engineering laboratory

Good Testing is Hard
Bad Testing is Easy

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NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Outline

- Types of Testing
- Characteristics of Testing
- NIST CAD PMI Testing Project
- Bad Testing
- Testing Lessons Learned

Disclaimer: Any mention of commercial products in this presentation is for information only; it does not imply recommendation or endorsement by NIST.

Types of Testing

- Conformance, Interoperability
  - Kindrick, Sauter, Matthews, “Improving Conformance and Interoperability Testing”, in StandardView, March 1996
- Syntax, Structure, Semantics
- Verification, Validation
- Representation, Presentation
- Manual, Automated
- Falsification
- Coverage Analysis

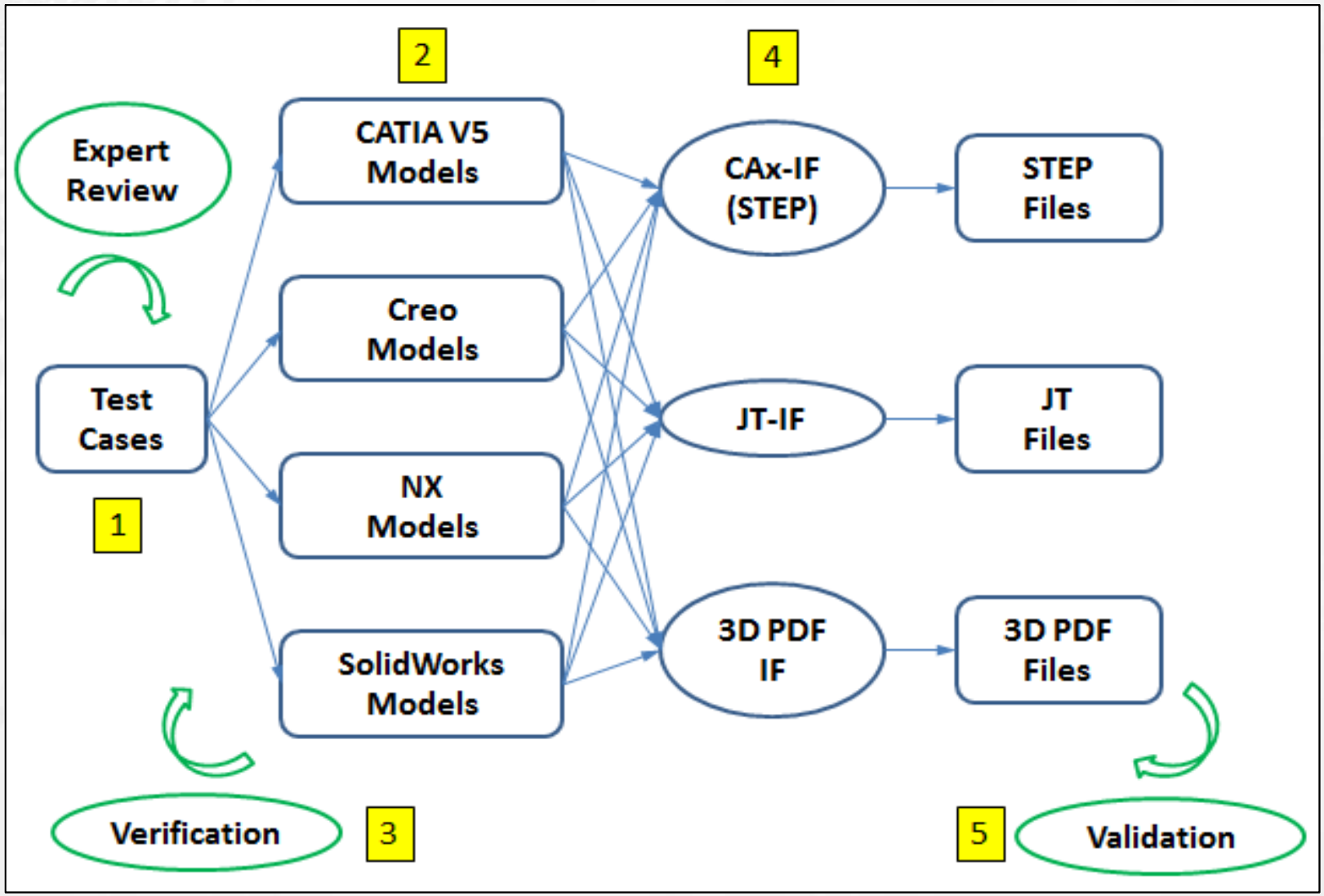
Characteristics of Testing

- Purpose
- Methodology
- Test cases, models, files
- Criteria
- Tools
- Results
- Certification

CAD PMI Testing Project

- Measure the conformance of CAD software and derivative files to ASME tolerance standards
- 11 test case definitions (2D drawing) based on Y14.5 and Y14.41
  - Approximately 100 PMI annotations and documentation
  - Expert review
- 8 (of 11) test cases modeled in CATIA, Creo, NX, SolidWorks
  - Verification of CAD models to test cases (CADIQ)
- Generate derivative STEP, JT, and 3D PDF files
  - Validation of derivative files to CAD models (CADIQ, STEP File Analyzer)
  - Testing by Implementor Forums
- Two verification and one validation reports
- https://go.usa.gov/mGVm

