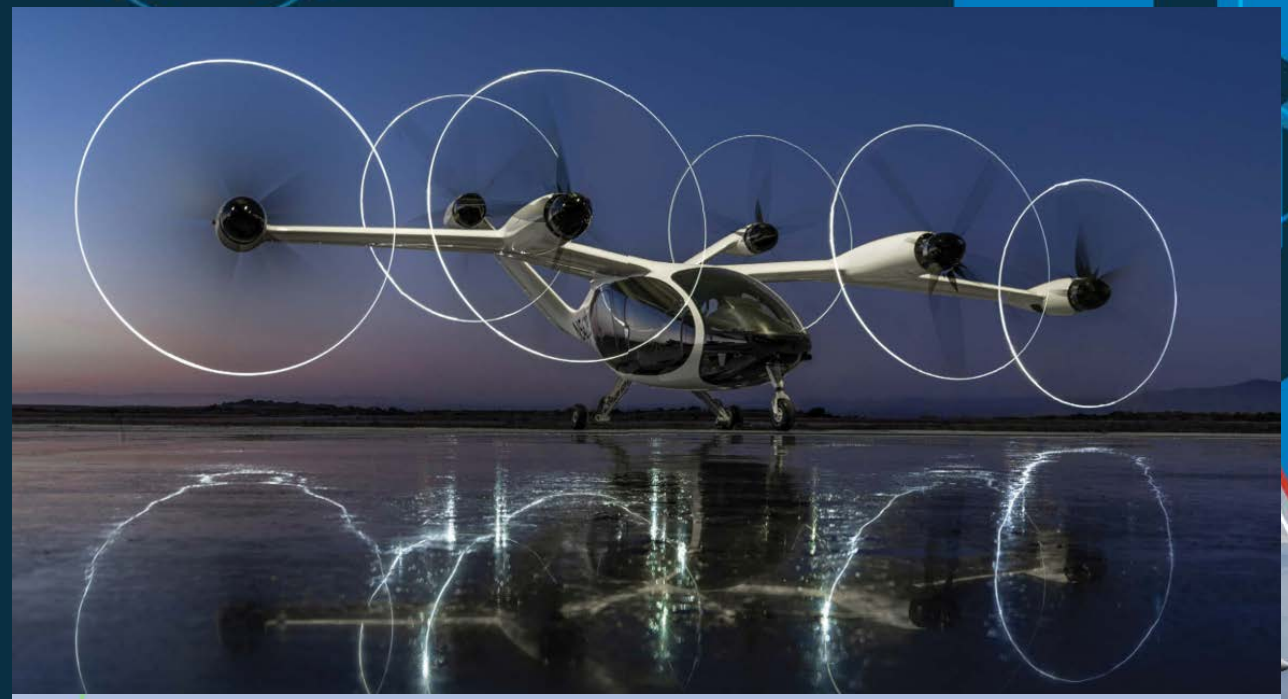
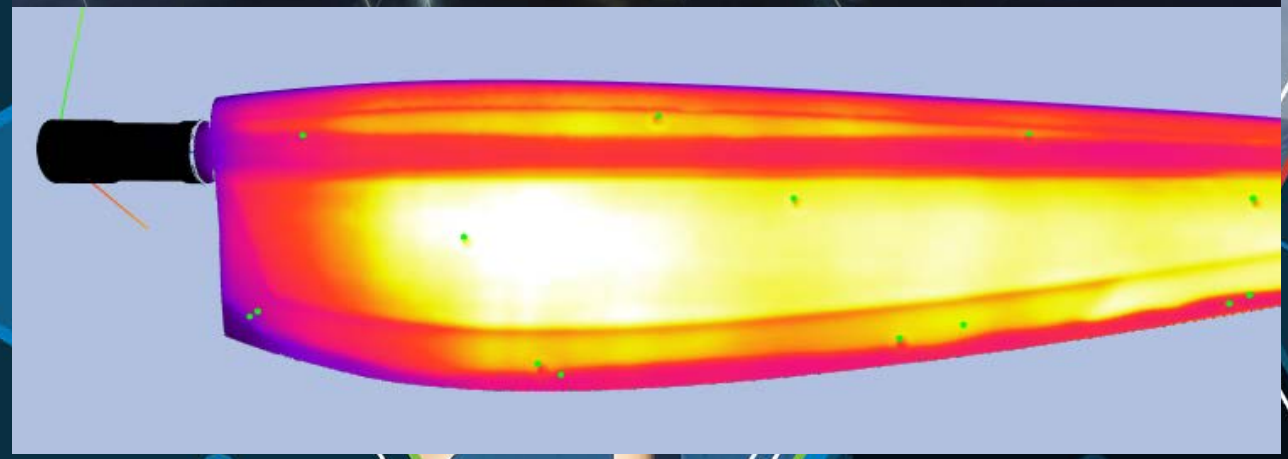
REAL-TIME INSITU NDE QUALITY CONTROL

Thermoplastic Composites Conference 2022

American Composites Manufacturing Association

John Tyson II, PE
President
Trilion Quality Systems
Trilion Engineering Services
www.trilion.com





DIGITAL MANUFACTURING
REAL-TIME, GLOBAL COORDINATES

gom a ZEISS company | certified partner trilion

ERP
MRP

Manufacturing Quality

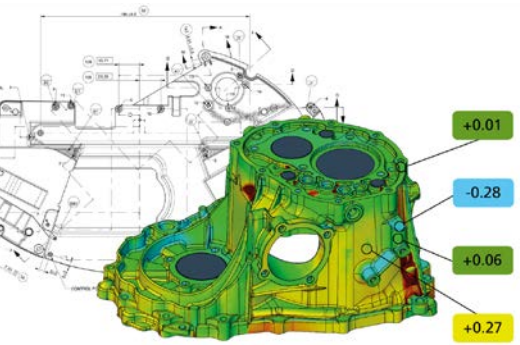
Xi Digital-Twin

Engineering
CAD/FEA

Incoming Properties/QA

GOM Suite

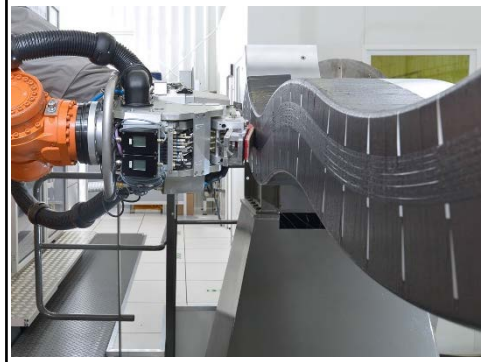
Optical Strain/Scanning
Material Properties
Dimensional Inspections



Real-time QA

InSitu NDE

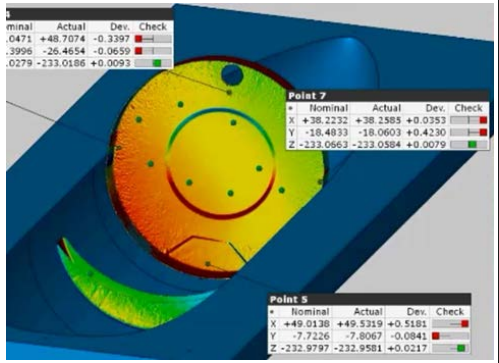
Hand Layup
AFP Robotic Layup
Welding/AM QA



Digital Assembly/QA

RVAT

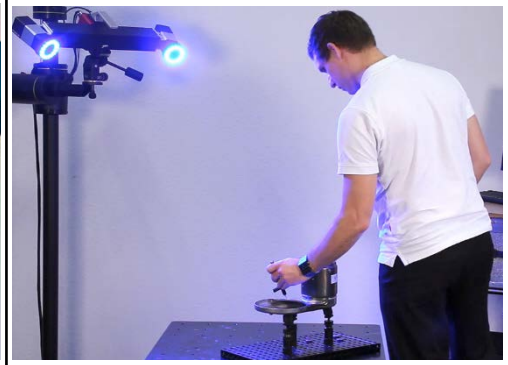
Real-time Quality
Operator Guidance
Smart Tools



Nondestructive Testing

Smart NDT

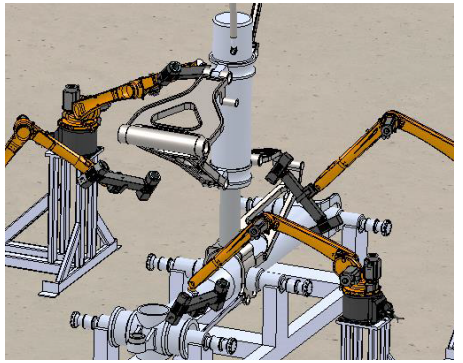
NDT in Global CAD Coordinates
3D Shape - CT - UT – TNDT - EC



Structural Validation

GOM Suite

Optical Strain
TRM – Real-time Monitor



TRILION ENGINEERING SERVICES

Industry 4.0 Manufacturing Support
Application Development – Testing – FEA Support

ACMA American Composites Manufacturers Association

Thermoplastic Composites Conference 2022

MATERIAL TESTING: ARAMIS OPTICAL STRAIN

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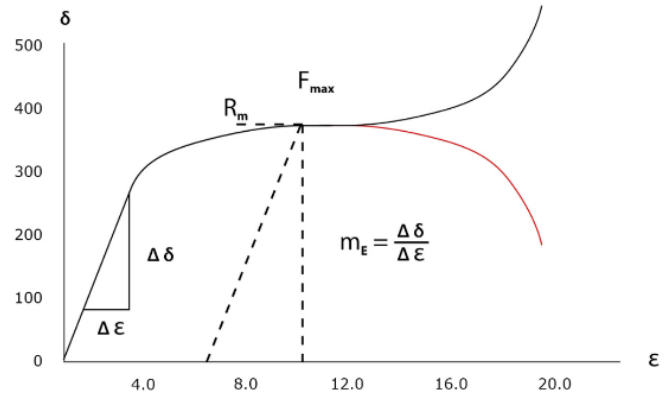
Video extensometer

Load

Automated stress strain curve



"ARAMIS provides the most consistent material properties"
NASA Glenn

Automated material properties

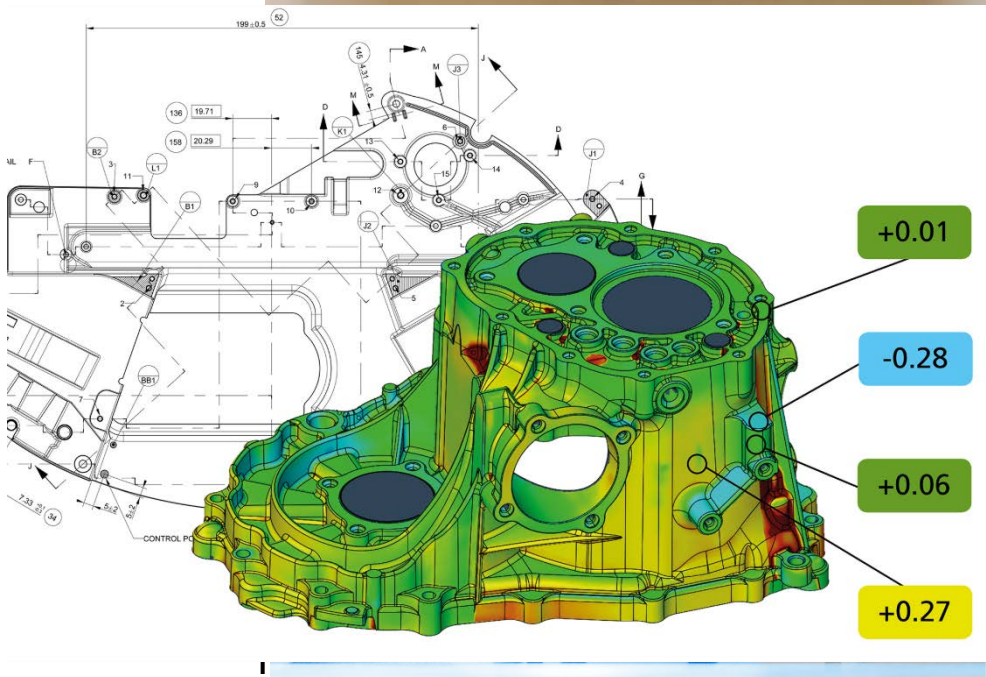
Tensile Test Region	
n	+0.326
r	+0.788
mE	+194856.252 MPa
Poisson	+0.250
Rp02	+332.970 MPa
Rm	+609.701 MPa
Ag	+31.712 %
Agt	+32.024 %
At	+38.199 %

Load frame

ARAMIS

ISO / ASTM Standards

ATOS SCANNING 3D SHAPE



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ATOS Q

ACMA
American Composites Manufacturers Association

CT (3D X-RAY) INTERNAL ANALYSIS – AM & COMPOSITES

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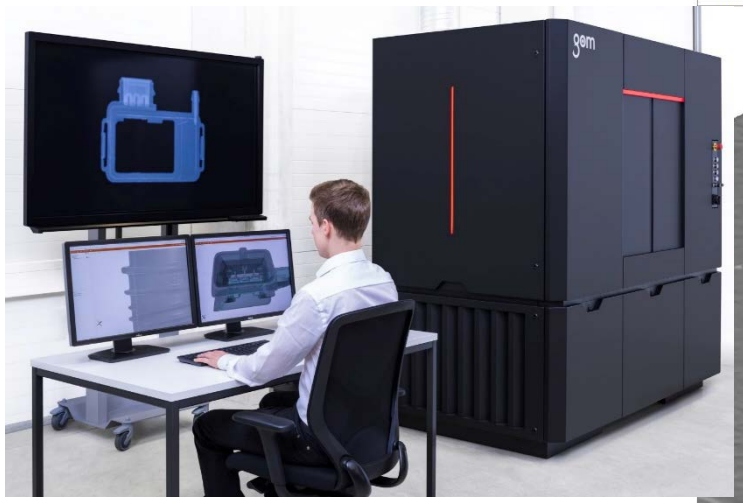
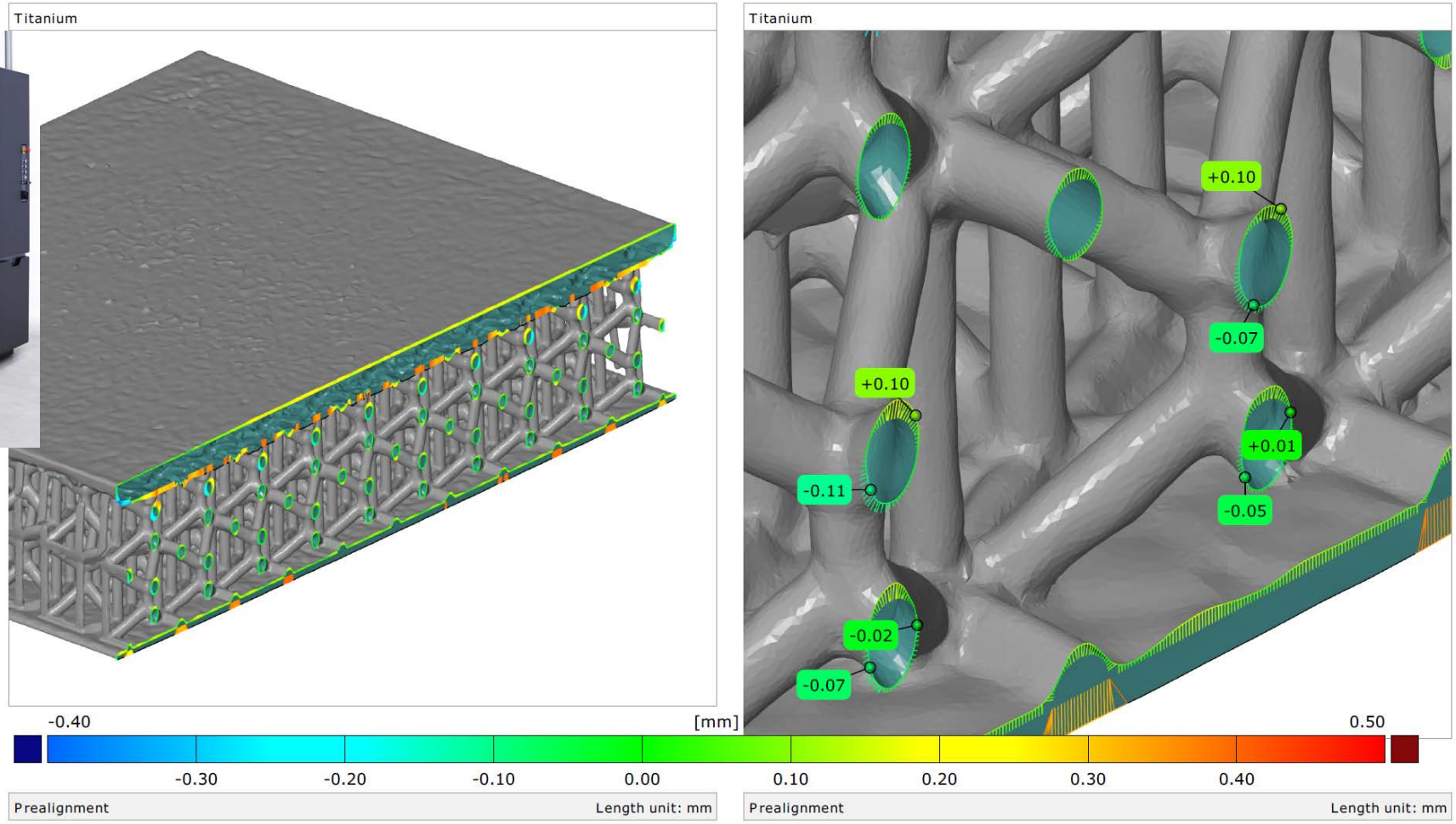


Inspection Section and Detail



SuPAR AR INTERACTIVE INSPECTION

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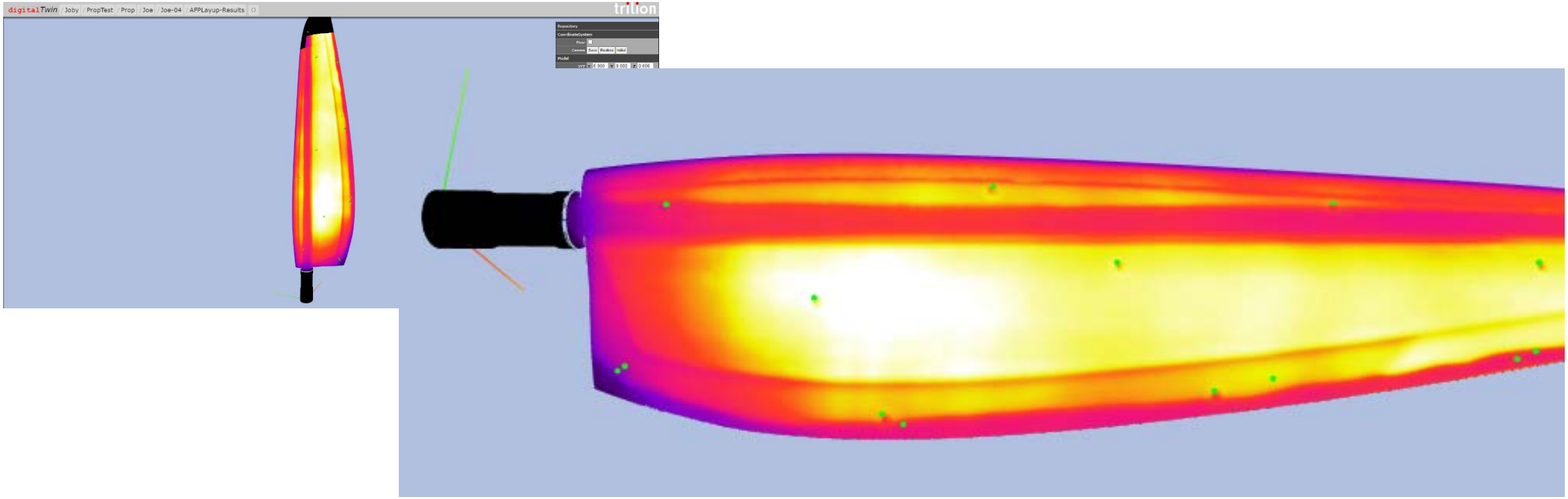
Inspection Targets

- Appearance[damage, crack, gap, rust, uneven]
- Nut condition [spec shortage]
- Bolt condition [spec shortage]
- Insulator [position, shortage]
- Sealing [position, shortage]
- Spot weld[number, position]
- ARC Weld [number, position]
- Rivet [number]
- ID mark [position, shortage]
- Ring and bottom and position [position, shortage]
- Hole [position, number]

THERMOGRAPHY NDT (T-NDT)

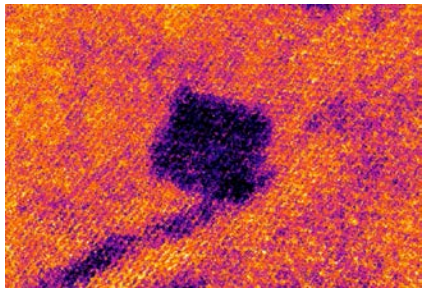
Scanning Thermography NDT data in true 3D coordinates is documented in the Xi Digital-Twin, along with all the other quality data about the component.



