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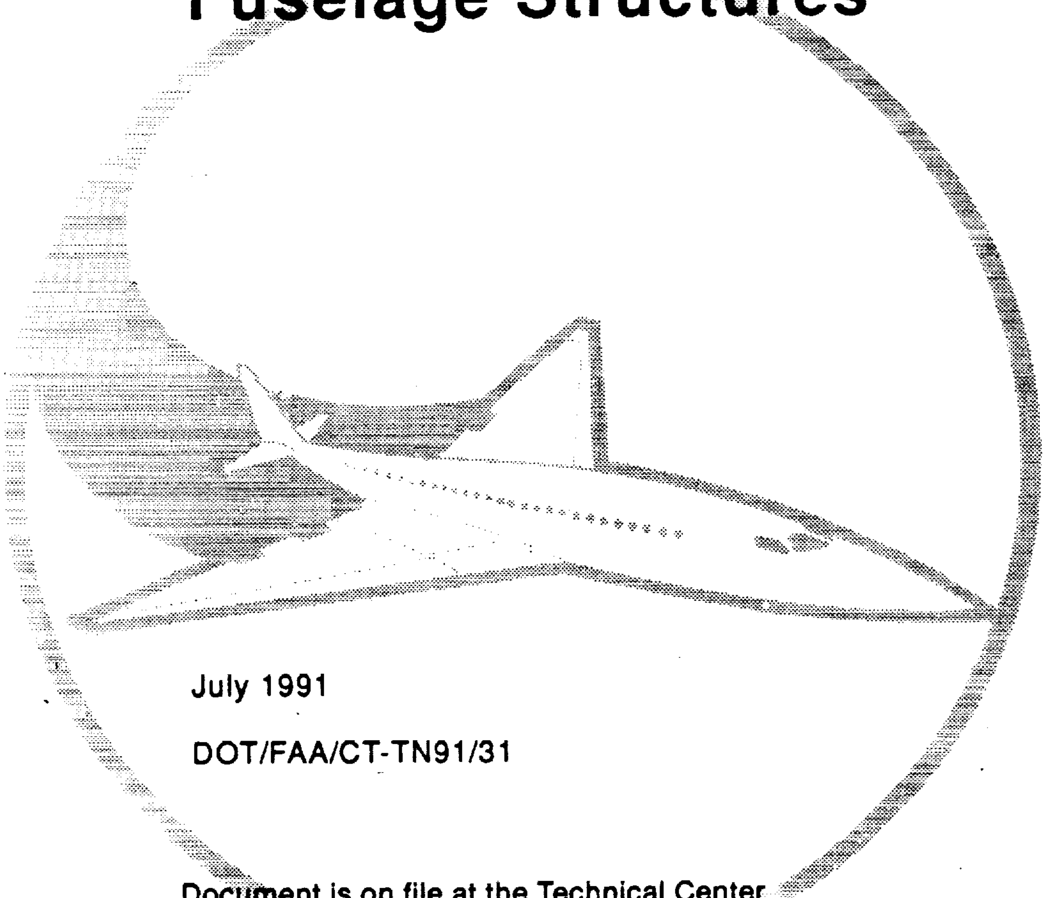
Evaluation of the Concept of Pressure Proof Testing Fuselage Structures



July 1991

DOT/FAA/CT-TN91/31

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(DOT/FAA/CT-TN91/31) EVALUATION OF THE CONCEPT OF PRESSURE PROOF TESTING FUSELAGE STRUCTURES (NASA) 8 p

N91-27155

Unclas
H2/05 0030098

U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-TN91/31	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF THE CONCEPT OF PRESSURE PROOF TESTING FUSELAGE STRUCTURES		5. Report Date July 1991
		6. Performing Organization Code
7. Author(s) Charles E. Harris (NASA) and Oscar Orringer (TSC)		8. Performing Organization Report No.
9. Performing Organization Name and Address Langley Research Center, NASA Transportation Systems Center, DOT		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, NJ 08405		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code ACD-210
15. Supplementary Notes John Fabry, FAA COTR		

