THE INTEGRATED MAINTENANCE SYSTEM (IMx+)

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Abstract: The use of tools and methodologies for capturing the digital thread data generated through on-aircraft maintenance actions continues to be a key focus area for improved execution of aircraft structural integrity programs across the aerospace community. This includes tools to perform nondestructive inspection and cold expansion of holes, as implemented in the new Integrated Maintenance System, an advanced maintenance technology integrating smart shop tools with automated data collection and spatial position tracking to improve aircraft quality assurance. The digital thread tools implemented within the IMx+ system helps to enable an effective Aircraft Structural Integrity Program (ASIP) to:

- Establish digital thread with customized data fidelity levels to better support fleet management and bridge the gap between maintenance tools and databases
- Enable automatic maintenance data capture and output to user-defined maintenance databases
- Establish quality assurance tools necessary for cold expansion full credit
- Expand flexibility to interface with various maintenance tools and spatial tracking technologies

While this type of technology is necessary to meet the growing needs for a sufficient digital thread, we must also be cognizant of their impacts on the maintenance community and find ways to meet structural integrity needs without overburdening the maintainer executing the work. The combination of defined methods and an array of tools as implemented in the Integrated Maintenance System is necessary to sew the digital thread, ensuring the necessary quality assurance requirements are achieved for critical maintenance processes and supplying the structural integrity community with the necessary data to optimize fleet management.

Keywords: digital thread, spatial tracking, data capture, nondestructive inspection

OVERVIEW

The Integrated Maintenance System, or IMx+, is a maintenance technology system that integrates smart maintenance tools with automated data collection and spatial position tracking to improve aircraft quality assurance. Similar to the terminology used for condition based maintenance (CBM+), the '+' is used here to indicate the ability of the system to adapt to new technologies and be flexible and modular to integrate additional tools. It is focused on critical maintenance operations such as cold expansion (Cx) and nondestructive inspection (NDI) of fastener holes, providing the user with a live spatial position of

the maintenance tool being used as well as live results of the maintenance process, streamlining the data capture of the full digital thread (see Figure 1) and dramatically improving upon legacy hand written logs (see Figure 2). The origin of the IMx+ stemmed from recognizing the lack of an automated integrated system for maintenance data capture observed across the United States Air Force (USAF) maintenance operations. As stated by USAF Lt. Col. Gary Steffes in 2020, "Current challenges include an automated method for digital procedural compliance and record retention, importing digital NDI equipment outputs, end item processing data, meta-data, photos, etc., interfacing with legacy maintenance (Mx) processing systems (i.e., NDI), and trending capabilities. In terms of capturing Mx data, an automated integrated system doesn't exist." [1]

The IMx+ currently integrates the components listed below, which are discussed in detail in the following sections.

- Integration Module & adaptations
- Spatial tracking system
- Maintenance tools
- User interface software

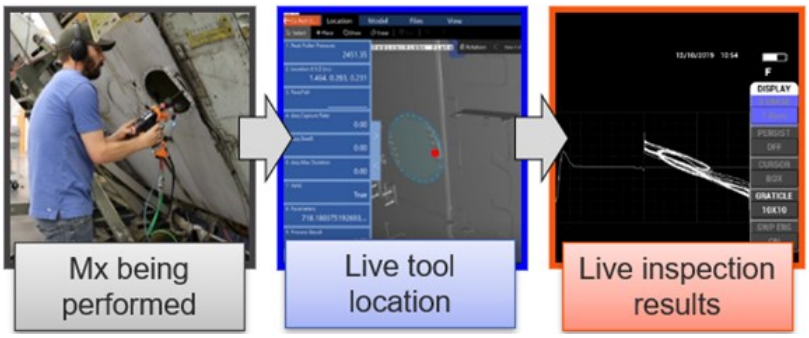

Figure 1: Process of capturing the complete digital thread.

