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EVALUATION OF STRUCTURAL RELIABILITY ANALYSIS PROCEDURES AS APPLIED TO A FIGHTER AIRCRAFT

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SEPTEMBER 1973

Air Force Materials Laboratory
Air Force Systems Command
Wright Patterson Air Force Base, Ohio

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FOREWORD

The research work reported herein was conducted by the McDonnell Aircraft Company(MCAIR), McDonnell Douglas Corporation, St. Louis, Mo. for the Metals and Ceramics Division, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under contract F33615-72-C-1882. This contract was initiated under Project 7351, "Metallic Materials", Task 735106, "Behavior of Metals", with Mr. R. C. Donat, AFML/LLN, acting as project engineer.

The study was conducted by the Structural Research Department of MCAIR under the guidance of Messrs. E. D. Bouchard and M. L. Rand and under the direct supervision of Mr. L. F. Impellizzeri, as Principal Investigator, with assistance from Messrs. A. E. Siegel and R. A. McGinnis. Other Structural Research Department personnel making valuable contributions to the program were Messrs. T. L. Benton and F. R. Foster. The period covered by this effort was 1 May 1972 to 1 May 1973. The report was submitted by the authors on 30 May 1973.

This report has been reviewed and is approved.

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Act. Asst. for Reliability
Metals and Ceramics Division
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ABSTRACT

Structural reliability analysis procedures were evaluated for estimating the variability in fighter aircraft fatigue performance. The expected magnitude of this variability was determined based on an investigation of scatter in fatigue test results for aluminum structures. This study revealed that (a) the scatter for spectrum fatigue tests is considerably less than for constant amplitude fatigue tests, (b) the Weibull probability distribution provides a better fit of the spectrum fatigue data than the log-normal, and (c) the Weibull shape parameter α is 5.27. The α value was determined from 1060 spectrum test results of which 243 were full-scale airplane and airplane component tests. These included the F-3H Demon wing and horizontal tail, the F-4 Phantom II wing box beam, the Lockheed wing test panel, the F-9F Panther wing, the Navy Lab box beam, the P-51 Mustang wing, the C-46 transport wing, and the British Piston Provost wing. In addition to these studies of experimental data, theoretical analyses were performed yielding the mathematical probability distribution for a Weibull based scatter factor which is

$$S = (R/1-R)^{1/\alpha}$$

where S is the scatter factor and R is reliability or the probability of no failure. VGH and load factor counting accelerometer data from the F-4 fighter airplane were utilized to correlate that airplane's laboratory and service fatigue experience. Probable minimum service lives considering the F-4 fleet size and individual airplane usage were computed based on the Weibull based scatter factor and order statistics. The combined effect of fatigue test scatter and usage severity scatter was derived utilizing a joint scatter factor concept. Three fatigue critical locations on the F-4 airplane were considered to be amenable to analysis using the methods of this report. The correlation was excellent for one of these, but not for the other two. Fabrication variations in a redundant load path joint and outer wing buffeting were considered the probable cause for the less than favorable correlation.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ABBREVIATIONS AND SYMBOLS

1. ABBREVIATIONS

exp = exponential function

log = common logarithm

BLUE = best linear unbiased estimator or estimate

2. SYMBOLS

α	= Weibull distribution shape or scatter-controlling parameter
β	= Weibull distribution scale parameter or characteristic life
f( )	= probability density function of the parameter within the parenthesis
F( )	= cumulative probability distribution function of the parameter within the parenthesis
μ	= log-normal distribution scale parameter or mean life
n	= number of failure observations in the test sample
R	= reliability of a randomly chosen fleet member or the probability of no failure (probability that the ratio of life in the laboratory to life in service is less than the scatter factor)
S	= scatter factor
σ	= log-normal standard deviation
W	= $\left(\frac{\bar{\beta}}{\beta}\right)^{\alpha}$
x	= life of individual laboratory specimen
y	= life of a randomly selected specimen or aircraft
ε	= usage severity scatter = actual counts/estimated counts
Γ( )	= Gamma function of argument within the parenthesis

3. ACCENT MARKS DENOTING ESTIMATION

(a) Bar, as in $\bar{\sigma}$ or $\bar{\alpha}$, denotes the sample point estimate for one group of specimens

(b) Double bar, as in $\bar{\bar{\sigma}}$ or $\bar{\bar{\alpha}}$ denotes the sample estimate for more than one group of specimens.

1. INTRODUCTION

1.1 General

The Metals and Ceramics Division of the Air Force Materials Laboratory, Air Force Systems Command, has sponsored research efforts on application of reliability methods to the estimation of probable aircraft structural fatigue performance. Results of these efforts are reported in References (1) and (2). The reliability analysis approach has been evaluated for cargo (C-130) and tanker (KC-135) type aircraft. The purpose of the present program has been to extend reliability analysis methods to fighter aircraft. This objective was achieved through utilization of fatigue test experience and service repeated load data which has been generated in conjunction with the McDonnell Phantom II (F-4) airplane.

1.2 Traditional Approach to Structural Reliability

Structural fatigue integrity is currently designed into present day aircraft utilizing a rather well organized plan. Spectrum fatigue tests are performed in the laboratory on the full scale structure with the target goal being some multiple of the expected service life. This is the traditional scatter factor approach which has been used for quite a few years. There have been aircraft accidents during this period, but there have been many causes other than airframe structural deficiencies; e.g., pilot error, power plant failure, electrical system malfunction. The percentage of accidents resulting from airframe fatigue failure has been small. However, fatigue failures have led to rather large structural maintenance expenditures over the years. In general, these have been caused by unexpectedly severe usage, an unusual design detail, or a material deficiency; but the simple scatter factor approach may have been partly responsible.

1.3 Additional Considerations

There are a number of questions that the traditional approach to structural reliability does not take into account. For example: Should the same scatter factor be used for fighters, bombers, transports, commercial airliners, for different materials, for different structural details and arrangements, etc.? Should not the number of laboratory test articles affect the required scatter factor? Should the expected fleet size affect the required scatter factor? General aircraft attrition due to factors other than fatigue is another important consideration. The fleet size is reduced by attrition. The consideration of damage tolerance could very well lead to different allowable scatter factors for different components on the same airplane. The underlying problem is the need for development of a method to compute the required scatter factor for any preselected reliability level and the associated time to first failure.

In terms of structural reliability, there are so many unknowns that the traditional approach certainly offers some advantages. For example, it is not possible to accurately predict the usage that an airplane will experience in some future time period. However, if certain variables of reliability can be quantified without adding undue complexity to an airplane design, it should be done. A list of pertinent considerations would include:

(a) basic fatigue scatter for material in question - defined by a distribution function and certain scaling parameters, e.g., mean and standard deviation.

(b) number of full scale laboratory test articles - these would define the probability distribution sample mean.

(c) expected size of total fleet.

(d) expected service usage severity scatter from airplane to airplane within the fleet.

(e) attrition considerations - loss of aircraft due to reasons not associated with structural failures, or retirement of aircraft due to obsolescence.

(f) damage tolerance of primary structural components.

(g) degree of simulation of the service loading including environmental effects by laboratory testing.

(h) level of confidence in the predicted repeated load usage severity.

(i) type of airplane, e.g., fighter, bomber, commercial transport, etc.

The first five considerations are strictly concerned with the statistical aspects of the overall structural reliability problem. In other words (a) through (e) provide an estimate of the failure probability associated with any given scatter factor and any number of airplanes out of the total fleet.

Considerations (f) through (k) have to do with design, maintenance, dollar, and safety trade-offs. What magnitude of failure probability is acceptable? What are the potential consequence of a failure in particular structural components? How much structural weight can be tolerated to minimize the failure probability? Some compromise must be reached between a high performance design on the one hand and one hundred percent safety of flight and zero maintenance expenditures on the other. In reaching this compromise, it is important to consider damage tolerance and the effectiveness of periodic inspection in detecting fatigue cracks before they can reach catastrophic proportions. The compromise is also affected by the type of aircraft. Some difference in philosophy would normally be expected between military and commercial aircraft. Further differences might be expected between fighters, bombers, and cargo type aircraft. On each new airplane, decisions regarding these areas must be made within the context of available funding, schedule, contingency planning, and national priorities.

1.4 Tailored Scatter Factor

Reliability requirements could be more effectively established if some quantitative measure of failure probability was calculable for various design trade-offs. If the design scatter factor is increased or decreased for a given component, how will this affect failure rates in a fleet of aircraft? How will maintenance expenditures be affected? A change in the design scatter factor will obviously affect structural weight. The influence of structural weight on cost and performance must then be considered. The basic payoff to be derived from using mathematical probability methods in structural fatigue design is to provide for the calculation of a "tailored scatter factor" that would fit the particular set of circumstances existing during an airplane's design stage. Aircraft program managers would be able to select a magnitude of scatter factor associated with whatever reliability level is deemed appropriate.

1.5 Utilization of Phantom II Data

The MCAIR Phantom II (F-4) aircraft was considered ideally suited for an investigation of structural reliability design methods for fighter aircraft. More than 4,000 F-4's have been delivered and are being used by the U.S. Air Force, Navy, and Marines. The airplane is currently being manufactured in various models for the U. S. military services and also foreign governments. A comprehensive and detailed flight loads monitoring program has been in effect continuously on the F-4 since its initial delivery to the Navy. This program has provided data from counting accelerometers and VGH recorders for training as well as combat operations in Southeast Asia. The VGH instruments provide an analog recording of load factor, speed, and altitude. Gross weights corresponding to the VGH data are provided from individual flight records. The counting accelerometers record load factor occurrences which equal or exceed four predetermined acceleration levels. More than 2,000,000 flight hours of load factor exceedance data have been accumulated in the counting accelerometer program. The reduction of these data has been completely automated. A typical computer print-out showing the load factor usage history on an individual airplane is shown on Figure 1. The laboratory fatigue test program on the F-4 has also been extensive; it has included five complete wing-center fuselage test articles, two half-wings, numerous smaller component tests, and hundreds of element tests. A brief summary of the F-4 full-scale testing is shown in Figure 2.

1.6 Overall Structural Reliability Program Outline

The subject program for evaluating structural reliability analysis methods for fighters was based largely on F-4 experience and was conducted in four phases:

- Phase I: Survey of Fatigue Test Scatter
- Phase II: Evaluation of Usage Severity Scatter
- Phase III: Documentation of Laboratory Test Results
- Phase IV: Correlation of Laboratory and Service Failure Experience

The general approach included a literature survey to determine basic fatigue scatter trends for fighter type repeated load spectra. This was performed in Phase I. A significant part of this effort was the study of in-house test results. MCAIR has performed about 1000 aluminum fatigue tests on simple elements and components. About two-thirds of these were conducted using fighter type repeated load spectra.

Study of scatter in severity of repeated load history from airplane to airplane in a given fleet was an important part of the program. This represented Phase II of the total effort. In recent years, numerous military aircraft have been equipped with load factor exceedance counters. Millions of flight hours have been logged with these instruments. The analysis of these data provides an excellent insight into loads scatter trends. The F-4 airplane loads monitoring program is the most extensive of its kind ever undertaken. The F-4 has logged more than 5,350,000 flight hours in numerous theaters of operation. As mentioned earlier, load factor exceedance data were available

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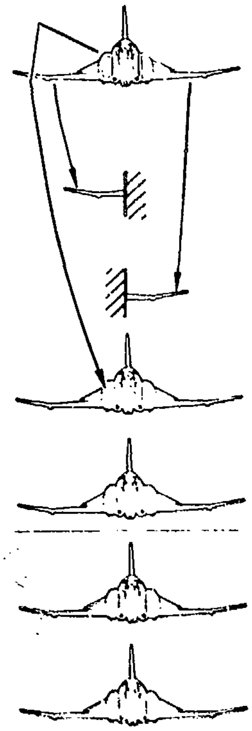
REPORT DATE	SQDN	ACT	TRAN S/N	ACCEL. IND S/N	INDIC. INST. DATE	TOTAL FLT HR ON A/C	FLT H WITH ACCEL	FLT H RTN READ	AVG FLT H /MO.	FLT HRS /MISSION CATEGORY GEN	A-A	A-G	CUM TOTAL CYC 4G	5G	6G	7G	CUM TOTAL CYCLES /1000 FLT HRS 4G	5G	6G	7G	ERR CODE
680131	VF121	MI	5779	585241	671205	4	0	.0	.0	.0	.0	.0	0	0	0	0	0	0	0	0	0
680229	VF121	MI	5779	585241	671205	4	0	.0	.0	.0	.0	.0	0	0	0	0	0	0	0	0	0
680331	VF121	MI	5779	585241	671205	13	8	8.4	4.6	.7	7.7	.0	11	2	0	0	1309	238	0	0	0
680430	VF121	MI	5779	585241	671205	13	8	.0	3.1	.0	.0	.0	11	2	0	0	1309	238	0	0	0
680531	VF121	MI	5779	585241	671205	13	8	.0	2.2	.0	.0	.0	11	2	0	0	1309	232	0	0	0
680630	VF21	MI	5779	585241	671205	52	48	39.6	10.4	17.2	3.4	9.5	307	170	25	3	6395	3542	520	63	0
680731	VF21	MI		585241	671205	133	129	81.2	23.0	54.8	.0	.0	817	382	42	14	6323	2956	479	108	0
680831	VF21	MI	5779	585241	671205	158	156	24.9	23.3	2.7	12.5	9.7	844	398	63	14	5976	2569	408	90	0
680930	VF121	MI	5779	585241	671205	161	157	1.0	20.9	.0	.0	.0	844	396	63	14	5372	2520	401	89	0
681209	VMF235	KA	5770	585241	671205	170	166	8.3	16.8	.6	.0	.0	851	399	65	14	5138	2409	388	84	0
690108	VMF235	KA	5770	585241	671205	170	166	.0	15.4	.0	.0	.0	851	399	65	14	5138	2409	388	84	0
690206	VMF235	KA	5770	585241	671205	188	184	18.6	15.8	6.3	.0	12.5	961	435	71	14	5217	2361	385	76	0
690303	VMF235	KA	5770	5852[illegible]	671205	193	189	0.3	15.2	3.3	.0	1.0	978	443	72	14	5166	2390	381	74	0
690404	VMF235	KA	5770	585241	671205	209	205	16.5	15.2	6.5	4.7	5.3	1080	479	79	15	5240	2336	385	73	0
690531	VMF235	KA	5770	585241	671205	214	210	4.8	13.7	2.7	2.9	.0	1427	653	122	19	6804	3113	581	90	0
690630	VMF235	KA	5770	585241	671205	214	210	.8	13.0	.0	.0	.0	1427	653	122	19	6804	3113	581	90	0
690731	VMF235	KA	5770	585241	671205	214	210	.0	12.2	.0	.0	.0	1427	653	122	19	6804	3113	581	90	0
690831	VMF235	KA	5770	585241	671205	231	227	16.8	12.5	3.4	8.4	.0	1478	685	133	25	6514	3024	587	105	0
690930	VMF235	KA	5770	585241	671205	249	245	18.2	12.8	.0	.0	.0	1572	727	144	29	6424	2970	588	118	1
700908	VMF333	RF	5770	585241	671205	316	312	66.8	10.3	4.1	9.6	.0	1649	758	156	30	5273	2433	494	96	0
701003	VMF333	RF		585241	671205	334	330	18.3	10.6	3.1	15.2	.0	1701	766	158	32	5157	2322	479	97	0
701104	VMF333	RF		585241	671205	367	363	33.1	11.3	8.1	22.6	2.6	1748	791	165	33	4816	2179	456	90	0
701203	VMF333	RF		585241	671205	371	367	3.6	11.3	1.3	2.1	.0	1758	798	168	33	4796	2177	458	95	0
710106	VMF333	RF		585241	671205	392	388	21.5	11.4	14.0	7.5	.0	1769	804	169	36	4559	2072	435	92	0
710209	VMF333	RF		585241	671205	437	433	45.3	12.3	3.3	41.8	.0	2060	976	274	113	[illegible]54	2252	632	260	0
710308	VMF333	RF		585241	671205	438	434	.8	12.0	.8	.0	.0	2060	976	274	113	[illegible]45	2248	631	260	0

TOTAL [illegible] GEN 133.3 A-A 130.0 A-G 40.2
PREV G READINGS 4G 2479 5G 1364 6G 678 7G 566
LAST G READINGS 4G 2479 5G 1386 6G 678 7G 566

Figure 1
Typical Computer Print Out Showing Load Factor History of an Individual Airplane



Test Article	Structural Configuration	Failure or Test Termination
Block 1	Original Structural Configuration	500 Hours*
R/H Remnant Wing	Original Structural Configuration	900 Hours*
L/H Remnant Wing	Steel Strap – Inner Wing	9300 Hours*NF
Block 6	Steel Strap – Inner Wing	4200 Hours*NF
Block 8	Lower Wing Skin Beef-Up	2700 Hours*
F-4B	Block 8 Configuration + Taper-Lok	11,800 Hours*
F-4J	Block 8 Configuration + Taper-Lok	6000 Hours*NF 2000 Drops NF

*The fatigue test loading in terms of load cycles per hour was approximately 10 times more severe than the original design spectrum.

Figure 2
Summary of the F-4 Full Scale Laboratory Fatigue Tests

from counting accelerometers for more than 2,000,000 flight hours. These were supplemented with about 9,000 hours of VGH data which were also studied in the second phase of the subject program. The extent of the available data is summarized in Figure 3. Note that about 650,000 flight hours of counting accelerometer data were from combat operations.

Comparison of laboratory and service failures was the obvious next step. This was accomplished in Phases III and IV. The study included a detailed investigation of test results on the five full-scale F-4 test articles and the two half-wings in a number of key areas. The time to failure for each key area on each test article was determined. A careful examination was made of any possible differences in laboratory loading and in-flight loading. The study of VGH data was used to assist in this examination. The final stage included a comparison of the service life predictions and actual service failures. The predictions were based on the laboratory testing, counter and VGH data, and scatter considerations evaluated in Phases I and II.

VGH Data

1965 – 3000 hr Training Data

1966 – 600 hr Training Data

1969 – 1800 hr SEA Combat Data

1970 – 3500 hr SEA Combat Data

Counting Accelerometer Data

F-4 Fighter Aircraft:	RF-4 Reconnaissance Aircraft:
2,394,000 Total hr	402,000 Total hr
517,000 Combat hr	124,000 Combat hr
1,877,000 Training hr	278,000 Training hr

Total Flight Time, all F-4 Aircraft – 5,350,000 hr

Figure 3
Summary of Available F-4 VGH and Counting Accelerometer Data

GP73-0439-1

2. PHASE I - SURVEY OF FATIGUE TEST SCATTER

2.1 General

The nature of fatigue is such that there is very little that can be determined in a purely analytic sense. Whatever is done on a theoretical basis usually allows simple interpolation or modest extrapolation of experimental information. Fatigue scatter falls in this same category. The theory of probability is applicable but there are many mathematical functions that might be used and each one has certain constants that need to be defined. An extensive detailed study of fatigue test results is required to determine which mathematical function is most appropriate and what constants are necessary to provide the best fit.

There are two mathematical functions in particular that have been widely used to describe fatigue scatter: the log-normal and the Weibull, and predominately the two parameter version of each. In recent years, the Weibull has gained favor partly due to a physical argument concerning its risk function compared to that of the log-normal. The risk function for fatigue is defined as the probability of failure on the (N + 1)th cycle given that the structure has sustained N cycles. The Weibull has a continuously increasing risk function while the log-normal risk function first increases and then decreases with increasing cycles. Since fatigue is considered to be a wearout process, an ever increasing risk function seems more reasonable. A plausible physical argument can also be made in favor of the log-normal. It is generally agreed that fatigue originates at some kind of discontinuity in the metal microstructure. It is highly improbable that any given specimen would be totally homogeneous and without discontinuities in its microstructure. The log-normal risk function does not start to decrease until the probability level reaches 0.999999 which is associated with a very long life. It is highly improbable for a specimen to last that long, but if it does, it could be an indication that the specimen is without discontinuities and therefore the risk function should start to decrease.

The discussion in the preceding paragraph is not presented as an argument to prove that the log-normal distribution is correct. It is included simply to indicate that experimental evidence and not theoretical analysis must be the primary determining factor.

Once a distribution function is established, the next step is to determine the constants of the distribution. Generally, two constants are sufficient. One of these defines the magnitude of scatter and the other some kind of average life. Average life is obviously peculiar to each type of airplane; but fatigue scatter is generally considered similar on different airplanes, at least if they are made of the same material and with the same type of construction and loaded in generally the same manner. This leads to the conclusion that the constant defining the magnitude of scatter can be determined by reviewing past test results. This was a basic underlying assumption in the literature survey and subsequent study of fatigue scatter trends reported in this Phase I portion of the program.

2.2 Literature Survey of Fatigue Test Data

As a result of an extensive literature survey, more than 2,400 groups of fatigue test data made up of over 12,000 specimens were collected. This search was limited to the 2000 and 7000 series aluminum alloys, which include 2020, 2024, 2124, 7075, 7079, 7175, and 7178. It included test data from MCAIR as well as from numerous other aerospace companies and government agencies. In particular, the MCAIR fatigue test results are from F-15, F-4, DC-10, and earlier in-house test programs. Specimens from sheet, plate, bar extrusion, and forging are included in configurations ranging from simple notched elements with and without holes to small components, as well as full-scale structures. Test loading conditions include axial loading, both tensile and compressive, and flexural loading. The greater portion of the test loading data, however, was axial. The fatigue tests consisted of both constant amplitude and spectrum loading. References of both the literature search and the MCAIR data are listed in Appendix I. Only those references in which the data were analyzed and summarized are listed. The following variables of the collected fatigue data were indexed so that comparisons could be made among different groups of specimens: type of structure, type of specimen, material, type of test machine, and type of loading. The actual test results analyzed in detail in this survey are presented along with the appropriate index numbers in Appendix II. In addition, the appropriate statistical parameters for the log-normal and Weibull distributions for each group of specimens are also presented in Appendix II.

2.2.1 Scatter Trends for Constant Amplitude and Spectrum Loading - Reference (1) presented an extensive literature survey and analysis of fatigue test data. A summary of these data is listed below:

Number of Specimens	6000*
Number of Groups	1250
Average Standard Deviation	0.168

The numbers above are for aluminum alloy specimens of varying configuration subjected to either spectrum or constant amplitude loading. These test results from Reference (1) were subdivided into groups according to loading as follows:

	Constant Amplitude Loading	Spectrum Loading
Number of Specimens	5000*	1000*
Number of Groups	1096	154
Average Standard Deviation	0.180	0.083

The difference between the constant amplitude and spectrum loading standard deviations is quite significant. It is possible of course that part of the difference could be a result of other variations besides loading in the two groups such as a comparison of perhaps more open hole specimens in one group to more complex lap joint specimens in the other. So in order to more carefully evaluate this difference between spectrum and constant amplitude data, 7075-T6 aluminum open hole, axial loaded specimens from Reference (1) were studied with the following results:

	Constant Amplitude Loading	Spectrum Loading
Number of Specimens	516	148
Number of Groups	138	26
Average Standard Deviation	0.211	0.125

The same trend as in the larger data set is evident from the above comparison. A possible explanation for the lower scatter of the spectrum data is that only the higher load levels in the spectrum produce the major part of the total damage; that is to say, the spectrum test results are effectively low cycle fatigue even though the total number of cycles in the spectrum might be quite large. Low cycle fatigue generally shows lower scatter (smaller standard deviation) than high cycle fatigue. This trend is illustrated by the histogram of Figure 4. The data in this graph, which include 970 specimens in 269

*Estimated

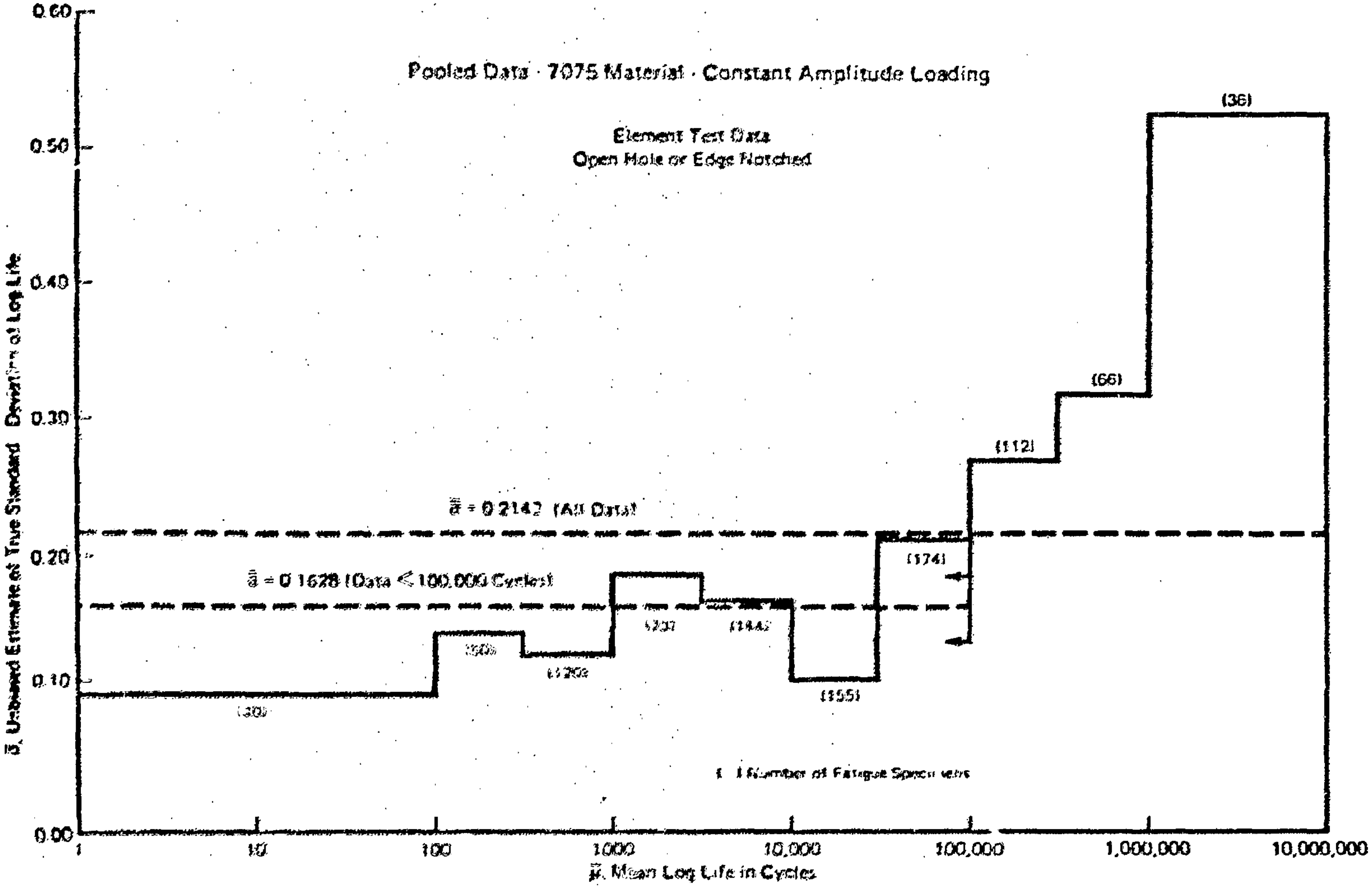


Figure 4
Observed Variation of Fatigue Scatter with Cyclic Life for 970 Aluminum 7075 Constant Amplitude Loaded Specimens - Log - Normal Distribution

groups, are for 7075-T6 aluminum axially loaded, edge notched or unloaded hole specimens.

To validate and further understand the trends found from Reference (1), MCAIR fatigue test data were assembled as a group for scatter trend studies. The MCAIR data were obtained from 44 test reports consisting of 288 groups of 947 specimens. The MCAIR fatigue test results included 7000 and 2000 series aluminum alloys, various specimen configurations, with constant amplitude or spectrum loadings. Separating the data based on the type of loading similar to the Reference (1) grouping gives the following comparison:

	Constant Amplitude Loading	Spectrum Loading
Number of Specimens	287	656
Number of Groups	93	196
Average Life in Cycles	140,000	200,000
Average Standard Deviation	.199	.109

The spectrum data again have the lower scatter. It is further hypothesized that, in addition to the low cycle fatigue consideration discussed in the preceding paragraph, the type of fatigue test machine also could influence the magnitude of scatter. Spectrum tests are in a great majority of cases run with either a servo or solenoid load controlling device, while the mechanical shaker type of test machine is more often used for constant amplitude testing. The mechanical shaker type machine has less load control accuracy. In order to verify the hypothesis of differences in scatter due to the type of fatigue test machine, the MCAIR constant amplitude test data were analyzed. The results are as follows:

	Mechanical Shaker	Servo Control
Number of Specimens	73	128
Number of Groups	27	39
Average Life in Cycles	178,000	206,000
Average Standard Deviation	0.238	0.158

Although the amount of fatigue test data is small, the hypothesized trend of inherently more scatter with the mechanical shaker machine than the servo control machine is evident.

2.2.2 No-Load Transfer Element Fatigue Test Data - Based on the results discussed in Section 2.2.1, spectrum fatigue test scatter is less than constant amplitude test scatter for two distinct reasons:

(a) low cycle fatigue effect, and

(b) fatigue machine effect.

Since fighter aircraft are subject to a spectrum of loads in service, the primary emphasis in this study of fatigue test scatter was directed toward spectrum data.

A literature survey was undertaken to obtain additional spectrum fatigue test results. These additional data were combined with MCAIR's spectrum test data and the spectrum test data from Reference (1). Only axially loaded, edge notched or unloaded hole specimens were included. Fatigue test data obtained from mechanical shaker machines were not included for the reasons discussed in Section 2.2.1. A compilation of the results of this study are given below:

No-Load Transfer Spectrum Fatigue Test Data

	Aluminum
Number of Specimens	1176
Number of Groups	239
Effective Average Life in Cycles	17,400
Average Standard Deviation	.0855
Average Weibull Shape Parameter	6.36

The effective average life denoted above is defined as the number of higher load level cycles to failure. The higher load levels are defined as the top two-thirds of the load levels of the spectrum. If there are nine load levels in a particular spectrum, only the cycles due to the six higher load levels would be considered effective. This technique was used to minimize the misleading effect of the large number of lower level load cycles in a spectrum that produces only a small percentage of the total fatigue damage. It should be noted that the average standard deviation is not simply a numerical average but the unbiased estimate of the true population standard deviation. Similarly, the Weibull number is the weighted average of the best linear unbiased estimator (BLUE) of the Weibull distribution shape parameter given in Reference (3). The Weibull shape parameter is a measure of fatigue test scatter similar to the standard deviation except in reverse; a large value indicates less scatter while a smaller value indicates more scatter.

Additional studies were conducted by grouping the data in different ways. The 7075 aluminum spectrum fatigue test results, for example, were subdivided according to stress concentration and material form. Neither stress concentration nor material form were shown to have a significant effect on fatigue scatter. Another study on these 7075 data included a histogram of standard deviations similar to Figure 4 except it was for spectrum data plotted versus effective average life. This histogram indicated that spectrum fatigue scatter is reasonably independent of average life.

2.2.3 Effects of Special Specimen Preparation - Specimen finish in the fatigue critical area was one of the parameters investigated for effect on fatigue scatter. A relatively large group of the no-load transfer element specimen data, generated at the NASA Research Center in Langley, West Virginia, is interesting in this respect. This group from References (47), (48), (49), (57), (58), and (59) of Appendix I includes a total of 682 edge notch specimens; the edge notch itself was machined with extreme care. A comparison of these data to all others is as follows:

	Smooth Finish Edge Notch Data	All Other No-Load Transfer Data
Number of Specimens	682	494
Number of Groups	120	119
Average Standard Deviation	.0747	.0995
Average Weibull Shape Parameter	7.19	5.41

The effect of the finish appears to be significant. For the purposes of the NASA work (determination of the effect of various fatigue spectrum parameters), the smooth finish edge notch provided a very useful specimen configuration. However, an extremely smooth finish would be too costly for typical aircraft fabrication procedures. Therefore, these data are not included in the analysis in the remaining sections of this report.

2.2.4 Load Transfer Element Fatigue Test Data - Lap joint and double shear joint specimen test results have been compiled through the literature survey. Pertinent details are as follows:

Load Transfer Spectrum Fatigue Test Data

	Aluminum
Number of Specimens	323
Number of Groups	59
Average Standard Deviation	.0998
Average Weibull Shape Parameter	5.00

It is of interest to note that the scatter parameters for these load transfer element test data are similar to those given in the preceding section for no-load transfer testing excluding the smooth finish edge notch data.

2.2.5 Full Scale Structure Fatigue Test Data - The scatter trends summarized in the previous three sections are based on tests of element specimens with unloaded holes and edge notches and simple joint specimens. For this kind of element specimen and also for full scale structure fatigue test, scatter is a result of life variations at a stress concentration. It could be expected therefore that the scatter trends in element tests and full scale structure tests would be similar. However, there are a number of considerations that could lead to differences. There is generally more than one single location on a full scale structure where the failure could originate. For example, it is usually the case that there are a number of holes in a row that are equally susceptible to fatigue. This kind of situation where there are multiple origin possibilities tends to reduce scatter. From another viewpoint, however, full scale structure might be expected to exhibit more scatter than element specimens. An airplane is a complex built-up structure with redundant load paths. The possibility of load differences at the critical location from one test article to another is therefore greater than with a simple element specimen. These internal load differences would tend to increase scatter.

As indicated in the previous paragraph, it is not a certainty that scatter in full scale testing is the same as in element fatigue testing. A literature survey of full scale airplane and component fatigue test data was therefore undertaken. A total of 243 spectrum test results and 491 constant amplitude test results were found. These test data are summarized below:

Full Scale Spectrum Fatigue Test Data

	Spectrum	Constant Amplitude
Number of Specimens	243	491
Number of Groups	82	143
Average Standard Deviation	.0985	.1486
Average Weibull Shape Parameter	5.44	3.70

Note that these full scale structure data show the same trend as the element test results; viz., the average standard deviation for the spectrum test results is significantly smaller than that for the constant amplitude test results. The full scale structure data include both 7075 and 2024 material. A detailed listing of the full scale structure spectrum fatigue test results is presented in Figure 5.

2.2.6 Pooled Spectrum Fatigue Test Data - It is expected that the scatter differences between 7075 and 2024 aluminum are probably small. This can be determined for the various kinds of element specimens and full scale structure discussed in the three preceding sections. The data comparisons for spectrum

Item Number	Structure Description	Material	Number of Specimens	Standard Deviation - σ	Weibull Shape Parameter - α
825 to 828	F-3H Demon Wing	7075	10	.0715	6.84
829 to 834	F-3H Demon Horizontal Tail	7075	18	.0898	6.02
340 to 342	F-4 Phantom Wing Box Beam	7075	11	.1326	3.51
822, 823 824	Lockheed Wing Panel	7075	7	.0983	5.91
866 to 867	F-9F Panther Wing	7075	4	.0415	10.96
856 to 861 868 to 918	Navy Lab Box Beam	7075	120	.0906	6.83
835, 985, 986	P-51 Mustang Wing	2024	18	.1326	3.38
989 to 990 924	C-46 Transport Wing	2024	14	.1244	4.43
988	British Piston Provost Wing	2024	41	.0870	5.95

Total Number of Specimens - 243

Average σ = .0985
Average α = 5.44

Figure 5
Full Scale Structure Spectrum Fatigue Test Data

fatigue test results are as follows:

No-Load Transfer Element Fatigue Test Data

	7075	2024	Total
Number of Specimens	407	87	494
Number of Groups	104	15	119
Average Standard Deviation	.1019	.0886	.0995
Average Weibull Shape Parameter	5.29	5.97	5.41

Load Transfer Element Fatigue Test Data

	7075	2024	Total
Number of Specimens	141	182	323
Number of Groups	38	21	59
Average Standard Deviation	.1100	.0927	.0998
Average Weibull Shape Parameter	4.90	5.06	5.00

Full Scale Structure Fatigue Test Data

	7075	2024	Total
Number of Specimens	170	73	243
Number of Groups	75	7	82
Average Standard Deviation	.0932	.1056	.0985
Average Weibull Shape Parameter	5.97	4.87	5.44

Note that the 7075 and 2024 values are generally about the same. There is a slightly larger scatter indication for 7075 element fatigue specimens, but this is offset by the smaller scatter indication for 7075 full scale structure. The total values do not show sizeable scatter difference among no-load transfer element fatigue specimens, load transfer element fatigue specimens, and full scale structure. Pooling all of these gives the following averages:

Aluminum Spectrum Fatigue Test Data

	Total
Number of Specimens	1060
Number of Groups	260
Average Standard Deviation	.0994
Average Weibull Shape Parameter	5.27

2.3 Scatter in Scatter

Figure 5 lists standard deviations and Weibull shape parameters computed from spectrum fatigue test data for full scale structure. It is hypothesized that all of these data are from the same statistical population in terms of scatter. The range in standard deviations is from .0415 to .1326; the range in Weibull shape parameters is from 10.96 to 3.38. It is further hypothesized that these data are in the same statistical population with the element spectrum fatigue test data discussed in previous sections. These element test data exhibit even a wider spread in computed standard deviations and Weibull shape parameters. The question might be asked at this point, "If all of these data are from the same parent population, why don't they all show a similar scatter number?" The answer is that the standard deviations and Weibull shape parameters computed from the data are sample values and as such are actually random variables. These random variables have their own theoretical probability distributions and should exhibit scatter according to those distributions. Figure 6 presents a comparison of the theoretical probability distribution to the spectrum fatigue data standard deviations for sample size n = 3. Figure 7 presents a comparison of the theoretical probability distribution to the spectrum fatigue data Weibull shape parameters also for sample size n = 3. Note that both graphs indicate reasonably good correlation between the data and the theoretical curves.

2.4 Theoretical Scatter Factor, Ratio of Two Fatigue Lives

Every discussion on scatter must include some definition of "scatter" and relate it to a parameters such as the mean, the median, or some characteristic value. In terms of airplane fatigue life, there is usually a full-scale laboratory test article. The life of this test article is the obvious choice for a number about which to center the scatter. However, the full-scale test article life is in fact a random variable. If one considers a fleet of aircraft, the laboratory test article can be thought of as one airplane selected at random from the total fleet. Then the scatter factor between the laboratory life and the service life of another airplane picked at random from the fleet is the "ratio of two" randomly selected variates from the same population. A scatter factor so defined being the ratio of two statistically independent random variables is itself a random variable. Its probability distribution can generally be derived given the distribution of the parent population.

2.4.1 Ratio of Two Log-Normal Variates - The probability distribution for the ratio of two statistically independent log-normal variates is utilized to evaluate fatigue scatter in Reference (4). The relationship between reliability R (probability of no failure) and scatter factor S is shown to be

$$S = 10^{t\sigma\sqrt{\frac{n+1}{n}}}$$

where n is the number of laboratory test articles and t is the normal variate obtainable from a normal probability table such as shown in Figure 8. The Area noted in Figure 8 corresponds to the reliability R. The scatter factor for the above formula is defined as the ratio of the log mean life of n

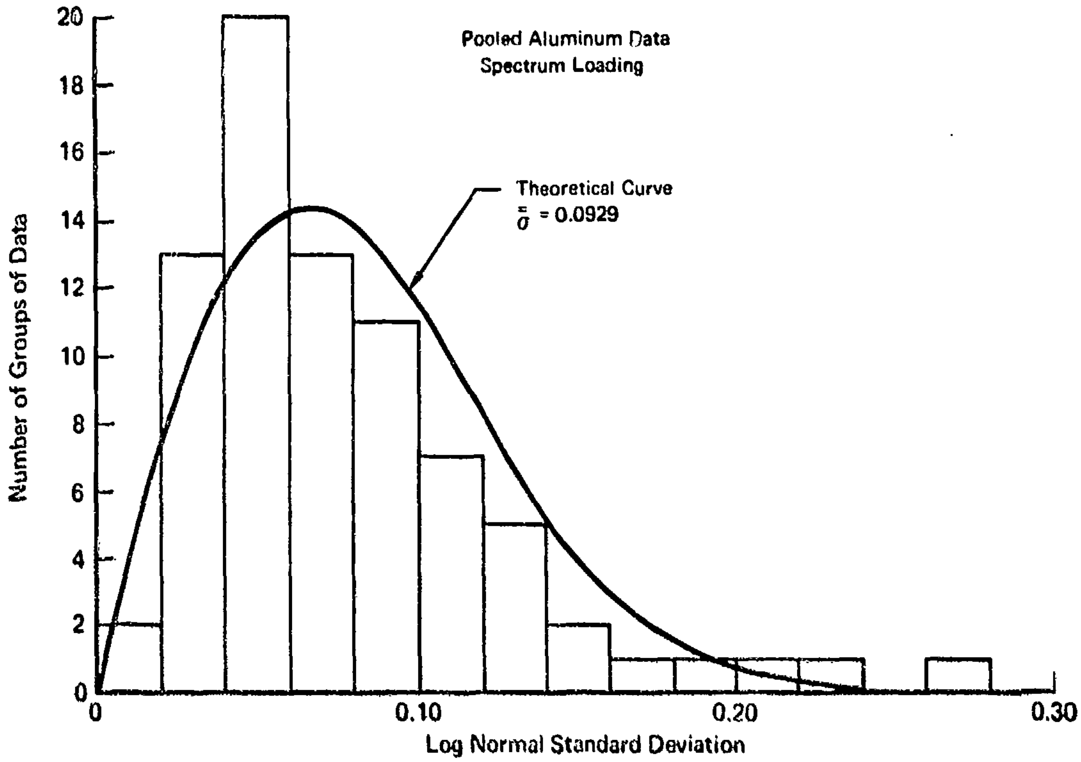


Figure 6
Comparison of the Theoretical and Observed Distributions of Estimates of the Log - Normal Standard Deviation for Sample Size n = 3

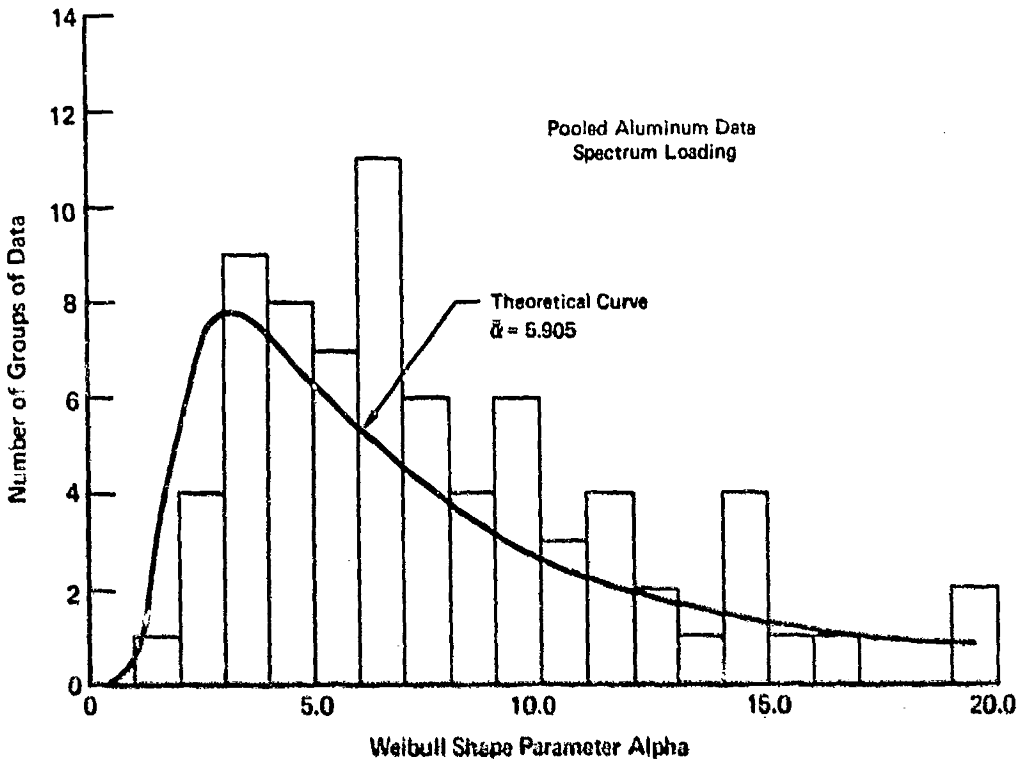
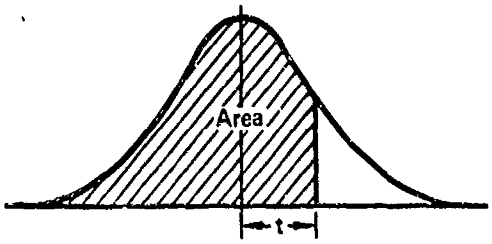


Figure 7
Comparison of the Theoretical and Observed Distributions of Estimates of the Weibull Shape Parameter Alpha for Sample Size n = 3



t	Area	t	Area	t	Area	t	Area	t	Area	t	Area	t	Area
0.00	0.5000	0.50	0.6915	1.00	0.8413	1.50	0.9332	2.00	0.9773	2.50	0.9938	3.00	0.9987
0.01	0.5040	0.51	0.6950	1.01	0.8438	1.51	0.9345	2.01	0.9778	2.51	0.9940	3.01	0.9987
0.02	0.5080	0.52	0.6985	1.02	0.8461	1.52	0.9357	2.02	0.9783	2.52	0.9941	3.02	0.9987
0.03	0.5120	0.53	0.7019	1.03	0.8485	1.53	0.9370	2.03	0.9788	2.53	0.9943	3.03	0.9988
0.04	0.5160	0.54	0.7054	1.04	0.8508	1.54	0.9382	2.04	0.9793	2.54	0.9945	3.04	0.9988
0.05	0.5199	0.55	0.7088	1.05	0.8531	1.55	0.9394	2.05	0.9798	2.55	0.9946	3.05	0.9989
0.06	0.5239	0.56	0.7123	1.06	0.8554	1.56	0.9406	2.06	0.9803	2.56	0.9948	3.06	0.9989
0.07	0.5279	0.57	0.7157	1.07	0.8577	1.57	0.9418	2.07	0.9808	2.57	0.9949	3.07	0.9989
0.08	0.5319	0.58	0.7190	1.08	0.8599	1.58	0.9430	2.08	0.9812	2.58	0.9451	3.08	0.9990
0.09	0.5359	0.59	0.7224	1.09	0.8621	1.59	0.9441	2.09	0.9817	2.59	0.9952	3.09	0.9990
0.10	0.5398	0.60	0.7258	1.10	0.8643	1.60	0.9452	2.10	0.9821	2.60	0.9953	3.10	0.9990
0.11	0.5438	0.61	0.7291	1.11	0.8665	1.61	0.9463	2.11	0.9826	2.61	0.9955	3.11	0.9991
0.12	0.5478	0.62	0.7324	1.12	0.8686	1.62	0.9474	2.12	0.9830	2.62	0.9956	3.12	0.9991
0.13	0.5517	0.63	0.7357	1.13	0.8708	1.63	0.9485	2.13	0.9834	2.63	0.9957	3.13	0.9991
0.14	0.5557	0.64	0.7389	1.14	0.8729	1.64	0.9495	2.14	0.9838	2.64	0.9959	3.14	0.9992
0.15	0.5596	0.65	0.7422	1.15	0.8749	1.65	0.9505	2.15	0.9842	2.65	0.9960	3.15	0.9992
0.16	0.5636	0.66	0.7454	1.16	0.8770	1.66	0.9515	2.16	0.9846	2.66	0.9961	3.16	0.9992
0.17	0.5675	0.67	0.7486	1.17	0.8790	1.67	0.9525	2.17	0.9850	2.67	0.9962	3.17	0.9992
0.18	0.5714	0.68	0.7518	1.18	0.8810	1.68	0.9535	2.18	0.9854	2.68	0.9963	3.18	0.9993
0.19	0.5754	0.69	0.7549	1.19	0.8830	1.69	0.9545	2.19	0.9857	2.69	0.9964	3.19	0.9993
0.20	0.5793	0.70	0.7580	1.20	0.8849	1.70	0.9554	2.20	0.9861	2.70	0.9965	3.20	0.9993
0.21	0.5832	0.71	0.7612	1.21	0.8869	1.71	0.9564	2.21	0.9865	2.71	0.9966	3.21	0.9993
0.22	0.5871	0.72	0.7642	1.22	0.8888	1.72	0.9573	2.22	0.0868	2.72	0.9967	3.22	0.9994
0.23	0.5910	0.73	0.7673	1.23	0.8907	1.73	0.9582	2.23	0.9871	2.73	0.9968	3.23	0.9994
0.24	0.5948	0.74	0.7704	1.24	0.8925	1.74	0.9591	2.24	0.9875	2.74	0.9969	3.24	0.9994
0.25	0.5987	0.75	0.7734	1.25	0.8944	1.75	0.9599	2.25	0.9878	2.75	0.9970	3.25	0.9994
0.26	0.6026	0.76	0.7764	1.26	0.8962	1.76	0.9608	2.26	0.9881	2.76	0.9971	3.26	0.9994
0.27	0.6064	0.77	0.7794	1.27	0.8980	1.77	0.9616	2.27	0.9884	2.77	0.9972	3.27	0.9995
0.28	0.6103	0.78	0.7823	1.28	0.8997	1.78	0.9625	2.28	0.9887	2.78	0.9973	3.28	0.9995
0.29	0.6141	0.79	0.7852	1.29	0.9015	1.79	0.9633	2.29	0.9890	2.79	0.9974	3.29	0.9995
0.30	0.6179	0.80	0.7881	1.30	0.9032	1.80	0.9641	2.30	0.9893	2.80	0.9974	3.30	0.9995
0.31	0.6217	0.81	0.7910	1.31	0.9049	1.81	0.9649	2.31	0.9896	2.81	0.9975	3.31	0.9995
0.32	0.6255	0.82	0.7939	1.32	0.9066	1.82	0.9656	2.32	0.9898	2.82	0.9976	3.32	0.9996
0.33	0.6293	0.83	0.7967	1.33	0.9082	1.83	0.9664	2.33	0.9901	2.83	0.9977	3.33	0.9996
0.34	0.6331	0.84	0.7995	1.34	0.9099	1.84	0.9671	2.34	0.9904	2.84	0.9977	3.34	0.9996
0.35	0.6368	0.85	0.8023	1.35	0.9115	1.85	0.9678	2.35	0.9906	2.85	0.9978	3.35	0.9996
0.36	0.6406	0.86	0.8051	1.36	0.9131	1.86	0.9686	2.36	0.9909	2.86	0.9979	3.36	0.9996
0.37	0.6443	0.87	0.8079	1.37	0.9147	1.87	0.9693	2.37	0.9911	2.87	0.9980	3.37	0.9996
0.38	0.6480	0.88	0.8106	1.38	0.9162	1.88	0.9700	2.38	0.9913	2.88	0.9980	3.38	0.9996
0.39	0.5517	0.89	0.8133	1.39	0.9177	1.89	0.9706	2.39	0.9916	2.89	0.9981	3.39	0.9997
0.40	0.6554	0.90	0.8159	1.40	0.9192	1.90	0.9713	2.40	0.9918	2.90	0.9981	3.40	0.9997
0.41	0.6591	0.91	0.8186	1.41	0.9207	1.91	0.9719	2.41	0.9920	2.91	0.9982	3.41	0.9997
0.42	0.6628	0.92	0.8212	1.42	0.9222	1.92	0.9726	2.42	0.9922	2.92	0.9983	3.42	0.9997
0.43	0.6664	0.93	0.8238	1.43	0.9236	1.93	0.9732	2.43	0.9925	2.93	0.9983	3.43	0.9997
0.44	0.6700	0.94	0.8264	1.44	0.9251	1.94	0.9738	2.44	0.9927	2.94	0.9984	3.44	0.9997
0.45	0.6736	0.95	0.8289	1.45	0.9265	1.95	0.9744	2.45	0.9929	2.95	0.9984	3.45	0.9997
0.46	0.6772	0.96	0.8315	1.46	0.9279	1.96	0.9750	2.46	0.9931	2.96	0.9985	3.46	0.9997
0.47	0.6808	0.97	0.8340	1.47	0.9292	1.97	0.9756	2.47	0.9932	2.97	0.9985	3.47	0.9997
0.48	0.6844	0.98	0.8365	1.48	0.9306	1.98	0.9762	2.48	0.9934	2.98	0.9986	3.48	0.9998
0.49	0.6879	0.99	0.8389	1.49	0.9319	1.99	0.9767	2.49	0.9936	2.99	0.9986	3.49	0.9998
0.50	0.6915	1.00	0.8413	1.50	0.9332	2.00	0.9773	2.50	0.9938	3.00	0.9987	3.50	0.9998

Figure 8
Normal Probability Table

laboratory test articles to the life of an individual airplane in service. Because of the economics of full scale airplane laboratory fatigue testing, there is usually only one test article which means n = 1. This is the ratio of two situation for which the scatter factor is

$$S = 10^{t\sigma\sqrt{2}}$$

Using this formula with σ = .0994 and t = 2.327 from Figure 8 gives a scatter factor equal to 2.12 for 99% reliability.

2.4.2 Ratio of Two Weibull Variates - The detailed mathematical derivation for the ratio of two Weibull variates is included in Appendix III. The result of the derivation giving the relationships between reliability R and scatter factor S is as follows:

$$R = \frac{n^n S^{\alpha n}}{(1+nS^{\alpha})^n}$$

where n again is the number of laboratory test articles. The scatter factor for the above formula is defined as the ratio of the sample characteristic life of n laboratory test articles to the life of an airplane in service. When there is only one laboratory test article, n = 1 and the formula reduces to the ratio of two case for which the scatter factor is

$$S = \left(\frac{R}{1-R}\right)^{\frac{1}{\alpha}}$$

Using this formula with α = 5.27 gives a scatter factor equal to 2.39 for 99% reliability.

2.5 Comparisons of Data to Weibull and Log-Normal

As mentioned in Section 2.1, experimental evidence must be the primary factor in evaluating what distribution function should be used. The difficulty has always been in obtaining enough data to allow a determination among the various probability distributions. The data studied herein include no-load transfer element specimens, load transfer element specimens, and full scale aircraft structure test results. A total of 1060 data points were compared and appeared to be from the same statistical population in terms of scatter. These test results can be plotted in different ways and compared to the Weibull and log-normal probability distribution functions.

The 1060 data points are from 260 groups where the group sizes vary from just two specimens to as many as twenty. Figure 9 presents an example group of six. For the purpose of comparing theoretical probability distributions for the ratio of two to experimental ratios of two, three statistically independent data points can be obtained from the example group of six. However, depending on the way the results are paired, a number of different sets of three can be obtained as shown in Figure 9. A total of fifteen different random sorts were used to pair the individual test results for the three types of specimens, i.e., no-load transfer, load transfer, and full scale structure. An additional five random sorts were made for all the data combined. The theoretical curves for the Weibull and log-normal ratio of two are compared to typical random sorts of the data in Figures 10 through 13. It appears that the Weibull provides the better fit.