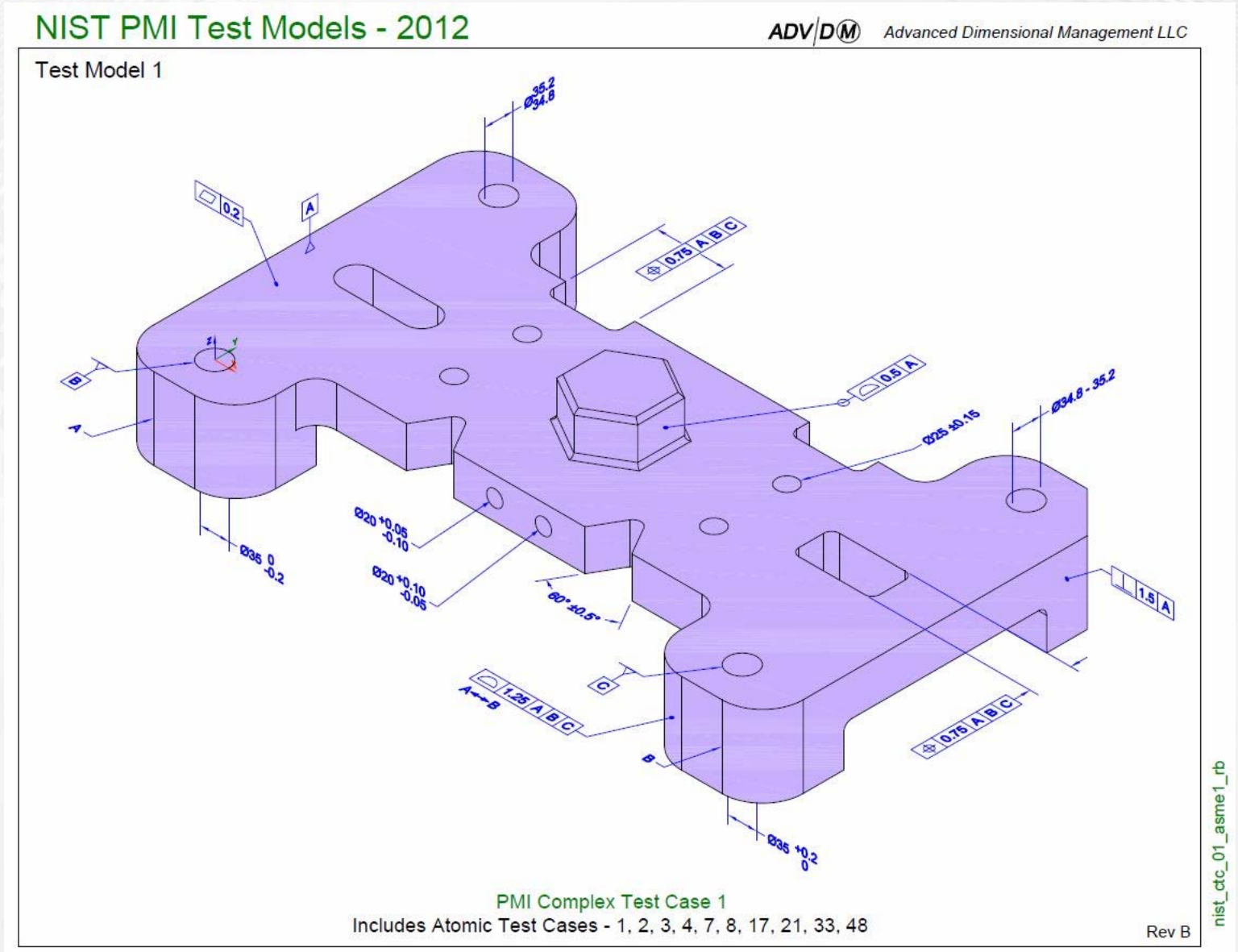
CAD PMI Testing Project



Two Types of Test Cases

- Combined Test Case
  - Not a complete specification of PMI
- Fully-toleranced Test Case
  - Each feature is adequately controlled and constrained
- Geometric and dimensional tolerances, datums, and modifiers
- Not necessarily best practice or how you might tolerance a part

