DESTRUCTIVE EVALUATION AND EXTENDED FATIGUE TESTING OF RETIRED AIRCRAFT FUSELAGE STRUCTURE

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ABSTRACT

The Federal Aviation Administration (FAA) and Delta Air Lines have teamed in an effort involving the inspection, teardown destructive evaluation, and extended fatigue testing of fuselage structure removed from a retired passenger aircraft near its design service goal. This paper reports on the major activities for this project. Eleven large sections were removed from a Boeing 727 aircraft representative of fuselage structure susceptible to widespread fatigue damage (WFD). Detailed inspections using both conventional and emerging nondestructive inspection (NDI) methods were made before and after the removal of the sections. Seven sections will be destructively evaluated to characterize the state of multiple-site damage (MSD) and multiple-element damage in fuselage structure. A teardown procedure was developed to disassemble joints and reveal fracture surfaces at fasteners for damage characterization. In the remaining four sections, the state of MSD will be advanced through extended fatigue testing using the FAA Full-Scale Aircraft Structural Test Evaluation and Research facility and then assessed through teardown destructive evaluation. Extended fatigue testing will provide data to enable calibration and validation of predictive methodologies for structural fatigue and will serve as a test bed to evaluate the sensitivity and effectiveness of standard and emerging NDI to detect small cracks. The data generated from this project will be used for developing and assessing programs to preclude WFD in the commercial fleet.

1 INTRODUCTION

Airframe teardown inspections and extended fatigue testing are an effective means for structural evaluations and assessments for continued airworthiness of high-time operational aircraft, particularly those approaching their design service goal (DSG). Essential information and data for evaluating airframe structures that are susceptible to widespread fatigue damage (WFD) are obtained from teardown inspections. Teardown destructive inspections and extended fatigue testing can provide key information for developing programs to preclude WFD. While the expertise and knowledge base to conduct teardown inspections are well established by the large commercial airframe original equipment manufacturers (OEM) and military sectors, comprehensive guidelines and data that are documented and available to the broader aviation community are lacking. The destructive testing and analysis of structure removed from retired aircraft will provide the Federal Aviation Administration (FAA) with first-hand knowledge of teardown procedures that may be conducted in support of applications for continued airworthiness certification. Experience and knowledge gained from this destructive analysis will enable the FAA to issue essential rules, policy, and advisory circulars pertaining to the prevention of WFD.

For this initiative, the FAA and Delta Air Lines (DAL) have teamed in a 3-year effort to perform destructive evaluation, inspection, and testing of 11 lap-spliced panels removed from a retired B727 narrow-body airplane at or near its DSG. The sections removed are representative of fuselage structure susceptible to WFD identified by the Aviation Rulemaking Advisory Committee, Airworthiness Assurance Working Group [1]. The primary focus will be to characterize the state of multiple-site damage (MSD) in the fuselage structure using detailed nondestructive inspection (NDI) and destructive fractographic examination. The state of MSD will be advanced through extended fatigue testing using the FAA Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility and then assessed through NDI and destructive fractographic evaluation. These tests provide a unique opportunity for researchers to measure the incremental development of WFD from cracks that initiated as the result of revenue service operations. A summary of the major activities in this research effort is presented in this paper.

2 DESCRIPTION OF AIRCRAFT AND TARGET STRUCTURE

The aircraft selected for this program was a Boeing 727-232, serial number 20751, line number 1000, and registration number N474DA. The airplane was placed into service in 1974 and retired in 1998 to the Southern California International Airport in Victorville, CA. While in service, the airplane accumulated 59,497 flight cycles and 66,412 flight hours and was near its DSG. The airplane was retired prior to the issuance of Airworthiness Directive (AD) 99-04-22, mandating inspections and repairs for inner layer cracking of the lap joints of the B727, thus the AD inspections and repairs were not made on this aircraft. The airplane was owned and operated exclusively by DAL, was well maintained and stored, and has a well-documented and accessible service history. Its use is representative of typical 14 CFR 121 revenue service passenger aircraft currently in the domestic fleet.

