Structures Bulletin

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Subject: Durability Test Programs to Validate Aircraft Structure Service Life Capability for Repairs, Modifications, and Materials & Processes Changes

References:

1. Department of Defense Standard Practice, MIL-STD-1530C, "Aircraft Structural Integrity Program", 1 November 2005.

Background:
Paragraph 5.3.4 in Reference 1 indicates that the full-scale durability test program may "identify critical areas of the aircraft structure not previously identified by analysis or component testing" and states "major component modifications which alter the structural load paths or which represent significant changes in structural concept shall require a durability test of a full-scale component". In addition, paragraph 5.3.4.2 in Reference 1 suggests it may be advantageous to continue testing beyond the minimum requirement to "validate repairs, modifications, inspection methods, and changes". Finally, paragraph 5.3.7 in Reference 1 states "structural modifications or changes derived from the results of the full-scale tests to meet the specified strength, rigidity, damage tolerance, and durability design requirements shall be substantiated by subsequent tests of components, assemblies, or full-scale article, as appropriate". These requirements should be achieved to the maximum extent practical. However, there are some cases where it is not practical and therefore subcomponent or lower level of complexity durability testing may be required to validate the design changes. In addition, component or higher level of complexity durability testing to evaluate unexpected cracking or failures in service and validate repair or modification designs may not be practical. Furthermore, proposed materials & processes changes that potentially impact the service life capability (e.g. metal cutting, coatings, paint removal) should include a durability and corrosion, if applicable, test program that includes all appropriate variables to validate the change prior to implementation.

Purpose:
The purpose of this bulletin is to establish a requirement to conduct “baseline” durability tests prior to conducting durability test programs at the subcomponent level or below to validate service life capability for repairs, modifications or materials & processes changes.

Discussion:
This Bulletin makes a distinction between subcomponent and lower level of complexity test specimens and component and higher level of complexity test specimens. The following provides some guidance in determining which group the durability test program to validate the design changes is associated with using examples from paragraph 5.2.14 in Reference 1 plus a few others. The test specimen types are listed in increasing order of complexity and collectively are commonly referred to as the “building block” approach.

1. Subcomponent and lower level of complexity test specimens includes:
   A. Coupons
   B. Elements (e.g. representative of a singular design detail, simple load transfer specimens)
   C. Subcomponents (e.g. combination of 2 or more elements, splices and joints, fittings, large portion of a bulkhead, structural operating mechanisms)
2. Component and higher level of complexity test specimens includes:
   A. Components (e.g. wing carry through, horizontal stabilizer pivot shaft, wing pivot)
   B. Assemblies, (e.g. wing, aft fuselage, vertical stabilizer)
   C. Full-scale articles (e.g. full-scale airframe durability tests conducted during aircraft development).

Durability test programs for validating the service life capability for repairs, modifications, or materials & processes changes (e.g. metal cutting, coatings, paint removal) at the subcomponent level and lower level of complexity should include “baseline” durability tests to ensure the test specimen design, loading, restraints, etc. represent the full-scale aircraft structure behavior (test or service experience) within a known and acceptable level of accuracy. While it is expected by many that this can be handled via analysis only such as finite element model and crack initiation and/or growth analysis, past experience has demonstrated that this is not always the case. Sometimes subtle changes in the test specimen design, applied loading, spectrum truncation method and/or level, test specimen restraints, etc. are required to match the test or service experience scenario (crack location, cycles to crack initiation, cycles to a crack at a given size(s), crack growth rate, shape of the crack growth curve, critical crack size, etc.) within a reasonable amount of scatter.

To be most cost-effective, the baseline tests should be conducted prior to testing of the proposed design change. In addition, the baseline test pass/fail criteria should be established prior to conducting the baseline tests. The pass/fail criteria should consider variability in the material properties (e.g. reasonable amount of da/dN scatter) and important aspects of the cracking scenario.

