ASIP Data Collection as a Critical Step Towards a Realistic Digital Twin

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ABSTRACT

A realistic digital twin requires all data from the entire lifecycle of an aircraft, from design, manufacturing, operations, and modifications, through retirement. A successful Aircraft Structural Integrity Program (ASIP) requires collecting and managing the same data, including, but not limited to, flight data recorder files to requests for engineering disposition to inspection data. Currently, the United States Air Force (USAF) F-16 System Program Office (SPO) uses the F-16 ASIP Portal website to collect and manage data through multiple interrelated modules. The web-based interface allows for easy collection of data over the entire ASIP cycle from dozens of worldwide USAF F-16 bases, multiple depot locations, and over 900 active aircraft. All the gathered data is stored in a centralized database that allows engineering to leverage all available information when making decisions. For over two decades, this data has been collected electronically, with digital tools developed and updated frequently based on field user and engineering needs, as well as USAF requirements. This data collection is why ASIP is a critical part of creating a realistic digital twin and driving many of the F-16's digital transformation efforts.

1.0 INTRODUCTION

The United States Air Force (USAF) has been pushing efforts towards a digital campaign, moving to more advanced digital engineering, including digital twins, and released a 'Guidebook for Digital engineering and e-Series' [1]. Mr. Thomas Fischer gave a lunchtime presentation at the 2021 ASIP Conference and discussed the USAF digital campaign drive [2]. The digital campaign involves the entire product lifecycle, with the objective to "Deliver capabilities at ever increasing speed and efficiency by designing, sustaining, and modernizing them in an integrated digital environment." Mr. Fischer cited the importance of data and seamless data sharing in this transformation as drivers to speed and agility. Mr. Chuck Babish wrote a "White Paper on Digital Engineering (DE) for Aircraft Structural Integrity Program (ASIP) Execution" in response to Mr. Fischer's ASIP presentation [3]. Digital engineering has been defined multiple ways, with Mr. Babish's definition being "the use of models and data for design, analysis, structural certification, and sustainment to enable informed decision making over the entire life cycle". The digital engineering efforts are not new within ASIP for many USAF weapon systems and have been practiced in order to have the necessary data and analysis capabilities to create a realistic digital twin. USAF F-16 ASIP has been collecting this digital data and applying digital engineering principles for decades.

A digital twin is the aggregate of models and data used to capture the design, build, operation, maintenance, and configuration of an aircraft. Development of a realistic digital twin requires all data, or digital threads, from the entire lifecycle of an aircraft. A successful ASIP requires collecting and managing all the same data, ranging from flight data recorder files to requests for engineering disposition to detailed inspection data. For the United States Air Force, these requirements are laid out in MIL-STD-1530 [4]. The USAF F-16 ASIP is in a unique situation since there are Foreign Military Sales (FMS) customers, as well as an Original Equipment Manufacturer (OEM), Lockheed Martin, that all work together to have a collaborative, successful program. The ability for USAF to easily collect, maintain, and share data is invaluable towards overall F-16

ASIP success. The F-16 System Program Office (SPO) has developed the F-16 ASIP Portal website for this data collection and management as part of the F-16 sustainment lifecycle. Engineering dispositions, detailed inspection data, flight data recorder files, and service life information are all stored in a centralized database. This data, combined with the F-16 Original Equipment Manufacturer (OEM) full scale test results, fatigue crack correlation, and finite element analyses create a powerful tool in the push towards a realistic digital twin.

2.0 F-16 ASIP PORTAL

The USAF F-16 SPO developed and maintains the F-16 ASIP Portal website to collect and manage data through six interrelated modules. Each module was designed to support a specific part of the ASIP process and be readily accessible for a wide range of users. These modules include Damage Evaluation System Technical/Repair Assistance Page (DESTRAP), Flight Data Capture (FDC), Common Inspection Reporting Engine (CIRE), Individual Aircraft Tracking (IAT), Service Life Reports (SLR), and Health Of The Fleet (HOTF). The web-based interface provides easy collection of data for the entire ASIP cycle from dozens of worldwide USAF F-16 bases, multiple depot locations, and almost one thousand active aircraft. All gathered data through the modules is in a centralized database that allows engineering to easily leverage the data. See Figure 1 for an overview of the overall system and the interactions between modules.

