The Digital Thread for Composite Repair

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Boeing Research & Technology

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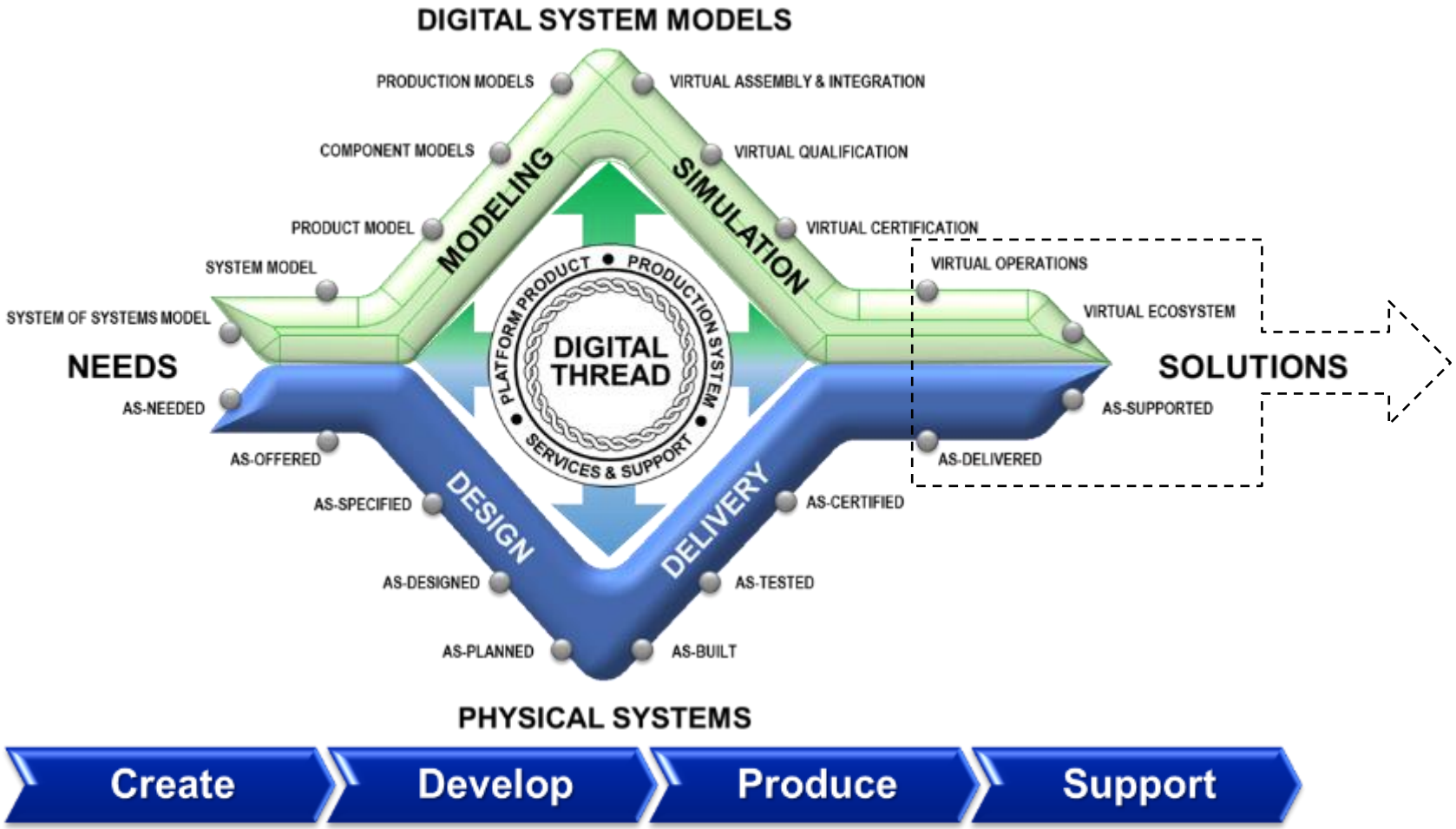
Digital Twin / Digital Thread Diamond

- **Digital Thread:** The communication framework that connects siloed elements and provides an integrated, authoritative database throughout the product lifecycle

- **Digital Twin:** An integrated digital simulation, enabled by Digital Thread, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin.



- Stable Design
- Stable Materials
- Stable Cert Database
- Well-Defined Business Cases
- Well-Defined Processes/Roles

- Scattered Data
- Data Capture (Front End)

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Composite Airframe Examples - Commercial

787 Dreamliner Composite Structures

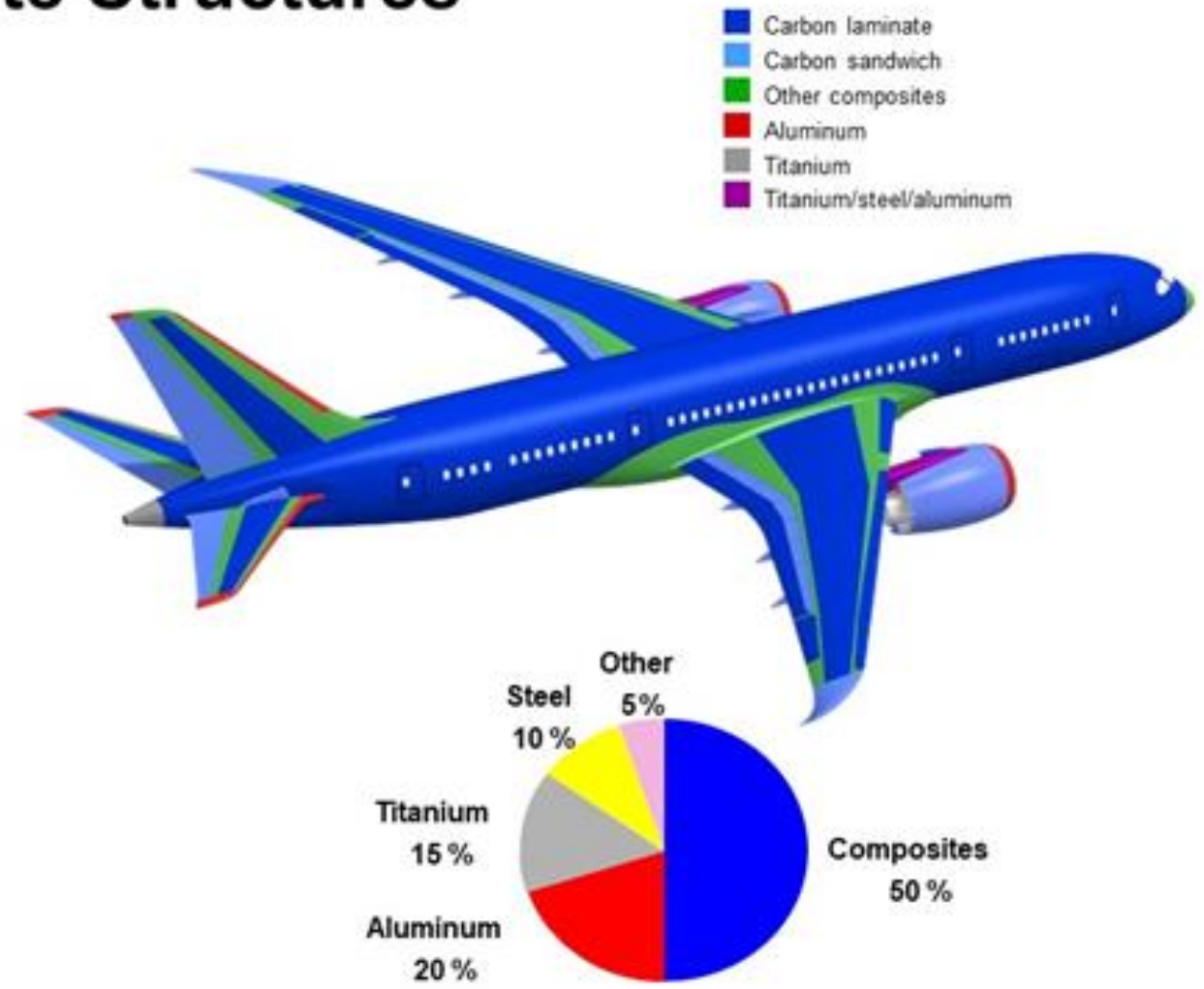
Lighter

More durable

Negligible corrosion and fatigue

Reduced scheduled maintenance

Opens new design possibilities



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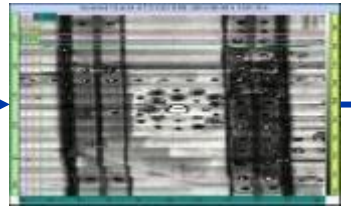
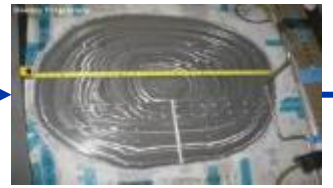
Composite Repair Flow

