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FITWEIB: A PROGRAM TO FIT FAILURE DATA TO WEIBULL PROBABILITY PARAMETERS

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ABSTRACT

The Weibull probability distribution describes the failures of many electrical and mechanical components. Tests can be carried out to obtain raw data on failures experienced by a given component type. The computer program described in this report can be used to find the parameters of the Weibull distribution that best fits these data. The fitting methods are discussed, the program is described, input instructions are given, and an example is presented.

I. INTRODUCTION

A prime objective of component testing is to determine whether a given component will perform satisfactorily when used as part of some larger piece of equipment. To use the failure data obtained from the tests to predict the performance of the larger system, it is advantageous to describe the failures by a probability distribution. The Weibull¹⁻³ distribution has great generality and describes many mechanical and electrical components. This report describes a computer program that can be used to fit failure data to a three-parameter Weibull distribution and that takes into account components on which testing was suspended before their failure. The latter feature allows periodic examination of operations data on components *in situ*, because a component may still be operating and also be weighed in the analysis.

II. THEORETICAL PRELIMINARIES

The Weibull distribution in complete generality is a function of three parameters; the cumulative distribution is given by

$$F(t) = 1 - e^{-\frac{(t-\gamma)^\beta}{\alpha}} \quad (1)$$

where

α = scale parameter,
 α^β = characteristic life,
 β = shape parameter or Weibull slope,
 γ = location parameter.

Equation (1) can be written as

$$\ln \ln \left(\frac{1}{1-F} \right) = \ln \alpha + \beta \ln(t-\gamma) \quad (2)$$

which is a linear relation between the variables,

$$y = \ln \ln \left(\frac{1}{1-F} \right)$$

and

$$x = \ln(t-\gamma)$$

The data available for fitting the distribution are the time t_i of the i^{th} failure and the fraction of the test sample which has failed through time t_i . The value of

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t_j can be used directly in Eq. (2), but the failed fraction of the sample does not accurately reflect the fraction of the population which would have failed, especially if the sample is small. One way of estimating the rank to be associated with a given fraction of sample failed is through use of median rank statistics.⁴ The procedure assigns a rank, a value of F which will be too high half the time and too low half the time; hence, it is a "median" rank. Median rank tables⁵ are available for samples of as many as 50 items. Johnson⁴ gives a formula that is good when the sample size n is greater than 20:

$$r_n(j) = \frac{j - (1 - \ln 2) - (2 \ln 2 - 1)(j - 1/n - 1)}{n}, \quad j = 1, \dots, n \quad (3)$$

The rank assigned to the j^{th} failure in a sample of size n is $r_n(j)$, provided there are no suspended items whose life is lower than t_j . Corrections for suspended items can be made by use of mean-order numbers.³ If no suspensions have occurred before the j^{th} failure, the order number assigned to the j^{th} failure is j . Let O_j equal the order number of the j^{th} failure and m be the number of items still good for all $t < t_j$. Then,

$$O_j = O_{j-1} + \frac{(n+1) - O_{j-1} - 1}{1+m} \quad (4)$$

Note that m includes the failure at t_j ; that is, the inequality $t < t_j$ is strict. Interpolation can be used in conjunction with Eq. (3) to assign median ranks to failures with fractional order numbers.

Given values of t_j and F_j , we now must find values of α , β , and γ which best fit them to Eq. (1), or equivalently, Eq. (2). We will work with Eq. (2) because if the value of γ is known, values of $\ln \alpha$ and β can be obtained directly from a linear least-squares fit. The difficulty is that we do not know γ . The literature is mostly silent about the problem of non-zero γ . There seems to be no analytical method of determining γ , and trial and error using the eye to determine the best value is recommended. FITWEIB uses a similar method. Least-squares fits are determined for three selected trial γ values, and the deviations of the fits are used as criteria to change the trial values. The value of γ obtained is that which yields the smallest deviation.

A word of caution is necessary here. FITWEIB assumes that γ is not zero and that only a single distribution is present and tries to find a straight line fit for Eq. (2). Components in a given sample often fail

by two or more different mechanisms. These failures can lead to data that appear as though a single mechanism were operative, but with a nonzero γ . If enough data are available, it is usually easy to distinguish between the two cases. When data are sparse and scattered, it is not easy. FITWEIB plots the raw data to enable the user to check the plot.

