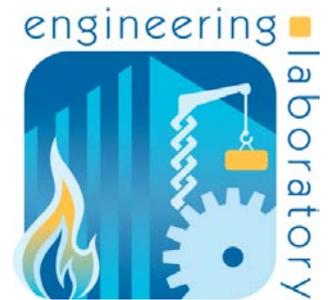


NIST MBE PMI Project Status Report

Simon Frechette, Josh Lubell, Robert Lipman

MBE Summit 2013
December 19, 2013

<http://cic.nist.gov/mbe>



*Engineering Laboratory
Systems Integration Division*

NIST MBE PMI Validation and Conformance Testing Program (NIST MBE PMI VCTP or NMPV)

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

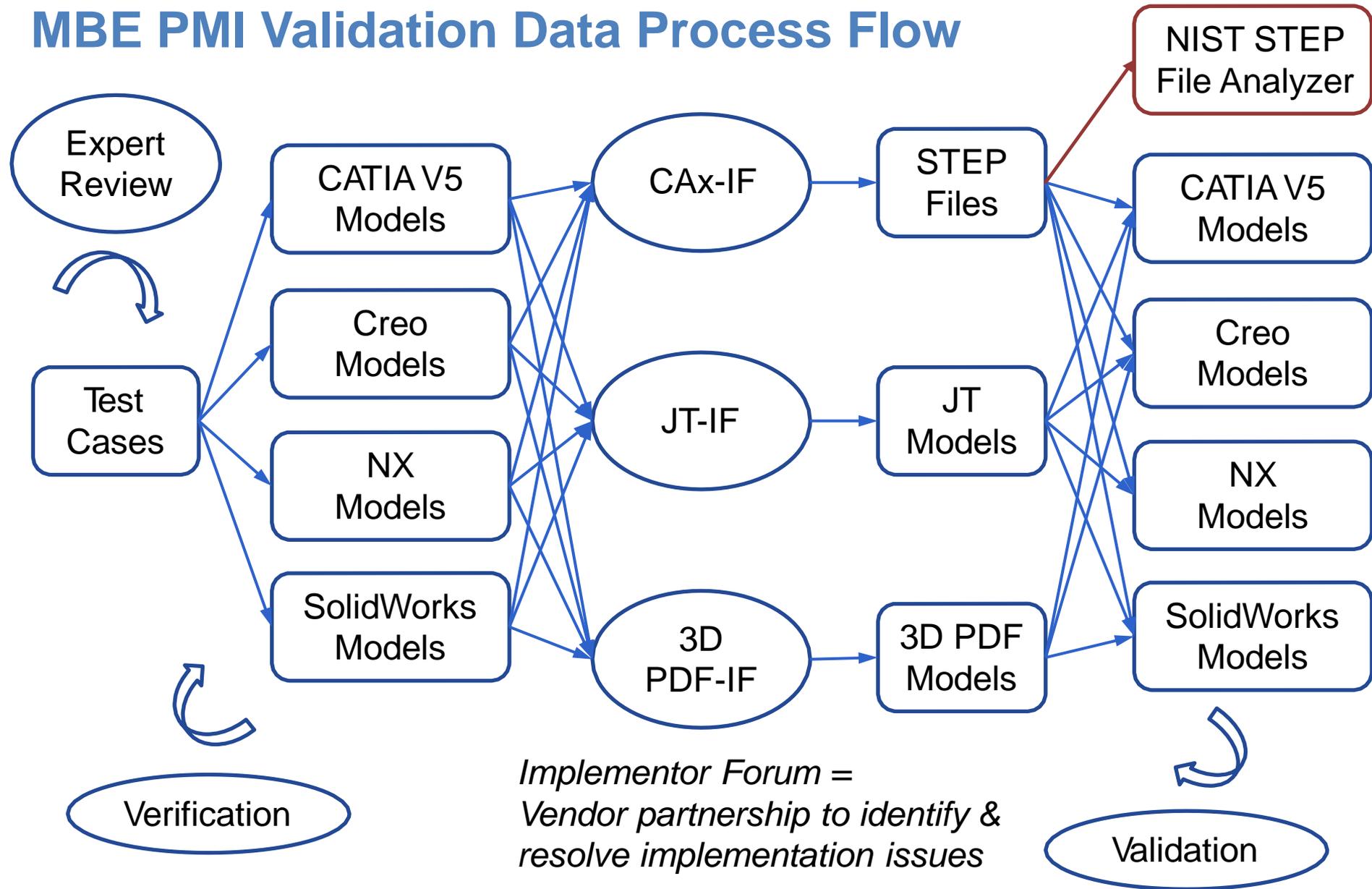
ASME Y14.5-1994 (Dimensioning and Tolerancing)

ASME Y14.41-2003 (Digital Product Data Definition Practices)

Project Components

- Test Cases
 - Select 50 PMI annotation constructs (Atomic Test Case – ATC)
 - Expert review of the PMI
 - Applied to 5 parts (Complex Test Case – CTC)
- Test Models
 - Each of the 5 parts with PMI modeled in 4 CAD systems (CATIA, Creo, NX, SolidWorks)
 - Focus on Semantic PMI
 - Precise, not graphical, machine interpretable
- Verification of CAD models
 - Comparison to test case definitions and to each other
 - Implementor Forums (IFs) to resolve modeling issues
- Release to IFs
 - Generate derivative STEP, JT, and 3D PDF files
 - Validate derivative files to original CAD models
 - Import derivation STEP files to CAD systems
 - Validate derivative CAD models to original CAD models
- Release test cases and CAD models to public (cic.nist.gov/mbe)

MBE PMI Validation Data Process Flow



Phase 1 PMI Annotation Constructs

ATC	Test Case Descriptions	Specification
1	Dimension with Equal-Bilateral Tolerance: Feature of Size	$\varnothing 25 \pm 0.15$
2	Dimension with Unequal-Bilateral Tolerance: Feature of Size	$\varnothing 20 +0.05/-0.10$ & $\varnothing 20 +0.10/-0.05$
3	Dimension with Unilateral Tolerance: Feature of Size	$\varnothing 35 0/-0.2$ & $\varnothing 35 +0.2/0$
4	Angular Dimension with Equal-Bilateral Tolerance: Simple	$60^\circ \pm 0.5^\circ$
5	Directly-toleranced dimension with nX (quantity)	30X $\varnothing 14 \pm 0.1$
6	Directly-Toleranced Dimension with Dimension Origin Symbol	4X $.82 \pm .06$
7	Symbol: All Around (Applied with a Leader-Directed Profile Tolerance)	$\bigcirc 0.5 A$ All Around
8	Dimension: Limit - Vertical (Stacked) and Horizontal with Diameter Symbol: Feature of Size	$\varnothing 34.8 - 35.2$ & $\varnothing 35.2/34.8$
9	Symbol: Counterbore; Symbol: Depth - Single-Line Specification of Two Dimensions and Tolerances - Complex	4X $\perp \varnothing 20 \pm 0.2 \times \nabla 20 \pm 0.2$
10	Symbol: Countersink - Single-Line Specification of Two Dimensions and Tolerances - Complex	30X $\sphericalangle \varnothing 20 \pm 0.3 \times 90^\circ \pm 1^\circ$
11	Directly-Toleranced Dimension with Statistical Tolerancing Symbol	$5.000 \pm .008 \overline{ST}$
12	Basic dimension	75 basic; $\varnothing 10$ basic
13	Reference Dimension, Simple	(.750)
14	Single Segment Feature Control Frame, Simple - Attached to Size Dimension & Tolerance	$\varnothing \varnothing .06 D B C$ $\perp \varnothing .01 E$
15	Composite Feature Control Frame - 2 Segments - Leader Directed - with String Grouping Mechanism	$\bigcirc 2 D G H$ (top); 0.2 D (bottom)
16	Composite Feature Control Frame - 2 segments - attached to size dim & tol	6X $\varnothing 6.65 \pm 0.12$ $\varnothing \varnothing 1.5 D E F$ (top); $\varnothing 0.3 D E$ (bottom)
17	Feature Control Frame Directed to Surface - Flatness	$\nabla 0.2$
18	Feature Control Frame Directed to Surface - Straightness with Represented Line Element	$_ .005$
19	Feature Control Frame Directed to Surface - Circularity	$\bigcirc .002$
20	Feature Control Frame Directed to Surface - Angularity	$\sphericalangle .04 A$
21	Feature Control Frame Directed to Surface - Perpendicularity	$\perp 1.5 A$
22	Feature Control Frame Directed to Surface - Position	$\varnothing \varnothing 0.35 A B C$
23	Feature Control Frame Directed to Surface - Concentricity	$\bigcirc \varnothing .030 B$
24	Feature Control Frame Directed to Surface - Circular Runout	$\nearrow .035 A-B, \nearrow .025 A-B$
25	Feature Control Frame Directed to Surface - Total Runout	$\nabla \nabla .002 A, \nabla \nabla .015 B$

