

A-10 and the Path to the Digital Twin for Legacy Defense Systems

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U.S. AIR FORCE



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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
- 2002 A USAF investigation declares A-10 Aircraft Structural Integrity Program (ASIP) “broken”
 - The path towards recovery for A-10 ASIP resulted in a USAF organic engineering capability that is often only realized by the OEM [1]
- 2007 Digital transformation begins for the A-10 with the design of an enhanced wing assembly (EWA) as part of a wing replacement program [2]



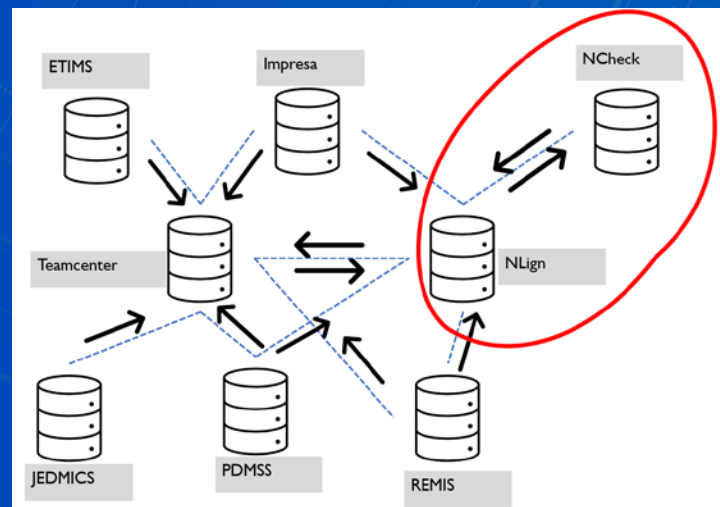
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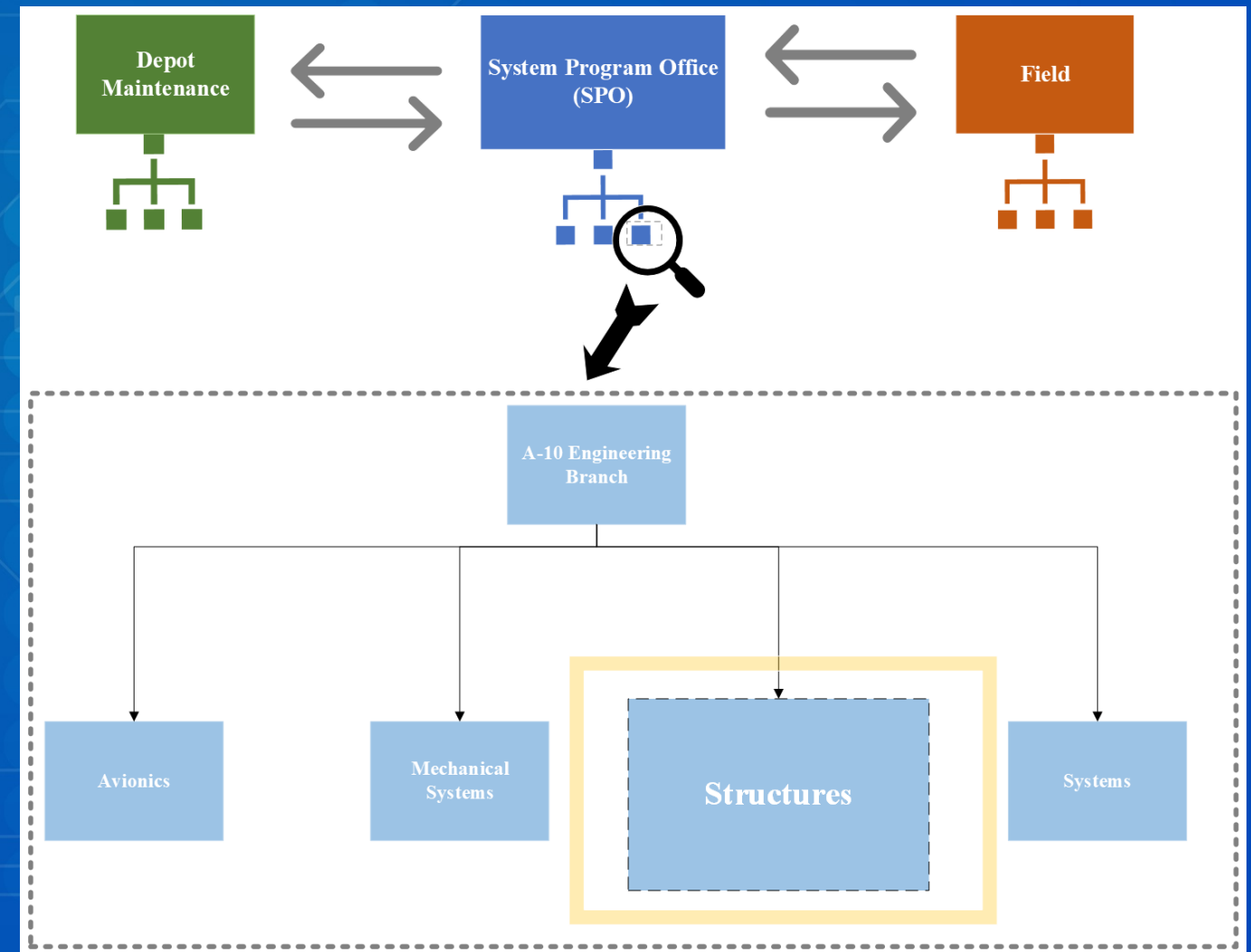
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Breadth of A-10 SPO Digital Twin

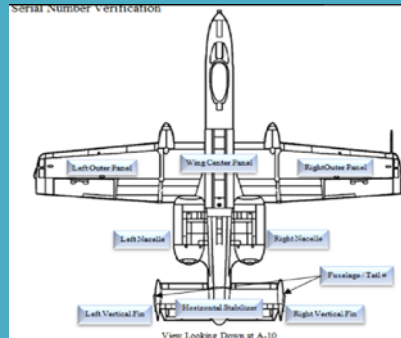
- Three main departments: Depot, Field, and System Program Office (SPO)
- Multiple digital thread systems utilized
- Focus on A-10 ASIP digital thread



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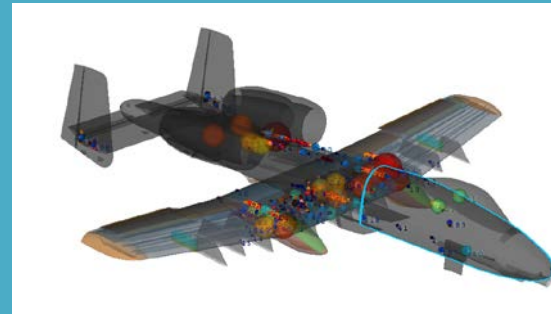


A-10 Digital Twin Data Types



Serialized Tracking

- AC Serialized Components
- Configuration Tracking
- Active aircraft Serialized configuration
- Repairs and overhauls



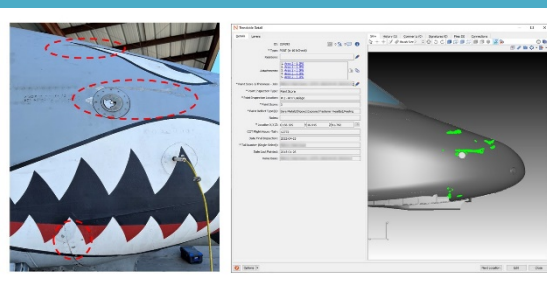
Inspection Results

- Depot NDI Inspection (SSI, ACI, & TCTO)
- Field NDI Inspection (Phase & TCTO)



Mx Discrepancies

- One off findings
- Blend operations



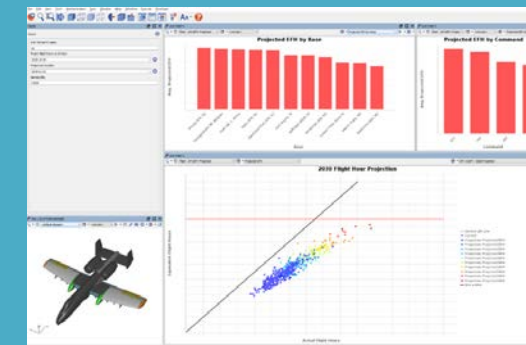
Corrosion

- Corrosion finding
- Paint inspection
- New coating products used



Production

- Wing replacements first article install
- Manufacturing non-conformance
- Hog-back



