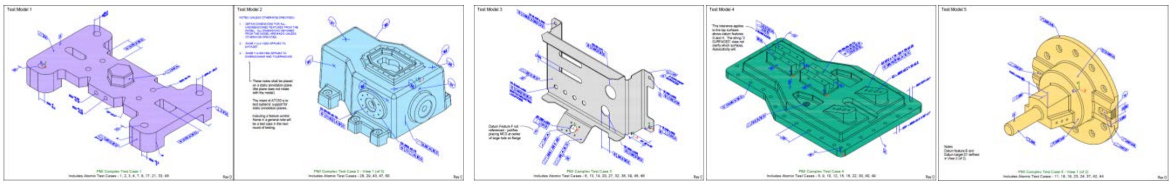
NIST GCR 15-997

Measuring the PMI Modeling Capability in CAD Systems: Report 1 - Combined Test Case Verification



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Measuring the PMI Modeling Capability in CAD Systems: Report 1 - Combined Test Case Verification

Prepared for
U.S. Department of Commerce
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U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Under Secretary of Commerce for Standards and Technology and Director

Preface

The National Institute of Standards and Technology (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. The test system has three main components: test cases, test CAD models, and verification and validation test results. The verification and validation results measure PMI implementation capabilities in CAD software and derivative STEP, JT, and 3D PDF files.

All of the test cases, test models, test results, and other presentations are available from the project website: http://www.nist.gov/el/msid/infotest/mbe-pmi-validation.cfm

This report is the first of three reports about the test system. The reports can be read independently of each other.

- Measuring the PMI Modeling Capability in CAD Systems: Report 1 - Combined Test Case Verification
- Measuring the PMI Modeling Capability in CAD Systems: Report 2 - Test Case Validation
- Measuring the PMI Modeling Capability in CAD Systems: Report 3 - Fully-Toleranced Test Case Verification

Disclaimers

The reports were prepared for the Engineering Laboratory of the National Institute of Standards and Technology under the following contracts:

- SB1341-12-SE-0860, RECON Services Inc., "PMI Conformance Testing Models"
- SB1341-12-SE-0853, International TechneGroup Inc., "PMI and Composite Information Validation and Conformance Testing"
- SB1341-14-SE-0061, International TechneGroup Inc., "PMI Test Cases and Models, Validation and Conformance Testing"

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Any mention of commercial products is for information purposes only; it does not imply recommendation or endorsement by NIST. The test system can be used without any restrictions. Its use in other software or hardware products does not imply a recommendation or endorsement by NIST of those products.

Project Participants

- International TechneGroup Inc. (ITI) - test model creation, expert review, verification, validation, and documentation
- Advanced Dimensional Management LLC - test case definition and expert review
- RECON Services Inc., Neilsoft Ltd. - test model creation and expert review
- Department of Energy Kansas City Plant (operated by Honeywell FM&T), RECON Services Inc., Sigmetrix - expert review

Cover image: Combined test cases

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1 Introduction

A methodology for measuring the product and manufacturing information (PMI) modeling capability of computer-aided design (CAD) systems has been developed to measure technology readiness and to track progress as functionality gaps are closed. A measurement methodology will enhance the ability of discrete-part manufacturing companies to implement a model-based enterprise (MBE) [1-5]. The use of a clear capability assessment will accelerate MBE technology development by CAD software vendors. This can increase the business opportunities for both manufacturing companies and technology providers.

Common practice in discrete-part manufacturing companies is to use CAD systems to create three-dimensional (3D) models that precisely define the shape of their products. The companies derive two-dimensional (2D) drawings from the 3D model that detail the product's dimensions, tolerances, and other manufacturing information. Manufacturing organizations have typically considered the drawings to be the master product definition for all downstream processes such as simulation, manufacturing, and inspection. Often a 3D model is recreated from the drawing in one or more downstream processes, especially when performed by external suppliers. In some cases, the original 3D model is released with the drawing as a reference document [6].

As the drawing goes through several engineering changes, the 3D model may become outdated because it is not the master design document. Therefore, model recreation from the drawing tends to increase as a product matures. Downstream consumers of the drawing visually interpret the dimensions, tolerances, and other manufacturing information and manually reenter this information into downstream systems. Manually reentering information is a potentially error-prone process. This human interpretation is repeated for each engineering change.

Global business requirements are driving companies to produce better and cheaper products in less time to market. Management initiatives target the reduction of risk due to variation and the elimination of all non-value-added tasks throughout the engineering, manufacturing, and sustainment phases of a product's lifecycle. A leading process improvement initiative today is the concept of MBE [7].

1.1 Model-Based Enterprise and Model-Based Definition

A model-based enterprise (MBE) builds on the foundation that all product data may be integrated into a single model-based definition (MBD). This eliminates the need for 2D drawing generation, the recreation of 3D models, and/or the visual interpretation of drawing data in downstream processes. It improves product quality by eliminating drawing-to-model inconsistencies, unintentional model changes during recreation, and drawing interpretation errors. It decreases overall time to market by enabling direct reuse of the digital product model in downstream software systems.

A key component of an MBD is the integration of all the product and manufacturing information (PMI) into the 3D model. Dimensions, tolerances, notes, and other data previously found on a drawing are displayed in the model with direct links to the affected portion of the model's shape definition or 3D geometry. The data is grouped into multiple saved views to aid visual consumption. More importantly, the visual data is linked to an internal representation that is well defined and structured for automated consumption in downstream software systems. Derivative models, such as STEP (ISO 10303 –known informally as the STandard for Exchange of Product model data) [8-10], JT [11-13] and 3D PDF [14-16] files, are created as needed for downstream consumers who do not have direct access to the CAD system in which the native MBD model is defined.

1.2 MBD Verification and Validation

In a drawing-based product lifecycle, the drawing is manually checked by a person before release and then visually interpreted by a person during downstream reuse. This results in processes that tolerate low-level variation in the digital data while being fairly controlled. In a model-based process, the checking task is often eliminated on the assumption that a precise native model should be directly reusable in downstream systems without error. This results in processes that are less tolerant of digital data variation while being less controlled. However, if a company is going to rely on an MBD model throughout its product's lifecycle, the model must be reliable. Therefore, quality checking of the geometry and PMI in the master model, and their equivalent entities in all derivatives, is critical before release to downstream processes.

Various automotive, aerospace, and defense industry groups have identified precise geometry and PMI quality criteria for native MBD models and their derivatives. These include:

- Strategic Automotive Special Interest Group (SASIG) Product Data Quality (PDQ) team [17]
- PDES, Inc. [18] and ProSTEP iViP [19] collaboration for Long-Term Archival (LOTAR) [20]
- Department of Defense's MBE team [1]

Each group has recently documented these requirements in international, regional, and domestic standards such as:

- Managed Model-based 3D Engineering - STEP ISO 10303-242 [21, 22]
- CAD mechanical 3D Explicit geometry information - EN9300-110 [23]
- DoD Standard Practice: Technical Data Packages - MIL-STD-31000A [24]

These groups generally agree that the process of quality checking a native CAD model should be called verification. This process verifies that the product definition data is complete, consistent, and conformant to relevant standards. They recommend that the process of determining whether the data in a derivative model is equivalent to the native model should be called validation. This process validates that all data has been translated with any digital variation within acceptable limits specified by the anticipated downstream processes.

Due to the complexity of MBD data, it is unrealistic to implement verification or validation using an interactive, manual process. Several CAD applications have been developed to automate verification and validation using the criteria referenced above. While these applications make MBD quality control feasible, they impose an important requirement on the CAD modeling systems: that all MBD data, including 3D geometry and PMI, must be accessible through an application programming interface (API) to third-party developers.

1.3 PMI Representation and Presentation

An MBD must contain sufficient PMI representation so that automated systems, such as machining and inspection, can reuse the information efficiently and correctly in all downstream processes. PMI representation (also known as semantic PMI) includes all information necessary to represent GD&T without any graphical presentation elements. The PMI presentation should also be clearly presented for visual (human) consumers so that they understand and trust the model-based definition. PMI presentation (also known as graphical PMI) consists of geometric elements such as lines and arcs preserving the exact appearance (color, shape, positioning) of the GD&T annotations. The internal PMI representation should be structured and defined so each element is clear, complete, and consistent. The PMI presentation should be organized into saved views with annotations that support cross-highlighting of affected geometry.

These two aspects of PMI, representation and presentation, are best understood by considering how their key characteristics are applied to the various components of an MBD. Table 1 and Table 2 list the characteristics of PMI representation and presentation, respectively. The following is an explanation how they apply to the product geometry, coordinate systems, supplemental geometry, annotations, and saved views in an MBD.

Table 1: Characteristics of PMI representation

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

Table 2: Characteristics of PMI presentation

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

MBD product geometry is structured to differentiate the geometric entities that define the 3D shape of the product from other entities used as reference, context, or supplemental geometry for annotations. For most discrete-part product models, a solid (closed volume) or shell (open surface) definition provides the highest level of definition for downstream processes. The parametric definition of the model is complete, correct, and useful for revisioning. The explicit definition of topology and geometry is free of defects that impede downstream reuse. The meta-data properties associated with the product model capture basic product management data, such as ownership and lifecycle state. The visibility status and display color of the product geometry are appropriate for visual interpretation by downstream users.

MBD annotations have a specified type (dimension, feature control frame, note, etc.) and named parameters (nominal value, tolerance, material modifier, etc.) that facilitate automated interpretation downstream. An annotation's associated geometry includes all affected surfaces in the product geometry and any supplemental geometry. It does not include any extraneous geometry. This facilitates both automated consumption and visual interpretation, also known as cross-highlighting. The visibility, layout, location, and orientation of the annotation in saved views, along with its color, display name, lines, and text, are appropriate for visual interpretation by downstream users.

MBD coordinate systems have explicit named associations with the feature control frames that rely on the datum reference frames they represent. Each coordinate system's location and orientation accurately represent the datum reference frame. The coordinate system's visibility in each saved view corresponds to the visibility of its associated annotations. Its color, name, and display text are appropriate for visual interpretation by downstream users.

Supplemental geometry is geometric elements that do not belong to the shape of a part. The geometric elements are used to create other shapes or contain information about part features such as hole centerlines. MBD supplemental geometry entities have the correct form or structure for the annotations that references them. For example, the limited area for a datum target defines the portion of the underlying solid face or surface that is inside versus outside. The location, orientation, and size of each supplemental geometry entity complete the conceptual definition of its associated annotations. Its visibility in saved views corresponds to the visibility of its associated annotations. Supplemental geometry color is appropriate for visual interpretation by downstream users.

A saved view facilitates the presentation of the model and associated PMI by defining a subset of the PMI and an orientation from which it is viewed. MBD saved views are structured to contain a related set of annotations, with their associated supplemental geometry and coordinate systems, along with the appropriate product geometry. Each saved view may contain the complete geometric definition of the product or a portion defined by a cross section. The contents of a saved view are displayed within a frustum, or pyramid of vision, that is intuitive for visual interpretation by downstream users.

1.4 PMI Verification and Validation

The process of querying PMI data in an MBD model for verification is straightforward as long as the CAD API provides sufficient access to the data. First, the type and properties of each annotation entity are retrieved and compared with those specified in the test case documentation. Second, any relationships between the annotation and other annotations or geometry entities are queried and compared with the specification. Since an MBD model may contain multiple annotations with similar types and properties, it may be necessary also to query the graphic presentation data in order to match reliably each annotation with its specification and to confirm its relationships are correct.

The process of comparing PMI constructs between MBD models in dissimilar CAD systems for equivalence validation is more complex. The primary challenge is to correctly match corresponding annotation entities before comparing their characteristics. Because all of the presentation characteristics can vary significantly without changing the meaning (representation), these cannot be reliably used for matching purposes. The test model images in Figures 8-11 illustrate the typical variation between the CAD systems used for this assessment. Reliable annotation matching requires that all product and supplemental geometry entities be matched. Then, the subset of annotations entities associated with each set of matching geometry entities are matched and compared. Annotations that have been added, removed, or had their geometry associations changed will remain unmatched.

Some PMI constructs make automation of the above verification and validation processes difficult (see section 3.4). The various CAD systems use different modeling methodologies for these constructs that are each considered valid within the ASME standards. Until the CAD systems converge toward common methodologies, or the standards are modified to require this, the MBD verification and validation technologies must implement advanced reasoning and exception handling to accommodate this allowable variation in PMI definition.

2 Methodology for PMI Modeling Capability Assessment

The PMI modeling capability of the CAD systems commonly used by discrete-part manufacturing companies to support MBE was assessed using a formal methodology [25], shown in Figure 1, involving:

1. Test case definition and expert review
2. Test CAD model creation based on the test case definitions
3. Verification of the CAD models against the test case definitions
4. Generation of derivative STEP, JT, and 3D PDF files by the Implementor Forums [12, 14, 26]
5. Validation of the derivative files against the CAD models and test case definitions

This report is concerned with steps 1-3 of the PMI modeling capability assessment. The validation of derivative files for one of the test cases is documented in second report of this series [27]. The verification of other test cases is documented in the third report of this series [28].

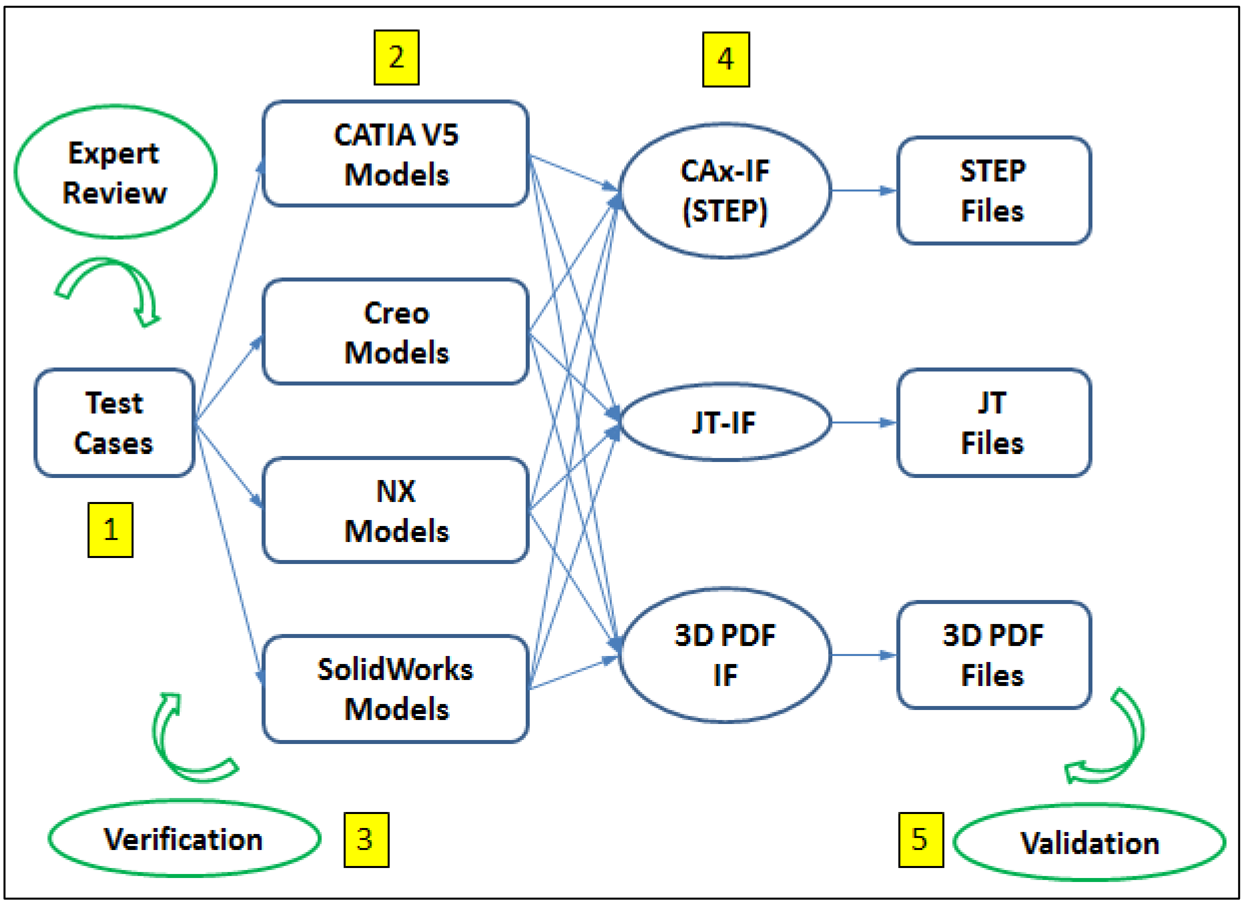

Figure 1: Methodology for PMI modeling capability assessment

2.1 Test Case Definition

For test case generation, an industry expert in geometric dimensioning and tolerancing (GD&T) defined representative PMI constructs allowed by the American Society of Mechanical Engineers (ASME) standards for 2D drawings Y14.5-1994 [29] and 3D models Y14.41-2003 [30]. (Newer versions of both standards are available.) A PMI construct is a group of annotation entities which define an elemental concept, for example: defining a datum feature with a datum feature symbol (one annotation) or controlling the variation of a hole with a size dimension, a feature control frame, and its associated datum features (3 to 5 annotations). Figure 2 shows the presentation of a typical GD&T annotation [31].

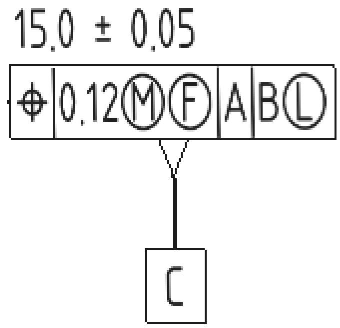

Figure 2: Typical presentation of a GD&T annotation

The constructs defined for this assessment are listed in Appendix A. The constructs were applied to five discrete-part geometry models, with approximately ten PMI constructs in each model.

Each combined test case (CTC) is documented with a set of drawings and explanatory text, as shown in Figures 3-7. Drawings of other views of each test case are in Appendix B.

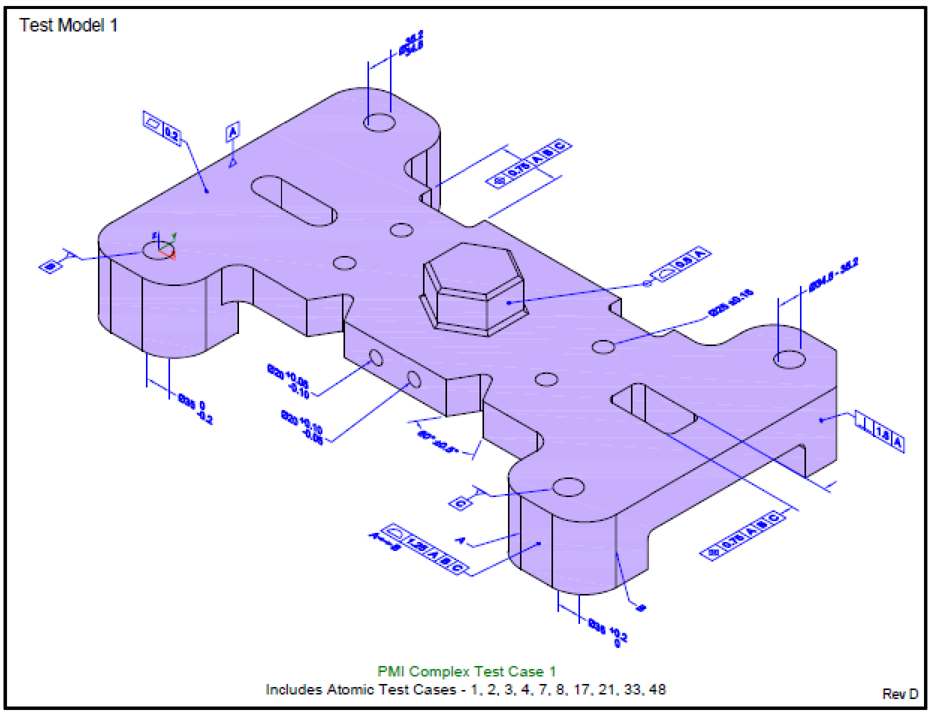

Figure 3: Combined test case 1 (CTC 1) drawing

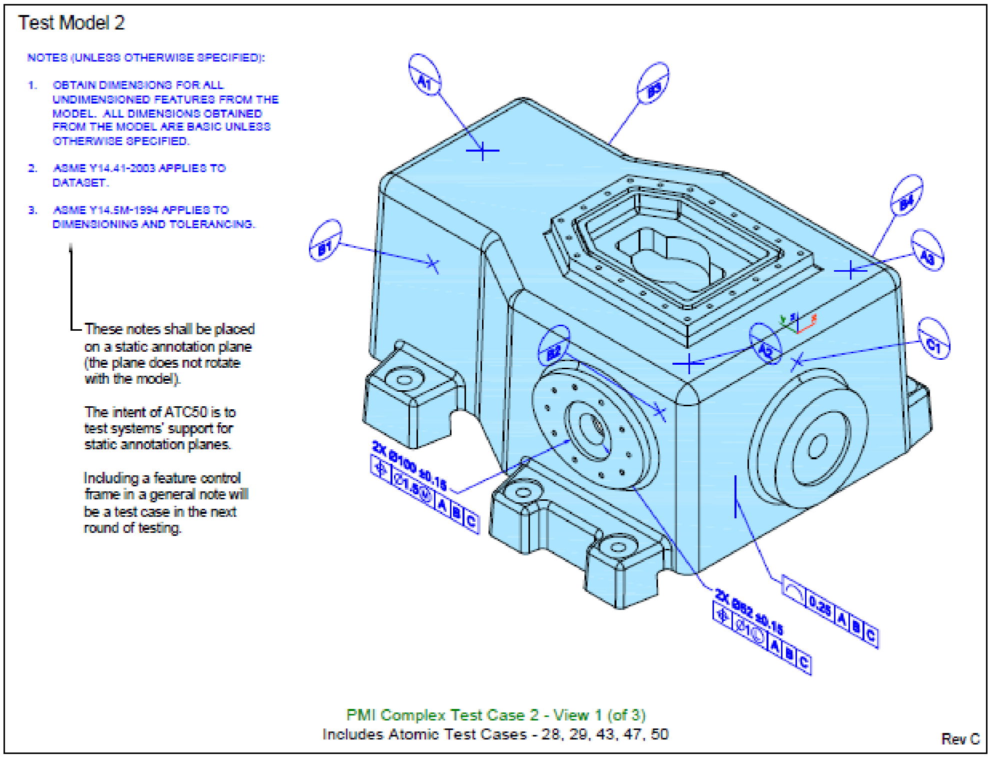

Figure 4: Combined test case 2 (CTC 2) drawing

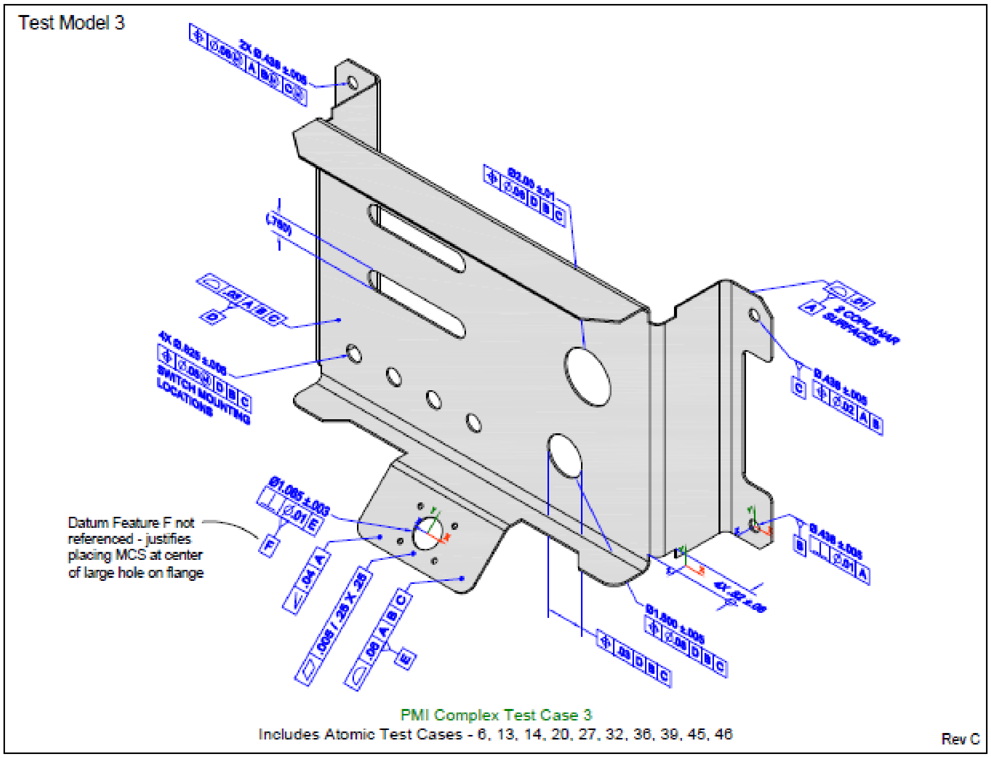

Figure 5: Combined test case 3 (CTC 3) drawing

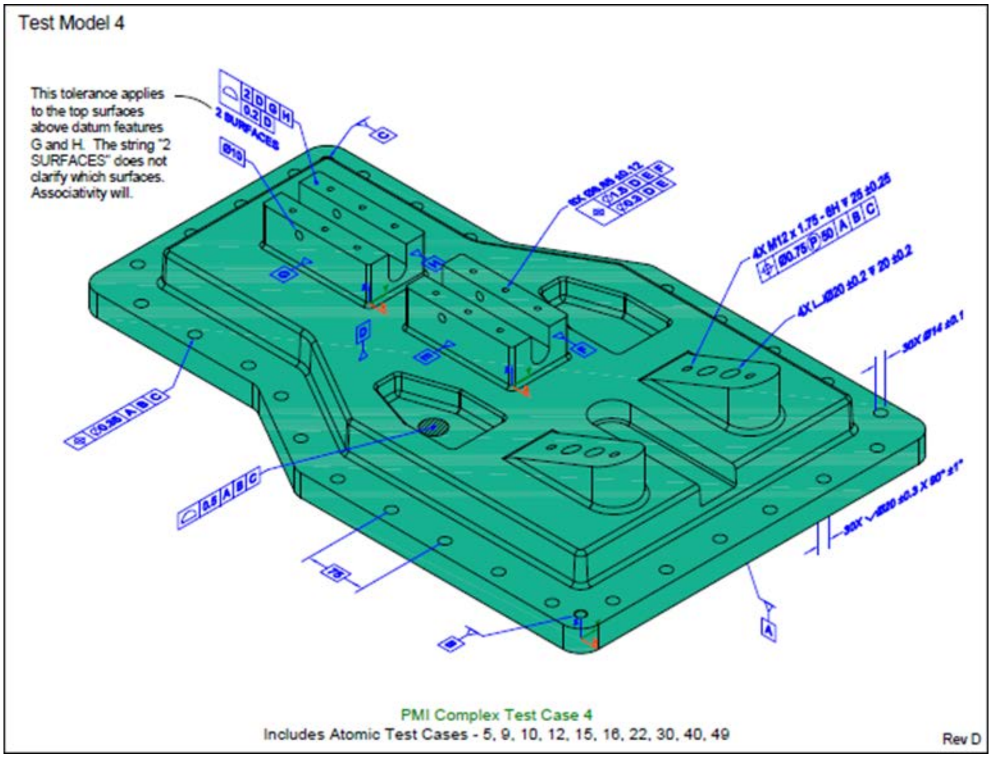

Figure 6: Combined test case 4 (CTC 4) drawing

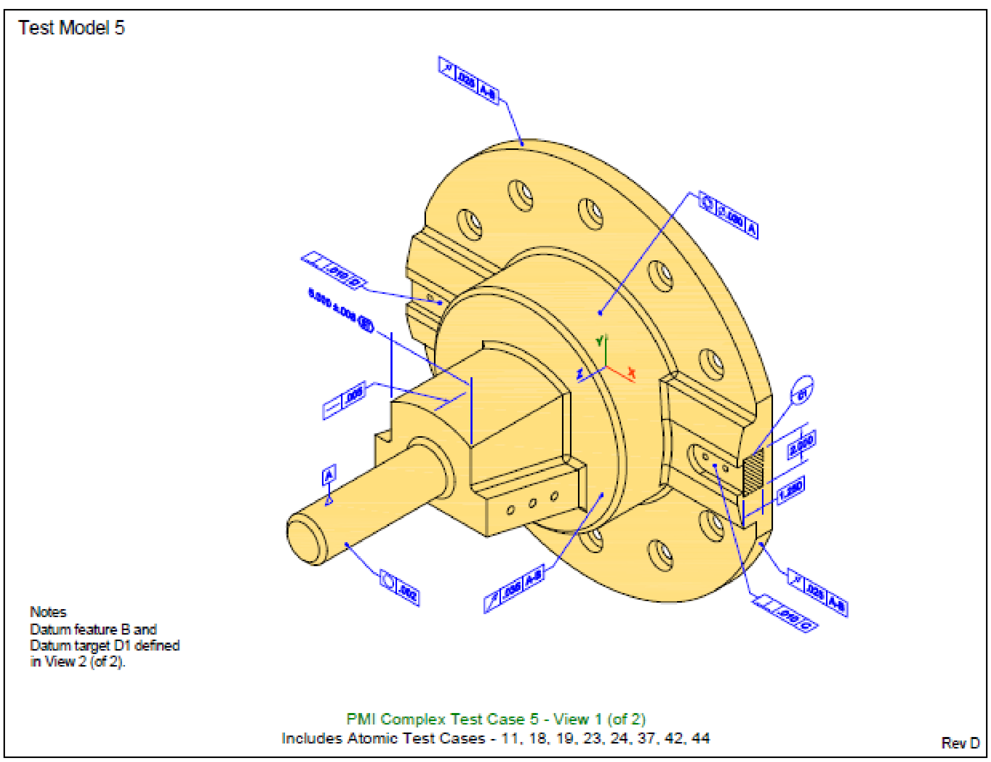

Figure 7: Combined test case 5 (CTC 5) drawing

Other industry GD&T experts reviewed the five CTCs for clarity and correctness. The CTCs were refined based on the expert feedback. All experts agreed that the CTCs are intended to simply combine representative constructs and do not define products that are fully-toleranced and/or functional for tolerance purposes. The test cases are also not intended to represent best practice in how to apply GD&T to a part. Simpler GD&T strategies could have been used. The test cases are intended to exercise valid presentations of GD&T defined in the ASME Y14 standards.

