Standards-Based Interoperability for Design to Manufacturing and Quality in the Supply Chain

Asa Trainer
GPDIS2016
Phoenix, AZ
Sep 2016

Introduction

- **International TechneGroup Incorporated (ITI)**
  - **Private company headquartered in Cincinnati since 1983**
  - **Development offices in the United States, England, Israel and India**
  - **Engineering software and services**
    - **PLM system migration solutions**
    - **CAD interoperability solutions**

- **Asa Trainer**
  - **New England upbringing, military veteran**
  - **Engineering education (UMD, WSU, RPI) and university educator/researcher**
  - **Both aerospace and CAD industry experience**
  - **Interoperability solutions development**
  - **US and foreign patents in interoperability**
  - **International consortia team member**
  - **Interoperability product / process / program management**

Acknowledgements

- The work described here is funded by
  - NIST Grant (CA) 70NANB14H314
    - Investigating the Impact of Standards-Based Interoperability for Design to Manufacturing and Quality in the Supply Chain
  - NIST Grant (CA) 70NANB14H256
    - Validation for Downstream Computer Aided Manufacturing and Coordinate Metrology Processes
  - DMDII-14-06-05
    - Digital Standards for the Advanced Manufacturing Enterprise "Operate, Orchestrate and Originate (O3)"

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

DMDII
DIGITAL MANUFACTURING AND DESIGN INNOVATION INSTITUTE

The Team

Global Product Data Interoperability Summit | **2016**

Rockwell Collins

Geater Machining & Manufacturing, Co.

ITI International TechneGroup

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

Mitutoyo

Mastercam

CORETECHNOLOGIE

ACCR ADVANCED COLLABORATION CONSULTING RESOURCES

Building Blocks to a Stds-based MBE Process

NIST Sponsored

D2MIV 2	Can we close upstream info gaps needed for downstream processes? Can we move downstream MBD back upstream as feedback via a Std?
D2MIV 1	Can we validate downstream MBD data against its upstream source? Can we map the upstream MBD Std to the downstream MBD Std?
D2MI	Can we move MBD data to downstream processes (CAM/CAI) via a Std? Is there a demonstrable ROI in taking the MBD downstream?
Conf/Val 2	Can we extend the Test Cases to include more “real-world” elements? If we do, what impact will it have on the results?
Conf/Val 1	Can we define meaningful MBD Test Cases and Model them in CAD? Can we Verify that the models accurately represent the test cases? Can we create MBD Std-based Derivatives and Validate them?
SFA	Can we Validate STEP files for proper STEP syntax? Can we coax better STEP file translators out of CAD OEMs & vendors?

Building Blocks to a Stds-based MBE Process

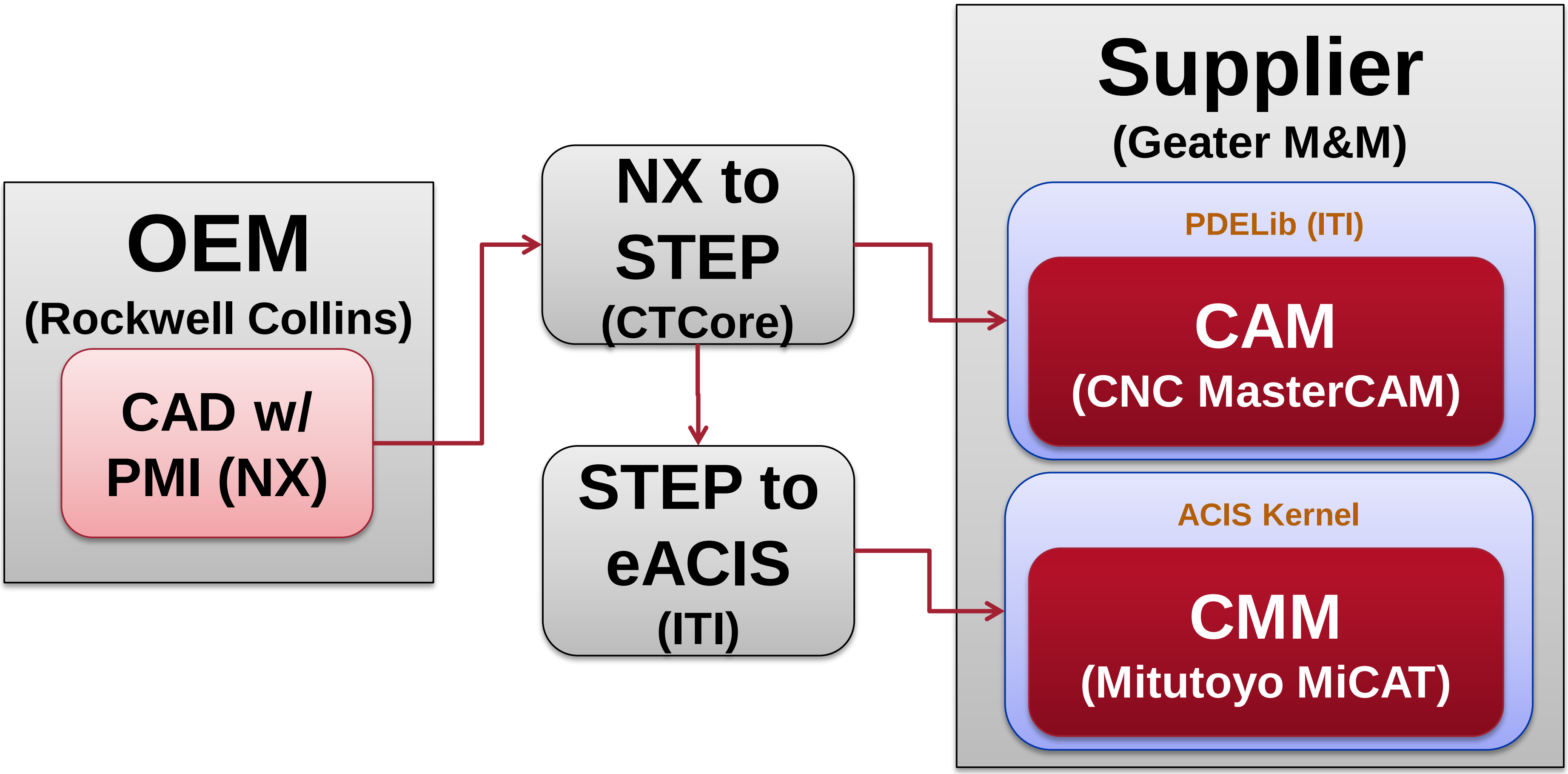
Commercially-sponsored
& other non-NIST research

DMDII O3	Can we provide near real-time design change to the downstream users? Can we provide rapid feedback to designers & planners during simulation or execution?
OSD TDGV Proto	Is there a better way to control geometric quality than global tolerances? Can tolerance data in PMI be used to control variation in nominal geometry?
CAx-IF 3DPDF-IF	Can the NIST benchmark data and verification/validation processes be used to drive improvement in commercial MBD (interoperability) processes?
JT-IF	Can the NIST benchmark data be used to drive improvement In commercial MBD (interoperability) processes?
End-user Companies	Can end-user companies leverage the NIST benchmark data and verification/validation processes?
CAx & Interop. Vendors	Can CAx and Interoperability vendors leverage the NIST benchmark data and verification/validation processes?