Damage Identified


Disassemble & NDI

Stress / Eng. Disposition

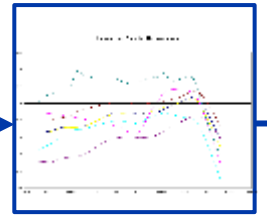

Taper Sanding

Create Master Template

Cut Plies

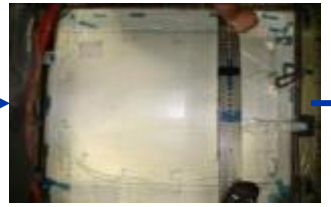
Assemble Patch

Perform Debulk

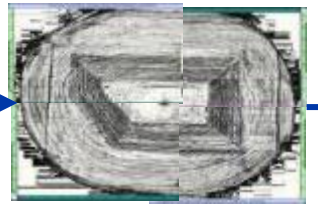

Thermal Survey
If Required

Drying Cycle

Install Patch


Cure Repair

Debag Repair
& Inspect


NDI Repair

Fill, Fair, Paint

Paper Work
Complete

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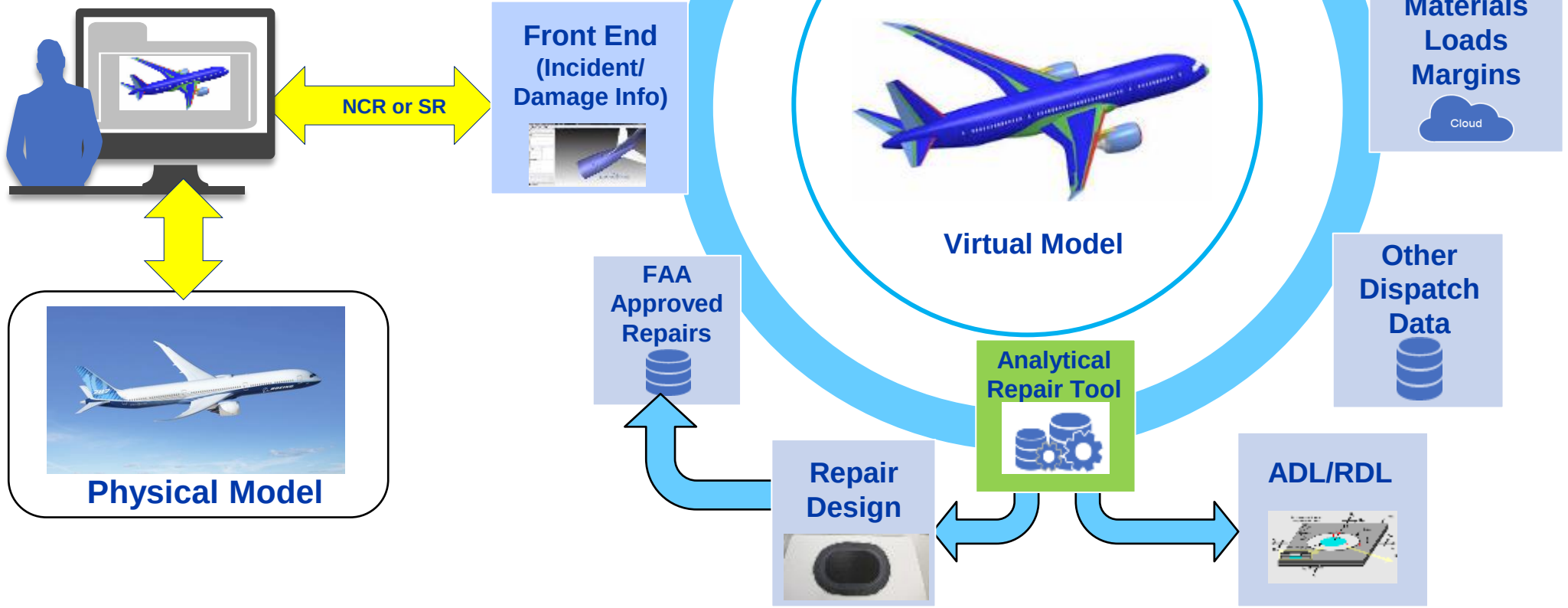
The Digital Thread for Structural Repair Analysis

Digital Thread
The communication framework that connects siloed elements and provides an integrated, authoritative database throughout the product lifecycle



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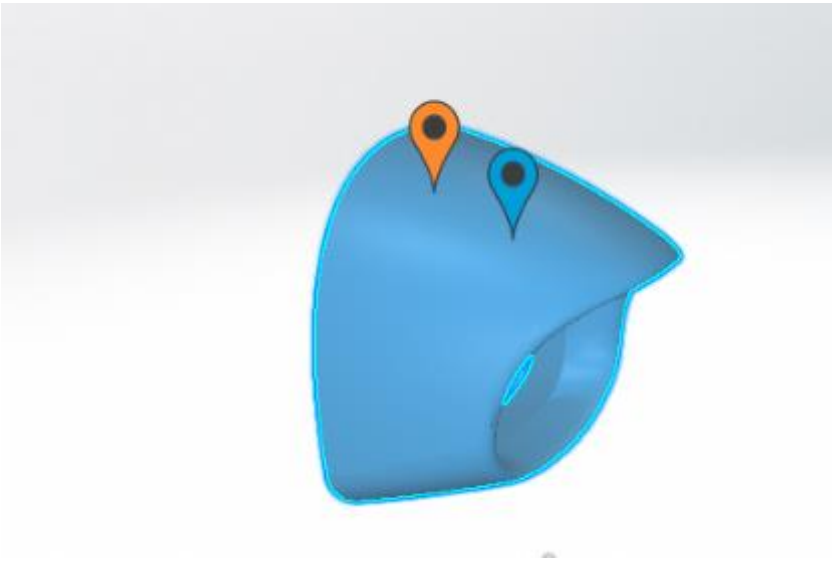
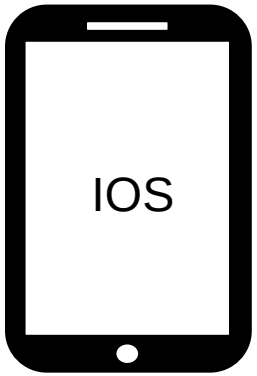
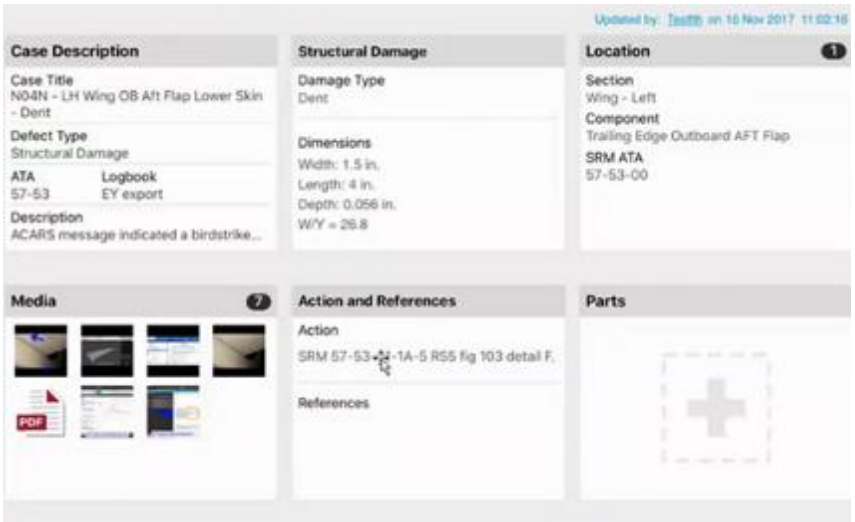
The Front End