2.2 Test Model Creation

A team of CAD experts created CAD models for each CTC in four CAD systems that were available in early 2013:

- CATIA V5 R21 from Dassault Systemes [32]
- Creo 2.0 from PTC [33]
- NX 8.0 from Siemens PLM [34]
- SOLIDWORKS 2012 from Dassault Systemes [35]

The CAD experts used the above PMI representation and presentation criteria to create models with equivalent meaning, and negligible graphical variation. When it was not possible to satisfy both sets of criteria, the representation was given precedence over the presentation. Figures 8-11 show combined test case 1 (CTC 1) modeled in each of the four CAD systems. Images of each test model, each with multiple saved views, are shown in Appendix C.

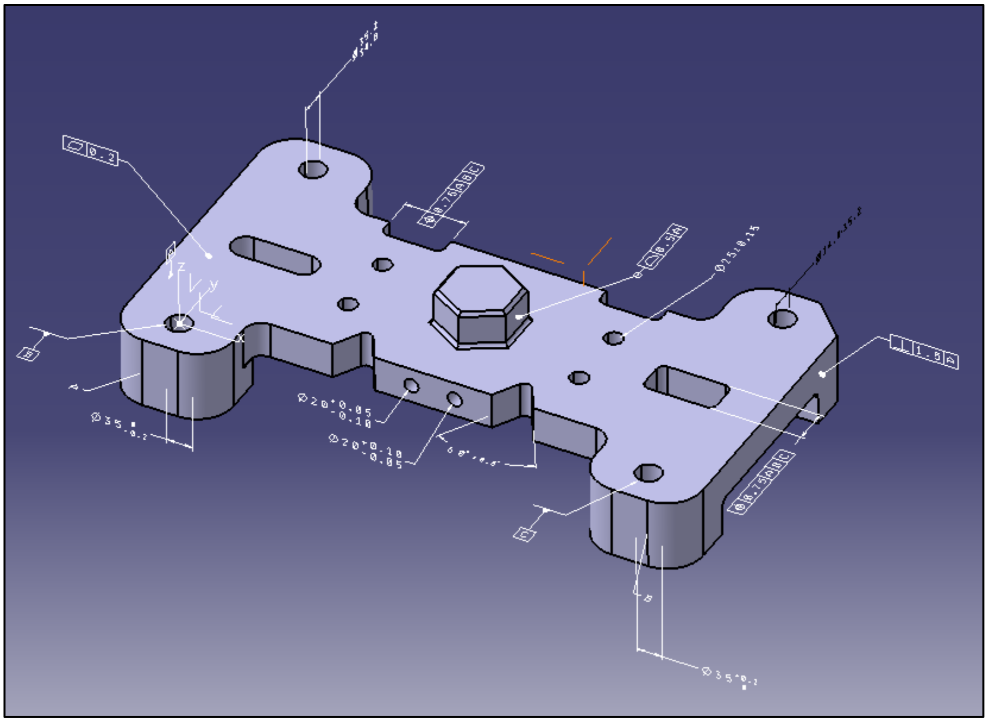

Figure 8: Combined test case 1 (CTC 1) modeled in CATIA V5 R21

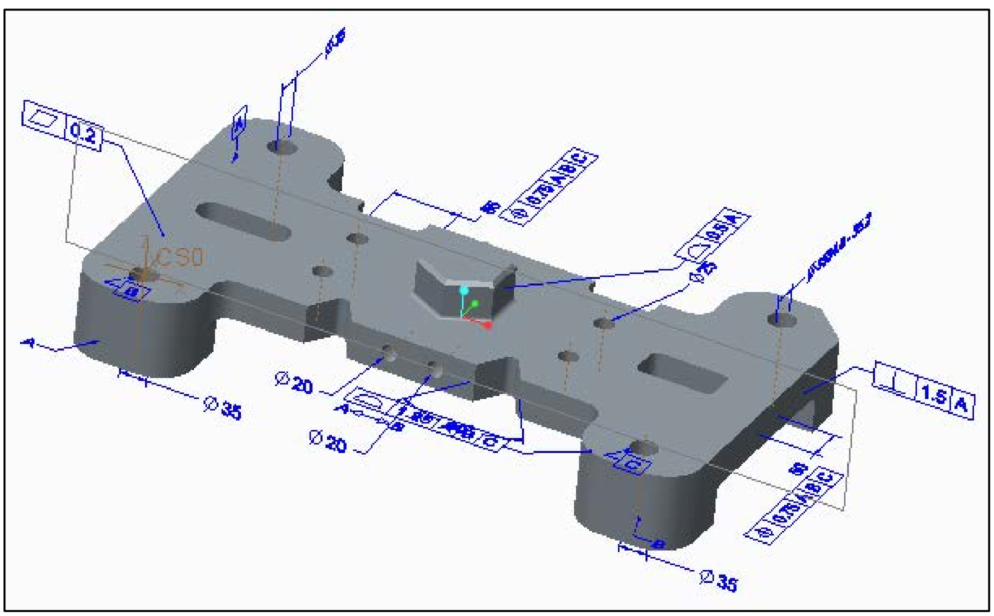

Figure 9: Combined test case 1 (CTC 1) modeled in Creo 2.0

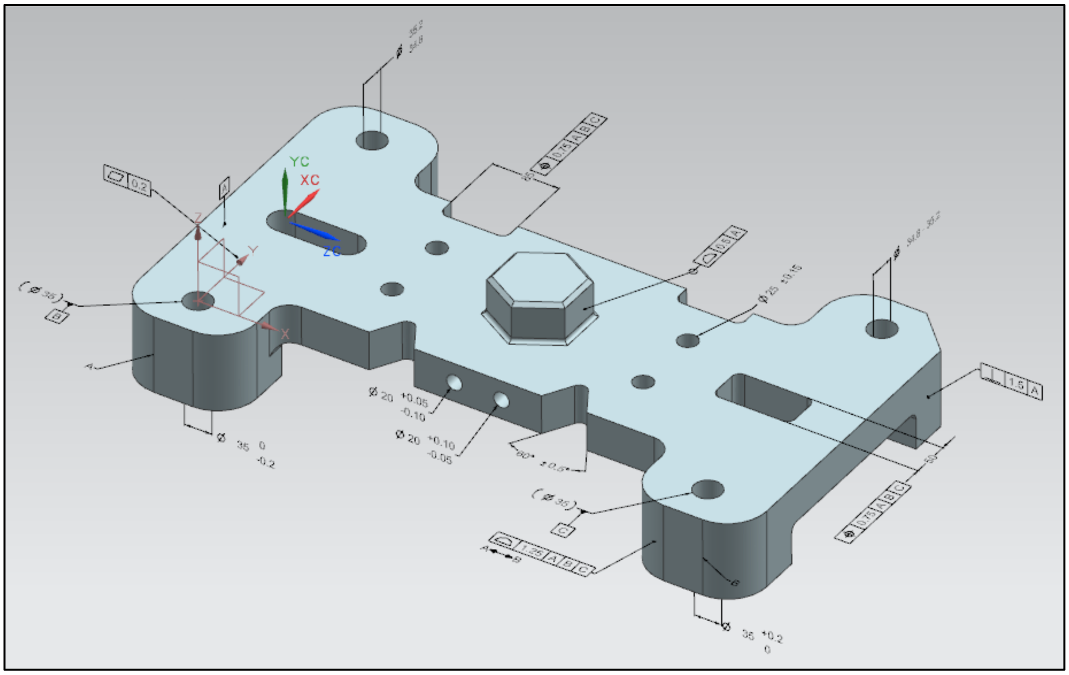

Figure 10: Combined test case 1 (CTC 1) modeled in NX 8.0

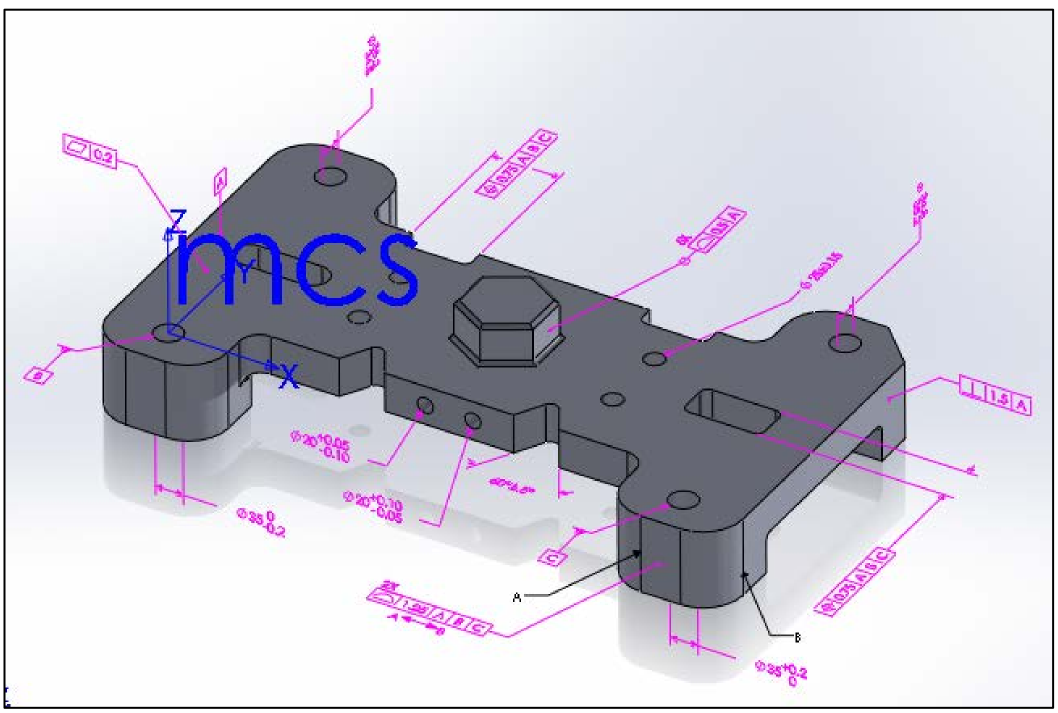

Figure 11: Combined test case 1 (CTC 1) modeled in SOLIDWORKS 2012

2.3 Test Model Verification

The CAD validation software CADIQ 8.0 [36] was used to query the PMI representation and presentation data in a 3D model using the API of each CAD system. The software vendor for CADIQ developed and refined algorithms for matching and comparing each data element between models in different CAD systems that were based on the same test case definition.

After the models were complete, a CAD validation specialist manually compared the data queried for each PMI element in the five models for one CAD system to the five test case definitions. Significant discrepancies or deficiencies were documented. Once the CAD modeling team resolved the identified issues in the models, the data set was designated as the reference set. Using the multi-CAD PMI validation technology, the specialist automatically compared each model from the other three CAD systems to the reference model.

Each discrepancy between the PMI in a model pair was compared with the test case to determine which model was inconsistent. Then, interactive CAD system queries were used to determine whether the discrepancy was due to measurement error in the validation tool or a difference in the test model. The validation software vendor resolved measurement errors while the CAD modeling team resolved model discrepancies within the limitations of the CAD system.

After several iterations of model refinement and verification, the outstanding discrepancies were documented as system limitations and the test models were released to the CAD software vendor representatives in the CAx Implementor Forum (CAx-IF) [26] for review. The CAD software vendors provided additional feedback to resolve any outstanding modeling issues.

3 PMI Modeling Capability Results

The testing methodology was used to determine whether the representation and presentation of each PMI element (i.e., annotation, coordinate system, supplemental geometry entity, saved view) in each test model were well defined. The PMI element counts for this representative data set are shown in Table 3.

Table 3: PMI element counts by type and test case

PMI Element	Element Count per Combined Test Case 1	2	3	4	5	Total
Annotation	19	40	28	20	20	127
Coordinate System	1	4	3	3	1	12
Supplemental Geometry Entity	0	2	0	1	3	6
Saved View	1	3	1	1	2	8
Total:	21	49	32	25	26	**153**

All PMI elements with a representation limitation were counted, by element type, across all test models for each CAD system. These counts were used to calculate a "Representation Limitation" percentage using this formula:

$$Limitation\ Percentage = 100\ x\ \frac{Limitation\ Count}{Element\ Count}$$

All PMI elements with only a presentation limitation were counted and likewise divided by the element count to produce a "Presentation Limitations Only" percentage. If an element had both a representation and a presentation limitation, it was included only in the representation percentage. If an element had two or more representation and/or presentation limitations, it was counted only once in the appropriate calculation. Elements with neither type of limitation were counted in a "No Limitations" percentage, thus:

$$No\ Limitations = 100\% - (Representation\ Limitations + Presentation\ Limitations)$$

These three modeling capability percentages for each CAD system are shown in Figure 12. The names of the CAD systems have been generalized to give the end-user community an overall summary of their capabilities without impugning any particular CAD vendor. The technical details have been shared separately with each CAD vendor so they know their opportunity for improvement in the MBE domain.

	CAD A	CAD B	CAD C	CAD D
No Limitations	85%	74%	69%	67%
Presentation Limitations only	2%	10%	18%	14%
Representation Limitations	13%	16%	13%	19%
Representation Level	87%	84%	87%	81%

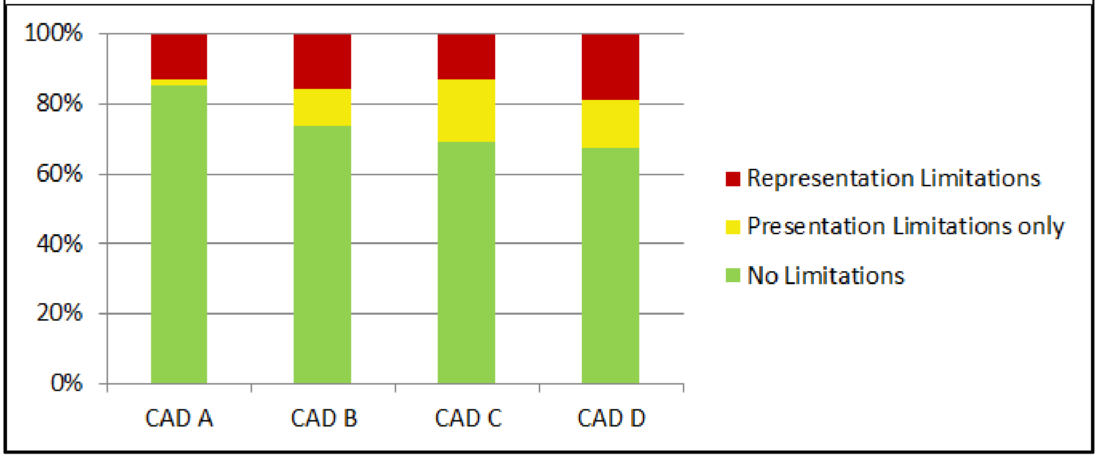

Figure 12: PMI modeling capability results by CAD system

In Figure 12, the “No Limitations” percentage can be interpreted as a measure of the capability of the CAD system to satisfy both the automated and visual consumption requirements of downstream MBE processes relative to the functional coverage of PMI constructs of this set of test cases. The “Representation Level” percentage, calculated as 100% less the “Representation Limitations” percentage, indicates the CAD system’s ability to satisfy only automated consumption requirements.

The representation and presentation limitations for each CAD system were then subtotaled by characteristic and divided by the count of PMI elements of the type appropriate for that characteristic using this formula:

$$Verification\ Percentage = 100\ x\ \frac{Element\ Count - Limitation\ Count}{Element\ Count}$$

For example, the count of annotation structure limitations for all models in each CAD system was divided by the count of annotations in the test case using the above formula. The verification percentages for each element type in each CAD system are shown in Table 4 and Table 5.

Table 4 reveals that all CAD systems failed to represent the expected structure of the specified coordinate systems. The remaining representation limitations were limited to annotations, although the specific percentages vary slightly.

Table 4: PMI representation limitations by characteristic and CAD system

Representation Limitations	Element Count	CAD A	CAD B	CAD C	CAD D
Annotation structure	127	98%	94%	98%	95%
Annotation parameters	127	96%	99%	98%	98%
Annotation geometry	127	100%	96%	98%	92%
Coordinate system structure	12	**0%**	**0%**	**0%**	**0%**
Coordinate system parameters	12	100%	100%	100%	100%
Supplemental geometry structure	6	100%	100%	100%	100%
Supplemental geometry parameters	6	100%	100%	100%	100%

Because the coordinate system structure limitations were consistent across all CAD systems, thus creating a uniform bias, it is useful to consider an adjustment to the overall statistics in Figure 12 that excludes all coordinate system limitations. Figure 13 shows these adjusted statistics.

	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

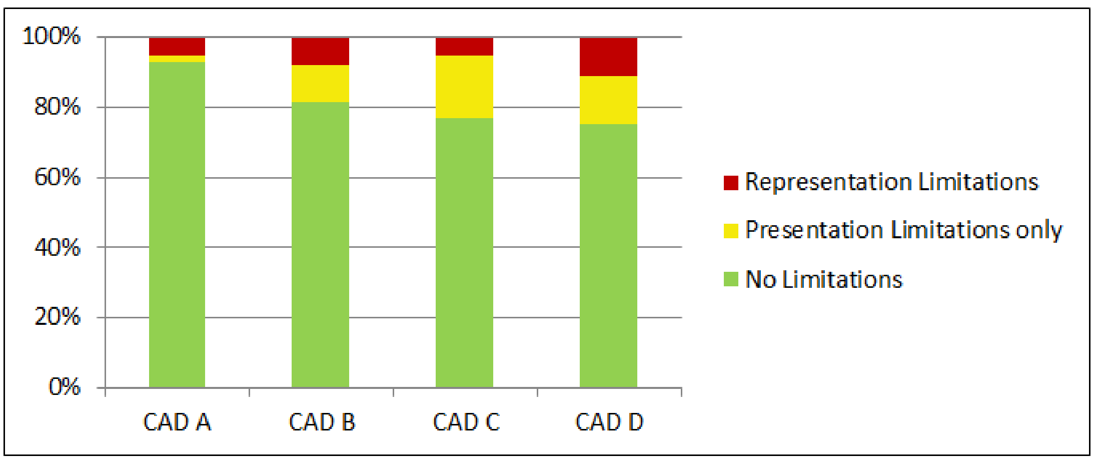

Figure 13: PMI modeling capability results by CAD system, excluding coordinate system structure limitations

Table 5 shows a much broader variation in the types of presentation limitations across CAD systems. Some of the systems were unable to adequately present coordinate system and saved view characteristics, which accounts for their larger overall "Presentation Limitations only" percentages relative to the other systems shown in Figure 13.

Table 5: PMI presentation limitations by characteristic and CAD system

Presentation Limitations	Element Count	CAD A	CAD B	CAD C	CAD D
Annotation visibility	127	100%	99%	96%	99%
Annotation color	127	100%	100%	100%	100%
Annotation name	127	100%	100%	100%	100%
Annotation layout	127	98%	96%	93%	98%
Annotation location	127	99%	100%	94%	98%
Annotation orientation	127	100%	100%	98%	99%
Annotation lines	127	100%	97%	96%	99%
Annotation text	127	98%	**89%**	100%	96%
Coordinate system visibility	12	100%	100%	100%	**67%**
Coordinate system color	12	100%	100%	100%	100%
Coordinate system name	12	100%	100%	**83%**	100%
Coordinate system text	12	100%	100%	100%	**67%**
Supplemental geometry visibility	6	100%	100%	100%	**0%**
Supplemental geometry color	6	100%	100%	100%	100%
Saved view structure	8	100%	100%	100%	**0%**
Saved view name	8	100%	100%	100%	100%
Saved view frustum	8	100%	100%	100%	**0%**

3.1 Representation Limitations

For each characteristic, there were often multiple types of limitations. Appendix D shows one example of each type of PMI representation limitation. The graphics in the appendices have been generalized to avoid identifying the specific CAD system involved. Figure 14 shows one example from Appendix D. Table 7 tabulates the count of representation limitations by characteristic and type across all CAD systems. Table 6 explains the PMI entity abbreviations used in Table 7.

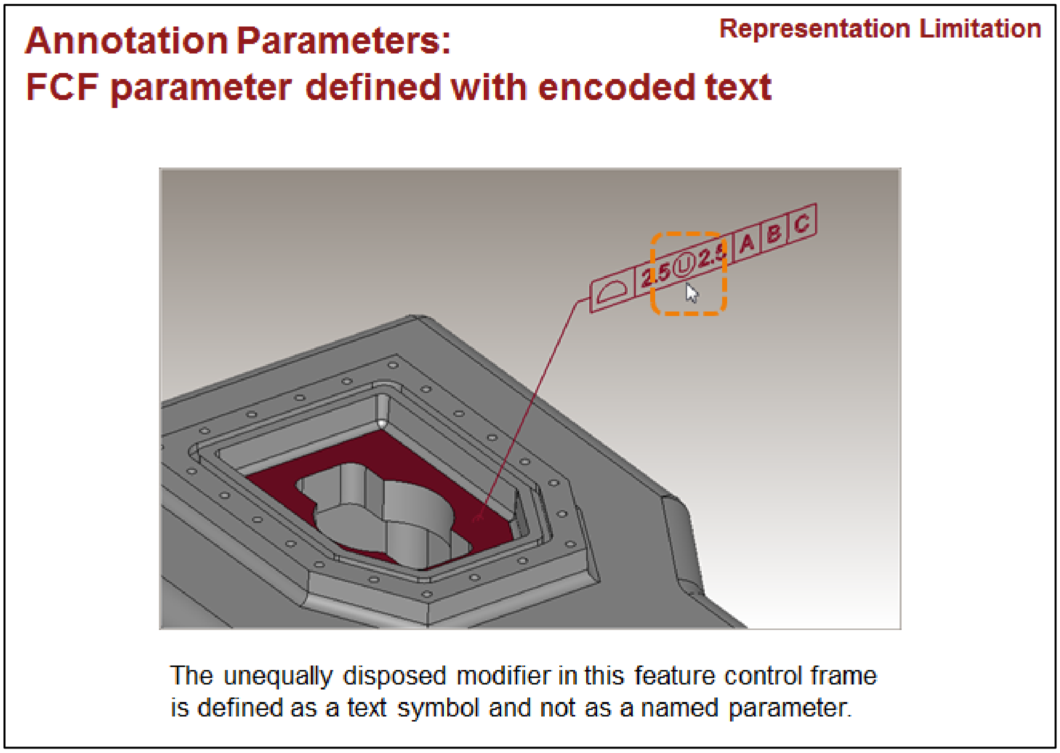

Figure 14: Example of a representation limitation

Table 6: PMI entity abbreviations

Abbrev	Definition
AN	Annotation
CS	Coordinate system
DFS	Datum feature symbol
DIM	Dimension
DRF	Datum reference frame
DTS	Datum target symbol
FCF	Feature control frame
PG	Product geometry
SG	Supplemental geometry
VW	View

Table 7: Representation limitation counts by characteristic and type

Representation Limitations	**96**
Annotation structure	**19**
Countersink diameter DIM not defined	1
DIM defined as part of DTS	4
FCF extension line defined as separate DIM	9
FCF projected tolerance zone defined as separate DIM	1
FCF text defined as separate note	3
Threaded hole depth DIM not defined	1
Annotation parameters	**11**
DIM origin not defined	1
DIM parameter defined with encoded text	3
FCF between-basis defined with encoded text	4
FCF parameter defined with encoded text	3
Annotation geometry	**18**
DIM associated with extra face	1
DIM not associated with complete set of faces	4
DTS associated with extra face	1
DTS not associated with face	1
DTS not associated with SG point	3
FCF associated with extra face	5
FCF not associated with SG curve	3
Coordinate system structure	**48**
CS not linked to FCF DRF	48

3.2 Presentation Limitations

Appendix E shows one example of each type of presentation limitation. Figure 15 shows one example from Appendix E. Table 8 tabulates the count of representation limitations by characteristic and type across all CAD systems. Table 6 explains the PMI entity abbreviations used in Table 8.

