LAB 9 - Flow visualization
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AE351
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- **INTRODUCTION AND THEORY:**

    - ***[NOTE:** experiments and objectives are mentioned after the Intro and Theory**]***

Aerodynamics :

- We have a symmetric airfoil, Cambered Airfoil and cylinder for this experiment. Airfoils are Symmetric and Cylinder is a bluff body .
- We can have a qualitative and quantitative description of the flow over an object. Flow visualization gives us the actual feeling of what is happening on it .

- In this experiment we will be dealing with incompressible flows .

- Pressure drag and Skin Friction Drag are the major components of drag force for an incompressible air flow . For a streamlined object the skin friction drag is going to be more significant than the Pressure Drag. For a bluff body Pressure drag is the most significant part.
- ***Smoke Flow Visualization :*** We are going to inject the Smoke along the streamlines and will see what's happening to it when the flow passes over the object . There are multiple ways to generate smoke. You can have vapors, fumes and can always have mists and these are all called smoke .Smoke comprises any form so that it travels along the stream of the flow . These objects or the traces should be neutrally bent should not create its own flow behavior; it should not change the flow behavior. We have tufts, we have surface visualizations . We have optical visualizations for compressible flows .
- For incompressible flows there are tufts and oil flow visualization technique
- To observe what is happening on the surface of the airfoil we use oil paint flow visualization technique.
- In an inviscid flow, there is no separation of Boundary layer.
- Distance between two streamlines can be considered as a volume flux.
- The wake structure predominantly decides the pressure drag. More area the wake covers, the higher is the pressure drag .
- In Hele Shaw flow we will observe that the flow remains attached at low Re <= 40
    - From 40 <= Re <= 200 we observe that the flow get laminar vortex street
    - From 200 <= Re <= $3*10^5$ we observe a laminar vortex wake

- After this the wake turns turbulent. The wake turning turbulent does not imply that the B/L separation turns turbulent

- **Model Blockage ratio :** Projected area should be <= 5% of the Cross sectional area of the test section of WT [*this is in case of the Subsonic Wind Tunnel*] .
- In supersonic WT you can go to even 20% or 30% Model blockage ratio .
- Maneuverability of the delta wing much higher than the normal airfoil wings .
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- ***EXPERIMENT [A] :*** Smoke Flow visualization using smoke tunnel

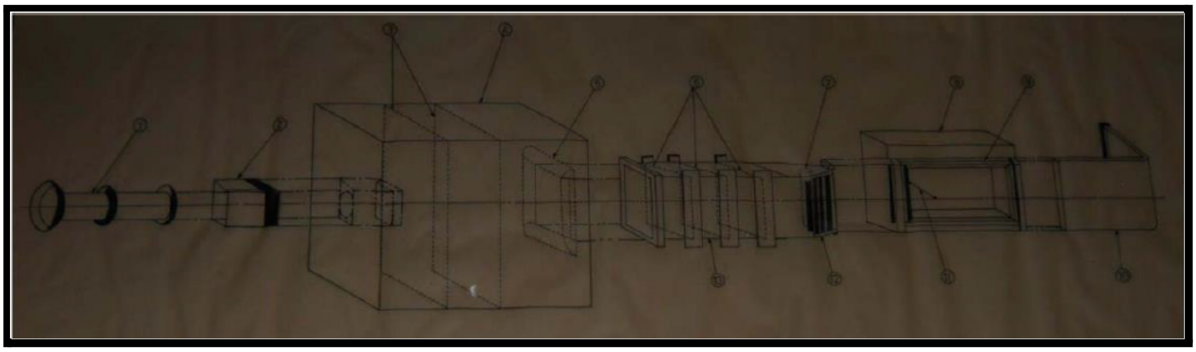
- **OBJECTIVE :** To study the flow patterns over streamlined and bluff bodies

- **EQUIPMENT AND OPERATING CONDITIONS:**

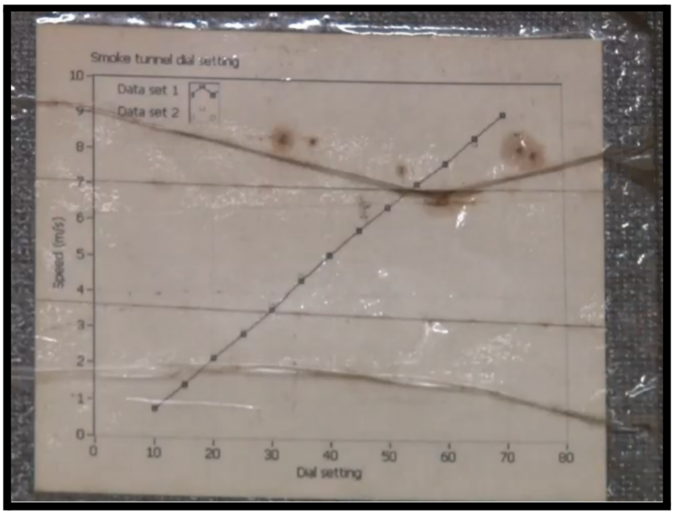
The experimental setup includes:

1. **Smoke tunnel :**
Smoke tunnel is an open-circuit type wind tunnel. The tunnel consists of a fan at the inlet and is followed by a big settling chamber. The large size of the settling chamber is to eliminate the disturbances generated by the fan. The settling chamber is then followed by screens and flows straight to make the flow uniform and further reduce its turbulence level. It is followed by a small diffusion section which connects to the test section.
   - 2D open section WT
   - Honeycomb structure mesh

The air blown has a lot of disturbances to reduce the disturbance. We use a settling chamber. The mesh and honeycomb structure reduces the turbulence. Screen allows the flow to be uniform and the contraction cone reduces the level of turbulence by accelerating the flow .



