News from the Working Group on Fluid Flow

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NIST Fluid Metrology Group
February 21, 2013

WGFF Meetings

2010 at FLOMEKO in Taipei, 28 attendees

2011 at BIPM, France, 11 attendees

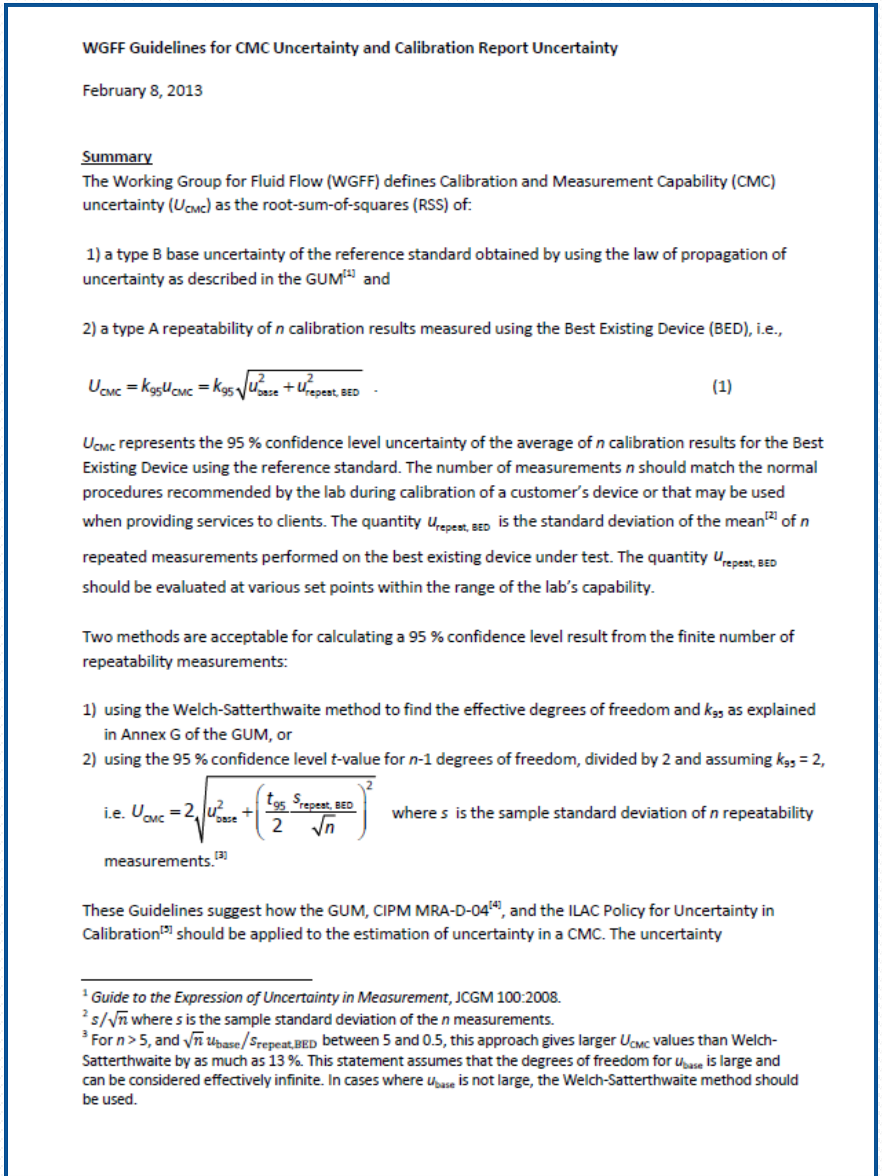
2012 at International Symposium on Fluid Flow Measurement, Colorado Springs, USA, 28 attendees

September 18 and 19, 2013 at

FLOMEKO, Poitiers, France

WGFF Guidelines for CMC and Calibration Report Uncertainties

- Inconsistent interpretations of CIPM MRA-D-04 and the ILAC Policy for Uncertainty in Calibration: not all labs are "*incorporating agreed-upon values for the best existing devices .*"
- 6 page document, written over a 2 year period, > 20 versions!
- Sub-group: Smits, Terao, Batista, Paton, Su, Arias, Mickan, van der Beek, and Shimada
- Can serve as a model for accreditation of commercial labs



WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty

February 8, 2013

Summary

The Working Group for Fluid Flow (WGFF) defines Calibration and Measurement Capability (CMC) uncertainty (U_{CMC}) as the root-sum-of-squares (RSS) of:

1) a type B base uncertainty of the reference standard obtained by using the law of propagation of uncertainty as described in the GUM[1] and

2) a type A repeatability of n calibration results measured using the Best Existing Device (BED), i.e.,

$$U_{CMC} = k_{95} u_{CMC} = k_{95} \sqrt{u_{base}^2 + u_{repeat,\,BED}^2} \quad . \qquad (1)$$

U_{CMC} represents the 95 % confidence level uncertainty of the average of n calibration results for the Best Existing Device using the reference standard. The number of measurements n should match the normal procedures recommended by the lab during calibration of a customer's device or that may be used when providing services to clients. The quantity $u_{repeat,\,BED}$ is the standard deviation of the mean[2] of n repeated measurements performed on the best existing device under test. The quantity $u_{repeat,\,BED}$ should be evaluated at various set points within the range of the lab's capability.

