

# **AERODYNAMICS AND PROPULSION LABORATORY**

## **LAB MANUAL**

**Course Code : AAEB12**  
**Regulation : IARE-R18**  
**Class : II Year II Semester**  
**Branch : Aeronautical Engineering**  
**Year : 2019- 2020**



**Department of Aeronautical Engineering**

**INSTITUTE OF AERONAUTICAL ENGINEERING**

**(Autonomous)**

**Dundigal – 500 043, Hyderabad**



# INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad - 500 043

## AERONAUTICAL ENGINEERING

<b>Program Outcomes</b>	
<b>PO1</b>	<b>Engineering knowledge:</b> Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
<b>PO2</b>	<b>Problem analysis:</b> Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences
<b>PO3</b>	<b>Design/development of solutions:</b> Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
<b>PO4</b>	<b>Conduct investigations of complex problems:</b> Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
<b>PO5</b>	<b>Modern tool usage:</b> Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
<b>PO6</b>	<b>The engineer and society:</b> Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
<b>PO7</b>	<b>Environment and sustainability:</b> Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
<b>PO8</b>	<b>Ethics:</b> Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
<b>PO9</b>	<b>Individual and team work:</b> Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
<b>PO10</b>	<b>Communication:</b> Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
<b>PO11</b>	<b>Life-long learning:</b> Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.
<b>PO12</b>	<b>Project management and finance:</b> Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

### Program Specific Outcomes

<b>PSO1</b>	<b>Professional skills:</b> Able to utilize the knowledge of aeronautical/aerospace engineering in innovative, dynamic and challenging environment for design and development of new products
<b>PSO2</b>	<b>Problem solving skills:</b> Imparted through simulation language skills and general purpose CAE packages to solve practical, design and analysis problems of components to complete the challenge of airworthiness for flight vehicles
<b>PSO3</b>	<b>Practical implementation and testing skills:</b> Providing different types of in house and training and industry practice to fabricate and test and develop the products with more innovative technologies
<b>PSO4</b>	<b>Successful career and entrepreneurship:</b> To prepare the students with broad aerospace knowledge to design and develop systems and subsystems of aerospace and allied systems and become technocrats.

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7	Calculation of work, power and Thrust requirement in gas turbine- combustion power input, work heat relationship.	
8	Elucidate T-S, H-S diagrams for the gas turbine and compare efficiencies of non-ideal engine components.	
9	Calculation of thermal, propulsive and overall efficiency of turbo jet cycle.	
10	Calculation of various nozzle performance with airflow	
11	Calculation of calorific value of different fuels and materials using digital bomb calorimeter and optimizing astute fuels	
12	Calculation of propeller efficiency and thrust availability using propeller test rig at various blade pitch angles.	

## ATTAINMENT OF PROGRAM OUTCOMES & PROGRAM SPECIFIC OUTCOMES

<b>Exp. No.</b>	<b>Experiment</b>	<b>Program Outcomes Attained</b>	<b>Program Specific Outcomes Attained</b>
1	Calibration of subsonic wind tunnel, Pressure distribution over cylinder.	PO1	PSO1
2	Pressure distribution and flow visualization over symmetric, cambered airfoil	PO1	PSO1
3	Force measurement using wind tunnel balance.	PO 1, PO 2, PO 3, PO 4	PSO1
4	Wake analysis over a cylinder and airfoils	PO 1, PO 2	PSO1
5	Flow over a flat plate	PO 1, PO 2, PO 3	PSO1
6	Efficiency of blower test rig for 3 different vane settings.	PO 1, PO 2, PO 3	PSO1
7	Calculation of work, power and Thrust requirement in gas turbine- combustion power input, work heat relationship.	PO 1, PO 2, PO 3	PSO1
8	Elucidate T-S, H-S diagrams for the gas turbine and compare efficiencies of non-ideal engine components.	PO 2, PO 3	PSO1
9	Calculation of thermal, propulsive and overall efficiency of turbo jet cycle.	PO 1, PO 3	PSO1
10	Calculation of various nozzle performance with airflow	PO 1, PO 3	PSO1
11	Calculation of calorific value of different fuels and materials using digital bomb calorimeter and optimizing astute fuels	PO 1,PO 2, PO 3	PSO1
12	Calculation of propeller efficiency and thrust availability using propeller test rig at various blade pitch angles.	PO 1, PO 3	PSO1

# **Aerodynamics and Propulsion Laboratory**

## **OBJECTIVE:**

The objective is to understand basic knowledge on aerodynamic behavior of aerodynamic models and to understand gas turbine engine performance.

## **OUTCOMES:**

Upon the completion of aerodynamics and propulsion course, the student will be able to attain the following:

Understand the behavior of flow properties over different models using subsonic wind tunnel

Demonstrate experimentally the pressure distribution over circular, symmetric and cambered airfoils and evaluate lift and drag.

Illustrate flow visualization studies at low speeds over different aerodynamic bodies.

Understand the basics of propulsion, working principles of reciprocating engines, performance estimation based on rotation angles, and components of engine and their functions

Calculation of percentage of carbon residue and flash and fire point temperatures of a Lubricating Oil.

## WEEK-1

### CALIBRATION AND PRESSURE DISTRIBUTION-CYLINDER

#### A. Calibration of Wind Tunnel

##### AIM:

To calibrate the wind tunnel test section velocity against the fan RPM.

##### APPARATUS:

- Wind tunnel with electronic controller
- Inclined tube manometer
- Multi tube manometer
- Pitot static probe

##### THEORY:

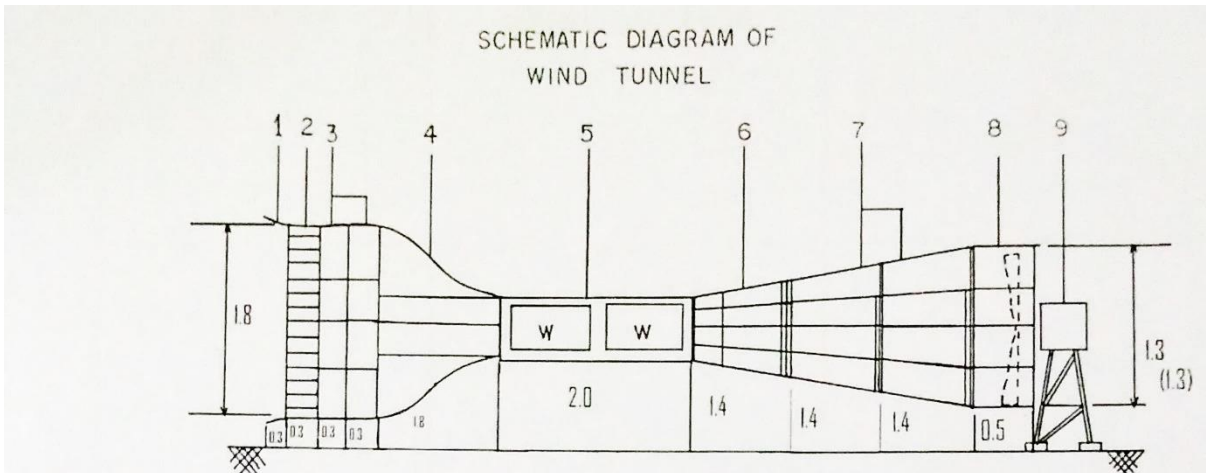
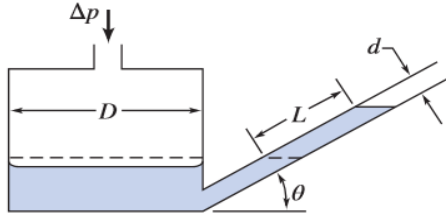


Figure1: Schematics of the wind tunnel.

#### PARTS.

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

### Inclined tube manometer



### PROCEDURE:

1. Note down the reading on the inclined tube of the manometer before switching on the fan motor of the wind tunnel.
2. Slowly start increasing the RPM of the fan motor and at some frequent intervals (say 10)
3. Precautions are ensured not to reach the maximum limits of the motor
4. Thus velocity is calculated using inclined tube manometer at every RPM observed.
5. Velocity is also calculated using Pitot static probe and multitube manometer board.
6. A best linear curve is fitted for the given observations.

### OBSERVATIONS:

RPM (controller)	Inclined manometer Reading $h_m$ (mm)( $h_m - h_i$ ) / 2 (mm)	Velocity (m/s) in the test section

### Calculations:

$h_i = h_m$  at zero RPM

$$h = (h_m - h_i) \times \sin(\theta) \quad \theta = 30^\circ$$

$$h = (h_m - h_i) / 2$$

$$V_{test\ section} = \frac{\left[ \sqrt{(\rho_l \times g \times h \times 2) \div \rho_{air}} \right]}{\sqrt{\left[ 1 - \frac{A_{test\ section}^2}{A_{inlet}^2} \right]}}$$

$$\rho_l = 800 \text{ Kg/m}^3 \text{ (methyl alcohol)}$$

$$g = 9.81 \text{ m/s}^2 \text{ (approximate)}$$

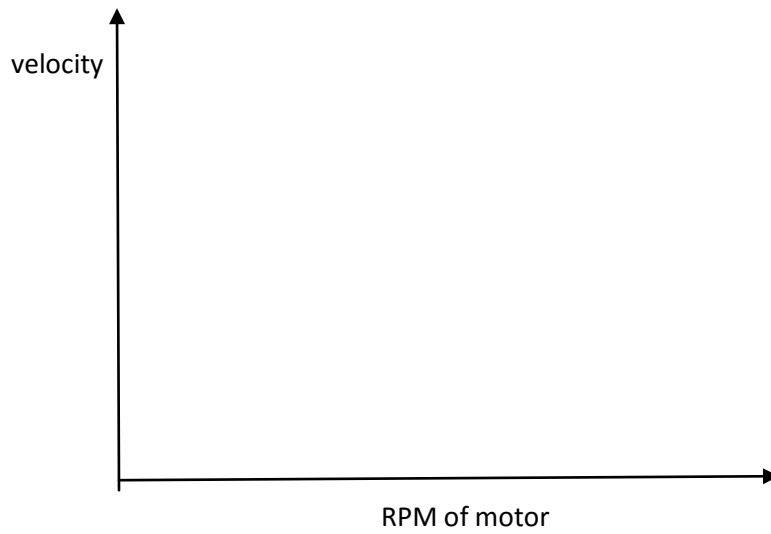
$$\rho_{air} = 1.2 \text{ Kg/m}^3 \text{ (approximate)}$$

$$v(m / s) = 3.68 \sqrt{h(mm)}$$



**Result:**

Fit a linear curve for the test section velocity vs RPM of the fan



Using the above fit try to set the RPM for a desired velocity and try to calculate the error from the inclined tube manometer for a random of five different velocities samples

Superimpose the fits of different groups (observations at different set of RPMs) and try to compare the results of the preceding activity (error estimation).

