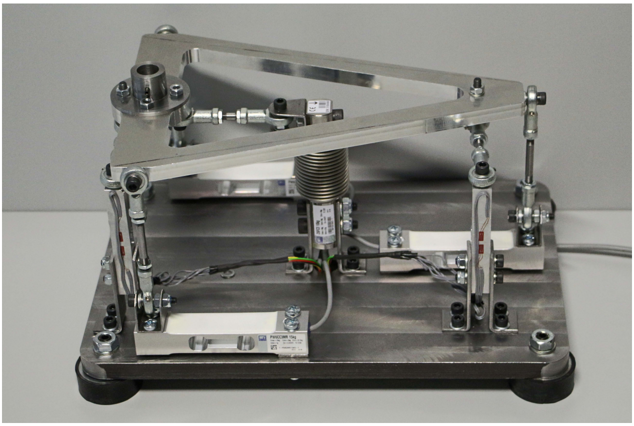
Aarhus University

School of Engineering

Windtunnel Balance

User Manual



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Part I

Basic use

Chapter 1
Specifications

The balance is made for *Aarhus University School of Engineering* and was manufactured and calibrated by 1^{st} of June 2015. The balance and all of its components are owned by *Aarhus University*.

1.1 Read before use

Any use of this wind tunnel balance is users responsibility and hazardous handling in any way is strictly forbidden. The load cells and their electrical components are fragile, and are dimensioned for use in wind tunnel testing and not for any other applications. The limit loads and maximum test object sizes are described in the following specifications.

There should **NOT** be performed any permanent modifications to the balance, such as drilling, welding or deformation.

1.2 Limit loads

The following forces and moments should not be exceeded when testing objects using this wind tunnel balance:

- Drag force: $\pm$ 50 N
- Side force: $\pm$ 150 N
- Lift force: $\pm$ 200 N
- Pitch moment: $\pm$ 10 Nm
- Roll moment: $\pm$ 10 Nm
- Yaw moment: $\pm$ 10 Nm

The balance consists of 6 load cells, 4 of which are bought from HBM and 2 of them are manufactured by the project team. The limit loads are written on each load cell and to get the best results and avoid breaking the load cells, it is important that the forces exerted on the load cells are kept below this limit.

1.3 Maximum test object size

To acquire proper results it is important to keep a constant velocity upon the entire model during test, avoiding interference with stagnant air. As a rule of thumb, the frontal area of the model should not exceed 20 % of the wind tunnel cross section, corresponding to a $0.05\,\mathrm{m}^2$ limit. The following plot shows the velocity profile across the bottom half of the wind tunnel, and can be a help during dimensioning and placement. The bottom of the inlet tube corresponds to 0 on the y-axis on the figure, and the x-axis is equal to the length between the inlet and outlet tube.

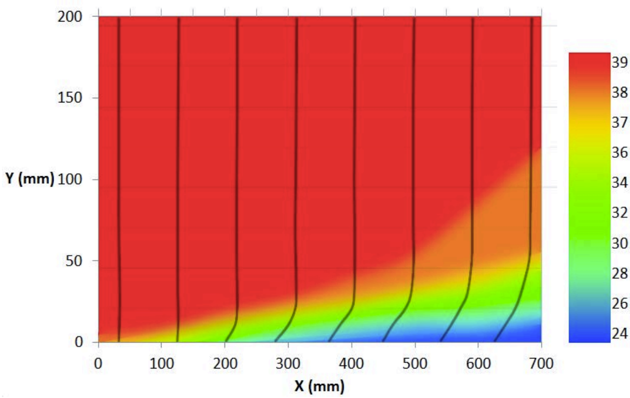


Figure 1.1. *Velocity plot of the windtunnel*

The weight of the test object should be taken into account, regarding the maximum load of the force balance.

