nVariate

Asa Trainer
Trainer Engineering Associates

Thomas R. Thurman
TRThurman Consulting, LLC

Thomas R. Kramer, Ph.D.
Thomas Kramer Consulting, LLC

Ben Urick, PhD, PE | President and co-founder, nVariate

From MBD to Production: A Standards-Driven, Model-Based Path to Digital Validation and Traceability

2026 MBE & QIF Summit

2026.04.15 WED | 09:35 – 10:05 AM CDT

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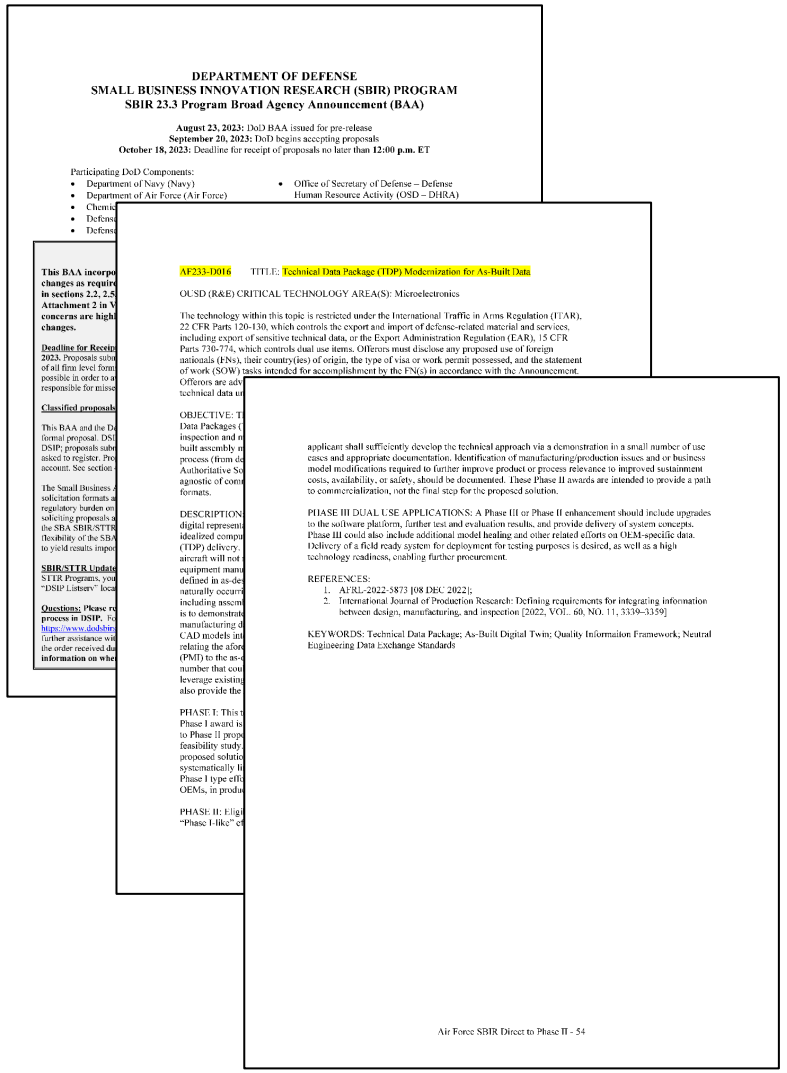
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Air Force SBIR Direct to Phase II: AF233-D016



DEPARTMENT OF DEFENSE
SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAM
SBIR 23.3 Program Broad Agency Announcement (BAA)

August 23, 2023: DoD BAA issued for pre-release
September 20, 2023: DoD begins accepting proposals
October 18, 2023: Deadline for receipt of proposals no later than **12:00 p.m. ET**

Participating DoD Components:

- Department of Navy (Navy)
- Department of Air Force (Air Force)
- Office of Secretary of Defense – Defense Human Resource Activity (OSD – DHRA)

AF233-D016 TITLE: Technical Data Package (TDP) Modernization for As-Built Data

OUSD (R&E) CRITICAL TECHNOLOGY AREA(S): Microelectronics

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the statement of work (SOW) tasks intended for accomplishment by the FN(s) in accordance with the Announcement. Offerors are adv
technical data u

OBJECTIVE: T
Data Packages (
inspection and m
built assembly m
process (from de
Authoritative So
agnostic of comm
formats.

DESCRIPTION:
digital represent
idealized compu
(TDP) delivery.
aircraft will not
equipment manu
defined in as-de
naturally occurri
including assemb
is to demonstrate
manufacturing d
CAD models int
relating the afore
(PMI) to the as-
number that cou
leverage existing
also provide the

PHASE I: This
Phase I award is
to Phase II propo
feasibility study.
proposed solutio
systematically li
Phase I type effo
OEMs, in produ

PHASE II: Eligi
"Phase I-like" ef

applicant shall sufficiently develop the technical approach via a demonstration in a small number of use cases and appropriate documentation. Identification of manufacturing/production issues and or business model modifications required to further improve product or process relevance to improved sustainment costs, availability, or safety, should be documented. These Phase II awards are intended to provide a path to commercialization, not the final step for the proposed solution.

PHASE III DUAL USE APPLICATIONS: A Phase III or Phase II enhancement should include upgrades to the software platform, further test and evaluation results, and provide delivery of system concepts. Phase III could also include additional model healing and other related efforts on OEM-specific data. Delivery of a field ready system for deployment for testing purposes is desired, as well as a high technology readiness, enabling further procurement.

REFERENCES:
1. AFRL-2022-5873 [08 DEC 2022];
2. International Journal of Production Research: Defining requirements for integrating information between design, manufacturing, and inspection [2022, VOL. 60, NO. 11, 3339–3359]

KEYWORDS: Technical Data Package; As-Built Digital Twin; Quality Information Framework; Neutral Engineering Data Exchange Standards

Air Force SBIR Direct to Phase II - 54

DEPARTMENT OF DEFENSE (DoD)
SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAM
SBIR 23.3 Program Broad Agency Announcement (BAA), 2023
Department of Air Force

Air Force SBIR Direct to Phase II

AF233-D016

Technical Data Package (TDP) Modernization for As-Built Data

***n*Variate** awarded project

04.APR.**2024** – 04.APR.**2026**

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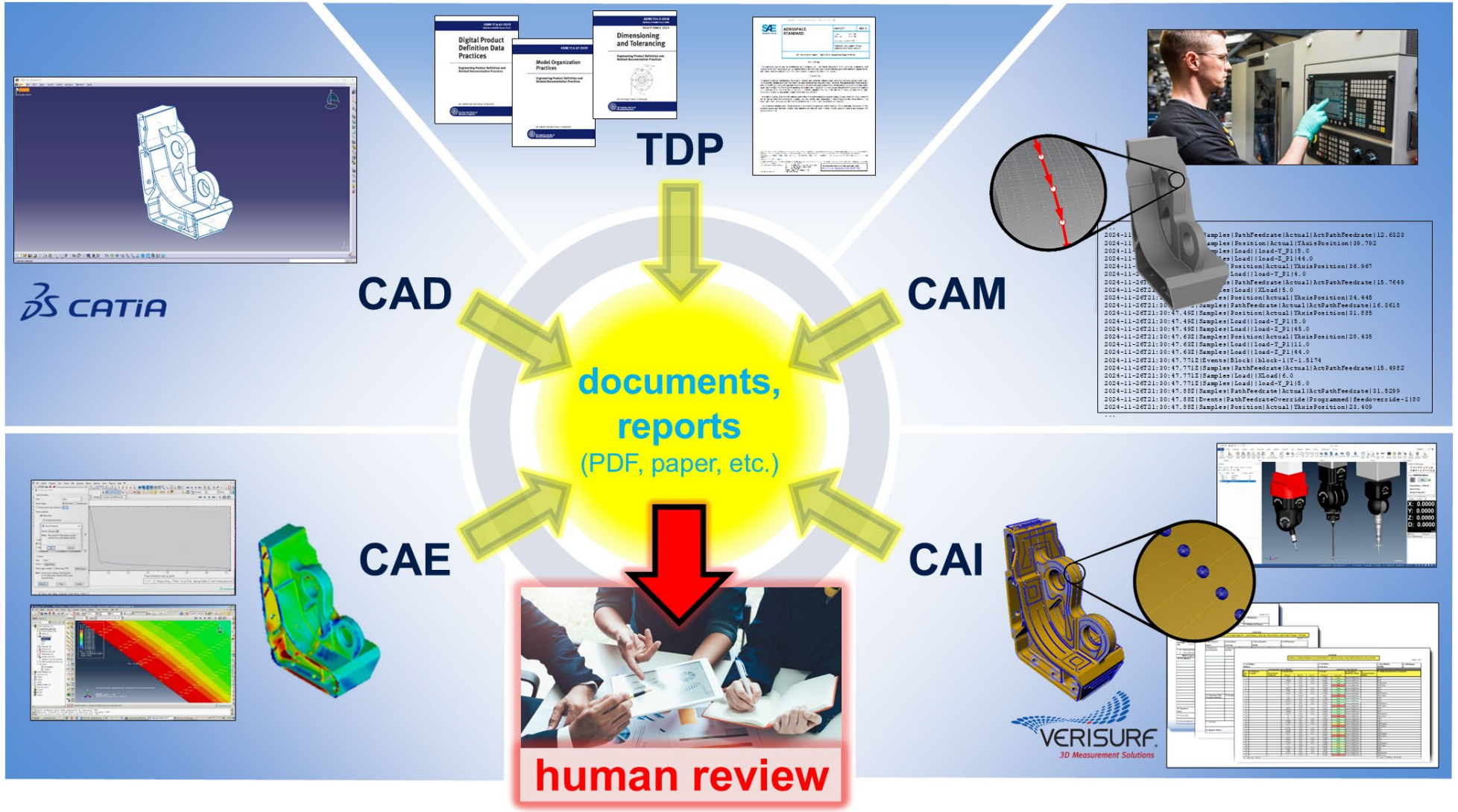
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TDP Conventional Process



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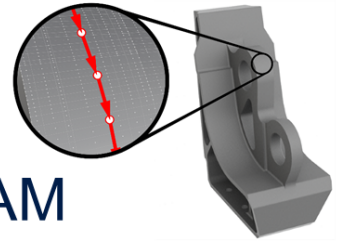
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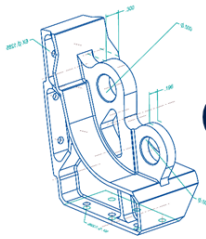
TDP Modernization for As-Built Data: Definition

TDP



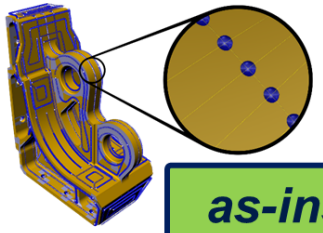
CAM

as-manufactured
(manufacturing execution data)



CAD

as-designed



CAI

as-inspected

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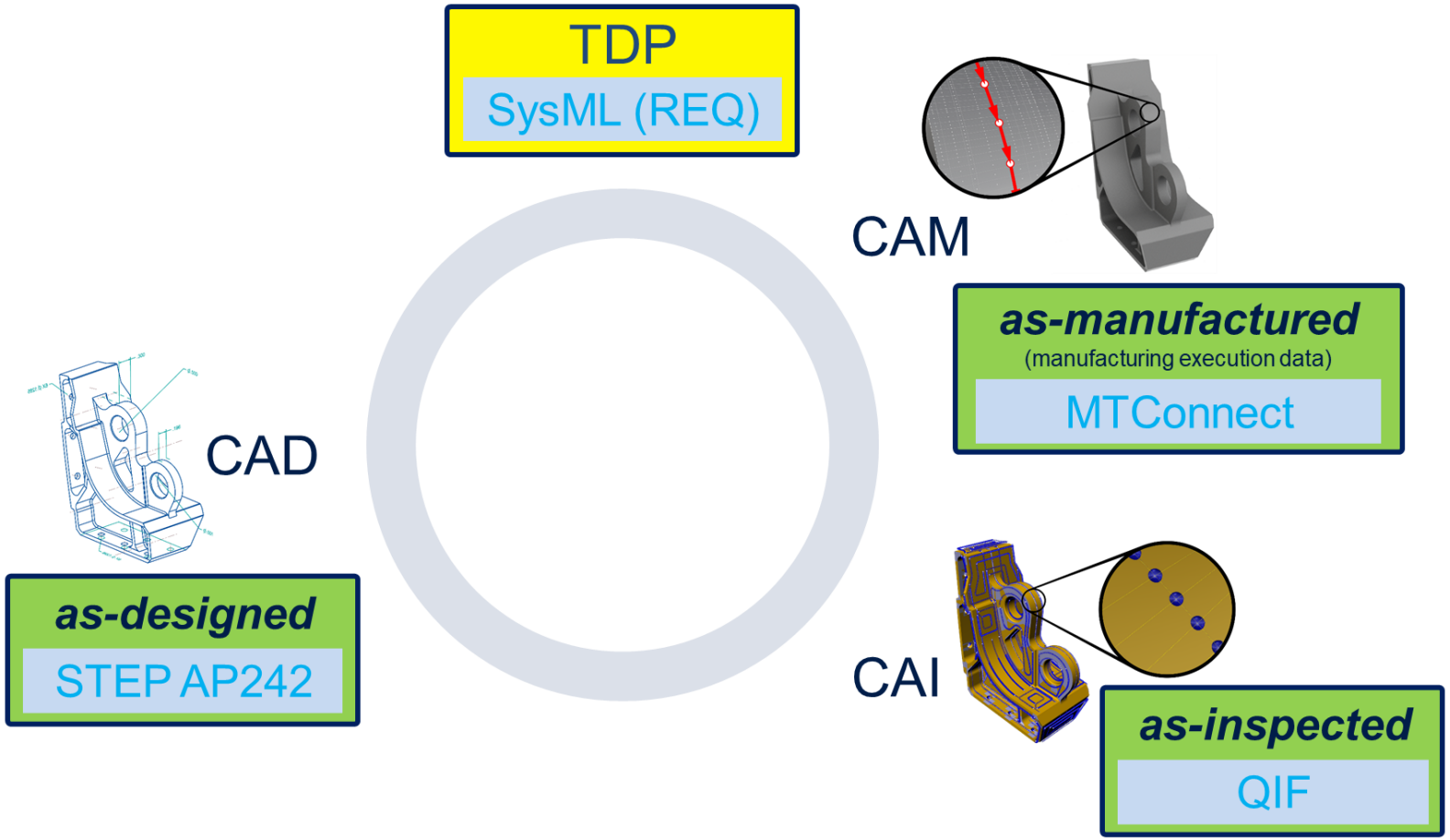
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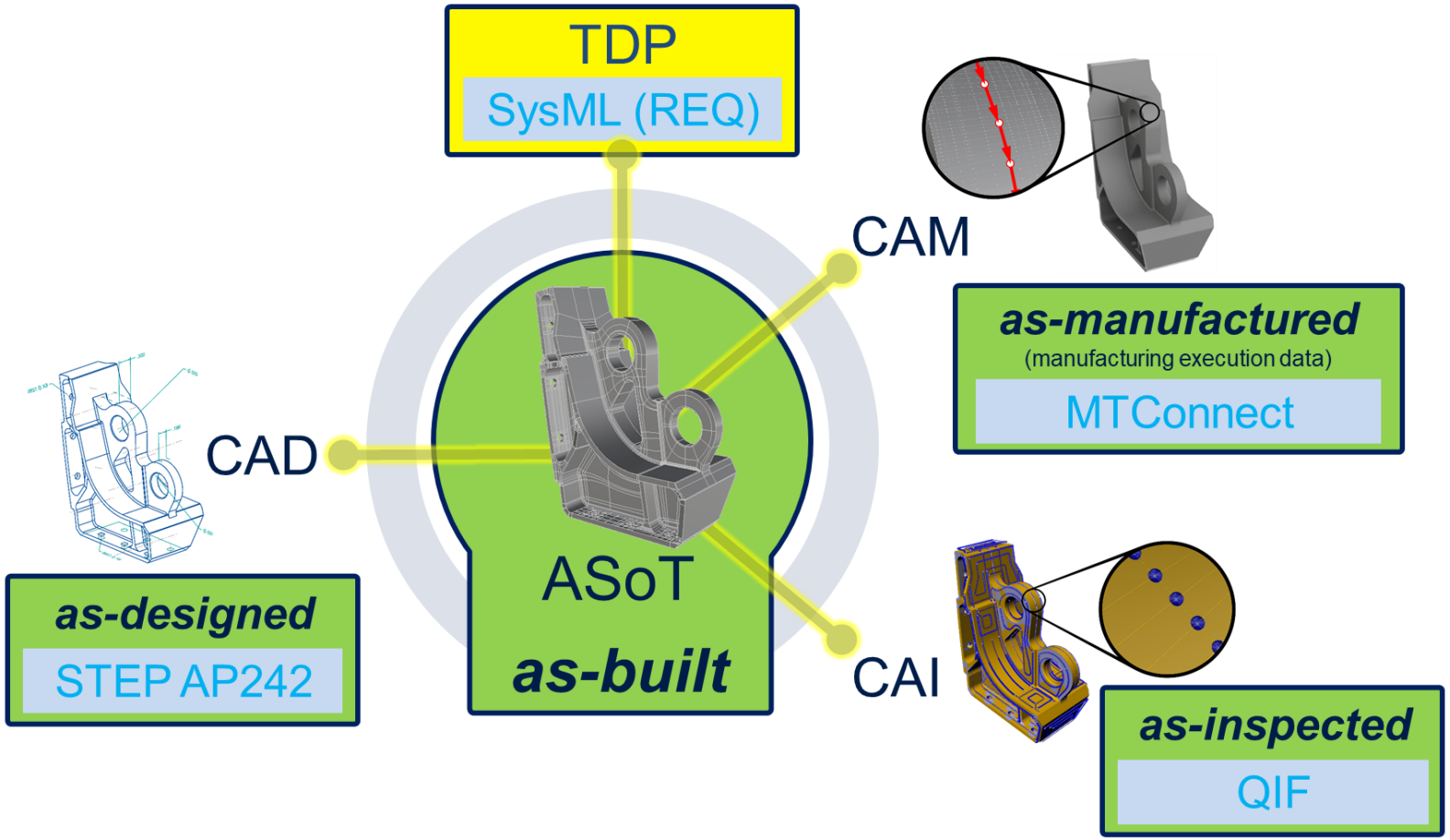
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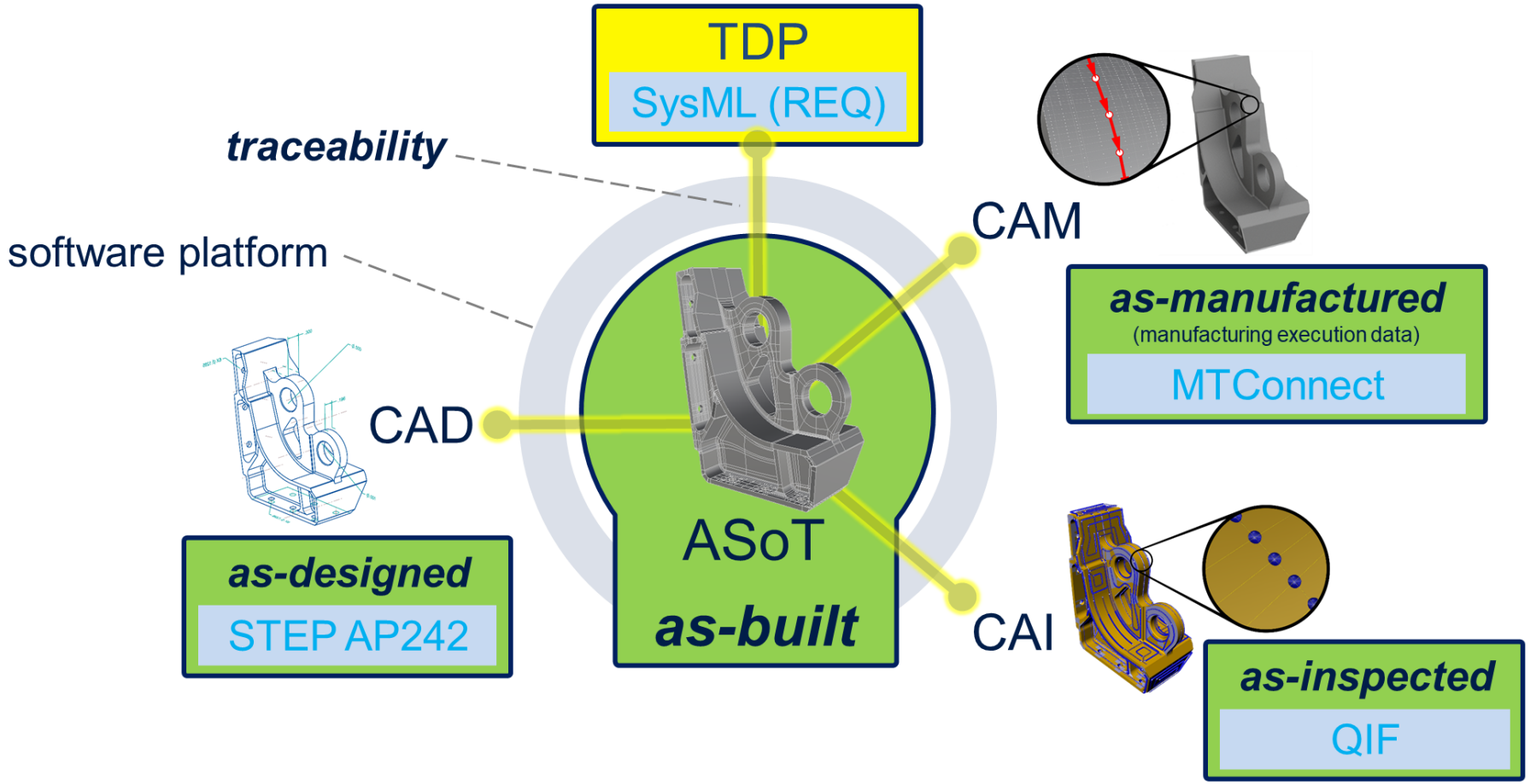
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Modeling: CAx <> Requirements

as-designed

STEP AP242

```
...
#136=VECTOR('',#135,7.5E-1);
#137=CARTESIAN_POINT('',(7.72E-1,5.E-1,7.5E-
1));
#138=LINE('',#137,#136);
#139=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#140=PRESENTATION_STYLE_ASSIGNMENT((#139));
#141=STYLED_ITEM('',(#140),#138);
#142=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#143=DIRECTION('',(0.E0,0.E0,-1.E0));
#144=DIRECTION('',(-1.E0,0.E0,0.E0));
#145=AXIS2_PLACEMENT_3D('',#142,#143,#144);
#147=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#148=PRESENTATION_STYLE_ASSIGNMENT((#147));
#149=STYLED_ITEM('',(#148),#146);
#150=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#151=DIRECTION('',(0.E0,0.E0,-1.E0));
#152=DIRECTION('',(1.E0,0.E0,0.E0));
#153=AXIS2_PLACEMENT_3D('',#150,#151,#152);
#155=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#156=PRESENTATION_STYLE_ASSIGNMENT((#155));
#157=STYLED_ITEM('',(#156),#154);
#158=CARTESIAN_POINT('',(2.5E0,5.E-1,7.5E-1));
#159=DIRECTION('',(0.E0,0.E0,-1.E0));
#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

as-planned

(manufacturing instruction data)

G-code

```
...
G01 X1.2661
G02 Y0.6385 J0.1252
G01 X5.1419
G03 Y0.8889 J0.1252
G01 X1.2661
G02 Y1.1393 J0.1252
G01 X5.1419
G18 G02 X5.1794 Z0.9275 K0.0375
G00 Z1.1
X5.1978 Y-1.1144
G01 Z0.8925 F20.
G03 X5.1603 Z0.855 I-0.0375 F60.
G01 X5.1419
X1.2661
G17 G02 Y-0.864 J0.1252
G01 X5.1419
G03 Y-0.6136 J0.1252
G01 X1.2661
G02 Y-0.3632 J0.1252
G01 X5.1419
G03 Y-0.1128 J0.1252
G01 X1.2661
G02 Y0.1376 J0.1252
G01 X5.1419
G03 Y0.388 J0.1252
G01 X1.2661
...
```

as-inspected

QIF

```
...
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          <Cylinder23Core scaleV="10">
            <Diameter>20</Diameter>
            <Length>50</Length>
            <Axis>
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50</AxisPoint>
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            </Axis>
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              <DomainAngle>0
6.28318530717959</DomainAngle>
            </Sweep>
          </Cylinder23Core>
        </Cylinder23>
        <Plane23 id="457">
          <Plane23Core domainU="-
25.742235784508 46.4287692639813"
            domainV="-7.5 82.5">
            <Origin>138.867513459481 -125
0</Origin>
            <DirU>-0.5 0.866025403784439
0</DirU>
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

as-manufactured

(manufacturing execution data)

MTConnect

```
...
20:22:36.217,16.863500,-7.606200,-13.223900,21
20:22:36.337,16.863500,-7.606200,-13.234600,21
20:22:36.467,16.863500,-7.606200,-13.245200,21
20:22:36.593,16.863500,-7.606200,-13.255900,21
20:22:36.723,16.863500,-7.606200,-13.266600,21
20:22:36.847,16.863500,-7.606200,-13.277200,21
20:22:36.990,16.863500,-7.606200,-13.287900,21
20:22:37.100,16.863500,-7.606200,-13.298600,21
20:22:37.230,16.863500,-7.606200,-13.309200,21
20:22:37.360,16.863500,-7.606200,-13.319900,21
20:22:37.487,16.863500,-7.606200,-13.330600,21
20:22:37.610,16.863500,-7.606200,-13.341200,21
20:22:37.737,16.863500,-7.606200,-13.351900,21
20:22:37.867,16.863500,-7.606200,-13.362600,21
20:22:38.000,16.863500,-7.606200,-13.373200,21
20:22:38.130,16.863500,-7.606200,-13.383900,21
20:22:38.253,16.863500,-7.606200,-13.394600,21
20:22:38.380,16.863500,-7.606200,-13.405200,21
20:22:38.507,16.863500,-7.606200,-13.413200,21
20:22:38.640,16.863500,-7.606200,-13.423900,21
20:22:38.760,16.863500,-7.606200,-13.434600,21
20:22:38.880,16.863500,-7.606200,-13.445200,21
20:22:39.007,16.863500,-7.606200,-13.455900,21
20:22:39.140,16.863500,-7.606200,-13.466600,21
20:22:39.270,16.863500,-7.606200,-13.477200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
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Modeling: CAx <> Requirements

as-designed

STEP AP242

```
...
#136=VECTOR('',#135,7.5E-1);
#137=CARTESIAN_POINT('',(7.72E-1,5.E-1,7.5E-
1));
#138=LINE('',#137,#136);
#139=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#140=PRESENTATION_STYL
#141=STYLED_ITEM('',(#
#142=CARTESIAN_POINT('
#143=DIRECTION('',(0.E
#144=DIRECTION('',(-1.
#145=AXIS2_PLACEMENT_3
#147=CURVE_STYLE('',#2
(2.E-2),#11);
#148=PRESENTATION_STYL
#149=STYLED_ITEM('',(#
#150=CARTESIAN_POINT('
#151=DIRECTION('',(0.E
#152=DIRECTION('',(1.E
#153=AXIS2_PLACEMENT_3
#155=CURVE_STYLE('',#2
(2.E-2),#11);
#156=PRESENTATION_STYLE_ASSIGNMENT((#155));
#157=STYLED_ITEM('',(#156),#154);
#158=CARTESIAN_POINT('',(2.5E0,5.E-1,7.5E-1));
#159=DIRECTION('',(0.E0,0.E0,-1.E0));
#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

as-planned

(manufacturing instruction data)

G-code

```
...
G01 X1.2661
G02 Y0.6385 J0.1252
G01 X5.1419
G03 Y0.8889 J0.1252
G01 X1.2661
...
G02 Y0.1376 J0.1252
G01 X5.1419
G03 Y0.388 J0.1252
G01 X1.2661
...
```

as-inspected

QIF

```
...
 <Cylinder23 id="448">
          <Cylinder23Core scaleV="10">
            <Diameter>20</Diameter>
            <Length>50</Length>
            <Axis>
...
            <DirU>-0.5 0.866025403784439
0</DirU>
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

as-manufactured

(manufacturing execution data)

MTConnect

```
...
20:22:36.217,16.863500,-7.606200,-13.223900,21
20:22:36.337,16.863500,-7.606200,-13.234600,21
20:22:36.467,16.863500,-7.606200,-13.245200,21
20:22:36.593,16.863500,-7.606200,-13.255900,21
20:22:36.723,16.863500,-7.606200,-13.266600,21
.863500,-7.606200,-13.277200,21
.863500,-7.606200,-13.287900,21
.863500,-7.606200,-13.298600,21
.863500,-7.606200,-13.309200,21
.863500,-7.606200,-13.319900,21
.863500,-7.606200,-13.330600,21
.863500,-7.606200,-13.341200,21
.863500,-7.606200,-13.351900,21
.863500,-7.606200,-13.362600,21
.863500,-7.606200,-13.373200,21
.863500,-7.606200,-13.383900,21
.863500,-7.606200,-13.394600,21
.863500,-7.606200,-13.405200,21
.863500,-7.606200,-13.413200,21
.863500,-7.606200,-13.423900,21
.863500,-7.606200,-13.434600,21
.863500,-7.606200,-13.445200,21
20:22:39.007,16.863500,-7.606200,-13.455900,21
20:22:39.140,16.863500,-7.606200,-13.466600,21
20:22:39.270,16.863500,-7.606200,-13.477200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
```

INFORMATION MODELS

CAx DOMAIN

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nVariate

Modeling: CAx <> Requirements

as-required

SysML

as-designed

STEP AP242

