# Challenges to the use of the GUM:

- **Issues with the uncertainty evaluation associated with the calibration of indicating instruments**
- **The growing problem with "outlier rejection" in measurements with measurands defined by "extreme values"**

Steve Phillips (NIST)

In collaboration with

Alessandro Balsamo (INRIM)

Michael Krystek (PTB)

Craig Shakarji (NIST)

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# Industrial problems with the uncertainty associated with the calibration of indicating measuring instruments

- **Industrial practice frequently includes incorrect uncertainty contributors**
- **The problem affects most dimension calibration labs (and others…), worldwide**
- **The issue involves confusion about the measurand**

Expanded Uncertainty in Verifying Specification

Caliper Accuracy Specification

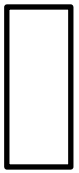
Survey presented at ISO TC213 WG6 on Digital Caliper calibration uncertainty

| Country | Uncertainty (±) | $E_{MPE}$ (±) | Zone of compliance (Apply ISO 14253-1) (±) | Proof of conformance (Apply ISO 14253-1) |
|---|---|---|---|---|
| France | 23 µm | 60 µm | 37 µm | Possible |
| UK | 16 µm | 20 µm | 4 µm | Not possible |
| Germany | 36 µm | 30 µm | none | Not possible |

Our Message:

- The GUM is “correct” but requires some careful thinking to address this subject; some explicit GUM examples are needed to definitively resolve this issue for practitioners

## Calibration of steel artifacts
## $0 < L \leq 10$ mm

Length Measurand defined by ISO XXX

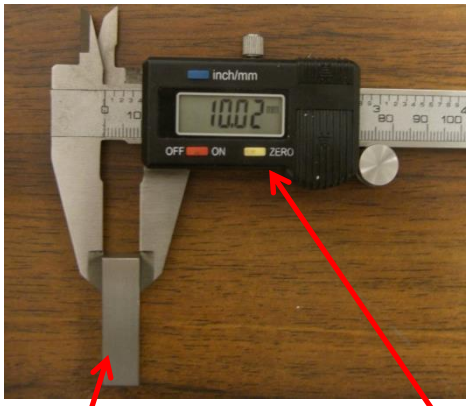
$L \pm 0.2$ @ T=20 °C

Specification by artifact designer

**Unknown** Information = Value of the manufacturing Error = Reference – Design Value

**Known** Information= Reference value of the calibrated Instrument
Ref = indicated value
$U_{ref} = 0.030$

## Calibration of a digital caliper for measuring steel artifacts $0 < L \leq 10$ mm




Accuracy Measurand defined by ISO YYY for one measurement

MPE = $\pm$ 0.03
18 °C $\leq$ T $\leq$ 22 °C

Specification by caliper manufacturer

**Known** Information = Reference Value from the Calibrated Gauge
Ref = 10.000000
$U_{ref} = 0.000051$

**Unknown** Information = Caliper Error = Indicated – Ref. Value

**Role Reversal**

Value of Manufacturing Error
= 10.090000 – 10.00000
= 0.090000

Value of Caliper Error
= 10.020000 – 10.000000
= 0.020000

**Report of Calibration of Steel Artifacts**

| L | Manufacturing Error | Uncertainty |
|---|---|---|
| 1.0 | 0.140 | 0.030 |
| 1.1 | -0.030 | 0.030 |
| … | … | … |
| 10.0 | 0.090 | 0.030 |

Quality of Artifact manufacturing

Quality of Calibration measurement

The magnitude of the manufacturing errors do not affect the uncertainty of their measurement.

**Report of Calibration of Digital Caliper for Measuring Steel Artifacts**

| L | Caliper Error | Uncertainty |
|---|---|---|
| 1.0 | 0.010000 | 0.000051 |
| 1.1 | -0.020000 | 0.000051 |
| … | … | … |
| 10.0 | 0.020000 | 0.000051 |

Quality Caliper manufacturing

Quality of Calibration measurement

The magnitude of the caliper errors do not affect the uncertainty of their measurement.