Phase 1 PMI Annotation Constructs

ATC	Test Case Descriptions	Specification
26	Feature Control Frame Directed to Surface - Profile of a Surface	$\overline{\Delta}0.75 A B C$
27	Feature Control Frame with Unit-Basis Tolerance - Flatness	$\overline{\square}.005 / .25 \times .25$
28	Feature Control Frame with MMC Modifier	$\Phi \varnothing 1.5(M) A B C$
29	Feature Control Frame with LMC Modifier	$\Phi \varnothing 1.2(L) A B C$
30	Feature Control Frame with Projected Tolerance and Projection Distance - ASME	4X M12 x 1.75 - 6H $\nabla 25 \pm 0.25$ $\Phi \varnothing 0.75 \textcircled{P} 50 A B C 4X$
31	Feature Control Frame with ASME Modifiers - Unequally-Disposed	$\overline{\Delta}2.5(U)1.25 A B C$ $\overline{\Delta}2.5(U)0.5 A B C$ $\overline{\Delta}2.5(U)2.5 A B C$ $\overline{\Delta}2.5(U)0 A B C$
32	Unidirectional Positional Tolerancing - Parallel Plane Tolerance Zone for Cylindrical Feature of Size	$\Phi .03 D B C$
33	Single Segment Feature Control Frame - Attached Directly to Dimension Lines - No Dimension Value	$\Phi 0.75 A B C$
34	Feature Control Frame with MMB Modifiers for Datum Feature References - ASME	$\overline{\Delta}0.5 D E(M) F(M)$ $\overline{\Delta}0.5 D E(M) F$ $\overline{\Delta}0.5 D E F(M)$ $\overline{\Delta}0.5 D E F$
35	Feature Control Frame with LMB Modifiers for Datum Feature References - ASME	$\overline{\Delta}0.8 G H(L) J$ $\overline{\Delta}0.8 G H(L) J(L)$ $\overline{\Delta}0.8 G H J(L)$ $\overline{\Delta}0.8 G H J$
36	Feature Control Frame with MMC and MMB Modifiers	$\Phi \varnothing .05(M) A B(M) C(M)$
37	Datum Feature symbol attached to Feature of Size	A
38	Datum Feature symbol attached to a Size Dimension	B
39	Datum Feature Symbol Attached to a Leader-Directed Feature Control Frame	$\overline{\Delta}0.01$ A $\overline{\Delta}0.03 A B C$ D $\overline{\Delta}0.06 A B C$ E
40	Datum Feature symbols for Primary, Secondary, Tertiary attached to surfaces	D, E, F, G, H

Phase 1 PMI Annotation Constructs

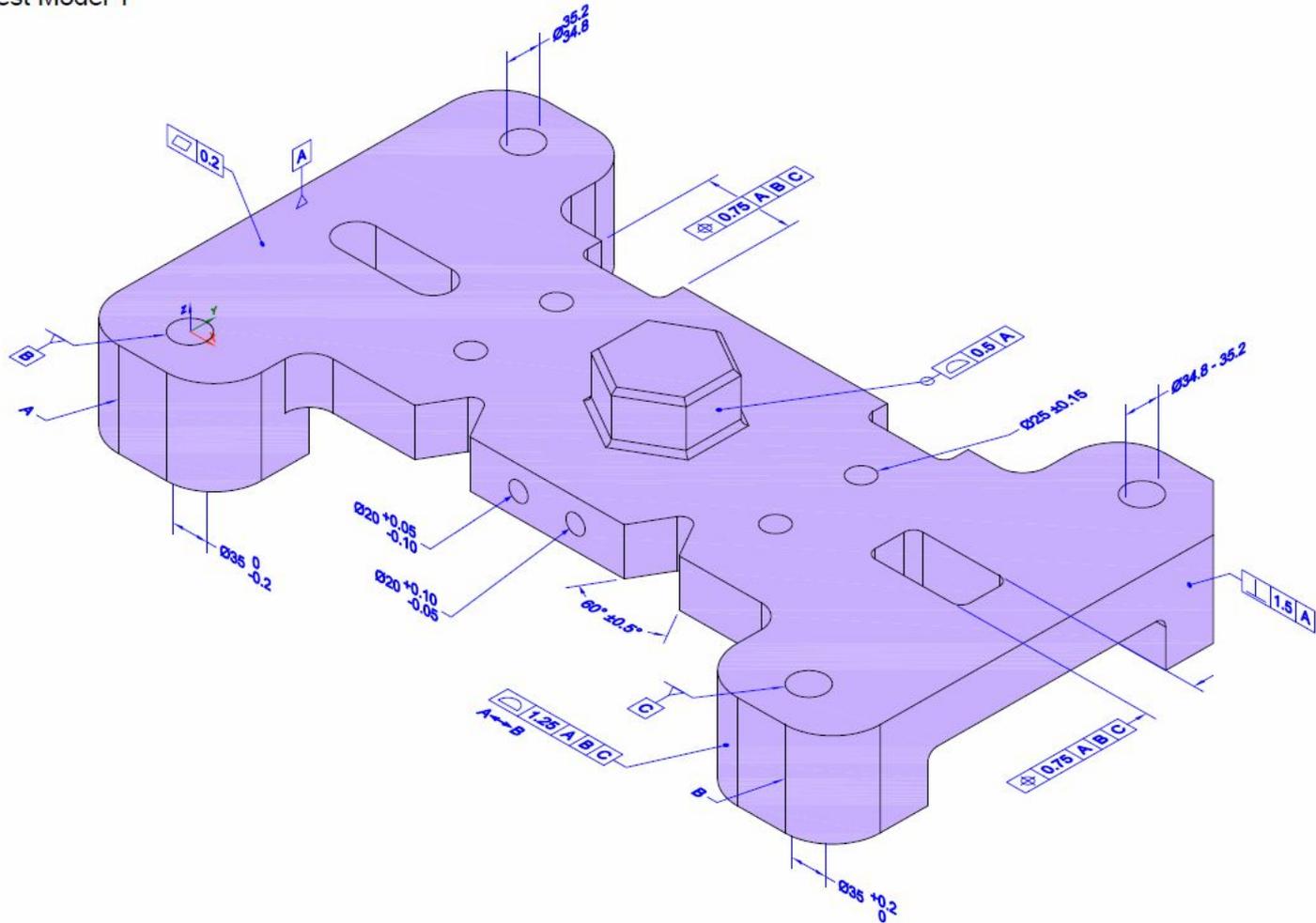
ATC	Test Case Descriptions	Specification
41	Datum Target Symbol and Target Area Symbol Applied to Surface: Area Defined in Datum Target Symbol (Ø)	Ø0.85 Area K1
42	Datum Target Symbol and Target Area Applied to Surface: Area Defined on Surface (Rectangular)	C1, D1
43	Set of Datum Target Symbols and Target Point Symbols Applied to Surfaces	A1, A2, A3, B1, B2, B3, B4, C1
44	Multiple Datum Feature	A-B
45	Size Dimension with Feature Control Frame and STRING - Applied nX	4X Ø.625 ±.005 $\text{⌀} \text{Ø}.05 \text{Ⓜ} \text{D} \text{B} \text{C}$ SWITCH MOUNTING LOCATIONS
46	Size Dimension with Feature Control Frame and Datum Feature Symbol Attached	Ø.438 ±.005 $\perp \text{Ø}.01 \text{A} \quad \text{B}$ Ø.438 ±.005 $\text{⌀} \text{Ø}.02 \text{A} \text{B} \quad \text{C}$ Ø1.065 ±.003 $\perp \text{Ø}.01 \text{E} \quad \text{F}$
47	Directional Geometric Tolerance with Represented Line Element	$\curvearrowright 0.25 \text{A} \text{B} \text{C}$
48	Profile Tolerance: Applied on a Between Basis	$\triangle 1.25 \text{A} \text{B} \text{C} \quad \text{A} \leftarrow \rightarrow \text{B}$
49	Profile tolerance applied to a limited area (circular area)	$\triangle 0.5 \text{A} \text{B} \text{C}$
50	General Notes Invoking ASME Y14.5M-1994 and Y14.41-2003 on Static Annotation Plane	Obtain dimensions from model... Model geometry is basic... ASME Y14.41-2003 applies... ASME Y14.5M-1994 applies...

