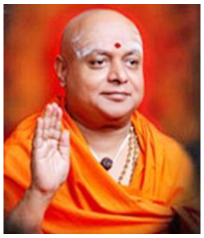

||Jai Sri Gurudev||

Sri Adichunchanagiri Shikshana Trust ®

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AERODYNAMICS LAB MANUAL- 18AEL57
2021-2022

Prepared by

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DEPARTMENT OF AERONAUTICAL ENGINEERING

//JAI SRI GURUDEV//

S.J.C. INSTITUTE OF TECHNOLOGY

DEPARTMENT OF AERONAUTICAL ENGINEERING

VISION:

PREPARING COMPETENT AERONAUTICAL ENGINEERS TO SERVE THE SOCIETY

MISSION:

M1: Strengthening the Fundamental concepts in Aeronautical Engineering.

M2: Building Analytical ability among students with innovative problem-solving techniques.

M3: Training students in multidisciplinary research areas in collaboration with Industries embedding the culture of continuous learning.

M4: Imparting skillset in line with emerging industrial needs with leadership qualities

M5: Making students responsible citizens to serve society with ethics and values.

OBJECTIVE:

The objective of this lab is to teach students, the importance of Aerodynamics through involvement in experiments. This lab helps to have knowledge of the world due to constant interplay between observations and hypothesis, experiment and theory in this subject. Students will gain knowledge in various areas of Aerodynamics so as to have real time applications in Aeronautical engineering stream.

OUTCOMES:

On successful completion of this course, students will be able to

CO1 – Calibrate the wind tunnel for various motor speeds (L4)

CO2 - Analyze the results of smoke and tuft flow visualization techniques (L4)

CO3 – Calculate and plot the pressure distribution around different airfoils and circular cylinders using pitot-static probes (L4)

CO4 – Estimate the drag co-efficient for 2-D objects using pitot-static wake survey method (L4)

CO5 - Predict the boundary layer velocity profile on wind tunnel wall and on the airfoil using pitot-static wake survey method (L4)

CO6 – Calculate the various aerodynamic coefficients acting on an aircraft model (L4)

CO-PO Mapping															
	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	3	1	1	-	1	1	1	3	2	-	2	3	2	1
CO2	3	3	1	-	1	1	-	-	3	2	1	2	3	2	1
CO3	3	3	3	2	2	1	-	-	3	2	1	2	3	2	1
CO4	3	3	3	2	2	1	-	-	3	2	1	2	3	2	1
CO5	3	3	3	2	2	1	-	-	3	2	1	2	3	2	1
CO6	3	2	1	-	2	1	-	-	3	2	-	2	3	2	1

CONTENTS

AERODYNAMICS LAB – 18AEL57

Maximum Marks for Internal Assessment = 40

WEEKLY: 3 hrs per batch

TEST: 16 MARKS

RECORD: 24 MARKS

TEST PROCEDURE:

NO. OF TEST TO BE CONDUCTED: 1

MAXIMUM MARKS: 24

DURATION: 3 hrs

1) No of experiment to be conducted: 2

   One group experiment: 08 marks

   One individual experiment: 08 marks

- Procedure for both the experiments
- Tabular column
- Necessary formula & ideal graph if any
- Conduction
- Calculation & results
- Graph & conclusion

2) VIVA: 08 MARKS

Scheme of Semester End Examination

ONE Question from Part-A:	**40 Marks**
ONE Question from Part-B:	**40 Marks**
Viva-Voce:	**20 Marks**
Total	**100 Marks**

EXPERIMENT NO: 1

CALIBRATION OF A SUBSONIC WIND TUNNEL: TEST SECTION STATIC PRESSURE AND TOTAL HEAD DISTRIBUTION

AIM: To calibrate the subsonic wind tunnel by preparing a calibration chart drawn between motor speeds (RPM) and test section velocity.

EQUIPMENT: Subsonic Wind Tunnel, Manometer, Pitot - static tube mounted in the Test Section

THEORY: The calibration of wind tunnel is done to measure the tunnel speed, which can be measured through Pitot-static tube. The tunnel speed is the mean speed at the test section when the tunnel is empty. The tunnel speed is measured in terms of the difference between a total head and a static pressure reading. Calibration also ensures the uniformity of flow parameters in the region to be used for model testing.

PROCEDURE:

1. Check the wind tunnel for any loose parts.
2. Set the reading of the velocity indicator to zero before starting the wind tunnel.
3. Run the tunnel at a particular speed and note down the actual velocity V_a from the air velocity indicator and manometer Δ_h by pressing the up arrow of the velocity indicator.
4. Repeat the process by running at different speeds
5. Gradually shut down the wind tunnel.
6. Calculate the velocity of air flow as per the formula given below.
7. Draw the calibration chart between calculated Flow velocity and Motor Speed.

FORMULA:

$$p_T - p_s = \frac{1}{2}\rho V^2$$

Where,
P_T - Total Pressure of tunnel, N/m^2
P_s - Static pressure of tunnel, N/m^2
ρ - Density of Air, Kg/m^3
V - Velocity of Air Flow
$P_T = P_a - P_\infty$, this is because it is an open tunnel
P_a = ambient pressure

(Thus total pressure in the tunnel remains constant irrespective of speed of flow in Tunnel, only the static pressure of the tunnel varies)

$$\frac{2(p_T - p_S)}{\rho} = \frac{2\Delta p}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{h_T - h_S} = 129.7\sqrt{\Delta h}$$

Where, Δh = manometer differential height in mm
Density of air is taken as 1.125 x 10^3 Kg/m^3.

$$V = 129.7\sqrt{\Delta h(mm)}$$

Percentage Error = $\frac{(V_a - V_c)}{V_a}$ x 100

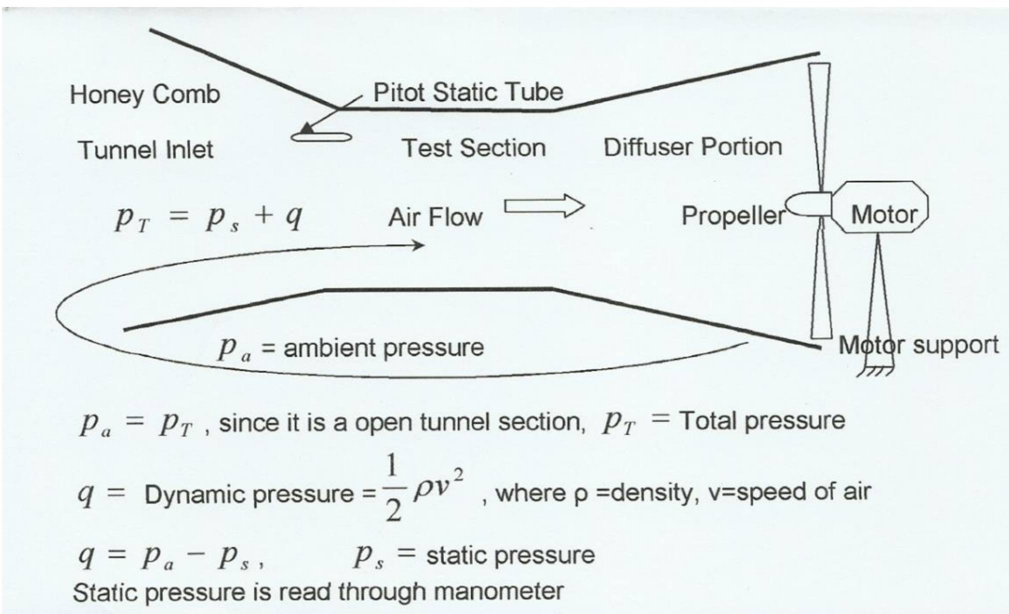


Fig. Tunnel static pressure concept

TABULAR COLUMN:

Sl. No.	Speed (RPM)	Actual Velocity V_a in m/s	Manometer Differential height, Δh (mm)	Flow Velocity $V_c = 129.7\sqrt{\Delta h}$ m/sec	Frequency Hz	Percentage Error
1						
2						
3						
4						
5						
6						

GRAPH:

1. Speed v/s Velocity

RESULT:

Thus the wind tunnel is calibrated using the pitot-static probe by measuring the total and static pressure.

VIVA QUESTIONS:

1. Define Calibration and explain its necessity.
2. What are the types of wind tunnel?
3. Explain the parts of a wind tunnel.
4. What is the cross section of the test section of the wind tunnel existing in the lab.
5. Define pressure and explain the different types of pressures such as total, static and dynamic pressures.
6. What is the maximum speed and velocity of the wind tunnel?
7. Which type of wind tunnel is this?
8. List the different methods of measuring air speeds.

EXPERIMENT NO: 2

SMOKE FLOW VISUALIZATION STUDIES ON A TWO DIMENSIONAL CIRCULAR CYLINDER AT LOW SPEEDS

AIM: To carry out the smoke flow visualization on a two dimensional circular cylinder and to draw the flow pattern observed at different speeds.

EQUIPMENT: Subsonic wind tunnel, Circular cylinder model with support mount, Smoke generation apparatus, liquid paraffin, manometer.

THEORY: In general, flow visualization is an experimental means of examining the flow pattern around a body or over its surface. The flow is "visualized" by introducing dye, smoke or pigment to the flow in the area under investigation. The primary advantage of such a method is the ability to provide a description of a flow over a model without complicated data reduction and analysis.

Smoke flow visualization involves the injection of streams of vapor into the flow. The vapor follows filament lines (lines made up of all the fluid particles passing through the injection point). In steady flow the filament lines are identical to streamlines (lines everywhere tangent to the velocity vector). Smoke-flow visualization can thus reveal the entire flow pattern around a body.

PROCEDURE:

1. Mount the circular cylinder model with its support and the smoke rake in the tunnel test section securely.
2. Ensure that the tunnel is not having any loose components.
3. Generate the smoke for the flow visualization through smoke generator.
4. Adjust the amount of smoke generated by adjusting heater control provided with smoke generator
5. Observe the flow pattern around the body and infer the location of stagnation point, flow separation, formation of eddies and vortex shedding nature at different speeds (at different Reynolds Number).
6. Tabulate the observed flow pattern at different Reynolds Number with a neat sketch with inference.

