Structures Bulletin

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Subject: Revised Damage Tolerance Requirements and Determination of Operational Life Limits for Slow Crack Growth Metallic Structures

Background:

The Air Force formally introduced damage tolerance requirements with the release of MIL-A-83444 in July of 1974. While this specification allowed the use of either fail-safe or slow crack growth design concepts, the primary focus was on the slow crack growth concept since most combat aircraft were designed with many single load path structures. With the slow crack growth concept, it is mandatory that material, manufacturing and/or service induced defects not be allowed to reach their critical crack sizes before they are detected and repaired. Initial crack sizes were specified in MIL-A-83444, and later in Joint Services Specification Guide JSSG-2006, for use in design and in establishing initial inspection intervals. These assumed initial flaw sizes were selected as surrogates for the myriad of manufacturing, material and in-service defects (i.e., rogue flaws) that can and occasionally do exist in aircraft.

Since the inception of damage tolerance, the slow crack growth inspection approach has greatly diminished the incidence of catastrophic structural failure. However, inspection reliability has become a significant issue both due to frailties of the nondestructive inspection (NDI) systems and concern over inspectors becoming complacent as a result of performing numerous repeat inspections looking for rogue flaws without any finds. The inspection issue becomes more acute as weapon systems age and approach the onset of widespread fatigue damage (WFD). The inspection burden and aircraft down-times will tend to overwhelm the aircraft depots and jeopardize both safety and operational readiness. Clearly, there is a need to develop operational life limits, beyond which the structure should be modified or replaced, or the aircraft retired.

Purpose:

The purpose of this bulletin is to make several revisions to the current JSSG-2006 requirements for slow crack growth design concepts (Table 1). These include changes to the residual strength requirements and flaw size assumptions for continuing damage (i.e. crack growth, when flaw growth terminates prior to reaching critical crack sizes). Additionally, this bulletin provides guidance in establishing operational life limits for slow crack growth design concepts. Requirements for fail-safe designs have also been revised and are provided in EN-SB-08-001 (Table 1). Fail-safe assessments of current aircraft to identify those safety-of-flight (SOF) locations which have inherent fail-safe capability are covered in Structures Bulletin EN-SB-08-003.

Table 1. – Revised Damage Tolerance Requirements

Damage Tolerance Approach	Structures Bulletin	Summary of Significant Changes
Fail-Safe Multiple Load Path	**EN-SB-08-001**	**Residual strength based on design limit load (DLL)** **Deleted 1.15 dynamic factor** **Deleted dependant and independent categories** **Added criterion to establish fail-safe life limit (FSLL)**
Fail-Safe Crack Arrest	**EN-SB-08-001**	**None**
Slow Crack Growth	**EN-SB-08-002**	**Residual strength based on DLL** **Changed initial flaw size assumptions for continuing damage** **Added guidance to determine operational life limit**

Discussion:

<u>Residual strength requirements for slow crack growth designs</u>

Like the revised residual strength requirements for fail-safe design concepts in Structures Bulletin EN-SB-08-001, the P_{xx} load (given in MIL-A-83444 and JSSG-2006) will no longer be used for slow crack growth concepts. It must now be shown by validated analysis that the assumed initial flaws will not grow to their critical sizes at design limit load (DLL). For those aircraft where the probability that DLL exceeds $1x10^{-7}$ occurrences per flight, the residual strength requirement shall be approved by the program office and ASC/EN.

The safe period of unrepaired usage is defined as the time for the initial flaw size or the in-service detectable flaw size to grow to the critical flaw size. The inspection interval shall be one half of this safe period of unrepaired usage. If the structure is judged to be uninspectable or if the critical crack sizes are less than the in-service detectable flaw sizes (see Table XXXII in JSSG-2006 Appendix A), the crack growth life for that structural component shall be a minimum of two design lifetimes.

Initial flaw size assumption for continuing damage

JSSG-2006 specifies initial flaw sizes in terms of specific flaw shapes, such as through the thickness or corner cracks at holes and semi-elliptical surface cracks or through the thickness cracks at locations other than holes. While new aircraft structures would not be expected to have initial fatigue cracks, there are a wide variety of other types of manufacturing and/or material defects and discrepancies that can and occasionally do exist. These include hole drilling defects (e.g., burrs, tears, score marks, double drilled holes, burns, nicks, short edge margins, etc.); other types of manufacturing defects (e.g., weld defects, heat treat cracks, scribe marks, gouges, dents, grinding burns, arc burns, tool marks, scratches, etc.); and material defects (e.g., inclusions, forging laps, sharp edged porosity, grain boundary separations, hydrogen blisters, cracks, etc.).