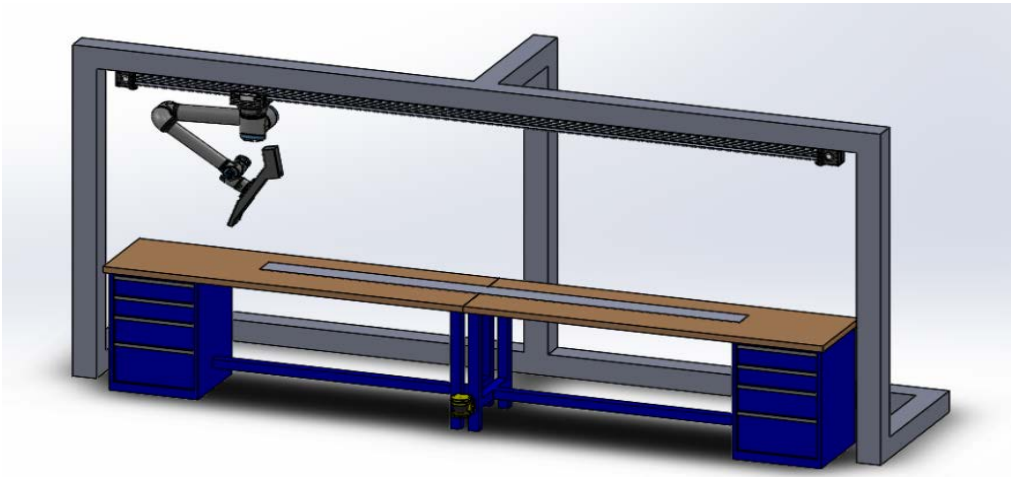
Each structure has a structural thermal signature. Defects, such as disbonds, fillets and excess adhesive, show up as variations in these structural element signatures. Automated defect detection is programmable to assist QA to accept parts within defined tolerances.

COOLSCAN™ INSITU QUALITY FOR LAY-UP & AFP

- **Hand Layup Guidance**
- **Ply Placement Validation**
- **Fiber Alignment**
- **FOD Detection**
- **Build Quality Assurance**
- **Digital Twin documentation**



Detection of internal FOD & Bridging
CoolScan™ InSitu NDE



- Mounted above workspace, taking no additional time for 100% quality during builds.

COOLSCAN™ INSITU QUALITY FOR LAY-UP & AFP

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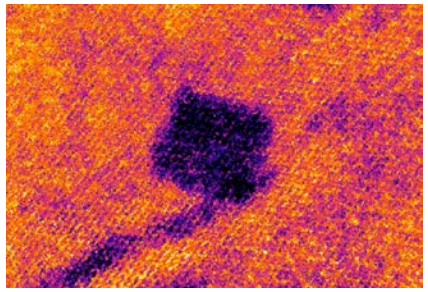
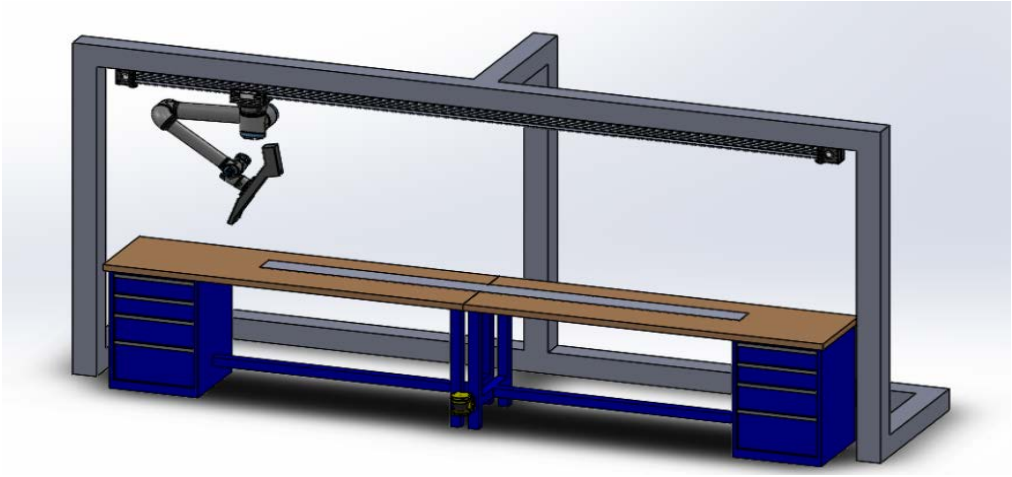


Detection of internal FOD & Bridging
CoolScan™ InSitu NDE

Indication	Definition	Tolerance
End-of-Ply (EOP)	Check Placement of Ply to CAD	<6mm
Fiber Alignment	Check Fiber Alignment to CAD	+/- 5°
Void/Bridging	Detect Voids and Bridging	Repair
FOD	Detect Backing, Fuzz, FOD	Repair
3D Shape to CAD	N.A. in tool, Post Curing Scan	Per Requirements
Bond Quality	N.A. with autoclave curing	



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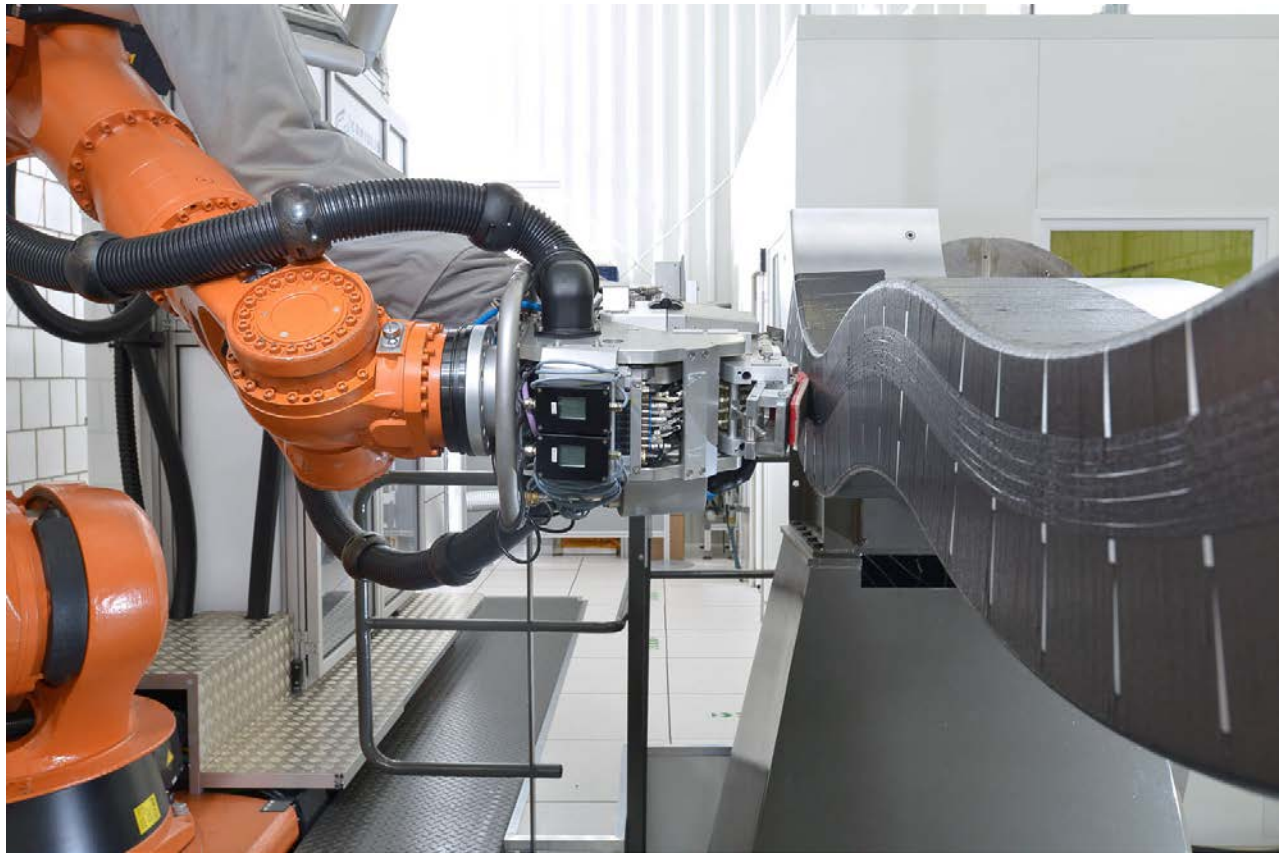
COMPOSITE BUILD – ATL/AFP INSITU QUALITY

Coriolis AFP Robotic Tape Layup



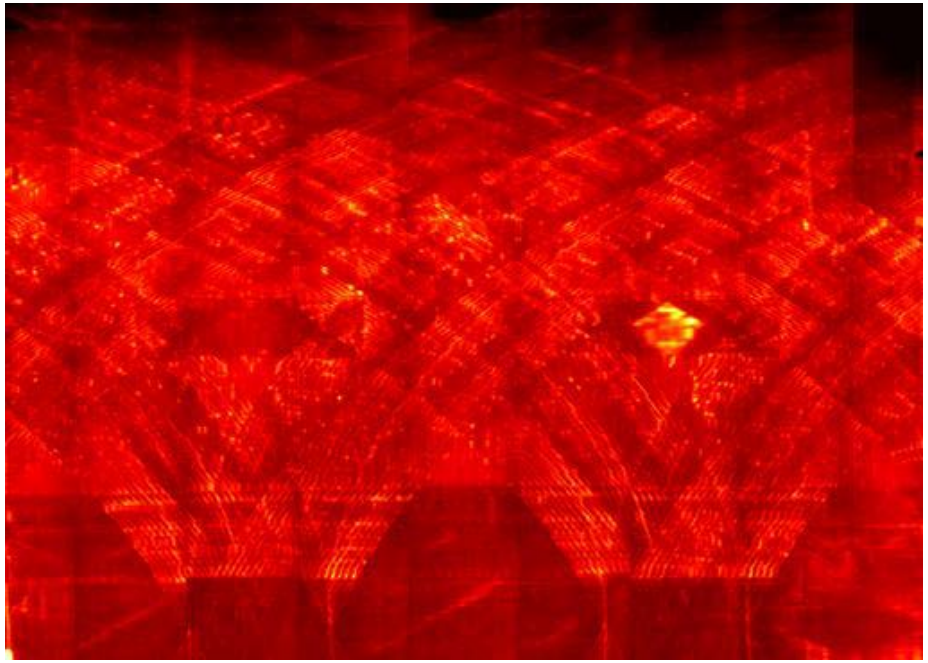
In-Situ NDE – Bond Quality
Bond quality known at every point of the component build.

Trilion InSitu NDE system on Joby Coriolis Robot Head.

COMPOSITE BUILD – ATL/AFP INSITU QUALITY

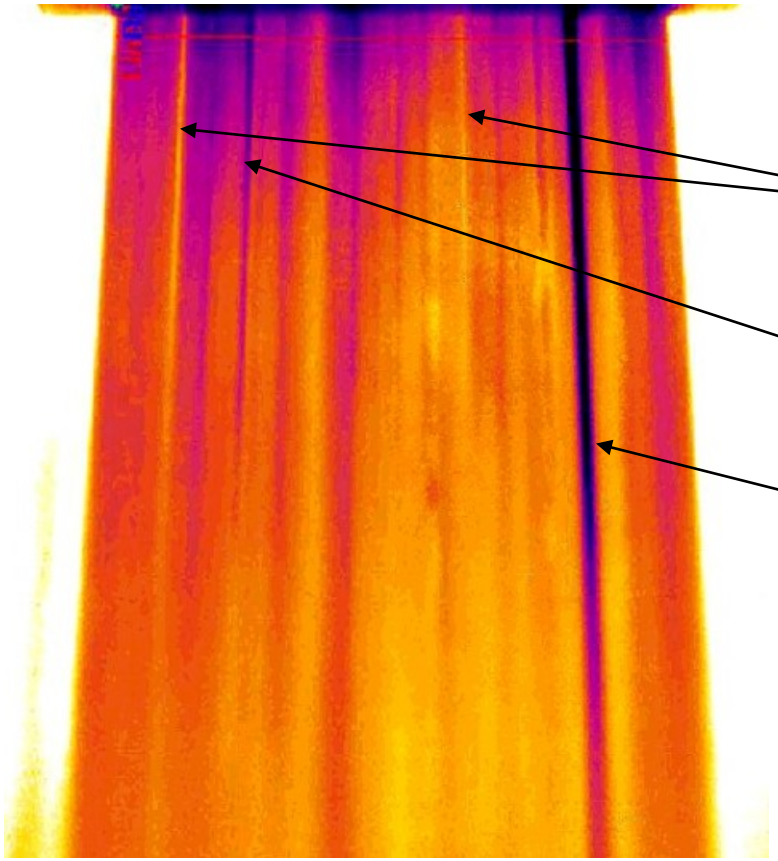
Robotic Tape Layup, Real-time Build Quality

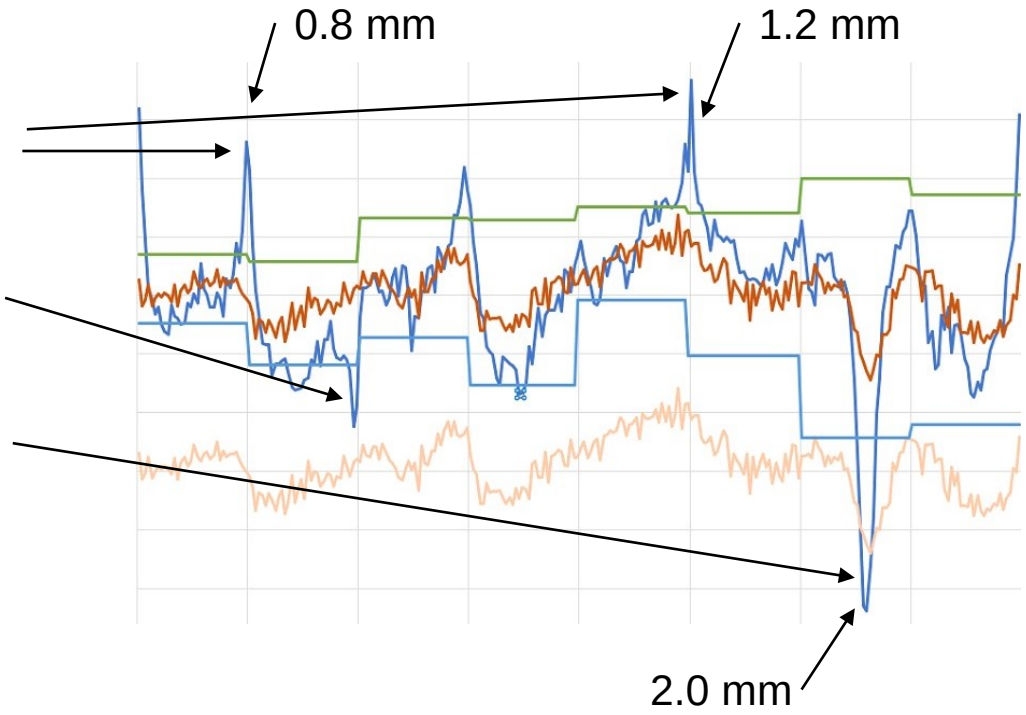
In-Situ NDE – Bond Quality
Bond quality known at every point of the component build.