Test Case 1

NIST PMI Test Models - 2012

ADV/D[®] Advanced Dimensional Management LLC

Test Model 1



PMI Complex Test Case 1

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

Rev B

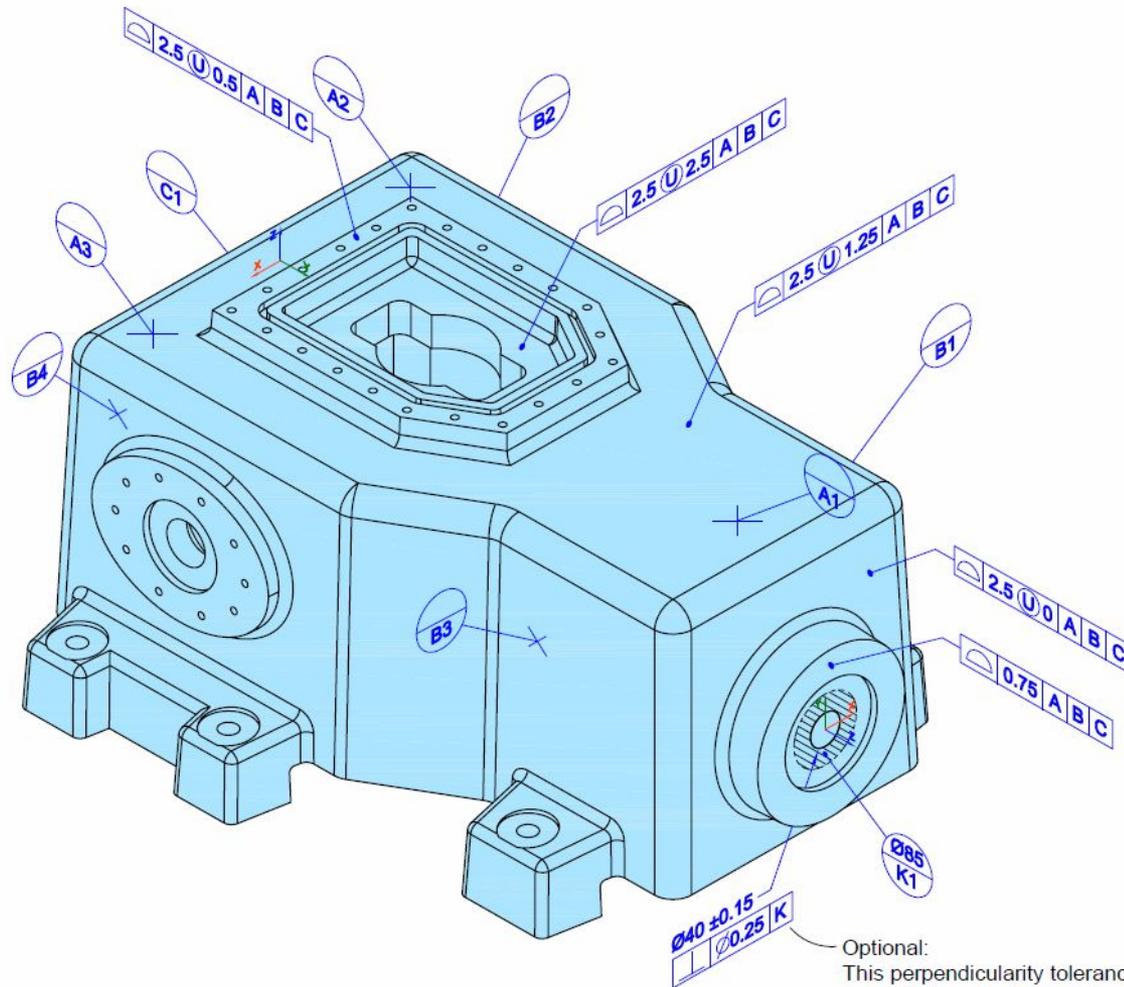
nist_ctc_01_asme1_rb

Test Case 2

NIST PMI Test Models - 2012

ADV/D^M Advanced Dimensional Management LLC

Test Model 2



Optional:
This perpendicularity tolerance is included
to legitimize specifying datum feature D.