It is virtually impossible to specify and analytically model all the types and sizes of initial defects that have existed in aircraft structures and in some cases have led to structural failures. To circumvent this difficulty, the Air Force (with the concurrence of an Aircraft Industries Association Committee) in 1974 decided to assume specific initial crack sizes and shapes to serve as the surrogates for all of these possible types of defects. These initial flaw size assumptions for slow crack growth design concepts are shown and discussed in JSSG-2006 and are still considered to be valid. However, it is believed that the flaw size assumptions for continuing crack growth (when flaw growth terminates prior to reaching its critical size) should be changed.

JSSG-2006 currently specifies the assumed continuing damage flaw size for corner flaws as a 0.005 inch radius corner flaw + Δa (amount of growth which occurs prior to primary element failure) on the diametrically opposite side of the hole where the flaw growth terminated. This initial flaw size assumption has been re-evaluated and it has been determined that it should be changed to a 0.01 inch radius corner flaw + Δa. The 0.01 inch flaw size assumption better represents the upper bound flaw size of normal quality fastener holes and is consistent with the size specified in JSSG-2006 for use in durability analysis and design. No changes are made to the surface flaw size requirements for continuing damage in JSSG-2006.

Operational life limits

When the Air Force originally developed damage tolerance requirements in the early 1970s it was believed that the damage tolerance based inspections would protect slow crack growth design concepts from rogue flaws (as well as most other types of defects) indefinitely. As the aircraft got older and there were more and more critical areas to be inspected, it was thought that the economic burden associated with all of the inspections and repairs would eventually force the retirement of the aircraft or the modification of the structure (i.e., economics would dictate the operational life of the structure). Thus, if inspections protected the structural safety and economics dictated the life, there would be no need to specify an operational limit.

Obviously, the problem with this scenario is that it assumes that all critical locations are identified, that all the required inspections will be performed, that inspections will reliably detect all cracks before they reach their critical sizes, and that the depots will have the resources (funding, skilled technicians, and NDI equipment) to handle the increased inspection and repair burden. As pointed out in the background, these assumptions are now being questioned. In fact, poor inspection reliability could jeopardize safety well before the onset of WFD. Compounding the problem is that some older aircraft have reached or are approaching the onset of WFD.

While inspection reliability needs to be improved to protect against early failures, operational limits need to be developed and enforced so as to minimize the risk of encountering catastrophic failures before the aircraft is retired or the structure is modified. For fail-safe design concepts, the operational limit is the onset of WFD, which is the point at which if there were a load path failure the remaining intact structure could no longer sustain limit load (see Structures Bulletin EN-SB-08-001). Beyond this point one cannot count on fail-safety, but must rely on the interim use of slow crack growth based inspections and/or flight restrictions to protect the safety until the structure is modified.

For non fail-safe multiple load path and single load path designs, the operational limit should be when the flaw population has increased to the point where the risk of in-service inspections missing a significant[1] crack size has become unacceptably high. This risk analysis requires data on flaw populations derived from full-scale durability tests and the inspection of high usage aircraft. The analysis must assess and account for NDI capabilities, human factors and depot resources. Paragraph 5.5.6.3 in MIL-STD-1530C describes the requirements for conducting the risk analysis and the actions to take for various probability of catastrophic failure ranges.

[1] A significant crack is one that could grow to critical size and cause a catastrophic failure prior to the next scheduled inspection.

Summary:

Residual strength

Change the residual strength requirement to design limit load (DLL). For those aircraft where the probability that DLL exceeds 1×10^{-7} occurrences per flight, the residual strength requirement shall be approved by the program office and ASC/EN.

Initial flaw size assumption for continuing damage

Change the continuing damage flaw size assumption for corner flaws to a 0.01 inch radius corner flaw + Δa.

Determination of operation life limit

Develop crack population data (EIFS distribution) from inspections of durability test articles and/or high usage operational aircraft, assess NDI capabilities including human factors and perform a risk analysis in accordance with MIL-STD-1530C to establish the operational life limit.

Validate the operational life limit from the results of teardown inspections of high usage aircraft and, if necessary, impose flight restrictions (including possible grounding) until the structure is modified or replaced, or the aircraft is retired.

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