## B. PRESSURE DISTRIBUTION OVER CYLINDER

### Aim:

To find  $C_p$  distribution over a Circular Cylinder.

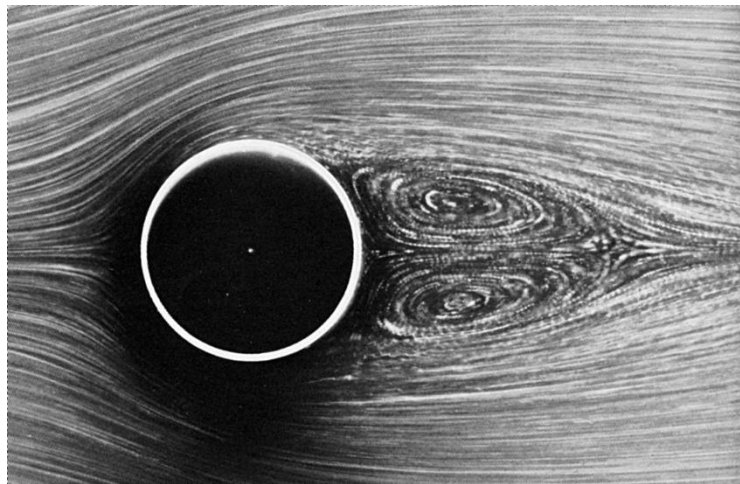
### Apparatus:

Wind Tunnel, Pitot Static Tube, Multi tube Manometers and Circular Cylinder.

### Principle:

Typically a cylinder is an axisymmetric body and thus the pressure distribution is expected to be symmetric from the potential theory, by superimposing uniform flow with a doublet. Potential theory assumes flow to be inviscid, steady and irrotational. In reality the above assumptions may become void. Thus experimental study is performed to ensure at which point the potential theory doesn't hold good is observed by varying Reynolds number.

Thus coefficient of pressure is given by  $C_{p,theoretical} = 1 - (4 \sin^2 \theta)$ , where  $\theta$  is the angle measured from the upstream horizontal point using the potential theory.



### Description:

Experimentally to evaluate the  $C_p$  distribution over a circular cylinder, pressure taps are provided over the surface of the circular cylinder at even number of locations for every  $5^\circ$  as shown in the figure.



### Procedure:

1. Mount the circular cylinder using the wall mounting point.
2. Connect all the pressure tap connections to the multitube manometer

### Precautions:

1. Ensure the RPM is not operated at the limits of the fan motor.

2. Ensure that no loose objects are in place inside the test section.
3. Ensure that there is no blockage upstream of the test section.
4. Moving downstream of the fan motor is hazardous during the operation of the tunnel.

**Observations:**

$h_{static} = \dots\dots\dots$  mm                      Inclined tube manometer reading ( $h_m$ ) =  $\dots\dots\dots$  mm

$h_{total} = \dots\dots\dots$ mm From Calibration     $V = 3.68\sqrt{h_m} = \dots\dots\dots$  m/s

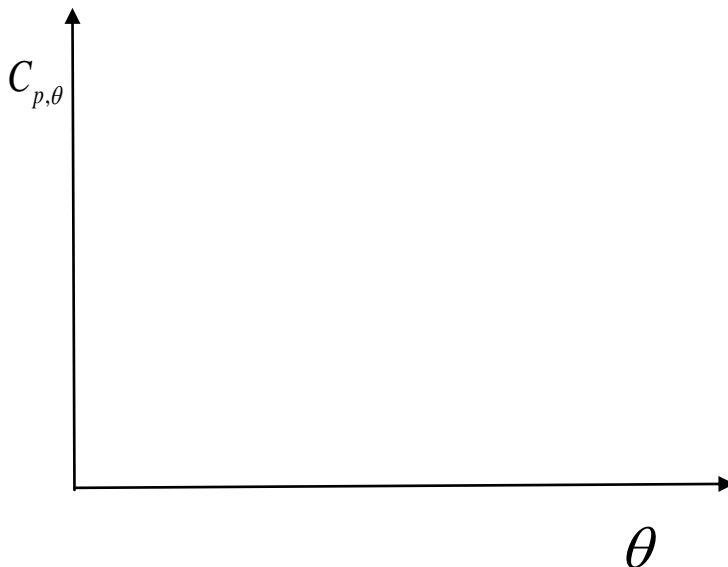
$$Re = \frac{\rho_{air} VD_{cylinder}}{\mu_{air}} = \dots\dots\dots$$

$$C_{p,\theta} = \frac{\Delta h_\theta}{h_{static} - h_{total}}$$

$\theta$	Port Number	$h_\theta$	$\Delta h_\theta = h_\theta - h_{static}$	Coefficient of pressure ( $C_{p,\theta}$ )	$C_{p,theoretical}$

**Result:**

Polyfit of  $C_{p,\theta}$  vs  $\theta$  performed to get a  $C_p$  distribution over cylinder along with the  $C_{p,theoretical}$  vs  $\theta$ . Students are also advised to be plotted on polar graph paper as the asymmetry can be visualized clearly.



Calculate lift and drag forces on the cylinder due to asymmetry in the pressure distribution. Thus calculate  $C_L$  &  $C_D$  based on its planform area or  $C_L$  &  $C_d$  based on its diameter for various Reynolds number.

**Viva questions:**

1. What is sensitivity and range of an instrument?
2. What is meant by calibration and how is it performed for wind tunnel test section velocity?
3. Why is diffuser section longer in length than contraction section even for a smaller area ratio than the contraction section?
4. How can sensitivity of the manometer be increased?
5. What is the adverse effect of increasing the sensitivity of the manometer?
6. Consider the methyl alcohol ( $SG = 0.8$ ) in the manometer has vaporized during the summer vacation and you are scheduled to conduct the calibration experiment on the very first day of the reopening of college for which you collect tap water and fill the tubes (after filtering it) ( $SG = 1.1$ (salty water). What would be the effect in its sensitivity? What would be the least count of the velocity that can be measured with that setup?
7. With the above situation in hand for what modification do you suggest to be done to the multitube manometer board to achieve the sensitivity of that of using the methyl alcohol?
8. Is the calibration process dependent on the sample set of RPM chosen?
9. Does the error decrease or increase as the sample set of RPM is more distributed over the range?
10. Why is the variation in height of the reservoir limb not considered? Isn't this an error in measurement?
11. Is the reservoir limb connected to stagnation pressure?
12. Is  $C_p$  defined or derived?
13. What is the limit of  $C_p$  value?
14. Does the shape and the size of the pressure taps cause any errors?
15. Can the pressure taps be elliptic or square in shape?
16. After which Reynolds number, there exists a potential difference between the theory and experimental results?
17. If the error in  $C_p$  can be defined as  $\left| C_{p,theoretical} - C_{p,experimental} \right|$ , what is this error corresponding to error of experiments or error of theory?
18. Is there any effect on location of the static pressure taps in the same cross section?

## WEEK-2

### PRESSURE DISTRIBUTION AND FLOW VISUALIZATION -SYMMETRIC, CAMBERED AIRFOIL

#### A. Pressure distribution over symmetric airfoil

##### AIM:

To find  $C_p$  distribution over a symmetrical airfoil and further evaluate  $C_l$  and  $C_d$  from the  $C_p$  distribution.

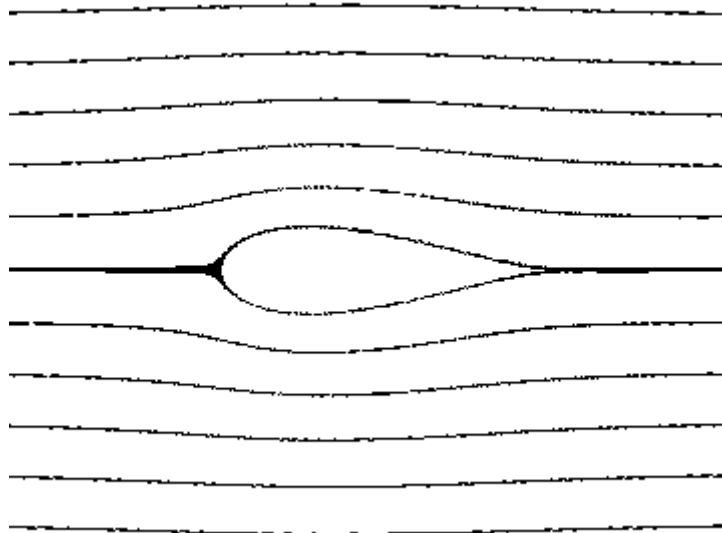
##### APPARATUS:

- Wind tunnel with electronic controller
- Multi tube manometer
- Pitot static probe
- Symmetrical airfoil

##### THEORY:

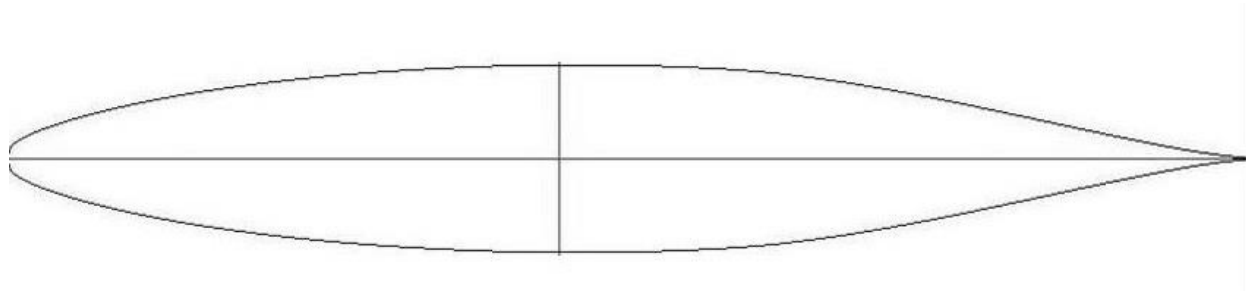
Theoretically flow over symmetrical airfoil is from the potential theory, by superimposing uniform flow with a linear distribution of vortices over its camber line. Potential theory assumes flow to be inviscid, steady and irrotational. In reality the above assumptions may become null and void. Thus experimental study is performed to ensure at which point the potential theory doesn't hold good is observed by varying Reynolds number. Thus coefficient of lift for a symmetric airfoil from thin airfoil theory is given by  $C_l = 2\pi\alpha$  is given where  $\alpha$  is the angle of attack which is an angle measured between chord line and relative velocity vector.