```
...
#136=VECTOR('',#135,7.5E-1);
#137=CARTESIAN_POINT('',(7.72E-1,5.E-1,7.5E-
1));
#138=LINE('',#137,#136);
#139=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#140=PRESENTATION_STYLE_ASSIGNMENT((#139));
#141=STYLED_ITEM('',(#140),#138);
#142=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#143=DIRECTION('',(0.E0,0.E0,-1.E0));
#144=DIRECTION('',(-1.E0,0.E0,0.E0));
#145=AXIS2_PLACEMENT_3D('',#142,#143,#144);
#147=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#148=PRESENTATION_STYLE_ASSIGNMENT((#147));
#149=STYLED_ITEM('',(#148),#146);
#150=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#151=DIRECTION('',(0.E0,0.E0,-1.E0));
#152=DIRECTION('',(1.E0,0.E0,0.E0));
#153=AXIS2_PLACEMENT_3D('',#150,#151,#152);
#155=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#156=PRESENTATION_STYLE_ASSIGNMENT((#155));
#157=STYLED_ITEM('',(#156),#154);
#158=CARTESIAN_POINT('',(2.5E0,5.E-1,7.5E-1));
#159=DIRECTION('',(0.E0,0.E0,-1.E0));
#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

as-planned

(manufacturing instruction data)

G-code

```
...
G01 X1.2661
G02 Y0.6385 J0.1252
G01 X5.1419
G03 Y0.8889 J0.1252
G01 X1.2661
G02 Y1.1393 J0.1252
G01 X5.1419
G18 G02 X5.1794 Z0.9275 K0.0375
G00 Z1.1
X5.1978 Y-1.1144
G01 Z0.8925 F20.
G03 X5.1603 Z0.855 I-0.0375 F60.
G01 X5.1419
X1.2661
G17 G02 Y-0.864 J0.1252
G01 X5.1419
G03 Y-0.6136 J0.1252
G01 X1.2661
G02 Y-0.3632 J0.1252
G01 X5.1419
G03 Y-0.1128 J0.1252
G01 X1.2661
G02 Y0.1376 J0.1252
G01 X5.1419
G03 Y0.388 J0.1252
G01 X1.2661
...
```

as-inspected

QIF

```
...
 <Cylinder23 id="448">
          <Cylinder23Core scaleV="10">
            <Diameter>20</Diameter>
            <Length>50</Length>
            <Axis>
              <AxisPoint>110 -95 -
50</AxisPoint>
              <Direction>0 0 1</Direction>
            </Axis>
            <Sweep>
              <DirBeg>1 0 0</DirBeg>
              <DomainAngle>0
6.28318530717959</DomainAngle>
            </Sweep>
          </Cylinder23Core>
        </Cylinder23>
        <Plane23 id="457">
          <Plane23Core domainU="-
25.742235784508 46.4287692639813"
            domainV="-7.5 82.5">
            <Origin>138.867513459481 -125
0</Origin>
            <DirU>-0.5 0.866025403784439
0</DirU>
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

as-manufactured

(manufacturing execution data)

MTConnect

```
...
20:22:36.217,16.863500,-7.606200,-13.223900,21
20:22:36.337,16.863500,-7.606200,-13.234600,21
20:22:36.467,16.863500,-7.606200,-13.245200,21
20:22:36.593,16.863500,-7.606200,-13.255900,21
20:22:36.723,16.863500,-7.606200,-13.266600,21
20:22:36.847,16.863500,-7.606200,-13.277200,21
20:22:36.990,16.863500,-7.606200,-13.287900,21
20:22:37.100,16.863500,-7.606200,-13.298600,21
20:22:37.230,16.863500,-7.606200,-13.309200,21
20:22:37.360,16.863500,-7.606200,-13.319900,21
20:22:37.487,16.863500,-7.606200,-13.330600,21
20:22:37.610,16.863500,-7.606200,-13.341200,21
20:22:37.737,16.863500,-7.606200,-13.351900,21
20:22:37.867,16.863500,-7.606200,-13.362600,21
20:22:38.000,16.863500,-7.606200,-13.373200,21
20:22:38.130,16.863500,-7.606200,-13.383900,21
20:22:38.253,16.863500,-7.606200,-13.394600,21
20:22:38.380,16.863500,-7.606200,-13.405200,21
20:22:38.507,16.863500,-7.606200,-13.413200,21
20:22:38.640,16.863500,-7.606200,-13.423900,21
20:22:38.760,16.863500,-7.606200,-13.434600,21
20:22:38.880,16.863500,-7.606200,-13.445200,21
20:22:39.007,16.863500,-7.606200,-13.455900,21
20:22:39.140,16.863500,-7.606200,-13.466600,21
20:22:39.270,16.863500,-7.606200,-13.477200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
```


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Modeling: CAx <> Requirements

as-required

SysML

SYSTEMS MODELS

Non-CAx DOMAIN

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nVariate

Modeling: CAx <> Requirements

as-required

SysML

as-designed

STEP AP242

```
...
#136=VECTOR('',#135,7.5E-1);
#137=CARTESIAN_POINT('',(7.72E-1,5.E-1,7.5E-
1));
#138=LINE('',#137,#136);
#139=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#140=PRESENTATION_STYLE_ASSIGNMENT((#139));
#141=STYLED_ITEM('',(#140),#138);
#142=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#143=DIRECTION('',(0.E0,0.E0,-1.E0));
#144=DIRECTION('',(-1.E0,0.E0,0.E0));
#145=AXIS2_PLACEMENT_3D('',#142,#143,#144);
#147=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#148=PRESENTATION_STYLE_ASSIGNMENT((#147));
#149=STYLED_ITEM('',(#148),#146);
#150=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#151=DIRECTION('',(0.E0,0.E0,-1.E0));
#152=DIRECTION('',(1.E0,0.E0,0.E0));
#153=AXIS2_PLACEMENT_3D('',#150,#151,#152);
#155=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#156=PRESENTATION_STYLE_ASSIGNMENT((#155));
#157=STYLED_ITEM('',(#156),#154);
#158=CARTESIAN_POINT('',(2.5E0,5.E-1,7.5E-1));
#159=DIRECTION('',(0.E0,0.E0,-1.E0));
#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

as-planned

(manufacturing instruction data)

G-code

```
...
G01 X1.2661
G02 Y0.6385 J0.1252
G01 X5.1419
G03 Y0.8889 J0.1252
G01 X1.2661
G02 Y1.1393 J0.1252
G01 X5.1419
G18 G02 X5.1794 Z0.9275 K0.0375
G00 Z1.1
X5.1978 Y-1.1144
G01 Z0.8925 F20.
G03 X5.1603 Z0.855 I-0.0375 F60.
G01 X5.1419
X1.2661
G17 G02 Y-0.864 J0.1252
G01 X5.1419
G03 Y-0.6136 J0.1252
G01 X1.2661
G02 Y-0.3632 J0.1252
G01 X5.1419
G03 Y-0.1128 J0.1252
G01 X1.2661
G02 Y0.1376 J0.1252
G01 X5.1419
G03 Y0.388 J0.1252
G01 X1.2661
...
```

as-inspected

QIF

```
...
 <Cylinder23 id="448">
          <Cylinder23Core scaleV="10">
            <Diameter>20</Diameter>
            <Length>50</Length>
            <Axis>
              <AxisPoint>110 -95 -
50</AxisPoint>
              <Direction>0 0 1</Direction>
            </Axis>
            <Sweep>
              <DirBeg>1 0 0</DirBeg>
              <DomainAngle>0
6.28318530717959</DomainAngle>
            </Sweep>
          </Cylinder23Core>
        </Cylinder23>
        <Plane23 id="457">
          <Plane23Core domainU="-
25.742235784508 46.4287692639813"
            domainV="-7.5 82.5">
            <Origin>138.867513459481 -125
0</Origin>
            <DirU>-0.5 0.866025403784439
0</DirU>
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

as-manufactured

(manufacturing execution data)

MTConnect

```
...
20:22:36.217,16.863500,-7.606200,-13.223900,21
20:22:36.337,16.863500,-7.606200,-13.234600,21
20:22:36.467,16.863500,-7.606200,-13.245200,21
20:22:36.593,16.863500,-7.606200,-13.255900,21
20:22:36.723,16.863500,-7.606200,-13.266600,21
20:22:36.847,16.863500,-7.606200,-13.277200,21
20:22:36.990,16.863500,-7.606200,-13.287900,21
20:22:37.100,16.863500,-7.606200,-13.298600,21
20:22:37.230,16.863500,-7.606200,-13.309200,21
20:22:37.360,16.863500,-7.606200,-13.319900,21
20:22:37.487,16.863500,-7.606200,-13.330600,21
20:22:37.610,16.863500,-7.606200,-13.341200,21
20:22:37.737,16.863500,-7.606200,-13.351900,21
20:22:37.867,16.863500,-7.606200,-13.362600,21
20:22:38.000,16.863500,-7.606200,-13.373200,21
20:22:38.130,16.863500,-7.606200,-13.383900,21
20:22:38.253,16.863500,-7.606200,-13.394600,21
20:22:38.380,16.863500,-7.606200,-13.405200,21
20:22:38.507,16.863500,-7.606200,-13.413200,21
20:22:38.640,16.863500,-7.606200,-13.423900,21
20:22:38.760,16.863500,-7.606200,-13.434600,21
20:22:38.880,16.863500,-7.606200,-13.445200,21
20:22:39.007,16.863500,-7.606200,-13.455900,21
20:22:39.140,16.863500,-7.606200,-13.466600,21
20:22:39.270,16.863500,-7.606200,-13.477200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
```


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nVariate

Modeling: CAx <> Requirements

as-required

SysML

as-designed

STEP AP242

```
...
#136=VECTOR('',#135,7.5E-1);
#137=CARTESIAN_POINT('',(7.72E-1,5.E-1,7.5E-
1));
#138=LINE('',#137,#136);
#139=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#140=PRESENTATION_STYLE_ASSIGNMENT((#139));
#141=STYLED_ITEM('',(#140),#138);
#142=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#143=DIRECTION('',(0.E0,0.E0,-1.E0));
#144=DIRECTION('',(-1.E0,0.E0,0.E0));
#145=AXIS2_PLACEMENT_3D('',#142,#143,#144);
#147=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#148=PRESENTATION_STYLE_ASSIGNMENT((#147));
#149=STYLED_ITEM('',(#148),#146);
#150=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#151=DIRECTION('',(0.E0,0.E0,-1.E0));
#152=DIRECTION('',(1.E0,0.E0,0.E0));
#153=AXIS2_PLACEMENT_3D('',#150,#151,#152);
#155=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#156=PRESENTATION_STYLE_ASSIGNMENT((#155));
#157=STYLED_ITEM('',(#156),#154);
#158=CARTESIAN_POINT('',(2.5E0,5.E-1,7.5E-1));
#159=DIRECTION('',(0.E0,0.E0,-1.E0));
#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

as-planned

(manufacturing instruction data)

G-code

```
...
G01 X1.2661
G02 Y0.6385 J0.1252
G01 X5.1419
G03 Y0.8889 J0.1252
G01 X1.2661
G02 Y1.1393 J0.1252
G01 X5.1419
G18 G02 X5.1794 Z0.9275 K0.0375
G00 Z1.1
X5.1978 Y-1.1144
G01 Z0.8925 F20.
G03 X5.1603 Z0.855 I-0.0375 F60.
G01 X5.1419
X1.2661
G17 G02 Y-0.864 J0.1252
G01 X5.1419
G03 Y-0.6136 J0.1252
G01 X1.2661
G02 Y-0.3632 J0.1252
G01 X5.1419
G03 Y-0.1128 J0.1252
G01 X1.2661
G02 Y0.1376 J0.1252
G01 X5.1419
G03 Y0.388 J0.1252
G01 X1.2661
...
```

as-inspected

QIF

```
...
 <Cylinder23 id="448">
          <Cylinder23Core scaleV="10">
            <Diameter>20</Diameter>
            <Length>50</Length>
            <Axis>
              <AxisPoint>110 -95 -
50</AxisPoint>
              <Direction>0 0 1</Direction>
            </Axis>
            <Sweep>
              <DirBeg>1 0 0</DirBeg>
              <DomainAngle>0
6.28318530717959</DomainAngle>
            </Sweep>
          </Cylinder23Core>
        </Cylinder23>
        <Plane23 id="457">
          <Plane23Core domainU="-
25.742235784508 46.4287692639813"
            domainV="-7.5 82.5">
            <Origin>138.867513459481 -125
0</Origin>
            <DirU>-0.5 0.866025403784439
0</DirU>
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

as-manufactured

(manufacturing execution data)

MTConnect

```
...
20:22:36.217,16.863500,-7.606200,-13.223900,21
20:22:36.337,16.863500,-7.606200,-13.234600,21
20:22:36.467,16.863500,-7.606200,-13.245200,21
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20:22:37.360,16.863500,-7.606200,-13.319900,21
20:22:37.487,16.863500,-7.606200,-13.330600,21
20:22:37.610,16.863500,-7.606200,-13.341200,21
20:22:37.737,16.863500,-7.606200,-13.351900,21
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20:22:38.000,16.863500,-7.606200,-13.373200,21
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20:22:39.270,16.863500,-7.606200,-13.477200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
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Modeling: CAx <> Requirements

MBSE

MBD

as- **red**

data)

ST

```
...
#136=VECTOR('
#137=CARTESIA
1));
#138=LINE('',
#139=CURVE_ST
(2.E-2),#11);
#140=PRESENTA
#141=STYLED_I
#142=CARTESIA
#143=DIRECTIO
#144=DIRECTIO
#145=AXIS2_PL
#147=CURVE_ST
(2.E-2),#11);
#148=PRESENTA
#149=STYLED_I
#150=CARTESIA
#151=DIRECTIO
#152=DIRECTIO
#153=AXIS2_PL
#155=CURVE_ST
(2.E-2),#11);
#156=PRESENTA
#157=STYLED_I
#158=CARTESIAN_POINT('',(2.3E0,5.E-1,7.5E-1));
#159=DIRECTION('',(0.E0,0.E0,-1.E0));
#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

```
G03 Y0.388 J0.1252
G01 X1.2661
...
```

```
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

```
900,21
600,21
200,21
900,21
600,21
200,21
900,21
600,21
200,21
900,21
600,21
200,21
900,21
600,21
200,21
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900,21
600,21
200,21
20:22:39.270,16.863500,-7.606200,-13.47200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
```


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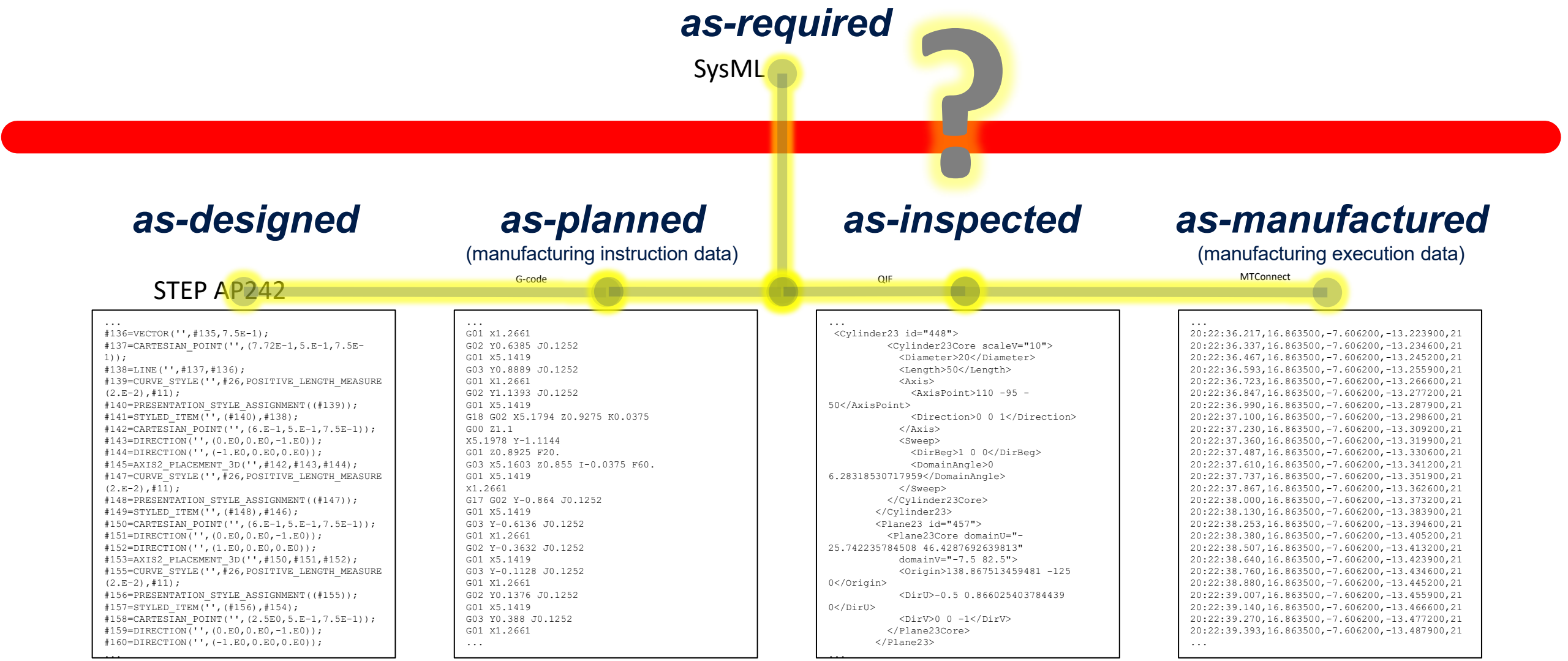
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Modeling: CAx <> Requirements




```
...
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1));
#138=LINE('',#137,#136);
#139=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#140=PRESENTATION_STYLE_ASSIGNMENT((#139));
#141=STYLED_ITEM('',(#140),#138);
#142=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
#143=DIRECTION('',(0.E0,0.E0,-1.E0));
#144=DIRECTION('',(-1.E0,0.E0,0.E0));
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#147=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
(2.E-2),#11);
#148=PRESENTATION_STYLE_ASSIGNMENT((#147));
#149=STYLED_ITEM('',(#148),#146);
#150=CARTESIAN_POINT('',(6.E-1,5.E-1,7.5E-1));
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#152=DIRECTION('',(1.E0,0.E0,0.E0));
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#155=CURVE_STYLE('',#26,POSITIVE_LENGTH_MEASURE
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#157=STYLED_ITEM('',(#156),#154);
#158=CARTESIAN_POINT('',(2.5E0,5.E-1,7.5E-1));
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#160=DIRECTION('',(-1.E0,0.E0,0.E0));
...
```

```
...
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G02 Y0.6385 J0.1252
G01 X5.1419
G03 Y0.8889 J0.1252
G01 X1.2661
G02 Y1.1393 J0.1252
G01 X5.1419
G18 G02 X5.1794 Z0.9275 K0.0375
G00 Z1.1
X5.1978 Y-1.1144
G01 Z0.8925 F20.
G03 X5.1603 Z0.855 I-0.0375 F60.
G01 X5.1419
X1.2661
G17 G02 Y-0.864 J0.1252
G01 X5.1419
G03 Y-0.6136 J0.1252
G01 X1.2661
G02 Y-0.3632 J0.1252
G01 X5.1419
G03 Y-0.1128 J0.1252
G01 X1.2661
G02 Y0.1376 J0.1252
G01 X5.1419
G03 Y0.388 J0.1252
G01 X1.2661
...
```

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50</AxisPoint>
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            </Axis>
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              <DirBeg>1 0 0</DirBeg>
              <DomainAngle>0
6.28318530717959</DomainAngle>
            </Sweep>
          </Cylinder23Core>
        </Cylinder23>
        <Plane23 id="457">
          <Plane23Core domainU="-
25.742235784508 46.4287692639813"
            domainV="-7.5 82.5">
            <Origin>138.867513459481 -125
0</Origin>
            <DirU>-0.5 0.866025403784439
0</DirU>
            <DirV>0 0 -1</DirV>
          </Plane23Core>
        </Plane23>
...
```

