# Structures Bulletin

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**Number:** EZ-SB-17-001

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**Subject:** Testing and Evaluation Requirements for Utilization of an Equivalent Initial Damage Size Method to Establish the Beneficial Effects of Cold Expanded Holes for Development of the Damage Tolerance Initial Inspection Interval

**References:**

1. JSSG-2006, "Joint Service Specification Guide Aircraft Structures", 30 Oct 98

2. MIL-A-83444, "Airplane Damage Tolerance Requirements", 2 Jul 74

3. EZ-SB-14-003, "Durability Test Programs to Validate Aircraft Structure Service Life Capability for Repairs, Modifications, and Materials & Processes Changes", 9 Apr 14

4. EZ-SB-13-002, "Correlating Durability Analysis to Unanticipated Fatigue Cracks in Metallic Structure", 26 Feb 13

5. ASTM E 647, "Standard Test Method for Measurement of Fatigue Crack Growth Rates"

6. EN-SB-08-012 Rev. C, "In-Service Inspection Flaw Assumptions for Metallic Structures", 23 May 13

7. AFML-TR-74-198, "Reliability Assessment of Aircraft Structures Based on Probabilistic Interpretation of the Scatter Factor", Apr 75

**Background:**

The effect of hole cold expansion in metallic structures is to increase service life. This effect is due to the fact that cold expansion introduces beneficial, compressive residual stresses around the perimeter of the hole. Many test programs have been completed for various materials and loads spectra and demonstrated significant improvements in the crack growth lives. In general, the USAF does not account for beneficial residual stresses during design, with exceptions as approved by the program office and documented in the Aircraft Structural Integrity Program (ASIP) Master Plan. For approved exceptions, the USAF typically only takes partial benefit during design to potentially mitigate the impacts of discovering unanticipated damage later. However, the USAF increases benefit during the aircraft sustainment phase to reduce the maintenance burden while maintaining aircraft safety. This Structures Bulletin (SB) is focused on establishing the beneficial effects of cold expanded holes during the sustainment phase for development of the damage tolerance initial inspection interval.

**Discussion:**

Reference 1 provides requirement guidance for the initial damage types and sizes to be used in the damage tolerance analyses and states the following regarding the fastener policy for damage tolerance:

> A.3.12.1.g. Fastener policy for damage tolerance:
>
> “To maximize safety of flight and to minimize the impact of potential manufacturing errors, it should be a goal to achieve compliance with the damage tolerance requirements of this specification without considering the beneficial effects of specific joint design and assembly procedures such as interference fasteners, cold expanded holes, or joint clamp-up. In general, this goal should be considered as a policy but exceptions can be considered on an individual basis. The limits of the beneficial effects to be used in design should be no greater than the benefit derived by assuming a .005 inch radius corner flaw at one side of an as-manufactured, non-expanded hole containing a neat fit fastener in a non-clamped-up joint. A situation that might be considered an exception would be one involving a localized area of the structure involving a small number of fasteners. In any exception, the burden of proof of compliance by analysis, inspection, and test is the responsibility of the contractor.”

Reference 1 is derived from Reference 2 but omitted some important text regarding the testing required to determine the beneficial effects that may be used. Reference 2 states the following regarding the fastener policy for damage tolerance:

> 3.1.1.1.c. The fastener policy:
>
> “The beneficial effects of interference fasteners, cold expanded holes, joint clamp-up and other specific joint design and assembly procedures may be used in achieving compliance to the flaw growth requirements of this specification. These beneficial effects shall be demonstrated by laboratory tests of joints representative of joints in the aircraft. The test specimens shall contain pre-cracked fastener holes. The limits of the beneficial effects to be used in design shall be approved by procuring activity, but in no case shall the assumed initial flaw be smaller than an 0.005 inch radius corner flaw at one side of an as manufactured, non-expanded hole containing a net fit fastener in a non-clamped-up joint.”

The reason for inclusion of the 0.005 inch limit is to provide protection for the possibility that not all critical locations were properly processed and/or assembled and that validated Non-Destructive Inspection (NDI) methods did not exist to verify the process was completed per design. These issues still exist today, although NDI methods are being developed and evaluated. The 0.005 inch limit was based on approximately the average equivalent initial flaw sizes characterized when the damage tolerance methods were initially established for the USAF.

