

Measuring the MBD Capabilities of CAD Systems & Translators

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GLOBAL PRODUCT DATA INTEROPERABILITY **S U M M I T** 2015



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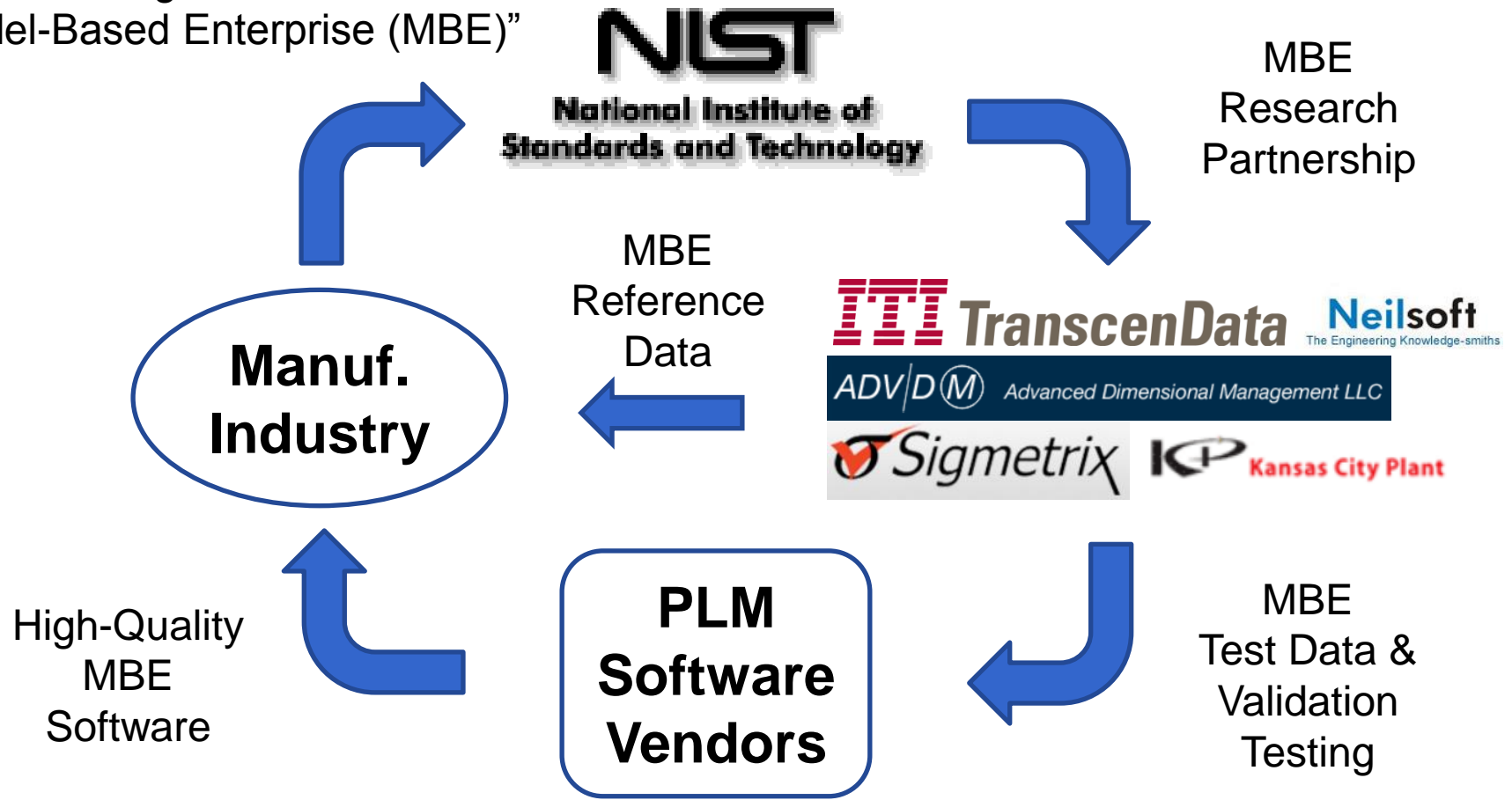


- **International TechneGroup Inc. (ITI)**
 - Private company headquartered in Cincinnati since 1983
 - Development offices in the United States, England, Israel and India
 - PLM system migration solutions
 - CAD interoperability solutions
- **Aerospace/Defense/Automotive Industry Group Memberships**
 - PDES Inc. and ProSTEP iViP
 - LOTAR (AIA, FAA, ASD-STAN, EASA, PDES, ProSTEP, ...)
 - JT Open
 - 3D PDF Consortium
 - MBE/MBD (U.S. DoD, DoE, NIST)
 - SASIG (AIAG, VDA, JAMA, GALIA, ...)
- **Doug Cheney**
 - CAD Validation Specialist for 20 years

NIST is Supporting the Discrete Part Manufacturing Industry for Long-term Growth

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“Our strategic direction is the Model-Based Enterprise (MBE)”



NIST MBE PMI Validation and Conformance Testing Program Objectives

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**Develop test cases,
test models and
software algorithms sufficient to
measure conformance of CAD systems to
American Society of Mechanical Engineers (ASME)
standards for Product and Manufacturing Information (PMI).**



ASME Y14.5M-1994
ASME Y14.41-2003

Dimensioning and Tolerancing
Digital Product Data Definition Practices

NIST MBE PMI Validation Program Web Site

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Engineering Laboratory

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NIST Home > EL > Systems Integration Division > Information Modeling and Testing Group > MBE PMI Validation and Conformance Testing


MBE PMI Validation and Conformance Testing


Overview

NIST has created a Test System to measure conformance of Computer-Aided Design (CAD) software to American Society of Mechanical Engineers (ASME) standards for Product and Manufacturing Information (PMI), specifically geometric dimensioning and tolerancing (GD&T) information.

PMI includes geometric dimensioning and tolerancing, 3D annotations, surface texture specifications, finish requirements, process notes, material specifications, welding symbols, and other information. One of the objectives of PMI standards is to define the semantics of the words and symbols used to communicate manufacturing information in 3D computer models. The use of PMI Representation (aka semantic PMI) will allow software developers to automate various design (CAD), manufacturing (CAM), and inspection (CMM) functions because the engineering application software associated with these functions can process the PMI directly. PMI presentation (aka graphical PMI) consists of geometric elements preserving the exact appearance of the PMI annotations and is meant to be human-readable.

<http://go.usa.gov/mGVm>

Select Language ▾ * 

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Download

Click here to download: CAD Models for both Datasets, 2D drawings with annotations for all test cases, STEP files for all test cases (geometry only), STEP AP203 and AP242 files with PMI generated from the Dataset 1 CAD models

Test Results

- [Dataset 1 CTC Verification Results](#) - compares test case specifications for PMI to CAD models
- [Dataset 1 CTC Validation Results](#) - compares CAD models to STEP, JT, and 3D PDF files
- [Dataset 2 FTC Verification Results](#) - compares test case specification for PMI to CAD models

Example Combined Test Case (CTC) and Test Models

Test Case

2015

CATIA V5 R21 Model

NX 8.0 Model

SolidWorks 2012 Model

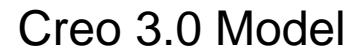
Creo 2.0 Model

Fully-toleranced vs. Combined Test Cases

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- **Combined Test Case (CTC)**
 - Combination of representative PMI constructs
 - Not intended to be realistic
- **Fully-toleranced Test Case (FTC)**
 - All geometric features are fully-toleranced in the context of the GD&T
 - Each tolerancing feature is adequately controlled and constrained by tolerances that comply with the applicable dimensioning, tolerancing, and modeling standards
 - Includes as many annotation types and constructs as needed to fully control and constrain each geometric feature relative to one or more datum reference frames
 - Accounts for the constraint requirements on the form, size, orientation, and location of features and hierarchical interrelationships between their tolerance zones and datum reference frames
 - Not intended to be functional

Test Case



Conformance Testing Terminology

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PMI Element	Annotation, coordinate system, supplemental geometry, or saved view
Presentation	What the human user sees (Visual consumption only)
Representation	What the downstream software receives (Visual and Automated consumption)
Verification	How well each PMI element is modeled (CAD system capability)
Validation	How well each PMI element is translated (Translator capability)

Verification Testing Methodology

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- **The representation and presentation of each PMI element is compared to the test case specification**
- **Any differences, which cannot be resolved with an alternate modeling technique, are categorized as a:**
 - Representation Limitation
 - Presentation Limitation
 - Style Difference (representation and presentation are correct but different between systems)
- **Each limitation/difference is grouped by characteristic**
- **System-independent statistics are compiled**

Verification Characteristics

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Representation Limitation

- Annotation structure
- Annotation parameters
- Annotation geometry
- Coordinate system structure
- Coordinate system parameters
- Supplemental geometry structure
- Supplemental geometry parameters

Style Difference

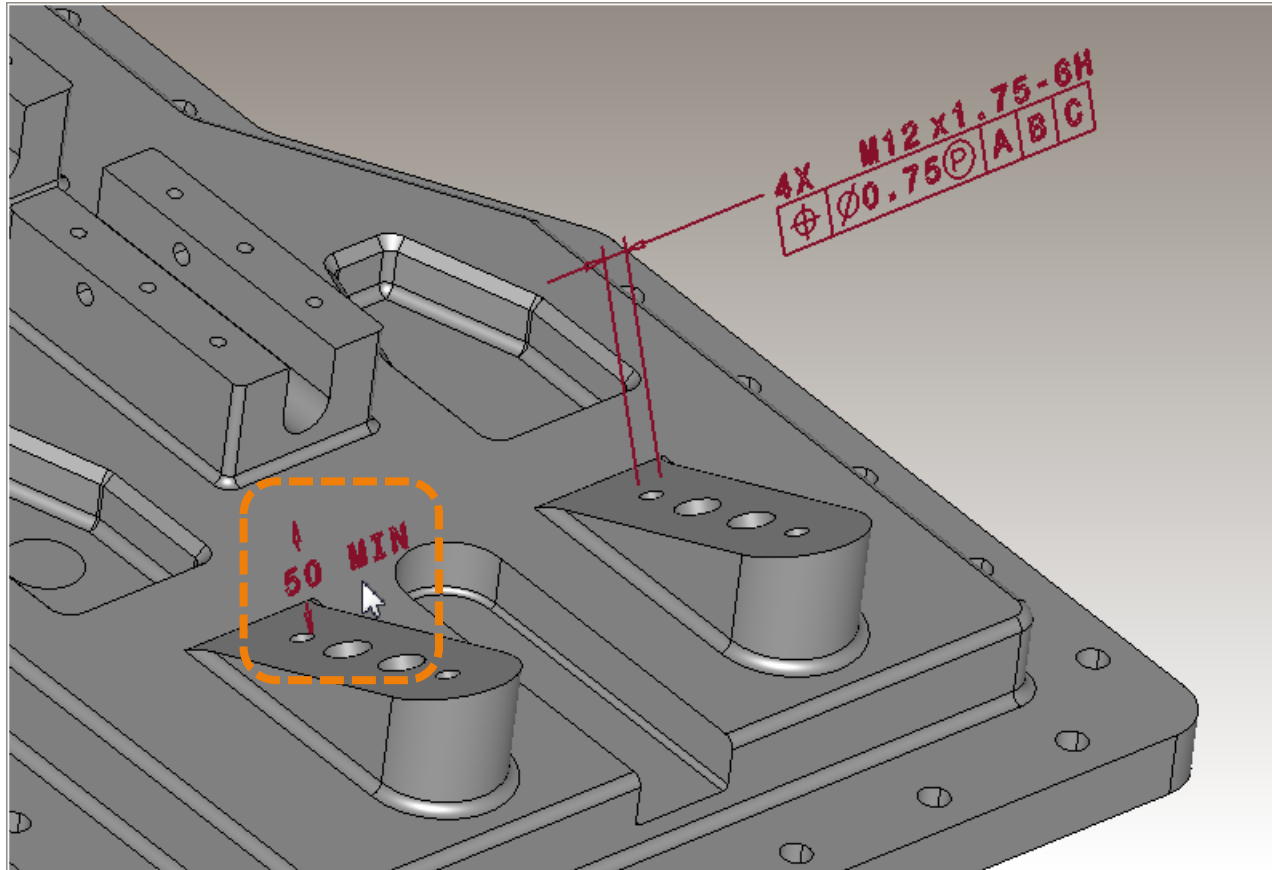
- Annotation structure
- Annotation geometry
- Supplemental geometry structure
- Product geometry parameters

Presentation Limitation

- Annotation visibility
- Annotation color
- Annotation name
- Annotation layout
- Annotation location
- Annotation orientation
- Annotation lines
- Annotation text
- Coordinate system visibility
- Coordinate system color
- Coordinate system name
- Coordinate system text
- Supplemental geometry visibility
- Supplemental geometry color
- Saved view structure
- Saved view name
- Saved view frustum

FCF projected tolerance zone defined as separate DIM

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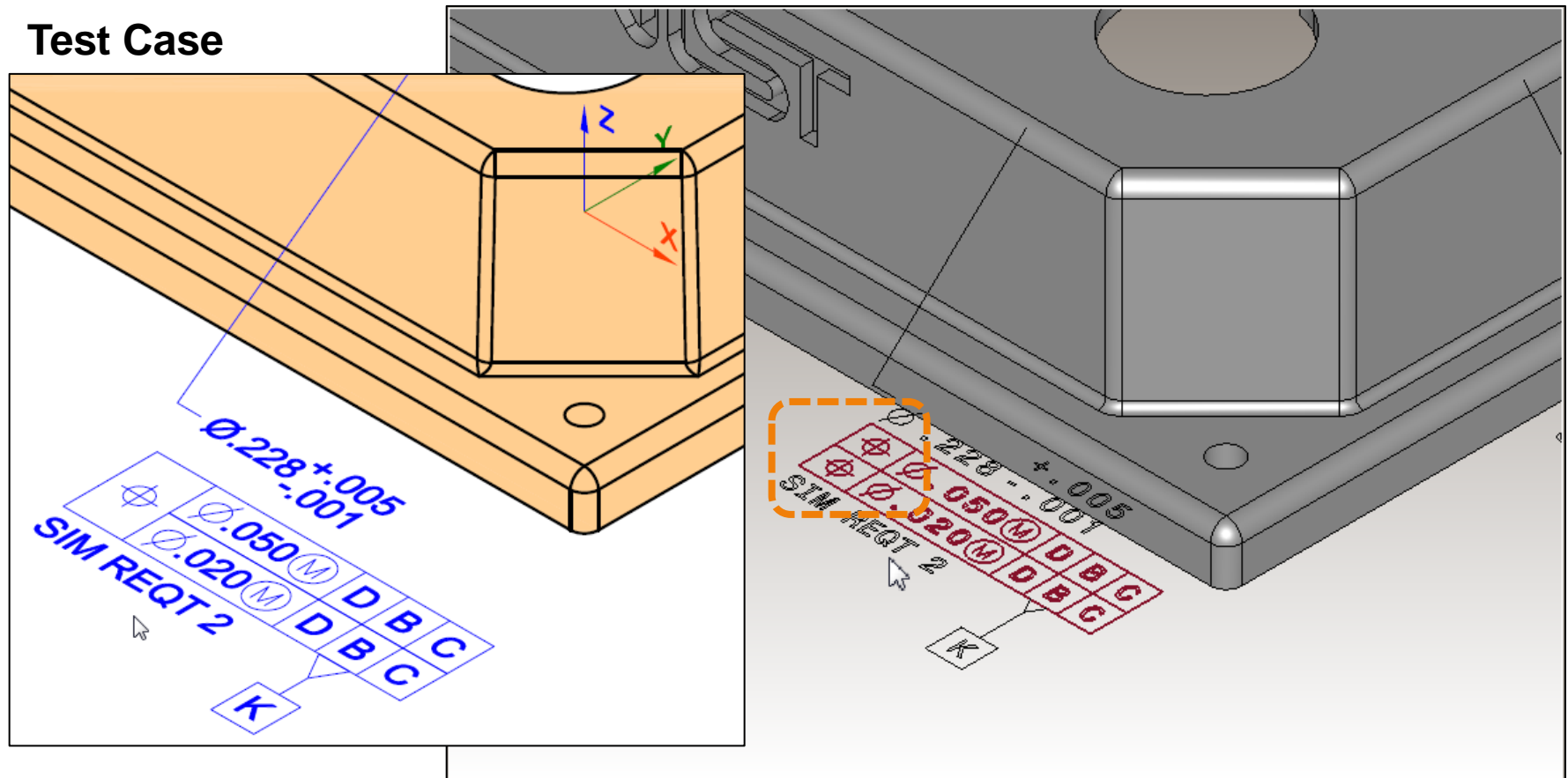
The length of the projected tolerance zone for this feature control frame is defined as a separate dimension.

Annotation Structure: FCF missing composite layout

Representation Limitation

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Test Case



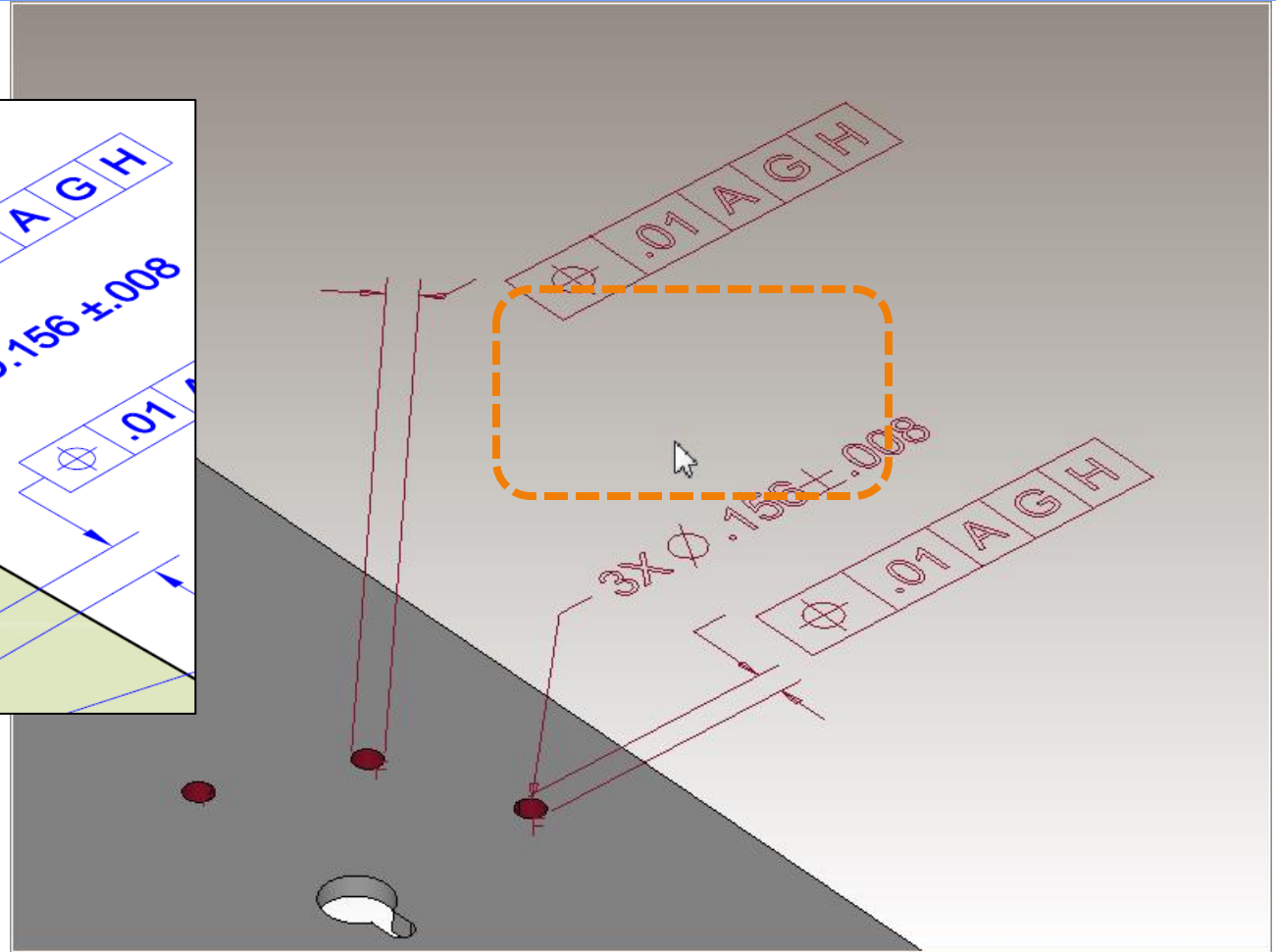
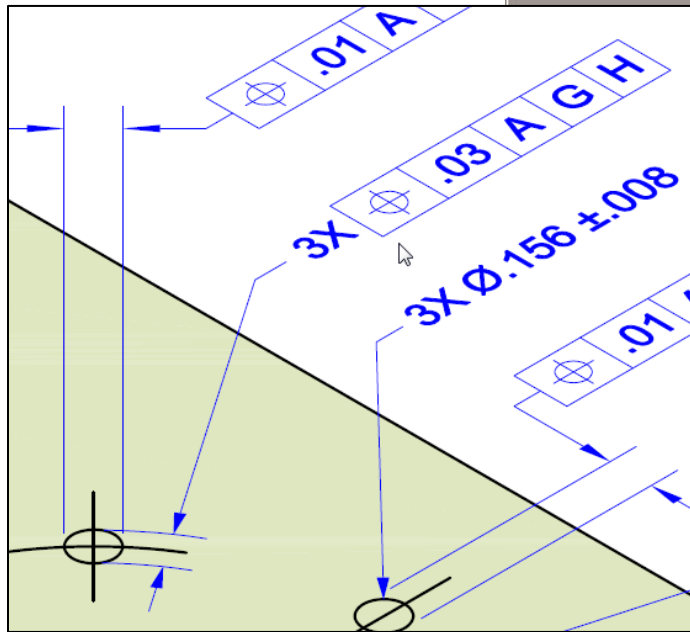
This feature control frame lacks the specified composite layout.

