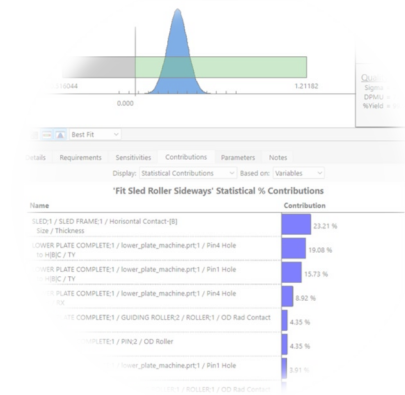
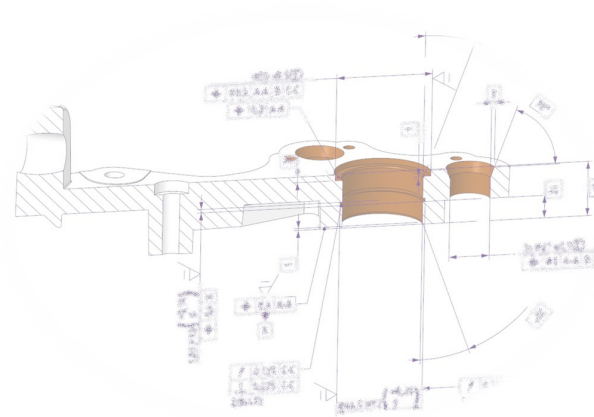
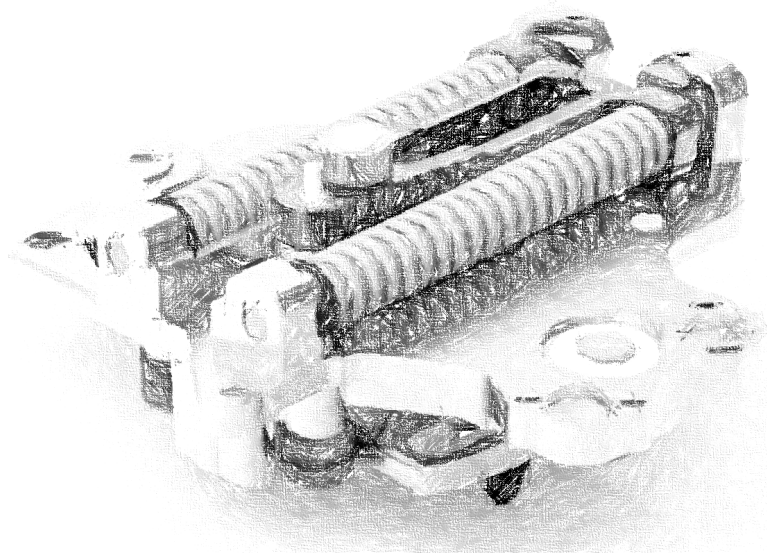


Model Based Tolerance Analysis



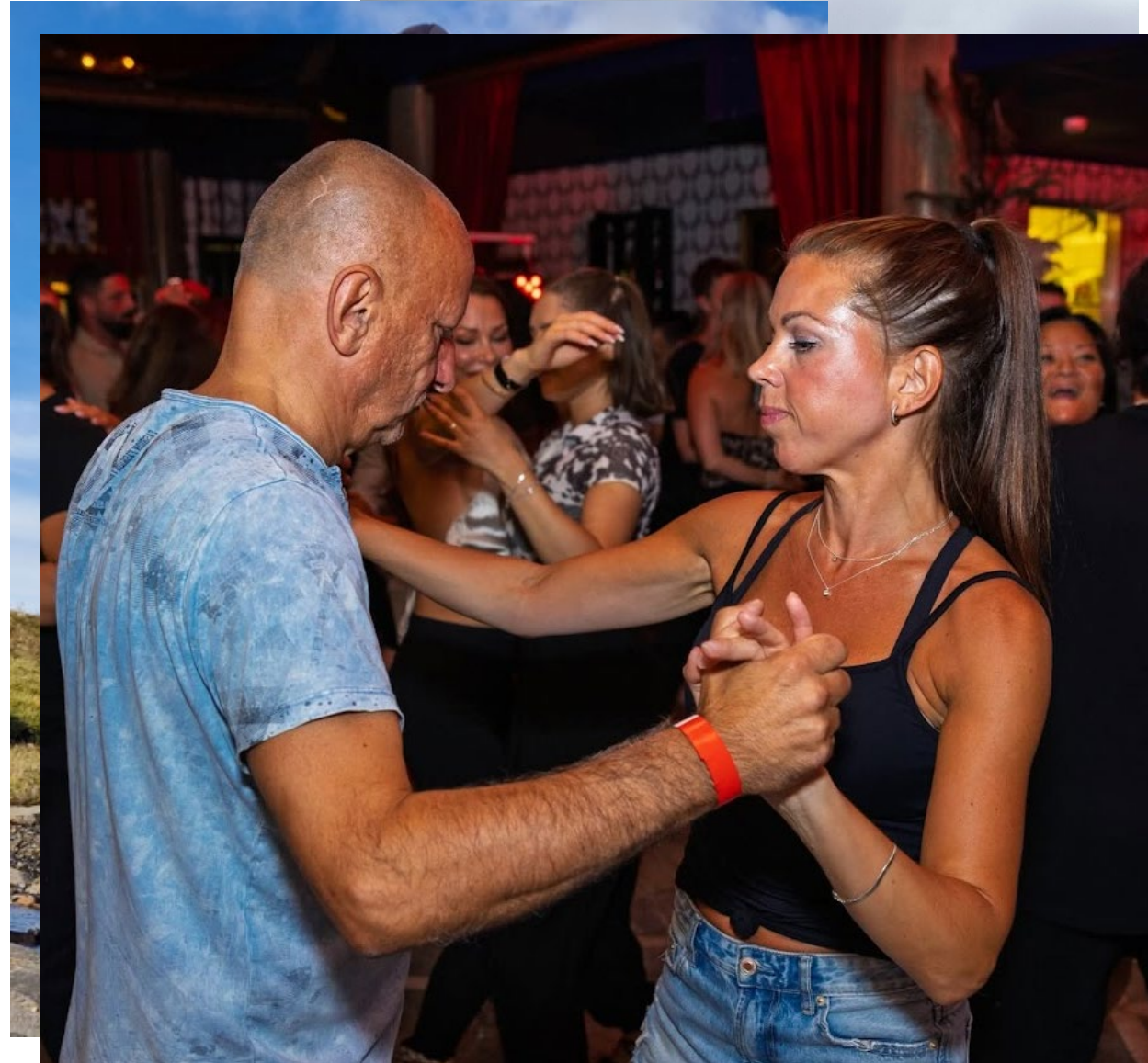
Mirosław Chamera
ARIADNE Engineering AB

Agenda

- Introduction
- Value of tolerance analysis
- How to perform tolerance analysis
- Challenges/Solutions
- Customer case Hitachi Energy Components
- Next level of tolerance analysis
- Q/A

Miro

- MSc – Mechanical Engineering
- Founder of ARIADNE
- FEM Analysis
- Tolerance Analysis
- ISO GPS/GD&T
- MBD Based Metrology
- Collaboration
- PTC User Sweden Chair

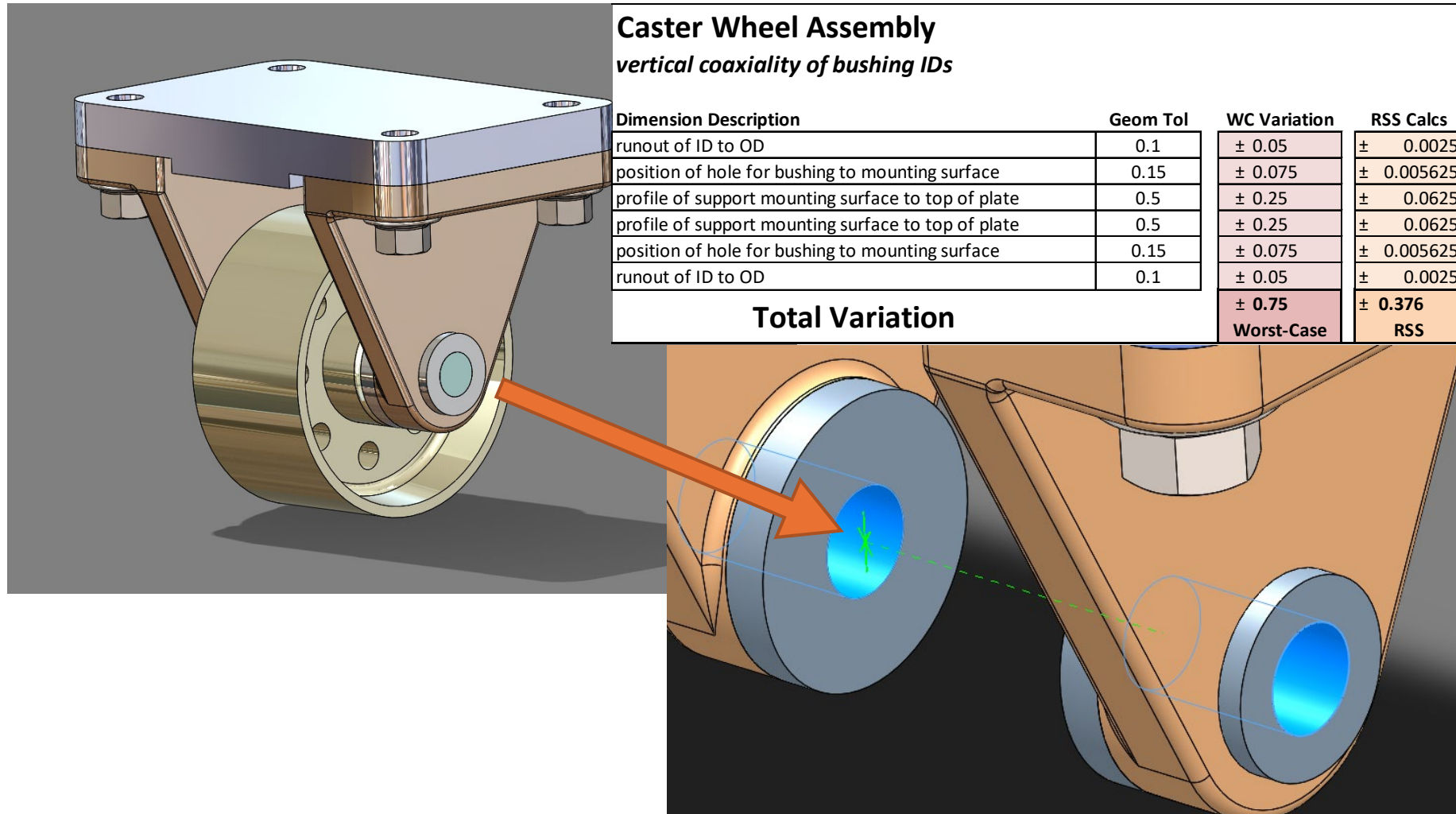


We help our customers to create **high quality products** at **lower cost** by implementing digital product development environment:

Model Based Enterprise



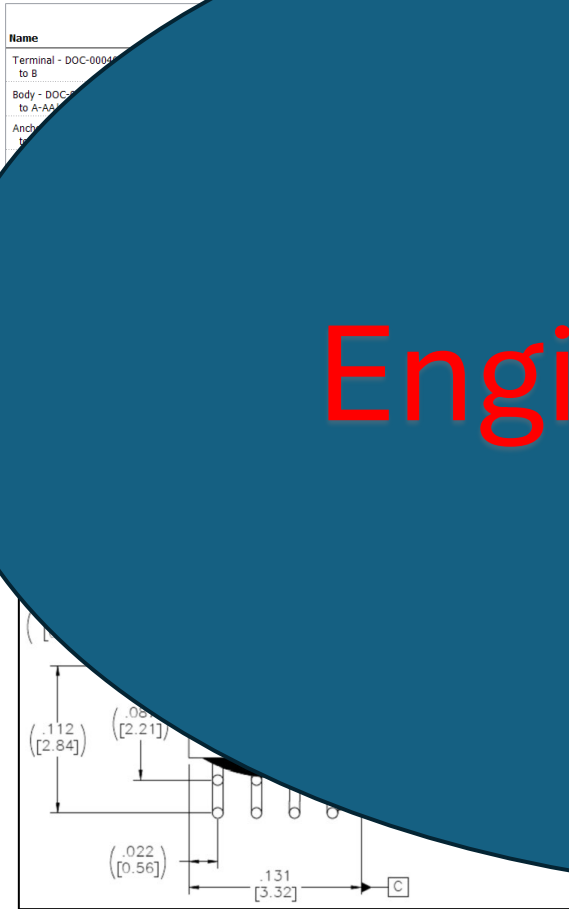
How Cool is Tolerance Analysis?



Requirement: Verify spreadsheet and understand horizontal coaxial variation as well

Oticon AS

Engineering Time



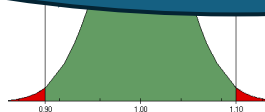
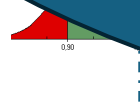
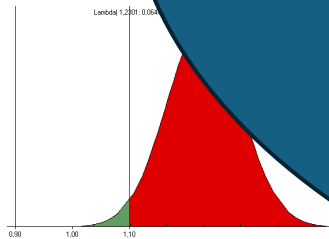
Tetra Pak AB

CETOL6 σ Tolerance Analysis

- Function analysis
- Mean shift
- Critical
- Imp
- C

QL

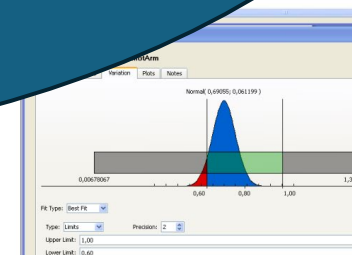
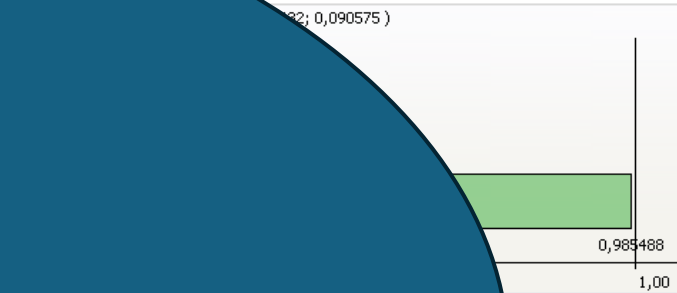
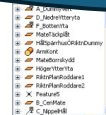
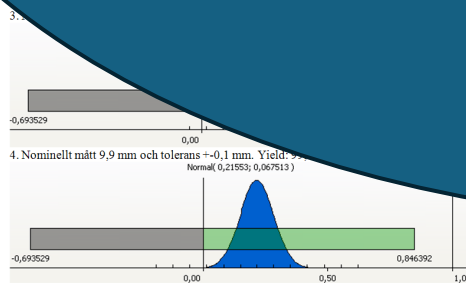
4%



Name	Contribution
Folding flap R:1 / C and Out to A	20.24 %
Folding flap L:1 / C and Top to A	19.75 %
Inductor:1 / Heating Jaw Blue - Inductor (Float) TY	12.70 %
Inductor:1 / Heating Jaw Blue - Inductor (Float) TY	12.35 %
Folding flap R:1 / B_OD_16 to A	6.65 %
Folding flap L:1 / B_OD_16 to A	5.45 %
Arm Orange:1 / ID10 to A B C	4.44 %
Arm Green:1 / ID_10 to A B C	4.44 %
Heating Jaw Grey:1 / Heating Jaw Grey - Heating Jaw Blue TY	1.51 %
Folding flap R:1 / C and Out Size	1.43 %
Folding flap L:1 / C and Top Size	1.40 %
Heating Jaw Blue:1 / Width_B to B	1.15 %
Heating Jaw Blue:1 / Top_Bottom_width to B	1.14 %
Heating Jaw Blue:1 / ID18_R Added	0.81 %
Heating Jaw Blue:1 / Opp to B	0.78 %
Heating Jaw Blue:1 / Opp to B	0.76 %
Heating Jaw Blue:1 / ID18_L	0.75 %
Heating Jaw Blue:1 / ID18_R	0.67 %
Heating Jaw Blue:1 / ID16	0.50 %
Heating Jaw Blue:1 / ID16	0.35 %
Heating Jaw Blue:1 / C to B	0.34 %
Heating Jaw Blue:1 / C to B	0.34 %
Heating Jaw Blue:1 / ID8 Size	0.34 %
Heating Jaw Blue:1 / ID8 Size	0.34 %
Folding flap R:1 / Top Bottom to C and Out	0.25 %
Folding flap L:1 / 16_In_Out to C and Top	0.24 %
Heating Jaw Blue:1 / Pin_L to B C_Added	0.16 %
Bushing OD16:1 / ID14 Size	0.09 %
Link Arm:1 / ID10_L to R Dummymatane Horiz B Dummymatane Vert	0.08 %