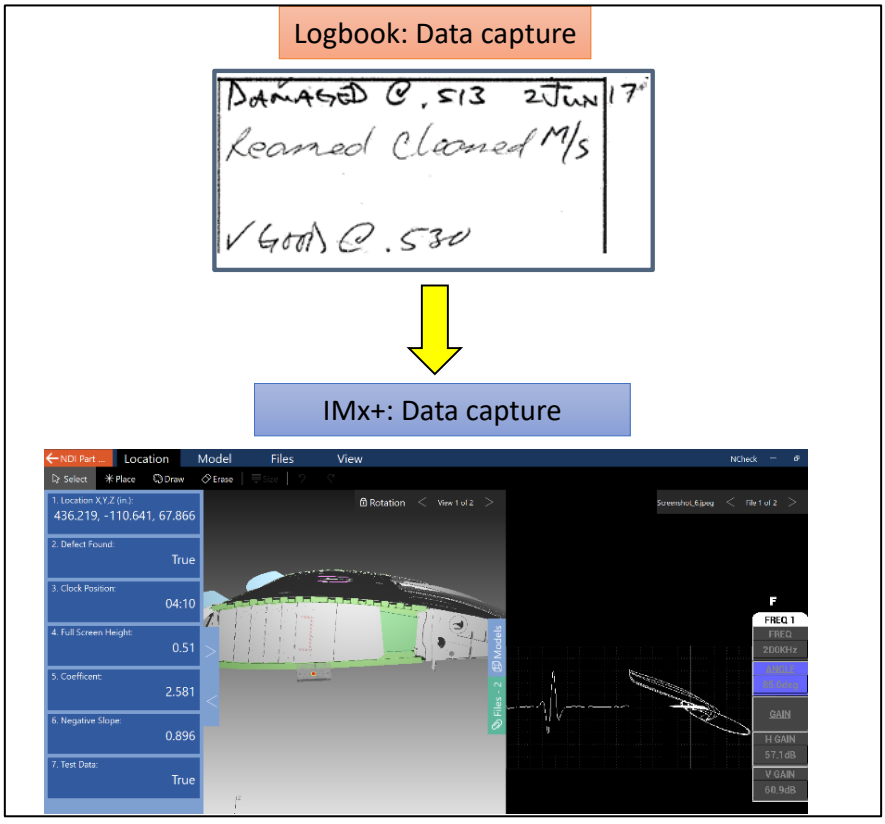

Figure 2: Improvements in capturing the complete digital thread.

INTEGRATION MODULE & ADAPTATIONS

The Integration Module (IM) is designed to be the hub of communication and connection between all components (see Figure 3). Produced by Hill Engineering, the IM integrates the location and maintenance results for upload to the user-defined digital thread database. IM software and hardware is designed to be adaptable to a wide range of new smart tools. The IM utilizes an Application Programming Interface (API) to be agnostic of a specific database structure allows for 3rd party user interfaces to connect, pass, and receive data from the IMx+ system.

Figure 3: Integration Module.

Integration module adapters are built and attached to the maintenance tools in order to provide real-time feedback and controls to the maintainer (LEDs and buttons), as well as to mount the spatial tracking hardware to the maintenance tool (see Figure 4). The user can customize the adapter buttons to perform user defined tasks, such as capturing images from equipment, capturing spatial position streams, accepting/rejecting operational data, and controlling the connected equipment. Common LED functionality can provide information on working areas and system status.

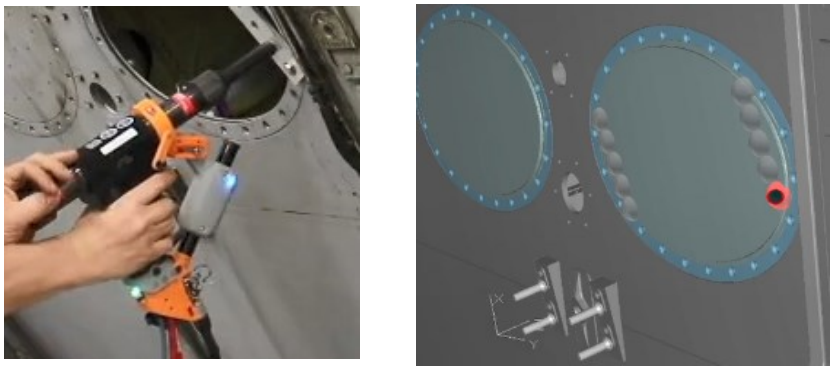

Figure 4: IM adapters with LED feedback and live model tracking.