Annotation Structure: FCF not defined

Representation Limitation

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Test Case



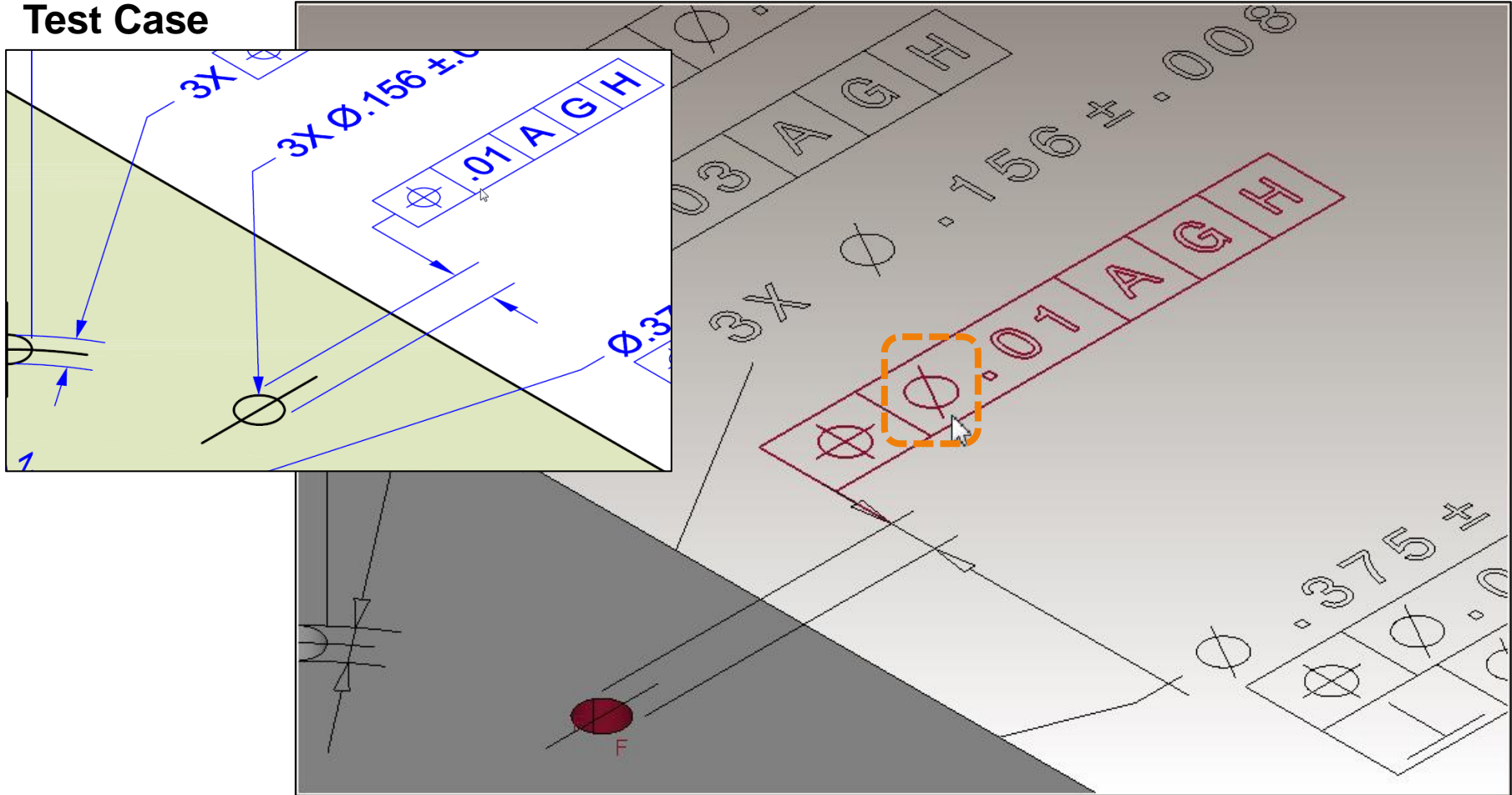
This specified feature control frame is defined.

Annotation Parameters: FCF diameter symbol not specified

Representation Limitation

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Test Case



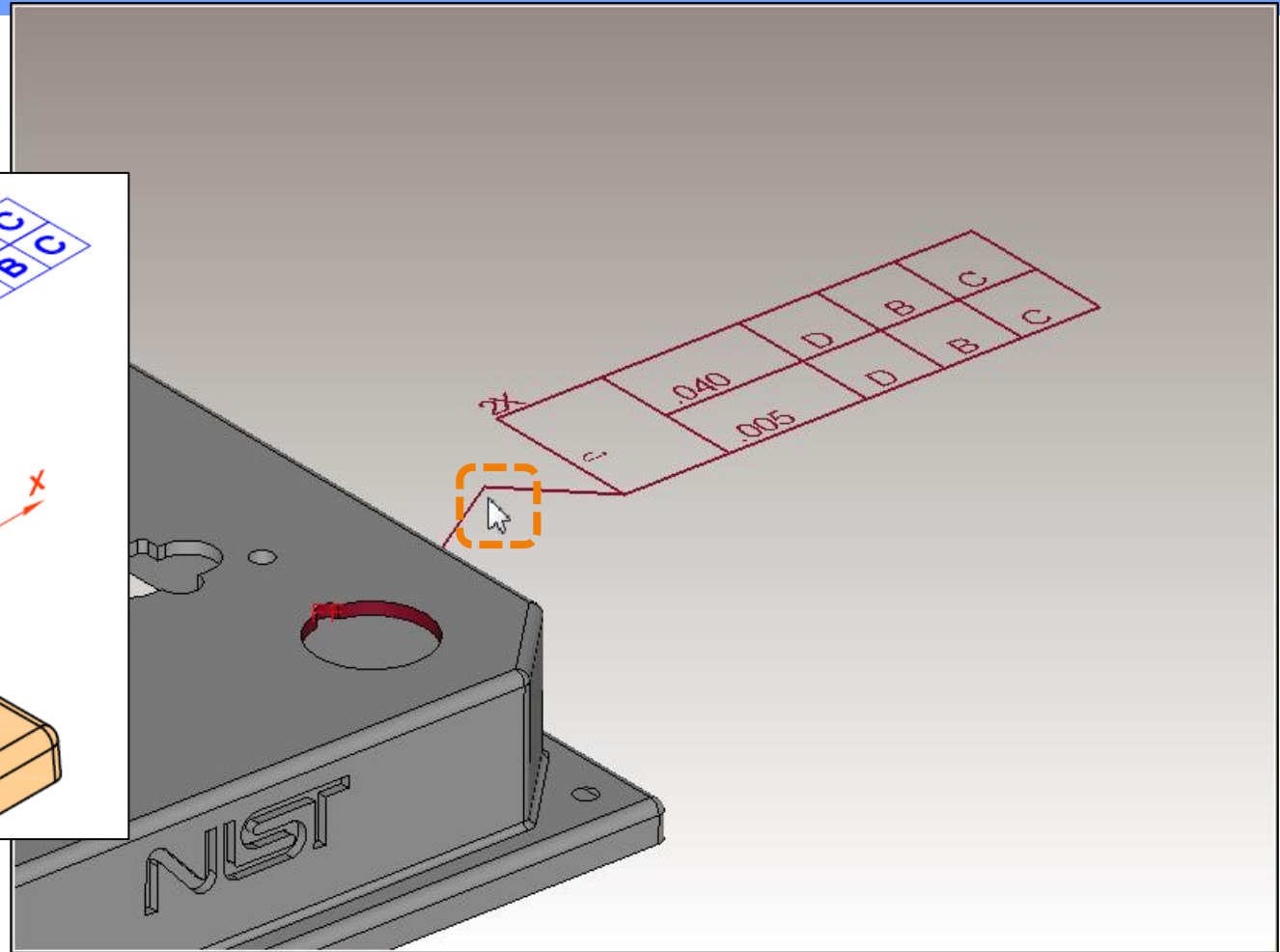
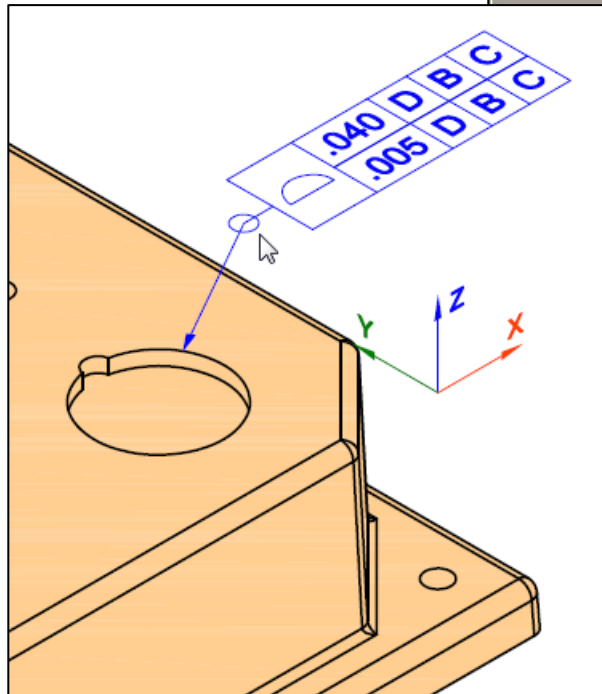
This geometric tolerance has an incorrect diameter symbol.

Annotation Parameters: FCF missing all-around designation

Representation Limitation

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Test Case



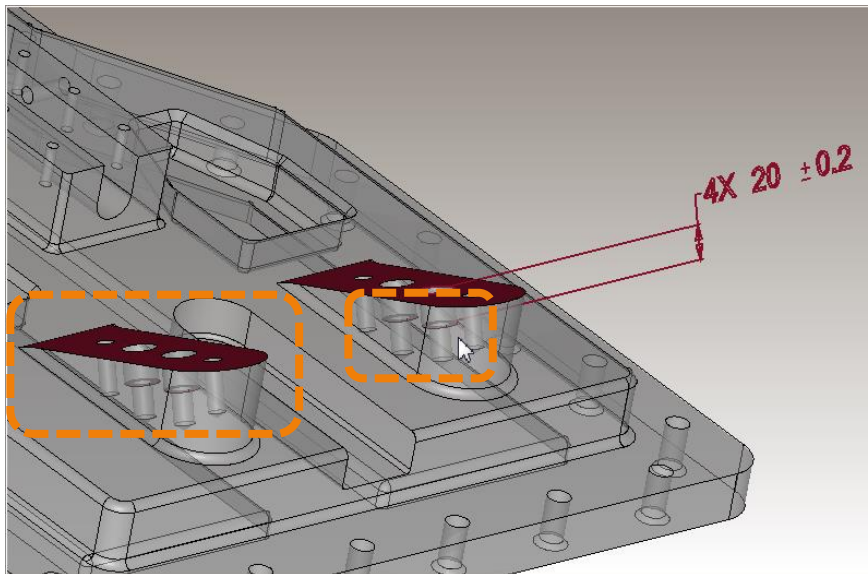
This feature control frame is missing an all-around symbol.

Annotation Geometry: DIM not associated with complete set of faces

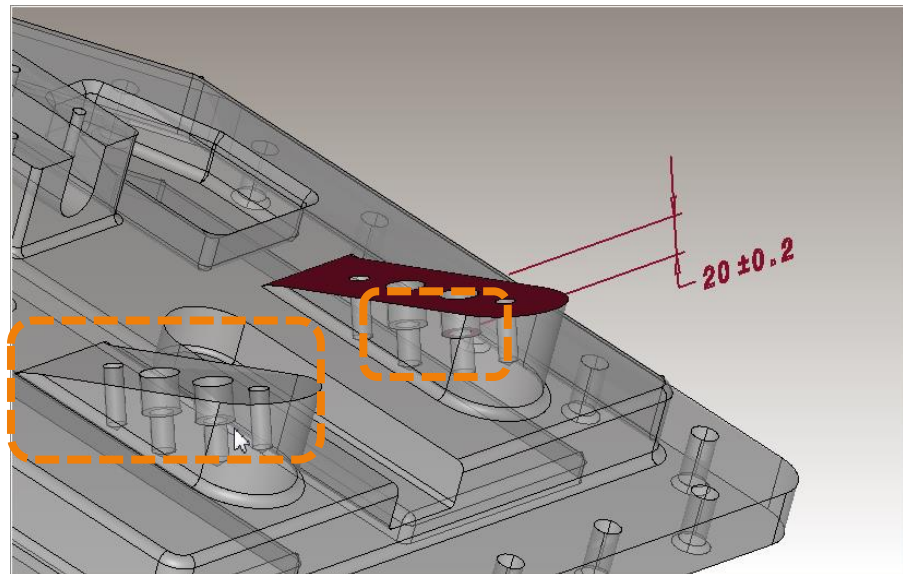
Representation Limitation

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Complete Representation



Incomplete Representation

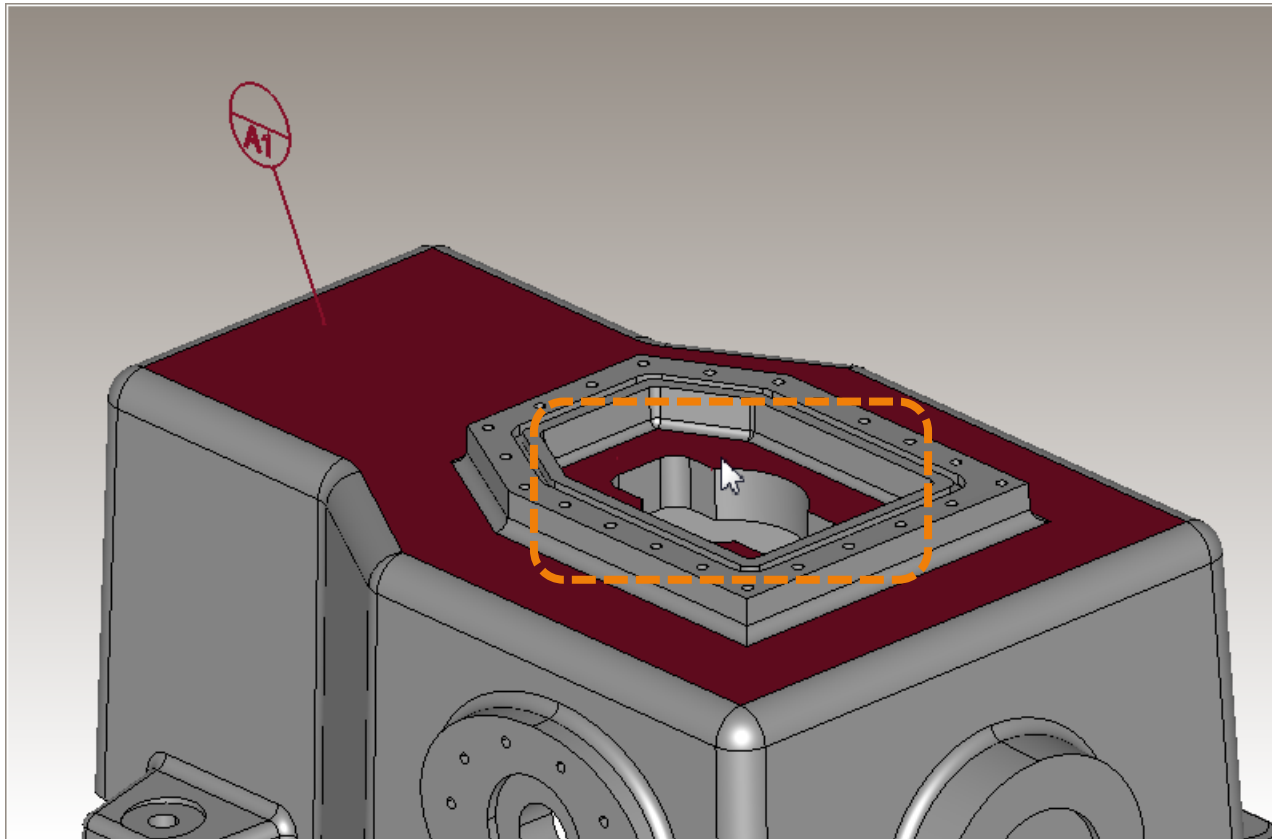


This counterbore depth dimension is not associated with both planar faces and all 4 bottom faces.

Annotation Geometry: DTS associated with extra face

Representation Limitation

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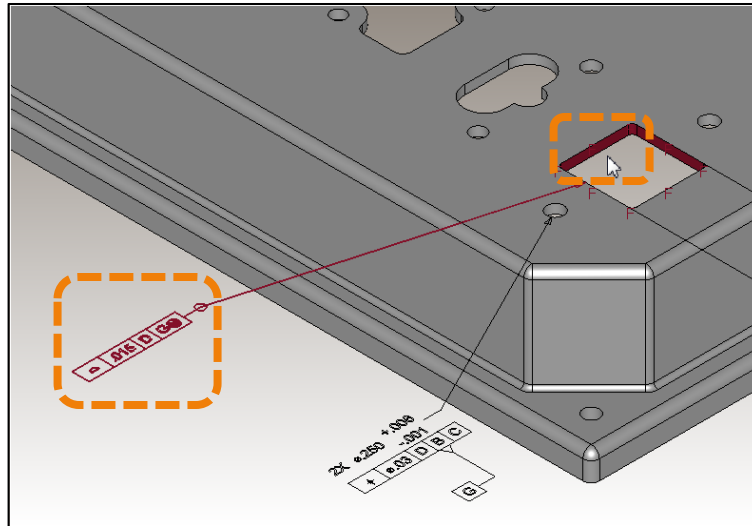
This datum target symbol is associated with an extra (coplanar) face and not just the specified face.