The Diagram of the Smoke Tunnel



This is the calibration of the dial setting with uniform velocity
We can get a uniform flow at different velocity in the WT using this graph

2. **Smoke Generator:**

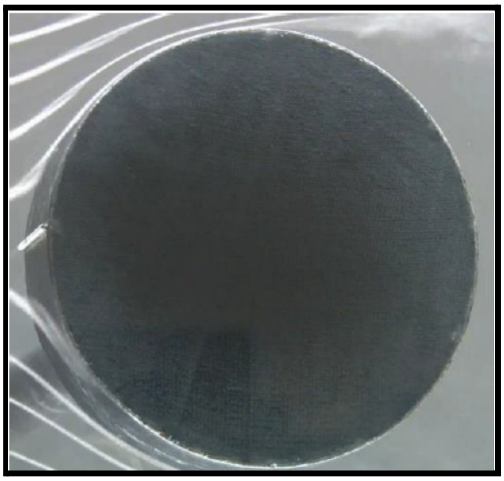
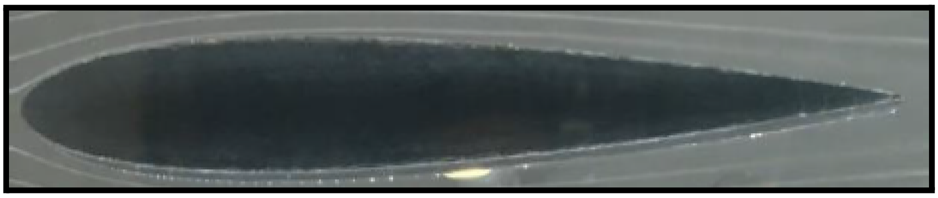
Smoke is generated using a Preston-Sweeting mist generator. It consists of a heating facility where kerosene is heated to a high temperature. The kerosene vapor formed is mixed with the relatively cooler air stream to produce the appropriate mist. To introduce smoke in the flow, a rake is used.

3. **Angle Change Mechanism :**

The mechanism for holding and changing the *Angle of Attack (henceforth AoA)* of the models consist of a hollow rod connected to a gear. The gear is driven by a motor connected to it to change the AoA.

4. **Smoke Rake**
The smoke generated is distributed through a rake which allows the formation of streamlines.

5. **Models :**
Three models are used in the current set of experiments. A circular cylinder, symmetric airfoil and a cambered airfoil.

 Circular Cylinder
 Symmetric Airfoil
 Cambered Airfoil

- **PROCEDURE:**

    1. Mount a model in the test section.
    2. Start the smoke generator after adequate time.
    3. Visualize the flow around the airfoil and photograph the flow.
    4. Change the AoA and visualize the change in flow features.
    5. Visualize the flow patterns for different models

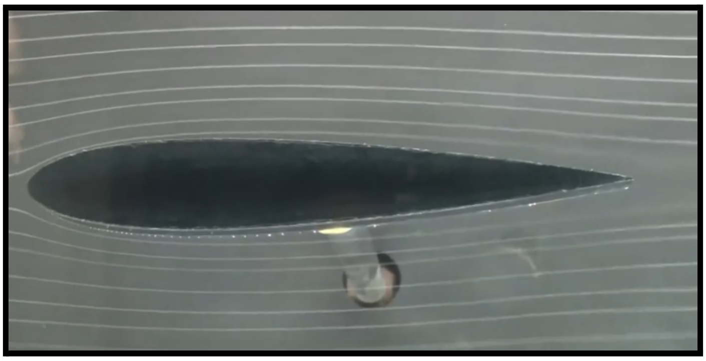
- **RESULTS AND DISCUSSION :**

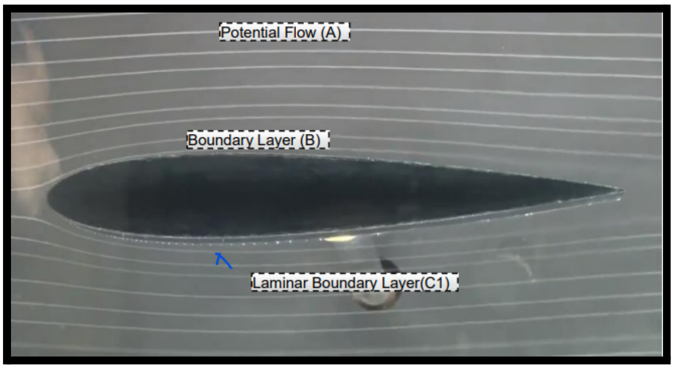
    (a) Observations :

    - Flow will separate at some point at the trailing edge. As one keeps on increasing the AoA the flow separation point keeps on moving upstream of the body. At higher AoA even a streamlined object can behave as a bluff body object.

