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Structural Integrity Evaluation of the Lear Fan 2100 Aircraft

May 1996

Final Report

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16. Abstract

An in-situ nondestructive inspection was conducted to detect manufacturing and assembly induced defects in the upper two wing surfaces (skins) and upper fuselage skin of the Lear Fan 2100 aircraft E009. The effects of the defects, detected during the inspection, on the integrity of the structure was analytically evaluated. A systematic evaluation was also conducted to determine the damage tolerance capability of the upper wing skin against impact threats and assembly induced damage. The upper wing skin was divided into small regions for damage tolerance evaluations. Structural reliability, margin of safety, allowable strains, and allowable damage size were computed. The results indicated that the impact damage threat imposed on composite military aircraft structures is too severe for the Lear Fan 2100 upper wing skin. However, the structural integrity is not significantly degraded by the assembly induced damage for properly assembled structures, such as the E009 aircraft.

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Composites, Damage Tolerance, Impact, Defects, Reliability, Nondestructive Inspection

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PREFACE

This report was prepared by the Northrop Grumann Corporation, Military Aircraft Division, Hawthorne, California, covering work performed under Task 12 of NASA Contract No. NAS1-19347 between November 1993 and October 1994. This specific task was conducted under an Interagency Agreement between the Federal Aviation Administration Technical Center, Atlantic City International Airport, New Jersey and the National Aeronautical and Space Administration Langley Research Center, Hampton, Virginia. Technical direction was provided by P. Shyprykevich, FAA Technical Center, with the advice of J. Soderquist, FAA Headquarters. Administrative support was provided by M. Rouse, NASA Langley Research Center.

The work was performed in Northrop Grumann's Structural Integrity and Materials Technology Department under the overall supervision of Dr. R. B. Deo. Dr. H. P. Kan was the Principal Investigator with the support of the following Northrop Grumann personnel.

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EXECUTIVE SUMMARY

The certification methodology for composite aircraft structures developed under a series of FAA/Navy sponsored programs was successfully demonstrated on military aircraft components. However, the effects of this methodology on structural design and certification requirements of general aviation and commercial aircraft have not been examined. The objective of this program is to conduct a systematic structural integrity evaluation of the damage prone components of the FAA owned Lear Fan 2100 aircraft, using the methodology developed under the FAA/Navy programs.

A Lear Fan 2100 aircraft was inspected using nondestructive techniques. The inspection was conducted on aircraft serial number E009, the third flying prototype manufactured. FAA personnel indicated that the aircraft had experienced approximately 230 hours of flight time. The upper wing skins and the upper fuselage skin, areas considered most likely to suffer damage during manufacturing and maintenance operations, were evaluated using ultrasonic and thermographic techniques. A total of 19 defects around the fastener heads in the upper wing skins were identified by the MAUS (Mobile Automated Ultrasonic System developed by McDonnell Douglas). In addition, one area of mild porosity in the wing skin and one area of possible disbond between mating fuselage skins were also detected. Analytical results showed that these defects are not severe enough to impose a threat to the integrity of the wing structure.

After an extensive review of the structural configurations, flight loads, and the full-scale test articles, a damage tolerance evaluation was conducted for the upper wing skins. The capability of the structure to tolerate impact damage and assembly induced defects was systematically evaluated. The upper wing skin was divided into small regions, based on the arrangement of the substructures and the distribution of the skin thickness, for the damage tolerance evaluations.

For the impact damage tolerance evaluation, both the probabilistic and discrete impact threats were considered. These threat scenarios were derived primarily based on damage tolerance design requirements of composite military aircraft structures. The results of the evaluation are presented in terms of allowable strain, margin of safety, and reliabilities at design limit and design ultimate loads. These results show that the upper wing skin has adequate damage tolerance capability against impact threats imposed on military aircraft structures only under the design limit loads. At design ultimate loads, the impact threats are too severe for the Lear Fan 2100 aircraft. Further investigation to define realistic impact threats and establish impact damage tolerance design criteria is needed for this class of aircraft using composite materials.

Damage tolerance capability of the upper wing skins against assembly/manufacturing induced damage was also analytically evaluated. The baseline damage scenario used in the study was defined based on the results of a recently completed FAA/Navy sponsored program, which generally produced damage more severe than the defects detected for the E009 aircraft. Margin of safety and reliabilities of the upper wing skins with the baseline damage were obtained analytically. In addition, allowable damage sizes were defined for various damage scenarios. The results show that the upper wing skins are capable of tolerating damage induced under properly controlled assembly procedures. However, poor assembly processes can induce more severe damage in the structure, which may impose a threat to the structural integrity. Therefore, assembly standards must be established to minimize damage. Nondestructive inspection (NDI) after final structural assembly should be performed if such standards do not exist.

SECTION 1

INTRODUCTION

The application of composite materials to primary aircraft structures requires proven certification procedures to demonstrate their structural integrity. The Federal Aviation Administration (FAA) has published their certification procedure for composite structures in the Advisory Circular (AC) 20-107A (reference 1). An overview of the FAA composite certification activity is presented in reference 2 and the important considerations of AC 20-107A can be found in reference 3. Recognizing the inherent differences between composites and metals, the FAA and the Navy jointly funded two programs (references 4 and 5) to address the issues of certifying undamaged composite structures. In these programs, various approaches to static strength and fatigue life certification were evaluated and used to establish a certification methodology for undamaged composite aircraft structures.

Subsequently, the FAA and the Navy funded two additional programs (references 6 and 7) to account for impact damage on the static strength and fatigue life of composite structures. The objective was to establish impact damage limits for structural certification and to integrate it with the previous work, references 4 and 5. The results of the two later programs enable certification of impact damaged composite structure with the same level of confidence as undamaged structure. More recently, this technology was developed further to incorporate the influence of delaminations and assembly induced damage on structural certification (reference 8).

The certification methodology developed in references 4, 6 and 8 was demonstrated on military aircraft components. However, the effects of this methodology on structural design and certification requirements of general aviation and commercial aircraft have not been examined. It is therefore desirable to utilize the FAA owned Lear Fan 2100 aircraft and the associated design and test data as a test bed for the evaluation of the certification methodology contained in references 4, 6 and 8.

The objective of this task is to conduct a systematic structural integrity evaluation of the damage prone components of the Lear Fan 2100 aircraft, using the methodology developed under the FAA/Navy programs. In section 2 of this report a brief description of the Lear Fan 2100 structure is presented. The results of an in-situ nondestructive inspection (NDI) of the upper surfaces of the wing and fuselage are documented in section 3. Section 4 summarizes the loads and strains used in the structural evaluation. Results of the detailed damage tolerance evaluation are given in section 5. A parametric study was conducted to evaluate to sensitivity of material and structural parameters on the damage tolerance capability of the structure, and the results of this study are included in section 6. Conclusions drawn from the structural integrity evaluation are summarized in section 7.

SECTION 2

STRUCTURAL DESCRIPTION

The Lear Fan 2100 is a twin engine, pressurized, low-wing monoplane, utilizing a single pusher propeller. The aircraft has provisions for nine to ten persons and suitable allowance for luggage and optional equipment. Clean aerodynamic design and light-weight structure utilizing graphite/ epoxy extensively give jet-class performance at reciprocating twin engine operating costs. The maximum takeoff weight of the airplane is 7200 lbs. The wing span of the aircraft is 39 ft. 4 in. with a overall length of 39 ft. 7 in. The fuselage cabin height is 53.6 in. and 58 in. wide with length from the forward pressure bulkhead to aft pressure bulkhead of 17 ft. 8 in. A three-view of the aircraft is shown in figure 1 and the major assembly breakdown of the airframe is shown in figure 2.

The airframe design relies upon extensive use of bonded graphite/epoxy structure for minimum weight, corrosion and fatigue resistance, and smooth external contours. Fuselage structure is close-spaced frames and longerons bonded to the outer skin. A noncircular fuselage section provides optimum cabin space for its size, and maximum headroom is provided through the use of a lower aisle. Eleven windows provide ample passenger visibility and cabin lighting. Normal cabin access is by means of a 32.25-in.-wide split air stair door forward of the wing on the left side of the fuselage. Emergency egress is through the cabin door and an escape hatch located behind the cockpit bulkhead on the right side of the fuselage. Large doors on each side of the aft fuselage plus removable intake scoops facilitate engine and accessary access.

The wing is a continuous three-spar cantilever structure attached to the fuselage at six points. The main landing gear is a conventional strut type incorporating single 6.5x8 wheels and brakes. All primary structures are designed to be fail-safe and damage tolerant. The composite materials and design approach assure a long service life and low airframe maintenance.

The Lear Fan Model 2100 aircraft was being certified per FAR, Part 23, reference 9. The guidelines of the Advisory Circular on composite structure were observed throughout the program. Since much of the airframe was constructed from advanced composite materials, AC 20-107 was used as a guide for the certification procedures. The static strength of the model was certified by test. Finite element and classical stress analysis, along with subcomponent testing, were conducted to ensure that the airframe had adequate strength. However, stress analysis was used only in minor cases as a certification tool.

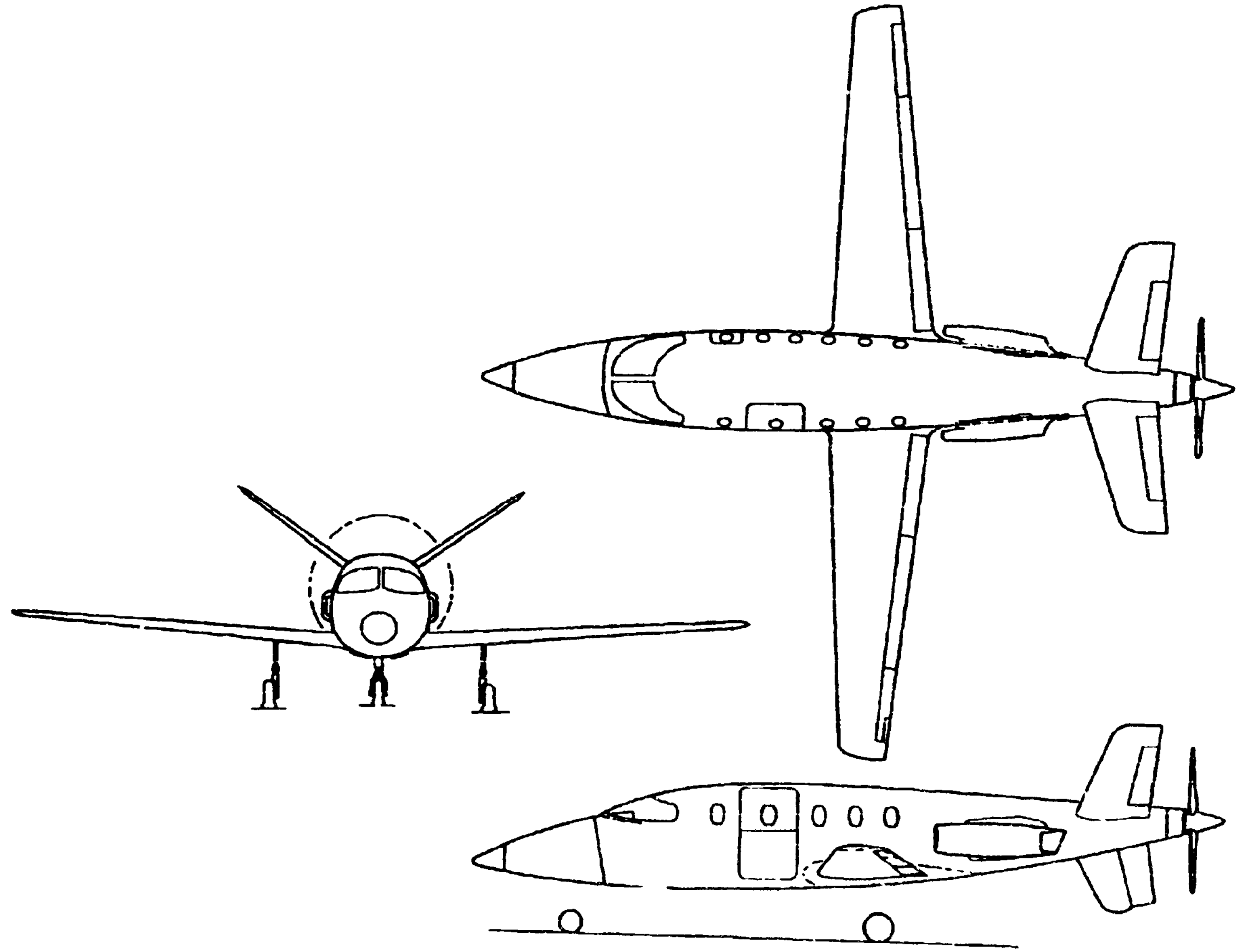

FIGURE 1. THREE-VIEW OF THE AIRCRAFT.

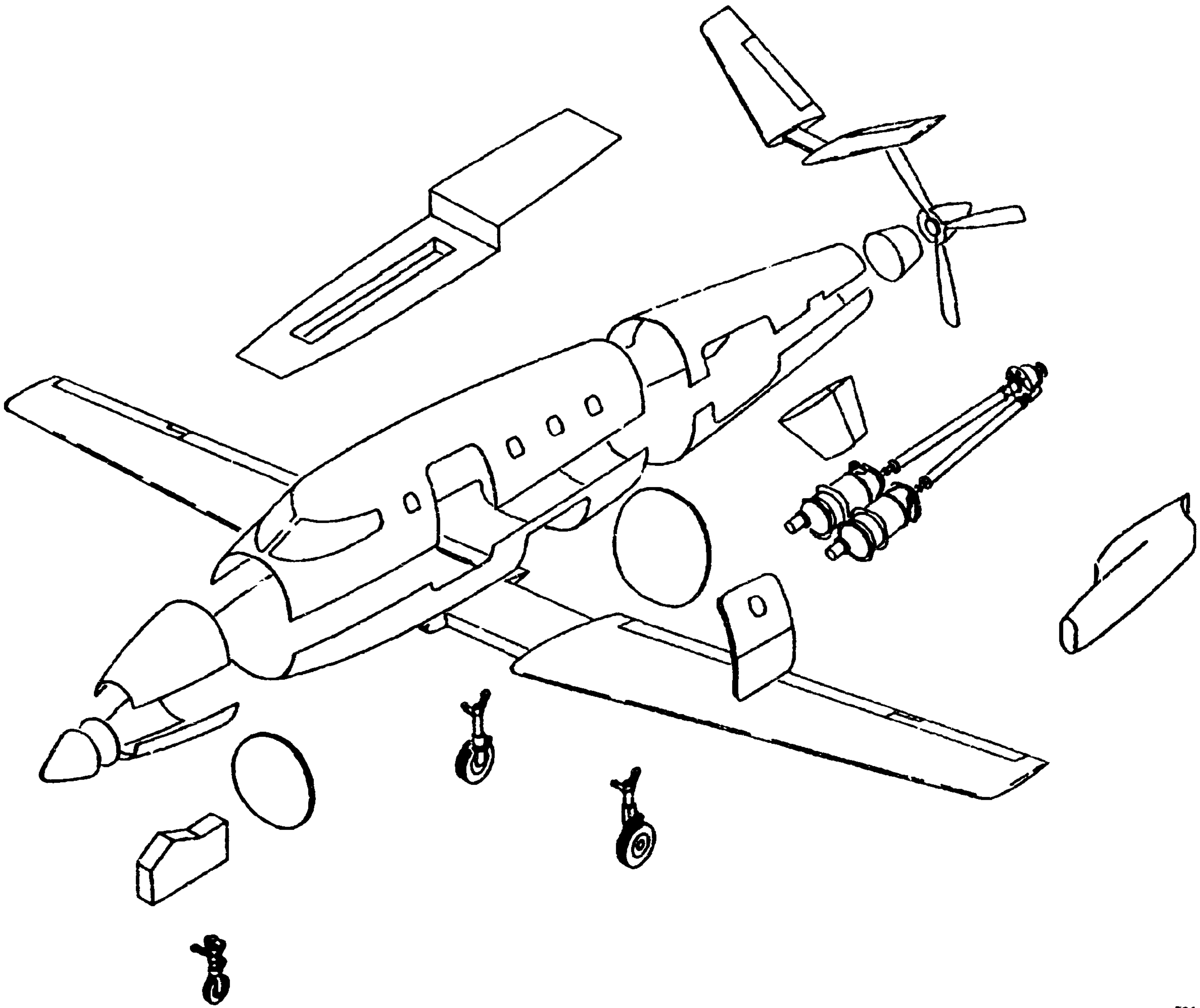

FIGURE 2. MAJOR ASSEMBLY BREAKDOWN.

The static test article was tested at room temperature without environmental conditioning. For the advanced composite components of the static article, the FAR Part 23 loads were adjusted to account for the environmental degradation of material properties and material variability. Each airframe component subjected to individual static tests was evaluated to determine the operational environment. Typical environments included the effects of moisture, temperature, and chemicals such as fuel, cleaning fluids, hydraulic fluids, etc. The environmental factor was determined by tests. The variability factor was determined by comparing the typical material test coupon strength with the "B" basis allowables.

Fail-safe and damage tolerance tests were conducted to substantiate the fail-safe requirements of FAR Part 23. The wing and fuselage structures were designed to be fail-safe/damage tolerant and were certified by this method. Full-scale fail-safe/damage tolerance tests were conducted on the fuselage and wing. In addition to FAR 23 requirements, the horizontal tail was also tested. The test cyclic loads were adjusted to account for the environmental factor. At least two lifetimes of testing were applied prior to certification. At least one lifetime of testing was conducted on structure with inflicted damage. Production type flaws were built into the test articles. The objectives of these fail-safe/damage tolerance tests were:

1. Identify any damage sensitive area in the structure.

2. Demonstrate acceptable damage tolerance.

3. Identify primary and secondary structures based on damage growth rates.

4. Define inspection techniques and schedules, based on damage or flaw growth rate.

5. Substantiate repair techniques for inclusion in the Maintenance Manual.

The structural integrity evaluation of the present task has been concentrated on the damage tolerance evaluation of the upper wing skin. The wing structure is a continuous three-spar cantilever. The main section of the wing skin spans 226 inches from the body centerline to the tip. The skin is made of AS4/3501-6 graphite/epoxy composite with combined use of tape and fabric plies. Its thickness ranges from 0.053 in. 0% of 0°-, 79% of 45°-, 21% of 90°-plies (0/79/21) layup near the tip to 0.109 in. (0/90/10) layup near the body centerline. A more detailed description of the cover skin is given in section 4.

SECTION 3

NONDESTRUCTIVE INSPECTION (NDI)

A Lear Fan 2100 aircraft was inspected using nondestructive techniques. Inspections were conducted during the week of 1 February, 1994. A Northrop Grumman inspection team consisting of T. Dyer, D. J. Williamson, C. Bohn, T. Kunst and D. Gray performed this task at the FAA Technical Center at Atlantic City International Airport, New Jersey. The inspection was conducted on aircraft serial number E009, the third flying prototype manufactured. FAA personnel indicated that the aircraft had experienced approximately 230 hours of flight time.

The objective of the inspection was to identify any damage growth in structural defects existing prior to flight and to determine the extent of any structural damage due to flight history. The upper wing skins and the upper fuselage skin, areas considered most likely to suffer damage during manufacturing and maintenance operations, were evaluated using ultrasonic and thermographic techniques. Overall, very little damage was detected; with the exception of one area of mild porosity and one area of possible disbond between mating fuselage skins. Defects consisting of relatively minor delaminations around wing skin fasteners were also detected. Damage growth in defects existing prior to flight could not be evaluated because manufacturing and maintenance inspection records were not available.

Initial ultrasonic inspection was performed using MAUS (Mobile Automated Ultrasonic System) equipment developed by McDonnell Douglas Aircraft Company. The MAUS consists of a hand-held sensor containing four conventional ultrasonic transducers which can simultaneously examine a four-inch-wide surface, and interface with a computer system that converts tranducer data into visual image that is used to evaluate damage. The transducers used a frequency of 5 MHz, the same frequency that was used for inspection during part manufacturing and aircraft assembly operations. After initial inspections, an A-Scan was performed, using a single conventional hand-held transducer at 5 MHz, on all defects identified by the MAUS, to verify MAUS data.

Defects identified by ultrasonic evaluation for the upper wing skins are summarized in figure 3, and the gray scale images of the MAUS data are shown in figures 4 through 13. Numbers next to defects shown in the MAUS images correlate with the defect numbers shown in figure 3 for the left and right wing skins, respectively. A total of 19 delaminations around the fastener heads were identified (5 on the left wing and 14 on the right wing) by the MAUS, all

DEFECT NUMBER	LOCATION	DEFECT SIZE (inch)			REMARKS
		WIDTH	LENGTH	DEPTH	
LEFT HAND WING					
1	Yw = 79.0 @ AFT SPAR	0.96	1.20	0.025 – 0.080	a
2	Yw = 81.6 @ AFT SPAR	0.72	1.00	0.025 – 0.070	a
3	Yw = 97.4 @ AFT SPAR	0.56	0.90	0.065	a
4	Yw = 99.3 @ AFT SPAR	0.50	0.30	0.070	a
5	Yw = 103.9 @ AFT SPAR	0.25	0.28	0.040 – 0.070	b
RIGHT HAND WING					
1	Yw = 96.4 @ AFT SPAR	0.30	0.50	0.025 – 0.080	b
2	Yw = 168.0 @ AFT SPAR	0.16	0.52	0.025	b
3	Yw = 189.8 @ AFT SPAR	0.20	0.40	0.075	b
4	Yw = 193.7 @ AFT SPAR	0.20	0.56	0.040	b
5	Yw = 198.3 @ AFT SPAR	0.28	0.56	0.035 – 0.055	b
6	Yw = 207.0 @ AFT SPAR	0.32	0.64	0.027 – 0.042	b
7	Yw = 212.5 @ AFT SPAR	0.44	0.84	0.025 – 0.075	b
8	Yw = 215.6 @ AFT SPAR	0.60	0.88	0.025 – 0.075	a
9	Yw = 218.8 @ AFT SPAR	0.50	0.90	0.025 – 0.052	b
10	Yw = 221.3 @ AFT SPAR	0.36	0.90	0.025	b
11	Yw = 224.4 @ AFT SPAR	0.20	0.80	0.062	b
12	Yw = 94.9 @ CENT SPAR	0.88	1.48	0.025 – 0.087	a
13	Yw = 221.7 @ CENT SPAR	0.28	1.00	0.032 – 0.062	b
14	Yw = 224.4 @ CENT SPAR	0.32	1.00	0.032	b

REMARKS: a MEASUREMENTS INCLUDE FASTENER
b MEASURED FROM EDGE OF FASTENER

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FIGURE 3. SUMMARY OF UPPER WING SKIN DEFECTS.

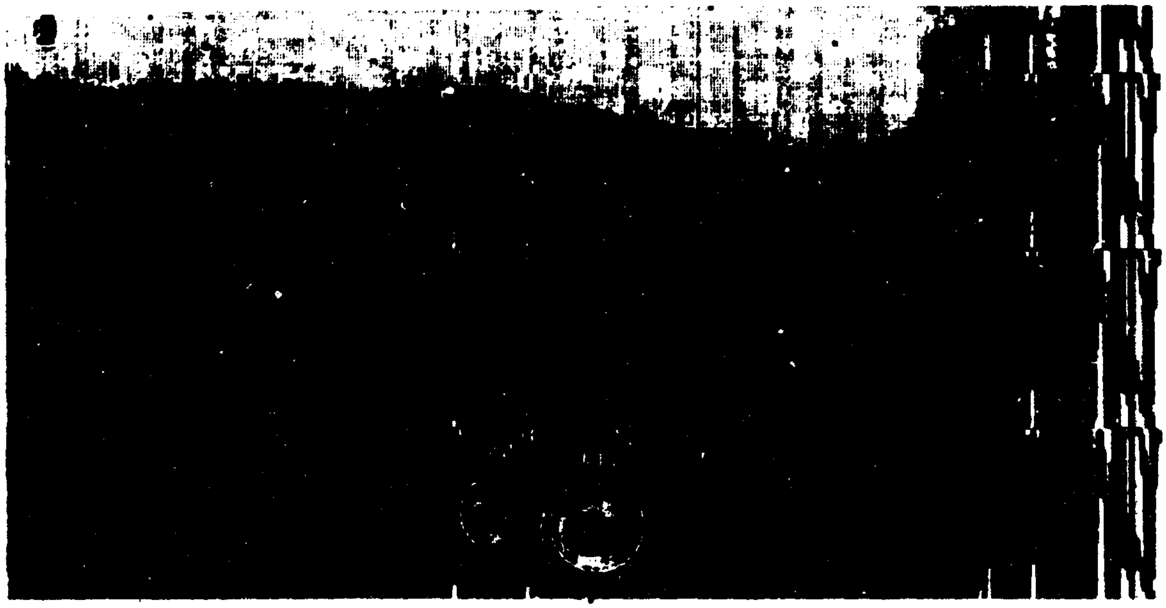

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FIGURE 4. MAUS IMAGES OF DEFECT NOS. 1 AND 2 ON THE UPPER LEFT WING SKIN.

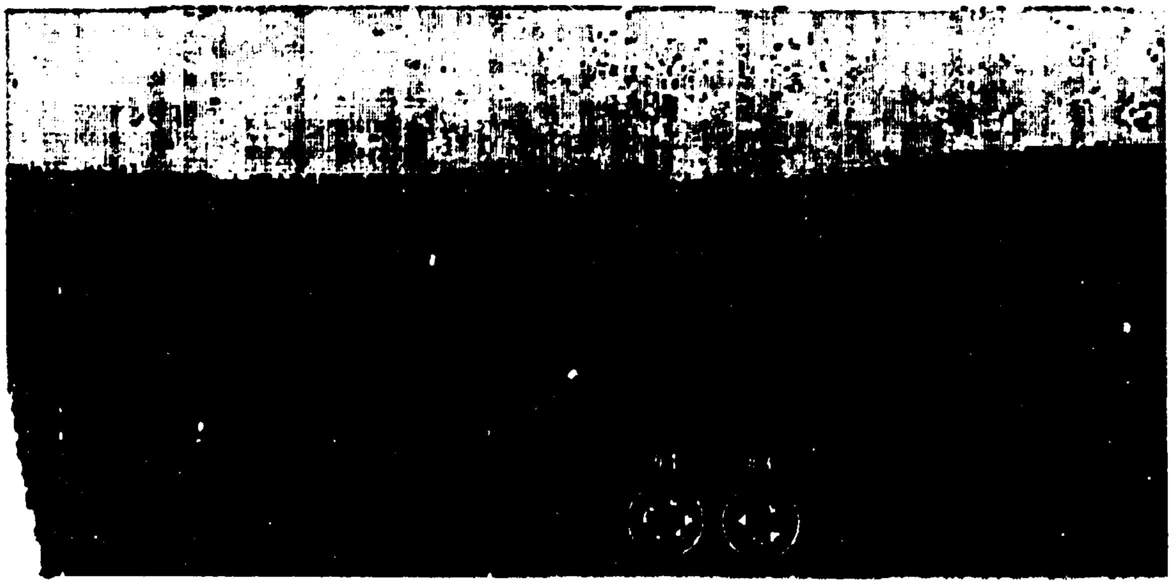

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FIGURE 5. MAUS IMAGES OF DEFECT NOS. 3 AND 4 ON THE UPPER LEFT WING SKIN.

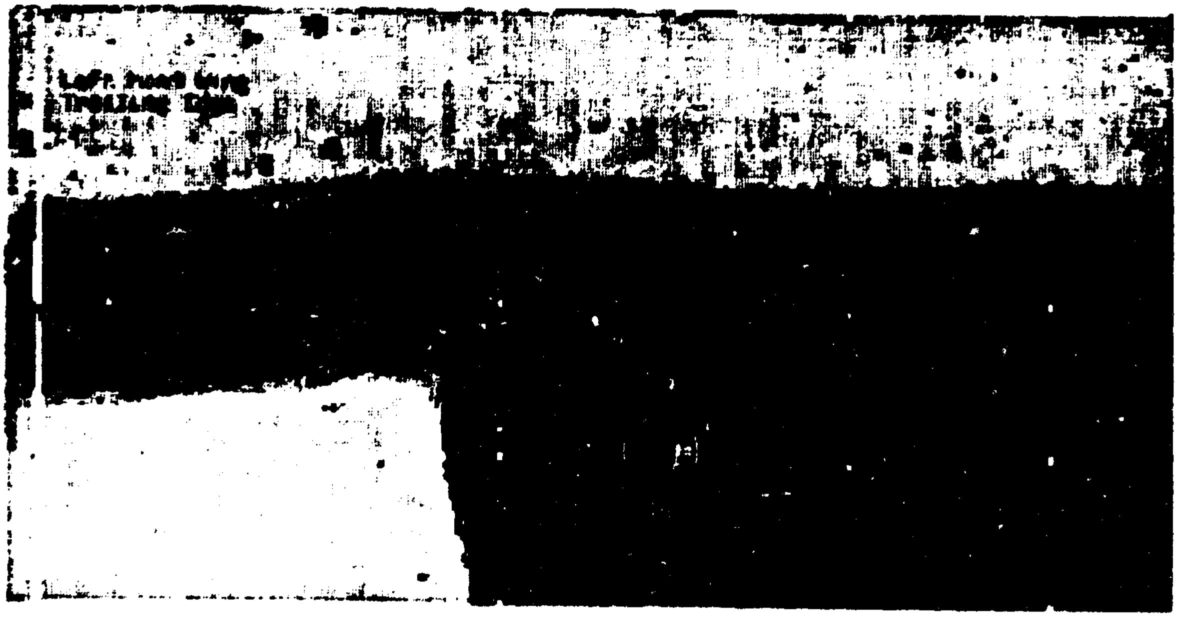

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FIGURE 6. MAUS IMAGE OF DEFECT NO. 5 ON THE UPPER LEFT WING SKIN.

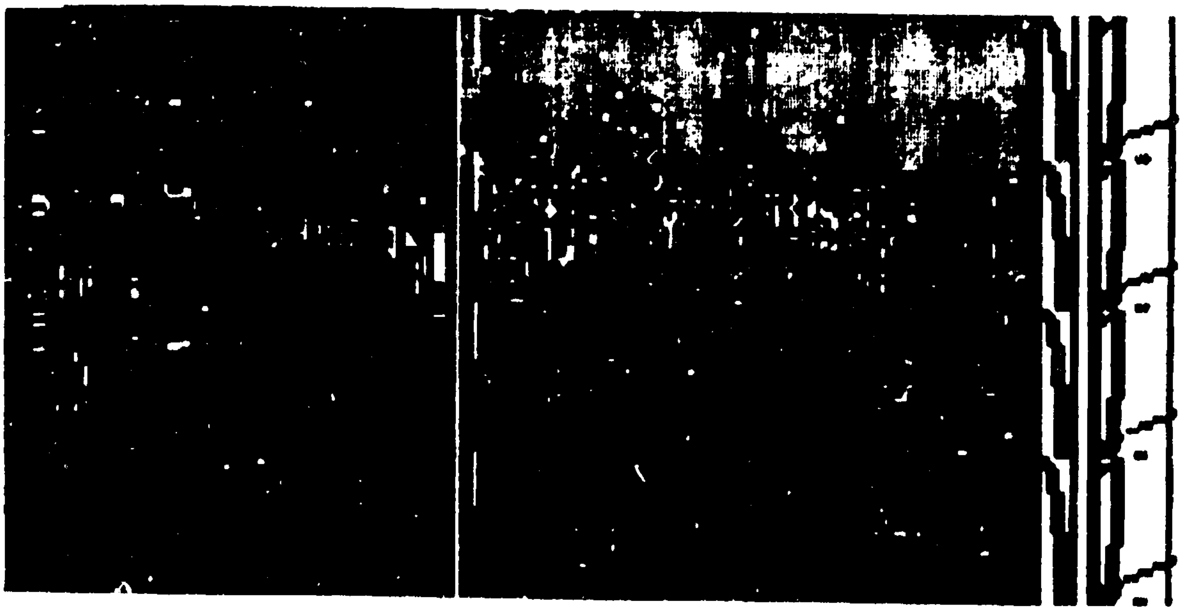

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FIGURE 7. MAUS IMAGE OF DEFECT NO. 1 ON THE UPPER RIGHT WING SKIN.

FIGURE 8. MAUS IMAGE OF DEFECT NO. 2 ON THE UPPER RIGHT WING SKIN.

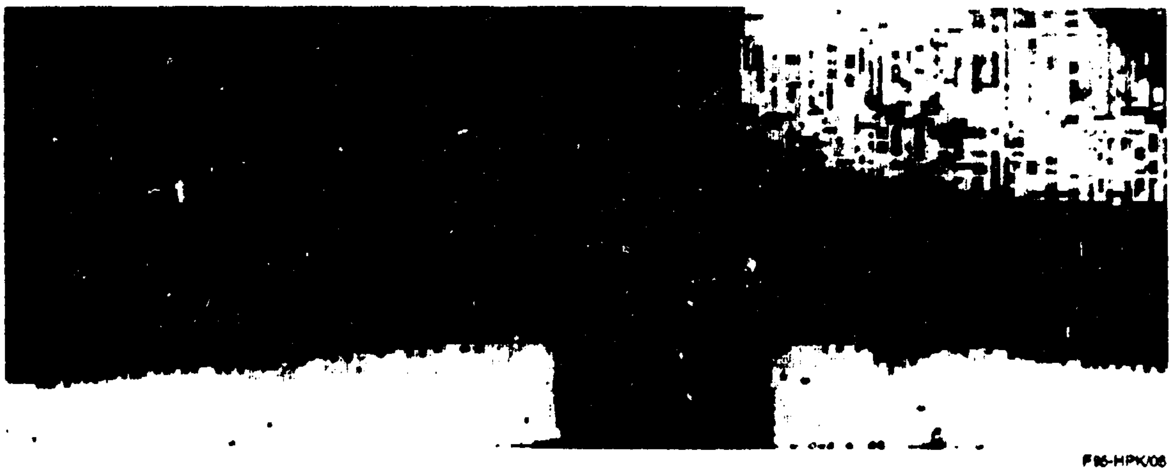

FIGURE 9. MAUS IMAGES OF DEFECT NOS. 3, 4 AND 5 ON THE UPPER RIGHT WING SKIN.

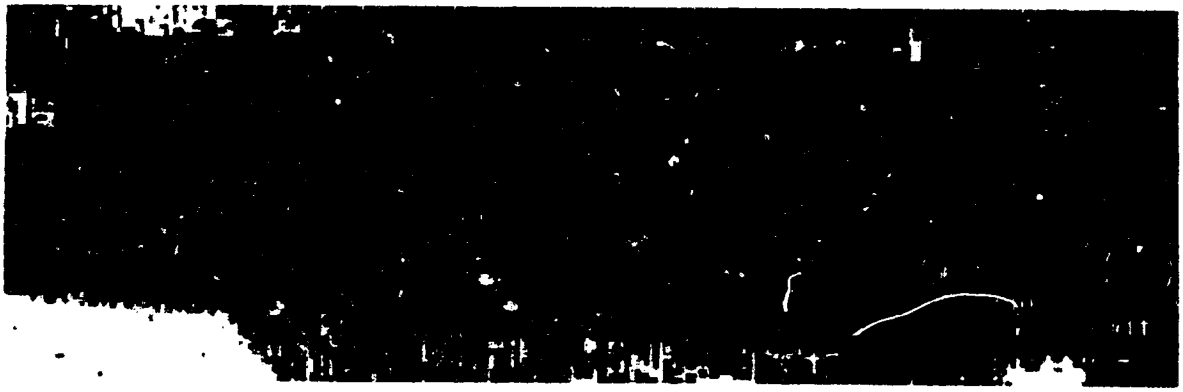

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FIGURE 10. MAUS IMAGES OF DEFECT NOS. 6 THROUGH 11 ON THE UPPER RIGHT WING SKIN.

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FIGURE 11. MAUS IMAGE OF DEFECT NO. 12 ON THE UPPER RIGHT WING SKIN.

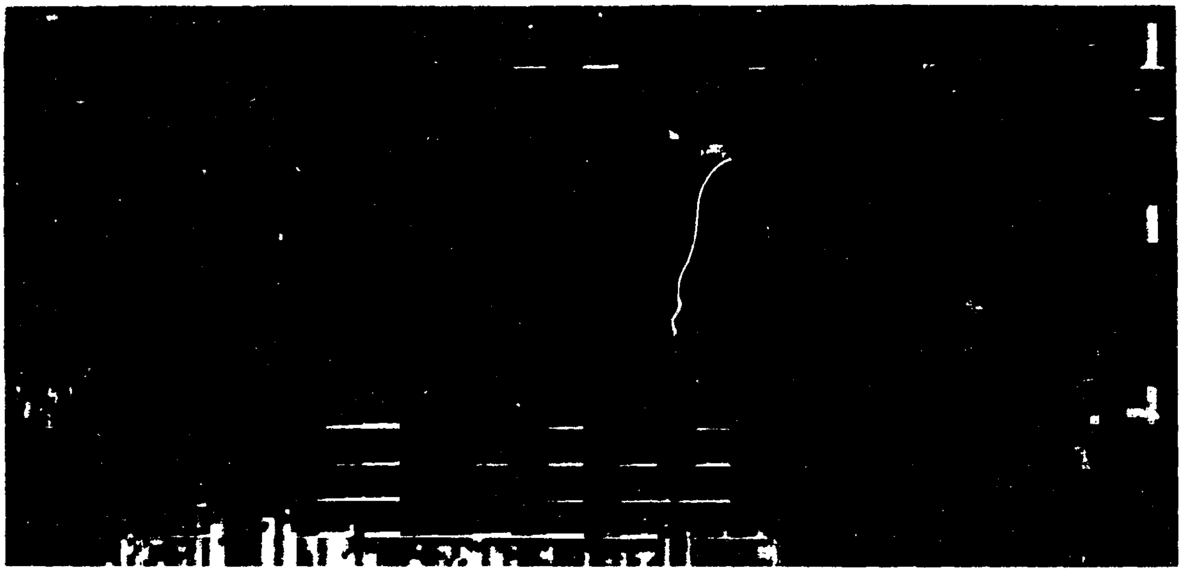

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FIGURE 12. MAUS IMAGES OF DEFECT NOS. 13 AND 14 ON THE UPPER RIGHT WING SKIN.

FIGURE 13. MAUS IMAGE OF MINOR POROUS AREA ON THE UPPER LEFT WING SKIN (BETWEEN Yw 28 AND 40).

F95-HPK/10

were verified by A-Scan. The majority of these delaminations were located around fasteners connecting the upper skins to the aft spars. One area of minor porosity was identified by the MAUS, located between wing stations Yw=28 and Yw=40, extending over the entire skin of the left wing in the chord direction, but could not be verified by A-Scan. Lack of verification by A-Scan indicates that MAUS equipment is more sensitive than conventional ultrasonic inspection equipment, which cannot detect defects that produce an ultrasonic attenuation less than 3dB.

In addtion to the defects detected on the wing skins, the MAUS also obtained images that looked similar to those for disbonds along the entire length of the step-lap splice between the upper and side skins of the fuselage. One area of the splice, at Yf=15 and between Xf=335 and 348, approximately 1.5 in. long on the right side of the aircraft, produced more clearly defined indications of delamination than other areas of the splice. An image of this area is shown in figure 14. However, no defects identified by the MAUS on the upper fuselage skin could be verified by A-Scan.

Thermographic inspection was conducted using equipment developed by Northrop's B2 Division, which consists of a simple heat source (heat lamp) and an infrared video camera capable of detecting subtle changes in part temperature. The technique is in the developmental stage and is based on the assumption that defective surface areas of a structure will absorb heat at a different rate than acceptable areas. Defect evaluation is based on a real-time examination of infrared video images.

Thermographic inspection was performed on all defects and suspect areas identified by the MAUS. All delaminations around upper wing skin fasteners that were identified by ultrasonic inspection were also detected by thermography. However, the majority of these defects appeared to be slightly smaller than ultrasonic inspection data indicated. Thermographic inspection of the splice between upper and side fuselage skins produced no indications of disbond, even in the area that ultrasonic inspection identified as worse than other splice areas. In addition, thermographic inspection could not detect the area of mild porosity on the left wing that was detected by the MAUS. These results indicate that thermographic inspection equipment used is not as sensitive as conventional ultrasonic equipment.

The majority of the defects detected on the upper wing skins were delaminations around fastener holes. This type of damage is usually produced during assembly of the composite structure. Assembly induced damage was investigated in detail in reference 8, where an analysis method was developed to evaluate the criticality of the damage. The defects detected during the inspection were evaluated using this method. The results of the analytical evaluation are presented in section 5.

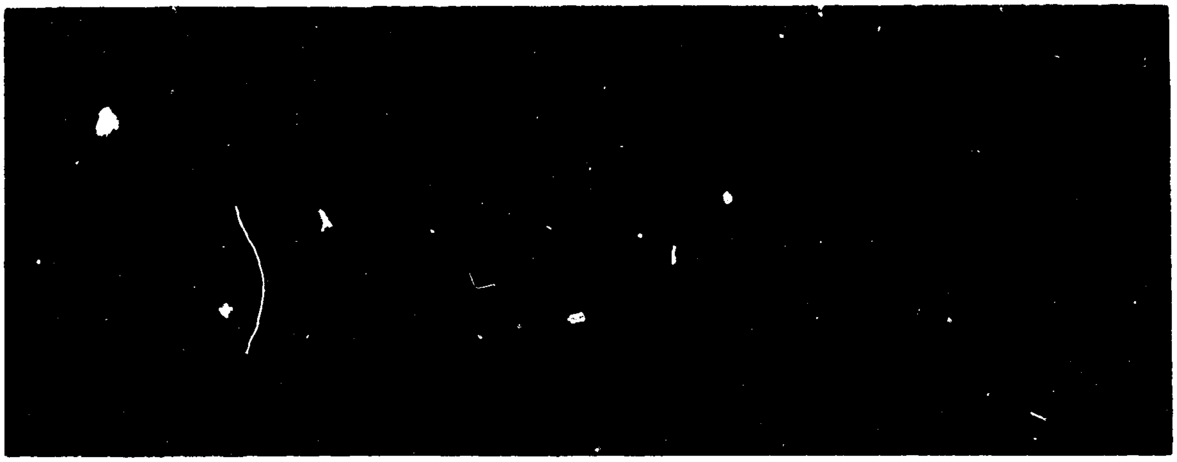

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FIGURE 14. MAUS IMAGE OF DISBONDS ALONG STEP-LAP SPLICE BETWEEN THE UPPER AND SIDE SKINS OF THE FUSELAGE.

SECTION 4

STRUCTURAL LOADS AND STRAINS

The Lear Fan Model 2100 aircraft component loads were generated in compliance with the portions of the FAR Part 23 concerned with determination of flight and ground loads. The basic data and operating conditions necessary to calculate the flight and ground loads includes external dimensional data, wing and empennage airfoils, control surface deflection limits, weights and center of gravity limits, operating speeds and altitudes, maximum lift coefficient, speed-load factor diagrams, and pressurization limits. In addition, environmental factors affecting structure are included, particularly the operating structural temperature limits. The applied loads for the full-scale wing test were derived from calculated theoretical loads. These applied loads will be used for the damage tolerance evaluations of the wing structure in the subsequent sections. A description of the test article, the applied loads, and the strain distribution in the upper wing skin is given in the following paragraphs.

4.1 FULL-SCALE WING TEST ARTICLE

The purpose of the full-scale wing static tests was to demonstrate the structural integrity of the Lear Fan 2100 wing to the FAA certification requirements. This was done by demonstrating that the wing is capable of withstanding limit load without permanent detrimental deformation and ultimate load for at least three seconds without failure. The following static tests were conducted on the test articles.

a. Symmetric down bending,

b. Maximum negative torque,

c. Asymmetric up bending,

d. Maximum positive torque,

e. Symmetric up bending.

f. Symmetric up bending with pressurized wing.