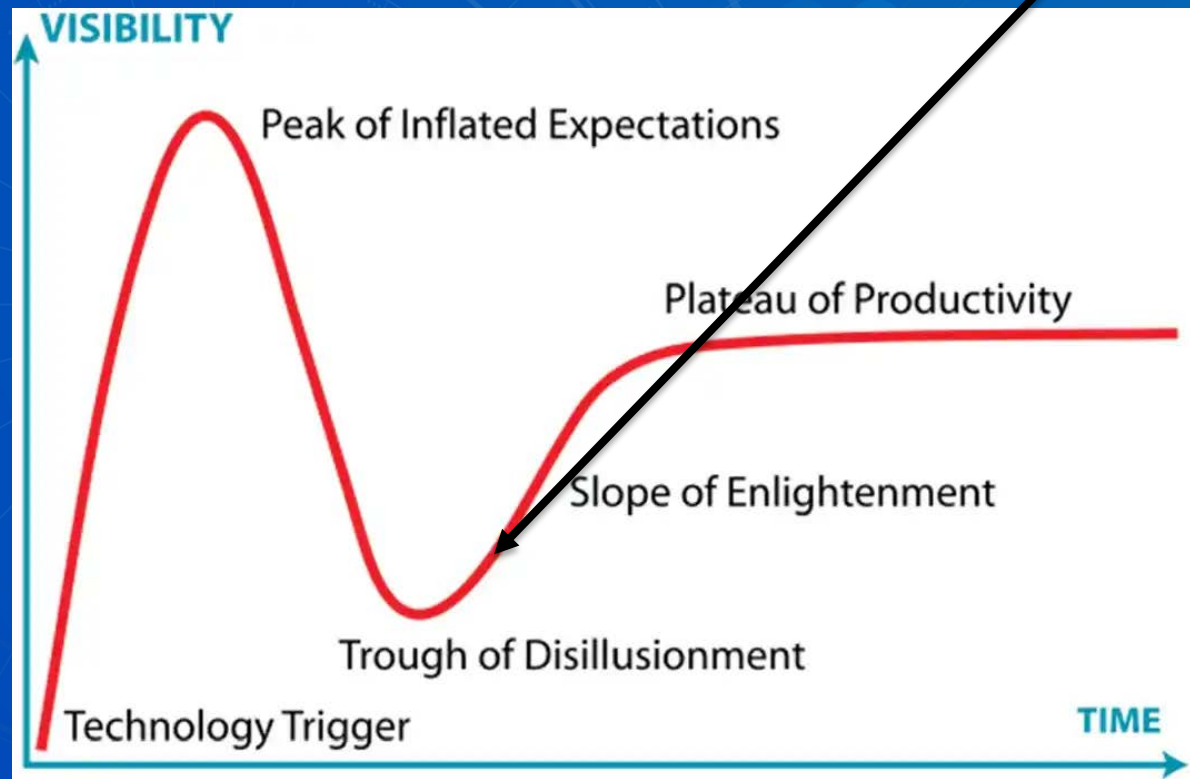
Engineering Support

- Engineering support analysis
- Liaison engineering reports (LENR)
- Test and teardown
- Engineering technical assistance requests (107s & 202s)

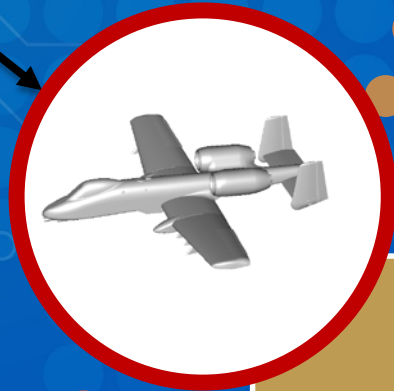
Aerospace Structures

State of the Digital Twin for A-10

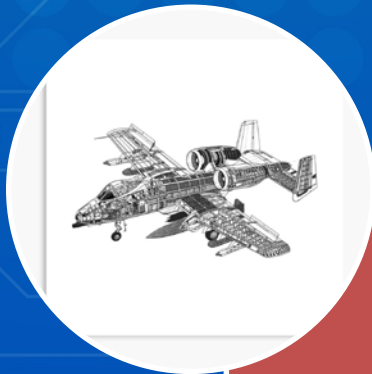
In my opinion...A-10 ASIP is here



Digital twin

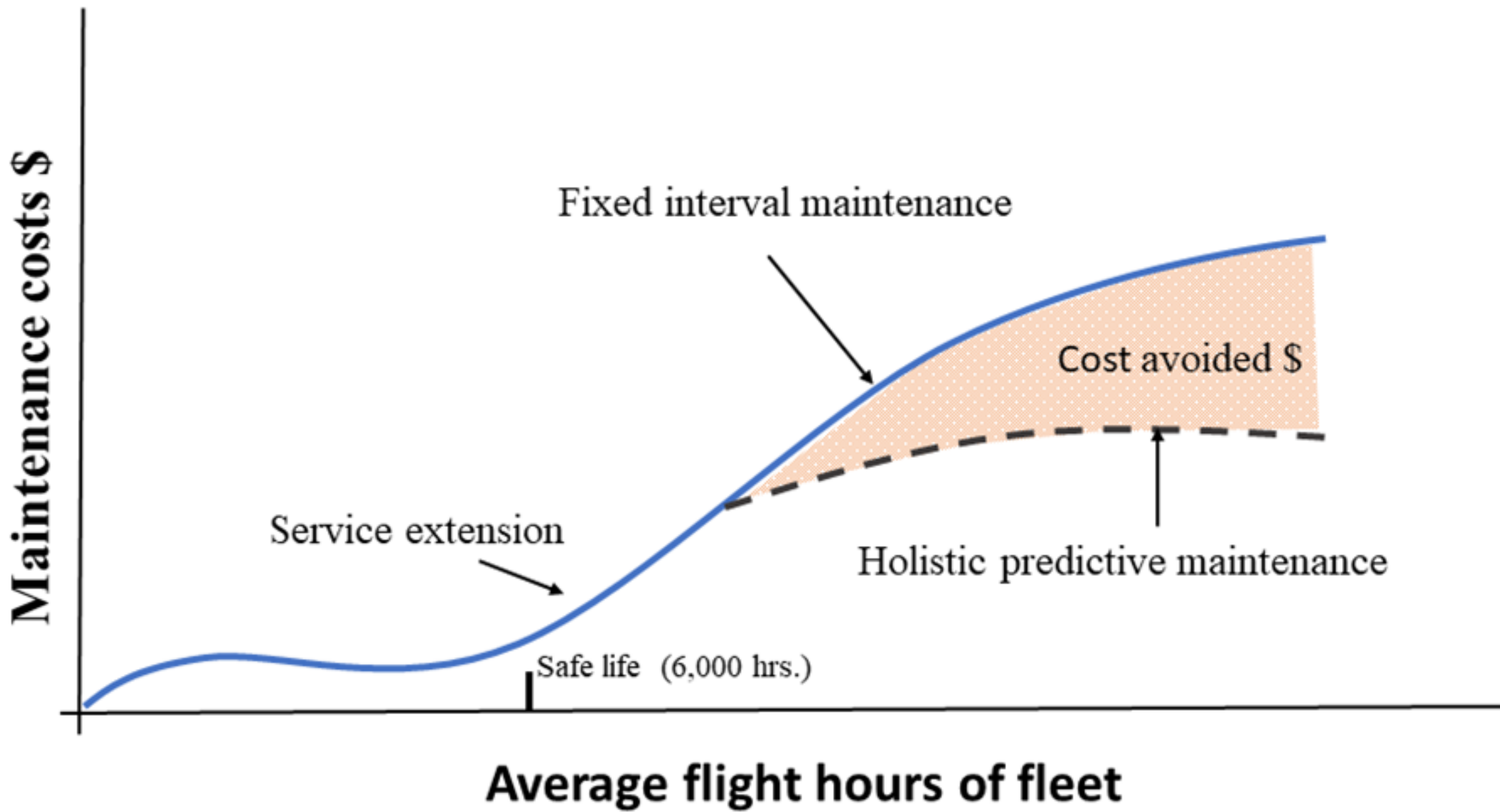


Digital relative



Historical systems

[4]



Data Requirements for A-10's Digital Twin

What are they?