- **Basics Requirements:**
  - Easy navigation to any part/location of an aircraft surrogate model
  - Record damage information on a **3D model** through a **structured data input** schema
  - Automatic generation of damage location **X, Y, Z coordinates**
  - Access and research critical information for troubleshooting non-routine defects at the airplane, such as **SRM** Allowable Damage Limits (**ADL**), Repairable Damage Limits (**RDL**), Common Repair Procedures, etc.
  - Communicate in real time with maintenance and engineering personnel during troubleshooting
  - Access aircraft maintenance history
  - Add photos or NDI data to a case from a mobile device







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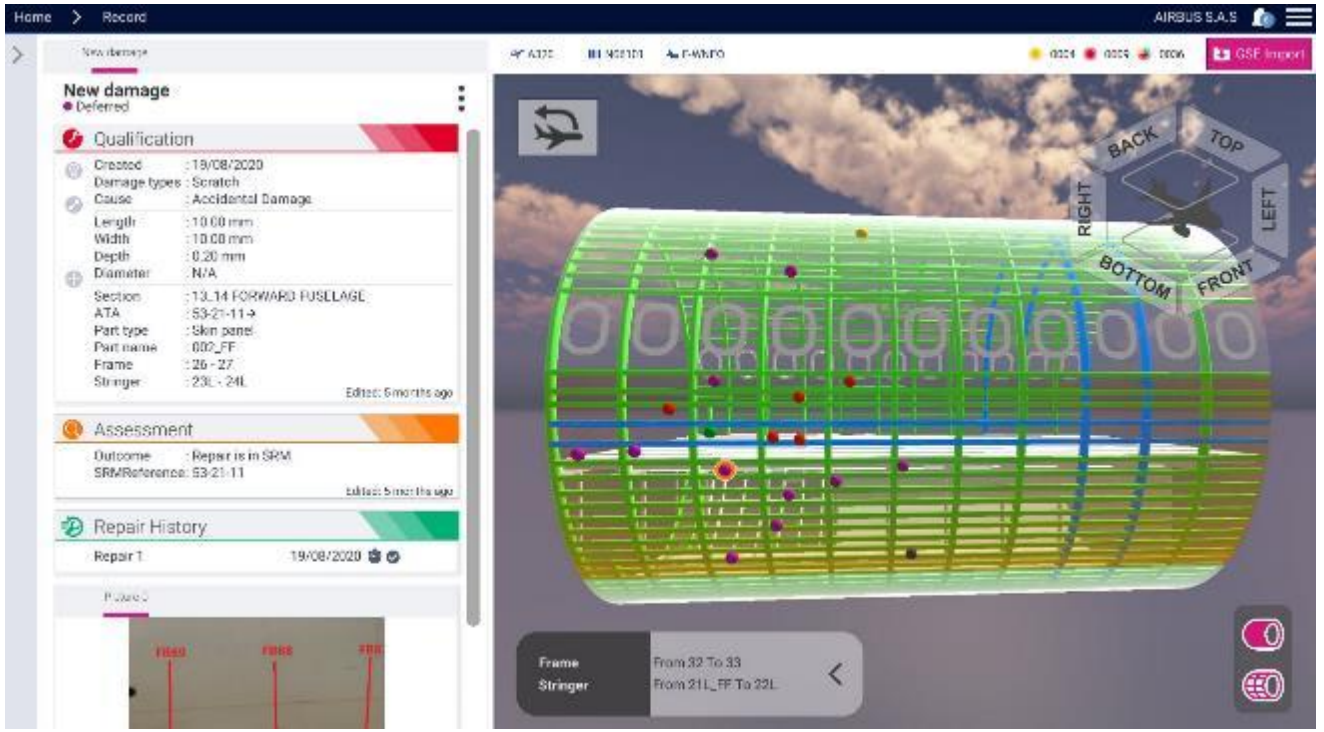
Public Domain Offerings

- **NLign Analytics (DoD Focused)**

- **eTech 3DRepair**

  A mixed fleet integrated solution for recording, assessing, monitoring and reporting aircraft structural damage via a tablet based portable tool (Airbus Services, Feb 2021)



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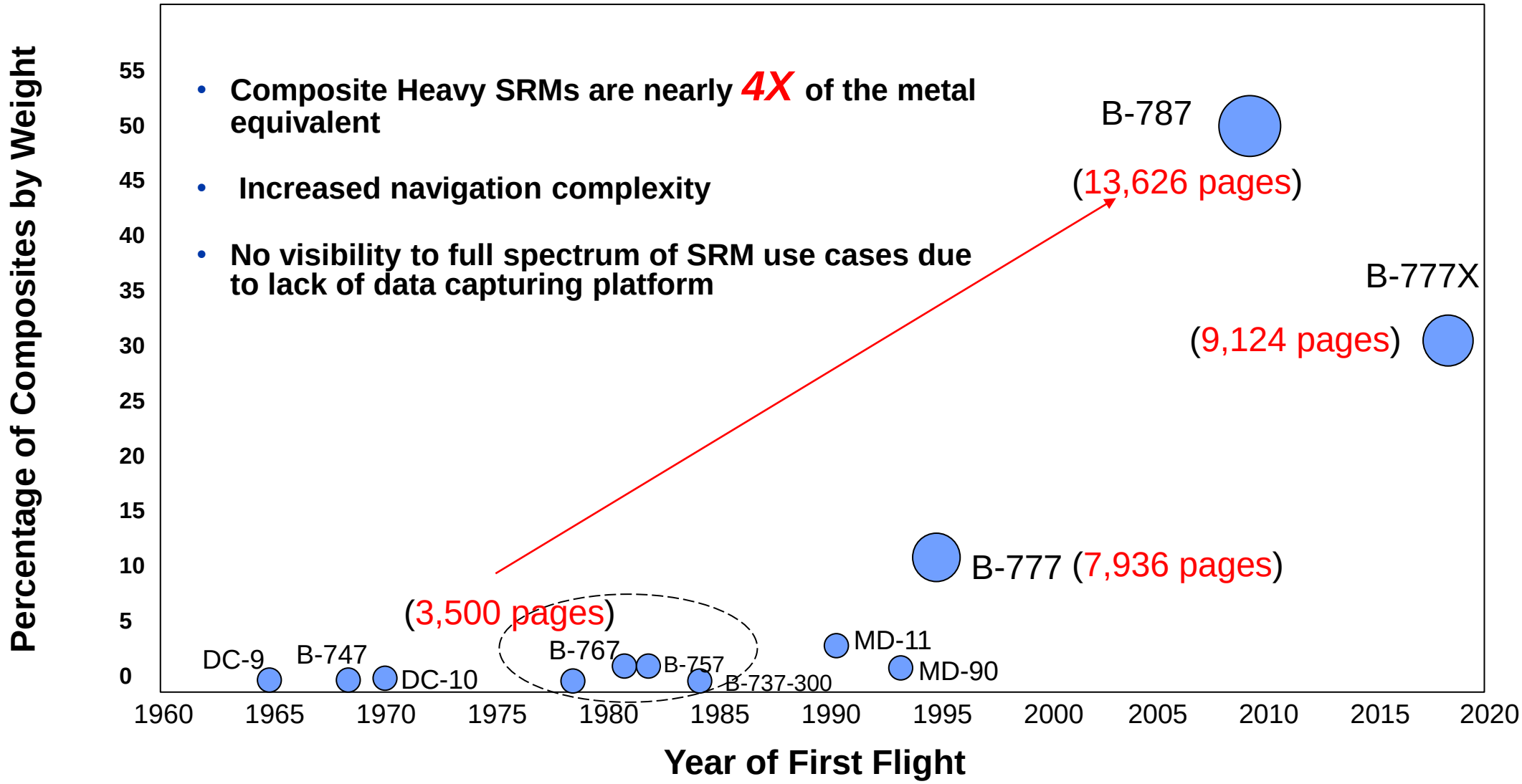
Structural Repair Manual (SRM) Needs a Digital Make-over