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**Description:**

Experimentally to evaluate the  $C_p$  distribution over a symmetrical airfoil NACA 66<sub>2</sub> – 015, static pressure taps are provided over the surface of the airfoil at number of locations (static pressure taps location is given the table below.



Typical profile of NACA 66<sub>2</sub>– 015

**Procedure:**

1. Mount the airfoil using the wall mounting point.
2. Connect all the pressure tap connections to the multitube manometer.
3. Set the airfoil at 0° angle of attack

**Observations:**

$h_{static} = \dots\dots\dots$  mm                      Inclined tube manometer reading ( $h_m$ ) =  $\dots\dots\dots$  mm  
 $h_{total} = \dots\dots\dots$  mm                      From Calibration  $V = 3.68\sqrt{h_m} = \dots\dots\dots$  m/s

$$Re = \frac{\rho_{air} V C_{chordlength}}{\mu_{air}} = \dots\dots\dots$$

$$C_{p,x/c} = \frac{\Delta h_i}{h_{static} - h_{total}}$$

$\alpha = \dots\dots\dots^\circ$

x/c	Port Number (i)	$h_i$	$\Delta h_i = h_i - h_{static}$	Coefficient of pressure ( $C_{p,x/c}$ )

Repeat the process for various angle of attacks ( $\alpha$ ) and compute the  $C_l$  and  $C_d$  as follows

$$C_n = \int \{C_{p,lower} d(x/c) - C_{p,upper} d(x/c)\}$$

$$C_a = \int \{C_{p,lower} d(y/c) - C_{p,upper} d(y/c)\}$$

$$C_l = C_n \cos \alpha - C_a \sin \alpha$$

$$C_d = C_n \sin \alpha - C_a \cos \alpha$$

For the above purpose the airfoil coordinates and the pressure tap location are given below

X, mm	Y, mm
0	0
0.75	1.683
1.125	2.015
1.875	2.513
3.75	3.353
7.5	4.65
11.25	5.672
15.00	6.537
22.50	7.929
30.00	8.993
37.50	9.815
45.00	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

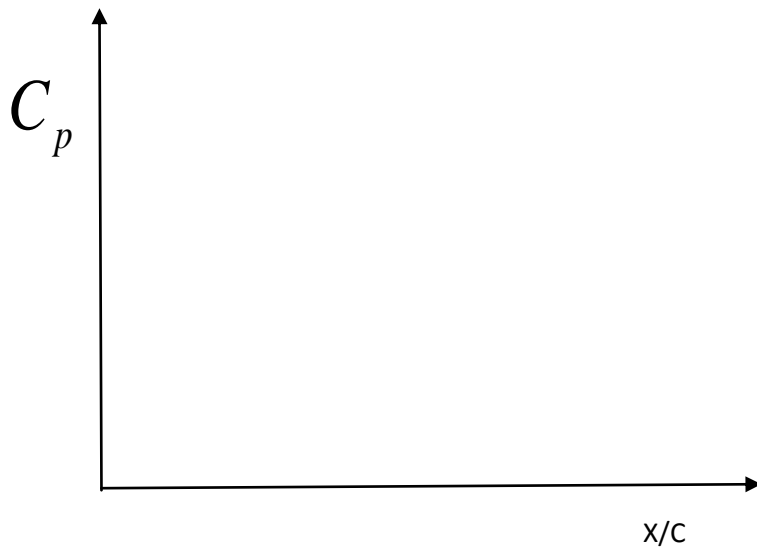
Upper surface			Lower surface		
Hole No	Distance from leading edge X(mm)	X/C × 10	Hole No	Distance from leading edge X(mm)	X/C × 10
1	0	0	14	6.0	0.4
2	1.5	0.1	15	12.0	0.8
3	3.0	0.2	16	22.5	1.5
4	6.0	0.4	17	40.5	2.7
5	12.0	0.8	18	58.5	3.9
6	22.5	1.5	19	78.0	5.2
7	40.5	2.7	20	97.0	6.5
8	58.5	3.9	21	117.0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

**Precautions:**

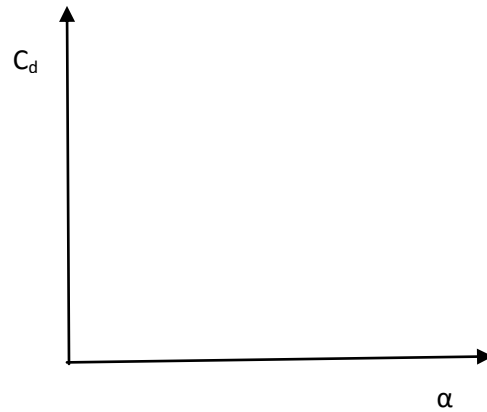
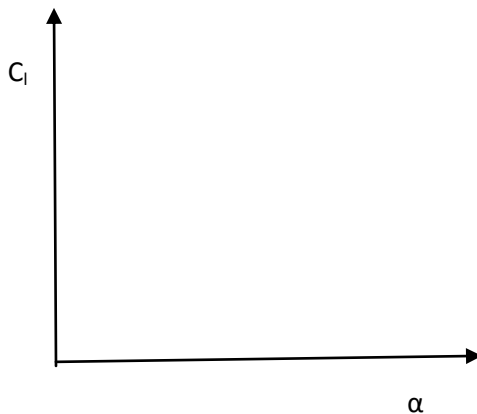
1. Ensure the RPM is not operated at the limits of the fan motor.
2. Ensure that no loose objects are in place inside the test section.
3. Ensure that there is no blockage upstream of the test section.
4. Moving downstream of the fan motor is hazardous during the operation of the tunnel.

**Result:**

Polyfit of  $C_{p,\theta}$  vs  $\theta$  performed to get a  $C_p$  distribution over cylinder along with the  $C_{p,theoretical}$  vs  $\theta$ . Students are also advised to be plotted on polar graph paper as the asymmetry can be visualized clearly.



Calculate lift and drag forces on the cylinder due to asymmetry in the pressure distribution. Thus calculate  $C_L$  &  $C_D$  based on its planform area or  $C_l$  and  $C_d$  based on its diameter for various Reynolds number. Stall angle of attack ( $\alpha_{\text{stall}}$ ) is observed.



**Viva questions:**

1. Is  $C_p$  defined or derived?
2. What is the limit of  $C_p$  value?
3. What is the error involved in computing  $C_l$  from  $C_p$  distribution?
4. Can the pressure taps be elliptic or square in shape?
5. Is the  $C_l$  vs  $\alpha$  plot same for all the Reynolds numbers? How does the  $C_l$  vary as the Reynolds number is increased? Reason out for the above behavior.
6. If the error in  $C_l$  can be defined as difference between  $C_l$  theory and that of experiment, what is this error corresponding to error of experiments or error of theory?
7. Is there any effect on location of the static pressure taps in the same cross section?
8. Compare the data from NACA reports for the given airfoil
9. What is the stall?
10. Is the maximum lift coefficient same in the case of all Reynolds numbers?



## B. Pressure distribution over cambered airfoil

### Aim:

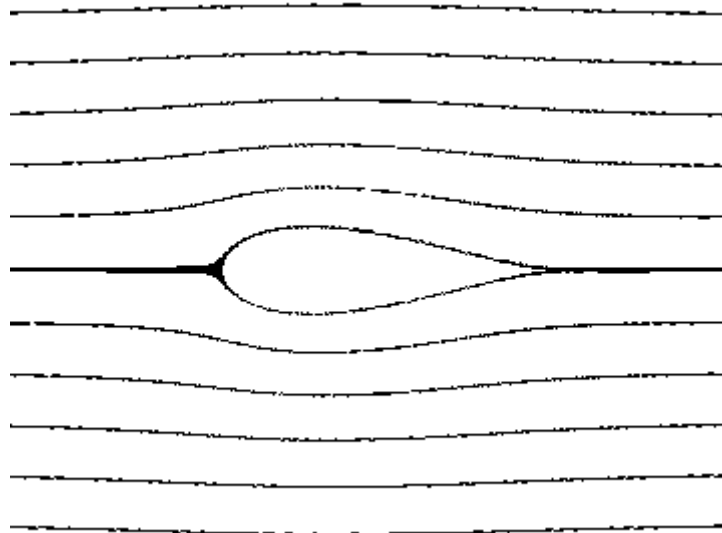
To find  $C_p$  distribution over a cambered airfoil and further evaluate  $C_l$  and  $C_d$  from the  $C_p$  distribution and estimate the zero lift angle of attack ( $\alpha_0$ ).

### Apparatus:

Wind Tunnel, Pitot Static Tube, Multi tube Manometers and cambered airfoil.

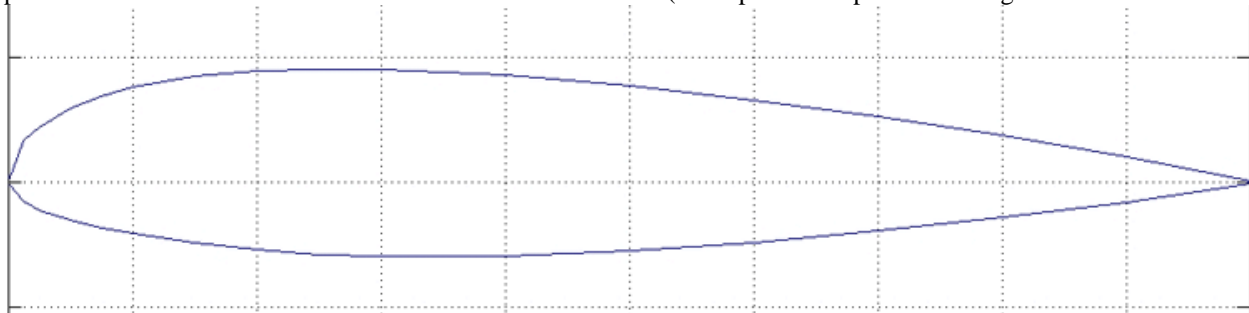
### Principle:

Theoretically flow over cambered airfoil is from the potential theory, by superimposing uniform flow with a linear distribution of vortex sheet over its camber line. Potential theory assumes flow to be inviscid, steady and irrotational. In reality the above assumptions may become null and void. Thus experimental study is performed to ensure at which point the potential theory doesn't hold good is observed by varying Reynolds number. Thus coefficient of lift for a cambered airfoil from thin airfoil theory is given by  $C_l = 2\pi(\alpha - \alpha_0)$  is given where  $\alpha$  is the angle of attack which is an angle measured between chord line and relative velocity vector. .



