



Incorporating Metrology Data Into 3D Tolerance Analysis for Design Refinement and Verification



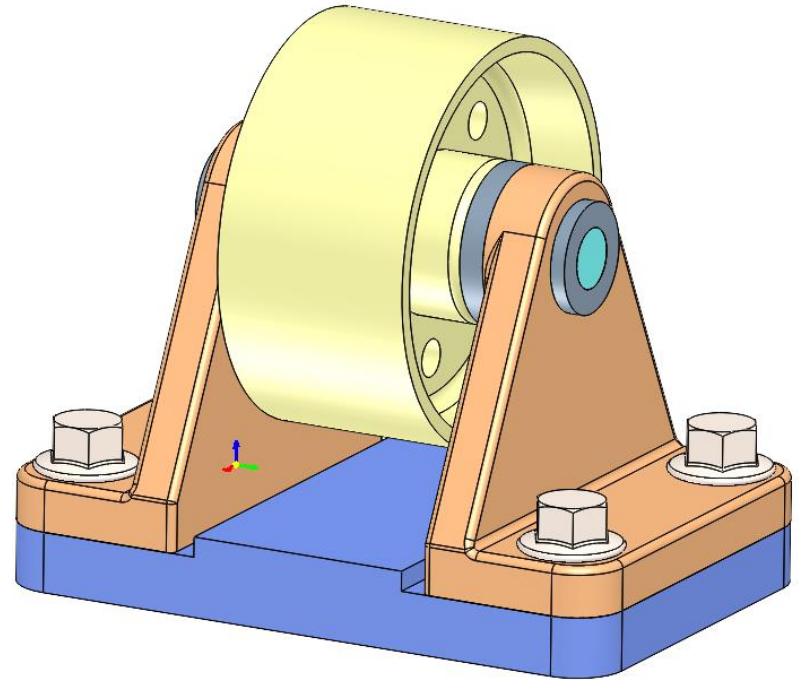
3D METROLOGY
CONFERENCE

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University of Loughborough

Matt Savage, EnginSoft UK

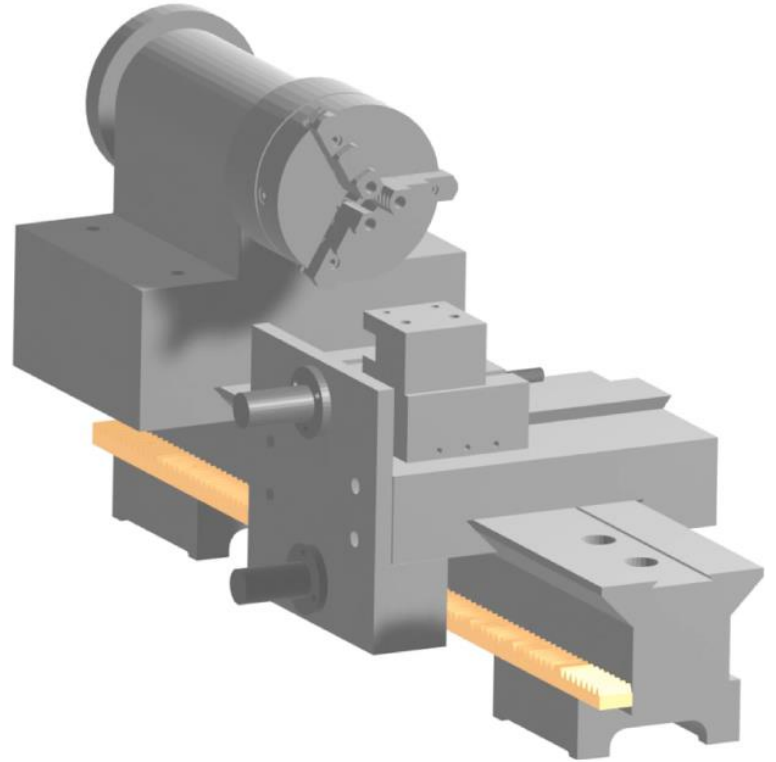
Aims

- Understand challenges with 1D tolerance analysis
- Gain an appreciation of 3D tolerance analysis for design refinement and verification
- Learn how to incorporate metrology data to ensure design quality

