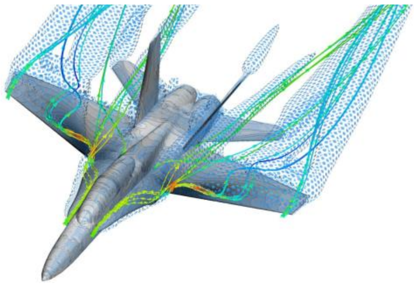
بسم الله الرحمن الرحيم

Fluid Mechanics I



Fayoum University

Faculty of Engineering
Mechanical Engineering Dept.

Lecture (8)

on

External Flow and Boundary Layer Concepts

By

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Characteristics of External Flow

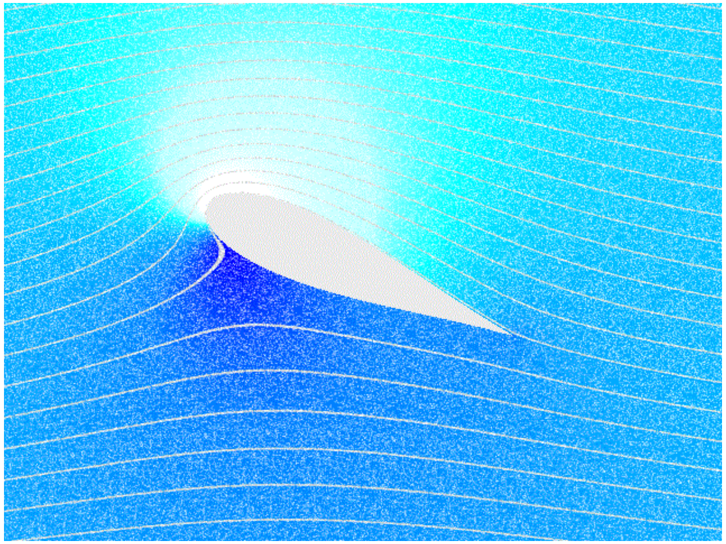
- Objects are completely surrounded by the fluid and the flows are termed external flows.
- Examples include the flow of air around airplane, automobiles, and falling snowflakes, or the flow of water around submarines and fish.
- External flows involving air are often termed aerodynamics in response to the important external flows produced when an object such as an airplane flies through the atmosphere.

