AERODYNAMICS
LAB MANUAL

Year	2017 - 2018
Course Code	AAE103
Regulations	R16
Class	IV Semester
Branch	Aeronautical Engineering

Prepared by

Mr. G. Satya Dileep
Mr. N. Venkata Raghavendra

Aeronautical Engineering
INSTITUTE OF AERONAUTICAL ENGINEERING
(AUTONOMOUS)
Dundigal – 500 043, Hyderabad

INSTITUTE OF AERONAUTICAL ENGINEERING

(AUTONOMOUS)

Dundigal, Hyderabad - 500 043

Certificate

This is to certify that it is a bona fide record of practical work done by Sri/Kum. ______________________________________ bearing Roll No. ______________________ of ____________ class ____ branch in the Aerodynamics laboratory during the academic year ___________________ under our supervision.

Head of the Department | **Lecture In-Charge**

External Examiner | **Internal Examiner**

AERODYNAMICS LAB SYLLABUS

AERODYNAMICS LABORATORY

OBJECTIVE:

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

OUTCOMES:

After completing this course the student must demonstrate the knowledge and ability to:

1. **Understand** the world around us.
2. **Understand** the concept of error and its analysis.
3. **Develop** experimental skills
4. **Design** new experiments in Engineering.
5. **Compare** the theory and correlate with experiment.
6. **Identify** the appropriate application of particular experiment.
7. **Understand** and apply fundamental electronic circuits.
8. **Analyze** the experimental result.
9. **Understand** the applications of physics experiments in day to day life.
10. **Examine** ideas about the real world.

INSTITUTE OF AERONAUTICAL ENGINEERING

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PROGRAM OUTCOMES

PO1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO3	**Design/development of solutions**: 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.
PO4	**Conduct investigations of complex problems**: 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.
PO5	**Modern tool usage**: Create, select, and apply appropriate techniques from the available set of experimental facilities, resources, and methods, to understand and solve complex engineering problems.
PO6	**The engineer and society**: 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.
PO7	**Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO8	**Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO9	**Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO10	**Communication**: 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.
PO11	**Project management and finance**: 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.
PO12	**Life-long learning**: 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.

PROGRAM SPECIFIC OUTCOMES

AERONAUTICAL ENGINEERING	
PSO1	**Professional skills:** Able to utilize the knowledge of aeronautical/aerospace engineering in innovative, dynamic and challenging environment for design and development of new products.
PSO2	**Problem solving skills**: imparted through an understanding of experimental facilities and techniques, to solve practical, design and analysis problems of components to complete the challenge of airworthiness for flight vehicles.
PSO3	**Practical implementation and testing skills**: Providing different types of in house and training and industry practice to fabricate and test and develop the products with more innovative technologies.
PSO4	**Successful career and entrepreneurship**: To prepare the students with broad aerospace knowledge to design and develop systems and subsystems of aerospace and allied systems and become technocrats.

ATTAINMENT OF PROGRAM OUTCOMES & PROGRAM SPECIFIC OUTCOMES

Expt. No.	Program Outcomes Attained	Program Specific Outcomes Attained
1	PO1, PO2, PO4, PO5, PO6, PO9, PO11, PO12	PSO1, PSO2, PSO3
2	PO1, PO2, PO4, PO5, PO6, PO9, PO11, PO12	PSO1, PSO2, PSO3
3	PO1, PO4, PO9, PO11, PO12	PSO1, PSO2, PSO3
4	PO1, PO2, PO4, PO9, PO11, PO12	PSO1, PSO2, PSO3
5	PO1, PO2, PO4, PO9, PO11, PO12	PSO1, PSO2, PSO3
6	PO1, PO3, PO4, PO5, PO9, PO11, PO12	PSO1, PSO2, PSO3
7	PO1, PO4, PO9, PO11, PO12	PSO1, PSO2, PSO3
8	PO1, PO4, PO9, PO11, PO12	PSO1, PSO2, PSO3
9	PO1, PO2, PO4, PO5, PO9, PO11, PO12	PSO1, PSO2, PSO3
10	PO1, PO3, PO4, PO5, PO9, PO11, PO12	PSO1, PSO2, PSO3
11	PO1, PO3, PO4, PO5, PO9, PO11, PO12	PSO1, PSO2, PSO3
12	PO1, PO3, PO4, PO5, PO9, PO11, PO12	PSO1, PSO2, PSO3

EXPERIMENT- I
CALIBRATION

Aim:

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

Apparatus:
Wind tunnel with electronic controller, inclined tube manometer, multitube manometer, Pitot static probe.

