

**DOT/FAA/AR-95/13**

Office of Aviation Research  
Washington, D.C. 20591

# **Structural Integrity Evaluation of the Lear Fan 2100 Aircraft**

**DTIC QUALITY INSPECTED 4**

**19960705 080**

May 1996

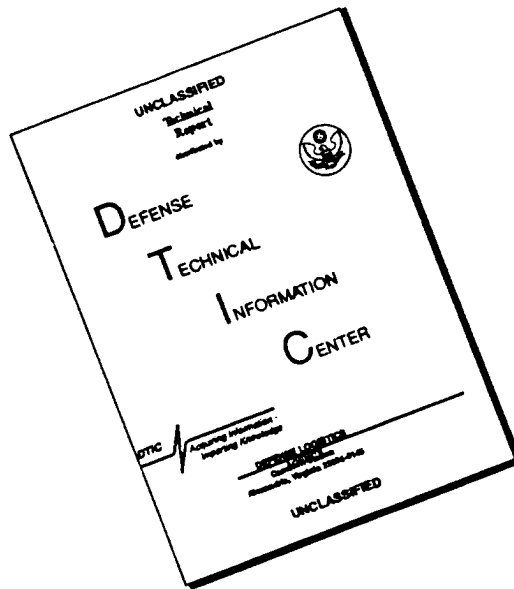
Final Report

This document is available to the U.S. public  
through the National Technical Information  
Service, Springfield, Virginia 22161.



U.S. Department of Transportation  
**Federal Aviation Administration**

# DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

## NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                          |                                                                                                                                                      |           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 1. Report No.<br>DOT/FAA/AR-95/13                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 2. Government Accession No.                              | 3. Recipient's Catalog No.                                                                                                                           |           |
| 4. Title and Subtitle<br><br>STRUCTURAL INTEGRITY EVALUATION OF THE<br>LEAR FAN 2100 AIRCRAFT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                          | 5. Report Date<br>May 1996                                                                                                                           |           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                          | 6. Performing Organization Code                                                                                                                      |           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                          | 8. Performing Organization Report No.                                                                                                                |           |
| 7. Author(s)<br>H.P. Kan and T.A. Dyer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                          | 10. Work Unit No. (TRAIS)                                                                                                                            |           |
| 9. Performing Organization Name and Address<br>Military Aircraft Division<br>Northrop Grumman Corporation<br>One Northrop Avenue<br>Hawthorne, California 90250-3277                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                          | 11. Contract or Grant No.<br>Task 12, NAS1-19347                                                                                                     |           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                          | 13. Type of Report and Period Covered<br>Final Report<br>November 1993 – October 1994                                                                |           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                          | 14. Sponsoring Agency Code<br>AAR-431                                                                                                                |           |
| 12. Sponsoring Agency Name and Address<br>U.S. Department of Transportation<br>Federal Aviation Administration<br>Office of Aviation Research<br>Washington, D.C. 20591<br>National Aeronautical and Space<br>Administration<br>Langley Research Center<br>Hampton, Virginia 23681-0001                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                          |                                                                                                                                                      |           |
| 15. Supplementary Notes<br>Technical Monitor: P. Shyprykevich, FAA Tech Center<br>Administrative Support: M. Rouse, NASA LaRC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                          |                                                                                                                                                      |           |
| 16. Abstract<br><br>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. |                                                          |                                                                                                                                                      |           |
| 17. Key Words<br><br>Composites, Damage Tolerance, Impact, Defects, Reliability, Nondestructive Inspection                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                          | 18. Distribution Statement<br><br>This document is available to the public through the National Technical Information Service, Springfield, VA 22161 |           |
| 19. Security Classif. (of this report)<br><br>UNCLASSIFIED                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 20. Security Classif. (of this page)<br><br>UNCLASSIFIED | 21. No. of Pages<br><br>166                                                                                                                          | 22. Price |

## PREFACE

This report was prepared by the Northrop Grumman 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 Grumman'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 Grumman personnel.

|                             |                  |
|-----------------------------|------------------|
| Structures and Loads Review | T. A. Dyer       |
| Nondestructive Inspection   | T. A. Dyer       |
|                             | D. J. Williamson |
|                             | B. Bohn          |
|                             | T. Kunst         |
|                             | D. Gray          |
| Documentation               | R. Cordero       |
|                             | H. Casarez       |
|                             | J. Baller        |

## TABLE OF CONTENTS

| Section |                                                       | Page |
|---------|-------------------------------------------------------|------|
|         | EXECUTIVE SUMMARY .....                               | xi   |
| 1       | INTRODUCTION .....                                    | 1    |
| 2       | STRUCTURAL DESCRIPTION .....                          | 3    |
| 3       | NONDESTRUCTIVE INSPECTION (NDI) .....                 | 7    |
| 4       | STRUCTURAL LOADS AND STRAINS .....                    | 17   |
|         | 4.1 FULL-SCALE WING TEST ARTICLE .....                | 17   |
|         | 4.2 TEST LOADS .....                                  | 19   |
|         | 4.3 UPPER WING SKIN STRAIN .....                      | 24   |
| 5       | DAMAGE TOLERANCE EVALUATION .....                     | 29   |
|         | 5.1 STRUCTURAL SUBDIVISION .....                      | 29   |
|         | 5.2 IMPACT DAMAGE TOLERANCE EVALUATION .....          | 36   |
|         | 5.3 ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION .... | 95   |
| 6       | PARAMETRIC STUDIES .....                              | 131  |
|         | 6.1 SENSITIVITY OF DAMAGE TOLERANCE CRITERIA .....    | 131  |
|         | 6.2 SENSITIVITY OF ASSEMBLY INDUCED DAMAGE PARAMETERS | 137  |
| 7       | SUMMARY AND CONCLUSIONS .....                         | 151  |
|         | 7.1 SUMMARY .....                                     | 151  |
|         | 7.2 CONCLUSIONS .....                                 | 152  |
|         | REFERENCES .....                                      | 153  |

## LIST OF FIGURES

| Figure |                                                                                                         | Page |
|--------|---------------------------------------------------------------------------------------------------------|------|
| 1      | THREE-VIEW OF THE AIRCRAFT .....                                                                        | 4    |
| 2      | MAJOR ASSEMBLY BREAKDOWN .....                                                                          | 5    |
| 3      | SUMMARY OF UPPER WING SKIN DEFECTS .....                                                                | 8    |
| 4      | MAUS IMAGES OF DEFECT NOS. 1 AND 2 ON THE UPPER LEFT WING SKIN .....                                    | 9    |
| 5      | MAUS IMAGES OF DEFECT NOS. 3 AND 4 ON THE UPPER LEFT WING SKIN .....                                    | 9    |
| 6      | MAUS IMAGE OF DEFECT NO. 5 ON THE UPPER LEFT WING SKIN ...                                              | 10   |
| 7      | MAUS IMAGE OF DEFECT NO. 1 ON THE UPPER RIGHT WING SKIN                                                 | 10   |
| 8      | MAUS IMAGE OF DEFECT NO. 2 ON THE UPPER RIGHT WING SKIN                                                 | 11   |
| 9      | MAUS IMAGES OF DEFECT NOS. 3, 4 AND 5 ON THE UPPER RIGHT WING SKIN .....                                | 11   |
| 10     | MAUS IMAGES OF DEFECT NOS 6 THROUGH 11 ON THE UPPER RIGHT WING SKIN .....                               | 12   |
| 11     | MAUS IMAGE OF DEFECT NO. 12 ON THE UPPER RIGHT WING SKIN                                                | 12   |
| 12     | MAUS IMAGES OF DEFECT NOS. 13 AND 14 ON THE UPPER RIGHT WING SKIN .....                                 | 13   |
| 13     | MAUS IMAGE OF MINOR POROUS AREA ON THE UPPER LEFT WING SKIN (BETWEEN Yw 28 AND 40) .....                | 13   |
| 14     | MAUS IMAGE OF DISBONDS ALONG THE STEP-LAP SPLICE BETWEEN THE UPPER AND SIDE SKINS OF THE FUSELAGE ..... | 15   |
| 15     | SCHEMATIC OF THE FULL-SCALE WING TEST ARTICLE AND SIGN CONVENTIONS OF APPLIED LOADS .....               | 18   |
| 16     | APPLIED TEST LOADS FOR THE SYMMETRIC UP BENDING TEST CASE .....                                         | 20   |
| 17     | COMPARISION OF THEORETICAL AND APPLIED WING SHEAR LOAD, SYMMETRIC UP BENDING CASE .....                 | 21   |
| 18     | COMPARISION OF THEORETICAL AND APPLIED WING BENDING MOMENT, SYMMETRIC UP BENDING CASE .....             | 22   |
| 19     | COMPARISION OF THEORETICAL AND APPLIED WING TORQUE LOAD, SYMMETRIC UP BENDING CASE .....                | 23   |
| 20     | SUMMARY OF STATIC WING TEST RESULTS .....                                                               | 25   |
| 21     | WORST CASE ULTIMATE STRAIN OF THE UPPER WING SKIN .....                                                 | 26   |
| 22     | ESTIMATED WORST CASE UPPER SKIN STRAINS ALONG THE SPARS                                                 | 27   |
| 23     | ESTIMATED WORST CASE STRAIN CONTOURS OF THE UPPER WING SKIN .....                                       | 28   |

## LIST OF FIGURES (Continued)

| Figure |                                                                                                                        | Page |
|--------|------------------------------------------------------------------------------------------------------------------------|------|
| 24     | SUBDIVISION OF THE UPPER WING SKIN FOR DAMAGE TOLERANCE EVALUATION .....                                               | 30   |
| 25     | SCHEMATIC OF THE INTEGRATED RELIABILITY ANALYSIS METHOD .....                                                          | 37   |
| 26     | PROBABILITY DISTRIBUTION OF IMPACT THREATS .....                                                                       | 38   |
| 27     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN .....                                 | 84   |
| 28     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN .....                              | 85   |
| 29     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN .....                                | 86   |
| 30     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN .....                                  | 87   |
| 31     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN .....                                 | 88   |
| 32     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN .....                              | 89   |
| 33     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN .....                                | 90   |
| 34     | RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN .....                                  | 91   |
| 35     | CRITICAL IMPACT DAMAGE LOCATIONS OF THE UPPER WING SKIN                                                                | 92   |
| 36     | RELIABILITY OF UPPER WING SKIN WITH 2.0-IN. DIAMETER ASSEMBLY INDUCED DAMAGE, $S_r=0.15$ , MAXIMUM STRAIN .....        | 121  |
| 37     | ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WINGSKIN, 90% RELIABILITY, $S_r=0.15$ , MAXIMUM STRAIN .....   | 123  |
| 38     | ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY, $S_r=0.01$ , MAXIMUM STRAIN .....  | 124  |
| 39     | ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY, $S_r=0.001$ , MAXIMUM STRAIN ..... | 125  |
| 40     | ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY, $S_r=0.01$ , AVERAGE STRAIN .....  | 128  |
| 41     | EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.053-IN.-THICK LAMINATE .....       | 142  |
| 42     | EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.067-IN.-THICK LAMINATE .....       | 143  |

## LIST OF FIGURES (Continued)

| Figure |                                                                                                                  | Page |
|--------|------------------------------------------------------------------------------------------------------------------|------|
| 43     | EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.081-IN.-THICK LAMINATE ..... | 144  |
| 44     | EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.109-IN.-THICK LAMINATE ..... | 145  |
| 45     | EFFECTS OF STIFFNESS RETENTION RATIO AND DATA SCATTER ON ALLOWABLE STRAIN FOR THE 0.125-IN.-THICK LAMINATE ..... | 146  |
| 46     | EFFECTS OF DAMAGED LAMINATE STRENGTH SCATTER ON ALLOWABLE STRAIN .....                                           | 147  |

## LIST OF TABLES

| Table |                                                                                                                                                                             | Page |
|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1     | SUBDIVISIONS FOR DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN STRAINS .....                                                                                   | 31   |
| 2     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION .....                                   | 39   |
| 3     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION .....                                | 44   |
| 4     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN IN EACH SUBDIVISION .....                                  | 49   |
| 5     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN IN EACH SUBDIVISION .....                                    | 54   |
| 6     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION .....                                   | 59   |
| 7     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION .....                                | 64   |
| 8     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN IN EACH SUBDIVISION .....                                  | 69   |
| 9     | RESULTS OF IMPACT DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION .....                                    | 74   |
| 10    | SUMMARY OF IMPACT CRITICAL LOCATIONS, LEAR FAN 2100 UPPER WING SKIN .....                                                                                                   | 79   |
| 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 ..... | 96   |
| 12    | RESULTS OF ASSEMBLY INDUCED DAMAGE TOLERANCE EVALUATION, LEAR FAN 2100 UPPER WING SKIN, ALLOWABLE DAMAGE DIAMETER, $S_f=0.15$ , MAXIMUM STRAIN IN EACH SUBDIVISION .....    | 101  |
| 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 .....    | 106  |
| 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 .....   | 111  |

## LIST OF TABLES (Continued)

| Table |                                                                                                                                                                          | Page |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 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 ..... | 116  |
| 16    | SUMMARY OF DETECTED DEFECT EVALUATION .....                                                                                                                              | 129  |
| 17    | SENSITIVITY OF DAMAGE TOLERANCE CRITERIA, LEAR FAN 2100 UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN IN EACH SUBDIVISION .....                                      | 132  |
| 18    | EFFECTS OF STIFFNESS RETENTION RATIO ON THE ALLOWABLE SIZE OF ASSEMBLY INDUCED DAMAGE FOR LEAR FAN 2100 UPPER WING SKIN LAMINATES .....                                  | 138  |
| 19    | EFFECTS OF SCATTER PARAMETERS ON THE ALLOWABLE STRAIN                                                                                                                    | 148  |
| 20    | EFFECTS OF SAMPLE SIZE ON THE ALLOWABLE STRAIN .....                                                                                                                     | 150  |

## 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

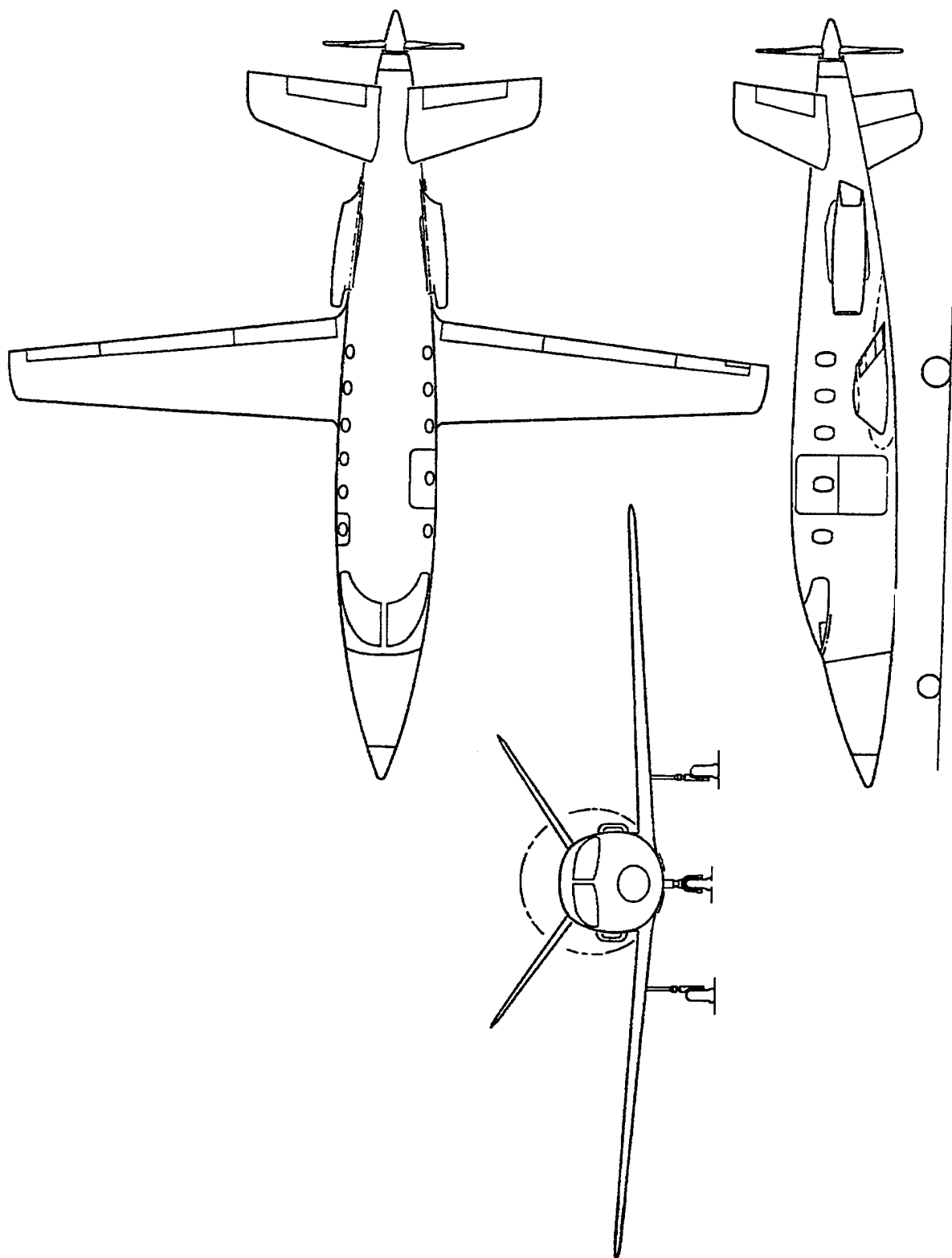
### STRUCTURAL DESCRIPTION

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 accessory 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.



F94-HPK/17

FIGURE 1. THREE-VIEW OF THE AIRCRAFT.

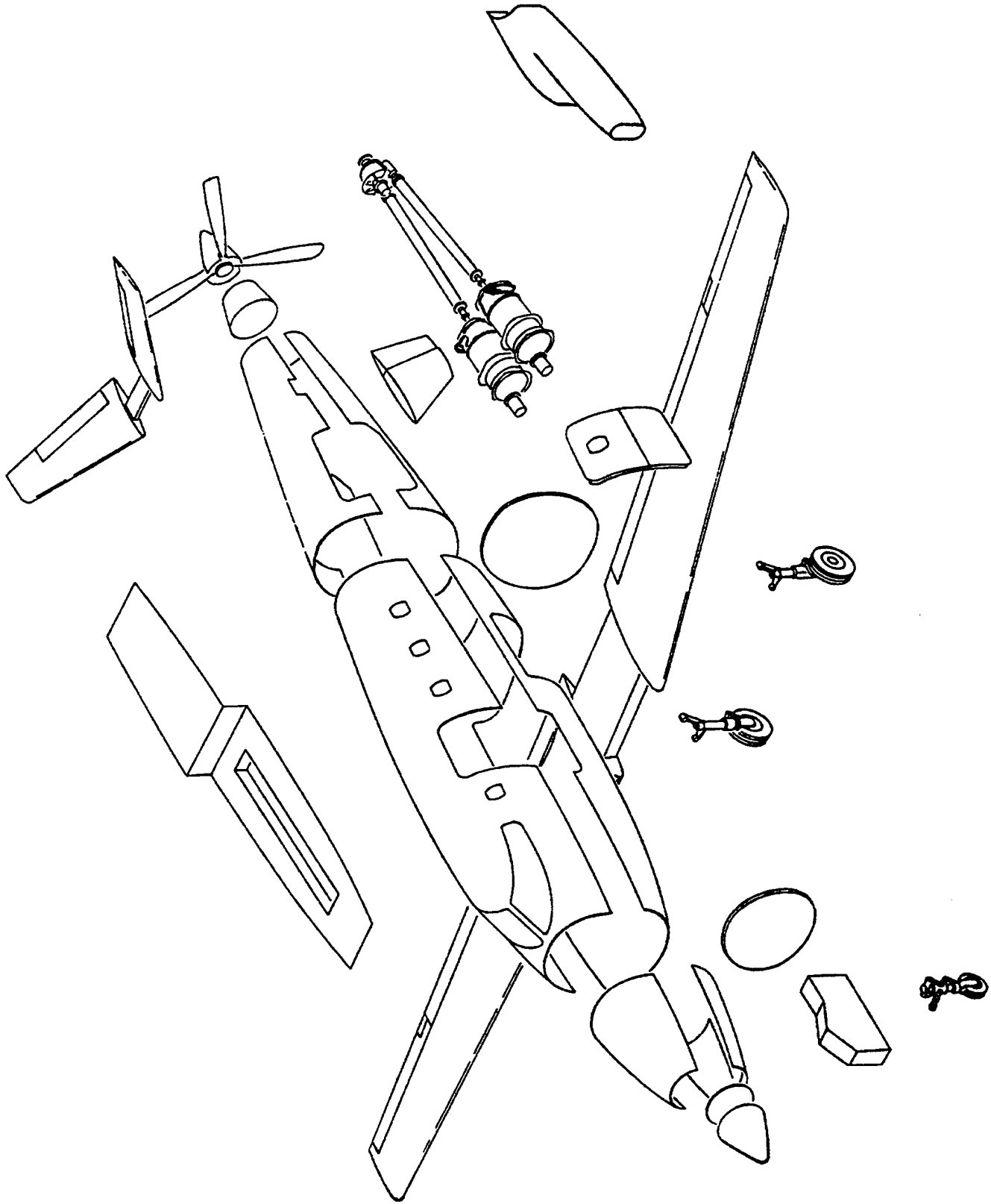


FIGURE 2. MAJOR ASSEMBLY BREAKDOWN.

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 transducer 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.

