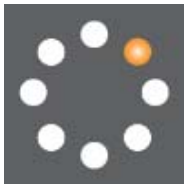
METROSAGE

CMM Measurement Uncertainties:

Applications & Case Studies



Kim D. Summerhays
Technical Director
MetroSage

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Topics

- Task-Specific Measurement Uncertainty
- Gauge R&R vs. Measurement Uncertainty
- Ways to Assess Measurement Uncertainty
- An Automotive Case Study
- CMM Measurement Traceability
- Optimizing Tolerance Schemes
- Economics of Measurement Uncertainty

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Task-Specific CMM Measurement Uncertainty

- Specific to a particular measurand.
- Specific to a particular level of confidence.
- Sample Statement: *"The uncertainty of the diameter of this nominal 10-mm diameter hole, measured with this particular CMM under these specific conditions is ±0.004 mm at 95% confidence."*

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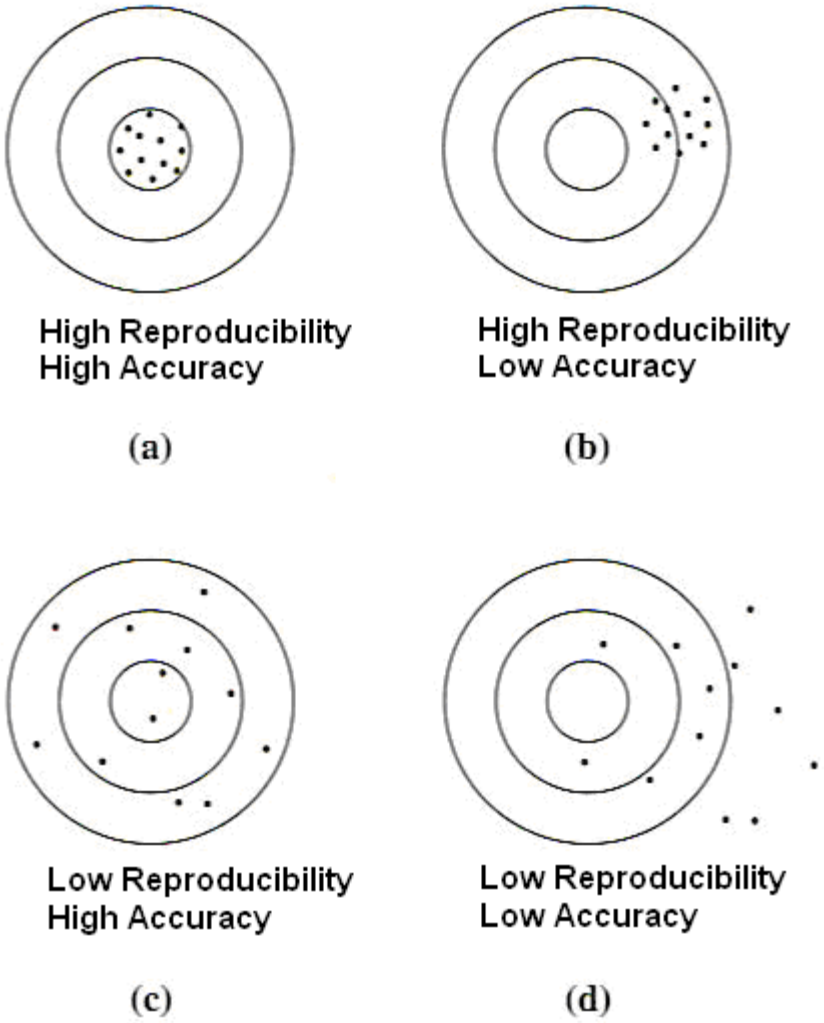
Reproducibility vs. Accuracy

Commonly Encountered Textbook Graphic



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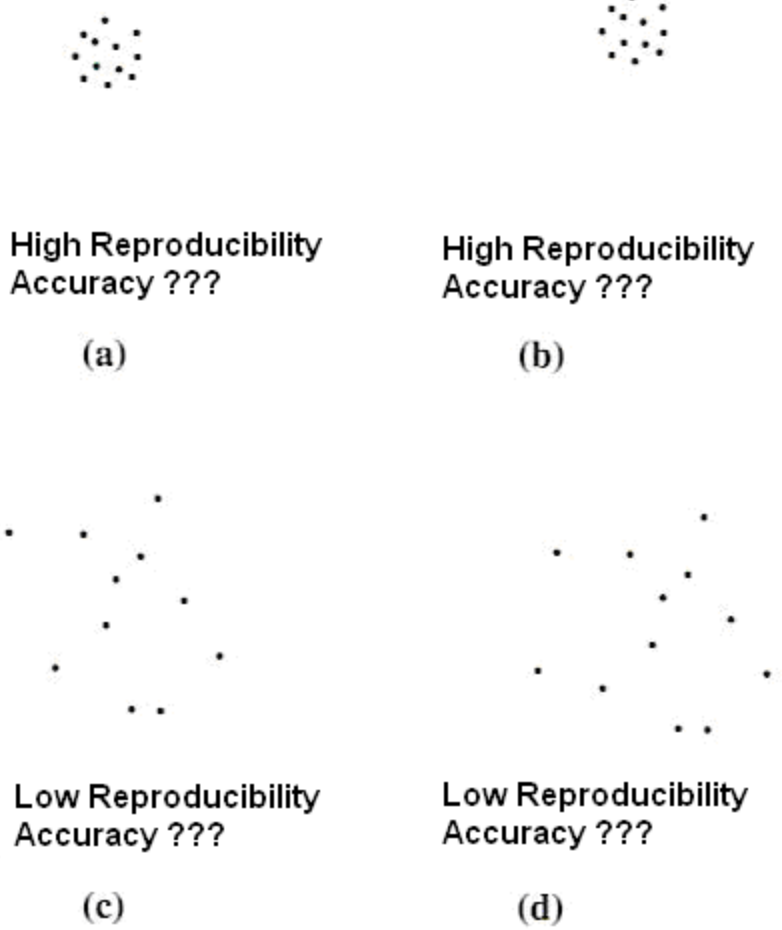
Reproducibility vs. Accuracy

Reality



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Gauge Repeatability & Reproducibility (GR&R)

"A concept to insure stabile measurements where a single person gets the exact same results each and every time they measure and/or collect data measurements."

- Six Sigma SPC's Quality Control Dictionary and Glossary

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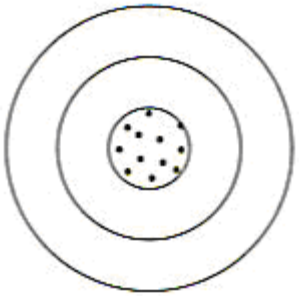
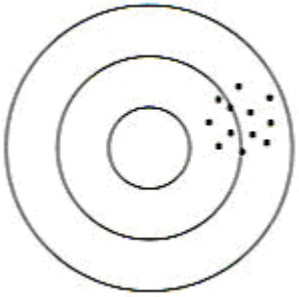
Gauge Repeatability & Reproducibility (GR&R)

Assesses *Reproducibility*, but not *Accuracy*:

Distinguishes  from 

but cannot distinguish  from 

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Bias in CMM Measurements

Some Sources:

- Repeatable Geometric Errors of CMM Axes
- Repeatable Probe Errors (e.g. Over-travel)
- Uncorrected Thermal Expansion of Scales
- Uncorrected Thermal Expansion of Part
- Sampling Strategy Inadequacies
- Wrong Point-Fitting Algorithm

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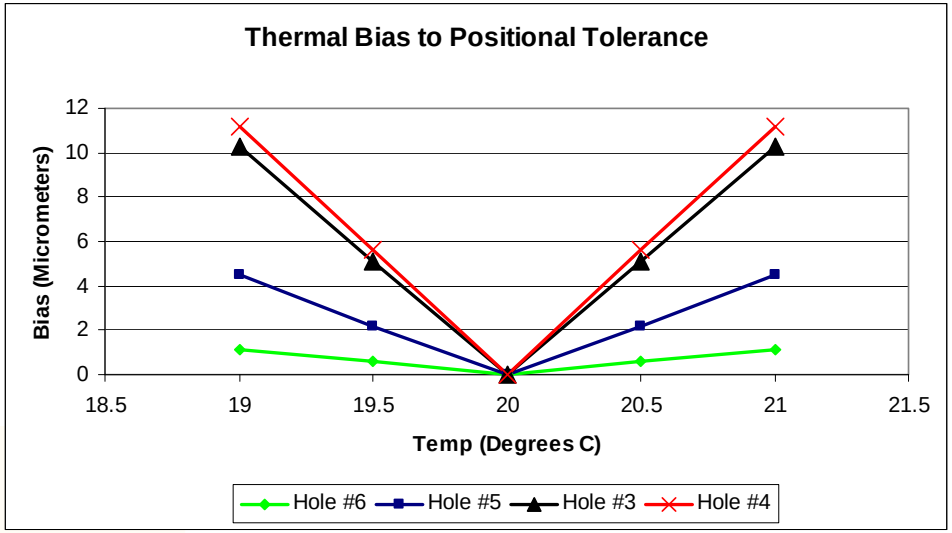
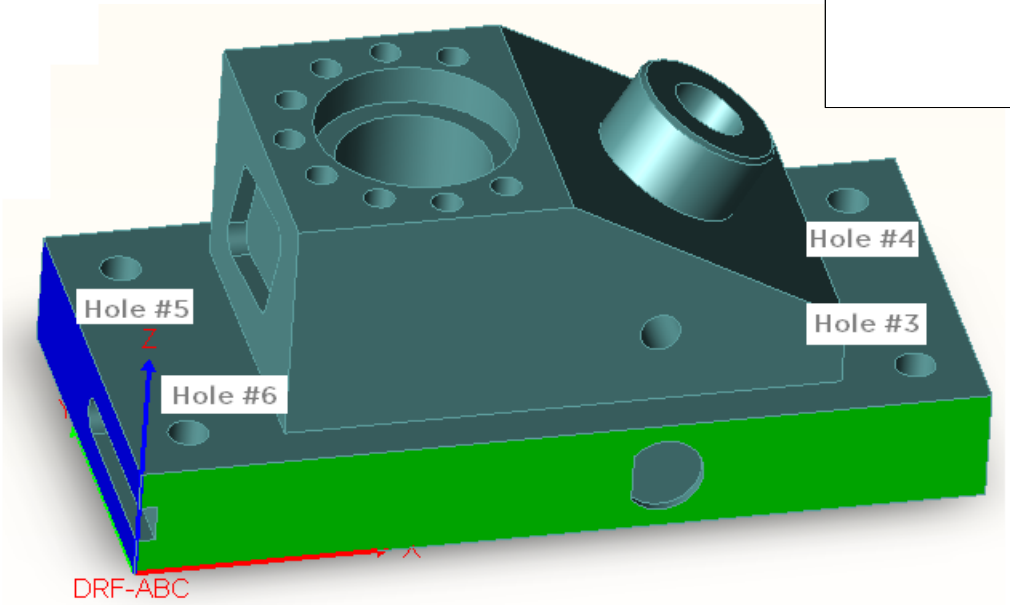
Thermally Induced Bias