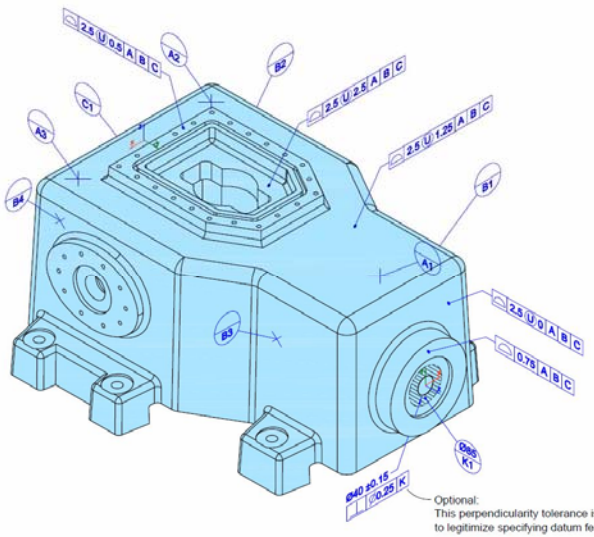
Combined Test Case



NIST PMI Test Models - 2012

ADV/DM Advanced Dimensional Management LLC

Test Model 2



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

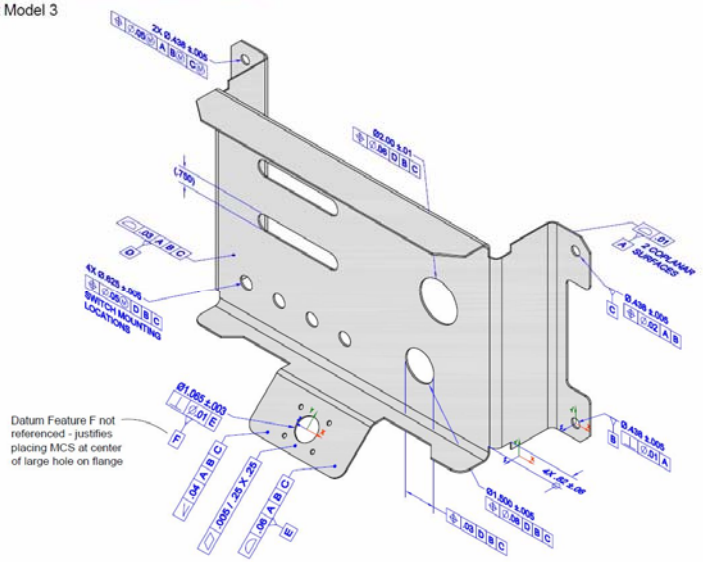
Rev B

nist_ctc_02_asme1_rb

NIST PMI Test Models - 2012

ADV/DM Advanced Dimensional Management LLC

Test Model 3



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

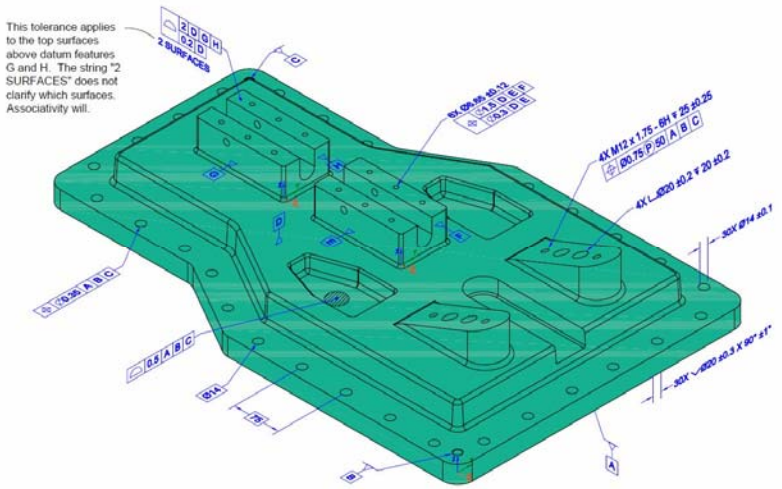
Rev B

nist_ctc_03_asme1_rb

NIST PMI Test Models - 2012

ADV/DM Advanced Dimensional Management LLC

Test Model 4



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

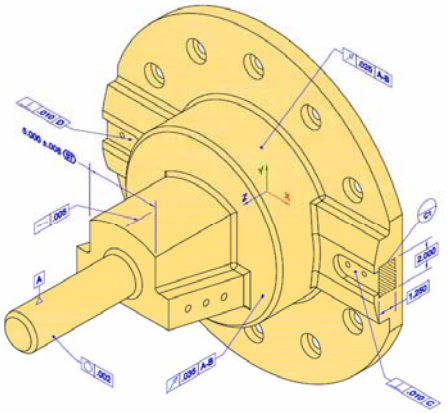
Rev C

nist_ctc_04_asme1_rc

NIST PMI Test Models - 2012

ADV/DM 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

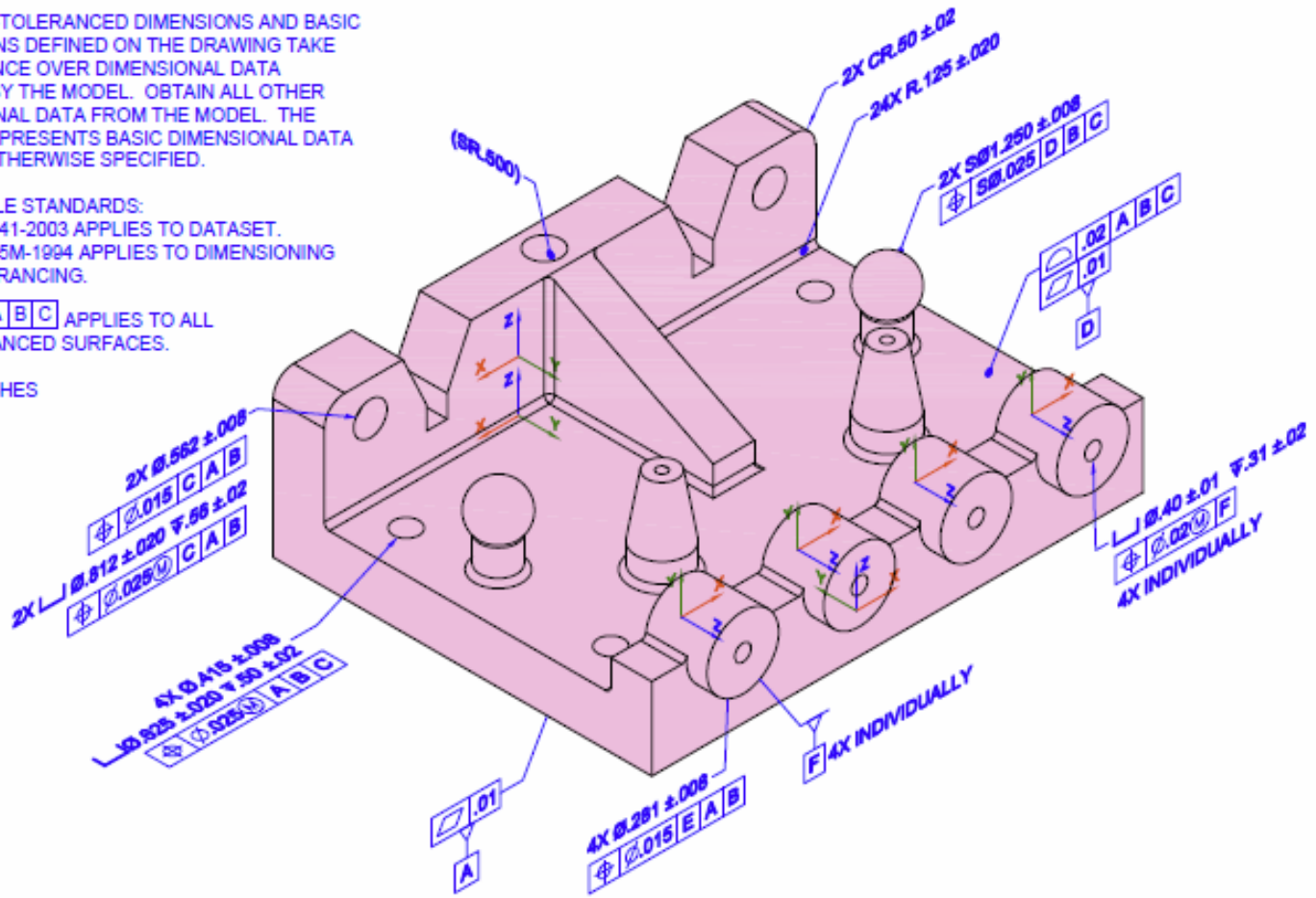
Fully-toleranced Test Case

NIST PMI Test Models - 2014

NOTES (UNLESS OTHERWISE SPECIFIED):

