DEPARTMENT OF AEROSPACE ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
KANPUR

AE 351

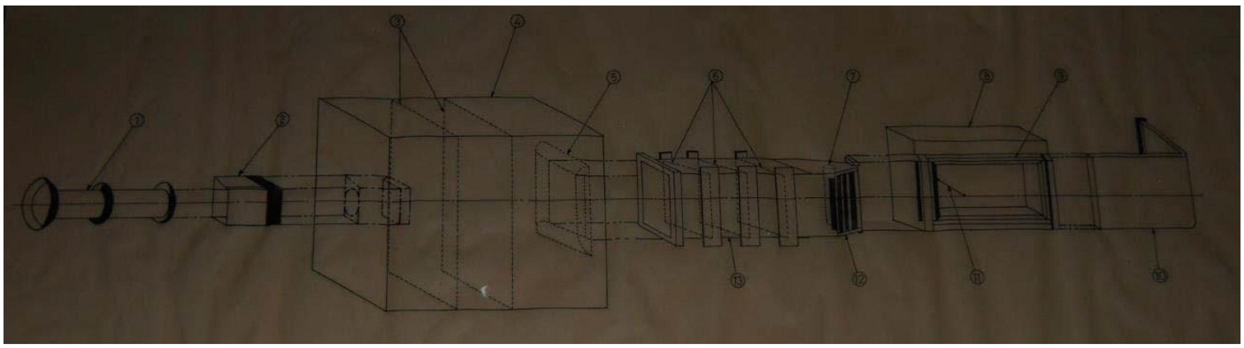
Experiments in Aerospace Engineering

Experiment No. 1(a)
Flow visualization over streamlined and bluff bodies

Objectives: To study the flow patterns over streamlined and bluff bodies.

Apparatus:

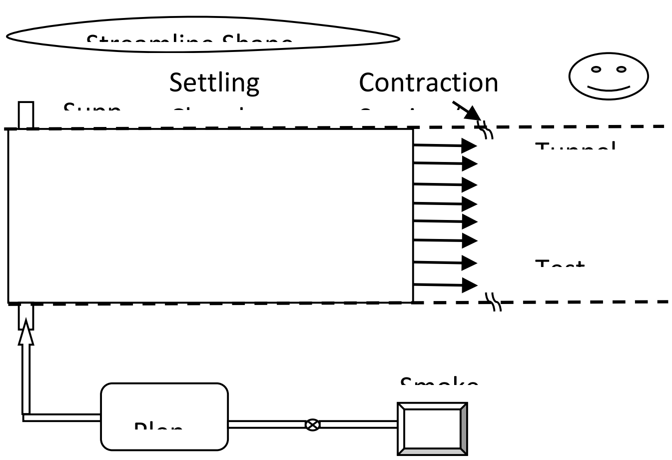
i) **Smoke tunnel:** Smoke tunnel is an open-circuit type wind tunnel. The tunnel consists of a fan at the inlet and is followed by a big settling chamber. The large size of the settling chamber is to kill the disturbances generated by the fan. The settling chamber is then followed by screens and flow straight to make the flow uniform and further reduce its turbulence level. It is followed by a small diffusion section which connects to the test section.



ii) **Smoke generator:** Smoke is generated using a Preston-Sweeting mist generator. It consists of a heating facility where kerosene is heated to a high temperature. The kerosene vapor formed is mixed with the relatively cooler air stream to produce the appropriate mist. To introduce smoke in the flow, a rake is used.

iii) **Angle Change Mechanism**: The mechanism for holding and changing the angle of attack of the models consist of a hollow rod connected to a gear. The gear is driven by a motor connected to it to change the angle of attack.

iv) **Smoke rake:**



v) **Models:**

Procedure:

1. Mount a model in the test section.
2. Start the smoke generator after adequate time.
3. Visualize the flow around the airfoil and photograph the flow.
4. Change the angle of attack and visualize the change in flow features.
5. Visualize the flow patterns for different models.

Suggested work:

a) Make a sketch of the smoke flow visualization wind tunnel identifying different components of the tunnel.

b) Identify the following: Contraction ratio, test section size, speed range, type of motor and motor horse power.

c) Sketch the kerosene smoke generation and injection device, identifying the major components.

d) Sketch the model mounting device and angle of attack change mechanism.

e) Mount a 2-D model. Obtain wind speed from the table of dial settings vs. wind speed. Calculate the Reynolds number of the test. Take pictures with a camera.

Observations:

1) Try to recognize and identify the followings:

- Potential flow region
- Boundary layer region
- Laminar and turbulent boundary layer
- Separation bubble
- Nature and extent of the wake
- Unsteadiness or vortex shedding in the wake

2) Find out the differences between flows over streamlined and bluff bodies.

3) Point out the difference between potential and real flows.