Figures:

Wind Tunnel:

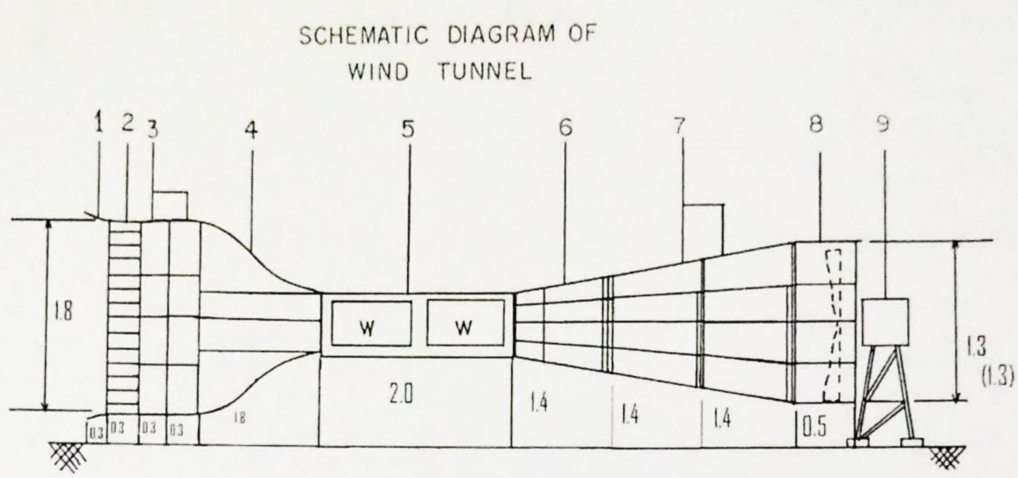
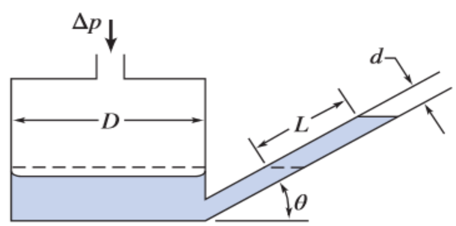


Figure1: Schematics of the wind tunnel.

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*

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

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

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

ρ_l = 800 Kg/m^3 (methyl alcohol)

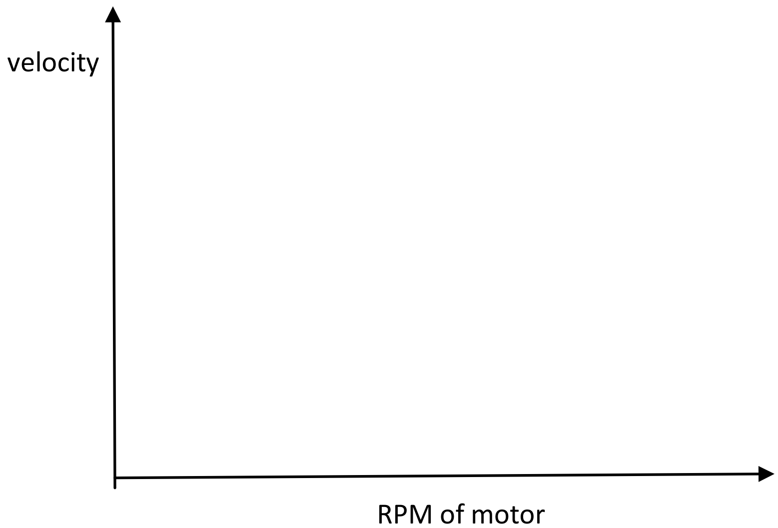
ρ_{air} =1.2 Kg/m^3 (approximate)

g = 9.81 m/s^2 (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)

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

EXPERIMENT-II

PRESSURE DISTRIBUTION OVER CYLINDER

Aim:

To find Cp distribution over a Circular Cylinder.

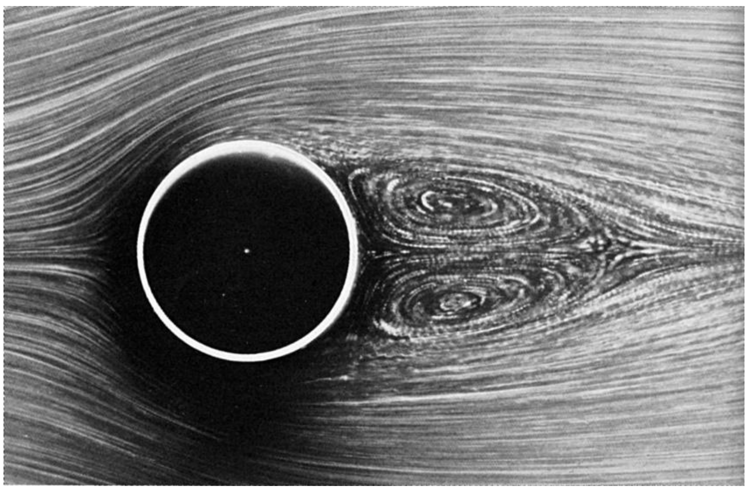
Apparatus:

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 θ 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^o 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} = ... mm Inclined tube manometer reading(h_m) = ... mm

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

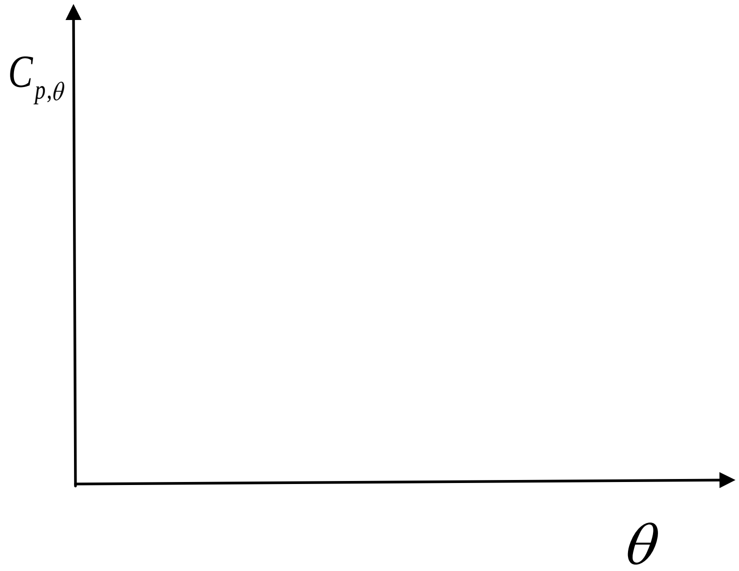
$\mathrm{Re} = \frac{\rho_{air} V D_{cylinder}}{\mu_{air}}$ = ...

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

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

Result:

Polyfit of $C_{p,\theta}$ vs θ performed to get a C_p distribution over cylinder along with the $C_{p,theoretical}$ vs θ . 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. Does the shape and the size of the pressure taps cause any errors?
4. Can the pressure taps be elliptic or square in shape?
5. After which Reynolds number, there exists a potential difference between the theory and experimental results?
6. If the error in C_p can be defined as $\left|C_{p,theoretical} - C_{p,\exp erimental}\right|$, 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?

EXPERIMENT - III

PRESSURE DISTRIBUTION OVER SYMMETRICAL AIRFOIL

Aim:

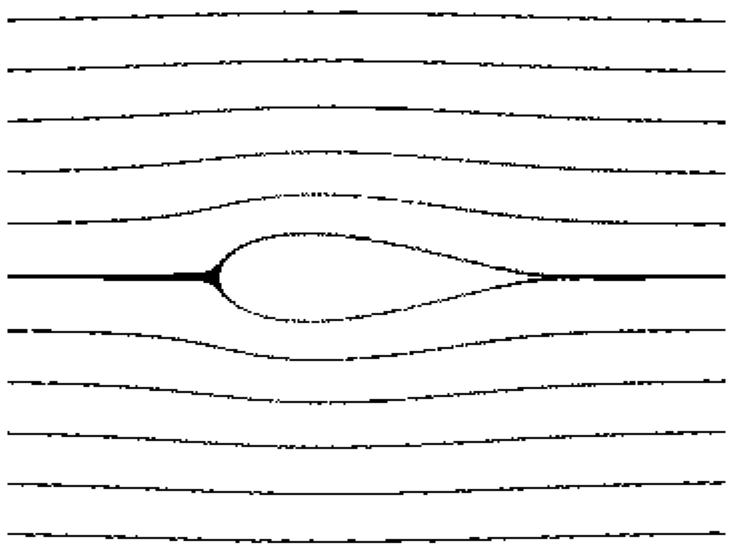
To find Cp distribution over a symmetrical airfoil and further evaluate C_l and C_d from the C_p distribution.

Apparatus:

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

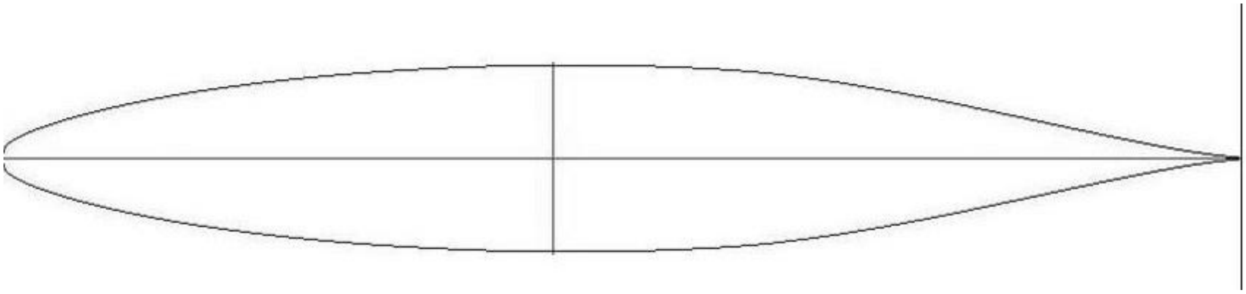
Principle:

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 α 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_2 – 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_2– 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^{o} 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} = ... mm

Inclined tube manometer reading (h_m) = ... mm

h_{total} = ... mm

From Calibration $V = 3.68\sqrt{h_m}$ = ... m/s

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

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

α= ....°

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 (α) 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

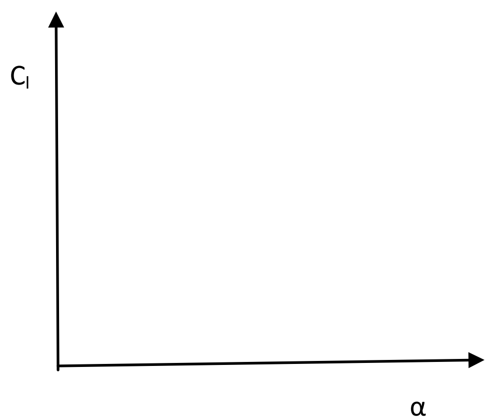
X, mm	Y, mm
0	0
0.75	1.683
1.125	2.015
1.875	2.513
3.75	3.353
7.5	4.65
11.25	5.672
15.00	6.537
22.50	7.929
30.00	8.993
37.50	9.815
45.00	10.434
52.50	10.875
60.00	11.145
67.50	11.243
75.00	11.175
82.50	10.925
90.00	10.439
97.50	9.558
105.00	8.364
112.50	6.448
120.00	5.397
127.50	3.795
135.00	2.22
142.50	0.849
150.00	0

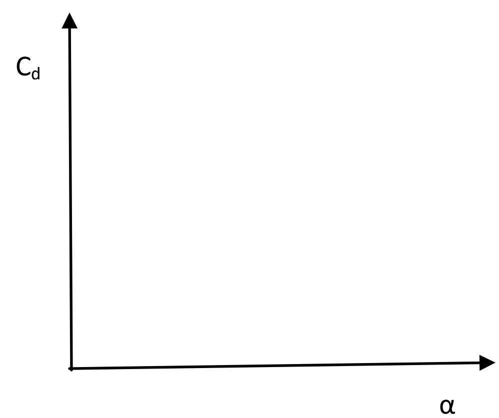
Upper surface			Lower surface		
Hole No	Distance from leading edge X(mm)	X/C × 10	Hole No	Distance from leading edge X(mm)	X/C × 10
1	0	0	14	6.0	0.4
2	1.5	0.1	15	12.0	0.8
3	3.0	0.2	16	22.5	1.5
4	6.0	0.4	17	40.5	2.7
5	12.0	0.8	18	58.5	3.9
6	22.5	1.5	19	78.0	5.2
7	40.5	2.7	20	97.0	6.5
8	58.5	3.9	21	117.0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

Result:

Polyfit of $C_{p,\theta}$ vs θ performed to get a C_p distribution over cylinder along with the $C_{p,theoretical}$ vs θ . 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 (α_{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 α 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?

EXPERIMENT - IV
PRESSURE DISTRIBUTION OVER CAMBERED AIRFOIL

Aim:

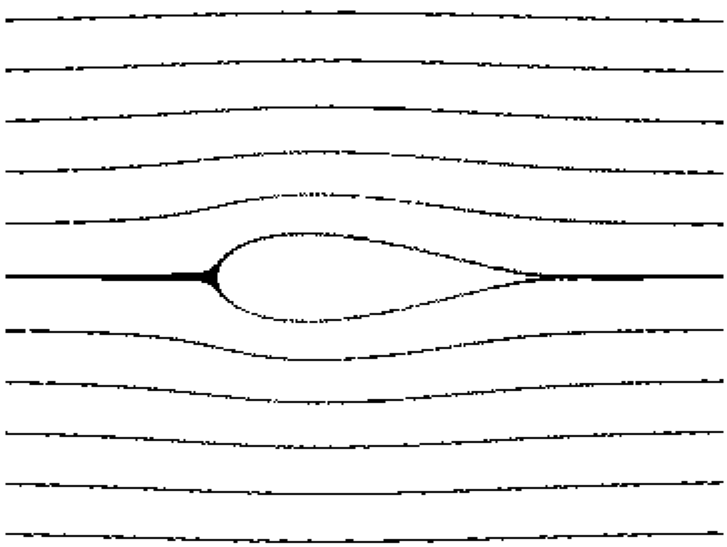
To find Cp distribution over a cambered airfoil and further evaluate C_l and C_d from the C_p distribution and estimate the zero lift angle of attack (α_0).