- High Quality
- Decisive



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



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

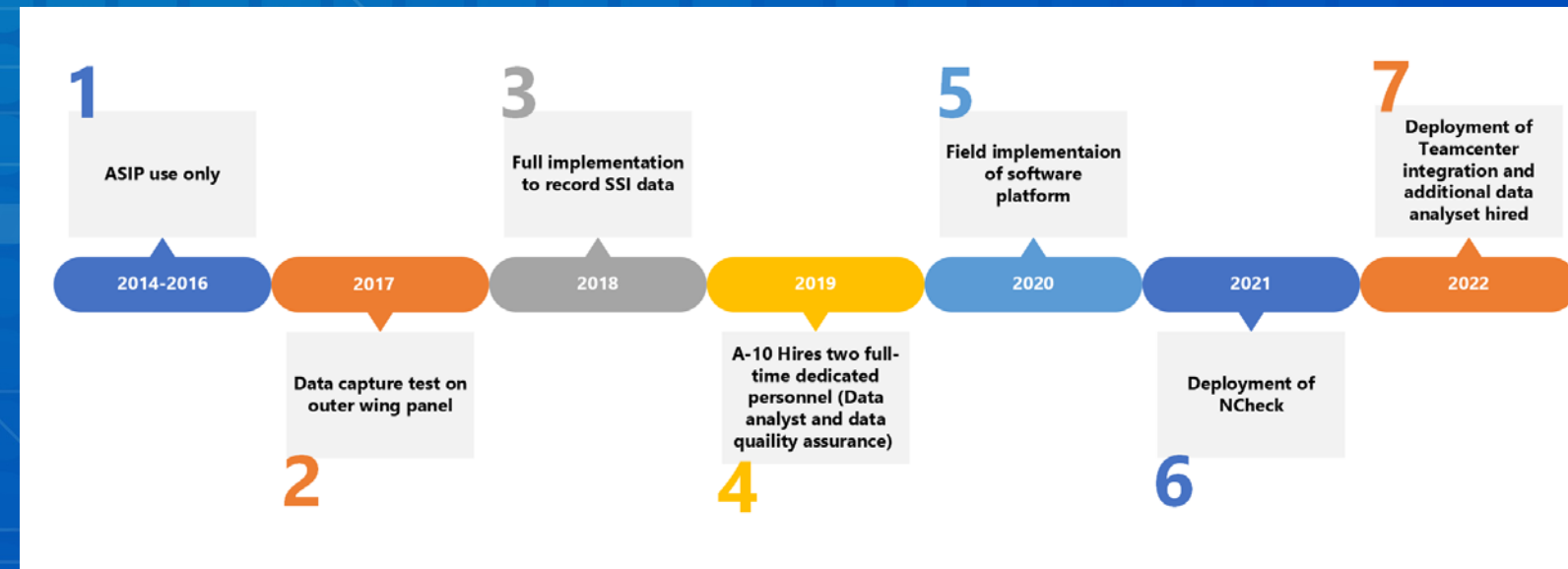
What does it takes to meet requirements?

- It might be more than you think!
- Data architects
 - 2 full time at A-10
- Data quality analyst
 - 1 full time at A-10
- We are all data wranglers
- Accountability

Digital Environments

- Teamcenter chosen as “Source of Truth”
 - Product Lifecycle Management (PLM)
 - Service Lifecycle Management (SLM)

- Nlign Analytics Platform
 - Originally designed for non-destructive inspections (NDI)
 - Small Business Innovation(SBIR) Funding
 - Sprints of software enhancements through more SBIR and Rapid innovation funding (RIF)

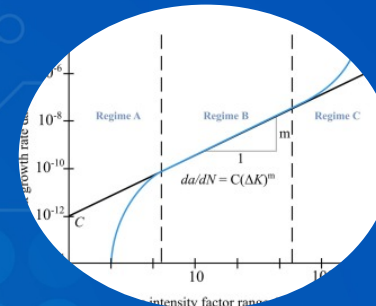


Timeline of Nlign implementation [5]

Digital Thread and Input Data



Maintenance



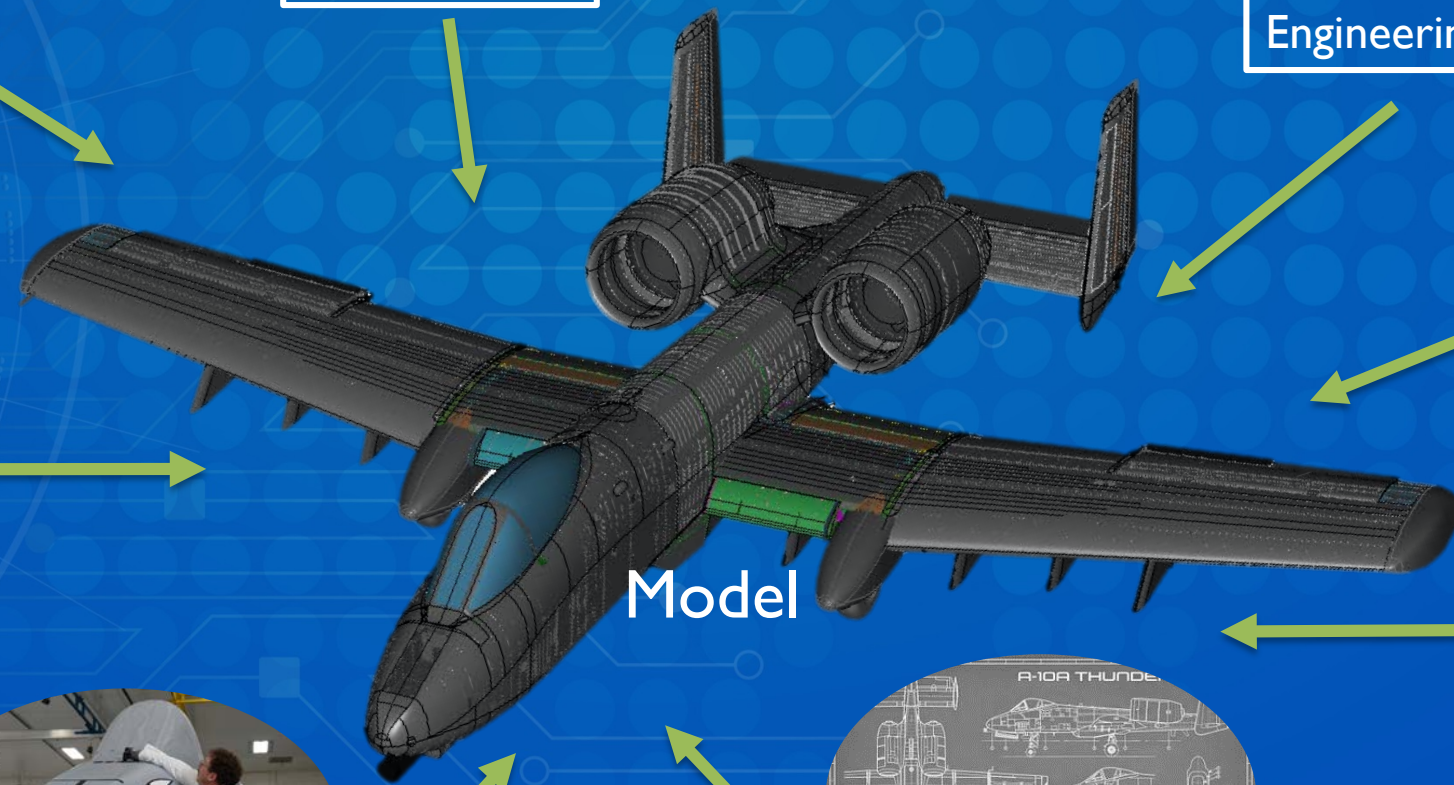
Engineering analysis



Testing



Inspections



Model



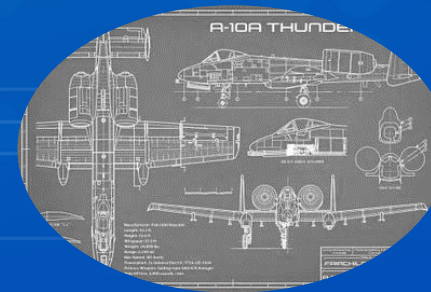
Modernization/Replacement



Usage Severity & Damage



Environmental Considerations



OEM Design

Aerospace Structures



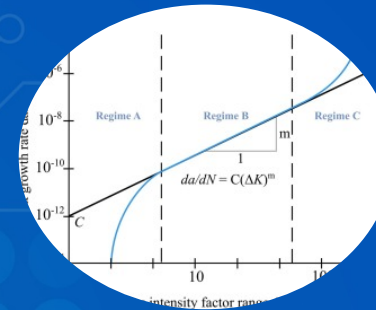
A-10's Digital Twin Input Data



Maintenance



Inspections



Engineering analysis



Testing

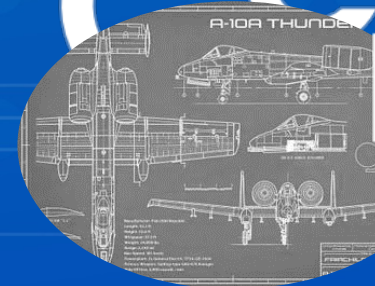


Modernization/Replacement

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Environmental Considerations