Two methods are acceptable for calculating a 95 % confidence level result from the finite number of repeatability measurements:

1) using the Welch-Satterthwaite method to find the effective degrees of freedom and k_{95} as explained in Annex G of the GUM, or
2) using the 95 % confidence level t-value for n-1 degrees of freedom, divided by 2 and assuming k_{95} = 2, i.e. $U_{CMC} = 2\sqrt{u_{base}^2 + \left(\frac{t_{95}}{2}\frac{s_{repeat,\,BED}}{\sqrt{n}}\right)^2}$ where s is the sample standard deviation of n repeatability measurements.[3]

These Guidelines suggest how the GUM, CIPM MRA-D-04[4], and the ILAC Policy for Uncertainty in Calibration[5] should be applied to the estimation of uncertainty in a CMC. The uncertainty

[1] *Guide to the Expression of Uncertainty in Measurement*, JCGM 100:2008.
[2] $s/\sqrt{n}$ where s is the sample standard deviation of the n measurements.
[3] For $n > 5$, and $\sqrt{n}\, u_{base}/s_{repeat,BED}$ between 5 and 0.5, this approach gives larger U_{CMC} values than Welch-Satterthwaite by as much as 13 %. This statement assumes that the degrees of freedom for u_{base} is large and can be considered effectively infinite. In cases where u_{base} is not large, the Welch-Satterthwaite method should be used.

WGFF Guidelines for CMC Uncertainties

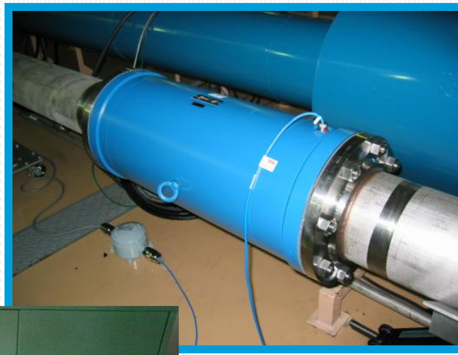
- CMCs include:
  1) type B base uncertainty of the reference standard and
  2) type A for *n* measurements using the Best Existing Device (BED)

$$U_{\mathrm{CMC}} = k_{95} u_{\mathrm{CMC}} = k_{95} \sqrt{u_{\mathrm{base}}^2 + u_{\mathrm{repeat,\ BED}}^2}$$

- Cite 7 good uncertainty analyses for common reference standard types
- Labs report averages, so type A is experimental standard deviation of the <u>mean</u>: $\sqrt{\ }$
- Coverage factor k_{95} from :
  1) Welch-Satterthwaite or
  2) t-value
- Correlation methods allowed with the comment "*Contributions to the uncertainty from the device are not included.*"

Status of Key Comparisons

- K1: Water Flow, Engel (PTB)
- K2.1: Hydrocarbon Liquid Flow, Smits (VSL)
- K2.2: Hydrocarbon Liquid Flow, Shimada & Terao (NMIJ)
- K3: Air Speed, Care (LNE), Mueller (PTB)
- K4.1: Volume, Arias (CENAM)
- K4.2: Volume, Batista (IPQ)
- K5: High Pressure Gas Flow, Mickan (PTB)
- K6: Low Pressure Gas Flow, Benkova (CMI)& Makovnik (SMU)



Hydrocarbon Liquid Flow Comparison

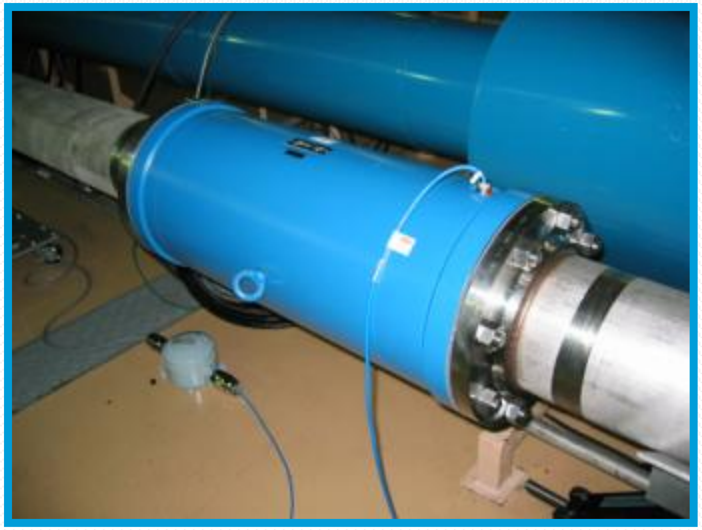
K2.2.2011 Hydrocarbon Liquid Flow, 13 to 67 kg/s