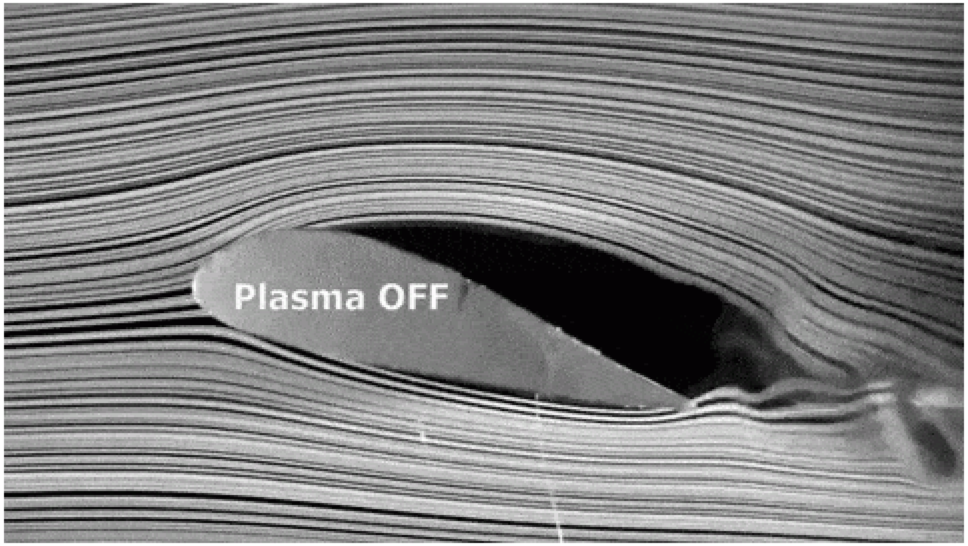
Characteristics of External Flow

Application

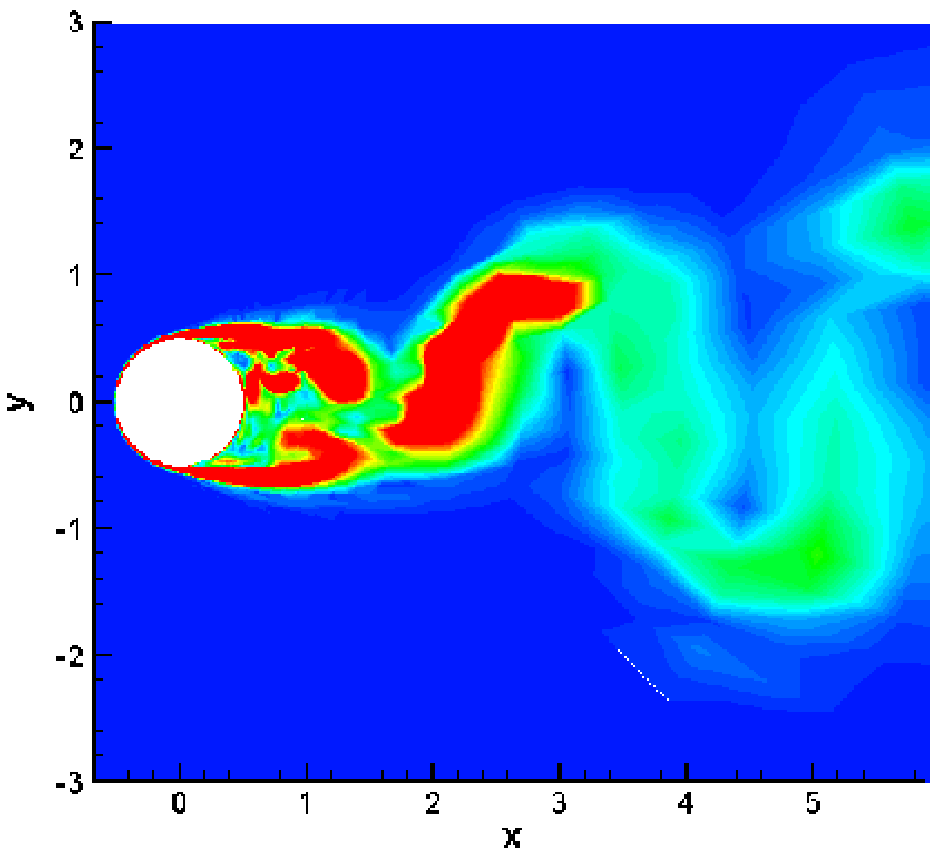
- Design of cars and trucks – to decrease the fuel consumption and improve the handling characteristics.
- Improve ships, whether they are surface vessels (surrounded by air and water) or submersible vessels.
- Design of building – consider the various wind effects

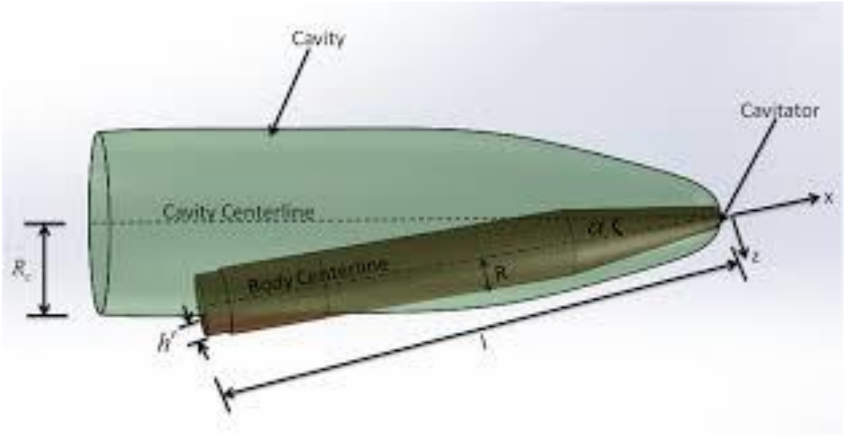
Characteristics of External Flow





Characteristics of External Flow

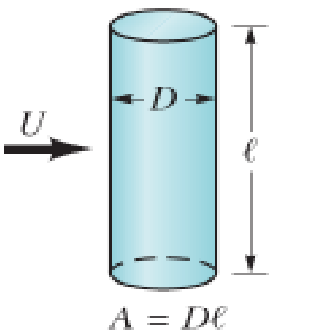


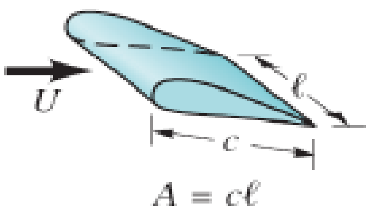


Characteristics of External Flow

Lift and Drag Concepts

- Without detailed information concerning the shear stress and pressure distributions on a body, the drag and the lift are difficult to obtain by integration.
- A widely used alternative is to define dimensionless lift and drag coefficients and determine their approximate values by means of either a simplified analysis, some numerical technique, or an appropriate experiment.