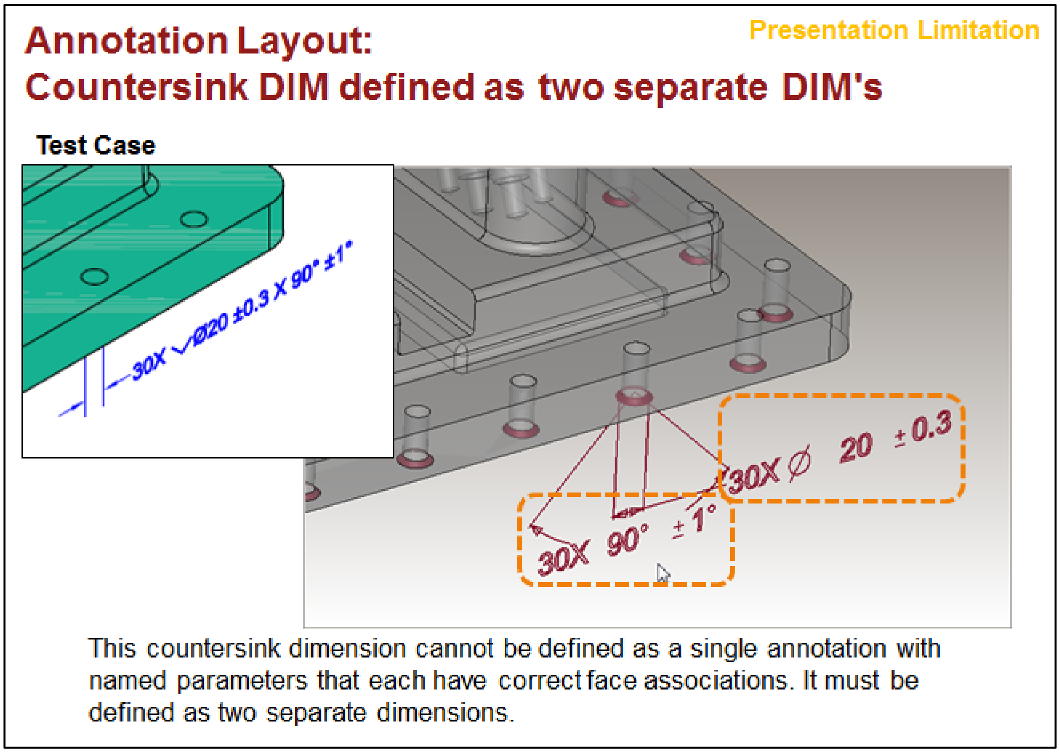

Figure 15: Example of a presentation limitation

Table 8: Presentation limitation counts by characteristic and type

Presentation Limitations	**108**
Annotation visibility	**7**
DFS is extraneous when DTS is defined	2
DFS not visible in specified view	1
DIM not visible in specified view	1
DTS visible in wrong view	3
Annotation layout	**20**
Counterbore DIM defined as two separate DIM's	4
Countersink DIM defined as two separate DIM's	4
DIM limits displayed in reversed order	1
DIM limits not displayed horizontally	2
DTS target area diameter defined as separate DIM	1
FCF text displayed above rather than below	2
FCF text displayed on right rather than below	3
Threaded hole DIM defined as two separate DIM's	3
Annotation location	**12**
DFS not attached to FCF	8
DFS overlaps DIM graphics	1
DFS partially buried in solid	1
FCF partially buried in solid	2
Annotation orientation	**4**
DIM text orientation is wrong	1
DTS text is backwards in this view	3
Annotation lines	**10**
DFS has no extension line	10
Annotation text	**22**
DIM has extraneous space	11
DTS text is extraneous	2
FCF missing note text	2
FCF missing projected tolerance zone length	1
FCF text is extraneous	6
Coordinate system visibility	**4**
CS visible in wrong view	4
Coordinate system name	**2**
CS name not same as DRF	2
Coordinate system text	**4**
CS name displayed with extra large text	4
Supplemental geometry visibility	**7**
SG curve visible in wrong view	2
SG point visible in wrong view	5
Saved view structure	**8**
View cannot contain annotations on different planes	8
Saved view frustum	**8**
View camera position not defined	8

3.3 Style Differences

In some cases, the representation and presentation for a PMI element were determined by the expert reviewers to be correct yet different between the CAD systems. These variations were categorized as style differences and not included in the representation or presentation limitation calculations. Appendix F documents one example of each type of style difference that was ignored. Figure 16 shows an example from Appendix F. Table 9 tabulates the count of style differences by characteristic and type across all systems. Table 6 explains the PMI entity abbreviations used in Table 9.

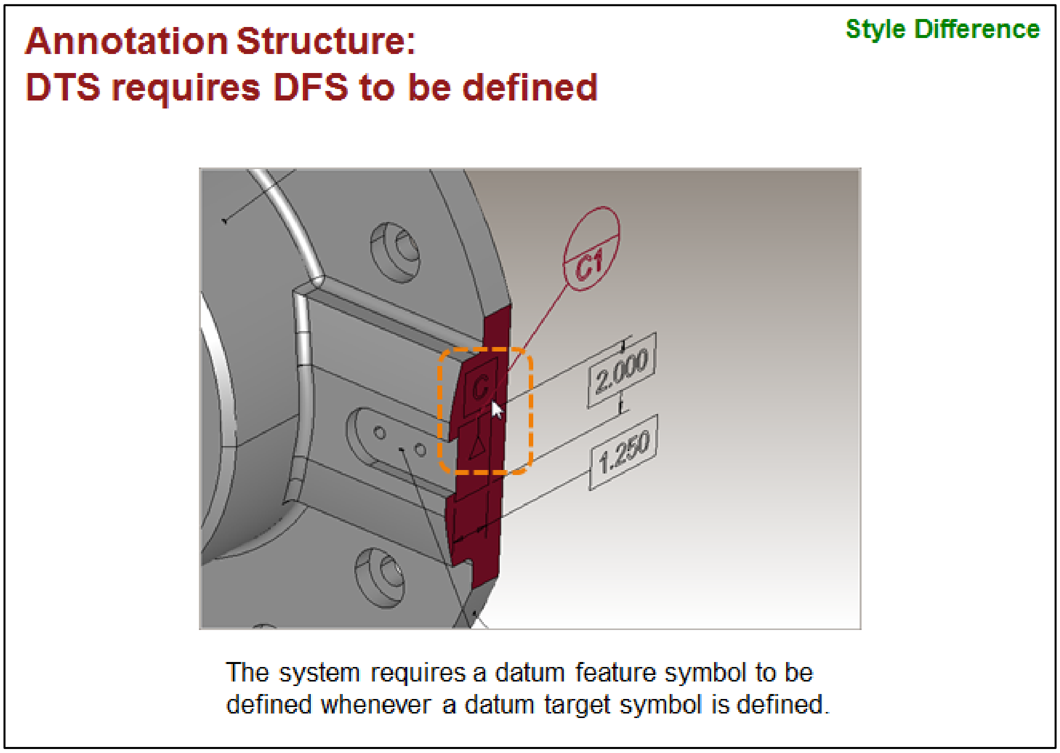

Figure 16: Example of a style difference

Table 9: Style difference counts by characteristic and type

Style Differences	**48**
Product geometry parameters	**1**
Threaded hole diameter different than other systems	1
Annotation structure	**19**
DTS requires DFS to be defined	18
FCF requires DFS to be defined	1
Annotation geometry	**11**
DFS edge association is extraneous	2
DIM edge association is extraneous	9
Supplemental geometry structure	**17**
DTS target area is non-solid surface on solid face	6
DTS target area is subdivided solid face	1
DTS target area is wireframe region on solid face	5
FCF limited area definition inconsistent with target area	1
FCF limited area is non-solid surface on solid face	3
FCF limited area is subdivided solid face	1

3.4 PMI Verification Challenges

A challenging construct is the representation of extension lines for datum feature symbols and feature control frames. In some CAD systems, this construct is represented as dimension entities that are separate from the attached annotation, as shown in Figure 17. These extra annotations introduce parameters (nominal value and limits) that must be ignored during verification.

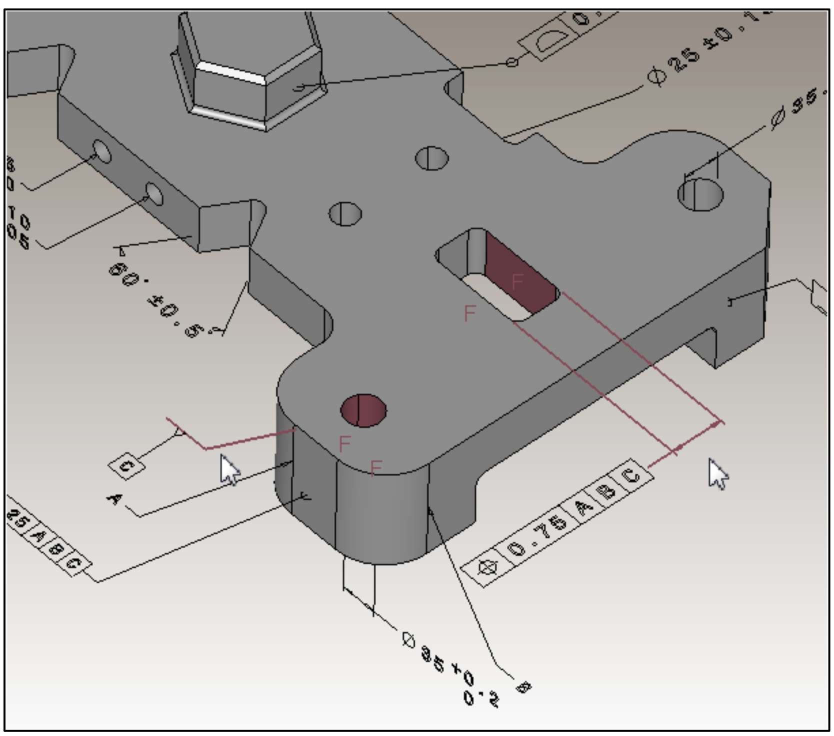

Figure 17: Extension lines represented as separate dimension annotations

Another challenging construct is the representation of threaded holes shown in Figure 18. The diameter of the simple hole in the solid model may be different for the same type of threaded hole in various CAD systems. Some systems use differing supplemental geometry, such as wireframe curves or non-solid surfaces, to represent the hole thread depth while others use no supplemental geometry.

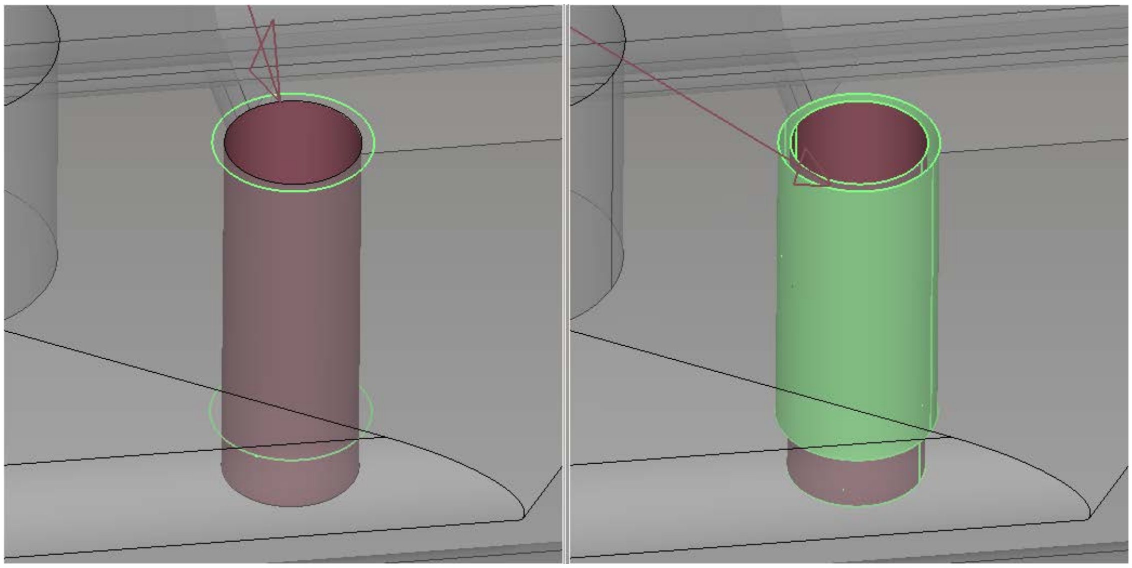

Figure 18: Different threaded hole supplemental geometry representations

Finally, when a PMI construct is specified with a limited area, such as a datum target or geometric tolerance, the portion of the product shapes that is within the target area is represented differently. Some CAD systems define a non-solid surface overlaid on the solid while others subdivide the portion of the solid face into a separate face shown in Figure 19. Still others indicate the area with a region defined by wireframe geometry. These modeling differences create significant variability that must be accounted for during annotation matching and comparison.

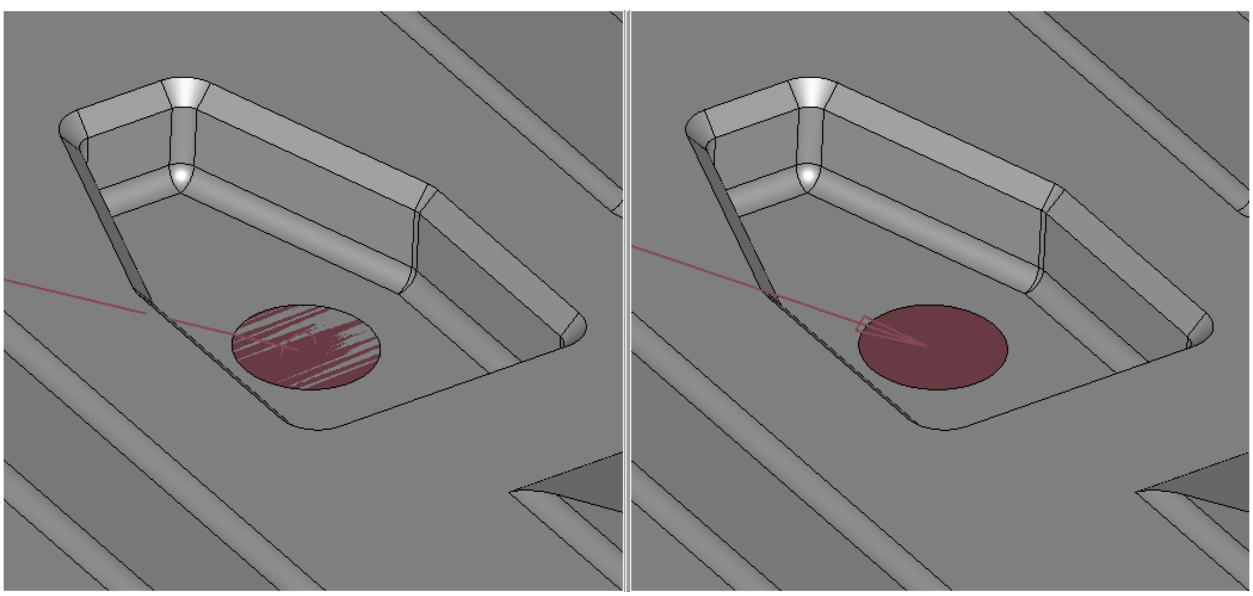

Figure 19: Different target area representations

4 Discussion

Using a formal methodology, implemented with advanced verification and validation technology, the MBE modeling capability of four leading CAD systems was quantified relative to the PMI requirements captured in five combined test cases.

The four CAD systems, which were tested at 2013 release levels, are roughly equivalent in their PMI representation modeling capability (between 81% and 87%) for the functionality within scope of this assessment (between 89% and 95% when adjusted for the consistent coordinate system limitation). Their capability measurements vary much more (between 67% and 85%) when both automated and visual consumption requirements are considered.

The specific PMI representation and presentation system limitations identified by this assessment have been clearly documented and communicated to the CAD vendors.

The specific test of the PMI capabilities in CAD systems documented in this report is a snapshot in time. Specific test cases were developed using particular versions of the ASME Y14 tolerancing standards and PMI constructs. The test cases were modeled in particular versions of four CAD systems with a specific modeling methodology to give precedence to PMI representation over PMI presentation. The CAD models were compared to each other with a particular version of CAD validation software. Results for PMI representation and presentation capabilities were reported based on four categories of PMI elements: annotations, coordinate systems, supplemental geometry, and saved views.

For a company that is transitioning from 2D drawings to 3D models to implement model-based design, this report can be used to identify the characteristics of PMI representation and presentation and the capabilities of CAD software that are important to achieve an MBD workflow. The test cases may or may not be representative of the types of PMI that might be typically used. The versions of the CAD systems and tolerancing standards might be newer or older than what a company requires. However, the report clearly identifies a wide variety of PMI representation and presentation issues that can be used to evaluate CAD software that is used in an MBD environment.

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Appendix A: PMI Constructs

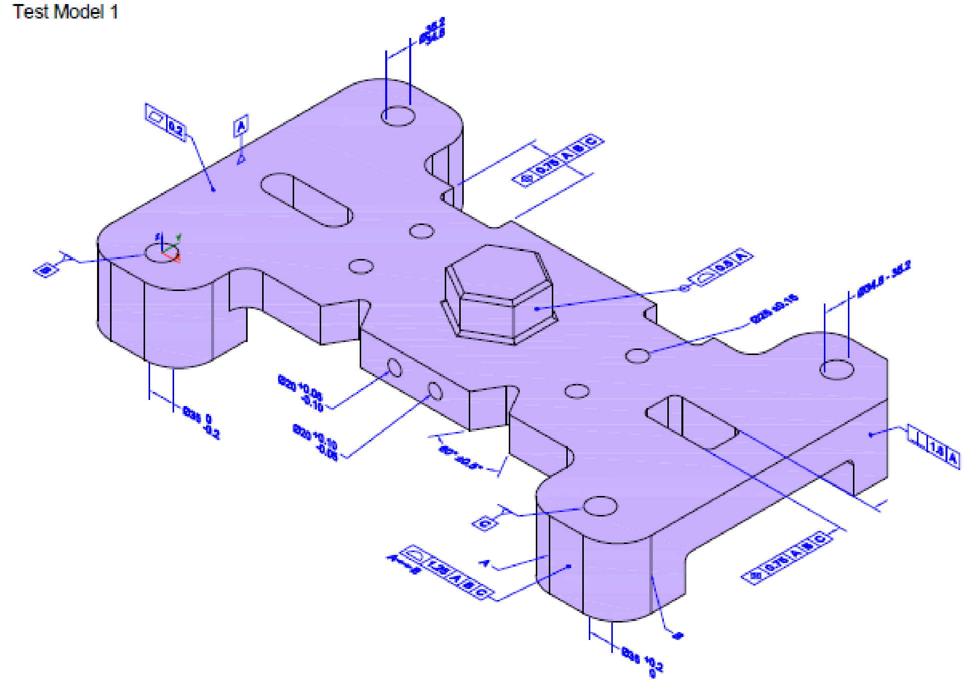
PMI Construc	CTC	Construct Description	Units	Construct Specification
1	1	Dimension with Equal-Bilateral Tolerance: Feature of Size	mm	Ø25 ±0.15
2	1	Dimension with Unequal-Bilateral Tolerance: Feature of Size	mm	Ø20 +0.05/-0.10 Ø20 +0.10/-0.05
3	1	Dimension with Unilateral Tolerance: Feature of Size	mm	Ø35 0/-0.2 Ø35 +0.2/0
4	1	Angular Dimension with Equal-Bilateral Tolerance: Simple	mm	60° ±0.5°
5	4	Directly-toleranced dimension with nX (quantity)	mm	30X ø14 ±0.1
6	3	Directly-Toleranced Dimension with Dimension Origin Symbol	inch	4X .82 ±.06 (origin)
7	1	Symbol: All Around (Applied with a Leader-Directed Profile Tolerance)	mm	⌓0.5|A All Around
8	1	Dimension: Limit - Vertical (Stacked) and Horizontal with Diameter Symbol: Feature of Size	mm	Ø34.8 - 35.2 Ø35.2/34.8
9	4	Symbol: Counterbore; Symbol: Depth - Single-Line Specification of Two Dimensions and Tolerances - Complex	mm	4X ⌴ø20 ±0.2 ↧20 ±0.2
10	4	Symbol: Countersink - Single-Line Specification of Two Dimensions and Tolerances - Complex	mm	30X ⌵ø20 ±0.3 X 90° ±1°
11	5	Directly-Toleranced Dimension with Statistical Tolerancing Symbol	inch	5.000 ±.008 ⟨ST⟩
12	4	Basic dimension	mm	75 basic Ø10 basic
13	3	Reference Dimension, Simple	inch	(.750)
14	3	Single Segment Feature Control Frame, Simple - Attached to Size Dimension & Tolerance	inch	⌖Ø.06|D|B|C ⊥Ø.01|E
15	4	Composite Feature Control Frame - 2 Segments - Leader Directed - with String Grouping Mechanism	mm	⌓2|D|G|H 0.2|D 2 SURFACES
16	4	Composite Feature Control Frame - 2 segments - Attached to Directly-Toleranced Size Dimension	mm	6X ø6.65 ±0.12 ⌖ø1.5|D|E|F ø0.3|D|E
17	1	Feature Control Frame Directed to Surface - Flatness	mm	⏥0.2
18	5	Feature Control Frame Directed to Surface - Straightness with Represented Line Element	inch	—.005
19	5	Feature Control Frame Directed to Surface - Circularity	inch	○.002
20	3	Feature Control Frame Directed to Surface - Angularity	inch	∠.04|A

PMI Construc	CTC	Construct Description	Units	Construct Specification
21	1	Feature Control Frame Directed to Surface - Perpendicularity	mm	⊥1.5|A
22	4	Feature Control Frame Directed to Surface - Position	mm	⌖Ø0.35|A|B|C
23	5	Feature Control Frame Directed to Surface - Concentricity	inch	◎Ø.030|B
24	5	Feature Control Frame Directed to Surface - Circular Runout	inch	↗.035|A-B ↗.025|A-B
25	5	Feature Control Frame Directed to Surface - Total Runout	inch	⌰.002|A ⌰.015|B
26	2	Feature Control Frame Directed to Surface - Profile of a Surface	mm	⌓0.75|A|B|C
27	3	Feature Control Frame with Unit-Basis Tolerance - Flatness	inch	▱.005 / .25 X .25
28	2	Feature Control Frame with MMC Modifier	mm	⌖Ø1.5Ⓜ|A|B|C
29	2	Feature Control Frame with LMC Modifier	mm	⌖Ø1Ⓛ|A|B|C
30	4	Feature Control Frame with Projected Tolerance and Projection Distance - ASME	mm	4X M12 x 1.75 - 6H ↧25 ±0.25 ⌖ø0.75Ⓟ50|A|B|C
31	2	Feature Control Frame with ASME Modifiers - Unequally-Disposed	mm	⌓2.5(U)0.5|A|B|C ⌓2.5(U)2.5|A|B|C ⌓2.5(U)0|A|B|C
32	3	Unidirectional Positional Tolerancing - Parallel Plane Tolerance Zone for Cylindrical Feature of Size	inch	⌖.03|D|B|C
33	1	Single Segment Feature Control Frame - Attached Directly to Dimension Lines - No Dimension Value	mm	⌖0.75|A|B|C
34	2	Feature Control Frame with MMB Modifiers for Datum Feature References - ASME	mm	⌓0.5|D|EⓂ|FⓂ ⌓0.5|D|EⓂ|F ⌓0.5|D|E|FⓂ ⌓0.5|D|E|F
35	2	Feature Control Frame with LMB Modifiers for Datum Feature References - ASME	mm	⌓0.8|G|HⓁ|J ⌓0.8|G|HⓁ|JⓁ ⌓0.8|G|H|JⓁ ⌓0.8|G|H|J DFS G 4 COPLANAR SURFACES

PMI Construc	CTC	Construct Description	Units	Construct Specification
36	3	Feature Control Frame with MMC and MMB Modifiers	inch	⌖Ø.05Ⓜ|A|BⓂ|CⓂ
37	5	Datum Feature symbol attached to Feature of Size	inch	A
38	5	Datum Feature symbol attached to a Size Dimension	inch	B Ø10.000 ±.001
39	3	Datum Feature Symbol Attached to a Leader-Directed Feature Control Frame	inch	⌓.01 2 COPLANAR SURFACES + DFS A ⌓.03|A|B|C + DFS D ⌓.06|A|B|C + DFS E
40	4	Datum Feature symbols for Primary, Secondary, Tertiary attached to surfaces	mm	D, E, F, G, H
41	2	Datum Target Symbol and Target Area Symbol Applied to Surface: Area Defined in Datum Target Symbol (Ø)	mm	Ø0.85 Area K1
42	5	Datum Target Symbol and Target Area Applied to Surface: Area Defined on Surface (Rectangular)	inch	C1, D1 2.000 (basic), 1.250 (basic)
43	2	Set of Datum Target Symbols and Target Point Symbols Applied to Surfaces	mm	A1, A2, A3 B1, B2, B3, B4 C1
44	5	Multiple Datum Feature	inch	↗.035|A-B ↗.025|A-B
45	3	Size Dimension with Feature Control Frame and STRING - Applied nX	inch	4X Ø.625 ±.005 ⌖Ø.05Ⓜ|D|B|C SWITCH MOUNTING LOCATIONS
46	3	Size Dimension with Feature Control Frame and Datum Feature Symbol Attached	inch	Ø.438 ±.005 ⊥Ø.01|A + DFS B Ø.438 ±.005 ⌖Ø.02|A|B + DFS C Ø1.065 ±.003 ⊥Ø.01|E + DFS F
47	2	Directional Geometric Tolerance with Represented Line Element	mm	⌒0.25|A|B|C
48	1	Profile Tolerance: Applied on a Between Basis	mm	⌓1.25|A|B|C A←→B
49	4	Profile Tolerance Applied to a Limited Area (Circular Area) - Area Not Explicitly Dimensioned	mm	⌓0.5|A|B|C
50	2	General Notes Invoking ASME Y14.5M-1994 and Y14.41-2003 on Static Annotation Plane	mm	Obtain dimensions from model… Model geometry is basic… ASME Y14.41-2003 applies… ASME Y14.5M-1994 applies…

Appendix B: Combined Test Case Drawings

Test Model 1



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

Rev D

Test Model 2

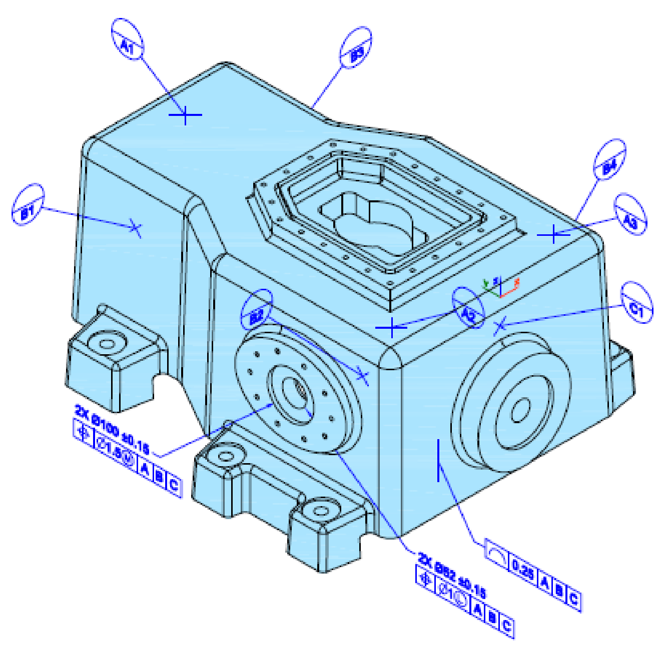
NOTES (UNLESS OTHERWISE SPECIFIED):

1. OBTAIN DIMENSIONS FOR ALL UNDIMENSIONED FEATURES FROM THE MODEL. ALL DIMENSIONS OBTAINED FROM THE MODEL ARE BASIC UNLESS OTHERWISE SPECIFIED.
2. ASME Y14.41-2003 APPLIES TO DATASET.
3. ASME Y14.5M-1994 APPLIES TO DIMENSIONING AND TOLERANCING.

