Calibration of Pressure Scanner and its application in Flow Measurement

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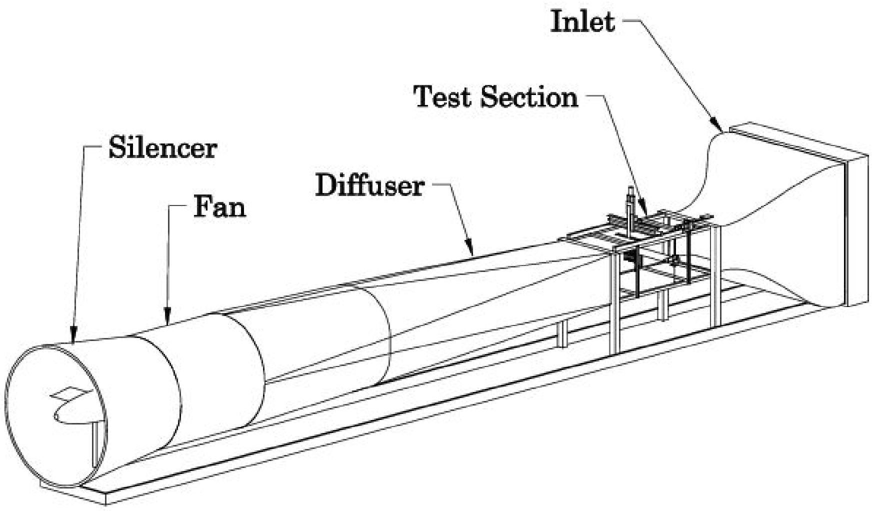
OBJECTIVE

1. To calibrate pressure measuring device.
2. To study the pressure distribution over an airfoil using a pressure scanner.

INTRODUCTION AND THEORY

LOW SPEED WIND TUNNEL



Wind tunnels are large tubes with air blowing through them. In the tunnel, the engineer can carefully control the flow conditions which affect the forces on the aircraft. By making careful measurements of the forces on the model, the engineer can predict the forces on the full scale aircraft. And by using special diagnostic techniques, the engineer can better understand and improve the performance of the aircraft.
Low-speed wind tunnels are used for operations at very low Mach numbers, with speeds in the test section up to 480 km/h (~ 134 m/s, M = 0.4). They may be of open-return type, or closed-return flow with air moved by a propulsion system usually consisting of large axial fans that increase the dynamic pressure to overcome the viscous losses.
The amount of air in the tunnel is constant, and we can use the conservation of mass to relate local speed in the tunnel to the cross-sectional area.
At every point in the tunnel, the velocity **V** times the air density ρ times the area **A** is a constant. For a low speed tunnel the density remains constant through the tunnel and we can further simplify the equation.

At every point in the tunnel:

density x velocity x cross-sectional area = constant

$$\rho \times V \times A = \text{constant}$$

For low speed (constant density):

$$(V \times A)_1 = (V \times A)_2$$

CALIBRATION

Calibration refers to the act of evaluating and adjusting the precision and accuracy of measurement equipment. Generally, after using an instrument for a long time inaccuracies develop in the device due to changes in environment condition or deterioration of parts. Instrument calibration is intended to eliminate or reduce these biases in an instrument's readings over a range for all continuous values. So, it is good practice to calibrate your instrument for best results.

MODEL

Model we are testing in our experiment is a symmetric NACA 0012 Airfoil at zero angle of attack. It has 24 ports at equal angles along the circumference.

DIGITAL MANOMETER

Digital manometers are devices that are capable of measuring pressure and its variations across two points that are a part of the same system-this is known as differential pressure. We use this device to measure velocity head at various points by connecting one port to Pitot Tube (for Stagnation Pressure) and other to holes on the wall (for Static Pressure). The device shows the pressure difference and the corresponding velocity.

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 the 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 pressure data and cal-mode is used for calibration of pressure ports.

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.

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 a computer by the DAQ board.

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.

EQUIPMENTS

For Calibration: Hand Pump, Calibration Setup and Electronically Scanned Pressure Sensor (ESP).
For calculating C_p: Electronically Scanned Pressure Sensor (ESP), Multiplexer Unit, Digital Interface and Line Driver (DILD) unit for ESP Scanners, Data Acquisition Board, Pressure Data Acquisition and Analysis Software, Digital manometer and an airfoil.

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.

