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Subject: Fail-Safe Assessments of Current Aircraft

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 size before they are detected and repaired. Initial crack sizes were specified in MIL-A-83444 (and later in the Joint Services Specification Guide, JSSG-2006) for use in design and in establishing inspection intervals.

Since the inception of damage tolerance, this 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 imperfections of the nondestructive inspection (NDI) systems and concern over inspectors becoming complacent as a result of performing numerous inspections looking for rogue flaws without any finds. The inspection issue becomes more critical as aging weapon systems approach the onset of widespread fatigue damage (WFD). The inspection burden and aircraft down times will tend to overwhelm the depots and jeopardize both safety and operational readiness. To prevent this from occurring, the recent Structures Bulletins EN-SB-08-001 and EN-SB-08-002 provide guidelines for establishing life limits for fail-safe and slow crack growth design concepts respectively. When these life limits (updated with fleet tracking usage data) are reached, the structure should be modified or replaced, or the aircraft retired.

Prior to reaching these life limits, there is still a need to minimize the possibility of inspection misses and potential catastrophic failure by improving NDI equipment and

procedures, and by focusing inspections on the most critical areas of safety-of-flight (SOF) structures. While the current combat aircraft are not certified as fail-safe, most do have some inherent fail-safe capability as a result of incorporating redundant load paths to meet survivability and vulnerability (i.e., battle damage) requirements. By taking advantage of this fail-safe capability, it could be possible to lessen NDI requirements on some SOF structure, thus allowing increased focus on the more critical non fail-safe areas. The purpose of this Bulletin is to describe the assessments necessary to achieve this result.

Discussion:

MIL-STD-1530C defines the requirement to perform periodic updates to the Durability and Damage Tolerance Analysis (DADTA) for each weapon system. These periodic updates result in updates to the Force Structural Maintenance Plan (FSMP), which includes updated inspection requirements. As an adjunct to these updates, it shall now be a requirement to assess the inherent fail-safe capability of previously certified slow crack growth SOF structure. This assessment shall consist of:

- *Identification of Potential Fail-Safe Structure*
- *Inspectability Considerations*
- *Residual Strength Analyses*

Identification of Potential Fail-Safe Structure

Most of the airlifters, tankers and surveillance aircraft are either derivatives of commercial transport aircraft or were developed for the Air Force with potential commercial sales in mind. The older aircraft were designed to the CAR 4b.270 fail-safe regulation and the newer aircraft to the FAR 25.571 damage tolerance requirements, which encompass both fail-safe and slow crack growth structure. It is believed that many if not most of the components in these aircraft can meet the revised fail-safe requirements described in Structures Bulletin EN-SB-08-001.

The CAR 4b.270 requirements had several shortcomings that have been corrected in the revised Air Force fail-safe requirements. These revised fail-safe requirements address: 1) possible adjacent structure damage, 2) the need for a safe period of unrepaired usage and 3) the eventual loss of fail-safety due to WFD, none of which were covered in CAR 4b.270.

The Air Force's bomber, fighter, attack and trainer aircraft have all been certified as slow crack growth structure, since they contain many single load paths. Many of these aircraft also have a significant number of redundant load paths and panelized structures with crack arrest characteristics. For example, it has been shown that some of the components in the F-16 fighter aircraft are fail-safe. It is likely that some components in

other combat and trainer aircraft also have sufficient redundancy and/or crack arrest capability to meet the revised fail-safe requirements.

The initial task of a fail-safe assessment shall be to examine all SOF structure and identify the candidate locations that may be able to comply with the revised fail-safe requirements. Particular attention should be given to structure that: 1) has experienced cracks in service and/or during full-scale durability tests; 2) has small critical crack sizes; 3) is susceptible to an inspection miss due to accessibility and/or NDI equipment limitations; or 4) are significantly impacted by the Air Force's NDI capability guidelines published in Structures Bulletin EN-SB-08-012.

Inspectability Considerations

To be considered a fail-safe location candidate, the structure must be visually inspectable and the load path failure or partial failure must be readily detectable or malfunction evident (e.g., loss of fuel, loss of cabin pressure, etc.). The criterion for readily detectable is that the load path failure or partial failure would be apparent from in-flight or post-flight visual observations or it would be obvious during a scheduled visual inspection. (See Structures Bulletin EN-SB-08-001 for additional information.) Each candidate fail-safe location should be examined to determine if it has the potential to comply with these inspectability criteria.

Residual Strength Analyses

A residual strength analysis shall be performed on each of the fail-safe candidates (i.e., load paths) to determine if the remaining adjacent load path(s) can sustain the redistributed limit loads at the time of and subsequent to the failure or partial failure of the candidate load path. The critical crack sizes in the adjacent load paths under the redistributed limit loads need to be calculated and an assessment made with regard to their probability of existing during the service life. A deterministic approach to predicting when these critical flaw sizes may exist in the adjacent load paths is suggested in Structures Bulletin EN-SB-08-001. A probabilistic approach (i.e., risk analysis) is also acceptable providing reliable crack population data is obtained as well as the other required inputs. While conducting residual strength analyses, each candidate load path must be considered as the failed load path with the adjacent load paths as the remaining intact structure. For each candidate fail-safe location that have satisfied this initial assessment, the criterion stated in Structures Bulletin EN-SB-08-001 should be used to determine if each location is fail-safe and to establish the fail-safe life limit.

Re-evaluation of NDI Requirements:

Only visual inspections to detect load path failure or partial failure are permitted for SOF structure that is found to be fail-safe per the revised requirements. However, the previous slow crack growth based NDI requirements may be retained at the discretion of the program office to prevent potentially expensive load path failures.

For SOF structure that is found to be non fail-safe, the slow crack growth based inspections shall be re-evaluated to assess the probability of missing a significant[1] crack. If this assessment concludes there is potential for this condition, then improvements in NDI equipment and/or procedures should be evaluated and implemented as appropriate. If there is still uncertainty, possible alternatives such as proof testing or structural modification should be considered.

Fail-safe Assessment Requirements for Current Aircraft:

1. Conduct assessments of the inherent fail-safe capability of current aircraft as an adjunct to DADTA updates required by MIL-STD-1530C.

- Examine all SOF structure and identify candidates that may comply with the new fail-safe requirements contained in Structures Bulletin EN-SB-08-001.

- Examine each candidate to determine if a load path failure or partial failure would be either readily detectable or malfunction evident.

- Predict critical crack sizes in the remaining adjacent structure under the redistributed limit loads and assess the probability of such flaws existing within the service life. Use criterion in Structures Bulletin EN-SB-08-001 for each candidate location that satisfies the initial assessment.

2. For all non fail-safe structure, reevaluate and refocus current NDI requirements so as to minimize the possibility of missing a significant flaw.

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

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