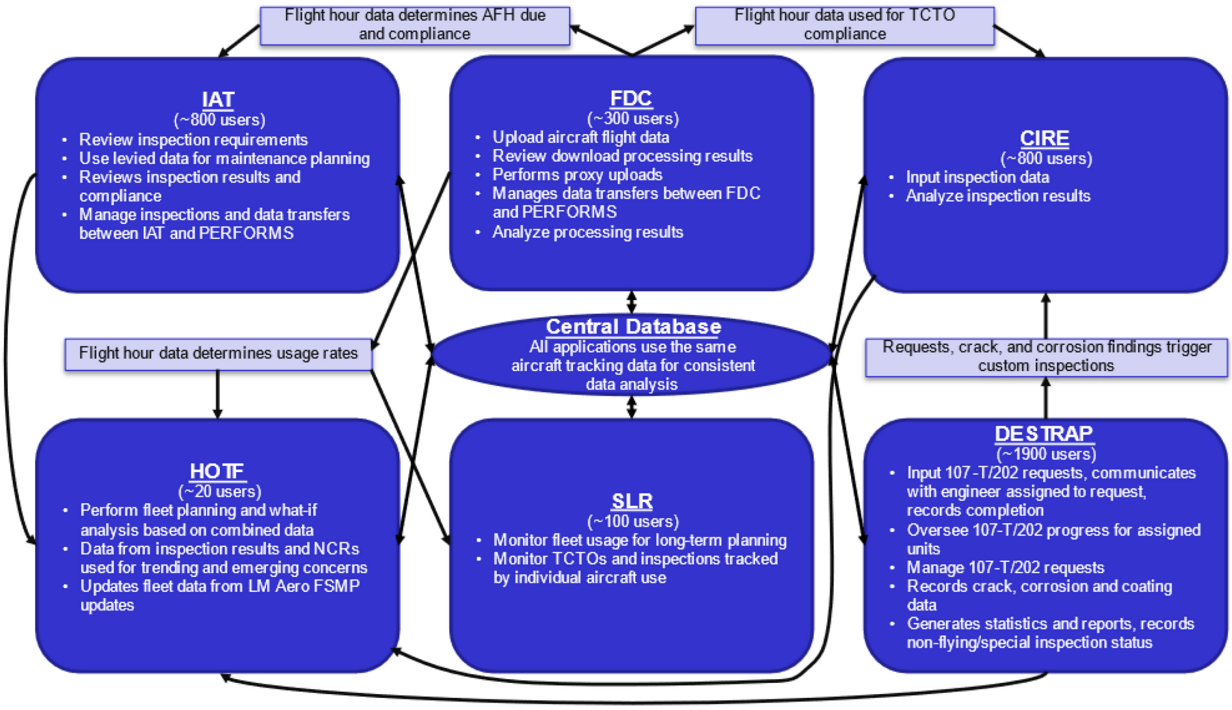


Figure 1: F-16 ASIP portal interactions [5].

2.1 DESTRAP

DESTRAP was the first module that came online in 2000 and is designed to streamline handling engineering disposition requests (107-Ts and 202s), also known as Engineering Technical Assistance Requests (ETARs). Each aircraft deficiency is entered into the online form that is modelled after the official AFMC Form 202 and any attachments can be included with the ETAR when submitted. Figure 2 shows an example of the ETAR form view on the website. Field units and depots can submit the ETARs and monitor the status online. Any additional communications that happen between the field and engineering are recorded in a message log within the ETAR so that there is no information loss during the answering process. Engineering only messages also are included within the ETAR to allow different engineering sections to coordinate an answer and to provide engineering justification for the answer given. As the engineer is answering the ETAR, they can add it to a Fatigue Crack Database or Corrosion and Coatings Database that allows the engineer to enter additional relevant information by part number to simplify the trending of both fatigue cracking and corrosion issues. This data is shared with the OEM and FMS partners to identify possible fleet-wide issues, understand worldwide fleet condition, and update analyses and fatigue crack correlations.

2.2 FDC

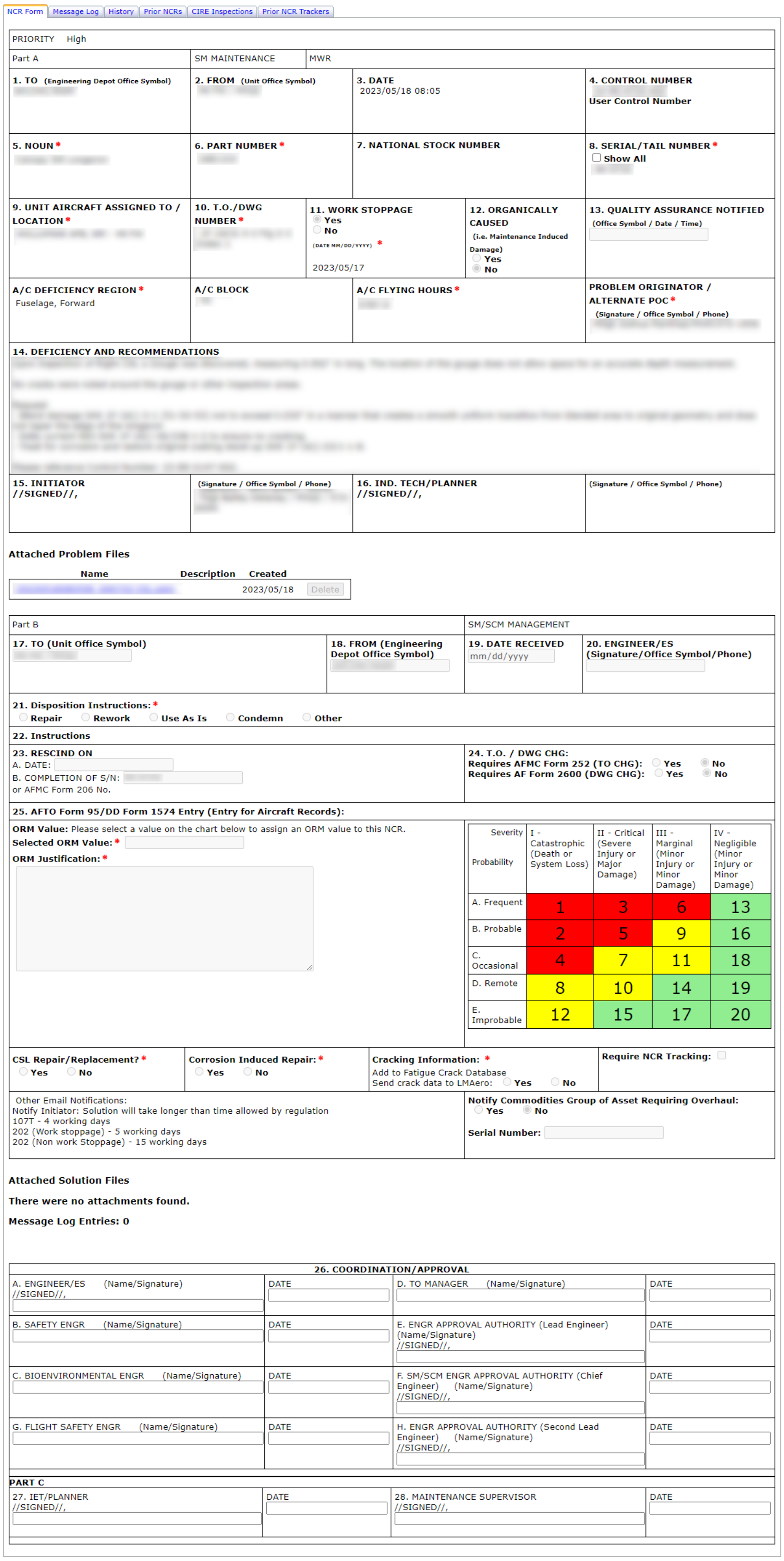
FDC provides a single point interface for units to upload flight data recorder downloads, request additional analysis, track recorder health, and provide additional data for mishap analysis. Figure 3 shows the upload screen when a user uploads flight data recorder files. The Technical Orders (TOs) require that units upload data at least every 75 hours with the average upload interval being approximately 60 hours. Units have found that it has been beneficial to upload data more often than required. FDC also contains multiple report views for units and data analysts to view the data capture percentages, monitor when downloads are due, and track any flight data recorder issues.