```
...
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20:22:36.337,16.863500,-7.606200,-13.234600,21
20:22:36.467,16.863500,-7.606200,-13.245200,21
20:22:36.593,16.863500,-7.606200,-13.255900,21
20:22:36.723,16.863500,-7.606200,-13.266600,21
20:22:36.847,16.863500,-7.606200,-13.277200,21
20:22:36.990,16.863500,-7.606200,-13.287900,21
20:22:37.100,16.863500,-7.606200,-13.298600,21
20:22:37.230,16.863500,-7.606200,-13.309200,21
20:22:37.360,16.863500,-7.606200,-13.319900,21
20:22:37.487,16.863500,-7.606200,-13.330600,21
20:22:37.610,16.863500,-7.606200,-13.341200,21
20:22:37.737,16.863500,-7.606200,-13.351900,21
20:22:37.867,16.863500,-7.606200,-13.362600,21
20:22:38.000,16.863500,-7.606200,-13.373200,21
20:22:38.130,16.863500,-7.606200,-13.383900,21
20:22:38.253,16.863500,-7.606200,-13.394600,21
20:22:38.380,16.863500,-7.606200,-13.405200,21
20:22:38.507,16.863500,-7.606200,-13.413200,21
20:22:38.640,16.863500,-7.606200,-13.423900,21
20:22:38.760,16.863500,-7.606200,-13.434600,21
20:22:38.880,16.863500,-7.606200,-13.445200,21
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20:22:39.270,16.863500,-7.606200,-13.477200,21
20:22:39.393,16.863500,-7.606200,-13.487900,21
...
```


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TDP Modernization for As-Built Data: Project Team

Digital Manufacturing and Supply Chain Branch (RXMD)
Dr. William (Bill) Bernstein

Thomas R. Kramer, Ph.D.
Thomas Kramer Consulting, LLC

Asa Trainer
Trainer Engineering Associates

Thomas R. Thurman
TRThurman Consulting, LLC

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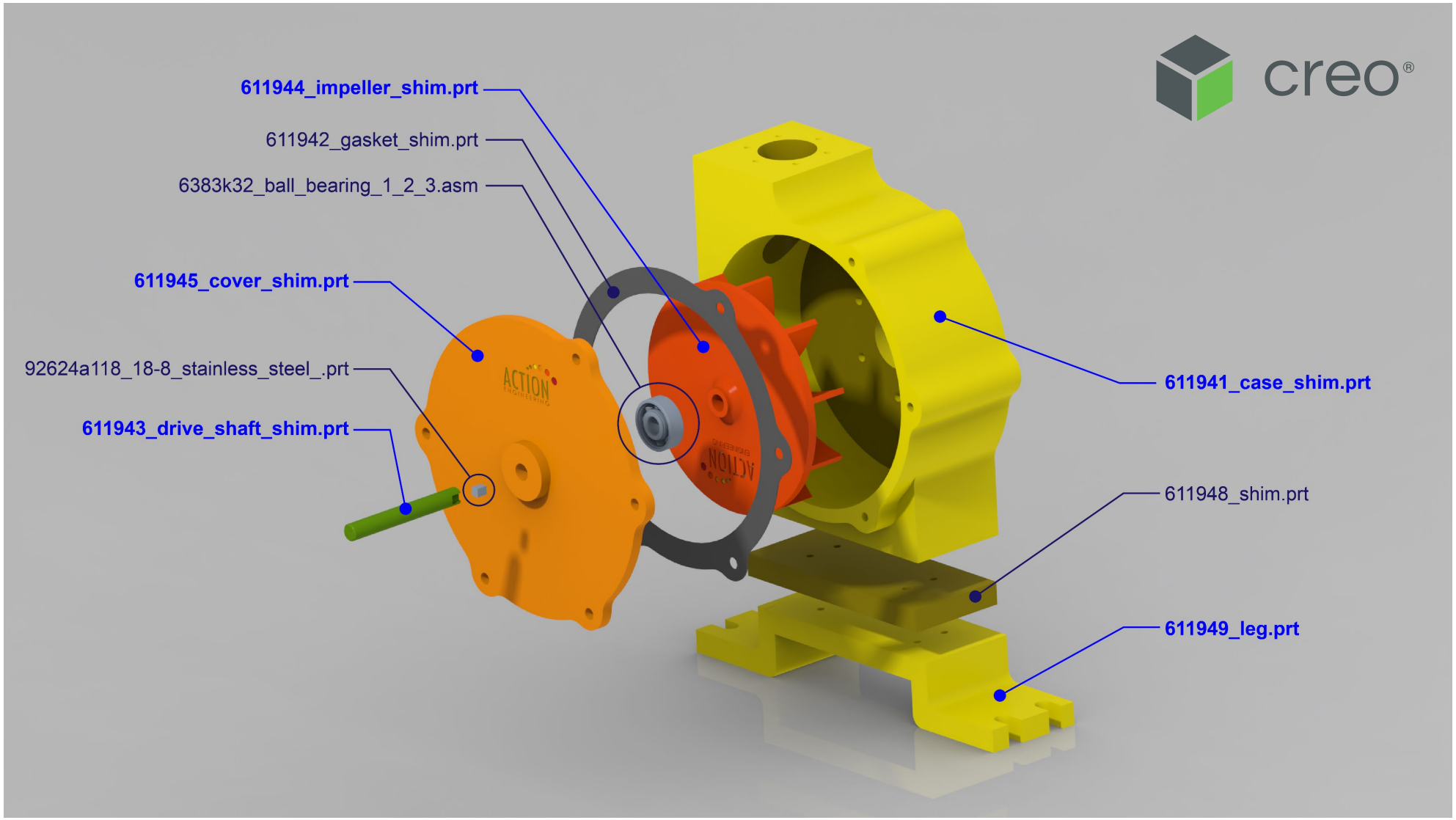
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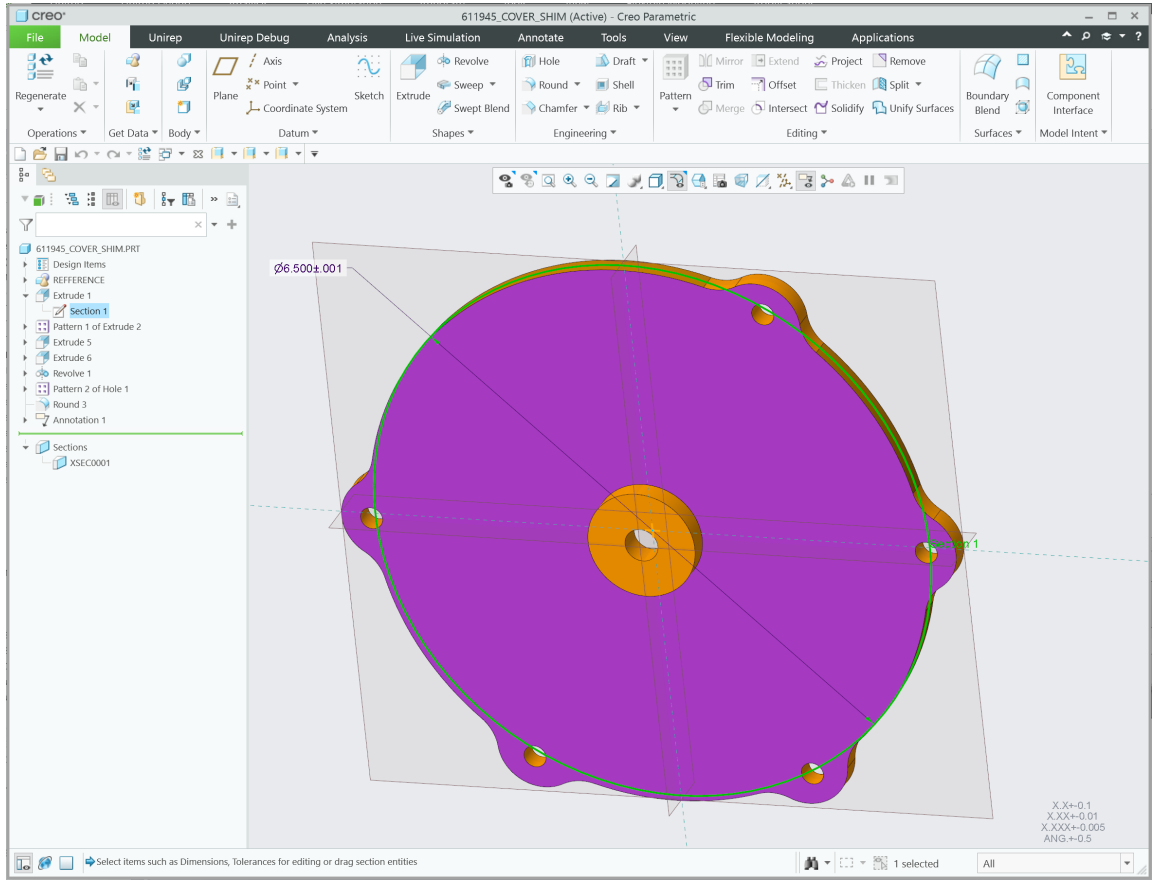
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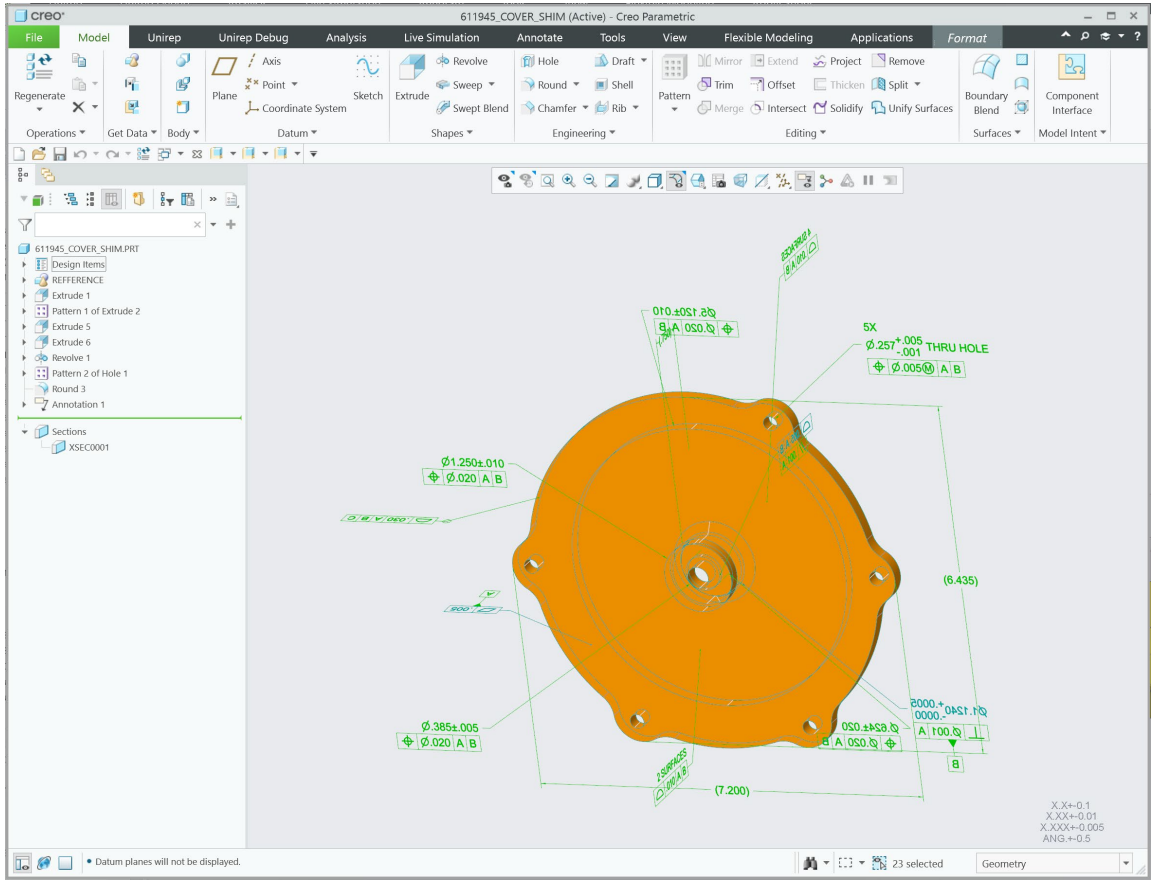
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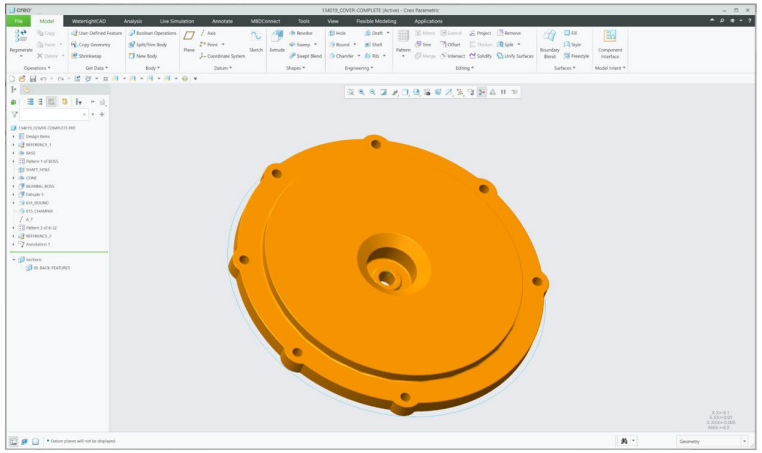
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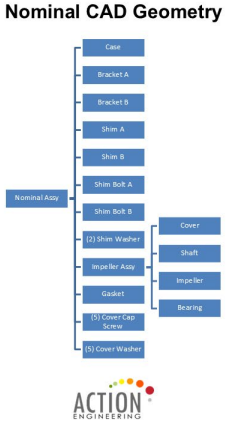
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TDP Modernization for As-Built Data: CAD

1 nominal model





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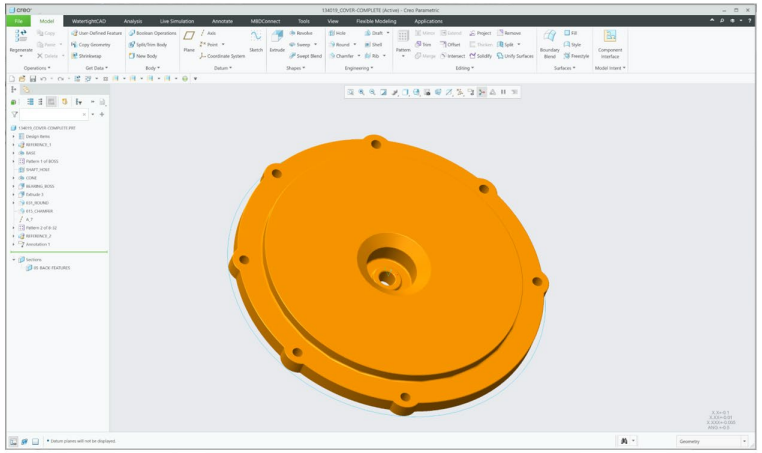
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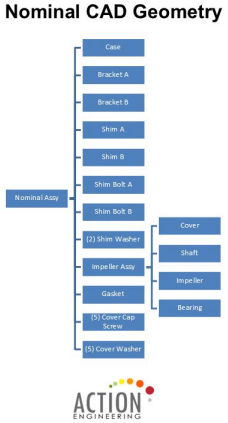
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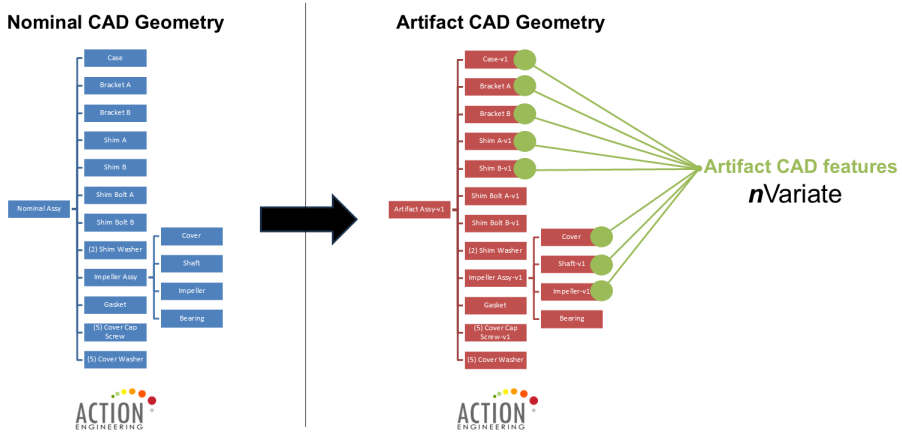
TDP Modernization for As-Built Data: CAD

1 nominal model





2 artifact model



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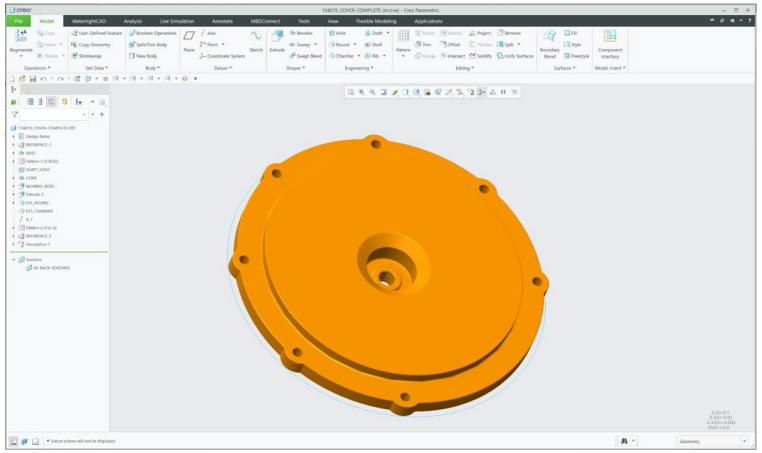
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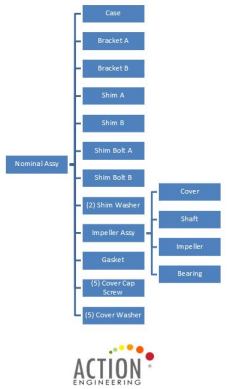
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TDP Modernization for As-Built Data: CAD

1 nominal model

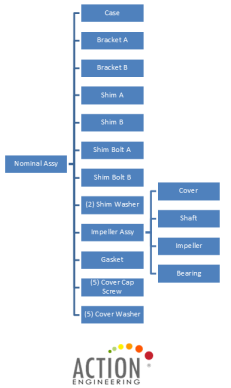


Nominal CAD Geometry

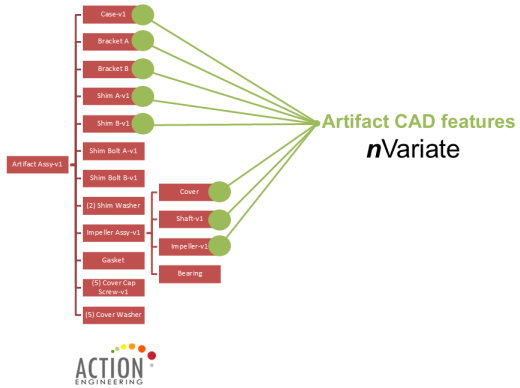


2 artifact model

Nominal CAD Geometry



Artifact CAD Geometry

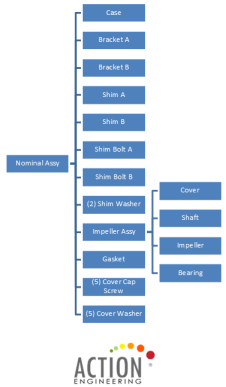


Artifact CAD features

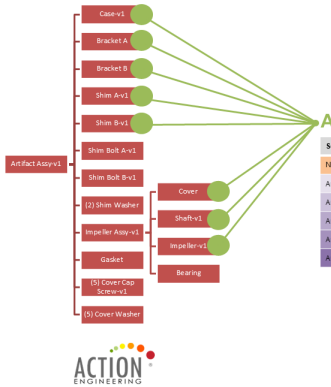
*n*Variate

3 artifact matrix

Nominal CAD Geometry



Artifact CAD Geometry



Artifact CAD features

Serial number	Parameter 1	Parameter 2
Nominal	0.340	0.65
Artifact 001	0.330	0.55
Artifact 002	0.335	0.60
Artifact 003	0.340	0.65
Artifact 004	0.345	0.70
Artifact 005	0.350	0.75

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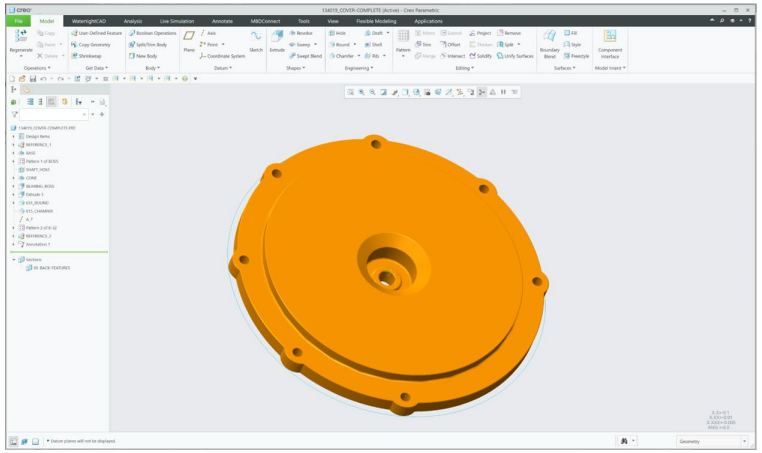
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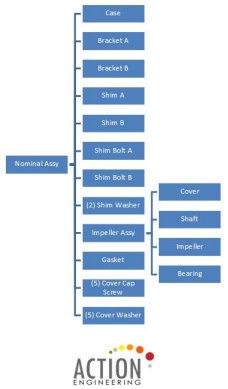
nVariate

TDP Modernization for As-Built Data: CAD

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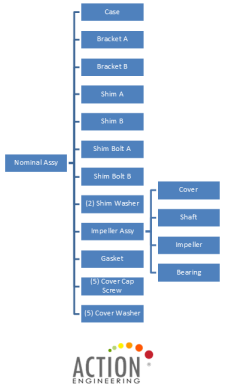


Nominal CAD Geometry

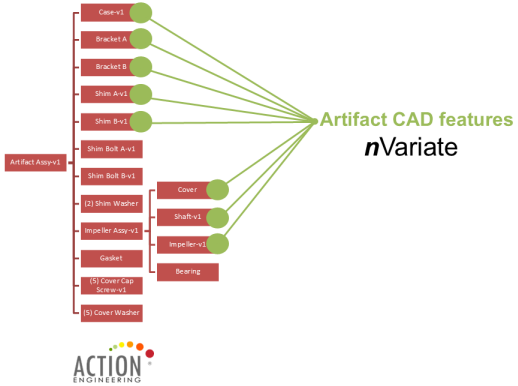


2 artifact model

Nominal CAD Geometry

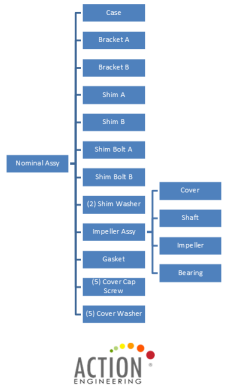


Artifact CAD Geometry

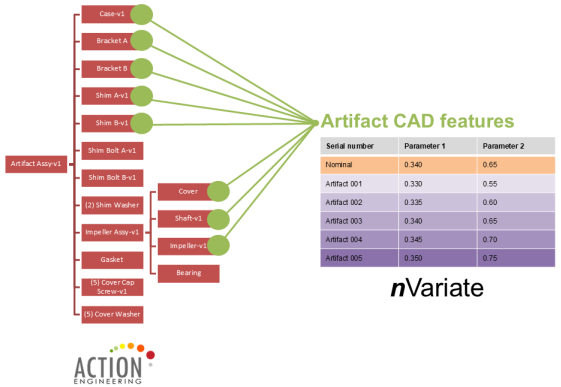


3 artifact matrix

Nominal CAD Geometry

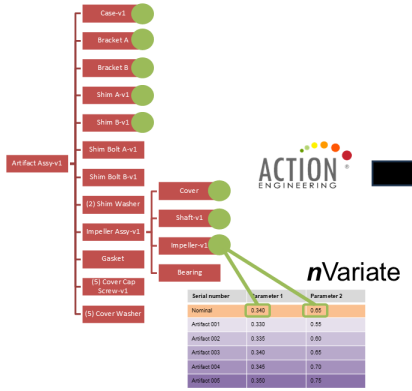


Artifact CAD Geometry

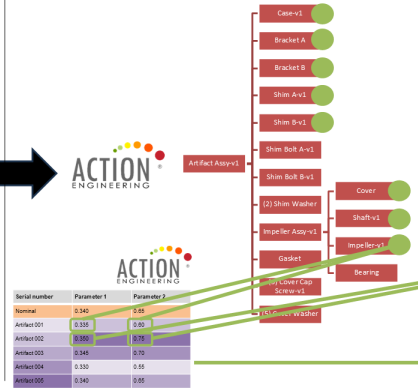


4 artifact matrix models

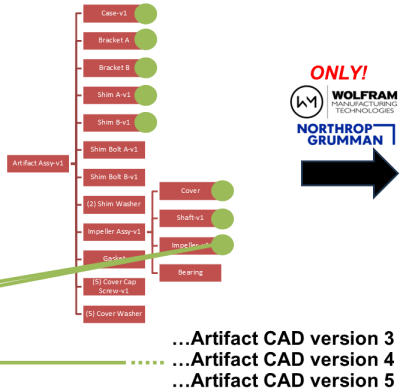
Artifact CAD Geometry



Artifact CAD version 1



Artifact CAD version 2



ONLY!
WOLFRAM MANUFACTURING TECHNOLOGIES
NORTHROP GRUMMAN

...Artifact CAD version 3
...Artifact CAD version 4
...Artifact CAD version 5

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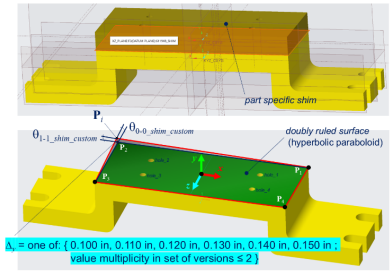
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TDP Modernization for As-Built Data: CAD

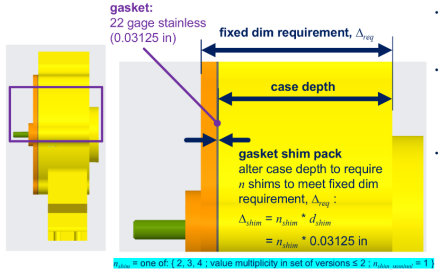
ACTION ENGINEERING

Artifact 01 shim1: shim-leg interface



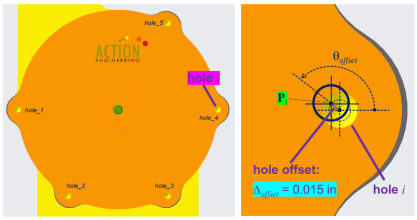
- Each version shall have one of the four corners randomly selected ($\mathbf{P}_i$). Result is a *doubly ruled surface* (hyperbolic paraboloid).
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to make part specific shims to satisfy assembled GD&T requirements.
- Value of offset Δ_s to represent stakeholder use case values to reflect currently experienced conditions: Δ_s = one of: { 0.100 in, 0.110 in, 0.120 in, 0.130 in, 0.140 in, 0.150 in ; value multiplicity in set of versions ≤ 2 }.
- **CMM note**: secondary additional inspection to the standard inspection to provide high-precision enhanced determination of surface profile.

Artifact 02 shim2: gasket stackup



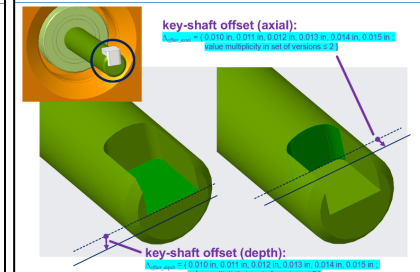
- Each version shall have a randomly selected number of shims, n_{shim} defining part specific case depth.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine specific number of gasket shims to satisfy assembled GD&T requirement, Δ_{req}.
- Value of n_{shim} to represent stakeholder use case values n_{shim} = one of: { 2, 3, 4 ; value multiplicity in set of versions ≤ 2 ; $n_{shim\ nominal}$ = 1 } to reflect currently experienced conditions.

Artifact 03 cover bolt hole misalign



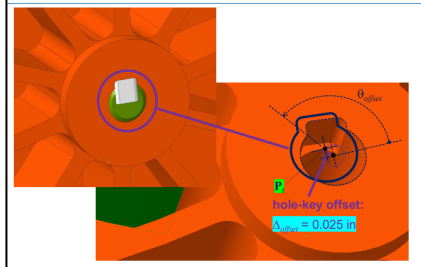
- Each version shall have a randomly selected hole, hole i, for bolt hole positional defect, Δ_{offset} = 0.015 in.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine hole i and location of defect, $\mathbf{P}_i$.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

Artifact 04 key – shaft interface defect



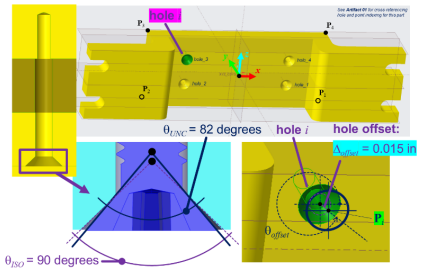
- Each version shall have (2) randomly selected key-pin interface positional defects, Δ_{offset_axial} and Δ_{offset_depth}.
- Result of offsets represents an assembly interface defect for fit tolerance.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine size of of defects, Δ_{offset_axial} and Δ_{offset_depth}.
- Note: orientation of surfaces to be maintained and *not* rotated when offset.
- Note: Δ_{offset_depth} to be *overcut only* and not undercut (as shown).
- Note: Δ_{offset_axial} to be *undercut only* and not overcut (as shown).

Artifact 05 impeller hole-key offset wobble



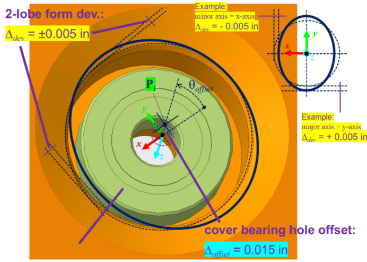
- Each version shall have a randomly selected hole-key positional defect, Δ_{offset} = 0.025 in.
- Result of offset represents a functional defect for impeller in service, i.e., rotational *wobble*.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine location of defect, $\mathbf{P}_i$.
- Note: orientation of hole-key to be maintained and *not* rotated when offset.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

Artifact 06 leg bolt countersink hole defect



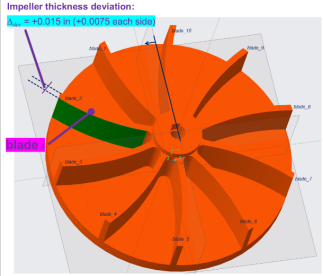
- Change from counterbore to **countersink** bolts in last nominal set affect trends
- Nominal model shall call out *UNC* hole size as a standard UNC screw design feature: **8-32 countersink** (*with its given countersink angle of 82 degrees*).
- Artifact model versions shall be selected at random to contain or not contain the same countersink bolt size (UNC 8-32) with a manual override angle of 90 degrees representing a manufacturing error of an ISO (M4) countersink tool [Yes / No artifact per version].
- In addition, every version shall have a randomly selected hole, hole i, for bolt hole positional defect, Δ_{offset} = 0.015 in regardless of countersink angle defect inclusion
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine hole i and location of defect, $\mathbf{P}_i$, as well as bolt hole form deviation.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

Artifact 07 cover – bearing misfit



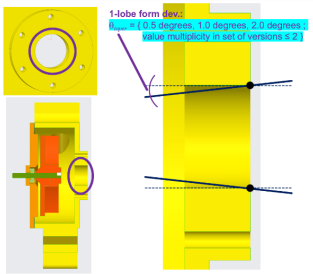
- Combined form-positional deviation.
- Functional defect: impeller positional misalignment in case. Performance, efficiency, and operational changes.
- Assembly defect: bearing-cover friction fit not to design intent. Potential in-service failure mode of system.
- 2-lobe (ovalization) form deviation, Δ_{form} = ±0.005 in. Random selection of major (Δ_{form} = + 0.005 in, each side) and minor (Δ_{form} = - 0.005 in, each side) elliptical axes (x-axis or y-axis).
- Positional cover bearing hole positional offset, Δ_{offset} = 0.015 in.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine location of defect, $\mathbf{P}_i$, and form defect type (i.e., 2-lobe versus others) and defect dimensions.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

Artifact 08 impeller blade profile defect



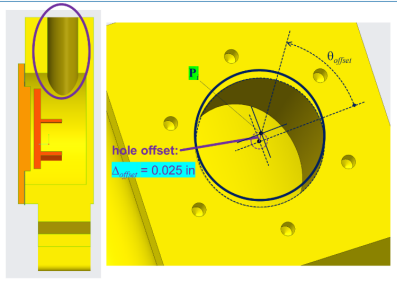
- Functional defect: impeller performance, efficiency, and operational changes.
- Each version shall have a randomly selected impeller blade, blade i, for blade thickness form defect, Δ_{form} = +0.015 in (+0.0075 each side).
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine blade i and thickness of blade.

Artifact 09 case back suction hole defect



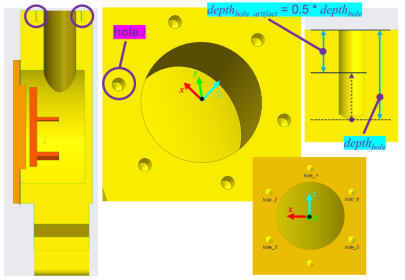
- Functional defect: suction performance, efficiency, and operational changes.
- Form deviation of suction hole to be made as a tapered hole. Each version shall have a randomly selected angle of taper, θ_{taper} = { 0.5 degrees, 1.0 degrees, 2.0 degrees ; value multiplicity in set of versions ≤ 2 }. Outside diameter to equal that of nominal model.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine form deviation type (taper) and actual surface form.

Artifact 10 case top discharge hole defect



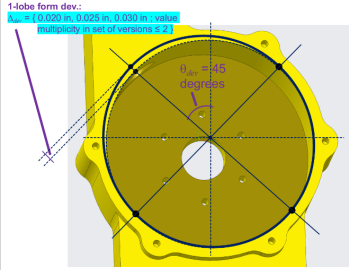
- Functional defect: suction performance, efficiency, and operational changes.
- Assembly defect: alignment of discharge components.
- Each version shall have a randomly selected positional defect, Δ_{offset} = 0.025 in.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine location of defect, $\mathbf{P}_i$.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

Artifact 11 case top discharge bolt hole defect



- Each version shall have a randomly selected hole, hole i, for bolt hole drill depth defect, $depth_{hole\_undrilled}$ = 0.5 * $depth_{hole}$.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine hole i.
- **WARNING TO CMM OPERATOR**: *alert CMM programmer so that probe does not crash and machine is not damaged.*

Artifact 12 case opening cylinder form deviation defect



- Form deviation (1-lobe) in case opening cylinder.
- Functional defect: performance, efficiency, and operational changes.
- Assembly defect: potential in-service failure mode of system (e.g., leaking).
- 1-lobe form deviation, Δ_{form} = { 0.020 in, 0.025 in, 0.030 in ; value multiplicity in set of versions ≤ 2 }.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine form defect type (i.e., 1-lobe versus others) and defect dimensions.

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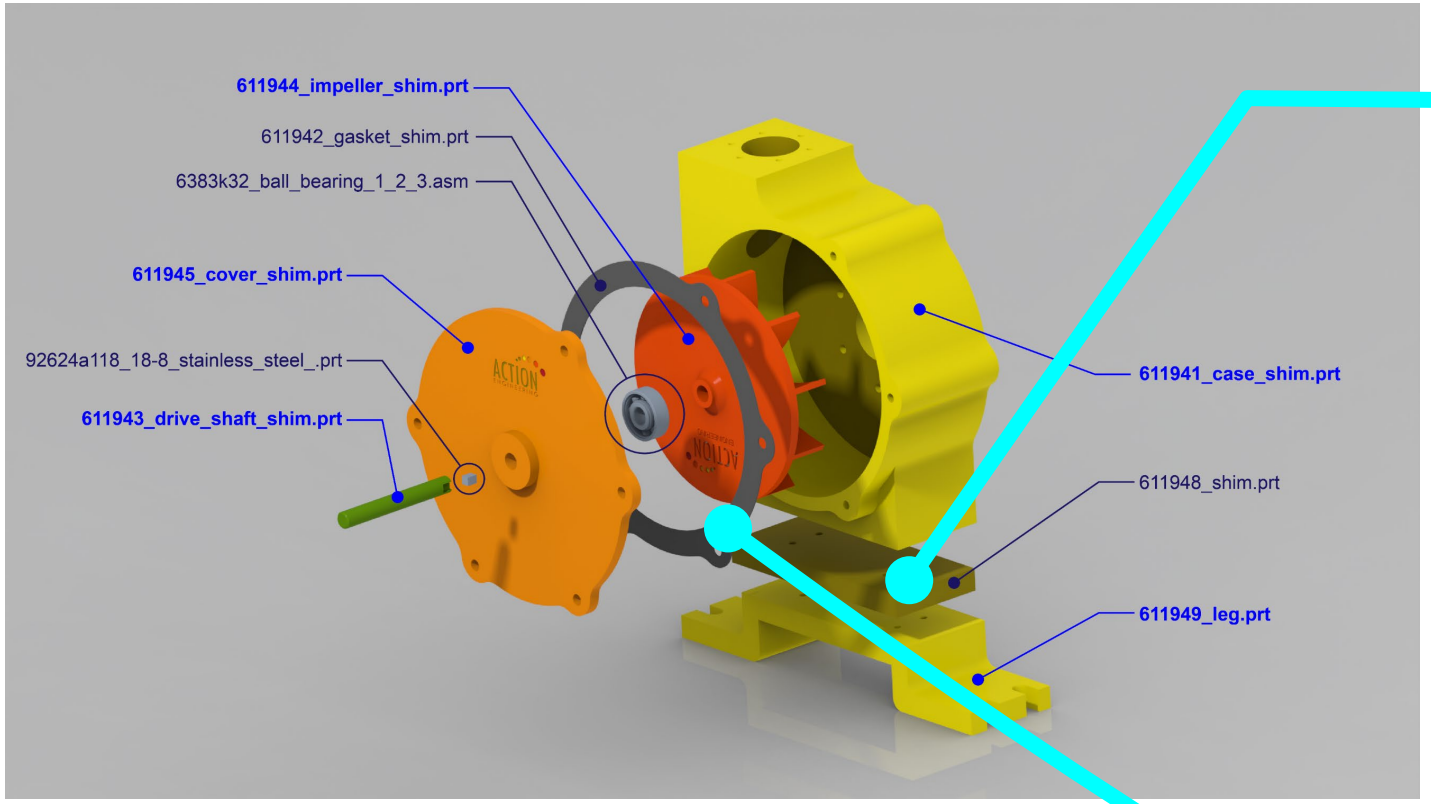
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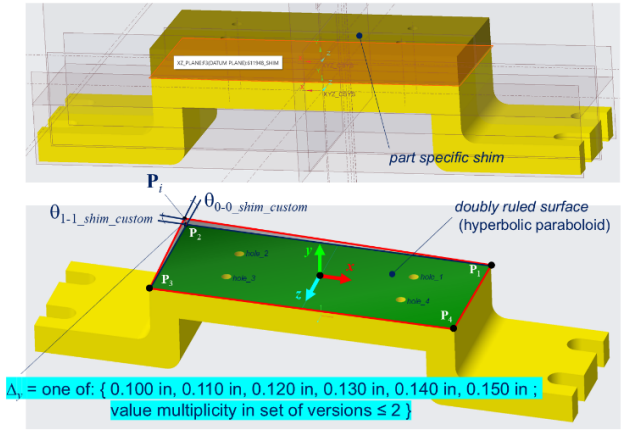