Aluminum Part

Glass Scales

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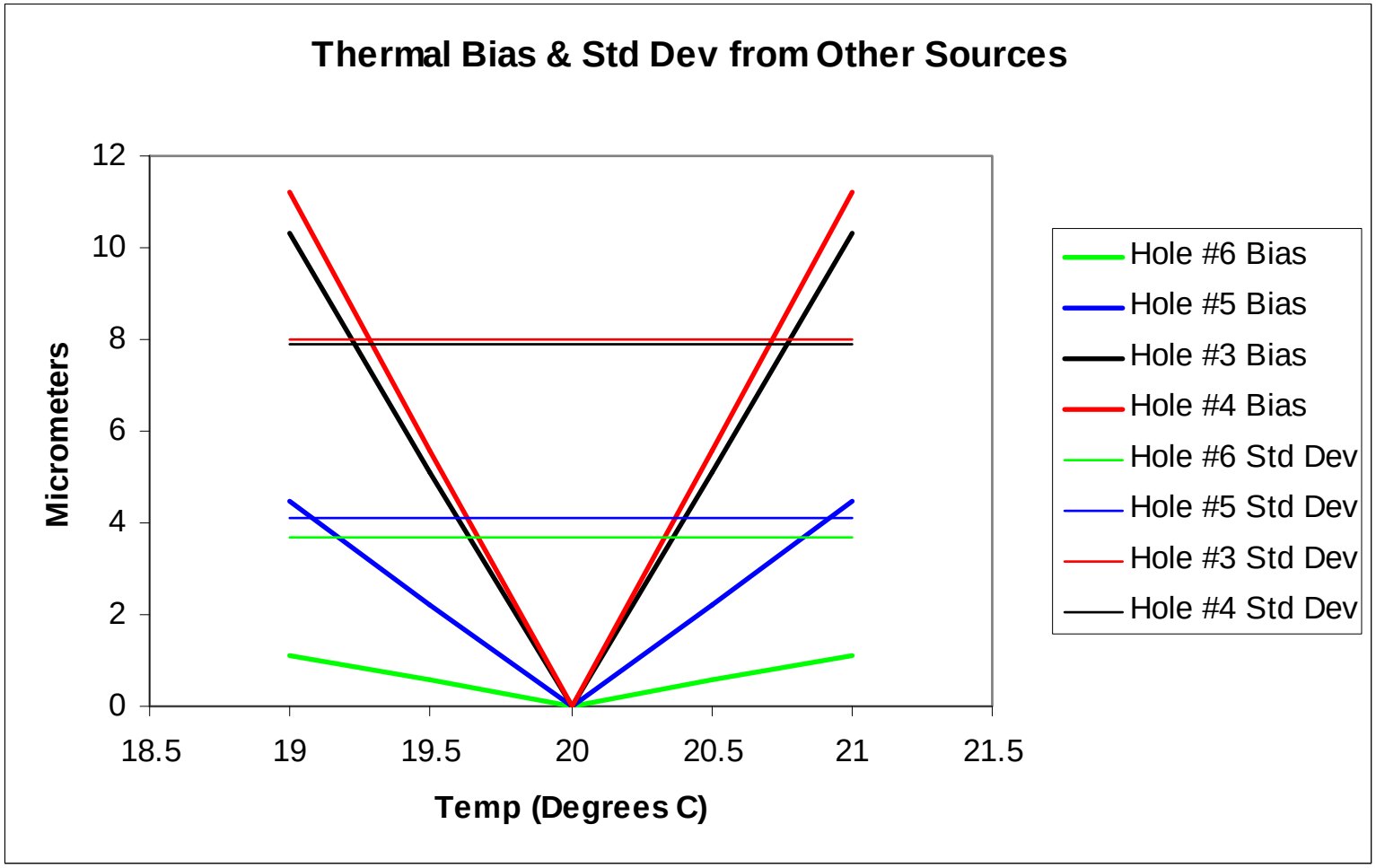
Thermal Bias Compared to Std Dev from Other Sources



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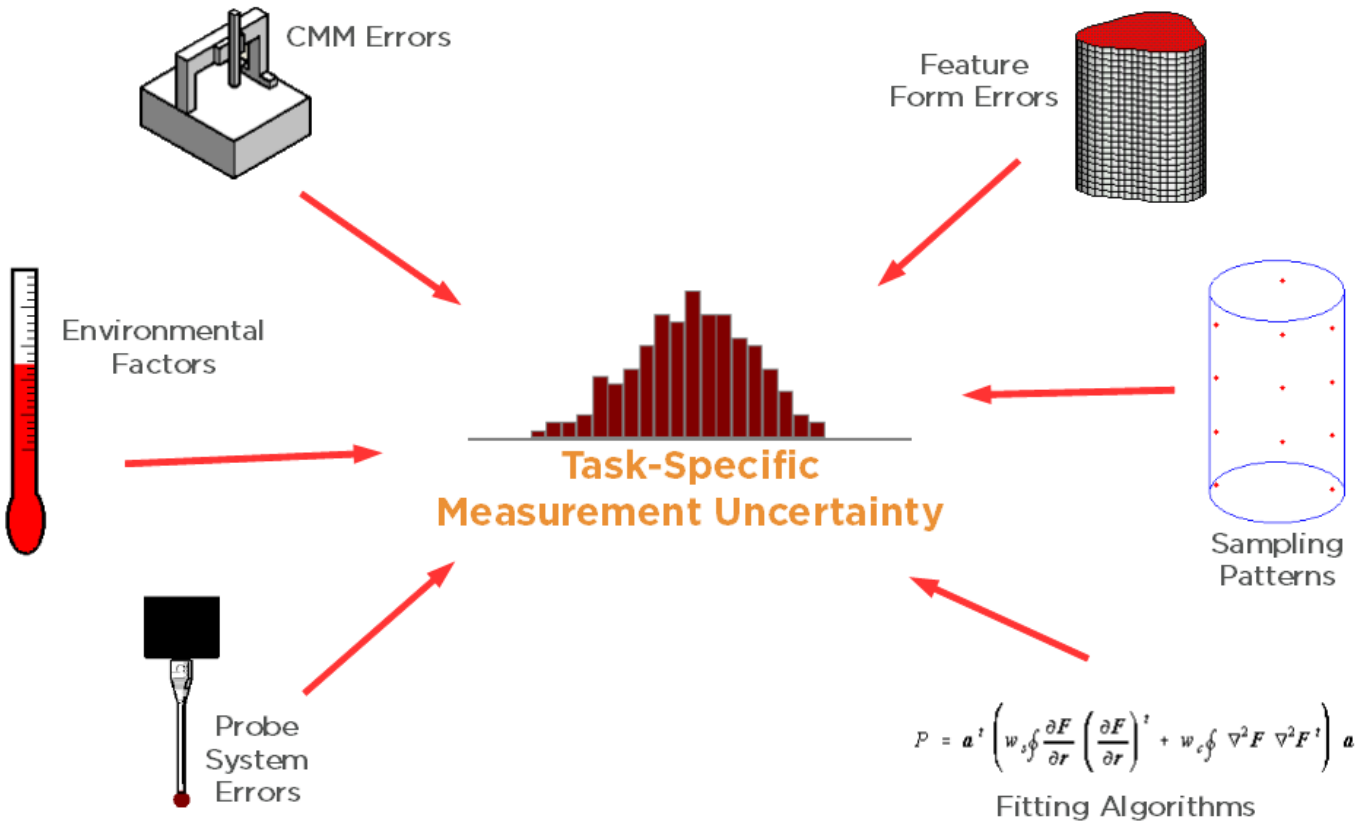
CMM Measurement Influence Quantities



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Methods to Estimate Measurement Uncertainty (ISO 15530 draft)

- Sensitivity Analysis – aka "Uncertainty Budgeting"; estimating various contributions
- Expert Judgment – "best-guess" estimate
- Substitution – repeated measurement of calibrated master part
- Simulation - modeling and simulating the measurement process, including the errors
- Measurement History – full range of measurements of part throughput

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Uncertainty Method Scorecard for 3-Dimensional Metrology

	Tractable	Comprehensive	Detects Measurement Bias	Detects Measurement Variability	Versatile	Predictive	Economical
Sensitivity Analysis	?	?	✓	✓	X	✓	X
Expert Judgment	✓	?	?	?	X	✓	?
Substitution	✓	✓	✓	✓	X	X	X
Computer Simulation	✓	?	✓	✓	✓	✓	?
Measurement History	✓	✓	X	?	X	X	X

The MetroSage Solution:

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Traceability

"The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties."

-ISO VIM 6.10

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Proof of CMM Measurement Traceability

The Problem:

Demonstrating measurement traceability to national or international standards

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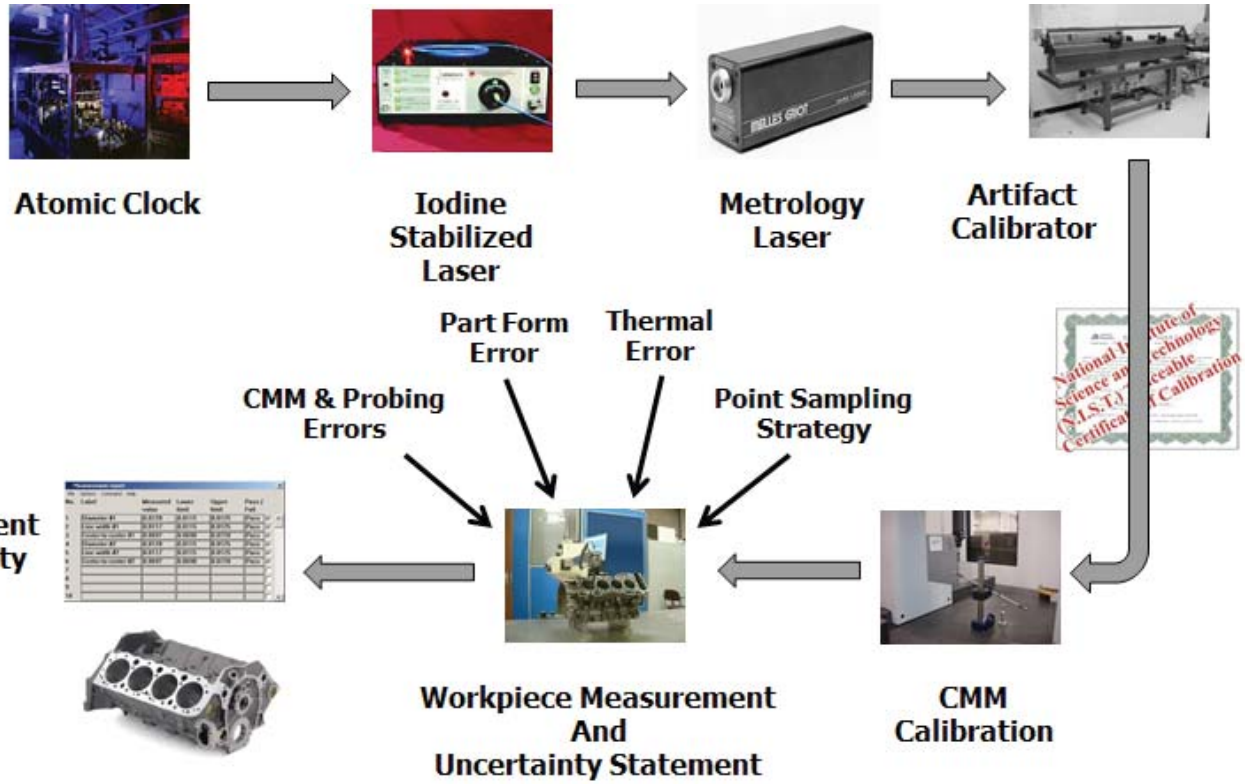
CMM Traceability Chain



