DEPARTMENT OF AEROSPACE ENGINEERING

ACS COLLEGE OF ENGINEERING

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AERODYNAMICS LAB MANUAL

(Prescribed for V – Semester Aerospace Engineering)

ACADEMIC YEAR 2020 – 2021

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List of Experiments

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6. Surface pressure distribution on a two-dimensional symmetric airfoil at zero angle of incidence at low speeds and calculation of Pressure drag.
7. Surface pressure distribution on a two-dimensional cambered airfoil at different angles of incidences and calculation of lift and pressure drag.
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9. Calculation of total drag of a two-dimensional cambered airfoil at low speeds at incidence using pitot-static probe wake survey.
10. 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.

Experiment No: 1 **Date:**

Calibration of a subsonic wind tunnel by Test section static pressure and total head distributions

Aim:

To calibrate the low speed subsonic open circuit wind tunnel.

Equipment:

Subsonic Wind tunnel, Manometer, Pitot - static tube.

Theory:

The calibration of wind tunnel is done to measure the tunnel speed, where the tunnel speed is the mean wind speed at the test section when the tunnel is empty. The tunnel speed is measured by measuring the dynamic pressure which can be measured through Pitot-static tube which is based on the Bernoulli's equation given by,

$$P_o - P = \frac{1}{2}\rho V^2$$

Where,
P_0-Total pressure of the fluid (air)
P -Static pressure of the fluid (air) in the test section
ρ -Density of fluid (air)
V -Velocity of fluid (air) in the test section

The dynamic pressure, $(P_0 - P)$ can be calculated by measuring the differential head in the multitube monometer connected to Pitot-static tube.

Procedure:

1. Check the wind tunnel for any loose parts.
2. Check the level of manometer liquid in multitube manometer.
3. Connect the total and static pressure port of the Pitot tube to the manometer tubes for measuring the pressure.
4. Note down the initial reading in the manometer.
5. Run the tunnel at different speeds and note down the manometer reading in multitube manometer and inclined manometer.
6. Calculate the velocity of air flow as per the formula.
7. Plot the graph, Flow velocity VsFan Speed (in rpm).

Formulae:

Velocity calculation using multitubemanometer:

From Bernoulli's equation, we have

$$V = \sqrt{\frac{2(P_o - P)}{\rho_{air}}}$$

or

$$V = 4.22\sqrt{(h_o - h)}$$

i.e. $V = 4.22\sqrt{(\Delta h)}$

Where, $(h_0 - h)$ or Δh is the differential head of the monometric fluid (water).Density of air at Bangalore is taken as 1.1 kg/m^3 andthe density of water is 1000 kg/m^3.

Tabular Column:

Sl.No.	Fan Speed (RPM)	Multitube Manometer Reading (mm)			Calculated Velocity (m/s)	Digital Panel Readings	
						Differential pressure head, Δh (mm)	Velocity (m/s)
		h_i	h_f	$\Delta h = h_f - h_i$			
1							
2							
3							
4							

Graph:

Fan speed VsFluid velocity

Result:

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

Experiment No:2 **Date:**

Smoke flow visualization studies on a two dimensional circular cylinder at low speeds

Aim:

To carryout 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 in the tunnel testsection 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.

Formulae:

1. Reynolds Number:

$$Re = \frac{\rho V D}{\mu}$$

Where, ρ - Density of air=1.1 Kg/m^3

V - Velocity of air, m/s

D - Diameter of cylinder=0.050 m

μ - Dynamic viscosity of air, $1.7e^{-5} Ns/m^2$

Tabular Column:

Sl.No	Fan speed (RPM)	Velocity (m/s)	Re	Flow pattern	Inference
1					
2					
3					

Result:

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

Experiment No:3 **Date:**

Smoke flow visualization studies on a two dimensional airfoil at different angle of incidence

Aim:

To carryout 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 wing 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 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. Reynolds Number:

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

Where, ρ - Density of air=1.1 Kg/m^3

V - Velocity of air, m/s

D - Chord length=0.150 m

μ - Dynamic viscosity of air, $1.7e^{-5}$ Ns/m^2

Tabular Column:

Sl.No	Angle of attack, α	Fan speed (RPM)	Velocity (m/s)	Re	Flow pattern	Inference
1						
2						
3						

Result:

Thus the flow visualization is carried out and the flow pattern around the body at different angle of attack and velocity is observed.