Reference 1 and Reference 2 were written when validated analysis methods that properly account for the beneficial residual stresses in the Durability and Damage Tolerance Analysis (DADTA) did not exist. As a result, the fastener policy relied upon testing to establish an empirical method to determine the benefit that may be used. Analysis methods are being developed and evaluated to account for the presence of residual stresses and the associated process variability. However, this SB only addresses the equivalent initial damage size (EIDS) method as the basis for establishing the beneficial effects to be used. Neither Reference 1 nor Reference 2 provides sufficient information on the testing required for this method. This SB provides the testing and evaluation requirements to establish the beneficial effects of cold expanded holes for development of the damage tolerance initial inspection interval to be used during the sustainment phase of the aircraft application being considered using the EIDS method.

**Recommendations:**

Testing and evaluation requirements to establish the beneficial effects of cold expanded holes for development of the damage tolerance initial inspection interval utilizing an empirical method should complete the following steps:

1. Establish the test specimen design, fixture, load application, load spectrum, etc. that is predicted to match the actual cracking scenario (cracks experienced in service or during testing) or predicted cracking scenario (analysis predictions only, no cracks discovered).

2. Conduct baseline tests that replicate all important parameters such as hole drilling/reaming, hole surface finish, pre-penetrant etch, etc. (see Reference 3) on 3 specimens and compare the test results to the prediction prior to conducting any subsequent tests. Particular attention must be given to compression loading effects, since compression underloads are known to reduce or even eliminate the beneficial compressive residual stress field. If the detail design relies on neat-fit or interference fit fastener or pin to mitigate compression loading effects, then the test must replicate the actual aircraft installation. Loose-fit or clearance-fit holes must be considered to be open holes. The comparison should consider the following: crack location, crack orientation, time to crack detection using an applicable method if established, crack growth rate, and final crack size. If the specimen is attempting to replicate test or service cracks, the baseline tests should neither be notched nor contain pre-cracks. If the baseline tests are attempting to match damage tolerance analysis shortfalls with no prior cracking data, the

baseline tests may be notched and contain pre-cracks, if desired. If an acceptable replication/match is not obtained, repeat this step and potentially step 1 until an acceptable match is obtained. Note that manufacturing test specimens for step 3 and 4 before completing this step may lead to increased costs.

3. Conduct durability tests on 5 specimens without: cold expanded holes, notches, and pre-cracks. The specimens from step 2 may be used as partial fulfillment of this step if the specimen design, loading, etc. are identical. Obtain crack growth measurements during testing and compare them to the durability crack growth analysis predictions using an initial crack size that is considered to represent near-typical material and manufacturing quality (e.g. 0.005 inch to 0.01 inch for many legacy aerospace materials). The use of marker bands should be considered to support crack growth measurements; especially for specimens that contain fasteners so that fastener removal is not required to obtain the crack growth data necessary for analysis correlation. If the test and analysis comparison satisfies the acceptance criteria below, use the durability crack growth analysis prediction for step 5. If the criteria is not satisfied, determine the root cause (see Reference 4) and re-evaluate the test specimen and fixture design and loading.

4. Conduct damage tolerance tests of 5 specimens with cold expanded holes and obtain crack growth measurements. The steps to notch, pre-crack, cold expand the hole, and cycle the specimens are listed below:

   a. Start with a hole that has a diameter that is smaller than design.

   b. Install initial notch (see Reference 5 for notch preparation procedures).

   c. Cycle specimen until a natural fatigue crack forms and grows to a size such that a 0.05 inch fatigue crack (or other approved initial damage size such as $a_{NDI}$ per Reference 6 for aircraft in operation prior to cold expansion being applied) remains after reaming the hole to design size.

   d. Ream hole to design size.

   e. Cold expand the hole using the planned tooling and process; to include controlling sleeve split orientation if required and if a split sleeve is part of the tool design. If the cold expansion process causes extension of the installed crack, then no cold work benefit may be assumed for damage tolerance.

   f. Ream after cold expansion to remove ridge (if part of the planned process).

   g. Cycle specimens and obtain crack growth measurements.

If the scatter in the test results is acceptable using the acceptance criteria below, proceed to step 5. If the scatter is unacceptable, determine the root cause and re-evaluate the test program.

5. Compare the durability crack growth analysis prediction from step 3 (excludes the beneficial residual stresses) with the average of the damage tolerance test results from step 4. Determine the initial crack size to be used in the damage tolerance analysis by comparing the test demonstrated damage tolerance life to the durability crack growth analysis result. Two scenarios are possible, as stated below and illustrated in the figures that follow:

    a. Scenario 1: 0.005 inch durability crack growth analysis life is less than or equal to the test demonstrated damage tolerance life. If the damage tolerance test results demonstrate equal or longer time to failure than the analysis (see Figure 1), use 0.005" in the damage tolerance analysis for the cold expanded hole, subject to the caveats stated below. This example shows that the beneficial effect allowable for sustainment applications is limited to 0.005" despite a longer damage tolerance test life.

    b. Scenario 2: 0.005 inch durability crack growth analysis is greater than the test demonstrated damage tolerance life. If the damage tolerance test results demonstrate less time to failure than the analysis (see Figure 2), then a larger EIDS must be used. The required EIDS is found by iterating the initial crack size used in the crack growth analysis until a match is achieved between analysis and test. Use that initial crack size in the damage tolerance analysis for the cold expanded hole, subject to the caveats stated below. Figure 2 shows an example in which an EIDS of 0.015" is required to match the damage tolerance test life.