FITWEIB fits the data for two sets of weights. One fit is made using a weight of 1, that is no weighting. A second fit is made using weights proportional to the reciprocal of the point's variance, assuming that the variance of F about its expected value is the same for all values of F . Thus, for the case at hand,

$$W_i \propto \frac{1}{\sigma_i^2}$$

$$\sigma_i^2 \propto \left\{ \frac{d}{dF} \left[\ln \ln \left(\frac{1}{1-F} \right) \right] \right\}^2$$

and

$$\propto \frac{1}{\left[\ln \left(\frac{1}{1-F} \right) \right]^2} \frac{1}{(1-F)^2}$$

This gives

$$W_i = (1-F)^2 \left[\ln \left(\frac{1}{1-F} \right) \right]^2 \quad (5)$$

Equation (5) is the theoretically correct weight, assuming uniform variance of F ,⁶ and it should give the preferred fit. However, the unweighted fit is included because it tends to emphasize the early failures and could be valuable in distinguishing whether two failure distributions are present.

There is a second reason for providing two fits. When the data include a large number of items on which tests were suspended before failure of the last failed item, convergence may not occur, because of inaccuracies in the data. In these circumstances, the fit with a weight of 1 will often converge when the fit with the correct weight will not.

III. DESCRIPTION OF THE PROGRAM

Figure 1 is a simplified flow diagram of the program, a listing is given in Appendix A and an example is provided in Appendix B. The sample size

Fig. 1.
The FITWEIB program.

no longer needed. The raw failure data can be plotted at this point. Next, the failure data are fitted to find the best α , β , and γ values, the fitted data are plotted, and the values of α , β , and γ are printed; this is done for each weight.

IV. FUNCTIONS OF FITWEIB SUBROUTINE

Subroutine	Function												
FITWEIB	Driver for program.												
1. INDATA	Reads sample size (N), number of items being read in (NF), and the code number for the time unit desired on plots (IUNIT). IUNIT may have the following values												
	<table> <tr> <th>IUNIT</th><th>TIME UNIT</th></tr> <tr> <td>1</td><td>shots</td></tr> <tr> <td>2</td><td>seconds</td></tr> <tr> <td>3</td><td>hours</td></tr> <tr> <td>4</td><td>days</td></tr> <tr> <td>5</td><td>operations</td></tr> </table>	IUNIT	TIME UNIT	1	shots	2	seconds	3	hours	4	days	5	operations
IUNIT	TIME UNIT												
1	shots												
2	seconds												
3	hours												
4	days												
5	operations												
2. SORT	NF test items (LIFE(I)) are read along with a failure code (IFL(I)), 1 if a failure, otherwise 0 to indicate whether the unit failed or was suspended. The input data are printed out. The life data are put in ascending order, and NF is set to the index of the longest lived failure.												
3. RANKS	A median rank table is computed for sample size N. If $N \leq 20$, ranks are taken from a table, if $N > 20$, they are computed using Eq. (3).												
4. ORDRNK	An order number and median rank are assigned to each failed item.												
5. RANCO	Called by ORDRNK. Calculates the median rank for an item having either integer or noninteger order number.												

and the necessary data are read and sorted to place the lives in ascending order. RANK is called and sets up a median rank table for a sample of the given size. Then a loop on the items assigns an order number and median rank to each failed item. The data are then edited to eliminate the suspended items that are

6. EDIT Edits the vector LIFE. After the call to EDIT, LIFE holds only failures and NF corresponds to the actual number of failures.
7. WBLPRAM Calculates the Weibull parameters α , β , and γ using an interactive search. Three values of γ are assumed, fits to obtain α and β are made for each value of γ , and the deviations of the fits are used to improve the γ values.
8. DEVIA Called by WBLPRAM. Makes three weighted least-squares fits for the three proposed γ values.
9. PLOTWIB Driver subroutine for producing Weibull plots.
10. PLOWB, WLGLNTM and WLNLN Plotting routines used to produce a standardized Weibull plot. PLOWB is based in part on the LASL library routine PLOJB; WLGLNTM, in part on two LASL library routines, DLNLGTM and DLNLG; and WLNLN, in part on LASL library routine DLNLN. These routines call a number of other LASL systems plotting routines.

