

A-10 IMPLEMENTING PROGNOSTICS WITH THE DIGITAL THREAD

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U.S. AIR FORCE

Background

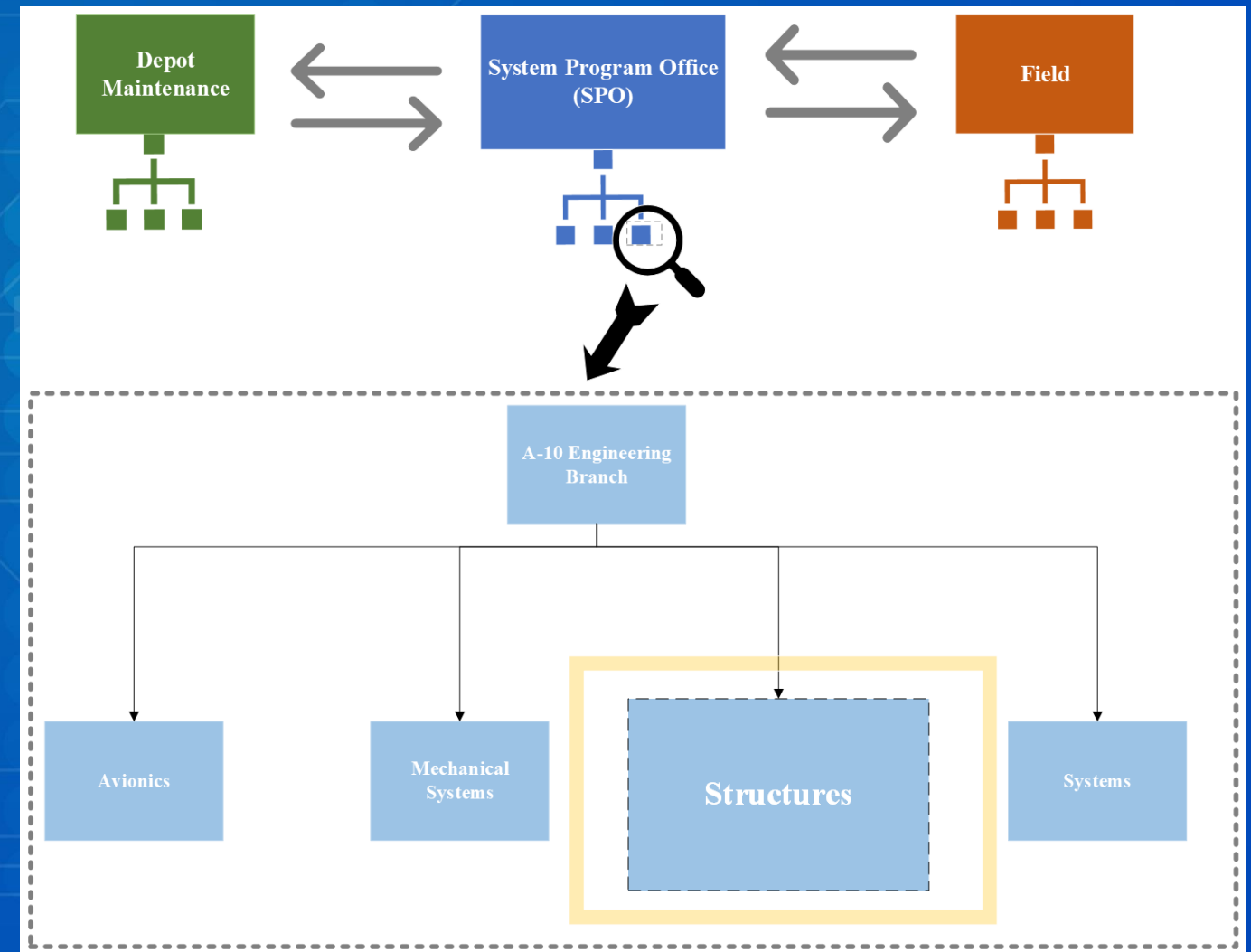
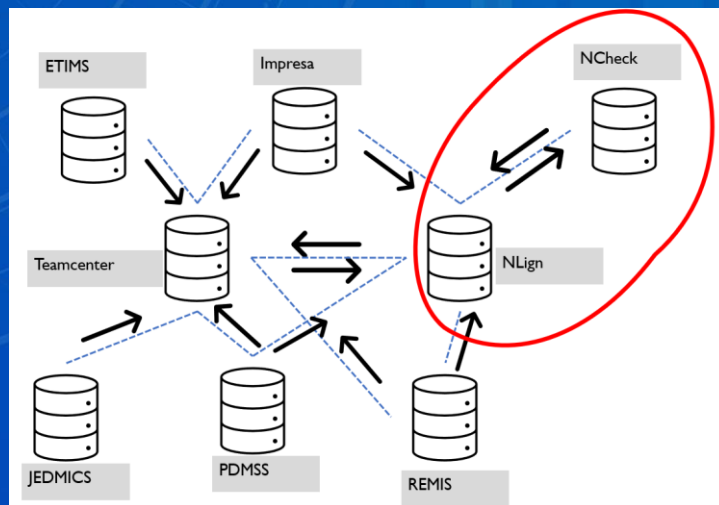
- 1973 A-10 Aircraft by Fairchild-Republic is selected to fulfill close-air support (CAS) by the United States Air force (USAF)
- 1997 A-10 fleet approaching safe service life of 6,000 hours[1]
- 2002 A USAF investigation declares A-10 ASIP “broken”
 - The path towards recovery for A-10 ASIP resulted in a cost-effective organic engineering expertise unique to the USAF [2]
- 2007 Digital transformation for the A-10 begins with the design of an enhanced wing assembly (EWA) as part of a wing replacement program



