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Version 1.1

Guidelines for Submission and Review of Calibration and Measurement Capabilities (CMCs)

Consultative Committee for Mass and Related Quantities (CCM)
Working Group on Force and Torque (CCM-WGFT)

1 Introduction

This document gives guidelines to readers both on the submission and on the review of calibration and measurement capabilities (CMCs) in the fields of force and torque.

Section 3 of CIPM MRA-G-13 [1] specifies the four criteria that need to be fulfilled in order to publish CMCs in the BIPM key comparison database (KCDB). These are:

- Metrological traceability of the national standard
- Metrological traceability of supporting measuring instruments that contribute to the measurement uncertainty
- Technical evidence
- Ensuring the validity of results

Within the "Technical evidence" section, it is specified that the range and measurement uncertainty of the CMCs should be consistent with information from at least some of the following sources:

- Results of key and supplementary comparisons
- Publicly-available information on technical activities, including publications
- Onsite 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

It goes on to state that, while key and supplementary comparison results are the ideal supporting evidence, the other specified sources may all be considered to underpin CMCs, and that Consultative Committees are responsible for providing specific guidance on the required technical evidence.

This document aims to give specific guidance on the submission, and subsequent review, of CMCs in the areas of force and torque. It details the required technical evidence to support CMCs in these two areas following a risk-based approach in which additional evidence is required to support more technically-challenging claims.

2 Technical evidence

This guidance mainly covers those CMCs related to the calibration of force or torque transducers within a force or torque standard machine, where the CMC is generally calculated and stated as the expanded uncertainty associated with the magnitude of the applied force or torque. There is also the option to apply for CMCs related to the calibrations of force calibration machines, reference torque wrenches, and torque tools calibration equipment. For these types of calibration, additional information is given later in this section.

As of May 2023, there are 226 force CMC lines within the CIPM MRA database (KCDB), all but two of which relate to transducer calibration. In the field of torque, there are 45 lines of which 39 relate to transducer calibration, five to reference torque wrench calibration, and one to torque tools calibration equipment. These transducer calibration CMCs are illustrated in Figure 1 and Figure 2 for force and torque respectively, but with no indication as to the standard machine's traceability principle. The markers represent the end points of individual CMC ranges – particularly within Figure 1, it can be seen that, at many levels of uncertainty, there are a large number of CMCs from different NMIs overlapping each other. It is also clear that, for the vast majority of CMCs in both force and torque, the claimed uncertainty is a constant value when expressed in relative terms.