COMPOSITE BUILD – ATL/AFP INSITU QUALITY

- **Real-time 3D Build Quality**
  - **Real-time Defect Detection – In-Situ NDE**





During AFP Layup & Consolidation

- Cool (black) = poor bonding or lap

COMPOSITE BUILD – ATL/AFP INSITU QUALITY

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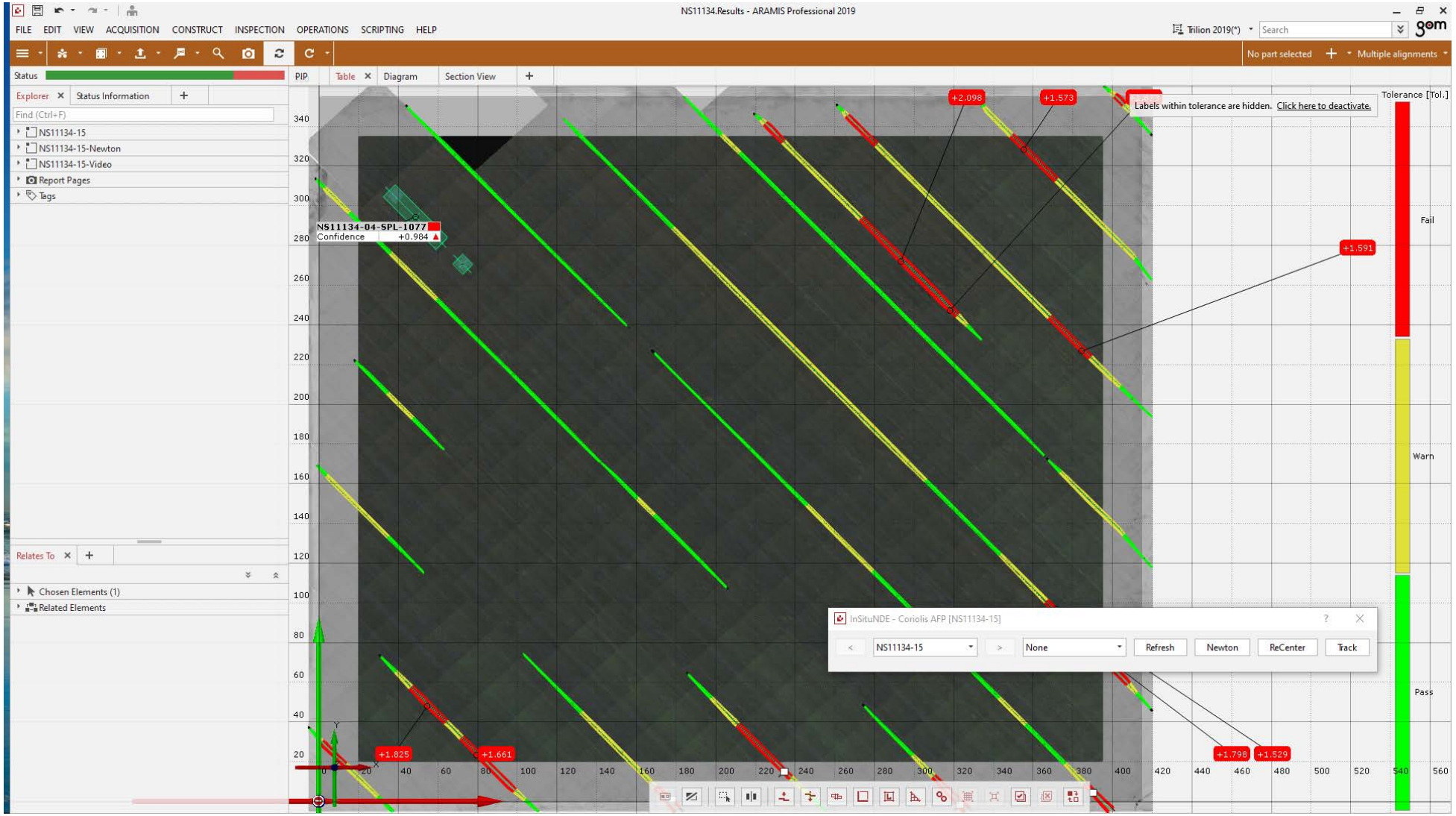
Real-time Build Quality

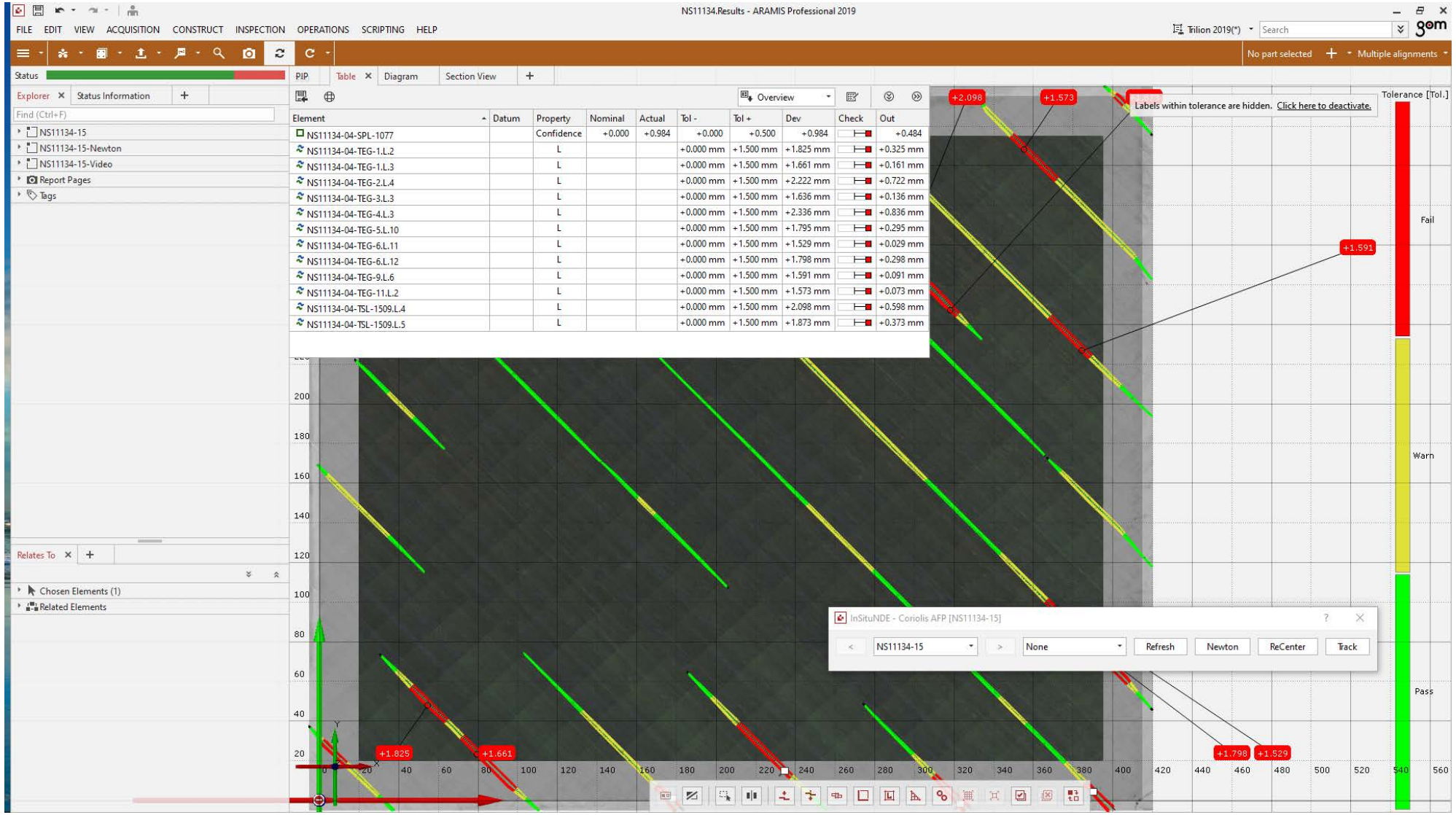
- **Defect Acceptance Criteria**

Indication	Definition	Tolerance
Gap	Gap between tows/tape	<2mm
Lap	Tow overlapping adjacent	<2mm
Twist	Tow twist	Repair
Splice	Tow splice	>150mm
Buckling/Puckering	Tape turn buckling	QA acceptance
Void	Tow voids, disbonds, bridging	<4mm
FOD	Foreign material, fuzz	<4mm
3D Defect Stacking	3D defect stacking	QA acceptance

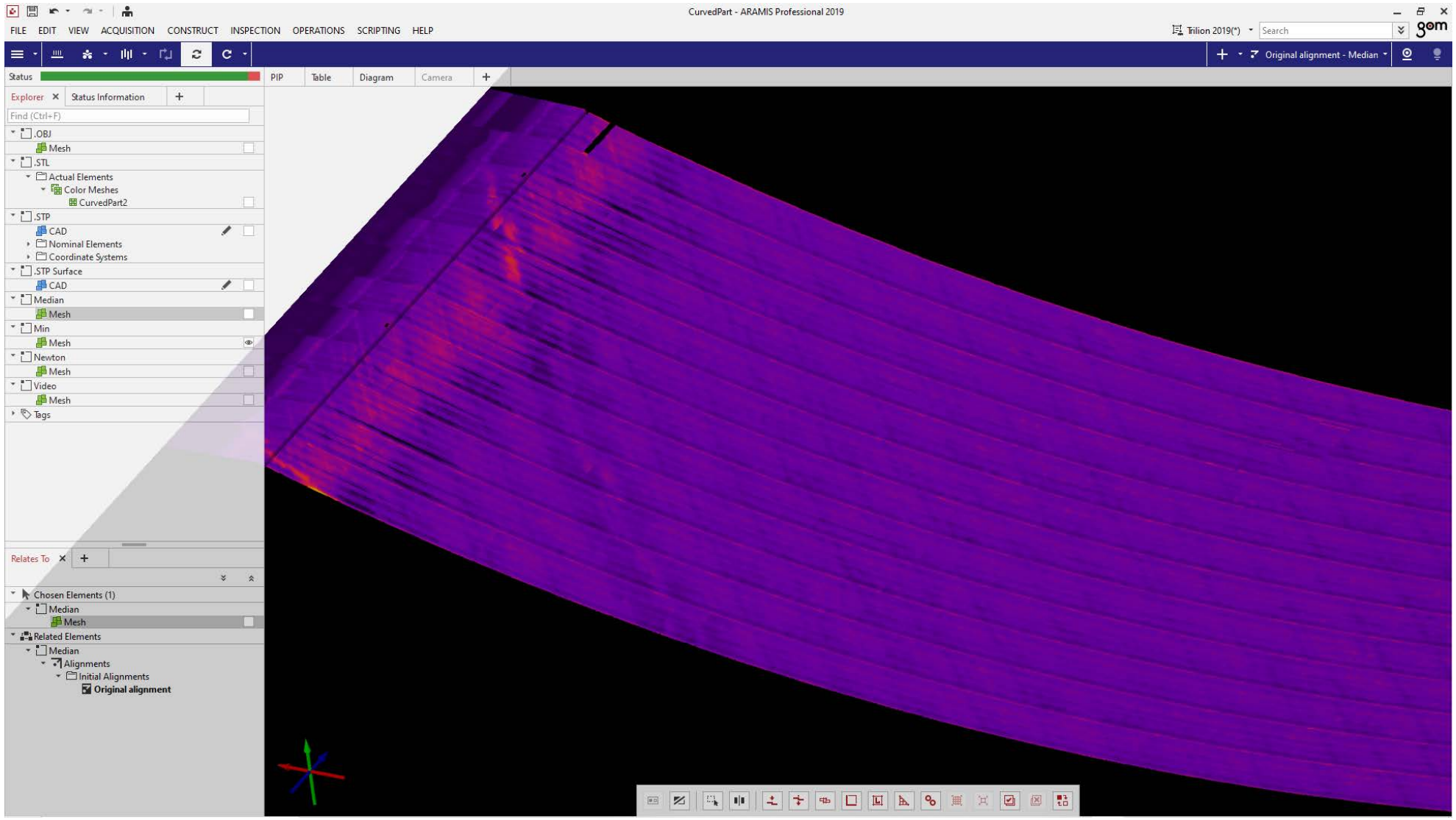
COMPOSITE BUILD – ATL/AFP INSITU QUALITY



COMPOSITE BUILD – ATL/AFP INSITU QUALITY



COMPOSITE BUILD – ATL/AFP INSITU QUALITY – FUSELAGE TOOL



COMPOSITE BUILD – ATL/AFP INSITU QUALITY

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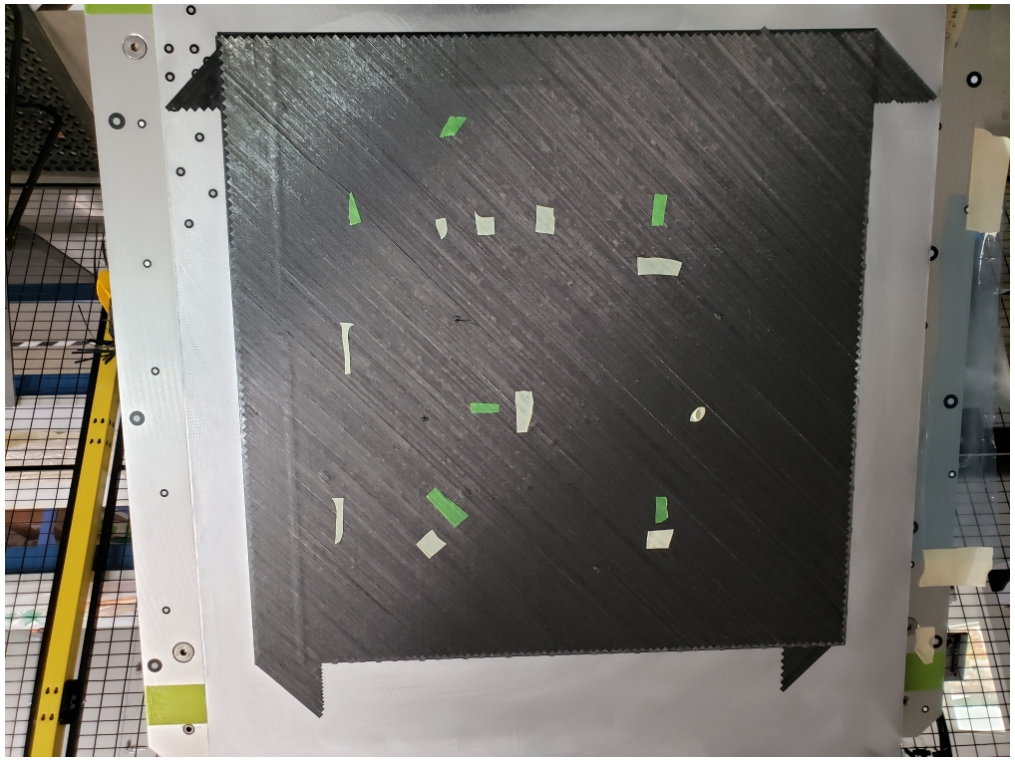
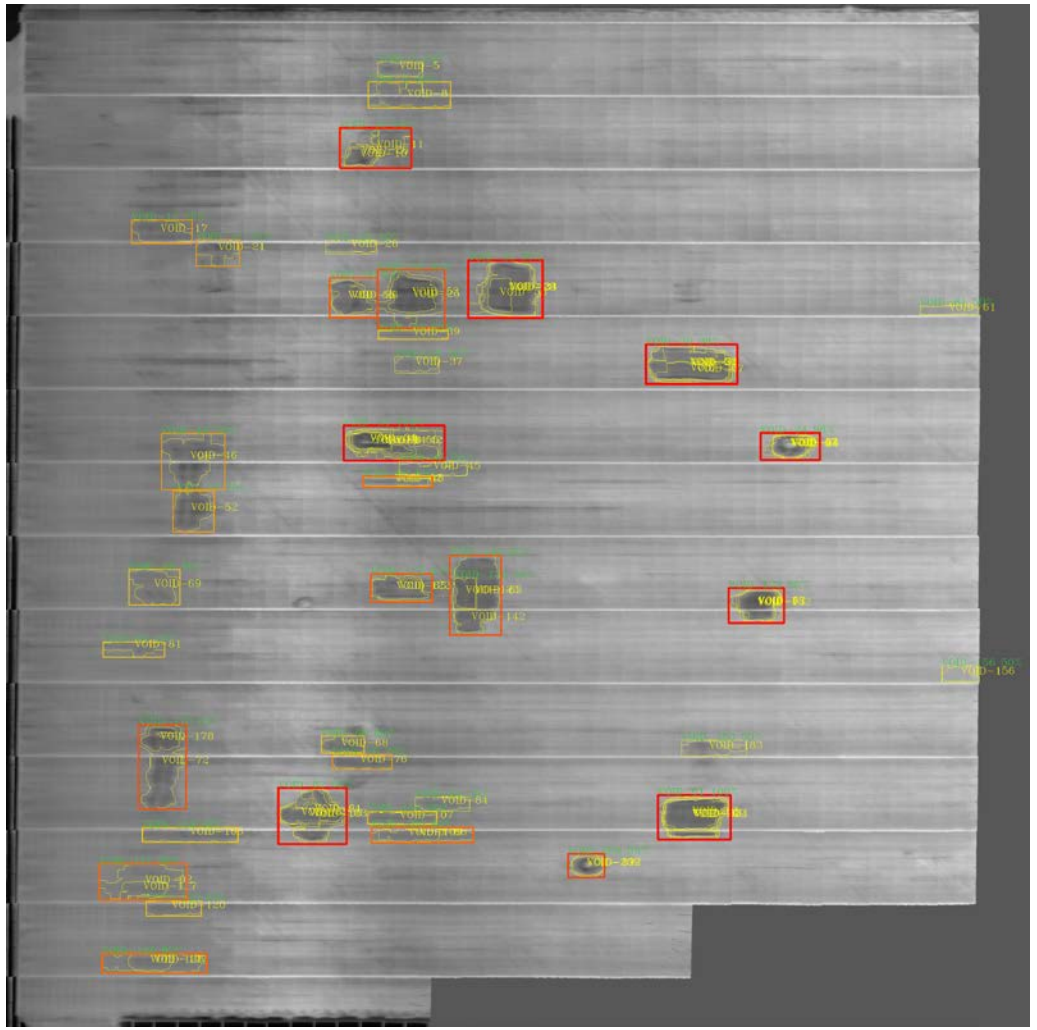
Programmed FOD defects



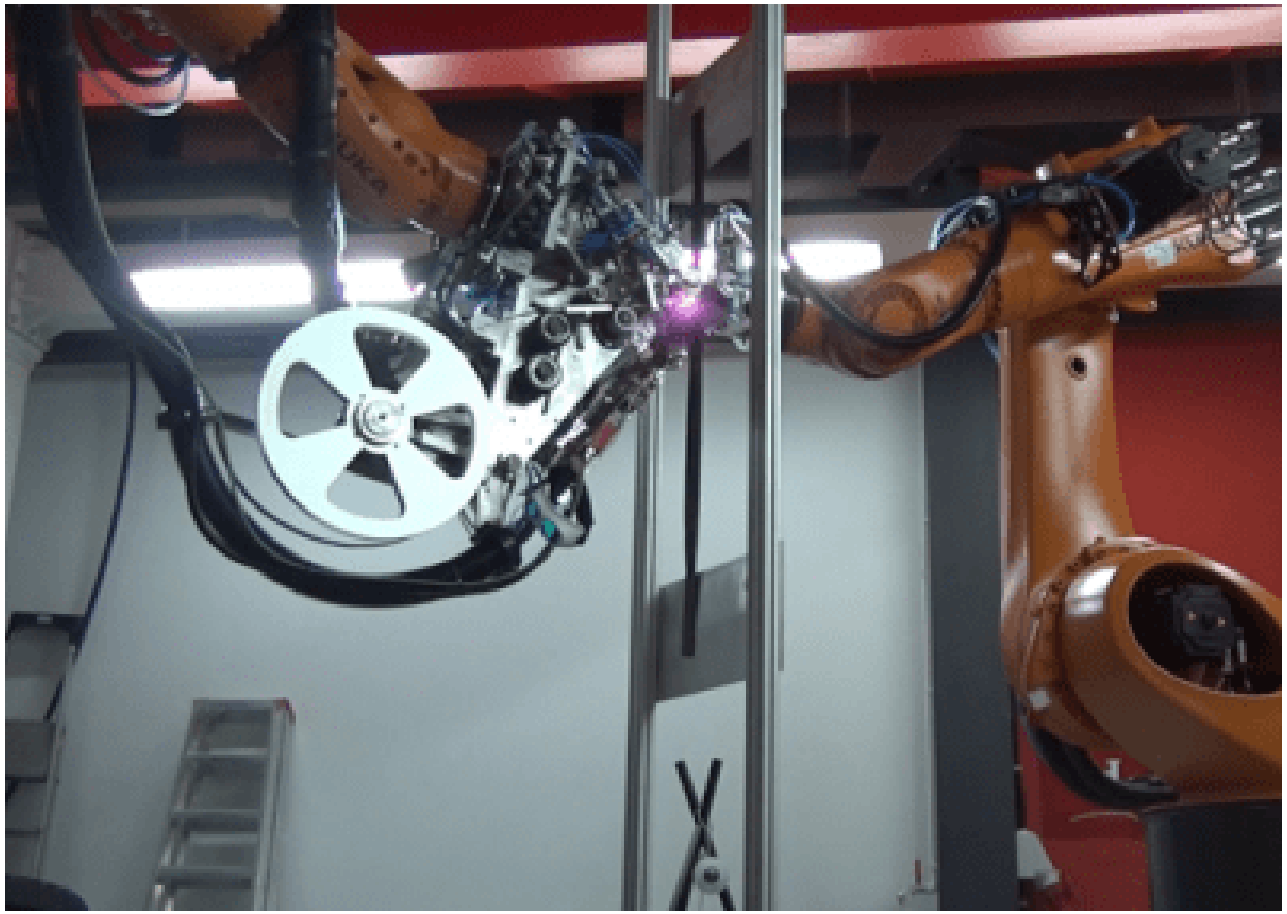


INSITU NDE TOOL-LESS THERMOPLASTIC BUILD

trilion

Tool-less Thermoplastic

- 3D Shape measurement real-time feedback for correct parts.
- InSitu NDE for quality detection.
- Detect laps & gaps, voids, porosity, crystallinity, FOD.
- Real-time quality inspection to make perfect parts.
- AR display of defects, precision measurement tools for documenting quality.