Annotation Geometry: FCF not associated with complete set of faces

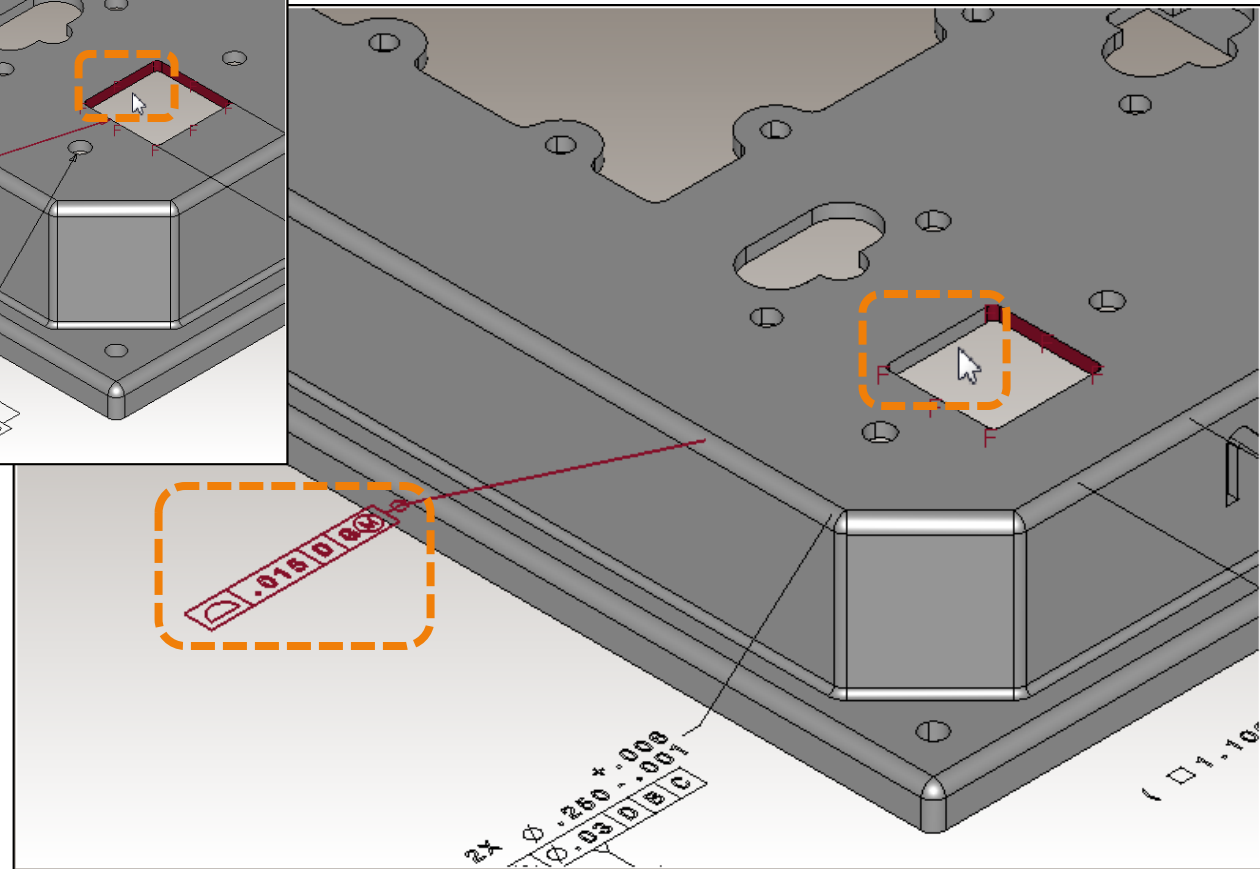
Representation Limitation

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Complete



Incomplete

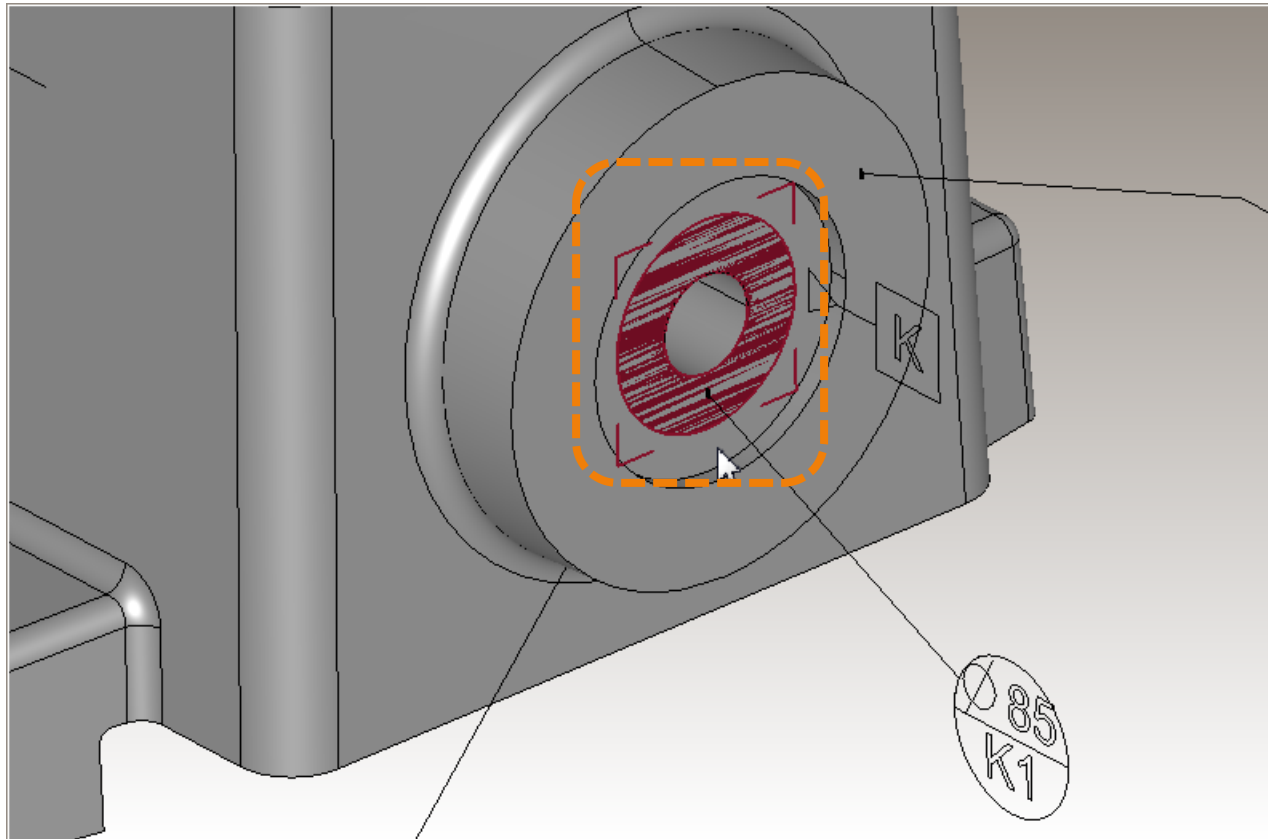


This feature control frame is not associated with all of the specified faces.

Supplemental Geometry Structure: DTS target area is non-solid surface on solid face

Style Difference

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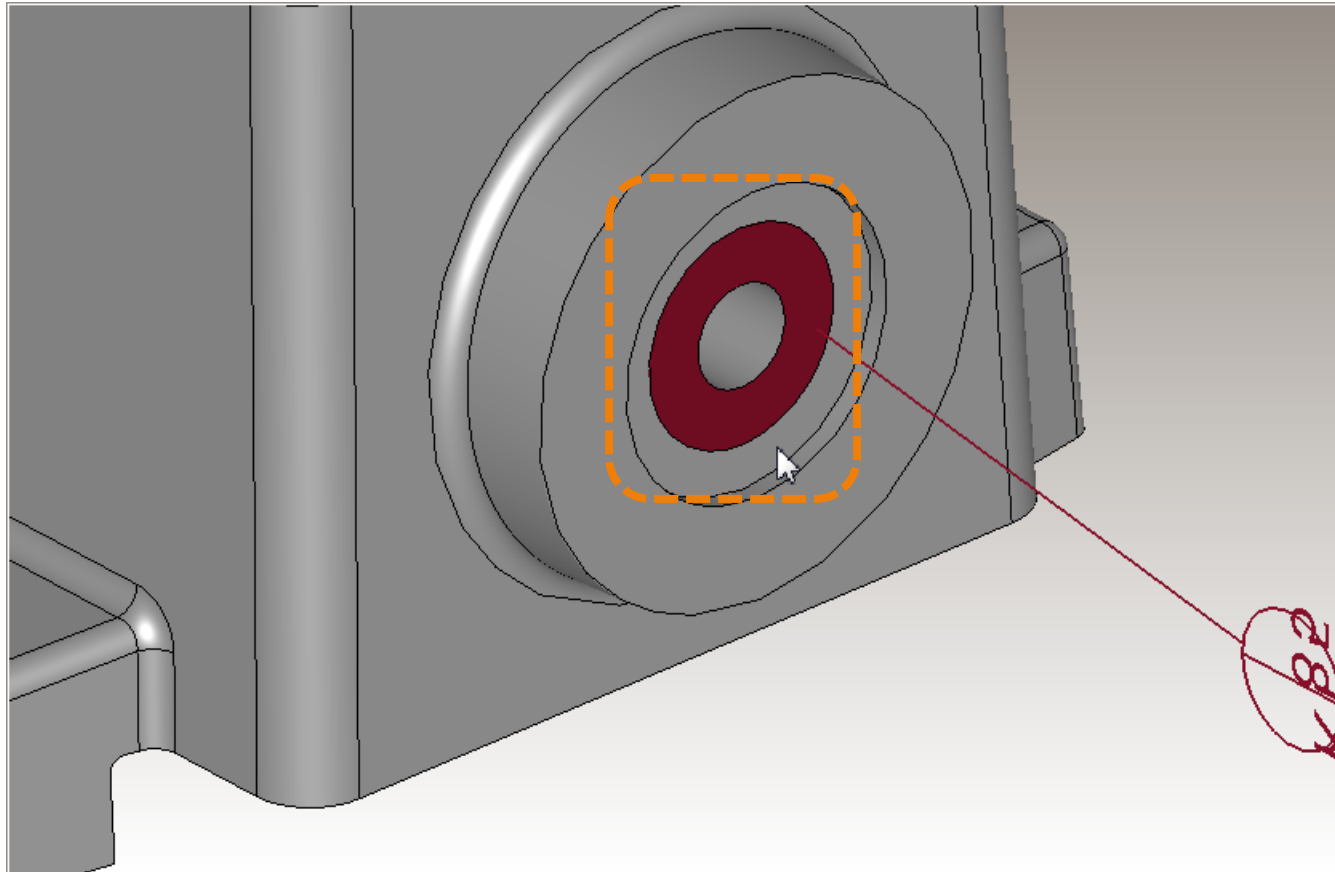


The target area for this datum target is defined as a non-solid surface placed on the solid face.

Supplemental Geometry Structure: DTS target area is subdivided solid face

Style Difference

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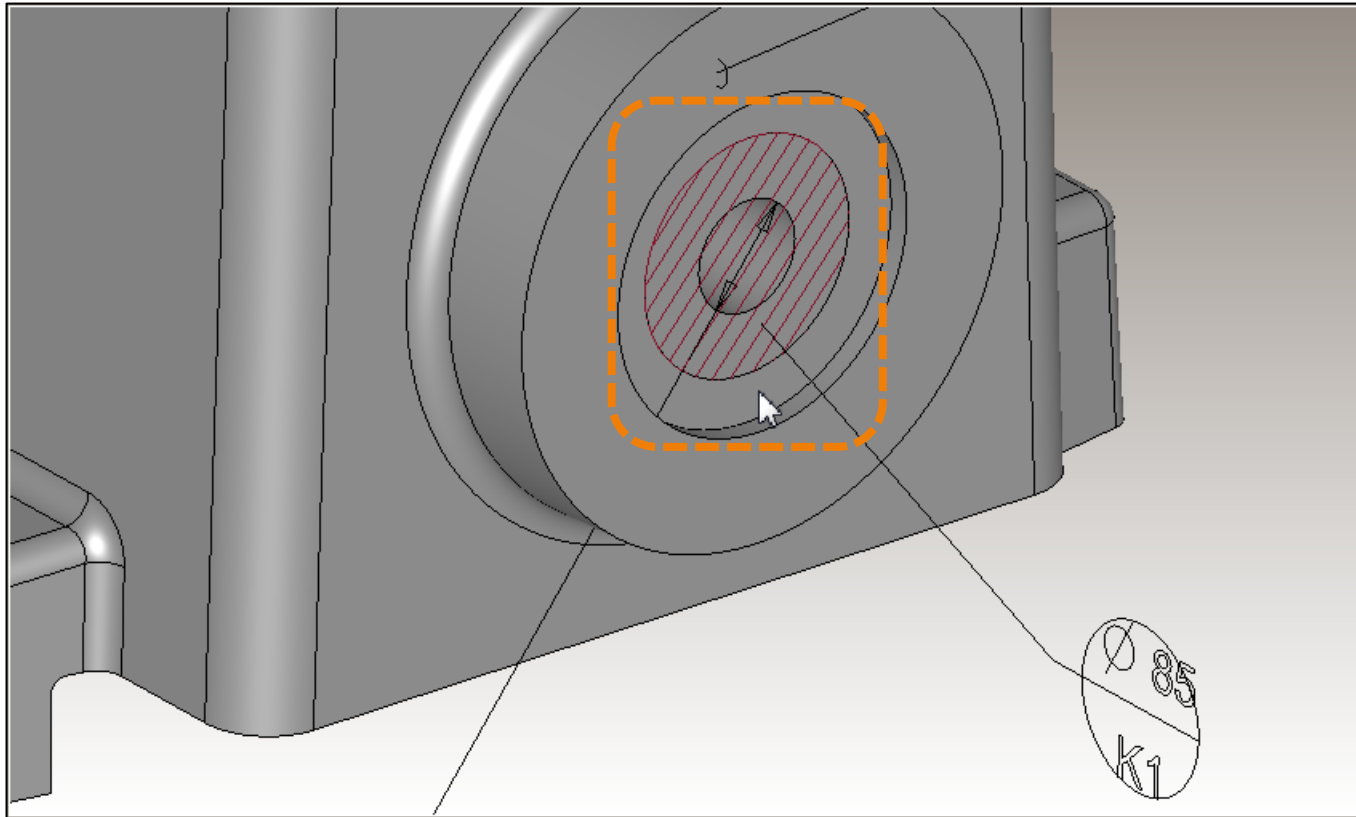


The target area for this datum target is defined as a solid face that has been separated from the adjacent faces in this solid.

Supplemental Geometry Structure: DTS target area is wireframe region on solid face

Style Difference

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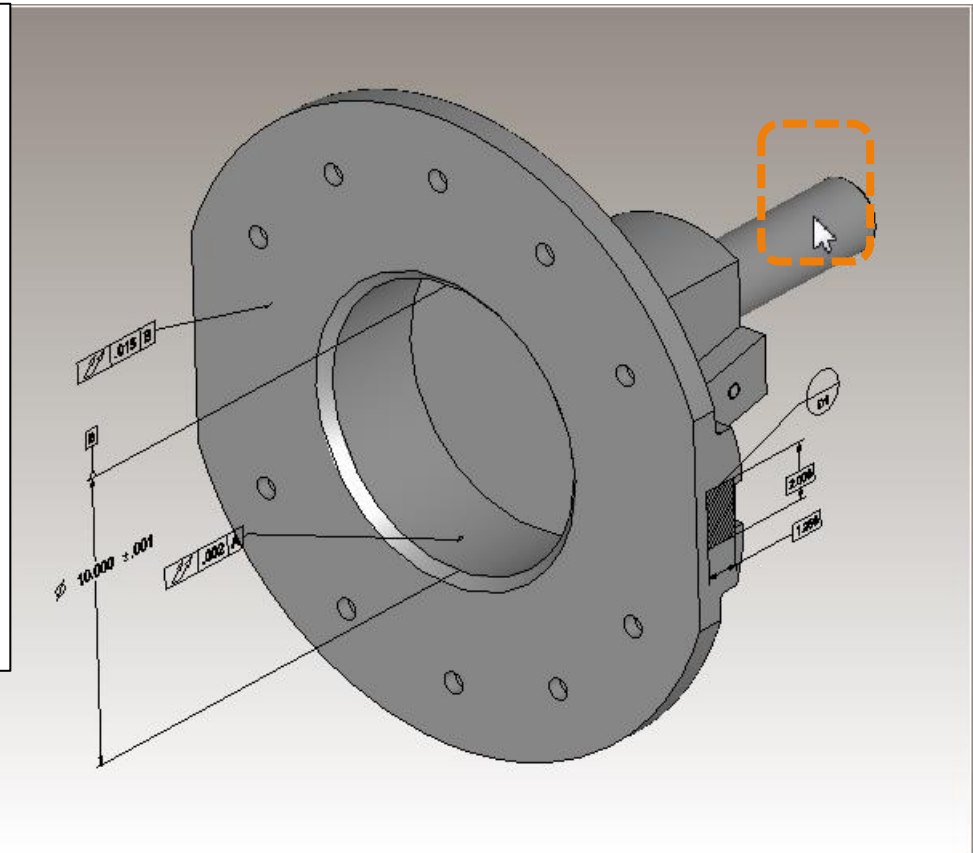
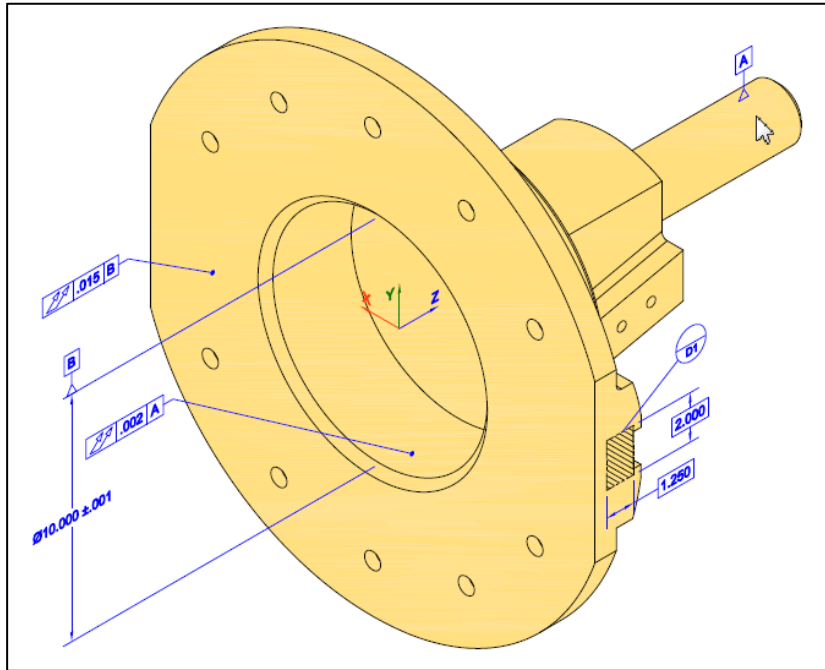
The target area for this datum target is defined as a wireframe region placed on the solid face.

Annotation Visibility: DFS not visible in specified view

Presentation Limitation

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Test Case

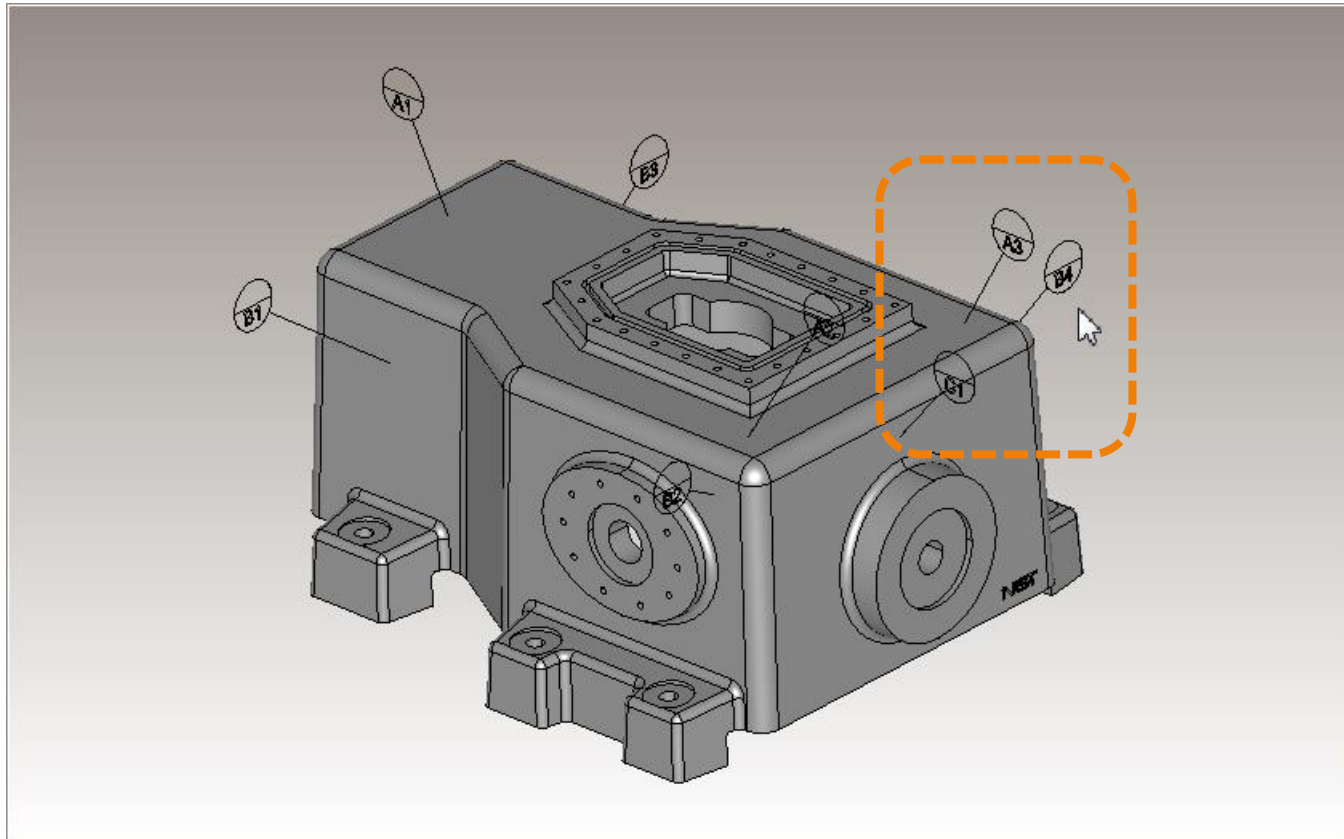


This model has datum feature symbol “A” defined in the first saved view.
But it cannot also be displayed in the second saved view as specified.

