INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad – 500043

COURSE CONTENT

AERODYNAMICS AND PROPULSION LABORATORY								
Course Code	**Category**	**Hours / Week**			**Credits**	**Maximum Marks**		
AAEC12	**Core**	**L**	**T**	**P**	**C**	**CIA**	**SEE**	**Total**
		0	0	3	1.5	30	70	100
Contact Classes: 48	**Tutorial Classes: Nil**	**Practical Classes: 48**				**Total Classes:48**		
Prerequisite: Fluid Dynamics and Thermodynamics								

I. COURSE OVERVIEW:

The aerodynamics and propulsion laboratory course typically involves hands-on experiments and practical applications to reinforce the theoretical concepts learned in aerodynamics and propulsion courses. The lab is designed to provide students with a deeper understanding of the principles related to the behaviour of aerodynamic concepts and propulsion systems used in aircrafts. This course offers a wide range of applications in aerodynamics and propulsion such as measurement of lift, drag, moment, boundary layer and thrust measurements. It forms an essential cornerstone for aerospace engineers, plays a pivotal role in the efficient design and testing of various aircraft components.

II. COURSE OBJECTIVES:

The students will try to learn:

I. The wind tunnel calibration and associated instrumentation.
II. The measurement of lift and drag coefficients of various aerodynamic components
III. The measurement of performance characteristics of compressor, blower, propeller and nozzle
IV. The thrust measurement and performance calculation of gas turbine engine.

III. COURSE OUTCOMES:

After successful completion of the course, students should be able to:

CO1	Make use of various calibration techniques for assessing the flow quality in wind tunnel test section.
CO2	Examine the pressure distribution over airfoil, cylinder and flat plate for predicting their aerodynamics characteristics.
CO3	Utilize the six-component force balancer for deducing the forces and moments of aircraft model and hence obtaining the aircraft performance and stability.
CO4	Determine the pressure, temperature across each component gas turbine engine for predicting its thrust and performance characteristics.
CO5	Examine the performance characteristics of compressor, blower, propeller and nozzle for their efficient design.
CO6	Identify the flash point, fire point and calorific value of different fuels for their suitability in aerospace applications

IV. COURSE CONTENT

EXERCISES FOR AERODYNAMICS AND PROPULSION LABORATORY

Note: Students are encouraged to bring their own laptops for laboratory practice sessions to plot the graph and do the calculation using excel.

1. Getting Started Exercises

Introduction to Low-Speed Wind Tunnel

All the experiments in the aerodynamics part will be carried out in suction type- open circuit low speed wind tunnel (Fig.1).

Specification

Test section size = 600 X 600 x 2000 mm
Maximum speed in test section= 54 m/s
Fan speed range= 60-1350 rpm

Fig 1: Low speed open circuit wind tunnel

Instrumentation

- Multitube manometer
- Inclined manometer
- Pitot tube
- Pitot-Static tube
- Wake rake
- Boundary layer rake
- Six component balance
- Digital anemometer

Introduction to Axial Flow Gas Turbine

The CM14 axial flow turbine engine, has been integrated into a sturdy metal frame that holds it firmly, while enabling accurate measurement of the thrust produced by the engine. Electronic preprogrammed controller constantly supervises the engine, ensuring safe operating conditions at all times. The engine is controlled via the software, which provides users with a graphical interface for real-time monitoring and operation (Fig.2).