Experiment No: 4 **Date:**

Tuft flow visualization studies on a two dimensional airfoil at different angle of incidence at low speeds

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. Reynolds Number:

$$Re = \frac{\rho V D}{\mu}$$

Where, ρ - Density of air=1.1 Kg/m^3

V - Velocity of air, m/s

D - Cord Length=0.150 m

μ - Dynamic viscosity of air, 1.7e^{-5} Ns/m^2

Tabular column:

Sl.No	Fan speed	Angle of Attack, α	Velocity (m/s)	Re	Inference
1					
2					
3					

Result:

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

Experiment No:5 **Date:**

Surface Pressure distributions on a two-dimensional 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:

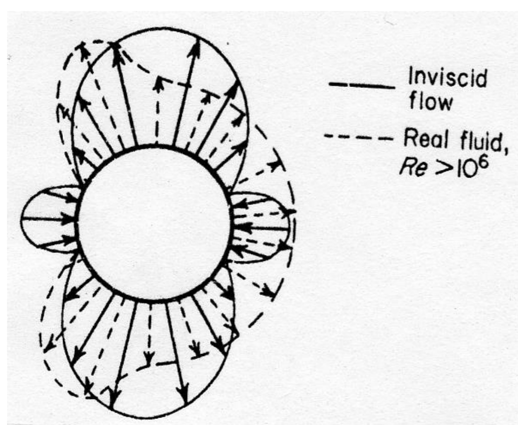


Fig: Ideal flow and Actual static pressure distribution over a circular cylinder

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.
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.

Formula:

1. Co-efficient of pressure:

$$C_p = \frac{P_i - P_\infty}{P_o - P_\infty} = \frac{h_i - h_\infty}{h_o - h_\infty}$$

Where, P_i= Local Static pressure values measured around cylinder
P_∞ = Free stream static pressure measured by pitot-static probe
P_o = Free stream total pressure measured by pitot-static probe
h = manometer liquid column height

2. Dynamic Pressure:

$$q = P_o - P_\infty = \frac{1}{2}\rho V^2$$

3. Pressure:

$$P = \rho g h$$

Where, ρ - Density of alcohol=0.8 Kg/m^3, h-manometer liquid height.

4. Co-efficient of Pressure theoretical:

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

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

5. Co-efficient of drag:

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

Tabular Column:

Sl. No	Manometer reading			Dynamic Pressure	Differential pressure	Experimental Coefficient of Pressure	Drag calculation				Theoretical Coefficient of pressure
	h_o	h_∞	h_i	q $=h_o - h_\infty$	$\Delta P = h_i - h_\infty$	$C_p = \Delta P/q$	θ (rad)	dθ	Cosθ	$C_p \text{Cos}\theta \times d\theta$	$1-4\text{Sin}^2\theta$
							$\sum C_p \cos\theta d\theta$				

Graph:

C_p Vs θ

Result:

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=

Experiment No:6 **Date:**

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, 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.

Formula:

1. Co-efficient of pressure:

$$C_p = \frac{P_i - P_\infty}{P_o - P_\infty} = \frac{h_i - h_\infty}{h_o - h_\infty} = \frac{\Delta P}{q}$$

Where, Pi= Local Static pressure values measured around cylinder
P_∞ = Free stream static pressure measured by pitot-static probe
P_o = Free stream total pressure measured by pitot-static probe
h = manometer liquid column height

2. Dynamic Pressure:

$$q = P_o - P_\infty = \frac{1}{2}\rho V^2$$

3. Pressure:

$$P = \rho g h$$

Where, ρ - Density of alcohol=0.8 Kg/m^3, h-manometer liquid height.

