

A QIF-supported workflow for estimating CMM measurement uncertainty through simulation

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What is measurement uncertainty?

*VIM 3 (JGCM 200:2012): [Uncertainty is a] “non-negative parameter characterizing the dispersion of the **quantity values** being attributed to a **measurand**, based on the information used”*

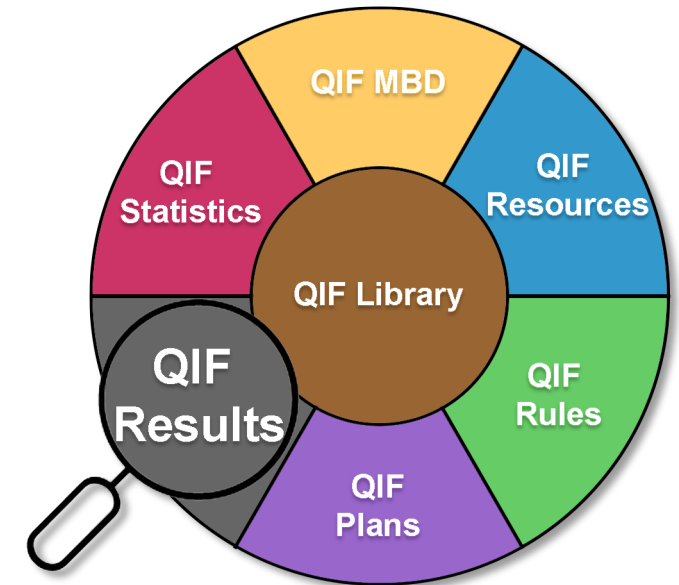
Uncertainty is an expression that describes the distribution of numerical values that could be assigned to a measurement result

Uncertainty is often how we communicate how “good” we think a measurement result is or how sure we are that the measurement result reflects reality



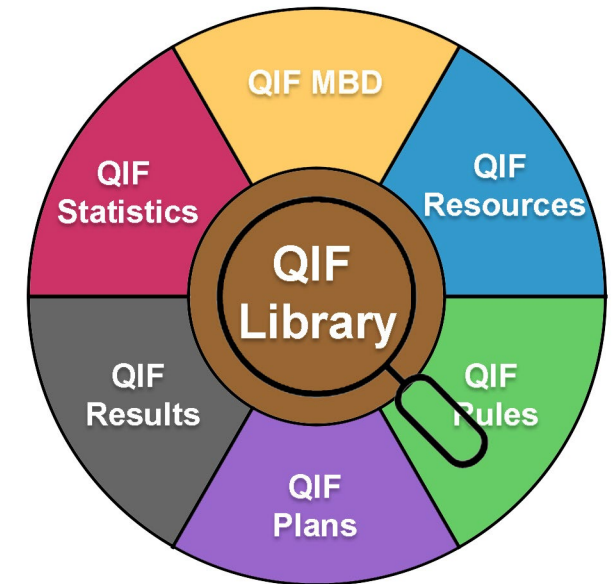
Measurement uncertainty in QIF

- Attached to QIF measurement results, not often used
 - Appears as an XML attribute to the MeasuredDoubleType
 - Also appears on Digital Calibration Certificates (DCCs)
- Uncertainty estimates can be time consuming
 - Sometimes conceptually difficult
 - Required data not always easy to find
- Automated (or semiautomated) uncertainty estimates would be useful



What uncertainty contributors can we find in QIF?

- Model-based definition (MBD) can be used to inform definition of measurand
- Instrument specifications in QIF Resources
 - Maximum Permissible Error (MPE) useful when more detailed information unavailable
- Statistical studies
 - Gage R&R, bias studies, stability/drift testing
- Digital Calibration Certificates (DCCs)
 - State uncertainty of reference artifact calibrations
- Environmental data
 - Object/ambient temperature, humidity, air pressure



Case study: CMM task-specific uncertainty

- What is task-specific measurement uncertainty?
 - Exactly what it says it is?
- Coordinate measuring machines are complex devices
 - Often three or more independently-moving axes
- Would a form measurement of an engine cylinder bore have the same errors as measuring the length of a long bar?
 - Characteristics are different in shape and in scale
 - Different sampling point distributions and evaluation algorithms
- Is measuring a vertical length equivalent to measuring a horizontal length?
 - Measuring along different axes could introduce different errors

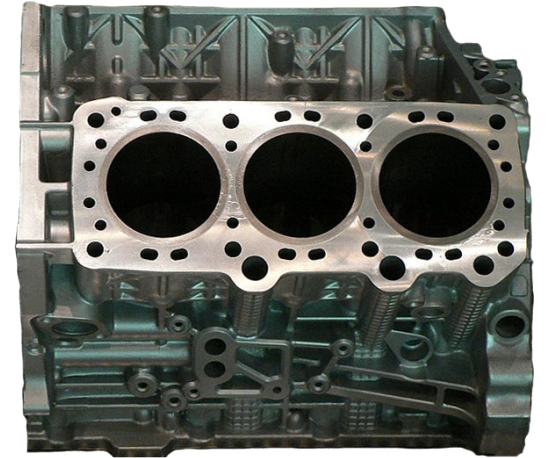


Image adapted from
https://commons.wikimedia.org/wiki/File:Cylinder_block_for_V6_Diesel.jpg
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In other words, they are different **tasks** that each require their own **specific uncertainty** estimates

