

Air velocity Sensors' Calibration Intercomparison using LDA as standards

by

Sánchez J.R.⁽¹⁾, Müller H.⁽²⁾, Care I.⁽³⁾, Cordier-Duperray Y.⁽⁴⁾ and Seynhaeve J.M.⁽⁵⁾

⁽¹⁾I INTA (Instituto Nacional de Técnica Aeroespacial “Esteban Terradas”)

E-Mail: sanchezq@inta.es

Road Ajalvir, pk 4 - 2850 Torrejón de Ardoz - Madrid – SPAIN

⁽²⁾PTB (Physikalisch Technische Bundesanstalt)

E-Mail: harald.mueller@ptb.de

Bundesallee 100 – 38116 Braunschweig – GERMANY

⁽³⁾CETIAT (Centre Technique des Industries Aérauliques et Thermiques)

E-Mail: isabelle.care@cetiat.fr

Domaine Scientifique de la Doua –25, avenue des Arts BP2042 – 69603 Villeurbanne Cedex – France

⁽⁴⁾CETIAT (Centre Technique des Industries Aérauliques et Thermiques)

E-Mail: yvan.cordier@cetiat.fr

Domaine Scientifique de la Doua –25, avenue des Arts BP2042 – 69603 Villeurbanne Cedex – France

⁽⁵⁾UCL (Université Catholique de Louvain)

jms@term.ucl.ac.be

Place de l'Université 1 – 1348 Louvain-la-Neuve - BELGIUM

ABSTRACT

Air velocity measurements are a very common and important activity within HVAC, security, comfort and aerodynamic testing techniques. When air velocity is measured we need to know the mean value and its uncertainty, so air velocity sensors must be calibrated by means of a velocity standard to know their metrological performances.

Along the history, pitot tubes have been usual standard but nowadays LDA (Laser Doppler Anemometer) are the most accurate so most laboratories are using these for this purpose. On the other hand, quality assurance standards, as ISO 17025, promote and demand intercomparison activities between several standards.

In the EEC (European Economic Community), PTB (Physikalisch Technische Bundesanstalt) in Germany, CETIAT (Centre Technique des Industries Aérauliques et Thermiques) in France, UCL (Université Catholique de Louvain) in Belgium and INTA (Instituto Nacional de Técnica Aeroespacial “Esteban Terradas”) in Spain have developed a wide intercomparison program to analyse the different work procedure effects, the different facility aspects, different calibration LDA procedures and any another subject that could arise during the program.

PTB, CETIAT and INTA agreed on a test program in January 2002 during a meeting at INTA. The test program includes different calibrations of the same pitot tube connected to the same pressure sensors carried out inside all the different facilities. They were made in PTB, CETIAT, UCL and INTA, applying four different procedures. Later when results of this intercomparison were finished, PTB, CETIAT and INTA agreed on a new test program in April 2003 during a meeting at PTB with a hot-wire anemometer applying each procedure. Along this time the four partners have been in touch in view to increase air velocity calibration world relationships, to discuss about primary standards or new laser systems or new facilities, etc...

1. INTRODUCTION

The traceability for the representation of the unit flow velocity in the different wind tunnels used for sensor calibration is the core of a calibration facility. The intercomparison measurements are directly given by the application of a Laser Doppler Anemometer used as velocity standard in each facility. To realize a flow velocity standard with an uncertainty explicitly less than 1% the Laser Doppler Anemometers have to be calibrated.

As a background we have EUROMET-Project 388: Intercomparison of Anemometers (April 1999) where was carried out an intercomparison activity with windmill-type anemometer (Schildknecht/MiniAir60 Mini). In this project, not all the laboratories involved were using LDA systems. Some were using Pitot tube or other kind of instruments as standard. The main conclusion was there are relatively big differences and this topic needs more investigations.