OEM Design

SIEMENS
PLM Software
TEAMCENTER

Usage Severity & Damage

Aerospace Structures



Data Collection Before Digital Transformation

- No central repository
- 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
- Engineering rigor not fully captured

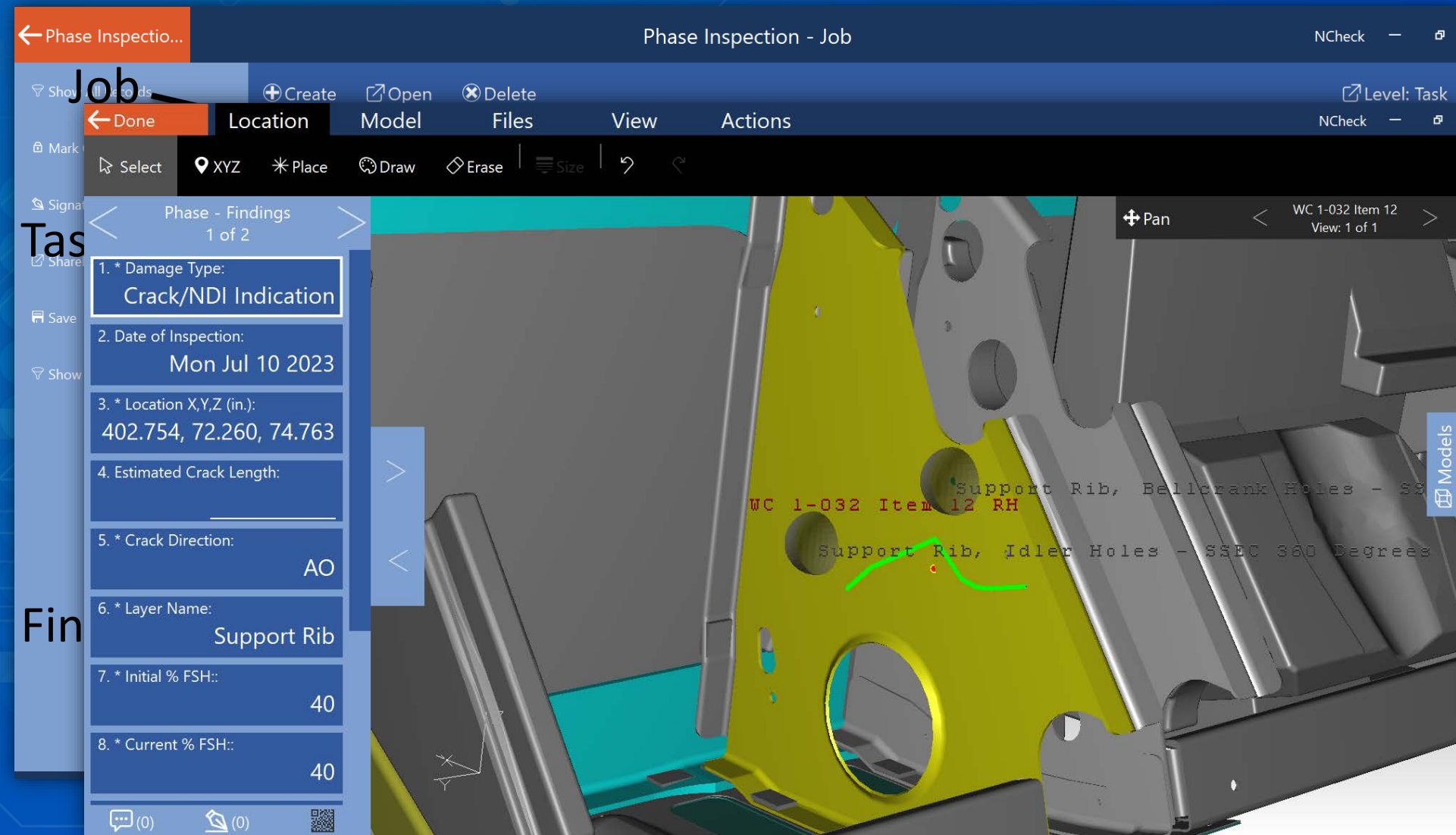
1	2	3 NDI: Record			5	7 MX: Record		8	9
		Upper Longeron Plate	Upper Longeron J-Extrusion	FS 468.50 Frame		-63 Strap	Hole Diameters (+/- 0.001 in.)		
Hole #	Holes 1 and 2 (0.183 in.) Hole 3, 4, 5 (0.250 in.)	Hole 3, 4, 5 (0.250 in.)	Holes 1 and 2 (0.460 in.)	Hole 5 (0.190 in.)	Initial	Repair (Pre-Coldwork)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

Example of fuselage inspection #2 with fabricated data



Current Digital Data Capture - NCheck

- Built in data structure: Jobs, Tasks, & Findings
- Jobs creation automated via integration with work control software
- Predefined tasks via job template
- Prescribed view of model