Eleven fuselage lap joint areas susceptible to WFD, each approximately 8 by 12 ft, were removed from the aircraft, seven will be destructively evaluated and four will be subjected to extended fatigue testing, Figure 1. Prior to removal, all target sections were labeled with boundaries and identification marks to indicate the location and orientation of the section with respect to the aircraft. In addition, weight and balance analyses were conducted to properly support the structure as well as to properly define the cutting sequence during removal. Ten of the fuselage lap joint areas are located on the crown of the fuselage along the lap joint at stringers S-4R and -4L. One large area located in the bilge of the fuselage along stringer S-26L will also be examined in this study. Based on in-service experience findings from fleetwide inspections subsequent to AD 99-04-22, it is anticipated that cracks will be found in the target structure of the selected aircraft.

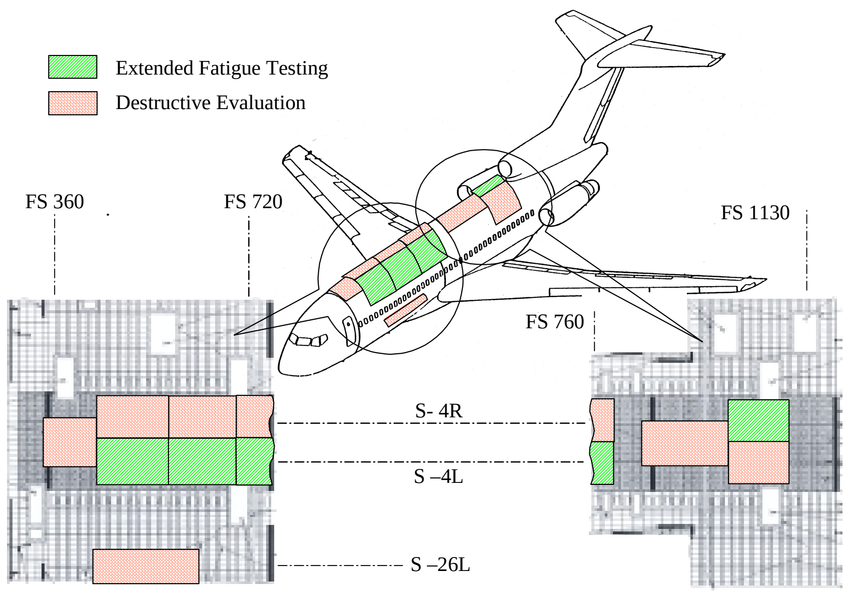

Figure 1. Target structure for test and analysis

3 INSPECTION RESULTS

Prior to removing the target structure, a field inspection was performed at the storage site at the Southern California International Airport in Victorville, CA. The purpose of the field inspection was to catalog the condition of the aircraft and target structure. Detailed visual inspections (DVI) and NDI evaluations were conducted using conventional internal mid-frequency eddy current (MFEC) and external low-frequency eddy current (LFEC) per standard industry practices, OEM specifications, mandated service bulletins, and ADs. After the target structure was removed and transported to the analysis site at DAL in Atlanta, GA, postremoval inspections were conducted. The methods used in the field inspection were repeated. Results in Table 1 show the distribution of crack indications within the frame stations along the lap joint in stringer S-4R using three conventional approaches: MFEC, LEFC, and DVI. As shown, for both inspections, the MFEC was the most sensitive of the conventional methods. There was good agreement in the results from both inspections. The postremoval inspection was conducted in a laboratory environment with controlled conditions, while the field inspections were done under harsh desert conditions.

Table 1. Number of fasteners with crack indications along stringer S-4R

Frame Stations	Field Inspections			Postremoval Inspections		
	MFEC	LFEC	DVI	MFEC	LFEC	DVI
420-440	1	0	0	1	0	0
440-460	1	0	0	1	0	0
480-500	1	1	0	0	1	0
500-520	3	0	1	7	0	1
520-540	8	4	6	8	4	6
540-560	12	1	10	11	2	10
560-580	6	0	1	12	0	1
580-600	10	0	0	13	0	0
600-620	5	2	3	4	2	0
620-640	5	0	5	6	0	5
640-660	0	0	0	2	0	0
660-680	4	1	0	2	0	0
680-700	1	1	0	1	0	0
700-720	6	0	0	8	0	0
720-720A	9	2	3	9	3	3
720A-720B	8	1	0	8	1	0
720B-720C	13	4	0	14	5	0
720C-720D	4	1	0	5	1	0
720D-720E	3	0	1	3	0	2
720E - 720F	0	0	0	1	0	0
Totals	100	18	30	116	19	28

Several emerging NDI technologies were assessed as part of the postremoval inspections, including magneto optical imaging, self-nulling rotating eddy-current probe, and the meandering winding magnetometer. All NDI data were collected so that the signal response data can be analyzed later. Both conventional and emerging NDI technologies will be assessed to determine their field capability to detect small cracks. Results from the NDI will be compared with the crack information obtained from teardown destructive evaluations. Second-layer fatigue crack detectability will be baselined with MFEC or LFEC techniques and compared with emerging inspection technologies.

