Final Report

LDA-based intercomparison of anemometers

EURAMET Project No. 827

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Abstract

A regional air speed comparison between six EURAMET laboratories used an ultrasonic anemometer and a laser Doppler anemometer (LDA) at air speeds between 0.2 m/s and 40 m/s. Based on periodic calibrations at the pilot lab (PTB), the uncertainty contributed to the comparison by the LDA was 0.2 % and the uncertainty contributed by the ultrasonic anemometer depended on the air speed and varied between 2.95 % and 0.11 %. The degrees of equivalence between the participants were notably better for the laser Doppler anemometer data than for the ultrasonic anemometer data. For example, using the 95 % chi squared consistency check, 16 of the original 59 participant data points were removed as discrepant from the ultrasonic data set, but only one point was discrepant in the LDA data. A possible explanation is that the LDA is non-intrusive and therefore does not alter the velocity field in the wind tunnel whereas the ultrasonic device does produce blockage effects. The results of this comparison (and prior EURAMET and CIPM comparisons) indicate a need for more attention to blockage effects during air speed calibrations and their effect on air speed uncertainty statements.

1 Introduction

Airspeed measurements are of increasing relevance for efficiency and safety related subject areas for example wind energy and environment including meteorology and occupational health and safety. The application of calibrated anemometers covers a variety of anemometer types and a wide velocity range from below 0,5 m/s up to over 40 m/s. Related to the different types and working principles of anemometers, the calibration results can depend on the specific features of the different calibration facilities and calibration procedures. This experience has already been gained within the EUROMET project 388 “intercomparison of anemometers” with anemometers of different sizes in laboratories with very different instrumentation for the calibration. Referring to this, relatively big deviations in the calibration results were obtained.

Up to now one key comparison CCM.FF-K3 initiated by the CCM Working Group for Fluid Flow with the four participating national metrology institutes NIST (United States), NMi (The Netherlands), NMIJ/AIST (Japan) and PTB (Germany) with NMIJ/AIST as assigned pilot laboratory has been performed. Key reference values have been determined based on the results of an ultrasonic anemometer as transfer standard for the two air speed values 2 m/s and 20 m/s. Required linkages to key comparisons are to be organized by the RMOs. For this the EURAMET project 514 “Intercomparison of anemometer test facilities using thermal anemometers and mechanical anemometers” in the velocity range 0,2 m/s up to 4,5 m/s with NMi (NL) as pilot, reported as “Euromet.M.FF-K3 Euromet Key Comparison for Airspeed Measurements”, will be completed in the velocity range by the EURAMET project 1050 “Comparison of Airspeed measurements at high speeds (2 m/s up to 50 m/s)” with INRiM as pilot laboratory.

The aim of the EURAMET project 827 was to accomplish appropriate pre-conditions for a detailed analysis of calibration results in order to decrease the deviations between calibration laboratories and to reduce the calibration uncertainties for different types of anemometers. The increasing use of Laser Doppler Velocimeter (LDV) systems as velocity standards in different calibration facilities ensures ideal conditions to realize low uncertainties for the representation of the unit “flow velocity” over a wide velocity range.

The main feature of the EURAMET project 827 is the use of a Laser Doppler Anemometer as transfer standard to ensure non-contact and non-reactive comparison measurements in order get a direct information about the degree of equivalence concerning the traceability in each calibration facility. The second transfer standard, a small sized ultrasonic anemometer, serves as conventional anemometer with marginal but not necessarily negligible interactions in the calibration facilities. The covered velocity range from 0,5 m/s up to 40 m/s overlaps the ranges of the comparison measurements carried out up to now.

Furthermore the use of a Laser Doppler anemometer as transfer standard is intended to give a hint for the future choice of appropriate transfer standards to assure the NMI’s best calibration and measurement capabilities (CMC) in range and uncertainty of measurement.

2 List of participants and time schedule

The list of participants initially planned to be involved in the comparison is shown in table 2.1.

Participating Laboratory **Country**	**Address**	**Contact person**
DTI Danish Technological Institute **Denmark**	Teknologisk Institute Kongsvang Allé 29 DK-8000 Aahus C Denmark	John Frederiksen john.frederiksen@teknologisk.dk Tel.: + 45 7220 1235
VSL Van Swinden Laboratorium **Netherlands**	VSL Thijsseweg 11 2629 JA Delft Nederland	Gerard Blom gblom@vsl.nl Tel.: + 31 1529 1765
INRiM **Italy**	DIASP, Politecnico di Torino Duca degli Abruzzi, 24 I10129 TORINO Italy	Pier Giorgio Spazzini P.SPAZZINI@INRIM.IT Tel.: +39 011 0906862
BEV/E+E ELEKTRONIK [1)] Austria	BEV/E+E Langwiesen 7 A-4209 Engerwitzdorf Österreich	Mathias Rohm Mathias.rohm@epluse.at Tel. : +43 7235 605275
UCL [2)] Université catholique de Louvain **Belgium**	UCL TERM-Place du Levant 2 B-1348 Louvain-la-Neuve Belgique	Jean-Marie Seynhaeve Jean-Marie.Seynhaeve@uclouvain.be Tel. : + 32 1047 2233
CETIAT Centre Technique des Industries Aéronauliques et Therniques **France**	CETIAT 27-29, bd du 11 Novembre 1918 BP 2042 – 69603 Villeurbanne Cedex France	Isabelle Care Isabelle.care@cetiat.fr Tel.: + 33 472 44 4992
INTA [3)] Instituto Nacional de Tecnica Aeroespacial **Spain**	INTA Carretera de Ajalvir, km4, 28850 Torrejón de Ardoz Spain	Raffael Bardera barderar@inta.es Tel.: + 34 91 520 1637
LEI Lithuanian Energy Institute **Lithuania**	LEI Breslaujos 3 LT-3035 Kaunas Lithuania	Antanas Pedisius testlab@mail.lei.lt Tel. + 37 037 35 1271
PTB [4)] Physikalisch-Technische Bundesanstalt **Germany**	PTB Bundesalle 100 38116 Braunschweig Germany	Harald Müller harald.mueller@ptb.de Tel.: + 49 531 592 1310

[1)] to become designated institute for airspeed in Austria

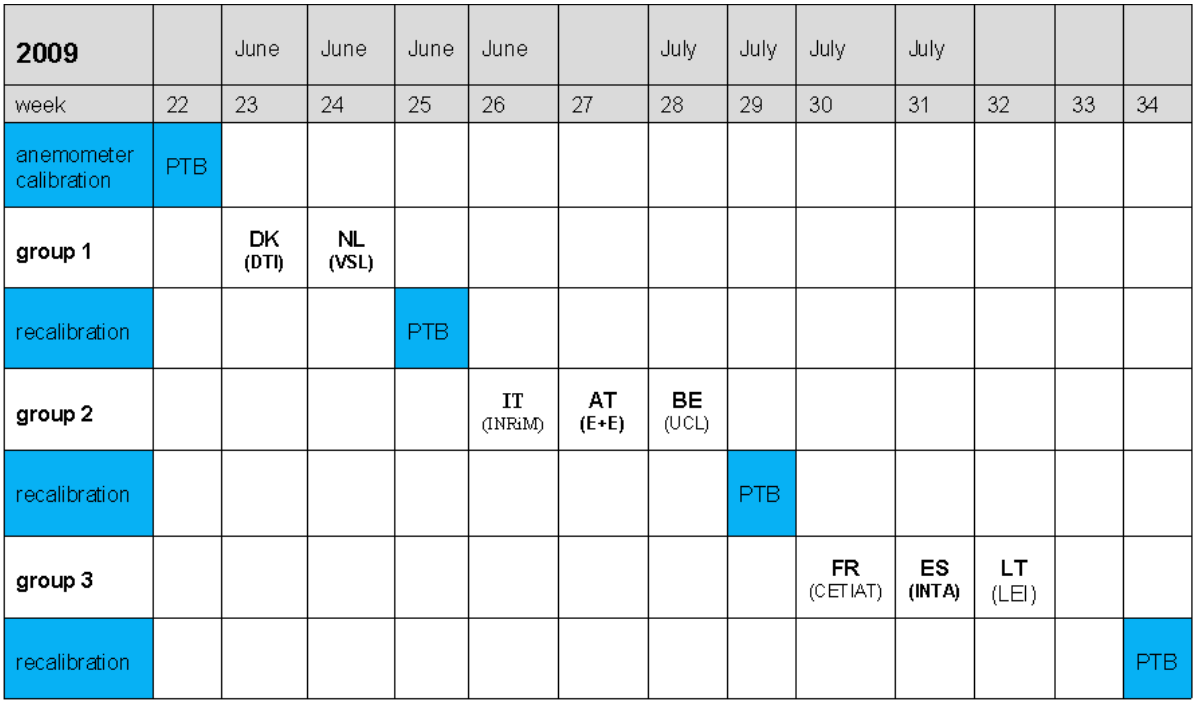
[2)] responsible calibration facility for air speed in Belgium

[3)] no associated laboratory of EURAMET

[4)] pilot laboratory

Table 2.1: List of participants initially planned to be involved in the comparison.

The comparison was performed according to the time schedule shown in table 2 apart from the measurements in “group 3” and the final recalibration at PTB. These activities had to be withdrawn, as the second transfer standard, the ultrasonic anemometer, irretrievably failed after its recalibration at PTB in July 2009.



2009		June	June	June	June		July	July	July	July			
week	22	23	24	25	26	27	28	29	30	31	32	33	34
anemometer calibration	PTB												
group 1		**DK** **(DTI)**	**NL** **(VSL)**										
recalibration				PTB									
group 2					**IT** (INRiM)	**AT** **(E+E)**	**BE** (UCL)						
recalibration								PTB					
group 3									**FR** (CETIAT)	**ES** **(INTA)**	**LT** (LEI)		
recalibration													PTB

Table 2.2: Time schedule of the intercomparison

Packaging and transportation of the transfer standards was carried out by PTB. PTB as pilot laboratory visited each participant by car to ensure safe transportation and consistent operation and reliability of the transfer standards.