7. Gradually shutdown the tunnel.

A typical image of smoke past a circular cylinder is shown below:

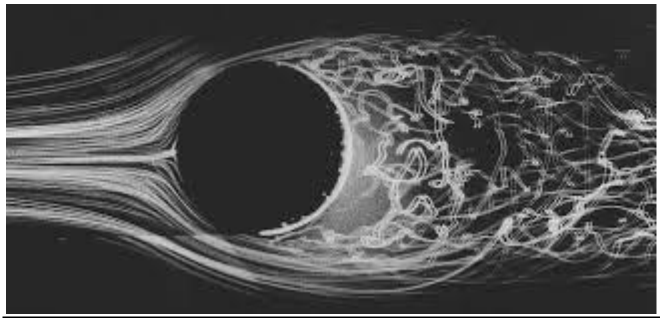
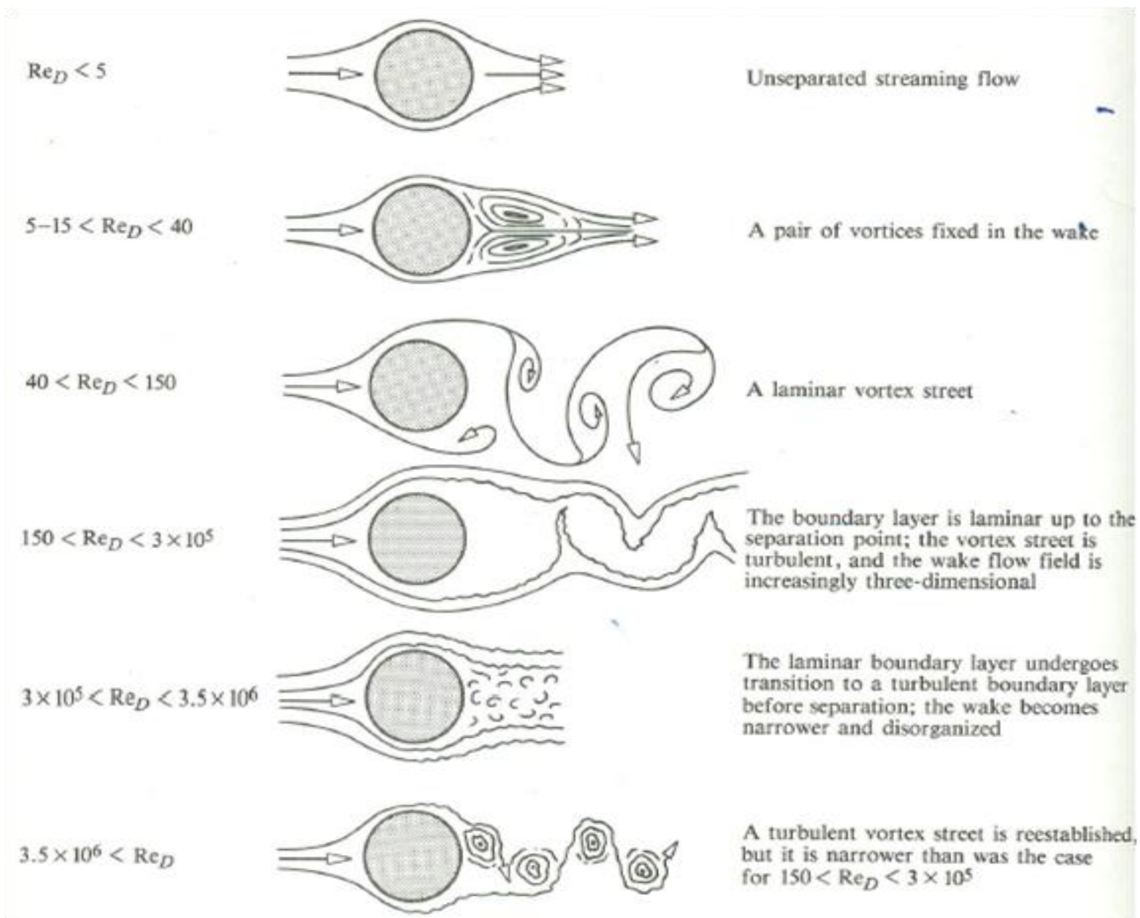


Fig. Smoke past a cylinder

Reynolds number has influence on nature of flow past objects as shown below:



FORMULA:

1. Velocity:

$$\frac{2(P_T - P_S)}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{h_t - h_s} = 129.7\sqrt{\Delta h}$$

2. Reynolds Number:

$$\mathrm{Re} = \frac{\rho VL}{\mu}$$

where
ρ - Density of air=1.165 Kg/m^3
V - Velocity of air in m/s
D -diameter of the cylinder in m
μ - Dynamic viscosity of air = $1.7e^{-5}$ Ns/m^2

TABULAR COLUMN:

Sl. No.	Speed* (RPM)	Manometer Diff height Δh in mm	Velocity = $129.7\sqrt{\Delta h}$	Re. No. $\mathrm{Re} = \frac{\rho VL}{\mu}$	Flow pattern	Inference
1.						
2.						
3.						
4.						
5.						

Note: Maintain a very Low Speed for Flow Visualization.

RESULT: Thus the flow visualization is carried out and the flow pattern around the body at different Reynolds number and velocity is observed

VIVA QUESTIONS:

1. List the different techniques of flow visualization.
2. Define Reynolds number and what is the different between laminar and turbulent flow
3. What are the types of flows and explain.
4. What is d'Alembert's Paradox
5. Explain lifting and non-lifting flow over a cylinder

EXPERIMENT NO: 3

SMOKE FLOW VISUALIZATION STUDIES ON A TWO DIMENSIONAL AIRFOIL AT DIFFERENT ANGLE OF INCIDENCE AT LOW SPEEDS

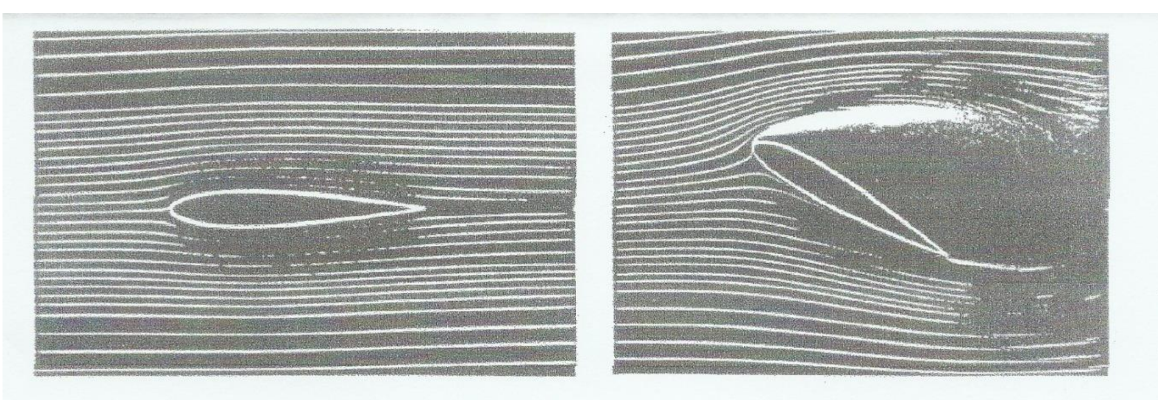
AIM: To carry out the smoke flow visualization on a two dimensional airfoil and to draw the flow pattern at different angle of incidence.

EQUIPMENT: Subsonic wind tunnel, two dimensional symmetric or cambered airfoil model with support mount, Smoke generation apparatus, liquid paraffin, manometer.

THEORY: In general, flow visualization is an experimental means of examining the flow pattern around a body or over its surface. The flow is "visualized" by introducing dye, smoke or pigment to the flow in the area under investigation. The primary advantage of such a method is the ability to provide a description of a flow over a model without complicated data reduction and analysis.

Smoke flow visualization involves the injection of streams of vapor into the flow. The vapor follows filament lines (lines made up of all the fluid particles passing through the injection point). In steady flow the filament lines are identical to streamlines (lines everywhere tangent to the velocity vector). Smoke-flow visualization can thus reveal the entire flow pattern around a body.

A picture below shows smoke flow patterns over aero foil at a) zero incidence and b) higher angle of attack. Note the separated flow at higher angles of attack.



(a) Low Incidence **b) High Incidence**

Fig. Smoke flow past at aero foil at different incidences

PROCEDURE:

1. Mount the aero foil model with its support in the tunnel test section securely.
2. Ensure that the tunnel is not having any loose components.
3. Generate the smoke for the flow visualization through smoke generator.
4. Adjust the amount of smoke generated by adjusting heater control provided with smoke generator.
5. Observe the flow pattern around the body and infer the location of stagnation point, flow separation, formation of eddies and vortex shedding nature at different speeds (at different Reynolds Number).
6. Tabulate the observed flow pattern at different Reynolds Number with a neat sketch with inference.
7. Gradually shutdown the tunnel.

FORMULA:

1. Velocity:

$$\frac{2(P_T - P_S)}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

2. Reynolds Number:

$$\mathrm{Re} = \frac{\rho V L}{\mu}$$

where
- ρ - Density of air=1.1 Kg/m^3
- V - Velocity of air, m/s
- L - Chord Length = 0.195 m
- μ - Dynamic viscosity of air, 1.7 x e^{-5} Ns/m^2

TABULAR COLUMN:

Angle of attack, α =

Sl. No.	Speed* (RPM)	Angle of Attack, α	Manometer Diff height Δh	Velocity= $129.7\sqrt{\Delta h}$	Re. No. $\mathrm{Re} = \frac{\rho V L}{\mu}$	Flow pattern	Inference
1.							
2.							
3.							
4.							
5.							

*** Maintain a very Low Speed for Flow Visualisation.**

Vary angle of attack and take more readings

RESULT:

Thus the flow visualization is carried out and the flow pattern around the body at different Reynolds number and velocity is observed.

VIVA QUESTIONS:

1. What are the types of airfoils?
2. Explain the nomenclature of an airfoil.
3. What is angle of attack?
4. What is critical angle of attack?
5. Explain stagnation point.
6. What is the difference between stream-lined and bluff bodies
7. What is the name of the chemical used to generate smoke in this lab? What are the other chemicals which can be used to generate smoke?

EXPERIMENT NO: 4

SMOKE FLOW VISUALIZATION STUDIES ON A TWO DIMENSIONAL MULTI-ELEMENT AIRFOIL WITH FLAPS AND SLATS AT DIFFERENT ANGLES OF INCIDENCE AT LOW SPEEDS.