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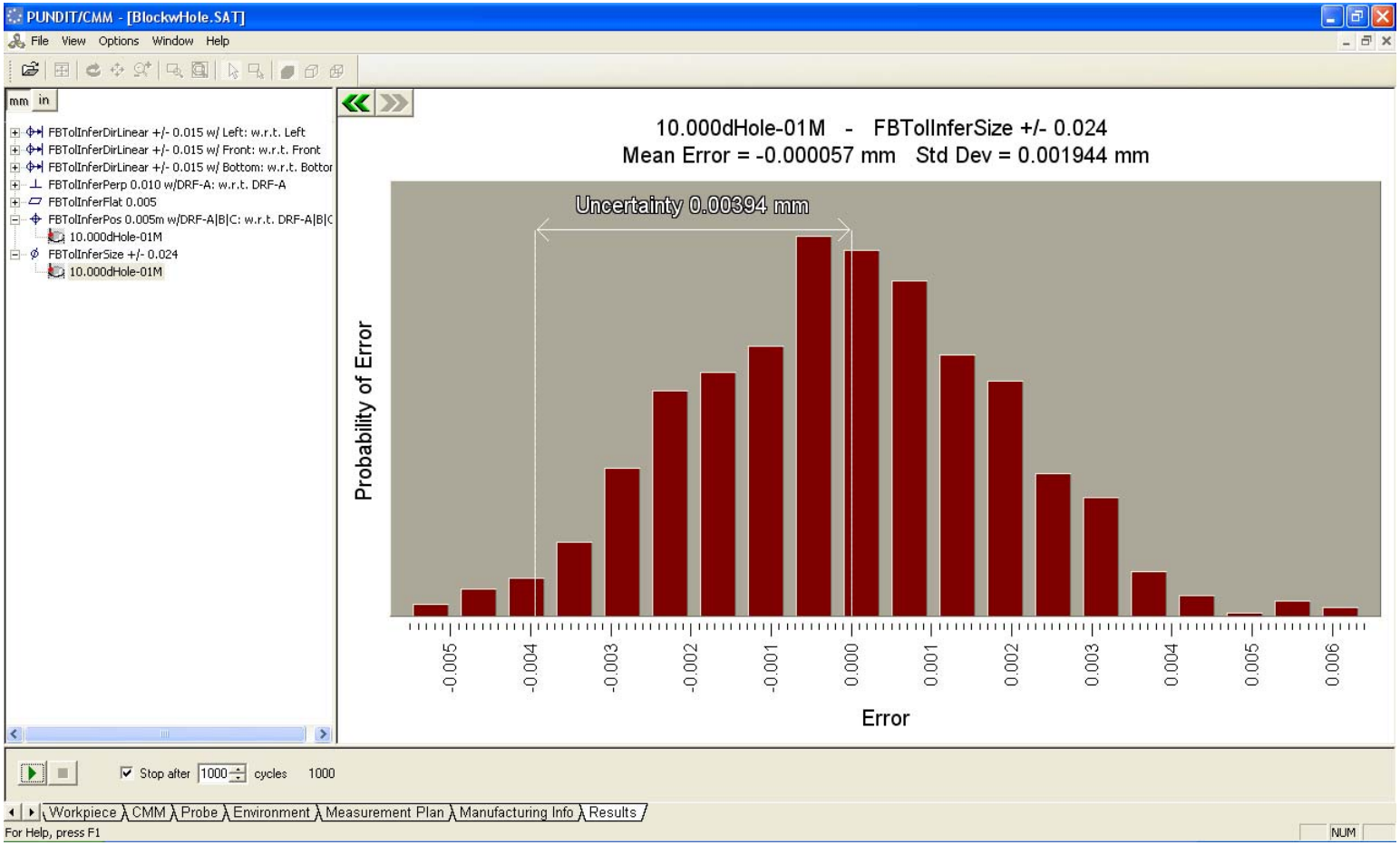
PUNDIT/CMM



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Task-Specific Measurement Uncertainty Report

Units:	mm			
		Tolerance	Uncertainty	%Tol Consumed
10.000dHole-10				
	Pos0.125mADsB: w.r.t. DRF-ADsB	0.125	0.0155	12.4% *
	Size +0.05 -0.00	0.05	0.0107	21.4% **
10.000dHole-11				
	Pos0.125mADsB: w.r.t. DRF-ADsB	0.125	0.015	12.0% *
	Size +0.05 -0.00	0.05	0.0108	21.6% **
13.000dHole-03				
	Pos0.10mABC: w.r.t. DRF-ABC	0.1	0.0299	29.9% **
	Size +/- 0.05	0.1	0.0109	10.9% *
13.000dHole-04				
	Pos0.10mABC: w.r.t. DRF-ABC	0.1	0.0318	31.8% ***
	Size +/- 0.05	0.1	0.011	11.0% *
BlockAngledTop				
	Angularity0.07: w.r.t. DRF-A	0.07	0.008	11.5% *
	Prof0.10ADsB: w.r.t. DRF-ADsB	2.54	0.0229	0.90%

⋮

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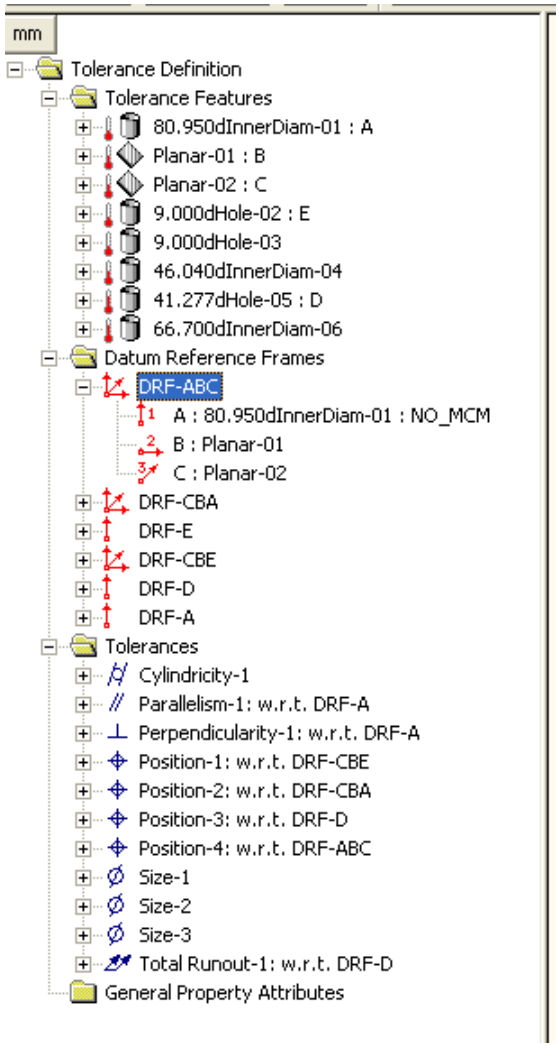
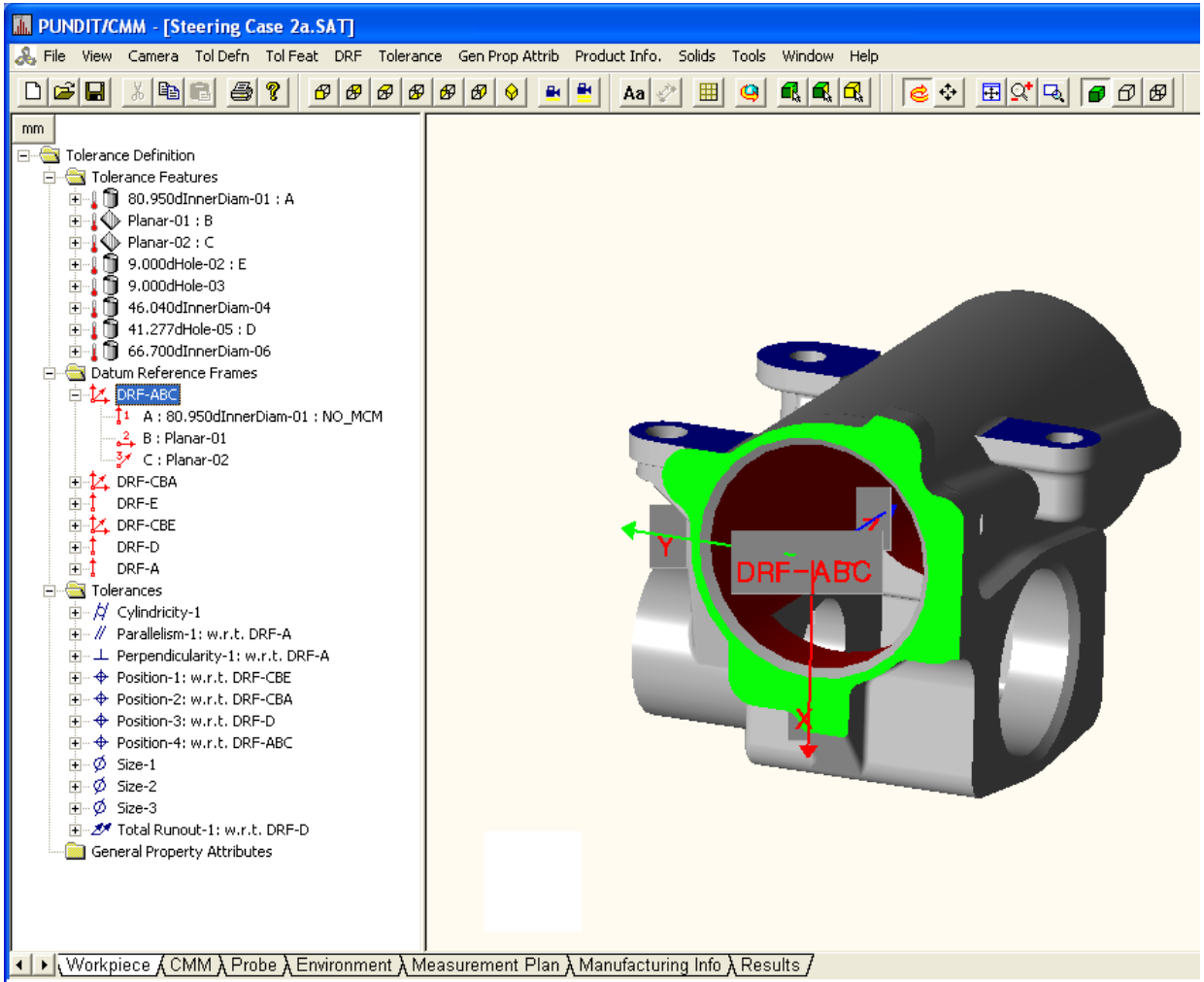
An Automotive Case Study



A Steering Case: Features, Datums & Tolerances



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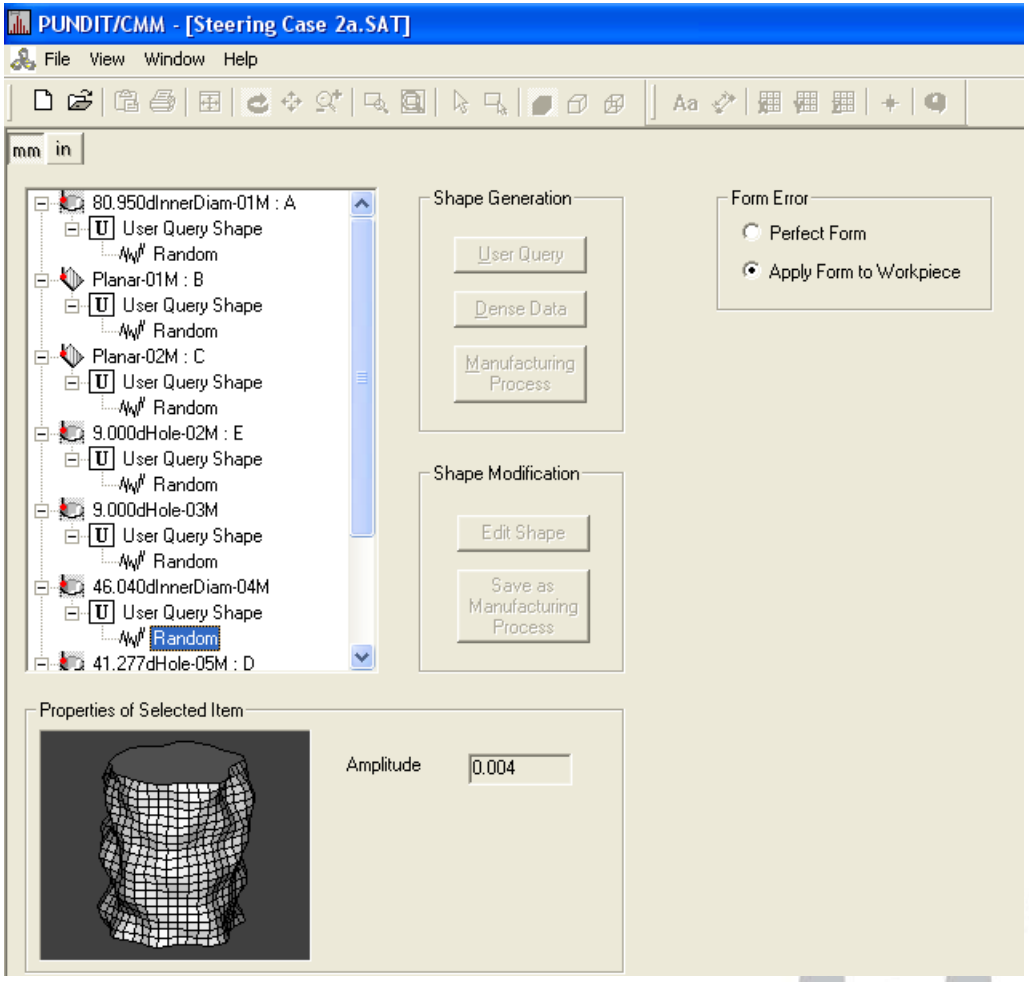
Feature Form Error Definitions