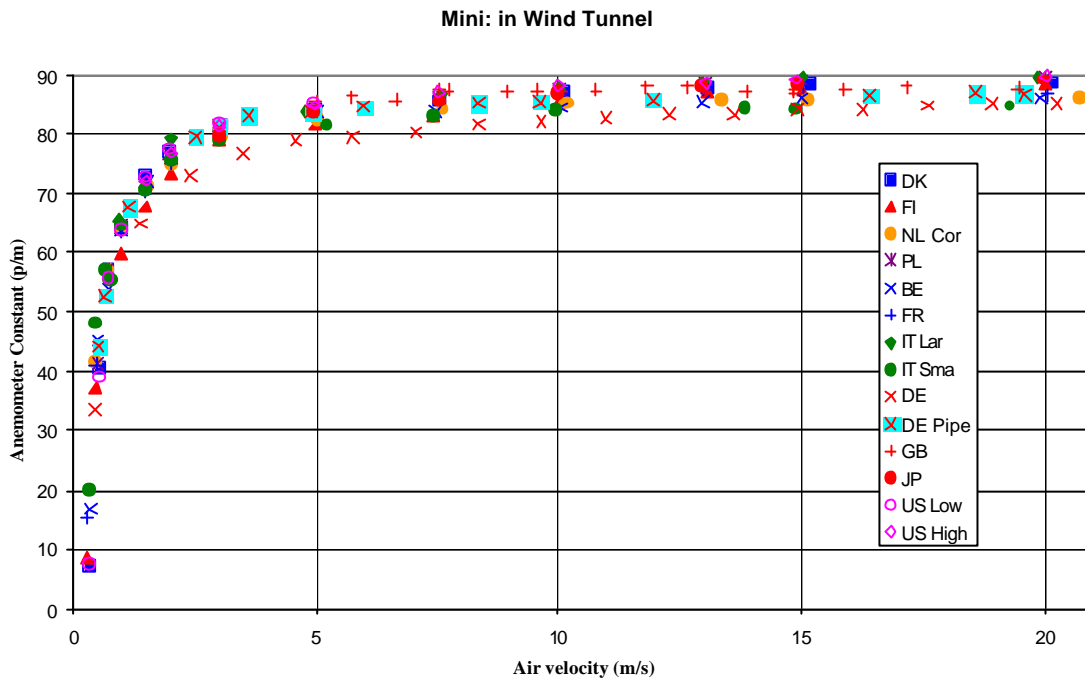


Figura 1: EM388 Calibration result of a windmill-type anemometer (Schildknecht/MiniAir60 Mini) in different wind tunnels, represented is the anemometer constant (pulses per meter) as a function of the air velocity.

Nowadays LDA are very spread on flow calibration facilities. PTB, CETIAT, UCL and INTA agreed to collaborate about LDA calibration subjects to upgrade European competence.

The two first steps have been the calibration of a Pitot tube and a hot wire anemometer. Each one has been calibrated inside each laboratory using their own test rig and procedures.

2. PTB FACILITY

The LDA system used for the intercomparison measurements has been a semiconductor LDA system, specially developed at PTB as transfer standard. The system has a laser output power of about 90 mW at a wavelength of 803 nm and works in backscattering direction with a laser beam separation of 50 mm and a working distance of 500 mm.

The wind tunnel used at PTB (see figure 2) is a wind tunnel of the Eiffel type, an open wind tunnel with a closed measuring chamber. The wind tunnel has a total length of 4450 mm and the measuring chamber allows to realize an effective measuring length of 500 mm. The circular shaped wind tunnel nozzle has a contraction ratio of 8 and an outlet nozzle diameter of 180 mm. The velocity can be tuned in the range of 0,1 m/s up to 60 m/s by adjusting the number of revolutions of the vane fan.



Figure 2: Picture of the wind tunnel used at PTB for the intercomparison measurements

3. CETIAT FACILITY

The velocity standard used is a LDA, manufactured by TSI, model IFA 655 with a Fringe spacing of 3.717 μm and a wavelength of 514.5 nm.

Two closed loop wind tunnels are available depending on the velocity range. Their test sections are closed.

The velocity range of the first one is 0.05 m.s⁻¹ up to 2 m.s⁻¹. In this “Low velocity” wind tunnel (see figure 3) and we can work at a temperature and a humidity different than ambient conditions and we can generate different flow directions (horizontal, upward or downward flow). The size of the test section is 250 x 250 x 700 mm.