### Description:

Experimentally to evaluate the  $C_p$  distribution over a symmetrical airfoil NACA 66<sub>2</sub> – 015, static pressure taps are provided over the surface of the airfoil at number of locations (static pressure taps location is given the table below).



Typical profile of NACA 23015

**Procedure:**

1. Mount the airfoil using the wall mounting point.
2. Connect all the pressure tap connections to the multitube manometer.
3. Set the airfoil at 0° angle of attack
4. Run the tunnel at desired speed and take the observations
5. Change the angle of attack and let the liquid column settle to a steady value
6. Repeat the same procedure for various angle of attack

**Precautions:**

1. Ensure the RPM is not operated at the limits of the fan motor.
2. Ensure that no loose objects are in place inside the test section.
3. Ensure that there is no blockage upstream of the test section.
4. Moving downstream of the fan motor is hazardous during the operation of the tunnel.

**Observations:**

$h_{static} = \dots\dots\dots$  mm                      Inclined tube manometer reading ( $h_m$ ) =  $\dots\dots\dots$  mm  
 $h_{total} = \dots\dots\dots$  mm                      From Calibration  $V = 3.68\sqrt{h_m} = \dots\dots\dots$  m/s

$$Re = \frac{\rho_{air} V C_{chordlength}}{\mu_{air}} = \dots\dots\dots$$

$$C_{p,x/c} = \frac{\Delta h_i}{h_{static} - h_{total}}$$

$\alpha = \dots\dots\dots^\circ$

x/c	Port Number (i)	$h_i$	$\Delta h_i = h_i - h_{static}$	Coefficient of pressure ( $C_{p,x/c}$ )

Repeat the process for various angle of attacks ( $\alpha$ ) and compute the  $C_l$  and  $C_d$  as follows

$$C_n = \int \{C_{p,lower} d(x/c) - C_{p,upper} d(x/c)\}$$

$$C_a = \int \{C_{p,lower} d(y/c) - C_{p,upper} d(y/c)\}$$

$$C_l = C_n \cos \alpha - C_a \sin \alpha$$

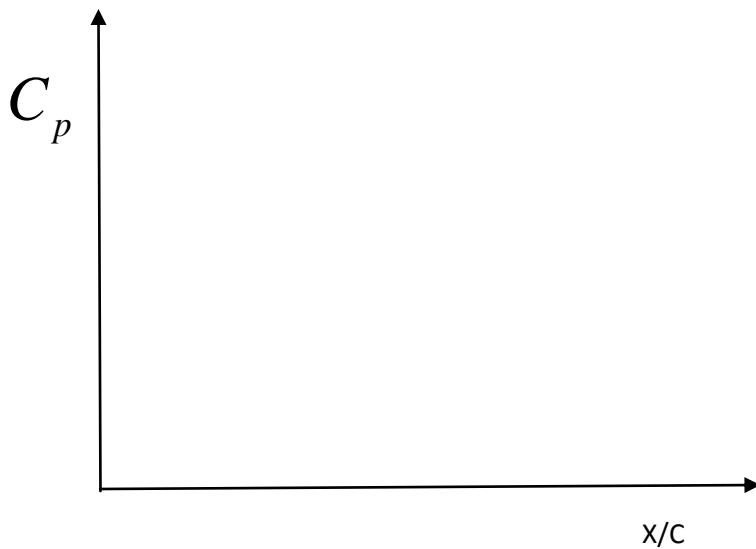
$$C_d = C_n \sin \alpha - C_a \cos \alpha$$

For the above purpose the airfoil coordinates and the pressure tap location are given below

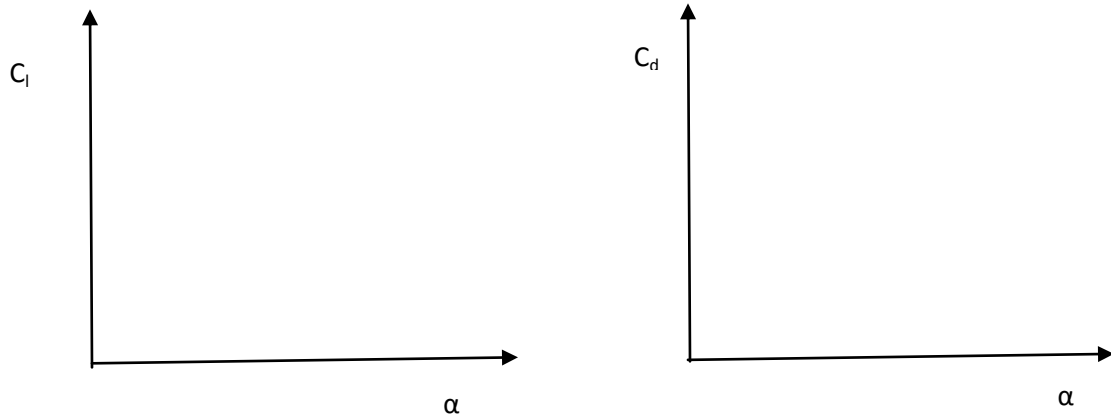
Bottom Y, mm	X, mm	Upper Y, mm	Upper surface			Lower surface		
			Hole No	Distance from leading edge X(mm)	X/C × 10	Hole No	Distance from leading edge X(mm)	X/C × 10
-0.990	0	0.0						
-0.993	0.75	2.373						
-1.054	1.125	2.9771						
-1.067	1.875	3.959						
-0.892	3.75	5.815						
-0.611	7.50	8.699						
-0.412	11.25	10.933						
-0.296	15.00	12.779						
-0.243	22.50	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	67.50	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						
-0.701	135.00	3.740						
-0.149	142.50	1.550						
0	150.00	0						
			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
			10	97.0	6.5			
			11	117.0	7.8			
			12	135.0	9			
			13	150.0	10			

**Result:**

Polyfit of  $C_{p,\theta}$  vs  $\theta$  performed to get a  $C_p$  distribution over cylinder along with the  $C_{p,theoretical}$  vs  $\theta$ . Students are also advised to be plotted on polar graph paper as the asymmetry can be visualized clearly.



Calculate lift and drag forces on the cylinder due to asymmetry in the pressure distribution.  
Thus calculate  $C_L$  &  $C_D$  based on its planform area or  $C_l$  &  $C_d$  based on its diameter for various Reynolds number.



**Viva questions:**

1. Is  $C_p$  defined or derived?
2. What is the limit of  $C_p$  value?
3. What is the error involved in computing  $C_l$  from  $C_p$  distribution?
4. Can the pressure taps be elliptic or square in shape?
5. Is the  $C_l$  vs  $\alpha$  plot same for all the Reynolds numbers? How does the  $C_l$  vary as the Reynolds number is increased? Reason out for the above behavior.
6. If the error in  $C_l$  can be defined as difference between  $C_l$  theory and that of experiment, what is this error corresponding to error of experiments or error of theory?
7. Is there any effect on location of the static pressure taps in the same cross section?
8. Compare the data from NACA reports for the given airfoil
9. Why is the zero lift angle of attack a negative value?
10. When will the zero lift angle of attack be a positive value?
11. Is the slope of the curve  $C_l$  vs  $\alpha$  is equal to  $2*\pi$ ? If not why?
12. Can the slope of  $C_l$  vs  $\alpha$  curve exceed  $2*\pi$ ?

## **C. FLOW VISUALIZATION OVER SYMMETRIC AND CAMBERED AIRFOIL**

### **Aim:**

To observe the smoke visualization over the symmetrical airfoil and cambered airfoil.

### **Apparatus:**

Wind tunnel, symmetrical airfoil, cambered airfoil, smoke generator, smoke rake.

### **Procedure:**

1. Mount the model using wall mounting.
2. Turn the smoke generator on till sufficient amount of the smoke is generated.
3. Turn the wind tunnel fan on to the desired test section velocity.
4. Turn the blower of smoke generator on.
5. Varying the angle of attacks try to observe the stream lines.
6. Note the angle of attack at which the stream lines separate from the surface.

### **Result:**

Compare the stall angle of attack with the results from the  $C_p$  distribution over various Reynolds number. Try to answer the question why the  $C_p$  distribution deviates from the potential theory at different Reynolds numbers

### **Viva questions:**

1. What are streak lines, streamlines, pathlines and timelines?
2. Which of the above are visualized in smoke visualization?
3. Why is smoke required for flow visualization?
4. What other things can be used in flow visualization?

## WEEK-3 FORCE MEASUREMENT

**Aim:**

To determine the 3 component forces and moments for a general aircraft model using wind tunnel balance.

**Apparatus:**

Wind tunnel, aircraft model with proper fixture, 6 component strain gauge balance.

**Principle:**

Aerodynamic forces acting on any given body in a given flow can be computed using the pressure distribution and done in previous experiments. But the above method basically misses the shear contribution which may not be significant in lift but has a significant contribution in drag estimation (skin friction drag) especially at low Reynolds numbers. Thus to obtain the net aerodynamic forces and moments without missing any, a direct force and moment measurement instrument is used called as 6 component wind tunnel balance. An optimized way of using 6 strain gauges, which in turn uses change in resistance due to elongation which is measured in terms of voltage across that, can be recalibrated to the force applied. Now a set of forces at a distance cause couple thus even moments can be measured.

**Procedure:**

1. Fix the wind tunnel balance in its position and ensure the fitting is proper.
2. Mount the aircraft model on the balance in the provision provided
3. Set the forces and moments to zero to cancel out the weight contribution to the final force measurement.
4. Run the tunnel at desired test section velocity and note down the 3 component forces and 3 component moments.
5. Change the angle of attack of the aircraft model using the lever in the balance itself.
6. Repeat the same process for various angles of attack ( $\alpha$ ).
7. Repeat the same process for various slid slip angles ( $\beta$ ).