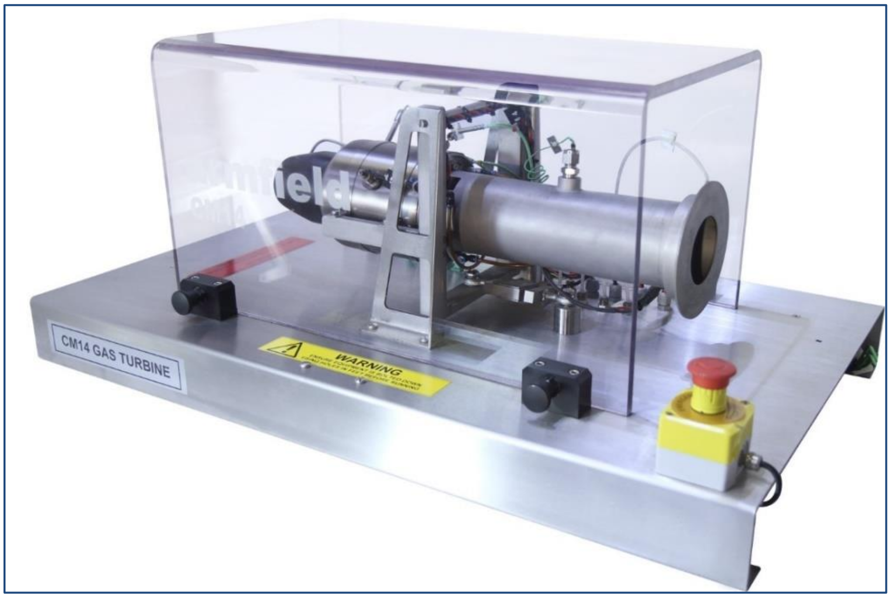

Fig. 2: CM14 axial flow turbine engine

Specification

- Typical fuel: One of the following choices
  – Paraffin
  – Jet A-1
  – JP-4/Kerosene
- Exhaust gas temperature: 800°C typical
- Mass flow: 450 g/s
- Ignition system: Glow plug
- Compressor type: Single-stage radial
- Turbine type: Single-stage, low-mass axial flow
- Engine rpm: 105,000rpm typical
- Engine mount: Single pivot point

1.1 Measurement of pressure and flow velocity

Measure the wind tunnel static, dynamic and total pressure with different flow velocity.

Try

1. Measure the flow velocity
2. Measure the static pressure
3. Measure the total pressure

2. Exercises on calibration and pressure distribution over cylinder

2.1 Calibration of subsonic wind tunnel

Determine the true speed and flow angularity in the wind tunnel test section for propeller rpms 100 to 1300 in steps of 100 and plot RPM vs velocity, and RPM vs flow angularity (Fig. 3).

Fig. 3: Wind tunnel calibration

Try

1. Change the propeller rpm to 200 to 500 in steps of 50 and plot RPM vs velocity.
2. Change the propeller rpm to 600 to 900 in steps of 100 and plot RPM vs angularity.
3. Change the propeller rpm to 1000 to 1400 in steps of 200 and plot RPM vs velocity.

2.2 Pressure distribution over cylinder

Measure the pressure distribution over a circular cylinder having span of 600 mm, diameter of 50 mm, and Reynolds number of 3×10^5 (laminar) and determine coefficient of pressure and drag coefficient. Also compare the experimental and theoretical cp values (Fig. 4).

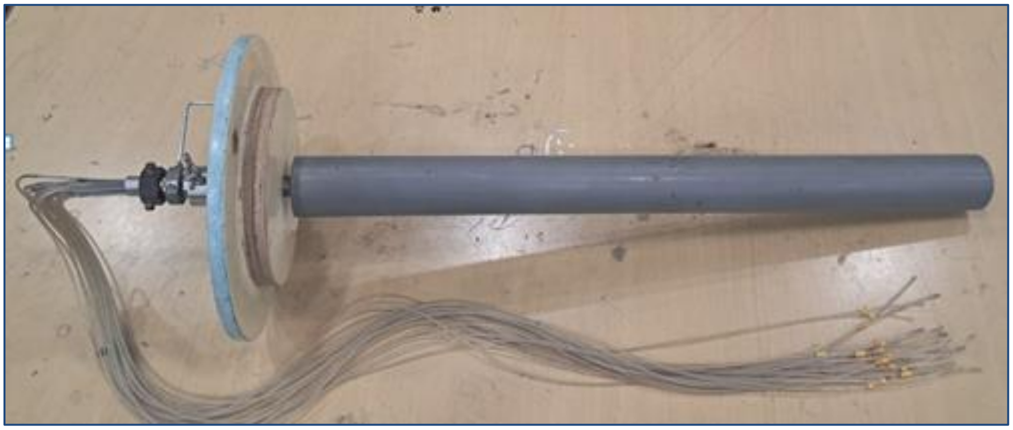

Fig. 4: Cylinder model

Try

1. Change the Reynolds number to 5.5x10^5 (transition) and determine the Cp distribution, drag coefficient.
2. Change the Reynolds number to 7 x10^5 (turbulent) and determine the Cp distribution, drag coefficient.

3. Exercises on pressure distribution and flow visualization

3.1 Pressure distribution over symmetrical airfoil

Measure the pressure distribution over a NACA 63(2)-215 symmetrical airfoil having span of 600 mm, chord length of 150 mm, Reynolds number of 3×10^5 (laminar) and determine coefficient of pressure, lift, and drag coefficient at different angle of attack. Also plot α vs C_L, α vs C_D, and x/c vs $C_{p,}$ (Fig. 5).