Detailed arrangements concerning arrival and measurement time on-site were organized by the pilot laboratory in agreement with each participating laboratory. The operation of the transfer standards on site was carried out by PTB staff and the comparison measurements were performed in cooperation with each participant according to individually applied calibration procedures.

3 Description of the transfer standards

3.1 Laser Doppler Anemometer

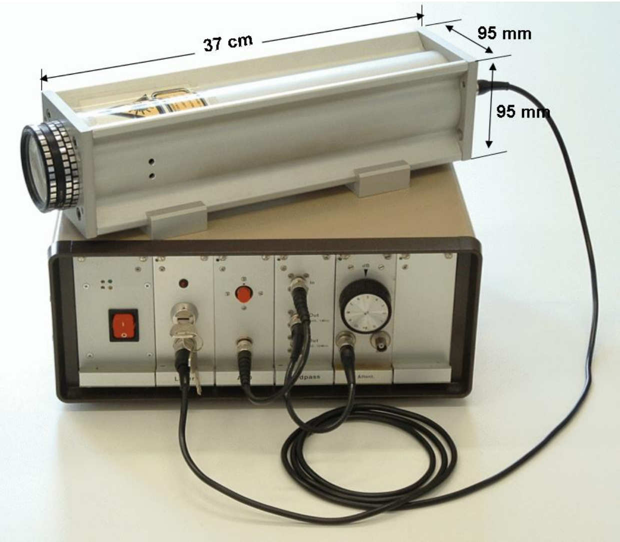
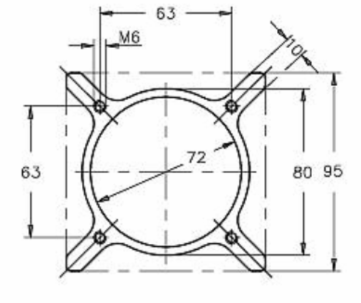
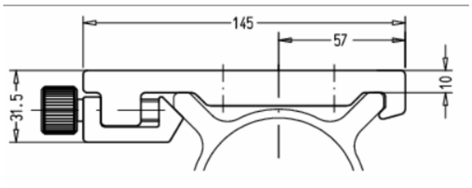


Fig. 3.1.1: Laser Doppler Anemometer:

Specifications of the LDA:	- working distance 40 cm - laser wavelength 852 nm - expanded uncertainty < 0,2%



LDA - housing is compatible to X 95 mounting system (LINOS)



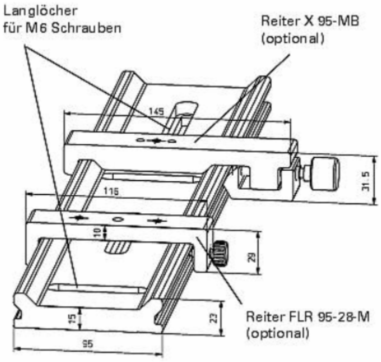


Fig. 3.1.2: Laser Doppler Anemometer mounting capabilities

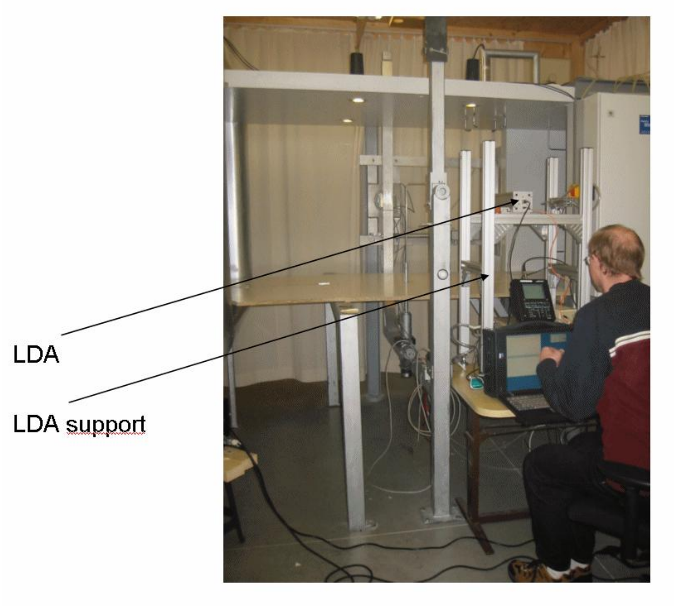


Fig. 3.1.3: LDA and LDA support

A mounting device as shown in figure 3.1.3 allowed where necessary a working height of the measurement position between 0,8 m and 1,2 m. The working distance from the front lens of the LDA was 0,4 m.

3.2 **Ultrasonic Anemometer** (UA6 – Airflow)

The ultrasonic anemometer used as second transfer standard was an Airflow-UA6 with a specially modified slim supporting bar see figure 3.2.1.

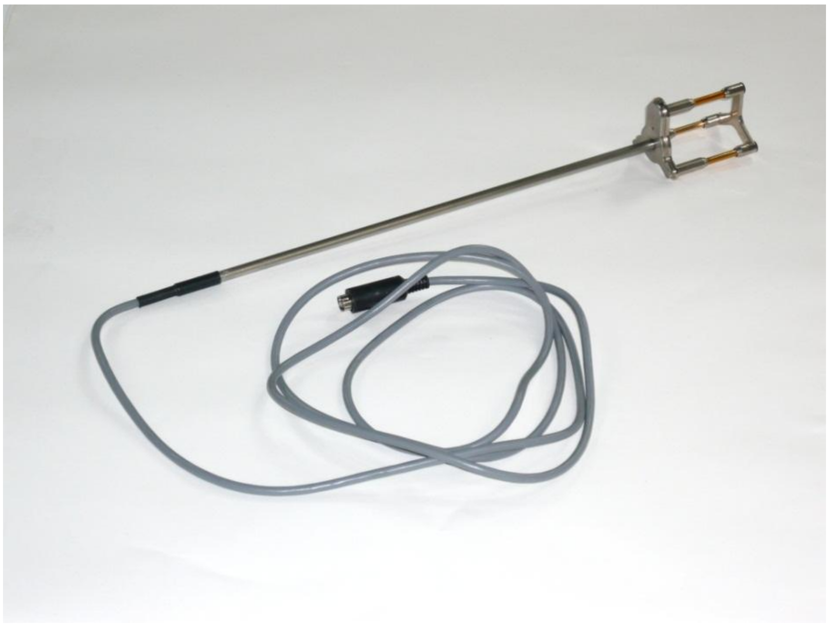


Fig. 3.2.1: Ultrasonic anemometer sensor probe

The geometrical dimensions of the probe which were needed for the mounting devices of the probe in each calibration facility are shown in figure 3.2.2.