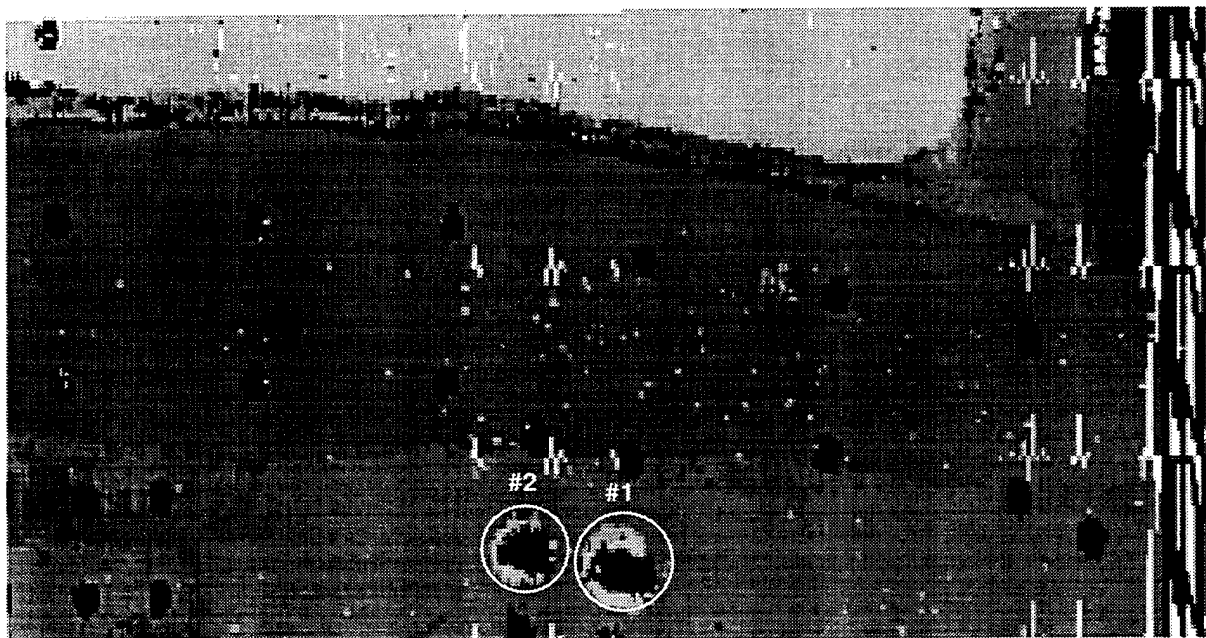
Defects identified by ultrasonic evaluation for the upper wing skins are summarized in figure 3, and the gray scale images of the MAUS data are shown in figures 4 through 13. Numbers next to defects shown in the MAUS images correlate with the defect numbers shown in figure 3 for the left and right wing 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<br>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               | 0.80   | 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

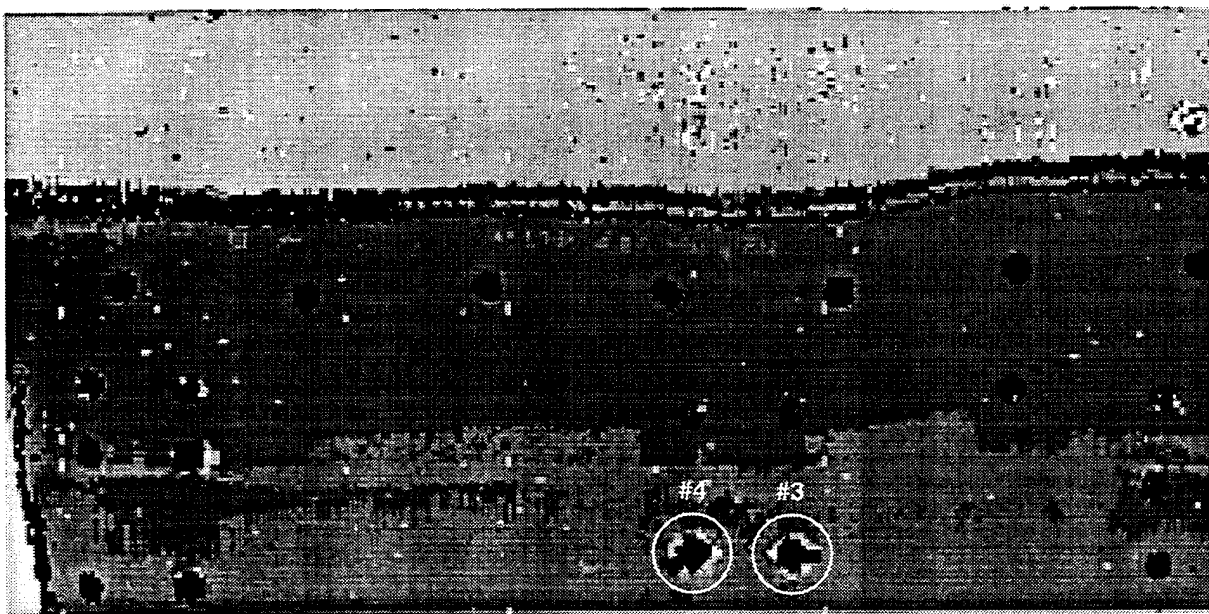
F94-HPK/19

**FIGURE 3. SUMMARY OF UPPER WING SKIN DEFECTS.**



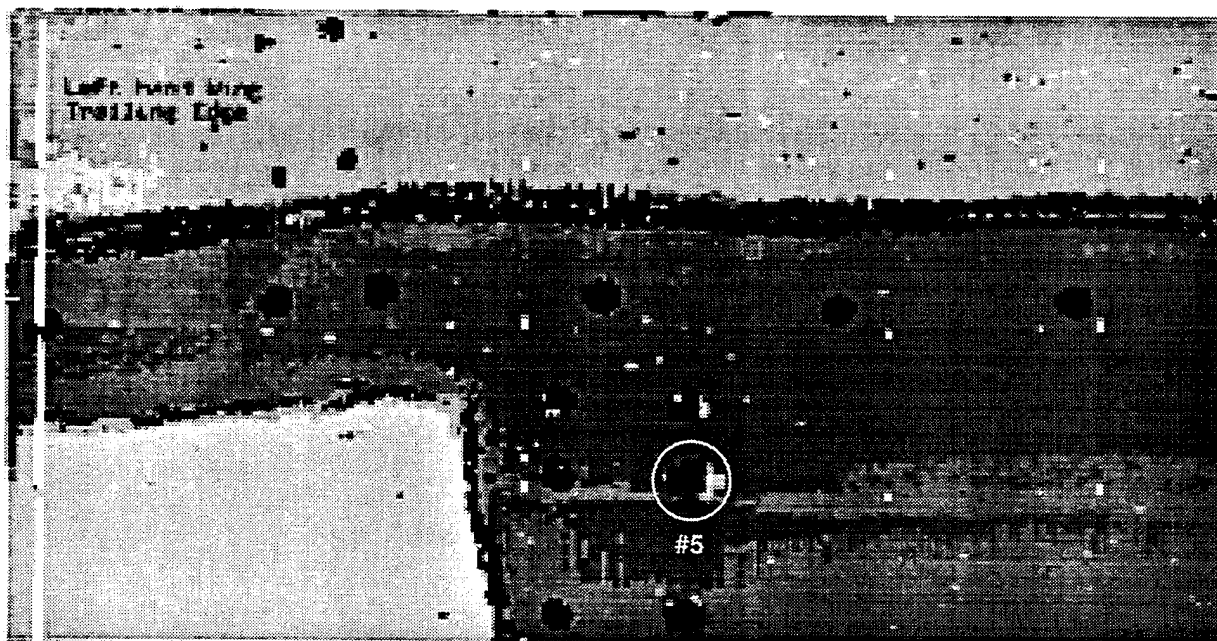
F95-HPK/01

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



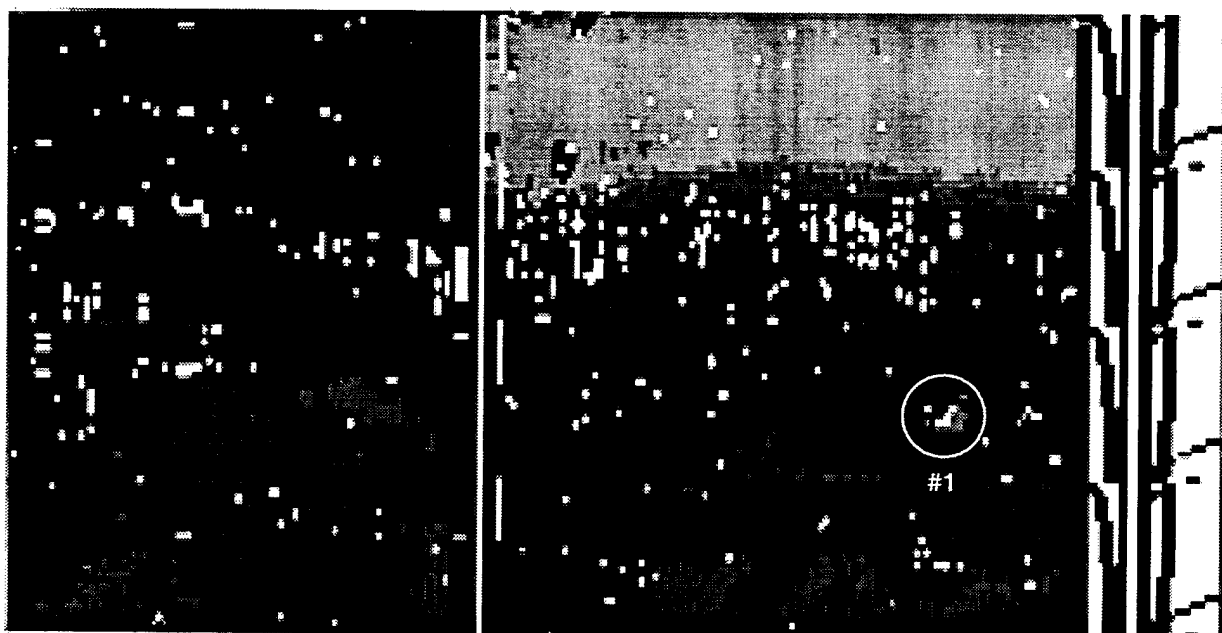
F95-HPK/02

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



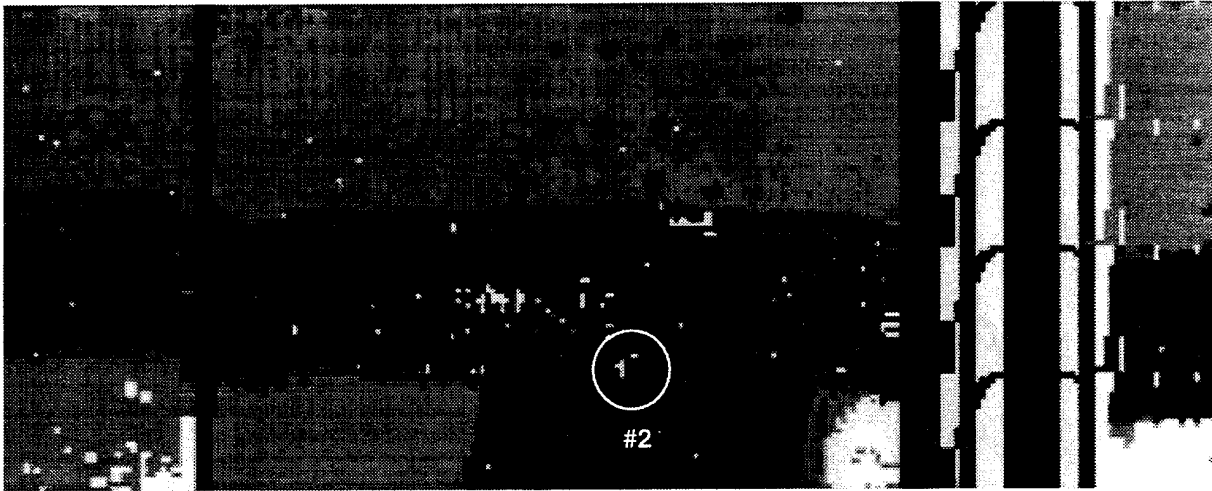
F95-HPK/03

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



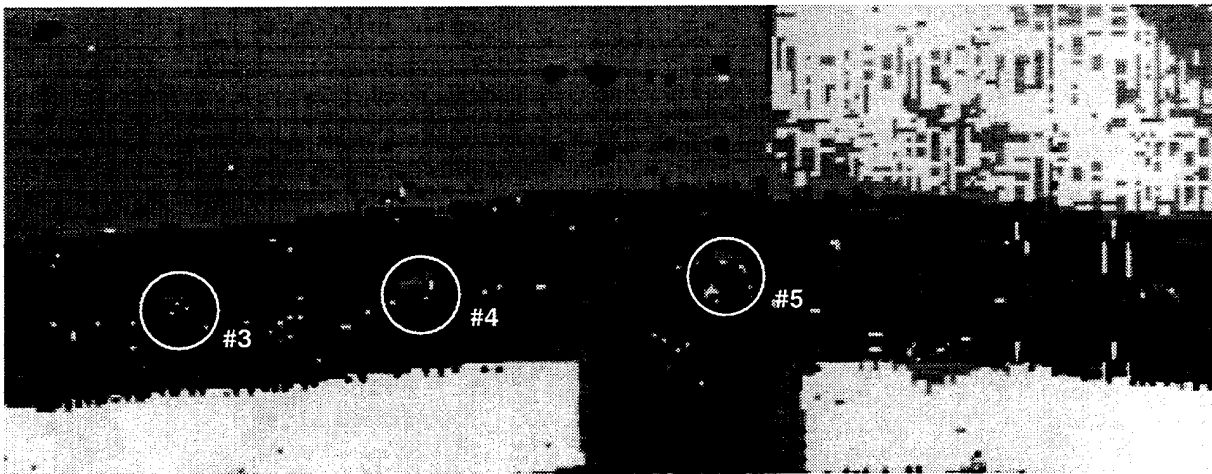
F95-HPK/04

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



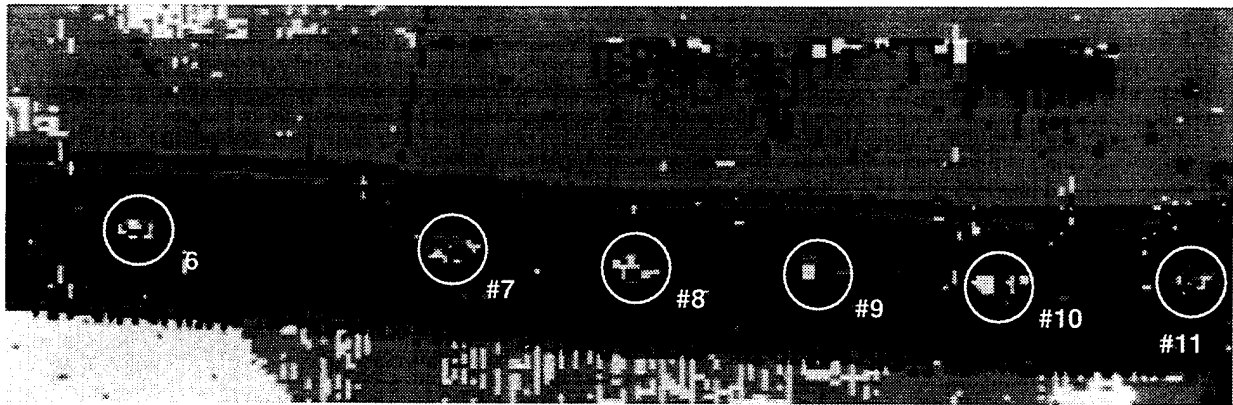
F95-HPK/05

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



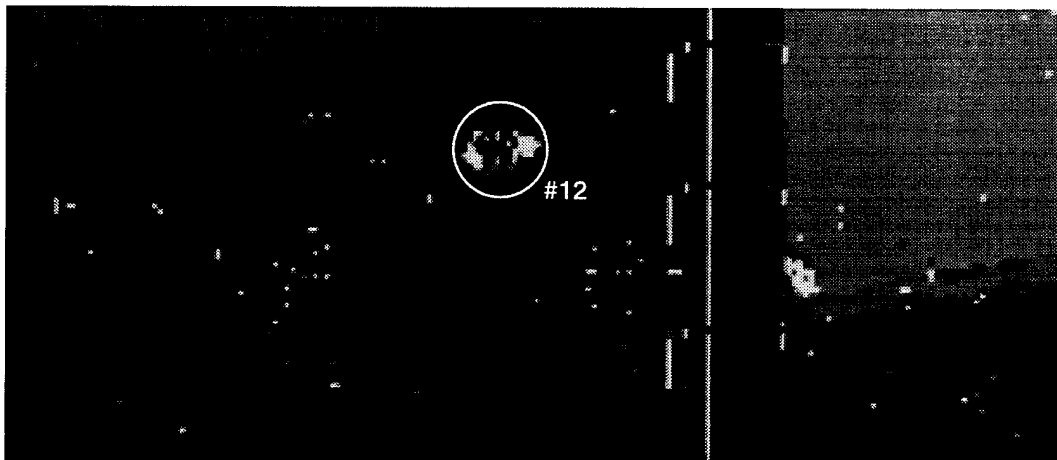
F95-HPK/06

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



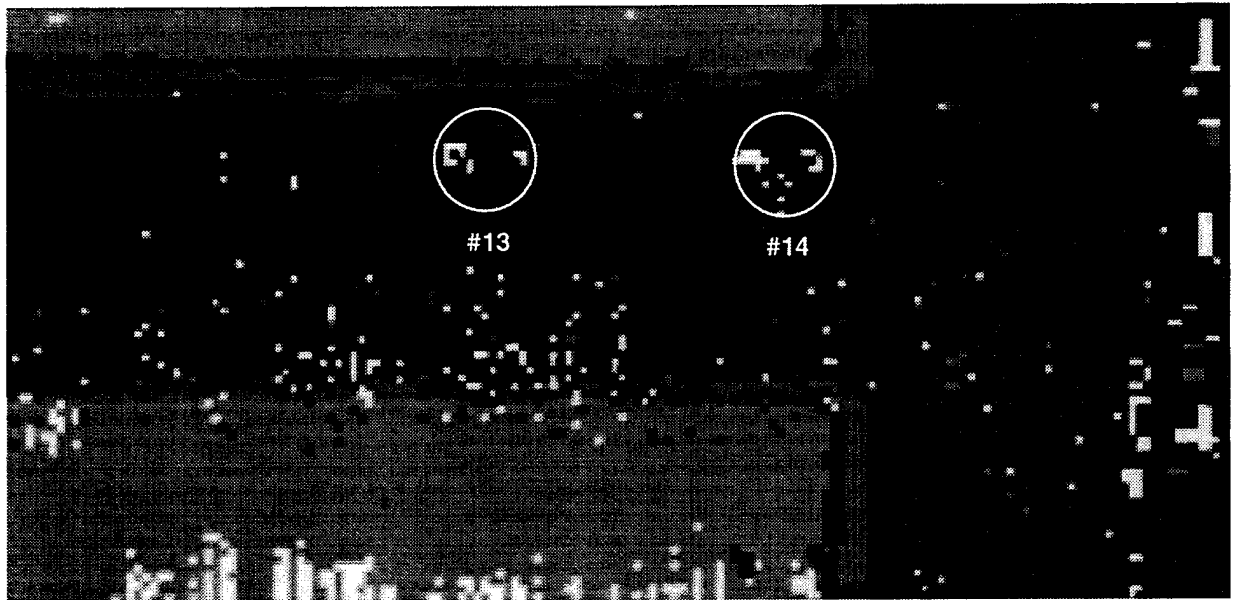
F95-HPK/07

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



F95-HPK/08

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



F95-HPK/09

**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

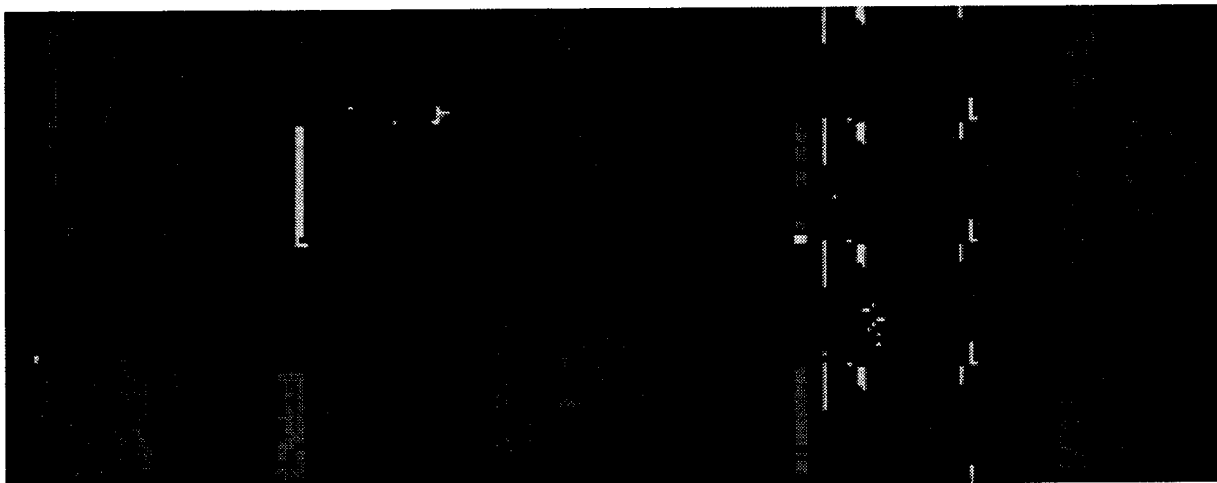
were verified by A-Scan. The majority of these delaminations were located around fasteners connecting the upper skins to the aft spars. One area of minor porosity was identified by the MAUS, located between wing stations Yw=28 and Yw=40, extending over the entire skin of the left wing in the chord direction, 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 addition 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.