**Observations:**

Reynolds number ( $\rho * V * L / \mu$ ) = \_\_\_\_\_ ,

$\alpha$	lift	drag	Pitching moment	Side force	Yawing moment	Rolling moment

**Precautions:**

1. Ensure the tunnel is not run at its limit RPM
2. Ensure the balance is not being operated beyond its permissible limits.
3. Ensure the units of the measurement data obtained are taken care of.
4. Frictions in the pulley should be least possible.

**Result:**

Plots of  $C_l$ ,  $C_d$  &  $C_m$  vs  $\alpha$  are plotted and thus static longitudinal stability can be observed  
Plots of  $C_s$ ,  $C_n$  &  $C_l$  vs  $\beta$  are plotted and thus lateral stability can be observed.

**Viva questions:**

1. Define strain gauge.
2. Under what conditions can only the strain gauge be 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.

**WEEK-4**  
**WAKE ANALYSIS**

**Aim:**

To determine aerodynamic drag on a given body by analyzing the wake.

**Apparatus:**

3D body like cylinder, symmetrical airfoil and cambered airfoil.

**Principle:**

Newton's second law of motion states that net external force applied is equal to the rate of change of linear momentum. Thus drag can be calculated if the velocity distribution is known in the wake of the object (assuming the upstream velocity is uniform with free stream velocity). Thus integrating the momentum in the wake and subtracting it from the upstream momentum drag acting on the body can be evaluated.

**Description:**

A wake rake is a set of total pressure probes. The concept behind the wake rake is that the velocity reduction contribution can be evaluated from the reduction of total pressure, as static pressure is assumed to be constant.

**Procedure:**

1. Mount the model in the tunnel section.
2. Fix the wake rake on the traverse mechanism.
3. Fix all the tubing from the rake to the remaining ports of multitube manometer.
4. Turn on the wind tunnel at desired test section velocity.
5. Gently operate the traverse mechanism to place it at least 10times the diameter of the cylinder or at least 3times of the chord length away from the airfoil.
6. Observe the readings and repeat the same process for the various Reynolds number.

**Observations:**

Port number (i)	Total pressure head ( $h_{0,i}$ )	Static pressure head ( $h_{static}$ )

**Calculations:**

$$V_i = \sqrt{(2 \times (h_{0,i} - h_{static}) \times \rho_{liquid} \times g \div \rho_{air}}$$

$$C_d = \int_{-\infty}^{\infty} \left\{ (\sqrt{\Delta p_i / \Delta P_{\infty}}) - (\Delta p_i / \Delta P_{\infty}) \right\} dy / d$$



**Wake Rake**

Distance from centerline of centre of Tube 1

Tube no.	Distance (mm)
1	0 mm
2	3.5 mm
3	6.0 mm
4	9.0 mm
5	12.0 mm
6	14.5 mm
7	17.5 mm
8	20.5 mm
9	24.0 mm
10	27.0 mm
11	30.0 mm
12	34.0 mm
13	37.0 mm
14	40.0 mm
15	43.0 mm
16	46.0 mm
17	48.5 mm
18	51.5 mm
19	54.5 mm
20	57.5 mm
21	61.0 mm
22	64.0 mm
23	67.5 mm
24	71.0 mm
25	74.5 mm
26	78.0 mm
27	81.0 mm
28	84.0 mm
29	88.0 mm
30	91.0 mm

**Result:**

The drag is evaluated at various Reynolds number for cylinder, symmetrical airfoil and cambered airfoil.

**Viva questions:**

1. What is wake?
2. What are the assumptions in the wake rake experiment?
3. Derive the equation for the coefficient of drag.

## WEEK-5

### FLOW OVER A FLAT PLATE

**Aim:**

To determine the boundary layer thickness by using boundary layer rake over a flat plate.

**Apparatus:**

Flat Plate, Wind Tunnel, boundary layer rake.

**Theory:**

Flows under realistic conditions have viscosity coming into picture. No slip boundary condition dictates that there doesn't exist any relative velocity between the solid and the immediate fluid layer on the surface. Thus along the length of the plate from leading edge considered a point if moved onto the vertical direction velocity changes from zero velocity to free stream velocity. This thickness till it reaches 0.99 times of free stream velocity is called boundary layer thickness. This thickness is a function of Reynolds number and the x – location from the leading edge. Based on the Reynolds number if  $< 2 \times 10^5$  the flow can be considered to be in the laminar region. If  $Re > 5 \times 10^5$  the flow is said to be in turbulent regime. If Re is in between flow is in transition.

**Procedure:**

1. Mount the flat plate on the supports provided in the mid height of the tunnel section.
2. Connect the static pressure ports of the plate to the multitube manometer.
3. Fix the boundary layer rake on the traverse mechanism.
4. Fix all the tubing from the rake to the remaining ports of multitube manometer.
5. Turn on the wind tunnel at desired test section velocity.
6. Gently operate the traverse mechanism to touch the surface of the plate.
7. Observe the readings and move the rake to next location and repeat the same process.

**Tabular form:**

X = .....(mm from leading edge)

Port number (i)	Total pressure head ( $h_{0,i}$ )	Static pressure head ( $h_{static}$ )	Velocity (m/s)

**Calculations:**

$$V_i = \sqrt{(2 \times (h_{0,i} - h_{static}) \times \rho_{liquid} \times g \div \rho_{air}}$$

## Boundary Layer Rake

Distance from the centre of first tube

Tube No.	Distance (mm)
1	0 mm *
2	1.5 mm
3	2.5 mm
4	4.5 mm
5	5.5 mm
6	7.0 mm
7	8.5 mm
8	10.5 mm
9	12.0 mm
10	14.5 mm
11	16.5 mm
12	20.0 mm
13	22.5 mm
14	24.5 mm
15	27.0 mm
16	31.0 mm
17	34.5 mm

\*The centre of the first tube is 0.3 mm from the wall, All tubes a 0.6 mm OD at the front end.

### **Result:**

Boundary layer thickness is measured at different locations from the leading edge by plotting the velocity profiles.

### **Viva questions:**

1. What is boundary layer thickness?
2. Calculate the displacement thickness and momentum thickness at a given set of points?
3. Was the transition point identified?

## WEEK-6

### BLOWER TEST RIG

#### Experimental procedure:

- Fill mercury in the manometer provided for Venturimeter, the levels must be equal, if not remove air blocks.
- Fill water in the manometer provided for Prandtl Pitot tubes, provided on the suction and delivery side.
- Close the cock connected to the inner pipe of the Pitot tube and leave this column of the manometer open to the atmosphere. Open the cock connecting to static pressure end of the Pitot tube.
- Close the delivery control valve and start the unit.
- Open delivery valve to 1/4<sup>th</sup> level.
- Note the time taken for 'n' revolutions of energy meter.
- Note the spring balance reading connected to the torque arm of the swinging field motor. Note the speed of the motor.
- Note the manometer readings.
- Repeat the experiment for different gate openings of the delivery valve and for different impeller vanes.

#### Calculations:

$$H_s \text{ (suction head)} = h_1 - h_2$$

$$H_D \text{ (delivery head)} = h_1 - h_2$$

$$H_g \text{ (Venturi head)} = h_1 - h_2$$

$$H_{H_2O} \text{ (Total head)} = H_s + H_D$$

$$H_{Air} = H_{H_2O} \times [(\rho_{H_2O} / \rho_{Air})],$$

$$h_{Air} = H_g \times [(\rho_{Hg} / \rho_{Air})],$$

$$\text{where } \rho_{Air} = 1.2 \text{ kg/m}^3, \rho_{H_2O} = 1000 \text{ kg/m}^3, \rho_{Hg} = 13456 \text{ kg/m}^3$$

To find the blower discharge Q:

$$Q = K\sqrt{h_{air}}$$

$$\text{where } K = \frac{a_1 a_2 \sqrt{2g}}{\sqrt{a_1^2 - a_2^2}}, g = 9.81 \text{ m/s}^2$$

$a_1$  = Area of Venturi Inlet, diameter of the inlet = 100mm

$a_2$  = Area of Venturi Outlet, diameter of the throat = 60mm

$$\text{Input Power of Blower: } P_i = \frac{3600 \times n}{E \times t}$$

where  $n$  = Number of Revolutions

$t$  = time taken (in seconds) for 'n' revolutions

$E$  = Energy meter constant = 150 revolutions/kW/hr

Output Power of Blower (P<sub>o</sub>):

$$P_o = \rho_{\text{Air}} \times Q \times 9.8 \times H_A$$

Efficiency of Blower ( $\eta$ ):

$$\eta = (P_o / P_i) \times 100 \%$$

In the case of the blower provided with the swinging field motor the input power may also be calculated as follows:

Input power:

$$P_i = \frac{2\pi NT}{60} \text{ Watts}$$

where T is the torque = torque arm length x spring balance reading  
N is the speed of motor

## BLOWER TEST RIG - FORWARD VANE

**Aim:** To conduct test on blower and to determine its overall efficiency using Forward vane.

**Apparatus:**

Blower, forward vane, AC Current Supply 230V 20Hz, Pitot static tube, Precessive tap, Venturimeter, Delivery Valve, and Stop Clock.

