Working Group of Fluid Flow - WGFF

Consultative Committee of Mass – CCM

Review Protocol for Fluid Flow Calibration and Measurement Capabilities (CMCs) V3

May 2026

Contents

1. Introduction

At the 2012 meeting, the WGFF decided to develop a protocol for the submission and review of fluid flow (FF) Calibration and Measurement Capabilities (CMCs) that could be applied by all RMOs during the intra- and inter-regional review process. The following protocol was developed, with JCRB guidelines and the MRA review protocol in mind, to provide harmonized procedures and acceptance criteria for the FF CMC reviews. The goal is an efficient and consistent review process to produce CMCs that concisely reflect the NMIs' capabilities.

At the 2019 meeting of the WGFF in Portugal, it was decided to revise this document and its Annex 1 tables.

In the 2025 online meeting, the tables of Annex 1 were revised, and it was decided to include a new Annex 2, regarding other CMC considerations.

2. Revision procedure of inter-RMO review

The inter-RMO review follows the general rules defined in the BIPM document CIPM MRA-G-13 (2022 version) [1]:

- The deadline for indicating participation in the review is 3 weeks after notification.
- If at least one of the reviewing RMOs require revision, the CMC will be made available to the Writer for appropriate action.
- The Writer shall revise the CMCs according to the comments received from the reviewing RMOs.
- The revision process has no formal deadline, but Writers are encouraged to revise CMCs as soon as possible.
- The Writer should communicate directly with the reviewing RMOs to resolve any issues raised in the review. CMCs may be revised several times "offline", but revised CMCs are allowed to be submitted only once through the web platform.
- When a revised CMC is acceptable to all reviewing RMOs, the CMC is forwarded by the Writer to the originating RMO TC/WG Chair who submits the revised CMC for approval. To complete the approval process, the reviewing RMO TC/WG Chairs shall vote on approval of the revised CMC in the KCDB platform.
- The voting period for the revised CMC is 3 weeks.

To reduce the time spent in the inter-RMO review, the followings additional have been proposed:

- When indicating their interest in participating in the review of CMCs, the RMO TC/WG Chairs will indicate a limit date for completion of the review. This date should be no longer than 60 days.

3. General instructions for filling of a CMC in the KCDB database

The CMCs submission is operated through the Key Comparison Database (KCDB), maintained by the BIPM and publicly available on the Web.
For further help and advice on the use of the KCDB platform and management of CMCs under this platform, please refer to guidance documents and videos available on the BIPM webpage: https://www.bipm.org/en/cipm-mra/kcdb-help

3.1 Language and symbols

- Only English shall be used in all evidence documents sent.
- Decimal point (.) should be used, and not a comma (,).
- For volume use L or m^3.
- To define a range, use the word "to", " but not a hyphen (-); e.g. use the format 10 L to 100 L or (10 to 100) L.

3.2 Criteria for creating a CMC row

- A separate CMC entry shall be made in for each case of a distinct type of artefact where it affects uncertainty (for example, volume), a distinct measurand, or a distinct calibration procedure.
- Use the classification services described in the KCDB and in clause 5.
- The range of relevant measurement parameters (e.g. temperature, pressure, fluid kinematic viscosity, gas types, pipe diameters, etc.) should be presented
- For the review process, explicitly mention the document and the exact paragraph where the reviewer can find the degree of equivalence for a given CMC.

3.3 Criteria for merging CMC

- In general, a single CMC should be used for a generic method and flow measurement apparatus. For example, a piston prover with multiple tubes should be entered as a single CMC. Another example can be a set of bell provers, or any other set of working standard flow meters (e.g.: turbine meters).

- Use only one CMC for both the volume flow and mass flow capabilities of a reference standard and give the effective uncertainty of the fluid density required to convert from mass flow to volumetric flows (or vice versa) in the "Comments" column. The smaller uncertainty measurand (volume flow or mass flow) should be listed in the "Expanded Uncertainty" since NMIs are not allowed to use smaller values in their calibration reports than those listed in their CMCs (refer to the ILAC Policy for Uncertainty in Calibration [2] and CIPM MRA-G-13 (2022 version) [1]).