SPATIAL TRACKING SYSTEM

The IMx+ utilizes a line-of-sight spatial tracking system developed and built by 7D Kinematic Metrology called iGPS (see Figure 5). It is a commercially available technology using infrared (IR) transmitters to track the spatial position of tool-mounted sensors. It provides 5 to 6 DOF spatial position with accuracies down to 0.254 mm (0.01 inch) and is scalable for small to large facilities. In addition, the IMx+ system has added on to the existing iGPS equipment to provide integrated feedback directly to the tool operator. This includes LEDs to indicate that the sensors are properly connected to the IR transmitters and to indicate that the maintenance tool is in the correct task location for the work being done.

In addition to iGPS, the IMx+ system is customizable to a wide array of other spatial tracking tools, such as linear and rotational encoders, fiber optics, and other line-of-sight systems. This combination of local position and global position is synced together by the IM (through customized functions for calibration and alignment) so the user gets the correct spatial position of the tool in the desired aircraft coordinates.

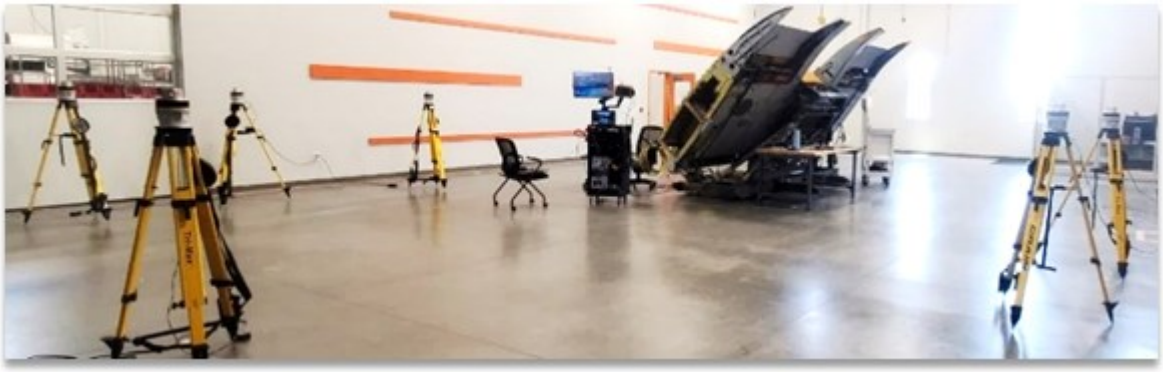

Figure 5: iGPS spatial tracking system.

MAINTENANCE TOOLS

Cold Expansion

The DigitalEx cold expansion instrumented puller system is developed and built by Fatigue Technology Inc. (FTI). The DigitalEx consists of the instrumented puller and an associated PowerPak (see Figure 6). These components physically and digitally interface with IMx+ system to collect key process parameters during the Cx operation and integrate instant process validation and quality assurance (go/no go). This integration allows for capturing the Cx data necessary for meeting the requirements for 'full credit' for engineered residual stress in associated analyses.

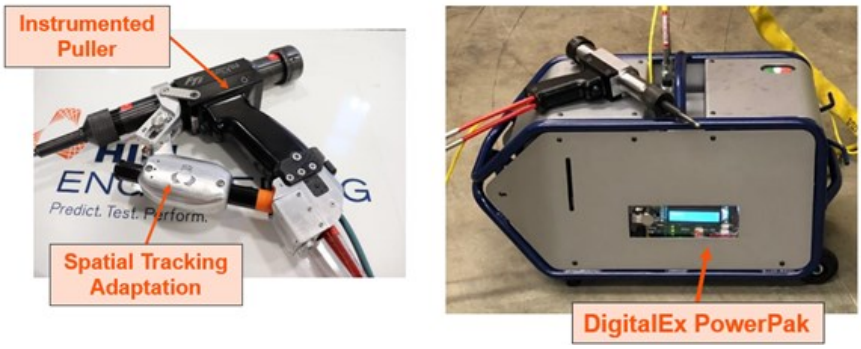

Figure 6: Cx Instrumented Puller with IMx+ adaption.

Nondestructive Inspection

For NDI applications, the IMx+ system is integrated with a range of standard NDI tools utilized by the USAF, which include the tooling listed below (see Figure 7 through Figure 9).