Some specific examples of lessons learned as a result of conducting baseline durability tests and therefore demonstrating their value follows:

1. F-16 F.S. 341 wing carry through bulkhead upper to lower bulkhead fuel shelf joint subcomponent test program. The 1st baseline subcomponent test did not provide a reasonable match of the F-16C Block 30 full-scale airframe durability test cracking scenario. Investigation concluded that small adjustments to the commanded jack loads were required to modify the bypass and bending stresses at the cracking location and the 2nd subcomponent test verified that the adjustment was sufficient. Subcomponent tests were then conducted of the modification design (cold-worked holes and necked down bolts to reduce the bearing stress in the critical location) to validate the planned retrofit configuration.

2. F-16 F.S. 479 bulkhead vertical stabilizer attachment subcomponent test program. The 1st baseline subcomponent test did not replicate the in service cracks. A dedicated strain survey was conducted on an instrumented aircraft and revealed a different load distribution between the 3 vertical stabilizer attachment bulkheads than predicted by the finite element model (that was thought to be adequately correlated at the time). In addition, IAT data revealed that some aircraft were occasionally exceeding design limit load. These two corrections were incorporated into the subcomponent baseline test and the in service cracking scenario was replicated. Subcomponent tests were then conducted to evaluate modification alternatives to extend the service life of the bulkhead.

3. C-17 main landing gear cross shaft fatigue test program. Qualification of the redesigned cross shaft was performed on a subcomponent level after the completion of the C-17 main landing gear full scale durability test program. Baseline subcomponent tests were conducted to verify that the test set-up and applied test loads provide a similar cracking scenario as observed on the full scale durability test article. The applied spectrum loads and actuator load distributions had to be adjusted after the first test to achieve a reasonable match. The revised test loads and distribution were verified on the second and the third test specimens prior to conducting the qualification test on the redesigned cross shafts.

4. C-17 wing to fuselage joint test program. The C-17 wing to fuselage joint is a complex structure that includes two very thick members joined together with net / small clearance fit, large diameter bolts. An element fatigue test program was conducted to determine the joint life improvement between the net fit versus light interference fit installed bolts. The baseline element test did not duplicate the same failure mode observed in the full scale durability test. In the baseline element tests, cracks initiated at the mating surface and failed in fretting fatigue instead of cracks emanating from the fastener holes as observed in the full scale test. It was determined the joint geometry and the loading are too complex to be properly tested at the simple element level.

5. F-22 fuselage wing attachment lug element test program. The F-22 fuselage wing attachment lower lugs lower fillet radii experienced cracking during the F-22 full-scale airframe durability test program. A lug element test program was conducted to evaluate and establish the Laser Shock Peening (LSP) parameters to maximize service life improvement prior to conducting the more expensive subcomponent tests (see next item). Baseline element tests were performed and the 1st baseline test result led to discovering that there was a loading inaccuracy issue when the loads transitioned through zero. To correct the loading accuracy, the mating clevis and pins were redesigned to match the tolerances in the actual joint. In addition, the baseline tests were used to demonstrate that the planned subcomponent tests must be stress relieved and etched (production configuration) versus an as machined surface being considered as a test specimen cost and schedule reduction initiative.

6. F-22 fuselage wing attachment lug subcomponent test program. The subcomponent test program was conducted to quantify the service life improvement (crack initiation and crack growth) for the planned retrofit configuration of the wing attachment lugs lower fillet radii. A baseline test was conducted and coupled with on-going refinements in the full-scale durability test correlation analysis, revealed that the actuator loading design concept was not sufficient to replicate the complex joint loading (all moments and joint friction). The actuator loading design was revised and the subsequent baseline subcomponent test demonstrated the revision was successful. Additional subcomponent tests were completed to quantify the durability and damage tolerance life improvement associated with the planned LSP retrofit configuration.

Recommendations:

Execute existing MIL-STD-1530C requirements to conduct full-scale component, assembly or full-scale airframe durability test programs to validate repairs, modifications or materials & processes changes to improve aircraft structure service life. When it is impractical to do so and the exception is approved by the aircraft certification authority, durability test programs conducted to validate repairs, modifications, or materials & processes changes at the subcomponent level or below should include "baseline" durability tests. The "baseline" tests should be conducted first to ensure the test specimen design, loading, restraints, etc. represents the full-scale aircraft structure behavior (test or service experience) within a known and acceptable level of accuracy.

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