- CETOL

Time to Market

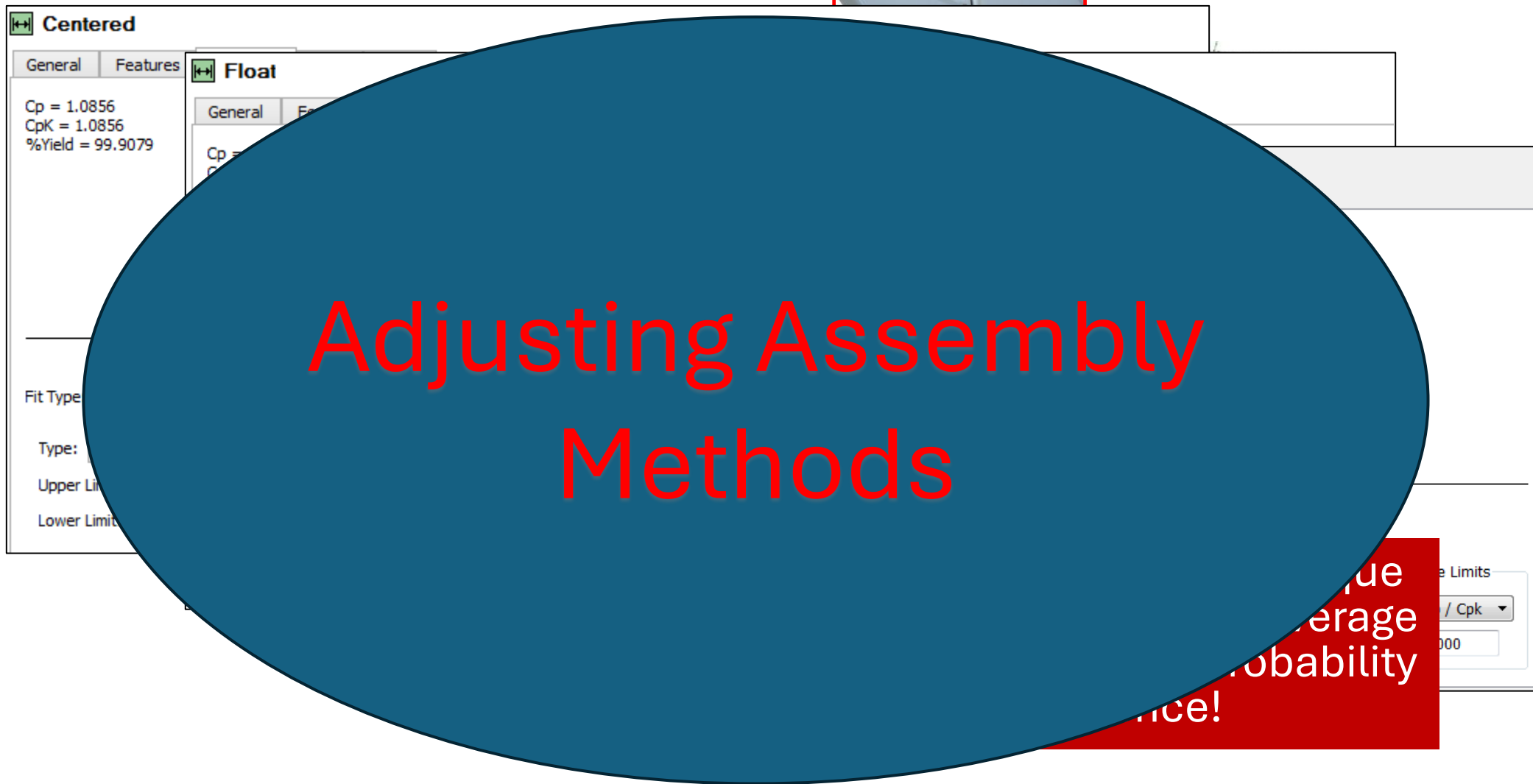
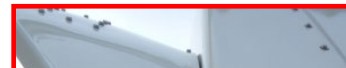


Finding Critical Dimensions

- The top contributor is the variation in the angle clearance.
- The two top contributors are the coaxiality tolerances of the gear wheel and companion flange. None were previously part of the inspection plan.

Design Robustness

- Sensitivity analysis shows that for every millimeter the diameter changes, the angle changes by 1 degree.
- Both the coaxiality tolerances discussed in the previous slide have very high sensitivities. They need to be watched closely during inspection.



Centered

General Features

Cp = 1.0856
CpK = 1.0856
%Yield = 99.9079

Float

General Features

Cp =
CpK =

Fit Type

Type:

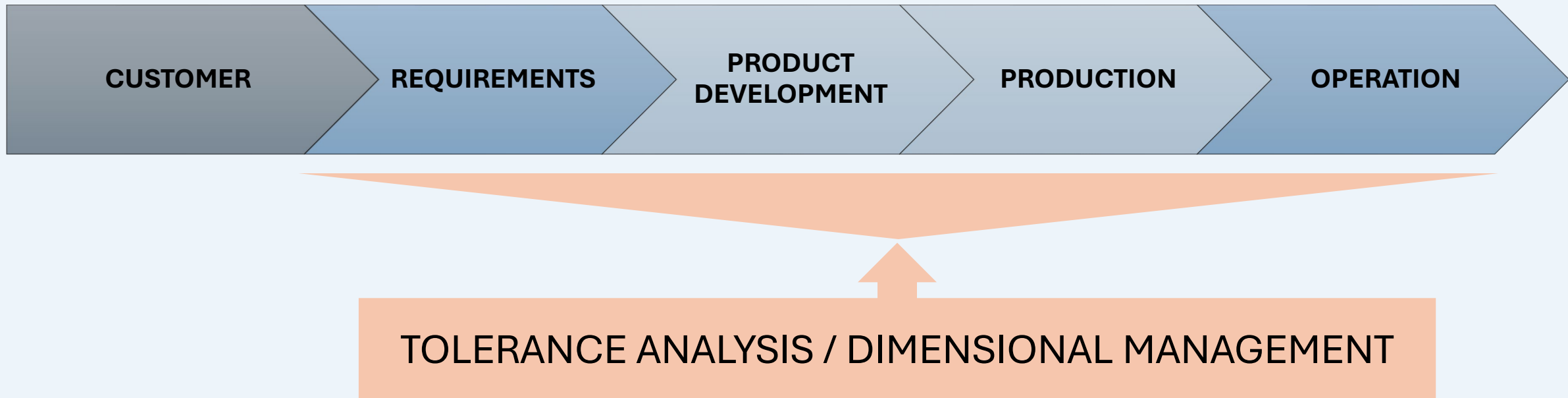
Upper Limit

Lower Limit

Due
Average
Probability

Price!

Why tolerance analysis?



Challenges

- **Engineers do not have the time.**
 - The administrative burden eats engineering time
- **Engineers find the threshold is too high.**
 - How to setup the tolerance analysis?
 - 1D stackups spreadsheets not enough the world is 3D!
 - Tolerance analysis consultants only have time to analyze the “most important functions”.
- **CAD models are not MBD Ready.**
 - Manual programming of tolerances using 2d drawings
 - PMI can't be automatically converted to tolerance analysis feature constraints.
 - A new way of working is needed but psychological inertia works against you.
- **Product specifications are neither 100% unambiguous, complete nor functional enough.**
 - Specifications are not functional enough – less value of tolerance analysis
 - Additional time needed to understand the specifications instead of just analyzing them.



Solutions

- **Free up engineering time**



- Develop an MBD workflow
- Guidelines of using the workflow to improve CAD model quality
- Training engineers in using the workflow

- **Improved product specification**

- Training ISO GPS/GD&T
- Training functional break-down

- **Easy to use MBD Ready software**

- Training in using the software
- Consulting services

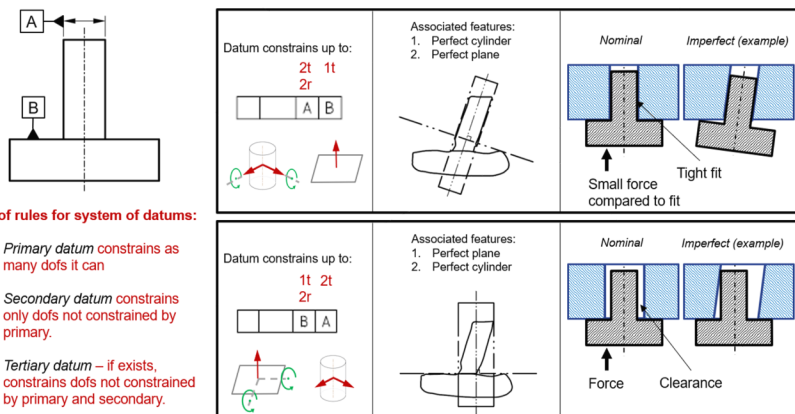
Systematic application of ISO GPS/GD&T

- 3 days training on site or web-based
- Focus on **function** and **systematic application**

8. Datum Systems

Multiple datums

Datum Axis and Plane - Combinations and constrained DOFs



11. Systematic Application of GPS

Create a main datum system.
Primary: Which feature orients?
Secondary: Which feature locates?
Tertiary: Which dof is left? Needed?

Repeat for all functional features.
(Start with datum features)

General tolerances and/or individual tolerances.

Try to adapt without losing too much design intent

1. Function

2. Datums

3. Size

4. Location

5. Orientation

6. Form

7. TEDs

8. Optimize

9. Surface Texture

10. Edges

11. Nonfunctional features

12. Adapt to manufacturing/inspection?

Identify functions.
Assembly? Clearance? Etc.

Introduce size dimensions
for features of size.

⊕ ⊙ ≡ ↗ ↘ ∩ ∪

// ⊥ ∠

— □ ○ ≠ ⊕

20

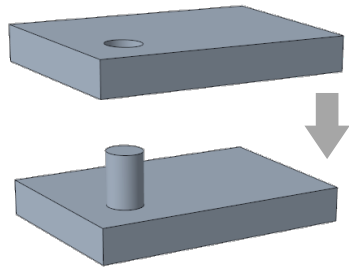
(Often included in 3-7). Tolerance analysis if needed?
Add more datums? Apply Material modifiers?

Ra 1,6

+1
-0.5

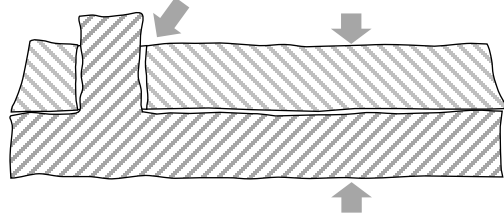
Why function?

FUNCTION



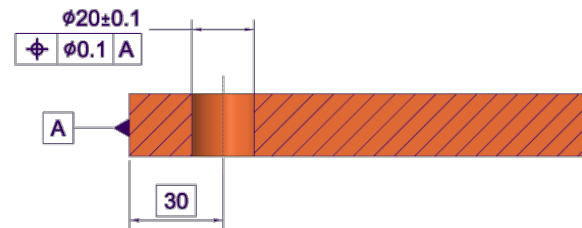
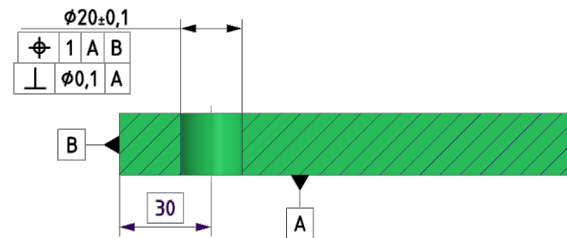
FITS!

CLAMPED



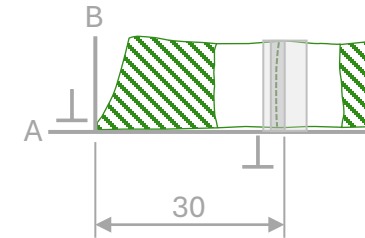
REAL GEOMETRY

FUNCTIONAL SPECIFICATION

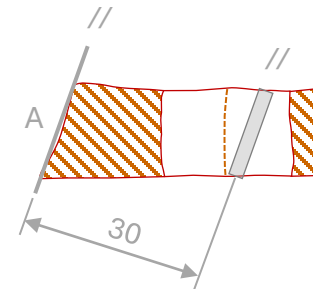


NON-FUNCTIONAL SPECIFICATION

PASS INSPECTION AND WORKS => **GOOD CORRELATION!**



Tolerance zone $\perp$ to primary datum



Tolerance zone $\parallel$ to primary datum

DOES NOT PASS BUT WORKS => **UNNECESSARY SCRAP**

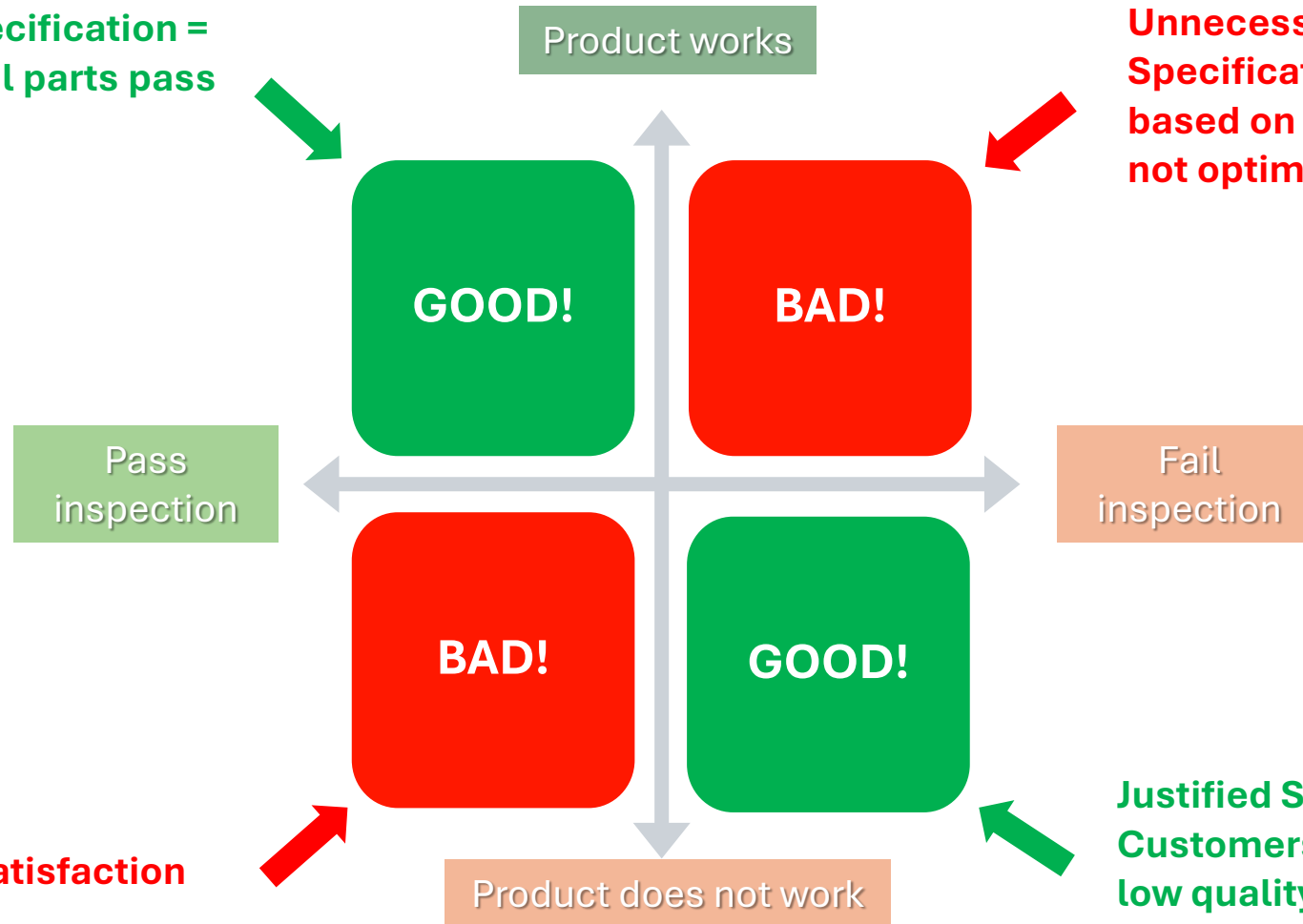
Why function?