- NORTEC 600 eddy current flaw detector (Olympus)
  - Spitfire Rotating Bolt Hole Scanner
  - MiniMite Rotating Bolt Hole Scanner
- EVi eddy current flaw detector (UniWest)
  - ECS-3 Rotating Eddy Current Scanner
  - ECS-5 Rotating Bolt Hole Scanner
- EPOCH 650 ultrasonic flaw detector (Olympus)
  - Custom-designed ultrasonic transducer using space pen adaption

Figure 7: NORTEC 600 adapted tools.

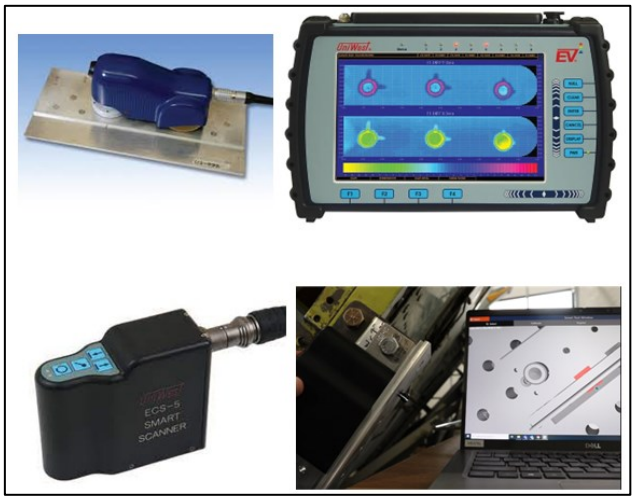

Figure 8: EVi adapted tools.

Figure 9: EPOCH 650 adapted tools.

Key features of the NDI-related capabilities of the IMx+ system include:

- Automatic data capture of the full data stream throughout the entire inspection process, such as waveform, vertical gain, and phase angle
- Automated interrogation of results to populate critical NDI fields such as damage type, percent full screen height, and clock orientation (see Figure 10)
- Automation of the collection of inspection spatial location with at least 1.27 mm (0.050 inch) accuracy

- Real-time spatial tracking feedback of the NDI tool to the inspector to allow for confirmation of the correct inspection location, the current layer being inspected in a multi-layer joint, and completion of the current inspection

Each NDI tool is capable of being used with IMx+ with or without spatial tracking. This allows the user to customize the system to their specific need, whether it's for streamlined automatic data capture only or if they require the associated spatial position to also be incorporated into the digital thread. Capturing the full data stream throughout the entire inspection process, coupled with spatial position, can be critical to have the necessary NDI data for immediate and future ASIP needs.

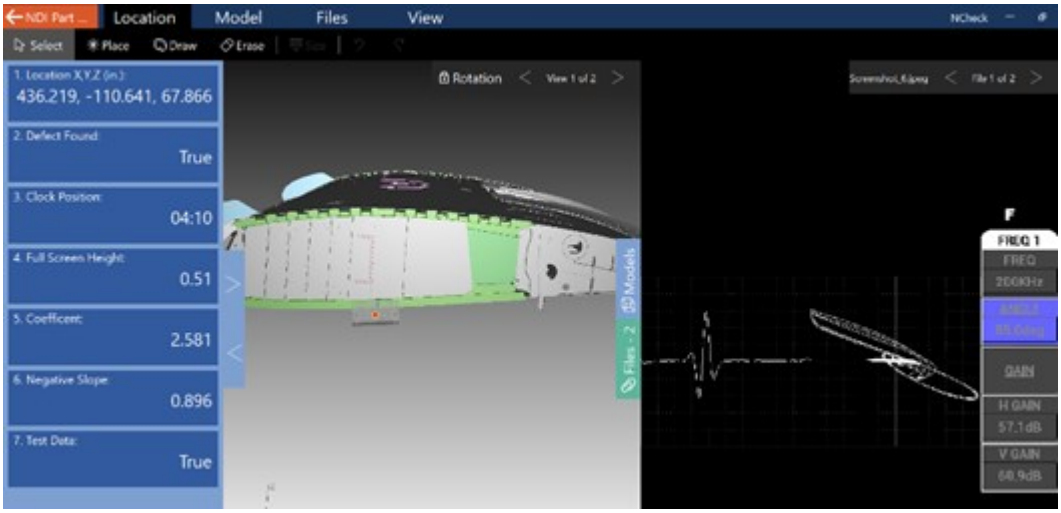

Figure 10: Screenshot of NDI data capture.