F95-HPK/11

**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**

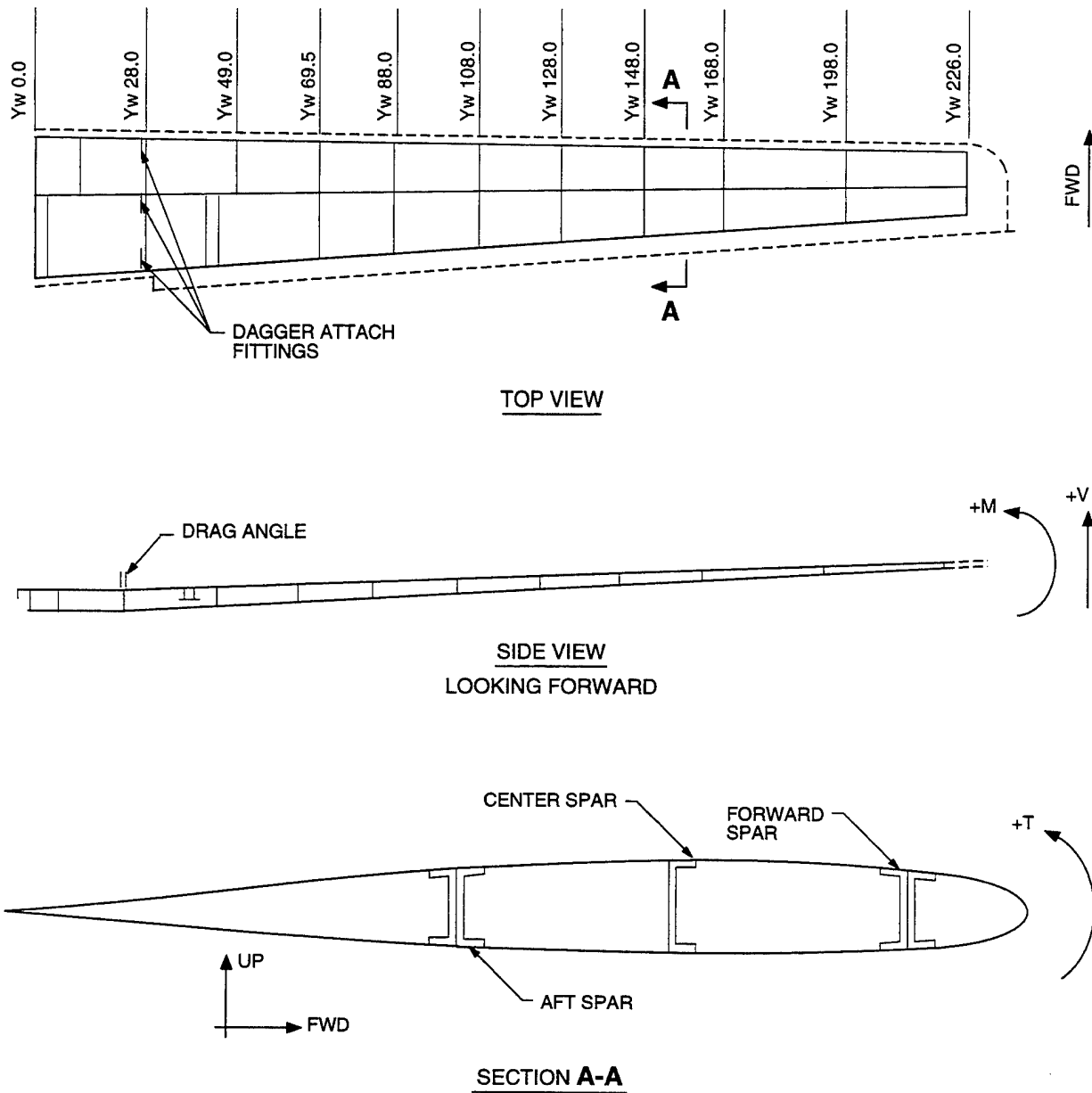
The Lear Fan Model 2100 aircraft component loads were generated in compliance with the portions of the FAR Part 23 concerned with determination of flight and ground loads. The basic data and operating conditions necessary to calculate the flight and ground loads includes external dimensional data, wing 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



F94-HPK/20

**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**

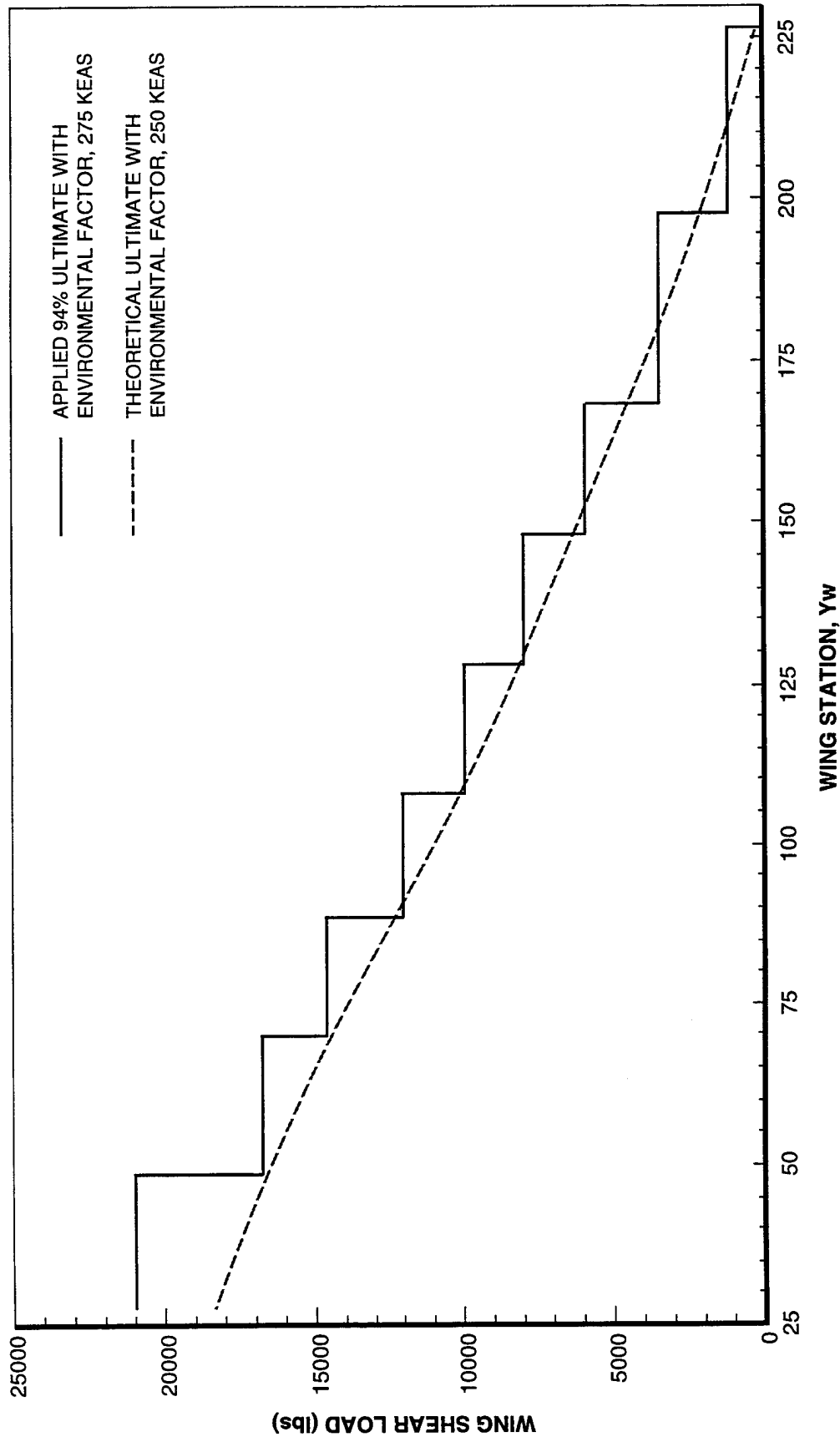
All test loads were derived from limit load 275 KEAS envelope data. Limit loads were increased by the static test factor of 1.14 to obtain the adjusted limit load used to satisfy the FAA limit load requirements. The FAA adjusted ultimate test load requirements were satisfied by further increasing the 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<br>STATION | FRONT<br>SPAR<br>(lb) | REAR<br>SPAR<br>(lb) | SHEAR<br>(Vz)<br>(lb) | MOMENT<br>(Mx)<br>(in-lb) | TORQUE<br>(ta)<br>(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                     |

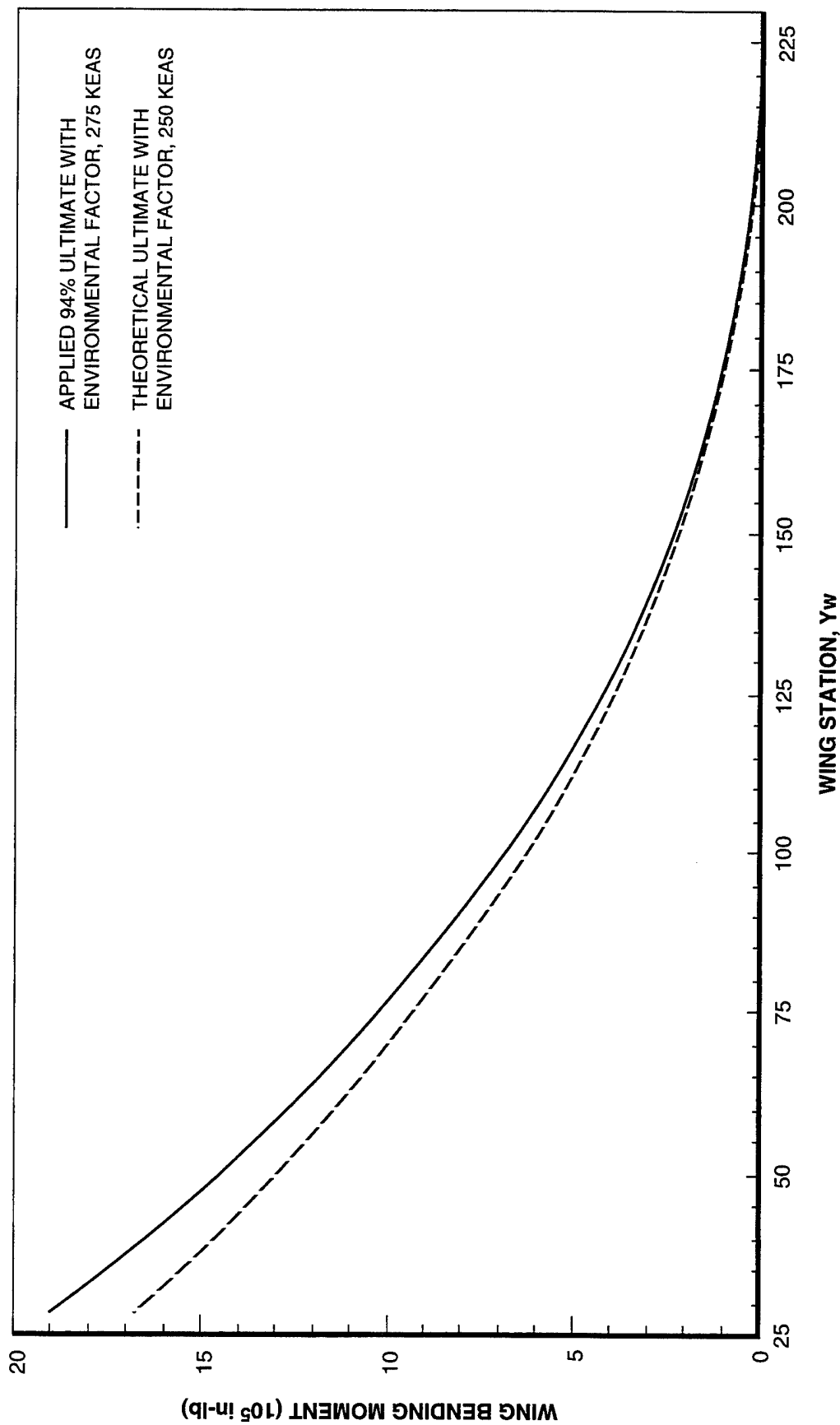
F94-HPK/21

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



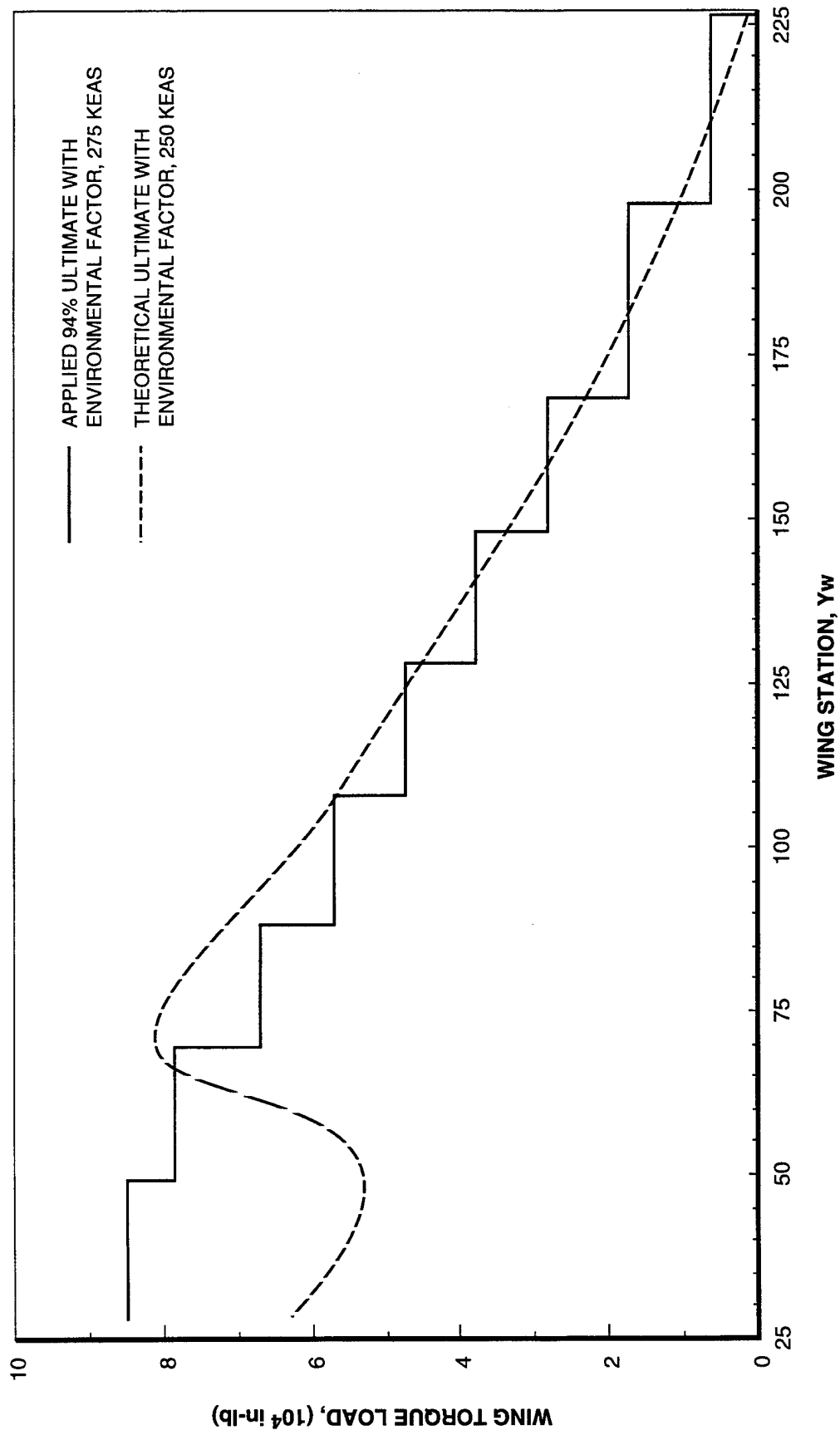
F94-HPK/22

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



F94-HPK/23

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 stiffeners, 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 |                    |
|-------------------------------------------------------|----------------|---------------------------------------------------------------|-----------------|--------------------|
|                                                       | $\mu$          | LOCATION                                                      | in.             | LOCATION           |
| <b>SYMMETRIC DOWN BENDING</b><br>LIMIT<br>ULTIMATE    | 1090<br>1630   | UPPER WING SKIN<br>Yw 38.5 CS                                 | 6.70<br>9.96    | Yw $\pm$ 226       |
| <b>MAX. NEGATIVE TORQUE</b><br>LIMIT<br>ULTIMATE      | 1150<br>1810   | FS MID-HEIGHT<br>Yw 38.5                                      | 2.77<br>3.95    | Yw $\pm$ 226<br>FS |
| <b>ASYMMETRIC UP BENDING (a)</b><br>LIMIT<br>ULTIMATE | -1520<br>-2570 | UPPER WING SKIN<br>Yw 38.5 CS<br>UPPER WING SKIN<br>Yw 118 CS | 10.37<br>16.60  | Yw 226<br>RT. WING |
| <b>MAX. POSITIVE TORQUE</b><br>LIMIT<br>ULTIMATE      | -1540<br>-2420 | RIGHT WING CS<br>Yw 38.5                                      | 8.48<br>13.44   | Yw $\pm$ 226       |
| <b>SYMMETRIC UP BENDING (b)</b><br>LIMIT<br>ULTIMATE  | -2260<br>-3390 | UPPER WING SKIN<br>Yw 38.5 CS                                 | 13.29<br>19.28  | Yw $\pm$ 226       |

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  $\pm$  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.

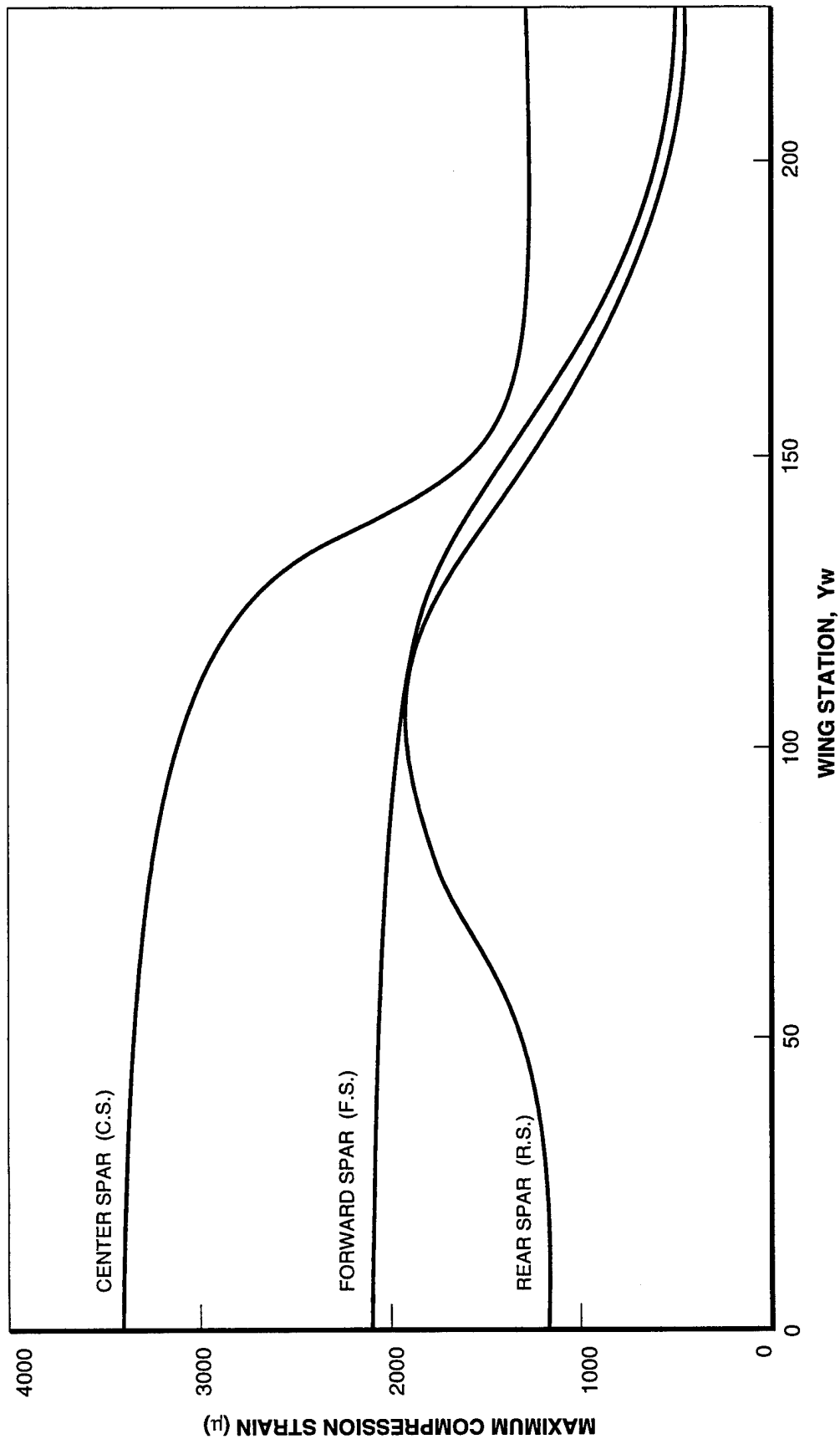
F94-HPK/25

**FIGURE 20. SUMMARY OF STATIC WING TEST RESULTS.**

| LOCATION |      | STRAIN<br>( $\mu$ ) | 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.**