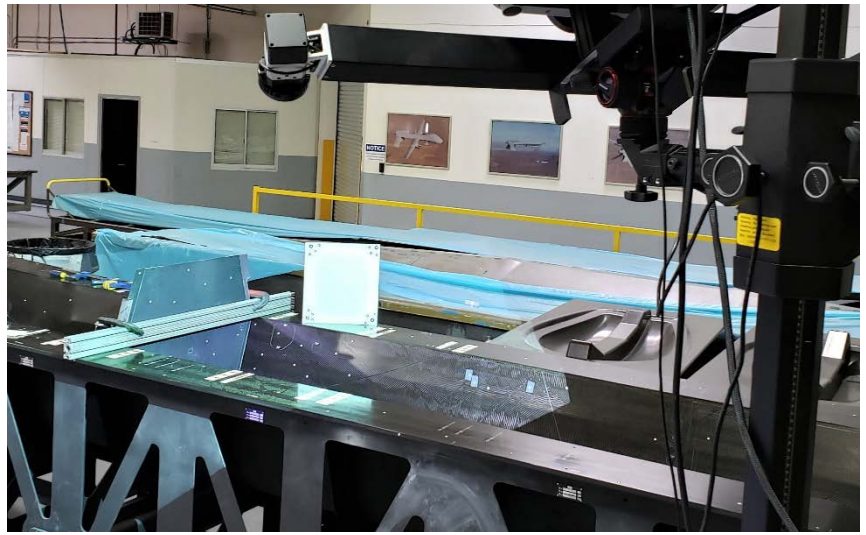
RVAT
REAL-TIME VIRTUAL ASSEMBLY TOOLING

trilion

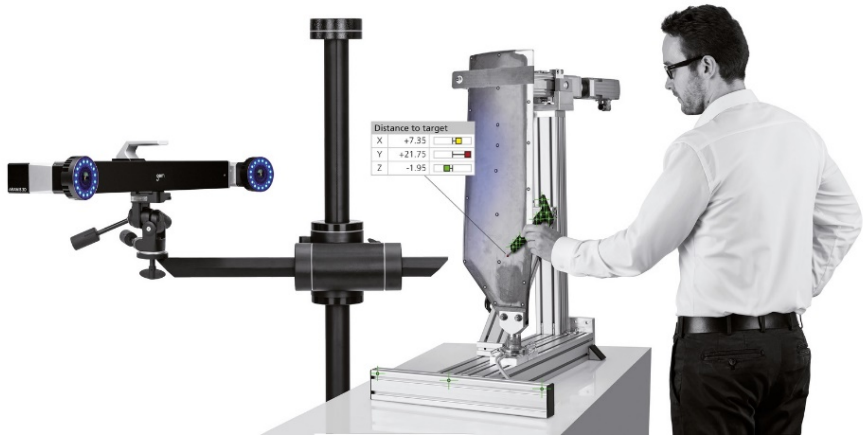
RVAT
ARAMIS – Stereo 3D Photogrammetry

trilion

- RVAT ARAMIS Sensor
  - Fast real-time positioning
  - Precision measurement
  - Accuracy to > 0.001 inches
  - Direct guidance to CAD design
  - Faster, more precise assembly
  - MRL-9 measurement capability



- Operator Guidance
  - Precision assembly guidance
  - Fast and easy to use
  - 60% faster assembly in use
  - More accurate
  - Capture manufacturing knowledge



RVAT COMPONENT ASSEMBLY IN 6-DOF (6 DEGREES-OF-FREEDOM)

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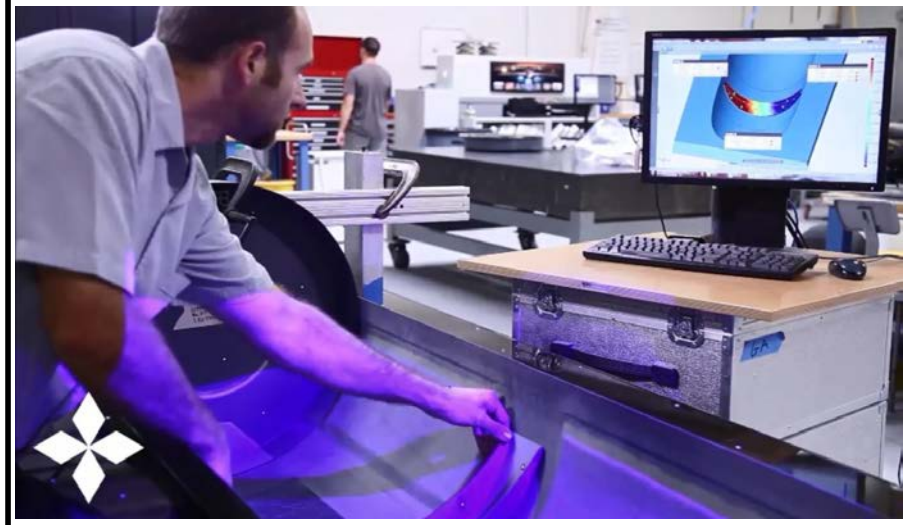
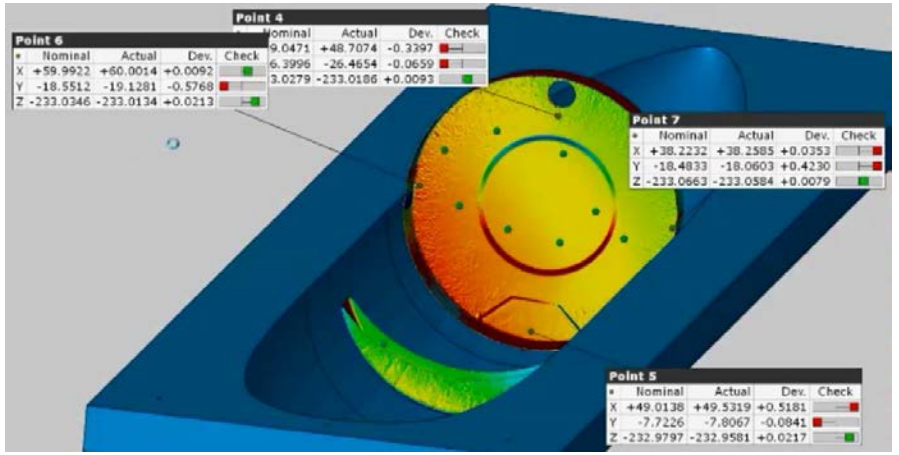
- Positioning a 3D component in complex 3D structure to CAD
  - Dynamic reference
  - RVAT tracks component position
  - Any complex 3D structure
  - All positioning in 6-DOF in CAD coordinates, to CAD location



- Digital-Twin
  - Digital Thread of each task
  - 6-DOF position of actual part
  - QA of each step, to CAD design
  - As-Built is marked and saved, with actual scan and CAD



RVAT VIRTUAL FIXTURING AND ASSEMBLY

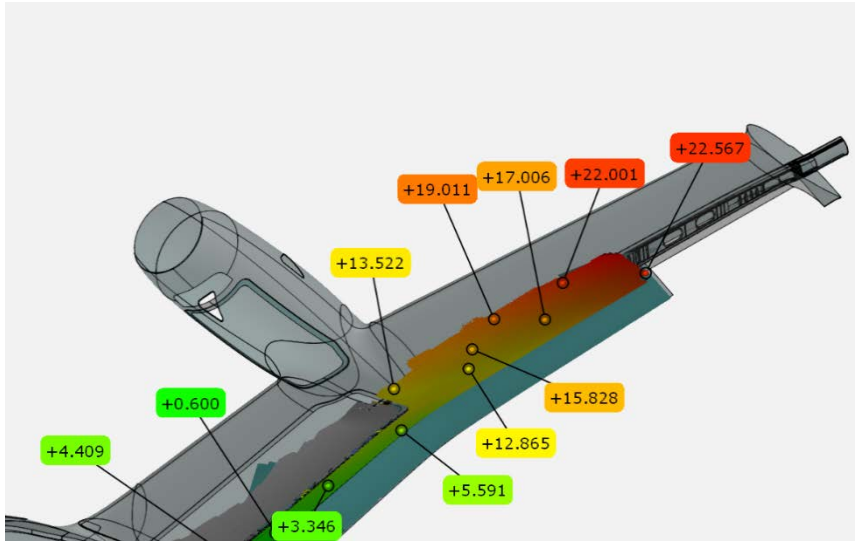
Digital assembly

RVAT Smart Tools
Click-Bond 3D Positioning

trilion

- Click-Bond SmartTool
  - Click-Bond tool precise position
  - Reference to complex 3D parts
  - Non-contact, dynamic tracking
  - Positioning to desired tolerance
  - Operators 10-50x faster and more precise, with QA build-in.

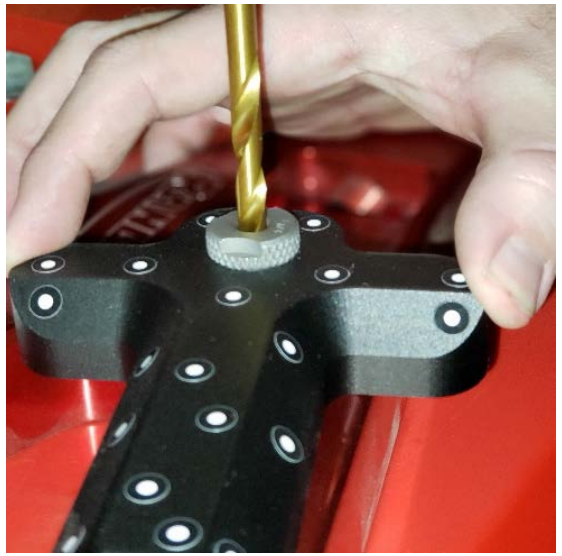
- Digital Alignment
  - Display alignment guidance
  - Fast 6-DOF alignments & QA
  - Digital Thread: 3D position of components,
    As-Built, is marked and saved



RVAT Smart Tools
Drilling 3D/6-DOF/Blind Drilling

trilion

- Rapid Drilling to CAD Design
  - 3D positioning of Drill Guide
  - Any complex 3D structure
  - Tracking to 0.001 inch, in real-time, dynamically, with operator or robot
  - Your team 10x more efficient and QA & Digital-Twin included.



- Blind Drilling
  - Drilling into structure below, known only in CAD
  - Digital Thread: 3D position of each drill hole, As-Built, is saved.

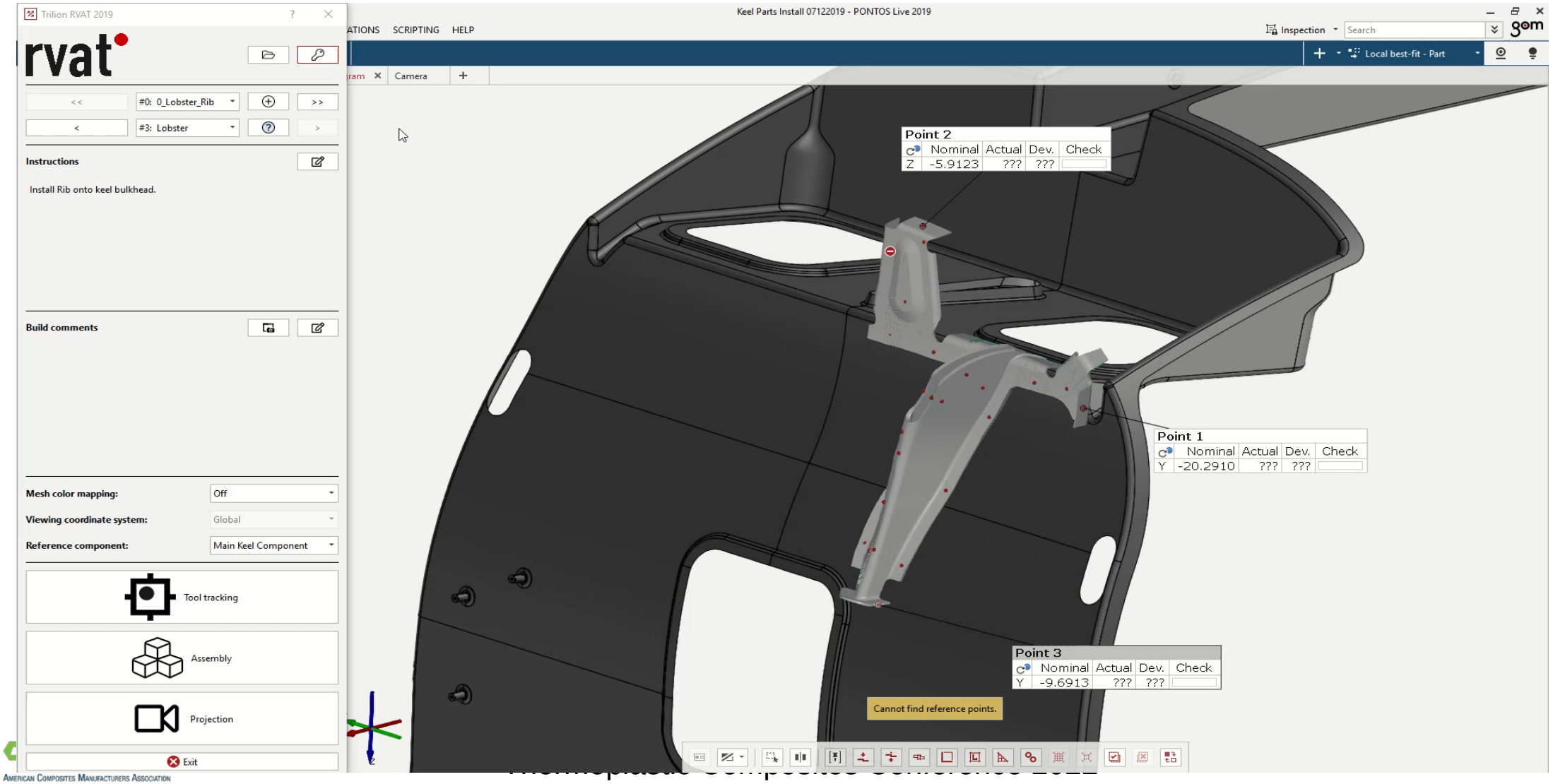
PHOTOGRAMMETRY OF STRUCTURE

- The 2D picture overlaid on the CAD model makes it easy to view the final positions of the Click Bonds before they are placed
- 2D views can verify that the area was properly prepared before bonding, giving more proof that the job was completed correctly
- 2D images can also show bumps or obstructions that need to be removed before bonding
- Documenting into the Digital Twin each step of the assembly process is easily captured in this manner.

RVAT UI and Virtual Assembly Workflow

trilion

Video:



RVAT SMART TOOLING
RIB BRACKETS

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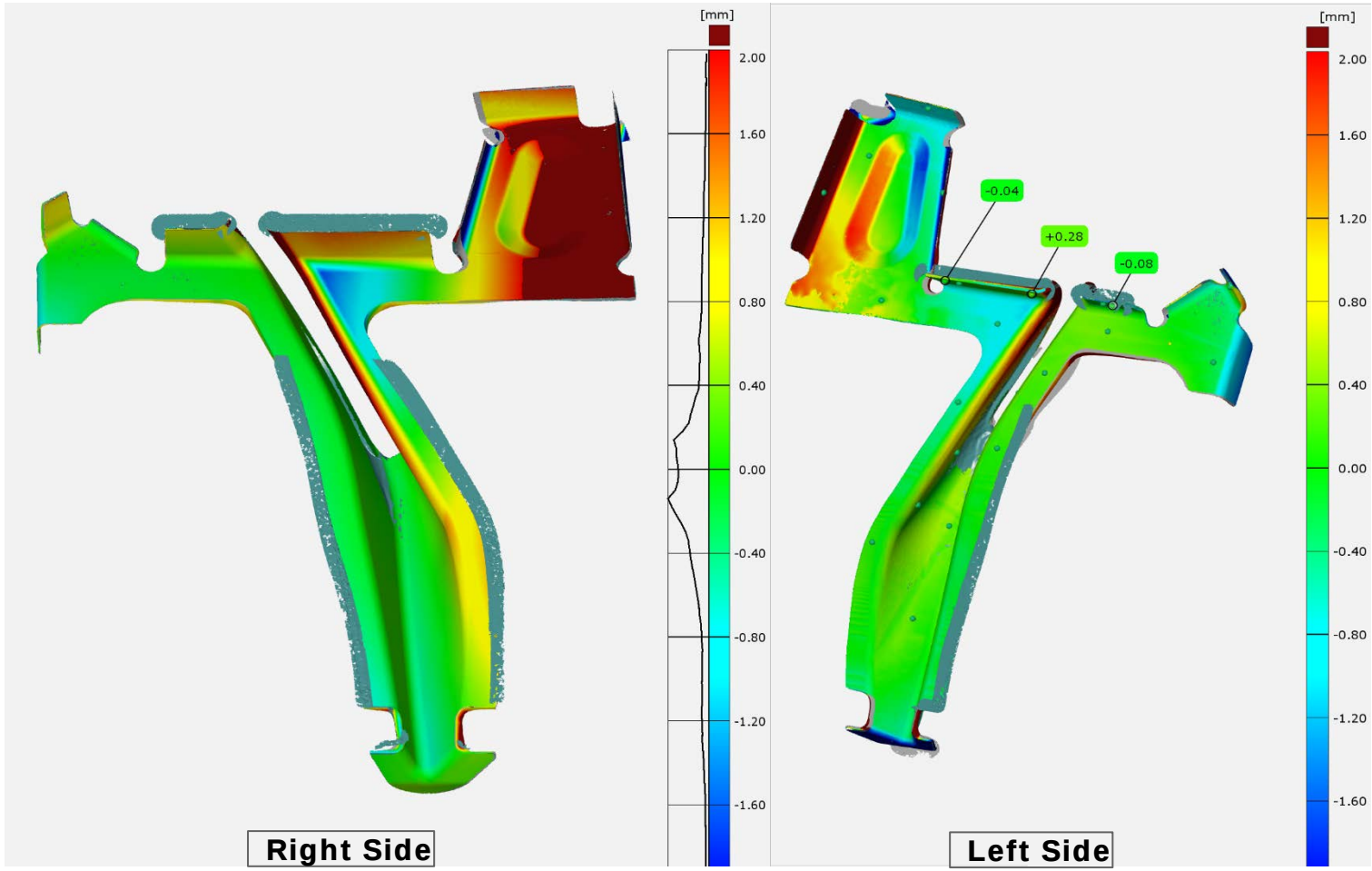
- Each landing gear rib bracket was scanned and aligned to their CAD models.
- Surface Inspection was made for each component to verify dimensions.
- Identified areas of the parts that were warped.
- Composite techs prepare assembly, knowing that extra clamping force will be needed.
- Tools reworked to compensate for spring-back warpage.
- Smart Tools make perfect parts.