Functional specification =
Only functional parts pass

Unnecessary Scrap =
Specifications are not
based on function / or are
not optimal

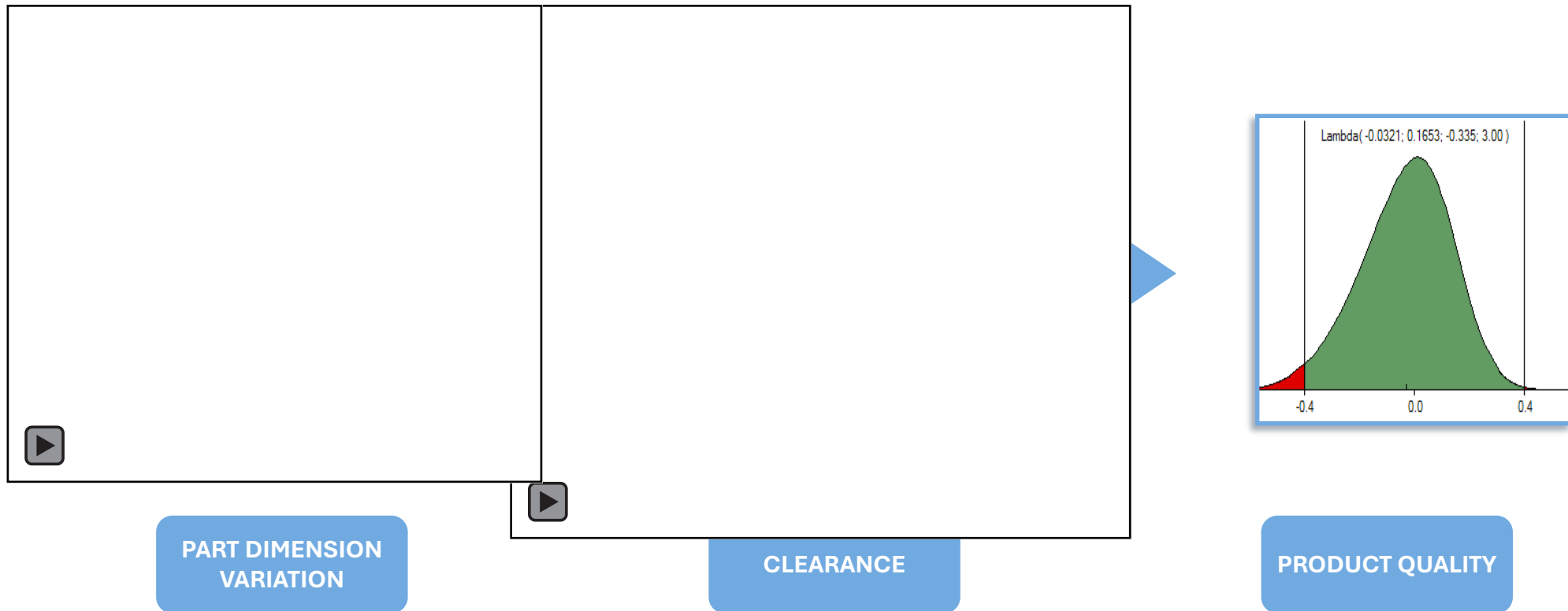
Safety risk
Customer dissatisfaction

Justified Scrap =
Customers do not receive
low quality products



What to consider in a tolerance analysis?

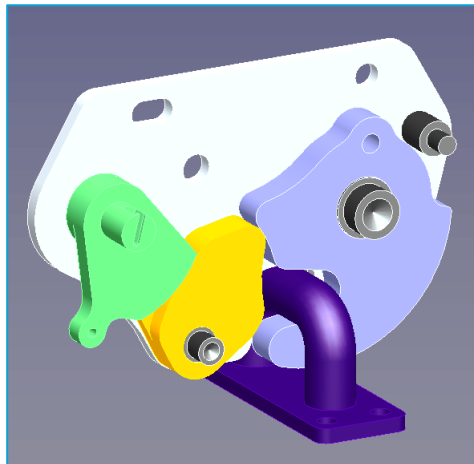
- If we can predict the quality, we can adjust it before production
- To do so, we need to consider how **part variation** affects assembly level
- We also need to consider how **clearance** impact assembly level



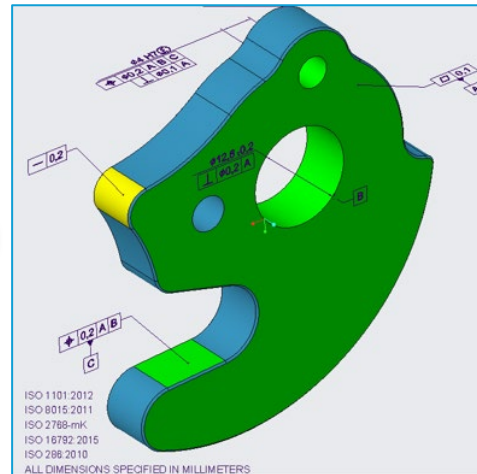
Tolerance analysis using CETOL6 σ

- Reuse of CAD Geometry, PMI and assembly constraints

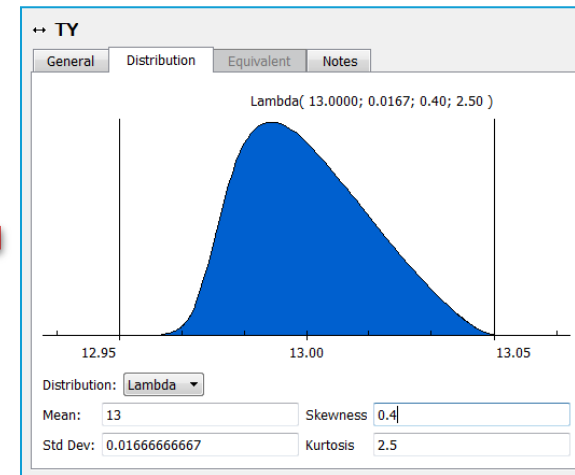
Functional Assembly
Interfaces



Semantic 3D PMI

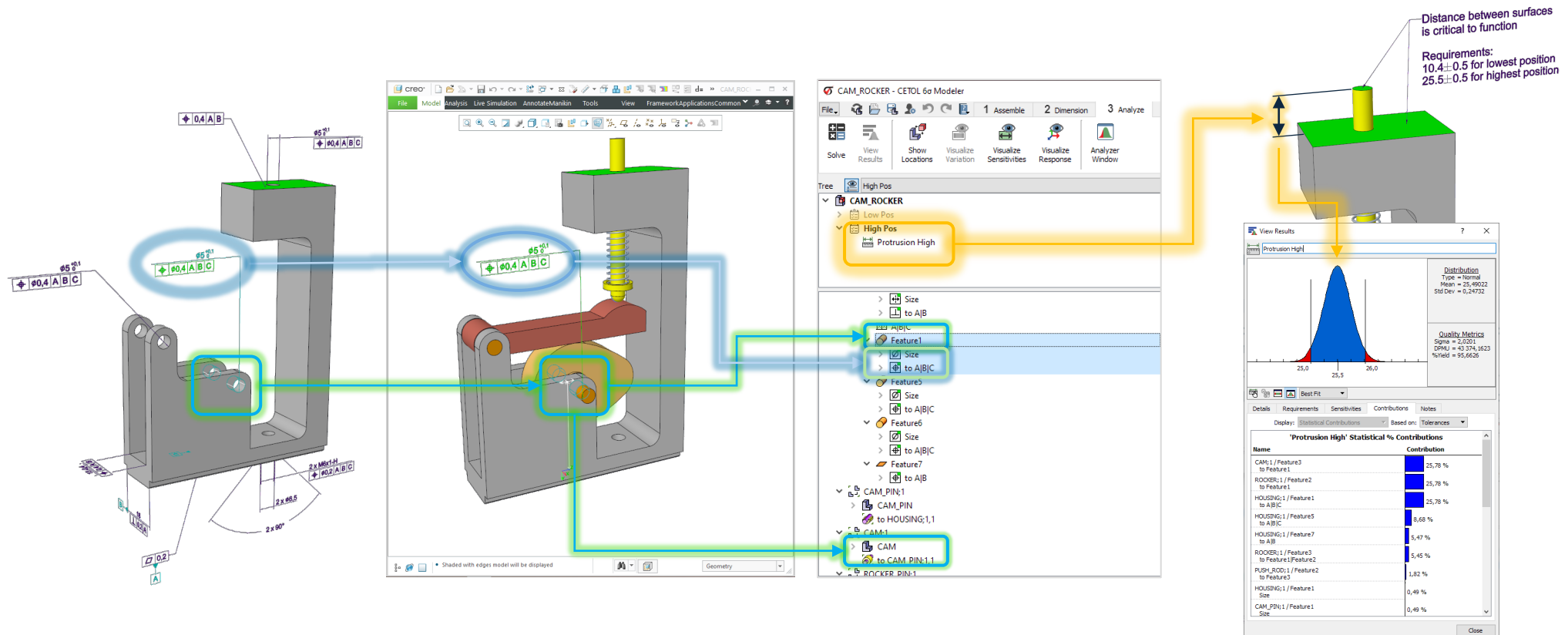


Expected Variation

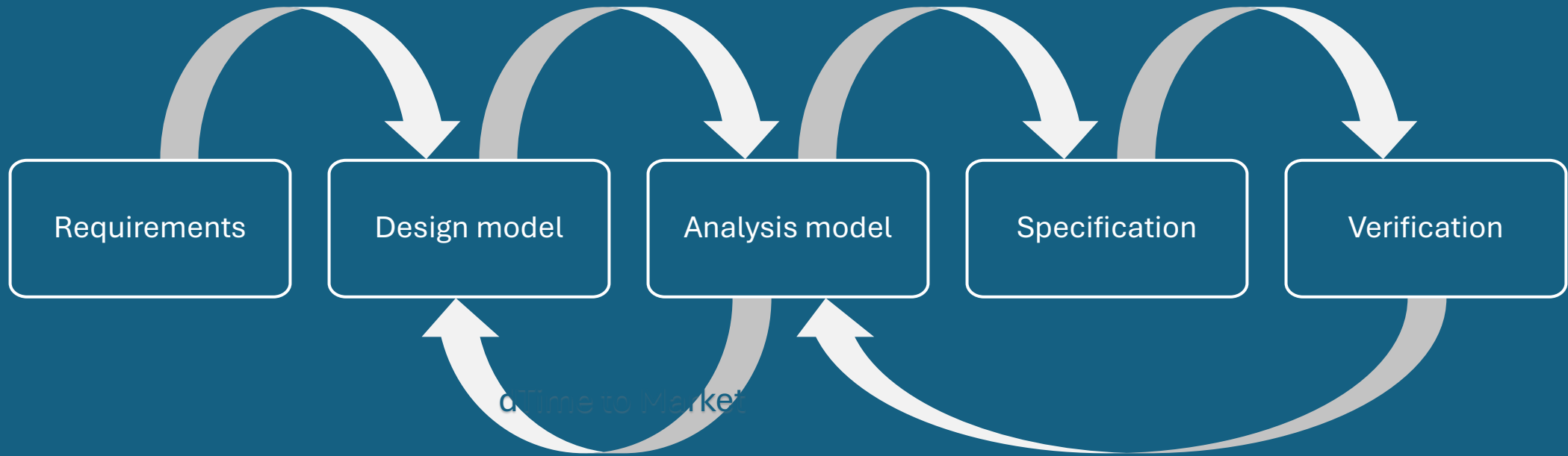


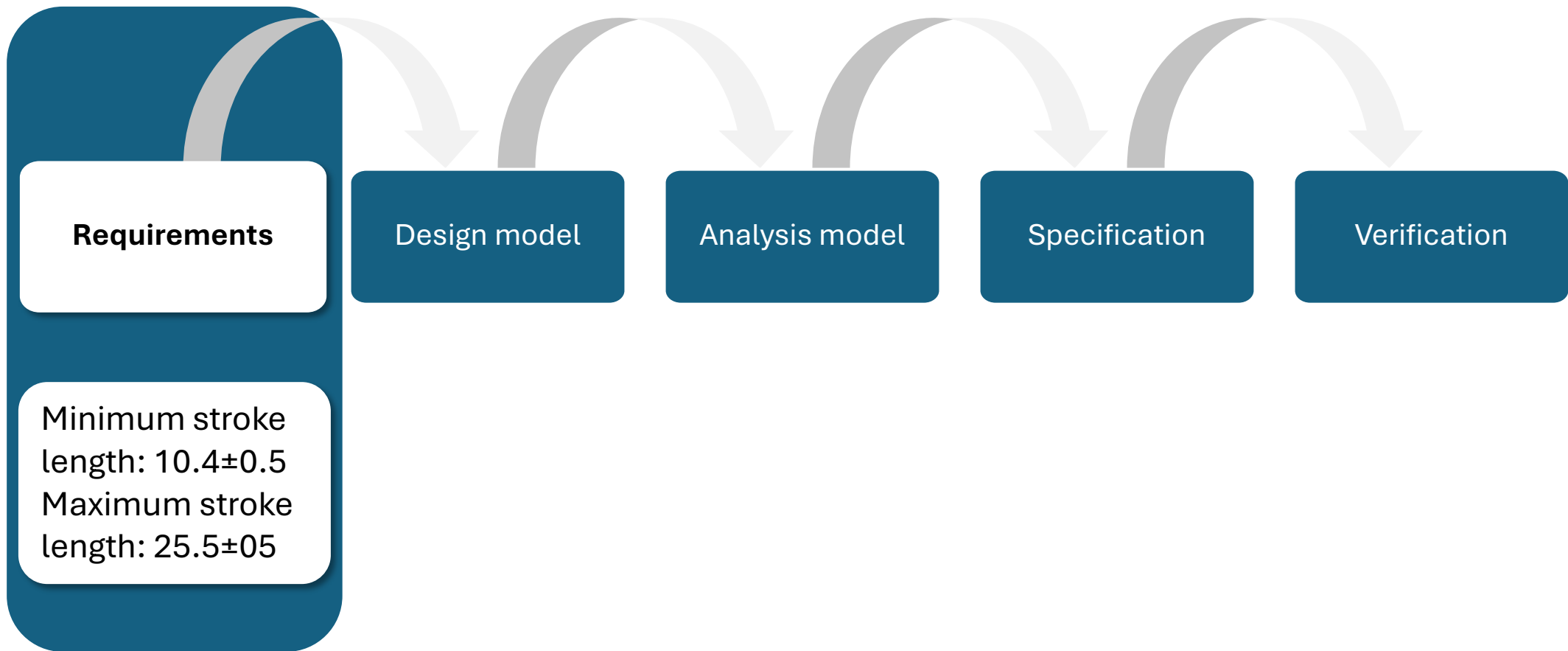
MBD tolerance analysis

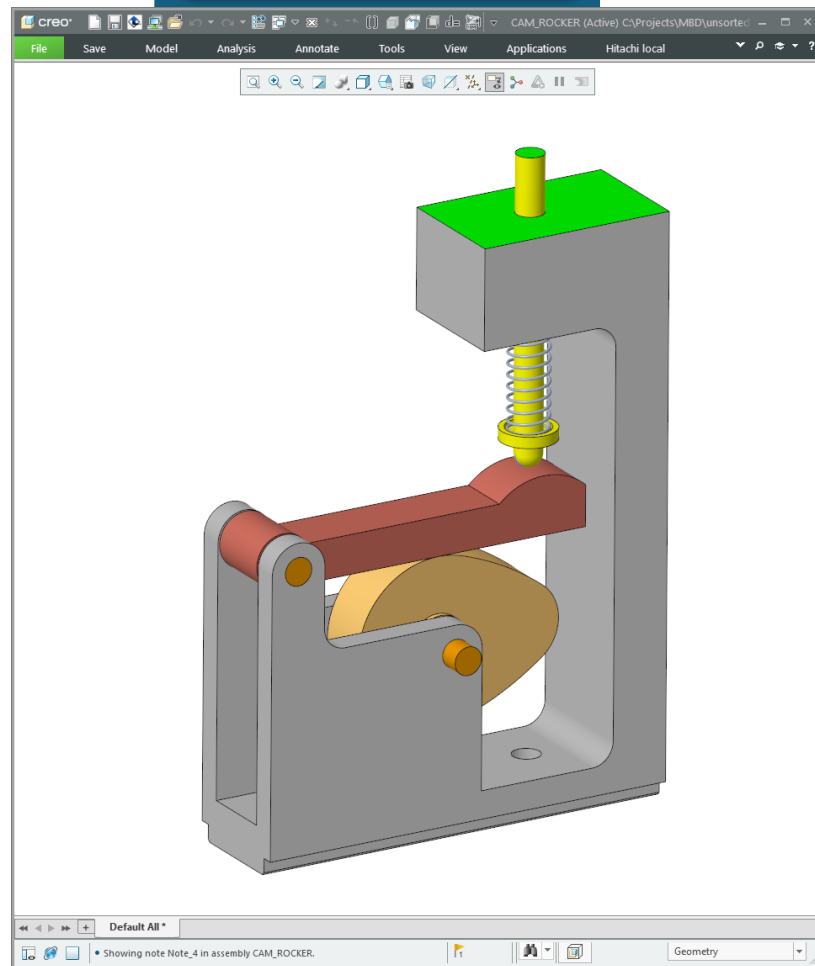
- CAD integrated and MBD Ready automated solution