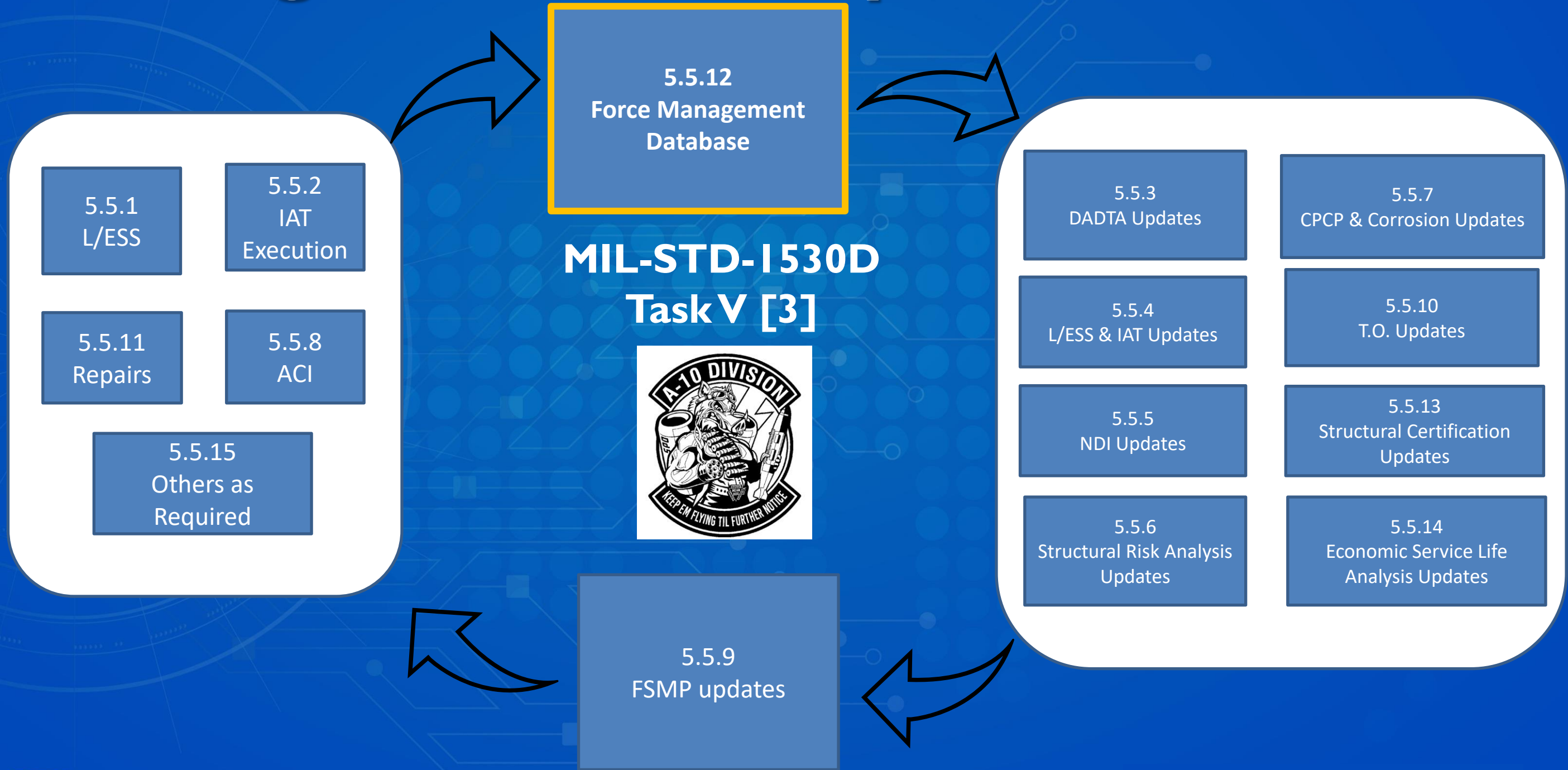
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Breadth of A-10 SPO Digital Thread

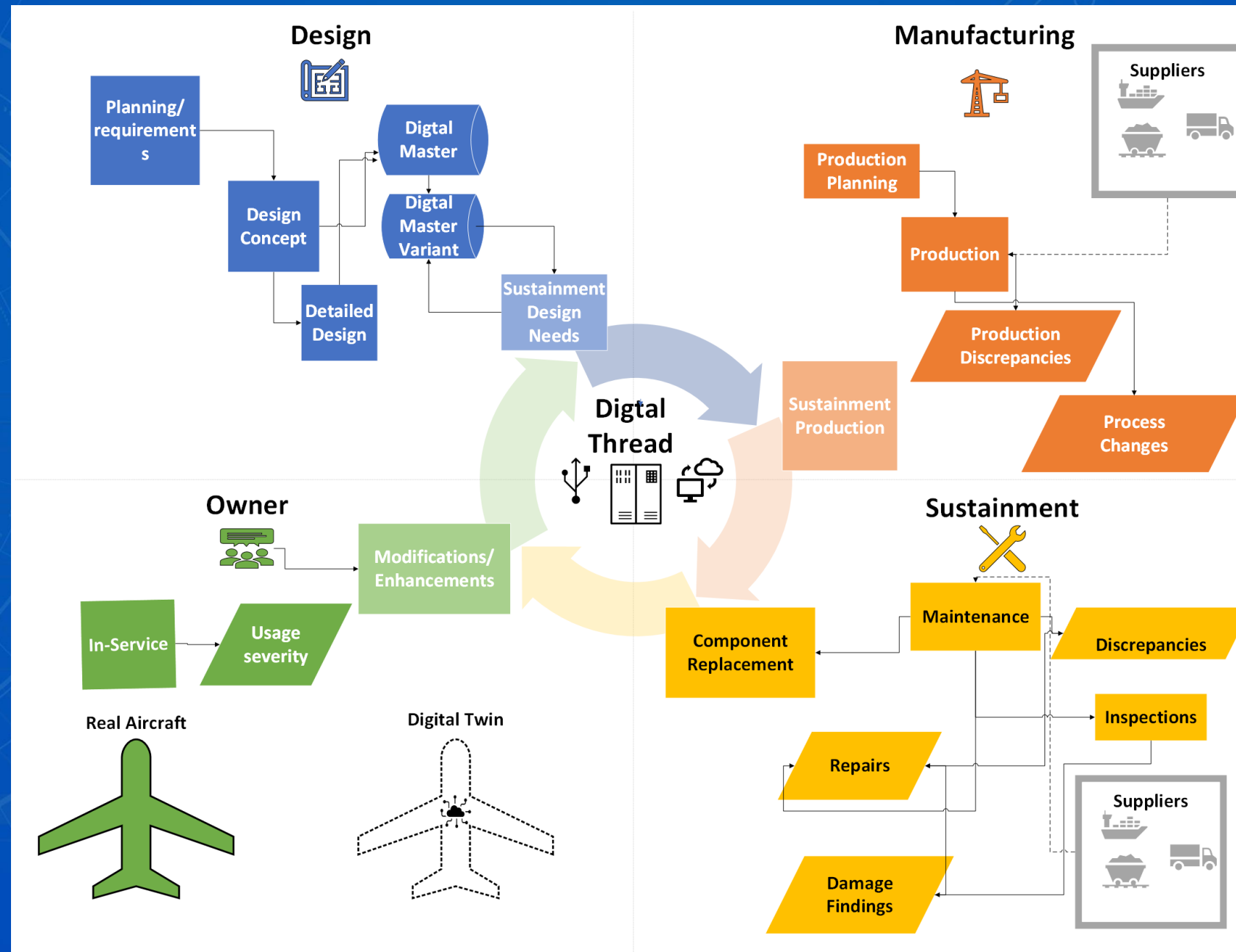
- Three main departments: Depot, Field, and System Program Office (SPO)
- Multiple digital thread systems utilized
- Focus on A-10 ASIP digital thread