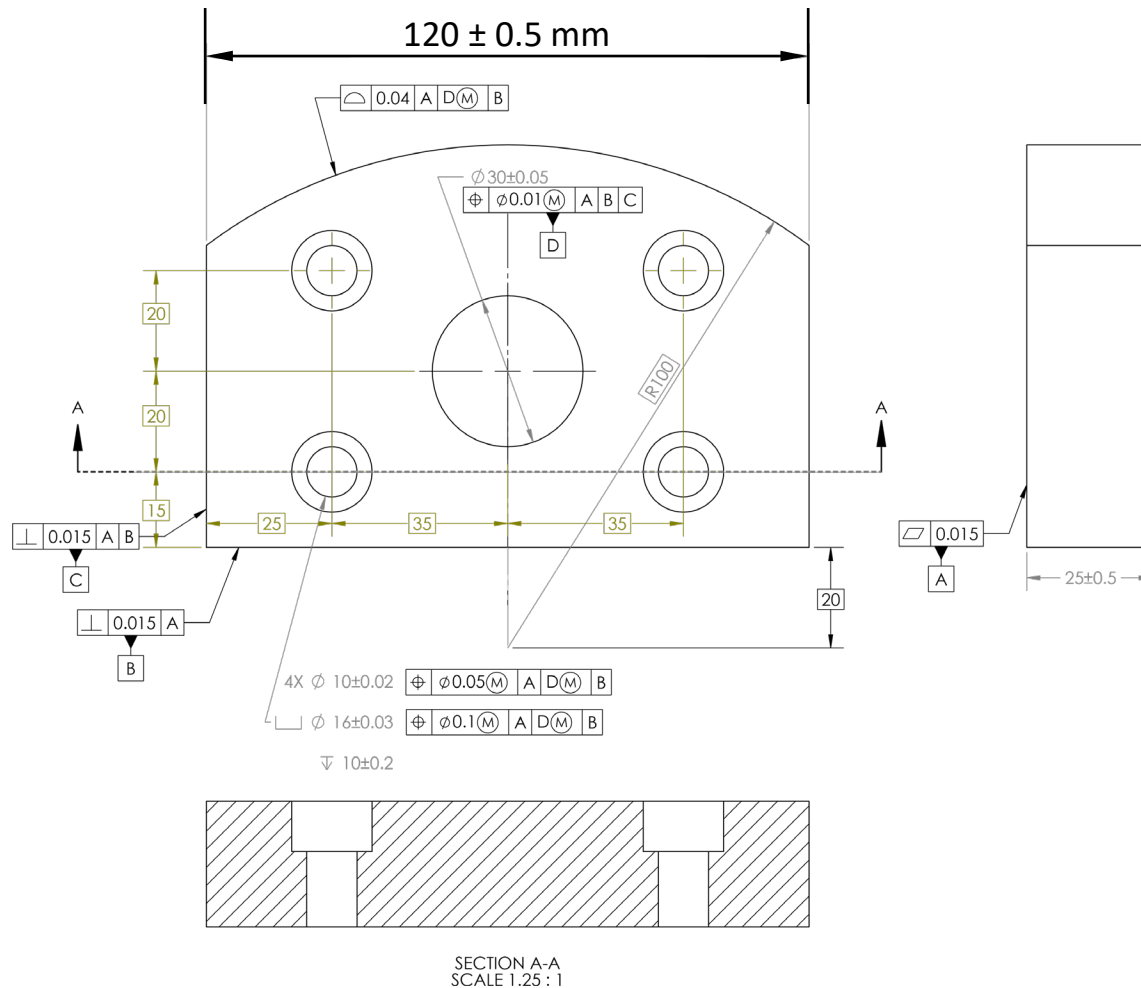


Case study: CMM task-specific uncertainty

- Ways to estimate measurement uncertainty:
 - ISO 15530-2: multiple workpiece orientations
 - Uncalibrated workpieces in multiple orientations
 - Simple calibrated artifacts
 - ISO 15530-3: using calibrated workpiece
 - Attempts to duplicate measured feature
 - Simulation: the Virtual CMM/Simulation by constraints
 - Usually implementations of Monte Carlo method
 - Uncertainty estimation using measurement history
 - Assumes process is stable
 - Assumes measured features “nominally identical”



Case study: CMM task-specific uncertainty

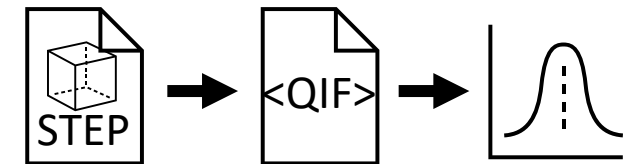
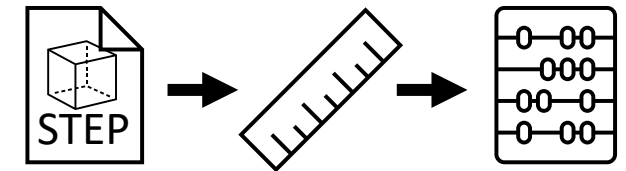