F94-HPK/27

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

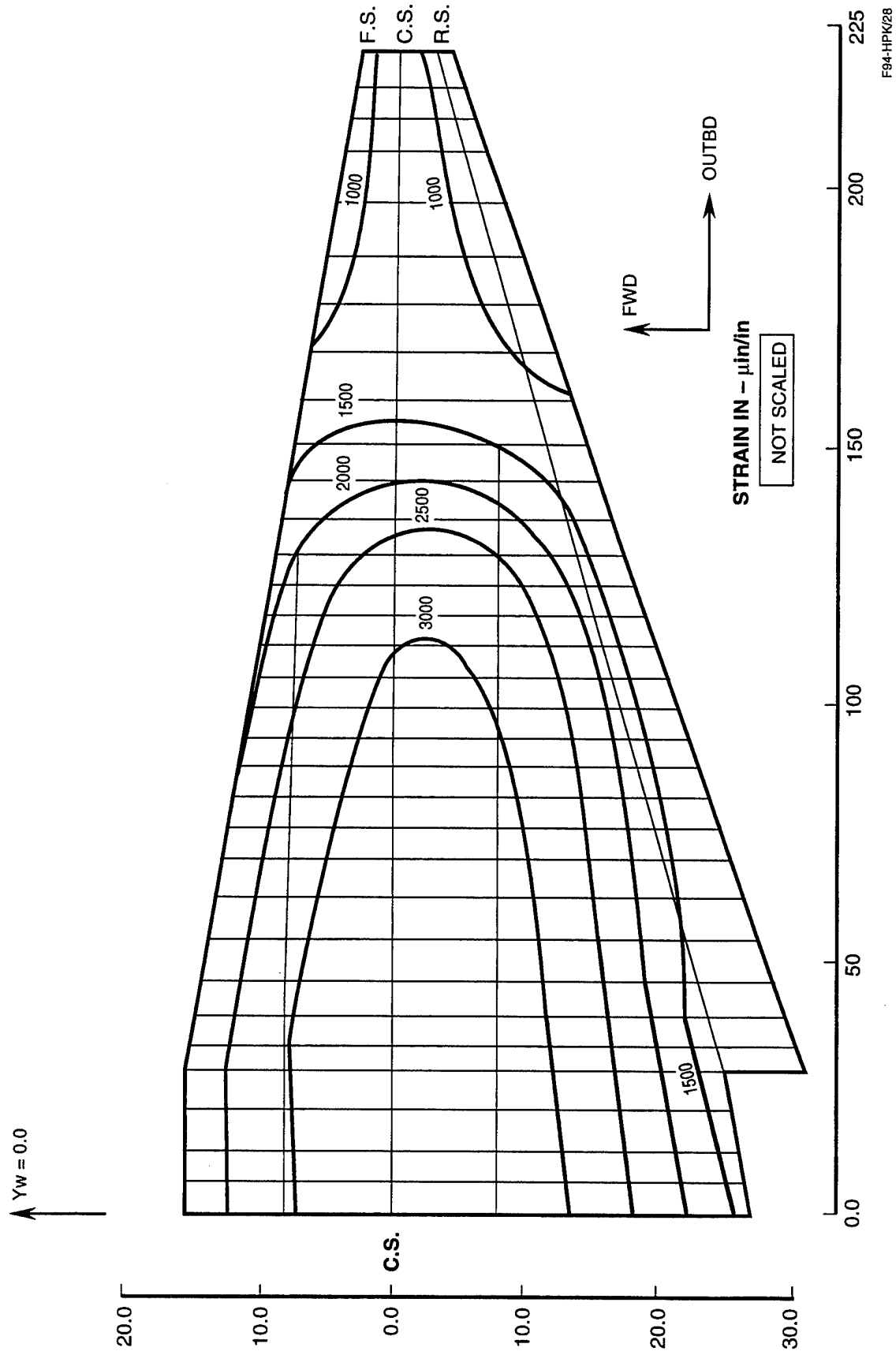


FIGURE 23. ESTIMATED WORST CASE STRAIN CONTOURS OF THE UPPER WING SKIN.

## 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 subdivisions 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 continuous wing structure, from  $Y_w=0.0$  to  $Y_w=226.0$ , 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  $Y_w=140$ , 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.

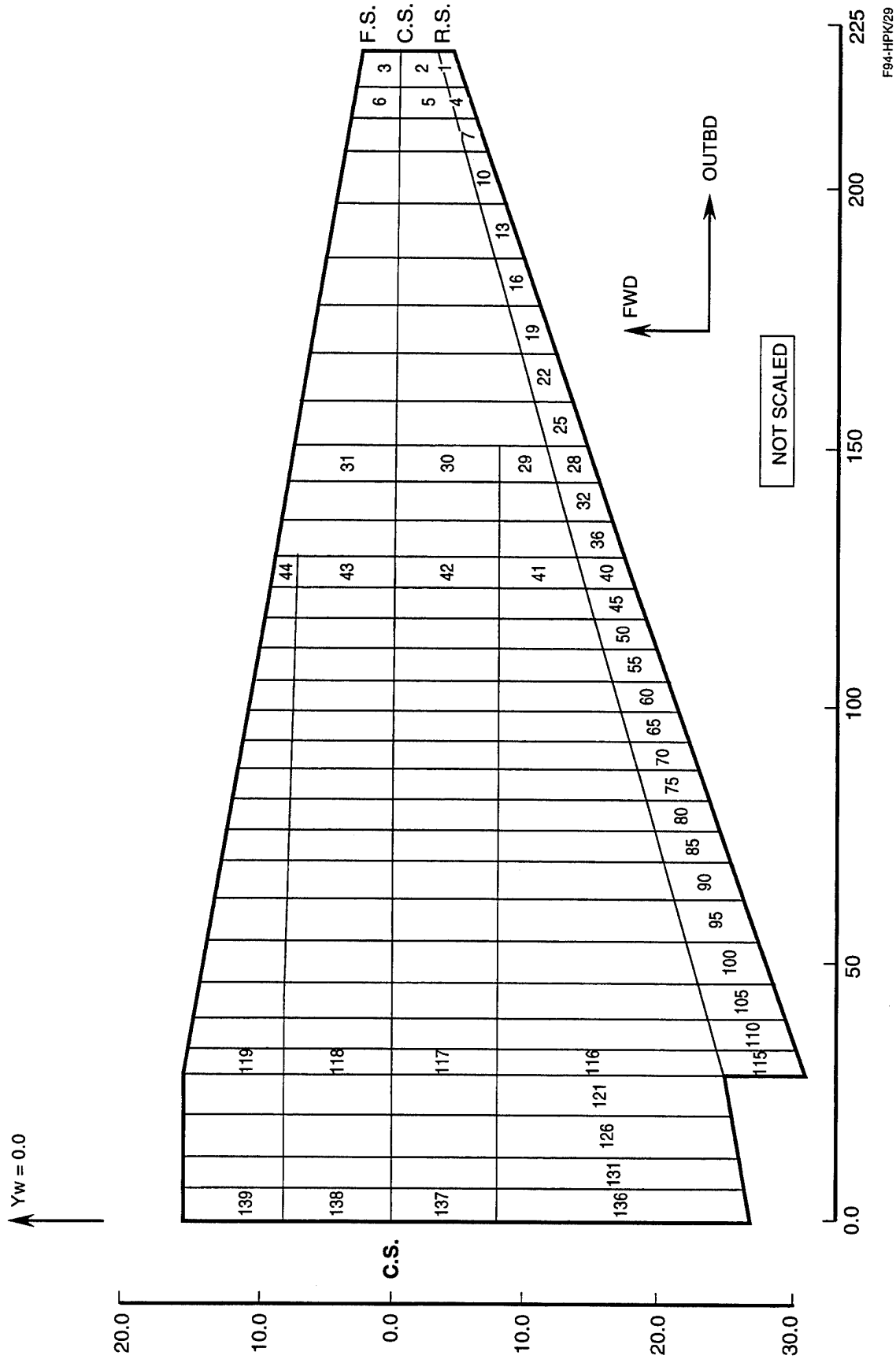


FIGURE 24. SUBDIVISION OF THE UPPER WING SKIN FOR DAMAGE TOLERANCE EVALUATION.

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

| REG. | Y <sub>w</sub> | t     | LAYUP    | W      | AE   | b <sub>1</sub> | b <sub>2</sub> | 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 <sub>w</sub> | t     | LAYUP    | W      | AE   | b <sub>1</sub> | b <sub>2</sub> | 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 <sub>w</sub> | t     | LAYUP    | W      | AE    | b <sub>1</sub> | b <sub>2</sub> | 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 <sub>w</sub> | t     | LAYUP    | W      | AE    | b <sub>1</sub> | b <sub>2</sub> | 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 <sub>w</sub> | t     | LAYUP    | W      | AE    | b <sub>1</sub> | b <sub>2</sub> | 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.

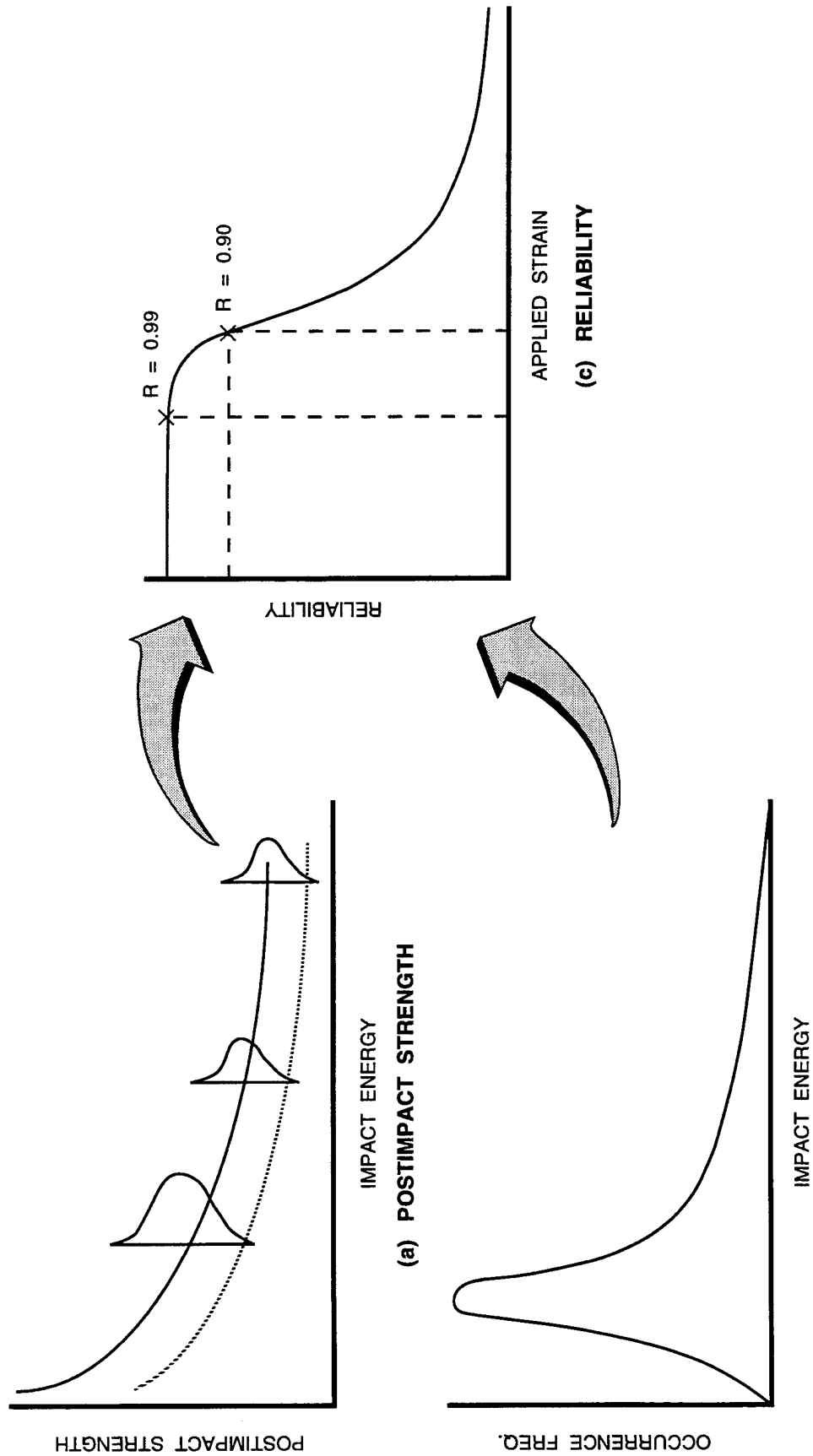
Total width of the structure  $W(\text{total}) = 2.0 \cdot W + b_1 + b_2$ . For regions along edges of the structure, the edge bay width ranges from 0.5 to 2.0 in.

## 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 analysis 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.

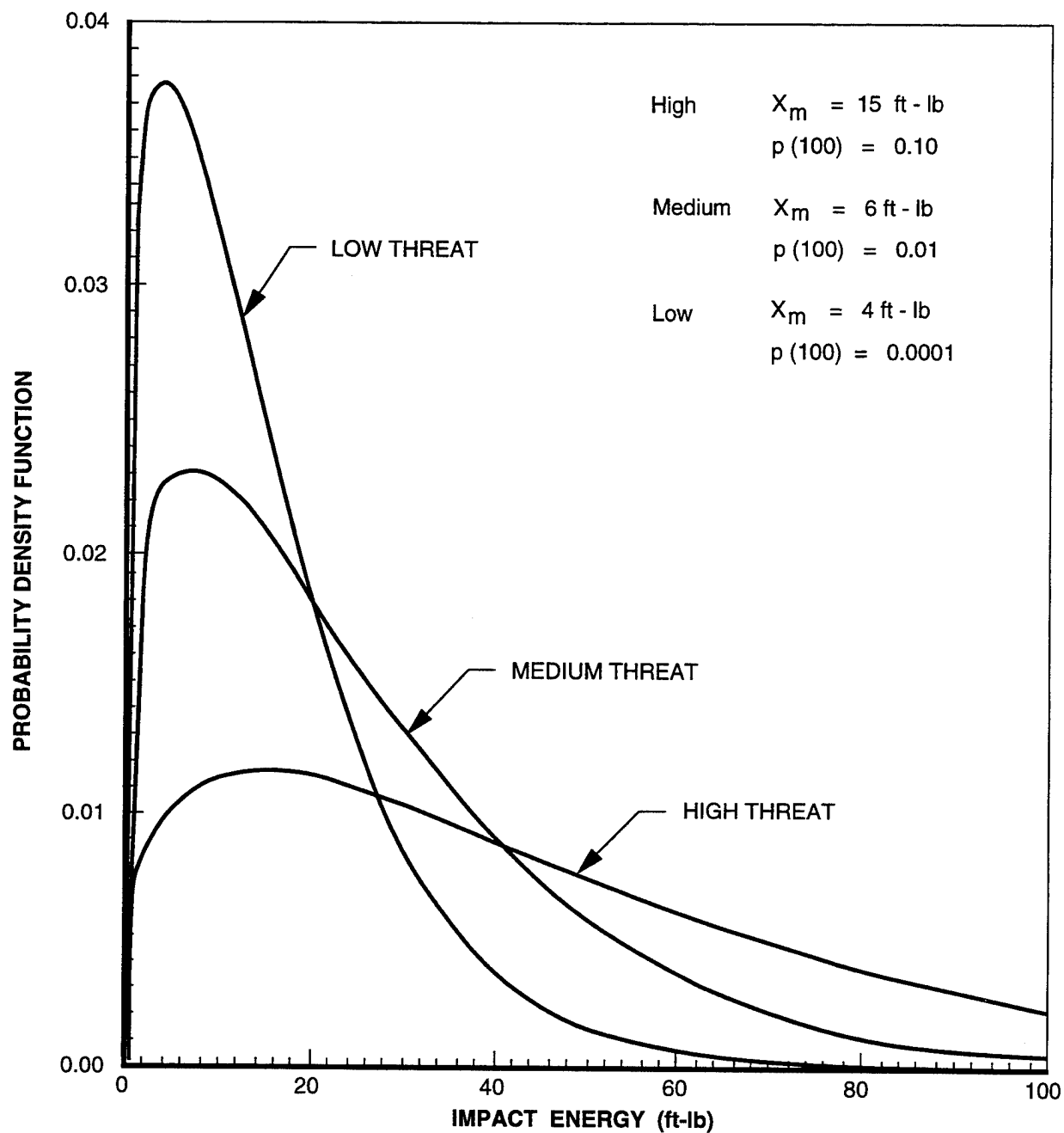
The results of the impact damage tolerance evaluation are summarized in tables 2 through 10 and the reliabilities of the local areas on the upper wing skin are given in figures 27 through 35. Each subdivision of the upper wing skin, figure 24, was evaluated against four impact threats. The impact threats 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



F94-HPK/30

FIGURE 25. SCHEMATIC OF THE INTEGRATED RELIABILITY ANALYSIS METHOD.



F94-HPK/31

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.<br>(MICRO) | M.S. | RELIABILITY |         |            |         |
|------|-------------------|------|-------------|---------|------------|---------|
|      |                   |      | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S. | RELIABILITY |         |         |         |
|------|-------------------|------|-------------|---------|---------|---------|
|      |                   |      | @DLL        |         | @DUL    |         |
|      |                   |      | IF          | FF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |            |         |
|------|-------------------|-------|-------------|---------|------------|---------|
|      |                   |       | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S. | RELIABILITY |         |            |         |
|------|-------------------|------|-------------|---------|------------|---------|
|      |                   |      | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S. | RELIABILITY |         |         |         |
|------|-------------------|------|-------------|---------|---------|---------|
|      |                   |      | @DLL        |         | @DUL    |         |
|      |                   |      | IF          | FF      | 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.<br>(MICRO) | M.S. | RELIABILITY |         |            |         |
|------|-------------------|------|-------------|---------|------------|---------|
|      |                   |      | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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   | 2480              | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |            |
|------|-------------------|-------|-------------|------------|------------|------------|
|      |                   |       | @DLL<br>IF  | @DLL<br>FF | @DUL<br>IF | @DUL<br>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  | 2725              | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S. | RELIABILITY |            |         |            |
|------|-------------------|------|-------------|------------|---------|------------|
|      |                   |      | IF          | @DLL<br>FF | IF      | @DUL<br>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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S. | RELIABILITY |         |            |         |
|------|-------------------|------|-------------|---------|------------|---------|
|      |                   |      | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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              | -0.26 | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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     | 0.98672 | 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 | 0.00066 |
| 104  | 2415              | -0.02 | 0.97226     | 0.99895 | 0.02599 | 0.87239 |
| 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | 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.<br>(MICRO) | M.S. | RELIABILITY |         |         |         |
|------|-------------------|------|-------------|---------|---------|---------|
|      |                   |      | @DLL        |         | @DUL    |         |
|      |                   |      | IF          | FF      | IF      | 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 | 1.00000     | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |            |         |
|------|-------------------|-------|-------------|---------|------------|---------|
|      |                   |       | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | 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.<br>(MICRO) | M.S. | RELIABILITY |         |         |         |
|------|-------------------|------|-------------|---------|---------|---------|
|      |                   |      | @DLL        |         | @DUL    |         |
|      |                   |      | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |            |
|------|-------------------|-------|-------------|------------|------------|------------|
|      |                   |       | @DLL<br>IF  | @DLL<br>FF | @DUL<br>IF | @DUL<br>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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |         |
|------|-------------------|-------|-------------|------------|------------|---------|
|      |                   |       | IF          | @DLL<br>FF | @DUL<br>IF | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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  | 2906              | -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.<br>(MICRO) | M.S. | RELIABILITY |         |            |         |
|------|-------------------|------|-------------|---------|------------|---------|
|      |                   |      | @DLL<br>IF  | FF      | @DUL<br>IF | 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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |            |
|------|-------------------|-------|-------------|------------|------------|------------|
|      |                   |       | @DLL<br>IF  | @DLL<br>FF | @DUL<br>IF | @DUL<br>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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |            |
|------|-------------------|-------|-------------|------------|------------|------------|
|      |                   |       | @DLL<br>IF  | @DLL<br>FF | @DUL<br>IF | @DUL<br>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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |         |
|------|-------------------|-------|-------------|------------|------------|---------|
|      |                   |       | IF          | @DLL<br>FF | @DUL<br>IF | 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.<br>(MICRO) | M.S.  | RELIABILITY |            |            |            |
|------|-------------------|-------|-------------|------------|------------|------------|
|      |                   |       | IF          | @DLL<br>FF | @DUL<br>IF | @DUL<br>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.<br>(MICRO) | M.S. | RELIABILITY |         |         |         |
|------|-------------------|------|-------------|---------|---------|---------|
|      |                   |      | @DLL        |         | @DUL    |         |
|      |                   |      | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        | @DUL    |         |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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.<br>(MICRO) | M.S.  | RELIABILITY |         |         |         |
|------|-------------------|-------|-------------|---------|---------|---------|
|      |                   |       | @DLL        |         | @DUL    |         |
|      |                   |       | IF          | FF      | IF      | 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<br>THREAT                                 | DUL  | REG. | RELIABILITY |         |         |         | @DUL    |
|--------------------------------------------------|------|------|-------------|---------|---------|---------|---------|
|                                                  |      |      | M.S.        | @DLL    |         |         |         |
|                                                  |      |      | IF          | FF      | IF      | FF      | 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<br>THREAT                                | DUL  | RELIABILITY |       |            |         | @DUL    |         |
|-------------------------------------------------|------|-------------|-------|------------|---------|---------|---------|
|                                                 |      | REG.        | M.S.  | @DLL<br>IF | FF      | IF      | 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<br>THREAT                                   | DUL  | RELIABILITY |       |            |         | @DUL<br>FF |         |
|----------------------------------------------------|------|-------------|-------|------------|---------|------------|---------|
|                                                    |      | REG.        | M.S.  | @DLL<br>IF | 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 |
| 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<br>THREAT                                | DUL  | RELIABILITY |       |         |         |         |         |
|-------------------------------------------------|------|-------------|-------|---------|---------|---------|---------|
|                                                 |      | REG.        | M.S.  | @DLL    |         | @DUL    |         |
|                                                 |      |             |       | IF      | FF      | IF      | 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<br>THREAT | DUL | RELIABILITY |      |            |    | @DUL |    |
|------------------|-----|-------------|------|------------|----|------|----|
|                  |     | REG.        | M.S. | @DLL<br>IF | FF | IF   | 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 |