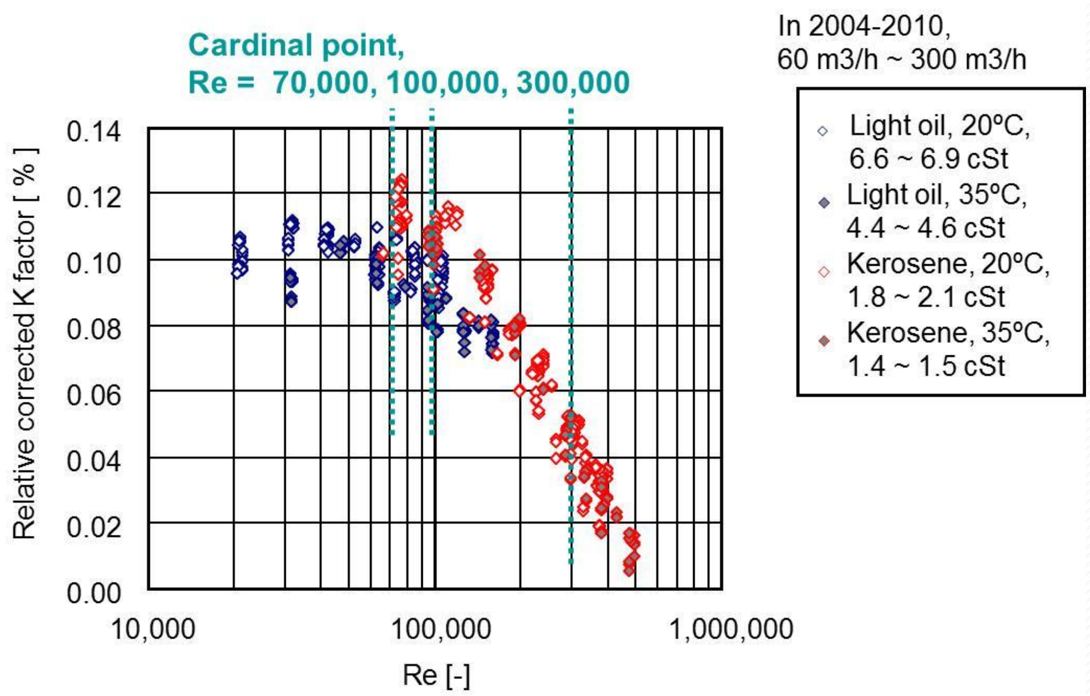
NMIJ, Takashi Shimada

Krall positive displacement meter, hydrocarbon liquid only

Preliminary tests show TS stability of < 0.03 %

KC scheduled to start November 2013 (following an APMP comparison)





Uncertainty Due to Transfer Standard

- Uncertainty of *K* factor at each lab for measurements at different conditions, u_i
  - $u_i^2 = u_{TS}^2 + u_{CAL,I}^2$
  - Uncertainty due to calibration at each lab, $u_{CAL,I}$
  - Uncertainty due to transfer standard, u_{TS}
    - Reproducibility due to transport
      - Deviation at the pilot lab before and after transport
    - Temperature and viscosity effect
      - +/- 0.01 % evaluated by pre-tests
    - Linearity
      - < +/- 0.005 % due to uncertainty due to Re of 5 %
    - Pressure effect
      - < +/- 0.002 % by pre-tests
    - Effect due to Strainer
      - < +/- 0.005 % evaluated by pre-tests

Liquid Flow Comparison

K2.1.2011 Hydrocarbon Liquid Flow, 5 to 60 kg/s

VSL, Erik Smits

Micromotion and Krohne coriolis meters

Merging hydrocarbon liquid and water

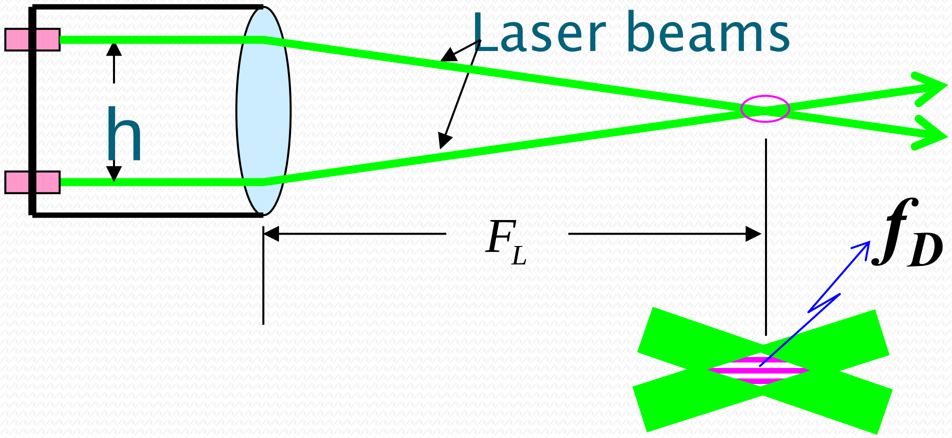
Preliminary tests show TS stability of < 0.03 %

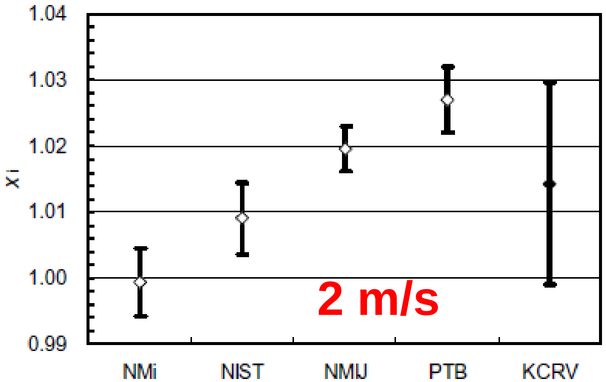
Protocol agreed, scheduled to start August 2013

