An Overview of Standardized Capability for US Air Force Inspections

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Abstract. The US Air Force publishes a Distribution A (unlimited release) Structures Bulletin, publication number EN-SB-08-012, Rev C titled “In-Service Inspection Flaw Assumptions for Metallic Structures,” which lists standardized capabilities for various inspection methods used in typical field applications. This paper reviews the content of the document, provides an overview of why this document was first assembled, and describes how the values for the capability were obtained. In addition, future plans to increase the number of defined capabilities are presented.

Introduction [1]

The U.S. Air Force’s ASIP was established in November 1958 in response to in-flight structural failures resulting in five destroyed B-47 aircraft from March through April 1958 [2]. Four of the B-47 losses were attributed to fatigue, which led to a probabilistic approach for establishing the aircraft service life capability. This was called the “safe life” approach, and it relied upon the results of a laboratory test of a full-scale airframe subjected to loading that simulated the operational service environment of the aircraft. The USAF established the safe-life of the aircraft by dividing the number of successfully test simulated flight hours by a scatter factor. The intent of the factor was to account for aircraft-to-aircraft variation in materials and manufacturing quality. The USAF believed the process to be sufficient to preclude in-service structural failures attributable to fatigue. The safe-life approach was the basis for all new designs during the 1960s and was also used to establish the safe-life of earlier designs that were subjected to a fatigue test.

Losses of an F-111 in December 1969 and an F-5 in April 1970 [2], each far short of their qualified safe-life, demonstrated that the safe-life approach had shortcomings. The safe-life approach allowed the use of low ductility materials operating at high stresses, which resulted in designs that were intolerant to manufacturing and service-induced defects. The aircraft failures arising from the deficiencies of the safe-life approach demanded a fundamental change be made in the design, qualification, and inspection of aircraft. The damage tolerance approach emerged as the candidate chosen for this change.

Developers of the damage tolerance approach recognized that an aircraft’s structure is subject to a wide range of initial quality from manufacturing processes as well as from service induced damage. They also recognized that the aircraft structure had to be
inspectable. To ensure the aircraft operates safely in the presence of anomalies, the USAF requires the structure to tolerate defects for some inspection-free period of service usage. The damage tolerance approach provides the USAF a safety limit for each critical area in the aircraft. The safety limit is the time, in flight hours, required for a crack to grow from either an assumed initial flaw size, or the inspectable flaw size, to a critical size. Inspections are scheduled to occur at a time equal to one-half the determined safety limit. The USAF used the damage tolerance approach to upgrade the structural integrity of several operational aircraft in the early 1970s including the F-111, C-5A and F-4. The success of these endeavors convinced the USAF that damage tolerance should be the structural safety basis for all future designs. In December 1975, the USAF formally integrated the damage tolerance approach into the ASIP.

During the 1970s and 1980s, the USAF performed a damage tolerance assessment on every major aircraft weapon system to develop inspection or modification programs necessary to maintain operational safety [3]. The results of the damage tolerance assessments were incorporated into USAF Technical Orders (TO) which established maintenance requirements to maintain structural integrity and to control risk to an acceptable level. As a measure of success for aircraft designed and/or maintained using a damage tolerance approach, the USAF destroyed aircraft rate due to structural reasons is between one and two destroyed aircraft per ten million flight hours accumulated in the fleet. This is at least ten times lower than the overall USAF destroyed aircraft rate due to all causes except combat related. Accordingly, the USAF believes the damage tolerance approach incorporated into the ASIP in the 1970s continues to be the cornerstone for protecting the safety of the USAF fleet.

1. Role of NDI in ASIP and Requirement for Standardized Capability

1.1 Role of NDI in ASIP [1]

The effectiveness of any military force depends, in part, on the safety and operational readiness of its weapon systems. One major item of an aircraft system that affects its operational readiness is the condition of the aircraft structure. The aircraft structure capabilities, condition, and operational limitations must be established to maintain operational readiness. Potential structural or material problems must be identified early in the life cycle to minimize their impact on the operational force. In addition, a preventive maintenance program must be developed and implemented for orderly scheduling of inspections, replacements, or repairs of life-limited elements of the aircraft structure. The overall program to provide USAF aircraft with the required aircraft structural characteristics is referred to as the Aircraft Structural Integrity Program, or ASIP. The goal of ASIP is to ensure the desired level of structural safety, performance, durability, and supportability with the least possible economic burden throughout the aircraft’s service life.

