THE UNIVERSITY OF TEXAS AT ARLINGTON
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

MAE 3182:

Calibration of the Force Balance for the AF-100 Low-Speed Wind Tunnel

Version - Fall 2023

I. Learning Objectives

- Calibrate a 3 component balance system for AF-100 wind tunnel
- Learn characteristics of fore/ft/drag force balance
- Create calibration curves for the fore, aft, and drag load cells
- Quantify resolution, sensitivity and error within measurement system
- Understanding the necessity of calibration of instrumentation systems

II. Equipment

- PC with external data acquisition system – Dell PC with PCI-6034E DAQ card
- SCB-68 DAQ connection box
- LabVIEW software
- Low-speed wind tunnel, Model AF100, TecQuipment Ltd.
- Three Component Balance, AFA3, TecQuipment Ltd.

III. Introduction

Experimental systems are limited by the accuracy of its instrumentation, and even with quality sensors there is no guarantee of reliable data. Whether analog or digital systems of measurement are used, proper calibration of instruments must be performed against a verifiable standard. The method of collecting experimental data is dependent on the physical attribute being measured, and in the case of force measurements the most common implementation of data acquisition is using digital strain gauges. Load cells for example use strain gauges with analog or digital controllers (amplifiers) to scale force measurements based upon induced voltage changes across the strain gauge. For any measurement of force, geometric orientation of the sensors must be considered. In the case of low speed wind tunnels, lift, drag and side force, pitching, roll and yaw moment can all be measured depending on the complexity of the measurement system. The most common forces measured are lift, drag, and pitching moment, and there are several geometric configurations that can be used. The AFA3 is a 3 component force balance that measures fore and aft lift, as well as drag. From these values, lift, drag and pitching moment can be calculated. The objective of this lab is to develop calibration curves for the AFA3 force balance and determine the accuracy and resolution of the measurement system.

IV. Theory

Fore/aft force balances are designed on the notion that any pitching moment generates a torque on the system which can be converted into a force when measured by a load cell offset from the rotation axis. To measure both lift and pitching moment two sensors are needed; the position of the two sensors must be considered during the conversion of the forces and moments, and so for simplicity of conversion, the AFA3 Fore and Aft sensors are equidistant from the axis of rotation. The aerodynamic forces and moments of interest, the lift force, drag force, and pitching moment are related to the forces measured by the AFA3 (fore, aft, and drag force) as shown in equations 1-3.

$$Lift(N) = Fore(N) + Aft(N) \tag{1}$$

$$Drag(N) = Drag(N) \tag{2}$$

$$Pitching\ Moment\ (Nm) = \big(Fore(N) - Aft(N)\big) * 0.0635 \tag{3}$$

However, the load cells do not directly output readings of force. Instead a voltage is recorded, which is proportional to the force applied to the tested model. Therefore, in order to retrieve the total lift, drag, and pitching moment on the tested model a calibration procedure must be performed to relate applied force to the measured voltage. By applying a series of known input forces to the apparatus, the calibration curve for each load can be determined.

V. Experiment Description

A. Apparatus

The AFA3 Force Balance, shown in Figure 1, is a 3 component force consists of two primary bodies- the mounting plate and the force plate. There are three supporting legs on the force plate that attach it to the mounting plate and allow it to move along a plane parallel to the mounting plate (2 degrees of freedom) using spherical U-joints; it is also able to rotate the horizontal axis defined by the mounting point of the model (1 degree of freedom). The mounting model point allows for 360 degrees of rotation within the force plate to adjust the angle of incidence of the model.