1. CAD MODEL _____ REV. __ IS REQUIRED TO COMPLETE PRODUCT DEFINITION.
2. DIRECTLY-TOLERANCED DIMENSIONS AND BASIC DIMENSIONS DEFINED ON THE DRAWING TAKE PRECEDENCE OVER DIMENSIONAL DATA DEFINED BY THE MODEL. OBTAIN ALL OTHER DIMENSIONAL DATA FROM THE MODEL. THE MODEL REPRESENTS BASIC DIMENSIONAL DATA UNLESS OTHERWISE SPECIFIED.
3. APPLICABLE STANDARDS:
   ASME Y14.41-2003 APPLIES TO DATASET.
   ASME Y14.5M-1994 APPLIES TO DIMENSIONING AND TOLERANCING.
4. .05 A B C APPLIES TO ALL UNTOLERANCED SURFACES.
5. UNITS: INCHES

Feature and Specification Index
nist_ftc_06_asme1_rd_fsi.pdf



PMI Fully-Toleranced Test Case 6 - View A
Includes Atomic Test Cases - 52, 53, 72, 87, 88, 89

Rev D

NIST PMI Test Models - 2014

NOTES (UNLESS OTHERWISE SPECIFIED):

1. CAD MODEL _____ REV. __ IS REQUIRED TO COMPLETE PRODUCT DEFINITION.
2. DIRECTLY-TOLERANCED DIMENSIONS AND BASIC DIMENSIONS DEFINED ON THE DRAWING TAKE PRECEDENCE OVER DIMENSIONAL DATA DEFINED BY THE MODEL. OBTAIN ALL OTHER DIMENSIONAL DATA FROM THE MODEL. THE MODEL REPRESENTS BASIC DIMENSIONAL DATA UNLESS OTHERWISE SPECIFIED.
3. APPLICABLE STANDARDS:
   ASME Y14.41-2003 APPLIES TO DATASET.
   ASME Y14.5M-1994 APPLIES TO DIMENSIONING AND TOLERANCING.
4. .06 A B C APPLIES TO ALL UNTOLERANCED SURFACES.
5. DIMENSIONING AND TOLERANCING APPLY WITH PART RESTRAINED AS FOLLOWS, EXCEPT AS INDICATED.

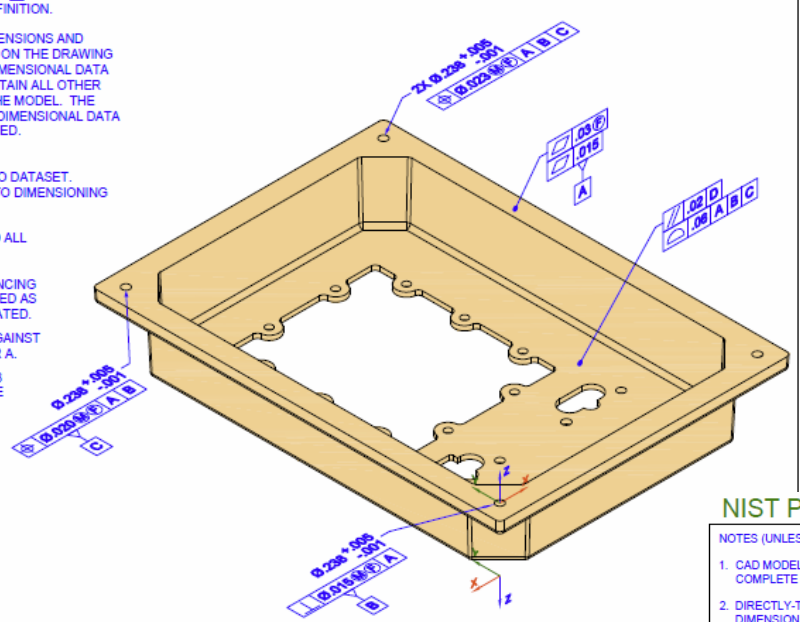
   PLACE DATUM FEATURE A AGAINST DATUM FEATURE SIMULATOR A.

   ENGAGE DATUM FEATURES B AND C WITH DATUM FEATURE SIMULATORS B AND C RESPECTIVELY.

   APPLY LOAD TO PART TO RESTRAIN DATUM FEATURE A AGAINST ITS SIMULATOR.

   DETAILED INSPECTION PLAN NEEDED TO COMPLETELY DEFINE RESTRAINT.
6. UNITS: INCHES

Feature and Specification Index
nist_ftc_08_asme1_rc_fsi.pdf



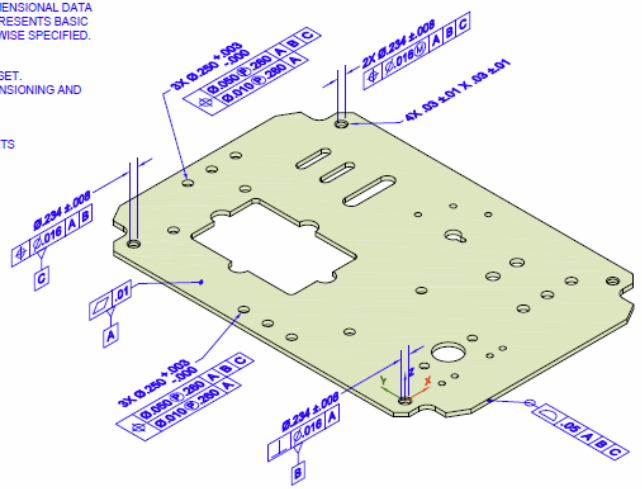
PMI Fully-Toleranced Test Case 8 - View A
Includes Atomic Test Cases - 66, 90

NIST PMI Test Models - 2014

NOTES (UNLESS OTHERWISE SPECIFIED):

1. CAD MODEL _____ REV. __ IS REQUIRED TO COMPLETE PRODUCT DEFINITION.
2. DIRECTLY-TOLERANCED DIMENSIONS AND BASIC DIMENSIONS DEFINED ON THE DRAWING TAKE PRECEDENCE OVER DIMENSIONAL DATA DEFINED BY THE MODEL. OBTAIN ALL OTHER DIMENSIONAL DATA FROM THE MODEL. THE MODEL REPRESENTS BASIC DIMENSIONAL DATA UNLESS OTHERWISE SPECIFIED.
3. APPLICABLE STANDARDS:
   ASME Y14.41-2003 APPLIES TO DATASET.
   ASME Y14.5M-1994 APPLIES TO DIMENSIONING AND TOLERANCING.
4. DIMENSION AND TOLERANCE VALUES SHOWN IN SQUARE BRACKETS [XXX] ARE MILLIMETERS.
5. MATERIAL: (.1195 THICK) 11 GA 304 SST SHT, ASTM A240.
6. UNITS: INCHES