Smart SRM with location-based automated ADL/RDL represents a huge opportunity

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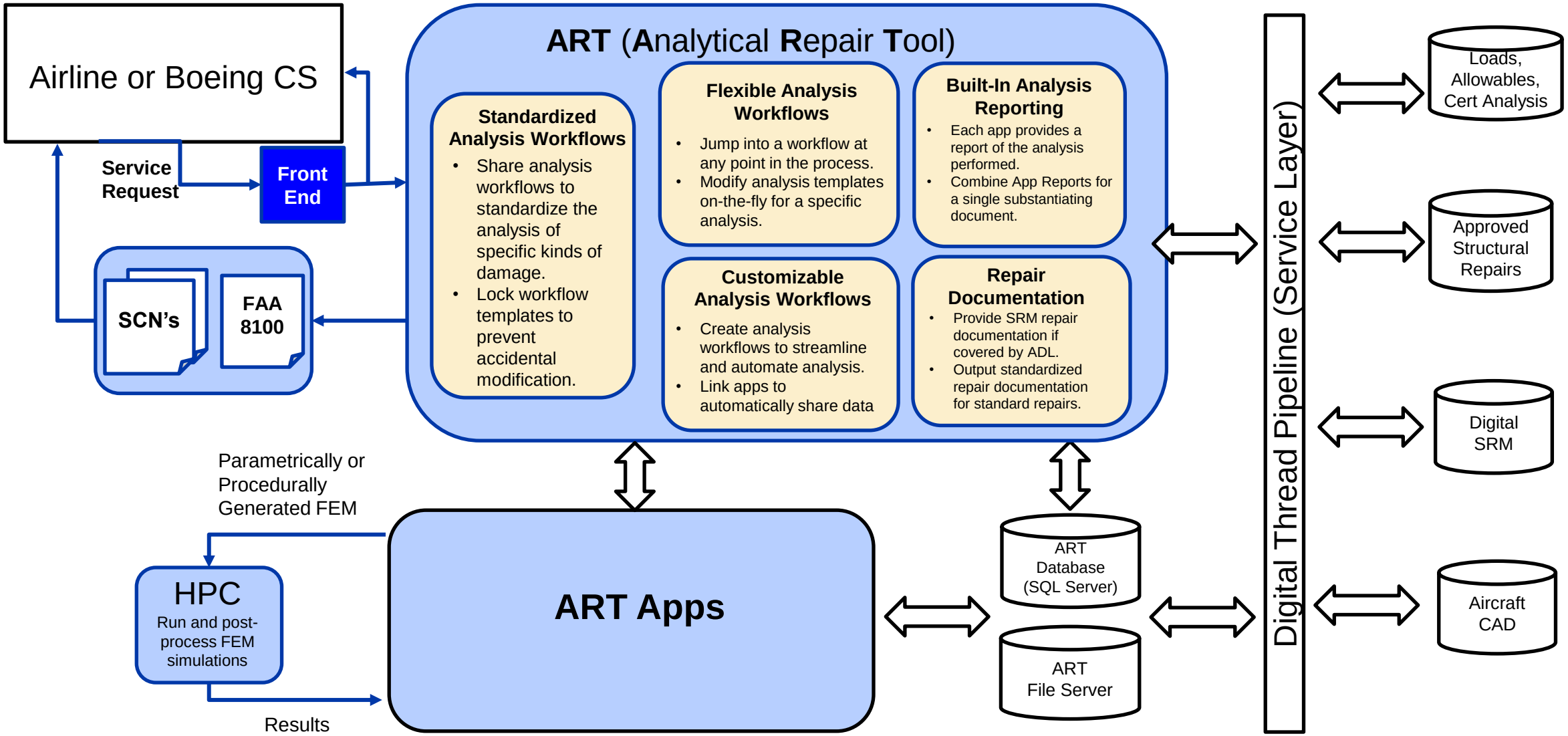
Digital Thread – Analysis Centric View



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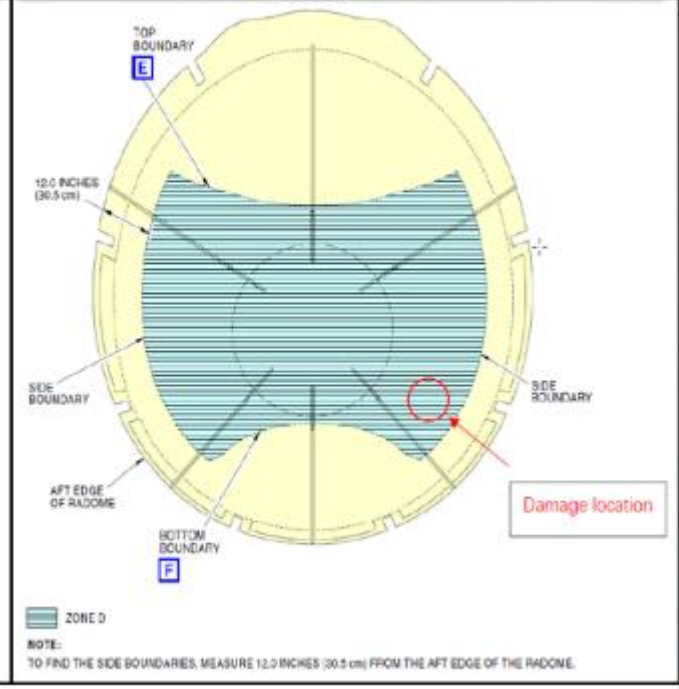
Automated Radome Dent Analysis

Zone:	6-2
Use Cache Loads?	No

Pull Loads | **Build Cache** | **Import Damage Sketch** | **Import Damage Photo**



Write PDF

Graphic Damage Location Input

Automated Loads

→

CSW Template ADL Impact Analysis

→

- ADL Impact Analysis Min Nx.csz
- ADL Impact Analysis Min Nx.pdf
- ADL Impact Analysis Min Ny.csz
- ADL Impact Analysis Min Ny.pdf
- ADL Impact Analysis.csz
- Rapid Radome Dent Analysis Tool v2_0.xlsm

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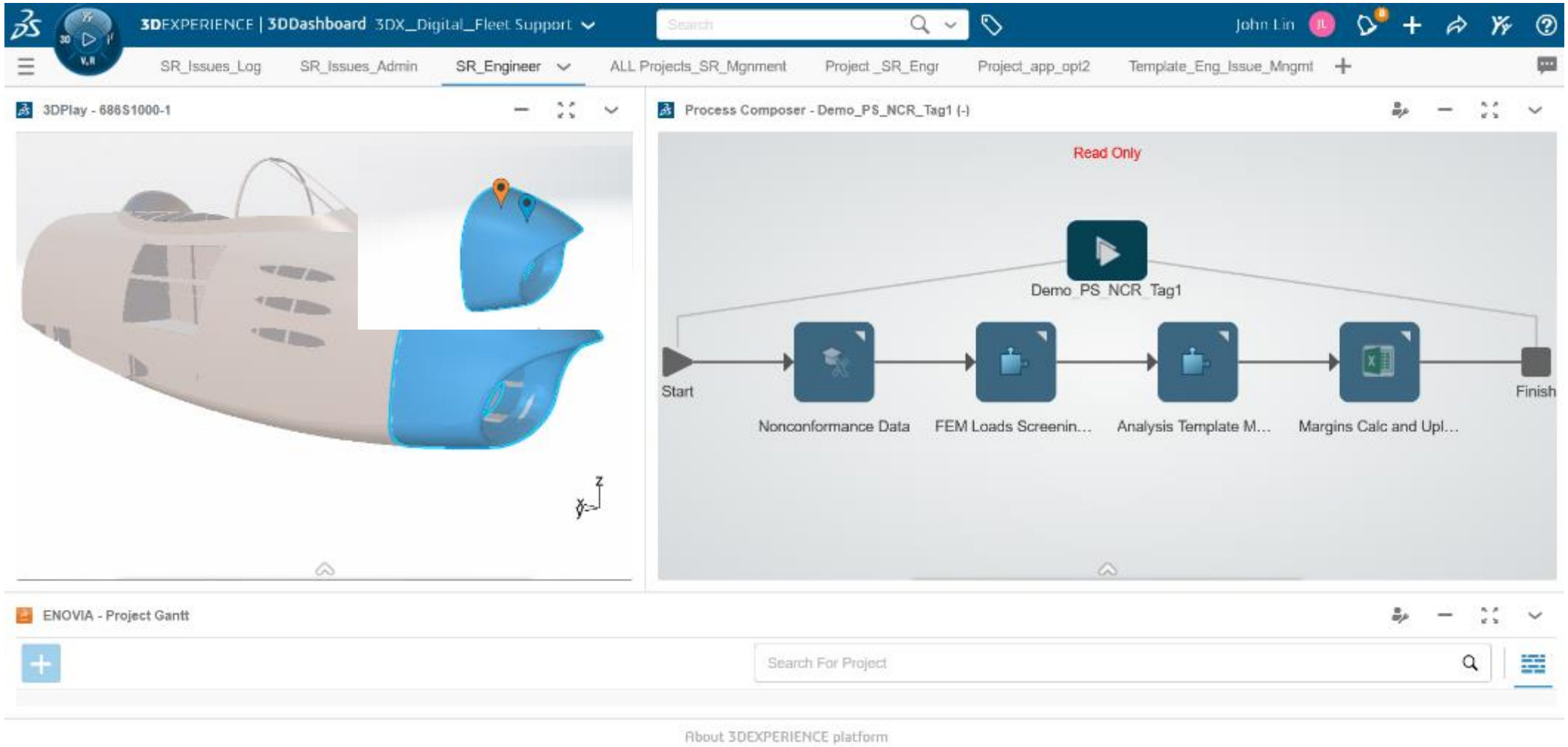
Integrated Digital Environment (IDE)