Annotation Visibility: DTS visible in wrong view

Presentation Limitation

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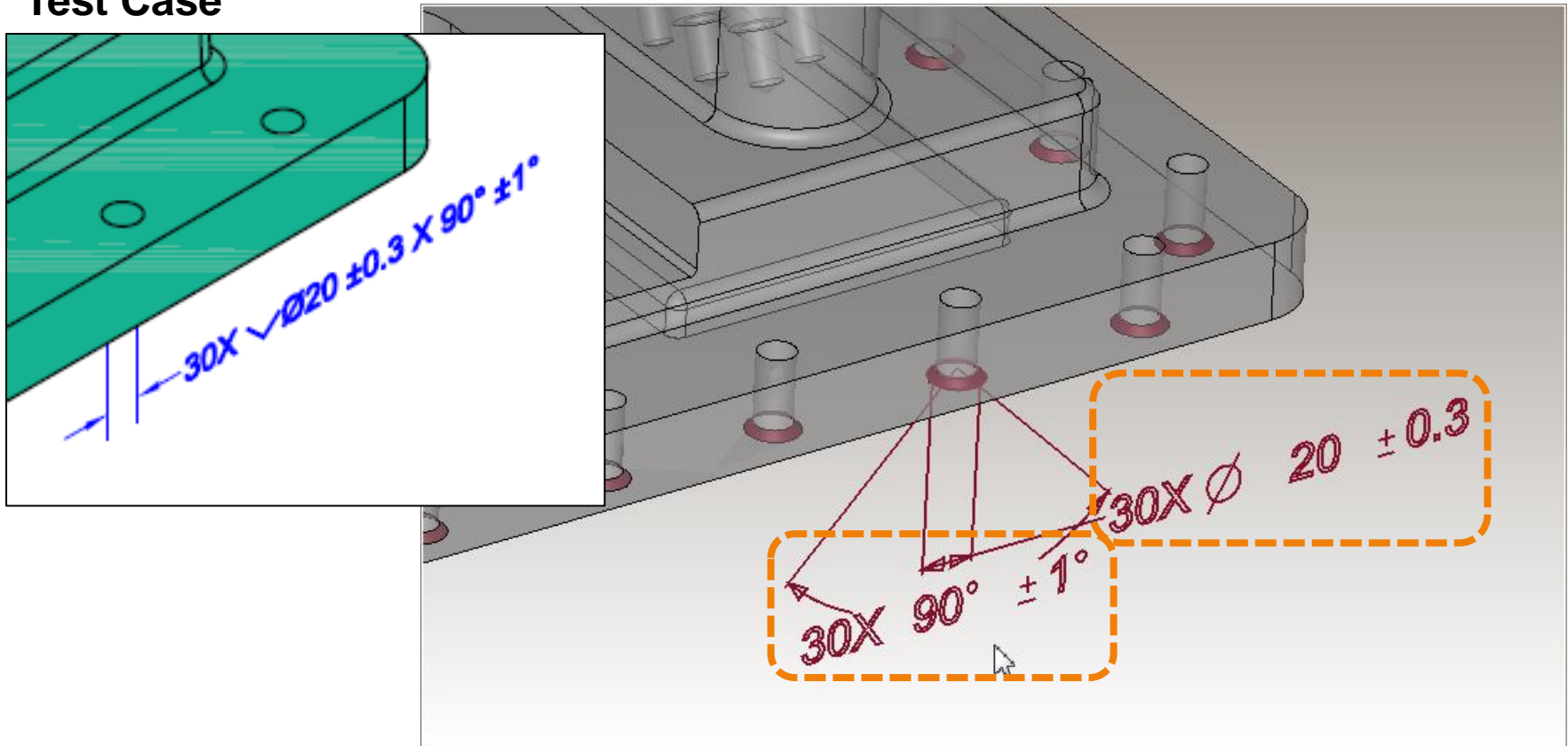
These datum target symbols are visible in a default (unspecified) saved view which cannot be deleted from the model.

Annotation Layout: Countersink DIM defined as two separate DIM's

Presentation Limitation

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Test Case



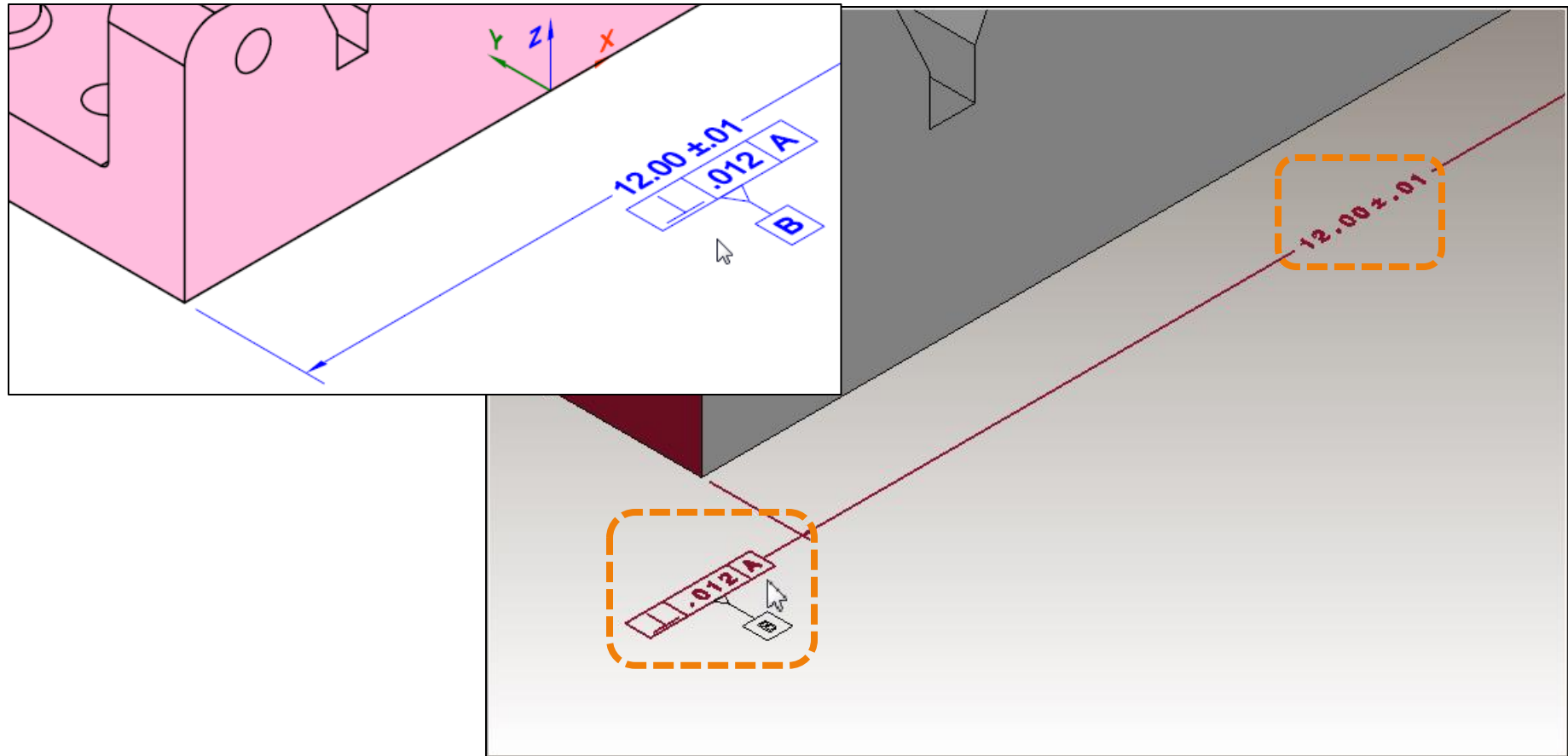
This countersink dimension cannot be defined as a single annotation with named parameters that each have correct face associations. It must be defined as two separate dimensions.

Annotation Location: FCF not attached to DIM

Presentation Limitation

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Test Case



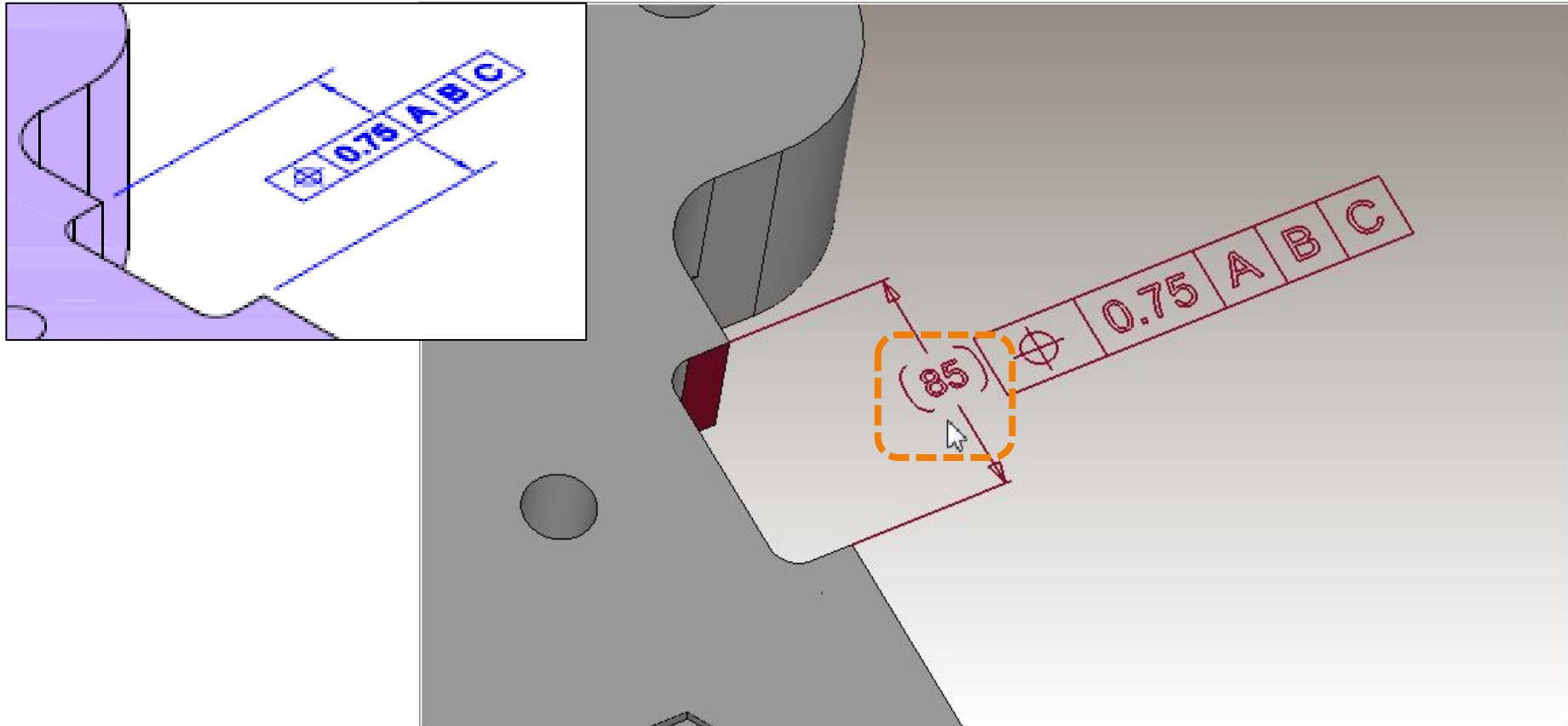
This feature control frame is not attached to it's associated dimension.

Annotation Text: FCF text is extraneous

Presentation Limitation

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Test Case



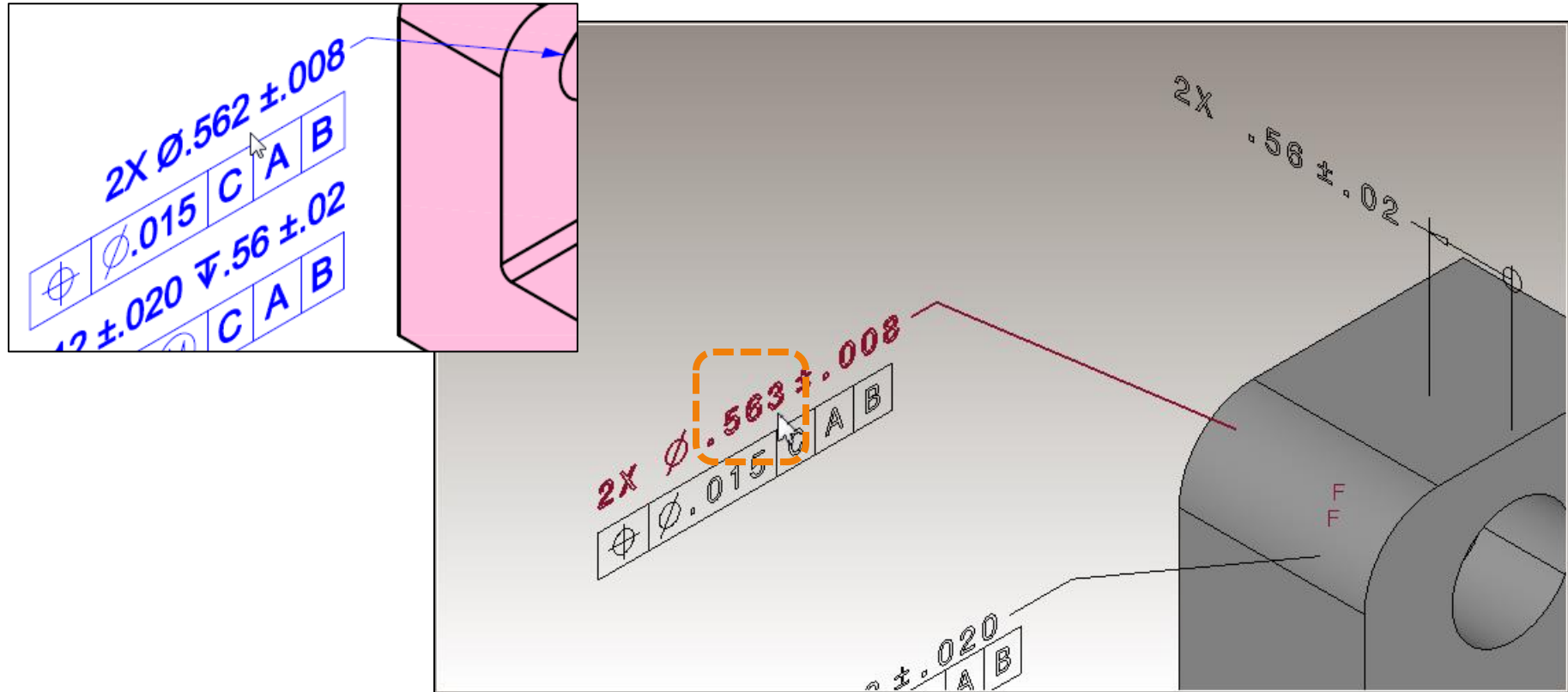
The “(85)” text on the left of this feature control frame is not specified in the test case.

Annotation Text: DIM nominal value rounded incorrectly

Presentation Limitation

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Test Case



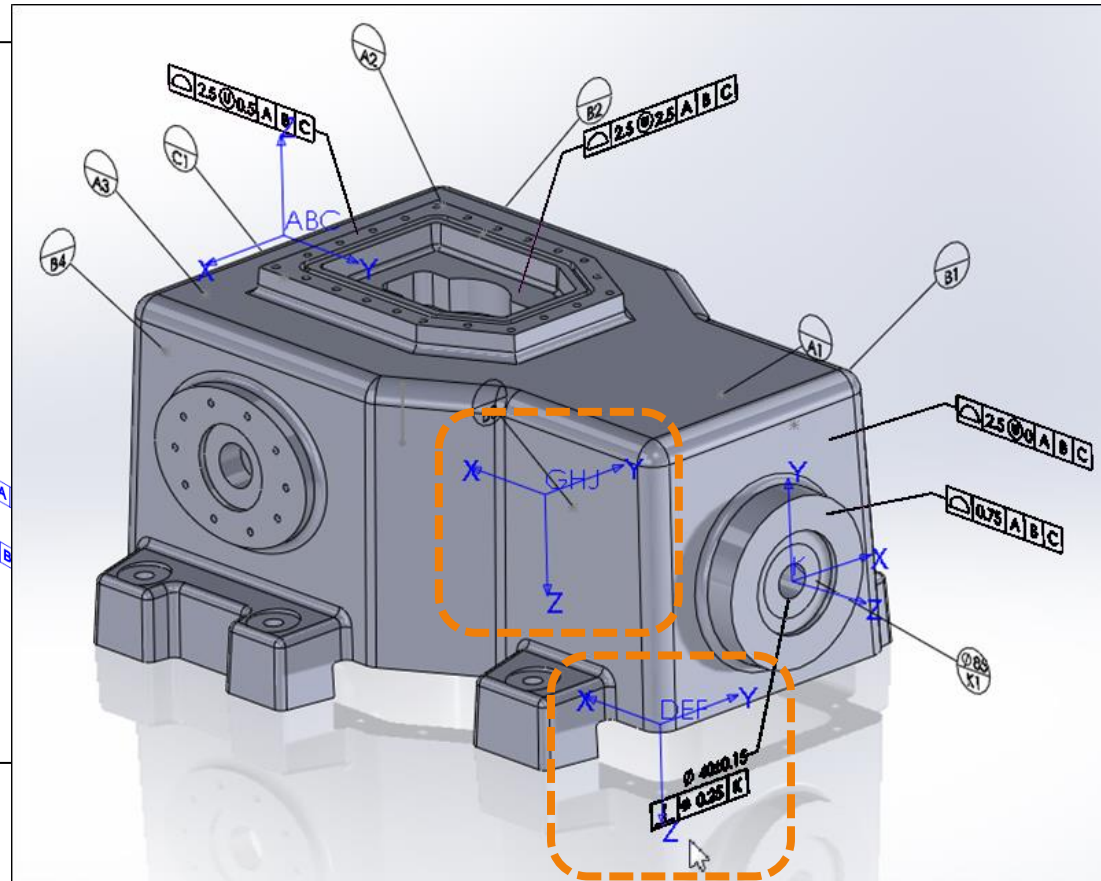
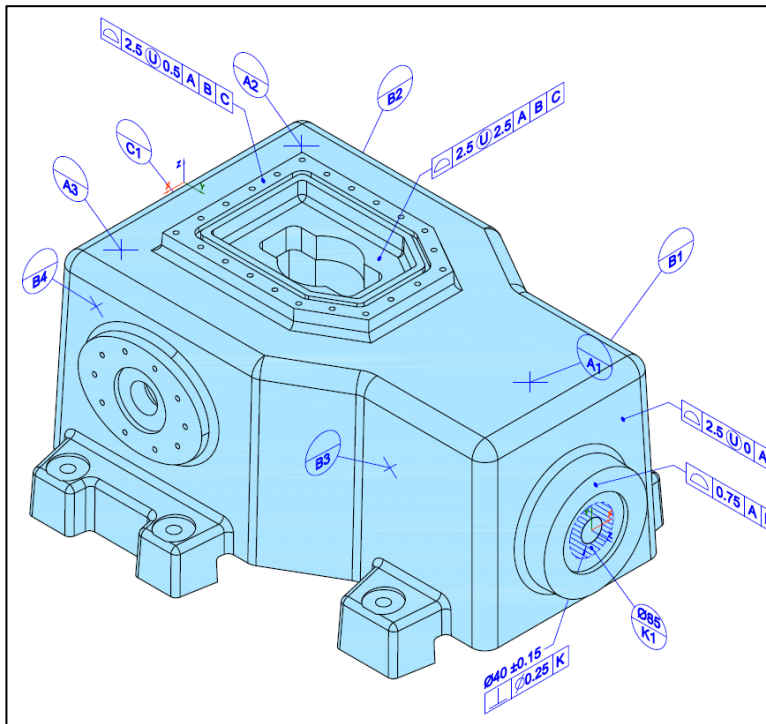
The nominal value of this dimension is rounded incorrectly.

Coordinate System Visibility: CS visible in wrong view

Presentation Limitation

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Test Case



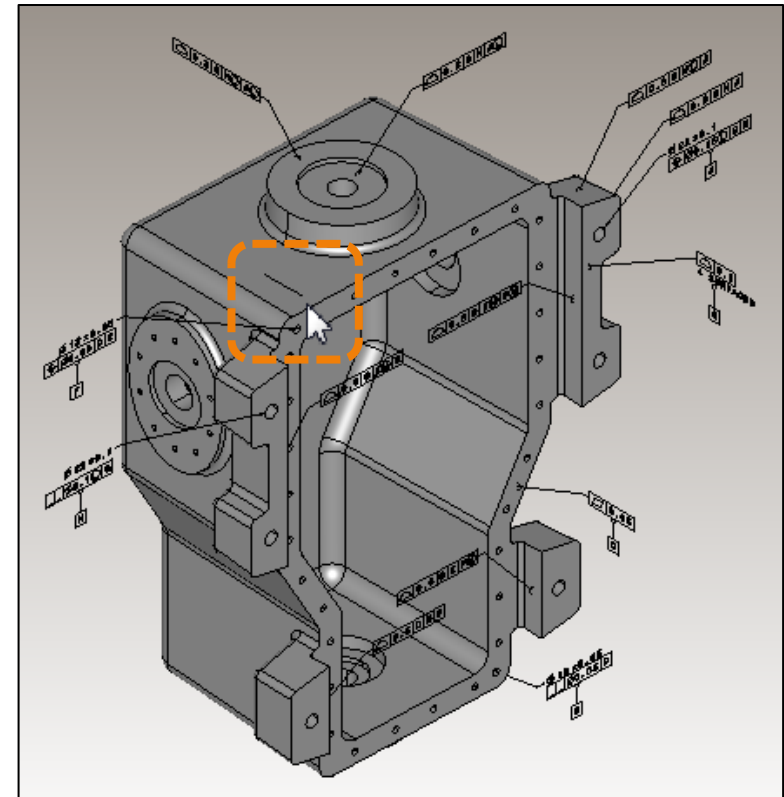
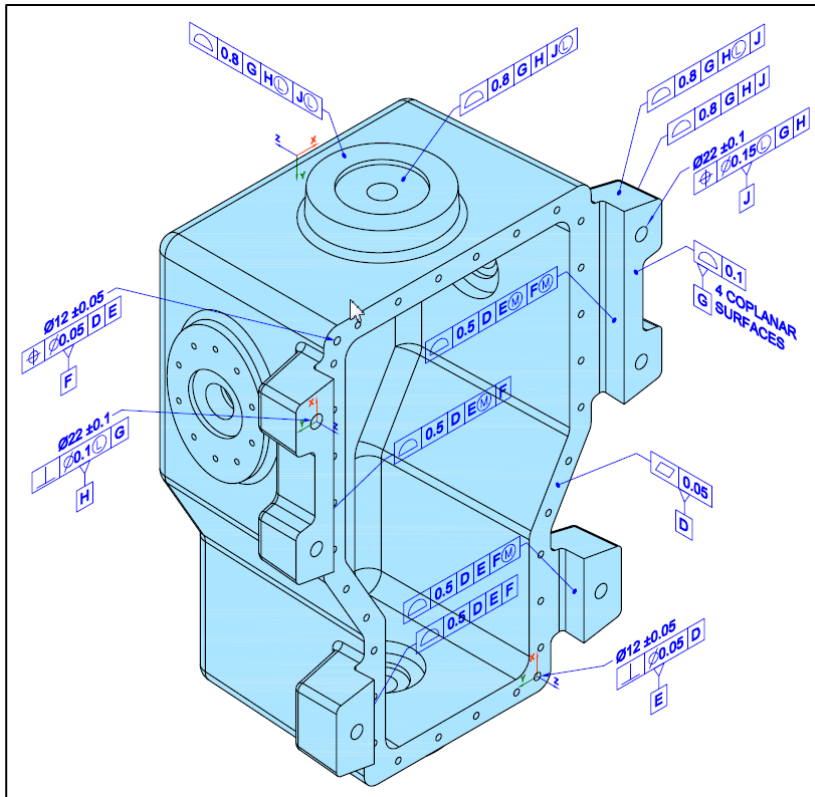
The “DEF” and “GHJ” coordinate systems are visible in a saved view in which they are not referenced.