The test articles were constructed and inspected in accordance with Lear Fan Standard Specifications and production drawings. A sketch of the test article, along with the sign conventions for shear, moment and torque, is shown in figure 15. The test article for the

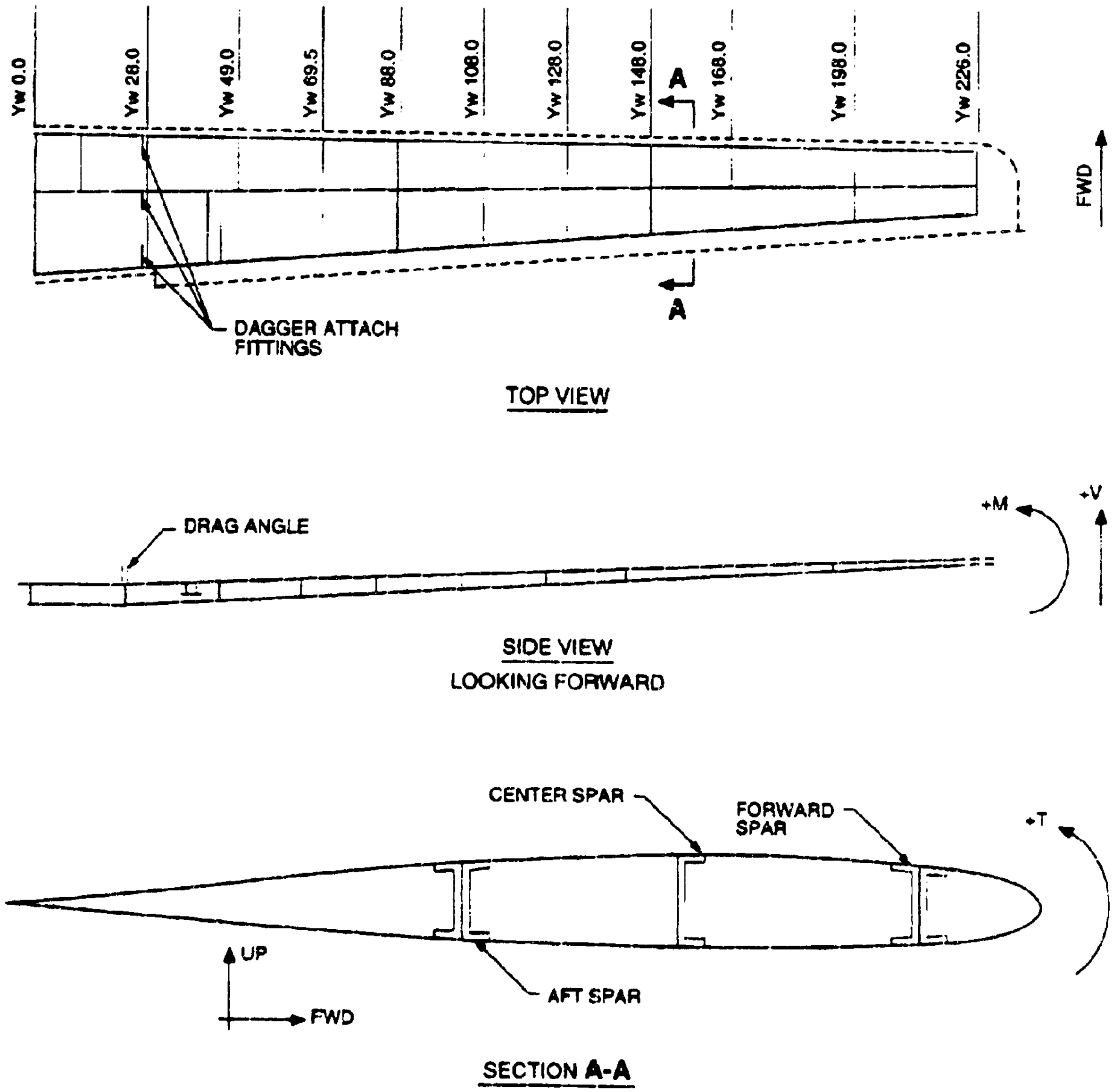

FIGURE 15. SCHEMATIC OF THE FULL-SCALE WING TEST ARTICLE AND SIGN CONVENTIONS OF APPLIED LOADS.

symmetric down bending, negative torque, symmetric up bending, asymmetric up bending and positive torque tests was the E002 wing and the test article for the symmetric up bending with pressurized wing test was the E004 wing.

All tests were performed under ambient conditions. The test articles were not environmentally conditioned prior to testing.

4.2 TEST LOADS

All test loads were derived from limit load 275 KEAS envelope data. Limit loads were increased by the static test factor of 1.14 to obtain the adjusted limit load used to satisfy the FAA limit load requirements. The FAA adjusted ultimate test load requirements were satisfied by further increasing the adjusted limit test loads by a factor of 1.5. After static tests were completed the loads were revised to reflect the 250 KEAS flight envelope. The applied ultimate test loads were compared to the required theoretical ultimate loads for the 250 KEAS flight envelope derived for the Type Certification. The applied test loads exceeded the theoretical loads for the load cases except for the maximum negative torque case. For the maximum negative torque case the applied torques exceeded the required torques by a minimum of 19 percent at all wing stations. Applied moments and shears were lower than the required theoretical loads. However, this is not considered a problem based on the test result interpretation.

The actual inflight loads are distributed loads, the theoretical shear, moment, and torque diagrams are smooth curves. However, the test loads are point loads applied at selected wing stations. The test loads were applied at locations shown in figure 15 (at Yw=28, 49, 69.5, 88, 108, 128, 148, 168, 198 and 226). Consequently, the shear and torque diagrams resulting from the applied test loads appear as step functions which closely approximate the theoretical shear and torque curves. In calculating the test loads, priority was given to matching the theoretical moment as closely as possible and the shear loads were adjusted accordingly. As a result, the test load are a very close match of the moment diagrams. The shears and torques meet or exceed the theoretical shears and torques at most wing rib stations and always at the wing root. The applied shear, bending moment, and torque for the symmetric up bending load case are summarized in figure 16 and the comparison between applied and theoretical loads are shown in figures 17, 18 and 19. This load case is selected as an example because this is the most critical load case for the upper wing skin which is used extensively in the damage tolerance evaluation. As can be seen in the following subsection on wing skin strains, the critical strains for the upper wing skin are primarily produced by the symmetric up bending loads.

WING STATION	FRONT SPAR (lb)	REAR SPAR (lb)	SHEAR (Vz) (lb)	MOMENT (Mx) (in-lb)	TORQUE (ta) (in-lb)
28	—	—	20924	1,903,438	84,824
49	2672	1513	20924	1,463,943	84,824
69.5	1577	537	16738	1,120,739	78,547
88	1863	780	14624	850,139	66,957
108	1477	548	12008	609,922	56,863
128	1502	543	9984	410,212	47,377
148	1532	543	7938	251,414	37,742
168	1796	655	5864	134,118	27,995
198	1720	561	3413	31,695	17,103
226	940	192	1132	—	6,404

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FIGURE 16. APPLIED TEST LOADS FOR THE SYMMETRIC UP BENDING TEST CASE.

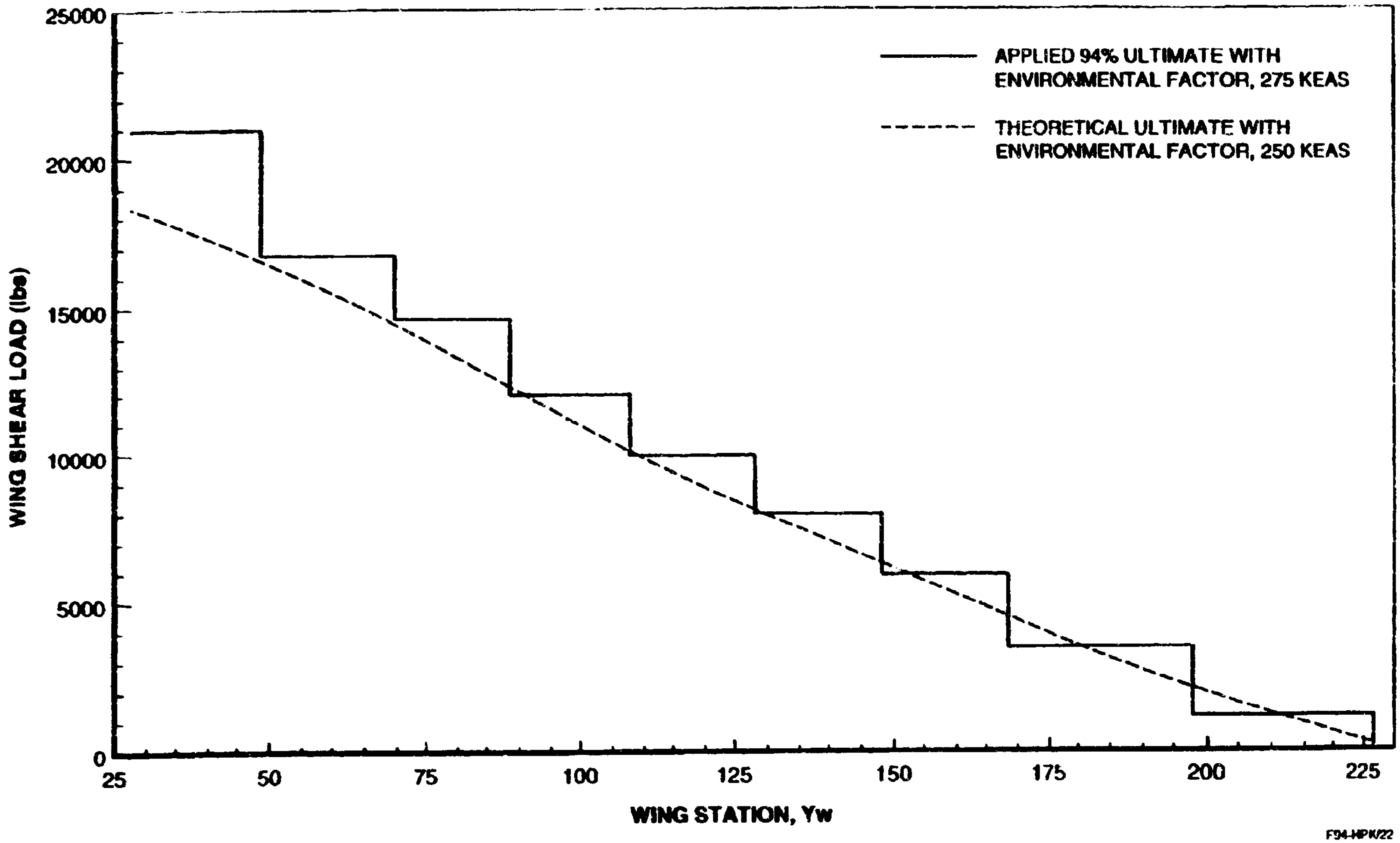


FIGURE 17. COMPARISON OF THEORETICAL AND APPLIED WING SHEAR LOAD, SYMMETRIC UP BENDING CASE.

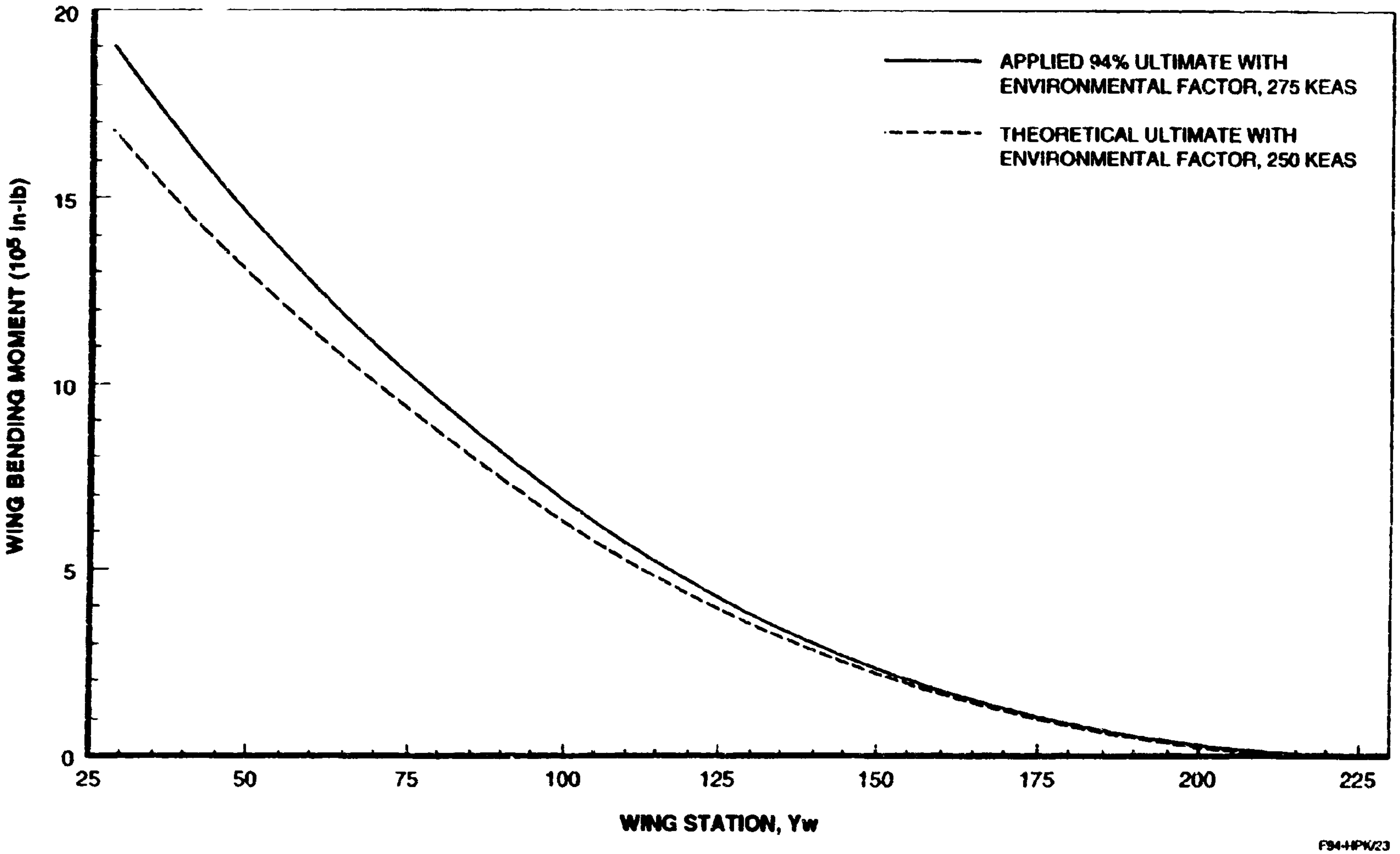
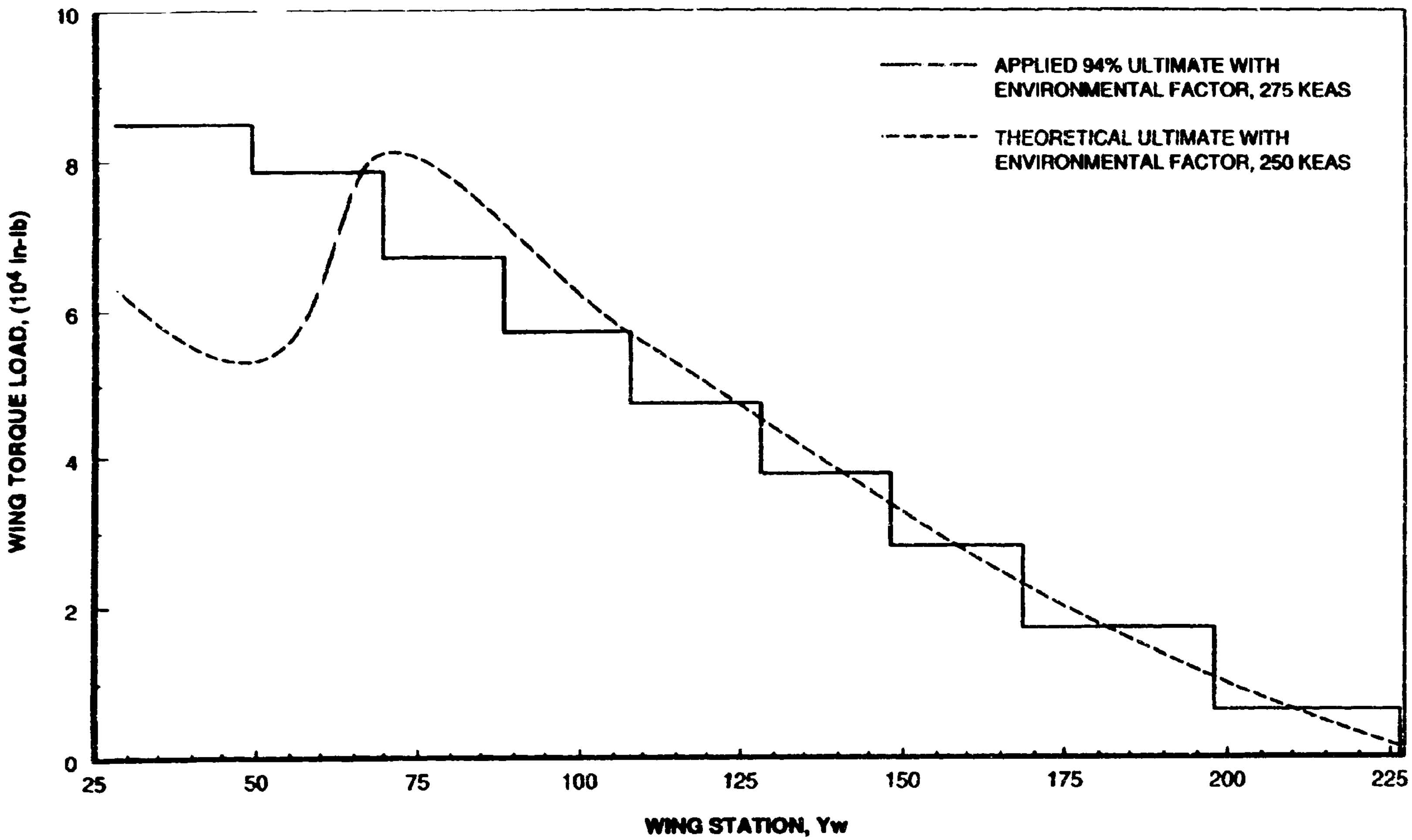


FIGURE 18. COMPARISON OF THEORETICAL AND APPLIED WING BENDING MOMENT, SYMMETRIC UP BENDING CASE.



F94-HPK/24

FIGURE 19. COMPARISON OF THEORETICAL AND APPLIED WING TORQUE LOAD, SYMMETRIC UP BENDING CASE.

The shear loads of the symmetric up bending case were derived from the "Maximum Positive Shear, Symmetric Flight Loads" data and the moment and torsion loads were derived from the "Maximum Positive Moment, Symmetric Flight Loads" data. The torque at wing station 28 was an exception because it would have required the introduction of a relieving torque at wing station 49. The torque load at wing station 28 was arbitrarily set to be equal to that at wing station 49. The maximum torque envelope was not combined with the maximum moment envelope as this would produce unrealistic relieving loads on the rear spar.

The limit load condition was achieved without accident during the symmetric up bending test. Buckling was observed between wing stations Yw 28 at 84 percent of the ultimate test load for the 275 KEAS flight envelope. The test was halted and the test article was modified with addition of external chordwise stiffeners to the upper wing skin. After the modification, the wing was retested. During loading to ultimate load, skin buckles were observed outboard of Yw 49 and loading was discontinued at 94 percent of the 275 KEAS flight envelope ultimate load. The test applied loads shown in figures 16 through 19 are actually the 94 percent of the 275 KEAS ultimate loads.

All major structural changes to Type Design generated during the wing static test program were incorporated in the E003 and E009 flight test articles with the exception of the upper skin external sitffeners, which were not retrofitted to E003. However, the E002 wing was successfully tested to 84 percent of the 275 KEAS flight loads without the additional upper skin stiffeners. In addition, the E009 wing which was mounted on the E003 flight test aircraft, was proof tested to 120 percent of the 275 KEAS limit load. A restricted flight envelope for both E003 and E009 based on the test results was therefore proposed by Lear Fan and approved by the FAA.

4.3 UPPER WING SKIN STRAIN

The maximum compressive ultimate strain of the upper wing skin observed during the wing static test program will be used for the damage tolerance evaluations. As expected, the symmetric up bending case produced the maximum compressive strain over the majority of the upper wing skin area. The significant wing static test results are summarized in figure 20 and the maximum compressive strains are shown in figure 21. The strain distributions along the spars on the upper wing skin were then estimated based on the worst case compression strains from figure 21. These distributions are shown in figure 22 and the strain contours are shown in figure 23. These strains will be used in the damage tolerance evaluation discussed in section 5.

TEST CONDITION	MAX. STRAIN		MAX. DEFLECTION	
	μ	LOCATION	in.	LOCATION
SYMMETRIC DOWN BENDING				
LIMIT	1090	UPPER WING SKIN Yw 38.5 CS	6.70	Yw ± 226
ULTIMATE	1630		9.96	
MAX. NEGATIVE TORQUE				
LIMIT	1150	FS MID-HEIGHT Yw 38.5	2.77	Yw ± 226 FS
ULTIMATE	1810		3.95	
ASYMMETRIC UP BENDING (a)				
LIMIT	-1520	UPPER WING SKIN Yw 38.5 CS	10.37	Yw 226 RT. WING
ULTIMATE	-2570	UPPER WING SKIN Yw 118 CS	16.60	
MAX. POSITIVE TORQUE				
LIMIT	-1540	RIGHT WING CS Yw 38.5	8.48	Yw ± 226
ULTIMATE	-2420		13.44	
SYMMETRIC UP BENDING (b)				
LIMIT	-2260	UPPER WING SKIN Yw 38.5 CS	13.29	Yw ± 226
ULTIMATE	-3390		19.28	

CS CENTER SPAR
FS FORWARD SPAR

(a) AT 98% ULTIMATE: SKIN DEFORMATION ON RIGHT WING UPPER SKIN BETWEEN Yw 110 AND 126 ALONG REAR SPAR.
AT ULTIMATE: SKIN DEFORMATION NEAR REAR SPAR AT Yw 49.
PAST TEST INSPECTION FOUND DISBONDS, REPAIRED WITH FASTENERS INSTALLED, TEST CONTINUED.

(b) SKIN BUCKLED BETWEEN Yw ± 28 AT 84% ULTIMATE.
EXTERNAL CHORDWISE STIFFENERS ADDED FOR TYPE DESIGN, TEST CONTINUED WITH ADDED STIFFENERS AND SKIN BUCKLED OUTBOARD OF Yw 49 AT 94% ULTIMATE.

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FIGURE 20. SUMMARY OF STATIC WING TEST RESULTS.

LOCATION		STRAIN (μ)	TEST CONDITION
Yw	Xes		
34.7	12	-2920	SYMMETRIC UP BENDING, 94% ULT.
34.7	12	-3660	SYMMETRIC UP BENDING, 94% ULT.
38.5	CS	-3390	SYMMETRIC UP BENDING, 94% ULT.
38.5	FS	-2070	SYMMETRIC UP BENDING, 94% ULT.
38.5	RS	-1190	SYMMETRIC UP BENDING, 94% ULT.
38.5	-7.9	-2440	SYMMETRIC UP BENDING, 94% ULT.
38.5	-7.9	-2670	SYMMETRIC UP BENDING, 94% ULT.
118	CS	92950	SYMMETRIC UP BENDING, 94% ULT.
118	FS	-1890	SYMMETRIC UP BENDING, 94% ULT.
118	RS	-1890	SYMMETRIC UP BENDING, 94% ULT.
118	-6.2	-690	ASYMMETRIC UP BENDING, 100% ULT.
118	-6.2	-1750	SYMMETRIC UP BENDING, 94% ULT.
118.2	8.5	-2100	ASYMMETRIC UP BENDING, 100% ULT.
118.2	8.5	-970	ASYMMETRIC UP BENDING, 100% ULT.
183	CS	-1290	SYMMETRIC UP BENDING, 94% ULT.
183	FS	-730	SYMMETRIC UP BENDING, 94% ULT.
183	RS	-660	SYMMETRIC UP BENDING. 94% ULT.
183.2	-5.0	-420	ASYMMETRIC UP BENDING, 100% ULT.
183.2	-5.0	-860	SYMMETRIC UP BENDING, 94% ULT.
183.2	5.1	-570	ASYMMETRIC UP BENDING, 100% ULT.
183.2	5.1	-970	ASYMMETRIC UP BENDING, 100% ULT.
-158	CS	-1330	SYMMETRIC UP BENDING, 94% ULT.
-158	RS	-1080	SYMMETRIC UP BENDING, 94% ULT.
-158	FS	-1236	SYMMETRIC UP BENDING, 94% ULT.

F94-HPK/26

FIGURE 21. WORST CASE ULTIMATE STRAIN OF THE UPPER WING SKIN.

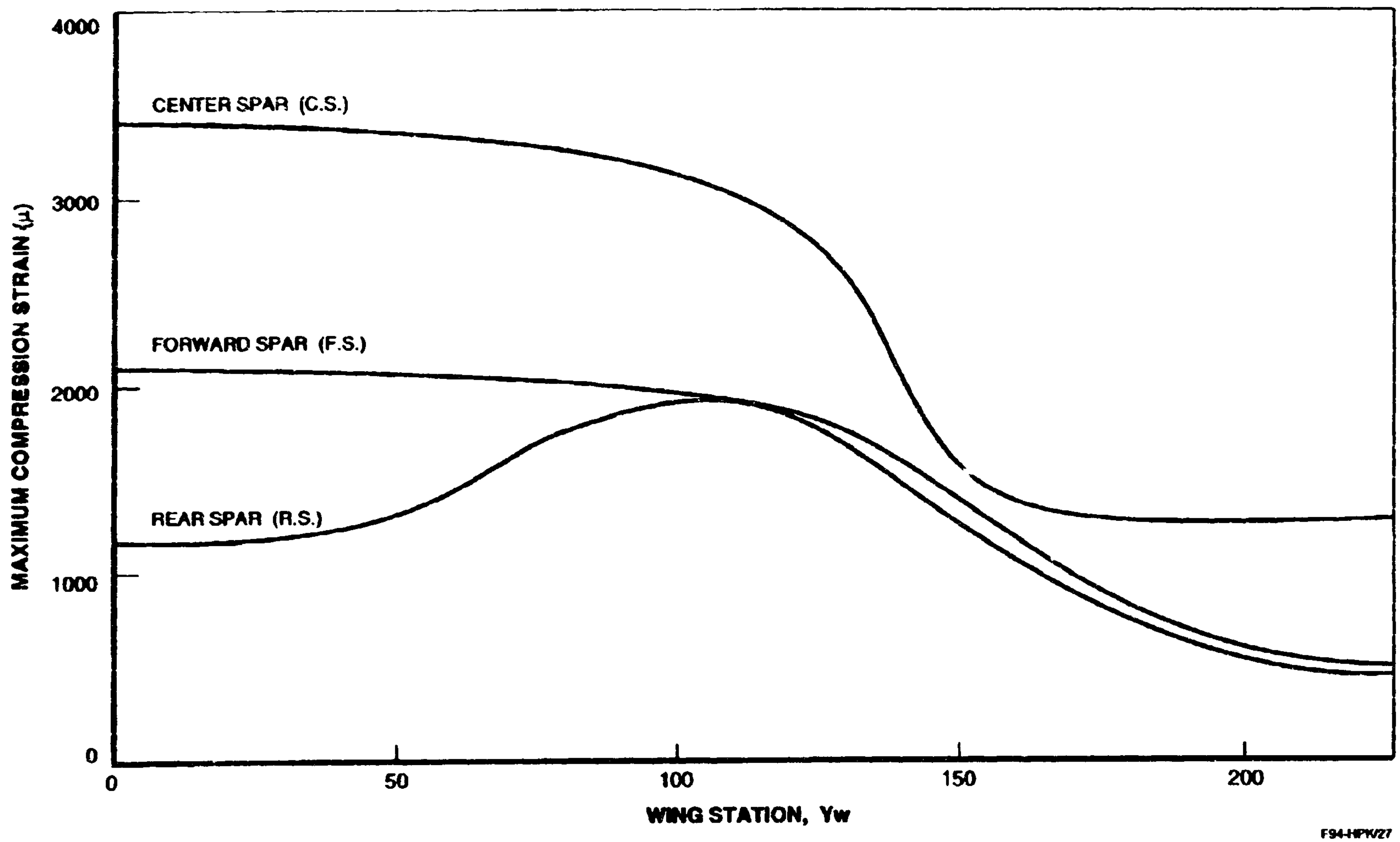

FIGURE 22. ESTIMATED WORST CASE UPPER SKIN STRAINS ALONG THE SPARS.

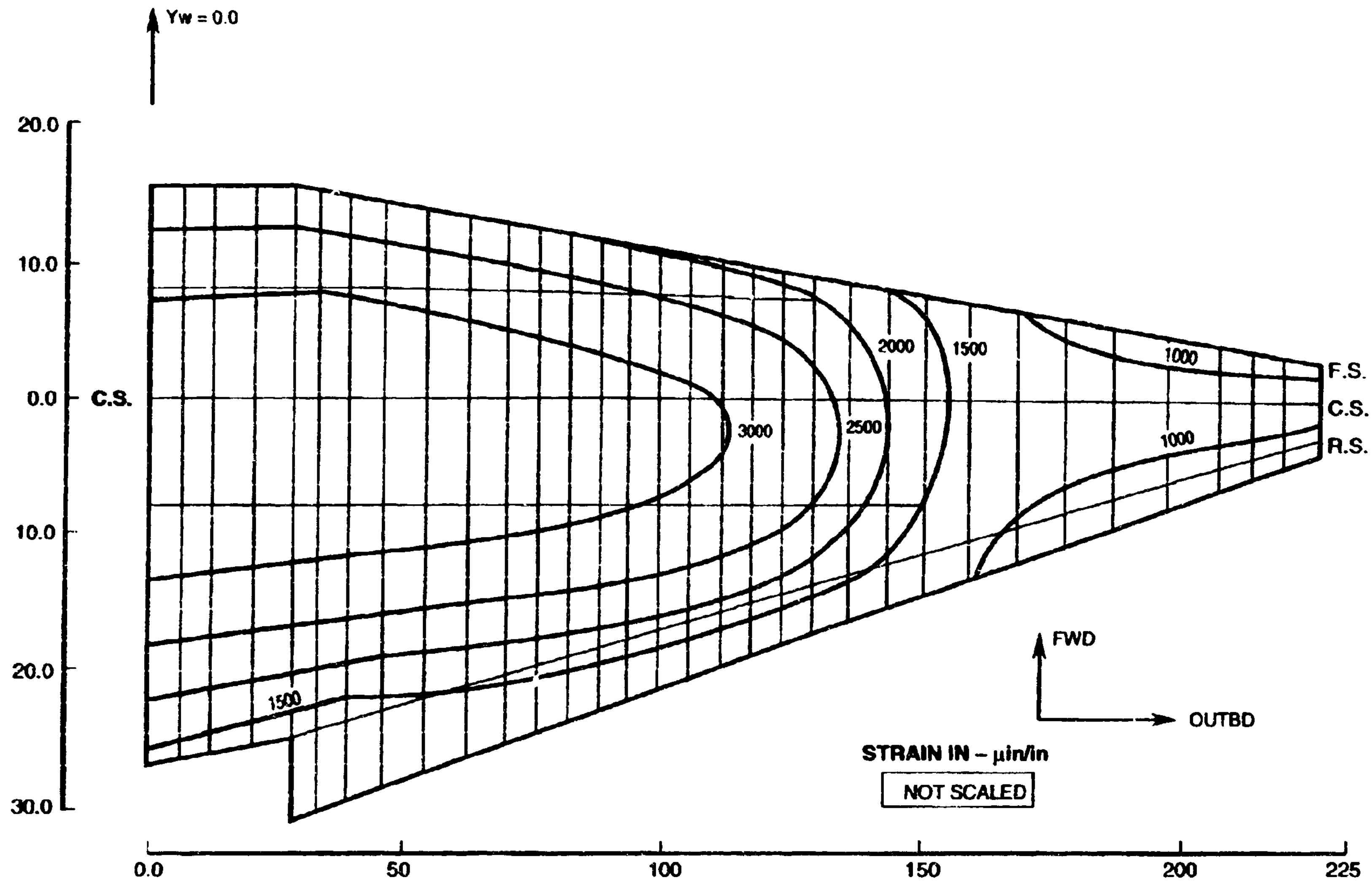

FIGURE 23. ESTIMATED WORST CASE STRAIN CONTOURS OF THE UPPER WING SKIN.

SECTION 5

DAMAGE TOLERANCE EVALUATION

The damage tolerance capability of the upper wing skin of the Lear Fan 2100 aircraft was evaluated and the results are presented in this section. The composite wing skin was evaluated for its impact damage tolerance capability and its ability to withstand assembly induced damage. The impact damage tolerance methodology developed in reference 6 was used to estimate the structural reliability for impact damage and the method developed in reference 8 was used for assembly induced damage. The upper wing skin was first divided into small regions, based on the substructural arrangement, suitable for damage tolerance evaluation. Structural reliability was then assessed for each subdivision based on the damage threat. The structural sudivisions and a brief summary of the analysis methods and the analytical results are discussed in the following paragraphs.

5.1 STRUCTURAL SUBDIVISION

The upper wing was divided into small subdivisions for damage tolerance evaluations. One half of the continueous wing structure, from Yw=0.0 to Yw=226.0, was considered in this evaluation. The flight control surfaces were not included. The subdivision was based on the arrangement of the substructures and the thickness distribution of the skin. Near the wing tip only the front, center, and rear spars were used for subdivision, this was because the tip area is relatively narrower. Inboard of Yw=140, in addition to the spars, the ply drop-off lines were also used to subdivide the skin. The subdivisions of the upper wing skin are shown in figure 24. A total of 139 regions resulted from the subdivision process, as shown in the figure.

After the wing skin was divided into small regions, the thickness and the mechanical properties in each region were nearly uniform. For the purposes of impact damage tolerance evaluations, additional data were required: the width of the skin bay, the stiffness of the adjacent stiffeners, and the width of the adjacent bays. In order to compute the reliability of the damaged structure, the ultimate strain of the region was also needed. These data are summarized in table 1. Two strain values are given in the table. The first value is the average strain computed for the four corners of the region and the second value is the maximum of the corner strains.

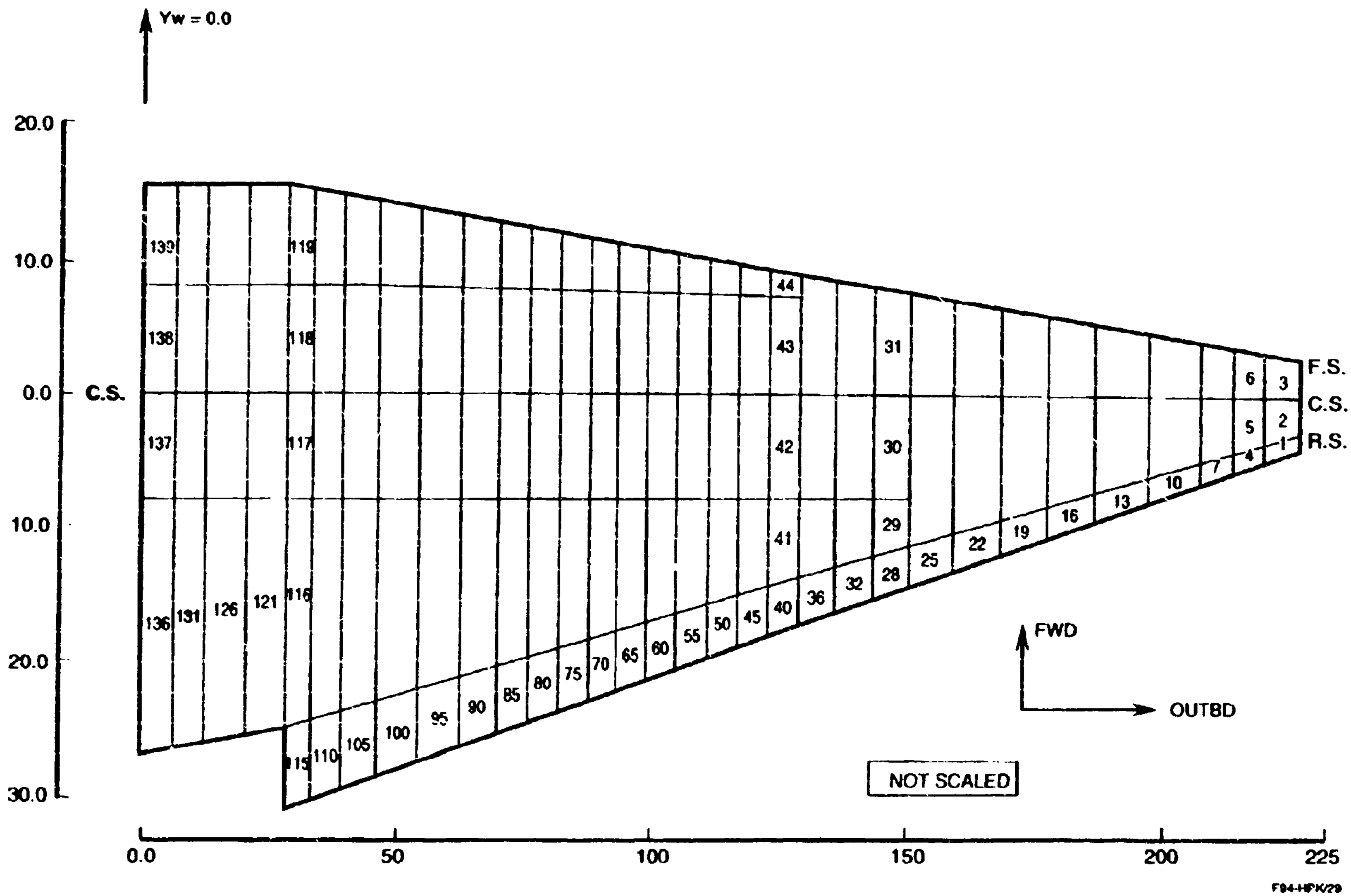

FIGURE 24. SUBDIVISION OF THE UPPER WING SKIN FOR DAMAGE TOLERANCE EVALUATION.

TABLE 1. SUBDIVISIONS FOR DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN STRAINS.

REG.	Y_w	t	LAYUP	W	AE	b_1	b_2	STRAIN
1	223.0	0.053	00/79/21	4.000	2.36	0.500	10.500	428/ 436
2	223.0	0.053	00/79/21	7.000	2.36	4.000	1.500	845/1263
3	223.0	0.053	00/79/21	7.500	3.27	3.500	1.500	879/1263
4	217.0	0.053	00/79/21	4.000	2.36	0.500	11.295	443/ 450
5	217.0	0.053	00/79/21	7.550	2.36	4.000	1.500	854/1267
6	217.0	0.053	00/79/21	7.745	3.27	3.805	1.500	888/1267
7	211.0	0.053	00/79/21	4.300	2.36	0.500	11.790	460/ 469
8	211.0	0.053	00/79/21	8.100	2.36	4.300	1.500	864/1271
9	211.0	0.053	00/79/21	7.990	3.27	4.410	1.500	897/1271
10	203.5	0.053	00/79/21	4.300	2.36	0.500	12.850	491/ 513
11	203.5	0.053	00/79/21	8.834	2.36	4.300	1.500	883/1278
12	203.5	0.053	00/79/21	8.316	3.27	4.818	1.500	916/1278
13	190.0	0.053	00/79/21	4.700	2.36	0.500	14.173	559/ 605
14	190.0	0.067	00/84/16	10.026	2.36	4.700	1.500	921/1286
15	190.0	0.125	35/56/09	8.847	3.27	5.879	1.500	956/1286
16	183.0	0.053	00/79/21	4.700	2.36	0.500	15.100	675/ 745
17	183.0	0.067	00/84/16	10.667	2.36	4.700	1.500	983/1297
18	183.0	0.053	00/79/21	9.133	3.27	6.234	1.500	1021/1297
19	173.0	0.053	00/79/21	4.800	2.36	0.500	16.325	830/ 914
20	173.0	0.067	00/84/16	11.584	2.36	4.800	1.500	1067/1312
21	173.0	0.053	00/79/21	9.541	3.27	6.843	1.500	1118/1312
22	163.0	0.053	00/79/21	5.000	2.36	0.500	17.450	997/1080
23	163.0	0.067	00/84/16	12.501	2.36	5.000	1.500	1159/1330
24	163.0	0.053	00/79/21	9.949	3.27	7.552	1.500	1229/1330
25	153.5	0.053	00/79/21	5.100	2.36	0.500	18.609	1164/1247
26	153.5	0.067	00/84/16	13.372	2.36	5.100	1.500	1390/1719
27	153.5	0.053	00/79/21	10.337	3.27	8.135	1.500	1426/1719
28	146.0	0.053	00/79/21	5.100	2.36	0.500	19.603	1317/1386
29	146.0	0.067	00/84/16	6.260	2.36	5.100	12.183	1508/1826
30	146.0	0.081	00/86/14	7.800	2.36	3.560	10.643	1775/1979
31	146.0	0.067	00/84/16	10.643	3.27	8.517	1.500	1659/1979

TABLE 1. SUBDIVISIONS FOR DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN STRAINS. (CONTINUED)

REG.	Y_w	t	LAYUP	W	AE	b_1	b_2	STRAIN
32	139.5	0.053	00/79/21	5.200	2.36	0.500	20.364	1468/1549
33	139.5	0 .067	00/84/16	6.856	2.36	5.200	11.852	1729/2155
34	139.5	0.081	00/86/14	7.800	2.65	4.256	10.908	2069/2314
35	139.5	0.067	00/84/16	10.908	3.27	8.948	1.500	1867/2314
36	132.5	0.053	00/79/21	5.200	2.36	0.500	21.291	1630/1710
37	132.5	0.067	00/84/16	7.497	2.36	5.200	11.497	1977/2494
38	132.5	0.081	00/86/14	7.800	2.84	4.897	11.194	2404/2651
39	132.5	0.067	00/84/16	11.194	3.27	9.303	1.500	2105/2651
40	126.0	0.053	00/79/21	5.400	2.36	0.500	21.952	1769/1827
41	126.0	0.067	00/84/16	8.093	2.36	5.400	11.166	2181/2692
42	126.0	0.081	00/86/14	7.800	3.13	5.693	11.459	2666/2828
43	126.0	0.081	00/86/14	8.200	3.13	13.093	3.259	2474/2828
44	126.0	0.067	00/84/16	3.259	3.27	26.234	1.500	2005/2274
45	120.0	0.053	00/79/21	5.500	2.36	0.500	22.647	1858/1888
46	120.0	0.067	00/84/16	8.643	2.36	5.500	10.861	2310/2834
47	120.0	0.081	00/86/14	7.800	3.41	6.343	11.704	2828/2958
48	120.0	0.081	00/86/14	8.200	3.41	13.743	3.504	2610/2958
49	120.0	0.067	00/84/16	3.504	3.27	26.639	1.500	2097/2381
50	114.0	0.053	00/79/21	5.500	2.36	0.500	23.443	1881/1888
51	114.0	0.067	00/84/16	9.194	2.36	5.500	10.555	2371/2889
52	114.0	0.081	00/86/14	7.800	3.60	6.894	11.949	2923/3009
53	114.0	0.081	00/86/14	8.200	3.60	14.294	3.749	2696/3009
54	114.0	0.067	00/84/16	3.749	3.27	26.945	1.500	2157/2436
55	108.0	0.053	00/79/21	5.600	2.36	0.500	24.138	1865/1873
56	108.0	0.067	00/84/16	9.744	2.36	5.600	10.250	2390/2941
57	108.0	0.081	00/86/14	7.800	3.79	7.544	12.194	2974/3056
58	108.0	0.081	00/86/14	8.200	3.79	27.350	1.500	2194/2488
60	102.0	0.125	35/56/09	5.900	2.36	0.500	24.633	1849/1857
61	102.0	0.067	00/84/16	10.294	2.36	5.900	9.945	2407/2991
62	102.0	0.081	00/86/14	7.800	4.08	8.394	12.439	3022/3101
63	102.0	0.081	00/86/14	8.200	4.08	15.794	4.239	2796/3101
64	102.0	0.067	00/84/16	4.239	3.27	27.955	1.500	2230/2539

TABLE 1. SUBDIVISIONS FOR DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN STRAINS. (CONTINUED)