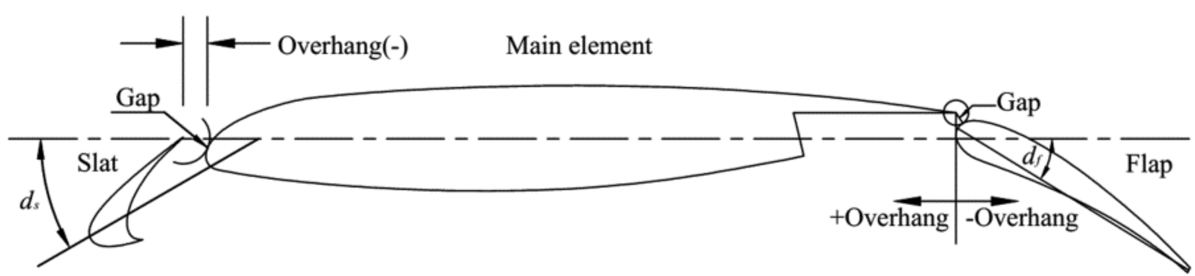
AIM: To carry out the smoke flow visualization on a two dimensional multi-element airfoil with flaps and slats and to draw the flow pattern at different angle of incidence.

EQUIPMENT: Subsonic wind tunnel, two dimensional multi-element airfoil model with support mount, Smoke generation apparatus, liquid paraffin, manometer.

THEORY: In general, flow visualization is an experimental means of examining the flow pattern around a body or over its surface. The flow is "visualized" by introducing dye, smoke or pigment to the flow in the area under investigation. The primary advantage of such a method is the ability to provide a description of a flow over a model without complicated data reduction and analysis.

Smoke flow visualization involves the injection of streams of vapor into the flow. The vapor follows filament lines (lines made up of all the fluid particles passing through the injection point). In steady flow the filament lines are identical to streamlines (lines everywhere tangent to the velocity vector). Smoke-flow visualization can thus reveal the entire flow pattern around a body.

A picture below shows different parts of a multi-element airfoil.



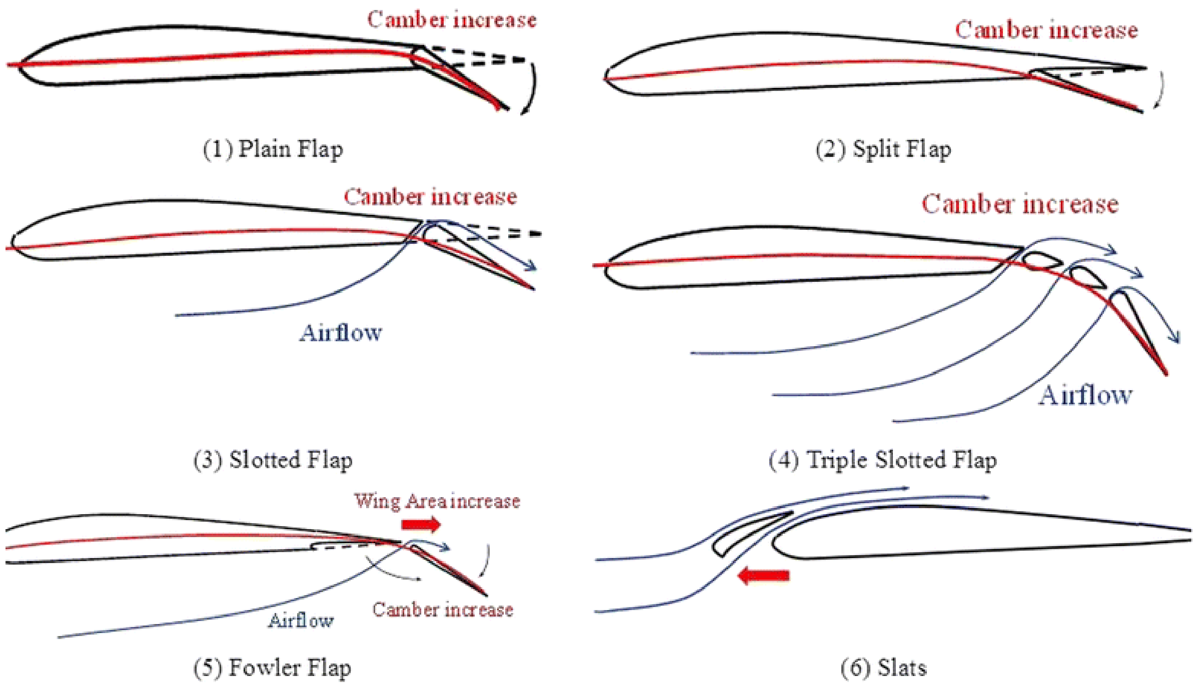


Fig. Flow past an aero foil with different types of flaps and slats

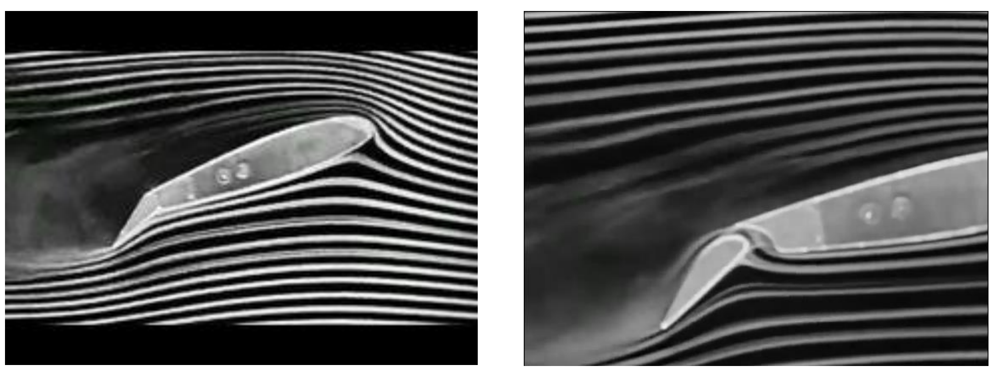


Fig: Smoke flow past a multi-element airfoil

PROCEDURE:

1. Mount the aero foil model with its support in the tunnel test section securely.
2. Ensure that the tunnel is not having any loose components.
3. Generate the smoke for the flow visualization through smoke generator.
4. Adjust the amount of smoke generated by adjusting heater control provided with smoke generator.
5. Observe the flow pattern around the body and infer the location of stagnation point, flow separation, formation of eddies and vortex shedding nature at different speeds (at different Reynolds Number).

6. Tabulate the observed flow pattern at different Reynolds Number with a neat sketch with inference.
7. Gradually shutdown the tunnel.

FORMULA:

1. Velocity:

$$\frac{2(P_T - P_S)}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

2. Reynolds Number:

$$\mathrm{Re} = \frac{\rho VL}{\mu}$$

where
- ρ - Density of air=1.1 Kg/m^3
- V - Velocity of air, m/s
- L - Chord Length = 0.195 m
- μ - Dynamic viscosity of air, 1.7 x e^{-5} Ns/m^2

TABULAR COLUMN:

Angle of attack, α =

Sl. No.	Speed* (RPM)	Angle of Attack, α	Manometer Diff height Δh	Velocity= $129.7\sqrt{\Delta h}$	Re. No. $\mathrm{Re} = \frac{\rho VL}{\mu}$	Flow pattern	Inference
1.							
2.							
3.							
4.							
5.							

*** Maintain a very Low Speed for Flow Visualisation.**

Vary angle of attack and take more readings

RESULT:

Thus the flow visualization is carried out and the flow pattern around the body at different Reynolds number and velocity is observed.

VIVA QUESTIONS:

1. What is a multi-element airfoil?
2. Name the different types of flaps and slats used.
3. Define Stream Function, Velocity Potential?
4. Define Stream line, streak lines, path line and stream tube?
5. Name the different primary and secondary lifting devices.

EXPERIMENT NO: 5

TUFT FLOW VISUALIZATION ON A WING MODEL AT DIFFERENT ANGLES OF INCIDENCE AT LOW SPEEDS: IDENTIFY ZONES OF ATTACHED AND SEPARATED FLOWS.

AIM: To carry out the tuft flow visualization on a two dimensional wing model at different angles of incidence.

EQUIPMENT: Subsonic wind tunnel, a wing model with support mount, Tufts, Scotch tape.

THEORY: Tuft flow visualization is a type of flow visualization and the tufts readily show where the flow is steady and where the flow is unsteady. Regions of complete separation and buffeting flow are readily identified. Tufts are light, flexible material that will align with the local surface flow. The most commonly used material is light yarn, and the weight and length are chosen according to model size and test speeds

PROCEDURE:

1. Cut equal sized tufts and place them at equidistant along the span of the wing.
2. Mount the tuft attached wing model to the test section with the help of supporting mount.
3. Ensure for any loose parts in the tunnel and run the tunnel at low speeds
4. Observe the flow pattern and gradually increase the speed there by varying the Reynolds number.
5. Observe the change in the flow pattern
6. Tabulate the inference of flow pattern at various Reynolds number.

FORMULA:

1. Velocity:

$$\frac{2(P_T - P_S)}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

2. Reynolds Number:

$$Re = \frac{\rho VL}{\mu}$$

where ρ - Density of air=1.1 Kg/m^3
V - Velocity of air, m/s
L - Cord Length=0.150 m
μ - Dynamic viscosity of air, 1.7 x e^{-5} Ns/m^2

TABULAR COLUMN:

Sl. No	Speed	Angle of Attack	Velocity	Re. No	Inference
1					
2					

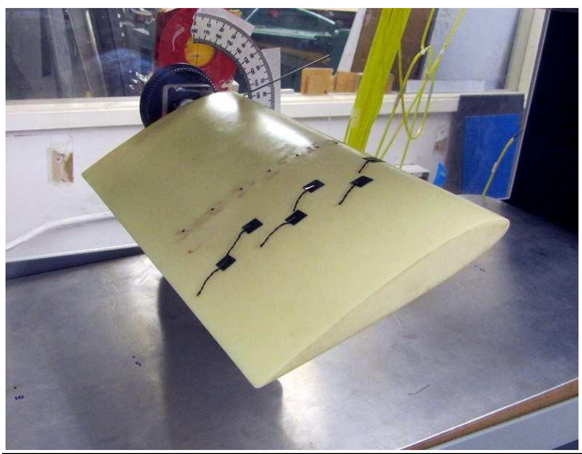


Fig. A Typical Test set up of Tufts is shown below:

Result:

Thus the tuft flow visualization is conducted and the flow pattern at different angles of incidence is observed.