ASIP Digital Thread Requirements



The Digital Thread Lifecycle



Data Collection Before Digital Transformation

- Paper Logbooks
 - Handwritten
 - Signatures and stamps
 - Stored in cabinets
 - Delivered periodically



Data Collection Before Digital Transformation

1. Mechanic prepares the aircraft or component for inspection
2. NDI notified, and an inspection performed.
3. Findings documented in the logbook
4. Mechanics perform corrective maintenance, typically oversizing the hole by a nominal size
5. NDI reinspects repaired holes.
6. Steps 4 and 5 would be repeated until NDI cleared the hole or maximum oversize diameter reached

Process

Example of fuselage inspection #2 with fabricated data

1	2	3	4	5	6	7	8	9
Hole #	NDI: Record				MX: Record		AFMC Form 202 #	Comments
	Upper Longeron Plate	Upper Longeron J-Extrusion	FS 468.50 Frame	-63 Strap	Hole Diameters (+/- 0.001 in.)			
	Holes 1 and 2 (0.183 in.) Hole 3, 4, 5 (0.250 in.)	Hole 3, 4, 5 (0.250 in.)	Holes 1 and 2 (0.460 in.)	Hole 5 (0.190 in.)	Initial	Repair (Pre-Coldwork)		
RH 1			All Clear		0.460			
					N/A			
					N/A			
					N/A			
RH 2					N/A			
					N/A			
					N/A			
					N/A			
RH 3	70%				0.25	0.266		
	50%				N/A	0.278		
	Clear				N/A			
					N/A			
					N/A			
RH 4					N/A			
					N/A			
					N/A			
					N/A			
RH 5					N/A			
					N/A			
					N/A			
					N/A			

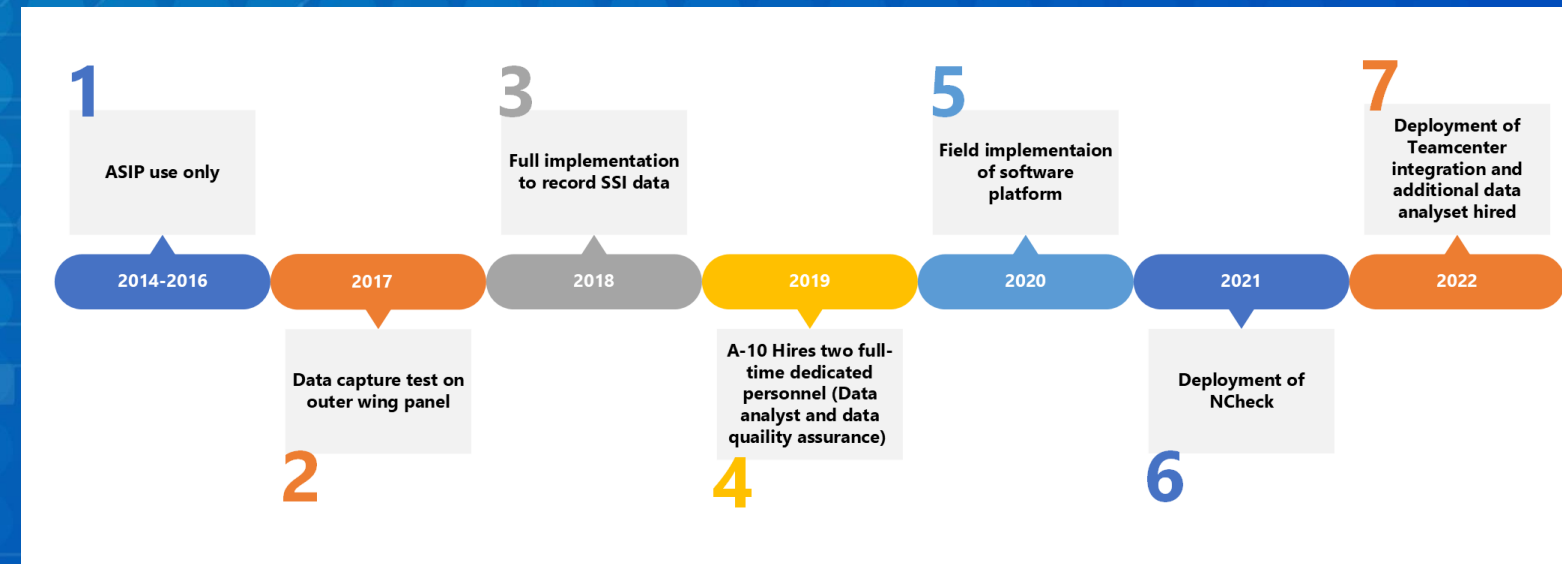
Requirements

F07-003S03-C06

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Digital Environments

- NAlign Analytics Platform
 - Small Business Innovation(SBIR) Funding
 - NDI data in the beginning
 - Sprints of software enhancements (USAF funded)