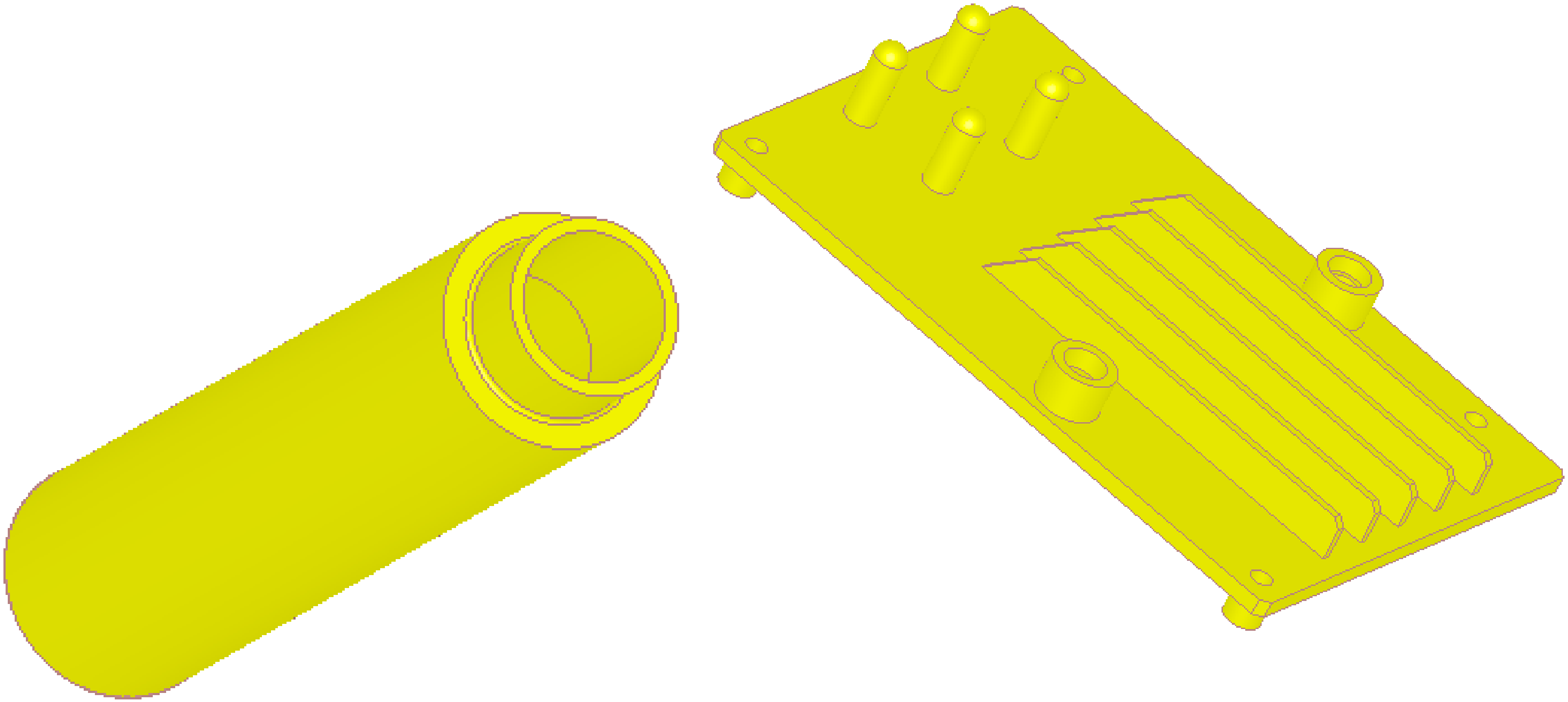
Design to Manufacturing

D2MI

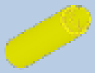
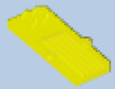
Data Exchange from CAD-to-CAM and CAD-to-CMM



Test Models

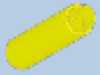
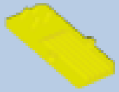


CAD Model Creation Metrics

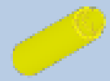
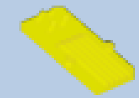
CAD Metrics	Rolled Standoff 			Heat Sink 		
827-9999	**-903**	**-905**	**-907**	**-904**	**-906**	**-908**
2D PDF drawing	---	full dimension with 2D PMI annotation	key 2D PMI annotation only (PDD)	---	full dimension with 2D PMI annotation	key 2D PMI annotation only (PDD)
3D model	includes embedded PMI	not provided	with no embedded PMI	includes embedded PMI	not provided	with no embedded PMI
Number of PMI entities	23 (24*)	---	---	78 (90*)	---	---
CAD model creation (modified existing part)	0.5 hours	0.5 hours	0.5 hours	0.5 hours	0.5 hours	0.5 hours
Model-embedded PMI	3.0 hours	---	---	6.0 hours	---	---
2D PDF drawing creation	0.5 hours	1.0 hours	0.7 hours	0.5 hours	2.4 hours	1.3 hours
CAD tool issue resolution and designer education	9.0 hours	0.5 hours	0.1 hours	4.9 hours	0.5 hours	0.1 hours
CAD model resolution to address downstream issues	2.3 hours + 4.5 hours to learn NX	---	---	3.0 hours + 1.3 hours to learn NX	original dwg missing dim – required ECO	---

* Original PMI entity count based on objects found in the NX Part navigator – eventually reduced count by issue resolution