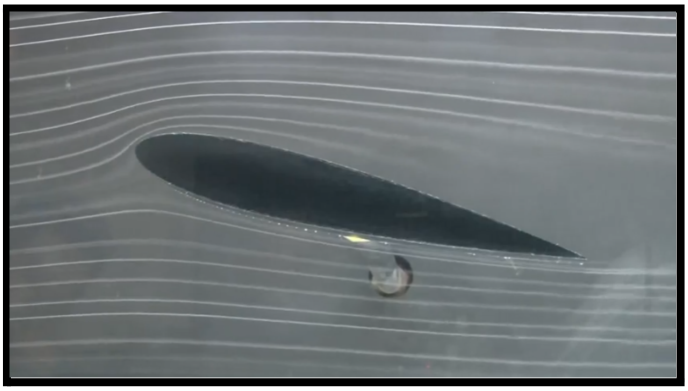
For a Symmetric Airfoil:

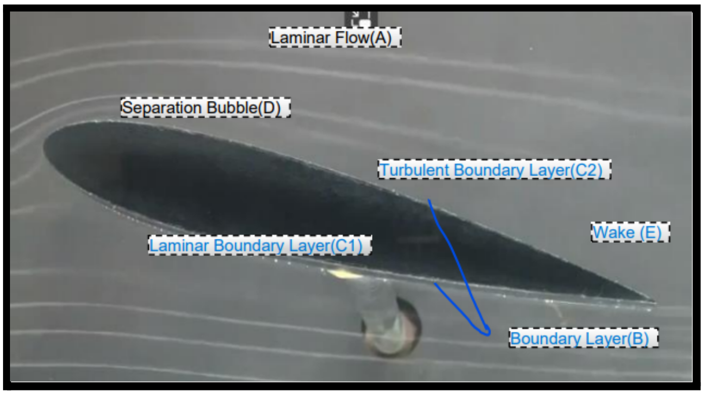
- *At 0° AoA, the flow is potential flow. There is no separation and the stagnation point is on the leading edge. The boundary layer is attached and laminar with no wake.*





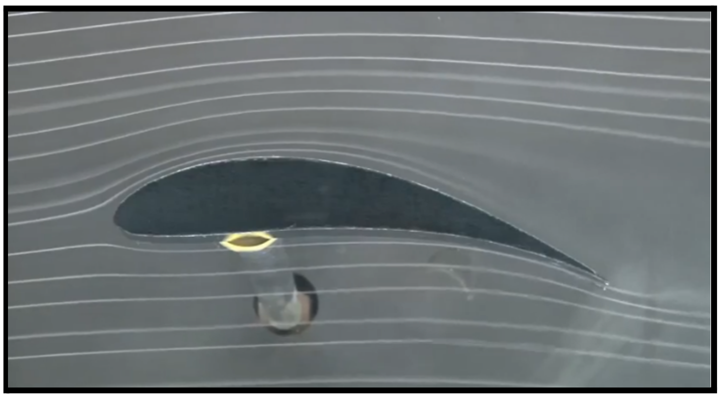
- *At about 15° AoA: The flow is not potential and gets separated at the upper side but stays attached at the lower side. The stagnation points shift slightly below the leading edge. There is a wake region formed and small vortices are seen at the end both of which get stronger and larger as AoA increases. There is laminar separation.*

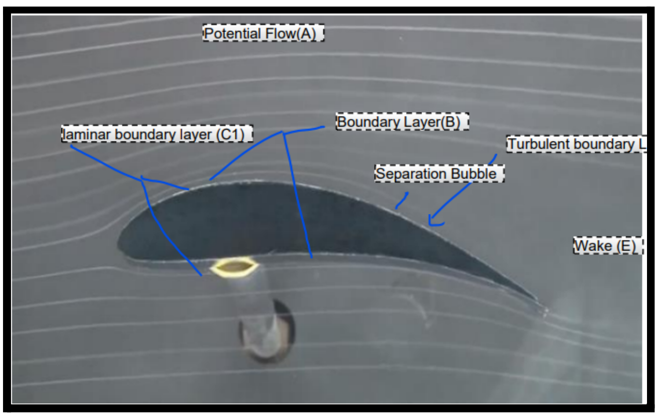




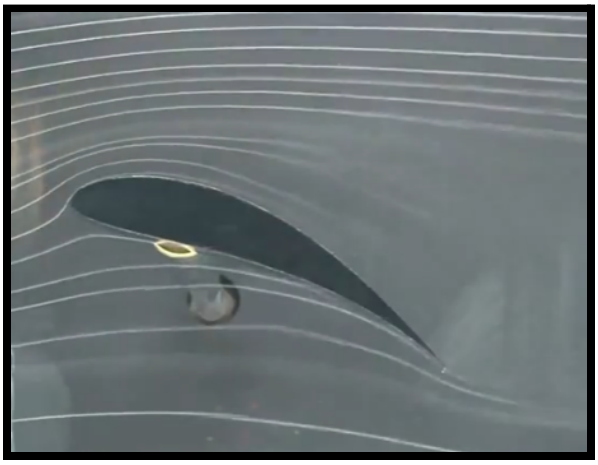
For Cambered Airfoil:

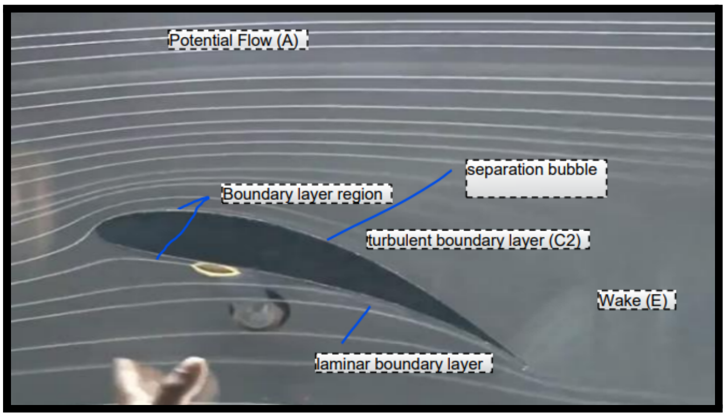
- *Flow separates much earlier than a symmetric airfoil, we see in this case that there is separation even at 0°, The flow is not potential. The separation point is on the upper side of the airfoil and the stagnation point is almost at the tip. A small wake area is formed with unsteady flow.*



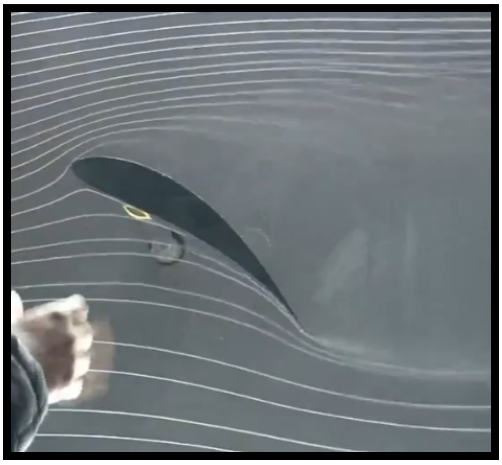


- *At higher angles of attack: Separation point moves ahead. The stagnation point moves below the leading edge of the airfoil. The size of the wake increases and small vortices can be seen. The wake is still laminar.*





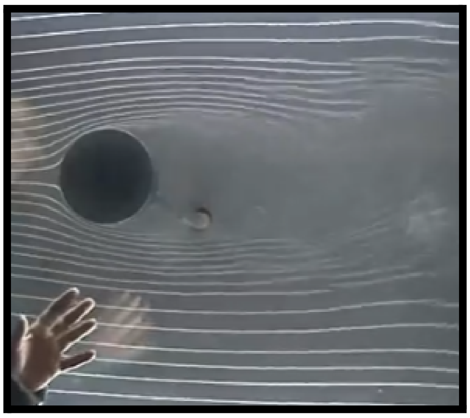
- *At an even higher AoA. The stagnation point starts oscillating below the nose of the airfoil. The flow becomes unsteady and the boundary layer past the separation is clearly turbulent. The size of the wake increases and vortex shedding also increases and becomes unsteady. The back pressure starts affecting the flow ahead of the airfoil. It acts more like a bluff body.* On increasing the AoA the separation point moves upstream

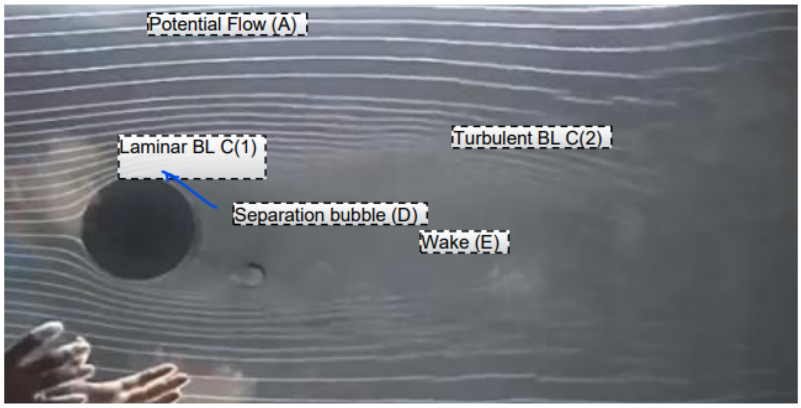


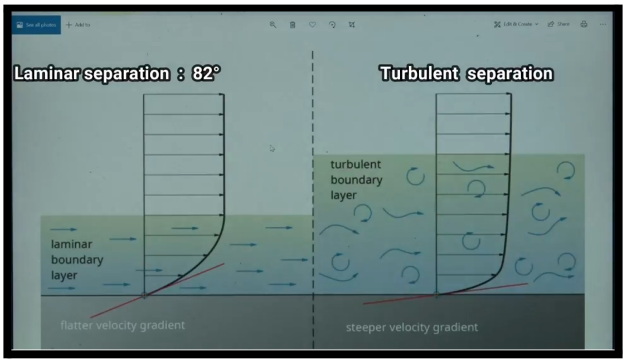
- *At higher AoA the Stagnation point becomes unstable and the flow separation occurs very close to the nose of the airfoil.*
- *The separation takes place because of adverse Pressure Gradient. Turbulent Boundary layer can withstand the adverse pressure grad better than the laminar B/L that's why the turbulent boundary layer separates later.*