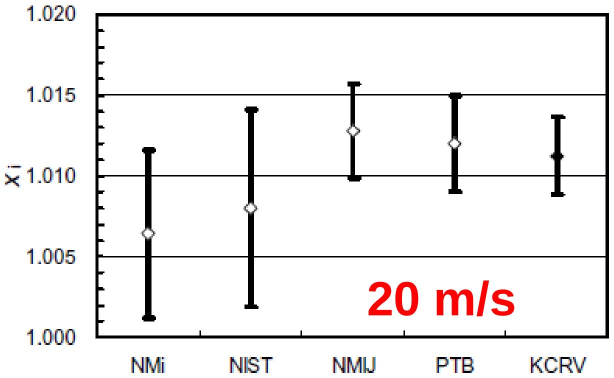
Air Speed Comparisons

CCM.FF-K3: 2005

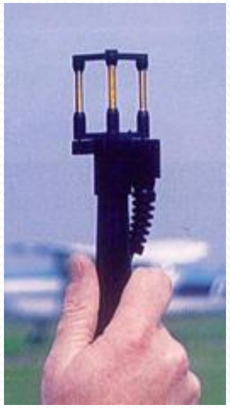
Utrasonic Anemometer



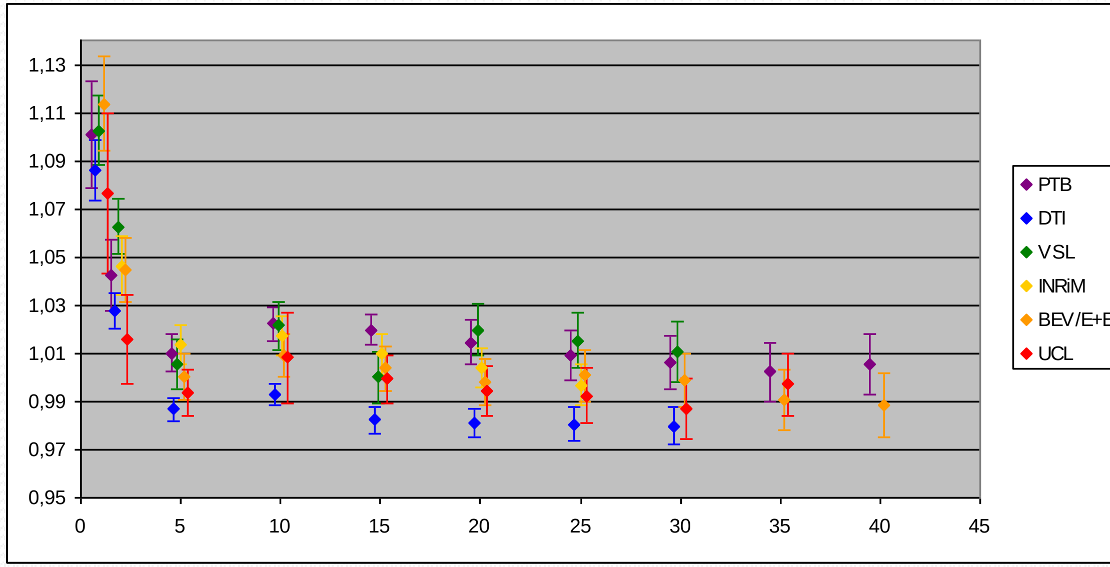




EURAMET Project 827: 2009

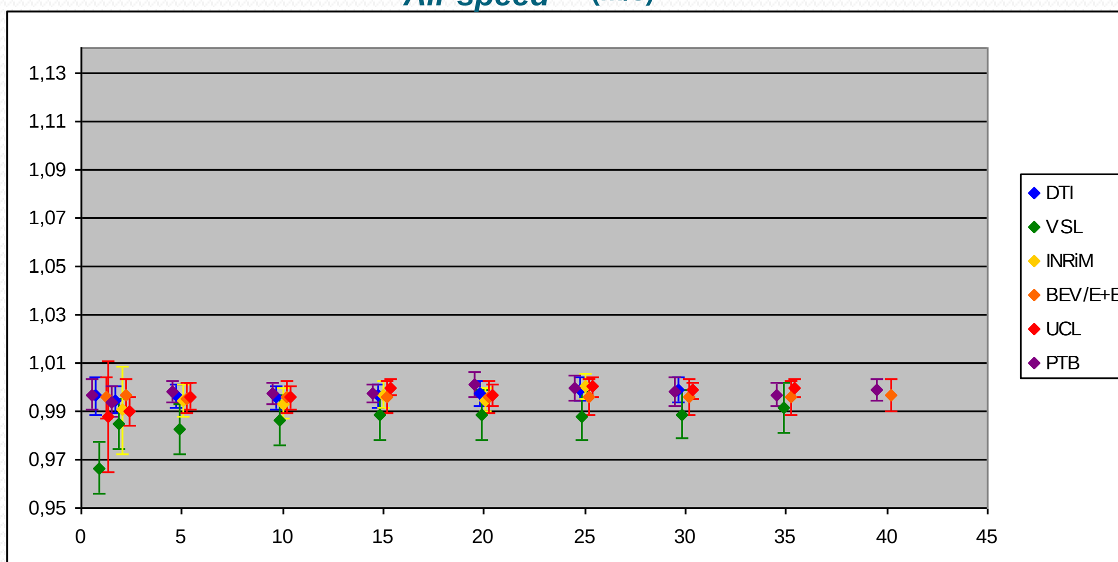


Utrasonic Anemometer



Air speed **(m/s)**

Laser Doppler Anemometer



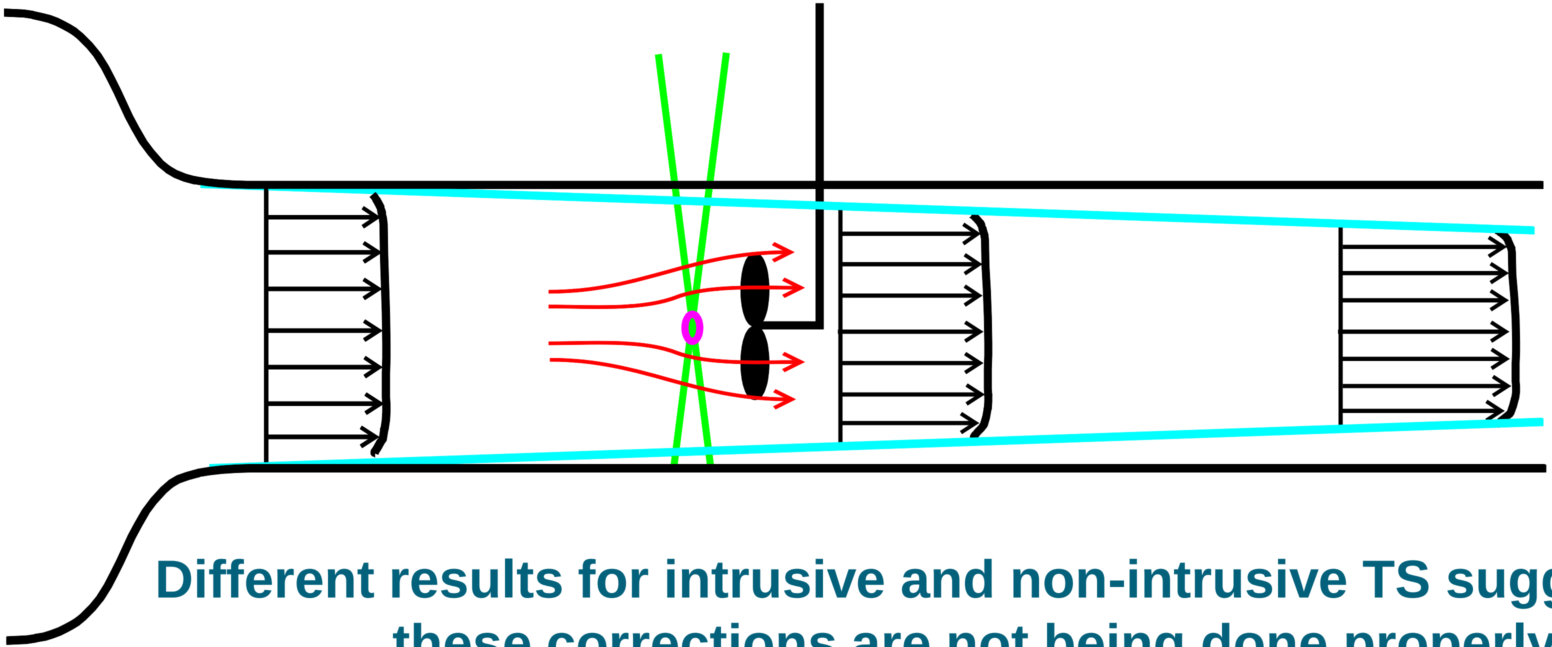
Air speed **(m/s)**

Why different results for different TSs?

Air speed sensors are calibrated to read the velocity that would occur if the sensor did not interfere with the flow.

To properly calibrate an air speed sensor one must:

1. **know the change in velocity with downstream distance caused by boundary layer growth (position correction factor)**