REG.	Y_w	t	LAYUP	W	AE	b_1	b_2	STRAIN
65	96.0	0.125	35/56/09	6.000	2.36	0.500	25.328	1830/1840
66	96.0	0 .067	00/84/16	10.844	2.36	6.000	9.640	2423/3039
67	96.0	0.081	00/86/14	7.800	4.27	9.044	12.684	3069/3144
68	96.0	0.081	00/86/14	8.200	4.27	16.444	4.484	2843/3144
69	96.0	0.067	00/84/16	4.484	3.27	28.360	1.500	2264/2587
70	90.0	0.125	35/56/09	6.000	2.36	0.500	26.123	1806/1820
71	90.0	0.067	00/84/16	11.394	2.36	6.000	9.335	2434/3084
72	90.0	0.081	00/86/14	7.800	4.50	9.594	12.929	3113/3186
73	90.0	0.081	00/86/14	8.200	4.50	16.994	4.729	2888/3186
74	90.0	0.067	00/84/16	4.729	3.27	28.665	1.500	2297/2635
75	84.0	0.125	35/56/09	6.000	2.36	0.500	26.917	1744/1792
76	84.0	0.067	00/84/16	11.944	2.36	6.000	9.029	2439/3125
77	84.0	0.081	00/86/14	7.800	5.70	10.144	13.173	3155/3225
78	84.0	0.081	00/86/14	8.200	5.70	17.544	4.973	2932/3225
79	84.0	0.067	00/84/16	4.973	3.27	28.971	1.500	2328/2680
80	78.0	0.125	35/56/09	6.200	2.36	0.500	27.512	1731/1756
81	78.0	0.067	00/84/16	12.494	2.36	6.200	8.724	2437/3160
82	78.0	0.081	00/86/14	7.800	6.38	10.894	13.418	3193/3261
83	78.0	0.081	00/86/14	8.200	6.38	18.294	5.218	2973/3261
84	78.0	0.067	00/84/16	5.218	3.27	29.476	1.500	2357/2724
85	72.0	0.125	35/56/09	6.200	2.36	0.500	28.307	1676/1705
86	72.0	0.067	00/84/16	13.044	2.36	6.200	8.419	2425/3190
87	72.0	0.081	00/86/14	7.800	7.15	11.444	13.663	3226/3294
88	72.0	0.081	00/86/14	8.200	7.15	18.844	5.463	3011/3294
89	72.0	0.067	00/84/16	5.463	3.27	29.781	1.500	2385/2765
90	66.0	0.125	35/56/09	6.300	3.30	0.500	29.002	1604/1646
91	66.0	0.067	00/84/16	13.594	3.30	6.300	8.114	2402/3210
92	66.0	0.109	00/90/10	7.800	8.91	12.094	13.908	3254/3321
93	66.0	0.109	00/90/10	8.200	8.91	19.494	5.708	3064/3321
94	66.0	0 .081	00/86/14	5.708	3.27	30.186	1.500	2410/2804
95	58.0	0.053	00/79/21	5.500	3.30	0.500	30.863	1499/1562
96	58.0	0.067	00/84/16	14.328	3.30	5.500	7.707	2360/3231
97	58.0	0.109	00/90/10	7.800	10.67	12.028	14.235	3279/3353
98	58.0	0.109	00/90/10	8.200	10.67	19.428	6.035	3083/3353
99	58.0	0.081	00/86/14	6.035	3.27	29.793	1.500	2438/2852

TABLE 1. SUBDIVISIONS FOR DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN STRAINS. (CONTINUED)

REG.	Y_w	t	LAYUP	W	AE	b_1	b_2	STRAIN
100	50.0	0.053	00/79/21	5.800	3.30	0.500	31.622	1353/1435
101	50.0	0 .067	00/84/16	15.061	3.30	5.800	7.300	2296/3245
102	50.0	0.109	00/90/10	7.800	11.55	13.061	14.561	3302/3380
103	50.0	0.109	00/90/10	8.200	11.55	20.461	6.361	3122/3380
104	50.0	0.081	00/86/14	6.361	3.27	30.500	1.500	2468/2903
105	42.0	0.053	00/79/21	5.800	3.30	0.500	32.683	1231/1271
106	42.0	0.067	00/84/16	15.795	3.30	5.800	6.893	2240/3252
107	42.0	0.109	00/90/10	7.800	13.07	13.795	14.888	3317/3390
108	42.0	0.109	00/90/10	8.200	13.07	21.195	6.688	3150/3390
109	42.0	0.081	00/86/14	6.688	3.27	30.907	1.500	2491/2928
110	36.0	0.125	35/56/09	6.100	3.30	0.500	33.178	1188/1191
111	36.0	0.067	00/84/16	16.345	3.30	6.100	6.588	2223/3264
112	36.0	0.109	00/90/10	7.800	14.40	14.645	15.133	3325/3392
113	36.0	0.109	00/90/10	8.200	14.40	22.045	6.933	3163/3392
114	36.0	0.081	00/86/14	6.933	3.27	31.512	1.500	2504/2942
115	30.0	0.125	35/56/09	6.200	3.30	0.500	33.873	1181/1184
116	30.0	0.067	00/84/16	16.895	3.30	6.200	6.283	2226/3276
117	30.0	0.109	00/90/10	7.800	15.28	15.295	15.378	3332/3394
118	30.0	0.109	00/90/10	8.200	15.28	22.695	7.178	3171/3394
119	30.0	0.081	00/86/14	7.178	3.27	31.917	1.500	2513/2955
120	24.0	—	—	—	—	—	—	—
121	24.0	0.067	00/84/16	17.401	3.30	2.000	5.899	2230/3294
122	24.0	0.109	00/90/10	7.800	15.28	9.601	15.500	3340/3396
123	24.0	0.109	00/90/10	8.200	15.28	17.001	7.300	3175/3396
124	24.0	0.081	00/86/14	7.300	3.27	26.101	1.500	2518/2955
125	16.0	—	—	—	—	—	—	—
126	16.0	0.067	00/84/16	18.017	3.30	2.000	5.283	2235/3314
127	16.0	0.109	00/90/10	7.800	15.28	10.217	15.500	3351/3398
128	16.0	0.109	00/90/10	8.200	15.28	17.617	7.300	3175/3398
129	16.0	0.081	00/86/14	7.300	3.27	26.717	1.500	2520/2953

TABLE 1. SUBDIVISIONS FOR DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN STRAINS. (CONCLUDED)

REG.	Y_w	t	LAYUP	W	AE	b_1	b_2	STRAIN
130	8.0	—	—	—	—	—	—	—
131	8.0	0.067	00/84/16	18.634	3.30	2.000	4.666	2241/3332
132	8.0	0.109	00/90/10	7.800	15.28	10.834	15.500	3361/3399
133	8.0	0.109	00/90/10	8.200	15.28	18.234	7.300	3174/3399
134	8.0	0.081	00/86/14	7.300	3.27	27.334	1.500	2522/2951
135	2.0	—	—	—	—	—	—	—
136	2.0	0.067	00/84/16	19.096	3.30	2.000	4.204	2244/3341
137	2.0	0.109	00/90/10	7.800	15.28	11.296	15.500	3368/3400
138	2.0	0.109	00/90/10	8.200	15.28	18.696	7.300	3174/3400
139	2.0	0.081	00/86/14	7.300	3.27	27.796	1.500	2523/2948

Note Two values of strains are given for each region as (1)/(2), where (1) is the average value From estimated strain at the corners of the given region, and (2) is the maximum of the corner strains of the given region.

All strains are compression.

Total width of the structure W(total) = $2.0*W+b_1+b_2$. For regions along edges of the structure, the edge bay width ranges from 0.5 to 2.0 in.

5.2 IMPACT DAMAGE TOLERANCE EVALUATION

The integrated reliability analysis method developed in reference 6 was used for impact damage tolerance evaluation of the upper wing skin. In this method, the reliability of a composite structure, under a given impact threat, is evaluated at various applied stress (strain) levels. The method integrates the postimpact strength anlaysis technique, the postimpact strength data scatter and the impact threat distribution into a single reliability computation. The analysis procedure is schematically shown in figure 25. Figure 25a shows the relationship between the postimpact strength and the impact energy. Also shown in figure 25a are the postimpact strength data scatter at different impact energy levels. The stiffness reduction model developed in reference 10 was used to establish the relationship between the postimpact strength and the impact energy. The strength scatter is described by a Weibull distribution and the numerical values of the Weibull parameters are established in reference 6. In figure 25b, the impact threat distribution is shown as a Weibull distribution. Three levels of impact threat were used in the evaluation. These are the high, medium, and low threats as defined in reference 6 and shown in figure 26. In addition, the discrete 100 ft-lb impact was also used in the evaluation. The postimpact strength and the impact threat are combined to form a compounded distribution to determine the reliability of the damaged structure at a given stress (strain), as shown in figure 25c. Computer programs 'PISTRE1' and 'PISTRE2' developed, based on this method, in reference 6 were used for numerical analysis.

The results of the impact damage tolerance evaluation are summarized in tables 2 through 10 and the reliabilities of the local areas on the upper wing skin are given in figures 27 through 35. Each subdivision of the upper wing skin, figure 24, was evaluated against four impact threats. The impact threats are the low, medium and high impact distributions as shown in figure 26 and a discrete 100 ft-lb impact at the center of the subdivision. The low impact threat is characterized by a modal impact energy level of 4 ft-lb and a 0.0001 probability of a 100 ft-lb impact. The medium threat has a modal impact energy of 6 ft-lb and 0.01 probability of 100 ft-lb impact. The modal impact energy for the high impact threat is 15 ft-lb and the probability of 100 ft-lb impact is 0.1. As pointed out in reference 6, these impact threats are very severe for a military aircraft. Even though there are no in-service records for the Lear Fan 2100 type of aircraft, these threats are considered to be more severe than those that the aircraft will encounter.

Both the average ultimate strains and the maximum strains as shown in table 1 were used in the impact damage tolerance evaluations. Tables 2 through 5 show the results obtained using the average strain in each subdivision. In these tables, the B-basis allowable for each

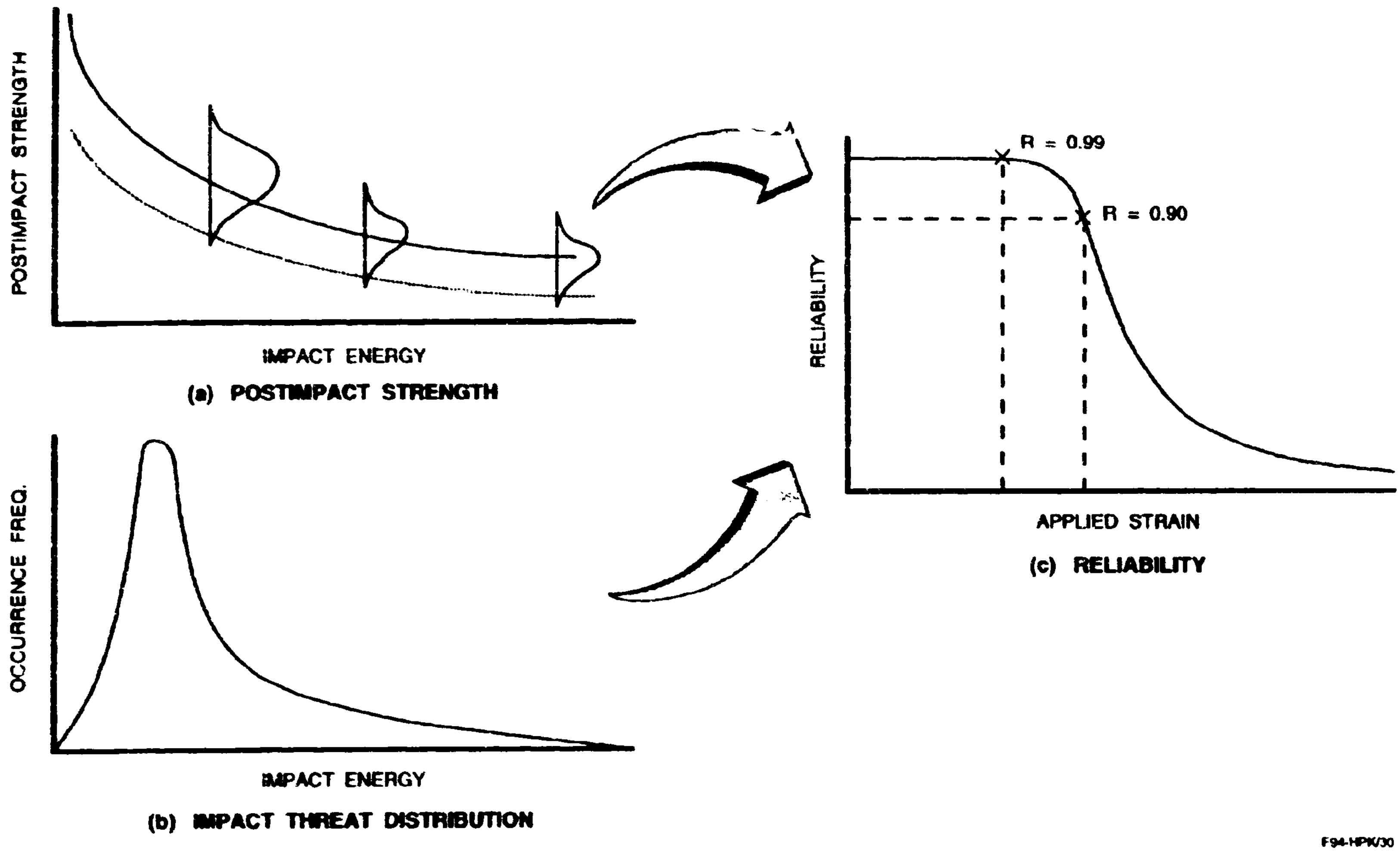

FIGURE 25. SCHEMATIC OF THE INTEGRATED RELIABILITY ANALYSIS METHOD.

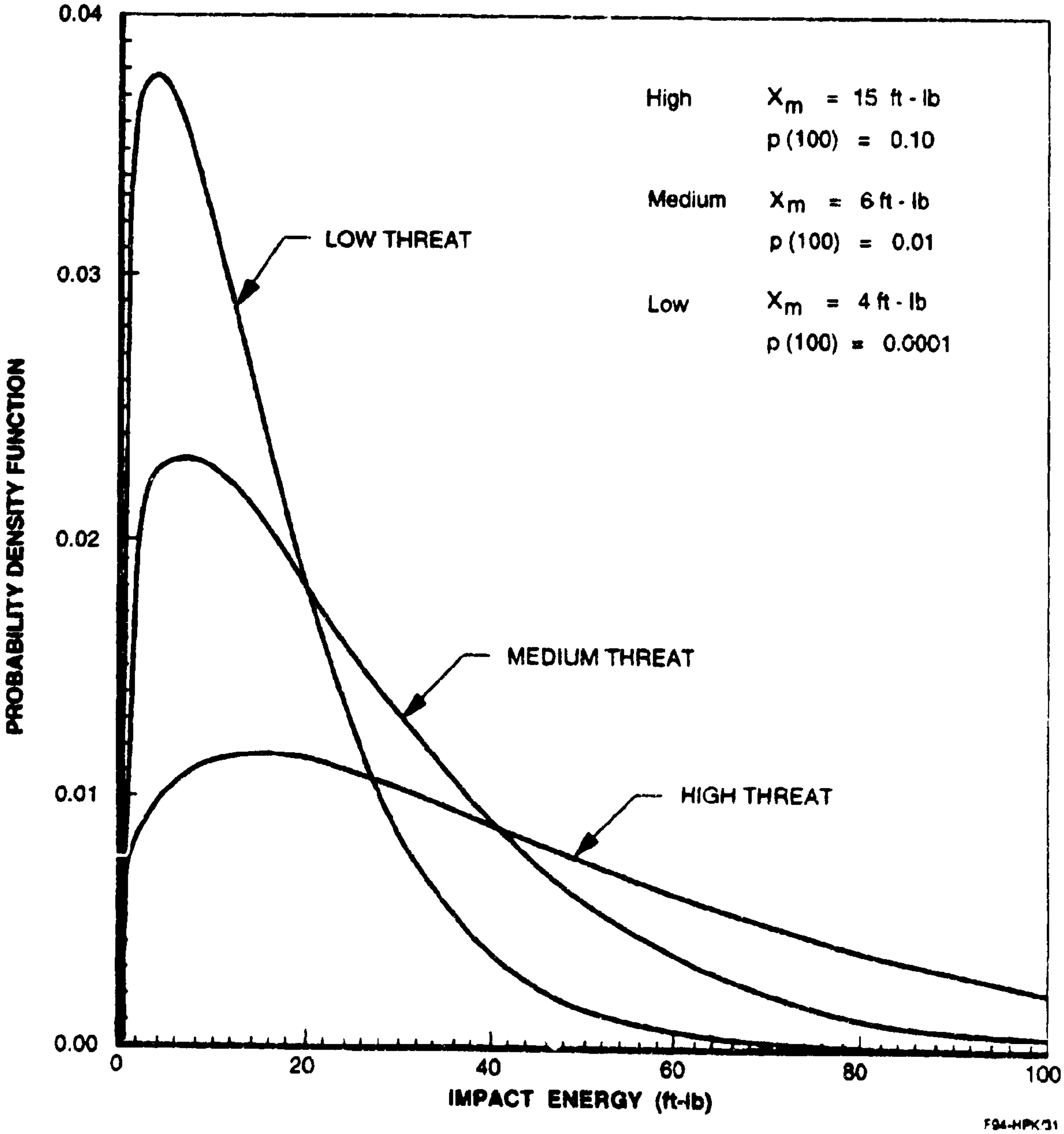

FIGURE 26. PROBABILITY DISTRIBUTION OF IMPACT THREATS.

TABLE 2. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION.

MODAL IMPACT ENERGY = 4 ft-lb
PROBABILITY FOR 100 ft-lb IMPACT = 0.0001

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
1	2570	5.00	1.00000	1.00000	1.00000	1.00000
2	2763	2.27	1.00000	1.00000	1.00000	1.00000
3	2738	2.11	1.00000	1.00000	1.00000	1.00000
4	2570	4.80	1.00000	1.00000	1.00000	1.00000
5	2732	2.20	1.00000	1.00000	1.00000	1.00000
6	2727	2.07	1.00000	1.00000	1.00000	1.00000
7	2580	4.61	1.00000	1.00000	1.00000	1.00000
8	2711	2.14	1.00000	1.00000	1.00000	1.00000
9	2719	2.03	1.00000	1.00000	1.00000	1.00000
10	2580	4.25	1.00000	1.00000	1.00000	1.00000
11	2692	2.05	1.00000	1.00000	1.00000	1.00000
12	2709	1.96	1.00000	1.00000	1.00000	1.00000
13	2594	3.64	1.00000	1.00000	1.00000	1.00000
14	2926	2.18	1.00000	1.00000	1.00000	1.00000
15	2658	1.78	1.00000	1.00000	0.99999	1.00000
16	2594	2.84	1.00000	1.00000	1.00000	1.00000
17	2926	1.98	1.00000	1.00000	1.00000	1.00000
18	2693	1.64	1.00000	1.00000	0.99999	1.00000
19	2598	2.13	1.00000	1.00000	1.00000	1.00000
20	2927	1.74	1.00000	1.00000	1.00000	1.00000
21	2689	1.41	1.00000	1.00000	0.99999	0.99999
22	2604	1.61	1.00000	1.00000	0.99999	1.00000
23	2927	1.53	1.00000	1.00000	0.99999	0.99999
24	2687	1.19	1.00000	1.00000	0.99999	0.99999
25	2606	1.24	1.00000	1.00000	0.99997	0.99998
26	2928	1.11	1.00000	1.00000	0.99996	0.99997
27	2686	0.88	1.00000	1.00000	0.99983	0.99992

TABLE 2. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	FF	@DUL IF	FF
28	2606	0.98	1.00000	1.00000	0.99990	0.99994
29	2964	0.97	1.00000	1.00000	0.99990	0.99997
30	3130	0.76	0.99999	1.00000	0.99971	0.99980
31	2932	0.77	0.99999	1.00000	0.99968	0.99977
32	2609	0.78	0.99999	1.00000	0.99966	0.99980
33	2940	0.70	0.99999	1.00000	0.99947	0.99980
34	3130	0.51	0.99998	0.99999	0.99823	0.99872
35	2932	0.57	0.99999	0.99999	0.99876	0.99903
36	2609	0.60	0.99999	0.99999	0.99885	0.99928
37	2928	0.48	0.99998	0.99999	0.99754	0.99880
38	3131	0.30	0.99991	0.99994	0.99075	0.99231
39	2932	0.39	0.99996	0.99997	0.99526	0.99591
40	2614	0.48	0.99997	0.99998	0.99718	0.99802
41	2926	0.34	0.99993	0.99996	0.99276	0.99540
42	3131	0.17	0.99970	0.99980	0.97358	0.97492
43	3132	0.27	0.99987	0.99991	0.98744	0.98865
44	3547	0.77	0.99997	1.00000	0.99726	0.99995
45	2616	0.41	0.99995	0.99997	0.99519	0.99637
46	2926	0.27	0.99986	0.99992	0.98691	0.99006
47	3131	0.11	0.99941	0.99959	0.95511	0.95553
48	3132	0.20	0.99977	0.99983	0.97866	0.97966
49	3449	0 64	0.99996	1.00000	0.99548	0.99987
50	2616	0.39	0.99995	0.99997	0.99458	0.99587
51	2926	0.23	0.99982	0.99989	0. 98293	0.98540
52	3131	0.07	0.99911	0.99938	0.94087	0.94095
53	3132	0.16	0.99967	0.99976	0.97104	0.97169
54	3366	0.56	0.99994	1.00000	0.99370	0.99971
55	2618	0.40	0.99995	0.99997	0.99505	0.99616
56	2927	0.22	0.99981	0.99987	0.98171	0.98352
57	3131	0.05	0.99894	0.99925	0.93209	0.93211
58	3132	0.14	0.99958	0.99968	0.96532	0.96575
59	3297	0.50	0.99993	0.99999	0.99258	0.99952

TABLE 2. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
60	2569	0.39	0.99994	0.99996	0.99438	0.99556
61	2927	0.22	0.99979	0.99986	0.98048	0.98168
62	3132	0.04	0.99872	0.99908	0.92315	0.92315
63	3132	0.12	0.99948	0.99961	0.95972	0.95996
64	3232	0.45	0.99991	0.99999	0.99105	0.99919
65	2571	0.40	0.99995	0.99997	0.99503	0.99609
66	2928	0.21	0.99977	0.99983	0.97908	0.97981
67	3132	0.02	0.99844	0.99888	0.91364	0.91364
68	3132	0.10	0.99939	0.99954	0.95315	0.95328
69	3180	0.40	0.99990	0.99999	0.98951	0.99872
70	2571	0.42	0.99996	0.99997	0.99579	0.99677
71	2928	0.20	0.99920	0.99975	0.97812	0.97855
72	3132	0.01	0.99819	0.99868	0.90435	0.90435
73	3132	0.08	0.99924	0.99943	0.94674	0.94679
74	3133	0.36	0.99988	0.99999	0.98803	0.99812
75	2571	0.47	0.99997	0.99998	0.99705	0.99780
76	2928	0.20	0.99975	0.99980	0.97769	0.97794
77	3132	-0.01	0.99792	0.99848	0.89461	0.89461
78	3133	0.07	0.99909	0.99931	0.93953	0.93954
79	3096	0.33	0.99985	0.99998	0.98609	0.99718
80	2574	0.49	0.99997	0.99998	0.99734	0.99796
81	2929	0.20	0.99975	0.99980	0.97790	0.97804
82	3132	-0.02	0.99756	0.99815	0.88580	0.88580
83	3133	0.05	0.99895	0.99920	0.93247	0.93247
84	3060	0.30	0.99983	0.99997	0.98423	0.99602
85	2574	0.54	0.99998	0.99999	0.99817	0.99864
86	2929	0.21	0.99977	0.99981	0.97898	0.97907
87	3132	-0.03	0.99725	0.99790	0.87741	0.87741
88	3133	0.04	0.99879	0.99907	0.92559	0.92559
89	3032	0.27	0.99982	0.99996	0.98243	0.99465

TABLE 2. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
90	2576	0.61	0.99999	0.99999	0.99893	0.99923
91	2929	0.22	0.99980	0.99983	0.98104	0.98110
92	3474	0.07	0.99920	0.99924	0.94058	0.94058
93	3475	0.13	0.99960	0.99962	0.96527	0.96527
94	3150	0.31	0.99991	0.99997	0.99053	0.99521
95	2616	0.75	0.99999	1.00000	0.99960	0.99975
96	2929	0.24	0.99983	0.99985	0.98380	0.98386
97	3474	0.06	0.99913	0.99918	0.93675	0.93675
98	3475	0.13	0.99957	0.99959	0.96333	0.96333
99	3140	0.29	0.99989	0.99995	0.98919	0.99372
100	2622	0.94	1.00000	1.00000	0.99988	0.99992
101	2929	0.28	0.99987	0.99989	0.98791	0.98798
102	3474	0.05	0.99907	0.99912	0.93319	0.93319
103	3475	0.11	0.99951	0.99953	0.95881	0.95881
104	3135	0.27	0.99988	0.99994	0.98776	0.99182
105	2622	1.13	1.00000	1.00000	0.99996	0.99997
106	2929	0.31	0.99991	0.99992	0.99048	0.99054
107	3474	0.05	0.99901	0.99906	0.93049	0.93049
108	3475	0.10	0.99947	0.99949	0.95527	0.95527
109	3133	0.26	0.99986	0.99993	0.98666	0.99027
110	2573	1.17	1.00000	1.00000	0.99997	0.99998
111	2930	0.32	0.99992	0.99992	0.99126	0.99132
112	3475	0.04	0.99898	0.99902	0.92906	0.92906
113	3475	0.10	0.99944	0.99946	0.95363	0.95363
114	3133	0.25	0.99986	0.99992	0.98596	0.98912
115	2574	1.18	1.00000	1.00000	0.99997	0.99998
116	2930	0.32	0.99992	0.99992	0.99113	0.99117
117	3475	0.04	0.99895	0.99899	0.92780	0.92780
118	3475	0.10	0.99942	0.99944	0.95262	0.95262
119	3133	0.25	0.99985	0.99991	0.98513	0.98805

TABLE 2. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	FF	@DUL IF	FF
120	—	—	—	—	—	—
121	2927	0.31	0.99991	0.99992	0.99084	0.99085
122	3474	0.04	0.99891	0.99896	0.92625	0.92625
123	3475	0.09	0.99940	0.99943	0.95208	0.95208
124	3133	0.24	0.99985	0.99990	0.98503	0.98743
125	—	—	—	—	—	—
126	2927	0.31	0.99991	0.99991	0.99063	0.99063
127	3474	0.04	0.99886	0.99891	0.92427	0.92427
128	3475	0.09	0.99941	0.99943	0.95208	0.95208
129	3133	0.24	0.99985	0.99990	0.98490	0.98730
130	—	—	—	—	—	—
131	2928	0.31	0.99991	0.99991	0.99036	0.99036
132	3474	0.03	0.99882	0.99887	0.92248	0.92248
133	3475	0.09	0.99941	0.99943	0.95221	0.95221
134	3133	0.24	0.99985	0.99990	0.98476	0.98717
135	—	—	—	—	—	—
136	2928	0.30	0.99991	0.99991	0.99023	0.99023
137	3474	0.03	0.99879	0.99885	0.92123	0.92123
138	3475	0.09	0.99941	0.99943	0.95222	0.95222
139	3133	0.24	0.99985	0.99990	0.98470	0.98711

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.

(2) "IF" is the initial failure of the impact damaged zone,
"FF" is the final failure of the impact damaged bay.

TABLE 3. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION.

MODAL IMPACT ENERGY = 6 ft-lb
PROBABILITY FOR 100 ft-lb IMPACT = 0.01

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
1	2283	4.33	0.99999	0.99999	0.99999	0.99999
2	2577	2.05	0.99999	0.99999	0.99999	0.99999
3	2526	1.87	0.99999	0.99999	0.99998	0.99999
4	2283	4.15	0.99999	0.99999	0.99999	0.99999
5	2524	1.96	0.99999	0.99999	0.99999	0.99999
6	2508	1.82	0.99999	0.99999	0.99998	0.99999
7	2253	3.90	0.99999	0.99999	0.99999	0.99999
8	2479	1.87	0.99999	0.99999	0.99999	0.99999
9	2487	1.77	0.99999	0.99999	0.99998	0.99999
10	2253	3.59	0.99999	0.99999	0.99999	0.99999
11	2429	1.75	0.99999	0.99999	0.99998	0.99999
12	2460	1.69	0.99999	0.99999	0.99998	0.99999
13	2226	2.98	0.99999	0.99999	0.99999	0.99999
14	2471	1.68	0.99999	0.99999	0.99999	0.99999
15	2424	1.54	0.99999	0.99999	0.99996	0.99999
16	2226	2.30	0.99999	0.99999	0.99999	0.99999
17	2453	1.50	0.99999	0.99999	0.99998	0.99999
18	2412	1.36	0.99999	0.99999	0.99994	0.99999
19	2221	1.68	0.99999	0.99999	0.99999	0.99999
20	2433	1.28	0.99999	0.99999	0.99997	0.99999
21	2390	1.14	0.99999	0.99999	0.99985	0.99999
22	2211	1.22	0.99999	0.99999	0.99994	0.99999
23	2420	1.09	0.99999	0.99999	0.99993	0.99998
24	2369	0.93	0.99999	0.99999	0.99954	0.99997
25	2206	0.90	0.99999	0.99999	0.99963	0.99996
26	2412	0.74	0.99999	0.99999	0.99946	0.99984
27	2351	0.65	0.99997	0.99999	0.99758	0.99982

TABLE 3. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
28	2206	0.68	0.99998	0.99999	0.99854	0.99983
29	2722	0.80	0.99998	0.99999	0.99859	0.99995
30	2669	0.50	0.99996	0.99999	0.99648	0.99935
31	2455	0.48	0.99996	0.99999	0.99599	0.99913
32	2202	0.50	0.99995	0.99999	0.99527	0.99933
33	2655	0.54	0.99993	0.99999	0.99359	0.99959
34	2668	0.29	0.99980	0.99997	0.98035	0.99541
35	2448	0.31	0.99984	0.99997	0.98670	0.99587
36	2202	0.35	0.99984	0.99998	0.98663	0.99745
37	2603	0.32	0.99969	0.99998	0.97686	0.99692
38	2668	0.11	0.99892	0.99982	0.94000	0.96966
39	2443	0.16	0.99942	0.99988	0.96188	0.98062
40	2193	0.24	0.99960	0.99995	0.97289	0.99217
41	2558	0.17	0.99904	0.99991	0.94827	0.98584
42	2668	0.00	0.99645	0.99934	0.87855	0.90056
43	2649	0.07	0.99844	0.99968	0.92602	0.95118
44	3471	0.73	0.99965	0.99999	0.97478	0.99994
45	2189	0.18	0.99928	0.99990	0.95991	0.98489
46	2528	0.09	0.99817	0.99979	0.92198	0.96527
47	2667	-0.06	0.99337	0.99862	0.82999	0.83739
48	2649	0.01	0.99716	0.99939	0.89413	0.91355
49	3361	0.60	0.99945	0.99999	0.96313	0.99985
50	2189	0.16	0.99918	0.99989	0.95615	0.98269
51	2503	0.06	0.99761	0.99966	0.90704	0.94396
52	2667	-0.09	0.99055	0.99783	0.79853	0.80046
53	2648	-0.02	0.99610	0.99913	0.87075	0.88322
54	3265	0.51	0.99918	0.99999	0.95335	0.99966
55	2186	0.17	0.99926	0.99989	0.95907	0.98353
56	2430	0.04	0.99745	0.99959	0.90248	0.93224
57	2667	-0.10	0.98890	0.99736	0.78090	0.78164
58	2648	-0.04	0.99508	0.99884	0.85551	0.86405
59	3182	0.45	0.99901	0.99999	0.94726	0.99940

TABLE 3. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	FF	@DUL IF	FF
60	2140	0.16	0.99914	0.99988	0.95498	0.98051
61	2462	0.02	0.99725	0.99949	0.89821	0.92048
62	2666	-0.12	0.98701	0.99675	0.76400	0.76411
63	2648	-0.05	0.99406	0.99856	0.84075	0.84556
64	3108	0.39	0.99885	0.99999	0.94014	0.99891
65	2137	0.17	0.99926	0.99989	0.95872	0.98262
66	2448	0.01	0.99699	0.99934	0.89379	0.90916
67	2666	-0.13	0.98477	0.99595	0.74707	0.74709
68	2648	-0.07	0.99309	0.99828	0.82552	0.82839
69	3039	0.34	0.99864	0.99998	0.93319	0.99816
70	2137	0.18	0.99940	0.99991	0.96312	0.98582
71	2437	+0.00	0.99681	0.99922	0.89076	0.90103
72	2666	-0.14	0.98268	0.99521	0.73105	0.73105
73	2647	-0.08	0.99172	0.99783	0.81084	0.81203
74	2981	0.30	0.99834	0.99998	0.92645	0.99711
75	2137	0.23	0.99957	0.99994	0.97184	0.99054
76	2438	-0.00	0.99673	0.99912	0.88941	0.89620
77	2665	-0.16	0.98059	0.99442	0.71553	0.71553
78	2647	-0.10	0.99030	0.99735	0.79585	0.79632
79	2927	0.26	0.99807	0.99997	0.91902	0.99534
80	2132	0.23	0.99960	0.99994	0.97394	0.99089
81	2421	-0.01	0.99677	0.99906	0.89007	0.89469
82	2665	-0.17	0.97807	0.99305	0.70150	0.70150
83	2646	-0.11	0.98898	0.99690	0.78167	0.78184
84	2880	0.22	0.99781	0.99996	0.91196	0.99296
85	2133	0.27	0.99973	0.99996	0.98036	0.99407
86	2415	-0.00	0.99697	0.99906	0.89350	0.89692
87	2664	-0.17	0.97588	0.99203	0.68918	0.68918
88	2646	-0.12	0.98759	0.99639	0.76835	0.76835
89	2835	0.19	0.99756	0.99994	0.90514	0.98988

TABLE 3. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
90	2131	0.33	0.99984	0.99997	0.98715	0.99670
91	2411	+0.00	0.99735	0.99913	0.90004	0.90260
92	2907	-0.11	0.99220	0.99569	0.80193	0.80193
93	2906	-0.05	0.99590	0.99775	0.85914	0.85914
94	2853	0.18	0.99889	0.99993	0.93914	0.98839
95	2193	0.46	0.99994	0.99999	0.99454	0.99911
96	2407	0.02	0.99774	0.99918	0.91034	0.91311
97	2907	-0.11	0.99163	0.99532	0.79393	0.79393
98	2906	-0.06	0.99562	0.99757	0.85393	0.85393
99	2814	0.15	0.99869	0.99990	0.93345	0.98319
100	2182	0.61	0.99998	0.99999	0.99814	0.99971
101	2404	0.05	0.99833	0.99933	0.92600	0.92852
102	2907	-0.12	0.99108	0.99496	0.78658	0.78658
103	2906	-0.07	0.99504	0.99715	0.84270	0.84270
104	2776	0.12	0.99848	0.99986	0.92737	0.97592
105	2182	0.77	0.99999	0.99999	0.99936	0.99990
106	2403	0.07	0.99879	0.99953	0.93753	0.94151
107	2907	-0.12	0.99057	0.99459	0.78156	0.78156
108	2906	-0.08	0.99462	0.99689	0.83434	0.83434
109	2744	0.10	0.99832	0.99982	0.92270	0.96883
110	2138	0.80	0.99999	0.99999	0.99948	0.99992
111	2403	0.08	0.99887	0.99954	0.94108	0.94476
112	2907	-0.13	0.99030	0.99430	0.77890	0.77890
113	2906	-0.08	0.99432	0.99668	0.83046	0.83046
114	272[illegible]	0.09	0.99823	0.99978	0.91992	0.96302
115	2135	0.81	0.99999	0.99999	0.99951	0.99992
116	2403	0.08	0.99885	0.99953	0.94050	0.94333
117	2907	-0.13	0.99007	0.99413	0.77657	0.77657
118	2906	-0.08	0.99414	0.99655	0.82808	0.82808
119	2707	0.08	0.99817	0.99975	0.91777	0.95705

TABLE 3. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
120	—	—	—	—	—	—
121	2400	0.08	0.99882	0.99940	0.93917	0.93975
122	2906	-0.13	0.98977	0.99402	0.77366	0.77366
123	2906	-0.08	0.99404	0.99648	0.82681	0.82681
124	2699	0.07	0.99814	0.99972	0.91655	0.95365
125	—	—	—	—	—	—
126	2401	0.07	0.99880	0.99937	0.93819	0.93851
127	2907	-0.13	0.98940	0.99365	0.77000	0.77000
128	2906	-0.08	0.99404	0.99648	0.82682	0.82682
129	2699	0.07	0.99812	0.99972	0.91608	0.95315
130	—	—	—	—	—	—
131	2401	0.07	0.99877	0.99932	0.93701	0.93717
132	2907	-0.14	0.98907	0.99340	0.76666	0.76666
133	2906	-0.08	0.99406	0.99650	0.82713	0.82713
134	2699	0.07	0.99811	0.99971	0.91561	0.95264
135	—	—	—	—	—	—
136	2401	0.07	0.99876	0.99929	0.93643	0.93654
137	2907	-0.14	0.98883	0.99323	0.76433	0.76433
138	2906	-0.08	0.99406	0.99650	0.82713	0.82713
139	2699	0.07	0.99810	0.99971	0.91537	0.95239

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.

(2) "IF" is the initial failure of the impact damaged zone, "FF" is the final failure of the impact damaged bay.

TABLE 4. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION.

MODAL IMPACT ENERGY = 15 ft-lb
PROBABILITY FOR 100 ft-lb IMPACT = 0.1

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
1	2157	4.04	0.99999	0.99999	0.99999	0.99999
2	2484	1.94	0.99999	0.99999	0.99988	0.99999
3	2423	1.76	0.99999	0.99999	0.99984	0.99999
4	2157	3.87	0.99999	0.99999	0.99999	0.99999
5	2423	1.84	0.99999	0.99999	0.99987	0.99999
6	2404	1.71	0.99999	0.99999	0.99983	0.99999
7	2119	3.61	0.99999	0.99999	0.99999	0.99999
8	2368	1.74	0.99999	0.99999	0.99986	0.99999
9	2376	1.65	0.99999	0.99999	0.99982	0.99999
10	2120	3.32	0.99999	0.99999	0.99999	0.99999
11	2312	1.62	0.99999	0.99999	0.99983	0.99999
12	2345	1.56	0.99999	0.99999	0.99975	0.99999
13	2076	2.71	0.99999	0.99999	0.99999	0.99999
14	2274	1.47	0.99999	0.99999	0.99992	0.99999
15	2316	1.42	0.99998	0.99999	0.99943	0.99999
16	2076	2.08	0.99999	0.99999	0.99998	0.99999
17	2242	1.28	0.99999	0.99999	0.99984	0.99999
18	2288	1.24	0.99998	0.99999	0.99914	0.99999
19	2067	1.49	0.99999	0.99999	0.99986	0.99999
20	2207	1.07	0.99999	0.99999	0.99959	0.99998
21	2257	1.02	0.99996	0.99999	0.99767	0.99998
22	2048	1.05	0.99998	0.99999	0.99908	0.99998
23	2171	0.87	0.99998	0.99999	0.99896	0.99996
24	2233	0.82	0.99992	0.99999	0.99357	0.99995
25	2039	0.75	0.99994	0.99999	0.99461	0.99993
26	2143	0.54	0.99991	0.99999	0.99283	0.99964
27	2213	0.55	0.99960	0.99999	0.97433	0.99971

TABLE 4. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
28	2039	0.55	0.99977	0.99999	0.98254	0.99969
29	2607	0.73	0.99980	0.99999	0.98368	0.99993
30	2465	0.39	0.99953	0.99998	0.96740	0.99874
31	2241	0.35	0.99944	0.99998	0.96325	0.99812
32	2032	0.38	0.99922	0.99998	0.95704	0.99870
33	2526	0.46	0.99899	0.99999	0.94803	0.99941
34	2464	0.19	0.99731	0.99994	0.89924	0.99010
35	2229	0.19	0.99773	0.99994	0.91329	0.99012
36	2033	0.25	0.99755	0.99996	0.91129	0.99467
37	2455	0.24	0.99573	0.99996	0.87456	0.99471
38	2463	0.02	0.98737	0.99968	0.77405	0.92801
39	2218	0.05	0.99231	0.99975	0.82746	0.94875
40	2019	0.14	0.99419	0.99991	0.85934	0.98215
41	2404	0.10	0.98826	0.99986	0.79226	0.97213
42	2463	0.08	0.96715	0.99871	0.65906	0.75862
43	2430	-0.02	0.98300	0.99937	0.74440	0.87621
44	3424	0.71	0.99513	0.99999	0.86704	0.99994
45	2013	0.08	0.99038	0.99982	0.82071	0.96376
46	2358	0.02	0.98004	0.99965	0.73438	0.92450
47	2462	-0.13	0.94752	0.99720	0.58807	0.62124
48	2429	-0.07	0.97255	0.99875	0.68452	0.77980
49	3310	0.58	0.99265	0.99999	0.83090	0.99985
50	2013	0.07	0.98917	0.99980	0.81016	0.95829
51	2321	-0.02	0.97518	0.99939	0.70623	0.86989
52	2461	-0.16	0.93271	0.99549	0.54773	0.55700
53	2429	-0.10	0.96449	0.99819	0.64632	0.70620
54	3209	0.49	0.98979	0.99999	0.80535	0.99963
55	2007	0.08	0.99011	0.99980	0.81832	0.95991
56	2290	-0.04	0.97371	0.99921	0.69762	0.83428
57	2461	-0.17	0.92435	0.99445	0.52667	0.53058
58	2428	-0.12	0.95810	0.99756	0.62391	0.66501
59	3117	0.42	0.98799	0.99999	0.78953	0.99932

TABLE 4. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
60	1959	0.06	0.98872	0.99976	0.80730	0.95171
61	2258	-0.06	0.97216	0.99898	0.69001	0.79702
62	2461	-0.19	0.91573	0.99306	0.50726	0.50819
63	2428	-0.13	0.95183	0.99692	0.60241	0.62569
64	3034	0.36	0.98624	0.99998	0.77345	0.99871
65	1953	0.07	0.99000	0.99979	0.81710	0.95654
66	2232	-0.08	0.97033	0.99858	0.68272	0.76065
67	2460	-0.20	0.90640	0.99125	0.48870	0.48904
68	2428	-0.15	0.94582	0.99630	0.58222	0.59632
69	2962	0.31	0.98417	0.99998	0.75813	0.99773
70	1954	0.08	0.99150	0.99984	0.82859	0.96497
71	2212	-0.09	0.96908	0.99824	0.67771	0.73275
72	2460	-0.21	0.89767	0.98955	0.47154	0.47154
73	2427	-0.16	0.93869	0.99525	0.56293	0.56902
74	2901	0.26	0.98159	0.99997	0.74325	0.99628
75	1954	0.12	0.99369	0.99988	0.85592	0.97707
76	2192	-0.10	0.96853	0.99793	0.67548	0.71409
77	2458	-0.22	0.88918	0.98770	0.45579	0.45579
78	2426	-0.17	0.93148	0.99412	0.54455	0.54715
79	2837	0.22	0.97916	0.99996	0.72894	0.99371
80	1942	0.12	0.99421	0.99988	0.86271	0.97740
81	2171	-0.11	0.96800	0.99769	0.67658	0.70450
82	2456	-0.23	0.88047	0.98457	0.44157	0.44157
83	2426	-0.18	0.92476	0.99306	0.52759	0.52868
84	2786	0.18	0.97688	0.99995	0.71552	0.99006
85	1943	0.16	0.99597	0.99992	0.88523	0.98566
86	2153	-0.11	0.97022	0.99761	0.68226	0.70420
87	2456	-0.24	0.87290	0.98215	0.42974	0.42974
88	2425	-0.19	0.91815	0.99183	0.51206	0.51218
89	2734	0.15	0.97469	0.99993	0.70256	0.98511

TABLE 4. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
90	1940	0.21	0.99746	0.99995	0.91273	0.99220
91	2136	-0.11	0.97291	0.99773	0.69308	0.71075
92	2545	-0.22	0.94335	0.98657	0.55442	0.55442
93	2520	-0.18	0.96519	0.99275	0.63188	0.63188
94	2716	0.13	0.98710	0.99991	0.77229	0.98021
95	2017	0.35	0.99912	0.99998	0.95177	0.99818
96	2117	-0.10	0.97630	0.99776	0.71244	0.73261
97	2545	-0.22	0.94015	0.98533	0.54446	0.54446
98	2520	-0.18	0.96332	0.99213	0.62401	0.62401
99	2663	0.09	0.98532	0.99986	0.76020	0.96922
100	2001	0.48	0.99973	0.99999	0.97892	0.99941
101	2103	-0.08	0.98141	0.99822	0.74227	0.76865
102	2544	-0.23	0.93716	0.98413	0.53538	0.53538
103	2519	-0.19	0.95949	0.99068	0.60801	0.60801
104	2617	0.06	0.98342	0.99979	0.74726	0.95327
105	2001	0.63	0.99989	0.99999	0.99124	0.99982
106	2087	-0.07	0.98557	0.99865	0.76766	0.80067
107	2544	-0.23	0.93481	0.98286	0.52964	0.52964
108	2518	-0.20	0.95674	0.98977	0.59660	0.59660
109	2575	0.03	0.98196	0.99971	0.73734	0.93576
110	1954	0.64	0.99992	0.99999	0.99252	0.99986
111	2076	-0.07	0.98642	0.99864	0.77546	0.80721
112	2543	-0.24	0.93356	0.98184	0.52659	0.52659
113	2518	-0.20	0.95508	0.98901	0.59131	0.59131
114	2545	0.02	0.98114	0.99964	0.73169	0.92057
115	1947	0.65	0.99992	0.99999	0.99292	0.99985
116	2066	-0.07	0.98629	0.99857	0.77418	0.79991
117	2543	-0.24	0.93246	0.98124	0.52392	0.52392
118	2518	-0.21	0.95406	0.98855	0.58805	0.58805
119	2520	+0.00	0.98057	0.99956	0.72772	0.90407

TABLE 4. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
120	—	—	—	—	—	—
121	2021	-0.09	0.98592	0.99793	0.77120	0.77818
122	2543	-0.24	0.93108	0.98090	0.52059	0.52059
123	2518	-0.21	0.95351	0.98832	0.58631	0.58631
124	2509	-0.00	0.98024	0.99951	0.72545	0.89482
125	—	—	—	—	—	—
126	2013	-0.10	0.98569	0.99771	0.76908	0.77339
127	2543	-0.24	0.92936	0.97964	0.51639	0.51639
128	2518	-0.21	0.95352	0.98832	0.58632	0.58632
129	2509	-0.00	0.98012	0.99950	0.72457	0.89362
130	—	—	—	—	—	—
131	2004	-0.11	0.98541	0.99747	0.76649	0.76900
132	2543	-0.24	0.92780	0.97880	0.51258	0.51258
133	2518	-0.21	0.95365	0.98838	0.58675	0.58675
134	2509	-0.01	0.97999	0.99950	0.72370	0.89243
135	—	—	—	—	—	—
136	1998	-0.11	0.98528	0.99728	0.76523	0.76694
137	2543	-0.25	0.92670	0.97822	0.50991	0.50991
138	2518	-0.21	0.95366	0.98838	0.58676	0.58676
139	2509	-0.01	0.97993	0.99950	0.72326	0.89182

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.
(2) "IF" is the initial failure of the impact damaged zone.
"FF" is the final failure of the impact damaged bay.