1.4 Accuracy

The accuracy of the balance has been measured to the following numbers, with its alignment and calibration as of 1^{st} of June 2015:

- Drag force: ±0.5% relative error **or** ±0.1% FSO absolute error
- Side force: ±0.5% relative error **or** ±0.1% FSO absolute error
- Lift force: ±0.5% relative error **or** ±0.1% FSO absolute error
- Pitch moment: ±1% relative error **or** ±0.5% FSO absolute error
- Roll moment: ±1% relative error **or** ±0.5% FSO absolute error
- Yaw moment: ±1% relative error **or** ±0.5% FSO absolute error

Chapter 2
Software and setup

This chapter will describe the use of the LabVIEW programme provided, along with instructions on how to connect the wires with the DAQ devices.

2.1 Wiring setup

The measurement wires are labeled according to the load cell they are connected to; the green wires should be connected to positive inputs, yellow wires should be connected to negative inputs.

Remote sensing wires are red and black, labeled accordingly; the red wires connect with the positive input, the black connect with the negative terminal.

The wiring diagram should be consulted in case of doubt.

2.2 Installation

Install the programme from the USB drive, with the default settings. Restart your computer, and run the program.

2.3 I/O setup

Set the pole height between the top of the platform and the reference point, as mentioned in the chapter 3.

The signals from the load cells are read with a NI 9213 module. The load cell input channels used should be specified in the program in the correct order, as illustrated on the figure next to the channel input.
The NI 9213 should show 16 analog inputs to choose from.

Match the analog input channels in this order:

1. Specify the input used for the *i1 - drag* load cell
2. Specify the input used for the *i2 - side* load cell
3. Specify the input used for the *i3 - yaw* load cell
4. Specify the input used for the *i4 - lift* load cell
5. Specify the input used for the *i5 - lift* load cell
6. Specify the input used for the *i6 - pitch* load cell

Remote sensing measures the exitation voltages with a NI 9219 module.
The NI 9219 should show 4 analog inputs channels to choose from

The channel *Sense chippower* specifies the analog input connected to wires labeled *Chip sense*.
The channel *Sense drag* specifies the analog input connected to wires labeled *Drag sense*.

Remote sensing greatly increases the accuracy of the measurements. If not possible, measure the exitation voltage manually as reference

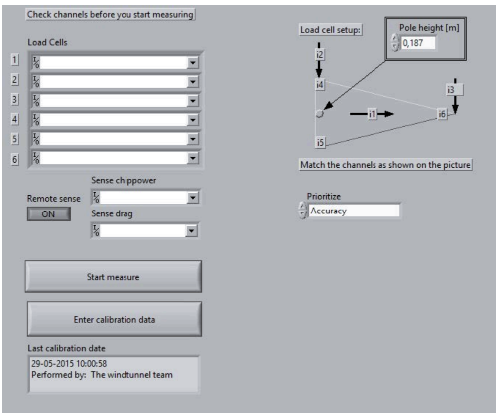


Figure 2.1. *I/O setup screen*

Press *Run* in the top left corner, and then *Start measure*.

Calibration data should only be changed by experienced users. If no calibration data is entered, the default calibration will be used.

2.4 Measure

After *Start measure* the following screen will appear

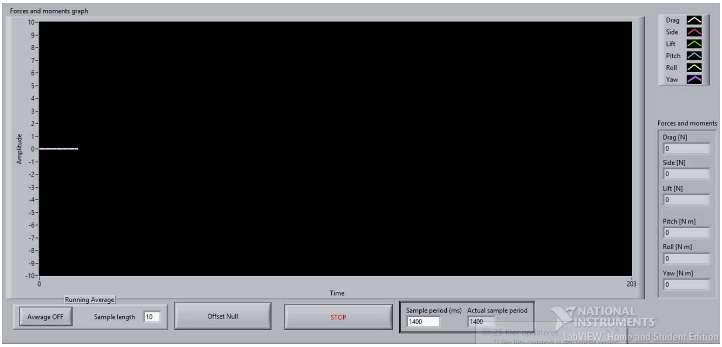


Figure 2.2. *Measure screen*

Reset the values of the load cells by pressing the *Offset null* button. The resetting should be done while the wind tunnel is shut down and no force are applied to the balance. The forces and moments can be read from the coloured curves, and their values can be read from the display to the right.

An averaging can be set on or off, which is done in the bottom left corner of the screen shown on figure 2.2. Set the desired sample length and press *Average ON*. The programme will now average the results over the number of samples set.