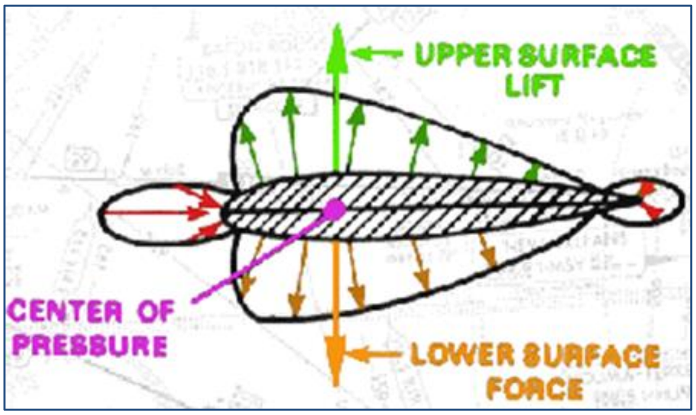

Fig. 5: Symmetrical airfoil pressure distribution

Try

1. Determine the c_l, c_d, c_p for NACA 63(2)-215 cambered airfoil at Reynolds number of 3×10^5
2. Change the Reynolds number to 7 $\times10^5$ (turbulent) and determine the c_l, c_d, c_p.
3. Determine c_l, c_d, and c_p for the NACA Symmetrical airfoil (Fig. 5).

3.2 Flow visualization (Circular cylinder)

Determine the wake width and flow separation point of a circular cylinder having span of 600 mm, diameter of 50 mm, at different Reynolds number (Fig. 6).

Fig. 6: Smoke flow visualization behind the circular cylinder [Sharad, 2021]

Try

1. Repeat the same experiment for a NACA 63(2)-215 symmetrical airfoil having different Reynolds number and angle of attack.
2. Repeat the same experiment for a NACA 0015 symmetrical airfoil having different velocity and angle of attack.

3.3 Flow visualization over a car model

Tuft/ smoke flow visualization on a car model with different speed (Fig. 7, 8).

Fig .7: Smoke flow visualization over the model car

Fig. 8: Tuft flow visualization over the model car

Try

1. Visualization of flow pattern at the rear end of the Fastback and Square back car model.
2. Flow visualization with rear spoilers on a car.
3. Influence of the slant angle in car back (Fig.9).

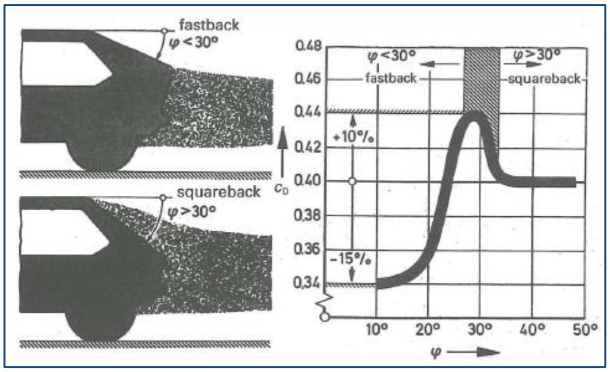

Fig. 9: Effect of slant angle and flow pattern on a car back [Hucho, 1998]

4. Exercises on wake analysis

4.1 Wake analysis of a circular cylinder / Car model

Determine the drag coefficient of a circular cylinder having span of 600 mm and diameter of 50 mm at Reynolds number of 1.0×10^6 by the wake survey method (Fig.10).

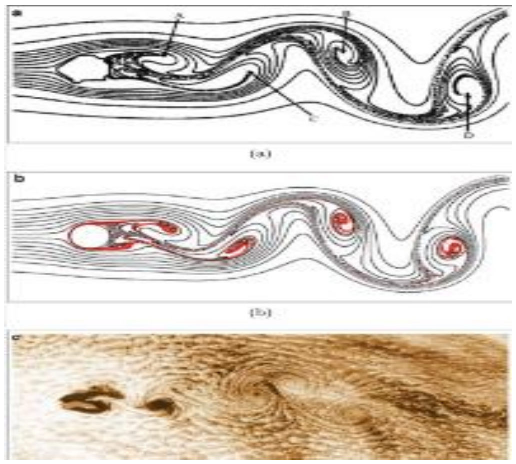

Fig .10: Wake analysis of circular cylinder

Try

1. Change the Reynolds number to 3.0×10^4 (laminar) and determine drag coefficient
2. Change the Reynolds number to 1.5×10^6 (turbulent) and determine drag coefficient
3. Wake analysis if the car model at given Reynolds number

4.2 Wake analysis of a symmetrical airfoil

Determine the drag coefficient of a NACA 63(2)-215 symmetrical airfoil having span of 600 mm and chord length of 150mm, Reynolds number of 3x10^5 (laminar) and angle of attack by the wake survey method (Fig.11).