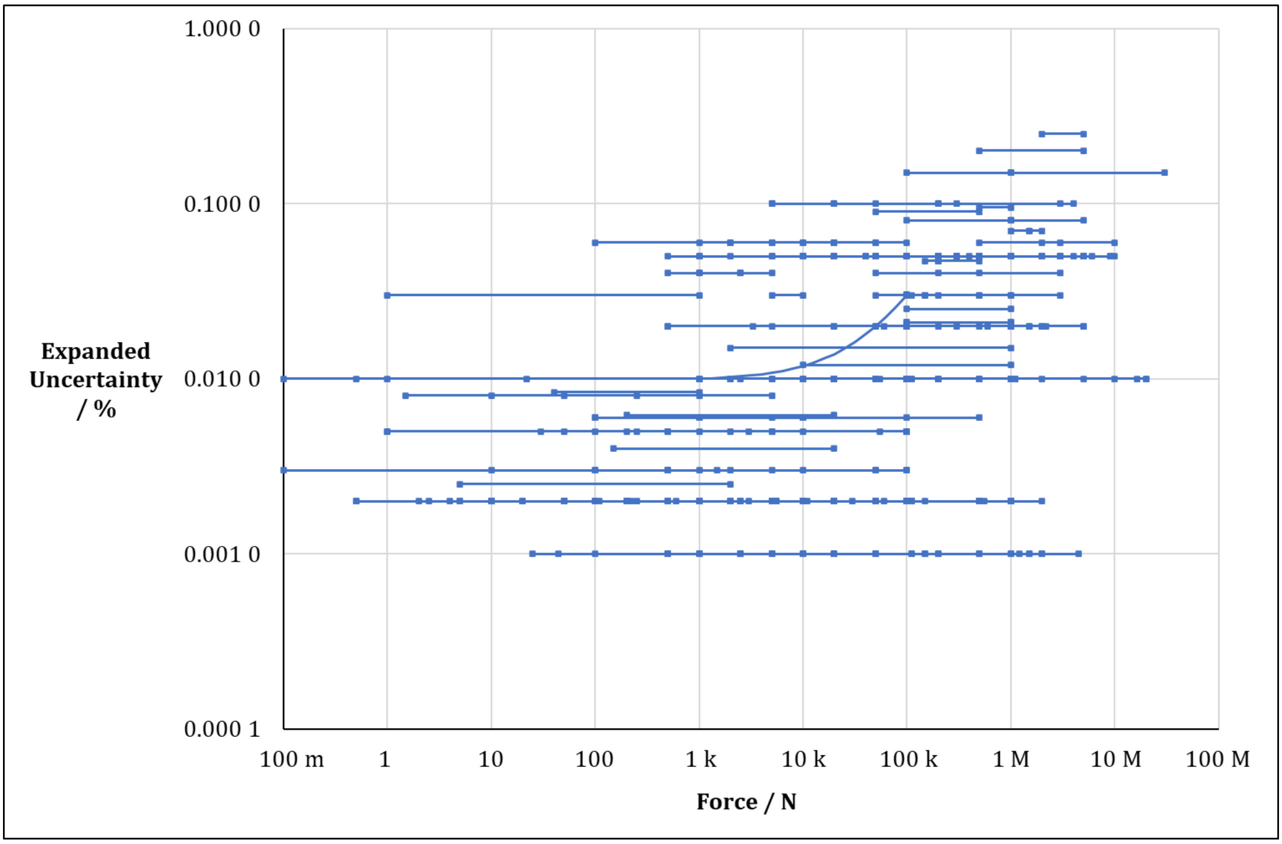


Figure 1: Force transducer calibration CMCs as of May 2023

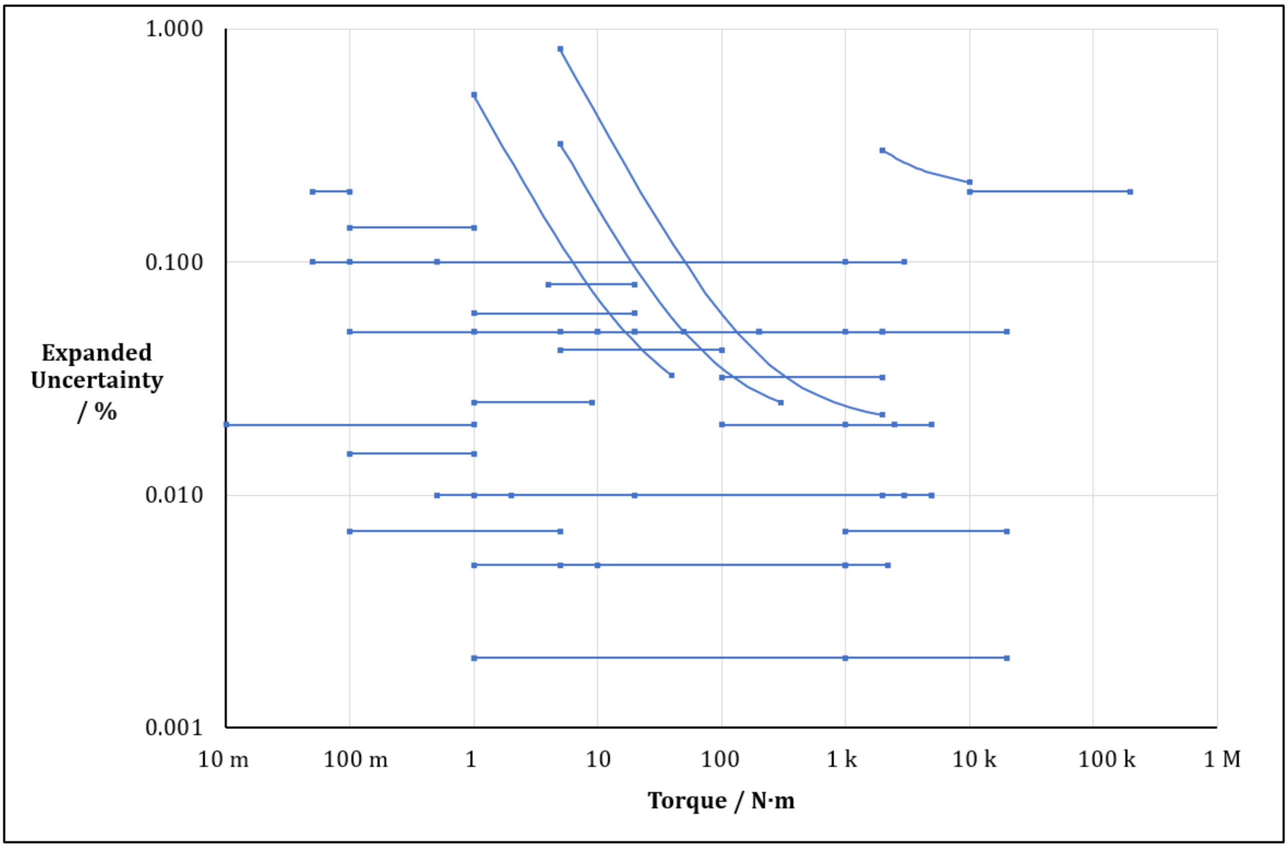


Figure 2: Torque transducer calibration CMCs as of May 2023

The general approach used within the WGFF and WGPV review guidance [2][3], in which a submitted CMC is assigned to one of three groups based on its level of difficulty, is employed. The level of difficulty is estimated as a function of up to three parameters:

- Claimed measurement uncertainty
- Principle of traceability, e.g. hydraulic amplification force, deadweight + lever torque
- In some cases, magnitude of applied force or torque

These difficulty levels are given in Table 1 and Table 2 for force and torque respectively. For a given traceability method and range, the difficulty level is determined on the basis of the claimed expanded measurement uncertainty W_{CMC}, expressed in relative terms, based in part on information contained within EURAMET Guide cg-04 [4]. Where W_{CMC} varies within the CMC range, its minimum value shall be used to determine the difficulty level. Note that, in this document, W is the designation for an expanded uncertainty expressed in relative terms while U is the designation for an expanded uncertainty expressed in units of either force (N) or torque (N·m).

For other methods of traceability, no uncertainty values relating to difficulty levels have yet been defined. It is up to the reviewers to use their experience to determine the level of evidence required to support the submitted CMC – these tables may be updated in future, based on these review exercises, to incorporate additional traceability methods.

Table 1: Force difficulty levels

Force traceability method	Force range	Difficulty level 1	Difficulty level 2	Difficulty level 3
Deadweight	$F \geq 1$ N	$W_{CMC} \leq W_1$ = 0.005 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.05 %
	$F < 1$ N	$W_{CMC} \leq W_1$ = 0.01 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.1 %