3.4 Expanded uncertainty

- The declared expanded uncertainty should take into consideration the best existing device according to the "Guidelines for CMC Uncertainty and Calibration Report Uncertainty" [3] developed by the WGFF and available on the BIPM webpage.
- Although tables of uncertainty values are allowed for presentation of the expanded uncertainty, it is recommended that a single value or an equation is only given.

- If a range of uncertainties is listed for a range of the measurand, the order of entries is important, and the uncertainty is assumed to vary linearly between the range endpoints. For example, if a CMC states “1 L/min to 50 L/min” and the uncertainty statement is “0.1 % to 0.05 %” the uncertainty at 1 L/min is 0.1 %, the uncertainty at 50 L/min is 0.05 %, and the uncertainty at 25.5 L/min is 0.075 %.
- It is recommended that the uncertainty be stated in percent rather than the units of the measurand. However, exceptions can be made in some case where the use of absolute values are more adequate; for example, for air speed, it is reasonable to use m/s.
- When submitting a CMC in the KCDB (new or existing) and a comparison report is presented as evidence, the value of the uncertainty claim cannot be better than the value declared in the comparison report used as evidence.
  e.g.:
  Considering the following result in the Comparison used as evidence of a CMC claim: $U = 0.2$ %
  Uncertainty in the CMC claim: $U = 0.15$ % (or any value below 0.2 %) NOT ACCEPTED
  Uncertainty in the CMC claim: $U = 0.2$ % OK, ACCEPTED
  Uncertainty in the CMC claim: $U = 0.21$ % (any value greater than 0.2 %) OK, ACCEPTED

3.5 Other documents submitted

- To improve CMCs review processes, when submitting a CMC in the KCDB, the WRITER shall include a document (e.g. pdf) as an 'INTRODUCTORY NOTE' intended to help REVIEWERS, explaining what the changes were made, or if it is a new CMC, describing the claim and the supporting evidence presented

4. RMO revision

The inter-regional review comments are given by the reviewers at the bottom of the form. The comments are accessible for the TC Chair. The Writer will access the comments when the CMC has been returned for revision.

5. General acceptance criteria (to be used in intra and inter-RMO review)

The CIPM guidance document CIPM MRA-G-13 (page 13§3.3 Technical evidence, version 2022) [1] says the following concerning criteria for acceptance of CMCs:
The range and measurement uncertainty of the CMCs should be consistent with information from some, or all, of the following sources:

- Results of key and supplementary comparisons;
- Publicly available information on technical activities including publications;
- On-site peer-assessment reports, including those from accreditation assessment with appropriate technical peers;
- Active participation in RMO projects;
- Other evidence of knowledge and experience, as agreed by the appropriate Consultative Committee, e.g. pilot studies.

While the results of key and supplementary comparisons are the ideal supporting evidence, all other sources listed above may be considered to underpin CMCs. Consultative Committees are responsible for providing specific guidance on the required technical evidence. The criteria for accepting CMCs rely on the values of the measurement uncertainty reported by the laboratory. Over the years, members of the WGFF have built experience and knowledge of uncertainty analyses for various areas of flow and volume measurements. Using these gained experience and knowledge, criteria have been developed for accepting CMCs based on the reported uncertainties by the laboratory. Logically, the more stringent is the claimed uncertainty the more emphasis is put on providing evidence. For each area of measurement (volume, liquid flow, gas flow and air speed), the criteria for accepting CMCs were divided into three tiers or categories. Annex 1 contains tables for each of the area of measurement and required documentations or evidences; refer to Tables A.1 to A.4.

In case the laboratory has participated in a key or supplementary comparison with consistent results and the declared uncertainty is equal or higher that the uncertainty stated in the comparison report, then their CMCs are usually accepted. However, considering that Pilot labs normally use uncertainty weighting to calculate the Key Comparison Reference Value (KCRV), it is not guaranteed that these comparisons will ensure the validity of claiming low values for their measurement uncertainty. Therefore, laboratories with exceptionally low uncertainties are to submit detailed review of their uncertainty analyses (refer to Tables A.1-A.4 in Annex 1).

In case there is no comparisons available for a specific entry and the laboratory can provide an established quality system, working procedures and/or publications, the CMC can be approved based on the supplied information. For example, if a lab has reference standards linked together and validated by internal comparisons, this should be considered during the CMC review, and a CMC can be approved based on supplied information.

