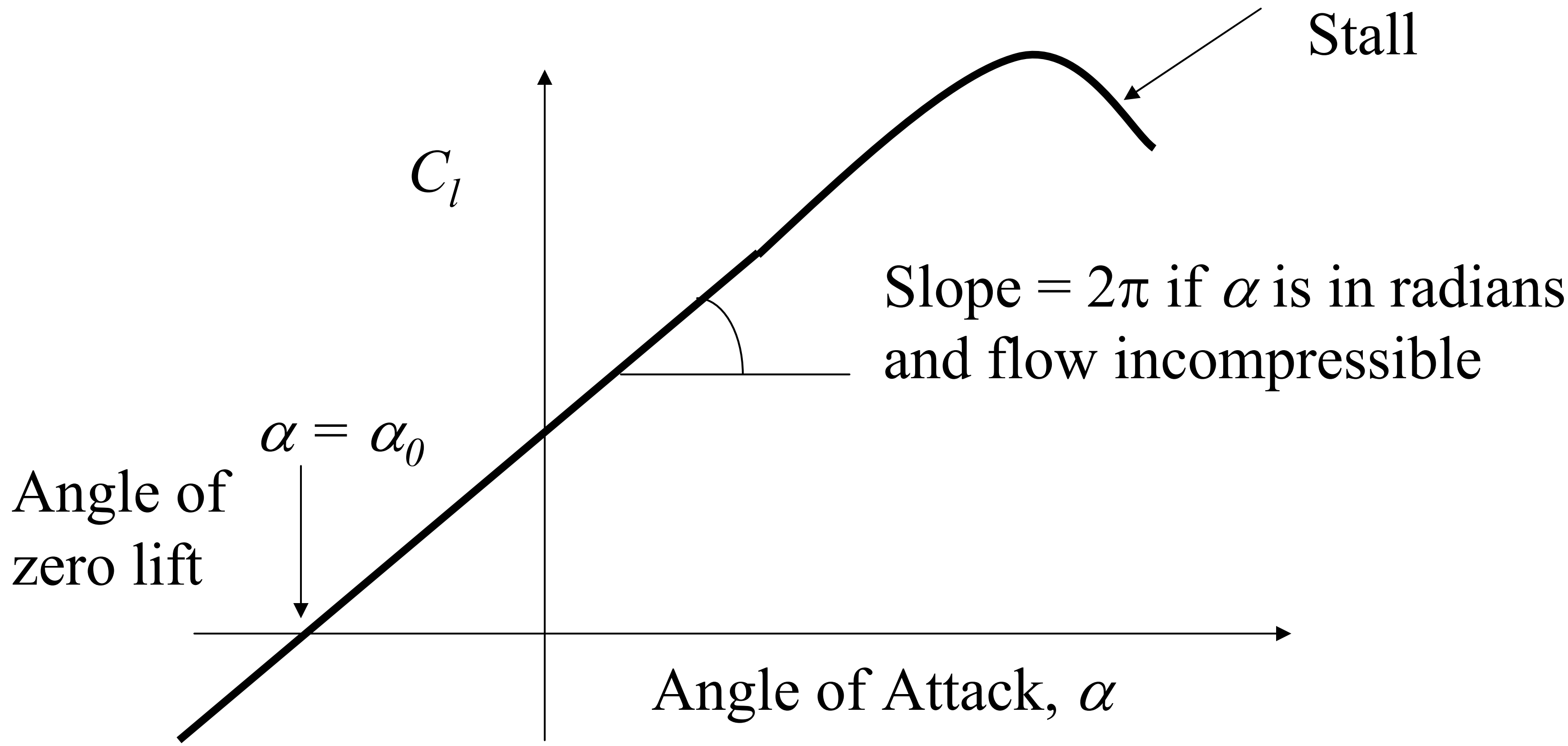


- The sectional lift and drag coefficients are defined by:

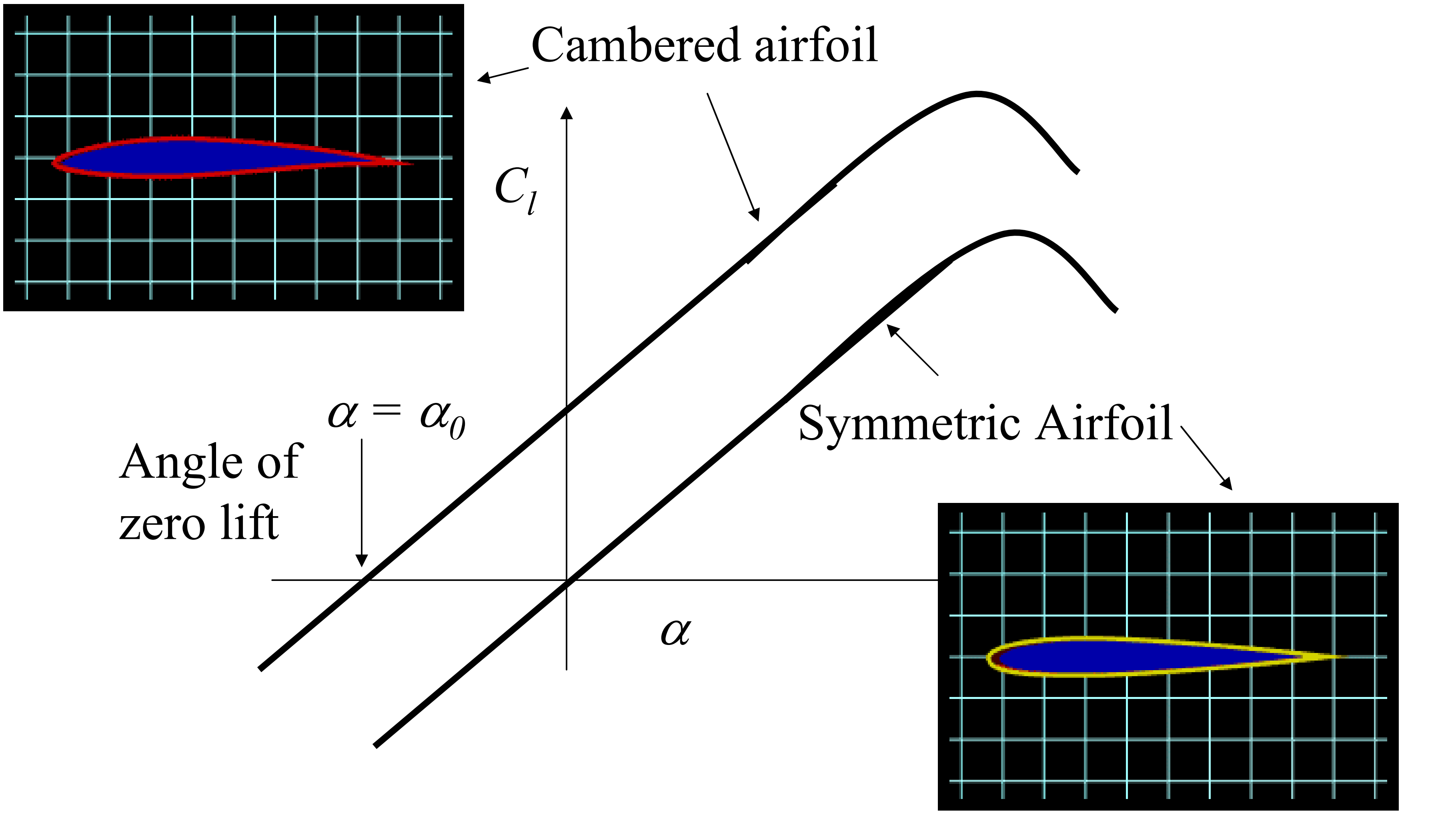
$$C_l = \frac{L'}{\frac{1}{2}\rho V_\infty^2 c} \qquad C_d = \frac{D'}{\frac{1}{2}\rho V_\infty^2 c}$$