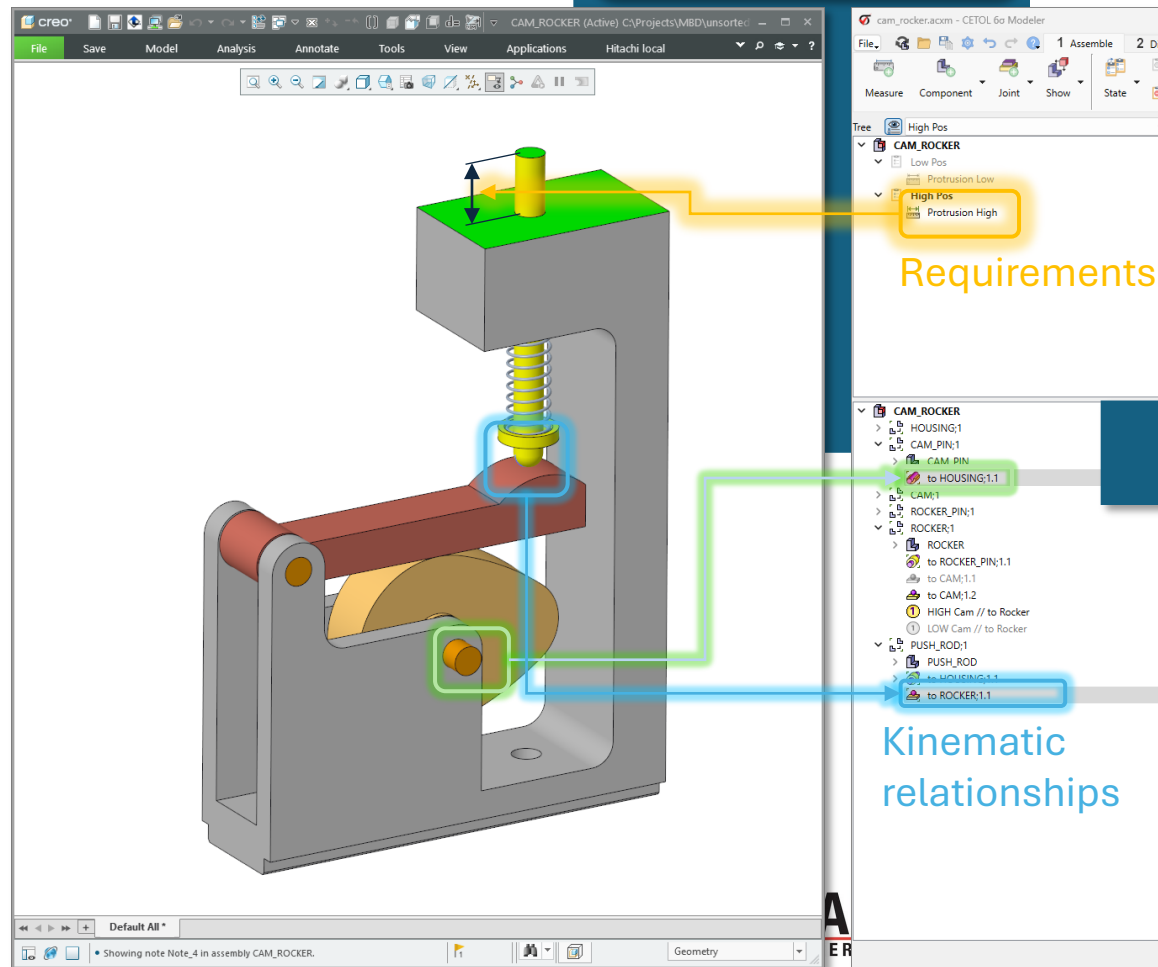
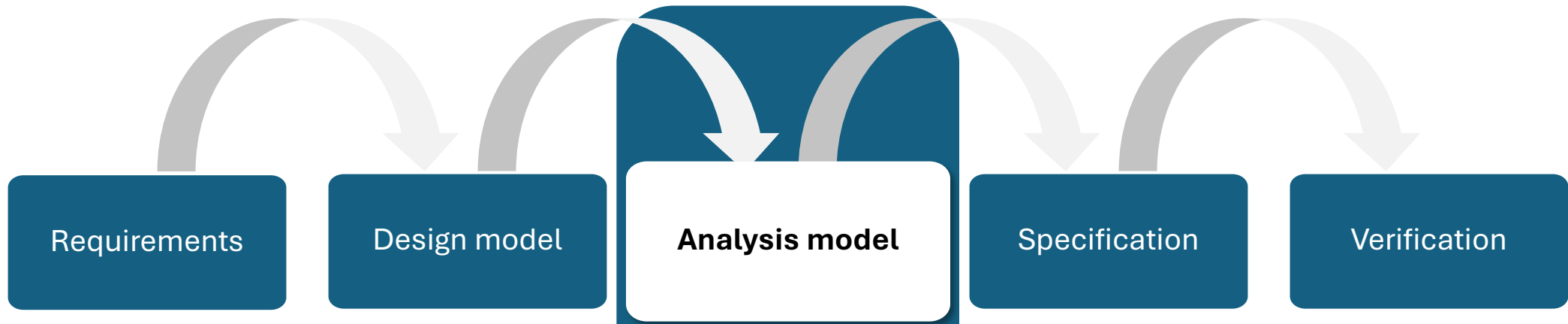


MBE Model



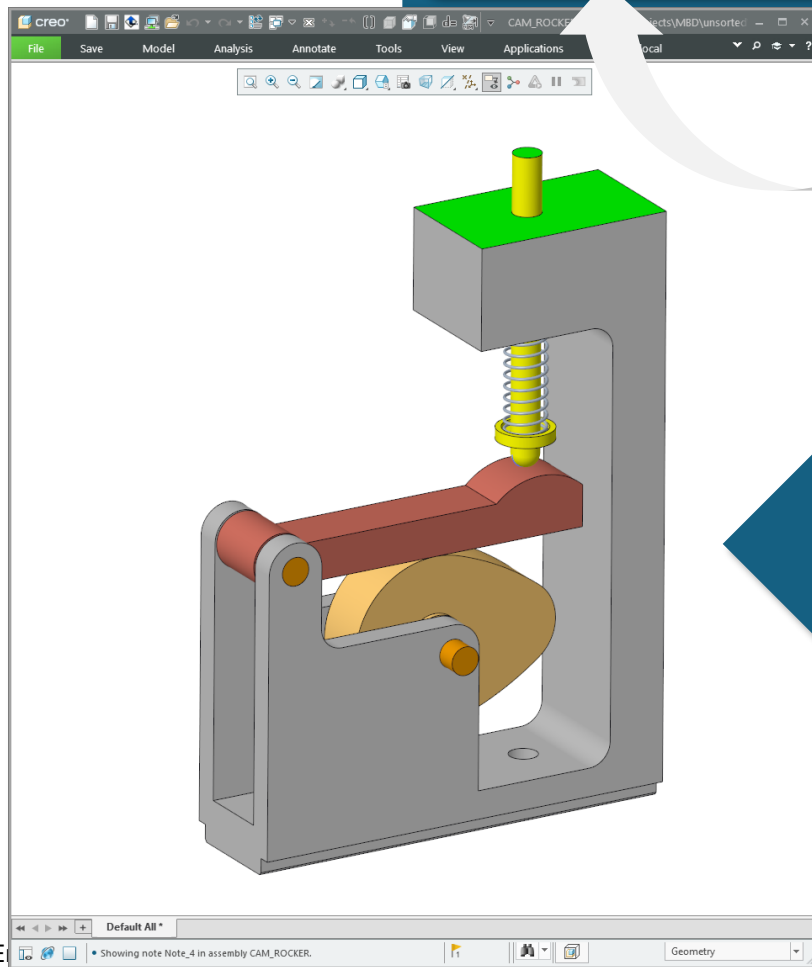






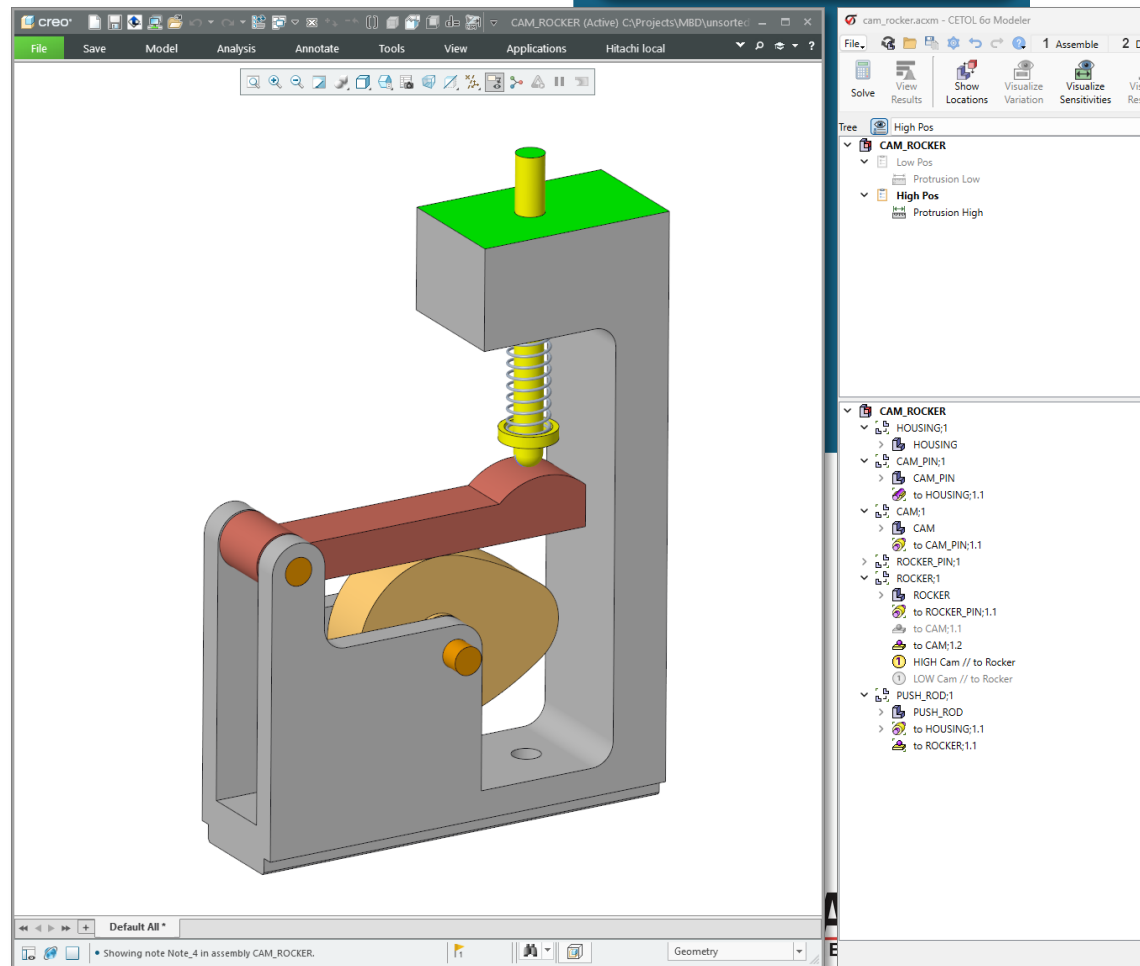
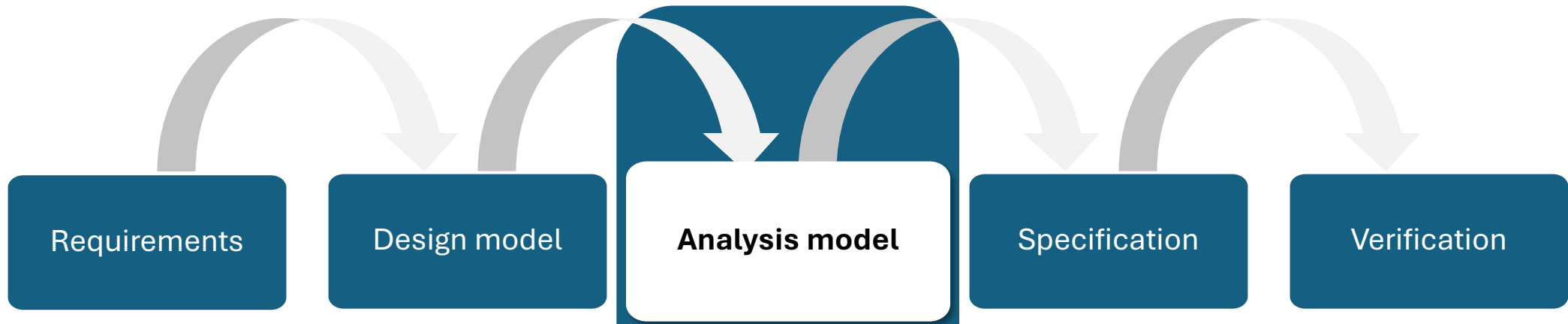
Feedback on design robustness.