6. If the durability life of the cold expanded configuration is desired to be estimated, conduct durability tests of 5 specimens with cold expanded holes and obtain crack growth measurements (no notches, pre-cracking, etc.). Use the average of the 5 specimen results to estimate the durability life unless the scatter in the test results is judged to be too high per the guidance below.

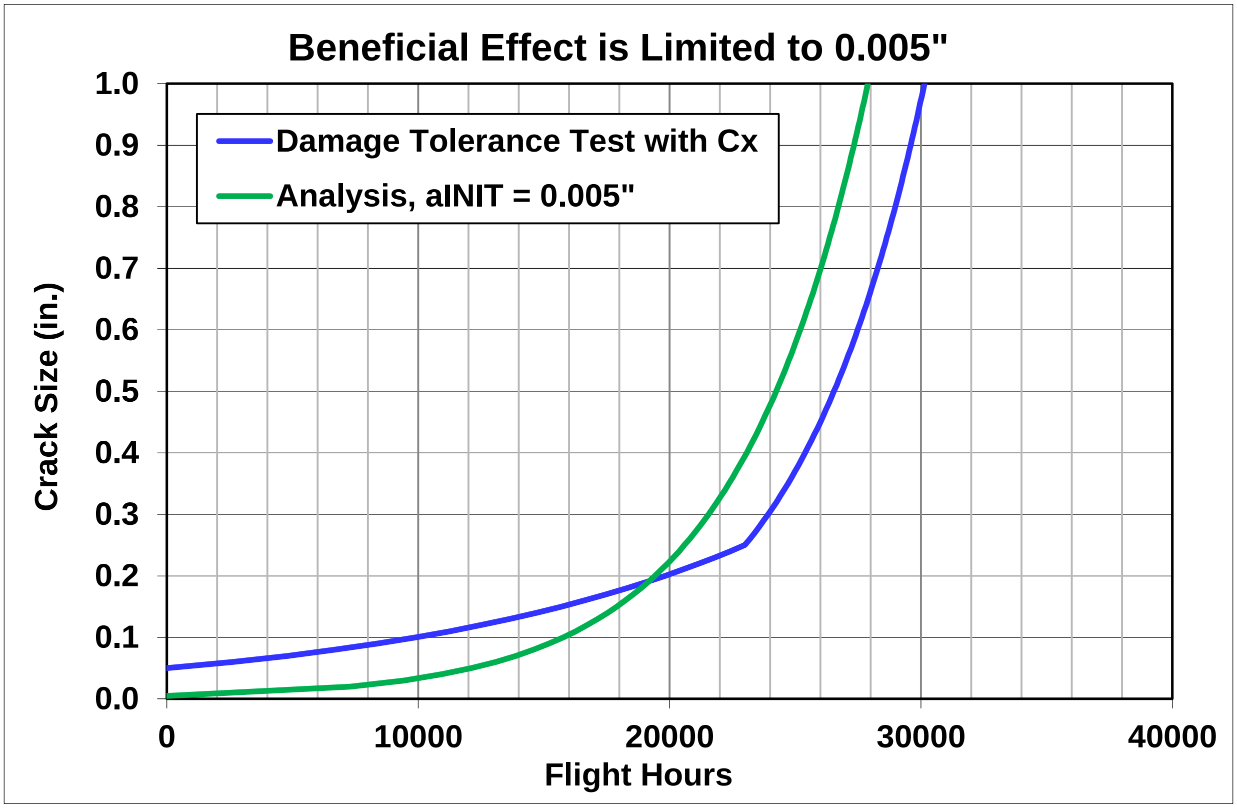


Figure 1. Beneficial Effect is Limited to Initial Crack Size = 0.005 inch

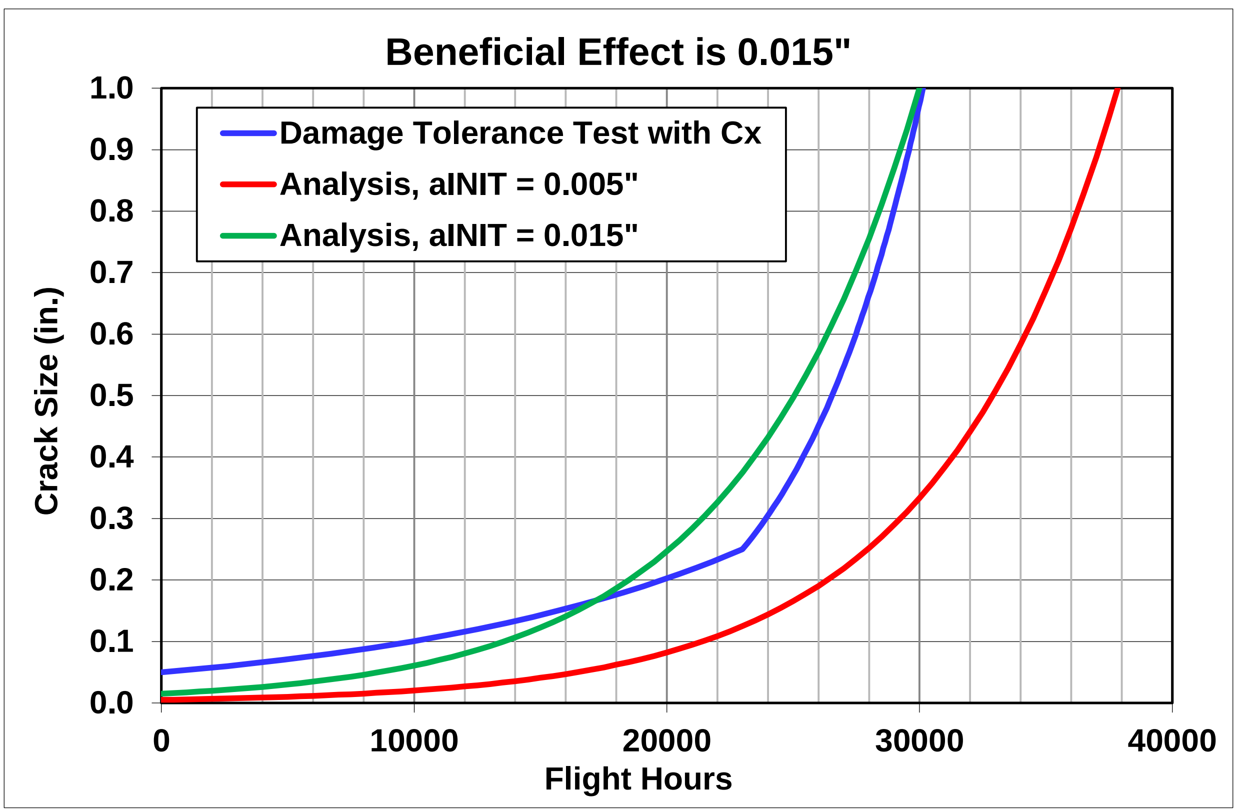


Figure 2. Beneficial Effect Requires Use of Initial Crack Size > 0.005 inch

**Acceptance Criteria:**

For the durability tests in step 3, the acceptance criteria are:

1. Analysis prediction matches average of all test results to within 20%.
2. Analysis prediction matches each test result to within 50%.
3. Weibull shape parameter for the test results is reasonable (engineering judgement required) such as the values cited in Reference 7 which are: ~3.5 for aluminum, ~2.5 for titanium, ~3.0 for steel with ultimate strength less than 200 ksi and ~2.0 for steel with ultimate strength greater than 200 ksi.

For the damage tolerance tests in step 4, the acceptance criteria are:

1. Cold expansion does not cause extension of the installed crack.
2. The damage tolerance life of each test result is within 50% of the average of all test results.
3. The crack growth curve shapes for the test results are reasonably consistent (engineering judgment required).

Note: These acceptance criteria should be used to determine when to re-evaluate the adequacy of the test specimen design, loading, etc., but not used as simple pass/fail criteria. It is possible that the test program is determined to be adequate if one or more criteria are not satisfied after the evaluation is completed. In other words, engineering judgment should be applied.

**Caveats:**

The following are the caveats that must be satisfied as stated in step 5:

1. The cold-expansion process is treated as a fracture-critical process.
2. The cold expansion process specification is approved by the procuring agency and establishes requirements for hole measurements, tool selections, verification check gage usage, etc.
3. Quality assurance requirements are approved by the procuring agency.
4. NDI probability of detection values per Reference 6, or other approved source, are used to establish subsequent inspection intervals.

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