16. Abstract

The National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) have recently completed independent technical evaluations of the concept of pressure proof testing the fuselage of commercial transport airplanes. The results of these evaluations are summarized in this Technical Note. The objectives of the evaluations were to establish the potential benefit of the pressure proof test, to quantify the most desirable proof test pressure, and to quantify the required proof test interval. The focus of the evaluations was on multiple-site cracks extending from adjacent rivet holes of a typical fuselage longitudinal lap splice joint. The FAA and NASA do not support pressure proof testing the fuselage of aging commercial transport aircraft. The argument against proof testing is as follows:

1. A single proof test will not insure an indefinite life. Therefore, the proof test must be repeated at regular intervals.
2. For a proof factor of 1.33, the required proof test interval must be below 300 flights to account for uncertainties in the evaluation.
3. Conducting the proof test at a proof factor of 1.5 would considerably exceed the fuselage design limit load and, therefore, is not consistent with accepted safe practice.
4. Better safety can be assured by implementing enhanced nondestructive inspection requirements, and adequate reliability can be achieved by an inspection interval several times longer than the proof test interval.

17. Key Words Pressure Proof Testing Nondestructive Inspection		18. Distribution Statement Document is on file at the Technical Center Library, Atlantic City International Airport, New Jersey 08405	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 5	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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INTRODUCTION

On April 28, 1988, an Aloha Airlines Boeing 737 experienced an in-flight structural failure when the upper fuselage ripped open and a large section of the skin peeled away. This failure was precipitated by the link up of small fatigue cracks extending from adjacent rivet holes in the fuselage lap splice joint. This incident of failure brought about by multiple-site damage (MSD) helped focus the attention of the industry to the problems of operating an aging commercial transport fleet. Currently, approximately 46 percent of the jet airplanes in the fleet are over 15 years old with 26 percent being over 20 years old. During the past 2 years the industry has acted to insure the continued safe operation of the aging fleet. These activities include increased emphasis on maintenance, inspection, and repair as well as mandatory modifications to various models in the fleet. Additional ways of insuring safety are being vigorously pursued. One such possibility is conducting a pressure proof test of the fuselage. While the proof test has the potential to be destructive, it has great appeal because it also has the potential to function as an unambiguous "pass/fail" indicator of safety. The purpose of this document is to establish the National Aeronautics and Space Administration/Federal Aviation Administration (NASA/FAA) position on conducting pressure proof tests of the fuselage of aging commercial transport jet airplanes.

The procedure of overpressurizing the fuselage has been postulated as a technique (proof test) that will insure the continued safe operation of airplanes with fatigue cracks in the fuselage skin. Therefore, the proof test is an alternative to nondestructive inspection (NDI) methods for detecting the presence of cracks before they reach a critical length that would produce a structural failure. Within this context, it must be assumed that cracks will exist in the fuselage after the proof test. Since the proof test pressure is higher than the normal in-flight cabin pressure, the test assures that the existing fatigue cracks which survive the test will be smaller than the critical crack length that would produce an in-flight failure, thereby insuring the continued safe operation of the airplane. However, the proof test will not guarantee an indefinite life for the fuselage because the existing cracks will continue to grow during normal service. Furthermore, existing cracks will extend more during the proof test than during a typical flight; thus, the residual strength of the fuselage will be lowered by the test. This reduction in the residual strength must not compromise the fail-safe or damage tolerance capabilities of the fuselage. Therefore, a technical evaluation is required to determine (1) the proof test pressure load for which a benefit in life is achieved and (2) the interval of flights for which the test must be repeated to assure continued flight safety.

A precedent for conducting the proof test at a pressure above the normal in-flight pressure (P) exists because many new airplanes are subjected to the design limit pressure of 1.33P. The purpose of this test is to demonstrate that the fuselage can survive the design limit pressure without structural failure. However, after this demonstration the fuselage is only required to be fail-safe or damage tolerant at 1.10P. At no other time in the life of the airplane would the fuselage be subjected to the design limit pressure unless a major structural repair or alteration required a new certification.