- **3DEXPERIENCE Example**



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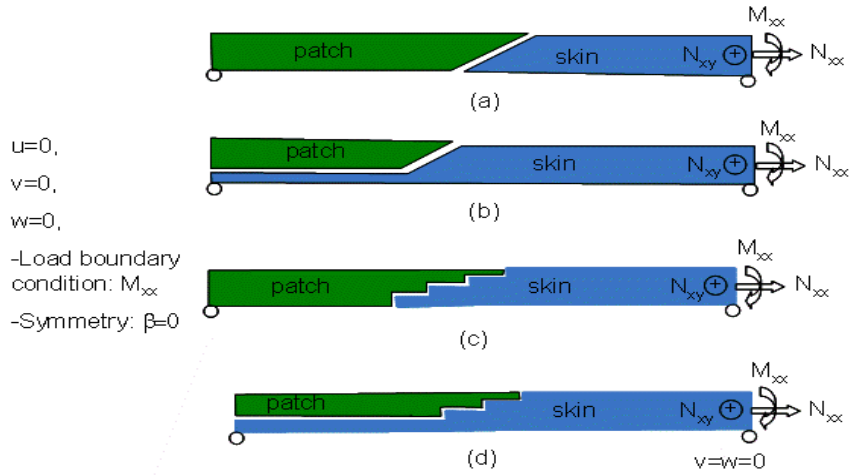
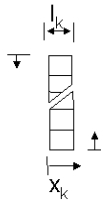
Scarf Joint Method (SJM)

- Category: Closed-Form
- Application: Bondline analysis (strength and damage tolerance) of a **scarf** or **multiple step joint/repair**
- New capabilities:
  - Peel and shear ***Coupling*** (beyond A4EI capabilities)
  - ***Disbond/delamination*** (beyond VCTeM capabilities)
  - Non-matching patch/parent material or thickness



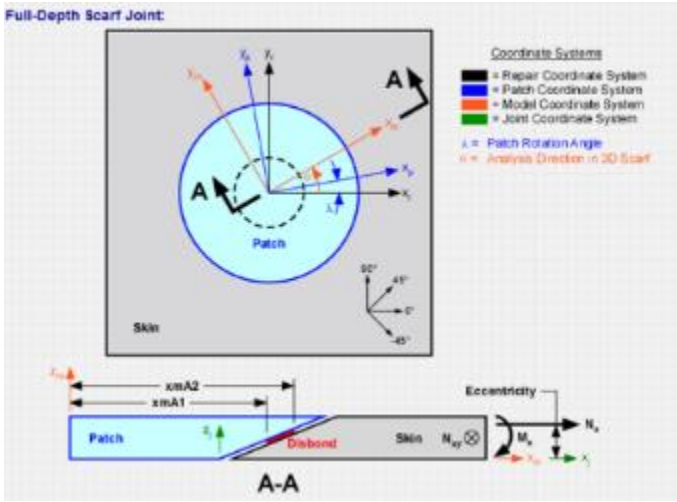
$t_s(x_k) = t_1 + t_2 + x_k * ratio * l_k$

$t_p(x_k) = t_{full\text{-}patch} - t_s(x_k)$



$$G_{II} = \frac{1}{2} \cdot \frac{F_x \cdot \Delta U_x}{\Delta a}$$

$$G_I = \frac{1}{2} \cdot \frac{F_y \cdot \Delta Uy}{\Delta a}$$



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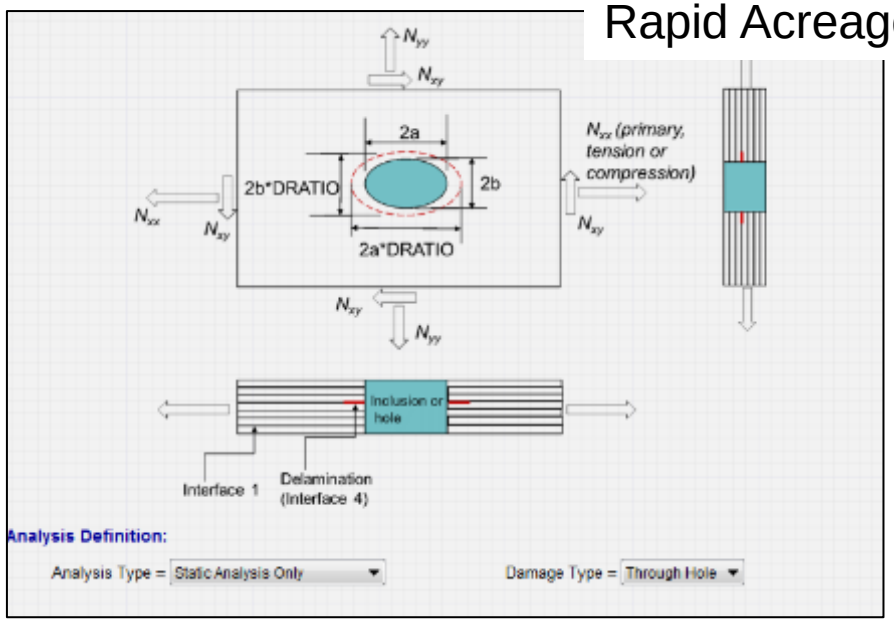
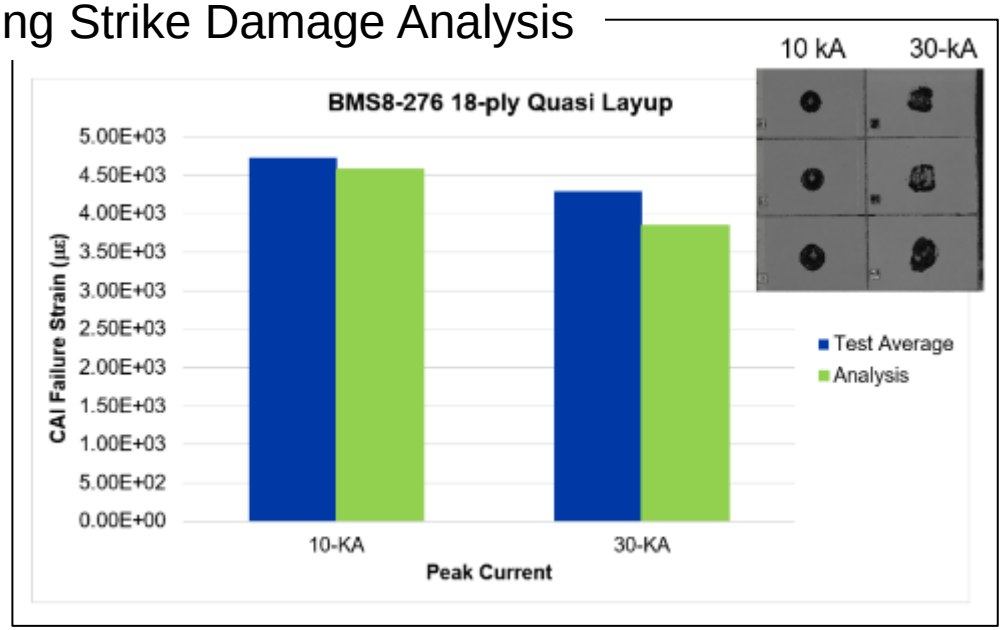
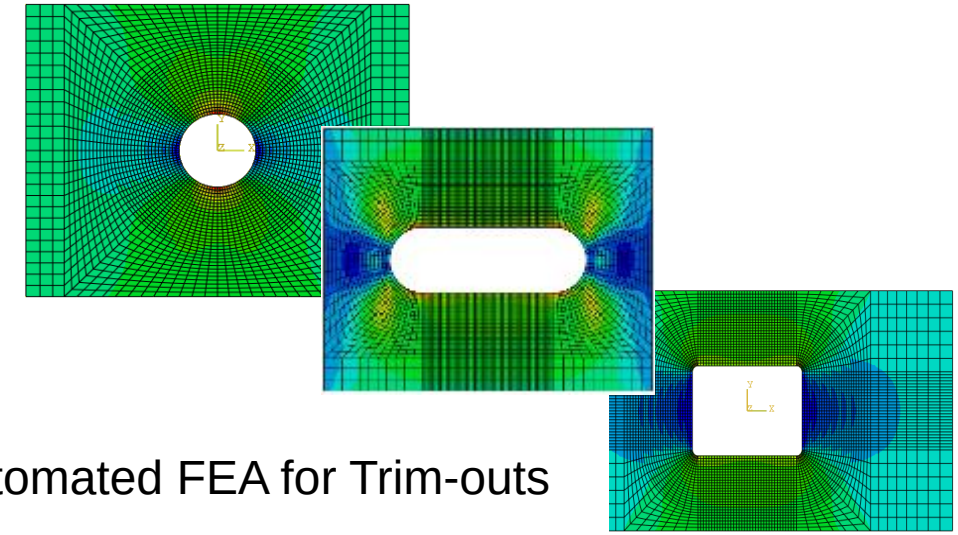
Other Repair Analysis Tools for 3DX