The objectives of the ASIP are to:
1. Define the structural integrity requirements necessary to support airworthiness assurance and the program manager’s assurance of operational safety, suitability, and effectiveness;
2. Establish, evaluate, substantiate, and certify the structural integrity of aircraft structures;
3. Acquire, evaluate, and apply usage and maintenance data to ensure the continued structural integrity of operational aircraft;
4. Provide quantitative information for decisions on force structure planning, inspection, modification priorities, risk management, expected life cycle costs, and related operational and support issues;
5. Provide a basis to improve structural criteria and methods of design, manufacturing, evaluation, and substantiation for future aircraft systems and modifications.

To achieve this goal and these objectives, ASIP consists of a series of five interrelated tasks as defined in MIL STD 1530C. Although these tasks have evolved over the years, they have had essentially the same focus since its inception. The first four tasks are primarily associated with aircraft development, while the last task occurs during an aircraft’s operational life until it is retired [4]. Thus, the five ASIP tasks span the entire life cycle of an aircraft, from conceptual design to retirement and NDI is integral to each task.

The first task develops the criteria that must be applied during design to ensure overall program requirements will be met and includes establishing the NDI program and an NDI Requirements Review Board (NDIRRB) to implement appropriate NDI process into all phases of the program. The second task focuses on operational environment characterization, plus initial testing of materials, components, and assemblies. Analysis includes ensuring design meets requirements. NDI capability for process monitoring and quality control is assessed with emphasis on fracture and/or mission critical structural parts.

The third task addresses full scale durability testing and includes NDI as an integral component to detect damage as early as possible, provide estimates of crack size, and minimize risk of catastrophic failure. The fourth task focuses on the analysis that leads to certification of the aircraft structure and the processes/procedures used for force operations. For NDI, this includes the selection of the method as a function of material, geometry, accessibility, and human factors. The resulting assumed detectable flaw size requires approval by the NDIRRB. The NDI methods and capabilities are documented in the force structural maintenance plan (FSMP) and appropriate TOs for execution.

The fifth task addresses once an aircraft is placed in use and includes the execution of recurring NDI required by the FSMP. In many cases, NDI requirements evolve during this phase due to mission and usage changes, modifications, updated analyses, additional testing, damage discovered during maintenance, quantitative risk analysis, and service life extensions. In addition, NDI is an integral part of the surveillance program which includes the analytical condition inspection (ACI) conducted throughout the life of the aircraft and the structural teardown program conducted on as needed basis.

1.2 Requirement for Standardized Capability

As NDI assessments are used as a critical component to ensure the integrity of USAF structures, it is important to have well-defined capability for each assessment. However, multiple organizations followed various protocols and processes to establish assume NDI capability. With the high degree of mobility of NDI inspectors, the large number of aircraft, and increasing inspection requirements as the fleet ages, this variability in assumed capability became a challenge. Therefore, a comprehensive analysis was performed on the assumed capability for ASIP inspections as a function of weapon system. It was found that different capabilities for the same inspection method were being used to establish inspection intervals for different aircraft [5]. This led to an internal effort within the USAF to baseline common inspection procedures and the assumed inspection capability as a function of general classes of structural geometric features. The outcome of this effort is the Structures Bulletin EN-SB-01-012 [6]. Currently this document is in its third revision as it is regularly updated as new technology or new capability studies for common USAF NDI are completed.
2. Content of Structures Bulletin EN-SB-08-012, Rev C

The content of EN-SB-08-012 includes an introduction, the applicability of the content, and recommended capabilities defined by the inspection method, structural material and geometry classes typically found on aircraft structure. The introduction includes a paragraph tying NDI capability to the relevant paragraphs in MIL STD 1530C that links NDI to the overall process that ensures the integrity of USAF structures. The values in EN-SB-08-012 are stated to “provide realistic in-service flaw assumptions that supersede information in Table XXXII of Reference 25,” where reference 25 is the JSSG-2006 [7].