CAM Model Creation Metrics

CAM Metrics	Rolled Standoff 			Heat Sink 		
827-9999	-903 3D model with embedded PMI	-905 2D drawing fully annotated	-907 2D PMI drawing and 3D model	-904 3D model with embedded PMI	-906 2D drawing fully annotated	-908 2D PMI drawing and 3D model
CAM Process Preparation a) Gather information b) Analyze job c) Determine approach	3.25 hours a) 0.25 hours b) 0.50 hours c) 2.50 hours	3.25 hours a) 0.25 hours b) 0.50 hours c) 2.50 hours	3.25 hours a) 0.25 hours b) 0.50 hours c) 2.50 hours	3.83 hours a) 0.33 hours b) 0.50 hours c) 3.00 hours	3.83 hours a) 0.33 hours b) 0.50 hours c) 3.00 hours	3.83 hours a) 0.33 hours b) 0.50 hours c) 3.00 hours
CAM Setup a) Model preparation b) Pre-program setup	0.45 hours a) 0.00 hours b) 0.45 hours	0.52 hours a) 0.07 hours b) 0.45 hours	0.45 hours a) 0.00 hours b) 0.45 hours	0.68 hours a) 0.45 hours b) 0.23 hours	0.64 hours a) 0.52 hours b) 0.12 hours	0.40 Hours a) 0.28 hours b) 0.12 hours
CAM Programming a) Part programming b) Tooling preparation	1.00 hours a) 0.50 hours b) 0.50 hours	1.00 hours a) 0.50 hours b) 0.50 hours	1.00 hour a) 0.50 hours b) 0.50 hours	3.23 hours a) 3.01 hours b) 0.22 hours	3.13 hours a) 2.75 hours b) 0.38 hours	2.30 hours a) 2.08 hours b) 0.22 hours
CAM Verification a) Create work instructions (setup sheets) b) Review process (Run VERICUT)	0.15 hours a) 0.10 hours b) 0.05 hours	0.15 hours a) 0.10 hours b) 0.05 hours	0.15 hours a) 0.10 hours b) 0.05 hours	0.42 hours a) 0.32 hours b) 0.10 hours	0.50 hours a) 0.35 hours b) 0.15 hours	0.53 hours a) 0.35 hours b) 0.18 hours
Total	4.85 hours	4.92 hours	4.85 hours	8.16 hours	8.10 hours	7.06 hours

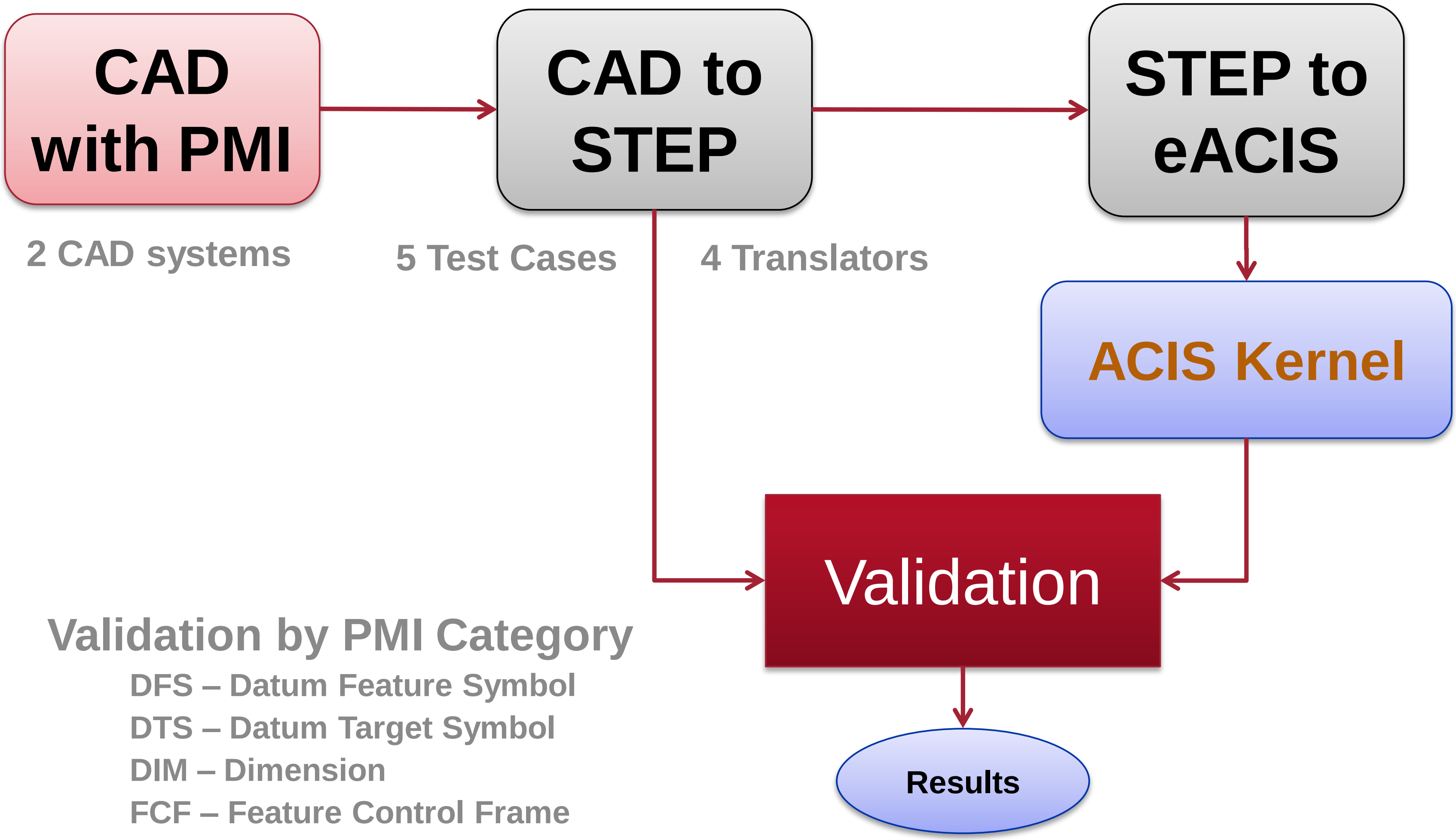
CMM Model Creation Metrics

CMM Metrics	Rolled Standoff 			Heat Sink 		
827-9999	-903 3D model with embedded PMI	-905 2D drawing fully annotated	-907 2D PMI drawing and 3D model	-904 3D model with embedded PMI	-906 2D drawing fully annotated	-908 2D PMI drawing and 3D model
CMM Process Preparation				0.10 hours	0.50 hours	0.75 hours
CMM Setup				0.10 hours	0.75 hours	1.00 hour
CMM Programming				0.50 hours	4.76 hours	4.75 hours
CMM Verification a) Verify information b) Verify for collisions				0.30 hours a) 0.15 hours b) 0.15 hours	1.00 hours a) 0.50 hours b) 0.50 hours	1.00 hour a) 0.50 hours b) 0.50 hours
Inspection a) CMM inspection b) Manual inspection	0.50 hours a) 0.00 hours b) 0.50 hours	0.25 hours a) 0.00 hours b) 0.25 hours	0.25 hours a) 0.00 hours b) 0.25 hours	0.70 hours a) 0.20 hours b) 0.50 hours	0.40 hours a) 0.20 hours b) 0.20 hours	0.40 hours a) 0.20 hours b) 0.20 hours
CMM Data Analysis				0.50 Hours	0.50 hours	0.50 hours
Total Time	0.50 hours	0.25 hours	0.25 hours	2.20 hours	7.91 hours	8.40 hours