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

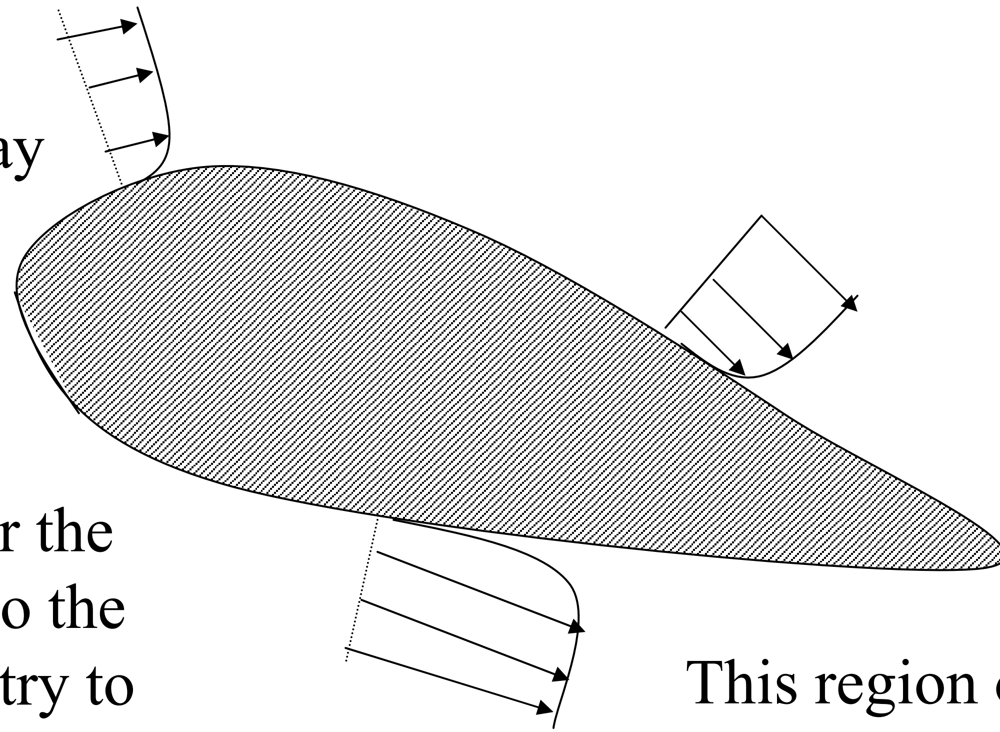
Compressible Flow: $C_l = \frac{2\pi}{\sqrt{1-M_\infty^2}}(\alpha - \alpha_0) = \frac{C_{l,incompressible}}{\sqrt{1-M_\infty^2}}$

- 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, 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

Skin Friction



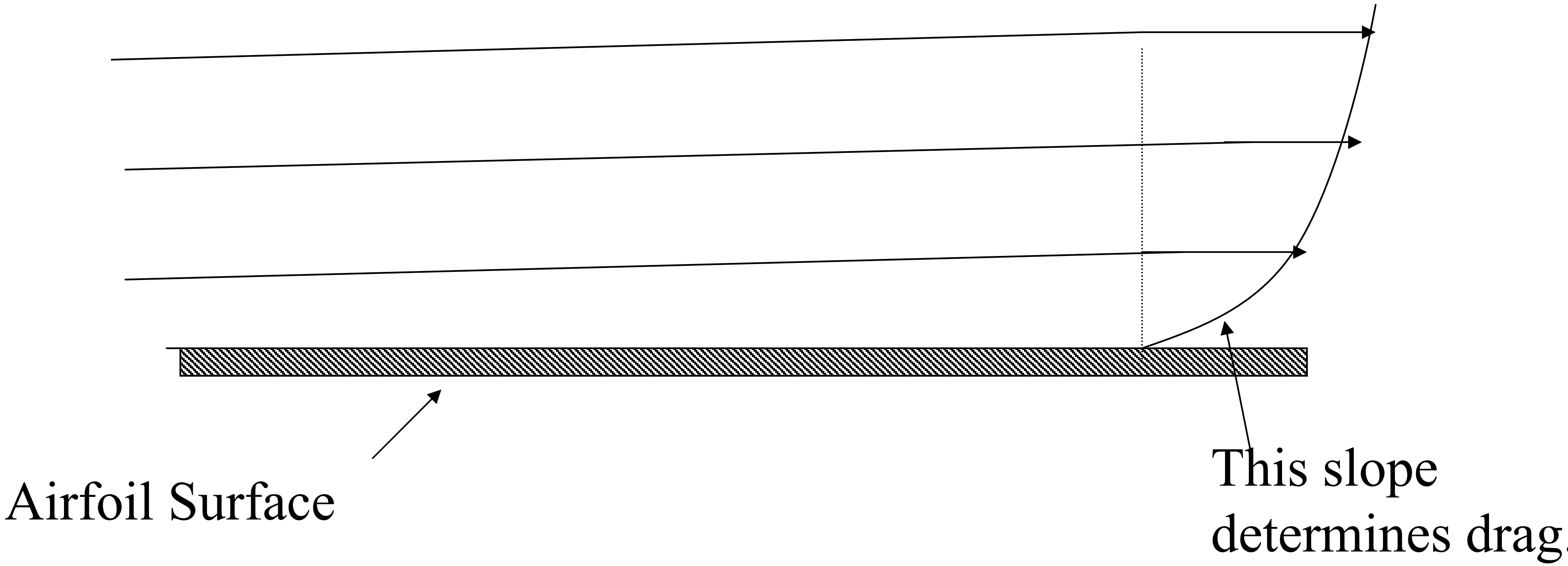
Particles away from the airfoil move unhindered.