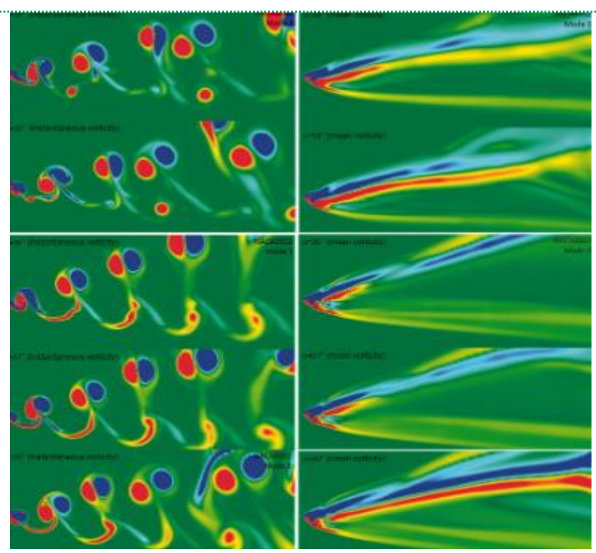

Fig.11: Wake pattern of symmetric airfoil

Try

1. Repeat the same experiment for a NACA 63(2)-215 cambered airfoil having angle of attack.
2. Change the Reynolds number to 7 x10^5 (turbulent) and determine drag coefficient.
3. Flow field on a backward facing step of a car model (Fig.12).

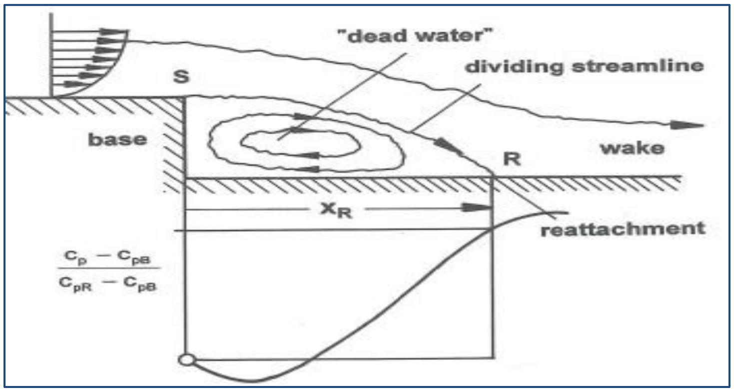

Fig.12: Flow field on a backward facing step of a car model [Hucho, 1998]

5. Exercises on force measurement

5.1 Force measurement of Aircraft model

Determine the lift, drag, side force, pitching moment, rolling moment, yawing moment of an aircraft model having Reynolds numbers of 3x10^5, 5.5x10^5 and 7 x10^5 at a given angle of attack using six component balance (Fig.13).

Fig.13: Six component balance with display and strain gauges

Try

1. Repeat the same experiment for different angle of attack and determine all the forces, moments
2. Introduce vortex generator on the wing surface and determine all the forces, moments
3. Determination of forces and moments over a car model to study its performance and stability.

5.2 Force measurement of Car model

Determine the lift, drag, side force, pitching moment, rolling moment, yawing moment of given car model having Reynolds numbers of $3x10^5$, and $7 x10^5$ at a zero-degree angle of attack using six component balance (Fig.14).

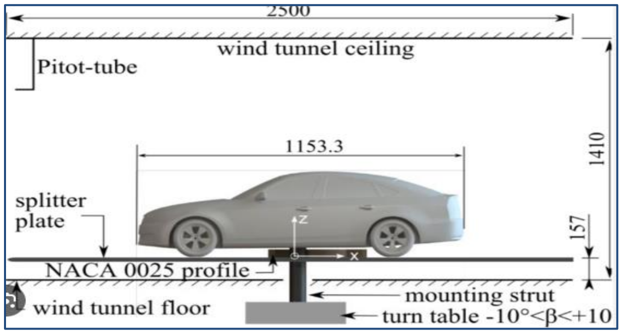

Fig. 14: Experimental setup of scaled down car model

Try

1. Undertake the experiment for different orientations to determine the forces, and moments at Re $5x10^5$.
2. Determine the side force and yawing moment with variation of side slip angle (Fig. 15).
3. Determine the stability of a given car model with varying velocity.

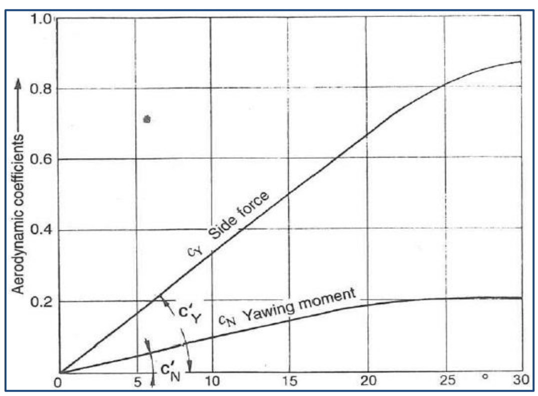

Fig.15: Plot of side force and yawing moment with different yawing angle [Hucho, 1998]

6. Exercises on flow over a flat plate

6.1 Boundary layer measurements on flat plate

Determine the boundary layer thickness at different station of a flat plate having characteristic length of 2000 mm at a given test section velocity. Also compare experimental results with theoretical results of laminar and turbulent approximation (Fig. 16).