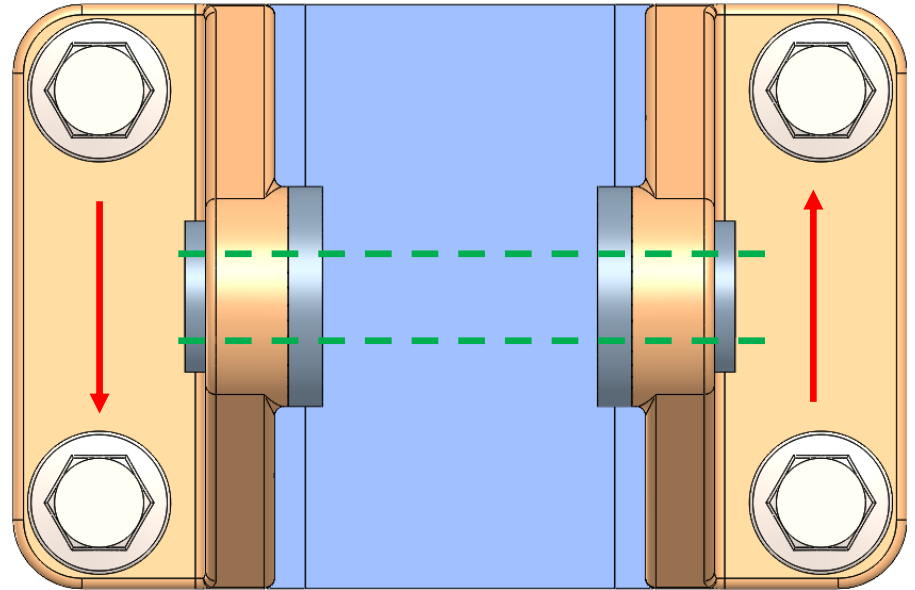
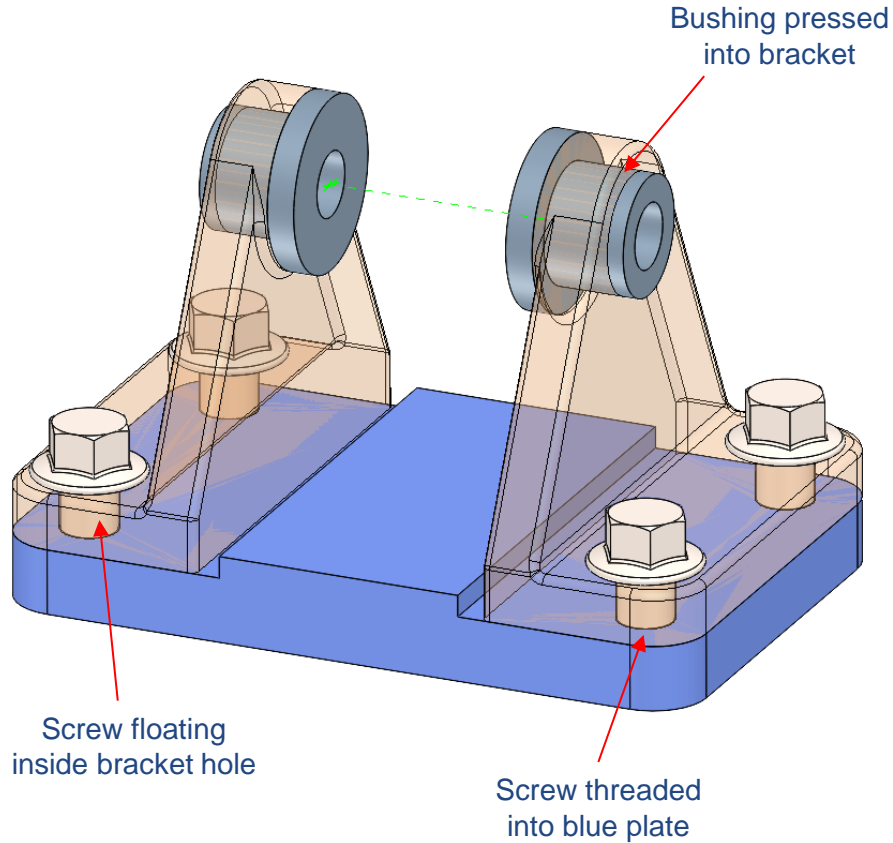


Background

- High accuracy measuring devices require **high precision components**
- **Controlling tolerances** is vital to control **quality**
- **Tight tolerances** will increase manufacturing **cost**
- Manufactured parts might not meet the **intended design specification**

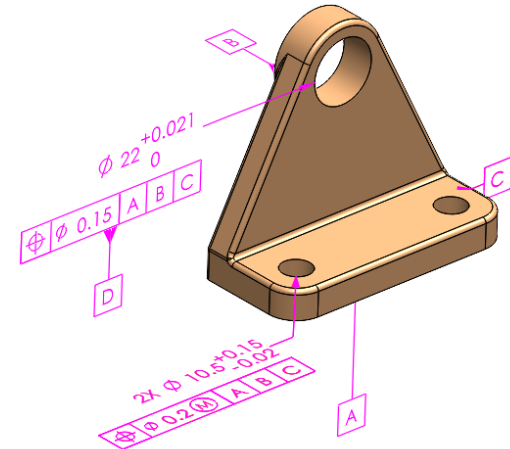
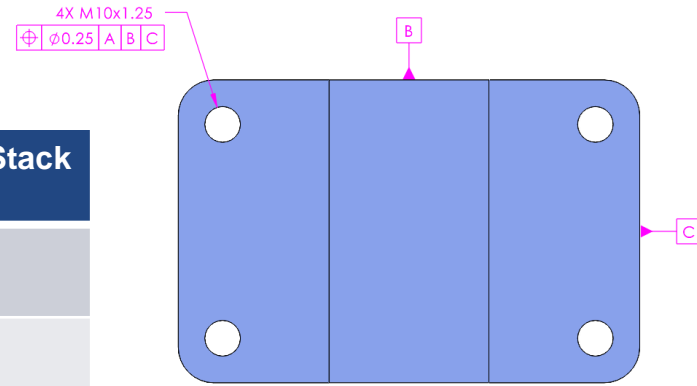