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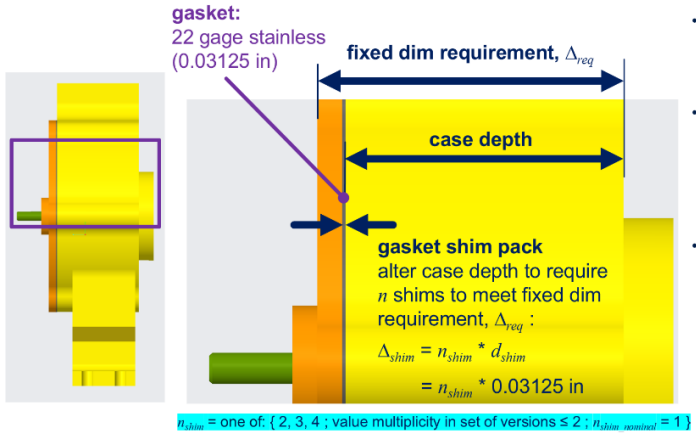


Artifact 01 shim1: shim-leg interface



- Each version shall have one of the four corners randomly selected ($\mathbf{P}_i$). Result is a *doubly ruled surface* (hyperbolic paraboloid).
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to make part specific shims to satisfy assembled GD&T requirements.
- Value of offset Δ_y to represent stakeholder use case values to reflect currently experienced conditions: Δ_y = one of: { 0.100 in, 0.110 in, 0.120 in, 0.130 in, 0.140 in, 0.150 in ; value multiplicity in set of versions ≤ 2 }.
- **CMM note**: secondary additional inspection to the standard inspection to provide high-precision enhanced determination of surface profile.

Artifact 02 shim2: gasket stackup



- Each version shall have a randomly selected number of shims, n_{shim}, defining part specific case depth.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine specific number of gasket shims to satisfy assembled GD&T requirement, Δ_{req}.
- Value of n_{shim} to represent stakeholder use case values n_{shim} = one of: { 2, 3, 4 ; value multiplicity in set of versions ≤ 2 ; $n_{shim\_nominal}$ = 1 } to reflect currently experienced conditions.

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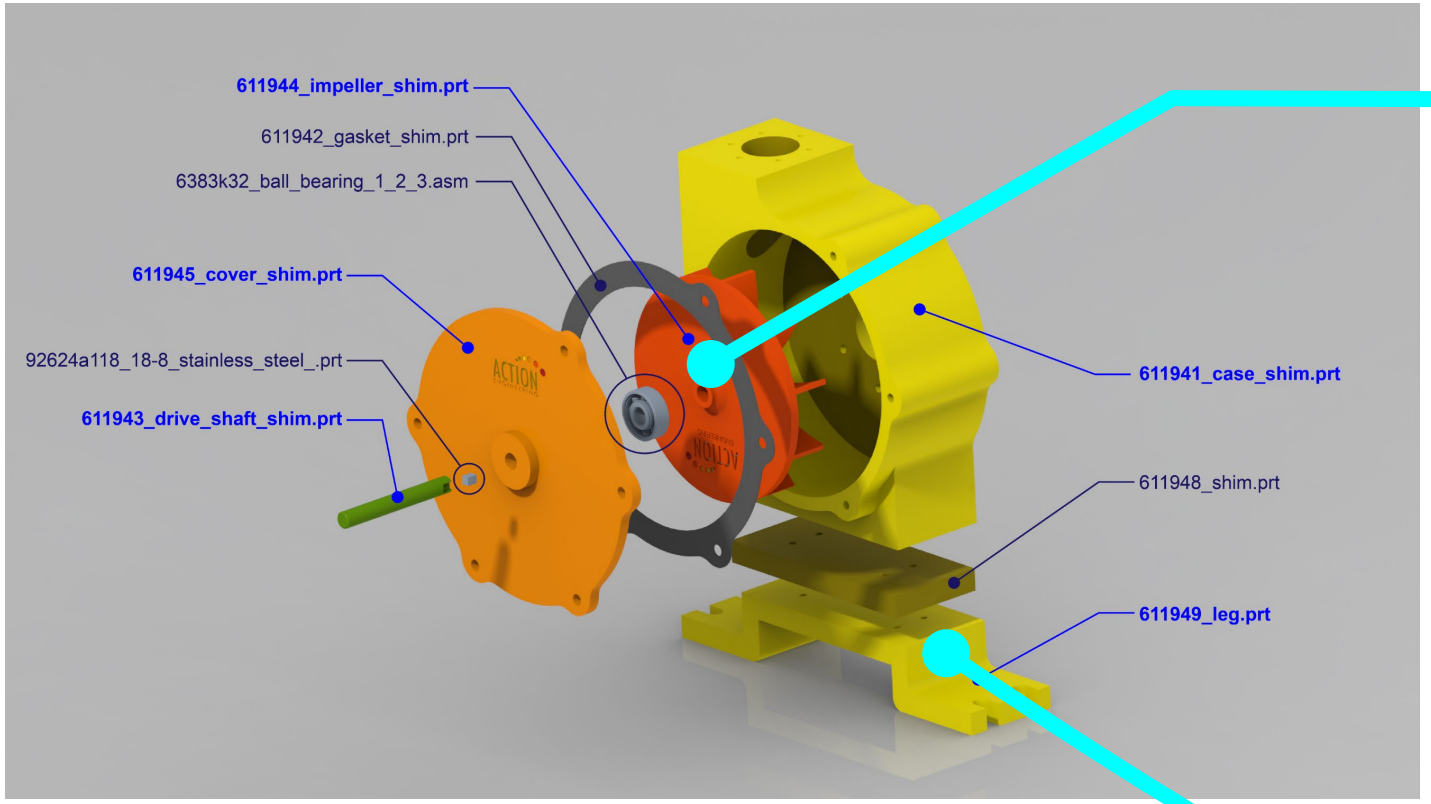
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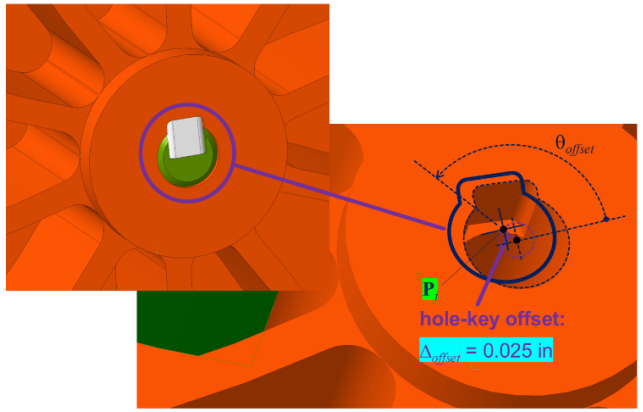
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TDP Modernization for As-Built Data: CAD

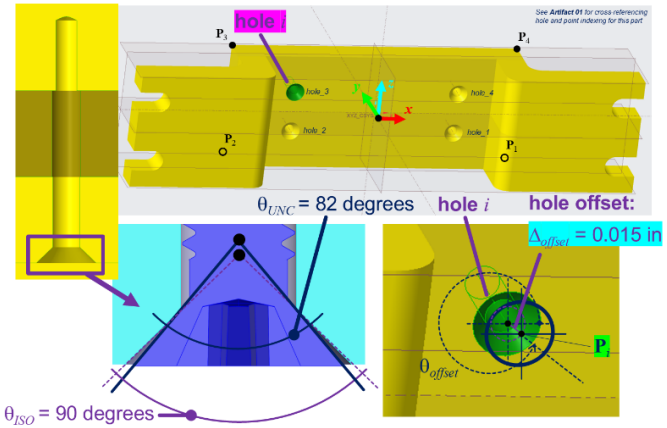


Artifact 05 impeller hole-key offset wobble



- Each version shall have a randomly selected hole-key positional defect, Δ_{offset} = 0.025 in.
- Result of offset represents a functional defect for impeller in service, i.e., rotational *wobble*.
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine location of defect, P_i.
- Note: orientation of hole-key to be maintained and *not* rotated when offset.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

Artifact 06 leg bolt countersink hole defect



- Change from counterbore to **countersink** bolts in both nominal and artifact models.
- Nominal model shall call out *UNC* hole size as a standard UNC screw design feature: **8-32 countersink** (*with its given countersink angle of 82 degrees*).
- Artifact model versions shall be selected at random to contain or not contain the same countersink bolt size (UNC 8-32) with a *manual override angle* of **90 degrees** representing a manufacturing error of an ISO (M4) countersink tool [Yes / No artifact per version].
- In addition, every version shall have a randomly selected hole, hole i, for bolt hole positional defect, Δ_{offset} = 0.015 in, regardless of countersink angle defect inclusion
- Use of as-inspected (QIF) and as-executed (MTConnect) data to be used to determine hole i and location of defect, P_i, as well as bolt hole form deviation.
- Positional offset to be restricted to θ_{offset} = {0, 45, 90, 135, 180, 225, 270, 315} degrees.

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TDP Modernization for As-Built Data: CAD

artifact version	artifact V1	artifact V2	artifact V3	artifact V4	artifact V5
CAD file ID	6119XX-01-YY	6119XX-02-YY	6119XX-03-YY	6119XX-04-YY	6119XX-05-YY
physical part serial number (01/03)	6119XX-01-01	6119XX-02-01	6119XX-03-01	6119XX-04-01	6119XX-05-01
physical part serial number (02/03)	6119XX-01-02	6119XX-02-02	6119XX-03-02	6119XX-04-02	6119XX-05-02
physical part serial number (03/03)	6119XX-01-03	6119XX-02-03	6119XX-03-03	6119XX-04-03	6119XX-05-03
611900_shim_assy.asm — CAD file ID	611900-01-YY	611900-02-YY	611900-03-YY	611900-04-YY	611900-05-YY
├─ 611941_case_shim.prt — CAD file ID	611941-01-YY	611941-02-YY	611941-03-YY	611941-04-YY	611941-05-YY
physical part serial number (01/03)	611941-01-01	611941-02-01	611941-03-01	611941-04-01	611941-05-01
physical part serial number (02/03)	611941-01-02	611941-02-02	611941-03-02	611941-04-02	611941-05-02
physical part serial number (03/03)	611941-01-03	611941-02-03	611941-03-03	611941-04-03	611941-05-03
├─ 611940_impeller_shim.asm — CAD file ID	611940-01-YY	611940-02-YY	611940-03-YY	611940-04-YY	611940-05-YY
├─ 611945_cover_shim.prt — CAD file ID	611945-01-YY	611945-02-YY	611945-03-YY	611945-04-YY	611945-05-YY
physical part serial number (01/03)	611945-01-01	611945-02-01	611945-03-01	611945-04-01	611945-05-01
physical part serial number (02/03)	611945-01-02	611945-02-02	611945-03-02	611945-04-02	611945-05-02
physical part serial number (03/03)	611945-01-03	611945-02-03	611945-03-03	611945-04-03	611945-05-03
├─ asm0002.asm	asm0002.asm	asm0002.asm	asm0002.asm	asm0002.asm	asm0002.asm
├─ 611944_impeller_shim.prt — CAD file ID	611944-01-YY	611944-02-YY	611944-03-YY	611944-04-YY	611944-05-YY
physical part serial number (01/03)	611944-01-01	611944-02-01	611944-03-01	611944-04-01	611944-05-01
physical part serial number (02/03)	611944-01-02	611944-02-02	611944-03-02	611944-04-02	611944-05-02
physical part serial number (03/03)	611944-01-03	611944-02-03	611944-03-03	611944-04-03	611944-05-03
├─ 611942_gasket_shim.prt — CAD file ID	611942-01-YY	611942-02-YY	611942-03-YY	611942-04-YY	611942-05-YY
physical part serial number (01/03)	611942-01-01	611942-02-01	611942-03-01	611942-04-01	611942-05-01
physical part serial number (02/03)	611942-01-02	611942-02-02	611942-03-02	611942-04-02	611942-05-02
physical part serial number (03/03)	611942-01-03	611942-02-03	611942-03-03	611942-04-03	611942-05-03
├─ 611943_drive_shaft_shim.prt — CAD file ID	611943-01-YY	611943-02-YY	611943-03-YY	611943-04-YY	611943-05-YY
physical part serial number (01/03)	611943-01-01	611943-02-01	611943-03-01	611943-04-01	611943-05-01
physical part serial number (02/03)	611943-01-02	611943-02-02	611943-03-02	611943-04-02	611943-05-02
physical part serial number (03/03)	611943-01-03	611943-02-03	611943-03-03	611943-04-03	611943-05-03
└─ 92624a118_18-8_stainless_steel_.prt	92624a118_18-8_stainless_steel_.prt	92624a118_18-8_stainless_steel_.prt	92624a118_18-8_stainless_steel_.prt	92624a118_18-8_stainless_steel_.prt	92624a118_18-8_stainless_steel_.prt
├─ 611948_shim.prt — CAD file ID	611948-01-YY	611948-02-YY	611948-03-YY	611948-04-YY	611948-05-YY
physical part serial number (01/03)	611948-01-01	611948-02-01	611948-03-01	611948-04-01	611948-05-01
physical part serial number (02/03)	611948-01-02	611948-02-02	611948-03-02	611948-04-02	611948-05-02
physical part serial number (03/03)	611948-01-03	611948-02-03	611948-03-03	611948-04-03	611948-05-03
└─ 611949_leg.prt — CAD file ID	611949-01-YY	611949-02-YY	611949-03-YY	611949-04-YY	611949-05-YY
physical part serial number (01/03)	611949-01-01	611949-02-01	611949-03-01	611949-04-01	611949-05-01
physical part serial number (02/03)	611949-01-02	611949-02-02	611949-03-02	611949-04-02	611949-05-02
physical part serial number (03/03)	611949-01-03	611949-02-03	611949-03-03	611949-04-03	611949-05-03

			Final values to populate CAD files				
artifact version			artifact V1	artifact V2	artifact V3	artifact V4	artifact V5
CAD file ID			6119XX-01-YY	6119XX-02-YY	6119XX-03-YY	6119XX-04-YY	6119XX-05-YY
physical part serial number (01/03)			6119XX-01-01	6119XX-02-01	6119XX-03-01	6119XX-04-01	6119XX-05-01
physical part serial number (02/03)			6119XX-01-02	6119XX-02-02	6119XX-03-02	6119XX-04-02	6119XX-05-02
physical part serial number (03/03)			6119XX-01-03	6119XX-02-03	6119XX-03-03	6119XX-04-03	6119XX-05-03
Artifact	**artifact parameter**						
Artifact 01		$\mathbf{P}_i$	3	4	2	3	3
		Δ_y	0.150	0.110	0.150	0.120	0.120
Artifact 02		n_{shim}	4	3	3	4	4
Artifact 03		$hole_i$	1	4	1	4	4
	Δ_{offset} = 0.015 in	θ_{offset}	315	180	270	225	225
Artifact 04		Δ_{offset_axial}	0.120	0.150	0.130	0.130	0.130
		Δ_{offset_depth}	0.100	0.150	0.150	0.140	0.120
Artifact 05	Δ_{offset} = 0.025 in	θ_{offset}	135	90	135	135	90
Artifact 06		*countersink*	Y : theta=90 deg	N : theta=82 deg	Y : theta=90 deg	Y : theta=90 deg	Y : theta=90 deg
		$hole_i$	1	1	1	1	3
	Δ_{offset} = 0.015 in	θ_{offset}	45	315	0	90	225
Artifact 07	Δ_{dev} = +0.005 in	$axis_{major}$	y-axis	y-axis	x-axis	y-axis	y-axis
	Δ_{dev} = -0.005 in	$axis_{minor}$	x-axis	x-axis	y-axis	x-axis	x-axis
	Δ_{offset} = 0.015 in	θ_{offset}	270	225	45	90	225
Artifact 08	Δ_{dev} = 0.015 in	$blade_i$	5	2	8	10	1
Artifact 09		θ_{taper}	0.5	2.0	1.0	1.0	1.0
Artifact 10	Δ_{offset} = 0.025 in	θ_{offset}	45	0	180	270	315
Artifact 11		$hole_i$	3	3	1	4	5
Artifact 12	θ_{dev} = 45 degrees	Δ_{dev}	0.025	0.030	0.020	0.030	0.030

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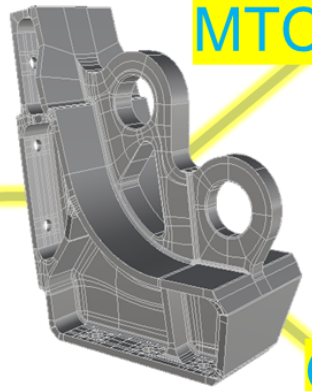
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TDP Modernization for As-Built Data: CAD



CAD
STEP AP242

CAM
MTConnect

QIF
CAI

ASoT

nVariate — nominal

LOCKHEED MARTIN
NORTHROP GRUMMAN
ACTION ENGINEERING — artifact

Thomas R. Thurman
(STEP AP242 subject matter expert)
Asa Trainer
(interoperability subject matter expert) — nominal

nVariate — nominal

WOLFRAM MANUFACTURING TECHNOLOGIES
NORTHROP GRUMMAN — artifact

METAlogi — nominal

nVariate
AIS ADVANCED INSPECTION SERVICES
PRODUCTIVITY QUALITY INC — nominal

Thomas R. Kramer, Ph.D.
(QIF subject matter expert)
Asa Trainer
(interoperability subject matter expert)

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Is your data in *really* in conformance?

	STEP AP242 Ed.3	QIF 3.0	MTConnect V2.5
Documentation			
Model			
Schema			
Data format			

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Is your data in *really* in conformance?

	STEP AP242 Ed.3	QIF 3.0	MTConnect V2.5
Documentation	AP242 -- HTML	XSD `<xs:documentation>` + Word content → **PDF** [19] **(normative)**	XMI → PDF [5] (informative) XMI → HTML [6] (informative)
Model	Domain Model -- XMI (SysML 1.x) (normative per 4442 Annex A A.2.2) [26][27] | - *mapping* -- XMI (SysML 1.x) [26][27] Core Model -- XMI (SysML 1.x) [21] | - *mapping* -- XMI (SysML 1.x) [25] Application Reference Model (ARM) -- [none] Module Interpreted Model (MIM) -- [none]	**XSD** [12][13][14][17] **XSLT** [15][18] **(normative)**	Cameo Enterprise Architect (SysML plugin) → **XMI** [3][7][8] **(normative)**
Schema	Domain Model -- XSD (text document normative per 4442 Annex A A.2.1) XSD, EXPRESS (machine data informative per 4442 Annex A A.2.1) XML (C.4 of AP242) AP242 XML conformance is by XSD | - *mapping* -- XSD Core Model -- | - *mapping* -- [none] Application Reference Model (ARM) -- EXPRESS | - *mapping* -- STEP mapping specification language [24] Module Interpreted Model (MIM) -- EXPRESS	**XSD** [12][13][14][17] **(normative)**	XMI → XSD [4][9][10][11] (informative)
Data format	Domain Model -- XML (C.4 of AP242) Core Model -- [none] Application Reference Model (ARM) -- [none] Module Interpreted Model (MIM) -- STEP-file (10303-21) [22] Standard data access interface or simply SDAI (10303-22) [22] HDF5 (10303-26) [22] STEP-XML (10303-28) [22]	**XML** [16][20] **(normative)**	XMI projection → **XML** [?] **(normative)**

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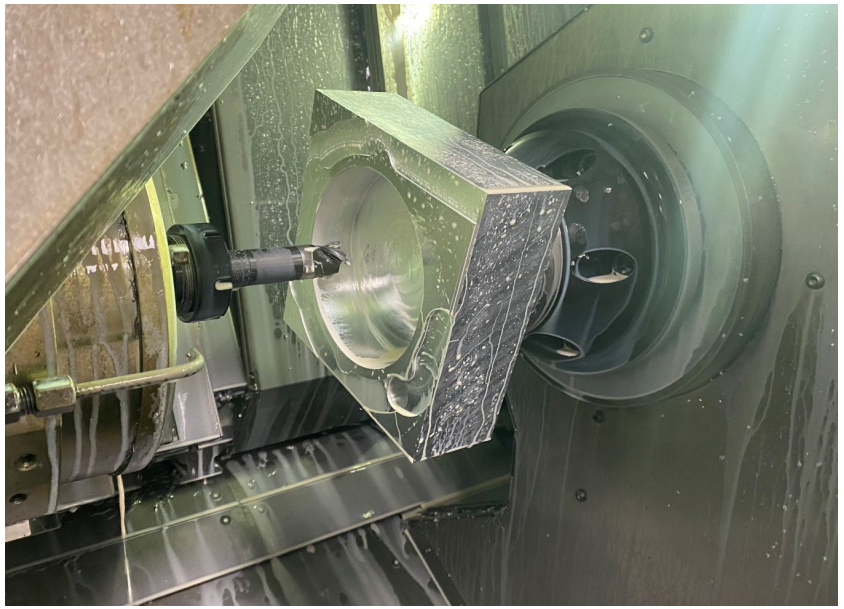
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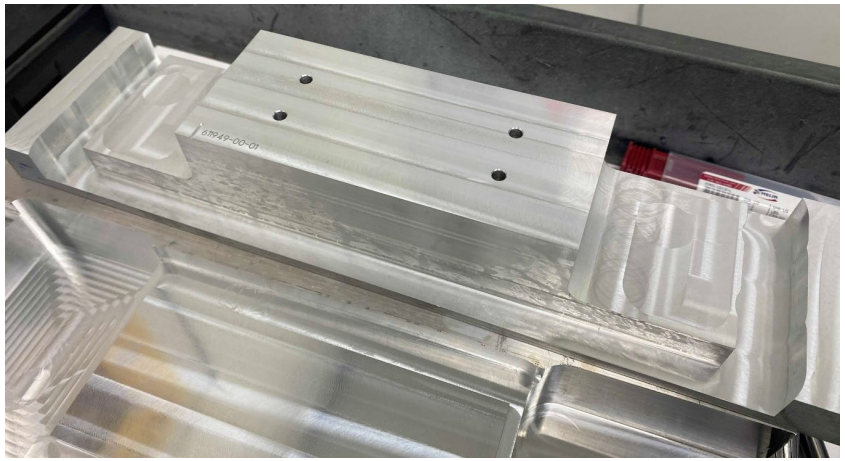
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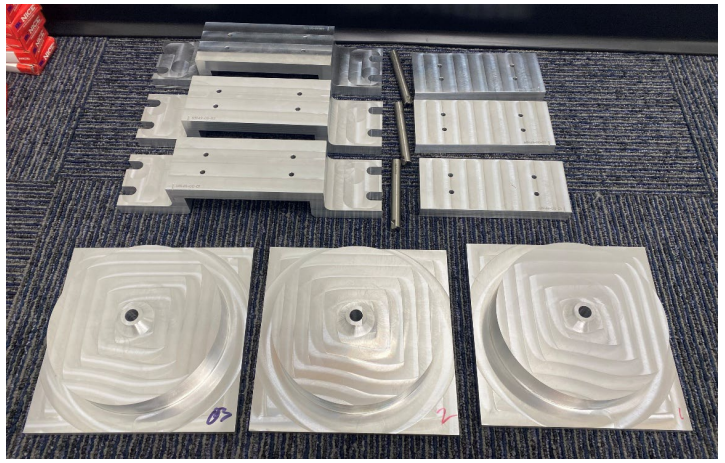
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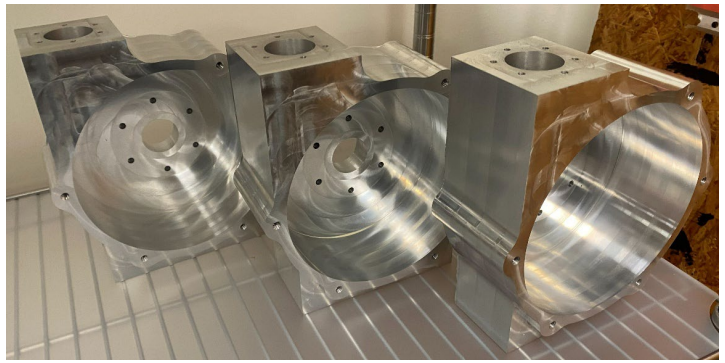
TDP Modernization for As-Built Data: CAM











WOLFRAM MANUFACTURING TECHNOLOGIES

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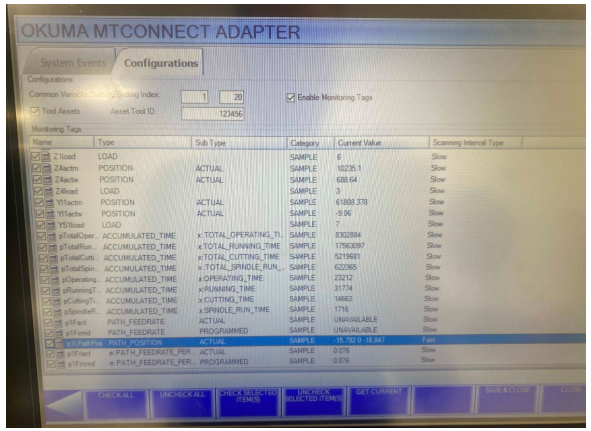
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TDP Modernization for As-Built Data: CAM

MTConnect®