These notes shall be placed on a static annotation plane (the plane does not rotate with the model).

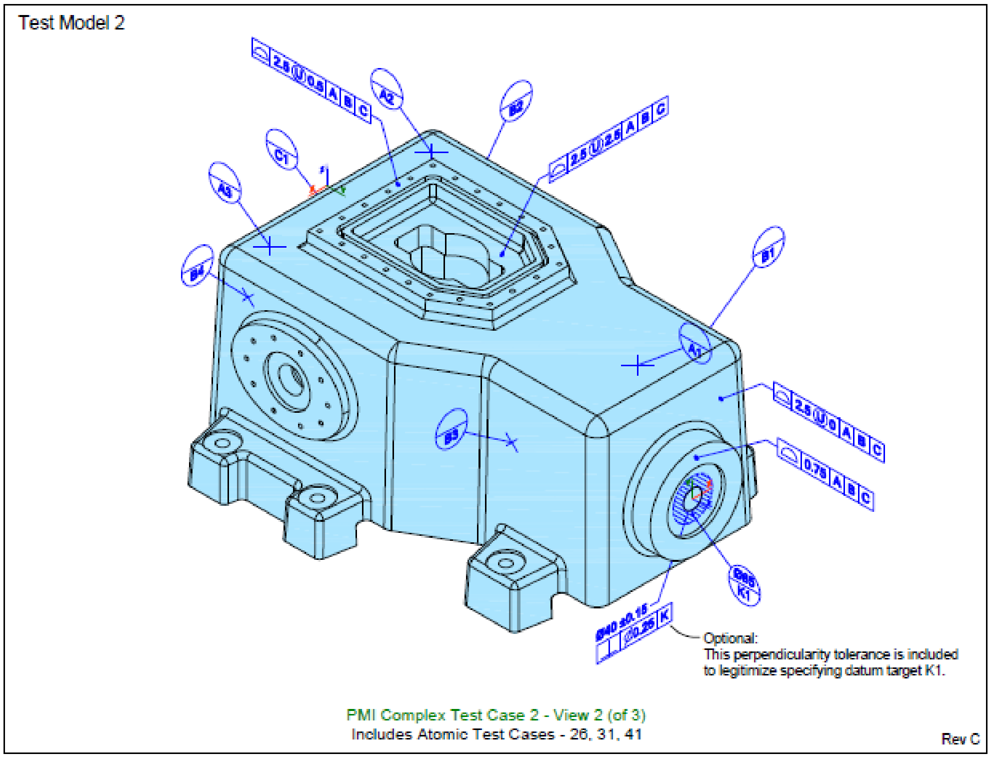
The intent of ATC50 is to test systems' support for static annotation planes.

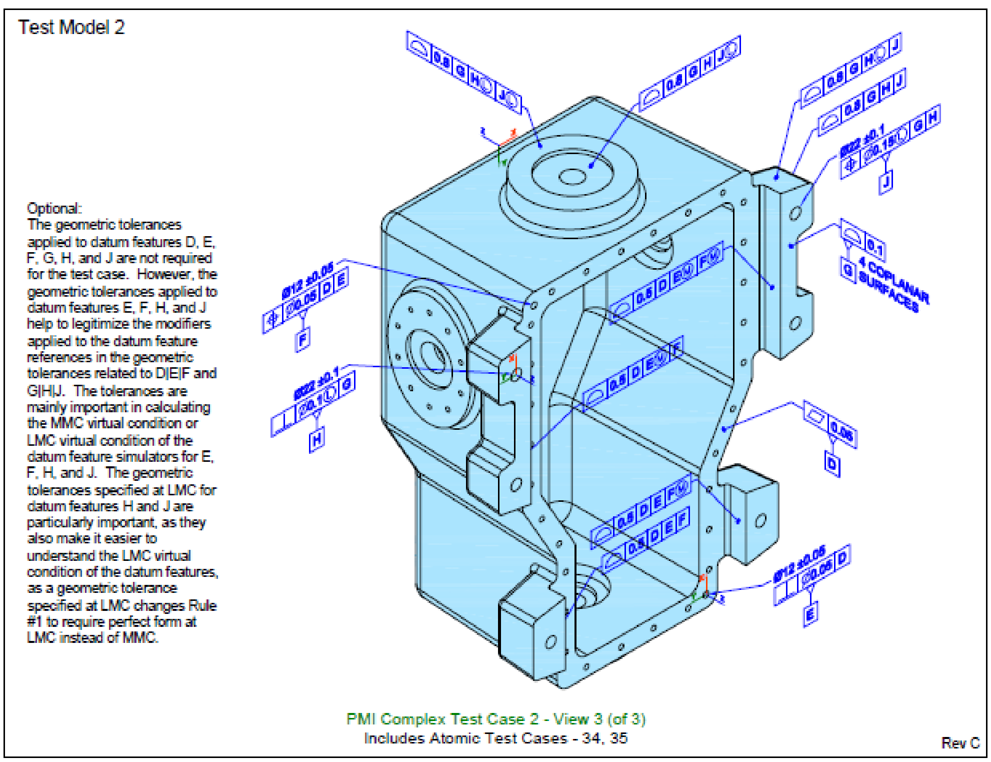
Including a feature control frame in a general note will be a test case in the next round of testing.



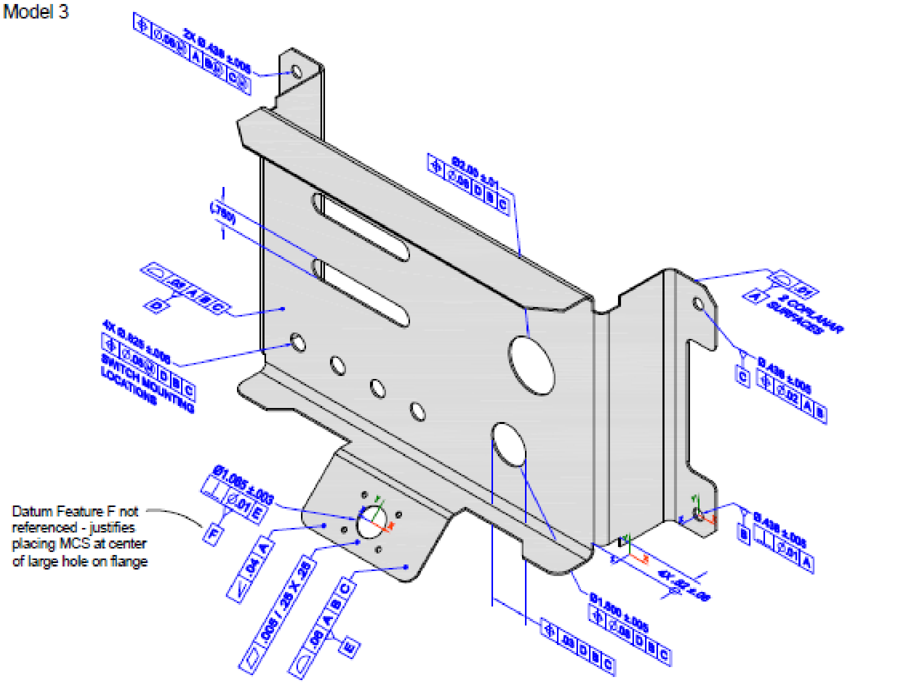
PMI Complex Test Case 2 - View 1 (of 3)
Includes Atomic Test Cases - 28, 29, 43, 47, 50

Rev C


Test Model 2
Optional:
This perpendicularity tolerance is included
to legitimize specifying datum target K1.
PMI Complex Test Case 2 - View 2 (of 3)
Includes Atomic Test Cases - 26, 31, 41
Rev C


Test Model 2
Optional:
The geometric tolerances applied to datum features D, E, F, G, H, and J are not required for the test case. However, the geometric tolerances applied to datum features E, F, H, and J help to legitimize the modifiers applied to the datum feature references in the geometric tolerances related to D|E|F and G|H|J. The tolerances are mainly important in calculating the MMC virtual condition or LMC virtual condition of the datum feature simulators for E, F, H, and J. The geometric tolerances specified at LMC for datum features H and J are particularly important, as they also make it easier to understand the LMC virtual condition of the datum features, as a geometric tolerance specified at LMC changes Rule #1 to require perfect form at LMC instead of MMC.
4 COPLANAR SURFACES
PMI Complex Test Case 2 - View 3 (of 3)
Includes Atomic Test Cases - 34, 35
Rev C

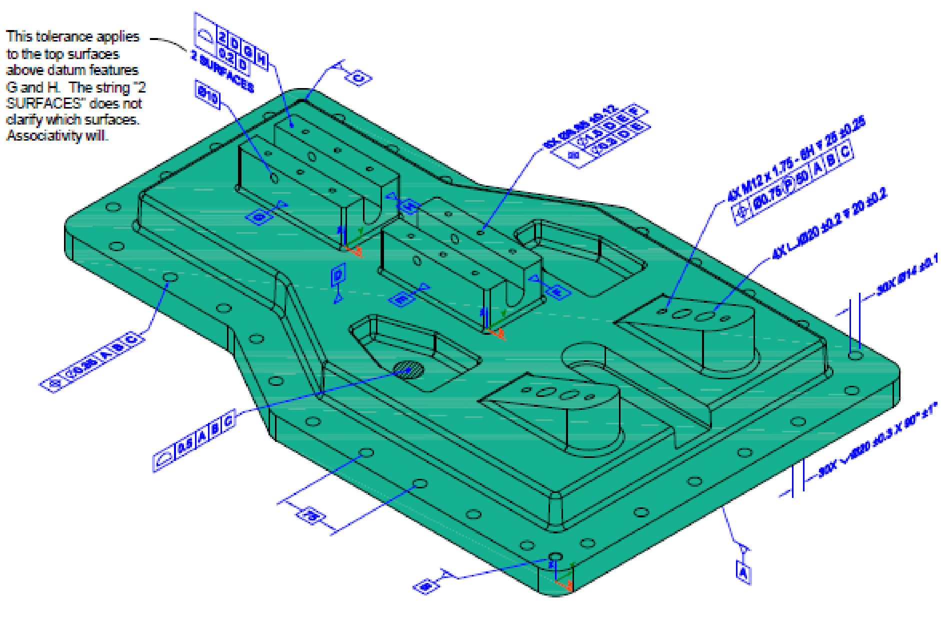
Test Model 3



PMI Complex Test Case 3
Includes Atomic Test Cases - 6, 13, 14, 20, 27, 32, 36, 39, 45, 46

Rev C

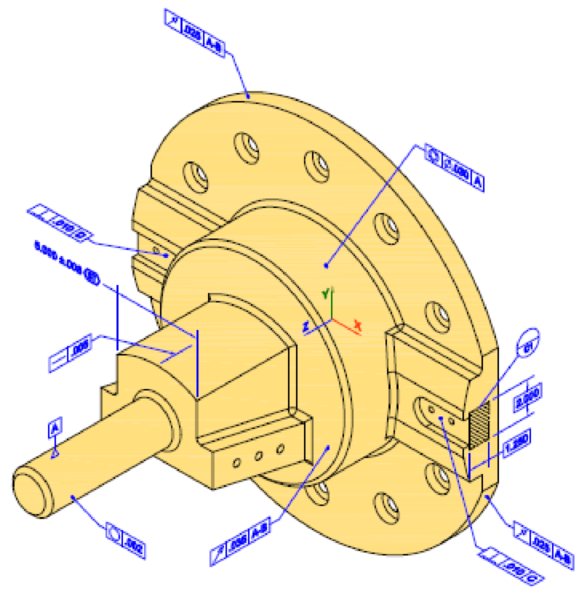
Test Model 4



PMI Complex Test Case 4
Includes Atomic Test Cases - 5, 9, 10, 12, 15, 16, 22, 30, 40, 49

Rev D

Test Model 5

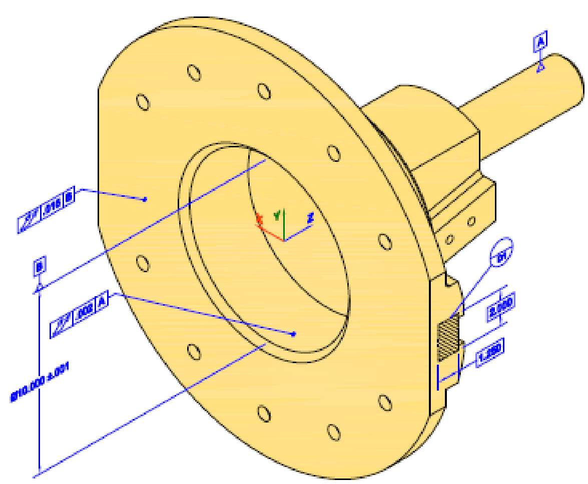


Notes
Datum feature B and
Datum target D1 defined
in View 2 (of 2).

PMI Complex Test Case 5 - View 1 (of 2)
Includes Atomic Test Cases - 11, 18, 19, 23, 24, 37, 42, 44

Rev D

Test Model 5



Notes
Datum feature A defined in
View 1 (of 2).

Datum target D1 referenced
in View 1 (of 2).

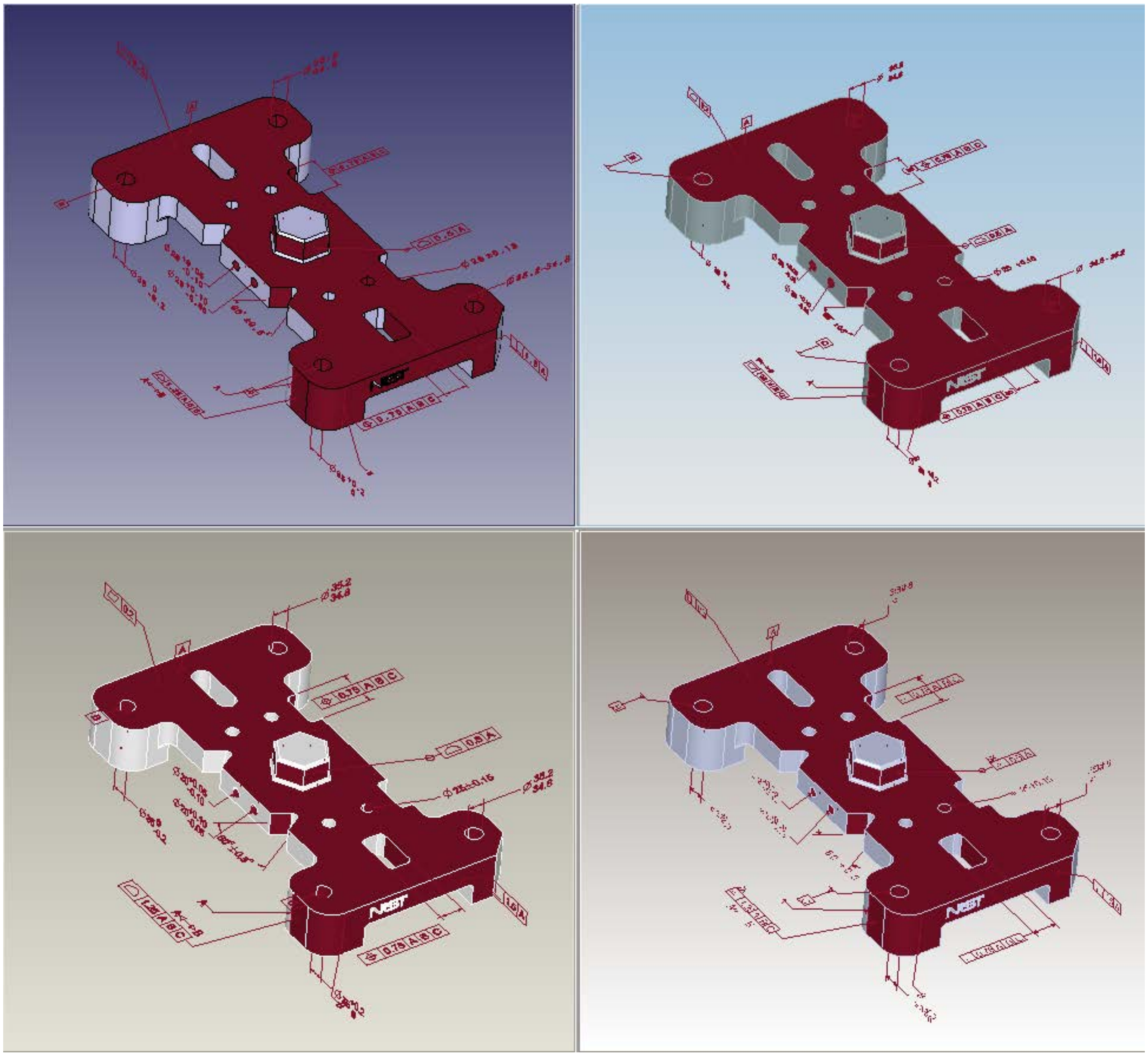
PMI Complex Test Case 5 - View 2 (of 2)
Includes Atomic Test Cases - 25, 38, 42