Metrology

In addition to Cx and NDI, the IMx+ system has also integrated several metrology tools (digital bore gage and calipers, see Figure 11) in order to streamline the data capture for critical geometric measurements that are frequently required as part of typical day-to-day depot or field aircraft repair procedures.

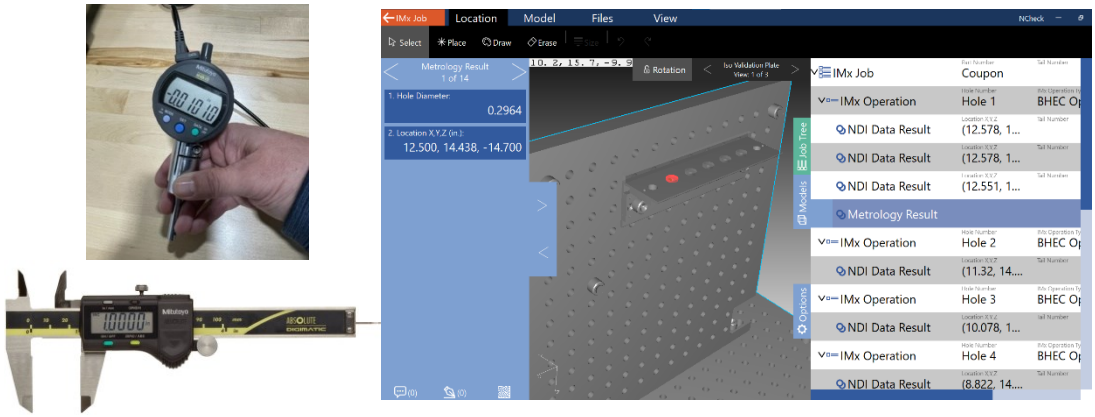

Figure 11: Metrology tools.

Auxiliary

Lastly, several auxiliary tooling has been integrated with the system in order to facilitate other data capture needs, including a digital camera and a custom-designed space pen tool. The photo output from the camera can be tagged to the specific location associated with it, while the space pen allows the user to spatially locate a specific point as well as do a surface scan of a specific geometry (e.g., blend, radius) and have that surface data cloud digitally captured.

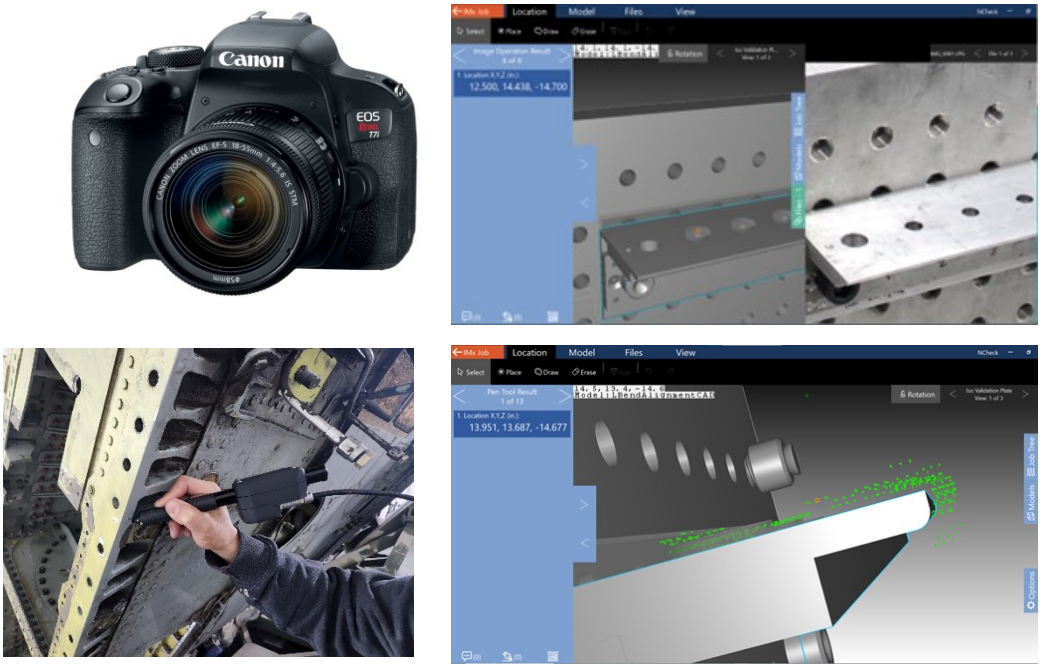

Figure 12: Auxiliary tools.