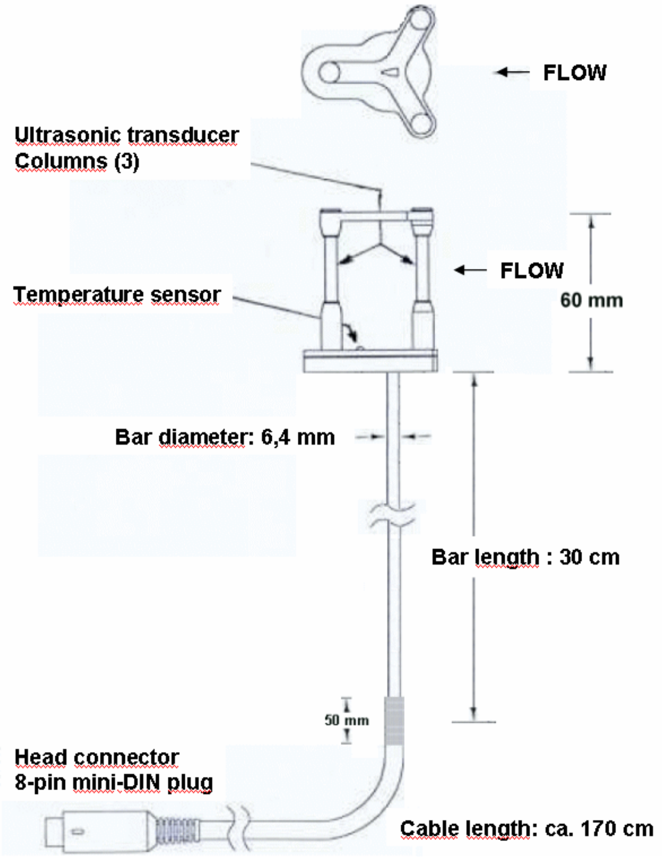


Fig. 3.2.2: Ultrasonic anemometer sensor probe dimensions

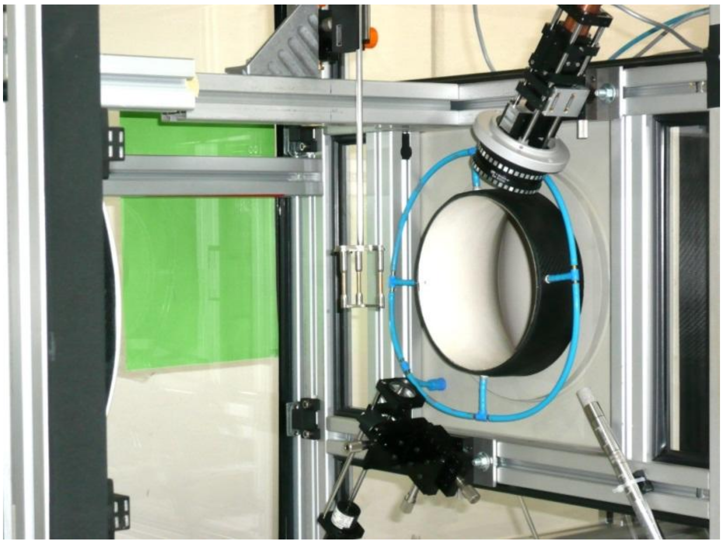
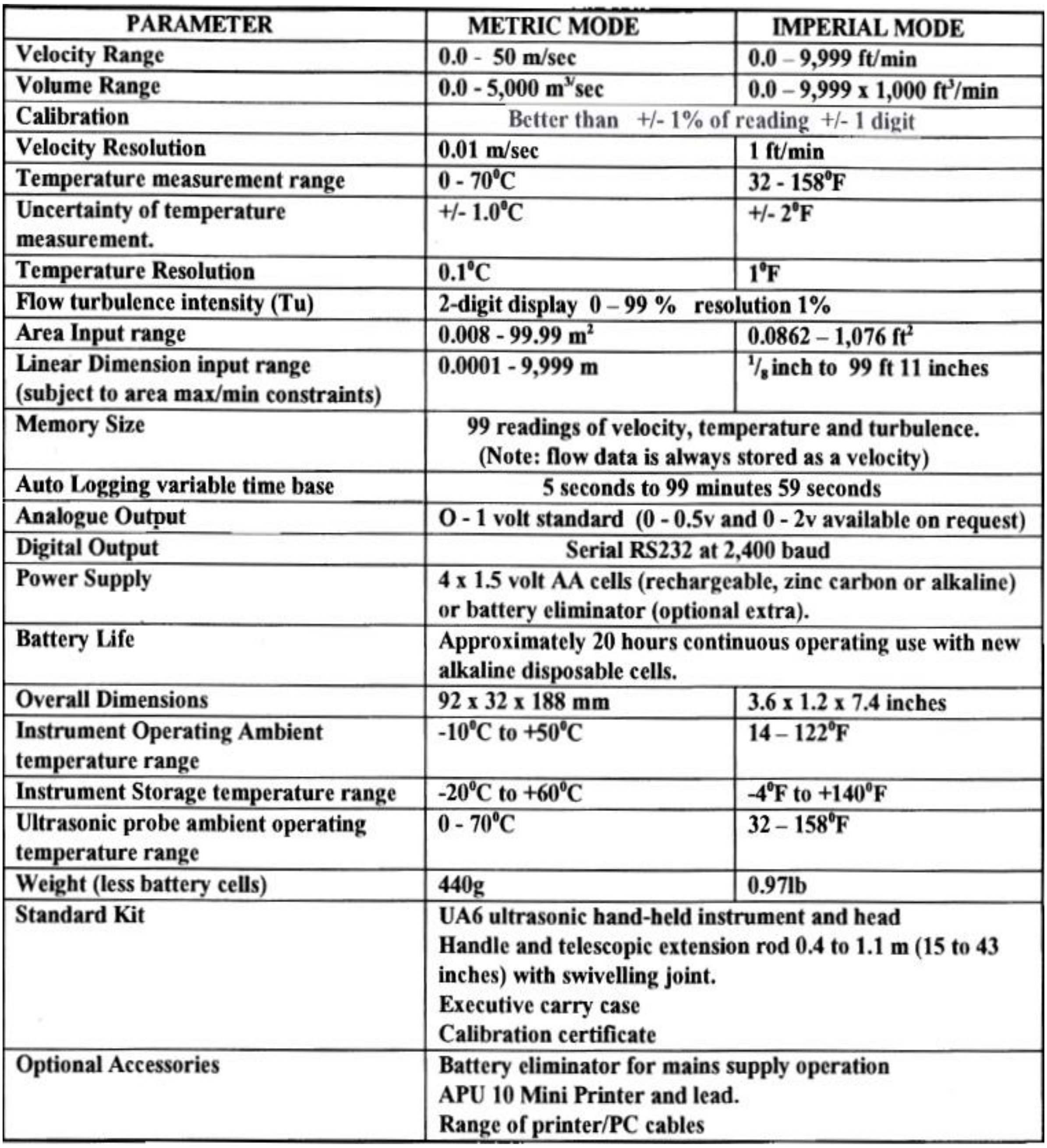


Fig. 3.2.3: Installation example of the ultrasonic anemometer

The specification of the ultrasonic anemometer UA6 are shown in the table below.



PARAMETER	METRIC MODE	IMPERIAL MODE
Velocity Range	0.0 - 50 m/sec	0.0 – 9,999 ft/min
Volume Range	0.0 - 5,000 m^3sec	0.0 – 9,999 x 1,000 ft^3/min
Calibration	Better than +/- 1% of reading +/- 1 digit	
Velocity Resolution	0.01 m/sec	1 ft/min
Temperature measurement range	0 - 70°C	32 - 158°F
Uncertainty of temperature measurement.	+/- 1.0°C	+/- 2°F
Temperature Resolution	0.1°C	1°F
Flow turbulence intensity (Tu)	2-digit display 0 – 99 % resolution 1%	
Area Input range	0.008 - 99.99 m^2	0.0862 – 1,076 ft^2
Linear Dimension input range (subject to area max/min constraints)	0.0001 - 9,999 m	$^1/_8$ inch to 99 ft 11 inches
Memory Size	99 readings of velocity, temperature and turbulence. (Note: flow data is always stored as a velocity)	
Auto Logging variable time base	5 seconds to 99 minutes 59 seconds	
Analogue Output	O - 1 volt standard (0 - 0.5v and 0 - 2v available on request)	
Digital Output	Serial RS232 at 2,400 baud	
Power Supply	4 x 1.5 volt AA cells (rechargeable, zinc carbon or alkaline) or battery eliminator (optional extra).	
Battery Life	Approximately 20 hours continuous operating use with new alkaline disposable cells.	
Overall Dimensions	92 x 32 x 188 mm	3.6 x 1.2 x 7.4 inches
Instrument Operating Ambient temperature range	-10°C to +50°C	14 – 122°F
Instrument Storage temperature range	-20°C to +60°C	-4°F to +140°F
Ultrasonic probe ambient operating temperature range	0 - 70°C	32 – 158°F
Weight (less battery cells)	440g	0.97lb
Standard Kit	UA6 ultrasonic hand-held instrument and head Handle and telescopic extension rod 0.4 to 1.1 m (15 to 43 inches) with swivelling joint. Executive carry case Calibration certificate	
Optional Accessories	Battery eliminator for mains supply operation APU 10 Mini Printer and lead. Range of printer/PC cables	

Table 3: Specifications of the ultrasonic anemometer UA6

3.3 Operation of the transfer standards

Both transfer standards were operated by colleagues of the pilot laboratory during the comparison measurements on site.

4 Measurement procedure

In each calibration facility two series of comparison measurements were performed successively, one with the LDA and one with the ultrasonic anemometer as transfer standard. For both of the comparison measurement series the probe volume of the transfer standard was placed at the measurement position used for anemometer calibrations according to the procedure applied in each laboratory.

A velocity range from 0,2 m/s up to 40 m/s with the individual air speed values: 0,2 m/s, 0,5 m/s, 1,0 m/s, 2,0 m/s, 5,0 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s, 30 m/s, 35 m/s, 40 m/s was considered and each laboratory was advised to realize its maximal operating range.

For each adjusted air speed ten reference air speed values v_{ref} were allocated to the velocity values v_{ts} simultaneously measured with the used transfer standard. In the case of the LDA as transfer standard one velocity value results from several hundred burst signals depending on the achieved data rate. In the case of the ultrasonic anemometer each velocity value has been calculated as mean value of the anemometer readings recorded within the given measurement time. The measurement time for each velocity value was in general approximately one minute.

5 Measurement results

For each velocity value the measurement result x_i, reported by laboratory i, is presented as the ratio of the laboratory reference air speed to the averaged air speed measured by the transfer standard. Each value x_i represents the mean value of ten measurement series simultaneously recorded for the reference velocity and the transfer standard.

The uncertainty of measurement is calculated from the uncertainty of the reference value given by every participant for each velocity value and the uncertainty of measurement resulting from the measurements with the transfer standards including type A and type B contributions. The type B contribution for the ultrasonic anemometer (see table 4a) has been merged from its resolution stated by the manufacturer and its stability having been estimated from the recalibration measurements at PTB. For the LDA transfer standard adjustment and recalibration after each tour ensured a stability within the calibration uncertainty (see table 4b).

v/(m/s)	$U\,(k=2)_{\mathrm{UA6}}$/%
0,2	2,95
0,5	1,62
1	1,03
2	0,56
5	0,19
10	0,11
15	0,36
20	0,36
25	0,55
30	0,64
35	0,95
40	1,05

a) UA6

v/(m/s)	$U\,(k=2)_{\mathrm{LDA}}$/%
0,2	0,20
0,5	0,20
1	0,20
2	0,20
5	0,20
10	0,20
15	0,20
20	0,20
25	0,20
30	0,20
35	0,20
40	0,20

b) LDA

Table 4: Type B uncertainties of the ultrasonic anemometer UA6 and the LDA transfer standard considering their stability during the comparison measurements.

5.1 Ultrasonic anemometer as transfer standard

Table 5.1 and figure 5.1 show the comparison results based on the ultrasonic anemometer UA6 .

v / (m/s)	DK		NL		IT		AT		BE		DE	
	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)
0,20			1,1528	0,1410							1,2819	0,0553
0,50	1,1434	0,0241	1,1227	0,0451			1,1835	0,0312	1,1182	0,0291	1,1079	0,0304
1,00	1,0858	0,0127	1,1025	0,0144			1,1134	0,0196	1,0766	0,0265	1,1008	0,0172
2,00	1,0275	0,0078	1,0627	0,0115	1,0464	0,0125	1,0447	0,0131	1,0159	0,0154	1,0426	0,0135
5,00	0,9869	0,0049	1,0055	0,0102	1,0137	0,0084	1,0001	0,0096	0,9938	0,0064	1,0101	0,0080
10,00	0,9928	0,0047	1,0215	0,0101	1,0174	0,0083	1,0090	0,0089	1,0082	0,0113	1,0223	0,0073
15,00	0,9822	0,0059	1,0000	0,0106	1,0097	0,0087	1,0039	0,0093	0,9993	0,0066	1,0196	0,0064
20,00	0,9809	0,0058	1,0197	0,0106	1,0037	0,0081	0,9981	0,0094	0,9944	0,0066	1,0146	0,0092
25,00	0,9806	0,0072	1,0153	0,0115	0,9969	0,0088	1,0008	0,0105	0,9924	0,0078	1,0091	0,0101
30,00	0,9798	0,0079	1,0105	0,0125			0,9987	0,0112	0,9871	0,0096	1,0062	0,0114
35,00							0,9908	0,0127	0,9971	0,0113	1,0024	0,0127
40,00							0,9886	0,0135			1,0054	0,0125

Table 5.1: Intercomparison result based on the ultrasonic anemometer “UA6”

