Assessment of Fatigue Behavior of Advanced Aluminum Alloys Under Complex Variable Amplitude Loading

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The Federal Aviation Administration (FAA) and Arconic have partnered in an effort to evaluate several emerging metallic structures technologies (EMSTs) through-full-scale tests and analyses. The goal is to demonstrate the potential for fuselage concepts using EMST to improve durability and damage tolerance compared with the current baseline aluminum fuselage. Also, results will be used to assess the relevance of existing damage tolerance regulations. A generic single-aisle aircraft fuselage configuration located on the crown forward of the wing front spar is used as the baseline structure. Several EMSTs are being considered, including single-piece frames, friction stir welded longitudinal skin joints, new metallic alloys (aluminum and aluminum-lithium), bonded stringers, and hybrid construction. Tests of the curved fuselage panels are being conducted using the FAA's Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility.

In support of the full-scale panel tests, the focus of this paper is a supplemental test program that is being carried out by the FAA and Arconic. The FASTER fixture operates by applying the major modes of loading to a curved fuselage panel that simulates operational loads caused by pressurization, maneuvers, and gusts. Though the FASTER fixture is capable of executing complex variable amplitude spectrum loading, it is not practical to run a full-scale fatigue or damage-tolerance testing program under such conditions. Instead, an equivalency approach using M(T) fatigue crack growth specimens was conducted to determine an equivalent constant amplitude loading in the axial direction that can be used in a test to accurately represent the complex flight loads. It was also of interest to study the effect of a once-per-cycle compressive load simulating landing.

For fuselage structure located in the crown of an aircraft, just forward of the front wing spar, the major modes of axial loading in the load spectrum include fuselage pressurization, vertical bending due to maneuver and gust flight loads, and landing loads. The maneuver and gust flights load spectrum used in this study was represented by a 50% acceleration excursion reduction of the Mini-Twist spectrum developed by NLR, which was shown to match flight loads data from typical narrow-body aircraft. Two versions of the spectrum were tested, one that included a once-per-cycle compressive load to simulate landing and a second that used approximately zero as the end cycle level. Comparison of the spectrum results, shown in Figure 1, revealed an approximate 32% reduction in fatigue crack growth life due to the landing load. To determine the simplified representation of the complex flight load spectrum, a series of tests was run using both the spectrum and constant amplitude loading for the alloys under consideration (e.g., AA2524-T3 baseline material, AA2029-T3, and Al-Li 2060-T8E30). The goal was to match the fatigue crack growth life of the spectrum with compressive landing load to a constant amplitude equivalent and to use that corresponding stress for the FASTER fixture full-scale panel tests.

However, the stress intensity factor (SIF) history for a crack in an M(T) coupon is significantly different from that of a stiffened curved panel with a broken stringer or frame. To account for this difference, the K-control approach was used to apply the identical SIFs versus crack lengths calculated from a finite element model of the curved panel to the M(T) specimen. The K-control approach is used for crack growth testing, and in this study both spectrum and constant amplitude K-control tests were conducted to determine the equivalent constant amplitude axial load. Crack length was monitored using an adjusted compliance ratio technique throughout each test. Results comparing the K-control M(T) specimens to directly controlled M(T) specimens (referred to as load control) indicate that the application of the fuselage panel SIF distribution via K-controlled test significantly reduces (by 34%) the fatigue crack growth life compared to that of a load control M(T) coupon test, as shown in Figure 2. This paper and presentation will describe in detail the background of the spectrum used, the finite element model of the curved panel, the K-control method used, the effect of the compressive landing load on fatigue crack growth life, and the resulting equivalent constant amplitude load. Additionally, the effects of crack morphology on crack growth rate and on full-scale panel crack growth will be discussed.