Caster Wheel Assembly

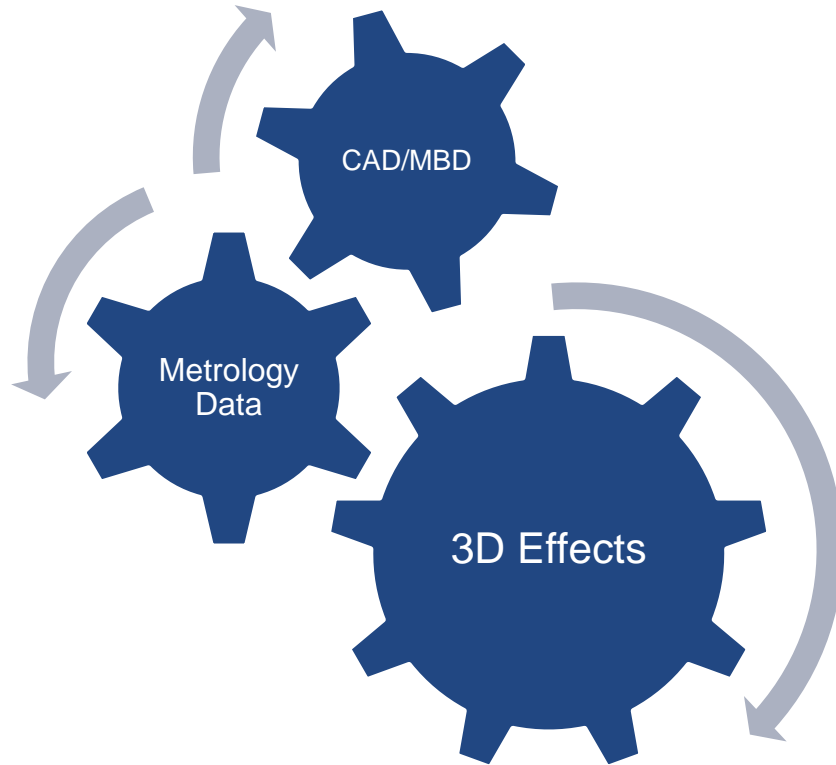


1D Tolerance Stack Up

Step	Tolerance (mm)	Added Variation (mm)	Cumulative Stack (mm)
1 – RHS Bushing Position	Pos 0.15	+0.075	0.075
2 – RHS Bracket Hole Position	Pos 0.2	+0.1	0.175
3 – RHS Bracket Hole Size	+0.15 (diameter) -0.02 (+0.25 float)	+0.375	0.55
4 – RHS Plate Hole Position	Pos 0.25	±0.125	0.675
5 – LHS Plate Hole Position	Pos 0.25	±0.125	0.8
6 – LHS Bracket Hole Size	+0.15 (diameter) -0.02 (+ 0.25 float)	+0.375	1.175
7 – LHS Bracket Hole Position	Pos 0.2	+0.1	1.275
8 – LHS Bushing Position	Pos 0.15	+0.075	1.35