**Uncertainty in Manufacturing Error**

| Source | Std. Unc. | Type | Notes |
|---|---|---|---|
| Ref. Std. (Caliper) | 0.015 = MPE/2 | B | From calibration report MPE=0.030 |
| Thermal * | 0.000005 | B | CTE uncertainty |
| $U_{k=2}(L)$ | 0.030 | | |

*uncertainty in the CTE value requested by the instrument; Measurement at T = 21 °C

**Uncertainty in Caliper Error**

| Source | Std. Unc. | Type | Notes |
|---|---|---|---|
| Ref. Std. (Gauge block) | 0.000025 | B | From $U/2$ on gauge cal. report |
| Thermal * | 0.000005 | B | CTE uncertainty |
| $U_{k=2}(E)$ | 0.000051 | | |

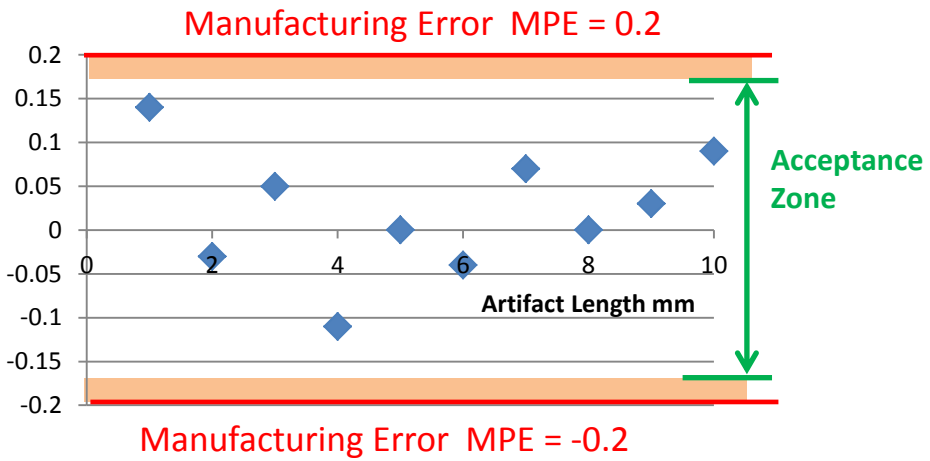
*uncertainty in the CTE value of the gauge block; Measurement at T = 21 °C

# What should happen next…

**Report of Calibration of Steel Artifacts**

| L | Manufacturing Error | Uncertainty |
|---|---|---|
| 1.0 | 0.140 | 0.030 |
| 1.1 | -0.030 | 0.030 |
| … | … | … |
| 10.0 | 0.090 | 0.030 |

Use the Cal. Report and perform "guarded acceptance" with a guardband = $U$ = 0.030



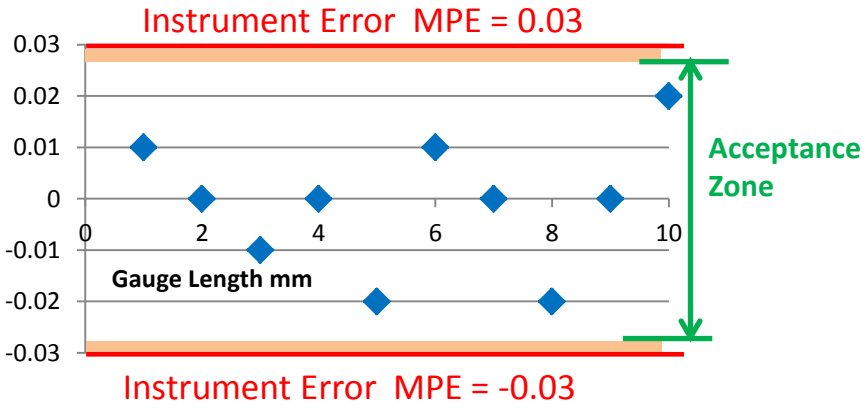

All manufacturing Errors are within the guarded acceptance zone…

This IS the current industrial practice ☺

**Report of Calibration of Digital Caliper for Measuring Steel Artifacts**

| L | Caliper Error | Uncertainty |
|---|---|---|
| 1.0 | 0.010000 | 0.000051 |
| 1.1 | -0.020000 | 0.000051 |
| … | … | … |
| 10.0 | 0.020000 | 0.000051 |

Use the Cal. Report and perform "guarded acceptance" with a guardband = $U$ = 0.000051