Tabular Column:

Angle of attack: Speed:

Port. No	Manometer reading			Dynamic Pressure	Differential pressure	Coefficient of Pressure	X/C
	h_o	h_∞	h_i	$q=h_o- h_\infty$	$\Delta P=h_i- h_\infty$	$C_p= \Delta P/q$	
1							
2							
3							

Graph:

C_pVsX/C

Result:

Thus the pressure distribution around the cylinder is measured and the drag of the cylinder is estimated.

Experiment No: 7 **Date:**

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.

Formula:

1. Co-efficient of pressure:

$$C_p = \frac{P_i - P_\infty}{P_o - P_\infty} = \frac{h_i - h_\infty}{h_o - h_\infty} = \frac{\Delta P}{q}$$

Where, P_i= Local Static pressure values measured around cylinder
P_∞ = Free stream static pressure measured by pitot-static probe
P_o = Free stream total pressure measured by pitot-static probe
h = manometer liquid column height

2. Dynamic Pressure:

$$q = P_o - P_\infty = \frac{1}{2}\rho V^2$$

3. Pressure:

$$P = \rho g h$$

Where, ρ - Density of alcohol=0.8 Kg/m^3, h-manometer liquid height.

4. Co.efficeient of lift and drag:

Normal coefficient, $C_n = \int_0^1 (C_{pl} - C_{pu}) \times d(X/C)$

Lift Coefficient, $C_l = C_n \times Cos\alpha$

Drag Coefficient, $C_d = C_n \times Sin\alpha$

Tabular Column:

Angle of attack: Speed:

Port. No	Manometer reading			Dynamic Pressure	Differential pressure	Coefficient of Pressure	X/C
	h_o	h_∞	h_i	$q=h_o- h_\infty$	$\Delta P=h_i- h_\infty$	$C_p= \Delta P/q$	
1							
2							
3							

Sl.No	C_{pl}	C_{pu}	$\Delta_{Cp} = C_{pl} - C_{pu}$	d(X/C)	$\Delta_{Cp} \times d(X/C)$

Graph:

C_p Vs X/C

C_l Vs α

C_d Vs α

Result:

Thus the pressure distribution around the airfoil is measured and the drag is estimated at various angles of attack.

Experiment No: 8 **Date:**

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, Multitubes 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.

Diagram:

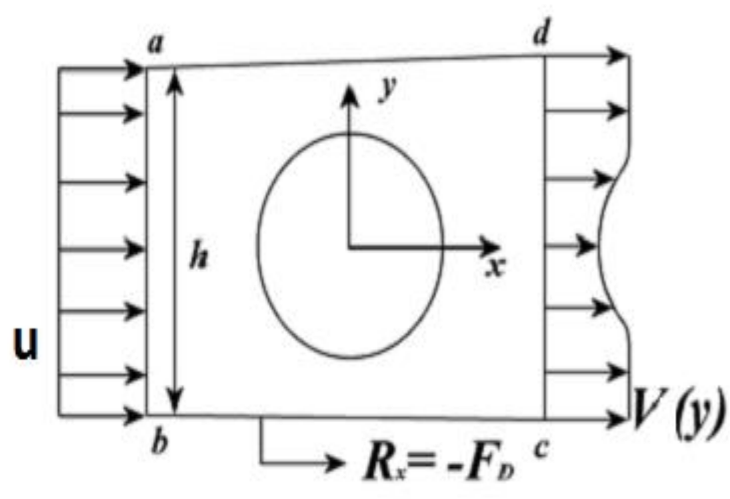


Fig 1: Velocity profile in the wake region

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:

$$C_d = 2\int \left[\sqrt{\frac{q_{wake}}{q_{freestream}}} - \frac{q_{wake}}{q_{freestream}} \right] \frac{dy}{c}$$

Where	q_{wake}	= $(h_o - h_\infty)_w$ (calculated in wake region)
	$q_{freestream}$	= $(h_o - h_\infty)_f$(calculated for free stream)
	dy	= Lateral spacing between tubes of wake probe rake
	c	= Circumference of the cylinder

i.e C_d = 2×∑XY, where ∑XY represents the entire integral term in the above equation

Note: In the absence of static probe in wake rake, free stream static pressure is taken as static pressure in wake.