- Style:

  Random surface error

- Amplitudes:

  Feature-dependent: 4 to 11 μm



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CMM Definition

- Style:

  Moving Bridge

- Dimensions:

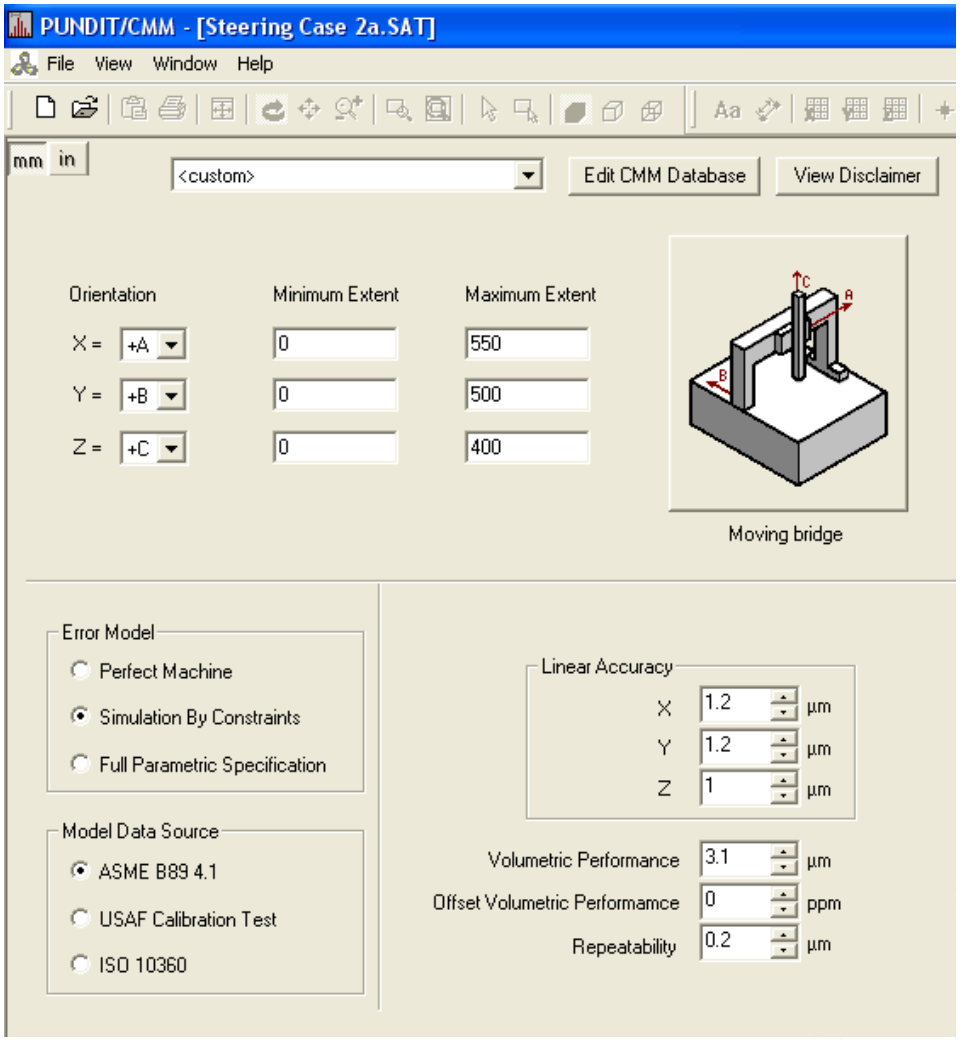
  X: 550mm Y: 500mm Z: 400mm

- Error Model:

  Simulation by Constraints

- Model Source Data:

  ASME B89 4.1



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Probe Definition

- Styli:

  Fixed Orientation, Multi-Tip

- Dimensions:

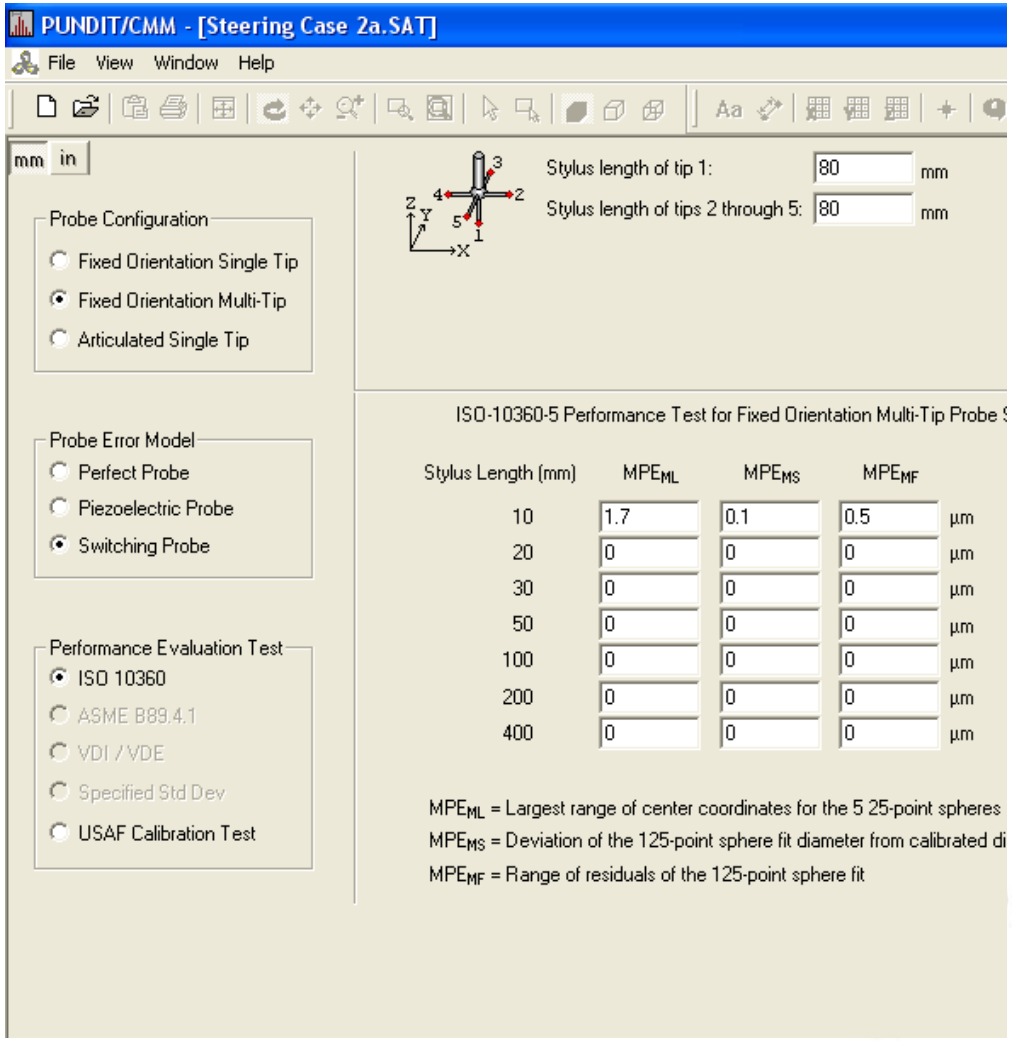
  All stylus lengths 80mm

- Error Model:

  Switching Probe

- Model Source Data:

  ISO 10360



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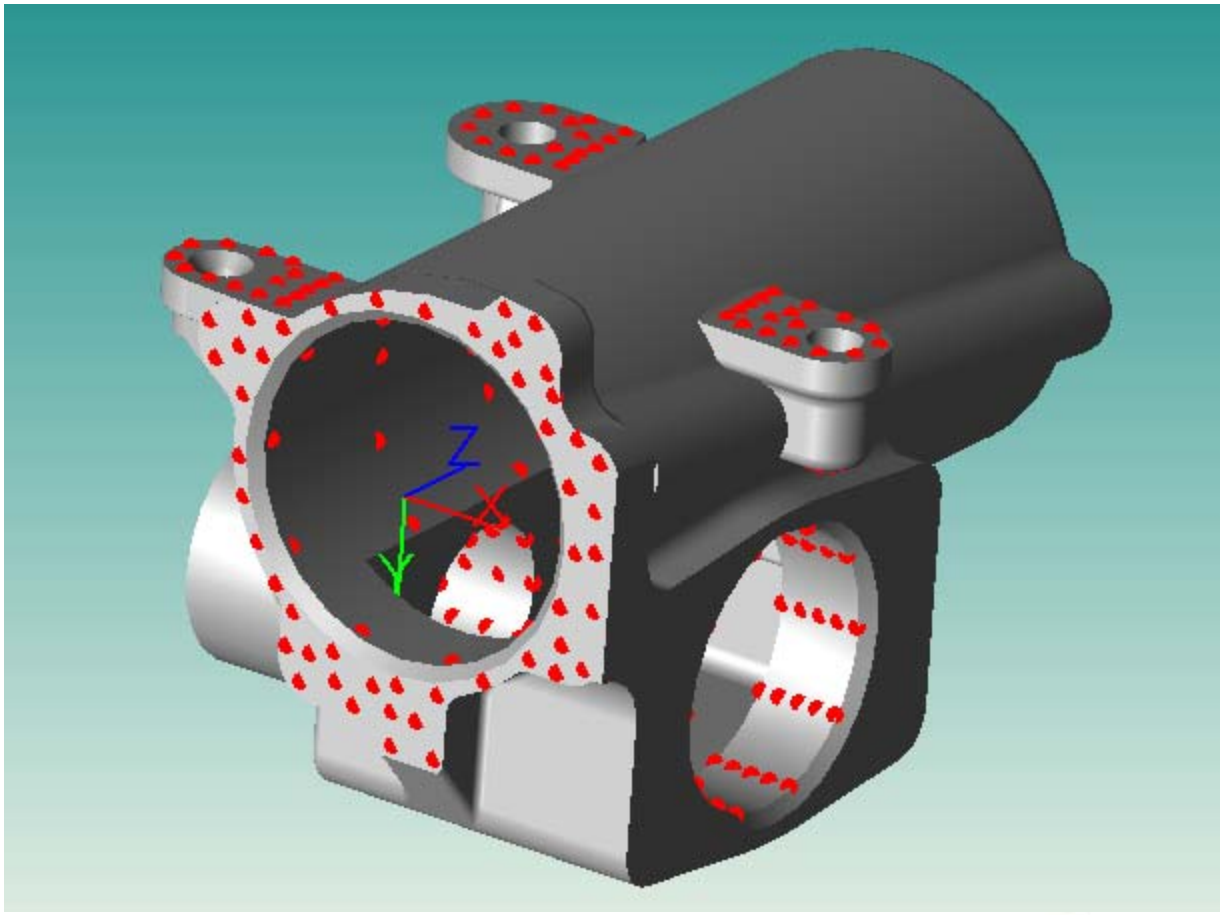
Sampling Point Specifications

- Apply probing points to features
  - Manual selection
  - Automated regular patterns
- Regular patterns can be uniform or staggered, rows & columns or by point density
- Edge offsets can be specified
- Points falling into voids are discarded automatically