All caliper Errors are within the guarded acceptance zone…

Unfortunately, this is NOT current industrial practice… ☹

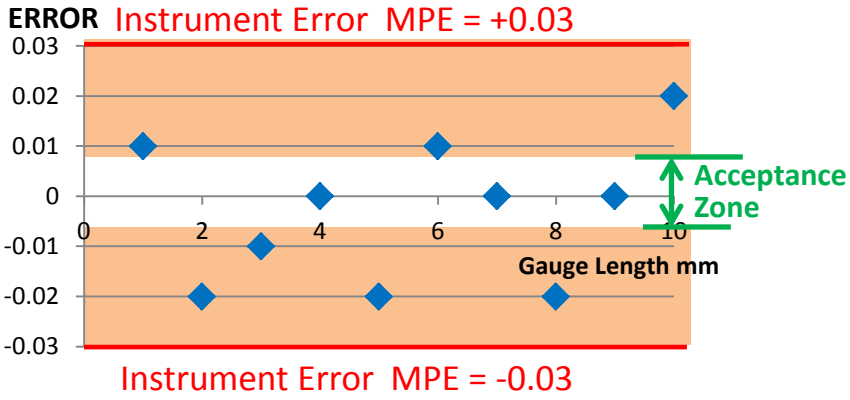
# What usually happens next for calibrating indicating instruments…

**Report of Calibration of Digital Caliper for Measuring Steel Artifacts**

| L | Caliper Error | Uncertainty | Uncertainty |
|---|---|---|---|
| 1.0 | 0.010000 | 0.000051 | 0.021005 |
| 1.1 | -0.020000 | 0.000051 | 0.021005 |
| … | … | … | |
| 10.0 | 0.020000 | 0.000051 | 0.021005 |

| Source | Std. Unc. | Type | Notes |
|---|---|---|---|
| Ref. Std. (Gauge block) | 0.000025 | B | From $U/2$ on gauge cal. report |
| Thermal * | 0.000005 | B | CTE uncertainty |
| Repeatability | 0.010502 | A | from "instrument" |
| $U_{k=2}(L)$ | 0.021005 | | |

Use the Cal. Report and perform "guarded acceptance" with a guardband = $U$ = 0.021005




Many caliper Errors are OUTSIDE the guarded acceptance zone…

The Mistake is thinking that the caliper is the "instrument" – it is NOT – it is the unknown quantity under test. The "instrument" is the known quantity – the calibrated gauge block, and its small repeatability is already included via the thermal uncertainty source.

Proper evaluation of Repeatability will reduce the uncertainty associated with verification to specifications to < 0.1 µm

Survey presented at ISO TC213 WG6 on digital caliper calibration uncertainty

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| France | 23 µm | 60 µm | 37 µm | Possible |
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The caliper repeatability is included in the MPE, and it is the MPE that is characterizes the uncertainty of the caliper when evaluating the uncertainty of a subsequent measurement made using the caliper

# Helpful Hints for Determining Uncertainty Sources for Indicating Instrument Calibrations

- Think about:
  - the “known information” providing the calibration
  - the “unknown information” under calibration
- The term “instrument” needs to be clearly associated with the Known Information

From This Perspective…

- Uncertainty sources arise from:
  - Imperfect information about the known quantity, i.e., the reference value (including its repeatability!)
  - Imperfect realizations of required measurement conditions that **DO** create dispersion in the Errors.