2. Wake Velocity:

$$\frac{2(P_o - P_\infty)_{wake}}{\rho} = V^2 \Rightarrow V = 3.77\sqrt{(h_o - h_\infty)_{wake}}$$

Tabular Column:

Sl No	PitotProbe Reading			Wake probe reading			A	MN	XY=MN× dy/c	Wake velocity
	h_o	h_∞	h_o-h_∞	h_o	h_∞	h_o-h_∞	$(h_o-h_\infty)_W/(h_o-h_\infty)_f$	$\sqrt{A} - A$		V
								$\sum XY=$		

Graph:

dyVs 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…………

Experiment No: 9 **Date:**

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, Multitubes 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 up stream 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:

$$C_d = 2\int\left[\sqrt{\frac{q_{wake}}{q_{freestream}}} - \frac{q_{wake}}{q_{freestream}}\right]\frac{dy}{c}$$

Where	q_{wake}	$= (h_o - h_\infty)_w$ (calculated in wake region)
	$q_{freestream}$	$= (h_o - h_\infty)_f$ (calculated for free stream)
	dy	= Lateral spacing between tubes of wake probe rake
	c	= Circumference of the cylinder

i.e C_d = 2×∑XY, where ∑XY represents the entire integral term in the above equation

Note: In the absence of static probe in wake rake, free stream static pressure is taken as static pressure in wake.

2. Wake Velocity:

$$\frac{2\left(P_o - P_\infty\right)_{wake}}{\rho} = V^2 \Rightarrow V = 3.77\sqrt{(h_o - h_\infty)_{wake}}$$

Tabular Column:

Sl No	Pitot Probe Reading			Wake probe reading			A	MN	XY=MN× dy/c	Wake velocity
	h_o	h_∞	h_o-h_∞	h_o	h_∞	h_o-h_∞	$(h_o-h_\infty)_w/(h_o-h_\infty)_f$	$\sqrt{A}$ - A		V
								∑XY=		

Graph:

dyVs 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…………

Experiment No: 10 **Date:**

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 static
Δh_f = height of liquid column from pitot probe with respect to tunnel static

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):

$$\frac{2\left(P_o - P_\infty\right)_{wake}}{\rho} = u^2 \Rightarrow u = 3.77\sqrt{(h_o - h_\infty)_{rake}}$$

Tabular Column:

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

Graph:

1. Probe no VS u

Result:

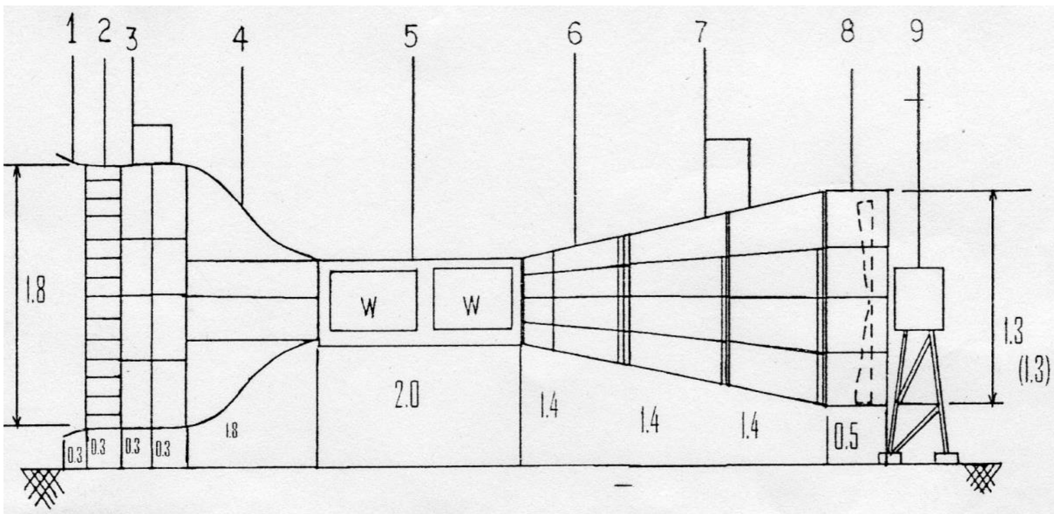
The boundary layer displacement thickness is…………..
The boundary layer momentum thickness is…………