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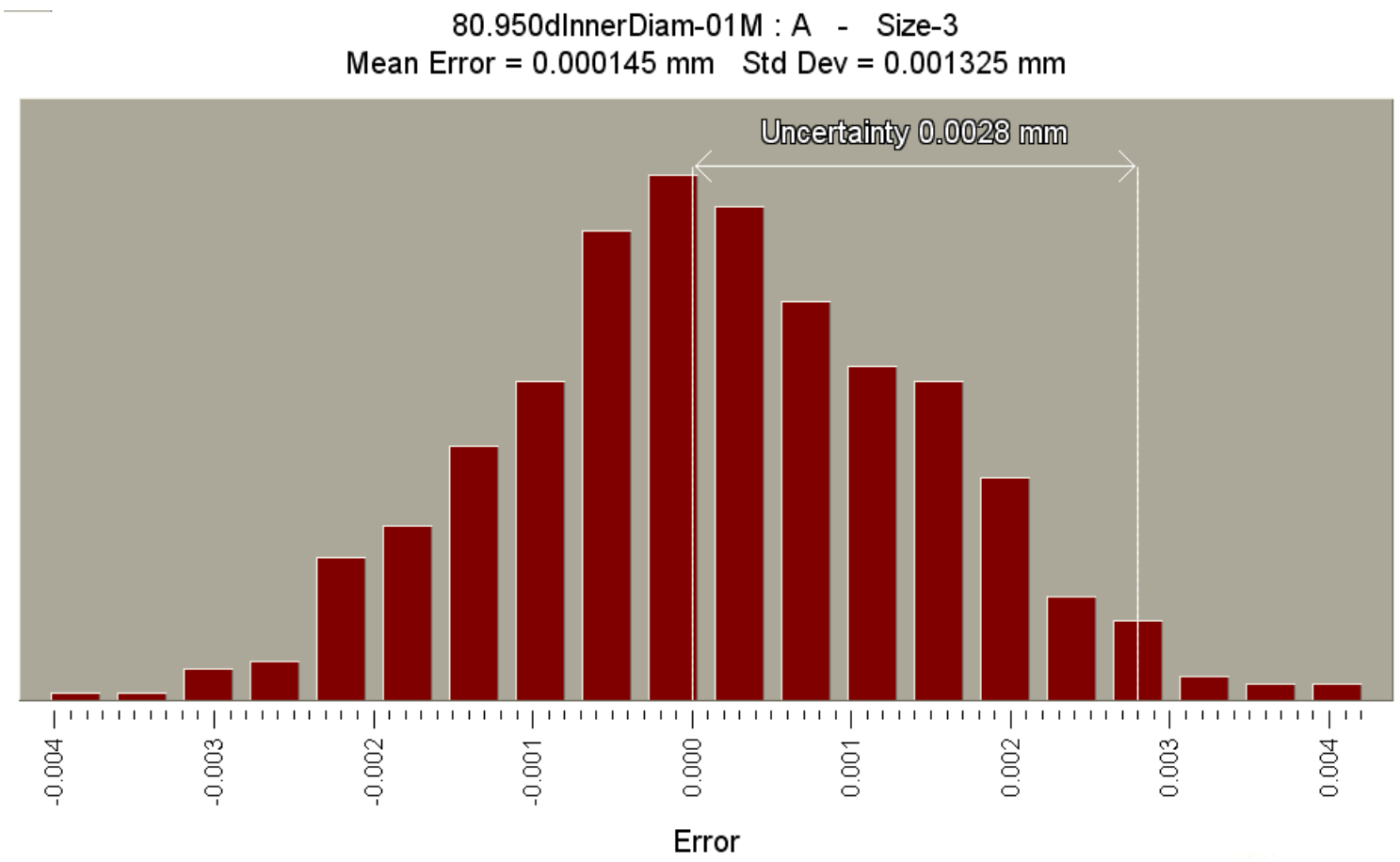
Results & Analysis

For each toleranced feature characteristic,

PUNDIT/CMM reports:

- Mean Error (i.e. bias in measurement)
- Standard Deviation
- Expanded Uncertainty at 95% certainty



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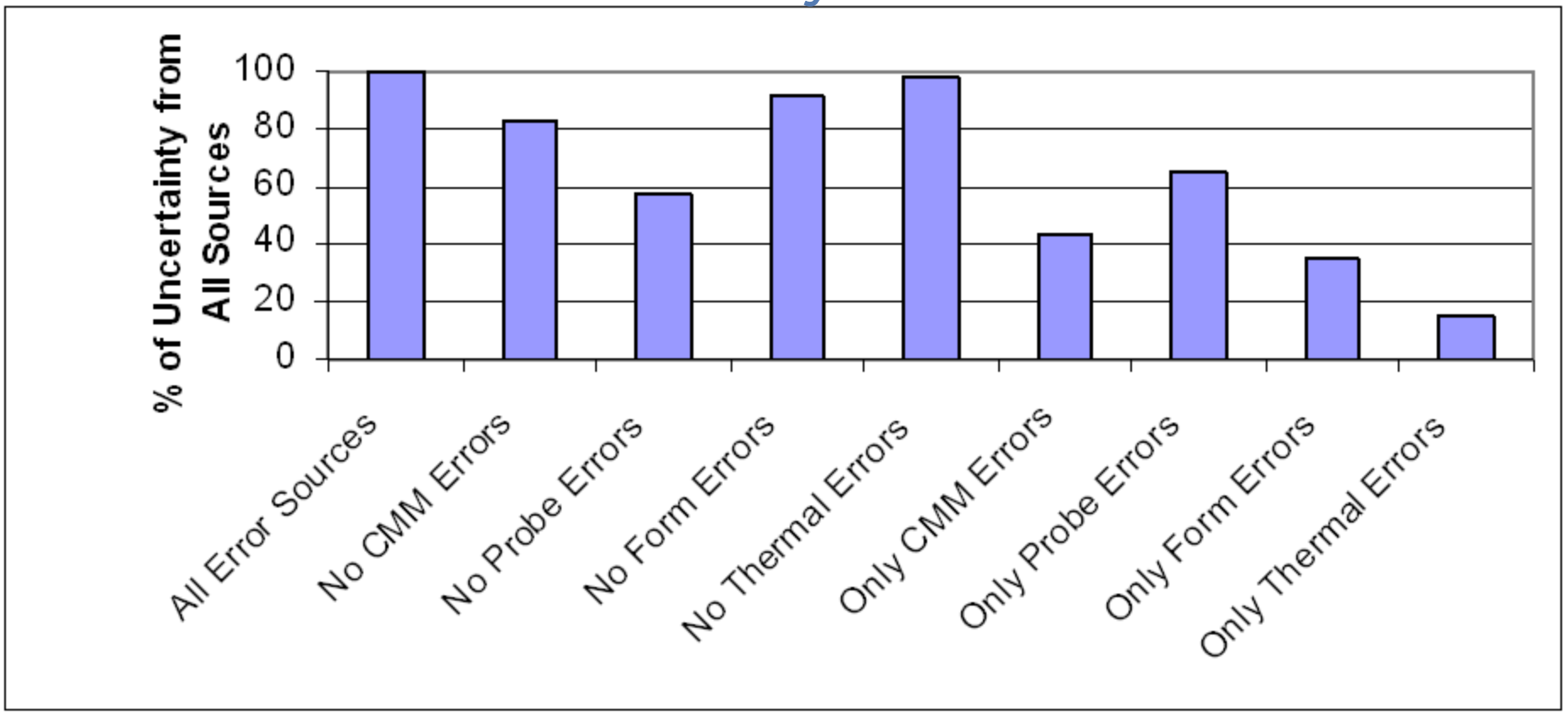
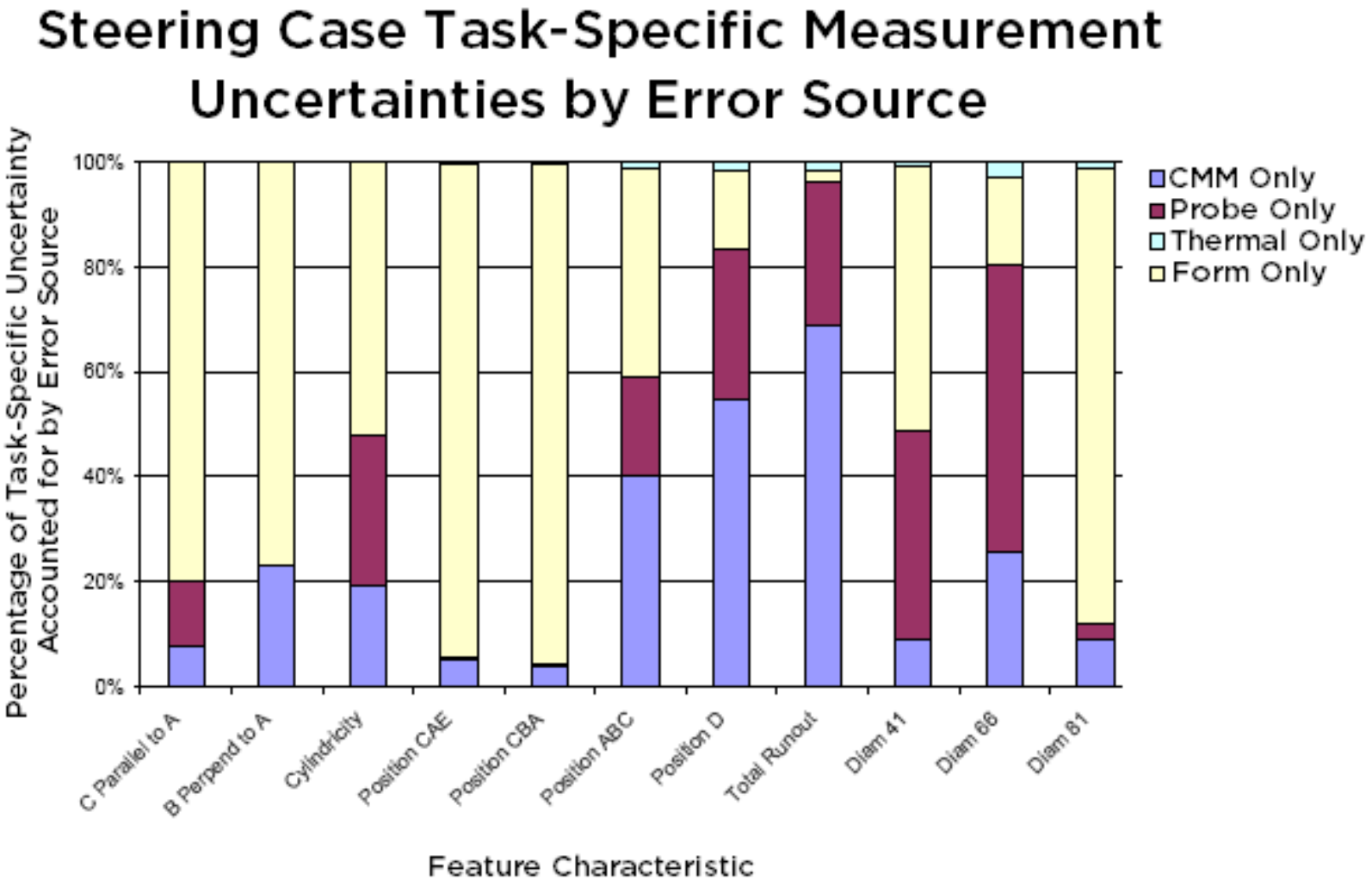
Task-Specific Measurement Uncertainty Analysis