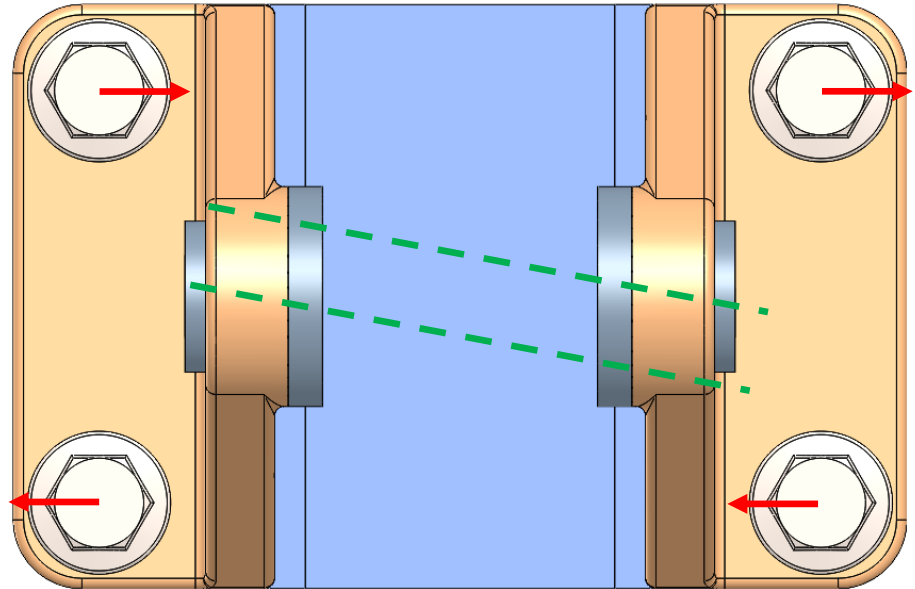


1D Challenges



3D Effects in Tolerance Analysis

- Lets looks again at the previous stack up...
- a) how difficult is an angular stack up?
- b) which combination of linear and angular variation provides the largest misalignment?
- c) how do we determine this with a spreadsheet?

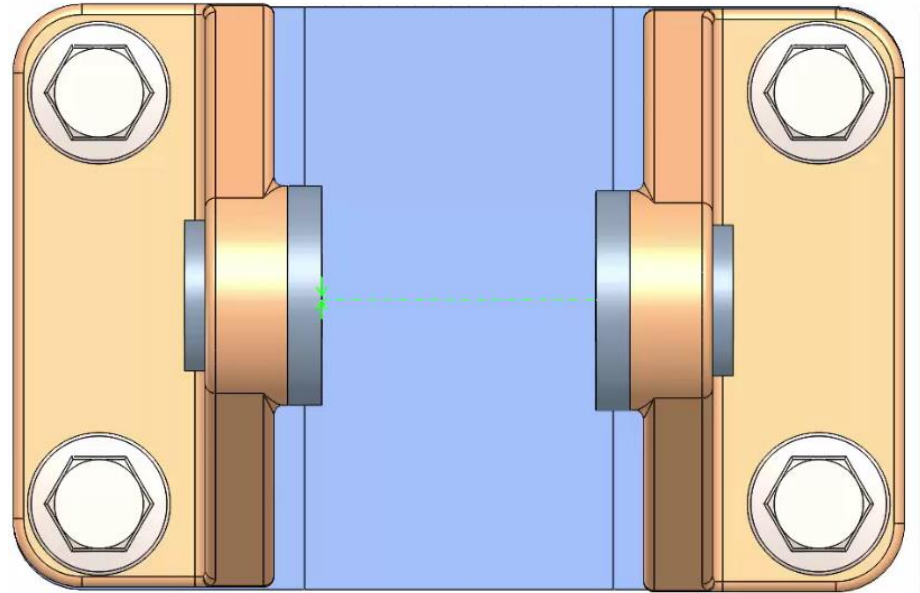


CETOL 6σ

The screenshot displays the SolidWorks CAD environment. The top ribbon shows the 'Assemble Mode' with options like 'Add Component', 'Add Joint', and 'Show Locations'. The left-hand 'Feature Tree' lists the assembly structure, including 'caster (Default)' and 'Linear Stack Up'. The central 3D view shows a mechanical assembly with orange and blue components. A 'CETOL' constraint is applied to a hole in the 'axle_support' part, with a coordinate system (X, Y, Z) visible. The right-hand 'CETOL Properties' panel is open, showing the 'axle_support (Default);1.1' constraint. The 'Bias' section has 'Floating' selected. The 'Concentric at Point' section is expanded, showing the 'Origin Feature' as 'axle_support (Default);1 / hole2, SCREW' and the 'Constrained Feature' as 'x flange screw, M10 x 1.5 x 20N;1 / Threads'. The 'Refinements' section shows 'Locate' and 'Orient' options.

3D Tolerance Analysis

- Dedicated software packages (e.g. CETOL 6 σ) allow you to:
 - Model assembly conditions
 - Add in GD&T definitions
- Worst case using this method is 2.6mm (compared to 1.35mm)