```
...
2024-11-26T21:30:46.756Z|Samples|PathFeedrate|Actual|ActPathFeedrate|0.0
2024-11-26T21:30:46.756Z|Samples|Position|Actual|YAxisPosition|40.485
2024-11-26T21:30:46.756Z|Samples|Load||load-Z_P1|43.0
2024-11-26T21:30:46.896Z|Events|PathFeedrateOverride|Programmed|feedoverride-
1|0
2024-11-26T21:30:47.166133Z|Samples|Torque||TMACHorsepower|0.062751
2024-11-26T21:30:47.006Z|Samples|PathFeedrate|Actual|ActPathFeedrate|12.6323
2024-11-26T21:30:47.006Z|Samples|Position|Actual|YAxisPosition|39.792
2024-11-26T21:30:47.006Z|Samples|Load||load-Y_P1|5.0
2024-11-26T21:30:47.006Z|Samples|Load||load-Z_P1|44.0
2024-11-26T21:30:47.13Z|Samples|Position|Actual|YAxisPosition|36.967
2024-11-26T21:30:47.13Z|Samples|Load||load-Y_P1|4.0
2024-11-26T21:30:47.271Z|Samples|PathFeedrate|Actual|ActPathFeedrate|15.7649
2024-11-26T21:30:47.271Z|Samples|Load||XLoad|5.0
2024-11-26T21:30:47.38Z|Samples|Position|Actual|YAxisPosition|34.445
2024-11-26T21:30:47.49Z|Samples|PathFeedrate|Actual|ActPathFeedrate|16.3618
2024-11-26T21:30:47.49Z|Samples|Position|Actual
2024-11-26T21:30:47.49Z|Samples|Load||load-Y_P1|5.0
2024-11-26T21:30:47.49Z|Samples|Load||load-Z_P1|45.0
2024-11-26T21:30:47.63Z|Samples|Position|Actual|YAxisPosition|28.435
2024-11-26T21:30:47.63Z|Samples|Load||load-Y_P1|11.0
2024-11-26T21:30:47.63Z|Samples|Load||load-Z_P1|44.0
2024-11-26T21:30:47.771Z|Events|Block||block-1|Y-1.5174
2024-11-26T21:30:47.771Z|Samples|PathFeedrate|Actual|ActPathFeedrate|15.4982
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...
```

torque (horsepower)

path feed rate

loa
d

tool position /orientation

METAlogi

WOLFRAM MANUFACTURING TECHNOLOGIES

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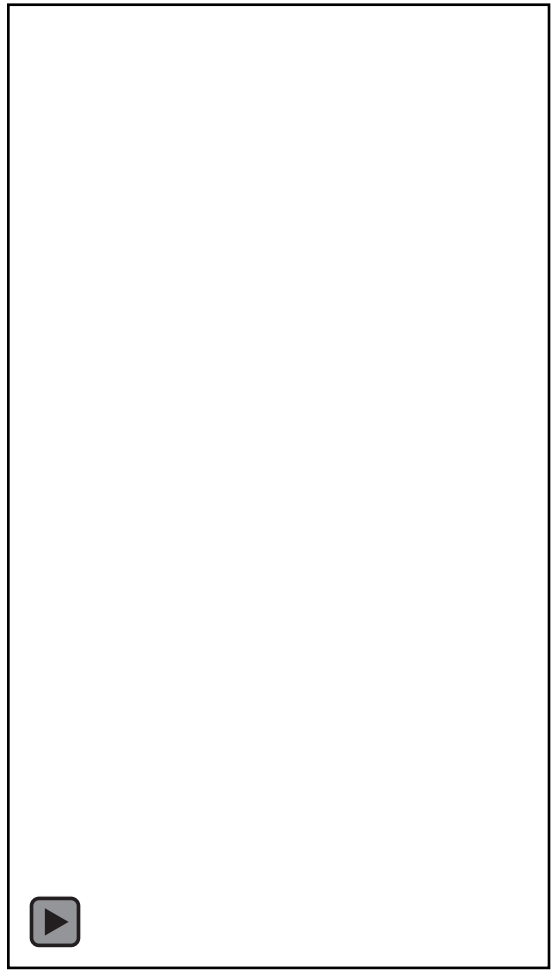
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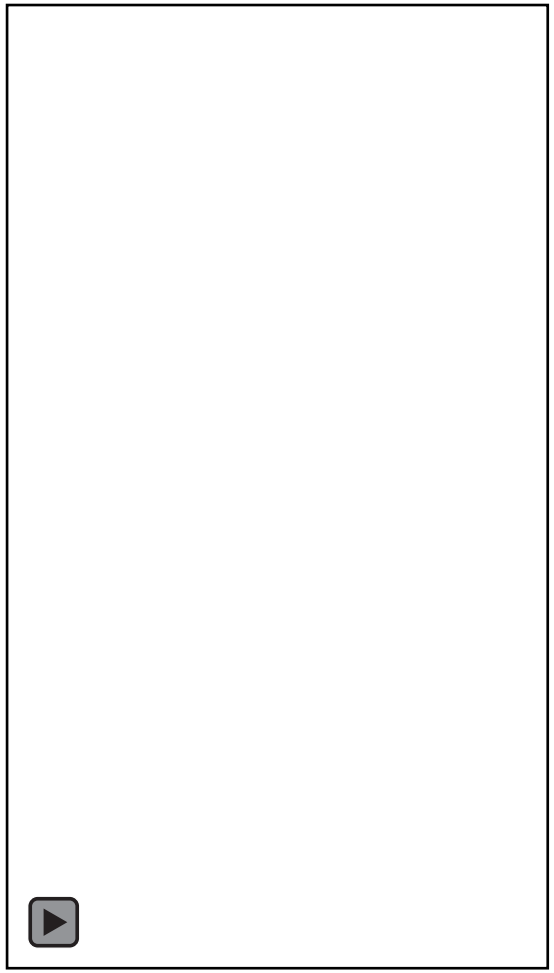
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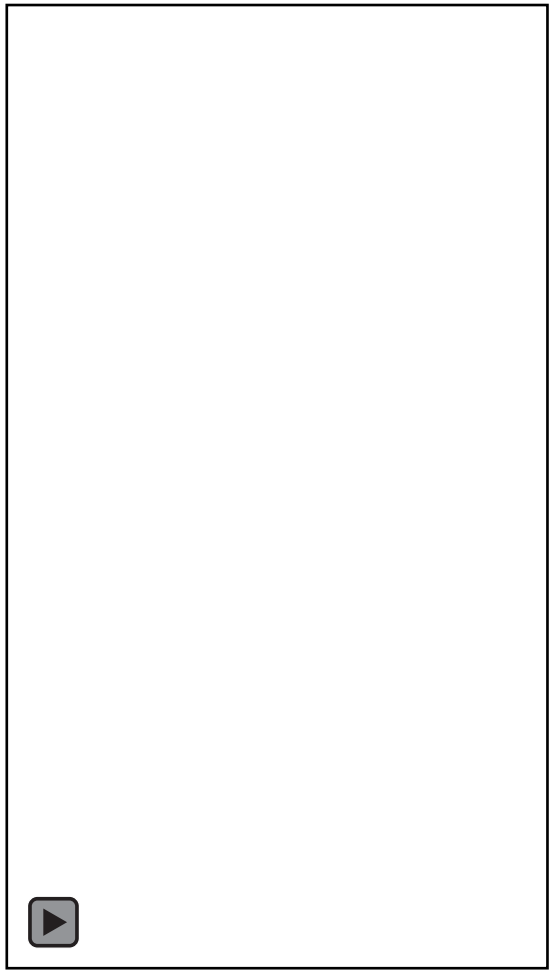
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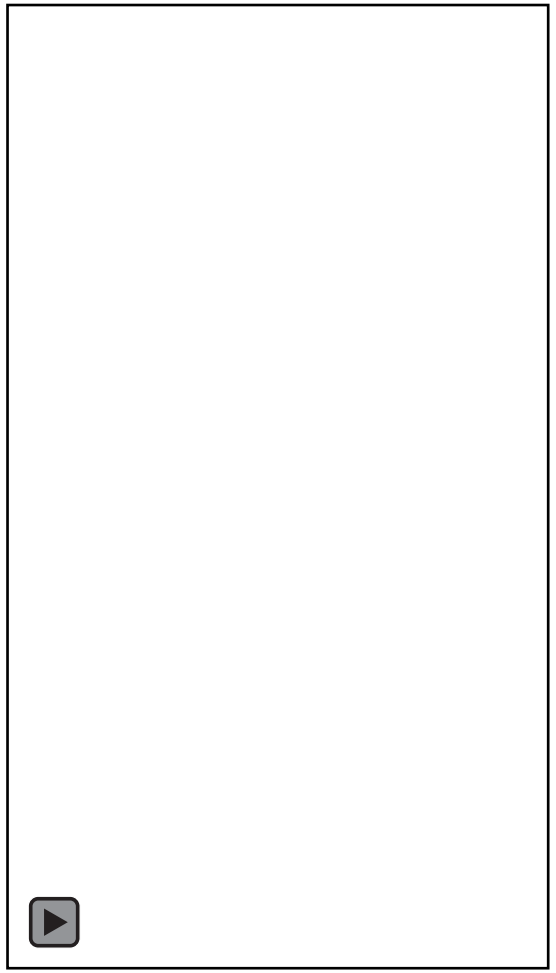
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TDP Modernization for As-Built Data: CAI









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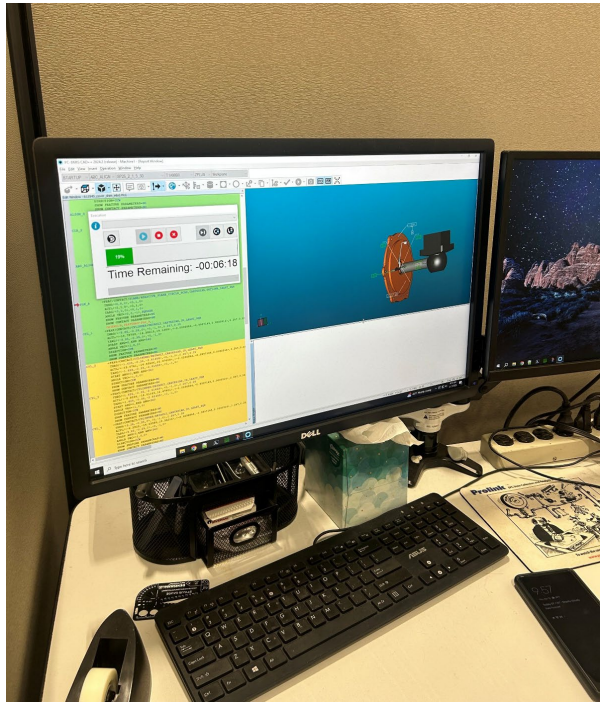
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TDP Modernization for As-Built Data: CAI




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Thomas R. Kramer, Ph.D.
Thomas Kramer Consulting, LLC

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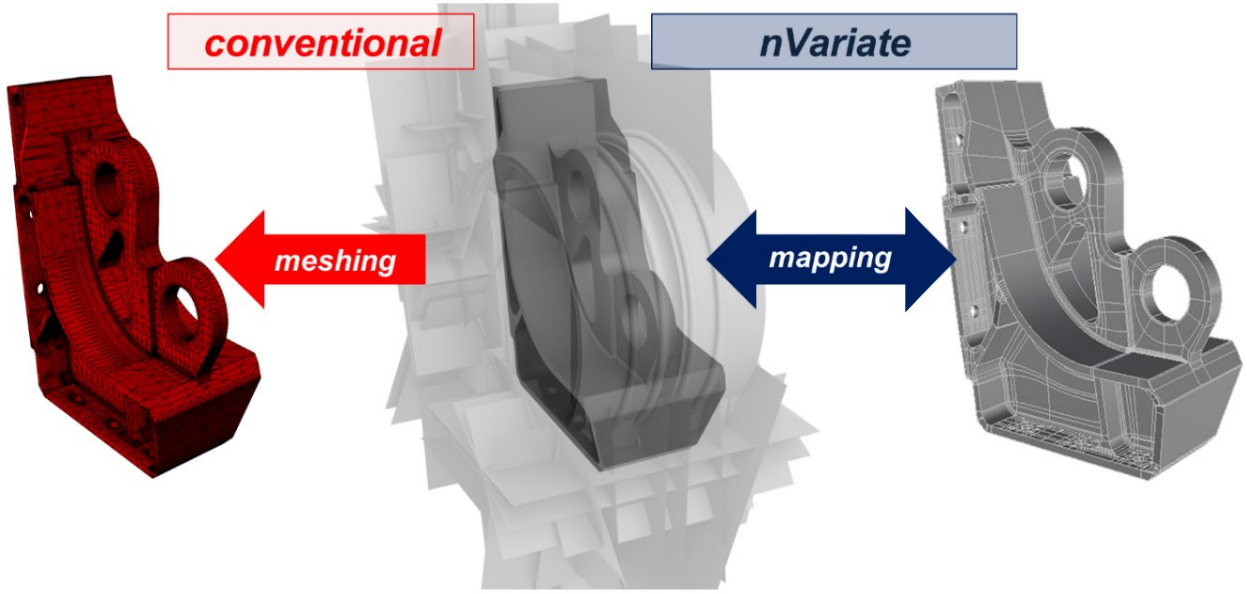
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TDP Modernization for As-Built Data: ASoT



CAx model
(*MBD – no PMI*)
faceted mesh

CAD model
(*MBD + PMI*)
trimmed surface B-rep

ASoT model
(*MBD + PMI*)
watertight surface B-rep

nVariate **Unirep**

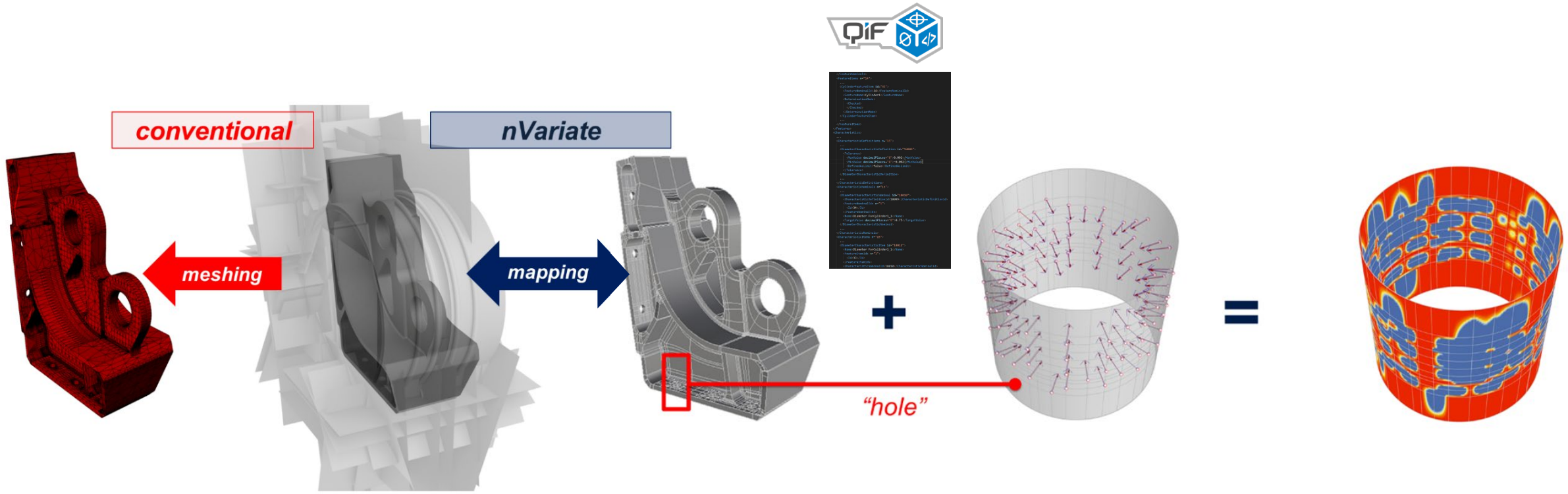
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TDP Modernization for As-Built Data: ASoT



CAx model
(*MBD – no PMI*)
faceted mesh

CAD model
(*MBD + PMI*)
trimmed surface B-rep

ASoT model
(*MBD + PMI*)
watertight surface B-rep

CAI data
(*PMI*)
CMM inspection data

CAI *as-inspected* model
(*MBD + PMI*)
morphed watertight surface B-rep

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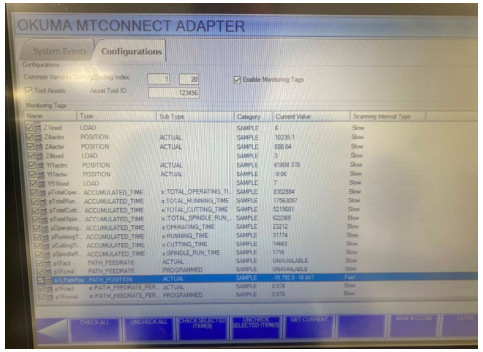
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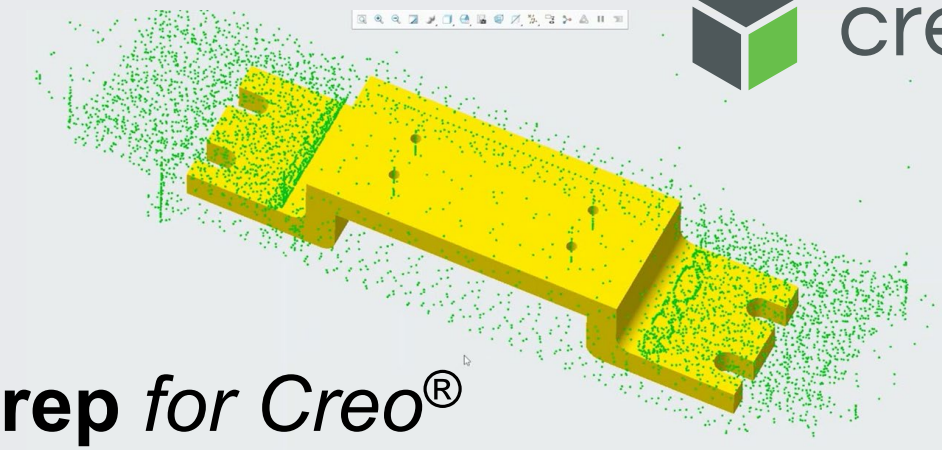
TDP Modernization for As-Built Data: as-man. model





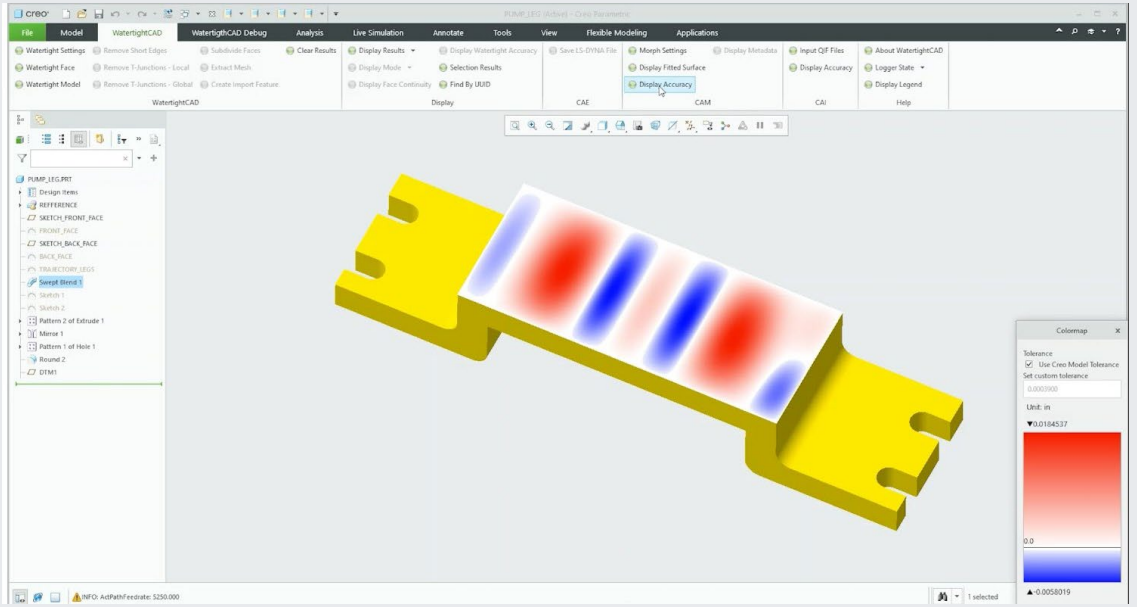
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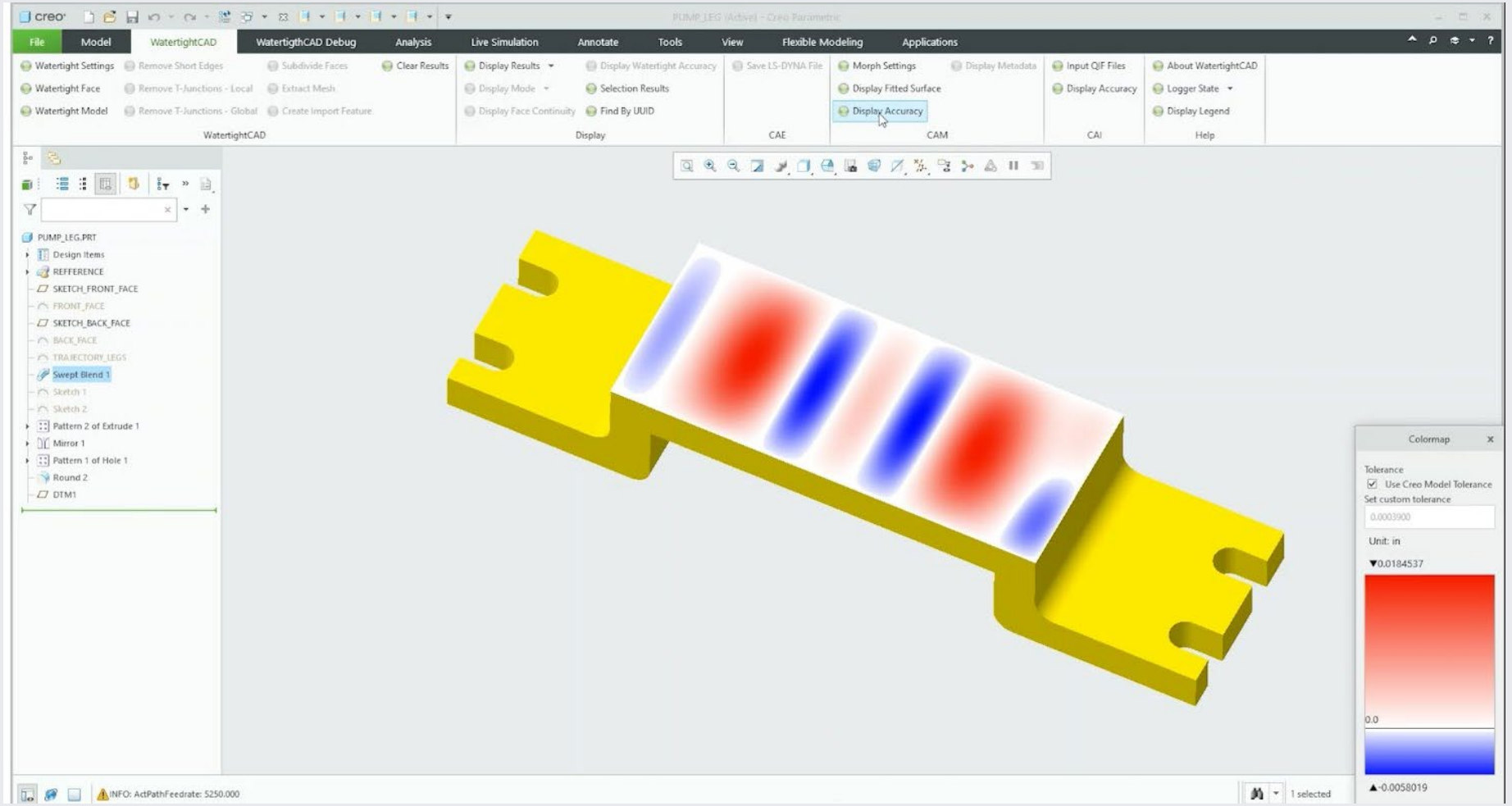
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TDP Modernization for As-Built Data: as-man. model

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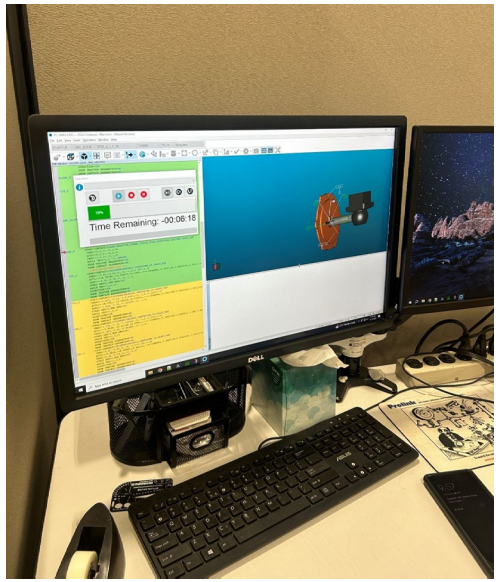
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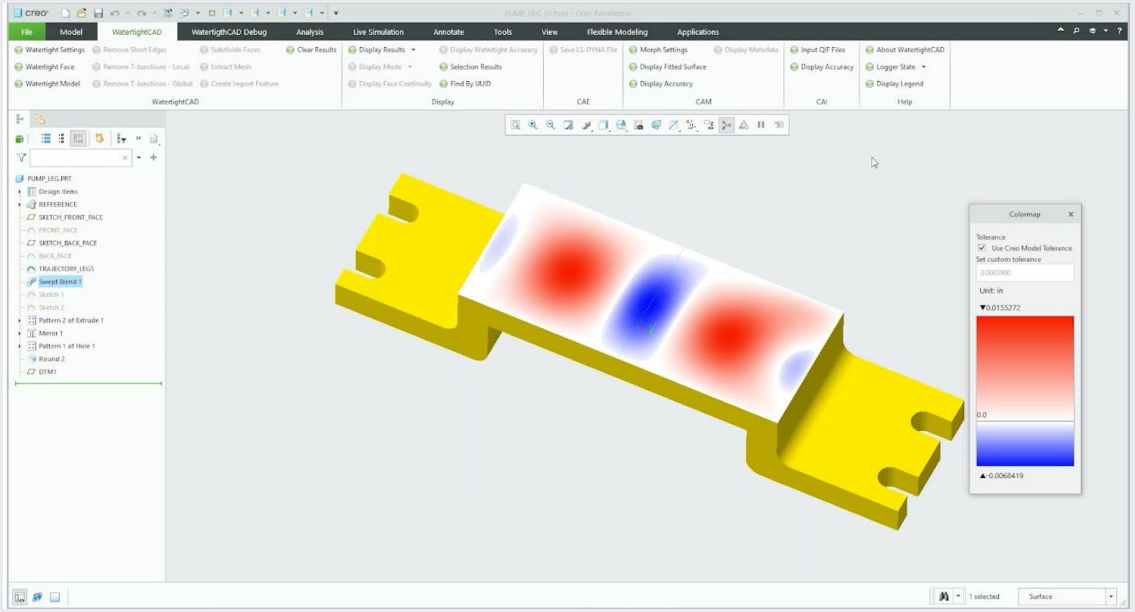
TDP Modernization for As-Built Data: as-ins. model




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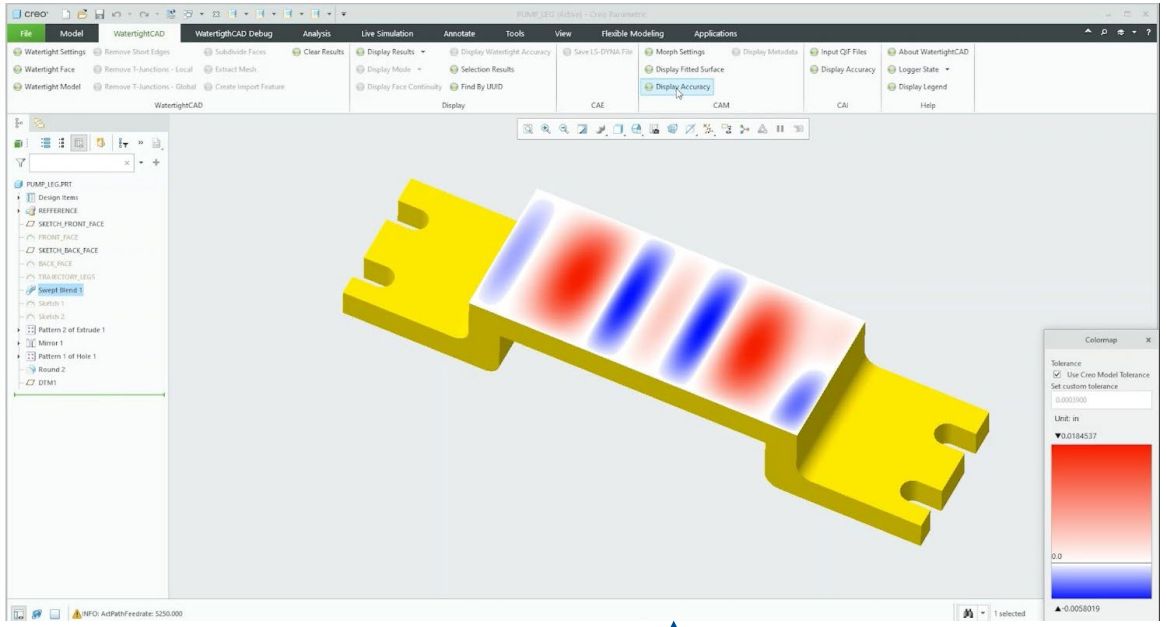
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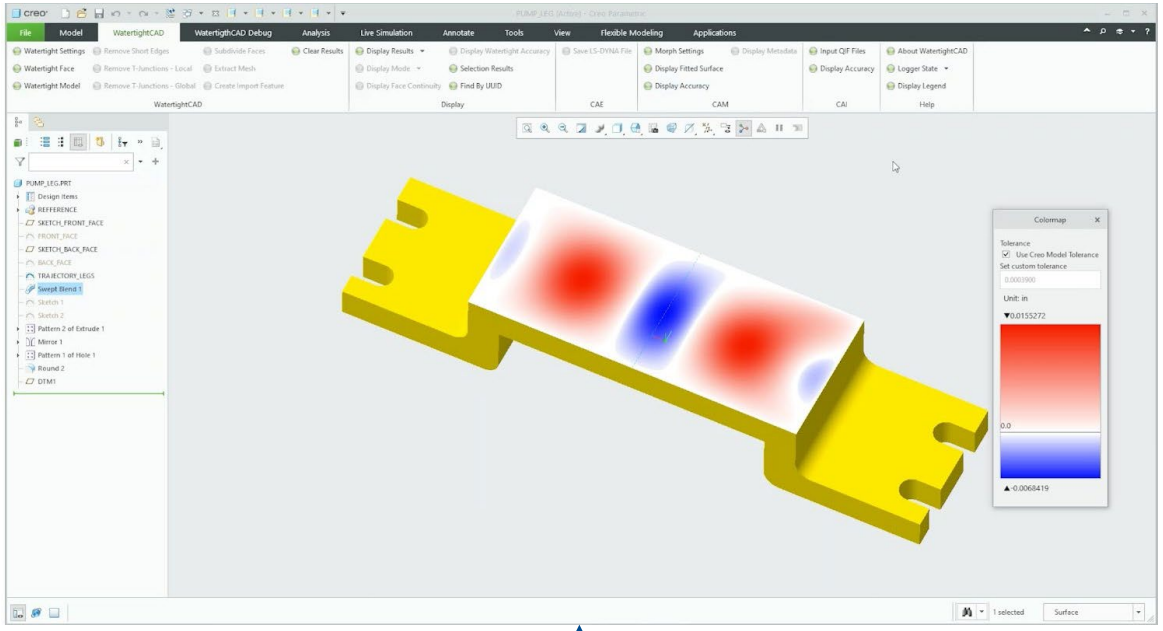
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TDP Modernization for As-Built Data: as-built model



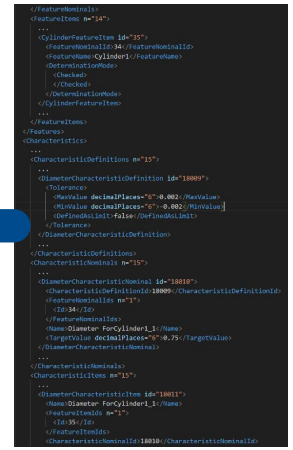


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2024-11-26T21:30:47.006Z|Samples|Load||load-Z_P1|44.0
2024-11-26T21:30:47.132|Samples|Position|Actual|YAxisPosition|36.967
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nVariate **Unirep** *for* Creo®

as-executed *digital twin*

as-inspected *digital twin*



MTConnect®

QIF

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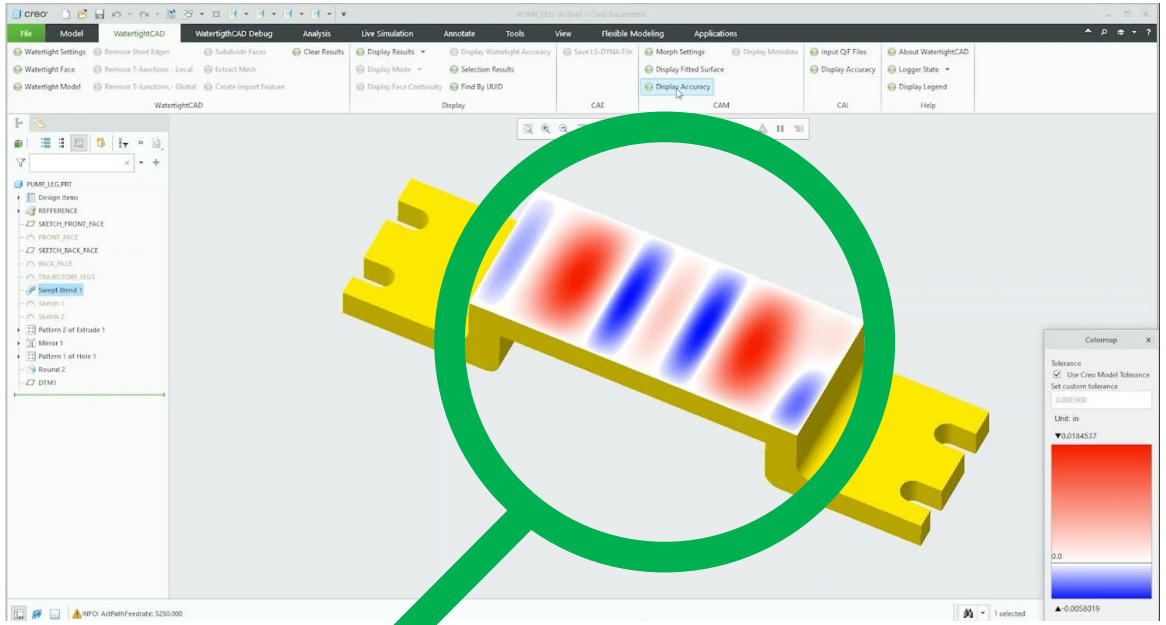
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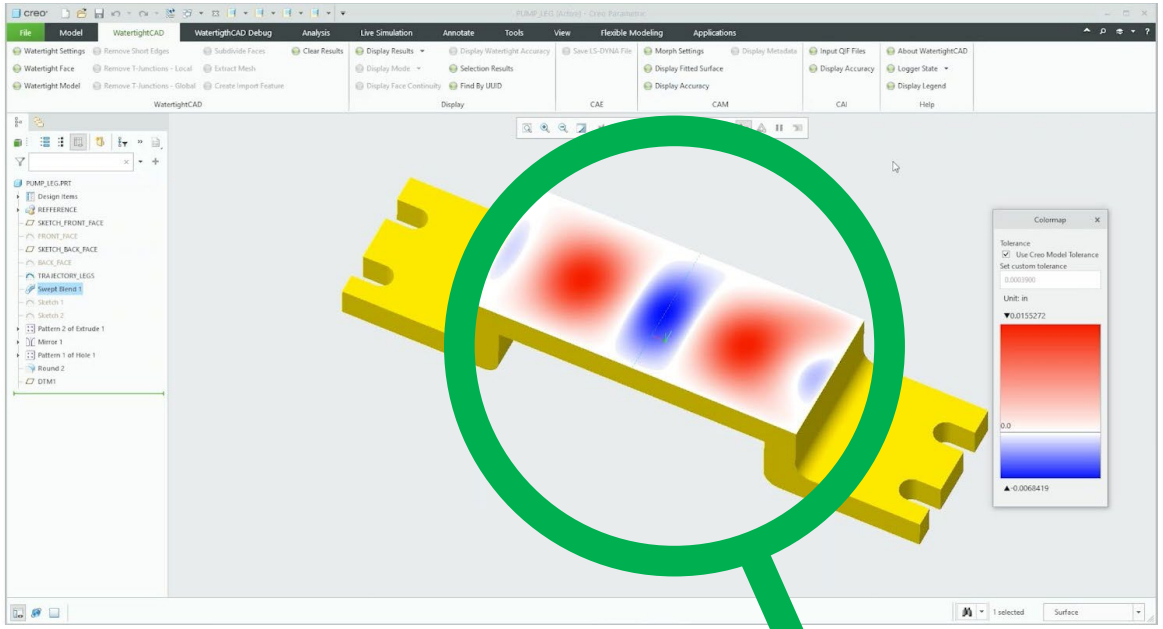
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TDP Modernization for As-Built Data: as-built model



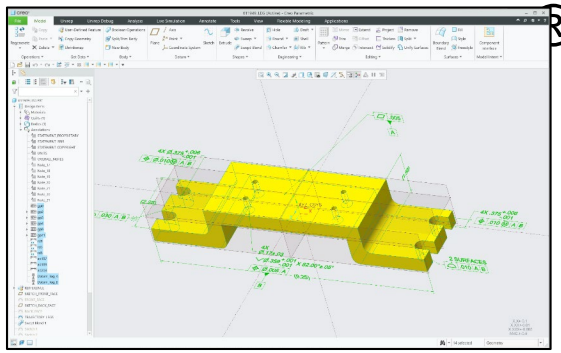


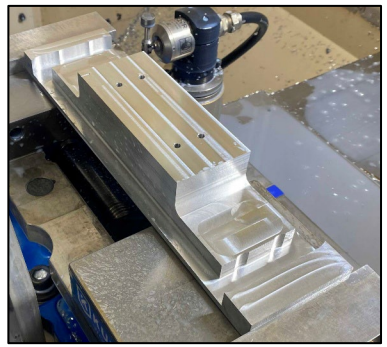
nVariate **Unirep** *for*

Unplanned Result:

as-executed

digital twin captured unintended artifacts in nominal parts *induced by tooling*.





Unplanned Result:

as-inspected

digital twin verified unintended artifacts **FAILED** GD&T requirements in nominal parts *induced by tooling*.

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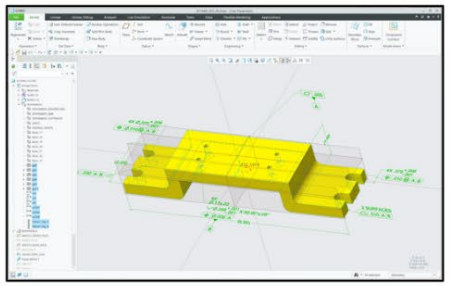
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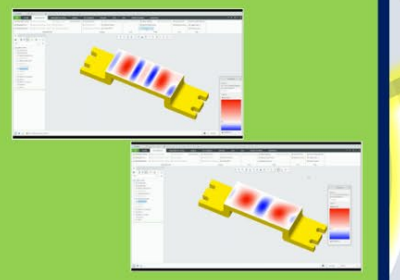


as-designed

CAD

creo®

STEP AP242



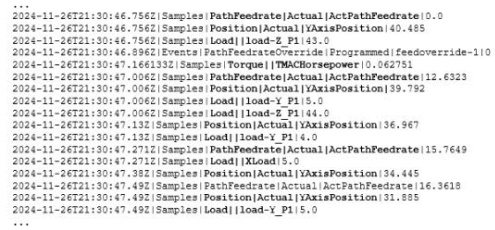
as-built

ASoT

CAM

MTConnect®

as-executed



CAI

QIF



as-inspected

nVariate **Unirep** *for Creo®*

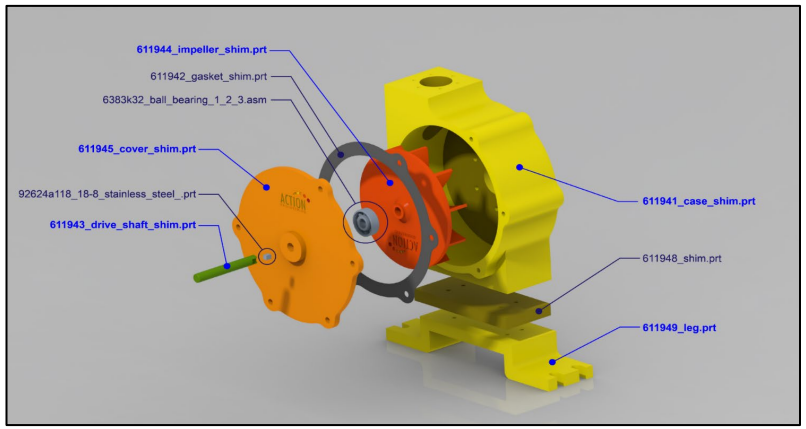
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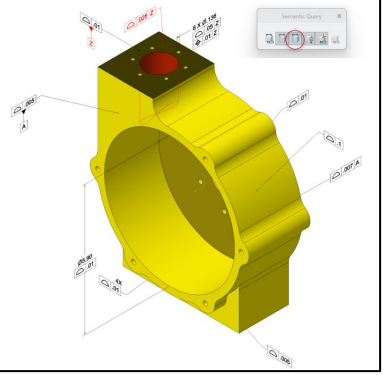
nVariate

Current development updates

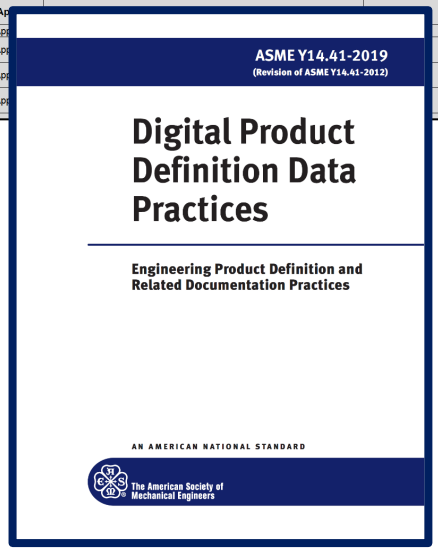


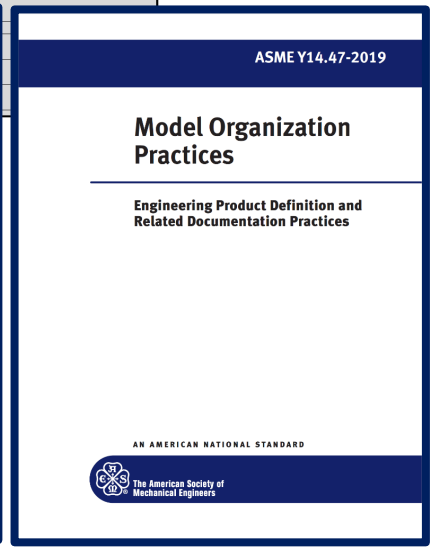
ASME Y14.41, Section 7.2.6.b.1

- Requirement: Query of an annotation causes all associated entities to be highlighted.
- Response: Upon semantic query of the profile annotation using Creo's "Display secondary reference" to the right, the associated surface specified as datum Z is highlighted in dark green



Shall #	Section	Requirement	Conformance Level	Comments / Explanation	Model Location (FID, annotation ID, image)
120	9.1.1.d	(d) A direct and permanent association to the originating model value shall be established and maintained for every resolved dimension.	Conforms Fully	config settings. PTC Support for Rounding Dimensions: https://support.ptc.com/help/creo/creo_pma/r11.0/usascii/index.html#page/detail/about_displaying_rounded_value_of_dim.html#	
121	9.1.1.e	(e) The use of model values or resolved dimensions for analyses and other processes shall be defined in appropriate documentation.	Notice to User		
122 - 124	9.2.1	Queried model values of feature(s) shall be interpreted as basic unless otherwise dimensionally specified in the data set. A model value shall be rounded to the number of decimal places required for the design. Queried model values of feature(s) that are controlled elsewhere shall be considered reference.	Notice to User		
		The following requirements apply to basic dimensions in an annotated model.			
125	9.2.2.a	(a) Querying of the model for the profile, location, and orientation of a feature shall occur within the appropriate coordinate system.	Notice to User		
126	9.2.2.b	(b) The display of basic dimensions may be necessary in defining some annotated model relationships. Displayed basic dimensions shall be enclosed in a box in accordance with ASME Y14.5.	Does Not Apply	Not on this model	
127	9.2.2.d	(d) Basic dimensions defining surface curvature or extent, such as fillets, rounds, or chamfers, shall be directed to the feature surface by a leader.	Does Not Apply	Not on this model	
128	9.2.2.e	(e) Basic dimensions defining linear distance or angular relation shall be shown using dimension and extension lines.	Does Not Apply		
129	9.2.2.f	(f) There are no 90 deg implied angles in a model. All angular values shall be queried from the model unless a dimension is displayed.	Notice to User		
130	9.2.3	**A displayed feature of size dimension shall always include a tolerance.**	Conforms Fully		
131 - 132	9.2.3.a	(a) A size dimension shall agree with the queried model value for the same feature when the model value is rounded to the same number of decimal places. This agreement shall meet one of the following requirements, depending on the tolerance expression used.	Conforms Fully		
133		(1) Bilateral or Unilateral Tolerance. The displayed size dimension shall equal the resolved model value.	Conforms Fully		ad1062, ad1064
134		(2) Limit Dimensions. The resolved model value shall equal one of the limit dimensions, or a value within the displayed range of limits.	Does Not Apply	No limit dimensions in the model	
135		(3) Dimensions With Plus/Plus or Minus/Minus Tolerances. The resolved model value shall not be within the displayed range of limits.	Does Not Apply	No plus/plus or minus/minus in the model	
		(b) Placement and Attachment. The placement and attachment methods for size dimensions are as follows:	Conforms Fully		
136	9.2.3.b.1	(1) Spherical Surface. The size dimension and leader shall be placed on an annotation plane containing the feature centerpoint.	Does Not Apply		
137	9.2.3.b.2	(2) Cylindrical Surface. The size dimension and leader shall be placed on an annotation plane perpendicular to the feature axis or containing the feature axis.	Conforms Fully		ad1062, ad1064
138 - 139	9.2.3.b.3	(3) Set of Two Opposed, Parallel Surfaces (a Width). The size dimension, dimension line, and extension lines shall be placed on an annotation plane perpendicular to or containing the feature centerplane. The extension lines shall clearly indicate the surfaces comprising the width.	Does Not Apply		
140	9.2.3.c	(c) Use of the Term TRUE. The term TRUE, when used with a dimension, shall not be used on annotated models	Conforms Fully		
141	9.3	Basic dimensions not displayed on a drawing graphic sheet shall be obtained by querying of the model.	Conforms Fully	Use note to describe this to the viewer	
		Requirements for dimensions on axonometric views of a drawing graphic sheet are defined in the following subparagraphs.	**Does Not Apply**		
142	9.3.1.a	(a) Displayed Dimensions. Dimensions shown in an axonometric view shall be true, and the use of the term TRUE is not required.	Does Not Apply		
143	9.3.1.b	(b) Displayed Basic Dimensions. Basic dimensions shall be enclosed in a box in accordance with ASME Y14.5.	Does Not Apply		
144 - 146	9.3.1.c	(c) Dimension Leader Lines. Leader lines shall be used to relate a dimension to a cylindrical feature. The leader line shall be directed to the intersection of the cylindrical feature and a surface. Leader lines shall terminate with an arrowhead.	Does Not Apply		
147	10.2.1	Oblique surface intersections, unequally disposed extents, or chamfers defined using a linear and angular dimension require the use of dimension and extension lines. The value shall be located and oriented in a manner that is clear.	Does Not Apply	No chamfers or slanted surfaces on the model	
		The following requirements apply to the relationship between the datum reference frames on the annotated model and the coordinate systems.	**Does Not Ap**		
