Smoke Flow Visualization Over Streamlined and Bluff Bodies

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Dye Flow Visualization over Streamlined and Bluff Bodies in Hele-Shaw Apparatus

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1(b) Dye Flow Visualization over Streamlined and Bluff Bodies in Hele-Shaw Apparatus

OBJECTIVE

- To study the potential flow patterns over streamlined and bluff bodies.
- To find the Reynolds number (Re) of the flow.

INTRODUCTION AND THEORY

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 governing equation of Hele-Shaw flows is identical to that of the inviscid potential flow. It thus permits visualization of this kind of flow in two dimensions.
Hele-Shaw apparatus produces streamlines in a laminar, steady flow. It allows one to study various source and sink arrangements, and look at flow around an unlimited variety of different shaped models. A dye flowing through several small holes at the upstream end produces streamlines.

Cross-Section = 2 x 85 = 170 mm^2
Dye used: $KMnO_4$ (Pink)
Density of water: 1g/cm^3 (assumed)
Viscosity of water: 0.89 cP(25°C) (assumed)

Flow passing through this tube is collected in a volume measuring cup. A stopwatch is used to measure time to collect a certain volume of fluid mixture to calculate the flow speed.

EQUIPEMENTS

Hele-Shaw Apparatus, a Dye, water, a stopwatch, a volume measuring cup and some bluff & streamline bodies (of appropriate thickness).

PROCEDURE

- Clean the apparatus.
- Place the model in the test section as required.
- Fill dye and liquid in the reservoir.
- Open the tap at the bottom as required.
- Observe the flow around the model and take images.
- Measure the volume flow rate and find the Reynolds number.
- Repeat the process with different flow rates and models.

OBSERVATIONS

Cross Section Area between the glass (A) = 170 mm^2

A Cambered airfoil with non-zero angle of attack (Streamline Body)

Volume Collected (V) = 10 mL
Time Taken (T) = 26.7 seconds
Chord Length (d) = 35.55 mm

Q = V/T = 3.745×10^{-7} m^3s^{-1}

Velocity: v = Q/A = 2.2×10^{-3} ms^{-1}

$$Re = \frac{\rho v d}{\mu}$$

= (1000) x (2.2 x 10^{-3}) x (0.0355) / (8.9 x 10^{-4})
= **87.87**

A Cambered airfoil with (approx.) zero angle of attack (Streamline Body)

Volume Collected (V) = 20.3 mL
Time Taken (T) = 45.1 seconds
Chord Length (d) = 35.55 mm

Q = V/T = 4.501×10^{-7} m^3s^{-1}

Velocity: v = Q/A = 2.65×10^{-3} ms^{-1}

$$Re = \frac{\rho v d}{\mu}$$

= (1000) x (2.65 x 10^{-3}) x (0.0355) / (8.9 x 10^{-4})
= **105.85**

A spherical body (Bluff Body)

Volume Collected (V) = 10 mL
Time Taken (T) = 44.1 seconds
Diameter (d) = 21.78 mm

Q = V/T = 2.267×10^{-7} m^3s^{-1}

Velocity: v = Q/A = 1.33×10^{-3} ms^{-1}

$$Re = \frac{\rho v d}{\mu}$$

= $(1000) \times (1.33 \times 10^{-3}) \times (0.02178) / (8.9\times10^{-4})$
= **32.55**

A long cylinder shape (Streamline Body)

Volume Collected (V) = 10 mL
Time Taken (T) = 12.14 seconds
Length (d) = 42.05 mm

Q = V/T = 8.237×10^{-7} m^3s^{-1}

Velocity: v = Q/A = 4.85×10^{-3} ms^{-1}

$$Re = \frac{\rho v d}{\mu}$$

= $(1000) \times (4.85 \times 10^{-3}) \times (0.04205)/(8.9\times10^{-4})$
= **229.15**

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Previous Body Rotated by 90° (Bluff Body)

Volume Collected (V) = 10 mL
Time Taken (T) = 25.13 seconds
Thickness (d) = 9.57 cm

Q = V/T = 3.979×10^{-7} m^3s^{-1}

Velocity: v = Q/A = 2.34×10^{-3} ms^{-1}

$$Re = \frac{\rho v d}{\mu}$$

= (1000) x (2.34×10^{-3}) x (0.00957) / (8.9×10^{-4})
= **25.16**

DISCUSSION

- **Discuss the effect of Re on flow pattern.**
  Reynolds number is very low for each of these cases implying flow similar to potential flows even though the flow is highly viscous in nature.