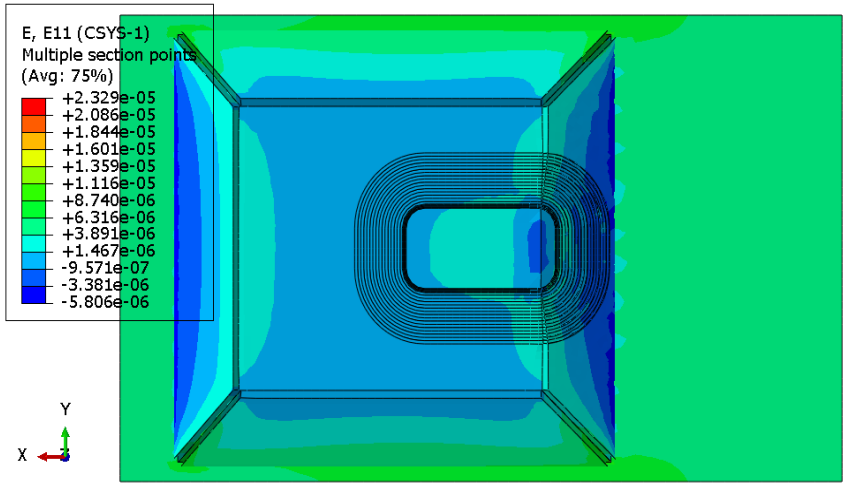
Rapid Acreage Lightning Strike Damage Analysis







Automated FEA for Trim-outs



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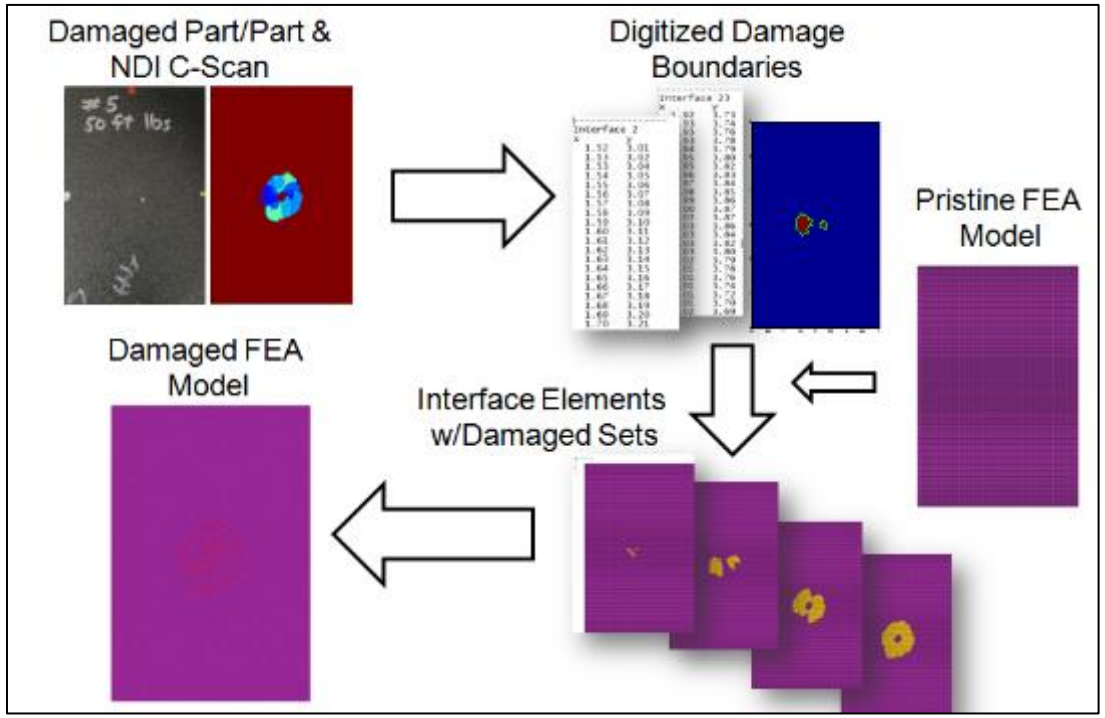
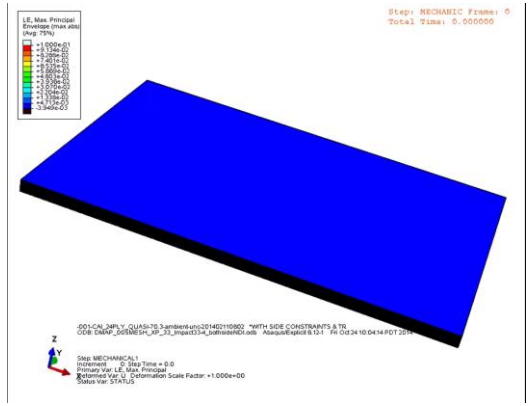
Damage Mapping

- **Customer/Need**
  - Reduce testing cost for barely visible impact damage (BVID)
- **Outcome**
  - Innovative solution combining real NDI data and FEM-based progressive failure analysis (PFA). Patent pending.
  - Damage mapping tool integrated with parametric FEA tool
  - Validated by Compression After Impact (CAI) tests
- **Impact**
  - Enable condition-based, in-situ damage assessment
  - Enable “Smart Testing” with reduced cost