VIVA QUESTIONS:

1. What is NACA?
2. Explain NACA 4 & 5 Digit Series Airfoil? What does each digit indicate
3. What is Lift and Drag and Explain significance of Lift and Drag coefficient?
4. Define Mach number
5. Explain Different Flow/Mach number Regimes

EXPERIMENT NO: 6

SURFACE PRESSURE DISTRIBUTIONS ON A TWO-DIMENSIONAL SMOOTH CIRCULAR CYLINDER AT LOW SPEEDS AND CALCULATION OF PRESSURE DRAG

AIM: To Measure the pressure distribution on a two-dimensional circular cylinder and to estimate the drag of the cylinder.

EQUIPMENT: Low speed wind tunnel, Multi tube manometer, Cylinder model with pressure tapings and with support mount, Pitot - static tube.

DIAGRAM:

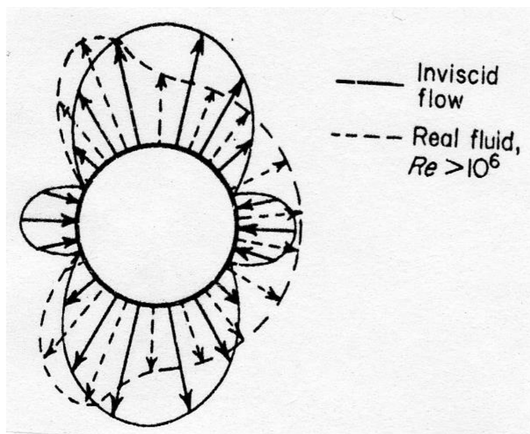


Fig: Ideal flow and Actual static pressure distribution over a circular cylinder

THEORY: There are various methods by which the drag of the bluff body can be measured. One such method is estimating the drag of the body by measuring the pressure distribution over the body. Here the pressure distribution over the cylinder is measured which comes from the pressure force created by the free stream flow over the cylinder. Then in turn by suitable formula the drag generated by the cylinder is calculated.

PROCEDURE:

1. Assemble the cylinder with pressure tapings in the test section with the help of support. Connect the pressure tapping to manometer.
2. Rotate the cylinder such that the static holes form the upper or lower surface of the cylinder.

3. Ensure the tunnel for any loose components and start the tunnel.
4. Run the tunnel at various desired speeds and note down the manometer reading which measures the surface pressure distribution of the cylinder.
5. Also note down the Pitot-Static tubes manometer reading.
6. Since the cylinder is axially symmetric the pressure distribution is measured for half the surface and the same trend follows for another half portion.
7. Gradually shut down the tunnel.

DATA REDUCTION:

1. Dynamic Pressure,q:

$$q = p_T - p_S = \frac{1}{2}\rho V_\infty^{\;2}$$

p_s = tunnel static pressure

2. Pressure Coefficient:

$$C_p = \frac{p_i - p_s}{q_\infty} = \frac{\Delta h_i}{q_\infty}$$

where, p_i= Static pressure values measured around cylinder
p_s= Tunnel static pressure
Δh_i = manometer differential column height wrt tunnel static

3. Pressure Coefficient (theoretical value):

$$C_p = 1 - 4Sin^2\theta$$

where ,θ= Angular location of static ports around the cylinder

4. Drag Coefficient :

$$C_D \approx \int_0^\pi C_p \cos\theta \, d\theta$$

$$C_D = C_{p\ exp} \cos\theta \, d\theta$$

We do not have continuous pressure distribution; therefore we evaluate this with a numerical summation.

TABULAR COLUMN:

$$\frac{2(P_T - P_S)}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

$$q = \frac{1}{2}\rho V_\infty^{\;2}$$

Experimental Pressure Drag, $C_D = C_{pexp} \times \cos\theta.d\theta$

Speed: **Velocity:**

Static Pressure, Ps (reading on 34th port):

Pressure Tappings	Pi	Cp Experimental $C_p = \frac{\Delta h_i}{q}$	Cp Theoretical $C_p = 1 - 4Sin^2\theta$	θ (rad)	Interval between ports dθ	Experimental Pressure drag
1						
2						
3						
					$C_D = \sum C_p \cos\theta\, d\theta$	

GRAPH:

C_p Vs θ theoretical and compare with experimental values

RESULTS:

1. Thus the pressure distribution around the cylinder is measured and the drag of the cylinder is estimated.
2. The coefficient of drag of cylinder, $C_D =$

VIVA QUESTIONS:

1. What is Bernoulli's principle and equation
2. Define drag and list the different types of drag.
3. Define aerodynamic center, center of pressure, center of gravity and coefficient of pressure.
4. Draw the pressure distribution over an airfoil
5. What is the basic purpose of wind tunnel testing?
6. Sketch the pressure distribution round a circular cylinder in ideal flow and in real flow

EXPERIMENT NO: 7
SURFACE PRESSURE DISTRIBUTIONS ON A TWO-DIMENSIONAL ROUGH CIRCULAR CYLINDER AT LOW SPEEDS AND CALCULATION OF PRESSURE DRAG

AIM: To Measure the pressure distribution on a two-dimensional circular cylinder and to estimate the drag of the cylinder.

EQUIPMENT: Low speed wind tunnel, Multi tube manometer, Cylinder model with pressure tapings and with support mount, Pitot - static tube.

DIAGRAM:

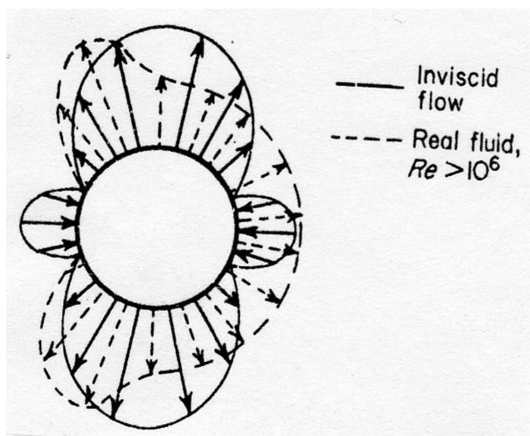


Fig: Ideal flow and Actual static pressure distribution over a circular cylinder

THEORY: There are various methods by which the drag of the bluff body can be measured. One such method is estimating the drag of the body by measuring the pressure distribution over the body. Here the pressure distribution over the cylinder is measured which comes from the pressure force created by the free stream flow over the cylinder. Then in turn by suitable formula the drag generated by the cylinder is calculated.

PROCEDURE:

1. Assemble the cylinder with pressure tapings in the test section with the help of support. Connect the pressure tapping to manometer.
2. Rotate the cylinder such that the static holes form the upper or lower surface of the cylinder.

3. Ensure the tunnel for any loose components and start the tunnel.
4. Run the tunnel at various desired speeds and note down the manometer reading which measures the surface pressure distribution of the cylinder.
5. Also note down the Pitot-Static tubes manometer reading.
6. Since the cylinder is axially symmetric the pressure distribution is measured for half the surface and the same trend follows for another half portion.
7. Gradually shut down the tunnel.

DATA REDUCTION:

1. Dynamic Pressure,q:

$$q = p_T - p_S = \frac{1}{2}\rho V_\infty^{\ 2}$$

p_s = tunnel static pressure

2. Pressure Coefficient:

$$C_p = \frac{p_i - p_s}{q_\infty} = \frac{\Delta h_i}{q_\infty}$$

where, p_i= Static pressure values measured around cylinder
p_s= Tunnel static pressure
Δh_i = manometer differential column height wrt tunnel static

3. Pressure Coefficient (theoretical value):

$$C_p = 1 - 4Sin^2\theta$$

where ,θ= Angular location of static ports around the cylinder

4. Drag Coefficient :

$$C_D \approx \int_0^\pi C_p \cos\theta \, d\theta$$

$$C_D = C_{p\ exp} \, Cos\ \theta\ d\theta$$

We do not have continuous pressure distribution; therefore we evaluate this with a numerical summation.

TABULAR COLUMN:

$$\frac{2(P_T - P_S)}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

$$q = \frac{1}{2}\rho V_\infty^{\ 2}$$

Experimental Pressure Drag, $C_D = C_{pexp} \times \cos\theta . d\theta$

Speed: **Velocity:**

Static Pressure, Ps (reading on 34th port):

Pressure Tappings	Pi	Cp Experimental $C_p = \frac{\Delta h_i}{q}$	Cp Theoretical $C_p = 1 - 4Sin^2\theta$	θ (rad)	Interval between ports dθ	Experimental Pressure drag
1						
2						
3						
$C_D = \sum Cp\cos\theta \, d\theta$						

GRAPH:

C_p Vs θ theoretical and compare with experimental values

RESULTS:

1. Thus the pressure distribution around the cylinder is measured and the drag of the cylinder is estimated.
2. The coefficient of drag of cylinder, C_D =

VIVA QUESTIONS:

1. What are two dimensional and three dimensional models
2. Explain Kelvins' Circulation Theorem, Kutta condition and Kutta Jouwvoski Theorum
3. Draw the C_l v/s α curve for symmetrical and cambered airfoil.
4. What is the basic purpose of wind tunnel testing?
5. Define Vorticity and Circulation.

EXPERIMENT NO: 8

SURFACE PRESSURE DISTRIBUTIONS ON A TWO-DIMENSIONAL SYMMETRIC AIRFOIL AT LOW SPEEDS

AIM: To Measure the pressure distribution on a two-dimensional symmetric airfoil at low speeds at different angle of attacks.

EQUIPMENT: Low speed wind tunnel, Multi tube manometer, wing model with pressure tapings and with support mount, Pitot - static tube.

THEORY: A symmetric airfoil is one which has same shape on both sides of the chord line i.e. the chord line and camber line for the symmetric airfoil coincides. The pressure distribution and shear stress distribution over the airfoil generates the aerodynamic forces. For a symmetric airfoil no lift is produced for zero angle of attack.

PROCEDURE:

1. Assemble the wing model with pressure tapings in the test section with the help of support.
2. Rotate the wing model such that the chord line is horizontal, thereby keeping the wing at zero angle of incidence.
3. Ensure the tunnel for any loose components and start the tunnel.
4. Run the tunnel at a desired speed and note down the manometer reading which measures the surface pressure distribution.
5. Also note down the Pitot-Static tubes manometer reading.
6. Gradually shut down the tunnel.
7. Again repeat the experiment for various angles of attack and tabulate the readings.