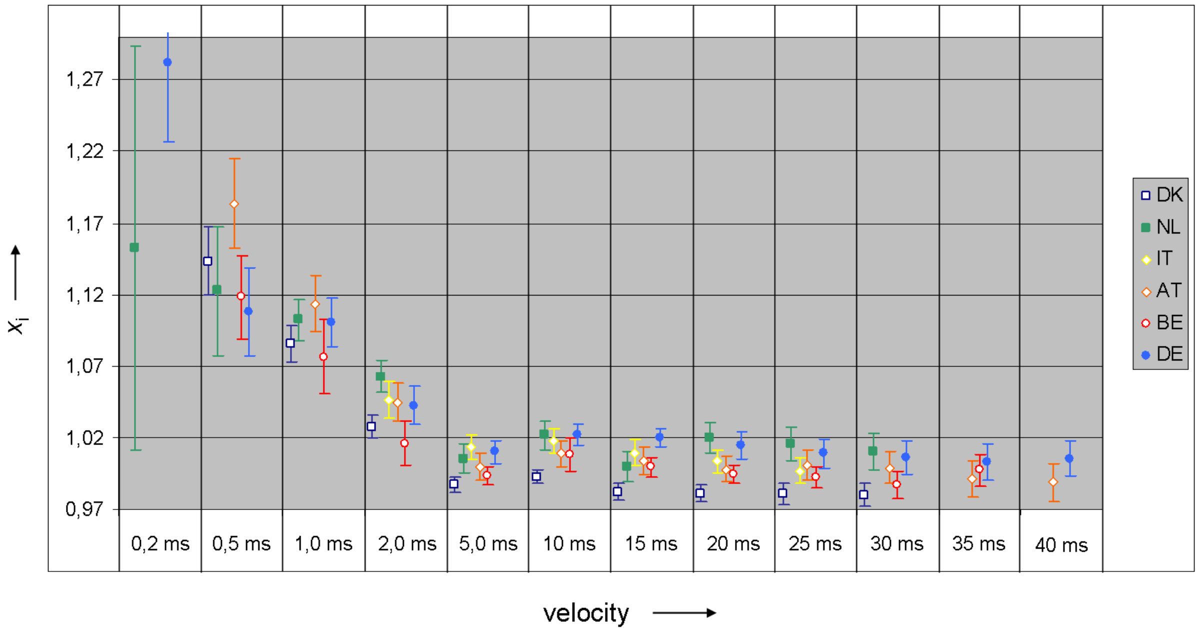


Figure 5.1: Intercomparison result based on the ultrasonic anemometer “UA6” according to table 5.1

The overview in figure 5.1 shows that all comparison measurements match within a range of approximately 2 % but that not all comparison results are equivalent within each other related to the stated uncertainties of the calibration facilities.

A more detailed analysis of the intercomparison results is given in chapter 6 “data evaluation”.

5.2 Laser-Doppler-Anemometer as transfer standard

Table 5.2 and figure 5.2 show the comparison results based on the LDA system as transfer standard.

v / (m/s)	DK		NL		IT		AT		BE		DE	
	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)
0,20			0,9161	0,1340							0,9862	0,0070
0,50	0,9932	0,0127	0,9482	0,0421			0,9960	0,0109	0,9911	0,0127	0,9959	0,0060
1,00	0,9962	0,0076	0,9666	0,0105			0,9956	0,0083	0,9878	0,0177	0,9969	0,0063
2,00	0,9946	0,0056	0,9848	0,0103	0,9967	0,0117	0,9964	0,0071	0,9901	0,0060	0,9937	0,0064
5,00	0,9963	0,0050	0,9823	0,0102	0,9947	0,0081	0,9955	0,0065	0,9962	0,0060	0,9981	0,0045
10,00	0,9957	0,0049	0,9860	0,0102	0,9942	0,0084	0,9958	0,0066	0,9955	0,0055	0,9972	0,0044
15,00	0,9962	0,0050	0,9882	0,0102	0,9921	0,0080	0,9960	0,0066	0,9999	0,0049	0,9976	0,0037
20,00	0,9973	0,0050	0,9886	0,0102	0,9902	0,0071	0,9959	0,0069	0,9965	0,0052	1,0009	0,0050
25,00	0,9990	0,0050	0,9880	0,0102	0,9922	0,0075	0,9958	0,0072	1,0002	0,0050	0,9995	0,0050
30,00	0,9990	0,0050	0,9887	0,0102			0,9959	0,0075	0,9985	0,0048	0,9981	0,0057
35,00			0,9913	0,0102			0,9957	0,0070	0,9992	0,0049	0,9968	0,0050
40,00							0,9964	0,0066			0,9988	0,0043

Table 5.2: Intercomparison result based on the PTB-LDA system

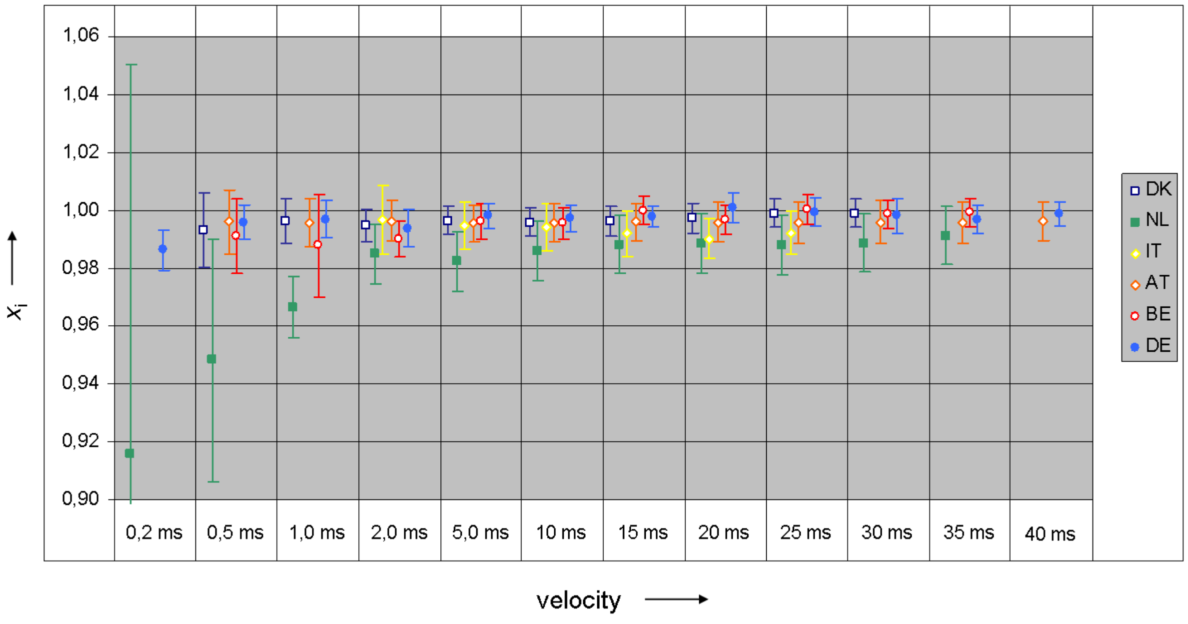


Figure 5.2: Intercomparison result based on PTB-LDA system

The first impression of the results presented in figures 5.1 and 5.2 is that the prevention of interactions in the calibration facilities by using a non contact transfer standard produced a higher degree of equivalence.

The comparison reference values $x_{i,KCVR}$, the uncertainty of the reference value $U(x_{i,KCVR})$, the deviation of each laboratory from the reference value d_i and the degrees of equivalence $d_{i,j}$ between the participating laboratories will be calculated based on Cox´s report.

6 Determination of KCR values and degrees of equivalence

6.1 Description of the method

Reference values based on both of the transfer standards were determined for each velocity value separately. The method of determination for each reference value corresponds to the procedure A presented by Cox.

There reference value $x_{\mathrm{i,\,KCRV}}$ was calculated as weighted mean according to:

$$x_{\mathrm{i,\,KCRV}} = \frac{\dfrac{x_1}{u_{x1}^2} + \dfrac{x_2}{u_{x2}^2} + \ldots\ldots\ldots \dfrac{x_n}{u_{xn}^2}}{\dfrac{1}{u_{x1}^2} + \dfrac{1}{u_{x2}^2} + \ldots\ldots\ldots \dfrac{1}{u_{xn}^2}},$$

where x_1, x_2, ….. x_n are the measurement results in the different laboratories *1, 2, ……n* as presented in chapter 5 table 5.1 and 5.2

u_{x1}, u_{x2},…..u_{xn} are standard uncertainties in the laboratories *1, 2, ……n* (not the expanded value listed in tables 5.1 and 5.2)

The standard uncertainty of the reference value $u_{x\mathrm{i,KCRV}}$ is given by

$$\frac{1}{u_{x\mathrm{i,KCRV}}^2} = \frac{1}{u_1^2} + \frac{1}{u_2^2} + \ldots\ldots\ldots \frac{1}{u_n^2}.$$

The expanded uncertainty of the reference value $U(x_{\mathrm{i,KCRV}})$ is

$$U(x_{\mathrm{i,\,KCRV}}) = 2u_{x\mathrm{i,\,KCRV}}$$

The chi-squared test for consistency check was performed using the measurement results for each velocity value. At first the chi-squared value χ^2_{obs} was calculated by

$$\chi^2_{obs} = \frac{(x_1 - x_{\mathrm{i,\,KCRV}})^2}{u_{x1}^2} + \frac{(x_2 - x_{\mathrm{i,\,KCRV}})^2}{u_{x2}^2} + \ldots\ldots\ldots\,.. \frac{(x_n - x_{\mathrm{i,\,KCRV}})^2}{u_{xn}^2}$$

The degrees of freedom were assigned as $n-1$ where n is the number of evaluated laboratories.

The consistency check was failing if

$$Pr\{\chi^2_{\nu} > \chi^2_{obs}\} < 0{,}05.$$

(The function *CHIINV(0,05;n)* in MS Excel was used. The consistency check was failing if *CHIINV(0,05;n)*< χ^2_{obs})

If the consistency check did not fail then $x_{\mathrm{i,KCRV}}$ was accepted as the key reference value $x_{\mathrm{i,KCVR}}$ and $U(x_{\mathrm{i,KCVR}})$ was accepted as the expanded uncertainty of the key reference value.