Feature and Specification Index
nist_ftc_09_asme1_rd_fsi.pdf

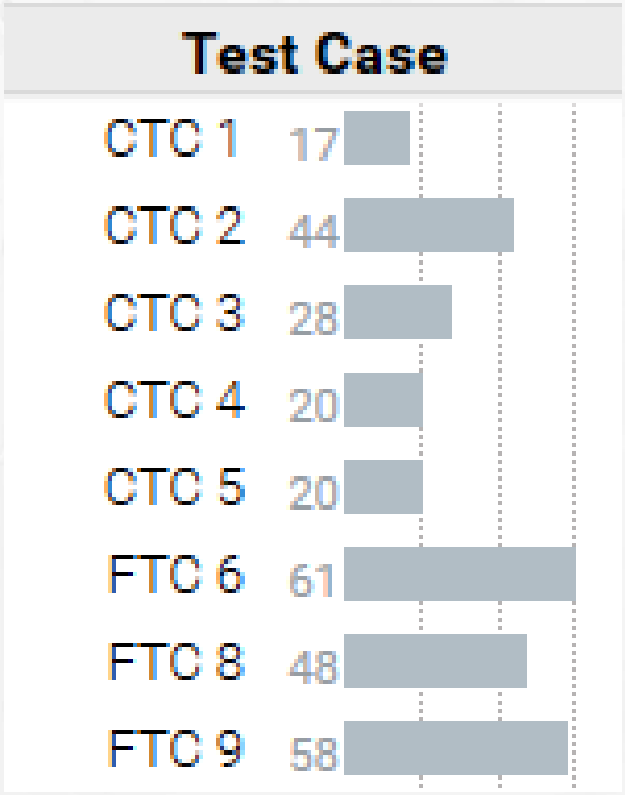


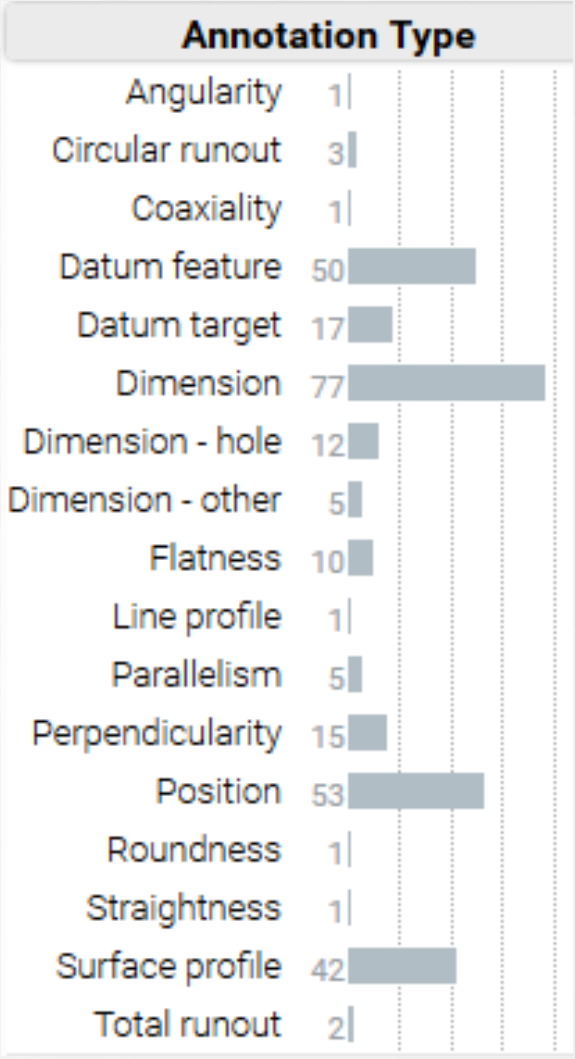
PMI Fully-Toleranced Test Case 9 - View A
Includes Atomic Test Cases - 59, 61

Rev D

CAD PMI Testing Project

- Test Case Browser
- Interactive coverage analysis of annotations
- https://pages.nist.gov/CAD-PMI-Testing/