- **Explain why such low Re flow pattern resembles potential flow pattern.**
  When we are approximating a flow to be a potential flow, we want our flow to be irrotational. **Low Reynolds Number corresponds to low flow speed and higher viscous forces.** So, if our flow speed is low and viscous forces are high, flow separation will be negligible, which implies there will be no wake region, which means there will be no vortex formation. This is the only region where vortex can develop and since there is no vortex formation, flow is irrotational.

$$R = \frac{vr\rho}{\eta} \qquad \frac{\text{Inertial Forces}}{\text{Viscous forces}}$$

PRECAUTIONS

- Make sure the apparatus is clean.
- Take repeated reading of volume flow rate for sufficient time.
- Make sure dye is cleaned after use.
- Don’t let the solution flow too fast, otherwise streamline will not be clearly visible.

1(a) Flow visualization over Streamlined and Bluff Bodies

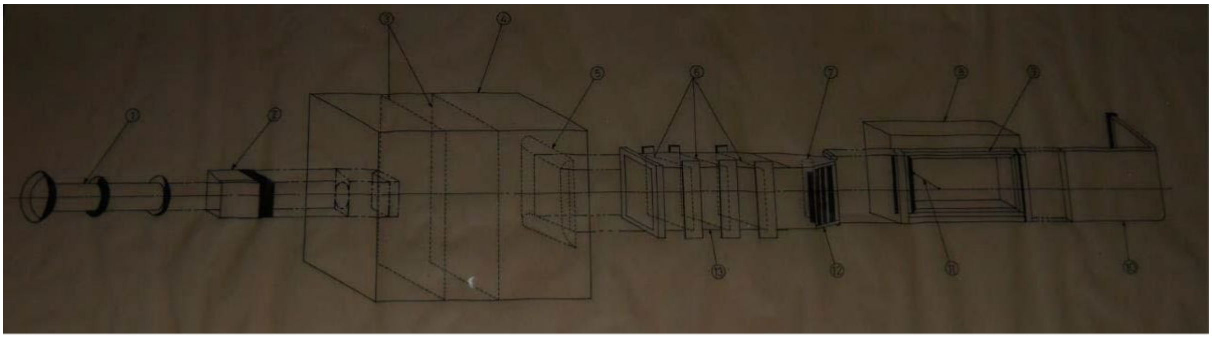
OBJECTIVE

To study the flow patterns over streamlined and bluff bodies.

INTRODUCTION AND THEORY

SMOKE TUNNEL

It 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 kill the disturbances generated by the fan. The settling chamber is then followed by some honeycomb like screens to make the flow uniform and laminar. It is followed by a small diffusion section which connects to the test section to increase the flow speed.
The test section has a very small width in which the models are mounted on a pipe which can be rotated using the motor connected to it to change the angle of attack of the model. Smoke enters the test section from small pores, so they flow in a streamline.



SMOKE GENERATOR

Smoke generator is a machine that heats a fuel (Kerosene in our experiment) for producing smoke which is stored in a glass jar and then transferred in the test section from small pores in the wind tunnel. Smoke helps in better visualisation of the flow pattern over Streamlined and Buffed bodies.

The specifications of the low speed wind tunnel are

S. No.	Property	Measurement
1	Type	Open – Return Suction Type
2	No. Of Screenings in the settling chamber	6
3	Contraction ratio	16:1
4	Test section dimensions	0.6 m X 0.6 m X 3 m
5	Max. Velocity	~ 25 m/s
6	Motor	20 Hp AC

(I got the specification of the smoke machine from another experiment to “**Visualize flow over Delta Wing**” which uses same smoke machine)

ANGLE CHANGING MECHANISM

The mechanism for holding and changing the angle of attack 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 angle of attack.

DIGITAL INCILNATOR

Inclinometers, also called tilt sensor, clinometers or slope sensors, are designed to measure the angle of an object with respect to the force of gravity. This is done by means of an accelerometer, which monitors the effect of gravity on a tiny mass suspended in an elastic support structure. When the device tilts, this mass will move slightly, causing a change of capacitance between the mass and the supporting structure. The tilt angle is calculated from the measured capacitances.

EQUIPEMENTS

- Smoke Tunnel
- Smoke generating machine
- an angle changing mechanism
- angle measuring device (Digital Inclinator)
- some buffed and streamlined models.

PROCEDURE

- Mount a model in the test section.
- Start the smoke generator after adequate time.
- Visualize the flow around the airfoil and photograph the flow.
- Change the angle of attack and visualize the change in flow features.
- Visualize the flow patterns for different models.