If the consistency check failed then the laboratory with the highest value of

$$\frac{\left(x_{\mathrm{i}} - x_{\mathrm{i,\,KCRV}}\right)^2}{u_{x_i}^2}$$

was excluded for the next round of evaluation and the new reference value, the new standard uncertainty of the reference value and the chi-squared value χ^2_{obs} were calculated again without the values of excluded laboratory. This procedure was repeated till the consistency check passed. When the consistency check passed, for each value x_{i} the degree of equivalence d_{i} between each laboratory and the key reference value $x_{\mathrm{i,KCRV}}$ was calculated

$$d_{\mathrm{i}} = x_{\mathrm{i}} - x_{\mathrm{i,KCRV}}$$

Then $U(d_{\mathrm{i}})$ was calculated.

$$U(d_{\mathrm{i}}) = 2 * \sqrt{u_{\mathrm{xi}}^2 - u_{\mathrm{xi,KCRV}}^2}$$

The degrees of equivalence are indicated in table 6.2.4 for the ultrasonic meter as transfer standard and in table 6.3.4 for the LDA transfer standard. The red colour indicates that

$$U(d_{\mathrm{i}}) < |d_{\mathrm{i}}|$$

corresponding to $|Ei| > 1$ (see below).

The degrees of equivalence between the laboratories have been determined according to the formulas:

$$d_{\mathrm{i,j}} = x_{\mathrm{i}} - x_{\mathrm{j}}$$

and

$$U(d_{\mathrm{ij}}) = 2 * u(d_{\mathrm{ij}})$$

with

$$u^2(d_{\mathrm{ij}}) = u^2(x_{\mathrm{i}}) + u^2(x_{\mathrm{j}})$$

The following tables 6.2.7 and 6.3.5 show the degrees of equivalence between the laboratories for each velocity. The red colour indicates that $U_{\mathrm{ij}} < d_{\mathrm{ij}}$.

The information given by the often calculated coefficients E_{i}

$$E_{\mathrm{i}} = \frac{d_{\mathrm{i}}}{U(d_{\mathrm{i}})}$$

stating that a laboratory passed if $|E_i| \leq 1$ and failed if $|E_i| > 1$ is congruent with the information given in the tables 6.2.4 and 6.3.4.

6.2 Ultrasonic anemometer transfer standard

6.2.1 Determination of the KCRV

According to the Cox procedure the data based on the UA6 ultrasonic anemometer transfer standard have been analysed and the KCRV has been determined. The chi-square test has been performed to find a consistent subset of comparison data for each velocity value. If the test failed, the successive exclusion of the largest inconsistency was applied (see 6.1). Considering the data presented in table 5.1 one gets:

airspeed	DK	NL	IT	AT	BE	DE	sum			
[m/s]	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	n	CHIINV(0,05;n-1)	passed
0,2		5,447				5,447	10,89	2	3,84	no
0,5	0,451	0,688		9,554	1,386	3,254	15,33	5	9,49	no
1,0	2,375	0,652		3,311	2,047	0,376	8,76	5	9,49	yes
2,0	6,814	13,573	1,924	1,120	7,987	0,515	31,93	6	11,07	no
5,0	19,834	3,535	13,968	0,198	1,669	9,193	48,40	6	11,07	no
10,0	41,353	14,029	5,267	0,060	0,004	15,780	76,49	6	11,07	no
15,0	41,120	0,082	4,002	0,405	0,248	34,359	80,22	6	11,07	no
20,0	32,586	23,142	2,324	0,015	0,871	13,655	72,59	6	11,07	no
25,0	18,775	14,327	0,030	0,764	0,957	6,537	41,39	6	11,07	no
30,0	11,385	9,277		1,018	1,554	5,273	28,51	5	9,49	no
35,0				0,872	0,003	0,773	1,65	3	5,99	yes
40,0				1,810		1,550	3,36	2	3,84	yes

Table 6.2.1: UA6 results of the Chi-squared test, round 1

In the first round only the data for the velocity values 1 m/s, 35 m/s and 40 m/s passed the chi-square test. For the velocity of 0,2 m/s a key comparison reference value could not be determined. After eliminating the data of the laboratories with the highest chi-square value for each airspeed value which did not pass the test (marked red) one gets:

airspeed	DK	NL	IT	AT	BE	DE	sum			
[m/s]	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	n	CHIINV(0,05;n-1)	passed
0,2										no result
0,5	2,202	0,035			0,255	1,348	3,84	4	7,81	yes
1,0	2,375	0,652		3,311	2,047	0,376	8,76	5	9,49	yes
2,0	2,888		3,826	2,568	5,587	1,550	16,42	5	9,49	no
5,0		0,238	5,807	0,518	9,252	2,687	18,50	5	9,49	no
10,0		1,330	0,001	3,495	2,573	1,904	9,30	5	9,49	yes
15,0		4,236	0,500	0,337	4,911	16,732	26,72	5	9,49	no
20,0		11,286	0,018	1,708	8,813	5,036	26,86	5	9,49	no
25,0		7,587	1,012	0,014	5,375	2,329	16,32	5	9,49	no
30,0		3,801		0,012	6,507	1,440	11,76	4	7,81	no
35,0				0,872	0,003	0,773	1,65	3	5,99	yes
40,0				1,810		1,550	3,36	2	3,84	yes

Table 6.2.2: UA6 results of the Chi-squared test, round 2

After the second round 58 % of the velocity values failed the test. Eliminating again the data of the laboratories with the highest chi-square value for each airspeed value, in this case data from VSL (NL), UCL (BE) and PTB (DE) already 75 % of the airspeed data passed the test (see table 6.2.3).

airspeed [m/s]	DK chi sqr	NL chi sqr	IT chi sqr	AT chi sqr	BE chi sqr	DE chi sqr	sum chi sqr	n	CHIINV(0,05;n-1)	passed
0,2										no result
0,5	2,202	0,035			0,255	1,348	3,84	4	7,81	yes
1,0	2,375	0,652		3,311	2,047	0,376	8,76	5	9,49	yes
2,0	5,179		2,547	1,583		0,831	10,14	4	7,81	no
5,0		0,327	1,961	2,578		0,336	5,20	4	7,81	yes
10,0		1,330	0,001	3,495	2,573	1,904	9,30	5	9,49	yes
15,0		0,449	2,961	0,139	0,756		4,30	4	7,81	yes
20,0			0,357	0,458	4,285	8,323	13,42	4	7,81	no
25,0			0,134	0,176	2,534	4,347	7,19	4	7,81	yes
30,0		0,907		1,278		0,041	2,23	3	5,99	yes
35,0				0,872	0,003	0,773	1,65	3	5,99	yes
40,0				1,810		1,550	3,36	2	3,84	yes

Table 6.2.3: UA6 results of the Chi-squared test, round 3

Again the data corresponding to the highest chi-square values for the velocities which did not pass were eliminated in round 4 of the rest. Now all data passed the test except for 0,2 m/s, where based on inconsistent data of only two participants no result was determined (see table 6.2.4).

airspeed [m/s]	DK chi sqr	NL chi sqr	IT chi sqr	AT chi sqr	BE chi sqr	DE chi sqr	sum chi sqr	n	CHIINV(0,05;n-1)	passed
0,2										no result
0,5	2,202	0,035			0,255	1,348	3,84	4	7,81	yes
1,0	2,375	0,652		3,311	2,047	0,376	8,76	5	9,49	yes
2,0			0,080	0,000		0,093	0,17	3	5,99	yes
5,0		0,327	1,961	2,578	0,000	0,336	5,20	4	7,81	yes
10,0		1,330	0,001	3,495	2,573	1,904	9,30	5	9,49	yes
15,0		0,449	2,961	0,139	0,756		4,30	4	7,81	yes
20,0			1,892	0,000	1,246		3,14	3	5,99	yes
25,0			0,134	0,176	2,534	4,347	7,19	4	7,81	yes
30,0		0,907		1,278		0,041	2,23	3	5,99	yes
35,0				0,872	0,003	0,773	1,65	3	5,99	yes
40,0				1,810		1,550	3,36	2	3,84	yes

Table 6.2.4: UA6 results of the Chi-squared test, round 4

Thus it was possible to determine key comparison reference values for 92 % of the given nominal velocity values covering the velocity range from 0,5 m/s up to 40 m/s and based on the remaining 71 % of the original input data.

The KCRV values determined according to the data which passed the chi-squared test (see table 6.2.4) are listed in the table 6.2.5 and presented in figure 6.2.1.

	DK		NL		IT		AT		BE		DE		**KCRV**	
v /(m/s)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	**x_i**	**U (k=2)**
0,20														
0,50	1,1434	0,0241	1,1227	0,0451					1,1182	0,0291	1,1079	0,0304	**1,1256**	**0,0140**
1,00	1,0858	0,0127	1,1025	0,0144			1,1134	0,0196	1,0766	0,0265	1,1008	0,0172	**1,0956**	**0,0077**
2,00					1,0464	0,0125	1,0447	0,0131			1,0426	0,0135	**1,0447**	**0,0075**
5,00			1,0055	0,0102	1,0137	0,0084	1,0001	0,0096			1,0101	0,0080	**1,0078**	**0,0042**
10,00			1,0215	0,0101	1,0174	0,0083	1,0090	0,0089	1,0082	0,0113	1,0223	0,0073	**1,0173**	**0,0037**
15,00			1,0000	0,0106	1,0097	0,0087	1,0039	0,0093	0,9993	0,0066			**1,0021**	**0,0037**
20,00					1,0037	0,0081	0,9981	0,0094	0,9944	0,0066			**0,9981**	**0,0045**
25,00					0,9969	0,0088	1,0008	0,0105	0,9924	0,0078	1,0091	0,0101	**0,9986**	**0,0046**
30,00			1,0105	0,0125			0,9987	0,0112			1,0062	0,0114	**1,0051**	**0,0066**
35,00							0,9908	0,0127	0,9971	0,0113	1,0024	0,0127	**0,9968**	**0,0070**
40,00							0,9886	0,0135			1,0054	0,0125	**0,9977**	**0,0091**