Next Steps for A-10's Data Capture

- 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 in progress now

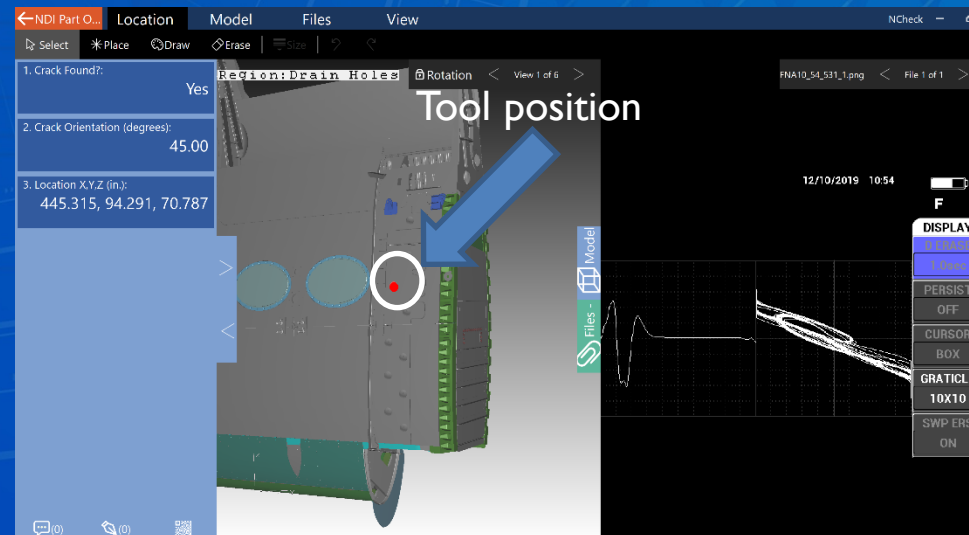


Cx puller

NDI EC probe



Spatial Position System



NCheck user interface

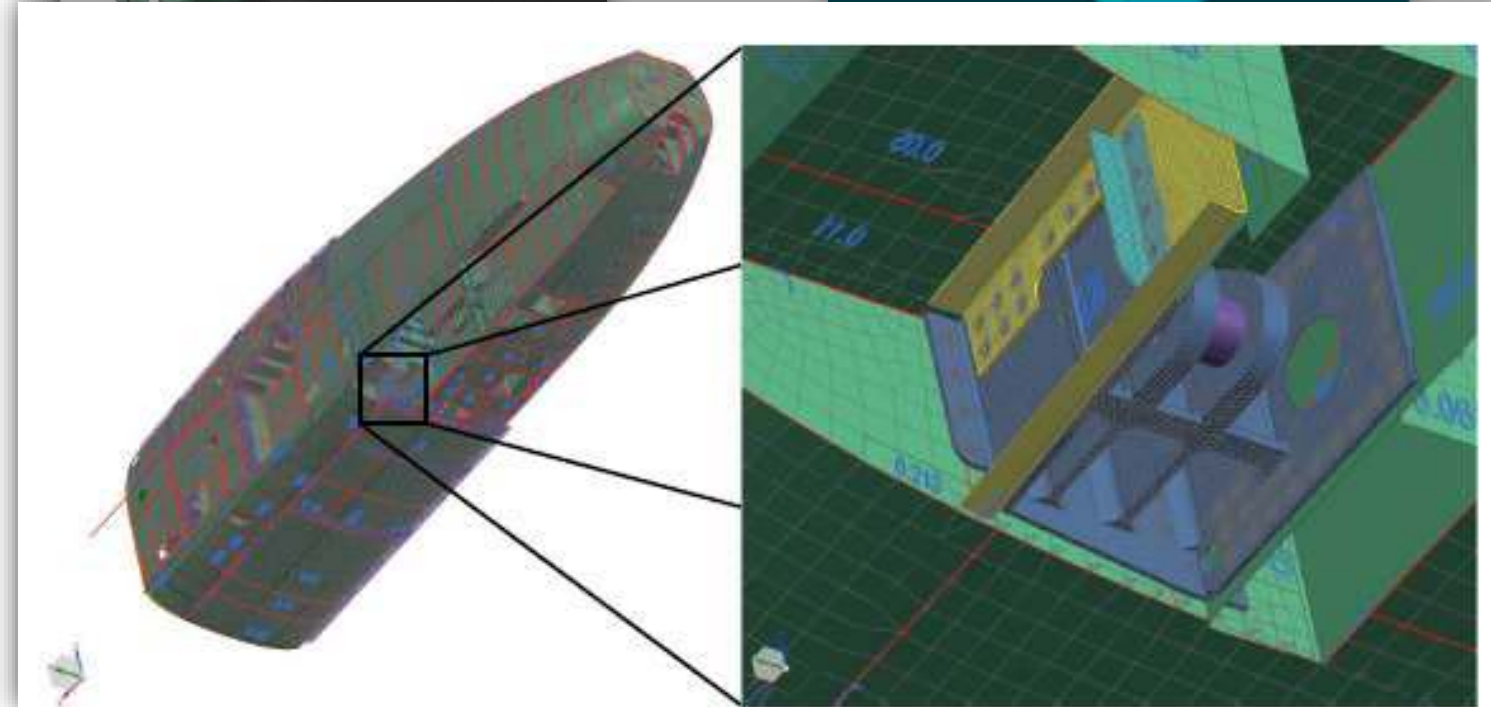
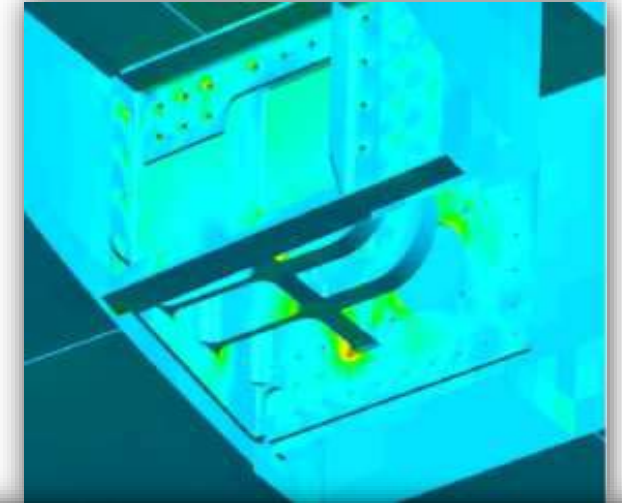
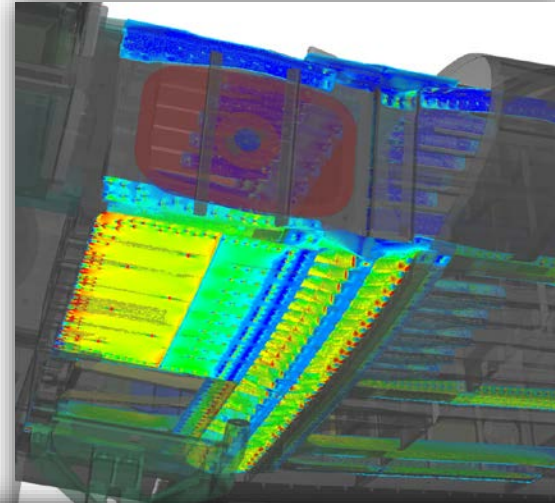


Aerospace Structures



Maintenance Data Visualization

- XYZ Location indicated on model
- Files available in real time
- Quickly identify hotspots
- Map damage to model
- Integrate FEM models into the same coordinate system as the aircraft



Outputs of Digital Twin

- Dashboards
- Datasets
- Reports

The screenshot displays a complex digital twin interface for aircraft maintenance and performance. It features several key components:

- 3D Models:** Two views of an aircraft are shown. The left view is a perspective view with various components highlighted in different colors (red, blue, green). The right view is a top-down view of the aircraft.
- Data Tables:** A table at the bottom left lists hole data with columns for Pin, Size, Damage Type, Hole Number, Final Diameter, Incoming Diameter, Location X (in), and Location Y (in).

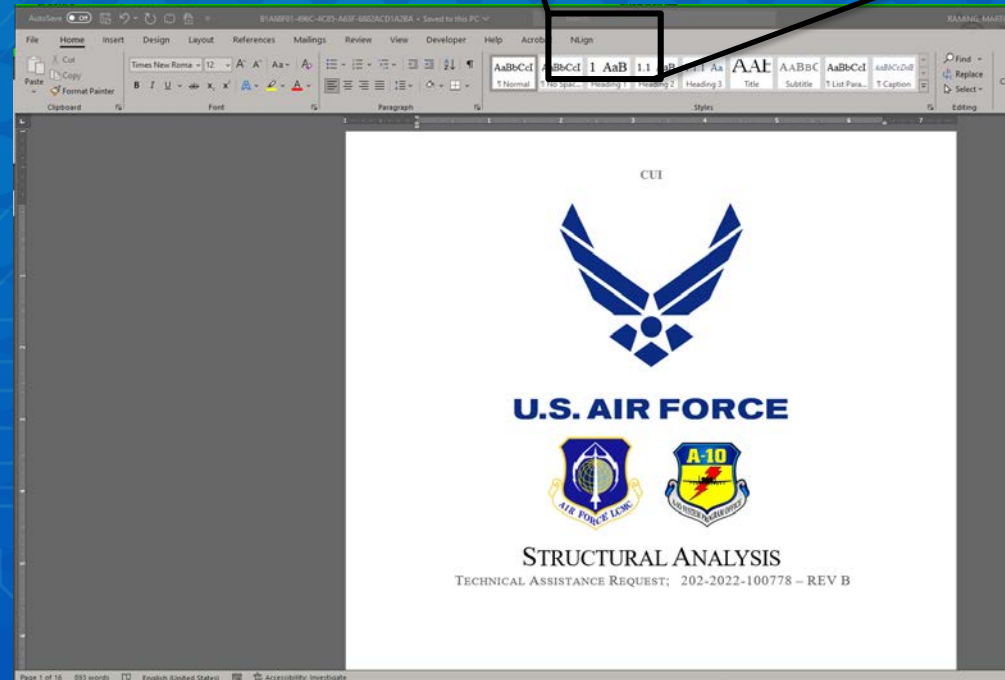
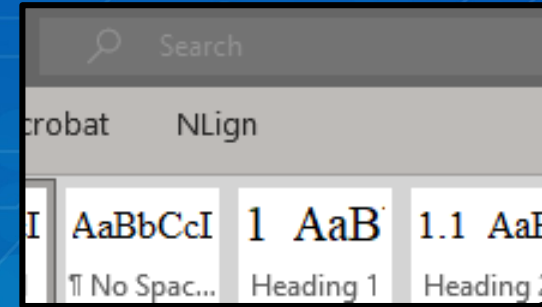
Pin	Size	Damage Type	Hole Number	Final Diameter	Incoming Diameter	Location X (in)	Location Y (in)
44	No Defect	4	0.275	0.342	403.99	26.4	
44	No Defect	5	0.375	0.342	405.35	26.4	
44	Out-Of-Round	6	0.262	0.247	407.67	-26.1	
44	No Defect	4	0.275	0.342	403.99	-26.4	
44	No Defect Found	Remissing Hole...			403.404	-20.342	
44	Corrosion	23	0.342	0.31	404.66	20.335	
44	Corrosion	21	0.342	0.31	407.67	20.320	
- Compliance Table:** A table titled 'TOTO COMPLIANCE (0 of 718 selected)' lists various tasks with columns for TOTO Number, TOTO Status, Date, TOTO Title, and TOTO Name/Status.