PMI Complex Test Case 2 - View 2 (of 3)
Includes Atomic Test Cases - 26, 31, 41

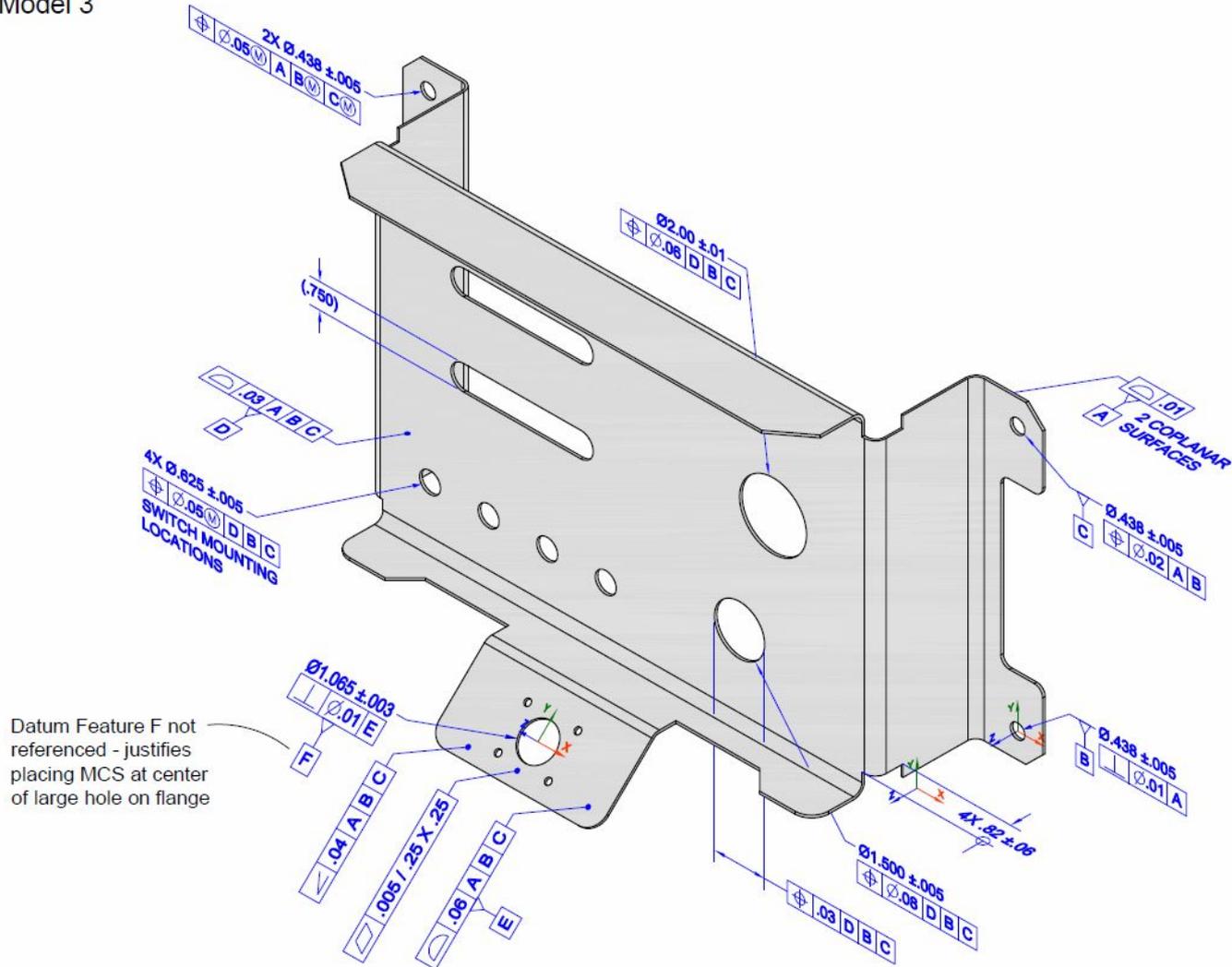
Rev B

nist_ctc_02_asme1_rb

Test Case 3

NIST PMI Test Models - 2012

Test Model 3



PMI Complex Test Case 3

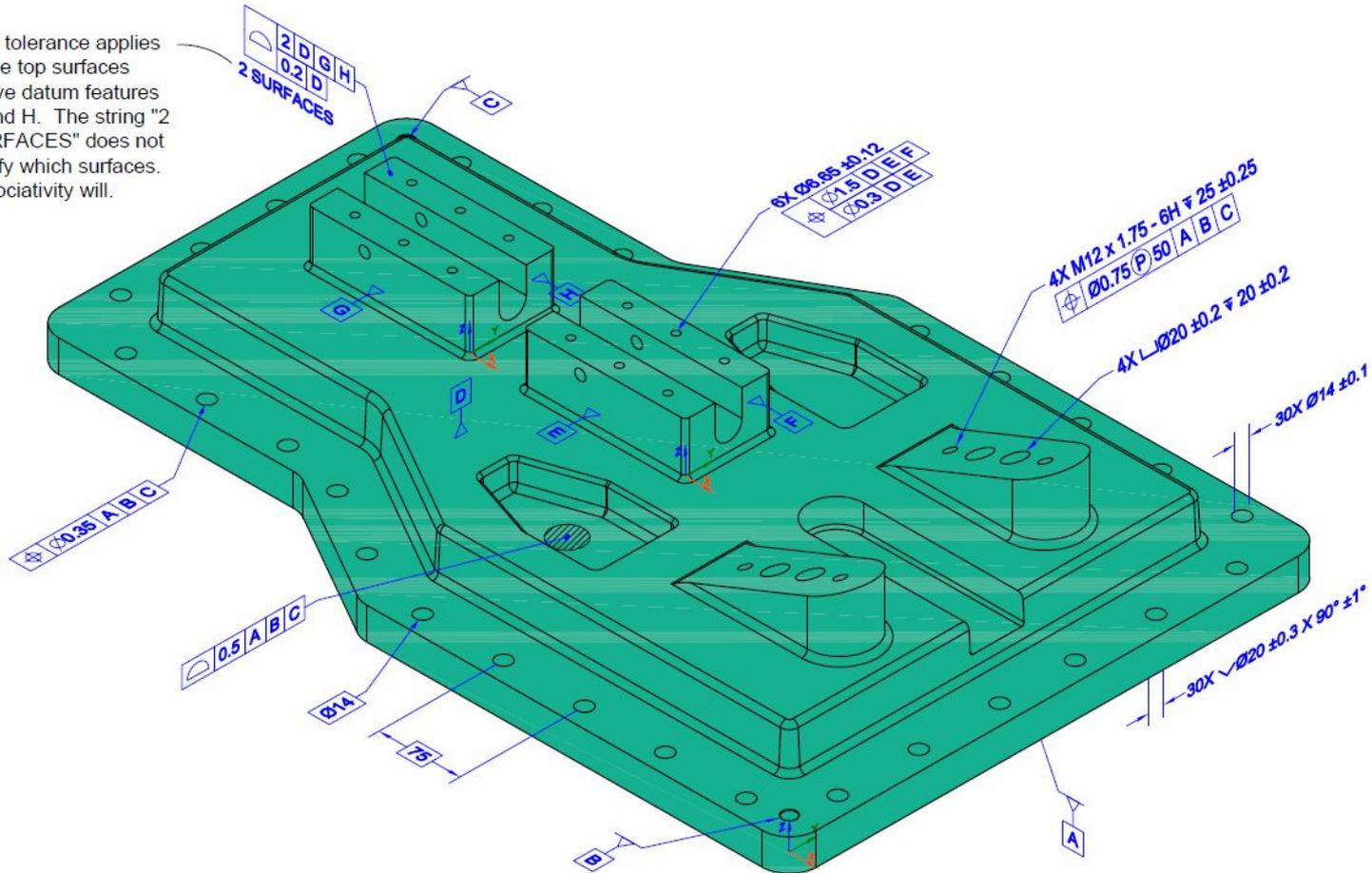
Includes Atomic Test Cases - 6, 13, 14, 20, 27, 32, 36, 39, 45, 46

Test Case 4

NIST PMI Test Models - 2012

Test Model 4

This tolerance applies to the top surfaces above datum features G and H. The string "2 SURFACES" does not clarify which surfaces. Associativity will.