Clicking *STOP* will end all processing done by the programme. This will reset the programme to its starting point, and calculation data can be changed or a new measuring can be started.

Chapter 3
Testing

Because of electronics and load cells being temperature dependant to some extent, the system can take as long as 30 minutes to fully stabilize. Therefore the system should be left to idle from the very beginning, while preparing the rest of the test.

3.1 Mounting

The default connector for mounting fits 16 mm shafts and most of the test models available in the wind tunnel. Secure the shaft by tightening the socket screw.

When attached correctly, the connection can withstand the maximum loads of the balance

After mounting, measure the distance from the top of the upper platform to the centre of gravity for the model, as in figure 3.2. This distance is noted during programme setup, and all moments are measured in reference to this point.
A sloppy measure will lead to unreliable moment readings.

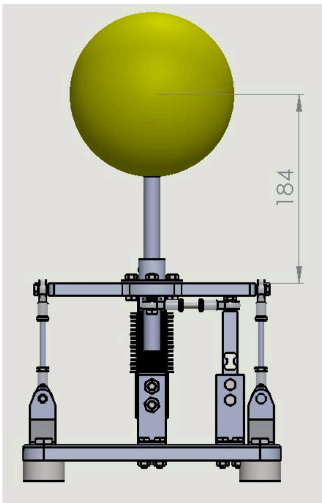


Figure 3.1. *Pole height*

3.2 Measuring

Everything should now be ready for the actual test. Make sure to *Offset null* before starting the wind tunnel or applying forces to the balance.

Start the wind tunnel, and bring the airflow up to desired velocity. Let everything stabilize and note the resultant forces and moments (turn on averaging if numbers are fluctuating), as well as the dynamic pressure, RPMs or other relevant input.

After testing, let the airflow go back to rest before touching the balance, and check whether the reactions approximately return to zero. If not, a new measure should be considered.

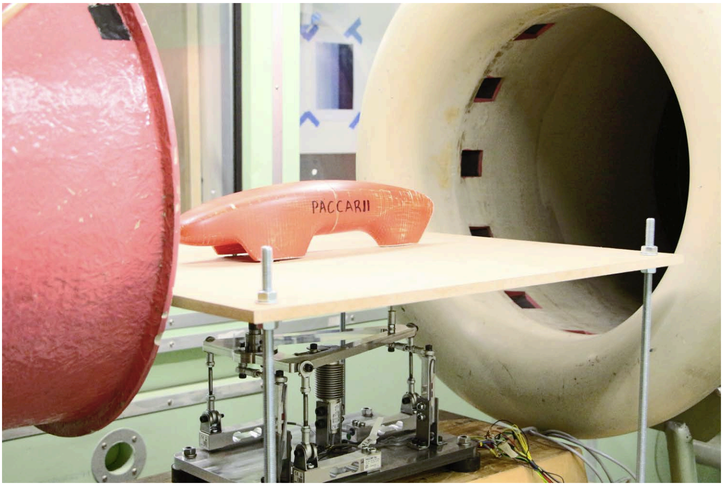


Figure 3.2. *Testing with the force balance*

Chapter 4
Recommendations

The project team wishes that you get on well with your work in the wind tunnel and that the force balance comes in handy to use. Here are some recommendations to be taken into consideration when testing aerodynamics in a wind tunnel.

- Make sure that the model is aligned horizontally and vertically in line with the direction of wind. For certain objects, even small angular misalignments can have a large impact on results.
- Model fixtures are a crucial part of getting reliable results in a wind tunnel. Investigate through CFD and tests whatever type of fixture suits the experiment. Ensure proper separation between the flow around model and fixture, to minimize whatever influence the fixture might have on the overall flow.
- If there is sufficient separation between fixture and model, the reactions in either can roughly be assumed as independent from another. Therefore an experiment should be run with and without model, and by subtracting one from another, the actual forces and moments should be known.