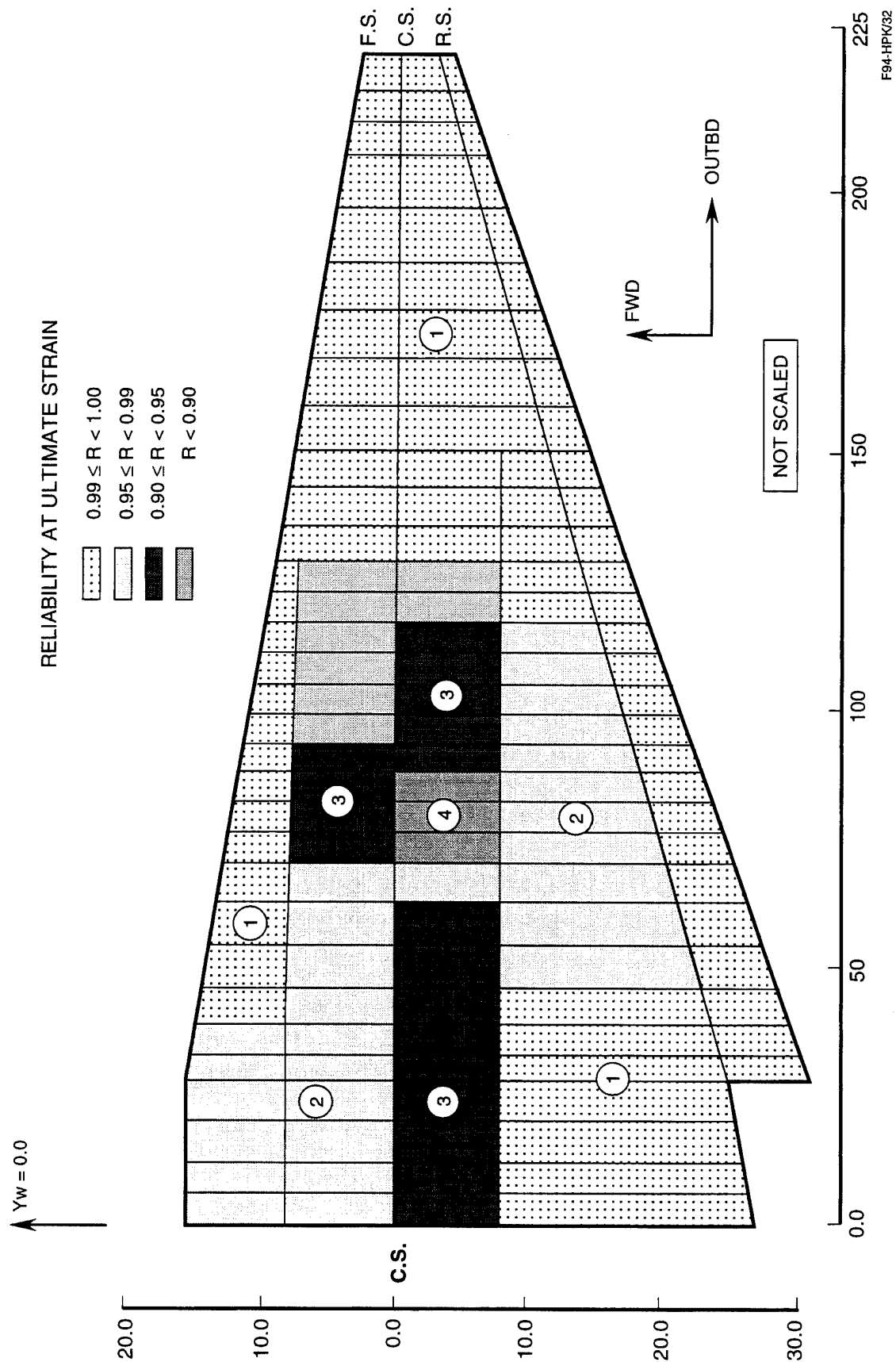


FIGURE 27. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, LOW IMPACT THREAT, AVERAGE STRAIN.

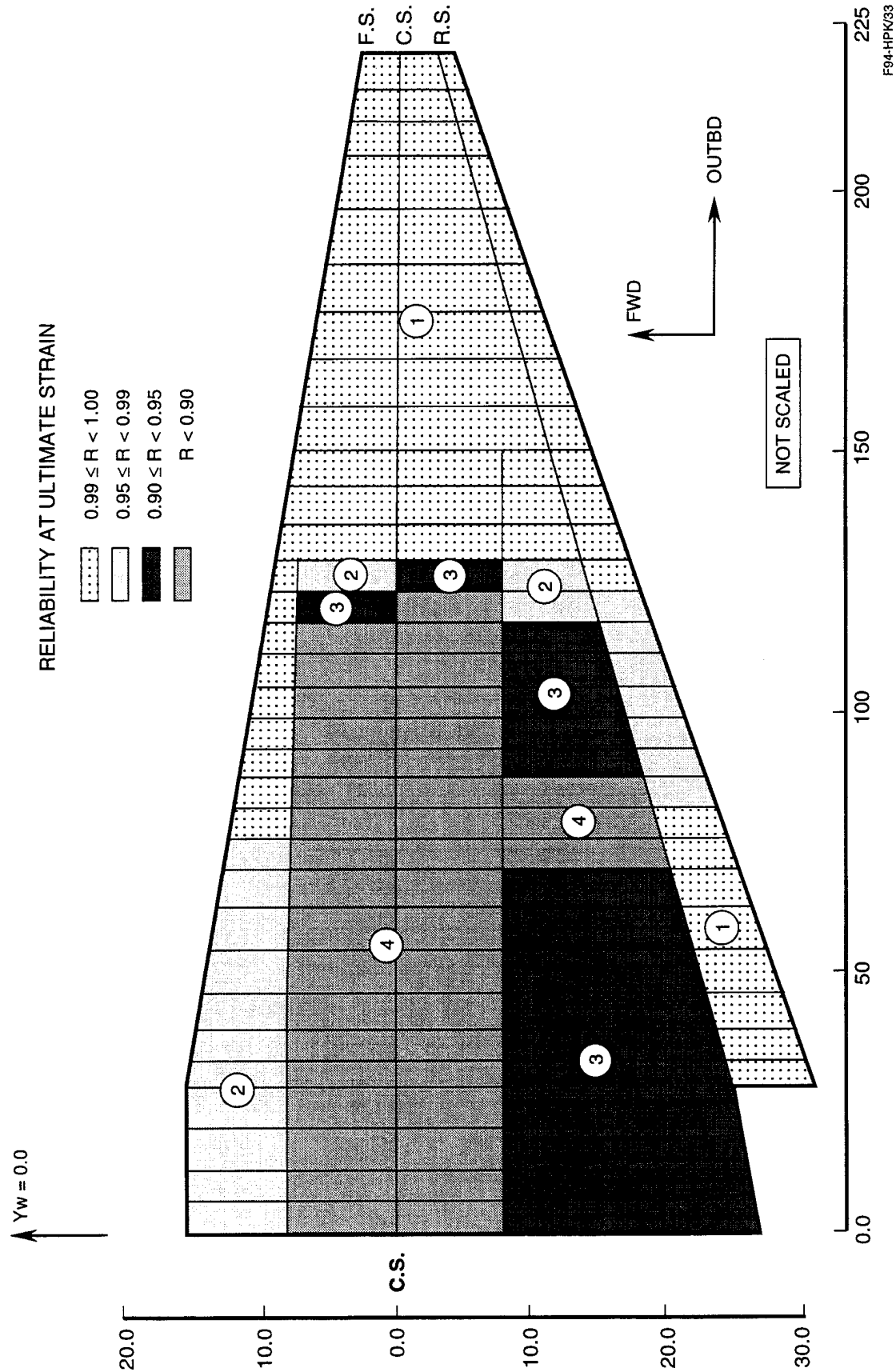


FIGURE 28. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, MEDIUM IMPACT THREAT, AVERAGE STRAIN.

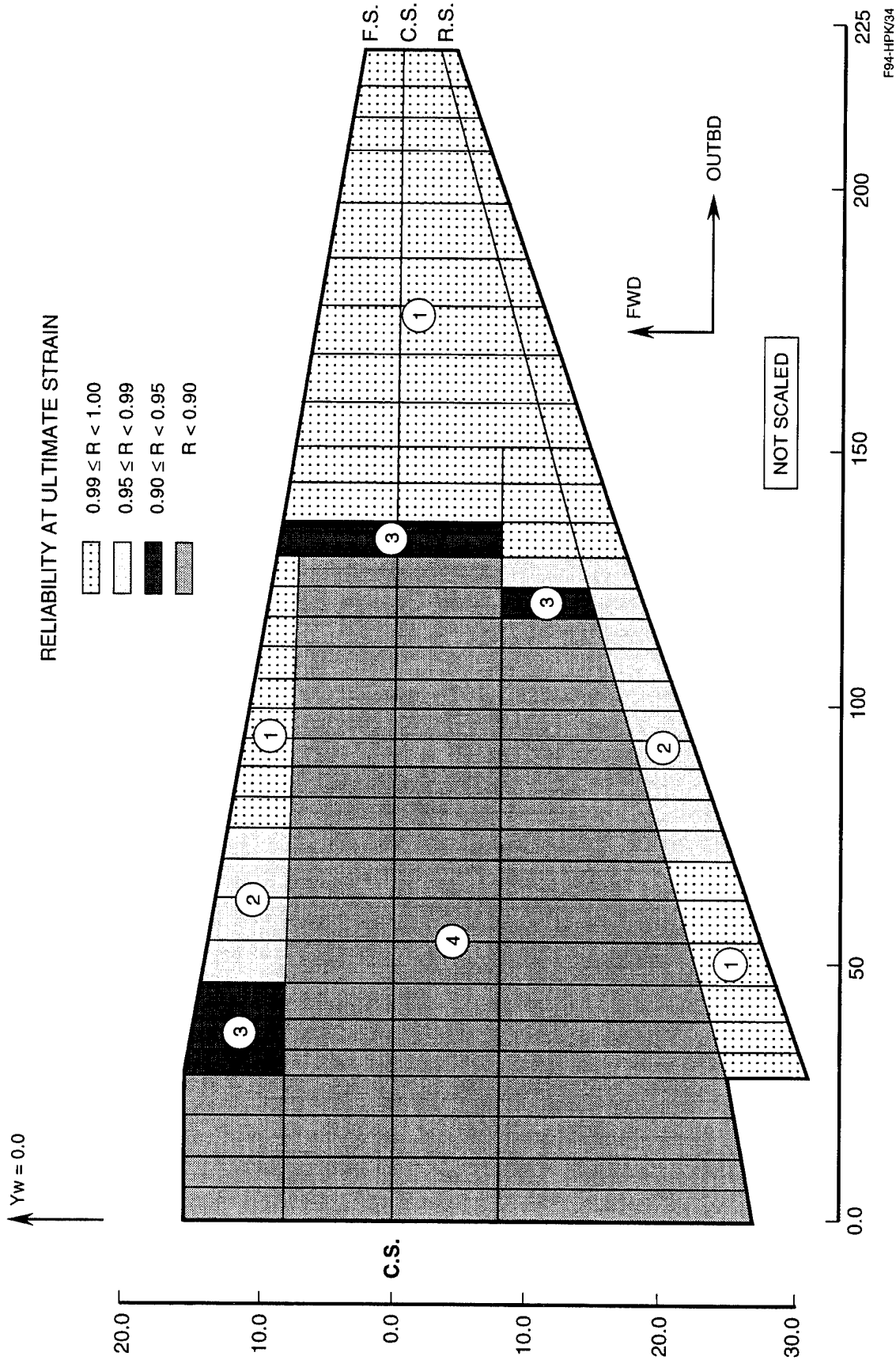


FIGURE 29. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, HIGH IMPACT THREAT, AVERAGE STRAIN.

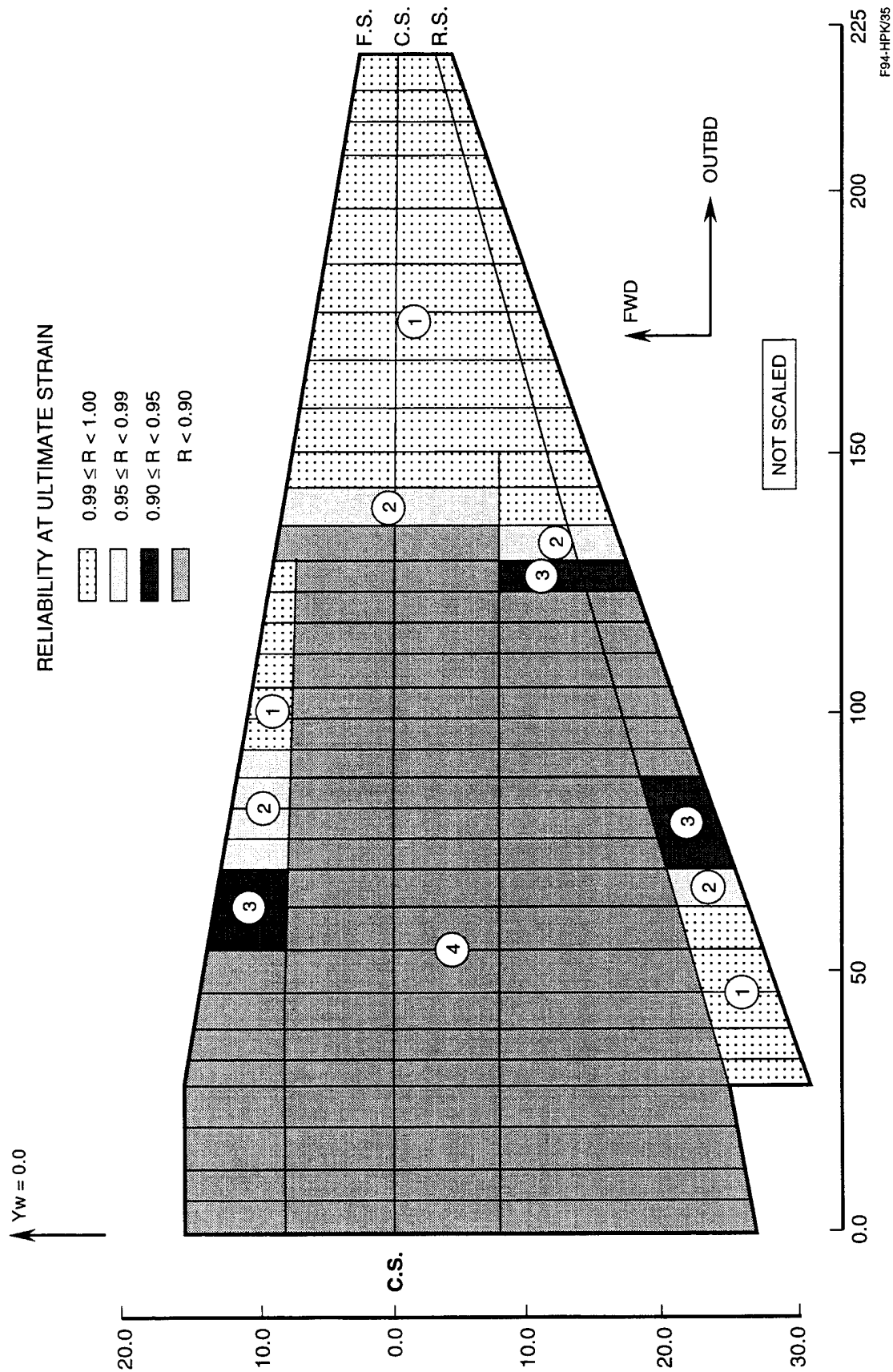


FIGURE 30. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, 100 FT-LB IMPACT, AVERAGE STRAIN.

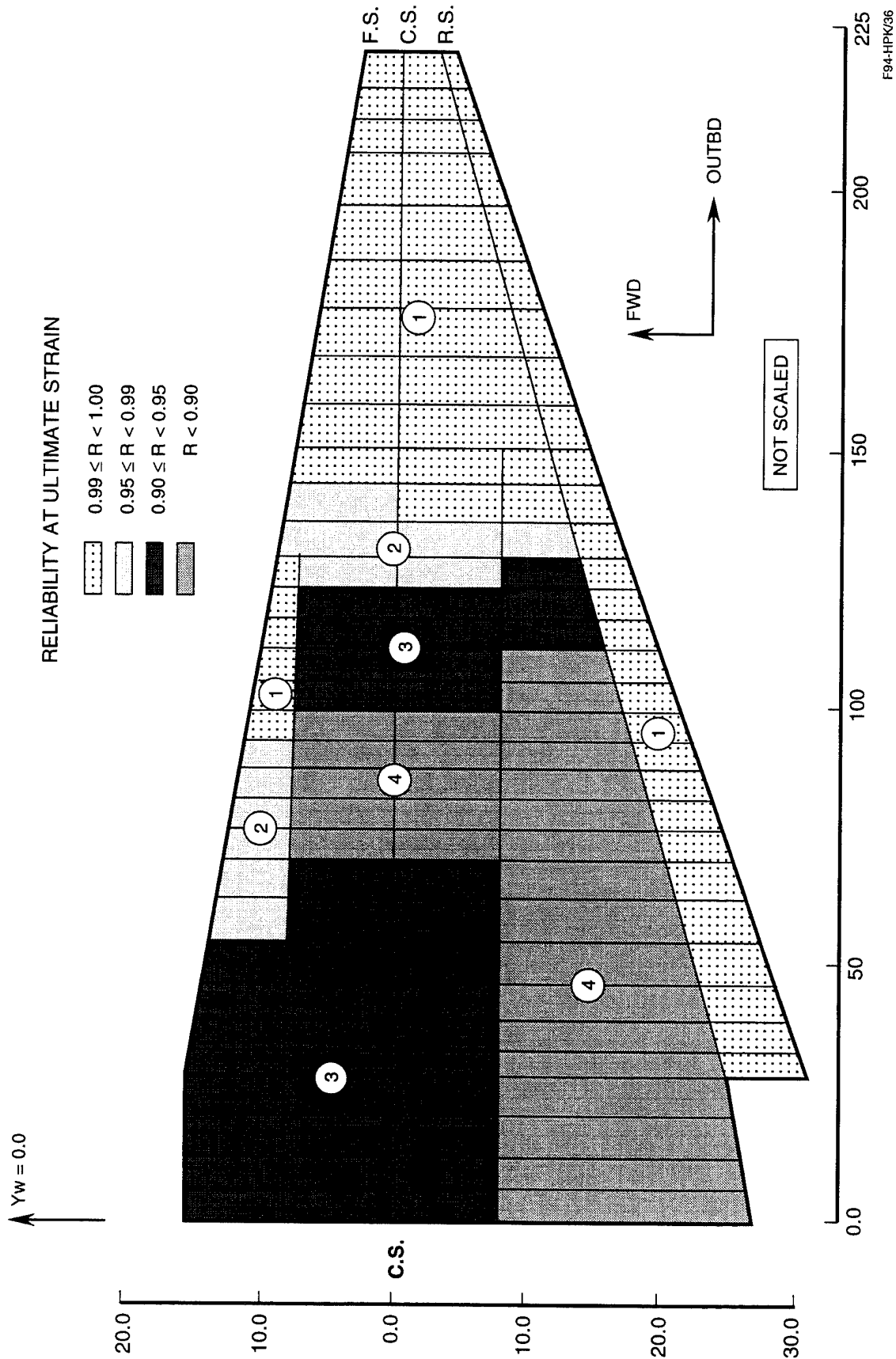


FIGURE 31. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, LOW IMPACT THREAT, MAXIMUM STRAIN.