**Formulae:**

$$H_s \text{ (suction head)} = h_1 - h_2$$

$$H_D \text{ (delivery head)} = h_1 - h_2$$

$$H_g \text{ (Venturi head)} = h_1 - h_2$$

$$H_{H_2O} \text{ (Total head)} = H_s + H_D$$

$$H_{Air} = H_{H_2O} \times [(\rho_{H_2O} / \rho_{Air})],$$

$$h_{Air} = H_g \times [(\rho_{Hg} / \rho_{Air})],$$

$$\text{where } \rho_{Air} = 1.2 \text{ kg/m}^3, \rho_{H_2O} = 1000 \text{ kg/m}^3, \rho_{Hg} = 13456 \text{ kg/m}^3$$

To find the blower discharge Q:

$$Q = K\sqrt{h_{air}}$$

$$\text{where } K = \frac{a_1 a_2 \sqrt{2g}}{\sqrt{a_1^2 - a_2^2}}, g = 9.81 \text{ m/s}^2$$

$a_1$  = Area of Venturi Inlet, diameter of the inlet = 100mm

$a_2$  = Area of Venturi Outlet, diameter of the throat = 60mm

$$\text{Input Power of Blower: } P_i = \frac{3600 \times n}{E \times t}$$

where  $n$  = Number of Revolutions

$t$  = time taken (in seconds) for ' $n$ ' revolutions

$E$  = Energy meter constant = 150 revolutions/kW/hr

Output Power of Blower ( $P_o$ ):

$$P_o = \rho_{Air} \times Q \times 9.8 \times H_{Air}$$

Efficiency of Blower ( $\eta$ ):

$$\eta = (P_o / P_i) \times 100 \%$$

**Tabular Column:**

**Table 1:**

Gate Openings	Suction Head			Delivery Head			Venturi Tube			Time (sec)
	$h_1$	$h_2$	$H_S$	$h_1$	$h_2$	$H_D$	$h_1$	$h_2$	$H_g$	
full										
3 / 4										
1 / 2										
1 / 4										
1 / 4										

**Table 2:**

$H_{H_2O} = H_S + H_D$	$H_{Air}$ (m)	$h_{Air}$ (m)	K	$Q(m^3/s)$	$P_o$ (KW)	$P_i$ (KW)	$\eta$

**Procedure:**

1. Mount the Forward vane to the blower.
2. Switch ON the power supply of the blower
3. Note the readings of the Suction head , Delivery head and Venturi head
4. These readings are taken at four different positions of gate valve openings
5. Note down the time taken for 'n' revolutions of energy meter
6. Tabulate the values and calculate the efficiency.

**Precautions:**

1. Wear tight overhauls and safety shoes.
2. Note the readings carefully by avoiding parallax errors.

**Result:** The overall efficiency of forward vane of blower test rig is \_\_\_\_\_.

## BLOWER TEST RIG – BACKWARD VANE

**Aim:** To conduct test on blower and to determine its overall efficiency using Backward vane.

**Apparatus:**

Blower, Backward vane, AC Current Supply 230V, 20Hz, Pitot static tube, Precessive tap, Venturimeter, Delivery Valve, and Stop Clock.

**Formulae:**

$$H_s \text{ (suction head)} = h_1 - h_2$$

$$H_D \text{ (delivery head)} = h_1 - h_2$$

$$H_g \text{ (Venturi head)} = h_1 - h_2$$

$$H_{H_2O} \text{ (Total head)} = H_s + H_D$$

$$H_{Air} = H_{H_2O} \times [(\rho_{H_2O} / \rho_{Air})],$$

$$h_{Air} = H_g \times [(\rho_{Hg} / \rho_{Air})],$$

$$\text{where } \rho_{Air} = 1.2 \text{ kg/m}^3, \rho_{H_2O} = 1000 \text{ kg/m}^3, \rho_{Hg} = 13456 \text{ kg/m}^3$$

To find the blower discharge Q:

$$Q = K\sqrt{h_{air}}$$

$$\text{where } K = \frac{a_1 a_2 \sqrt{2g}}{\sqrt{a_1^2 - a_2^2}}, g = 9.81 \text{ m/s}^2$$

$a_1$  = Area of Venturi Inlet, diameter of the inlet = 100mm

$a_2$  = Area of Venturi Outlet, diameter of the throat = 60mm

$$\text{Input Power of Blower: } P_i = \frac{3600 \times n}{E \times t}$$

where  $n$  = Number of Revolutions

$t$  = time taken (in seconds) for ' $n$ ' revolutions

$E$  = Energy meter constant = 150 revolutions/kW/hr

Output Power of Blower ( $P_o$ ):

$$P_o = \rho_{Air} \times Q \times 9.8 \times H_{Air}$$

Efficiency of Blower ( $\eta$ ):

$$\eta = (P_o / P_i) \times 100 \%$$



**Tabular Column:**

**Table 1:**

Gate Openings	Suction Head			Delivery Head			Venturi Tube			Time (sec)
	$h_1$	$h_2$	$H_S$	$h_1$	$h_2$	$H_D$	$h_1$	$h_2$	$H_g$	
full open										
3/4 open										
1/2 open										
1/4 open										
full close										

**Table 2:**

$H_{H_2O} = H_S + H_D$	$H_{Air} (m)$	$h_{Air} (m)$	K	$Q(m^3/s)$	$P_o (KW)$	$P_i (KW)$	$\eta$

**Procedure:**

1. Mount the Backward vane to the blower.
2. Switch ON the power supply of the blower
3. Note the readings of the Suction head , Delivery head and Venturi head
4. These readings are taken at four different positions of gate valve openings
5. Note down the time taken for 'n' revolutions of energy meter
6. Tabulate the values and calculate the efficiency.

**Precautions:**

1. Wear tight overhauls and safety shoes.
2. Note the readings carefully by avoiding parallax errors.

**Result:** The overall efficiency of Backward vane of blower test rig is \_\_\_\_\_.

## BLOWER TEST RIG - RADIAL VANE

**Aim:** To conduct test on blower and to determine its overall efficiency using Radial vane.

**Apparatus:**

Blower, Radial vane, AC Current Supply 230V, 20Hz, Pitot static tube, Precessive tap, Venturimeter, Delivery Valve, and Stop Clock.

**Formulae:**

$$H_s \text{ (suction head)} = h_1 - h_2$$

$$H_D \text{ (delivery head)} = h_1 - h_2$$

$$H_g \text{ (Venturi head)} = h_1 - h_2$$

$$H_{H_2O} \text{ (Total head)} = H_s + H_D$$

$$H_{Air} = H_{H_2O} \times [(\rho_{H_2O} / \rho_{Air})],$$

$$h_{Air} = H_g \times [(\rho_{Hg} / \rho_{Air})],$$

$$\text{where } \rho_{Air} = 1.2 \text{ kg/m}^3, \rho_{H_2O} = 1000 \text{ kg/m}^3, \rho_{Hg} = 13456 \text{ kg/m}^3$$

To find the blower discharge Q:

$$Q = K\sqrt{h_{air}}$$

$$\text{where } K = \frac{a_1 a_2 \sqrt{2g}}{\sqrt{a_1^2 - a_2^2}}, g = 9.81 \text{ m/s}^2$$

$a_1$  = Area of Venturi Inlet, diameter of the inlet = 100mm

$a_2$  = Area of Venturi Outlet, diameter of the throat = 60mm

$$\text{Input Power of Blower: } P_i = \frac{3600 \times n}{E \times t}$$

where  $n$  = Number of Revolutions

$t$  = time taken (in seconds) for ' $n$ ' revolutions

$E$  = Energy meter constant = 150 revolutions/kW/hr

Output Power of Blower ( $P_o$ ):

$$P_o = \rho_{Air} \times Q \times 9.8 \times H_{Air}$$

Efficiency of Blower ( $\eta$ ):

$$\eta = (P_o / P_i) \times 100 \%$$

**Tabular Column:**

**Table 1:**

Gate Openings	Suction Head			Delivery Head			Venturi Tube			Time (sec)
	$h_1$	$h_2$	$H_S$	$h_1$	$h_2$	$H_D$	$h_1$	$h_2$	$H_g$	
full open										
3/4 open										
1/2 open										
1/4 open										
full close										

**Table 2:**

$H_{H_2O} = H_S + H_D$	$H_{Air} (m)$	$h_{Air} (m)$	K	$Q(m^3/s)$	$P_o (KW)$	$P_i (KW)$	$\eta$

**Procedure:**

1. Mount the Radial vane to the blower.
2. Switch ON the power supply of the blower
3. Note the readings of the Suction head , Delivery head and Venturi head
4. These readings are taken at four different positions of gate valve openings
5. Note down the time taken for 'n' revolutions of energy meter
6. Tabulate the values and calculate the efficiency.

**Precautions:**

3. Wear tight overhauls and safety shoes.
4. Note the readings carefully by avoiding parallax errors.

**Result:** The overall efficiency of Radial vane of blower test rig is \_\_\_\_\_.

## WEEK-7

### GAS TURBINE PARAMETER CALCULATION

**Aim:**

To calculate the gas turbine parameters.

**Apparatus:**

Gas turbine test rig.

**Description:**

1. The engine is the compact Olympus HP E-start turbine engine, comprising a single-stage radial compressor and a low-mass, and high performance axial flow turbine.
2. The engine has been integrated into a sturdy metal frame that holds it firmly, while enabling accurate measurement of the thrust produced by the engine.
3. The engine inlet has been replaced with a custom fabricated frontal duct, to enable the air mass flow rate to be accurately measured.
4. An electronic preprogrammed controller constantly supervises the engine, ensuring safe operating conditions at all times.
5. The engine is controlled via the software, which provides users with a friendly graphical interface for real-time monitoring and operation. This software controls the engine speed, which is electronically controlled using a high-precision fuel feed pump. This method gives a very fast engine response.

**Instrumentation included:****Inlet Duct**

- Inlet temperature
- Inlet pressure

**Compressor**

- Exit total pressure
- Exit pressure
- Exit total temperature

**Turbine**

- Entry total temperature
- Entry total pressure
- Exit total temperature
- Exit total pressure

**Nozzle**

- Exit total temperature
- Fuel flow

**Performance specification:**

1. Thrust: 200N typical

2. Typical fuel: One of the following
  - Paraffin
  - Jet A-1
  - JP-4/Kerosene
3. Exhaust gas temperature: 800oC typical
4. Mass flow:450g/s
5. Ignition system: Glow plug
6. Compressor type: Single-stage radial
7. Turbine type: Single-stage low mass
8. Engine RPM: 105,000rpm typical
9. Engine mount: Single pivot point

**Specification:**

An aeronautical axial flow gas turbine engine mounted in a stainless steel plinth, suitable for bench mounting. An electronic console and 51 'explo safe' fuel tank are also provided. An optional mounting frame is available for floor standing operation The engine has a maximum speed in excess of 100,000 rpm and generates thrust of at least 195N. Full instrumentation to measure RPM, thrust, temperature and pressure at each stage of the jet engine. Stainless steel air inlet duct to measure airflow. The engine is easy to start, without the need for propane gas or compressed air. The equipment is fully controlled form a user –supplied PC .This software includes the powerful educational features together with sophisticated graph-plotting and data logging capability. In the panel that in the mimic diagram is named 'Controls' the Watchdog button should blink. This means that the software detect the presence of the Electronic Console.