Part II

Advanced use

Important notice

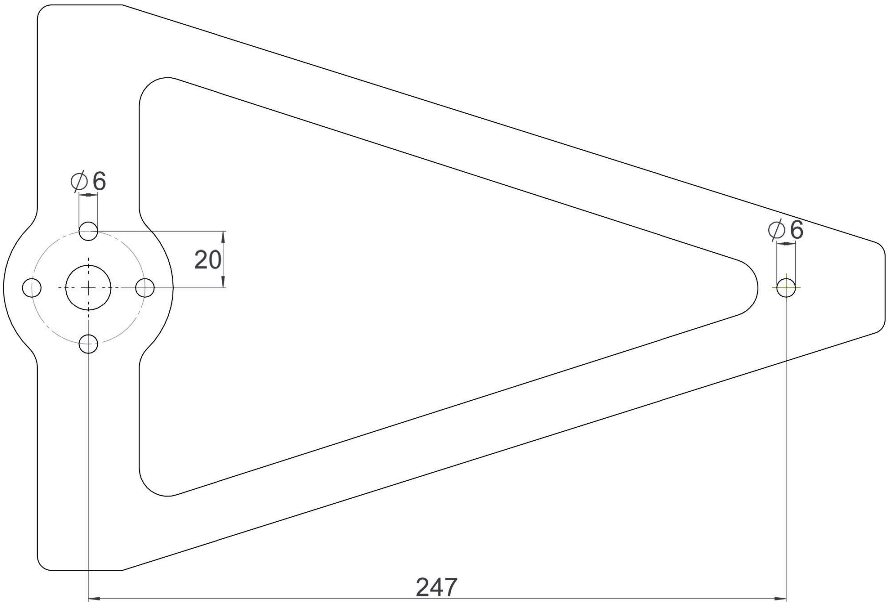
Because of its complex design, the validity of the balance is highly dependent on alignment and calibration. Adjusting one affects the other and vice versa. Therefore, calibration should only be performed by qualified personnel following this guide in every detail.

Do **NOT** perform any changes to geometry or calibration if any uncertainties are present, as it will affect **ALL** future use of the balance.

Chapter 5
Custom mounts

If the default mount is unsuitable for testing, a custom mount can be manufactured. Because of the upper platform being threaded, it is possible to change mount without disassembling the balance.

The default mount detaches by loosening its four nuts. The four revealed bolts can now be used for attaching the custom mount. The upper platform and its holes have the following dimensions:

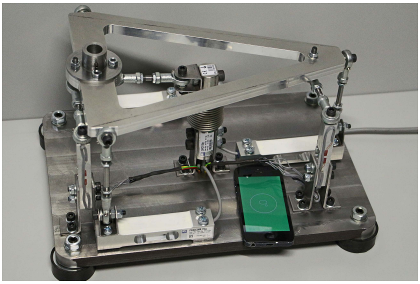


The flange of the mount should have a 3 mm thickness for optimal fitting.

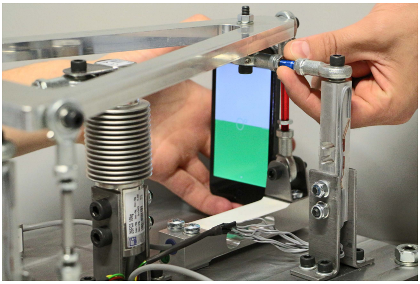
Chapter 6
Alignment of geometry

To ensure alignment and orthogonality, this guide should be followed closely. The rod to align is marked with red, the adjusted rod is marked with blue.

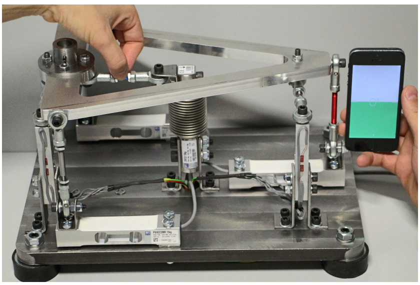
1. The starting point of the adjustment is the fundamental platform. This needs to be horizontal across its length and width. This can be done by adjusting the feet or the table underneath, but should normally be leveled by default.