Diameter Uncertainty for Nominal 66.7mm ID Cylindrical Feature



METROSAGE

Task-Specific Measurement Uncertainty Analysis



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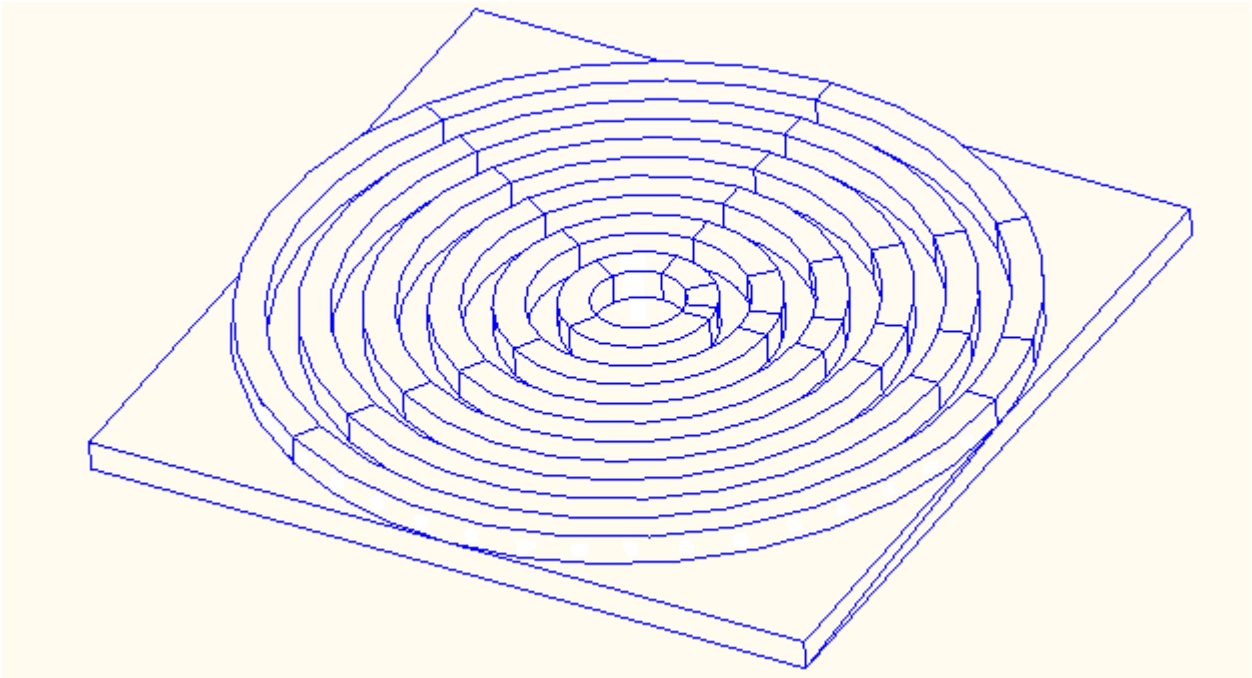
Arc Feature Measurement

Virtual Part

Concentric Rings of Outside Diameters from 100 mm to 500 mm and Inside Diameters from 60 mm to 460 mm Sliced into Arcs of 15°, 30°, 45°, 60°, 90° and 120°



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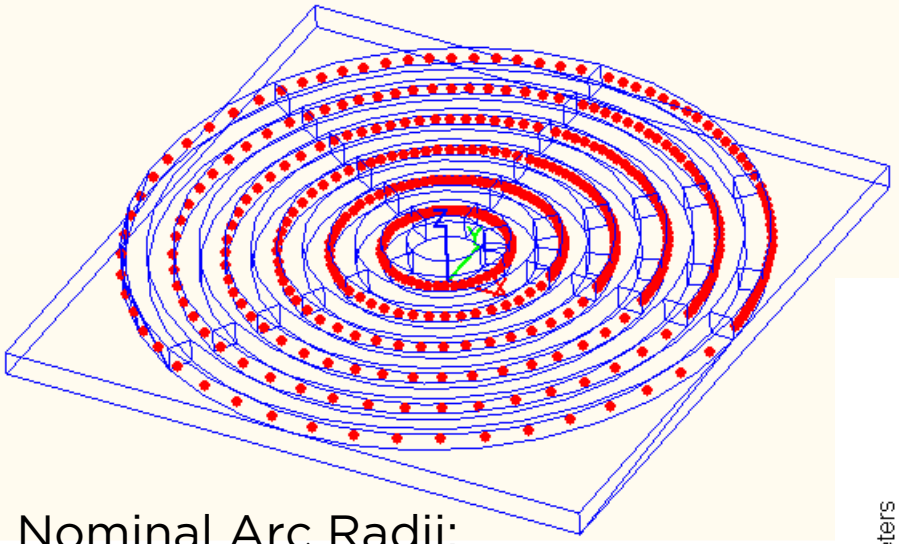
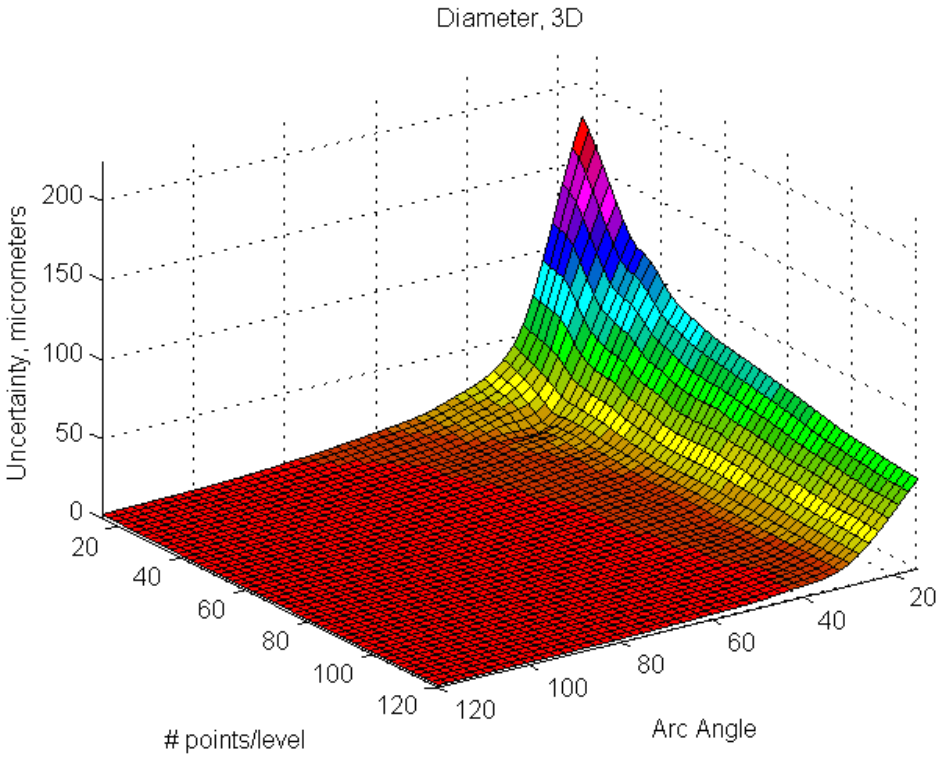
Size Controlled by Diameter Location/Orientation by Position



Random Probe Error with σ = 0.65µm

Uncertainties Largely Insensitive to Size of Feature or ID/OD Type

Positional Data Similar to Diameter:



Nominal Arc Radii:

50, 90, 130, 170, 210, 250 mm

Arc Segments:

15°, 30°, 45°, 60°, 90°, 120°

Sampling Points over Arc:

2 x 15, 30, 60, 80, 100, 120

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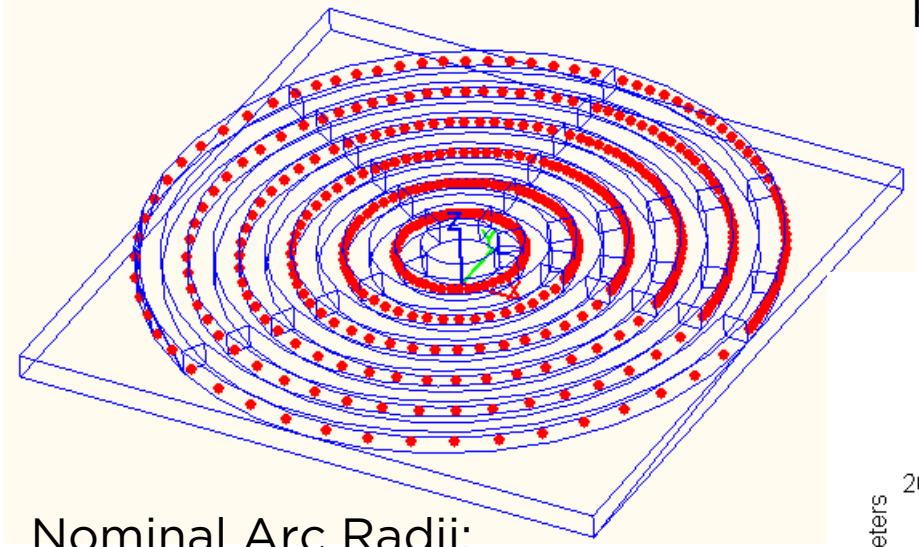
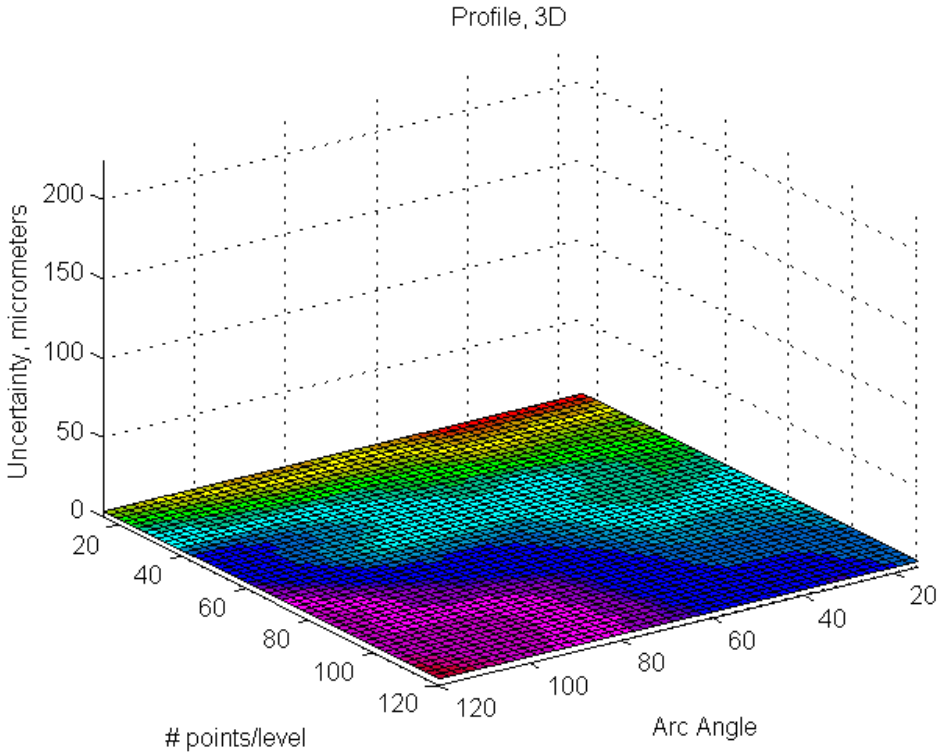
Size, Location & Orientation Controlled by Profile



Random Probe Error with σ = 0.65µm

Uncertainties Largely Insensitive to Size of Feature or ID/OD Type

Profile Uncertainties in 3-4 µm range



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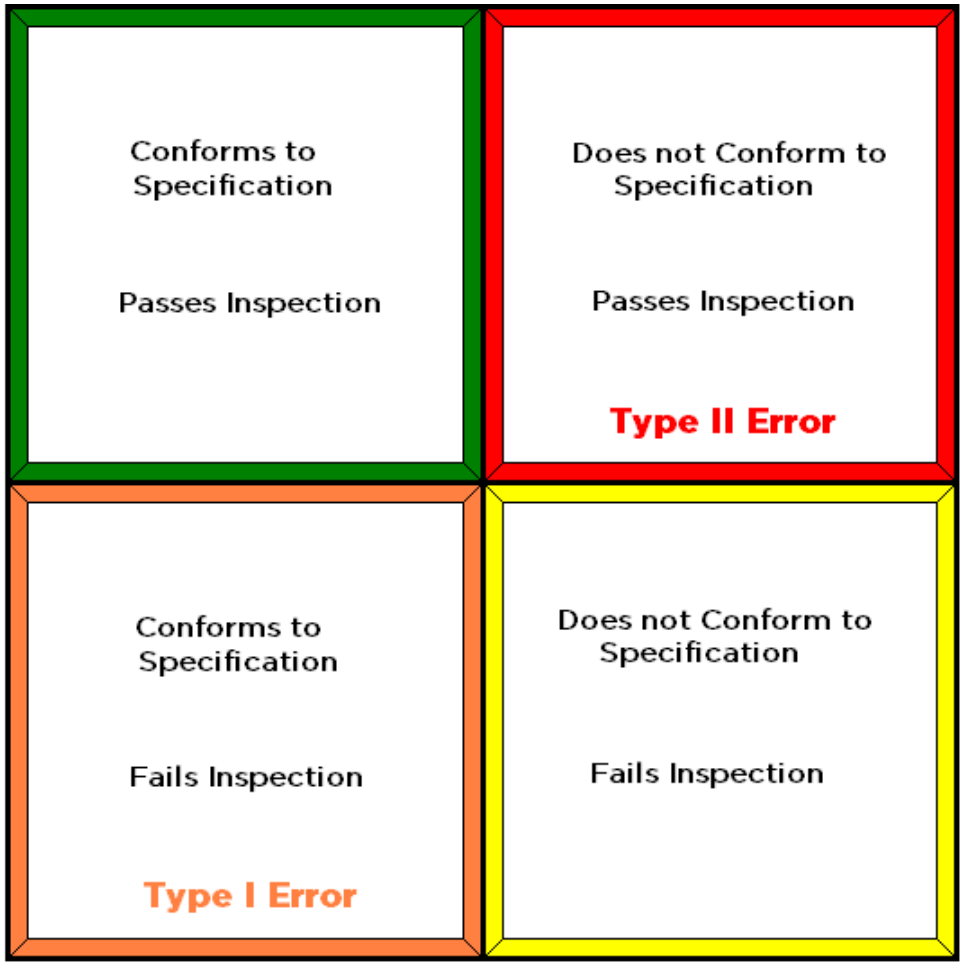
Production & Measurement