Apparatus:

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

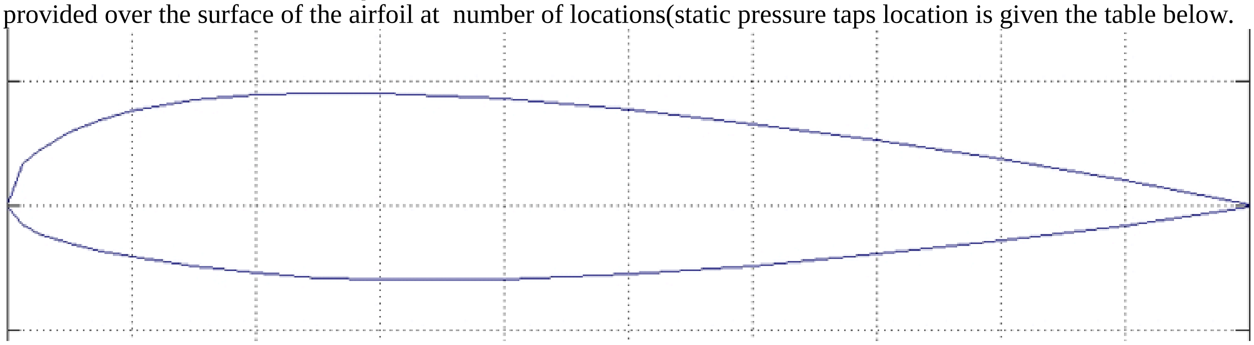
Principle:

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 α 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_2 – 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^o 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} = ... mm

Inclined tube manometer reading (h_m) = ... mm

h_{total} = ... mm

From Calibration $V = 3.68\sqrt{h_m}$ = ... m/s

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

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

α= ....°

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 (α) 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

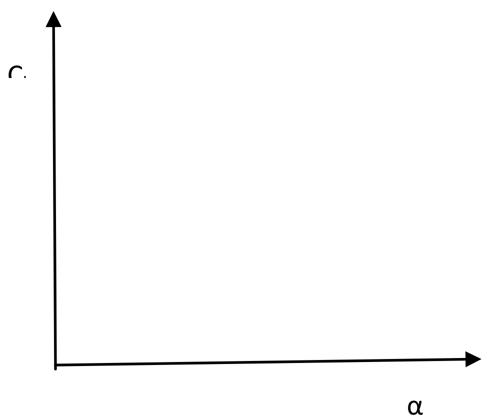
Bottom Y, mm	X, mm	Upper Y, mm
-0.990	0	0.0
-0.993	0.75	2.373
-1.054	1.125	2.9771
-1.067	1.875	3.959
-0.892	3.75	5.815
-0.611	7.50	8.699
-0.412	11.25	10.933
-0.296	15.00	12.779
-0.243	22.50	15.615
-0.373	30.00	17.614
-0.644	37.50	18.986
-1.019	45.00	19.850
-1.466	52.50	20.285
-1.950	60.00	20.340
-2.437	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

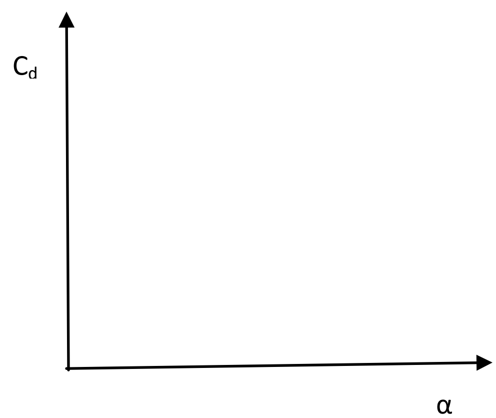
Upper surface			Lower surface		
Hole No	Distance from leading edge X(mm)	X/C × 10	Hole No	Distance from leading edge X(mm)	X/C × 10
1	0	0	14	6.0	0.4
2	1.5	0.1	15	12.0	0.8
3	3.0	0.2	16	22.5	1.5
4	6.0	0.4	17	40.5	2.7
5	12.0	0.8	18	58.5	3.9
6	22.5	1.5	19	78.0	5.2
7	40.5	2.7	20	97.0	6.5
8	58.5	3.9	21	117.0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

Result:

Polyfit of $C_{p,\theta}$ vs θ performed to get a C_p distribution over cylinder along with the $C_{p,theoretical}$ vs θ . 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 Cp 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 α 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 α is equal to 2*π? If not why?
12. Can the slope of C_l vs α curve exceed 2*π?

EXPERIMENT - V
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 (α).
7. Repeat the same process for various slid slip angles (β).