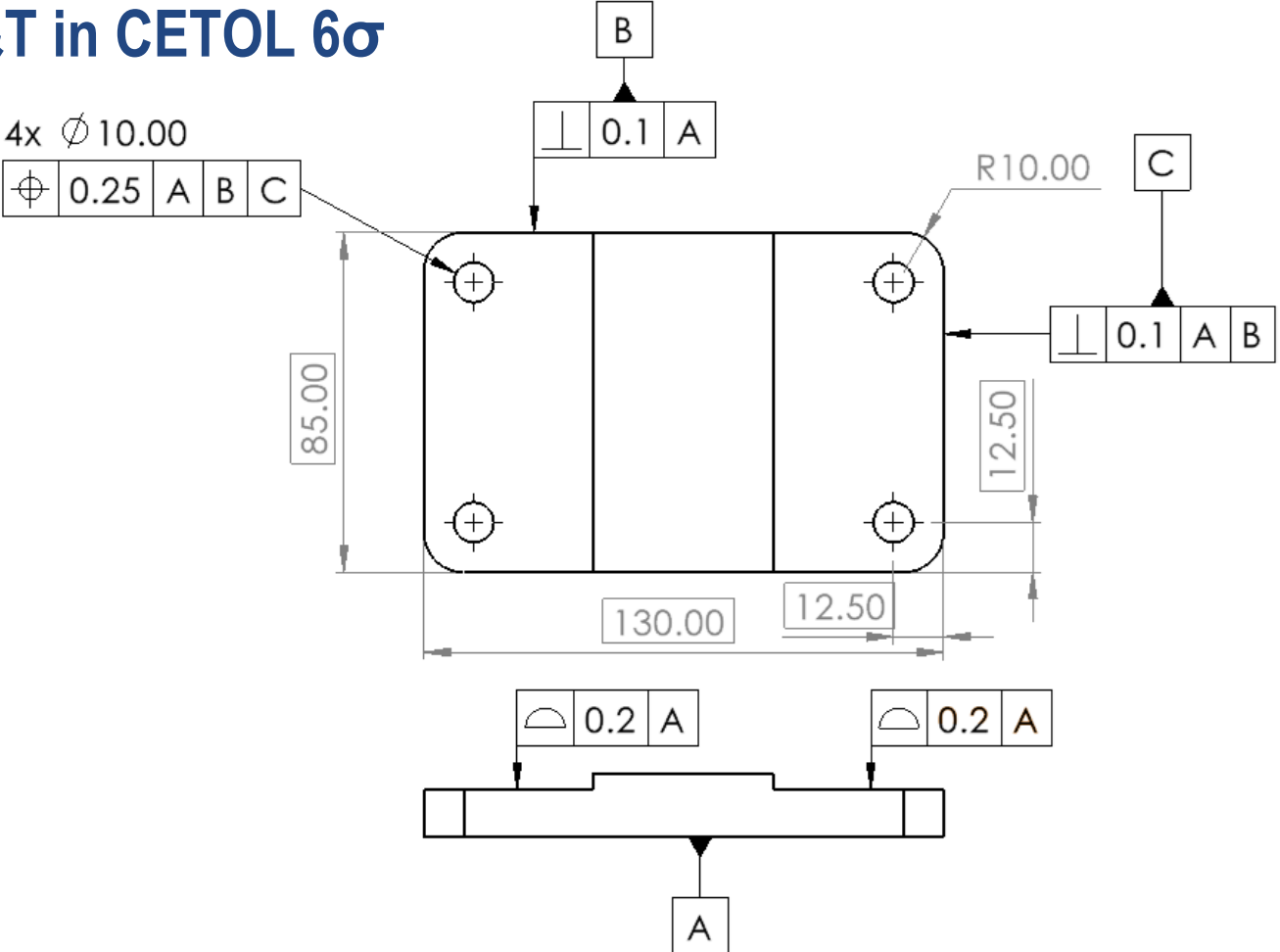


3D GD&T Definitions

- How do we account for these kinds of variation?
 - What does a position tolerance mean?
 - Does it control angular variation as well as position?
 - Which datums is it referencing?
 - Does the pin that fits inside it always go in straight?