4 Possible Outcomes:



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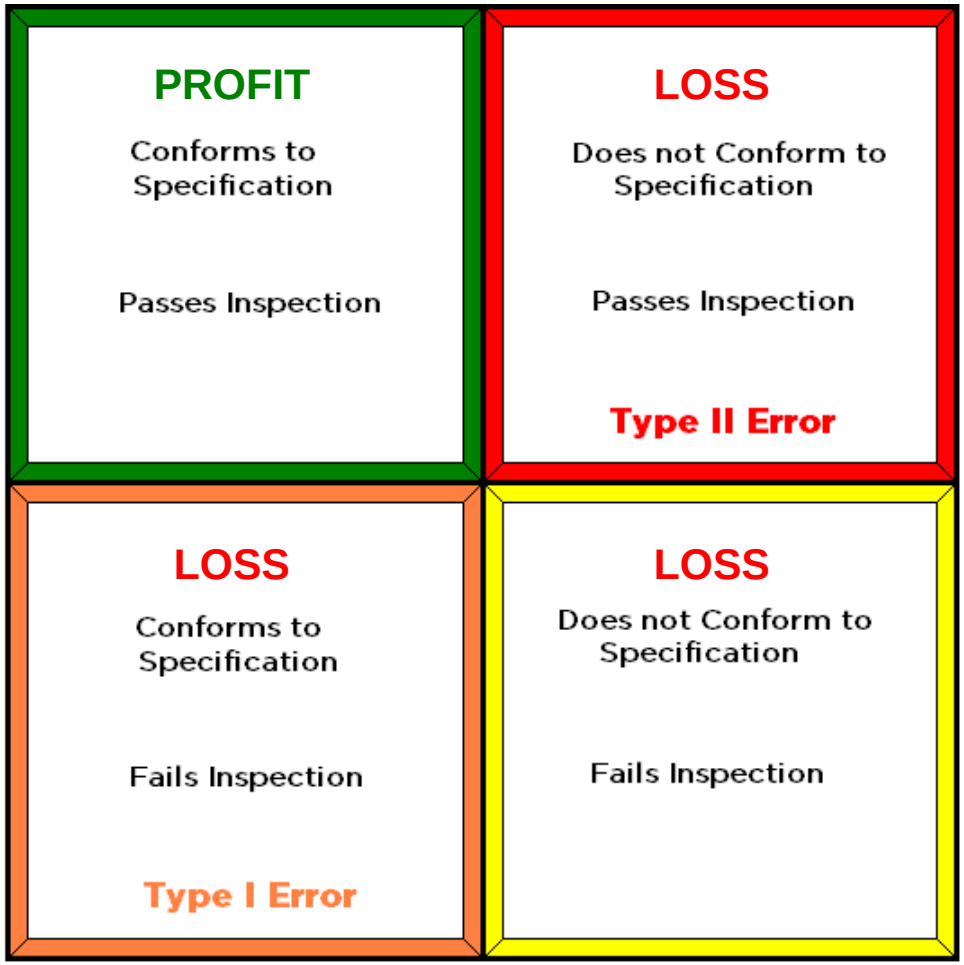
Production & Measurement

3 out of 4

Yield Losses



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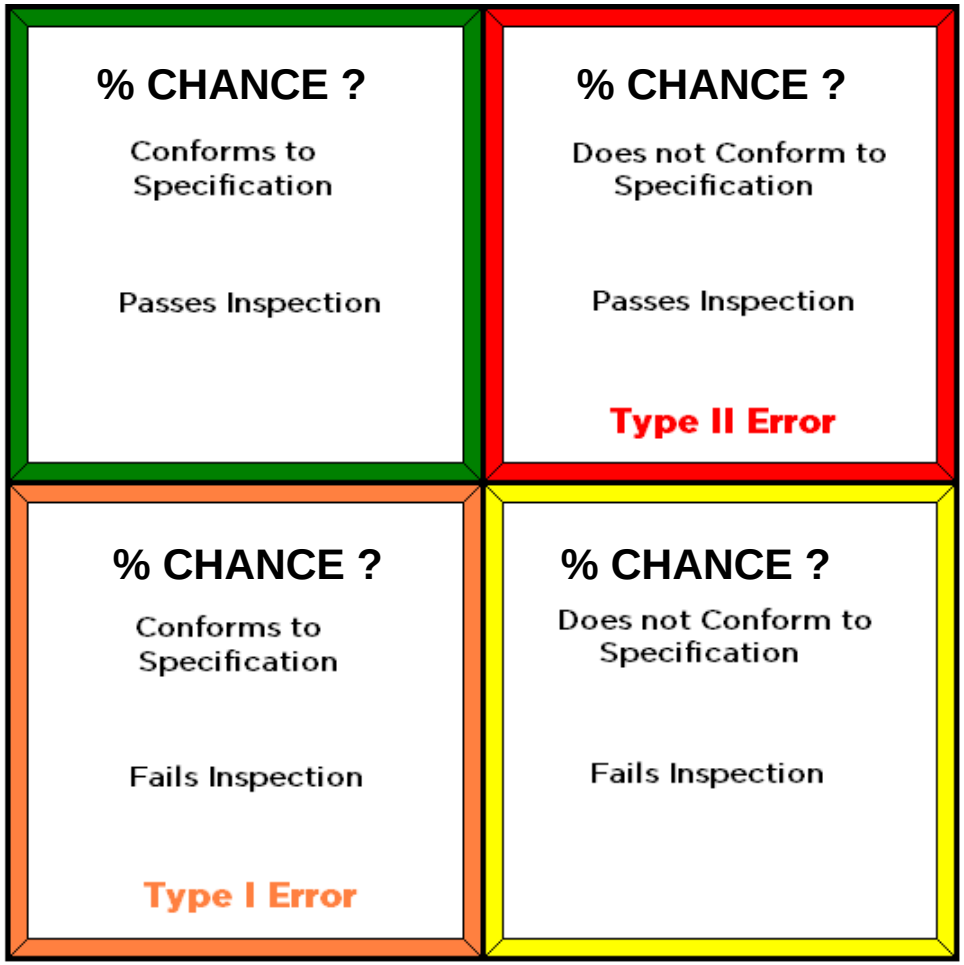
Production & Measurement



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Economics of Measurement Uncertainty

Factors for Consideration:

- ✓ Production Capability
- ✓ Measurement Capability
- ✓ Cost of Rejecting a Good Part (Type I Error)
- ✓ Cost of Accepting a Bad Part (Type II Error)

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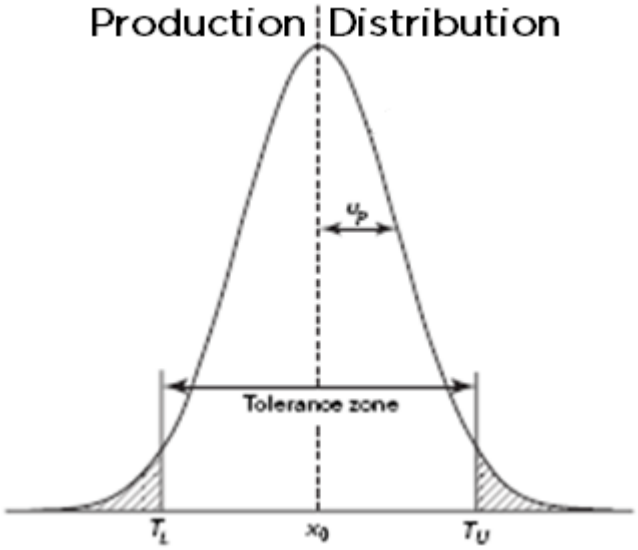
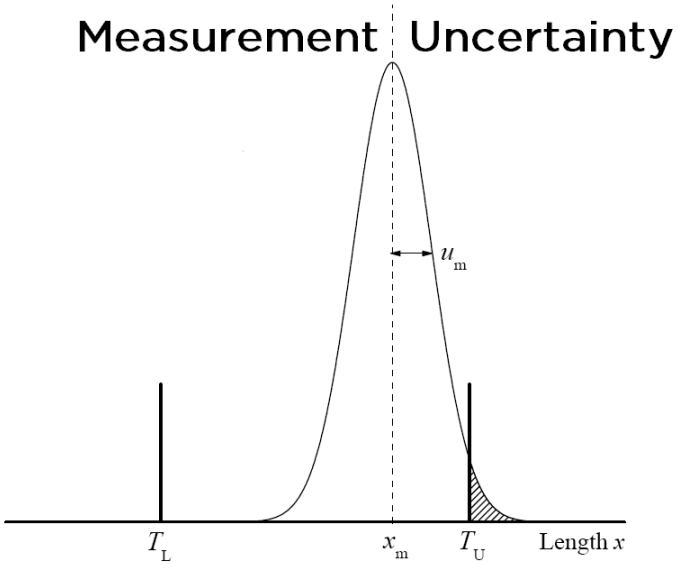
Production & Measurement Capabilities





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Decision Rule without Regard to Measurement Uncertainty

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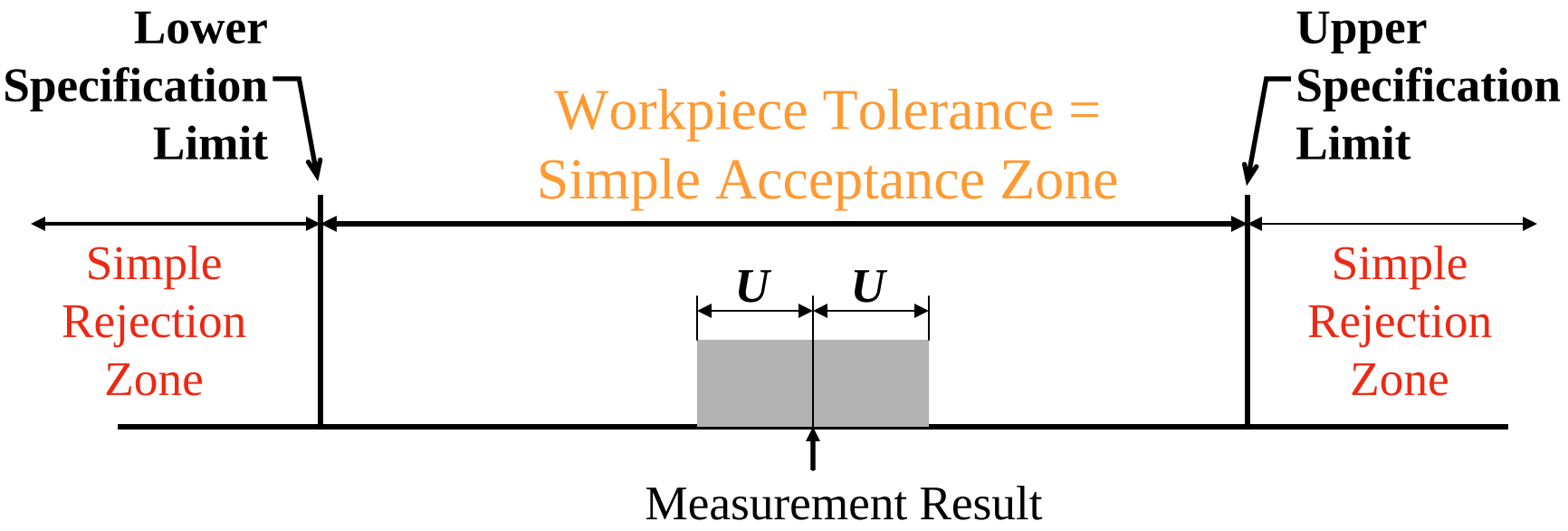
Factoring in Measurement Uncertainty



