University of Sydney School of Civil Engineering Atmospheric Boundary Layer Wind Tunnel: New Developments

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1 INTRODUCTION

The School of Civil Engineering atmospheric boundary layer wind tunnel was built in the mid 70's to study wind load on building, building motion and pedestrian wind comfort. The tunnel is an open circuit wind tunnel with a test section of 2.0 x 2.4 m and a fetch of 20 meters. The fetch can be equipped with variable levels of roughness to produce different boundary layer profiles with specific turbulence characteristics. The maximum wind speed in the boundary layer section is in the order of 16 m/s.

During summer 2009, the decision to upgrade the acquisition system was taken while keeping the existing instrumentation. This paper describes the major modifications made during the past year and presents a typical test that can be achieved with the new system. Emphasis is given on the new acquisition controller and the stereo Particle Image Velocimetry (PIV) system.

2 INSTRUMENTATION

2.1 Existing instrumentation

The existing instrumentation was composed of 256 pressure transducers, 2 six-degree-of-freedom balances, 1 Cobra probe, a Constant Temperature Anemometer (CTA) system with the ability to record two velocities simultaneously, and many stress gauges. All these measurement systems were working and have been kept, except for the CTA controller.

The existing analogue-to-digital (A/D) cards and the associated computer were defective and have been replaced by a new controller (see Section 2.3).

2.2 Constant Temperature Anemometer

The new CTA is composed of a controller, 6 hot-wire velocity probes, 1 temperature probe and 1 reference probe. The 6 hot-wires are calibrated against the reference probe for which the relationship voltage-velocity is well known. As the heat transfer of the hot-wire is not only a function of the velocity but also depends of the air temperature, the temperature probe corrects of the velocity when the air temperature fluctuates. The temperature probe is used during both the calibration process and during normal tests to correct the computed velocity as a function of the temperature variations.

2.3 Controller

The new acquisition controller, a National Instrument PXI-1044, is equipped with a dual-core processor (PXI-8102) and 10 acquisition cards (PXI-6624). Each card can record up to 32 analogue signals, 2 digital signals and can generate 16 signals. Each analogue signal is converted into a 32 bit digital signal before being processed.

The 320 channels can simultaneously acquire at 2 kHz, however during a typical test the acquisition frequency is set at 1 kHz, except for the CTA (1.5 kHz), to reduce the amount of stored data. To further reduce the amount of data recorded during a test, the user can specify which channels will be recorded. Each channel can be visualized during a test, regardless of whether it is recorded or not. The acquisition system is versatile and new instruments can easily be added.

2.3.1 *Graphic User Interface (GUI)*

Except for the versatility of the system, one major reason to have chosen a National Instrument solution was its well-documented graphical programming language LabVIEW. Using this tool, a friendly Graphic User Interface (GUI) was built that enables any user to run the instrumentation. The GUI guides the user through the different steps of preparing and running a complete test.

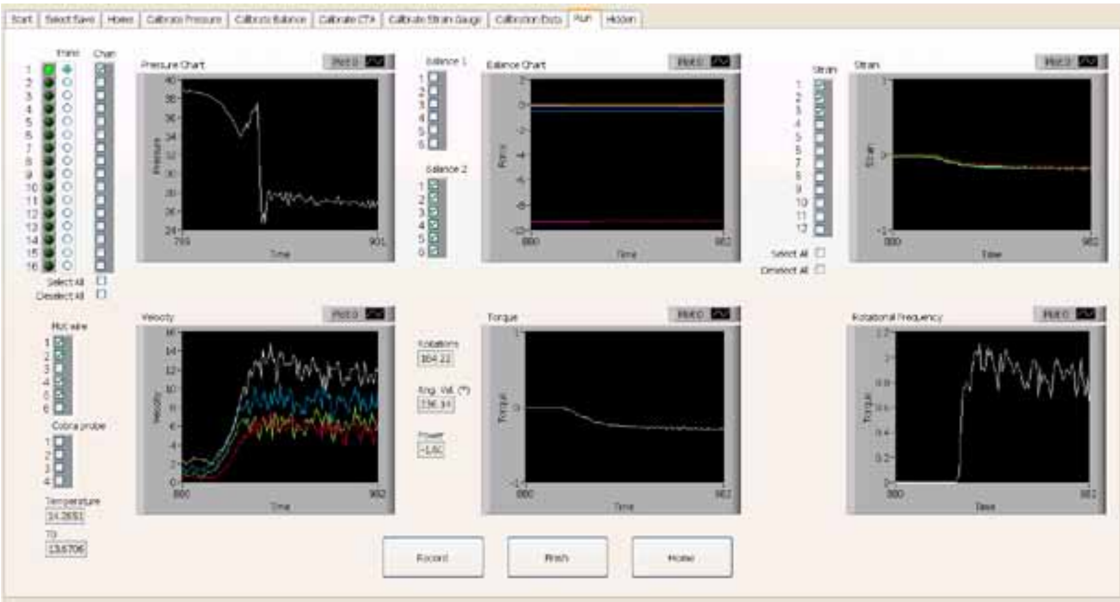

Figure 1: GUI during a test.