Hydraulic or lever amplification	all	$W_{CMC} \leq W_1$ = 0.01 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.1 %
Single reference transducer	$F \geq 10$ N	$W_{CMC} \leq W_1$ = 0.02 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.2 %
	$F < 10$ N	$W_{CMC} \leq W_1$ = 0.05 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.5 %
Multiple reference transducers / build-up system	all	$W_{CMC} \leq W_1$ = 0.02 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.2 %

Table 2: Torque difficulty levels

Torque traceability method	Torque range	Difficulty level 1	Difficulty level 2	Difficulty level 3
Deadweight + lever(s)	$T \geq 1$ N·m	$W_{CMC} \leq W_1$ = 0.005 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.05 %
	$T < 1$ N·m	$W_{CMC} \leq W_1$ = 0.01 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.1 %
Jockey weights + lever	all	$W_{CMC} \leq W_1$ = 0.02 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.2 %
Load cell(s) + lever(s)	all	$W_{CMC} \leq W_1$ = 0.02 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.2 %
Reference transducer	$T \geq 10$ N·m	$W_{CMC} \leq W_1$ = 0.02 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.2 %
	$T < 10$ N·m	$W_{CMC} \leq W_1$ = 0.05 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.5 %
Reference torque wrench*	all	$W_{CMC} \leq W_1$ = 0.02 %	$W_1 < W_{CMC} \leq W_3$	$W_{CMC} > W_3$ = 0.2 %
*used to calibrate torque wrench calibration equipment				

Where the CMC is related to the calibration of force calibration machines as detailed in, for example, [4], the difficulty level is determined from the single reference transducer rows in Table 1, and the minimum uncertainty level that the NMI wishes to be able to assign to the calibration machine.

Where the CMC is related to the calibration of the force indicator of testing machines (e.g. in accordance with ISO 7500-1 [5]), the difficulty level is determined from the expanded uncertainty of the calibration results of the calibrating instrument.