OBSERVATIONS

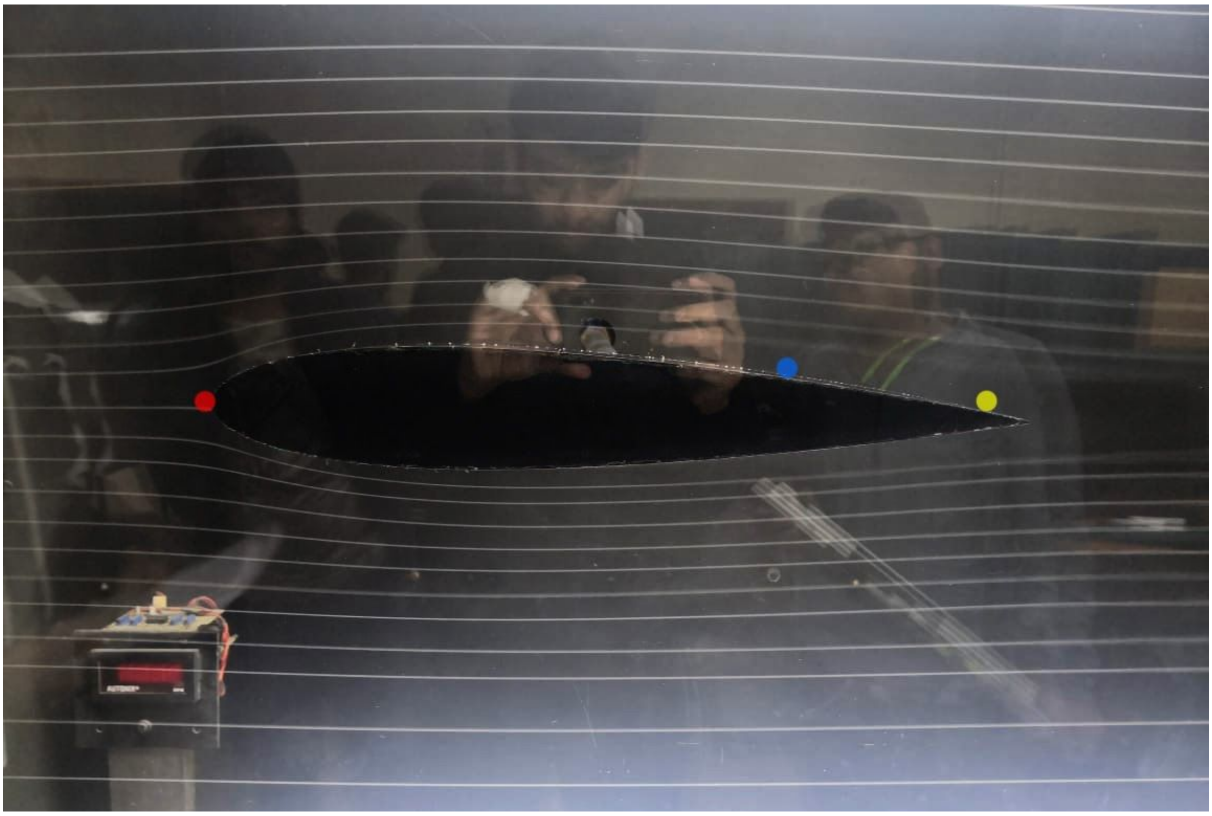
Images presented below are marked with RED and BLUE dots to observe the position of stagnation point and point where flow separates from the body to analyse the flow.

-------> Primary Stagnation Point

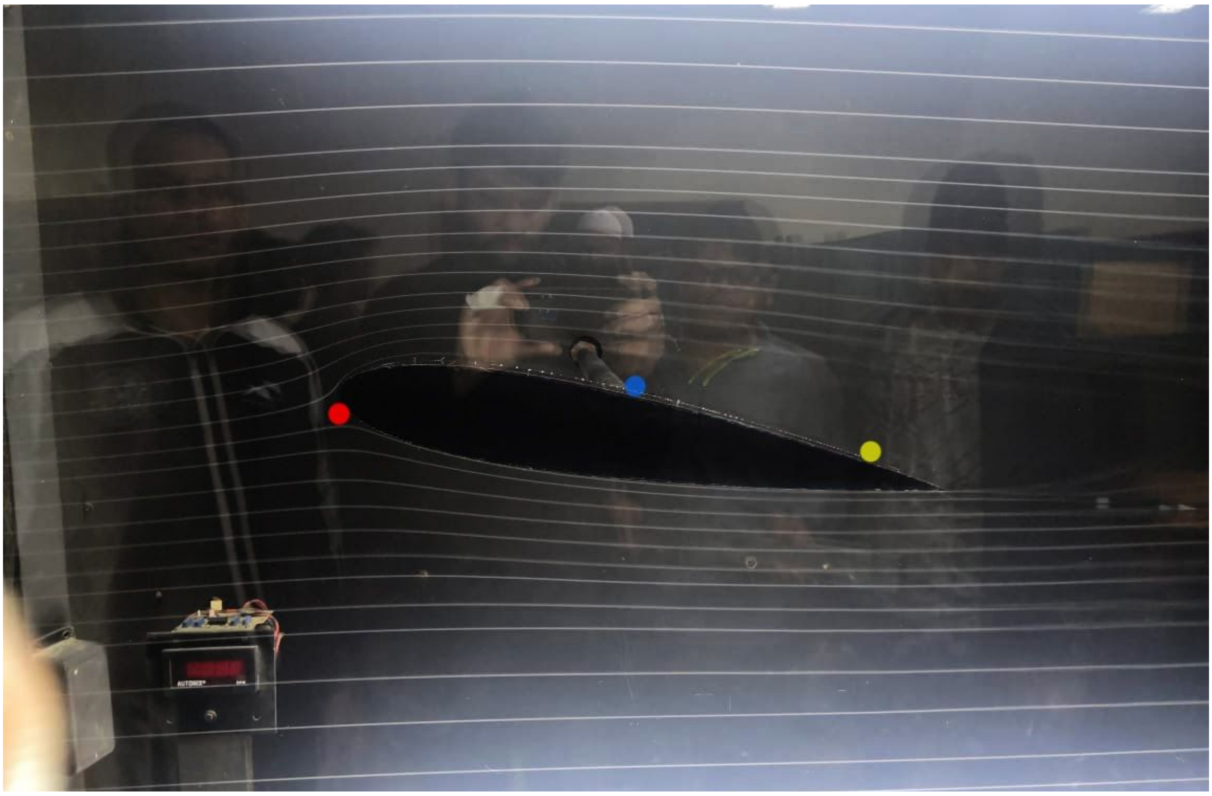
-------> Point where flow separates from the body