2.3 CIRE

CIRE is one of the inspection data collection modules on the F-16 ASIP Portal. The inspections can be driven by TOs, Time Compliance Technical Orders (TCTOs), Analytical Condition Inspections (ACIs), modification or repair programs, or any other method. The inspections are fully customizable to the stakeholder's requirements and can collect any data types required, including any type of attachments. Figure 4 shows an example inspection from CIRE of a fracture critical part that includes requirements to upload images of the inspection area. The inspection data can be tracked in real-time to identify any unanticipated issues or make any updates, as necessary. CIRE also is in use by various F-16 sections beyond structures, including mechanical systems, commodities, and avionics, to support their inspection data needs. There are 98 total inspections with 68 actives currently, with new inspections added frequently.

2.4 IAT

IAT is a module designed to levy inspections on an individual aircraft basis generated from flight data recorder downloads and subsequent flight severity compared to design/test baselines. OEM proprietary F-16 Flight Data Recorder Processing, Evaluating, and Reporting of FORce Management Data Software (PERFORMS) processes the flight recorder data captured in FDC and inspections are then levied based on outputs from the software which incorporates fatigue crack growth models, mission types, and flight maneuver severity. These inspection requirements on the website are currently updated every six months based on updated aircraft usage and units are driven to look for updated inspection requirements by the TOs; messages are also sent to the field units to inform them of the inspection updates. IAT inspections are different from CIRE inspections in that they have predefined fields based on requirements to load inspection results back into PERFORMS. Figure 5 shows an example inspection with the predefined data fields. Additional capabilities built into IAT include non-PERFORMS driven inspections that can be levied on an individual aircraft basis to support quick data collection for risk assessment purposes or targeted inspections on high-risk aircraft.


NCR Form | Message Log | History | Prior NCRs | CIRE Inspections | Prior NCR Trackers

PRIORITY High

Part A	SM MAINTENANCE	MWR		
1. TO (Engineering Depot Office Symbol)	2. FROM (Unit Office Symbol)		3. DATE 2023/05/18 08:05	4. CONTROL NUMBER User Control Number
5. NOUN *	6. PART NUMBER *		7. NATIONAL STOCK NUMBER	8. SERIAL/TAIL NUMBER * Show All
9. UNIT AIRCRAFT ASSIGNED TO / LOCATION *	10. T.O./DWG NUMBER *	11. WORK STOPPAGE Yes No (DATE MM/DD/YYYY) * 2023/05/17	12. ORGANICALLY CAUSED (i.e. Maintenance Induced Damage) Yes No	13. QUALITY ASSURANCE NOTIFIED (Office Symbol / Date / Time)
A/C DEFICIENCY REGION * Fuselage, Forward	A/C BLOCK		A/C FLYING HOURS *	PROBLEM ORIGINATOR / ALTERNATE POC * (Signature / Office Symbol / Phone)
14. DEFICIENCY AND RECOMMENDATIONS				
15. INITIATOR //SIGNED//,	(Signature / Office Symbol / Phone)		16. IND. TECH/PLANNER //SIGNED//,	(Signature / Office Symbol / Phone)