2. **identify region where velocity is influenced by the DUT (blockage effects)**



Different results for intrusive and non-intrusive TS suggest these corrections are not being done properly

Air Speed Comparison

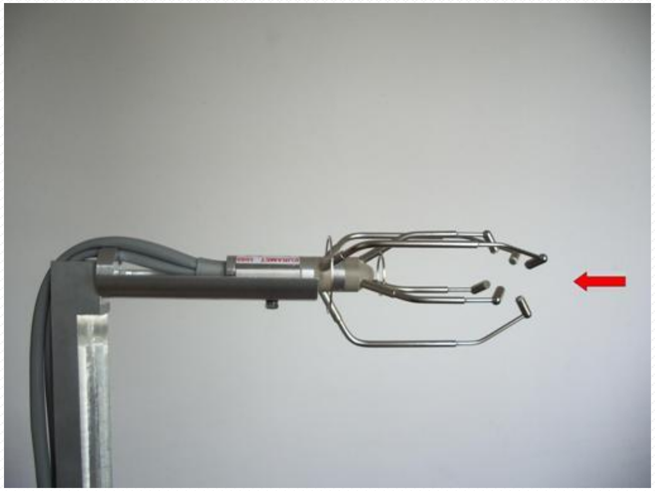
K3 Air Speed, 0.5 to 40 m/s

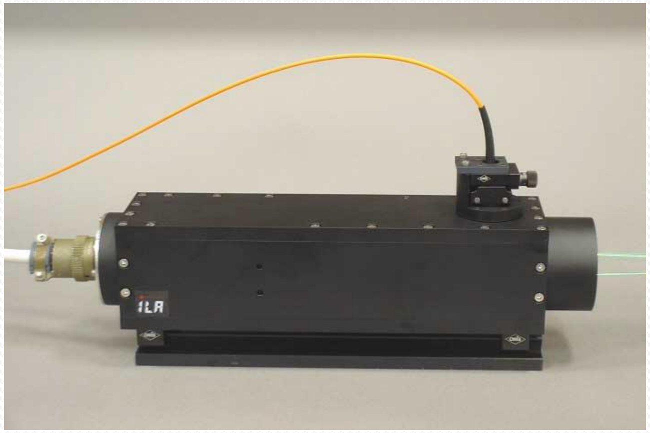
LNE-CETIAT, Isabelle Care and PTB, Harald Mueller

Kaijo ultrasonic anemometer andILA GmbH Laser Doppler

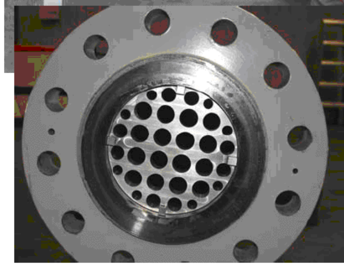
Comparison of spinning disks, assessment of labs' handling of blockage effects

Protocol agreed, scheduled to start April 2013





Gas Flow Comparisons



K5 High Pressure Gas Flow

PTB, Bodo Mickan

2 Elster turbine meters and 6 critical flow venturis

Merging FF-K5a (natural gas) and K5b (air and nitrogen)