4 DAMAGE CHARACTERIZATION

The state of damage will be characterized for all 11 target structures. Samples will be prepared for fracture surface examinations using high-resolution microscope and scanning electron microscope. The extent of fatigue cracking, corrosion, faying surface fretting-fatigue, and structural disbanding will be quantified through fractographic examinations.

A teardown protocol was established to characterize the state of damage; to measure crack sizes, shapes, and distributions; to study crack initiation sources and sites; and to reconstruct crack growth histories through striation counts. A procedure was established to disassemble joints and reveal fracture surfaces using a section of the lap joint with both visual and NDI crack indications at several fasteners, as shown in Figure 2. First, 1" square pieces were cut from the joint with the fasteners in the center. These parts were mounted in a stereo microscope to determine the location of cracks around the fastener and to identify the region around the base of the fastener. In regions away from the cracks, two cuts were made through fastener-hole interface to remove the fastener. The samples were soaked in a solution to soften the sealant and pry open the layers. A slot was machined in the plane of the crack, leaving a 0.05" ligament to the crack tip. The samples were cooled using liquid nitrogen, and the ligament was broken using a pair of pliers, exposing the fracture surface of the crack.

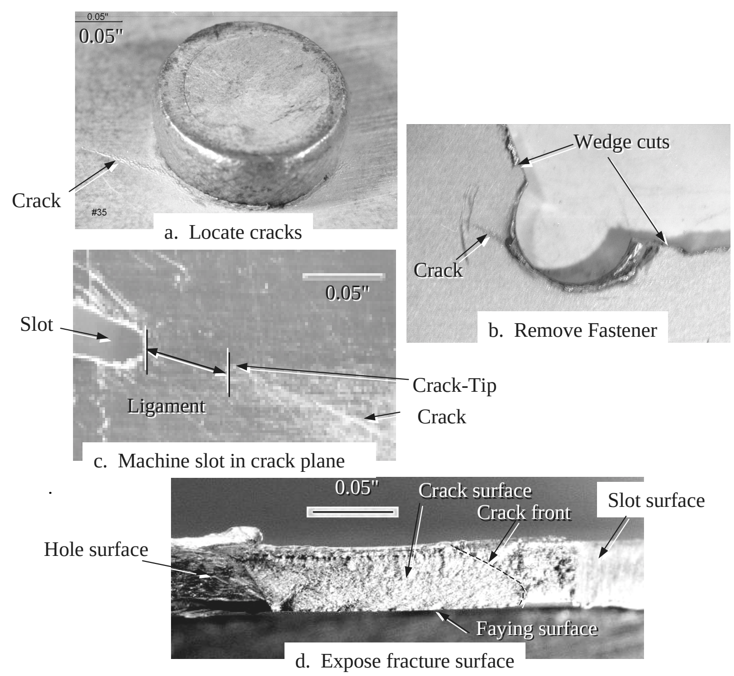

Figure 2. Steps in teardown procedure

The crack data (patterns, distributions, sizes, and shapes) generated will be analyzed and used to (1) characterize MSD crack initiation, crack linkup, and residual strength; (2) assess the inspection capability of NNI in crack detection; and (3) determine the WFD average behavior in the structures removed. Analysis methods will be developed to correlate the state of MSD at any point in time. Preliminary findings included the following:

1. The primary origin of the cracks were at the corner of the hole and the faying surface.
2. The general direction of the cracks were normal to the hoop direction.
3. The crack fronts were semi-elliptic with the longer side on the faying surface.
4. The cracks ranged in size from 0.01" to 0.2"
5. The fracture surfaces were free of corrosion and any gross mechanical rubbing damage.

