# Structures Bulletin

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**Subject:** Durability and Damage Tolerance Certification for Additive Manufacturing of Aircraft Structural Metallic Parts

**References:**

1. MIL-STD-1530D Change 1, "Aircraft Structural Integrity Program", 13 October 2016
2. MIL-HDBK-516C, "Airworthiness Certification Criteria", 12 December 2014
3. FAA Order 8110.101A, "Type Certification Procedures for Military Commercial Derivative Aircraft",
4. EN-SB-11-001, "Guidance on Correlating Finite Element Models to Measurements from Structural Ground Tests", 24 June 2011
5. EZ-SB-13-002, "Correlating Durability Analysis to Unanticipated Fatigue Cracks in Metallic Structure", 26 June 2013
6. EZ-SB-14-003, "Durability Test Programs to Validate Aircraft Structure Service Life Capability for Repairs, Modifications, and Materials & Processes Changes", 9 April 2014
7. EZ-SB-13-001, "Substitution Guidelines Covering New Material, Product Form, and Processes for Aircraft Metallic Components Parts", 11 January 2013
8. EN-SB-08-001 Rev A, "Revised Damage Tolerance Requirements and Determination of Fail-Safety Life Limits for Fail-Safe Metallic Structures", 18 March 2011

**Purpose:**

The purpose of this Structures Bulletin (SB) is to establish the requirements for Durability and Damage Tolerance (DADT) certification of aircraft structural metallic parts fabricated from an Additive Manufacturing (AM) process. Alternate approaches may be used for Military Commercial Derivative Aircraft (MCDA) that are approved by the Federal Aviation Administration (FAA).

**Discussion:**
Aircraft Structural Integrity Program (ASIP) MIL-STD-1530 (Reference 1) states: "materials, processes, joining methods, and structural concepts shall be selected to result in a structurally efficient, cost-effective aircraft structure that meets the strength, rigidity, durability, damage tolerance, and other requirements of the applicable specifications. Prior to a commitment to new materials, processes, joining methods, and/or structural concepts (for example, those not previously used in the military and/or commercial aviation industry), an evaluation of their stability, producibility, characterization of mechanical and physical properties, predictability of structural performance, and supportability shall be performed by the Durability and Damage Tolerance Control Team (DADTCT), Corrosion Prevention and Control Team (CPCT), Nondestructive Inspection Team (NDIT) and others. The risk associated with the selection of the new materials, processes, joining methods and/or structural concepts shall be estimated and risk mitigation actions defined."

Reference 1 establishes the evaluation requirements for these 5 factors and they are repeated below:

1. Stability. "Maturity of material, process, and joining method selections shall be evaluated to determine if consistent and repeatable quality and if predictable costs can be achieved to meet system performance and production requirements. Process parameters and methods shall be established and controlled via specifications, standards, and manufacturing instructions."

2. Producibility. "Material, process, and joining method selections shall be evaluated to determine if scale-up to production sizes and rates can be achieved without adversely affecting performance, costs, and quality. The material, process, and joining method selections shall consider inspectability during the manufacturing process."

3. Characterization of mechanical and physical properties. "Material, process, and joining method selections shall be characterized to determine mechanical and physical properties for the appropriate environments in the as-fabricated condition using the manufacturing processes and joining methods. Key mechanical properties include but are not limited to: strength, elongation, fracture toughness, damage growth rates, fatigue, stress corrosion and damage growth rate thresholds. Key physical properties include but are not limited to: density, corrosion resistance, damage population, surface reflectivity, thermal stability, coefficient of thermal expansion, fire resistance, fluid resistance, and surface roughness."

4. Predictability of structural performance. "Material, process, and joining method selections shall be evaluated to determine if validated analysis methods and/or empirical methods are established to enable <u>accurate prediction of structural performance</u> (for example, strength, rigidity, durability, damage tolerance). If validated methods don't exist at the time of selection, risk mitigation actions shall be established."