Attached Problem Files

Name	Description	Created	
		2023/05/18	Delete

Part B		SM/SCM MANAGEMENT	
17. TO (Unit Office Symbol)	18. FROM (Engineering Depot Office Symbol)	19. DATE RECEIVED mm/dd/yyyy	20. ENGINEER/ES (Signature/Office Symbol/Phone)

21. Disposition Instructions: *
Repair | Rework | Use As Is | Condemn | Other

22. Instructions

23. RESCIND ON
A. DATE:
B. COMPLETION OF S/N:
or AFMC Form 206 No.

24. T.O. / DWG CHG:
Requires AFMC Form 252 (TO CHG): Yes No
Requires AF Form 2600 (DWG CHG): Yes No

25. AFTO Form 95/DD Form 1574 Entry (Entry for Aircraft Records):

ORM Value: Please select a value on the chart below to assign an ORM value to this NCR.
Selected ORM Value: *
ORM Justification: *

Severity / Probability	I - Catastrophic (Death or System Loss)	II - Critical (Severe Injury or Major Damage)	III - Marginal (Minor Injury or Minor Damage)	IV - Negligible (Minor Injury or Minor Damage)
A. Frequent	1	3	6	13
B. Probable	2	5	9	16
C. Occasional	4	7	11	18
D. Remote	8	10	14	19
E. Improbable	12	15	17	20

CSL Repair/Replacement? * Yes No
Corrosion Induced Repair: * Yes No
Cracking Information: *
Add to Fatigue Crack Database
Send crack data to LMAero: Yes No
Require NCR Tracking:

Other Email Notifications:
Notify Initiator: Solution will take longer than time allowed by regulation
107T - 4 working days
202 (Work stoppage) - 5 working days
202 (Non work Stoppage) - 15 working days

Notify Commodities Group of Asset Requiring Overhaul:
Yes No
Serial Number:

Attached Solution Files
There were no attachments found.
Message Log Entries: 0

26. COORDINATION/APPROVAL

A. ENGINEER/ES (Name/Signature) //SIGNED//,	DATE	D. TO MANAGER (Name/Signature)	DATE
B. SAFETY ENGR (Name/Signature)	DATE	E. ENGR APPROVAL AUTHORITY (Lead Engineer) (Name/Signature) //SIGNED//,	DATE
C. BIOENVIRONMENTAL ENGR (Name/Signature)	DATE	F. SM/SCM ENGR APPROVAL AUTHORITY (Chief Engineer) (Name/Signature) //SIGNED//,	DATE
G. FLIGHT SAFETY ENGR (Name/Signature)	DATE	H. ENGR APPROVAL AUTHORITY (Second Lead Engineer) (Name/Signature) //SIGNED//,	DATE

PART C

27. IET/PLANNER //SIGNED//,	DATE	28. MAINTENANCE SUPERVISOR //SIGNED//,	DATE

Figure 2: ETAR form view.

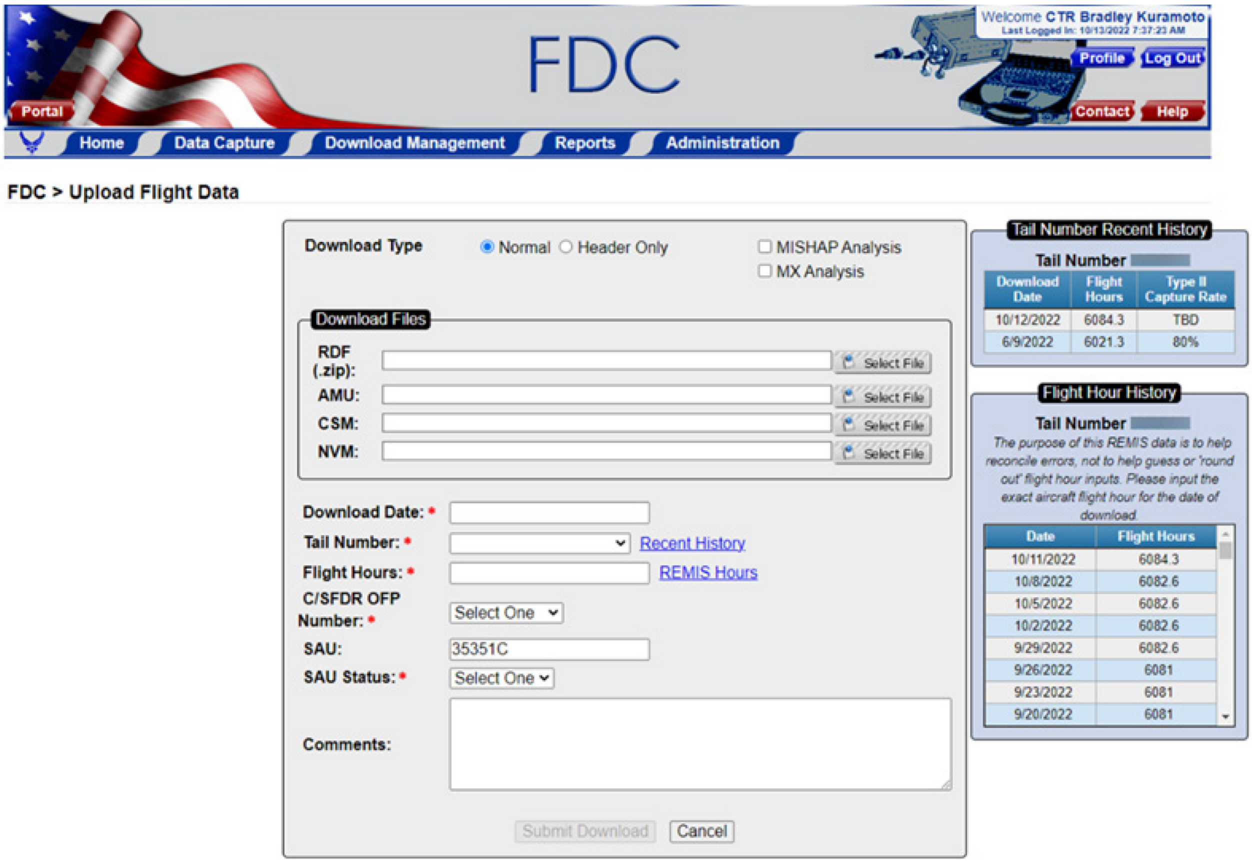
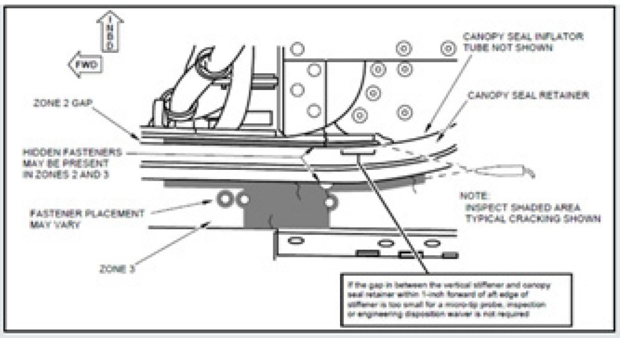