TABLE 5. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN IN EACH SUBDIVISION.

DISCRETE IMPACT AT 100 ft-lb ENERGY LEVEL

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
1	1999	3.67	1.00000	1.00000	1.00000	1.00000
2	2332	1.76	1.00000	1.00000	0.99991	1.00000
3	2270	1.58	1.00000	1.00000	0.99986	1.00000
4	1999	3.51	1.00000	1.00000	1.00000	1.00000
5	2268	1.66	1.00000	1.00000	0.99989	1.00000
6	2243	1.53	1.00000	1.00000	0.99984	1.00000
7	1955	3.25	1.00000	1.00000	1.00000	1.00000
8	2212	1.56	1.00000	1.00000	0.99988	1.00000
9	2219	1.47	1.00000	1.00000	0.99982	1.00000
10	1955	2.98	1.00000	1.00000	1.00000	1.00000
11	2148	1.43	1.00000	1.00000	0.99984	1.00000
12	2188	1.39	1.00000	1.00000	0.99976	1.00000
13	1904	2.41	1.00000	1.00000	1.00000	1.00000
14	2066	1.24	1.00000	1.00000	0.99993	0.99999
15	2159	1.26	1.00000	1.00000	0.99948	0.99999
16	1904	1.82	1.00000	1.00000	0.99999	1.00000
17	2027	1.06	1.00000	1.00000	0.99984	0.99998
18	2121	1.08	0.99999	1.00000	0.99914	0.99998
19	1893	1.28	1.00000	1.00000	0.99989	0.99999
20	1980	0.86	1.00000	1.00000	0.99958	0.99994
21	2091	0.87	0.99998	1.00000	0.99745	0.99994
22	1872	0.88	0.99999	1.00000	0.99900	0.99995
23	1939	0.67	0.99999	1.00000	0.99887	0.99978
24	2064	0.68	0.99994	1.00000	0.99207	0.99979
25	1862	0.60	0.99995	1.00000	0.99370	0.99962
26	1905	0.37	0.99992	0.99998	0.99005	0.99760
27	2040	0.43	0.99964	0.99999	0.95375	0.99857

TABLE 5. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
28	1862	0.41	0.99979	0.99999	0.97257	0.99835
29	2434	0.61	0.99979	1.00000	0.97305	0.99966
30	2242	0.26	0.99945	0.99995	0.93164	0.99364
31	2025	0.22	0.99937	0.99993	0.92139	0.99039
32	1853	0.26	0.99922	0.99995	0.90406	0.99356
33	2349	0.36	0.99892	0.99998	0.86909	0.99734
34	2241	0.08	0.99658	0.99969	0.64089	0.96042
35	2010	0.08	0.99740	0.99967	0.71340	0.95749
36	1853	0.14	0.99727	0.99983	0.70174	0.97760
37	2272	0.15	0.99463	0.99985	0.49736	0.98038
38	2240	-0.07	0.97947	0.99811	0.06782	0.78227
39	1995	-0.05	0.98908	0.99846	0.24061	0.81843
40	1834	0.04	0.99293	0.99947	0.39823	0.93405
41	2211	0.01	0.98274	0.99931	0.10448	0.91466
42	2239	-0.16	0.93083	0.99344	0.00009	0.42562
43	2201	-0.11	0.97136	0.99669	0.02306	0.65082
44	3274	0.63	0.99391	1.00000	0.45241	0.99971
45	1826	-0.02	0.98745	0.99900	0.19419	0.87795
46	2162	-0.06	0.96600	0.99821	0.01125	0.79245
47	2239	-0.21	0.86470	0.98667	0.00000	0.17527
48	2200	-0.16	0.94629	0.99370	0.00077	0.44038
49	3158	0.51	0.98958	0.99999	0.25701	0.99923
50	1826	-0.03	0.98547	0.99884	0.14962	0.86014
51	2119	-0.11	0.95391	0.99688	0.00219	0.66666
52	2238	-0.23	0.80575	0.98019	0.00000	0.07454
53	2199	-0.18	0.92178	0.99069	0.00003	0.29706
54	3055	0.42	0.98542	0.99999	0.14872	0.99838
55	1817	-0.03	0.98703	0.99889	0.18370	0.86615
56	2081	-0.13	0.94952	0.99572	0.00121	0.57350
57	2237	-0.25	0.76673	0.97561	0.00000	0.04059
58	2199	-0.20	0.90307	0.98832	0.00000	0.21776
59	2963	0.35	0.98215	0.99998	0.09663	0.99714

TABLE 5. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION. LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
60	1776	-0.04	0.98480	0.99869	0.13702	0.84313
61	2046	-0.15	0.94534	0.99431	0.00068	0.47721
62	2237	-0.25	0.72496	0.97041	0.00000	0.02029
63	2198	-0.21	0.88159	0.98552	0.00000	0.15078
64	2881	0.29	0.97835	0.99996	0.05841	0.99513
65	1769	-0.03	0.98669	0.99878	0.17575	0.85353
66	2015	-0.17	0.94106	0.99261	0.00038	0.38212
67	2236	-0.27	0.67918	0.96441	0.00000	0.00908
68	2198	-0.23	0.85736	0.98230	0.00000	0.09861
69	2807	0.24	0.97409	0.99994	0.03319	0.99203
70	1770	-0.02	0.98863	0.99896	0.22674	0.87409
71	1987	-0.18	0.93795	0.99078	0.00025	0.30073
72	2236	-0.28	0.63207	0.95782	0.00000	0.00373
73	2197	-0.24	0.83045	0.97862	0.00000	0.06056
74	2739	0.19	0.96926	0.99990	0.01741	0.98734
75	1770	0.02	0.99251	0.99932	0.37689	0.91565
76	1962	-0.20	0.93653	0.98898	0.00020	0.23751
77	2234	-0.29	0.58358	0.95022	0.00000	0.00133
78	2195	-0.25	0.80034	0.97419	0.00000	0.03360
79	2678	0.15	0.96400	0.99985	0.00859	0.98058
80	1756	0.01	0.99327	0.99931	0.41657	0.91492
81	1938	-0.20	0.93725	0.98742	0.00022	0.19346
82	2233	-0.30	0.53714	0.94252	0.00000	0.00046
83	2195	-0.26	0.76870	0.96944	0.00000	0.01784
84	2622	0.11	0.95836	0.99977	0.00401	0.97111
85	1756	0.05	0.99543	0.99954	0.55190	0.94167
86	1917	-0.21	0.94081	0.98646	0.00036	0.17053
87	2233	-0.31	0.49515	0.93497	0.00000	0.00016
88	2194	-0.27	0.73615	0.96436	0.00000	0.00901
89	2571	0.08	0.95218	0.99967	0.00173	0.95807

TABLE 5. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
90	1752	0.09	0.99732	0.99972	0.70615	0.96407
91	1895	-0.21	0.94709	0.98609	0.00087	0.16251
92	2233	-0.31	0.84724	0.92817	0.00000	0.00006
93	2194	-0.28	0.92282	0.95627	0.00003	0.00302
94	2524	0.05	0.97907	0.99953	0.06430	0.94140
95	1831	0.22	0.99904	0.99993	0.88282	0.99049
96	1869	-0.21	0.95690	0.986[illegible]2	0.00039	0.17638
97	2232	-0.32	0.83383	0.92111	0.00000	0.00002
98	2193	-0.29	0.91712	0.95271	0.00001	0.00186
99	2467	0.01	0.97600	0.99930	0.04276	0.91266
100	1807	0.34	0.99973	0.99997	0.96538	0.99672
101	1847	-0.20	0.96889	0.98902	0.01657	0.23859
102	2231	-0.32	0.82075	0.91429	0.00000	0.00001
103	2192	-0.30	0.90431	0.94507	0.00000	0.00[illegible]
104	2415	-0.02	0.97226	0.99895	0.02599	0.[illegible]
105	1807	0.47	0.99991	0.99999	0.98873	0.99895
106	1827	-0.18	0.97680	0.99066	0.04757	0.29582
107	2231	-0.33	0.81179	0.90940	0.00000	0.00000
108	2192	-0.30	0.89410	0.93883	0.00000	0.00028
109	2368	-0.05	0.96905	0.99851	0.01692	0.82426
110	1769	0.49	0.99993	0.99999	0.99040	0.99911
111	1814	-0.18	0.97884	0.99070	0.06233	0.29748
112	2230	-0.33	0.80690	0.90663	0.00000	0.00000
113	2191	-0.31	0.88906	0.93565	0.00000	0.00018
114	2336	-0.07	0.96709	0.99813	0.01301	0.78435
115	1762	0.49	0.99993	0.99999	0.99113	0.99913
116	1801	-0.19	0.97851	0.98970	0.05973	0.26105
117	2230	-0.33	0.80253	0.90421	0.00000	0.00000
118	2191	-0.31	0.88586	0.93363	0.00000	0.00013
119	2305	-0.08	0.96567	0.99772	0.01075	0.74321

TABLE 5. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	FF	@DUL IF	FF
120	—	—	—	—	—	—
121	1735	-0.22	0.97773	0.98359	0.05381	0.11681
122	2230	-0.33	0.79689	0.90165	0.00000	0.00000
123	2191	-0.31	0.88410	0.93272	0.00000	0.00012
124	2292	-0.09	0.96483	0.99749	0.00961	0.72162
125	—	—	—	—	—	—
126	1719	-0.23	0.97717	0.98127	0.04996	0.08602
127	2230	-0.33	0.78972	0.89789	0.00000	0.00000
128	2191	-0.31	0.88411	0.93271	0.00000	0.00012
129	2292	-0.09	0.96451	0.99746	0.00920	0.71925
130	—	—	—	—	—	—
131	1705	-0.24	0.97647	0.98862	0.04552	0.06058
132	2230	-0.34	0.78303	0.89436	0.00000	0.00000
133	2191	-0.31	0.88454	0.93295	0.00000	0.00012
134	2291	-0.09	0.96418	0.99744	0.00880	0.71688
135	—	—	—	—	—	—
136	1695	-0.24	0.97612	0.97666	0.04346	0.04669
137	2230	-0.34	0.77825	0.89184	0.00000	0.00000
138	2191	-0.31	0.88455	0.93294	0.00000	0.00012
139	2291	-0.09	0.96401	0.99742	0.00860	0.71566

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.

(2) "IF" is the initial failure of the impact damaged zone, "FF" is the final failure of the impact damaged bay.

TABLE 6. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION.

MODAL IMPACT ENERGY = 4 ft-lb
PROBABILITY FOR 100 ft-lb IMPACT = 0.0001

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
1	2570	4.89	1.00000	1.00000	1.00000	1.00000
2	2763	1.19	1.00000	1.00000	0.99996	0.99999
3	2738	1.17	1.00000	1.00000	0.99996	0.99999
4	2570	4.71	1.00000	1.00000	1.00000	1.00000
5	2732	1.16	1.00000	1.00000	0.99995	0.99999
6	2727	1.15	1.00000	1.00000	0.99996	0.99999
7	2580	4.50	1.00000	1.00000	1.00000	1.00000
8	2711	1.13	1.00000	1.00000	0.99995	0.99999
9	2719	1.14	1.00000	1.00000	0.99995	0.99999
10	2580	4.03	1.00000	1.00000	1.00000	1.00000
11	2692	1.12	1.00000	1.00000	0.99995	0.99998
12	2709	1.13	1.00000	1.00000	0.99995	0.99999
13	2594	3.29	1.00000	1.00000	1.00000	1.00000
14	2926	1.27	1.00000	1.00000	0.99998	0.99999
15	2658	1.07	1.00000	1.00000	0.99994	0.99998
16	2594	2.48	1.00000	1.00000	1.00000	1.00000
17	2926	1.26	1.00000	1.00000	0.99998	0.99999
18	2693	1.08	1.00000	1.00000	0.99995	0.99998
19	2598	1.84	1.00000	1.00000	1.00000	1.00000
20	2927	1.23	1.00000	1.00000	0.99998	0.99998
21	2689	1.05	1.00000	1.00000	0.99994	0.99998
22	2604	1.41	1.00000	1.00000	0.99999	0.99999
23	2927	1.20	1.00000	1.00000	0.99997	0.99998
24	2687	1.02	1.00000	1.00000	0.99992	0.99997
25	2606	1.09	.00000	1.00000	0.99995	0.99997
26	2928	0.70	0.99999	0.99999	0.99952	0.99959
27	2686	0.56	0.99998	0.99999	0.99854	0.99930

TABLE 6. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
28	2606	0.88	1.00000	1.00000	0.99983	0.99990
29	2964	0.62	0.99999	0.99999	0.99900	0.99970
30	3130	0.58	0.99999	0.99999	0.99895	0.99926
31	2932	0.48	0.99998	0.99998	0.99759	0.99811
32	2609	0.68	0.99999	0.99999	0.99936	0.99961
33	2940	0.36	0.99994	0.99998	0.99352	0.99707
34	3130	0.35	0.99994	0.99996	0.99382	0.99508
35	2932	0.27	0.99986	0.99990	0.98696	0.98788
36	2609	0.53	0.99998	0.99999	0.99806	0.99875
37	2928	0.17	0.99967	0.99985	0.97243	0.97968
38	3131	0.18	0.99972	0.99981	0.97490	0.97632
39	2932	0.11	0.99934	0.99948	0.95367	0.95370
40	2614	0.43	0.99996	0.99998	0.99597	0.99706
41	2926	0.09	0.99921	0.99959	0.94662	0.94956
42	3131	0.11	0.99941	0.99959	0.95509	0.95552
43	3132	0.11	0.99941	0.99956	0.95525	0.95543
44	3547	0.56	0.99989	1.00000	0.98906	0.99974
45	2616	0.39	0.99994	0.99996	0.99440	0.99572
46	2926	0.03	0.99856	0.99915	0.92031	0.92050
47	3131	0.06	0.99899	0.99929	0.93481	0.93485
48	3132	0.06	0.99900	0.99924	0.93501	0.93502
49	3449	0.45	0.99982	0.99999	0.98267	0.99929
50	2616	0.39	0.99994	0.99996	0.99440	0.99572
51	2926	0.01	0.99818	0.99878	0.90871	0.90871
52	3131	0.04	0.99879	0.99914	0.92574	0.92574
53	3132	0.04	0.99880	0.99908	0.92595	0.92595
54	3366	0.38	0.99976	0.99999	0.97829	0.99860
55	2618	0.40	0.99995	0.99997	0.99484	0.99598
56	2927	-0.00	0.99776	0.99840	0.89649	0.89649
57	3131	0.02	0.99852	0.99893	0.91623	0.91623
58	3132	0.02	0.99852	0.99886	0.91644	0.91644
59	3297	0.33	0.99969	0.99998	0.97372	0.99750

TABLE 6. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
60	2569	0.38	0.99994	0.99996	0.99413	0.99533
61	2927	-0.02	0.99736	0.99800	0.88448	0.88448
62	3132	0.01	0.99825	0.99873	0.90710	0.90710
63	3132	0.01	0.99826	0.99865	0.90730	0.90730
64	3232	0.27	0.99962	0.99997	0.96818	0.99558
65	2571	0.40	0.99995	0.99997	0.99471	0.99580
66	2928	-0.04	0.99678	0.99737	0.87176	0.87176
67	3132	-0.00	0.99800	0.99854	0.89713	0.89713
68	3132	-0.00	0.99801	0.99845	0.89732	0.89732
69	3180	0.23	0.99951	0.99996	0.96265	0.99285
70	2571	0.41	0.99996	0.99997	0.99535	0.99637
71	2928	-0.05	0.99620	0.99675	0.85956	0.85956
72	3132	-0.02	0.99763	0.99824	0.88738	0.88738
73	3132	-0.02	0.99763	0.99813	0.88757	0.88757
74	3133	0.19	0.99939	0.99993	0.95607	0.98848
75	2571	0.43	0.99996	0.99998	0.99614	0.99706
76	2928	-0.06	0.99566	0.99617	0.84780	0.84780
77	3132	-0.03	0.99726	0.99795	0.87763	0.87763
78	3133	-0.03	0.99726	0.99782	0.87782	0.87782
79	3096	0.16	0.99927	0.99990	0.94952	0.98277
80	2574	0.47	0.99997	0.99998	0.99687	0.99757
81	2929	-0.07	0.99514	0.99558	0.83746	0.83746
82	3132	-0.04	0.99691	0.99763	0.86828	0.86828
83	3133	-0.04	0.99692	0.99753	0.86845	0.86845
84	3060	0.12	0.99911	0.99985	0.94236	0.97480
85	2574	0.51	0.99998	0.99998	0.99782	0.99837
86	2929	-0.08	0.99453	0.99489	0.82856	0.82856
87	3132	-0.05	0.99660	0.99737	0.85970	0.85970
88	3133	-0.05	0.99661	0.99726	0.85987	0.85987
89	3032	0.10	0.99892	0.99979	0.93508	0.96492

TABLE 6. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
90	2576	0.57	0.99999	0.99999	0.99849	0.99889
91	2929	-0.09	0.99413	0.99441	0.82245	0.82245
92	3474	0.05	0.99899	0.99904	0.92974	0.92974
93	3475	0.05	0.99899	0.99903	0.92984	0.92984
94	3150	0.12	0.99946	0.99979	0.95875	0.96971
95	2616	0.67	0.99999	0.99999	0.99932	0.99956
96	2929	-0.09	0.99369	0.99388	0.81561	0.81561
97	3474	0.04	0.99886	0.99891	0.92395	0.92395
98	3475	0.04	0.99886	0.99890	0.92406	0.92406
99	3140	0.10	0.99937	0.99972	0.95192	0.95943
100	2622	0.83	0.99999	1.00000	0.99975	0.99984
101	2929	-0.10	0.99342	0.99355	0.81127	0.81127
102	3474	0.03	0.99874	0.99880	0.91910	0.91910
103	3475	0.03	0.99875	0.99875	0.91920	0.91920
104	3135	0.08	0.99919	0.99958	0.94458	0.94873
105	2622	1.06	1.00000	1.00000	0.99994	0.99996
106	2929	-0.10	0.99328	0.99337	0.80909	0.80909
107	3474	0.02	0.99870	0.99876	0.91730	0.91730
108	3475	0.03	0.99870	0.99874	0.91740	0.91740
109	3133	0.07	0.99910	0.99950	0.94028	0.94223
110	2573	1.16	1.00000	1.00000	0.99996	0.99998
111	2930	-0.10	0.99304	0.99311	0.80535	0.80535
112	3475	0.02	0.99869	0.99875	0.91696	0.91696
113	3475	0.02	0.99870	0.99873	0.91704	0.91704
114	3133	0.06	0.99905	0.99943	0.93787	0.93887
115	2574	1.17	1.00000	1.00000	0.99997	0.99998
116	2930	-0.11	0.99280	0.99285	0.80156	0.80156
117	3475	0.02	0.99869	0.99874	0.91661	0.91661
118	3475	0.02	0.99869	0.99873	0.91669	0.91669
119	3133	0.06	0.99901	0.99937	0.93564	0.93609

TABLE 6. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	FF	@DUL IF	FF
120	—	—	—	—	—	—
121	2927	-0.11	0.99235	0.99235	0.79474	0.79474
122	3474	0.02	0.99867	0.99873	0.91612	0.91612
123	3475	0.02	0.99868	0.99872	0.91628	0.91628
124	3133	0.06	0.99901	0.99934	0.93561	0.93597
125	—	—	—	—	—	—
126	2927	-0.12	0.99181	0.99181	0.78818	0.78818
127	3474	0.02	0.99867	0.99872	0.91578	0.91578
128	3475	0.02	0.99867	0.99871	0.91592	0.91592
129	3133	0.06	0.99902	0.99935	0.93596	0.93632
130	—	—	—	—	—	—
131	2928	-0.12	0.99127	0.99127	0.78219	0.78219
132	3474	0.02	0.99866	0.99872	0.91562	0.91562
133	3475	0.02	0.99867	0.99870	0.91575	0.91575
134	3133	0.06	0.99902	0.99935	0.93631	0.93668
135	—	—	—	—	—	—
136	2928	-0.12	0.99100	0.99100	0.77922	0.77922
137	3474	0.02	0.99866	0.99871	0.91545	0.91545
138	3475	0.02	0.99866	0.99870	0.91557	0.91557
139	3133	0.06	0.99903	0.99936	0.93683	0.93721

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.

(2) "IF" is the initial failure of the impact damaged zone.
"FF" is the final failure of the impact damaged bay.

TABLE 7. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION.

MODAL IMPACT ENERGY = 6 ft-lb
PROBABILITY FOR 100 ft-lb IMPACT = 0.01

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
1	2283	4.24	0.99999	0.99999	0.99999	0.99999
2	2577	1.04	0.99999	0.99999	0.99934	0.99998
3	2526	1.00	0.99999	0.99999	0.99937	0.99998
4	2283	4.07	0.99999	0.99999	0.99999	0.99999
5	2524	0.99	0.99999	0.99999	0.99932	0.99998
6	2508	0.98	0.99999	0.99999	0.99935	0.99998
7	2253	3.80	0.99999	0.99999	0.99999	0.99999
8	2479	0.95	0.99999	0.99999	0.99931	0.99998
9	2487	0.96	0.99999	0.99999	0.99933	0.99998
10	2253	3.39	0.99999	0.99999	0.99999	0.99999
11	2429	0.91	0.99999	0.99999	0.99931	0.99997
12	2460	0.94	0.99999	0.99999	0.99934	0.99997
13	2226	2.68	0.99999	0.99999	0.99999	0.99999
14	2471	0.92	0.99999	0.99999	0.99978	0.99996
15	2424	0.89	0.99998	0.99999	0.99903	0.99997
16	2226	1.99	0.99999	0.99999	0.99999	0.99999
17	2453	0.89	0.99999	0.99999	0.99976	0.99996
18	2412	0.86	0.99999	0.99999	0.99921	0.99996
19	2221	1.43	0.99999	0.99999	0.99997	0.99999
20	2433	0.85	0.99999	0.99999	0.99972	0.99994
21	2390	0.82	0.99999	0.99999	0.99907	0.99995
22	2211	1.05	0.99999	0.99999	0.99995	0.99998
23	2420	0.82	0.99999	0.99999	0.99966	0.99991
24	2369	0.78	0.99998	0.99999	0.99888	0.99993
25	2206	0.77	0.99999	0.99999	0.99919	0.99991
26	2412	0.40	0.99993	0.99998	0.99413	0.99784
27	2351	0.37	0.99979	0.99998	0.98401	0.99809

TABLE 7. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
28	2206	0.59	0.99997	0.99999	0.99747	0.99969
29	2722	0.49	0.99987	0.99999	0.98888	0.99943
30	2669	0.35	0.99988	0.99998	0.98930	0.99743
31	2455	0.24	0.99970	0.99994	0.97731	0.99197
32	2202	0.42	0.99990	0.99998	0.99177	0.99866
33	2655	0.23	0.99916	0.99995	0.95239	0.99298
34	2668	0.15	0.99927	0.99988	0.95521	0.98101
35	2448	0.06	0.99819	0.99962	0.92231	0.94317
36	2202	0.29	0.99971	0.99996	0.97960	0.99543
37	2603	0.04	0.99576	0.99966	0.87279	0.93932
38	2668	0.01	0.99663	0.99938	0.88258	0.90601
39	2443	-0.08	0.99227	0.99779	0.82478	0.82550
40	2193	0.20	0.99942	0.99992	0.96471	0.98813
41	2558	0.05	0.99090	0.99888	0.80844	0.83678
42	2668	-0.06	0.99336	0.99862	0.82993	0.83746
43	2649	-0.06	0.99340	0.99838	0.83034	0.83404
44	3471	0.53	0.99855	0.99999	0.93112	0.99972
45	2189	0.16	0.99915	0.99989	0.95500	0.98201
46	2528	-0.11	0.98492	0.99741	0.75693	0.75958
47	2667	-0.10	0.98940	0.99751	0.78635	0.78751
48	2649	-0.10	0.98945	0.99709	0.78676	0.78712
49	3361	0.41	0.99759	0.99999	0.90607	0.99917
50	2189	0.16	0.99915	0.99989	0.95500	0.98202
51	2503	-0.13	0.98181	0.99585	0.73639	0.73654
52	2667	-0.11	0.98762	0.99697	0.76859	0.76874
53	2648	-0.12	0.98767	0.99646	0.76898	0.76899
54	3265	0.34	0.99685	0.99999	0.89136	0.99824
55	2186	0.17	0.99922	0.99989	0.95776	0.98273
56	2480	-0.16	0.97859	0.99403	0.71665	0.71665
57	2667	-0.13	0.98538	0.99618	0.75166	0.75171
58	2648	-0.13	0.98543	0.99555	0.75203	0.75203
59	3182	0.28	0.99601	0.99998	0.87680	0.99663

TABLE 7. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	FF	@DUL IF	FF
60	2140	0.15	0.99910	0.99987	0.95350	0.97948
61	2462	-0.18	0.97552	0.99192	0.69768	0.69768
62	2666	-0.14	0.98324	0.99542	0.73542	0.73542
63	2648	-0.15	0.98329	0.99467	0.73579	0.73579
64	3108	0.22	0.99519	0.99997	0.86127	0.99357
65	2137	0.16	0.99920	0.99988	0.95688	0.98130
66	2448	-0.19	0.97166	0.98838	0.67923	0.67923
67	2666	-0.15	0.98119	0.99469	0.71954	0.71954
68	2648	-0.16	0.98125	0.99383	0.71987	0.71987
69	3039	0.17	0.99401	0.99994	0.84629	0.98883
70	2137	0.17	0.99932	0.99990	0.96055	0.98398
71	2437	-0.21	0.96784	0.98460	0.66186	0.66186
72	2666	-0.16	0.97852	0.99352	0.70402	0.70402
73	2647	-0.17	0.97858	0.99248	0.70432	0.70432
74	2981	0.13	0.99272	0.99991	0.83037	0.98058
75	2137	0.19	0.99945	0.99992	0.96531	0.98720
76	2428	-0.22	0.96436	0.98069	0.64607	0.64607
77	2665	-0.17	0.97593	0.99233	0.68949	0.68949
78	2647	-0.18	0.97599	0.99112	0.68977	0.68977
79	2927	0.09	0.99150	0.99986	0.81511	0.96879
80	2132	0.21	0.99954	0.99993	0.97057	0.98904
81	2421	-0.23	0.96116	0.97646	0.63268	0.63268
82	2665	-0.18	0.97355	0.99098	0.67602	0.67602
83	2646	-0.19	0.97361	0.98987	0.67628	0.67628
84	2880	0.06	0.98995	0.99978	0.79969	0.95098
85	2133	0.25	0.99967	0.99995	0.97745	0.99282
86	2415	-0.24	0.95786	0.97152	0.62116	0.62116
87	2664	-0.19	0.97136	0.98996	0.66366	0.66366
88	2646	-0.20	0.97142	0.98872	0.66390	0.66390
89	2835	0.03	0.98823	0.99965	0.78493	0.92696

TABLE 7. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
90	2131	0.29	0.99980	0.99997	0.98326	0.99514
91	2411	-0.25	0.95568	0.96764	0.61357	0.61357
92	2907	-0.12	0.99043	0.99451	0.78016	0.78016
93	2906	-0.12	0.99045	0.99402	0.78036	0.78036
94	2853	0.02	0.99391	0.99956	0.83838	0.91939
95	2193	0.40	0.99990	0.99998	0.99137	0.99839
96	2407	-0.26	0.95331	0.96269	0.60543	0.60543
97	2907	-0.13	0.98935	0.99372	0.76940	0.76940
98	2906	-0.13	0.98937	0.99317	0.76961	0.76961
99	2814	-0.01	0.99290	0.99937	0.82271	0.88297
100	2182	0.52	0.99996	0.99999	0.99648	0.99939
101	2405	-0.26	0.95128	0.95936	0.60027	0.60027
102	2907	-0.14	0.98843	0.99306	0.76037	0.76037
103	2906	-0.14	0.98846	0.99341	0.76055	0.76055
104	2776	-0.04	0.99125	0.99894	0.80602	0.84310
105	2182	0.72	0.99998	0.99999	0.99909	0.99986
106	2403	-0.26	0.95108	0.95702	0.59769	0.59769
107	2907	-0.14	0.98810	0.99281	0.75703	0.75703
108	2906	-0.14	0.98812	0.99209	0.75720	0.75720
109	2744	-0.06	0.99045	0.99862	0.79737	0.81751
110	2138	0.79	0.99999	0.99999	0.99947	0.99992
111	2403	-0.26	0.94980	0.95466	0.59323	0.59323
112	2907	-0.14	0.98803	0.99265	0.75639	0.75639
113	2906	-0.14	0.98805	0.99203	0.75654	0.75654
114	2725	-0.07	0.99000	0.99835	0.79253	0.80420
115	2135	0.80	0.99999	0.99999	0.99950	0.99992
116	2403	-0.27	0.94850	0.95235	0.58873	0.58873
117	2907	-0.14	0.98797	0.99260	0.75573	0.75573
118	2906	-0.14	0.98799	0.99197	0.75588	0.75588
119	2707	-0.08	0.98958	0.99806	0.78803	0.79413

TABLE 7. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
120	—	—	—	—	—	—
121	2400	-0.27	0.94604	0.94692	0.58063	0.58063
122	2906	-0.14	0.98787	0.99264	0.75484	0.75484
123	2906	-0.14	0.98791	0.99191	0.75512	0.75512
124	2699	-0.09	0.98957	0.99790	0.78799	0.79283
125	—	—	—	—	—	—
126	2401	-0.28	0.94350	0.94395	0.57326	0.57326
127	2907	-0.14	0.98781	0.99249	0.75420	0.75420
128	2905	-0.14	0.98784	0.99816	0.75446	0.75446
129	2699	-0.09	0.98964	0.99791	0.78869	0.79365
130	—	—	—	—	—	—
131	2401	-0.28	0.94107	0.94129	0.56668	0.56668
132	2907	-0.14	0.98778	0.99246	0.75389	0.75389
133	2906	-0.15	0.98781	0.99184	0.75413	0.75413
134	2699	-0.09	0.98970	0.99793	0.78938	0.79446
135	—	—	—	—	—	—
136	2401	-0.28	0.93987	0.94001	0.56341	0.56341
137	2907	-0.14	0.98775	0.99244	0.75358	0.75358
138	2906	-0.15	0.98778	0.99181	0.75380	0.75380
139	2699	-0.08	0.98980	0.99795	0.79043	0.79569

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.
(2) "IF" is the initial failure of the impact damaged zone,
"FF" is the final failure of the impact damaged bay.

TABLE 8. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION.

MODAL IMPACT ENERGY = 15 ft-lb
PROBABILITY FOR 100 ft-lb IMPACT = 0.1

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
1	2156	3.94	0.99999	0.99999	0.99999	0.99999
2	2486	0.97	0.99989	0.99999	0.99110	0.99998
3	2425	0.92	0.99989	0.99999	0.99106	0.99998
4	2156	3.79	0.99999	0.99999	0.99999	0.99999
5	2424	0.91	0.99988	0.99999	0.99088	0.99997
6	2403	0.90	0.99988	0.99999	0.99087	0.99997
7	2118	3.52	0.99999	0.99999	0.99999	0.99999
8	2370	0.86	0.99988	0.99999	0.99070	0.99997
9	2376	0.87	0.99988	0.99999	0.99071	0.99997
10	2119	3.13	0.99999	0.99999	0.99999	0.99999
11	2314	0.82	0.99988	0.99999	0.99074	0.99996
12	2348	0.85	0.99988	0.99999	0.99076	0.99997
13	2075	2.43	0.99999	0.99999	0.99999	0.99999
14	2278	0.77	0.99996	0.99999	0.99680	0.99994
15	2321	0.80	0.99983	0.99999	0.98715	0.99996
16	2075	1.79	0.99999	0.99999	0.99995	0.99999
17	2244	0.73	0.99995	0.99999	0.99658	0.99992
18	2289	0.76	0.99986	0.99999	0.98929	0.99995
19	2065	1.26	0.99999	0.99999	0.99961	0.99999
20	2208	0.68	0.99995	0.99999	0.99603	0.99988
21	2258	0.72	0.99985	0.99999	0.98785	0.99992
22	2047	0.90	0.99996	0.99999	0.99760	0.99997
23	2173	0.63	0.99995	0.99999	0.99530	0.99982
24	2234	0.68	0.99983	0.99999	0.98595	0.99989
25	2038	0.63	0.99986	0.99999	0.98926	0.99984
26	2145	0.25	0.99907	0.99996	0.95113	0.99422
27	2214	0.29	0.99682	0.99997	0.89952	0.99666

TABLE 8. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
28	2038	0.47	0.99957	0.99999	0.97290	0.99942
29	2608	0.43	0.99819	0.99998	0.92323	0.99921
30	2464	0.25	0.99826	0.99996	0.92287	0.99457
31	2242	0.13	0.99578	0.99990	0.87542	0.98058
32	2031	0.31	0.99850	0.99997	0.93644	0.99727
33	2527	0.17	0.98949	0.99994	0.80284	0.98835
34	2464	0.06	0.99072	0.99978	0.80826	0.95578
35	2231	-0.04	0.98003	0.99919	0.73421	0.84840
36	2032	0.19	0.99567	0.99994	0.88225	0.99010
37	2457	-0.01	0.96160	0.99947	0.64807	0.88134
38	2463	-0.07	0.96777	0.99878	0.66266	0.77166
39	2220	-0.16	0.94013	0.99500	0.57905	0.58305
40	2018	0.10	0.99193	0.99986	0.83411	0.97213
41	2407	-0.11	0.93277	0.99818	0.55856	0.65766
42	2463	-0.13	0.94658	0.99719	0.58557	0.62056
43	2431	-0.14	0.94748	0.99654	0.58797	0.60652
44	3424	0.51	0.98337	0.99999	0.75348	0.99971
45	2012	0.07	0.98881	0.99979	0.80695	0.95619
46	2360	-0.17	0.90518	0.99509	0.49837	0.50935
47	2462	-0.17	0.92595	0.99477	0.53116	0.53729
48	2430	-0.18	0.92692	0.99358	0.53316	0.53528
49	3311	0.39	0.97496	0.99999	0.70424	0.99910
50	2012	0.07	0.98881	0.99979	0.80695	0.95624
51	2323	-0.20	0.89301	0.99155	0.47605	0.47685
52	2462	-0.18	0.91732	0.99357	0.51053	0.51184
53	2430	-0.19	0.91824	0.99211	0.51127	0.51250
54	3209	0.32	0.96933	0.99998	0.67869	0.99800
55	2006	0.07	0.98970	0.99979	0.81446	0.95755
56	2293	-0.22	0.88101	0.98696	0.45592	0.45592
57	2461	-0.19	0.90807	0.99177	0.49223	0.49284
58	2429	-0.21	0.90892	0.98991	0.49372	0.49382
59	3117	0.25	0.96336	0.99997	0.65450	0.99597

TABLE 8. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
60	1954	0.05	0.98822	0.99975	0.80346	0.94752
61	2261	-0.24	0.86954	0.98125	0.43687	0.43687
62	2461	-0.21	0.89924	0.99004	0.47475	0.47475
63	2429	-0.22	0.90000	0.98779	0.47598	0.47598
64	3035	0.20	0.95749	0.99996	0.63099	0.99191
65	1948	0.06	0.98938	0.99976	0.81231	0.95095
66	2234	-0.26	0.85728	0.97136	0.41941	0.41941
67	2460	-0.22	0.89077	0.98838	0.45880	0.45880
68	2428	-0.23	0.89147	0.98577	0.45986	0.45986
69	2962	0.15	0.95050	0.99994	0.60894	0.98528
70	1948	0.07	0.99063	0.99979	0.82189	0.95829
71	2214	-0.28	0.84551	0.95988	0.40320	0.40320
72	2460	-0.23	0.88136	0.98562	0.44317	0.44317
73	2428	-0.24	0.88202	0.98242	0.44412	0.44412
74	2901	0.10	0.94306	0.99990	0.58731	0.97313
75	1949	0.09	0.99214	0.99984	0.83496	0.96703
76	2195	-0.30	0.83480	0.94717	0.38903	0.38903
77	2459	-0.24	0.87245	0.98277	0.42919	0.42919
78	2427	-0.25	0.87307	0.97898	0.43003	0.43003
79	2838	0.06	0.93608	0.99983	0.56717	0.95484
80	1938	0.10	0.99341	0.99986	0.85184	0.97178
81	2173	-0.31	0.82548	0.93268	0.37733	0.37733
82	2458	-0.25	0.86425	0.98018	0.41659	0.41659
83	2426	-0.26	0.86482	0.97584	0.41730	0.41730
84	2787	0.02	0.92831	0.99973	0.54791	0.92581
85	1939	0.14	0.99504	0.99990	0.87402	0.98198
86	2155	-0.32	0.81697	0.91514	0.36725	0.36725
87	2457	-0.25	0.85672	0.97779	0.40499	0.40499
88	2425	-0.26	0.85725	0.97294	0.40563	0.40563
89	2735	-0.01	0.92032	0.99956	0.53027	0.88468

TABLE 8. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
90	1936	0.18	0.99688	0.99994	0.89696	0.98793
91	2138	-0.33	0.81134	0.89871	0.36081	0.36081
92	2545	-0.23	0.93385	0.98262	0.52737	0.52737
93	2520	-0.24	0.93414	0.97974	0.52802	0.52802
94	2716	-0.03	0.95084	0.99937	0.59904	0.85162
95	2016	0.29	0.99841	0.99997	0.93424	0.99658
96	2117	-0.34	0.80523	0.87909	0.35411	0.35411
97	2545	-0.24	0.92878	0.97991	0.51506	0.51506
98	2520	-0.25	0.92908	0.97662	0.51571	0.51571
99	2664	-0.07	0.94463	0.99902	0.57845	0.77207
100	2000	0.39	0.99941	0.99998	0.96566	0.99872
101	2105	-0.35	0.80138	0.86335	0.34986	0.34986
102	2544	-0.25	0.92457	0.97766	0.50482	0.50482
103	2519	-0.25	0.92484	0.97400	0.50537	0.50537
104	2617	-0.10	0.93627	0.99825	0.55663	0.68085
105	2000	0.57	0.99984	0.99999	0.98817	0.99974
106	2089	-0.36	0.79946	0.85101	0.34773	0.34773
107	2544	-0.25	0.92303	0.97679	0.50106	0.50106
108	2519	-0.26	0.92328	0.97299	0.50155	0.50155
109	2576	-0.12	0.93217	0.99758	0.54629	0.61840
110	1949	0.64	0.99991	0.99999	0.99238	0.99984
111	2079	-0.36	0.79615	0.83997	0.34406	0.34406
112	2544	-0.25	0.92276	0.97659	0.50037	0.50037
113	2518	-0.26	0.92297	0.97238	0.50081	0.50081
114	2546	-0.13	0.92988	0.99698	0.54050	0.58479
115	1944	0.64	0.99992	0.99999	0.99277	0.99985
116	2068	-0.37	0.79278	0.82910	0.34035	0.34035
117	2543	-0.25	0.92247	0.97640	0.49966	0.49966
118	2518	-0.26	0.92267	0.97216	0.50006	0.50006
119	2521	-0.15	0.92775	0.99629	0.53513	0.55985

TABLE 8. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
120	—	—	—	—	—	—
121	2017	-0.39	0.78650	0.79532	0.33369	0.33369
122	2543	-0.25	0.92172	0.97615	0.49806	0.49806
123	2518	-0.26	0.92222	0.97195	0.49904	0.49904
124	2511	-0.15	0.92771	0.99611	0.53502	0.55429
125	—	—	—	—	—	—
126	2008	-0.39	0.78069	0.78545	0.32786	0.32786
127	2543	-0.25	0.92148	0.97600	0.49743	0.49743
128	2518	-0.26	0.92193	0.97176	0.49830	0.49830
129	2511	-0.15	0.92804	0.99614	0.53586	0.55560
130	—	—	—	—	—	—
131	1999	-0.40	0.77539	0.77792	0.32274	0.32274
132	2543	-0.25	0.92138	0.97593	0.49717	0.49717
133	2518	-0.26	0.92179	0.97166	0.49795	0.49795
134	2511	-0.15	0.92837	0.99616	0.53671	0.55690
135	—	—	—	—	—	—
136	1991	-0.40	0.77276	0.77437	0.32020	0.32020
137	2543	-0.25	0.92127	0.97586	0.49687	0.49687
138	2518	-0.26	0.92164	0.97157	0.49759	0.49759
139	2511	-0.15	0.92887	0.99621	0.53796	0.55888

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.

(2) "IF" is the initial failure of the impact damaged zone, "FF" is the final failure of the impact damaged bay.

TABLE 9. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION.