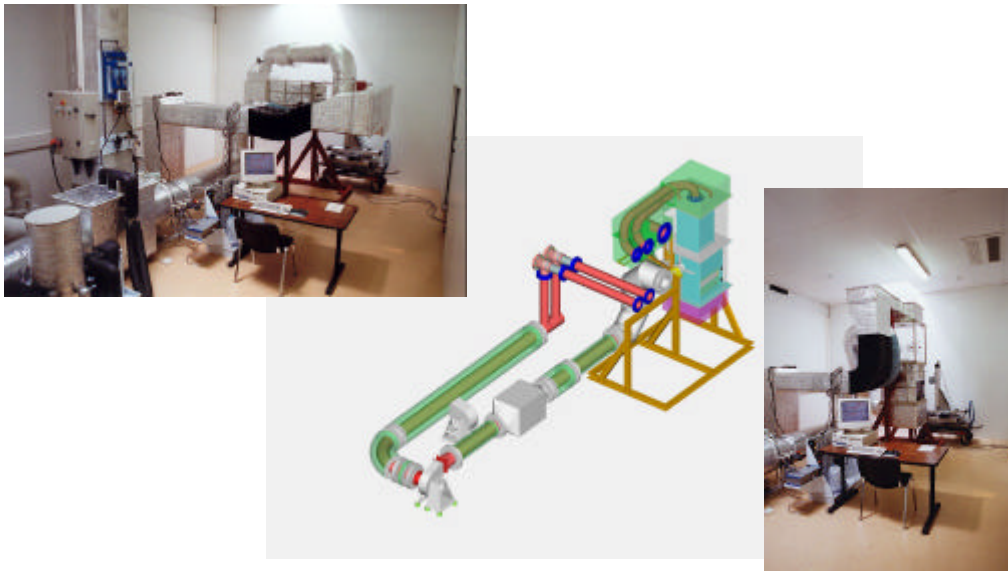


Figure 3: Pictures of the “Low velocity” wind tunnel

The velocity range of the second wind tunnel is 0.15 m.s⁻¹ up to 40 m.s⁻¹. In this “High velocity” wind tunnel (see figure 4), the temperature is controlled inside the wind tunnel and we can work at a temperature different than ambient temperature for velocity higher than 2 m.s⁻¹ .

The size of the test section of this wind tunnel is 500 x 500 x 1000 mm



Figure 4 – Pictures of the “High velocity” wind tunnel

4. UCL FACILITY

The air velocity are measured by an AEROMETRICS two-component LDA equipment.

The main features and specifications of this equipment are Maximum velocity: 750 m/s, Velocity dynamic measurement range: 725 m/s, Mean velocity accuracy: 0.2 %, Wavelength : 488 μm , Focal length : 500 mm or 300 mm, Beam separation : 60.1 mm, Laser beam diameter : 3.5 mm, Fringe spacing : 4.07 μm and Beam waist : 88.76 μm

The air flow is provided by a centrifugal fan driven by a DC motor supplied by a Ward-Leonard group. This equipment allows to cover a wide range of air velocity (0.3 to 60 m/s) with stable operating conditions.

The open test section of 560 x 420 mm is located downstream from a sinusoidal convergent which guarantees a constant velocity profile at an accuracy better than 1 %.

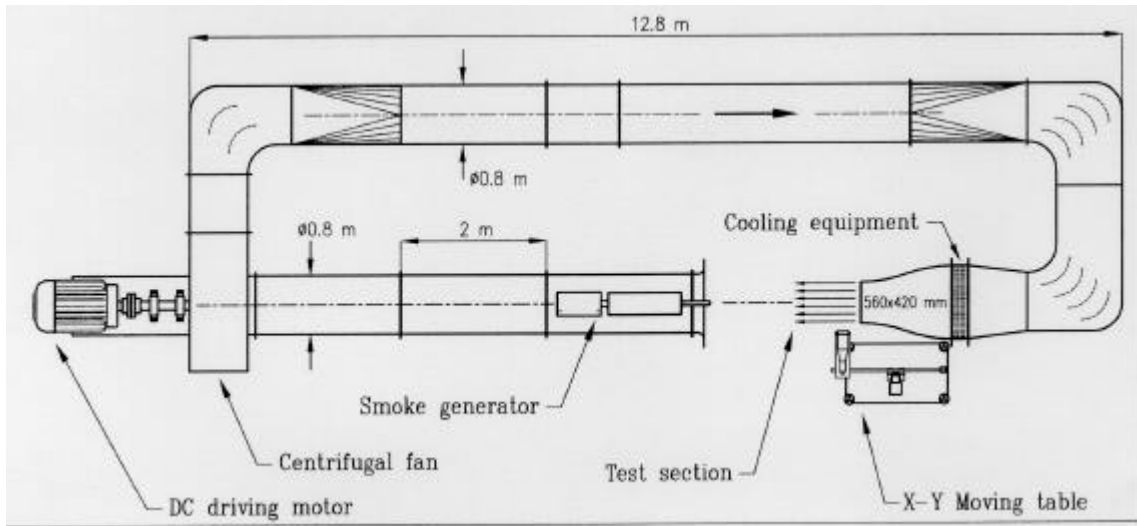


Figure 5 : Calibration Aerodynamic tunnel draw

5. INTA FACILITY

The flow velocity standard for the intercomparison activity is a L.D.A. DANTEC, Type: HeNe, Class 3B continuous, Power:10 mW, Wavelength: 632.8 nm, Laser beam diameter: 1.68 mm, Beam separation : 38.4 mm and Focal length : 160 mm.