TOTO Number	TOTO Status	Date	TOTO Title	TOTO Name/Status
1A-10C-658	Unaccomplished	2020-09-21	INSPECTION OF OBVIOUS MODIFIED AC TUBING & HOSES	T.O. N/A THIS EQUIPMENT
1A-10C-659	Accomplished	2020-09-21	VISUAL INSPECTION ACES 1 EJECTION SEAT	COMPLETELY COMPLIED WITH
1A-10C-657	Accomplished	2020-09-15	MODIFY HMCS TO ACCOMMODATE HOBIT	COMPLETELY COMPLIED WITH
1A-10C-657	Accomplished	2020-05-10	RELOCATION OF CANOPY SEAL CHECK VALVE	COMPLETELY COMPLIED WITH
1A-10C-650	Unaccomplished	2020-09-22	INSTALL SUITE 9 SPIRAL 1 SOFTWARE	N/C/W, TOTO READY FOR WORK
1A-10C-648	Accomplished	2020-05-22	REMOVE/INSTALL SURVIVAL KIT ACES 1	COMPLETELY COMPLIED WITH
1A-10C-638	Unaccomplished	2020-05-22	INSTALLATION OF SUITE 9 SOFTWARE	N/C/W, TOTO READY FOR WORK
1A-10C-634	Unaccomplished	2020-05-22	INSTALL WOW SIGNAL TO ALU-213 PROCESSOR	N/C/W, TOTO READY FOR WORK
1A-10C-629	Unaccomplished	2020-05-22	ALTITUDE AND AIRSPEED SWITCH RE HOST	N/C/W, TOTO READY FOR WORK
1A-10C-617	Unaccomplished	2020-05-22	INSTALL ARC-210 3RD ISS CONNECTION	N/C/W, TOTO READY FOR WORK
- Flight Hour History:** A line graph titled 'Flight Hour History' showing flight hours over time for three categories: AFH (red), Air-Hr (blue), and EPH (pink). The x-axis is labeled 'Time' and the y-axis is 'Flight Hours'. The AFH and Air-Hr lines show a steady upward trend, while the EPH line shows a more gradual increase.

Documents and the Digital Twin



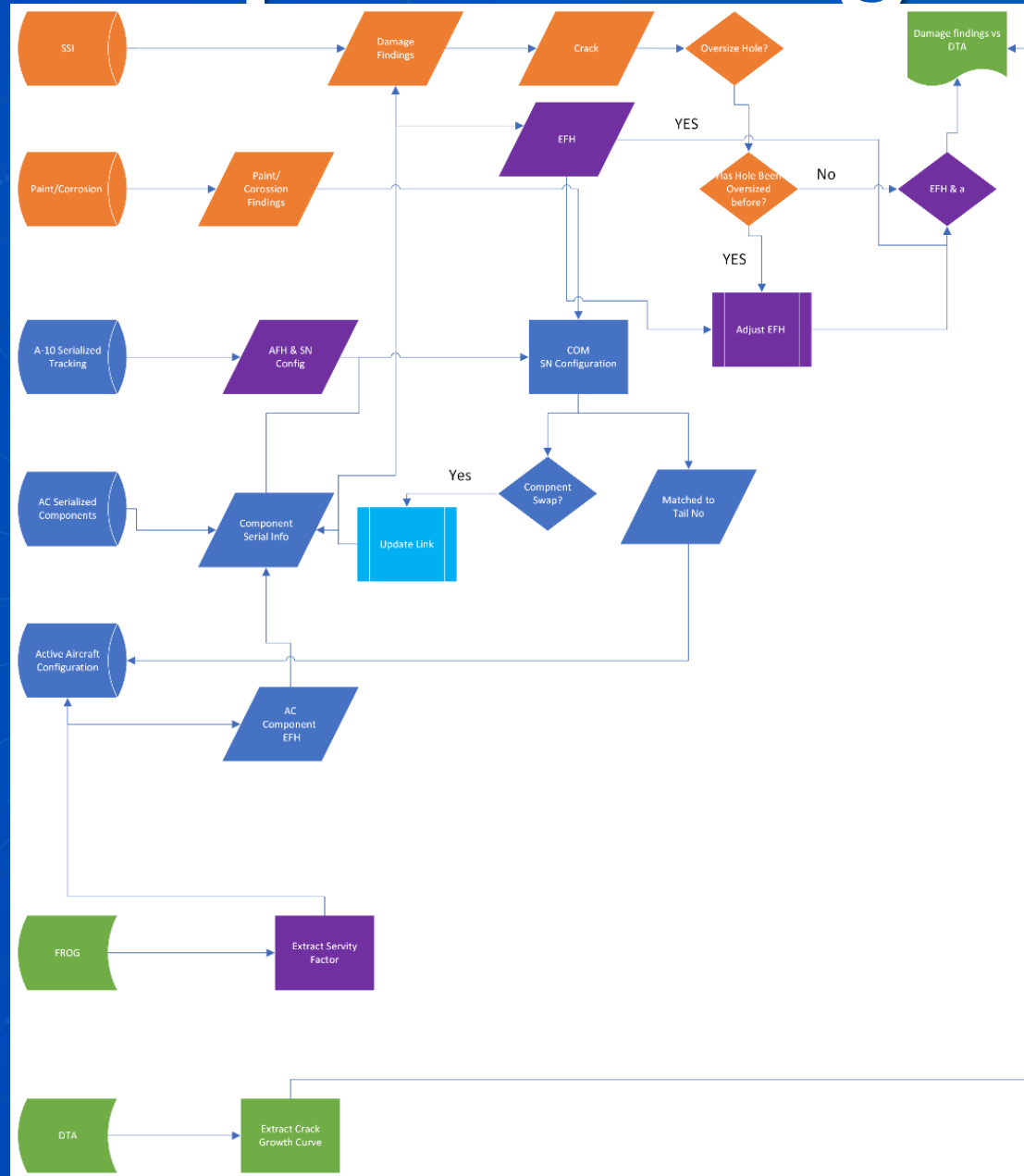
- Documents or written reports will still be needed and likely not going away
- The USAF maintenance groups still strongly prefer to utilize paper-based documentation for accountability
- It is important to have the ability to go back and forth between documents and digital data files



Example of COM in MS Word to allow a two-way sync with A-10's NLIgn database.

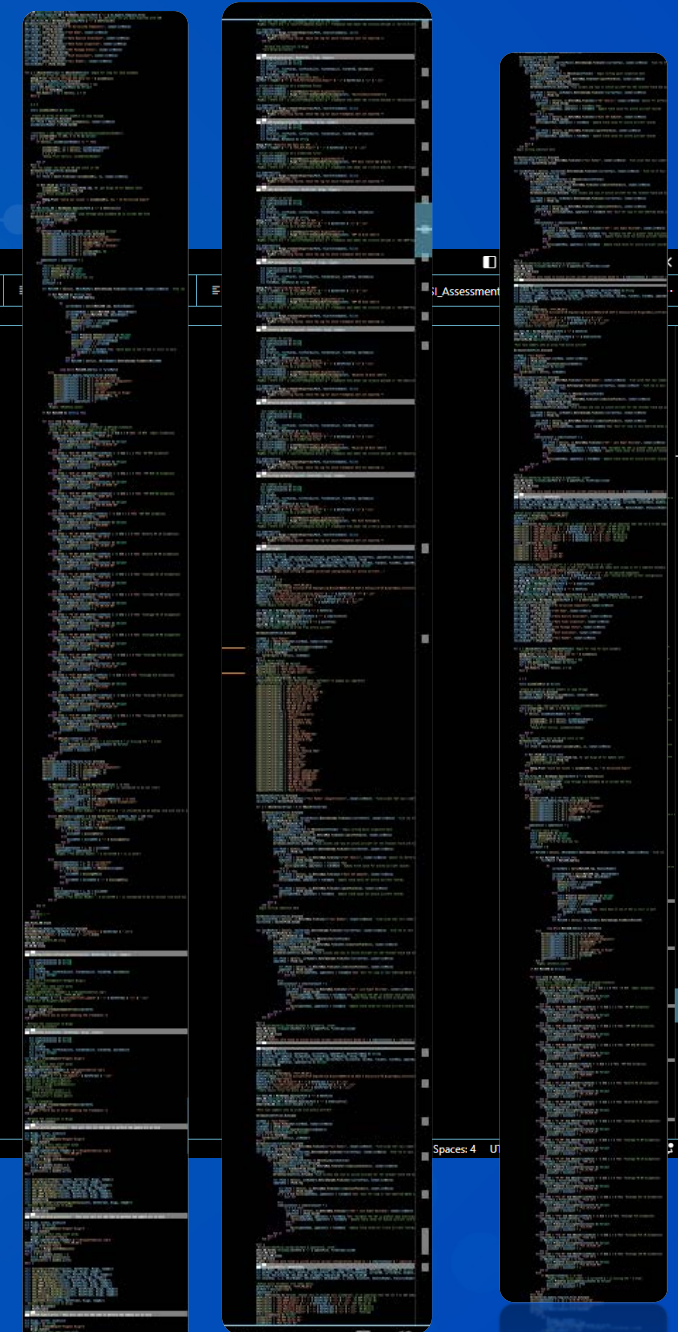
- A-10 ASIP utilizes report template tools in NLIgn to generate reports based on metadata available in the digital thread
- Double data entry can be avoided through COM automations