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.

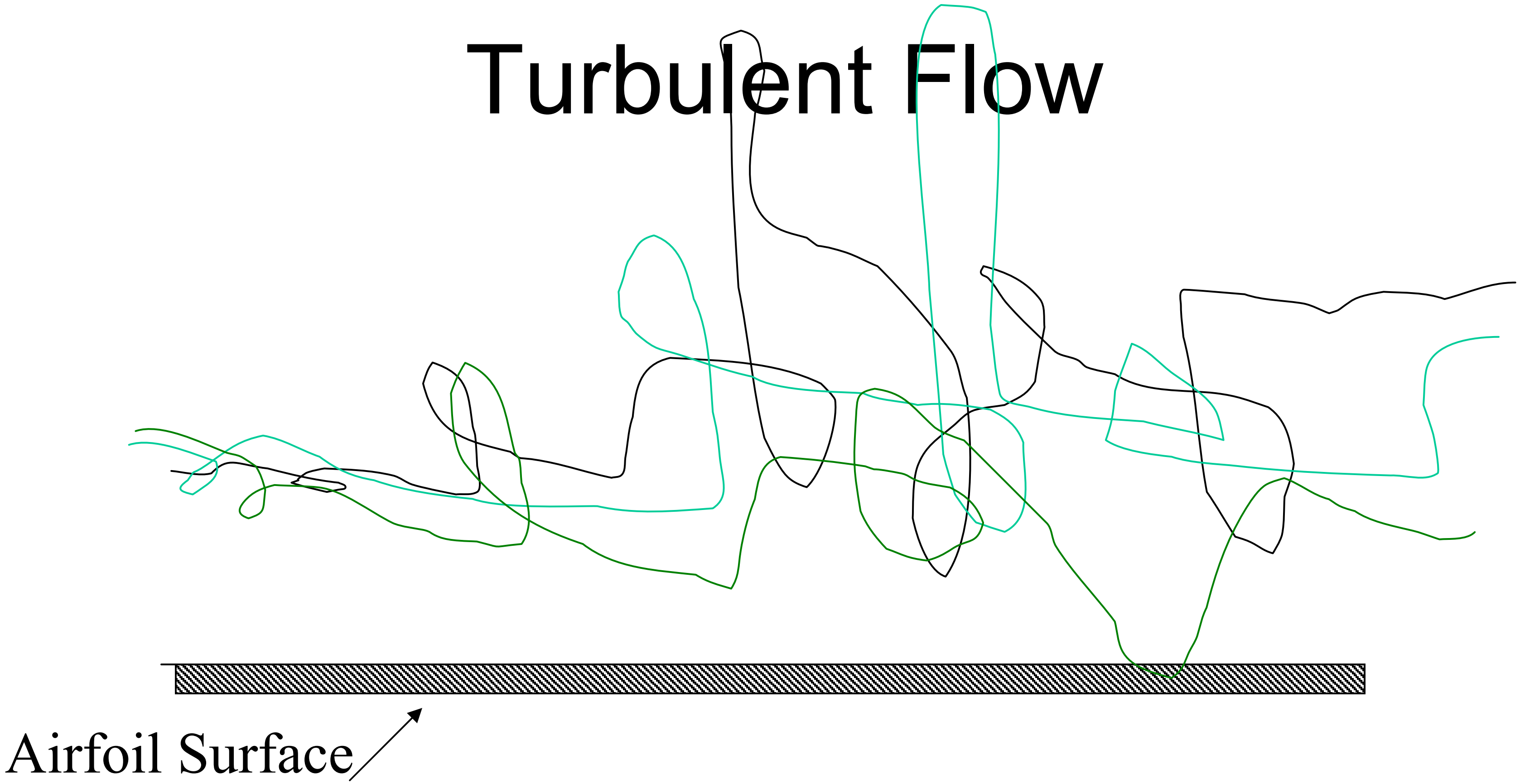
A tug of war results - airfoil is dragged back with the flow.