The next section of EN-SB-08-012 provides insight to who are members of the Air Force NDI Capability Task Group and that the values published in the bulletin are consensus values of all members in the Task Group. This paragraph is followed by a description of the assumptions in training, procedures, and assessments that are made by the Task Group in determining the capability values and the additional steps that need to be followed if alternative values of capability are used to establish alternate assumptions for specific inspections.

The document provides a description of the applicability of the values. The capability is relevant for both field and depot inspection when performed by USAF personnel, but is not the assumed capability for contractor personnel or where commercial procedures are used. In addition, the capability applies to the detection of fatigue cracks in metallic structures to support damage tolerance or durability analysis. Thus, these values are relevant for the sustainment phase of an aircraft. For example, NDI capability in a production environment could be different than the NDI performed in a field or depot environment. Furthermore, these assumptions would not apply for unique or other inspection needs, such as the support of a repair process, or for other damage modes that cannot be managed via a damage tolerance analysis (e.g. corrosion).

The final section of EN-SB-08-012 contains the majority of the content, providing NDI capability values by inspection method. Each section defines the method specific requirements, including access and surface preparation that must be followed for the assumptions to be valid. Furthermore, each inspection must be validated and verified on a representative aircraft and structure to ensure all the assumptions of access and preparation can be met before the inspection is performed.

After the assumptions are listed, the method specific capability values are stated for each material, such as aluminium and titanium, and geometry class. The values provided are the $a_{90/95}$ value (90 percent probability of detection at 95 percent confidence), used to establish $a_{NDI}$ for calculating recurring inspection intervals. In addition, $a_{90}$ values are provided for reference only. Representative geometry includes flat surfaces, radii, edges, and bolt hole inspections. Eddy current is listed first as it is the most commonly applied field level inspection method. This section also includes specific capability values for various probes include pencil probes, with and without guides, and conformal probes [1]. In addition to eddy current, values are provided for fluorescent penetration inspection. Guidance that should be used for ultrasonic, visual, and magneto optical imaging are also included in the current version of EN-SB-08-012.

3. How Values were Determined in Structures Bulletin EN-SB-08-012, Rev C

Whenever possible, $a_{90/95}$ and $a_{90}$ values defined within EN-SB-08-012 are derived through studies following the guidance provided in MIL HDBK 1823A, a Department of Defense Handbook for Nondestructive Evaluation System Reliability Assessment [8]. This document is available for unlimited distribution and is readily available at various websites, such as the
following: http://evyrespec.com/MIL-HDBK/MIL-HDBK-1800-1999/MIL-HDBK-1823_10221. Critical elements of this document include the need for known defects well characterized in terms of their size and location and a sufficient number of independent flaws to enable the use of statistics to generate sufficient POD data required for the calculation of risk. POD studies should be performed in a representative environment that would be encountered during the inspection, such as in a typical depot or field location. However, for some data, such as the capabilities for fluorescent penetrant inspection, the members of the Air Force NDI Capability Task Group reviews published studies in the area, including those completed by industry and/or other federal agencies such as the Federal Aviation Administration (FAA) or the National Aeronautics and Space Agency (NASA). Once the data is generated via experimentation or extracted from available reports, the members of the Air Force NDI Capability Task Group meet and provide appropriate engineering judgment to ensure the values are representative of operational constraints present in field and/or depot environments that can affect the published values in the Structures Bulletin. This includes applying the appropriate knock-down factors as needed to capture representative variance typically found in the operational environment.

A representative case study of how these values are obtained using data acquired by USAF using the guidance of MIL HDBK 1823A was recently presented at the 28th International Conference of Aerospace Fatigue Symposium in Helsinki, Finland in June of 2015 [5]. The case study starts with open communication between the System Program Office and the Air Force NDI community to fully understand the inspection requirements to ensure safety is maintained within acceptable limits. The structure in this case was a radius in an upper carry-through bulkhead of the F-16 as shown in Figure 1 [5]. The part geometry and challenging access required the development of a special eddy current probe and, thus, the capability needed to be validated by performing a POD study.