DISCRETE IMPACT AT 100 ft-lb ENERGY LEVEL

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
1	1999	3.58	1.00000	1.00000	1.00000	1.00000
2	2332	0.85	0.99991	1.00000	0.98835	0.99993
3	2270	0.80	0.99991	1.00000	0.98891	0.99991
4	1999	3.44	1.00000	1.00000	1.00000	1.00000
5	2268	0.79	0.99991	1.00000	0.98796	0.99990
6	2243	0.77	0.99991	1.00000	0.98850	0.99989
7	1955	3.17	1.00000	1.00000	1.00000	1.00000
8	2212	0.74	0.99990	1.00000	0.98760	0.99986
9	2219	0.75	0.99991	1.00000	0.98808	0.99987
10	1955	2.81	1.00000	1.00000	1.00000	1.00000
11	2148	0.69	0.99990	1.00000	0.98766	0.99981
12	2188	0.72	0.99991	1.00000	0.98810	0.99984
13	1904	2.15	1.00000	1.00000	1.00000	1.00000
14	2066	0.61	0.99997	1.00000	0.99603	0.99964
15	2159	0.68	0.99986	1.00000	0.98173	0.99979
16	1904	1.56	1.00000	1.00000	0.99997	1.00000
17	2027	0.56	0.99997	1.00000	0.99561	0.99951
18	2121	0.64	0.99988	1.00000	0.98490	0.99971
19	1893	1.07	1.00000	1.00000	0.99964	0.99998
20	1980	0.51	0.99996	0.99999	0.99498	0.99924
21	2091	0.59	0.99987	1.00000	0.98270	0.99961
22	1872	0.73	0.99998	1.00000	0.99739	0.99986
23	1939	0.46	0.99995	0.99999	0.99412	0.99886
24	2064	0.55	0.99984	1.00000	0.97968	0.99946
25	1862	0.49	0.99989	0.99999	0.98566	0.99914
26	1905	0.11	0.99901	0.99976	0.87992	0.96978
27	2040	0.19	0.99657	0.99990	0.64026	0.98661

TABLE 9. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	RELIABILITY @DLL FF	RELIABILITY @DUL IF	RELIABILITY @DUL FF
28	1862	0.34	0.99960	0.99998	0.94996	0.99696
29	2434	0.33	0.99791	0.99997	0.76227	0.99666
30	2242	0.13	0.99799	0.99982	0.77009	0.97674
31	2025	0.02	0.99477	0.99938	0.50676	0.92293
32	1853	0.20	0.99852	0.99991	0.82520	0.98777
33	2349	0.09	0.98492	0.99971	0.13917	0.96330
34	2241	-0.03	0.98695	0.99881	0.18194	0.85667
35	2010	-0.13	0.96637	0.99561	0.01182	0.56502
36	1853	0.08	0.99516	0.99969	0.53290	0.96055
37	2272	-0.09	0.91627	0.99752	0.00001	0.72486
38	2240	-0.15	0.93513	0.99390	0.00017	0.45200
39	1995	-0.25	0.83964	0.97572	0.00000	0.04119
40	1834	+0.00	0.98960	0.99923	0.25769	0.90440
41	2211	-0.18	0.80439	0.99144	0.00000	0.32778
42	2239	-0.21	0.86459	0.98673	0.00000	0.17662
43	2201	-0.22	0.86536	0.98366	0.00000	0.11793
44	3274	0.44	0.97269	0.99999	0.02751	0.99867
45	1826	-0.03	0.98481	0.99878	0.13721	0.85406
46	2162	-0.24	0.66890	0.97937	0.00000	0.06690
47	2239	-0.24	0.77935	0.97725	0.00000	0.05047
48	2200	-0.26	0.78043	0.97201	0.00000	0.02515
49	3158	0.33	0.95306	0.99997	0.00195	0.99645
50	1826	-0.03	0.98481	0.99879	0.13721	0.85425
51	2119	-0.27	0.60326	0.96708	0.00000	0.01300
52	2238	-0.26	0.73649	0.97206	0.00000	0.02530
53	2199	-0.27	0.73764	0.96565	0.00000	0.01073
54	3055	0.25	0.93873	0.99995	0.00027	0.99306
55	1817	-0.03	0.98635	0.99883	0.16800	0.85961
56	2081	-0.29	0.53554	0.94965	0.00000	0.00123
57	2237	-0.27	0.69202	0.96635	0.00000	0.01178
58	2199	-0.28	0.69322	0.95866	0.00000	0.00418
59	2963	0.19	0.92178	0.99990	0.00003	0.98715

TABLE 9. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
60	1776	-0.04	0.98400	0.99862	0.12328	0.83551
61	2046	-0.32	0.46677	0.92563	0.00000	0.00004
62	2237	-0.28	0.64508	0.95988	0.00000	0.00493
63	2198	-0.29	0.64627	0.95074	0.00000	0.00143
64	2881	0.13	0.90133	0.99982	0.00000	0.97712
65	1769	-0.04	0.98580	0.99870	0.15627	0.84445
66	2015	-0.34	0.39831	0.89372	0.00000	0.00000
67	2236	-0.29	0.59638	0.95274	0.00000	0.00187
68	2198	-0.30	0.59757	0.94202	0.00000	0.00043
69	2807	0.08	0.87805	0.99969	0.00000	0.96113
70	1770	-0.03	0.98753	0.99886	0.19632	0.86274
71	1987	-0.36	0.33398	0.85338	0.00000	0.00000
72	2236	-0.30	0.54560	0.94468	0.00000	0.00062
73	2197	-0.31	0.54680	0.93218	0.00000	0.00011
74	2739	0.04	0.85032	0.99949	0.00000	0.93598
75	1770	-0.01	0.98964	0.99906	0.25882	0.88510
76	1962	-0.37	0.27707	0.80504	0.00000	0.00000
77	2234	-0.31	0.49617	0.93572	0.00000	0.00018
78	2195	-0.32	0.49735	0.92126	0.00000	0.00002
79	2678	-0.00	0.81984	0.99918	0.00000	0.89921
80	1756	-0.00	0.99202	0.99919	0.35341	0.89978
81	1938	-0.39	0.23126	0.75123	0.00000	0.00000
82	2233	-0.32	0.44919	0.92660	0.00000	0.00005
83	2195	-0.33	0.45030	0.91017	0.00000	0.00000
84	2622	-0.04	0.78546	0.99872	0.00000	0.84665
85	1756	0.03	0.99439	0.99943	0.48178	0.92882
86	1917	-0.40	0.19429	0.69347	0.00000	0.00000
87	2233	-0.32	0.40543	0.91725	0.00000	0.00001
88	2194	-0.33	0.40649	0.89883	0.00000	0.00000
89	2571	-0.07	0.74910	0.99806	0.00000	0.77686

TABLE 9. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
90	1752	0.06	0.99635	0.99962	0.62223	0.95133
91	1895	-0.41	0.17140	0.63482	0.00000	0.00000
92	2233	-0.33	0.80920	0.90919	0.00000	0.00000
93	2194	-0.34	0.80964	0.88909	0.00000	0.00000
94	2524	-0.10	0.87796	0.99714	0.00000	0.68963
95	1831	0.17	0.99843	0.99988	0.81525	0.98446
96	1869	-0.42	0.14806	0.55997	0.00000	0.00000
97	2232	-0.33	0.78857	0.89815	0.00000	0.00000
98	2193	-0.35	0.78905	0.87575	0.00000	0.00000
99	2467	-0.13	0.85253	0.99538	0.00000	0.54869
100	1807	0.26	0.99945	0.99995	0.93111	0.99337
101	1847	0.43	0.13434	0.49581	0.00000	0.00000
102	2231	-0.34	0.76997	0.88818	0.00000	0.00000
103	2192	-0.35	0.77043	0.86374	0.00000	0.00000
104	2415	-0.17	0.82091	0.99265	0.00000	0.38377
105	1807	0.42	0.99987	0.99999	0.98350	0.99845
106	1827	-0.44	0.12774	0.43912	0.00000	0.00000
107	2231	-0.34	0.76280	0.88399	0.00000	0.00000
108	2192	-0.35	0.76324	0.85868	0.00000	0.00000
109	2368	-0.19	0.80356	0.98969	0.00000	0.26068
110	1769	0.49	0.99992	0.99999	0.99010	0.99909
111	1814	-0.44	0.11678	0.39134	0.00000	0.00000
112	2230	-0.34	0.76140	0.88291	0.00000	0.00000
113	2191	-0.35	0.76181	0.85737	0.00000	0.00000
114	2336	-0.21	0.79329	0.98713	0.00000	0.18621
115	1762	0.49	0.99993	0.99999	0.99086	0.99911
116	1801	-0.45	0.10623	0.34348	0.00000	0.00000
117	2230	-0.34	0.75998	0.88195	0.00000	0.00000
118	2191	-0.35	0.76036	0.85621	0.00000	0.00000
119	2305	-0.22	0.78339	0.98414	0.00000	0.12568

TABLE 9. RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
120	—	—	—	—	—	—
121	1735	-0.47	0.08802	0.16768	0.00000	0.00000
122	2230	-0.34	0.75792	0.88127	0.00000	0.00000
123	2191	-0.35	0.75864	0.85540	0.00000	0.00000
124	2292	-0.22	0.78327	0.98299	0.00000	0.10793
125	—	—	—	—	—	—
126	1719	-0.48	0.07363	0.11816	0.00000	0.00000
127	2230	-0.34	0.75652	0.88047	0.00000	0.00000
128	2191	-0.36	0.75719	0.85444	0.00000	0.00000
129	2292	-0.22	0.78483	0.98312	0.00000	0.10977
130	—	—	—	—	—	—
131	1705	-0.49	0.06207	0.08027	0.00000	0.00000
132	2230	-0.34	0.75585	0.88006	0.00000	0.00000
133	2191	-0.36	0.75648	0.85395	0.00000	0.00000
134	2291	-0.22	0.78639	0.98324	0.00000	0.11164
135	—	—	—	—	—	—
136	1695	-0.49	0.05683	0.06068	0.00000	0.00000
137	2230	-0.34	0.75516	0.87965	0.00000	0.00000
138	2191	-0.36	0.75576	0.85346	0.00000	0.00000
139	2291	-0.22	0.78870	0.98344	0.00000	0.11456

Note: (1) B-basis allowable strain is based on the damage tolerance design criterion for no structural failure at DUL.
(2) "IF" is the initial failure of the impact damaged zone, "FF" is the final failure of the impact damaged bay.

TABLE 10. SUMMARY OF IMPACT DAMAGE CRITICAL LOCATIONS, LEAR FAN 2100 UPPER WING SKIN.

IMPACT THREAT	DUL	REG.	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
I. LOWEST RELIABILITY AT DLL FOR INITIAL FAILURE							
LOW	AVE.	87	-0.03	0.99725	0.99790	0.87741	0.87741
LOW	AVE.	82	-0.02	0.99756	0.99815	0.88580	0.88580
LOW	AVE.	77	-0.01	0.99792	0.99848	0.89461	0.89461
LOW	MAX.	36	-0.12	0.99100	0.99100	0.77922	0.77922
LOW	MAX.	131	-0.12	0.99127	0.99127	0.78219	0.78219
LOW	MAX.	126	-0.12	0.99181	0.99181	0.78818	0.78818
MED.	AVE.	87	-0.17	0.97588	0.99203	0.68918	0.68918
MED.	AVE.	82	-0.17	0.97807	0.99305	0.70150	0.70150
MED.	AVE.	77	-0.16	0.98059	0.99442	0.71553	0.71553
MED.	MAX.	136	-0.28	0.93987	0.94001	0.56341	0.56341
MED.	MAX.	131	-0.28	0.94107	0.94129	0.56668	0.56668
MED.	MAX.	126	-0.28	0.94350	0.94395	0.57326	0.57326
HIGH	AVE.	87	-0.24	0.87290	0.98215	0.42974	0.42974
HIGH	AVE.	82	-0.23	0.88047	0.98457	0.44157	0.44157
HIGH	AVE.	77	-0.22	0.88918	0.98770	0.45579	0.45579
HIGH	MAX.	136	-0.40	0.77276	0.77497	0.32020	0.32020
HIGH	MAX.	131	-0.40	0.77539	0.77870	0.32274	0.32274
HIGH	MAX.	126	-0.39	0.78069	0.78655	0.32786	0.32786
100fb	AVE.	87	-0.31	0.49515	0.93497	0.00000	0.00016
100fb	AVE.	82	-0.30	0.53714	0.94252	0.00000	0.00046
100fb	AVE.	77	-0.29	0.58358	0.95022	0.00000	0.00133
100fb	MAX.	136	-0.49	0.05683	0.06068	0.00000	0.00000
100fb	MAX.	131	-0.49	0.06207	0.08027	0.00000	0.00000
100fb	MAX.	126	-0.48	0.07363	0.11816	0.00000	0.00000

TABLE 10. SUMMARY OF IMPACT DAMAGE CRITICAL LOCATIONS, LEAR FAN 2100 UPPER WING SKIN. (CONTINUED)

IMPACT THREAT	DUL	REG.	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
II. LOWEST RELIABILITY AT DLL FOR FINAL FAILURE							
LOW	AVE.	87	-0.03	0.99725	0.99790	0.87741	0.87741
LOW	AVE.	82	-0.02	0.99756	0.99815	0.88580	0.88580
LOW	AVE.	77	-0.01	0.99792	0.99848	0.89461	0.89461
LOW	MAX.	136	-0.12	0.99100	0.99100	0.77922	0.77922
LOW	MAX.	131	-0.12	0.99127	0.99127	0.78219	0.78219
LOW	MAX.	126	-0.12	0.99181	0.99181	0.78818	0.78818
MED.	AVE.	87	-0.17	0.97588	0.99203	0.68918	0.68918
MED.	AVE.	82	-0.17	0.97807	0.99305	0.70150	0.70150
MED.	AVE.	137	-0.14	0.98883	0.99323	0.76433	0.76433
MED.	MAX.	136	-0.28	0.93987	0.94001	0.56341	0.56341
MED.	MAX.	131	-0.28	0.94107	0.94129	0.56668	0.56668
MED.	MAX.	126	-0.28	0.94350	0.94395	0.57326	0.57326
HIGH	AVE.	137	-0.25	0.92670	0.97822	0.50991	0.50991
HIGH	AVE.	132	-0.24	0.92780	0.97880	0.51258	0.51258
HIGH	AVE.	127	-0.24	0.92936	0.97964	0.51639	0.51639
HIGH	MAX.	136	-0.40	0.77276	0.77497	0.32020	0.32020
HIGH	MAX.	131	-0.40	0.77539	0.77870	0.32274	0.32274
HIGH	MAX.	126	-0.39	0.78069	0.78655	0.32786	0.32786
100fb	AVE.	137	-0.34	0.77825	0.89184	0.00000	0.00000
100fb	AVE.	132	-0.34	0.78303	0.89436	0.00000	0.00000
100fb	AVE.	127	-0.33	0.78972	0.89789	0.00000	0.00000
100fb	MAX.	136	-0.49	0.05683	0.06068	0.00000	0.00000
100fb	MAX.	131	-0.49	0.06207	0.08027	0.00000	0.00000
100fb	MAX.	126	-0.48	0.07363	0.11816	0.00000	0.00000

TABLE 10. SUMMARY OF IMPACT DAMAGE CRITICAL LOCATIONS, LEAR FAN 2100 UPPER WING SKIN. (CONTINUED)

IMPACT THREAT	DUL	REG.	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
III. LOWEST RELIABILITY AT DUL FOR INITIAL FAILURE							
LOW	AVE.	87	-0.03	0.99725	0.99790	0.87741	0.87741
LOW	AVE.	82	-0.02	0.99756	0.99815	0.88580	0.88580
LOW	AVE.	77	-0.01	0.99792	0.99848	0.89461	0.89461
LOW	MAX.	136	-0.12	0.99100	0.99100	0.77922	0.77922
LOW	MAX.	131	-0.12	0.99127	0.99127	0.78219	0.78219
LOW	MAX.	126	-0.12	0.99181	0.99181	0.78818	0.78818
MED.	AVE.	87	-0.17	0.97588	0.99203	0.68918	0.68918
MED.	AVE.	82	-0.17	0.97807	0.99305	0.70150	0.70150
MED.	AVE.	77	-0.16	0.98059	0.99442	0.71553	0.71553
MED.	MAX.	136	-0.28	0.93987	0.94001	0.56341	0.56341
MED.	MAX.	131	-0.28	0.94107	0.94129	0.56668	0.56668
MED.	MAX.	126	-0.28	0.94350	0.94395	0.57326	0.57326
HIGH	AVE.	87	-0.24	0.87290	0.98215	0.42974	0.42974
HIGH	AVE.	82	-0.23	0.88047	0.98457	0.44157	0.44157
HIGH	AVE.	77	-0.22	0.88918	0.98770	0.45579	0.45579
HIGH	MAX.	136	-0.40	0.77276	0.77497	0.32020	0.32020
HIGH	MAX.	131	-0.40	0.77539	0.77870	0.32274	0.32274
HIGH	MAX.	126	-0.39	0.78069	0.78655	0.32786	0.32786
100ft-lb	AVE.	137	-0.34	0.77825	0.89184	0.00000	0.00000
100ft-lb	AVE.	132	-0.34	0.78303	0.89436	0.00000	0.00000
100ft-lb	AVE.	127	-0.33	0.78972	0.89789	0.00000	0.00000
100ft-lb	MAX.	136	-0.49	0.05683	0.06068	0.00000	0.00000
100ft-lb	MAX.	131	-0.49	0.06207	0.08027	0.00000	0.00000
100ft-lb	MAX.	126	-0.48	0.07363	0.11816	0.00000	0.00000

TABLE 10. SUMMARY OF IMPACT DAMAGE CRITICAL LOCATIONS, LEAR FAN 2100 UPPER WING SKIN. (CONTINUED)

IMPACT THREAT	DUL	REG.	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
IV. LOWEST RELIABILITY AT DUL FOR FINAL FAILURE							
LOW	AVE.	87	-0.03	0.99725	0.99790	0.87741	0.87741
LOW	AVE.	82	-0.02	0.99756	0.99815	0.88580	0.88580
LOW	AVE.	77	-0.01	0.99792	0.99848	0.89461	0.89461
LOW	MAX.	136	-0.12	0.99100	0.99100	0.77922	0.77922
LOW	MAX.	131	-0.12	0.99127	0.99127	0.78219	0.78219
LOW	MAX.	126	-0.12	0.99181	0.99181	0.78818	0.78818
MED.	AVE.	87	-0.17	0.97588	0.99203	0.68918	0.68918
MED.	AVE.	82	-0.17	0.97808	0.99305	0.70150	0.70150
MED.	AVE.	77	-0.16	0.98059	0.99442	0.71553	0.71553
MED.	MAX.	136	-0.28	0.93987	0.94001	0.56341	0.56341
MED.	MAX.	131	-0.28	0.94107	0.94129	0.56668	0.56668
MED.	MAX.	126	-0.28	0.94350	0.94395	0.57326	0.57326
HIGH	AVE.	87	-0.24	0.87290	0.98215	0.42974	0.42974
HIGH	AVE.	82	-0.23	0.88047	0.98457	0.44157	0.44157
HIGH	AVE.	77	-0.22	0.88918	0.98770	0.45579	0.45579
HIGH	MAX.	136	-0.40	0.77276	0.77497	0.32020	0.32020
HIGH	MAX.	131	-0.40	0.77539	0.77870	0.32274	0.32274
HIGH	MAX.	126	-0.39	0.78069	0.78655	0.32786	0.32786
100fb	AVE.	137	-0.34	0.77825	0.89184	0.00000	0.00000
100fb	AVE.	132	-0.34	0.78303	0.89436	0.00000	0.00000
100fb	AVE.	127	-0.33	0.78972	0.89789	0.00000	0.00000
100fb	MAX.	136	-0.49	0.05683	0.06068	0.00000	0.00000
100fb	MAX.	131	-0.49	0.06207	0.08027	0.00000	0.00000
100fb	MAX.	126	-0.48	0.07363	0.11816	0.00000	0.00000

TABLE 10. SUMMARY OF IMPACT DAMAGE CRITICAL LOCATIONS, LEAR FAN 2100 UPPER WING SKIN. (CONCLUDED)

IMPACT THREAT	DUL	REG.	M.S.	RELIABILITY @DLL IF	@DLL FF	@DUL IF	@DUL FF
V. LOWEST MARGIN OF SAFETY							
LOW	AVE.	87	-0.03	0.99725	0.99790	0.87741	0.87741
LOW	MAX.	136	-0.12	0.99100	0.99100	0.77922	0.77922
MED.	AVE.	87	-0.17	0.97588	0.99203	0.68918	0.68918
MED.	MAX.	136	-0.28	0.93987	0.94001	0.56341	0.56341
HIGH	AVE.	137	-0.25	0.92670	0.97822	0.50991	0.50991
HIGH	MAX.	136	-0.40	0.77276	0.77497	0.32020	0.32020
100fb	AVE.	137	-0.34	0.77825	0.89184	0.00000	0.00000
100fb	MAX.	136	-0.49	0.05683	0.06068	0.00000	0.00000
VI. HIGHEST MARGIN OF SAFETY							
LOW	AVE.	1	5.00	1.00000	1.00000	1.00000	1.00000
LOW	MAX.	1	4.89	1.00000	1.00000	1.00000	1.00000
MED.	AVE.	1	4.33	0.99999	0.99999	0.99999	0.99999
MED.	MAX.	1	4.24	0.99999	0.99999	0.99999	0.99999
HIGH	AVE.	1	4.04	0.99999	0.99999	0.99999	0.99999
HIGH	MAX.	1	3.95	0.99999	0.99999	0.99999	0.99999
100fb	AVE.	1	3.67	1.00000	1.00000	1.00000	1.00000
100fb	MAX.	1	3.58	1.00000	1.00000	1.00000	1.00000

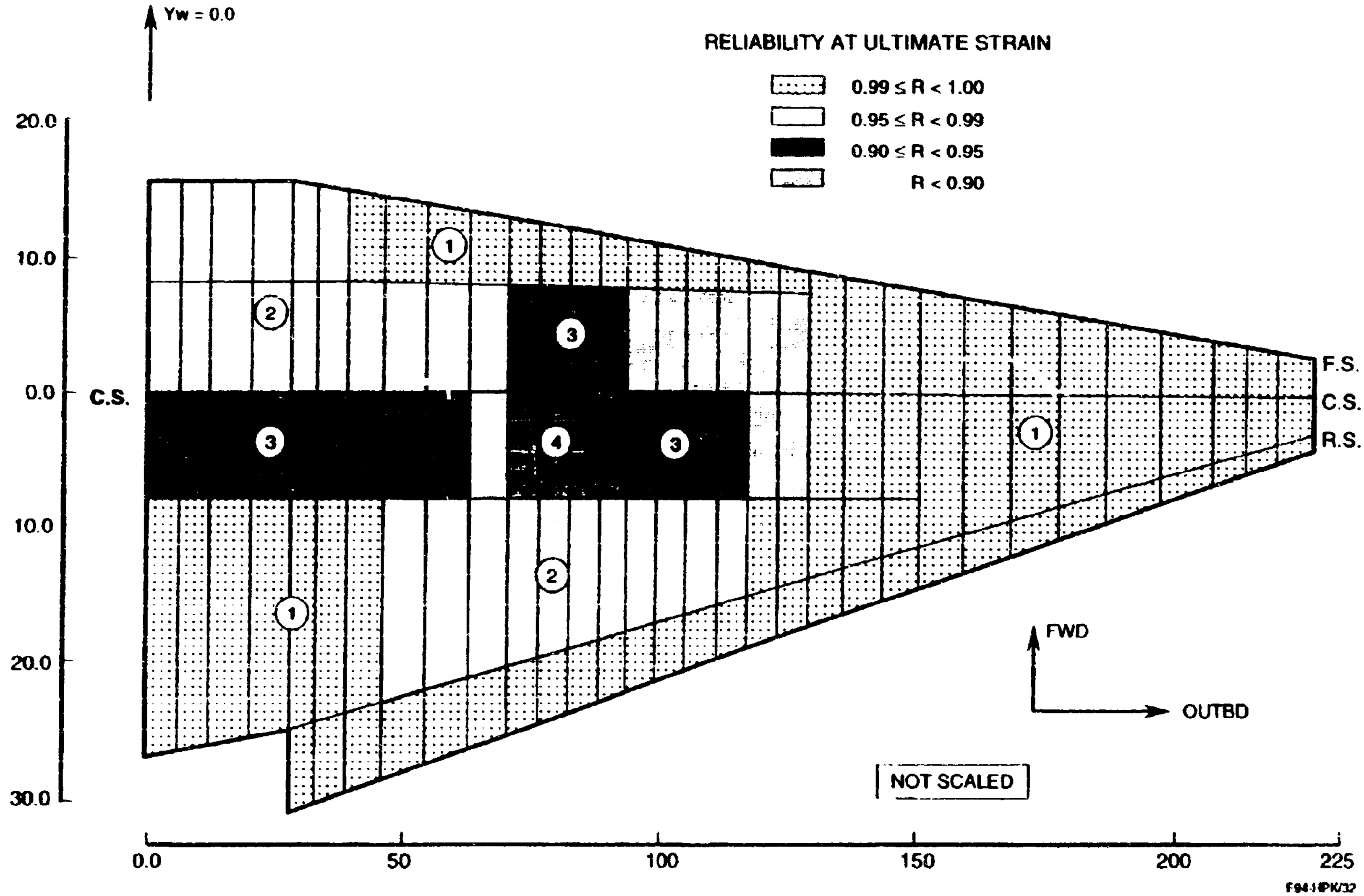

FIGURE 27. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN.

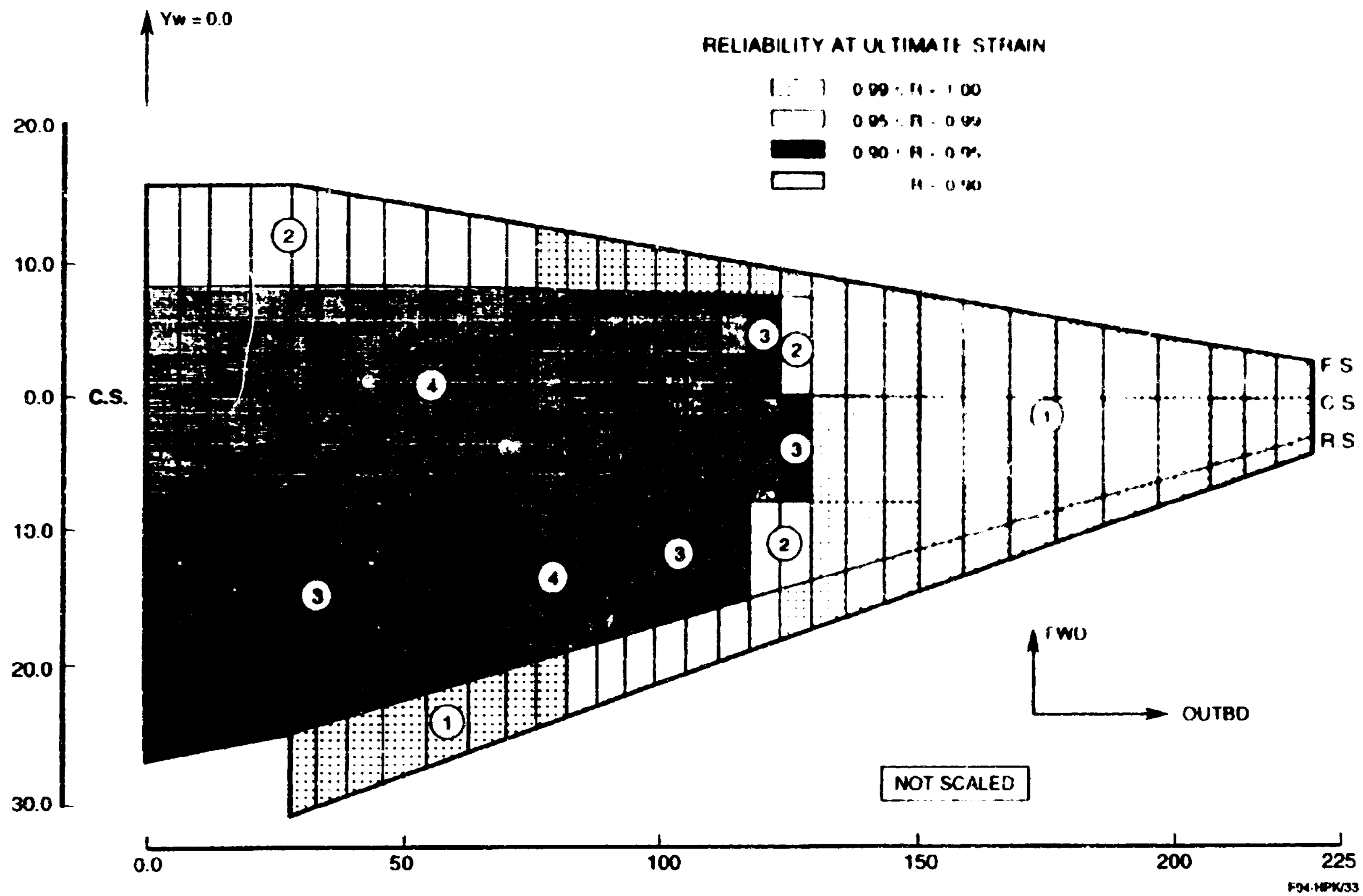

FIGURE 28. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN.

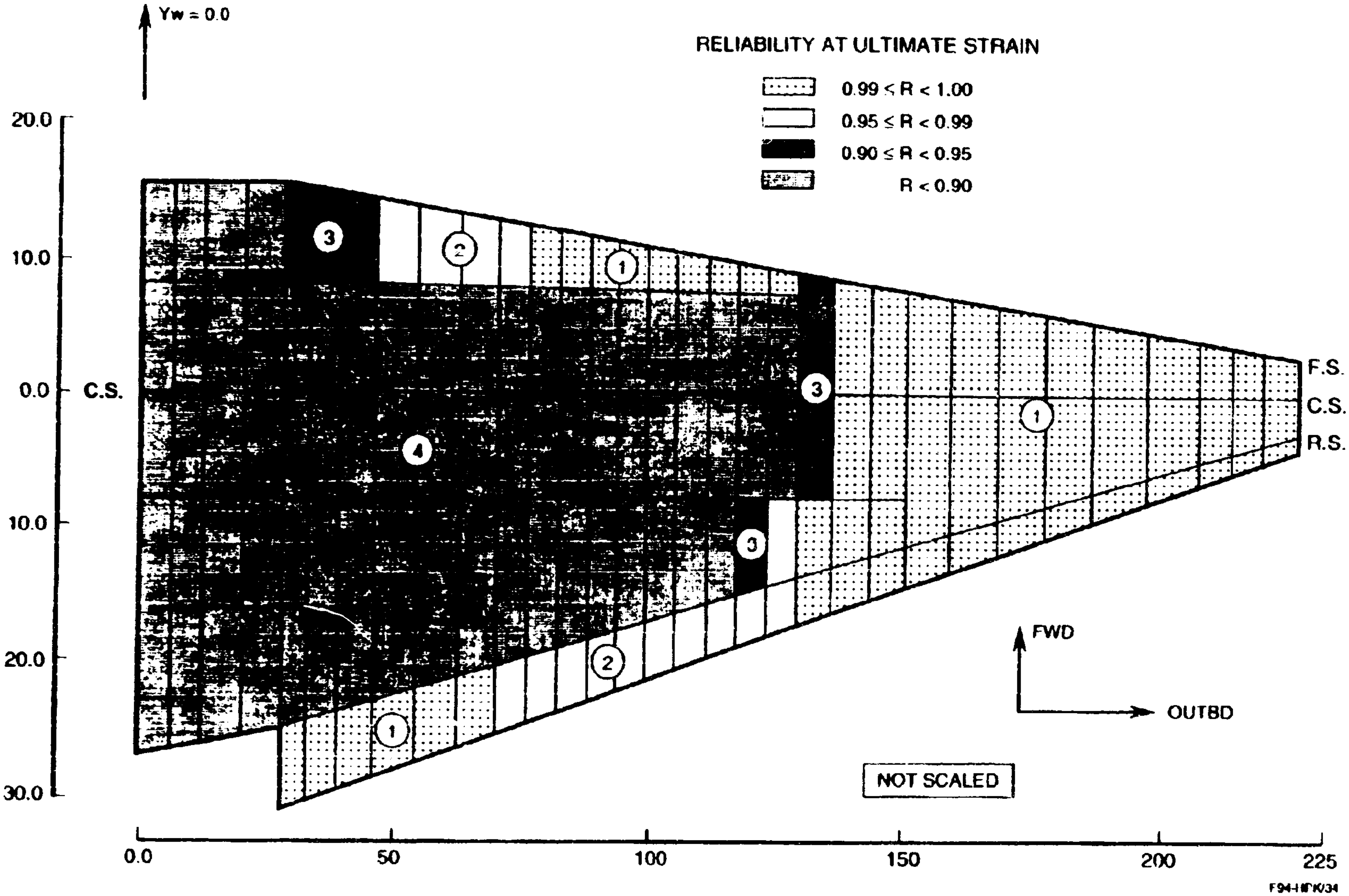

FIGURE 29. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN.

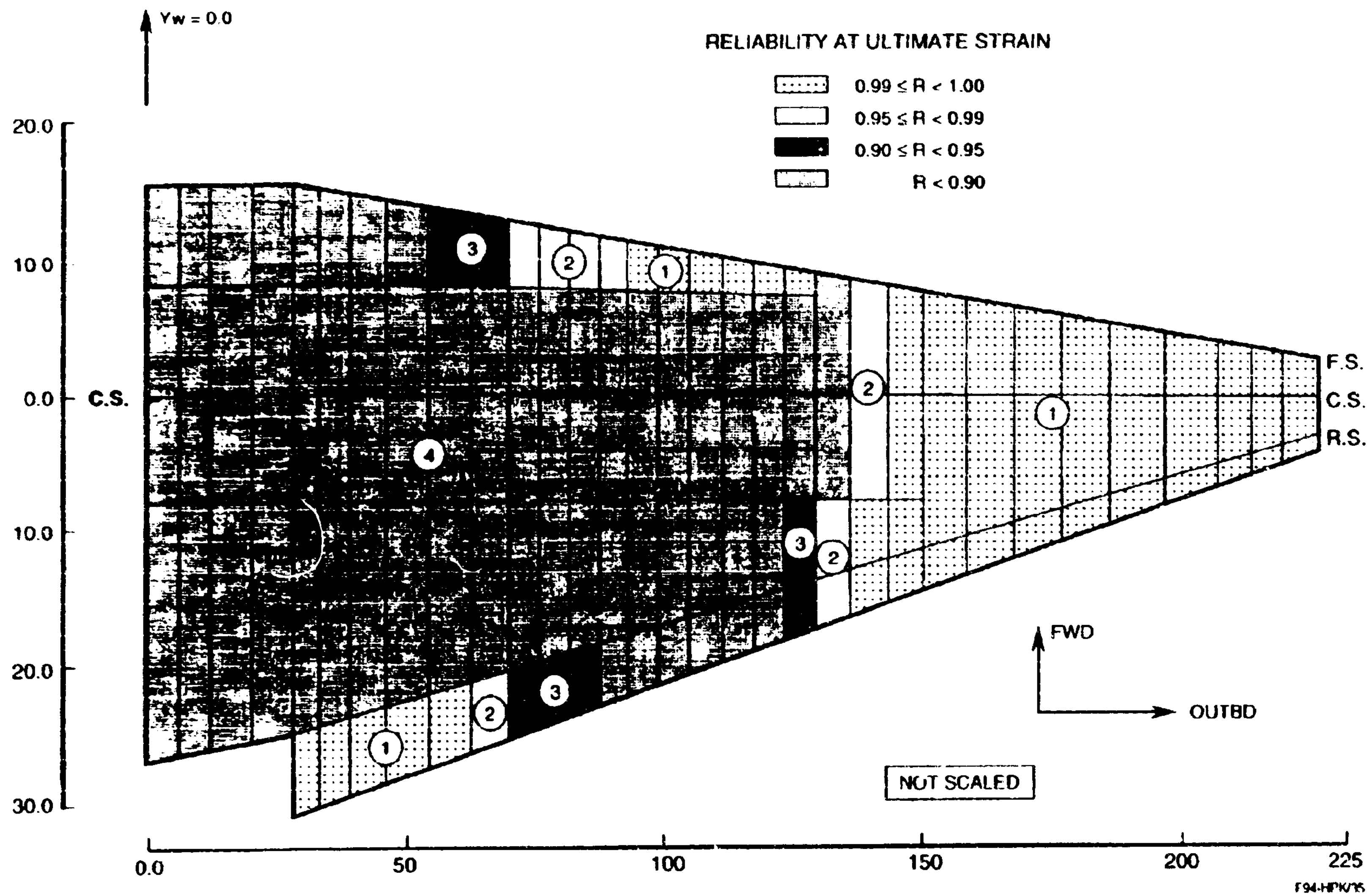

FIGURE 30. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN.

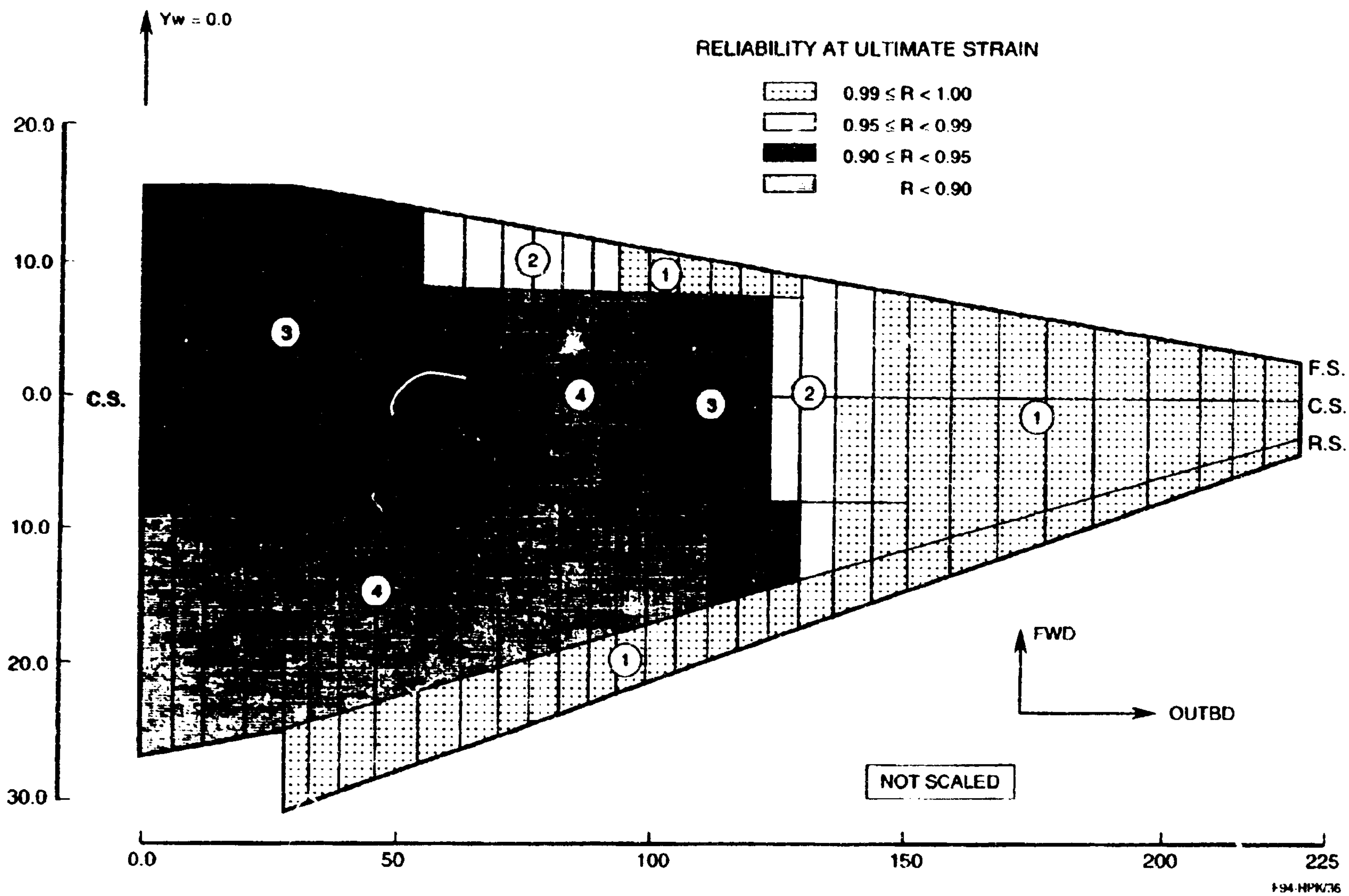

FIGURE 31. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN.

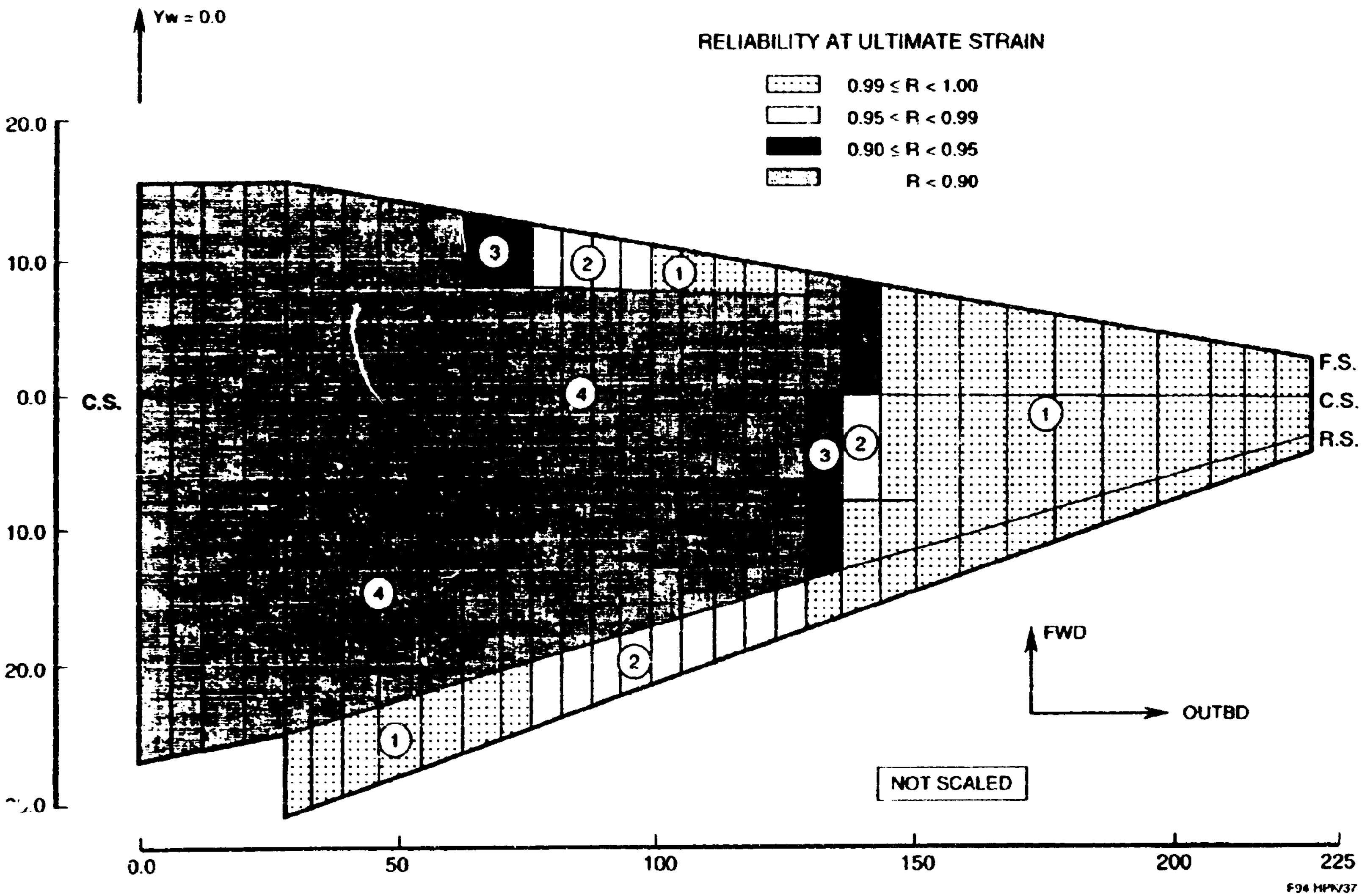

FIGURE 32. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN.