PMI Complex Test Case 4

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

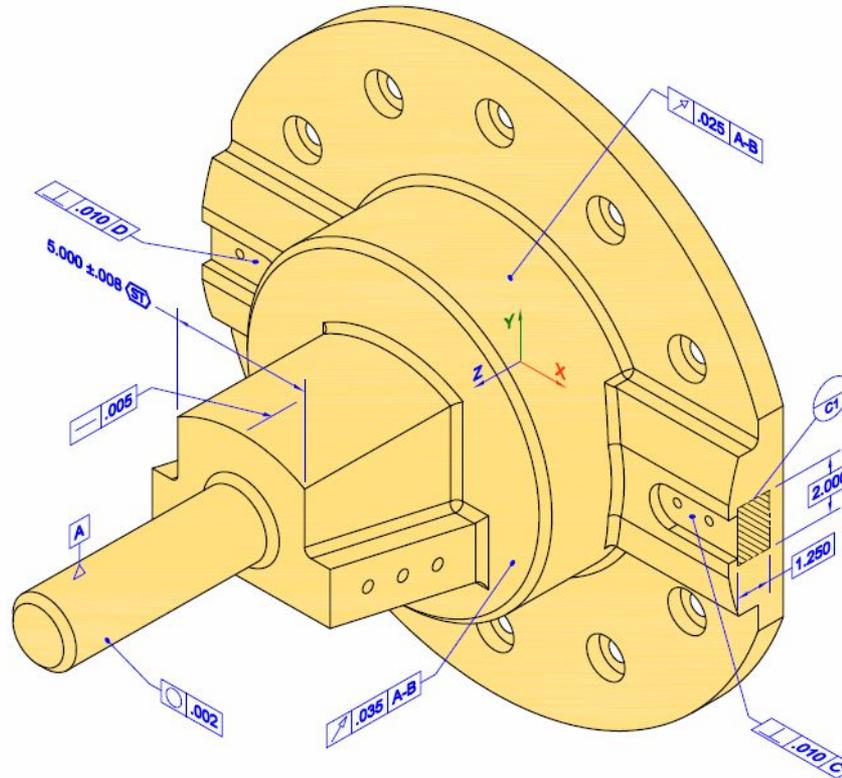
Rev C

Test Case 5

NIST PMI Test Models - 2012

ADV/D[®] Advanced Dimensional Management LLC

Test Model 5



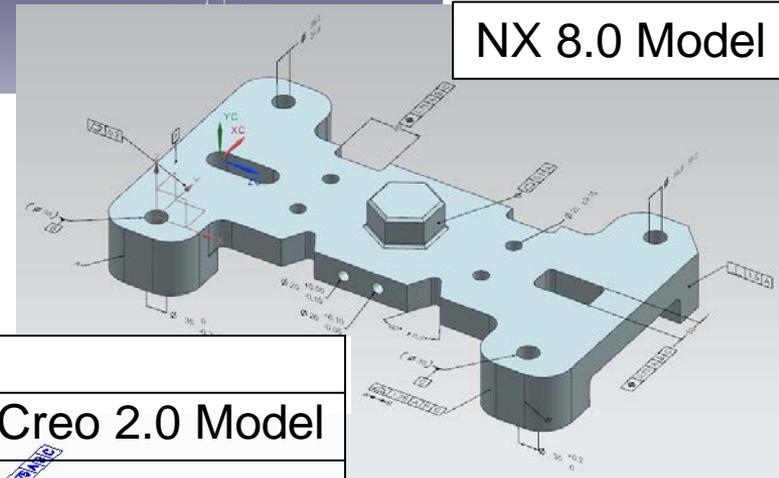
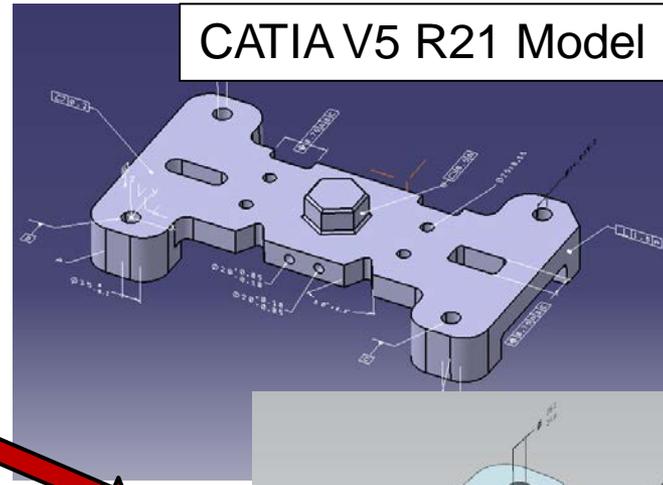
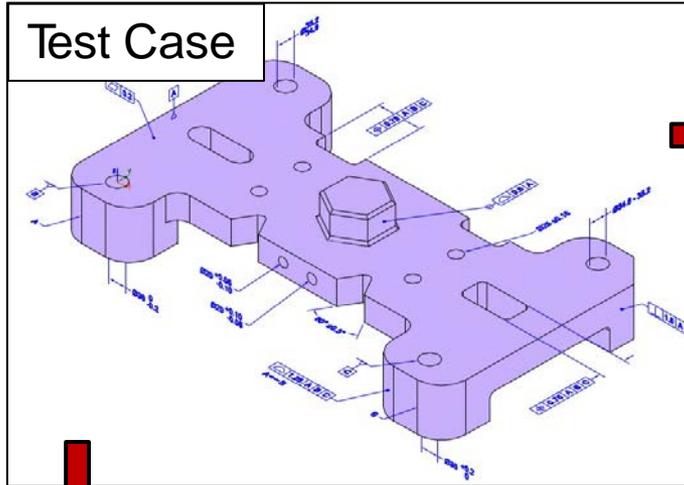
Notes
Datum feature B and
Datum target D1 defined
in View 2 (of 2).

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

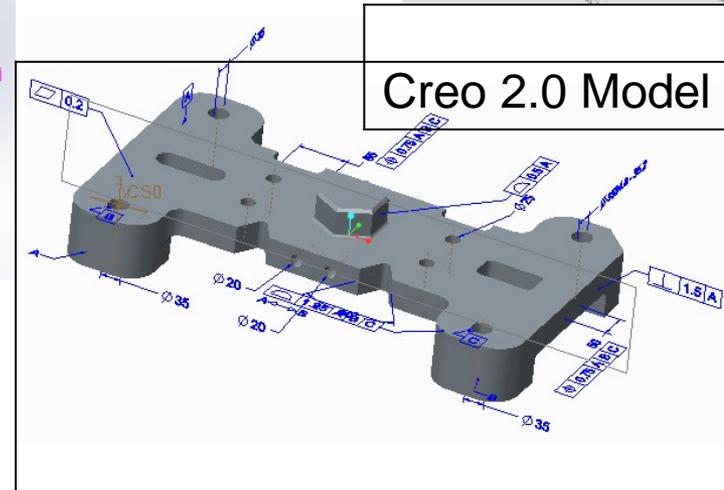
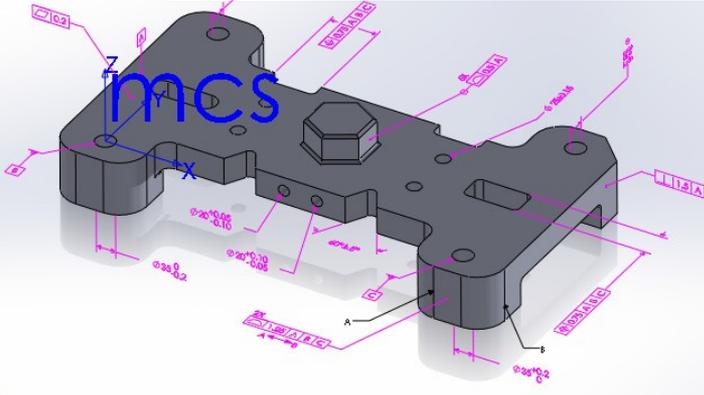
Rev C