APPENDIX-1

OPEN CIRCUIT 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
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.

$$V(m/\sec) = 3.77\sqrt{h(mm)} \qquad (2)$$

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:

Test section size: Cross Section: 600mm x 600mm

Length: 2 meters

Maximum Speed = 50 m/sec

Max r.p.m. = 1500

Contraction ratio = 9:1

Contraction length: 1.8m

Test section has four Perspex windows for viewing inside the rest test section. The top can be opened for easy access to the test section so that it becomes convenient to set up experiment.

The fabrication of tunnel is done using teak wood and water proof plywood.

Tunnel Performance:

The table below indicates measured performance of tunnel

R.P.M. (Controller)	Velocity m/sec
100	3.77
200	7.31
300	10.51
500	17.81
700	25.55
900	33.00
1100	39.9
1400	50.78

Avoid running tunnel below 100 r.p.m. to avoid overheating.

PRECAUTIONS TO BE TAKEN WHILE RUINING THE TUNNEL:

1. Do not allow any one to stand behind the motor while the tunnel is being run.
2. While staring tunnel motor, see that fan is clear **<u>and that no one is around that area</u>. 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.

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

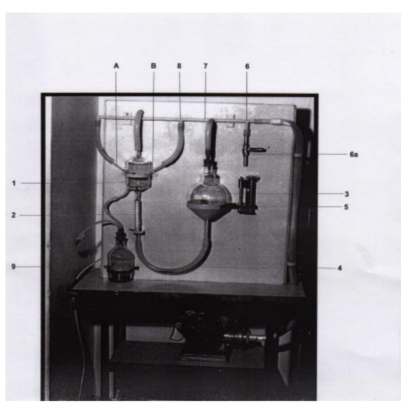


Fig.1. Front view of Smoke Generator with variousparts numbered.

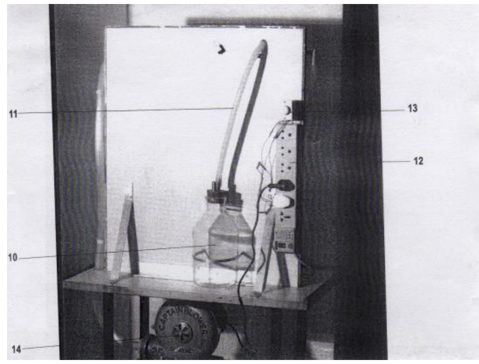


Fig.2. Back view of the Smoke Generator withvarious parts numbered.

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 by pass 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 Aerofoil available for experiment has the following data.

150 mm chord length.

15% thick Aerofoil: NACA 66_2-015

X,mm	Y,mm
0	0
.75	1.683
1.125	2.015
1.875	2.513
3.75	3.353
7.50	4.65
11.25	5.672
15.00	6.537
22.50	7.929
30.00	8.993
37.50	9.815
45.0	10.434
52.50	10.875
60.00	11.145
67.50	11.243
75.00	11.175
82.50	10.925
90.00	10.439
97.50	9.558
105.00	8.364
112.50	6.448
120.00	5.397
127.50	3.795
135.00	2.22
142.50	0.849
150.00	0.

Source of Data `Abot and Van-Doenoff`- Theory of wings

Location of pressure port holes along the chord.