Data Grouped in Ascending Order

	Fatigue Life
# 1	2500
# 2	2800
# 3	3900
# 4	4000
# 5	4200
# 6	4700

First Random Sort

	Fatigue Life	Scatter Factor
# 2	2800	0.60
# 6	4700	
# 4	4000	1.60
# 1	2500	
# 5	4200	1.08
# 3	3900	

Second Random Sort

	Fatigue Life	Scatter Factor
# 4	4000	0.95
# 5	4200	
# 2	2800	0.60
# 6	4700	
# 3	3900	1.56
# 1	2500	

Third Random Sort

	Fatigue Life	Scatter Factor
# 4	4000	1.03
# 3	3900	
# 2	2800	0.67
# 5	4200	
# 1	2500	0.53
# 6	4700	

Fourth Random Sort

	Fatigue Life	Scatter Factor
# 3	3900	0.83
# 6	4700	
# 2	2800	1.12
# 1	2500	
# 5	4200	1.05
# 4	4000	

Fifth Random Sort

	Fatigue Life	Scatter Factor
# 5	4200	1.68
# 1	2500	
# 6	4700	1.21
# 3	3900	
# 2	2800	0.70
# 4	4000	

Figure 9
Scatter Factors for Five Different Random Sorts of a Group of n = 6
7075 Spectrum Test Results

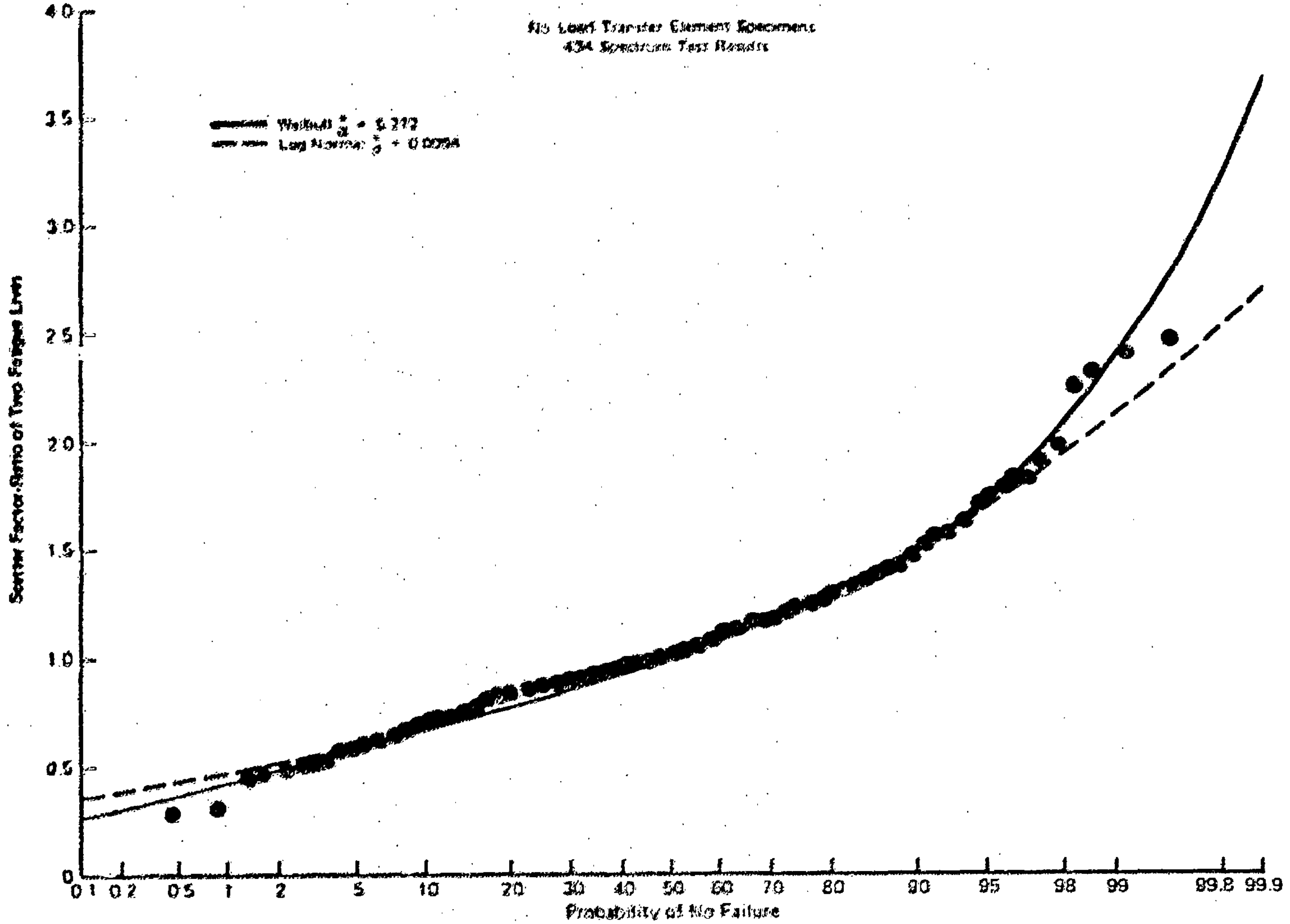


Figure 10
Comparison of Theoretical Probability Distributions to Aluminum Fatigue Test Data

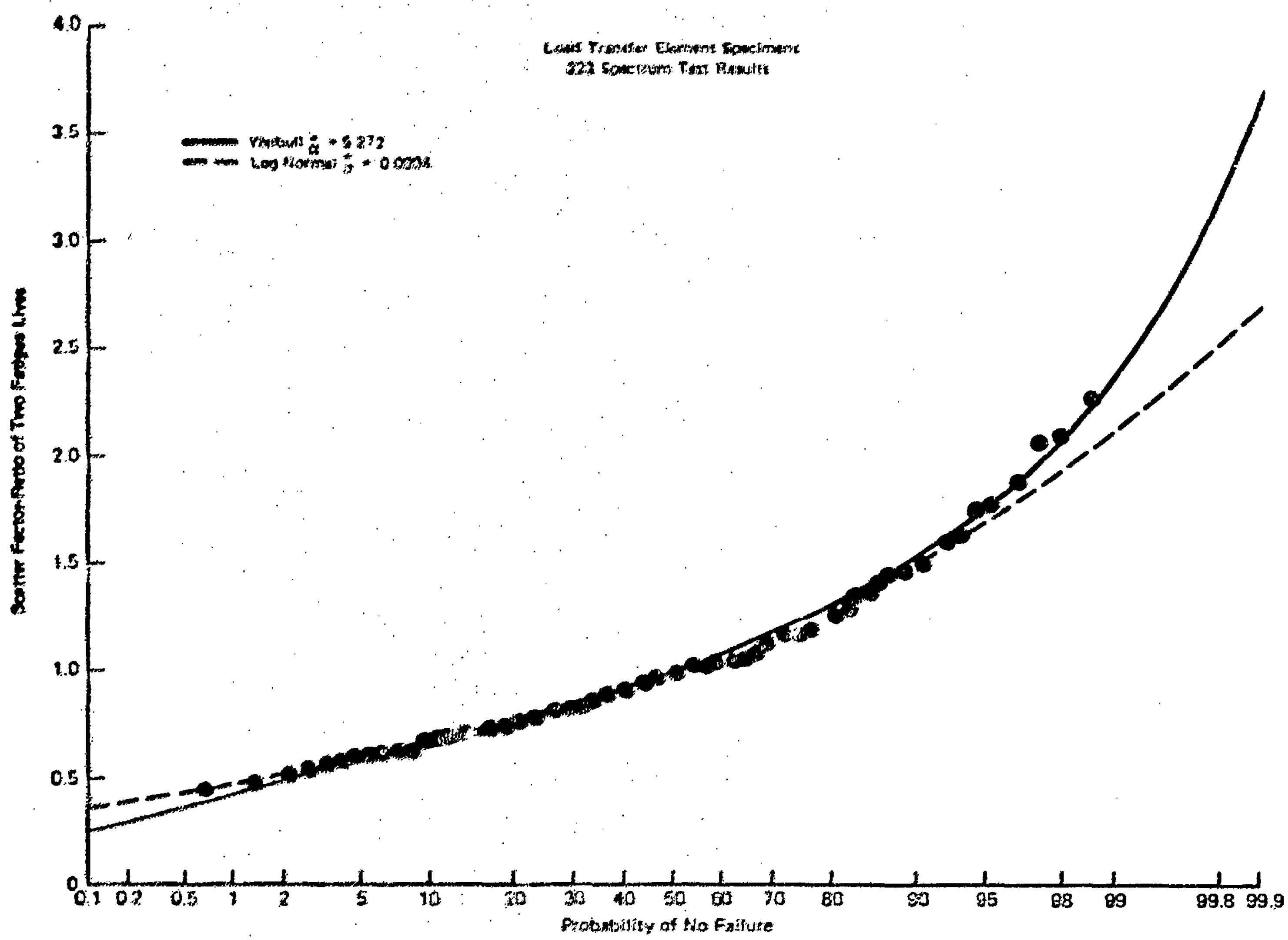


Figure 11
Comparison of Theoretical Probability Distributions to Aluminum Fatigue Test Data

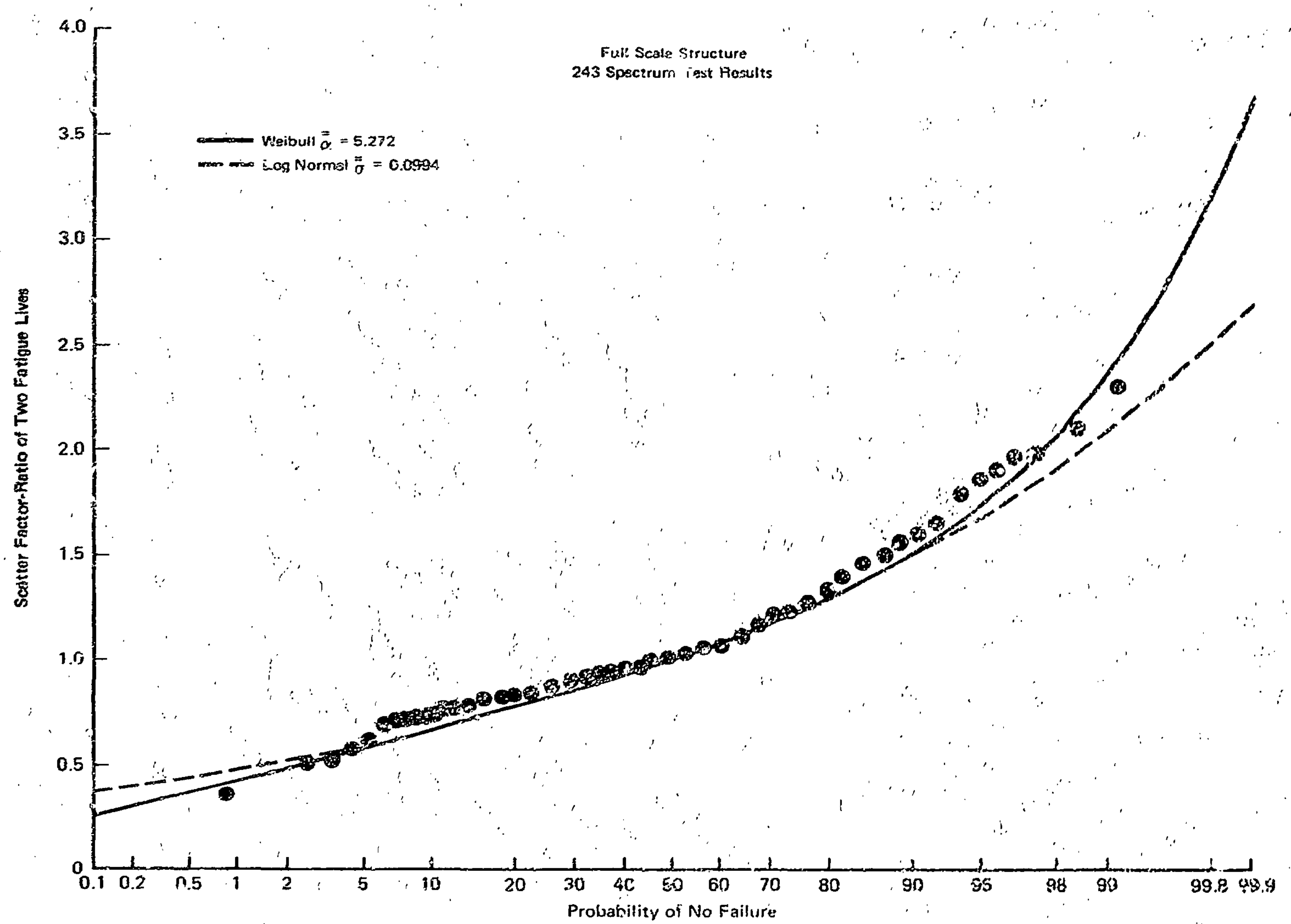


Figure 12
Comparison of Theoretical Probability Distributions to Aluminum Fatigue Test Data

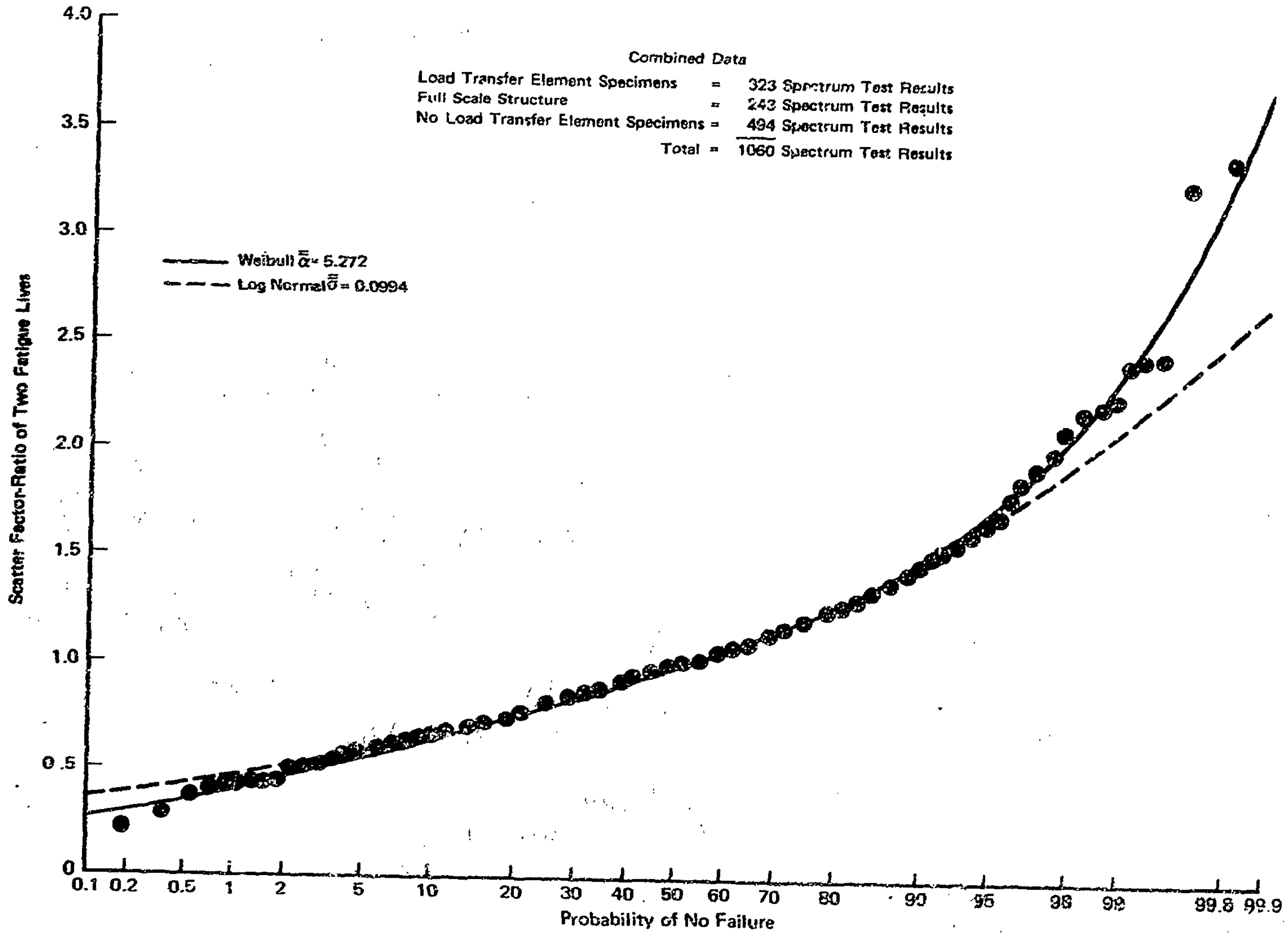


Figure 13
Comparison of Theoretical Probability Distributions to Aluminum Fatigue Test Data

3. PHASE II - EVALUATION OF USAGE SEVERITY SCATTER

3.1 General

The study of fighter airplane usage data is presented in this section. It includes identifying scatter trends in usage severity, examining effects of changes in operational usage, identifying scatter trends in total hour accumulation, and evaluating probability distributions for "goodness of fit" with compiled data. Counting accelerometer and total flight hour data were studied to quantitatively identify variations in usage from airplane to airplane in a given fleet. In addition, VGH data were analyzed to determine trends in speed, altitude, and gross weight usage. These data, the speed/altitude/gross weight information, are utilized in conjunction with counting accelerometer data to compute service fatigue damage at various fatigue critical locations on the airplane.

3.2 F-4 Training and Combat VGH Data

A total of 8200 hours of F-4 Phantom II VGH data were analyzed to determine trends for airspeed, altitude, and gross weight usage both in combat and training operations. Histograms for these parameters were prepared for maneuvers exceeding 3.0g's, 4.6g's, and 6.6g's (levels consistent with VGH recording intervals). Average values for each parameter for maneuvers exceeding each of the three load factors levels were computed for both combat and training operations. In addition, the flight regimes in which the majority of maneuvers occur in both training and combat were determined.

The histograms for maneuvers exceeding 4.6g's for combat and for training operations are presented in Figures 14 through 19. These histograms illustrate usage trends typical of those noted at each of the three load factor levels examined. The summary of average speeds, altitudes, and gross weights for combat and training operations for maneuvers exceeding each of the three load factor levels is presented in Figure 20. The F-4 usage trends apparent from all of these data are as follows:

(a) The majority of maneuvers in both combat and training operations are pulled in a limited Mach number/altitude regime. In both types of operation, the majority of maneuvers are pulled at between 350 and 550 knots and below 10,000 feet (the combat average altitudes being slightly higher than those for training).

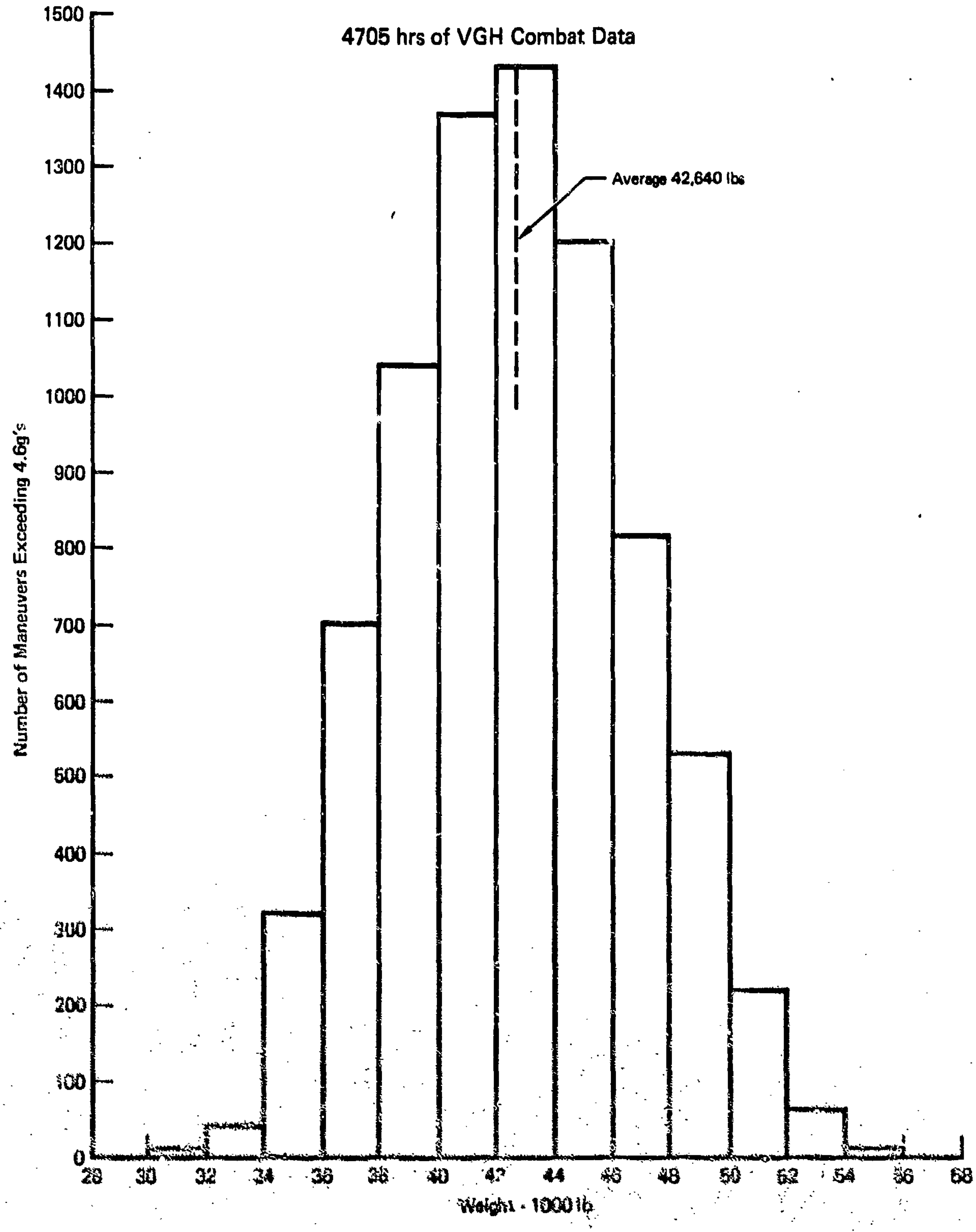


Figure 14
Histogram of Weight Usage During Maneuvers for Combat Operations

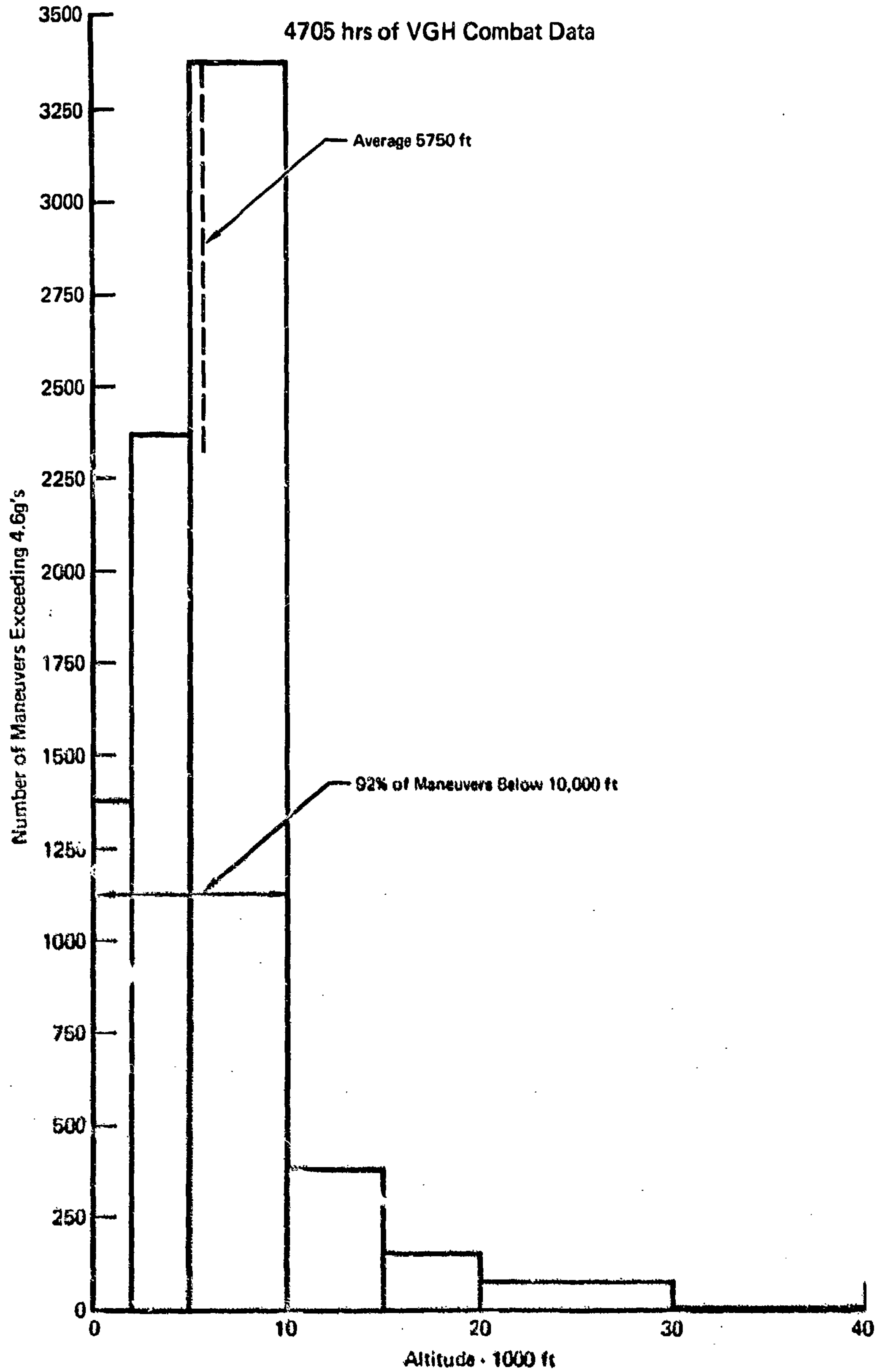


Figure 15
Histogram of Altitude Usage During Maneuvers for Combat Operations

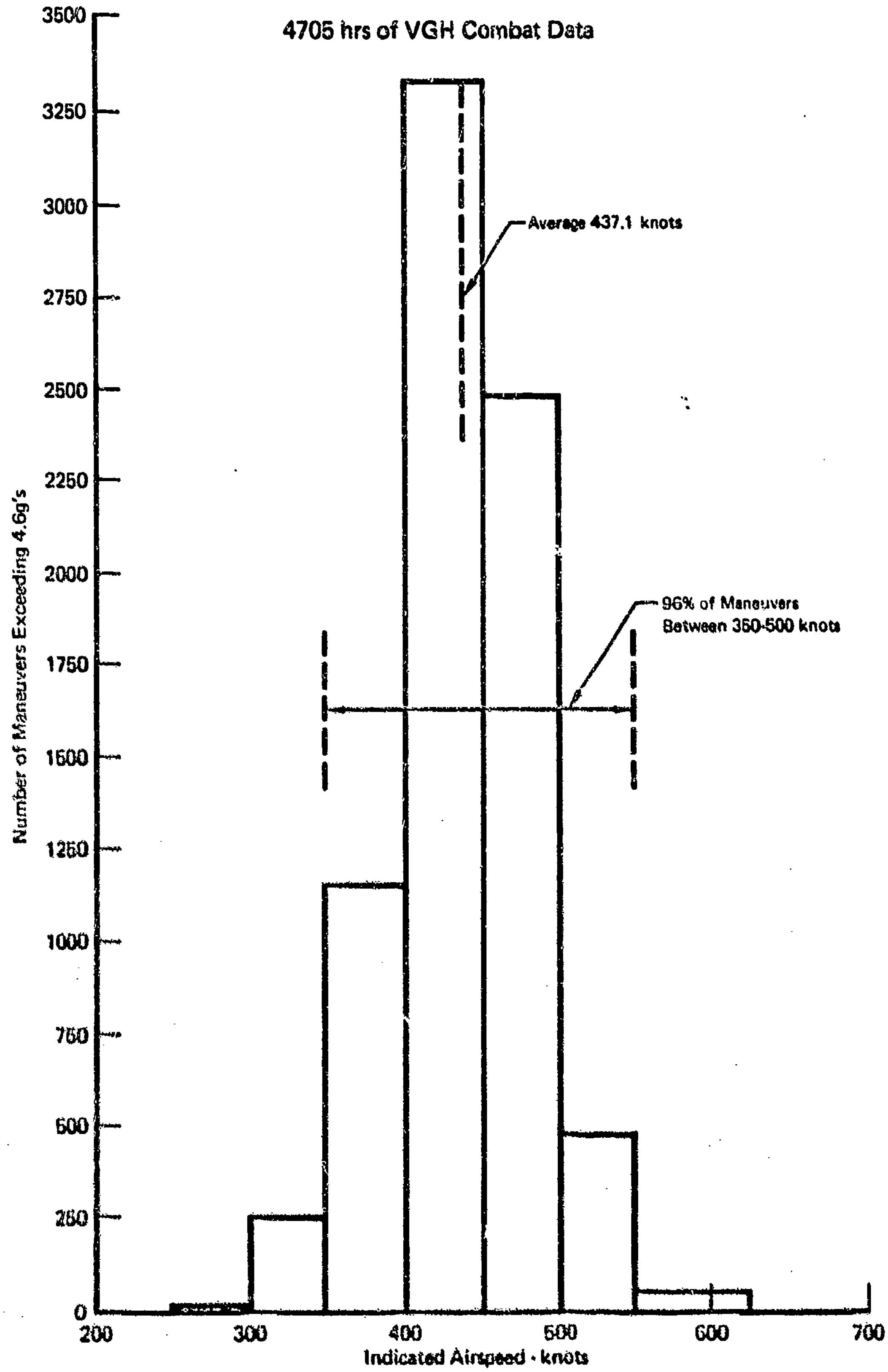


Figure 16
Histogram of Speed Usage During Maneuvers for Combat Operations

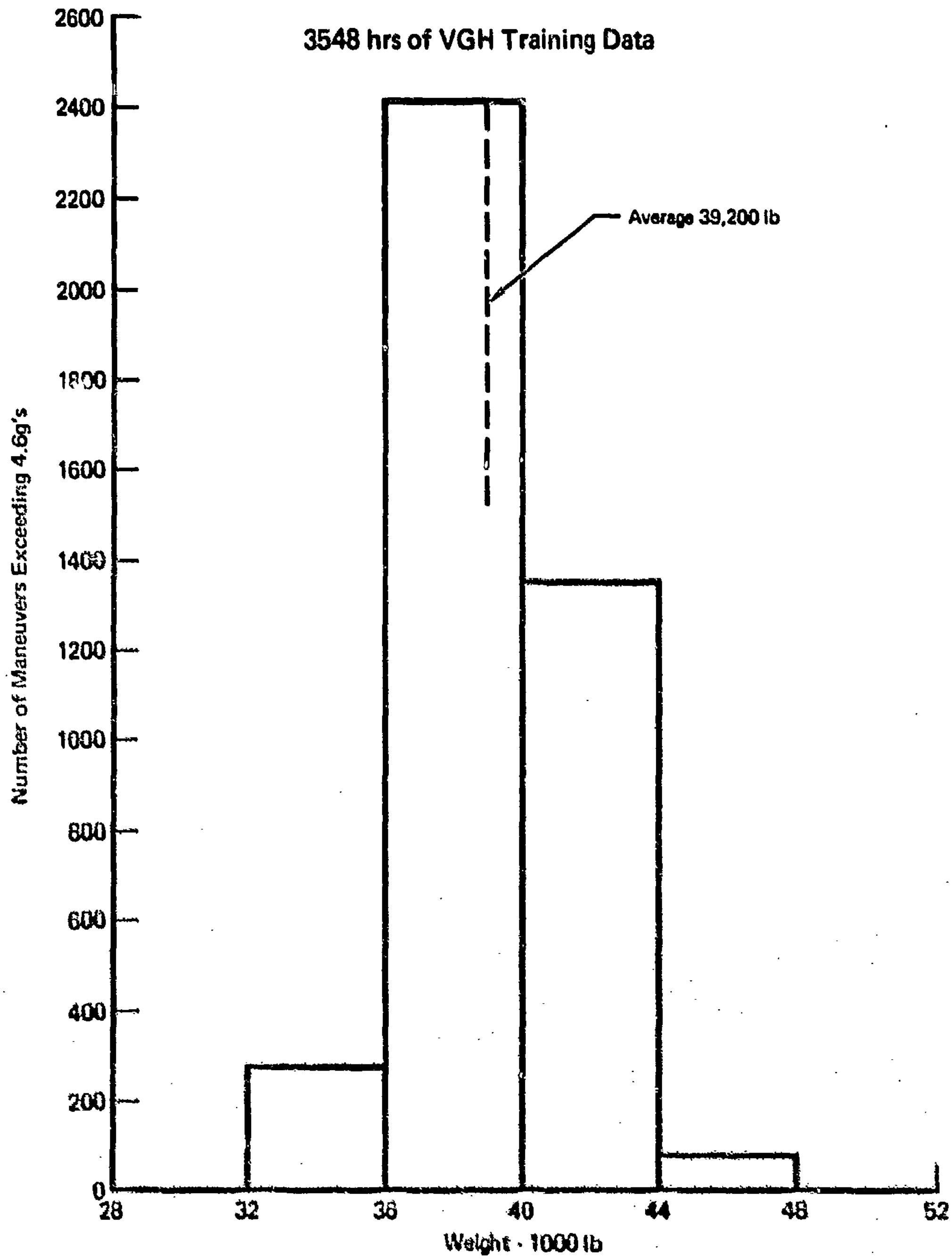


Figure 17
Histogram of Weight Usage During Maneuvers for Training Operations

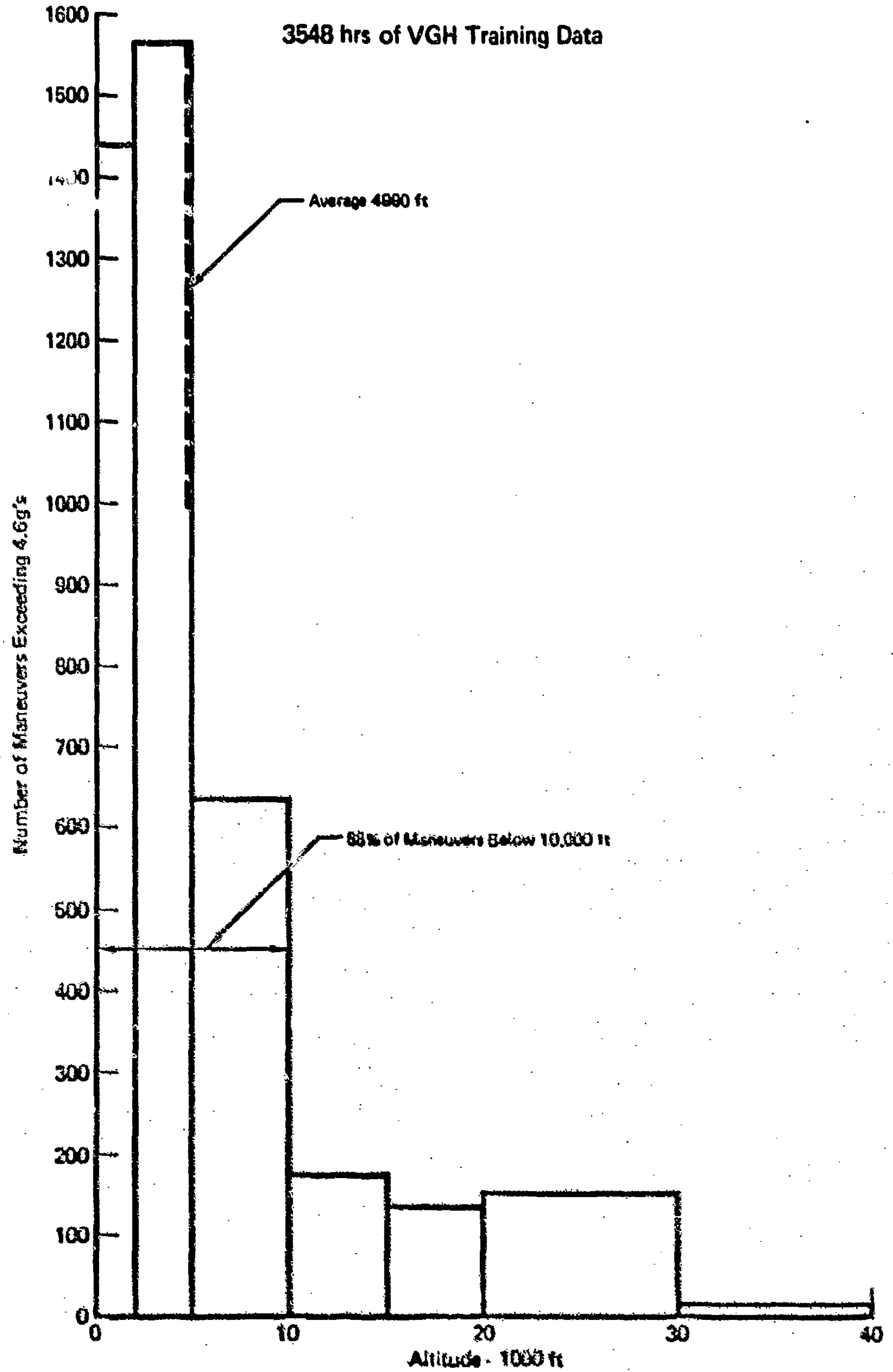


Figure 18
Histogram of Altitude Usage During Maneuvers for Training Operations

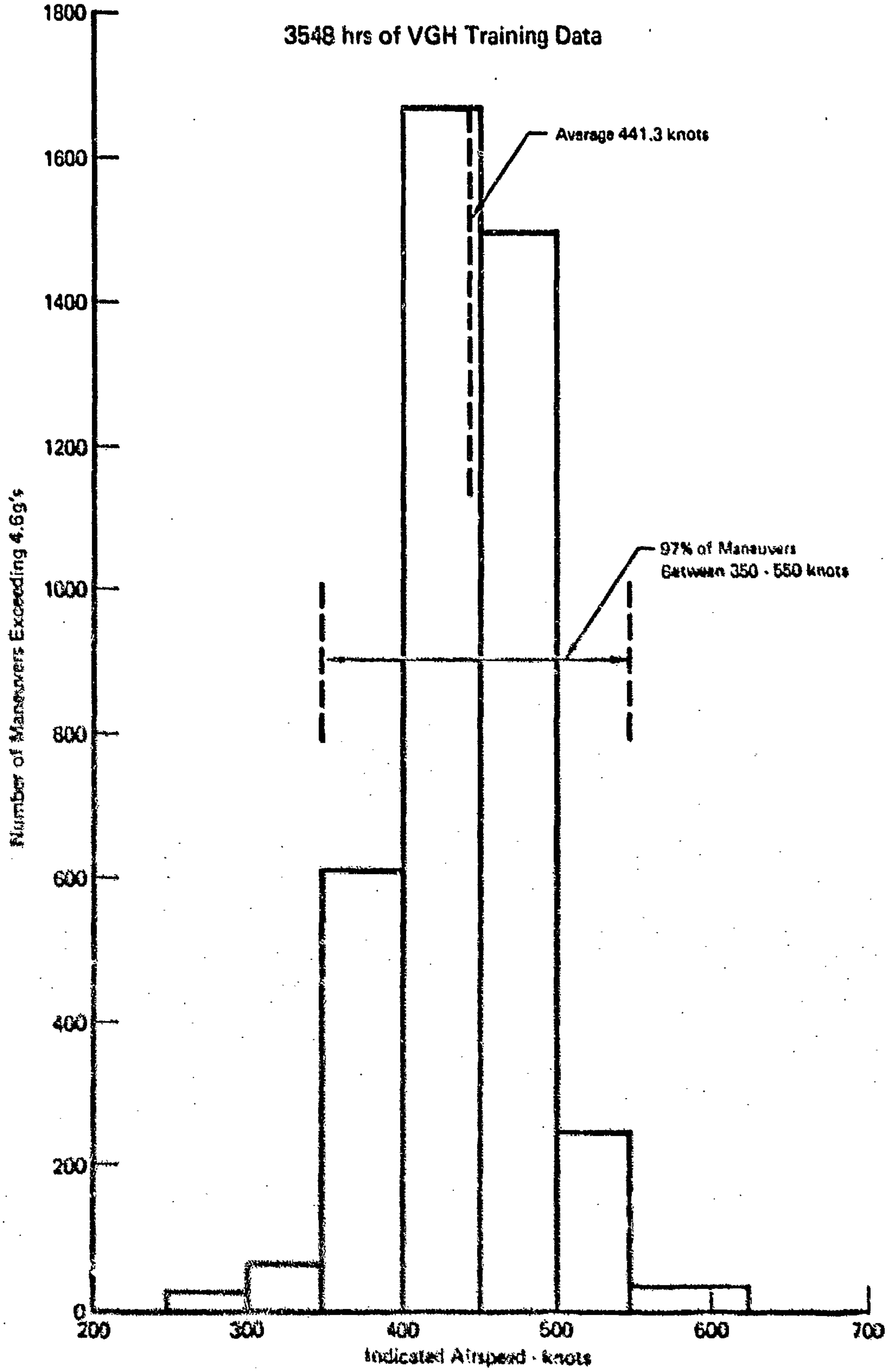


Figure 19
Histogram of Speed Usage During Maneuvers for Training Operations

Usage Parameter	Type of Operation	Average Value for Usage Parameter for Maneuvers Exceeding		
		3.0g	4.6g	6.6g
Weight (lbs)	Combat	42,730	42,640	41,680
	Training	38,890	39,200	39,160
Altitude (ft)	Combat	6,960	5,750	5,010
	Training	6,990	4,990	3,690
Indicated Airspeed (knots)	Combat	408	437	470
	Training	402	441	471

*Based on a total of 8253 flight hours of VGH data
4705 Hours of VGH combat data
3548 Hours of VGH training data

Figure 20
Summary of F-4 Weight/Altitude/Airspeed Usage for Combat and Training Operations*

(b) The gross weights in combat for maneuvers exceeding each of the three load factor levels are higher than those for maneuvers executed in training operations.

(c) In both training and combat, the average speed at which maneuvers are pulled increases as the load factor increases.

The above trends were not unexpected. The F-4 has been used primarily for air-to-ground weapon drops for which low speed and low altitude provide more accurate deliveries. Thus, the majority of maneuvers should be expected to be executed in a limited speed/altitude range. The slightly higher average altitude in combat reflects ground fire avoidance. The higher gross weights for combat reflect the higher weapon payload required in actual combat service. Finally, load factor capability is dependent upon airspeed. Higher airspeeds are required to pull high load factor maneuvers. Thus, higher level maneuvers should be expected to be executed at correspondingly higher average airspeeds than lower level maneuvers.

In Phase IV of this study service failures are compared to life predictions based on all the available data. Average life predictions for each key area were derived from counting accelerometer information describing each airplane's load factor usage, and from VGH data which helped define stress versus load factor relationships. Load factor exceedance information was essential for making a reasonable estimate of an airplane's expected fatigue life, but an accurate assessment required even more information. Speed, altitude, and gross weight are the important parameters that influence internal structural loads. The VGH information noted above thus provided the primary data necessary to define the relationships between stress and maneuvering load factor. For example, Figure 21 shows how stress in the F-4 wing main torque box lower skin varies with speed and altitude. From the VGH trends it may be noted that the majority of maneuvers are pulled in a flight regime in which wing bending moment per g is about 85% of that at the critical design condition.

3.3 F-4 Counting Accelerometer Data

3.3.1 Method for Evaluating Usage Scatter - The examination of scatter trends in load factor counting accelerometer data was a completely automated operation. A computer program developed for this purpose calculated scatter in load factor count accumulation versus effective flight hours for all airplanes reporting counting accelerometer data. The scatter computed represents

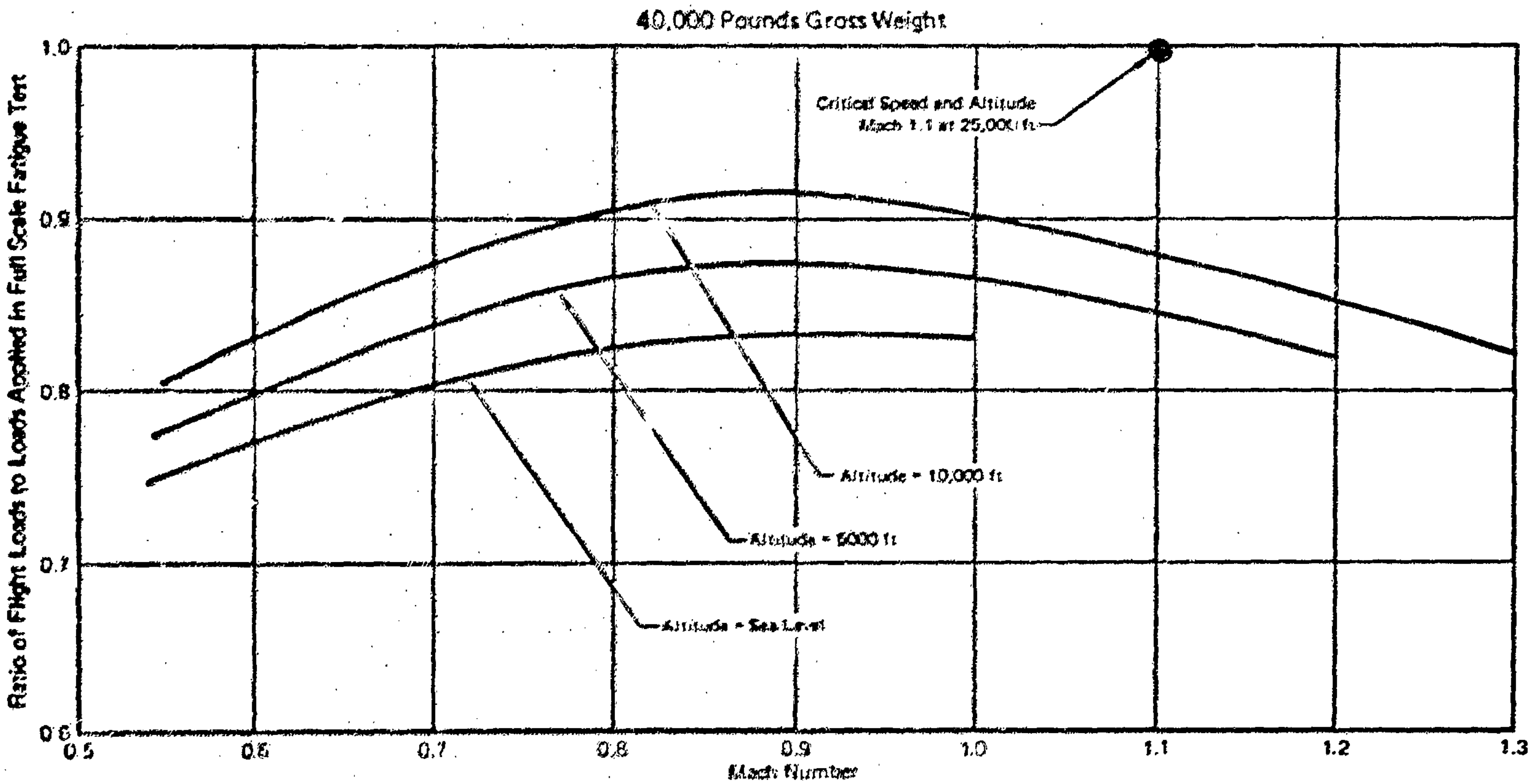


Figure 21
Typical F-4 Wing Station Comparison of Flight Condition and Laboratory Test Bending Moments Per g

the ratio between the load factor counts accumulated by a given airplane and the load factor counts which would have been accumulated by that airplane if it had been operating at the fleet average accumulation rate.

Counting accelerometer data for F-4 airplanes are stored on magnetic tape. The computer program used was designed to read the data directly off the storage tapes. For each airplane reporting counting accelerometer data, the reporting dates, counts accumulated, and aircraft flight hours were read directly from the storage tapes. Fleet average daily count per hour rates were then computed using the data from all aircraft in the fleet. Following this, scatter for a given load factor exceedance level was computed at each of the reporting dates listed for each airplane. These scatter values were determined by taking the ratio of the actual counts accumulated through the reporting date divided by the estimated accumulated counts (estimated counts were represented by the summation of the products of the flight hours accumulated on given days by the airplane multiplied by the applicable fleet average daily count per hour rates). Finally, the usage scatter data were scanned and evaluated, and information necessary to construct histograms showing the distribution of scatter at various numbers of effective flight hours was produced. Effective hours (estimated counts divided by the fleet overall average counts per hour) were used in this study so that usage scatter from aircraft operating in different time periods could be compared directly. The significance of effective hours is discussed in the following section.

3.3.2 Effective Flight Hours - F-4 operational usage has varied significantly since the airplane was introduced into service. As discussed in Section 3.3.5, monthly load factor count accumulation rates have shown substantial fluctuations over the years. An aircraft entering service early in the F-4 program would be expected to have accumulated considerably fewer counts in the same number of hours than would an airplane entering service in the last few years. Therefore, if aircraft with the same actual number of hours were directly compared, the estimated number of counts would in general vary from one airplane to another. The estimated number of counts is representative of the expected number of counts or the average. Hence, a comparison based on actual number of hours would consist of airplanes with different averages in the same group, and scatter trends based on such a comparison would not really be meaningful. On the other hand, observed scatter trends would have more significance if based on comparisons of airplanes with the same average or estimated number of counts.

Effective hours is equal to estimated number of counts divided by the fleet overall average counts per hour. Then comparing airplanes based on the number of effective hours they have accumulated would place airplanes in the same group that have the same estimated number of counts or, in other words, the same average. The main difference between actual hours and effective hours is that aircraft which flew predominantly early in the history of the F-4 program have fewer effective hours than actual hours since they flew at a time when count accumulation rates were relatively low; whereas, aircraft entering service in the more recent history have more effective hours than actual hours because they were flying in a period in which usage was more severe than the overall average.

3.3.3 Usage Scatter Trends Versus Hours - Computer runs were made to evaluate 4g and 6g usage scatter exhibited by Air Force and by Navy/Marine airplanes. The data showing the distribution of scatter at selected flight hour intervals was generated during those computer runs. This information is presented in Figures 22 through 25. The outputs show the number of airplanes with scatter values in given ranges versus effective hours. It should be noted that in each 200 hour interval, only one scatter value is counted for each airplane. The scatter value included is the one at the number of hours closest to the midpoint of the interval. Thus, the column labeled "401 to 600 hours" yields the distribution of the number of airplanes with various scatter values at 500 hours.

Figures 22 through 25 indicate that the dispersion of usage scatter points decreases significantly with increasing hours. This trend may be explained intuitively on the basis that the longer an airplane is flying, the more likely that it will have been subjected to a variety of usages and its repeated loading will have "averaged out." The trend is also in qualitative agreement with probability theory which states that the ratio of the standard deviation to the mean for number of occurrences in a given time interval is inversely proportional to the square root of the time interval length. Although the trend toward decreasing scatter agrees qualitatively with this theory, an examination of the data has indicated that the data and the theory are not in exact quantitative agreement.

Usage severity scatter means and variances versus effective hours for Air Force and Navy/Marine 4g and 6g maneuver accumulations are presented in Figures 26 through 29. These data show how usage severity scatter variances

826,171 Total Flight Hours of Data Examined

Usage Severity Scatter *	Effective Hours												
	0 to 200	201 to 400	401 to 600	601 to 800	801 to 1000	1001 to 1200	1201 to 1400	1401 to 1600	1601 to 1800	1801 to 2000	2001 to 2200	2201 to 2400	2401 to 2600
0.0 - 0.2	90	37	18	5	2	2	1	1	1	1	1		
0.2 - 0.4	96	56	33	18	7	3	1	2	1	0	0		
0.4 - 0.6	151	141	92	64	43	23	8	4	3	0	1	1	
0.6 - 0.8	177	171	173	146	93	55	27	11	7	7	2	1	1
0.8 - 1.0	175	181	173	127	85	52	29	16	9	4	1		
1.0 - 1.2	158	153	135	110	80	44	19	10	7	2	1		
1.2 - 1.4	107	109	99	64	45	24	14	7	2	3	1		
1.4 - 1.6	78	91	60	53	28	16	3	4	4	2	0		
1.6 - 1.8	64	47	48	33	17	8	8	2	2	0	0		
1.8 - 2.0	38	34	27	16	11	11	6	4	3	2	1		
2.0 - 2.2	16	22	13	6	3	5	3	2					
2.2 - 2.4	16	12	6	3	5	1	1						
2.4 - 2.6	18	7	3	4	3	1							
2.6 - 2.8	3	2	5	2									
2.8 - 3.0	3	3	1										
3.0 - 3.2	6	0											
3.2 - 3.4	5	1											
3.4 - 3.6	2												
3.6 - 3.8	0												
3.8 - 4.0	3												
4.0 - 4.2	2												
4.2 - 4.4	0												
4.4 - 4.6	1												
Total Number of Aircraft	1209	1067	886	651	422	245	120	63	39	21	8	2	1

* Usage Severity Scatter = Actual 4g Counts/Estimated 4g Counts

Figure 22
4g Usage Severity Scatter Distribution for 1209 Air Force Airplanes

1,015,955 Total Flight Hours of Data Examined

Usage Severity Scatter *	Effective Hours													
	0 to 200	201 to 400	401 to 600	601 to 800	801 to 1000	1001 to 1200	1201 to 1400	1401 to 1600	1601 to 1800	1801 to 2000	2001 to 2200	2201 to 2400	2401 to 2600	2601 to 2800
0.0 - 0.2	94	36	20	15	5	3	2							
0.2 - 0.4	129	80	48	39	29	20	11	9	6	6	3	1		
0.4 - 0.6	151	99	60	64	61	53	47	33	24	15	9	5	3	1
0.6 - 0.8	131	128	141	122	101	89	73	61	54	38	30	17	10	3
0.8 - 1.0	132	152	154	131	131	99	90	72	43	31	18	12	8	4
1.0 - 1.2	109	134	114	91	74	62	46	28	28	20	12	5	3	2
1.2 - 1.4	81	94	90	74	57	59	28	25	14	9	5	4	2	2
1.4 - 1.6	60	78	55	49	34	29	25	17	10	4	2	3	1	1
1.6 - 1.8	40	43	30	30	29	26	10	6	4	1	0	0		
1.8 - 2.0	43	34	31	25	21	8	8	6	1	2	2	1		
2.0 - 2.2	26	19	10	14	4	6	6	6	6	3				
2.2 - 2.4	24	14	11	7	7	7	3	5	2	1				
2.4 - 2.6	22	13	10	6	6	4	6	1	0					
2.6 - 2.8	9	6	4	1	5	4	0	0	0					
2.8 - 3.0	16	3	5	2	3	3	0	0	0					
3.0 - 3.2	7	4	1	3			0	0	1					
3.2 - 3.4	9	1	1				0	1						
3.4 - 3.6	4	1	0				1							
3.6 - 3.8	3	2	0											
3.8 - 4.0	2	2	1											
4.0 - 4.2	5	1												
4.2 - 4.4	4													
4.4 - 4.6	1													
4.6 - 4.8	0													
4.8 - 5.0	0													
5.0 - 5.2	0													
5.2 - 5.4	1													
5.4 - 5.6	1													
5.6 - 5.8	0													
5.8 - 6.0	0													
6.0 - 6.2	1													
6.2 - 6.4	0													
6.4 - 6.6	0													
6.6 - 6.8	0													
6.8 - 7.0	0													
7.0 - 7.2	0													
7.2 - 7.4	0													
7.4 - 7.6	0													
7.6 - 7.8	0													
7.8 - 8.0	0													
8.0 - 8.2	0													
8.2 - 8.4	1													
Total Number of Aircraft	1105	933	786	672	567	452	346	270	193	130	81	48	27	13

* Usage Severity Scatter = Actual 4g Counts/Estimated 4g Counts

Figure 23
4g Usage Severity Scatter Distribution for 1106 Navy/Marine Airplanes

826,171 Total Flight Hours of Data Examined

Usage Severity Scatter *	Effective Hours													
	0 to 200	201 to 400	401 to 600	601 to 800	801 to 1000	1001 to 1200	1201 to 1400	1401 to 1600	1601 to 1800	1801 to 2000	2001 to 2200	2201 to 2400	2401 to 2600	2601 to 2800
0.0 - 0.2	171	60	33	16	11	7	5	4	1	1	1			
0.2 - 0.4	151	119	63	31	19	13	9	3	5	4	2	1	1	1
0.4 - 0.6	175	160	115	104	60	37	14	7	5	3	3	2		
0.6 - 0.8	152	167	153	113	86	41	25	14	12	8	2	0		
0.8 - 1.0	137	130	127	98	65	40	17	10	4	4	1	1		
1.0 - 1.2	102	110	101	87	52	28	23	7	3	0	0			
1.2 - 1.4	74	82	69	57	41	28	13	11	5	2	0			
1.4 - 1.6	52	79	62	40	41	25	7	2	3	1	0			
1.6 - 1.8	57	42	40	33	23	15	8	6	2	1	2			
1.8 - 2.0	30	41	41	23	16	7	5	2	3	2				
2.0 - 2.2	23	18	16	13	7	3	4	4	3					
2.2 - 2.4	16	13	14	10	1	4	2	1						
2.4 - 2.6	18	11	12	2	2	1	0	0						
2.6 - 2.8	7	13	2	0	2	2	1	1						
2.8 - 3.0	8	5	1	5	1	0								
3.0 - 3.2	10	4	5	1	0	1								
3.2 - 3.4	8	4	1	0	1									
3.4 - 3.6	9	2	3	0										
3.6 - 3.8	6	2	0	0										
3.8 - 4.0	4		0	0										
4.0 - 4.2	5		0	1										
4.2 - 4.4	0		1											
4.4 - 4.6	0													
4.6 - 4.8	1													
4.8 - 5.0	2													
5.0 - 5.2	0													
5.2 - 5.4	1													
5.4 - 5.6	0													
5.6 - 5.8	0													
5.8 - 6.0	0													
6.0 - 6.2	2													
Total Number of Aircraft	1209	1062	859	634	428	252	133	72	46	26	11	4	1	1

* Usage Severity Scatter = Actual 6g Counts/Estimated 6g Counts

Figure 24
6g Usage Severity Scatter Distribution for 1209 Air Force Airplanes

1,015,955 Total Flight Hours of Data Examined

Usage Severity Scatter *	Effective Hours													
	0 to 200	201 to 400	401 to 600	601 to 800	801 to 1000	1001 to 1200	1201 to 1400	1401 to 1600	1601 to 1800	1801 to 2000	2001 to 2200	2201 to 2400	2401 to 2600	2601 to 2800
0.0 - 0.2	228	119	64	46	31	22	18	14	6	5	2	1	1	
0.2 - 0.4	154	120	110	94	90	77	63	50	44	31	19	7	6	6
0.4 - 0.6	151	138	126	101	81	74	61	50	35	24	24	15	6	4
0.6 - 0.8	119	114	141	87	83	54	54	45	35	20	13	7	3	2
0.8 - 1.0	89	93	76	92	65	51	34	29	20	13	9	8	4	4
1.0 - 1.2	71	71	64	66	44	37	29	27	18	15	10	4	4	2
1.2 - 1.4	53	55	59	35	29	22	29	22	17	11	7	4	1	0
1.4 - 1.6	31	31	40	26	13	21	22	14	7	5	2	2	1	1
1.6 - 1.8	37	33	28	18	26	26	6	6	6	5	3	0	1	0
1.8 - 2.0	31	25	15	21	14	10	13	10	10	7	1	1	0	0
2.0 - 2.2	21	21	10	14	14	7	6	9	2	1	0	0	1	1
2.2 - 2.4	20	12	12	6	7	5	8	4	1	2	1	0	0	0
2.4 - 2.6	9	9	7	8	6	10	8	3	4	3	1	1	0	0
2.6 - 2.8	14	12	7	3	7	4	3	3	4	2	1	1	1	0
2.8 - 3.0	12	7	8	4	3	7	1	2	1	1	2	0		1
3.0 - 3.2	7	5	5	5	3	2	4	1	0	1		0		
3.2 - 3.4	15	5	4	6	3	0	1	0	1	0		0		
3.4 - 3.6	6	3	2	1	1	1	1	1	0	2		0		
3.6 - 3.8	3	4	6	1	3	2	0	1	3	1		1		
3.8 - 4.0	3	3	2	2	1	0	0	1	1	0				
4.0 - 4.2	2	6	0	2	0	1	1	2	1	1				
4.2 - 4.4	4	0	1	2	1	0	0	1	1					
4.4 - 4.6	5	0	3	3	1	2	3	2						
4.6 - 4.8	5	2	2	3	3	0	0							
4.8 - 5.0	1	0	1	1	2	6	3							
5.0 - 5.2	4	2	1	1	1	0								
5.2 - 5.4	3	2	3	3	0	0								
5.4 - 5.6	0	0	2	0	2	1								
5.6 - 5.8	0	1	0	0	0	1								
5.8 - 6.0	1	1	0	0	0									
6.0 - 6.2	0	5	0	0	0									
6.2 - 6.4	1	2	1	0	0									
6.4 - 6.6	0	0		0	0									
6.6 - 6.8	0	0		1	1									
6.8 - 7.0	1	0												
7.0 - 7.2	0	0												
7.2 - 7.4	0	0												
7.4 - 7.6	0	0												
7.6 - 7.8	0	0												
7.8 - 8.0	0	0												
8.0 - 8.2	0	0												
8.2 - 8.4	1	0												
8.4 - 8.6	0	1												
8.6 - 8.8	0	0												
8.8 - 9.0	0	0												
9.0 - 9.2	1	0												
9.2 - 9.4	0	0												
9.4 - 9.6	1	0												
9.6 - 9.8		1												
Total Number of Aircraft	1104	905	759	652	537	451	368	297	217	150	95	52	29	21

* Usage Severity Scatter = Actual 6g Counts/Estimated 6g Counts

Figure 25
6g Usage Severity Scatter Distribution for 1106 Navy/Marine Airplanes

EFFECTIVE HOURS	USAGE SEVERITY SCATTER		TOTAL NUMBER OF AIRCRAFT WITH INDICATED EFFECTIVE HOURS
	MEAN	VARIANCE	
100	.9961	.4108	1209
300	1.0059	.2615	1067
500	1.0153	.2169	886
700	1.0131	.1836	651
900	1.0166	.1726	422
1100	1.0257	.1778	245
1300	1.055	.1830	120
1500	1.0492	.1930	65
1700	1.0333	.1894	39
1900	1.0238	.1847	21
2100	.9000	.260	8
2300	.60	.01	2

NOTES

(1) Usage Severity Scatter = Actual 4g Counts/Estimated 4g Counts

(2) 826,171 Total Hours of Data Examined

(3) Reference Figure 22 for Usage Severity Scatter Data

Figure 26
4g Usage Severity Scatter Mean and Variance vs Effective Hours for Air Force Aircraft

EFFECTIVE HOURS	USAGE SEVERITY SCATTER		TOTAL NUMBER OF AIRCRAFT WITH INDICATED EFFECTIVE HOURS
	MEAN	VARIANCE	
100	1.0732	.7520	1105
300	1.0593	.3793	933
500	1.0501	.2935	786
700	1.0339	.2659	672
900	1.0330	.2546	567
1100	1.0270	.2549	452
1300	.9965	.2278	346
1500	.9889	.2099	270
1700	.9497	.1845	193
1900	.9046	.1437	130
2100	.8531	.0931	81
2300	.8875	.0990	48
2500	.8556	.0602	27
2700	.9615	.0762	13

NOTES

(1) Usage Severity Scatter = Actual 4g Counts/Estimated 4g Counts

(2) 1,015,955 Total Hours of Data Examined

(3) Reference Figure 23 for Usage Severity Scatter Data

Figure 27
4g Usage Severity Scatter Mean and Variance vs Effective Hours for Navy/Marine Aircraft

EFFECTIVE HOURS	USAGE SEVERITY SCATTER MEAN	VARIANCE	TOTAL NUMBER OF AIRCRAFT WITH INDICATED EFFECTIVE HOURS
100	.9552	.7066	1209
300	.9753	.4092	1062
500	1.0227	.3642	859
700	1.0044	.2923	634
900	1.0061	.2561	428
1100	1.0230	.2784	252
1300	1.0113	.2751	133
1500	1.0556	.3214	72
1700	.9957	.3022	46
1900	.8308	.2337	26
2100	.7182	.2579	11
2300	.5500	.0475	4

NOTES

(1) Usage Severity Scatter = Actual 6g Counts/Estimated 6g Counts

(2) 826,171 Total Hours of Data Examined

(3) Reference Figure 24 for Usage Severity Scatter Data

Figure 28
6g Usage Severity Scatter Mean and Variance vs Effective Hours for Air Force Aircraft

EFFECTIVE HOURS	USAGE SEVERITY SCATTER		TOTAL NUMBER OF AIRCRAFT WITH INDICATED EFFECTIVE HOURS
	MEAN	VARIANCE	
100	.9801	1.2066	1104
300	1.0229	1.1270	903
500	1.0115	.8344	759
700	1.0196	.8349	652
900	1.0262	.8562	537
1100	1.0377	.8427	453
1300	1.0071	.7065	368
1500	.9855	.6420	297
1700	.9783	.6326	217
1900	.9867	.6146	150
2100	.8263	.3461	95
2300	.8692	.4221	52
2500	.8379	.3368	29
2700	.8333	.4127	21

NOTES

(1) Usage Severity Scatter = Actual 6g Counts/Estimated 6g Counts

(2) 1,015,955 Total Hours of Data Examined

(3) Reference Figure 25 for Usage Severity Scatter Data

Figure 29
6g Usage Severity Scatter Mean and Variance vs Effective Hours for Navy/Marine Aircraft

change with increasing time. As may be noted, the variances decrease with increasing time but not in proportion to the inverse of time as is suggested by probability theory. In Reference (5), it is indicated that for such a relation to hold, the accumulation of flight maneuvers by airplanes in a fleet would have to be a stationary random process. One of the requirements for such a process is that the mean frequency of occurrence of maneuvers must be constant with respect to time. As has been shown, this has not been the case with F-4 service usage; operational usage has changed and fleet average maneuver frequencies of occurrence have fluctuated greatly. Usage severity scatter variances could not, therefore, be expected to decrease exactly in proportion to the inverse of time. However, the fact that scatter variances are shown to decrease and not increase with time can be used. The variance at 1500 hours is calculable from the available data. The question is what will be the variance at a design life of say 4000 hours. Since variances are shown not to increase but decrease, although not inversely proportional to the square root of time, it would certainly be reasonable to assume that the variance at 4000 hours is not larger than the value at 1500 hours.

3.3.3.1 Graphical Presentation of Usage Severity Scatter - Plots of 4g and 6g usage severity scatter versus flight hours were generated for both Air Force airplanes and Navy/Marine airplanes. The plots, presented in Figures 30 through 33, illustrate graphically the decrease in scatter with increasing hours. As may be noted, in all cases, the dispersion of usage severity scatter is shown to decrease significantly with increasing flight hours. As has been indicated previously, this trend may be explained intuitively on the basis that the longer an airplane is flying, the more likely that it will have been subjected to a variety of usages and its repeated loading will have averaged out.