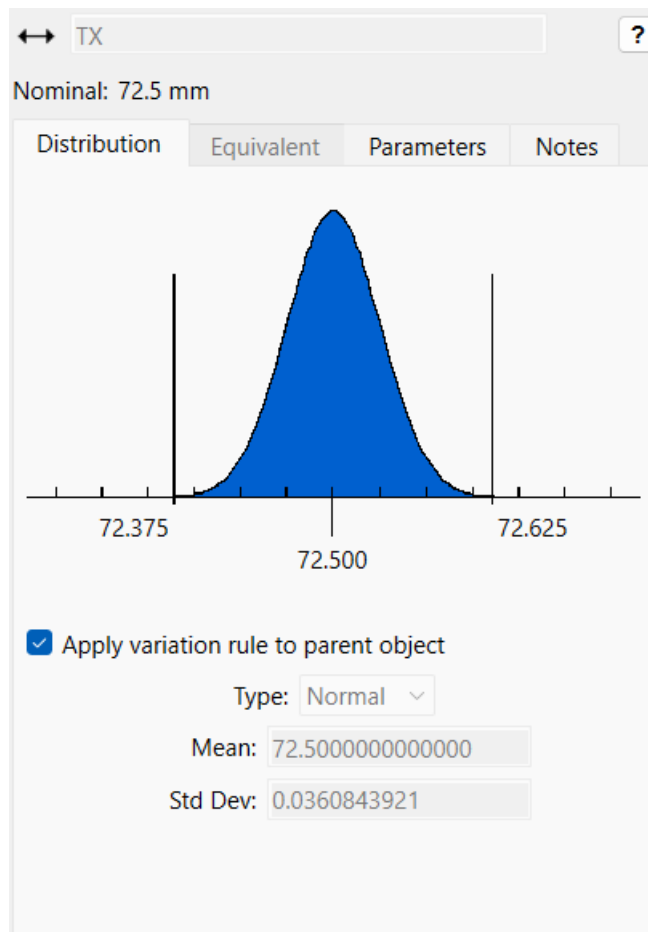
GD&T in CETOL 6 σ



- A \perp A
 - A
 - B \perp B
 - > \perp 0.1 A
 - A B
 - C \perp C
 - > \perp 0.1 A B
 - A B C
- mount, AXLE SUPPORT-R
 - > 0.2 A
- hole1, SCREW
 - > \varnothing 10.00 \pm 0.005
 - > \varnothing 0.25 A B C
- hole2, SCREW
 - \varnothing 10.00
 - > \varnothing 0.25 A B C
- mount, AXLE SUPPORT-L
 - > 0.2 A
- hole3, SCREW
 - \varnothing 10.00
 - > \varnothing 0.25 A B C
- hole4, SCREW
 - > \varnothing 10.00 \pm 0.005
 - > \varnothing 0.25 A B C

GD&T Distributions

- hole1, SCREW
 - $\varnothing 10,000 \pm 0,005$
 - $\varnothing 0,25$ A B C
 - TX
 - RX
 - TY
 - RY



Metrology in 1D Stack Ups

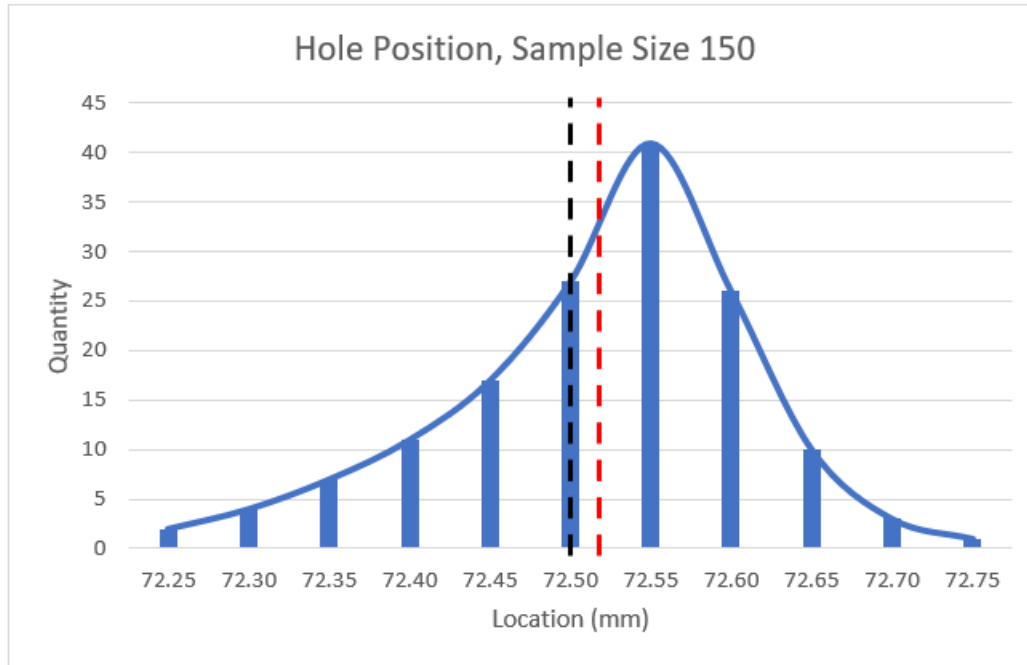
- Statistical analysis requires Standard Deviation (σ)

$$\sigma_{ASM} = \sum_{i=1}^n \sigma_i^2^{\frac{1}{2}}$$

- Metrology data provides four moments of distribution
 - Mean
 - Standard Deviation
 - Skewness ←————— These two make 1D
 - Kurtosis ←————— stack ups challenging