Supplemental Geometry Visibility: SG curve visible in wrong view

Presentation Limitation

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Test Case



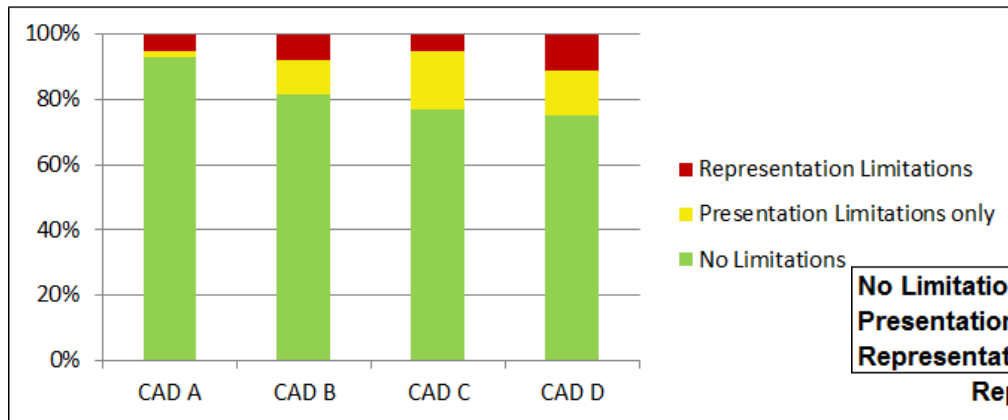
Because the profile of a line feature control frame in this model is not specified as visible in this saved view, then its associated supplemental geometry curve should not be visible.

Verification Percentages by System and Dataset

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	CAD A	CAD B	CAD C	CAD D
No Limitations	93%	82%	77%	75%
Presentation Limitations only	2%	10%	18%	14%
Representation Limitations	5%	8%	5%	11%
Representation Level	95%	92%	95%	89%

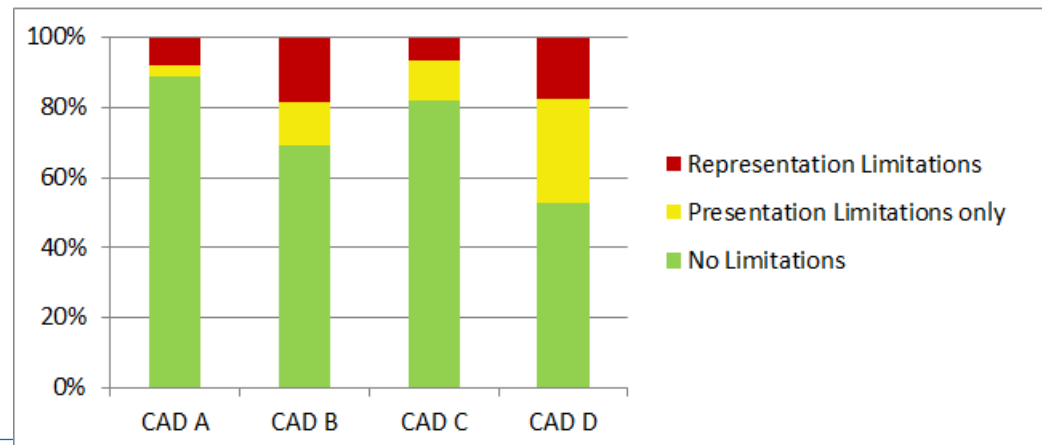
*Coordinate system
issues excluded*



Fully-toleranced Models

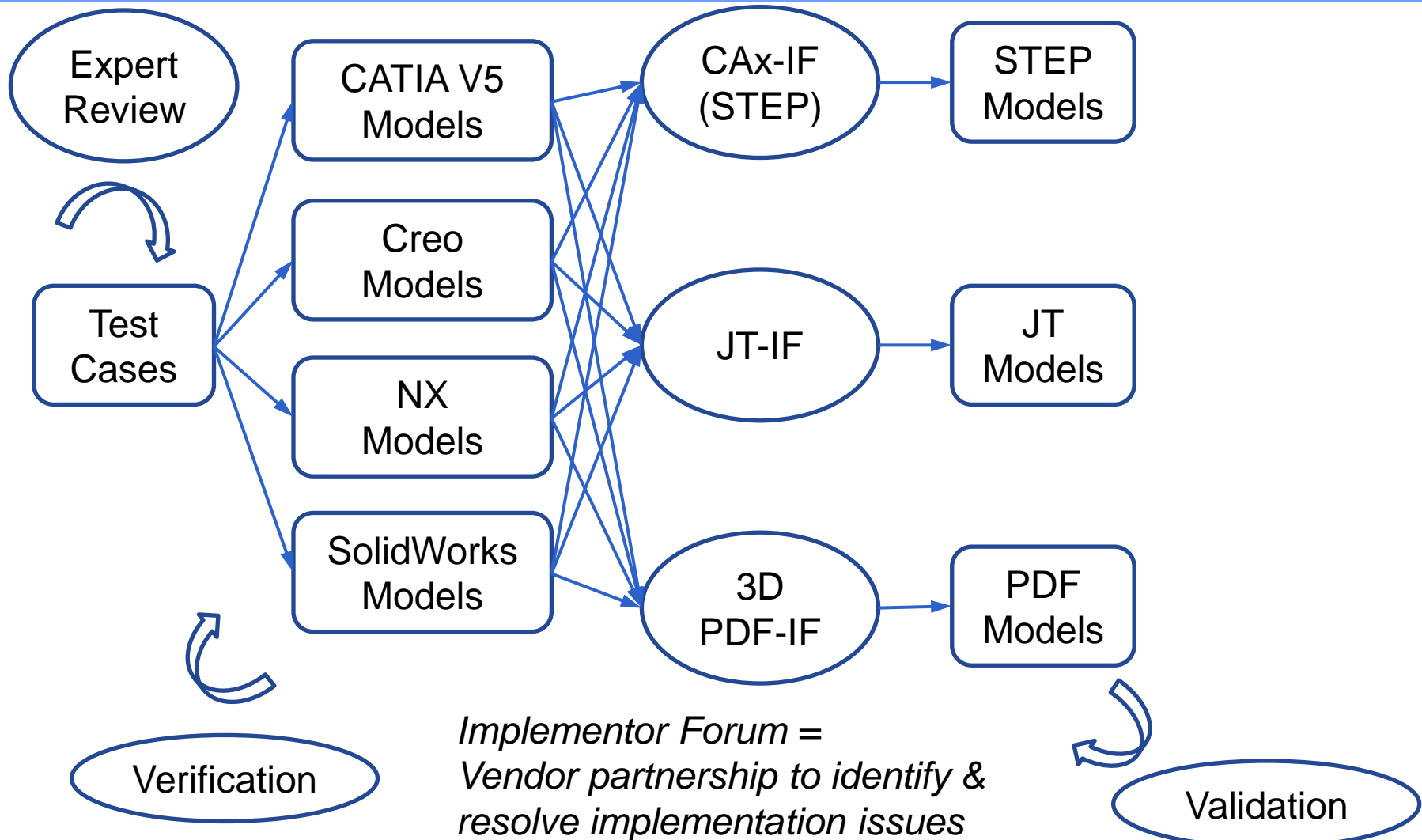
	CAD A	CAD B	CAD C	CAD D
No Limitations	89%	69%	82%	52%
Presentation Limitations only	3%	12%	12%	30%
Representation Limitations	8%	19%	7%	18%
Representation Level	92%	81%	93%	82%

Combined Models



Conformance Testing Process

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Validation Scenarios

Quality checking
Revision comparison
Data stability testing
Derivative validation
Archival validation

Model Analysis

Assembly structure
Assembly properties
Assembly PMI
Part structure
Part properties
Part features
Part geometry
Part PMI
Part graphics

Reports

Controller statistics
Excel statistics
Log File
Model Summary Report
Batch Summary Report
Viewer graphics
2D PDF
3D PDF

System Interfaces

CATIA V5
NX
Creo
SOLIDWORKS
Inventor
Solid Edge

File Interfaces

CATIA V4
Parasolid
ACIS
STEP
JT
3D PDF

Operating Systems

(only 64-bit)
Windows Vista
Windows 7
Windows Server

For more information:
<http://www.cadiq.com>

NIST STEP File Analyzer

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- **Generate a spreadsheet from a STEP file**
 - Worksheets for each entity type
 - Each row is an entity instance
 - Columns are the entity attributes

	A	B	C	D	E	F
1	datum_system (5)					
2						
3	ID	name	description	of_shape	product_definitional	constituents
4	5380			product_definition_shape 12	FALSE	(1) datum_reference_compartment 5378
5	5448			product_definition_shape 12	FALSE	(1) datum_reference_compartment 5446
6	5495			product_definition_shape 12	FALSE	(3) datum_reference_compartment 5491 5492 5493
7	5542			product_definition_shape 12	FALSE	(3) datum_reference_compartment 5538 5539 5540
8	5589			product_definition_shape 12	FALSE	(3) datum_reference_compartment 5585 5586 5587

datum_system worksheet – Rows 4-8 – five entity instances

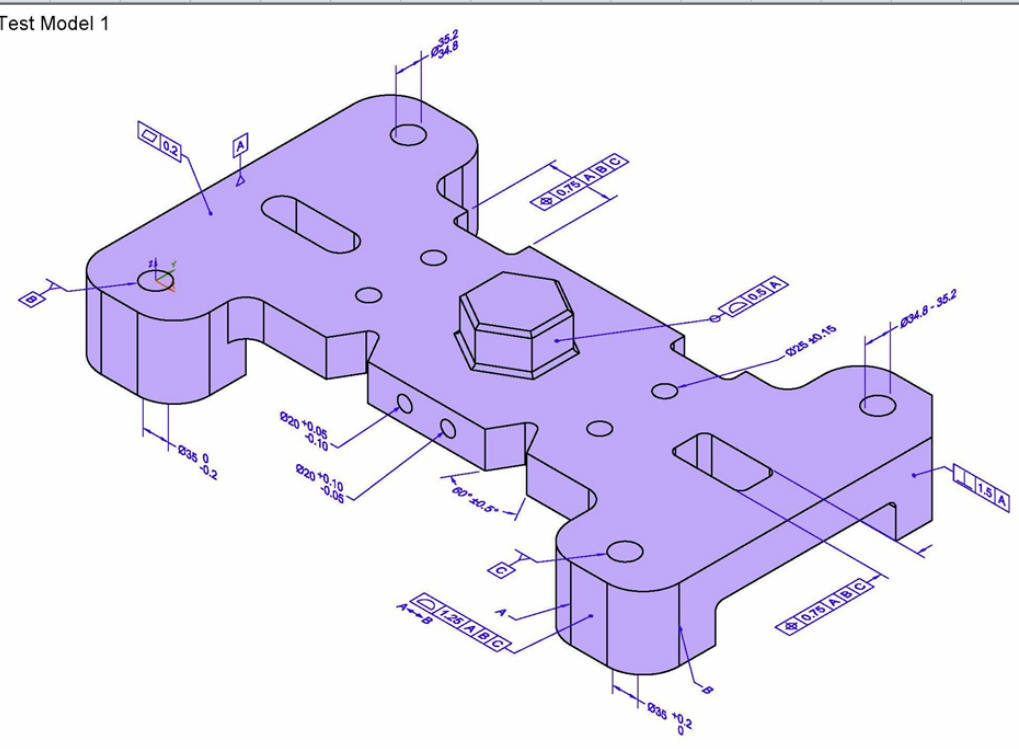
Column D – of_shape attribute refers to product_definition_shape entity #12

Column F – constituents attribute refers to multiple datum_reference_compartment

NIST STEP File Analyzer

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- **Visual recreation of PMI representation – Column C**
 - Manual comparison to test case definition
 - Use to debug PMI representation and presentation

A		B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	sp4_01_ct-d5-242.stp				Test Model 1														
2																			
3	ID	Entity	PMI Representation																
4	5380	datum_system	A																
5	5448	datum_system	A																
6	5495	datum_system	A B C																
7	5542	datum_system	A B C																
8	5589	datum_system	A B C																
9	5625	dimensional_characteristic_representation	Ø35.0 0.0 -0.2																
10	5660	dimensional_characteristic_representation	Ø35.0 +0.2 0.0																
11	5705	dimensional_characteristic_representation	Ø20.0 +0.05 -0.1																
12	5750	dimensional_characteristic_representation	Ø20.0 +0.1 -0.05																
13	5794	dimensional_characteristic_representation	60.0° ± 0.5																
14	5852	dimensional_characteristic_representation	Ø34.8-35.2																
15	5894	dimensional_characteristic_representation	Ø34.8-35.2																
16	5935	dimensional_characteristic_representation	Ø25.0 ± 0.15																
17	5340	flatness_tolerance	0.2 [A]																
18	5496	(geometric_tolerance_with_datum_reference) (position_tolerance)	2X ⊕ 0.75 A B C																
19	5543	(geometric_tolerance_with_datum_reference) (position_tolerance)	2X ⊕ 0.75 A B C																
20	5449	(geometric_tolerance_with_datum_reference) (surface_profile_tolerance)	6X = 0.5 A																
21	5590	(geometric_tolerance_with_datum_reference) (surface_profile_tolerance)	1.25 A B C																
22	5381	perpendicularity_tolerance	1.5 A																
23																			
24																			
25	See CAX-IF Recommended Practice for Representation and Presentation of PMI (
26																			
27																			
28																			
29																			
30																			

PMI Complex Test Case 1

Includes Atomic Test Cases - 1, 2, 3, 4, 7, 8, 17, 21, 33, 48

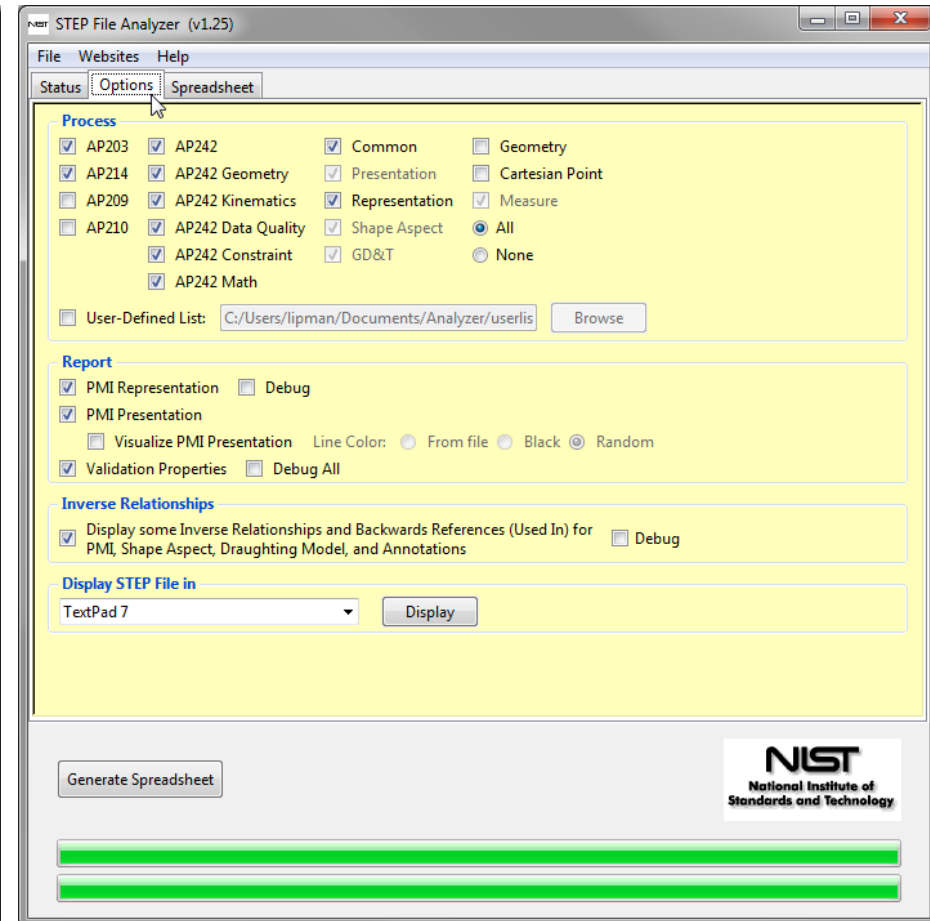
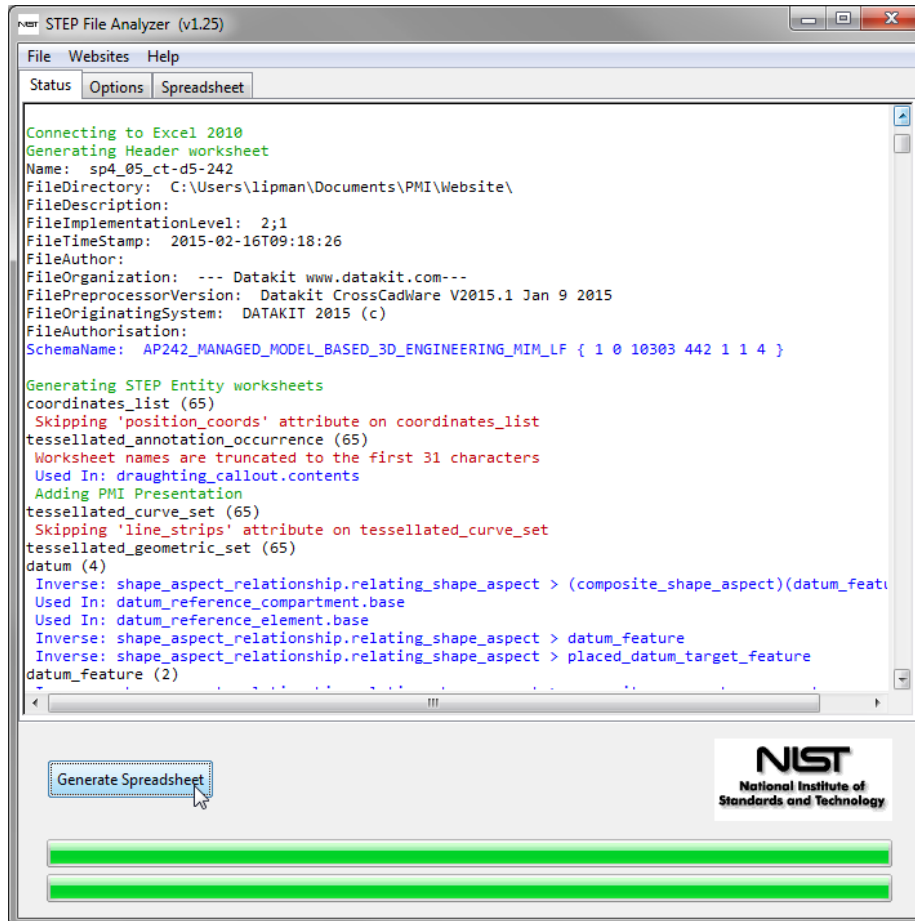
Rev D