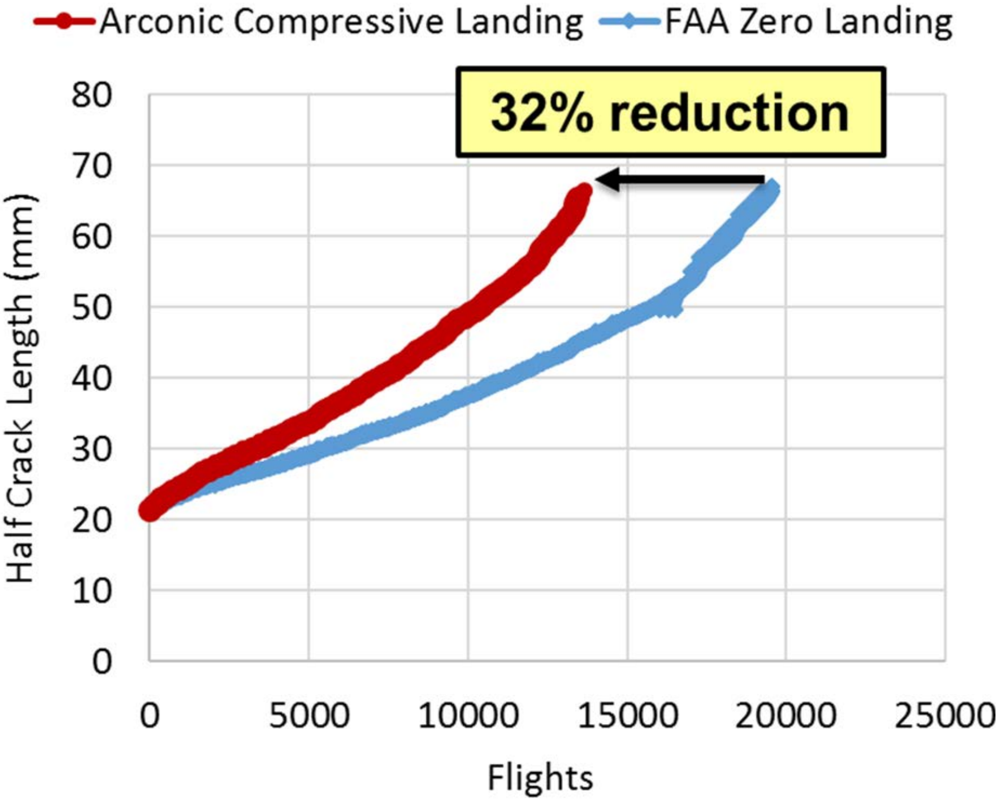

Figure 1. Fatigue crack growth life reduction due to compressive landing load

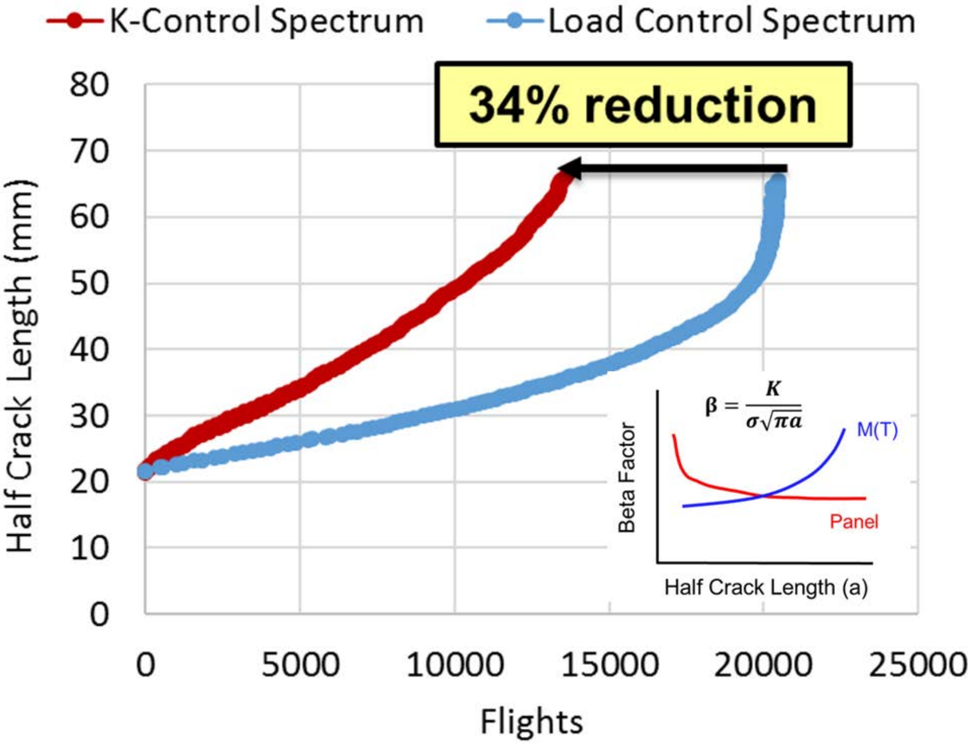

Figure 2. Comparison of results from K-Control and Load Control tests

Keywords: aluminum, aluminum-lithium, fatigue crack growth, structures