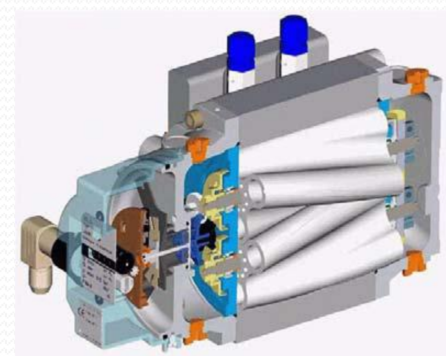
Scheduled to start October 2013

K6 Low Pressure Gas Flow, 2 to 100 m^3/h

CMI, Miroslova Benkova and SMU, Makovnik

Actaris positive displacement flow meter

Testing by 11 participants is complete, report being written



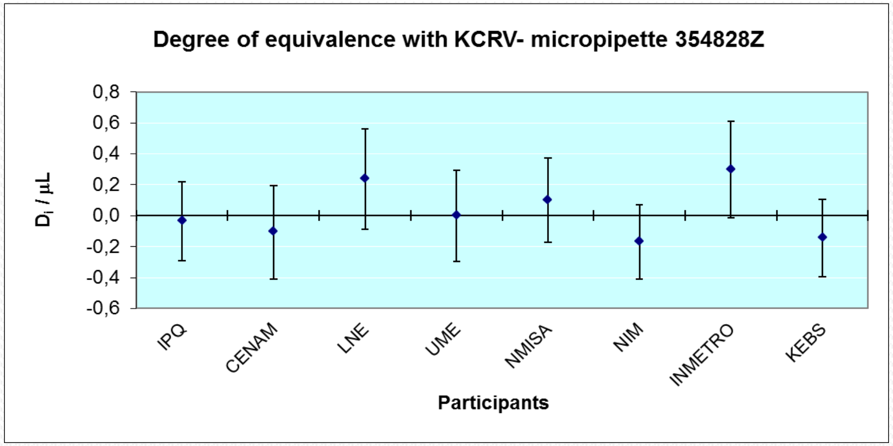
Micropipette Comparison

K4.2 Volume, 5 different 100 µL pipettes

IPQ, Elsa Batista

Air cushion is affected by environmental air density

"Laboratories must always correct their reported volume results to a reference pressure condition and temperature (for example 101.325 kPa and 20 °C) and this information should be stated in the calibration certificate of the micropipette."



Volume Comparison

K4.1 Volume, 100 mL (x6) and 20 L (x3)

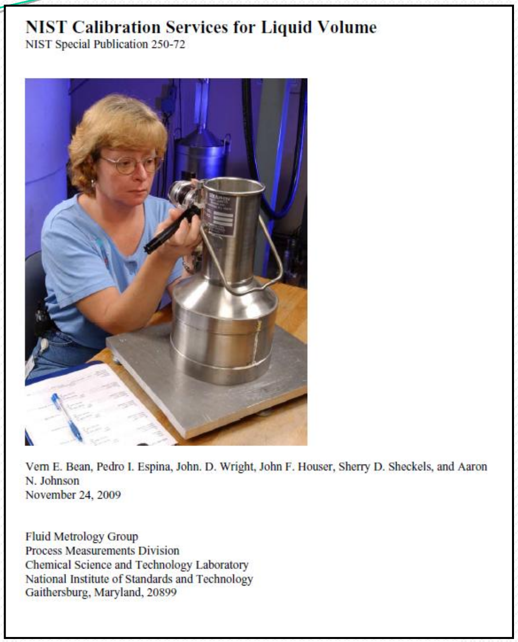
CENAM, Roberto Arias

9 out of 10 participants have completed testing

Calibrated by weighing drained and full of pure water

$$V = \Delta m \,/\, \rho$$

Liquid Volume: Petroleum Traceability


NIST Calibration Services for Liquid Volume
NIST Special Publication 250-72

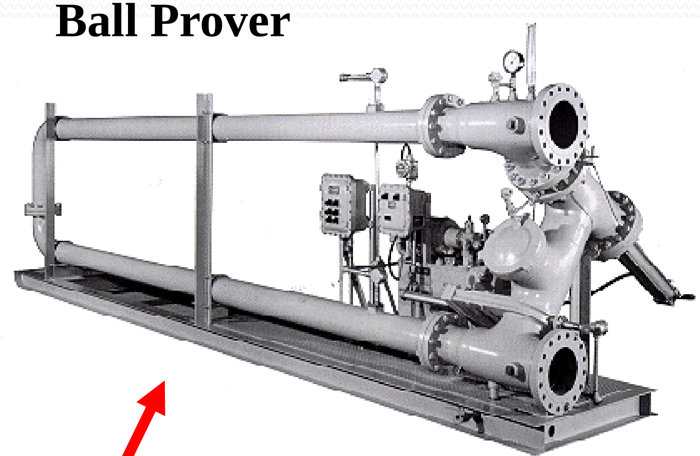
Vern E. Bean, Pedro I. Espina, John. D. Wright, John F. Houser, Sherry D. Sheckels, and Aaron N. Johnson
November 24, 2009

Fluid Metrology Group
Process Measurements Division
Chemical Science and Technology Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland, 20899