V. INPUT REQUIREMENTS

Title card	(6A10)
Cols	1-60
Control Card	(2I6)
1-6	Number of items in test sample N
7-12	Number of items to be read in NF

LIFE DATA CARDS (F12.3, I12)	NF in number
1-12	Life LIFE (I)
13-24	Failure code IFL (I)

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APPENDIX A

PROGRAM LISTING OF FITWEIB

C	PROGRAM FITWEIB (INP,OUT,FILM)	FITW0001
C	A PROGRAM TO CALCULATE THE MEDIAN RANKS FOR A SET OF FAILURE DATA	FITW0002
C	WHICH CONTAINS SUSPENDED TESTS, FIT THE DATA TO WEIBULL PARAMETERS	FITW0003
C	AND TO PLOT THE RAW AND FITTED DATA.	FITW0004
C	N=NO OF UNITS TESTED	FITW0005
C	NF=NO OF UNITS FAILED OR SUSPENDED	FITW0006
C	RANK----- VECTOR HOLDING MEDIAN RANK TABLE	FITW0007
C	ARANK---- VECTOR HOLDING ACTUAL RANK OF ELEMENTS IN LIFE	FITW0008
C	LIFE----- VECTOR HOLDING LIVES OF UNITS	FITW0009
C	IFL----- IFL(I)=0 IF UNIT HAS NOT FAILED =1 IF UNIT HAS FAILED	FITW0010
C	ORDER --- VECTOR HOLDING ORDER NUMBERS FOR THE COMPONENTS OF LIFE	FITW0011
	PARAMETER (NDIM=1500)	FITW0012
	COMMON /DAT2/ TITLE(8),N,NF,NTRYs,IUNIT	FITW0013
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	FITW0014
	REAL LIFE	FITW0015
	COMMON /TIME/ LIFE(NDIM),IFL(NDIM)	FITW0016
	COMMON /RZLT/ ALPHA,BETA,GAMMA	FITW0017
	DIMENSION PLIFE(NDIM)	FITW0018
	CALL INDATA	FITW0019
C	SORT FAILURE DATA TO GET LIVES IN ASCENDING ORDER.	FITW0020
	CALL SORT	FITW0021
	CALL RANKS	FITW0022
	CALL ORDRNK	FITW0023
C	EDIT LIFE, ORDER AND ARANK VECTORS TO HOLD ONLY FAILURES.	FITW0024
C	REDUCE NF TO REFLECT ONLY FAILURES. PRINT EDITED DATA.	FITW0025
	CALL EDIT	FITW0026
	TITLE(7)=10H	FITW0027
	TITLE(8)=10HRAW DATA	FITW0028
	JP=0	FITW0029
	CALL PLOTWIB (JP,LIFE)	FITW0030
	TITLE(7)=10H FIT	FITW0031
	TITLE(8)=10HTED DATA	FITW0032
	DO 2 JW=1,2	FITW0033
	CALL WBLPRAM (JW,IFLAG)	FITW0034
	IF (IFLAG.EQ.1) GO TO 2	FITW0035
	DO 1 I=1,NF	FITW0036
1	PLIFE(I)=LIFE(I)- GAMMA	FITW0037
	CALL PLOTWIB (JW,PLIFE)	FITW0038
2	CONTINUE	FITW0039
	RETURN	FITW0040
	END	FITW0041
	SUBROUTINE INDATA	INDAT001
	PARAMETER (NDIM=1500)	INDAT002
	REAL LIFE	INDAT003
	COMMON /TIME/ LIFE(NDIM),IFL(NDIM)	INDAT004
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	INDAT005
	COMMON /DAT2/ TITLE(8),N,NF,NTRYs,IUNIT	INDAT006
	READ 6, (TITLE(I),I=1,6)	INDAT007
	READ 3, N,NF,IUNIT,NTRYs	INDAT008
	IF (NF.GT.N) GO TO 2	INDAT009
	IF (NTRYs.LT.20) NTRYs=50	INDAT010
	READ 4, ((LIFE(I),IFL(I)),I=1,NF)	INDAT011
C	PRINT OUT INDATA	INDAT012
	PRINT 5, (TITLE(I),I=1,6)	INDAT013
	PRINT 7, N,NF	INDAT014
	PRINT 8	INDAT015
	DO 1 I=1,NF	INDAT016
1	PRINT 9, I,LIFE(I),IFL(I)	INDAT017
C	IFL=0 IF UNIT DID NOT FAIL, OTHERWISE IT FAILED.	INDAT018
	RETURN	INDAT019
2	PRINT 10	INDAT020
	STOP	INDAT021
C		INDAT022
3	FORMAT (4I6)	INDAT023
4	FORMAT (F12.3,I12)	INDAT024