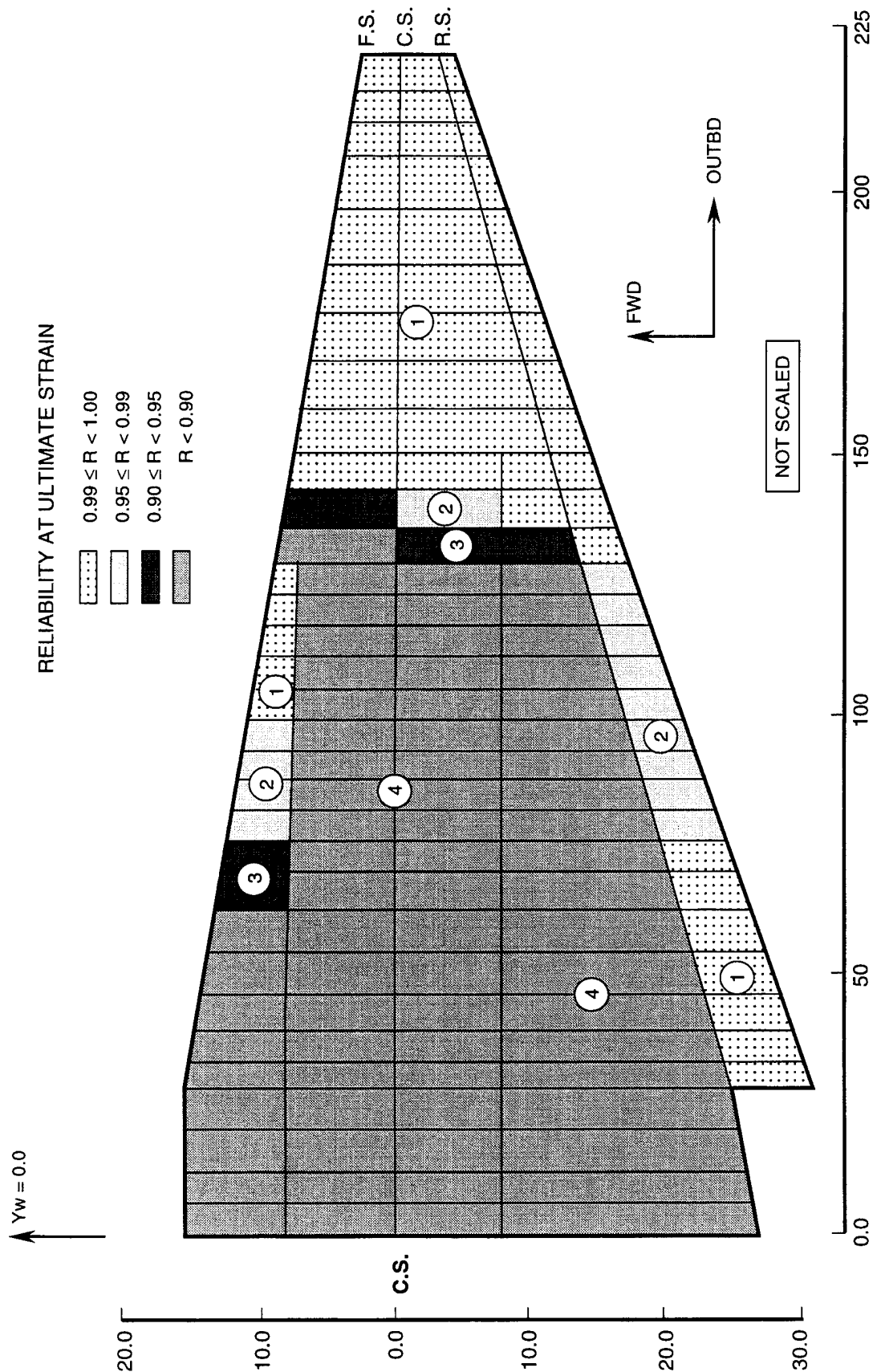


FIGURE 32. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, MEDIUM IMPACT THREAT, MAXIMUM STRAIN.

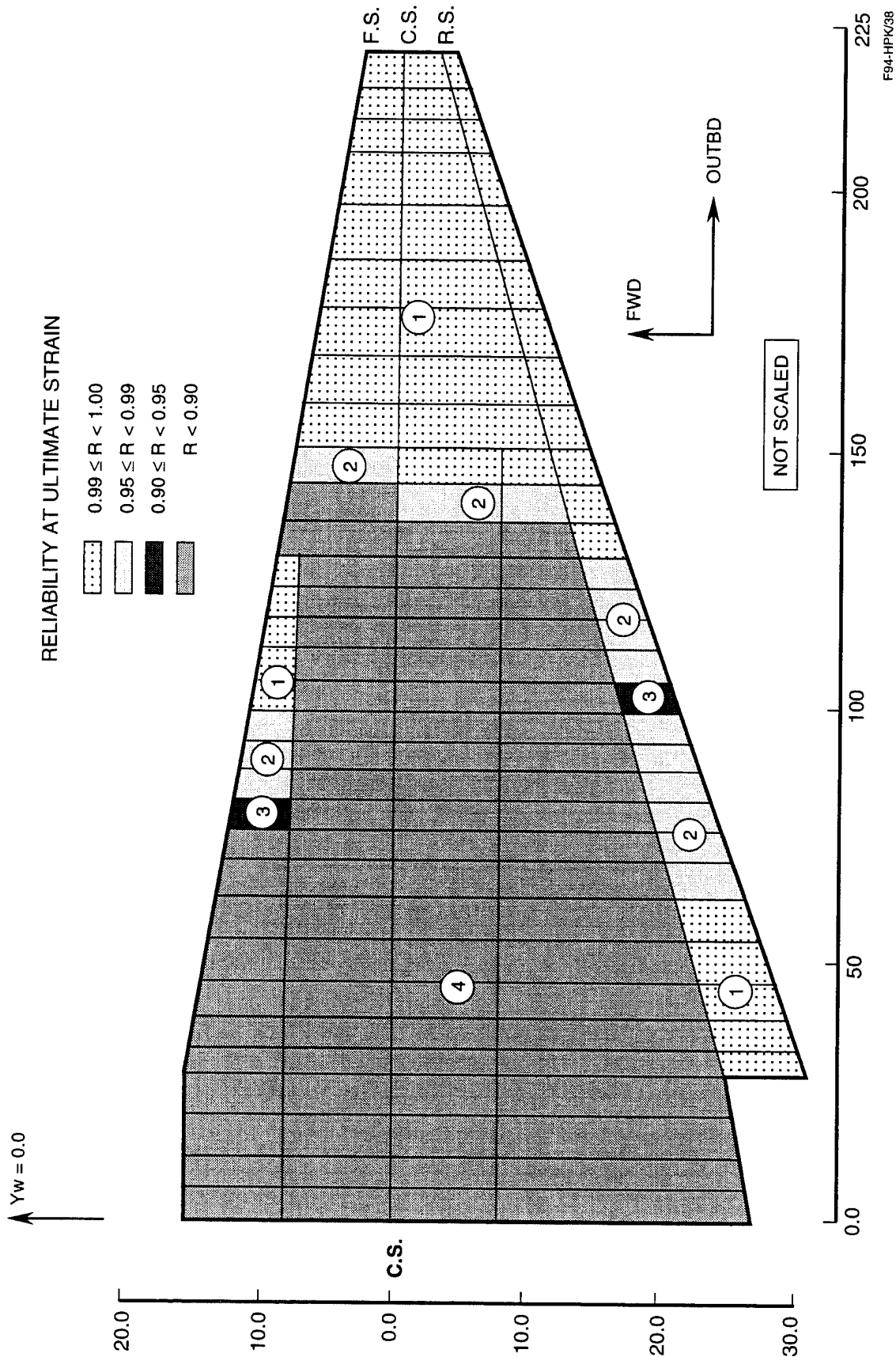


FIGURE 33. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, HIGH IMPACT THREAT, MAXIMUM STRAIN.

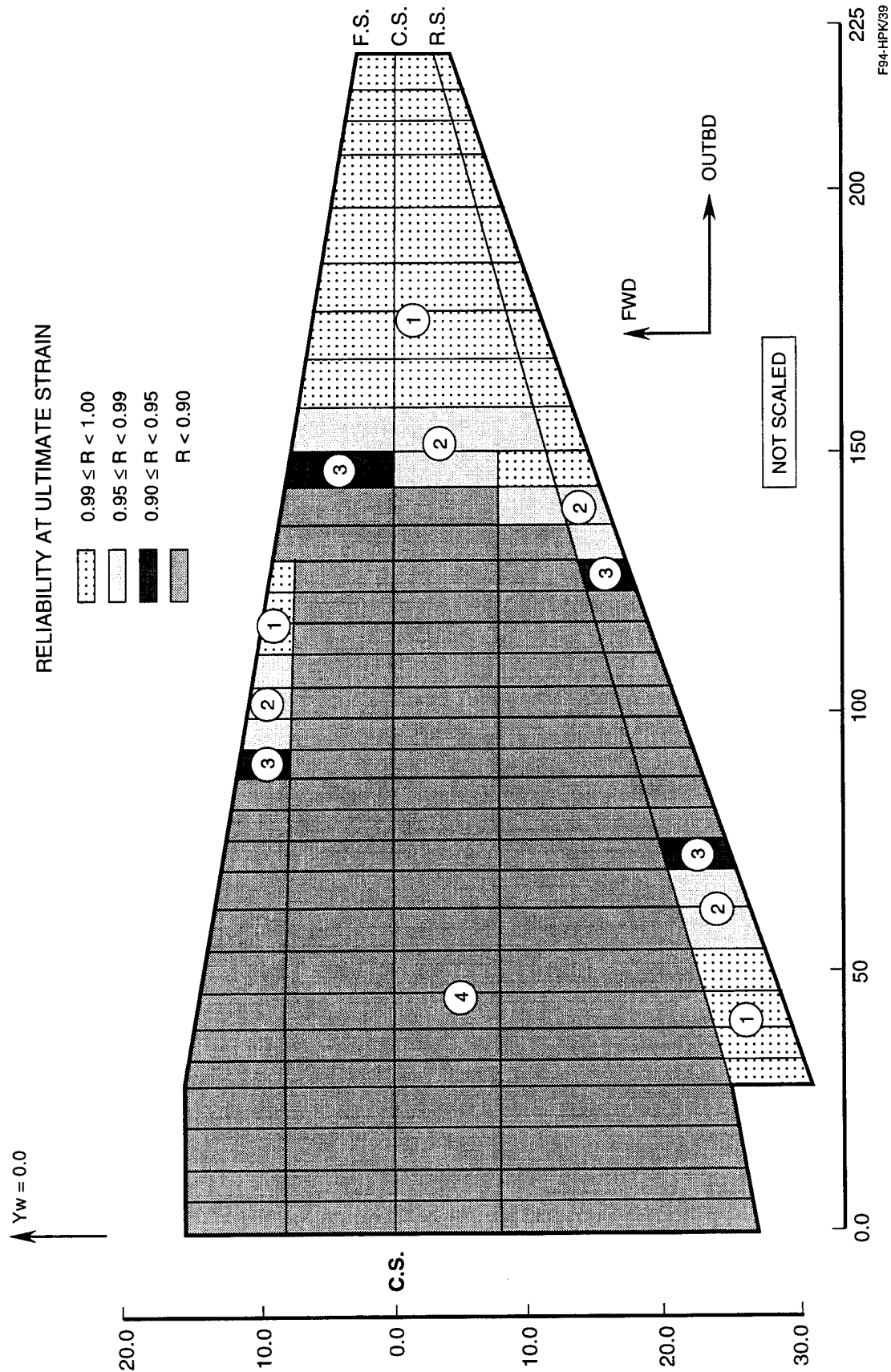


FIGURE 34. RELIABILITY OF IMPACT DAMAGED UPPER WING SKIN, 100 FT-LB IMPACT, MAXIMUM STRAIN.

F94-HPK/39

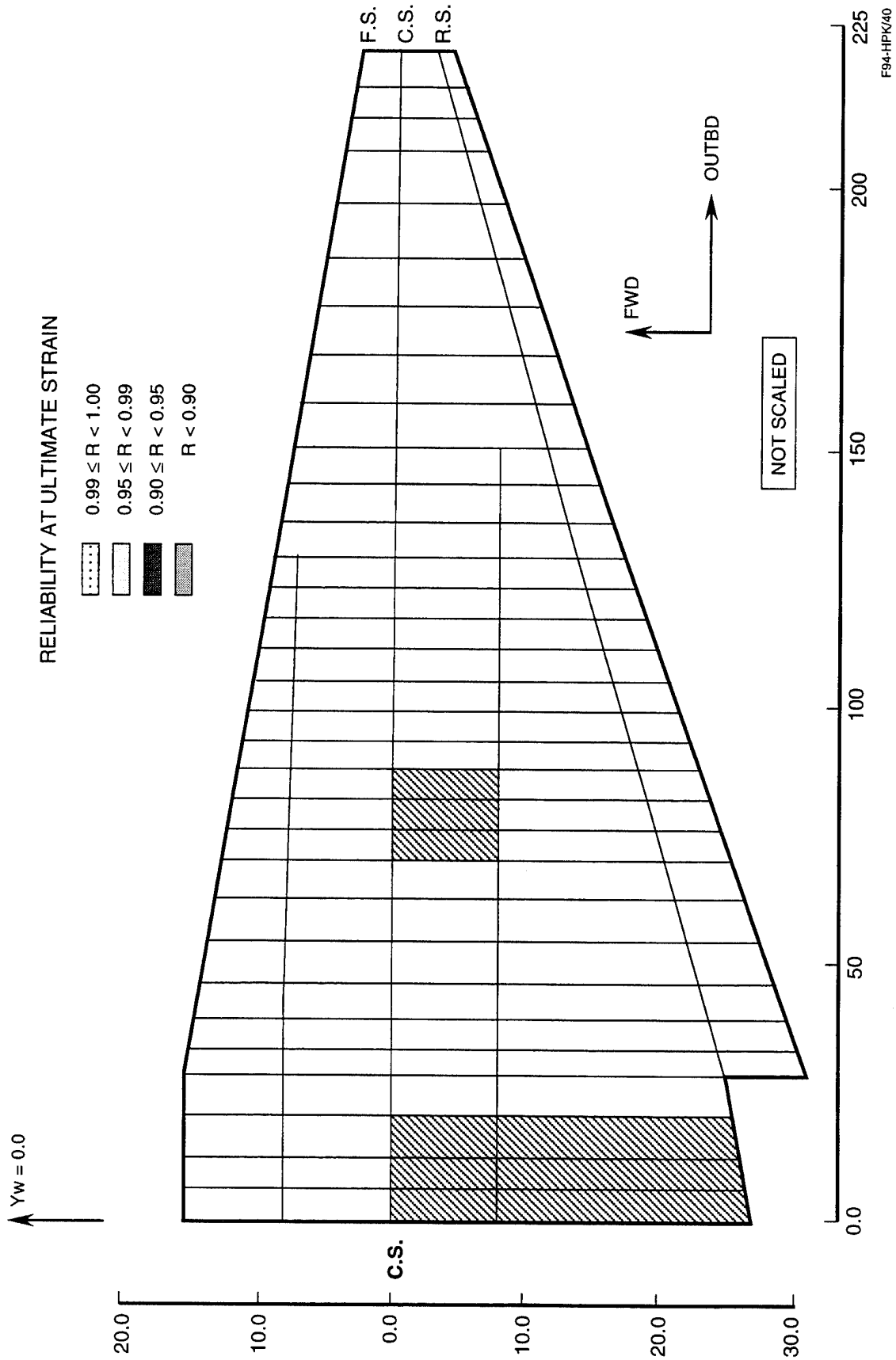


FIGURE 35. CRITICAL IMPACT DAMAGE LOCATIONS OF THE UPPER WING SKIN.

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 characterized by stiffness retention ratios ( $S_r$ ). 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  $S_r=0.15$  was used in the evaluation. The characteristic length ( $a_0$ ) 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 extremely 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.<br>(MICRO) | M.S. | RELIABILITY |          |         |
|------|-------------------|------|-------------|----------|---------|
|      |                   |      | @DLL        | @1.25DLL | @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,  $S_r=0.15$ , MAXIMUM STRAIN IN  
EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(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.<br>(MICRO) | M.S. | RELIABILITY |          |         |
|------|-------------------|------|-------------|----------|---------|
|      |                   |      | @DLL        | @1.25DLL | @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.<br>(MICRO) | M.S. | RELIABILITY |          |         |
|------|-------------------|------|-------------|----------|---------|
|      |                   |      | @DLL        | @1.25DLL | @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.<br>(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.<br>(MICRO) | DUL STRAIN<br>(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              | 1286                  | *                         | *    | *    |
| 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.<br>(MICRO) | DUL STRAIN<br>(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              | 1888                  | *                         | *    | *     |
| 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                  | *                         | *    | 0.581 |
| 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.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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              | 2953                  | *                         | *     | 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.

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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,  $S_t=0.01$ , MAXIMUM  
STRAIN IN EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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,  $S_f=0.01$ , MAXIMUM  
STRAIN IN EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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,  $S_r=0.001$ , MAXIMUM  
STRAIN IN EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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,  $S_f=0.001$ , MAXIMUM  
STRAIN IN EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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,  $S_t=0.01$ , AVERAGE  
STRAIN IN EACH SUBDIVISION.

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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,  $S_r=0.01$ , AVERAGE  
STRAIN IN EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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,  $S_t=0.01$ , AVERAGE  
STRAIN IN EACH SUBDIVISION. (CONTINUED)

| REG. | B-ALL.<br>(MICRO) | DUL STRAIN<br>(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.<br>(MICRO) | DUL STRAIN<br>(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.

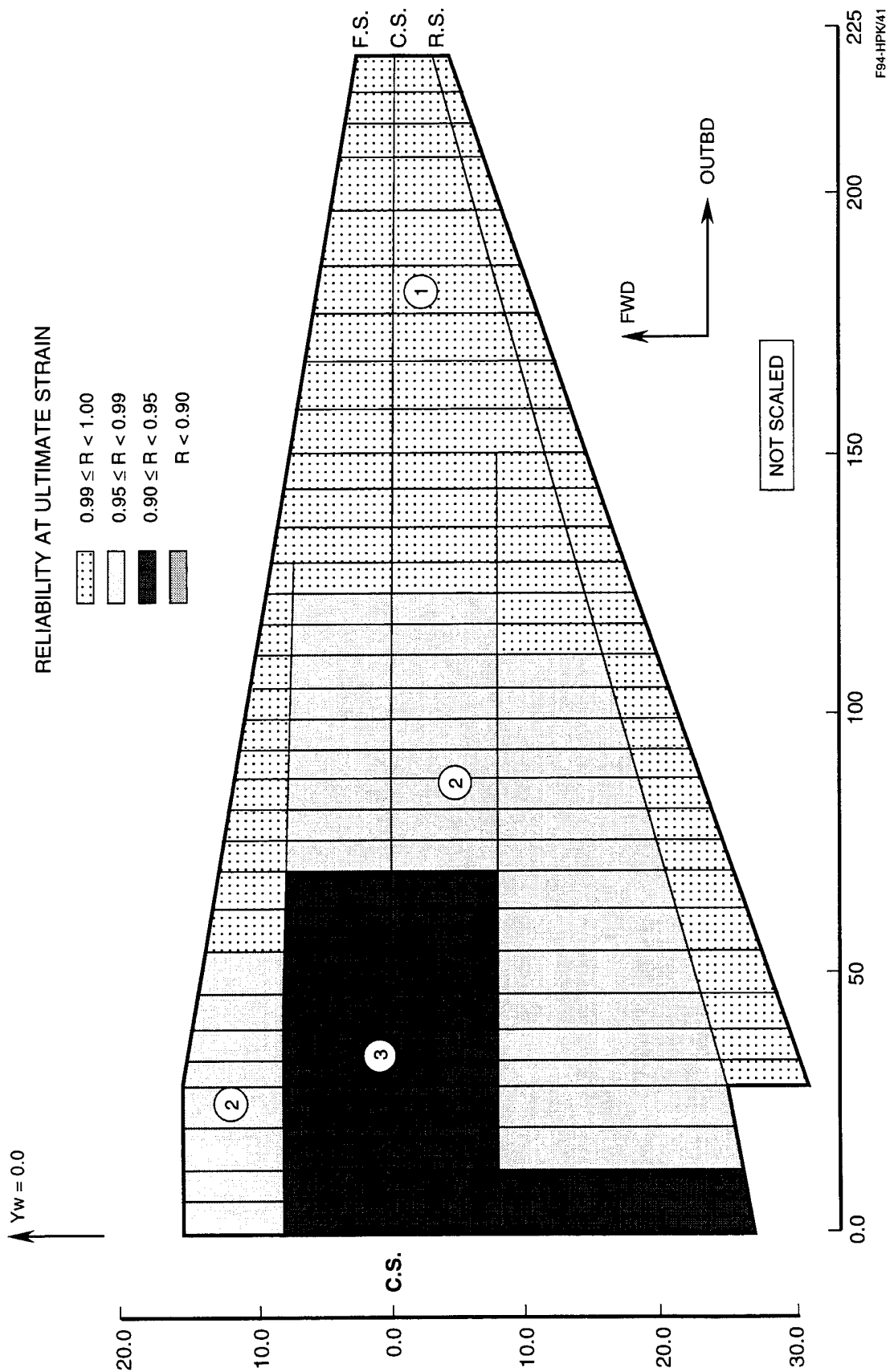


FIGURE 36. RELIABILITY OF UPPER WING SKIN WITH 2.0-IN.-DIAMETER ASSEMBLY INDUCED DAMAGE,  $S_r = 0.15$ , MAXIMUM STRAIN.