5. Supportability. “Material, process, and joining method selections shall be evaluated to determine if cost-effective inspection and repair methods are either available or can be developed in a timely manner considering the sustainment environment throughout the entire life cycle. If supportability methods don’t exist at the time of selection, risk mitigation actions shall be established.”

While AM is certainly not new and has been used in a variety of aircraft structural applications, consideration of these 5 factors outlined in MIL-STD-1530 serves as a useful framework to describe the overall DADT certification approach and to advance AM technology further.

For structural parts manufactured from an AM process, the most difficult challenge within these 5 factors is to establish an “accurate prediction of structural performance” specific to DADT. Therefore, the remainder of this document is focused on the DADT requirements for structural parts manufactured from an AM process. The subsequent focus on DADT requirements isn’t meant to minimize the significance of other structural performance requirements such as static strength and stiffness. The focus on DADT requirements is emphasized in this SB because it contains the greatest challenges and therefore should be addressed earlier during AM feasibilities studies for structural parts.

This SB applies to all ASIP MIL-STD-1530 (reference 1) part classifications which include safety-of-flight parts designated as either Fracture Critical Traceable (FCT) or Fracture Critical Non-Traceable (FCNT) as well as non-safety-of-flight parts designated as either Durability Critical (DC) or Normal Controls (NC). See Reference 1 for definitions of part classifications and a flow chart for part selection. Damage tolerance requirements only apply to Fracture Critical (FC) parts, both traceable and non-traceable. Durability requirements apply to all four part classifications.

**DADT Certification Requirements:**

This section of the SB establishes the requirements for DADT certification of aircraft structural parts fabricated from an AM process. This SB is not intended to include all of the detailed requirements associated with AM part certification. Alternate approaches may be used for Military Commercial Derivative Aircraft (MCDA) that are approved by the FAA (Reference 2 and 3).

**1. Established DADTA foundation**

For the USAF, predicting DADT performance of metallic structure requires validated crack growth analysis based on linear-elastic fracture mechanics (LEFM) principles. Durability crack growth analysis is required for all structural parts. Damage tolerance crack growth analysis is required for all FC structural parts, with exceptions approved by the procuring agency. The differences between durability and damage tolerance crack growth are typically limited to the initial crack size assumption (see paragraph 2) and spectrum severity used in the analysis. The following describes some of the key requirements for accurately predicting DADT performance, recognizing many other important aspects are covered in the DADT control section (see paragraph 3).

**1.1. Validated DADTA Method**

A validated DADTA method shall be developed or shown to already exist that adequately accounts for complex geometries, interaction associated with the flight-by-flight, cycle-by-cycle load sequence (crack retardation and/or acceleration due to the effects of previous load cycles), residual stresses, and other important parameters. The dominant / controlling fatigue damage growth behaviors shall be characterized and DADTA models of these behaviors shall be validated. If heterogeneity, anisotropy, etc. are sufficient to introduce damage progression behaviors not normally considered in classical DADTA, such as mixed-mode cracking or crack branching; then DADTA models for these behaviors shall be developed, validated and approved by the USAF for use in DADT certification.

Note: Validation of the DADTA method is achieved when crack growth rate predictions compare favorably with test results for a range of variables. References 4 through 6 provide some information on achieving DADTA validation. It is not the intent of this SB to fully describe the process for achieving a validated DADTA method.

**1.2. Material Data**

Material data shall be generated for the AM technology (e.g., laser powder bed fusion, electron beam powder bed fusion, wire-feed directed energy deposition), build process, and part geometry (e.g., thickness, complex contours) and processes planned for the candidate AM part. These tests shall also include sufficient replicates to demonstrate material consistency and statistical characterization (Reference 7). Material fatigue crack growth rate test data shall be generated for the range of stress ratios contained in the stress spectra and the testing shall be sufficient to allow development of damage crack growth thresholds. In addition, material fracture toughness test data shall be generated. Furthermore, additional types of mechanical property testing necessary for complex damage progression behaviors described above shall be generated. AM technology is particularly susceptible to producing parts with defects/damage that can serve as sites for crack nucleation and therefore effects of defects testing shall be performed.