The WGFF recommends that all NMIs review their CMCs that are already published on the KCDB at least 10 years. In case changes are needed, the CMC should be updated and resubmitted for inter-RMO review. This will ensure that these CMCs are maintained to be current and up to date. It is the concern of the NMI to ensure updating and within the RMO-TCs, it should be supervised.

The CMC can be accepted based on the $E_n < 1$ criteria.
From $1 < |E_n| \leqslant 1.2$ the CMC can also be accepted, but its consider to be in a warning level. In this case the NMI has to be clear what consequences “Warning” has in its measurements and what would happen if “failed”. This warning level also does not consider in detail some aspects of a comparison like non ideal comparisons where the results are influenced by the TS performance and underestimated uncertainty budgets.

6. Service categories

Flow service categories are divided as follows:

9.10 Fluid Flow
- 9.10.1 Liquid flow
- 9.10.2 Gas flow

9.10.3 Quantity of fluid
9.10.4 Flow speed
9.10.5 Multiphase flow
9.10.6 Heat flow

7. References

1. CIPM MRA-G-13, CMCs in the context of the CIPM MRA: Guidelines for their review, acceptance and maintenance (2022).
2. ILAC Policy for uncertainty in calibration, ILAC P14:09/2020.
3. WGFF - Guidelines for CMC Uncertainty and Calibration Report Uncertainty, 2012.
4. CIPM MRA-G-12, Quality management systems in the CIPM MRA: Guidelines for monitoring and reporting (2021).

Annex 1: Specific measurand acceptance criteria and minimum documentation requirement (to be used in intra- and inter-RMO review) (mandatory)

A1.1 - Volume

- For the gravimetric method there are three different types of instruments that need separate comparison evidences: glassware, proving tanks (test measures), and piston operating apparatus. The evidences can also depend on the volume, mainly for syringes and micropipettes at very low values.
- The volumetric method should have a separate entry from the gravimetric method.
- The capacity of the instrument used in the comparisons is not a restriction to the presented range of the CMCs if the calibration method used and reference conditions are the same, this does not apply to volumes lower than 10 μL (special for syringes and micropipettes), or higher than 10 000 L (for proving tanks)
- A different CMC line should be present for on-site volume calibrations.
- Micropipettes and syringes CMC uncertainties should be presented in an equation format, preferentially.
- In gravimetric method it is expected that the uncertainty of calibration a volume instrument to contain is the same as for deliver.

Table A.1.1 – Volume CMC minimum documentation requirements and uncertainty values

Instrument/method	Detailed uncertainty analysis review and consistent RMO or BIPM comparison results required	Consistent RMO or BIPM comparison results required	Internal documents, publications, or other proof required (including bilateral comparison, pilot studies, hybrid comparison, PT or ILC)
Glassware and piston operating apparatus (burettes and dispensers) /gravimetric	< 0.01 %	0.01 % up to 0.05 %	> 0.05 %
Pycnometer and Overflow type volume devices /gravimetric	< 0.005 %	0.005 % up to 0.01 %	> 0.01 %
Piston operating apparatus (syringes and micropipettes)/gravimetric higher than 10 μL	< 0.2 %	0.2 % up to 0.5 %	> 0.5 %
Piston operating apparatus (syringes and micropipettes)/gravimetric lower or equal to 10 μL	< (2/V) %, volume V in μL	> (2/V) % and < (4/V)%, volume V in μL	> (4/V)%, volume in μL
Proving tanks (test measures)/gravimetric	< 0.01 %	0.01 % up to 0.05 %	> 0.05 %
Proving tanks (test measures)/volumetric	< 0.02 %	0.02 % up to 0.07 %	> 0.07 %

A1.2 - Liquid flow

- The criteria in Table A.2 is not applied for flow standards at extreme conditions, such as cryogenic flow, high temperature flow, volatile liquid flow, high viscosity flow and so on. For these standards, which are difficult to realize, detailed uncertainty analysis review is necessary regardless of the uncertainty value.