Similarly, in the field of torque calibration, the uncertainty associated with the calibration results of the torque instrument used for the calibration of torque generation equipment shall be used to determine the difficulty level.

For each difficulty level, a different amount of technical evidence is required to support it – this is the basic principle of the risk-based approach. As detailed in [1], comparison results are the ideal supporting evidence, but a combination of other sources may also be used. Rather than specifying exactly what is required in the way of supporting evidence, Table 3 assigns a points value to each of a range of different evidence sources. For a given CMC, these are summed and the total must equal or exceed the value for a given difficulty level as specified in Table 4. Note that, to meet any of the required points totals, a fully-documented uncertainty budget will always be needed.

Table 3: Technical evidence points values

Technical evidence	**Points**
CMC consistent with information from:	
Fully-documented uncertainty budget	16
Results of key or supplementary comparison	12
Onsite peer assessment reports	6
Publicly-available information on technical activities	4
Active participation in RMO projects	3
Other evidence of knowledge and experience	2

Table 4: Required points for difficulty levels

Difficulty level	**Required points**
1	36
2	31
3	28

In the event that the total does not reach the required value, either additional evidence should be supplied, or the uncertainty associated with the CMC should be increased. If no comparison is possible, the value of required points may be reduced by 12.

3 Submission of CMCs

An Excel template to assist in the submission of force and torque CMCs has been developed and can be accessed via the BIPM website. A screenshot of the template's "CMC" tab is given in Figure 3. There are five rows (row 6 to row 10) for FORCE entries and five rows (row 12 to row 16) for TORQUE entries – if further rows are needed, additional copies of the spreadsheet shall be used.

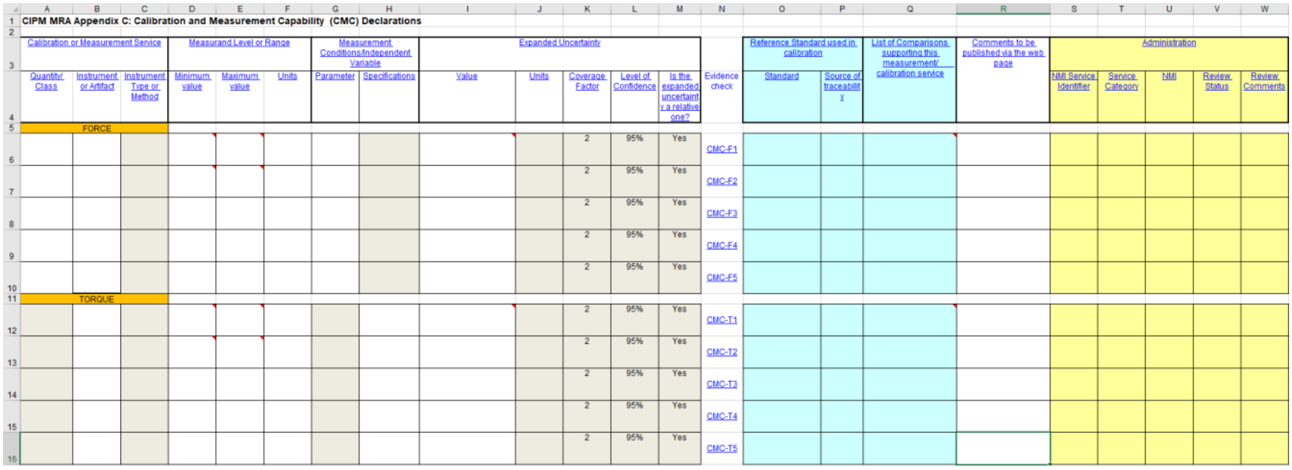


Figure 3: Excel template's "CMC" tab

The major aim when submitting a set of CMCs is to minimise the number of rows required to summarise the institute's calibration offering, by avoiding any duplication of information resulting from overlapping measurement ranges. For example, three deadweight force standard machines covering overlapping force ranges, each with an expanded uncertainty of 0.002 %, shall be recorded in a single row, with the minimum and maximum forces being based on the minimum force from the lowest capacity machine and the maximum force from the highest capacity one. Where a higher capacity machine with an overlapping measurement range has a larger uncertainty, a new CMC row shall be submitted, with the minimum force set equal to the maximum force associated with the lower uncertainty range rather than the minimum force of the higher uncertainty machine. Similarly, where a lower capacity machine with an overlapping measurement range has a larger uncertainty, a new CMC row shall be submitted, with the maximum force set equal to the minimum force associated with the lower uncertainty range rather than the maximum force of the higher uncertainty machine. In this way, the CMC will be based simply on the magnitude (and possibly mode) of the applied quantity, not the machine in which the quantity is realised, as illustrated in Figure 4.