5	FORMAT (1H ,6A10)	INDAT025
6	FORMAT (6A10)	INDAT026
7	FORMAT (1H ,* NUMBER IN SAMPLE-----*,I6/* NUMBER	INDAT027
1	OF DATA POINTS READ IN-----*,I6)	INDAT028
8	FORMAT (1H0,* LIFE(I) FAIL*)	INDAT029
9	FORMAT (1H ,I5,F13.1,I9)	INDAT030
10	FORMAT (1H1,* NUMBER OF ITEMS EXCEEDS NUMBER IN SAMPLE. RUN TERMIN	INDAT031
1	ATED. *)	INDAT032
	END	INDAT033

	SUBROUTINE SORT	SORT0001
	PARAMETER (NDIM=1500)	SORT0002
	COMMON /TIME/ LIFE(NDIM),IFL(NDIM)	SORT0003
	REAL LIFE	SORT0004
	COMMON /DAT2/ TITLE(8),N,NF,NTRY,S,IUNIT	SORT0005
	NFM1=NF-1	SORT0006
	DO 2 I=1,NFM1	SORT0007
	IP1=I+1	SORT0008
	DO 1 J=IP1,NF	SORT0009
	IF (LIFE(I).LE. LIFE(J)) GO TO 1	SORT0010
	TEMP=LIFE(I)	SORT0011
	LIFE(I)=LIFE(J)	SORT0012
	LIFE(J)=TEMP	SORT0013
	ITEMP=IFL(I)	SORT0014
	IFL(I)=IFL(J)	SORT0015
	IFL(J)=ITEMP	SORT0016
1	CONTINUE	SORT0017
2	CONTINUE	SORT0018
C	ADJUST NF IF HIGHEST LIFE IS NOT A FAILURE.	SORT0019
	DO 3 I=1,NF	SORT0020
3	IF (IFL(NF-I+1).EQ.1) GO TO 4	SORT0021
4	NF=NF-I+1	SORT0022
	RETURN	SORT0023
	END	SORT0024

	SUBROUTINE RANKS	RANKS001
C	ROUTINE COMPUTES A MEDIAN RANK TABLE FOR A TEST SAMPLE OF SIZE N	RANKS002
	PARAMETER (NDIM=1500)	RANKS003
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	RANKS004
	COMMON /DAT2/ TITLE(8),N,NF,NTRY,S,IUNIT	RANKS005
	DIMENSION R(210)	RANKS006
	DATA (R(I),I=1,171)/. 5., 29289., 70711., 2063., 5., 7937., 1591., 38573.,	RANKS007
1	61427., 8409., 12945., 31381., 5., 68619., 87055., 1091., 26445., 42141., 57	RANKS008
2	859., 73555., 8909., 09428., 22849., 36412., 5., 63588., 77151., 90572., 083	RANKS009
3	., 20113., 32052., 44015., 55984., 67948., 79887., 917., 07412., 17962., 286	RANKS010
4	24., 39308., 5., 60691., 71376., 82038., 92587., 06697., 16226., 25857., 355	RANKS011
5	1., 45169., 54831., 6449., 74142., 83774., 93303., 06107., 14796., 23578., 3	RANKS012
6	238., 41189., 5., 58811., 6762., 76421., 85204., 93893., 05613., 13598., 216	RANKS013
7	69., 29758., 37853., 45951., 54049., 62147., 70242., 78331., 86402., 94387,	RANKS014
8	. 05192., 12579., 20045., 27528., 35016., 42508., 5., 57492., 64984., 72472,	RANKS015
9	. 79955., 87421., 94808., 0483., 11702., 18647., 25608., 32575., 39544., 465	RANKS016
\$	15., 53485., 60456., 67425., 74392., 81353., 88298., 95169., 04516., 1094.,	RANKS017
\$	17432., 23939., 30452., 36967., 43483., 5., 56517., 63033., 69548., 76061.,	RANKS018
\$	82568., 8906., 95484., 0442., 1027., 16365., 22474., 28589., 34705., 40823,	RANKS019
\$	. 46941., 53059., 59177., 65295., 71411., 77525., 83635., 8973., 9576., 0399	RANKS020
\$	5., 09678., 15422., 21178., 2694., 32704., 38469., 44234., 5., 55766., 61531	RANKS021
\$	., 67296., 7306., 78821., 84578., 90322., 96005., 03778., 09151., 14581., 20	RANKS022
\$	024., 25471., 30921., 36371., 41823., 47274., 52726., 58177., 63629., 09079	RANKS023
\$	., 74529., 79376., 85419., 90849., 96222/	RANKS024
	DATA (R(I),I=172,210)/. 03582., 08677., 13827., 18988., 24154., 29322., 3	RANKS025
1	4491., 3966., 4483., 5., 5517., 6034., 65509., 70678., 75846., 81011., 86173	RANKS026
2	., 91322., 96418., 03406., 08251., 13147., 18055., 22967., 2788., 32795., 37	RANKS027
3	71., 42626., 47542., 52458., 57374., 62289., 67205., 72119., 77033., 81945,	RANKS028
4	. 86853., 91749., 96594/	RANKS029
	IF (N. LE. 20) GO TO 2	RANKS030
	O=1. - ALOG(2.)	RANKS031
	S=2. *ALOG(2.)-1.	RANKS032