-------> Secondary Stagnation Point

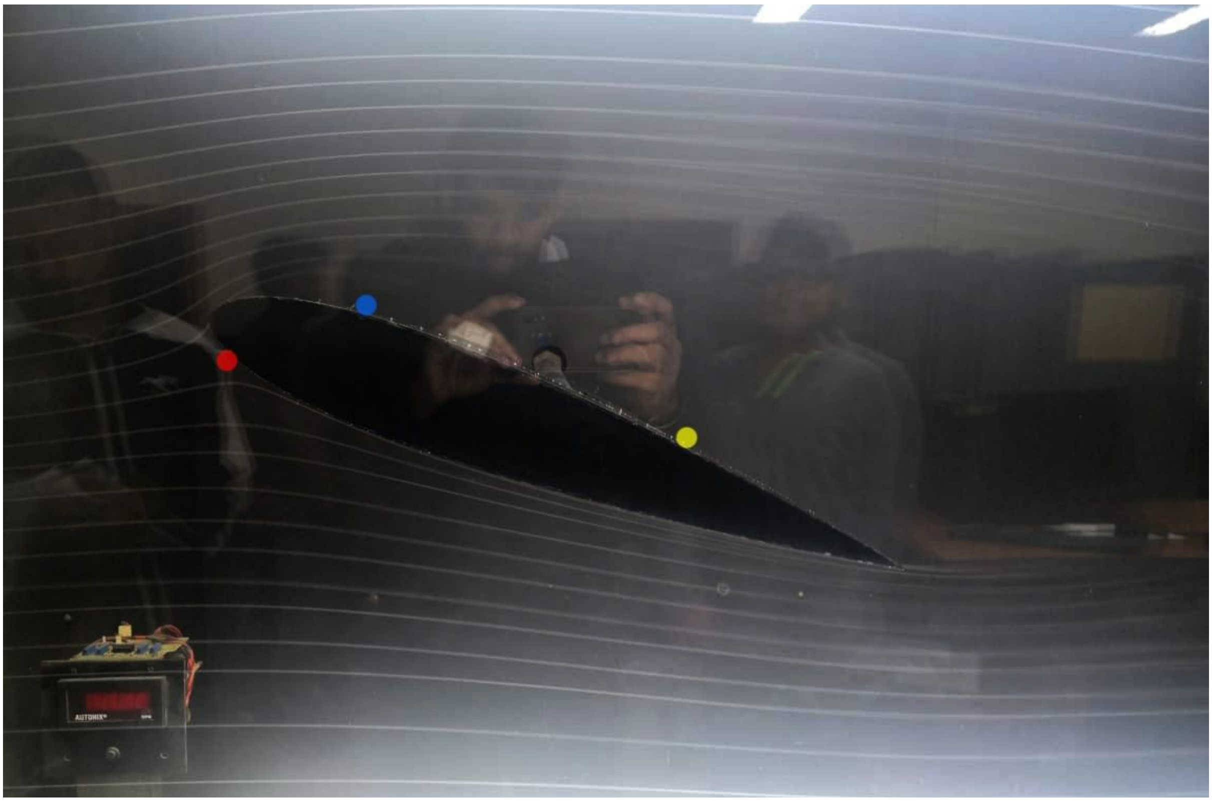
Symmetric Airfoil at 0.1^{O} angle of attack -------------> STREAMLINE BODY