Rev D

Appendix C: Test Model Images

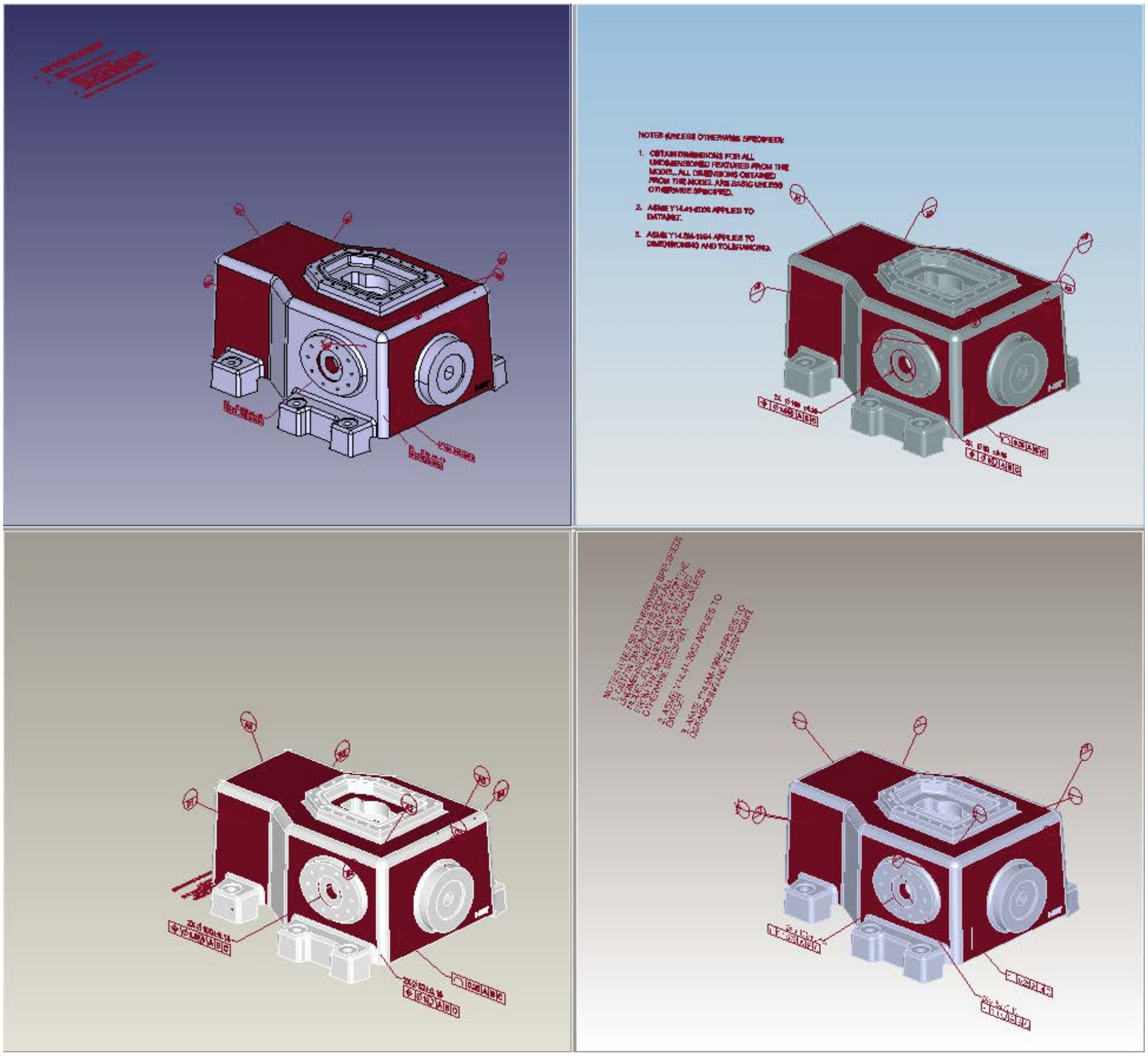
Combined Test Case 1
Saved View MBD_0

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



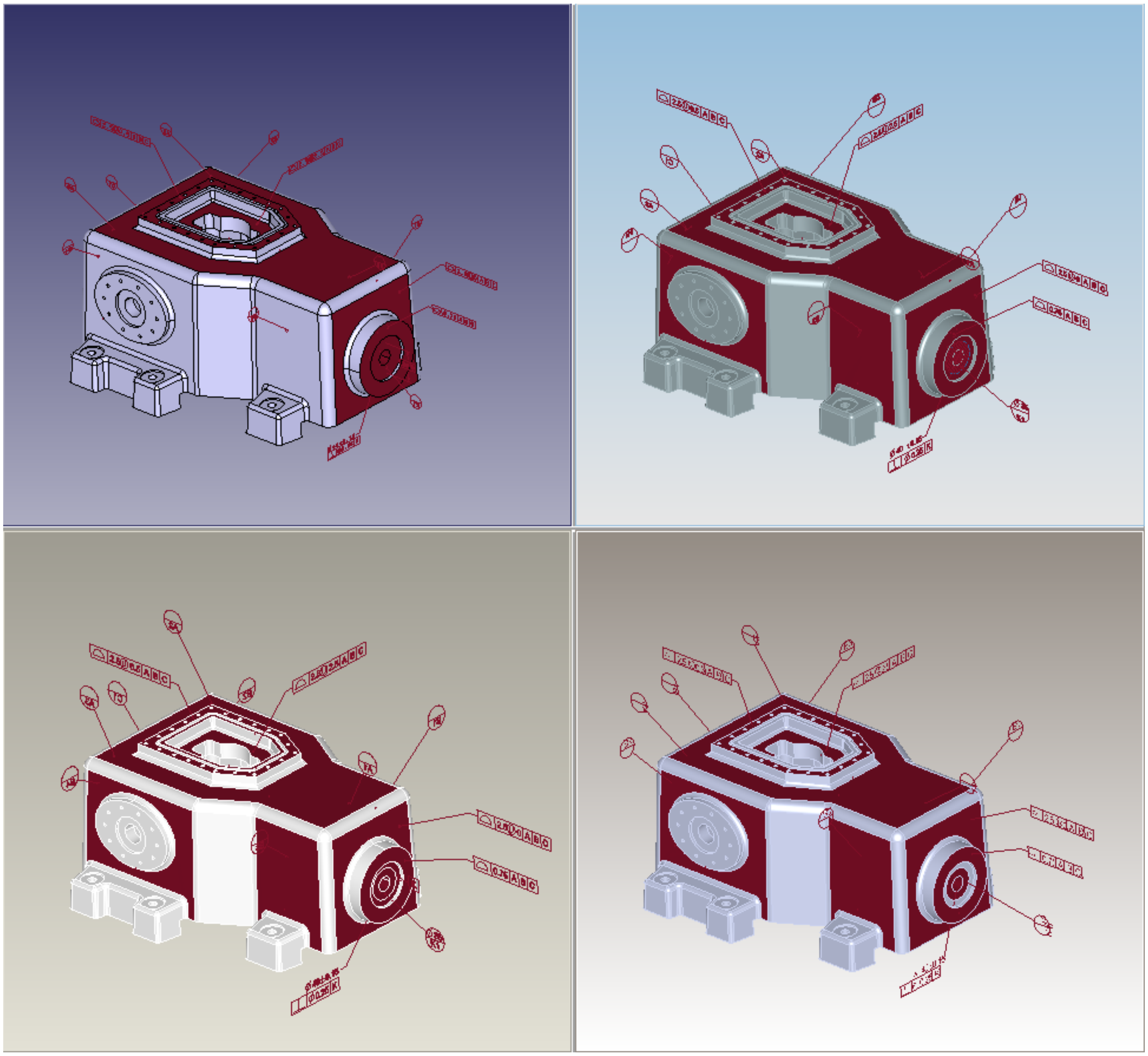
Combined Test Case 2
Saved View MBD_A

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



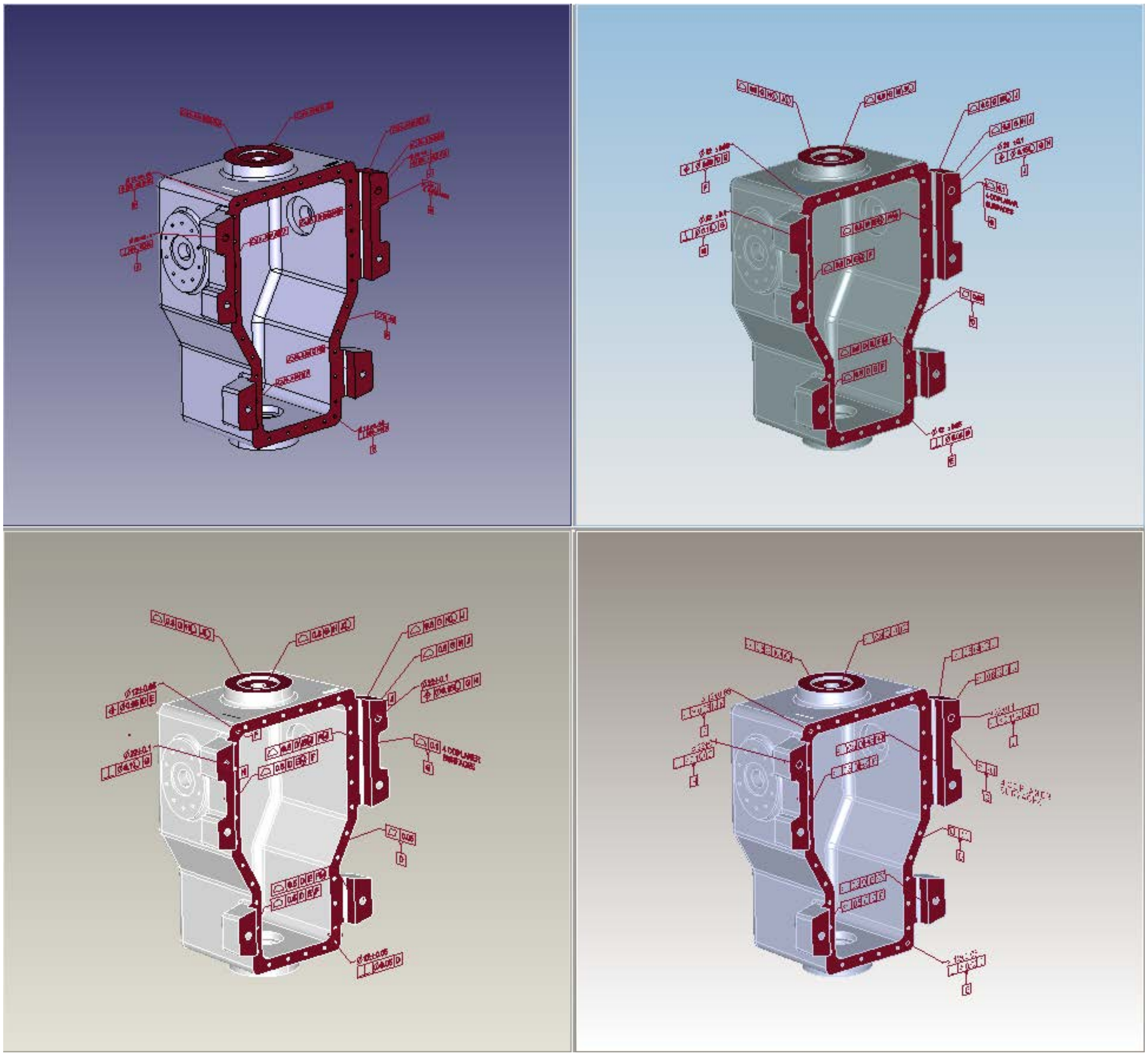
Combined Test Case 2
Saved View MBD_B

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



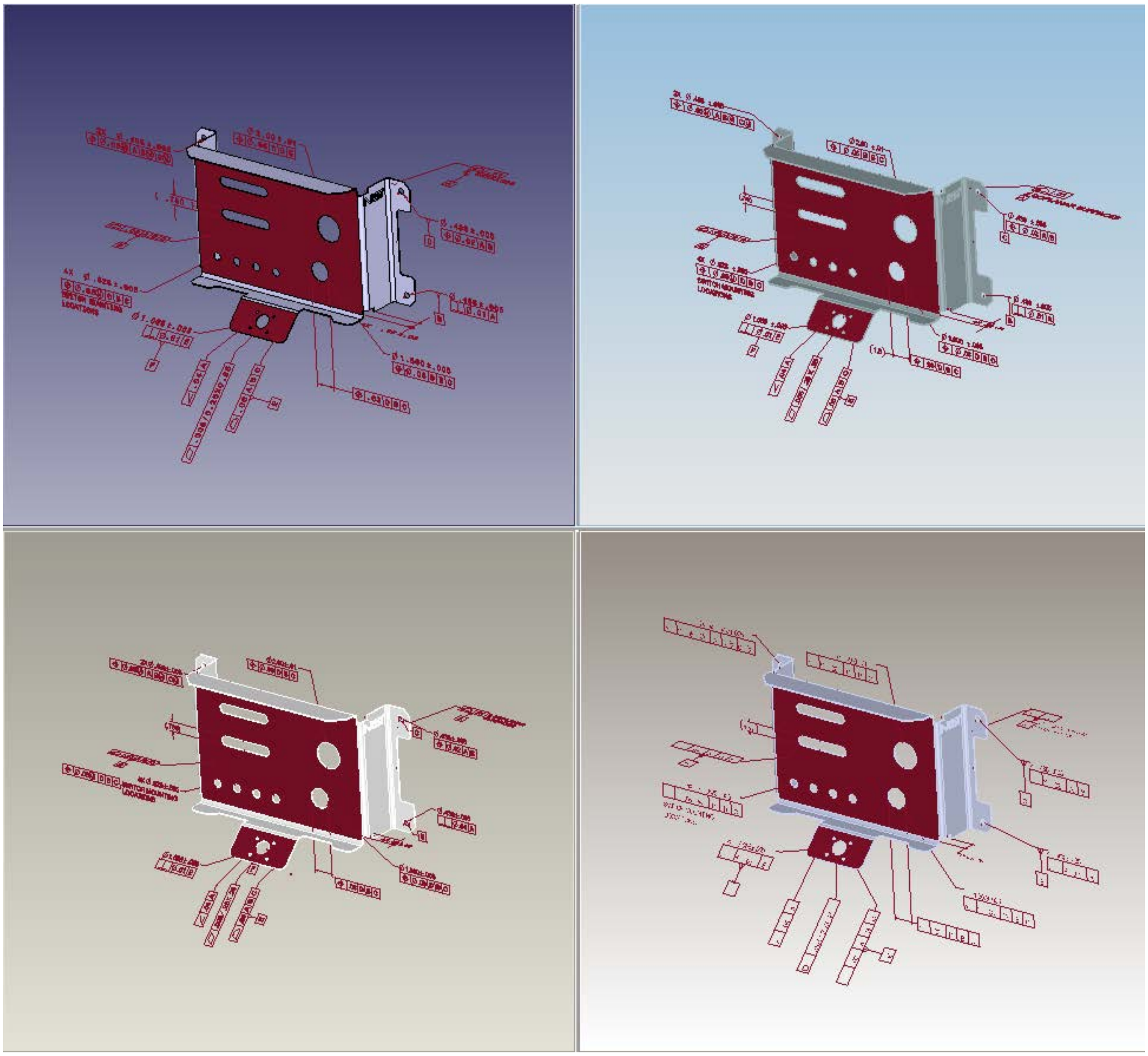
Combined Test Case 2
Saved View MBD_C

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



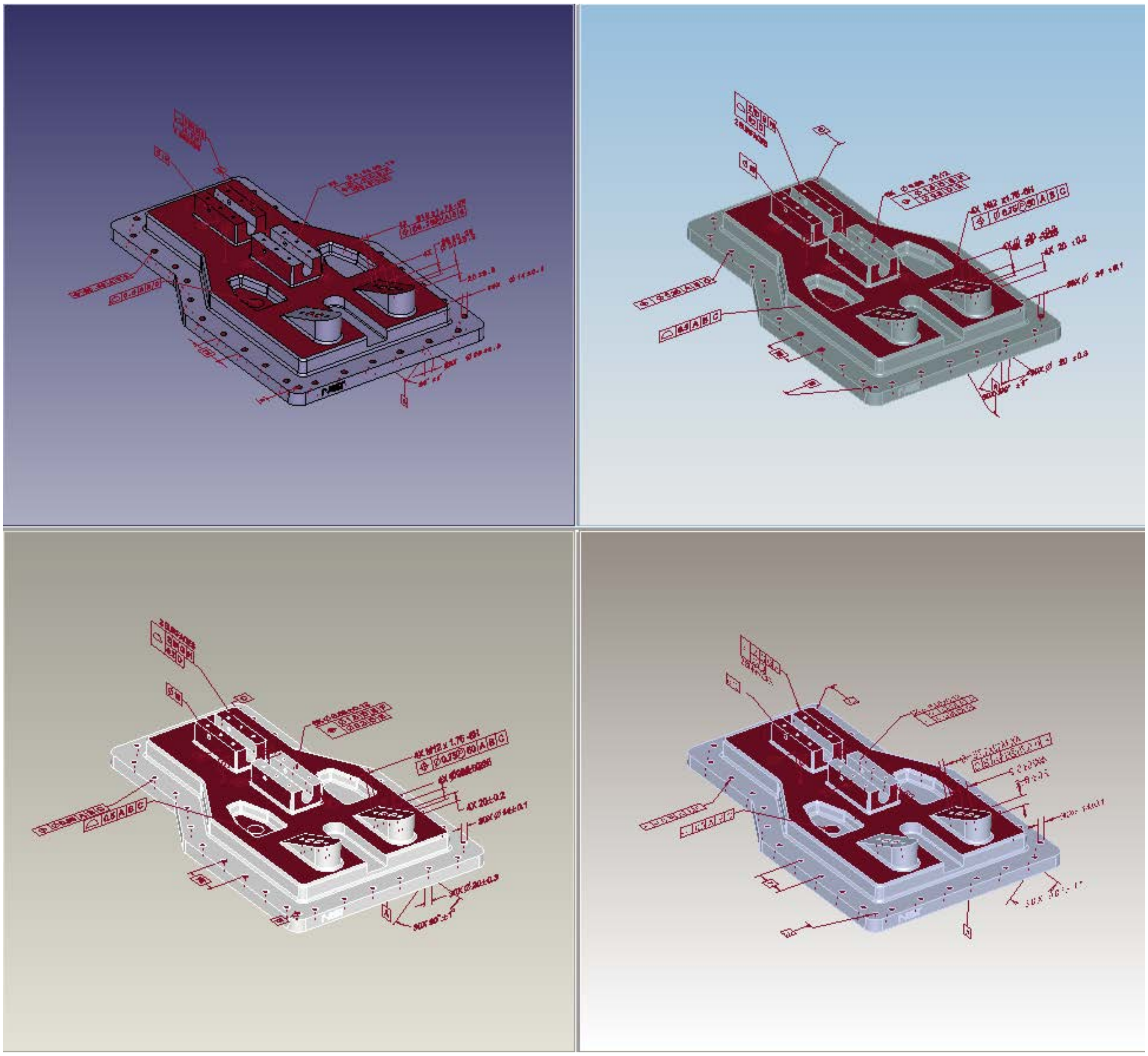
Combined Test Case 3
Saved View MBD_0

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



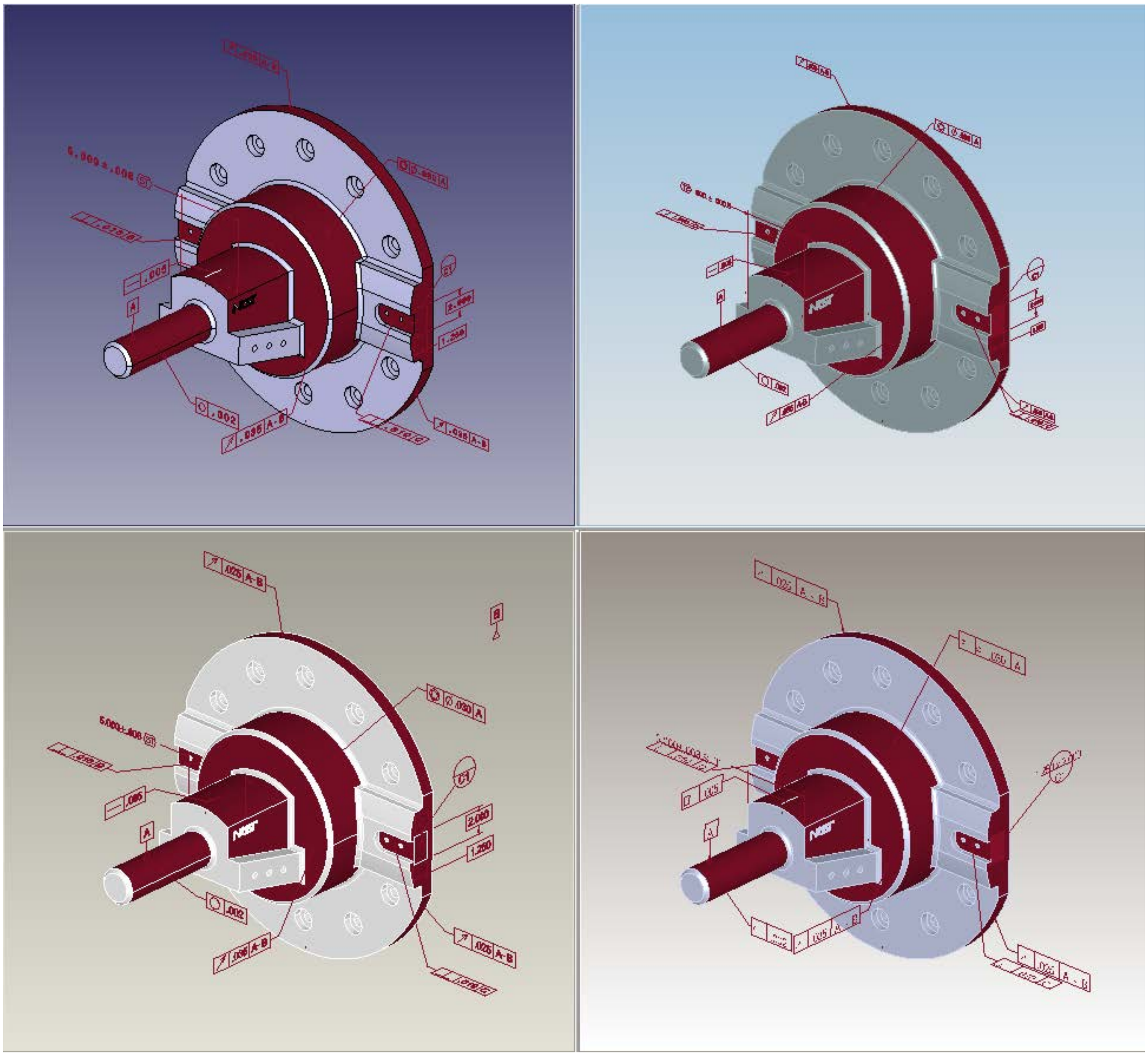
Combined Test Case 4
Saved View MBD_0

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



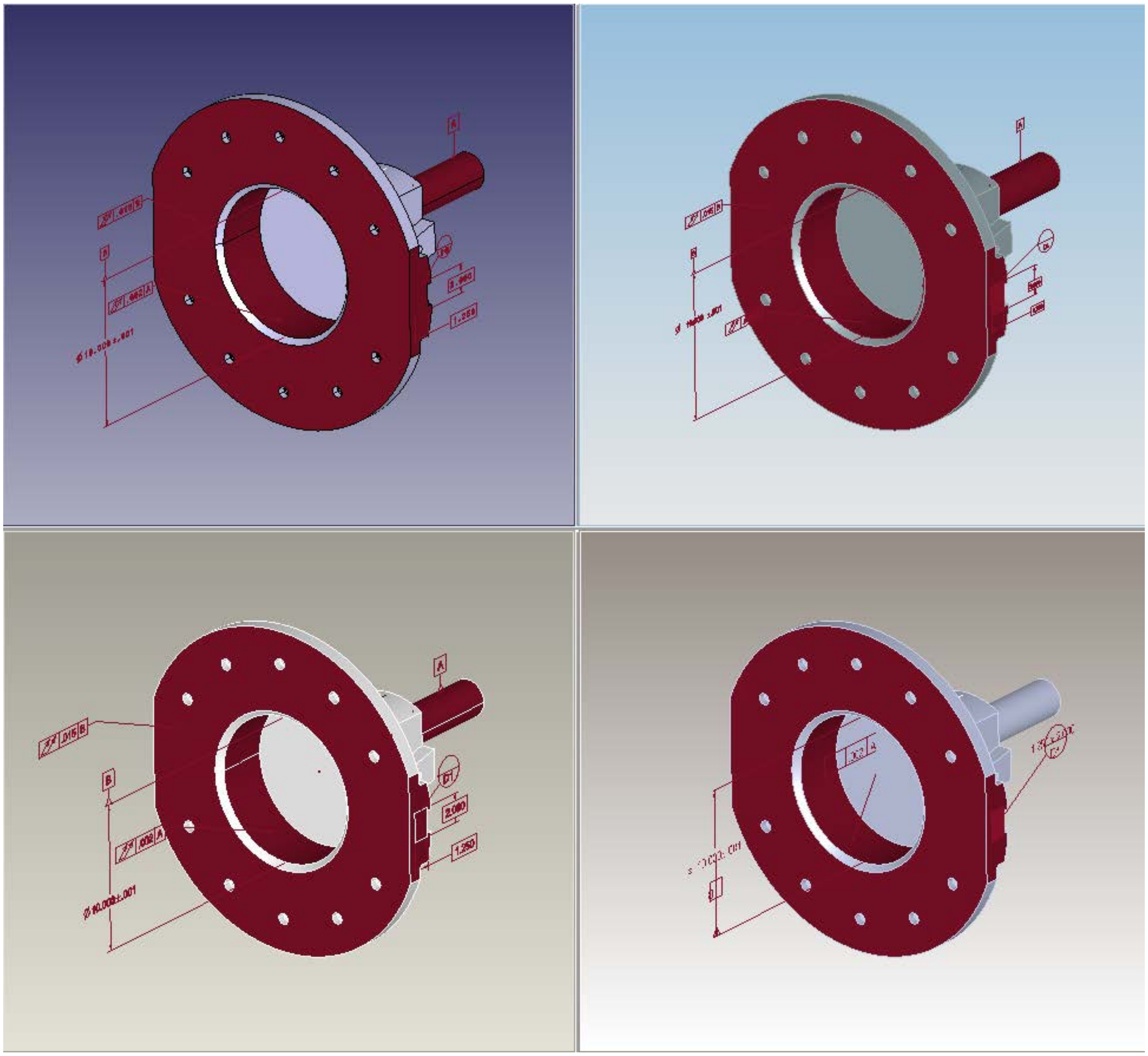
Combined Test Case 5
Saved View MBD_A

- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



Combined Test Case 5
Saved View MBD_B

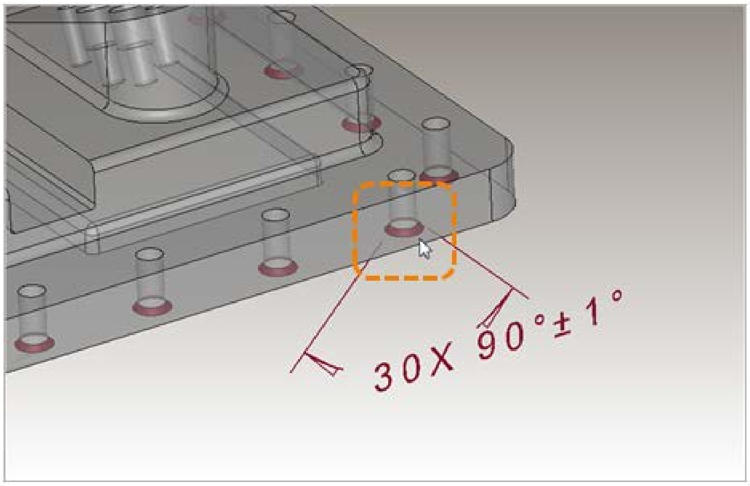
- Clockwise from upper left - Test Models for CATIA V5 R21, NX 8.0, SOLIDWORKS 2012 and Creo 2.0
- Screenshot is of each test model displayed in CADIQ
- Annotations and their associated geometry are highlighted in red



Appendix D: Representation Limitation Examples

Annotation Structure: Countersink diameter DIM not defined

Representation Limitation

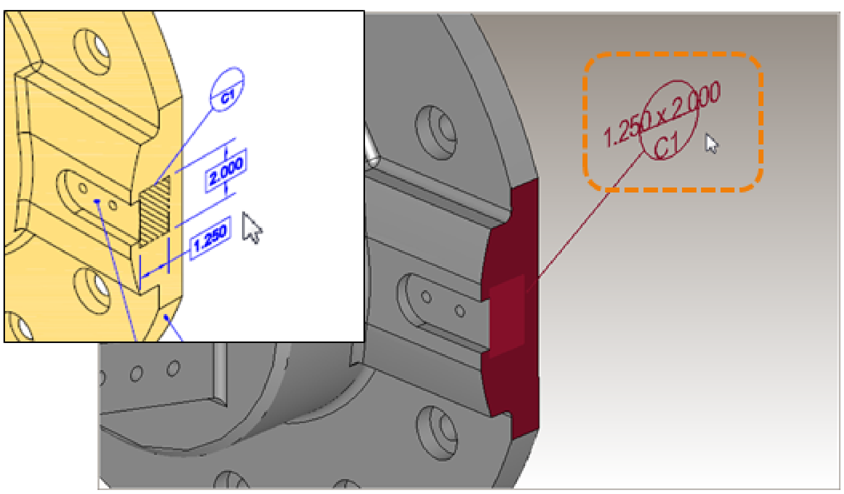


The diameter dimension for the outside (larger, circular) edge of this countersink is not defined.

Annotation Structure: DIM defined as part of DTS

Representation Limitation

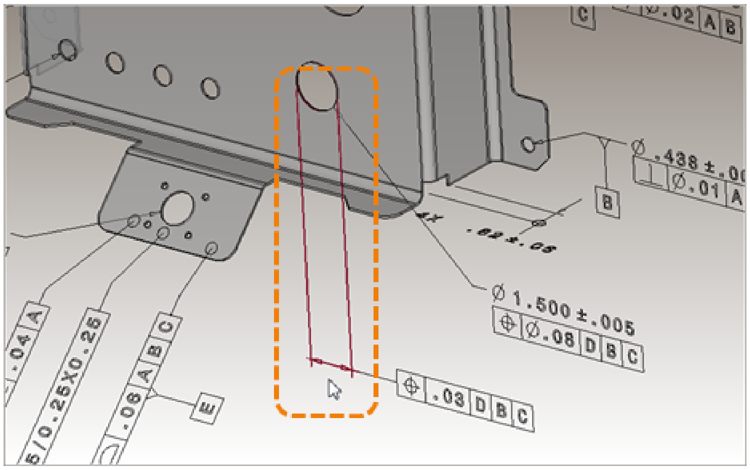
Test Case



The dimensions for the target area of this datum target are represented as parameters in the datum target symbol and not as separate dimensions.

Representation Limitation

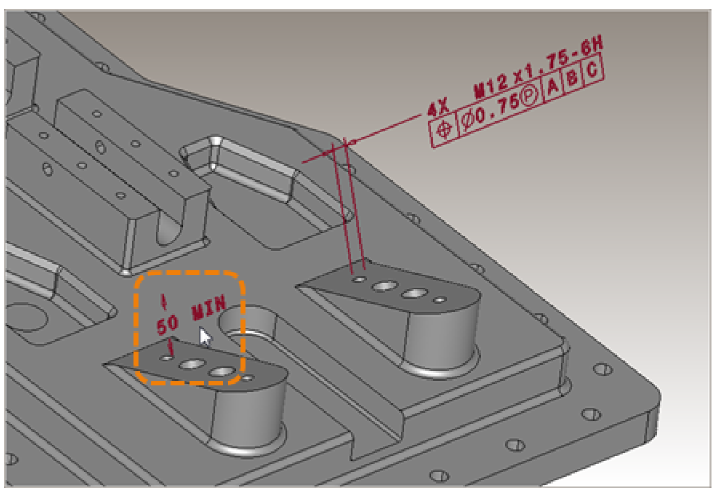
Annotation Structure:
FCF extension line defined as separate DIM



The extension lines for this feature control frame, whose orientation is critical to the tolerance zone definition, are defined as a separate dimension with no displayed value.

Representation Limitation

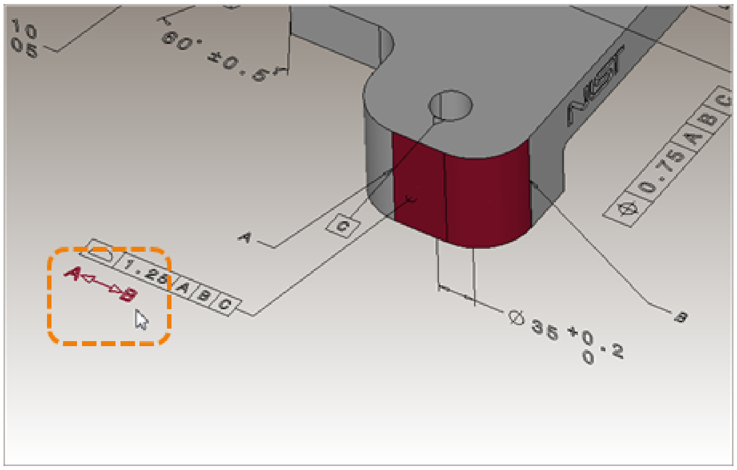
Annotation Structure:
FCF projected tolerance zone defined as separate DIM



The length of the projected tolerance zone for this feature control frame is defined as a separate dimension.
(See related Presentation Limitation)

Representation Limitation

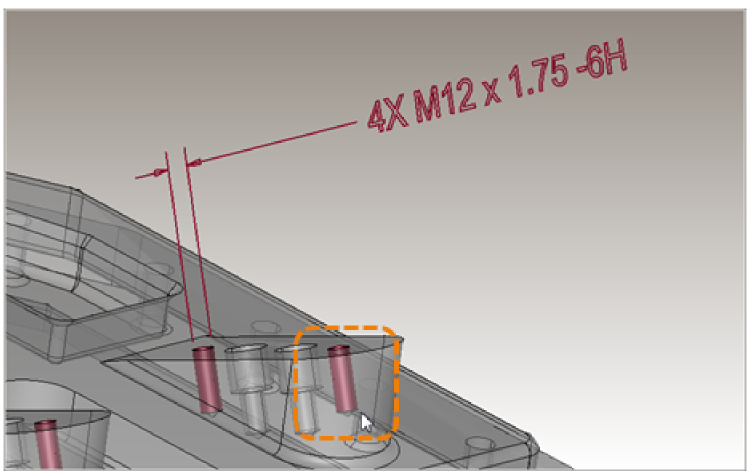
Annotation Structure:
FCF text defined as separate note



The text which defines the between-basis for this feature control frame is defined as a separate note annotation.