Figure 1. Upper carry-through Bulkheads, web-to-outboard end pad fillet radius at lower wing attach.

To ensure an adequate number of flaws were used for the capability study, an analysis was performed to capture a suitable number of flaws over the size range and location within the radius of the structure. This yielded 75 electric discharged machined (EDM) notches to be placed in representative structural elements that could be bolted into a representative structure that closely mimicked the access the inspector would have on the aircraft. During development, the inspection access and inspector position was simulated to conduct and initial POD experiment (Figure 2). Figure 2a is the access to the region of interest, Figure 2b is the laboratory mock-up representing inspector access, Figure 2c is the positioning of the defect samples inside the mock-up, and Figure 2d is the initial POD data being collected with the inspector having the same access and geometric positioning as the on wing inspection [5]. The test samples were configured to have aspect ratios that matched the values anticipated for the structure and were placed in such a manner in the radius that 150
independent assessments were possible to reflect various configurations of the structure, including radii without blend repairs, radii with blend repaired. Flaws were also located in various positions within the radius to represent the range of possible crack initiation locations. After successful completion of the laboratory based POD demonstration, the inspection was verified by repeating the POD experiment within the depot environment by placing POD samples within the aircraft structure and executing the inspections with a qualified depot inspector as shown in Figure 3 [5].

Figure 2. Inspection validation using laboratory mock-up.

As the defects in this case were EDM notches, a transfer function was required to address any differences in eddy current signal magnitude between EDM notches and fatigue cracks. Data acquired by previous work and verified for this work indicated that minimal amplitude change occurs between the fatigue cracks in aluminium and the EDM notches. However, to ensure any variance in the amplitude response was properly addressed, the POD curve that was generated a -6dB knock-down factor was applied. The outcome of this POD was the ability to detect fatigue cracks with an a₉₀/₉₅ capability of 0.050 inch depth for this inspection. This capability is due, in part, to the tailored eddy current probe, detailed inspection procedures and task specific training developed for this specific inspection [5].
4. Future Plans for Structures Bulletin EN-SB-08-012

The next version of the Structures Bulletin is currently being prepared. Plans for additional guidance in the document include capability for bolt hole eddy current in several different types of steel, guidance on the use of computed radiography, and additional guidance on the use of ultrasound to detect fatigue cracks. It is anticipated that some of these may not be fully developed by the time the version is released, in which case greater detail will be provided in later revisions. The intent of this Structures Bulletin is to eventually provide capability values for all common NDI techniques used by the US Air Force.

5. Summary

The US Air Force relies on the use of nondestructive inspection (NDI) as a key process to assist in maintaining aircraft structural safety within desired risk limits. To ensure this capability is common across all locations where NDI is performed, the Air Force NDI Capability Task Group was formed and authors Structures Bulletin EN-SB-08-012 to provide guidance on the expected detection capability for standardized inspection methods as a function of geometry and material typically found in aircraft. Thought not complete for all inspection methods and material types, the Structures Bulletin provides valuable information for the inspections currently listed for use by the structures community to set inspection intervals for representative inspections.

The data in the Structures Bulletin is either linked to comprehensive POD studies that follow the guidance set forth in MIL HDBK 1823A or leverages other published studies that have analysed other NDI techniques, such as fluorescent penetrant inspection. The task group adjusts sensitivity values to less capable values if there is a consensus that the published data is not representative of typical depot and/or field environments. It is preferred that data be acquired using typical fatigue cracks found in aircraft, but occasional use of EDM notches with appropriate knock-down factors are allowed for specialized inspections. However, extreme caution should be exercised when using EDM notches for ultrasonic inspection POD studies. Factors affecting ultrasonic response (e.g. crack closure) must be thoroughly explored when developing transfer functions to correct POD results.
Future revisions of the Structures Bulletin will be issued periodically to reflect additional information regarding various inspection methods as more data is generated. Near-term updates will address bolt hole eddy current for steel structure, guidance on the use of computed radiography to replace film-based radiography, and additional comments regarding the use of ultrasound to detect fatigue cracks. The Structures Bulletin is cleared to be shared with the world aerospace community.

References