Try

1. Introduce vortex generators at the leading edge of flat plate and determine the boundary layer thickness at different stations.

2. Determine the boundary layer thickness at different station of a symmetrical airfoil having characteristic length of 30 mm at a given test section velocity 0f 30 m/s.
3. Determine the boundary layer thickness at different station of a symmetrical airfoil having characteristic length of 50 mm at a given test section velocity 0f 20 m/s.

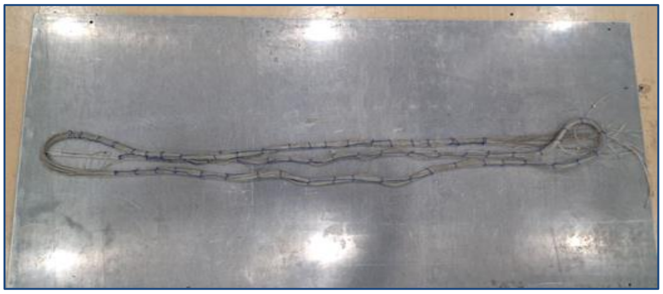

Fig.16: Flat plate

6.2 Prediction of skin friction drag by boundary layer measurement

Determine the skin friction of a flat plate by measuring the boundary layer. Also compare experimental results with computational results of laminar and turbulent approximation. (Fig. 16).

Try

1. Introduce vortex generators at the leading edge of flat plate and determine the shear stress.
2. Measure the velocity gradient in vertical plane and calculate the skin friction at different speed.
3. Determine the boundary layer thickness of a flat plate having characteristic length of 50 mm at a test section velocity 0f 30 m/s.

7. Exercises on gas turbine parameters calculation

7.1 Prediction of Gas Turbine parameters

Estimate the thrust output CM14 – axial flow gas turbine engine, using the momentum equation, and compare this result to the measured thrust (Fig.17).

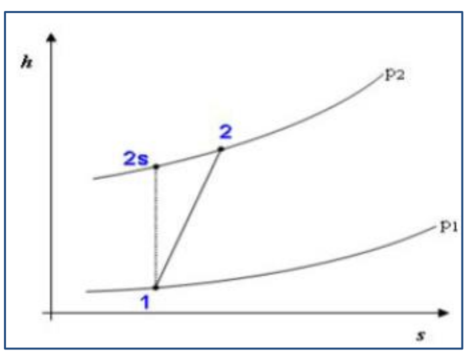

Fig. 17: Enthalpy and entropy plots of Gas turbine

Try

1. Calculate the thrust for different fuel flow rate.
2. Determine the thrust for different airflow rate.
3. Evaluate the power developed of the gas turbine at different rpm.

7.2 Prediction of Gas Turbine temperature variation

Measure the temperature variation of output CM14 – axial flow gas turbine engine, using thermal sensor, and compare this result to the measured computer value (Fig.17).

Try

1. Measure the temperature at inlet of the turbine.
2. Find the temperature at compressor inlet zone.
3. Evaluate the temperature at exhaust area.

8. Exercises on gas turbine performance diagrams and efficiency

8.1 Prediction of Gas Turbine performance

Estimate the actual thermodynamic cycle experienced by the flow throughout the CM14 – axial flow gas turbine engine and represent it in the form of the Temperature vs. Specific Entropy diagram. Also calculate thermal, propulsive and overall efficiency of engine (Fig. 18)

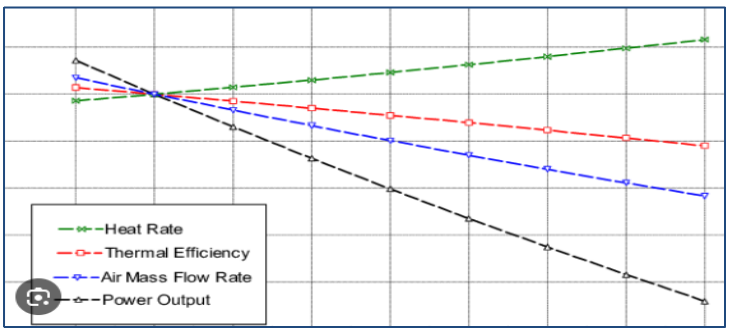

Fig. 18: Performance characteristics of Gas turbine

Try

1. Plot the Temperature vs. Specific Entropy diagram for different fuel flow rate.
2. Plot the Temperature vs. Specific Entropy diagram for different air flow rate.
3. Plot the Temperature vs. Specific Entropy diagram for different air fuel mix flow rate.