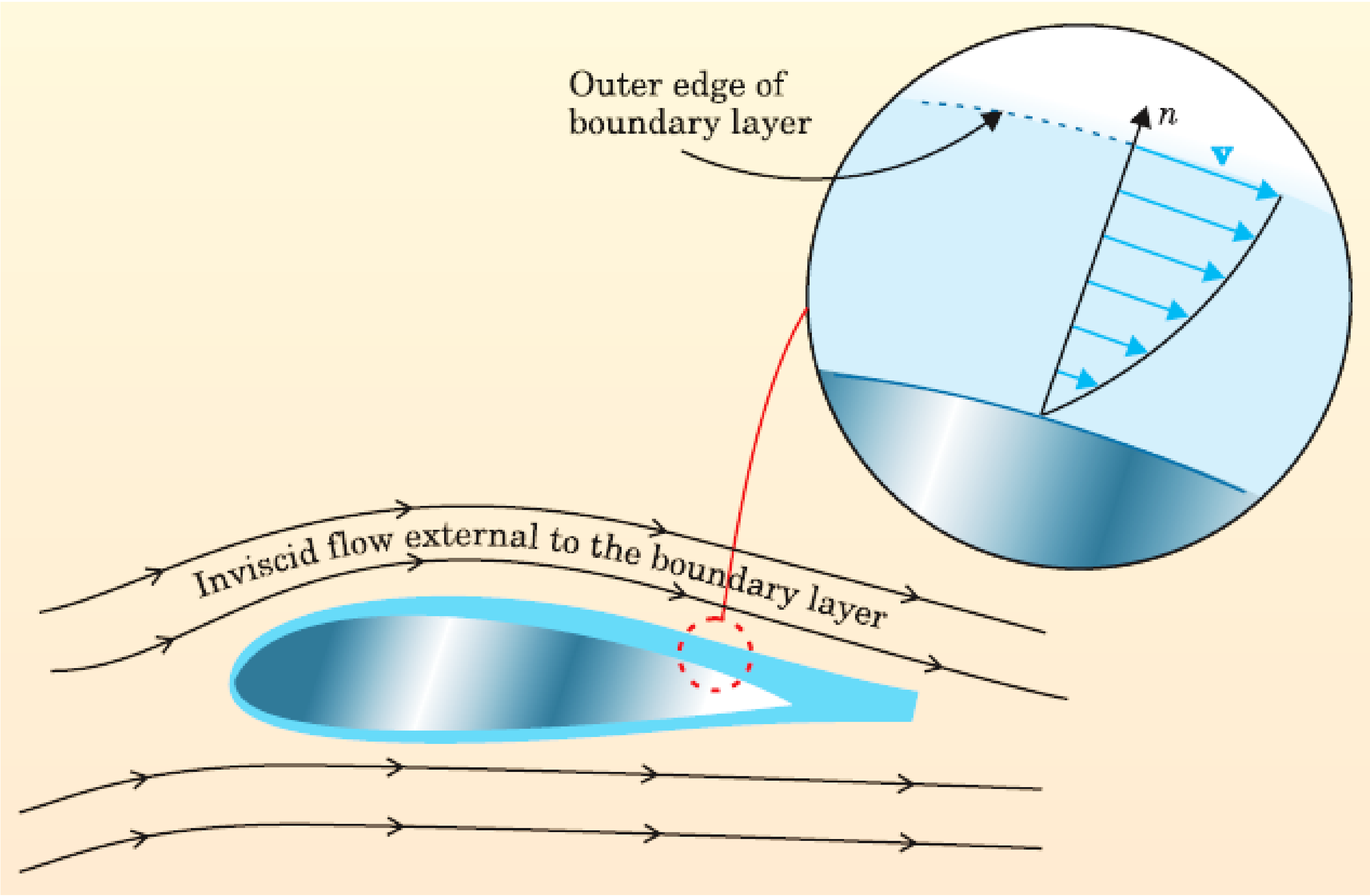


Lift coefficient $C_L = \dfrac{L}{\frac{1}{2}\rho U^2 A}$

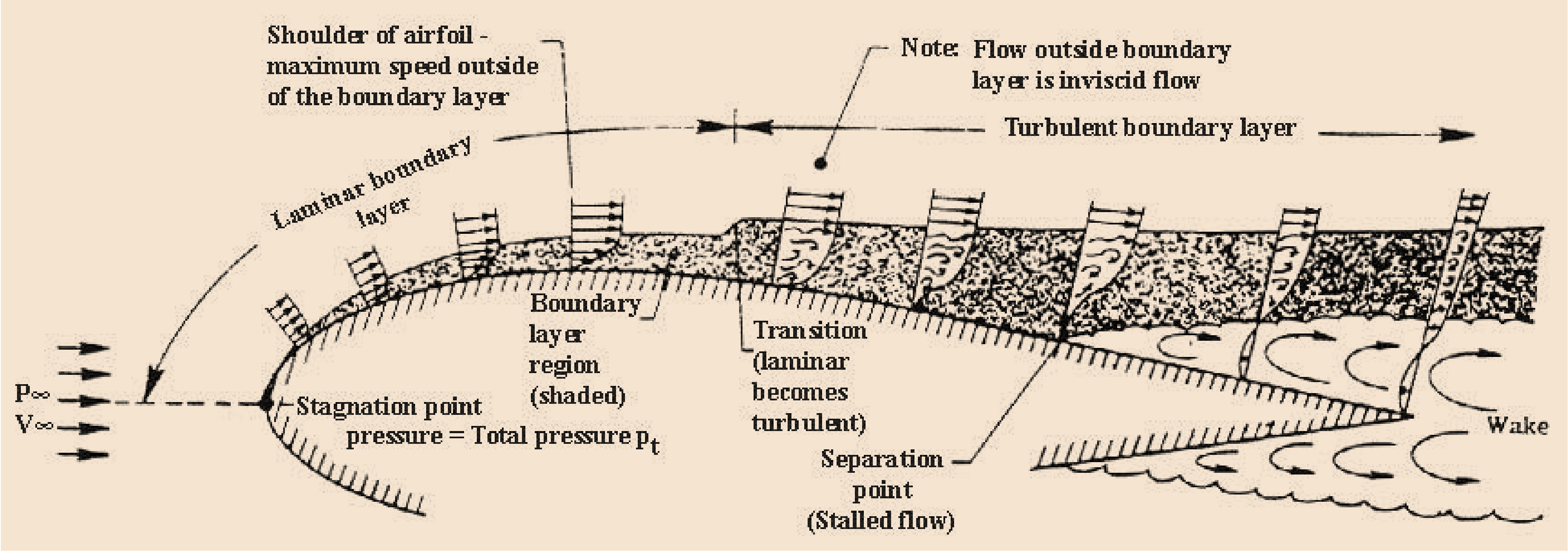
Drag coefficient $C_D = \dfrac{D}{\frac{1}{2}\rho U^2 A}$