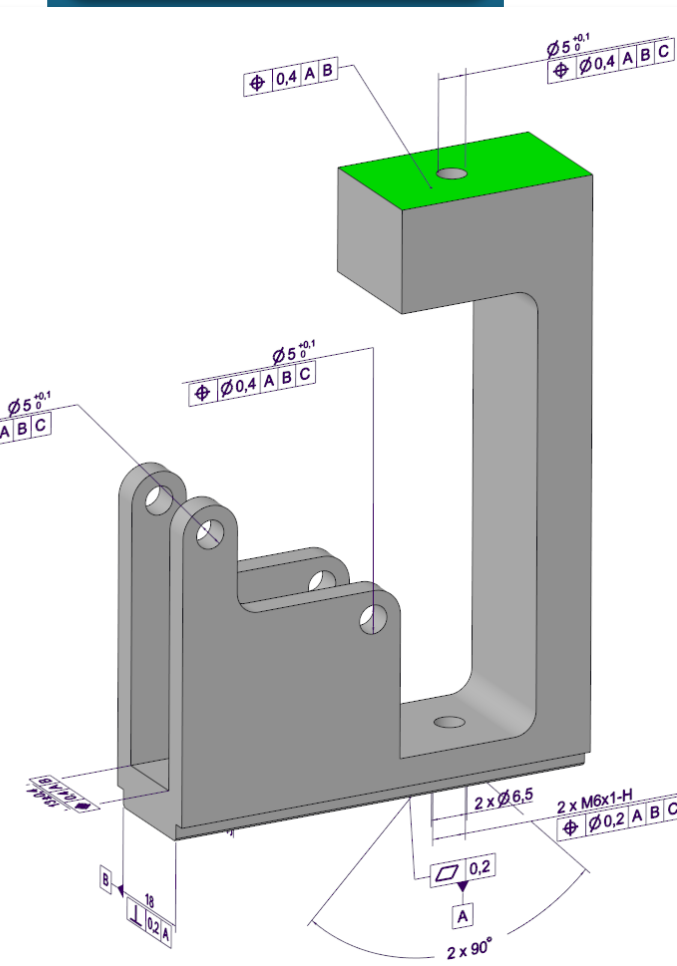
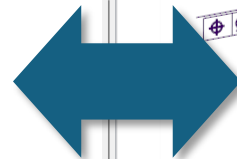
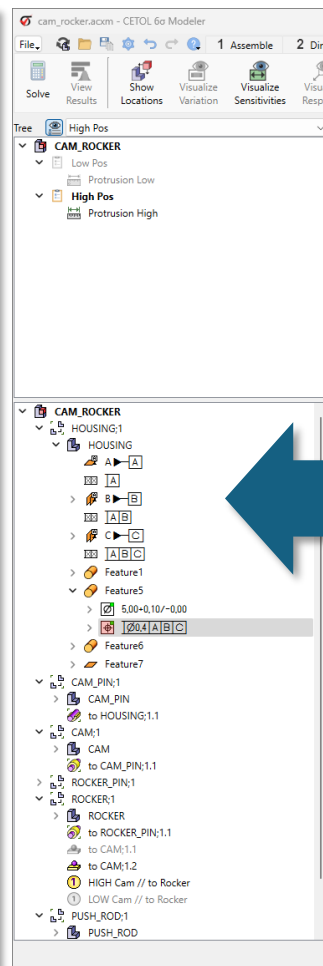
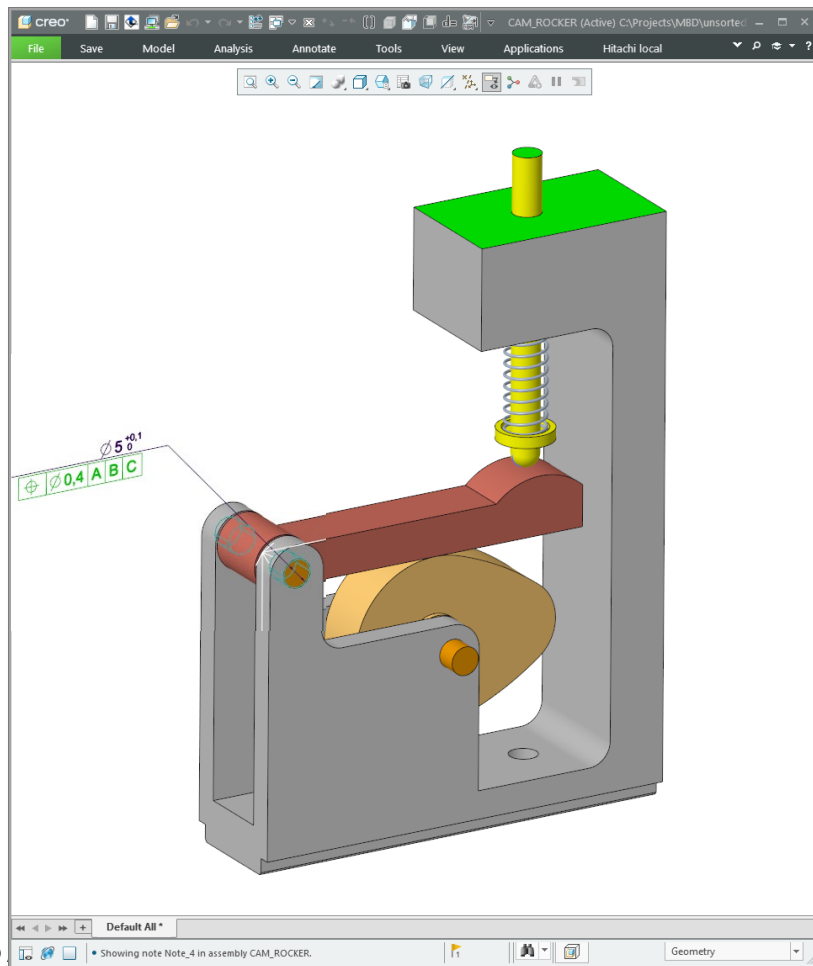
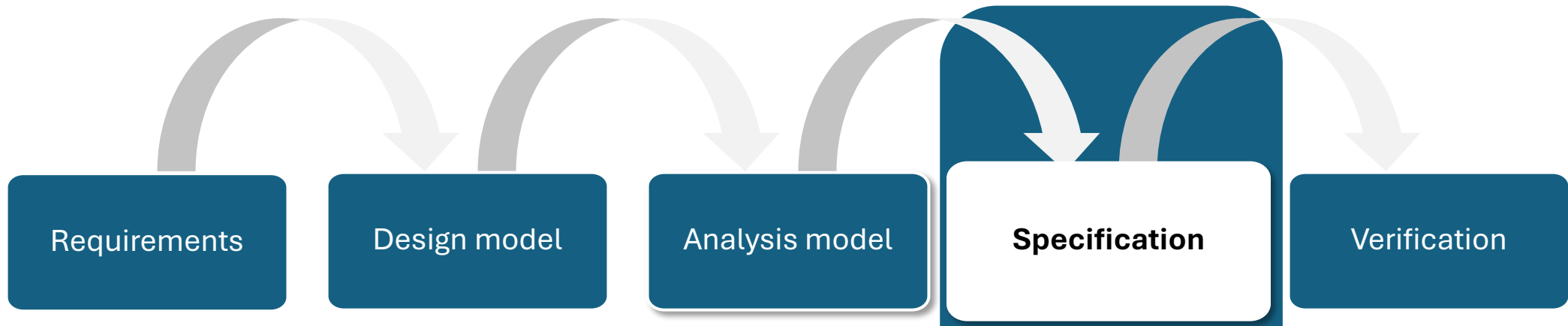
'Protrusion High' Sensitivities		
Name		Sensitivity
CAM:1 / Feature3 to Feature1 / Radius	2.17482 mm/mm	
ROCKER:1 / Feature2-[Feature2] to Feature1 / TY	2.17482 mm/mm	
CAM:1 / Feature3 to Feature1 / TY	2.17482 mm/mm	
HOUSING:1 / Feature1 to A[B]C / TX	2.0796 mm/mm	
HOUSING:1 / Feature5 to A[B]C / TX	-1.0796 mm/mm	
HOUSING:1 / Feature1 to A[B]C / TX	-1.0398 mm/mm	
HOUSING:1 / Feature1 to A[B]C / TX	1.0398 mm/mm	
HOUSING:1 / Feature3 to Feature2 / Radius	1.00016 mm/mm	
HOUSING:1 / Feature7 to Feature2 / Radius	-1 mm/mm	
HOUSING:1 / Feature2 to Feature3 / TZ	1 mm/mm	
ROCKER:1 / Feature3 to Feature1[Feature2 / TY	-0.951002 mm/mm	
HOUSING:1 / Feature5 to A[B]C / TY	-0.654313 mm/mm	
HOUSING:1 / Feature1 to A[B]C / TY	-0.636507 mm/mm	
ROCKER_PIN:1 / Feature1 Size / Diameter	0.539798 mm/mm	
HOUSING:1 / Feature5 Size / Diameter	-0.539798 mm/mm	
ROCKER:1 / Feature3 to Feature1[Feature2 / TX	0.309697 mm/mm	
PUSH_ROD:1 / Feature2 to A / TY	-0.017806 mm/mm	
PUSH_ROD:1 / to HOUSING:1.1 Float / TY	-0.017806 mm/mm	
HOUSING:1 / Feature6 to A[B]C / TY	-0.017806 mm/mm	

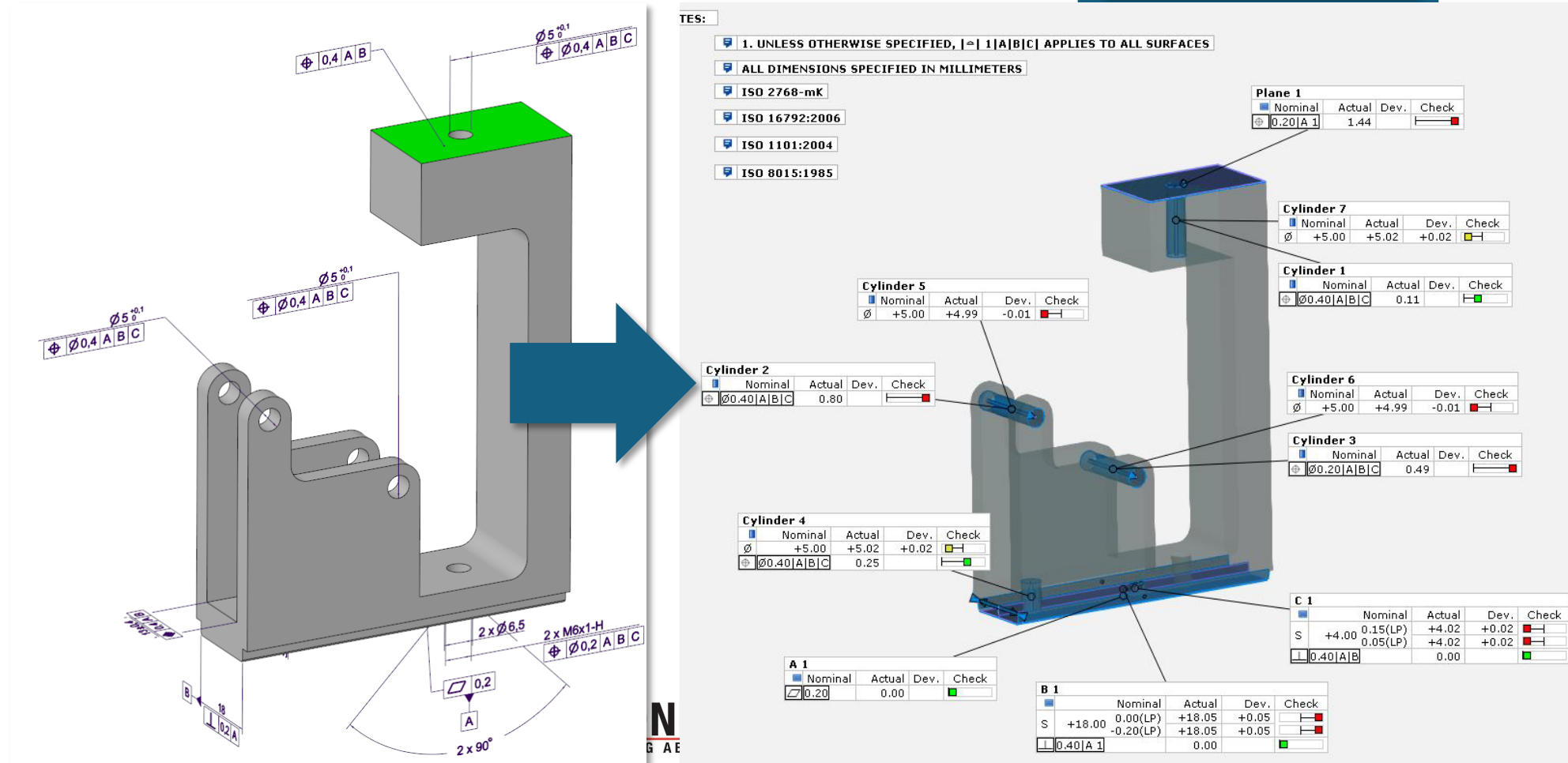
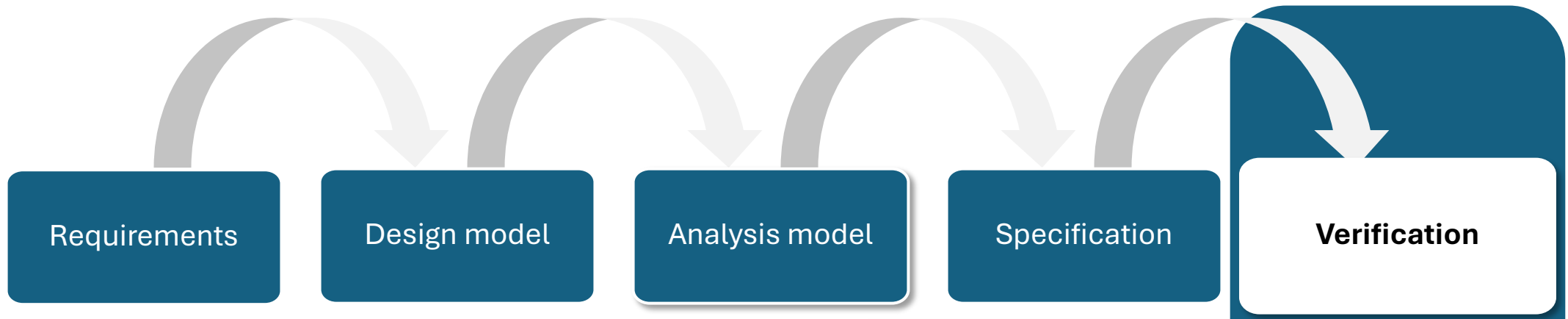


Feedback on design robustness.