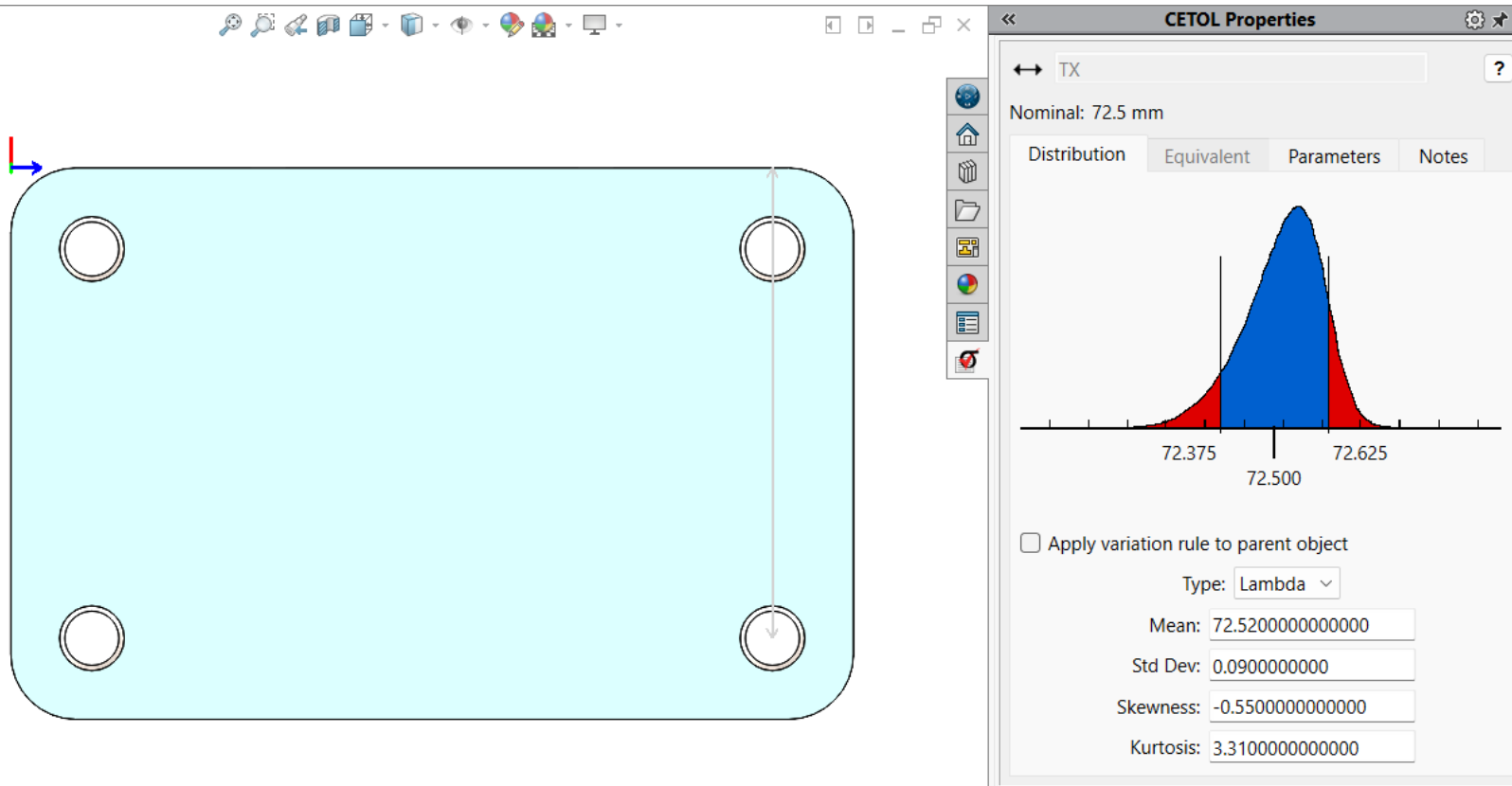
Adding Metrology Data

Location (mm)	Quantity
72.25	2
72.30	4
72.35	7
72.40	11
72.45	17
72.50	27
72.55	41
72.60	26
72.65	10
72.70	3
72.75	1



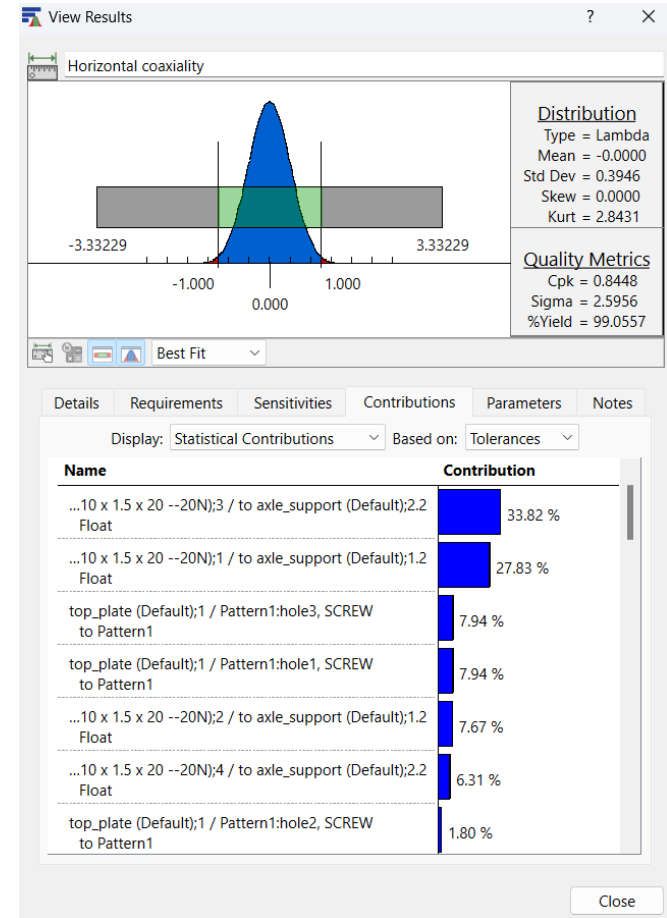
Statistical Moment	Value
Mean	72.52
Standard Deviation	0.09
Skewness	-0.55
Kurtosis	0.31