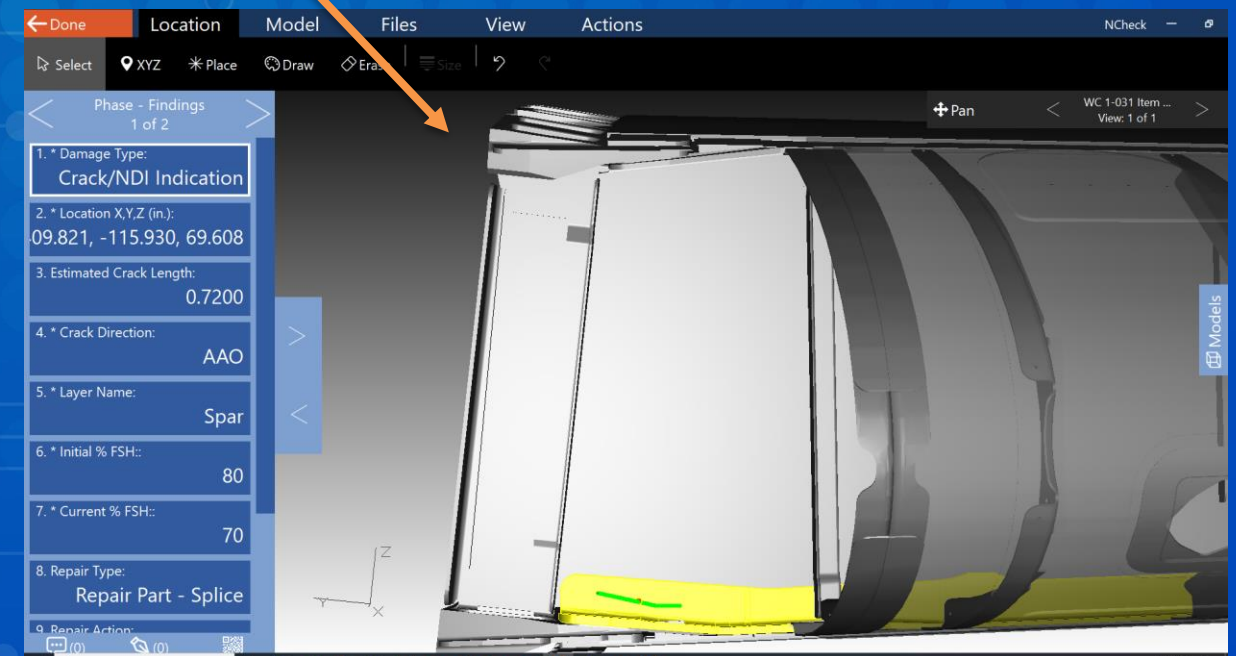
Timeline of NAlign implementation [6]

Digital Data Capture

- NLog as data capture software replaces logbooks in 2018
- NCheck developed with SIBR funding
- Full transition to NCheck as data capture software at the shop floor

The screenshot shows the NCheck software interface. On the left is a navigation pane with options like 'Job', 'Tasks', and 'Finding'. The main area displays a table of inspection records. The top record is for 'Job' with a date of '2023-06-15' and 'Phase 1'. Below it is a list of tasks with columns for 'Work Card #', 'Item', and 'Date of Inspection'. A specific finding is highlighted, showing 'Crack/NDI...' with a 'Layer Name' of 'Spar', 'Current % FSH' of 70, and a 'Date of Inspection' of '2023-06-15'. An orange arrow points from the 'Finding' label in the navigation pane to the highlighted finding record.

Work Card #	Item	Date of Inspection
1-031	2 LH	2023-06-15
1-045	3.B	2023-06-15
1-045	3.A	2023-06-15
1-032	12 RH	2023-06-15
1-032	12 LH	2023-06-15
1-032	11	2023-06-15
1-032	10	2023-06-15
1-032	9 RH	2023-06-15
1-032	9 LH	2023-06-15