Design to Metrology Validation

D2MIV 1

Data Exchange from CAD-to-CMM (STEP to eACIS) with Validation



Validation by PMI Category

- DFS – Datum Feature Symbol
- DTS – Datum Target Symbol
- DIM – Dimension
- FCF – Feature Control Frame
- Notes – Free Standing Notes

D2MIV Phase 1 Results – RC Models

Model File	DFS Clean	DIM Clean	FCF Clean	Clean Percent
827-9999-903	2 of 2	3 of 8	6 of 6	69%
827-9999-904	3 of 3	53 of 54	13 of 13	99%

DFS = Datum Feature Symbol
DIM = Dimension
FCF = Feature Control Frame

D2MIV Phase 1 Results – NIST CTCs

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eACIS Targets Validated w.r.t. STEP AP242 Sources

Model File	DFS Clean	DIM Clean	FCF Clean	Percent Clean (xN)	Percent Clean (xNDTS)
nist_ctc_01_asme1_ct5210_rd_ct242repr.stp	2	7	6	79%	79%
nist_ctc_01_asme1_ct5210_rd_dk242repr.stp	3	6	6	79%	79%
nist_ctc_01_asme1_nx800_rd_ct242repr.stp	3	7	6	84%	84%
nist_ctc_01_asme1_nx800_rd_nx.stp	3	1	6	53%	53%
nist_ctc_01_asme1_nx800_rd_th.stp	3	9	6	95%	95%
nist_ctc_02_asme1_ct5210_rc_ct242repr.stp	0	0	0	0%	0%
nist_ctc_02_asme1_ct5210_rc_dk242repr.stp	0	0	0	0%	0%
nist_ctc_02_asme1_nx800_rc_ct242repr.stp	0	0	0	0%	0%
nist_ctc_02_asme1_nx800_rc_nx.stp	6	7	22	80%	100%
nist_ctc_02_asme1_nx800_rc_th.stp	0	0	0	0%	0%
nist_ctc_03_asme1_ct5210_rc_ct242repr.stp	6	8	13	93%	93%
nist_ctc_03_asme1_ct5210_rc_dk242repr.stp	6	8	13	93%	93%
nist_ctc_03_asme1_nx800_rc_ct242repr.stp	6	8	13	93%	93%
nist_ctc_03_asme1_nx800_rc_nx.stp	6	8	13	93%	93%
nist_ctc_03_asme1_nx800_rc_th.stp	6	9	13	97%	97%
nist_ctc_04_asme1_ct5210_rd_ct242repr.stp	8	7	5	87%	87%
nist_ctc_04_asme1_ct5210_rd_dk242repr.stp	8	9	3	83%	83%
nist_ctc_04_asme1_nx800_rd_ct242repr.stp	8	7	4	83%	83%
nist_ctc_04_asme1_nx800_rd_nx.stp	8	5	5	78%	78%
nist_ctc_04_asme1_nx800_rd_th.stp	8	7	5	87%	87%
nist_ctc_05_asme1_ct5210_rd_ct242repr.stp	4	2	6	55%	60%
nist_ctc_05_asme1_ct5210_rd_dk242repr.stp	4	3	7	64%	70%
nist_ctc_05_asme1_nx800_rd_ct242repr.stp	2	2	5	45%	50%
nist_ctc_05_asme1_nx800_rd_nx.stp	2	2	10	70%	78%
nist_ctc_05_asme1_nx800_rd_th.stp	2	2	6	45%	50%
Counts:	107	178	186	62%	67%
Percents:	72%	64%	62%		

DFS = Datum Feature Symbol
DIM = Dimension
FCF = Feature Control Frame
xN = Percent Clean excluding Note entities
xNDTS = Percent Clean excluding Note and Datum Target Symbols

Validation of extended-ACIS PMI representation with Source STEP Model

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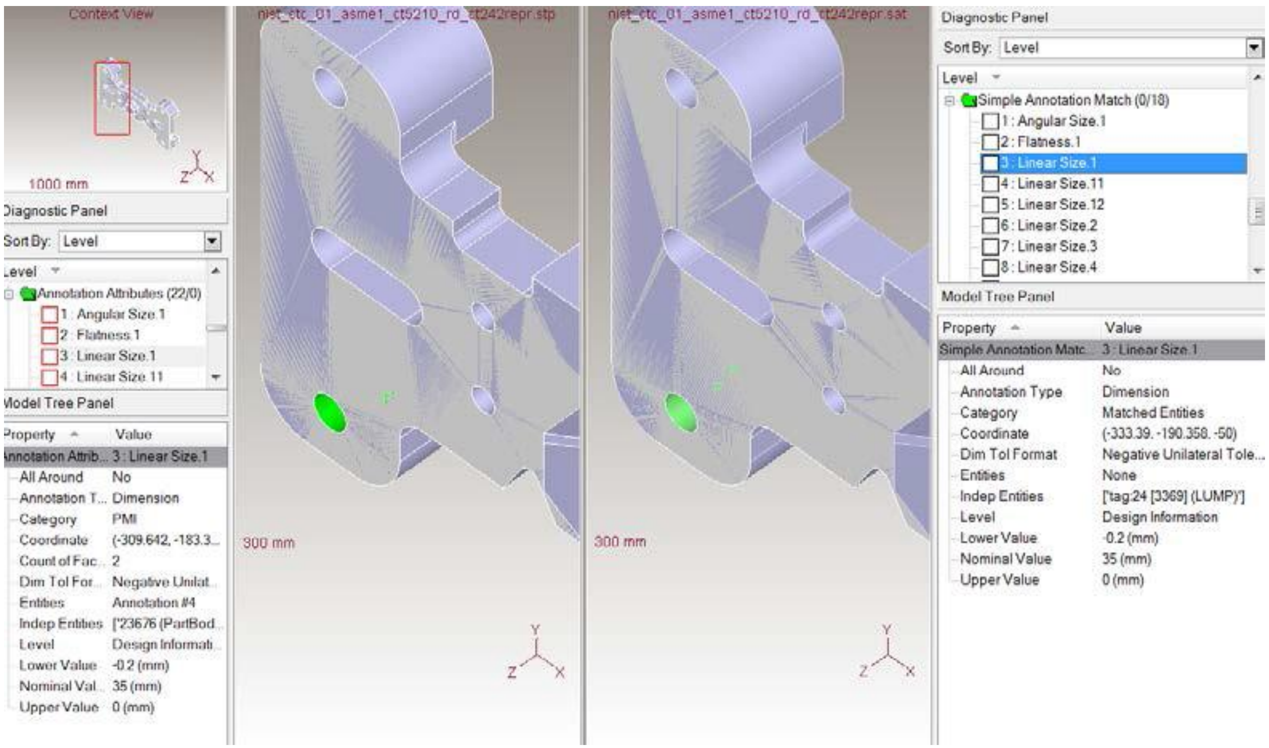

Validation of extended-ACIS PMI representation with source STEP Model illustrating an anomaly