Figure 3: FDC upload capture page.



Note:

- If cracked, report the 107/202 control number
- If cracked, do not pull the seal retainer to measure crack unless directed
- Provide any additional information in the comments block
- Report any life limiting restrictions

Longeron PN: * ○ 16B1103 ○ 16B1105 ○ 16B1107

Left Canopy Sill Longeron	
Cracks Found?	○ Yes ○ No
If crack was found, include 107/202 control number, crack length, and zone.	
Zone	
Do not pull the seal retainer to measure crack unless directed	
Crack Length	
107/202 Control Number	
Comments	
16RB098 Installed?	○ Yes ○ No
Date 16RB098 Installed	
Flight Hours 16RB098 Installed	
Flight Hours Given in 107/202	
Longeron Replaced?	○ Yes ○ No
Date Longeron Replaced	
Flight Hours Longeron Replaced	

Right Canopy Sill Longeron	
Cracks Found?	○ Yes ○ No
If crack was found, include 107/202 control number, crack length, and zone.	
Zone	
Do not pull the seal retainer to measure crack unless directed	
Crack Length	
107/202 Control Number	
Comments	
16RB098 Installed?	○ Yes ○ No
Date 16RB098 Installed	
Flight Hours 16RB098 Installed	
Flight Hours Given in 107/202	
Longeron Replaced?	○ Yes ○ No
Date Longeron Replaced	
Flight Hours Longeron Replaced	

Inspection Attachments
20220922120111_1663868113121.jpg
20220922120135_1663868110925.jpg

Download All Attachments

Figure 4: CIRE inspection example of a fracture critical part.