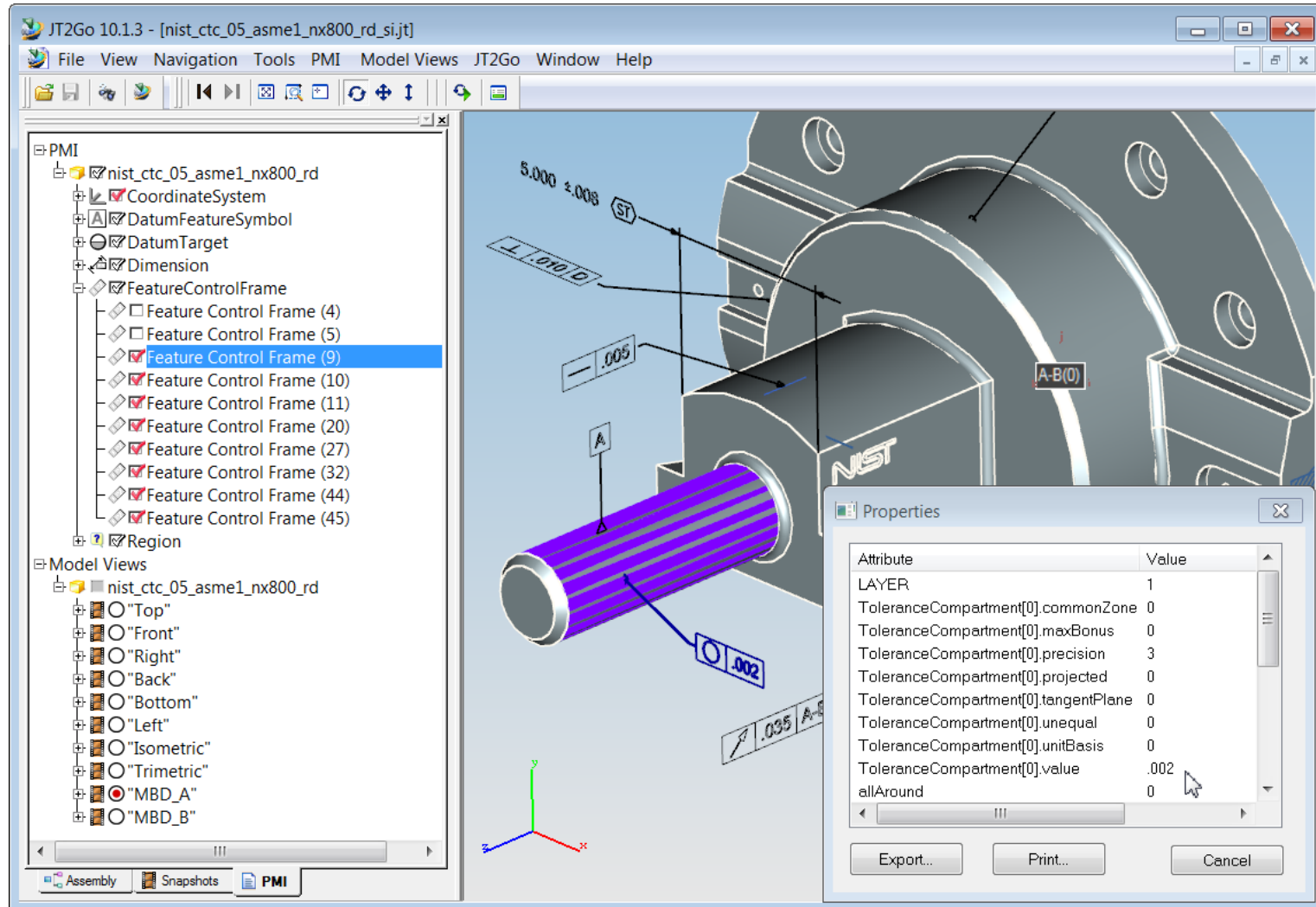
NIST STEP File Analyzer

Free download from:
<http://go.usa.gov/yccx>

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Journal article: http://www.nist.gov/manuscript-publication-search.cfm?pub_id=917105

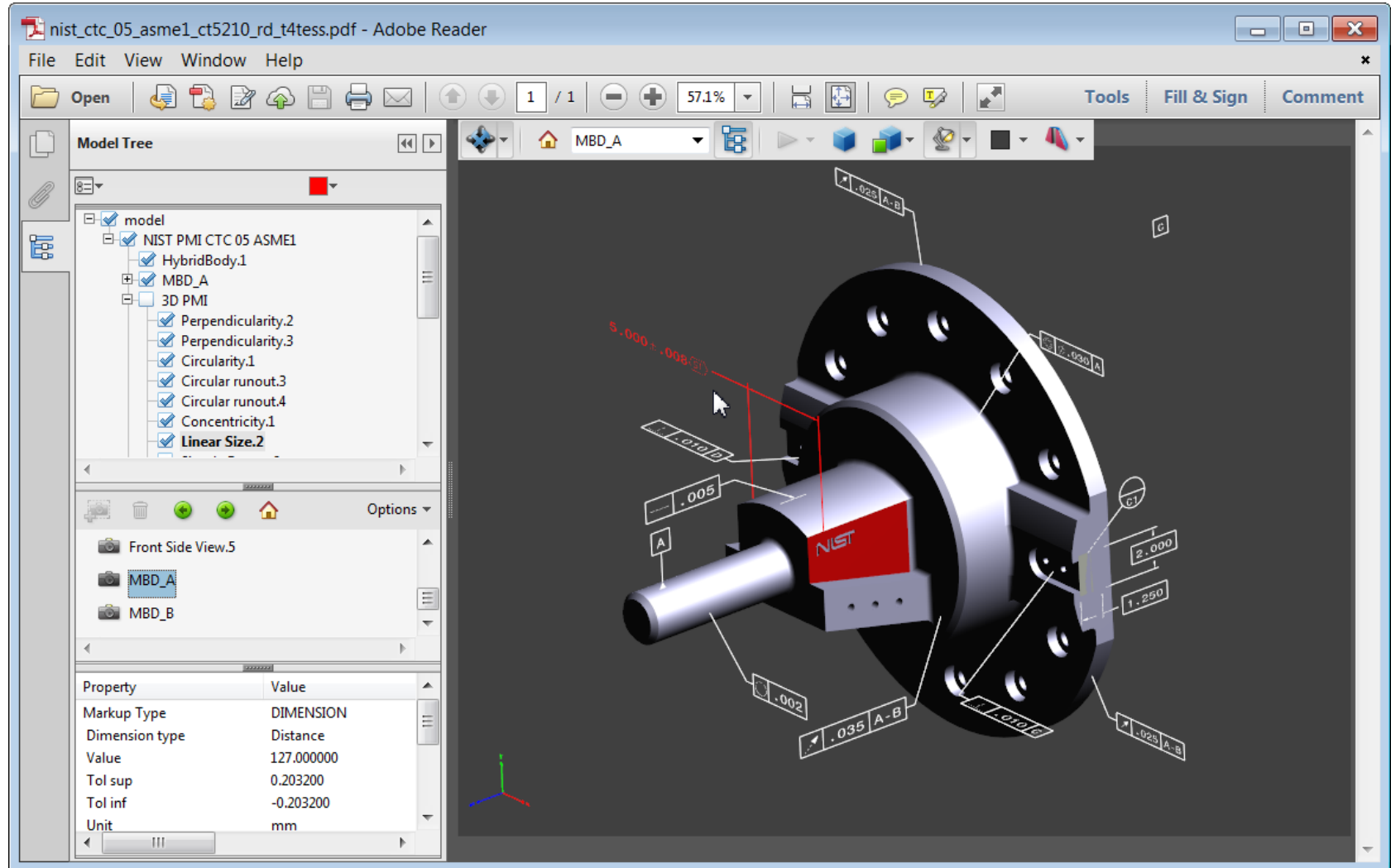




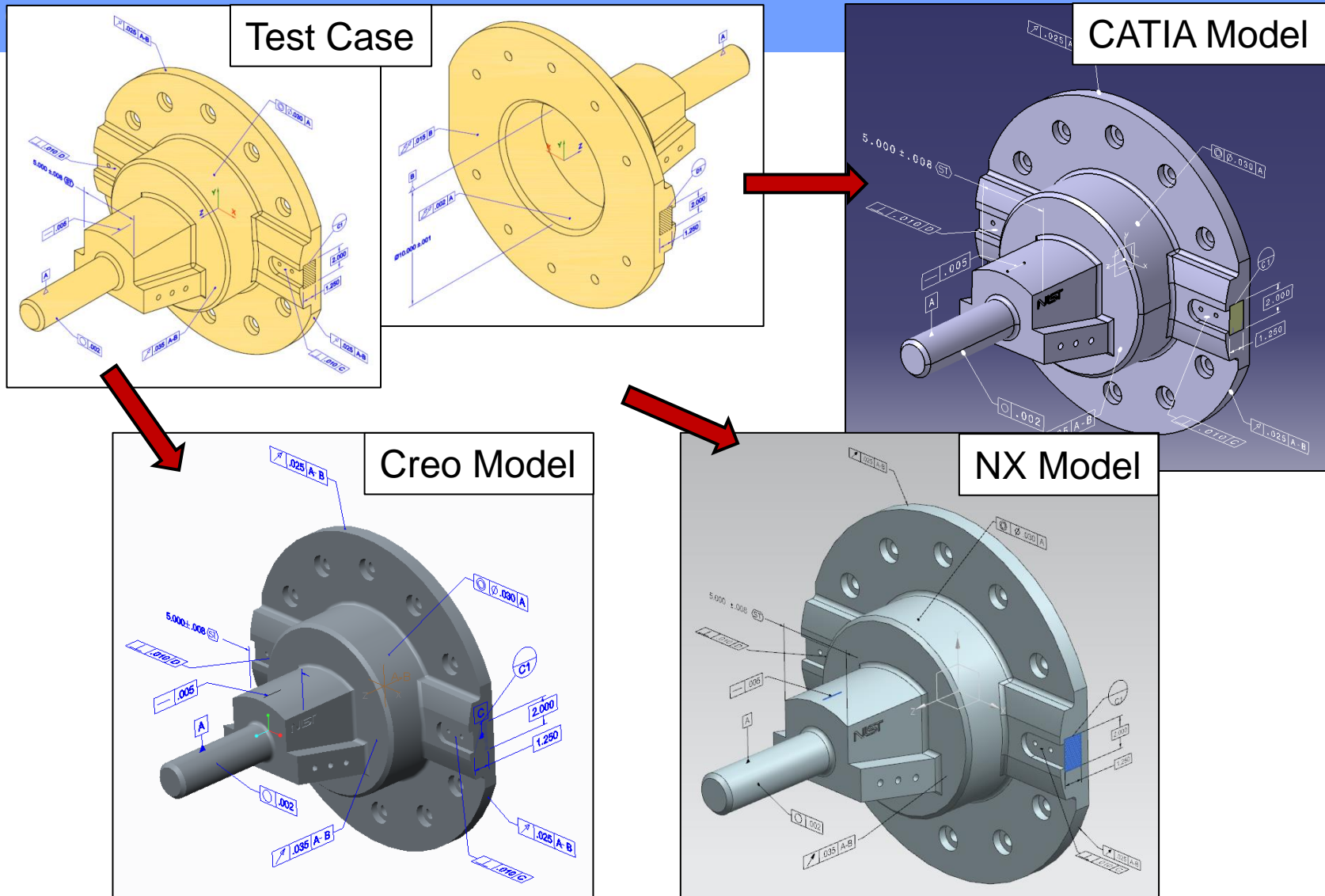
Adobe Reader

Free download from:
<https://get.adobe.com/reader>

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Selected Combined Test Case (CTC 05) and Models



Test Case and Test Model Selection Considerations

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- **Representative PMI elements**
 - Datums: datum feature symbols and datum target symbols
 - Dimensions: basic, bidirectional, statistical, diameter
 - Tolerances: multiple geometric types and datum reference frames
 - Coordinate system: compound datum reference frame
 - Supplemental Geometry: target area and direction curve
 - Views: View-specific annotation and supplemental geometry visibility
- **Representative translations**
 - 10 – 13 per native format (CATIA V5 R21, Creo 2.0, NX 8.0)
 - 11 – 12 per neutral format (STEP AP203/242, JT XT BREP, PDF/PRC)
 - 35 total translations
- **Representative vendor participation**
 - 3 PLM vendors
 - 8 third-party vendors

Validation Testing Methodology

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- **Each PMI element in a translated model is matched with the corresponding element in the corresponding native model.**
- **The representation and presentation data are compared between each pair of matched PMI elements.**
- **Each significant difference, that would impeded visual or automated consumption, is categorized as a presentation or representation validation issue, respectively.**
- **Each issue is grouped by PMI element type and impact (removed, changed, or added).**

Validation Issues

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Representation Issue

- Annotation removed
- Annotation changed
- Annotation added
- Coordinate system removed
- Coordinate system changed
- Coordinate system added
- Product geometry removed
- Product geometry changed
- Product geometry added
- Supplemental geometry removed
- Supplemental geometry changed
- Supplemental geometry added
- Model property removed
- Model property changed
- Model property added

Presentation Issue

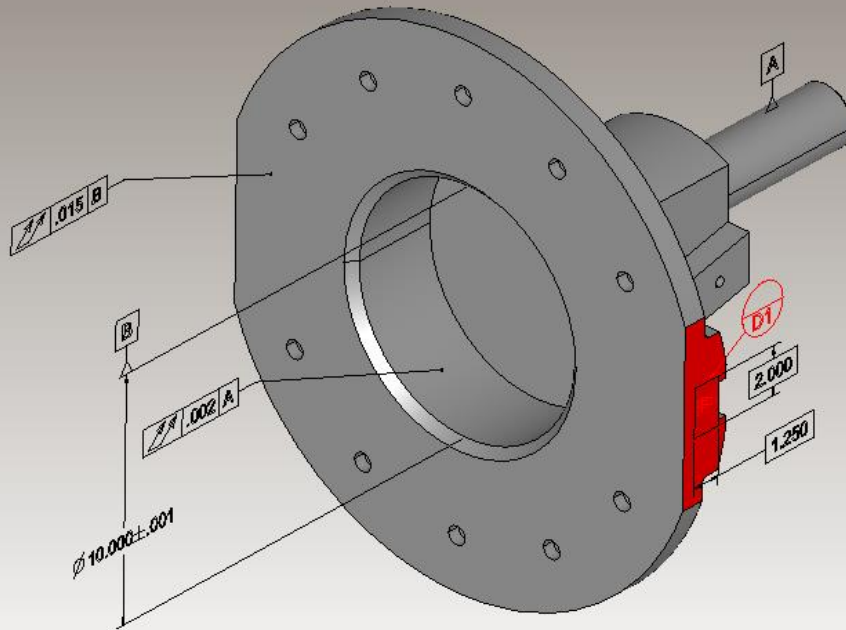
- Annotation removed
- Annotation changed
- Annotation added
- Coordinate system removed
- Coordinate system changed
- Coordinate system added
- Product geometry removed
- Product geometry changed
- Product geometry added
- Supplemental geometry removed
- Supplemental geometry changed
- Supplemental geometry added
- Saved view removed
- Saved view changed
- Saved view added

Validation Issues NOT Found in This Dataset

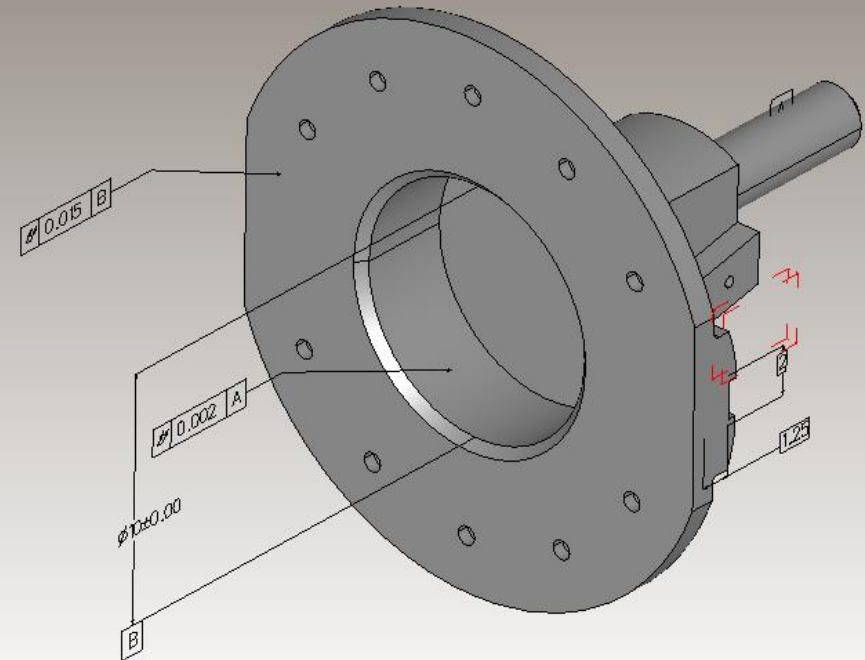
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- **Coordinate system representation**
 - Location or orientation changed
- **Coordinate system presentation**
 - Color or name changed
- **Product geometry representation**
 - Face removed or added
- **Product geometry presentation**
 - Face visibility or color changed
- **Supplemental geometry representation**
 - Surface/curve location or orientation changed
 - Point location changed
- **Supplemental geometry presentation**
 - Surface color changed
- **Model property representation**
 - Name or value changed

Native Model



Neutral Model



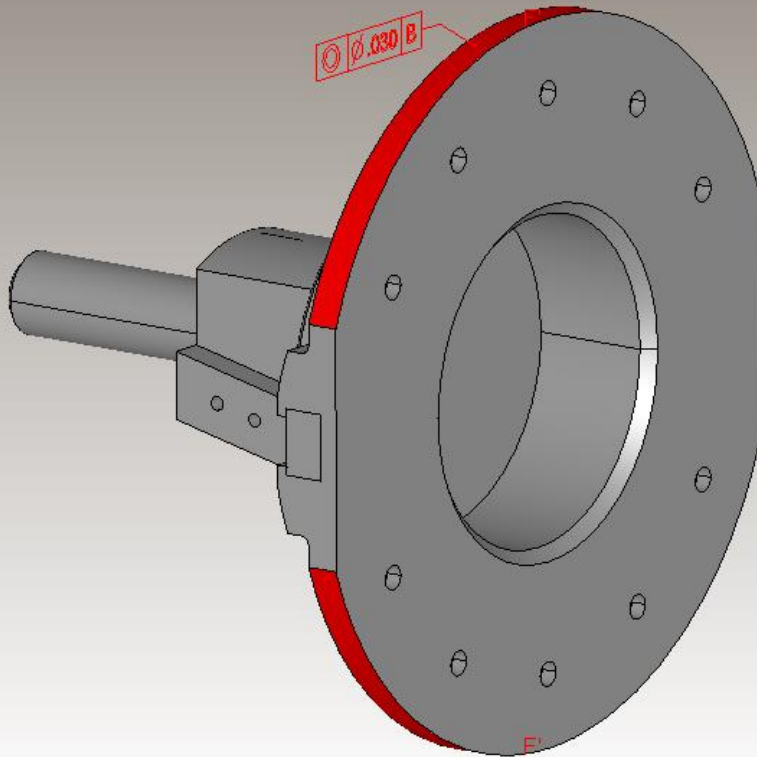
The definition of this datum target symbol was lost.

Annotation Face Association Changed

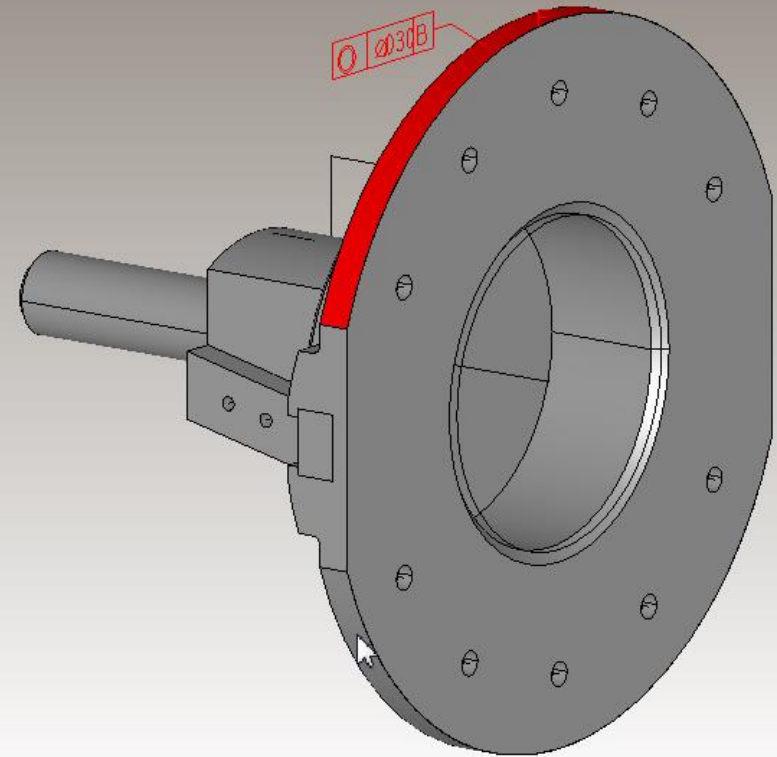
Representation Issue

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Native Model



Neutral Model



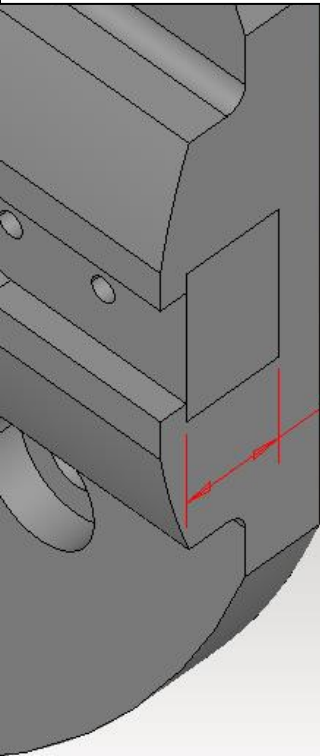
Part of the associativity of this feature control frame with its faces was lost.