8.2 Prediction of Gas Turbine efficiency

Estimate the actual thermodynamic cycle efficiency by the flow throughout the CM14 – axial flow gas turbine engine and represent it in the form of the Temperature vs. Specific Entropy diagram (Fig. 18).

Try

1. Calculate thermal, propulsive and overall efficiency of engine.
2. Estimate thermal, propulsive and overall efficiency of engine.
3. Plot the Temperature vs. Specific Entropy diagram for different air fuel mix flow rate.

9. Exercises on gas turbine components efficiency

9.1 Prediction of Gas Turbine components efficiency

Estimate the efficiencies of intake, compressor, combustion chamber, turbine and nozzle of CM14-axial flow gas turbine engine for given fuel flow rate (Fig. 19)

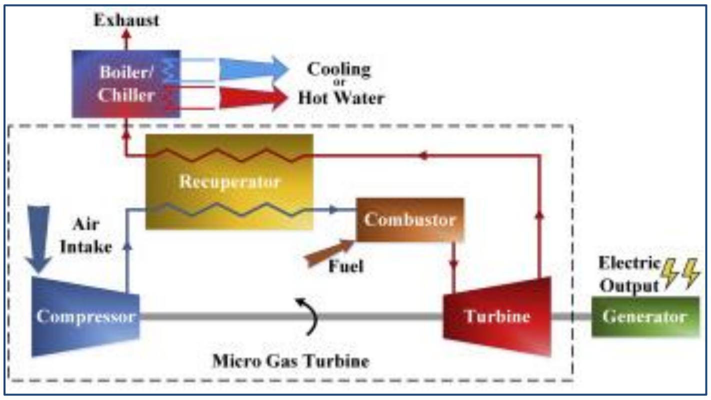

Fig. 19: Micro gas turbine components

Try

1. Calculate the efficiency of gas turbine at different fuel flow rate.
2. Undertake turbine efficiency at different air flow rate.
3. Examine the turbine efficiency at different mixed flow rate.

9.2 Prediction of compressor efficiency

Estimate the efficiencies of compressor of CM14-axial flow gas turbine engine for given fuel flow rate (Fig. 19).

Try

1. Calculate the compressor or turbine efficiency at different fuel flow rate
2. Undertake the above analysis different air flow rate
3. Examine the above analysis different mixture flow rate

10. Exercises on blower test rig

10.1 Estimation of blower efficiency

Estimate the discharge, and suction head, of the centrifugal blower with forward vane impellor at different operating condition. Also plot Efficiency vs Discharge and Discharge vs Head (Fig. 20).

Fig. 20: Blower test rig

Try

1. Undertake the above analysis for centrifugal blower with radial vane impellor.
2. Repeat the above analysis for centrifugal blower with backward vane impellor.
3. Repeat the above analysis for centrifugal blower with straight vane impellor.

10.2 Estimation of blower Performance

Estimate the delivery head and efficiency of the centrifugal blower with forward vane impellor at different operating condition. Also plot Efficiency vs Discharge and Discharge vs Head (Fig. 20).

Try

1. Cary out the above analysis for centrifugal blower with radial vane impellor.
2. Undertake the above analysis for centrifugal blower with backward vane impellor.

11. Exercises on compressor

11.1 Centrifugal compressor

Estimate the discharge, suction head, delivery head and efficiency of the centrifugal compressor with forward vane impellor at different operating condition. Also plot Efficiency vs Discharge and Discharge vs Head (Fig. 21).

Try

1. Repeat the above analysis for centrifugal compressor with half valve opening
2. Repeat the above analysis for centrifugal compressor with full valve opening
3. Repeat the above analysis for centrifugal compressor with 1/4 valve opening

Fig. 21: Centrifugal compressor test rig

11.2 Axial flow compressor

Estimate the discharge, suction head, delivery head and efficiency of the centrifugal blower with forward vane impellor at different operating condition. Also plot Efficiency vs Discharge and Discharge vs Head.

Fig. 22: Axial flow compressor test rig

Try

1. Repeat the above analysis for 1000 rpm (Fig. 22)
2. Repeat the above analysis for 1500 rpm (Fig. 22).
3. Repeat the above analysis for 2000 rpm (Fig. 22).

12. Exercises on nozzle Performance

12.1 Estimation of nozzle discharge and head

Estimate the discharge, and head across multiple stations. Also plot Discharge Vs Velocity. (Fig. 23).