	X=FLOAT(N)	RANKS033
	DO 1 I=1,N	RANKS034
	RANK(I)=(FLOAT(I)-Q-S*(FLOAT(I)-1.)/(X-1.))/X	RANKS035
1	CONTINUE	RANKS036
	RETURN	RANKS037
2	IPOS=(N*(N-1))/2	RANKS038
	DO 3 I=1,N	RANKS039
3	RANK(I)=R(IPOS+I)	RANKS040
	RETURN	RANKS041
	END	RANKS042
	SUBROUTINE RANCO(I)	RANCO001
C	A SUBROUTINE TO CALCULATE THE MEDIAN RANK FOR A DATA POINT	RANCO002
C	HAVING INTEGER OR NONINTEGER ORDER NUMBER	RANCO003
C	I INDEX OF ORDER NUMBER	RANCO004
C	K LARGEST INTEGER EQUAL TO OR LESS THAN ORDER(I)	RANCO005
	PARAMETER (NDIM=1500)	RANCO006
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	RANCO007
	K=INT(ORDER(I))	RANCO008
	DO 2 J=K,N	RANCO009
	IF (ORDER(I).GT.FLOAT(J)) GO TO 2	RANCO010
	IF (ORDER(I).EQ.FLCAT(J)) GO TO 1	RANCO011
	ARANK(I)=RANK(J-1)+(RANK(J)-RANK(J-1))*(ORDER(I)-FLOAT(J-1))	RANCO012
	GO TO 3	RANCO013
1	ARANK(I)=RANK(J)	RANCO014
	GO TO 3	RANCO015
2	CONTINUE	RANCO016
3	RETURN	RANCO017
	END	RANCO018
	SUBROUTINE ORDRNK	ORDR0001
	PARAMETER (NDIM=1500)	ORDR0002
	COMMON /DAT2/ TITLE(8),N,NF,NTRY5,IUNIT	ORDR0003
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	ORDR0004
	REAL LIFE	ORDR0005
	COMMON /TIME/ LIFE(NDIM),IFL(NDIM)	ORDR0006
	DORDER=1.	ORDR0007
	ORDER(0)=0.	ORDR0008
	DO 2 I=1,NF	ORDR0009
	J=0	ORDR0010
	IF (IFL(I).EQ.0) GO TO 1	ORDR0011
	ORDER(I)=DORDER+ORDER(I-1)	ORDR0012
	CALL RANCO (I)	ORDR0013
	GO TO 2	ORDR0014
1	J=J+1	ORDR0015
	IF (IFL(I+J).EQ.0) GO TO 1	ORDR0016
	DORDER=(FLOAT(N+1)-ORDER(I-1))/(1.+FLOAT(N-(I+J-1)))	ORDR0017
	ORDER(I+J)=DORDER+ORDER(I-1)	ORDR0018
	I=I+J	ORDR0019
	CALL RANCO (I)	ORDR0020
2	CONTINUE	ORDR0021
	RETURN	ORDR0022
C	END	ORDR0023
		ORDR0024
	SUBROUTINE EDIT	EDIT0001
	PARAMETER (NDIM=1500)	EDIT0002
	COMMON /DAT2/ TITLE(8),N,NF,NTRY5,IUNIT	EDIT0003
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	EDIT0004
	REAL LIFE	EDIT0005
	COMMON /TIME/ LIFE(NDIM),IFL(NDIM)	EDIT0006
	INF=0	EDIT0007
	DO 1 I=1,NF	EDIT0008
	IF (IFL(I).EQ.0) GO TO 1	EDIT0009
	INF=INF+1	EDIT0010