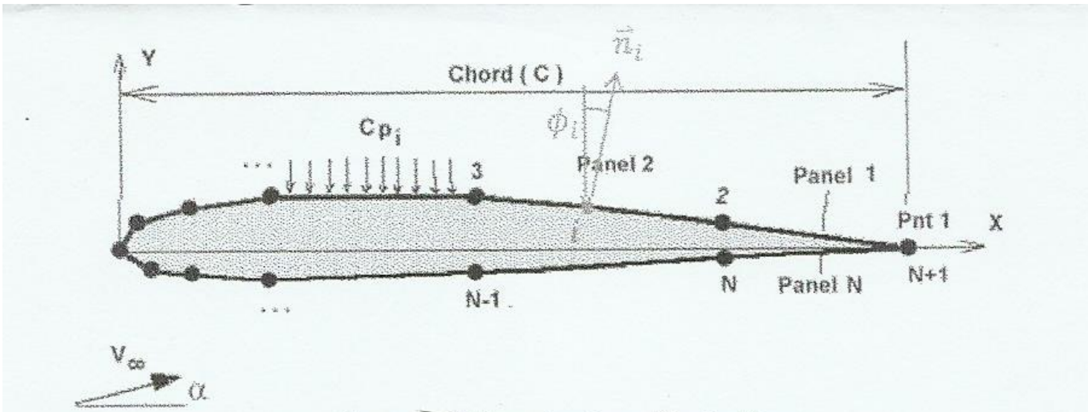


Figure Wing planform illustration

Figure. Shows the port points and nomenclatures

$$C_{p_i} = \frac{p_i - p_s}{q} = \frac{\Delta h_i}{q}$$

where, p_i= Static pressure values measured around cylinder(note it is also the stagnation pressure at the leading edge and is equal to tunnel total)

p_s= Tunnel static pressure

Δh_i = manometer differential column height w.r.t tunnel total

$$q = \frac{1}{2}\rho V^2$$

TABULAR COLUMN:

Angle of attack: Speed: Velocity:

Static Pressure, Ps (reading on 34th port):

Port. No	Pi	Pressure Coefficient $C_p = \frac{\Delta h_i}{q}$
1		
2		
3		
4		
5		

GRAPH:

C_p vs X/C

RESULT: Explain the nature of pressure distribution

VIVA QUESTIONS:

1. Define Uniform flow, Source flow, Sink flow, Doublet flow
2. Explain Classical thin airfoil theory for symmetric and cambered airfoils
3. State Biot-Savart law and Helmholtz's theorems,
4. Explain Vortex filament, Infinite and semi-infinite vortex filament
5. Explain Downwash and induced drag

EXPERIMENT NO: 9

SURFACE PRESSURE DISTRIBUTIONS ON A TWO-DIMENSIONAL CAMBERED AIRFOIL AT DIFFERENT ANGLES OF INCIDENCE AND CALCULATION OF LIFT AND PRESSURE DRAG

AIM: The purpose of the experiment is to measure the surface pressure distribution and calculate the aerodynamic coefficients from those pressure measurements for a cambered airfoil at a specified Reynolds number.

EQUIPMENT: Low speed wind tunnel, Multi tube manometer, wing model with pressure tapings and with support mount, Pitot - static tube.

THEORY: An airfoil is a two dimensional cross section of a wing, sliced in the general direction of the flow. The airfoil displays the aerodynamic shape used to produce a pressure imbalance. The net force of the pressure imbalance (in a real fluid, frictional forces are also present), summed over the wing, is resolved into lift and drag. By definition, lift is the net force component perpendicular to the flow and drag is the net force component parallel to the flow.

The curvature in the airfoil shape is called camber. Note that if the upper and lower surfaces are identical in shape, the mean camber line and the chord line coincide and the airfoil is symmetric. A cambered airfoil will produce lift, even at $\alpha = 0$ degree.

PROCEDURE:

1. Assemble the cambered wing model with pressure tapings in the test section with the help of support.
2. Rotate the wing model such that the chord line is horizontal, there by keeping the wing at zero angle of incidence.
3. Ensure the tunnel for any loose components and start the tunnel.
4. Run the tunnel at a desired speed and note down the manometer reading which measures the surface pressure distribution.
5. Also note down the Pitot-Static tubes manometer reading.

6. Gradually shut down the tunnel.
7. Again repeat the experiment for various angles of attack and tabulate the readings.

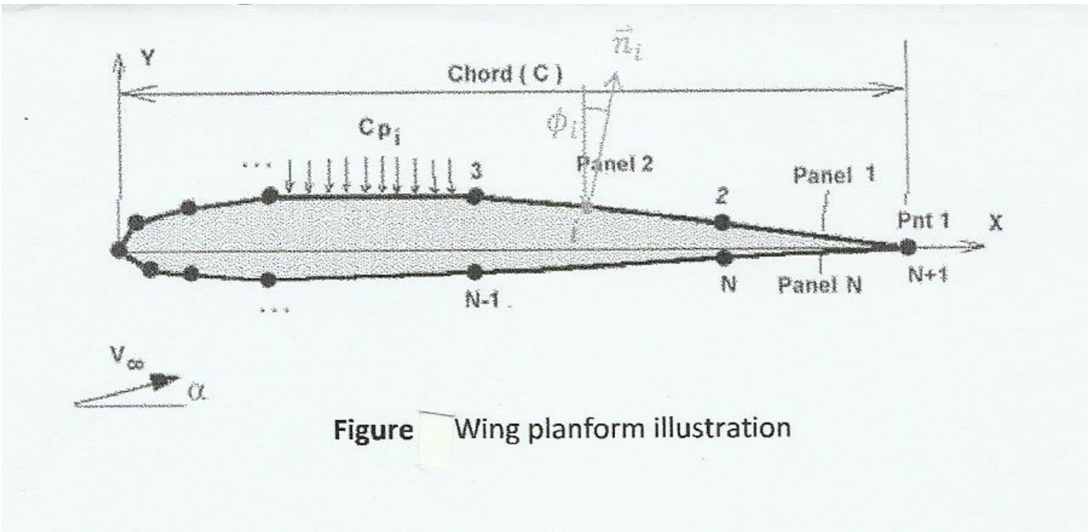


Figure- Shows the port points and nomenclatures

$$C_{p_i} = \frac{p_i - p_s}{q} = \frac{\Delta h_i}{q}$$

where, p_i= Static pressure values measured around cylinder
p_s= Tunnel staticl pressure
Δh_i = manometer differential column height wrt tunnel total

The lift and drag force are given as:

$$L = F_y = \int -p((\cos\alpha + \varphi))dA$$
$$D = F_x = \int -p((\sin\alpha + \varphi))dA$$

We do not have continuous pressure distribution; therefore we evaluate this with a numerical summation as below.

$$L = F_y = \sum_i - p_i(\cos(\alpha + \phi_i)\Delta A_i$$
$$D = F_x = \sum_i - p_i(\sin(\alpha + \phi_i)\Delta A_i$$

TABULAR COLUMN:

Surface Pressure Distribution:

Angle of attack: **Speed:** **Velocity:**

Static Pressure, Ps (reading on 34th port):

Port. No	Pi	Pressure Coefficient $C_p = \frac{\Delta h_i}{q}$
1		
2		
3		
4		
5		

Calculation of Lift and Pressure Drag:

Sl. No.	C_{pu}	C_{Pl}	$\Delta C_p = C_{Pl} - C_{pu}$	d(x/c)	$\Delta C_P.d(x/c)$

Normal Co-efficient, $C_n = \sum \Delta Cp.\, d(\frac{x}{c})$

Lift Co-efficient, $C_l = C_n \cos\alpha$

Drag Co-efficient, $C_d = C_n \sin\alpha$

GRAPH:

C_p vs x/C for different angles of attack

RESULT:

VIVA QUESTIONS:

1. What are Subsonic and Supersonic leading edges
2. What is camber and aspect ratio of wings
3. Explain Mach cone and Mach angle
4. Explain Non-lifting flow over a circular cylinder.
5. Explain Lifting flow over a circular cylinder

EXPERIMENT NO: 10

CALCULATION OF TOTAL DRAG OF A TWO-DIMENSIONAL CIRCULAR CYLINDER AT LOW SPEEDS USING PITOT-STATIC PROBE WAKE SURVEY

AIM: To determine the drag of a two-dimensional circular cylinder using Pitot-Static probe wake survey.

EQUIPMENT: Subsonic wind tunnel, two-dimensional circular cylinder, pitot-static probe rake, Multitube manometer.

THEORY: Drag can be determined experimentally by mounting a model on a balance and measuring the force directly, it can be determined by integrating a measured static pressure distribution over theentire surface, or it can be determined from a momentum balance on a control volume which contains a model. This momentum balance would require velocity measurements both up streamand downstream from the model. This is the method which will be utilized in this experiment.

Undisturbed flow enters the control volume containing the bluff body. When the only flow disturbance in the control volume is the bluff body, any loss of fluid momentum is realized as a force on the body. An application of the momentum equation to the control volume will yield the drag force when analyzed in the stream wise direction.

DIAGRAM:

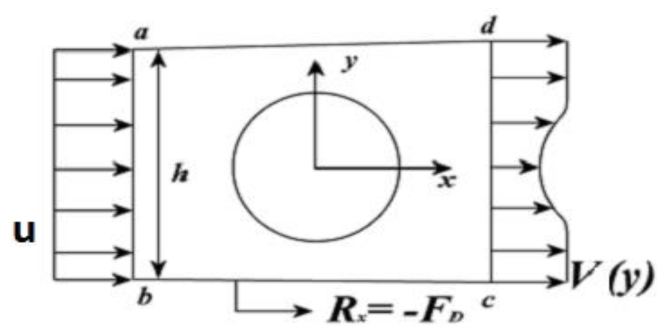


Fig. Velocity profile in the wake region

PROCEDURE:

1. Assemble the cylinder model in the test section securely with the help of support mounting
2. Place the Pitot-static wake rake behind the cylinder at a distance of 1D from the cylinder such that the probe is in the wake region of cylinder.
3. Connect the tubing to multitube manometer.
4. Start the tunnel and run at a constant speed
5. Note down the manometer reading and tabulate to find the drag coefficient.
6. Gradually shutdown the tunnel.

FORMULA:

1. Drag coefficient:

$$C_d = 2\int\left[\sqrt{\frac{P_i}{P_s}} - \frac{P_i}{p_s}\right]\frac{dy}{c}$$

2. Wake Velocity:

$$\frac{2(p_i - p_\infty)_{wake}}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

TABULAR COLUMN:

Velocity: Speed: Static Pressure, Ps (at 34th port):

Sl No	Dynamic Pressure, Pi	Δy	Δy/c	Drag Co-efficient
1				
2				
3				

GRAPH:

1. dy Vs V

RESULT: Thus the drag of the two-dimensional cylinder is measured by the pitot-static probe wake survey method.