Observations:

Reynolds number (ρ*V*L/μ) = _____ ,

α	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 α are plotted and thus static longitudinal stability can be observed
Plots of $C_{s,}$ C_n & C_l vs β 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.

EXPERIMENT- VI

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*10^5 the flow can be considered to be in the laminar region. If Re > 5*10^5 the flow is said to be in turbulent regime. If Re is in between flow in 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:

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

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

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?

EXPERIMENT - VII

FLOW VISUALIZATION

Aim:

To observe the smoke visualization over the circular cylinder..

Apparatus:

Wind tunnel, circular cylinder, 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 Reynolds number try to observe the stream lines.
6. Note the angle of attack at which the stream lines separate from the surface.

Result:

Compare the flow separation point with the results from the Cp distribution over various Reynolds number.

Try to answer the question why the Cp 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?

EXPERIMENT - VIII

FLOW VISUALIZATION

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 Cp distribution over various Reynolds number.

Try to answer the question why the Cp 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?

EXPERIMENT - IX

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:

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

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

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

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.

EXPERIMENT– X
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 $1/4^{th}$ 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 (suction head) = $h_1 - h_2$

H_D (delivery head) = $h_1 - h_2$

H_g (Venturi head) = $h_1 - h_2$

H_{H2O} (Total head) = $H_s + H_D$

$H_{Air} = H_{H2O} \times [(\rho_{H2O} / \rho_{Air})]$,

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

where $\rho_{Air} = 1.2$ kg/m^3, $\rho_{H2O} = 1000$ kg/m^3, $\rho_{Hg} = 13456$ kg/m^3

To find the blower discharge Q:

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

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

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

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

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 (Po):

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

Efficiency of Blower (η):

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

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 (suction head) = $h_1 - h_2$

H_D (delivery head) = $h_1 - h_2$

H_g (Venturi head) = $h_1 - h_2$

H_{H2O} (Total head) = $H_s + H_D$

$H_{Air} = H_{H2O} \times [(\rho_{H2O} / \rho_{Air})]$,

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

where $\rho_{Air} = 1.2$ kg/m^3, $\rho_{H2O} = 1000$ kg/m^3, $\rho_{Hg} = 13456$ kg/m^3

To find the blower discharge Q:

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

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

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

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

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 (Po):

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

Efficiency of Blower (η):

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

Tabular Column:

Table 1:

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

Table 2:

$H_{H2O} = H_S + H_D$	H_{Air} (m)	h_{Air} (m)	K	$Q(m^3/s)$	P_o (KW)	P_i (KW)	η

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 (suction head) = $h_1 - h_2$

H_D (delivery head) = $h_1 - h_2$

H_g (Venturi head) = $h_1 - h_2$

H_{H2O} (Total head) = $H_s + H_D$

$H_{Air} = H_{H2O} \times [(\rho_{H2O} / \rho_{Air})]$,

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

where $\rho_{Air} = 1.2$ kg/m^3, $\rho_{H2O} = 1000$ kg/m^3, $\rho_{Hg} = 13456$ kg/m^3

To find the blower discharge Q:

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

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

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

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

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 (Po):

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

Efficiency of Blower (η):

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

Tabular Column:

Table 1:

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

Table 2:

$H_{H2O}= H_S + H_D$	H_{Air} (m)	h_{Air} (m)	K	$Q(m^3/s)$	P_o (KW)	P_i (KW)	η

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 (suction head) = $h_1 - h_2$

H_D (delivery head) = $h_1 - h_2$

H_g (Venturi head) = $h_1 - h_2$

H_{H2O} (Total head) = $H_s + H_D$

$H_{Air} = H_{H2O} \times [(\rho_{H2O} / \rho_{Air})]$,

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

where $\rho_{Air} = 1.2$ kg/m^3, $\rho_{H2O} = 1000$ kg/m^3, $\rho_{Hg} = 13456$ kg/m^3

To find the blower discharge Q:

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

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

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

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

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 (Po):

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

Efficiency of Blower (η):

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

Tabular Column:

Table 1:

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

Table 2:

$H_{H2O} = H_S + H_D$	H_{Air} (m)	h_{Air} (m)	K	$Q(m^3/s)$	P_o (KW)	P_i (KW)	η

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 ___________________.

EXPERIMENT - XI

AXIAL FLOW COMPRESSOR TEST RIG

Aim:

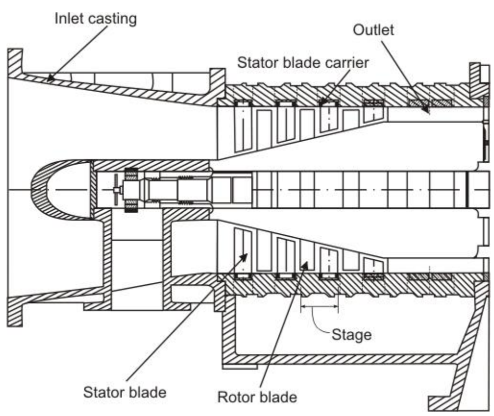
To determine efficiency of an axial flow compressor.