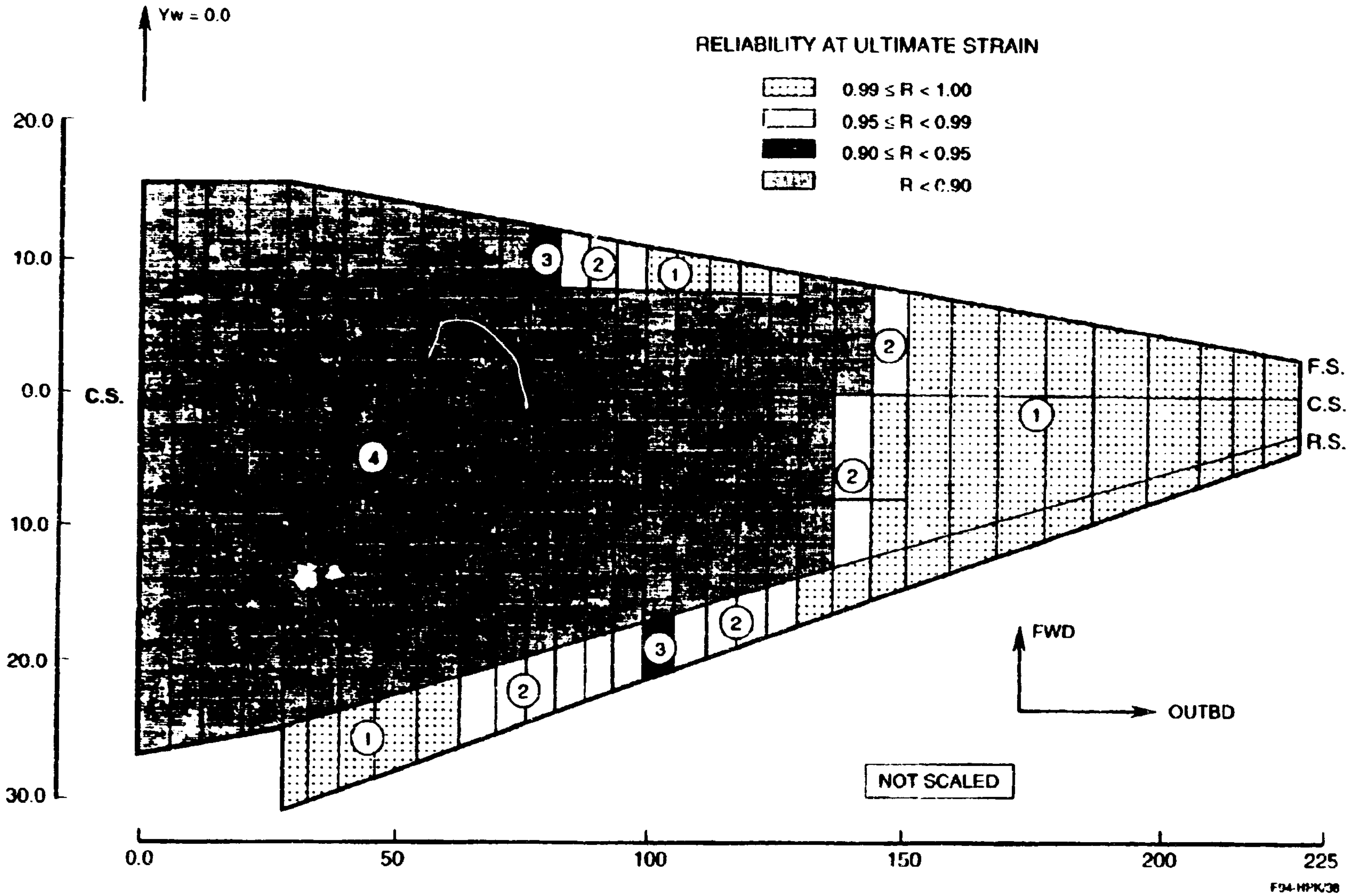

FIGURE 33. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN.

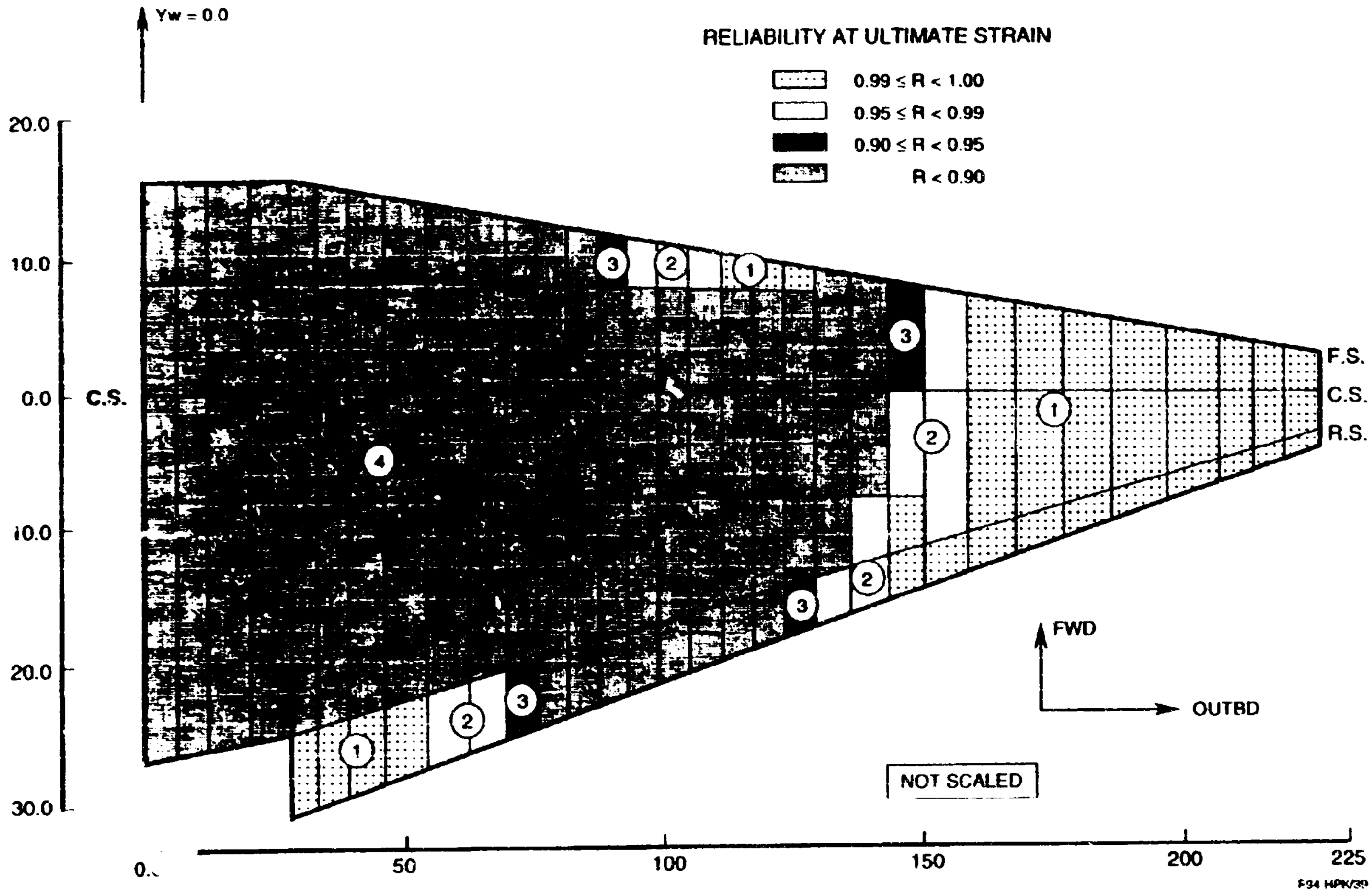

FIGURE 34. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN.

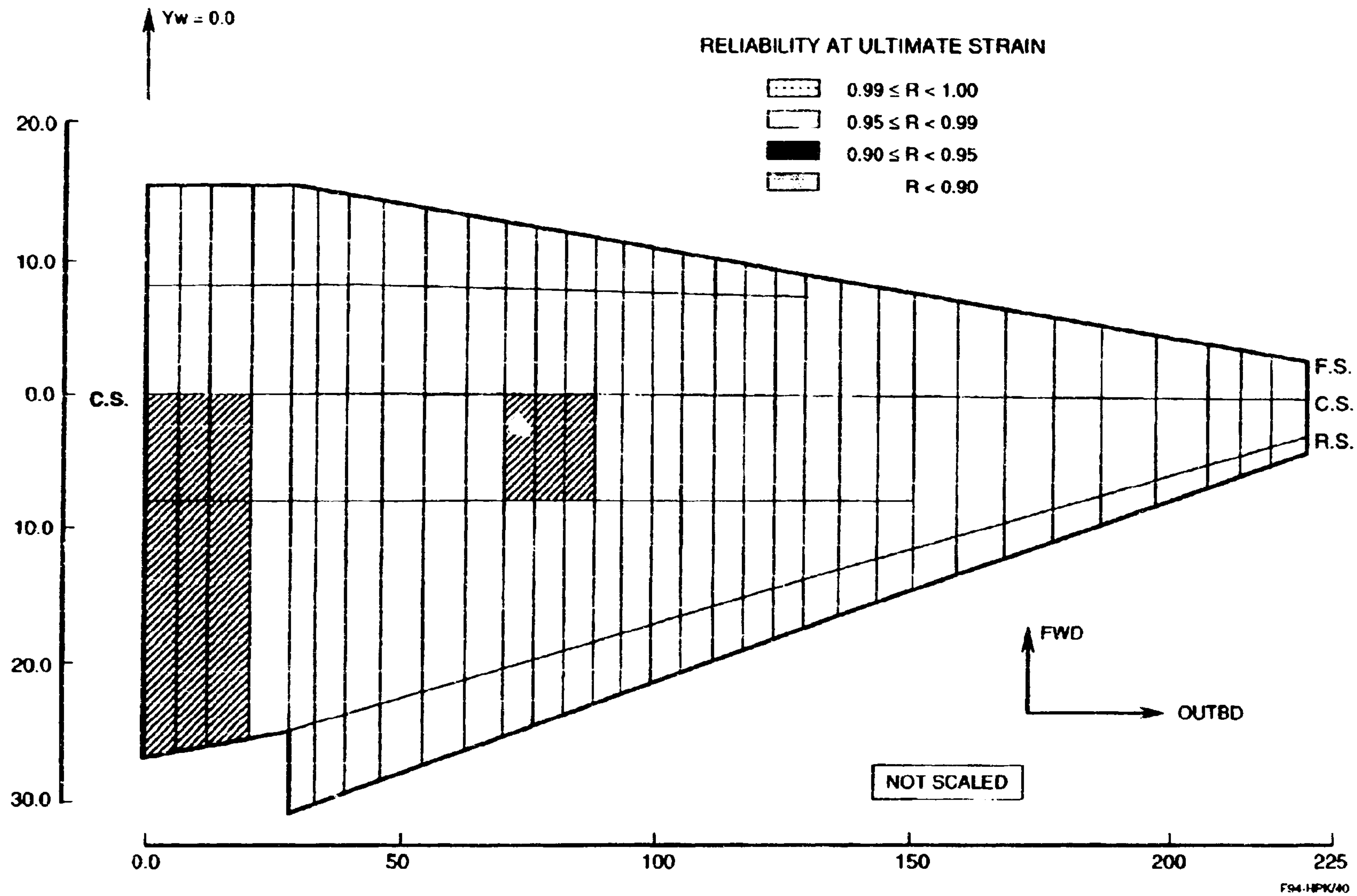

FIGURE 35. CRITICAL IMPACT DAMAGE LOCATIONS OF THE UPPER WING SKIN.

subdivision is the strain level that produces a 0.90 reliability at ultimate condition. Therefore, the margin of safety (M.S.) is evaluated against the ultimate strain of the subdivision. Four values of reliabilities are given for each subdivision. They are the reliability for (1) local failure at limit strain (IF @DLL); (2) structural failure at limit strain (FF @DLL); (3) local failure at ultimate strain (IF @DUL); and, (4) structural failure at ultimate strain (FF @DUL). Similar results obtained by using the maximum ultimate strain in each subdivision are shown in table 6 through 9.

The results shown in table 2 indicate that the upper skin under the average limit strain has very high reliability against low impact threat. The reliability exceeds 0.99 for the entire skin with a minimum of 0.99725 for initial failure and 0.99790 for final failure. The reliability remains relatively high for the majority of the skin under ultimate strain, except for a region aft of the center spar between Yw 69 and 87 where the reliability falls below 0.90. It may be noted that the worst case ultimate strain in the area with low reliability exceeds 3000 micro. The distribution of the damaged structural reliability for structural failure under the average ultimate strain is depicted in figure 27. The figure shows that the reliability in the wing tip area is high and decreases towards the aircraft centerline. Also, the reliability decreases from the leading and trailing edges towards the center spar. That is, the reliability distribution follows closely with the strain distribution within the upper wing skin. This same distribution trend was observed for all results of the impact damage tolerance evaluations.

The results of impact damage tolerance evaluation for the upper wing skin with average strain against medium impact threat are summarized in table 3, and the reliability distribution for structural failure at ultimate strain is shown in figure 28. Table 3 indicates that the structural reliability against medium threat is high at limit strains. The minimum reliability in subdivision 87 is 0.97588 for initial failure and 0.99203 for structural failure. That is, the skin reliability exceeds 0.99 under limit applied strain. Figure 28 shows that the reliability exceeds 0.99 for the area outboard of Yw 129. The reliability decreases inboard of Yw 129. It becomes lower than 0.90 inboard of Yw 123 immediately aft and forward of the center spar, as shown by region 4 of figure 28.

Similar results for the skin under average strain against high-impact threat are summarized in table 4 and the reliability distribution at ultimate strain is shown in figure 29. Table 4 shows that the reliability at limit strain remains relatively high, with a minimum of 0.98215 for final structural failure and 0.87290 for initial failure in subdivision 87, the same critical location as in the previous cases. Figure 29, however, shows that the reliability is significantly reduced from the previous cases. Even though the wing tip area, outboard of Yw

136, still has reliabilities exceeding 0.99, the reliability for the majority of the wing skin inboard of Yw 129 is reduced to below 0.90.

The results for the discrete 100 ft-lb impact threat are summarized in table 5 and the reliability under ultimate strain is plotted in figure 30. These results show that the reduction in reliability against this impact threat is even more significant as compared to the high-probabilistic threat scenario. Also, the results shown in table 5 indicate that the most critical location for limit strain shifted further inboard. The minimum reliability under limit strain is 0.89184 for initial failure and 0.77825 for final failure in subdivision 137 near the aircraft centerline. Figure 30 shows that under ultimate strain the reliability is either very high outboard of Yw 143 or very low inboard of Yw 123. Only a very small area of the skin has reliability between 0.90 and 0.99.

The evaluation was repeated for the four impact threats under the maximum ultimate strain shown in table 1. The trend of the results is similar. As expected, the reliabilities are lower. The results are summarized in tables 6 through 9 and the reliability distributions for final failure under ultimate strain are shown in figures 31 through 34. Figures 31 through 34 show that the region with reliabilities below 0.90 for all impact threats is significantly expanded. In the case of the 100 ft-lb impact threat, the area with reliability exceeding 0.99 is reduced to the wing tip area outboard of Yw 158 and the area with less than 0.90 reliability expanded from Yw 143 inboard.

The critical locations on the upper wing skin against impact threat are summarized in table 10 and shown in figure 35. As shown in figure 35 there are two distinct critical locations. These are subdivisions 77, 82 and 87 in one group and subdivisions 126, 127, 131, 132, 136 and 137 in the second group. The first group is located aft of the center spar between Yw 69 and 87. This location is most critical for the distributed impact threats under average strains. The second group is located between the center and rear spars inboard of Yw 20. This group is most critical for the distributed impact threats under maximum strains and the 100 ft-lb impact, or the more severe threat.

The results of the impact damage tolerance evaluations indicate that the Lear Fan 2100 upper wing skin is capable of withstanding the low- and medium-impact threat defined in reference 6. Against the high-impact threat and the 100 ft-lb discrete impact, the reliability of the skin is relatively low. As discussed earlier, the impact threats used in this study are considered to be very severe for this type of aircraft. Therefore, it may be concluded that the skin has reasonable damage tolerance capability against impact threats under the limit conditions.

5.3 ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION

The residual strength prediction method developed in reference 8 for composite laminate with assembly induced damage was used to evaluate the damage tolerance capability of the upper skin. In this analysis, an equivalent hole with size equal to that of the apparent delamination is modelled for the damage. The strength of the laminate is reduced by using a stiffness reduction technique. Such an analytical technique has been used in references 10 and 11. This technique is based on the analysis method of reference 12 for an anisotropic plate with a solid inclusion coupled with the average stress criterion proposed in reference 13. The computer program 'REDSTF' developed in reference 8 was used for the upper wing skin evaluation.

In the damage tolerance evaluation of the Lear Fan 2100 upper wing skin with assembly induced damage, the stiffness in the damage zone is characterization by stiffness retention ratios (Sr). These are the ratios of the Young's moduli and the shear modulus of the damaged zone to those of the undamaged laminate. For simplicity of the evaluation, only one stiffness ratio was used. Based on the experimental data analyzed in reference 8, a baseline value of Sr=0.15 was used in the evaluation. The characteristic length (a0) for the average stress criterion (reference 13) was determined based on data published in open literature, and the baseline value is 0.10. The scatter parameters needed for reliability analysis were obtained based on the statistical survey conducted in reference 8. The baseline values are: Weibull shape parameter of 20 with sample size of 30 for the undamaged laminate and Weibull shape parameter of 12 with sample size of 10 for the damaged laminate.

The results of damage tolerance evaluation for the upper wing skin with assembly induced damage around fastener holes are summarized in tables 11 through 15 and are shown in figures 36 through 40. All results are based on assembly induced damage around 0.25-in. fastener holes, and the damage is assumed to be circular in shape. Table 11 and figure 36 show the structural reliabilities of the skin with a 2.0-in.-diameter damage. This damage size exceeds the largest defect detected during the nondestructive inspection (see figure 3). This damage size also is comparable with those observed in the existing composite aircraft structures as documented in reference 14 and recommended in reference 8 for damage tolerance certification. Only the maximum strain in each subdivision was considered in this evaluation because of the extremly high reliabilities obtained from the analysis. table 11 shows the reliabilities at limit, 1.25 times limit and ultimate strains. The 1.25 times limit is considered because this load level is used as the maximum spectrum load for the military aircraft. The results shown in table 11 indicate that the reliability is very high at all load levels considered.

TABLE 11. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 2.0-IN. DIAMETER DAMAGE ZONE, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION.

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL	RELIABILITY @1.25DLL	RELIABILITY @DUL
1	3545	7.13	1.00000	1.00000	1.00000
2	3545	1.81	1.00000	1.00000	1.00000
3	3545	1.81	1.00000	1.00000	1.00000
4	3545	6.88	1.00000	1.00000	1.00000
5	3545	1.80	1.00000	1.00000	1.00000
6	3545	1.80	1.00000	1.00000	1.00000
7	3545	6.56	1.00000	1.00000	1.00000
8	3545	1.79	1.00000	1.00000	1.00000
9	3545	1.79	1.00000	1.00000	1.00000
10	3545	5.91	1.00000	1.00000	1.00000
11	3545	1.79	1.00000	1.00000	1.00000
12	3545	1.79	1.00000	1.00000	1.00000
13	3545	4.86	1.00000	1.00000	1.00000
14	3532	1.75	1.00000	1.00000	1.00000
15	3092	1.40	1.00000	1.00000	1.00000
16	3545	3.76	1.00000	1.00000	1.00000
17	3532	1.72	1.00000	1.00000	1.00000
18	3545	1.73	1.00000	1.00000	1.00000
19	3545	2.88	1.00000	1.00000	1.00000
20	3532	1.69	1.00000	1.00000	1.00000
21	3545	1.70	1.00000	1.00000	1.00000
22	3545	2.28	1.00000	1.00000	1.00000
23	3532	1.66	1.00000	1.00000	1.00000
24	3545	1.67	1.00000	1.00000	1.00000
25	3545	1.84	1.00000	1.00000	1.00000
26	3532	1.05	1.00000	1.00000	0.99998
27	3545	1.06	1.00000	1.00000	0.99998
28	3545	1.56	1.00000	1.00000	1.00000
29	3532	0.93	1.00000	1.00000	0.99996
30	3520	0.78	1.00000	0.99999	0.99989
31	3532	0.78	1.00000	0.99999	0.99990

TABLE 11. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 2.0-IN. DIAMETER DAMAGE ZONE, S_f=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL	@1.25DLL	@DUL
32	3545	1.29	1.00000	1.00000	0.99999
33	3532	0.64	1.00000	0.99997	0.99972
34	3520	0.52	0.99999	0.99992	0.99931
35	3532	0.53	0.99999	0.99993	0.99934
36	3545	1.07	1.00000	1.00000	0.99998
37	3532	0.42	0.99999	0.99982	0.99838
38	3520	0.33	0.99997	0.99961	0.99650
39	3542	0.33	0.99997	0.99962	0.99664
40	3545	0.94	1.00000	1.00000	0.99996
41	3532	0.31	0.99997	0.99955	0.99596
42	3520	0.24	0.99994	0.99915	0.99241
43	3520	0.24	0.99994	0.99915	0.99241
44	3532	0.55	1.00000	0.99994	0.99947
45	3545	0.88	1.00000	0.99999	0.99995
46	3532	0.25	0.99994	0.99916	0.99253
47	3520	0.19	0.99990	0.99854	0.98702
48	3520	0.19	0.99990	0.99854	0.98702
49	3532	0.48	0.99999	0.99990	0.99907
50	3545	0.88	1.00000	0.99999	0.99995
51	3532	0.22	0.99993	0.99894	0.99060
52	3520	0.17	0.99988	0.99820	0.98409
53	3520	0.17	0.99988	0.99820	0.98409
54	3532	0.45	0.99999	0.99986	0.99878
55	3545	0.89	1.00000	0.99999	0.99995
56	3532	0.20	0.99991	0.99869	0.98837
57	3520	0.15	0.99985	0.99784	0.98087
58	3520	0.15	0.99985	0.99784	0.98087
59	3532	0.42	0.99999	0.99982	0.99843
60	3092	0.67	1.00000	0.99997	0.99977
61	3532	0.18	0.99989	0.99840	0.98578
62	3520	0.14	0.99982	0.99742	0.97724
63	3520	0.14	0.99982	0.99742	0.97724
64	3532	0.39	0.99998	0.99978	0.99800

TABLE 11. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 2.0-IN. DIAMETER DAMAGE ZONE, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL	RELIABILITY @1.25DLL	RELIABILITY @DUL
65	3092	0.68	1.00000	0.99998	0.99979
66	3532	0.16	0.99987	0.99806	0.98282
67	3520	0.12	0.99979	0.99696	0.97321
68	3520	0.12	0.99979	0.99696	0.97321
69	3532	0.37	0.99998	0.99972	0.99749
70	3092	0.70	1.00000	0.99998	0.99982
71	3532	0.15	0.99984	0.99768	0.97954
72	3520	0.10	0.99975	0.99643	0.96866
73	3520	0.10	0.99975	0.99643	0.96866
74	3532	0.34	0.99998	0.99965	0.99688
75	3092	0.73	1.00000	0.99998	0.99985
76	3532	0.13	0.99981	0.99729	0.97606
77	3520	0.09	0.99972	0.99588	0.96382
78	3520	0.09	0.99972	0.99588	0.96382
79	3532	0.32	0.99997	0.99957	0.99617
80	3092	0.76	1.00000	0.99999	0.99988
81	3532	0.12	0.99979	0.99690	0.97269
82	3520	0.08	0.99968	0.99529	0.95877
83	3520	0.08	0.99968	0.99529	0.95877
84	3532	0.30	0.99996	0.99948	0.99535
85	3092	0.81	1.00000	0.99999	0.99992
86	3532	0.11	0.99976	0.99653	0.96946
87	3520	0.07	0.99963	0.99469	0.95360
88	3520	0.07	0.99963	0.99469	0.95360
89	3532	0.28	0.99996	0.99937	0.99444
90	3092	0.88	1.00000	0.99999	0.99995
91	3532	0.10	0.99974	0.99626	0.96712
92	3500	0.05	0.99957	0.99372	0.94539
93	3500	0.05	0.99957	0.99372	0.94539
94	3520	0.26	0.99995	0.99923	0.99315

TABLE 11. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 2.0-IN. DIAMETER DAMAGE ZONE, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL	RELIABILITY @1.25DLL	RELIABILITY @DUL
95	3545	1.27	1.00000	1.00000	0.99999
96	3532	0.09	0.99972	0.99595	0.96449
97	3500	0.04	0.99951	0.99296	0.93894
98	3500	0.04	0.99951	0.99296	0.93894
99	3520	0.23	0.99994	0.99905	0.99160
100	3545	1.47	1.00000	1.00000	1.00000
101	3532	0.09	0.99971	0.99574	0.96264
102	3500	0.04	0.99947	0.99225	0.93298
103	3500	0.04	0.99947	0.99225	0.93298
104	3520	0.21	0.99992	0.99883	.98963
105	3545	1.79	1.00000	1.00000	1.00000
106	3532	0.09	0.99970	0.99563	0.96168
107	3500	0.03	0.99945	0.99197	0.93065
108	3500	0.03	0.99945	0.99197	0.93065
109	3520	0.20	0.99991	0.99870	0.98851
110	3092	1.60	1.00000	1.00000	1.00000
111	3532	0.08	0.99969	0.99543	0.95998
112	3500	0.03	0.99944	0.99191	0.93018
113	3500	0.03	0.99944	0.99191	0.93018
114	3520	0.20	0.99991	0.99863	0.98783
115	3092	1.61	1.00000	1.00000	1.00000
116	3532	0.08	0.99967	0.99522	0.95822
117	3500	0.03	0.99944	0.99186	0.92970
118	3500	0.03	0.99944	0.99186	0.92970
119	3520	0.19	0.99990	0.99855	0.98718
120	---	---	---	---	---
121	3532	0.07	0.99965	0.99490	0.95544
122	3500	0.03	0.99943	0.99180	0.92922
123	3500	0.03	0.99943	0.99180	0.92922
124	3520	0.19	0.99990	0.99855	0.98718

TABLE 11. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 2.0-IN. DIAMETER DAMAGE ZONE, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG	B-ALL. (MICRO)	M.S.	RELIABILITY @DLL	@1.25DLL	@DUL
125	—	—	—	—	—
126	3532	0.07	0.99962	0.99452	0.95217
127	3500	0.03	0.99943	0.99174	0.92873
128	3500	0.03	0.99943	0.99174	0.92873
129	3520	0.19	0.99990	0.99857	0.98728
130	—	—	—	—	—
131	3532	0.06	0.99960	0.99415	0.94904
132	3500	0.03	0.99943	0.99171	0.92849
133	3500	0.03	0.99943	0.99171	0.92849
134	3520	0.19	0.99990	0.99858	0.98738
135	—	—	—	—	—
136	3532	0.06	0.99958	0.99396	0.94740
137	3500	0.03	0.99943	0.99168	0.92825
138	3500	0.03	0.99943	0.99168	0.92825
139	3520	0.19	0.99990	0.99859	0.98753

Note: (1) Damage zone has a reduced stiffness around a 0.25-in. diameter fastener.
(2) S_r is the stiffness retention ratio.

TABLE 12. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION.

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
1	3545	436	*	*	*
2	3545	1263	*	*	*
3	3545	1263	*	*	*
4	3545	450	*	*	*
5	3545	1267	*	*	*
6	3545	1267	*	*	*
7	3545	469	*	*	*
8	3545	1271	*	*	*
9	3545	1271	*	*	*
10	3545	513	*	*	*
11	3545	1271	*	*	*
12	3545	1271	*	*	*
13	3545	605	*	*	*
14	3532	1286	*	*	*
15	3092	1285	*	*	*
16	3545	745	*	*	*
17	3532	1297	*	*	*
18	3545	1297	*	*	*
19	3545	914	*	*	*
20	3532	1312	*	*	*
21	3545	1312	*	*	*
22	3545	1080	*	*	*
23	3532	1330	*	*	*
24	3545	1330	*	*	*
25	3545	1247	*	*	*
26	3532	1719	*	*	*
27	3545	1719	*	*	*
28	3545	1386	*	*	*
29	3532	1826	*	*	*
30	3520	1979	*	*	*
31	3532	1979	*	*	*

TABLE 12. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
32	3545	1549	*	*	*
33	3532	2155	*	*	*
34	3520	2314	*	*	*
35	3532	2314	*	*	*
36	3545	1710	*	*	*
37	3532	2494	*	*	*
38	3520	2651	*	*	*
39	3542	2651	*	*	*
40	3545	1827	*	*	*
41	3532	2692	*	*	*
42	3520	2828	*	*	3.800
43	3520	2828	*	*	3.800
44	3532	2274	*	*	*
45	3545	1888	*	*	*
46	3532	2834	*	*	4.338
47	3520	2958	*	*	1.162
48	3520	2958	*	*	1.162
49	3532	2381	*	*	*
50	3545	1[illegible]38	*	*	*
51	3532	2889	*	*	2.332
52	3520	3009	*	*	0.847
53	3520	3009	*	*	0.847
54	3532	2436	*	*	*
55	3545	1873	*	*	*
56	3532	2941	*	*	1.414
57	3520	3056	*	*	0.683
58	3520	3056	*	*	0.683
59	3532	2488	*	*	*
60	3092	1857	*	*	*
61	3532	2991	*	*	0.986
62	3520	3101	*	*	0.581
63	3520	3101	*	*	0.531
64	3532	2539	*	*	*

TABLE 12. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
65	3092	1840	*	*	*
66	3532	3039	*	*	0.768
67	3520	3144	*	*	0.512
68	3520	3144	*	*	0.512
69	3532	2587	*	*	*
70	3092	1820	*	*	*
71	3532	3084	*	*	0.641
72	3520	3186	*	6.746	0.459
73	3520	3186	*	6.746	0.459
74	3532	2635	*	*	*
75	3092	1792	*	*	*
76	3532	3125	*	*	0.560
77	3520	3225	*	4.370	0.420
78	3520	3225	*	4.370	0.420
79	3532	2680	*	*	*
80	3092	1756	*	*	*
81	3532	3160	*	*	0.507
82	3520	3261	*	3.128	0.390
83	3520	3261	*	3.128	0.390
84	3532	2724	*	*	*
85	3092	1705	*	*	*
86	3532	3190	*	9.390	0.470
87	3520	3294	*	2.372	0.366
88	3520	3294	*	2.372	0.366
89	3532	2765	*	*	*
90	3092	1646	*	*	*
91	3532	3210	*	6.826	0.448
92	3500	3321	8.606	1.675	0.338
93	3500	3321	8.606	1.675	0.338
94	3520	2804	*	*	5.000

TABLE 12. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
95	3545	1562	*	*	*
96	3532	3231	*	5.186	0.427
97	3500	3353	6.102	1.335	0.320
98	3500	3353	6.102	1.335	0.320
99	3520	2852	*	*	2.974
100	3545	1435	*	*	*
101	3532	3245	*	4.400	0.414
102	3500	3380	4.782	1.118	0.306
103	3500	3380	4.782	1.118	0.306
104	3520	2903	*	*	1.842
105	3545	1271	*	*	*
106	3532	3252	*	4.072	0.408
107	3500	3390	4.392	1.052	0.302
108	3500	3390	4.392	1.052	0.302
109	3520	2928	*	*	1.474
110	3092	1191	*	*	*
111	3532	3264	*	3.590	0.398
112	3500	3392	4.321	1.039	0.301
113	3500	3392	4.321	1.039	0.301
114	3520	2942	*	*	1.312
115	3092	1184	*	*	*
116	3532	3276	*	3.185	0.388
117	3500	3394	4.253	1.027	0.300
118	3500	3394	4.253	1.027	0.300
119	3520	2955	*	*	1.188
120	—	—	—	—	—
121	3532	3294	*	2.684	0.375
122	3500	3396	4.187	1.015	0.299
123	3500	3396	4.187	1.015	0.299
124	3520	2955	*	*	1.188

TABLE 12. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.15, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
125	—	—	—	—	—
126	3532	3314	*	2.237	0.363
127	3500	3398	4.120	1.004	0.298
128	3500	3398	4.120	1.004	0.298
129	3520	2955	*	*	1.206
130	—	—	—	—	—
131	3532	3332	*	1.907	0.351
132	3500	3399	4.086	0.998	0.297
133	3500	3399	4.086	0.998	0.297
134	3520	2951	*	*	1.224
135	—	—	—	—	—
136	3532	3341	*	1.766	0.344
137	3500	3400	4.054	0.992	0.297
138	3500	3400	4.054	0.992	0.297
139	3520	2948	*	*	1.252

Note: (1) B-basis allowable strain is for a damage 2.0-in. in diameter and with a stiffness retention ratio S_r=0.15.
(2) Damage zone includes a 0.25-in. diameter fastener hole.
(3) * denotes allowable damage diameter larger than 10.0-in.

TABLE 13. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, MAXIMUM STRAIN IN EACH SUBDIVISION.

REC.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
1	2988	436	*	*	*
2	2988	1263	*	*	*
3	2988	1263	*	*	*
4	2988	450	*	*	*
5	2988	1267	*	*	*
6	2988	1267	*	*	*
7	2988	469	*	*	*
8	2988	1271	*	*	*
9	2988	1271	*	*	*
10	2988	513	*	*	*
11	2988	1271	*	*	*
12	2988	1271	*	*	*
13	2988	605	*	*	*
14	2969	1286	*	*	*
15	2969	1297	*	*	*
16	2988	745	*	*	*
17	2969	1297	*	*	*
18	2988	1297	*	*	*
19	2988	914	*	*	*
20	2969	1312	*	*	*
21	2988	1312	*	*	*
22	2988	1080	*	*	*
23	2969	1330	*	*	*
24	2988	1330	*	*	*
25	2988	1247	*	*	*
26	2969	1719	*	*	*
27	2988	1719	*	*	*
28	2988	1386	*	*	*
29	2969	1826	*	*	*
30	2952	1979	*	*	*
31	2969	1979	*	*	*

TABLE 13. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_f=0.01, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
32	2988	1549	*	*	*
33	2969	2155	*	*	*
34	2952	2314	*	*	4.802
35	2969	2314	*	*	6.246
36	2988	1710	*	*	*
37	2969	2494	*	*	1.376
38	2952	2651	*	4.788	0.605
39	2969	2651	*	6.218	0.631
40	2988	1827	*	*	*
41	2969	2692	*	4.208	0.553
42	2952	2828	4.331	1.518	0.388
43	2952	2828	4.331	1.518	0.388
44	2969	2274	*	*	*
45	2988	1888	*	*	*
46	2969	2834	5.900	1.581	0.394
47	2952	2958	1.935	0.790	0.309
48	2952	2958	1.935	0.790	0.309
49	2969	2381	*	*	3.180
50	2988	1888	*	*	*
51	2969	2889	3.343	1.147	0.355
52	2952	3009	1.468	0.658	0.286
53	2952	3009	1.468	0.658	0.286
54	2969	2436	*	*	2.074
55	2988	1873	*	*	*
56	2969	2941	2.369	0.890	0.325
57	2952	3056	1.147	0.573	0.267
58	2952	3056	1.147	0.573	0.267
59	2969	2488	*	*	1.434
60	2433	1857	*	*	6.818
61	2969	2991	1.756	0.731	0.300
62	2952	3101	0.929	0.511	0.251
63	2952	3101	0.929	0.511	0.251
64	2969	2539	*	*	1.037

TABLE 13. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
65	2433	1840	*	*	9.500
66	2969	3039	1.334	0.625	0.279
67	2952	3144	0.781	0.464	**
68	2952	3144	0.781	0.464	**
69	2969	2587	*	*	0.811
70	2433	1820	*	*	*
71	2969	3084	1.058	0.553	0.262
72	2952	3186	0.677	0.447	**
73	2952	3186	0.677	0.447	**
74	2969	2635	*	7.470	0.666
75	2433	1792	*	*	*
76	2969	3125	0.882	0.500	**
77	2952	3225	0.604	0.398	**
78	2952	3225	0.604	0.398	**
79	2969	2680	*	4.674	0.573
80	2433	1756	*	*	*
81	2969	3160	0.772	0.464	**
82	2952	3261	0.550	0.374	**
83	2952	3261	0.550	0.374	**
84	2969	2724	*	3.263	0.506
85	2433	1705	*	*	*
86	2969	3190	0.698	0.437	**
87	2952	3294	0.510	0.355	**
88	2952	3294	0.510	0.355	**
89	2969	2765	*	2.446	0.457
90	2433	1646	*	*	*
91	2969	3210	0.656	0.420	**
92	2926	3321	0.459	0.329	**
93	2926	3321	0.459	0.329	**
94	2952	2804	5.231	1.742	0.407

TABLE 13. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER		
			0.90	0.95	0.99
95	2988	1562	*	*	*
96	2969	3231	0.618	0.405	**
97	2926	3353	0.432	0.315	**
98	2926	3353	0.432	0.315	**
99	2952	2852	3.653	1.324	0.370
100	2988	1435	*	*	*
101	2969	3245	0.595	0.395	**
102	2926	3380	0.411	0.303	**
103	2926	3380	0.411	0.303	**
104	2952	2903	2.645	1.009	0.338
105	2988	1271	*	*	*
106	2969	3252	0.585	0.390	**
107	2926	3390	0.404	0.299	**
108	2926	3390	0.404	0.299	**
109	2952	2928	2.286	0.897	0.324
110	2433	1191	*	*	*
111	2969	3264	0.567	0.382	**
112	2926	3392	0.403	0.299	**
113	2926	3392	0.403	0.299	**
114	2952	2942	2.114	0.844	0.317
115	2433	1184	*	*	*
116	2969	3276	0.551	0.375	**
117	2926	3394	0.402	0.298	**
118	2926	3394	0.402	0.298	**
119	2952	2955	1.967	0.800	0.310
120	—	—	—	—	—
121	2969	3294	0.528	0.364	**
122	2926	3396	0.400	0.297	**
123	2926	3396	0.400	0.297	**
124	2952	2955	1.967	0.800	0.310

TABLE 13. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER		
			0.90	0.95	0.99
125	—	—	—	—	—
126	2969	3314	0.505	0.352	**
127	2926	3398	0.399	0.296	**
128	2926	3398	0.399	0.296	**
129	2952	2953	1.989	0.806	0.311
130	—	—	—	—	—
131	2969	3332	0.486	0.345	**
132	2926	3399	0.398	0.296	**
133	2926	3399	0.398	0.296	**
134	2952	2951	2.011	0.813	0.312
135	—	—	—	—	—
136	2969	3341	0.477	0.338	**
137	2926	3400	0.398	0.295	**
138	2926	3400	0.398	0.295	**
139	2952	2948	2.045	0.823	0.314

Note: (1) B-basis allowable strain is for a damage 2.0-in. in diameter and with stiffness retention ratio S_r=0.01.
(2) Damage zone includes a 0.25-in. diameter fastener hole.
(3) * denotes allowable damage diameter larger than 10.0-in.;
** denotes allowable damage diameter smaller than 0.25-in.

TABLE 14. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.001, MAXIMUM STRAIN IN EACH SUBDIVISION.

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
1	2952	436	*	*	*
2	2952	1263	*	*	*
3	2952	1263	*	*	*
4	2952	450	*	*	*
5	2952	1267	*	*	*
6	2952	1267	*	*	*
7	2952	469	*	*	*
8	2952	1271	*	*	*
9	2952	1271	*	*	*
10	2952	513	*	*	*
11	2952	1271	*	*	*
12	2952	1271	*	*	*
13	2952	605	*	*	*
14	2932	1286	*	*	*
15	2390	1286	*	*	*
16	2952	745	*	*	*
17	2932	1297	*	*	*
18	2952	1297	*	*	*
19	2952	914	*	*	*
20	2932	1312	*	*	*
21	2952	1312	*	*	*
22	2952	1080	*	*	*
23	2932	1330	*	*	*
24	2952	1330	*	*	*
25	2952	1247	*	*	*
26	2932	1719	*	*	*
27	2952	1719	*	*	*
28	2952	1386	*	*	*
29	2932	1826	*	*	*
30	2915	1979	*	*	*
31	2932	1979	*	*	*

TABLE 14. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_f=0.001, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
32	2952	1549	*	*	*
33	2932	2155	*	*	*
34	2915	2314	*	*	3.635
35	2932	2314	*	*	4.404
36	2952	1710	*	*	*
37	2932	2494	*	*	1.140
38	2915	2651	*	3.624	0.552
39	2932	2651	*	4.394	0.574
40	2952	1827	*	*	*
41	2932	2692	*	3.179	0.510
42	2915	2828	3.324	1.254	0.367
43	2915	2828	3.324	1.254	0.367
44	2932	2274	*	*	6.935
45	2952	1888	*	*	*
46	2932	2834	3.787	1.293	0.372
47	2915	2958	1.588	0.699	0.295
48	2915	2958	1.588	0.699	0.295
49	2932	2381	*	*	2.490
50	2952	1888	*	*	*
51	2932	2889	2.600	0.970	0.337
52	2915	3009	1.215	0.596	0.274
53	2915	3009	1.215	0.596	0.274
54	2932	2436	*	*	1.674
55	2952	1873	*	*	*
56	2932	2941	1.900	0.778	0.310
57	2915	3056	0.969	0.526	0.257
58	2915	3056	0.969	0.526	0.257
59	2932	2488	*	*	1.183
60	2390	1857	*	*	4.332
61	2932	2991	1.428	0.655	0.287
62	2915	3101	0.805	0.474	**
63	2915	3101	0.805	0.474	**
64	2932	2539	*	*	0.888

TABLE 14. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.001, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
65	2390	1840	*	*	5.292
66	2932	3039	1.109	0.570	0.268
67	2915	3144	0.692	0.434	**
68	2915	3144	0.692	0.434	**
69	2932	2587	*	8.668	0.717
70	2390	1820	*	*	7.148
71	2932	3084	0.904	0.510	0.251
72	2915	3186	0.610	0.402	**
73	2915	3186	0.610	0.402	**
74	2932	2635	*	5.078	0.603
75	2390	1792	*	*	*
76	2932	3125	0.772	0.466	**
77	2915	3225	0.551	0.376	**
78	2915	3225	0.551	0.376	**
79	2932	2680	*	3.477	0.527
80	2390	1756	*	*	*
81	2932	3160	0.687	0.434	**
82	2915	3261	0.507	0.355	**
83	2915	3261	0.507	0.355	**
84	2932	2724	*	2.545	0.470
85	2390	1705	*	*	*
86	2932	3190	0.628	0.410	**
87	2915	3294	0.473	0.337	**
88	2915	3294	0.473	0.337	**
89	2932	2765	7.006	1.956	0.428
90	2390	1646	*	*	*
91	2932	3210	0.595	0.396	**
92	2888	3321	0.429	0.314	**
93	2888	3321	0.429	0.314	**
94	2915	2804	3.903	1.433	0.384

TABLE 14. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.001, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
95	2952	1562	*	*	*
96	2932	3231	0.564	0.382	**
97	2888	3353	0.405	0.301	**
98	2888	3353	0.405	0.301	**
99	2915	2852	2.862	1.103	0.351
100	2952	1435	*	*	*
101	2932	3245	0.545	0.373	**
102	2888	3380	0.388	0.290	**
103	2888	3380	0.388	0.290	**
104	2915	2903	2.134	0.865	0.322
105	2952	1271	*	*	*
106	2932	3252	0.537	0.369	**
107	2888	3390	0.381	0.286	**
108	2888	3390	0.381	0.286	**
109	2915	2928	1.864	0.781	0.309
110	2390	1191	*	*	*
111	2932	3264	0.522	0.362	**
112	2888	3392	0.380	0.286	**
113	2888	3392	0.380	0.286	**
114	2915	2942	1.730	0.740	**
115	2390	1184	*	*	*
116	2932	3276	0.508	0.355	**
117	2888	3394	0.379	0.285	**
118	2888	3394	0.379	0.285	**
119	2915	2955	1.614	0.706	0.297
120	—	—	—	—	—
121	2932	3294	0.489	0.345	**
122	2888	3396	0.378	0.284	**
123	2888	3396	0.378	0.284	**
124	2915	2955	1.614	0.706	0.297

TABLE 14. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.001, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
125	—	—	—	—	—
126	2932	3314	0.470	0.335	**
127	2888	3398	0.377	0.283	**
128	2888	3398	0.377	0.283	**
129	2915	2953	1.631	0.711	0.298
130	—	—	—	—	—
131	2932	3332	0.453	0.326	**
132	2888	3399	0.376	0.283	**
133	2888	3399	0.376	0.283	**
134	2915	2951	1.649	0.716	0.299
135	—	—	—	—	—
136	2932	3341	0.446	0.322	**
137	2888	3400	0.375	0.283	**
138	2888	3400	0.375	0.283	**
139	2915	2948	1.675	0.724	0.300

Note: (1) B-basis allowable strain is for a damage 2.0-in. in diameter and with stiffness retention ratio S_r=0.001.
(2) Damage zone includes a 0.25-in. diameter fastener hole.
(3) * denotes allowable damage diameter larger than 10.0-in.;
** denotes allowable damage diameter smaller than 0.25-in.

TABLE 15. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, AVERAGE STRAIN IN EACH SUBDIVISION.