For Cylinder (Bluff-body):

- *Boundary Layer separation at about 82° and laminar at both sides from stagnation point (at 0°). Laminar Vortex wakes after separation. Vortex Shedding in the wake. The wake size is larger than the previously tested airfoils. Large vortices are observed. At higher speeds and AoA the trip side flow becomes turbulent.*







(b) Sources of Error:

1. Do not exceed the pressure limits of the settling chamber.
2. Make sure that there are no loose parts and there are no objects placed inside the duct.
3. Make sure that the pressure ports are not blocked by dust or any other materials.
4. Always turn off the tunnel before opening the test section for model removal or mounting.
5. Keep the room well ventilated while running the smoke-generator.

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- ***EXPERIMENT [B] :*** 2-D Dye Flow visualization using Hele-Shaw Apparatus

- **OBJECTIVE :** To study the potential flow patterns over streamlined and bluff bodies

- **EQUIPMENT AND OPERATING CONDITIONS:**

The experimental setup includes:

1. **Hele-Shaw Apparatus :** Hele-Shaw flow is defined as Stokes flow between two parallel flat plates separated by an infinitesimally small gap, named after Henry Selby Hele-Shaw, who studied the problem in 1898. The Hele-Shaw apparatus produces streamlines in a laminar, steady flow. The equipment consists of a channel formed between two glass plates. Water flows along the channel at a low Reynolds number. Two separate tanks are available at the top of the apparatus where water and die can be stored separately. Tiny holes at the bottom of the tank allows the dye to flow down through the channel forming streamlines. The fluid can be poured out of the apparatus with the help of the value and pipe connection. The dimensions of this apparatus is dimensions $2mm$ × 85mm × 100mm.
Flow in Hele Shaw Apparatus is Primarily because of gravity .

2. **Dye and water:** Potassium permanganate (KMnO4) is used as the dye

3. **Beakers :** Beakers are used to fill and collect the fluid from the apparatus

4. **Models :** Thin plastic models of various shapes including: 2D Circular cylinder, Symmetric airfoil and Cambered airfoil.

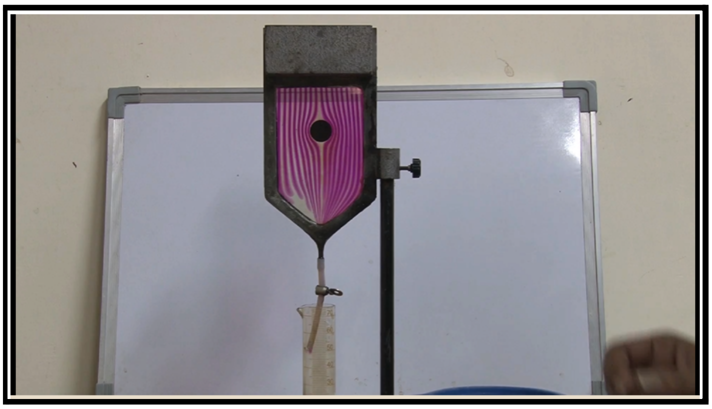
- **PROCEDURE:**

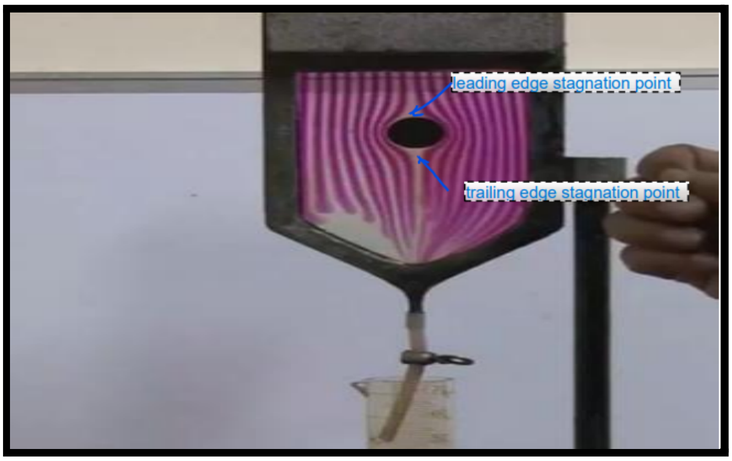
1. Place the model in the test section as required.
2. Fill water in the reservoir.
3. Once the channel is filled with water with no bubble formation inside the channel, pour dye in the reservoir.
4. Open the valve at the bottom as required to allow dye to form streamlines.
5. Observe the flow around the model.
6. Repeat the process with different flow rates and models
7. Clean the apparatus after completing the experiments.