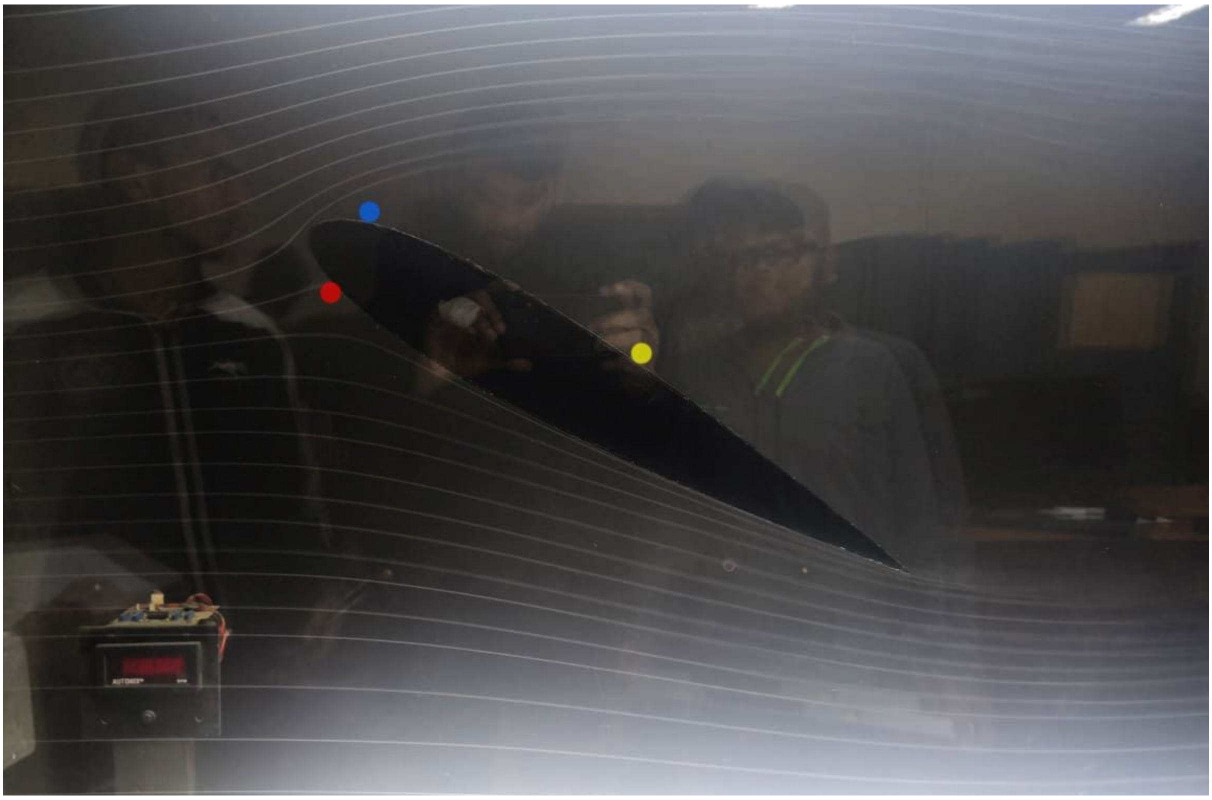
Symmetric Airfoil at 10^{O} angle of attack -------------> STREAMLINE BODY