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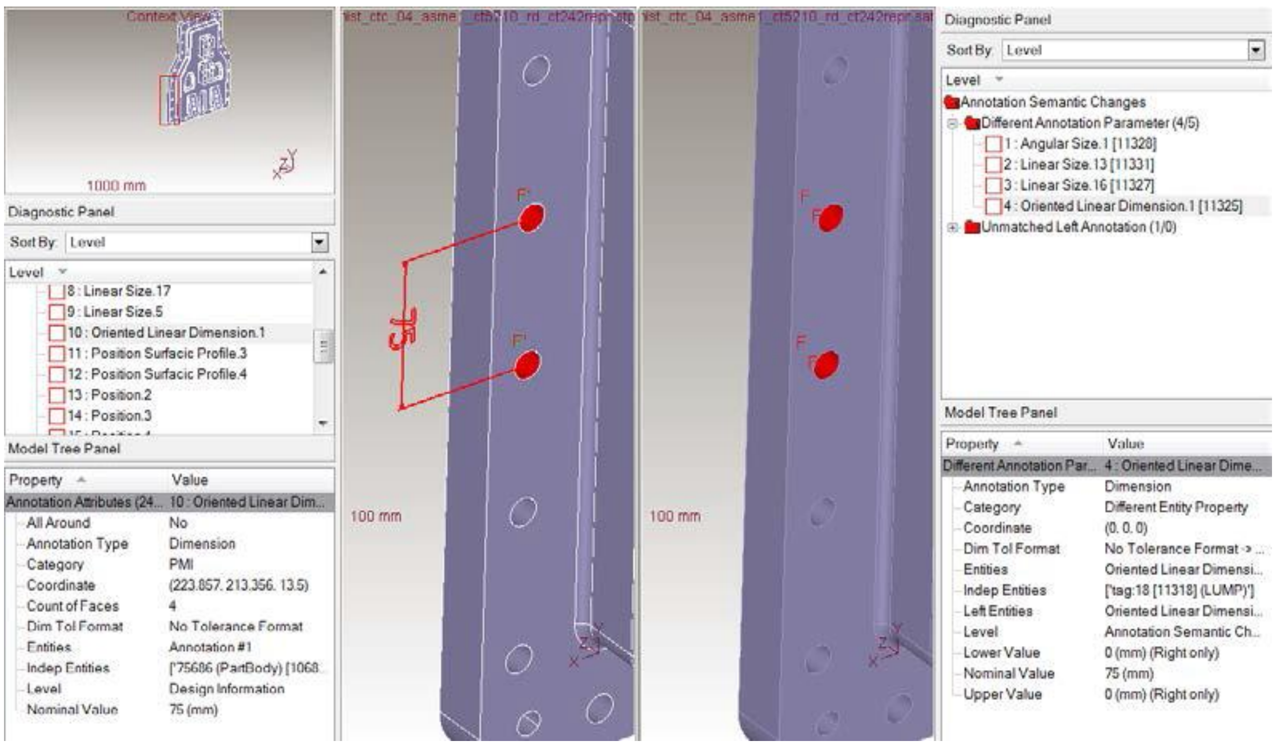
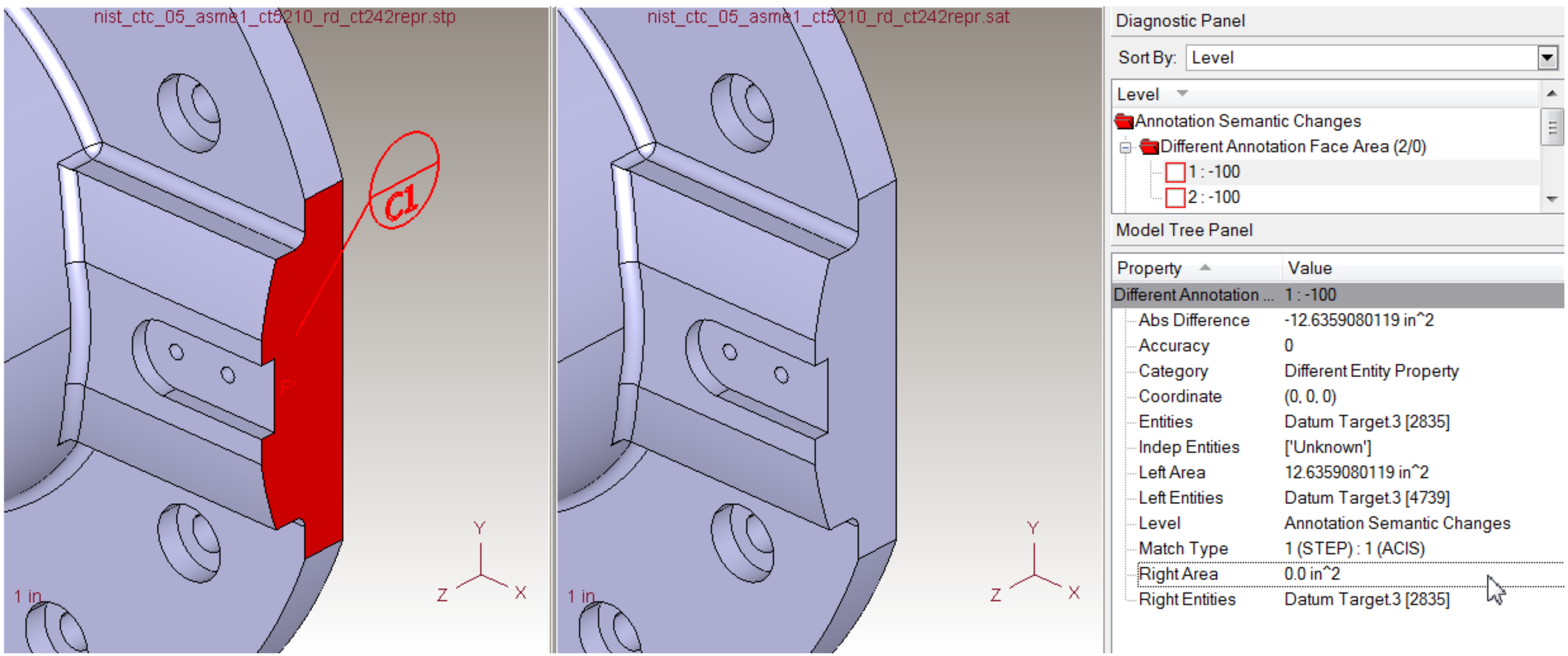


Validation illustrating loss of Associated Geometry for a Datum Target Symbol in target ACIS model