nist_ctc_05_asme1_rc

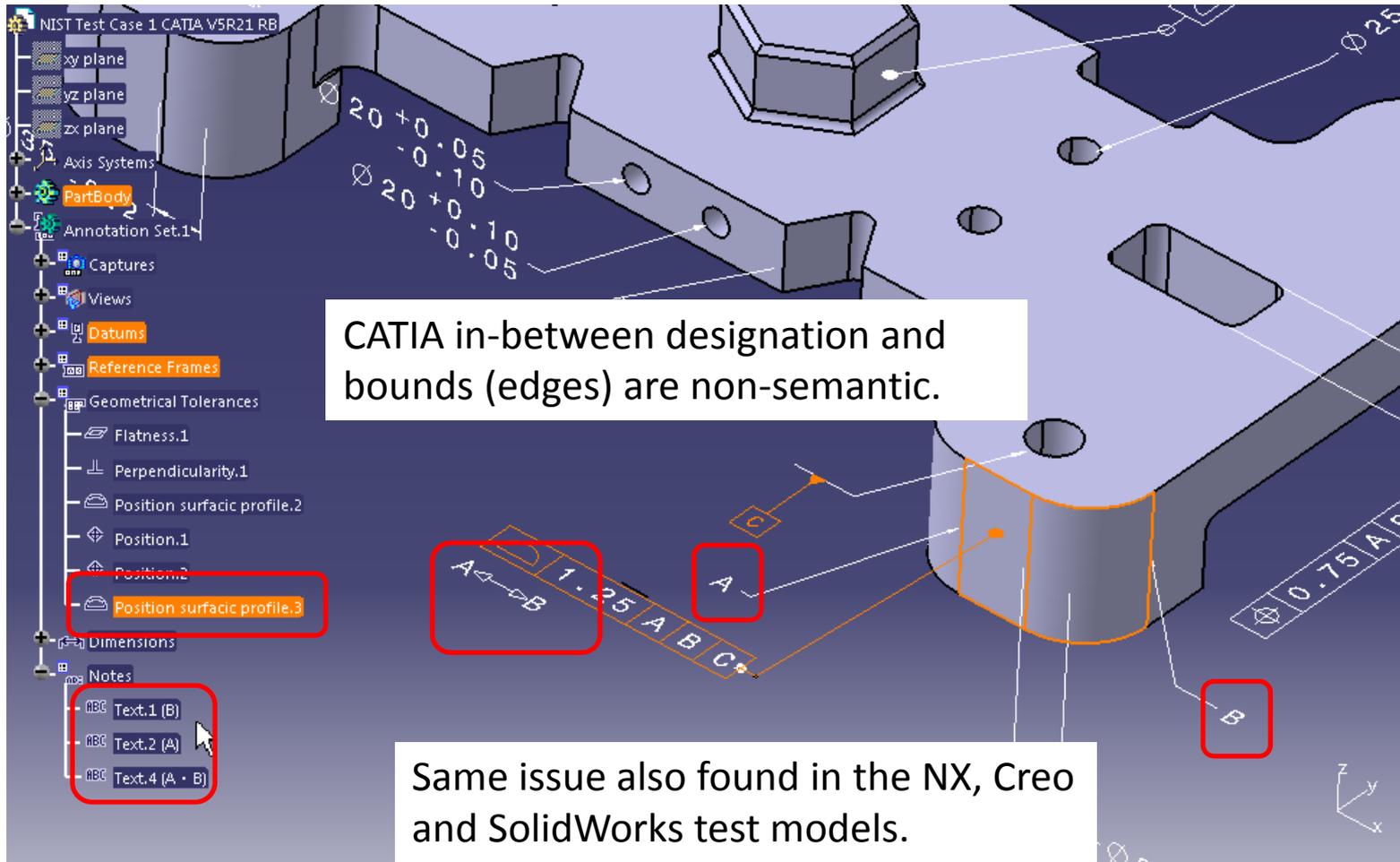
Test Cases Modeled in 4 CAD Systems



SolidWorks 2012 Model



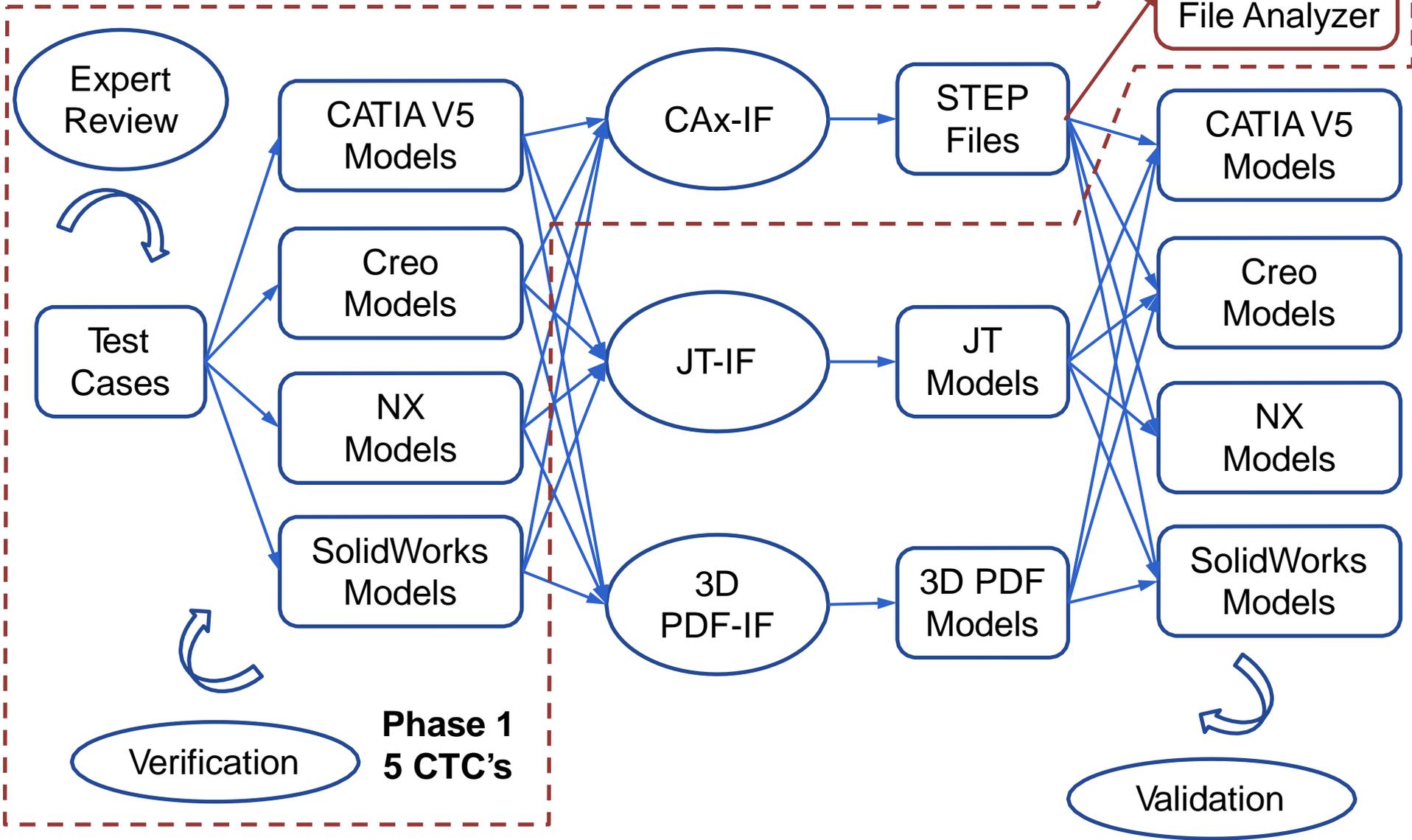
Example Semantic Verification Issue



Phase 1 Results (Oct 2012 – Sep 2013)

- Test Cases
 - Select 50 PMI annotation constructs
 - Applied to 5 parts (10 per part)
 - Documented with PDF, images, and explanatory text (Bryan Fischer, Advanced Dimensional Measurement)
 - Expert review of the PMI (Curtis Brown, DoE and RECON Services)
- Test Models
 - Each of the 5 parts with PMI modeled in 4 CAD systems (Rich Eckenrode, RECON Services)
- Verification of CAD models
 - Comparison to test case definitions and to each other (Doug Cheney, ITI TranscenData, CADIQ)
- Release to Implementor Forums
 - Resolve modeling issues
 - Generate derivative STEP and JT files (no 3D PDF)
 - Validate derivative files to original CAD models (delayed)
- NIST STEP File Analyzer and public release (cic.nist.gov/mbe)

MBE PMI Validation Data Process Flow



NIST STEP File Analyzer and Semantic PMI

- STEP File Analyzer parses file and displays in spreadsheet
 - Dimensional Tolerance
 - Diameter, Length
 - Plus-minus
 - Value Range
 - Datum Reference Frame
 - Modifiers
 - Geometric Tolerance
 - Value
 - Modifiers
 - Tolerance Zone
 - Datum Feature
- Recreate Visual Presentation of the Semantic PMI
 - Compare to test case definition
 - Identify source of discrepancies
 - STEP file, CAD model, Analyzer