Data Requirements for Prognostics

- High Quality
- Decisive



<https://www.tokresource.org/tip-of-the-iceberg>



<https://xkcd.com/1838/>

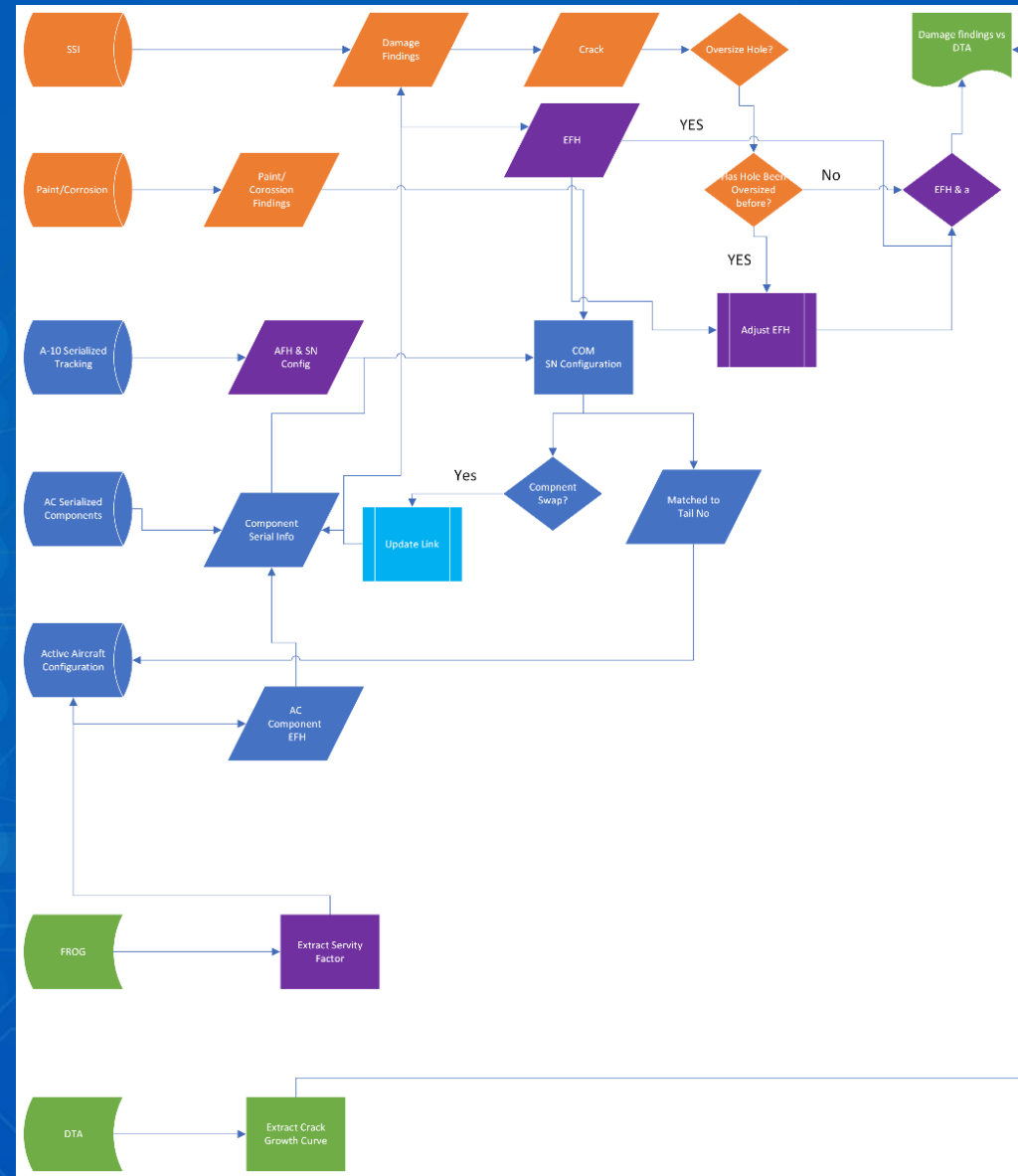
What it takes to meet requirements

- Data architects
 - 2 full time at A-10
- Data quality analyst
 - 1 full time at A-10
- We are all data wranglers and it takes up a lot of time
- Accountability from the shop

Prognostic Data Model

Data alone is insufficient to convey technical statements [6]

- Structure
- Context
- Relationships



- Data Model

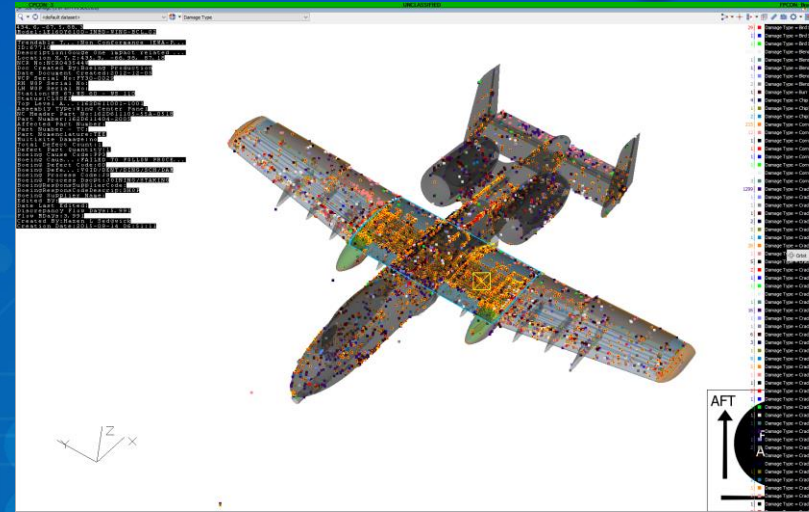
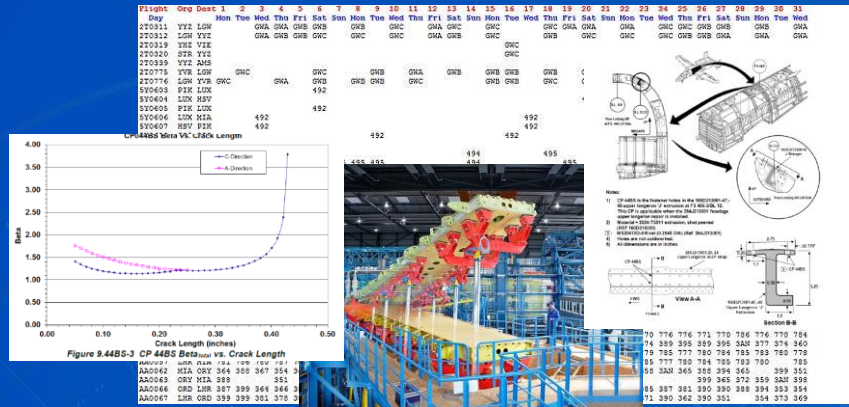
- Applying the data model with COMs
- AEROSPACE STRUCTURES

NLign User Interface and Dashboards

The screenshot displays the NLign software interface, which is used for managing and analyzing aircraft data. The interface is divided into several main sections:

- Left Panel (Details):** Contains metadata for the selected asset, including ID (228692), document ID, and various inspection and maintenance records. It also includes sections for Corrosion Data and Aircraft Component Serial Numbers.
- Layers Panel:** A tree view showing different layers of the aircraft model, such as 2D Shell Models, Empennage, Fuselage, Model Color Scheme, Mx Models, Nacelle, Named Regions, NCheck, NDI Clocking, Stored Views, Wing Center Panel, and Wing Outer Panel.
- Inputs Panel:** A section for entering or managing A/C Serialized Components.
- Central 3D View:** A 3D model of an aircraft with numerous colored dots representing data points. A legend on the right side of the 3D view lists various Trendable Types and their corresponding colors.
- Right Panel (Dashboards):** Contains several data visualization tools:
 - Trending Results 1:** A table showing analysis results for various components, including Analysis Engineer, Date, Risk Factor, Supervised By, Total Defect Count, and Asset Type.
 - Live Chart 1:** A bar chart titled "Tail Counts and Risk Associated with Component Types" showing the number of tails for different component types: LH Fuselage (157), RH Fuselage (156), RH Wing (89), NCF (88), and LH Wing (95).