NMI Volume Calibration Service

1

Ball Prover



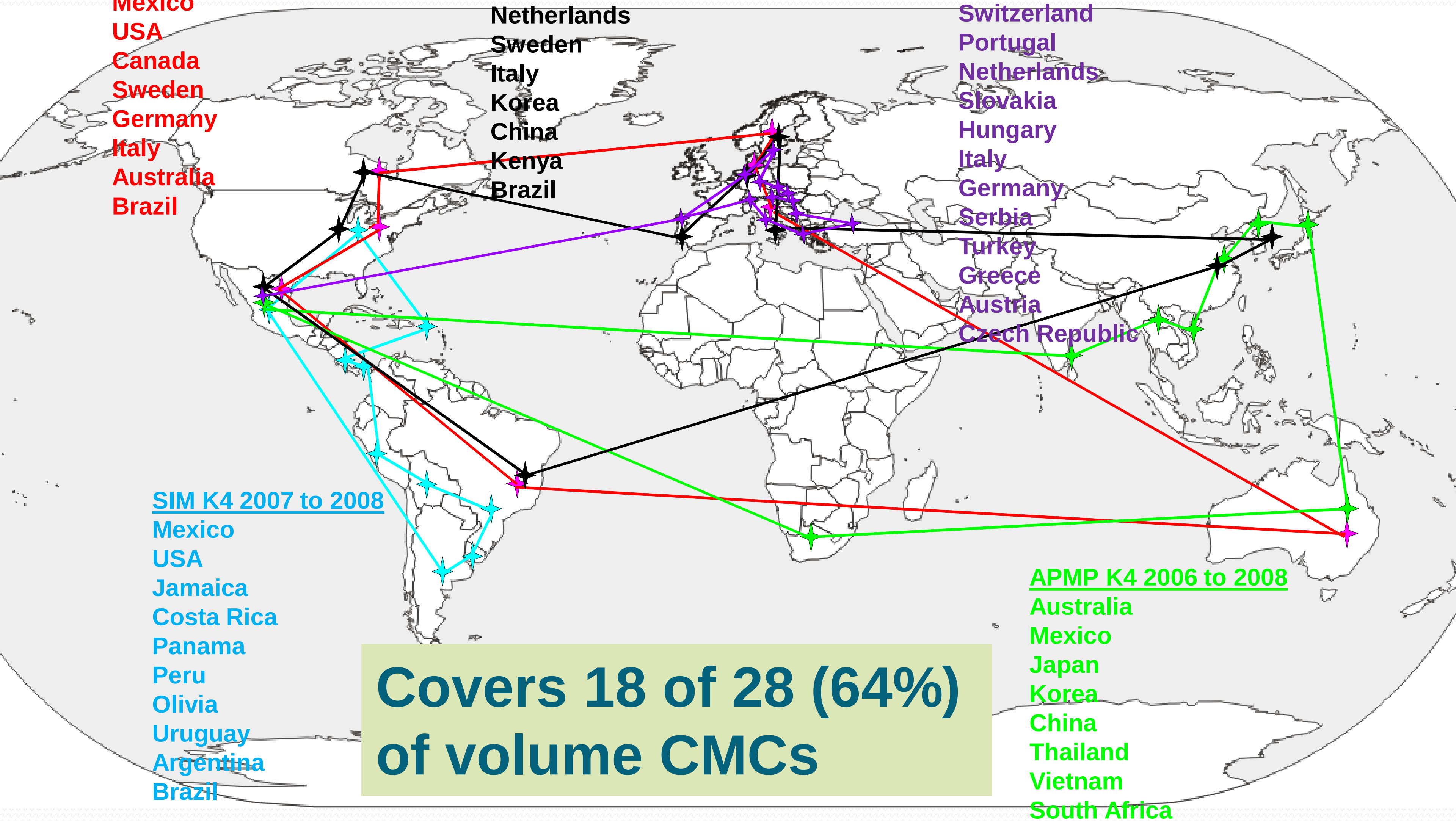
2

3

Field Test Measures

Flow Meter

Volume Comparisons



K4 2003 to 2005
Mexico
USA
Canada
Sweden
Germany
Italy
Australia
Brazil

K4 2011
Mexico
USA
Canada
Netherlands
Sweden
Italy
Korea
China
Kenya
Brazil

EURAMET K4 2007 to 2008
Mexico
Sweden
Norway
Switzerland
Portugal
Netherlands
Slovakia
Hungary
Italy
Germany
Serbia
Turkey
Greece
Austria
Czech Republic

SIM K4 2007 to 2008
Mexico
USA
Jamaica
Costa Rica
Panama
Peru
Olivia
Uruguay
Argentina
Brazil

APMP K4 2006 to 2008
Australia
Mexico
Japan
Korea
China
Thailand
Vietnam
South Africa
Sri Lanka

Covers 18 of 28 (64%) of volume CMCs

Reports Posted to KCDB

Comparison	Measurand	Date published
APMP.M.FF-K1	Water flow	Jan 2011
APMP.M.FF-K4	Liquid volume (0.1 and 20 L)	Jan 2011
APMP.M.FF-K6	Low P gas flow	Jan 2011
APMP.M.FF-K2	Hydrocarbon liquid flow	March 2012
SIM.M.FF-S5	Liquid volume (50 mL)	June 2012
EURAMET.M.FF-S2	Water flow	Jan 2013
CCM.FF-K4.2.2011	Liquid volume (100 µL)	Feb 2013
CCM.FF-K5.a.2	Natural gas flow	Feb 2013
EUROMET.M.FF-S2	Air speed	Feb 2013