Table A.1.2 – Liquid flow CMC minimum documentation requirement

Instrument/method	Detailed uncertainty analysis review and consistent RMO or BIPM comparison results required	Consistent RMO or BIPM comparison results required	Internal documents, publications, or other proof required (including bilateral comparison, pilot studies, hybrid comparison, PT or ILC)
Piston or displacement prover, gravimetric standard < 2 L/h	< 0.1 %	0.1 % up to 1 %	> 1 %
Piston or displacement prover, gravimetric standard ⩾ 2 L/h	< 0.05 %	0.05 % up to 0.1 %	> 0.1 %
Secondary standard flow devices (e.g., turbine, Coriolis, ultrasonic).	< 0.1 %	0.1 % up to 0.25 %	> 0.25 %

A1.3 - Gas flow

- According to the principle of measurement, the instrument could be classified to primary type such as piston prover, bell prover, pVTt or gravimetric standard and secondary type with critical flow Venturi nozzle (CFVN), turbine, Coriolis, rotary flowmeter as reference flow meters;
- For primary type instrument, there is a set of equipment with declared operation range which is mainly determined by one core-equipment: e.g. tank, bell, collection tank or balance. For secondary type instrument, which is mainly determined by reference flow meters covering single line equipment and multi-line equipment.

Table A.1.3 – Gas flow CMC minimum documentation requirement

Instrument/method	Detailed uncertainty analysis review and consistent RMO or BIPM comparison results required	Consistent RMO or BIPM comparison results required	Internal documents, publications, or other proof required (including bilateral comparison, pilot studies, hybrid comparison, PT or ILC)
Piston prover	< 0.1 %	0.1 % up to 0.2 %	> 0.2 %
Bell prover	< 0.1 %	0.1 % up to 0.2 %	> 0.2 %
pVTt or gravimetric standard	< 0.1 %	0.1 % up to 0.2 %	> 0.2 %
Secondary standard flow devices (e.g., critical flow Venturi nozzle (CFVN), turbine, Coriolis, rotary)	< 0.12 %	0.12 % up to 0.25 %	> 0.25 %

Note: In a CMC claim, in the case that the claimed range is greater than the comparison range used as evidence, a technical explanation of the bootstraping process shall be presented (including uncertainty budget, secondary effects, line pack, leakage, etc,)

A1.4 Flow speed

- Because of the wide dynamic range, formulas expressing the uncertainty as a function of the flow speed are commonly used, e.g. [0.6 + 1/u(m/s)] % where u is the flow speed.

Table A.1.4 – Flow speed CMC minimum documentation requirement

Instrument/method	Detailed uncertainty analysis review and consistent RMO or BIPM comparison results required	Consistent RMO or BIPM comparison results required	Internal documents, publications, or other proof required (including bilateral comparison, pilot studies, hybrid comparison, PT or ILC)
LDV	≤ 0.1 %	0.1 % up to 0.3 %	> 0.3 %
Anemometer	≤ [0.3 + 0.2/u(m/s)] %	[0.3 + 0.2/u(m/s)] % up to [1 + 1/u(m/s)] %	> [1 + 1/u(m/s)] %
Water Current meter	≤ [0.1 + 0.3/u(m/s)] %	[0.1 + 0.3/u(m/s)] % up to [0.5 + 1.0/u(m/s)] %	> [0.5 + 1.0/u(m/s)] %

Unique standard

- If the metrological standard under review is unique and there is no possibility to conduct an inter-comparison, the calibration principle, facility, calibration procedure and uncertainty analysis must be described in a separate document in detail. Prior to the CMC submission, it is highly recommended to make the above descriptions public by publishing a research paper or making a presentation at an academic meeting, such as a WGFF workshop, FLOMEKO, etc.. An on-site review by a technical expert can be an alternative.

Annex 2: Other CMC considerations

A2.1 - Scaling of CMCs in Flow Measurements
Scaling of Calibration and Measurement Capabilities (CMCs) is permissible in both directions—expansion and reduction—provided it is properly justified.

- Expansion of CMCs:
  For flow measurements, scaling to higher values is generally acceptable if supported by evidence. This expansion must be based on reasonable uncertainty claims, technical explanations and validation reports and is not applicable to very low uncertainty values (e.g., those listed in the first column of Annex 1). If a range extension is declared, it must be accompanied by a correspondingly larger uncertainty. Any other form of expansion must be supported by documented evidence.