The steps can be summarised as follow:

- choice of the instruments to record during the test,
- calibration of:
    - the pressure sensors. Using a manometer, a known pressure is applied to the pressure transducers and a corresponding voltage is recorded. A linear best fit is then computed and saved for each individual transducer.
    - the hot-wires. The velocity probes are calibrated against the reference probe for a range of velocities between 0 and 16 m/s. The temperature is also recorded for each sample. After correcting the velocity as a function of the temperature variations, a 4^{th} order polynomial is fitted using a least square approach.
    - the balances. The balances are tared. Models can be placed on the balances but only the aerodynamic forces are measured.
    - the stress gauges. Known stresses are applied to the gauges and the corresponding voltage are recorded.
- the user can choose to calibrate all, some, or none of the instruments. In the case an instrument is not recalibrated, the last calibration is then used. A figure then summarises the calibration parameters used, which allows the user to control the calibration parameters. The program records the physical values and not the raw voltages, so it is essential to be sure the correct calibrations are used.
- the test itself is done in two steps;
    1. the user chooses which channels are to be displayed on the screen and sets the air speed to the desired value. To manage the large amount of data to display, the GUI only refreshes the screen at 4 Hz (for an acquisition at 1kHz). It should be stressed that this does not affect the acquisition rate but avoids overloading the graphic card.

2. once the parameters are set to the desired values the user can start to acquire the different signals, by simply pressing a 'start' button. Fig. 1 shows the run windows with the different instruments displayed in the respective graphs.

- Once the test is finished, the recorded data, saved in a TDMS format, are loaded and saved as CVS files. Programs like Matlab or Excel can easily read CVS files.

The data are then analysed using a companion GUI developed with Matlab.

2.4 Torque and angular position sensor

The torque and angular position sensor is a new addition to the wind-tunnel measurement system. The main purpose of this device is to measure the angular velocity and torque at the shaft of wind-turbines so the power output can be computed. This allows for different wind-turbine configurations to be tested and compared. The efficiency of the wind-turbine can rapidly be measured for different wind speeds and boundary layers.

The position sensor is also used to trigger the PIV system. As Microsoft Windows is not a real time operating system, the triggering of the PIV has to be done directly through the acquisition cards. The digital angular position is used as a reference clock for a digital channel that is then used to trigger the PIV. Each acquisition card has an onboard clock acquiring data at 20 MHz, which guarantee, in our case, a position accuracy of the blade in the order of 50 micro-degrees when the laser is fired.

2.5 Stereo-PIV

PIV is a non-penetrative technique of extracting the two components of the velocity from a desired planar flow region (see Fig. 2) [1]. A laser pulse lights a plane section of the flow and highlights particle tracers while a camera records their position. A second laser pulse illuminates, a short time later (~100 μs), the same section of the flow. Two components of the velocity fields can be retrieved from the position difference of the particles in the plan of the laser sheet. To measure the three components of the velocity, two cameras take images of the laser sheet from different angles. The two images combined together give the three components of the velocity [2], [3].

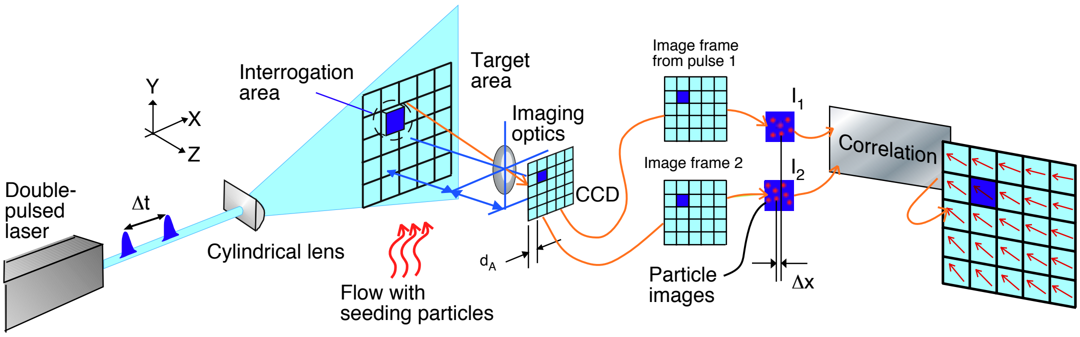

Figure 2: Principle of a PIV system (adapted from Dantec PIV poster)

