frequency of vortex shedding f.
In non-dimensional form, the vortex shedding frequency is expressed as $\frac{fD}{U_\infty}$, known as the strouhal number.
The strouhal number shows a slight but ~~so~~ continuous variation with Re. around a value of 0.21. At about Re = 500, multiple frequencies starts showing up and the wake tends to become turbulant.

Several Events of Transition :—

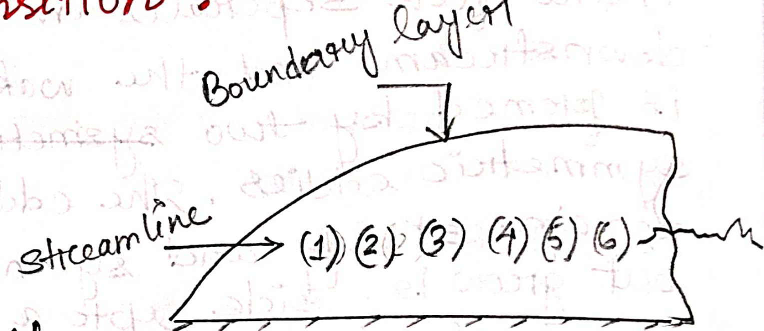

Fig (a) sequence of event involved in transition

1. Region of instability of small wavy disturbances —

Consider a laminar flow over a flat plate aligned with the flow direction :

- In the presence of an adverse pressure gradient, at high Re., two dimensional waves appear.
  These waves are called Tollmien - Schlichting wave.
  These waves can be made visible by a method known as tellurium method.

2. Three dimensional waves and vortex formation —

- Disturbances in the free stream or oscillations in the upstream boundary layer can generate wave growth, which has a variation in the span wise direction.
- This leads an initially two dimensional wave to a three dimensional form.

3. Peak Valley Development with streamwise vortices :—

• As the ~~the~~ three dimensional wave propagates downstream the boundary layer flow develops into a complex streamwise vortex system.

• Within this vortex system, at some spanwise location, the velocities fluctuate violently.

This locations are called peaks and the neighbouring locations of the peaks are valleys.

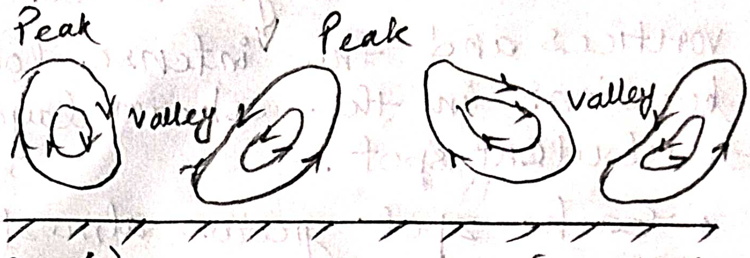

Fig. 6) Cross-stream view of the streamwise vortex system

4. Vorticity concentration and shear layer development :—

At the spanwise locations corresponding to the peak, the instantaneous streamwise velocity profiles demonstrate the following —

• an inflexion is observed on the velocity profile.

• The inflectional profile appears and disappears once after each cycle of the basic wave.

5. Breakdown :—

• The velocity fluctuations develop from the shear layer at a higher frequency and these velocity fluctuations have strong ability to amplify any slight three dimensionality and as a result a ~~stro~~ staggered vortex pattern evolves with the streamwise wavelength twice the wavelength of Tollmien Schlichting wavelength.

• The span wise wavelength of these structures is about one half of the stream wise value.

• The high frequency fluctuations are referred as hairpin eddies.

⟶ This is known as breakdown

6. Turbulent spot development :—

- The hairpin eddies travel at a speed greater than that of the basic waves.
- The ~~vortices~~ eddies spread in the spanwise direction and towards the wall, as they travel ~~downward~~ downstream.
- The vortices begin a cascading breakdown into smaller vortices and the intense local changes occur at random locations in the shear layer near the wall in the form of turbulent spot.
- Each spot grows almost linearly with the downstream distance.

Drag :—

Drag refers to forces that oppose the relative motion of an object through the air. Drag always oppose the motion of the object and it is overcome by thrust.

Form Drag :— It is the drag caused by the seperation of the boundary layer from a surface ~~fluid~~ and the wake created by that seperation. It is primarily dependent upon the shape of the object. It is also known as pressure drag or profile drag.

Skin Friction Drag :— Skin friction drag is a component of parasitic drag, which is resistant force exerted on an object moving in a fluid. Skin friction drag is caused by the viscosity of fluids and is developed from laminar ~~flow~~ drag to turbulent drag as a fluid moves on the surface of an object.