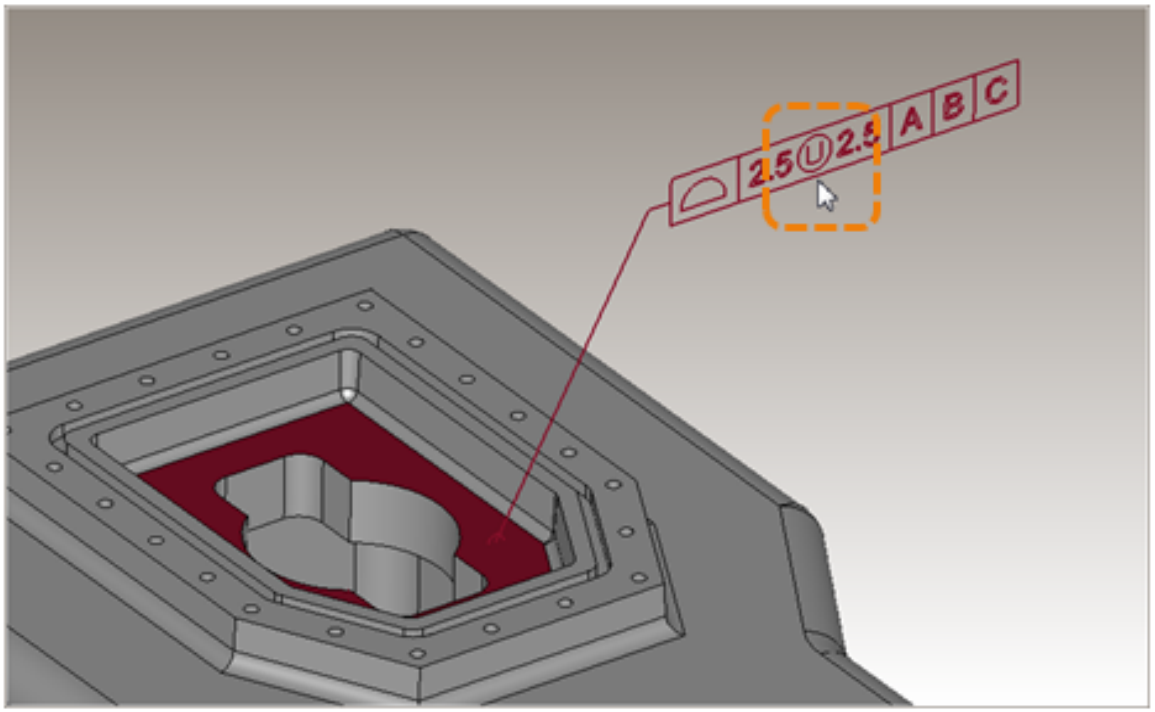
CAD PMI Testing Project

- Verification of CAD models and validation of derivative files
  - Characteristics of graphic and semantic PMI
  - High-level synthesis of raw results
- Report generic results from the CAD systems
- Interactive browser for raw results
- Exploratory data analysis

Semantic (Representation) PMI Error

Representation Limitation

Annotation Parameters:
FCF parameter defined with encoded text



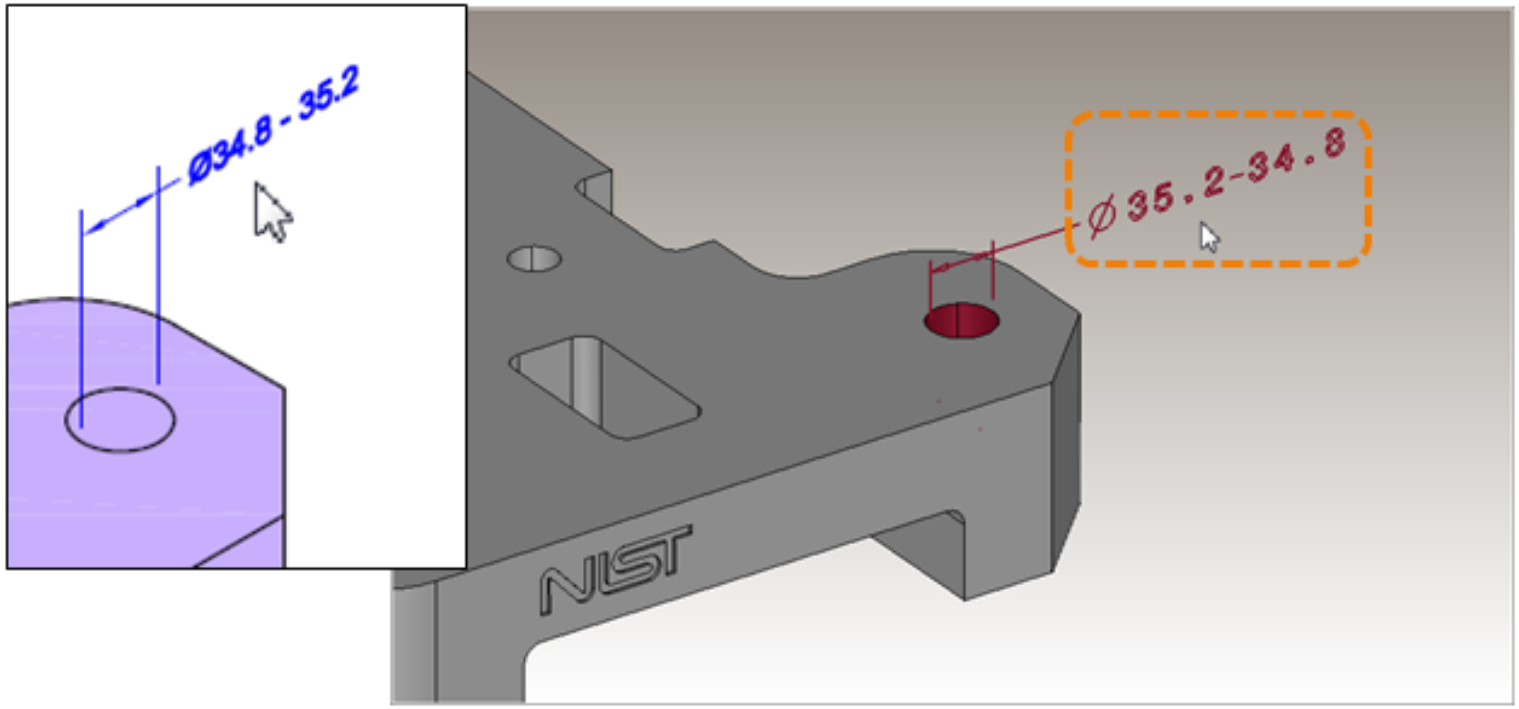
The unequally disposed modifier in this feature control frame is defined as a text symbol and not as a named parameter.