- **RESULTS AND DISCUSSION :**

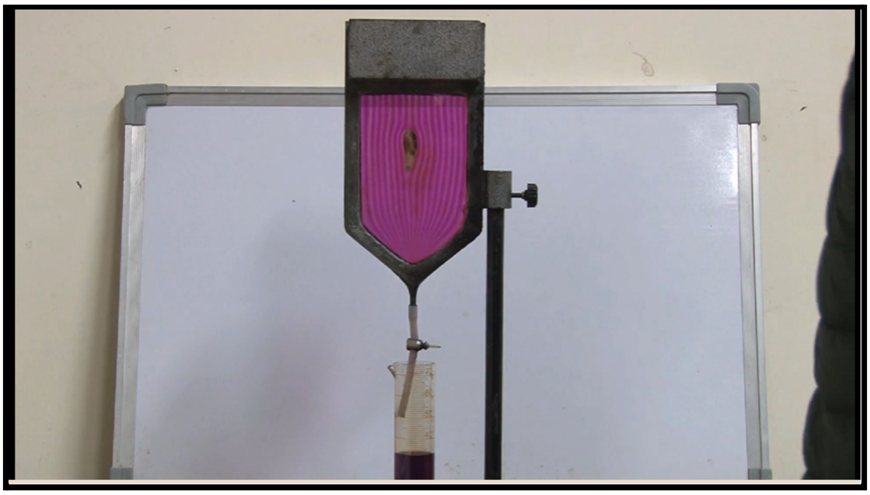
(a) observation

- Highly viscous flow gives a very low Reynolds number and potential flow or Stokes flow solution, there is no flow separation and the flow is attached and Kutta Condition is applicable. The flow is completely laminar. There is no vortex shedding.

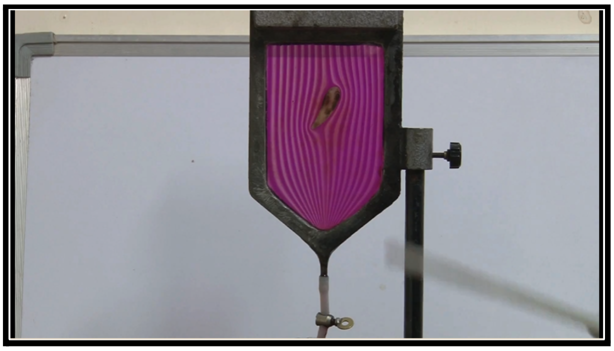


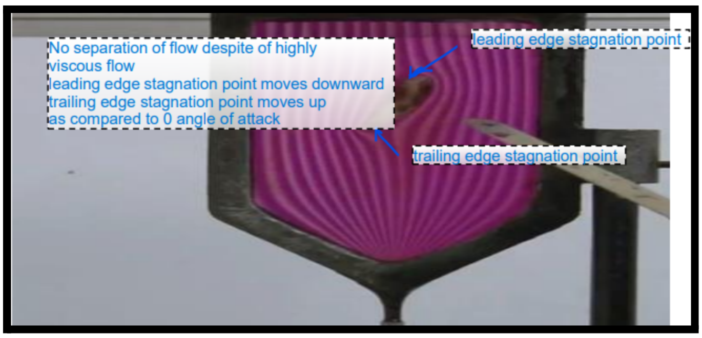


- The stagnation points are at the leading and trailing edge at zero degree AoA.



- The stagnation points are below the leading edge and upstream the trailing edge at a finite positive AoA.





Sources of Error:

1. Make sure that the Hele Shaw apparatus is kept in a disturbance free environment as the Steadiness of flow can be affected by even small perturbations .
2. The dye , Kmno4 should be kept away from the Sun, in a dark chamber otherwise it will oxidize.

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- ***EXPERIMENT [C] :*** 3-D Flow visualization over a Delta Wing
- **OBJECTIVE :** Observe the vortex pair formed on top of the delta wing, and study their breakdown
- **EQUIPMENT AND OPERATING CONDITIONS:**

The experimental setup includes:

1. **Low speed wind tunnel :** The specifications of the low speed wind tunnel are:
The fan is equipped with a variable speed control.

Sl. No.	Property	Measurement
1	Type	Open - Return Suction type
2	No. of Screenings in the settling chambers	6
3	Contraction ratio	16:1
4	Test section dimension	0.6 m X 0.6m X 3m
5	Max. Velocity	~ 25m/s
6	Motor	20 Hp AC

2. **Delta wing (model) :** When a slender delta wing with a sharp leading edge is at a moderate AoA, a vortex pair is generated on top of the delta wing. This happens due to the separation of the flow along the leading edge of the delta wing forming a separated shear layer. This shear layer rolls up to form a counter rotating vortex pair which moves past the top surface of the wing. The formation of these vortices delays the stall which happens at a relatively high angle.

3. **Laser :** For flow illumination a continuous low power green laser is used.