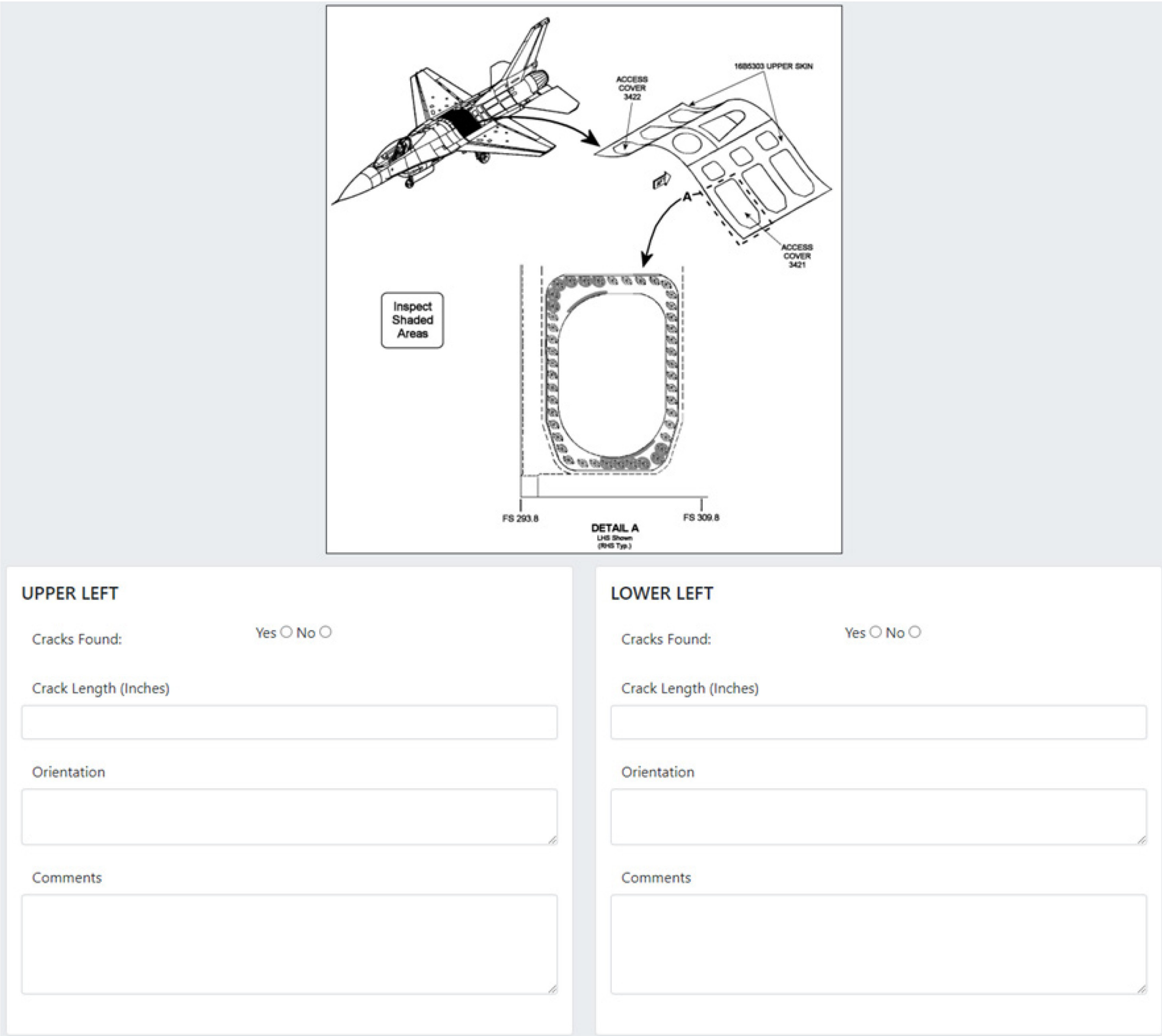
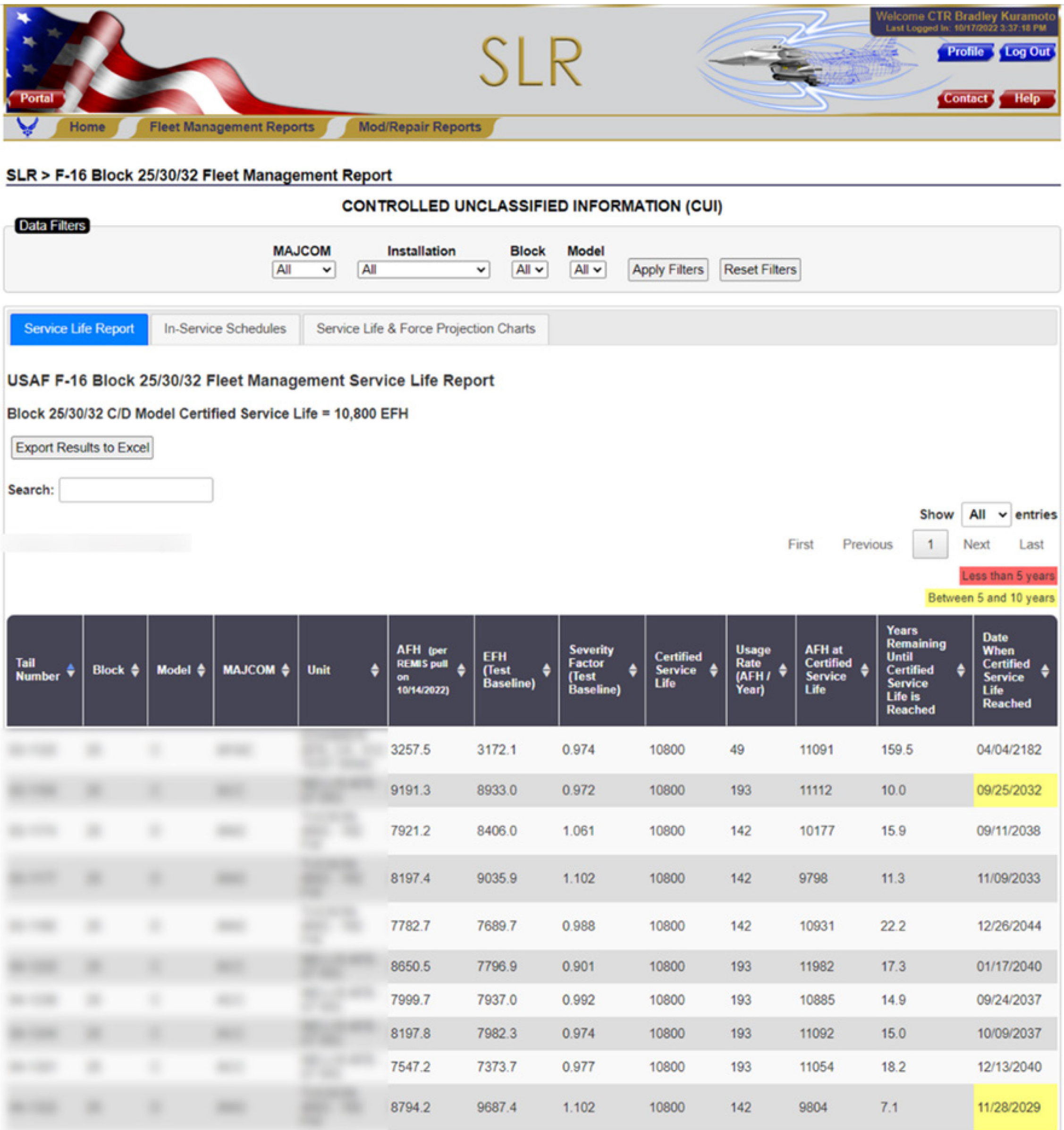