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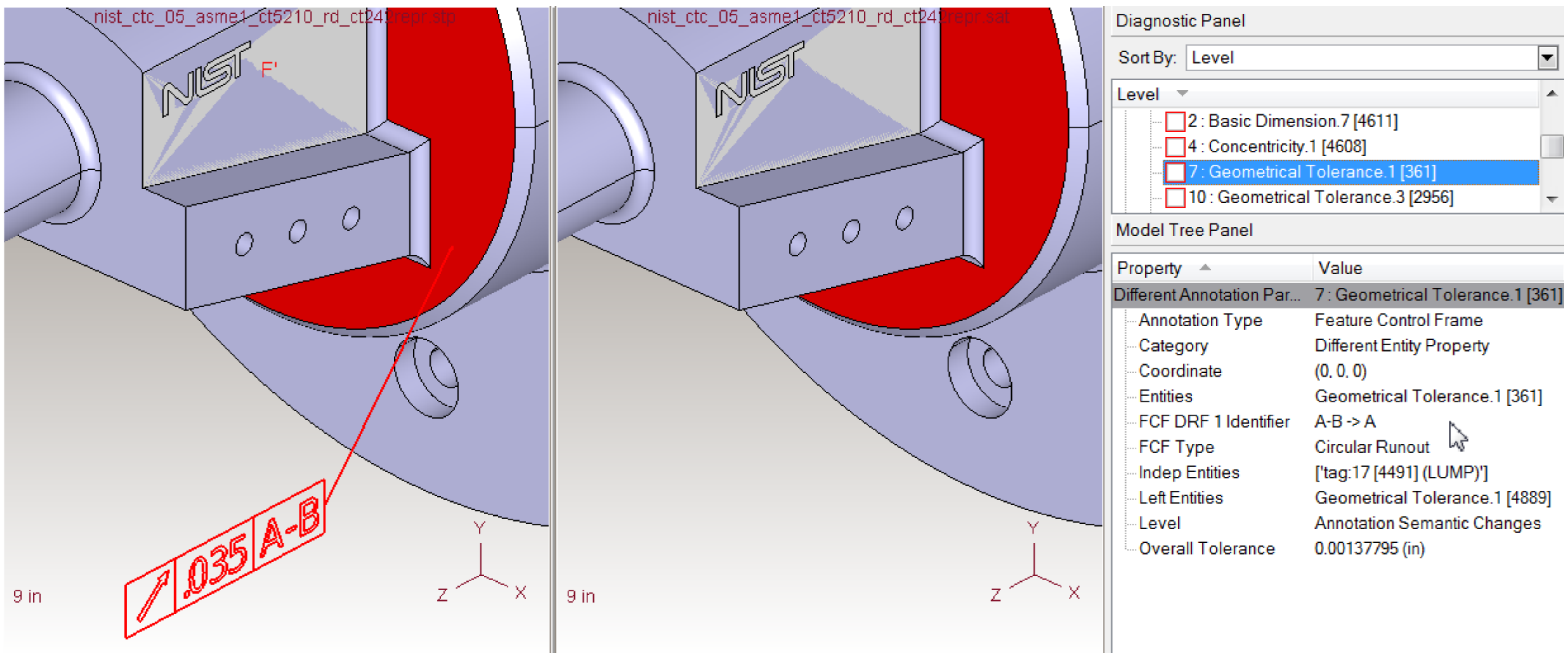
Change to Feature Control Frame primary datum reference frame identifier



Unformatted dimension with no tolerances gets tolerances set to zero

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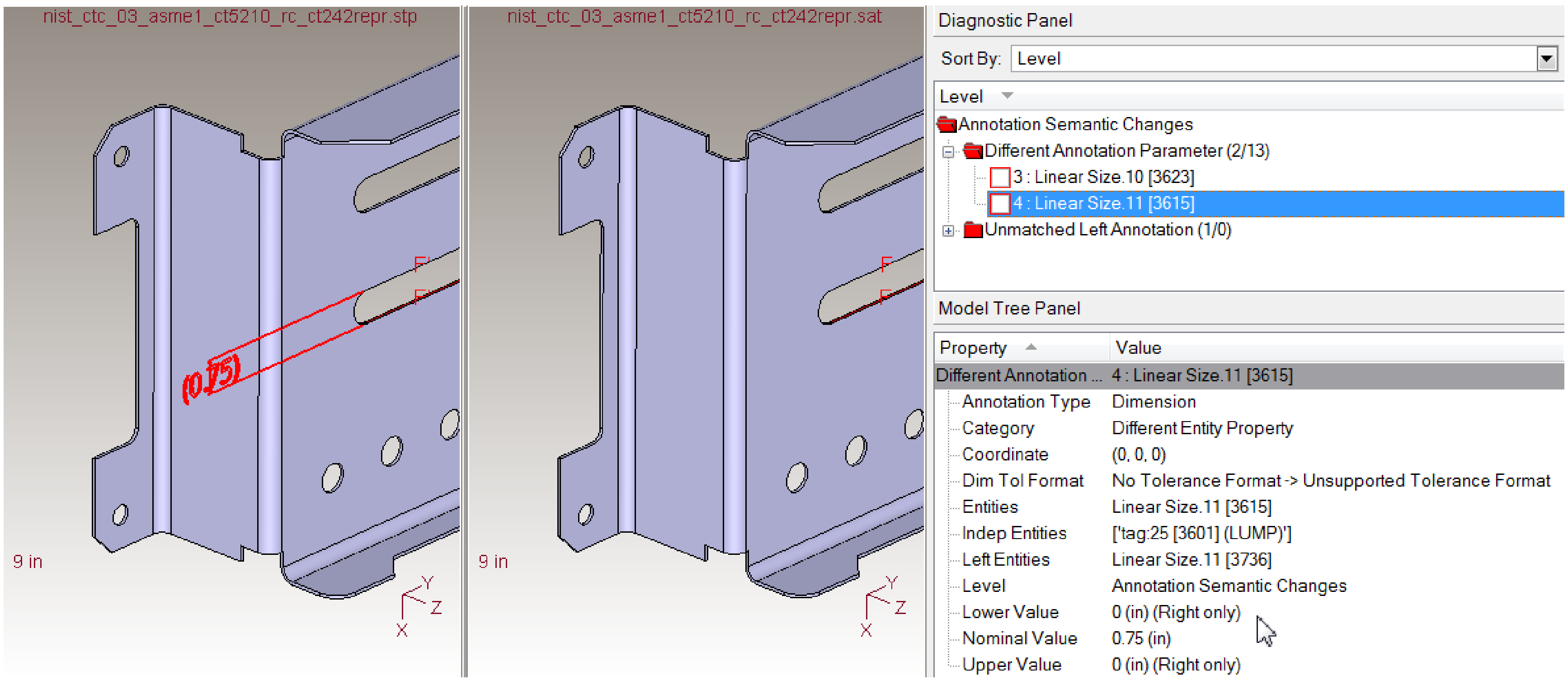