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 ( $S_r$ ) 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

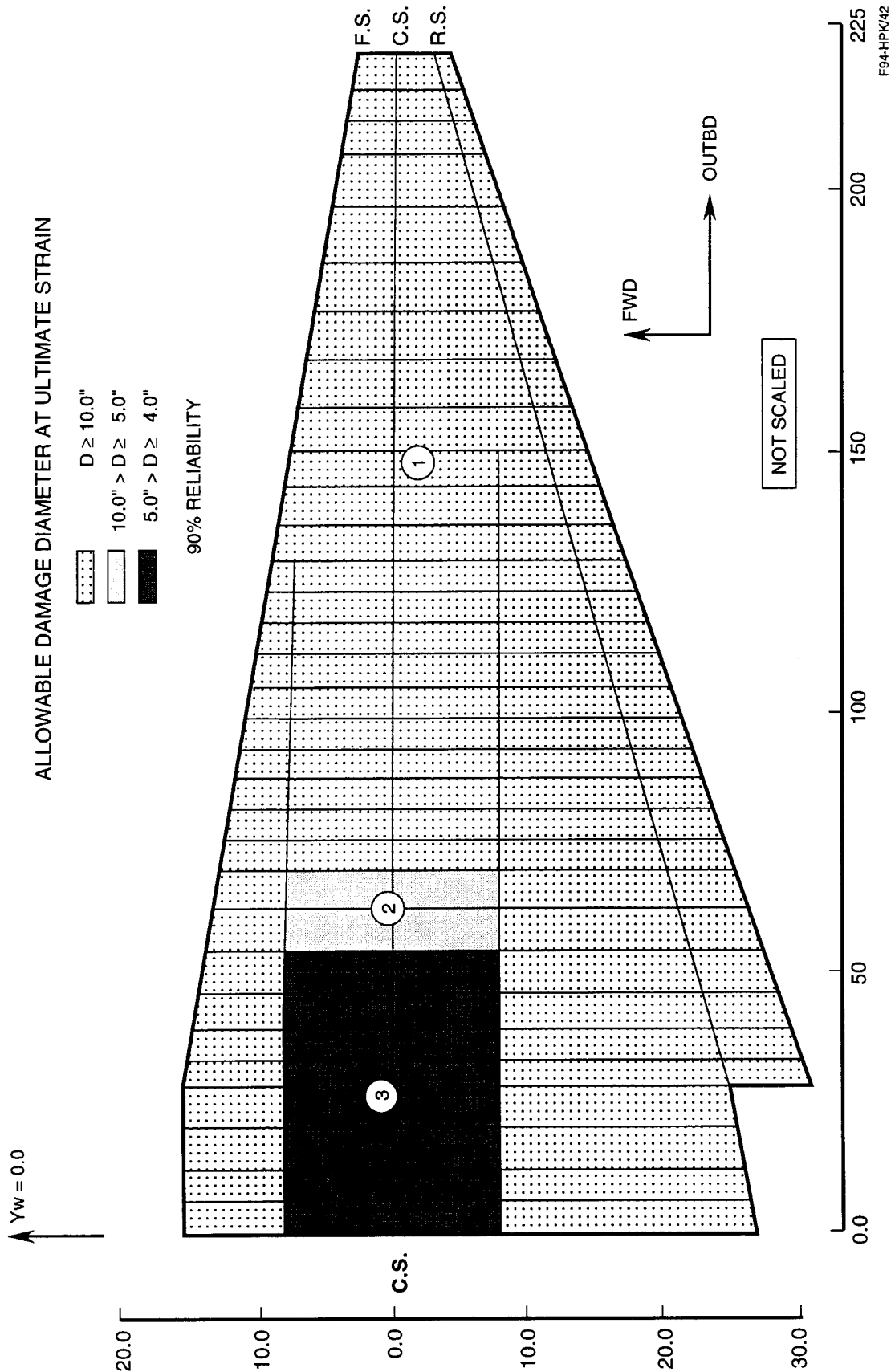


FIGURE 37. ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY,  
 $S_r = 0.15$ , MAXIMUM STRAIN.

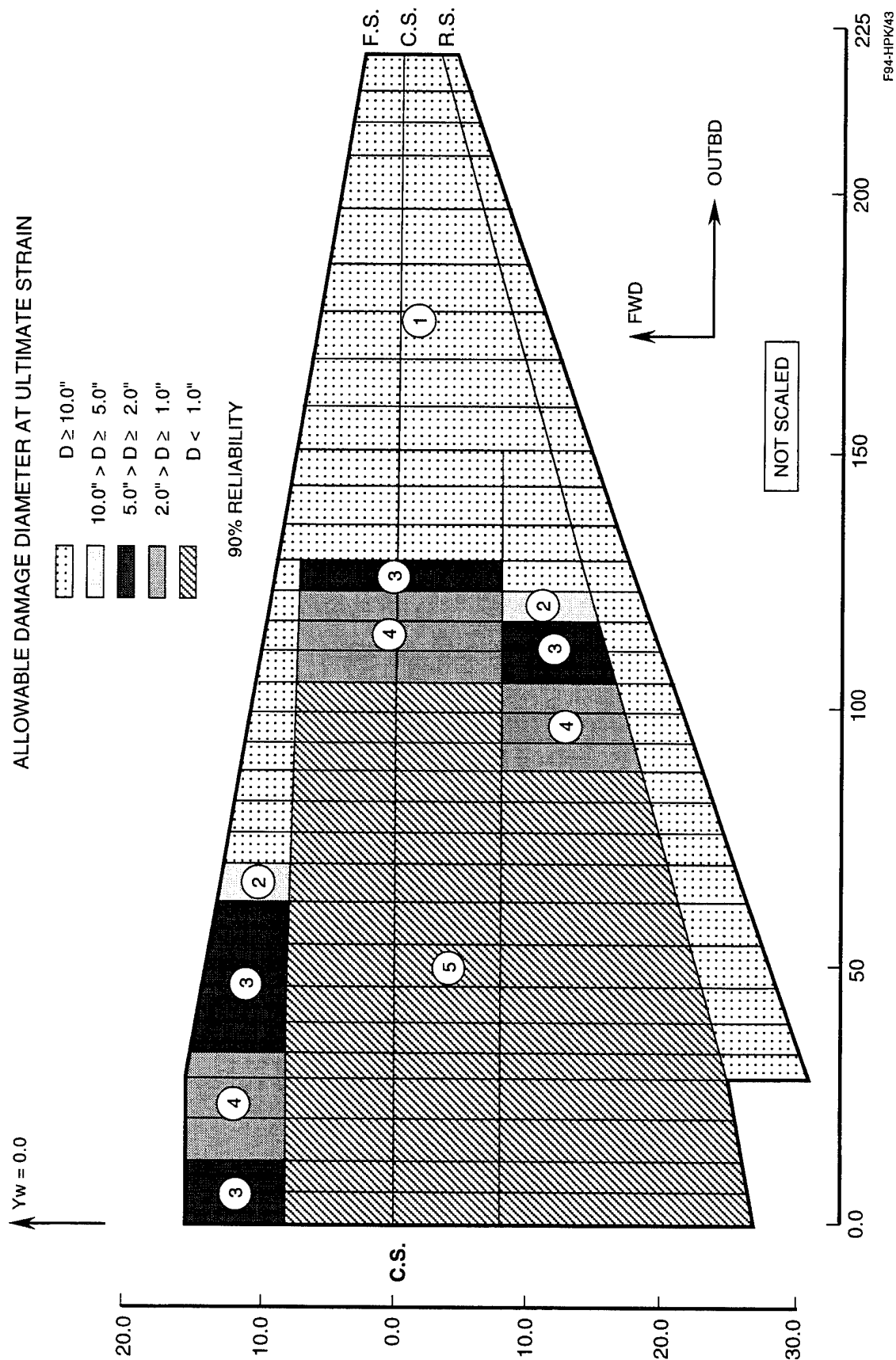


FIGURE 38. ALLOWABLE ASSEMBLY INDUCED DAMAGE DIAMETER IN THE UPPER WING SKIN, 90% RELIABILITY,  $S_r = 0.01$ , MAXIMUM STRAIN.

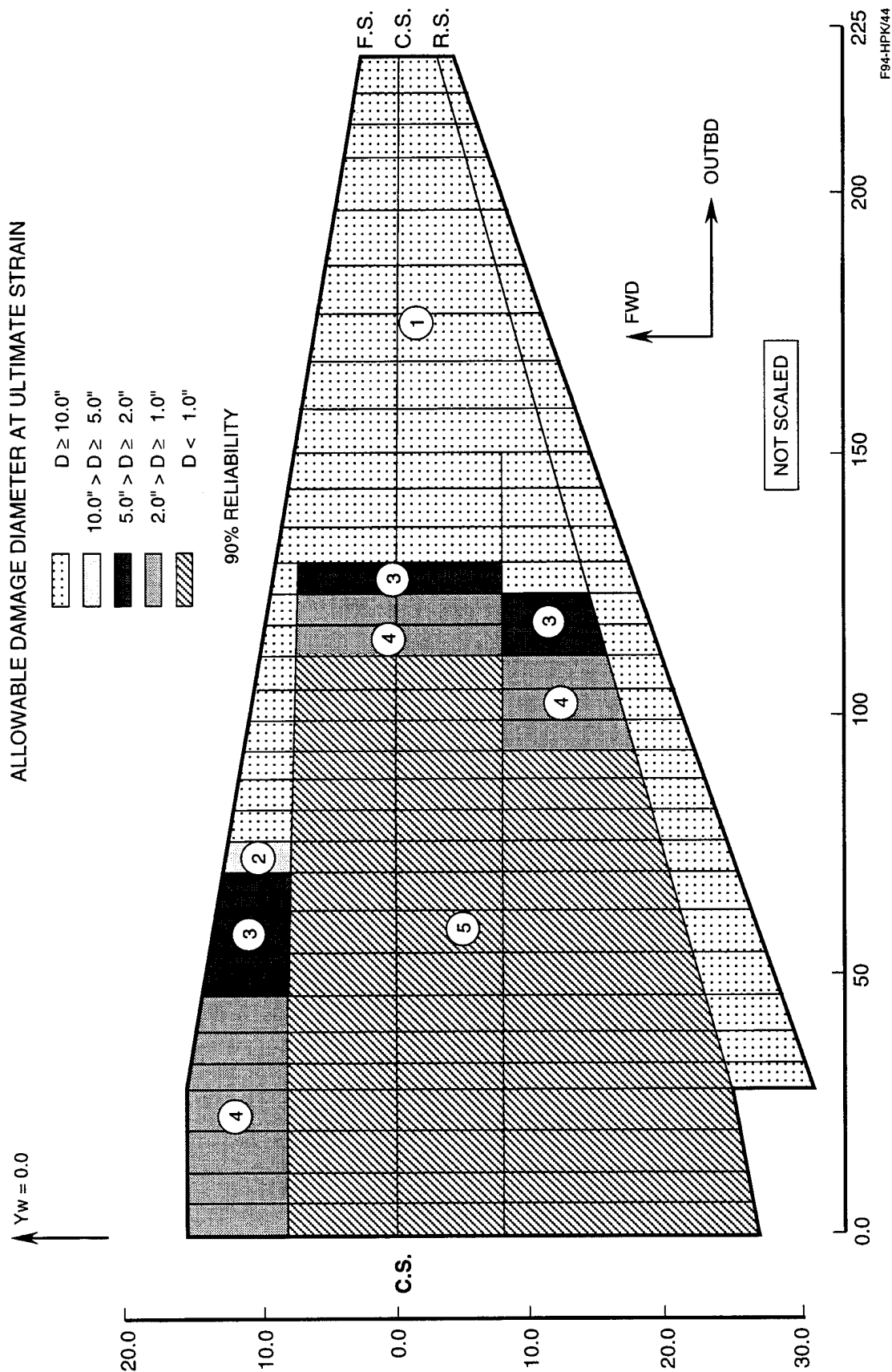


**FIGURE 39. ALLOWABLE ASSEMBLY INDUCED DAMAGE SIZE IN THE UPPER WING SKIN, 90% RELIABILITY,  $S_f = 0.001$ , MAXIMUM STRAIN.**

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  $S_r=0.001$ , 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  $S_r=0.01$ , 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.

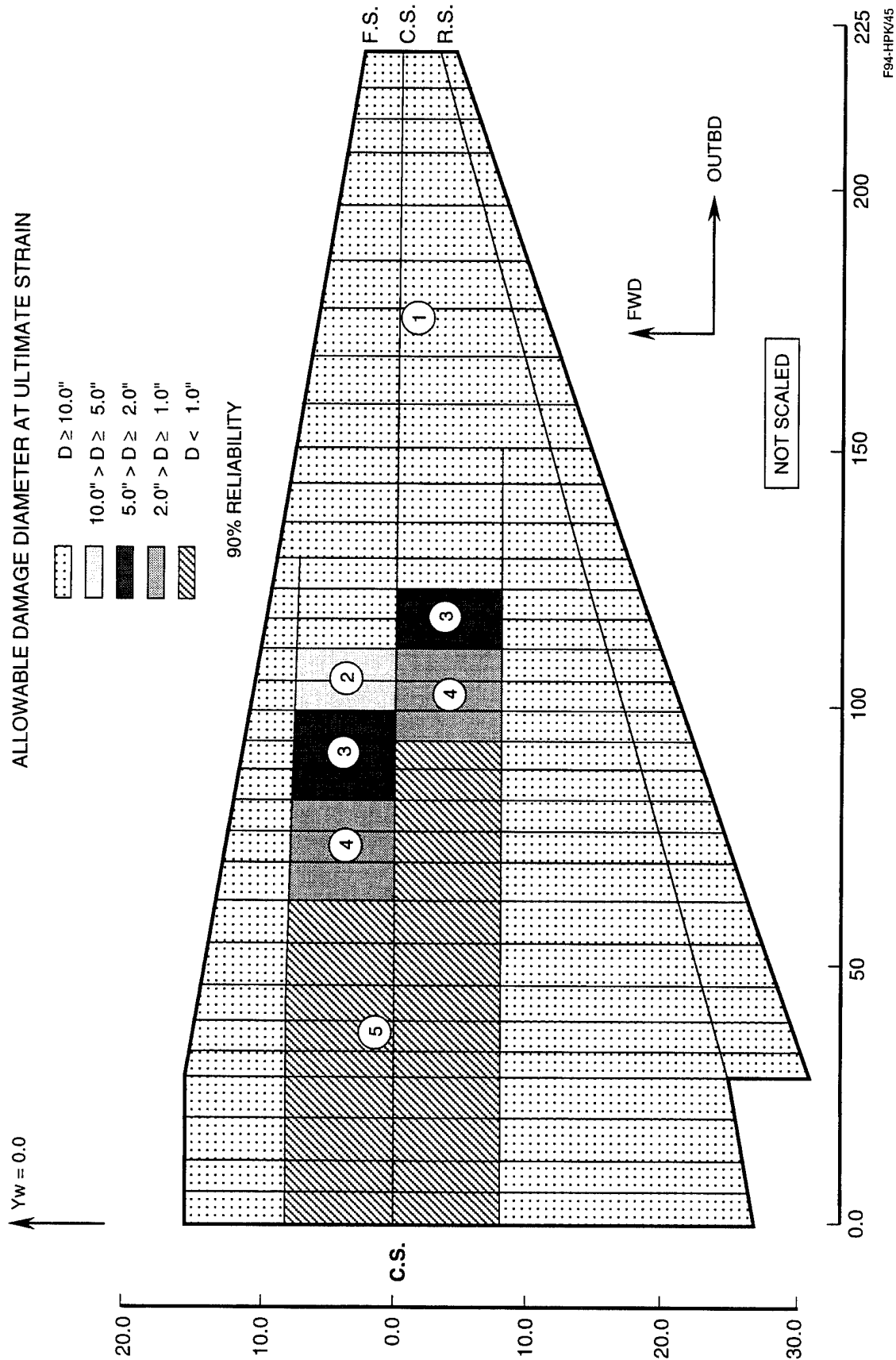


FIGURE 40. ALLOWABLE ASSEMBLY INDUCED DAMAGE SIZE IN THE UPPER WING SKIN, 90% RELIABILITY,  $S_f = 0.01$ , AVERAGE STRAIN.

TABLE 16. SUMMARY OF DETECTED DEFECT EVALUATION.

| DEFECT NO.      | REGION | B-ALL.<br>(MICRO) | M.S. | RELIABILITY<br>AT DUL | 0.90 RELIAB.<br>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<br>(MICRO) |      |      |      | MARGIN OF SAFETY<br>(B-BASIS) |      |      |       |
|------|------------------------|------|------|------|-------------------------------|------|------|-------|
|      | I                      | II   | III  | IV   | 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<br>(MICRO) |      |      |      | MARGIN OF SAFETY<br>(B-BASIS) |       |       |       |
|------|------------------------|------|------|------|-------------------------------|-------|-------|-------|
|      | I                      | II   | III  | IV   | 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<br>(MICRO) |      |      |      | MARGIN OF SAFETY<br>(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<br>(MICRO) |      |      |      | MARGIN OF SAFETY<br>(B-BASIS) |       |       |       |
|------|------------------------|------|------|------|-------------------------------|-------|-------|-------|
|      | I                      | II   | III  | IV   | 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<br>(MICRO) |      |      |      | MARGIN OF SAFETY<br>(B-BASIS) |       |       |       |
|------|------------------------|------|------|------|-------------------------------|-------|-------|-------|
|      | I                      | II   | III  | IV   | 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 failure at 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 <sub>r</sub> | 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 <sub>r</sub> | 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      | **(0.97716) |
| 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 <sub>r</sub> | 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 reliability 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 reliability 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,  $\alpha$ . The values of  $\alpha$  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.

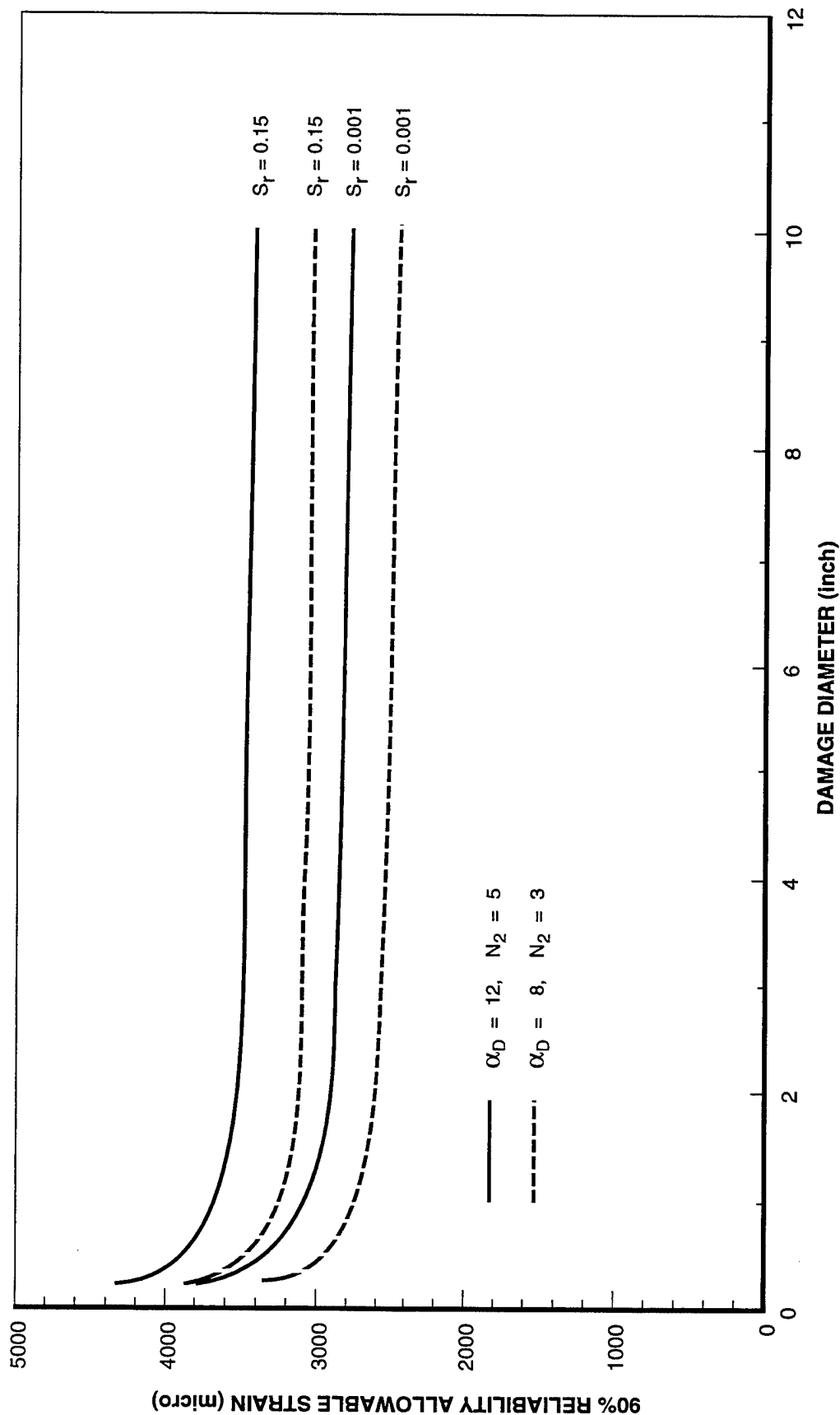
$$\text{Resp} = [\ln(R)/\ln(0.90)]^{**}(1/\alpha_d) \quad (1)$$