5 EXTENDED FATIGUE TESTING

In four fuselage panels, the existing state of MSD will be advanced through extended fatigue testing using the FASTER facility and then assessed through teardown destructive evaluation. The FASTER test fixture, shown in Figure 3, located and operated at the FAA William J. Hughes Technical Center, was established to assess the structural integrity of aircraft fuselage structure. The FASTER test fixture is capable of applying realistic flight load conditions, including differential pressure, longitudinal, hoop and shear load in the skin, and hoop load in the frames. A full explanation of this unique test capability can be found in reference 2.

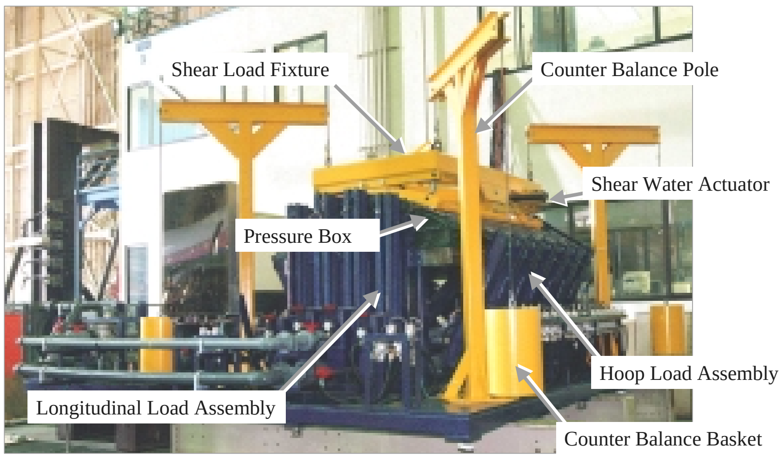

Figure 3. Full-Scale Aircraft Structural Test Evaluation and Research test fixture

The objectives of the extended testing are to (1) propagate the state of damage beyond one DSG; (2) characterize and document the state of damage through real-time NDI, high-magnification visual measurements, and posttest destructive inspections; and (3) correlate analysis methods to determine crack detection, first linkup, and residual strength. Each panel will be subjected to three phases of testing:

Phase 1. Apply the load spectra until cracks can be measured visually. The load spectra will simulate the actual in-service flight load conditions and will include underload marker bands to assist in the striation counts during posttest fractographic examinations. Both conventional and emerging NDI will be used to document the cycles to detectable crack.

Phase 2. Continue with the same spectrum in Phase 1 measuring crack growth to final damage state, possibly a 1.0" MSD crack or the first MSD linkup, whichever occurs first.

Phase 3. Determine the size and state of damage at which the residual strength requirements of 14 CFR 25.571 can no longer be met. The applied test load will be increased to the limit load conditions and will be applied at every cycle.

6 SUMMARY

This paper summarizes the major activities of an effort involving the inspection, teardown destructive evaluation, and extended fatigue testing of fuselage structure removed from a retired passenger aircraft near its design service goal. Eleven sections were removed and are representative of fuselage structure susceptible to widespread fatigue damage (WFD). The primary focus will be on characterizing the state of multiple-site damage (MSD) using detailed nondestructive inspection (NDI) and destructive fractographic examination. In four fuselage sections, the state of MSD will be advanced through extended fatigue testing using the Federal Aviation Administration (FAA) Full-Scale Aircraft Structural Test Evaluation and Research facility. During testing, damage will be monitored and recorded in real-time using NDI. Extended fatigue and residual strength testing of sections of actual fleet aircraft will provide data that will enable calibration and validation of prediction methodologies and will aid in evaluating the sensitivity and effectiveness of standard and emerging inspection technologies to detect small cracks. The data generated from this effort will be used to substantiate WFD assessment methods with data obtained from the analysis of real structure with natural fatigue crack initiation and accumulation of other environmental and accidental damage-induced small flaws that are representative of commercial transport use over an extended period of time (20-30 years). The experience and knowledge gained from this project will aid the FAA to issue essential rules, policy, and advisory circulars pertaining to the prevention of WFD in the commercial fleet.

7 REFERENCES

1. Airworthiness Assurance Working Group (AAWG) report Recommendations for Regulatory Action to Prevent Widespread Fatigue Damage in the Commercial Airplane Fleet, revision A, June 29, 1999, J. McGuire and J. Foucault, Chairpersons.

2. Bakuckas, J.G. Jr., “Full-Scale Testing and Analysis of Fuselage Structure Containing Multiple Cracks,” FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ, DOT/FAA/AR-01/46, July 2002.