Metrology Results in CETOL 6 σ



Results and Contributors

- True worst case is 3.3mm misalignment
 - Production sees a 1% scrap rate
- CETOL 6 σ highlights key contributors
 - Float between screw and bracket hole has largest effect on variation
- What If Analysis
 - Alter tolerances to visualise change in results



Conclusions



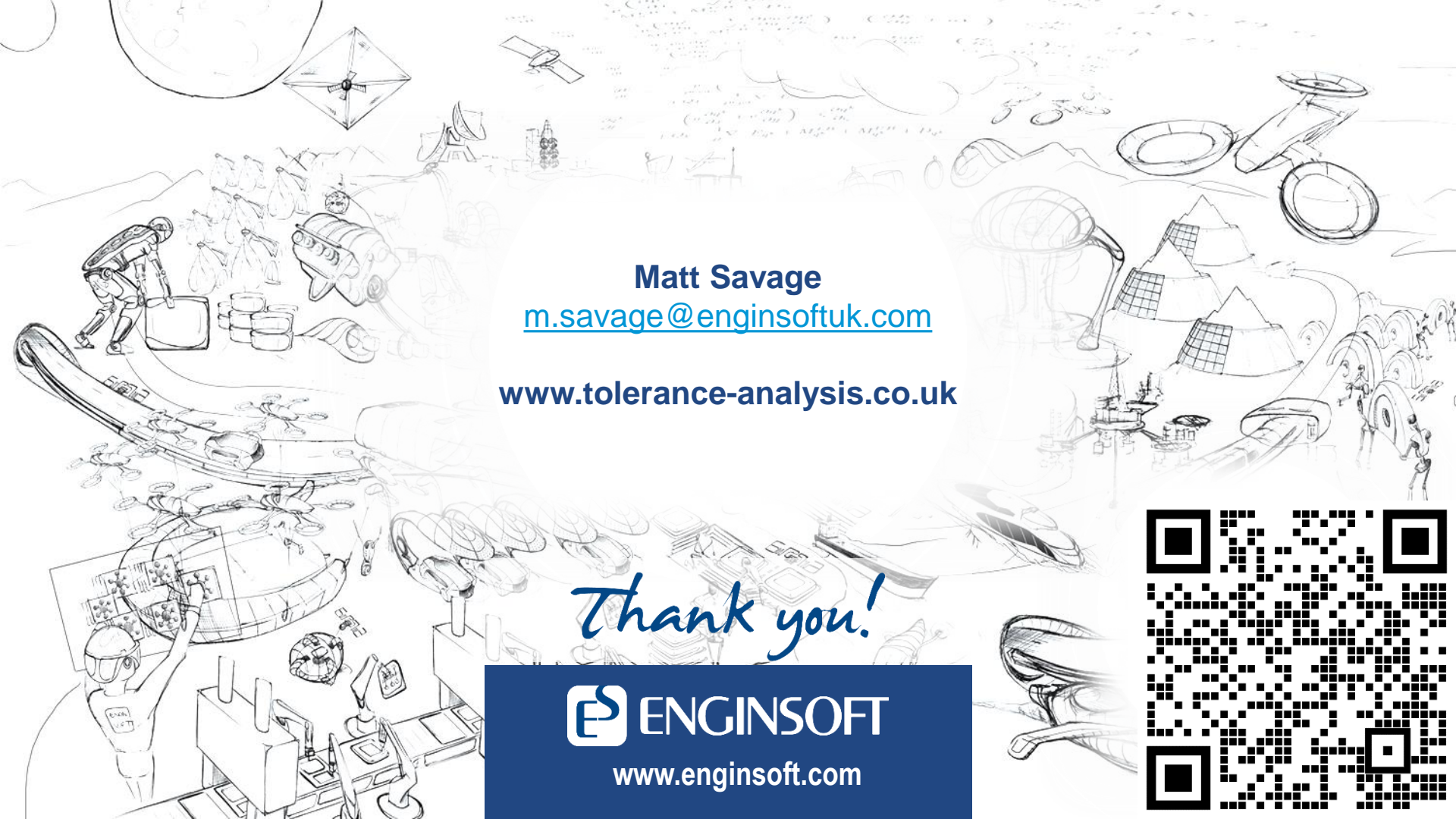
3D tolerance analysis using **CETOL 6 σ** provides further insight not available using 1D stack ups



Metrology data can be included for every variable from any sample size



Design iteration and **model rework limited** once the model is built



Matt Savage
m.savage@enginsoftuk.com

www.tolerance-analysis.co.uk

Thank you!

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