Apparatus:

Axial flow compressor test rig, temperature measurement instruments, pressure taps, manometer.

Theory:

Axial flow compressors are work consuming rotary machines that are intended to compress any compressible medium say air or gas to a higher pressure (compression ratio). Here the flow takes place in the longitudinal direction as the shaft exists. Often used in gas turbine engines as part of propulsion system in aeronautical applications or as part of power generation devices in mechanical engineering applications. The compressor consists of a rotating set of blades called as rotor and fixed set of blades called as stator or diffuser blades. Here the rotor imparts kinetic energy to the flow whereas the stator section decelerates the flow and converts the kinetic energy to pressure energy. A set of stator and rotor is called a stage. There could be as many stages as possible. The shape of the blades dictates the aerodynamic efficiency of the compressor system in converting shaft work to pressure energy of the flow. The type of thermodynamic process with which the gas is taken from inlet thermodynamic state to outlet thermodynamic state is the point of concern for the compressor to consume minimum amount of work for a given compression ratio. Ideally this should be an isentropic process. In reality, it deviates because of various factors like slip, shocks and boundary layer.



Description:

A three stage axial compressor is part of the setup. The supplier provides instrumentation for calculating the isothermal efficiency of the whole setup rather than the compressor as such.

$$\eta_{whole\ setup} = \eta_{aerodynamic,compressor} \times \eta_{shaft,mechanical} \times \eta_{electrical}$$

$$\eta_{aerodynamic,compressor} = \frac{W_{ideal,isothermal}}{W_{real\_work\_done\_on\_gas}}$$

$$\eta_{shaft,mechanical} = \frac{W_{real\_work\_done\_on\_gas}}{W_{shaft\_work}}$$

$$\eta_{electrical} = \frac{W_{shaft\_work}}{W_{electrical\_energy\_consumption}}$$

$$\eta_{whole\_test\_rig} = \frac{W_{ideal\_work\_done\_on\_gas}}{W_{electrical\_energy\_consumption}}$$

$$W_{ideal\_work\_done\_on\_gas} = P_i \times Q \times ln(r) \text{ under isothermal assumption}$$

where r = pressure ratio of outlet to inlet
t = time taken (in seconds) for 'n' revolutions
Q = discharge calculated at inlet = A*v (A: area of inlet cross section; v: velocity of the flow calculated from static and total pressure heads)

$$W_{electrical\_energy\_consumption} = \frac{3600 \times n}{E \times t}$$

where n = Number of Revolutions of the meter indicator
t = time taken (in seconds) for 'n' revolutions
E = Energy meter constant = ………………… revolutions/kW/hr

Procedure:

1. Switch on the compressor and fix at an rpm.
2. Take down the static and total pressure readings at inlet and outlet from the multitube manometer
3. Take the energy meter readings.
4. Repeat the same experiment for different RPMs.

Observations:

RPM = ………………………….
H_t = total inlet manometer head reading = ………………………mm of alcohol
h_i = static inlet manometer head reading = ………………………mm of alcohol
h_o = static outlet manometer head reading = ………………………mm of alcohol

$P_{o,i}$ = total inlet pressure = $P_{atm} + \rho_{alcohol}\ g*H_i$ = ………………………….
$P_{o,i}$ = total outlet pressure = $P_{atm} + \rho_{alcohol}\ g*H_i$ = ………………………….
$P_{o,o}$ = total outlet pressure = $P_{atm} + \rho_{alcohol}\ g*Ho$ = ………………………….
P_i = static inlet pressure = $P_{atm} + \rho_{alcohol}\ g*h_i$ = ………………………….
P_o = static outlet pressure = $P_{atm} + \rho_{alcohol}\ g*h_i$ = ………………………….
$r = P_o/P_i$

$$\mathbf{V = \sqrt{2 \times \rho_{alcohol} \times (H_i - h_i) \div \rho_{air}}}$$

Calculations:

Result: The overall efficiency of the axial flow compressor test rig is calculated.

