Calibration of
Six Component Force Balance

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OBJECTIVE

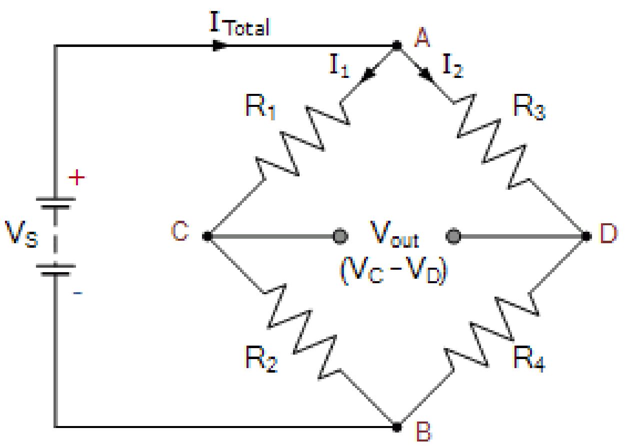
To study the calibration procedure of a six component force balance which is generally used to measure the aerodynamic forces acting on a test model.

INTRODUCTION AND THEORY

Aerodynamicists use wind tunnels to test models of proposed aircraft and engine components. Force balances are used to directly measure the aerodynamic forces and moments on the model. A six-component balance is required to measure all three forces (lift, drag, and side) and three moments (pitch, roll, and yaw) that determine an aircraft's motion through the air.

WHEATSTONE BRIDGE TRANSDUCER

Wheatstone Bridge is an electrical circuit with one unknown resistor. It is used to measure the unknown resistance. Resistance of the unknown resistor is determined by applying pressure. Thus, the resistor becomes a pressure gauge. Applied pressure changes resistance (R) of all the resistance by some amount (ΔR).



$$V_{OUT} \propto (\Delta R_1/R_1 - \Delta R_2/R_2 + \Delta R_3/R_3 - \Delta R_4/R_4)\, V_S$$

$$V_{OUT} = (1/4) \times G \times (\Delta R/R)^{*}\, V_S$$

$$V_{OUT} = (1/4) \times G \times K \times (\Delta l/L) \times V_S$$

$$V_{OUT} = (1/4) \times G \times K \times (F/A) \times E_Y \times V_S\ Vo$$

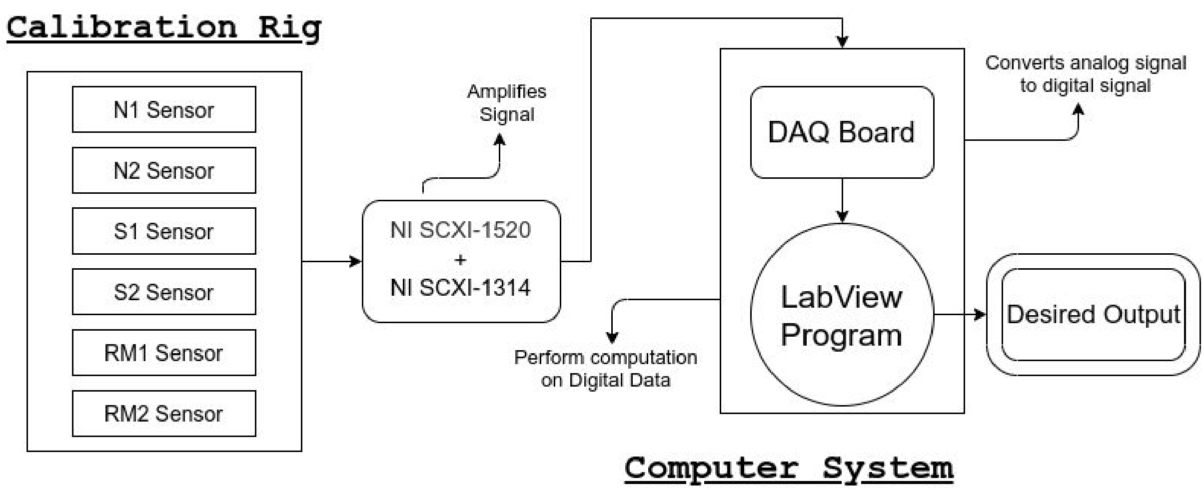
$$= \{(1/4A) \times G \times K \times V_S \times E_Y)\ F$$