where    Resp is the strain ratio,

          R is the required reliability,

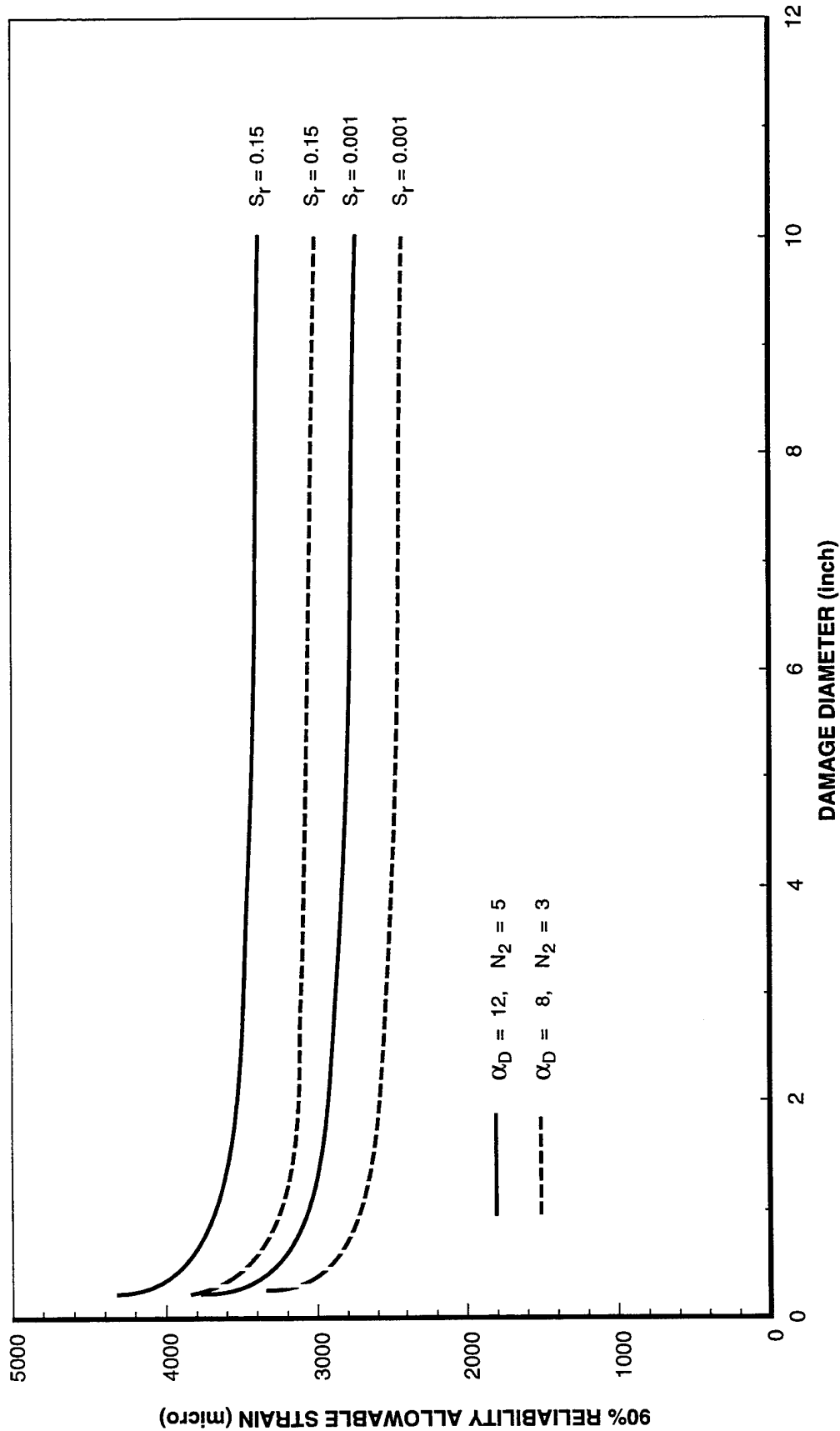
$\alpha_d$  is the Weibull shape parameter of the damaged laminate.

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 ( $\alpha_d$  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.



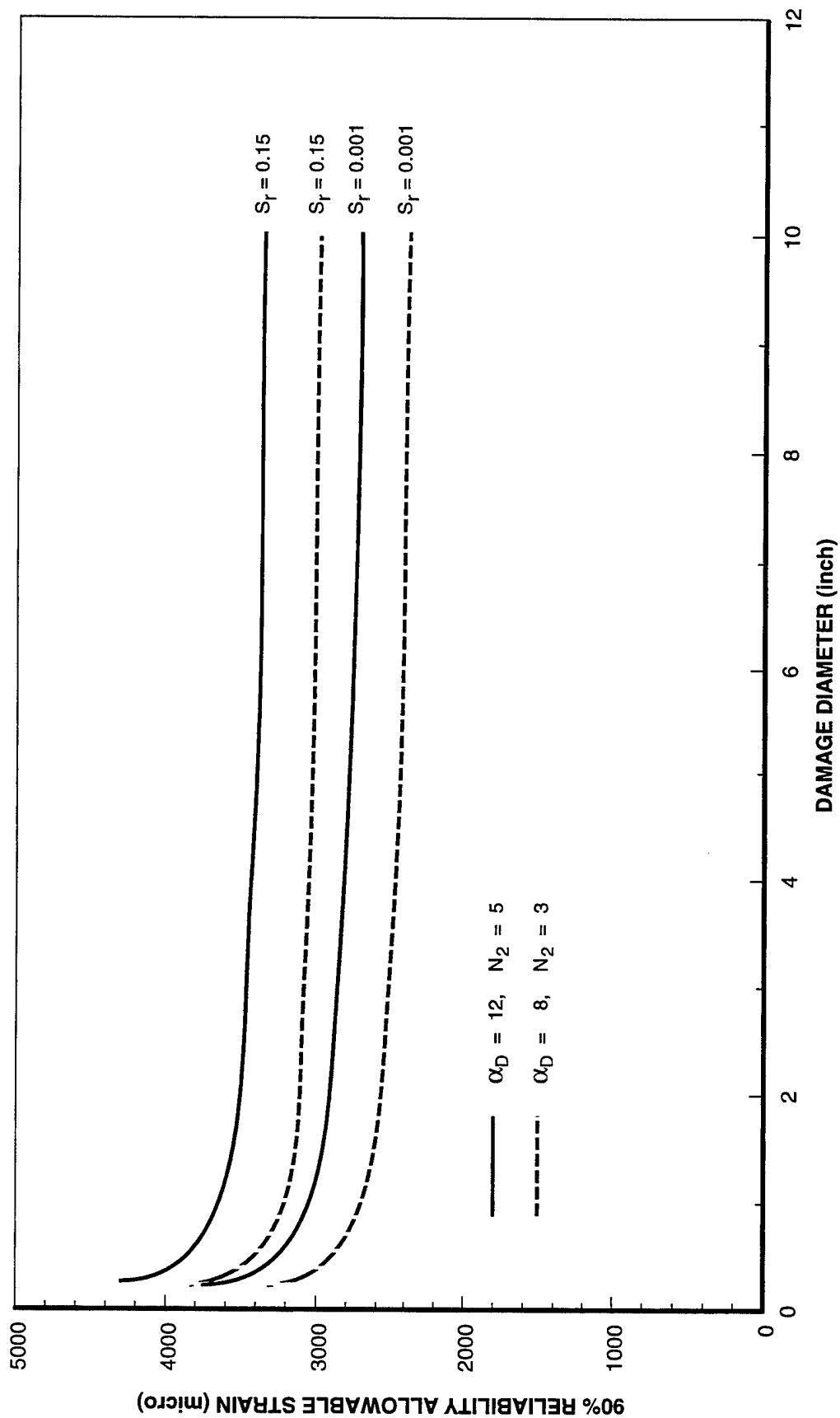
F94-HPK/46

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



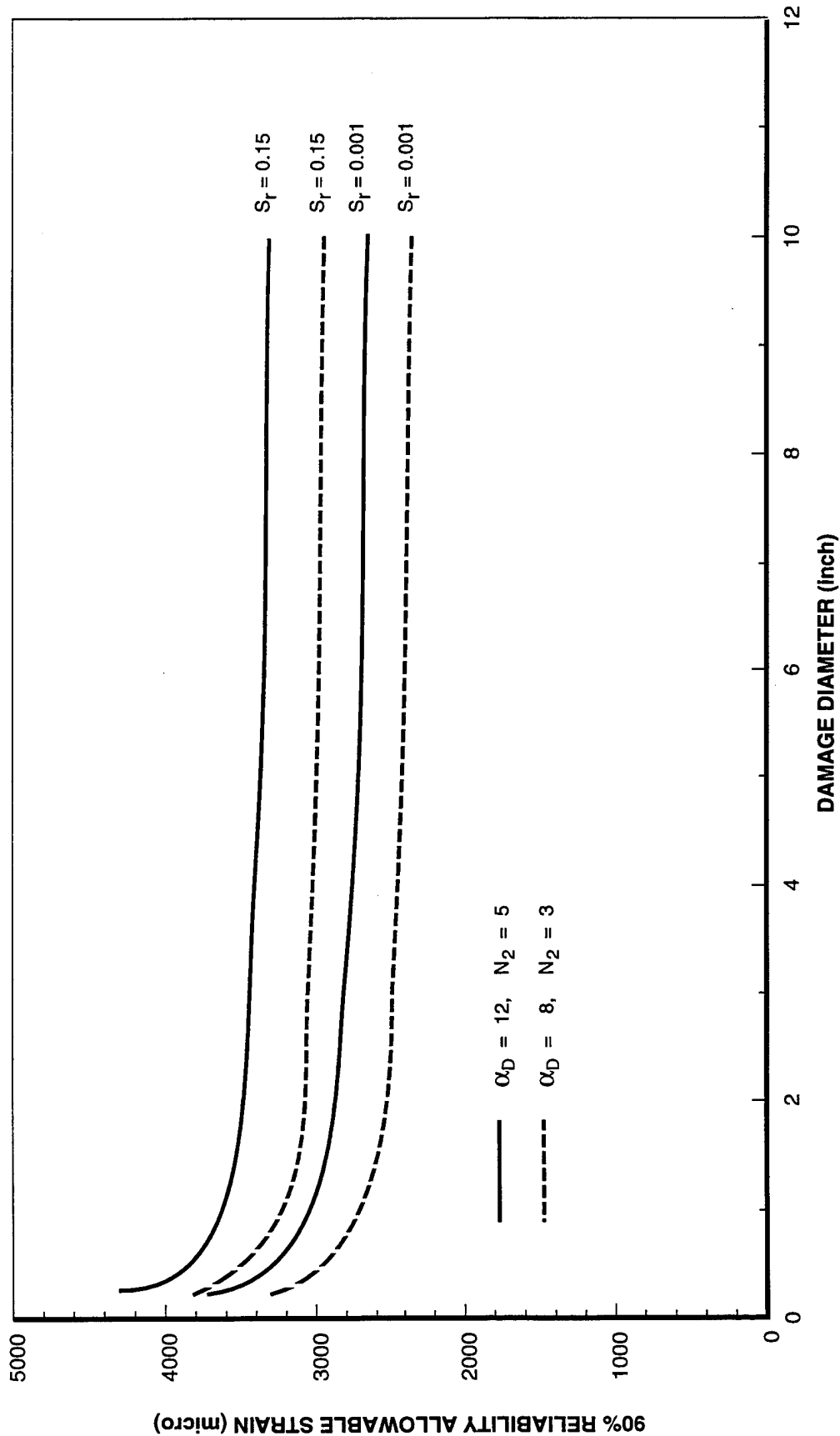
F94-HPK/47

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



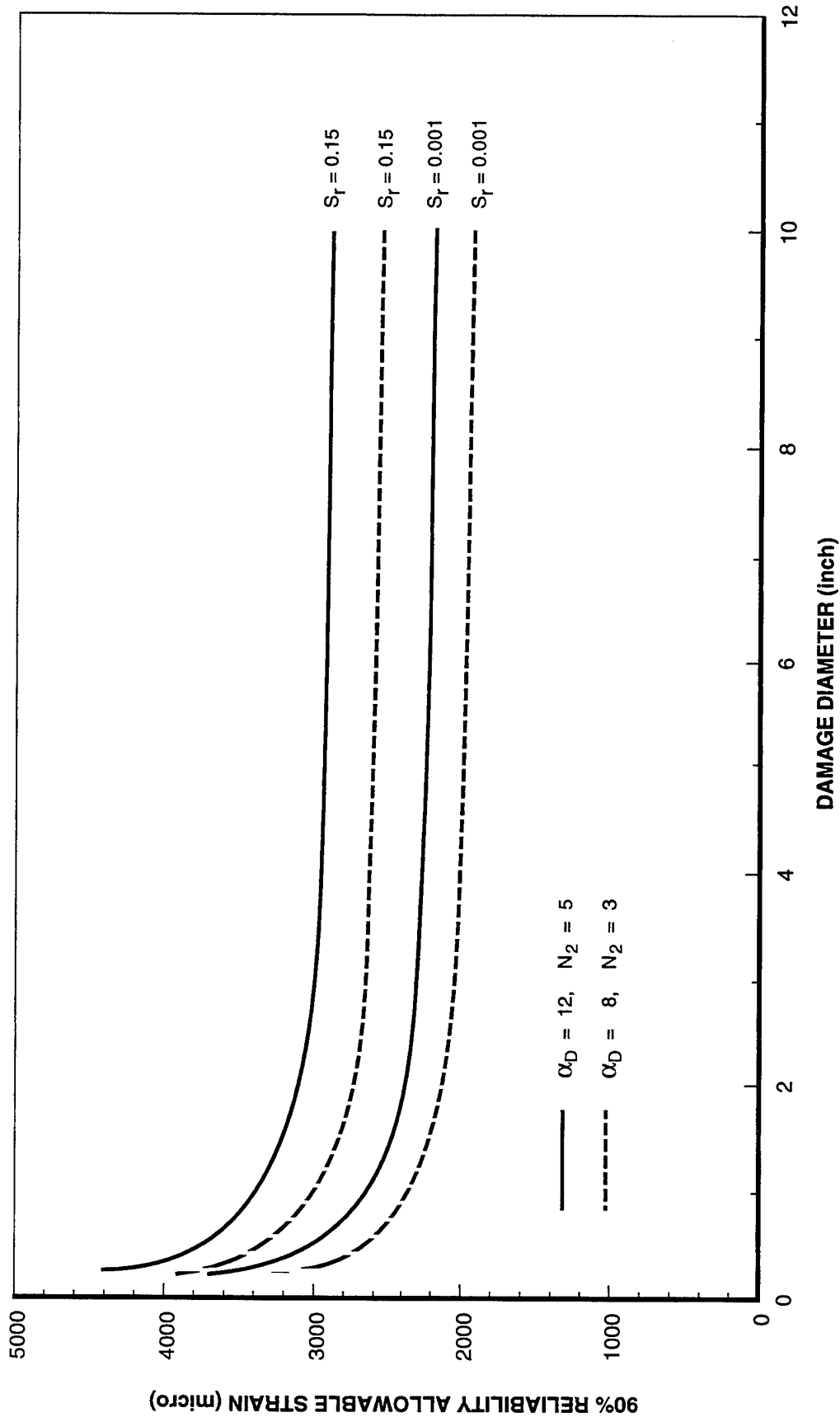
F94-HPK/48

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



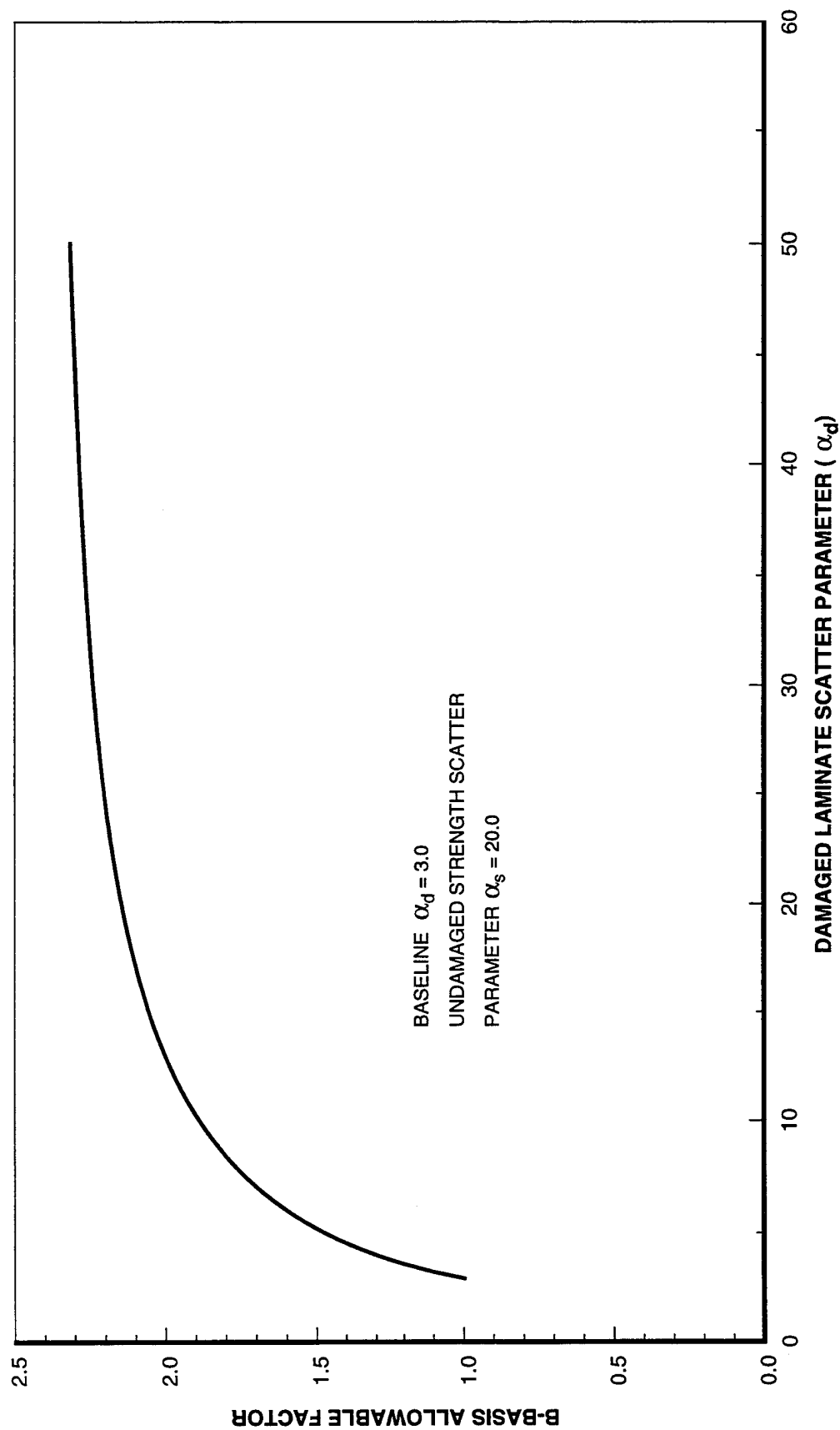
F94-HPK/49

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



F94-HPK/50

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



F94-HPK/51

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

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

| $\alpha_d$ | RATIO  | $\alpha_s$ | RATIO  |
|------------|--------|------------|--------|
| 3.0        | 1.0000 | 5.0        | 0.7258 |
| 4.0        | 1.2642 | 6.0        | 0.7815 |
| 5.0        | 1.4493 | 7.0        | 0.8230 |
| 6.0        | 1.5848 | 8.0        | 0.8553 |
| 7.0        | 1.6877 | 9.0        | 0.8809 |
| 8.0        | 1.7684 | 10.0       | 0.9018 |
| 9.0        | 1.8333 | 11.0       | 0.9192 |
| 10.0       | 1.8866 | 12.0       | 0.9338 |
| 11.0       | 1.9310 | 13.0       | 0.9463 |
| 12.0       | 1.9686 | 14.0       | 0.9571 |
| 13.0       | 2.0009 | 15.0       | 0.9665 |
| 14.0       | 2.0289 | 16.0       | 0.9748 |
| 15.0       | 2.0535 | 17.0       | 0.9822 |
| 16.0       | 2.0751 | 18.0       | 0.9887 |
| 17.0       | 2.0944 | 19.0       | 0.9946 |
| 18.0       | 2.1115 | 20.0       | 1.0000 |
| 19.0       | 2.1270 | 21.0       | 1.0048 |
| 20.0       | 2.1411 | 22.0       | 1.0092 |
| 21.0       | 2.1538 | 23.0       | 1.0133 |
| 22.0       | 2.1654 | 24.0       | 1.0170 |
| 23.0       | 2.1761 | 25.0       | 1.0204 |
| 24.0       | 2.1859 | 26.0       | 1.0236 |
| 25.0       | 2.1950 | 27.0       | 1.0265 |
| 26.0       | 2.2033 | 28.0       | 1.0292 |
| 27.0       | 2.2111 | 29.0       | 1.0318 |
| 28.0       | 2.2183 | 30.0       | 1.0341 |
| 29.0       | 2.2251 | 32.5       | 1.0395 |
| 30.0       | 2.2314 | 35.0       | 1.0440 |
| 50.0       | 2.3058 | 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)  $\alpha_s$  is Weibull shape parameter of the undamaged laminate strength;  $\alpha_d$  is the Weibull shape parameter of the damaged laminate strength.

(2) Baseline is  $\alpha_d=3.0$  and  $\alpha_s=20.0$ .

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 ( $\alpha_s$  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 ( $N_s$ ) of 30 and damaged laminate strength ( $N_d$ ) 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 ( $N_s$ ) |        |        |        |        |        |        |
|-------|-----------------------------------------------------------|--------|--------|--------|--------|--------|--------|
|       | 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 respect to the B-basis allowable strain with baseline parameters.
- (2)  $\alpha_s$  is Weibull shape parameter of the undamaged laminate strength;  $\alpha_d$  is the Weibull shape parameter of the damaged laminate strength.
- (3)  $N_s$  is the sample size for the undamaged laminate strength;  $N_d$  is the sample size for the damaged laminate strength.
- (4) Baseline is  $\alpha_s=20.0$  and  $\alpha_d=12.0$ ,  $N_s=30$  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.