Implementing a Data Model



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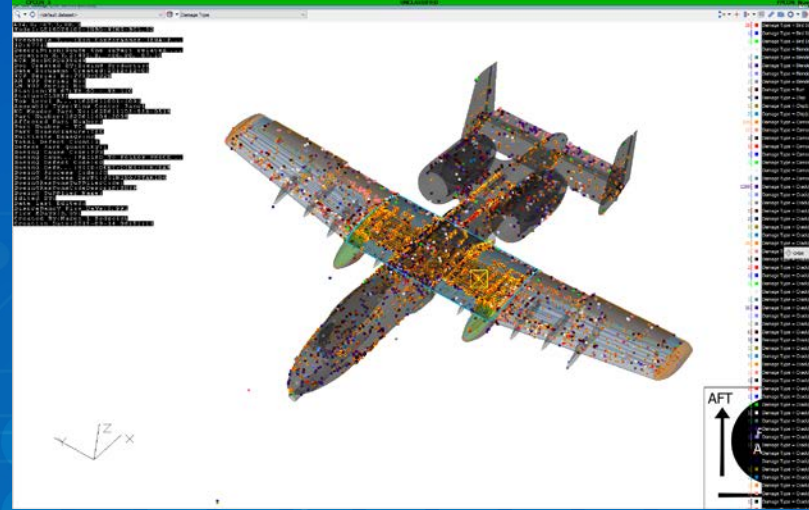
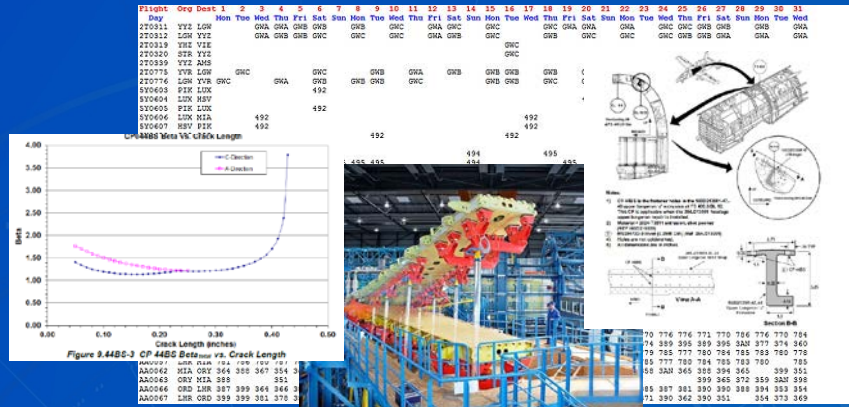
File Edit Selection View Go Run Terminal Help
MasterCopyAll(Apr 2023).vb - Visual Studio Code
C:\Users\1574146069E> OneDrive - United States Air Force > Documents > A-10 Fleet Risk Data > Prognostics Project > MasterCopyAll(Apr 2023).vb
931 End Sub
932 Sub UpdateSSI_Risk(assets, DateFormat, Nlign, tempDir)
933
934 Dim csvFileLocation As String
935 Dim logfileLocation As String
936 Dim Nlign
937 Dim docPath
938 Dim listFields, listFieldLists, fieldItemList, fieldItem, matchedList
939 Dim i, j As Integer
940 Dim success
941 Set Nlign = CreateObject("Etegent.Nlign")
942 'Nlign.Connect
943 'Can delete this when stuff works
944 tempDir = Environ("Temp")
945 Nlign.logEnableFile (tempDir & "\\NlignAutomation.log")
946 DateFormat = Format(Date, "YYYY_MM_DD")
947 docPath = tempDir & "\\" & "AC_Update_" & DateFormat & ".csv"
948 Dim assets As NlignStringVector
949 'Set assets = Nlign.assetNameList()
950 'ReDim assetList(0)
951 'For i = 0 To assets.Size() - 1
952 'ReDim Preserve assetList(i)
953 'assetList(i) = assets.get(i)
954 'Next i
955 'Update trendables
956 success = Nlign.trendableUpdateFromCsv(docPath)
957 If Not success Then
958 MsgBox ("There was an error updating the trendables.")
959 End If
960 'Release the connection to Nlign
961 Call Nlign.Disconnect
962 End Sub
963 Sub Master_Active_UpdateCom() ' This will call all the subs to perform the update all at once
964
965 Dim Nlign, assets, assetList
966 Dim tempDir As String
967 Set Nlign = CreateObject("Etegent.Nlign")
968 Nlign.Connect
969 'Can delete this when stuff works
970 tempDir = Environ("Temp")
971 Nlign.logEnableFile (tempDir & "\\NlignAutomation.log")
972 DateFormat = Format(Date, "YYYY_MM_DD")
973 tempDir = Environ("Temp")
974 Set assets = Nlign.assetNameList()
975 ReDim assetList(0)
976 For i = 0 To assets.Size() - 1
  
```