> Note: AM material properties can vary depending on the local thermal history which is a function of process, machine type, local geometry and part orientation on the build surface. This means that coupon level tests need to be verified to be representative of local part features. Other material test data can be generated to include fatigue crack initiation, stress-life or strain-life, and stress corrosion cracking (SCC) test data, although these are not used in crack growth analysis.

### 1.3. DADT Criteria

DADT criteria specific to the AM application shall be established for use in the DADTA and to establish the part-specific inspection intervals and onset of widespread fatigue damage limits that appropriately accounts for differences in variability or scatter compared to parts manufactured from wrought materials.

> Note: For reference, the standard DADT criteria include: average usage for damage tolerance stress spectra, 90$^{th}$ percentile usage for durability stress spectra (current requirement), nominal part dimensions, average crack growth rate, lower bound fracture toughness, typically no explicit residual stresses, specified initial crack sizes, and a factor of 2 on DADTA predictions to establish the initial inspection requirement. The factor of 2 and/or use of average crack growth rate is adjusted if the material data scatter is judged to be too high.

## 2. Established Surrogate Damage

Reference 1 defines damage as “any flaw, defect, crack, corrosion, disbond, delamination, discontinuity, or other type that degrades, or has the potential to degrade, the performance of the affected component.” Reference 1 states that “damage tolerance criteria shall be applied to all safety-of-flight structure” and “include establishment of surrogate damage types, sizes, orientations, locations, with consideration of all phases of the life cycle to include: material processing, shipping, handling, manufacturing, flight operations, and maintenance.” Therefore, this section focuses on the four attributes of surrogate damage: damage type, damage size, damage orientation, and damage location.

For damage tolerance of structural parts made from wrought metallic materials; the surrogate damage type has been a fatigue crack, in the most critical orientation, in all critical locations. The remaining of the four damage attributes is establishing the appropriate initial crack size. When the USAF developed the damage tolerance philosophy in the mid-1970s, it relied upon Equivalent Initial Damage Size (EIDS) distribution data to establish a “rogue” initial crack size assumption for use in the damage tolerance analysis. Reference 1 states that the EIDS “is an analytical characterization of the initial quality of the aircraft structure at the time of manufacture, modification, or repair. The EIDS distribution is derived by analytically determining the initial damage size distribution that characterizes the measured damage size distribution observed during test or in service.” The USAF selected an initial crack size for wrought material (e.g., 0.05 inch corner crack) that was believed to have a very low probability of being exceeded during the entire production run of any given aircraft type based on the EIDS data generated during the USAF’s inception of damage tolerance. Characterization of various EIDS distributions over the last 40+ years has shown that the probability of exceeding this assumed initial crack size in wrought product forms is typically less than $1 \times 10^{-7}$ based on extrapolation of the EIDS data. This crack size assumption (0.05 inch corner crack at a hole) has served the USAF well for conventional wrought product forms.

For damage tolerance of structural parts made from cast metallic materials, the USAF has had an unfortunate hard lesson learned in a recent aircraft development program. The USAF increased the initial crack size assumption to cover expected increases in frequency and size of damage (porosity, shrink, shell contamination, and hard-alpha contamination) without developing sufficient EIDS distribution data from which to establish the appropriate criteria. It was subsequently demonstrated that the size increase was insufficient despite the processes implemented during aircraft production such as hot isostatic pressing (HIP) to mitigate the effects of some of the expected damage types. As a result, the initial crack size assumption was increased to the demonstrated NDI capability and the parts were redesigned based on these increased sizes. Because the cast parts were no longer advantageous from a weight and cost perspective, the parts were redesigned again to a wrought product form. This is an example of a possible negative outcome of improper or premature use of AM for aircraft structural parts if the stability and producibility factors described in the Discussion section are not thoroughly evaluated, and if EIDS distribution data are not used to select a proper “rogue” initial damage size.