Example of PMI/STEP/ACIS/QIF Mapping Table

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	STEP AP242	ACIS	QIF
PMI			
dimension types			
linear dimension	dimensional_location	*spaxpmi_dimension (DIMSUBTYPE_LENGTH_OR_DISTANCE)*	LengthCharacteristicDefinitionType
angular dimension	angular_location/angular_size	*spaxpmi_dimension (DIMSUBTYPE_ANGLE)(no way to specify m*	AngularCharacteristicDefinitionType
radius dimension	dimensional_size	*spaxpmi_dimension (DIMSUBTYPE_RADIUS)*	RadiusCharacteristicDefinitionType
diameter dimension	dimensional_size	*spaxpmi_dimension(DIMSUBTYPE_DIAMETER)*	DiameterCharacteristicDefinitionType
oriented dimension	oriented_dimensional_location	not covered	--
curved dimension	dimensional_location_with_path/dimensional_size_with_path	*spaxpmi_dimension(DIMSUBTYPE_CURVILINEAR)*	CurvedLengthCharacteristicDefinitionType
coordinate dimension		*spaxpmi_dimension(DIMSUBTYPE_COORDDIM2D, DIMSUBTYPE_*	LinearCoordinateCharacteristicDefinitionType
dimension tolerance principle			
independency	shape_dimension_representation.name	not covered	<>EnvelopeRequirement(FALSE)
envelope	shape_dimension_representation.name	not covered	<>EnvelopeRequirement(TRUE)
dimension values			
nominal value	measure_representation_item	dimension value	<>TargetValue
nominal value with qualifier	qualified_representation_item	not covered	<>TargetValue
nominal value with plus/minus bounds	plus_minus_tolerance	not covered	<>DefinedAsLimit(FALSE)
value range	measure_representation_item	dimtol lower limit/dimtol upper limit	<>DefinedAsLimit(TRUE)
tolerance class	limits_and_fits	not covered	
dimension modifiers			
basic/theoretical	descriptive_representation_item	dimension_type (dimtype_basic)	<>DimensionType(BASIC)
reference/auxiliary	descriptive_representation_item	dimension_type (dimtype_reference)	<>DimensionType(REFERENCE)
controlled radius	descriptive_representation_item	not covered	RadiusCharacteristicDefinitionType<>ControlledRadius(TRUE)
square	descriptive_representation_item	not covered	SquareCharacteristicDefinitionType
statistical tolerance	descriptive_representation_item	dimension_type (dimtype_tolerance)	CharacteristicDefinitionBaseType<>StatisticalCharacteristic(TRUE)
continuous feature	descriptive_representation_item	not covered	

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STEP-QIF Mapping Tables - Classes

- **PMI**
  - **Dimension Types (19/21)**
  - **Dimension Tolerance Principle (2/2)**
  - **Dimension values (45/48)**
  - **Tolerance Types (15/18)**
  - **Tolerance Zone (13/18)**
  - **Tolerance Modifiers (17/21)**
  - **Unit based Tolerance (9/9)**
  - **Datum reference modifiers (25/32)**
- **Shape**
  - **Topology (8/8)**
  - **Surface Geometry (11/11)**
  - **Curve Geometry (10/10)**
- **Links**
  - **PMI <-> Brep (both)**
  - **PMI <-> Polyline presentation (both)**
- **Miscellaneous**
  - **Notes (both)**
  - **Flag Notes (QIF)**
  - **Surface Finish (QIF)**
  - **Tables (none)**
  - **Global or General Tolerances (none)**
  - **Views (both)**

(# of STEP elements / # of QIF elements)

Results

- **Successfully demonstrated transfer of MBD design models from OEM to Supplier and from CAD to CAM and CM systems**
- **Proved that, for metrology, savings for MBD transfer over traditional, non-MBD, was significant (70% reduction in overall process time)**
- **Validation was a valuable check on data quality**
- **STEP and QIF have similar coverage, ACIS had gaps**

Conclusions

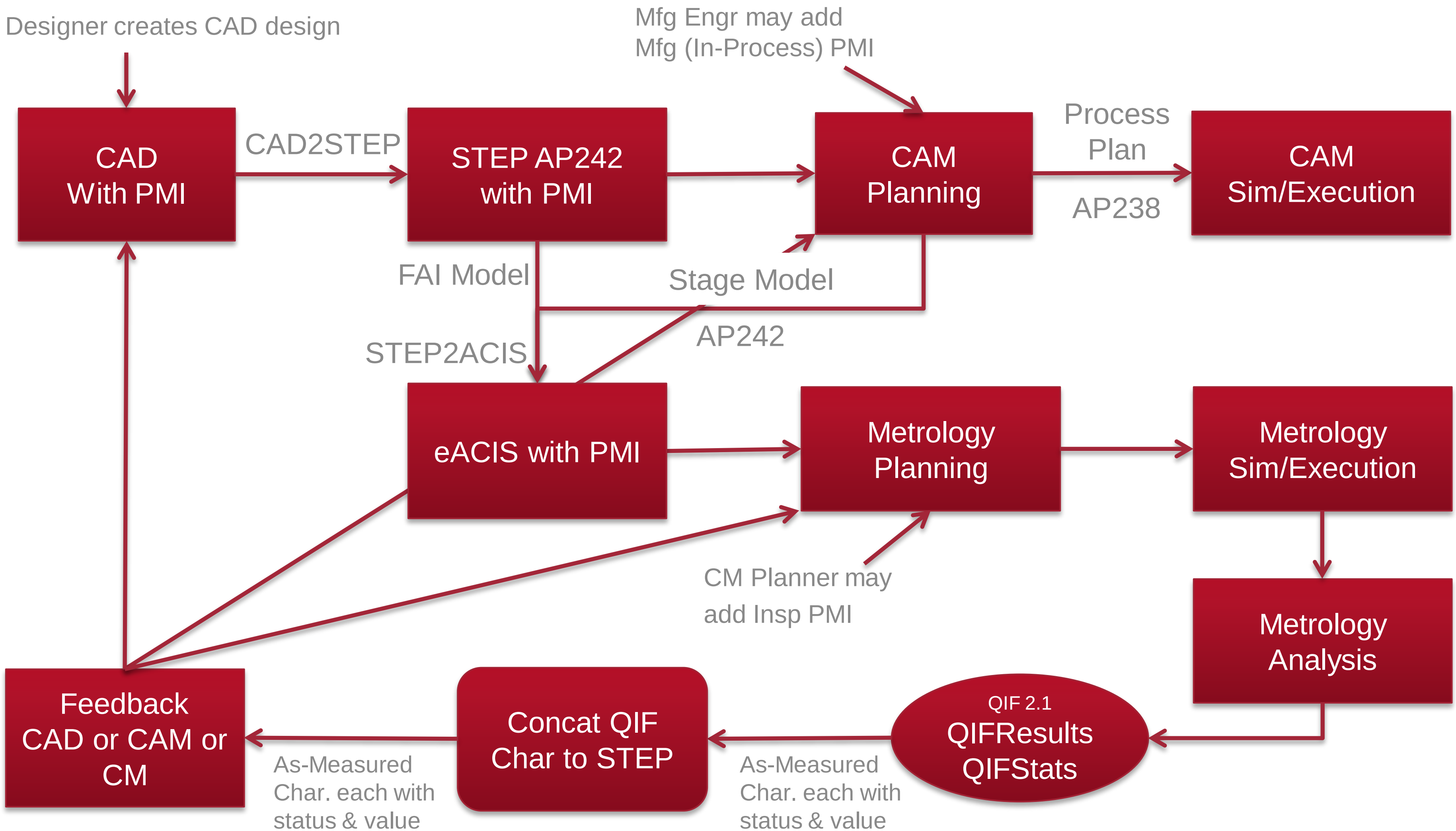
- **Transformation of MBD downstream is still immature**
- **Transformation of Representation structures from STEP to ACIS requires automated validation**
  - **to ensure data integrity**
  - **to flag any losses during the transformation process**
  - **to establish confidence in the transformed data**
- **New recommended practices documents are required for data and processes associated with downstream uses**
  - **To address both near- and longer-term gaps**
- **QIF might be a stronger contender as the mechanism of choice for exchange between design and metrology**
  - **It has a better schema, more well aligned to the MBD domain**
  - **Few systems support this format yet**