- Chose to conduct and compare results from ISO 15530-2 (multiple orientations) and simulation by constraints
- Test artifact is “B-89 block”
 - Anodized aluminum
- Measurements taken on Zeiss Prismo Navigator, simulation attempts to model the same CMM
- Interested in how easily uncertainty-related data is transmitted



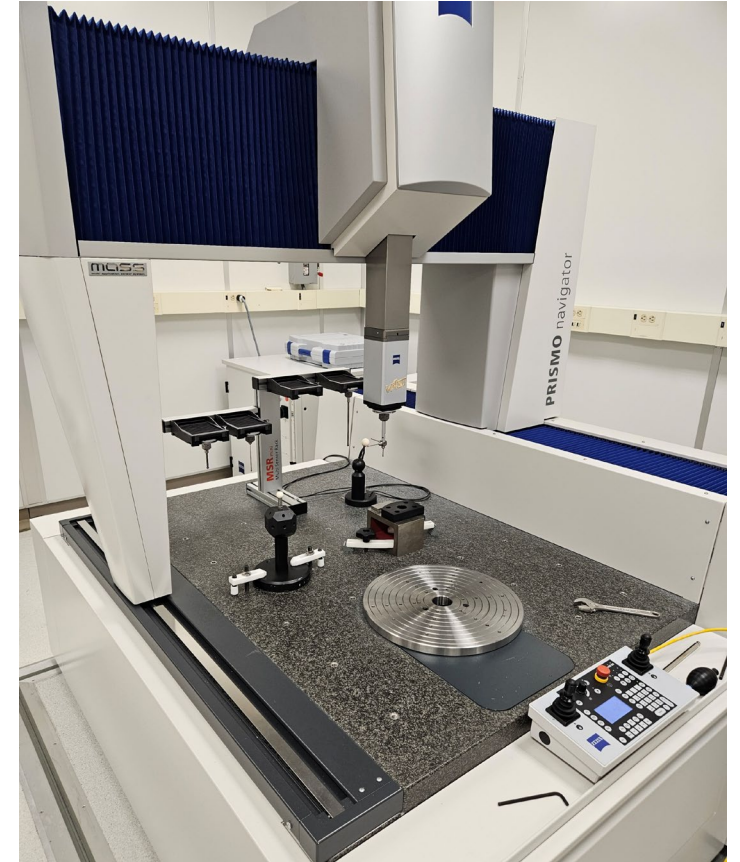
Uncertainty estimation workflow

- Design originated as a 2D drawing and STEP file
- **CMM Measurement data path:**
 - Imported STEP geometry into Zeiss Calypso
 - Defined and ran measurement plan according to 2D drawing
 - Exported text measurement results, calculated uncertainty manually
- **Simulation data path:**
 - Built MBD in Kotem Evolve Design, exported as QIF 3
 - Imported QIF 3 MBD into Pundit CMM
 - Built model of Prismo Navigator using its calibration certificate
 - Defined point sampling plan to match as closely to CMM points as possible
- Possible to export QIF point locations and results from Calypso, though not using the version we have currently