RVAT DIGITAL ASSEMBLY
DIGITAL PRE-FIT

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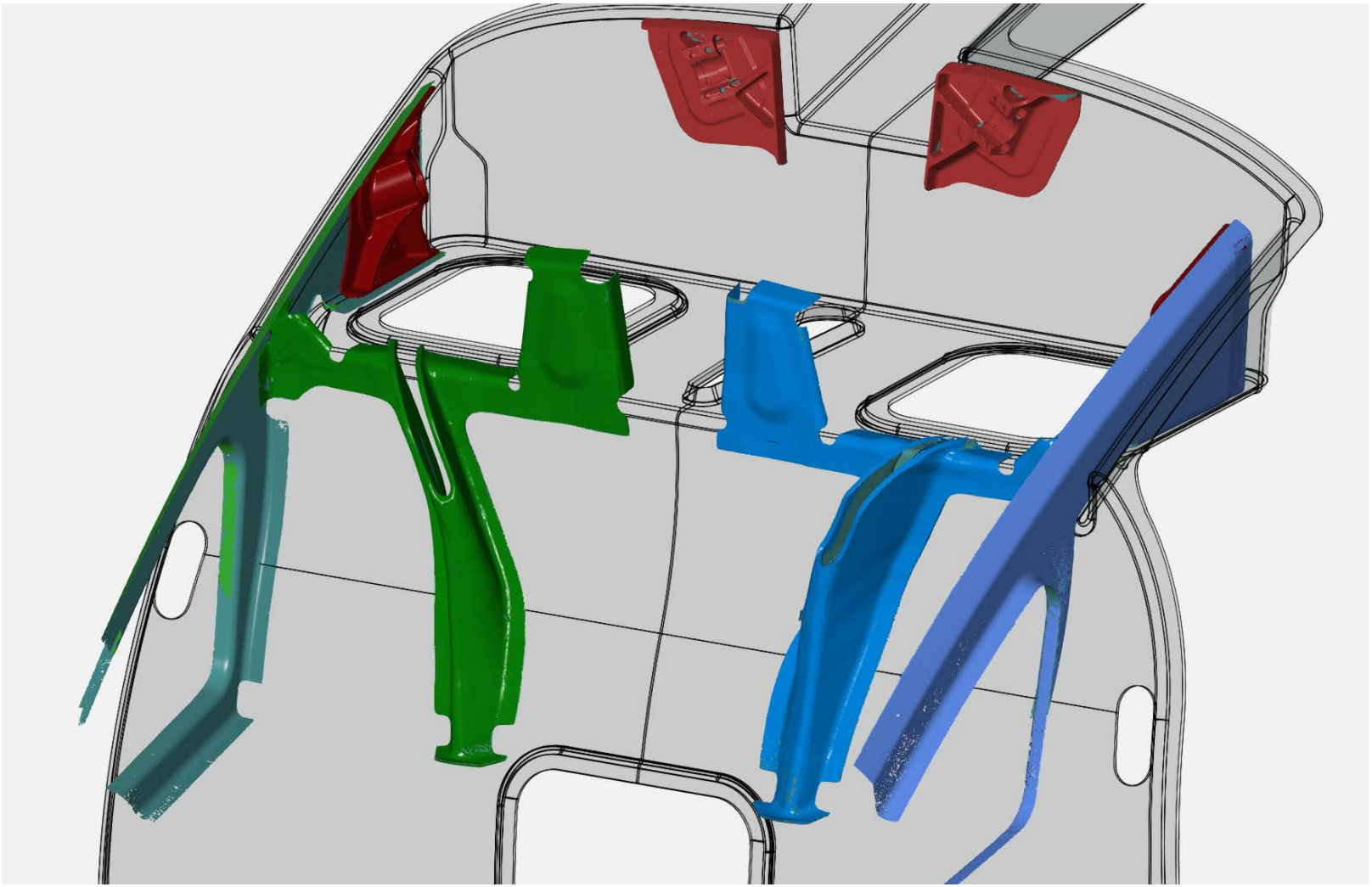
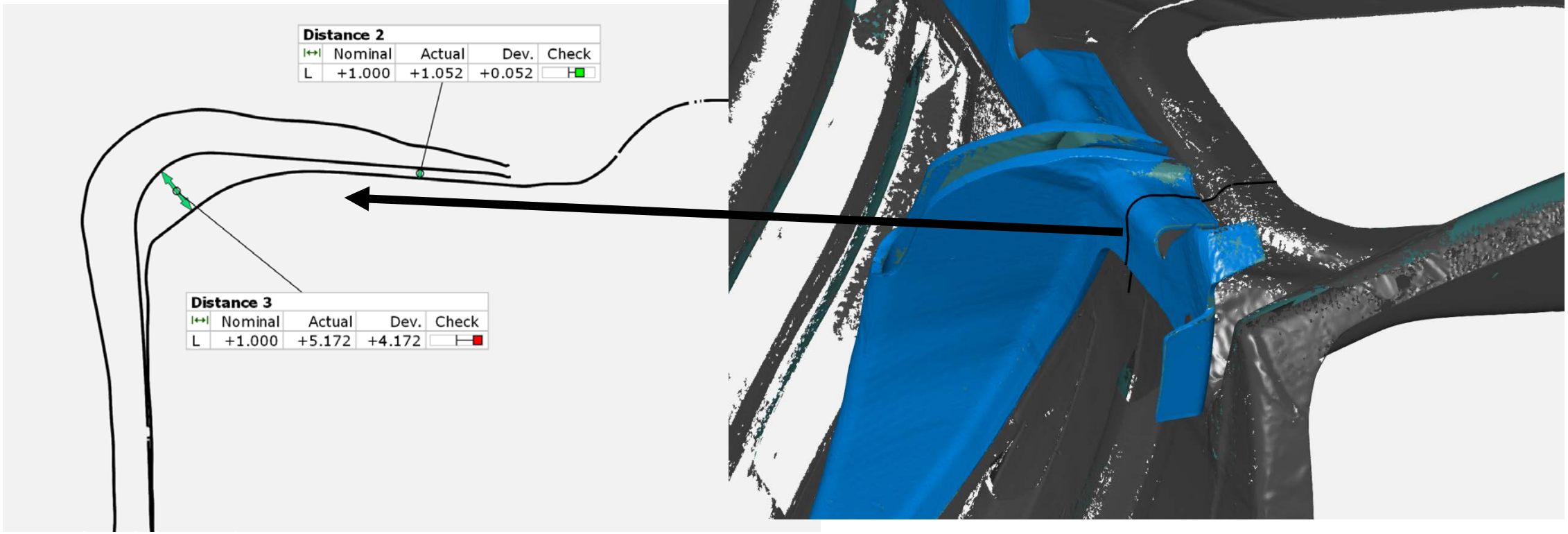
- Each part is scanned, and imported into a Master Project.
- Master Project showed interference between parts or bond lines that were not acceptable.
- This shows which parts will need to be trimmed before they are physically assembled



RVAT DIGITAL ASSEMBLY
BOND THICKNESS

- Bond Thickness measurement
- Cross sections are made of the digital assembly and bond line thicknesses measured on areas that cannot be seen by the technician.



RVAT DIGITAL ASSEMBLY AS-BUILT INSPECTION

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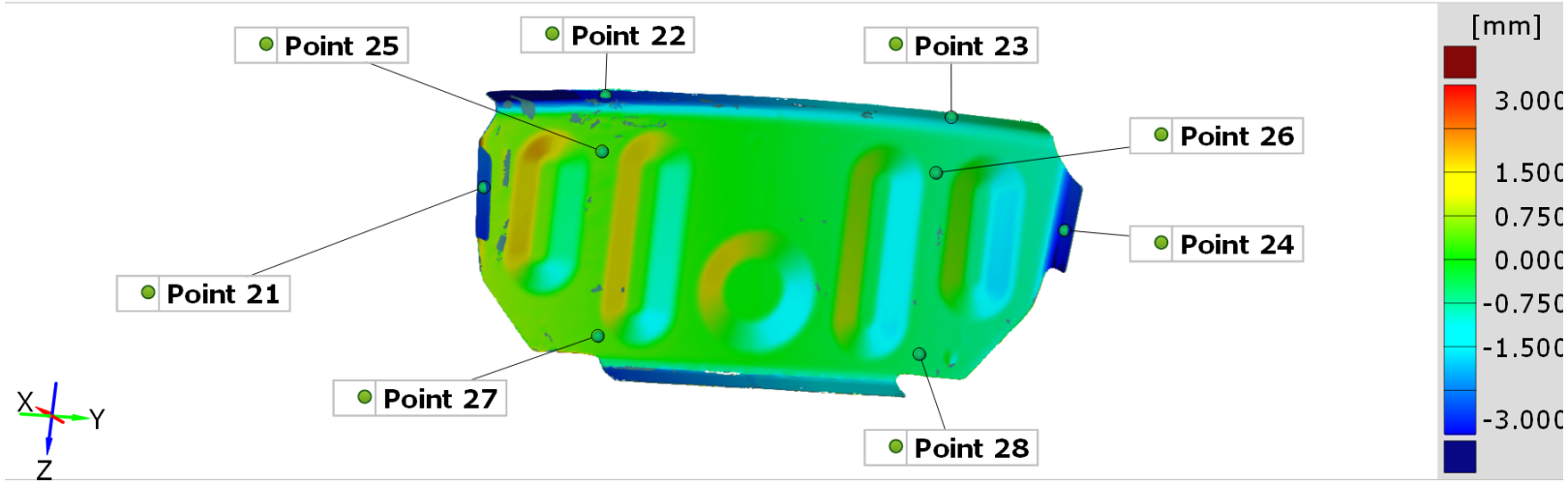
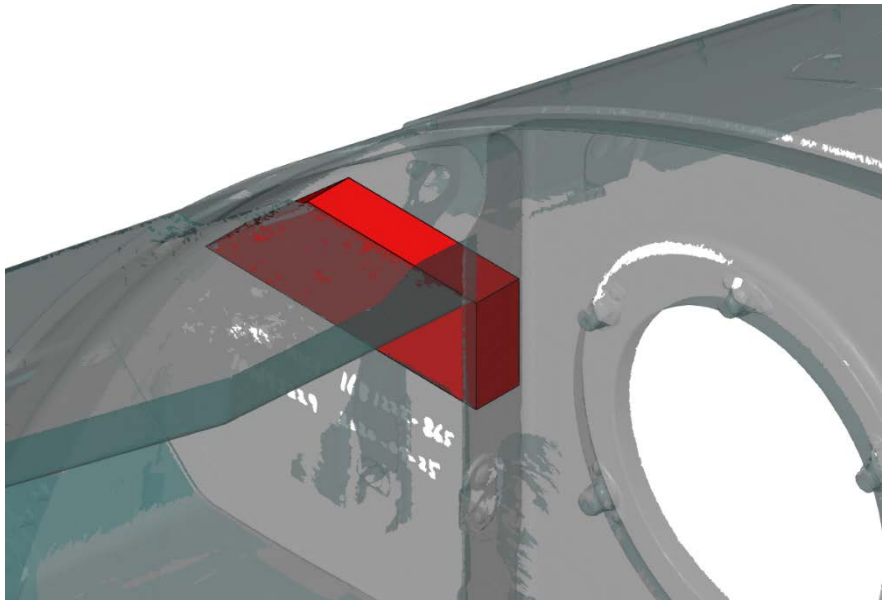
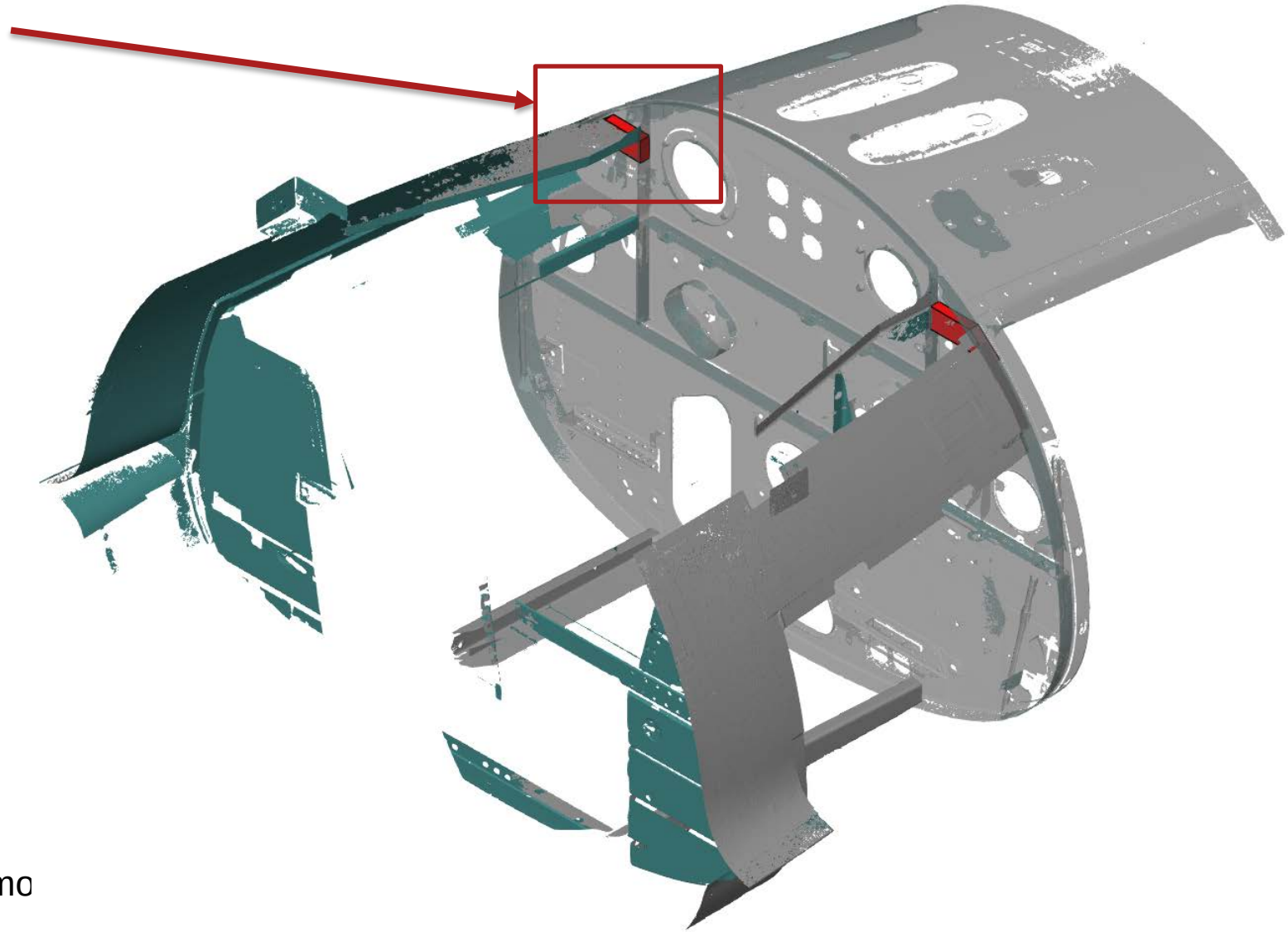
- Parts were lived tracked using RVAT.
- Parts were then drilled and Clecos were added to hold the part in place.
- Parts were bonded to the assembly.
- After the curing, the final position of the part was captured and documented for quality assurance and As-Buiilt Digital-Thread.



Element	Datum	Property	Nominal	Actual	Tol -	Tol +	Dev	Check	Out
Point 28		X	+1539.028	+1539.491	-0.800	+0.800	+0.463		
Point 27		X	+1538.981	+1538.596	-0.800	+0.800	-0.385		
Point 26		X	+1538.959	+1539.510	-0.800	+0.800	+0.550		
Point 25		X	+1538.975	+1538.645	-0.800	+0.800	-0.330		
Point 24		Y	+201.743	+204.571	-0.800	+0.800	+2.828		+2.028
Point 23		Z	-298.235	-297.330	-0.800	+0.800	+0.906		+0.106

VIRTUAL ASSEMBLY – SHIM & TRIM
SHIM MODELING AND CREATION

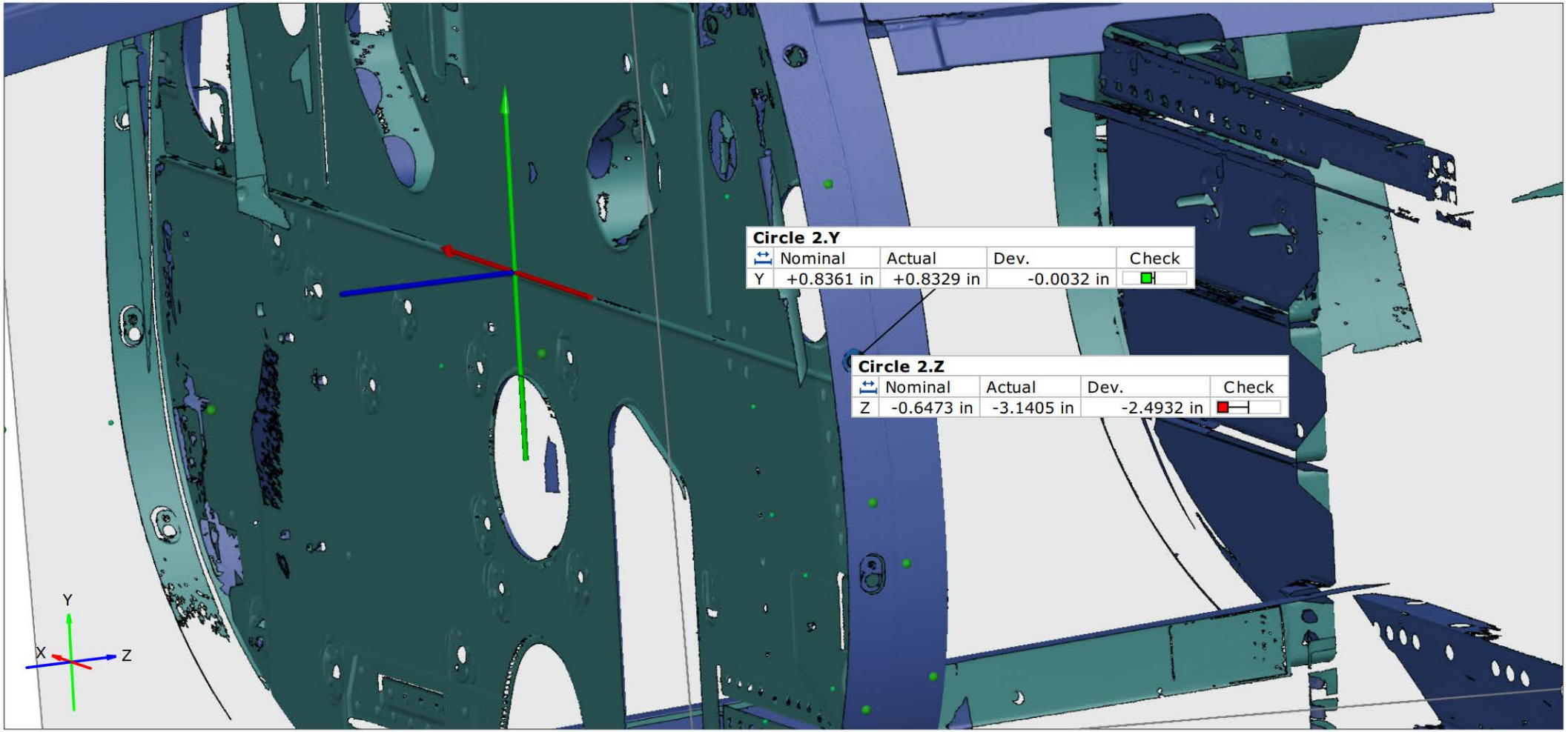




Virtual Assembly

- Virtual Shim measurements where components do not meet mating.
- Geomagic DesignX design of Shim model for machining.