Name	Sensitivity
CAM:1 / Feature3 to Feature1 / Radius	2.17482 mm/mm
ROCKER:1 / Feature2-[Feature2] to Feature1 / TY	2.17482 mm/mm
CAM:1 / Feature3 to Feature1 / TY	2.17482 mm/mm
HOUSING:1 / Feature1 to A[B]C / TX	2.0796 mm/mm
HOUSING:1 / Feature5 to A[B]C / TX	-1.0796 mm/mm
HOUSING:1 / Feature1 Size / Diameter	-1.0398 mm/mm
CAM_PIN:1 / Feature1 Size / Diameter	1.0398 mm/mm
ROCKER:1 / Feature3 to Feature1[Feature2] / Radius	1.00016 mm/mm
HOUSING:1 / Feature7 to A[B] / TY	-1 mm/mm
feature2 Z	1 mm/mm
feature3 Feature2 / TY	-0.951002 mm/mm
feature5	-0.654313 mm/mm
HOUSING:1 / Feature1 to A[B]C / TY	-0.636507 mm/mm
ROCKER_PIN:1 / Feature1 Size / Diameter	0.539798 mm/mm
HOUSING:1 / Feature5 Size / Diameter	-0.539798 mm/mm
ROCKER:1 / Feature3 to Feature1[Feature2] / TX	0.309697 mm/mm
PUSH_ROD:1 / Feature2 to A / TY	-0.017806 mm/mm
PUSH_ROD:1 / to HOUSING:1.1 Float / TY	-0.017806 mm/mm
HOUSING:1 / Feature6 to A[B]C / TY	-0.017806 mm/mm







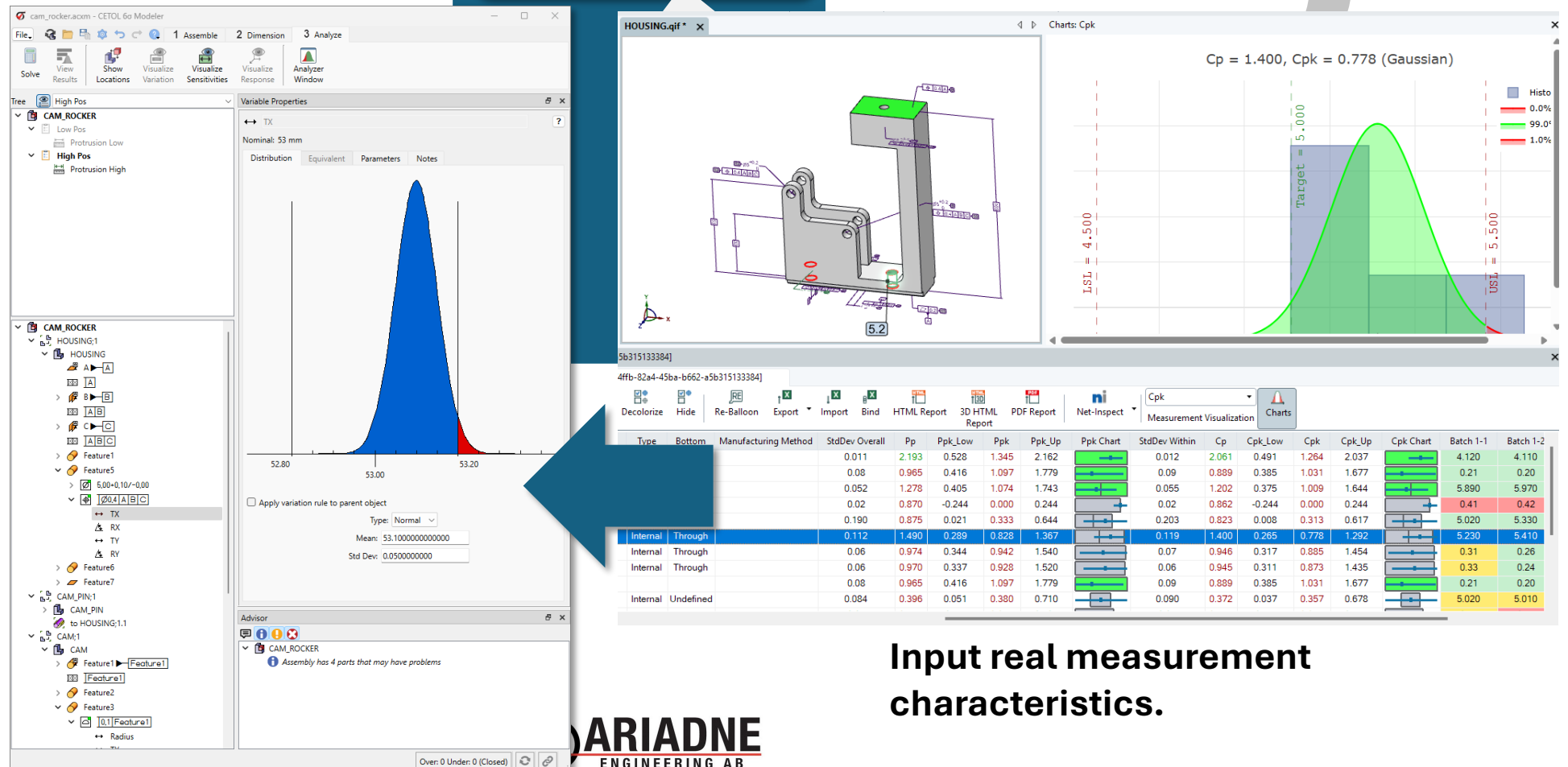
Requirements

Design model

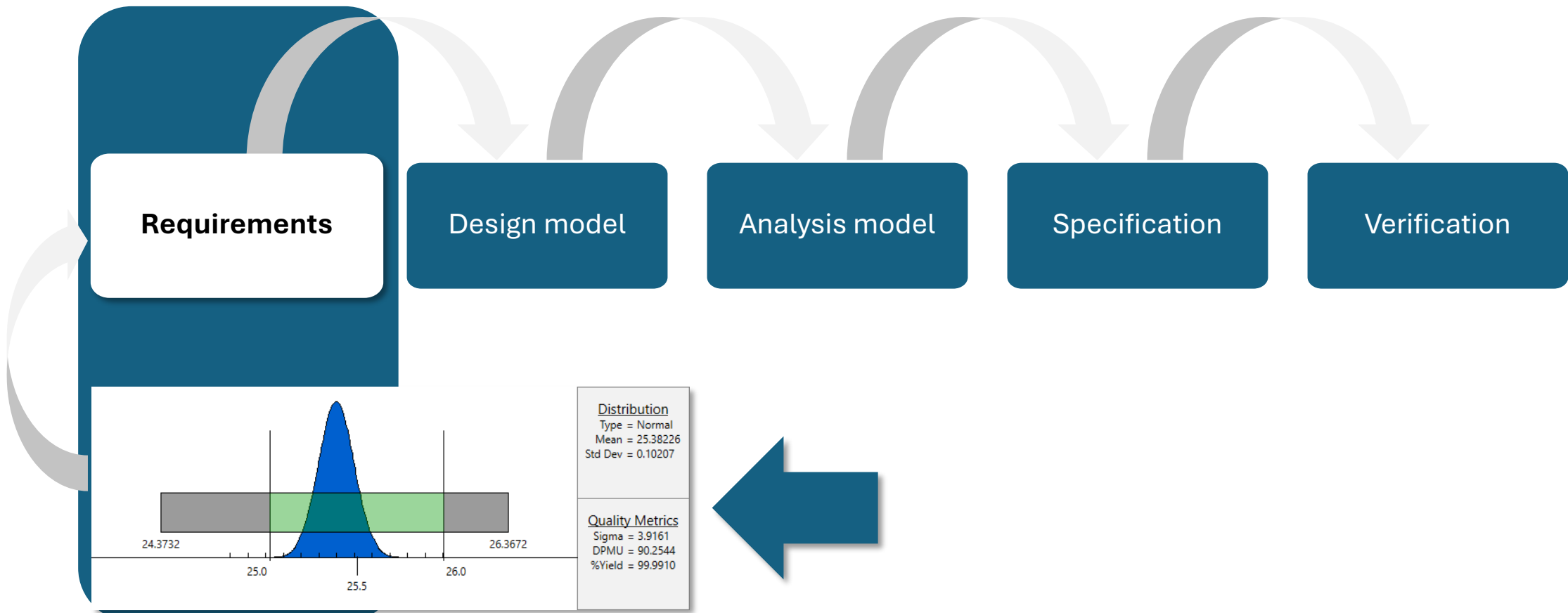
Analysis model

Specification

Verification



Input real measurement characteristics.



**And evaluate results.
..is it still OK?**

Requirements

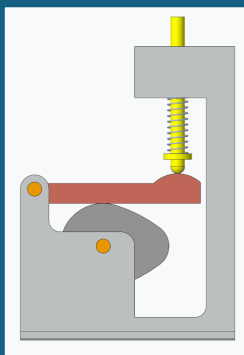
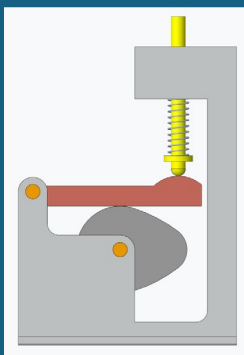
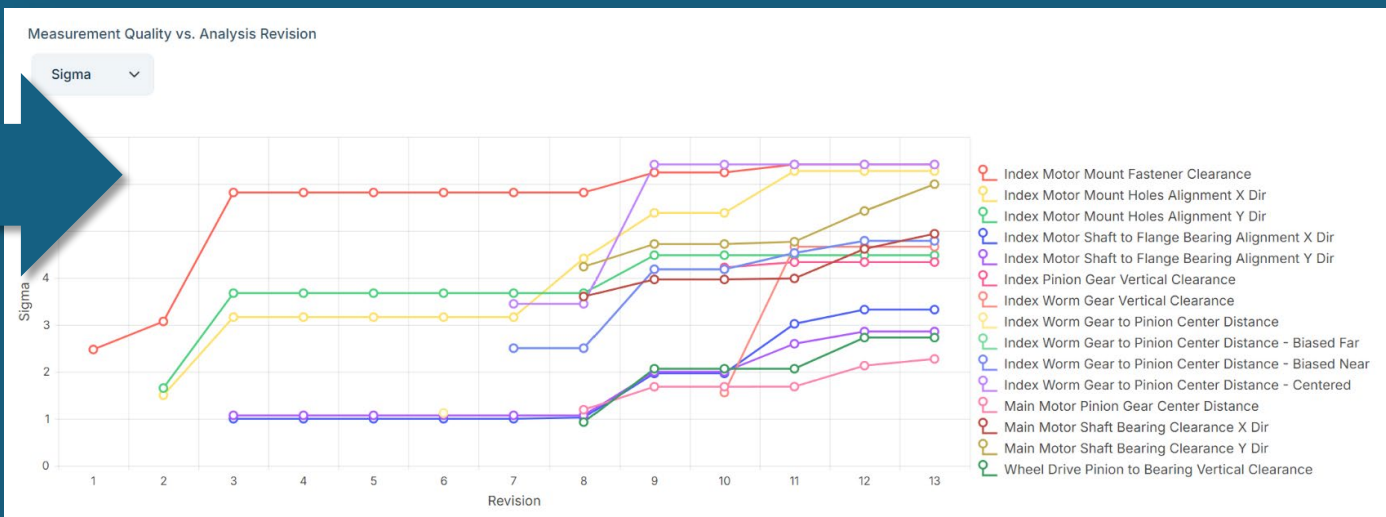
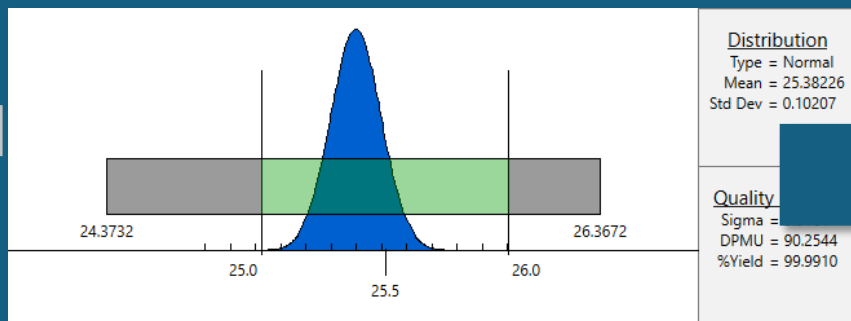
Design model

Analysis model

Specification

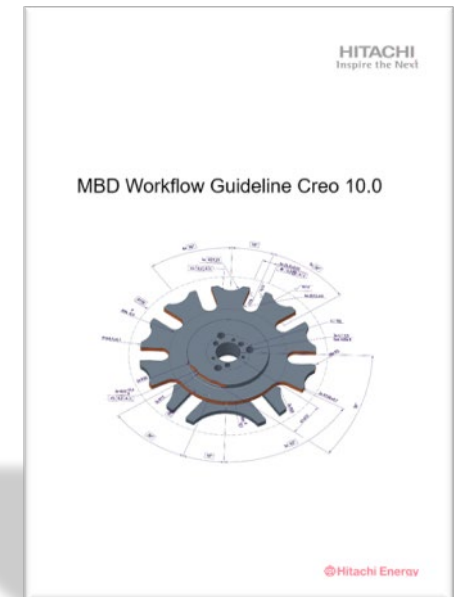
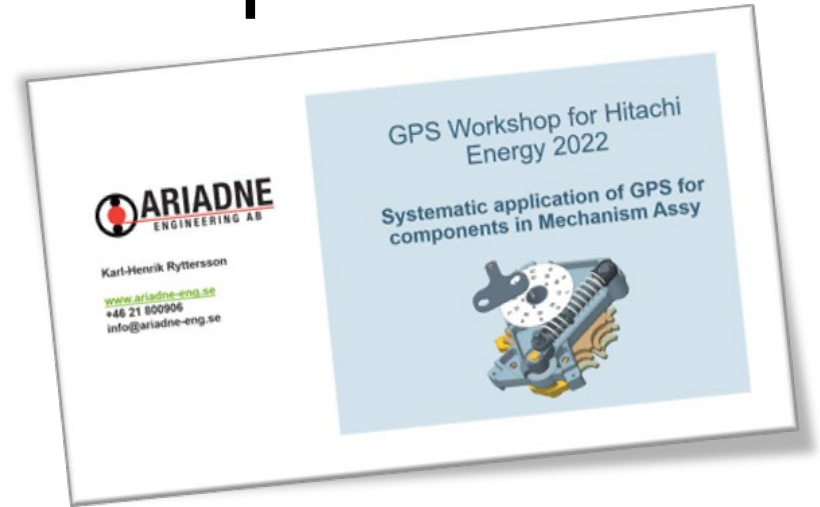
Verification

Track changes over design iterations



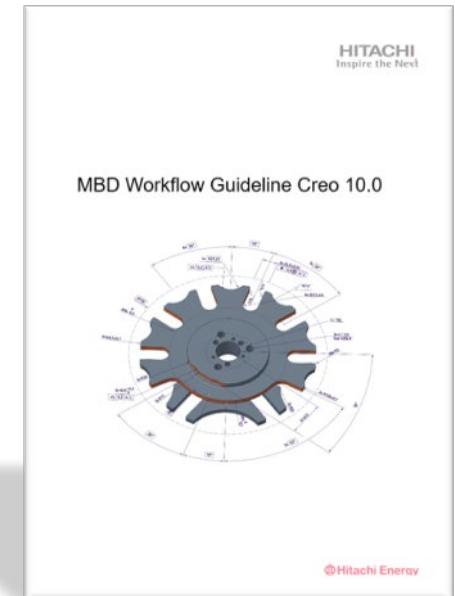
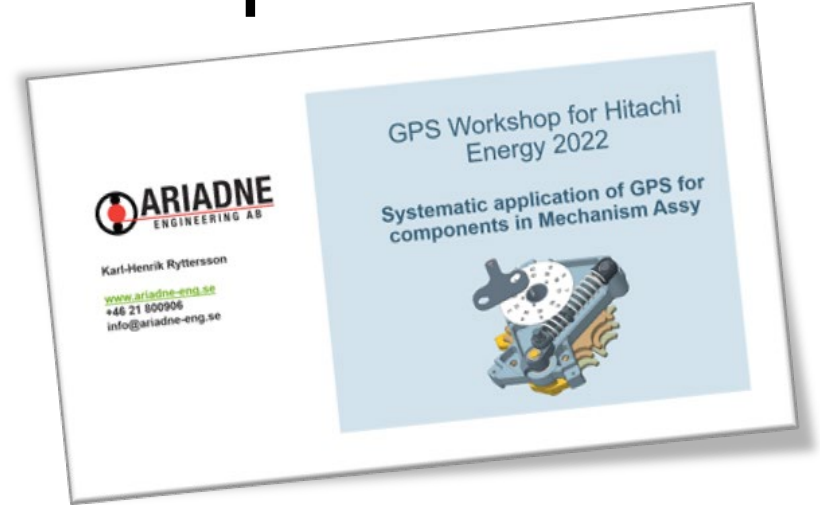
Customer case: Hitachi Energy Components

- **Easy to use and MBD Ready tolerance analysis software**
 - CETOL 6Sigma
- **Consulting services**
 - Many discussions of drawing specifications
 - Many discussions of functions
- **ISO GPS Training**
 - Less ambiguous and more functional specifications gained
 - Fewer iterations of setting up tolerance analyses
- **Training workshop - functional break-down**
 - More functional requirements => more value out of analysis
 - Better understanding of setting up tolerance analyses => more value out of analysis
- **MBD Workflow introduced using Creo Parametric 10.0**
 - Improved CAD model quality.
 - Faster setup of tolerance analysis though automated re-use of PMI.