148	11.2.1.a	(a) Each datum reference frame shall be associated to a corresponding coordinate system.	Does Not Ap		
149	11.2.1.b	(b) A definite visual association between any datum reference frame and the corresponding coordinate system shall be preserved throughout navigation and interrogation of the presented design data.	Does Not Ap		
150	11.2.1.c	(c) When more than one datum reference frame is imposed upon an annotated model, each distinguished datum reference frame-to-coordinate system relationship shall be clearly presented and maintained.	Does Not Ap		
151	11.2.1.d	(d) A coordinate system shall be used to indicate the orientation of a datum reference frame that has been defined from complex or irregular surfaces.	Does Not Ap		





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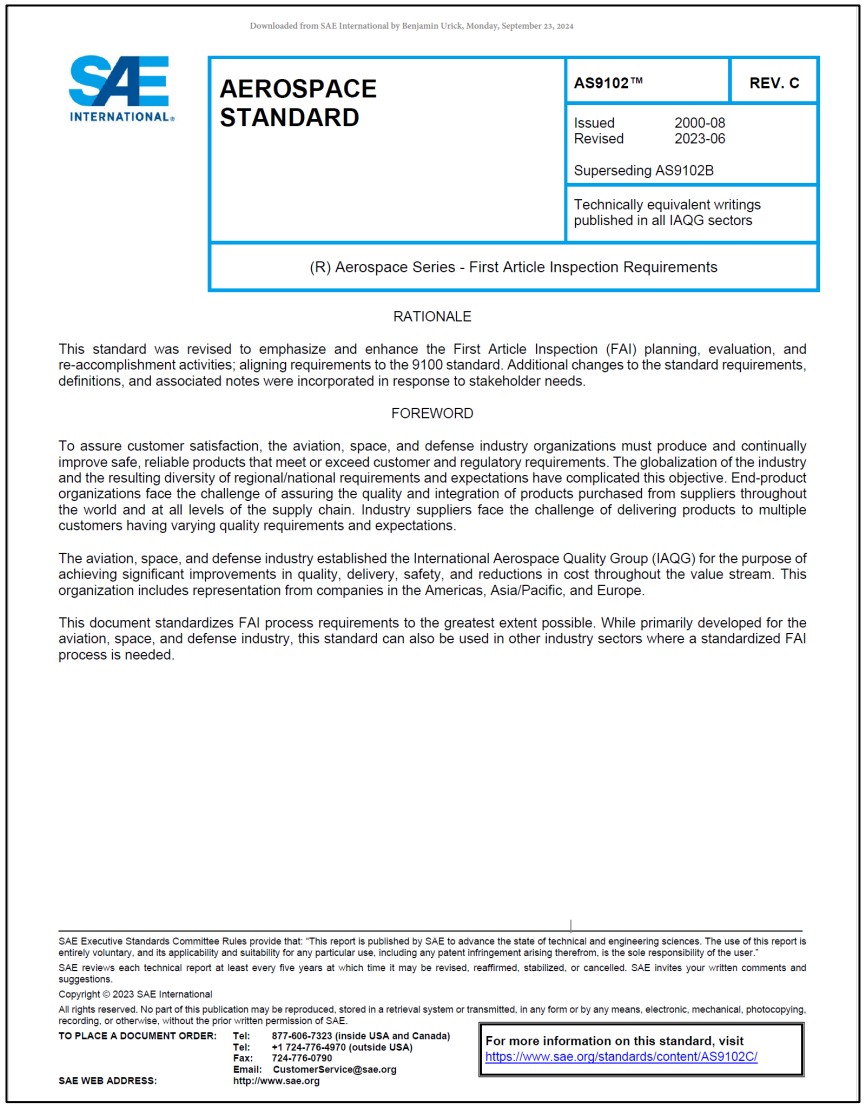
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TDP Modernization for As-Built Data: as-req model



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AEROSPACE STANDARD	AS9102™	REV. C
	Issued 2000-08 Revised 2023-06 Superseding AS9102B	
	Technically equivalent writings published in all IAQG sectors	
(R) Aerospace Series - First Article Inspection Requirements		

RATIONALE

This standard was revised to emphasize and enhance the First Article Inspection (FAI) planning, evaluation, and re-accomplishment activities; aligning requirements to the 9100 standard. Additional changes to the standard requirements, definitions, and associated notes were incorporated in response to stakeholder needs.

FOREWORD

To assure customer satisfaction, the aviation, space, and defense industry organizations must produce and continually improve safe, reliable products that meet or exceed customer and regulatory requirements. The globalization of the industry and the resulting diversity of regional/national requirements and expectations have complicated this objective. End-product organizations face the challenge of assuring the quality and integration of products purchased from suppliers throughout the world and at all levels of the supply chain. Industry suppliers face the challenge of delivering products to multiple customers having varying quality requirements and expectations.

The aviation, space, and defense industry established the International Aerospace Quality Group (IAQG) for the purpose of achieving significant improvements in quality, delivery, safety, and reductions in cost throughout the value stream. This organization includes representation from companies in the Americas, Asia/Pacific, and Europe.

This document standardizes FAI process requirements to the greatest extent possible. While primarily developed for the aviation, space, and defense industry, this standard can also be used in other industry sectors where a standardized FAI process is needed.

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AEROSPACE STANDARD	AS9102™	REV. C
	Issued 2000-08 Revised 2023-06 Superseding AS9102B	
	Technically equivalent writings published in all IAQG sectors	
(R) Aerospace Series - First Article Inspection Requirements		

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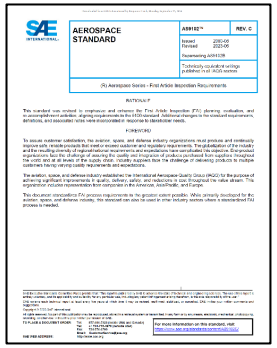
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TDP Modernization for As-Built Data: as-req model



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This standard applies to assemblies, sub-assemblies, and detail parts including castings, forgings, and modifications to standard catalogue or Commercial-Off-the-Shelf (COTS) items. Each of these items shall have a separate FAI.

Unless contractually required, this standard does not apply to:

- Development and prototype parts that are not considered as part of the first production run.
- Procured standard catalogue item, COTS, or deliverable software. When these items are included in an assembly, they shall be documented in the index of part numbers in an assembly FAIR.

1.4 Informative

If there is a conflict between the requirements of this standard, and customer or applicable statutory/regulatory requirements, the latter shall take precedence.

In this standard, the following verbal forms are used:

- "Shall" indicates a requirement.
- "Should" indicates a recommendation.
- "May" indicates a permission.
- "Can" indicates a possibility or a capability.

Information marked as "NOTE" is for guidance in understanding or clarifying the associated requirement.

2. APPLICABLE DOCUMENTS

The following referenced documents support the application/use of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. When a conflict in requirements between this standard and the referenced documents below exist, the requirements of this document shall take precedence.

9100 Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations

9103 Aerospace Series - Quality Management Systems - Variation Management of Key Characteristics

As developed under the auspices of the IAQG and published by various standards bodies [e.g., ASD-STAN, SAE International, European Committee for Standardization (CEN), Japanese Standards Association (JSA)/Society of Japanese Aerospace Companies (SJAC), Brazilian Association for Technical Norms (ABNT)].

ASME Y14.41 Digital Product Definition Data Practices

ISO 9000 Quality management systems - Fundamentals and vocabulary

ISO 16792 Digital Product Definition Data Practices

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4.3 Digital Product Definition Requirements

a. When design requirements are in a DPD format and traditional 2D drawing inform[illegible]vailable [illegible]ble design requirements, DPD design characteristics required for product realiza[illegible]n shall b[illegible]extracte[illegible] verified [illegible]nd included in the FAIR.

b. The organiza[illegible]n shall:

1. Establish a process to extract the applicable DPD design characteristics.
2. Extract the DPD design characteristics required for product realization.
3. Ensure the production, inspection, and operations requiring verification have been completed as planned to achieve DPD design characteristics.

NOTE: For additional information on DPD, refer to ASME Y14.41 and/or ISO 16792.

4.4 Evaluation Activities

The organiza[illegible]n shall c[illegible]duct the following activities during product realization in support of FAI to ensure conformance with design [illegible].

a. Review the manufacturing process documentation (e.g., routing sheets, risk analysis, manufacturing or quality plans, manufacturing work instructions) to ensure all operations are complete as planned and call out the correct specification, material types, conditions, and approvals.

b. Review supporting documentation for completeness.

Verify [illegible]e raw material and special process certifications (e.g., CofC, special process completion certification, raw [illegible]est report number, modified standard catalogue item compliance report number, traceability number) call out the correct specification, material types, conditions, and approvals.

Verify [illegible]t required customer approved sources are utilized (e.g., directed source, approved suppliers list).

e. Review nonconformance documentation for completeness.

Verify [illegible]t required designed tooling (e.g., part specific gauges) is used.

Verify [illegible]t every design characteristic requirement, including DPD characteristics as required per 4.3.b, is accounted for, [illegible]uely identified, and has inspection results traceable to each unique identifier (e.g., ballooned design [illegible]eristic).

Verify [illegible] design characteristics resulting from the output of the manufacturing process are measured, inspected, tested, [illegible]d to determine conformance, including DPD characteristics as required per 4.3.b.

Verify [illegible]rt marking has met defined requirements, such as legibility (i.e., human/machine readable), method, material, [illegible]size, and location.

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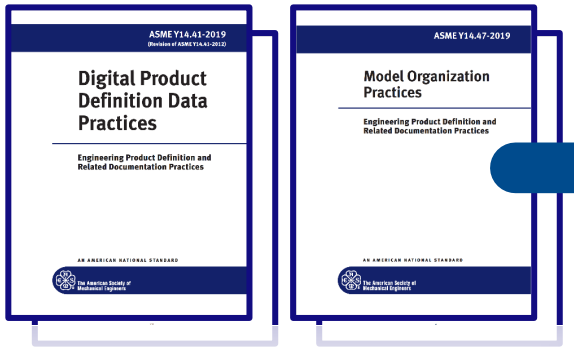
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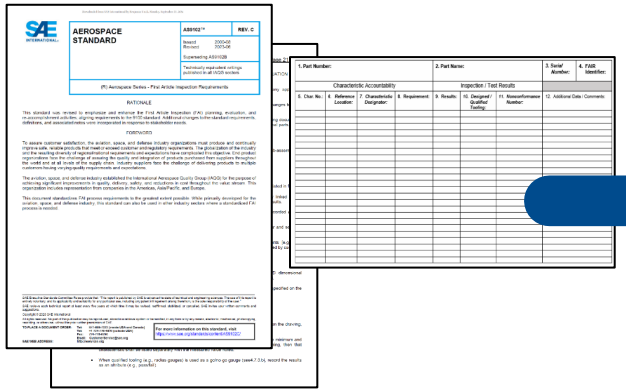
TDP Modernization for As-Built Data: as-req model

ASME
Y14-41
Y14-47

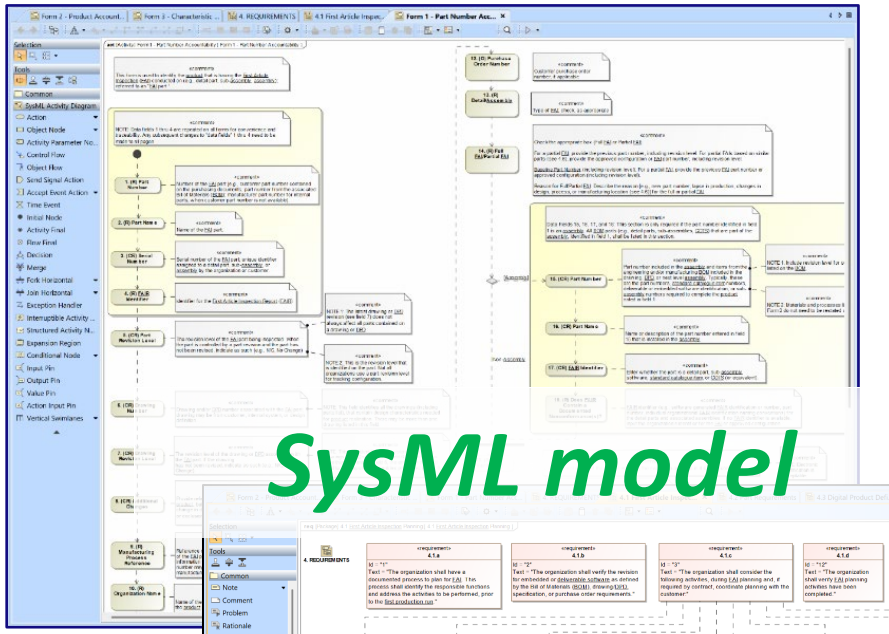


static documents

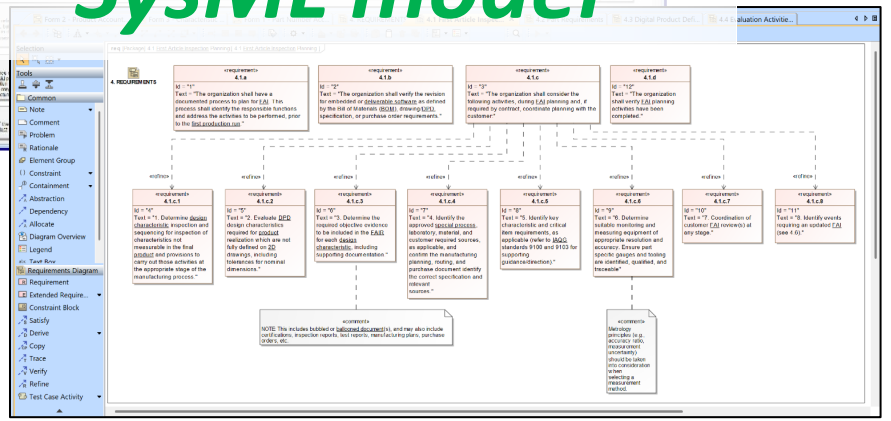
SAE
AS9102C



SysML™



SysML model



Unirep *for MagicDraw®*

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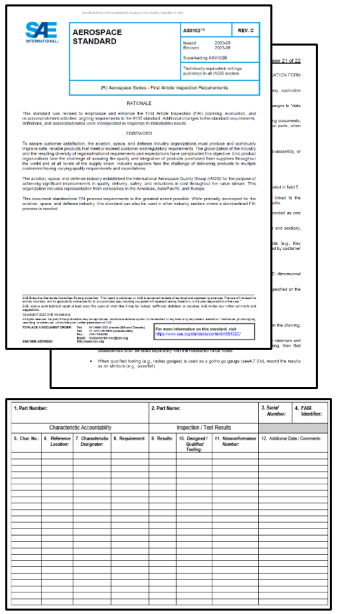
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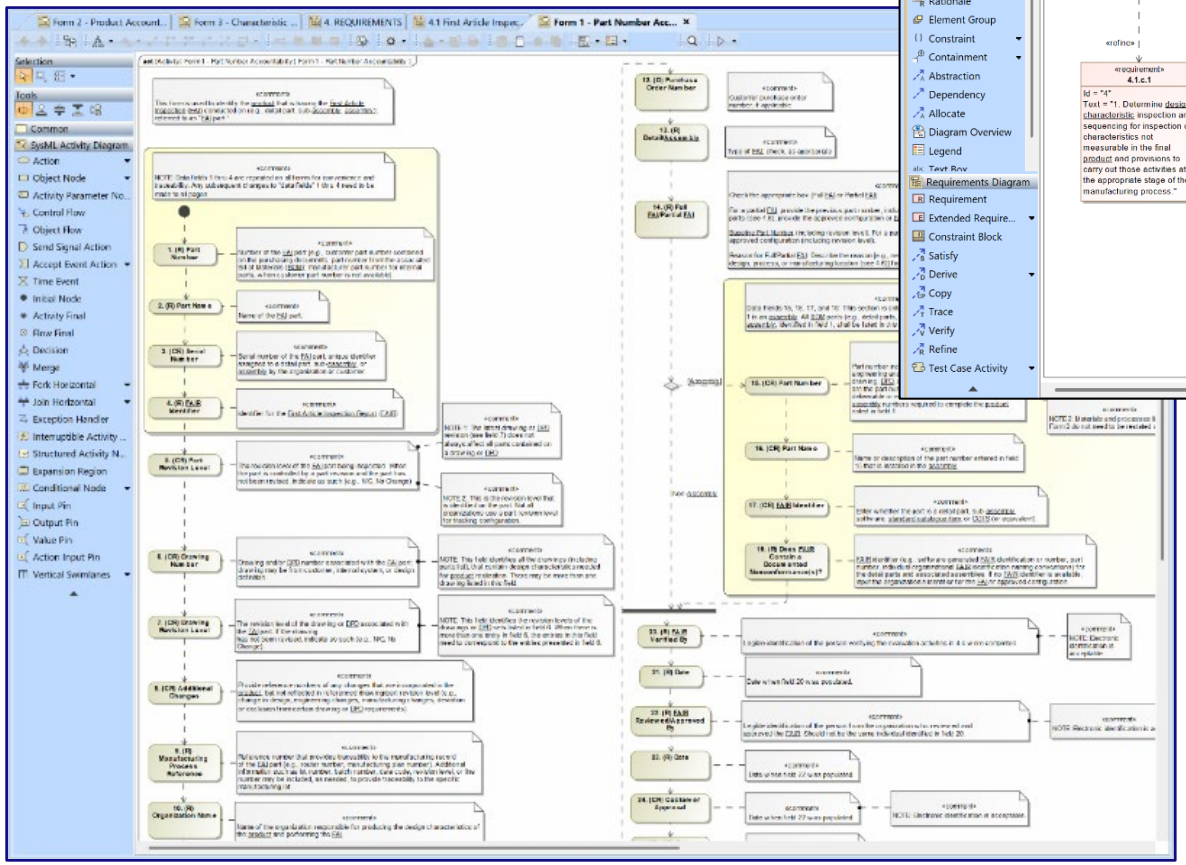
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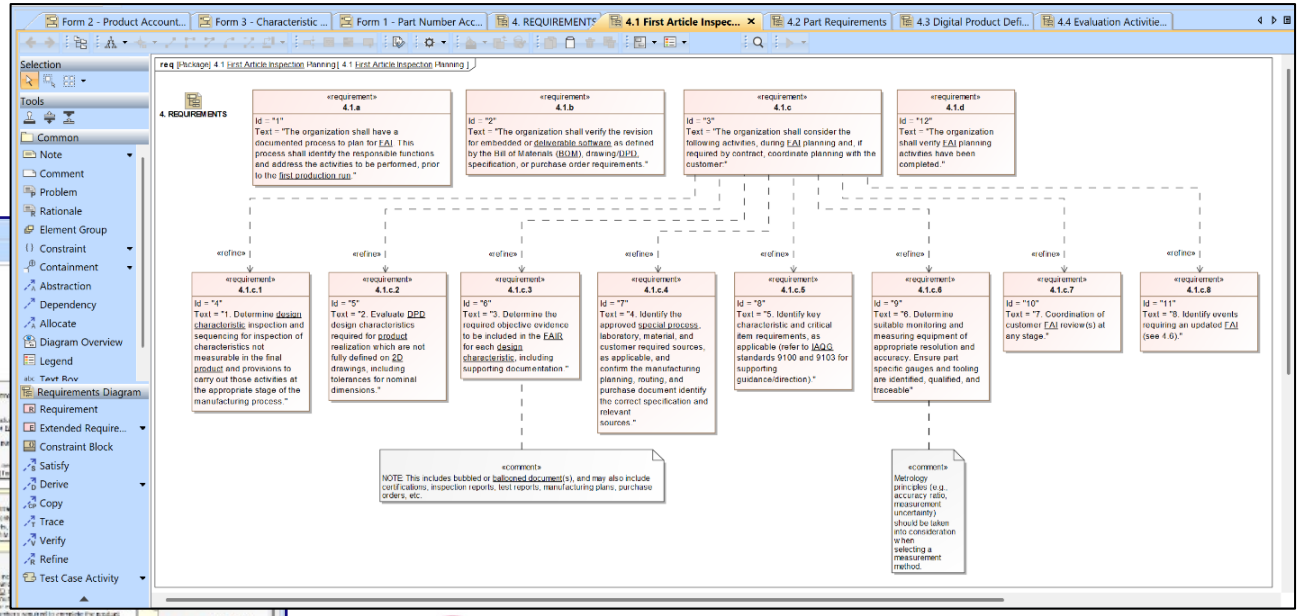
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SAE

AS9102C







SysML

TM



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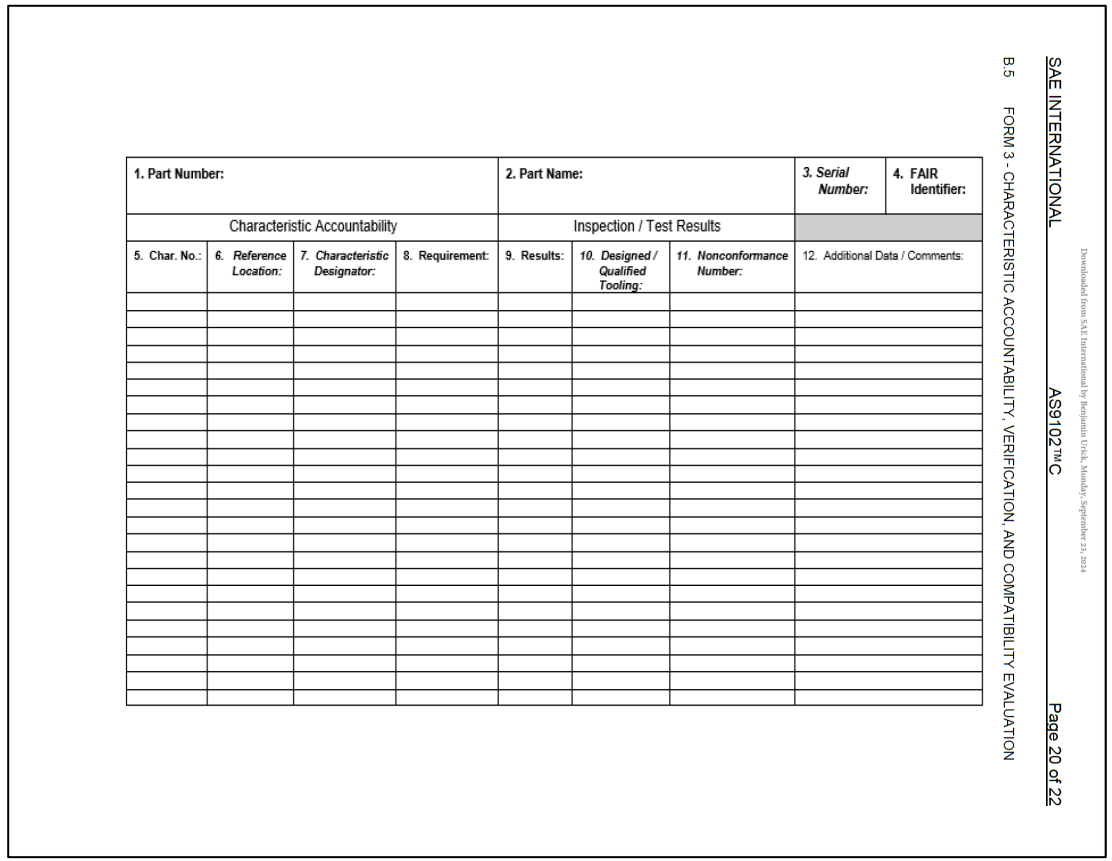
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TDP Modernization for As-Built Data: as-req model



1. Part Number:				2. Part Name:			3. Serial Number:	4. FAIR Identifier:
Characteristic Accountability				Inspection / Test Results				
5. Char. No.:	6. Reference Location:	7. Characteristic Designator:	8. Requirement:	9. Results:	10. Designed / Qualified Tooling:	11. Nonconformance Number:	12. Additional Data / Comments:	

B.5 FORM 3 - CHARACTERISTIC ACCOUNTABILITY, VERIFICATION, AND COMPATIBILITY EVALUATION

SAE INTERNATIONAL AS9102™C Page 20 of 22

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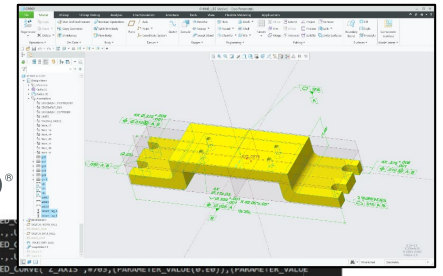
First Article Inspection Requirements

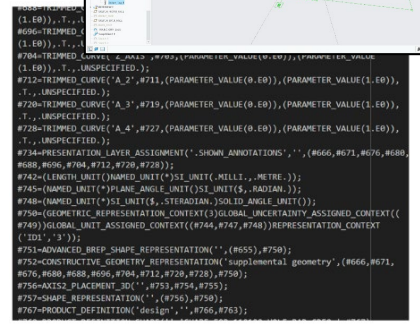
Cameo SysML
[req] model
(MBSE)

QIF
XML model
(MBD)

Creo / STEP
model
(MBD)







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STEP AP242

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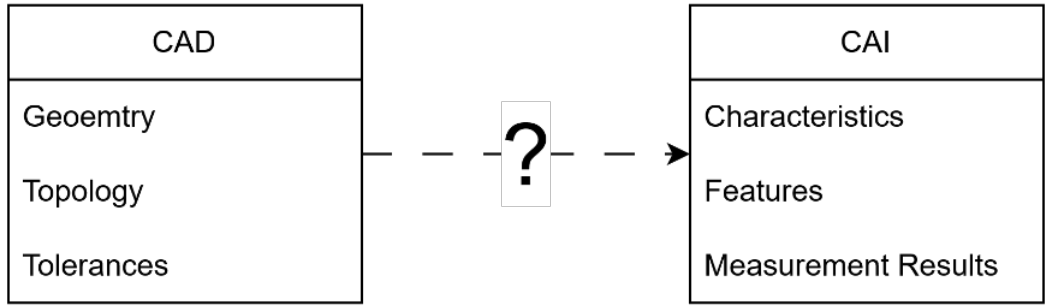
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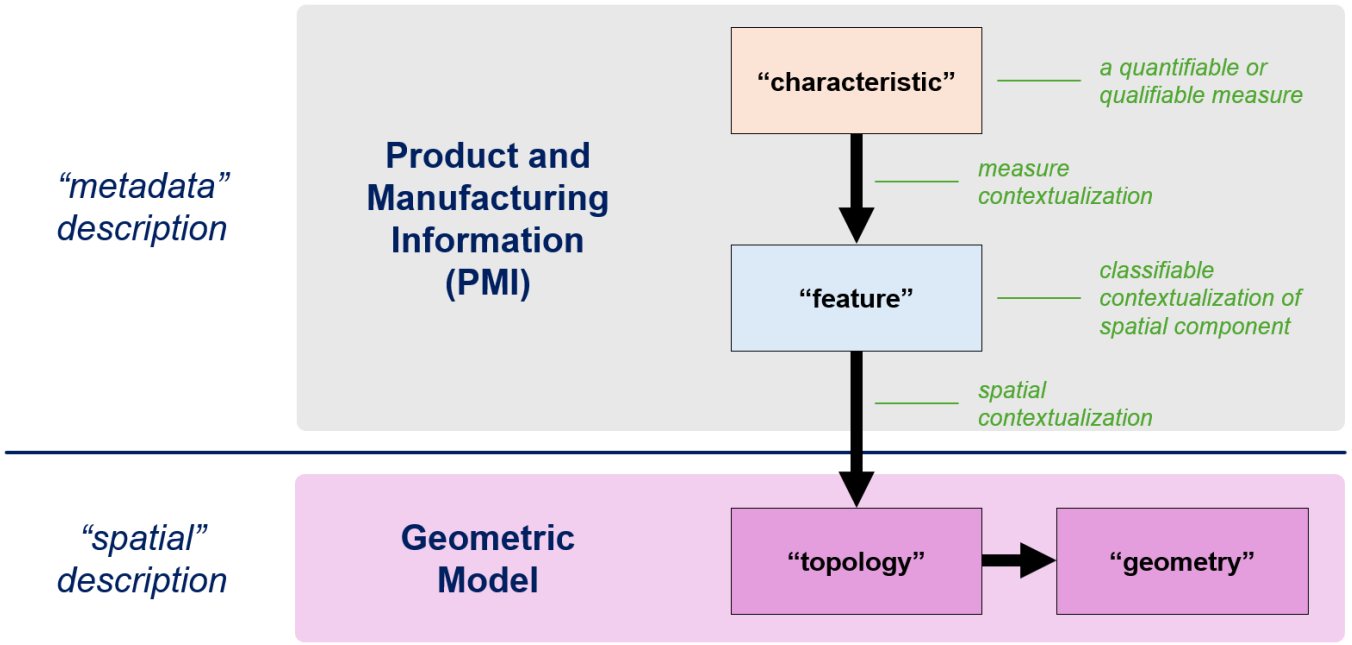
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TDP Modernization for As-Built Data: as-req model



Generalized CAx model Architecture



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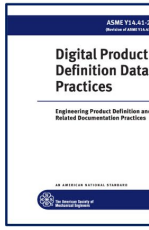
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Design (CAD) ***Requirements***

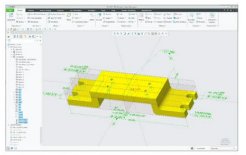






Cameo SysML [req] model (MBSE)

Creo native / STEP P21 model (MBD)

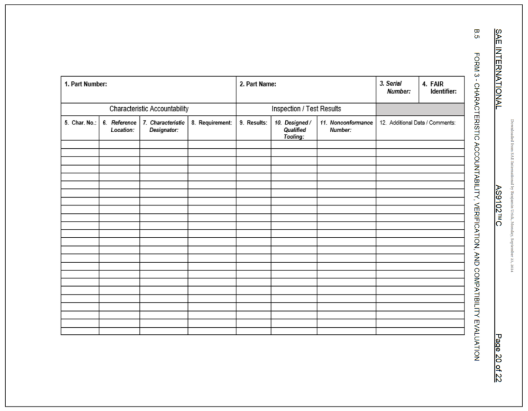




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Design (CAD) ***MBD Data***

Quality / Inspection (CAI) ***Requirements***



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First Article Inspection Requirements

Cameo SysML [req] model (MBSE)

QIF XML model (MBD)



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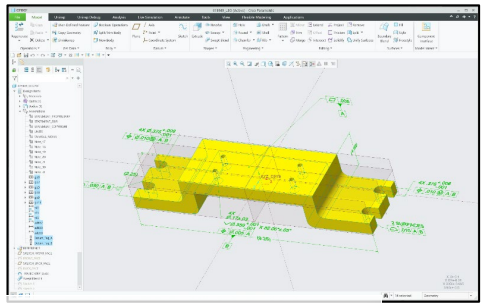
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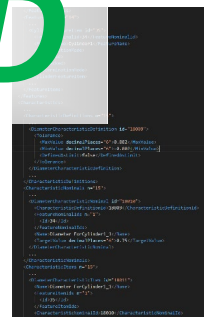
TDP Modernization for As-Built Data: as-req model



creo®

STEP AP242

MBD



QIF

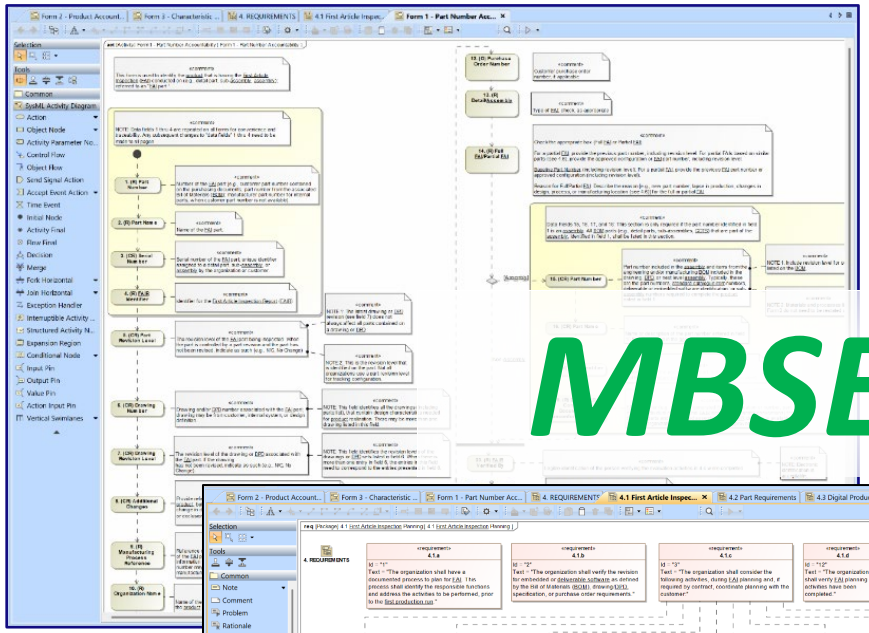
MTConnect®

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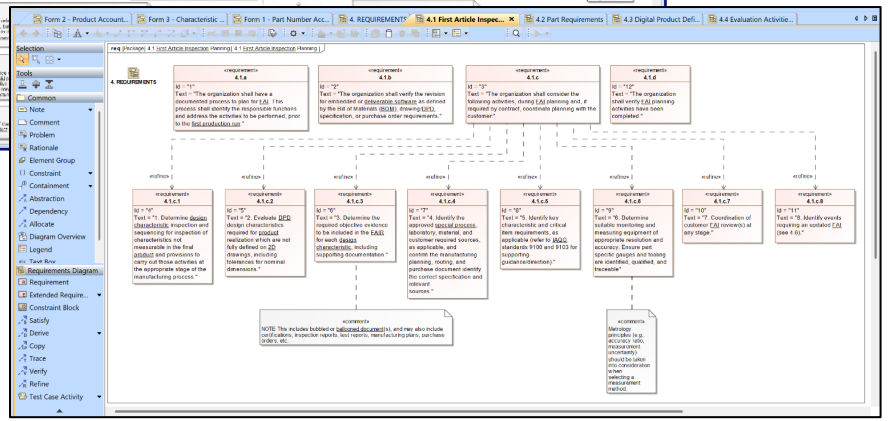
SysML™

as-required

V&V, VVUQ



MBSE



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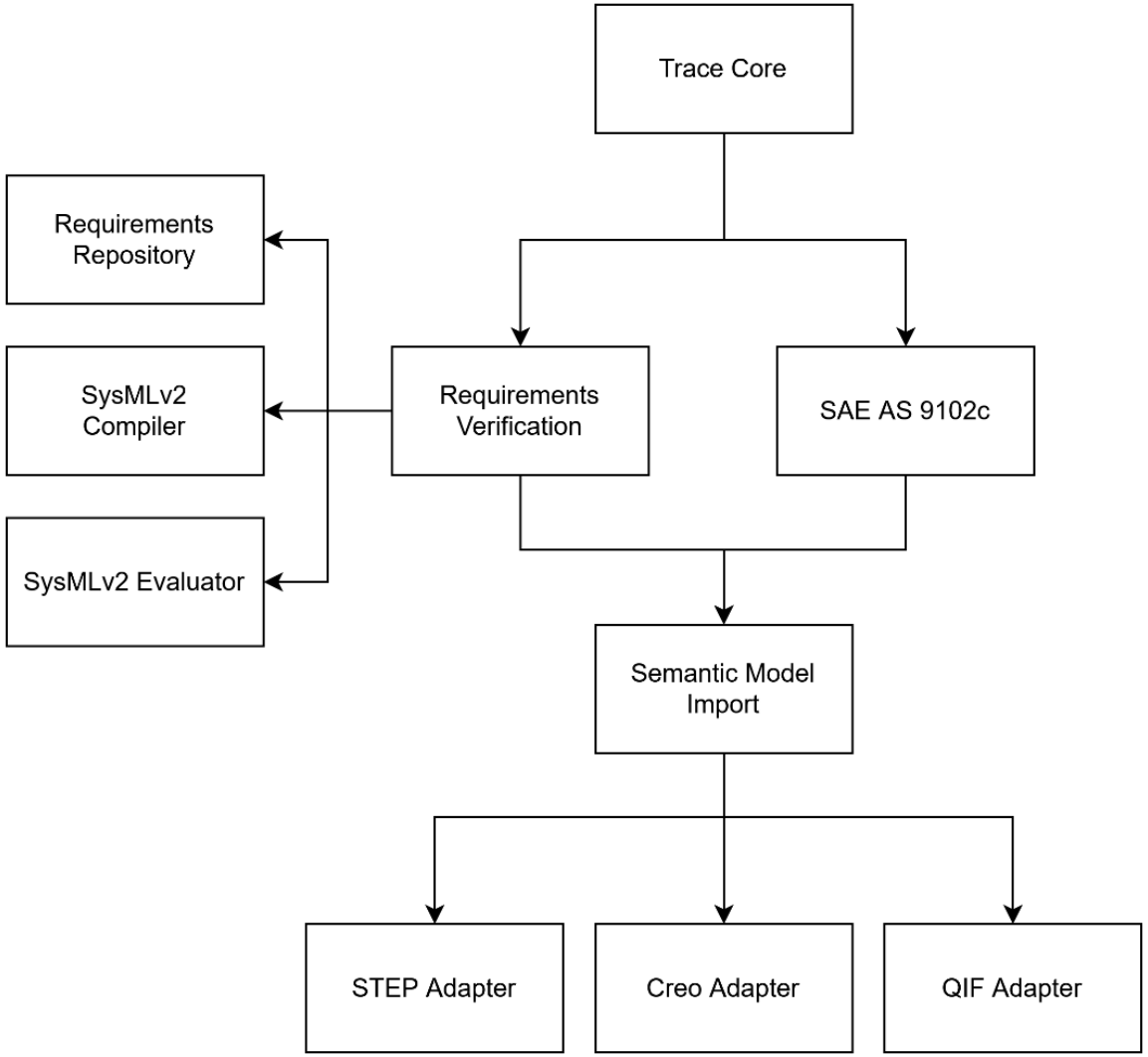
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TDP Modernization for As-Built Data: as-req model



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TDP Modernization for As-Built Data: as-req model