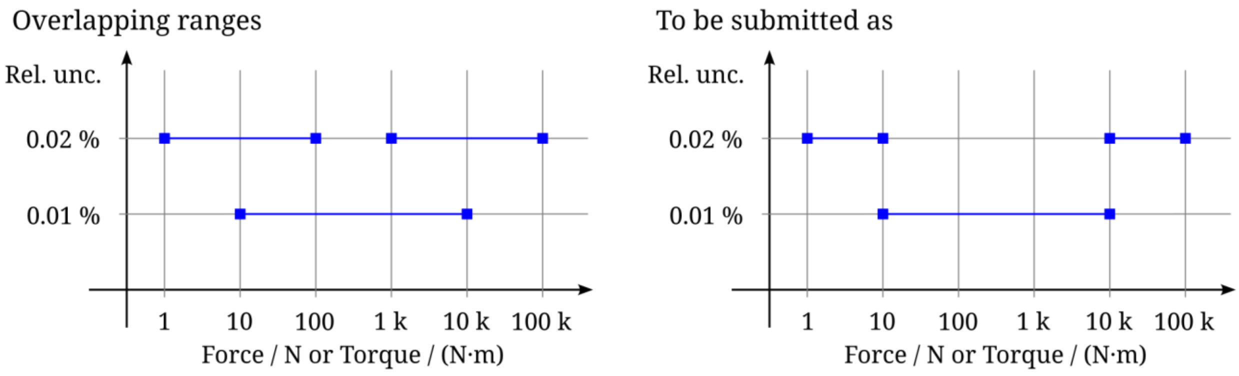


Figure 4: CMC submission for overlapping ranges

The completed spreadsheet should be submitted to the relevant RMO together with all required technical evidence to support all CMCs being applied for.

Advice about the required inputs in the various columns is given in the following sections – information in columns preceded by an asterisk (*) is not published in the KCDB.

3.1 Column A – Calibration or Measurement Service – Quantity/Class

For FORCE, the pull-down list gives options of:

- Force - tension and compression
- Force - tension only
- Force - compression only

No selection is required for TORQUE entries.

3.2 Column B – Calibration or Measurement Service – Instrument or Artifact

For FORCE, the pull-down list gives options of:

- Force measuring device
- Force calibration machine

For TORQUE, the pull-down list gives options of:

- Torque measuring device
- Reference torque wrench
- Torque tools calibration equipment

Any of these torque choices will automatically insert "Torque" in column A.

3.3 Column C – Calibration or Measurement Service – Instrument Type or Method

This column is currently not required for force or torque applications and is therefore left blank.

3.4 Column D – Measurand Level or Range – Minimum value

This is the minimum value, expressed in the units specified in column F, of the force or torque range to which the expanded uncertainty given in column J applies.

Numbers can be integers (e.g. 1, 1000), decimal fractions (e.g. 0.1, 0.0001), or expressed in scientific notation (e.g. 1E3, 1E-3, 1.2E-3). Note that no digit grouping characters are permitted, and exponential positive symbols and leading zeroes are not required. Examples of correctly formatted numbers are given in the note which appears when hovering the cursor over the cell.

3.5 Column E – Measurand Level or Range – Maximum value

This is the maximum value, expressed in the units specified in column F, of the force or torque range to which the expanded uncertainty given in column J applies. The number formatting rules given for column D also apply here.

3.6 Column F – Measurand Level or Range – Units

For FORCE, the pull-down list gives the SI unit options of:

- mN
- N
- kN
- MN

For TORQUE, the pull-down list gives the SI unit options of:

- mN m
- N m
- kN m
- MN m

3.7 Column G –Measurement Conditions/Independent Variable – Parameter

For force CMCs, the default assumption is that the CMC applies to both incremental and decremental forces. For incremental-only forces, the pull-down list for this cell gives the option to select “Force application mode” and “incremental only” is automatically inserted in column H.

For torque CMCs, “Torque application mode” is automatically inserted if a selection is made in column H.