**A Caliper is the indicating instrument under calibration**

MPE = $\pm$ 0.03 when 18 °C $\leq$ T $\leq$ 22 °C

Measurement at 21 °C

Imperfect CTE Information: 11 < CTE < 12

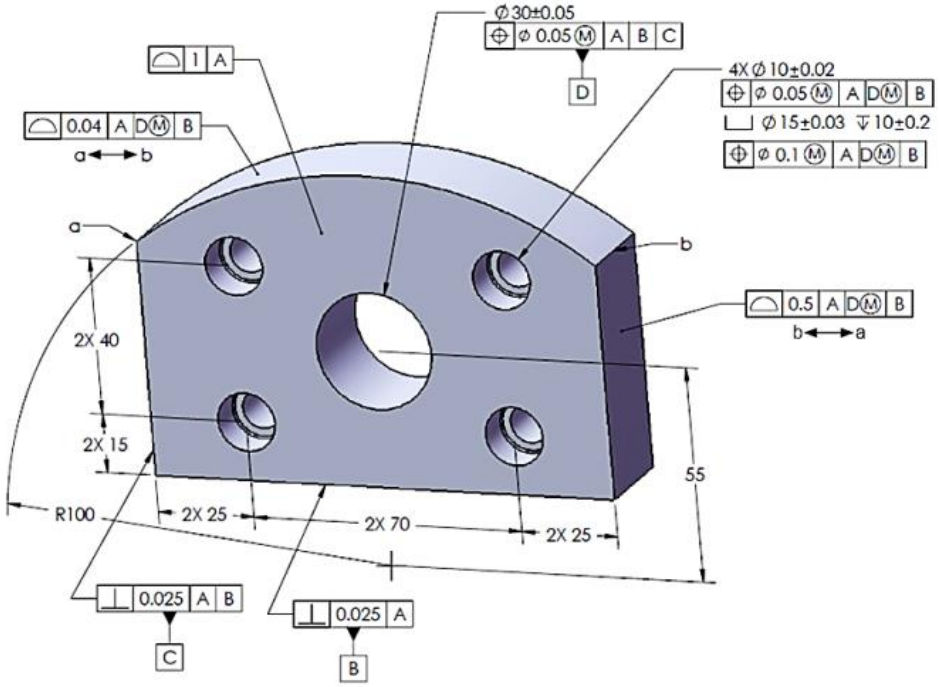
| | Uncertainty Source? YES | NO |
|---|---|---|
| 1. Caliper Requires the user entered CTE value for normal operation: | ✓ | |
| 2. Caliper Does Not Require the CTE value for normal operation: | | ✓ |
| 3. Caliper Requires Selection of CTE via a pull down menu listing materials: “glass”, “steel”, “aluminum” & We select “steel”: | | ✓ |
| 4. Caliper Requires Selection of CTE via a pull down menu listing selected values: “10.5”, “11.5”, “12.5” & We select “11.5”: | | ✓ |
| 5. Caliper Requires Selection of CTE via a pull down menu listing selected values: “10.4”, “11.1”, “11.8”, “12.5” & We select “11.8”: | ✓ | |

## Summary of Measurement Uncertainty Associated with the Calibration of Indicating Instruments

- Widespread problem in industry & calibration labs
- The GUM provides a consistent and unified approach to the calibration of both artifacts and instruments but careful consideration is needed to successfully address each case
- We believe the problem has a well-defined solution:
  GUM “instrument” ≡ system providing the Known Information
- Industrial practitioners would greatly benefit from explicit examples in the GUM

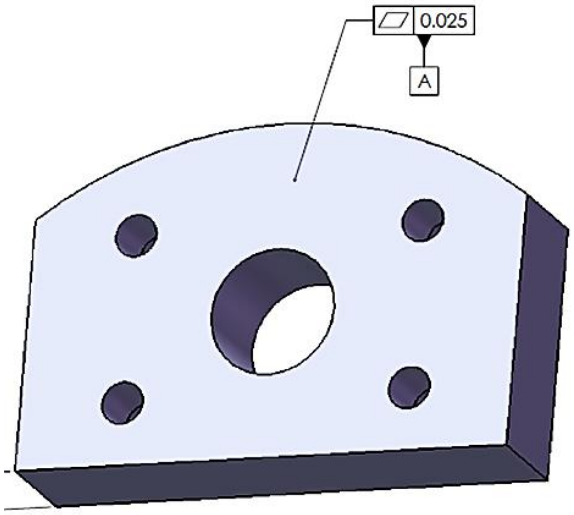
**The growing problem in with "outlier rejection" in measurements with measurands defined by "extreme values"**