Figure 5: IAT inspection example.

2.5 SLR

SLR is a module designed to communicate service life data to commanders, fleet planners, and all relevant parties. It is designed to be the one authoritative source to communicate Equivalent Flight Hours (EFH) and other fleet management data. There are multiple reports and charts to help communicate all service life-related information. Figure 2-6 shows the fleet management report designed to show the current EFH of each aircraft. Additionally, there are reference reports to track time/hours flown since completion of modification programs and major part replacements. There are currently multiple risk-based TCTOs levied on the fleet that are required to be completed at certain aircraft flight hours, which is also communicated to units, fleet planners, depot schedulers, and program managers through SLR.



Tail Number	Block	Model	MAJCOM	Unit	AFH (per REMIS pull on 10/14/2022)	EFH (Test Baseline)	Severity Factor (Test Baseline)	Certified Service Life	Usage Rate (AFH / Year)	AFH at Certified Service Life	Years Remaining Until Certified Service Life is Reached	Date When Certified Service Life Reached
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3257.5	3172.1	0.974	10800	49	11091	159.5	04/04/2182
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9191.3	8933.0	0.972	10800	193	11112	10.0	09/25/2032
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7921.2	8406.0	1.061	10800	142	10177	15.9	09/11/2038
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8197.4	9035.9	1.102	10800	142	9798	11.3	11/09/2033
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7782.7	7689.7	0.988	10800	142	10931	22.2	12/26/2044
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8650.5	7796.9	0.901	10800	193	11982	17.3	01/17/2040
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7999.7	7937.0	0.992	10800	193	10885	14.9	09/24/2037
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8197.8	7982.3	0.974	10800	193	11092	15.0	10/09/2037
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7547.2	7373.7	0.977	10800	193	11054	18.2	12/13/2040
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8794.2	9687.4	1.102	10800	142	9804	7.1	11/28/2029

Figure 6: Fleet management report.

2.6 HOTF

HOTF is an engineering-only toolbox that houses tools to do "what-if" analyses, advanced reports that include additional service life data beyond SLR, and any other requirements to leverage any of the data collected in the F-16 ASIP Portal. The administration for severity factors, usage rates, and attrition rate used on the SLR reports is contained in HOTF. HOTF has replaced spreadsheets with reports that pull data directly from Portal resources, which has reduced the possibility of revision issues or user errors. It also contains reports using up-to-date commonly requested data. There is also a risk tracking tool that enables engineers to see all tracked risk assessments and TCTOs to monitor fleet risk status.

3.0 F-16 DIGITAL THREADS

The data captured within all the modules of the F-16 ASIP Portal is used for risk analyses, updating fatigue crack model correlation, maintenance, and modification planning, and identifying and monitoring high risk areas. This information provides valuable insight into the overall condition of the USAF F-16 fleet, as well as being vital toward the development of a realistic digital twin for a 30+ year old aircraft fleet that has decades left to fly. Having all the data stored in a centralized, easily searchable database to understand the full history of an aircraft aids engineers in future dispositions and greatly speeds up the process of answering ETARs. Figure 7 shows a simplified concept of the digital threads between the F-16 ASIP Portal, the OEM, and FMS customers. Each of these digital threads is not currently automated but has been created through over 20 years of collaboration to get to the current maturity level. Improvements such as the cloud migration that recently occurred will increase the automation and improve data collaboration further. Cloud migration has improved access to the F-16 ASIP Portal and PERFORMS and allows for additional automated interactions with other systems, including the OEM, to be developed. An example of where this has added benefit is with the FDC aircraft download processing in PERFORMS. This processing occurred with an air gap and manually moving files between systems, including reporting download status in FDC once identified. The cloud removed the air gap in ASIP data processing and streamlines the raw flight data recorder files chain of custody.

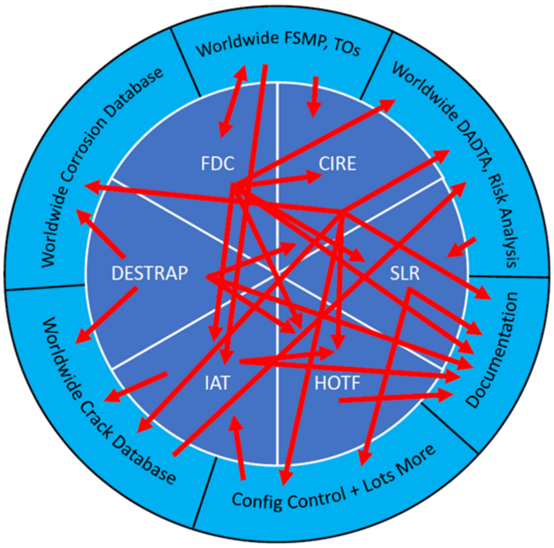


Figure 7: F-16 ASIP engineering threads.