3.8 Column H – Measurement Conditions/Independent Variable – Specifications

For force CMCs, “incremental only” is automatically inserted if “Force application mode” is selected in column G.

For torque CMCs, the default assumption is that the CMC applies to both incremental and decremental loading and to both clockwise and anticlockwise torque application. If this is not the case, the pull-down list gives options of:

- incremental only
- clockwise only
- incremental only and clockwise only

3.9 Column I – Expanded Uncertainty – Value

The default assumption is that this expanded uncertainty is given in percentage terms and applies to the whole range, so any single number entered in this cell will be treated as such, with “%” being automatically entered in column J.

If the uncertainty is to be given in percentage terms but this percentage value varies throughout the range as an inverse function of force or torque, the corresponding equation should be entered in this cell, using the symbols “F” and “T” for force and torque respectively, expressing their values in units of newtons (N) or newton-metres (N m), and using “N” or “N m” to represent other quantities within the equation. Where “F” or “T” is used within the entry, the entry must be completed by either “; F in N” or “; T in N m”. For example, if an expanded uncertainty decreases from 0.02 % to 0.01 % in the range from 20 kN to 100 kN, this relationship would be represented by the equation $W = 0.0075 + 250\ \mathrm{N} / F$ and entered into the cell as “0.0075 + 250 N / F; F in N”. Note that if either of the terms in the equation is preceded by a negative sign, this must be the first term of the equation. Again, “%” is automatically entered in column J.

If the uncertainty is a fixed amount throughout the range in either force or torque units, this should be expressed by entering the value and its associated unit (N or N m) in this cell. “N” or “N m” are then automatically entered in column J.

If the uncertainty, expressed in N or N m, varies linearly throughout the range as a function of force or torque, the corresponding equation should be entered in this cell, using the symbols “F” and “T” for force and torque respectively, expressing their values in units of newtons (N) or newton-metres (N m), and using “N” or “N m” to represent other quantities within the equation. Again, where “F” or “T” is used within the entry, the entry must be completed by either “; F in N” or “; T in N m”. For example, if an expanded uncertainty increases linearly from 0.016 N m to 0.075 N m in the range from 5 N m to 300 N m, this relationship would be expressed by the equation $U = 0.015\ \mathrm{N\ m} + 0.0002\ T$ and entered as “0.015 N m + 0.0002 T; T in N m”, with “N m” being automatically entered in column J. Again, if either of the terms in the equation is preceded by a negative sign, this must be the first term of the equation. Note that neglecting the constant term in such an equation would result in a quantity, rather than percentage, input – entries of “0.0002 T; T in N m” and “0.02” would be equivalent as both would represent 0.02 % of the applied torque but, for consistency between CMC entries, the simpler percentage option (“0.02”) is preferred.

Examples of correctly formatted equations are given in the note which appears when hovering the cursor over the cell.

Note that the only use of the “+” symbol should be as the separator between the two terms in a two-term equation.

3.10 Column J – Expanded Uncertainty – Units

The cell is automatically filled in based on the format of the entry given in column I.

3.11 Column K – Expanded Uncertainty – Coverage Factor

A default value of 2 is used for the coverage factor in this cell. If the uncertainty has been calculated for a different coverage factor, it should be recalculated for a coverage factor of 2, to ensure consistency between entries for users of the KCDB.

3.12 Column L – Expanded Uncertainty – Level of Confidence

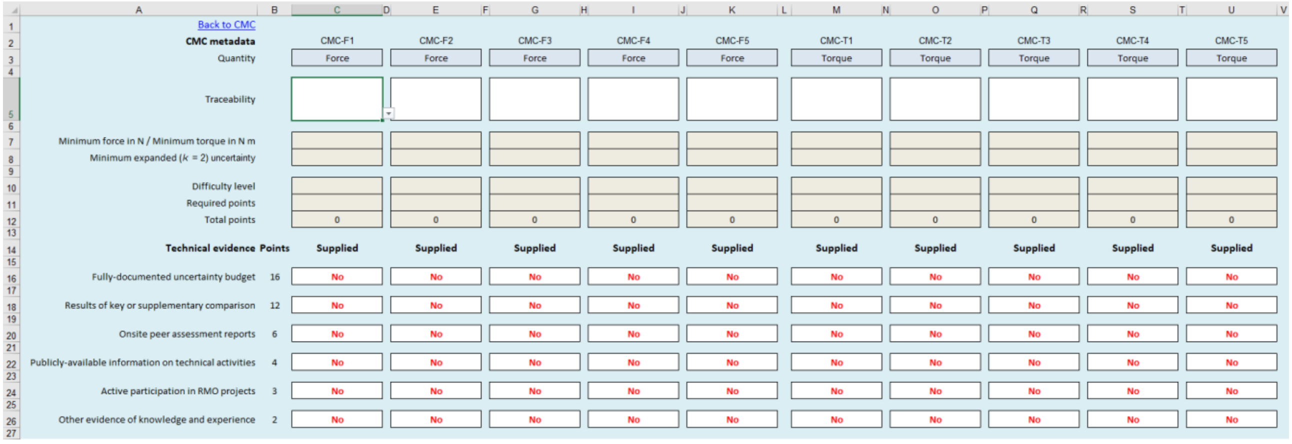
A default level of confidence of 95 %, relating to the coverage factor of 2 entered in column K, is automatically entered in this cell.