4. **Smoke Generator:** For flow seeding a kerosene based smoke generator is used

- **PROCEDURE:**

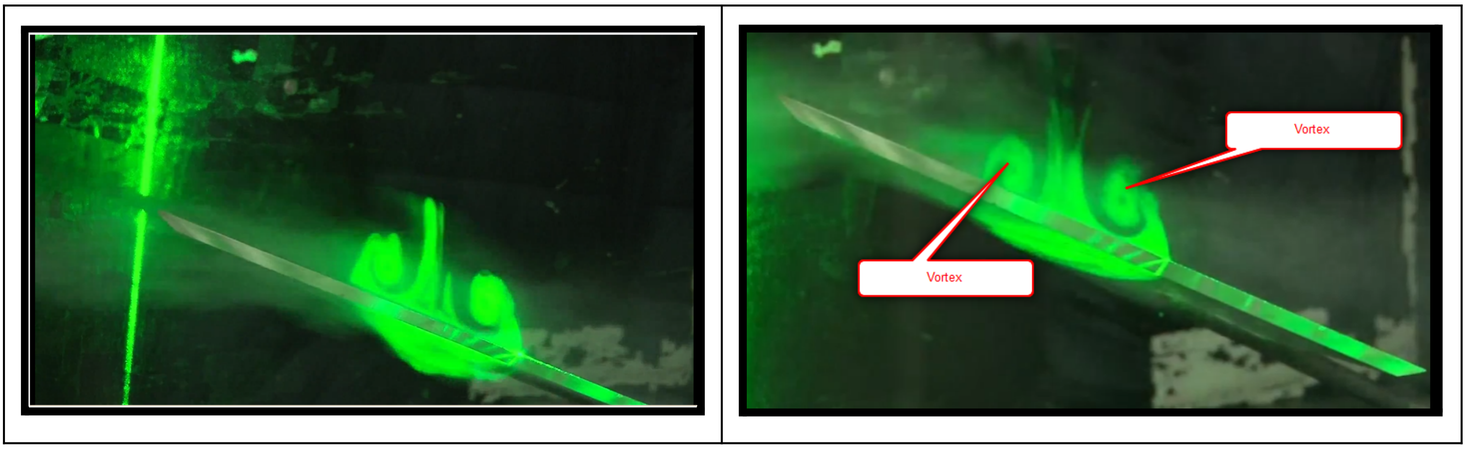
    1. Mount the delta wing for flow visualization in the test section.
    2. Start the tunnel, smoke generator and laser for illumination. Observe the vortices formed at different angles of attack.
    3. Observe the Vortices formed at different angles of attack.

- **RESULTS AND DISCUSSION :**

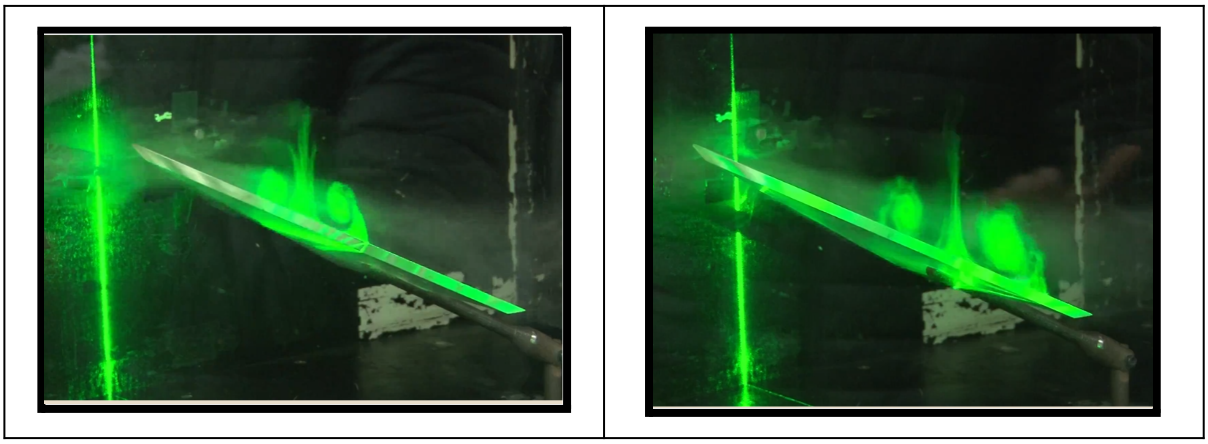
(a) Observation

The Delta Wing has variable chord .
The formation of trailing edge vortices is observed .
The laser beam enhances the visibility of vortices.

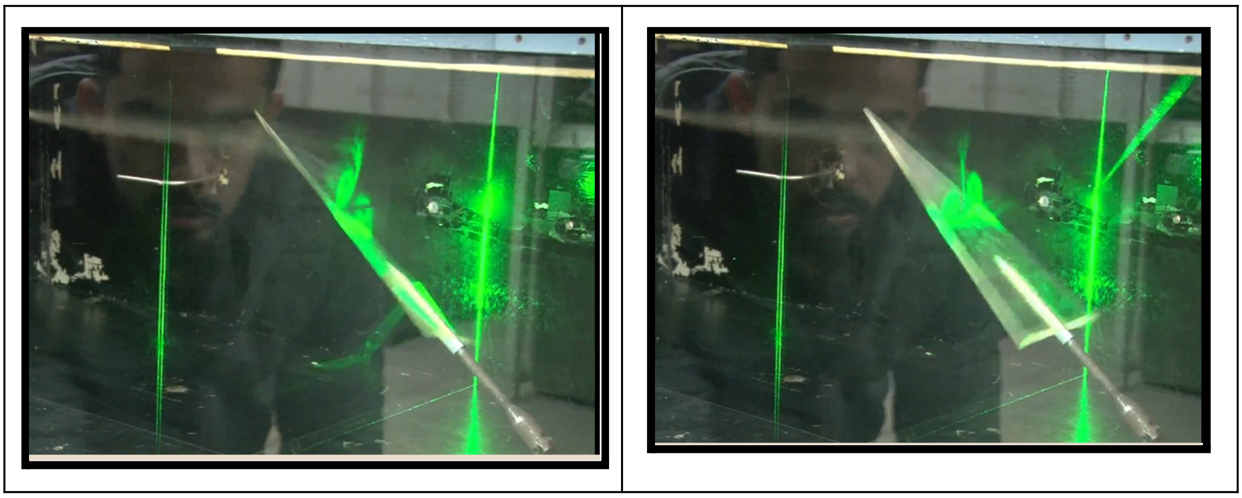
- *On varying the AoA, the size-variation of the vortex changes.*
- *As the AoA is increased vortex breakdown happens at much upstream direction. Primary Vortices keep on growing and finally vortex breakdown happens .*