$\frac{1}{2}\rho U^2$: *Characteristic pressure*

Boundary-layer



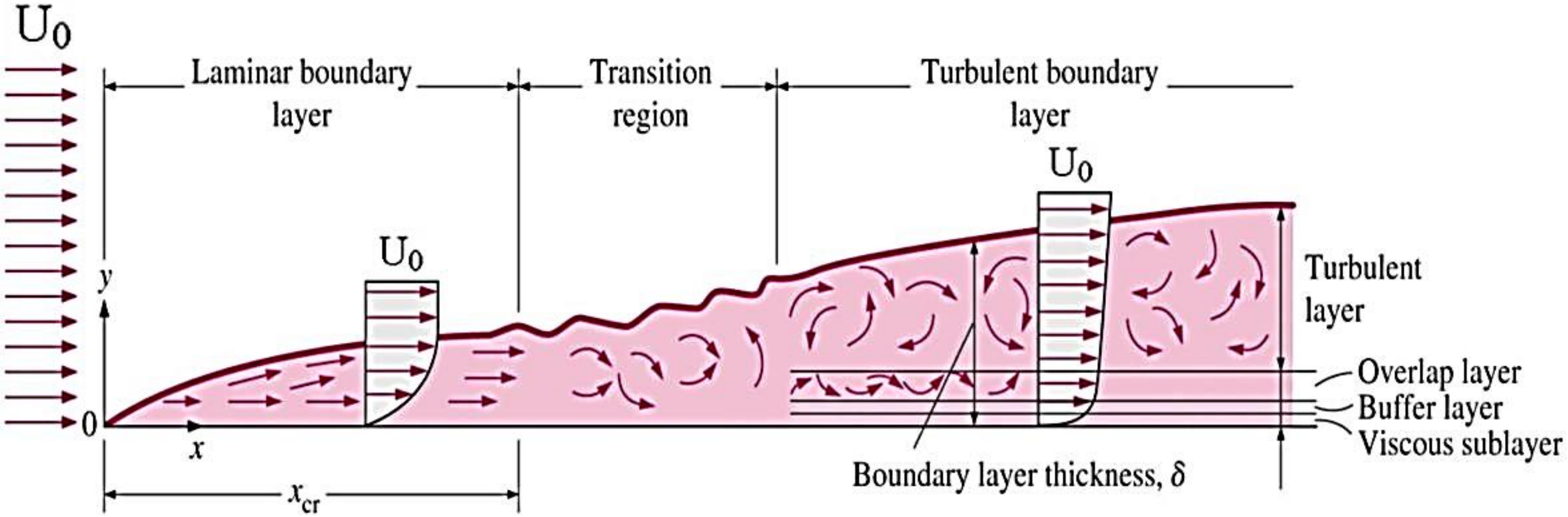
Boundary-layer



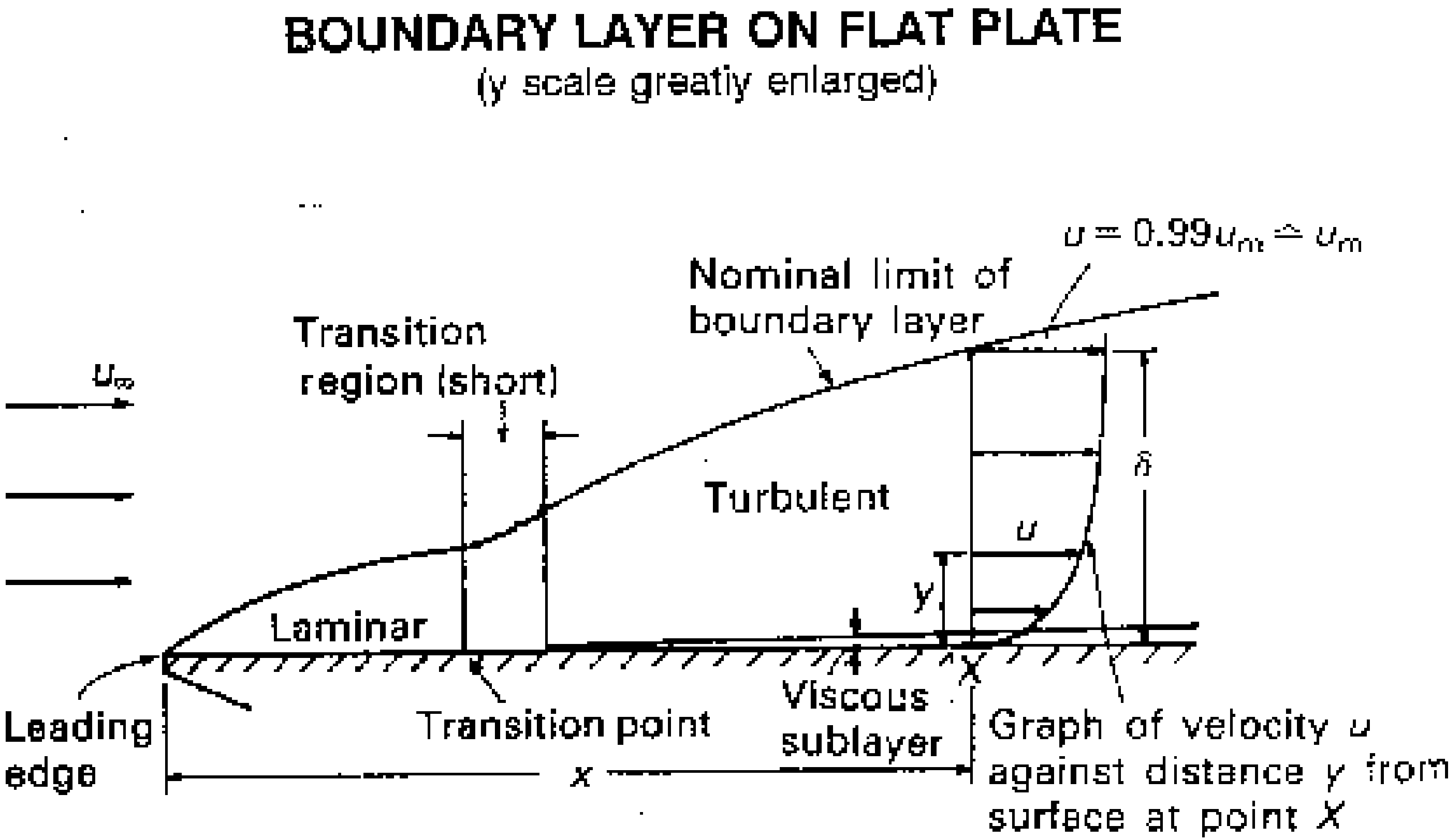
Boundary-layer Concept

Upstream the velocity profile is uniform, (free stream flow) a long way downstream we have the velocity profile as shown in figure. This is the known as fully developed flow. But how do we get to that state?

This region, where there is a velocity profile in the flow due to the shear stress at the wall, we call the boundary layer or is the layer of fluid in the immediate vicinity of a bounding surface where the effects of viscosity are significant. The stages of the formation of the boundary layer are shown in the figure below:



Boundary-layer Concept



Boundary-layer Concept

- We define the thickness of this boundary layer as the distance from the wall to the point where the velocity is 99% of the "free stream" velocity, the velocity in the middle of the pipe or river.
- Boundary layer thickness, δ = distance from wall to point where $u = 0.99\ u_{main\ stream}$
- The value of δ will increase with distance from the point where the fluid first starts to pass over the boundary - the flat plate in our example. It increases to a maximum in fully developed flow.
- Correspondingly, the drag force D on the fluid due to shear stress to at the wall increases from zero at the start of the plate to a maximum in the fully developed flow region where it remains constant. We can calculate the magnitude of the drag force by using the momentum equation.
- Our interest in the boundary layer is that its presence greatly affects the flow through or round an object. So here we will examine some of the phenomena associated with the boundary layer and discuss why these occur.