Symmetric Airfoil at 20.3^{O} angle of attack



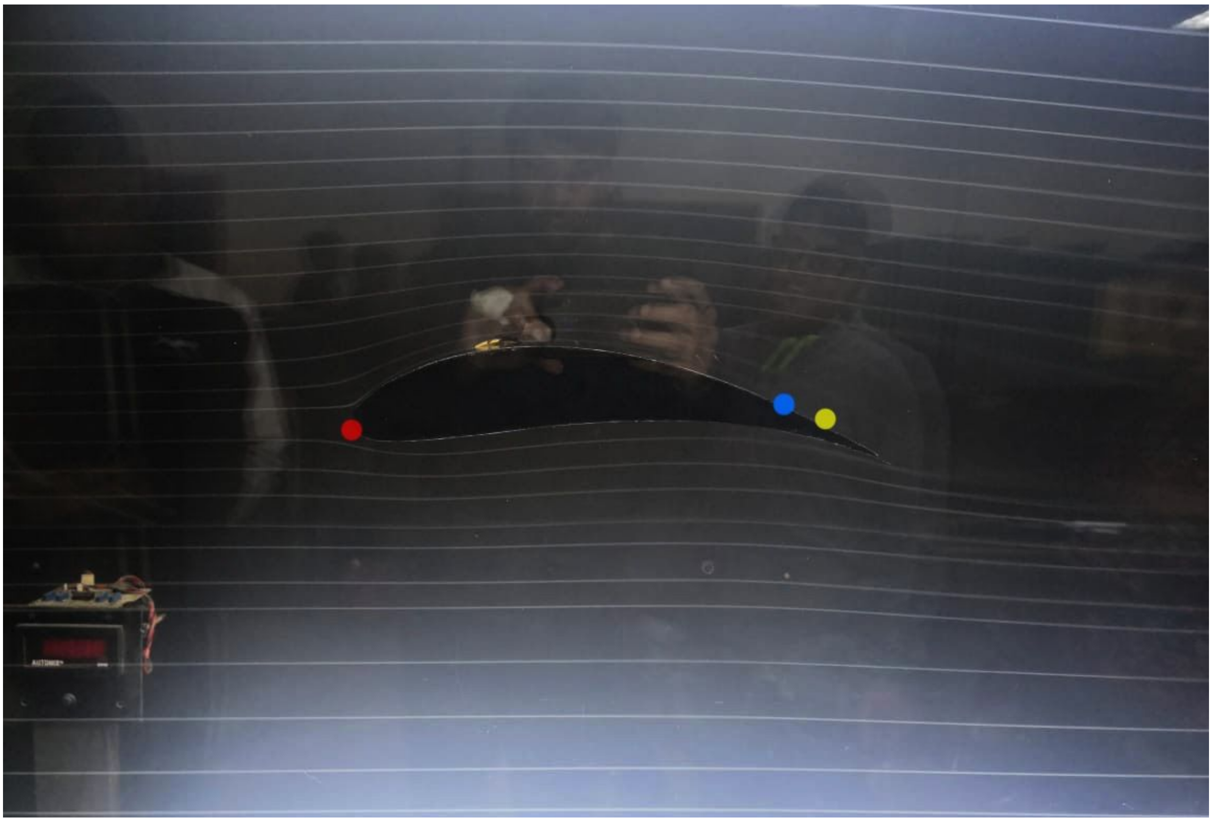
Symmetric Airfoil at 29.4^{O} angle of attack



As angle of attack is increased in symmetric airfoil:

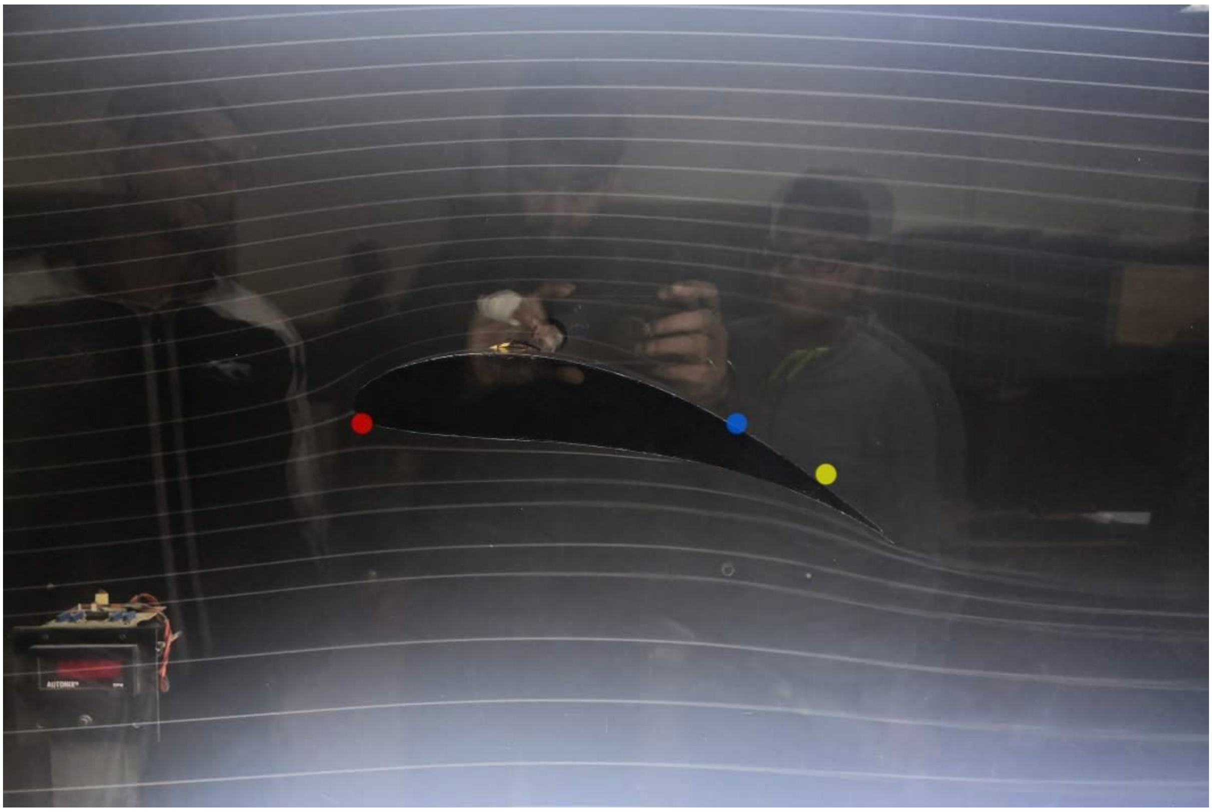
- Stagnation point moves downwards.
- Flow is separating earlier than at a lower angle of attacks.
- Drag is increased significantly.
- The Wake region is increasing in size.
- Incoming flow starts oscillating when angle of attack becomes significantly large due to strong vortices.