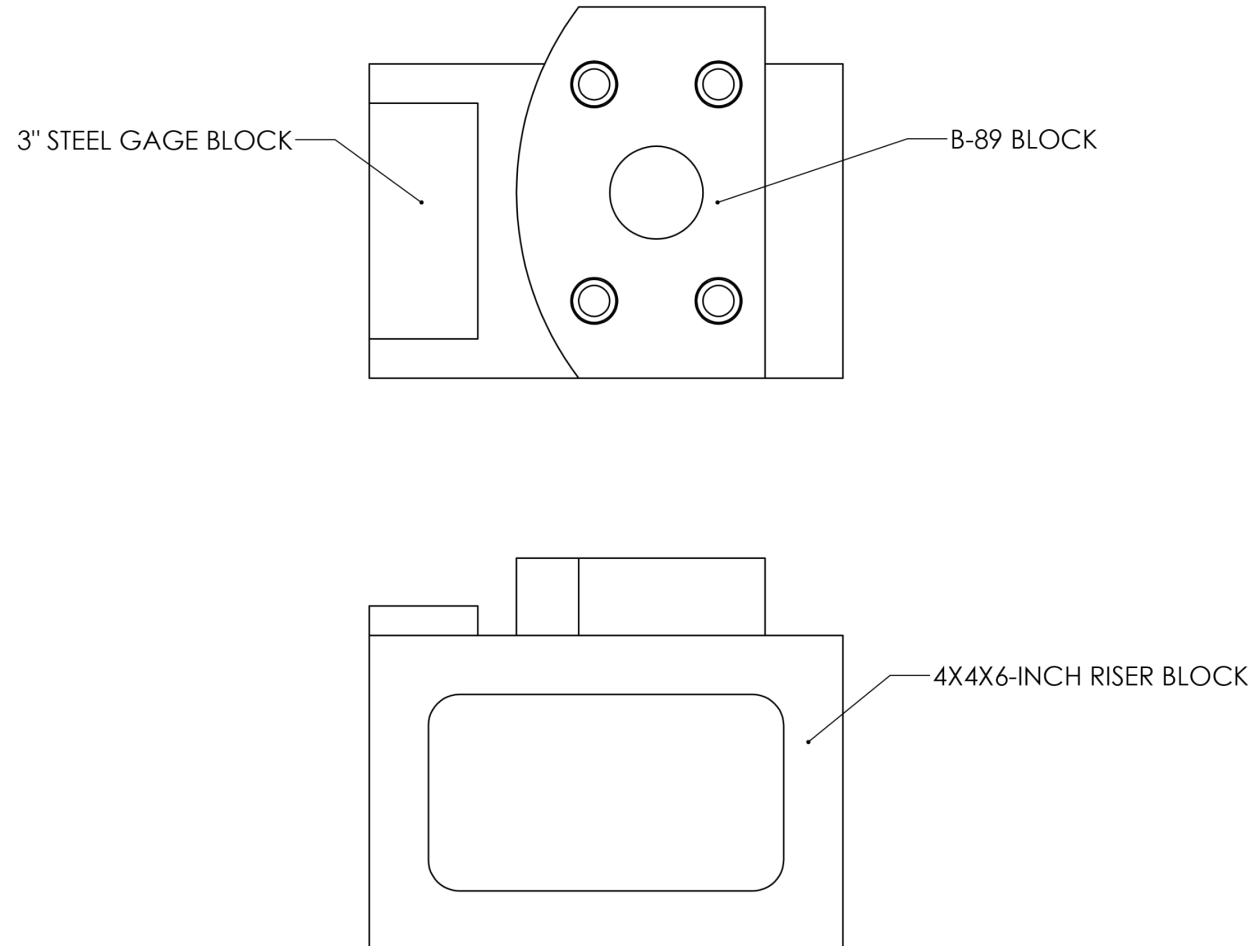


ISO 15530-2: multiple orientations

- Artifact is measured three times in each of four orientations
- Simple reference artifact measurements
 - Stylus qualification with reference sphere
 - Stylus verification with second calibrated sphere
 - Simple calibrated length standard(s) along three axes, three repetitions each
 - In this case, 3-inch gage block
- Attempts to randomize contributions of systematic errors by varying magnitudes and error propagation coefficients
 - Different orientations → different combinations/magnitudes of contributors