Boundary-layer Types

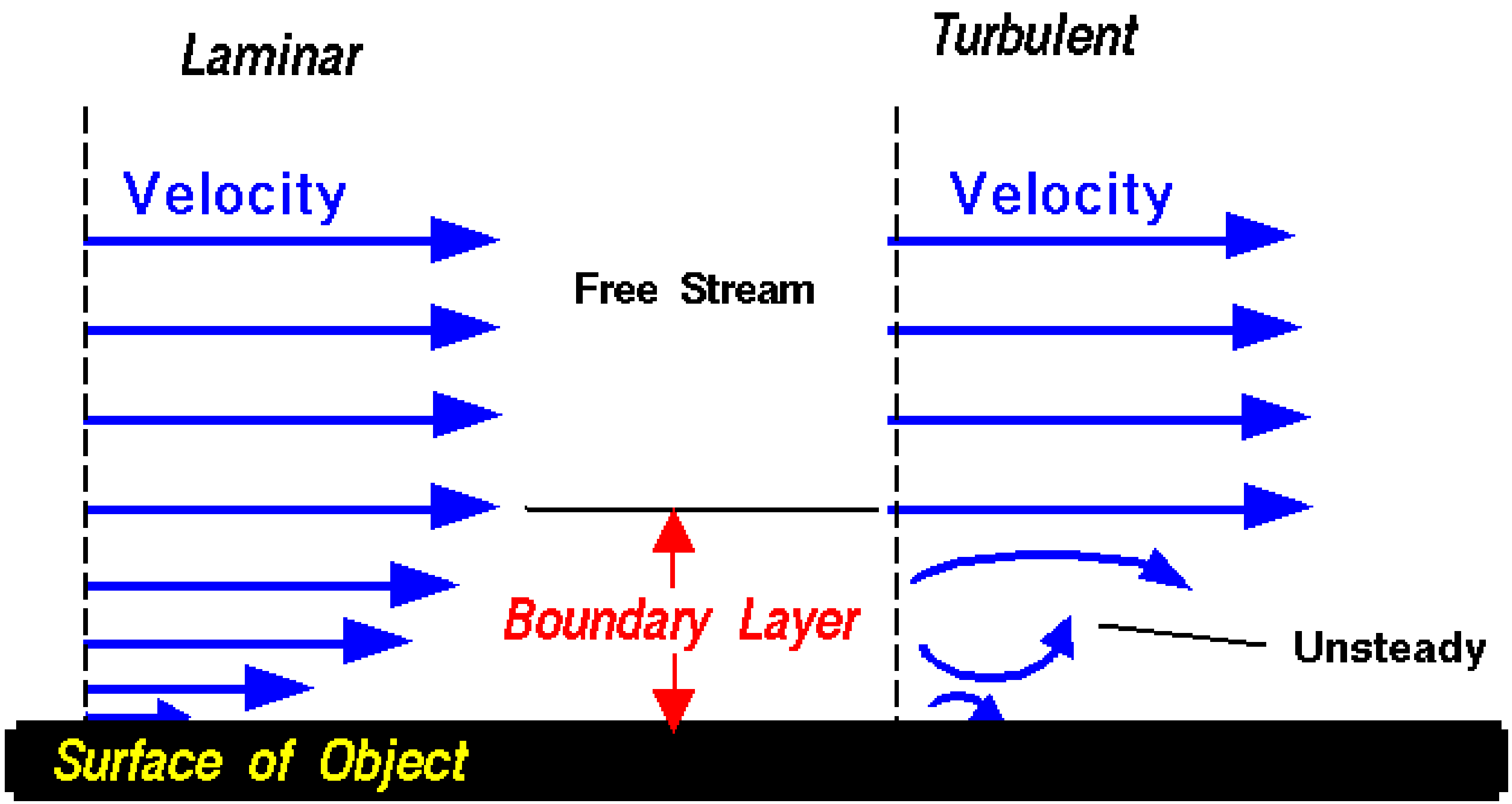
1. Laminar Boundary Layer Flow

The laminar boundary is a very smooth flow, while the turbulent boundary layer contains swirls or "eddies." The laminar flow creates less skin friction drag than the turbulent flow, but is less stable. Boundary layer flow over a wing surface begins as a smooth laminar flow. As the flow continues back from the leading edge, the laminar boundary layer increases in thickness.

2. Turbulent Boundary Layer Flow

At some distance back from the leading edge, the smooth laminar flow breaks down and transitions to a turbulent flow. From a drag standpoint, it is advisable to have the transition from laminar to turbulent flow as far aft on the wing as possible, or have a large amount of the wing surface within the laminar portion of the boundary layer. The low energy laminar flow, however, tends to break down more suddenly than the turbulent layer.