Animation

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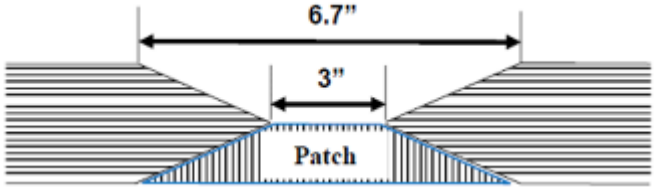
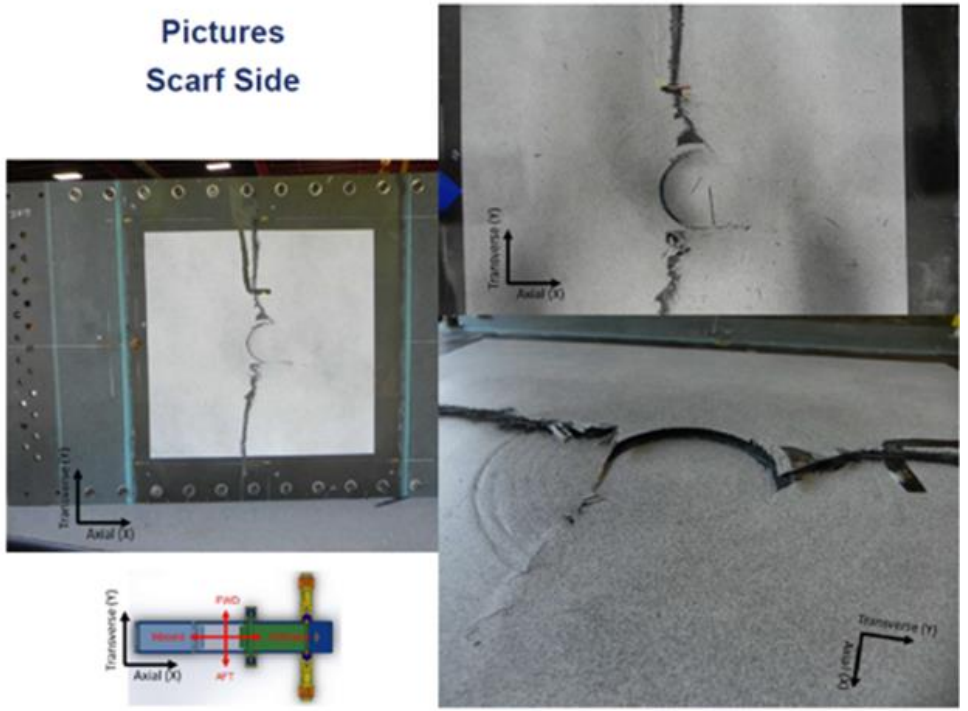
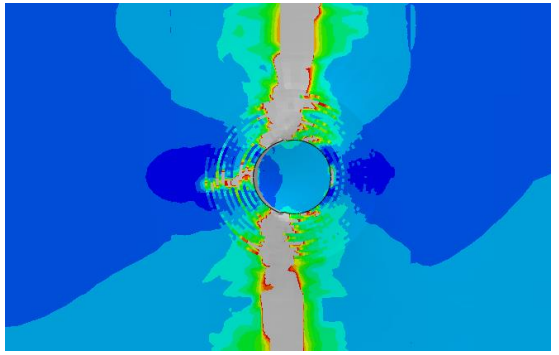
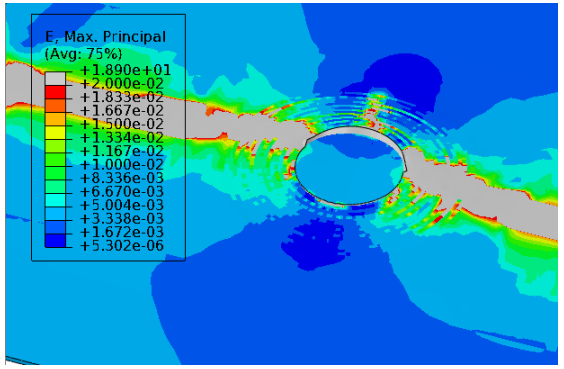
Scarf Repair Fail-Safety

- **One-side repair patch remaining**
- **Progressive Failure Analysis Performed using Helius Continuum Damage Model (CDM)**









Progressive Failure Analysis for Smarter Testing

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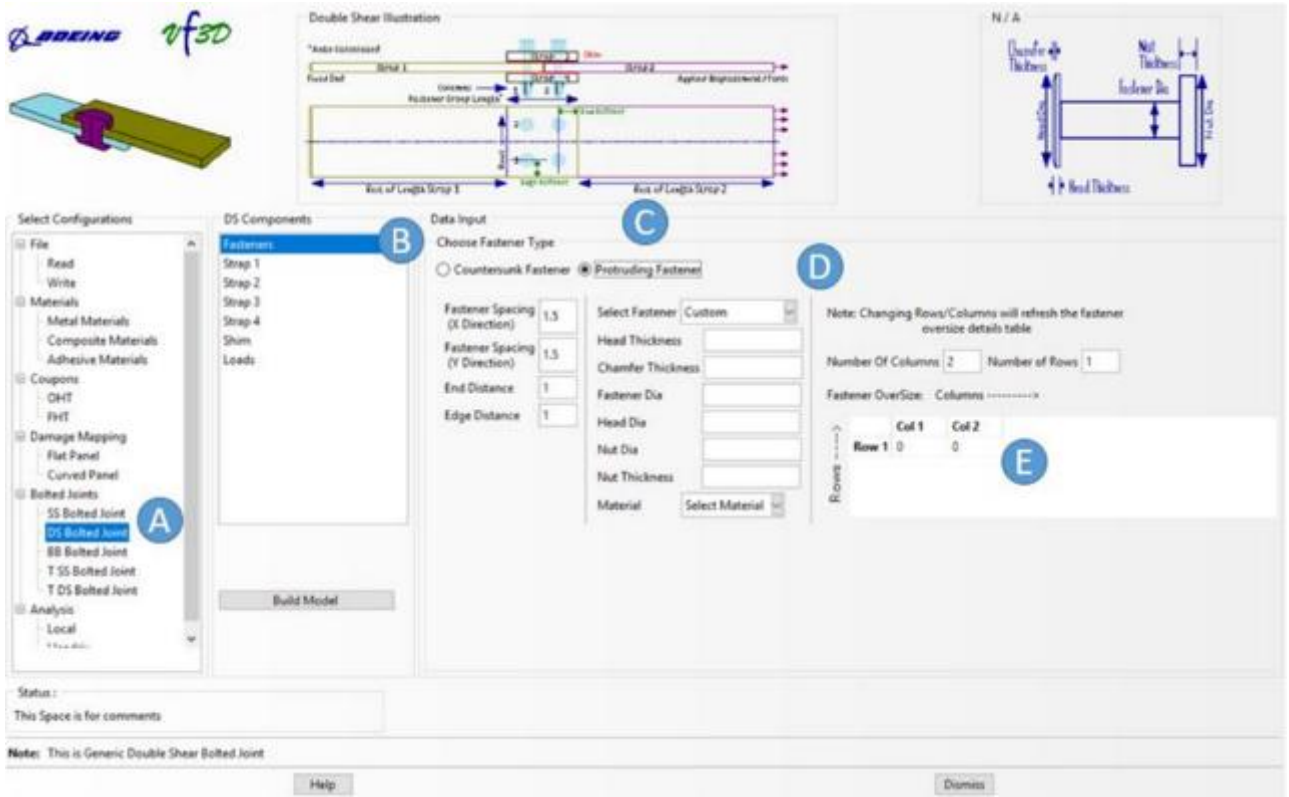
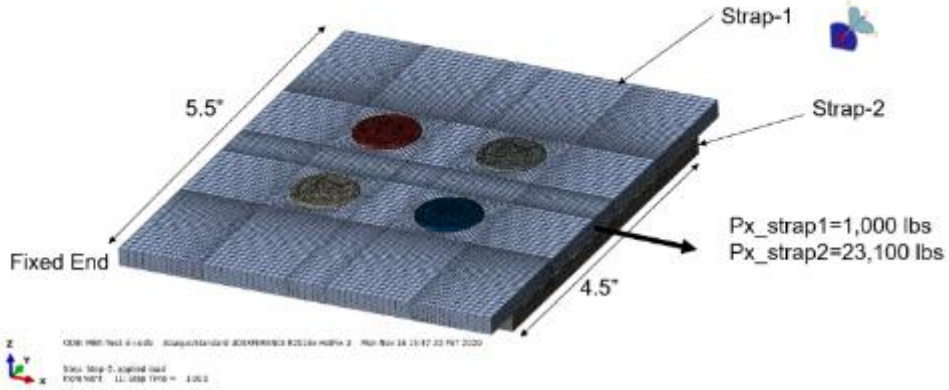
Fully Parameterized Bolted Joint Model – *Vari-Fast3D*

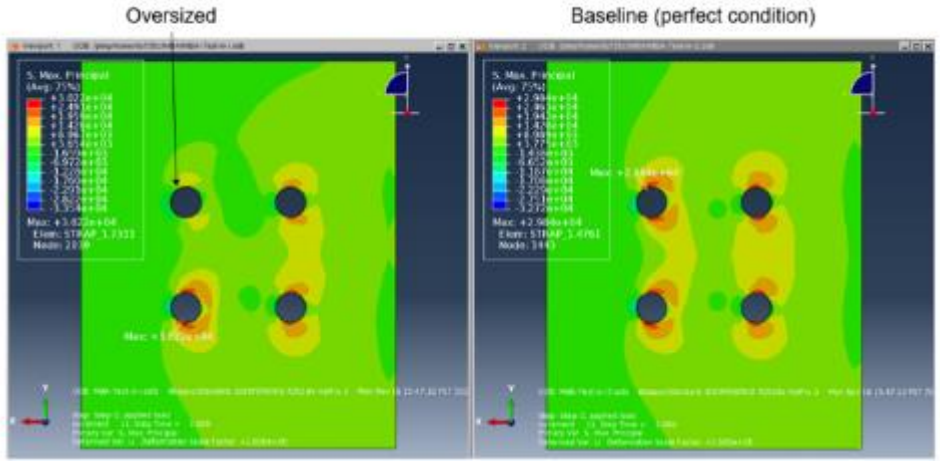
- BR&T developed ABAQUS plug-in for parametric bolted joint detail modeling