```
package ASME_Y14_41 {

    part def ASME_Y14_41_2019_Part { ···
    }

    requirement def DataSetIdentifierSafeCharacters {
        @RequirementSource {
            reference = "Y14.41-2019";
            section = "4.1.b";
            statement_number = "4";
        }
        subject CADModel : ASME_Y14_41_2019_Part;
        assume constraint { has(CADModel.dataset_identifier) }

        require constraint { contains(CADModel.dataset_identifier, "-") == false }
        require constraint { contains(CADModel.dataset_identifier, "/") == false }
        require constraint { contains(CADModel.dataset_identifier, "*") == false }
    }
```




```
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            "message": "OK",
            "passed": true
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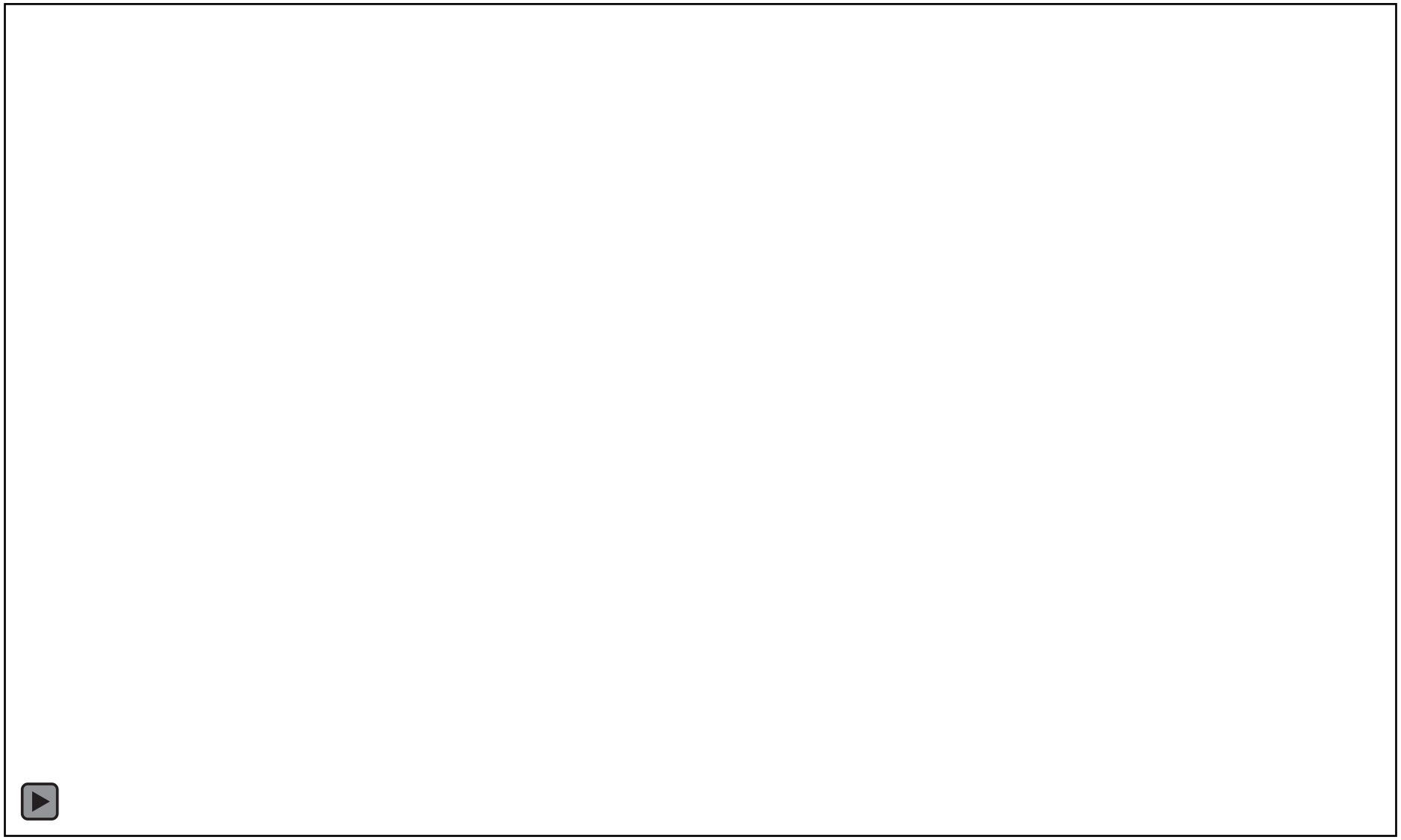
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TDP Modernization for As-Built Data: as-req model