3.13 Column M – Expanded Uncertainty – Is the expanded uncertainty a relative one?

This cell is automatically completed based on the value of Units given in column J – for a Units entry of “%”, column M reads “Yes” while, for a Units entry of “N” or “N m”, column M reads “No”.

3.14 Column N – Evidence check

For each row, this column gives a hyperlink to the cell in the “Evidence” tab in which the measurement traceability for this CMC line is recorded. Once the traceability path has been selected from the pull-down list, the cells below it should correctly display the minimum force or torque value, the minimum expanded uncertainty being applied for within the force or torque range, the difficulty level associated with the CMC, and the required number of technical evidence points, together with a running total of the points obtained based on the selections made in rows 16 to 26 of the "Evidence" tab (screenshot shown in Figure 5).



		CMC-F1	CMC-F2	CMC-F3	CMC-F4	CMC-F5	CMC-T1	CMC-T2	CMC-T3	CMC-T4	CMC-T5
Back to CMC											
CMC metadata		CMC-F1	CMC-F2	CMC-F3	CMC-F4	CMC-F5	CMC-T1	CMC-T2	CMC-T3	CMC-T4	CMC-T5
Quantity		Force	Force	Force	Force	Force	Torque	Torque	Torque	Torque	Torque
Traceability											
Minimum force in N / Minimum torque in N m											
Minimum expanded (k = 2) uncertainty											
Difficulty level											
Required points											
Total points		0	0	0	0	0	0	0	0	0	0
Technical evidence	**Points**	**Supplied**	**Supplied**	**Supplied**	**Supplied**	**Supplied**	**Supplied**	**Supplied**	**Supplied**	**Supplied**	**Supplied**
Fully-documented uncertainty budget	16	No	No	No	No	No	No	No	No	No	No
Results of key or supplementary comparison	12	No	No	No	No	No	No	No	No	No	No
Onsite peer assessment reports	6	No	No	No	No	No	No	No	No	No	No
Publicly-available information on technical activities	4	No	No	No	No	No	No	No	No	No	No
Active participation in RMO projects	3	No	No	No	No	No	No	No	No	No	No
Other evidence of knowledge and experience	2	No	No	No	No	No	No	No	No	No	No

Figure 5: Excel template's "Evidence" tab

3.15 * Column O – Reference Standard used in calibration – Standard

If traceability to the SI is obtained from another NMI, specify the identity of the standard used to perform the calibration.

3.16 * Column P – Reference Standard used in calibration – Source of traceability

If traceability to the SI is obtained from another NMI, specify the name/acronym of this NMI (from which the standard entered in column O obtains its traceability) together with the names of any intermediate laboratories.

3.17 * Column Q – List of Comparisons supporting this measurement/calibration service

List the identifiers, separated by semi-colons, of all comparisons which support this CMC.

3.18 Column R – Comments to be published via the web page

Information listed in this cell will be published with the CMC and may include items such as restrictions on the scope of the service requested by reviewers. The publication date is automatically added by the KCDB.

3.19 Column S – Administration – NMI Service Identifier

This is the internal NMI identifier for the associated measurement service – identifiers including blank spaces or series of words should be avoided.

3.20 * Column T – Administration – Service Category

This is the service number drawn from the list of CCM service categories. Currently the relevant ones are:

- 4.1.1 Force – Tension – Force-measuring device
- 4.1.2 Force – Compression – Force-measuring device
- 4.1.3 Force – Tension and compression – Force-measuring device
- 5.1.1 Torque – Torque – Torque-measuring device

3.21 Column U – Administration – NMI

This is the official abbreviation for the NMI (or other service provider) responsible for the CMC declaration.