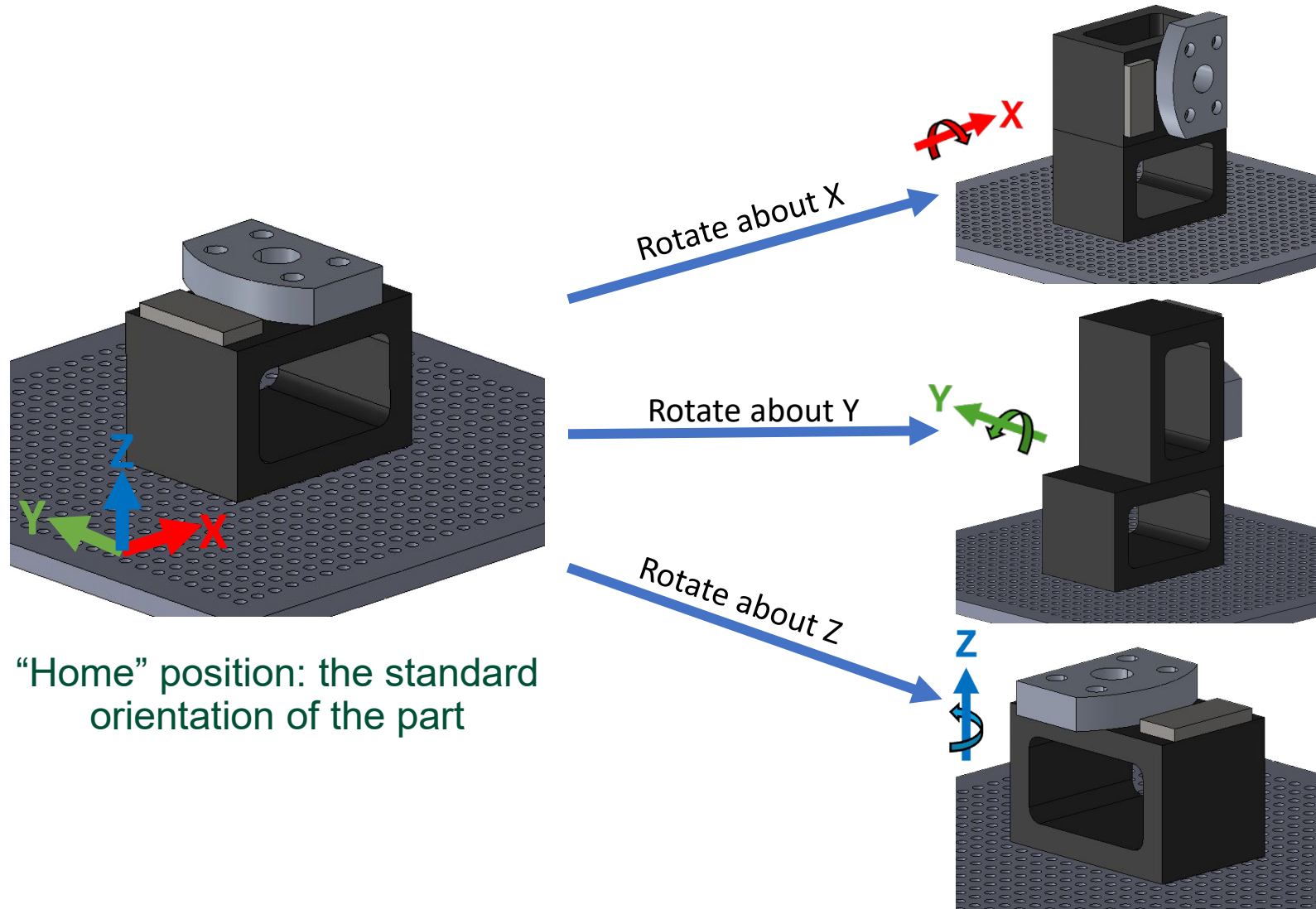
ISO 15530-2: test assembly



Gage block and B-89 test artifact glued to 4x4x6-inch riser block, allows orientation change while minimizing changes in stress due to mounting



ISO 15530-2: measurement orientations

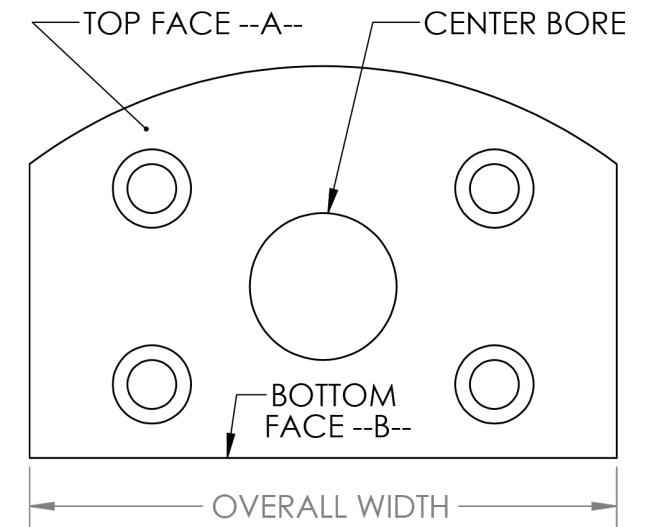


- Four total orientations
- Artifact and gage block measured three times in each orientation
- Measurements taken in same part of measurement volume



ISO 15530-2: measurement results

Feature/characteristic	Uncorrected estimate (y) [mm]	u [mm]	u [um]
Diameter of center bore	30.0740	0.0004	0.4
Position error of center bore	0.2768	0.0005	0.5
Flatness of front face -A-	0.0047	0.0005	0.5
Perpendicularity of -B- to -A-	0.0267	0.0005	0.5
Overall part width	119.8491	0.0006	0.6
CMM MPE: $0.6 * L/500$ [um] with L in [mm]			



Measurement results can be exported to QIF! (Zeiss Calypso)



Simulation by constraints

- Schrodinger's CMM
- A CMM has (at least) 21 parametric errors
 - If each of these errors can vary, a variable can be assigned
 - A CMM can therefore be represented as a point in (at least) 21-dimensional space
 - By assuming distribution shapes for these errors and bounding their values (applying constraints), we can perform a Monte-Carlo simulation
 - In other words, we generate a large number of hypothetical CMMs that virtually measure our part. The results are the distributions of results taken by these virtual CMMs