4.0 INDIVIDUAL AIRCRAFT MANAGEMENT

One area where the data captured in Portal has been vital is the prioritization of depot inductions for the F-16 fleet due to limited depot capacity. Multiple risk analyses have been considered in order to maximize depot induction intervals for applicable USAF F-16 aircraft. The primary risk driver in this scenario has been the lower end pad radii on the center fuselage bulkheads near where the wing bolts attach the wings to the fuselage structure. Multiple depot-level TCTOs have been issued to drive inspections at these radii. Data of the findings and blend depths when cracks have been found are reported in CIRE and have been vital to perform the risk assessments and re-evaluate aircraft as needed. Large amounts of robust flight data recorder and inspection data collection, combined with the updated risk assessments, have provided each aircraft a specific inspection interval and individual aircraft tracking capabilities that are monitored closely by engineering and communicated to the field through SLR. This information is used to program depot inductions for the highest risk aircraft.

A current item of interest for F-16s involves a fracture critical part, part condition, and properly preparing the surface for eddy current inspection. From a damage tolerance perspective, gouges in a fracture critical part are clearly not acceptable without characterization and subsequent analysis, so part condition has shown its importance as far as a crack nucleation mechanism. Figure 4 shows an example reference image of this fracture critical part and data that is currently collected in CIRE for this inspection. Many changes have been made over the past eight years to further clarify and define inspection and preparation procedures, mainly to counteract the human factors element. This inspection work package was first added to the TOs in early 2015 with seven inspection zones. Due to the critical nature of the inspection area, several warnings and cautions were included in the work package to highlight the importance of part preparation. In 2016, the inspection was updated to exclude a small portion of the inspection area just outside the crack nucleation area due to extremely limited access. Additionally, the inspection area was extended based on cracking identified during the block 50 F-16 full scale durability test, completed in 2015. In 2018, the inspection was reduced from seven zones to three to simplify the procedure. In 2020, the work package was updated again to clarify the removal of a filler plate that was removed during a TCTO in 2014. Notes to identify surface roughness, a clarification where one of the required eddy current probes can and cannot be used, a graphic added to clarify preparation area, and a requirement to input any crack findings into the CIRE database were also added. In late 2021 and early 2022, cracks were found in the USAF fleet that were larger than expected. To investigate why cracks were being missed, the work package was updated in 2022 to include a requirement to upload a photo of the primary area to the CIRE database. It was found when monitoring the uploaded images, that even with multiple TO refinements, the surface preparation was insufficient, and inspections were occurring in a manner that could not find cracks at the appropriate time and size – the human factors element cannot be ignored and must be accounted for during aircraft sustainment. Online training was created to provide surface preparation and inspection details to all field units expediently. Through the digital tools and data available on Portal, a majority of the USAF F-16 fleet is known to be compliant with the surface preparation requirement.

As the digital engineering tools and data collection of the USAF F-16 fleet have improved over the past several decades, the amount of data that the needs to be managed and maintained has grown exponentially. The F-16 ASIP Portal has provided a means to collect, manage, and successfully leverage all the data. It also has allowed for large improvements in data quality. This combined data is what has allowed F-16 ASIP to maintain safety and a successful collaborative program. The accumulated information has provided a means for the F-16 SPO to push towards a digital transformation, culminating in realistic digital twin efforts.

5.0 CONCLUSIONS

Development of a realistic digital twin requires all data, or digital threads, from the entire lifecycle of an aircraft including design and operation, through retirement. A successful ASIP requires collecting and managing all this data, ranging from flight data recorder files to requests for engineering disposition to inspection data. USAF F-16 ASIP is in a unique situation since there are FMS customers, as well as an OEM, Lockheed Martin, that all work together to have a successful, collaborative program. The ability to easily collect, maintain, and share data is invaluable toward the program’s success. This data also is required to develop a realistic digital twin. F-16 ASIP has a significant number of digital threads that are used to generate various representations of a given aircraft’s condition. This information, when combined with OEM and FMS data, is a powerful tool in the F-16’s push towards full digital transformation.

The USAF F-16 SPO developed and maintains the F-16 ASIP Portal website to collect and manage data through multiple interrelated modules. Each module was designed to support a specific part of the ASIP process and be readily accessible for a wide range of users. The web-based interface provides easy collection of data for the entire ASIP cycle from dozens of worldwide USAF F-16 bases, multiple depot locations, and almost one thousand aircraft. For over two decades, data has been collected and managed electronically with digital tools developed and updated frequently based on user and engineering requirements. These continuous improvements have allowed the F-16 SPO to develop a solution to the F-16's digital requirements. Recent improvement efforts include a cloud migration effort to expand communication between F-16 ASIP Portal and PERFORMS, in addition to external OEM systems and other resources. This data collection is why ASIP is a critical part of creating a realistic digital twin and driving many of the F-16's digital transformation efforts.

6.0 REFERENCES

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