Boundary-layer Types

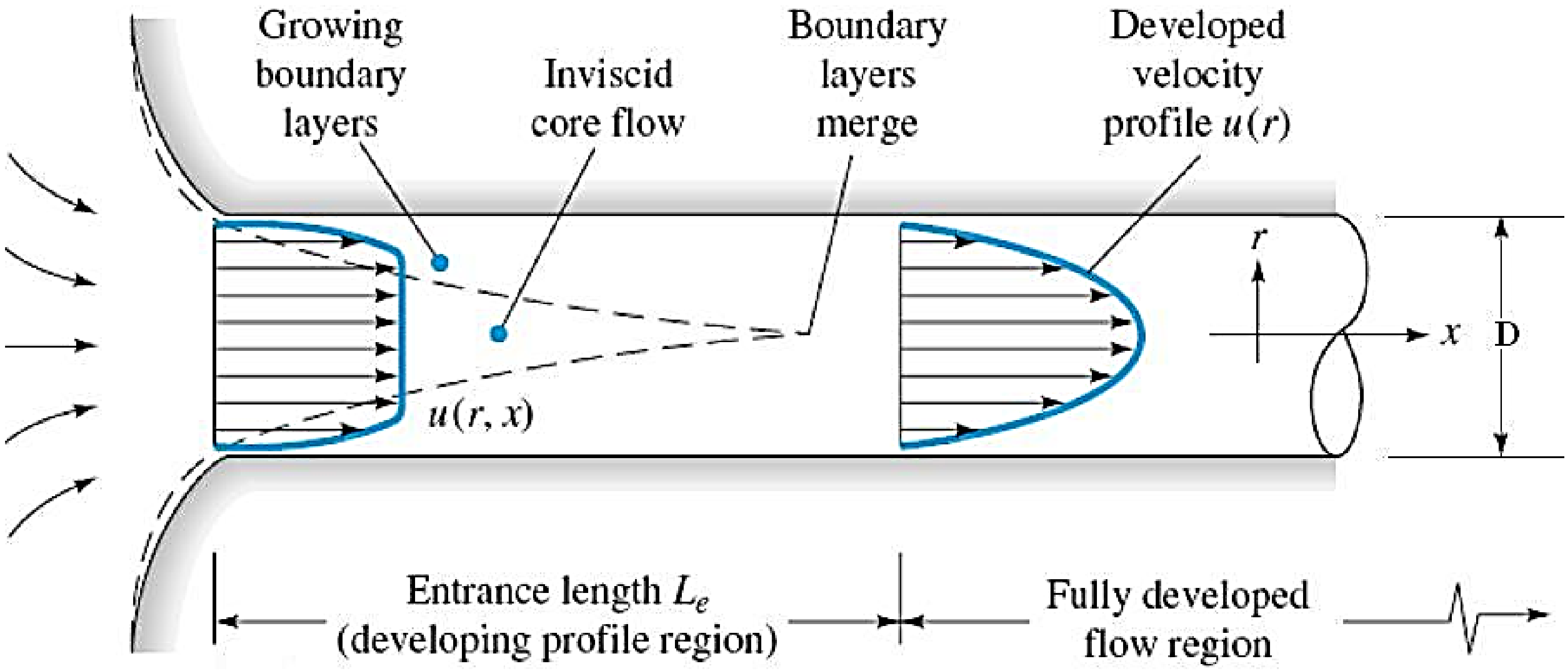


Surface Roughness Effect on Boundary-layer

- In turbulent flow if the height of the roughness of a pipe is greater than the thickness of the laminar sub-layer then this increases the amount of turbulence and energy losses in the flow. If the height of roughness is less than the thickness of the laminar sub-layer the pipe is said to be smooth and it has little effect on the boundary layer.
- In laminar flow the height of roughness has very little effect