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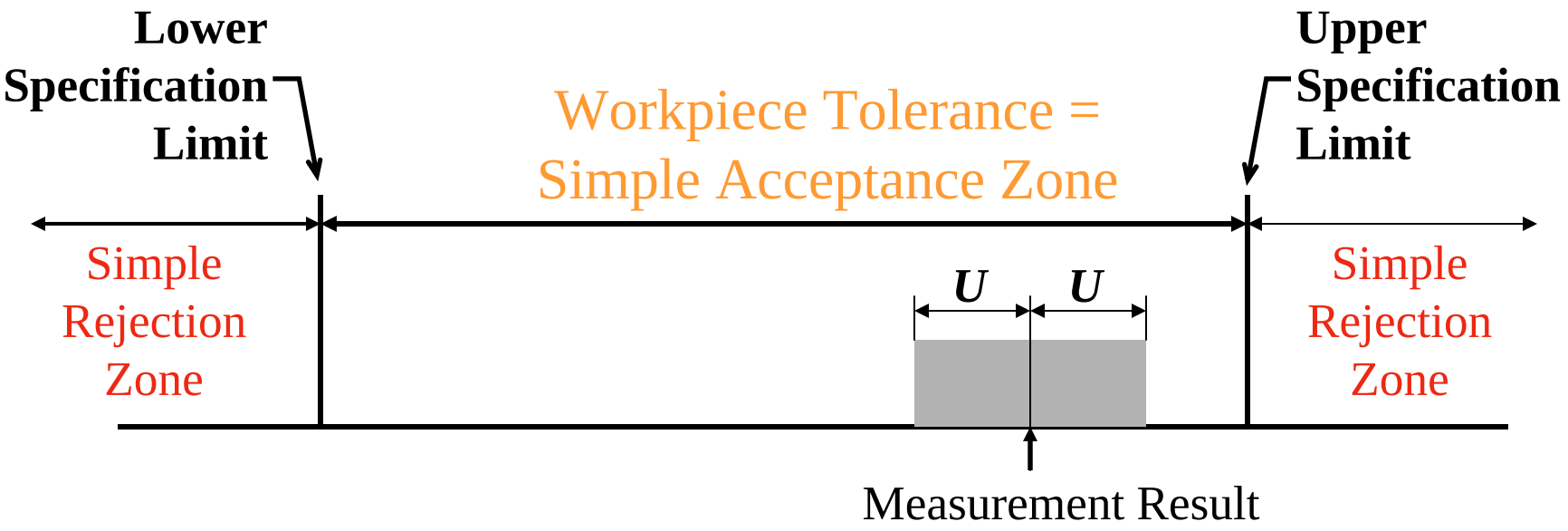
Factoring in Measurement Uncertainty



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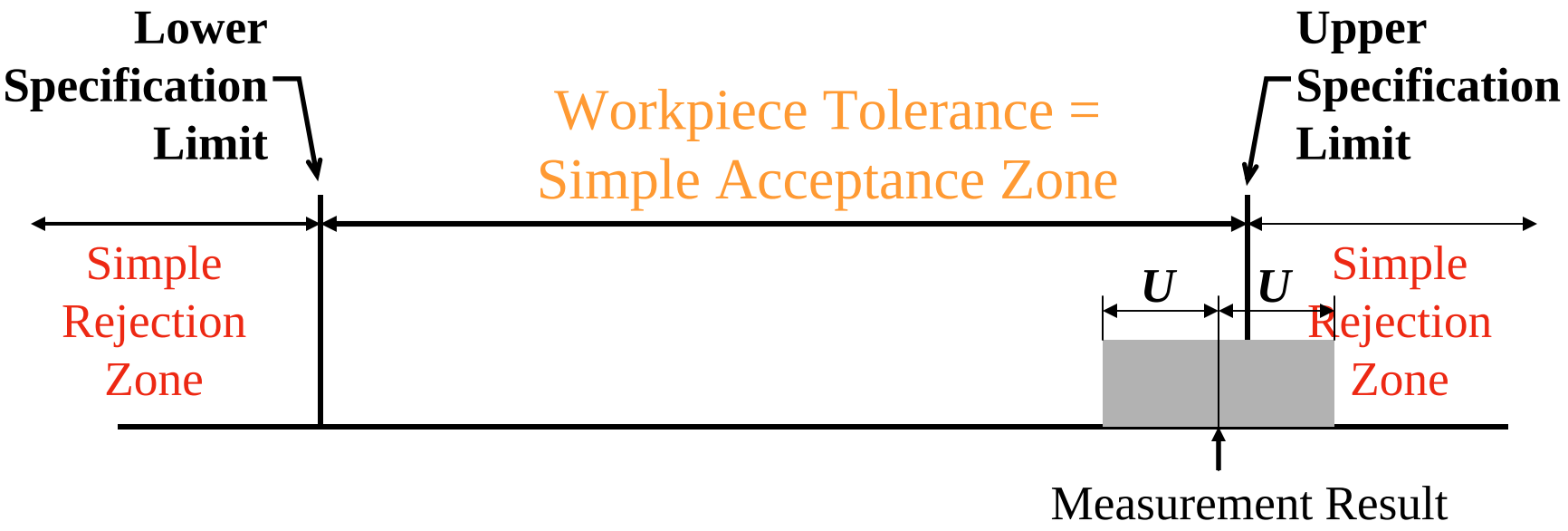
Factoring in Measurement Uncertainty



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Decision Rule: Stringent Acceptance

Less chance of accepting a bad part

Greater chance of rejecting a good part

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Decision Rule: Stringent Rejection

Greater chance of accepting a bad part

Less chance of rejecting a good part

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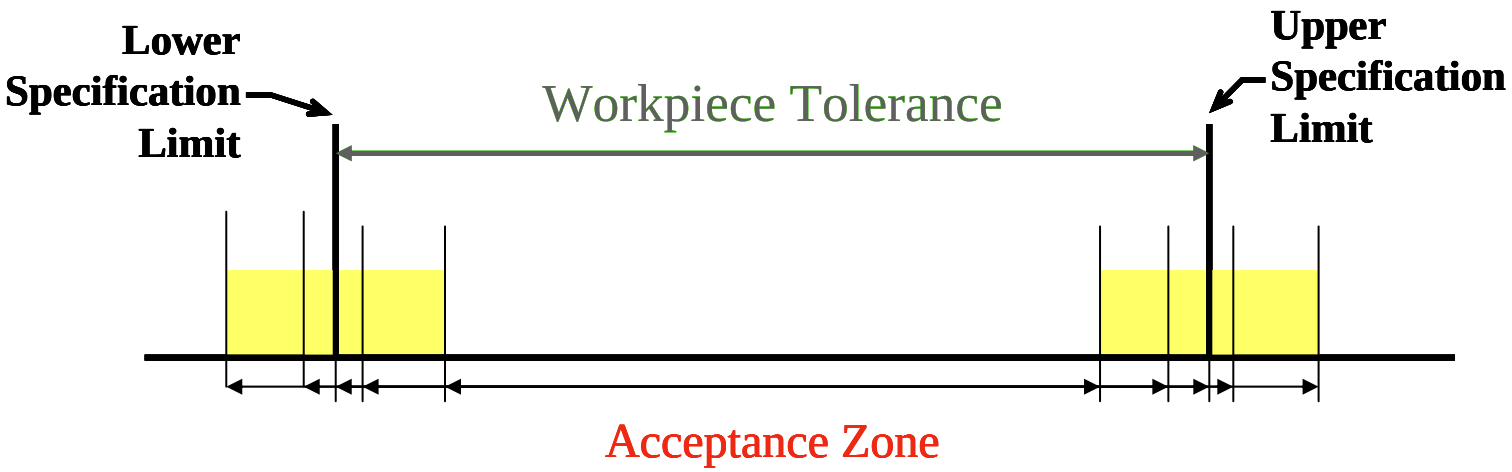
Economic Optimization of Decision Rules Guardband Selection



Which Decision Rule Maximizes Profits?

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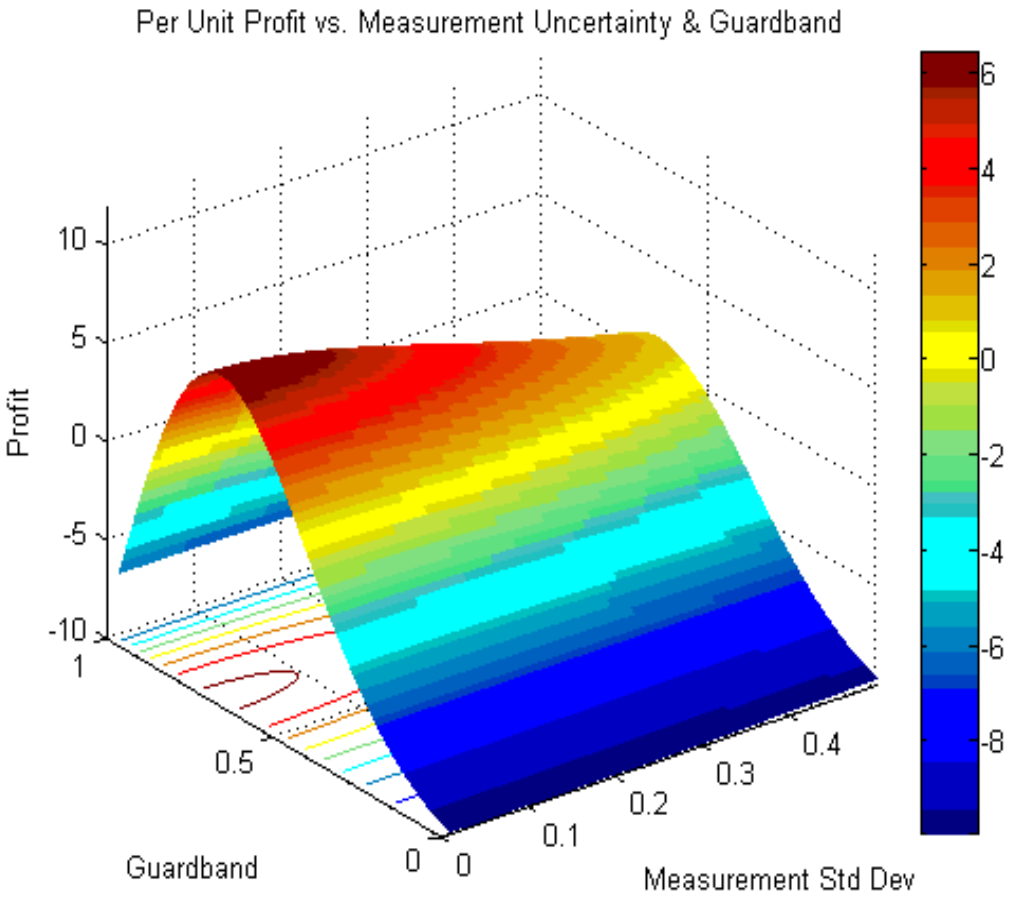
Measurement Uncertainty & Profitability



100 mm diameter shaft

Tolerance ± 1 mm

Production Process Centered

Production Std Dev. 0.33 mm

Measurement Unbiased

Cost of unit production: $7. 50

Sales Price: $30

Expense of release of bad part (Type II Error): $300

Profit Maximized when each Guardband = 0.65 mm

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