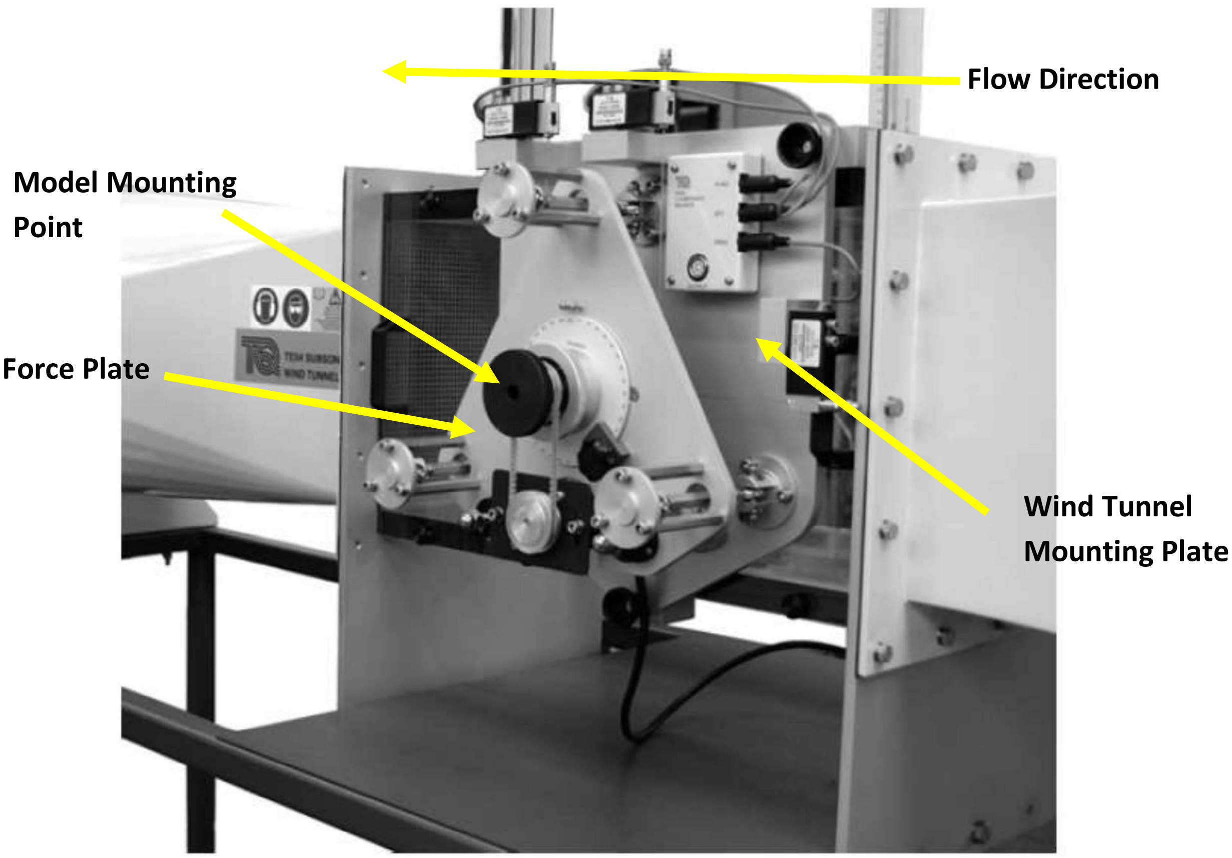

Figure 1. AFA3 mounted on AF100 Wind tunnel located in WH221

Cables must be tension The transmission of load from the force plate to the load cells is done using flexible cables which means that the force balance system works with only one method of orientation (cables cannot transmit compressive loads), such as is shown in Figure 1.

The flexible cables are attached between the force plate and the load cells, which are fastened to the mounting plate- this allows for any displacement of the force plate due to aerodynamic forces to be translated to the load cell instead of to the U-joints between the force plate and mounting plate. The full schematic of the AFA3 is shown in Figure 2 Below. The control module that the load cells are connected to is shown in Figure 3.

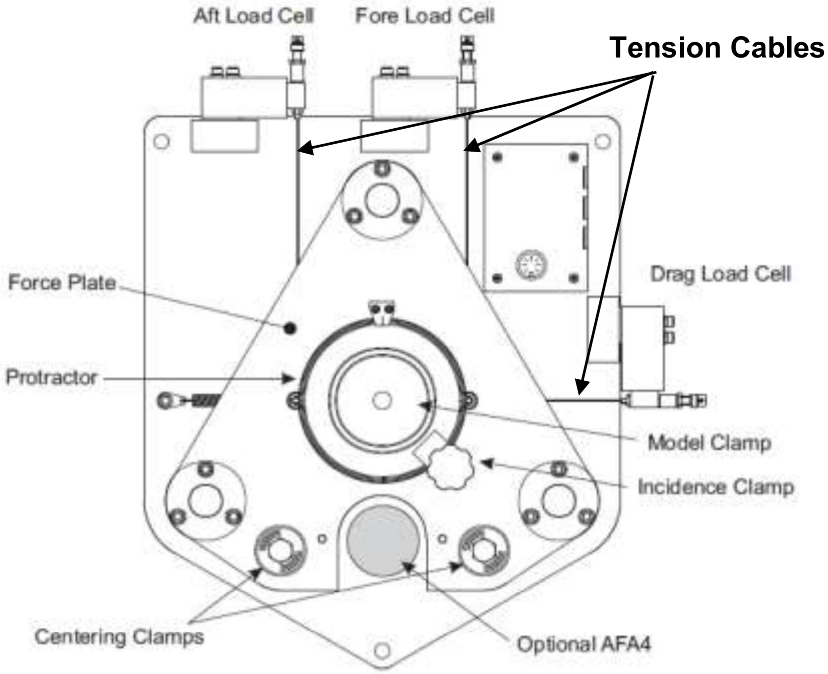

Figure 2. Schematic of the AFA3 force balance, all major components **Figure 3. AFA3 control module**

The drag force measurement is taken using a horizontal cable that acts on a line through the center of the model support. The Fore and Aft force measurements are taken using two vertical cables acting equidistant from the vertical centerline of the models support. There is also a drag balance spring that acts on the force plate to apply pre-load to the drag load cell (this not necessary for the vertical load cells due to gravity).