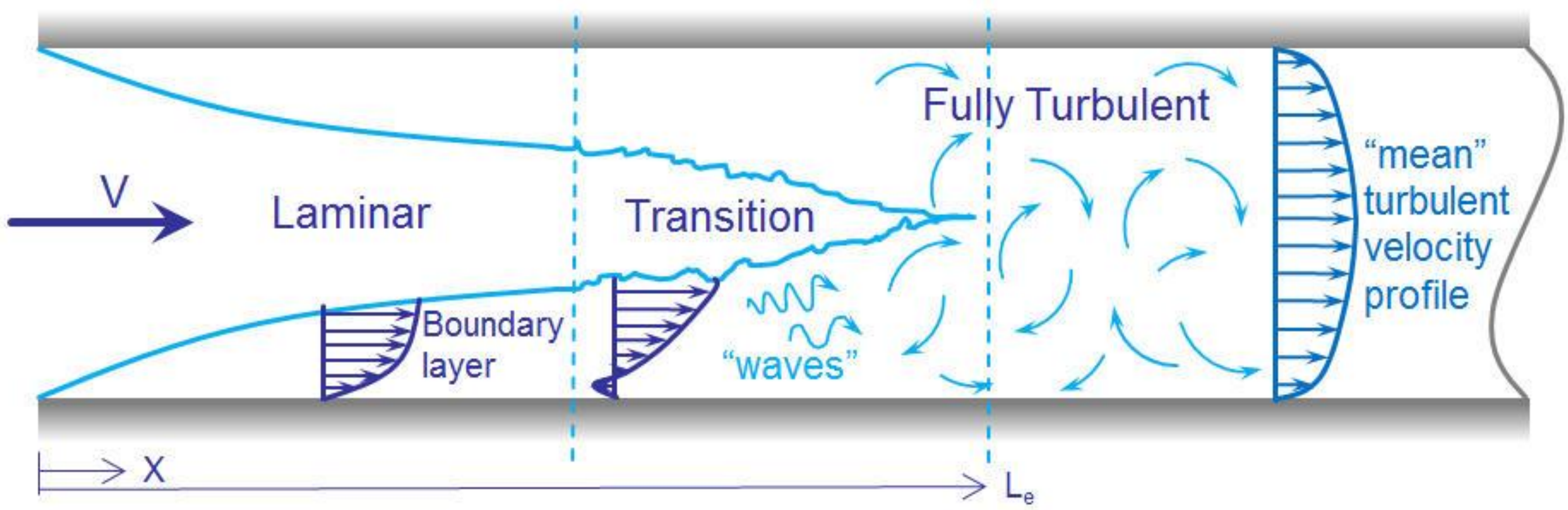
Boundary layers in Pipes

Fully developed laminar parabolic velocity profile



Boundary layers in Pipes

Fully developed turbulent velocity profile



Boundary layers in Pipes

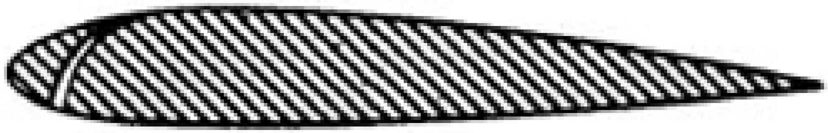
Once the boundary layer has reached the center of the pipe the flow is said to be fully developed. (Note that at this point the whole of the fluid is now affected by the boundary friction)

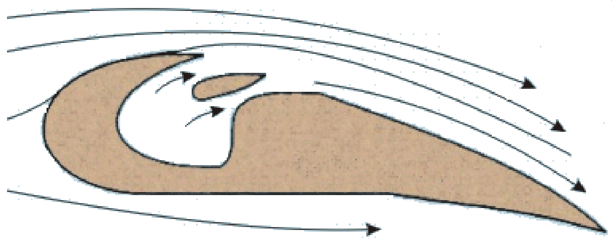
The length of pipe before fully developed flow is achieved is different for the two types of flow. The length is known as the entry length.

- **Laminar flow entry length 120 diameter i.e. $L_e = 120\ D$**
- **Turbulent flow entry length 60 diameter i.e. $L_e = 60\ D$**

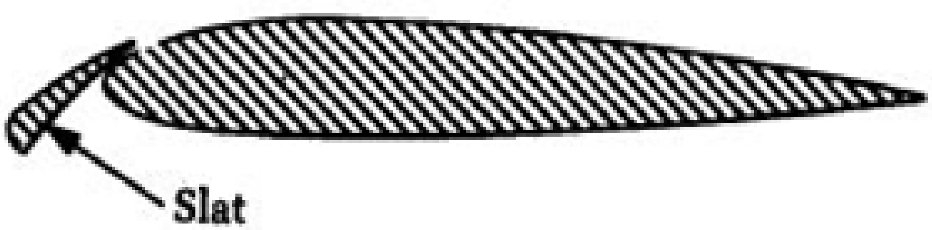
Boundary-layer Control

Fixed slot

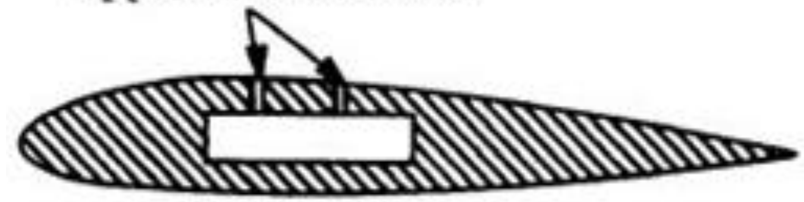


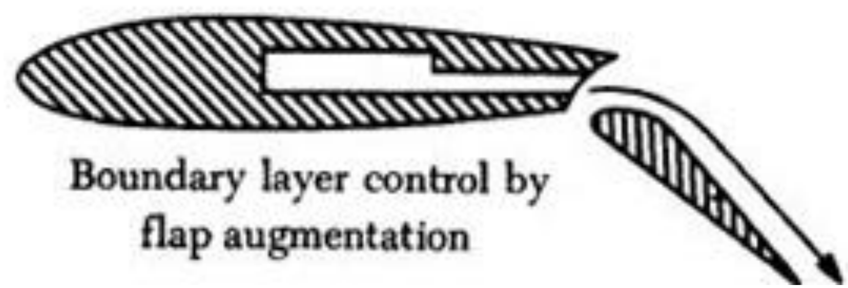


Automatic slot



Boundary layer control by upper surface suction





Thank you