In accordance with this theory of repeated load averaging over long periods, large scatter factors can be expected only early in an airplane's life when the numbers of actual and estimated counts are relatively low. There are exceptions to this rule however. The plot of 6g usage scatter for Navy/Marine airplanes shown in Figure 33 contains 85 data points for F-4B Bureau No. 150492 plotted at between 62 and 2482 flight hours. The last of these, a scatter factor of 9.31 at 2482 flight hours (see Figure 33), is unusually high for that many flight hours and is obviously inconsistent with the data from the other aircraft in the fleet. Prior to November 1966, this

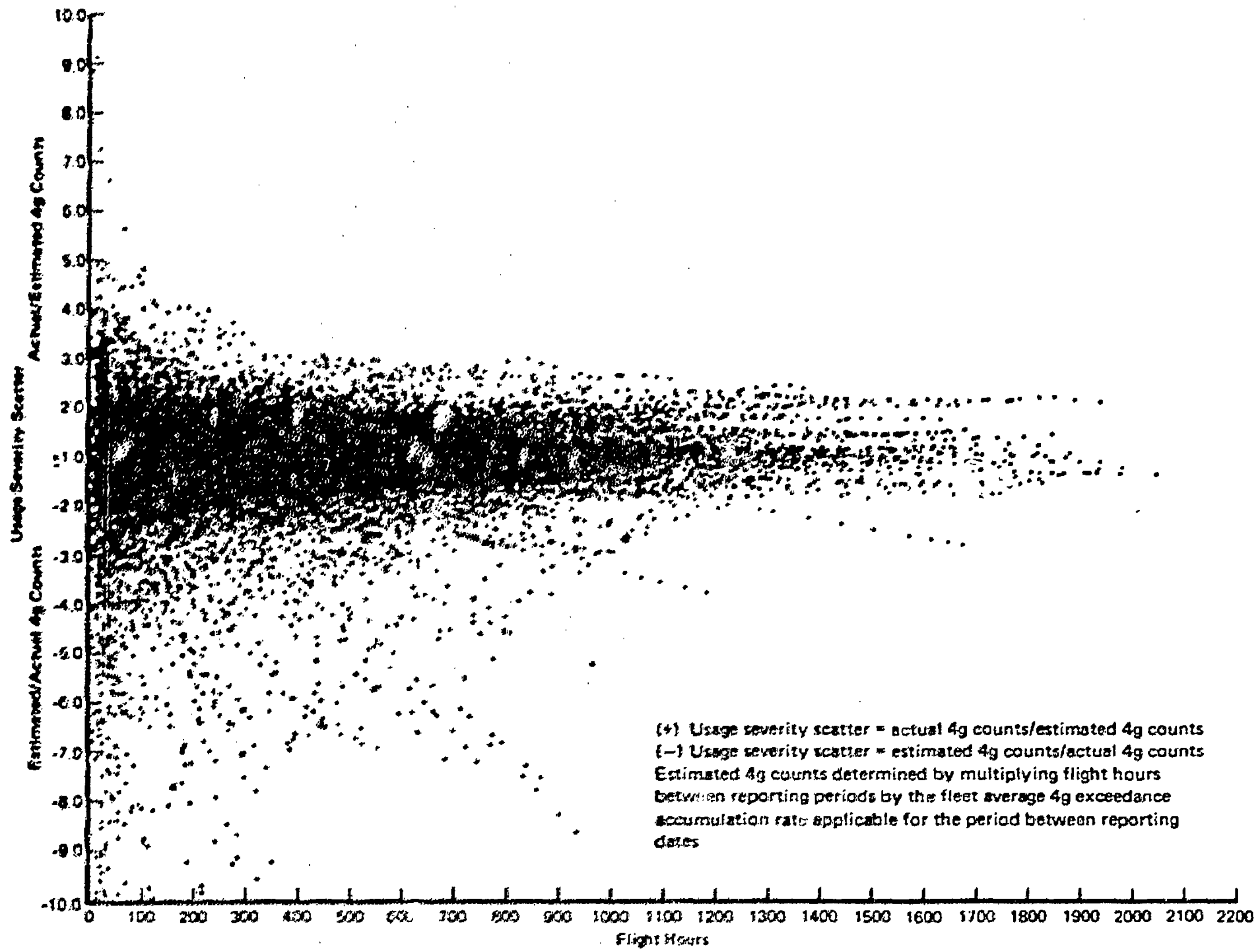


Figure 30
4g Usage Severity Scatter vs Flight Hours for Air Force F-4 Aircraft
Reporting Counting Accelerometer Data
(1151 Aircraft, 791,913 Flight Hours of Data Through March 1972, 23,228 Data Points Plotted)

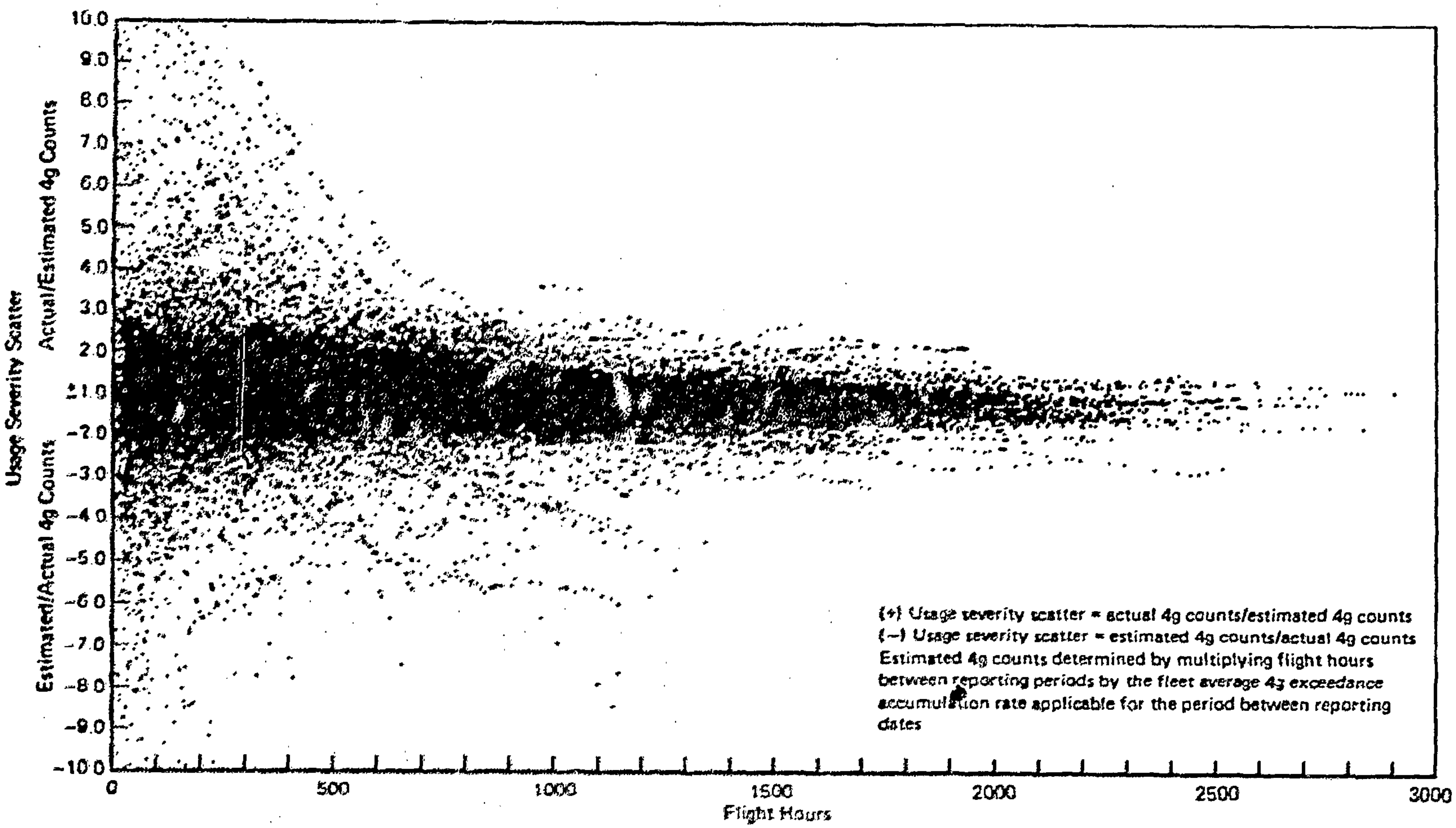


Figure 31
4g Usage Severity Scatter vs Flight Hours for Navy/Marine F-4 Aircraft
Reporting Counting Accelerometer Data
(1039 Aircraft 958,377 Flight Hours of Data Through March 1972, 29,507 Data Points Plotted)

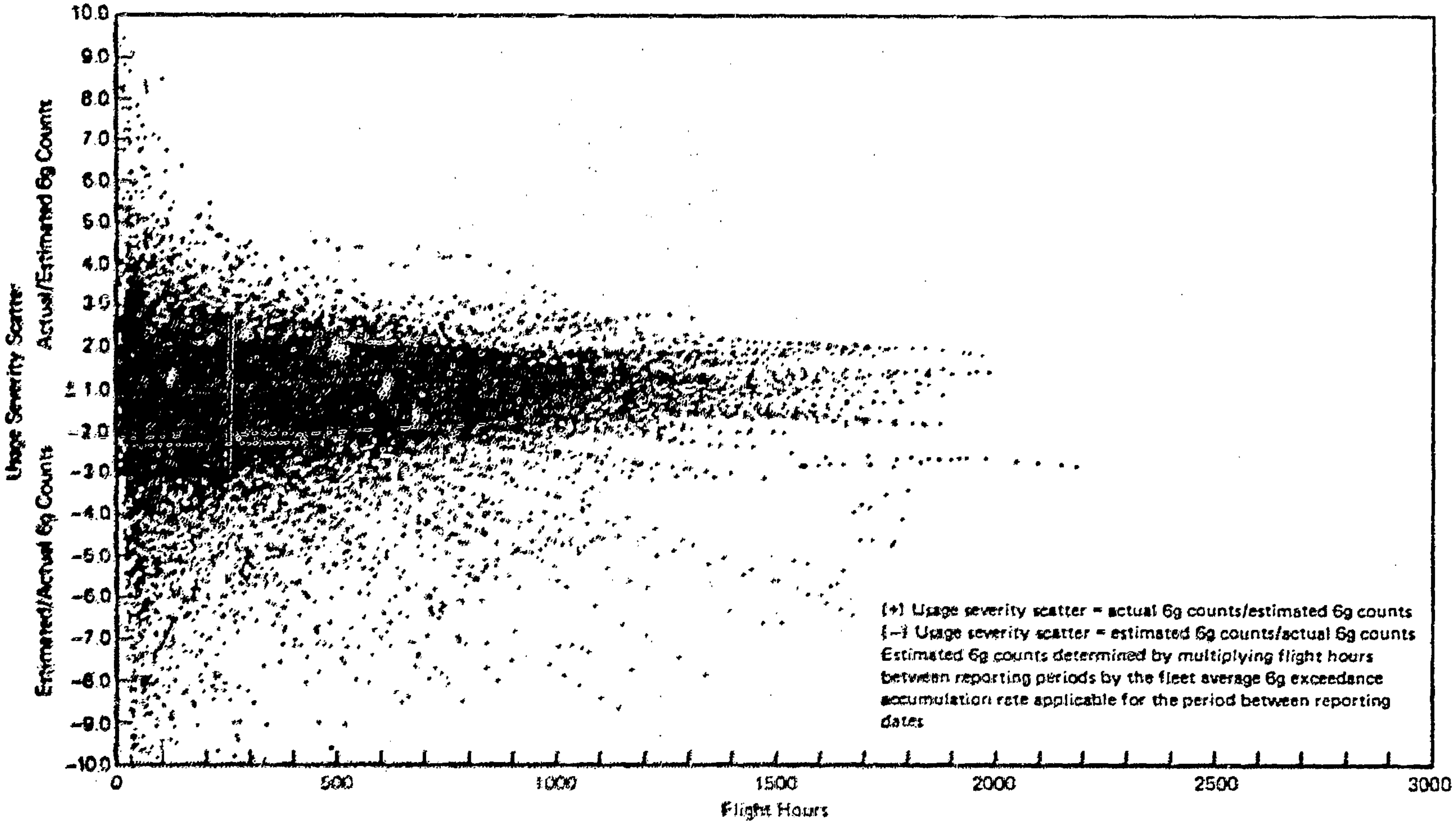


Figure 32
6g Usage Severity Scatter vs Flight Hours for Air Force F-4 Aircraft
Reporting Counting Accelerometer Data
(1134 Aircraft, 772,159 Flight Hours of Data Through March 1972, 22,447 Data Points Plotted)

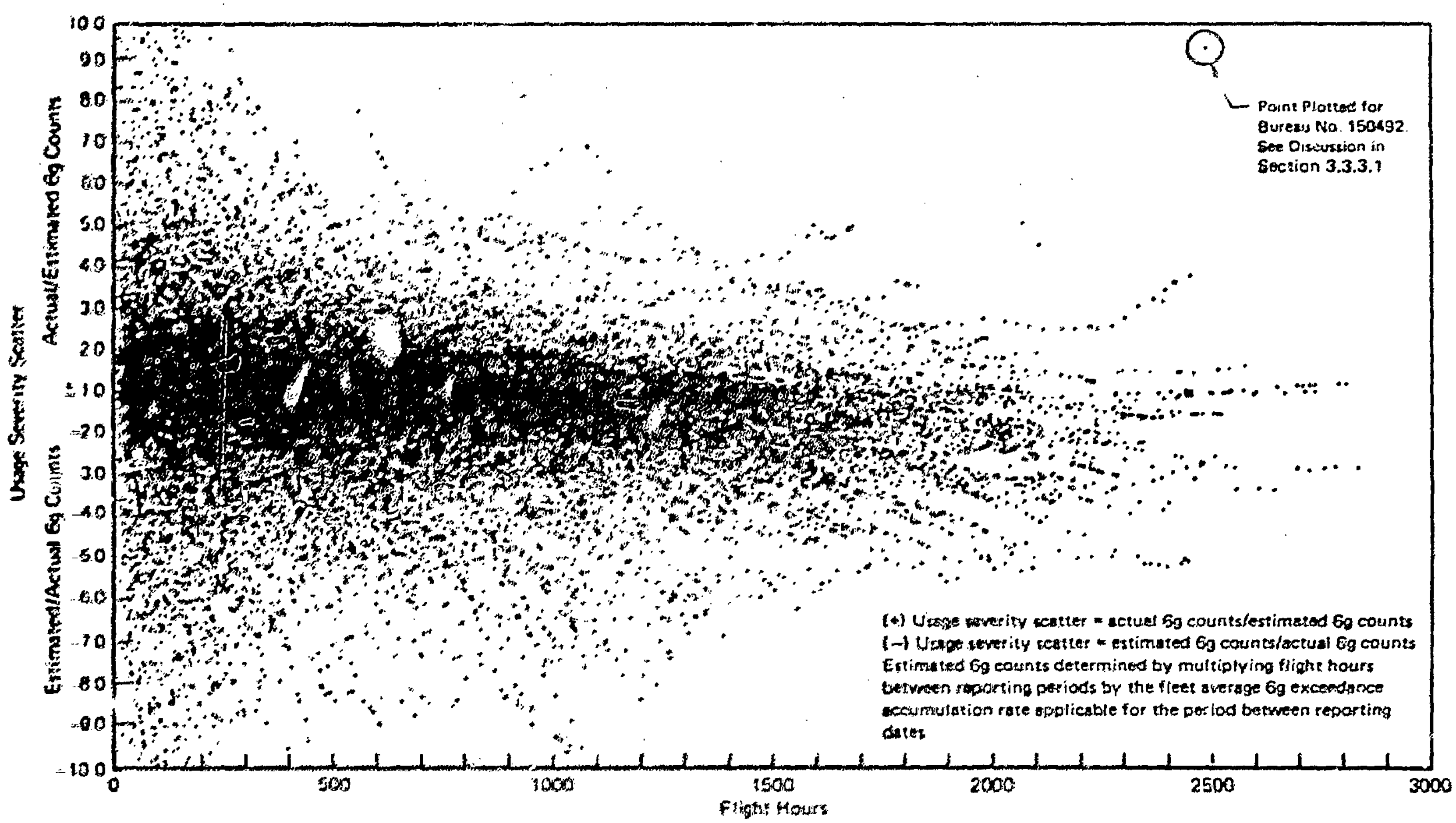


Figure 33
6g Usage Severity Scatter vs Flight Hours for Navy/Marine F-4 Aircraft
Reporting Counting Accelerometer Data
(947 Aircraft, 836,616 Flight Hours of Data Through March 1972, 25,104 Data Points Plotted)

airplane had accumulated approximately 1200 flight hours and had been engaged in operations typical of an average airplane in the fleet. Since that time, however, the airplane has been engaged in development of weapon delivery techniques. Since transferring into such operations, the aircraft's 6g exceedance accumulation rate has continually increased. Recently, the airplane's average usage has been 12 times more severe than that of a typical airplane in the fleet. This represents an activity which is not at all comparable to typical operations in the overall fleet of Navy/Marine aircraft. The flight hours accumulated by Bureau No. 150492 are thus considered to be from unusual operations, and as such, the data from this usage are not included in any scatter evaluations herein.

It is frequently found that unusual usage such as that experienced by Bureau No. 150492 leads to fatigue problems. Failure of an airplane such as this in unknown or unrecognized special operations would cast a shadow of doubt on the structural integrity of the total fleet of aircraft. By having counting accelerometers installed in each aircraft, however, these operations can be recognized and special periodic inspections of the aircraft involved can be conducted. This should preclude any major problems. In addition, scatter can be controlled, if deemed advisable, by transferring airplanes in and out of unusual activities.

3.3.4 Evaluation of Probability Distribution - The statistical representation of aircraft flight maneuver accumulation is discussed in detail in Reference (5). It is shown that the distribution of the numbers of maneuvers accumulated by individual aircraft in a fleet may be described using the negative binomial distribution. Usage severity scatter, as used herein, is defined as the ratio of the actual number of load factor counts accumulated by an airplane divided by the number of counts which would have been accumulated by that airplane had it been operating at the fleet average maneuver accumulation rate. Since this ratio is a measure of an individual airplane's accumulation of maneuvers, the distribution of usage severity scatter should also follow the negative binomial distribution.

The negative binomial distribution, defined by the probability density function,

$$f(z) = \left[\frac{b}{b+1}\right]^{bm} \left[\frac{1}{\Gamma(bm)}\right] \left[\frac{1}{b+1}\right]^{z} \frac{\Gamma(z+bm)}{\Gamma(z+1)}$$

where:

z = usage severity scatter = actual counts/estimated counts

m = mean value z

$b = m/(\sigma^2 - m)$, and

σ = standard deviation of z

has been evaluated for "goodness of fit" with the usage severity scatter data generated for both Air Force and Navy/Marine airplanes. The evaluation has shown definite correlation between the theoretical distribution and the data. As an example, Figures 34 through 36 show comparisons between the negative binomial distribution and the 4g scatter exhibited by Air Force airplanes having accumulated 100, 500, and 1500 effective hours. These comparisons show that the scatter in usage severity at any given number of effective hours can be represented using the negative binomial distribution.

3.3.5 Effects of Changes in Operational Usage - The definition of a particular airplane's usage may change completely from the design mission due to the character of the actual theatre of operations. This has been clearly illustrated by the usage of the F-4 airplane in service. As is well known, the F-4 has been developed into a highly diversified weapons system. It has been utilized as an interceptor, a fighter-bomber, and in numerous ground support operations. The differences between the usages in these roles has been drastic. The SEA conflict has likewise had a significant effect on operational usage considerations. In addition to increased maneuver frequency resulting from deployment in conventional bombing operations, the utilization rates and the actual flight gross weights went beyond initial expectations. Instead of being flown 20 to 30 hours per month, the rate for combat squadron activities increased to 60 to 70 hours per month. Also, as illustrated by the VGH data presented in Section 3.2, the average gross weight in combat operations increased to a level significantly above the design gross weight of 37,500 pounds. None of these changes could have been predicted statistically during the design phase of the airplane.

Air Force and Navy/Marine 4g and 6g fleet average exceedance accumulation rates versus time are shown in Figure 37. These plots show how F-4 usage has varied. As noted previously, the usage scatter factors computed herein represent the scatter between the exceedances accumulated by a given airplane and the exceedances which would have been accumulated by that airplane if it had been operating at the fleet average exceedance accumulation

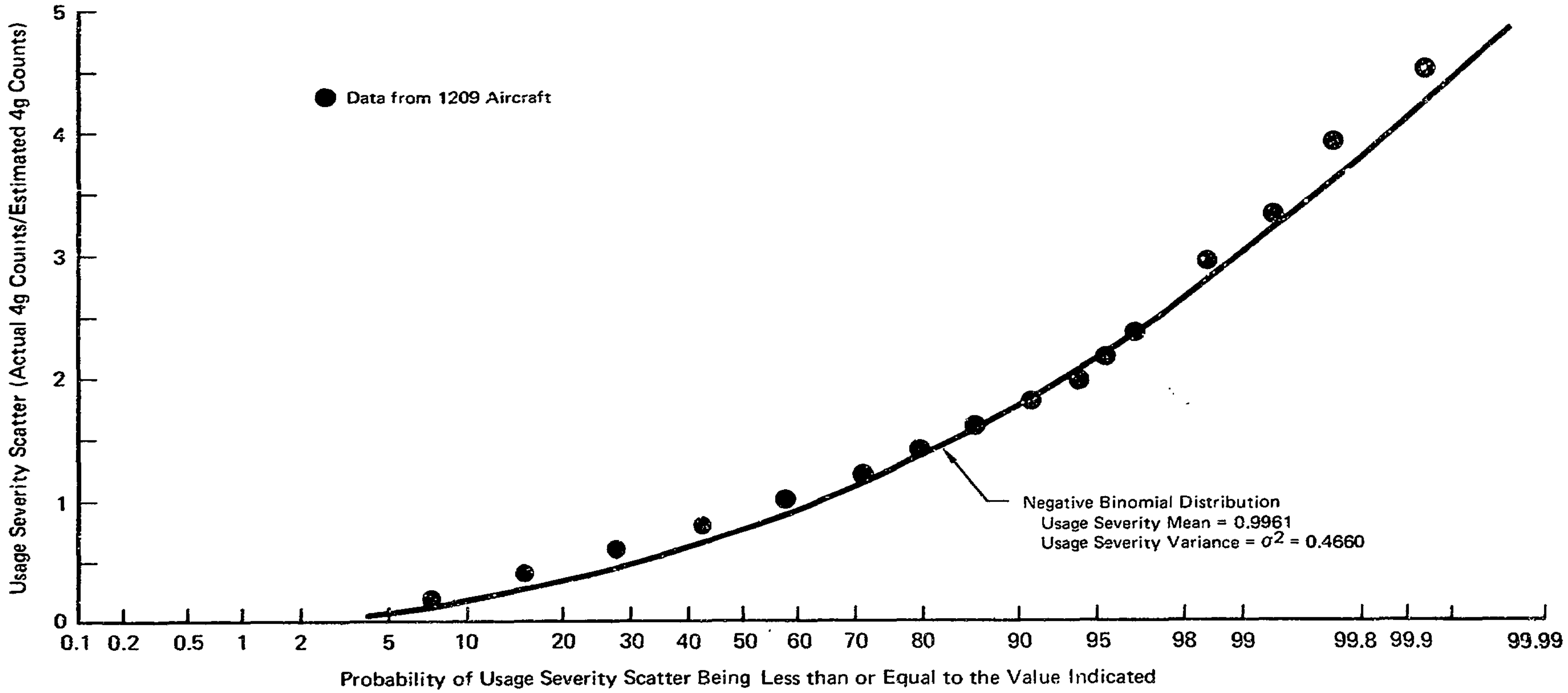


Figure 34
Comparison of Air Force 4g Usage Severity Scatter to the Negative Binomial Distribution (100 Effective Hours)

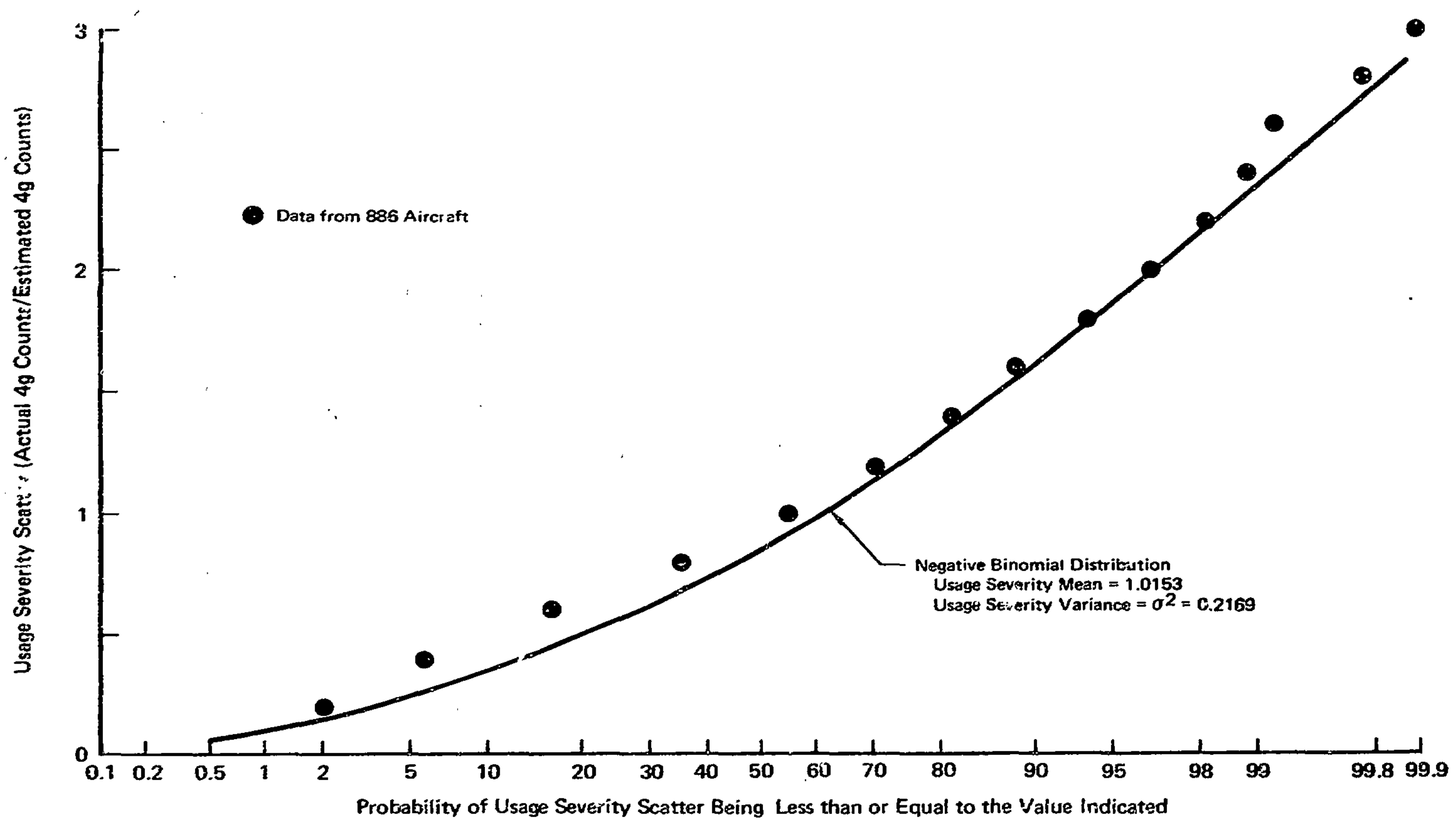


Figure 35
Comparison of Air Force 4g Usage Severity Scatter to the Negative Binomial Distribution (500 Effective Hours)

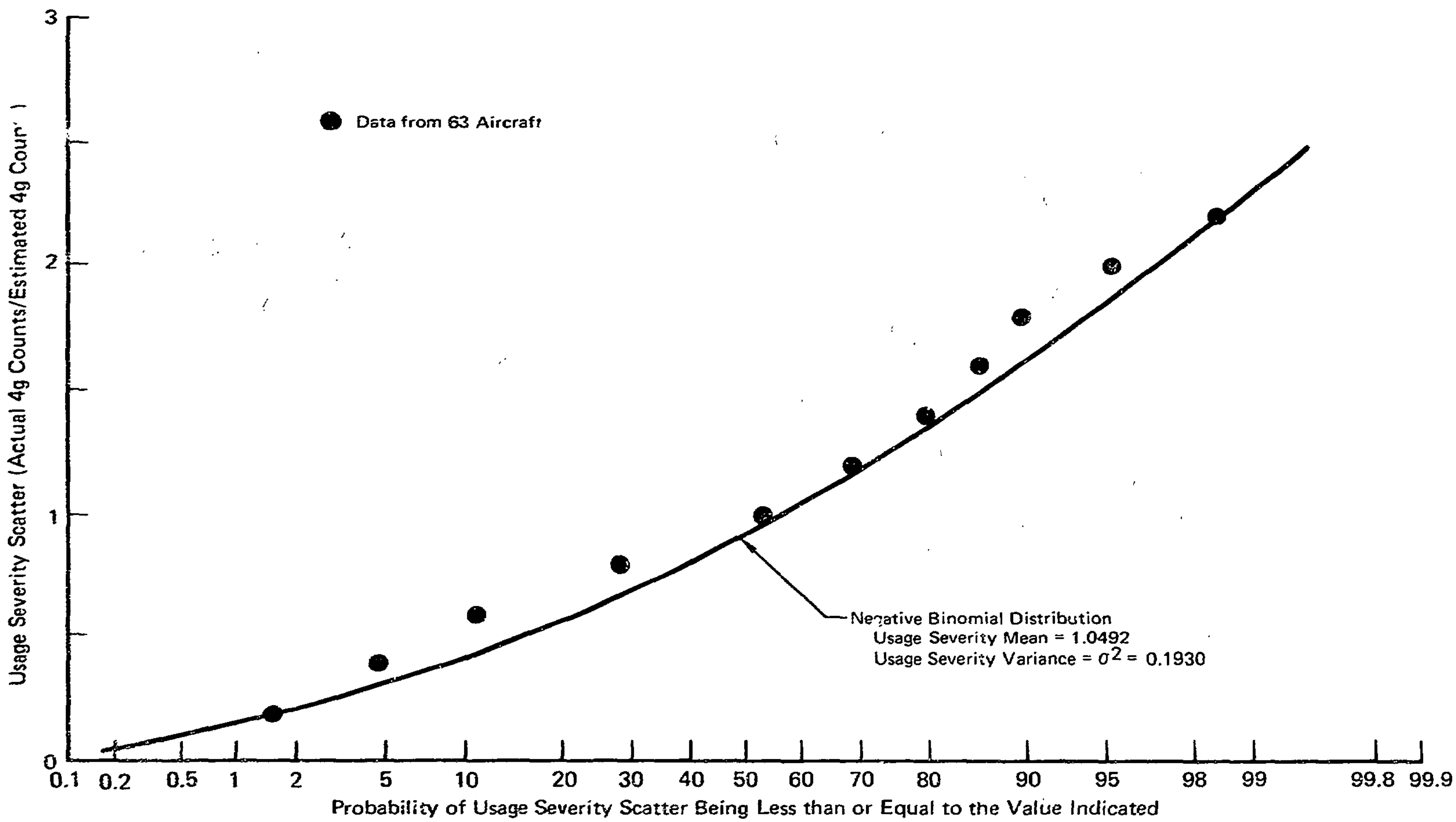


Figure 36
Comparison of Air Force 4g Usage Severity Scatter to the Negative Binomial Distribution (1500 Effective Hours)

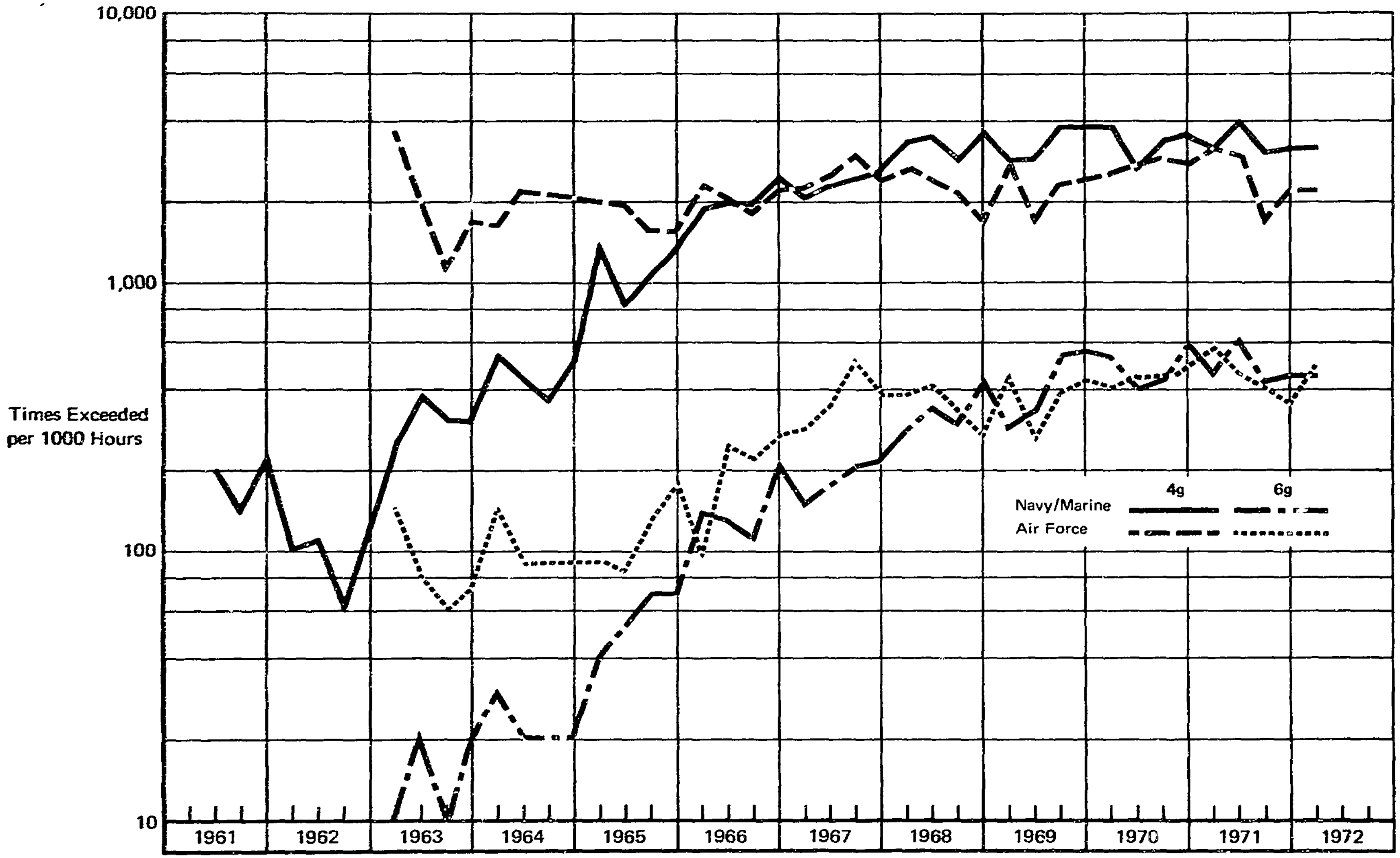


Figure 37
Load Factor Usage Variation with Time for Air Force and Navy/Marine Aircraft

rate. Scatter factors were computed at each reporting date. This factor is the ratio of the actual counts accumulated through that date divided by the estimated accumulated counts. Both the actual counts accumulated and the estimated counts reflect changes in operational usage. The actual counts, having been recorded in service operations, necessarily include changes in operational usage. The estimated counts, being computed from fleet average daily count per hour rates, reflect changes in operational usage occurring during the period in which the aircraft was in service. Thus, if an aircraft had been operating in a period in which load factor frequencies continually increased, both the actual counts and the estimated counts would exhibit corresponding increases. By taking the ratio of these counts, the effects of changes in operational usage have been removed, and the scatter is simply that between a given airplane and an average airplane in the fleet.

Although it can have a significant effect on service fatigue life, a change in operational usage is not a statistical variable and cannot, therefore, be approached on a statistical basis. In arriving at a total scatter factor, the scatter in fatigue test results and in usage can be handled statistically, but it is necessary to make a "best guess" as to how the airplane will be used in service. Changes in operational usage, although quite important, cannot be anticipated or accurately estimated during the aircraft's design phase.

3.4 Scatter in Total Hour Accumulation on Individual Aircraft

In addition to developing data and procedures for computing a design scatter factor for a preselected reliability level, it is also important to determine what should be the design life of an airplane in terms of hours or years of service operations. Data reflecting scatter in the total hour accumulation on individual F-4 aircraft have thus been investigated to obtain information which can be used to aid in establishing an aircraft's design life. The study performed and the information obtained are described in the following paragraphs.

3.4.1 Method for Evaluating Hour Accumulation Scatter - In this study, the scatter numbers computed represented the scatter between the flight hours accumulated by a given airplane and the flight hours which would have been accumulated by that airplane if it had been operating at the fleet average hour accumulation rate. Total flight hour data for F-4 airplanes are stored on the magnetic tapes which contain the F-4 counting accelerometer data.

Aircraft reporting dates and hours accumulated were read directly from the storage tapes. A daily fleet average hour accumulation rate was first established by determining the total flight hours accumulated on any given day and dividing by the total number of aircraft in the service inventory on that day. Aircraft known to not have flown were included in the inventory count in order to account for expected aircraft down-time. Scatter was then computed at each reporting date listed for every airplane. Estimated hours for individual aircraft were computed by accumulating the fleet daily average hour accumulation rates applicable for periods between reporting dates. The scatter at each reporting date was then computed by taking the ratio of the actual hours accumulated through that date divided by the estimated accumulated hours. Finally, the scatter data were scanned and evaluated and information necessary to construct histograms showing the distribution of scatter at selected intervals of years was produced.

3.4.2 Hour Accumulation Scatter Versus Years - Computer runs were made to evaluate the hour accumulation scatter exhibited by Air Force airplanes and by Navy/Marine airplanes. In the Air Force run, 1,701,964 flight hours of data accumulated by 1232 Air Force airplanes were examined. In the Navy/Marine run, 1,372,702 flight hours of data accumulted by 1114 Navy/Marine airplanes were examined. As was the case in the usage severity scatter study, the scatter in flight hours accumulated was also noted to decrease significantly with increasing time. The trend, exhibited in both the Air Force and Navy/Marine runs, indicates that flight hour usage also averages out and that aircraft placed in the fleet at the same time will tend to accumulate similar numbers of hours over a period of years.

3.4.3 Histograms of Hour Accumulation Scatter at Selected Intervals - The information necessary to construct histograms showing the distribution of hour accumulation scatter at selected year intervals was generated during the computer runs. This information for Air Force airplanes and for Navy/Marine airplanes is presented in Figures 38 and 39. It should be noted that in each 2 year interval, only one scatter value is counted for each airplane. The scatter value included is the one at the number of years closest to the midpoint of the interval. The columns thus yield the distribution of the number of airplanes with various scatter values at the number of years at the interval midpoints. The histograms plotted from the data are shown in Figures 40 and 41. Histograms for the data from the Air Force run show the

1,701,964 Total Hours of Data

Flight * Hour Scatter	Total Years in Service				
	0 to 2.00	2.01 to 4.00	4.01 to 6.00	6.01 to 8.00	8.01 to 10.00
0.0 - 0.2	3		1	1	
0.2 - 0.4	12	6	6	1	
0.4 - 0.6	48	26	9	5	
0.6 - 0.8	244	181	129	38	
0.8 1.0	284	297	292	143	
1.0 - 1.2	243	203	136	54	
1.2 - 1.4	172	117	69	16	
1.4 - 1.6	119	59	34	2	
1.6 - 1.8	54	31	15		
1.8 - 2.0	35	9	6		
2.0 - 2.2	10				
2.2 - 2.4	2				
2.4 - 2.6	3				
Total Number of Aircraft	1229	929	697	260	0

* Flight Hour Scatter = Actual Flight Hours/Estimated Flight Hours

Figure 38
Flight Hour Scatter Distribution for 1232 Air Force Airplanes

1,372,702 Total Hours of Data

Flight * Hour Scatter	Total Years in Service						
	0 to 2.00	2.01 to 4.00	4.01 to 6.00	6.01 to 8.00	8.01 to 10.00	10.01 to 12.00	12.01 to 14.00
0.0 - 0.2	7	2					
0.2 - 0.4	39	8	3	2	1		
0.4 - 0.6	68	40	31	19	9		
0.6 - 0.8	80	100	76	54	41	2	
0.8 - 1.0	131	208	166	94	57	7	
1.0 - 1.2	211	204	202	99	38	3	
1.2 - 1.4	224	129	86	37	7		
1.4 - 1.6	157	59	25	10			
1.6 - 1.8	95	26	5				
1.8 - 2.0	50	4	2				
2.0 - 2.2	24	1					
2.2 - 2.4	12						
2.4 - 2.6	6						
2.6 - 2.8	4						
2.8 - 3.0	5						
3.0 - 3.2	0						
3.2 - 3.4	1						
Total Number of Aircraft	1114	781	596	315	153	12	0

* Flight Hour Scatter = Actual Flight Hours/Estimated Flight Hours

Figure 39
Flight Hour Scatter Distribution for 1114 Navy/Marine Airplanes

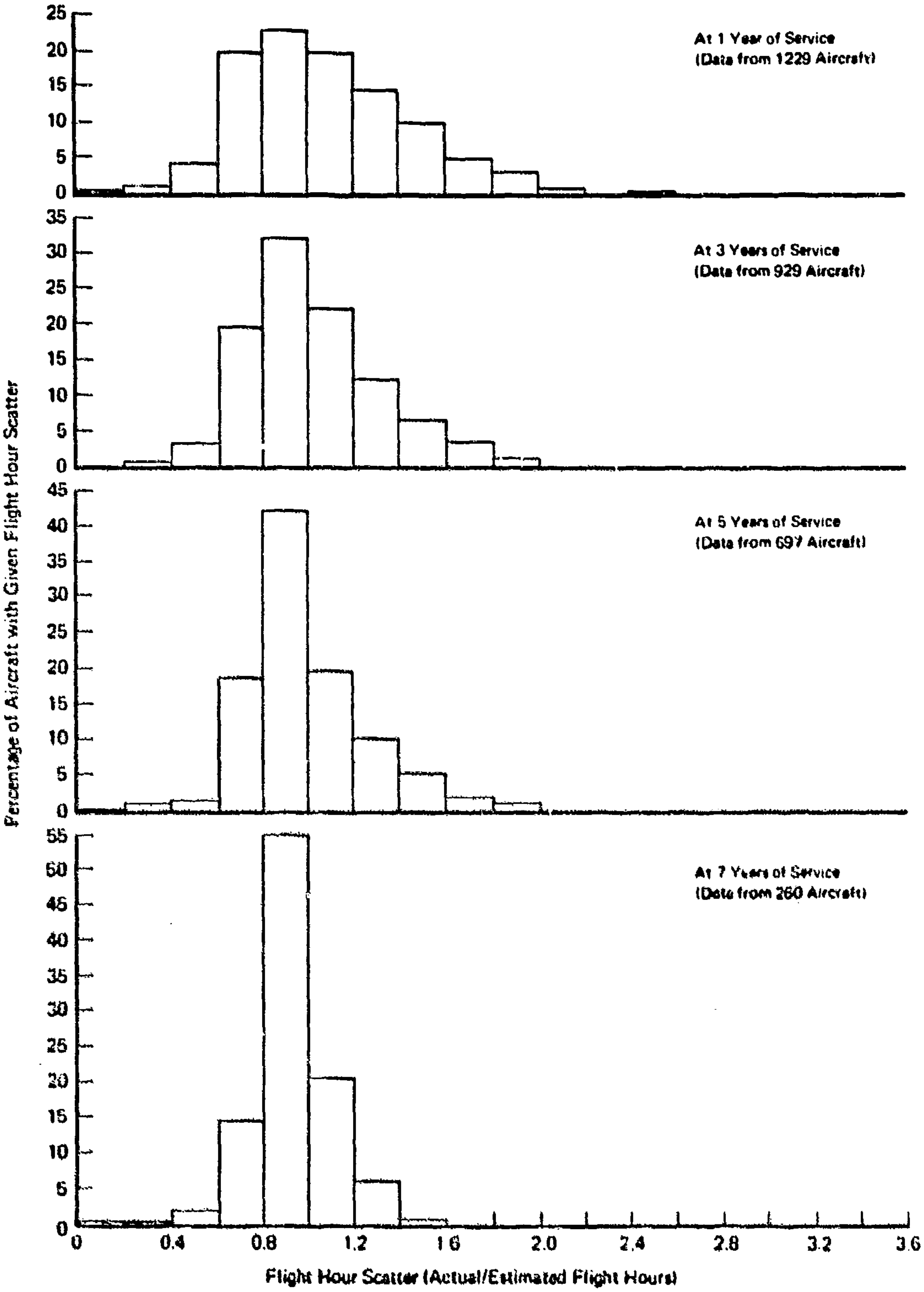


Figure 40
Percentage of Air Force Aircraft with Given Flight Hour Scatter

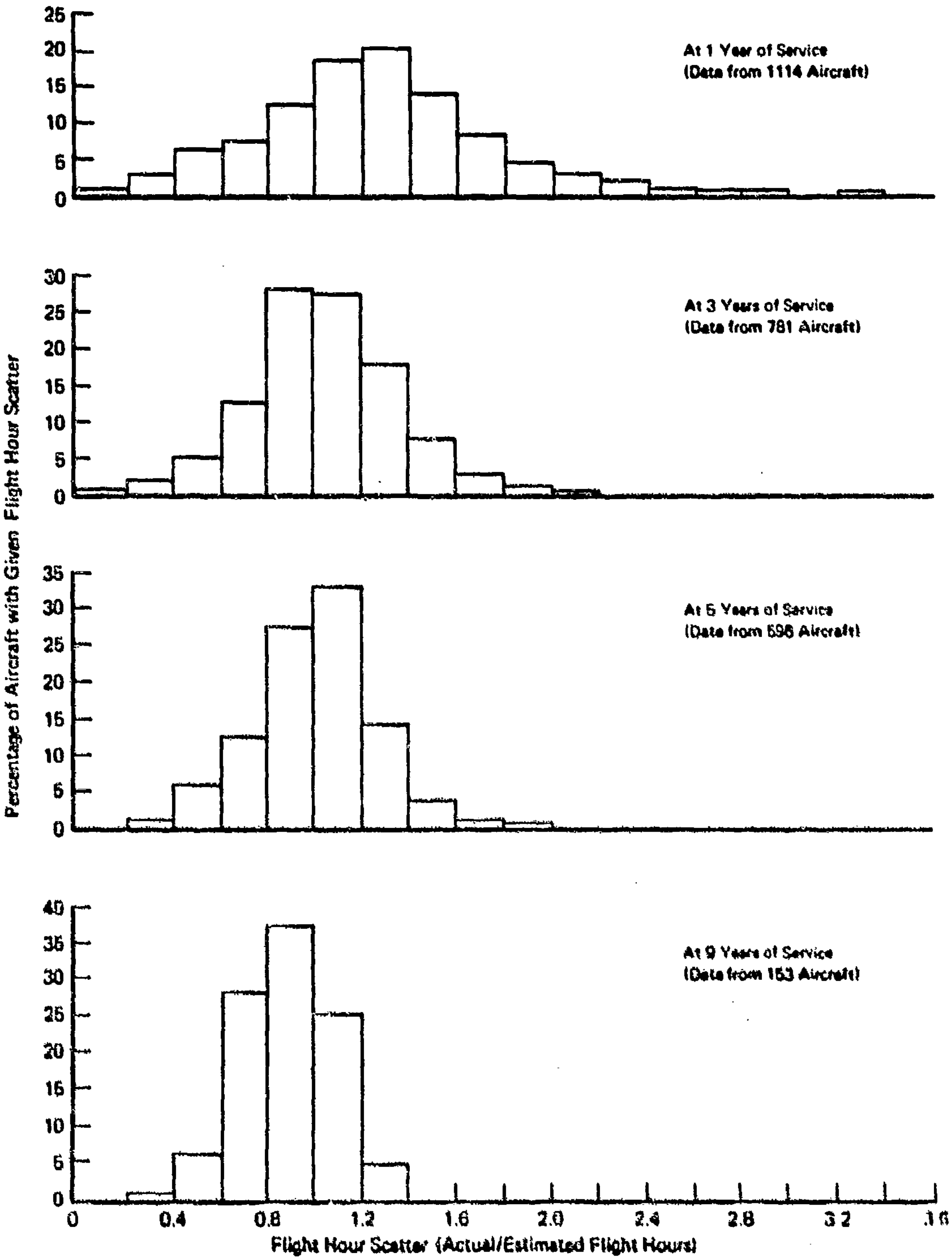


Figure 41
Percentage of Navy/Marine Aircraft with Given Flight Hour Scatter

distribution of scatter at 1, 3, 5, and 7 years. Histograms for the data from the Navy/Marine run show the distribution of scatter at 1, 3, 5, and 9 years.

3.4.4 Effects of Operations Changes on Hour Accumulation Scatter - Air Force and Navy/Marine fleet average hour accumulation rates versus time are shown in Figure 42. These curves show how F-4 hour accumulation rates have varied. As previously indicated, the hour accumulation scatter values computed herein represent the scatter between the hours accumulated by a given airplane and the hours which would have been accumulated by that airplane if it had been operating at the fleet average hour accumulation rate. Both the actual hours and the estimated hours used in computing the scatter values include operational usage change effects. The actual hours necessarily reflect changes in operational usage. Estimated hours, being computed from daily hour accumulation rates, reflect changes in operational usage occurring during the period in which the aircraft was in service. By taking the ratio, the effects of operational usage changes have been removed, and the scatter is simply that between a given airplane and an average airplane operating in the fleet during the same period. As has been noted previously, this scatter decreases with increasing time. Since usage changes have been removed, this trend of decreasing scatter indicates that aircraft placed in the fleet at the same time will accumulate similar numbers of hours during their service tours. In addition to this, however, since F-4 flight hour accumulation rates indicate that monthly hour usage is relatively invariant, the data would also indicate that all aircraft in a fleet may be expected to accumulate a similar number of hours after a like number of years in service.

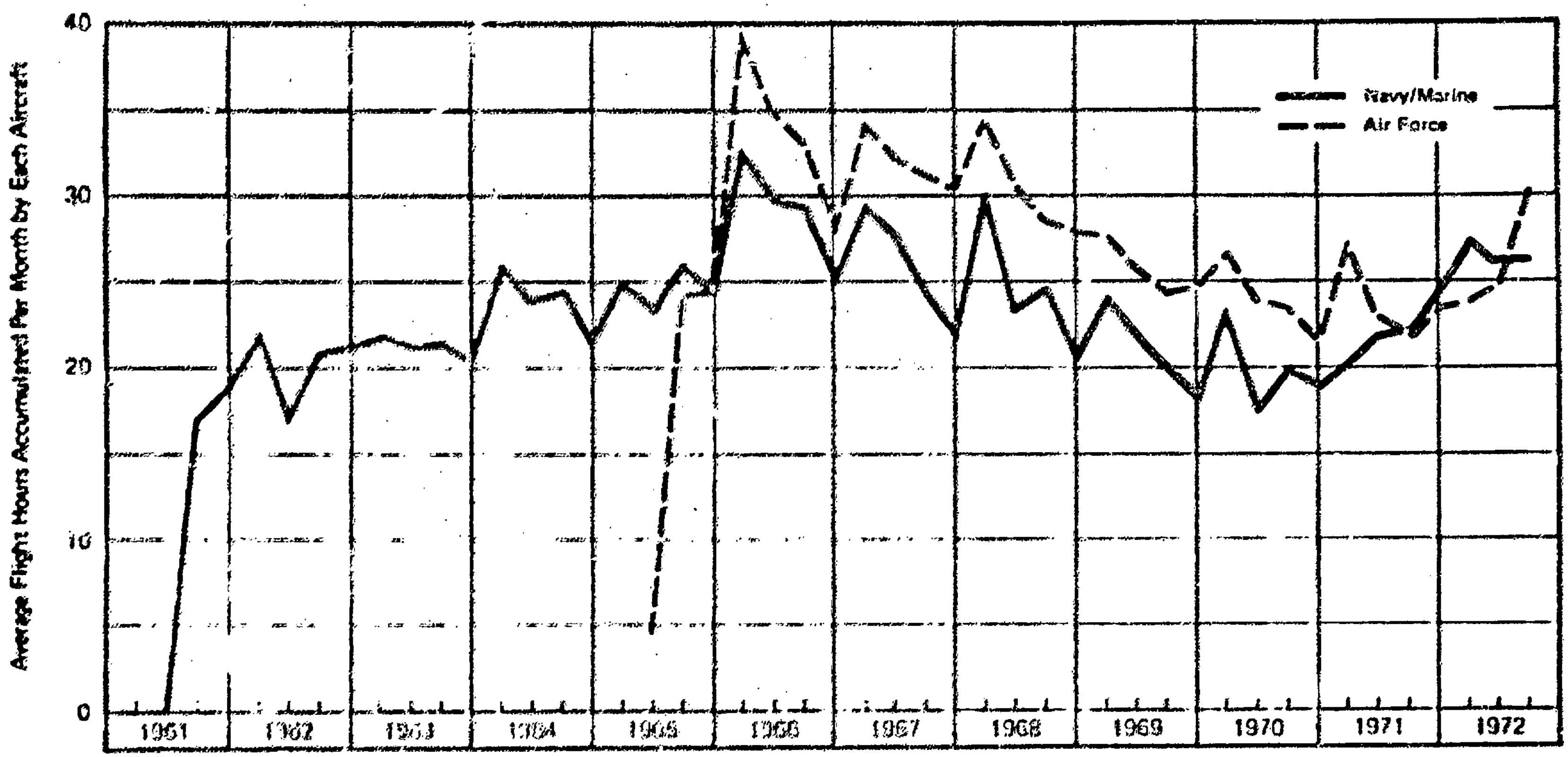


Figure 42
Flight Hour Usage Variation with Time for Air Force and Navy/Marine Aircraft

4. PHASE III - DOCUMENTATION OF LABORATORY TEST RESULTS

4.1 General

F-4 full scale laboratory fatigue testing has been conducted in a series of test programs involving five complete wing-center fuselage fatigue test articles and two half-wings. The fatigue characteristics of five fatigue critical key areas based on this laboratory testing were documented in Phase III of this program. Efforts in this area included the compilation of spectrum hours to failure and the determination of the crack growth characteristics for each key area. The key areas studied were:

(1) the wing main torque box lower skin,

(2) the outer wing lower skin,

(3) the F.S. 303 bulkhead,

(4) the wing main torque box upper skin, and

(5) the lower longeron dog bone fitting.

4.2 F-4 Fatigue Test Program History

F-4 full scale fatigue testing has been conducted in a series of test programs that have included seven full scale test articles. The test articles that have been utilized are depicted in Figure 2. The test programs, which were performed to substantiate the airframe fatigue life and to define fatique critical areas, are described briefly in subsequent paragraphs. This test history provides the information necessary to identify the laboratory failures referred to in this study.

Block 1 Test Program - The test article consisted of a center fuselage and complete wing assembly representative of the Ship 1 through 95 configuration. Test loads represented the critical loading condition for a flight gross weight of 34,500 pounds and were applied in accordance with spectrum A of MIL-A-8866. This resulted in the application of a test loading spectrum which was considerably more severe than the original design spectrum. Failure occurred at the end of the fifth load program when both R/H and L/H wings failed simultaneously at the wing root. The failures were precipitated by repeated buckling of the wing carry through auxiliary beam shear webs at high load levels. Modifications to the auxiliary beam were developed and refined in subsequent jig testing. A retrofit fix was incorporated in Ships 1 through 40 and redesigned auxiliary beams were installed effective Ship 41 and up.

Revision of Test Loads and Repeated Load Spectrum - A flight load measurement program indicated that the analytically determined loads used in the Block 1 test were conservative. The test loading distribution was revised to reflect the results of flight test measurements, but concurrently, the magnitude of test loads was increased to reflect an increase in gross weight from 34,500 pounds to 40,000 pounds. The combination of these changes increased test loads by a factor of 1.039 above the Block 1 fatigue test loading and resulted in loads representative of flight loads at critical design speed and altitude (Mach 1.1 at 25,000 ft.). In addition to the test loads revision, the load spectrum was changed from Spectrum A of MIL-A-8866 to what has come to be known as the F-4 test spectrum (the list of cycles applied in the F-4 test spectrum, which was utilized in all subsequent fatigue testing, is presented in Figure 43). This combination of changes resulted in a test spectrum which was also considerably more severe than the original design spectrum.

Block 1 R/H Remnant Wing Test - The R/H remnant wing from the Block 1 fatigue test article was jig supported (critical loads simulated outboard of B.L. 80) and spectrum testing was continued using the F-4 test spectrum and loads (40,000 pounds gross weight, Mach 1.1 at 25,000 ft.). Failure occurred in the wing main torque box lower skin at B.L. 100 (fatigue critical area shown in Figure 44) after 400 additional spectrum hours.

Block 1 L/H Remnant Wing Test - A lower wing skin reinforcing strap (retrofit fix for Ships 1 through 95) was installed on the L/H remnant wing from the Block 1 fatigue test article and testing was continued as in the R/H remnant wing test. Testing was discontinued after 9300 spectrum hours without a catastrophic fatigue failure.

Block 6 Test Program - The test article consisted of the Block 1 test fuselage and a new 1 through 95 wing with redesigned auxiliary beams. Test loads were applied in accordance with the F-4 test spectrum and loads (40,000 pounds gross weight, Mach 1.1 at 25,000 ft.). Four hundred spectrum hours were applied prior to installation of the lower wing skin reinforcing strap to simulate possible service history experienced by airplanes prior to the reinforcement. Testing was discontinued after the completion of 4200 spectrum hours without a catastrophic fatigue failure.

Block 8 Test Program - The test article consisted of a new center fuselage and a wing representative of Ship No. 96 and up (primary modifications consisting of increased strength in lower skin). Test loads were applied in accordance with the F-4 test spectrum and loads (40,000 pounds gross weight, Mach 1.1 at 25,000 ft.). Failure of both wings occurred simultaneously in the fatigue critical area at B.L. 100 (same location as R/H remnant wing failure as shown in Figure 44) after 2700 spectrum hours.

MAXIMUM LOAD * (% TEST LIMIT LOAD)	CYCLES PER 100 SPECTRUM HOURS
35	1200
45	910
55	550
65	315
75	137
85	67
95	16
103	4
111	1
118	.2

* Minimum load equals 15.4% test limit load except minimum load equals 0.0% test limit load on every 15th cycle

Figure 43
List of Cycles Applied in the F-4 Test Spectrum

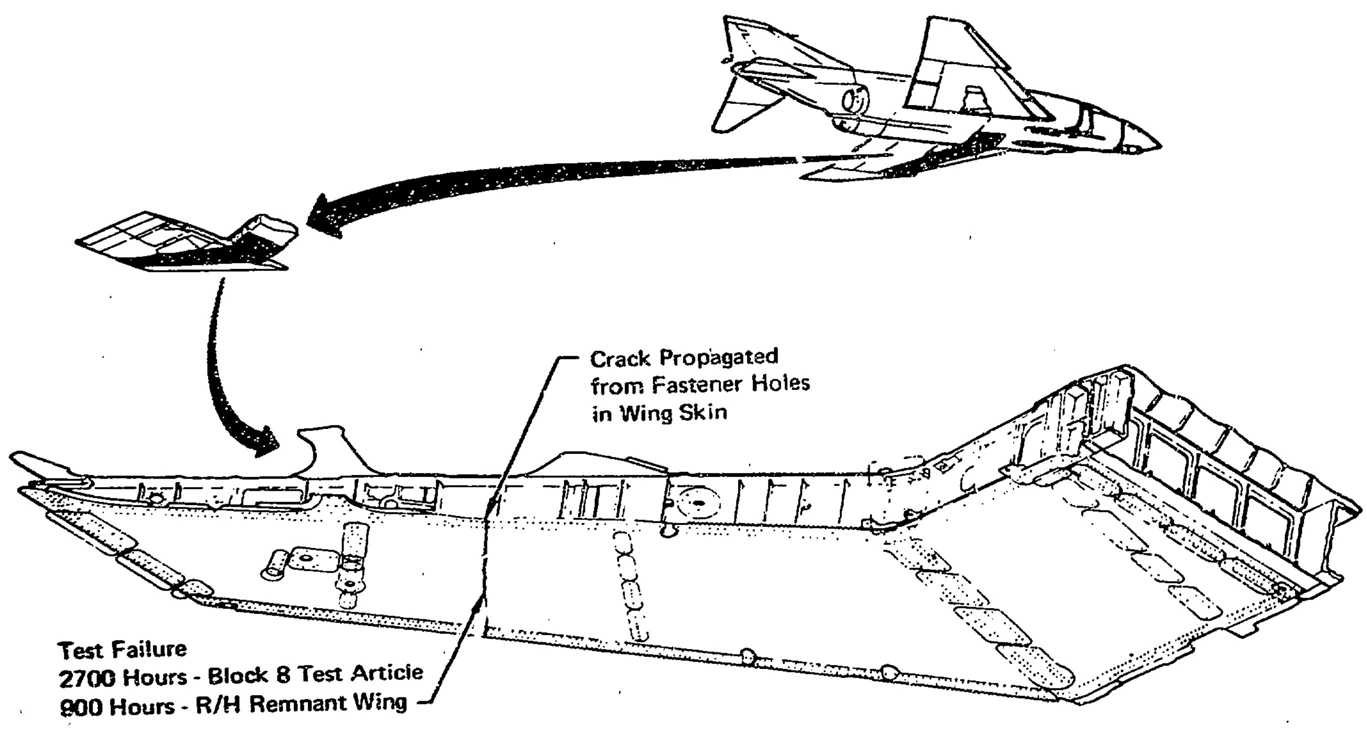


Figure 44
Failure Location - R/H Remnant Wing and Block 8 Test Article

ECP-613 Test Program - This test program was initiated to demonstrate that the F-4 test life could be extended from 2700 to 6000 spectrum hours by installing Taper-Lok fasteners in the lower wing skin fatigue critical area. The test articles consisted of two full scale aircraft:

(1) F-4B Test Article - Representative of early aircraft with 7079-T6 spars, ribs, and 7075-T651 bulkheads, and with conventional fasteners installed in the fatigue critical area in production.

(2) F-4J Test Article - Representative of higher effectivity aircraft with 7075-T73 spars, ribs and bulkheads. R/H wing representative of aircraft with conventional fasteners installed in the fatigue critical area in production and the L/H wing representative of aircraft with Taper-Lok fasteners installed in the critical area in production.

Test loads were applied in accordance with the F-4 test spectrum and loads (40,000 pounds gross weight, Mach 1.1 at 25,000 ft.). After approximately 1700 spectrum hours, Taper-Lok fasteners were installed in the fatigue critical area of the F-4B test article wings and in the critical area of the R/H wing of the F-4J test article (1700 spectrum hours applied to simulate possible service history experienced by airplanes prior to incorporation of Taper-Lok retrofit fix). Testing of both test articles was discontinued following the completion of 6000 spectrum hours without catastrophic failure.

FSCP 46 Extension - This testing was conducted to determine whether the Taper-Lok installation could extend the test life of the F-4B test article used in the ECP-613 test program to 8000 spectrum hours. Cycling of the test article was continued in the same manner as in the ECP-613 test program except cycles in the 35%, 45%, and 55% load levels of the F-4 test spectrum were not applied. Cycling of the test article was discontinued following the completion of 8000 spectrum hours without catastrophic failure.

FSCP 60R1 Extension - This testing was conducted to determine whether the test life of the F-4B test article utilized in ECP-613 and FSCP-46 testing could be extended to 12000 spectrum hours. Cycling was continued in the same manner as in the FSCP 46 extension. Testing of the article was discontinued after 11800 spectrum hours when the L/H wing failed catastrophically. This failure was found to have originated at the pylon fitting hole in the wing main torque box lower skin at B.L. 132.50.

4.3 Compilation of Test Results

Locations of the five fatigue critical key areas and photographs of typical damage detected in the laboratory are shown in Figures 45 through 53. Detailed lists of fatigue damage detected in each of the five areas are presented in Figures 54 through 59.