Risk Based Inductions and Prognostics



<https://www.dvidshub.net/news/432685/re-winging-10-makeover>

PRoF

- Individual aircraft tracking (IAT) and usage severities
- Fatigue characteristics of specific material
- Unique geometries that are considered the most critical
- DTA
- Fatigue test data

+

Holistic Prognostics

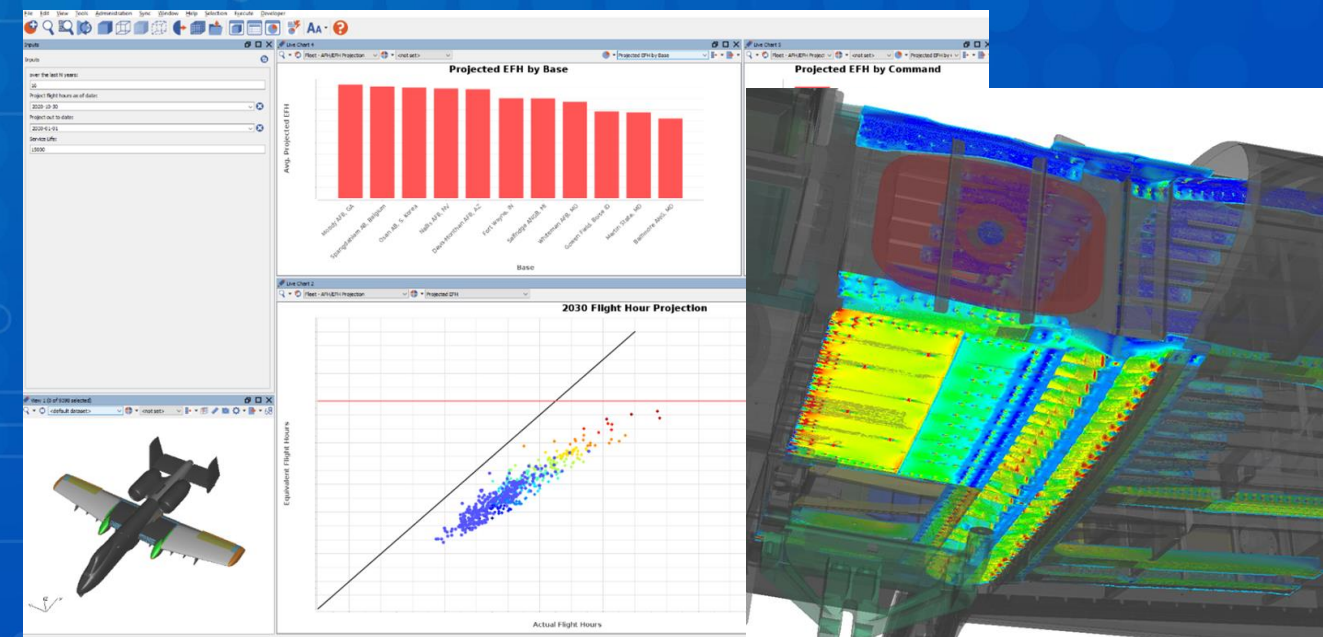
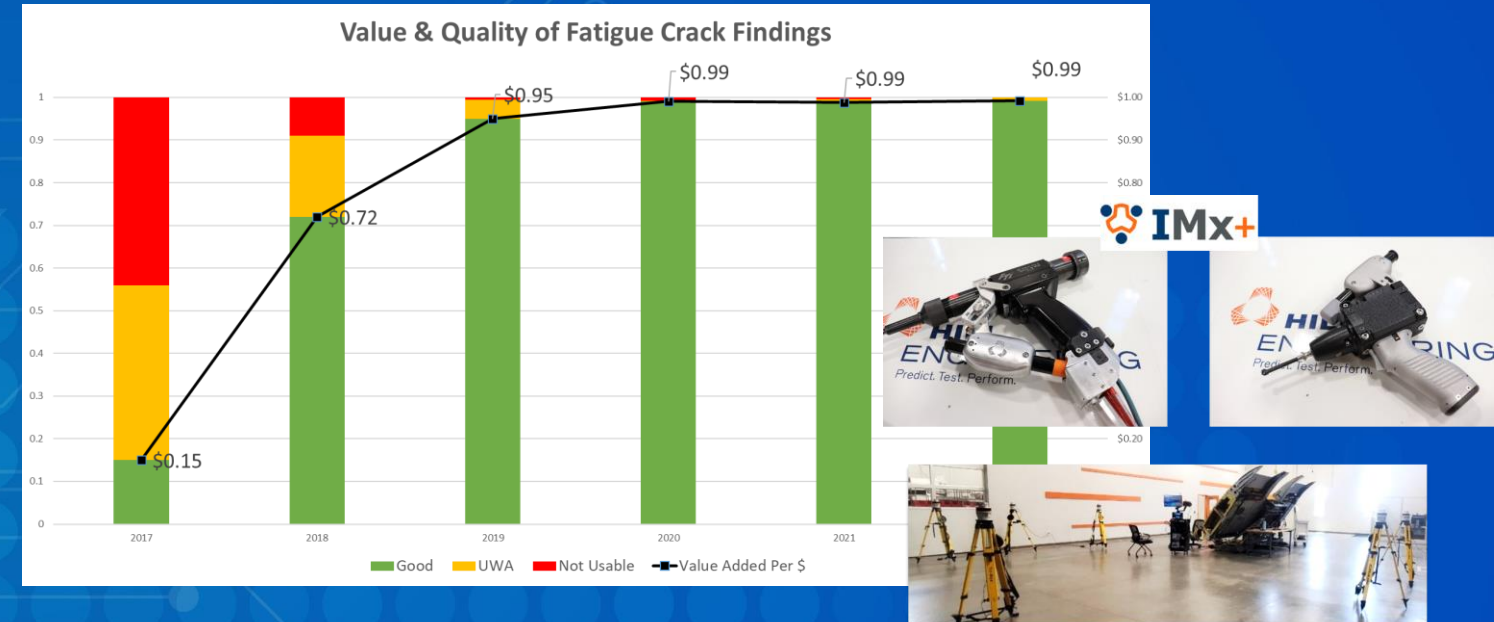
- High Level overview to component specific
- Live inspection findings
- Repairs
- Maintenance discrepancies
- ETAR, TCTOs, ACI