3.22 * Column V – Administration – Review Status

This cell is used by the RMO review panel.

3.23 * Column W – Administration – Review Comments

This cell is used by the RMO review panel for comments or by the issuing NMI to communicate comments to reviewers.

4 Review of CMCs

4.1 Background

The CCM Strategy Document for 2022-2032 [6] states that, to support and simplify the process of CMC review, "specific guidance on criteria for a risk-based approach in each mass related quantity will be established by the relevant CCM Working Group".

This section of the document aims to give specific guidance on the review of CMCs in the areas of force and torque. This guidance has been prepared for, and may relate to, either the intra-RMO review of the submitted CMC or the subsequent JCRB (inter-RMO) review.

4.2 Approach

It is the responsibility of the NMI submitting the CMC to ensure that the required technical evidence to support the CMC is made available. The purpose of the review is to ensure that the submitted technical evidence does indeed support the requested CMC. Guidance on the validity of the technical evidence is given in the following sections.

<u>Fully-documented uncertainty budget</u>

For all CMCs, the associated uncertainty budget shall cover the full range of forces / torques and include all potentially significant uncertainty contributions, resulting in uncertainty values equal to or lower than those being applied for. For a number of different machine types, reference [4] details a non-exhaustive list of potential uncertainty sources – each list can act as a useful starting point for the development of an uncertainty budget for that specific machine type but, for any individual machine, other sources of uncertainty may also be present.

<u>Results of key or supplementary comparison</u>

The results of the comparison submitted as evidence shall demonstrate that, with the uncertainty associated with the CMC, the NMI's results would be consistent with the comparison's final reference value/s. A short report detailing a critical analysis of the results would be useful additional evidence supporting both the CMC and technical competence of the NMI, particularly for difficulty level 1 or 2 submissions. Comparisons shall have been carried out in the appropriate force ranges for such evidence to be applicable, as is also the case where the submitted CMC relates to the calibration of force calibration machines.

<u>Onsite peer assessment reports</u>

The onsite peer assessment (or accreditation assessment with appropriate technical peers) shall have included validation of the uncertainty budget associated with the CMC and verification of the traceability of the national standard and supporting measurement instruments. It is also permissible for the assessment to have been performed virtually.

Publicly-available information on technical activities

For this evidence, at least one peer-reviewed publication referencing the performance of the standard is mandatory. Copies of relevant publications should be submitted by the NMI as part of the evidence package supporting its CMC submission.

Active participation in RMO projects

It should be checked that the scope and content of the cited RMO projects relate specifically to the CMC being applied for.

Other evidence of knowledge and experience

This evidence will, by definition, be slightly more subjective and will be affected by the individual reviewer's knowledge of the NMI submitting the CMC. Objective evidence submitted by the NMI could include recent metrics related to the experience of laboratory staff (numbers, lengths of service), scientific activities (comparisons performed, papers published), and measurement services (annual numbers of calibrations, consultancies, training courses).

5 References

[1] CIPM MRA-G-13, "Calibration and measurement capabilities in the context of the CIPM MRA – Guidelines for their review, acceptance and maintenance", Version 1.2, July 2022

[2] CCM-WGFF, "Review Protocol for Fluid Flow Calibration and Measurement Capabilities", August 2014

[3] CCM-WGPV, "Guideline for reviewers of CMC entries in the field of the CCM WG Pressure and Vacuum: Risk based approach", December 2022

[4] EURAMET Calibration Guide No. 4, "Guidelines on the Uncertainty of Force Measurements", Version 3.0, February 2022

[5] ISO 7500-1, "Metallic materials – Calibration and verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Calibration and verification of the force measuring system", February 2018

[6] CCM, "Strategy 2022-2032", Version 1.8, March 2022

Document History

Version	Date	Approval	Remarks
1.0	2023-05-16		Draft document produced after first subgroup meeting
1.01	2023-05-17		Edits to Figure 2 (removal of torque wrench lines) and Table 2 (F changed to T). DRAFT watermark added
1.02	2023-06-12		Comments incorporated for discussion at second subgroup meeting
1.03	2023-06-13		Version edited during second subgroup meeting
1.04	2023-12-01		Include references to Excel template
1.1	2024-04-11	WGFT	First publicly-available version