References:

1. Merzkich, “Flow Visualization”, Academic Press, 1987.

2. Werle, “Hydrodynamic flow visualization”, Annual review of Fluid Mechanics, vol. 5, 1973.

3. Van Dyke, “An album of fluid motion”, Parabolic Press, Stanford, CA, 1982.

Experiment No. 1(b)

Title: Dye Flow Visualization over Streamlined and Bluff Bodies in Hele-Shaw Apparatus

Objectives:

- To study the potential flow patterns over streamlined and bluff bodies.
- To study the viscous flow at low Reynolds number (Re)

Description of equipment used:

The experimental set up consists of two parallel glass plates placed in a very narrow distance. Water and dye mixture is poured in the narrow section between the two glass plates. The model (very thin plastic models) is placed in the narrow section. Below the glass plates there is a tube whose opening can be varied using a control valve. Flow passing through this tube is collected in a volume measuring cup. A stopwatch is used to measure time to collect a certain volume of fluid mixture.

Fig. Hele-Shaw Apparatus

- Hele-Shaw apparatus with dimensions $2mm \times 85mm \times 100mm$.
- $KMnO_4$ is used as dye.

Procedure

- Clean the apparatus.
- Place the model in test section as required.
- Fill dye and liquid in the reservoir.
- Open the tap at the bottom as required.
- Observe the flow around the model and take images.
- Measure the volume flow rate and find the Reynolds number.
- Repeat the process with different flow rates and models

Precautions

- Make sure apparatus is clean.
- Take repeated reading of volume flow rate for the same valve opening with sufficient time.

1. **Suggested works:**

a) Discuss the effect of Re on flow pattern

b) Explain why such low Re flow pattern resembles potential flow pattern.

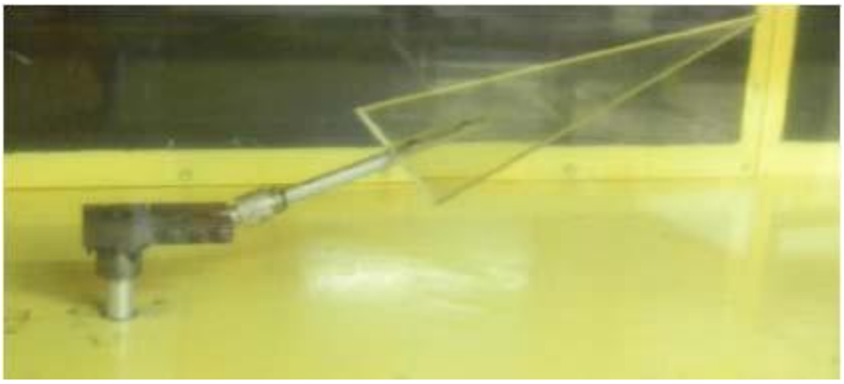
Experiment No. 2: Measurement of pressure distribution in the wind tunnel test section and flow visualization over a Delta wing

2. **Objective:**
    i. Study and sketch the low turbulence tunnel.
    ii. Measure the C_p distribution in the test section.
    iii. Observe the vortex pair on the lee side of a delta wing at incidence, and study their breakdown.

3. **Apparatus:**
    i. **Low speed wind tunnel:**
    The specifications of the low speed wind tunnel are

S. No.	Property	Measurement
1	Type	Open – Return Suction Type
2	No. Of Screenings in the settling chamber	6
3	Contraction ratio	16:1
4	Test section dimensions	0.6 m X 0.6 m X 3 m
5	Max. Velocity	~ 25 m/s
6	Motor	20 Hp AC

    ii. **Delta wing (model):** When a slender delta wing with a sharp leading edge is at a moderate angle of attack, a vortex pair is generated on the lee side of the delta wing. This happens due to the separation of the flow along the leading edge of the delta wing forming a separated shear layer. This shear layer rolls up to form a counter rotating vortex pair which move past the top surface of the wing. The formation of these vortices delays the stall which happens at relatively high angle.



    iii. **Laser:** For flow illumination a continuous low power green laser is used.

iv. **Smoke Generator:** For flow seeding a smoke generator as shown in the figure below is used.

v. **Pitot Static tube:** The Pitot static tube is used to measure the fluid velocity.

4. Procedure:

a) Mount the Pitot static tube in the test section to measure the flow velocity.
b) Connect the Pitot static tube to the digital manometer.
c) Connect the manometer to the DAQ system and acquire the velocity data.
d) Remove the Pitot static tube and mount the delta wing for flow visualization in the test section.
e) Start the tunnel, smoke generator and laser for illumination. Observe the vortices formed at moderate angle of attack.

5. Precautions:

a) Follow the safety instructions while running the laser.

b) Do not stand in the laser light path.
c) Make sure that the laser light reflected back from the wing surface do not hit any person visualizing the flow.
d) Always turn off the tunnel before opening the test section for model removal or mounting.
e) Keep the room well ventilated while running the fog-generator.