MEASUREMENT

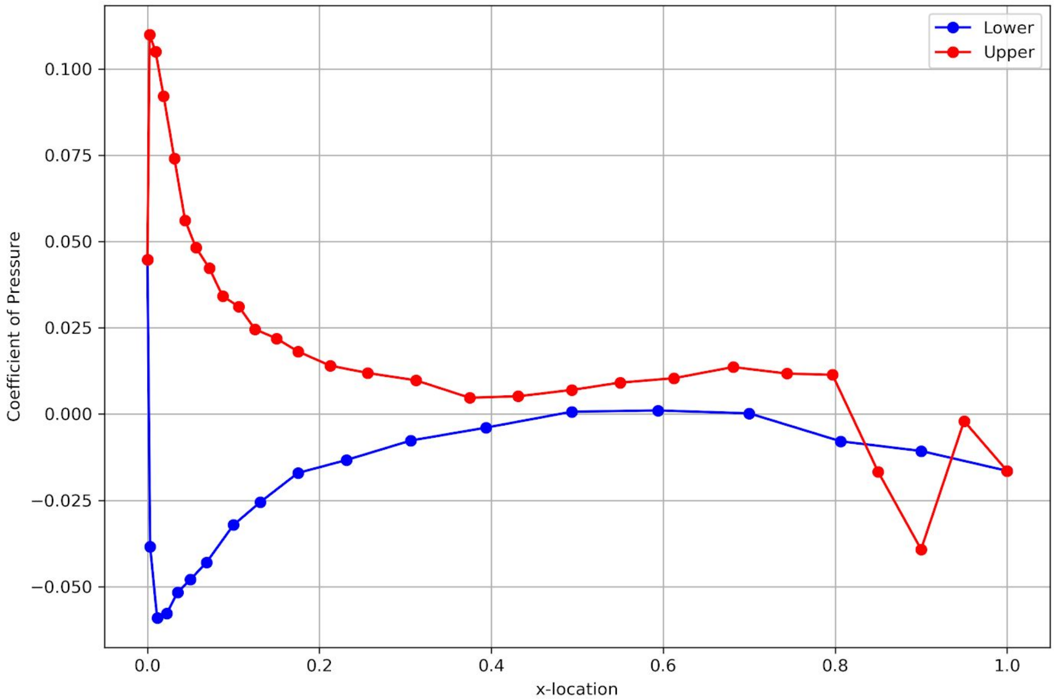
LabView program build automatically generates calibration constants which will be used in further experiments. We take pressure reading for two velocities, i.e, 7.96 m/s and 9.65 m/s.

Density(ρ) : 1.225 Kg/m^3 ; Dynamics Viscosity(μ) : 1.825 x 10^{-5} Kg/m-s ;

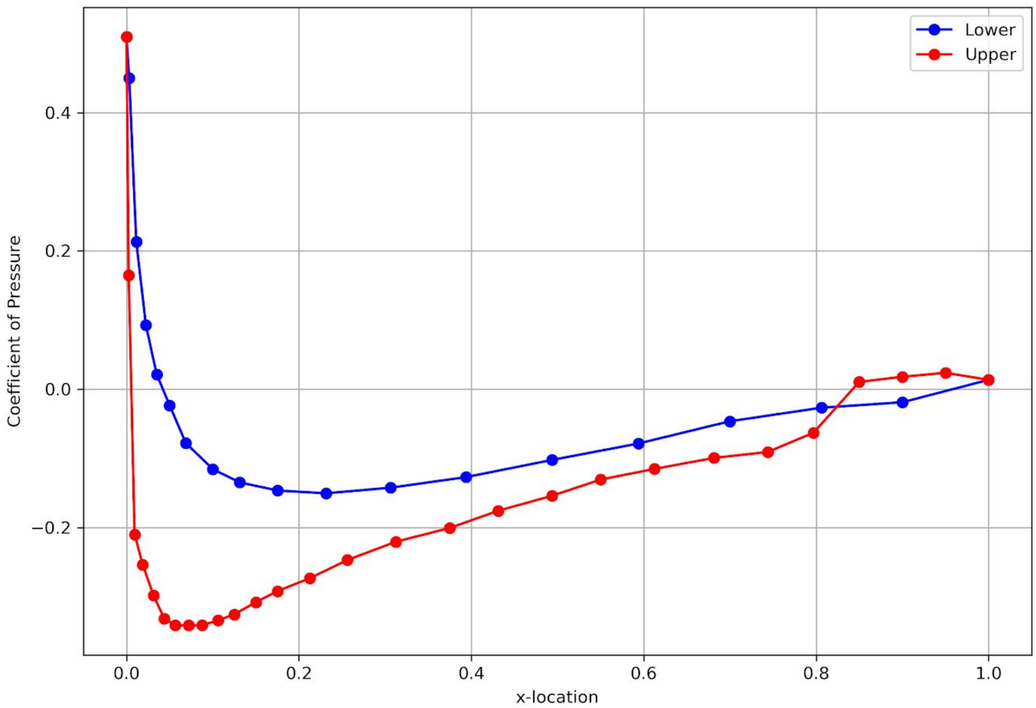
Chord length(D): 15.4 cm

RESULT

For v = 7.96 m/s,



For v = 9.65 m/s,



Reynold's Number (at v = 7.96 m/s) = 82282.41
Reynold's Number (at v = 9.65 m/s) = 99751.72

DISCUSSION

- PCI extension for Instrumentation (PXI) is one of several modular electronic instrumentation platforms in current use. These platforms are used as a basis for building electronic test equipment, automation systems, and modular laboratory instruments. As the PXI is 14-bit and the reference voltage we selected is 5V; the least voltage that can be measured is 10 x 2^{-14} volts.
- DAQ hardware is what usually interfaces between the signal and a PC. DAQ cards are connected to slots in the motherboard. It contains multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a bus by a microcontroller, which can run small programs.
- ESP Pressure Scanners are miniature electronic differential pressure measurement units consisting of an array of silicon piezo-resistive pressure sensors, one for each pressure port. Pitot probe can get blocked. Pitot probes are bulky and therefore can affect the flow. We will need 32 pitot probes and then as many manometers. Therefore, to overcome all these problems ESP scanner is the better choice.