The value of C_d is…………

VIVA QUESTIONS:

1. What is the difference between compressible and incompressible flow
2. What is the difference between viscid and inviscid flow
3. What is the difference between steady and unsteady flow
4. What is the difference laminar and turbulent flow
5. List some of the bluff and streamlined bodies

EXPERIMENT NO: 11

CALCULATION OF TOTAL DRAG OF A TWO-DIMENSIONAL CAMBERED AIRFOIL AT LOW SPEEDS AT AN INCIDENCE USING PITOT-STATIC PROBE WAKE SURVEY

AIM: To determine the drag of a two-dimensional circular cylinder using Pitot-Static probe wake survey.

EQUIPMENT: Subsonic wind tunnel, wing model, pitot-static probe rake, Multitube manometer.

THEORY: Drag can be determined experimentally by mounting a model on a balance and measuring the force directly, it can be determined by integrating a measured static pressure distribution over the entire surface, or it can be determined from a momentum balance on a control volume which contains a model. This momentum balance would require velocity measurements both upstream and downstream from the model. This is the method which will be utilized in this experiment.

Undisturbed flow enters the control volume containing the bluff body. When the only flow disturbance in the control volume is the bluff body, any loss of fluid momentum is realized as a force on the body. An application of the momentum equation to the control volume will yield the drag force when analyzed in the stream wise direction.

PROCEDURE:

1. Assemble the wing model in the test section securely with the help of support mounting
2. Place the Pitot-static wake rake behind the wing at a distance of 1 chord from the wing such that the probe is in the wake region of wing.
3. Connect the tubing to multitube manometer.
4. Start the tunnel and run at a constant speed
5. Note down the manometer reading and tabulate to find the drag coefficient.
6. Gradually shutdown the tunnel.

FORMULA:

1. Drag coefficient: $C_d = 2\int \left[\sqrt{\frac{p_i}{P_s}} - \frac{P_i}{P_s} \right] \frac{dy}{c}$

2. Wake Velocity:

$$\frac{2(p_i - p_\infty)_{wake}}{\rho} = V^2 \Rightarrow V = 129.7\sqrt{\Delta h}$$

TABULAR COLUMN:

Speed: **Velocity:**

Satic Pressure (reading on 38th port):

Pressure Tappings	Dynamic Pressure, Pi	Δy	Δy/c	Drag Co-efficient, Cd
1				
2				
3				
4				

GRAPH:

dy v/s V

RESULT:

Thus the drag of the two-dimensional wing is measured by the pitot-static probe wake survey method.

The value of C_d is…………

VIVA QUESTIONS:

1. What is the stall?
2. Is the maximum lift coefficient same in the case of all Reynolds numbers?
3. Define stalling angle of attack
4. What is the difference between rotational and ir-rotational flow
5. What is the physical principle of Continuity, Momentum and energy equations?

EXPERIMENT NO: 12

MEASUREMENT OF A TYPICAL BOUNDARY LAYER VELOCITY PROFILE ON THE TUNNEL WALL (AT LOW SPEEDS) USING A PITOT PROBE AND CALCULATION OF BOUNDARY LAYER DISPLACEMENT AND MOMENTUM THICKNESS

AIM: To determine the boundary layer displacement thickness and momentum thickness by using pitot probe.

EQUIPMENT: Subsonic wind tunnel, boundary layer rake, multitube manometer

THEORY:

Boundary layer thickness (δ): It is defined as the distance from the boundary of the solid body measured in the y-direction to the point, where the velocity of fluid approximately reaches the free stream velocity of fluid.

Displacement thickness (δ*) : It is the distance measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in flow rate on account of boundary layer formation.

Momentum thickness (θ): Momentum thickness is defined as the distance measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in momentum of the flowing fluid on account of boundary layer formation.

PROCEDURE:

1. Insert the boundary layer probe in the tunnel.
2. Connect the probe to manometer.
3. Connect the total head and pitot static tubes to manometer.
4. Note down the manometer reading and tabulate to get the boundary layer displacement thickness and momentum thickness.

FORMULA:

1. Displacement thickness (δ*):

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{U}\right) dy = \left(1 - \sqrt{\frac{\Delta h_r}{\Delta h_f}}\right) dy$$

Where,
- y = distance of elemental strip from the plate
- dy = thickness of elemental strip
- u = velocity of fluid at the elemental strip
- U = free stream velocity
- Δh_r = height of liquid column from probe rake with respect to tunnel total
- Δh_f = height of liquid column from pitot probe with respect to tunnel total

2. Momentum thickness (θ):

$$\theta = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy = \sqrt{\frac{\Delta h_r}{\Delta h_f}} \times \left(1 - \sqrt{\frac{\Delta h_r}{\Delta h_f}}\right) dy$$

3. Wake velocity (u):

$$\frac{2(p_i - p_\infty)_{wake}}{\rho} = u^2 \Rightarrow u = 129.7\sqrt{\Delta_{h(rake)}}$$

TABULAR COLUMN:

Probe No	Probe rake			Pitot probe	dy	δ*	θ	Wake Velocity, u
	h_i	h_∞	$\Delta h_r = h_i - h_\infty$	$\Delta h_f = h_i - h_\infty$				

GRAPH:

1. dy vs Displacement Thickness
2. dy vs Momentum Thickness

RESULT:

The boundary layer displacement thickness is……………

The boundary layer momentum thickness is…………

VIVA QUESTIONS:

1. What is boundary layer thickness?
2. Calculate the displacement thickness and momentum thickness at a given set of points?
3. What is wake?
4. What are the assumptions in the wake rake experiment?

EXPERIMENT NO: 13

CALCULATION OF AERODYNAMIC COEFFICIENTS AND FORCES ACTING ON A MODEL AIRCRAFT USING FORCE BALANCE AT VARIOUS ANGLES OF INCIDENCE AND SPEED

AIM: To determine the aerodynamic coefficients and forces acting on a model aircraft using force balance at various speeds

EQUIPMENT: Subsonic wind tunnel, aircraft model, vertical sting

THEORY:

The variations of Lift, Drag and Moment depend on

- Free –stream velocity
- Free-stream density i.e. altitude
- Size of the aerodynamic surface
- Angle of attack
- Shape of the airfoil
- Viscosity coefficient
- Compressibility of the air flow

The Aerodynamic coefficients are given by

$$c_l = \frac{L}{q_\infty S}$$

$$c_d = \frac{D}{q_\infty S}$$

$$c_m = \frac{M}{q_\infty Sc}$$

PROCEDURE:

1. Fix the required force model in the vertical sting and tighten the bolts properly in such a way that the orientation will not be varied due to wind velocity.
2. Always fix the model facing towards upstream direction of the tunnel
3. Set the force and moment indicators to zero before starting the experiment

4. Now set the required air velocity using AC motor controller knob or potentiometer provided on the panel board.
5. Make a note of lift, drag and pitch moment values indicated on the corresponding digital indicators.
6. Repeat the experiment for different speeds

TABULAR COLUMN:

Sl. No.	Speed (rpm)	Coefficient of lift, c_l	Coefficient of drag, c_d	Coefficient of moment, c_m

RESULT:

VIVA QUESTIONS:

1. Define strain gauge.
2. Under what conditions can only the strain gauge are operated?
3. What is Wheatstone bridge principle?
4. How can the skin friction drag be evaluated for an airfoil?
5. Develop a process to estimate the induced drag and interference drag.

EXPERIMENT NO: 14

MEASUREMENT OF A TYPICAL BOUNDARY LAYER VELOCITY PROFILE ON THE AIRFOIL AT VARIOUS ANGLES OF INCIDENCE FROM LEADING EDGE TO TRAILING EDGE

AIM: To measure the boundary layer velocity profile by using pitot probe.

EQUIPMENT: Subsonic wind tunnel, boundary layer rake, multitube manometer

THEORY:

Boundary layer thickness (δ): It is defined as the distance from the boundary of the solid body measured in the y-direction to the point, where the velocity of fluid approximately reaches the free stream velocity of fluid.

Displacement thickness (δ*) : It is the distance measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in flow rate on account of boundary layer formation.

Momentum thickness (θ): Momentum thickness is defined as the distance measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in momentum of the flowing fluid on account of boundary layer formation.

PROCEDURE:

1. Mount the airfoil model in the test section at the required angle of attack and insert the boundary layer probe in the tunnel.
2. Connect the probe to manometer.
3. Connect the total head and pitot static tubes to manometer.
4. Note down the manometer reading and tabulate to get the boundary layer displacement thickness and momentum thickness.

FORMULA:

1. Displacement thickness (δ*):

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{U}\right) dy = \left(1 - \sqrt{\frac{\Delta h_r}{\Delta h_f}}\right) dy$$

Where,
- y = distance of elemental strip from the plate
- dy = thickness of elemental strip
- u = velocity of fluid at the elemental strip
- U = free stream velocity
- Δh_r = height of liquid column from probe rake with respect to tunnel total
- Δh_f = height of liquid column from pitot probe with respect to tunnel total

2. Momentum thickness (θ):

$$\theta = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy = \sqrt{\frac{\Delta h_r}{\Delta h_f}} \times \left(1 - \sqrt{\frac{\Delta h_r}{\Delta h_f}}\right) dy$$

3. Wake velocity (u):

$$\frac{2(p_i - p_\infty)_{wake}}{\rho} = u^2 \Rightarrow u = 129.7\sqrt{\Delta_{h(rake)}}$$

TABULAR COLUMN:

Probe No	Probe rake			Pitot probe	dy	δ*	θ	Wake Velocity, u
	h_i	h_∞	$\Delta h_r = h_i - h_\infty$	$\Delta h_f = h_i - h_\infty$				

GRAPH:

3. dy vs Displacement Thickness
4. dy vs Momentum Thickness

RESULT:

The boundary layer displacement thickness is……………

The boundary layer momentum thickness is…………

VIVA QUESTIONS:

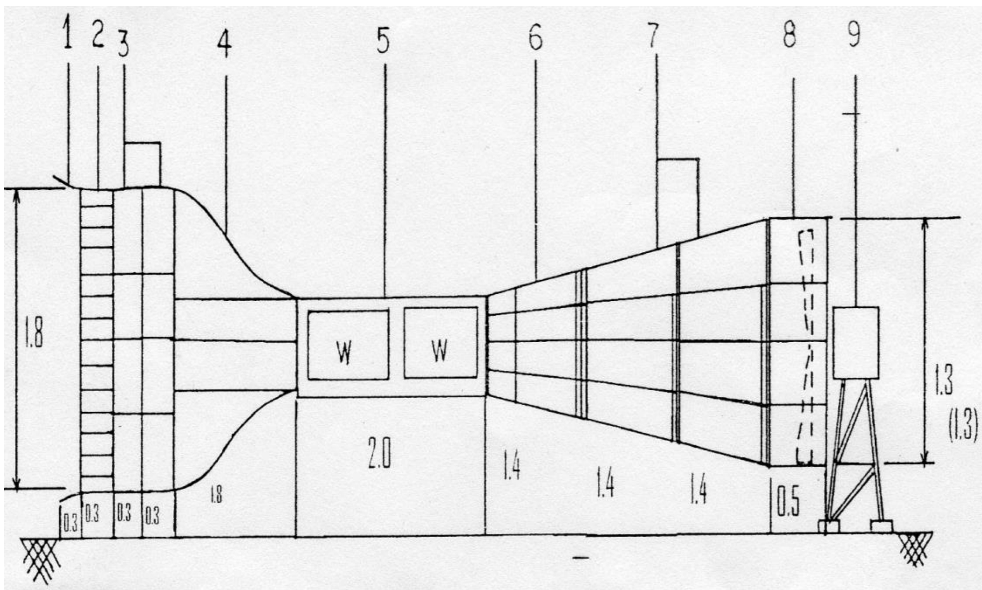
1. What is boundary layer thickness?
2. Calculate the displacement thickness and momentum thickness at a given set of points?
3. What is wake?
4. What are the assumptions in the wake rake experiment?

APPENDIX-1

OPEN CIRCUIT LOW SPEED SUBSONIC WIND TUNNEL FACILITY

Introduction:

Schematic of the wind tunnel at the aerodynamic laboratory is shown below:



PARTS

1. Bell mouthed section
2. Honey Comb
3. Settling Chamber, and screen section
4. Contraction cone OR Effuser
5. Test Section
6. Transition (square to circular)
7. Diffuser
8. Fan Duct
9. Motor and Stand

Performance of the Facility: The tunnel top speed is 50m/sec at 1500 r.p.m. The fan is driven by 3 phase AC motor. The speed in the tunnel is worked out as below:

Bernoulli's theorem: $p_0 - p = \frac{1}{2}\rho V^2$ (1)

p_0 = Static pressure in the settling chamber, and p= Static pressure in the test section

ρ = Density of air
v= velocity of air

$(p_0 - p)$, measured value is given by $\rho_w gh$, where ρ_w is the density of the liquid used in the manometer (Methyl alcohol is used at present), `g` is acceleration due to gravity and `h` is the vertical length of the liquid column sustaining the pressure measured (the difference between tunnel static and total). The total pressure of tunnel remains at atmospheric pressure at any speed of tunnel, since it is an open type tunnel.
Density of air at Bangalore is taken as 1.2. The density of alcohol is 0.8. If `h` is measured in mm of alcohol column, the velocity is given by the following relationship.

$$V(m/\sec) = 129.7\sqrt{\Delta h(mm)} \qquad (2)$$

If the measured liquid column length on the inclined manometer is h_m then h= { h_m-h_m (initial)}/2 because the inclination is 30^0 to the horizontal.

Tunnel Specifications:

- Wind Tunnel Type: Low Speed Subsonic, Open Circuit, Suction type
- Contraction ratio : 9:1
- Honey Comb Construction; Square Cross-Section
- Test Section Size: 600 x 600 x 2000 mm
- Test Section Velocity: 50 m/s
- Velocity Measurement: Pitot tube with digital velocity indicator
- Force measurement: using strain gauge with digital load/force indicator
- Speed Measurement: Digital speed indicator with proximity sensor
- Fan type: Axial Flow
- Number of Blades : 18
- Motor Capacity: 20 HP AC Motor
- Motor Control: AC Drive (50 Hz frequency)
- Power requirement: Ac 3 ph, 440 V, 32A with Earth and Neutral connection

Material of Construction:

- Effuser and Diffuser: wood
- Blower Frames and supporting Frames : Mild Steel
- Airfoil Pressure and Force Models: wood
- Smooth and Rough Cylinder Models : Mild steel
- Flow Visualization Models: Mild Steel and Wood

PRECAUTIONS TO BE TAKEN WHILE RUNNING THE TUNNEL:

1. Do not stand behind the motor while the tunnel is being run.
2. While starting tunnel motor, see that fan is clear **and that no one is around that area. Only competent people should handle the controller.** Main power must be highly secured .
3. Before starting the tunnel, check whether any loose parts are in the test section and remove these before start. See that test section is secured with C clamps.
4. Do not run tunnel below 100 r.p.m., as this will result in heating up of motor. Intermittent running at lower speeds is allowed. But do not exceed more than a minute or two.
5. As far as possible do not run the tunnel for long time at higher speeds.
6. It is recommended that blade angle setting be checked regularly once in few months. While checking the blade angle setting, check also the gaps between the blades and the surface of the fan section of the diffuser. Check also if any blade has become lose.
7. While Stopping, gradually decrease the speed and then switch OFF the AC motor controller

Smoke Generator

A picture of the smoke generator is shown in the figure 1, various parts of the smoke generator are numbered and nomenclature of those parts is given below:

1) Smoke generator module made of glass
2) Heating coil
3) Kerosene or liquid paraffin reservoir jar
4) Silicone tube connecting smoke generator and reservoir jar
5) Traverse to traverse the oil reservoir up and down
6) T connector -1 for by pass of pressurized air
6a) By pass valve
7) T connector-2 connecting pressurized air to reservoir jar as well as smoke generator module
8) T connector-3 for connecting the pressurized air to the two inlets A and B of smoke generator module
9) Oil drain flask
10) Smoke collector flask
11) Outlet tube for smoke generator
12) Spike buster extension/junction box with four sockets and individual switches for these sockets
13) Heater control
14) Centrifugal blower with inlet control disc

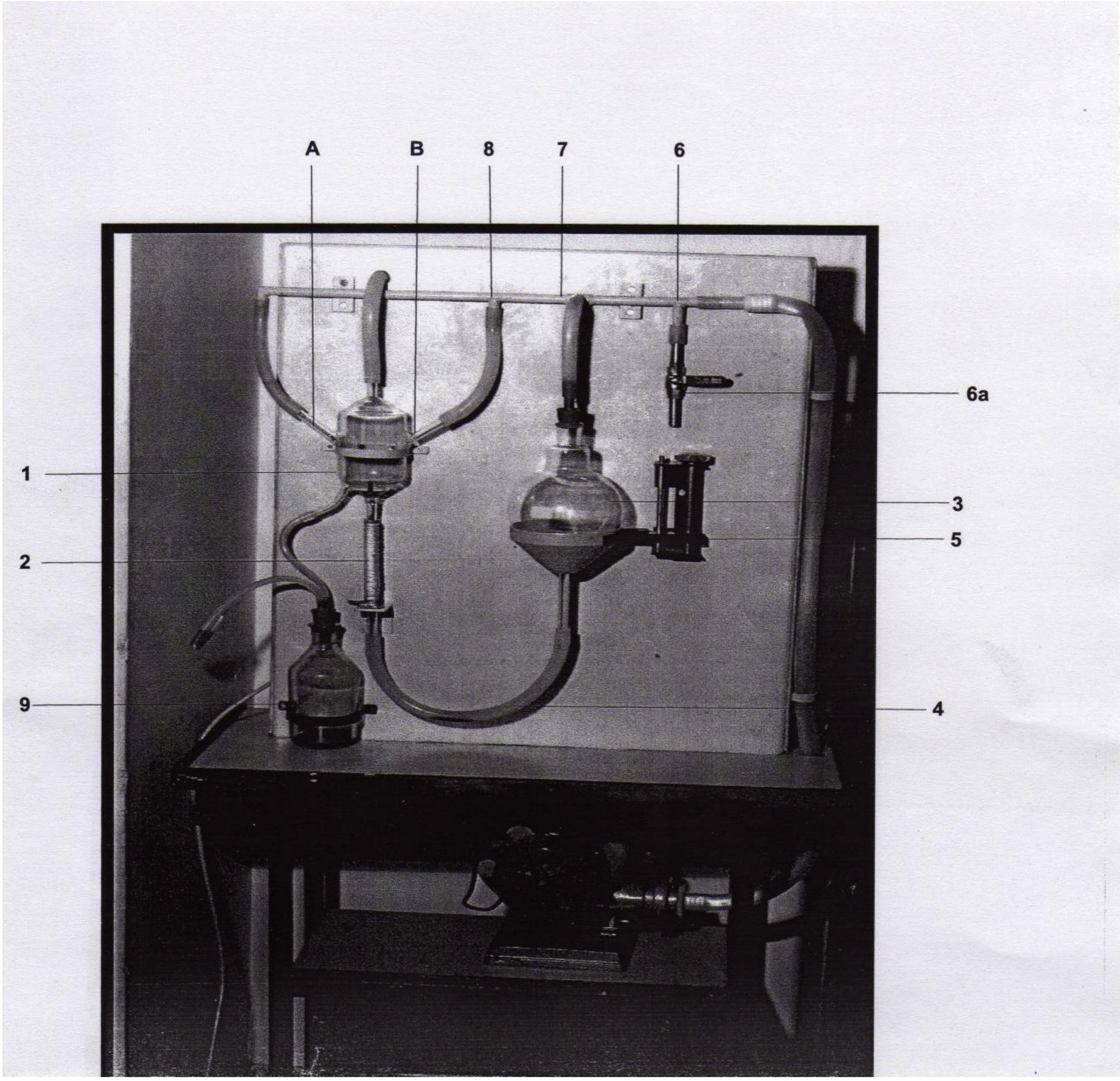


Fig. Front view of Smoke Generator with various parts numbered

There is an air blower at the bottom of the stand. The air from the blower is connected to a house pipe. The connection is made such that the pressurized air goes through a bypass T connector-1. The pressurized air through the systems can be controlled by opening the bypass valve so that a part of air is bleed out.