USER INTERFACE SOFTWARE

The user interface for the maintainers for the execution of digital tech data requirements is through the NCheck software, which transmits the task requirements in relation to a 2D or 3D model of the structure. It displays the spatial position of the maintenance tool in real time, shows the task locations to be worked, and highlights the current operation. It will also display the maintenance operations that have been completed and the results. It captures and displays operation results automatically from the IM (e.g., spatial location, operation details, raw process data). Screenshots of the NCheck software are given in Figure 13 and Figure 14. The user interface for engineering to setup the digital tech data is the NLign software, which includes the digital thread and full data repository. NLign has extensive data analytics, visualization, and mapping capabilities.

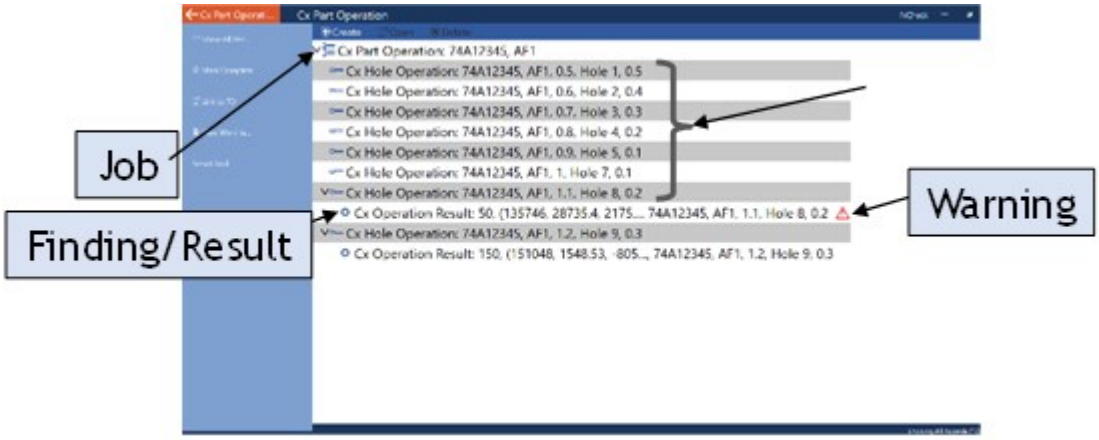

Figure 13: NCheck operation result window.

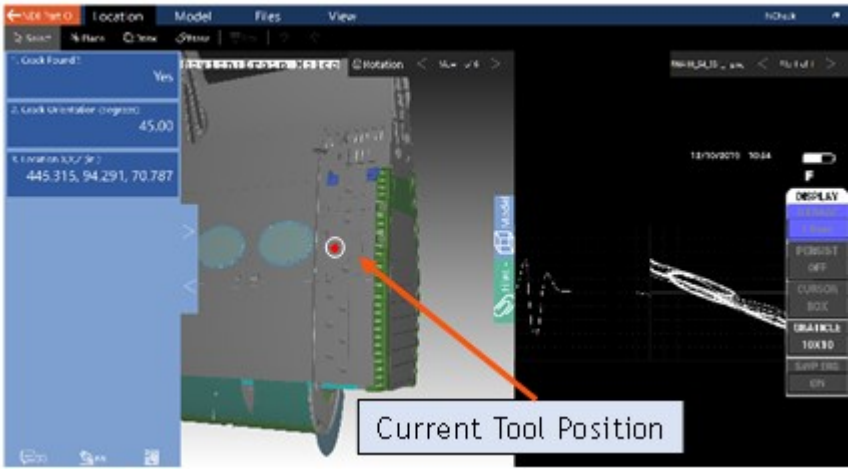

Figure 14: NCheck live tool location window.