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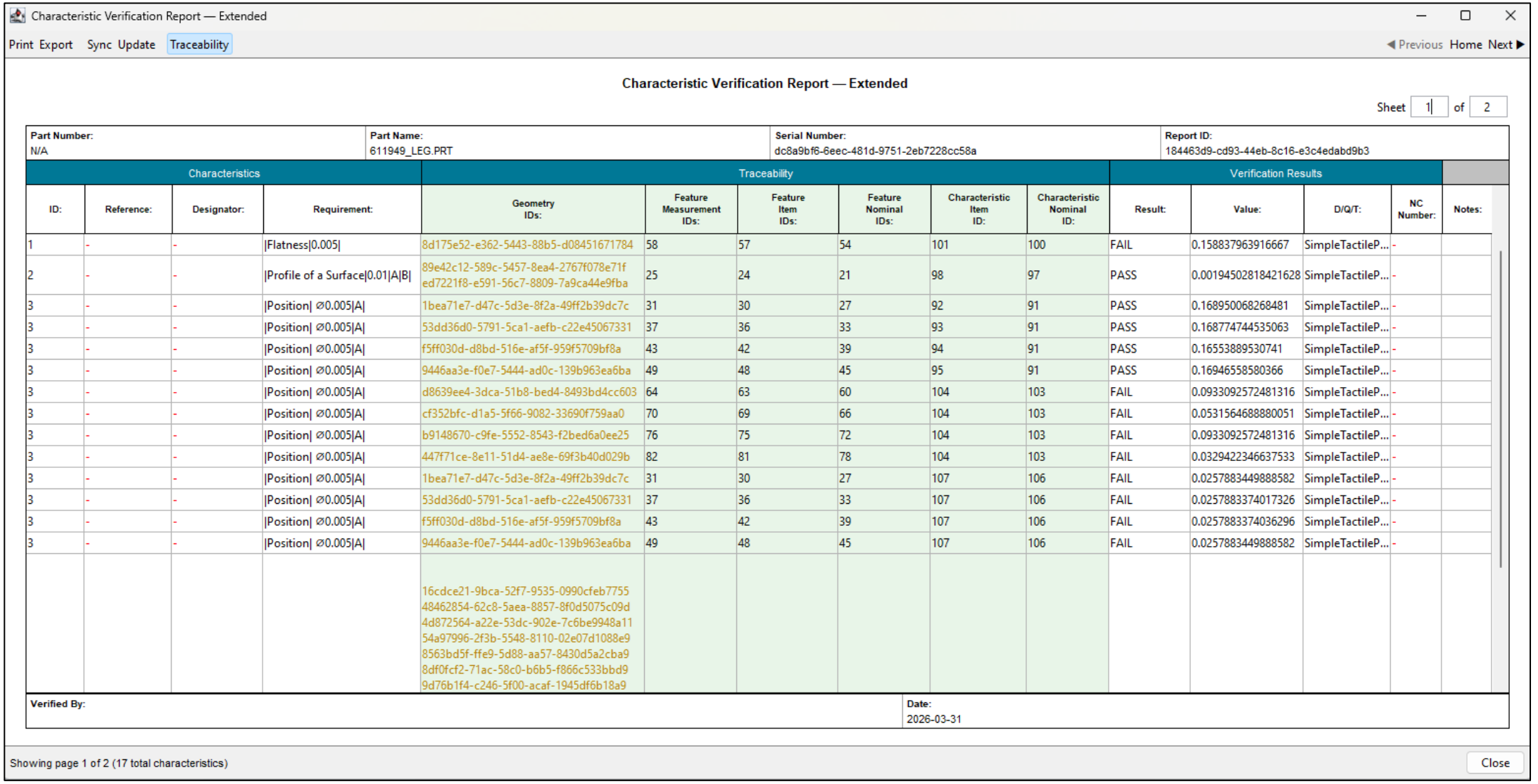
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Characteristic Verification Report — Extended

Print Export Sync Update Traceability ◀ Previous Home Next ▶

Characteristic Verification Report — Extended

Sheet 1 of 2

Part Number:	Part Name:	Serial Number:	Report ID:
N/A	611949_LEG.PRT	dc8a9bf6-6eec-481d-9751-2eb7228cc58a	184463d9-cd93-44eb-8c16-e3c4edabd9b3

Characteristics				Traceability						Verification Results				
ID:	Reference:	Designator:	Requirement:	Geometry IDs:	Feature Measurement IDs:	Feature Item IDs:	Feature Nominal IDs:	Characteristic Item ID:	Characteristic Nominal ID:	Result:	Value:	D/Q/T:	NC Number:	Notes:
1	-	-	|Flatness|0.005|	8d175e52-e362-5443-88b5-d08451671784	58	57	54	101	100	FAIL	0.158837963916667	SimpleTactileP...	-	
2	-	-	|Profile of a Surface|0.01|A|B|	89e42c12-589c-5457-8ea4-2767f078e71f ed7221f8-e591-56c7-8809-7a9ca44e9fba	25	24	21	98	97	PASS	0.00194502818421628	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	1bea71e7-d47c-5d3e-8f2a-49ff2b39dc7c	31	30	27	92	91	PASS	0.168950068268481	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	53dd36d0-5791-5ca1-aefb-c22e45067331	37	36	33	93	91	PASS	0.168774744535063	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	f5ff030d-d8bd-516e-af5f-959f5709bf8a	43	42	39	94	91	PASS	0.16553889530741	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	9446aa3e-f0e7-5444-ad0c-139b963ea6ba	49	48	45	95	91	PASS	0.16946558580366	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	d8639ee4-3dca-51b8-bed4-8493bd4cc603	64	63	60	104	103	FAIL	0.0933092572481316	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	cf352bfc-d1a5-5f66-9082-33690f759aa0	70	69	66	104	103	FAIL	0.0531564688880051	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	b9148670-c9fe-5552-8543-f2bed6a0ee25	76	75	72	104	103	FAIL	0.0933092572481316	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	447f71ce-8e11-51d4-ae8e-69f3b40d029b	82	81	78	104	103	FAIL	0.0329422346637533	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	1bea71e7-d47c-5d3e-8f2a-49ff2b39dc7c	31	30	27	107	106	FAIL	0.0257883449888582	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	53dd36d0-5791-5ca1-aefb-c22e45067331	37	36	33	107	106	FAIL	0.0257883374017326	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	f5ff030d-d8bd-516e-af5f-959f5709bf8a	43	42	39	107	106	FAIL	0.0257883374036296	SimpleTactileP...	-	
3	-	-	|Position| ⌀0.005|A|	9446aa3e-f0e7-5444-ad0c-139b963ea6ba	49	48	45	107	106	FAIL	0.0257883449888582	SimpleTactileP...	-	
				16cdce21-9bca-52f7-9535-0990cfeb7755 48462854-62c8-5aea-8857-8f0d5075c09d 4d872564-a22e-53dc-902e-7c6be9948a11 54a97996-2f3b-5548-8110-02e07d1088e9 8563bd5f-ffe9-5d88-aa57-8430d5a2cba9 8df0fcf2-71ac-58c0-b6b5-f866c533bbd9 9d76b1f4-c246-5f00-acaf-1945df6b18a9									

Verified By:	Date:
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TDP Modernization for As-Built Data: as-req model

Part Name:	Serial Number:
611949_leg	SN-001

cs	Traceability						
Requirement:	Geometry IDs:	Feature Measurement IDs:	Feature Item IDs:	Feature Nominal IDs:	Characteristic Item ID:	Characteristic Nominal ID:	Result:
|Profile of a Surface|0.030|A...	16cdce21-9bca-52f7-9535-0990cfeb7755 48462854-62c8-5aea-8857-8f0d5075c09d 4d872564-a22e-53dc-902e-7c6be9948a11 54a97996-2f3b-5548-8110-02e07d1088e9 8563bd5f-ffe9-5d88-aa57-8430d5a2cba9 8df0fcf2-71ac-58c0-b6b5-f866c533bbd9 9d76b1f4-c246-5f00-acaf-1945df6b18a9 bb211501-59e3-583a-9d33-37562c9829de c0b3365d-1769-55f9-a77f-a1b86c609fbd c98c53a0-8fee-5ff1-a286-e3f4416611de d88d7dfc-fbb4-5881-bc2d-7b7cb360e6d4 e04abb2b-d0b3-5a25-9a6a-3868fa59e8bd ed157ec3-be18-5075-972f-2da8d0637285 fb02dc6e-37c4-5d8b-8b87-7e57dc6945c3	89	88	87	110	109	PASS

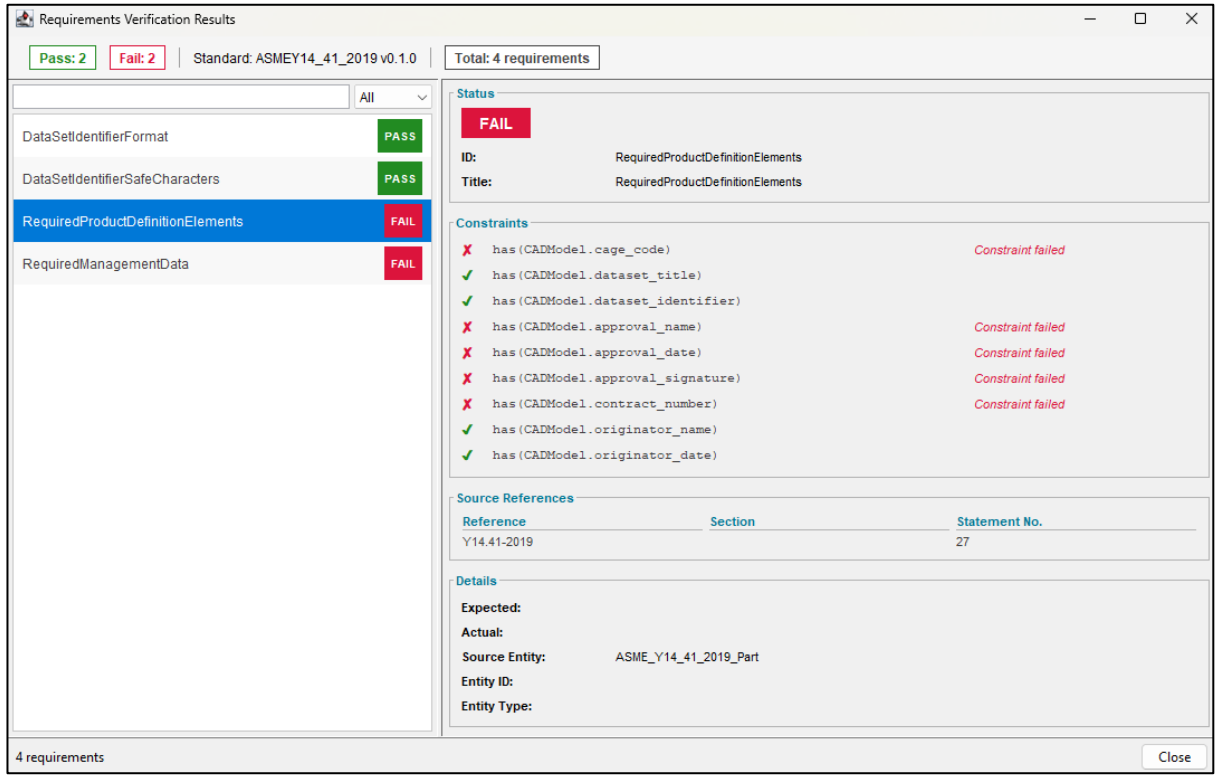
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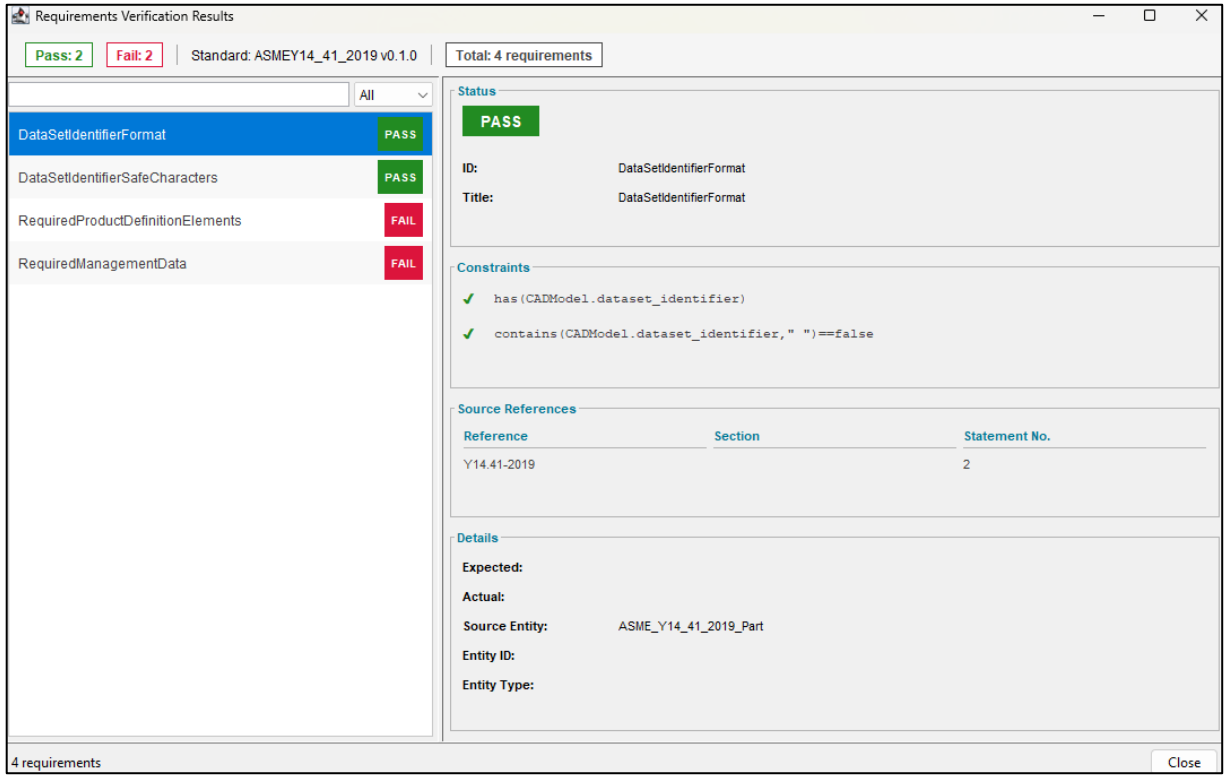
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TDP Modernization for As-Built Data: realization

AF233-D016 TITLE: Technical Data Package (TDP) Modernization for As-Built Data

OBJECTIVE: The topic seeks to develop a software platform that facilitates the delivery of Technical Data Packages (TDPs) with the necessary Product Manufacturing Information (PMI), including inspection and machine controller data, using neutral data exchange standards to provide a complete as-built assembly model. The envisioned platform will provide traceability throughout the manufacturing process (from design through final inspection), while maintaining a linked single fit-for-purpose Authoritative Source of Truth (ASoT) geometric model. The underlying models are expected to be agnostic of commercial computer-aided engineering platforms; i.e., the models should leverage open data formats.

- develop a software platform
- TDPs with PMI
- as-inspected and as-manufactured data
- neutral standards
- traceability
- ASoT geometric model

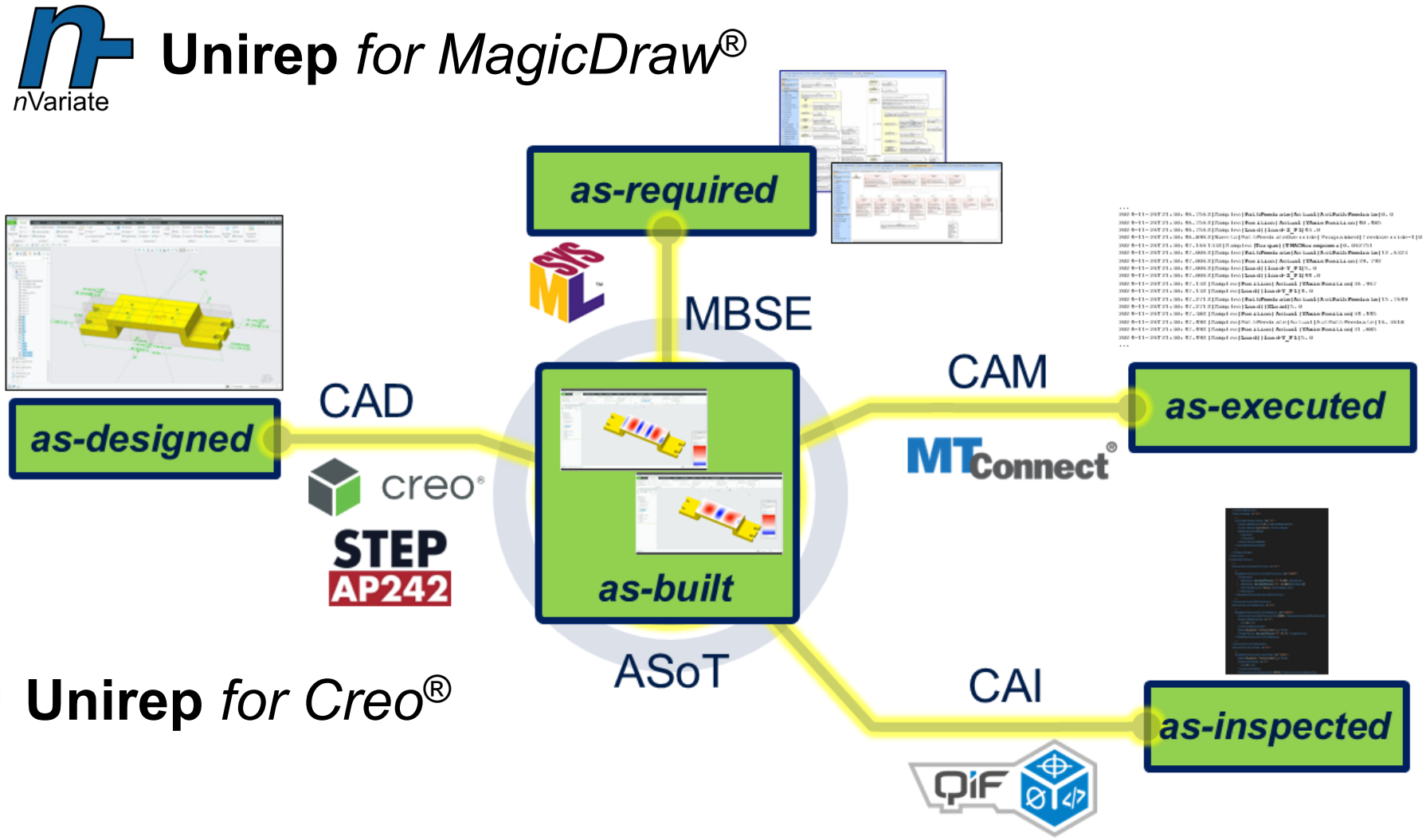
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TDP Modernization for As-Built Data: realization



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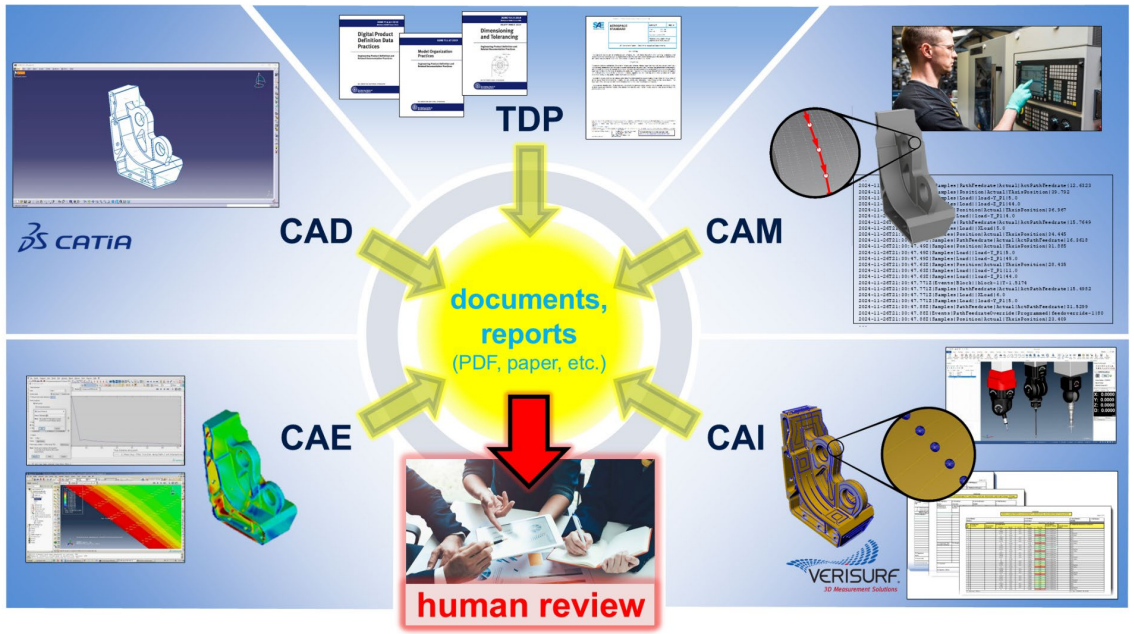
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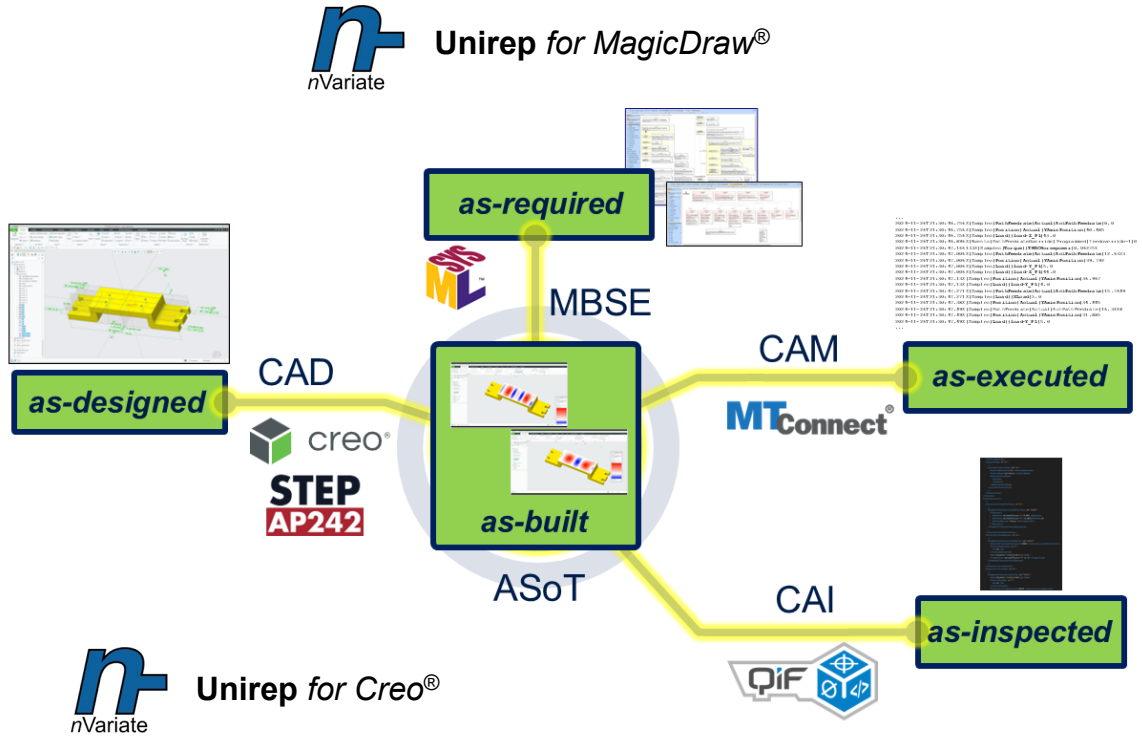
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TDP Modernization for As-Built Data: realization





conventional → ***modernized***

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TDP Modernization for As-Built Data: open issues

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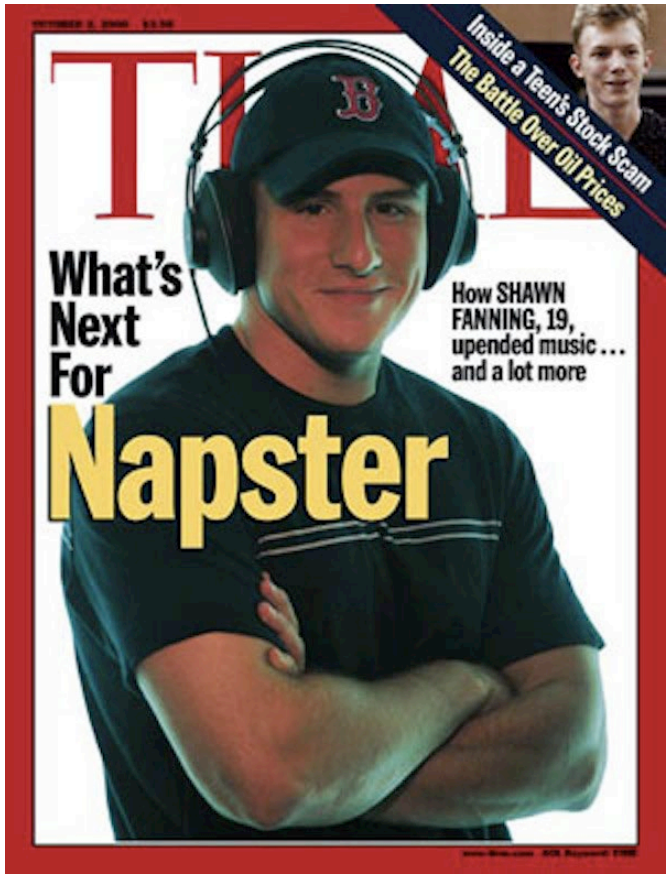
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TDP Modernization for As-Built Data: open issues

- **Standards Development Organizations (SDOs)**: *model-based hesitancy.*
  - solution: SDO model-based standards monetarization or SDO extinction?



napster™

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TDP Modernization for As-Built Data: open issues

- **Standards Development Organizations (SDOs)**: *model-based hesitancy.*
  - solution: SDO model-based standards monetarization or SDO extinction?
- **Standards modeling from documents**: *translation or transformation?*
  - solution: CAx-IF for requirements alignment to MBD standards (MBSE-IF?).

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TDP Modernization for As-Built Data: open issues

- **Standards Development Organizations (SDOs)**: *model-based hesitancy.*
  - solution: SDO model-based standards monetarization or SDO extinction?
- **Standards modeling from documents**: *translation or transformation?*
  - solution: CAx-IF for requirements alignment to MBD standards (MBSE-IF?).
- **CAM as-instructed data**: *remains a frustrating void in the CAx standards atlas.*
  - solution: CAM vendors follow the CAI path (i.e., QIF) and do something as a group.

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TDP Modernization for As-Built Data: open issues

- **Standards Development Organizations (SDOs)**: *model-based hesitancy.*
  - solution: SDO model-based standards monetarization or SDO extinction?
- **Standards modeling from documents**: *translation or transformation?*
  - solution: CAx-IF for requirements alignment to MBD standards (MBSE-IF?).
- **CAM as-instructed data**: *remains a frustrating void in the CAx standards atlas.*
  - solution: CAM vendors follow the CAI path (i.e., QIF) and do something as a group.
- **CAx model registration**: *extremely burdensome; extremely, preventable.*
  - solution: CAx-IF requirement of 4 x 4 transformation matrix $T(\mathbf{x}) = A\mathbf{x}$.

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- **MTConnect data capture**: *high rate of machine data collection? don't even ask…*
  - solution: allocate portion of AI budget to as-executed data collection.

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Questions? Comments?

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