4.4 Electron Microscopic Examinations of Fatigue Fracture Surfaces

The markings on a fatigue fracture surface represent successive positions of the crack front. Electron microscopy provides the means for correlating this crack growth to the loading history. Crack growth curves generated during microscopic examinations thus define the fatigue characteristics of components in terms of times to crack initiation, crack detection, and complete rupture.

Fracture surfaces from each of the five key areas were examined using the electron microscope. Crack growth curves generated for the critical areas in the wing main torque box lower skin, in the F.S. 303 bulkhead, and in the outer wing lower skin, are presented in Figures 60 through 62. Attempts to obtain crack growth data from fracture surfaces from the wing main torque box upper skin and from two lower longeron dog bone fittings did not prove to be successful. These areas are loaded in compression, and although cracks developed due to residual tensile stresses, subsequent compressive cycles damaged the fracture surfaces to such an extent that crack growth could not be determined.

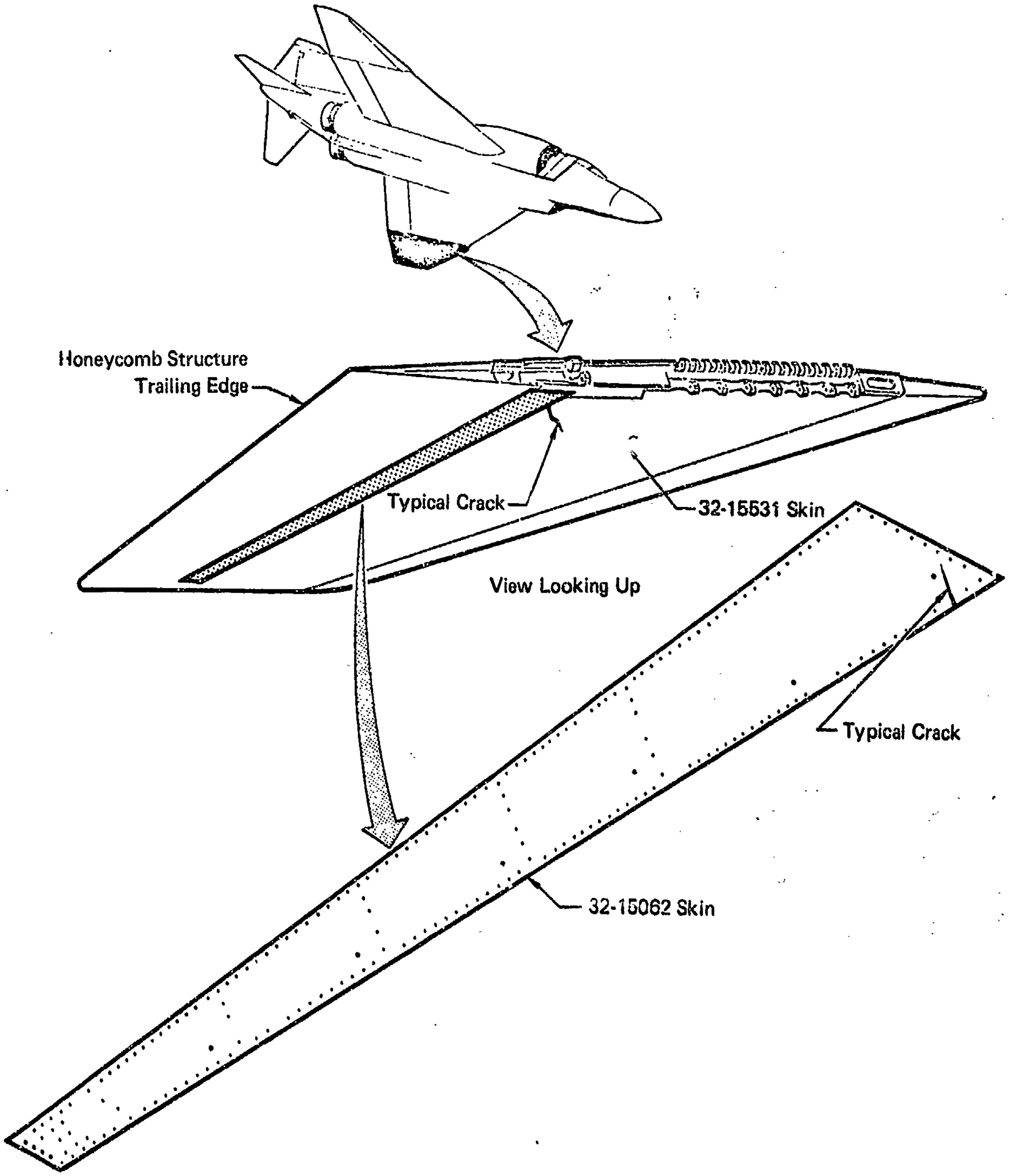


Figure 45
32-15062 and 32-15531 Outer Wing Lower Skins

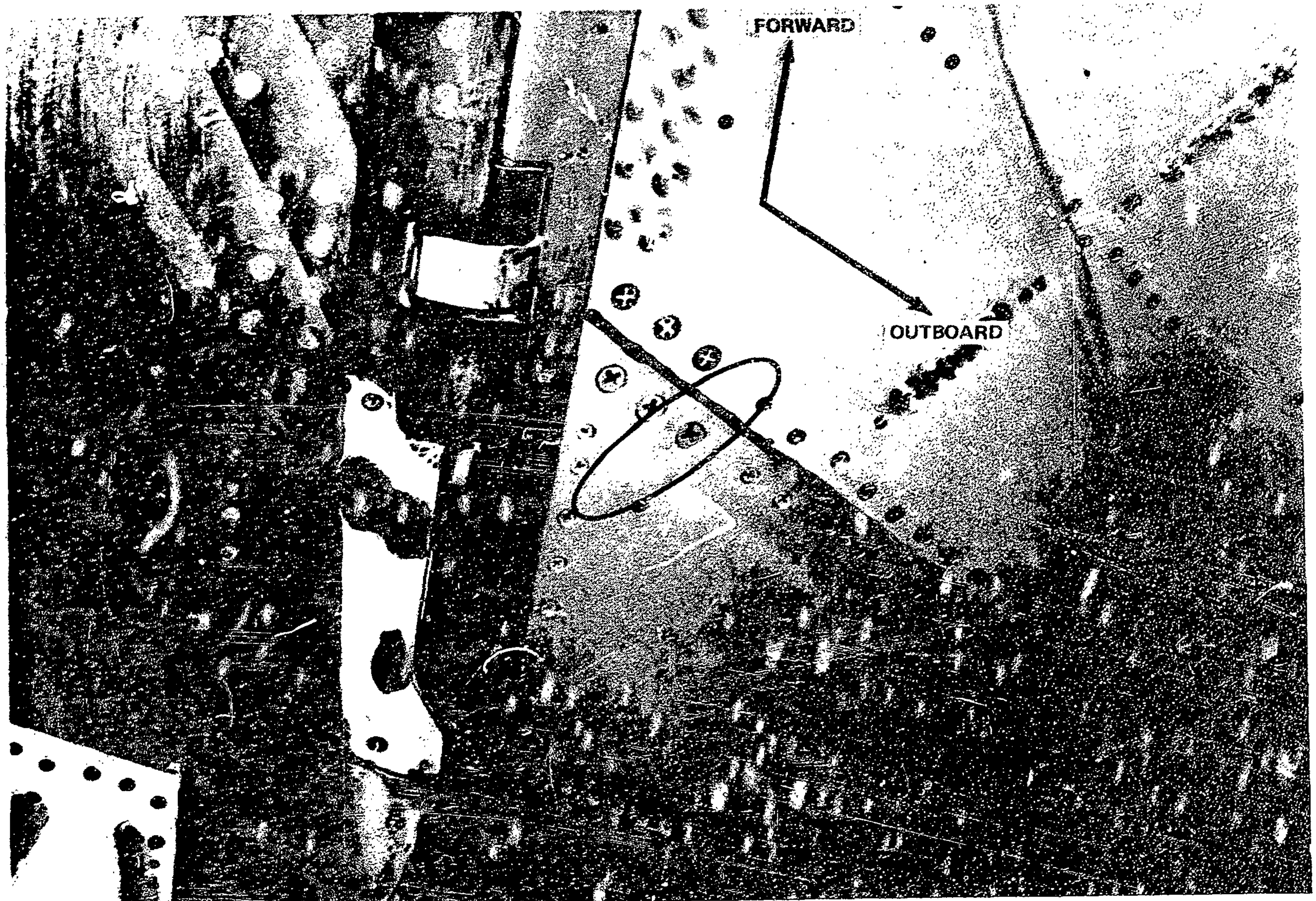


Figure 46
Typical Outer Wing Lower Skin Failure

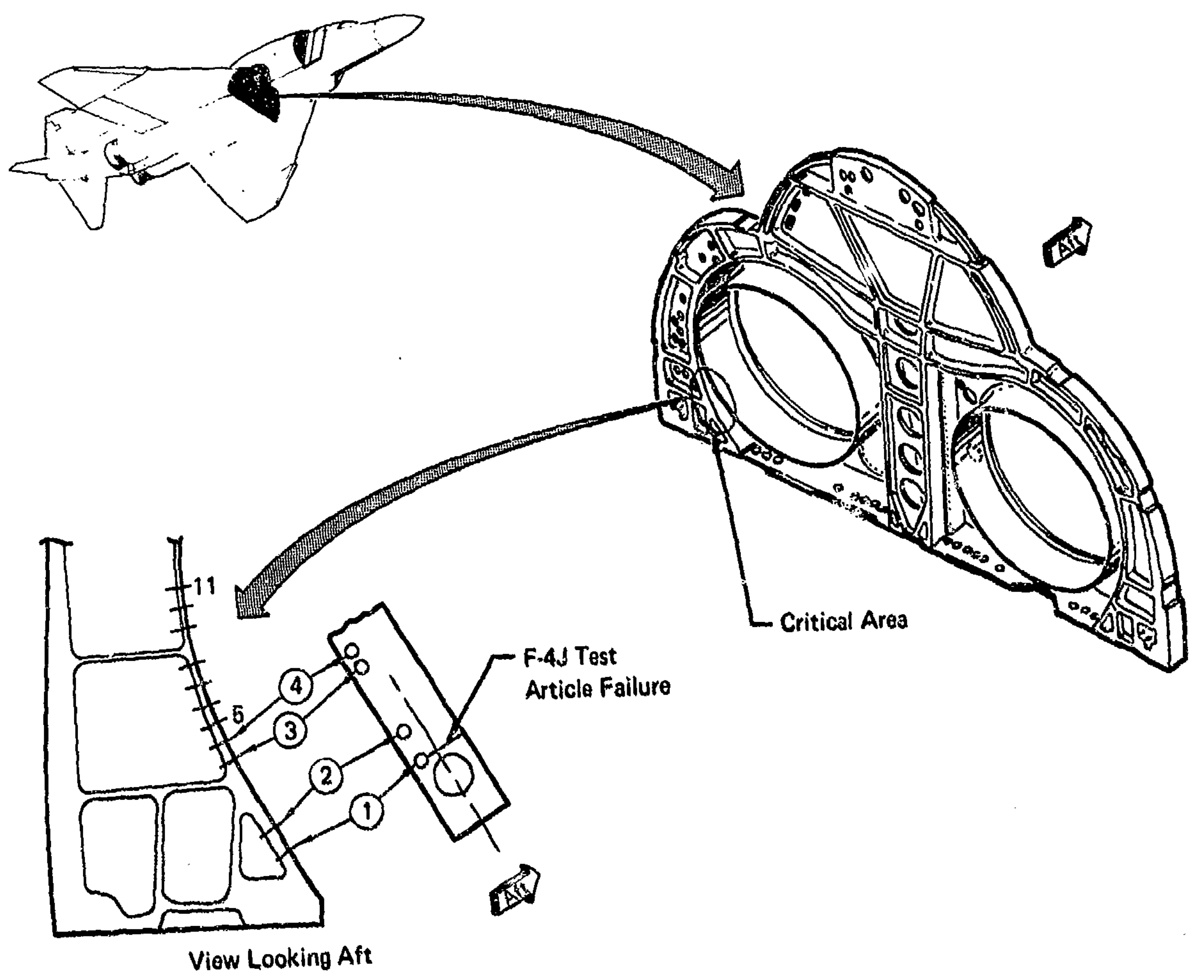


Figure 47
Fuselage Station 303 Bulkhead

GP73-0438-19

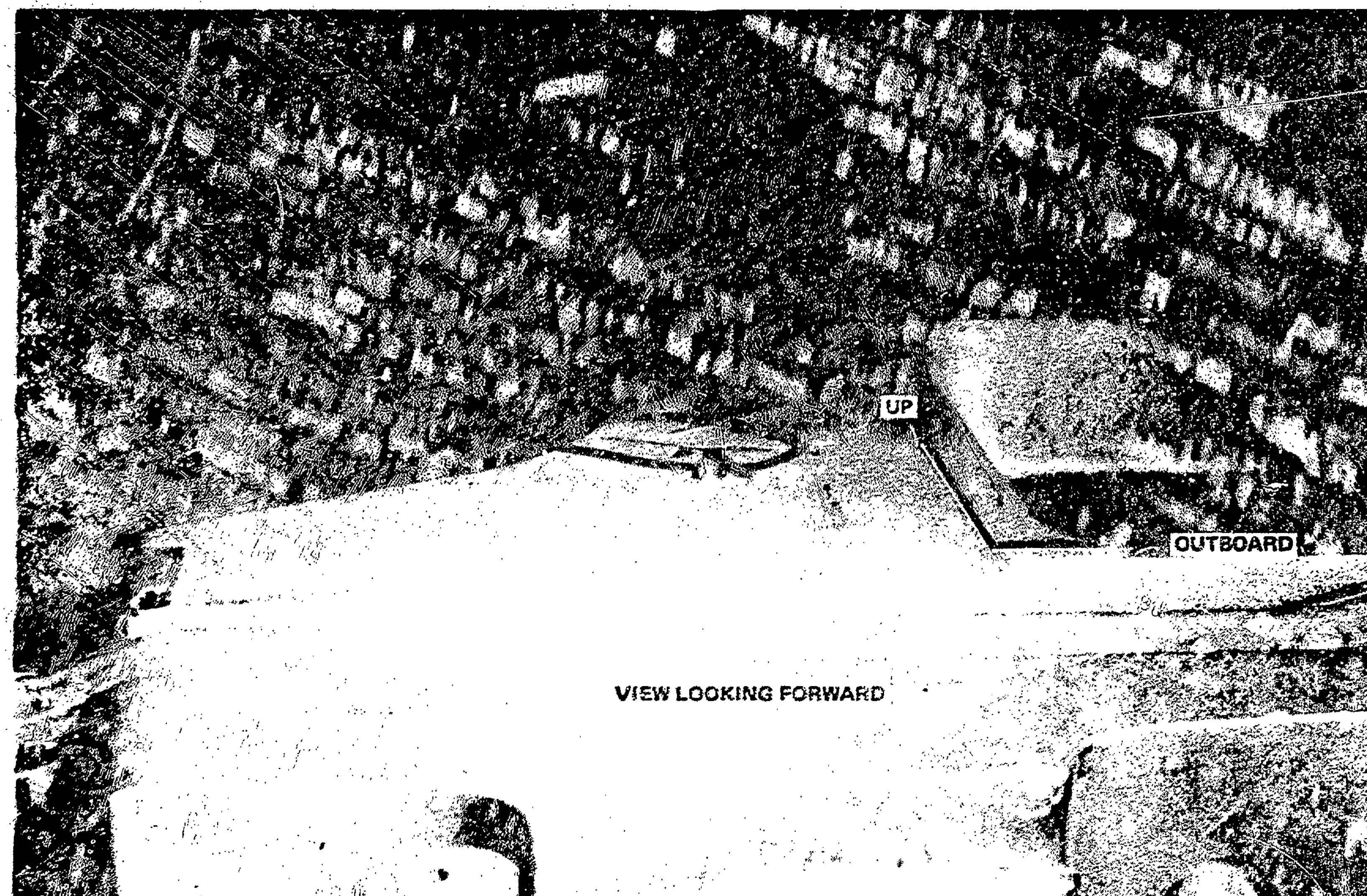


Figure 48
Fuselage Station 303 Bulkhead Failure F-4J Test Article

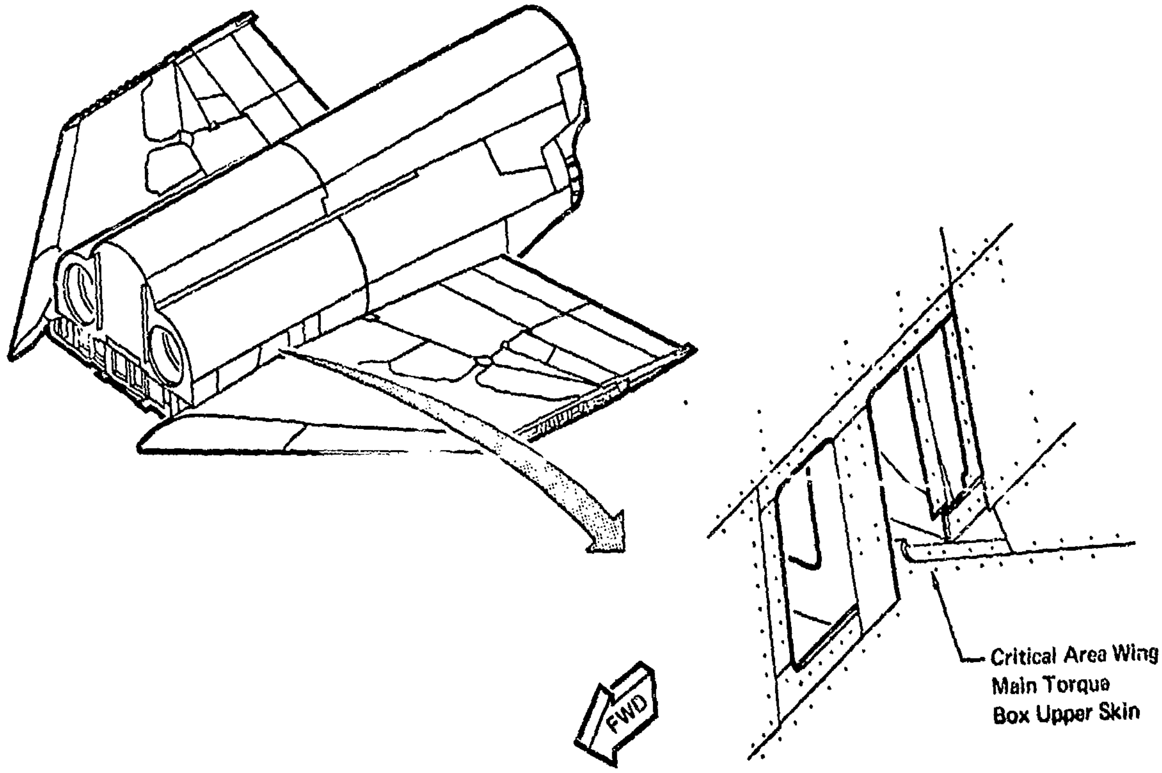


Figure 49
Wing Main Torque Box Upper Skin at Wing Root

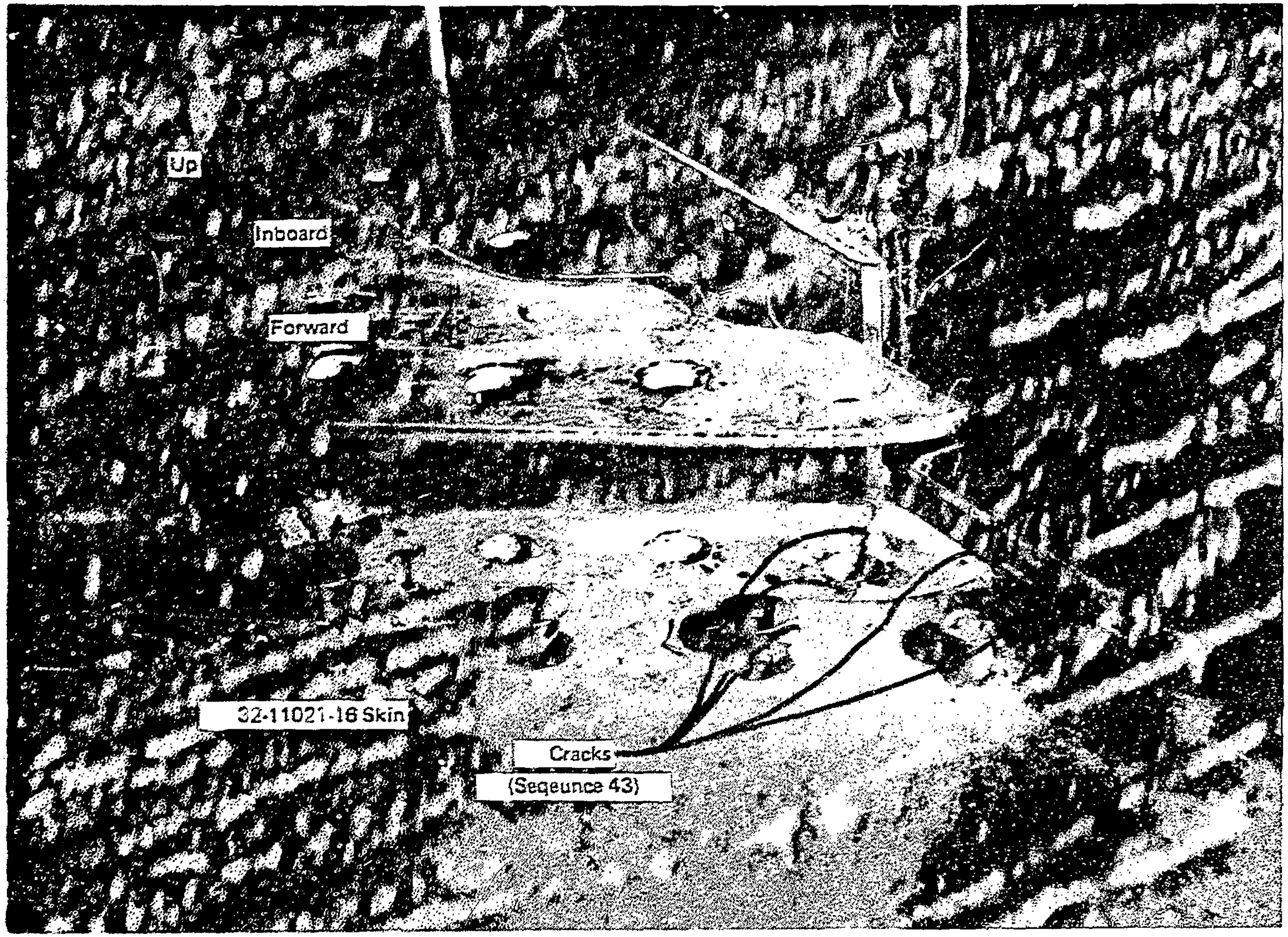


Figure 50
Upper Torque Box Wing Skin Failure
Block 8 Fatigue Test Article

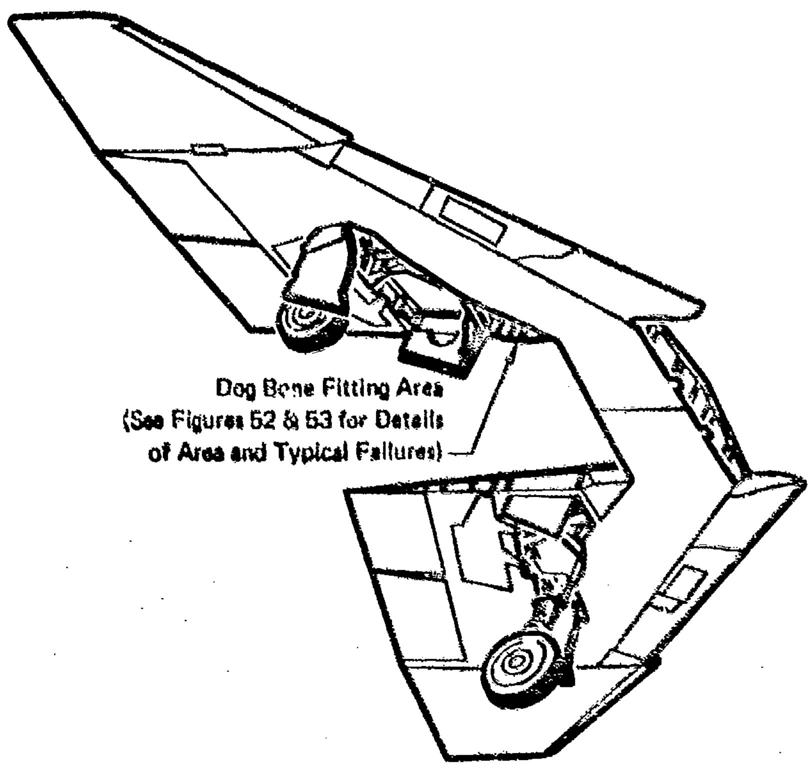


Figure 51
Dog Bone Fitting (Lower Longeron Splice Fitting)

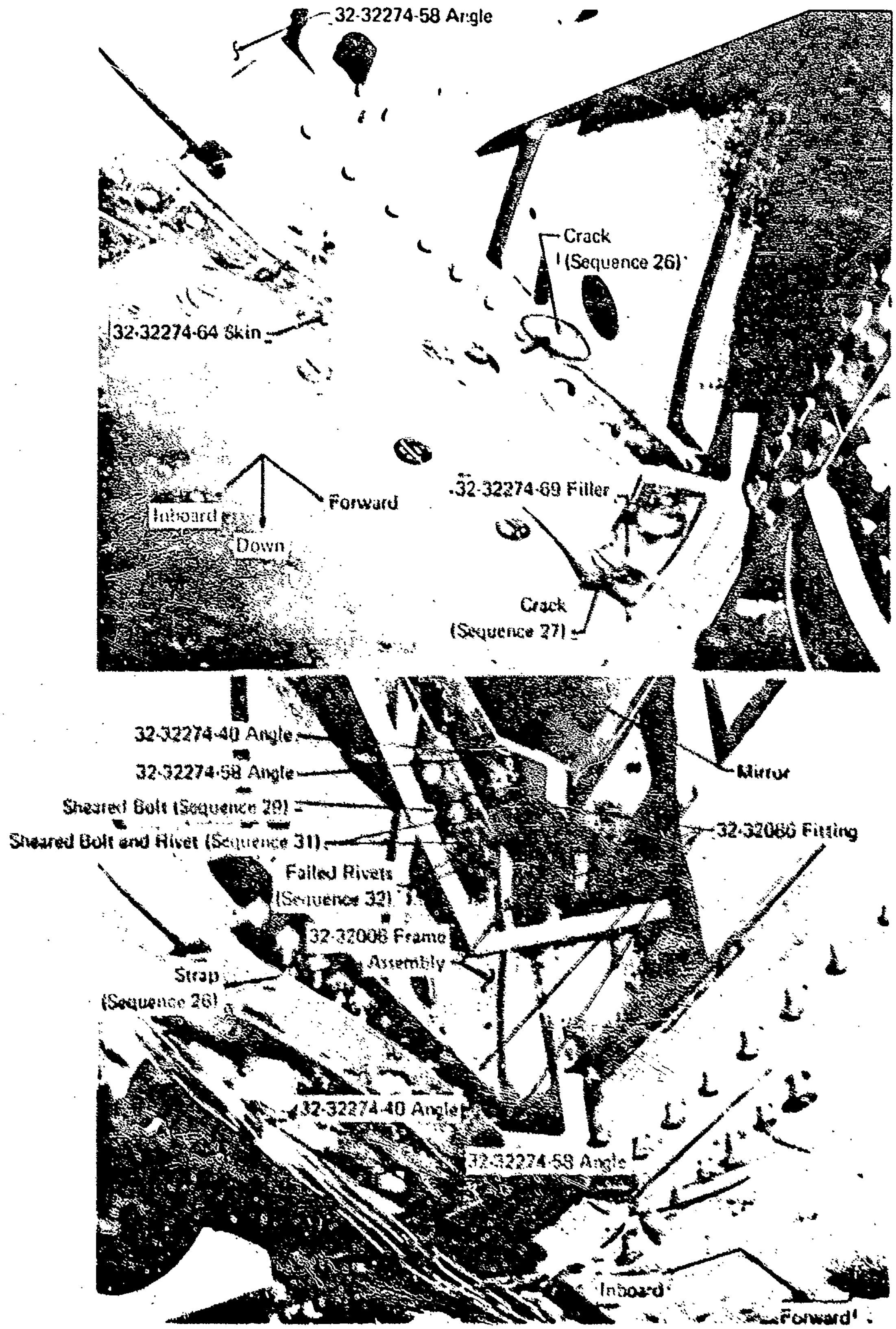


Figure 52
Details of Dog Bone Fitting Area

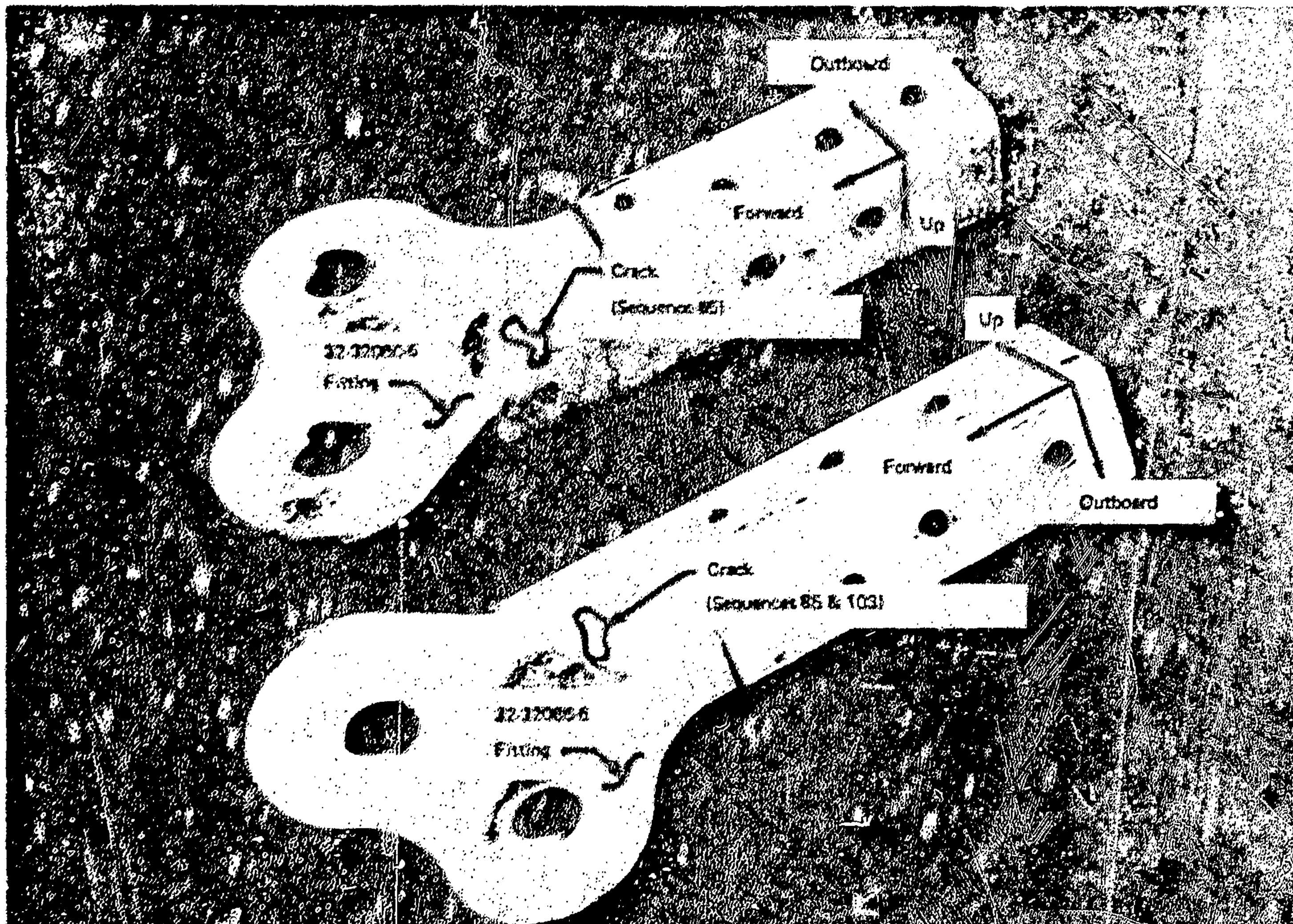
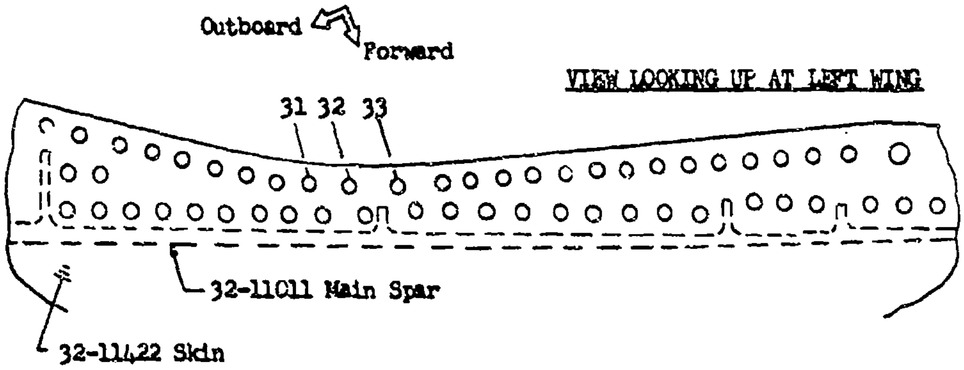


Figure 63
Dog Bone Fitting Failures Block 8 Fatigue Test Article



TEST ARTICLE	CRACK DETECTED AFTER BLOCK NO. ①	CRACK DETECTED IN HOLE NO. ②③	REMARKS
R/H Remnant	9	32 R/H	Wing failed catastrophically. Origin of failure was fatigue crack in Hole No. 32.
Block 8 Test Article	27 27	31 L/H 31 R/H	L/H and R/H wings failed simultaneously. Cracks precipitating failures originated in holes 31 L/H and 31 R/H.
F-4B Test Article	16 17	33 R/H ④ ⑤ 31 L/H ④ ⑤	④ Cracks detected by Eddy Current Inspection. ⑤ Reamed oversize after Block No. 17 and taper-lok fasteners installed.
F-4J Test Article	15 17	31 R/H ④⑤ 33 R/H ④⑤	

① 100 Spectrum Hours Per Block
② All Cracks Detected in 32-11422 Skin
③ Hole Numbers Correspond to Taper-Lok Retrofit Hole Identification Numbers

Figure 54
List of Failures Detected in the Wing Main Torque Box Lower Skin at BL 100 in Laboratory Testing

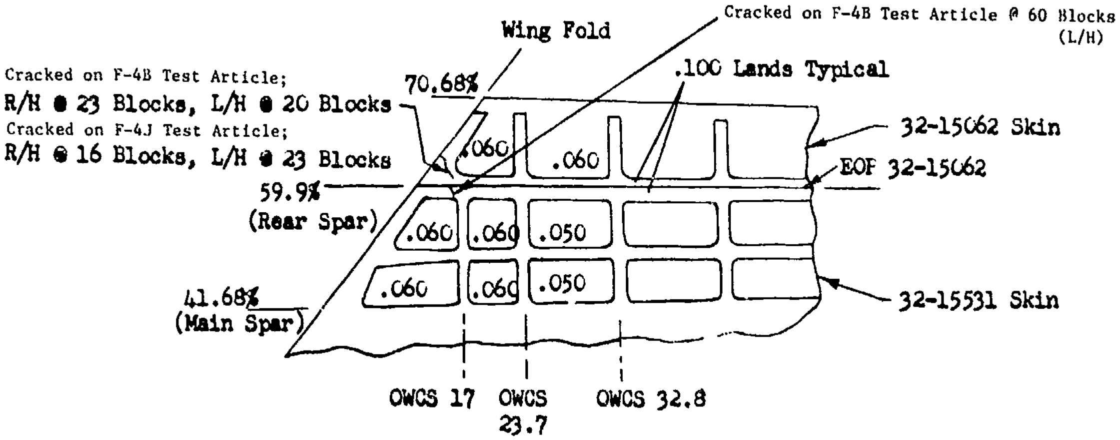
TEST ARTICLE	DATA SOURCE REFERENCE	FAILURE NUMBER	PART NUMBER ①	FAILURE DETECTED AFTER BLOCK NUMBER ②③	BLOCKS TO FAILURE ②	REMARKS	ACTION
L/H Remnant Wing	9	8	32-15531-5	46.6	46.6	Cracked	Doubler Installed
	9	10	32-15062-3	52	52	Cracked	Doubler Installed
	9	11	32-15531-5	69.8	69.8	Cracked	Doubler Installed
	9	14	32-15531-5	80.3	80.3	Numerous Cracks Detected	No Action
Block 6 Test Article	10	60	32-15531-7	42	42	Cracks Found Eminating From Two Fastener Holes	No Action - Testing Terminated
Block 8 Test Article	11	89	32-15531-12	20	20	Cracked	Doubler Installed
F-4J Test Article (Block 26 & Up Configuration)	12	12	32-15062-6	16	16	Cracked	Crack Stop Drilled and Doubler Installed
	12	25	32-15062-5	23	23	Cracked	Crack Stop Drilled and Doubler Installed
F-4B Test Article (Block 26 & Up Configuration)	13	16	32-15062-5	20	20	Cracked	Doubler Installed
	13	20	32-15062-6	23	23	Cracked	No Action
	Unreported		32-15531-13	60	60	Cracked	Doubler Installed
F-4B Test Article (Block 26 & Up Configuration)	14	4	32-15062-6	73	-	Crack Detected in Test Article Following Block 23	Crack Stop Drilled and Doubler Installed

① Odd dash numbers installed on L/H side of airplane, Even dash numbers installed on R/H side of airplane.

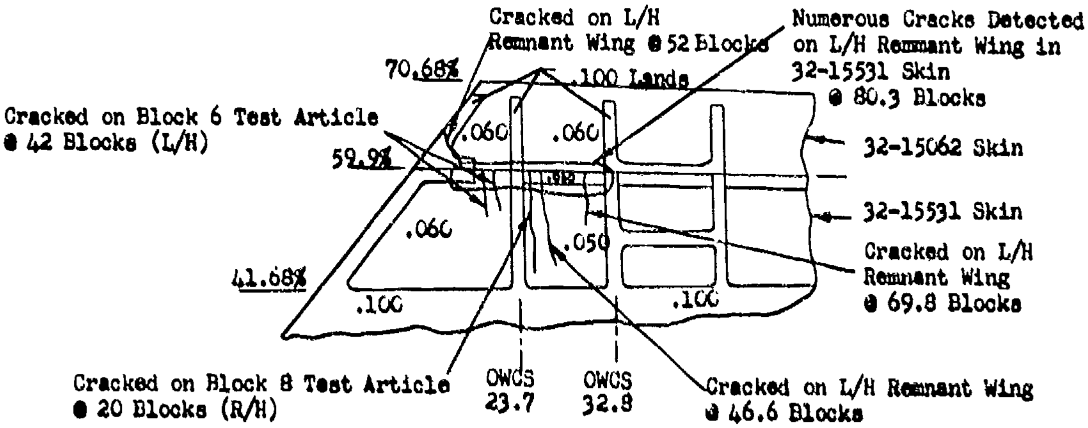
② 100 Spectrum hours per block

③ See Figure 56 for descriptions of failures

Figure 55
List of Failures Detected in the 32-15062 and the 32-15531 Outer Wing Lower Skins in Laboratory Testing



CONFIGURATION TYPICAL OF BLOCK 26 AND UP AIRCRAFT



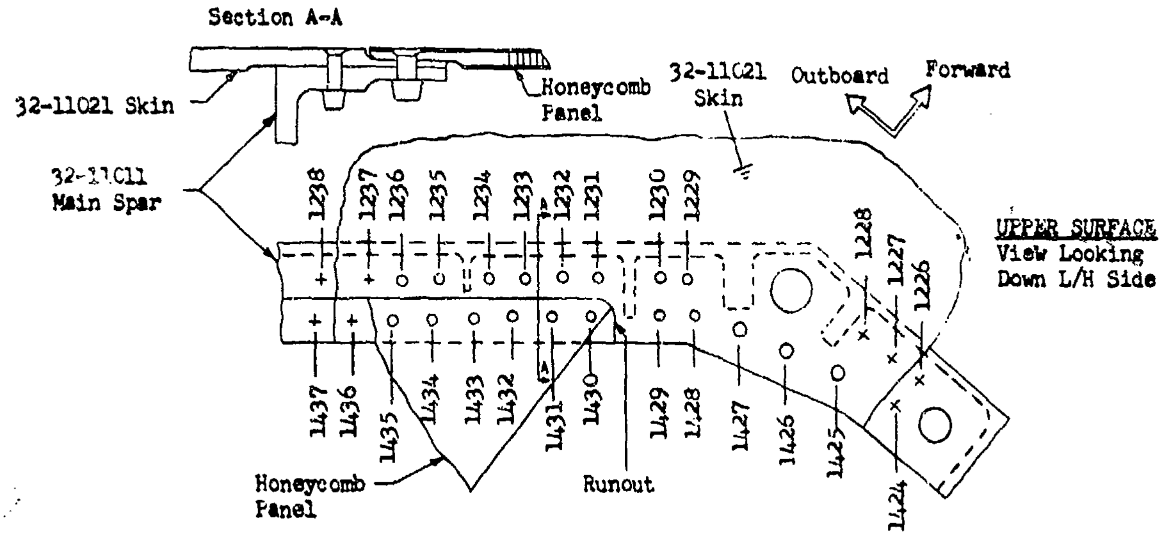
CONFIGURATION TYPICAL OF AIRCRAFT BELOW BLOCK 26

Figure 56
Summary-Outer Wing Lower Skin Fatigue Cracks

Test Article	Failure Detected (1) After Block Number	Failure Detected (2) In Hole No.	Crack Indication (3) L/H	Crack Indication (3) R/H	Remarks
Block 6 Test Article	42	1	X	X	Inspection performed following completion of testing
	42	2		X	
F-4B Test Article	73 (4)	1	X (5)	X (5)	(4) First eddy current inspection performed after block 73
	80	2		X	
	80	3	X	X	(5) Holes reamed and oversize fasteners installed.
	80	4	X		
	80	5		X	
	80	11		X	
F-4J Test Article	52	1	X (6)	Visible (7) Failure	(6) Hole reamed and oversize fastener installed.
	60	2	X		
	60	3	X		(7) Large Crack - Initiated at 16 Blocks Failed at 52 Blocks Damaged section removed, Steel section spliced in.
	60	4	X		

(1) 100 spectrum hours per block
(2) see Figure 47 for hole locations
(3) cracks detected by eddy current inspection unless noted

Figure 57
List of Failures Detected in the FS 303 Bulkhead in Laboratory Testi



TEST ARTICLE	CRACKS DETECTED AFTER BLOCK NO. (1)	HOLE	CRACK LOCATIONS (2) R/H WING SKIN	R/H WING SPAR	L/H WING SKIN	L/H WING SPAR
Block 8 Test Article	8		In Runout		In Runout	
Block 8 Test Article	9		In Runout		In Runout	
		1430	X	X	X	X
		1431		X		
F-4B Test Article	60	1430	X			
F-4B Test Article	80	1429	X		X	
		1432	X			
		1433	X		X	
F-4B Test Article	118	1229	X		X	
		1230	X			
		1430			X	
		1431			X	
		1434	X			
F-4J Test Article	60 (3)	1428				X
		1429			X	X
		1430	X		X	X
		1431			X	

(1) 100 Spectrum Hours Per Block
(2) Hole Numbers Correspond to Hole Identification Numbers Used During Inspections for Fatigue Cracks During Testing
(3) Detected After 60 Blocks and 2000 Simulated Landings in Airplane Drop Test Program.

Figure 58
List of Failures Detected in Wing Main Torque Box Upper Surface at Wing Root in Laboratory Testing

TEST ARTICLE	DATA SOURCE REFERENCE	DATA SOURCE FAILURE NUMBER	PART NUMBER (1)	FAILURE DETECTED AFTER BLOCK NUMBER (2)	BLOCKS TO FAILURE (2)	REMARKS	ACTION
Block 6 Test Article	10	12	32-32086-5	6	6	Cracked	Replaced
	10	13	32-32086-6	7	7	Cracked	Replaced
	10	26	32-32086-5	15	9	Cracked	Replaced
	10	27	32-32086-6	15	8	Cracked	Replaced
	10	40	32-32086-6	21	6	Cracked	Replaced
	10	46	32-32086-6	26	5	Cracked	Replaced
	10	47	32-32086-5	28	13	Cracked	Replaced
	10	57	32-32086-6	35	9	Cracked	Replaced
Block 8 Test Article	11	85	32-32086-5	19	19	Cracked	Replaced
	11	85	32-32086-6	19	19	Cracked	Replaced
	11	103	32-32086-6	26	7	Cracked	Replaced
F-4J Test Article	12	57	32-32086-2	37	37	Cracked	No Action
	12	69	32-32086-2	42	-	Broken	Replaced
	12	92	32-32086-2	56	14	Cracked	No Action
F-4B Test Article	13	29	32-32086-2	33	33	Cracked	Replaced
	13	35	32-32086-1	34	34	Cracked	Replaced
	13	50	32-32086-1	42	8	Cracked	Replaced During Block 45
	13	54	32-32086-2	48	15	Cracked	No Action
	13	59	32-32086-1	50	5	Cracked	No Action
F-4B Test Article	14	2	32-32086-1	73	-	Broken	Replaced
	14	2	32-32086-2	73	-	Broken	Replaced
F-4B Test Article	15	4	32-32086-1	85	12	Cracked	No Action
	15	4	32-32086-2	85	12	Cracked	No Action

(1) Odd dash numbers installed on L/H side of airplane, Even dash numbers installed on R/H side of airplane.

(2) 100 Spectrum hours per block

Figure 59
List of Failures Detected in the 32-32086 Lower Longeron Dog Bone Fitting in Laboratory Testing

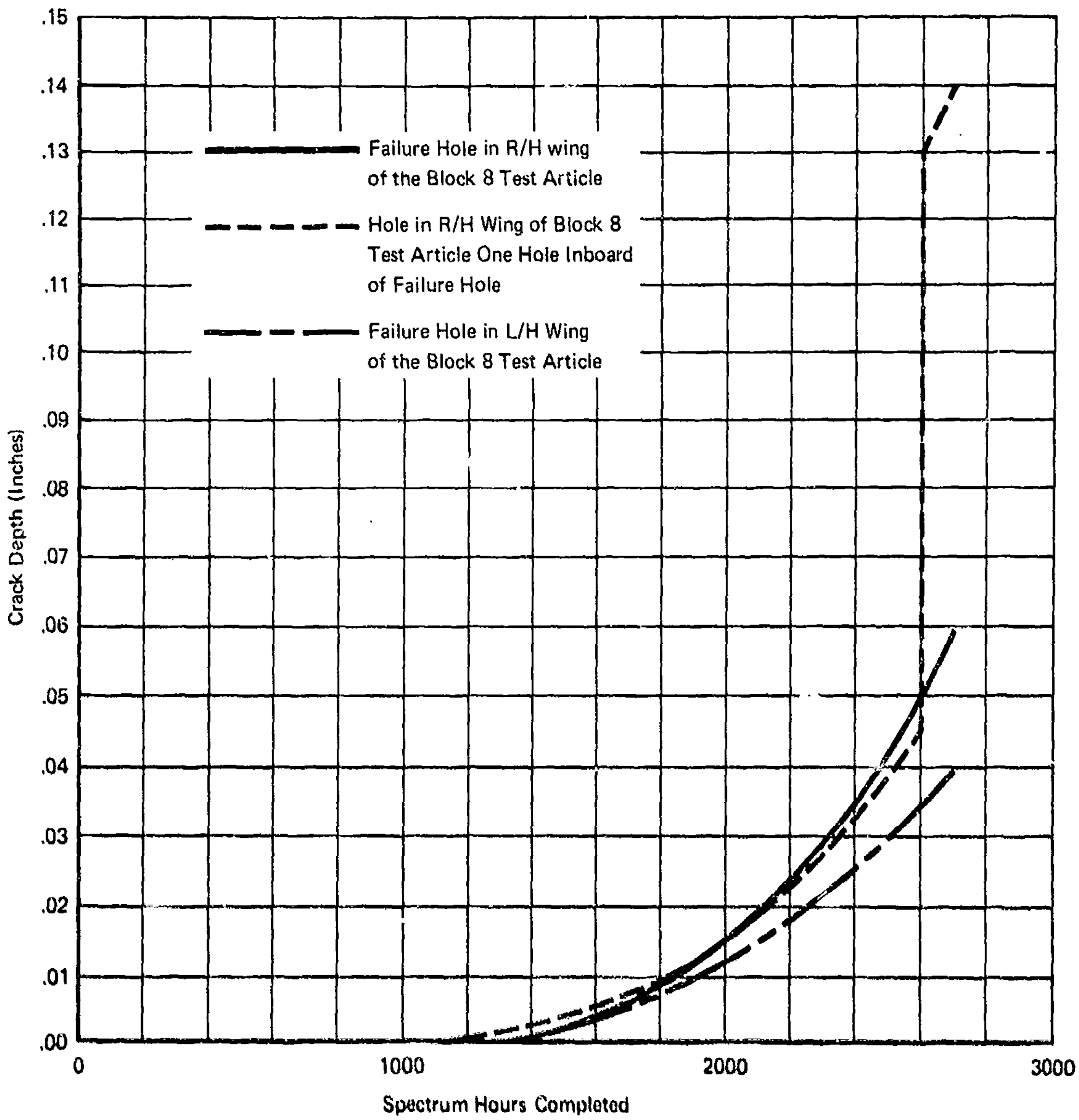
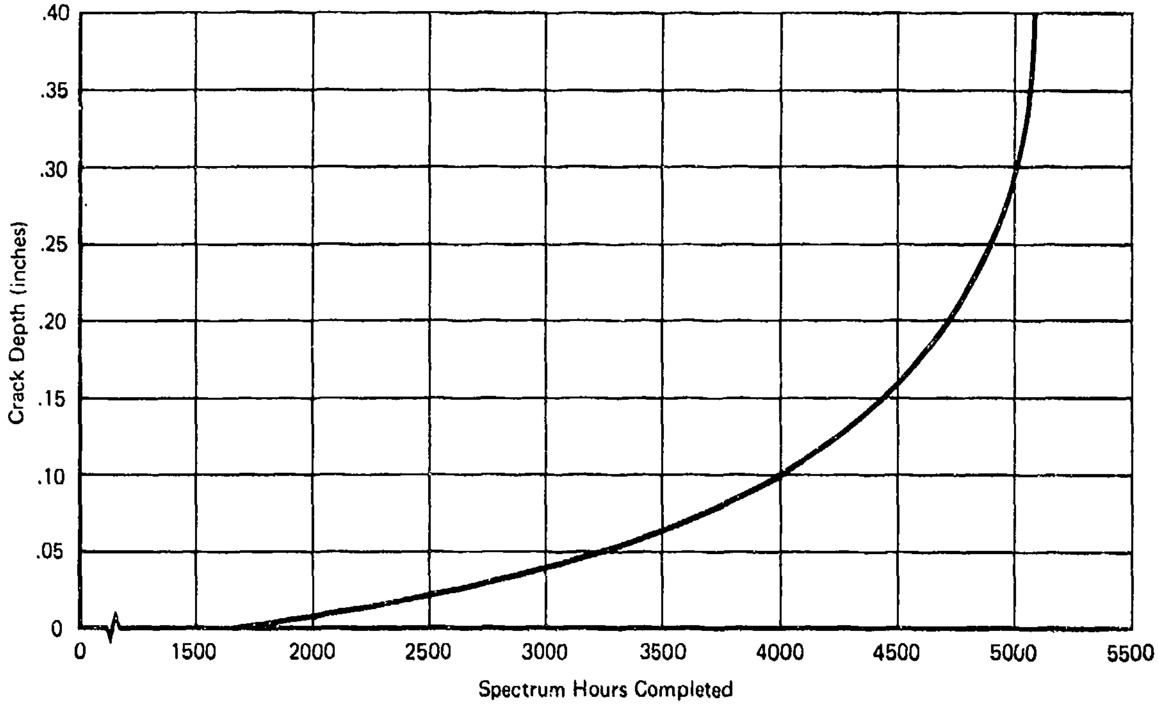
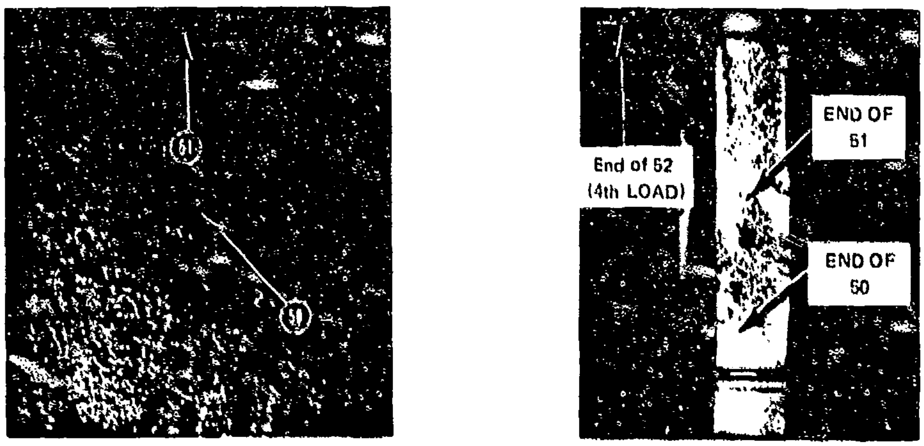


Figure 60
Crack Growth Curves for Key Area in Wing Main Torque Box Lower Skin

Crack Growth Curve



View of Failed Section



Failure Detected after 52 Blocks in R/H Side of
F-4J Test Article

Figure 61
Crack Growth Curve for Key Area in the FS 303 Bulkhead

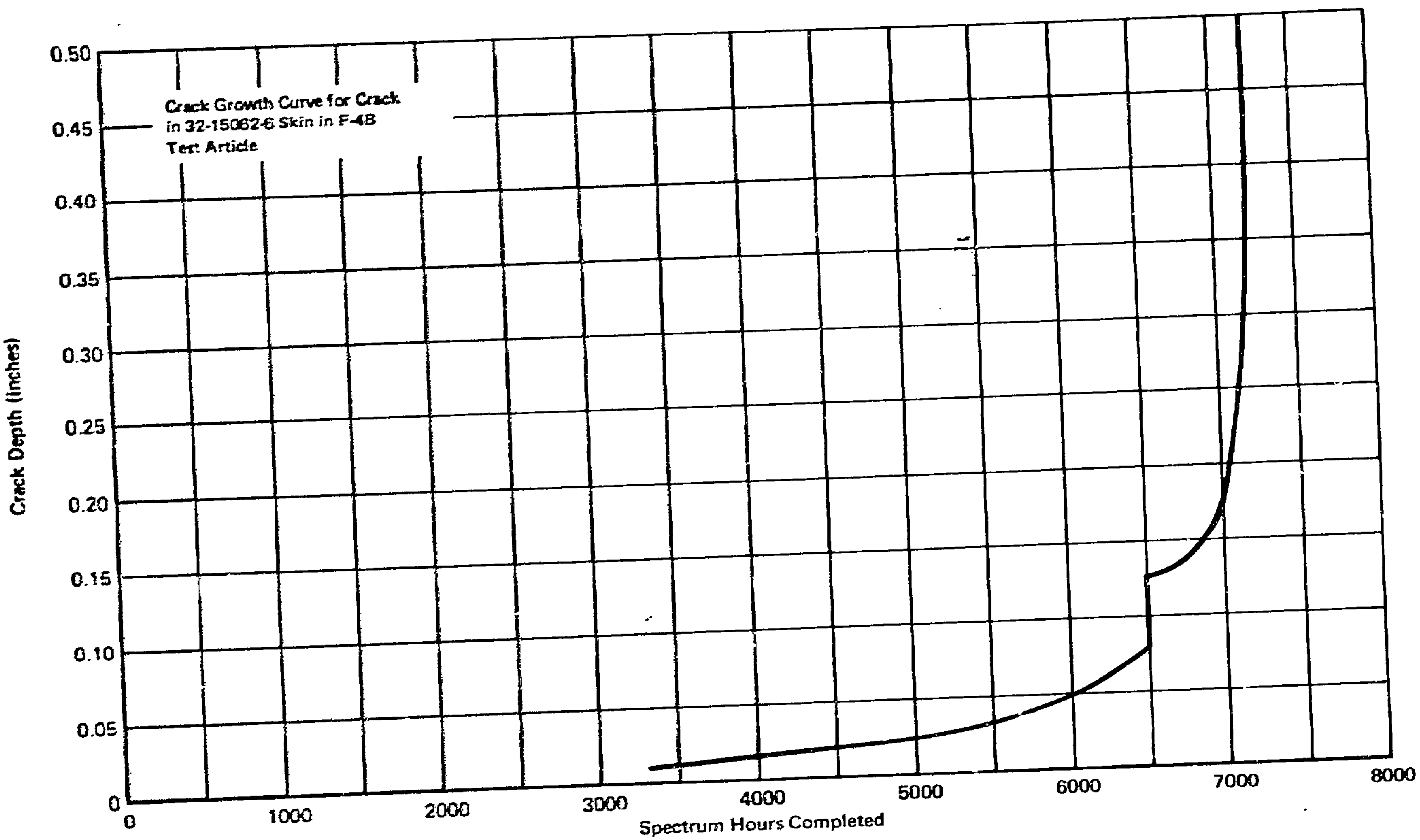


Figure 62
Crack Growth Curve for Key Area in Outer Wing Lower Skin

5. PHASE IV - LAB AND SERVICE FAILURE CORRELATION

5.1 General

The correlation of laboratory and service experience for the fatigue critical key areas was performed in Phase IV of this program. This work included compiling data on fatigue cracks detected in service aircraft for comparison with laboratory test results compiled in Phase III, evaluating the degree of simulation of the service loading environment in laboratory testing, and comparing the service experience to life predictions based on all the data gathered in the first three phases. The combination of fatigue test results scatter and loads usage severity scatter into a joint scatter factor was a major part of this effort.

5.2 Compilation of Service Failures

Lists showing the service experience for each of the five key areas discussed in Phase III are presented in Appendix IV. These lists were compiled based on studies of MCAIR in-house aircraft inspection records and supplemental information obtained from the Air Force and the Navy. As may be noted, the lists include information on demonstration team aircraft (Blue Angels and Thunderbirds) as well as fleet airplanes, and information on aircraft in which fatigue cracks were and were not detected. The lists of aircraft with cracks were developed mainly from the MCAIR records of incidents of reported fatigue cracks. The lists of aircraft inspected in which no cracks were detected were developed mainly from the information obtained from the services. This information, i.e., that used in preparing the lists of aircraft in which no cracks were detected, is discussed in the following paragraphs.

For the critical area in the wing main torque box lower skin, the list reflecting crack free performance in service operations was developed based on hole inspection records compiled by the Air Force during performance of F-4 Taper-Lok retrofit operations. Taper-Loks are being installed in this area of the wing main torque box lower skin as a result of the full scale laboratory test program discussed in Section 4.2. Crack inspection information sheets were obtained from the Air Force for 474 airplanes in which Taper-Lok fasteners were installed in the wing main torque box lower surface at B.L. 100 on a retrofit basis. An examination of the data sheets from these aircraft revealed 462 airplanes in which all fastener holes were free of crack indications. These are the 462 aircraft listed in Figure IV-1 of Appendix IV. There were data sheets on twelve aircraft in which indications of some sort of discrepancy were noted for one or more fastener holes. The sheets were not clear, however, as to whether there were fatigue cracks in the fastener holes or not. In general, it would appear that what was described was probably a scratch or an indication of a stress corrosion crack since the location of the discrepancy in the hole did not correspond to where fatigue cracking would be expected. Efforts were expended in an attempt to substantiate whether or not the twelve aircraft in question contained fatigue cracks at retrofit. Although no positive information could be obtained on the particular twelve aircraft, conversations with cognizant personnel at the repair facility indicated that fatigue cracks were not detected on any aircraft during the retrofit operation. Since the results of the twelve inspections could not be verified, the aircraft were not included in this study and data from the aircraft are not presented herein.

In the case of the critical area in the lower surface of the outer wing, the lists reflecting crack free performance were developed based on an outer wing inspection of Air Force airplanes in March 1970. The results reported to MCAIR were by bases and included the number of aircraft checked and the Bureau Numbers of airplanes in which cracks were detected (the aircraft with cracks are included in the list of failures). MCAIR records of aircraft stationed at the various bases at that time were examined to determine the airplanes that were inspected and found to be crack free. These aircraft are the ones listed in Figure IV-4 of Appendix IV.

For the critical area in the F.S. 303 bulkhead, the list of fleet aircraft indicating crack free performance in service operations is composed primarily of aircraft inspected by the Navy (a small portion of this list and the lists of failures and of demonstration team aircraft with no cracks were developed from data from a limited number of bulkhead inspections conducted by MCAIR). As a result of testing, MCAIR proposed certain modifications for the F-4 including a modification of the F.S. 303 bulkhead incorporating an eddy current examination prior to rework. This modification of the bulkhead was approved by the Navy for the rework of a selected number of F-4B's and F-4J's. A limited number of airplanes have been inducted for repair and are currently being reworked. None of these aircraft have been found to contain cracks. These airplanes are the ones comprising the bulk of the list in Figure IV-7 of Appendix IV.

5.3 Correlation of Laboratory and Service Loadings

The development of reliability procedures for estimating time to early failure on fighter aircraft was the basic objective of this program. The material presented in the following section provides a quantitative evaluation of methods developed toward this end. In this final phase, service life predictions are compared to the actual service failures. The life predictions are based on data gathered in the first three phases, i.e., laboratory test results, counter and VGH data, and usage and fatigue test results scatter information. The comparison itself is on the basis of equivalent laboratory test hours and not in terms of actual flight hours at failure. This type of comparison attempts to account for the differences between the laboratory and service loading environments.