- Data flow for damage tolerance prediction validation

- Example of code written to implement data model

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
- Inspection history

Holistic Prognostics

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

Predictive depot induction priorities

Digital Twin and the Lessons Learned

- Data interoperability is important to achieve a true digital twin
- Culture change at the shop requires effort from all parties
- Data wrangling consumes a significant amount of human resources
- Hardware limitations for maintainers is significant
- Merging data to be meaningful requires significant effort
- A.I. tools are needed to fully implement digital engineering solutions
- IT support is mandatory but often lacking

References

- [1] M. L. Thomsen Ph.D., P. N. Clark Ph.D. 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] R. E. Heller, T. Wilson, M. Thomsen 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.
- [3] L. Wright and S. Davidson, “How to tell the difference between a model and a digital twin”, *Adv. Model. And Simul. in Eng. Sci.*, Feb 2020
- [4] J. Gomez-Escalonilla, F. Sanchez, O. Valencia and M. J. Rebollo, “A holistic digital twin for service life extension programs,” in *International Committee on Aeronautical Fatigue and Structural Integrity (ICAF)*, Delft, 2023.
- [5] H. Sedgwick, Interviewee, On the Origins of A-10 ASIPs use of NLign and Prognostic Goals. [Interview]. 18 April 2023.

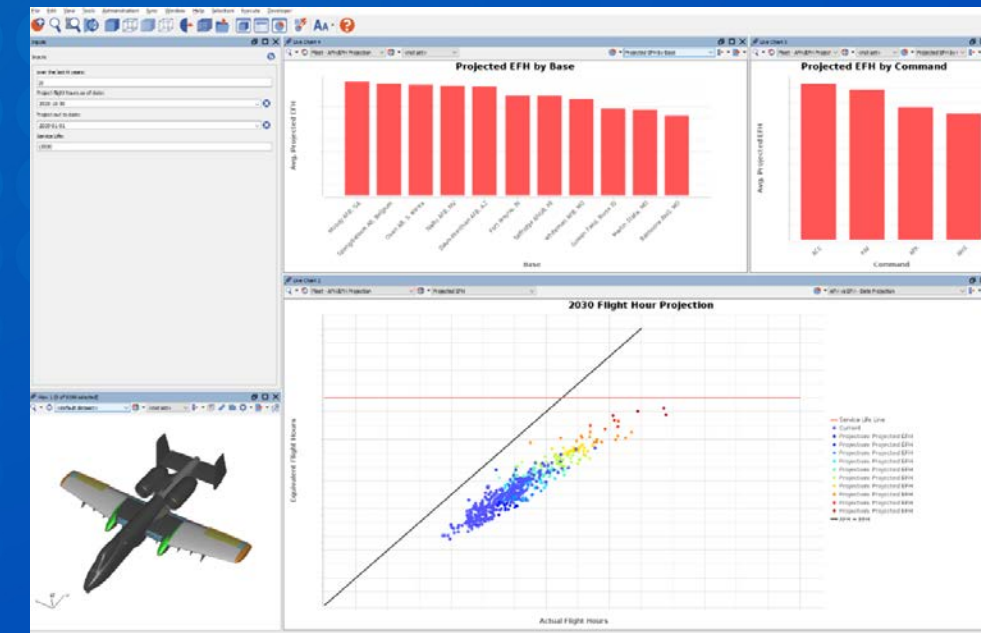
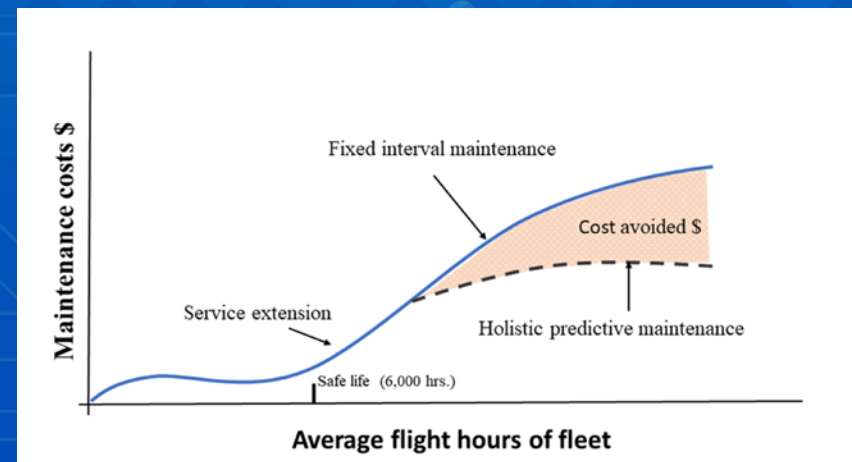
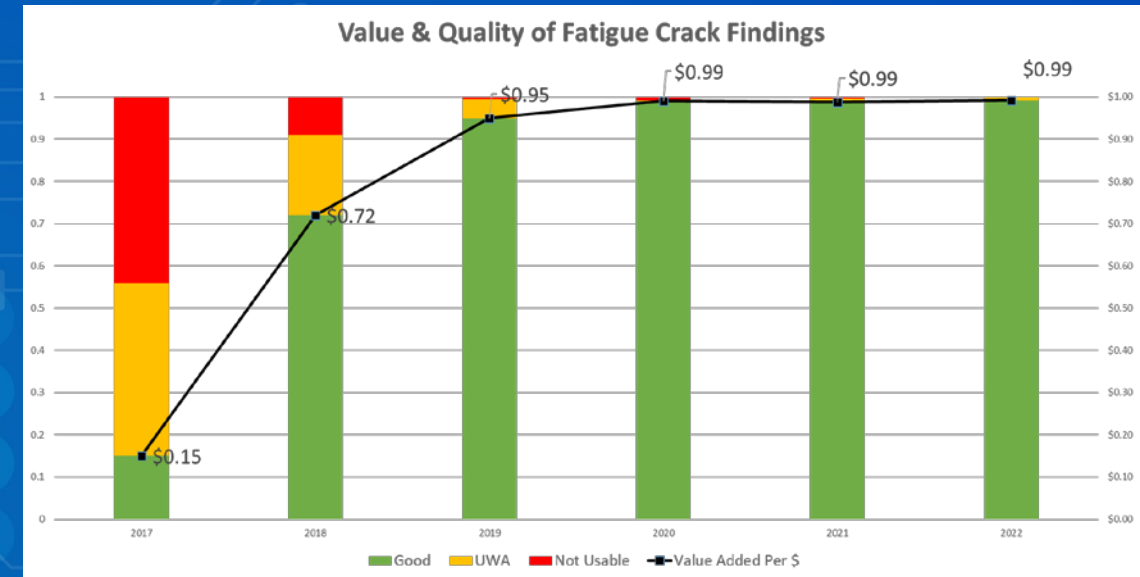
Thank you!



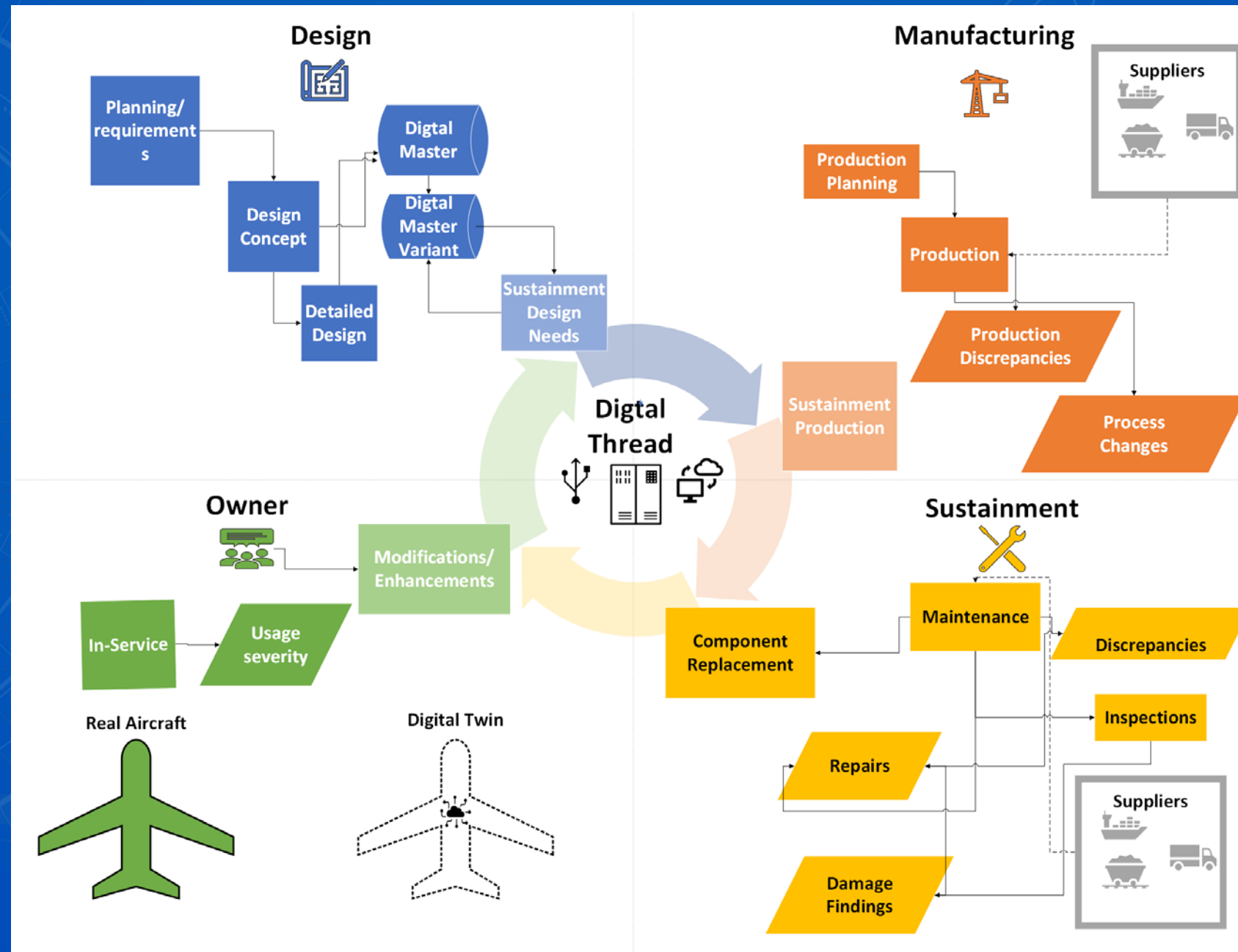
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Results

- Holistic prognostic capabilities allowing real-time predictive prioritization
- 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
- Issues addressed while asset is open and accessible
- 10s of millions \$\$ in cost avoidance



The Digital Thread Lifecycle



ASIP Digital Thread Requirements