**Table:**

Enthalpy	h	kJ/kg
Isentropic Enthalpy	hs	kJ/kg
Ideal gas constant	R=0.2871	kJ/kg

**Procedure:**

**Start-up:**

In order to start the engine properly the following actions need to be done in the right order

- The 'Power On' button on the PC screen is clicked
- The 'Enable' button on the PC screen is clicked
- The 'Start' button on the PC screen is clicked

1. The start-up sequence is initiated only on clicking on the 'Start' button. There is no need to do anything till the start-up sequence has finished.
2. On clicking the 'Start' button there is a delay of several seconds, and then the electric starter tries to start the engine.
3. After 30 sec ,start up sequence is complete.
4. To set the automatic sampling the 'Automatic' option in the panel 'Sampling Operation 'must be selected. In the panel 'Automatic Sample Parameters' 1 second sampling time amplitude is set in the edit box 'Sample Interval'. A value of 15 seconds is set for the 'Fixed Duration' mode sampling which must be selected.
5. With these settings the software will sample at 1 second intervals for 15 seconds which in practice mans that the software will take 15 samples. To actually activate the automatic sampling after having clicked 'OK' on the 'Sample Configuration' window it is necessary to push the green 'GO' button in the main mimic diagram window. Then 15 samples will be added to the spreadsheet adjoined to those that may have been taken manually.
6. For further details about how to use the Arm field software refer to its online manual.
7. It is important to manage to take samples before running out of fuel from the tank and therefore it is necessary to keep track of the time the engine has been running. It is possible to consider that the average fuel flow rate at maximum speed is about 0.81 I/min and consequently every run should limited to about 5-7 minutes when the 5 liters fuel tank is fuel is full at the beginning of the experiment.

**Power-down:**

1. After having taken samples the engine must be switched off.
2. On the mimic diagram two buttons are located within the section 'Controls' these are named 'Power On' and 'Start' respectively.
3. The engine must not be switched off clicking on 'Power On' button unless it is an emergency. The 'Start' button is used to start and power down the engine instead.
4. When the engine is running and 'Start' button is clicked the power down sequence is initiated.
5. This sequence is supervised by the Engine Control Unit and allows for mellow cooling down of the engine in order to avoid excessive thermal stress. When this sequence is activated the Engine Control Unit runs the engine at full speed foe a brief period of time. This is done in order to allow enough lubricant in the engine and its ball bearings along with the flow.

**Precautions:**

1. Be careful while operating the gas turbine test rig.
2. Parameters are carefully evaluated.

**Result:**

Gas turbine parameters are calculated

## WEEK-8 GAS TURBINE EFFICIENCY AND PERFORMANCE DIAGRAMS

### Aim:

To estimate the thrust output from the engine, using the momentum equation, and to compare this result to the measured thrust.

### Apparatus:

Gas turbine test rig, Engine module, Electronic console, User PC with arm field software.

### Method:

Basic application of the momentum equation.

### Theory:

The momentum equation applied to the system shown in the figure above states that the engine receives a thrust which is made of the contribution of four terms. The first two terms take into account the change in momentum for the air flow and the fuel flow throughout the engine. The last two terms take into account the effect of having different pressure at the inlet and exhaust sections when  $p_{exp}$  is the pressure of the outside environment.

In many applications the contribution of the last two terms to the thrust is usually much less significant than the contribution of the first two terms. When this condition is satisfied it is possible to simplify the momentum equation to its first two terms.

$$T_c = \dot{m}_a(u_{out} - u_{in}) + \dot{m}_f u_{out}$$

This condition is usually satisfied when aircraft fly at a speed  $u_{in}$  called the "design speed". This speed is obviously also the speed at which the outside air is ingested at the inlet.

In this formula it is considered the vena contracta effect due to the inlet nozzle geometry:

$$A_{in}^* = C_d A_{in} = 0.62 * \left(\frac{\pi}{4}\right) * (0.1m)^2$$

The cases of the minimum and maximum RPM are taken into consideration. The average air mass flow rate measured at the inlet at minimum RPM is about 0.24Kg/s and considering an average value of 1.2Kg/cube meters for the specific mass of the air flow it is possible to estimate the following speed at the inlet.

$$Min u_{in} = 41 m/s$$

Equivalently, the maximum speed at the inlet is calculated knowing that the measured air mass flow rate at maximum RPM is about 0.85 Kg/s.

$$Max u_{in} = 145 m/s$$

This justifies the assumption of subsonic flow at the inlet of the engine in all experimental conditions.

The presence of the compressor and the turbine does not affect significantly the axial component of the flow velocity throughout the engine and the speed of the sound is proportional to the square root of the

temperature. This allows for the assumption of subsonic flow throughout the engine up to the exit section of the turbine in all experimental conditions.

It is also clear that at the inlet the pressure equals the external pressure (ambient pressure).

$$p_{in} = p_{ext}$$

Consequently the last term in the momentum equation can be neglected allowing for the following simplified equation to be applied.

$$T_c = \dot{m}_a(u_g - u_{in}) + \dot{m}_f u_g + A_g(p_g - p_{ext})$$

In this equation  $u_{out}$  has been renamed as  $u_\varepsilon$ , the speed of the flow at the nozzle exit section. In order to estimate the thrust it is necessary to determine this velocity and the pressure at the exit section  $p_\varepsilon$  of the nozzle while the exit section area is directly measurable. Moreover, the thrust produced by the fuel mass flow rate can be neglected due to the fact that this quantity is always a fraction of the air mass flow rate.

$$T_c = \dot{m}_a(u_g - u_{in}) + A_g(p_g - p_{ext})$$

To determine  $u_\varepsilon$  and  $p_\varepsilon$ , it is possible to consider the isentropic model of the nozzle as approximation of the real nozzle. The equipment allows for determining the total condition at the nozzle entrance T4 and P5 and in accordance to this model the following equations are applicable.

$$t_4 \left( 1 + \frac{\gamma - 1}{2} M_4^2 \right) = t_g \left( 1 + \frac{\gamma - 1}{2} M_g^2 \right) = T_4$$

Example, the theory does not consider friction effects, boundary layer effects and loss of homogeneity in the flow for all the variables involved in the formulation.

It is possible to investigate the thermodynamics and the fluid dynamics of the processes involved in the jet engine using simple equations that refer to the isentropic and one – dimensional flow theory. The investigations may be extended further using more sophisticated features of the theory on the experimental data obtained by operating the engine in different conditions and removing some of the simplification to the theory.



## WEEK-9

### GAS TURBINE EFFICIENCY CALCULATIONS

**Aim:**

To calculate the efficiencies of each stage of the engine and the back work ratio.

**Apparatus:**

Gas turbine engine

**Theory**

We can define the isentropic efficiency of a process as the ratio of the enthalpy change during the real process to the enthalpy change during the equivalent isentropic process. For example, in the compressor stage of the jet engine, the air is compressed from state (1) to state (2):

The isentropic efficiency of the compressor is given by:

In order to find  $h_{2s}$  (the enthalpy at pressure  $p_2$  if there were no entropy change) it is possible to use the following general formula.

In this formula the '0' index refers to a status that is chosen as reference. Usually this status is the one assumed by the fluid under investigation at standard ambient temperature and pressure.

Applying this formula between status 1 and status 2 across the compressor the following formula is obtained:

The back work ratio is defined as the amount of work done in the compressor divided by the work developed in the turbine.

Lastly, the isentropic efficiency of the nozzle is evaluated using the following formula.

Where the  $h_{5s}$  is calculated considering the isentropic expansion that the flow would undergo between the status soon after the turbine and the atmospheric pressure. The isentropic efficiency of a nozzle is usually very high and in practical cases it is common to consider the nozzle perfectly isentropic and therefore having efficiency of 100%.

Considering this hypothesis another index could be defined for the nozzle. The previous formula can be applied to an isentropic nozzle and shows that the exit pressure is only slightly dependent on the exit Mach number. As a consequence of this it is possible to assume that the difference between the measured thrust and the calculated thrust is mainly due to the difference between the real dynamic thrust and the theoretical dynamic thrust. This in turn means that the actual speed at the exit section nozzle is less than the value predicted using the theoretical formulation. To take into account this fact it is possible to define the following efficiency of the nozzle:

## WEEK-10

### NOZZLE PRERFORMANCE

**Aim:**

To determine the pressure distribution of nozzle.

**Apparatus:**

Nozzle test rig.

**Description:**

1. The set up consists of blower unit coupled to A.C motor.
2. The pressure tapings (10Nos) is made in the nozzle surface and it is connected to multi bank manometer.
3. The orifice plate is fitted in the pipeline of the blower outlet, to measure the discharge of flow and is connected to differential manometer.
4. The control panel consist of the mains on indicator, console switch,A.C motor blower switch, differential manometer and multi bank manometer and whole instrumentation is mounted on a self-contained sturdy table.
5. With this the whole arrangement is mounted on aesthetically designed self-sustained MS powder coated frame with a separate NOVAPAN board control panel.

**Procedure:**

1. Switch on the MCB and then console on switch to activate the control panel.
2. Switch on the blower unit first and adjust the flow of air of blower to a desired difference in manometer.
3. Note down the differential manometer and multi bank manometer readings.
4. Repeat the experiment for different air flow rates.

**Observations:**

	Velocity head (pitot tube)			Air flow across orifice			Pressure tapping reading along the nozzle in mm of water												

## Calculations:

Discharge Q

$$Q = C_d \cdot a \sqrt{2gH_a}$$

Where ,

$C_d$  = coefficient of discharge of orifice = 0.62

A = area at the orifice =  $(3.14 \cdot (d)^2 / 4)$

$H_a$  = head in air column , m of air

$$H_a = h_w \cdot \frac{\rho_{\text{water}}}{\rho_{\text{air}}}$$

$$\rho_{\text{water}} = 1000 \text{ kg/m}^3$$

$$\rho_{\text{air}} = 1.2 \text{ kg/m}^3 @ \text{ R.T.P}$$

$h_w$  is the head in water column in "m" of water

Pressure head:

$$\text{Pressure head} = \frac{P}{\rho \cdot g} = h \text{ m of water}$$

$$P = \rho \cdot g \cdot h$$

Where ,

$$\rho = \text{density of water} = 1000 \text{ kg/m}^3$$

$$g = \text{gravitational constant} = 9.81 \text{ m/sec}^2$$

$$h = \text{head measured , m of water column}$$

Velocity head,

$$\text{Velocity head} = \frac{v^2}{2g} \text{ m of water}$$

Where ,

$$V = \frac{Q}{a}$$

Where,

a = area at the particular section of the nozzle  $\text{m}^2$

### 1. Verification of Bernoulli's equation:

Bernoulli's equation is given as:

$$\frac{P}{\rho \cdot g} + \frac{v^2}{2g} + z = 0$$

After finding ,

- a. Pressure head, h
- b. Velocity head,

At different cross-section of the nozzle.