In laboratory testing, all efforts are directed toward attaining the best possible simulation of the loading experienced by the aircraft in service. The problem of cost, however, as it always does, necessitates that simplified test approaches actually be utilized. For the F-4 laboratory test condition chosen, major structural components (e.g., the lower wing skin) were loaded in much the same way that they are loaded in service. The loading was an approximation, however, and as a result, other areas may not have been loaded in exactly the same manner as in service operations. The F-4 outer wing is subjected to buffeting and small amplitude vibrations in service. This was not simulated in the laboratory testing. The lower longeron dog bone fitting and the wing main torque box upper surface are primarily subjected to compressive loads; failures in these areas result from the inducement of residual tensile stresses. The dog bone fitting and upper surface failures, therefore, depend very much on when high loads are applied.

For the reasons noted above, and also because of changes in operational usage, laboratory test hours and service flight hours could not be correlated on a one to one basis for any of the key areas considered herein. Such a flight hour correlation would not be exactly correct for either the wing main torque box lower skin or the F.S. 303 bulkhead, and would be particularly inaccurate for the outer wing lower skins, the lower longeron dog bone fittings, and the wing main torque box upper surface at the root. Fatigue analysis, element test results, flight loads measurements, and full scale test results information have thus been used to correlate the laboratory and service failure experience. Fatigue analysis procedures were formulated to calculate fatigue damage such that $\Sigma n/N = 1$ at the time of failure. The same procedures were then employed to predict the $\Sigma n/N$ damage sustained at inspection or failure in service operations. These procedures utilized element fatigue test data, full scale airplane strain surveys, and flight loads measurements. The damage numbers were then converted to equivalent laboratory hours by multiplying the $\Sigma n/N$ value times the laboratory life.

It should be noted that comparisons were actually made only for the critical areas in the wing main torque box lower skin, the outer wing lower surface, and the F.S. 303 bulkhead. The remaining two critical areas were not amenable to analysis by the methods of the subject program. As noted previously, both the upper wing skin and the lower longeron dog bone fitting develop fatigue cracks by the mechanism of an overload in compression producing residual tension stresses. The service fatigue life is therefore very much influenced by when an overload occurs. An overload could be the result of a high positive maneuver or a hard carrier landing. The resulting life scatter is expected to be extreme. The compilation of service failures bears this out. For example, the upper wing skin was found cracked on one F-4 after only 195 flight hours; and on another F-4, no cracks were detected after 700 flight hours.

5.4 Comparison of Laboratory and Service Failures

The actual comparison of laboratory and service failures included efforts in the following areas: equivalent laboratory hours for all service failures were determined; scatter in fatigue and in usage severity were combined and the joint probability of scatter in fatigue and usage severity was evaluated; service failures were compared to predicted failures on the basis of the expected number of failures versus the actual number of failures for each key area; and finally, actual times to first failure, second failure, etc., were compared to the times at which failures were predicted. Details of these efforts are delineated in the following paragraphs.

5.4.1 Equivalent Laboratory Hours - The equivalent laboratory hours sustained at each of the service failures (or each service inspection in which no cracks were detected) are listed in Figures IV-1 through IV-10 of Appendix IV. As indicated previously, these hours were determined by computing the $\Sigma n/N$ damage number for a particular component and then multiplying that number by the life demonstrated by the component in laboratory testing. The detailed methods are described in the following paragraphs.

5.3 Correlation of Laboratory and Service Loadings

The development of reliability procedures for estimating time to early failure on fighter aircraft was the basic objective of this program. The material presented in the following section provides a quantitative evaluation of methods developed toward this end. In this final phase, service life predictions are compared to the actual service failures. The life predictions are based on data gathered in the first three phases, i.e., laboratory test results, counter and VGH data, and usage and fatigue test results scatter information. The comparison itself is on the basis of equivalent laboratory test hours and not in terms of actual flight hours at failure. This type of comparison attempts to account for the differences between the laboratory and service loading environments.

In laboratory testing, all efforts are directed toward attaining the best possible simulation of the loading experienced by the aircraft in service. The problem of cost, however, as it always does, necessitates that simplified test approaches actually be utilized. For the F-4 laboratory test condition chosen, major structural components (e.g., the lower wing skin) were loaded in much the same way that they are loaded in service. The loading was an approximation, however, and as a result, other areas may not have been loaded in exactly the same manner as in service operations. The F-4 outer wing is subjected to buffeting and small amplitude vibrations in service. This was not simulated in the laboratory testing. The lower longeron dog bone fitting and the wing main torque box upper surface are primarily subjected to compressive loads; failures in these areas result from the inducement of residual tensile stresses. The dog bone fitting and upper surface failures, therefore, depend very much on when high loads are applied.

For the reasons noted above, and also because of changes in operational usage, laboratory test hours and service flight hours could not be correlated on a one to one basis for any of the key areas considered herein. Such a flight hour correlation would not be exactly correct for either the wing main torque box lower skin or the F.S. 303 bulkhead, and would be particularly inaccurate for the outer wing lower skins, the lower longeron dog bone fittings, and the wing main torque box upper surface at the root. Fatigue analysis, element test results, flight loads measurements, and full scale test results information have thus been used to correlate the laboratory and service failure experience. Fatigue analysis procedures were formulated to

The laboratory fatigue lives for the key critical areas in the wing main torque box lower skin, the F.S. 303 bulkhead, and the outer wing lower surface as determined from the data presented in Section 4.3 are shown in Figure 63. Fatigue analysis procedures were formulated which would predict these laboratory lives. The same procedures were then employed to predict the damages sustained in service operations. The actual computations of the $\Sigma n/N$ damage numbers sustained by the serv' e aircraft were made using an existing F-4 fatigue damage computation program. In making the predictions, the program utilized each airplane's counting accelerometer data, the overall fleet average count frequency for estimating counts for those periods when an airplane's counter was inoperative, and the VGH data discussed in Section 3.2 for correcting counter load factor data to wing bending moment or to F.S. 303 bulkhead load. Periods in which the aircraft were engaged in combat or in training were tracked and the appropriate VGH correction was utilized. The resulting $\Sigma n/N$ damage numbers were then multiplied by the component laboratory lives to establish the equivalent laboratory hours.

In addition to the full scale test results information of Figure 63, flight loads measurements and element test results information were used to aid in determining the equivalent hours. Flight loads measurements provided the factors to be applied to the counting accelerometer data to reflect the differences between the flight regimes represented in the laboratory and in actual operations. In Section 3.2 it was noted that the majority of maneuvers are pulled in a flight regime in which wing bending moment per g is about 85% of that used in laboratory testing. Flight loads measurements indicated that F.S. 303 bulkhead loads follow the same relationship (bulkhead loads were found to be approximately proportional to the wing root bending moment). On the other hand, flight loads measurements indicated that the outer wing is loaded more severely in service in relation to the laboratory loading than are either the bulkhead or the wing main torque box lower skin. This is borne out by the Figure 64 summary of average flight hours to crack detection for the three key areas. The summary shows outer wing lower skin fatigue cracks at considerably fewer hours in relation to the bulkhead and the wing main torque box lower skin than the laboratory test results would suggest. The factors from flight loads measurements thus had to be included to account for the differences between the "points in the sky" represented in the laboratory and in actual flight operations. As indicated earlier, element test

Location	Eddy Current Crack Detection	Dye Penetrant Crack Detection	Separation
Inner Wing Lower Skin BL 100	1600	2400*	2700
FS 303 Bulkhead	2700*		5200
Outer Wing Aft Lower Skin (32-15062 Block 26 and Up Configuration)			2050
Outer Wing Fwd Lower Skin (32-15531 Block 26 and Up Configuration)			6000

*Estimated Based on Crack Growth Curves of Figures 60 and 61

GP73-0439-16

Figure 63
Component Fatigue Lives in Terms of Laboratory Test Hours

Location	Number of Cracked Aircraft	Average Flight Hours
Inner Wing Lower Skin BL 100	0 (2)	– (213)
FS 303 Bulkhead	2 (8)	1486 (603)
Outer Wing Aft Lower Skin (32-15062 Block 26 and Up Configuration)	34 (1)	745 (307)
Outer Wing Fwd Lower Skin (32-15531 Block 26 and Up Configuration)	6 (1)	1445 (307)

Numbers in Parentheses Indicate Blue Angel and Thunderbird Experience

Figure 64
Summary of Actual Flight Hours to Crack Detection in Service Operations

GP73-0439-17

results were also utilized. Demonstration team aircraft pull considerably more negative g maneuvers than do fleet airplanes; and, within demonstration team groups, the solo airplanes are subjected to a more severe negative load spectrum than are the diamond airplanes. Factors for the effects of negative loads on the damages sustained by the demonstration team airplanes were obtained from MCAIR element tests utilizing spectra derived from Blue Angel counting accelerometer data. Different factors were developed for solo usage and for diamond usage. Different factors were also developed for different time periods to reflect variations in the negative load factor usage which have occurred over the period in which F-4 aircraft have been engaged in demonstration team operations. These factors were then applied to the calculated $\Sigma n/N$ damage numbers to determine the equivalent laboratory hours exhibited at the failure or inspection of demonstration team airplanes.

As indicated above, the equivalent laboratory hours listed in Figures IV-1 through IV-10 are the equivalent hours computed as having been accumulated at the time of crack detection or at the time of inspection. These hours are the best estimates of the equivalent hours accumulated through that time. Where counting accelerometer data was missing and damage had to be estimated for more than 50% of the flight hours, that fact is indicated. Also, in the case of the outer wing lower skins, equivalent hours were computed only if there was no indication of switching of outer wings on the airplane in question. Wherever possible, outer wing serial numbers for the aircraft in the lists of Figures IV-4 through IV-6 were checked against the serial numbers of the outer wings installed on the aircraft when they left MCAIR. Where outer wings had been switched, equivalent hours were not computed since the counting accelerometer data for the airplane might not bear any relation to the usage experienced by the outer wings. The inspection information of such aircraft have been listed for reference, but these data were not used in any further studies.

5.4.2 Joint Probability of Scatter in Fatigue and Usage Severity - The combination of fatigue test results scatter and loads usage severity scatter into a joint scatter factor was a major part of the effort involved in the comparison of laboratory and service failures. As noted in Section 2.5, scatter in fatigue data is reasonably approximated using the Weibull distribution, and as noted in Section 3.3.4, scatter in usage severity can be described by the negative binomial distribution. Since they are statistically independent, the joint probability density function representative of combined scatter from fatigue and usage severity is given by the product of the two distributions. To determine probability levels, this complex function had to be integrated which was not feasible analytically. A computer program was thus developed to do the integration numerically. The program was designed to evaluate the function for a preselected joint scatter factor and then determine the area under the curve. This area represented the probability of the joint scatter factor for combined fatigue and usage severity being less than or equal to the preselected value. A number of computer runs were thus required to completely establish the relationship between the probability of a fatigue failure and the joint scatter factor for combined scatter in fatigue and usage.

Curves showing the probability of failure versus the joint scatter factor for fatigue and usage severity are presented in Figure 65. These curves were derived using the means and standard deviations listed for the 4g usage severity scatter in Figure 26 and the Weibull Shape Parameter α of 5.27 determined in Section 2.2.6. The 4g usage severity scatter means and variances were used because a major portion of fatigue damage is caused by maneuvering at this load factor level.

It should be noted that a commonly used approach for obtaining a joint scatter factor for fatigue and usage severity is to multiply the two scatter factors to obtain a total scatter factor. This approach results in an overly conservative estimate of what the true joint scatter factor should be. This is illustrated by the comparison shown in Figure 66.

5.4.3 Comparison of Service Experience and Minimum Service Life Predictions - The actual comparison of service and laboratory experience has been made on the basis of the expected number of cracked aircraft versus the actual number and also on the basis of the predicted times to crack detection versus the actual times. The detailed calculation procedures to obtain these comparisons are presented in the following paragraphs.

The comparisons of the number of cracked aircraft versus the expected number for each of the key fatigue critical areas are presented in Figures 67 through 71. In arriving at these comparisons, the expected number of cracked aircraft was found by taking the summation of the probability of crack detection on each airplane inspected. As an example, if one hundred airplanes would be inspected at the point in time when the probability of

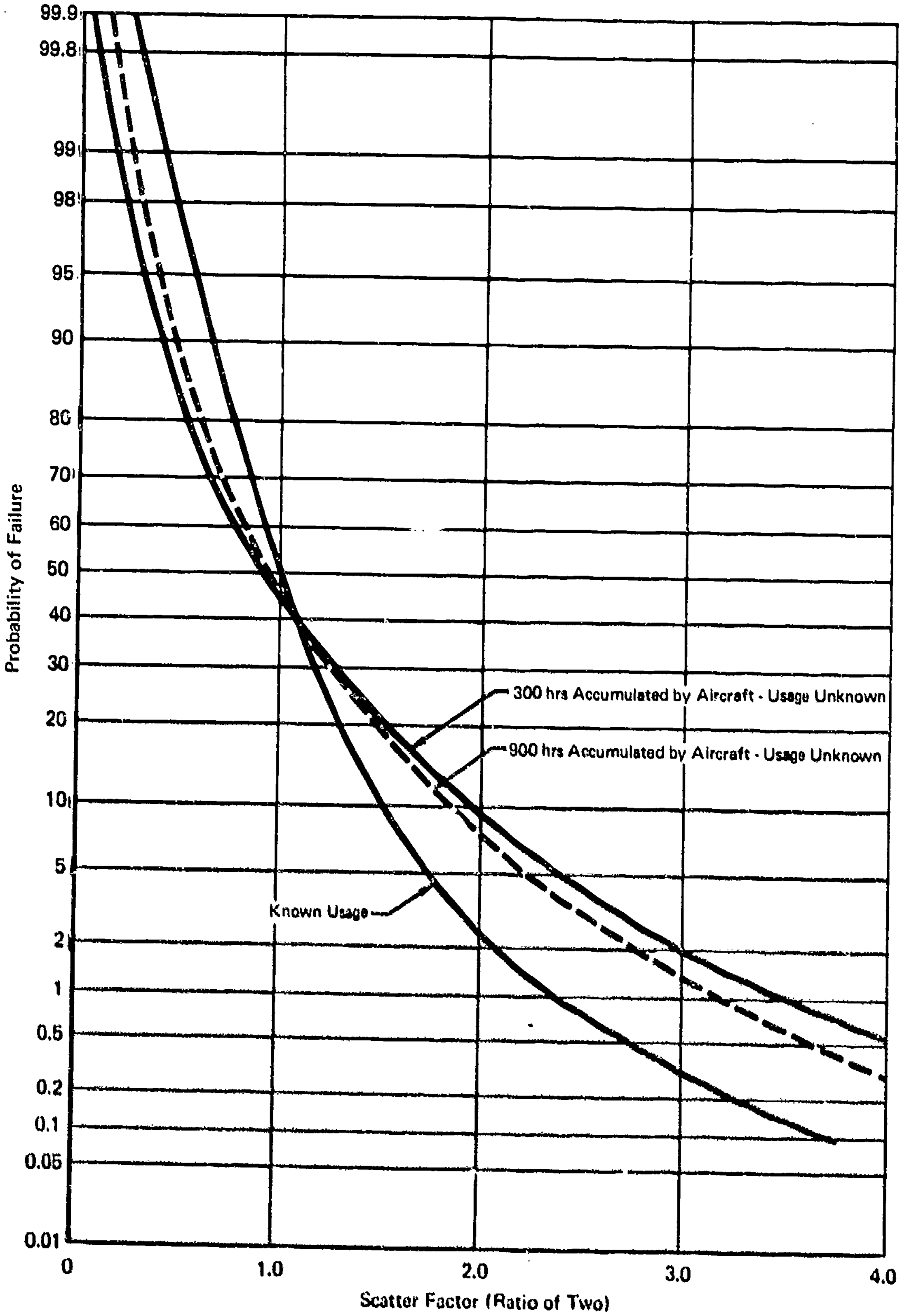


Figure 65
Joint Probability for Combined Scatter in Fatigue and Usage

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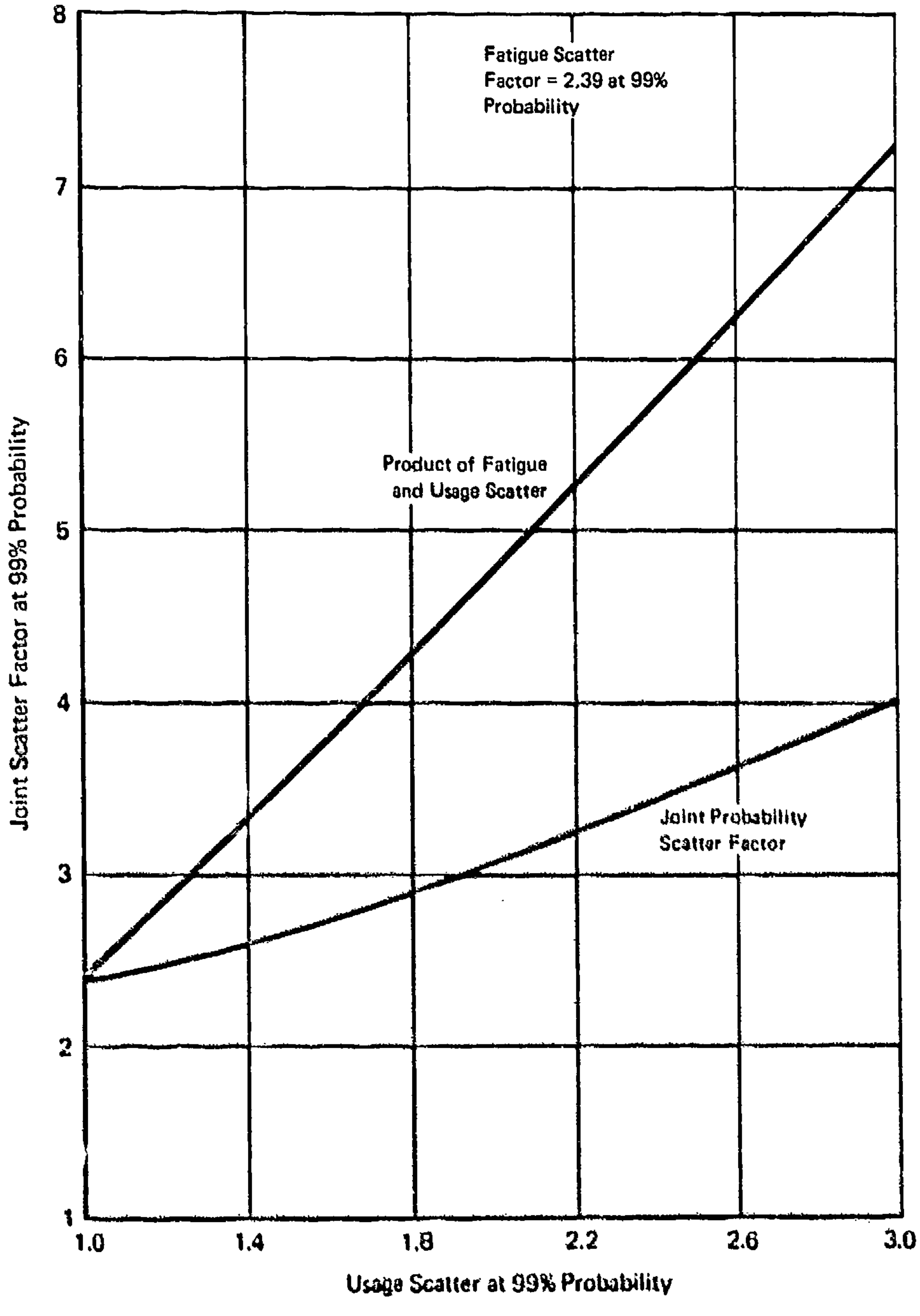

Figure 66
Comparison of Joint Probability Scatter Factor to Product of Fatigue and Usage Scatter

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	Equivalent Laboratory Test Hours	
• Two Solo Blue Angel Aircraft Inspected		
BuNo 153080	2100	Cracks Detected
BuNo 153081	1830	
• Four Diamond Blue Angel Aircraft Inspected		
BuNo 153075	340	No Cracks Detected
BuNo 153076	410	
BuNo 153079	250	
BuNo 153082	250	

- Laboratory Eddy Current Crack Detection at 1600 Hours

Number of Cracked Aircraft = 2
Expected Number = 1.4

Figure 67
Service Experience
Wing Main Torque Box Lower Skin Inspection Summary - Demonstration Team Airplanes
Inspection by Eddy Current

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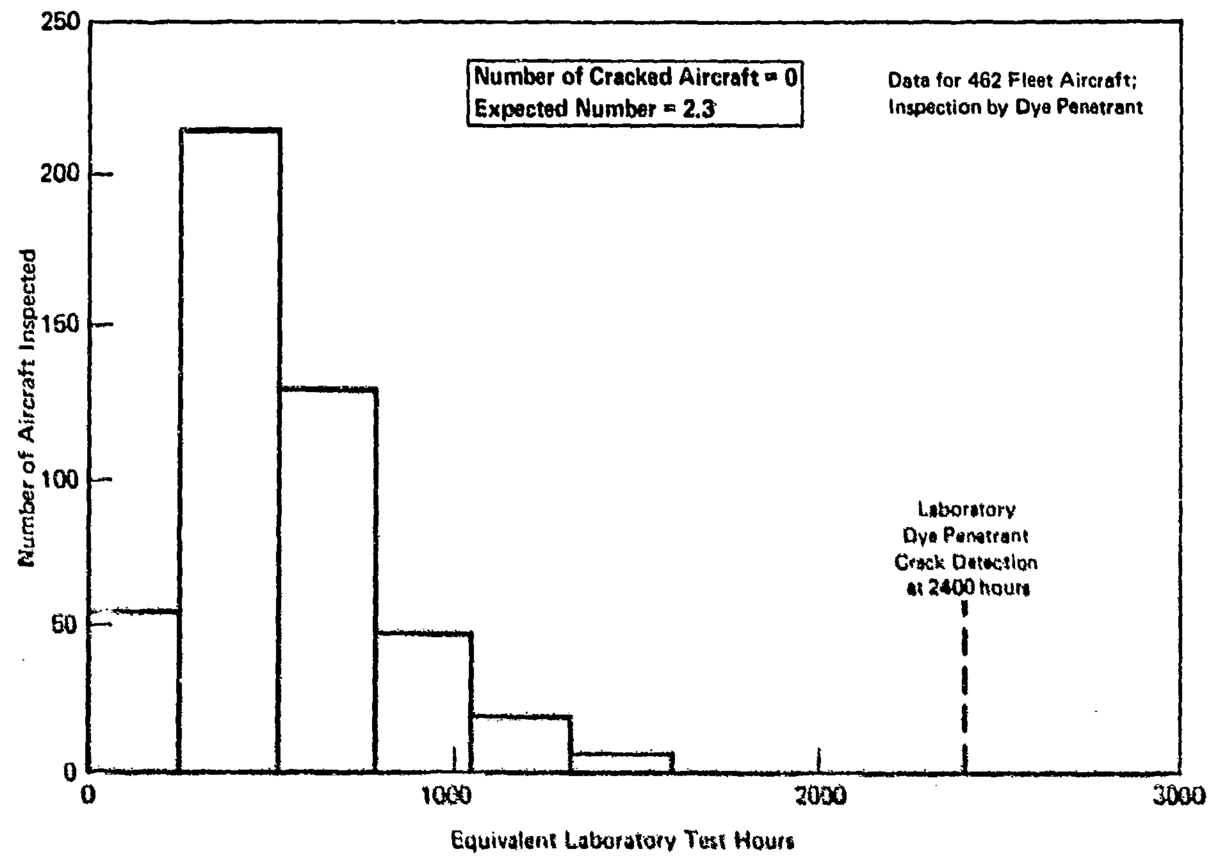

Figure 68
Service Experience
Wing Main Torque Box Lower Skin Inspection Summary - Fleet Aircraft

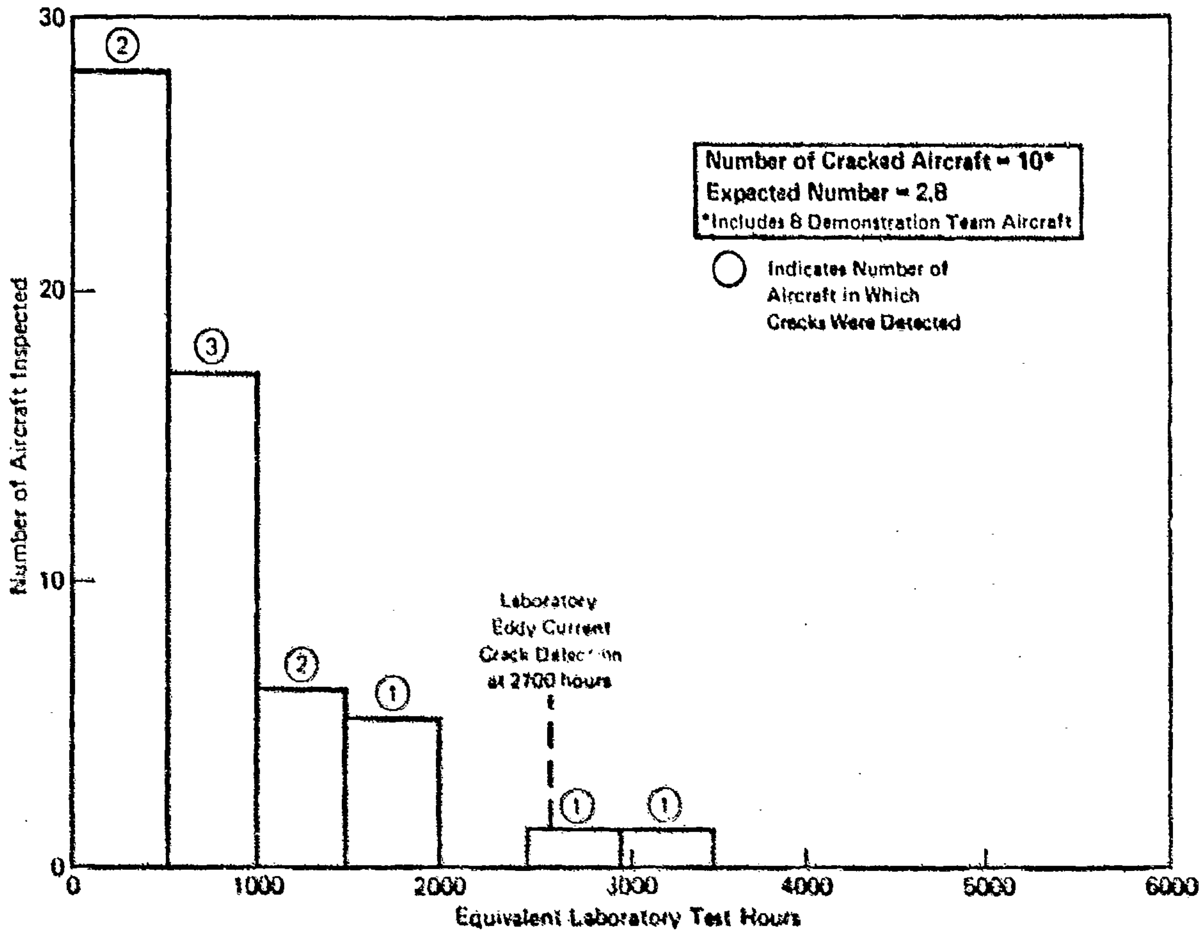

Figure 69
Service Experience
FS 303 Bulkhead Inspection Summary
Inspection by Eddy Current

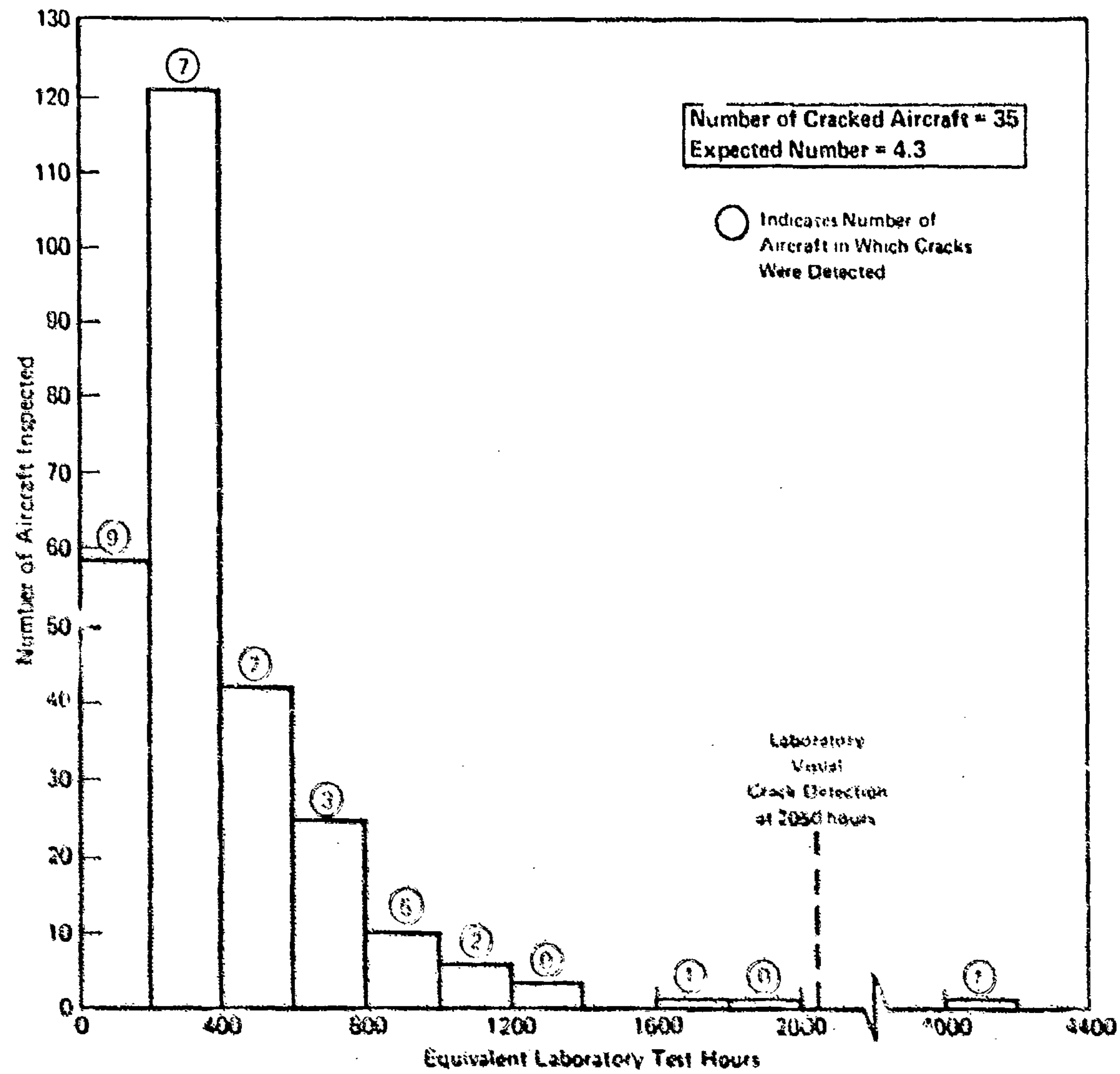

Figure 70
Service Experience
Outer Wing Aft Lower Skin (32-15062 Block 26 and Up Configuration) Inspection Summary
Visual Inspection

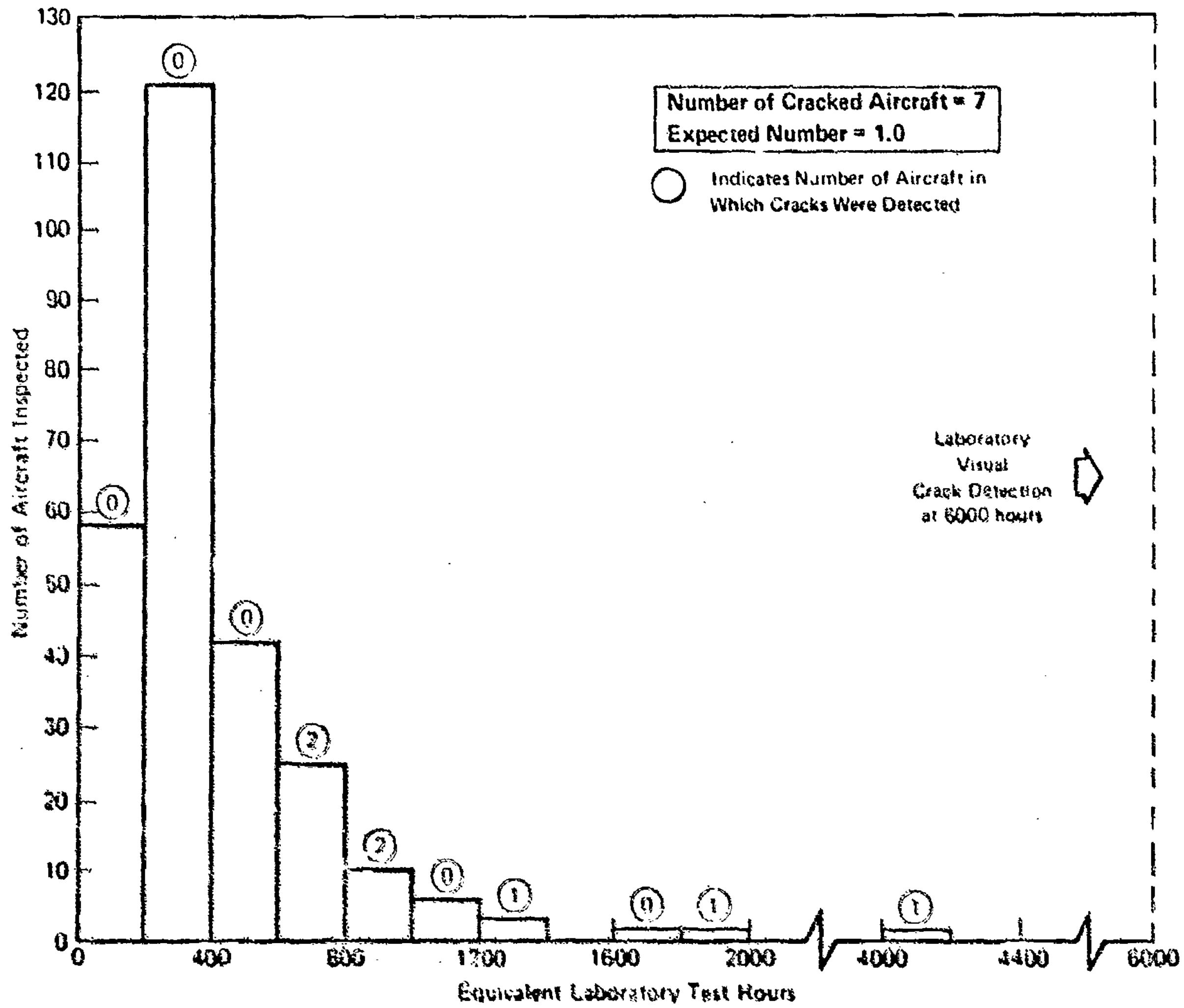

Figure 71
Service Experience
Outer Wing Forward Lower Skin (32-15531 Block 26 and Up Configuration) Inspection Summary
Visual Inspection

crack detection is .01, the expected number of cracked aircraft would be 100 x .01 = 1. The curves of Figure 65 were used for determining the probability of crack detection for each airplane inspected. The scatter factor to be used for each airplane was found by dividing the laboratory life (i.e., the number of laboratory test hours to crack detection) by the equivalent laboratory test hours accumulated by the particular airplane. Figure 65 was then entered using this scatter factor and the probability of a crack being detected was read. When counting accelerometer data was available for more than 50% of the flight hours accumulated by a given airplane, the curve denoted as "known usage" in Figure 65 was utilized. Where counter data had to be estimated for more than 50% of the flight hours accumulated by a given airplane, the probability of failure was determined using the curves denoted as "usage unknown." As would be expected, this resulted in a greater probability of failure for a given scatter factor when the usage of an airplane was unknown.

The predicted times to crack detection for a fleet of aircraft depends, of course, on the number of aircraft in the fleet. For purposes of correlation in this report, since all airplanes in the fleet were not flying at the same rate of damage accumulation, the calculation of expected times to crack detection required special consideration. For example, say the laboratory test life is 3000 hours and that there is a 1000 airplane fleet. Further assume that all 1000 airplanes have reached or exceeded 500 equivalent laboratory test hours, then the expected number of cracked aircraft is 1000 times the probability of failure determined from Figure 65 at a scatter factor equal to 3000/500 = 6. The calculation at 500 hours is fairly straightforward since all 1000 airplanes in the fleet have reached or exceeded 500 hours. However, to calculate the expected number of cracked aircraft in less than or equal to 1000 hours is somewhat different if it is assumed that all the aircraft have not reached 1000 hours. Assume, for example, that 750 of the 1000 aircraft have reached or exceeded 1000 hours. Then in terms of those 750 aircraft, the expected number that would be found cracked is 750 times the probability of failure determined from Figure 65 at a scatter factor equal to 3000/1000 = 3. This is not, however, the total expected number out of 1000. The reason is that the 250 aircraft that have not reached 1000 hours also contribute toward the probability of failure in less than or equal to 1000 hours. Their contribution would be calculated based on the probabilities of failure determined from Figure 65 at the appropriate scatter factor for each airplane; and then each of these probabilities would be summed and finally added to the expected number for the 750 aircraft that have reached or exceeded 1000 hours. This process can be continued to provide a graph of expected number of cracked aircraft versus hours. The graph can then be entered at expected number equals one to determine the predicted life for the first cracked aircraft, it can be entered at expected number equals two to determine the predicted life for the second cracked aircraft, etc. The predicted lives, thusly determined, are 50% probable type numbers.

Using the technique discussed in the preceeding paragraph, graphs of expected number of cracked aircraft versus equivalent laboratory test hours were constructed for each of the key fatigue critical areas. These graphs are presented in Figures 72 through 74. Then entering these graphs at expected number equals one and two, the predicted lives for the first and second cracked aircraft, respectively, were determined and are shown in Figures 75 through 78. Also presented for comparison are the actual service lives from the lists of Figures IV-1 through IV-10 in Appendix IV.

5.4.4 Discussion of Lab and Service Experience Correlation - A review of the lab and service experience comparisons in Figures 67 through 78 indicate favorable correlation for the wing main torque box lower skin but somewhat less than favorable for the F.S. 303 bulkhead and the outer wing lower skins. Pertinent considerations are discussed in the following paragraphs.

Figure 67 indicates that six Navy Blue Angel airplanes were inspected using the eddy current technique in the wing main torque box lower skin fatigue critical area. Two of these were the aircraft deployed in the severe solo operation. One had accumulated 1830 equivalent laboratory test hours and the other had accumulated 2100 hours. Fatigue cracks were detected in both aircraft as expected since cracks were detected in the laboratory at 1600 hours. The remaining four airplanes were flown in the much less severe diamond formation and had accumulated on the order of 400 hours. None of the four were found to be cracked. Figure 75 shows that the predicted life for the first cracked aircraft is 1570 hours as compared to the actual value of 1830 hours.

Figure 68 indicates that 462 F-4 aircraft were inspected using the dye penetrant technique in the wing main torque box lower skin fatigue critical area. None of these were found to be cracked. This is not unreasonable

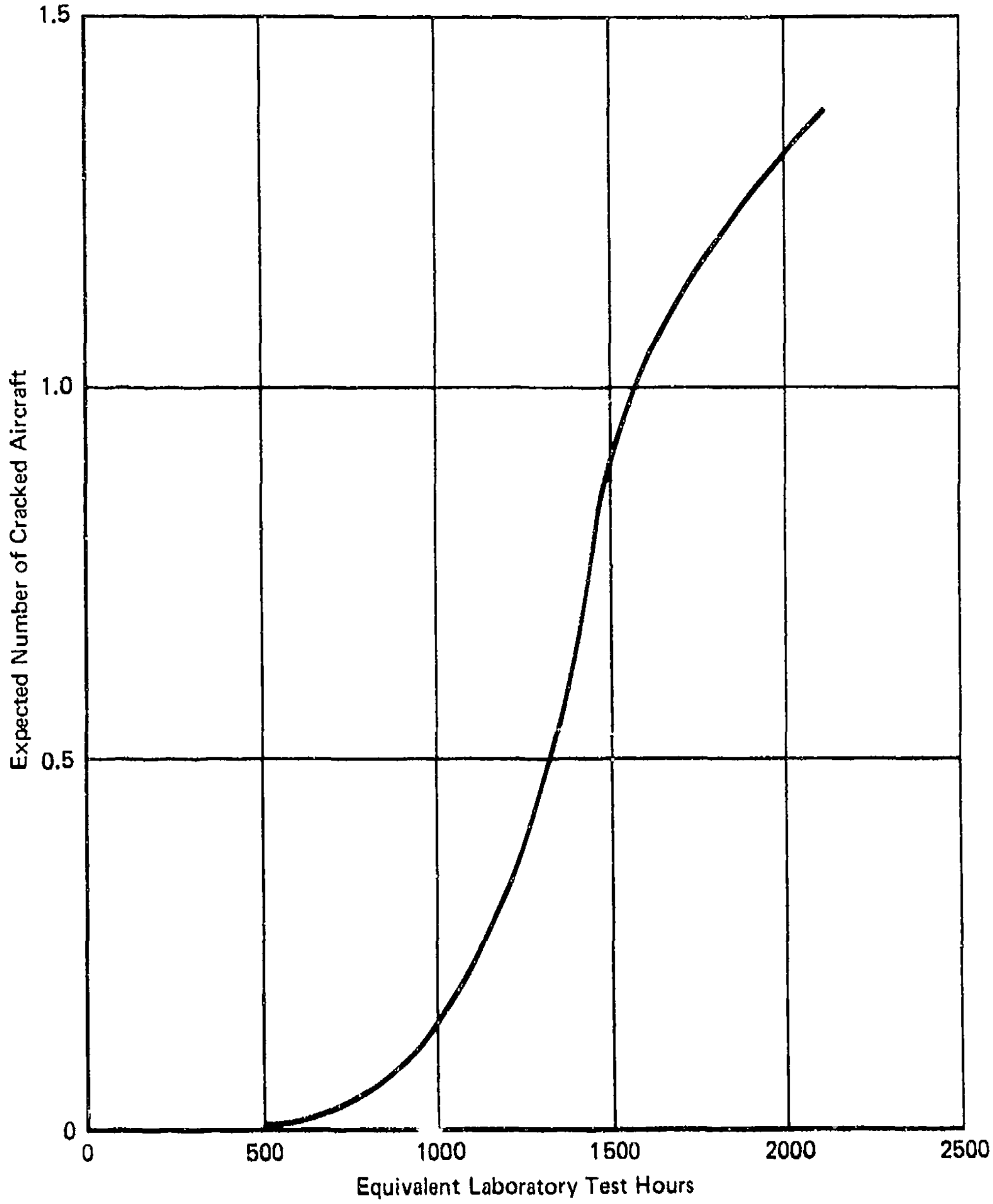

Figure 72
Expected Time to First Cracked Aircraft and Second Cracked Aircraft for the Key Area in the Wing Main Torque Box Lower Skin
(Demonstration Team Airplanes)

GP73-0430-4

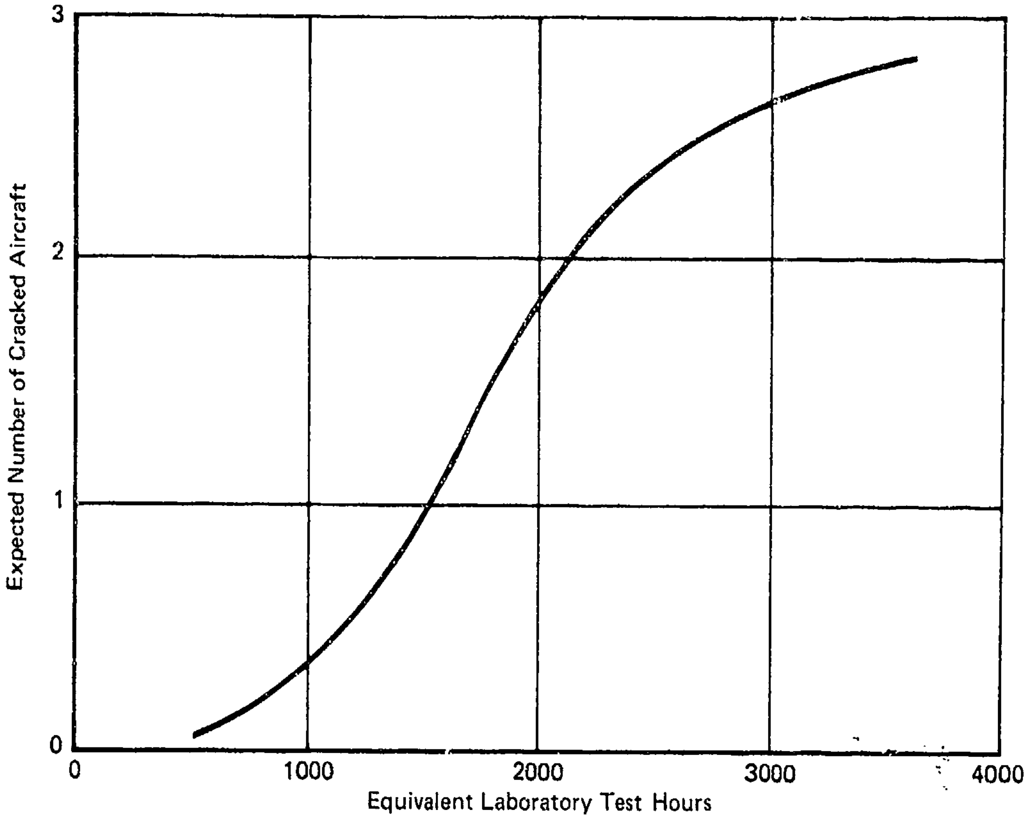

Figure 73
Expected Time to First Cracked Aircraft, Second Cracked Aircraft, Etc., for the Key Area in the FS 303 Bulkhead

GP73-0439-7

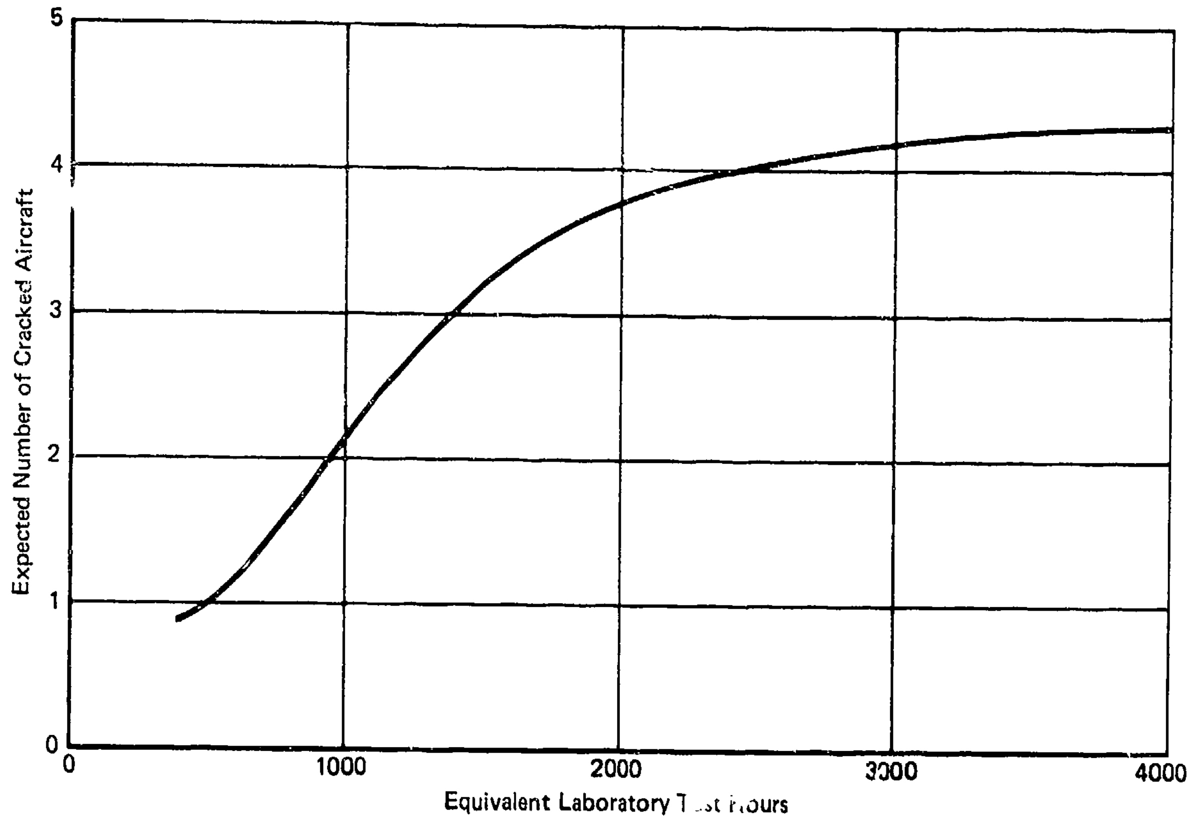

Figure 74
Expected Time to First Cracked Aircraft, Second Cracked Aircraft, Etc., for the Key Area in the Outer Wing Aft Lower Skin (32-15062 Block 26 and Up Configuration)

GP73-0439-8

	Inner Wing Lower Skin Time to Crack Detection (Equivalent Laboratory Test Hours)	
Cracked Aircraft	Expected	Actual
First	1570 hrs	1830 hrs
Second	>2100 hrs	2100 hrs

Figure 75
Comparison of Expected and Actual Times to First Cracked Aircraft and Second Cracked Aircraft for the Key Area in the Wing Main Torque Box Lower Skin

(Demonstration Team Airplanes)

GP73-0430-6

	FS 303 Bulkhead Time to Crack Detection (Equivalent Laboratory Test Hours)	
Cracked Aircraft	Expected	Actual
First	1530 hrs	407 hrs
Second	2140 hrs	410 hrs
Third	> 3500 hrs	672 hrs

Note: Unfavorable correlation between predicted and actual lives due to fabrication variations. See Section 5.4.4 and Figure 69.

Figure 76
Comparison of Expected and Actual Times to First Cracked Aircraft, Second Cracked Aircraft, Etc., for the Key Area in the FS 303 Bulkhead

GP73-0439-13

	Outer Wing Aft Lower Skin Time to Crack Detection (Equivalent Laboratory Test Hours)	
Cracked Aircraft	Expected	Actual
First	500 hrs	114 hrs
Second	935 hrs	138 hrs
Third	1395 hrs	141 hrs
Fourth	2450 hrs	151 hrs

Note: Unfavorable correlation between predicted and actual lives due to outer wing buffeting. See Section 5.4.4 and Figure 70.

Figure 77
Comparison of Expected and Actual Times to First Cracked Aircraft, Second Cracked Aircraft, Etc., for the Key Area in the Outer Wing Aft Lower Skin (32-15062 Block 26 and Up Configuration)

GP73-0439-12

	Outer Wing Forward Lower Skin Time to Crack Detection (Equivalent Laboratory Test Hours)	
Cracked Aircraft	Expected	Actual
First	4100 hrs	666 hrs

Note: Unfavorable correlation between predicted and actual lives due to outer wing buffeting. See Section 5.4.4 and Figure 71.

Figure 78
Comparison of Expected and Actual Times to First Cracked Aircraft for the Key Area in the Outer Wing Forward Lower Skin (32-15531 Block 26 and Up Configuration)

GP73-0439-9

since cracks could not be reliably detected with dye penetrant in the laboratory until 2400 hours, and the majority of the 462 airplanes inspected in service had accumulated less than 1000 equivalent laboratory test hours. The highest number of hours on any of the 462 airplanes was 1500.

The F.S. 303 bulkhead fatigue cracking originates in fastener holes in the bulkhead flange as shown in Figure 47. A more detailed view of the attachment of the bulkhead to the wing main spar is shown in Figure 79. Note that the tension stresses in the critical flange result from wing spar curvature tending to pull the sparcap away from the "foot" of the bulkhead through the two inboard fasteners. The magnitude of tension stress depends significantly on each fasteners torque-up, the exact location of the fasteners, and the stiffness of the bolt and nut combination. These types of parameters can vary from one airplane to another. It is considered probable that these fabrication variations are the cause of the relatively poor correlation between predicted and actual lives for the F.S. 303 bulkhead shown in Figure 76.

Within the speed-altitude envelope where the F-4 airplane executes the majority of its maneuvers, buffeting is fairly common at high angles of attack. For example, at the airplane's design gross weight of 37,500 lbs. and at Mach 0.7 and 10,000 ft. altitude, buffet onset is about 4 g's. However, the buffeting originates and primarily remains in the outer wing panel. The resulting vibratory loads superimpose on the basic maneuver wing airloads to increase the stresses in the outer wing. These vibratory loads also increase the inner wing stresses, but by a much smaller percentage because of the relatively small contribution to inner wing stresses from outer wing loads. The unfavorable comparison between predicted and actual lives for the outer wing lower skins in Figures 77 and 78 is considered to be caused by outer wing buffeting which was not simulated in the laboratory testing.

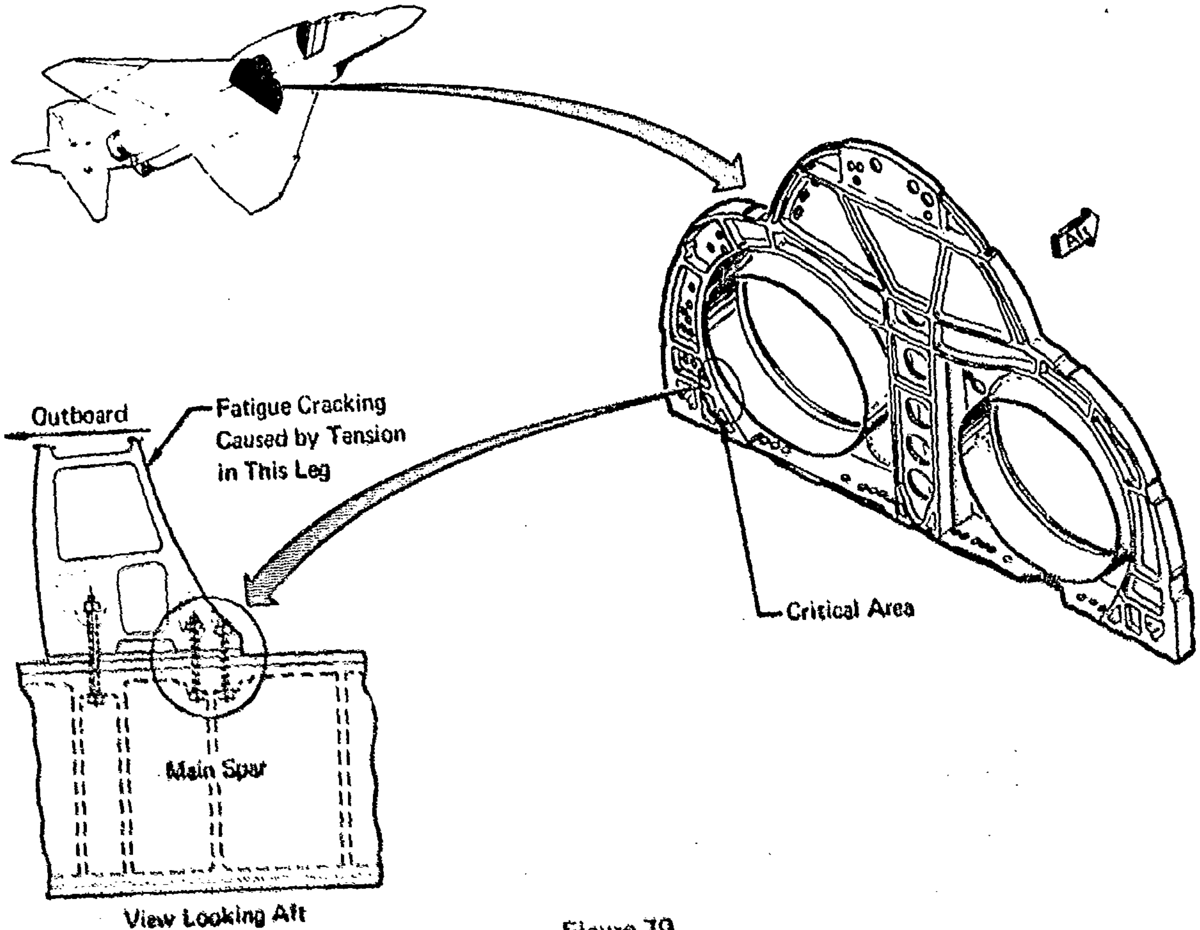

Figure 79
Details of Wing to Fuselage Attachment Area

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The conclusions which may be formulated from this four phase program on the evaluation of structural reliability analysis procedures as applied to a fighter aircraft are as follows:

(1) Scatter in spectrum fatigue tests is considerably less than that in constant amplitude fatigue tests. This was found to be true for both element and full scale fatigue test specimens. For the full scale test article results, the comparison is as follows:

	Spectrum	Constant Amplitude
Number of Specimens	243	491
Number of Groups	82	143
Average Standard Deviation	.0985	.1486
Average Weibull Shape Parameter	5.44	3.70

(2) The scatter in spectrum testing exhibited by 7075 and 2024 aluminum in both element and full scale specimens is generally about the same. Pooling all of the data gives the following averages:

	Average Spectrum Fatigue Test Data
Number of Specimens	1060
Number of Groups	260
Average Standard Deviation (σ)	.0994
Average Weibull Shape Parameter (α)	5.27

(3) Comparisons of the Weibull and the log-normal probability distributions to the actual spectrum fatigue test data indicate that the Weibull distribution (shape parameter α = 5.27) provides a better fit of the data than the log-normal distribution (standard deviation σ = .0994)

(4) In addition to studies of experimental data, theoretical analyses were performed yielding the mathematical probability distribution for a Weibull based scatter factor. A laboratory test article can be thought of as one airplane selected at random from the total fleet. The scatter between the laboratory life and the service life of another airplane picked at random from the fleet is then the ratio of two randomly selected variates from the same population. A scatter factor so defined as the ratio of two statistically independent random variables is itself a random variable and its probability distribution can thus be derived from the distribution of the parent population. The relationship between

the reliability R (probability of no failure) and the scatter factor S for a parent population described by the Weibull distribution is

$$S = \left(\frac{R}{1-R}\right)^{\frac{1}{\alpha}}$$

Using this formula with $\alpha = 5.27$ gives a fatigue scatter factor of 2.39 for 99% reliability.

(5) A total of 8200 hours of F-4 VGH data were analyzed. The trends from this data are as follows:

(a) The majority of maneuvers in both combat and training operations are executed in a limited Mach number/altitude regime. In both types of operations, the majority of maneuvers are pulled at between 350 and 550 knots and at below 10,000 feet (the combat average altitudes being slightly higher than those for training due to ground fire avoidance).

(b) The gross weights for maneuvers pulled in combat are higher than those for maneuvers pulled in training operations (due to the higher weapon payload required in actual combat service).

(c) In both training and combat, the average speed at which maneuvers are pulled increases as the load factor increases (higher airspeeds required in order to pull high load factor maneuvers).

(6) More than 2,000,000 flight hours of F-4 counting accelerometer data were studied to determine usage severity scatter trends. The data indicate marked reduction in scatter with increasing flight hours. This trend reflects the fact that the longer aircraft are in service, the more likely they will be subjected to a variety of usages and their repeated loading histories will "average out".

(7) The usage severity scatter exhibited in the counting accelerometer data was evaluated for "goodness of fit" with the negative binomial distribution. Comparisons for airplanes having accumulated 100, 500, and 1500 hours show definite correlation between the theoretical distribution and the data.

(8) A study was also conducted on the total hour accumulation on individual F-4 aircraft to obtain information which can be used to aid in establishing an aircraft's design life. This study showed a trend similar to that detected for usage severity scatter, i.e., flight hour usage also averages out and aircraft placed in the fleet at the same time will tend to accumulate similar numbers of hours over a period of years. In addition to this, however, since F-4 flight hour monthly accumulation rates were shown to be relatively invarient, the study also indicated that all aircraft in a fleet can be expected to accumulate a similar number of hours after a like number of years in service. The overall average for the F-4 is 25 flight hours per month.

(9) The combined effect of fatigue test scatter and usage severity scatter was derived utilizing a joint scatter factor concept. The total scatter factor derived in this manner is significantly smaller than that determined by an overly conservative simple multiplication approach.

(10) Probable minimum lives were computed for three key fatigue critical areas on the F-4 airplane based on the reliability procedures presented in this report and on F-4 laboratory fatigue and usage data. The correlation with actual service experience was excellent for one of the areas, but not for the other two. Navy Blue Angel airplanes were inspected in the wing main torque box lower skin critical area using the eddy current technique. Two aircraft were found to be cracked as expected. For these aircraft, the predicted time to detection of the first crack was 1570 hours as compared to the actual value of 1830 hours. Among 462 fleet aircraft inspected in the same area using the dye penetrant technique, there were no aircraft found to contain cracks. This was not unreasonable since cracks could not be reliably detected in the laboratory by this method until 2400 hours, and the majority of the fleet aircraft had accumulated less than 1000 hours. The correlations for the critical areas in the F.S. 303 bulkhead and in the outer wing lower skins were not as favorable. This is attibuted to fabrication variations and to outer wing buffeting.

The theoretical reliability procedures outlined in Reference (1) and expanded in this report for use on fighter aircraft provide satisfactory results. The formulation of systematic techniques for the incorporation of these methods in designing for structural reliability in fighter aircraft is now needed. Two basic approaches could be defined: (1) method for fail safe components, and (2) method for non fail safe components. Method (1) would determine scatter factor magnitudes for fail safe components based on maintenance versus scatter factor trade off studies to give minimum total system cost at a given performance level. The trade off studies would be made during each airplane's design stage. Method (2) would determine scatter factor magnitudes for non fail safe components such that the failure probability within the design lifetime is extremely small. The exact magnitude of this failure probability would be determined during each airplane's design stage. It should be noted that these methods will yield different scatter factor magnitudes for different components on the same airplane.

The method for fail safe components would utilize the concept of time to first failure, second failure, etc., to determine how many aircraft would require maintenance action in a given time period. This type of analysis would be used in the maintenance versus scatter factor trade off studies. In addition, this same type of analysis would be used to define inspection intervals. The method for non fail safe components would be based on requiring an extremely small probability of failure for individual airplanes.