The military has successfully employed the concept of proof testing the F-111 to insure against in-flight failures brought about by fatigue cracking in steel components. The proof test subjected the wings and fuselage to body-bending loads produced by hydraulic actuators. However, the F-111 proof test program is not directly relevant to the issue of pressure-proof testing the fuselage of commercial transport airplanes. This is because of the fundamentally different fatigue crack growth characteristics of the steel components and the aluminum fuselage components. In another instance, the wings of the B-52D fleet were also successfully proof tested. This was a one-time test to assure continued operational safety until the wings were re-skinned. The test was performed to limit load, and the fleet had to be placed under payload and maneuver restrictions until the repairs were completed. Finally, there are provisions for proof testing in the established standards for gas cylinders (49 CFR 173), pipelines (49 CFR 192), and railroad tank cars (49 CFR 179). However, these standards are based on hydraulic testing; a method that is impractical for aircraft fuselages.

The FAA and NASA have recently completed independent technical evaluations of the concept of pressure proof testing the fuselage of commercial transport airplanes. The results of these evaluations are summarized herein. (The complete technical details may be found in references 1 and 2.) The objectives of the evaluations were to establish the potential benefit of the pressure proof tests, to quantify the most desirable proof test pressure, and to quantify the required proof test interval. The focus of the evaluations was on multiple-site cracks extending from adjacent rivet holes of a typical fuselage longitudinal lap splice joint. The conclusions are based solely on the technical results of the subject evaluations as summarized in this document.

EXPERIMENTAL AND ANALYTICAL INVESTIGATION

NASA conducted a combined experimental and analytical investigation. Experimental tests were conducted on panels with a long, central through-crack to simulate multiple-site damage after linkup. Tests were also conducted on panels with evenly spaced unloaded holes and panels with a lap splice joint attached by a single row of rivets to simulate multiple-site damage before linkup. The FAA evaluation involved a damage tolerance analysis of the Boeing 737 lap splice joint. The effects of stress, proof pressure load, material data, rivet hole size, and rivet spacing were assessed. While a range of proof factors were evaluated, both investigations focused on proof factors of 1.33 and 1.50. (The proof factor is defined as the ratio of the proof test pressure load divided by the normal in-flight pressure load.)

RESULTS

The results from the two independent evaluations are summarized in table 1 showing the required proof test interval for proof factors of 1.33 and 1.50. For consistency with the standard practice for establishing nondestructive inspection intervals, a factor-of-safety of 2.0 has been applied to the proof test intervals to achieve the results in table 1. This factor is intended to compensate for the uncertainties involved in making crack growth life predictions.

TABLE 1. REQUIRED PROOF TEST INTERVAL TO SCREEN CRITICAL MULTIPLE-SITE CRACKING IN RIVETED SPLICE JOINTS

	PROOF FACTOR	
Evaluation	1.33	1.50
	(# of Flights)	(# of Flights)
NASA	275	765
FAA	200	600

One additional experimental evaluation was conducted by Arthur D. Little, Inc., under the FAA research program. This test simulated the 1.33 proof factor and produced the same inspection interval as the corresponding NASA test.

General qualitative results obtained from both investigations are:

1. The remaining life with the proof test is longer than without the proof test.

2. The remaining life after the proof test increases with increasing proof factor.

3. The FAA evaluation revealed that safety equal to that of proof testing could be achieved by eddy current inspection of the rivets in the splice joints at an inspection interval of about 1200 flights.

CONCLUSIONS

The FAA and NASA do not support pressure proof testing the fuselage of aging commercial transport aircraft. The argument against proof testing is as follows:

1. A single proof test will not insure an indefinite life. Therefore, the proof test must be repeated at regular intervals.

2. For a proof factor of 1.33, the required proof test interval must be below 300 flights to account for uncertainties in the evaluation.

3. Conducting the proof test at a proof factor of 1.5 would considerably exceed the fuselage design limit load and, therefore, is not consistent with accepted safe practice.

4. Better safety can be assured by implementing enhanced nondestructive inspection requirements, and adequate reliability can be achieved by an inspection interval several times longer than the proof test interval.

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