For DADT of structural parts that employ welds, the surrogate damage sizes should properly account for damage such as lack of fusion, inclusions, and arc damage. In addition, the DADT analysis may need to account for residual stresses. Most metallic AM processes involve micro welding/casting. A one inch cube made with powder bed fusion has the equivalent of several miles of welds. Defects such as lack of fusion can have dimensions several times the layer thickness and can extend through multiple layers.

For durability considerations of wrought materials, the USAF uses a similar approach as for damage tolerance. The primary differences are the basis for the surrogate damage size criteria and the severity of the spectrum used in the analysis and testing. For durability, the USAF uses an upper bound on normal quality based on EIDS distribution data. This translates into a probability of exceeding the assumed size on the order of 1 x $10^{-3}$. The USAF has selected an initial durability crack size of 0.01 inch corner crack at a hole for use in most durability crack growth analyses. This approach also needs to be re-evaluated for AM metallic materials to include the need to account for the probabilities of having multiple defects/cracks in AM parts.

For AM metallic materials, the four surrogate damage attributes (type, size, orientation, and location) shall be established using the process described below. The surrogate damage shall be used in validated DADTA methods consistent with the approaches described above. Since the type, size, and orientation of defects in AM parts are highly process dependent to include post-processing (e.g., as-built surface, machined surface), once all final processing parameters are established for a given part, all parameters shall be strictly controlled so as the type, size, and orientation attributes remain valid throughout part production.

### 2.1. Damage Type

The surrogate damage type(s) and corresponding DADTA methods shall be established. Data shall be generated and provided that demonstrates that the surrogate damage type(s) covers the full range of potential defects for the AM process (such as lack of fusion, porosity, aligned porosity associated with the scan pattern, cracking, and lack of penetration in AM parts for powder bed fusion).

Note: R&D needs to support this include determining if fatigue cracking can be the sole surrogate damage type or if new validated DADTA methods and data are needed for new surrogate damage types.

### 2.2. Damage Size

The surrogate damage sizes and corresponding DADTA methods shall be established. Damage size for durability crack growth analysis of NC parts shall be based on a probability of exceeding the EIDS of $1x10^{-1}$; but not less than 0.01 inches. Damage size for durability crack growth analysis of DC and FC parts shall be based on a probability of exceeding the EIDS of $1x10^{-3}$; but not less than 0.01 inches. Damage size for damage tolerance crack growth analysis of FC parts shall be based on the larger of a probability of exceeding the EIDS of $1x10^{-7}$ and the NDI capability (see Section 3.4); but not less than 0.05 inches.

Note 1: R&D needs to support this include generation of EIDS values from AM parts (not witness samples, etc.) manufactured using all of the planned processes and subjected to repeated loads until fatigue cracking occurs. For those early NC part applications, EIDS data generated from fatigue test specimens may be used until actual part EIDS data are generated.

Note 2: there may be cases where proof-testing each part is considered to reduce the damage size used in the damage tolerance analysis. This is not a trivial task so this approach must be thoroughly examined before being pursued. Typical questions to be answered are: what is the stress level that was reached in all critical locations and what EIDS did it screen out if it passed the test? Did the test loading invalidate the DADTA method (e.g., yielding)? What NDI method and criteria are required to determine if it passed the test? What is the approach for locations where the applied stress is not high enough? What environmental conditions should be used for the proof test so as to properly capture those experienced in operational use?

### 2.3. Damage Orientation

The surrogate damage orientation(s) and corresponding DADTA methods shall be established. The damage orientation shall be in the most critical orientation for the part, i.e., normal to the principal stress direction expected for crack propagation.

Note: R&D needs to support this may include new validated stress intensity factor solutions or new fatigue crack scenarios such as embedded cracks at various orientations and directional variability with respect to the build direction.

