Structures Bulletin

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Subject: Damage Tolerance Inspection Methodology for Slow Crack Growth Metallic Structure

References:

1. Department of Defense Joint Service Specification Guide, Aircraft Structures, JSSG-2006, 30 October 1998.
2. Department of Defense Standard Practice, Aircraft Structural Integrity Program, MIL-STD-1530C, 1 November 2005.
3. Structures Bulletin, *Revised Damage Tolerance Requirements for Slow Crack Growth Design Concepts for Metallic Structures*, EN-SB-08-002, Rev A, 18 March 2011.
4. Structures Bulletin, *Nondestructive Inspection Capability Guidelines for United States Air Force Aircraft Structures*, EN-SB-08-012, Rev. B, 11 July 2011.
5. *USAF Damage Tolerant Design Handbook: Guidelines for the Analysis and Design of Damage Tolerant Aircraft Structures*, AFRL-VA-WP-TR-2003-3002, November 2002.

Background:

Reference 1 contains damage tolerance requirements for design of military airframe structures. This guidance provides initial flaw size assumptions, continuing damage criteria, and in-service flaw size assumptions, as well as a requirement that inspections be conducted at one-half of the calculated time it takes for an assumed flaw to grow to a critical size. Reference 2 provides additional clarification regarding the establishment of initial and repeat inspection intervals for slow damage growth designs. Additionally, Reference 3 provides revised damage tolerance requirements for slow crack growth structure in addition to revised continuing damage flaw sizes. Finally, Reference 4 contains nondestructive inspection (NDI) capability values that provide recommended values for a_{NDI}. Guidance in both References 3 and 4 supersede the requirements of Reference 1.

Purpose:

The purpose of this bulletin is to provide clear guidance on the damage tolerance inspection methodology for slow crack growth metallic structure, which includes the determination of initial and repeat inspection intervals.

Discussion:

The basic concept of damage tolerance is that damage is assumed to exist in each element of structure in the most critical location and orientation with respect to the stress field. The structure must successfully sustain the growth of the assumed damage for a specified period of service, and must maintain a minimum level of residual strength both during and at the end of this period. USAF damage tolerance design guidelines are specified in References 1 and 2 and apply to all safety of flight structure, i.e., structure whose failure could cause direct loss of the aircraft, or whose failure, if it remained undetected, could result in the loss of aircraft or aircrew or cause inadvertent store release.

From References 1, 2, and 5, a structure can be certified using one of two categories of damage; either slow damage growth or fail-safe. In the slow damage growth category, structures are designed such that the assumed initial damage grows at a stable, slow rate when subjected to the design service loads and environment and does not reach a critical size for two design service lifetimes. For metallic structure using fracture mechanics, this is called slow crack growth. In the fail-safe category, structures are designed such that catastrophic failure or deformation affecting flight characteristics will not occur after a load path failure or partial failure where rapid propagation is arrested due to damage containment features in the design, up to the fail-safe life limit (FSLL).

Inspections are required to be performed at ½ the safety limit, where the safety limit is defined as the crack growth life from the assumed initial flaw size (a_I or a_{NDI}) to the critical flaw size (a_{CRIT}). Ideally, the safety limit should be very long with no inspections required during the life of the aircraft. In practice however, aircraft structure certified to the slow crack growth damage tolerance requirements often requires inspections to ensure structural integrity. The causes for this include but are not limited to the following reasons:

1. Hot spots identified by full scale durability test (FSDT) (not discovered during analysis or developmental tests)
2. Usage more severe than design
3. Service life extension program (SLEP)
4. Subsequent findings of material or manufacturing issues

For most aircraft, at least one of the conditions outlined above exist and result in the need for inspection to maintain structural integrity. The methodology to determine the inspection intervals is described in the following sections. It should be noted that the same methodology can be applied to durability critical structure (i.e., durability crack growth) on the basis of economic considerations; however, the term safety limit would not be applicable.

Initial Inspection (T_{II})

$$T_{II} = \frac{1}{2} Ta_{CRIT} \tag{1}$$

Where T_{II} is the time for the initial inspection and Ta_{CRIT} is the time when the flaw reaches the critical size (a_{CRIT}) or safety limit, starting from the assumed initial flaw size (a_I).