BUSHING TRACKING



QA INSPECTION
DRILL & BUSHING LOCATIONS AS-BUILT

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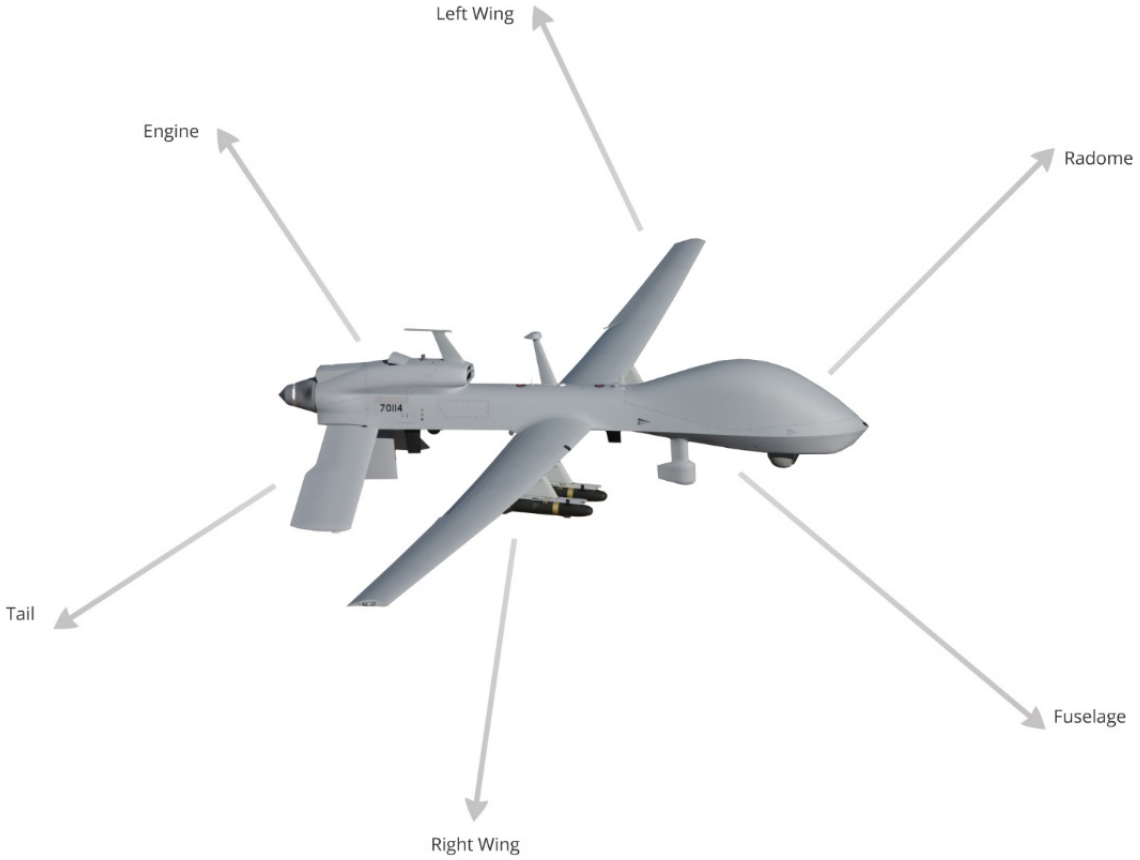
Element	Datum	Property	Nominal	Actual	Tol -	Tol +	Dev	Check	Out
Point 1		Y	+11.2789	+11.2855	-0.0100	+0.0100	+0.0066		
Point 1		Z	+2.1490	+2.1402	-0.0100	+0.0100	-0.0088		
Point 2		Y	+8.6543	???	-0.0100	+0.0100	???		
Point 2		Z	+2.1986	???	-0.0100	+0.0100	???		
Circle 2		X	-20.9628	-21.0497	-0.0100	+0.0100	-0.0869		-0.0769
Circle 2		Y	+0.8361	+0.8329	-0.0100	+0.0100	-0.0032		
Circle 2		Z	-0.6473	-3.1405	-0.0100	+0.0100	-2.4932		-2.4832
Distance 1		LZ	+1.5955	+2.9195	-0.0100	+0.0100	+1.3240		+1.3140
Distance 2		LZ	+1.5654	+2.9030	-0.0100	+0.0100	+1.3376		+1.3276
Distance 3		LZ	+0.5156	+3.0031	-0.0100	+0.0100	+2.4875		+2.4775
Distance 4		LZ	+0.4730	+2.9662	-0.0100	+0.0100	+2.4932		+2.4832
Distance 5		LZ	+1.5950	+4.0820	-0.0100	+0.0100	+2.4870		+2.4770

XI DIGITAL TWIN
REAL-TIME VIRTUAL ASSEMBLY TOOLING

RVAT Digital Threads capture assembly steps, assembly process and manufacturing data associated with entire build.

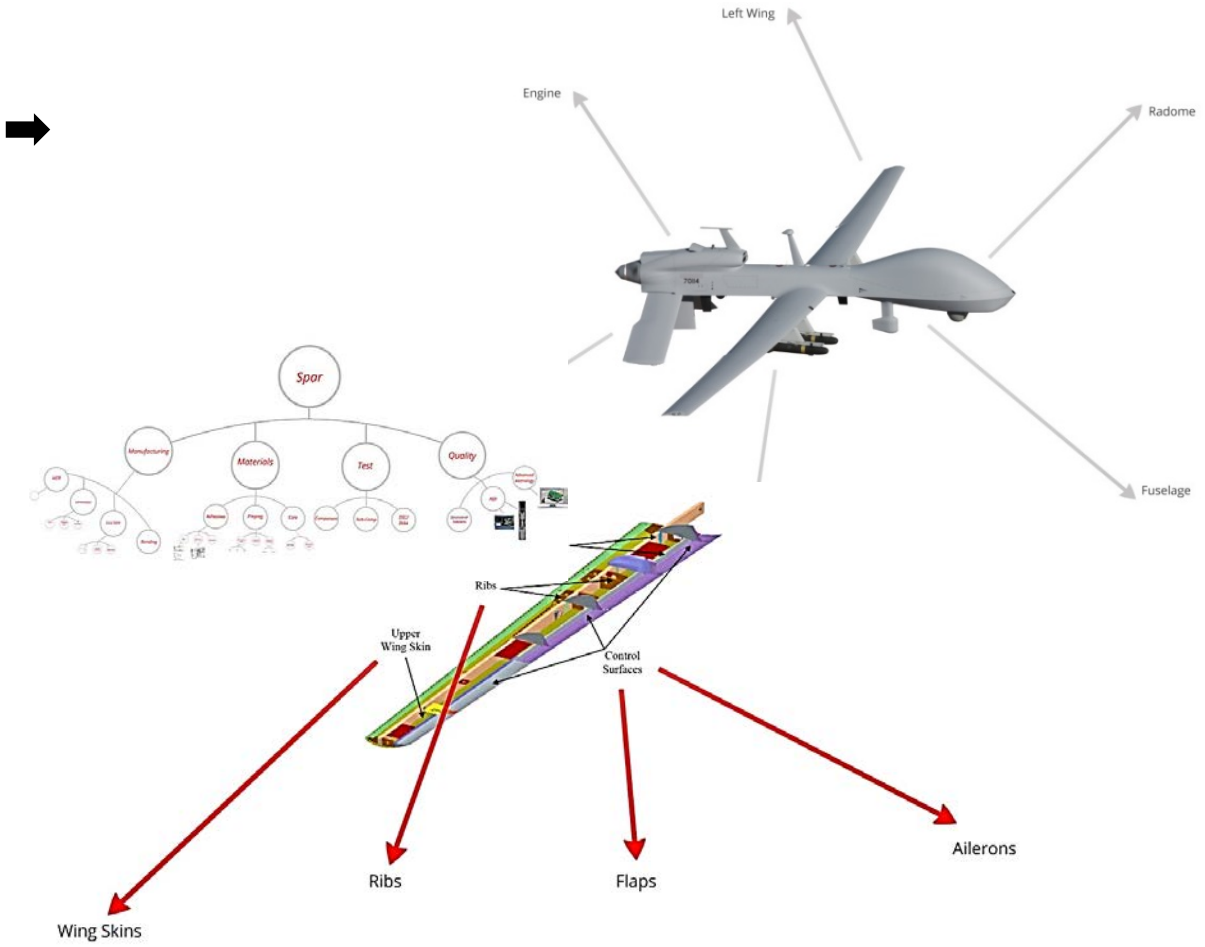
1. Each component is documented As-Built:
   a) CAD Drawings
   b) Component Scans
   c) Engineering Data
   d) Assembly Data
   e) QA Review Data
2. Digital Threads: Engineering and Manufacturing data gathered into Digital-Twin.



XI DIGITAL TWIN
REAL-TIME VIRTUAL ASSEMBLY TOOLING

Xi Digital-Twin graphical structure relates engineering data, digital assembly and manufacturing data of the entire vehicle.

1. Each Structure is documented As-Built, in 3D Global Coordinates
2. Engineering data
   a) Materials
   b) CAD/FEA
   c) 3D Baseline
   d) Assembly data & QA
   e) NDT
   f) Structural Testing
3. SPC and Production Analysis across entire production and all monitored processes.



XI DIGITAL TWIN
REAL-TIME VIRTUAL ASSEMBLY TOOLING

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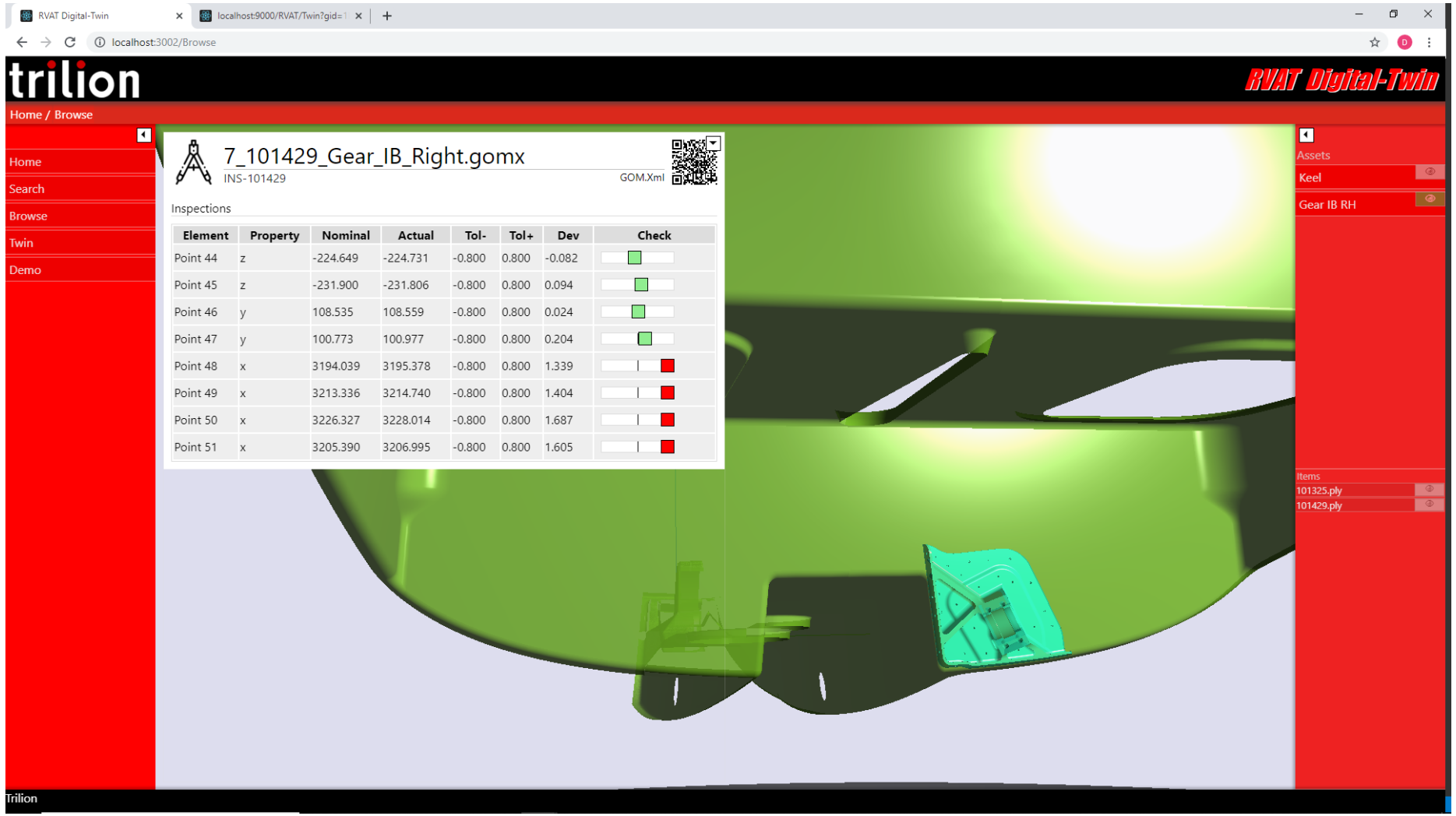

DISPLACEMENT MEASUREMENT

ARAMIS Optical Strain verses String Pots or LVDTs

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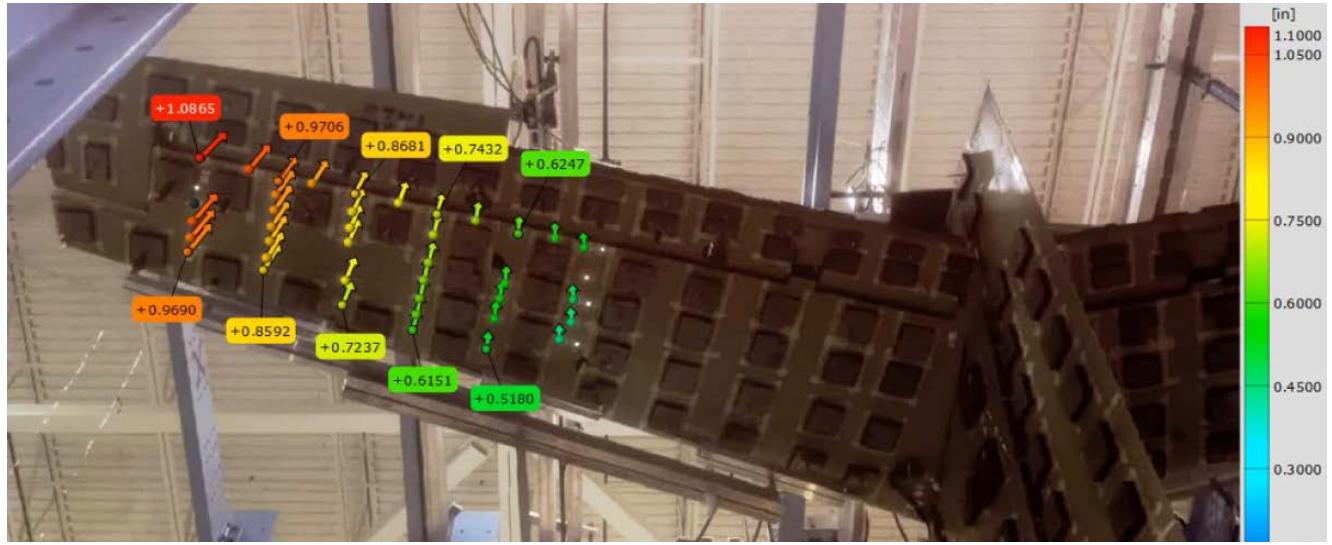
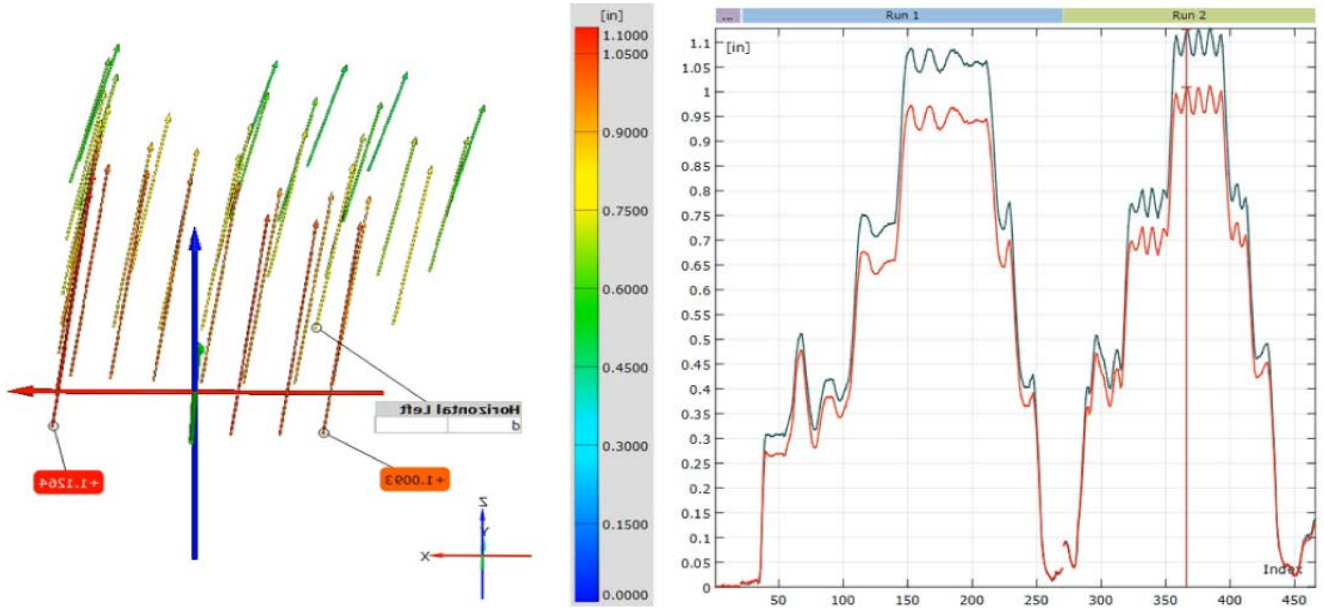


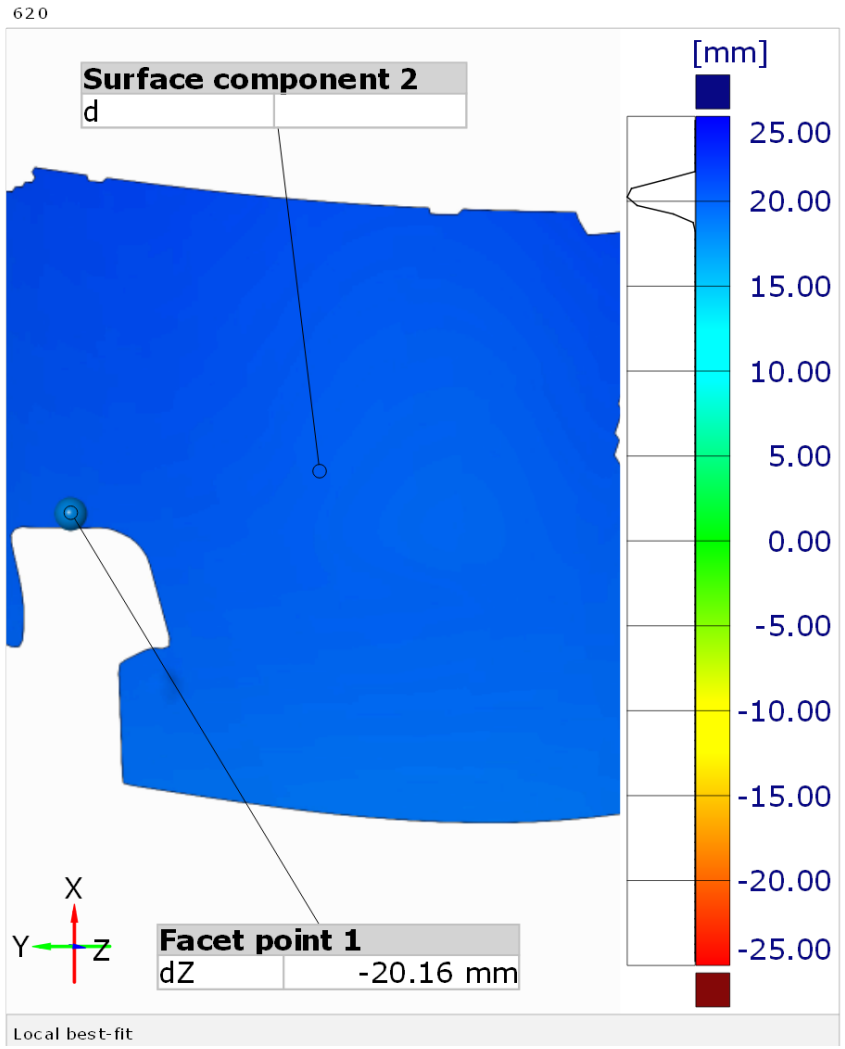


1. **Rapid Setup**: 60 minutes verses 4 Days
2. **3D Measurement**: Linear data, with correction
3. **Optical Line of Sight**: No interferences
4. **Adjustable Reference**
5. **Save on Schedule**
6. **Real-time Accurate Data**
7. **No Operational Costs**