Semantic PMI Summary Worksheet

- Recreate Visual Presentation of the Semantic PMI
 - Datum systems, dimensional and geometric tolerances

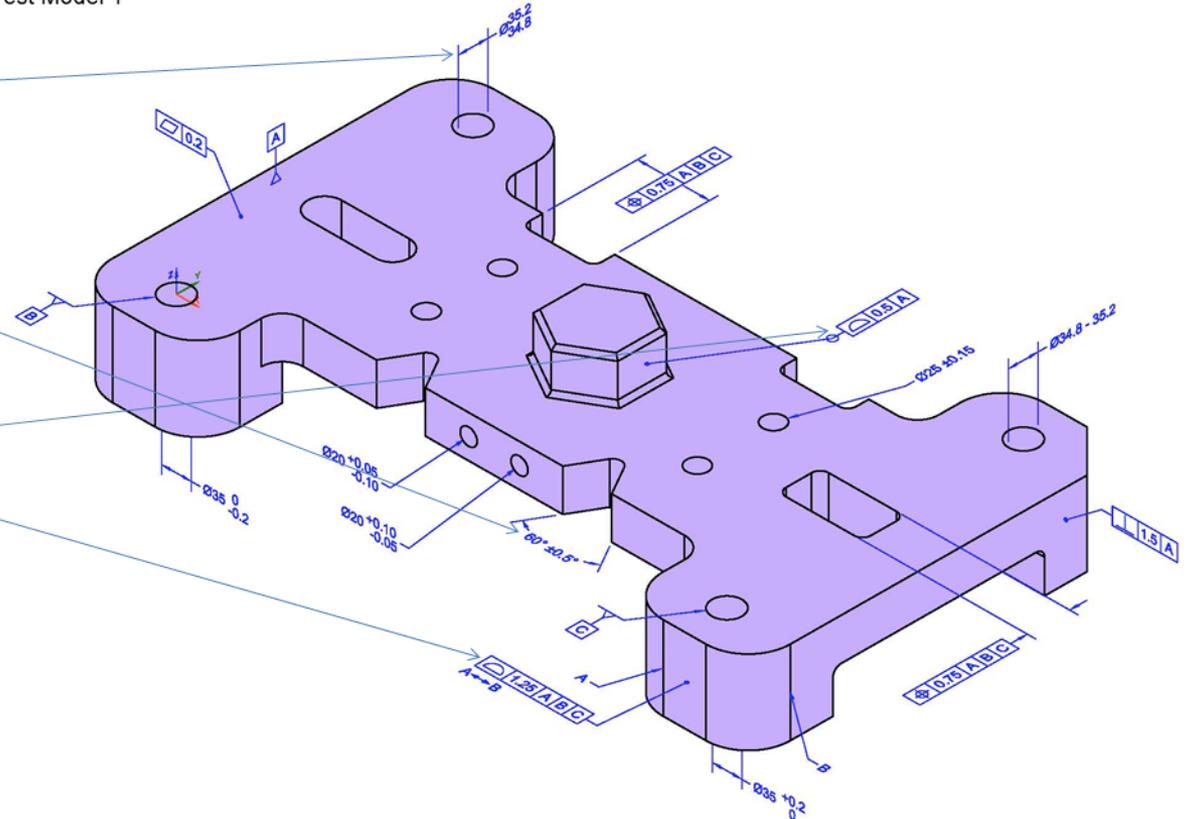
3	ID	Entity	Semantic PMI
4	5704	datum system	A
5	5845	datum system	A
6	5925	datum system	A B C
7	6010	datum system	A B C
8	6095	datum system	A B C
9	5109	dimensional characteristic representation	34.8-35.2
10	5179	dimensional characteristic representation	34.8-35.2
11	5237	dimensional characteristic representation	Ø25.0 ± 0.15
12	5295	dimensional characteristic representation	Ø20.0 +0.1 -0.05
13	5365	dimensional characteristic representation	Ø20.0 +0.05 -0.1
14	5435	dimensional characteristic representation	35.0 +0.2 0.0
15	5497	dimensional characteristic representation	35.0 0.0 -0.2
16	5562	dimensional characteristic representation	35.0 0.0 -0.2-60.0
17	5779	flatness tolerance	\square 0.2 ∇ [A]
18	5926	geometric tolerance with datum reference and position tolerance	⊕ 0.75 A B C
19	6011	geometric tolerance with datum reference and position tolerance	⊕ 0.75 A B C
20	5705	geometric tolerance with datum reference and surface profile tolerance	⌒ 0.5 A
21	6096	geometric tolerance with datum reference and surface profile tolerance	⌒ 1.25 A B C
22	5846	perpendicularity tolerance	⊥ 1.5 A

Manual Association of Semantic PMI to Test Case Image

ID	Entity	Semantic PMI
3		
4	5704 datum_system	A
5	5845 datum_system	A
6	5925 datum_system	A B C
7	6010 datum_system	A B C
8	6095 datum_system	A B C
9	5109 dimensional_characteristic	34.8-35.2
10	5179 dimensional_characteristic	34.8-35.2
11	5237 dimensional_characteristic	025.0 ± 0.15
12	5295 dimensional_characteristic	020.0 +0.1 -0.05
13	5365 dimensional_characteristic	020.0 +0.05 -0.1
14	5435 dimensional_characteristic	35.0 +0.2 0.0
15	5497 dimensional_characteristic	35.0 0.0 -0.2
16	5562 dimensional_characteristic	35.0 0.0 -0.2-60.0
17	5779 flatness_tolerance	0.2 [A]
18	5926 geometric_tolerance_with_d	0.75 A B C
19	6011 geometric_tolerance_with_d	0.75 A B C
20	5705 geometric_tolerance_with_d	0.5 A
21	6096 geometric_tolerance_with_d	1.25 A B C
22	5846 perpendicularity_tolerance	1.5 A
23		
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38		

NIST PMI Test Models - 2012

Test Model 1



PMI Complex Test Case 1

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

Rev D

Green – GD&T match

Yellow – GD&T incorrect or incomplete

Possible issue with STEP file, Analyzer, or Recommended Practice

Red - GD&T incorrect, possible issue with STEP file (diameter symbol is missing in this example)

Coverage Analysis

- Test Cases
 - Only 50 PMI annotation constructs out of many
 - Phase 2 considering 50 more
- Test Models
 - Modeled in only 4 CAD systems
 - Limitations of CAD systems to model some PMI constructs
 - Graphical workarounds
- Limitations of derivative STEP files
 - Focus on AP242
 - Not supported by some CAD systems
 - CAX-IF Recommended Practices do not cover all Test Cases
- STEP File Analyzer Coverage Analysis
 - Geometric and dimensional tolerances, modifiers
 - Reference documentation in CAX-IF Recommended Practices
 - Constructs without Recommended Practices

STEP File Analyzer - Coverage Analysis

		R31 sp3-d5-	R31 sp3_11l	R31 sp3_11l	R31 sp3_16 242.stp	R31 sp3_16'
3	Semantic PMI					
4	angularity_tolerance \sphericalangle					
5	circular_runout_tolerance \nearrow					
6	coaxiality_tolerance \odot					
7	concentricity_tolerance \odot					
8	cylindricity_tolerance Ⓢ					
9	flatness_tolerance \square	X	X	X	X	X
10	line_profile_tolerance \frown					
11	parallelism_tolerance $//$					
12	perpendicularity_tolerance \perp	X		X		
13	position_tolerance \oplus	X	X	X	X	X
14	roundness_tolerance \bigcirc					
15	straightness_tolerance $-$					
16	surface_profile_tolerance \triangle	X		X	X	X
17	symmetry_tolerance \rightleftharpoons					
18	total_runout_tolerance Ⓢ					
19	diameter \emptyset					
20	radius R					
21	thickness $++$					
22	spherical diameter $S\emptyset$					
23	spherical radius SR					
24	dimensional location (5.1.1)	X	X	X		
25	angular location (5.1.2)	X	X	X		
26	dimensional size (5.1.5)	X		X		X