Upper Surface			**Lower Surface**		
Hole no.	**Distance from leading edge X (mm)**	**X/C x 10**	**Hole no.**	**Distance from leading edge X (mm)**	**X/C x 10**
1	**0**	**0**	**14**	**6.0**	**0.4**
2	**1.5**	**0.1**	**15**	**12.0**	**0.8**
3	**3.0**	**0.2**	**16**	**22.5**	**1.5**
4	**6.0**	**0.4**	**17**	**40.5**	**2.7**
5	**12.0**	**0.8**	**18**	**58.5**	**3.9**
6	**22.5**	**1.5**	**19**	**78.0**	**5.2**
7	**40.5**	**2.7**	**20**	**97.0**	**6.5**
8	**58.5**	**3.9**	**21**	**117.0**	**7.8**
9	**78.0**	**5.2**	**22**	**135.0**	**9.0**
10	**97.0**	**6.5**			
11	**117.0**	**7.8**			
12	**135.0**	**9**			
13	**150.0**	**10**			

APPENDIX-3

Cambered airfoil

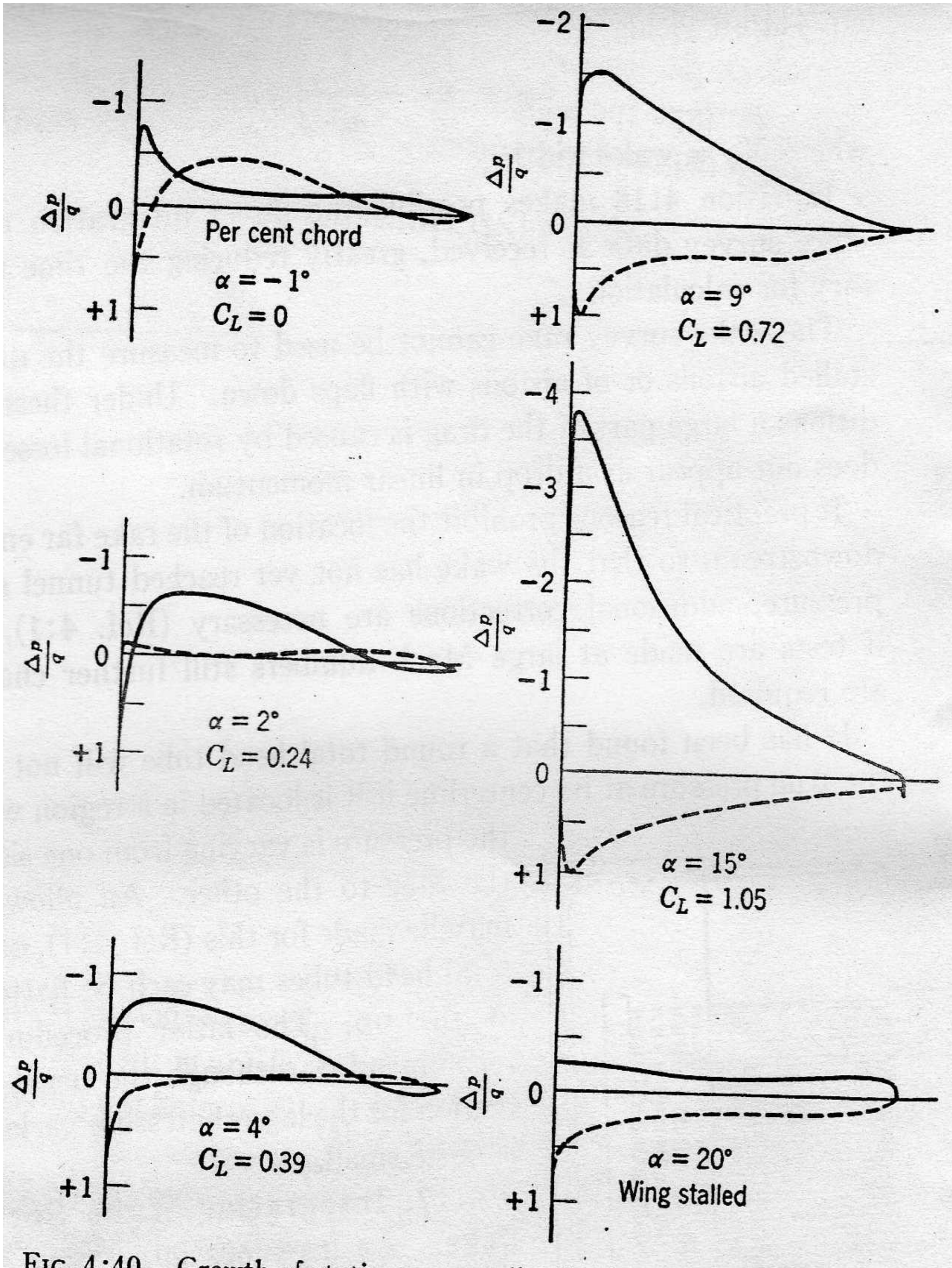


FIG. 4:40. Growth of static-pressure distribution with angle of attack.

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

150 mm chord length, 15% thickness,

Basic Aerofoil: NACA 66_2-015

C_L (Incompressible) 1.0 at 4.56^0 angle of attack and

C_m at quarter chord point= 0.083

Bottom Y,mm	**X,mm**	**Upper Y,mm**
-.990	**0.**	**0.**
-.993	**0.75**	**2.373**
-1.054	**1.125**	**2.9771**
-1.067	**1.875**	**3.959**
-0.892	**3.75**	**5.815**
-0.611	**7.50**	**8.699**
-0.412	**11.25**	**10.933**
-0.296	**15.00**	**12.779**
-0.243	**22.5**	**15.615**
-0.373	**30.00**	**17.614**
-0.644	**37.50**	**18.986**
-1.019	**45.00**	**19.850**
-1.466	**52.50**	**20.285**
-1.950	**60.00**	**20.340**
-2.437	**67.5**	**20.050**