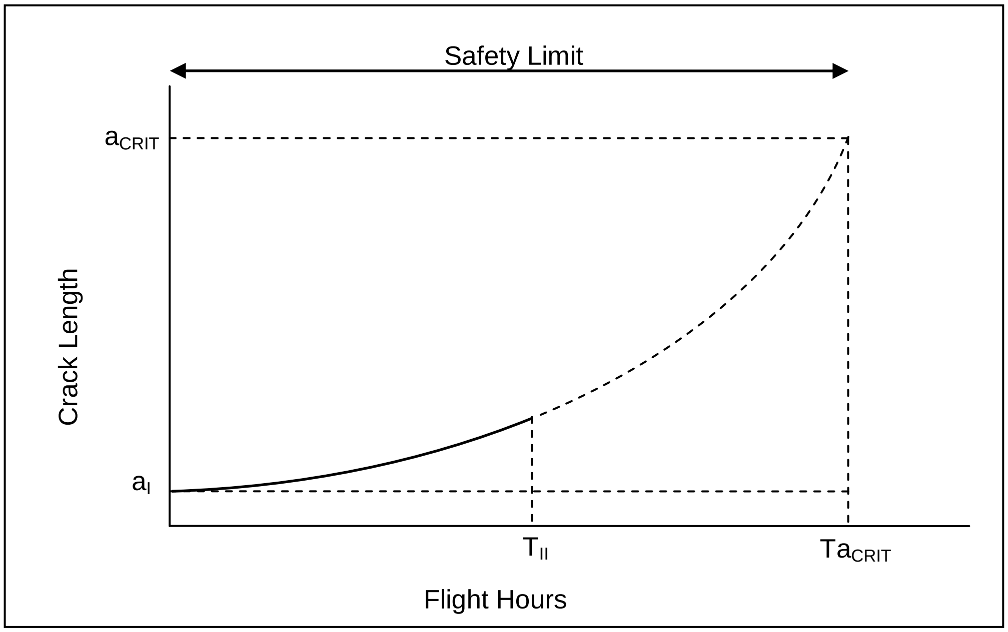

Figure 1 - Initial Inspection Interval

Recurring Inspection (T_{RI})

Once a part has been inspected, it must be assumed that a flaw remains that is just below the reliably detectable flaw size (a_{NDI}) based on the particular NDI method used for the inspection. The NDI capability flaw sizes contained in Reference 1, Table XXXII, have been updated with Reference 4 and should be used to establish the appropriate a_{NDI} value for each inspection location.

Equation 2 is used to calculate the time for the recurring inspection intervals.

$$T_{RI} = \frac{1}{2}(Ta_{CRIT} - Ta_{NDI}) \quad (2)$$

where T_{RI} is the time of the recurring inspection, Ta_{CRIT} is the safety limit, and Ta_{NDI} is the time associated with the NDI capability (a_{NDI}). Figure 2 shows how the recurring inspection interval is established.

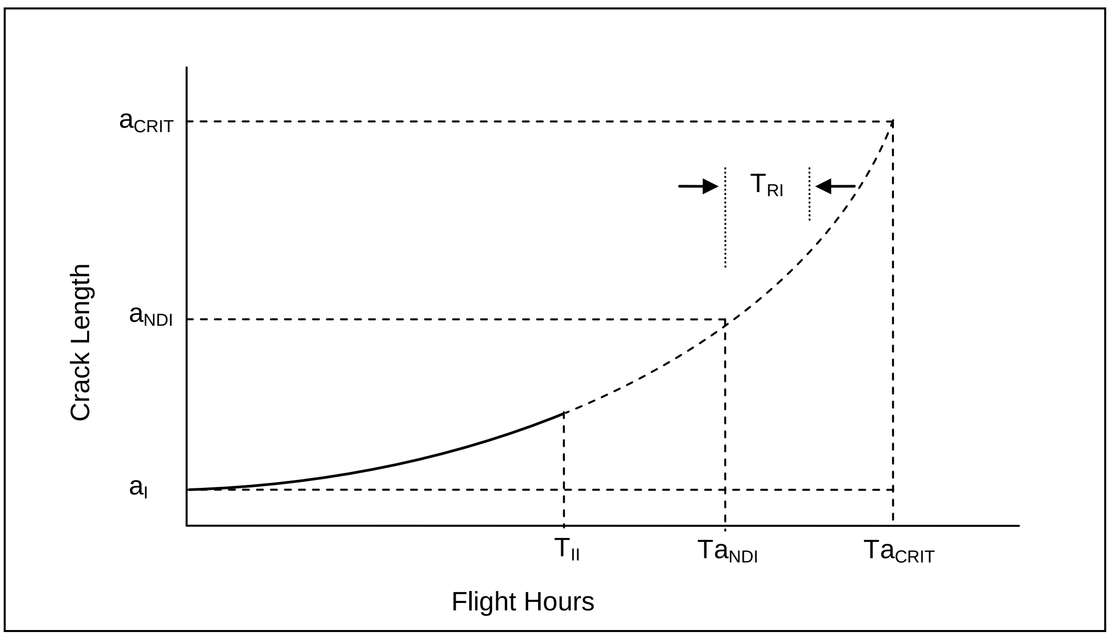

Figure 2 - Recurring Inspection Intervals

Initial and Recurring Inspections Example

The following illustrates an example diagram for a particular structural detail that has required four inspections to date. In this example, the interval for T_{RI} is shorter than for T_{II} due to an increased initial flaw size assumption. This is a typical result for most structural details.