The wind tunnel performance and characteristics are Closed circuit with opened test section of elliptical size 300 x 200 mm, Continuous flow and a velocity range from 0 and 60 m/s



Figure 6: INTA Wind Tunnel Calibration Facility

6. INTERCOMPARISON METHOD AND PROCEDURES

The intercomparison method has been based on repeating Pitot tube and Hot Wire anemometer calibration by each laboratory. Each calibration has been carried out independently by the different facilities with its own LDA system, wind tunnel, staff and procedures.

For intercomparison analysis according to E.A, the normalised deviation is a criteria which is calculated using the following relationship :

$$N = \frac{|E1 - E2|}{\sqrt{(\sum U_{Lab}^2)}}$$

Acceptance criteria on the normalised deviation is:

$$N \leq 1$$

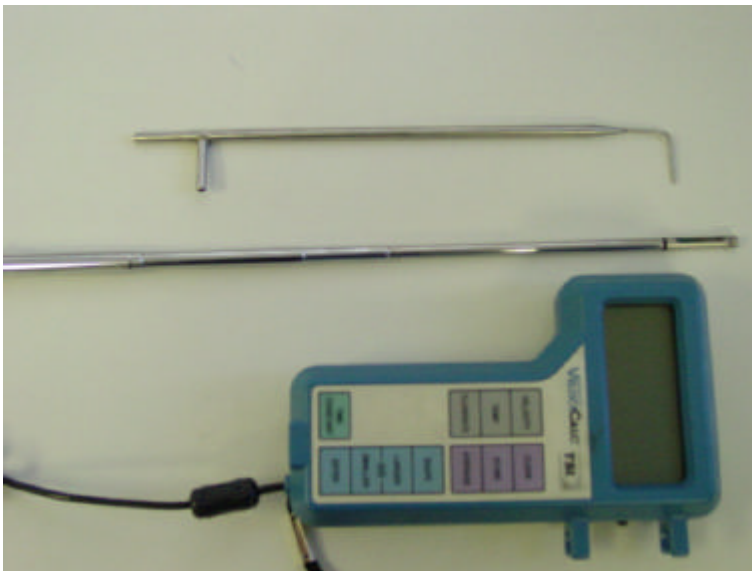


Figure 7: Pitot tube and Hot wire anemometer

6.1 PTB Procedure

Preparation procedure

1. Calibration of the LDA with a rotating glass wheel to ensure an uncertainty for a single burst velocity measurement as low as possible
2. Measurement of pressure, temperature and humidity in the laboratory
3. Switching on the remote controlled wind tunnel fan and the seeding system
4. LDA-measurement of the flow profile in the wind tunnel without anemometer at a velocity of 20 m/s adjusted by the number of revolutions of the fan
5. Measurement of the differential pressure between the inlet and the outlet of the wind tunnel nozzle for the adjusted velocity
6. Mounting of the anemometer inside the test chamber 5 probe diameters behind the LDA measuring plane
7. Measurement of pressure, temperature and humidity in the laboratory
8. Switching on the remote controlled wind tunnel fan and the seeding system
9. Adjusting the number of revolutions of the fan for getting the same differential pressure at the wind tunnel nozzle as before (without anemometer in the wind tunnel) to consider the blockage effect
10. LDA-measurement of the flow velocity profile 5 probe diameters in front of the anemometer probe

11. Comparison of the LDA-velocity profiles (with and without anemometer probe) taken at the same position in the wind tunnel and determination of the reference measuring point for the calibration procedure at which the flow velocity is not influenced by the anemometer probe
12. If between step 4 and 10 the temperature difference is $> 0,1$ K, the pressure difference is $> 0,1$ mbar and the dew point difference is $> 0,5$ K, the velocities have to be normalized by $\sqrt{(2\Delta p/\rho)}$ in step 11

Start of calibration

13. Setting of the wind tunnel to the first calibration velocity and measurement of the flow velocity by evaluating at least 500 LDA bursts at the reference measuring point
14. Measurement of the dynamic pressure of the probe for the first calibration velocity
15. Repetition of steps 13 and 14 for each calibration velocity

6.2 CETIAT Procedure

1°/ Environmental conditions required:

Ambient temperature inside the wind tunnel : $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$
 Dew temperature inside the wind tunnel : ambient dew point.
 Pressure : atmospheric pressure inside the wind tunnel.