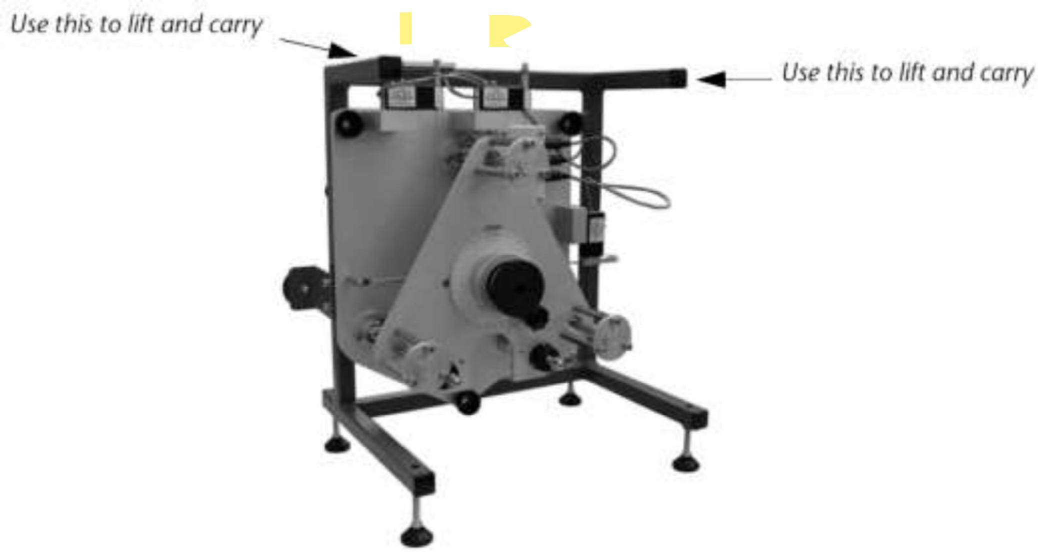

Figure 4. Force Calibration/Storage Frame with AFA3 mounted

Before the AFA3 may be used on the wind tunnel for determining aerodynamic forces, it must first be calibrated. This must be done after any instance that could be considered to skew the calibration- this could include bumping the force balance, specifically one of the tension cables, or after moving the system. The AFA3 includes a mounting frame off of the wind tunnel for the purposes of calibration. The AFA3 Balance must be carefully removed and fastened to this calibration structure, which is shown in Figure 4.

The mounted pulley should be fastened to the opposite side of the apparatus from the drag load cell. Insert the calibration bar into the model clamp, as shown in Figure 5. The roller positions of the pulley and the calibration bar are aligned as shown in Figure 6, and a bubble level is used to position the calibration bar cross beam horizontally to balance the initial system. The model collar on the back side of the apparatus is used to tighten the alignment bar into position. Then the Incidence Clamp is tightened to hold the calibration bar in the horizontal position.

Figure 5. Mounted Calibration Bar aligned with pulley apparatus. **Figure 6. Aligning Calibration Bar**

A 7 pin DIN type lead is used to connect the force balance to the display module (the control module) and is shown in Figure 7. Then the display module is connected through VDAS to the computer, and a LabView program is opened to monitor voltages and forces input to the system. The system takes some time to warm up, so this should be done approximately 15 minutes before the lab experiment begins.

Figure 7. 7 pin DIN Force Balance Connector

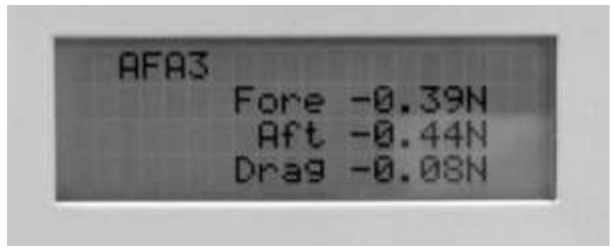

Figure 8. Display Module Display for Calibration

B. Experimental Procedure

Using the instructions below, the experimental calibration of the AFA3 three force balance component system will be performed. The Load Cells on the AFA3 measure ± 10 VDC, which will be monitored on the LabView VI during calibration.