Our stereo-PIV system is composed of a double head 200 mJ-per-pulse laser and 2 x 11 MPx cameras. This setup enables us to measure the velocity field on a plane of 0.5 x 0.5 m.

The acquisition frequency of the PIV system is 2 Hz if the images are recorded directly on the computer RAM and 0.5 Hz if the pictures are grabbed on the hard disc. The RAM can only store 12-14 images so for tests requiring more images there is no choice but to record them on the hard disk.

2.5.1 PIV-CTA

Working with a CTA and a PIV has the advantage of combining the temporal resolution of the CTA and the spatial resolution of the PIV. The hot wire probes allow us to better interpret the results from the PIV and, vice-versa, the PIV images help us understand reasons behind the velocity fluctuations recorded by the hot-wires.

3 EXAMPLE

The following example presents the wake behind a small 4 blade-fan of 30 cm in diameter. Both, the amplitude of the velocity components along the *x* and *z*-direction, respectively *U* and *W,* are shown in Fig.3. The vectors represent the velocity field *V* and *U* minus the average of *U*. Removing the mean velocity *U* from the vector field allows an easier study of the flow field, and structures, such as the tip vortices can be observed (highlighted by circles in Fig.3). The *W* velocity field clearly show the rotation of the wake around the axis of rotation of the fan (*y=0*); the upper part of the graphic displaying negative values of *W* (in blue), while the lowest part displays positive values of *W* (in red).

During this test, the PIV was controlled by the position of the blade. The mean velocity and the turbulence intensity were compared between the PIV images and the CTA and showed good correlation.

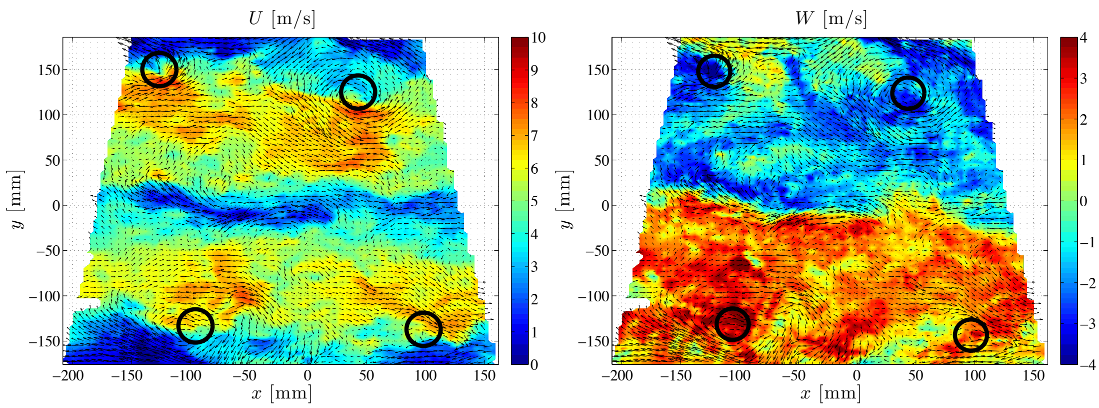

Figure 3: Velocity field behind a 30 cm in diameter fan. The tip vortices are highlighted by circles.

4 CONCLUSION

The School of Civil Engineering atmospheric boundary layer wind tunnel has been updated with a new acquisition system and a stereo-PIV system. A friendly Graphic User Interface (GUI) leads the user through each step of the calibration procedure and the test. The acquisition system is set up to record simultaneously 258 pressure taps, 6 hot-wire, one Cobra probe, 2 six-axis-balances, a couple of stain gauges and 1 torque and angular position sensor at a frequency of 1 kHz. The angular position is also used to trigger the stereo-PIV system, which is composed of a 200 mJ laser and two 11 MPx cameras.

5 REFERENCES

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[3] Prasad, A. K. (2000). "Stereoscopic particle image velocimetry." Experiments in Fluids 29, 103--116.