2°/ Previous operations :

- 2.1°/ The LDA must be switch on an our before the calibration starts.
- 2.2°/ The anemometer must be placed inside the wind tunnel, downstream the LDA system, at a distance between 100 mm and 250 mm of the LDA measurement volume depending on the size of the anemometer.
- 2.3°/ The wind tunnel must be switch on at least 10 minutes before the calibration starts.
- 2.4°/ The seeding system must be switch on during 10 minutes before the calibration starts.
- 2.5°/ For air velocity below 20 m/s, the seeding system is switch off. It is maintain on only for velocities higher than 20m/s to ensure sufficient data rate.

3°/ Anemometer Calibration :

- 3.1°/ Generate the lowest needed value using the fan controller
- 3.2°/ Wait 30 seconds for the flow to stabilize.
- 3.2°/ Check data rate level to ensure data acquisition is carried out during at least 10 seconds and to be sure at least 1000 datae are collected.
- 3.3°/ Start data collection and take the value given by the anemometer during this time with its fluctuations if any.
- 3.4°/ Generate the next value using the fan controller.
- 3.5°/ Repeat operations 3.2 to 3.4 till the maximum value is reached and then start again the same operations by decreasing values (i.e. from the maximum value to the minimum value).

N.B.1 : At the end if 10 calibration values were carried out, there must be 20 reference values and 20 instrument values. 10 by increasing values and 10 by decreasing value to be able to evaluate the instrument repeatability.

N.B.2 : Wind tunnel absolute pressure and temperature are data acquired within the same time as the LDA values.

6.3 UCL Procedure

The probe is placed in the centre of the open test section at distance of 150 mm from the output plane of the aerodynamic tunnel (figure 8).

The air velocities measurements are performed by the LDV equipment in a cross-section plane located at 100 mm upstream from the probe. For each selected velocity, the measurement volume of the laser beam are positioned by the automatic moving table at nine different locations in this cross-section on a circle of 30 mm of diameter. Two measurements are taken at the centre of this circle (figures 8).

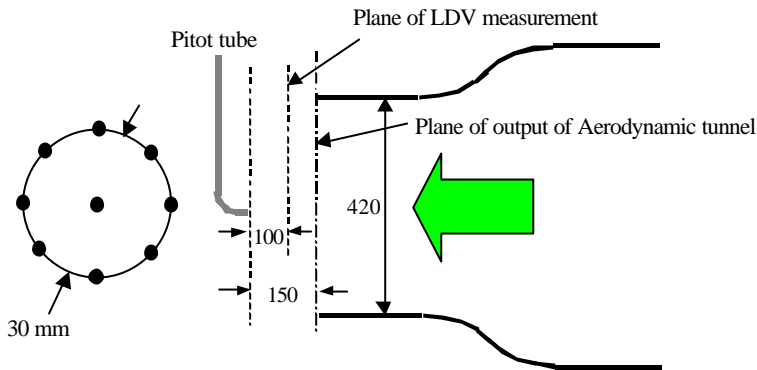


Figure 8: Location of velocity measurements

For each position, the following measurements are kept :

- Air velocity by the LDV equipment and the standard deviation (RMS)
- Probe parameter.
- Temperature of the air in the output plane of the aerodynamic tunnel.

The following measurement are taken before and after the Pitot tube calibration :

- Atmospheric pressure
- Atmospheric dry bulk temperature
- Atmospheric wet bulk temperature

6.4 INTA Procedure

1. Blockage anemometer surface measurement.
2. LDA, wind tunnel pressure and wind tunnel must be switched on for 10 minutes.
3. Set anemometer inside test chamber.
4. Switch on seeding system.
5. Measure pressure, temperature and humidity laboratory.
6. Run wind tunnel to 1,6 m/s or the first calibration points without the anemometer and measure wind tunnel temperature.
7. Measure wind tunnel speed by LDA and the stagnation pressure without anemometer. Later measure anemometer speed and the stagnation pressure. Go on measuring wind tunnel speed and anemometer speed to achieve 11 LDA data and 10 anemometer data. We must overcome 80 % in validation LDA data.
8. Measure wind tunnel temperature.
9. Repeat step 6 to 8 speeding air velocity up 5, 10, 15, 20,25, 30, 35 and 40 m/s or another calibration points inside its range.
10. Measure pressure, temperature and humidity laboratory.