1. Switch off the Power on the display module. Press and Hold the "zero" button. While holding the zero button, turn on the power to the display module. It will show the reading "Fore", "Aft" and "Drag" (instead of the normal "Lift", "Drag", and "Pitching Moment").
2. The three readings on the display module should read near zero. If they do not, tighten or loosen the respective tensioning nut on the load cell, shown in Figure 9 until the display module reads zero for each of the sensors.
3. Start the LabView Data Acquisition Software. The voltages should also read near zero for the "Fore", "Aft", and "Drag" measurements.
4. Hang the string and ring from the calibration bar pulley and let it hang below the apparatus, as shown in Figure 10.
5. Start the LabView Data Acquisition Software. The voltages should also read near zero for the "Fore", "Aft", and "Drag" measurements
6. For data collection, five second increments of data will be taken with different masses applied to the string.
    - With no weight on the string, press the "Start" button on the LabView VI.
    - Record data for 5 seconds, then press the "Start" button again to stop collecting data- do Not press the "Stop" button on the LabView VI or the data will be saved into separate files.
    - Record several data points from the display module of the fore/aft voltage measurements for comparison with the LabView results
7. Repeat Step 6 for 1kg, 2kg, 3kg, and 5kg masses on the string.
8. Stop the LabView Software. Hang the string from the mounted pulley on the side as shown in Figure 11. Repeat steps 5, 6 and 7 for this configuration

9. There should be two data files with 5 sets of data each.

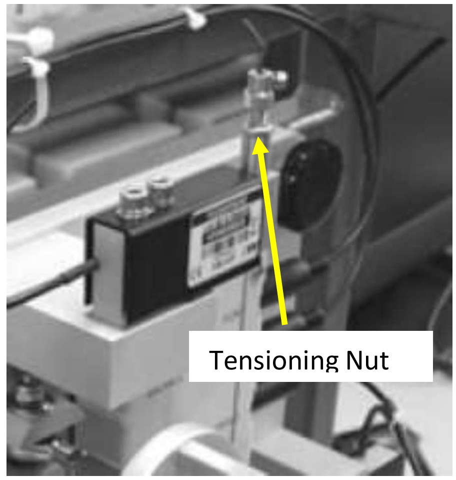

Figure 9. AFA3 Load Cell Showing Tensioning nut

Figure 10. Fore/Aft Calibration

Figure 11. Drag Calibration

VI. Report Requirements

The report should include an appropriate introduction and procedure. It should be written from the standpoint that you are calibrating the Force Balance Device and are determining its accuracy, sensitivity and error.

a. Calibration Measurements for Fore, Aft, and Drag

1. Take the data from the Drag File and take an average of each mass data set (0kg, 1kg, 2kg, etc) for the voltage from the drag load cell only.
2. Take the known forces supplied by each of the masses ($W = mg$) and plot a calibration curve of the drag as a function of voltage, along with the averaged values as data points
3. Repeat Steps 1-3 for the Fore and Aft measurement data.
    a. **NOTE**: Because the fore and aft load cells equally share the load applied during their calibration the force experienced by each individual cell is half of the weight applied, i.e. the calibration curves must be generated assuming the application of 0kg, 0.5 kg, 1kg, etc., masses to the fore and aft cells.
4. Generate calibration curves of the form $F = K*(V-V_{offset})+B$, where F is the desired force in Newtons, K is the slope of the calibration curve, V is the voltage read by the load cell in Volts, V_{offset} is the voltage read by the load cell with no force applied, and B is the y-intercept. Report the equation of each calibration curve as well as the coefficient of determination (R^2).
5. Plot the calibration curves (solid lines) and average data (single data points) of each of the 3 calibration curves on separate plots.
6. Using the calibration curves generated in 4, determine the error between the actual forces of each mass applied and the respective point on the calibration curve.
7. Calculate the sensor variation within each data set to determine the approximate precision of the system throughout the calibration curve.
8. Based on a known range of ± 10 V for the sensor, calculate the loading range of the sensor and setup for any one load cell
9. If the voltage readings of the load cells are as follows during a wind tunnel test:
    - Fore = 2.21 V
    - Aft = 2.56 V
    - Drag = 3.04 V

    What are the resulting lift, drag, and pitching moment on the model under test?

b. Discussion of measurements and results

1. Comment on the variation between the LabView Data and the display module output.
2. Discuss what possible sources of error exist in the system that could cause the error in measurement
3. Discuss the resolution of the system and why it is important to use the proper range of the sensors during calibration.

References

[1] "AFA3 Three Component Balance User Guide". TecQuipment Limited 2014. DM/MB/AD/0814.