Table 6.2.5: Resulting KCRV based on the UA6 transfer standard data

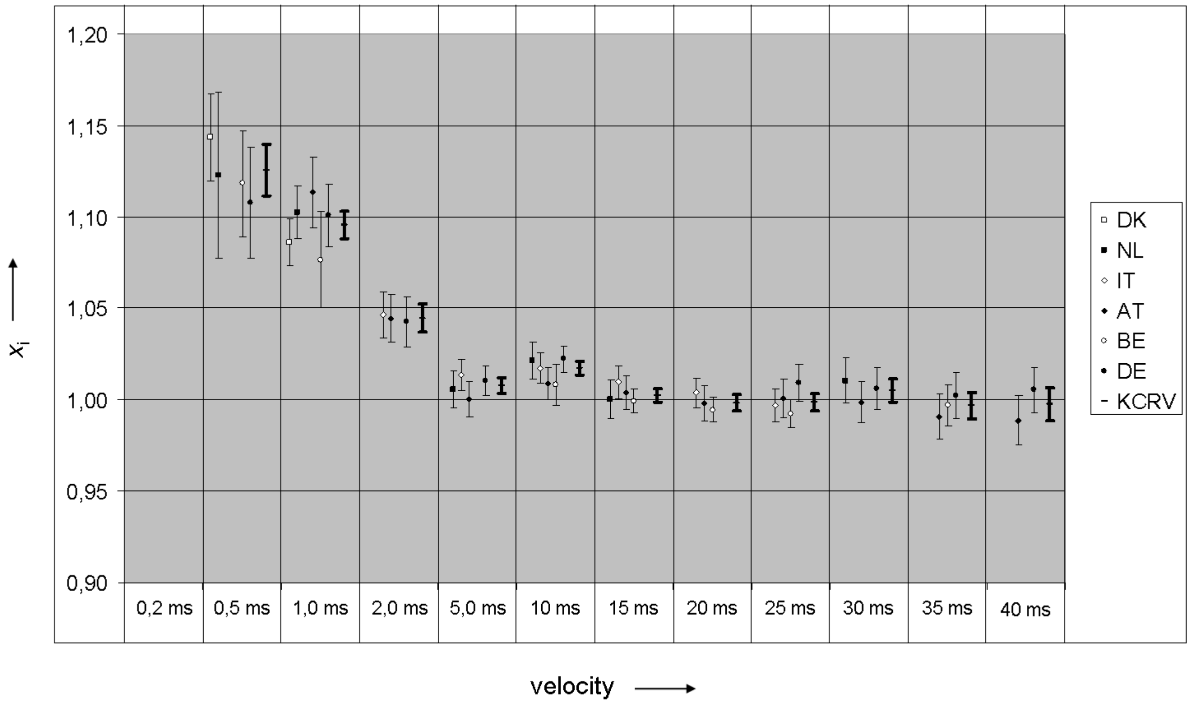


Figure 6.2.1: Resulting KCRV based on the UA6 transfer standard data

6.2.2 Degree of equivalence

Table 6.2.6 indicates the degree of equivalence between each laboratory and the KCRVs according to the comparison measurement data in table 6.2.5 and the method described in chapter 6.1. The red colour indicates that $|d_i| > U(d_i)$.

$\lvert d_i\rvert > U(d_i)$	DK		NL		IT		AT		BE		DE	
v/(m/s)	$\lvert d_i\rvert = \lvert x_i - x_{i,KCRV}\rvert$	$U(d_i)$	$\lvert d_i\rvert = \lvert x_i - x_{i,KCRV}\rvert$	$U(d_i)$	$\lvert d_i\rvert = \lvert x_i - x_{i,KCRV}\rvert$	$U(d_i)$	$\lvert d_i\rvert = \lvert x_i - x_{i,KCRV}\rvert$	$U(d_i)$	$\lvert d_i\rvert = \lvert x_i - x_{i,KCRV}\rvert$	$U(d_i)$	$\lvert d_i\rvert = \lvert x_i - x_{i,KCRV}\rvert$	$U(d_i)$
0,2												
0,5	0,0178	0,0195	0,0028	0,0429					0,0073	0,0255	0,0177	0,0270
1	0,0098	0,0101	0,0069	0,0122			0,0179	0,0181	0,0190	0,0254	0,0053	0,0154
2					0,0018	0,0100	0,0000	0,0107			0,0021	0,0113
5			0,0023	0,0093	0,0059	0,0073	0,0077	0,0086			0,0023	0,0068
10			0,0042	0,0094	0,0001	0,0074	0,0083	0,0081	0,0091	0,0107	0,0050	0,0063
15			0,0021	0,0100	0,0075	0,0079	0,0017	0,0085	0,0029	0,0054		
20					0,0056	0,0067	0,0000	0,0083	0,0037	0,0048		
25					0,0016	0,0076	0,0022	0,0095	0,0062	0,0063	0,0106	0,0090
30			0,0054	0,0106			0,0063	0,0091			0,0012	0,0094
35							0,0059	0,0106	0,0003	0,0088	0,0056	0,0106
40							0,0091	0,0099			0,0078	0,0085

Table 6.2.6: Degree of equivalence to the KCRV according to table 6.2.5

Table 6.2.7 includes for each velocity value a table with the degrees of equivalence between the laboratories where the red colour indicates that $|d_{ij}| > U_{ij}$.

0,5 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			0,021	0,051					0,025	0,038	0,036	0,039
NL	-0,021	0,051							0,004	0,054	0,015	0,054
IT												
AT												
BE	-0,025	0,038	-0,004	0,054							0,010	0,042
DE	-0,036	0,039	-0,015	0,054					-0,010	0,042		

1,0 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			-0,02	0,02			-0,03	0,02	0,01	0,03	-0,02	0,02
NL	0,02	0,02					-0,01	0,02	0,03	0,03	0,00	0,02
IT												
AT	0,03	0,02	0,01	0,02					0,04	0,03	0,01	0,03
BE	-0,01	0,03	-0,03	0,03			-0,04	0,03			-0,02	0,03
DE	0,02	0,02	0,00	0,02			-0,01	0,03	0,02	0,03		

2,0 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL												
IT							0,002	0,018			0,004	0,018
AT					-0,002	0,018					0,002	0,019
BE												
DE					-0,004	0,018	-0,002	0,019				

5,0 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL					-0,008	0,013	0,005	0,014			-0,005	0,013
IT			0,008	0,013			0,014	0,013			0,004	0,012
AT			-0,005	0,014	-0,014	0,013					-0,010	0,013
BE												
DE			0,005	0,013	-0,004	0,012	0,010	0,013				

10 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL					0,004	0,013	0,013	0,013	0,013	0,015	-0,001	0,012
IT			-0,004	0,013			0,008	0,012	0,009	0,014	-0,005	0,011
AT			-0,013	0,013	-0,008	0,012			0,001	0,014	-0,013	0,012
BE			-0,013	0,015	-0,009	0,014	-0,001	0,014			-0,014	0,013
DE			0,001	0,012	0,005	0,011	0,013	0,012	0,014	0,013		

15 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL					-0,010	0,014	-0,004	0,014	0,001	0,013		
IT			0,010	0,014			0,006	0,013	0,010	0,011		
AT			0,004	0,014	-0,006	0,013			0,005	0,011		
BE			-0,001	0,013	-0,010	0,011	-0,005	0,011				
DE												

20 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL												
IT							0,006	0,012	0,009	0,010		
AT					-0,006	0,012			0,004	0,011		
BE					-0,009	0,010	-0,004	0,011				
DE												

25 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL												
IT							-0,004	0,014	0,005	0,012	-0,012	0,013
AT					0,004	0,014			0,008	0,013	-0,008	0,015
BE					-0,005	0,012	-0,008	0,013			-0,017	0,013
DE					0,012	0,013	0,008	0,015	0,017	0,013		

30 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL							0,012	0,017			0,004	0,017
IT												
AT			-0,012	0,017							-0,007	0,016
BE												
DE			-0,004	0,017			0,007	0,016				

35 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL												
IT												
AT									-0,006	0,017	-0,012	0,018
BE							0,006	0,017			-0,005	0,017
DE							0,012	0,018	0,005	0,017		

40 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL												
IT												
AT											-0,017	0,018
BE												
DE							0,017	0,018				

Table 6.2.7: Degree of equivalence between laboratories for each velocity value

6.3 LDA transfer standard

6.3.1 Determination of the KCRV

According to Cox the data based on the use of the LDA transfer standard have been analysed and the KCRV has been determined. To evaluate the consistency of the data the chi-squared test has been performed.

airspeed [m/s]	DK chi sqr	NL chi sqr	IT chi sqr	AT chi sqr	BE chi sqr	DE chi sqr	sum chi sqr	n	CHIINV(0,05;n-1)	passed
0,2		1,089				0,003	1,09	2	3,84	yes
0,5	0,037	4,828		0,088	0,283	0,242	5,48	5	9,49	yes
1,0	1,219	23,570		0,702	0,238	2,369	28,10	5	9,49	no
2,0	0,322	2,565	0,379	0,908	0,977	0,042	5,19	6	11,07	yes
5,0	0,058	6,933	0,068	0,008	0,023	1,065	8,15	6	11,07	yes
10,0	0,009	3,415	0,095	0,009	0,000	0,647	4,18	6	11,07	yes
15,0	0,046	2,798	1,374	0,048	1,592	0,228	6,09	6	11,07	yes
20,0	0,110	2,353	3,196	0,027	0,000	3,177	8,86	6	11,07	yes
25,0	0,291	3,602	2,121	0,279	1,002	0,536	7,83	6	11,07	yes
30,0	0,319	3,028		0,189	0,163	0,032	3,73	5	9,49	yes
35,0		1,292		0,143	0,794	0,007	2,24	4	7,81	yes
40,0				0,260		0,109	0,37	2	3,84	yes

Table 6.3.1: Results of the Chi-squared test, round 1

As can be seen in table 6.3.1 over 90 % of the results based on the measurements with the LDA transfer standard passed the test in the first round. After eliminating the result with the highest chi-square value for the measurement point which did not pass the test, all data passed the test already in the second round (see table 6.3.2).