EXPERIMENT - XII

CENTRIFUGAL FLOW COMPRESSOR TEST RIG

Aim:

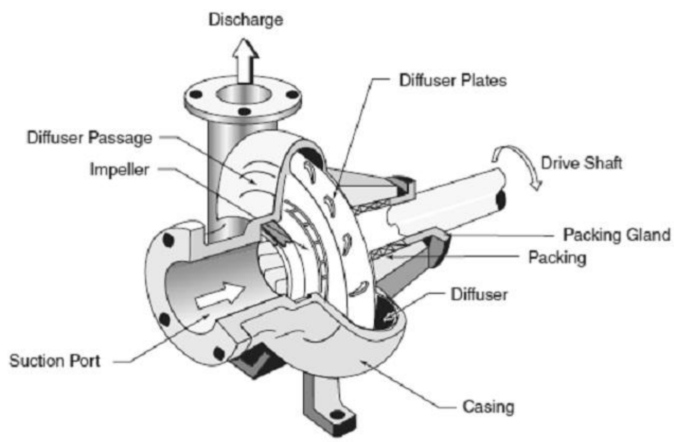
To determine efficiency of a centrifugal flow compressor.

Apparatus:

Centrifugal flow compressor test rig, temperature measurement instruments, pressure taps, manometer.

Theory:

Centrifugal flow compressors are work consuming rotary machines that are intended to compress any compressible medium say air or gas to a higher pressure (compression ratio). Here the flow enters in the eye of the impeller and turns in the radial direction perpendicular to the shaft exists. Often used in small gas turbine engines as part of propulsion systems in aeronautical applications, or as part of power generation devices in mechanical engineering applications. The compressor consists of a rotating set of blades called as impeller and a volute casting called as diffuser. The rotor imparts kinetic energy to the flow whereas the diffuser section decelerates the flow and converts the kinetic energy to pressure energy. A set of stator and rotor is called a stage. There could be as many stages as possible. The shape of the blades dictates the aerodynamic efficiency of the compressor system in converting shaft work to pressure energy of the flow. The type of thermodynamic process with which the gas is taken from inlet thermodynamic state to outlet thermodynamic state is the point of concern for the compressor to consume minimum amount of work for a given compression ratio. Ideally this should be an isentropic process. In reality, it deviates because of various factors like slip, shocks and boundary layer.



Description:

A centrifugal flow compressor is part of the setup. The supplier provides instrumentation for calculating the isothermal efficiency of the whole setup rather than the compressor as such.

$$\eta_{whole\ setup} = \eta_{aerodynamic,compressor} \times \eta_{shaft,mechanical} \times \eta_{electrical}$$

$$\eta_{aerodynamic,compressor} = \frac{W_{ideal,isothermal}}{W_{real\_work\_done\_on\_gas}}$$

$$\eta_{shaft,mechanical} = \frac{W_{real\_work\_done\_on\_gas}}{W_{shaft\_work}}$$

$$\eta_{electrical} = \frac{W_{shaft\_work}}{W_{electrical\_energy\_consumption}}$$

$$\eta_{whole\_test\_rig} = \frac{W_{ideal\_work\_done\_on\_gas}}{W_{electrical\_energy\_consumption}}$$

$$W_{ideal\_work\_done\_on\_gas} = \mathrm{P_i} \times Q \times ln(r) \text{ under isothermal assumption}$$

where r = pressure ratio of outlet to inlet
t = time taken (in seconds) for 'n' revolutions
Q = discharge calculated at inlet = A*v (A: area of inlet cross section; v: velocity of the flow calculated from static and total pressure heads)

$$W_{electrical\_energy\_consumption} = \frac{3600 \times n}{\mathrm{E} \times \mathrm{t}}$$

where n = Number of Revolutions of the meter indicator
t = time taken (in seconds) for 'n' revolutions
E = Energy meter constant = ………………… revolutions/kW/hr

Procedure:

1. Switch on the compressor and fix at an rpm.
2. Take down the static and total pressure readings at inlet and outlet from the multitube manometer.
3. Take the energy readings.
4. Repeat the same experiment for different RPMs.

Observations:

RPM = ………………………….
H_t = total inlet manometer head reading = ………………………mm of alcohol
h_i = static inlet manometer head reading = ………………………mm of alcohol
h_o = static outlet manometer head reading = ………………………mm of alcohol

$P_{o,i}$ = total inlet pressure = $P_{atm} + \rho_{alcohol}\ g*H_i$ = ………………………….
$P_{o,i}$ = total outlet pressure = $P_{atm} + \rho_{alcohol}\ g*H_i$ = ………………………….
$P_{o,o}$ = total outlet pressure = $P_{atm} + \rho_{alcohol}\ g*Ho$ = ………………………….
P_i = static inlet pressure = $P_{atm} + \rho_{alcohol}\ g*h_i$ = ………………………….
P_o = static outlet pressure = $P_{atm} + \rho_{alcohol}\ g*h_i$ = ………………………….
$r = P_o/P_i$

$$\mathbf{V} = \sqrt{\mathbf{2} \times \boldsymbol{\rho}_{\mathbf{alcohol}} \times (\mathbf{H_i} - \mathbf{h_i}) \div \boldsymbol{\rho}_{\mathbf{air}}}$$

Calculations:

Result:

The overall efficiency of the centrifugal flow compressor test rig is calculated.