### 2.4. Damage Location

The surrogate damage locations and corresponding DADTA methods shall be established. The damage location(s) shall be at the most critical location(s) for the part.

Note: R&D needs to support this may include new validated stress intensity factor solutions for complicated stress fields to include residual stresses and both internal and surface-breaking discontinuities.

## 3. Established DADT Control

For each AM part, DADT control should be established that considers part classification (FC, DC, and NC), materials and processes selection, structural design, manufacturing, quality control, non-destructive inspection (NDI), corrosion prevention and control, and other disciplines. Reference 7 describes many requirements for DADT control for AM parts. This document is not intended to repeat the detailed requirements contained in Reference 7 nor to fully describe the DADT control requirements. However, this document is intended to emphasize many important aspects of DADT control that should be implemented for AM parts. The following DADT control requirements shall be implemented:

### 3.1. Demonstrated Material Controls

The AM raw material shall be demonstrated to be in control through specifications, acceptance testing, and material re-use limitations as approved by the procuring agency. The material controls shall be specific to each part or specific to each part classification type.

### 3.2. Demonstrated Equipment Controls

The AM equipment shall be demonstrated to be in control through manufacturing instructions, machine qualification, software version control, and periodic machine requalification or calibration as approved by the procuring agency. The equipment controls shall be specific to each part or specific to each part classification type.

### 3.3. Demonstrated Process Control

The AM process shall be demonstrated to be in control and shall address the stability and producibility factors described in the Discussion section. This includes residual stress management efforts such as stress relief and additional manufacturing steps such as heat-treating, hot isostatic pressing (HIPing), and machining to achieve surface finish requirements. The demonstrated process control shall be performed by either routine dissection of production AM parts or in-process monitoring that has been validated with dissection of production AM parts as approved by the procuring agency. Dissection of AM parts shall include both metallographic and micrographic examinations to determine if defects/damage are within requirements with a frequency and dissection plan as approved by the procuring agency. In addition, the demonstrated process control shall include coupons fabricated from production parts and tested to verify properties with a frequency and test specimen design as approved by the procuring agency. The process controls shall be specific to each part or specific to each part classification.

> Note: HIPing can be helpful, especially for unknown defects but it is different for AM methods that use inert atmospheres such as Argon gas for titanium material applications. Argon gas does not dissolve into the metallic crystal structure so while the pores will collapse under HIPing, they may not be

eliminated and the compressed gas can cause the pores to expand upon subsequent thermal exposure. Worst case would be that HIPing could change a more easily detected volumetric defect into a difficult to detect linear defect.

### 3.4. NDI Development, Validation, Verification, and Implementation

NDI shall be developed, validated, verified, and implemented to enable effective QA for all structural parts, to determine one of the two considerations for establishing the initial damage size assumption for FC parts (the other being a rogue EIDS elaborated on in section 4.3), and to determine if cost-effective inspection and repair are either available or can be developed in a timely manner for sustainment applications (supportability factor). The NDI capability (probability of detection distribution with 95% confidence interval) shall be determined for all damage types, damage orientations, and damage locations within specific regions of each part considering access, part thickness, and other important factors.

Note 1: NDI of complex AM components is challenging and cost-effective methods for reliable detection of the range of damage types and sizes typical of AM processes haven't been established. For example, Computed Tomography (CT) has been proposed as a solution for inspection of AM components but randomly oriented lack-of fusion (linear) defects and clusters of small pores are very difficult to detect in complex geometries by using CT or any other conventional NDI method. Another limitation of CT is that commercial systems have limited penetration capability. Also typical systems can only inspect at one energy level so high aspect ratio features may underexpose some areas and saturate the detectors for thin areas to prevent reconstruction of the 3D image.