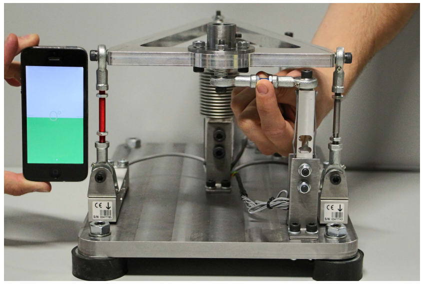
2. The length of the back arm is adjusted, until the back leg is vertical when looking along the direction of wind.



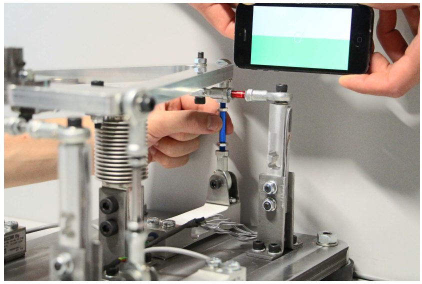
3. The length of the drag arm is adjusted, until the back leg is vertical when looking across the direction of wind.



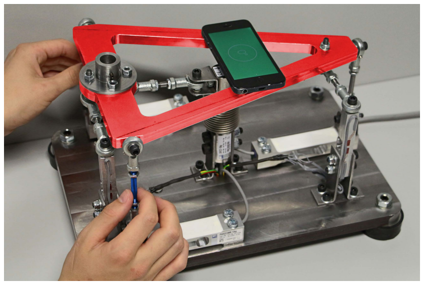
4. The length of the front arm is adjusted, until the front legs are vertical when looking along the direction of wind.



5. The length of the back leg is adjusted, until the back arm are horizontal when looking along the direction of wind.



6. The length of the front legs are adjusted, until the top frame is horizontal across its length and width.



It might be necessary to perform this process more than twice, depending on the amount of misalignment. Every repetition should improve the orthogonality of the rods.

The rods are adjusted by loosing the 10 mm counter nuts, and screwing the rods clock- or counterclockwise

Chapter 7
Calibration

If any changes are made to the platform setup, it is advised to calibrate the force balance before use for the most accurate results. In the following, such a calibration will be made step by step.
Initially the force balance should be aligned according to the previous chapter in the manual. The forces exerted on the balance would theoretically be given by the readout on the load cells following the mathematics of the force balance but in reality this is not the case. In order to achieve the most accurate results such a calibration matrix must be made given by equation (7.1).

$$[\mathbf{F}] = [\mathbf{K}] \cdot [\mathbf{R}] \tag{7.1}$$

$[\mathbf{F}]$	Force matrix
$[\mathbf{K}]$	Calibration matrix
$[\mathbf{R}]$	Readout matrix

It is desirable to use a heavy load in the calibration test, as it minimizes the influence on the random uncertainties as well as increasing the linear systematic errors. It is important the forces applied to the force balance is carefully measured, as small errors will be accumulated and transferred to the final calculations.

A calibration example, with weight blocks of 7968 g, is used as reference. On figure 7.1 the force is exerted in the positive drag direction, which should give the drag force in $i = j = 1$ and *zero* in the remaining entries of $j = 1$ this is entered in matrix $[\mathbf{F}]_{j=2}$ in equation 7.2.

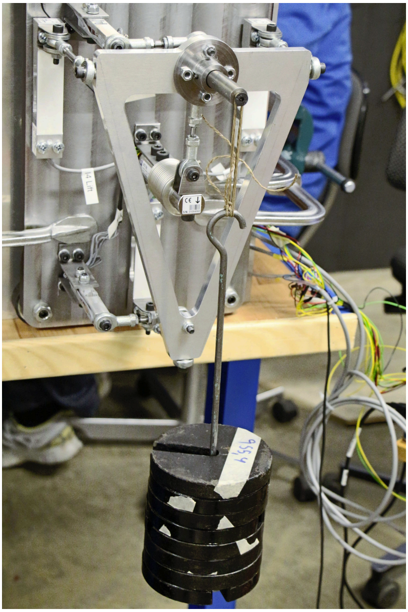


Figure 7.1. *Weight blocks exerted in positive drag direction, ($\boldsymbol{F}_{1,1}$)*

The force of the weight block is exerted on the platform balance in all its directions using the gravitational force by changing the orientation of the forcebalance. This yields the force matrix [**F**] given by the following:

$$[\mathbf{F}] = \begin{bmatrix} 0 & 7968 & 0 & 0 & 7968 & 7968 \\ 0 & 0 & 7968 & 7968 & 0 & 0 \\ -7968 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 645 & 0 \\ 0 & 0 & 0 & -645 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 669 \end{bmatrix} \tag{7.2}$$

The moments are a result of the arm between the force and center of the balance.