Alternatively, a new product set called “NCheck Lite” and “NCheck Lite Creator” have been implemented in the IMx+ system to facilitate utilization without requiring the user to have access to the NLign commercial software or the associated databases. Deployable in standalone environments without any server infrastructure for customers who do not use the full NLign Analytics’ suite, this software set guides the maintenance job and task execution, captures the data, and pushes that data directly into the USAF Non-Secure Internet Protocol Router Network (NIPRNET) system. The API allows the 3rd party UI to output maintenance data into a format that can be imported into a wide array of weapon system databases.

SUMMARY

Ultimately, integrated tools are necessary to automate the collection of critical maintenance data and ensure the correct maintenance events were accomplished. The IMx+ system provides an automated method for digital procedural compliance and record retention, importing digital equipment outputs, end item processing data, meta-data, photos, interfacing with legacy maintenance processing systems, and trending capabilities. Current operators of IMx+ have stated that they use it because it helps them to meet MIL-STD-1530D requirements, automate data entry and upload (faster and easier for inspector), improve inspection value by saving inspection data (not just pass/fail), includes Mx location in aircraft coordinates, and identifies correct location of Mx.

Why use IMx+ for NDI? It provides a method to automatically capture critical data to support NDI and engineering, identify critical layers and crack locations for stack-ups, and provides an estimated 50% reduction in time to document inspection results with an estimated 20% reduction in inspection time through real time feedback.

Why use IMx+ for Cx? It helps to establish the Cx digital thread, addresses next-step-questions faced by ASIP to develop inspection intervals, and answers three critical questions required for residual stress full credit (see Figure 15):

- Was Cx accomplished at the correct location?
- Was Cx accomplished (go/no-go)?
- What are the analysis requirements for full credit?

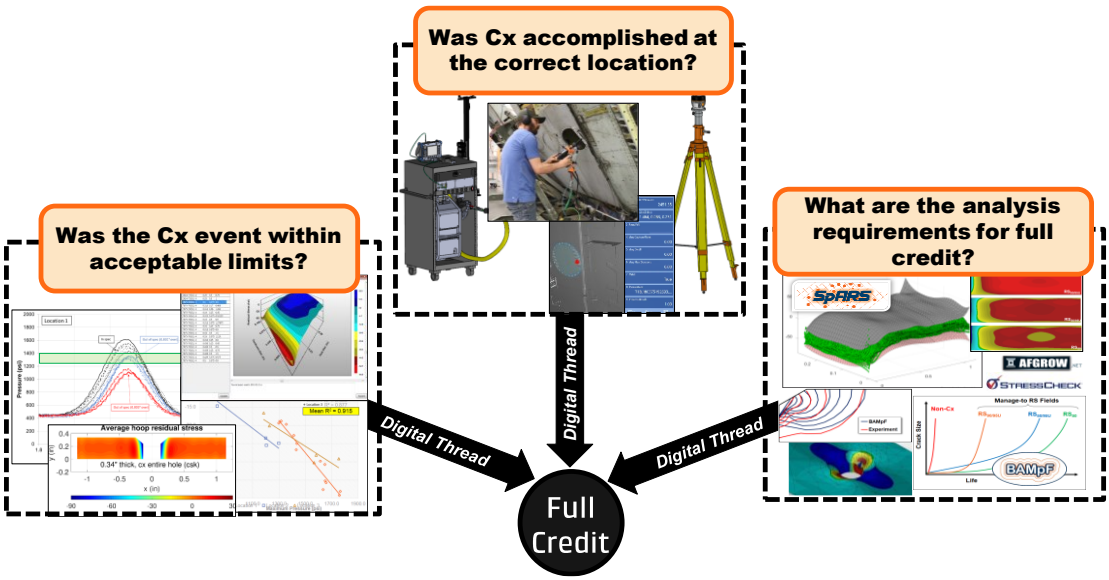

Figure 15: Process of capturing the complete Cx digital thread [2].

The mission impact to aircraft fleets will be improved quality assurance of maintenance actions ensuring safety of flight, reduced maintenance labor hours to create and archive quality assurance records, and potential to use the quality data for justification to extend future maintenance intervals.

REFERENCES

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[2] Andrew, D. (2021). *Tools and Methodologies to Sew the Digital Thread*, Proceedings of the 2021 ASIP Conference, Austin, TX.