6. Suggested works:

c) Measure the pressure distribution in the test section.
d) Study and sketch the low turbulence tunnel. Note special features of the tunnel which gives a low turbulence stream.
e) Sketch the delta wing and angle of attack variation system.
f) Study the Furness electronic micro-manometer unit.
g) Study the smoke injection and illumination system.
h) Observe the vortex structure and its bursting location at incidence using smoke and the light box.

Try to answer the following questions:

a) What is the effect of the sharp leading edge of delta wing?
b) Does the vortex pair always remain symmetric with increasing angle of attack?
c) What are the advantages due to the lee side vortices of a delta wing?
d) What is vortex breakdown or bursting?
e) How does it affect the performance of a delta wing aircraft?

References:

1. Payne, Ng, Nelson, and Schiff, "Visualization and wake surveys of vortical flow over a delta wing", AIAA Journal, Vol. 26, No. 2, 1988, pp. 137--143.

2. Josef Rom, "High angle of attack Aerodynamics", Springer-Verlag.

3. Kuchemann, "The Aerodynamic Design of Aircraft", American Institute of Aeronautics & Astronautics, 2012.

Experiment No. 3: Calibration of Pressure scanner and its application in flow measurement

1. Objective

To study the pressure distribution over an airfoil using pressure scanner

2. Apparatus

I. **Wind Tunnel:** The open-circuit low turbulence wind tunnel consists of an axial fan driven by a 2HP AC electric motor. The fan acts as a suction device. The honeycomb structure after contraction chamber makes the flow in test section quiescent with a turbulence intensity as low as 0.1%.

II. **Model:** The model is an airfoil mounted in the test section. It has 24 ports at equal angles along the circumference.

III. **Electronically Scanned Pressure sensor:** 32-HD ESP scanners are differential pressure measurement units housing an array of 32 piezo-resistive sensors, one for each pressure port consisting of a Wheatstone bridge diffused onto a single silicon crystal. These scanners have two-position manifold, one is run-mode and other one is cal-mode. The manifold position can be changed by applying a momentary pulse of control pressure. Run-mode is used to acquire a pressure data and cal-mode is used for calibration of pressure ports. In cal-mode position, all sensors are connected to a common calibration pressure port. The accuracy of the scanners is maintained within ±0.05% of full scale pressure range through their periodic calibration. The frequency of calibration is dependent on ambient conditions and it changes with time. Calibration performed immediately before a set of data is acquired assures the highest accuracy of the scanners. The voltage output from the pressure sensors is connected to multiplexers which can acquire data at rate up to 20,000 Hz.

IV. **Multiplexer Unit:** Each sensor output is selectively routed to the onboard instrumentation amplifier by applying its unique binary address to the multiplexers. The multiplexed and amplified analog outputs of the scanners are capable of driving long lengths (up to 30fts) of cable to the remote A/D converter of DAQ board. Scanners require 12V DC power supply for the operation of built-in analog/digital devices and a +5V DC power supply as the excitation voltage source for the sensors.

V. **Digital Interface and Line Driver (DILD) unit for ESP Scanners:** The DAQ board provides 5-volts (TTL) logic level signals through its digital I/O lines, whereas the pressure scanners require 12-Volt (CMOS) logic level signals for binary addressing. Thus, there is a logic (TTL-CMOS) level mismatch between DAQ board and scanners. The logic level shifters of the DILD unit compensates for this logic level mismatch. The DILD unit also provides digital fan-out to drive upto 8 pressure scanners, and long cable (30 ft) drive capability. The regulated DC power (12V and 5V) required for the operation of pressure scanners are also supplied by this unit.

VI. **Data Acquisition Board:** A 14-bit high speed data acquisition board from National Instruments is used for the pressure measurement, which acts as an interface between sensors and computer. The data acquired is digitized and transferred to computer by the DAQ board.

VII. **Pressure Data Acquisition and Analysis Software:** Data acquisition and controlling is done by the LabVIEW 12.0 application software. In-house developed pressure data acquisition and analysis software is capable of acquiring the data at desired data acquisition parameters, analysis, and presenting in the engineering units.

VIII. **Digital manometer**: It is used to directly measure the gauge pressure between the two terminals.

IX. **Calibration Setup:** The electronic output of the ESPs is calibrated to convert electronic signals to pressure data. For that purpose, known pressure is applied using hand pump measured using digital manometer, which is used to calibrate the electronic data from the ESP.

4. Precautions

1. Ensure that the maximum pressure at any port should be within the range of the sensor.
2. While calibrating, sufficient time should be given for the pressure to stabilize.
3. Make sure that there are no blockages or leakage in the tubes.
4. The excitation voltage given to the scanner must be within the range of 5V.
5. There should not be any obstacle near the entry or exit of wind tunnel flow causing disturbance in the freestream flow.