airspeed [m/s]	DK chi sqr	NL chi sqr	IT chi sqr	AT chi sqr	BE chi sqr	DE chi sqr	sum chi sqr	n	CHIINV(0,05;n-1)	passed
0,2		1,089				0,003	1,09	2	3,84	yes
0,5	0,037	4,828		0,088	0,283	0,242	5,48	5	9,49	yes
1,0	0,007			0,008	0,852	0,106	0,97	4	7,81	yes
2,0	0,322	2,565	0,379	0,908	0,977	0,042	5,19	6	11,07	yes
5,0	0,058	6,933	0,068	0,008	0,023	1,065	8,15	6	11,07	yes
10,0	0,009	3,415	0,095	0,009	0,000	0,647	4,18	6	11,07	yes
15,0	0,046	2,798	1,374	0,048	1,592	0,228	6,09	6	11,07	yes
20,0	0,110	2,353	3,196	0,027	0,000	3,177	8,86	6	11,07	yes
25,0	0,291	3,602	2,121	0,279	1,002	0,536	7,83	6	11,07	yes
30,0	0,319	3,028		0,189	0,163	0,032	3,73	5	9,49	yes
35,0		1,292		0,143	0,794	0,007	2,24	4	7,81	yes
40,0				0,260		0,109	0,37	2	3,84	yes

Table 6.3.2: Results of the Chi-squared test, round 2

The KCRV values determined according to the data which passed the chi-squared test (table 6.3.2) are listed in the table 6.3.3 and presented in figure 6.3.1. This result illustrates that the consistency of the comparison results and the achievement of minimum uncertainties of KCR values highly depend on the selection of the transfer standard (ideally non-contact!) provided that the traceability of each participating laboratory is reliable within the stated uncertainties.

v /(m/s)	DK		NL		IT		AT		BE		DE		**KCRV**	
	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	x_i	U (k = 2)	$\mathbf{x_i}$	**U (k = 2)**
0,20			0,9161	0,1340							0,9862	0,0070	**0,9860**	**0,0070**
0,50	0,9932	0,0127	0,9482	0,0421			0,9960	0,0109	0,9911	0,0127	0,9959	0,0060	**0,9944**	**0,0045**
1,00	0,9962	0,0076					0,9956	0,0083	0,9878	0,0177	0,9969	0,0063	**0,9959**	**0,0041**
2,00	0,9946	0,0056	0,9848	0,0103	0,9967	0,0117	0,9964	0,0071	0,9901	0,0060	0,9937	0,0064	**0,9931**	**0,0029**
5,00	0,9963	0,0050	0,9823	0,0102	0,9947	0,0081	0,9955	0,0065	0,9962	0,0060	0,9981	0,0045	**0,9957**	**0,0025**
10,00	0,9957	0,0049	0,9860	0,0102	0,9942	0,0084	0,9958	0,0066	0,9955	0,0055	0,9972	0,0044	**0,9955**	**0,0024**
15,00	0,9962	0,0050	0,9882	0,0102	0,9921	0,0080	0,9960	0,0066	0,9999	0,0049	0,9976	0,0037	**0,9967**	**0,0022**
20,00	0,9973	0,0050	0,9886	0,0102	0,9902	0,0071	0,9959	0,0069	0,9965	0,0052	1,0009	0,0050	**0,9965**	**0,0024**
25,00	0,9990	0,0050	0,9880	0,0102	0,9922	0,0075	0,9958	0,0072	1,0002	0,0050	0,9995	0,0050	**0,9977**	**0,0025**
30,00	0,9990	0,0050	0,9887	0,0102			0,9959	0,0075	0,9985	0,0048	0,9981	0,0057	**0,9975**	**0,0027**
35,00			0,9913	0,0102			0,9957	0,0070	0,9992	0,0049	0,9968	0,0050	**0,9971**	**0,0030**
40,00							0,9964	0,0066			0,9988	0,0043	**0,9981**	**0,0036**

Table 6.3.3: Resulting KCRV based on the LDA transfer standard data

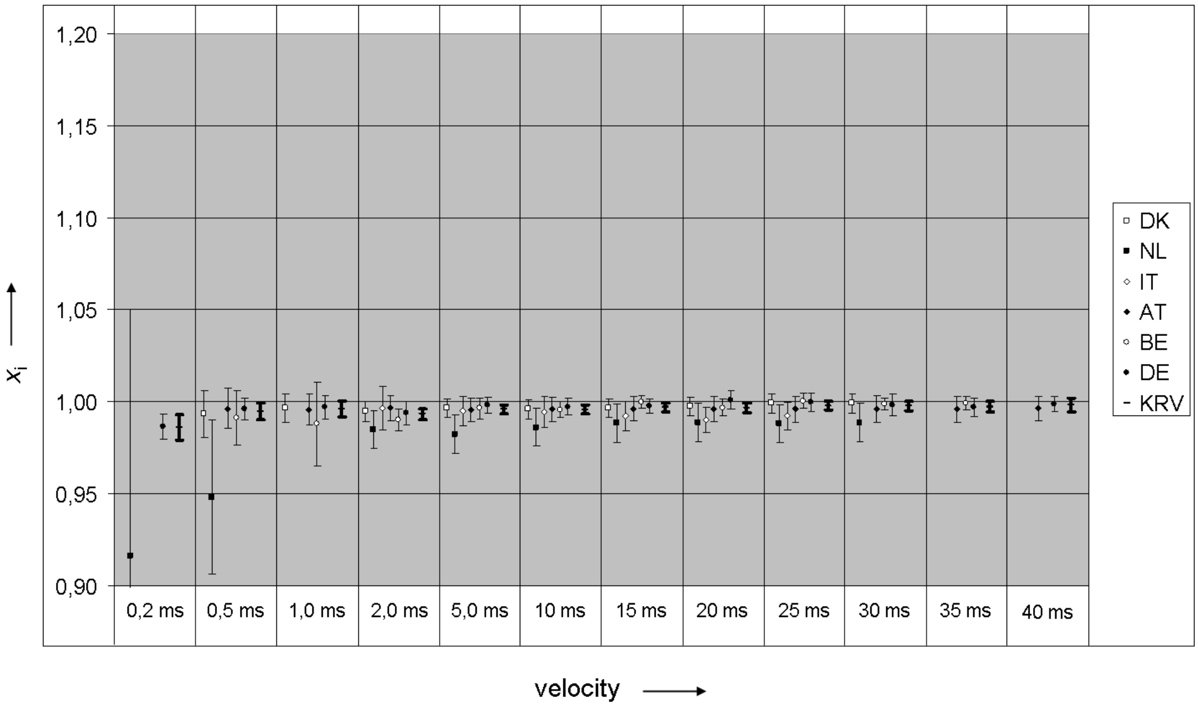


Figure 6.3.1: Resulting KCRV based on the LDA transfer standard data

6.3.2 Degree of equivalence

Table 6.3.4 indicates the degree of equivalence between each laboratory and the KCRVs according to the comparison measurement data in table 6.3.3 and the method described in chapter 6.1. The red colour indicates that $|d_i| > U(d_i)$.

$\lvert d_i\rvert>U(d_i)$	DK		NL		IT		AT		BE		DE	
v/(m/s)	$\lvert d_i\rvert=\lvert x_i-x_{ref}\rvert$	$U(d_i)$	$\lvert d_i\rvert=\lvert x_i-x_{ref}\rvert$	$U(d_i)$	$\lvert d_i\rvert=\lvert x_i-x_{ref}\rvert$	$U(d_i)$	$\lvert d_i\rvert=\lvert x_i-x_{ref}\rvert$	$U(d_i)$	$\lvert d_i\rvert=\lvert x_i-x_{ref}\rvert$	$U(d_i)$	$\lvert d_i\rvert=\lvert x_i-x_{ref}\rvert$	$U(d_i)$
0,2			0,0699	0,1338							0,0002	0,0010
0,5	0,0012	0,0119	0,0462	0,0418			0,0016	0,0100	0,0034	0,0142	0,0015	0,0038
1	0,0042	0,0065					0,0035	0,0074	0,0043	0,0224	0,0049	0,0049
2	0,0019	0,0048	0,0080	0,0099	0,0039	0,0113	0,0037	0,0065	0,0027	0,0053	0,0009	0,0056
5	0,0007	0,0044	0,0134	0,0099	0,0010	0,0077	0,0002	0,0061	0,0005	0,0053	0,0024	0,0037
10	0,0005	0,0043	0,0092	0,0099	0,0011	0,0081	0,0006	0,0062	0,0002	0,0040	0,0020	0,0037
15	0,0009	0,0045	0,0089	0,0100	0,0051	0,0077	0,0011	0,0062	0,0027	0,0029	0,0005	0,0030
20	0,0006	0,0044	0,0080	0,0100	0,0065	0,0067	0,0008	0,0065	0,0001	0,0039	0,0042	0,0044
25	0,0003	0,0044	0,0107	0,0100	0,0065	0,0072	0,0029	0,0068	0,0015	0,0032	0,0008	0,0044
30	0,0014	0,0042	0,0089	0,0099			0,0016	0,0071	0,0010	0,0020	0,0005	0,0050
35			0,0058	0,0098			0,0013	0,0064	0,0022	0,0022	0,0002	0,0040
40							0,0017	0,0055			0,0007	0,0023

Table 6.3.4: Degree of equivalence to the KCRV according to table 6.3.3

Table 6.3.5 includes for each velocity value a table with the degrees of equivalence between the laboratories where the red colour indicates that $|d_{ij}| > U_{ij}$.