Cambered Airfoil at 1.8^{o} angle of attack -------------> STREAMLINE BODY



- Stagnation point is already higher than symmetric airfoil.
- Wake region is also smaller than symmetric airfoil.
- Flow remains attached for a longer time.

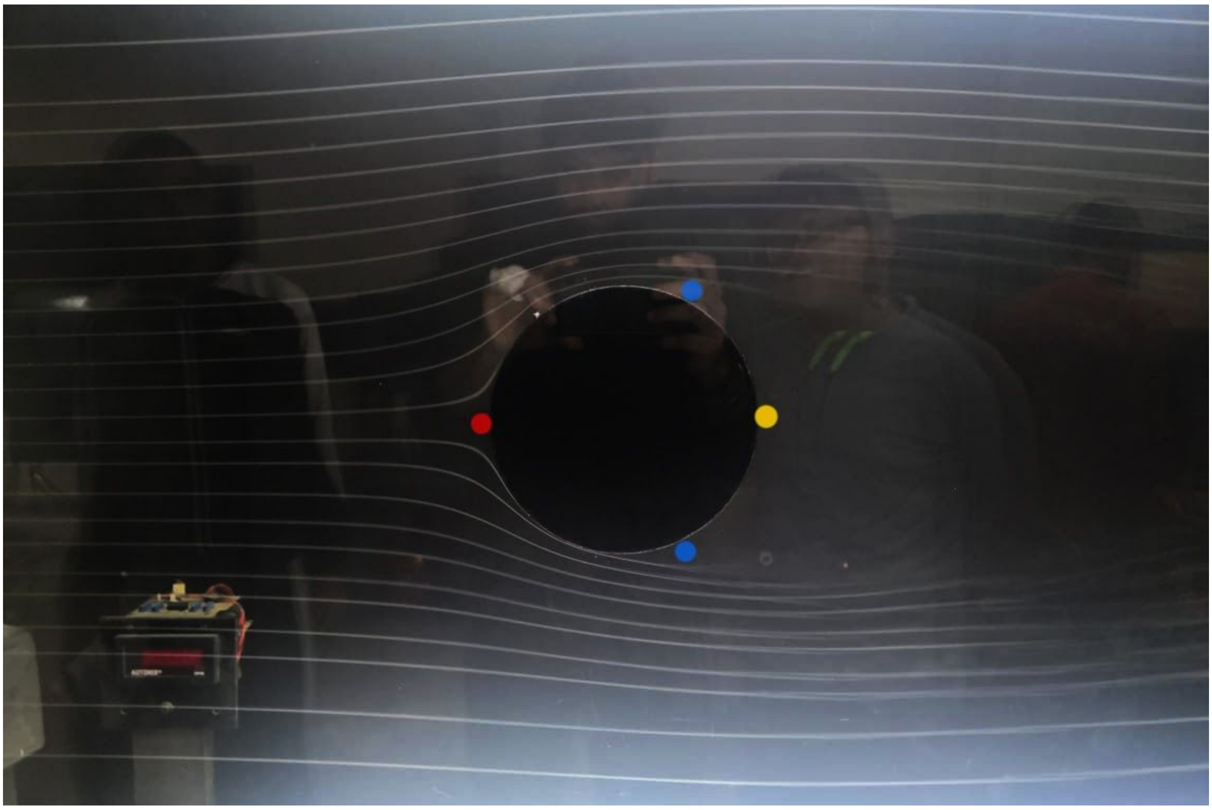
Cambered Airfoil at 14.3^{O} angle of attack -------------> STREAMLINE BODY