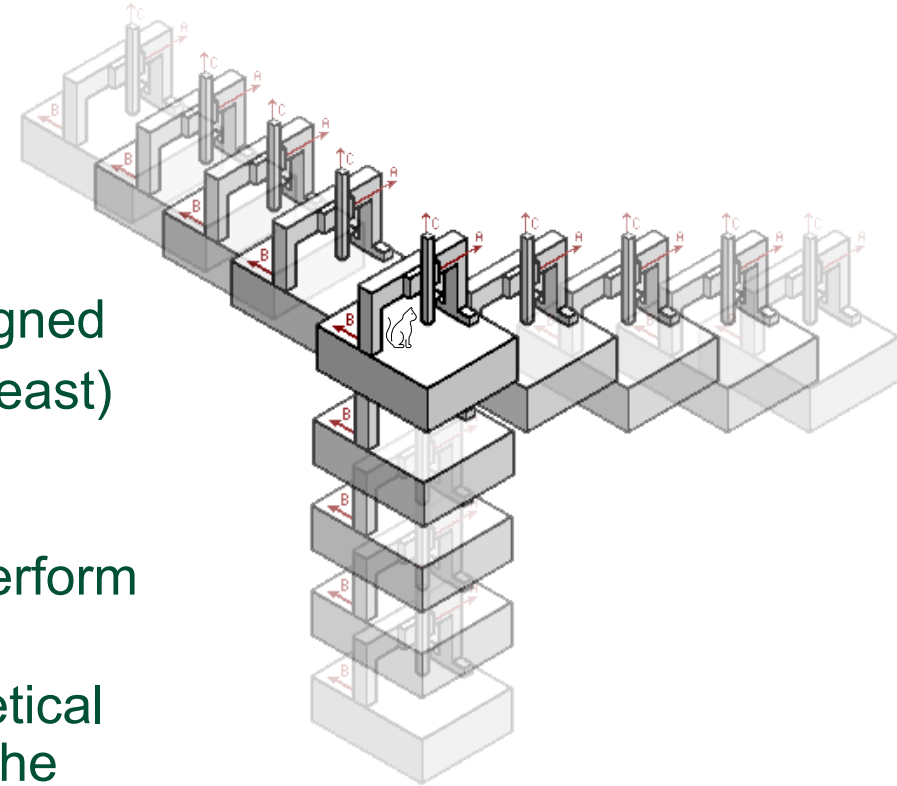
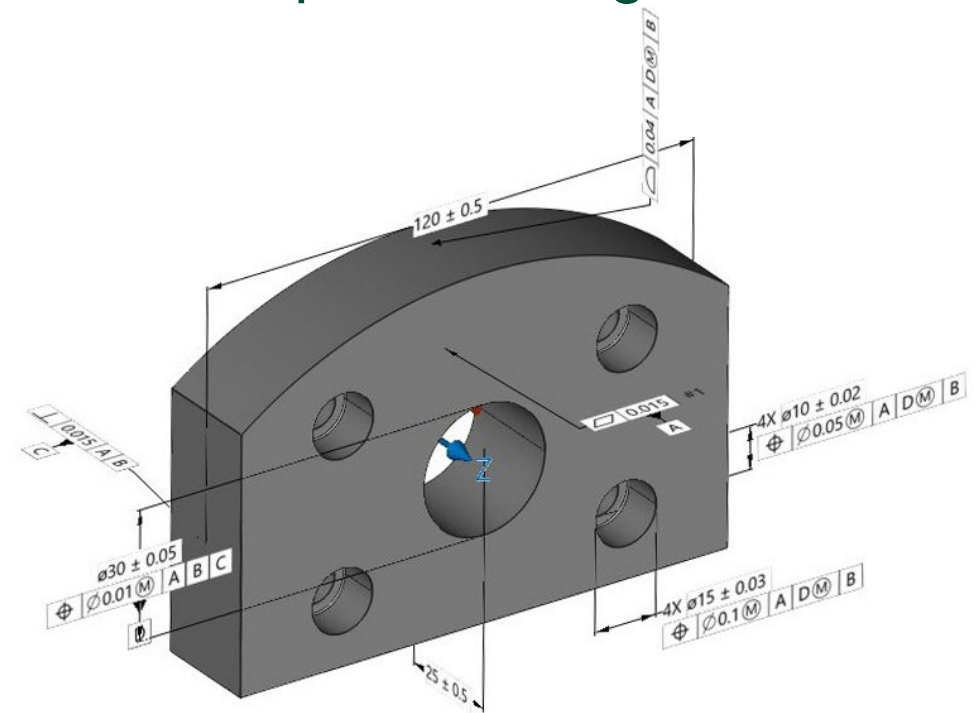
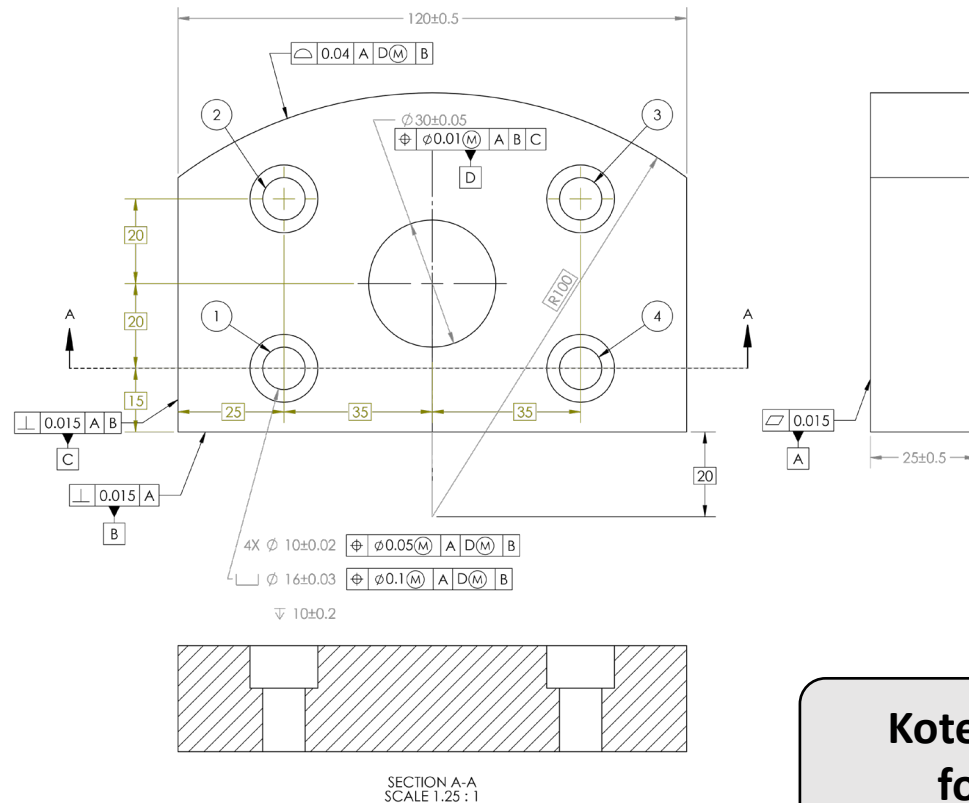