Note 2: An NDI-based initial damage size assumption approach is not a trivial task. For example, a large casting in an FC application required over 300 radiographs to inspect for plate-like shell defects throughout the volume of the complex part geometry. Although estimates of detection capability were initially developed, these estimates were later found to be non-conservative driving changes to the shell formulation to improve radiographic detectability. The finding also resulted in an increase to the initial crack size assumption and on-wing inspections for delivered aircraft. The parts were redesigned based on these increased sizes. Ultimately, neutron radiography (very expensive and time consuming) was implemented to detect shell defects through thick sections. In addition, hard alpha inclusions (a new unanticipated defect type) were discovered driving development and implementation of production phased array ultrasonic inspection of all critical casting details and additional on-wing inspections for delivered aircraft. Most of the new or different defects detected in the castings were the result of machining into the defects rather than discovery via NDI. With AM, the amount of machining is significantly reduced so that method of flaw discovery will be less useful.

### 3.5. Dimensional Control and Verification

Dimensional control and verification shall be performed after the AM process is completed and after all post-processing is completed.

### 3.6. Established Accept/Reject Criteria

Part accept/reject criteria shall be established considering all of the DADT control results. This shall include establishing criteria to reject an AM part based on the frequency of defects/damage, proximity of defects/damage, and orientation of adjacent defects/damage, even if none of the defects/damage exceed the initial damage size assumption.

Note: the frequency of defects/damage approach was implemented in large castings used in SOF locations based on defects/damage found and the NDI Probability of Detection (PoD) function to determine the probability of missing a defect/damage of a significant size. Defects/damage in AM parts may not be as random as in a casting (e.g., defects in an AM part exist in the same pass, like a perforation).

### 3.7. Serialization and Traceability

Serialization and traceability requirements shall be established for each AM part that considers part classification, raw material source and lot, material re-use, and specific AM machine and software version used to manufacture the part.

## 4. Methodical Parts Selection and Associated DADT Criteria

A challenge with AM is the rapid advancements in materials, processes, and equipment used to manufacture parts. The approach described below shall only occur after satisfying the five factors stated in the Discussion section for the combination of materials, processes, and equipment selected for the AM application. It is recommended that the sequence of parts selection be in the order of increasing criticality starting with NC parts, then DC parts, and finally FC parts.

### 4.1. NC Parts

It is recommended that experience with DADT certification processes on NC parts is obtained by both the manufacturer and procuring agency before DC or FC parts are pursued. NC parts require durability predictions using validated analysis methods as part of the certification effort. To accomplish this, durability crack growth and fracture toughness test data are required. This test data shall be of sufficient scope such that the variability in crack growth rate is quantified, the scatter in fracture toughness is characterized, and the normal quality EIDS (e.g., probability of exceeding the EIDS is $1x10^{-1}$) is determined. Test results from other efforts with the same controls described in Section 3 can be used/combined if they demonstrate behavior consistent with the population being evaluated.

The test data shall be evaluated to determine the DADT criteria to be used in the durability analysis considering variability (scatter) in the results and other factors (see paragraph 1.3). The surrogate damage type and normal quality damage size shall be used in the durability crack growth analysis using the agreed-to DADT criteria to determine the service life capability of the NC part compared to the requirements.

If the use of an AM process is advantageous for the part, production parts shall be tested to generate EIDS data to confirm, or revise, the initial damage size used in the durability analysis. The test frequency and method shall be approved by the procuring agency and continue until such time as the collected data provides an adequate basis for the DADT criteria and analysis, after which the testing requirements may be reviewed. If the initial damage size is increased based on subsequent EIDS data, the durability analysis shall be revised and the procuring agency shall use the results to revise the force management actions, if necessary.

> Note: it is envisioned that the aggregate of NC parts with varying geometries and complexities, using multiple lots of materials, manufactured from a range of AM machines and operators, and with characterized EIDS, durability crack growth, and fracture toughness variability; will provide the data and experience necessary to evaluate the risk of proceeding with DC aircraft structural parts.