Representation Limitation

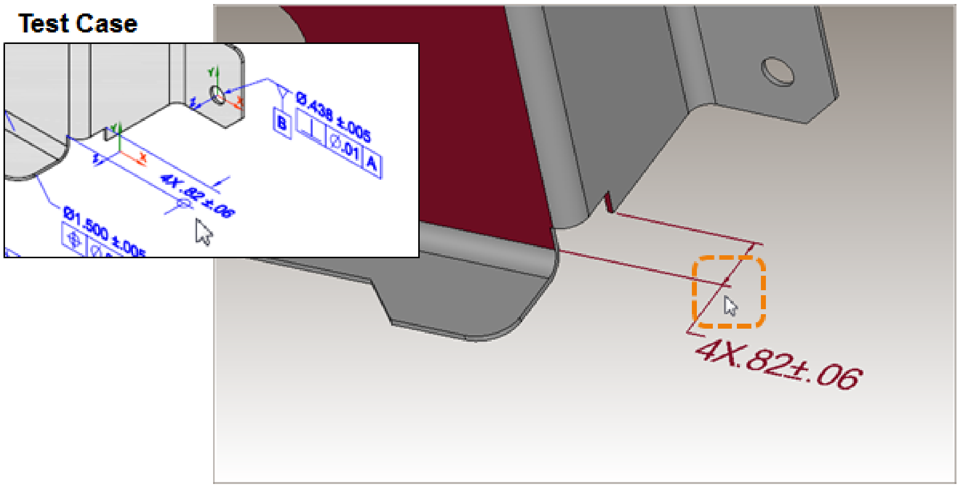
Annotation Structure:
Threaded hole depth DIM not defined



The depth dimension for each threaded hole, between the top (flat) surface and the bottom (circular) edge, is not defined.

Annotation Parameters: DIM origin not defined

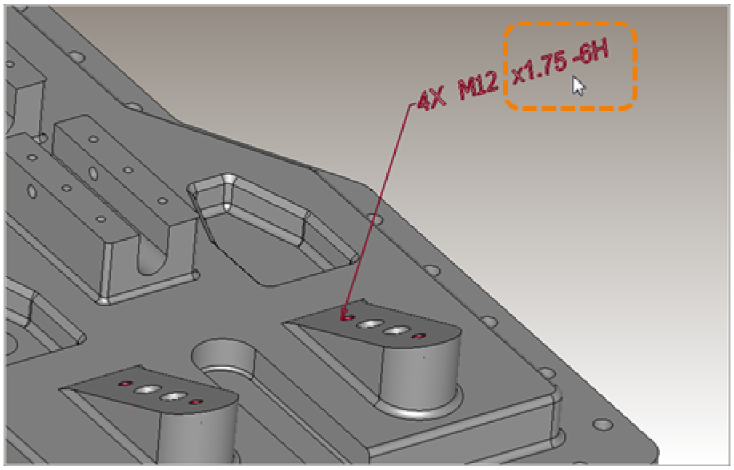
Representation Limitation



The origin for this oriented dimension is not defined.

Annotation Parameters: DIM parameter defined with encoded text

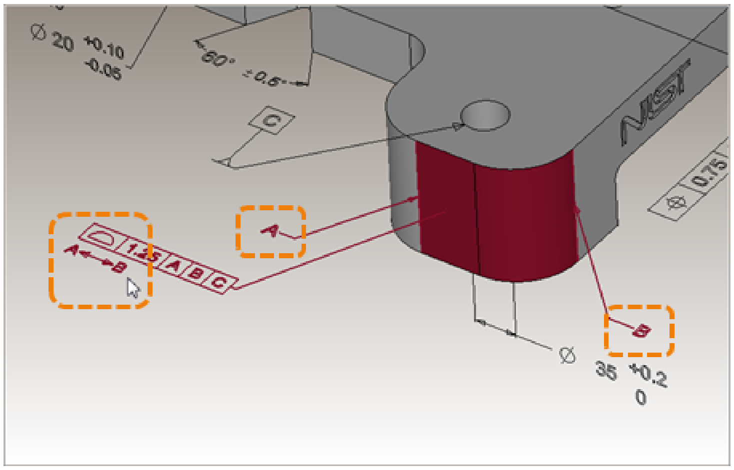
Representation Limitation



The thread parameters for this threaded hole dimension are defined as encoded text and not as named parameters.

Representation Limitation

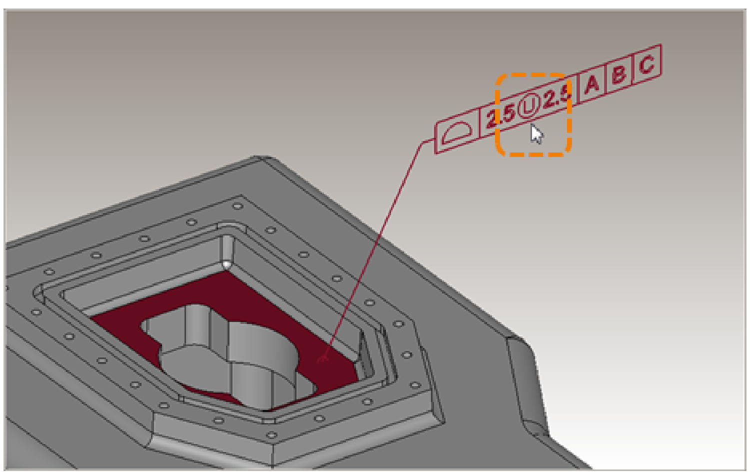
Annotation Parameters:
FCF between-basis defined with encoded text



The between-basis for this feature control frame is defined as encoded text and not with named parameters.

Representation Limitation

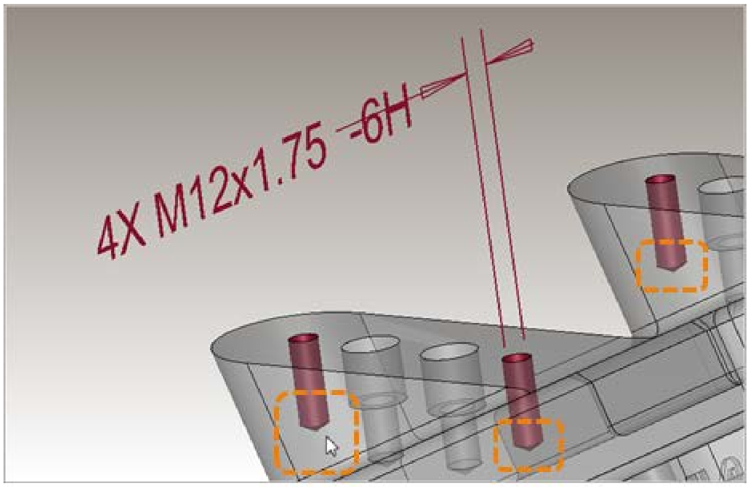
Annotation Parameters:
FCF parameter defined with encoded text



The unequally disposed modifier in this feature control frame is defined as a text symbol and not as a named parameter.

Annotation Geometry: DIM associated with extra face

Representation Limitation

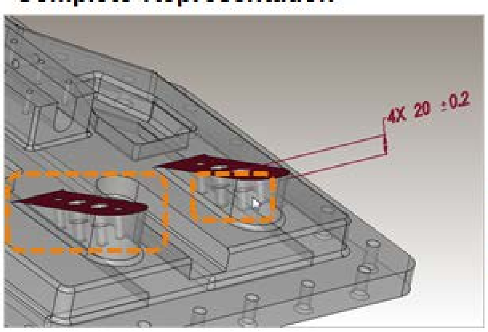


This hole diameter dimension is associated with the bottom face of each hole and not just the side faces.

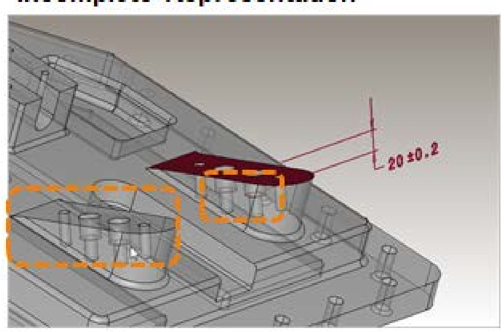
Annotation Geometry: DIM not associated with complete set of faces

Representation Limitation

Complete Representation



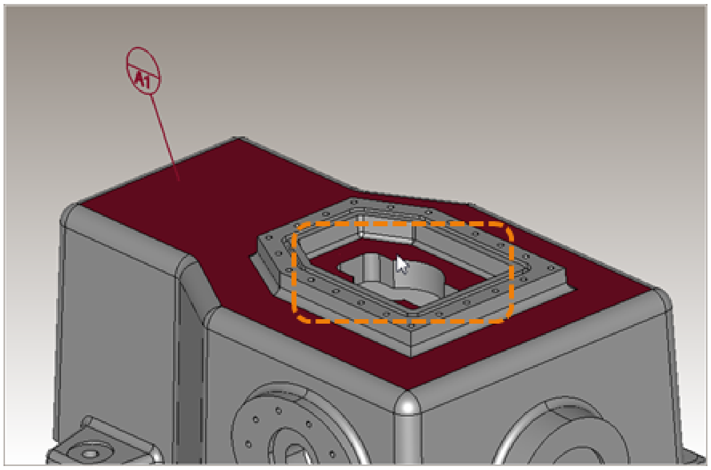
Incomplete Representation



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

Annotation Geometry: DTS associated with extra face

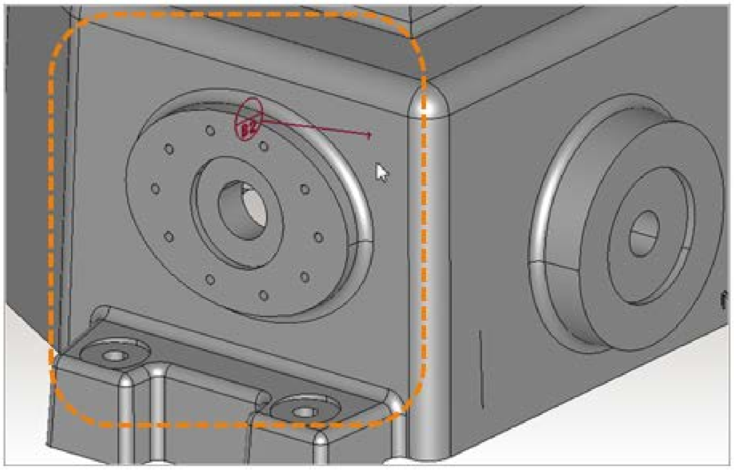
Representation Limitation



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

Annotation Geometry: DTS not associated with face

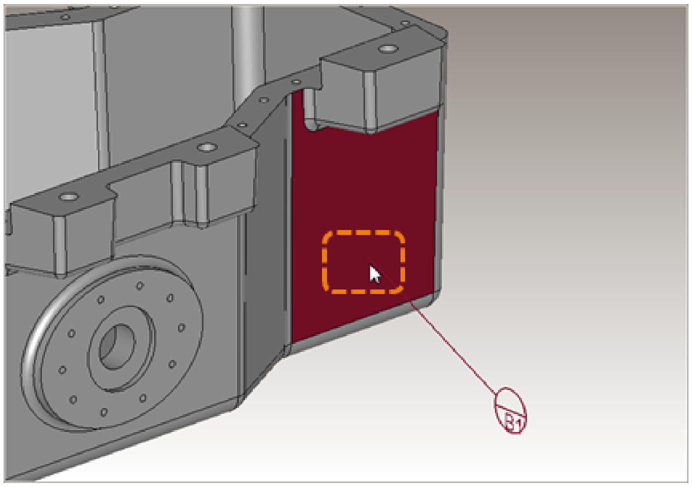
Representation Limitation



This datum target symbol is not associated with the face on which the datum target is located.

Annotation Geometry: DTS not associated with SG point

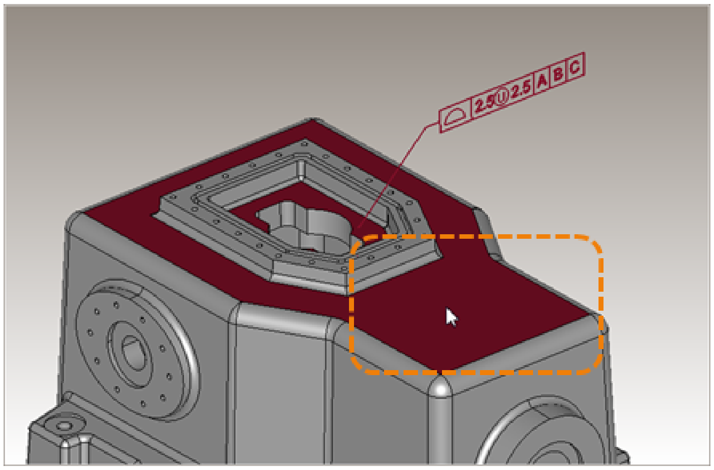
Representation Limitation



This datum target symbol is not associated with the supplemental geometry point that defines its location on the face.

Annotation Geometry: FCF associated with extra face

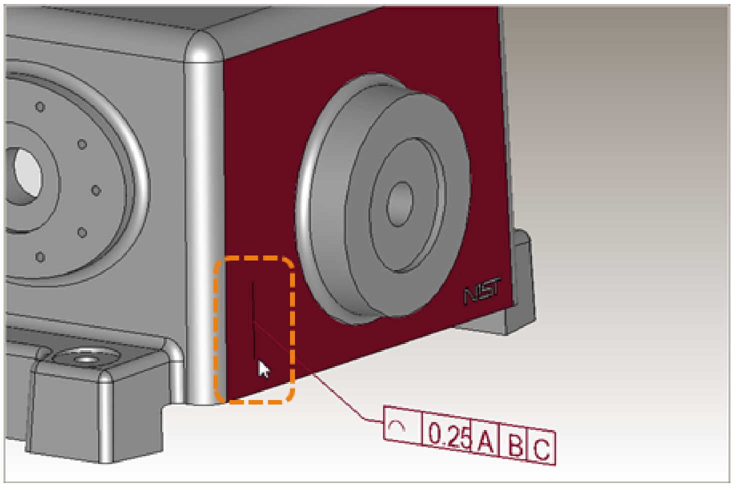
Representation Limitation



This feature control frame is associated with an extra (coplanar) face and not just the specified face.

Annotation Geometry: FCF not associated with SG curve

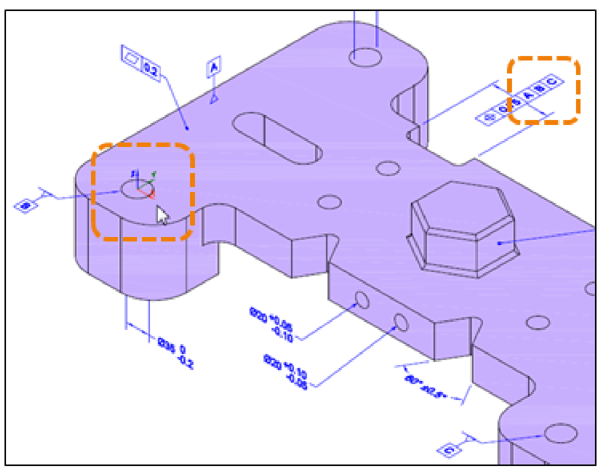
Representation Limitation



This feature control frame is not associated with the supplemental geometry curve that defines its profile direction on this face.

Coordinate System Structure: CS not linked to FCF DRF

Representation Limitation

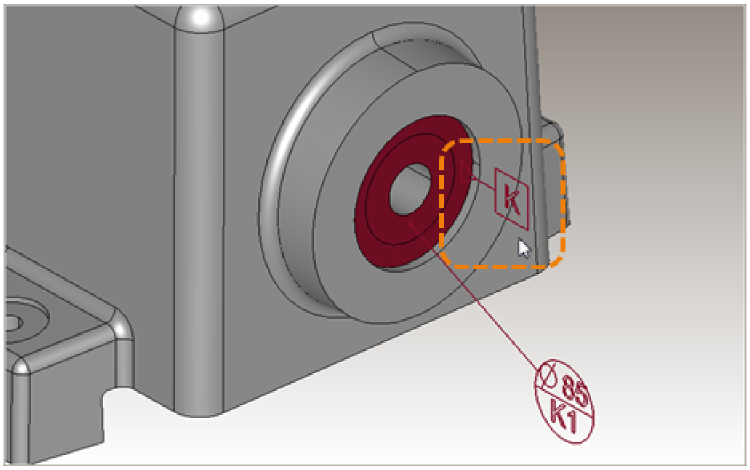


The model has no explicit (named) link from each feature control frame to the coordinate system that represents its datum reference frame.

Appendix E: Presentation Limitation Examples

Presentation Limitation

Annotation Visibility:
DFS is extraneous when DTS is defined

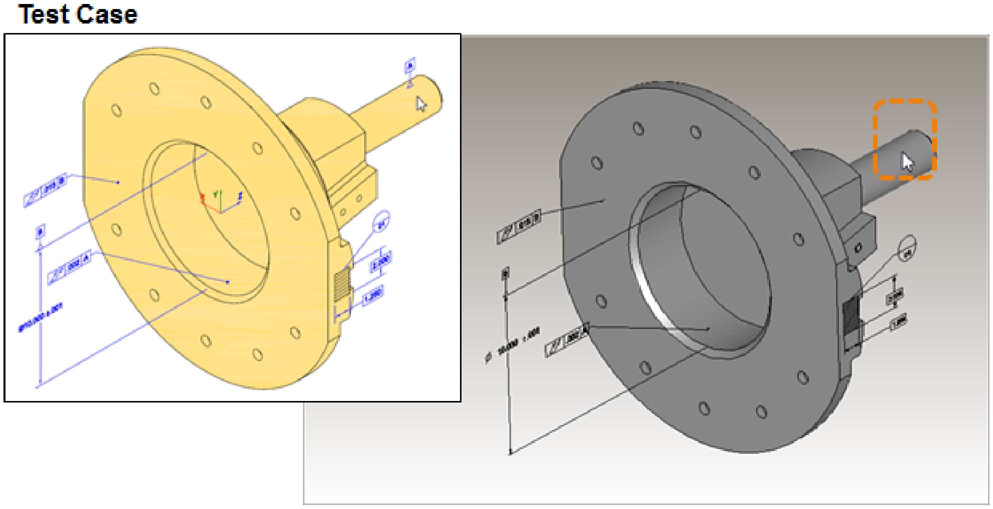


This datum feature symbol is not needed when the datum target symbol is defined. But the system will not allow it to be removed or hidden from this saved view.

Presentation Limitation

Annotation Visibility:
DFS not visible in specified view

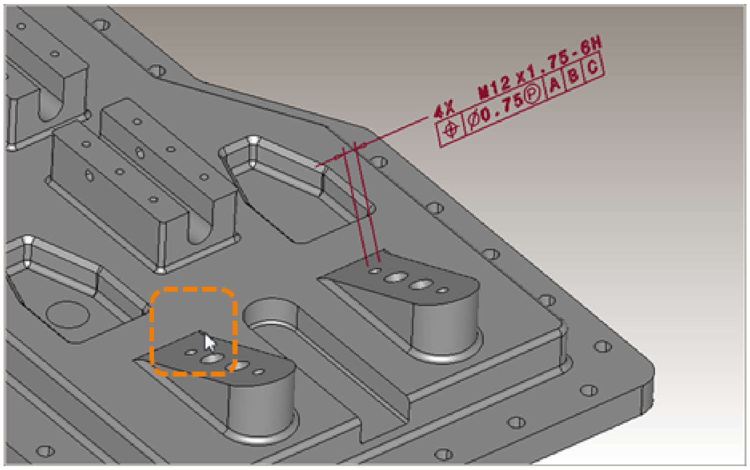
Test Case



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: DIM not visible in specified view

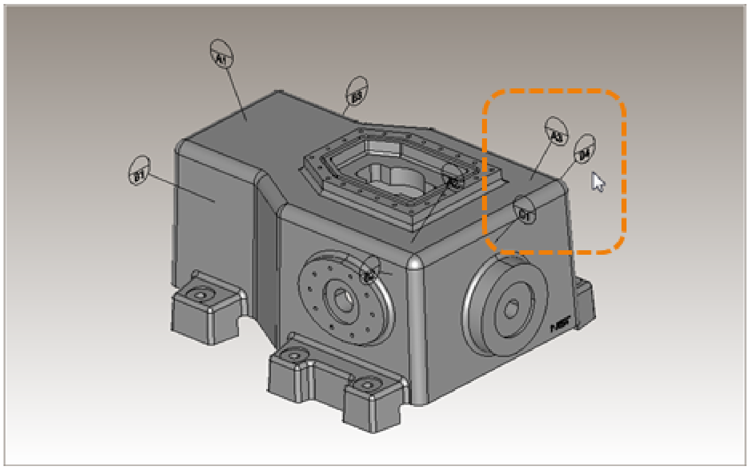
Presentation Limitation



The length of the projected tolerance zone for this feature control frame is defined as a separate dimension. (See related Representation Limitation) This dimension cannot be displayed in this saved view.

Annotation Visibility: DTS visible in wrong view

Presentation Limitation

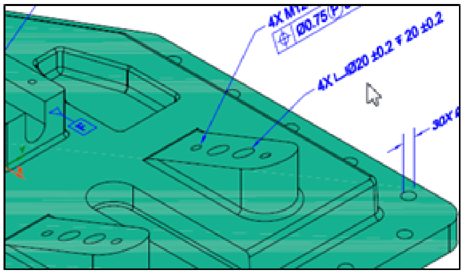


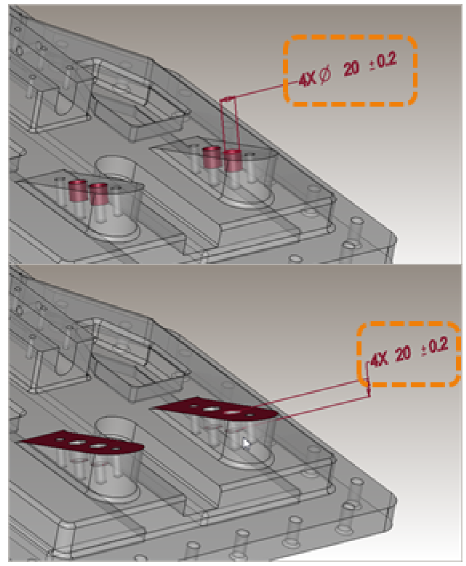
These datum target symbols are visible in a default (unspecified) saved view which cannot be deleted from the model.

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

Presentation Limitation

Test Case



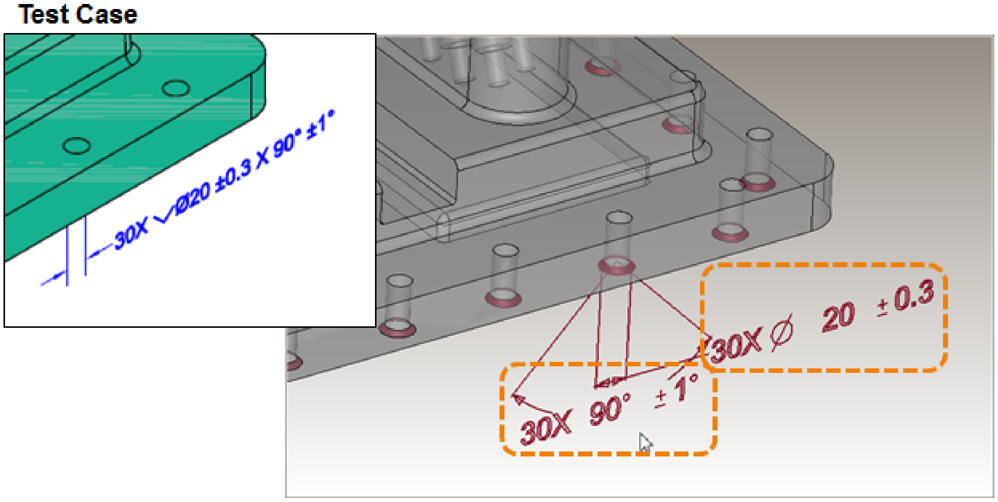


This counterbore dimension cannot be defined as a single annotation with named parameters that each have correct face associations. It must be defined as two separate dimensions.

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

Presentation Limitation

Test Case

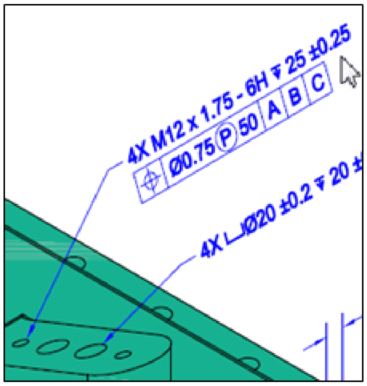


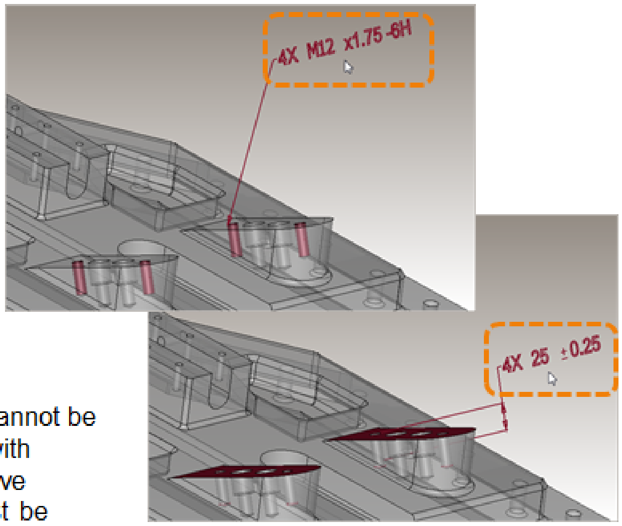
This countersink dimension cannot be defined as a single annotation with named parameters that each have correct face associations. It must be defined as two separate dimensions.