Image adapted from ANSI/DMSC QIF 3.0 - 2018, Figure 223 (page 400)



Building QIF MBD

Created QIF 3 MBD in Kotem Evolve Design from 2D part drawing and supplied STEP solid model



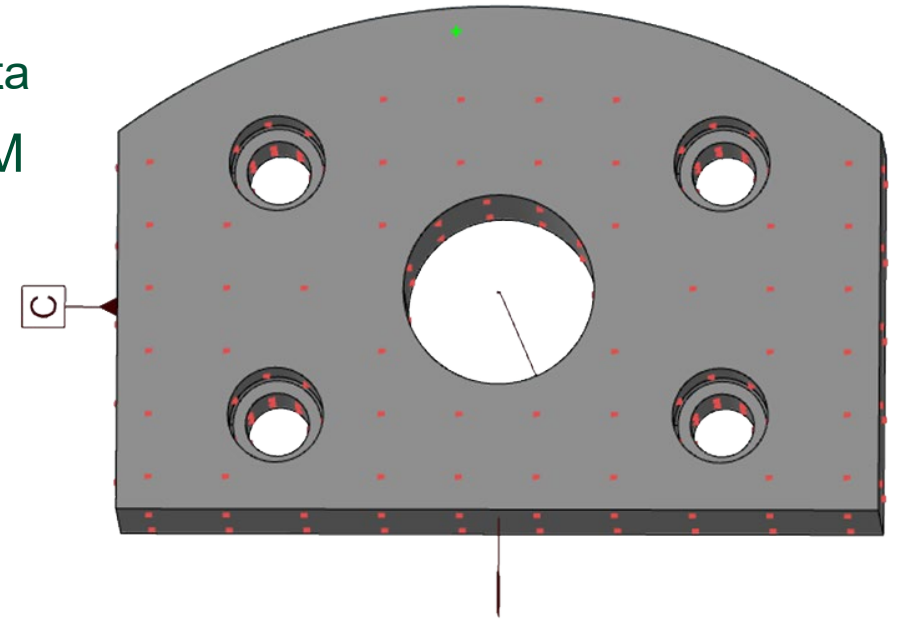
Kotem Evolve Design checks GD&T
for completeness and validity



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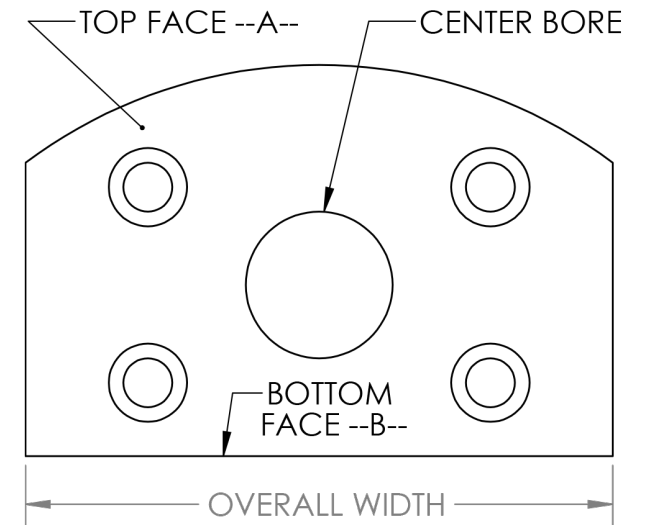
Pundit CMM

- Simulation by constraints software package by Capvidia
- Runs on a QIF back-end
 - Able to import QIF MBD, measurement points, resource data
- Can define point distribution to mimic those taken on CMM
- Can simulate variability due to
 - CMM kinematics
 - Environment
 - Probe/stylus system
 - Workpiece variation
- Easy to edit and quickly re-run simulations
 - Try out different probing patterns
 - Choose between measuring machines
 - Evaluate feasibility of measuring tolerances



Comparison of results

Feature/characteristic	Uncorrected estimate (y) [mm]	ISO 15530-2 one-sided unc. (u) [um]	Pundit standard dev. (approx. u) [um]
Diameter of center bore	30.0740	0.4	0.9
Position error of center bore	0.2768	0.5	2.1
Flatness of front face -A-	0.0047	0.5	0.2
Perpendicularity of -B- to -A-	0.0267	0.5	0.2
Overall part width	119.8491	0.6	3.5



- Results heavily dependent on CMM model definition
- Pundit easily consumes QIF MBD, point locations
 - Does not directly export results or uncertainty statements in QIF format