- ***On moving towards the trailing side of the wing, vortex size increases****. A small vortex also can be observed below the big one which turns the flow in an anticlockwise direction*.



- *When external disturbances are introduced, the wing model of the lower aspect-ratio starts to oscillate [**Wing Rocking**]. There is Unsteady Vortex shedding . This happens due to the formation of vortices such that the lift coefficient varies along the span of the model, causing the change in strength of the vortex and vice versa.*



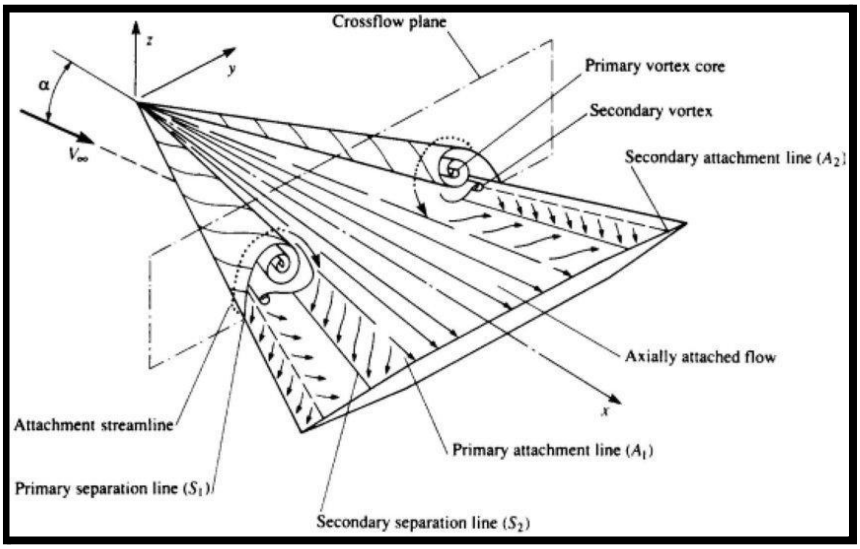
Sources of Error:

1. Follow the safety instructions while running the laser.
2. Do not stand in the laser light path.
3. Make sure that the laser light reflected back from the wing surface does not hit any person visualizing the flow.
4. Always turn off the tunnel before opening the test section for model removal or mounting.
5. Keep the room well ventilated while running the smoke-generator.

Self-assessment questions :

1. What is the effect of the sharp leading edge of the delta wing?

- Wind-tunnel studies of sharp-leading-edge delta wings have shown that even at relatively low angles of attack the flow separates from the leading edges and rolls up into two vortex sheets or cone-shaped cores of rotating fluid. This sharp leading edge facilitates the formation of vortices.



2. Does the vortex pair always remain symmetric with increasing AoA?

- Yes, it remains symmetric as long as there is no other external disturbance introduced in the system.

3. What are the advantages due to the lee side vortices of a delta wing?
- The vortices produce vortex lift, so flow separation can be turned into a means of increasing lift. This also results in the ability of the delta wing to fly at much higher AoA than conventional wings, thus increasing the maneuverability of the aircraft giving huge potentials in military aircrafts.

4. What is vortex breakdown or bursting?

- Breakdown, or "bursting" occurs due to an increase in vortex diameter of the primary vortex as it travels downstream of the delta wing. It is followed by large-scale turbulence dissipation, and a decrease in axial and circumferential velocity.

5. How does it affect the performance of a delta wing aircraft?

- Due to vortex breakdown on one side of the wing because of disturbances it loses lift on that side. The other side tries to move up and then vortex breakdown occurs on that side. As a result the delta wing oscillates about its axis making the wing unstable. The frequency of oscillation increases as the flow velocity or AoA is increased.
- Delta wing performance is limited by **vortex breakdown**. It leads to a loss of lift and a reduction in the magnitude of the nose down pitching moment which again makes the aircraft unstable.

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- **References:**

1. Pictures and descriptions from Google, Lectures and Lecture Notes of AE351 (Lab9)
2. - Payne, Ng, Nelson, and Schiff, “Visualization and wake surveys of vertical flow over a delta wing”, AIAA Journal, Vol. 26, No. 2, 1988, pp. 137--143.

- Josef Rom, “High angle of attack Aerodynamics”, Springer-Verlag.
- Kuchemann, “The Aerodynamic Design of Aircraft”, American Institute of Aeronautics & Astronautics, 2012.