CONCLUSION

We learnt why and how to calibrate pressure sensors. We learnt how to measure pressure or coefficient of pressure distribution over an airfoil and how we can scale it to a large model. Most of the errors in the coefficient of pressure were caused due to numerical integration schemes employed.

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.

APPENDIX

Formula for calculating C_P,

$$\boxed{C_p = \frac{p_i - p_\infty}{\frac{1}{2}\rho U_\infty^2}}$$

Formula for calculating Re,

Density of fluid

Velocity of fluid

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

Dian of p

Reynolds Number

Dynamic Viscosity of fluid

In [3]:

```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
```

In [7]:

```
# Pressure Locations
low=[0.00000, 0.00310, 0.01130, 0.02250, 0.03500, 0.05000, 0.06880, 0.10000, 0.13130, 0.17500, 0.23130, 0.30630, 0.39380,
     0.49380, 0.59380, 0.70000, 0.80630, 0.90000, 1.00000]
upp=[0.00000, 0.00250, 0.00940, 0.01880, 0.03130, 0.04380, 0.05630, 0.07190, 0.08750, 0.10630, 0.12500, 0.15000, 0.17500,
     0.21250, 0.25630, 0.31250, 0.37500, 0.43130, 0.49380, 0.55000, 0.61250, 0.68130, 0.74380, 0.79690, 0.85000, 0.90000,
     0.95000, 1.00000]

# pressure differences at v = 7.96 m/s
l8=np.array([1.73409, -1.49228, -2.29341, -2.24096, -2.00396, -1.86021, -1.66611, -1.24702, -0.98909, -0.66211, -0.51694,
             -0.29736, -0.15229, 0.02707, 0.04078, 0.00853, -0.30550, -0.41460, -0.63767])
u8=np.array([1.73409, 4.26583, 4.07522, 3.57597, 2.87169, 2.17735, 1.87367, 1.64150, 1.32489, 1.20948, 0.95444, 0.85041,
             0.70472, 0.54483, 0.46200, 0.37916, 0.18322, 0.20037, 0.27189, 0.35432, 0.40334, 0.52898, 0.45550, 0.44161,
             -0.64859, -1.52073, -0.07820, -0.63767])

# pressure differences at v = 9.65 m/s
l10=np.array([29.06512, 25.67111, 12.16835, 5.27642, 1.23058, -1.32958, -4.43348, -6.58659, -7.67785, -8.34854, -8.57931,
              -8.11771, -7.24604, -5.82624, -4.47572, -2.63794, -1.51863, -1.07201, 0.77369])
u10=np.array([29.06512, 9.41322, -11.98164, -14.46116, -17.00449, -18.91118, -19.44797, -19.4726, -19.46541, -19.06395,
              -18.56619, -17.56055, -16.64742, -15.5884, -14.08034, -12.57229, -11.43915, -10.01661, -8.7844, -7.4489,
              -6.56822, -5.66594, -5.17357, -3.58939, 0.60951, 1.02747, 1.35957, 0.77369])

v8 = 7.96 # in m/s
v10 = 9.65 # in m/s
D = 0.154 # Chord Length in meters

# Calculating Reynolds Number
Re_8 = 1.225*v8*D/(1.825/100000)
Re_10 = 1.225*v10*D/(1.825/100000)

print('Reynolds Number for v = 7.96 m/s = ',Re_8 ,'\nReynolds Number for v = 9.65 m/s = ', Re_10)

pd8=0.5*1.225*v8*v8
pd10=0.5*1.225*v10*v10

# Plotting values
fig=plt.figure(figsize=(10,7))
l1,=plt.plot(low,l8/pd8, marker='o', color='b')
l2,=plt.plot(upp,u8/pd8, marker='o', color='r')
plt.xlabel('x-location')
plt.ylabel('Coefficient of Pressure')
plt.legend((l1,l2),('Lower','Upper'))
plt.grid()
fig.savefig('8.png', format='png', dpi=300)

fig1=plt.figure(figsize=(10,7))
l3,=plt.plot(low,l10/pd10, marker='o', color='b')
l4,=plt.plot(upp,u10/pd10, marker='o', color='r')
plt.xlabel('x-location')
plt.ylabel('Coefficient of Pressure')
plt.legend((l3,l4),('Lower','Upper'))
plt.grid()
fig1.savefig('10.png', format='png', dpi=300)
```

```
Reynolds Number for v = 7.96 m/s =  82282.41095890412
Reynolds Number for v = 9.65 m/s =  99751.9178082192
```