As shown in Figure 3, after the initial inspection, the flaw size is reset to the a_{NDI} value. Assuming the NDI method doesn't change, this repeat inspection is continued until the aircraft is retired or until risk analysis is performed and shows that a revised interval (which is usually shorter) is required to control safety to acceptable levels.

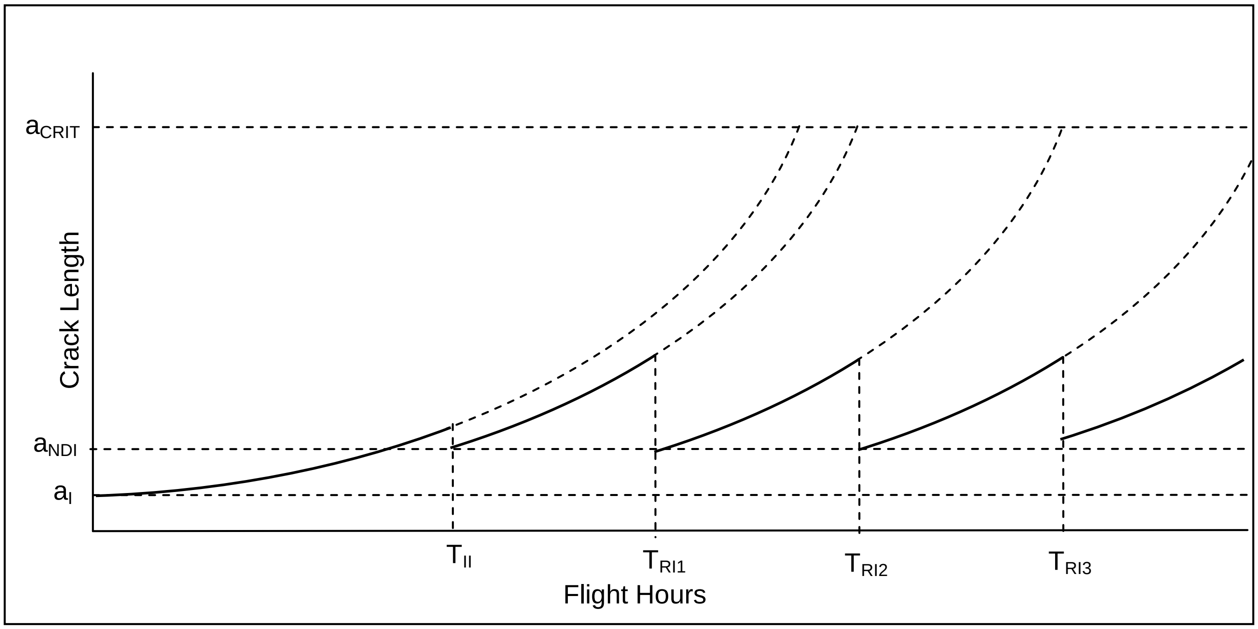

Figure 3 - Initial and Recurring Inspection Intervals where $a_{NDI} > a_I$.

Adjusting Inspection Intervals Based on Actual Usage

In a particular aircraft, the actual usage may be more or less severe than the repeated loads spectrum used in the damage tolerance analysis. Reference 2 requires each program to perform individual aircraft tracking (IAT) to obtain actual usage data that can be used to adjust maintenance intervals on a tail number basis. Figures 4 and 5 show examples of how to adjust for less and more severe usage, respectively.