Limitations of this experiment

- Single reference length
- Calculated ISO 15530-2 uncertainty estimates on per-characteristic basis, not on per-point basis
- Sampling points differ slightly between simulation and experiment
- CMM defined in simulation using MPE from calibration certificate
 - Based on ISO 10360-2 tests conducted during instrument calibration
 - Our CMM performed *much* better than its MPE during calibration
 - Could conduct new performance tests or use measured error to get (potentially) better results

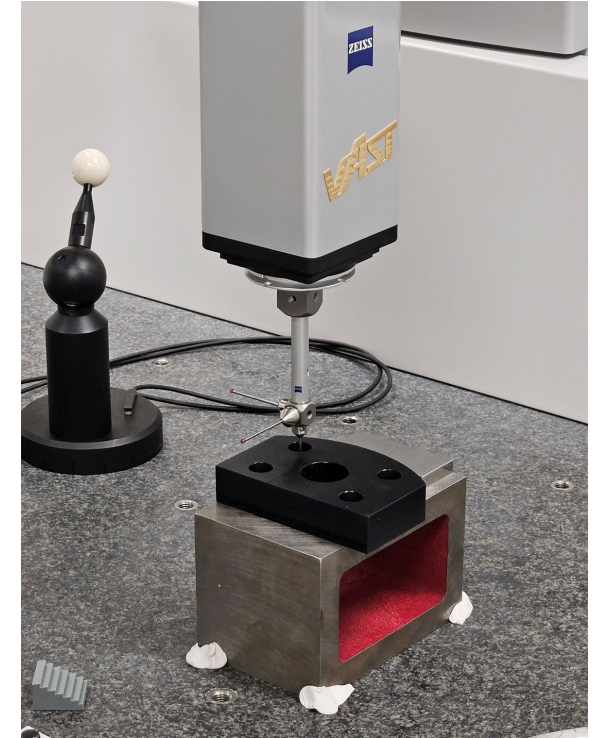
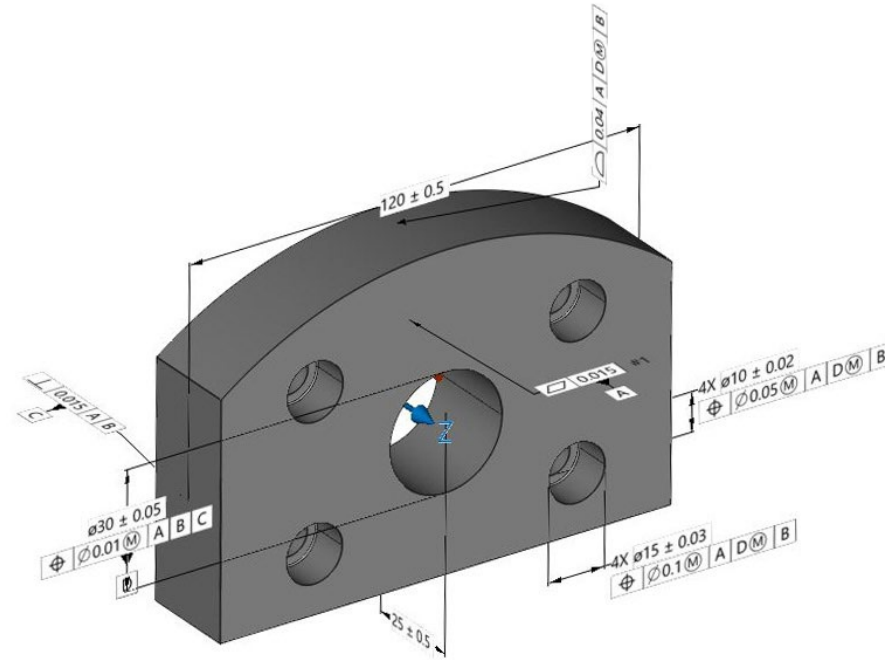
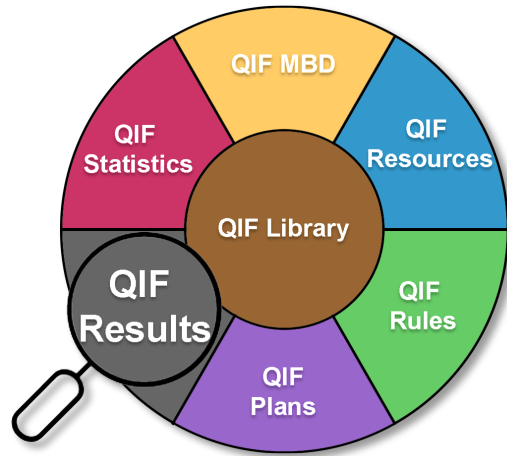


Future work

- QIF could eventually carry more uncertainty data
 - Contributors, distribution shapes, coverage factors, etc.
- A more conventional combined approach
 - Build QIF MBD as before
 - Define measurement and sampling strategies in CMM software
 - Export nominal point locations in QIF format
 - Import nominal point locations into simulation software
 - Run simulation, adjust measurement strategy to meet requirements
- Plan to study ISO 15530-2 further, perform more comprehensive experiments on multiple CMMs
- Looking to update CMM software licenses for better QIF compatibility



Thank you for your time!



Feel free to email me or come find me during the break!

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