$$V_{OUT} = C\ F$$

Once we calculate C (calibration matrix) from the experiment, we can use $F = C^{-1} V_{OUT}$ to find forces on large scale models using this calibration matrix.

F is a vector with Axial Force (a), Normal Force (N1), Normal Force (N2), Side Force (S1), Side Force (S2) and Rolling Moment (rm). V_{OUT} is a vector of output voltages of corresponding forces in F.

FLOWCHART OF THE SETUP



EQUIPMENTS

1. **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.
2. **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.
3. **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.
4. **Precise level gauge:** A digital level gauge is used to align the balance in horizontal position.
5. **Dead weights:** These are used to load the balance with constant loads.
6. **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.
7. **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.
8. **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 a maximum of 16 voltage input channels is used.

9. **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

1. Draw the schematic of six component force balance calibration setup and describe the calibration procedure in detail. 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).
2. Repeat the above procedure for loads at remaining locations.
3. Evaluate the coefficients of calibration matrix using the data in step two and find its inverse.
4. Write the equations for evaluating the orthogonal forces and moments at the force balance center acted upon by a random force.
5. 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.
6. Follow the detailed calibration procedure given in the force balance manual available in the low speed aerodynamic lab.

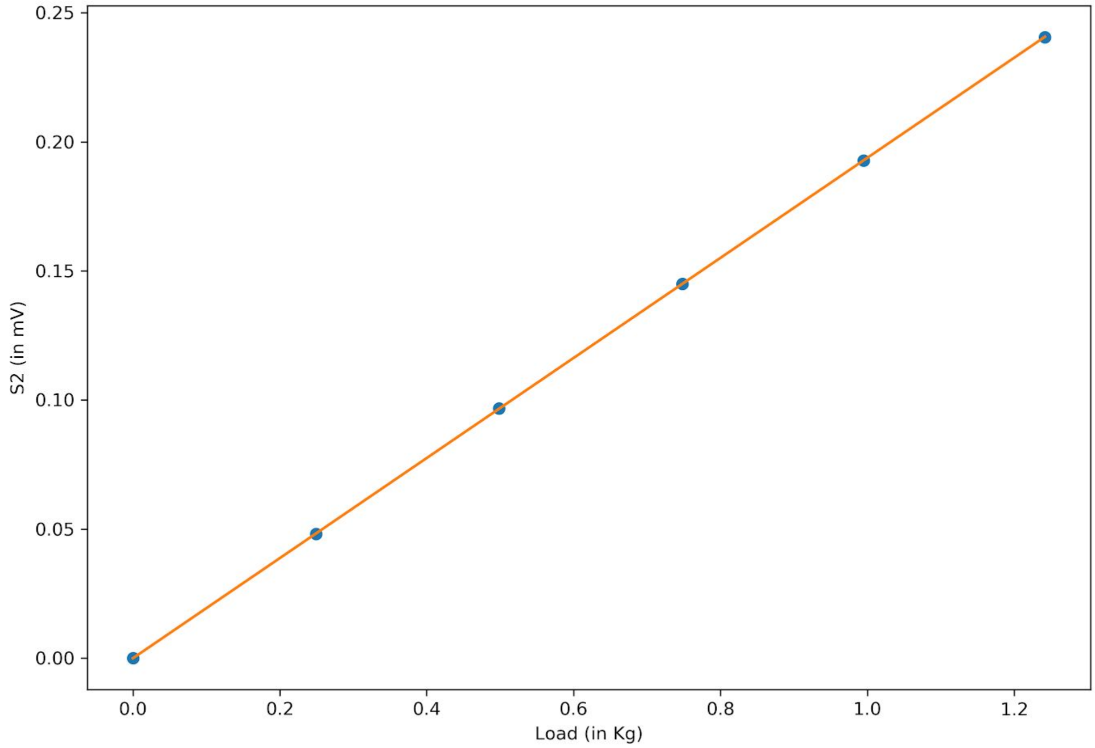
MEASUREMENT

Observation Table 1 for S2:

Load (Kg)	**O_A (mV)**	**O_{N1} (mV)**	**O_{N2} (mV)**	**O_{S1} (mV)**	**O_{S2} (mV)**	**O_{RM} (mV)**
0.0000	-0.000006	-0.000025	-0.000044	0.000031	-0.000054	-0.000032
0.2493	-0.000533	-0.000019	-0.002361	-0.000114	0.048197	0.000802
0.4987	-0.001039	0.000013	-0.004648	-0.000250	0.096662	0.001560
0.7479	-0.001380	0.000051	-0.007032	-0.000366	0.145027	0.002289
0.9949	-0.002130	0.000124	-0.009279	-0.000475	0.192837	0.003121
1.2419	-0.002633	0.000050	-0.011563	-0.000666	0.240622	0.003990

RESULTS

Best Fit Line for measured points at S2,



Equation of best fit line: y = 0.193855x - 0.000052

This means coefficient of S2 = 0.193855

Similarly, we can plot and find coefficients for all forces and moments to find the calibration matrix. We can use this calibration on a large scale model to find the acting aerodynamics forces and moments.

CONCLUSION

Plotted curve is our graph for calibration and as it is almost linear, we have successfully calibrated our Six Component Force Balance System.

QUESTION / ANSWER

- **What are the different aerodynamic forces acting on a model?**
  Three Aerodynamic forces: Lift, Drag, Side force and three moment: Rolling Moment, Pitching Moment and Yawing Moment.

- **What is the working principle of this force balance?**
  The forces are calculated by measuring the strain due to the application of a load which is measured by strain gages (works on Wheatstone bridge principle). Force is calculated from the strain via Hooke’s Law.

- **What are the other types of force balances?**
  Strain Gage Load Cells, Piezoelectric Crystals, Hydraulic Load Cells, Pneumatic Load cells, Magneto-elastic Force Transducer, etc.,

PRECAUTIONS

1. Do not apply a load on transducer over the limit of Normal, Side or Axial forces.
   [Limit of Normal Force: 10 Kg ; Limit of other Forces: 5 Kg]
2. Do not apply disturbance to the system as the transducer is very sensitive and will not give the best results.
3. Wait for at least 30 seconds to measure reading to get stabilised.

APPENDIX

Strength of Material

The stress strain relationship is given by, $\sigma = \frac{F}{A}$ **and** $\varepsilon = \frac{\delta L}{L}$

Material Properties

The relation of resistance of a material with its length is given by,

$$R \propto l\,,\ \ \Delta R/R \propto \delta l/L\,, \Rightarrow \Delta R/R = K\ \delta l/L$$

Lab 3

February 25, 2020

[1]:
```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
```

[16]:
```
l=np.array([0,0.2493,0.4987,0.7479,0.9949,1.2419])
s=np.array([-0.000054, 0.048197, 0.096662, 0.145027, 0.192837, 0.240622])

m,c=np.polyfit(l,s,1)
print('Best fit line equation: y = ',m,'x ',c)

fig=plt.figure(figsize=(4,3))
plt.plot(l, s, 'o')
plt.plot(l, m*l + c)
plt.xlabel('Load (in Kg)')
plt.ylabel('S2 (in mV)')
fig.savefig('plot_s2.png', format='png', dpi=300)
```

```
Best fit line equation: y =  0.19385514014967575 x  -5.2013606115782745e-05
```