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APPENDIX I

LIST OF FATIGUE TEST DATA REFERENCES

1. F-15 Fatigue Design Analysis Report, MCAIR MDC A0928, 1 Jan. 1972.
2. Evaluation of F-4 Blue Angel Fatigue Life, MCAIR TM 253.224, 25 June 1970 (Also TRJ32-253.32,300-107).
3. Effect of interspersing negative load level sequence spectrum fatigue tests, MCAIR Report 604-110 (Also TR 604-110.10, -116, -135, -180), 18 August 1965.
4. Repeated cyclic load testing for ECP 613 elements, MCAIR Report F623, 30 Dec. 1968 (Also TR 32A-616.12.10, 32A-602).
5. A comparison of the fatigue capabilities of 7075-T6 and Titanium 6-4, MCAIR Final Report 604-124, 31 August 1966 (Also 604-124.10, -152, -159, -162, -176).
6. A comparison of the fatigue capabilities of 2020-T6, 2024-T81, 7075-T6 aluminum and 6AL-6VA-2SN, 8AL-1VA-1MO, 6AL-4VA Titanium, MCAIR Final Report 604-125, -125, -157, 16 Jan. 1967.
7. Comparison of fatigue life for spectra of various slopes, MCAIR Report 604-179, 8 August 1966 (Also TR 604-179.10, -194).
8. Effect on the fatigue life of inserting mandrel prior to installation of Taper-Loks, MCAIR Report 604-212, 10 Jan. 1967. (Also TR 32-253.32, 300-197).
9. Effect of negative loads on F-4 Blue Angel Fatigue Life, MCAIR Report TM 253.226, 25 June 1970 (Also TR J32-339.13).
10. Evaluation of Taper-Lok fasteners installed in titanium and aluminum combinations, MCAIR Report 701-117, 8 Jan. 1970 (DC-10).
11. Effect of fatigue cracks on the residual static strength of 7075-T651 aluminum, MCAIR Report 604-287 (EMA), 1 May 1969.
12. Fatigue and exfoliation corrosion properties of 7178 and 7075 aluminum alloys, MCAIR Report 513-547, 25 Aug. 1966.
13. Fatigue evaluation of coining fix for the F-4 303 bulkhead, MCAIR Report TR J32-339.12, 10 March 1971.
14. Effect of negative loads on F-4 Thunderbird Fatigue Life, MCAIR TM253.393, 2 Dec. 1970 (Also TR J32-339.13.10).
15. Effect of negative loads on spar element specimens, MCAIR Report J32-339. 13.11 (F-4), 25 Feb. 1971.
16. Effect of negative loads on F-4 Fatigue Life, MCAIR TM253.333, 7 Aug. 1970, (Also TR J32-339.17).

17. Effects of countersinking depth on Fatigue Life, MCAIR Final Report J32-340.11, 7 July 1970.

18. Evaluation of crack growth characteristics for 7075-T651 aluminum, MCAIR Final Report 604-339, 19 June 1969.

19. Engine Auxiliary air door cyclic test (F-4J), MCAIR Final Report 32A-569, 20 June 1967.

20. Evaluation of the resistance to fatigue of the F-4 wing main torque box lower skin, MCAIR Final Report 604-304, 28 Feb. 1969.

21. Investigation of various coatings as lubricants between stringer and clip to reduce fretting (DC-10), MCAIR TM 253.24, 30 April 1969 (Also TR EO 1A1003).

22. DC-10 stringer-rib clip fatigue test for stringer loading, MCAIR Final Report 701-110 (DC-10), 13 June 1969.

23. Element fatigue tests evaluation of short edge distance (F-4), MCAIR Report TR J32-339.15.10, Jan. 1972.

24. Fatigue element tests F-4 outer wing, lower skin, MCAIR Report J32-340.10, 12 Feb. 1971.

25. Fatigue evaluation of F-4 outer wing fatigue critical area, MCAIR Report J32-340.12, 1 Feb. 1971.

26. Fuselage station 303 bulkhead element test for 5/32" skin-duct fastener hole, MCAIR Final Report J32-339.15, 3 Aug. 1971.

27. Tapered joint fatigue life evaluation (DC-10), MCAIR Report 701-133, 22 Dec. 1970.

28. Stringer joint fatigue life evaluation, MCAIR Final Report 701-137, 29 January 1971.

29. Fracture surface examination of DC-10 fatigue test specimens, MCAIR TM 256.285, 18 Feb. 1969 (Also TR 701-101.10).

30. Fatigue and stress corrosion tests of 2024 shot peened specimens, MCAIR Final Report 701-101, 13 Nov. 1969 (Also 701-101.10 and .11).

31. Effect of Taper-Loks on the fatigue life of vs (X) element test specimens (2024-T351, 7075-T651 aluminum alloys), MCAIR Final Report E6610-177, 16 March 1967.

32. Element fatigue test with a reversed-cycle spectrum (7075-T651 aluminum alloy), MCAIR Final Report 604-219, 24 April 1967.

33. Element test to investigate the repeated load failure on main torque box upper skin on blocks 1, 6, and 8 test articles, MCAIR Report 32-540.04 (F4H-1), 18 Dec. 1962.

34. Fatigue test-airplane wing splice, MCAIR Report TM TR 4477.6.1, 12, 13, April 1956.

35. Improvement in fatigue life of 7075-T651 plate by various means of surface working, MCAIR Final Report 32-433 (F4H-1), 23 Aug. 1960.

36. Element fatigue test to evaluate short edge distance, MCAIR Final Report 032-722 (F4H-1), 16 Dec. 1960.

37. Fatigue tests to determine possible increase in fatigue life of aluminum through special processing techniques, MCAIR TRM 32-132.1, -132.2, 14 Jan. 1958.

38. Fatigue tests to determine possible increase in fatigue life of aluminum through special processing techniques, MCAIR TRM 32-132, PTM2, 13 Jan. 1959.

39. Fatigue test of specimens to evaluate BUWEPS spectra and stresses typical of F4H-1 airplane wings, MCAIR Report 32-650.08, .08.01, 10 August 1961.

40. Evaluation of a fatigue damage indicator, MCAIR Final Report 604-298.10, 10 April 1969.

41. Relationship between size of fatigue crack and fatigue life remaining, MCAIR Final Report 604-266, 7 Feb. 1968.

42. Effects of local pre-stressing on fatigue properties of 7075-T6 aluminum plate, Briles Metal Laboratory Test Report #151, 26 Sept. 1963.

43. Evaluation of Taper-Lok bolts on the fatigue life of the lower torque box skin element, MCAIR Final Report 32A-054, 12 Nov. 1963.

44. Axial Tension-Tension fatigue tests to determine the fatigue life of various loading spectra using K_T=4.0, MCAIR Final Report 32-622.01, 11 Aug. 1960.

45. W. J. Crichlow, A. J. McCulloch, L. Young, and M. A. Melcon: An Engineering Evaluation of Methods for the Prediction of Fatigue Life in Airframe Structures, Technical Report No. ASD-TR-61-434, May 1962.

46. S. Kelsey and J. B. Spooner: Direct Stress Fatigue Tests on Redux Bonded and Riveted Double Strap Joints in 10 S.W.G. Aluminum Alloy Sheet, ARC Technical Report CP No. 353, December 1955.

47. E. C. Naumann: Evaluation of the Influence of Load Randomization and of Ground-Air-Ground Cycles on Fatigue Life, NASA TN D-1584, October 1964.

48. E. C. Naumann: Fatigue Under Random Loads, NASA TN D-2629, February 1965.

49. P. L. Corbin and E. C. Naumann: Influence of Programming Techniques and of Varying Limit Load Factors on Maneuver Load Fatigue Test Results, NASA TN D-3149, January 1966.

50. H. J. Grover, S. M. Bishop, and L. R. Jackson: Fatigue Strength of Aircraft Materials: Axial Load Fatigue Tests on Notched Sheet Specimens of 2024-T3 and 7075-T6 Aluminum Alloy and of SAE 4130 Steel with Stress Concentration Factors of 2.0 and 4.0, NACA TN 2389, July 1951.

51. J. Schijve and F. A. Jacobs: Fatigue Tests on Notched and Unnotched Clad 24S-T Sheet Specimens to Verify the Cumulative Damage Hypotheses, NLL Report M.1982, April 1955.

52. I. E. Wilks and D. M. Howard: Effect of Mean Stress on the Fatigue Life of Alclad 24S-T3 and Alclad 75S-T6 Aluminum Alloy, WADC Technical Report 53-40, June 1953.

53. C. B. Landers and H. F. Hardrath: Results of Axial-Load Fatigue Tests on Electropolished 2024-T3 and 7075-T6 Aluminum-Alloy-Sheet Specimens With Central Holes, NACA Technical Note 3631, March 1956.

54. S. R. Swanson: An Investigation of the Fatigue of Aluminum Alloy Due to Random Loading, UTIA Report No. 84, September 1963.

55. I. N. Vaughan: Static and Fatigue Tests of Various Stringer-to-Frame Attachments, Boeing document T-29023, January 1958.

56. Boeing Test Progress Report No. T-29025, Section 2, March 1955.

57. E. C. Naumann, H. F. Hardrath, and D. E. Guthrie: Axial-Load Fatigue Tests of 2024-T3 and 7075-T6 Aluminum-Alloy Sheet Specimens Under Constant - and Variable - Amplitude Loads, NASA Technical Note D-212, December 1959.

58. E. C. Naumann and R. L. Schott: Axial-Load Fatigue Testing Using Loading Schedules Based on Maneuver-Load Statistics, NASA Technical Note D-1253, May 1962.

59. E. C. Naumann: Variable-Amplitude Fatigue Tests with Particular Attention to the Effects of High and Low Loads, NASA Technical Note D-1522, December 1962.

60. W. Illg: Fatigue Tests on Notched and Un-notched Sheet Specimen of 2024-T3 a[illegible]6 Aluminum Alloys and of SAE 4130 Steel with Special

Consideration of the Life Range from 2 to 10,000 Cycles, NACA Technical Note 3866, December 1965.

61. D. A. Paul and D. Y. Wang: Fatigue Behavior of 2014-T6, 7075-T6, and 7079-T6 Aluminum Alloy Regular Hand Forgings, WADC Technical Report 59-591, January 1960.

62. I. G. Hendrickson and R. W. Walter: Compilation of Structural Test Data for Reliability Research Program, Boeing document D6-14085, February 1966.

63. P. J. Mitchell: The Laboratory Fatigue Performance of Aircraft Structural Parts, Vol. I, Boeing document D6-23298TN (unreleased).

64. Boeing Test Progress Report (KC-135) No. T-29040, September 23, 1955.

65. G. S. Jost: The Fatigue of 24S-T Aluminum Alloy Wings Under Asymmetrical Spectrum Loading, ARL Structures and Materials Report 295, Feb. 1964.

66. M. S. Rosenfeld: Aircraft Structural Fatigue Research in the Navy, ASTM Special Technical Publication No. 338, October 1962.

67. J. Schijve and F. A. Jacobs: Research on Cumulative Damage in Fatigue of Riveted Aluminum Alloy Joints, NLL Report M.1999, January 1956.

68 R. P. Swartz and M. S. Rosenfeld: Variable Amplitude Fatigue Characteristics of a Slab Horizontal Tail for a Typical Fighter Aircraft, ASL Report NAMATCEN-ASL-1023 Part II, 1961.

69. R. P. Swartz and M. S. Rosenfeld: The Effect of Preloading on the Variable Amplitude Fatigue Characteristics of a Slab Horizontal Tail for a Typical Fighter Aircraft, ASL Report NAMATCEN-ASL-1023, Part III, 1961.

70. L. Mordfin and N. Halsey: Programmed Maneuver-Spectrum Fatigue Tests of Aircraft Beam Specimens, NBS Report 7472, Nat. Bureau Standards, 1962.

71. H. Yeomans: Programmed Loading Fatigue Tests on a Bolted Joint, RAE TN No. Structures 327, March 1963.

72. H. E. Parish: Fatigue Test Results and Analysis of 42 Piston Provost Wings, ARC reports and memoranda No. 3474, April 1965.

73. L. R. Foster Jr., and R. E. Whaley: Fatigue Investigation of Full-Scale Transport-Airplane Wings, NASA TN D-547, October 1960.

74. A. O. Payne: Random and Programmed Load Sequence Fatigue Tests on 24ST Aluminum Alloy Wings, ARL Report SM.244, September 1956.

75. J. Y. Mann and C. A. Patching: Fatigue Tests on Mustang Wings and Notched Aluminum Alloy Specimens Under Random Gust Loading, With and Without Ground to Air Cycles of Loading, ARL SM Note 268, June 1961.

76. R. A. Carl and T. J. Wegeng: "Investigations Concerning the Fatigue of Aircraft Structures," ASTM Proceedings, 1954.

77. C. B. Castle and J. F. Ward: Fatigue Investigation of Full-Scale Wing Panels of 7075 Alumunum Alloy, NASA Technical Note D-635, April 1951

78. M. J. McGuigan, Jr., D. F. Bryan, and R. E. Whaley: Fatigue Investigation of Full-Scale Transport-Airplane Wings, NACA TN 3190, March 1954

79. Breyan, William: "Effects of Block Size, Stress Level, and Loading Sequence on Fatigue Characteristics of Aluminum-Alloy Box Beams", Effects of Environment and Complex Load History on Fatigue Life, ASTM STP 462, American Society for Testing and Materials, 1970, pp. 127-166.

80. K. D. Raithby: Fatigue Tests on Typical Two-Spar Light Alloy Structures (Meteor 4 Tailplanes) Under Reversed Loading, RAE Report No. Structures 108, May 1951.

81. J. P. Ruane: Component Fatigue Test W. S. 396 and W.B.L. 315, Boeing document T6-2560, October 1963.

82. Breyan, William: Effects of Block Size and Stress Level on Fatigue Characteristics of Aluminum Alloy Box Beams Under Fixed Sequence Unidirectional Loading, Naval Air Development Center Report No. NADC-ST-6811, September 1968.

83. R. E. Whaley, M. J. McGuigan Jr., and D. F. Bryan: Fatigue-Crack-Propagation and Residual-Static-Strength Results on Full-Scale Transport-Airplane Wings, NACA 3847, December 1956.

84. R. E. Whaley: Fatigue Investigation of Full-Scale Transport-Airplane Wings; Variable-Amplitude Tests With A Gust-Loads Spectrum, NACA 4132, November 1957.

85. D. G. Ford and A. O. Payne: Fatigue Characteristics of a Riveted 24S-T Aluminum Alloy Wing; Part IV. Analysis of Results, Australian Defense Scientific Service, Aeronautical Research Laboratories, Report SM 263.

APPENDIX II

LIST OF CYCLES TO FAILURE AND UNBIASED POINT ESTIMATES OF POPULATION PARAMETERS OF COLLECTED FATIGUE DATA

DATA CODING SYSTEM

X X X X X X

MATERIALS:
(two digits)

01 - 2020-T6
02 - 2024-T3
03 - 2024-T351
04 - 2024-T4, -T42
05 - 2024-T81
06 - 2024-T851
07 - 2124-T851
08 - 7075-T651, -T6
09 - 7075-T73, -T7351, -T7352
10 - 7075-T76
11 - 7079-T652, -T6
12 - 7175-T736
13 - 7178-T6
14 - 7178-T76

TYPE OF STRUCTURE:

0 - No Load Transfer Element

1 - Lap Joint (Load Transfer Element)
2 - Scarf Joint (Load Transfer Element)
3 - Double Shear (Load Transfer Element)

4 - Structural Components & Full Scale Structures

TYPE OF SPECIMEN:

0 - Open Holes

1 - Clearance Fit Fasteners (Riveted Included)

2 - Interference Fit Fasteners

3 - Edge-Notched

TYPE OF LOADING:

0 - Constant Amplitude

1 - Spectrum (Maneuver)

2 - Spectrum (Gust)

TYPE OF TEST MACHINE:

0 - Servo-Control

1 - Mechanical Shaker

2 - Solenoid Type

3 - Other

4 - Unknown

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
100	1	060001	4	59593	.0605	63240	9.2559
101	1	060001	2	17113	.0000	17113	VERY HIGH
102	1	060001	2	28391	.0350	29196	12.1694
103	1	090001	4	59070	.0692	63438	5.6678
104	1	120001	4	63969	.0894	70834	4.3568
105	1	080001	2	34885	.0362	35600	11.7698
106	1	060101	3	48365	.0735	51490	7.3459
107	2	090001	5	19591	.0678	20979	6.2777
108	9	080001	3	3156	.0496	3293	9.8727
109	9	080001	2	1503	.0471	1560	9.0293
110	2	080001	4	883	.0940	968	4.4283
111	2	080001	2	868	.0410	896	10.3818
112	9	080001	3	2894	.0526	3032	8.5583
113	9	080001	3	7080	.0504	7401	9.0947
114	2	080001	2	1981	.0404	2046	10.5307
115	2	080001	3	538	.0560	566	11.9600
116	2	080001	2	11097	.2015	13001	2.1128
117	5	080021	4	11187	.1052	12362	5.6483
118	7	080021	2	14476	.0456	15013	9.3426
119	5	080021	3	15977	.0731	17055	6.0421
120	5	080021	3	24513	.0238	25189	14.1400
121	3	080021	7	11556	.1168	12983	4.4063
122	5	080021	3	10249	.0908	11080	6.4334
123	5	080021	3	10235	.0947	11107	5.1033
124	5	080021	3	19607	.0546	20672	7.2988
125	8	080021	3	24515	.0288	25191	14.1410
126	8	080021	3	20567	.0335	21192	19.9697
127	8	080021	4	47540	.2551	61088	1.6688
128	8	080021	2	201613	.0000	201613	VERY HIGH
129	8	080021	3	228171	.0187	232279	21.5575
130	8	080021	3	151829	.0942	164734	6.4853
131	7	080021	3	8731	.0572	9168	9.1916
132	3	080021	6	7072	.1450	8248	2.8384
133	3	080021	6	7209	.0870	7884	5.1072
134	5	080021	2	22809	.0382	23479	11.7664
135	5	080021	3	69977	.0530	73273	8.5726
136	3	080021	3	12839	.0958	14036	6.7588
137	3	080021	4	18317	[illegible]	19947	6.0852
138	7	080021	4	7478	.0987	8122	5.1589
139	7	080021	4	431	.0612	458	6.5457
140	7	080021	4	1291	.0685	1378	8.1087
141	7	080021	4	1401	.0843	1525	6.4068
142	7	080021	3	1343	.0402	1391	11.8450
143	5	080021	4	14045	.0324	14494	15.7928
144	3	080021	3	3343	.0583	3523	7.4487
145	7	080021	5	1167	.0928	1292	4.1998
146	8	080021	4	1347	.1032	1484	4.4706
147	5	090021	4	5591	.0681	6018	5.7883
148	3	090021	2	5889	.0560	6159	7.5984
149	3	090021	3	6014	.0844	6844	4.7126

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
150	6	010021	4	15234	.1292	17153	3.7340
151	6	050021	4	9076	.0593	9652	8.9512
152	4	080101	6	19323	.1079	21421	4.9777
153	4	080201	4	160130	.0659	171792	5.9686
154	4	110201	3	90820	.0154	92093	28.1457
155	4	110101	4	32899	.1126	36749	4.1738
156	4	110101	3	19673	.1499	22380	3.2887
157	4	110201	3	157774	.1280	177030	3.3991
158	4	110201	3	39669	.2152	48767	1.8618
159	4	110201	2	64515	.1767	74302	2.4090
160	4	080101	7	17331	.0503	18366	7.5845
161	4	080201	3	51187	.0815	55114	5.2755
162	4	080201	4	113855	.1852	133784	3.1381
163	4	080101	4	11900	.0880	13167	4.4153
164	4	080201	4	43003	.2815	55433	2.1634
165	4	080201	3	14495	.2482	17931	2.3390
166	4	080201	3	71767	.2212	86655	2.4185
167	4	110101	6	36357	.0905	39721	5.2127
168	4	090101	5	24515	.0918	26886	6.0372
169	10	080200	3	103572	.0539	108794	7.8963
170	11	080001	6	25444	.0842	27241	10.6462
171	11	080001	4	15947	.0758	17125	5.5780
172	12	080010	4	435654	.4182	687219	.9150
173	12	080010	4	49786	.0444	52084	9.6910
174	12	080010	4	12589	.0846	13648	5.0203
175	12	080010	4	4298	.0776	4629	6.6048
176	12	100010	4	232206	.1410	269791	2.7328
177	12	100010	4	34718	.0212	35462	15.1669
178	12	100010	4	11626	.0574	12215	10.1202
179	12	090010	4	251746	.1336	268151	3.1449
180	12	090010	4	28802	.0256	29576	18.2360
181	12	090010	4	10348	.0357	10719	13.8107
182	12	090010	2	3783	.0462	4131	9.2243
183	12	130010	4	540604	.2649	702097	1.5664
184	12	130010	4	42210	.0972	46442	5.1891
185	12	130010	4	9794	.1143	11008	4.5270
186	12	130010	4	3838	.0882	4109	5.5577
187	12	140010	4	38967	.0203	39733	22.3822
188	12	140010	4	10459	.0995	11410	5.4591
189	12	140010	4	2980	.0561	3166	6.82[illegible]
190	13	080001	3	8357	.0229	8531	19.0244
191	13	080001	3	7871	.0485	8242	9.0463
192	13	080001	2	7675	.0685	8318	6.2126
193	14	050201	3	1465	.0385	1522	10.3300
194	14	080201	3	2287	.0882	2474	6.0339
195	15	110201	3	21709	.3250	25624	1.2157
196	15	110201	3	3406	.0919	3735	4.3293
197	15	090201	3	35500	.0491	37348	8.0821
198	15	090201	3	7773	.2455	9672	1.6015
199	16	084201	2	22832	.1067	24865	3.5506

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
200	16	084101	2	9434	.0500	9818	8.5186
201	16	084101	4	12583	.2891	17094	1.3665
202	16	084101	2	3101	.0057	3116	74.1391
203	16	084101	2	2101	.2038	2472	2.0893
204	16	084201	2	56417	.3629	75401	1.1732
205	16	084201	2	165001	.0430	170775	9.8951
206	17	130010	4	321716	.5013	564575	.7692
207	17	130010	2	37000	.0000	37000	VERY HIGH
208	17	130010	2	64722	.0569	67731	7.4879
209	17	130010	2	13490	.0228	13738	18.7063
210	17	130010	2	109498	.0028	110000	VERY HIGH
211	17	130010	2	14491	.0212	14739	20.0937
212	17	130010	3	27849	.1307	31166	3.7469
213	17	130010	2	75299	.0448	78045	9.4980
214	17	130010	4	176583	.3057	243458	1.2665
215	17	130010	4	751208	.5214	1232377	.9754
216	17	130010	3	7030	.0155	7132	26.8011
217	17	130010	3	35397	.0647	37737	6.1132
218	17	130010	3	79837	.1334	89854	3.3610
219	17	130010	3	138553	.0424	144208	9.6142
220	17	130010	5	402962	.7827	912919	.6370
221	17	130010	2	30463	.0302	31208	14.0826
222	17	130010	3	18757	.0856	20197	5.9565
223	17	130010	2	5477	.0560	5727	7.6036
224	18	040001	2	66017	.0350	67890	12.1670
225	19	134130	3	8327	.1546	9626	2.6578
226	19	134130	3	20845	.1790	24440	2.3177
227	20	080201	2	3672	.0436	3803	9.7620
228	21	080100	4	158853	.0890	173261	4.8198
229	21	080100	2	201408	.0615	211553	6.9241
230	21	080100	2	137625	.0886	147725	4.8257
231	21	080100	3	320723	.4521	492446	.8969
232	22	082200	2	95635	.1180	105097	3.6068
233	22	082200	4	92847	.1471	106013	3.4333
234	22	082200	2	69216	.0341	71130	12.4735
235	22	082200	2	150994	.0594	162178	4.7630
236	22	082200	2	334879	.1231	369506	3.4584
237	22	082200	2	140974	.0113	142258	37.5905
238	23	080001	3	12432	.1961	12440	2.2269
239	23	080001	3	9447	.0719	10062	6.4190
240	23	080001	3	9718	.1037	10633	4.5938
241	23	080001	3	18407	.1260	20525	4.5982
242	23	080001	3	27051	.0727	28798	6.7429
243	23	080001	3	122289	.0314	125770	21.3281
244	23	080001	3	266392	.0436	277648	9.2925
245	23	090201	2	82622	.0554	86572	7.6852
246	23	090201	2	80111	.0421	82855	10.1042
247	23	090201	2	89292	.0151	90379	28.1329
248	23	090201	2	177898	.0010	178200	VERY HIGH
249	23	090201	3	264097	.0355	277960	11.9894

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
250	24	080101	3	897	.0922	984	4.3119
251	24	080101	2	33070	.1452	37142	2.9310
252	24	080101	3	9052	.0449	9447	8.9855
253	25	130101	5	19330	.1150	21342	5.3442
254	26	080101	2	7530	.0324	7727	13.1542
255	26	090101	2	14758	.0275	16086	15.4697
256	26	080101	3	6140	.0560	6455	11.9607
257	26	080101	5	6644	.0401	6917	10.7307
258	26	090101	5	1888	.0952	2063	7.1379
259	26	090101	3	2570	.0613	2710	7.7825
260	26	090101	5	2740	.0897	2988	5.1887
261	26	080101	3	13709	.0659	14631	5.9984
262	26	080101	3	13913	.0294	14310	13.6892
263	26	080101	3	10163	.1783	11900	2.5270
264	26	080101	3	10071	.2110	12181	2.0587
265	26	080101	2	9988	.1079	10888	3.9451
266	26	090101	3	3743	.0543	3950	7.2759
267	26	090201	3	5356	.2073	6447	3.2282
268	26	090201	3	8262	.2021	9821	2.8273
269	26	090201	2	6600	.0410	6820	10.3818
270	26	090201	3	38545	.1546	44156	4.0980
271	28	020100	3	209710	.0644	221607	9.0182
272	28	020100	3	343439	.3056	447027	1.9630
273	39	080131	5	6336	.0823	6893	4.6029
274	39	080131	8	4985	.1020	5485	5.0700
275	39	080131	6	23898	.1800	28521	2.4516
276	30	040100	2	692242	.0529	722183	8.0427
277	30	040100	6	177559	.1792	207067	3.5412
278	30	030100	5	257340	.1147	290458	3.9089
279	30	030100	2	295597	.1161	324333	3.6682
280	30	040100	2	561277	.0743	595616	5.7306
281	30	040100	2	209393	.1919	244109	2.2183
282	30	020100	3	165389	.3379	224768	1.2697
283	30	040100	8	290205	.0688	314650	6.0344
284	30	040100	4	286435	.0591	303462	7.6191
285	30	040100	4	105400	.0382	109456	10.8301
286	30	040100	5	115528	.0752	124941	5.8251
287	30	042200	3	152175	.0437	158959	9.0791
288	30	042200	3	168540	.1940	203635	2.0514
289	30	030100	4	83595	.0184	85069	23.0408
290	30	020100	3	171339	.0638	182426	6.2039
291	30	020100	3	132790	.1714	154939	2.5410
292	30	040100	4	362894	.1642	441922	2.3477
293	30	020100	2	335812	.2425	427047	1.7555
294	30	040100	5	143325	.2287	176612	2.1829
295	30	020100	3	102853	.0671	109586	6.0839
296	31	030102	3	8839	.0842	9619	4.7147
297	31	030002	3	4632	.0501	4861	7.9869
298	31	030002	2	6563	.0492	6826	8.6502
299	31	030002	2	9460	.1105	10334	3.8810

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
300	31	080002	4	8848	.0862	9133	6.3860
301	31	080002	3	2436	.0699	2601	5.8598
302	31	080002	2	17380	.0449	18016	9.4780
303	31	080002	2	2388	.0686	2488	6.2099
304	32	080002	2	492	.3849	649	1.1061
305	32	080002	2	1117	.2129	1324	2.0000
306	32	080002	2	4827	.1605	5510	2.5717
307	33	084221	2	5393	.0000	5393	VERY HIGH
308	34	084121	4	1639	.1103	1926	3.8433
309	34	084121	3	5215	.1177	5829	3.4536
310	34	084121	3	5185	.2746	6713	1.4679
311	34	084121	3	2356	.1181	2618	3.7478
312	34	084121	2	4205	.1273	4710	3.3459
313	35	084121	4	1676	.0316	1727	14.1635
314	35	084121	3	2148	.0426	2231	10.8848
315	35	084121	3	2056	.0722	2192	6.2363
316	35	084121	3	1922	.0798	2059	6.1640
317	35	084121	3	2200	.0297	2258	1[illegible]773
318	35	084121	3	4933	.0878	5319	6.6825
319	35	084121	3	1865	.0341	1941	14.3369
320	35	084121	3	4531	.1304	5085	3.9028
321	35	084121	3	6869	.0757	7348	8.7817
322	35	084121	3	11218	.0369	11612	11.1443
323	35	084121	3	8404	.1220	9382	3.5567
324	35	084121	3	9139	.1126	10206	3.9174
325	35	084121	3	3776	.0244	3862	20.2566
326	35	084121	3	12109	.0361	12396	16.9277
327	35	084121	3	12291	.0785	13223	5.2703
328	35	084121	3	12392	.1074	13330	5.1018
329	35	084121	3	11098	.1340	12516	3.1869
330	35	084121	3	5086	.2260	6169	2.4938
331	35	084121	4	52936	.0479	55139	14.2332
332	36	080001	4	751	.0500	790	9.1557
333	36	080001	4	646	.0272	662	17.7849
334	36	080001	4	459	.0694	487	10.4500
335	36	080001	4	480	.0330	496	13.6087
336	36	080001	4	1191	.1733	1294	3.2517
337	36	080001	4	837	.0583	850	7.1649
338	36	080001	4	706	.0519	738	12.6487
339	36	080001	4	690	.0375	715	11.4010
340	37	084121	4	3432	.1890	4088	2.3923
341	37	094121	2	3885	.1316	4231	3.2380
342	37	094121	5	4034	.0739	4371	9.3168
343	37	084120	2	11606	.1190	12764	3.3789
344	37	084120	2	2890	.0692	3107	6.1518
345	38	094121	4	6201	.0894	6709	4.8758
346	38	084121	4	8294	.0957	9106	4.4118
347	38	094121	4	7288	.3697	7808	7.5424
348	38	084121	4	11172	.0744	11933	6.4636
349	38	094121	12	1480	.0502	1559	9.9149

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
350	38	084121	8	887	.1147	1002	4.1288
351	38	094120	4	13494	.1085	14903	4.4615
352	38	084120	4	1368	.0317	1408	16.0205
353	41	080201	3	90821	.0154	92094	28.1427
354	42	080210	2	130582	.1763	150344	2.4148
355	42	080210	2	61991	.0099	62484	42.9730
356	42	080210	2	124377	.0271	127107	15.6804
357	42	080210	2	77794	.0826	83107	5.1510
358	42	080210	2	55866	.0439	57853	9.6876
359	42	080210	2	75046	.0978	81148	4.3632
360	42	080210	2	121407	.0606	127434	7.0242
361	42	080210	2	87988	.0662	92768	6.4324
362	42	080210	2	104923	.0234	106908	18.1864
363	42	080210	2	75973	.0162	76961	26.3355
364	42	080210	2	113000	.0000	115000	VERY HIGH
365	42	080210	2	89999	.1120	98426	3.8018
366	42	080210	2	93327	.2036	109817	2.0914
367	42	080210	2	68373	.1337	76084	3.1846
368	42	080210	2	80962	.2155	96185	1.9751
369	42	080210	2	76765	.0480	79768	8.8772
370	42	080210	6	101023	.0762	109257	5.8880
371	42	080110	6	9965	.0968	11076	4.7808
372	1	070001	2	58358	.0007	58423	VERY HIGH
373	43	080121	5	14747	.1506	16766	4.7464
374	43	080121	5	21550	.1365	24482	3.8415
375	43	080121	2	25537	.0392	26351	10.8473
376	43	080121	2	16379	.0000	16379	VERY HIGH
377	44	080021	4	58177	.0114	58846	35.5367
378	44	080021	4	25808	.0074	25984	VERY HIGH
379	44	080021	4	9764	.0727	10464	6.3981
380	44	080021	3	727	.0254	0	80.6472
381	44	080021	4	8639	.0499	9067	9.6714
382	44	080021	4	82217	.0339	84790	14.2407
383	44	080021	4	27272	.0091	27509	63.3409
384	44	060021	4	13187	.0074	13294	VERY HIGH
385	45	080000	5	6171	.2768	7901	2.0187
386	45	080000	5	4609	.1308	5311	3.6967
387	45	080000	5	4589	.1968	5579	2.2452
388	45	080000	5	4268	.0820	4624	6.1167
389	45	080000	5	2881	.2269	3557	2.2180
390	45	080000	5	5043	.0655	5400	6.1151
391	45	080000	5	37627	.3562	53390	1.3281
392	45	080000	[illegible]	20430	.2413	25921	1.8477
393	45	080000	5	12748	.1420	14758	2.9788
394	45	080000	5	9788	.0601	10421	8.4262
395	45	080000	5	14309	.0546	15146	9.3118
396	45	080000	5	5739	.1217	6397	5.5465
397	45	080000	5	15867	.1264	18211	3.0376
398	45	080000	5	68997	.6699	173023	.8084
399	45	080000	5	40490	.1578	47337	3.6007

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
400	45	080000	5	39457	.2087	49589	1.8729
401	45	080000	5	27131	.3586	39571	1.1927
402	45	080000	5	65044	.2179	78639	3.1874
403	45	080000	5	206215	.0364	215764	10.3721
404	45	080000	5	242450	.1688	293476	2.2655
405	45	080000	5	5032	.1273	5737	3.5138
406	45	080000	5	3456	.2325	4422	2.0728
407	45	080000	5	2437	.1341	2752	4.4628
408	45	080000	5	246106	.5469	436271	.7761
409	45	080000	2	13360	.0652	14074	6.5315
410	45	080000	5	2357	.2246	2943	1.9445
411	45	080000	5	31444	.0675	33716	6.7468
412	45	080000	5	12528	.1944	15722	1.9278
413	45	080000	5	8105	.1554	9736	2.4120
414	45	080000	5	79474	.5264	143691	.7340
415	45	080000	5	7339	.0670	7831	7.6045
416	45	080000	5	22114	.1696	26419	2.7699
417	45	080000	5	349369	.5196	611483	.7738
418	45	080000	5	5644	.1659	6486	4.5940
419	45	080000	5	141335	.4800	251510	.8037
420	45	080000	5	3073	.2076	3728	2.5598
421	45	080000	5	38344	.1880	46781	2.3798
422	45	080000	5	4733	.5041	7805	.8744
423	45	080000	6	37744	.1005	41462	6.8535
424	45	080000	5	3730	.0487	3924	8.6911
425	45	080000	6	12420	.0733	13389	7.2345
426	47	080100	5	15890	.0681	17184	5.7672
427	50	080100	3	4915	.0777	5260	8.0635
428	50	080100	2	11696	.0158	11844	27.0269
429	50	080100	2	10723	.0429	11098	9.9190
430	50	080100	2	13934	.0286	14257	14.8656
431	50	080000	2	2649	.0116	2674	36.7316
432	50	080000	3	37124	.0569	38969	9.4652
433	50	080000	2	42533	.0454	44106	9.3679
434	50	080000	2	107470	.1624	122367	2.6213
435	50	080000	2	10599	.0058	10648	73.4721
436	50	080000	2	8831	.0763	9387	5.5795
437	53	080100	2	17435	.0528	18186	8.0669
438	53	080100	2	51497	.1707	59027	2.4936
439	53	080100	2	93096	.0855	99680	4.9799
440	53	080100	2	201988	.2429	245282	1.7523
441	53	080100	2	9049	.0034	9100	VERY HIGH
442	53	080100	2	52411	.1508	59126	2.8228
443	53	080100	2	93465	.0164	94701	25.9187
444	53	080100	2	398618	.3623	532499	1.1751
445	53	080100	2	21424	.1421	24000	2.9966
446	53	080100	2	47486	.0902	51037	4.7191
447	53	080100	2	195712	.0938	210948	4.5396
448	53	080100	2	8485	.0362	8734	11.7698
449	53	080100	2	102468	.1221	112971	3.4875

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
450	53	080100	2	14966	.0410	15465	10.3818
451	53	080100	2	39999	.2887	50381	1.4748
452	53	080100	2	57271	.2204	68306	1.9312
453	53	080100	2	127989	.0551	133748	7.7242
454	53	080100	2	19442	.0473	20191	8.3931
455	53	080100	2	39949	.0307	40943	13.8514
456	53	080100	2	447317	.1721	513291	2.4735
457	53	080100	2	25396	.3234	32888	1.3163
458	53	080100	2	34409	.0446	35657	9.5467
459	53	080100	2	90464	.1937	105611	2.1983
460	53	080100	2	16970	.0362	17468	11.7701
461	53	080100	2	47738	.0642	50252	6.6300
462	53	080100	2	164561	.0447	170554	9.5138
463	64	080100	6	39430	.0520	41588	8.6847
464	52	080100	4	3266	.0502	3425	11.4351
465	52	080100	4	4377	.0446	4555	12.0098
466	52	080100	4	6083	.0464	6365	9.5666
467	52	080100	4	11650	.0689	12452	7.3092
468	52	080100	4	29850	.0741	31997	6.2628
469	52	080100	4	5821	.0967	6323	7.3799
470	52	080100	4	10393	.0502	10998	7.6495
471	52	080100	4	13339	.0673	14250	7.1003
472	52	080100	4	28127	.0540	29697	10.0999
473	52	080100	5	68800	.0506	72571	9.7482
474	52	080100	4	10504	.0720	11278	5.7658
475	52	080100	4	15619	.1308	17843	3.0444
476	52	080100	4	30874	.0489	32382	9.1562
477	52	080100	5	71419	.0727	76841	5.8101
478	52	080100	4	36313	.0755	38909	6.3518
479	52	080100	4	71684	.1588	82462	3.7241
480	52	080100	4	206074	.1936	245468	3.1839
481	52	080100	4	139103	.0956	153010	5.2236
482	52	080100	4	377988	.2075	457997	2.8959
483	53	080100	2	315434	.1428	353573	2.9813
484	53	080100	2	12049	.0025	12100	VERY HIGH
485	53	080100	2	27964	.3057	35704	1.3927
486	53	080100	2	45166	.2513	55214	1.6941
487	53	080100	2	215434	.1675	246305	2.5410
488	53	080100	2	205790	.0995	222833	4.2767
489	53	080100	2	12489	.0246	12737	17.3194
490	53	080100	2	49799	.1346	55455	3.1632
491	53	080100	3	205462	.6149	379335	.6441
492	53	080100	3	376181	.1871	446024	2.3363
493	53	080100	2	14422	.0638	15176	6.6764
494	53	080100	2	26049	.0012	26100	VERY HIGH
495	53	080100	2	68992	.0089	69485	47.8171
496	53	080100	3	456198	.9761	1148027	.4166
497	53	080100	2	238154	.3351	311314	1.2703
498	53	080100	2	35874	.0513	37376	8.2985
499	53	080100	2	180685	.0982	196434	4.3371

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND
WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
500	[illegible]	080100	2	24453	.0377	25201	11.3073
501	53	080100	2	89860	.0342	92347	12.4641
502	53	080100	2	124474	.4381	176663	.9718
503	53	080100	2	11489	.0267	11737	15.9324
504	53	080100	2	32726	.2725	40689	1.5624
505	53	080100	2	208560	.0837	222986	5.0882
506	53	080100	2	23366	.0656	24624	6.4909
507	53	080100	2	56160	.2399	68032	1.7745
508	53	080100	2	22360	.0685	23619	6.2125
509	53	080100	2	79371	.0772	84423	5.5163
510	53	080100	2	27549	.1109	30102	3.8400
511	53	080100	2	115242	.4324	162821	.9846
512	53	080100	2	10488	.0293	10736	14.5451
513	53	080100	2	38884	.2017	45686	2.1107
514	53	080100	2	121588	.2271	145796	1.8742
515	45	080100	5	1414	.3835	2100	1.0645
516	45	080100	5	1436	.1873	1750	2.1265
517	45	080100	5	1703	.2113	2071	2.7234
518	45	080100	5	928	.0887	1004	6.8905
519	45	080100	5	1890	.1491	2187	3.0814
520	45	080100	5	705	.1024	777	5.5917
521	45	080100	5	403	.0865	440	4.6907
522	45	080100	5	256	.1440	292	3.8952
523	45	080100	5	204	.1108	232	3.3890
524	45	080100	5	499	.1111	555	4.4207
525	45	080100	5	113	.2886	145	2.4184
526	45	080100	5	232	.1493	268	3.0407
527	45	080100	5	862	.0787	919	6.7464
528	45	080100	5	679	.1229	771	3.3864
529	45	080100	5	781	.1726	924	2.8477
530	45	080100	5	956	.2246	1192	1.9680
531	45	080100	5	248	.0765	268	6.7526
532	45	080100	5	552	.1465	640	2.8585
533	45	080100	5	683	.0884	738	7.0780
534	45	080100	5	1850	.1178	2069	4.2850
535	45	080100	5	193	.2233	240	2.1624
536	45	080100	5	162	.1543	186	3.6731
537	45	080100	5	306	.2066	370	2.5212
538	45	080100	5	692	.2563	925	1.4700
539	45	080100	5	175	.0396	182	10.6181
540	45	080100	5	186	.1061	204	5.0414
541	45	080100	5	508	.1223	578	3.7244
542	45	080100	5	512	.1768	632	2.1541
543	45	080100	5	745	.3819	1170	.9891
544	45	080100	5	1500	.2591	1956	1.6438
545	45	080100	5	740	.1139	825	4.2573
546	45	080100	5	650	.1073	720	4.5395
547	45	080100	5	1211	.2555	1541	2.2329
548	45	080100	5	1330	.1377	1496	4.5099
549	45	080100	5	511	.0188	521	23.5434

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
550	45	080100	2	1343	.0065	0	77.6248
551	45	080100	5	4722896	.2267	5812954	2.3128
552	52	080100	4	1279314	.0321	1321623	12.5096
553	52	080100	4	3769058	.2678	4916528	1.8734
554	45	080100	5	200298	.2403	253753	1.9132
555	45	080100	5	179198	.7641	448034	.5021
556	45	080100	5	958531	.3312	1352169	1.2639
557	45	080100	5	20634	.3303	29178	1.3490
558	45	080100	5	66682	.4358	101358	1.4008
559	45	080100	5	381419	.2523	492335	1.9816
560	45	080100	5	3436	.2855	4622	1.4165
561	45	080100	5	53987	.1754	63719	3.6098
562	45	080100	5	42715	.1868	53012	2.0374
563	45	080100	5	722476	.4884	1177914	.8771
564	45	080100	5	195577	.6129	375102	.7832
565	52	080100	4	417206	.0963	454976	5.0708
566	45	080100	5	780496	.6123	1414067	.8048
567	58	080120	5	282	.0399	293	13.3692
568	58	080120	5	460	.0479	472	9.1528
569	58	080120	5	667	.0505	702	10.2380
570	58	080120	7	935	.0966	1023	5.8447
571	58	080120	5	1534	.0618	1625	9.4851
572	58	080120	8	2973	.0519	3156	7.4867
573	58	080120	5	4393	.1080	4837	6.0625
574	58	080120	5	9413	.0364	9753	15.3070
575	58	080120	5	20048	.0352	20821	11.1036
576	58	080120	5	31829	.0949	34563	6.2431
577	58	080120	6	71673	.2179	93144	1.7542
578	58	080120	5	185257	.4979	312633	.9116
579	58	080120	4	3674221	.7465	7266620	.6542
580	58	080120	4	46838454	.2970	61584375	1.5986
581	57	080110	2	37	.0324	38	13.1576
582	57	080110	2	132	.0139	0	30.7252
583	57	080110	3	802	.0783	858	7.0335
584	57	080110	2	6000	.0000	6000	VERY HIGH
585	57	080110	3	26637	.1512	30302	3.4650
586	57	080110	3	122541	.1002	133572	4.9131
587	57	080110	5	579561	.2299	739292	1.7466
588	57	080110	3	3084808	.1172	3411687	4.2138
589	57	080110	3	95	.0660	101	6.1079
590	57	080110	2	405	.0499	422	8.5301
591	57	080110	4	33408	.1731	39987	2.2867
592	57	080110	5	111981	.6050	220879	.6264
593	57	080110	3	1726750	.1726	2004414	3.5037
594	57	080110	3	14043958	.2338	17368698	1.8324
595	57	080110	2	334	.0495	348	8.6073
596	57	080110	3	10811	.0799	11621	5.3992
597	57	080110	5	194614	.3722	288433	1.0833
598	57	080110	4	63318	.1273	70895	4.4191
599	57	080110	3	2152700	.9479	4863032	.6146

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
600	57	080110	3	19058375	.3639	26542038	1.1741
601	60	080120	2	16	.0560	17	7.6036
602	60	080120	2	123	.0891	132	4.7800
603	60	080110	5	25588	.1367	29288	3.5451
604	60	080110	4	65229	.1698	76786	2.6114
605	60	080110	4	97650	.7101	182138	.7758
606	60	080110	8	392408	.1990	491683	2.1971
607	60	080120	2	6	.0473	6	8.9932
608	60	080120	3	8	.0783	8	5.2428
609	60	080120	2	49	.0492	51	8.6459
610	60	080120	3	123	.0486	129	8.1373
611	60	080120	3	295	.0541	309	8.7028
612	60	080120	4	1336	.0555	1406	10.0199
613	60	080110	3	4915	.0777	5260	8.0635
614	60	080110	2	7000	.0000	7000	VERY HIGH
615	60	080110	2	11696	.0158	11844	27.0269
616	60	080110	3	680218	.3323	931531	1.2225
617	60	080120	2	6	.3374	9	.2619
618	60	080120	3	422	.0498	443	7.9500
619	60	080110	2	7167600	.2378	8659499	1.7904
620	60	080120	2	4	.0685	4	6.2126
621	60	080120	2	15	.0384	16	11.0758
622	60	080120	2	24	.0000	24	VERY HIGH
623	60	080120	2	98	.0928	106	4.5861
624	60	080120	2	346	.0319	355	13.3603
625	60	080110	2	2793212	.3225	3614477	1.3202
626	60	080120	2	8	.0362	8	11.7699
627	60	080120	2	11	.0267	0	15.9320
628	60	080120	2	13	.0228	0	18.7068
629	60	080120	2	702	.0454	728	9.3672
630	60	080110	3	9906	.0436	10364	10.0435
631	60	080110	2	10599	.0058	10648	73.4721
632	60	080110	3	128666	.1648	146364	2.9246
633	60	080110	9	1264493	.5932	3105607	.6128
634	60	080110	2	2433890	.8953	4978647	.4755
635	47	020102	6	783	.0180	797	28.0548
636	47	020102	6	4458	.0757	4819	5.9964
637	48	020101	6	7113	.0484	7474	10.8259
638	48	020101	6	6374	.0438	6714	8.5112
639	48	020101	6	7742	.0661	8280	7.1134
640	48	020101	6	7809	.0413	8125	12.0146
641	48	020101	6	7344	.0541	7765	6.7623
642	48	020101	6	14107	.0594	15104	8.1203
643	48	020101	6	7701	.0484	8135	8.6622
644	48	020101	6	7372	.0674	7865	9.9413
645	48	020101	6	27489	.0182	20871	24.7478
646	48	020101	6	18685	.0491	19758	7.8342
647	48	020101	6	24182	.0499	25488	9.0548
648	48	020101	6	13746	.0408	14344	10.2340
649	48	020101	6	11326	.0357	11774	11.8093

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
650	48	020101	6	52627	.0632	55987	7.9874
651	48	020101	6	13188	.0645	14052	7.3577
652	48	020101	6	10846	.0546	11520	7.1926
653	48	020101	6	24613	.0510	26080	7.5798
654	48	020101	6	25821	.0256	26701	14.7574
655	48	020101	6	30369	.0365	31587	10.8894
656	48	020101	6	20786	.0413	21820	10.8985
657	48	020101	6	29036	.0578	30765	7.9822
658	48	020101	6	42625	.0319	44134	12.2961
659	48	020101	6	40508	.0224	41442	19.9740
660	48	020101	6	69176	.0599	73547	7.4791
661	48	020101	6	41565	.0248	42630	18.2195
662	48	020101	6	14599	.0436	15245	13.4921
663	48	020101	6	46515	.0672	49944	8.5359
664	48	020101	6	43945	.0469	46069	10.1757
665	48	020101	6	30681	.0434	31763	13.8216
666	48	020101	6	29560	.0543	31191	8.5333
667	48	020101	6	22018	.0608	23433	7.2140
668	48	020101	6	42920	.0309	44252	14.9506
669	48	020101	6	38167	.0428	39903	9.9785
670	48	020101	6	62797	.0369	64620	14.5349
671	48	020101	6	39524	.0634	42289	7.9080
672	48	020101	6	41443	.0500	43833	7.8309
673	48	020101	6	58507	.0510	61491	9.6308
674	48	020101	6	49523	.0521	52369	7.6792
675	48	020101	6	25918	.0588	27332	12.2807
676	48	020101	6	21437	.0591	21666	9.1348
677	48	020101	6	22328	.0359	23033	17.6647
678	51	020101	10	109	.0408	114	10.2724
679	51	020101	10	124	.0692	134	7.5577
680	51	020101	10	115	.0762	123	7.9274
681	51	020101	10	112	.1120	128	4.8852
682	57	020122	3	1746	.1027	1935	3.8493
683	57	020122	4	1778	.0889	1935	5.2384
684	57	020122	4	5009	.0588	5322	4.6512
685	57	020122	4	3017	.1376	3434	3.8333
686	57	020122	4	3853	.0468	4041	11.5176
687	57	020122	3	2607	.0481	2782	9.0540
688	57	020122	3	1478	.1013	1503	4.9067
689	57	020122	6	1011	.0972	1120	4.[illegible]
690	57	020122	6	949	.1702	1156	2.2453
691	57	020122	5	1851	.0865	2022	6.0480
692	57	020122	3	1657	.0906	2016	4.7134
693	57	020122	6	1475	.1907	1807	2.1665
694	57	020122	2	8149	.0038	8160	VERY HIGH
695	57	020122	9	3827	.0954	4218	5.4931
696	57	020122	3	11858	.1938	13066	2.3487
697	57	020122	6	14566	.1714	17381	2.3210
698	57	020122	6	6990	.1305	7960	4.0167
699	57	020122	4	15232	.1151	17051	3.6648

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
700	57	020122	3	2405	.0730	2567	6.0519
701	57	020122	3	9266	.0569	9752	7.7010
702	57	020122	3	6510	.0546	6861	7.3359
703	57	020122	3	6135	.0558	6478	7.1247
704	57	020122	4	4884	.0902	5308	6.9390
705	57	020122	3	8104	.0709	8693	6.3707
706	57	020122	6	1628	.1143	1845	3.4796
707	57	020122	3	1237	.0702	1318	9.5281
708	58	080121	6	15373	.0942	16949	5.4888
709	58	080121	6	21991	.0716	23509	7.3444
710	58	080121	7	21129	.0984	23014	6.0705
711	58	080121	6	23214	.0502	24641	9.0132
712	58	080121	6	13368	.0287	13828	15.7739
713	58	080121	7	20351	.0848	21852	9.5653
714	58	080121	6	5399	.0376	5595	16.0513
715	58	080121	6	5613	.0549	5959	8.7171
716	58	080121	6	13000	.0472	13666	8.9689
717	58	080121	6	5727	.0560	6069	9.4368
718	59	080121	6	2406	.0743	2581	8.3738
719	59	080121	6	2614	.0630	2787	6.9712
720	59	080122	6	1509	.1956	1841	2.1669
721	59	080122	6	1883	.1976	2249	2.96[illegible]2
722	59	080122	6	7695	.0447	8048	12.9297
723	59	080122	6	14485	.0539	15362	7.5404
724	59	080121	6	5194	.1056	5758	5.4473
725	59	080122	6	6968	.0983	7674	4.7790
726	47	080102	6	482	.0349	504	10.6284
727	47	080102	6	195	.0369	203	10.7577
728	47	080102	7	192	.0679	206	7.4245
729	47	080102	6	186	.0361	193	13.5135
730	47	080102	6	167	.1062	187	4.5107
731	47	080102	6	505	.0436	527	11.9829
732	47	080102	6	185	.0363	193	13.2457
733	47	080102	6	1581	.0541	1665	9.0857
734	47	080102	6	368	.0588	389	8.8862
735	47	080102	6	80	.0465	84	11.1809
736	47	080102	6	744	.0589	792	7.0450
737	47	080102	6	151	.0344	157	10.9487
738	47	080102	6	146	.0411	152	11.5997
739	47	080102	6	2016	.0383	2103	10.5455
740	47	080102	6	417	.0488	438	10.1297
741	47	080102	6	2421	.0830	2627	6.1497
742	47	080102	6	435	.0617	470	6.2835
743	47	080102	6	361	.0423	376	12.0527
744	47	080102	6	62	.0927	67	4.8179
745	47	080102	7	65	.0694	70	7.1572
746	47	080102	6	61	.0324	63	11.6771
747	47	080102	6	66	.0809	72	5.8924
748	49	080101	6	12447	.0457	13068	8.8430
749	49	080101	6	11486	.0580	12253	7.9332

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
750	49	080101	6	13532	.0480	14192	10.9576
751	49	080101	7	8718	.0873	9647	4.4681
752	49	080101	6	4308	.0417	4488	11.8348
753	49	080101	6	7314	.0472	7689	8.9674
754	49	080101	8	34845	.0372	36304	11.3046
755	49	080101	6	92982	.0585	98894	7.1431
756	49	080101	6	64742	.0773	70149	6.3479
757	49	080101	6	37078	.1323	42533	3.3233
758	49	080101	6	38256	.0495	40559	7.5630
759	45	080002	4	2474	.0623	2630	7.1609
760	45	080002	5	492	.2722	635	2.1520
761	45	080002	6	1416	.0967	1570	4.2502
762	45	080002	5	3620	.0673	3870	6.8944
763	45	080002	8	23025	.1891	28151	2.2813
764	45	080002	5	8566	.1635	10181	2.6796
765	45	080002	5	3991	.0587	4219	8.4418
766	45	080002	6	1487	.1264	1731	3.1535
767	45	080002	6	4269	.0766	4568	7.9628
768	45	080002	10	8191	.0605	8789	6.4660
769	45	080002	5	16515	.1114	18322	5.0487
770	45	080002	5	36515	.0733	39541	5.4376
771	45	080002	6	880	.0845	971	4.5207
772	45	080002	6	51731	.1039	57741	4.4388
773	45	080002	7	9441	.1230	10843	3.3620
774	45	080002	5	3889	.1090	4343	3.9324
775	45	080002	5	2866	.1171	3211	4.0180
776	45	080002	5	3319	.0699	3566	5.9926
777	45	080002	5	10594	.1062	11798	4.6781
778	45	080002	5	21498	.0879	23561	4.6428
779	45	080002	8	33638	.0937	36969	6.0907
780	45	080002	5	188685	.0838	204865	6.0692
781	45	080102	5	540[illegible]31	.1314	630735	2.9029
782	45	080102	7	6599	.1526	7789	2.6562
783	45	080002	5	4049	.1868	5025	2.0374
784	62	084140	2	12670	.0372	12950	11.4420
785	62	084140	3	97392	.2469	120694	1.9177
786	62	084140	3	438213	.1488	507968	2.6584
787	62	084140	3	13092	.1000	14434	3.9649
788	62	084140	3	1170494	.1358	1328994	3.0299
789	63	084140	2	75906	.1506	85616	2.8268
790	63	084140	2	10261	.0806	10944	5.2839
791	63	084140	3	17652	.2854	22686	1.6940
792	63	084140	2	35326	.0608	37084	7.0076
793	63	084140	2	37425	.0500	38951	8.5149
794	62	084140	3	1344	.0882	1468	4.5021
795	62	084140	3	1259	.1738	1499	2.2881
796	63	084140	3	132269	.0828	143546	4.7753
797	62	084140	2	599	.0761	637	5.5957
798	63	084140	3	9221	.0419	9566	15.1009
799	63	084140	2	1631	.1491	1838	2.8553

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
800	63	084140	2	1382	.0742	1466	5.7346
801	63	084140	2	13729	.0335	14102	12.6951
802	63	084140	5	16987	.2239	20812	2.4414
803	63	084140	2	18827	.0700	19910	6.0831
804	63	084140	3	18390	.2298	22759	1.8094
805	55	084140	4	6593	.1519	7523	3.6537
806	55	084140	4	33495	.1422	37993	4.2656
807	55	084140	5	39449	.2208	48860	2.3968
808	55	084140	3	59701	.1517	69379	5.3008
809	55	084140	4	12156	.0628	12862	8.0258
810	55	084140	4	39779	.0965	43636	5.6489
811	55	084140	3	10675	.0798	11564	4.9804
812	55	084140	4	14019	.0538	14752	8.2858
813	55	084140	7	12474	.0870	13596	5.5644
814	55	084140	4	5438	.0731	5915	5.3202
815	55	044140	2	994	.0616	1045	6.9083
816	63	084140	2	1212334	.1982	1420417	2.1482
817	63	084140	2	1507968	.1312	1674664	3.2457
818	63	084140	2	32403	.0473	33653	8.9931
819	63	084140	2	141904	.4795	208191	.8878
820	63	084140	2	39599	.1232	43699	3.4541
821	63	084140	3	1291677	.2706	1641169	2.4103
822	45	084101	3	32689	.0405	33848	14.7203
823	45	084101	2	71386	.0524	74439	8.1265
824	45	084101	2	52821	.1808	61032	2.3552
825	66	084111	3	14317	.0709	15351	5.5826
826	66	084111	3	15628	.0314	16115	12.6343
827	66	084111	2	17087	.0194	17354	21.9365
828	66	084111	2	15482	.1351	17248	3.1514
829	66	084111	3	10260	.1207	11362	4.3059
830	66	084111	3	14071	.1143	15543	4.1146
831	66	084111	3	8083	.0944	8779	6.7064
832	66	084111	3	6622	.0816	7104	6.0140
833	66	084111	3	12083	.0524	12644	9.1142
834	66	084111	3	20911	.0493	21810	10.4648
835	65	024132	6	105615	.0727	114189	5.8878
836	67	020111	10	95	.0979	105	4.5053
837	67	020111	10	111	.1022	128	3.7765
838	67	020111	10	98	.0840	107	5.8752
839	67	020111	5	88	.0484	92	10.6947
840	67	020111	10	86	.1020	96	4.4184
841	67	020111	10	124	.0894	134	7.0640
842	67	020111	10	94	.1001	105	4.6070
843	67	020111	5	84	.0284	86	20.9827
844	67	020111	10	122	.0617	131	7.3312
845	67	020111	13	89	.1223	101	3.9104
846	67	020111	10	79	.1043	91	3.5687
847	67	020111	5	83	.0520	88	7.3013
848	67	020111	10	107	.1079	121	3.7752
849	67	020111	5	107	.0887	117	4.7768

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
850	67	020111	10	92	.0648	98	8.4619
851	67	020111	5	87	.0829	95	5.3466
852	67	020111	10	128	.0991	142	4.6494
853	67	020111	10	104	.1160	118	3.7434
854	67	040111	10	119	.0853	130	5.9465
855	67	020111	10	164	.0884	180	5.0787
856	70	084141	3	22768	.1141	25455	3.[illegible]737
857	70	084141	3	13804	.0736	14814	5.4513
858	70	084141	2	33888	.0279	34654	15.2388
859	70	084141	2	31074	.2093	36732	2.0343
860	70	084141	3	24764	.1407	27994	3.3333
861	70	084141	3	18900	.0899	20657	4.3968
862	71	084131	5	739159	.1921	896545	2.4167
863	71	084131	5	232012	.0982	254909	5.0117
864	71	084131	3	212906	.0372	219980	12.3425
865	71	084131	3	251651	.0521	263099	10.7002
866	76	084121	2	1752	.0242	1786	17.6113
867	76	084121	2	2987	.0535	3117	7.9584
868	79	084101	2	20988	.0099	21155	42.7669
869	79	084101	2	20570	.0873	22056	4.8786
870	79	084101	2	14435	.0183	14647	23.2992
871	79	084101	2	17965	.0624	18884	6.8258
872	79	084101	2	18072	.0346	18579	12.2876
873	79	084101	2	17170	.0381	17702	11.1618
874	79	084101	2	21002	.0483	21829	8.8132
875	79	084101	2	14592	.1557	16526	2.7351
876	79	084101	2	11185	.0577	11713	7.3809
877	79	084101	2	8569	.0311	8784	13.7082
878	79	084101	2	9155	.0810	9767	5.2555
879	79	084101	2	8577	.0262	8758	16.2718
880	79	084101	2	29979	.0055	30112	76.9712
881	79	084101	2	39158	.0127	39558	33.4701
882	79	084101	2	63934	.0000	63934	VERY HIGH
883	79	084101	2	12418	.0089	12507	47.6905
884	79	084101	2	14030	.0247	14297	17.9973
885	79	084101	2	33264	.0332	34159	12.8087
886	79	084101	2	29282	.0025	29404	VERY HIGH
887	79	084101	2	29336	.0288	30019	14.7671
888	79	084101	2	32192	.1069	35058	3.9874
889	79	084101	2	16213	.0284	16322	50.9725
890	79	084101	2	19944	.0125	20144	34.0942
891	79	084101	2	22389	.0776	23823	5.4849
892	79	084101	2	23120	.0258	23601	16.5269
893	79	084101	2	31436	.0509	32742	8.3567
894	79	084101	2	39776	.0182	40458	23.3989
895	79	084101	2	17932	.0248	18291	17.1492
896	79	084101	2	12394	.0162	12555	26.3559
897	79	084101	2	14679	.0152	14858	28.0710
898	79	084101	2	14585	.0360	15011	11.8177
899	79	084101	4	24691	.2348	31463	1.7075