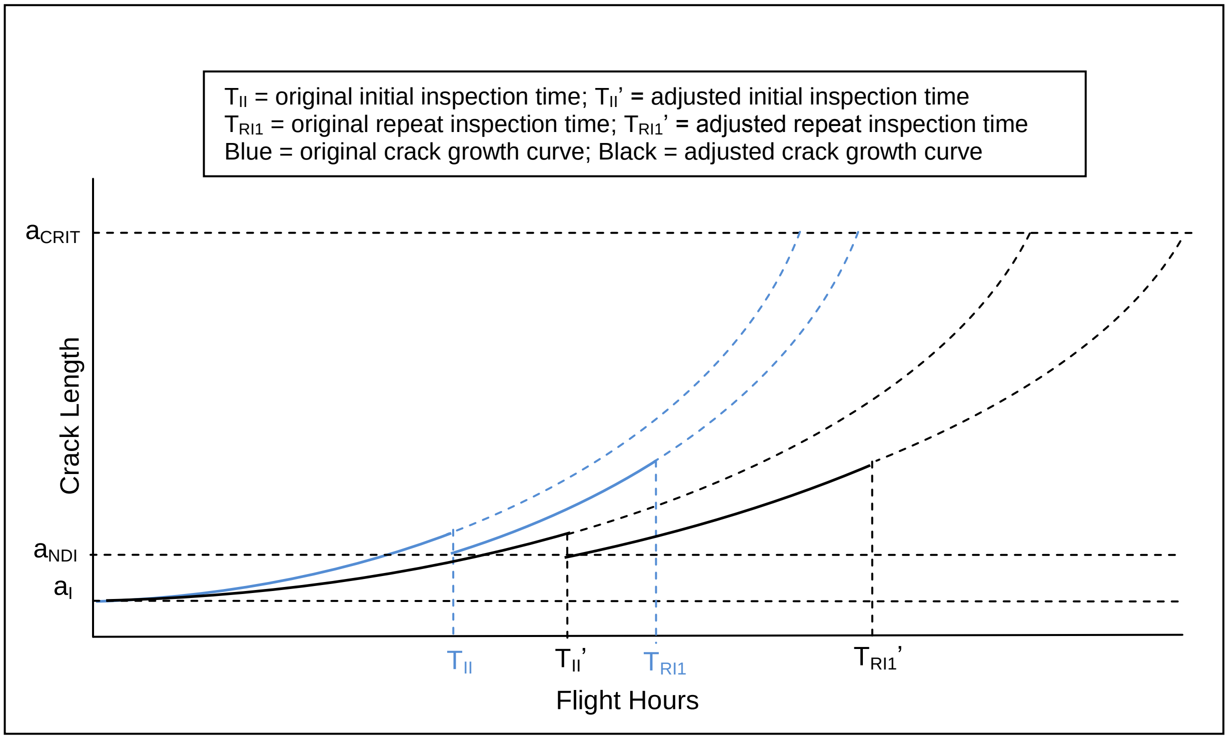

Figure 4 - Less Severe Usage Adjustment of Inspection Intervals

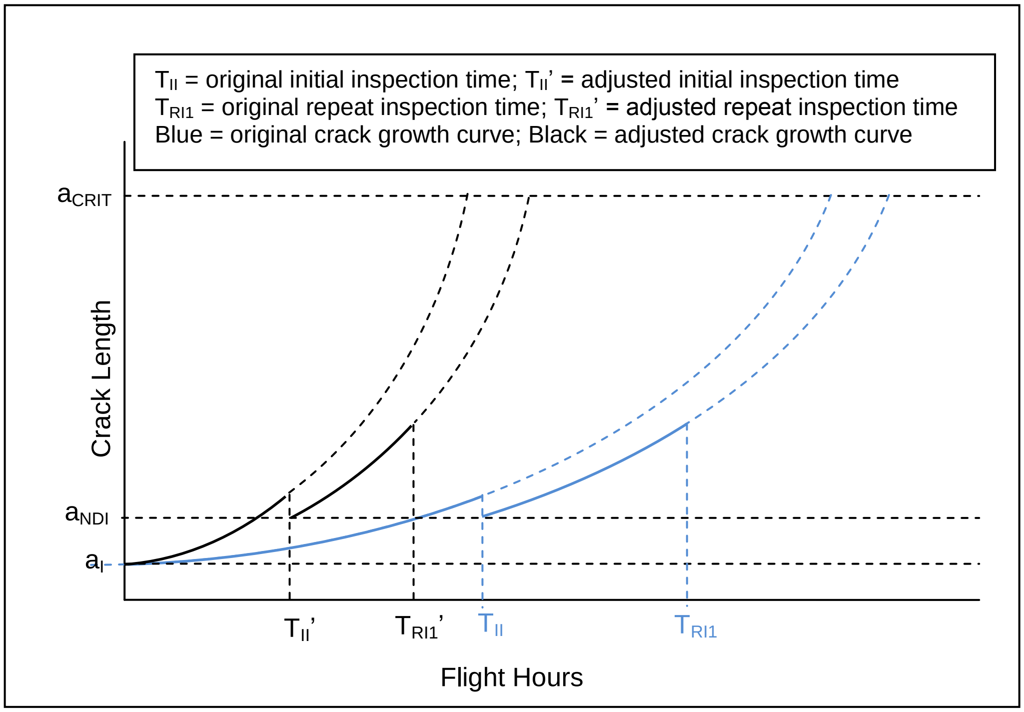

Figure 5 - More Severe Usage Adjustment of Inspection Intervals

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