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
1	2988	428	*	*	*
2	2988	845	*	*	*
3	2988	879	*	*	*
4	2988	443	*	*	*
5	2988	854	*	*	*
6	2988	888	*	*	*
7	2988	460	*	*	*
8	2988	864	*	*	*
9	2988	897	*	*	*
10	2988	491	*	*	*
11	2988	883	*	*	*
12	2988	916	*	*	*
13	2988	559	*	*	*
14	2969	921	*	*	*
15	2433	956	*	*	*
16	2988	675	*	*	*
17	2969	983	*	*	*
18	2988	1021	*	*	*
19	2988	830	*	*	*
20	2969	1067	*	*	*
21	2988	1118	*	*	*
22	2988	997	*	*	*
23	2969	1159	*	*	*
24	2988	1229	*	*	*
25	2988	1164	*	*	*
26	2969	1390	*	*	*
27	2988	1426	*	*	*
28	2988	1317	*	*	*
29	2969	1508	*	*	*
30	2952	1775	*	*	*
31	2969	1659	*	*	*

TABLE 15. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
32	2988	1468	*	*	*
33	2969	1729	*	*	*
34	2952	2069	*	*	*
35	2969	1867	*	*	*
36	2988	1630	*	*	*
37	2969	1977	*	*	*
38	2952	2404	*	*	2.340
39	2969	2105	*	*	*
40	2988	1769	*	*	*
41	2969	2181	*	*	*
42	2952	2666	*	4.244	0.576
43	2952	2474	*	*	1.466
44	2969	2005	*	*	*
45	2988	1858	*	*	*
46	2969	2310	*	*	6.560
47	2952	2828	4.331	1.518	0.388
48	2952	2610	*	7.040	0.702
49	2969	2097	*	*	*
50	2988	1881	*	*	*
51	2969	2371	*	*	3.466
52	2952	2923	2.353	0.918	0.327
53	2952	2696	*	3.401	0.527
54	2969	2157	*	*	*
55	2988	1865	*	*	*
56	2969	2390	*	*	2.952
57	2952	2974	1.774	0.743	0.301
58	2952	2747	9.214	2.438	0.462
59	2969	2194	*	*	*
60	2433	1849	*	*	7.859
61	2969	2407	*	*	2.580
62	2952	3022	1.369	0.632	0.280
63	2952	2796	5.598	1.824	0.414
64	2969	2230	*	*	*

TABLE 15. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_f=0.01, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
65	2433	1830	*	*	*
66	2969	2423	*	*	2.282
67	2952	3069	1.076	0.553	0.262
68	2952	2843	3.886	1.394	0.377
69	2969	2264	*	*	*
70	2433	1806	*	*	*
71	2969	2434	*	*	2.104
72	2952	3113	0.882	0.497	**
73	2952	2888	2.895	1.089	0.347
74	2969	2297	*	*	7.826
75	2433	1744	*	*	*
76	2969	2439	*	*	2.030
77	2952	3155	0.751	0.454	**
78	2952	2932	2.235	0.881	0.322
79	2969	2328	*	*	5.296
80	2433	1731	*	*	*
81	2969	2437	*	*	2.060
82	2952	3193	0.662	0.421	**
83	2952	2973	1.783	0.746	0.302
84	2969	2357	*	*	3.942
85	2433	1676	*	*	*
86	2969	2425	*	*	2.246
87	2952	3226	0.602	0.397	**
88	2952	3011	1.452	0.654	0.285
89	2969	2385	*	*	3.076
90	2433	1604	*	*	*
91	2969	2402	*	*	2.680
92	2926	3254	0.530	0.364	**
93	2926	3064	1.013	0.531	0.258
94	2952	2410	*	*	2.244

TABLE 15. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, AVERAGE STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
95	2988	1499	*	*	*
96	2969	2360	*	*	3.826
97	2926	3279	0.501	0.351	**
98	2926	3083	0.929	0.507	0.251
99	2952	2438	*	*	1.860
100	2988	1353	*	*	*
101	2969	2296	*	*	7.954
102	2926	3302	0.477	0.339	**
103	2926	3122	0.791	0.464	**
104	2952	2468	*	*	1.526
105	2988	1231	*	*	*
106	2969	2240	*	*	*
107	2926	3317	0.462	0.331	**
108	2926	3150	0.714	0.438	**
109	2952	2491	*	*	1.314
110	2433	1188	*	*	*
111	2969	2223	*	*	*
112	2926	3325	0.455	0.327	**
113	2926	3163	0.683	0.427	**
114	2952	2504	*	*	1.209
115	2433	1181	*	*	*
116	2969	2226	*	*	*
117	2926	3332	0.449	0.324	**
118	2926	3171	0.666	0.421	**
119	2952	2513	*	*	1.144
120	—	—	—	—	—
121	2969	2230	*	*	*
122	2926	3340	0.442	0.321	**
123	2926	3175	0.657	0.418	**
124	2952	2518	*	*	1.110

TABLE 15. RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, S_r=0.01, AVERAGE STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALL. (MICRO)	DUL STRAIN (MICRO)	ALLOWABLE DAMAGE DIAMETER 0.90	0.95	0.99
125	----	----	------	------	------
126	2969	2235	*	*	*
127	2926	3351	0.433	0.316	**
128	2926	3175	0.657	0.418	**
129	2952	2520	*	*	1.096
130	----	----	------	------	------
131	2969	2241	*	*	*
132	2926	3361	0.425	0.311	**
133	2926	3174	0.660	0.418	**
134	2952	2522	*	*	1.084
135	----	----	------	------	------
136	2969	2244	*	*	*
137	2926	3368	0.420	0.308	**
138	2926	3174	0.660	0.418	**
139	2952	2523	*	*	1.077

Note: (1) B-basis allowable strain is for a damage 2.0-in. in diameter and with stiffness retention ratio S_r=0.01.

(2) Damage zone includes a 0.25-in. diameter fastener hole.

(3) * denotes allowable damage diameter larger than 10.0-in.;
** denotes allowable damage diameter smaller than 0.25-in.

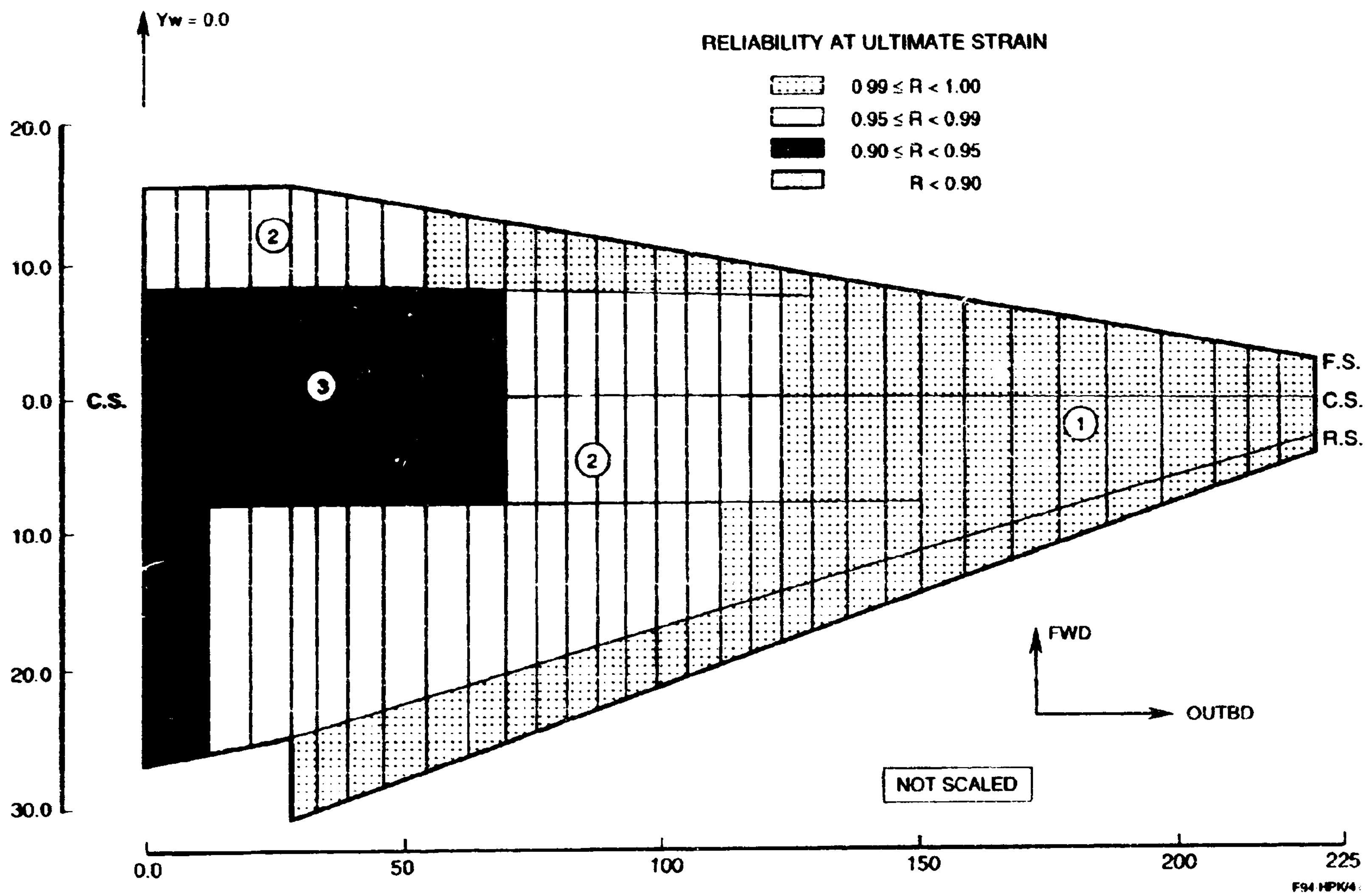

FIGURE 36. RELIABILITY OF UPPER WING SKIN WITH 2.0-IN.-DIAMETER ASSEMBLY INDUCED DAMAGE, S_T = 0.15, MAXIMUM STRAIN.

The minimum reliabilities at limit and 1.25 times limit strains exceed 0.99 and the minimum reliability at ultimate strain is 0.92825. Figure 36 shows the reliability distribution within the upper wing skin with 2.0-in.-diameter assembly induced damage under maximum ultimate strain. The figure shows that the reliability exceeds 0.90 for the entire wing skin. These results indicate that the baseline assembly induced damage is less severe as compared to the impact threats.

Tables 12 through 15 show the allowable damage size in the wing skin. Allowable damage sizes for 0.90, 0.95 and 0.99 reliabilities under maximum ultimate strains are shown in tables 12 through 14. Similar results for the skin under average ultimate strain are shown in table 15 for comparison purposes. Table 12 shows the results for the baseline damage scenario, that is for a stiffness retention ratio of 0.15. The results indicate that the allowable damage size is very sensitive to the reliability requirement. For the 0.90 reliability at ultimate condition, or the equivalent of a B-basis reliability requirement, the allowable damage diameter is large over the entire skin. The minimum allowable damage diameter is 4.045-in. which is considered to be a very rare damage scenario induced by the assembly processes. The distribution of the allowable damage size over the upper wing skin for this baseline case with 0.90 reliability under ultimate strain is shown in figure 37. The figure shows that the major portion of the wing skin can withstand damage larger than 10 in. in diameter. The minimum allowable damage size is between 4.0 and 5.0-in. located aft and forward of the center spar inboard of Yw 55.

As the reliability requirement is enhanced, the allowable damage size is reduced. This can be observed from the results shown in table 12. At the 0.95 reliability level, the minimum allowable damage diameter is reduced to approximately 1.0 in. in the region inboard of Yw 55 near the center spar. This critical damage size is further reduced to approximately 0.30 in. as the reliability requirement becomes 0.99 under ultimate condition.

Similar results for reduced stiffness retention ratio are summarized in tables 13 and 14 and are shown in figures 38 and 39. Table 13 shows the results for a stiffness retention ratio (Sr) of 0.01. This level of damage is usually induced by a poor assembly process due to severe overtorque or fastening composite parts with large unshimmed gaps. The results shown in table 13 indicate that the minimum allowable damage diameter is approximately 0.4 in. for the 0.90 reliability requirement in the most critical area of the wing skin. For a 0.99 reliability requirement, no damage of this type will be tolerated in the critical area, as the minimum allowable damage diameter is smaller than the fastener hole diameter of 0.25-in. The distribution of the allowable damage size is shown in figure 38. This figure shows that the allowable damage

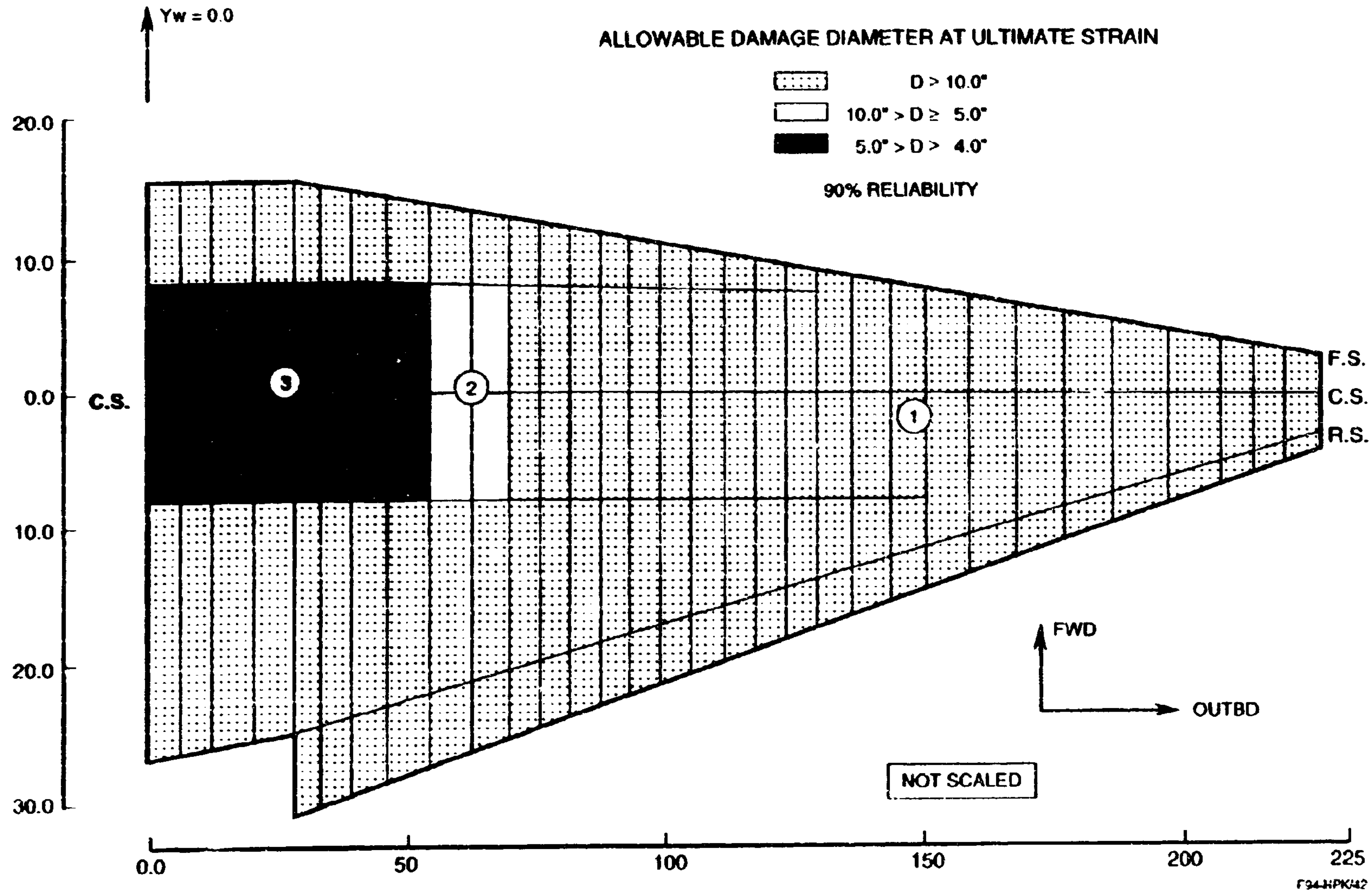

FIGURE 37. ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY, $S_r = 0.15$, MAXIMUM STRAIN.

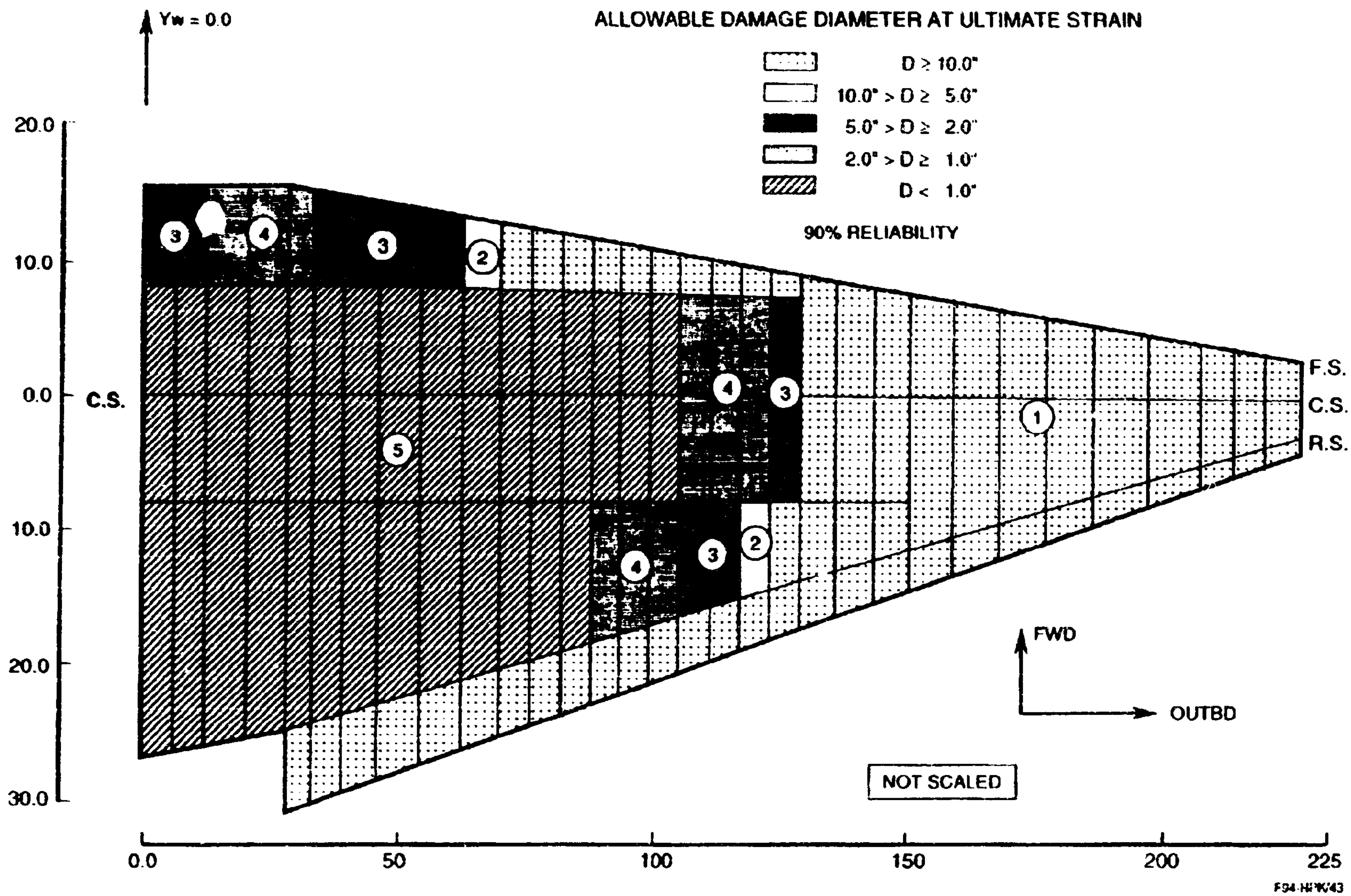

FIGURE 38. ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY, $S_T = 0.01$, MAXIMUM STRAIN.

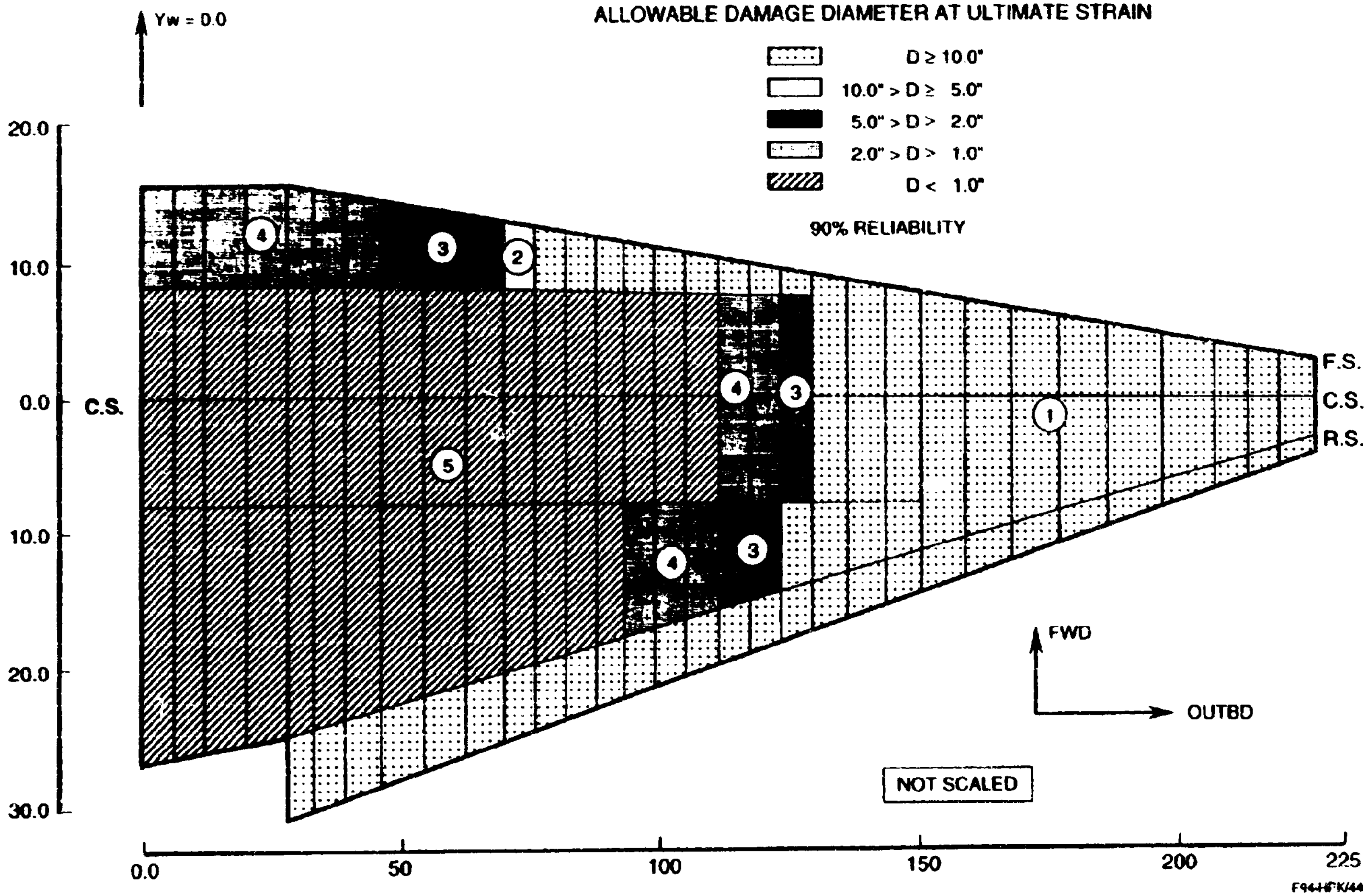

FIGURE 39. ALLOWABLE ASSEMBLY INDUCED DAMAGE SIZE IN THE UPPER WING SKIN, 90% RELIABILITY, S_r = 0.001, MAXIMUM STRAIN.

size is still large in the wing tip area. However, the allowable damage diameter is smaller than 2.0-in. for a large portion of the skin inboard of Yw 123.

Table 14 shows results for Sr=0.001, which represents damage induced by a very poor assembly procedure with nearly visible fastener pull-through. As expected, the results show a very significant reduction in the allowable damage size in the critical locations of the wing skin. The minimum allowable damage diameter for a 0.90 reliability, is 0.375-in. in subdivisions 137 and 138. The 0.90 reliability damage size distribution is shown in figure 39. As shown in the figure, the allowable damage diameter is smaller than 1.0 in. for a large portion of the skin inboard of Yw 111.

Table 15 and figure 40 show the results of allowable damage size for the wing skin under average ultimate strain in each subdivision with Sr=0.01, for comparison purposes. These results show that a large portion of the skin is capable of tolerating large size damage. However, the allowable damage diameter is smaller than 1.0 in. for portions of the inboard area near the center spar.

In addition to the damage tolerance evaluation of the wing skin with the assumed damage scenarios discussed above, the effects of the defects detected during NDI was also analytically evaluated. The majority of the defects detected during NDI, fall into the category of assembly induced damage and they are summarized in figure 3. Based on the results of the inspection, the baseline damage scenario was modelled for evaluation. The results are summarized in table 16. The actual defect sizes were not used to obtain the results shown in table 16 because they are relatively small and the analysis indicated that with the actual damage size the reliability at ultimate strain is 1.0 for all defects. Table 16 shows the B-basis allowable strain, the margin of safety and the reliability at maximum ultimate strain for each damage location with a 2.0-in.-diameter circular damage and a stiffness retention ratio of 0.15. The allowable damage diameter for a 0.90 reliability level under ultimate strain is also shown in the table. As can be seen in table 16, the reliabilities at ultimate strain are very high and the allowable damage sizes are very large for all detected defects. Therefore, it may be concluded that the assembly induced defects on the Lear Fan 2100 aircraft E009 do not impose a threat to the integrity of the wing structure.

The results of the assembly induced damage tolerance evaluation for the Lear Fan 2100 upper wing skin show that the structure is capable of tolerating damage induced by normal assembly operation. This is evident by the defects detected on the E009 aircraft. However, NDI after final assembly is needed to assure that the structures are properly assembled, because the results of the evaluation indicate that poor assembly operation may degrade the integrity of the structure. Local structural failure under ultimate strains may be initiated at locations with severe assembly induced damage.

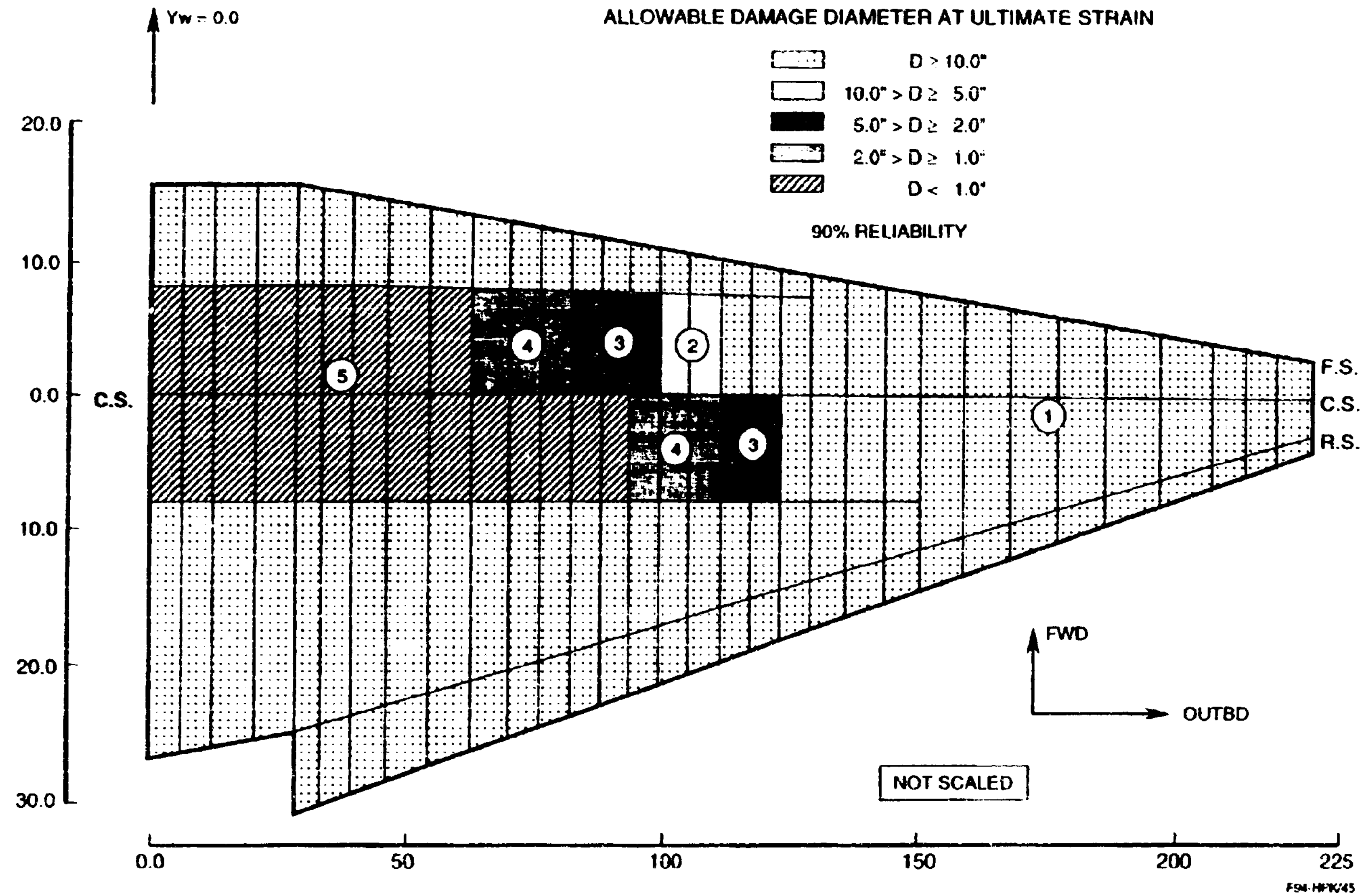

FIGURE 40. ALLOWABLE ASSEMBLY INDUCED DAMAGE SIZE IN THE UPPER WING SKIN, 90% RELIABILITY, S_r = 0.01, AVERAGE STRAIN.

TABLE 16. SUMMARY OF DETECTED DEFECT EVALUATION.

DEFECT NO.	REGION	B-ALL. (MICRO)	M.S.	RELIABILITY AT DUL	0.90 RELIAB. ALL. DIA.
LEFT HAND WING					
1	81	3532	0.12	0.97269	>10.0
2	76	3532	0.13	0.97606	>10.0
3	66	3532	0.16	0.98282	>10.0
4	61	3532	0.18	0.98282	>10.0
5	61	3532	0.18	0.98282	>10.0
RIGHT HAND WING					
1	66	3532	0.16	0.98282	>10.0
2	20	3532	1.69	1.00000	>10.0
3	14	3532	1.75	1.00000	>10.0
4	14	3532	1.75	1.00000	>10.0
5	11	3545	1.79	1.00000	>10.0
6	11	3545	1.79	1.00000	>10.0
7	8	3545	1.79	1.00000	>10.0
8	5	3545	1.80	1.00000	>10.0
9	5	3545	1.80	1.00000	>10.0
10	2	3545	1.81	1.00000	>10.0
11	2	3545	1.81	1.00000	>10.0
12	67/68	3520	0.12	0.97321	>10.0
13	2/3	3545	1.81	1.00000	>10.0
14	2/3	3545	1.81	1.00000	>10.0

Note: Refer to figure 3 for defect number and location.

SECTION 6

PARAMETRIC STUDIES

A parametric study was conducted to evaluate the effects of the significant parameters on the damage tolerance capability of the Lear Fan 2100 upper wing skin. The parameters considered for the impact damage tolerance were the damage tolerance certification criteria. The parameters considered in the assembly induced damage study were the stiffness retention factor, the scatter factors of the damaged and undamaged laminate strengths, the mechanical properties of the undamaged material, and the characteristic length used in the average stress criterion. The results of these studies are discussed in the following paragraphs.

6.1 SENSITIVITY OF DAMAGE TOLERANCE CRITERIA

Four damage tolerance certification criteria were considered in the parametric study. These are:

(1) No structural failure at design ultimate loads,

(2) No structural failure at 1.25 times design limit loads,

(3) No local failure at design limit load and no structural failure at 1.25 times design limit loads, and

(4) No local failure nor structural failure at design limit loads.

These criteria were used in reference 6 for impact damage tolerance evaluations. The impact damage tolerance design allowable strain is affected by the different criteria because of the two stage failure process of the impact damaged composite structures. Criterion (1) allows initial or local failure to occur below ultimate load, and therefore, it is less conservative than criterion (4). In criteria (2) and (3), a factor of 1.25 is used because 1.25 times limit load is considered as the maximum spectrum load for the military aircraft. The design allowables based on criteria (2) and (3) are usually less conservative because the allowables are used for ultimate design.

The B-basis impact damage tolerance design allowables based on the four certification criteria are summarized in table 17. These results are for the Lear Fan 2100 upper wing skin with 100 ft-lb impact. The table also shows the margin of safety based on the maximum ultimate

TABLE 17. SENSITIVITY OF DAMAGE TOLERANCE CRITERIA, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION.

REG.	B-ALLOWABLE (MICRO) I	II	III	IV	MARGIN OF SAFETY (B-BASIS) I	II	III	IV
1	1998	2498	2167	1444	3.58	4.73	3.97	2.31
2	2334	2917	2275	1517	0.85	1.31	0.80	0.20
3	2271	2839	2274	1516	0.80	1.25	0.80	0.20
4	1998	2498	2167	1444	3.44	4.55	3.81	2.21
5	2269	2837	2276	1517	0.79	1.24	0.80	0.20
6	2245	2860	2276	1517	0.77	1.21	0.80	0.20
7	1954	2442	2180	1454	3.17	4.21	3.65	2.10
8	2214	2767	2277	1518	0.74	1.18	0.79	0.19
9	2220	2775	2278	1518	0.75	1.18	0.79	0.19
10	1954	2442	2180	1454	2.81	3.76	3.25	1.83
11	2150	2687	2278	1519	0.69	1.11	0.79	0.20
12	2190	2737	2279	1519	0.72	1.15	0.79	0.20
13	1903	2379	2195	1464	2.15	2.93	2.63	1.42
14	2068	2585	2535	1690	0.61	1.01	0.97	0.31
15	2167	2708	2226	1484	0.68	1.11	0.73	0.15
16	1903	2379	2195	1464	1.55	2.19	1.95	0.96
17	2030	2538	2535	1690	0.57	0.96	0.95	0.30
18	2122	2653	2282	1521	0.88	1.05	0.76	0.17
19	1892	2365	2199	1466	1.07	1.59	1.41	0.60
20	1982	2478	2478	1691	0.51	0.89	0.89	0.29
21	2093	2616	2282	1522	0.60	0.99	0.74	0.16
22	1870	2338	2205	1470	0.73	1.16	1.04	0.36
23	1942	2427	2427	1691	0.46	0.82	0.82	0.27
24	2066	2582	2283	1522	0.55	0.94	0.72	0.14
25	1860	2326	2207	1472	0.49	0.86	0.77	0.18
26	1908	2385	2385	1691	0.11	0.39	0.39	-0.02
27	2042	2552	2284	1522	0.19	0.48	0.33	-0.11
28	1861	2326	2207	1472	0.34	0.68	0.59	0.06
29	2436	3045	2531	1688	0.33	0.67	0.39	-0.08
30	2244	2805	2741	1827	0.13	0.42	0.39	-0.08
31	2027	2534	2534	1692	0.02	0.28	0.28	-0.14

TABLE 17. SENSITIVITY OF DAMAGE TOLERANCE CRITERIA, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALLOWABLE (MICRO) I	II	III	IV	MARGIN OF SAFETY (B-BASIS) I	II	III	IV
32	1851	2314	2210	1473	0.19	0.49	0.43	-0.05
33	2351	2939	2532	1688	0.09	0.36	0.18	-0.22
34	2243	2804	2743	1829	-0.03	0.21	0.19	-0.21
35	2012	2515	2515	1693	-0.13	0.09	0.09	-0.27
36	1851	2314	2210	1473	0.08	0.35	0.29	-0.14
37	2274	2843	2533	1689	-0.09	0.14	0.02	-0.32
38	2242	2803	2745	1830	-0.15	0.06	0.04	-0.31
39	1998	2497	2497	1693	-0.25	-0.06	-0.06	-0.36
40	1833	2291	2215	1477	+0.00	0.25	0.21	-0.19
41	2213	2767	2534	1689	-0.18	0.03	-0.06	-0.37
42	2241	2801	2747	1831	-0.21	-0.01	-0.03	-0.35
43	2202	2753	2753	1835	-0.22	-0.03	-0.03	-0.35
44	3274	4092	2542	1694	0.44	0.80	0.12	-0.25
45	1824	2280	2217	1478	-0.03	0.21	0.17	-0.22
46	2165	2706	2535	1690	-0.24	-0.05	-0.11	-0.40
47	2240	2800	2748	1832	-0.24	-0.05	-0.07	-0.38
48	2201	2752	2752	1835	-0.26	-0.07	-0.07	-0.38
49	3158	3948	2542	1694	0.33	0.66	0.07	-0.29
50	1824	2280	2217	1478	-0.03	0.21	0.17	-0.22
51	2121	2652	2535	1690	-0.27	-0.08	-0.12	-0.41
52	2239	2799	2749	1832	-0.26	-0.07	-0.09	-0.39
53	2201	2751	2751	1835	-0.27	-0.09	-0.09	-0.39
54	3055	3819	2542	1694	0.25	0.37	0.04	-0.30
55	1816	2270	2219	1480	-0.03	0.21	0.18	-0.21
56	2083	2604	2536	1690	-0.29	-0.11	-0.14	-0.43
57	2239	2798	2749	1833	-0.27	-0.08	-0.10	-0.40
58	2200	2750	2750	1836	-0.28	-0.10	-0.10	-0.40
59	2964	3705	2542	1694	0.19	0.49	0.02	-0.32
60	1771	2213	2171	1448	-0.05	0.19	0.17	-0.22
61	2049	2561	2536	1691	-0.31	-0.14	-0.15	-0.43
62	2238	2797	2750	1834	-0.28	-0.10	-0.11	-0.41
63	2199	2749	2749	1836	-0.29	-0.11	-0.11	-0.41
64	2881	3602	2542	1695	0.13	0.42	+0.00	-0.33

TABLE 17. SENSITIVITY OF DAMAGE TOLERANCE CRITERIA, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALLOWABLE (MICRO)				MARGIN OF SAFETY (B-BASIS)			
	I	II	III	IV	I	II	III	IV
65	1763	2204	2173	1449	-0.04	0.20	0.18	-0.21
66	2018	2523	2523	1691	-0.34	-0.17	-0.17	-0.44
67	2237	2797	2751	1834	-0.29	-0.11	-0.13	-0.42
68	2199	2748	2748	1836	-0.30	-0.13	-0.13	-0.42
69	2807	3509	2542	1695	0.09	0.36	-0.02	-0.34
70	1764	2205	2173	1449	-0.03	0.21	0.19	-0.20
71	1990	2488	2488	1691	-0.35	-0.19	-0.19	-0.45
72	2237	2796	2751	1834	-0.30	-0.12	-0.14	-0.42
73	2198	2748	2748	1836	-0.31	-0.14	-0.14	-0.42
74	2740	3425	2542	1695	0.04	0.30	-0.04	-0.36
75	1765	2206	2173	1449	-0.02	0.23	0.21	-0.19
76	1965	2456	2456	1692	-0.37	-0.21	-0.21	-0.46
77	2235	2794	2752	1834	-0.31	-0.13	-0.15	-0.43
78	2196	2745	2745	1836	-0.32	-0.15	-0.15	-0.43
79	2679	3348	2542	1695	-0.00	0.25	-0.05	-0.37
80	1750	2188	2176	1451	-0.00	0.25	0.24	-0.17
81	1942	2427	2427	1692	-0.39	-0.23	-0.23	-0.46
82	2234	2793	2752	1835	-0.31	-0.14	-0.16	-0.44
83	2195	2744	2744	1836	-0.33	-0.16	-0.16	-0.44
84	2623	3278	2542	1695	-0.04	0.20	-0.07	-0.38
85	1751	2189	2176	1451	0.03	0.28	0.28	-0.15
86	1921	2401	2401	1692	-0.40	-0.25	-0.25	-0.47
87	2233	2792	2752	1835	-0.32	-0.15	-0.16	-0.44
88	2194	2743	2743	1836	-0.33	-0.17	-0.17	-0.44
89	2571	3214	2542	1695	-0.07	0.16	-0.08	-0.39
90	1747	2184	2178	1452	0.06	0.33	0.33	-0.12
91	1897	2372	2372	1692	-0.41	-0.26	-0.26	-0.47
92	2233	2792	2792	2088	-0.33	-0.16	-0.16	-0.37
93	2194	2743	2743	2089	-0.34	-0.17	-0.17	-0.37
94	2525	3157	2755	1837	-0.10	0.13	-0.02	-0.35

TABLE 17. SENSITIVITY OF DAMAGE TOLERANCE CRITERIA, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONTINUED)

REG.	B-ALLOWABLE (MICRO) I	II	III	IV	MARGIN OF SAFETY (B-BASIS) I	II	III	IV
95	1830	2287	2217	1478	0.17	0.46	0.42	-0.05
96	1871	2339	2339	1692	-0.42	-0.28	-0.28	-0.48
97	2232	2790	2790	2088	-0.33	-0.17	-0.17	-0.38
98	2193	2742	2742	2089	-0.35	-0.18	-0.18	-0.38
99	2468	3085	2755	1837	-0.13	0.08	-0.03	-0.36
100	1805	2257	2223	1482	0.26	0.57	0.55	0.03
101	1850	2312	2312	1692	-0.43	-0.29	-0.29	-0.48
102	2232	2790	2790	2088	-0.34	-0.17	-0.17	-0.38
103	2193	2741	2741	2089	-0.35	-0.19	-0.19	-0.38
104	2416	3020	2755	1837	-0.17	0.04	-0.05	-0.37
105	1806	2257	2223	1482	0.42	0.78	0.75	0.17
106	1829	2287	2287	1692	-0.44	-0.30	-0.30	-0.48
107	2231	2789	2789	2088	-0.34	-0.18	-0.18	-0.38
108	2192	2740	2740	2089	-0.35	-0.19	-0.19	-0.38
109	2369	2961	2755	1837	-0.19	0.01	-0.06	-0.37
110	1765	2206	2175	1450	0.48	0.85	0.83	0.22
111	1816	2270	2270	1693	-0.44	-0.30	-0.30	-0.48
112	2230	2788	2788	2088	-0.34	-0.18	-0.18	-0.38
113	2191	2739	2739	2089	-0.35	-0.19	-0.19	-0.38
114	2337	2921	2755	1837	-0.21	-0.01	-0.06	-0.38
115	1758	2197	2176	1451	0.48	0.86	0.84	0.23
116	1803	2254	2254	1693	-0.45	-0.31	-0.31	-0.48
117	2230	2787	2787	2088	-0.34	-0.18	-0.18	-0.38
118	2191	2739	2739	2089	-0.35	-0.19	-0.19	-0.38
119	2306	2883	2755	1837	-0.22	-0.02	-0.07	-0.38
120	—	—	—	—	—	—	—	—
121	1727	2159	2159	1691	-0.48	-0.34	-0.34	-0.49
122	2230	2788	2788	2087	-0.34	-0.18	-0.18	-0.39
123	2191	2739	2739	2089	-0.35	-0.19	-0.19	-0.38
124	2293	2866	2755	1836	-0.22	-0.03	-0.07	-0.38

TABLE 17. SENSITIVITY OF DAMAGE TOLERANCE CRITERIA, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION. (CONCLUDED)

REG.	B-ALLOWABLE (MICRO) I	II	III	IV	MARGIN OF SAFETY (B-BASIS) I	II	III	IV
125	—	—	—	—	—	—	—	—
126	1711	2139	2139	1691	-0.48	-0.35	-0.35	-0.49
127	2230	2788	2788	2087	-0.34	-0.18	-0.18	-0.39
128	2191	2739	2739	2089	-0.36	-0.19	-0.19	-0.39
129	2293	2866	2755	1836	-0.22	-0.03	-0.07	-0.38
130	—	—	—	—	—	—	—	—
131	1696	2120	2120	1691	-0.49	-0.36	-0.36	-0.49
132	2230	2788	2788	2087	-0.34	-0.18	-0.18	-0.39
133	2191	2739	2739	2089	-0.36	-0.19	-0.19	-0.39
134	2293	2866	2755	1837	-0.22	-0.03	-0.07	-0.38
135	—	—	—	—	—	—	—	—
136	1691	2114	2114	1691	-0.49	-0.37	-0.37	-0.49
137	2230	2788	2788	2087	-0.34	-0.18	-0.18	-0.39
138	2191	2739	2739	2089	-0.36	-0.19	-0.19	-0.39
139	2293	2866	2755	1837	-0.22	-0.03	-0.07	-0.38

Note: Damage tolerance design criteria are defined as:

I No structural failure at ultimate loads.
II No structural failure at 1.25 times limit loads.
III No local failure at limit loads and no structural failure at 1.25 times limit loads.
IV No local nor structural failureat limit loads.