0,2 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}
DK												
NL											-0,07	0,13
IT												
AT												
BE												
DE			0,07	0,13								

0,5 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}
DK			0,045	0,044			-0,003	0,017	0,002	0,018	-0,003	0,014
NL	-0,045	0,044					-0,048	0,043	-0,043	0,044	-0,048	0,042
IT												
AT	0,003	0,017	0,048	0,043					0,005	0,017	0,000	0,012
BE	-0,002	0,018	0,043	0,044			-0,005	0,017			-0,005	0,014
DE	0,003	0,014	0,048	0,042			0,000	0,012	0,005	0,014		

1,0 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}
DK							0,001	0,011	0,008	0,019	-0,001	0,010
NL												
IT												
AT	-0,001	0,011							0,008	0,020	-0,001	0,010
BE	-0,008	0,019					-0,008	0,020			-0,009	0,019
DE	0,001	0,010					0,001	0,010	0,009	0,019		

2,0 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}
DK			0,010	0,012	-0,002	0,013	-0,002	0,009	0,005	0,008	0,001	0,009
NL	-0,010	0,012			-0,012	0,016	-0,012	0,013	-0,005	0,012	-0,009	0,012
IT	0,002	0,013	0,012	0,016			0,000	0,014	0,007	0,013	0,003	0,013
AT	0,002	0,009	0,012	0,013	0,000	0,014			0,006	0,009	0,003	0,010
BE	-0,005	0,008	0,005	0,012	-0,007	0,013	-0,006	0,009			-0,004	0,009
DE	-0,001	0,009	0,009	0,012	-0,003	0,013	-0,003	0,010	0,004	0,009		

5,0 m/s	DK		NL		IT		AT		BE		DE	
$\lvert d_{ij}\rvert > U_{ij}$	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}	$d_{ij} = x_i-x_j$	U_{ij}
DK			0,014	0,011	0,002	0,009	0,001	0,008	0,000	0,008	-0,002	0,007
NL	-0,014	0,011			-0,012	0,013	-0,013	0,012	-0,014	0,012	-0,016	0,011
IT	-0,002	0,009	0,012	0,013			-0,001	0,010	-0,002	0,010	-0,003	0,009
AT	-0,001	0,008	0,013	0,012	0,001	0,010			-0,001	0,009	-0,003	0,008
BE	0,000	0,008	0,014	0,012	0,002	0,010	0,001	0,009			-0,002	0,008
DE	0,002	0,007	0,016	0,011	0,003	0,009	0,003	0,008	0,002	0,008		

10 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			0,010	0,011	0,002	0,010	0,000	0,008	0,000	0,007	-0,002	0,007
NL	-0,010	0,011			-0,008	0,013	-0,010	0,012	-0,009	0,012	-0,011	0,011
IT	-0,002	0,010	0,008	0,013			-0,002	0,011	-0,001	0,010	-0,003	0,009
AT	0,000	0,008	0,010	0,012	0,002	0,011			0,000	0,009	-0,001	0,008
BE	0,000	0,007	0,009	0,012	0,001	0,010	0,000	0,009			-0,002	0,007
DE	0,002	0,007	0,011	0,011	0,003	0,009	0,001	0,008	0,002	0,007		

15 m/s	DK		NL		IT		AT		BE		DE	
$\|d_{ij}\| > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			0,008	0,011	0,004	0,009	0,000	0,008	-0,004	0,007	-0,001	0,006
NL	-0,008	0,011			-0,004	0,013	-0,008	0,012	-0,012	0,011	-0,009	0,011
IT	-0,004	0,009	0,004	0,013			-0,004	0,010	-0,008	0,009	-0,006	0,009
AT	0,000	0,008	0,008	0,012	0,004	0,010			-0,004	0,008	-0,002	0,008
BE	0,004	0,007	0,012	0,011	0,008	0,009	0,004	0,008			0,002	0,006
DE	0,001	0,006	0,009	0,011	0,006	0,009	0,002	0,008	-0,002	0,006		

20 m/s	DK		NL		IT		AT		BE		DE	
$\|d_{ij}\| > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			0,009	0,011	0,007	0,009	0,001	0,008	0,001	0,007	-0,004	0,007
NL	-0,009	0,011			-0,002	0,012	-0,007	0,012	-0,008	0,011	-0,012	0,011
IT	-0,007	0,009	0,002	0,012			-0,006	0,010	-0,006	0,009	-0,011	0,009
AT	-0,001	0,008	0,007	0,012	0,006	0,010			-0,001	0,009	-0,005	0,008
BE	-0,001	0,007	0,008	0,011	0,006	0,009	0,001	0,009			-0,004	0,007
DE	0,004	0,007	0,012	0,011	0,011	0,009	0,005	0,008	0,004	0,007		

25 m/s	DK		NL		IT		AT		BE		DE	
$\|d_{ij}\| > U_{ij}$	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			0,011	0,011	0,007	0,009	0,003	0,009	-0,001	0,007	-0,001	0,007
NL	-0,011	0,011			-0,004	0,013	-0,008	0,012	-0,012	0,011	-0,012	0,011
IT	-0,007	0,009	0,004	0,013			-0,004	0,010	-0,008	0,009	-0,007	0,009
AT	-0,003	0,009	0,008	0,012	0,004	0,010			-0,004	0,009	-0,004	0,009
BE	0,001	0,007	0,012	0,011	0,008	0,009	0,004	0,009			0,001	0,007
DE	0,001	0,007	0,012	0,011	0,007	0,009	0,004	0,009	-0,001	0,007		

30 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK			0,010	0,011			0,003	0,009	0,000	0,007	0,001	0,008
NL	-0,010	0,011					-0,007	0,013	-0,010	0,011	-0,009	0,012
IT												
AT	-0,003	0,009	0,007	0,013					-0,003	0,009	-0,002	0,009
BE	0,000	0,007	0,010	0,011			0,003	0,009			0,000	0,007
DE	-0,001	0,008	0,009	0,012			0,002	0,009	0,000	0,007		

35 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL							-0,004	0,012	-0,008	0,011	-0,006	0,011
IT												
AT			0,004	0,012					-0,004	0,009	-0,001	0,009
BE			0,008	0,011			0,004	0,009			0,002	0,007
DE			0,006	0,011			0,001	0,009	-0,002	0,007		

40 m/s	DK		NL		IT		AT		BE		DE	
	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}	$d_{ij} = x_i - x_j$	U_{ij}
DK												
NL												
IT												
AT											-0,002	0,008
BE												
DE							0,002	0,008				

Table 6.3.5: Degree of equivalence between laboratories for each velocity value

The degree of equivalence of all LDA based results was remarkably good for almost all data. Inconsistencies were mainly observed in view of some data from VSL (NL), where the usually applied procedure based on the approved volume flow rate traceability was slightly modified in order to provide the seeding for the LDA measurements. This may have had a bigger influence than originally estimated.

7. Conclusion

A comparative diagram of the comparison results based on the two transfer standards, the ultrasonic anemometer used as conventional standard with low but not necessarily negligible interactions in the different facilities and the laser Doppler anemometer used for the first time as non contact transfer standard is shown in figure 7.1.

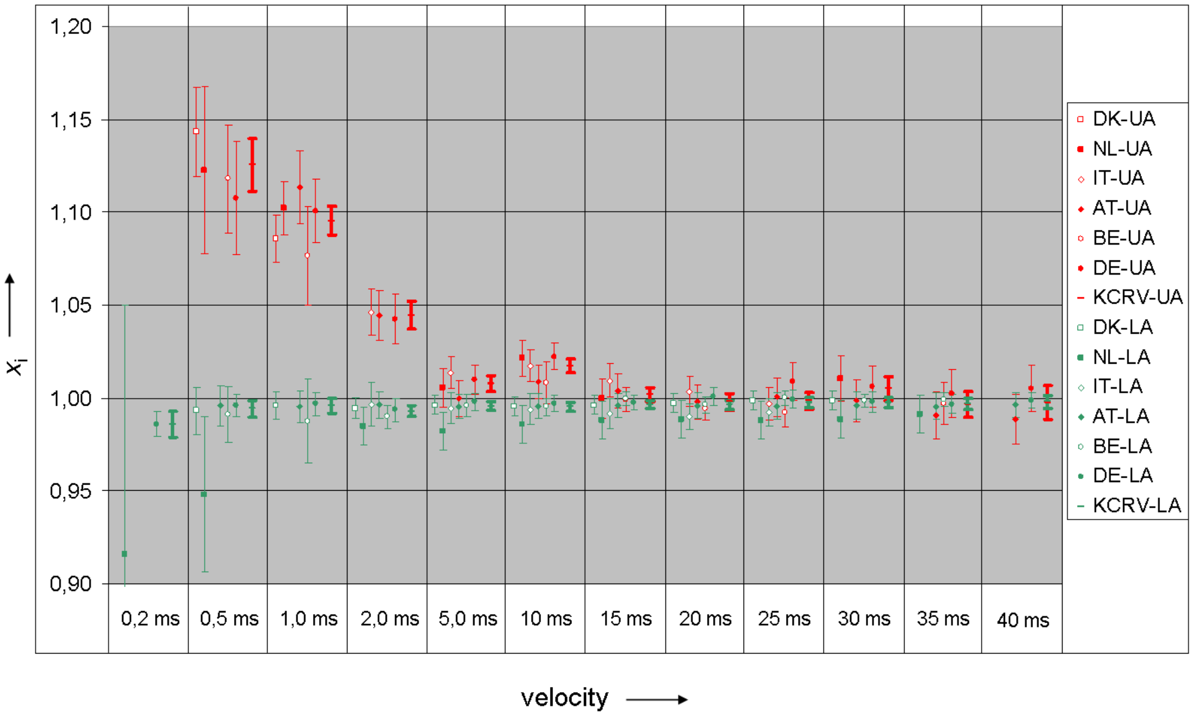


Figure 7.1: Consistent data sets and resulting KCRV´s for both transfer standards; ultrasonic anemometer (UA, red), laser Doppler anemometer (LA, green)

The use of the laser Doppler anemometer as transfer standard assured the largest consistent data sets of all participating laboratories, the highest degrees of equivalence and the lowest achievable uncertainties of the resulting key reference values in the velocity range from 0,2 m/s up to 40 m/s.

8 References

(1) Guidelines for CIPM key comparisons

(2) Cox, M. G., The Evaluation of Key Comparison Data, Metrologia 39, 589-595, 2002.

(3) Cox, M. G., The evaluation of key comparison data: determining the largest consistent subset, Metrologia 44, 187 - 200, 2007.

(4) Comité International des Poids et Mesures (CIPM), Mutual Recognition of National Measurement Standards and of Calibration and Measurement Certificates Issued by National Metrology Institutes, Paris, France, October, 1999.