Graphical (Presentation) PMI Error

Presentation Limitation

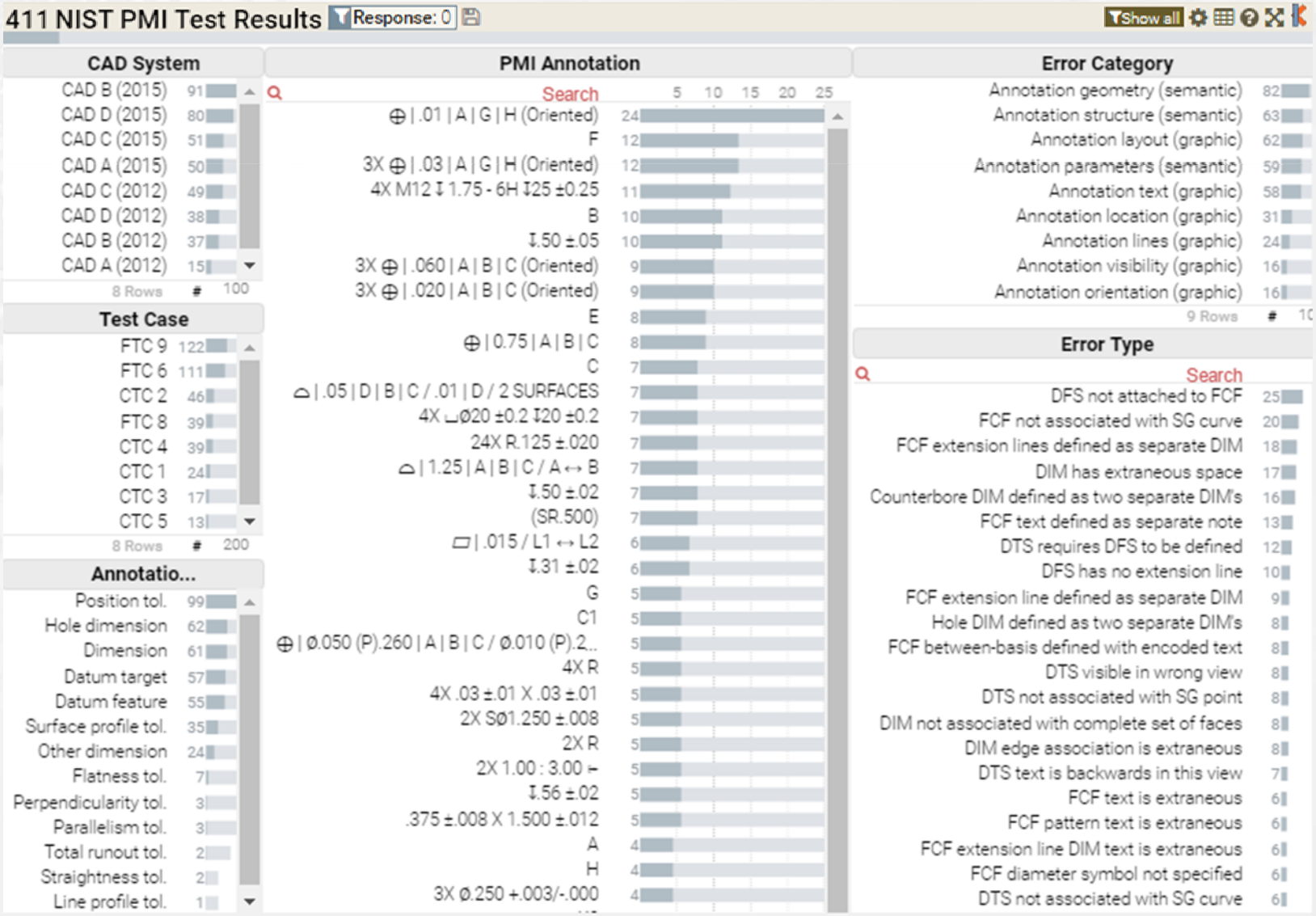
Annotation Layout:
DIM limits displayed in reversed order