## 4.2. DC Parts

It is recommended the DADT certification process for AM be expanded to DC parts only when sufficient data and experience with NC parts are obtained by both the manufacturer and procuring agency. As more EIDS data are generated from the same or similar (similarity requires additional scrutiny) AM materials, processes, and equipment for a range of NC parts, statistical confidence increases such that the upper bound of normal quality can be determined (e.g., probability of exceeding the EIDS is $1 \times 10^{-3}$). When this point is demonstrated, DC parts can be pursued subject to approval of the procuring agency.

The test data from Section 4.1 shall be evaluated to determine the DADT criteria to be used in the durability analysis for the DC parts considering variability (scatter) in the results and other factors (see paragraph 1.3). The upper bound of normal quality EIDS (e.g., probability of exceeding the EIDS is $1 \times 10^{-3}$) shall be used in the durability crack growth analysis using the agreed-to DADT criteria to determine the service life capability of the DC part compared to the requirements. In addition, safety-of-flight (SOF) parts that are managed via fail-safety per Reference 8 can be pursued.

If the use of an AM process is advantageous for the part, production parts shall be tested to generate EIDS data to confirm, or revise, the initial damage size used in the durability analysis. The test frequency and method shall be approved by the procuring agency and continue until such time as the collected data provides an adequate basis for the DADT criteria and analysis, after which the testing requirements may be reviewed. If the initial damage size is increased based on subsequent EIDS data, the durability analysis shall be revised and the procuring agency shall use the results to revise the force management actions, if necessary.

> Note: it is envisioned that the aggregate of NC plus DC parts with varying geometries and complexities, using multiple lots of materials, manufactured from a range of AM machines and operators, and with characterized EIDS, durability crack growth, and fracture toughness variability; will provide the data and experience necessary to evaluate the risk of proceeding with FC aircraft structural parts. However, if DADT criteria variation is justified based on test data, the risk of proceeding with FC structural parts increases and should be carefully evaluated before pursuing them.

## 4.3. FC Parts

It is recommended the DADT certification process for AM be expanded to FC parts only when sufficient data and experience are obtained from NC and DC parts by both the manufacturer and procuring agency. FC parts require damage tolerance predictions using validated analysis methods as part of the certification effort. As even more EIDS data are generated from the same or similar (similarity argument for FC parts requires further scrutiny) materials, processes, and equipment for an increased range of parts, additional statistical confidence increases such that the rogue EIDS can be determined (e.g., probability of exceeding the EIDS is $1 \times 10^{-7}$);

with extrapolation consistent with historic practices. When the rogue EIDS and NDI capability for the candidate part is determined, the initial pursuit of FC parts can begin subject to approval of the procuring agency.

The combined NC and DC test data shall be evaluated to determine the DADT criteria to be used in the damage tolerance analysis considering variability (scatter) in the results and other factors (see paragraph 1.3). An increased focus on potential variability is expected for FC applications and test data that indicates part-specific DADT criteria are required may indicate AM is not a viable manufacturing method for the FC part. If AM is viable, the larger of the rogue EIDS-based size and NDI-based size and appropriate DADT criteria, subject to approval by the procuring agency, shall be used in the damage tolerance analysis to determine the service life capability of the FC part compared to the requirements.

If the use of an AM process is advantageous for the part, production parts shall be tested to generate EIDS data to confirm, or revise, the initial damage size used in the damage tolerance analysis. The test frequency and method shall be approved by the procuring agency and continue until such time as the collected data provides an adequate basis for the DADT criteria and analysis, after which the testing requirements may be reviewed. If the initial damage size is increased based on subsequent EIDS data, the damage tolerance analysis shall be revised and the procuring agency shall use the results to revise the force management actions, if necessary.

**Summary:**
DADT certification of structural parts requires more than the evaluation of static strength and rigidity. It requires significant test data to characterize the variability in DADT properties and to establish the initial damage type and size assumptions used in the DADTA. The implementation of AM on critical applications (FC) requires rigorous and extensive evaluation of material, process, analysis methods, and NDI. It is recommended that the experiences with AM structural part applications first be gained on NC parts before pursuing DC and then FC parts.

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