Annotation Parameter Changed

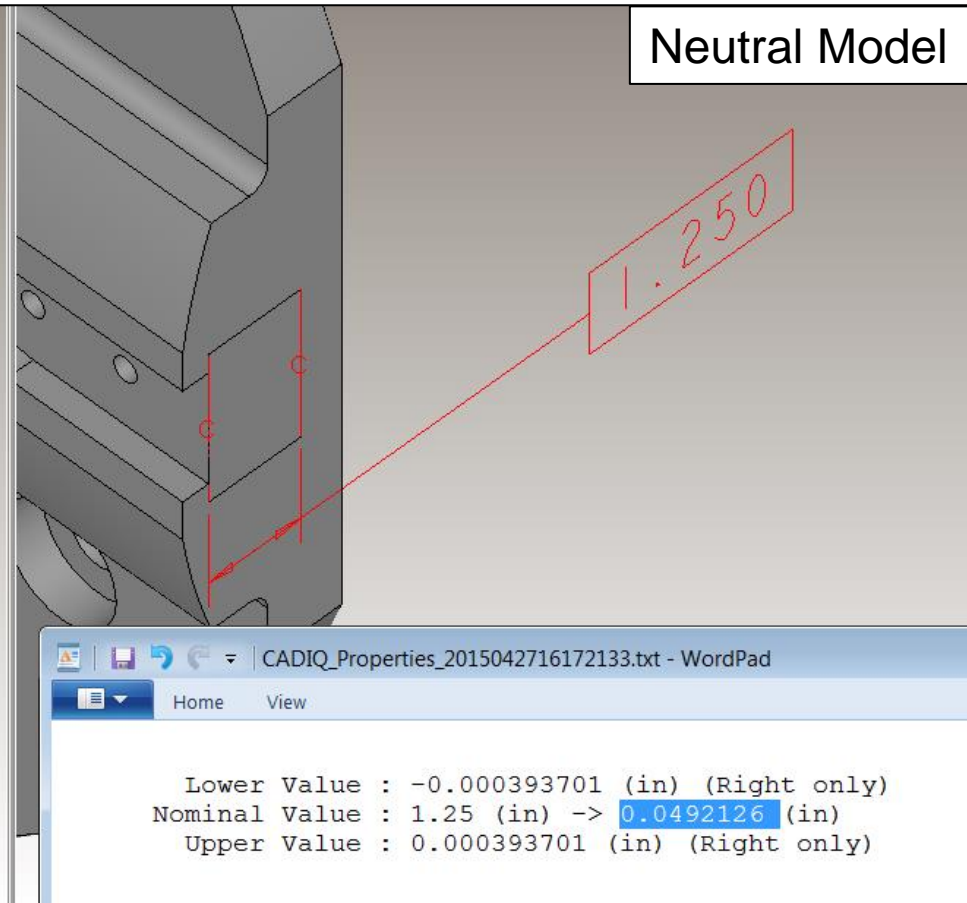
Representation Issue

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Native Model

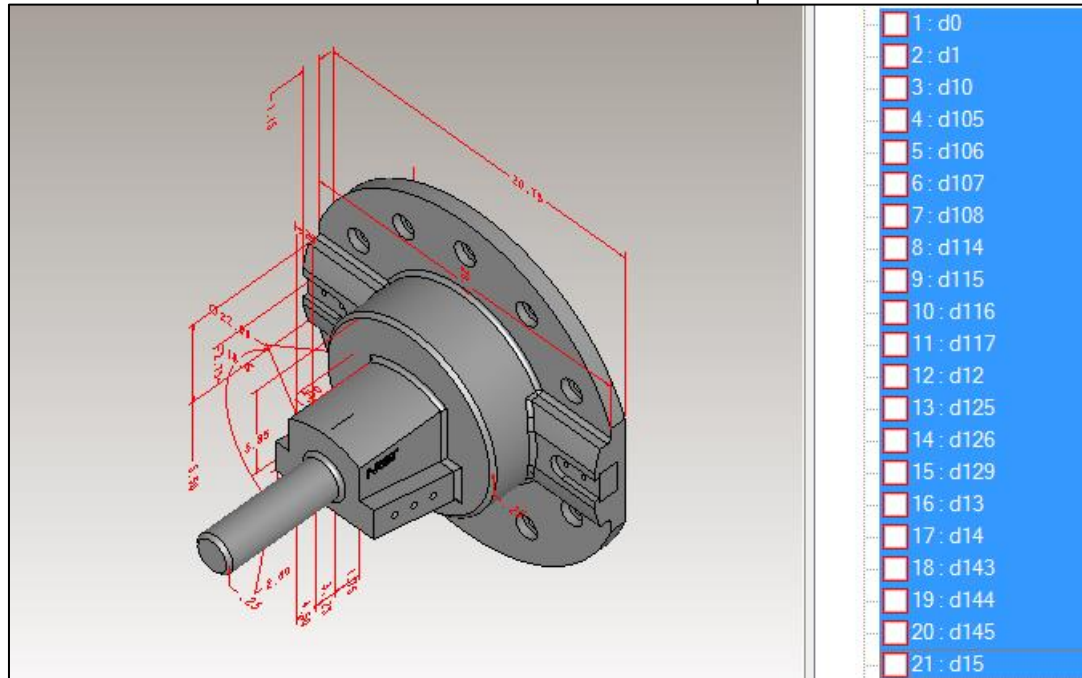


Neutral Model



While the displayed text for this dimension is correct in the neutral model, the semantic (internal) value has changed.

Neutral Model

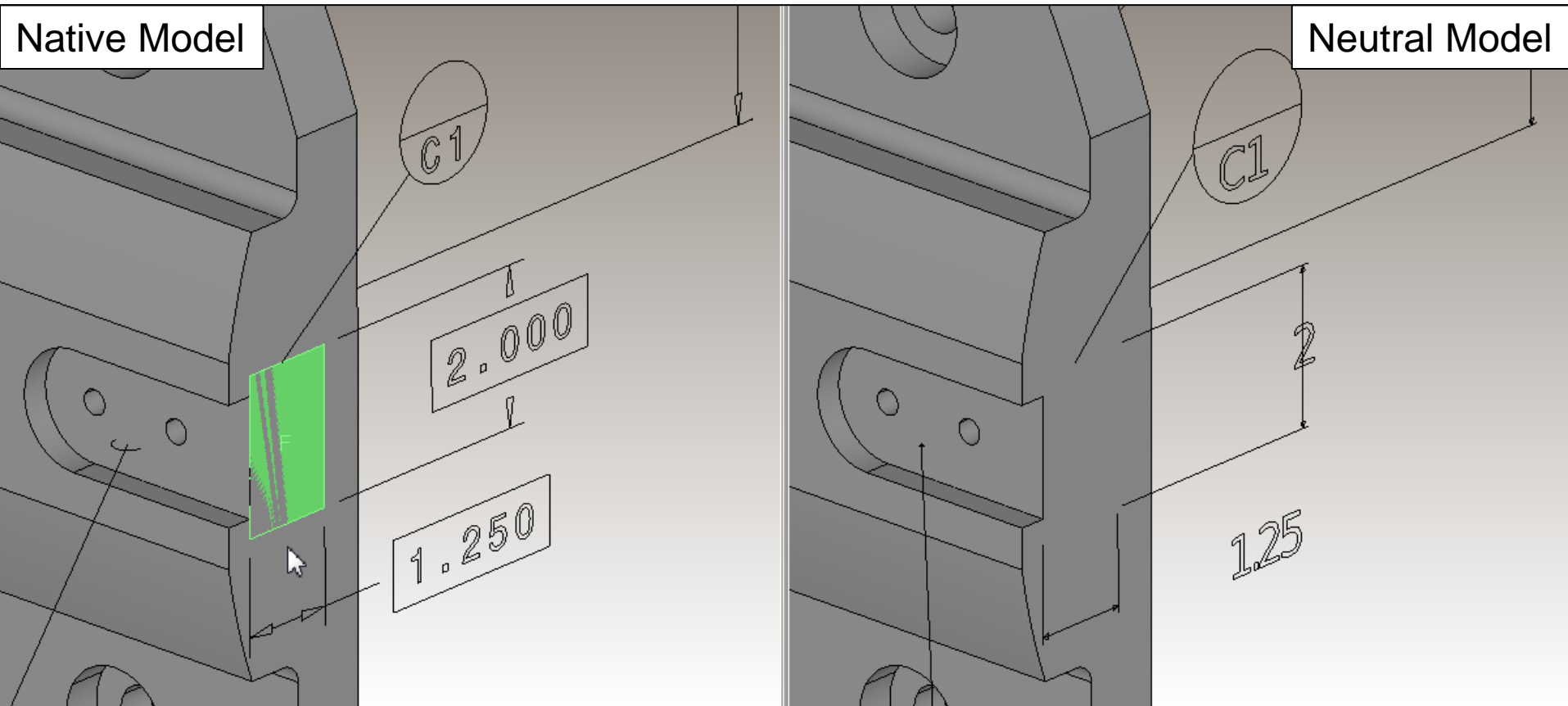


These “sketch” dimensions are defined in the native model but not visible in the MBD views. They were translated into the neutral model and made visible.

Surface Removed

Representation Issue

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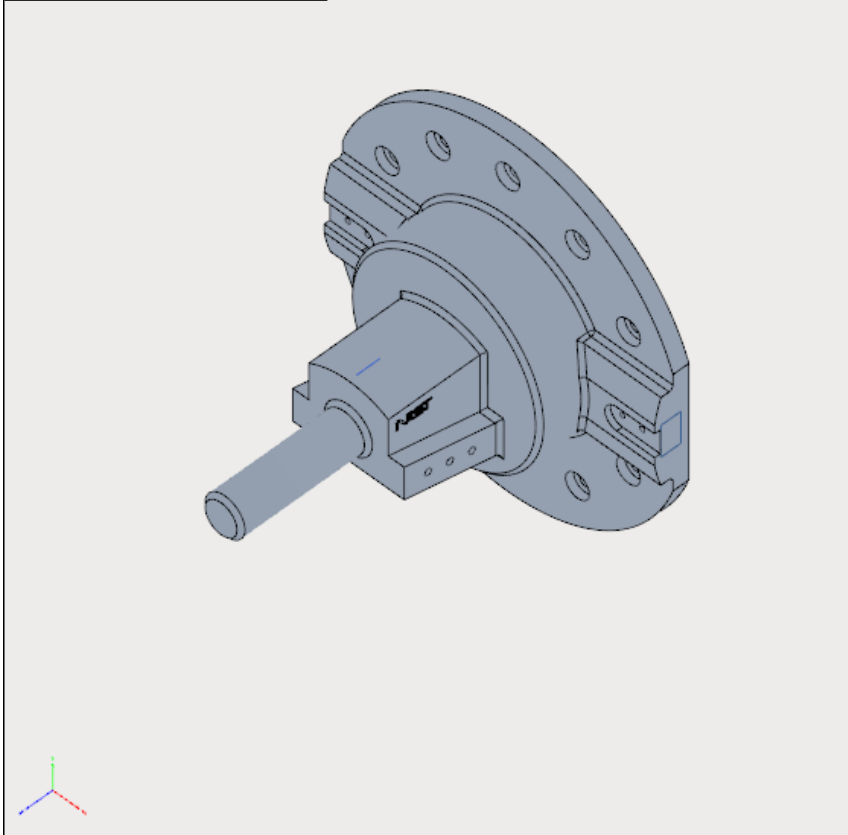
This target area is defined by a non-solid surface that was not translated into the neutral model.

Curve Added

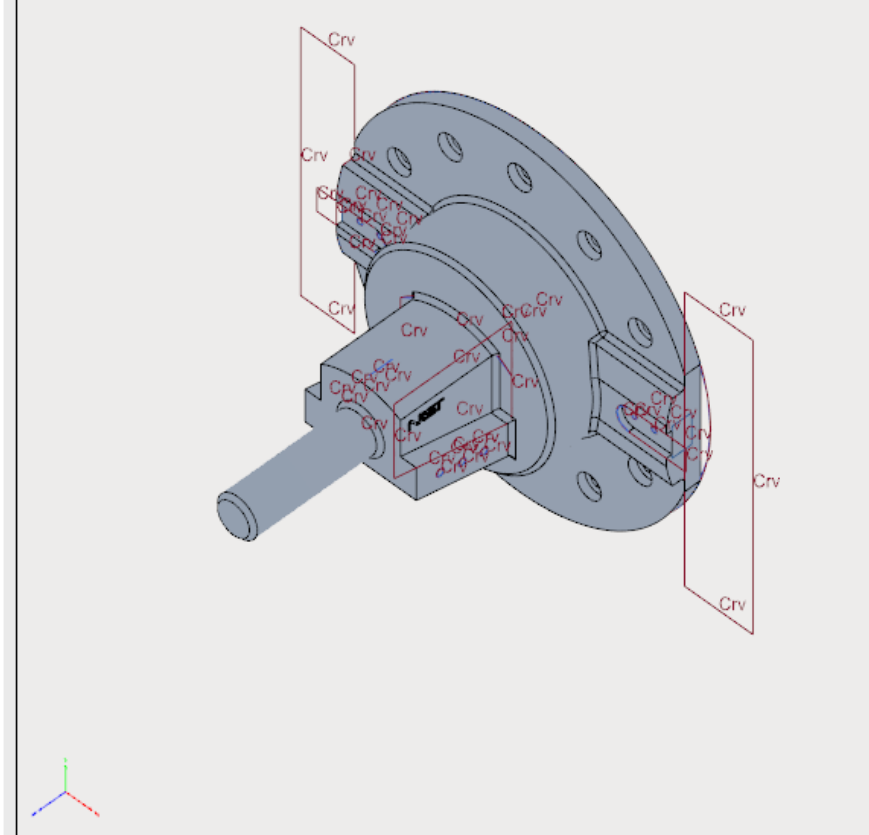
Representation Issue

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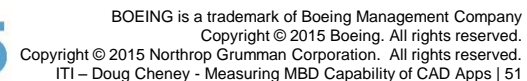
Native Model



Neutral Model

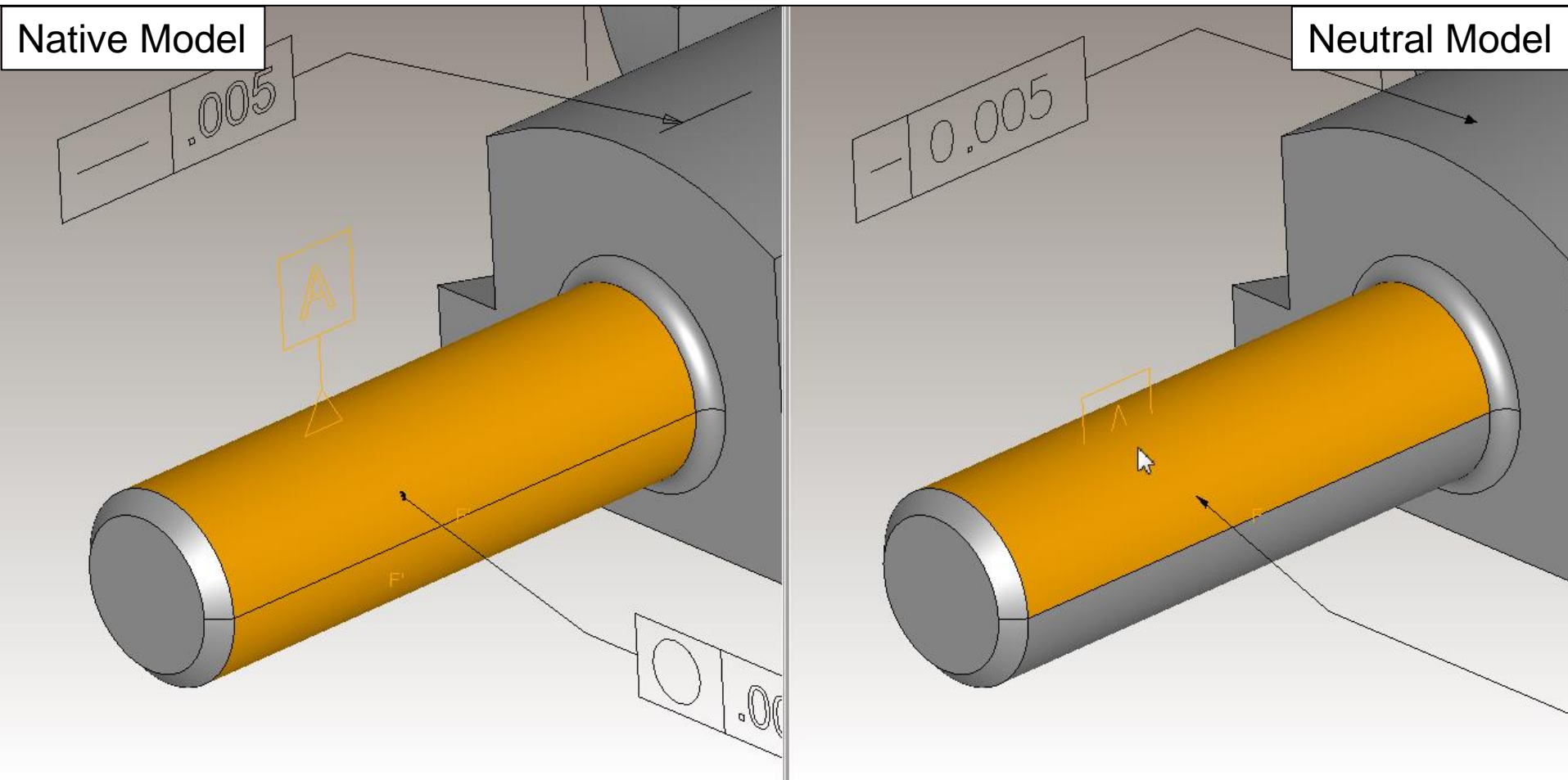


These “sketch” curves are defined in the native model but not visible in the MBD views. They were translated into the neutral model and made visible.



Annotation Location Changed

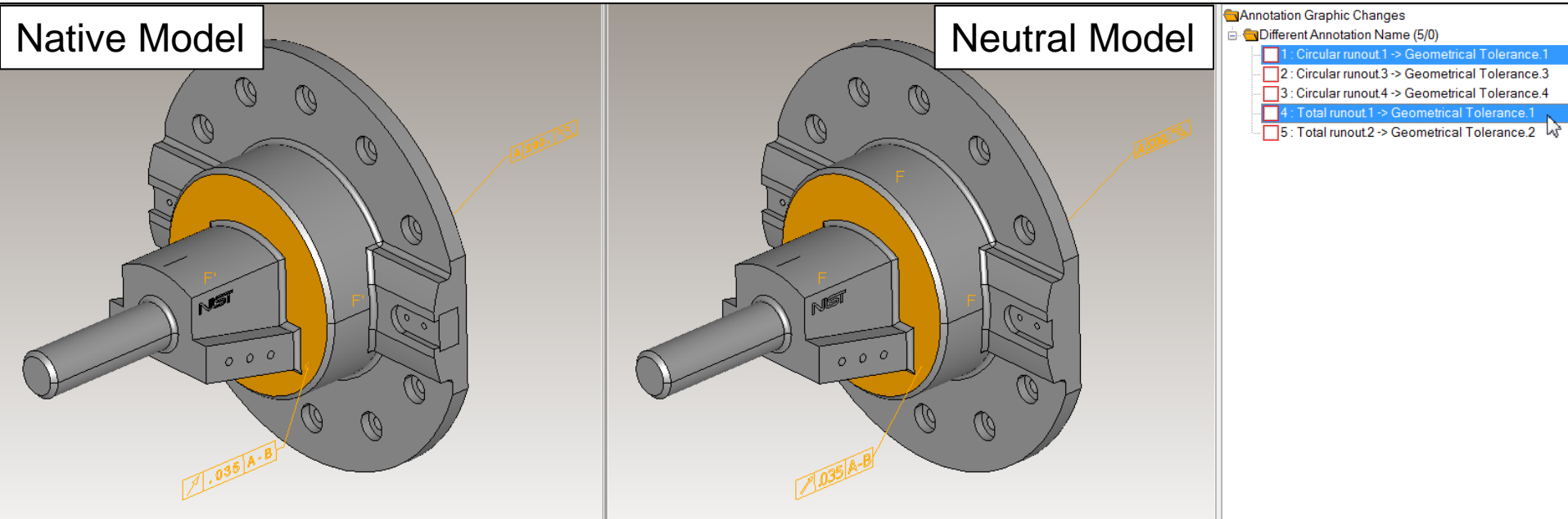
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This datum feature symbol was moved so that it is partially buried in the solid.