=

Predictive depot induction priorities

Results

- Risk based induction prioritization
 - ~35% increase in hours on average between inductions
 - Depot burden reduce and cost avoidance of millions
- Instant risk assessment of components, aircraft, and fleet
- Data usability improvements, fewer assumptions
 - ~ 100% captured data
- Data accessibility improvements
 - ~800% Faster
 - XYZ coordinates
 - Continued interaction with maintenance group
- Engineering response time reduced from weeks to days
- Implementation of Smart Tools
- Issues addressed while asset is open and accessible
- 10s of millions \$\$ in cost avoidance



Digital Thread and the Lessons Learned

- **It is not trivial !**
- Data wrangling consumes a significant amount of human resources
- A.I. tools are needed to fully implement digital engineering solutions
- Merging data to be meaningful requires significant effort
- Culture change at the shop requires effort from all parties
- Hardware limitations for maintainers is significant
- IT support is mandatory but often lacking
- It is critical to consider goals before data collection begins

Thank you!



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References

[1]

S. R. Jones and G.A. Zsidisin, "Performance Implications of Product Life Cycle Extension: The Case of the A-10 Aircraft," *Journal of Business Logistics*, vol. 29, no. 2, pp. 189-214, 2008.

[2]

M. L. Thomsen, P. N. Clark and R. E. Heller, "Development of Cost Effective Organic Engineering Expertise Balancing Weapon System Support Between Government and Engineering Support Contractors," in *United States ASIP Conference*, San Antonio, TX, 2011.

[2]

USAF, *MIL-STD-1530D DoD Standard Aircraft Structural Integrity Program*, 2016.

[4]

R. E. Heller, T. Wilson, M. Thomson Ph.D and P. N. Clark Ph.D., "Development of an Enhanced Wing for the A-10 Wing Replacement Program," in *Structural Dynamics and Materials Conference*, Honolulu, 2012.

[5]

W. Roper Ph.D., *Guidbook for Digital Engineering "The Bending Spoon"*, USAF, 2021.

[6]

H. Sedgwick, Interviewee, *Origins of A-10 ASIP use of NLogn*. [Interview]. 18 April 2023.

[7]

B. Caesar, A. Hänel, E. Wnkler, C. Corinth, S. Ihlenfeldt and A. Fay, "Information Model of a Digital Process Twin for Machining Processes," in *IEEE International Conference on Emerging Technologies and Factory*, Vienna, Austria, 2020.

Summary

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AEROSPACE STRUCTURES swri.org

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NLign User Interface and Dashboards

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Risk Based Inductions and Prognostics

PRoF + Holistic Prognostics = Predictive depot induction priorities

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Smart Maintenance Tools

- Spatial Position Tracking
 - 4-6 infrared transmitters
 - Requires line-of-sight & provides up to 6 DOF spatial positional accuracy down to 0.01 inch
- Automatic data population with validation checks
- Expanded Digital thread with full data repository
 - NDI - full wave form for Automated Defect Analysis
 - Cx Puller - key data and process parameters for “full credit”
 - Screenshots, videos, measurements, and report files
- NCheck as user interface and digital thread repository
- A-10 Val/Ver tentatively scheduled for summer of 2023



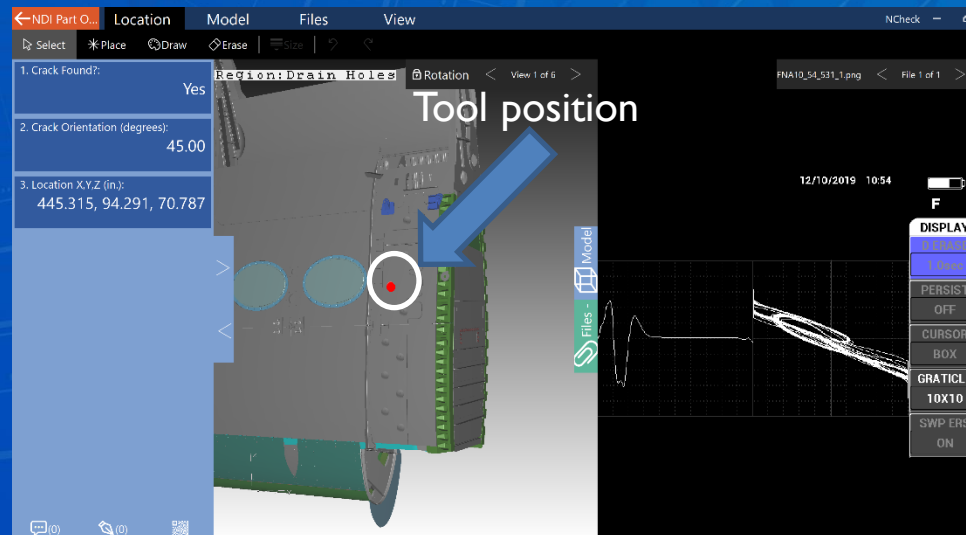
Cx puller



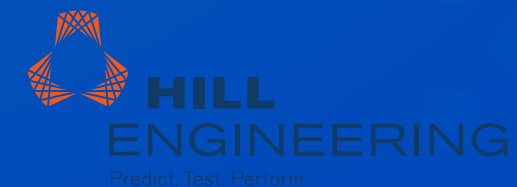
NDI EC probe



Spatial position system



NCheck user interface



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The Digital Thread – Legacy Aircraft

▪ Aircraft State at Start of Digital Thread Implementation

- As-Designed State
 - 3D CAD assemblies
 - Part materials
 - Design requirements
- As-Built State
 - Tests and inspections
 - Discrepant conditions
 - Repairs and modifications
 - Part serialization
- As-Maintained State
 - Usage information
 - Component installation history
 - Tests and inspections
 - Discrepant condition
 - Repairs and modifications
 - Part serialization

Legacy Aircraft Often Have Key Components of the Digital Thread ...