1.25 times limit load is considered as the maximum spectrum load.

strain in each subdivision. The 100 ft-lb impact threat was used in this study because this threat clearly showed the effects of the damage tolerance criteria, even though the threat is too severe for the skin. The results shown in table 17 indicate, as expected, that criterion (2) provides the highest impact tolerance design allowable strain, whereas criterion (4) gives the lowest allowable. The margins of safety are negative for a large portion of the skin because, as discussed before, the skin is not designed for such severe damage.

6.2 SENSITIVITY OF ASSEMBLY INDUCED DAMAGE PARAMETERS

The effects of assembly induced damage parameters were investigated for the five major laminates in the upper wing skin of the aircraft. The key laminate thicknesses and their layups are shown in shown in table 1 and they are:

(1) 0.053 in. thick with (0/79/21) layup,

(2) 0.067 in. thick with (0/84/16) layup,

(3) 0.081 in. thick with (0/86/14) layup,

(4) 0.109 in. thick with (0/90/10) layup,

(5) 0.125 in. thick with (35/56/9) layup.

The effects of the stiffness retention ratio in the damage zone were evaluated for the five laminates. The allowable damage diameters at 0.90, 0.95 and 0.99 reliability levels were computed for a range of stiffness retention ratios. The allowable damage size was determined for the maximum ultimate strain of the respective laminate in the upper wing skin. The results of this evaluation are summarized in table 18. The lowest stiffness retention ratio used in the evaluation was 0.0001. The maximum stiffness retention ratio used corresponds to a damage diameter larger than 10.0 in. at the 0.99 reliability level. The results of this evaluation provide an indication of the effects of assembly standards on the integrity of the structure. If a stiffness retention ratio of 0.1 is used as a criterion for assembly standards, then the 0.125- and 0.053-in.-thick areas of the wing skin can tolerate relatively poor assembly operation. This is because the maximum ultimate strains in these areas are relatively low. However, for the 0.109-in.-thick-laminate, the allowable damage diameter is only approximately 1.0 in. at a 0.90 reliability for the structural areas with highest strains. The allowable damage diameter for the 0.081- and 0.067-in.-thick laminates with stiffness retention ratio of 0.10 are 2.36 and 1.88 in., respectively. The results shown in table 18 also indicate that higher assembly standards are required to achieve high structural reliability.

TABLE 18. EFFECTS OF STIFFNESS RETENTION RATIO ON THE ALLOWABLE SIZE OF ASSEMBLY INDUCED DAMAGE FOR THE LEAR FAN 2100 UPPER WING SKIN LAMINATES.

THICKNESS	STRAIN	S_r	MAXIMUM DAMAGE DIAMETER		
			0.90	0.95	0.99
0.125	1857	0.0001	*(0.98554)	*(0.98554)	4.174
0.125	1857	0.0005	*(0.98568)	*(0.98568)	4.242
0.125	1857	0.001	*(0.98586)	*(0.98586)	4.328
0.125	1857	0.005	*(0.98720)	*(0.98720)	5.170
0.125	1857	0.01	*(0.98868)	*(0.98868)	6.806
0.125	1857	0.02	*(0.99112)	*(0.99112)	*(0.99112)
0.109	3400	0.0001	0.373	0.282	**(0.96419)
0.109	3400	0.0005	0.374	0.282	**(0.96437)
0.109	3400	0.001	0.375	0.283	**(0.96460)
0.109	3400	0.005	0.385	0.288	**(0.96636)
0.109	3400	0.01	0.398	0.295	**(0.96841)
0.109	3400	0.02	0.426	0.311	**(0.97211)
0.109	3400	0.03	0.458	0.327	**(0.97532)
0.109	3400	0.04	0.496	0.345	**(0.97811)
0.109	3400	0.05	0.542	0.365	**(0.98054)
0.109	3400	0.06	0.599	0.388	**(0.98267)
0.109	3400	0.07	0.672	0.413	**(0.98453)
0.109	3400	0.08	0.769	0.443	**(0.98617)
0.109	3400	0.09	0.904	0.477	**(0.98761)
0.109	3400	0.10	1.095	0.518	**(0.98888)
0.109	3400	0.125	1.981	0.669	0.266
0.109	3400	0.150	4.054	0.992	0.297
0.109	3400	0.175	*(0.90673)	1.871	0.335
0.109	3400	0.200	*(0.93571)	4.222	0.384
0.109	3400	0.225	*(0.95544)	*(0.95544)	0.452
0.109	3400	0.250	*(0.96891)	*(0.96891)	0.556
0.109	3400	0.275	*(0.97813)	*(0.97813)	0.754
0.109	3400	0.300	*(0.98449)	*(0.98449)	1.360
0.109	3400	0.325	*(0.98891)	*(0.98891)	5.094
0.109	3400	0.350	*(0.99198)	*(0.99198)	*(0.99198)

TABLE 18. EFFECTS OF STIFFNESS RETENTION RATIO ON THE ALLOWABLE SIZE OF ASSEMBLY INDUCED DAMAGE FOR THE LEAR FAN 2100 UPPER WING SKIN LAMINATES. (CONTINUED)

THICKNESS	STRAIN	S_r	MAXIMUM DAMAGE DIAMETER 0.90	0.95	0.99
0.081	3294	0.0001	0.470	0.335	**(0.97707)
0.081	3294	0.0005	0.471	0.336	**(0.97719)
0.081	3294	0.001	0.473	0.337	**(0.97733)
0.081	3294	0.005	0.489	0.345	**(0.97844)
0.081	3294	0.01	0.510	0.355	**(0.97974)
0.081	3294	0.02	0.558	0.376	**(0.98208)
0.081	3294	0.03	0.618	0.401	**(0.98412)
0.081	3294	0.04	0.695	0.428	**(0.98598)
0.081	3294	0.05	0.796	0.460	**(0.98744)
0.081	3294	0.06	0.934	0.498	**(0.98880)
0.081	3294	0.07	1.130	0.543	**(0.98999)
0.081	3294	0.08	1.411	0.598	0.261
0.081	3294	0.09	1.809	0.668	0.272
0.081	3294	0.10	2.359	0.760	0.285
0.081	3294	0.125	5.460	1.190	0.321
0.081	3294	0.150	*(0.91860)	2.372	0.366
0.081	3294	0.175	*(0.94411)	6.300	0.426
0.081	3294	0.200	*(0.96137)	*(0.96137)	0.514
0.081	3294	0.225	*(0.97309)	*(0.97309)	0.659
0.081	3294	0.250	*(0.98109)	*(0.98109)	0.976
0.081	3294	0.300	*(0.99039)	*(0.99039)	*(0.99039)
0.067	3341	0.0001	0.443	0.321	**(0.97420)
0.067	3341	0.0005	0.444	0.321	**(0.97433)
0.067	3341	0.001	0.446	0.322	**(0.97449)
0.067	3341	0.005	0.459	0.329	**(0.97572)
0.067	3341	0.01	0.477	0.338	**(.097716)
0.067	3341	0.02	0.518	0.358	**(0.97977)
0.067	3341	0.03	0.568	0.380	**(0.98204)
0.067	3341	0.04	0.629	0.404	**(0.98402)
0.067	3341	0.05	0.706	0.432	**(0.98576)
0.067	3341	0.06	0.807	0.464	**(0.98729)
0.067	3341	0.07	0.946	0.502	**(0.98863)
0.067	3341	0.08	1.144	0.547	**(0.98981)

TABLE 18. EFFECTS OF STIFFNESS RETENTION RATIO ON THE ALLOWABLE SIZE OF ASSEMBLY INDUCED DAMAGE FOR THE LEAR FAN 2100 UPPER WING SKIN LAMINATES. (CONCLUDED)

THICKNESS	STRAIN	S_r	MAXIMUM DAMAGE DIAMETER		
			0.90	0.95	0.99
0.067	3341	0.09	1.439	0.602	0.259
0.067	3341	0.100	1.883	0.671	0.270
0.067	3341	0.125	4.347	0.964	0.303
0.067	3341	0.150	*(0.91345)	1.766	0.344
0.067	3341	0.175	*(0.94011)	4.588	0.396
0.067	3341	0.200	*(0.95829)	*(0.95829)	0.469
0.067	3341	0.225	*(0.97071)	*(0.97071)	0.581
0.067	3341	0.250	*(0.97924)	*(0.97924)	0.784
0.067	3341	0.275	*(0.98515)	*(0.98515)	1.322
0.067	3341	0.300	*(0.98925)	*(0.98925)	5.309
0.067	3341	0.325	*(0.99213)	*(0.99213)	*(0.99213)
0.053	1888	0.0001	*(0.99897)	*(0.99897)	*(0.99897)

Note: (1) The strain is the maximum compression strain of the laminate in the upper wing skin.
(2) Refer to table 1 for laminate layup.
(3) * denotes that the allowable damage diameter larger than 10.0-in. and the number in ( ) is the reliablity for the laminate with a 10.0-in. diameter damage.
(4) ** denotes that the allowable damage diameter smaller than 0.25-in. and the number in ( ) is the relibility for the laminate with a 0.25-in. diameter damage.

For the 0.99 reliability level, little or no damage induced by assembly can be tolerated (allowable damage diameter less than the fastener hole size) in the high strain areas of the 0.067-, 0.081- and 0.109-in.-thick laminates with a stiffness retention ratio of 0.1.

The scatter in the residual strength of the damaged laminates also has a significant effect on the damage tolerance design allowable strains. These effects are shown in figures 41 through 45 for the five laminates. The scatter in the laminate strength is characterized by the Weibull shape parameter, α. The values of α used in the baseline evaluation, discussed in section 5, were 20 for the undamaged laminates and 12 for the damaged laminates. These values were obtained based on the surveys of experimental data conducted in references 4 and 8. Figures 41 through 45 show the 90 percent reliability allowable strain for damaged laminate scatter parameters of 12 and 8. These figures show that the allowable strain is reduced by 12.5 percent as the damaged laminate scatter parameter is reduced from 12 to 8. Only the 90 percent reliability results are shown in figures 41 through 45. Allowable strain at other reliability levels, for a fixed scatter parameter of the undamaged laminate, can be easily computed by the following formula.

$$Resp = [\ln(R)/\ln(0.90)]^{**}(1/\alpha_d) \quad (1)$$

where Resp is the strain ratio,

R is the required reliability,

α_d is the Weibull shape parameter of the damaged laminate.

The allowable strain of the damaged structure is also influenced by the scatter parameters of the damaged and undamaged laminate strengths. A normalized allowable strain ratio was computed to evaluate the effects of the scatters. The results are shown in table 19. The effects of damaged laminate strength scatter are shown on the two left columns in the table. The strain ratios were computed for $\alpha_s = 20$ (Weibull shape parameter for the undamaged laminate strength) and normalized to the strain corresponding to $\alpha_d = 3$ (Weibull shape parameter for the damaged laminate strength). As can be observed from the table, the allowable strain ratio between the highly scattered data ($\alpha_d = 3$) to little scattered data ($\alpha_d = 50$) is more than 2.3. However, within the range of scatter observed in published data (α_d between 6 and 12) the ratio is between 1.58 and 1.97. Therefore, the allowable strain of the damaged laminate may be conservatively estimated for commonly used composites, when the damaged laminate strength scatter data is not readily available. These strain ratios are also plotted in figure 46.

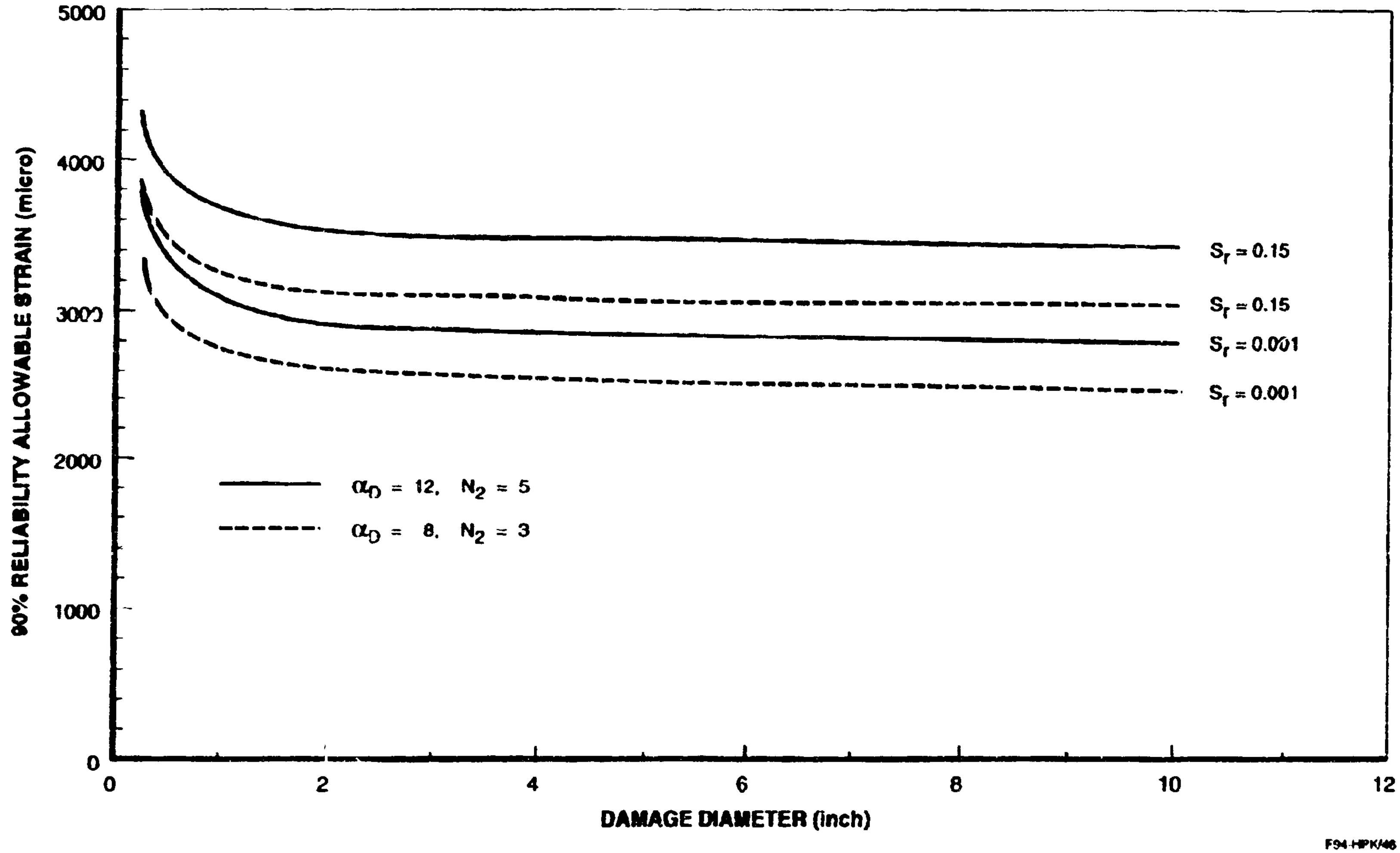

FIGURE 41. EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.053-IN.-THICK LAMINATE.

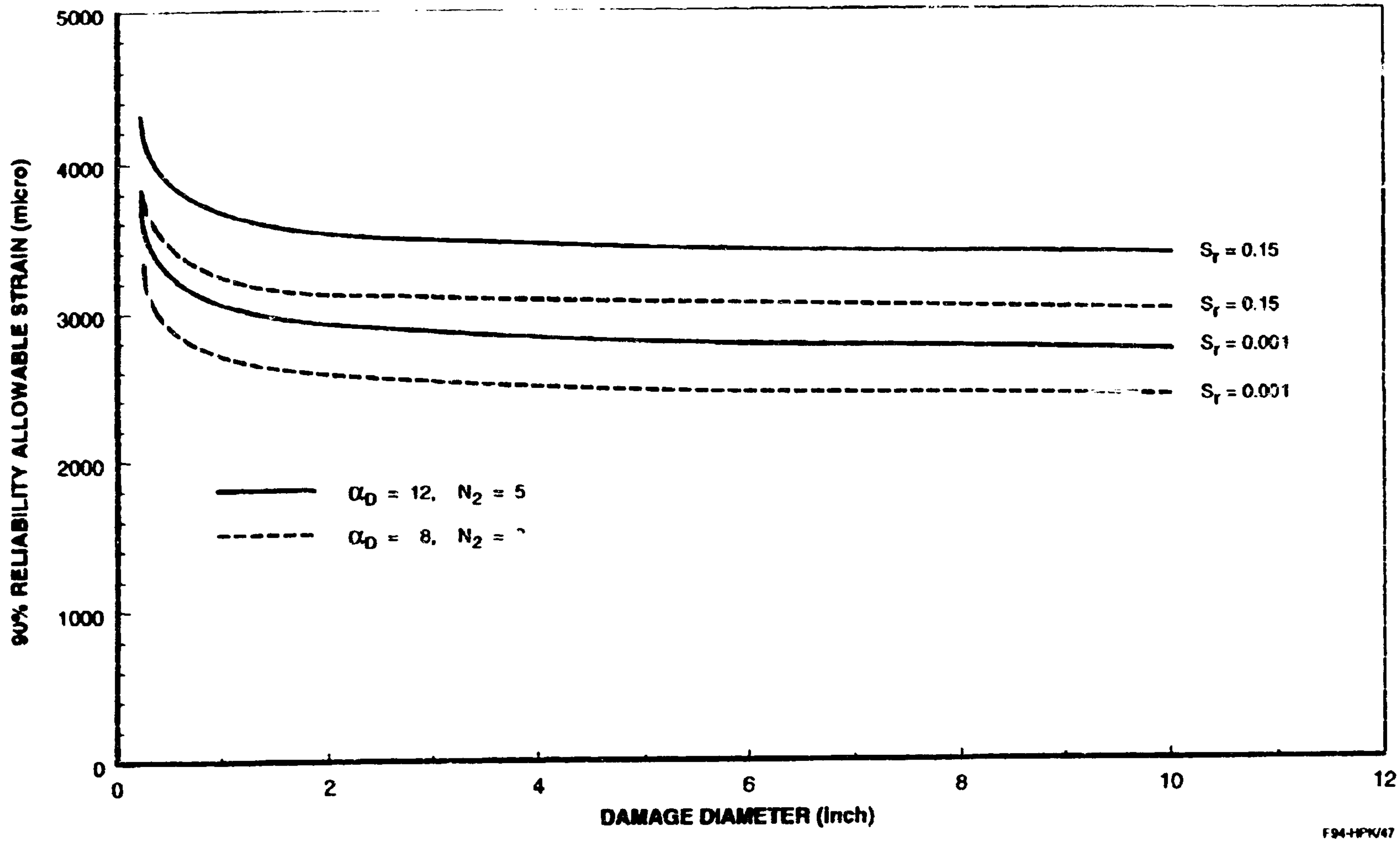

FIGURE 42. EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.067-IN.-THICK LAMINATE.

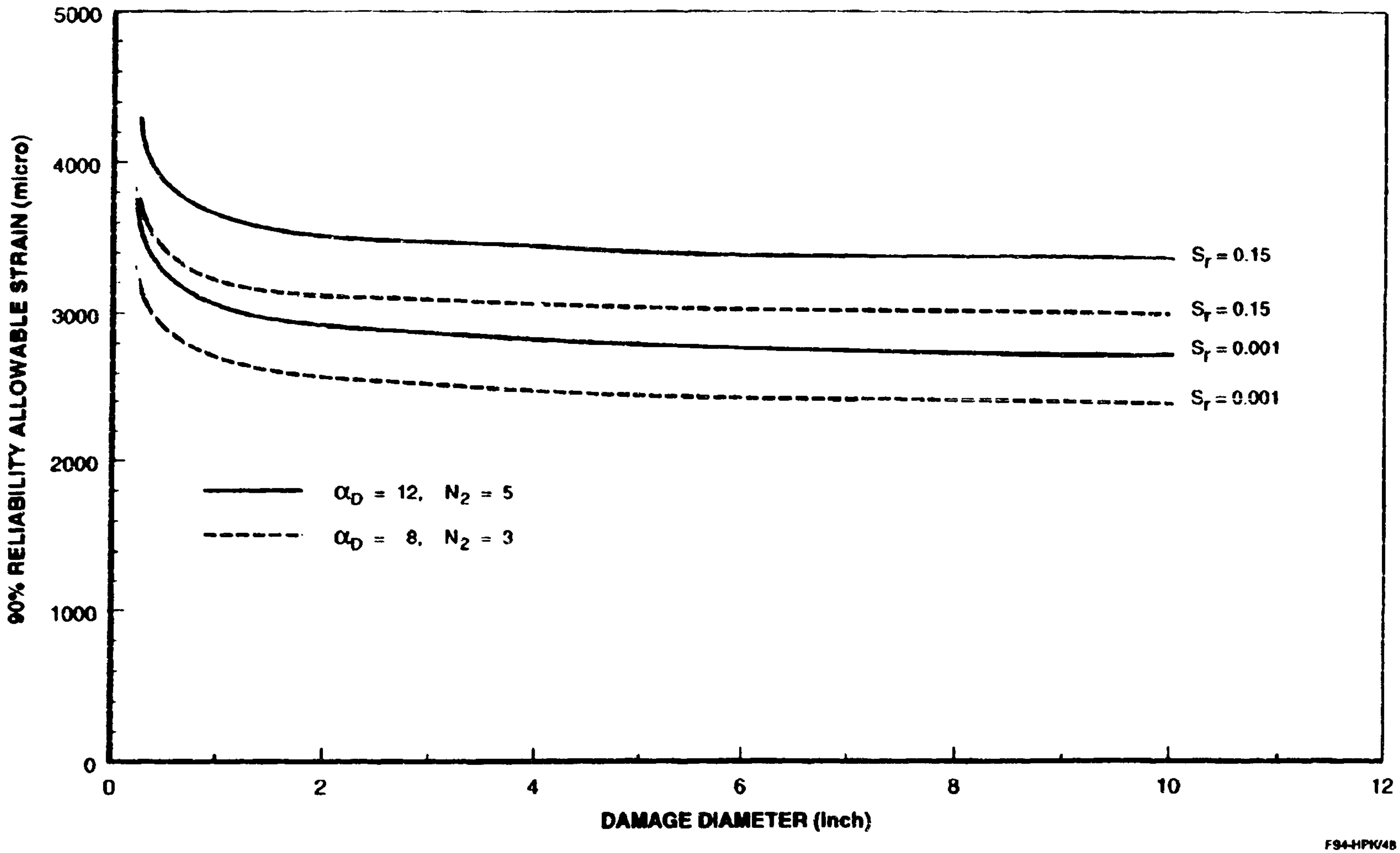

FIGURE 43. EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.081-IN.-THICK LAMINATE.

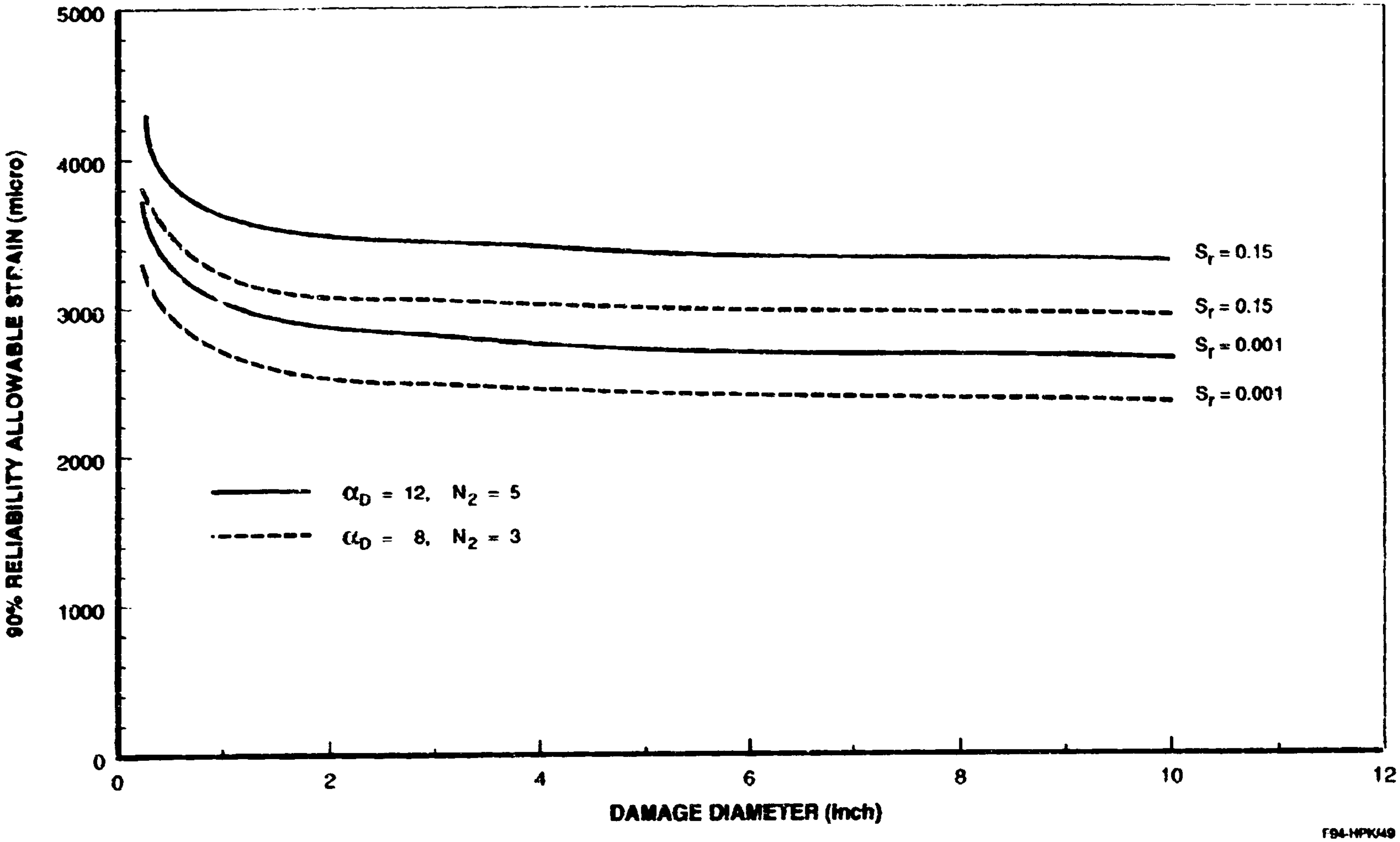

FIGURE 44. EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.109-IN.-THICK LAMINATE.

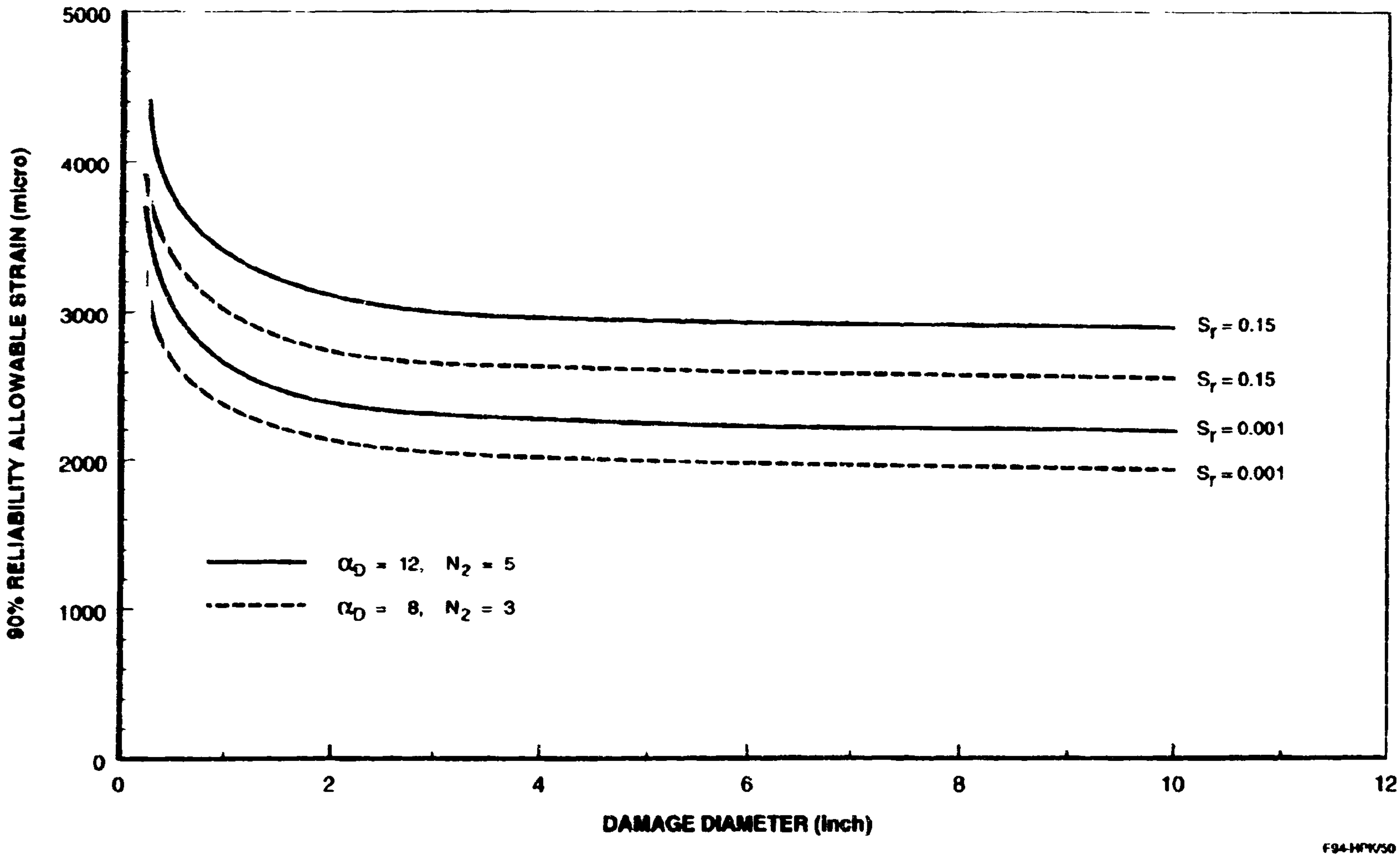

FIGURE 45. EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.125-IN.-THICK LAMINATE.

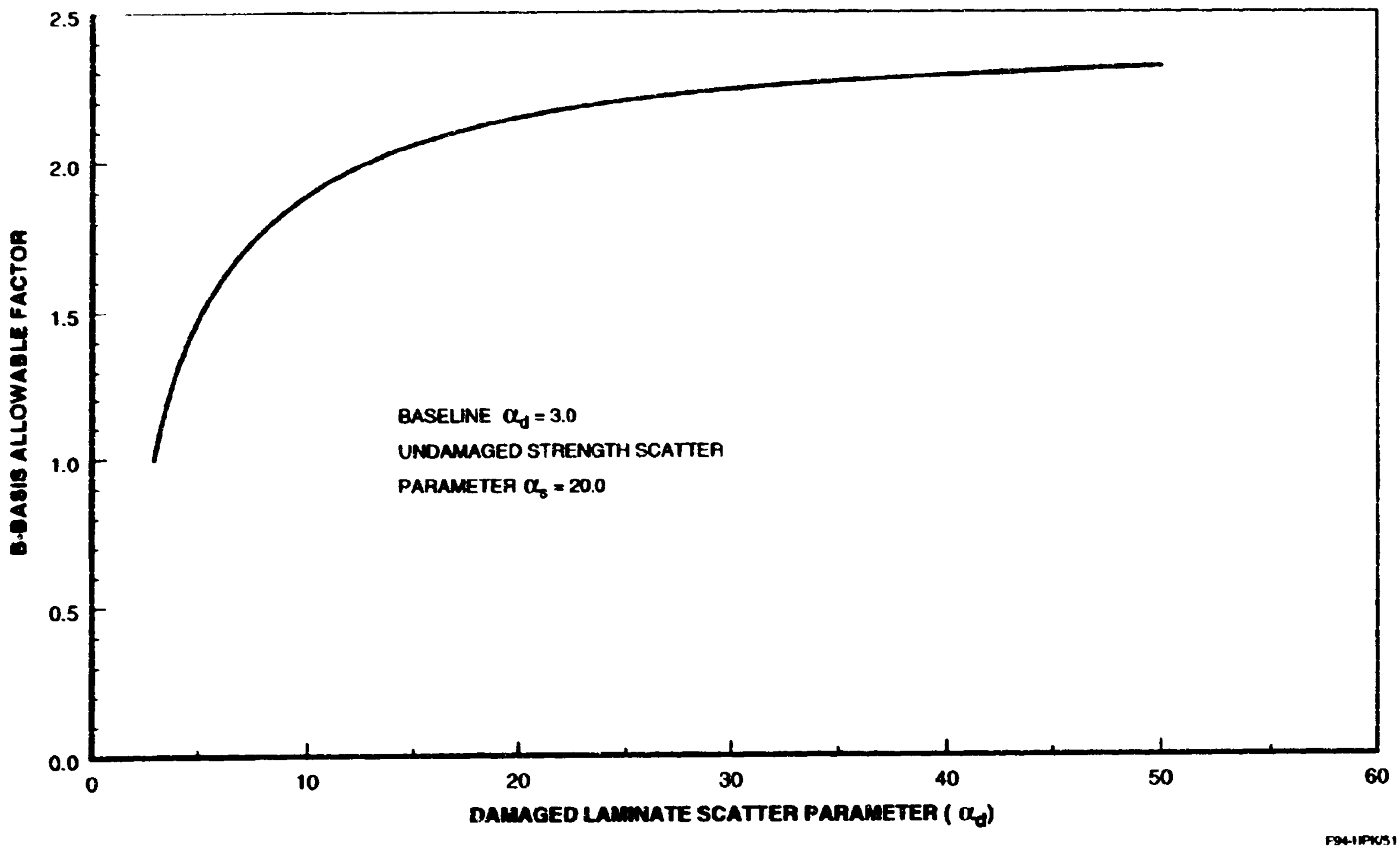

FIGURE 46. EFFECTS OF DAMAGED LAMINATE STRENGTH SCATTER ON ALLOWABLE STRAIN.

TABLE 19. EFFECTS OF SCATTER PARAMETERS ON THE ALLOWABLE STRAIN.

α_d	RATIO
3.0	1.0000
4.0	1.2642
5.0	1.4493
6.0	1.5848
7.0	1.6877
8.0	1.7684
9.0	1.8333
10.0	1.8866
11.0	1.9310
12.0	1.9686
13.0	2.0009
14.0	2.0289
15.0	2.0535
16.0	2.0751
17.0	2.0944
18.0	2.1115
19.0	2.1270
20.0	2.1411
21.0	2.1538
22.0	2.165[illegible]
23.0	2.1761
24.0	2.1859
25.0	2.1950
26.0	2.2033
27.0	2.2111
28.0	2.2183
29.0	2.2251
30.0	2.2314
50.0	2.3058

α_s	RATIO
5.0	0.7258
6.0	0.7815
7.0	0.8230
8.0	0.8553
9.0	0.8809
10.0	0.9018
11.0	0.9192
12.0	0.9338
13.0	0.9463
14.0	0.9571
15.0	0.9665
16.0	0.9748
17.0	0.9822
18.0	0.9887
19.0	0.9946
20.0	1.0000
21.0	1.0048
22.0	1.0092
23.0	1.0133
24.0	1.0170
25.0	1.0204
26.0	1.0236
27.0	1.0265
28.0	1.0292
29.0	1.0318
30.0	1.0341
32.5	1.0395
35.0	1.0440
37.5	1.0480
40.0	1.0515
45.0	1.0573
50.0	1.0620
55.0	1.0658
60.0	1.0690
70.0	1.0740
80.0	1.0778
90.0	1.0808
100.0	1.0832

Note: (1) α_s is Weibull shape parameter of the undamaged laminate strength; α_d is the Weibull shape parameter of the damaged laminate strength.
(2) Baseline is α_d=3.0 and α_s=20.0.

The influence of the undamaged laminate strength scatter is shown on the two right columns of table 19. The strain ratios shown in the table indicate that the undamaged laminate strength scatter has less effect on the allowable strain ratio, as compared to the scatter of the damaged laminate. Within the range of the scatter parameter observed for commonly used composites (α_s between 15 and 25), the ratio ranges from 0.97 to 1.02.

The effects of sample size, based on which the scatter parameters are derived, on the damaged laminate allowable strain are shown in table 20. The table shows the normalized strain ratio with a baseline for $\alpha_s = 20$, $\alpha_d = 12$ and the sample sizes for undamaged laminate strength (Ns) of 30 and damaged laminate strength (Nd) of 5. The table shows that the sample size effect is significantly less than the effect of the scatter parameters.

TABLE 20. EFFECTS OF SAMPLE SIZE ON THE ALLOWABLE STRAIN.

N_d	SAMPLE SIZE FOR THE UNDAMAGED LAMINATE STRENGTH (N_u) 6	10	15	20	30	50	100
2	0.9648	0.9701	0.9737	0.9759	0.9786	0.9815	0.9845
3	0.9747	0.9801	0.9837	0.9859	0.9887	0.9916	0.9946
4	0.9812	0.9866	0.9902	0.9925	0.9952	0.9982	1.0012
5	0.9859	0.9913	0.9949	0.9972	1.0000	1.0029	1.0060
6	0.9895	0.9949	0.9986	1.0009	1.0037	1.0066	1.0097
7	0.9924	0.9978	1.0015	1.0038	1.0066	1.0095	1.0126
8	0.9948	1.0002	1.0039	1.0062	1.0090	1.0120	1.0151
9	0.9968	1.0023	1.0060	1.0083	1.0111	1.0140	1.0171
10	0.9985	1.0040	1.0077	1.0100	1.0129	1.0158	1.0189
11	1.0001	1.0056	1.0093	1.0116	1.0144	1.0174	1.0205
12	1.0014	1.0069	1.0106	1.0129	1.0158	1.0187	1.0218
15	1.0047	1.0102	1.0139	1.0162	1.0191	1.0221	1.0252
20	1.0085	1.0141	1.0178	1.0201	1.0230	1.0260	1.0291
25	1.0112	1.0168	1.0205	1.0228	1.0257	1.0287	1.0318
30	1.0132	1.0188	1.0226	1.0249	1.0278	1.0308	1.0339
40	1.0161	1.0217	1.0255	1.0278	1.0307	1.0337	1.0369
50	1.0182	1.0238	1.0275	1.0299	1.0328	1.0358	1.0389
100	1.0233	1.0290	1.0328	1.0351	1.0380	1.0410	1.0442

Note: (1) The allowable are normalized with repective to the B-basis allowable strain with baseline parameters.

(2) α_u is Weibull shape parameter of the undamaged laminate strength; α_d is the Weibull shape parameter of the damaged laminate strength.

(3) N_u is the sample size for the undamaged laminate strength; N_d is the sample size for the damaged laminate strength.

(4) Baseline is α_u=20.0 and α_d=12.0, N_u=30 and N_d=5.

SECTION 7

SUMMARY AND CONCLUSIONS

7.1 SUMMARY

The results of this research program are summarized below:

1. The structural configurations, loads, and full-scale test results of the Lear Fan 2100 aircraft were carefully reviewed. Based on the results of this review, the worst case strain distribution over the upper wing skin was obtained for damage tolerance evaluations.

2. A nondestructive inspection (NDI) was conducted over the upper wing skins and the upper fuselage skin, using ultrasonic and thermographic techniques.

3. A total of 19 defects on the upper wing skins were identified by the NDI. The majority of these defects were located around fasteners connecting the upper wing skins to the aft spars. In addition, an area of mild porosity in the wing skin was also detected.

4. Defects similar to those for disbonds were detected along the step-lap splice between the upper and side skins of the fuselage.

5. The upper wing skin was subdivided in small regions for damage tolerance evaluations. The subdivision was based on the arrangement of the substructures and the thickness distribution of the skin.

6. An impact damage tolerance evaluation was conducted. Probabilistic impact threats as well as a discrete impact threat were imposed on the upper wing skin. The reliability of the wing skin at design limit and design ultimate strains was determined.

7. Damage tolerance capability of the upper wing skin against assembly induced damage was also evaluated. Margin of safety and reliability of the skin with a baseline damage scenario were obtained. In addition, allowable damage sizes were defined for various damage scenarios.

8. A parametric study was conducted to assess the effects of damage tolerance design criteria, the assembly induced damage parameters and the scatter parameters of the

damaged and undamaged strengths of the skin laminates on the structural integrity of the upper wing skin.

7.2 CONCLUSIONS

The following conclusions may be drawn from the investigations undertaken in this program.

1. The NDI detected defects on the upper wing skins of the Lear Fan 2100 aircraft E009 were minor defects and did not impose a threat to the integrity of the wing skin.

2. Impact damage tolerance requirements for the composite military aircraft structures are too severe for the Lear Fan 2100 structures. The B-basis reliability at design ultimate conditions is difficult to achieve against either probabilistic or discrete impact threat. However, the reliabilities appear to be adequate at the design limit load conditions.

3. The damage tolerance capability of the upper wing skin is adequate against assembly induced damage.

4. Damage tolerance design criterion and impact threat need to be defined for the Lear Fan class of aircraft.

5. Poor assembly processes induce severe damage in the structure which may degrade the structural integrity. Therefore, assembly standards should be established to assure that no induced damage will significantly reduce the strength of the structure. NDI after final structure assembly is also needed if assembly procedures are poor.

REFERENCES

1. Federal Aviation Administration, "Composite Aircraft Structure," Advisory Circular AC 20-107A, April 25, 1984.

2. Davies, C. R., "Certification of Composites for Commercial Aircraft," Aerospace Technology Conference and Exposition, Anaheim, CA, September 1989, TPS 892212.

3. Soderquist, J. R., "Design/Certification Considerations in Civil Composite Aircraft Structures," Aerospace Technology Conference and Exposition, Long Beach, CA, October 1987, TPS 871846.

4. Whitehead, R. S., Kan, H. P., Cordero, R., and Saether, E. S., "Certification Testing Methodology for Composite Structures," Report No. NADC-87042-60, October 1986, Volumes I and II.

5. Sanger, K. B., "Certification Testing Methodology for Composite Structures," Report No. NADC-86132-60, January 1986.

6. Kan, H. P., Cordero, R., and Whitehead, R. S., "Advanced Certification Methodology for Composite Structures," Draft Final Report, NADC Contract No. N62269-87-C-0259, September 1989.

7. Rapoff, A. J., et al., "An Improved Certification Methodology for Composite Structures," Draft Final Report, NADC Contract No. N62269-87-C-0258, August 1989.

8. Kan, H. P., "Delamination Methodology for Composite Structures," Report No. NAWCADWAR-94097-60, and DOT/FAA/CT-93/64, February 1994.

9. Federal Aviation Administration, "Federal Aviation Regulations, Part 23 (FAR Part 23), "Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes," February 1965.

10. Horton, R. E., Whitehead, R. S., et al., "Damage Tolerance of Composites, Volumes I, II and III, Report No. AFWAL-TR-87-3030, July 1988.

11. Cairns, D. C., "Impact and Post-Impact Response of Graphite/Epoxy and Kevlar/Epoxy Structures," TELAC Report 87-105, PhD thesis, MIT, August 1987.

12. Lekhnitskii, S. G., "Anisotropic Plates," 2nd Edition, Translated from Russian by S. Tsai and T. Cheron, Gordon and Breach, 1968.

13. Whitney, J. M. and Nuismer, R. J., "Stress Fracture Criteria for Laminated Composites Containing Stress Concentrations," Journal of Composite Materials, Volume 8, 1974.

14. Fracchia, C., Wenthal, S., and Goering, J., "Survey of Assembly Induced Delaminations in Composite Structures and Related Analysis," Report No. NAWCADWAR-92057-60, July 1992.