5. Procedure

1. Familiarize with the basic principles of data acquisition.

2. Notice and learn about the entire measurement chain used for pressure data acquisition.

3. Calibration of Pressure sensor:

a) Connect the high pressure port of pressure sensor to the calibrator via T-joint and leave the other port of the pressure sensor open to the atmosphere.

b) Obtain the output voltage from the sensor at different pressures applied using the hand pump.

c) Using the acquired data, find the best fit curve (2nd degree in single variable), which defines the calibration equation for the sensor.

4. Measure the airfoil chord and note down the ambient temperature and pressure which will be used for calculating Reynolds number.

5. Run the data acquisition VI and take the no wind readings.

6. Increase the speed to the desired value, and after the flow stabilizes, save the wind data.

7. Repeat the same for another set of speed.

8. Run the data analysis VI to write the data to a spreadsheet file.

6. Error Analysis

The error in measurement can be classified as:-

a) Systematic Error: These arise due to improper calibration of instruments or some other unknown reasons. They can be eliminated by proper calibration of instruments or rectifying the fault. This defines the accuracy of the measurement made. The lesser the bias, the higher the accuracy. These are biased in nature.

b) Random Error: These occur due to the natural disturbances that occur during the measurement process. These cannot be eliminated. This defines the precision of the measurement made. These are statistical in nature.

7. Results and Discussions

1. Mention the name, specification and need of PXI system, DAQ card and ESP scanner used for the experiment.

2. Explain in brief about Pitot probe and ESP, and the benefit of using ESP over pitot tube.

3. Calculate and plot the coefficient of pressure over an airfoil using the measured calibration coefficients, port map and the no-wind and wind data at different wind velocities.

4. Calculate the lift, drag and pitching moment coefficients and the Reynolds numbers at which experiment is conducted.

5. Comment on the nature of the results and explain inconsistencies, if any. Does the

6. Calculate the percentage error in the measurements.

References:

1. Schlichting, ``Boundary Layer Theory," McGraw Hill Book Co., New York, 1960.

2. Morkovin, ``Flow Around Circular Cylinder - A Kaleidoscope of Challenging Fluid Phenomena," Symposium on fully separated flows, ASME, 1964.

3. Equipments manuals

Experiment no 4

Calibration of six component force balance

Objective:

To study the calibration procedure of a six component force balance which is generally used to measure the aerodynamic forces acting on a test model.

Apparatus:

- **Six component force balance (HEE, Bangalore)**: It is a cylindrical body on which an aerodynamics model can be mounted to measure different forces acting on it.

- **Calibration body:** It is used to facilitate loading of the balance with pure loads (in specific directions at particular locations) in order to calibrate it.

- **Calibration rig:** It is a truss structure with leveling screws on which the force balance fitted with calibration body is mounted to apply the desired pure loads. The leveling screws are required to align the force balance in horizontal position under the action of the force due to dead weights.

- **Precise level gauge:** A digital level gauge is used to align the balance in horizontal position.

- **Dead weights:** These are used to load the balance with constant loads.

- **NI SCXI-1520**: is an 8-channel universal strain gage input module that offers all of the features you need for simple or advanced strain- and bridge-based sensor measurement.
- **NI SCXI-1314** terminal block is used with the SCXI-1520 universal strain/bridge module enabling you to conveniently connect strain gauges through screw terminals.
- **Data acquisition card:** The voltage output of the strain gauges is required to be measured under the loading on the balance. For this a data acquisition card PXI-1002 with maximum of 16 voltage input channels is used.

- **Labview software:** Labview software facilitate to provide/acquire the input/output voltage signals to/from the strain gauge bridges using a specially built VI program.

Procedure:

- Draw the schematic of six component force balance calibration setup and describe the calibration procedure in details.

- Measure the output voltages of the bridges at all locations (AX, N1, N2, S1, S2, RM) at each known applied load at a particular bridge location (say N1).
- Repeat above procedure for loads at remaining locations.
- Evaluate the coefficients of calibration matrix using the data in step two and find its inverse.
- Write the equations for evaluating the orthogonal forces and moments at the force balance center acted upon by a random force.
- Write the equations for real orthogonal forces and moments acting on a model (attached to the force balance) at a reference point by a random aerodynamic force in terms of loads measured by the force balance.
- Follow the detailed calibration procedure given in the force balance manual available in the low speed aerodynamic lab.

Questions:

- What are the different aerodynamic forces acting on a model?
- What is the working principle of this force balance?
- What are the other types of force balances?

References:

- Low-speed wind tunnel testing - W. E. Rae, Jr. and Alan Pope.
- Fundamental of Aerodynamics - J. D. Anderson.
- NI manual for DAQ cards used.