7. RESULTS AND DISCUSSION

Figures 9, 10, 11 and 12 show results of calibration comparison for Pitot tube and Hot wire anemometer carried out by the four different laboratories. All datae have been corrected to include air density, atmospheric pressure and facility temperature.

Each laboratory applied its own procedures to measure air velocity and process the datae.

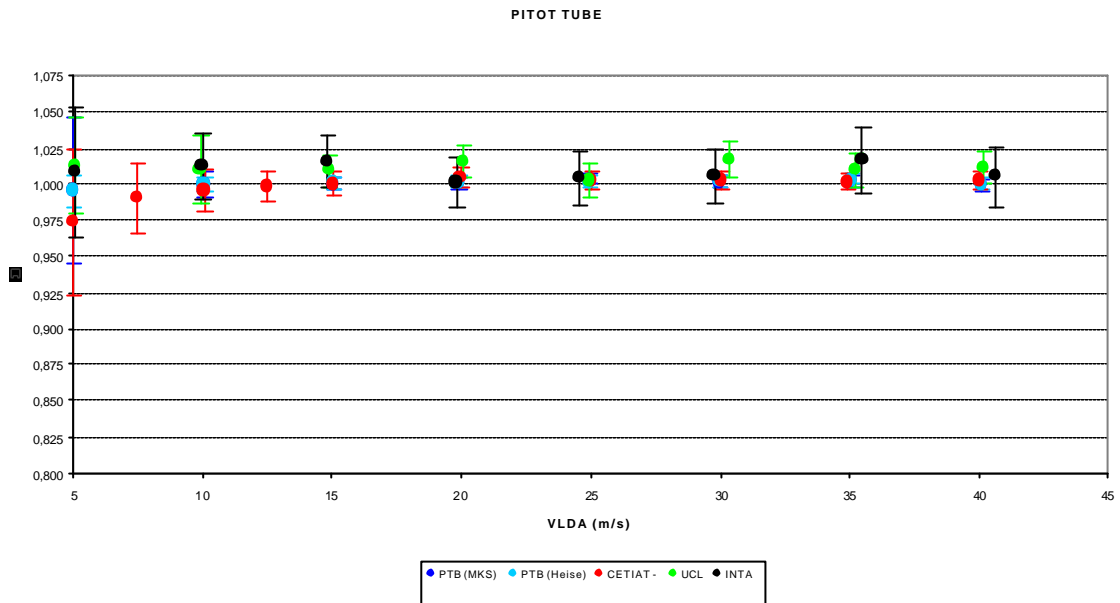


Figura 9: Intercomparison datae Pitot Tube

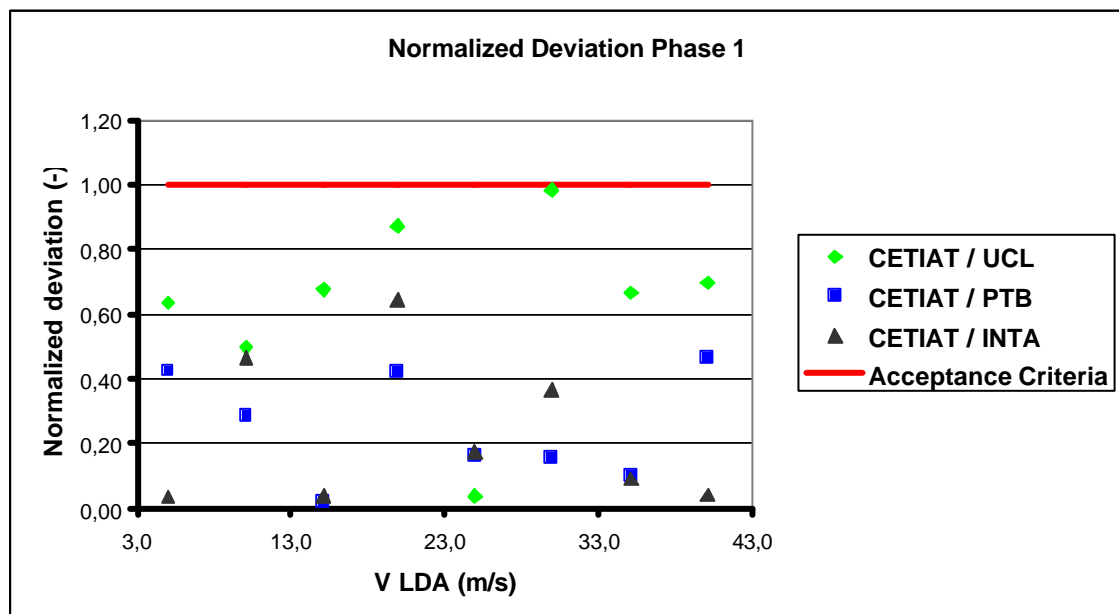


Figura 10:Acceptance criteria Pitot Tube

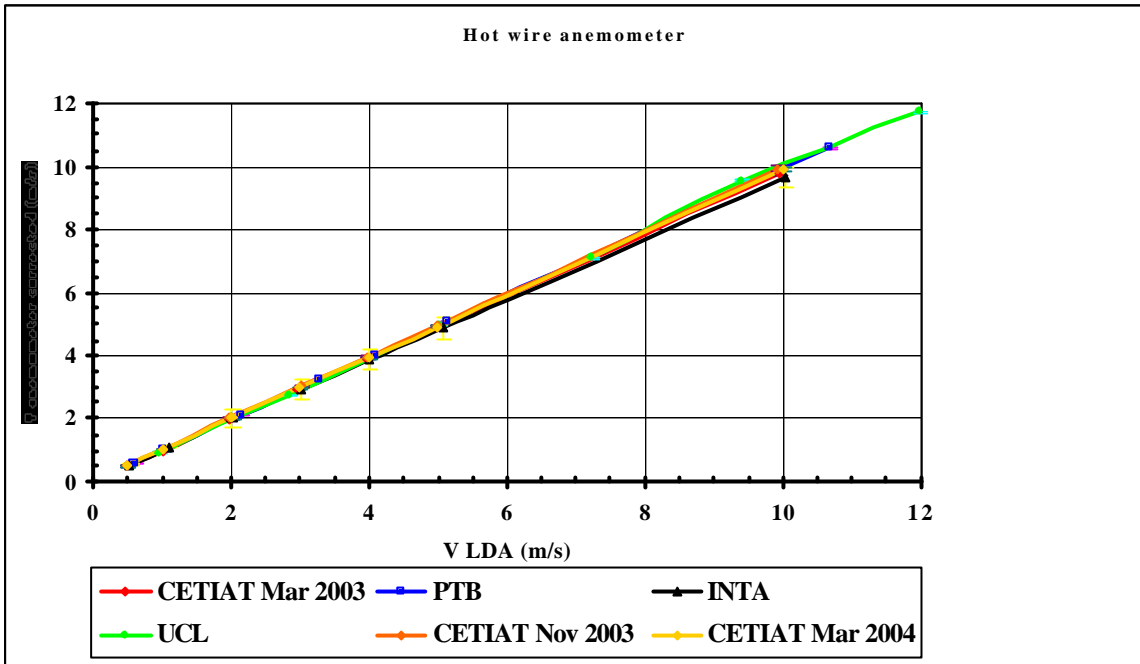
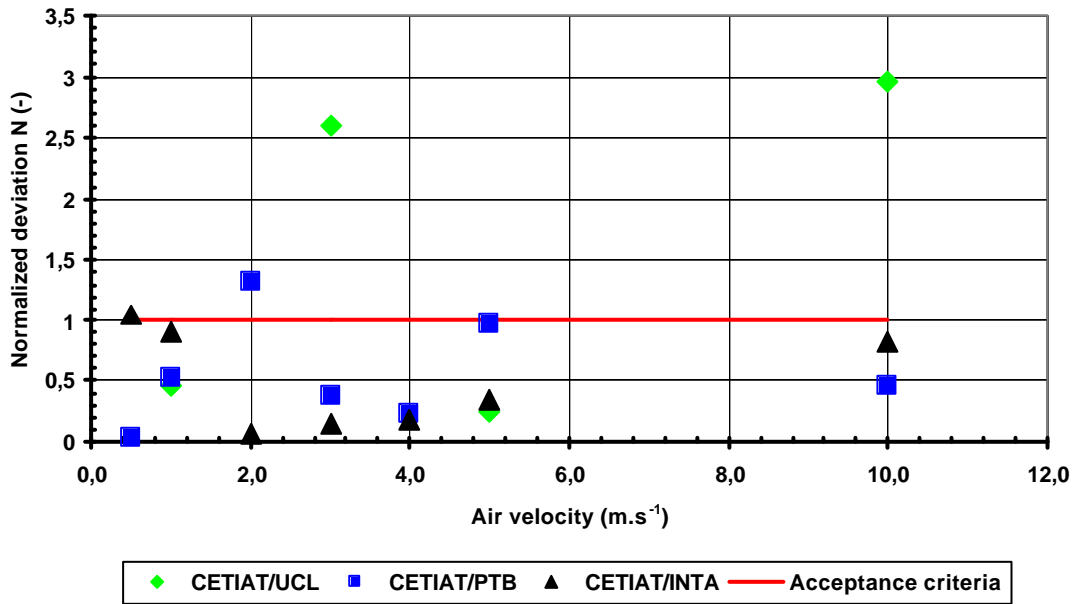