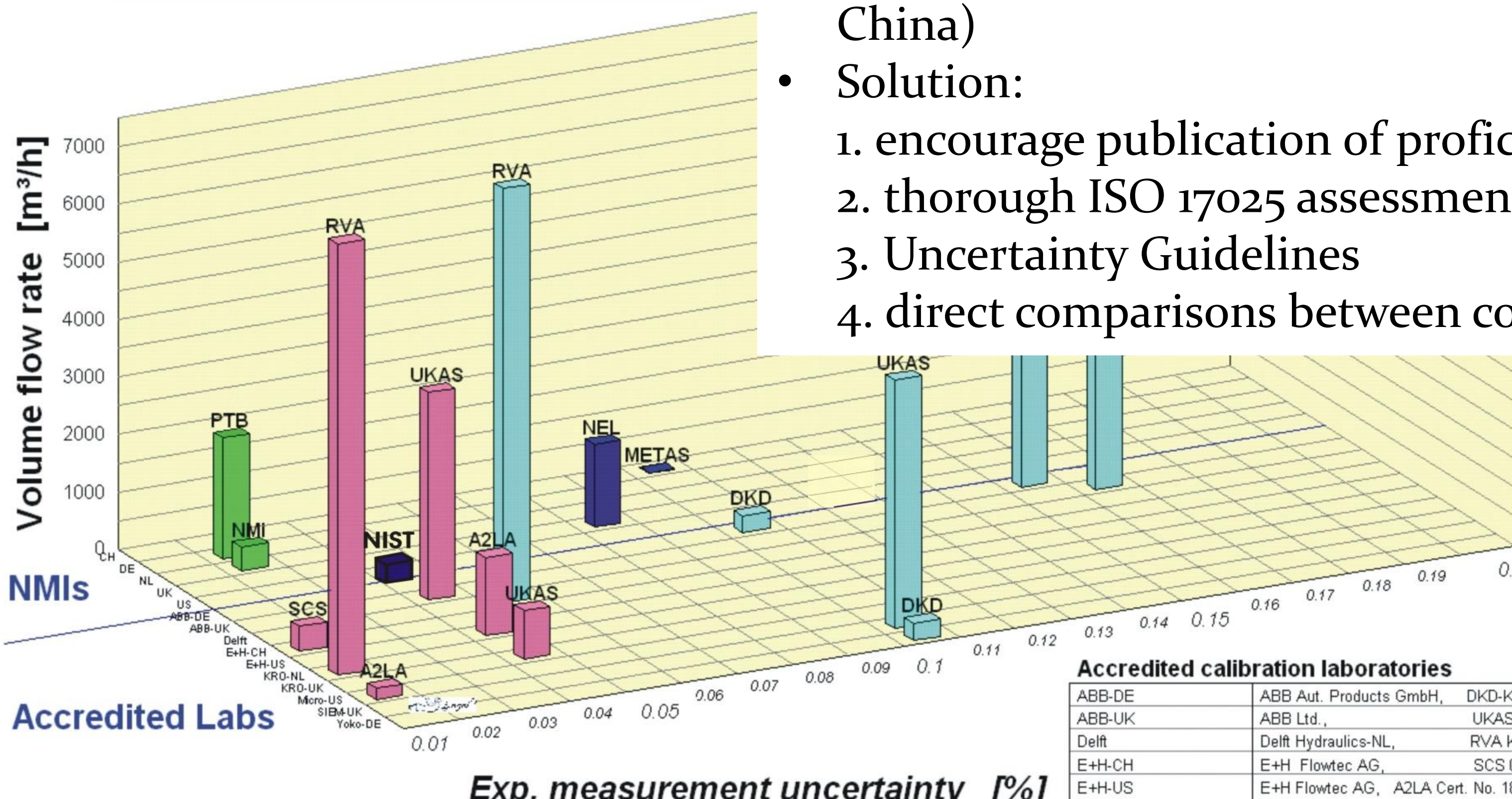
Other WGFF Topics…

- Improving KC reports: shorter, standard format
- Expand WG participation and increase electronic communication
- Guidelines on linkage, via common transfer standard or common participants
- Some members are concerned about low uncertainties of accredited commercial labs

Accreditation

Accreditation bodies	Traceability to
A2LA	NIST
DKD	PTB
RVA	NMi
SCS	METAS
UKAS	TUV NEL

- Commercial labs can achieve lower uncertainties than NMIs for derived quantities (e.g. flow, pressure)
- Some economies have rules against this (Japan, China)
- Solution:
  1. encourage publication of proficiency tests
  2. thorough ISO 17025 assessments
  3. Uncertainty Guidelines
  4. direct comparisons between commercial labs



Accredited calibration laboratories

ABB-DE	ABB Aut. Products GmbH,	DKD-K-18101
ABB-UK	ABB Ltd.,	UKAS 0255
Delft	Delft Hydraulics-NL,	RVA K 015
E+H-CH	E+H Flowtec AG,	SCS 052
E+H-US	E+H Flowtec AG,	A2LA Cert. No. 1897.01
KRO-NL	KROHNE Altometer,	RVA K 070
KRO-UK	KROHNE Ltd.,	UKAS 0812
Micro-US	Micro Motion Inc.,	A2LA Cert. No. 2033.01
SIEM-UK	Siemens Flow Instrum. Ltd,	UKAS 0301
Yoko-DE	Rota Yokogawa GmbH,	DKD-K-03901

From Gudrun Wendt, PTB

A sub-group (Terao) is working on revised Classification Categories

Present

9. Fluid Flow

- **9.1 Volume liquid flow rate**
  - 9.1.1 Volume water flow rate
  - 9.1.2 Volume hydrocarbon flow rate
- **9.2 Volume gas flow rate**
  - 9.2.1 Volume gas flow rate
- **9.3 Mass liquid flow rate**
  - 9.3.1 Mass water flow rate
  - 9.3.2 Mass hydrocarbon flow rate
- **9.4 Gas flow rate**
  - 9.4.1 Mass gas flow rate
  - 9.4.2 Molar flow rate
- **9.5 Volume of liquid**
  - 9.5.1 Volume of liquid
- **9.6 Mass of liquid**
  - 9.6.1 Mass of liquid
- **9.7 Flow speed**
  - 9.7.1 Gas flow speed
  - 9.7.2 Liquid flow speed
- **9.8 Multiphase flow**
  - 9.8.1 Multiphase flow
- **9.9 Heat flow rate**
  - 9.9.1 Heat flow rate

Future?

9. Fluid Flow

- 9.1 Liquid flow
  - 9.1.1 Water flow
  - 9.1.2 Hydrocarbon flow
  - 9.1.3 Cryogenic flow
- 9.2 Gas flow
  - 9.2.1 Gas flow
- 9.3 Static volume of liquid
  - 9.3.1 Static Volume of liquid
- 9.4 Fluid speed
  - 9.4.1 Gas speed
  - 9.4.2 Liquid speed
- 9.5 Multiphase flow
  - 9.5.1 Multiphase flow
- 9.6 Heat flow (Hot water flow, Enthalpy flow?)
  - 9.6.1 Heat flow
- 9.7 Dynamic flow?

EURAMET and SIM flow TCs are working on updated CMCs
A sub-group (Batista) is working on “Review Protocol for Fluid Flow CMCs”

Working Group of Fluid Flow - WGFF

Consultative Committee of Mass – CCM

Review protocol for Fluid Flow CMCs
Draft A

September 2012

Contents