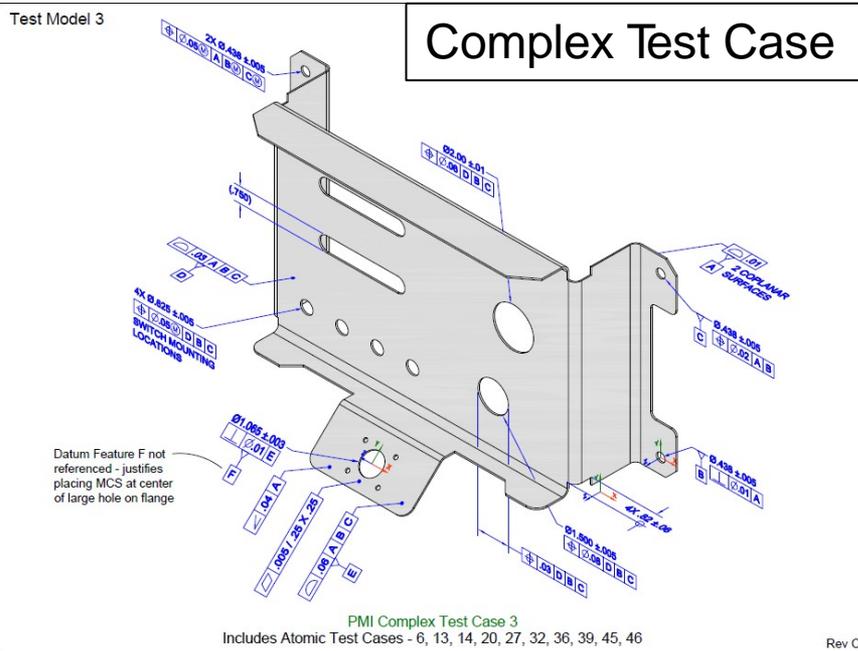
Column A – Types of GD&T, numbers in parentheses refer to CAX-IF Recommended Practice

Other Columns – One per STEP file, X indicates the file contains that type of GD&T

Phase 2 Plans (Proposed)

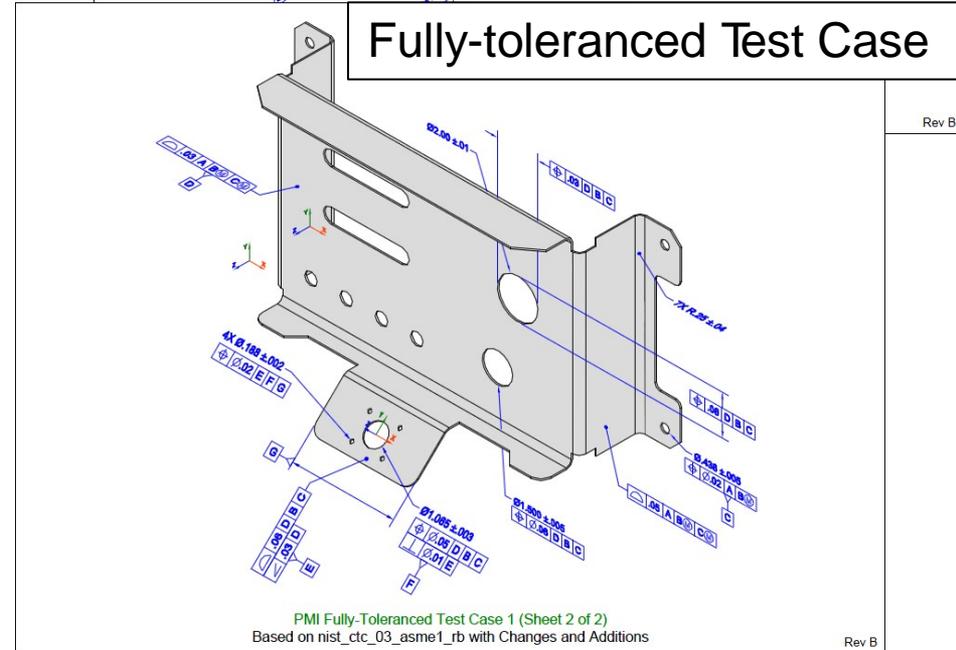
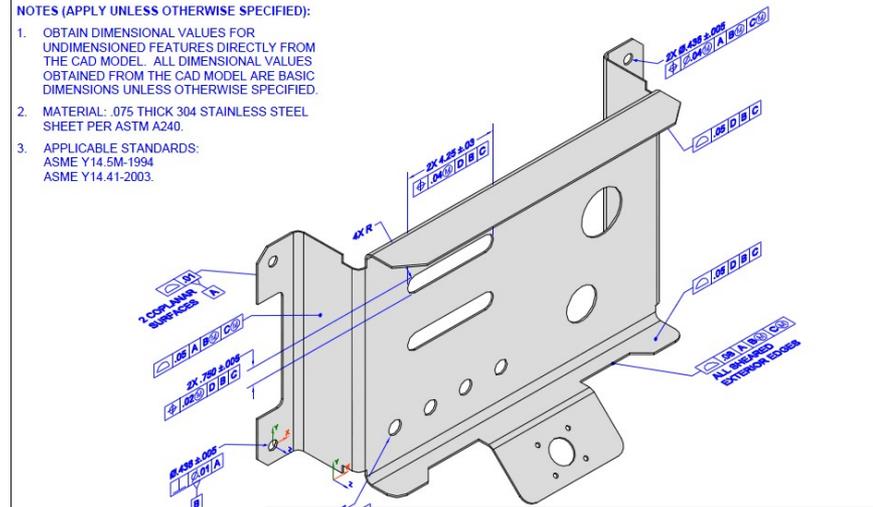
- Test Cases
 - Select 50 more PMI annotation constructs (Atomic Test Case – ATC)
 - Expert review of the PMI
 - Applied to 5 parts (Fully-toleranced Test Case – FTC)
- Test Models
 - Each of the 5 parts with PMI modeled in 4 CAD systems (more recent versions of CATIA, Creo, NX, SolidWorks)
 - Focus on Semantic PMI
- Verification of CAD models
 - Comparison to test case definitions and to each other
 - Implementor Forums (IFs) to resolve modeling issues
- Release to IFs
 - Generate derivative STEP, JT, and 3D PDF files
 - Validate derivative files to original CAD models
 - Import derivation STEP files to CAD systems
 - Validate derivative CAD models to original CAD models
- Complete delayed Phase 1 tasks

Complex vs. Fully-toleranced Test Case



NOTES (APPLY UNLESS OTHERWISE SPECIFIED):

- OBTAIN DIMENSIONAL VALUES FOR UNDIMENSIONED FEATURES DIRECTLY FROM THE CAD MODEL. ALL DIMENSIONAL VALUES OBTAINED FROM THE CAD MODEL ARE BASIC DIMENSIONS UNLESS OTHERWISE SPECIFIED.
- MATERIAL: .075 THICK 304 STAINLESS STEEL SHEET PER ASTM A240.
- APPLICABLE STANDARDS:
ASME Y14.5M-1994
ASME Y14.41-2003.



Possible Future Extensions

- Cross sections (single plane and multiple planes)
- Assembly PMI
- ISO PMI standards
- Newer versions of ASME and ISO standards
- More CAD systems (Solid Edge, Inventor, ...)
- Import into CAM systems, especially inspection planning and measurement