Figura 11: Intercomparison datae Hot wire anemometer



Figura

12:Acceptance criteria Hot wire anemometer

8. SUMMARY

Intercomparison results show a high level of compatibility between the different facilities specially between CETIAT, PTB and INTA. UCL has some differences with the other laboratories.

Differences might be related with :

- seeding product (size, material, etc.),
- procedures used which are not the same,
- temperature and pressure inside laboratories are different than pressure and temperature inside wind tunnels,
- the relative humidities are very different depending on the season and the location of each laboratory,
- the time to carry out one calibration point is short for PTB and CETIAT and long for UCL and INTA.
- The wind tunnels test sections are closed for PTB and CETIAT and open for UCL and INTA

Other points which might be taken into account are the following :

- wind tunnels turbulences and stabilities,
- wind tunnels Reynolds number,

In a further step, an other intercomparison might be carried out by using the same calibration procedure in each laboratory. By this way, we might reduce the differences obtained during the first two phases.

REFERENCES

- Chuang, H.S, (2000). "Development in Microscope Laser Doppler Anemometry on the Studies of Micro-Fluid Velocity Measurements", MS Thesis, NCJU, Tainan, Taiwan.
- Durst, F., Melling, A. and Whitelaw, J.H. (1981). "Principles and Practice of laser-Doppler Anemometry", Academic Press.
- Erdman, J.C. and Tropea, C.D. (1981). "Turbulence-induced Statistical in Laser Anemometers". Proc. 7th Biennial Symp. on Turbulence, Rolla, Missouri.
- Hardalupas, Y., Tagawa, M. and Taylor, A.M.K.P (1996). "Characteristics of Counter-Gradient Heat Transfer in a Non Premixed Swirling Flame". In: , ed. Durst et al., Springer-Verlag, pp. 159-184
- Jabczynski, J.K. (1996). "Novel solid state lasers for optical velocimetry". SPIE Proc. Vol. 2729, pp. 22-30.
- Ladin L., (1987). "Spectrum analysis of LDA signal", Dantec Information, 5, pp. 2-8
- Heinrich L. "EUROMET Project 388 - Intercomparison of anemometers" (1996).
- Rinkevichius B.S., (1998). "Laser Diagnostics in Fluid Mechanics". New York: Begell House Inc. 303 p.
- Yang, C.T., Wu, M.C., and Chuang, H.S. (2001). "Adjustment and Evaluation of an LDA Probe for Accurate Flow Measurement, "Optics & Lasers Technology Review"
- Tolkachev A.V., Gagina N.M., Grechikhin V.A. et al. (1997) "Experimental research of LDA signals from a large particle". In: Laser anemometry. Advances and applications. Eds. B. Ruck, A. Leder, D. Dopheide. Karlsruhe: pp 371-378.
- Yanta, W.J. and Smith, R.A. (1978). "Measurements of Turbulent Transport Properties with a Laser Doppler velocimeter", 11th Aerospace Science Meeting, AIAA paper 73-169, Washington, USA
- "Guide pour l'expression de l'incertitude de mesure " First edition 1993, corrected and reprinted 1995, ISO
- "Expression of the Uncertainty of Measurement in calibration" EAL -4/02, 1999
- "Engineering Analysis of Experimental Data" ASHRAE Guideline 2-1986 (RA 96),
- "Formule pour la détermination de la masse volumique de l'air humide" BIPM 1979.