Design to Metrology
Filling in the Gaps

D2MIV 2

DMDII O3

MBE Processes



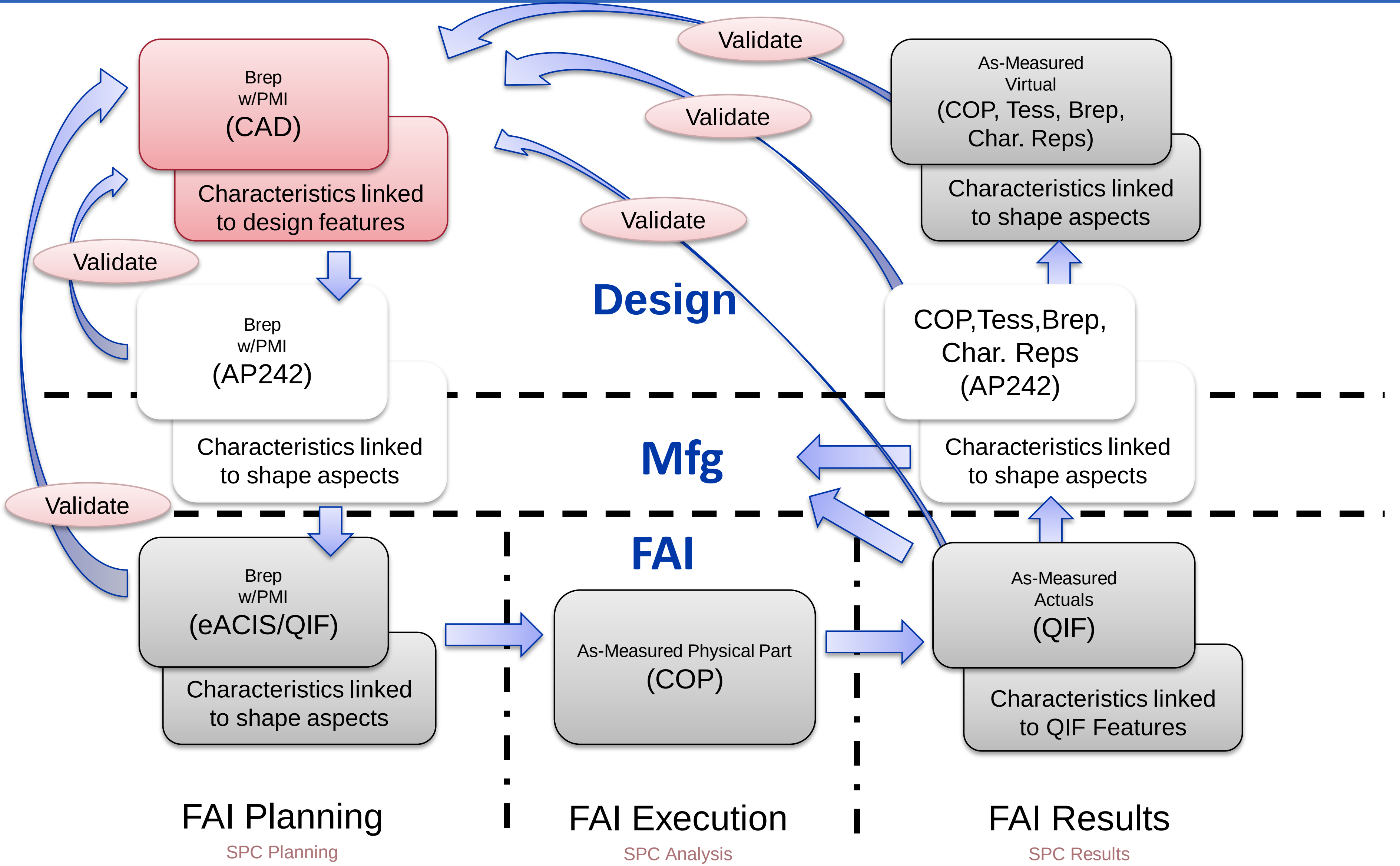
D2MIV 2 and DMDII O3

- **Near-term Gaps**
  - **Measurement Geometry – Taper Circle example (NIST FTC)**
  - **UOS Tolerance**
  - **Surface Roughness**
  - **Agreed upon list of assoc. features and characteristics**
  - **Criticality Attribute - safety or functional**
  - **Traceability - UUIDs/QPids**
  - **QIF Results back to Design and Manufacturing**
- **Longer-term Gaps**
  - **Authentication - security checksum**
  - **Extending Validation**
  - **Metadata – External to the model (who, what, where when and why)**
  - **Certification to Standards**

Design to Metrology - Vision

TBD

A Vision for Interop. between Design & Inspection



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Next Steps

- **Gaps in PMI support important for Mfg/Metrology**
  - **Surface Finish, Welds, Material**
  - **Inclusion of Precision**
  - **UOS Tolerance**
- **Management of UUIDs for Traceability**
  - **Choice of UUID class**
  - **Insertion/Extraction of UUIDs on PMI**
- **Demonstration of feedback from Metrology (QIF) to Design/Manufacturing (STEP)**
  - **Alternate Shape Representations**
  - **Alternate PMI elements**
  - **Status**

In closing…

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- **The building blocks we are setting into place are now forming the foundation for a Standards-based MBE process**
  - **CAD companies, interop. vendors, end-users, and consortia are all engaged and benefiting from the results of early research**
  - **Engaging downstream vendors and consumers in the process will accelerate the momentum around MBE**
  - **Research is now beginning to deliver the promise of real benefits to downstream consumers of MBD data**