OPERATION OF THE SMOKE GENERATOR

Check all the connections of the tubes as shown in figure 1 and 2. Pour liquid paraffin into the reservoir so that half of it is filled. Then raise or lower the reservoir such that the liquid level in the bottom tube of the smoke generator modules is about 50mm below the nozzle outlet. Connect the heater through the heater control which is a 400W controller. Keep the controller at the minimum and switch on the heater using the junction box. Slowly increase the heating up to the ½ the capacity. Observe the liquid paraffin in the tube. It will start slowly boiling. The liquid level increases in the tube and the bubbles of liquid paraffin start reaching the nozzle exit. At this point of time, turn on the blower to send pressurized air. The cold air mixes with the vaporized oil and forms dense smoke. By properly controlling the heating as well the liquid level in the tube, a good dense white smoke can be generated. The out flow of smoke can be controlled by the bypass valve as well as the inlet control disc at the inlet to the bowler.

PRECAUTIONS

1. **Do not switch on the heater without the liquid paraffin being present in the tube level indicated already.**
2. **Unless the smoke is required, do not generate it and allow it to the atmosphere. Prolonged breathing of the smoke may be very disturbing.**
3. **Sometimes overheating may not produce the smoke. At these times restart the smoke generator from low heat again.**

APPENDIX-2

The symmetric Airfoil available for experiment has the following data.

LOCATION OF PRESSURE PORT HOLES ALONG THE CHORD.

Suction Surface (Upper)			Pressure Surface (Bottom)		
Pressure Tappings No.	X distance (Along Chord) mm	x/c	Pressure Tappings No.	X distance (Along Chord) mm	x/c
1	11.00	0.63	17	11.00	0.63
2	22.00	1.25	18	22.00	1.25
3	33.00	1.88	19	33.00	1.88
4	44.00	2.50	20	44.00	2.50
5	55.00	3.13	21	55.00	3.13
6	66.00	3.75	22	66.00	3.75
7	77.00	4.38	23	77.00	4.38
8	88.00	5.00	24	88.00	5.00
9	99.00	5.63	25	99.00	5.63
10	110.00	6.25	26	110.00	6.25
11	121.00	6.88	27	121.00	6.88
12	132.00	7.50	28	132.00	7.50
13	143.00	8.13	29	143.00	8.13
14	154.00	8.75	30	154.00	8.75
15	165.00	9.38	31	165.00	9.38
16	176.00	10.00	32	176.00	10.00
			33	0.00	0.00 (At Leading Edge)

Pressure Tapping No. 33 is at leading edge of an airfoil

Airfoil Data:

- Chord Length : 195 mm
- Span : 585 mm
- Aspect Ratio : 3
- Basic Airfoil : NACA 0015

APPENDIX-3
CAMBERED AIRFOIL

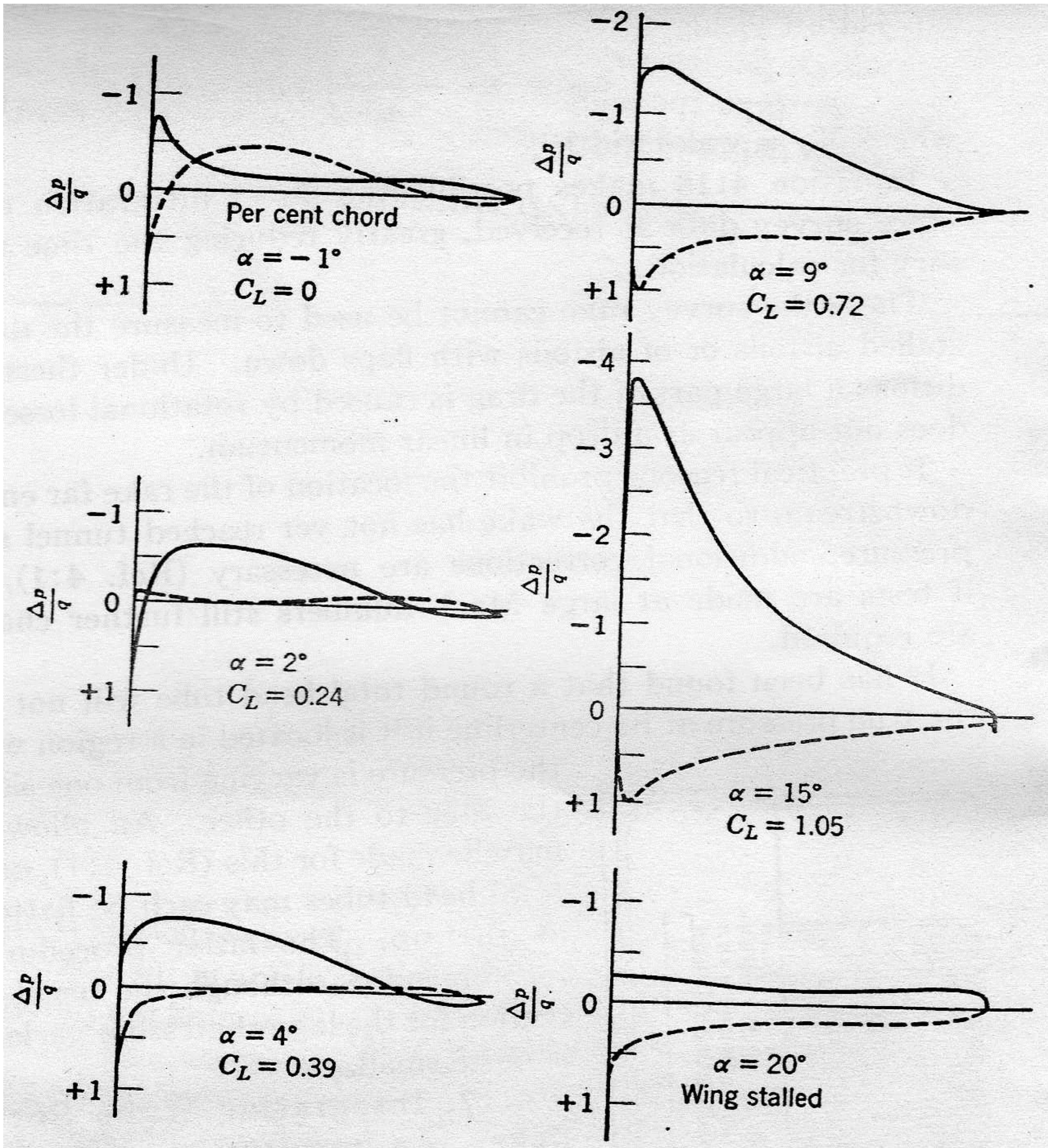


FIG. 4:40. Growth of static-pressure distribution with angle of attack.

The Cambered aerofoil data of experimental wing model is as below:

Suction Surface (Upper)			Pressure Surface (Bottom)		
Pressure Tappings No.	X distance (Along Chord) mm	x/c	Pressure Tappings No.	X distance (Along Chord) mm	x/c
1	11.00	0.63	17	11.00	0.63
2	22.00	1.25	18	22.00	1.25
3	33.00	1.88	19	33.00	1.88
4	44.00	2.50	20	44.00	2.50
5	55.00	3.13	21	55.00	3.13
6	66.00	3.75	22	66.00	3.75
7	77.00	4.38	23	77.00	4.38
8	88.00	5.00	24	88.00	5.00
9	99.00	5.63	25	99.00	5.63
10	110.00	6.25	26	110.00	6.25
11	121.00	6.88	27	121.00	6.88
12	132.00	7.50	28	132.00	7.50
13	143.00	8.13	29	143.00	8.13
14	154.00	8.75	30	154.00	8.75
15	165.00	9.38	31	165.00	9.38
16	176.00	10.00	32	176.00	10.00
			33	0.00	0.00 (At Leading Edge)

Pressure Tapping No. 33 is at leading edge of an airfoil

Airfoil Data:

- Chord Length : 195 mm
- Span : 585 mm
- Aspect Ratio : 3
- Basic Airfoil : NACA 2415

For NACA 2415

- Max camber : 2 %
- Max camber location : 40% from leading edge
- Max thickness : 15 %

APPENDIX 3

Location of Pressure Port along the circumference of the Cylinder

Cylinder							
Pressure Tappings No.	Angle, for graph	Angle, for calculations	Pressure Tapping Distance, mm	Pressure Tappings No.	Angle, for graph	Angle, for calculations	Pressure Tapping Distance, mm
1	0.00	-174.55	0.00	23	240.02	65.45	161.92
2	10.91	-163.64	7.36	24	250.93	76.36	169.28
3	21.82	-152.73	14.72	25	261.84	87.27	176.64
4	32.73	-141.82	22.08	26	272.75	98.18	184.00
5	43.64	-130.91	29.44	27	283.66	109.09	191.36
6	54.55	-120.00	36.80	28	294.57	120.00	198.72
7	65.46	-109.09	44.16	29	305.48	130.91	206.08
8	76.37	-98.18	51.52	30	316.39	141.82	213.44
9	87.28	-87.27	58.88	31	327.30	152.73	220.80
10	98.19	-76.36	66.24	32	338.21	163.64	228.16
11	109.10	-65.45	73.60	33	349.12	174.55	

12	120.01	-54.55	80.96				
13	130.92	-43.64	88.32				
14	141.83	-32.73	95.68				
15	152.74	-21.82	103.04				
16	163.65	-10.91	110.40				
17	174.56	0.00	117.76				
18	185.47	10.91	125.12				
19	196.38	21.82	132.48				
20	207.29	32.73	139.84				
21	218.20	43.64	147.20				
22	229.11	54.55	154.56				

APPENDIX 4

The Wake Rake used has the following data:

S.No	Δy	Δy/c
1	9.15	0.05
2	6	0.03
3	5.3	0.03
4	4.8	0.02
5	4.8	0.02
6	5.3	0.03
7	5.3	0.03
8	5.3	0.03
9	5.3	0.03
10	5.8	0.03
11	4.8	0.02
12	4.3	0.02
13	5.8	0.03
14	5.8	0.03
15	5.3	0.03
16	4.3	0.02
17	5.8	0.03
18	4.8	0.02
19	5.3	0.03
20	5.3	0.03
21	5.3	0.03
22	5.8	0.03
23	5.8	0.03
24	5.8	0.03
25	4.8	0.02
26	5.3	0.03
27	5.3	0.03
28	5.8	0.03
29	5.8	0.03
30	5.3	0.03
31	5.3	0.03

APPENDIX- 5

The Boundary Layer Rake data for calculation of dy is as below:
Distance from the Wall of RAKE tapings

Sl. No	dy
1	0.0018
2	0.0026
3	0.0026
4	0.0026
5	0.0026
6	0.0026
7	0.0026
8	0.0041
9	0.0041
10	0.0036
11	0.0041
12	0.0031
13	0.0046
14	0.0041
15	0.0056

Rake must be aligned with flow direction and the tube no. 1 should touch the wall of tunnel.