Cambered Airfoil at 25.3^{O} angle of attack -------------> STREAMLINE BODY

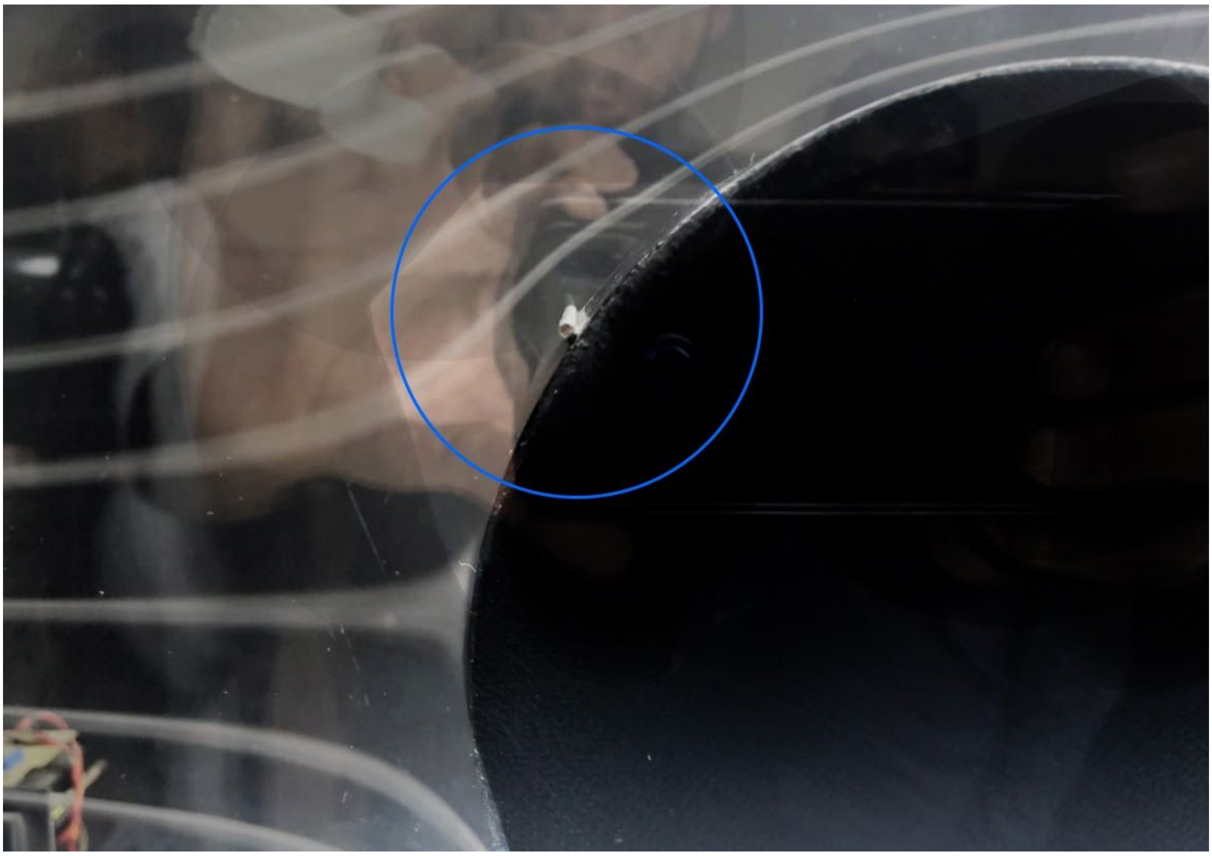
- Stagnation points don’t move too much wrt to symmetric airfoil.
- Flow remains attached longer than in symmetric airfoil.
- Wake region increases at angle of attack increases.
- The Wake region is smaller in cambered airfoil at the same angle of attack.
- Experiences less drag force than symmetric at the same angle of attack.

Circular Disc-------------> BUFFED BODY



- Flow separates between blue points.
- Large wake region are formed due to early flow separation.
- Strong vortex formation.
- Produces enormous drag forces.

The image below shows an obstruction in circular disc. It is added to induce some turbulence to study how turbulent flow affects the flow over a body.



DISCUSSION

A streamlined body is defined as that body whose surface is aligned with the streamlines when the body is placed in the flow and the separation takes place close to the trailing edge. Clearly, cambered and symmetric airfoil has lower flow separation than the circular body. Therefore, both airfoils are the streamline bodies and the circular disc is a buffed body.

For aircraft to produce more lift and have control it is necessary for flow to remain attached to the body as much as possible.
BLUE dot moves very little in cambered airfoil, when angle of attack is increased, in comparison to the symmetric airfoil. It suggests that a cambered airfoil can operate on a larger angle range than the symmetric airfoils.Also, Stall angle will be higher for cambered airfoils.

Also, as flow remains attached longer in cambered airfoil, they are more efficient (produces more lift at the same angle of attack) than symmetric airfoil.

PRECAUTIONS

- Make sure to feed enough smoke for clear visualization of the flow.
- Models that are used to study should be smooth.