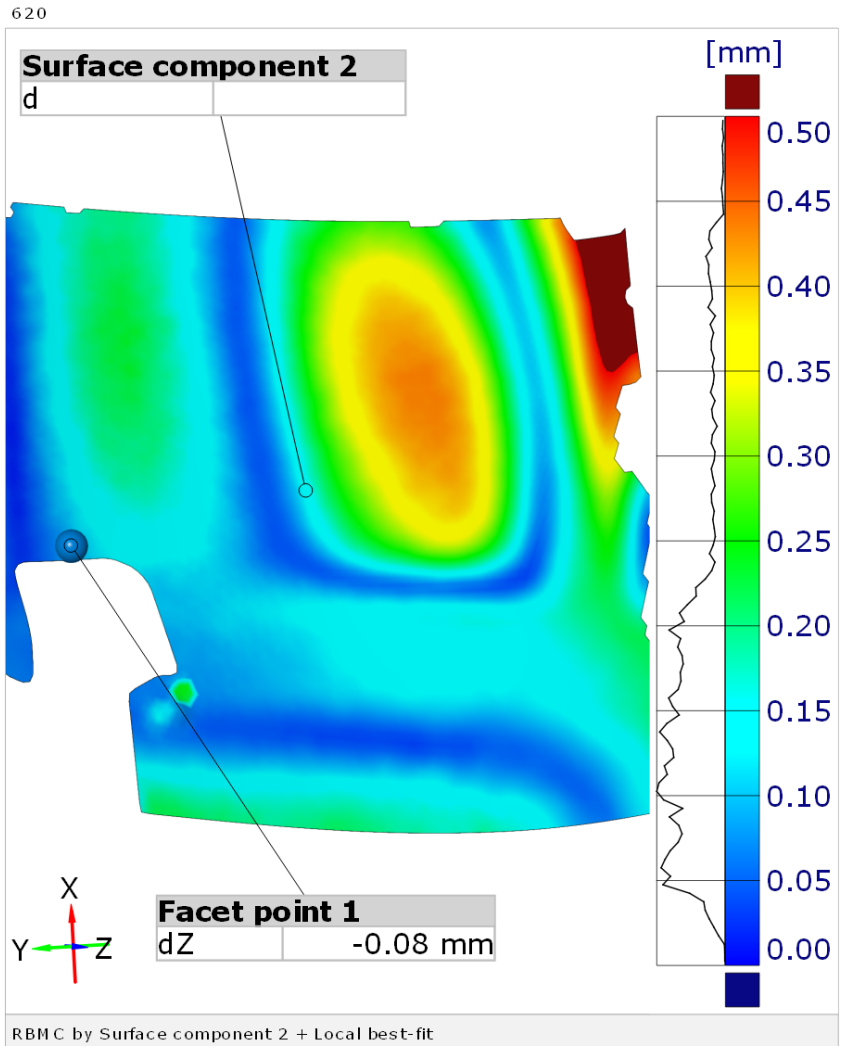
dZ - TOTAL DISPLACEMENT

The displacement measurements in any direction can easily be made with and without RBMC (Rigid Body Motion Compensation. Both 3D surfaces were measured at the stage time to display surface buckling.

Total Displacement



Total Displacement with RBMC



P1

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The highest strain was measured at Ref point 4. The coordinates of this point are:

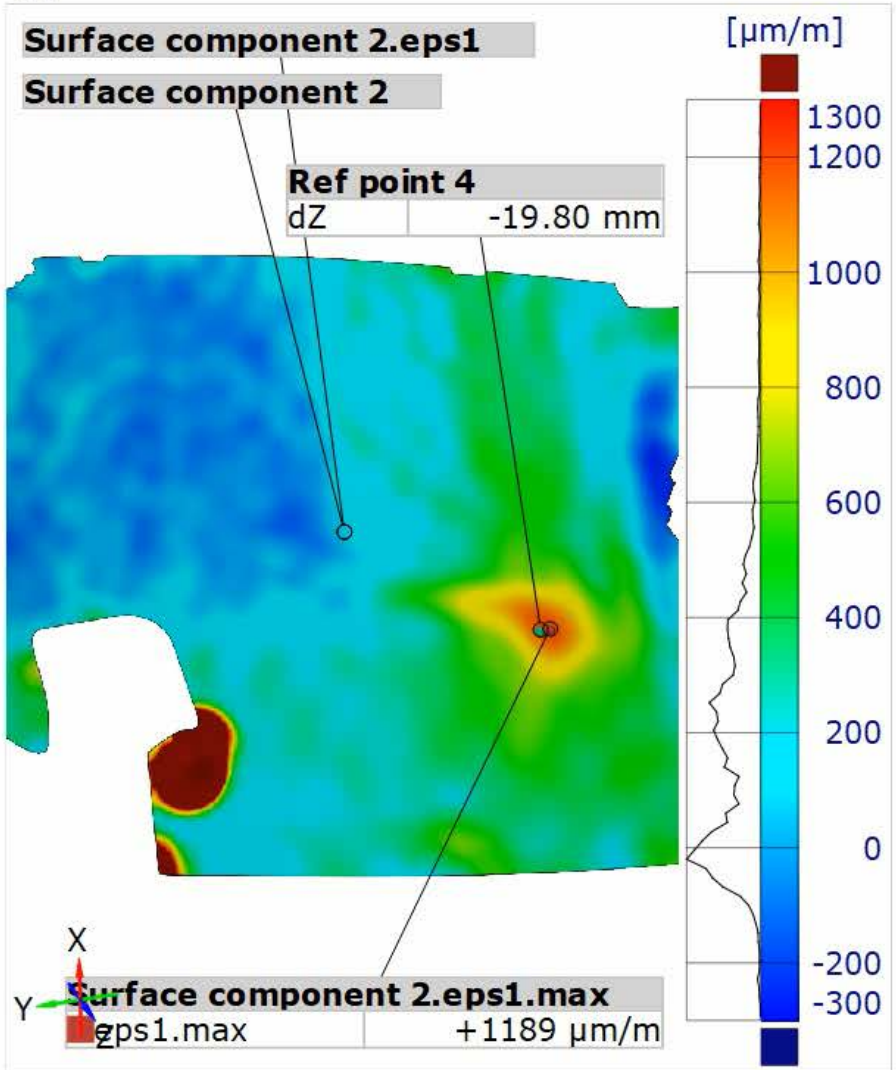
X:5860.0 mm

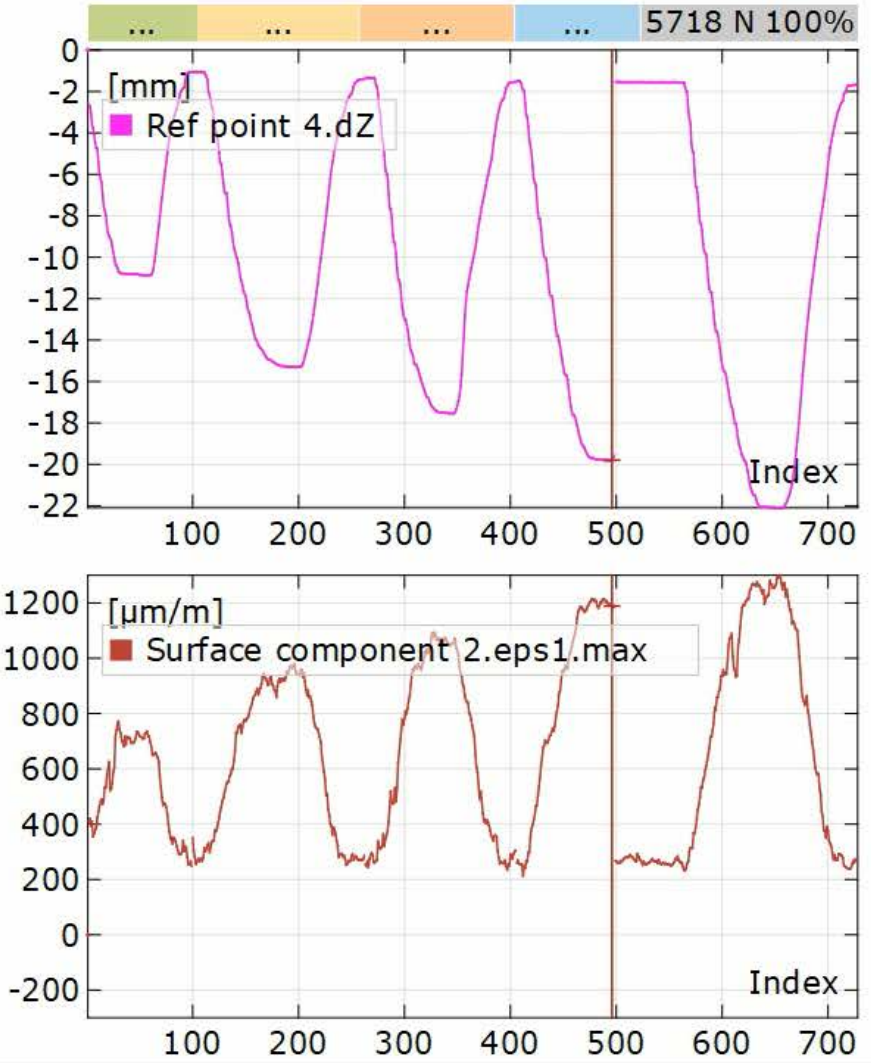
Y: 202.4 mm

Z: 891.6 mm

Major Strain

496



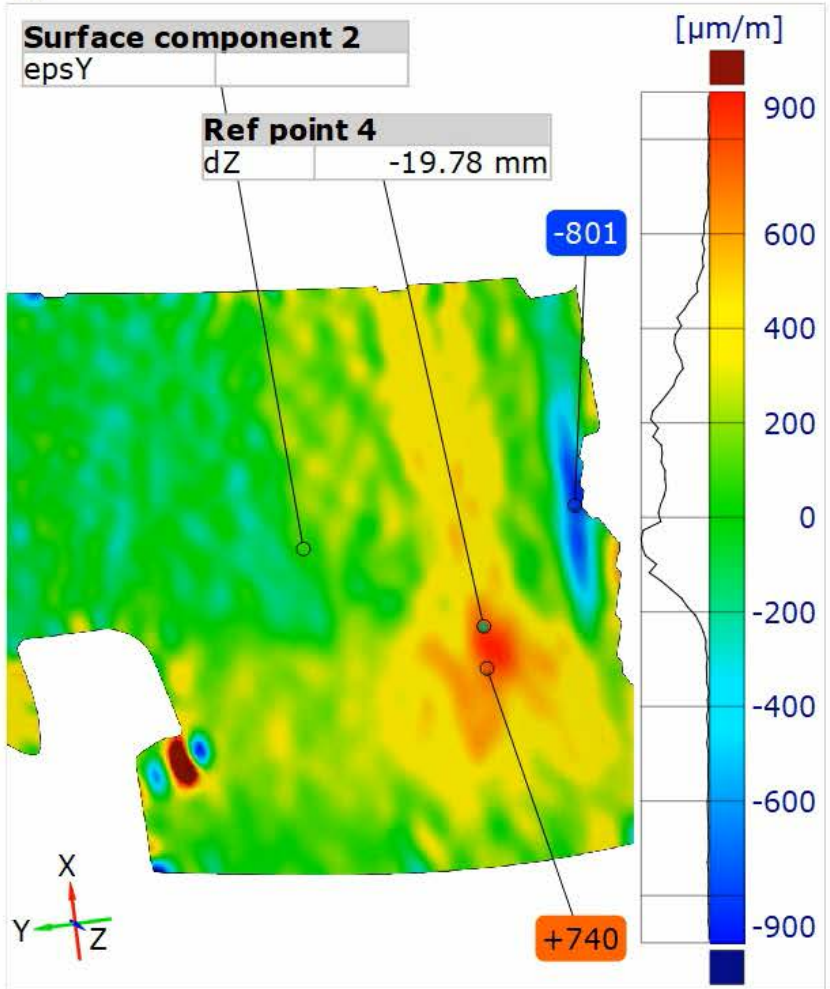


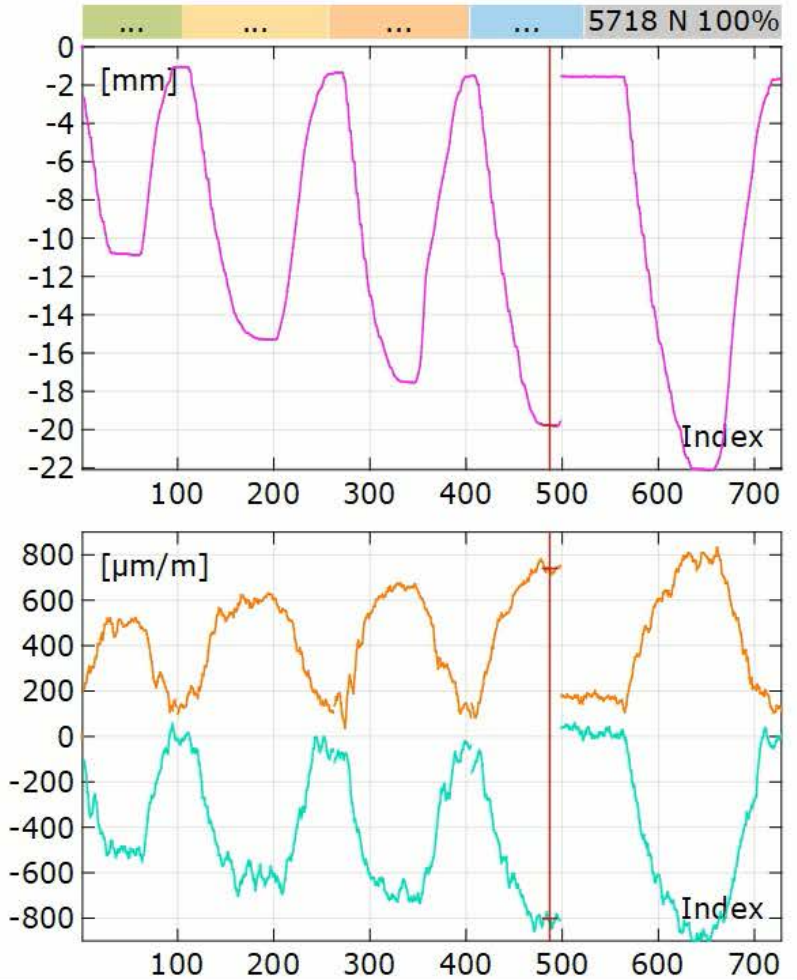
Local best-fit

-

Epsilon Y

487



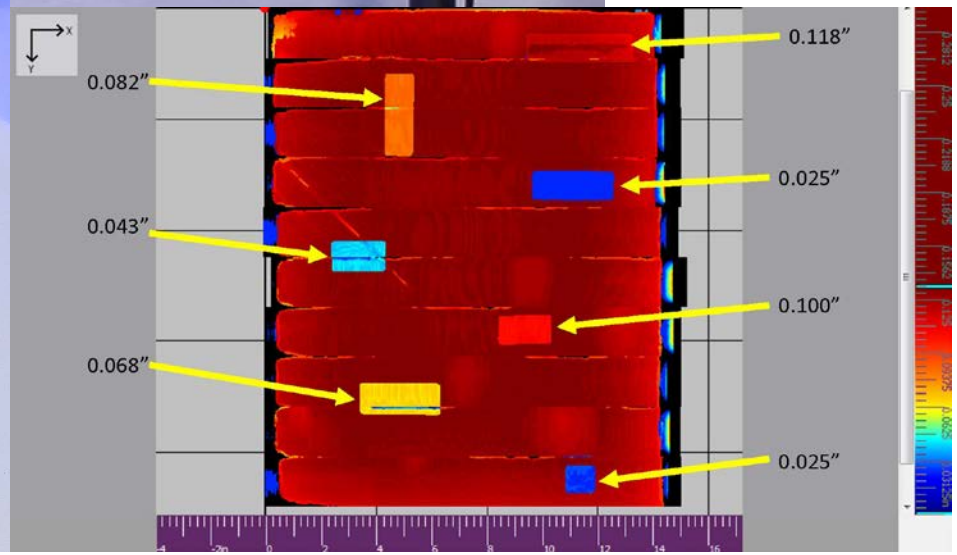


Local best-fit

-

POSITIONAL MEASUREMENT

ARAMIS Optical Strain tracking/mapping NDT Sensors



1. **6-DOF Tracking of NDT Sensor**
2. **Real-time Mapping to CAD/Surface**
3. **True Documentation of NDT Scans**
4. **3D Mapped into Xi Digital-Twin**

SuPAR™

AR Overlay Final Inspections

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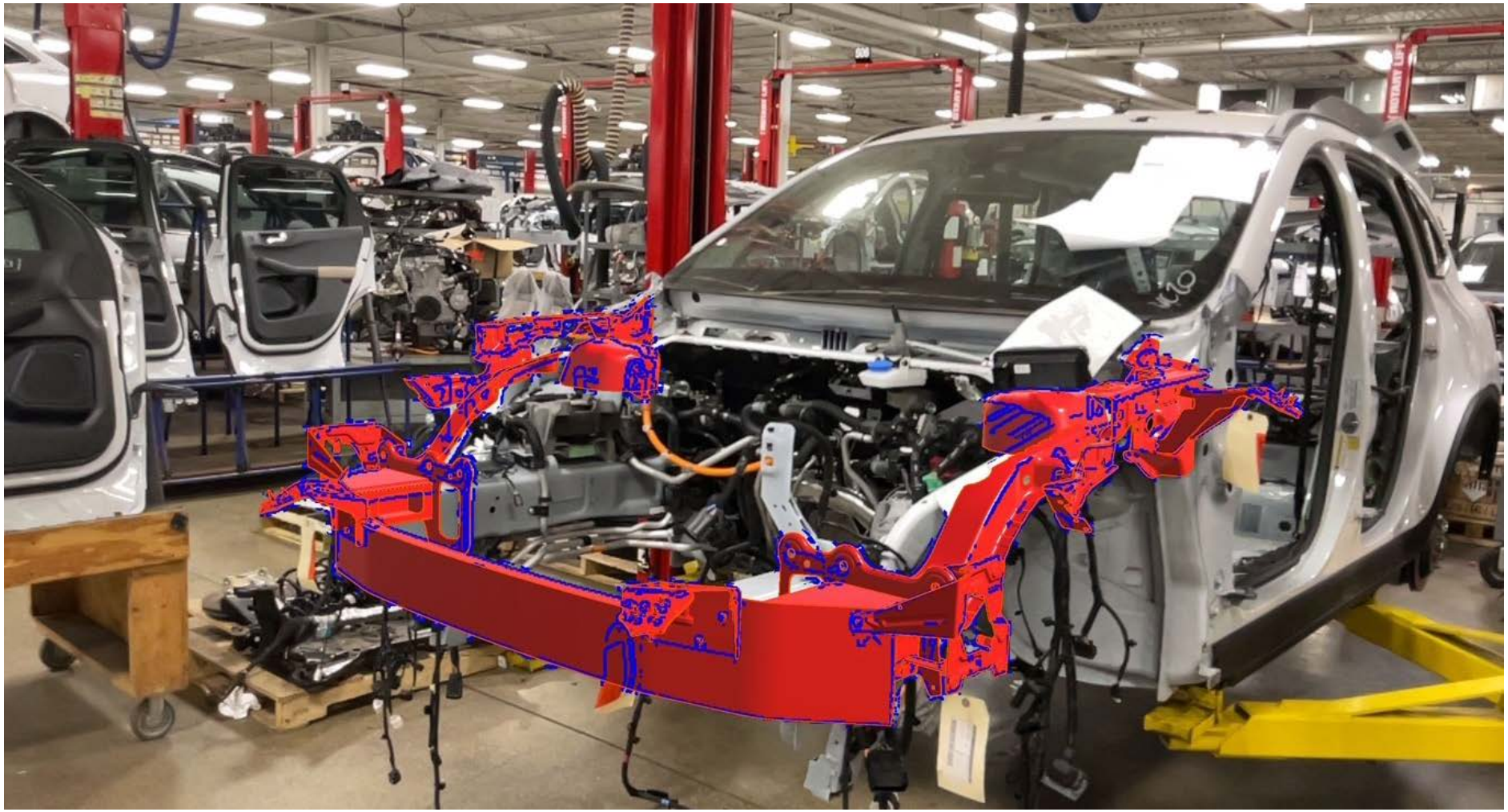