Laminar Flow



Streamlines move in an orderly fashion - layer by layer.
The mixing between layers is due to molecular motion.
Laminar mixing takes place very slowly.
Drag per unit area is proportional to the slope of the velocity profile at the wall.
In laminar flow, drag is small.

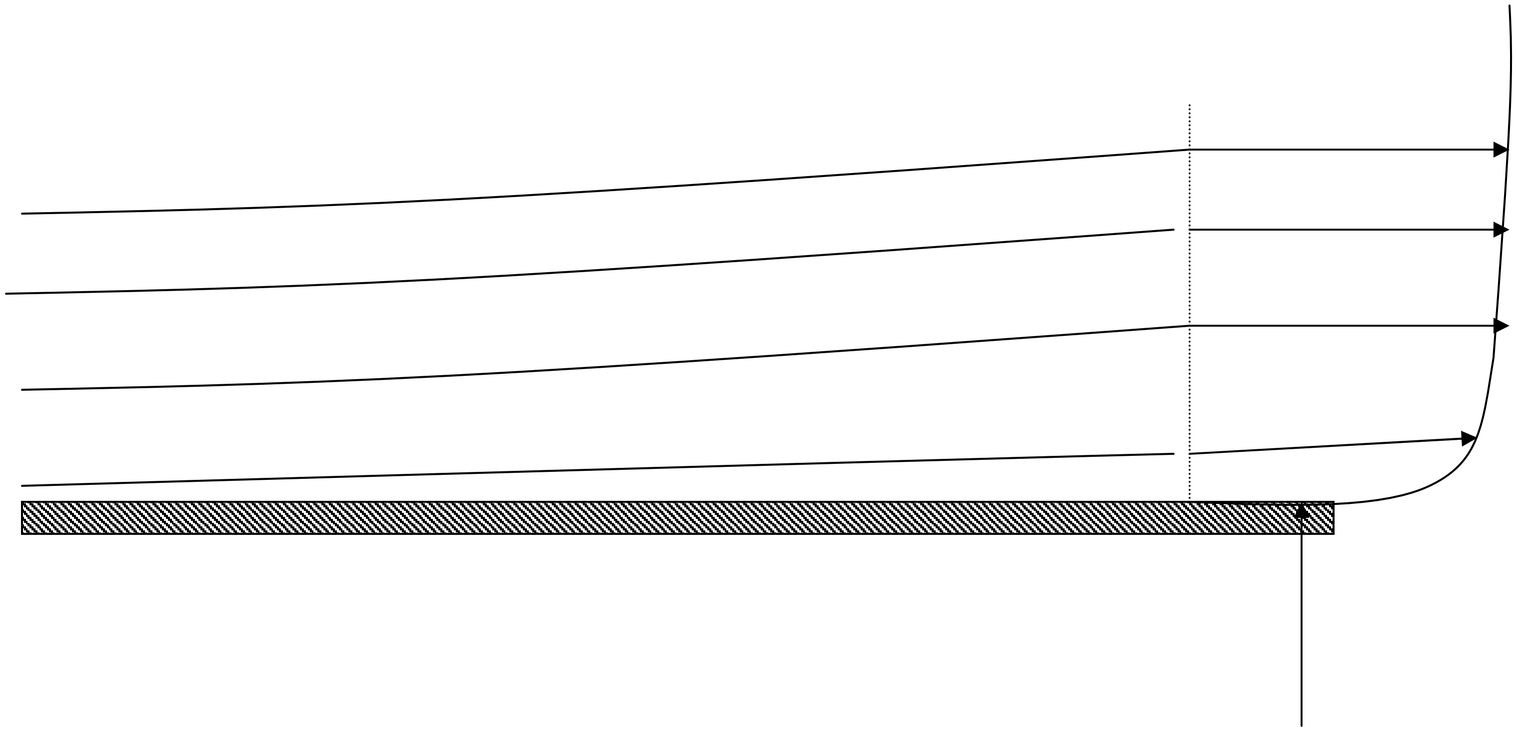
Turbulent Flow



Turbulent flow is 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 and average it.

“Time-Averaged” Turbulent Flow



Velocity varies rapidly
near the wall due to increased
mixing.
The slope is higher. Drag is higher.