- Unavailable
- Variable over time
- Paper only
- Inconsistent
- Incomplete
- Unreliable

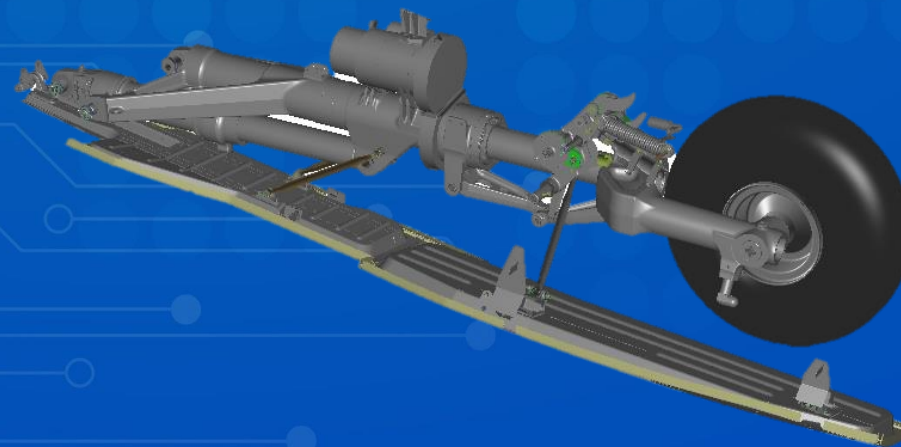
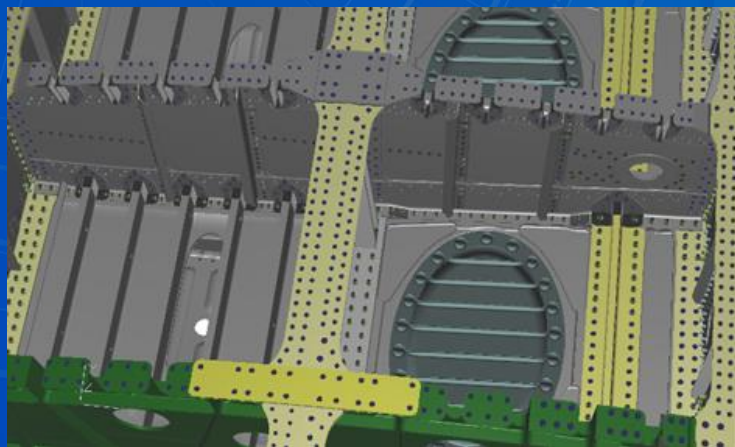
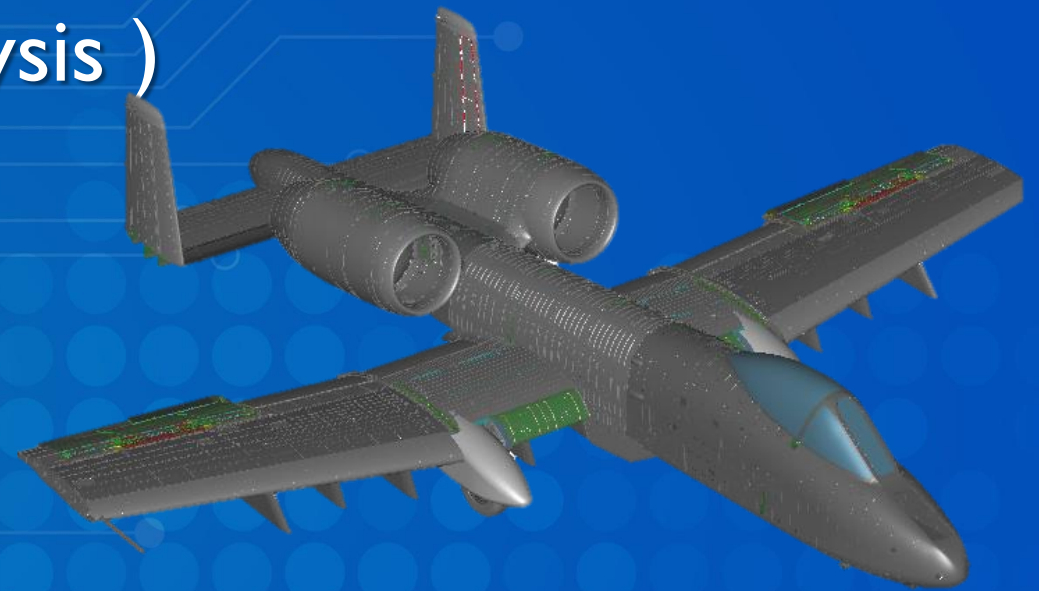


[https://www.cnn.com/travel/article/20-
iconic-aircraft-vintage/index.html](https://www.cnn.com/travel/article/20-
iconic-aircraft-vintage/index.html)

Digital Transition at the Beginning

- EWA Wing Replacement Program (the catalysis)
 - Model based definition
 - Configuration control
 - Engineering bill of materials (EBOM)

[4]



Data Collection Before Digital Transformation

- Engineering Access 7-9 Months AFTER the aircraft leaves depot
- No guarantee an inspection was performed
- No ability for engineering to address data issues while the asset is open and accessible
- Engineer Tech required to manually input data into database
- Limited data type request