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
900	79	084101	2	26927	.1367	30037	3.1135
901	79	084101	2	17539	.0732	18596	5.8140
902	79	084101	2	14679	.0123	14824	34.5539
903	79	084101	2	13079	.0284	13380	14.9666
904	79	084101	2	10190	.0000	10190	VERY HIGH
905	79	084101	2	15357	.0110	15492	38.7804
906	79	084101	2	17761	.1493	20013	2.8509
907	79	084101	2	5364	.0122	5417	34.7558
908	79	084101	2	7605	.0173	7711	24.6395
909	79	084101	2	9845	.0968	10635	4.3996
910	79	084101	2	12277	.0068	12344	62.8050
911	79	084101	2	10650	.0693	11256	6.1444
912	79	084101	2	18872	.0794	20109	5.3597
913	79	084101	2	18029	.1026	19571	4.1478
914	79	084101	2	9577	.0137	9682	31.0964
915	79	084101	2	11452	.2106	13552	2.0212
916	79	084101	2	3481	.0783	3706	5.4379
917	79	084101	2	4850	.0615	5094	6.9219
918	79	084101	2	7356	.0099	7414	42.8467
919	83	024110	3	81433	.0273	89303	4.1668
920	83	024112	5	330097	.0834	359531	5.1277
921	83	024110	2	1214900	.0076	10699	56.1343
922	83	024110	2	2419286	.2292	3506315	1.8572
923	84	024110	2	4568356	.0554	4775397	7.6775
924	84	024112	6	16494	.0308	18090	4.6048
925	85	024130	6	4918	.1399	5697	2.9437
926	85	024130	2	4746	.0277	4896	15.3567
927	85	024111	12	1145932	.1472	1328581	3.4277
928	85	024114	4	4086802	.5550	4946232	9.8288
929	85	024110	6	234728	.2267	259433	1.9015
930	85	024110	2	71919	.0290	73607	14.6680
931	85	024110	2	115064	.3395	150541	1.2538
932	85	024110	4	105291	.1591	122180	2.8700
933	85	024110	4	42725	.4346	63508	1.1195
934	85	024110	2	70575	.1142	77322	3.7275
935	85	024110	4	21269	.2439	27169	1.6747
936	85	024110	2	51319	.5344	78665	.7967
937	85	024110	8	924225	.1452	952856	4.1481
938	85	024110	8	22157	.1443	26623	3.3217
939	85	024130	27	17879	.1469	20940	3.2327
940	85	024130	6	2956	.0705	3177	7.4398
941	85	024130	4	45978	.1240	51597	3.9526
942	85	024130	6	32125	.1452	34666	3.2681
943	85	024130	4	57582	.1198	64892	3.4207
944	85	024130	4	60187	.0609	63871	7.3532
945	85	024130	7	14495	.1022	16813	4.1660
946	85	024130	4	75621	.0493	79492	8.0979
947	85	024130	6	4002	.1276	4508	4.3903
948	85	024130	4	4975	.0148	5047	27.3282
949	85	024130	4	782	.1401	900	2.9111

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND
WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
950	85	024130	4	7680	.1376	8673	3.7922
951	85	024130	6	12742	.0601	13541	8.1607
952	85	024130	4	580	.0810	621	8.4122
953	85	024130	6	4615	.0213	4723	18.5336
954	85	024130	10	79505	.1144	89769	4.1143
955	85	024130	4	29618	.0773	32048	6.8084
956	63	084140	2	37425	.0500	38951	8.5149
957	63	084140	3	132269	.0828	143546	4.7753
958	63	084140	2	1631	.1491	1838	2.8553
959	63	084140	2	1382	.0742	1466	5.7346
960	63	084140	2	19827	.0700	19910	6.0831
961	63	084140	3	18390	.2298	22759	1.8094
962	55	084140	4	6593	.1519	7523	3.6537
963	55	084140	4	33495	.1422	37993	4.2556
964	55	084140	4	34619	.2131	42946	2.3023
965	55	084140	2	55135	.1971	64544	2.1599
966	55	084140	4	12156	.0628	12862	8.0258
967	55	084140	4	39779	.0965	43636	5.6439
968	55	084140	3	10675	.0798	11564	4.9804
969	55	084140	4	14019	.0538	14752	8.2858
970	55	084140	7	12474	.0870	13596	5.5644
971	55	084140	4	5435	.0741	5915	5.3202
972	55	084140	2	994	.0616	1045	6.9083
973	63	084140	2	1507968	.1319	1674664	3.2957
974	63	084140	2	141904	.4795	208191	.8870
975	63	084140	2	38599	.1232	43699	3.4541
976	63	084140	3	1291677	.2706	1641189	2.4103
977	62	024140	3	287345	.3124	375010	1.6920
978	63	024140	4	337730	.0846	365087	6.0228
979	62	024140	3	52617	.1383	56926	3.1075
980	62	024140	3	75349	.3429	104762	1.1677
981	62	024140	3	1661441	.0243	1696208	22.6772
982	62	024140	3	[illegible]6494	.1265	769630	3.4178
983	62	024140	3	176502	.1173	195050	4.5743
984	62	024140	3	1395862	.1947	1657325	2.2829
985	74	024101	4	925176	.0810	1002026	5.1139
986	74	024101	8	231713	.1763	281177	2.3473
987	51	022101	73	173	.1191	196	4.0835
988	72	224211	41	37716	.0834	41973	5.9500
989	73	024112	4	10887	.0692	11658	7.5308
990	73	024111	4	23618	.1956	27979	2.8755
991	73	024113	2	12251	.0538	13102	7.9195
992	78	024110	4	87160	.1018	96139	4.7507
993	78	024110	4	309010	.0573	328837	9.5288
994	78	024110	3	1227696	.0177	1247680	23.9821
995	78	024110	2	2009469	.0069	2019000	VERY HIGH
996	82	084130	2	378	.0073	0	58.2980
997	82	084130	2	599	.0517	624	8.2366
998	82	084130	2	708	.1382	791	3.0781
999	82	084130	4	1852	.1400	2118	3.1731

THE UNBIASED POINT ESTIMATES OF LOG-NORMAL AND WEIBULL POPULATION PARAMETERS FOR DATA GROUPS.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	LOG-NORMAL SCALE (MU)	LOG-NORMAL SHAPE (SIGMA)	WEIBULL SCALE (BETA)	WEIBULL SHAPE (ALPHA)
1000	82	084130	4	5635	.0406	5835	15.8171
1001	82	084130	6	10261	.0693	11013	6.2499
1002	82	084130	2	26802	.0598	28114	7.1212
1003	82	084130	4	156108	.1058	173526	3.6330
1004	82	084130	2	117583	.0146	118966	25.1324
1005	66	084130	2	45000	.0192	45695	22.2119
1006	66	084130	4	2076	.0903	2246	7.1179
1007	66	084130	2	5208	.0688	5502	6.1840
1008	66	084130	2	26793	.0603	28116	7.0596
1009	66	084130	2	149906	.0085	10704	49.8362
1010	66	084130	2	746	.1149	813	3.7038
1011	66	084130	6	1498	.0871	1687	4.3285
1012	66	084130	5	3830	.0451	3988	12.4300
1013	66	084130	4	1001[illegible]	.0561	10553	8.0915
1014	66	084130	6	50137	.2105	63696	1.8396
1015	66	084130	2	4087	.2245	4891	1.8959
1016	66	084130	2	10640	.1107	11614	3.8446
1017	66	084130	2	32152	.1040	32766	4.0934
1018	66	084130	2	146912	.1708	167948	2.4922
1019	66	084130	2	1163	.1079	1208	3.9447
1020	66	084130	2	12306	.2267	14751	1.8783
1021	66	084130	2	48731	.2960	61836	1.4288
1022	66	084130	2	109623	.0370	112912	11.5126
1023	66	084130	2	1617	.0990	1751	4.2989
1024	66	084130	2	11490	.0916	11243	4.6460
1025	76	084120	2	1858	.0020	1873	VERY HIGH
1026	76	084120	2	16786	.1176	18440	3.6199

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE						
100	1	060001	4	50015	56740	66621	66712			
101	1	060001	2	17113	17113					
102	1	080001	2	26820	30056					
103	1	090001	4	51662	53375	60102	73467			
104	1	120001	4	53306	57510	64069	85257			
105	1	080001	2	32608	36684					
106	1	060101	3	39921	51563	54962				
107	2	050001	5	16129	18280	18817	21505	24194		
108	9	080001	3	2783	3247	3479				
109	9	080001	2	1392	1623					
110	2	080001	4	696	812	928	1160			
111	2	080001	2	812	928					
112	9	080001	3	2551	2928	3247				
113	9	080001	3	6262	7190	7885				
114	2	080001	2	1855	2116					
115	2	080001	3	464	580	580				
116	2	080001	2	7972	15365					
117	5	080021	4	8065	10753	13441	13441			
118	7	080021	2	13441	15591					
119	5	080021	3	13440	16128	18816				
120	5	080021	3	23116	24192	26342				
121	3	080021	7	7527	9140	10215	13441	13441	13441	16129
122	5	080021	3	8064	11290	11828				
123	5	080021	3	8064	10753	12366				
124	5	080021	3	17742	18817	22581				
125	8	080021	3	23118	24194	26344				
126	8	080021	3	18816	21504	21504				
127	8	080021	4	29032	29570	61828	96236			
128	8	080021	2	201613	201613					
129	8	080021	3	219892	225806	239247				
130	8	080021	3	118279	169355	174731				
131	7	080021	3	7526	9140	9677				
132	3	080021	6	5269	5376	5376	8065	8602	11828	
133	3	080021	6	5269	6989	6989	6989	8065	9677	
134	5	080021	2	21505	24194					
135	5	080021	3	61290	71720	77957				
136	3	080021	3	10000	14570	14731				
137	3	080021	4	13548	18064	21075	21828			
138	7	080021	4	5753	7312	7903	9409			
139	7	080021	4	365	424	434	515			
140	7	080021	4	1134	1142	1458	1474			
141	7	080021	4	1118	1272	1644	1652			
142	7	080021	3	1213	1369	1458				
143	5	080021	4	12863	13555	14842	15040			
144	3	080021	3	2920	3350	3820				
145	7	080021	5	1011	1011	1011	1291	1628		
146	8	080021	4	1011	1235	1516	1740			
147	5	090021	4	4839	5376	5376	6989			
148	3	090021	2	5376	6452					
149	3	090021	3	5376	5376	7527				

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE						
150	6	010021	4	10215	15591	16129	20968			
151	6	050021	4	8065	8065	10215	10215			
152	4	080101	6	13441	15054	20968	21505	22581	28269	
153	4	080201	4	138709	153225	155945	198385			
154	4	110201	3	87634	90859	94085				
155	4	110101	4	26344	26344	39247	43010			
156	4	110101	3	13441	21505	26344				
157	4	110201	3	117203	158601	211289				
158	4	110201	3	26344	34408	68817				
159	4	110201	2	48387	86021					
160	4	080101	7	15591	16129	16129	16129	17742	18817	21505
161	4	080201	3	42473	51075	61827				
162	4	080201	4	61827	118279	142472	161289			
163	4	080101	4	10753	10753	10753	16129			
164	4	080201	4	17204	43010	66128	69892			
165	4	080201	3	7527	18817	21505				
166	4	080201	3	40322	86558	105913				
167	4	110101	6	26344	32258	34946	38709	42473	47311	
168	4	090101	5	18817	20430	26344	29570	29570		
169	10	080200	3	91720	103050	117500				
170	11	080001	6	17204	26882	26682	26882	28495	28495	
171	11	080001	4	12903	15054	17204	19355			
172	12	080010	4	212000	264000	362000	1778000			
173	12	080010	4	45000	46000	53000	56000			
174	12	080010	4	10000	12000	13000	16000			
175	12	080010	4	3500	4000	4600	5300			
176	12	100010	4	178000	195000	227000	369000			
177	12	100010	4	33000	34000	35000	37000			
178	12	100010	4	9600	12000	12200	13000			
179	12	090010	4	177000	245000	247000	375000			
180	12	090010	4	27000	28000	29900	30700			
181	12	090010	4	9500	9800	11000	11200			
182	12	090010	2	3700	4300					
183	12	130010	4	304000	362000	672000	1155000			
184	12	130010	4	33000	37000	50000	52000			
185	12	130010	4	7700	7900	12200	12400			
186	12	130010	4	3300	3500	4000	4700			
187	12	140010	4	37000	38000	40000	41000			
188	12	140010	4	7600	10400	11800	12800			
189	12	140010	4	2700	2800	2900	3600			
190	13	080001	3	7925	8365	8805				
191	13	080001	3	7044	7925	8805				
192	13	080001	2	7044	8805					
193	14	080201	3	1392	1392	1623				
194	14	080201	3	1855	2319	2783				
195	15	110201	3	12408	16235	50792				
196	15	110201	3	3015	3015	4349				
197	15	090201	3	32702	34093	40471				
198	15	090201	3	4349	8030	13452				
199	16	084201	2	19192	27164					

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE				
200	16	084101	2	8697	10234			
201	16	084101	4	6610	10437	11364	31977	
202	16	084101	2	3073	3131			
203	16	C84101	2	1508	2928			
204	16	084201	2	31249	101859			
205	16	C84201	2	153840	176976			
206	17	130010	4	143000	202000	208000	1783000	
207	17	130010	2	37000	37000			
208	17	130010	2	59000	71000			
209	17	130010	2	13000	14000			
210	17	130010	2	109000	110000			
211	17	130010	2	14000	15000			
212	17	130010	3	20000	30000	36000		
213	17	130010	2	70000	81000			
214	17	130010	4	100000	115000	178000	475000	
215	17	130010	4	172000	470000	1715000	2297000	
216	17	130010	3	6800	7000	7300		
217	17	130010	3	32000	33000	42000		
218	17	130010	3	58000	82000	107000		
219	17	130010	3	127000	136000	154000		
220	17	130010	5	61000	74000	388000	2416000	2511000
221	17	130010	2	29000	32000			
222	17	130010	3	15000	20000	22000		
223	17	130010	2	5000	6000			
224	18	040001	2	62362	69888			
225	19	134130	3	6024	7864	12190		
226	19	134130	3	14087	19676	31980		
227	20	C80201	2	3421	3943			
228	21	C80100	4	130545	138005	174650	202383	
229	21	C80100	2	182223	222615			
230	21	080100	2	119142	158980			
231	21	080100	3	129645	254475	1000000		
232	22	C80200	2	78915	115900			
233	22	C80200	4	58900	89200	109800	128827	
234	22	C80200	2	65475	73172			
235	22	C80200	2	130545	174650			
236	22	C80200	2	274060	409200			
237	22	C80200	2	138400	143600			
238	23	080001	3	6600	10560	16280		
239	23	C80001	3	7920	9680	11000		
240	23	C80001	3	7500	10200	12000		
241	23	C80001	3	13200	21000	22500		
242	23	080001	3	22500	28200	31200		
243	23	C80001	3	112500	127500	127500		
244	23	C80001	3	244200	260400	297300		
245	23	C90201	2	75680	90640			
246	23	C90201	2	74800	85800			
247	23	C90201	2	87120	91520			
248	23	C90201	2	177600	178200			
249	23	090201	3	248400	268200	292500		

LISTED NUMBERS OF CYCLES TO FAILURE FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE							
250	24	080101	3	794	794	1147					
251	24	080101	2	26106	41894						
252	24	080101	3	8291	8820	10143					
253	25	130101	5	12319	19530	20732	22234	24338			
254	26	080101	2	7144	7938						
255	26	090101	2	14112	15435						
256	26	080101	3	5292	6615	6615					
257	26	080101	5	5997	6174	6615	7056	7497			
258	26	090101	5	1323	1764	2117	2205	2205			
259	26	090101	3	2205	2646	2911					
260	26	090101	5	2029	2646	2646	3087	3588			
261	26	080101	3	12348	12789	16316					
262	26	080101	3	13141	13671	14994					
263	26	080101	3	6615	10584	14994					
264	26	080101	3	6174	10143	16316					
265	26	080101	2	8379	11907						
266	26	090101	3	3440	3528	4322					
267	26	090201	3	3087	7056	7056					
268	26	090201	3	4851	10143	11466					
269	26	090201	2	6174	7056						
270	26	090201	3	25577	46656	48067					
271	28	020100	3	176929	224393	232305					
272	28	020100	3	152860	484130	547397					
273	39	080131	5	5574	5574	6112	6112	8802			
274	39	080131	8	3766	3766	3766	5380	5380	5380	6456	6456
275	39	080131	6	11836	22056	22596	26900	27976	41964		
276	30	040100	2	635103	754575						
277	30	040100	6	80100	183000	185500	194700	228200	259400		
278	30	030100	5	198028	216544	225600	329600	354100			
279	30	030100	2	244703	357084						
280	30	040100	2	497339	633446						
281	30	040100	2	153200	286200						
282	30	020100	3	76542	162968	362686					
283	30	040100	5	207621	299043	300696	301706	364192			
284	30	040100	4	254743	255714	310613	332694				
285	30	040100	4	95600	102238	107100	117900				
286	30	040100	5	96990	102823	107000	134400	143500			
287	30	040200	3	143100	144100	170900					
288	30	040200	3	118694	144730	278694					
289	30	030100	4	80206	81274	85036	87933				
290	30	020100	3	154173	161018	202626					
291	30	020100	3	89149	133847	196241					
292	30	040100	4	273440	317840	332167	641500				
293	30	020100	2	226268	498403						
294	30	040100	5	79979	104100	135400	211400	253800			
295	30	020100	3	89702	99724	121636					
296	31	030102	3	7902	7902	11062					
297	31	030002	3	4214	4478	5268					
298	31	030002	2	6058	7111						
299	31	030002	2	7902	11326						

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE				
300	31	C80002	4	7375	7638	9218	10272	
301	31	C80002	3	2107	2370	2897		
302	31	C80002	2	16154	18700			
303	31	C80002	2	2107	2634			
304	32	C80002	2	263	921			
305	32	C80002	2	790	1580			
306	32	C80002	2	3687	6321			
307	33	C84221	2	5393	5393			
308	34	C84121	4	1237	1471	1779	2234	
309	34	C84121	3	4107	4932	7002		
310	34	C84121	3	3068	4284	10426		
311	34	C84121	3	1782	2394	3067		
312	34	C84121	2	3459	5235			
313	35	C84121	4	1535	1640	1723	1821	
314	35	C84121	3	1940	2169	2358		
315	35	C84121	3	1729	2090	2408		
316	35	C84121	3	1570	2015	2247		
317	35	C84121	3	2047	2219	2345		
318	35	C84121	3	3912	5422	5662		
319	35	C84121	3	1729	1922	2016		
320	35	C84121	3	3187	5058	5771		
321	35	C84121	3	5617	7590	7603		
322	35	C84121	3	10385	11066	12286		
323	35	C84121	3	6337	8430	11113		
324	35	C84121	3	7574	8206	12282		
325	35	C84121	3	3525	3862	3956		
326	35	C84121	3	11048	12682	12831		
327	35	C84121	3	10398	11996	14888		
328	35	C84121	3	9354	13667	14888		
329	35	C84121	3	9287	9471	15374		
330	35	C84121	3	2806	6357	7377		
331	35	C84121	4	44945	55283	55283	57170	
332	36	C80001	4	663	730	752	875	
333	36	C80001	4	595	640	664	689	
334	36	C80001	4	362	483	501	507	
335	36	C80001	4	449	453	503	523	
336	36	C80001	4	620	1077	1445	1528	
337	36	C80001	4	776	846	931	1061	
338	36	C80001	4	592	734	744	770	
339	36	C80001	4	643	661	696	770	
340	37	C84121	4	2073	2985	4001	5610	
341	37	C94121	2	3089	4741			
342	37	C94121	5	3270	3842	3982	4074	5244
343	37	C84120	2	9563	14087			
344	37	C84120	2	2627	3291			
345	38	C94121	4	4962	6031	6170	8010	
346	38	C84121	4	6454	7701	8758	10894	
347	38	C94121	4	6359	6397	8323	8323	
348	38	C84121	4	9006	10494	12270	13246	

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
349	39	094121	12	1227	1247	1306	1465	1425	1524	1524	1592	1602
				1621	1646	1760						
350	39	084121	8	652	652	731	615	914	1151	1151	1250	
351	39	094120	4	9900	12300	15600	17300					
352	39	084120	4	1237	1333	1392	1473					
353	41	080201	3	87634	90860	94086						
354	42	080210	2	93000	174000							
355	42	080210	2	61000	63000							
356	42	080210	2	119000	130000							
357	42	080210	2	68000	89000							
358	42	080210	2	52000	60000							
359	42	080210	2	64000	88000							
360	42	080210	2	110000	134000							
361	42	080210	2	79000	98000							
362	42	080210	2	101000	109000							
363	42	080210	2	74000	78000							
364	42	080210	2	115000	115000							
365	42	080210	2	75000	108000							
366	42	080210	2	67000	130000							
367	42	080210	2	55000	85000							
368	42	080210	2	57000	115000							
369	42	080210	2	71000	83000							
370	42	080210	6	82000	89000	90000	108000	118000	127000			
371	42	080110	6	8000	8000	9000	10000	13000	13000			
372	1	070201	2	58294	58423							
373	43	080121	5	8065	15591	16129	18280	18817				
374	43	080121	5	13441	18817	23118	26882	29570				
375	43	080121	2	23957	27223							
376	43	080121	2	16379	16379							
377	44	080021	4	56615	57523	58422	60211					
378	44	080021	4	25157	25934	26038	26065					
379	44	080021	4	8071	8979	10768	11648					
380	44	080021	3	719	728	737						
381	44	080021	4	7622	8073	9349	9685					
382	44	080021	4	74136	81598	84712	89171					
383	44	080021	4	26615	27059	27494	27942					
384	44	080021	4	12857	13234	13301	13305					
385	45	080000	5	2144	6200	7500	7573	11860				
386	45	080000	5	3300	3954	3960	6315	6377				
387	45	080000	5	2765	3130	4641	6264	8091				
388	45	080000	5	3272	3934	4269	4998	5200				
389	45	080000	5	1250	2445	3379	3600	5179				
390	45	080000	5	4331	4500	4924	5400	6300				
391	45	080000	5	10800	37500	39600	43200	108000				
392	45	080000	5	10800	12600	23400	27000	41400				
393	45	080000	5	3000	10800	10800	16200	19800				
394	45	080000	5	7995	8722	10655	10707	11295				
395	45	080000	5	12600	12600	14400	16200	16200				
396	45	080000	5	3600	5400	6650	6800	7050				
397	45	080000	5	12600	12600	14400	17460	25200				
398	45	080000	5	7200	36000	75600	270000	295560				

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE					
399	45	.80000	5	27000	27540	49650	52800	55800	
400	45	.80000	5	23400	32400	34200	43600	84600	
401	45	.80000	5	13860	14400	16920	54600	79740	
402	45	.80000	5	27600	63000	82800	86400	93600	
403	45	.80000	5	196560	198000	198540	201600	239400	
404	45	.80000	5	178400	180000	232200	246600	460800	
405	45	.80000	5	3600	4233	4458	6480	7200	
406	45	.80000	5	1660	2550	2900	5946	6150	
407	45	.80000	5	1471	2325	2630	3053	3170	
408	45	.80000	5	43200	88200	129600	691000	1296000	
409	45	.80000	2	12015	14856				
410	45	.80000	5	1200	1800	2310	3150	4633	
411	45	.80000	5	26280	28800	29700	36180	37800	
412	45	.80000	3	9000	9600	10500	12600	27000	
413	45	.80000	5	6300	6452	7220	7950	15040	
414	45	.80000	5	25200	36000	73440	82620	576000	
415	45	.80000	5	6100	6300	7872	8100	8620	
416	45	.80000	5	14400	16740	19800	32400	34200	
417	45	.80000	5	90000	174600	370800	406800	2196000	
418	45	.80000	5	2460	6176	6343	6999	7258	
419	45	.80000	5	51400	101500	102600	111900	941600	
420	45	.80000	5	1500	2450	3600	4189	4950	
421	45	.80000	5	25200	28800	30600	57600	64800	
422	45	.80000	5	916	3600	4438	7200	22544	
423	45	.80000	6	25200	32400	41400	43400	43800	45000
424	45	.80000	5	3342	3465	3537	4075	4330	
425	45	.80000	6	2900	10620	11500	13700	14600	14700
426	47	.80100	5	13430	15030	15530	15650	20570	
427	50	.80100	3	4000	5400	5500			
428	50	.80100	2	11400	17000				
429	50	.80100	2	10000	41500				
430	50	.80100	2	13300	54600				
431	50	.80100	2	2600	2700				
432	50	.80100	3	32000	39000	41000			
433	50	.80100	2	39500	45800				
434	50	.80100	2	82500	140000				
435	50	.80100	2	10500	10700				
436	50	.80100	2	7800	10000				
437	53	.80100	2	16000	15000				
438	53	.80100	2	39000	65000				
439	53	.80100	2	41000	107000				
440	53	.80100	2	135000	400000				
441	53	.80100	2	3000	9100				
442	53	.80100	2	45000	67000				
443	53	.80100	2	91000	96000				
444	53	.80100	2	221000	719000				
445	53	.80100	2	17000	27000				
446	53	.80100	2	41000	55000				
447	53	.80100	2	164000	222000				
448	53	.80100	2	4000	9000				

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE					
449	53	280100	2	84000	125000				
450	53	280100	2	14000	16000				
451	53	280100	2	35000	64000				
452	53	280100	2	40000	82000				
453	53	280100	2	117000	140000				
454	53	280100	2	18000	21000				
455	53	280100	2	38000	42000				
456	53	280100	2	335000	592000				
457	53	280100	2	15000	43000				
458	53	280100	2	32000	37000				
459	53	280100	2	66000	124000				
460	53	280100	2	16000	18000				
461	53	280100	2	43000	53000				
462	53	280100	2	153000	177000				
463	64	280100	6	34000	36000	37000	41000	44000	46000
464	52	280100	4	2800	3190	3560	3580		
465	52	280100	4	3800	4350	4630	4600		
466	52	280100	4	5550	5570	6460	6860		
467	52	280100	4	9680	10780	13060	13520		
468	52	280100	4	23890	30010	30600	36190		
469	52	280100	4	4180	6260	6540	6710		
470	52	280100	4	9680	9810	9950	12350		
471	52	280100	4	11470	11930	14880	15590		
472	52	280100	4	24310	26460	31190	31200		
473	52	280100	5	60770	62120	68000	77420	77570	
474	52	280100	4	8990	9410	11150	12910		
475	52	280100	4	12380	12410	16600	23340		
476	52	280100	4	27910	28240	32960	34580		
477	52	280100	5	58210	64570	70720	77830	89820	
478	52	280100	4	24780	36410	37940	43740		
479	52	280100	4	42610	72790	89010	95650		
480	52	280100	4	109620	206790	277960	286220		
481	52	280100	4	111710	118690	164950	171200		
482	52	280100	4	195150	363160	531590	541850		
483	53	280100	2	253000	496000				
484	53	280100	2	12000	12100				
485	53	280100	2	17000	46000				
486	53	280100	2	37000	68000				
487	53	280100	2	164000	283000				
488	53	280100	2	175000	242000				
489	53	280100	2	12000	13000				
490	53	280100	2	43000	62000				
491	53	280100	3	85000	97000	1052000			
492	53	280100	3	247000	481000	575000			
493	53	280100	2	13000	16000				
494	53	280100	2	26000	26100				
495	53	280100	2	68000	70000				
496	53	280100	3	67000	287000	5251000			
497	53	280100	2	134000	411000				
498	53	280100	2	37000	39000				

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE				
499	53	.80100	2	154000	212000			
500	53	.80100	2	23000	26000			
501	53	.80100	2	85000	95000			
502	53	.80100	2	61000	254000			
503	53	.80100	2	11000	12000			
504	53	.80100	2	21000	51000			
505	53	.80100	2	182000	239000			
506	53	.80100	2	21000	26000			
507	53	.80100	2	38000	83000			
508	53	.80100	2	23000	25000			
509	53	.80100	2	70000	90000			
510	53	.80100	2	23000	33000			
511	53	.80100	2	57000	233000			
512	53	.80100	2	10000	11000			
513	53	.80100	2	28000	54000			
514	53	.80100	2	84000	176000			
515	45	.80100	5	601	640	1425	2044	5055
516	45	.80100	5	901	1031	1384	1642	2760
517	45	.80100	5	786	1509	1866	2476	2621
518	45	.80100	5	661	915	965	1072	1101
519	45	.80100	5	1215	1519	1897	2424	2843
520	45	.80100	5	500	610	806	812	873
521	45	.80100	5	331	342	393	445	537
522	45	.80100	5	150	250	260	324	350
523	45	.80100	5	171	175	180	212	315
524	45	.80100	5	343	450	516	590	664
525	45	.80100	5	36	119	140	172	183
526	45	.80100	5	142	215	224	277	360
527	45	.80100	5	670	741	914	975	1016
528	45	.80100	5	521	531	640	820	1001
529	45	.80100	5	491	540	890	1030	1203
530	45	.80100	5	474	743	1006	1200	1883
531	45	.80100	5	195	228	247	293	296
532	45	.80100	5	386	413	573	636	884
533	45	.80100	5	485	672	748	753	813
534	45	.80100	5	1245	1650	1886	2274	2460
535	45	.80100	5	100	130	240	250	350
536	45	.80100	5	90	160	180	190	230
537	45	.80100	5	147	263	336	415	501
538	45	.80100	5	450	450	562	753	1855
539	45	.80100	5	156	168	177	179	200
540	45	.80100	5	125	184	199	202	242
541	45	.80100	5	383	425	440	668	708
542	45	.80100	5	360	430	460	480	1033
543	45	.80100	5	360	478	575	685	3387
544	45	.80100	5	780	1031	1231	2331	3300
545	45	.80100	5	493	728	766	794	1021
546	45	.80100	5	450	605	655	761	861
547	45	.80100	5	500	900	1510	1880	2040
548	45	.80100	5	772	1391	1462	1501	1766

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE							
549	45	080100	5	485	502	503	529	540			
550	45	080100	2	1332	1356						
551	45	080100	5	2098500	3979800	5440000	6378000	8109720			
552	52	080100	4	1185350	1241840	1289150	1411570				
553	52	080100	4	1982590	2500000	6061190	6717590				
554	45	080100	5	100800	135000	203400	302400	388200			
555	45	080100	5	37440	91800	117000	124200	3700000			
556	45	080100	5	484200	525600	698400	1674000	2719600			
557	45	080100	5	9540	12600	14400	41400	52200			
558	45	080100	5	14580	40140	102780	147600	148500			
559	45	080100	5	185000	248000	390400	651600	691700			
560	45	080100	5	1660	2215	3215	4500	9011			
561	45	080100	5	28800	45000	66600	72000	73800			
562	45	080100	5	28800	36000	36000	43200	88200			
563	45	080100	5	185400	352800	658800	1420200	3216600			
564	45	080100	5	48600	55800	144000	824760	888480			
565	52	080100	4	310720	416020	445970	525560				
566	45	080100	5	163000	189000	1306800	1998000	3601000			
567	58	080120	5	246	275	283	305	309			
568	58	080120	5	387	436	442	476	521			
569	58	080120	5	573	618	673	744	748			
570	58	080120	7	610	834	913	1000	1019	1119	1186	
571	58	080120	5	1237	1425	1659	1671	1739			
572	58	080120	8	2615	2653	2795	2864	2945	2991	3352	3726
573	58	080120	5	2892	4300	4737	5238	5305			
574	58	080120	5	8390	8870	9720	10070	10150			
575	58	080120	5	18420	19150	19610	20590	22740			
576	58	080120	5	22000	32000	34000	35000	39000			
577	58	080120	6	41940	54040	62370	69620	75090	182000		
578	58	080120	5	56590	85030	115000	549240	718000			
579	58	080120	4	388820	2647420	8510000	20805000				
580	58	080120	4	19523000	40019300	64297610	95811110				
581	57	080110	2	36	40						
582	57	080110	2	130	136						
583	57	080110	3	654	863	917					
584	57	080110	2	6000	6000						
585	57	080110	3	18000	30000	35000					
586	57	080110	3	95000	130000	149000					
587	57	080110	5	310000	456000	532000	673000	1292000			
588	57	080110	3	2290000	3309000	3874000					
589	57	080110	3	84	92	113					
590	57	080110	2	374	440						
591	57	080110	4	22520	29000	42990	57820				
592	57	080110	5	42000	45000	52000	162000	1106000			
593	57	080110	3	1093000	2102000	2241000					
594	57	080110	3	8247000	13877000	24204000					
595	57	080110	2	309	363						
596	57	080110	3	9000	10800	13000					
597	57	080110	5	92000	112000	120000	335000	674000			
598	57	080110	4	42000	63000	75000	81000				

LISTED NUMBERS OF CYCLES TO FAILURE
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ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
599	57	180110	3	174000	5875000	9648000						
600	57	180110	3	4359000	18475000	44606000						
601	60	180120	2	15	18							
602	60	180120	2	107	143							
603	60	180110	5	13000	19000	27000	33000	36000				
604	60	180110	4	40000	64000	68000	104000					
605	60	180110	4	9500	147000	149000	437000					
606	60	180110	8	245000	262000	295000	303000	324000	549000	718000	758000	
607	60	180120	2	4	7							
608	60	180120	3	7	8	10						
609	60	180120	2	46	54							
610	60	180120	3	114	117	140						
611	60	180120	3	255	302	330						
612	60	180120	4	1124	1313	1454	1488					
613	60	180110	3	4000	5400	5500						
614	60	180110	2	7000	7000							
615	60	180110	2	11400	12000							
616	60	180110	3	347500	579000	1564300						
617	60	180120	2	4	12							
618	60	180120	3	392	399	482						
619	60	180110	2	4862000	10546000							
620	60	180120	2	4	5							
621	60	180120	2	15	17							
622	60	180120	2	24	24							
623	60	180120	2	85	115							
624	60	180120	2	329	365							
625	60	180110	2	1652300	4722000							
626	60	180120	2	8	9							
627	60	180120	2	11	12							
628	60	180120	2	13	14							
629	60	180120	2	652	756							
630	60	180110	3	9000	10000	11000						
631	60	180110	2	10500	10700							
632	60	180110	3	85000	140000	179000						
633	60	180110	9	573000	646000	656000	660000	704000	771500	1148000	1992000	41524000
634	60	180110	2	565500	10457000							
635	47	120102	6	734	767	772	804	804	822			
636	47	120102	6	3729	3765	3958	4971	5039	5602			
637	45	120101	6	6212	6251	7149	7350	7970	7970			
638	45	120101	6	5869	5930	6121	6199	6606	7690			
639	45	120101	6	6416	6725	7300	8260	8859	9304			
640	45	120101	6	6655	7606	7623	8170	8180	8794			
641	45	120101	6	6321	6456	7073	7959	7967	8575			
642	45	120101	6	12197	12221	14056	14056	16567	16572			
643	45	120101	6	7135	7155	7165	7207	8697	9074			
644	45	120101	6	5497	7292	7292	8069	8142	8361			
645	45	120101	6	19395	19751	20262	20959	20959	21699			
646	45	120101	6	16524	17400	18059	18327	19610	22809			
647	45	120101	6	20942	22509	22711	24459	27283	27997			
648	45	120101	6	12147	12975	13226	14052	14525	15863			

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE									
649	45	220101	6	10468	10710	10710	11188	12345	12732				
650	45	220101	6	46565	48132	52993	56008	59252	61915				
651	45	220101	6	13822	14341	13373	13718	14728	15875				
652	45	220101	6	9786	9732	10191	10433	12002	13320				
653	45	220101	6	21810	22360	23800	24780	25552	30258				
654	45	220101	6	23276	25689	25689	25854	25854	28870				
655	45	220101	6	24119	28449	28695	30456	32316	34730				
656	45	220101	6	19206	19562	19641	19819	23486	23486				
657	45	220101	6	23355	27692	29225	29595	30674	35033				
658	45	220101	6	37727	40233	40714	43083	44440	48141				
659	45	220101	6	37518	38438	40731	41171	41481	43584				
660	45	220101	6	54447	63534	65307	69727	78373	82993				
661	45	220101	6	34052	41092	41092	41092	43407	44998				
662	45	220101	6	12414	13738	14300	15739	15786	15978				
663	45	220101	6	27472	40195	46253	52724	53390	53390				
664	45	220101	6	37589	40658	42734	45097	48672	49999				
665	45	220101	6	25263	30563	31210	31316	31988	33884				
666	45	220101	6	24643	27616	29917	30106	31565	35073				
667	45	220101	6	14755	14855	21859	27261	23522	26946				
668	45	220101	6	38143	42090	42668	43089	44694	47338				
669	45	220101	6	33787	35664	45140	39907	40324	44126				
670	45	220101	6	45724	50554	53116	54726	55622	57960				
671	45	220101	6	33241	35566	45566	42557	46172	46202				
672	45	220101	6	37100	38327	39725	39725	45115	50225				
673	45	220101	6	48841	54467	56670	62201	63569	67293				
674	45	220101	6	41279	45838	46135	49797	53726	59988				
675	45	220101	6	23192	24793	26722	27596	28514	28514				
676	45	220101	6	16293	19380	19954	21121	23362	23443				
677	45	220101	6	19464	22311	22591	22612	23611	24043				
678	51	220101	10	93	100	103	105	107	109	113	113	122	140
679	51	220101	10	95	103	107	110	132	136	137	140	147	152
680	51	220101	10	76	104	111	113	115	115	129	131	136	139
681	51	220101	10	67	97	114	117	118	120	121	124	134	162
682	57	280122	3	1487	1568	2234							
683	57	280122	4	1432	1628	2095	2226						
684	57	280122	4	4429	4659	5061	6031						
685	57	280122	4	2310	2748	3754	4001						
686	57	280122	4	2419	3620	4221	4221						
687	57	280122	3	2331	2613	2939							
688	57	280122	3	1465	1458	1676							
689	57	280122	4	757	859	977	994	1169	1432				
690	57	280122	4	671	753	754	783	1196	1902				
691	57	280122	5	1459	1567	1593	2238	2238					
692	57	280122	3	1311	1849	2235							
693	57	280122	4	783	1234	1234	1465	2015	2892				
694	57	280122	3	4065	8133								

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	MIL	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
695	57	27122	9	3500	3447	2494	2500	3500	4453	4500	[illegible]	5000
696	57	27122	3	7435	12574	18000						
697	57	27122	6	4396	11026	13028	17061	17630	26037			
698	57	27122	4	3904	5915	7061	7362	7435	7879	9185	10143	
699	57	27122	4	11765	12812	16975	21008					
700	57	27122	3	[illegible]	2476	2812						
701	57	27122	3	8135	9411	10539						
702	57	27122	3	5073	6275	7469						
703	57	27122	2	5525	5555	7094						
704	57	27122	4	4049	4656	5667	5668					
705	57	27122	3	4892	8353	9526						
706	57	27122	6	1149	1369	1561	1561	1874	2523			
707	57	27122	1	1227	1359	1359						
708	54	40121	4	11782	12516	13916	17810	18752	19265			
709	54	40121	4	14915	22348	22895	22954	24055	26624			
710	54	40121	7	17341	20713	20714	21358	22909	24778	26776		
711	54	40121	6	21479	21746	21568	21572	26944	26951			
712	54	40121	6	17333	12670	12890	12890	14549	14550			
713	54	40121	7	11446	19416	20507	22514	22515	22516	23342		
714	54	40121	6	4975	5016	5018	5639	5642	5866			
715	54	40121	9	5443	5527	5527	5863	6483	6483			
716	54	40121	4	11214	12336	13346	13564	13568	15374			
717	59	40121	4	596	4934	5541	6159	6510	6510			
718	59	40121	4	1756	2173	2548	2575	2779	2779			
719	59	40121	4	2445	2241	2567	2745	2841	3212			
720	59	40122	4	778	1297	1257	1513	2052	2946			
721	59	40122	4	[illegible]	1754	2154	2172	2172	3072			
722	57	80122	6	4641	6952	7714	8195	8437	8437			
723	59	80122	6	12604	12867	14526	14526	15208	17753			
724	57	80121	6	3517	4913	5414	5671	6492	6494			
725	59	80122	6	4750	5952	6813	7412	8276	9280			
726	47	80102	6	490	452	453	463	492	564			
727	47	80102	6	174	154	132	192	207	225			
728	47	80102	7	154	160	132	192	207	225	231		
729	47	80102	6	102	155	155	192	192	209			
730	47	80102	6	124	138	146	192	209	224			
731	47	80102	6	434	462	526	527	527	569			
732	47	80102	6	162	184	184	192	192	209			
733	47	80102	6	1286	1487	1588	1620	1727	1 42			
734	47	80102	6	273	350	358	386	410	427			
735	47	80102	6	65	76	82	82	89	91			
736	47	80102	6	643	658	692	792	792	919			
737	47	80102	6	142	142	146	151	156	175			
738	47	80102	6	140	135	142	147	163	163			
739	47	80102	6	1804	1923	1951	1987	2129	2328			
740	47	80102	6	455	398	423	432	462	476			
741	47	80102	6	1815	1915	2621	2621	2621	3052			
742	47	80102	6	402	412	402	402	487	560			
743	47	80102	6	338	439	356	372	384	495			
744	47	80102	6	50	50	54	61					

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	MSF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
745	47	.80102	7	54	56	61	62	76	77	79		
746	47	.80102	6	59	59	59	59	60	71			
747	47	.80102	6	56	57	67	73	81	83			
748	49	.80101	6	11325	11325	11637	12525	13547	14639			
749	49	.80101	6	9895	13382	11020	11146	13485	13538			
750	49	.80101	6	11400	12523	13127	14637	14637	15233			
751	49	.80101	7	6737	8003	4503	8007	9004	9695	12703		
752	49	.80101	6	3842	4263	4336	4372	4431	4902			
753	49	.80101	6	4339	6940	6941	7632	7634	8650			
754	49	.80101	8	31920	32728	33544	33553	34051	25844	38620	40007	
755	49	.80101	6	77181	86527	91363	91624	100751	114581			
756	49	.80101	6	53045	55238	57627	73832	74606	79456			
757	49	.80101	6	27309	27735	40685	40757	49122	55628			
758	49	.80101	6	34951	35785	36573	36573	40254	47200			
759	45	.80202	4	2183	2255	2698	2596					
760	45	.80202	5	183	412	558	818	841				
761	45	.80202	6	1094	1240	1321	1482	1562	2021			
762	45	.80202	5	2996	3236	3637	4104	4331				
763	45	.80202	8	13485	14229	17484	19251	28272	28458	32829	46314	
764	45	.80202	5	6142	6527	6356	12047	13734				
765	45	.80202	5	3272	3752	4235	4219	4657				
766	45	.80202	6	1041	1373	1373	1489	1489	2517			
767	45	.80202	6	3049	4124	4324	4681	4681	5052			
768	45	.80202	10	6908	7242	7272	7696	7878	7939	8393	9090	9363
				13878								
769	45	.80202	5	11968	15990	16564	20193	20910				
770	45	.80202	5	23986	34049	45848	37453	47517				
771	45	.80202	6	717	734	800	883	926	1253			
772	45	.80202	6	32569	43938	47610	53429	67077	69246			
773	45	.80202	7	6245	7781	9338	9338	9338	10894	15563		
774	45	.80202	5	2741	3686	3686	4286	5514				
775	45	.80202	5	1903	2855	2855	3087	4039				
776	45	.80202	5	2782	3302	3153	3704	4132				
777	45	.80202	5	8400	8239	10866	13239	13634				
778	45	.80202	5	17714	17865	21953	22661	28917				
779	45	.80202	8	23827	26900	29725	34836	36181	37122	40485	45461	
780	45	.80202	5	143903	171098	189762	222785	229671				
781	45	.80202	5	409720	454740	455100	528660	905040				
782	45	.80202	7	4378	4563	5958	6164	7286	8409	11997		
783	45	.80202	5	2730	3413	3413	4095	8361				
784	62	.84140	2	11832	13356							
785	62	.84140	3	57844	108676	161536						
786	62	.84140	3	352000	389940	500000						
787	62	.84140	3	11400	17000	47000						
788	62	.84140	3	432840	1115200	1684700						
789	61	.84140	2	59400	97000							
790	61	.84140	2	9000	117[illegible]							
791	61	.84140	3	4600	23200	41200						
792	61	.84140	2	37200	39400							
793	61	.84140	2	34900	42400							

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
794	62	C84140	3	1192	1200	1700						
795	62	C84140	3	1000	1000	2000						
796	63	C84140	3	116000	121200	164600						
797	62	C84140	2	530	679							
798	63	C84140	3	8250	9710	9790						
799	63	C84140	2	1280	2030							
800	63	C84140	2	1225	1560							
801	63	C84140	2	13000	14500							
802	63	C84140	5	7500	14700	19600	23300	28100				
803	63	C84140	2	16800	21100							
804	63	C84140	3	11200	17300	32100						
805	55	C84140	4	4000	7000	7500	9000					
806	55	C84140	4	21000	34000	41000	43000					
807	55	C84140	5	21000	25000	50000	56000	65000				
808	55	C84140	3	40000	76000	70000						
809	55	C84140	4	10000	12000	13000	14000					
810	55	C84140	4	30000	37000	47000	48000					
811	55	C84140	3	9600	9600	13200						
812	55	C84140	4	12000	13800	14400	16200					
813	55	C84140	7	9600	9600	12000	13200	13800	14400	16200		
814	55	C84140	4	5000	5000	5000	7000					
815	55	C44140	2	900	1100							
816	63	C84140	2	878000	1674000							
817	63	C84140	2	1218000	1867000							
818	63	C84140	2	30000	35000							
819	63	C84140	2	65000	409800							
820	63	C84140	2	32400	48400							
821	63	C84140	3	629100	1829000	1873000						
822	45	C84101	3	29370	34188	34791						
823	45	C84101	2	65550	77743							
824	45	C84101	2	39355	70897							
825	66	C84111	3	12748	13343	17253						
826	66	C84111	3	14804	15200	16965						
827	66	C84111	2	16556	17636							
828	66	C84111	2	12426	19292							
829	66	C84111	3	7501	11241	12775						
830	66	C84111	3	10594	14759	17819						
831	66	C84111	3	6291	9078	9248						
832	66	C84111	3	5384	6942	7770						
833	66	C84111	3	10600	12387	13438						
834	66	C84111	3	18409	21693	22897						
835	65	C24132	6	86077	89831	108510	109113	110548	137145			
836	67	C20111	10	67	70	87	91	95	96	102	103	124
				140								
837	67	C20111	10	79	95	100	104	106	111	114	117	122
				197								
838	67	C20111	10	74	78	81	90	97	107	113	115	119
				128								
839	67	C20111	5	77	80	93	95	79				

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
840	67	C20111	10	63	67	68	73	87	94	96	96	116
				124								
841	67	C20111	10	74	115	118	119	126	132	140	140	142
				156								
842	67	C20111	10	65	72	81	88	94	96	98	115	125
				133								
843	67	C20111	5	76	85	86	88	90				
844	67	C20111	10	96	110	114	115	117	121	130	140	145
				153								
845	67	C20111	13	59	59	63	70	80	92	96	104	105
				105	111	115	143					
846	67	C20111	10	65	67	68	71	72	73	74	94	95
				140								
847	67	C20111	5	75	78	81	82	102				
848	67	C20111	10	80	88	89	91	95	102	109	139	143
				168								
849	67	C20111	5	82	98	108	114	143				
850	67	C20111	10	68	78	88	92	96	96	97	100	110
				111								
851	67	C20111	5	68	82	84	99	112				
852	67	C20111	10	81	111	118	121	121	130	133	153	161
				186								
853	67	C20111	10	78	82	84	85	91	96	124	132	149
				158								
854	67	C40111	10	87	88	114	119	119	121	128	136	153
				155								
855	67	C20111	10	121	128	136	153	155	174	192	201	205
				208								
856	70	C84141	3	18700	20570	30685						
857	70	C84141	3	11985	13175	16660						
858	70	C84141	2	32382	35466							
859	70	C84141	2	22102	43690							
860	70	C84141	3	17476	26214	33153						
861	70	C84141	3	16405	17170	23970						
862	71	C84131	5	434868	540078	709416	1077150	1229454				
863	71	C84131	5	168336	207414	236472	274548	296592				
864	71	C84131	3	194388	215430	230460						
865	71	C84131	3	219438	264528	274548						
866	76	C84121	2	1685	1823							
867	76	C84121	2	2736	3259							
868	79	C84101	2	20651	21331							
869	79	C84101	2	17846	23711							
870	79	C84101	2	14012	14871							
871	79	C84101	2	16231	19886							
872	79	C84101	2	17081	19121							
873	79	C84101	2	16137	18271							
874	79	C84101	2	19414	22721							
875	79	C84101	2	11326	18802							
876	79	C84101	2	10183	12287							
877	79	C84101	2	6147	9014							
878	79	C84101	2	3024	10446							

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE									
879	79	084101	2	8220	8951								
880	79	084101	2	29711	30251								
881	79	084101	2	38356	39978								
882	79	084101	2	63934	63934								
883	79	084101	2	12239	12600								
884	79	084101	2	13500	14581								
885	79	084101	2	31512	35114								
886	79	084101	2	29161	29404								
887	79	084101	2	27991	30746								
888	79	084101	2	27054	38302								
889	79	084101	2	15995	16436								
890	79	084101	2	19543	20354								
891	79	084101	2	19732	25406								
892	79	084101	2	22171	24111								
893	79	084101	2	28934	34155								
894	79	084101	2	38615	40972								
895	79	084101	2	17222	18672								
896	79	084101	2	12073	12725								
897	79	084101	2	14321	15046								
898	79	084101	2	13755	15467								
899	73	084101	4	14107	21211	24133	51476						
900	79	084101	2	21553	33642								
901	79	084101	2	15568	19760								
902	79	084101	2	14388	14977								
903	79	084101	2	12488	13700								
904	79	084101	2	10190	10190								
905	79	084101	2	15085	15634								
906	79	084101	2	13928	22650								
907	79	084101	2	5259	5473								
908	79	084101	2	7395	7823								
909	79	084101	2	8410	11525								
910	79	084101	2	12143	12414								
911	79	084101	2	9514	11922								
912	79	084101	2	16583	21478								
913	79	084101	2	15255	21309								
914	79	084101	2	9366	9793								
915	79	084101	2	8128	16138								
916	79	084101	2	3065	3955								
917	79	084101	2	4388	5361								
918	79	084101	2	7238	7476								
919	83	024110	3	67000	77500	104000							
920	83	024110	5	260000	293000	345000	345000	432000					
921	83	024110	2	1200000	1230000								
922	83	024110	2	2010000	4240000								
923	84	024110	2	4174000	5000000								
924	84	024112	6	12216	14761	15270	17611	18629	22294				
925	85	024130	6	3290	3910	4350	5250	5950	8100				
926	85	024130	2	4531	4959								
927	85	024110	10	608500	796700	869500	1098800	1139100	1295000	1395000	1401000	1605100	
				1821900									

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
928	85	024110	4	4015000	4448000	5177000	5219000					
929	85	024110	8	106000	174300	178000	192800	216500	301600	420000	530000	
930	85	024110	2	68600	75400							
931	85	024110	2	66200	200000							
932	85	024110	4	72100	85300	127000	157000					
933	85	024110	4	11500	36000	68100	118200					
934	85	024110	2	58600	85000							
935	85	024110	4	12200	15600	24700	43700					
936	85	024110	2	21500	122500							
937	85	024110	8	486000	521200	732100	936000	980100	1014900	1106300	1137000	
938	85	024110	8	12100	19200	22000	23600	25000	25400	27900	38700	
939	85	024130	20	8580	10910	11990	12300	14600	14610	15700	16380	16500
				17860	19240	19400	21910	22000	22250	23200	23300	24300
				28700	33090							
940	85	024130	6	2270	2830	2860	2950	3510	3510			
941	85	024130	4	32120	42000	54310	61000					
942	85	024130	6	17120	23190	29400	31080	35730	47250			
943	85	024130	4	44930	47700	62490	82000					
944	85	024130	4	52990	53930	65320	70300					
945	85	024130	2	13120	18300							
946	85	024130	4	68270	70410	77400	87900					
947	85	024130	6	2440	3300	4360	4400	4930	5400			
948	85	024130	4	4800	4900	5000	5200					
949	85	024130	4	550	730	770	1200					
950	85	024130	4	4940	7810	8690	10380					
951	85	024130	6	10620	11180	12400	13400	14560	14900			
952	85	024130	4	440	620	630	660					
953	85	024130	6	4390	4440	4550	4560	4780	5000			
954	85	024130	10	56750	56860	64300	65090	76010	83500	98070	100000	103500
				116000								
955	85	024130	4	24650	26230	34430	34600					
956	63	084140	2	34500	40600							
957	63	084140	3	116000	121200	164600						
958	63	084140	2	1280	2080							
959	63	084140	2	1225	1560							
960	63	084140	2	16800	21100							
961	63	084140	3	11200	17300	32100						
962	55	084140	4	4000	7000	7500	9000					
963	55	084140	4	21000	34000	41000	43000					
964	55	084140	4	21000	25000	50000	56[illegible]					
965	55	084140	2	40000	76000							
966	55	084140	4	10000	12000	13000	14000					
967	55	084140	4	30000	37000	47000	48000					
968	55	084140	3	9600	9600	13200						
969	55	084140	4	12000	13800	14400	16200					
970	55	084140	7	9600	9600	12000	13200	13800	14400	16200		
971	55	084140	4	5000	5000	5000	7000					
972	55	084140	2	900	1100							
973	63	084140	2	1213000	1867000							
974	63	084140	2	65000	309800							

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE								
975	63	84140	2	32400	48400							
976	63	84140	3	629100	1829000	1873000						
977	63	24140	3	127600	370400	502000						
978	63	24140	4	253200	348400	360600	409000					
979	62	24140	3	36600	50000	69200						
980	62	24140	3	39400	59800	181500						
981	62	24140	3	1559000	1699100	1731400						
982	62	24140	3	513000	686700	918400						
983	62	24140	3	130000	195100	216800						
984	62	24140	3	895900	1408100	2156000						
985	74	24101	4	751067	757790	965808	1171254					
986	74	24101	8	150057	155034	168975	192166	201991	285314	375654	446600	
987	51	20101	20	100	110	133	135	140	157	163	165	165
				170	180	183	185	200	201	205	215	240
				253	280							
988	72	24211	41	22100	27140	27148	28052	29548	30388	30520	30772	32692
				32900	33228	34324	34640	35344	35616	36152	37036	37504
				38188	38292	38500	38800	39580	39600	40216	40588	41456
				41632	41656	41936	43776	44152	44352	44388	44688	45844
				47342	47532	47548	48688	61388				
989	73	24112	4	9678	9996	12342	12546					
990	73	24111	4	12372	25775	27837	35054					
991	73	024110	2	11500	13700							
992	73	024110	4	67000	76700	102100	110000					
993	73	024110	4	262000	292000	342000	344000					
994	73	024110	3	1180000	1225000	1280000						
995	73	024110	2	2000000	2019000							
996	82	C84130	2	374	383							
997	82	C84130	2	551	652							
998	82	C84130	2	566	888							
999	82	C84130	4	1237	1825	1919	2719					
1000	82	C84130	4	4913	5749	5921	6030					
1001	82	C84130	6	8118	9415	9928	10538	11263	12964			
1002	82	C84130	2	24317	29543							
1003	82	C84130	4	130787	138144	141025	221370					
1004	82	C84130	2	114820	120416							
1005	66	C84130	2	43613	46427							
1006	66	C84130	4	1534	2146	2345	2409					
1007	66	C84130	2	4656	5826							
1008	66	C84130	2	24288	29558							
1009	66	C84130	2	147837	152007							
1010	66	C84130	2	619	900							
1011	66	C84130	6	1352	1370	1371	1382	1431	2252			
1012	66	C84130	4	3316	3811	4077	4180					
1013	66	C84130	4	8566	9569	10611	11546					
1014	66	C84130	6	36195	36295	36307	40134	72806	113973			
1015	66	C84130	2	2836	5892							
1016	66	C84130	2	8877	12731							
1017	66	C84130	2	25456	35716							
1018	66	C84130	2	110940	193494							

LISTED NUMBERS OF CYCLES TO FAILURE
FOR ALL GROUPS IN THE DATA COLLECTION.

ITEM	REF	DESCRIPTION	SAMPLE SIZE	CYCLES AT FAILURE	
1019	66	C84130	2	976	1387
1020	66	C84130	2	8509	17800
1021	66	C84130	2	30000	79160
1022	66	C84130	2	103218	116427
1023	66	C84130	2	1377	1901
1024	66	C84130	2	8993	12120
1025	76	C84120	2	1861	1873
1026	76	C84120	2	13861	20329

APPENDIX III

DERIVATION OF PROBABILITY DISTRIBUTION FOR THE RATIO OF TWO WEIBULL VARIATES

This appendix discusses the derivation of the probability distribution and density function for the ratio of the sample characteristic life of n laboratory test articles to the life of a randomly selected aircraft in service. The scatter factor is written as

$$S = \bar{\beta}/y \tag{1}$$

where $\bar{\beta}$ is the point estimator of the Weibull characteristic life (scale parameter) for a sample of n failure times given by

$$\bar{\beta} = \left[\frac{1}{n} \sum_{i=1}^{n} x_i^{\alpha}\right]^{\frac{1}{\alpha}} \tag{2}$$

The x_i's in Equation (2) are the lives of the individual laboratory specimens and α is the known Weibull shape parameter. In Equation (1), y is the life of a randomly selected aircraft in service that is a Weibull variate.

