

1.4 Sustainment/Aging Aircraft

The life of an aircraft is determined by its operational capabilities and maintenance costs rather than its initial design life goal. The guidelines of MIL-HDBK-1530 call for a Force Structural Maintenance Plan (FSMP) that is the basis of planned maintenance actions for a fleet. If unanticipated structural problems are identified due to design deficiencies or unplanned usage, the FSMP is updated using the deterministic damage tolerance methods of MIL-HDBK-1530. However, the effects of usage and time will cause fatigue cracks and corrosion damage to initiate and grow, compromising structural integrity of the fleet. Because of the uncertain nature of the sizes of the cracks that are in the fleet and the need to evaluate the interaction of cracks in multiple elements, the assessment of the effect of a population of fatigue cracks is typically made using probabilistic risk analysis. When such widespread fatigue cracking, corrosion, or use beyond the original life goals cause the deterministically based maintenance plan to be changed to ensure adequate structural integrity, the fleet is considered to be aging [Lincoln, 2000].

Sustainment is the process by which an aging aircraft fleet is maintained in an operational state. Sustainment encompasses both the actual maintenance of the structures and the analyses and tests needed to plan the maintenance tasks. As such, damage tolerance analyses are an integral part of sustainment.

1.4.1 Widespread Fatigue Damage

Widespread fatigue damage (WFD) is considered a primary threat to structural safety on aircraft. The National Materials Advisory Board report on the aging of USAF aircraft [Tiffany, et al., 1997] summarized this with the statement - “The onset of WFD in a structure is characterized by the simultaneous presence of small cracks in multiple structural details; where the cracks are of sufficient size and density, the structure can no longer sustain the required residual strength load level in the event of a primary load-path failure or a large partial damage incident.” Thus, the presence of small cracks can reduce the safe load carrying capability of a fail-safe structure below its design requirement.

The objective of WFD studies is to determine when (in-service time) the crack population reaches the size and density to invalidate the initial design assumptions. Most older transport aircraft were designed (or later checked) using fail-safe damage tolerant design assumptions whereby if a discrete event (major local damage by fatigue or ballistic penetration) caused a rather large crack to form in the structure. And then the design loads were set to preclude loss of the aircraft due to the nature of the redundant structure. The assumption was that the discrete damage could occur anytime during the design lifetime of the aircraft. The discrete damage was assumed to be of such a size that it would be evident either in flight or during routine inspections. The design rules required that the structure could withstand this level of damage (with some growth) during an additional period of operation that was based on some multiple of the inspection period. This design approach assumed that only the discrete damage was present and that only this damage was allowed to grow. If the crack population in the surrounding structure could influence the stress intensity factors associated with this discrete damage event, then the initial design considerations were violated and it would be necessary to determine when this crack population became a threat to the behavior of the discrete damage.

Subsets of WFD are Multi-Site Damage (MSD) and Multiple-Element Damage (MED). MSD refers to the cracking scenario where cracks are developing in the same structural element

(fuselage joint) and MED refers to the cracking scenario where cracks are simultaneously developing in several elements (skin, spars, etc.) in a structural component (wing). Multi-Site Damage has been found to be an important consideration in the continued safe operation of aircraft [Steadman, et al. 1999].

1.4.2 The Effect of Environment and Corrosion

In-service environments can have a broad range of effects on aircraft structural behavior. In some situations, the in-service environment might affect neither the residual strength nor the crack growth life of a structural element or component. However, this is not normally the case.

Typically, the environment and choice of the structural material will change the rates at which cracks nucleate and grow, and can cause cracks to nucleate in locations where the risk for cracking damage without the environment is negligible. As a result of using military aircraft past their initial planned design life (about 20-25 years), new categories of structural integrity problems caused by environmental attack have been identified. Developing a damage tolerant design guidelines handbook that covers corrosion damage and environmental attack requires a more systematic approach for presenting approaches and methods that engineers can use to control the risk of structural failure.

Stress corrosion cracking (SCC) is a particularly deleterious form of environmental attack that will create opportunities for cracks to nucleate and grow to failure, even under limited fatigue loading conditions (mechanism requires constant tensile stress conditions, and low material resistance to this kind of attack). SCC has caused extensive (and expensive) problems due to the limited resistance of older forging alloys initially used in the C-141, KC-135, B-52, C-130 and C-5 aircraft. These problems have been recognized and, as materials have been developed for service in the newer KC-10 and C-17 aircraft, the problem has been controlled. Besides potentially causing SCC problems, the environment frequently will accelerate or enhance the fatigue process by creating corrosion sites (pits, exfoliation damage, surface roughness, etc.) where fatigue cracks will develop, accelerate the crack nucleation process, and then accelerate the rate at which these fatigue cracks grow. In fuselage lap joints, the crevice corrosion that occurs will result in pressure build up between the layers, sometimes to the point where rivet heads will pop off and the joint will look pillowed, such as shown in [Figure 1.4.1](#).



Figure 1.4.1. Photo of Lap Joint Illustrating the Localized Pillowing Caused by Crevice Corrosion Occurring between the Two Layers

There are several different features of corrosion that can be used to characterize the severity and extent of damage. These corrosion metrics include thickness loss, pitting, surface roughness and pillowing, deformation in the metal caused by the excess corrosion by product produced between layers (see [Figure 1.4.1](#)). Corrosion can grow in exposed areas, under paint, around fasteners, between layers of skin, and inside structural components. Depending on the type of corrosion, it can grow in depth and area. It can grow along grain boundaries. Growth rates are influenced by environmental and load factors. The impact that each of these characteristics have on structural integrity continues to be the subject of current research, but will depend upon the structure within which the corrosion is located.

Stress corrosion cracking is another form of corrosion damage found in aircraft structures. As stated in Tiffany, et al. [1996], “Stress corrosion cracking (SCC) is an environmentally induced, sustained-stress cracking mechanism.” Of particular interest is the identification of the operational need to reevaluate, possibly during ASIP durability and damage tolerant assessments, SCC-susceptible components to look for potential safety risks.

Currently the ALCs are operating under a maintenance philosophy that has been termed “find it – fix it”. Under this mode of operation, when corrosion is detected, it must be dealt with by either repairing the damage, or replacing the component with the damage. Corrosion is considered an economic issue at this time, but the costs associated with maintaining the aircraft in accordance with this philosophy are escalating. Correspondingly, the readiness of the fleet is adversely affected. To respond to this trend, the Air Force is pursuing the technologies necessary to implement a corrosion management maintenance philosophy. This so-called “Anticipate and Manage” mode of operation attempts to make disposition decisions based on the impact of the damage to structural integrity. This requires knowing the condition of the corrosion damage through nondestructive inspection, understanding the corrosion growth rates as affected by the environment, and predicting the future corrosion condition using models of corrosion growth. The present and future states of corrosion can then be used in structural integrity calculations to determine remaining strength and life. Disposition may now include

flying the aircraft with known corrosion present, among other alternatives. Economical disposition can then be made while maintaining safety of the aircraft.

Other areas of ongoing research include understanding corrosion growth mechanisms, corrosion inhibition and arrest, coating technology and the replacement of chromate in coating systems.