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Load-Time Dependent Relaxation of Residual Stresses

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Introduction

A DIFFICULTY in the structural design of aircraft with respect to preventing fatigue failures is the application of data obtained from tests of a few days duration for the prediction of aircraft life of several years. One commonly observed phenomenon in specimen test is life lengthening due to compressive residual stresses which occur as a result of plastic tensile deformation at a stress concentration.[1–4] In a recent test of an aluminum alloy, a load-time relaxation of residual stresses which shortened the life of a specimen has been experimentally observed. These results are in contrast to those obtained by Smith[5] and Gassner (reported by Schijve[6]) where no significant decrease in life was observed. In these latter tests only time dependent relaxation was studied, since the specimens were unloaded during hold periods.

The current cyclic tests were conducted to determine the influence on residual stress benefits due to applying compressive loads to specimens, holding these loads for specified time periods, and then cycling to failure. These tests were conducted as a part of a larger program investigating, among other effects, appropriate high end truncation levels for flight simulation laboratory fatigue tests. Spectra selected for this program were representative of transport lower wing surface location loadings.

Test Procedures and Results

The specimens tested were center hole specimens as shown in Fig. 1. The theoretical stress concentration factor was 2.54 based on net section stresses. The material was aluminum 7075-T651 bare.

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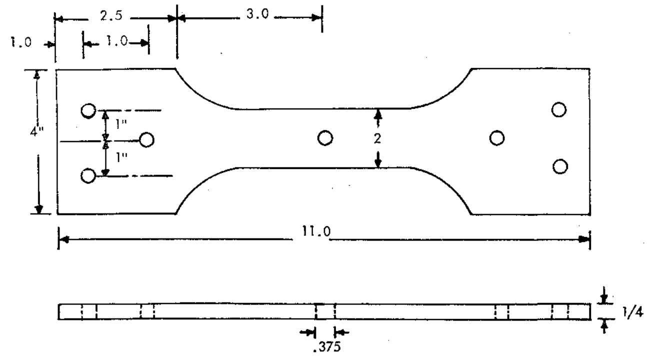

Fig. 1 Specimen geometry.

The test load sequences were as shown in Fig. 2. Test sequences 1 and 2 were run to establish baseline data for comparison with results for test sequences 3 and 4. The constant amplitude loading varied from 5–25 KSI net section stress in all four sequences. The single preload was 45 KSI net section stress in all four sequences while the compressive load in sequence 2 and the compressive load held for a specified time in sequences 3 and 4 was −7.5 KSI net section stress. The single hold period in sequence 3 and the two hold periods in sequence 4 were of 24 hours duration each. Between the two hold periods in sequence 4, 3000 constant amplitude cycles were applied. The sequences were applied to specimens in laboratory air except during the hold periods when the temperature was controlled at 85°F. Constant amplitude loads were applied at a rate of 5 Hz.

The results of these tests are given in Table 1.

Discussion

The results presented in Table 1 indicate that all benefits due to compressive residual stresses observed in aluminum specimen tests of a few days duration may not be observed in actual aircraft lower wing surface structures which sustain

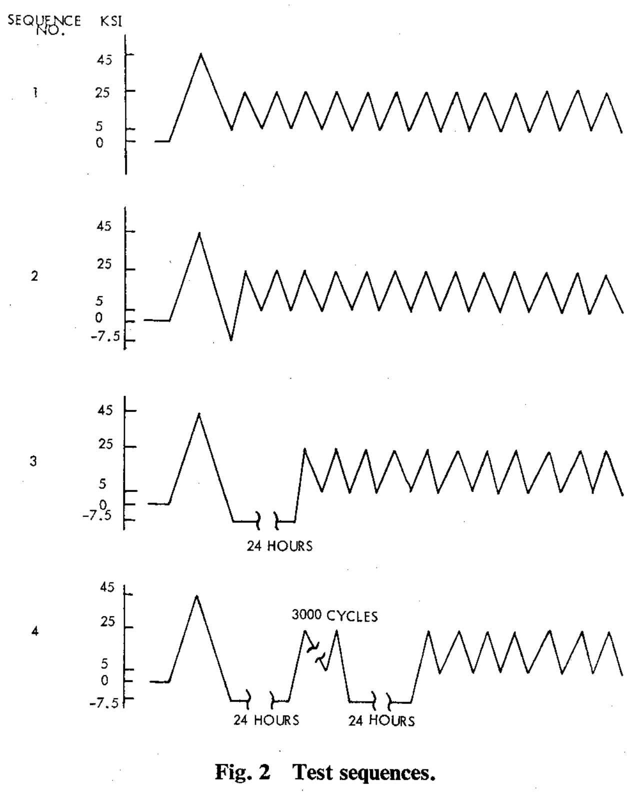

Fig. 2 Test sequences.

Table 1 Test results

Sequence No.	Specimen life	Mean life
1	1,322,000 cycles 1,009,200 399,200	910,133 cycles
2	212,200 171,000 260,000	214,400
3	158,400 112,200 97,800 135,800	126,050
4	118,700 124,400 148,400	130,500

compressive loads of 24 hr and longer when parked. For aircraft, the beneficial effects of high loads which induce yielding at stress concentrations may be primarily restricted to the flight in which the load occurred; a specimen may benefit for several flights when no compressive loads are held in the test. Since loads which induce yielding occur infrequently, specimen lives may be significantly longer than those of corresponding aircraft parts.

The results from Table 1 for sequences 3 and 4 imply that almost all load-time relaxation occurred within a 24 hr period. Further investigation of the decrease of benefits from compressive residual stresses with time would be of interest. Also, tests where the compressive load was representative of a fighter aircraft and tests on other structural materials with representative load levels will be important in understanding the relationship between specimen test lives and actual aircraft fatigue life. The relaxation phenomenon observed in the present specimen tests are applicable to the crack initiation phase. The crack propagation phase must also be considered.

Based on these test results, high load truncation, at levels producing stresses near the yield point at stress concentrations, should be considered when testing 7000 series aluminum specimens in flight-by-flight simulation. Theoretical approaches[1,2] should also account for this phenomena where applicable.

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