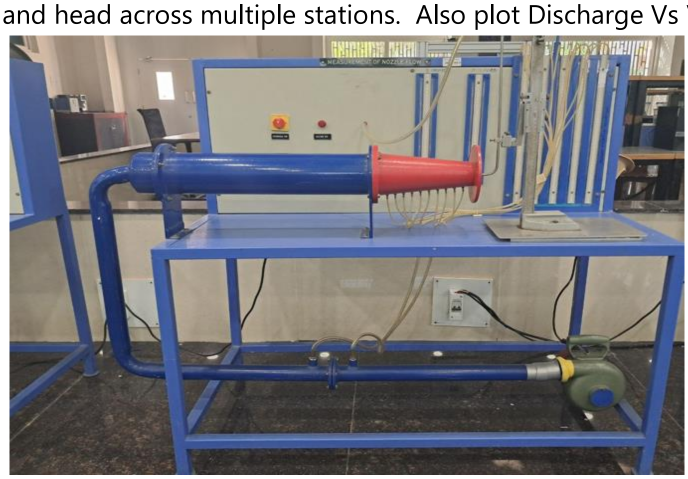

Fig. 23: Nozzle performance test rig

Try

1. Estimate the discharge, head, and efficiency for different inlet conditions.
2. Estimate the discharge, head, and thrust for different outlet conditions.
3. Estimate the efficiency, and thrust for ambient conditions.

12.2 Estimation of nozzle discharge and head

Estimate the, efficiency, thrust, wall pressure distribution and velocity variation across multiple stations. Also plot Discharge Vs Velocity (Fig. 23).

Try

1. Estimate the efficiency and thrust for different inlet conditions.
2. Estimate the head, and thrust for different outlet conditions.
3. Estimate the efficiency, and thrust for ambient conditions.

13. Exercises on propeller test rig

13.1 Estimation of nozzle discharge and head

Estimate the thrust, and mass flow rate of air, of propeller at different RPMs. Also compare the theoretical propulsive efficiency and estimated propulsive efficiency.

Fig. 24: Propeller test rig

Try

1. Repeat the above analysis by changing the pitch of propeller.
2. Undertake a case study on variable pitch propeller
3. Prepare a report for 5 best propeller aircrafts of the world.

13.2 Estimation of nozzle discharge and head

Estimate torque, and efficiency of propeller at different RPMs. Also compare the theoretical propulsive efficiency and estimated propulsive efficiency.

Try

1. Examine the discharge and head by changing the pitch of propeller.
2. Undertake a case study on variable pitch propeller.
3. Prepare a report for 5 best propeller aircrafts of the world with efficiency.

14. Exercises on Sports aerodynamics

14.1 Cricket ball aerodynamic analysis

Determine the effects of seam position, and roughness of cricket ball with different used overs.

Try

1. Undertake wind tunnel testing to find the effect of seam for fast bowler (Fig. 25).
2. Undertake wind tunnel testing to find the effect of seam for spinners (Fig. 26).
3. Undertake wind tunnel testing of used (old) cricket ball (Fig. 27).

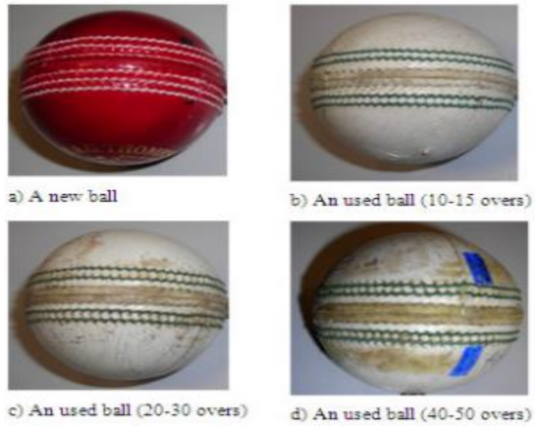

Fig. 25: Types of ball used in cricket [Alam et. al, 2010]

Fig. 26: Experimental setup to study cricket ball [Alam et. al, 2010]

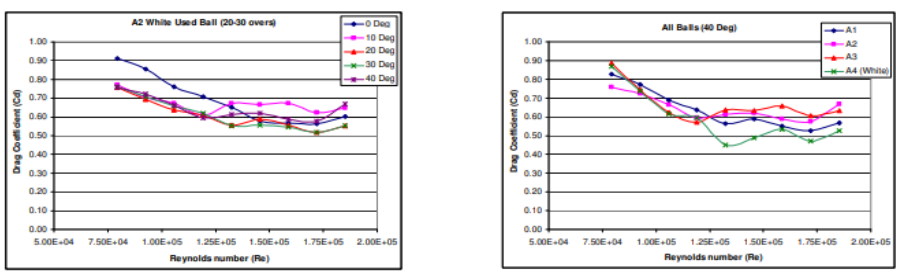

Fig. 27: Results of to study cricket ball [Alam et. al, 2010]

14.2 Javelin throws aerodynamics

Determine the effects of wind direction on the range of javelin throw.

Try

1. Undertake the effect of tail wing on Javelin throw range (Fig. 28).
2. Undertake the effect of head wing on Javelin throw range (Fig. 29).
3. Undertake the effect of angle of throw on Javelin range (Fig. 28).