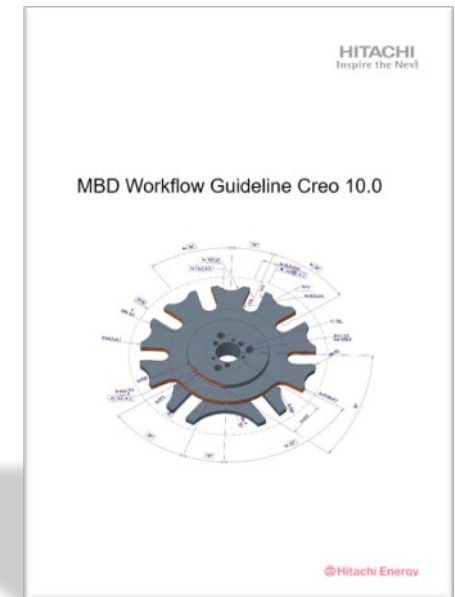
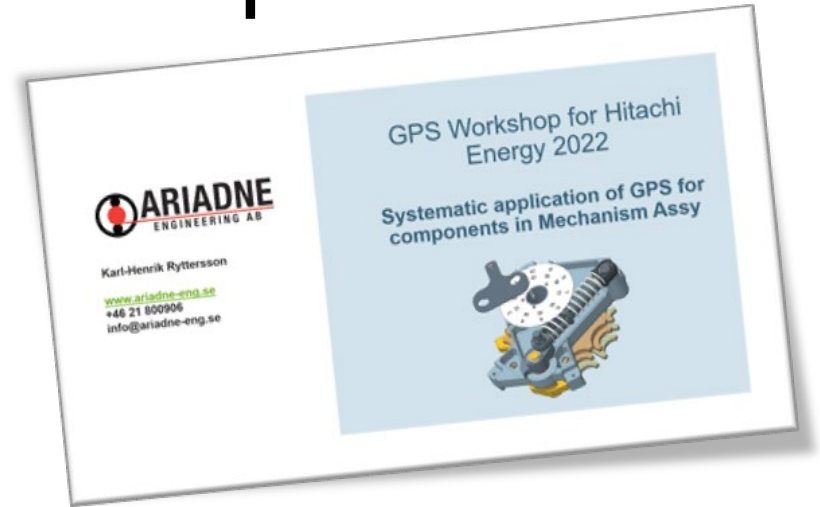
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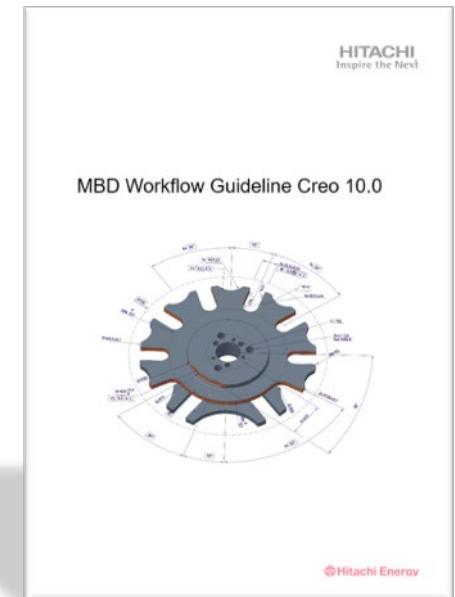
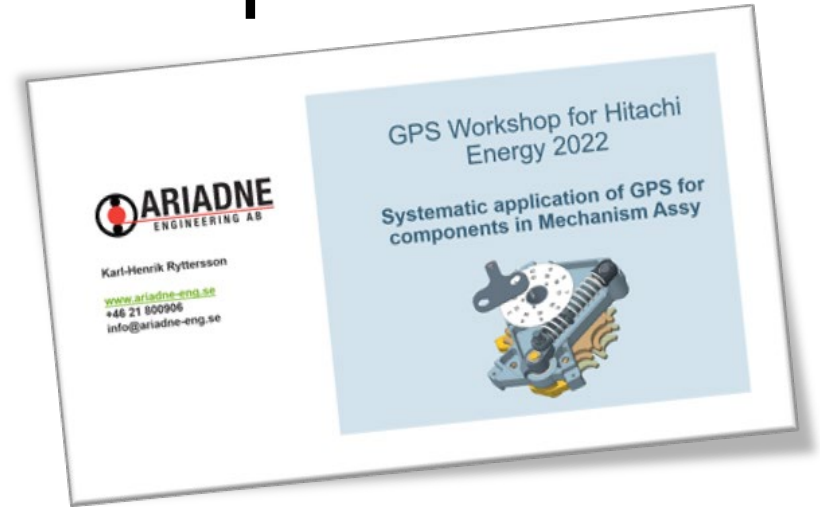
Customer case: Hitachi Energy Components

- **Easy to use and MBD Ready tolerance analysis software**
 - CETOL 6Sigma
- **Consulting services**
 - Many discussions of drawing specifications
 - Many discussions of functions
- **ISO GPS Training**
 - Less ambiguous and more functional specifications gained
 - Fewer iterations of setting up tolerance analyses
- **Training workshop - functional break-down**
 - More functional requirements => more value out of analysis
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- **MBD Workflow introduced using Creo Parametric 10.0**
 - Improved CAD model quality.
 - Faster setup of tolerance analysis though automated re-use of PMI.



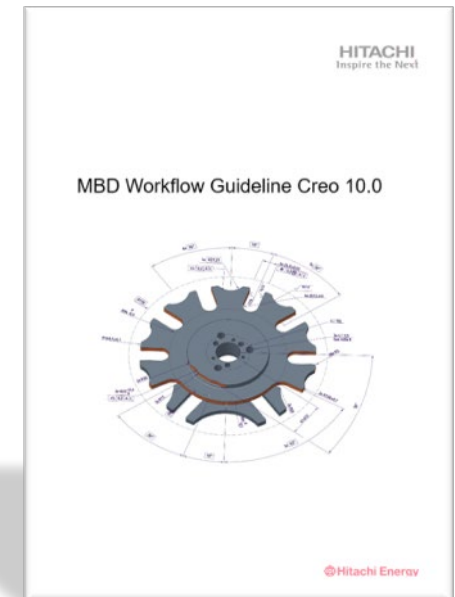
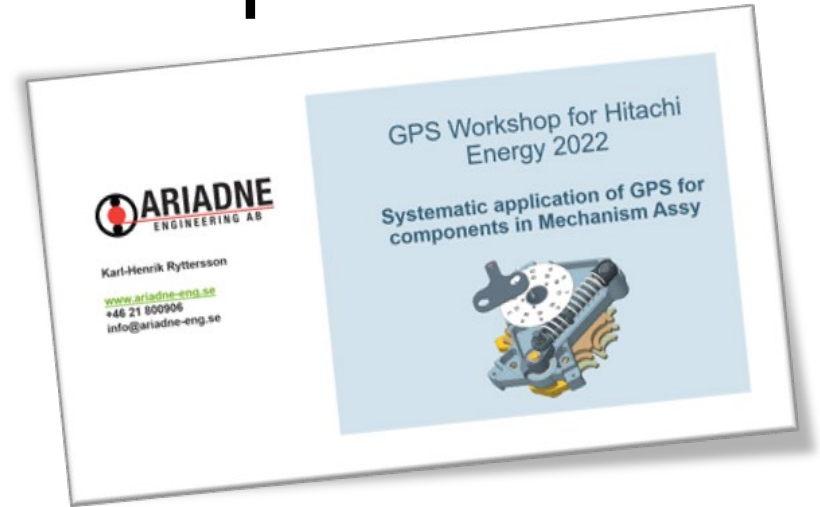
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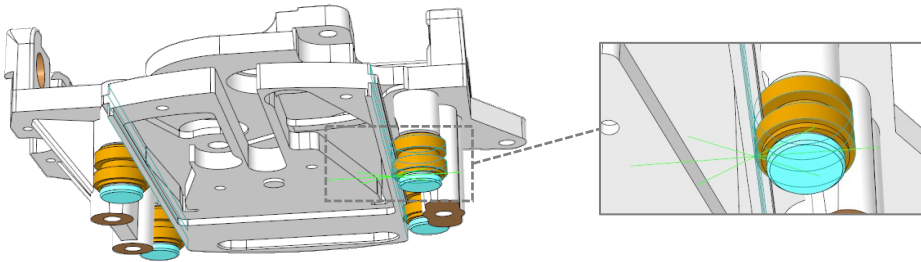


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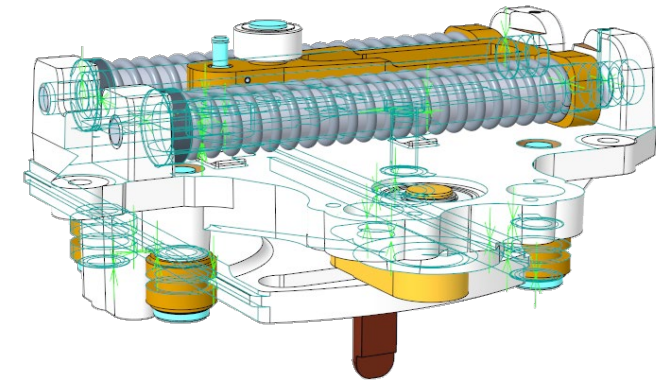


Benchmark



Function: Sled fit rollers sideways (1 measurement)

	Before MBD	After MBD
	Time in minutes	
Collecting Models	10	10
Define measurements	10	10
Determine components part of tolerance chain	15	15
Collecting Drawings	45	0
Analyzing Drawings	240	0
Programming of tolerances	240	30
Define joints / Configure State	30	30
Define measurements	10	10
Running analysis	1	1
Evaluate results	30	30
Reporting	120	120
Total	751	256
% Time Reduction		66%



All critical functions considered, 29 measurements

Assembly Level	Component	Number of PMI 100% reusable	Number of PMI only visually usable	Number of tolerances requiring manual programming	MBD
Lower Plate Complete	Lower Plate	64	7	0	Y
Lower Plate Complete	Washer	3	0	0	Y
Lower Plate Complete	Retaining Ring	1	0	0	Y
Lower Plate Complete	Pin	12	0	0	Y
Lower Plate Complete	Roller	8	1	0	Y
Lower Plate Complete	Flanged Bushing	2	0	0	Y
Lower Plate Complete	Ball Bearing	0	0	4	N
Lower Plate Complete	Roll Pin	1	0	1	N
Lower Plate Complete	Shaft	6	2	0	Y
Wagon	Sleight	7	0	10	N
Wagon	Shaft	2	0	5	N
Wagon	Pin	0	0	1	N
Wagon	Bearing	0	0	3	N
Top Level	Sled	5	0	0	Y
Top Level	Crank	3	0	7	N
Top Level	Drive Pin	2	0	3	N
Top Level	Roller	2	0	0	Y
Total for MBD Components		103	10	0	
		91%	9%	0%	
Total non MBD components		15	0	34	
		31%	0%	69%	

The next level

- **Level 1**

Robust and fast workflow to perform tolerance analysis for product development.

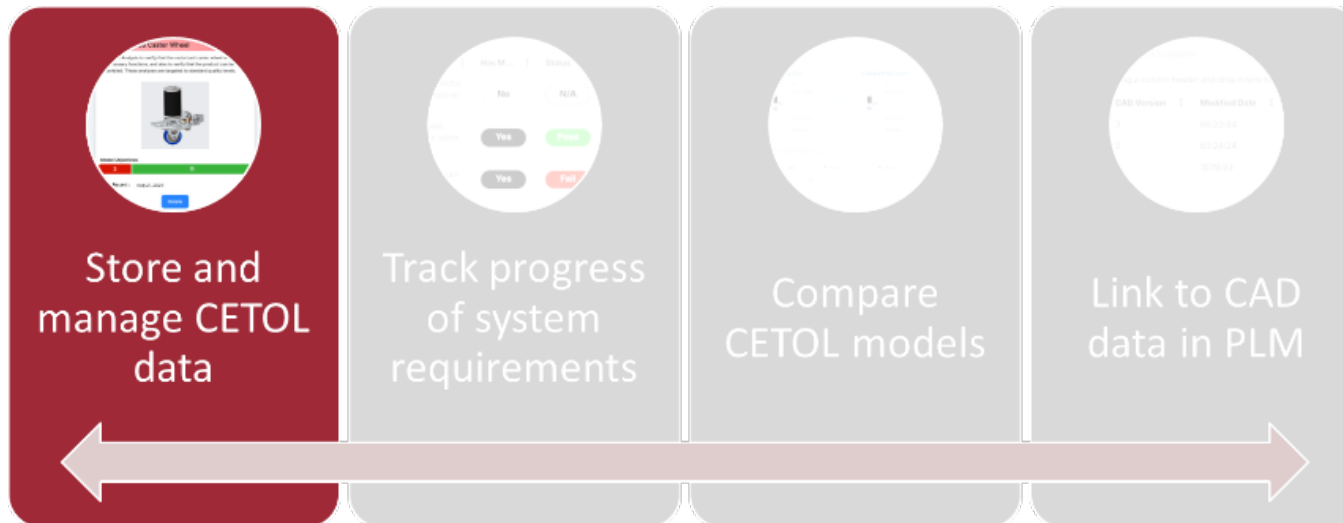
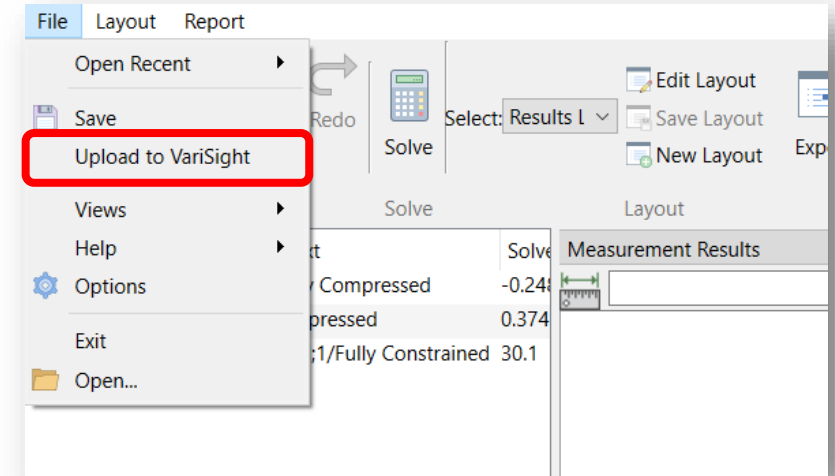
- **Functional focus a must!**
- **An MBD Workflow is essential!**

- **Level 2**

Management of tolerance analysis data

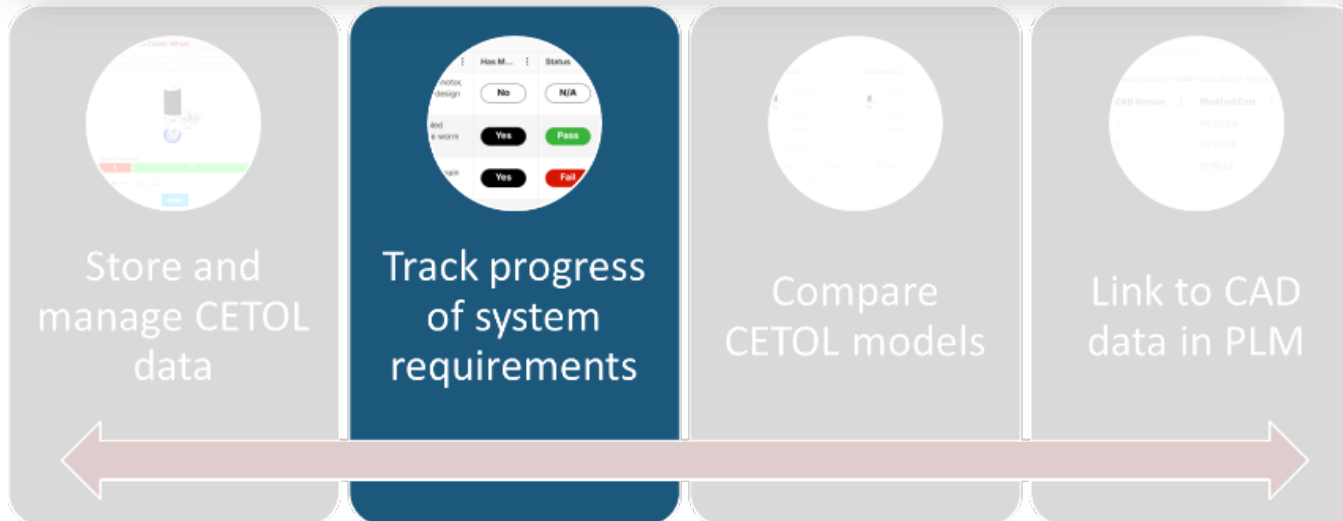
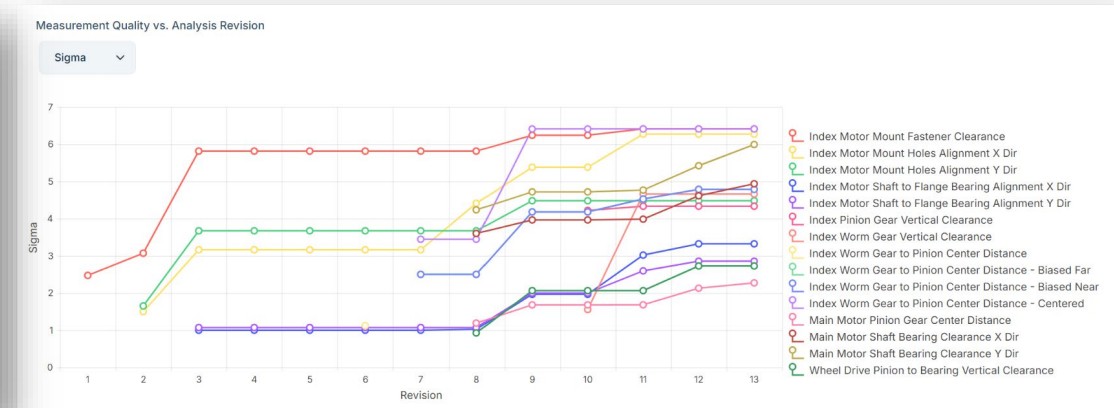
- *Management of tolerance analysis data*
- *Synchronize with CAD PLM*
- *Versions management*
- *Track system level requirements*
- *Comparison of measurement variational data to tolerance analysis data*
- **PLM for tolerance analysis needed!**