Annotation Name Changed

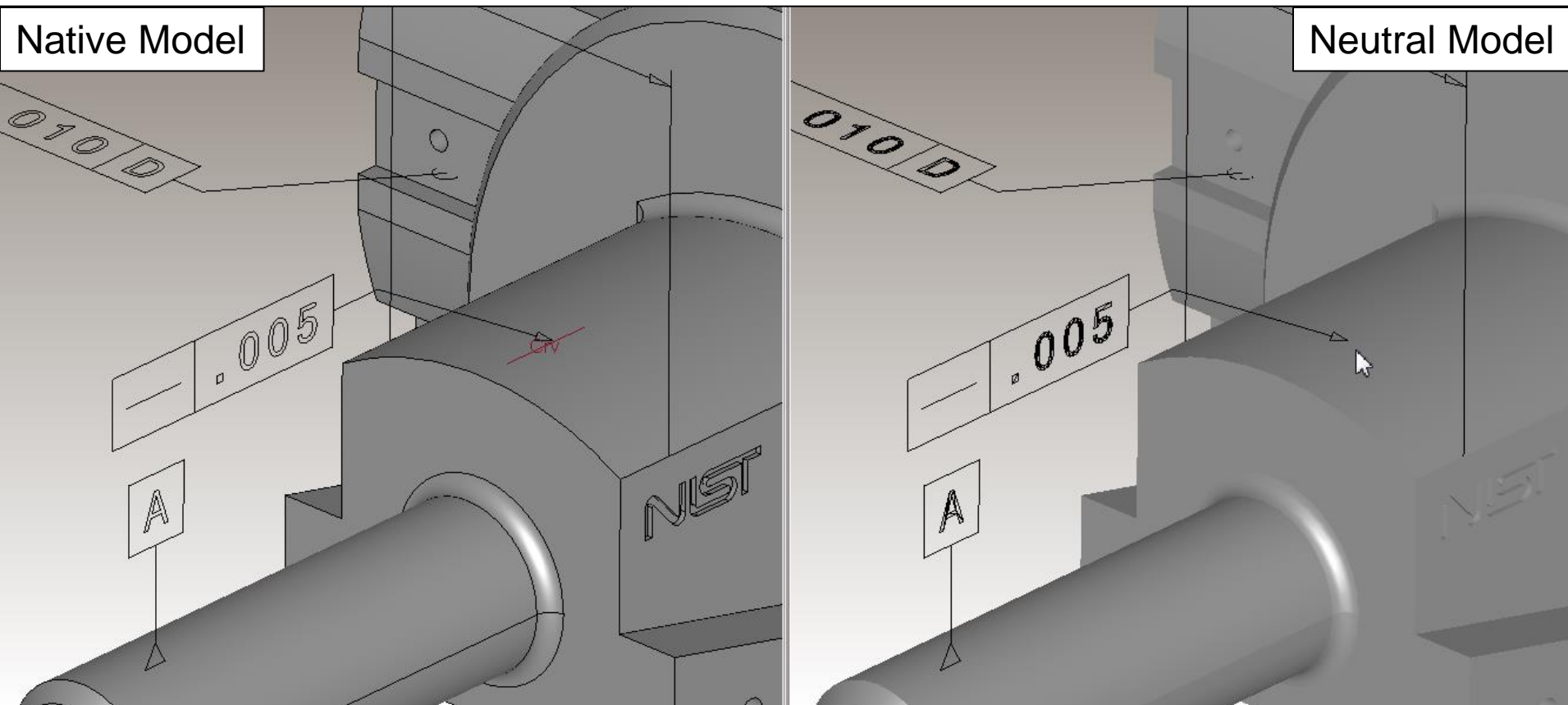
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The display names of five annotations were changed.
The two highlighted annotations were changed to the same name.

Curve Hidden

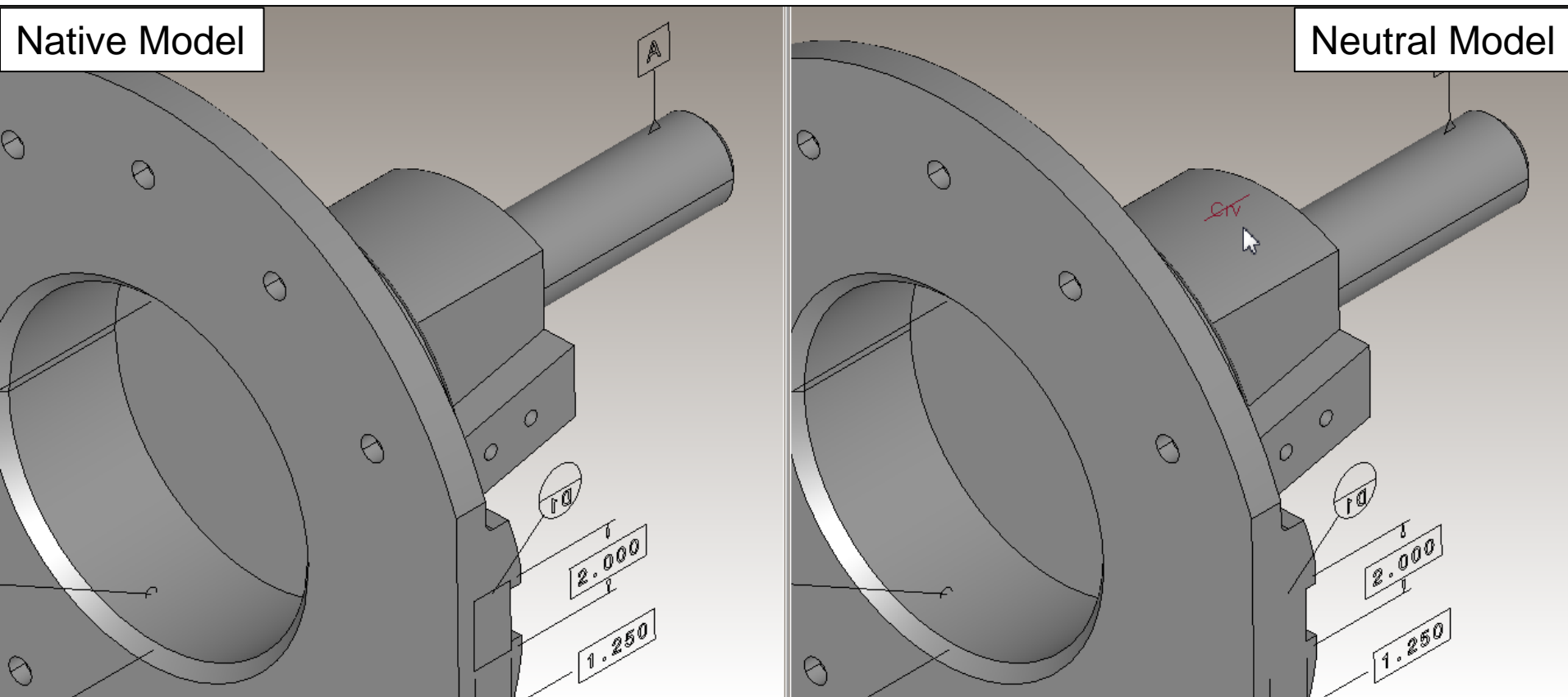
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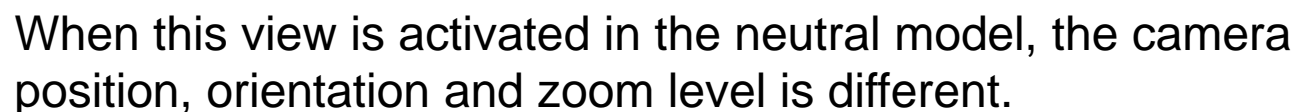
The represented line element for this straightness tolerance was translated but removed from this view.

Curve Shown

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This curve was added to this view in which it is not used.



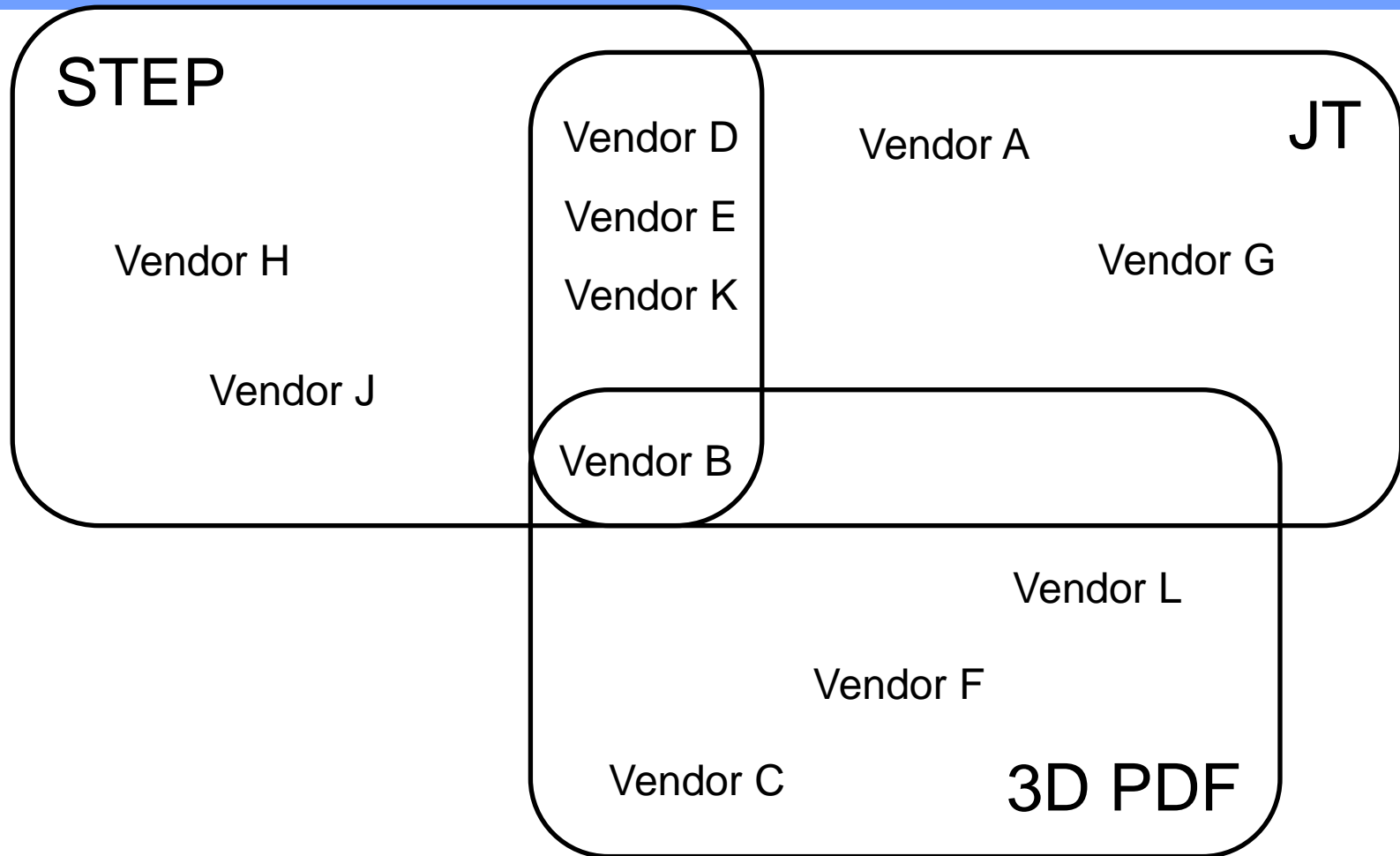
Negligible Annotation Differences (Ignored)

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- **Layout (if visible in view)**
- **Text font, size, spacing (if readable)**
- **Leader line routing (if not intersecting any text)**
- **Arrowhead style (if well-formed)**

Participating Translation Vendors

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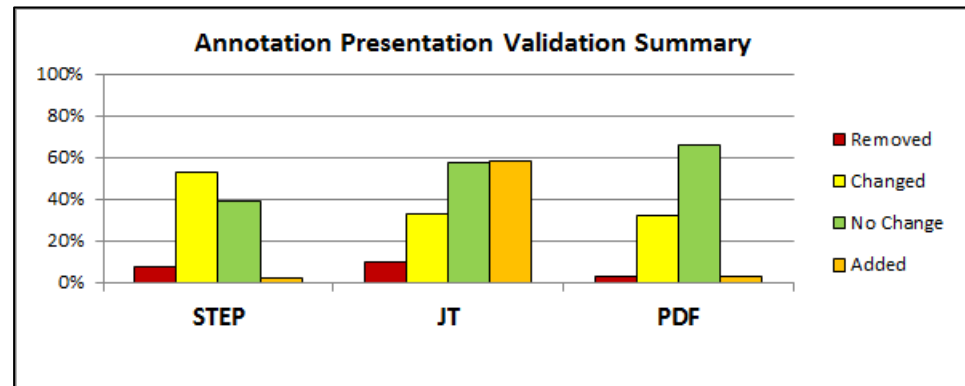
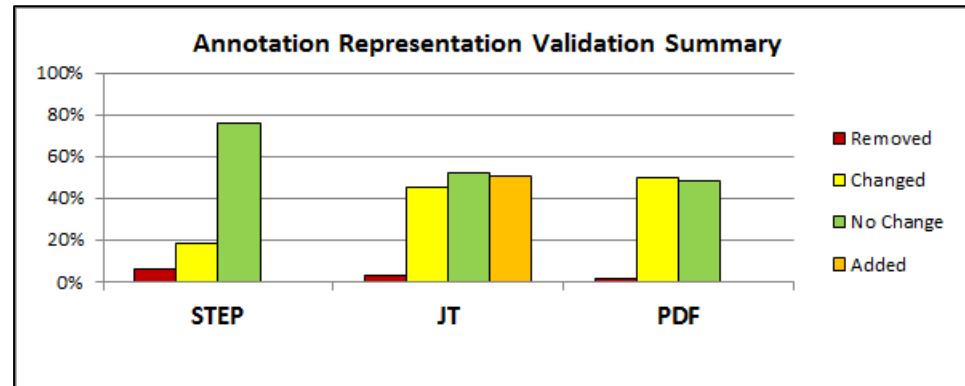


Important: The validation comparison statistics on the following slides are a comparison of translation software maturity rather than format capabilities.

Annotation Validation Summary by Category and Neutral Format

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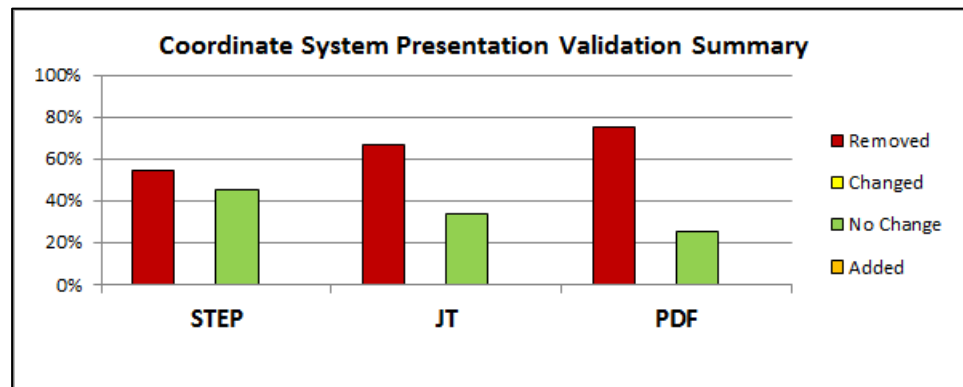
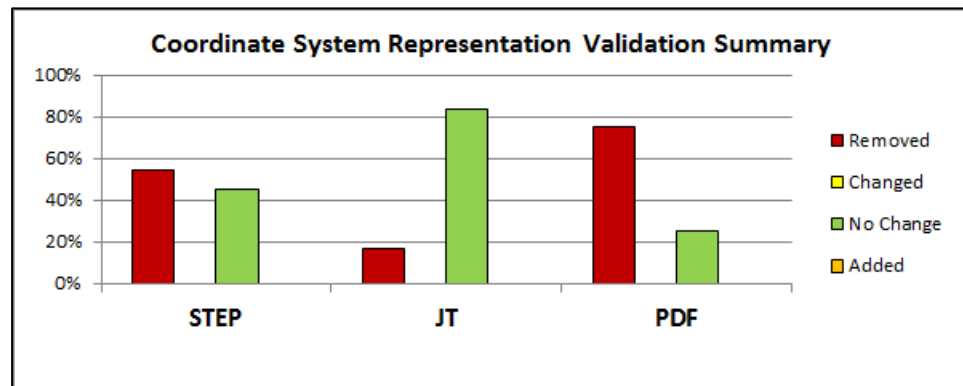
Validation Issue	Element Percentages		
	STEP	JT	PDF
Annotations			
Representation			
Removed	6%	3%	2%
Annotation removed	6%	3%	2%
Changed	18%	45%	50%
Annotation edge association changed	17%	6%	17%
Annotation face association changed	6%	13%	12%
Annotation parameter changed	18%	45%	50%
Added	0%	51%	0%
Annotation added	0%	51%	0%
Presentation			
Removed	8%	10%	3%
Annotation hidden	8%	10%	3%
Changed	53%	33%	32%
Annotation color changed	0%	0%	16%
Annotation lines changed	13%	6%	6%
Annotation location changed	1%	1%	0%
Annotation name changed	53%	33%	32%
Annotation orientation changed	0%	0%	1%
Annotation text changed	12%	17%	6%
Added	2%	58%	3%
Annotation shown	2%	58%	3%



Coordinate System Validation Summary by Category and Neutral Format

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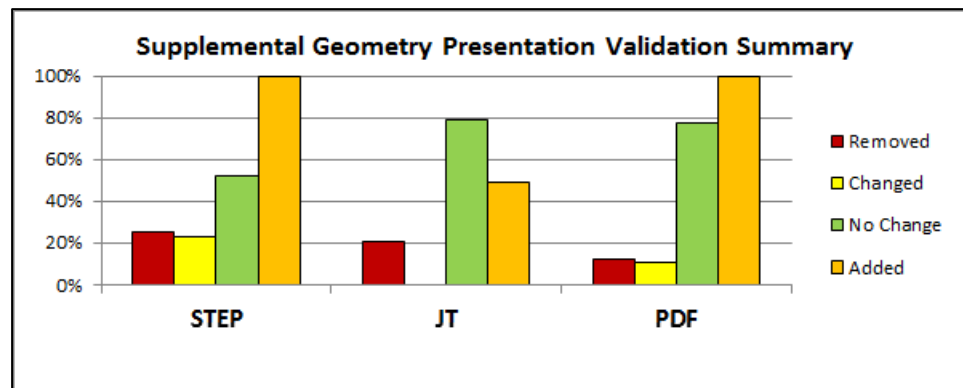
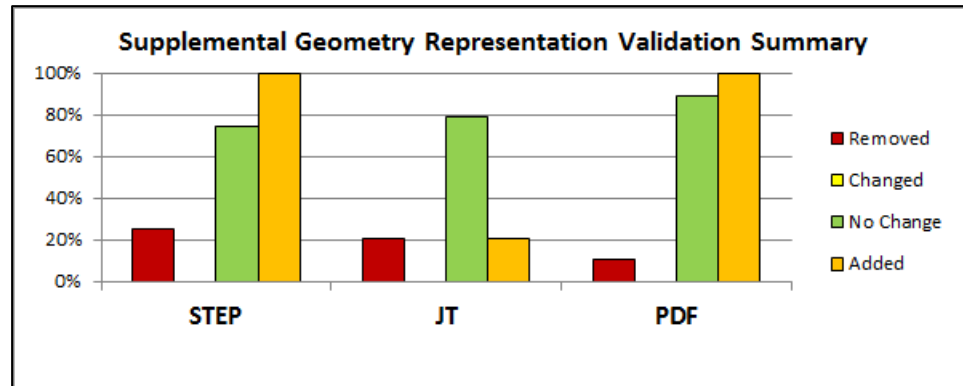
Validation Issue	Element Percentages		
	STEP	JT	PDF
Coordinate Systems Representation			
Removed	55%	17%	75%
Coordinate system removed	55%	17%	75%
Presentation			
Removed	55%	67%	75%
Coordinate system hidden	55%	67%	75%



Supplemental Geometry Validation Summary by Category and Neutral Format

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Validation Issue	Element Percentages		
	STEP	JT	PDF
Supplemental Geometry Representation			
Removed	25%	21%	11%
Curve removed	25%	21%	11%
Point removed	0%	3%	1%
Surface removed	5%	5%	7%
Added	100%	21%	100%
Curve added	100%	21%	100%
Point added	71%	0%	36%
Surface added	8%	0%	0%
Supplemental Geometry Presentation			
Removed	25%	21%	12%
Curve hidden	25%	21%	12%
Point hidden	0%	3%	1%
Surface hidden	5%	5%	7%
Changed	23%	0%	11%
Curve color changed	23%	0%	11%
Added	100%	49%	100%
Curve shown	100%	49%	100%
Point shown	71%	0%	36%
Surface shown	9%	10%	2%



Next Steps – *and an invitation*

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- **Update verification results using new CAD releases**
- **Update validation results using new translator releases**
- **Validate FTC translations**
- **Extend test cases and test models**
 - Newer ASME GD&T standards (Y14.5-2009, Y14.41-2012)
 - ISO GD&T standards (1101:2004, 16792:2006, ...)
 - Section views
 - Surface finish and weld annotations
 - Composites, piping/tubing, electrical harness
 - Assembly PMI
- **Create test models for other CAD systems**
 - Inventor, Solid Edge

Invitation:

*Please contact
your CAD system &
translation vendors,
and your industry
consortia leaders,
to express support
for continuing this
program.*