-2.901	**75.00**	**19.449**
-3.304	**82.50**	**18.547**
-3.568	**90.00**	**17.311**
-3.51	**97.50**	**15.606**
-3.197	**105.00**	**13.532**
-2.694	**112.50**	**11.202**
-2.072	**120.00**	**8.723**
-1.389	**127.50**	**6.201**
-.701	**135.00**	**3.740**
-0.149	**142.50**	**1.550**
0.	**150.00**	**0.**

Source of Data `Abot and Van-Doenoff`-Theory of wing sections

Location of pressure port holes along the chord.

Upper Surface			Lower Surface		
Hole no.	**Distance from leading edge X (mm)**	**X/C x 10**	**Hole no.**	**Distance from leading edge X (mm)**	**X/C x 10**
1	0	0	14	6.0	0.4
2	1.5	0.1	15	12.0	0.8
3	3.0	0.2	16	22.5	1.5
4	6.0	0.4	17	40.5	2.7
5	12.0	0.8	18	58.5	3.9
6	22.5	1.5	19	78.0	5.2
7	40.5	2.7	20	97.0	6.5
8	58.5	3.9	21	117.0	7.8
9	78.0	5.2	22	135.0	9.0
10	97.0	6.5			
11	117.0	7.8			
12	135.0	9			
13	150.0	10			

Appendix 4

The Wake Rake used has the following data:

DISTANCE FROM CENTER OF TUBE No 1

1	0.0
2	3.7
3	6.7
4	9.2
5	12.7
6	15.7
7	18.7
8	21.7
9	24.7
10	28.2
11	30.7
12	32.7
13	36.2
14	39.7
15	42.7
16	44.7
17	48.2
18	50.7
19	53.7
20	56.7
21	59.7
22	63.2
23	66.7
24	69.2
25	71.7
26	74.7
27	77.7
28	81.2
29	84.5
30	87.5

APPENDIX- 5

The Boundary Layer Rake data for calculation of dy is as below:

Distance from the Wall of RAKE tapings

Tube no.	Distance (mm)
1	0.3
2	1.0
3	2.0
4	3.0
5	4.5
6	5.5
7	6.5
8	9.0
9	11.5
10	13.5
11	16.0
12	17.5
13	20.5
14	23.0
15	25.5

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