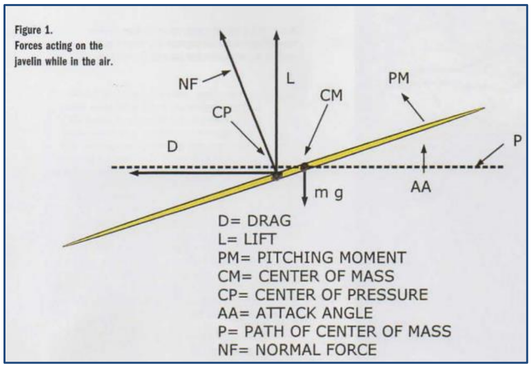

Fig. 28: Forces acting on Javelin [A. Maheras, 2013]

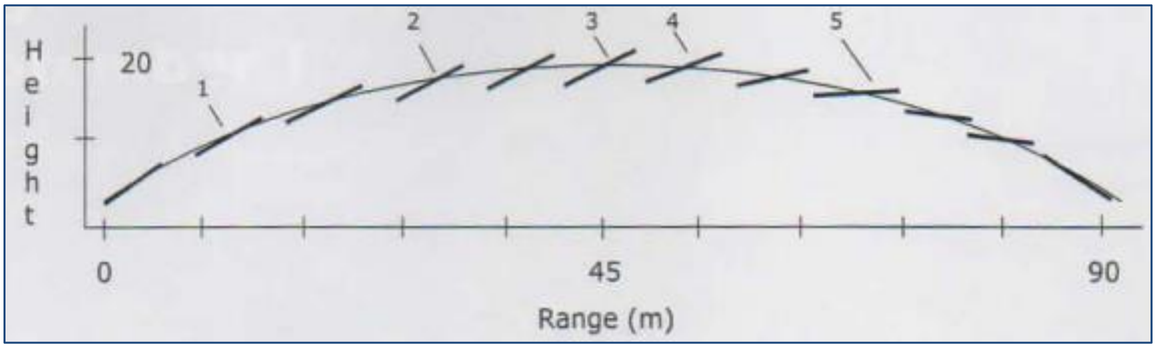

Fig. 29: Javelin trajectory [A. Maheras, 2013]

14.3 Study of Badminton Shuttlecock aerodynamics

Determine the aerodynamic drag with variation of the Reynolds number for synthetic and natural feather shuttlecocks.

Fig. 30: Synthetic and natural feather shuttlecock [Alam et. al, 2009]

Fig. 31: Complete experimental setup [Alam et. al, 2009]

Try

1. Investigate the drag of natural feather shuttlecock (Fig. 32).
2. Compute the drag of synthetic feather shuttlecock (Fig. 31).
3. Examine the drag of all feather shuttlecocks (Fig. 30).

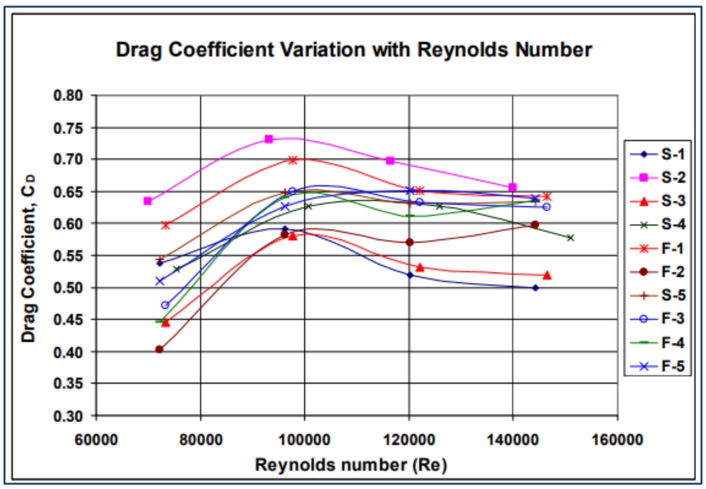

Fig. 32: Drag coefficient variation with Reynolds number for all Shuttlecocks

V. TEXT BOOKS:

1. Alan pope, "Low Speed Wind Tunnel Testing", John Wiley, 2nd edition, 1999.

VI. REFERENCE BOOKS:

2. Mattingly J.D., "Elements of Propulsion: Gas Turbines and Rocket", AIAA, 1991.

VII. ELECTRONICS RESOURCES:

1.www.loc.gov/rr/scitech/tracer-bullets/aerodynamicstb.html
2.www.myopencourses.com/subject/aerodynamics-2
3.https://researchrepository.rmit.edu.au/esploro/outputs/9921862713801341

VIII. MATERIALS ONLINE

1. Course template
2. Lab manual