VariSight



VariSight

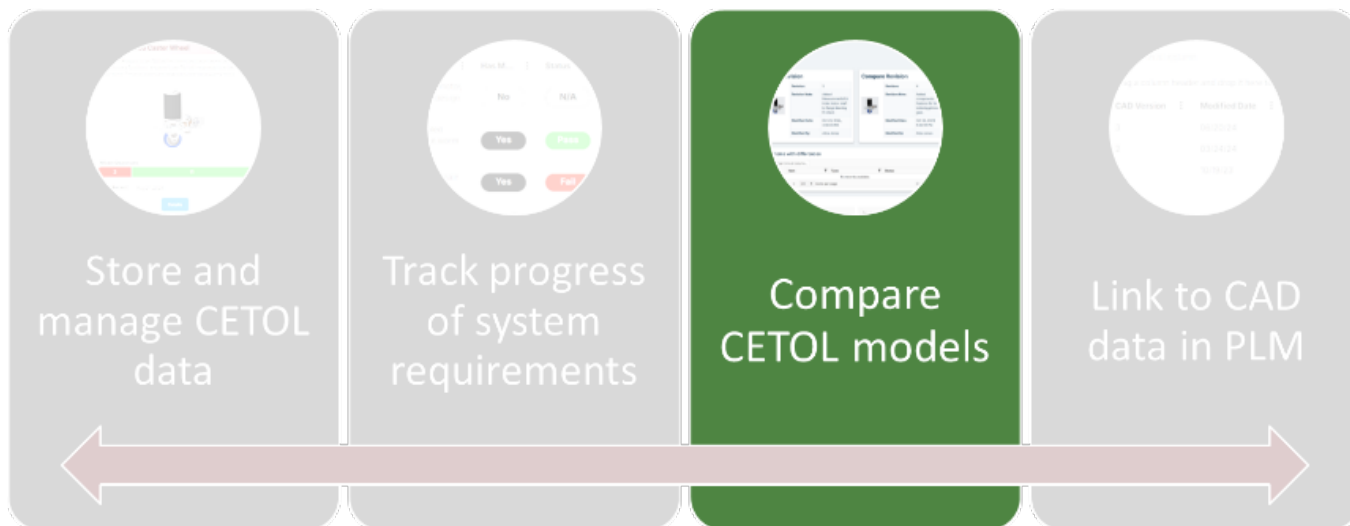
Action	Sy...	Name	Description	Has Mea...	Status
 Actions	OP-03	Operation - Index Worm Gears	Verify operating characteristics of the gears associated with the index motor, including the worm gears. Check that the gears will mesh within their design center distance.	No	N/A
 Actions	AS-03	Assembly - Index Worm Gears	Verify that the gears associated with the index motor can be assembled without any interferences between the components. This includes the worm gears themselves and the pinion gear.	Yes	Pass
 Actions	OP-02	Operation - Main Motor	Verify operating characteristics of the main motor by checking that the main gears mesh correctly and are within limits of their design center distance	Yes	Fail
 Actions	AS-02	Assembly - Main Motor	Verify that the main motor, including the pinion gear, can be assembled without any interferences between the components.	Yes	Fail
 Actions	OP-01	Operation - Index Motor Gears	Verify operating characteristics of the index motor by checking that the gears mesh correctly and are within 0.3 mm of their design center distance.	Yes	Pass
 Actions	AS-01	Assembly - Index Motor	Verify that the index motor and associated parts including the worm gear can be assembled without any interferences between the components. Particularly check the assembly of the shaft to the bearings in the motor mounts.	Yes	Fail



VariSight

Requi...	Obj...	Objectiv...	Objec...
0.000±0.100	Sigma ≥ 3	Sigma = 3.162	Pass
0.0000±0....	Sigma ≥ 3	Sigma = 3.673	Pass
23.000±0....	Sigma ≥ 3	Sigma = 2.348	Fail
23.000±0....	Sigma ≥ 3	Sigma = 2.348	Fail
23.000±0....	Sigma ≥ 3	Sigma = 4.020	Pass

Requi...	Obj...	Objectiv...	Objective St...
0.000±0.100	Sigma ≥ 3	Sigma = 3.162	Pass
0.0000±0.0200	Sigma ≥ 3	Sigma = 3.673	Pass
23.000±0.350	Sigma ≥ 3	Sigma = 3.183	Pass
23.000±0.350	Sigma ≥ 3	Sigma = 3.183	Pass
23.000±0.350	Sigma ≥ 3	Sigma = 4.020	Pass



Base Revision		Compare Revision	
	Revision:	3	4
	Revision Note:	Added Measurements for index motor shaft to flange bearing fit check	Added components and features for the indexing pinion gear.
	Modified Date:	Oct 24, 2024, 3:30:03 PM	Oct 24, 2024, 6:32:55 PM
	Modified By:	Alice Jones	Alice Jones

VariSight

CAD Models History

Search in all column...

Drag a column header and drop it here to group by that column

Ver...	Modified Date	Modified By	Lifecycle State
A.2	10/22/24, 9:40 PM	Alice Jones	PROTOTYPE
A.1	10/22/24, 9:16 PM	Alice Jones	PROTOTYPE
-.4	10/22/24, 9:13 PM	Alice Jones	RELEASED
-.3	10/22/24, 9:12 PM	Alice Jones	RELEASED
-.2	10/22/24, 9:11 PM	Alice Jones	RELEASED
1.2	10/22/24, 6:13 PM	Alice Jones	RELEASED
1.1	10/22/24, 1:01 PM	Alice Jones	RELEASED
-.1	10/22/24, 9:03 PM	Alice Jones	RELEASED

ajones

Products > Motorized Wheel > CAD_Documents

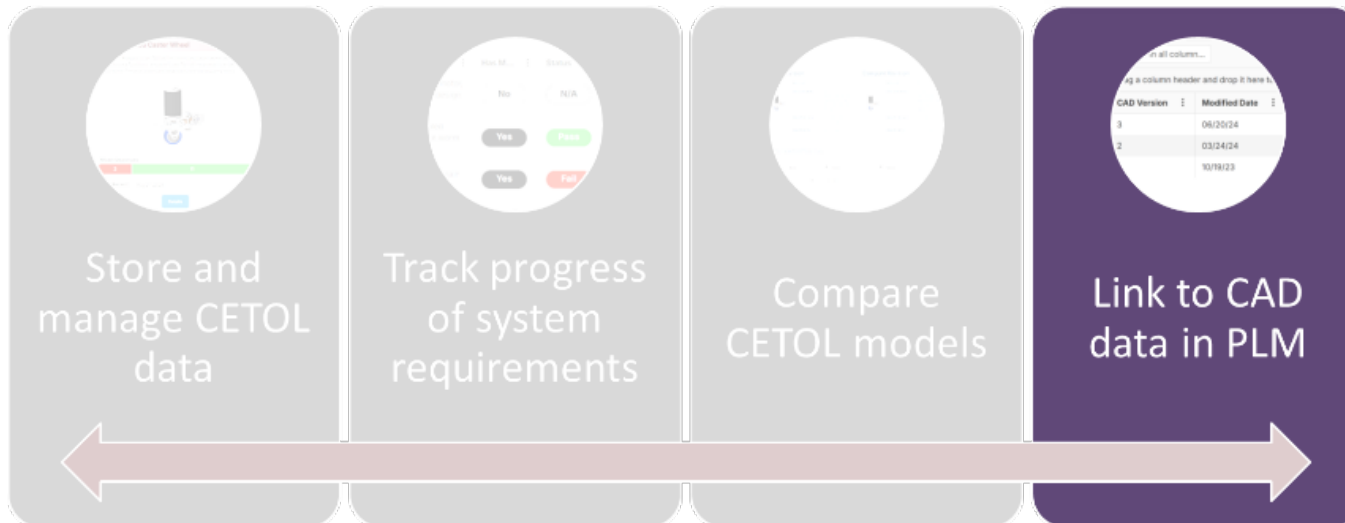
Assembly - 0000000206.asm, A.2

Details Structure Content Related Objects Changes History

Version History | Timeline

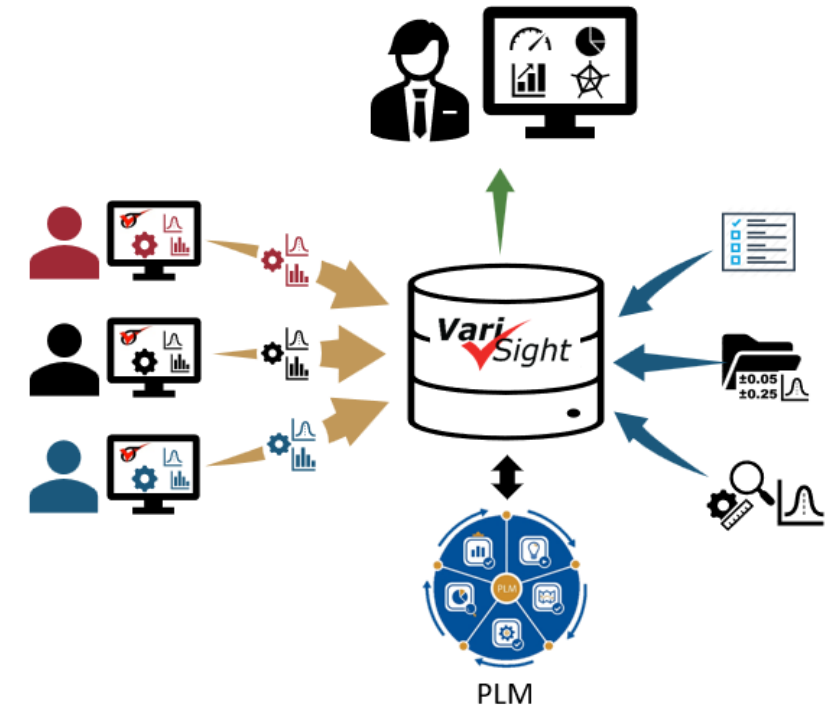
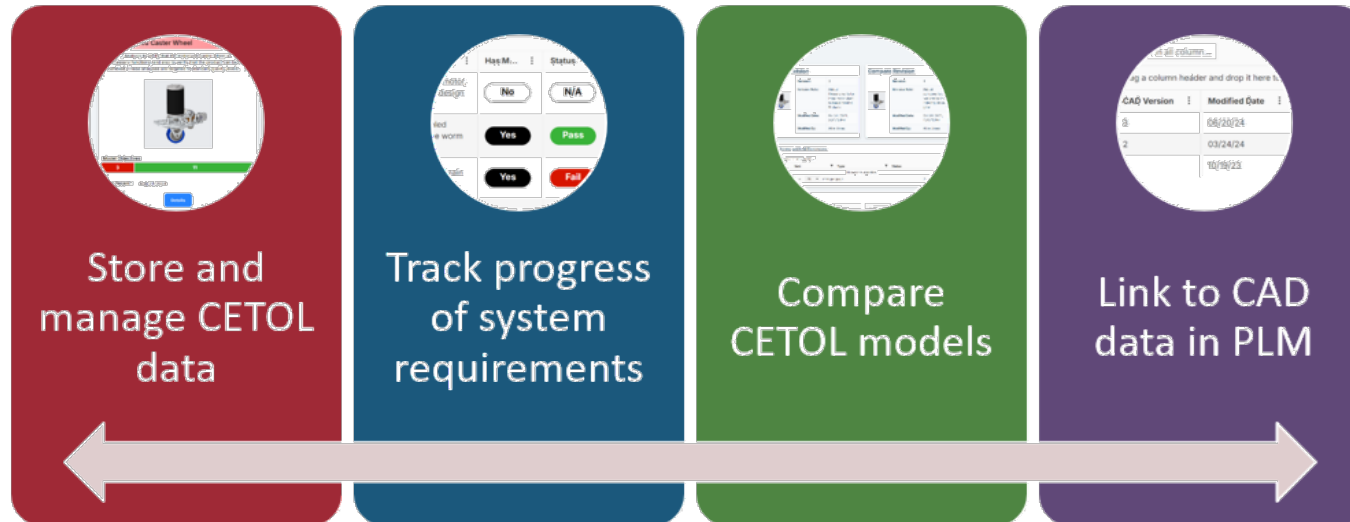
Version History General

	Version	File Name	TITLE
	A.2	0000000206.asm	MOTORIZED
	A.1	0000000206.asm	MOTORIZED
	-.4	0000000206.asm	MOTORIZED
	-.3	0000000206.asm	MOTORIZED
	-.2	0000000206.asm	MOTORIZED
	-.1	0000000206.asm	MOTORIZED
	1.2	0000000206.asm	MOTORIZED
	1.1	0000000206.asm	MOTORIZED



VariSight

- New Product 2025!

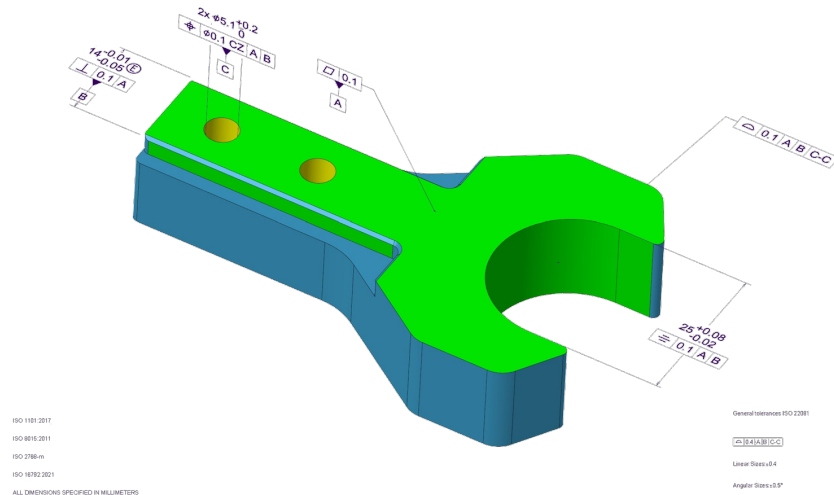


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Promote collaboration and discussion
around

Model Based Definition (MBD)
and its transformative impact on
product development processes.



The Steam Hotel
7-8 October, Västerås

Nordic MBE Forum Västerås

Presentations



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•Questions ?

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Thanks!