To find the probability distribution of the scatter factor defined in Equation (1), the probability density functions of both the sample characteristic life $\bar{\beta}$ as well as the Weibull variate y must be known. The probability density function of the Weibull variate is given by

$$f(y) = \frac{\alpha}{\beta}\left(\frac{y}{\beta}\right)^{\alpha-1} \exp\left[-\left(\frac{y}{\beta}\right)^{\alpha}\right] \tag{3}$$

for $y > 0$ where α and β are the Weibull shape and scale parameters, respectively. The probability density function of $\bar{\beta}$ can be determined from the fact proven in Reference (1) that the statistic

$$2nW = 2n\left(\frac{\bar{\beta}}{\beta}\right)^{\alpha} \tag{4}$$

has a chi-squared distribution with 2n degrees of freedom where n is the number of failure observations in the test sample. This gives that the probability density function for the statistic $\bar{\beta}$ is given by

$$f(\bar{\beta}) = \frac{n^n}{\Gamma(n)}\left(\frac{\alpha}{\beta}\right)\left(\frac{\bar{\beta}}{\beta}\right)^{\alpha n-1} \exp\left[-n\left(\frac{\bar{\beta}}{\beta}\right)^{\alpha}\right] \quad \text{for } \bar{\beta} > 0. \tag{5}$$

The probability density function of the ratio $S = \bar{\beta}/y$ is

$$f(S) = \int_0^\infty \frac{\bar{\beta}}{S^2} f(\bar{\beta}, y = \frac{\bar{\beta}}{S}) \, d\bar{\beta} \qquad \text{for } S > 0 \tag{6}$$

where $f(\bar{\beta}, y) = f(\bar{\beta})f(y)$ since $\bar{\beta}$ and y are statistically independent, and $f(y)$ and $f(\bar{\beta})$ are given by Equations (3) and (5). Putting $f(\bar{\beta}, y)$ into Equation (6) and collecting terms gives

$$f(S) = \frac{n^n}{\Gamma(n)} \left(\frac{\alpha^2}{\beta}\right) \left(\frac{1}{S}\right)^{\alpha+1} I \tag{7}$$

where

$$I = \int_0^\infty \left(\frac{\bar{\beta}}{\beta}\right)^{\alpha(n+1)-1} \exp\left[-A\left(\frac{\bar{\beta}}{\beta}\right)^\alpha\right] \, d\bar{\beta} \tag{8}$$

and

$$A = n + \left(\frac{1}{S}\right)^\alpha \tag{9}$$

If u is substituted for $A\left(\frac{\bar{\beta}}{\beta}\right)^\alpha$ then the integral reduces to

$$I = \frac{\beta}{\alpha\left[n+\left(\frac{1}{S}\right)^\alpha\right]^{n+1}} \int_0^\infty u^n e^{-u} \, du. \tag{10}$$

The remaining integral is in the form of the Gamma function which gives

$$\int_0^\infty u^n e^{-u} du = n\Gamma(n) \tag{11}$$

This leads to the final expression for the probability density function of the scatter factor

$$f(S) = \frac{\alpha n^{n+1} S^{\alpha n-1}}{(nS^\alpha+1)^{n+1}} \tag{12}$$

Integration of Equation (12) with respect to S from 0 to S gives the cumulative probability distribution of S which is

$$F(S) = \frac{n^n S^{\alpha n}}{(1+nS^\alpha)^n} \tag{13}$$

If reliability R is defined as in Reference (1) as the probability of no failure (probability that the ratio of life in the laboratory to life in service is less than S), the relationship between R and the scatter factor S is

$$R = \frac{n^n S^{\alpha n}}{(1+nS^\alpha)^n} \tag{14}$$

APPENDIX IV

LISTS OF SERVICE INSPECTION RESULTS

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4C	637411	328	3085.7	944
F-4C	637412	332	2079.0	1340
F-4C	637413	335	2126.3	1509
F-4C	637414	339	2158.3	722
F-4C	637415	342	2256.9	759
F-4C	637417	349	2253.6	1226
F-4C	637418	352	2965.9	1081
F-4C	637419	355	2947.3	634
F-4C	637420	357	2202.6	890
F-4C	637422	361	1572.6	821
F-4C	637423	364	1668.3	818
F-4C	637426	371	1747.4	783
F-4C	637428	376	1650.0	1132
F-4C	637430	381	2959.7	728
F-4C	637431	383	1635.5	680
F-4C	637432	385	2008.3	972
F-4C	637433	387	1809.7	985
F-4C	637434	389	2039.3	1486
F-4C	637436	393	1716.1	942
F-4C	637437	395	2008.0	913
F-4C	637439	399	2609.3	755
F-4C	637440	401	2017.9	896
F-4C	637442	405	2045.9	1120
F-4C	637446	413	1639.6	790
F-4C	637447	415	1139.8	339
F-4C	637448	417	2309.5	1952
F-4C	637449	419	1821.3	1164
F-4C	637450	420	1864.7	905
F-4C	637452	424	2177.1	940
F-4C	637453	426	2285.2	1161
F-4C	637454	427	2105.2	1154
F-4C	637455	429	2038.3	704
F-4C	637457	434	2059.8	862
F-4C	637459	437	1894.2	939
F-4C	637460	439	1992.9	794
F-4C	637462	442	1602.3	1122
F-4C	637463	443	2197.8	[illegible]

* Inspection by Dye Penetrant

Figure IV-1
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4C	637465	447	1951.1	914
F-4C	637468	455	1872.9	1373
F-4C	637470	459	1476.0	465
F-4C	637471	461	1966.1	1023
F-4C	637473	463	2047.3	1065
F-4C	637474	465	1803.7	857
F-4C	637475	466	2092.8	1376
F-4C	637476	468	1760.2	1278
F-4C	637477	469	1753.9	564
F-4C	637478	471	2063.2	761
F-4C	637479	472	1673.7	925
F-4C	637482	476	2016.9	896
F-4C	637484	479	1784.4	1660
F-4C	637487	485	1836.3	1054
F-4C	637490	489	2291.5	1460
F-4C	637491	491	2201.6	1841
F-4C	637492	492	1677.1	509
F-4C	637495	498	1873.6	910
F-4C	637497	501	2032.4	817
F-4C	637500	505	2039.7	1166
F-4C	637501	506	2217.4	1199
F-4C	637505	513	2011.9	1666
F-4C	637508	518	2031.0	764
F-4C	637510	522	2146.7	830
F-4C	637512	525	2123.0	1352
F-4C	637515	529	2086.7	933
F-4C	637516	530	1731.1	629
F-4C	637520	537	1525.6	681
F-4C	637523	541	2342.1	1935
F-4C	637530	553	1811.1	867
F-4C	637532	556	2197.0	1275
F-4C	637534	559	1995.7	1350
F-4C	637536	562	1639.4	628
F-4C	637537	564	1636.3	559
F-4C	637540	568	1682.0	497
F-4C	637541	570	1950.7	642
F-4C	637542	572	2433.1	1240

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at * Time of Retrofit	Equivalent Lab Hours
F-4C	637543	573	1612.3	792
F-4C	637545	576	1492.1	603
F-4C	637550	584	1539.6	302
F-4C	637552	588	2553.8	1512
F-4C	637553	589	1485.4	403
F-4C	637555	592	1716.9	827
F-4C	637556	593	2135.2	1515
F-4C	637562	603	1814.9	948
F-4C	637565	607	2178.0	1447
F-4C	637566	609	1940.2	871
F-4C	637568	612	1699.0	759
F-4C	637569	613	1261.5	617
F-4C	637570	615	1436.4	596
F-4C	637572	618	1478.0	451
F-4C	637574	621	1642.3	899
F-4C	637575	622	1689.6	651
F-4C	637578	627	1954.5	1170
F-4C	637581	632	2128.9	591
F-4C	637584	636	1791.7	603
F-4C	637585	638	1770.9	1096
F-4C	638589	644	1703.7	982
F-4C	637592	649	1783.6	901
F-4C	637594	653	1977.9	1327
F-4C	637595	654	1967.1	992
F-4C	637601	673	1630.6	990
F-4C	637602	675	1333.9	658
F-4C	637607	684	2175.7	1258
F-4C	637609	686	2147.0	991
F-4C	637611	689	1572.9	731
F-4C	637617	699	2094.5	1118
F-4C	637618	701	2020.9	1010
F-4C	637622	708	1696.0	1100
F-4C	637623	709	2007.4	896
F-4C	637624	710	1589.8	715
F-4C	637625	713	1662.5	807
F-4C	637626	714	1462.9	678
F-4C	637628	717	1814.3	683

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4C	637629	718	1967.6	1117
F-4C	637630	720	1903.3	711
F-4C	637631	722	2290.0	1866
F-4C	637632	723	1666.0	1298
F-4C	637633	726	1579.0	865
F-4C	637635	729	1823.8	922
F-4C	637637	731	1990.8	742
F-4C	637638	734	1530.1	980
F-4C	637644	745	1734.0	832
F-4C	637646	748	1376.3	774
F-4C	637647	750	1865.0	773
F-4C	637650	755	1898.5	796
F-4C	637654	762	933.6	164
F-4C	637655	763	1944.1	876
F-4C	637657	767	1851.2	1195
F-4C	637661	774	1932.8	1332
F-4C	637662	775	1490.6	633
F-4C	637666	782	1865.4	964
F-4C	637671	791	1917.0	1331
F-4C	637672	793	2064.1	1193
F-4C	637675	794	1893.4	1240
F-4C	637679	805	1697.8	1125
F-4C	637685	815	2091.7	1549
F-4C	637686	817	2437.7	2025
F-4C	637688	820	1484.2	[illegible]
F-4C	637691	828	1397.9	648
F-4C	637696	834	1518.3	672
F-4C	637702	844	1650.8	1226
F-4C	637703	846	1471.7	520
F-4C	637704	848	1865.8	542
F-4C	637705	849	1995.9	618
F-4C	637707	852	1527.9	558
F-4C	640655	868	1576.9	752
F-4C	640654	873	957.7	419
F-4C	640659	876	1644.0	765
F-4C	640661	878	1399.6	540
F-4C	640664	882	347.9	26

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit*	Equivalent Lab Hours
F-4C	640665	885	2147.5	1470
F-4C	640672	896	2305.5	1572
F-4C	64067[illegible]	898	2291.1	2227
F-4C	640675	903	1374.6	603
F-4C	640677	907	2333.8	1235
F-4C	640679	911	2578.8	1599
F-4C	640682	916	2135.3	[illegible]
F-4C	640693	917	1059.3	359
F-4C	640694	937	2370.4	1759
F-4C	640695	939	2126.1	1331
F-4C	640699	945	1772.1	936
F-4C	640707	959	2181.6	1116
F-4C	640711	966	2409.[illegible]	1087
F-4C	640712	969	2350.2	1345
F-4C	640713	971	2016.6	1182
F-4C	640724	991	2235.4	1368
F-4C	640725	994	2529.1	2369
F-4C	640726	995	2331.6	2065
F-4C	640737	1015	2177.0	1426
F-4C	640738	1018	1926.3	2251
F-4C	640741	1023	2152.3	1100
F-4C	640745	1028	1366.3	411
F-4C	640747	1031	1952.4	[illegible]
F-4C	640748	1033	1532.3	[illegible]
F-4C	640749	1035	2059.3	1118
F-4C	640750	1036	2240.0	1398
F-4C	640754	1043	2184.3	1605
F-4C	640757	1047	1561.6	[illegible]
F-4C	640758	1049	1459.2	[illegible]
F-4C	640761	1055	1095.3	[illegible]
F-4C	640765	1061	1352.6	[illegible]
F-4C	640766	1063	2249.0	1961
F-4C	640770	1069	2096.9	2111
F-4C	640772	1072	1329.5	556
F-4C	640775	1077	1363.7	1177
F-4C	[illegible]	1080	1639.6	1195
F-4C	[illegible]	1085	1526.9	[illegible]

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cus No.	Flight Hours at Time of Retrofit*	Equivalent Lab Hours
F-4C	640784	1092	1627.5	738
F-4C	640792	1105	2369.7	1540
F-4C	640793	1107	2052.3	1409
F-4C	640796	1112	1049.3	363
F-4C	640802	1122	1747.2	1790
F-4C	640806	1128	1999.0	1483
F-4C	640811	1137	1683.1	804
F-4C	640813	1141	1897.9	1288
F-4C	640817	1147	700.9	55
F-4C	640822	1155	2050.4	1748
F-4C	640825	1162	2150.7	1693
F-4C	640828	1167	883.3	445
F-4C	640829	1169	2014.0	1452
F-4C	640831	1173	2083.7	1707
F-4C	640836	1183	1952.1	996
F-4C	640838	1187	2370.0	1881
F-4C	640841	1191	2165.6	1964
F-4C	640844	1197	990.4	453
F-4C	640847	1204	1475.2	1361
F-4C	640854	1216	1169.4	691
F-4C	640855	1220	1110.4	810
F-4C	640856	1221	1300.0	786
F-4C	640857	1224	1217.4	705
F-4C	640858	1225	1355.3	809
F-4C	640859	1229	1344.5	1086
F-4C	640861	1233	1279.5	610
F-4C	640862	1235	1219.7	489
F-4C	640863	1238	1407.0	805
F-4C	640864	1240	1497.1	695
F-4C	640869	1250	623.3	132
F-4C	640872	1257	1162.8	589
F-4C	640875	1265	772.8	85
F-4C	640877	1270	1132.8	808
F-4C	640878	1272	1297.6	501
F-4C	640879	1276	1158.1	668
F-4C	640880	1277	1166.1	966
F-4C	640881	1281	1168.1	833

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Gun No.	Flight hours at Time of Retrofit *	Equivalent Lab Hours
F-4C	640883	1286	1155.3	681
F-4C	640884	1289	1438.6	977
F-4C	640887	1296	1280.2	1030
F-4C	640890	1304	1483.8	741
F-4C	640891	1307	1554.7	750
F-4C	640892	1308	1266.8	888
F-4C	640893	1311	1045.5	643
F-4C	640896	1320	1282.0	725
F-4C	640899	1328	1209.2	682
F-4C	640900	1331	1574.7	590
F-4C	640902	1337	1326.1	666
F-4C	640903	1339	1554.9	912
F-4C	640905	1346	1429.7	529
F-4C	640906	1349	1607.0	1011
F-4C	640907	1353	1213.0	583
F-4C	640911	1365	1328.0	492
F-4C	640912	1368	1529.6	1384
F-4C	640913	1372	1001.0	770
F-4C	640914	1376	1118.9	662
F-4C	640915	1378	1854.0	910
F-4C	640917	1385	1799.0	778
F-4C	640918	1387	1459.2	1071
F-4C	640919	1390	1303.3	901
F-4C	640922	1401	1494.3	1066
F-4C	640923	1403	1296.1	774
F-4C	640926	1414	1103.4	279
F-4D	640942	1312	1130.8	761
F-4D	640954	1374	1260.1	447
F-4D	640956	1383	939.8	620
F-4D	640959	1398	1403.1	717
F-4D	640965	1423	1174.0	610
F-4D	640975	1454	1173.1	414
F-4D	640976	1456	1022.8	380
F-4D	640977	1459	1278.7	485
F-4D	640978	1462	1448.3	415
F-4D	640979	1464	1229.0	540
F-4D	640980	1467	1031.5	477

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at * Time of Retrofit	Equivalent Lab Hours
F-4D	650582	1475	1261.4	386
F-4D	650584	1480	1368.0	684
F-4D	650585	1483	1220.0	451
F-4D	650586	1485	1363.0	532
F-4D	650588	1492	1173.0	538
F-4D	650590	1497	1037.1	437
F-4D	650600	1523	1720.0	559
F-4D	650601	1526	1481.2	361
F-4D	650603	1531	1047.2	327
F-4D	650608	1545	1534.8	423
F-4D	650614	1560	1185.6	606
F-4D	650617	1566	1641.1	498
F-4D	650620	1575	1352.8	444
F-4D	650621	1576	1717.6	628
F-4D	650629	1597	1732.2	1123
F-4D	650635	1613	982.1	278
F-4D	650637	1618	2165.9	822
F-4D	650644	1635	1739.8	1003
F-4D	650647	1641	997.4	369
F-4D	650648	1644	1620.6	621
F-4D	650652	1655	966.3	287
F-4D	650654	1659	1067.8	330
F-4D	650655	1661	1086.4	241
F-4D	650661	1676	1505.1	664
F-4D	650666	1688	1126.3	682
F-4D	650674	1702	1826.5	1190
F-4D	650680	1711	1649.8	814
F-4D	650685	1717	1452.0	377
F-4D	650690	1725	1487.0	767
F-4D	650691	1728	1600.4	593
F-4D	650692	1729	1377.1	510
F-4D	650694	1732	1176.6	514
F-4D	650697	1737	1545.8	668
F-4D	650698	1738	477.0	14
F-4D	650699	1740	1393.0	692
F-4D	650701	1742	1399.6	933
F-4D	650707	1751	1538.1	871

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4D	650708	1753	1562.8	1014
F-4D	650714	176[illegible]	1027.8	255
F-4D	650718	1768	1853.1	892
F-4D	650729	1785	1243.6	809
F-4D	650738	1799	1232.1	512
F-4D	650743	1805	1092.3	436
F-4D	650755	1820	1984.7	1033
F-4D	650756	1821	1303.4	482
F-4D	650757	1824	1590.1	730
F-4D	650763	1831	1311.0	476
F-4D	650764	1832	1231.7	550
F-4D	65076[illegible]	1834	1035.0	342
F-4D	650768	1837	1109.5	598
F-4D	650772	1842	1354.5	652
F-4D	650773	1844	1256.0	1190
F-4D	650775	1847	1125.4	739
F-4D	650777	1849	1276.0	650
F-4D	650779	1851	1193.4	780
F-4D	650780	1853	1015.2	372
F-4D	650781	1854	1029.5	431
F-4D	650790	1866	1170.6	1083
F-4D	650791	1867	1110.6	1016
F-4D	650793	1869	889.1	543
F-4D	650798	1876	1087.9	324
F-4D	650799	1877	1237.0	477
F-4D	660227	1883	1437.0	1458
F-4D	660228	1884	1025.6	792
F-4D	660234	1891	811.9	1020
F-4D	660235	1893	1422.9	1534
F-4D	660240	1899	1164.6	879
F-4D	660241	1900	1307.0	795
F-4D	660244	1904	1384.0	1208
F-4D	660251	1913	1054.6	[illegible]44
F-4D	660253	1916	981.4	442
F-4D	660256	1920	1438.0	412
F-4D	660257	1921	952.2	369
F-4D	660261	1926	1286.4	1381

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4D	660262	1927	1058.0	742
F-4D	660263	1929	2024.3	744
F-4D	660266	1932	1473.0	865
F-4D	660268	1935	1186.9	635
F-4D	660269	1936	911.0	701
F-4D	660271	1939	1183.0	1049
F-4D	660273	1941	1475.0	1000
F-4D	660275	1944	1500.0	1510
F-4D	660277	1947	1023.7	382
F-4D	660278	1948	1149.0	544
F-4D	660282	1954	992.0	669
F-4D	667455	1957	897.0	896
F-4D	667456	1958	1202.0	1025
F-4D	667459	1962	1314.9	668
F-4D	667461	1965	918.3	409
F-4D	667463	1967	798.6	253
F-4D	667464	1968	1724.3	2178
F-4D	667466	1971	1460.8	1614
F-4D	667469	1975	1496.0	881
F-4D	667470	1976	1013.2	647
F-4D	667471	1977	1016.9	522
F-4D	667473	1980	1335.9	1549
F-4D	667475	1982	1535.4	1614
F-4D	667477	1985	1027.7	498
F-4D	667478	1986	1690.0	1070
F-4D	667484	1994	934.7	631
F-4D	667485	1995	1286.7	1128
F-4D	667486	1997	1317.8	481
F-4D	667488	1999	935.0	535
F-4D	667489	2000	1471.0	1005
F-4D	667490	2001	1244.7	1087
F-4D	667491	2002	1261.0	1228
F-4D	667498	2011	1164.0	705
F-4D	667500	2015	1574.0	1456
F-4D	667502	2017	1287.9	597
F-4D	667503	2018	1681.0	1129
F-4D	667507	2025	1141.2	808

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4D	667509	2028	1038.0	660
F-4D	667514	2035	949.8	863
F-4D	667519	2041	1022.0	452
F-4D	667522	2046	899.8	655
F-4D	667529	2056	964.2	616
F-4D	667536	2065	1010.7	460
F-4D	667537	2067	860.6	693
F-4D	667539	2070	761.6	411
F-4D	667542	2074	890.5	361
F-4D	667545	2079	756.5	635
F-4D	667547	2081	1086.8	709
F-4D	667551	2086	964.4	506
F-4D	667552	2089	882.3	703
F-4D	667553	2090	1101.4	848
F-4D	667556	2093	798.5	394
F-4D	667558	2098	1356.6	1145
F-4D	667559	2100	988.2	751
F-4D	667570	2116	737.0	411
F-4D	667575	2122	959.5	738
F-4D	667577	2126	1074.7	701
F-4D	667578	2127	823.9	606
F-4D	667580	2129	1430.0	709
F-4D	667582	2133	1171.0	701
F-4D	667588	2141	1092.1	444
F-4D	667589	2143	1054.8	1043
F-4D	667595	2150	783.6	290
F-4D	667596	2153	1202.6	900
F-4D	667607	2168	916.6	535
F-4D	667608	2169	1450.1	610
F-4D	667609	2170	1388.0	1112
F-4D	667611	2174	1069.0	610
F-4D	667614	2178	1490.0	689
F-4D	667615	2179	1387.0	1005
F-4D	667616	2180	1392.2	896
F-4D	667619	2185	866.4	651
F-4D	667620	2187	1184.1	848
F-4D	667621	2188	1081.3	402

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4D	667622	2189	788.6	626
F-4D	667623	2190	1029.9	647
F-4D	667625	2194	1056.0	917
F-4D	667627	2197	1034.2	299
F-4D	667629	2199	879.9	523
F-4D	667634	2206	846.3	543
F-4D	667635	2208	1076.0	614
F-4D	667636	2209	1288.9	523
F-4D	667638	2213	1334.0	792
F-4D	667640	2215	1412.0	1066
F-4D	667642	2218	1258.6	577
F-4D	667645	2223	734.4	444
F-4D	667648	2228	1085.6	514
F-4D	667649	2229	1450.0	651
F-4D	667652	2235	1267.5	1448
F-4D	667660	2246	1420.0	608
F-4D	667662	2248	1030.6	781
F-4D	667663	2252	860.4	718
F-4D	667664	2253	875.6	'
F-4D	667665	2255	1439.0	552
F-4D	667667	2258	1083.0	845
F-4D	667668	2259	763.1	440
F-4D	667669	2260	927.1	680
F-4D	667674	2268	1327.1	2019
F-4D	667677	2272	809.8	378
F-4D	667680	2277	1054.2	452
F-4D	667681	2278	867.1	672
F-4D	667689	2292	855.4	390
F-4D	667692	2298	934.1	520
F-4D	667693	2300	1041.0	358
F-4D	667694	2301	680.2	409
F-4D	667698	2307	1284.0	1050
F-4D	667702	2313	896.9	676
F-4D	667705	2318	834.0	657
F-4D	667706	2319	718.0	485
F-4D	667708	2321	923.0	631
F-4D	667709	2322	1186.5	216

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inpsection

Type	Bu. No.	MAC Gun No.	Flight Hours at Time of Retrofit *	Equivalent Lab Hours
F-4D	667710	2325	1459.0	585
F-4D	667713	2330	929.4	357
F-4D	667715	2332	1371.1	1066
F-4D	667722	2346	1376.0	751
F-4D	667723	2347	993.9	448
F-4D	667724	2349	756.5	261
F-4D	667732	2361	1055.8	908
F-4D	667733	2362	1258.6	722
F-4D	667737	2368	1121.4	527
F-4D	667741	2376	413.4	195
F-4D	667747	2386	931.3	166
F-4D	667751	2392	1022.9	95
F-4D	667752	2393	1032.8	506
F-4D	667755	2398	1020.4	141
F-4D	667759	2402	1433.0	875
F-4D	667767	2416	2042.4	1311
F-4D	667773	2428	1080.7	535
F-4D	668686	2431	1211.8	805

* Inspection by Dye Penetrant

Figure IV-1 (Continued)
Fleet Aircraft With no Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Activity	Flight Hours at Time of Inspection *	Accelerometer Hours at Time of Inspection	Exceedances for Listed Number of Accelerometer Hours	Equivalent Lab Hours
F-4J	153075	1552	Fleet	605	576	4g's/880, 5g's/191, 6g's/22, 7g's/5	340
			Blue Angel	363	333	6g's/230, 7g's/133, 8.5g's/17, 10g's/0	
F-4J	153076	1567	Fleet	689	643	4g's/1376, 5g's/298, 6g's/51, 7g's/5	410
			Blue Angel	365	348	6g's/315, 7g's/143, 8.5g's/17, 10g's/0	
F-4J	153079	1601	Fleet	689	644	4g's/1572, 5g's/291, 6g's/41, 7g's/7	246
			Blue Angel	255	238	6g's/127, 7g's/60, 8.5g's/12, 10g's/0	
F-4J	153082	1636	Fleet	644	594	4g's/1693, 5g's/340, 6g's/49, 7g's/2	250
			Blue Angel	343	326	6g's/186, 7g's/36, 8.5g's/0, 10g's/0	

* Inspection by Eddy Current

Figure IV-2
Demonstration Team Aircraft with No Cracks Indicated in the Key Area in the Wing Main Torque Box Lower Skin at Time of Inspection

Type	Bu. No.	MAC Cum No.	Activity	Flight Hours at Time of Inspection *	Accelerometer Hours at Time of Inspection	Exceedances for Listed Number of Accelerometer Hours	Equivalent Lab Hours
F-4J	153080	1614	Fleet	633	624	4g's/1386, 5g's/312, 6g's/59, 7g's/11	2100
			Blue Angel	193	168	6g's/800, 7g's/395, 8.5g's/64, 10g's/2	
F-4J	153081	1623	Fleet	698	686	4g's/1576, 5g's/305, 6g's/45, 7g's/16	1830
			Blue Angel	232	219	6g's/740, 7g's/292, 8.5g's/42, 10g's/1	

* Inspection by Eddy Current

Figure IV-3
Demonstration Team Aircraft in Which Cracks were Detected in the Key Area in the Wing Main Torque Box Lower Skin During Inspection

Type	Pr. No.	MAI Jum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4C	637411	328	15		[illegible]	[illegible] *
F-4C	637412	332	15		2180	1432
F-4C	637414	339	15		2225	795 *
F-4C	637415	342	15		2312	909 *
F-4C	637417	349	15		2334	1320
F-4C	637418	352	15		2597	1109 *
F-4C	637419	355	15		3943	707
F-4C	637420	[illegible]	15		[illegible]	921 *
F-4C	637422	[illegible]	15		1675	[illegible]
F-4C	637430	381	16		2865	[illegible]
F-4C	637431	383	16		1644	[illegible]
F-4C	637434	389	16		2126	[illegible]
F-4C	637436	393	16		1751	933 *
F-4C	637439	399	16		2543	770
F-4C	637442	405	16		2046	1120 *
F-4C	637446	413	17		1763	992
F-4C	637453	426	17		2285	1141
F-4C	637454	427	17		2145	1162
F-4C	637455	429	17		2155	785 *
F-4C	637457	434	17		2159	[illegible] *
F-4C	637460	439	17		2135	[illegible] *
F-4C	637463	443	17		[illegible]	[illegible] *
F-4C	637465	447	17		1969	[illegible] *
F-4C	637469	[illegible]	17		1902	[illegible] *
F-4C	[illegible]	[illegible]	18		[illegible]	[illegible] *
F-4C	[illegible]	[illegible]	18		[illegible]	[illegible] *
F-4C	[illegible]	[illegible]	[illegible]		[illegible]	[illegible] *
F-4C	[illegible]	[illegible]	18	√	[illegible]	
F-4C	[illegible]	[illegible]	18		1759	[illegible] *
F-4C	[illegible]	[illegible]	[illegible]		[illegible]	[illegible] *
F-4C	[illegible]	[illegible]	18		[illegible]	[illegible]
F-4C	[illegible]	[illegible]	18		[illegible]	[illegible]
F-4C	[illegible]	[illegible]	[illegible]	√	[illegible]	
F-4C	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
F-4C	[illegible]	[illegible]	[illegible]		[illegible]	[illegible] *
F-4C	[illegible]	[illegible]	18		[illegible]	[illegible] *
F-4C	[illegible]	[illegible]	[illegible]		[illegible]	[illegible] *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4

Fleet Aircraft with No Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	NAS Jun No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4C	637510	522	18		2316	[illegible]53 *
F-4C	637514	527	18		1770	569
F-4C	637516	530	19		1791	763
F-4C	637519	535	19	√	1355	
F-4C	637520	537	19	√	1571	
F-4C	637529	552	19		2334	1414 *
F-4C	7536	562	19		1652	646
F-4C	637537	564	19		1718	691
F-4C	637541	570	19		1932	593 *
F-4C	637542	572	19		2430	1243
F-4C	637550	586	19		1562	366
F-4C	637553	589	19		1482	469
F-4C	637555	592	19	√	1723	
F-4C	637556	593	19		2189	1546
F-4C	637559	594	19		1761	949 *
F-4C	637562	603	19		1919	848 *
F-4C	637564	608	19		1113	374 *
F-4C	637565	609	19		2412	557 *
F-4C	637569	635	19		759	474
F-4C	[illegible]	638	19		1798	563
F-4C	637584	643	19		[illegible]	1076
F-4C	637587	644	19		3327	1447
F-4C	637591	647	19		1515	747 *
F-4C	637603	679	20		1627	596
F-4C	637602	675	20		1325	433 *
F-4C	637609	695	20		2266	1046
F-4C	637617	695	20		1989	1143 *
F-4C	637622	703	20		1733	842 *
F-4C	637623	706	20		1962	843 *
F-4C	637624	717	20		1734	784 *
F-4C	637626	724	20		1546	764
F-4C	637628	727	20		1933	722 *
F-4C	637670	[illegible]	20		1993	[illegible] *
F-4C	637632	722	20		2317	1082
F-4C	637672	723	20		1647	1327
F-4C	637637	733	20		2101	767 *
F-4C	637642	741	20		1764	534 *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key
Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Gum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4C	637649	754	20		2013	1387
F-4C	637655	763	20		1552	376
F-4C	637667	785	21		1718	593 *
F-4C	637676	799	21	√	1329	
F-4C	637683	811	21		2095	242
F-4C	637685	815	21		2295	1569
F-4C	637688	820	21		1480	902 *
F-4C	637693	828	21		1312	548 *
F-4C	640665	885	21		2146	1470
F-4C	640666	886	21		2199	1493
F-4C	640682	916	22		2142	1032 *
F-4C	640686	923	22		1688	1196
F-4C	640695	939	22		2082	1329 *
F-4C	640699	945	22		1767	61
F-4C	640706	957	22		1675	1061
F-4C	640712	969	22		2303	1332
F-4C	640724	991	22		2225	1368 *
F-4C	640725	993	22		2508	2346
F-4C	640737	1015	22		1188	702 *
F-4C	640747	1031	23		1932	929 *
F-4C	640759	1051	23		1358	490
F-4C	640763	1059	23		1492	999 *
F-4C	640777	1080	23		1767	1459 *
F-4C	640781	1087	23		1441	587 *
F-4C	640783	1091	23		1570	1396
F-4C	640802	1122	23		1360	1854
F-4C	640804	1125	23		2413	2024
F-4C	640806	1128	23		2028	1505
F-4C	640813	1141	23		1921	1312 *
F-4C	640815	1143	23		1072	287
F-4	640840	1190	24		1598	1211
F-4C	640844	1197	24		1043	287
F-4C	640847	1204	24		1411	1307
F-4D	640952	1304	25		1163	807
F-4C	640892	1308	25		1250	866
F-4C	640913	1372	25		1083	825
F-4C	640914	1376	25		1117	662

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Cum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4D	640955	1383	25		938	520
F-4D	640959	1393	25		1039	430 *
F-4D	[illegible]	1423	26		1064	492
F-4D	650660	1574	27		392	225
F-4D	650702	1782	28		1228	755
F-4D	650730	1787	28		1400	641
F-4D	650777	1949	29		631	375
F-4D	650790	1866	29		1134	677
F-4D	650798	1876	29		1119	213
F-4D	650799	1977	29		1297	309
F-4D	660227	1983	29		1289	1394
F-4D	660228	1984	29		970	718
F-4D	660244	1904	29		1249	1121
F-4D	660254	1917	29		937	497 *
F-4D	660261	1926	29		1145	1311
F-4D	660262	1927	29		923	637
F-4D	660266	1932	29		1272	752
F-4D	660269	1936	29		946	456
F-4D	660270	1938	29		978	462
F-4D	660271	1939	29		1022	965
F-4D	660272	1940	29		1147	786 *
F-4D	660276	1945	29		1092	683
F-4D	660278	1948	29		977	478
F-4D	660283	1956	29		1046	577
F-4D	667456	1958	29		969	904
F-4D	667461	1965	29		1002	293 *
F-4D	667467	1972	29		1075	754
F-4D	667469	1975	29		1190	662
F-4D	667479	1986	29		1424	854
F-4D	667484	1994	29		929	623
F-4D	667487	1998	29		1212	724
F-4D	667489	2000	29		1238	785
F-4D	667490	2001	29		1146	1008
F-4D	667491	2002	29		1114	1131
F-4D	667494	2007	29		950	551
F-4D	667496	2009	29		886	513
F-4D	667500	2015	29		1192	780 *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Cum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4D	667504	2019	29		1237	763 *
F-4D	667519	2041	30		1010	446
F-4D	667525	2050	30		1000	710
F-4D	667529	2056	30		975	370
F-4D	667548	2083	30		1137	540
F-4D	667550	2085	30		1234	590
F-4D	667556	2093	30		1202	1024
F-4D	667573	2119	30		1041	323
F-4D	667580	2129	30		1244	608 *
F-4D	667582	2133	30		683	331
F-4D	667589	2143	30		935	929
F-4D	667608	2169	30		1284	529 *
F-4D	667614	2178	30		1311	552
F-4D	667618	2184	30		1212	436
F-4D	667621	2188	30		1135	272
F-4D	667627	2197	30		1028	295
F-4D	667636	2209	30		1195	468
F-4D	667642	2218	30		1226	521
F-4D	667648	2228	30		1098	317
F-4D	667649	2229	30		1225	539
F-4D	667650	2230	30		1290	773
F-4D	667660	2246	31		1247	517
F-4D	667665	2255	31		1328	449
F-4D	667675	2270	31	√	1080	
F-4D	667678	2273	31		1184	441
F-4D	667687	2290	31		810	523
F-4D	667690	2296	31		60	29
F-4D	667709	2322	31	√	1035	
F-4D	667710	2325	31		1263	477
F-4D	667725	2350	31		1109	593 *
F-4D	667731	2360	31		910	623
F-4D	667733	2362	31		1163	312
F-4D	667737	2368	31		1054	476
F-4D	667739	2371	31		887	283
F-4D	667743	2379	31		1052	535 *
F-4D	667745	2381	31		1019	594 *
F-4D	667746	2382	31		989	322

* Fatigue Damage Estimated for more than 50% of Flight Hours
** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key
Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Cum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4D	667749	2389	31		979	527 *
F-4D	667755	2398	31		915	34
F-4D	667759	2402	31		631	58
F-4D	667768	2418	31		755	384 *
F-4D	667773	2428	31		1032	527
F-4D	668700	2455	32		66	34 *
F-4D	668701	2458	32		44	22 *
F-4E	660303	2479	32		694	353 *
F-4E	660304	2484	32		900	458 *
F-4E	660306	2494	32		648	330 *
F-4E	660318	2553	32		668	340 *
F-4E	660327	2594	32		902	459 *
F-4E	660338	2653	32		619	315 *
F-4E	660342	2676	33		962	490 *
F-4D	668804	2757	33	✓	530	
F-4D	668808	2778	33		574	85
F-4E	660377	2794	33		597	304 *
F-4E	670211	2825	33		553	281 *
F-4D	668824	2857	33		220	54 *
F-4E	670220	2866	34		721	367 *
F-4E	670222	2873	34		522	266 *
F-4E	670227	2886	34		662	337 *
F-4E	670229	2891	34		541	275 *
F-4E	670232	2899	34		826	420 *
F-4E	670233	2902	34		741	377 *
F-4E	670236	2909	34		792	403 *
F-4E	670238	2914	34		533	271 *
F-4E	670239	2917	34		743	378 *
F-4E	670240	2920	34		840	428 *
F-4E	670242	2925	34		652	332 *
F-4E	670243	2927	34		719	366 *
F-4E	670254	2957	34		729	371 *
F-4E	670255	2959	34		767	390 *
F-4E	670257	2963	34		746	380 *
F-4E	670258	2966	34		862	439 *
F-4E	670260	2972	34		735	374 *
F-4E	670264	2982	34		764	389 *
F-4D	667754	2996	34		999	530 *

* Fatigue Damage Estimated for more than 50% of Flight Hours
** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Cum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4E	670285	3037	35		502	256 *
F-4E	670289	3048	35		498	253 *
F-4E	670310	3105	35		497	253 *
F-4E	670318	3127	35		446	227 *
F-4E	670320	3133	35		508	259 *
F-4E	670322	3139	35		576	293 *
F-4E	670327	3151	35		489	249 *
F-4E	670331	3163	35		399	203 *
F-4E	670337	3179	35		423	215 *
F-4E	670343	3194	36		495	252 *
F-4E	670345	3200	36		495	252 *
F-4E	670348	3207	36		549	279 *
F-4E	670349	3210	36		495	252 *
F-4E	670350	3212	36		536	273 *
F-4E	670351	3215	36		496	252 *
F-4E	670353	3219	36		496	252 *
F-4E	670354	3221	36		605	308 *
F-4E	670355	3223	36		495	252 *
F-4E	670356	3225	36		510	260 *
F-4E	670360	3234	36		525	267 *
F-4E	670361	3236	36		497	253 *
F-4E	670362	3238	36		424	216 *
F-4E	670363	3240	36		493	251 *
F-4E	670364	3242	36		582	296 *
F-4E	670365	3244	36		544	277 *
F-4E	670366	3246	36		497	253 *
F-4E	670367	3248	36		401	204 *
F-4E	670368	3250	36	√	506	
F-4E	670369	3252	36		535	272 *
F-4E	670370	3254	36		495	252 *
F-4E	670371	3256	36		570	290 *
F-4E	670372	3258	36		500	255 *
F-4E	670374	3262	36		458	233 *
F-4E	670375	3264	36		495	252 *
F-4E	670376	3267	36		587	299 *
F-4E	670377	3269	36		503	256 *
F-4E	670378	3271	36		599	305 *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Own No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4E	670379	3273	36		422	215 *
F-4E	670381	3277	36		477	243 *
F-4E	670382	3279	36		517	263 *
F-4E	670383	3281	36		508	259 *
F-4E	670384	3283	36		506	258 *
F-4E	670385	3285	36		483	246 *
F-4E	670386	3287	36		478	243 *
F-4E	670387	3289	36		435	221 *
F-4E	670388	3292	36		466	237 *
F-4E	670389	3294	36		390	199 *
F-4E	670390	3297	36		464	236 *
F-4E	670391	3299	36		541	275 *
F-4E	670392	3301	36		386	196 *
F-4E	670394	3305	36		461	235 *
F-4E	670396	3310	36		379	193 *
F-4E	670397	3312	36		462	235 *
F-4E	680305	3320	37		499	254 *
F-4E	680308	3326	37		523	266 *
F-4E	680309	3328	37		520	265 *
F-4E	680311	3332	37		459	234 *
F-4E	680312	3333	37		353	180 *
F-4E	680314	3337	37		459	234 *
F-4E	680318	3345	37		439	223 *
F-4E	680319	3347	37		480	244 *
F-4E	680320	3349	37		470	239 *
F-4E	680321	3351	37		428	218 *
F-4E	680324	3356	37		462	235 *
F-4E	680325	3358	37		458	233 *
F-4E	680326	3360	37		458	233 *
F-4E	680327	3362	37		458	233 *
F-4E	680328	3364	37		459	234 *
F-4E	680330	3368	37		458	233 *
F-4E	680335	3378	37		455	232 *
F-4E	680336	3379	37		457	233 *
F-4E	680338	3383	37		433	220 *
F-4E	680339	3385	37		389	198 *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with No Cracks Indicated in the Key
Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Gun No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4E	680343	3393	37		432	220 *
F-4E	680345	3397	37		471	240 *
F-4E	680347	3400	37		419	213 *
F-4E	680348	3402	37		388	197 *
F-4E	680351	3408	37		402	205 *
F-4E	680353	3412	37		420	214 *
F-4E	680354	3414	37		422	215 *
F-4E	680355	3416	37		389	198 *
F-4E	680357	3419	37		460	234 *
F-4E	680358	3421	37		332	169 *
F-4E	680359	3423	37		400	204 *
F-4E	6[illegible]360	3425	37		352	179 *
F-4E	680361	3427	37		432	220 *
F-4E	680362	3429	37		329	167 *
F-4E	680363	3431	37		385	196 *
F-4E	680364	3433	37		399	203 *
F-4E	680365	3435	37		397	202 *
F-4E	680367	3439	38		398	203 *
F-4E	680369	3441	38		398	203 *
F-4E	680383	3467	38		338	172 *
F-4E	680385	3471	38		275	140 *
F-4E	680387	3473	38		361	184 *
F-4E	680390	3479	38		299	152 *
F-4E	680395	3488	38		260	132 *
F-4E	680400	3498	38		308	157 *
F-4E	680418	3530	39		255	130 *
F-4E	680423	3540	39		276	140 *
F-4E	680[illegible]8	3550	39		272	138 *
F-4E	680429	3551	39		260	132 *
F-4E	680432	3558	39		294	150 *
F-4E	680439	3572	39		221	112 *
F-4E	680449	3591	39		190	97 *
F-4E	680450	3594	39		202	103 *
F-4E	680451	3595	39		161	82 *
F-4E	680453	3600	40	✓	243	
F-4E	680461	3614	40		138	70 *
F-4E	680462	3617	40		190	97 *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Cum No.	Block No.	Indication That Original Outer Wing was Removed Prior to Detection of Crack	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4L	680463	3613	40		190	97 *
F-4L	680466	3623	40		191	97 *
F-4L	680468	3627	40		179	91 *
F-4L	680479	3647	40		196	100 *
F-4L	680482	3654	40		158	80 *
F-4L	680488	3664	40		136	69 *
F-4L	680492	3672	40		144	73 *
F-4L	680493	3673	40		143	73 *
F-4L	680504	3690	41		89	45 *
F-4L	680505	3691	41		48	24 *
F-4L	680510	3699	41		94	48 *
F-4L	680511	3701	41		113	58 *
F-4L	680518	3711	41		102	52 *

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-4 (Continued)
Fleet Aircraft with no Cracks Indicated in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	F.. No.	MAC Dsh No.	Block No.	Failure Detected In 35-15052	Failure Detected In 32-15531	Indication That Original Outer Wing was Removed Prior to Detection of Crack	** Flight Hours at Time of Failure	Accelerometer Hours at Time of Failure	Exceedances for Listed Number of Accelerometer Hours 4g	5g	6g	7g	Equivalent Lab Hours
F-4B	148392	77				✓							
F-4J	149429	113	8	R/H			1588	1340	2309	674	150	19	437
F-4B	151004	329	15	L/H			2325	2229	3762	1278	218	37	555
F-4J	151007	333	15				2767	2523	7144	2230	513	100	1045
F-4B	151422	400	16		L/H		2366	2322	1938	621	106	19	382
F-4C	637450	420				✓							
F-4C	637465	447	17		L/H		1794	700	3g's 4264	4g's 1421	5g's 524	6g's 188	805 *
F-4C	637518	701				✓							
F-4B	152221	800	21		L/H		1717	1466	2497	765	136	37	415
F-4C	637575	839	21	R/H			1782	1410	3g's 7249	4g's 2525	5g's 1133	6g's 493	795
F-4B	152250	922				✓							
F-4C	640705	953	22	R/H			2095						1313 *
F-4J	152307	1156	24		L/H		1645	1133	1660	576	134	24	374
F-4B	152325	1216	24		L/H		2503	2292	3332	739	99	14	395
F-4D	650753	1818	28				1709.7	1406	3g's 5475	4g's 3349	5g's 1495	6g's 372	912
F-4D	650800	1978	29		R/H		1509						1344 *
F-4J	153799	2014	29	R/H			1295	908	6040	2650	839	204	1799
F-4D	667515	2035	30		L/H		2787						1822 *
F-4J	153812	2088	30	L/H			603	468	2784	723	147	27	427
F-4D	667555	2239	31	R/H			1709.2						1081 *
F-4J	153842	2245	31		R/H		1013	898	5550	1887	655	142	795
F-4J	153855	2323	31	L/H			944	362	4366	1633	360	68	758

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-5

Fleet Ai. .raft in Which Cracks Were Detected in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	MAC Ser No.	Block No.	Failure Detected In		Indication That Original Outer Wing was Removed Prior to Detection of Crack	** Flight Hours at Time of Failure	Accelerometer Hours at Time of Failure	Exceedances for Listed Number of Accelerometer Hours				Equivalent Lab Hours
				35-15062	32-15532				4g	5g	6g	7g	
F-4J	153761	2359				✓							
F-4D	668686	2431	32		L/H		2259						825 *
F-4J	153792	2464	32	R/H			281	256	346	333	106	55	251
F-4J	153809	2517	32	L/H			1137	[illegible]	4207	1450	569	175	888
F-4J	153811	2528	32	R/H			358	333	2524	569	102	20	290
F-4J	154782	2539	32	R/H			792	715	2925	935	339	72	584
F-4J	154784	2549	32	L/H			1355	1001	2723	1102	417	105	869
F-4E	660375	2787	33	L/H			794						391 *
F-4J	155549	2809	33	R/H			747						622 *
F-4J	155550	2811	33	L/H			1020.9						814 *
F-4J	155563	2849				✓							
F-4J	155565	2855	33				876	320	2161	1024	464	97	1044 *
F-4E	670225	2901	34	L/H			812						400 *
F-4J	155579	2872	34				737	532	3583	1408	400	131	974
F-4E	[illegible]	2934	34	L/H & R/H			347						173 *
F-4J	155731	2899	34	L/H			459						319 *
F-4J	155734	2905	34			No Information Available							
F-4J	155772	3000	34	L/H & R/H			270						178 *
F-4E	670274	3009	34	L/H & R/H			538						314 *
F-4E	670275	3011	34	R/H			370						428 *
F-4E	670290	3052	35	R/H			1025						505 *

* Fatigue Damage Estimated for more than 50% of Flight Hours
** Visual Inspection

Figure IV-5 (Continued)
Fleet Aircraft in Which Cracks Were Detected in the Key
rea in the Outer Wing Lower Surface at Time of Inspection

Type	Ser. No.	MAC Own No.	Block No.	Failure Detected in 32-15052	Failure Detected in 32-15531	Indication That Original Outer Wing was Removed Prior to Detection of Crack	** Flight Hours at Time of Failure	Accelerometer Hours at Time of Failure	Exceedances for Listed Number of Accelerometer Hours 4g	5g	6g	7g	Equivalent Lab Hours
F-4E	670295	3064	35	R/H			1218						600 *
F-4E	670296	3067	35	L/H & R/H			1230						606 *
F-4E	670302	3081	35	R/H			1653						518 *
F-4E	670306	3095	35		R/H		949						566 *
F-4E	670312	3104	35				621						306 *
F-4E	670313	3108	35	L/H	L/H		1156						825 *
F-4E	670315	3122	35	L/H			1152						567 *
F-4E	670344	3197	36	R/H			535						263 *
F-4J	155852	3216	35			✓							
F-4J	155852	3228	35	L/H			No Information Available						
F-4E	670392	3277	36		R/H	✓							
F-4E	670390	3277	36	L/H			286						141 *
F-4E	670395	3327	36	R/H			No Information Available						
F-4E	680341	3382				✓							
F-4E	680346	3394	37	L/H			306						151 *
F-4E	680349	3426	37	R/H			No Information Available						
F-4E	680378	3496	38	R/H			280						138 *
F-4E	680430	3532	38	L/H			339						167 *
F-4E	680431	3535	38	L/H			232						114 *
F-4J	155898	3553	38	L/H			257						192 *
F-4J	155903	3562	38	R/H			215						164 *
F-4E	680447	3587	39				No Information Available						

* Fatigue Damage Estimated for more than 90% of Flight Hours

** Visual Inspection

Figure IV-5 (Continued)
Fleet Aircraft in Which Cracks Were Detected in the Key
Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	[illegible] No.	Block No.	Failure Detected In		Indication That Original Outer Wing was Removed Prior to Detection of Crack	** Flight Hours at Time of Failure	Accelerometer Hours at Time of Failure	Exceedances for Listed Number of Accelerometer Hours				Equivalent Lab Hours
				[illegible]	[illegible]				4g	5g	6g	7g	
F-4J	[illegible]	[illegible]	27	L/H	L/H		633 in Fleet usage 307 as Blue Angel	624 245.7	1386 6g's / 926	312 7g's / 467	59 8.5g's / 76	11 10 g's / 3	4140
F-4J	[illegible]	[illegible]	32	L/H		No Information Available							
F-4J	[illegible]	[illegible]	32	L/H		No Information Available							
F-4J	[illegible]	[illegible]				✓							
F-4J	[illegible]	[illegible]	32	L/H		No Information Available							

* Fatigue Damage Estimated for more than 90% of Flight Hours

** Visual Inspection

Figure IV-6
Demonstration Team Aircraft in Which Cracks Were Detected in the Key Area in the Outer Wing Lower Surface at Time of Inspection

Type	Bu. No.	NAC Cum No.	Bulkhead Material	Flight Hours at ** Time of Inspection	Equivalent Lab Hours
F-4B	150407	193	7075-T651	2791	365
F-4B	150412	198	7075-T651	2118	446 *
F-4B	150422	208	7075-T651	2206	338
F-4B	150425	211	7075-T651	2686	270
F-4B	150430	216	7075-T651	2471	311
F-4B	150441	227	7075-T651	2321	540
F-4B	150444	230	7075-T651	2241	338 *
F-4B	150445	231	7075-T651	2515	450
F-4B	150450	236	7075-T651	2261	270
F-4B	150452	238	7075-T651	2552	438
F-4B	[illegible]	[illegible]	7075-T651	2512	405 *
F-4B	150472	258	7075-T651	2793	473
F-4B	150479	265	7075-T651	3056	360 *
F-4B	150485	271	7075-T651	2502	[illegible]
F-4B	150625	273	7075-T651	1174	164 *
F-4B	150627	[illegible]	7075-T651	4935	456
F-4B	[illegible]	292	7075-T651	[illegible]	[illegible]
F-4B	[illegible]	[illegible]	7075-T651	[illegible]	365
[illegible]	[illegible]	[illegible]	7075-T651	[illegible]	1555
[illegible]	[illegible]	[illegible]	7075-T651	[illegible]	339
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] *
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	561 *
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	314
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1726	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] *
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] *
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Inspection by [illegible]

Figure IV-7

Fleet Aircraft With No Cracks Indicated in the Key Area in the F.S. 303 Bulkhead at Time of Inspection

Type	Bu. No.	McD Run No.	Bulkhead Material	Flight Hours at ** Time of Inspection	Equivalent *at Hours
F-4E	152254	939	7075-T651	1395	427
F-4C	640725	993	7075-T651	2525	1542
F-4B	153008	1466	7075-T651	1320	1057
F-4J	15307[illegible]	1506	7075-T651	847	79
F-4B	153034	1574	7075-T651	No Information Available	
F-4J	153776	1719	7075-T651	1313	537
F-4J	153773	1759	7075-T651	1216	430
F-4J	153777	1811	7075-T651	937	353
F-4J	153797	1866	7075-T7351	1172	1383

* Fatigue Damage Estimated f[illegible]r more than 50% of Flight Hours

** Inspection by Eddy Current

Figure IV-7 (Continued)
Fleet Aircraft with No Cracks Indicated in the Key Area
in the F.S. 303 Bulkhead at Time of Inspection

Type	Bu. No.	MAC Cum No.	Bulkhead Material	Flight Hours at ** Time of Inspection	Equivalent Lab Hours	Remarks
F-4P	148419	103	7075-T651	1316	672 *	Broken - Further information not available
F-4L	660314	2533	7075-T7351	1155	407 *	Broken - Further information not available

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Visual Inspection

Figure IV-8
Fleet Aircraft in Which Cracks were Detected in the Key Area in the F.S. 303 Bulkhead

Type	Bu. No.	MAC Cum No.	Bulkhead Material	Activity	Flight Hours at ** Time of Inspection	Accelerometer Hours at Time of Inspection	Exceedances for Listed Number of Accelerometer Hours 4g	5g	6g	7g	Equivalent Lab Hours
F-4J	153082	1636	7075-T651	Fleet	643.3	594	1693	340	49	2	538
				Blue Angel	880.4	685.7	6g's 358	7g's 85	8.5 g's 9	10 g's 3	
F-4J	153084	1649	7075-T651	Fleet	1034	933	2584	715	116	14	1916
				Blue Angel	488	390.6	6g's 593	7g's 191	8.5 g's 81	10 g's 16	
F-4J	153086	1667	7075-T651	Fleet	635	353	961	376	134	53	576*
				Blue Angel	187.9	NONE					

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Inspection by Eddy Current

Figure IV-9
Demonstration Team Aircraft with No Cracks Indicated in the Key Area in the F.S. 303 Bulkhead at Time of Inspection

Type	Bu. No.	VAC Gun No.	Bulkhead Material	Activity	Flight Hours at ** Time of Inspection	Accelerometer Hours at Time of Inspection	Exceedances for Listed Number of Accelerometer Hours 4g	5g	6g	7g	Equivalent Lab Hours	Remarks
F-4J	153076	1567	7075-T651	Fleet	689	643	1376	298	51	5	1322	Inspection revealed crack indications on R/H side of bulkhead
				Blue Angel	367.6	694.2	6g's 854	7g's 333	8.5 g's 53	10 g's 3		
F-4J	153079	1601	7075-T651	Fleet	689.4	644	1572	291	41	7	838	Inspection revealed crack indications on L/H and R/H sides of bulkhead
				Blue Angel	480.8	316.3	6g's 297	7g's 268	8.5 g's 35	10 g's 1		
F-4J	153080	1614	7075-T651	Fleet	632.8	624	1386	312	59	11	2928	Inspection revealed crack indications on L/H and R/H sides of bulkhead
				Blue Angel	520.5	304.2	6g's 942	7g's 631	8.5 g's 92	10 g's 3		
F-4J	153081	1623	7075-T651	Fleet	698.1	686	1576	305	45	16	3027	Inspection revealed crack indications on L/H and R/H sides of bulkhead
				Blue Angel	659.5	350.6	6g's 861	7g's 568	8.5 g's 73	10 g's 4		
F-4J	153083	1643	7075-T651	Fleet	1084.9	822	1547	371	41	5	1584	Inspection revealed crack indications on R/H side of bulkhead
				Blue Angel	648	536.7	6g's 455	7g's 189	8.5 g's 36	10 g's 3		
F-4E	660315	2538	7075-T7351	Fleet	489.7	NONE					410*	Inspection revealed crack indications on R/H side of bulkhead
				Thunderbird	767.3	64.8	6g's 212	7g's 54	8.5 g's 3	10 g's 0		
F-4E	660321	2566	7075-T7351	Fleet	501.1	NONE					1190*	Inspection revealed crack indications on L/H and R/H sides of bulkhead
				Thunderbird	320.3	NONE						
F-4E	660329	2604	7075-T7351	Fleet	446.7	NONE					842*	Inspection revealed crack indications on L/H and R/H sides of bulkhead
				Thunderbird	558.8	NONE						

* Fatigue Damage Estimated for more than 50% of Flight Hours

** Inspection by Eddy Current

Figure IV-10
Demonstration Team Aircraft in Which Cracks Were Detected in the Key Area in the F.S. 303 Bulkhead During Inspection

Failure Information		Flight Information					
Aircraft Bu. No.	Flight Hours at Which Failure Detected	Flight Hours at Report	Accelerometer Hours at Report	Exceedances for Listed Number of Accelerometer Hours			
				4g	5g	6g	7g
148258	813	811	676	245	54	11	2
148259	736	737	596	59	4	0	0
148260							
148262	552.4	572	289	97	35	14	1
148263	777	776	635	164	47	11	0
148264	790	790	639	220	43	[illegible]	2
148269	566	574	427	113	30	8	1
148270	711.5	712	540	181	31	7	3
148272	779.2	773	561	179	50	13	1
148275	694.4	694	463	182	46	13	5
148367	407	411	240	80	13	4	0
148373	633.7	629	243	126	40	2	0
148376	614.7	604	417	85	22	4	0
148377	594.3	593	349	159	26	6	1
148378							
148379							
148386	589	580	162	40	13	1	0
148387	819.8	833	553	248	71	18	5
148388	325.3	331	78	115	12	0	0
148391	291	290	253	60	9	2	0
148392	463.6						
148395	711.5	689					
148397	763	787	404	46	10	2	1
148401	508	508	164	48	9	1	0
148404	486.8	486	139	33	3	0	0
148407	418.3	431	186	45	7	0	0
148408	524.4	527	324	40	8	0	0
148409	415.5	445	261	24	2	0	0
148410	817.1	827	484	87	21	4	1
148414	389.3	390	267	142	12	2	0
148415	418.3	418					
148416	441.5	442	283	0	0	0	0
148420	542.7	569	423	57	4	0	0
148421	630.3	645	495	30	6	0	0
148422	786	786	366	155	52	13	1

Figure IV-11
Cracks Detected in the Wing Main Torque Box Upper Skin in Service Operations

Failure Information		Flight Information					
Aircraft Bu. No.	Flight Hours at Which Failure Detected	Flight Hours at Report	Accelerometer Hours at Report	Exceedances for Listed Number of Accelerometer Hours			
				4g	5g	6g	7g
148424	323.6	326					
148426							
148427	473	473	98	104	34	5	1
148428	511.5	517	414	135	29	4	0
148429	847.5	838	296	77	10	1	0
148430	463.1	479	290	33	6	1	0
148433	796.4	796	331	112	34	16	4
149404							
149407	536	537	504	65	13	1	0
149410	441.5	442	388	51	3	0	0
149411	732.2	732	696	86	13	1	0
149414							
149415	502.3	523	511	145	30	13	3
149418							
149419							
149421	692.5	698	668	45	8	2	0
149423	623	623	523	62	10	2	0
149424	374.8	415	401	36	8	2	1
149426							
149427							
14[illegible]							
149429	381	381	314	196	72	10	1
149430							
149432	320.2	299	270	3	0	0	0
149434							
149435	495.5	496	424	49	3	1	0
149438	588	588	554	237	33	1	0
149440	552	552	540	230	44	5	0
149441	530.5	531	517	179	47	6	3
149443							
149444	572.8	581	570	212	62	5	0
149445							
149446							
149447	682.5	683	670	222	50	7	0
149448							

Figure IV-11 (Continued)
Cracks Detected in the Wing Main Torque Box Upper Skin in Service Operations

Failure Information		Flight Information					
Aircraft Bu. No.	Flight Hours at Which Failure Detected	Flight Hours at Report	Accelerometer Hours at Report	Exceedances for Listed Number of Accelerometer Hours			
				4g	5g	6g	7g
149450	466.1	467	420	330	98	18	1
149452	625.6	626	609	314	94	10	1
149453	933.3	934	917	741	211	31	4
149456	684.8	684	613	282	102	11	2
149457	648.7	655	644	451	94	10	0
149458							
149459							
149461							
149463							
149465	552.7	555	490	192	35	9	2
149466							
149467	658.7	669	534	109	25	3	1
149468	429.8	434	404	109	28	8	2
149469							
149471							
149474	536.8	537	494	231	49	8	1
150406	474.6	472	382	696	269	33	3
150407	665.3	664	626	247	44	9	2
150409	801.6	802	742	229	44	4	1
150410	673.6	674	660	247	62	15	3
150411	685.3	685	590	116	36	11	1
150412							
150413	195	195	83	71	29	8	3
150414							
150415	258.8	255					
150416							
150417							
150418							
150420	710.5	711	657	244	53	10	3
150422							
150423							
150424							
150425							
150426	626.4	628	618	491	180	25	4
150427							

Figure IV-11 (Continued)
Cracks Detected in the Wing Main Torque Box Upper Skin in Service Operations

Failure Information		Flight Information					
Aircraft Bu. No.	Flight Hours at Which Failure Detected	Flight Hours at Report	Accelerometer Hours at Report	Exceedances for Listed Number of Accelerometer Hours			
				4g	5g	og	7g
150428							
150429	652	657	644	315	53	4	0
150430	615	615	606	313	101	22	2
150431							
150432							
150434	529.5	530	492	82	24	10	3
150435	356.6	357	326	90	13	5	1
150436	778.9	778	726	353	100	16	2
150439							
150440	454.1	358	329	844	364	66	4
150441	617.5	589	490	111	18	2	1
150443							
150447	495	496	373	106	15	2	1
150448							
150449	457.9	458	434	146	33	12	4
150453	550.1	546	530	137	33	6	1
150455	539.3	515	503	141	29	2	0
150456	454.9	459	414	87	20	5	2
150459	376.3	362	196	31	9	1	1
150465	641.7	630	541	107	29	2	0
150468	468	465	391	266	116	25	18
150470							
150472	491	477	455	712	337	61	7
150473	412.3	411	391	807	305	75	6
150474	554	600	462	223	50	6	3
150475	536.2	491	489	134	34	4	1
150476	314.9	314	270	24	2	0	0
150478	574.4	574	561	139	48	16	1
150480	633	629	619	164	35	3	0
150481	387.5	388	376	178	31	2	2
150482							
150484	384.5	382	348	76	23	5	1
150486	454	462	390	891	345	75	11
150492	418.3	427	402	69	17	7	2
150645	276.1	280	204	68	22	6	1
150648	431	413	387	260	70	15	4
150650	483.4	498	403	287	105	25	4
150651	434.5	434	409	824	252	62	11

Note: All aircraft included in this list are F-4B's

Figure IV-11 (Continued)

Cracks Detected in the Wing Main Torque Box Upper Skin in Service Operations

Failure Information			Flight Information					
Aircraft Type	Bu. No.	Flight Hours at Time of Failure	Accelerometer Hours at Time of Failure	Exceedances for Listed Number of Accelerometer Hours				Side of Aircraft on Which Failure was Detected
				4g	5g	6g	7g	
F-4B	151482	1785	1456	2716	1075	210	17	L/H and R/H
F-4B	150634							L/H and R/H
F-4B	150424	2037	1951	1139	269	57	8	L/H and R/H
F-4B	151413	2046	1965	2388	978	280	31	L/H and R/H
F-4B	151444	1482	1457	2037	662	180	44	R/H
F-4B	150406							L/H and R/H
F-4B	148416	1388						L/H and R/H
F-4J	153824	258	255	1231	326	64	9	L/H and R/H
F-4B	151000	2245	2051	3880	1337	236	60	R/H
F-4B	150636	1873	1595	3306	1396	434	160	R/H
F-4B	151405	1119	1081	1290	288	42	21	L/H and R/H
F-4B	148428	1337	1100	1685	479	112	14	L/H and R/H
F-4B	151462	1577	1567	2798	771	152	18	L/H
F-4B	151422	2344	2300	1908	614	105	19	L/H
F-4B	149466	1905	1794	2100	599	104	15	L/H
F-4B	150436	2092	2002	3484	1229	246	45	L/H
F-4B	148406	1824	1510	1399	499	104	12	L/H
F-4B	149413	1648	1436	1007	205	42	6	L/H
F-4B	152967							R/H
F-4B	150435							
F-4B	152965							L/H and R/H
F-4B	149464							L/H
F-4B	150627							
F-4B	152246							L/H
F-4B	150628							L/H
F-4B	150644							L/H
F-4B	150440							
F-4J	153857							R/H

Figure IV-12

Cracks Detected in the Lower Longeron Dog Bone Fitting in Service Operations

REFERENCES

1. Whittaker, I. C., and Sesuner, P. M.: A Reliability Approach to Fatigue Life Variability of Aircraft Structures, Air Force Materials Laboratory Technical Report No. AFML-TR-69-65, February 1969.

2. Sarphie, C. S., Jr. and Watson, R. S.: Evaluation of a Reliability Analysis Approach to Fatigue Life Variability of Aircraft Structures Using C-130 In-Service Operational Data, Air Force Materials Laboratory Technical Report No. AFML-TR-70-272, February 1971.

3. Nancy R. Mann, "Tables for Obtaining the Best Linear Invariant Estimates of Parameters of the Weibull Distribution," Technometrics, Vol. 9, No. 4, November 1967.

4. Impellizzeri, L. F., "Development of a Scatter Factor Applicable to Aircraft Fatigue Life," Structural Fatigue in Aircraft, ASTM STP 404, Am. Soc. Testing Mats., 1966.

5. Impellizzeri, L. F., "A Statistical Analysis of the Frequency of Occurrence of Aircraft Maneuvers," A Thesis Presented to the Faculty of The Graduate School of St. Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science (Research), 1966.

6. MAC 8528, Model F4H-1 Fatigue Test Results Remnant Wings and 35% Auxiliary Beam, 25 August 1964.

7. MAC 4571, Vol. II, Wing Integral Fuel Tank Qualification and Wing Center Fuselage Fatigue Life Test Results Block 6 (Modified Wing) Vol. II, 21 September 1964.

8. MAC 7439, Model F-4B Wing Fatigue Test Block 8 and Up, 18 September 1964

9. MCAIR F623, Vol. III, Results of Repeated Load Test for ECP-613 F-4J Wing and Fuselage Test, Revision A, 10 November 1969.

10. MCAIR F623, Vol. II, Results of Repeated Load Test for ECP-613 F-4B Wing Test, 25 April 1969.

11. MCAIR F623, Vol. IV, Results of Repeated Load Tests for FSCP 46 F-4B Wing Test, Revision A, 22 November 1971.

12. MCAIR F623, Vol. V, Results of Repeated Load Tests for FSCP 60R1 F-4B Wing Fatigue, 14 April 1972

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Structural reliability analysis procedures were evaluated for estimating the variability in fighter aircraft fatigue performance. The expected magnitude of this variability was determined based on an investigation of scatter in fatigue test results for aluminum structures. This study revealed that (a) the scatter for spectrum fatigue tests is considerably less than for constant amplitude fatigue tests, (b) the Weibull probability distribution provides a

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) better fit of the spectrum fatigue data than the log-normal, and (c) the Weibull shape parameter α is 5.27. The α value was determined from 1060 spectrum test results of which 243 were full-scale airplane and airplane component tests. These included the F-3H Demon wing and horizontal tail, the F-4 Phantom II wing box beam, the Lockheed wing test panel, the F-9F Panther wing, the Navy Lab box beam, the P-51 Mustang wing, the C-46 transport wing, and the British Piston Provost wing. In addition to these studies of experimental data, theoretical analyses were performed yielding the mathematical probability distribution for a Weibull based scatter factor which is

$$S = (R/1-R)^{1/\alpha}$$

where S is the scatter factor and R is reliability or the probability of no failure. VGH and load factor counting accelerometer data from the F-4 fighter airplane were utilized to correlate that airplane's laboratory and service fatigue experience. Probable minimum service lives considering the F-4 fleet size and individual airplane usage were computed based on the Weibull based scatter factor and order statistics. The combined effect of fatigue test scatter and usage severity scatter was derived utilizing a joint scatter factor concept. Three fatigue critical locations on the F-4 airplane were considered to be amenable to analysis using the methods of this report. The correlation was excellent for one of these, but not for the other two. Fabrication variations in a redundant load path joint and outer wing buffeting were considered the probable cause for the less than favorable correlation.