Annotation Layout:
Threaded hole DIM defined as two separate DIM's

Presentation Limitation

Test Case



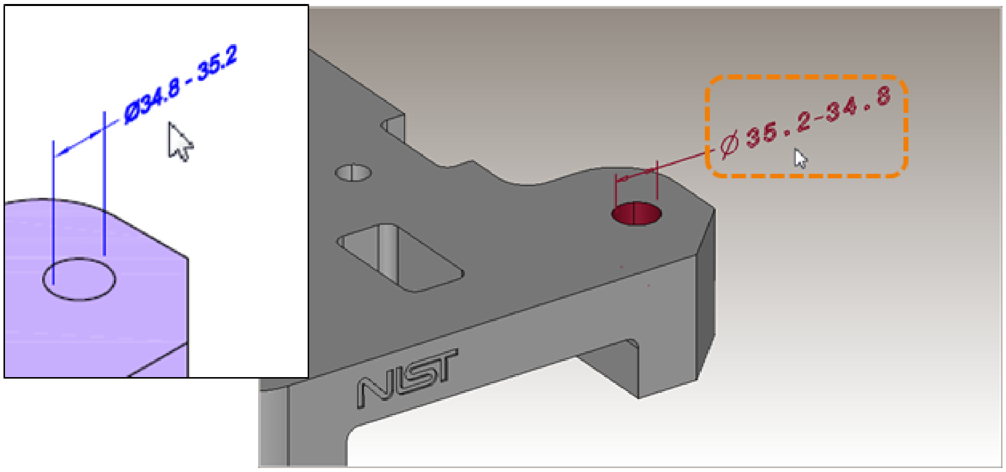


This threaded hole dimension cannot be defined as a single annotation with named parameters that each have correct face associations. It must be defined as two separate dimensions.

Annotation Layout:
DIM limits displayed in reversed order

Presentation Limitation

Test Case

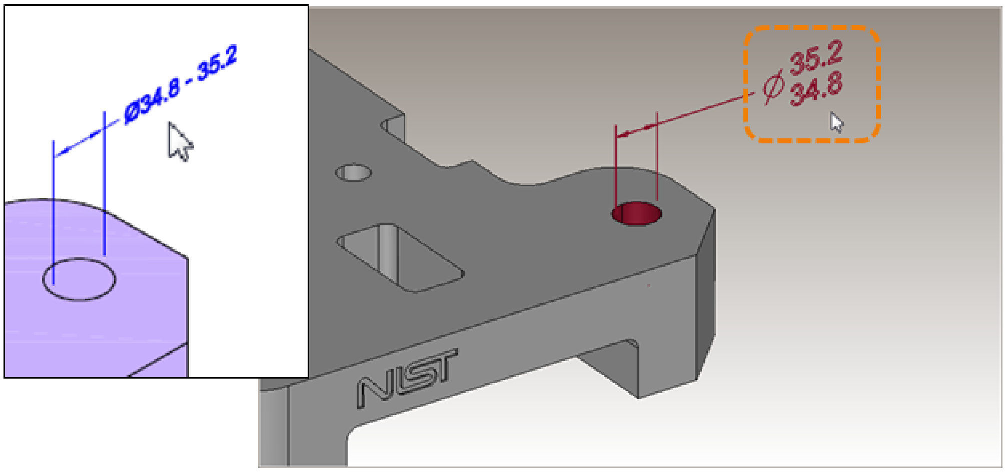


The lower and upper limits of this dimension are displayed in the reverse order from what is specified.

Annotation Layout: DIM limits not displayed horizontally

Presentation Limitation

Test Case

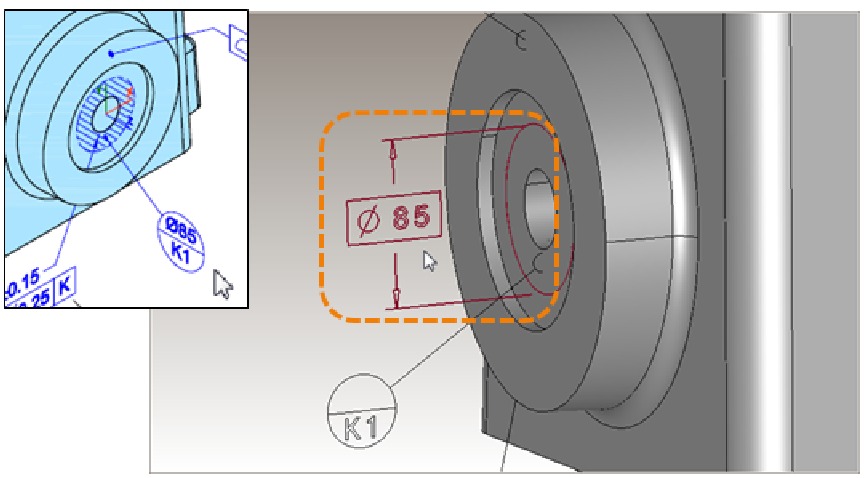


The lower and upper limits of this dimension are not displayed horizontally as specified.

Annotation Layout: DTS target area diameter defined as separate DIM

Presentation Limitation

Test Case

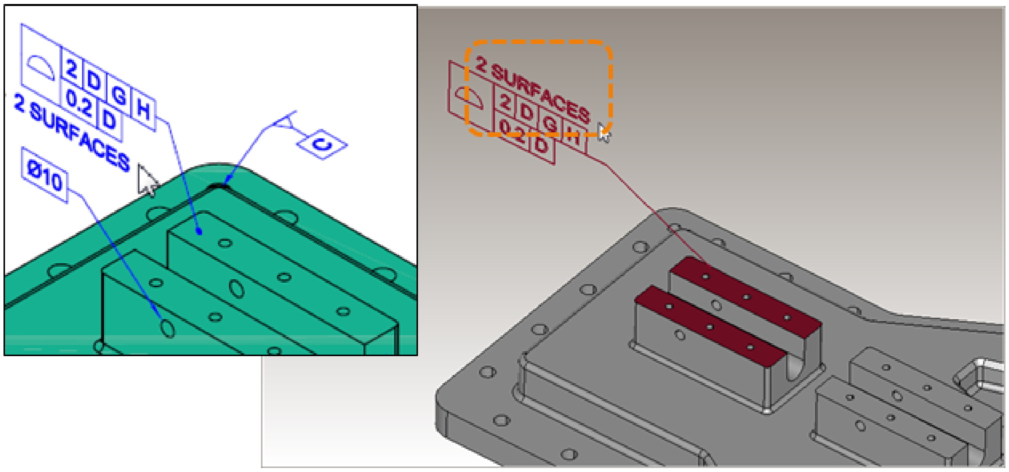


The diameter of this datum target area is defined as a separate dimension and not shown in the upper half of the datum target symbol as specified.

Presentation Limitation

Annotation Layout:
FCF text displayed above rather than below

Test Case

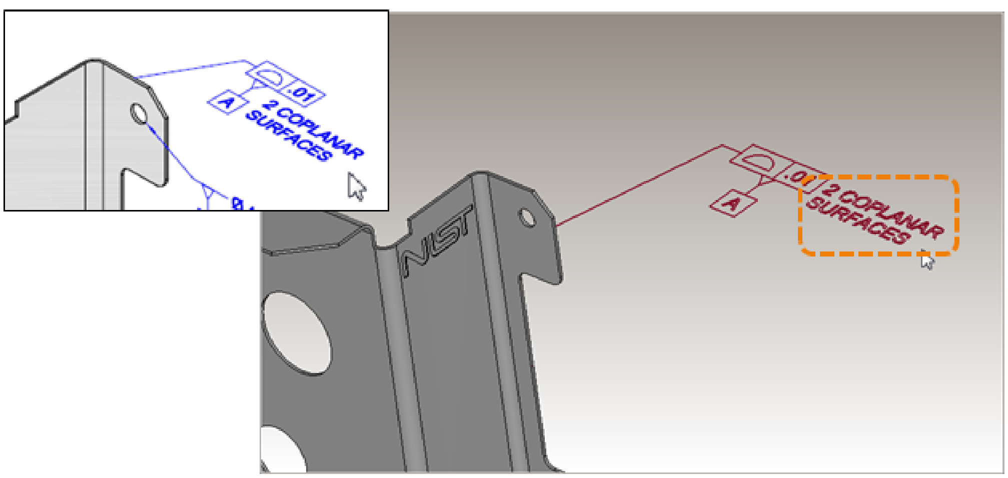


The “2 SURFACES” text is displayed above this feature control frame and not below as specified.

Presentation Limitation

Annotation Layout:
FCF text displayed on right rather than below

Test Case

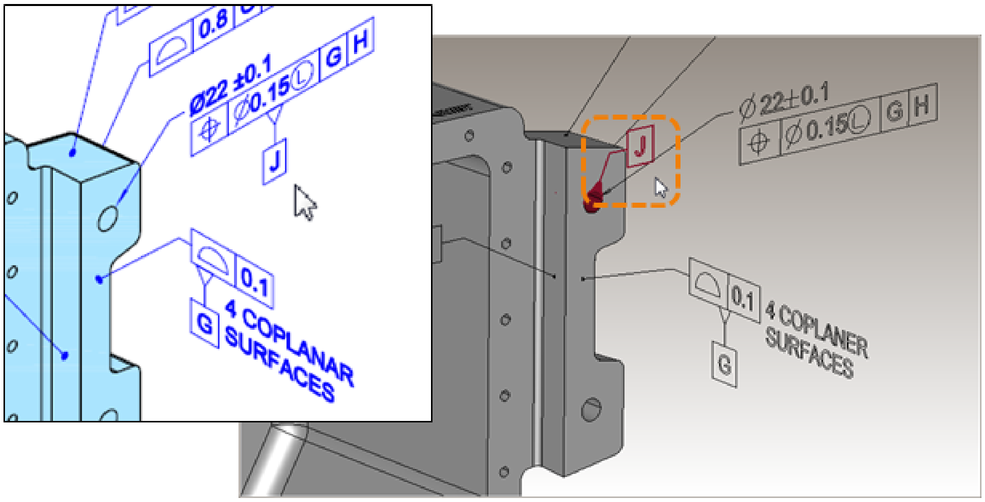


The “2 COPLANAR SURFACES” text is displayed on the right of this feature control frame and not below as specified.

Annotation Location: DFS not attached to FCF

Presentation Limitation

Test Case

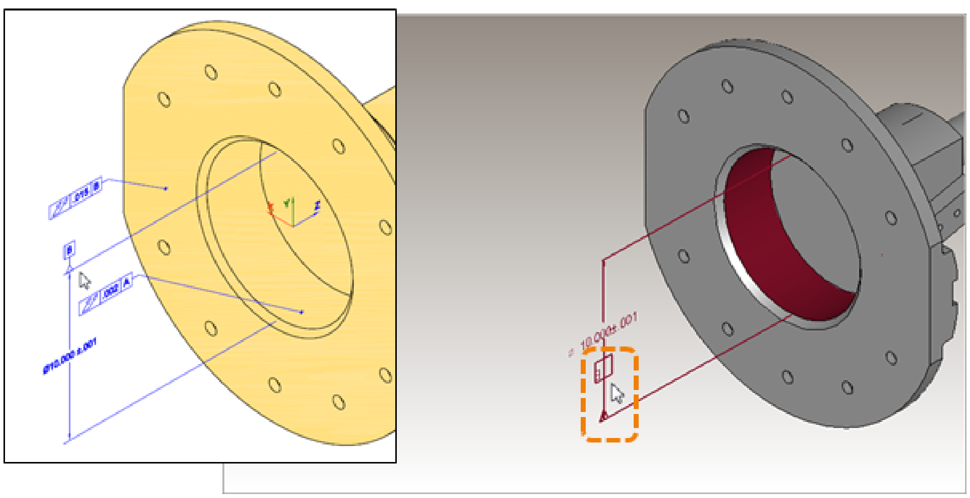


This datum feature symbol is not attached to the feature control frame as specified.

Annotation Location: DFS overlaps DIM graphics

Presentation Limitation

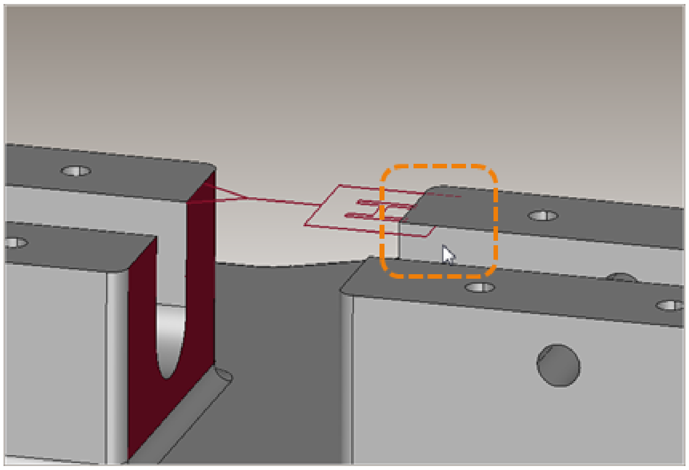
Test Case



The display of this datum feature symbol overlaps the dimension to which it is attached.

Annotation Location: DFS partially buried in solid

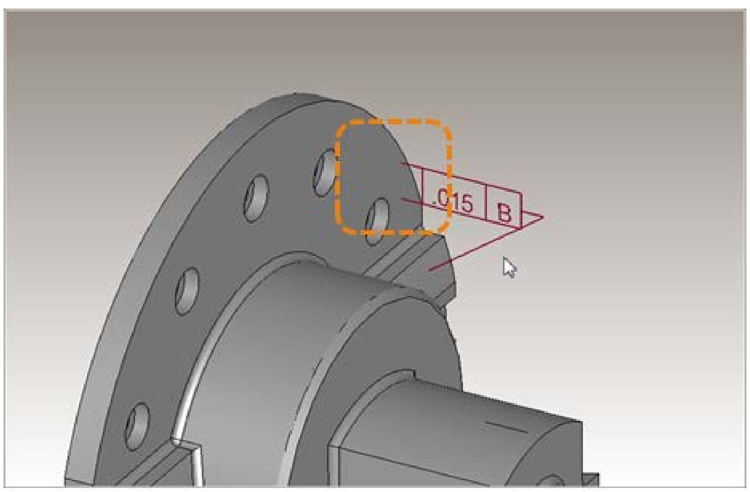
Presentation Limitation



A portion of this datum feature symbol extends into the solid model, obscuring its display.

Annotation Location: FCF partially buried in solid

Presentation Limitation

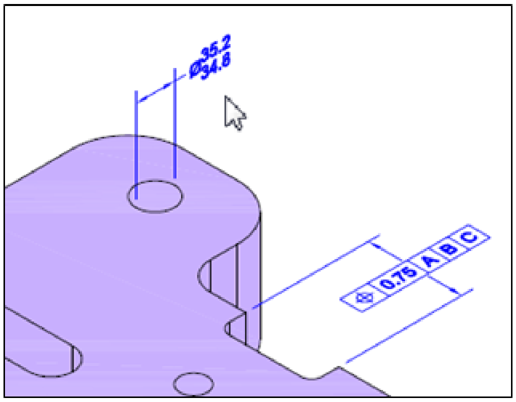


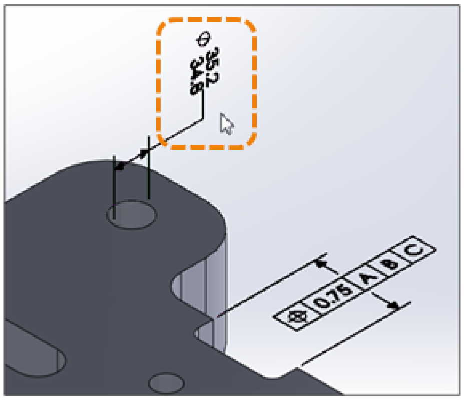
A portion of this feature control frame extends into the solid model, obscuring its display.

Annotation Orientation: DIM text orientation is wrong

Presentation Limitation

Test Case



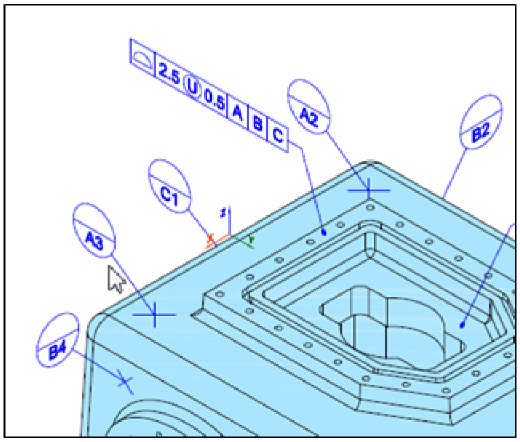


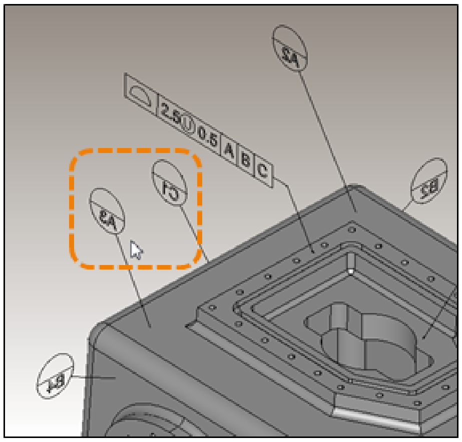
This dimension is not oriented horizontally as specified.

Annotation Orientation: DTS text is backwards in this view

Presentation Limitation

Test Case



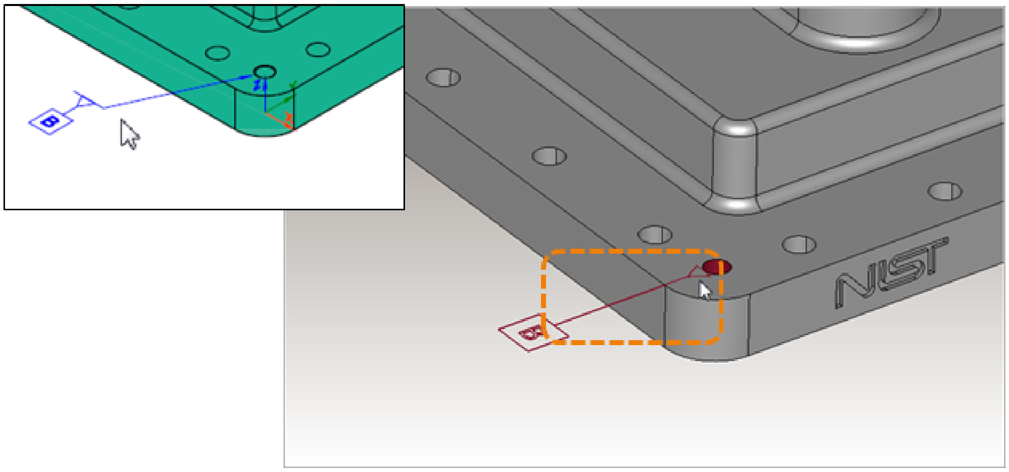


The read direction for the datum target symbols' text is backwards in this view from what is specified.

Presentation Limitation

Annotation Lines:
DFS has no extension line

Test Case

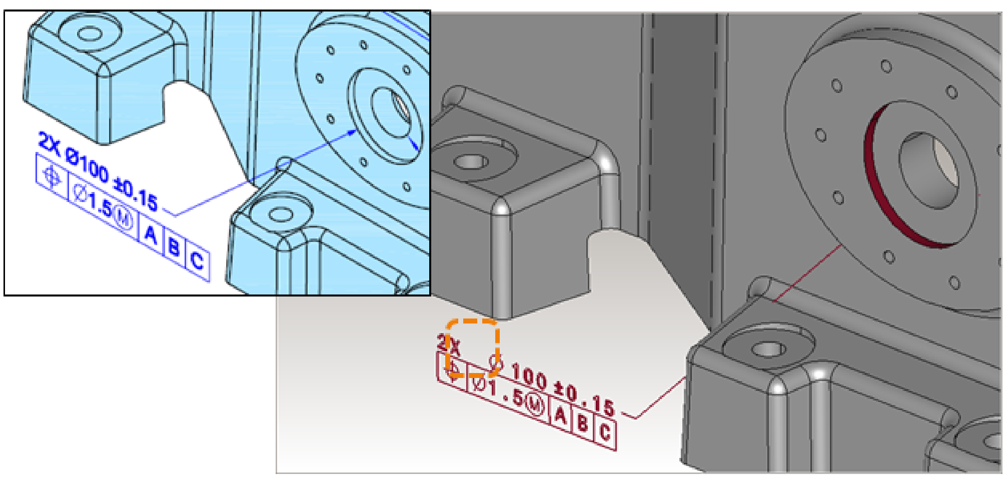


This datum feature symbol does not have the specified extension line.

Presentation Limitation

Annotation Text:
DIM has extraneous space

Test Case

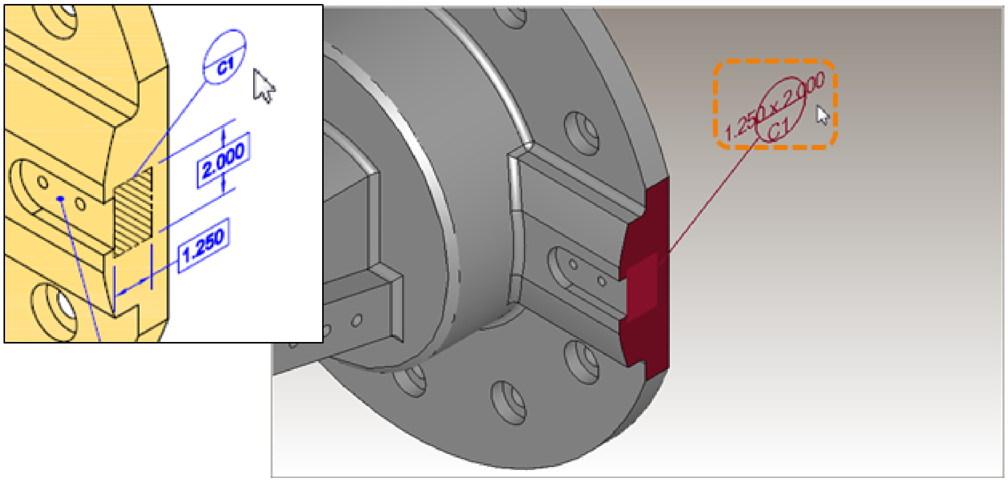


This dimension has an extra space after the pattern text ("2X") which is not specified.

Presentation Limitation

Annotation Text: DTS text is extraneous

Test Case

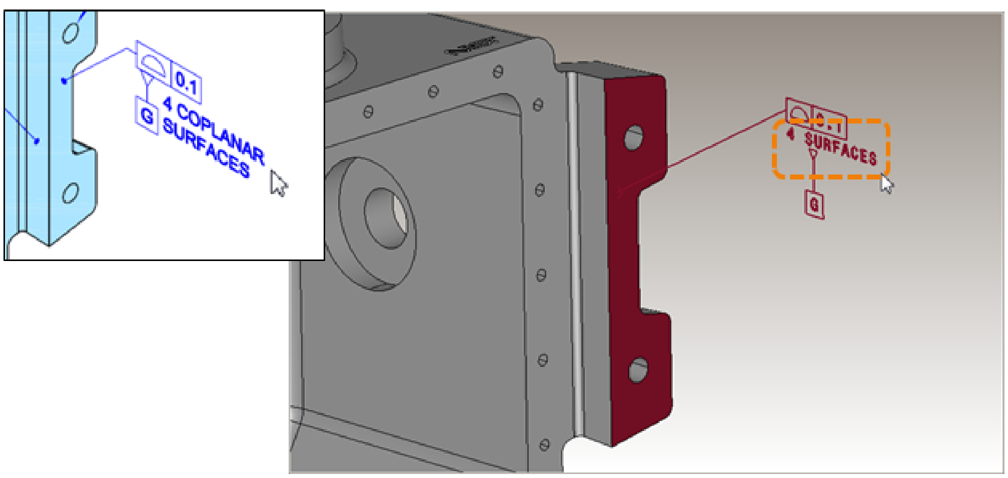


The target area dimensions shown in the upper half of this datum target symbol are not specified.

Presentation Limitation

Annotation Text: FCF missing note text

Test Case

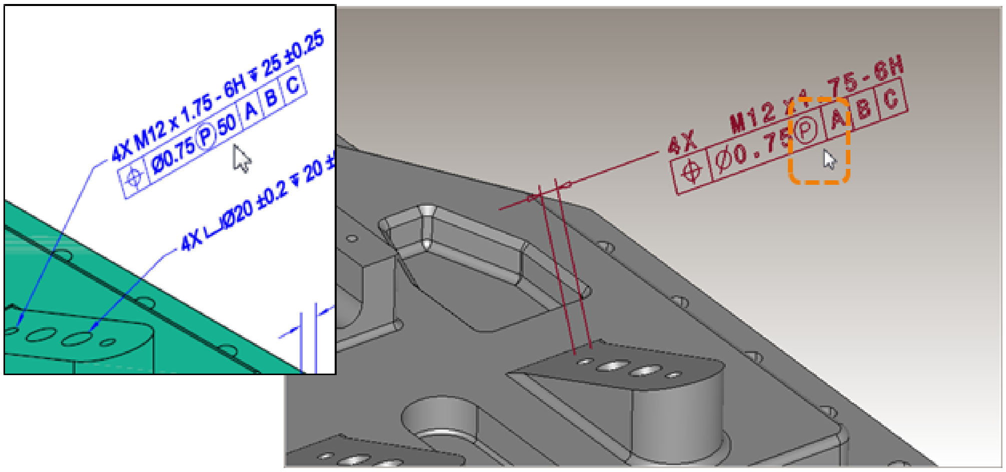


The specified “COPLANAR” text is missing for this feature control frame.

Annotation Text: FCF missing projected tolerance zone length

Presentation Limitation

Test Case

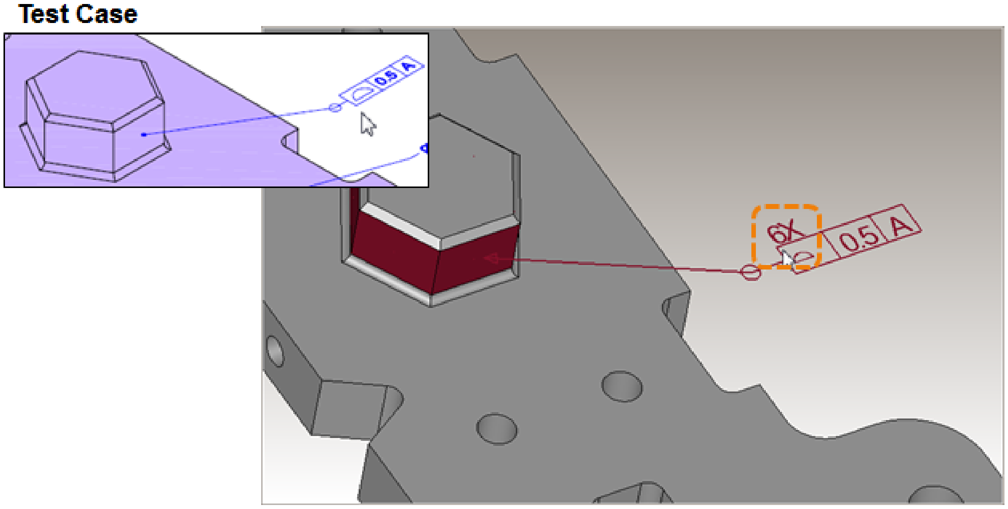


The length of the projected tolerance zone for this feature control frame is not display as specified.