Generic Bearing Bypass Model



One fastener hole oversized by 0.01"



A. Joint Configuration (SS, DS, Tapered Joint, generic bearing bypass)
B. Joint Component Definition (two straps + shim)
C. Fastener Library/Custom (Protruding Head, Counter-sink)
D. Fastener Pattern (up to 4 x 4 array)
E. Oversizing (Pre-load included, specifiable hole/fastener)

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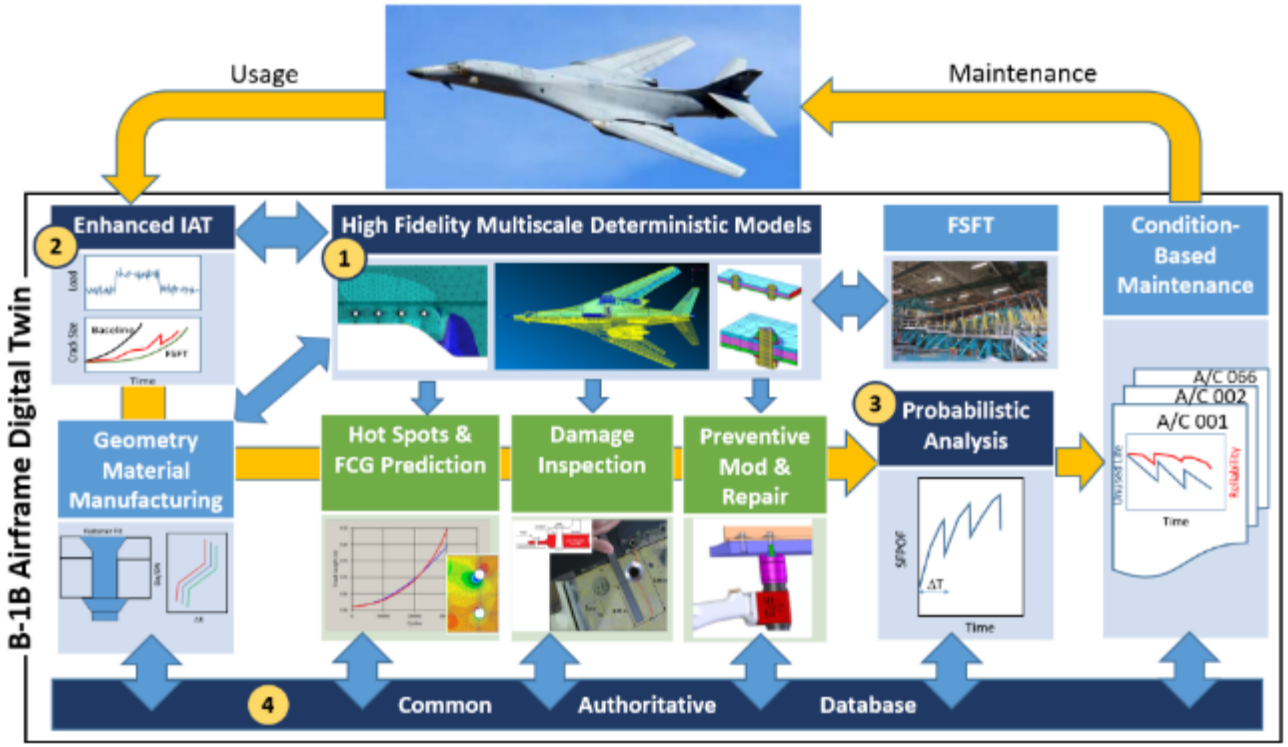
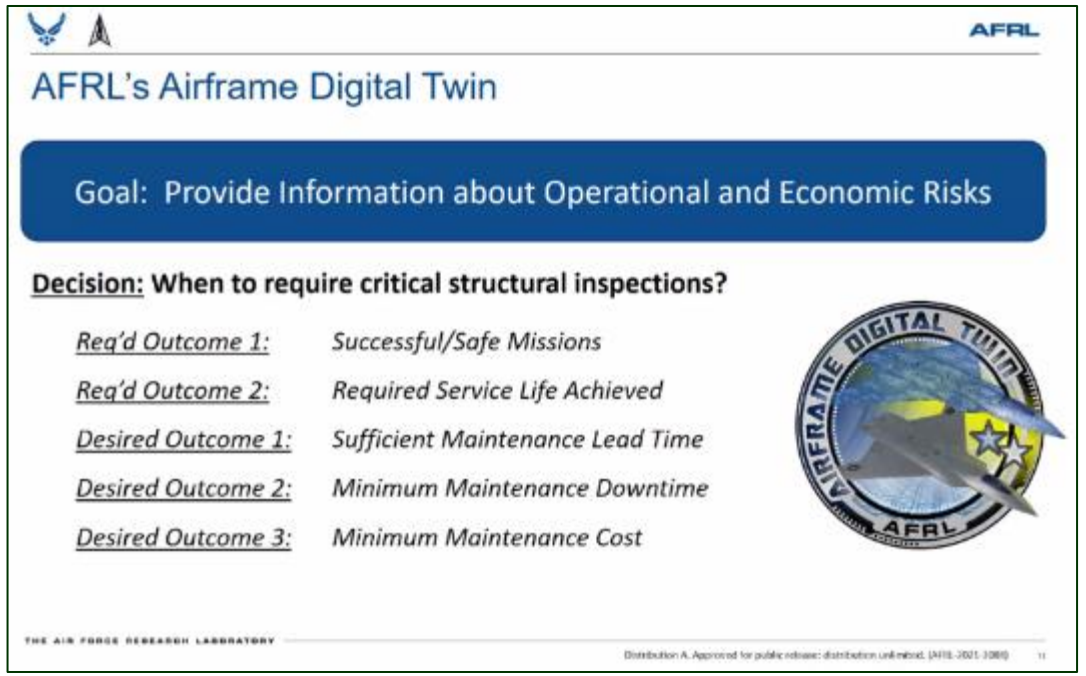
Military Airframe Digital Twin for Sustainment



Ref: Lin, et al, "Digital Twin Development for B-1B Service Life Extension", White Paper to USAF, August, 2019



Ref: Major General Heather Pringle, "The Potential of Digital Twins", AFRL Presentation at Aerospace & Defense Working Group of Digital Twin Consortium, Sept, 2021

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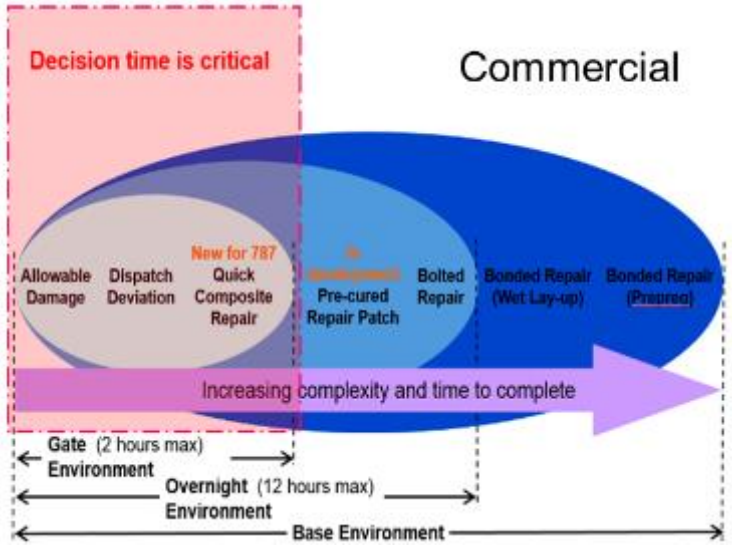
Summary

- **Develop Digital Thread / Digital Twin for structural repair by**
  - Fully digitizing Structural Repair Manuals (SRMs)
  - Developing connected databases from front-end to final regulatory approval
  - Providing automated Allowable Damage Limits (ADL) and Repairable Damage Limits (RDL) disposition
  - Integrating rapid analysis toolset for non-SRM damage disposition and repair design analysis
  - Providing data analytics that feeds Maintenance, Structural Design and Design for Reparability



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