Test Case



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

Raw Results

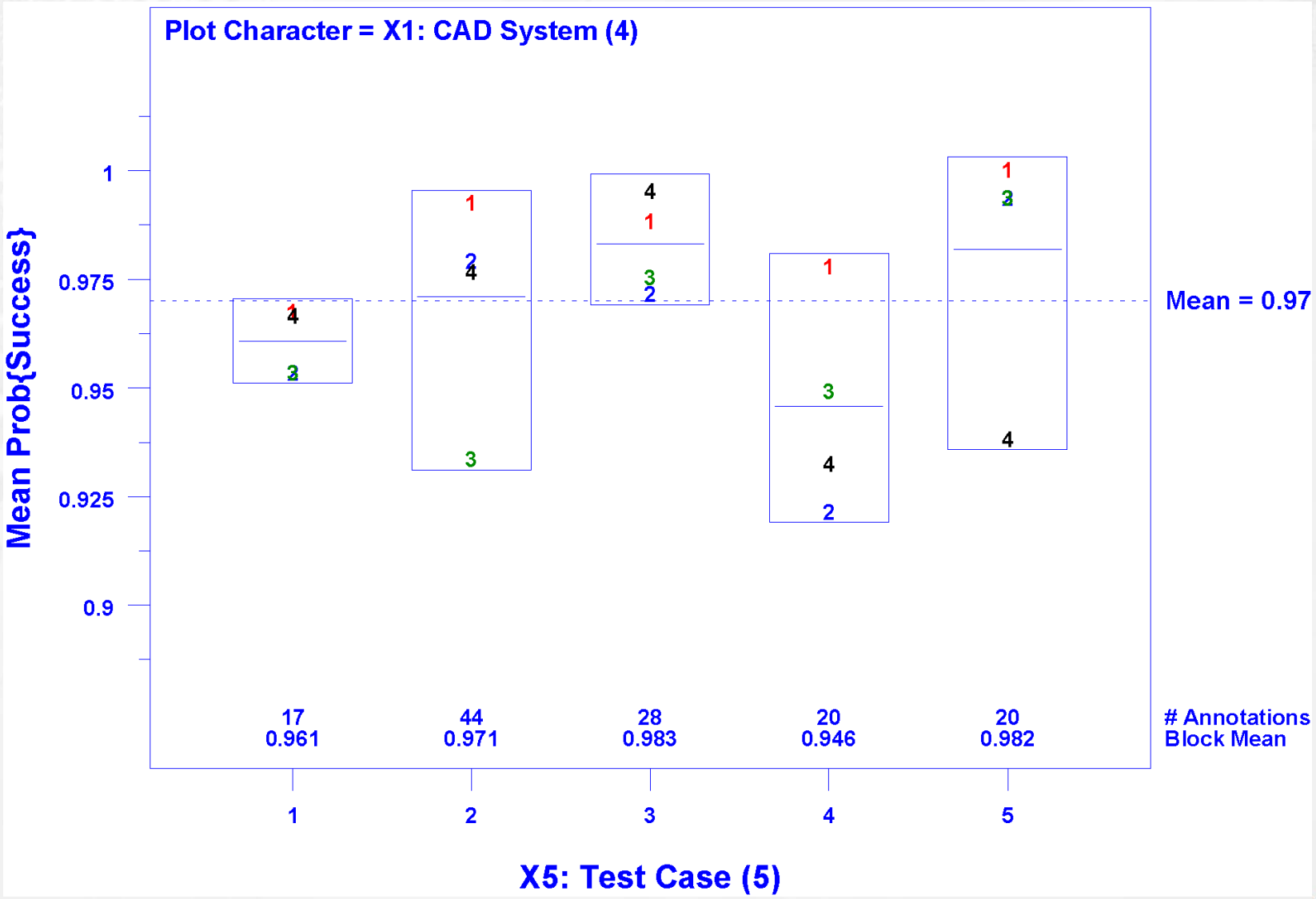

411 NIST PMI Test Results
Response: 0
Show all
CAD System
CAD B (2015) 91
CAD D (2015) 80
CAD C (2015) 51
CAD A (2015) 50
CAD C (2012) 49
CAD D (2012) 38
CAD B (2012) 37
CAD A (2012) 15
8 Rows # 100
Test Case
FTC 9 122
FTC 6 111
CTC 2 46
FTC 8 39
CTC 4 39
CTC 1 24
CTC 3 17
CTC 5 13
8 Rows # 200
Annotatio...
Position tol. 99
Hole dimension 62
Dimension 61
Datum target 57
Datum feature 55
Surface profile tol. 35
Other dimension 24
Flatness tol. 7
Perpendicularity tol. 3
Parallelism tol. 3
Total runout tol. 2
Straightness tol. 2
Line profile tol. 1
PMI Annotation
Search
5 10 15 20 25
⌖ | .01 | A | G | H (Oriented) 24
F 12
3X ⌖ | .03 | A | G | H (Oriented) 12
4X M12 ↧ 1.75 - 6H ↧25 ±0.25 11
B 10
↧.50 ±.05 10
3X ⌖ | .060 | A | B | C (Oriented) 9
3X ⌖ | .020 | A | B | C (Oriented) 9
E 8
⌖ | 0.75 | A | B | C 8
C 7
⌓ | .05 | D | B | C / .01 | D / 2 SURFACES 7
4X ⌴Ø20 ±0.2 ↧20 ±0.2 7
24X R.125 ±.020 7
⌓ | 1.25 | A | B | C / A ↔ B 7
↧.50 ±.02 7
(SR.500) 7
▱ | .015 / L1 ↔ L2 6
↧.31 ±.02 6
G 5
C1 5
⌖ | Ø.050 (P).260 | A | B | C / Ø.010 (P).2... 5
4X R 5
4X .03 ±.01 X .03 ±.01 5
2X SØ1.250 ±.008 5
2X R 5
2X 1.00 : 3.00 ⊢ 5
↧.56 ±.02 5
.375 ±.008 X 1.500 ±.012 5
A 4
H 4
3X Ø.250 +.003/-.000 4
Error Category
Annotation geometry (semantic) 82
Annotation structure (semantic) 63
Annotation layout (graphic) 62
Annotation parameters (semantic) 59
Annotation text (graphic) 58
Annotation location (graphic) 31
Annotation lines (graphic) 24
Annotation visibility (graphic) 16
Annotation orientation (graphic) 16
9 Rows # 10
Error Type
Search
DFS not attached to FCF 25
FCF not associated with SG curve 20
FCF extension lines defined as separate DIM 18
DIM has extraneous space 17
Counterbore DIM defined as two separate DIM's 16
FCF text defined as separate note 13
DTS requires DFS to be defined 12
DFS has no extension line 10
FCF extension line defined as separate DIM 9
Hole DIM defined as two separate DIM's 8
FCF between-basis defined with encoded text 8
DTS visible in wrong view 8
DTS not associated with SG point 8
DIM not associated with complete set of faces 8
DIM edge association is extraneous 8
DTS text is backwards in this view 7
FCF text is extraneous 6
FCF pattern text is extraneous 6
FCF extension line DIM text is extraneous 6
FCF diameter symbol not specified 6
DTS not associated with SG curve 6

High-level Results

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%

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%**

Exploratory Data Analysis



Bad Testing

- IFC – Industry Foundation Classes (building industry)
- Current IFC Certification Testing is good
  - Well-defined test cases, methodology, criteria
- Some previous IFC testing was not as good
  - Lipman, Palmer, Palacios, “Assessment of conformance and interoperability testing methods used for construction industry product models”, in Journal of Automation in Construction, 2011.
  - Poorly characterized test cases
  - Unrealistic test purposes
  - Meaningless test criteria

Testing Lessons Learned

- Purpose
- Methodology
- Test cases, models, files
- Criteria
- Tools
- Results

Testing Lessons Learned

- Purpose
  - Very specific
  - Did not consider other possible uses of the CAD models
- Methodology
- Test cases, models, files
- Criteria
- Tools
- Results

Testing Lessons Learned

- Purpose
- Methodology
  - Costly, time-consuming
  - Consider efficiency
- Test cases, models, files
- Criteria
- Tools
- Results

Testing Lessons Learned

- Purpose
- Methodology
- Test cases, models, files
  - Driven by ASME Y14 annotation standards
  - Not necessarily common practice or common geometry
  - Distribution of tolerances skews results
- Criteria
- Tools
- Results

Testing Lessons Learned

- Purpose
- Methodology
- Test cases, models, files
- Criteria
  - Scope
  - Dependent on purpose and tools
- Tools
- Results

Testing Lessons Learned

- Purpose
- Methodology
- Test cases, models, files
- Criteria
- Tools
  - Who validates the validator?
- Results

Testing Lessons Learned

- Purpose
- Methodology
- Test cases, models, files
- Criteria
- Tools
- Results
  - Raw vs. high-level vs. statistical
  - Skewed by distribution of annotations
  - Not weighted

Testing Lessons Learned

- Good testing is challenging
- Good testing is time-consuming
- Good testing requires funding

Resources

- NIST CAD PMI Testing Project - https://go.usa.gov/mGVm
  - Interactive Test Case and Verification Results Browser https://pages.nist.gov/CAD-PMI-Testing/
- STEP File Analyzer - https://go.usa.gov/yccx
- CAx-IF - https://www.cax-if.org/
- JT-IF - http://www.prostep.org/en/projects/jt-implementor-forum.html
- 3D PDF-IF - http://www.3dpdfconsortium.org/implementor-forum/
- AP242 Benchmark Testing - http://benchmark.ap242.org/