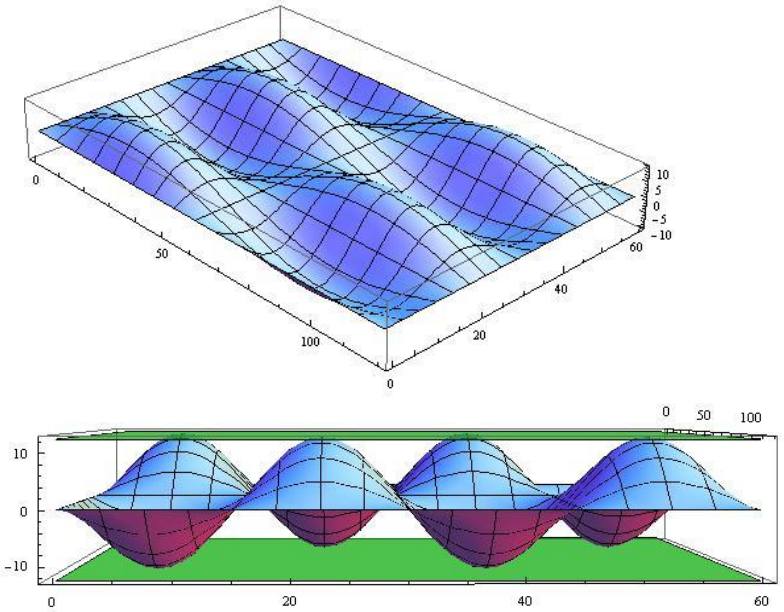
- In Dimensional Metrology (DM) the measurands of geometrical features, e.g., size, location, orientation and form, are determined entirely by the "extreme" points on the feature surface



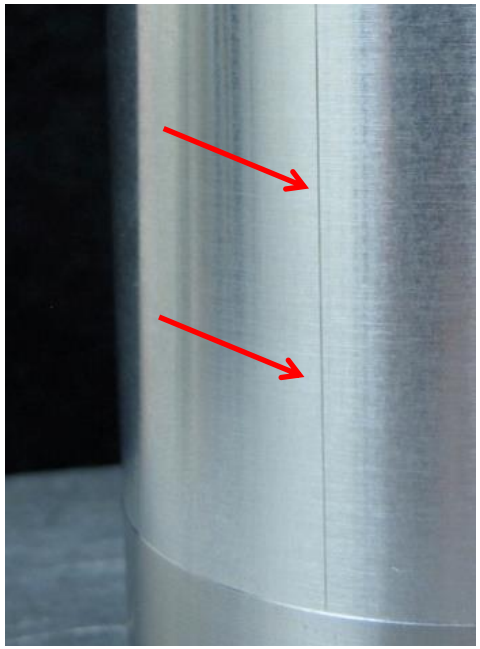
- For example: The Flatness of a plane is defined the distance between two parallel planes.

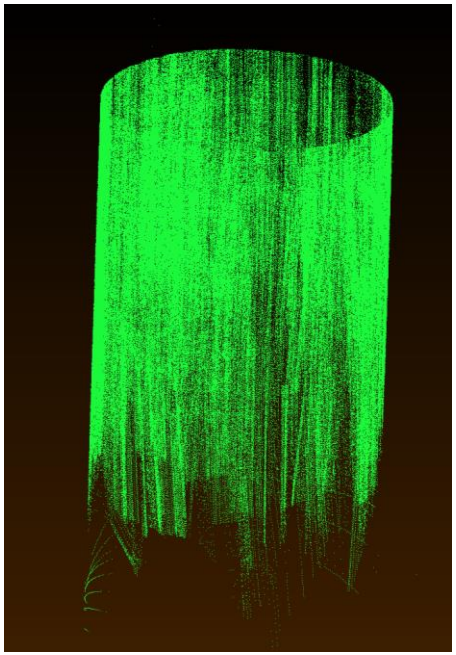
(Only a few points on the physical surface determines the flatness value)



- In the past 20 years DM measurements have increased point coordinate collection from $10^2 \rightarrow 10^7$ points.
- Outlier rejection is now a significant problem because:
  - the “real” extreme points that determine the true value of the measurand may also be rejected by the outlier filter…
  - Averaging repeated measurement results converges on the magnitude of the mean erroneous outlier value…





# The GUM Does Comment on Blunders & Mistakes… But Not on Outliers…

- No consistent definition of outliers…
- Outlier filters are widely used but not reported…
- Changing filters on the same raw data set can change the measured value (e.g., by 10 *U)*, but no uncertainty source for this in the *U* budget
- Some argue that outliers are mistakes and hence do not need to be addressed by uncertainty
- The GUM is silent on this topic…
  - Even a short paragraph about this issue in the GUM would be valuable!

# Closing Thoughts

- Uncertainty of Calibrating Indicating instruments
  - A wide spread problem
  - Has a well-defined solution: Examples in the GUM
- Outlier rejection of large data sets
  - A wide spread problem
  - Some general guidance in the GUM would be valuable

Thank You For the Opportunity to
Discuss these Issues