For $i, j = 1, 2..6$
Where i being the test no. and j being the load type in the order:

F_{1j}	Drag force[g]
F_{2j}	Side force[g]
F_{3j}	Lift force [g]
F_{4j}	Pitch moment [g·m]
F_{5j}	Roll moment [g·m]
F_{6j}	Yaw moment [g·m]

This results in a read out matrix [**R**], from the load cells on:

$$[\mathbf{R}] = \begin{bmatrix} -82 & 7853 & 130 & 126 & 7850 & 7780 \\ -25 & 358 & 7963 & 7963 & 349 & 366 \\ -7933 & 24 & -55 & -60 & 17 & -6 \\ 17 & 2 & -21 & -10 & 643 & -1 \\ -3 & 30 & -4 & -651 & 2 & 48 \\ -3 & 5 & 11 & 11 & 10 & 650 \end{bmatrix}$$

Using equation (7.1) this gives the calibration matrix [**K**], which in this case gives the following calibration factors:

$$[\mathbf{K}] = \begin{bmatrix} 1.0188 & -0.0154 & -0.0049 & 0.0002 & 0.0010 & 0.1321 \\ -0.0048 & 1.0068 & -0.0021 & 0.0000 & -0.0001 & -0.0087 \\ -0.0095 & 0.0240 & 1.0047 & 0.0000 & -0.0001 & -0.0086 \\ -0.0017 & 0.0043 & 0.0000 & 1.0193 & 0.0146 & -0.0545 \\ 0.0000 & 0.0013 & 0.0000 & 0.0047 & 1.0070 & 0.0041 \\ 0.0000 & 0.0006 & -0.0006 & 0.0013 & 0.0079 & 0.9997 \end{bmatrix}$$

The values from the calibration matrix [**K**], can be entered in the LabVIEW programme and your wind tunnel test is ready to be executed.

Software input

If the *Enter Calibration Data* button is pressed, a pop-up will appear where the password *123firefem* should be typed. The following screen will prompt asking for calibration data, which is calculated according to the mathematics described previously in chapter.

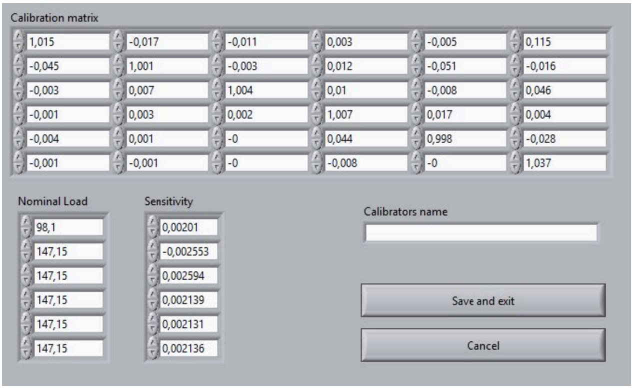


Figure 7.2. *Calibration data entries screen*

Fill in calibration factors in all entries and type in the calibrators name. The sensitivity for each load cell can also be seen here, but can't be changed, as they have been calculated carefully upon installation. The calibration matrix calculated is linearly dependent on the sensitivities of the load cells. Is the calibration matrix properly calculated there will be an accurate measurement on the forces and moments regardless whether the calibration of sensitivities has been changed a little over time.

Press *Save and exit* and the *I/O setup* screen will reappear. In the box in the bottom left corner on figure 2.1 the new calibration date and who the calibration was performed by will be shown. The default entities in the calibration matrix is saved in the installation file. Reinstalling the measurement programme will reset the calibration matrix.