Put the same in the above equation for different points and verify whether all the values obtained are same.

Note: consider the datum , z to be constant.

**Result Table:**

S. no	Velocity of air at the exit of the nozzle (m/s)	Discharge through the orifice (m <sup>3</sup> /s)	Maximum pressure in the nozzle (Pa)	Maximum velocity in the nozzle (m/s)

**Precautions:**

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not obstruct flow of air while experiment is going on.
4. Do not attempt to alter the equipment as this may cause damage to the whole system.

**Result:**

Max press of the nozzle is.....

Max vel of the nozzle is .....

## WEEK-11

### CALORIFIC VALUE OF DIFFERENT FUELS

#### AIM

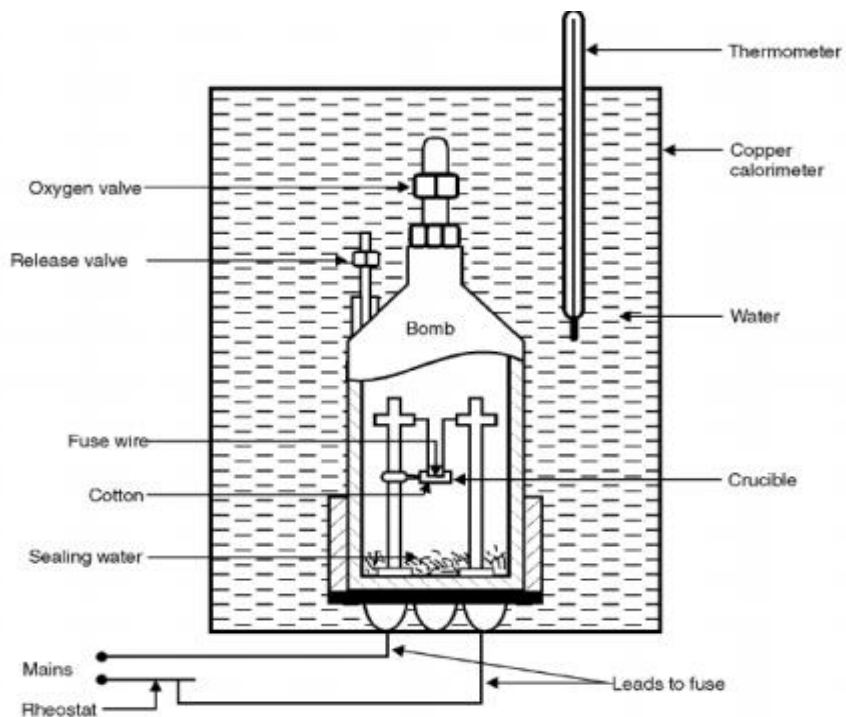
To study determination of Calorific Value of Fuels by using Bomb calorimeter.

#### Apparatus:

Bomb Calorimeter

#### Theory:

The “calorific value or heating value” of the fuel is defined as the energy liberated by the complete oxidation of a unit mass or volume of a fuel. It is expressed in kJ/kg for solid and liquid fuels and kJ/m<sup>3</sup> for gases. The higher heating value, HHV, is obtained when the water formed by combustion is completely condensed. The lower heating value, LHV, is obtained when the water formed by combustion exists completely in the vapour phase. Bomb calorimeter: The calorific value of solid and liquid fuels is determined in the laboratory by ‘Bomb calorimeter’. It is so named because its shape resembles that of a bomb. Fig. 1 shows the schematic sketch of a bomb calorimeter. The calorimeter is made of austenitic steel which provides considerable resistance to corrosion and enables it to withstand high pressure. In the calorimeter is a strong cylindrical bomb in which combustion occurs. The bomb has two valves at the top. One supplies oxygen to the bomb and other releases the exhaust gases. A crucible in which a weighted quantity of fuel sample is burnt is arranged between the two electrodes as shown in Fig. The calorimeter is fitted with water jacket which surrounds the bomb. To reduce the losses due to radiation, calorimeter is further provided with a jacket of water and air. A stirrer for keeping the temperature of water uniform and a thermometer to measure the temperature up to an accuracy of 0.001°C are fitted through the lid of the calorimeter.



**Bomb calorimeter.**

**Procedure:**

To start with, about 1 gm of fuel sample is accurately weighed into the crucible and a fuse wire (whose weight is known) is stretched between the electrodes. It should be ensured that wire is in close contact with the fuel. To absorb the combustion products of sulphur and nitrogen 2 ml of water is poured in the bomb. Bomb is then supplied with pure oxygen through the valve to an amount of 25 atmosphere. The bomb is then placed in the weighed quantity of water, in the calorimeter. The stirring is started after making necessary electrical connections, and when the thermometer indicates a steady temperature fuel is fired and temperature readings are recorded after 1/2 minute intervals until maximum temperature is attained. The bomb is then removed; the pressure slowly released through the exhaust valve and the contents of the bomb are carefully weighed for further analysis. The heat released by the fuel on combustion is absorbed by the surrounding water and the calorimeter.

From the above data the calorific value of the fuel can be found in the following way:

Let

$W_f$  = Weight of fuel sample (kg),

$W$  = Weight of water (kg),

$C$  = Calorific value (higher) of the fuel (kJ/kg),

$W_e$  = Water equivalent of calorimeter (kg),

$T_1$  = Initial temperature of water and calorimeter,

$T_2$  = Final temperature of water and calorimeter,

$T_c$  = Radiation corrections, and

$c$  = Specific heat of water.

Heat released by the fuel sample =  $W_f \times C$

Heat received by water and calorimeter =  $(W_w + W_e) \times c \times [(T_2 - T_1) + T_c]$ .

Heat lost = Heat gained

$W_f \times C = (W + W_e) \times c \times [(T_2 - T_1) + T_c]$

$$C = \frac{(W + W_e) \times c \times [(T_2 - T_1) + T_c]}{W_f}$$

i.e.,

[Value of  $c$  is 4.18 in SI units and unity in MKS units.]

Note:

1. Corrections pertain to the heat of oxidation of fuse wire, heat liberated as a result of formation of sulphuric and nitric acids in the bomb itself.
2. It should be noted that bomb calorimeter measures the higher or gross calorific value because the fuel sample is burnt at a constant volume in the bomb. Further the bomb calorimeter will measure the H.C.V. directly if the bomb contains adequate amount of water before firing to saturate the oxygen. Any water formed from combustion of hydrogen will, therefore, be condensed. The procedure of determining calorific values of liquid fuels is similar to that described above. However, if the liquid fuel sample is volatile, it is weighed in a glass bulb and broken in a tray just before the bomb is closed. In this way the loss of volatile constituents of fuels during weighing operation is prevented.

## WEEK-12

### PROPELLER TEST RIG

**Aim:**

To study the performance of a propeller at different speeds and measure the thrust force and to find the propulsion efficiency of the propeller.

**Apparatus:**

Propeller test rig.

**Description:**

1. The basic propeller test rig consists of a wooden propeller with two blade and with a constant pitch and it is dynamically balanced the propeller is coupled to D.C motor and mounted on a base plate and the whole unit is mounted on linear bearing and it is connected to a load cell for thrust measurement.
2. The speed of the propeller is sensed by a rpm sensor and it is connected to digital rpm indicator the power consumed by the D.C voltmeter and ammeter.
3. The experiment can be done for different speed.
4. there is an isolated control panel which houses all the measurement units like digital force indicator ,digital speed indicator ,D.C motor thyristor drive and speed control knob , voltmeter and ammeter .
5. Air flow measurement before and after the propeller is done using handy digital anemometer.
6. With this the whole arrangement is mounted on a frame with a separate NOVAPAN Board control panel Aesthetically designed self-sustained MS powder coated frame with a separate NOVAPAN board control panel.

**Procedure:**

1. Ensure the propeller blade is firmly locked in position and mesh guard is safe enough to protect.
2. Connect the power cable and observe the “mains on” indicator to glow.
3. Ensure the speed controller knob is set to zero position.
4. Switch on force indicator and press the tare button , set it to zero and keep it in normal position.
5. Slowly increase the speed by operating the speed control knob some desired RPM value .
6. A\*2000RPM (max ammeter reading A= 8amps).
7. Note down the rpm indicator reading and thrust force reading by putting the switch to peak position (keep the switch always in normal position while running the test rig).
8. Record the air flow measurement at inlet and outlet of the propeller .
9. Repeat the experiment at different speed .
10. Draw the graph of thrust vs rotational speed, thrust vs inlet velocity of air, thrust vs outlet velocity of air,rpmvs propulsion efficiency.



**Observations:**

S.NO	Speed of the propeller in rpm	Thrust force in Newton Tact	Air flow measurement in m/s		Voltmeter reading (volts)	Ammeter reading(amps)
			Inlet (vin)	outlet(vout)		
1	600					
2	800					
3	1000					
4	1200					
5	1400					
6	1600					
7	1800					
8	2000					

**Result Table:**

S.NO	Speed in rpm	Power input to the propeller in KW	Actual thrust (Tact) in N	Theoretical thrust (Tth)in N	Propulsion efficiency( $\eta_p$ )

**Calculations:**

- Power input to the propeller,

$$P_{in} = \frac{V_{si}}{\eta_m \times 1000} \text{ KW}$$

Where,

$$\eta_m = \text{motor efficiency} = 0.75$$

- Theoretical thrust generated by the propeller,

$$T_{th} = \rho A V_{in} (V_{out} - V_{in})$$

Where,

$\rho$  = density of air at room temperature.

A= cross sectional area of duct.

D= .....mm

- Propulsion efficiency,

$$\eta_p = \frac{2}{[1 + \frac{V_{out}}{V_{in}}]}$$

**Precautions:**

1. It is safe to run the propeller at affixed pitch and relatively low speed.
2. Before starting, ensure all the screws ,bolts and nuts are firmly tight and mesh guard in secured position.
3. While doing experiment, be always little away from the propeller and control the speed of the propeller gradually by carefully observing the vibrations.

**Result:**

The performances of a propeller at different speeds are studied. The efficiency of the propeller is 0.78