OPTICAL STRUCTURAL HEALTH MONITORING
ARAMIS – Strain on Turbine Blade after 1 year

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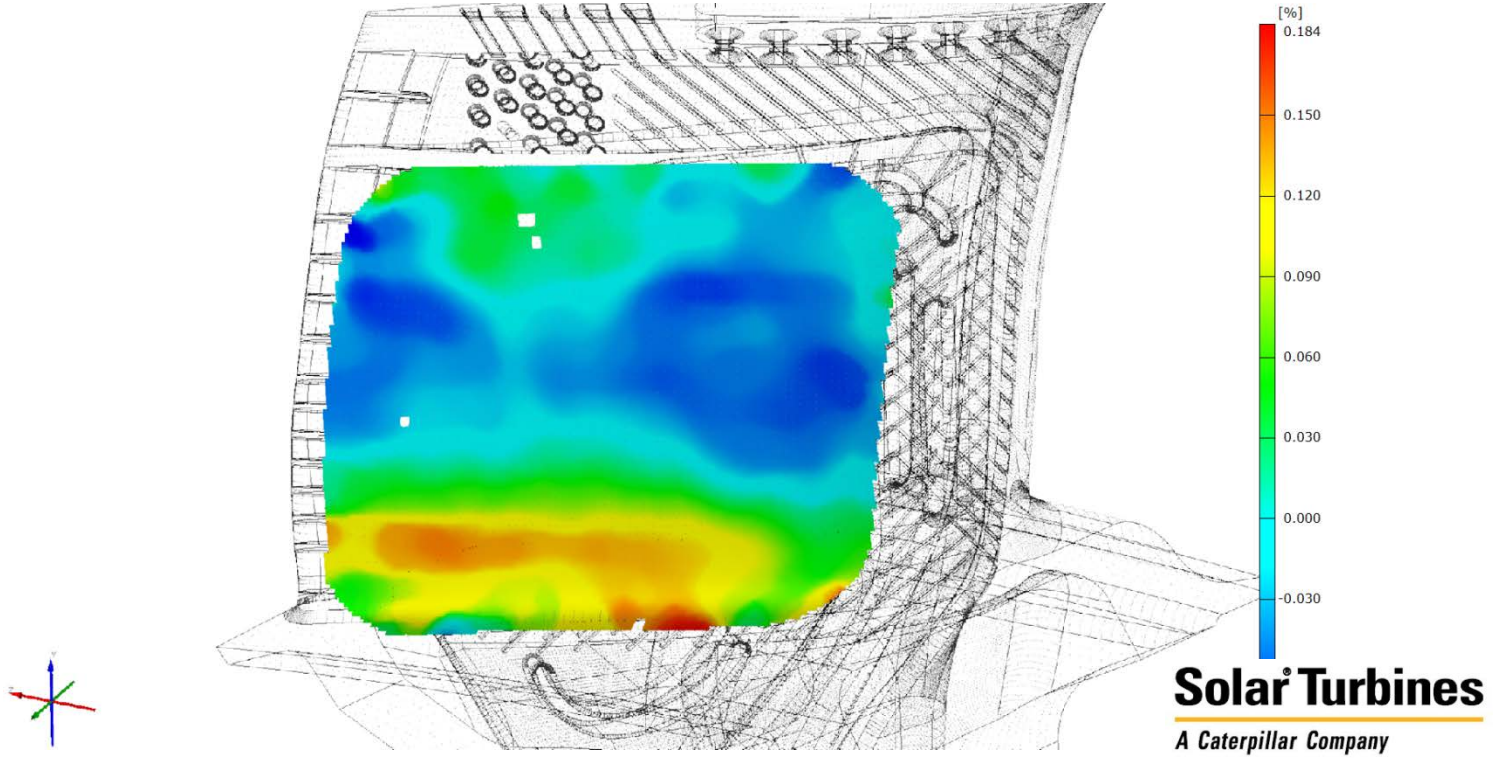

- **Creep Strain on set of turbine blades, running in an engine for 1 year, est. 10,000 hours.**
- **Special Pattern for long-term survival in hot section of jet engine.**

OPTICAL STRUCTURAL HEALTH MONITORING
ARAMIS / Xi Digital-Twin – Trilion Smart Paint

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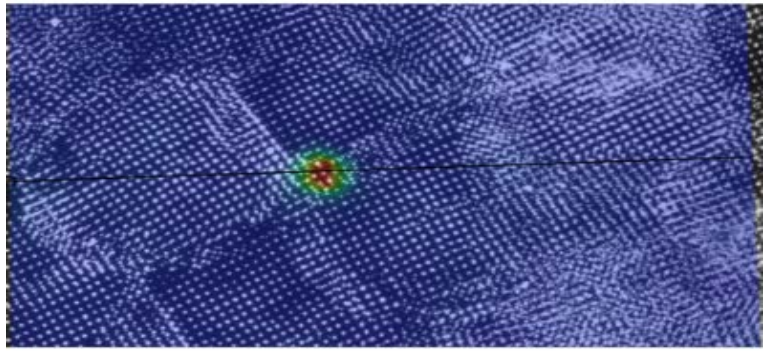
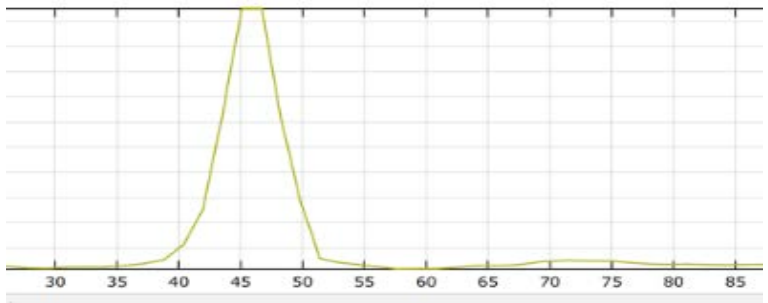
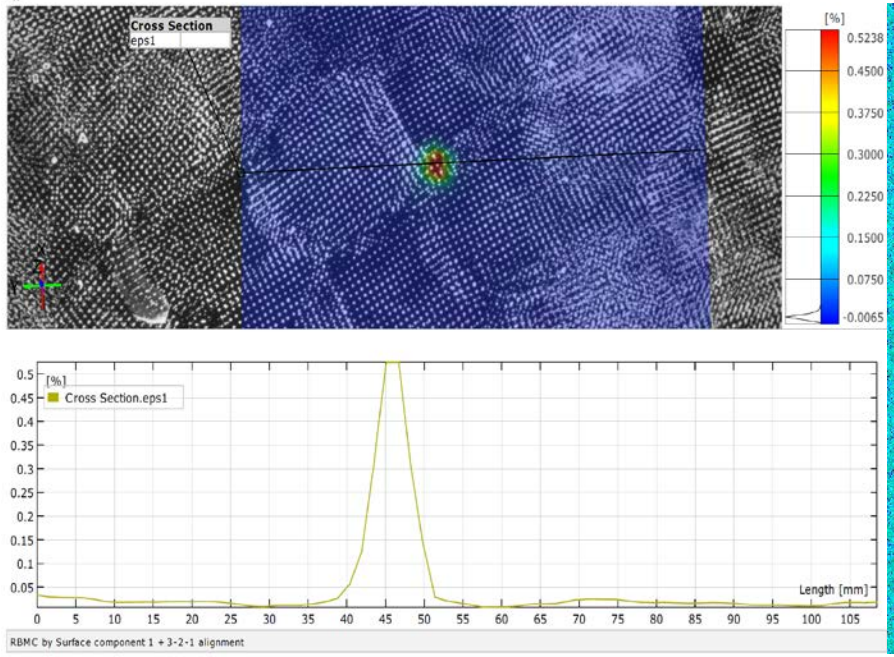
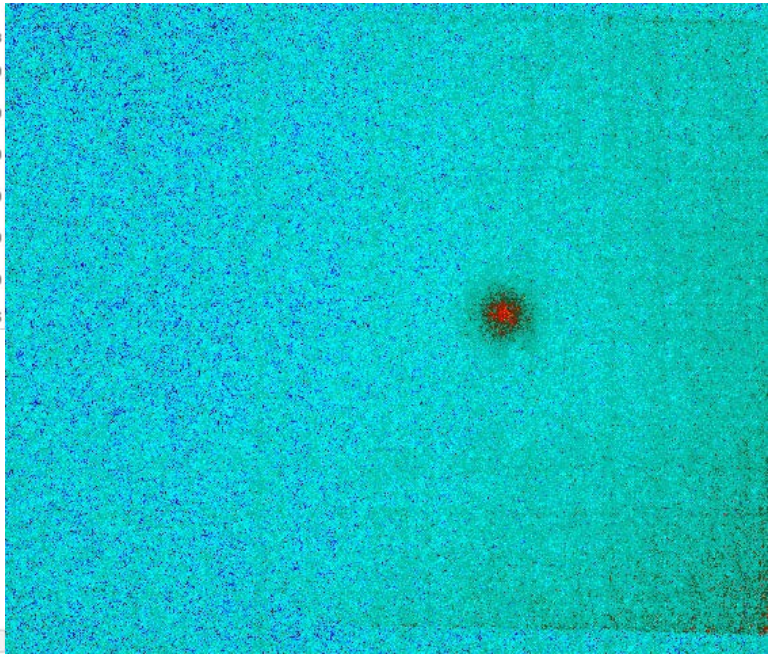




- **XiDT ARAMIS SHM Digital-Twin measurements detect slight changes over time of shape, 3D deformation and strain of all structures.**

OPTICAL STRUCTURAL HEALTH MONITORING
ARAMIS / Xi Digital-Twin – Trilion Smart Paint





- **ARAMIS found Barely Visible Damage (BVD) prior to Delamination.**
- **Thermography NDT detected delamination with highly loads (right)**

OPTICAL STRUCTURAL HEALTH MONITORING
ARAMIS / Xi Digital-Twin – Trilion Smart Paint

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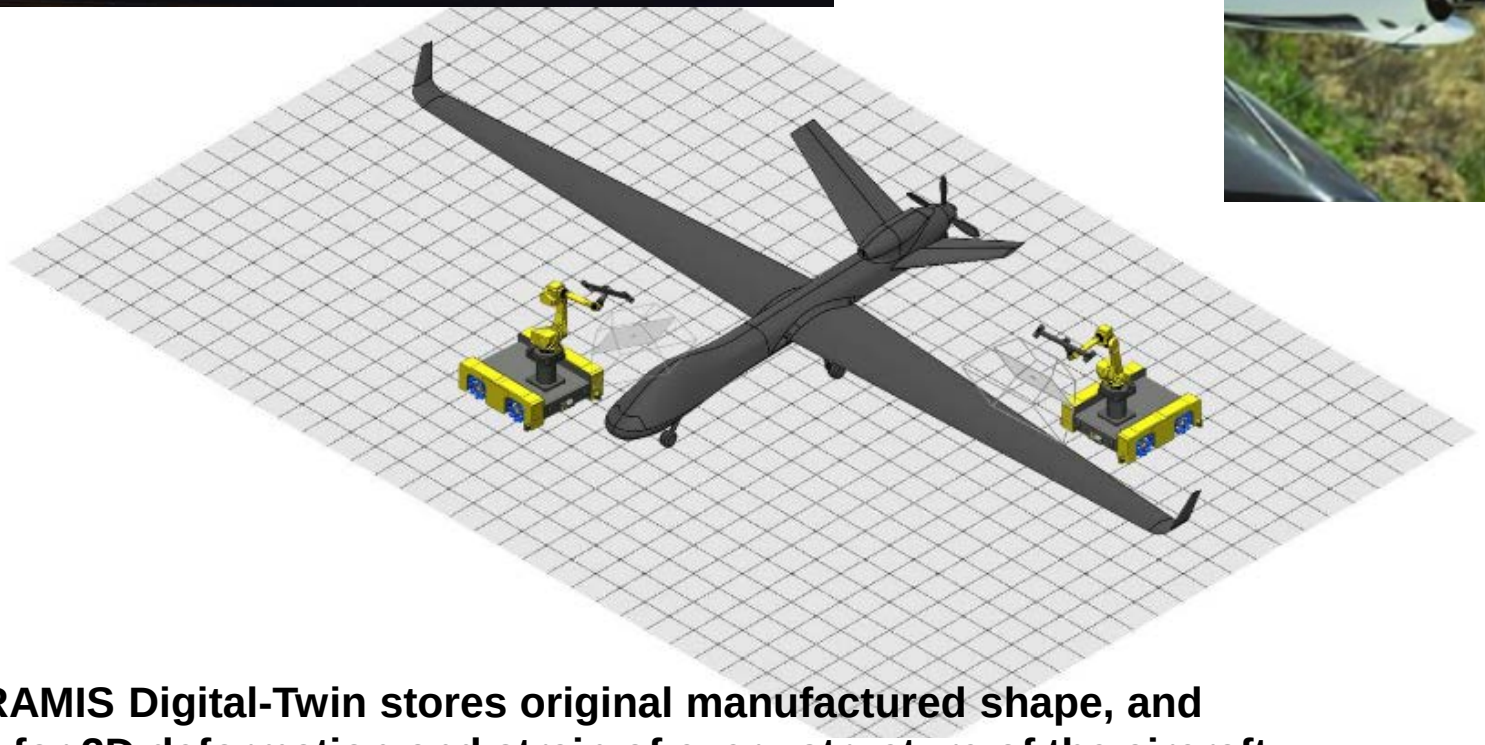

- **RVAT ARAMIS Digital-Twin stores original manufactured shape, and baseline for 3D deformation and strain of every structure of the aircraft.**

OPTICAL STRUCTURAL HEALTH MONITORING

ARAMIS / Xi Digital-Twin – Trilion Smart Paint

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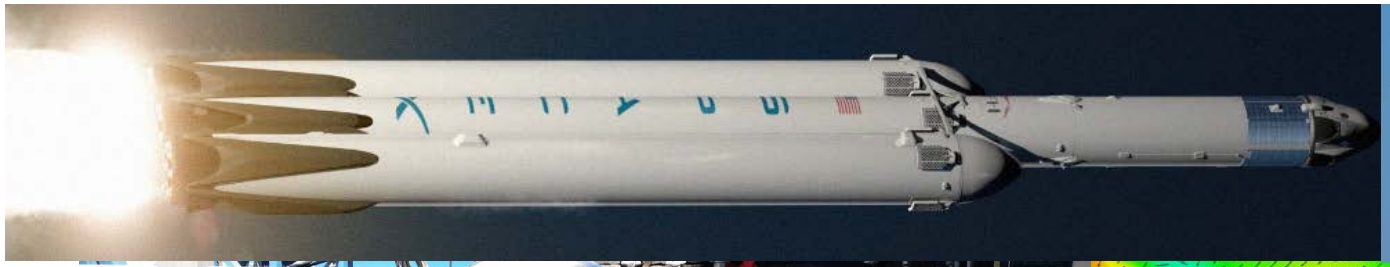

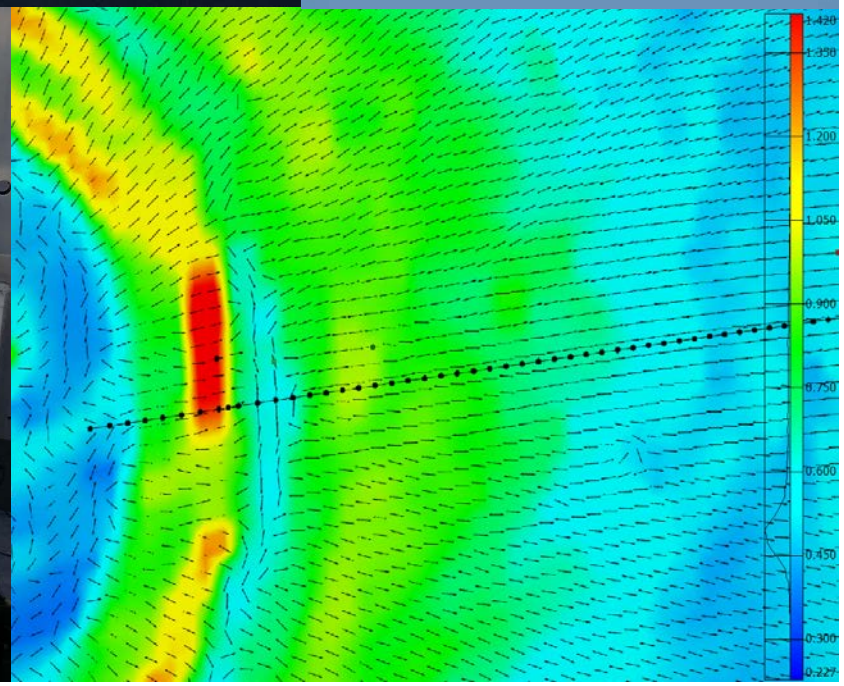

OPTICAL STRUCURAL HEALTH MONITORING

- **Reusability is a critical area for developing aerospace applications**
- **Enhanced Visual Inspection with the power of trillions of strain gages, provides a powerful tool for the future.**

ARAMIS OPTICAL STRAIN

Return-on-investment

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Customer	Application	ROI
Boeing	Replace Strain Gages, due to high cost VP: Find a better way!	10:1 Cost Savings 50:1 Man-power Savings 100:1 Data Improvement B787 FAA Certification
James Webb Space telescope	Structural Testing Replace LVDTs	1 week saved for each month of schedule $2M savings for a 3 month project
Alcoa	Material Properties measurements 3 systems under one engineer	32 days return on investment
General Motors	Quality Control in Stamping Operations in 15 stamping facilities + 6 die buyoff egrs	$100M/year saving $2M Investment
Ford Motor Company	Formability Studies	2,000 Man-hours/year per $80K
	Materials Properties Studies	Allowed change of material from steel to aluminum for F150 trucks

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“

You originally purchased the ARAMIS system for composite buckling studies, what are you using the system for now?

“EVERYTHING.”

— RON SALMINKO, BOEING

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QUESTIONS, OR MORE DISCUSSION?

THANK YOU ACMA!