Annotation Text: FCF text is extraneous

Presentation Limitation

Test Case

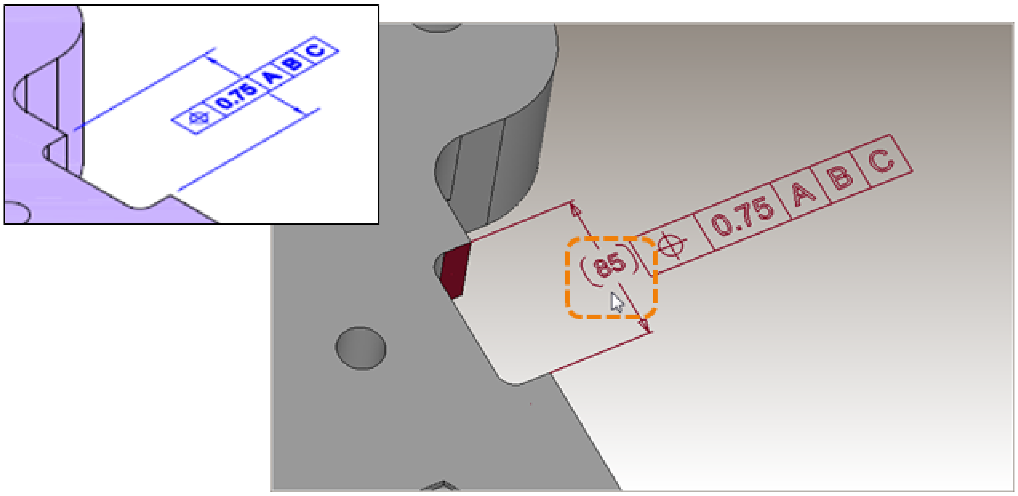


The “6X” text above this feature control frame is not specified in the test case and is extraneous with the all-around symbol.

Presentation Limitation

Annotation Text:
FCF text is extraneous

Test Case

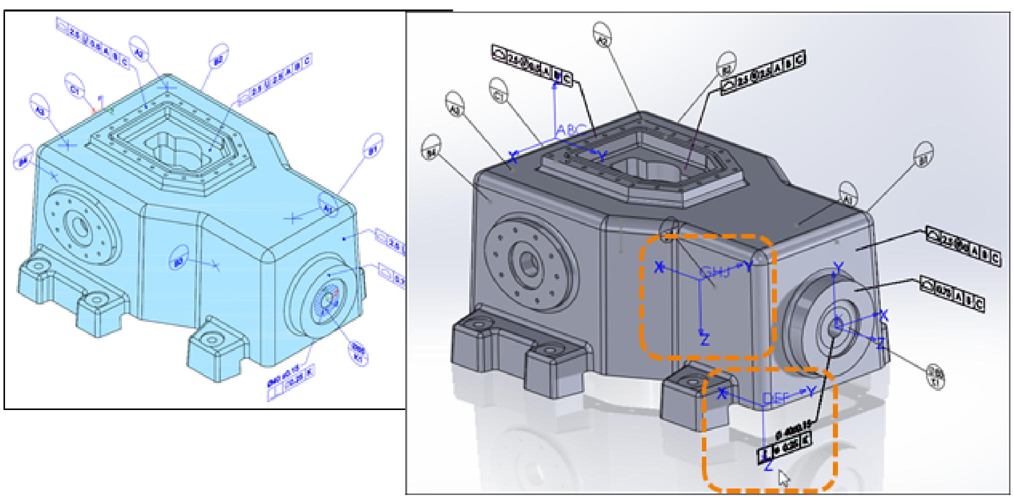


The “(85)” text on the left of this feature control frame is not specified in the test case.

Presentation Limitation

Coordinate System Visibility:
CS visible in wrong view

Test Case

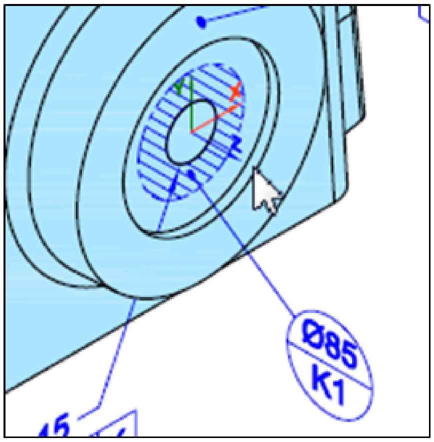


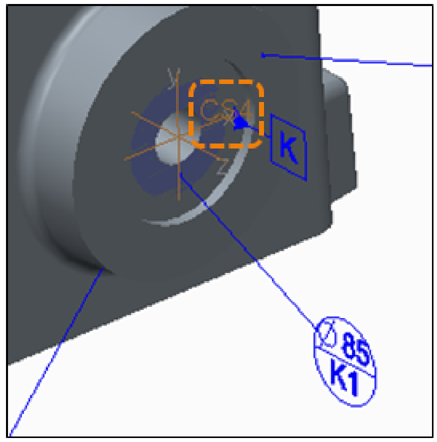
The “DEF” and “GHJ” coordinate systems are visible in a saved view in which they are not referenced.

Coordinate System Name: CS name not same as DRF

Presentation Limitation

Test Case





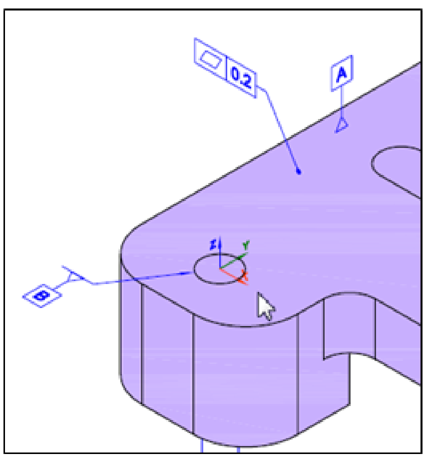
Because none of the systems enable an explicit link between annotations and coordinate systems, the name of each coordinate system should match its datum reference frame, thus providing an implicit (visual) link.

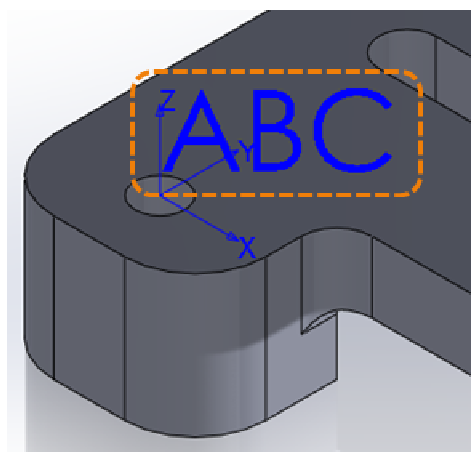
This coordinate system cannot be named with a single letter (“K”).

Coordinate System Text: CS name displayed with extra large text

Presentation Limitation

Test Case



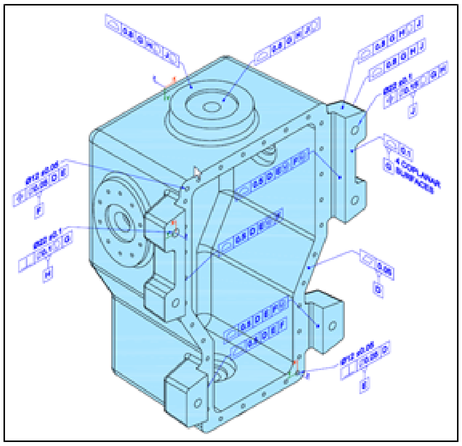


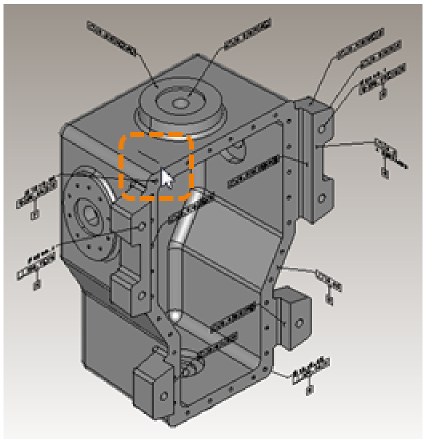
The display name for this coordinate system is extremely large.

Supplemental Geometry Visibility: SG curve visible in wrong view

Presentation Limitation

Test Case



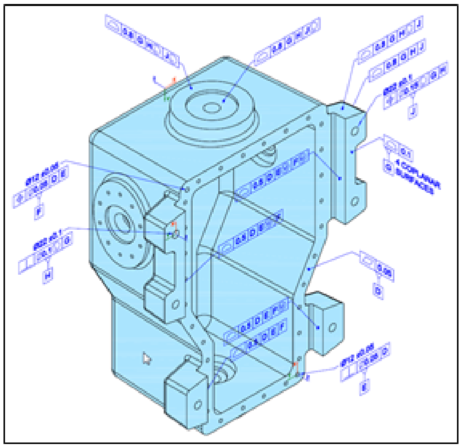


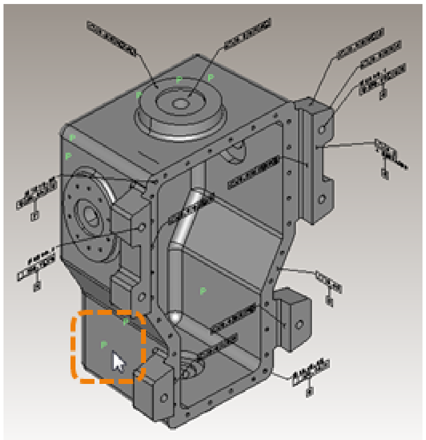
Because the profile of a line feature control frame in this model is not specified as visible in this saved view, then its associated supplemental geometry curve should not be visible.

Supplemental Geometry Visibility: SG point visible in wrong view

Presentation Limitation

Test Case



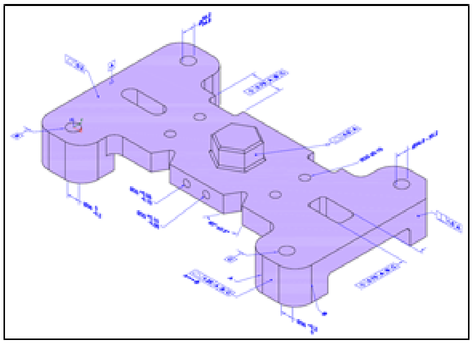


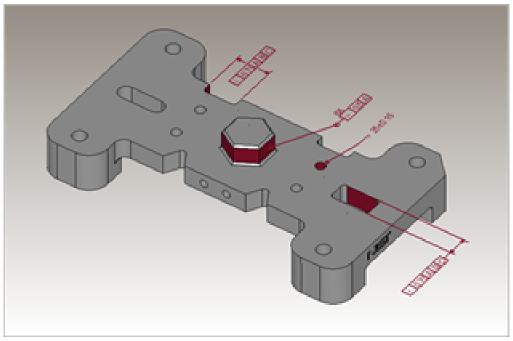
Because the datum targets for this model are not specified as visible in this saved view, then their associated supplemental geometry points should not be visible.

Saved View Structure:
View cannot contain annotations on different planes

Presentation Limitation

Test Case



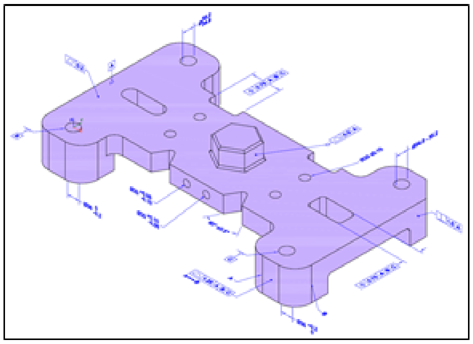


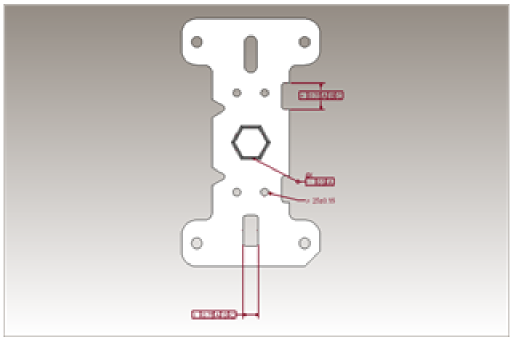
The PMI views in this system are limited to annotations with the same view and reading directions. The specified saved view has annotations with multiple view and reading directions.

Saved View Frustum:
View camera position not defined

Presentation Limitation

Test Case



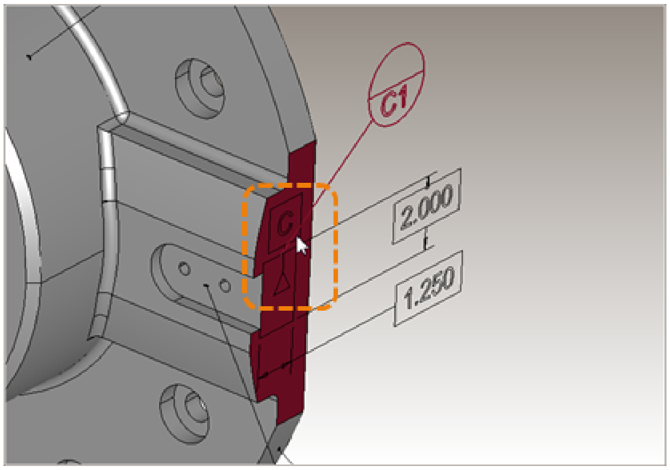


Each saved view in the test case has a specified camera position (view direction and zoom level). This system is unable to store a camera position in its PMI view definition.

Appendix F: Style Difference Examples

Style Difference

Annotation Structure: DTS requires DFS to be defined

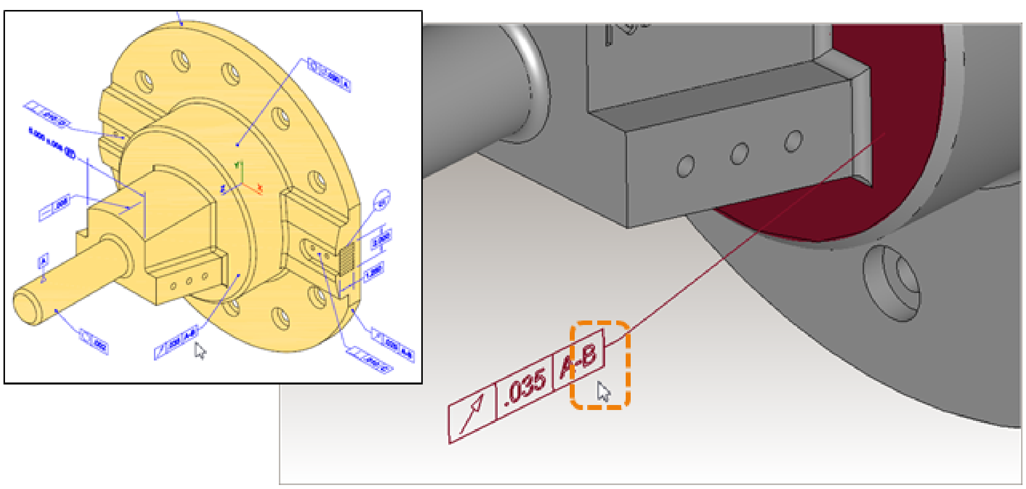


The system requires a datum feature symbol to be defined whenever a datum target symbol is defined.

Style Difference

Annotation Structure: FCF requires DFS to be defined

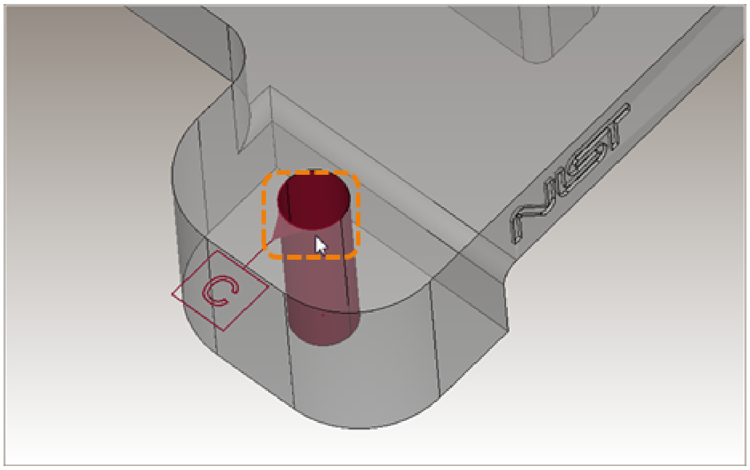
Test Case



Because this feature control frame references datum "B", its datum feature symbol must be defined in this saved view, although it can be hidden (not visible).

Annotation Geometry: DFS edge association is extraneous

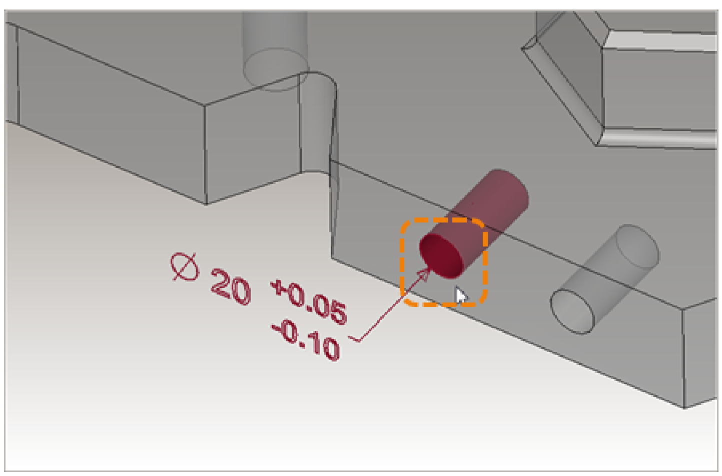
Style Difference



The association of this datum feature symbol with the edge of the hole is used to indicate graphical placement. It is not specified in the test case.

Annotation Geometry: DIM edge association is extraneous

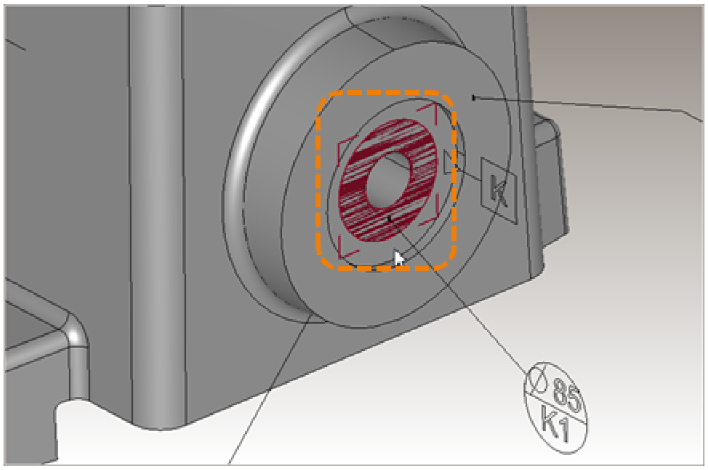
Style Difference



The association of this dimension with the edge of the hole is used to indicate graphical placement. It is not specified in the test case.

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

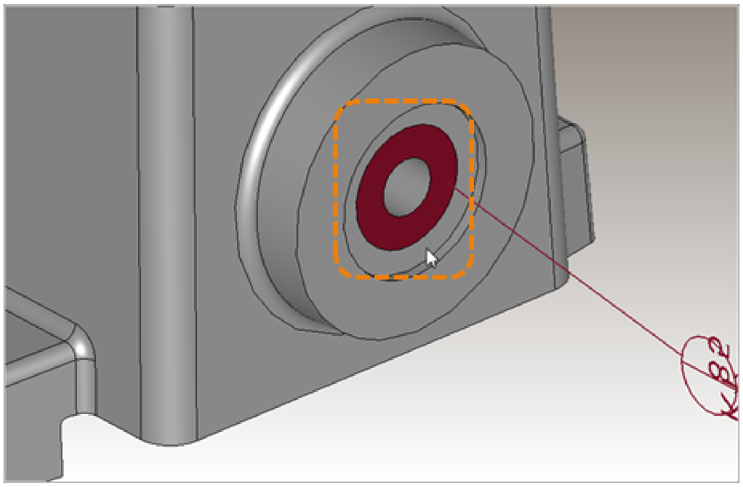
Style Difference



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

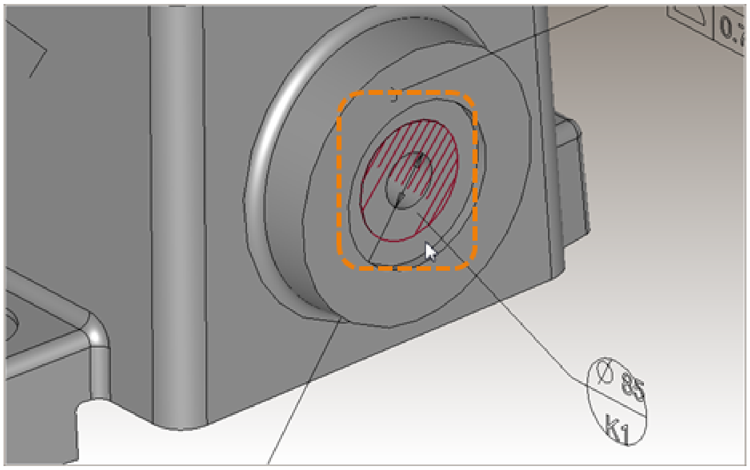
Style Difference



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

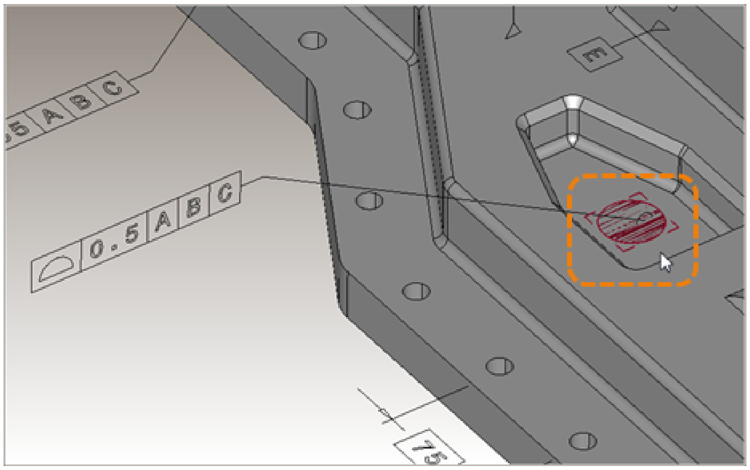
Style Difference



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

Supplemental Geometry Structure: FCF limited area is non-solid surface on solid face

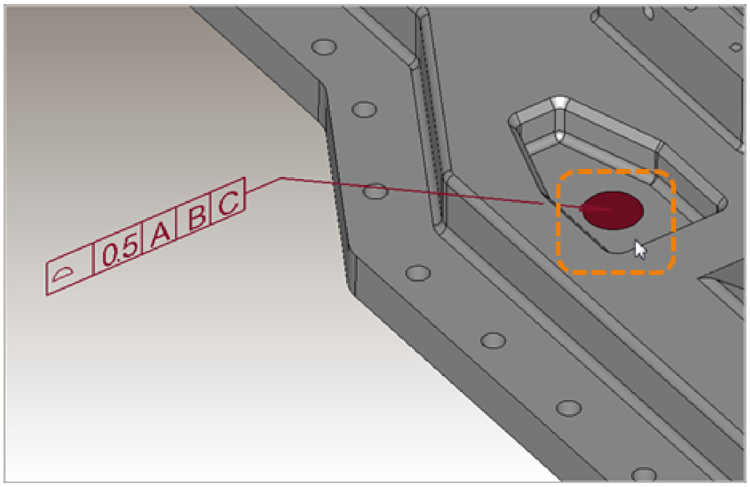
Style Difference



The limited area for this feature control frame is defined as a non-solid surface placed on the solid face.

Style Difference

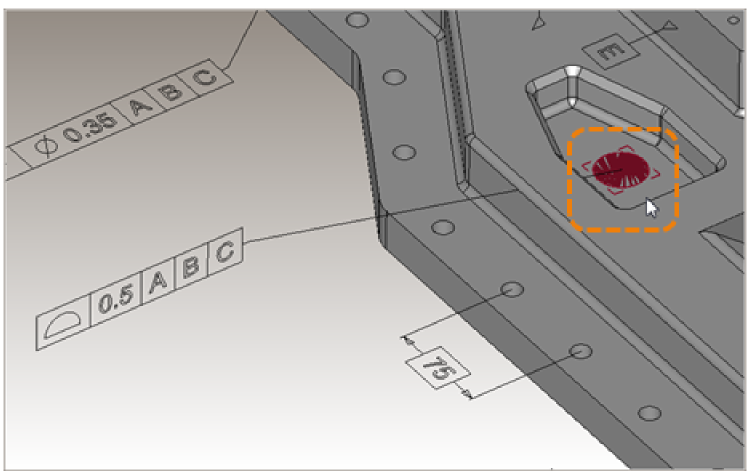
Supplemental Geometry Structure:
FCF limited area is subdivided solid face



The limited area for this feature control frame is defined as a solid face that has been separated from the adjacent faces in this solid.

Style Difference

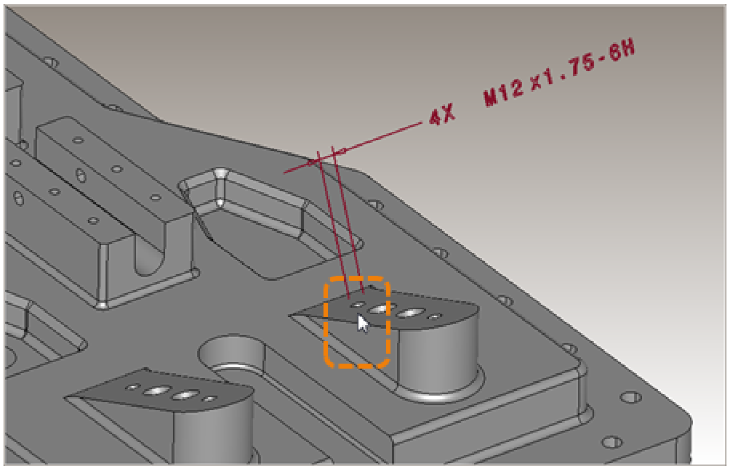
Supplemental Geometry Structure:
FCF limited area definition inconsistent with target area



The limited area for this feature control frame is defined as a non-solid surface placed on the solid face. This is inconsistent with the wireframe region used to define datum target areas in this system.

Style Difference

Product Geometry Parameters:
Threaded hole diameter different than other systems



The nominal diameter of the geometric hole associated with this threaded hole diameter dimension is slightly different (by default) than in other systems.