- Reduction of CMCs:
  Scaling down is more challenging due to the increased complexity and sensitivity of measurements at lower levels. A reduction factor of 2 may be acceptable when using the same test bench, but this also requires justification. In general, downward scaling demands more rigorous validation due to the higher risk of underestimating uncertainties.

A2.2 - Direct Traceability via Internal Chain
Direct traceability established through an internal measurement chain must be clearly demonstrated and documented.
When using the same reference meter and balances, the setup may be considered nearly identical to the original test bench, but if it operates on a different line, it is treated as a separate configuration.
It is not necessary to include all lines in the CMCs, as long as traceability and equivalence are properly justified.
In the context of National Metrology Institutes (NMIs), only one En value per measurement point is recognized. Therefore, it is not permissible to participate in a comparison using two different lines for the same point, as this would compromise the integrity of the comparison and the traceability claims.

A2.3 - Consistency of Results in Comparisons
To consider a comparison valid, the number and quality of consistent results must meet reasonable statistical criteria.

- Minimum Acceptance Criteria:
  It is questionable to submit a CMC if 4 out of 5 points have En values greater than 1.2, as this indicates poor consistency.
  In a comparison involving 20 points, it is statistically acceptable for one point to fall outside the expected range, depending on the confidence level—95% confidence is a commonly used metric.
- Recommended Acceptance Thresholds (these criteria can be used for the evaluation each individual laboratory and also for the evaluation of the entire comparison as a whole):
  A comparison may be considered valid if at least 80% of the results meet the following conditions:

- $E_n < 1$
- $P_i > 0.35$
- Results are bidirectional and not clustered at the same extreme of the range

- Handling Inconsistencies:
  Even when the above criteria are met, it is recommended to conduct a bilateral comparison to investigate and resolve any inconsistent results. This helps ensure the robustness and reliability of the CMC submission.

A2.4 - Use of Pi for supporting comparison

Consistency in comparison results should not be evaluated solely based on En values. The P_i value—which reflects the probability of agreement between laboratories—can also be a valid and informative metric.

An example of data analysis in a comparison in presented in the following table.

a) represents laboratory results at "warning level" with $1.00 < E_N \leq 1.20$

d) represents inconclusive results with values of $P_i < 0.35$

		Expanded uncertainty (k = 2)				Criterion A	Criterion B	Criterion D	
Flow	Measure-ment error	Labo-ratory	Measure-ment	Transfer meter measure-ments	Degree of equiva-lence	Normalized degree of equivalence	$U_{comp,i}$ / $U_{lab,i}$	P_i	CMC decision status
	$\varepsilon_{lab,i}$	$U_{lab,i}$	$U_{\varepsilon,lab,i}$	$U_{comp,i}$	d_i	$E_{N,i}$			
(kg/h)	(%)	(%)	(%)	(%)	(%)	-	-	-	
50	-0.126	0.070	0.107	0.082	-0.09	0.91	1.16	0.08 d)	inconclusive
1 000	-0.049	0.030	0.055	0.046	-0.04	0.83	1.52	0.11 d)	inconclusive
2 000	0.015	0.030	0.050	0.040	0.01	0.17	1.32	0.99	passed
4 000	-0.024	0.030	0.045	0.033	-0.02	0.56	1.10	0.76	passed

		Expanded uncertainty (k = 2)				Criterion A	Criterion B	Criterion D	
Flow	Relative measure-ment error	Labo-ratory	Measure-ment	Transfer meter measure-ments	Degree of equiva-lence	Normalized degree of equivalence	$U_{comp,i}$ / $U_{lab,i}$	P_i	CMC decision status
	$\varepsilon_{lab,i}$	$U_{lab,i}$	$U_{\varepsilon,lab,i}$	$U_{comp,i}$	d_i	$E_{N,i}$			
(kg/h)	(%)	(%)	(%)	(%)	(%)	-	-	-	
4 000	-0.060	0.030	0.071	0.064	-0.07	1.06 a)	2.13	0.00 d)	warning level & inconclusive
10 000	0.041	0.030	0.048	0.037	0.02	0.37	1.25	0.91	passed
20 000	0.060	0.030	0.039	0.025	0.02	0.65	0.83	0.78	passed