	LIFE(INF)=LIFE(I)	EDIT0011
	ORDER(INF)=ORDER(I)	EDIT0012
	ARANK(INF)=ARANK(I)	EDIT0013
1	CONTINUE	EDIT0014
	NF=INF	EDIT0015
	PRINT 3	EDIT0016
	PRINT 4, (TITLE(I),I=1,6)	EDIT0017
	PRINT 6	EDIT0018
	DO 2 I=1,NF	EDIT0019
	PRINT 5, I,ORDER(I),ARANK(I),LIFE(I)	EDIT0020
2	CONTINUE	EDIT0021
	RETURN	EDIT0022
C		EDIT0023
3	FORMAT (1H1)	EDIT0024
4	FORMAT (1H ,6A10)	EDIT0025
5	FORMAT (1H ,15,F13. 5,F13. 5,F11. 0)	EDIT0026
6	FORMAT (1H0,* I ORDER(I) RANK(I) LIFE(I)*)	EDIT0027
	END	EDIT0028

	SUBROUTINE WBLPRAM(IWEIGHT,IFLAG)	WBLPR001
	PARAMETER (NDIM=1500)	WBLPR002
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	WBLPR003
	COMMON /DAT2/ TITLE(8),N,NF,NTRYIS,UNIT	WBLPR004
	COMMON /RZLT/ ALPHA,BETA,GAMMA	WBLPR005
	DIMENSION WEIGHT(2)	WBLPR006
	REAL LIFE	WBLPR007
	COMMON /TIME/ LIFE(NDIM),IFL(NDIM)	WBLPR008
	COMMON /DEV// X(NDIM),Y(NDIM),POS(3),DEV(3),A0(3),A1(3),WINDIM)	WBLPR009
C	ROUTINE FINDS THE ALPHA, BETA AND GAMMA PARAMETERS OF A WEIBULL	WBLPR010
C	DISTRIBUTION SATISFIED BY THE FAILURE DATA IN LIFE. DATA IS	WBLPR011
C	ASSUMED ORDERED. MEDIAN RANKS ARE IN ARANK.	WBLPR012
	DATA WEIGHT/10H1 ,10H1/VARIANCE/	WBLPR013
	GO TO (1,3), IWEIGHT	WBLPR014
1	DO 2 I=1,NF	WBLPR015
	Y(I)=ALOG(ALOG(1. /(1. - ARANK(I))))	WBLPR016
2	W(I)=1. 0	WBLPR017
	GO TO 5	WBLPR018
3	DO 4 I=1,NF	WBLPR019
	TEMP=ALOG(1. /(1. - ARANK(I)))	WBLPR020
	Y(I)=ALOG(TEMP)	WBLPR021
4	W(I)=(TEMP**2)*((1. - ARANK(I))**2)	WBLPR022
5	CONTINUE	WBLPR023
	POS(1)=0.	WBLPR024
	NFM2=NF- 2	WBLPR025
	DO 6 I=1,NFM2	WBLPR026
6	IF (LIFE(I). NE. 0.) GO TO 7	WBLPR027
7	POS(2)= LIFE(I)	WBLPR028
	DEL=POS(2)	WBLPR029
	POS(3)=POS(2)+ DEL	WBLPR030
	DO 13 J=1,NTRYIS	WBLPR031
	CALL DEVIA (IFLAG)	WBLPR032
	IF (IFLAG. EQ. 1) RETURN	WBLPR033
	IF (DEV(1). GT. DEV(2). A. DEV(2). GT. DEV(3)) GO TO 3	WBLPR034
	IF (DEV(1). LT. DEV(2). A. DEV(2). LT. DEV(3)) GO TO 11	WBLPR035
	IF (DEV(1). EQ. DEV(2). A. DEV(2). LT. DEV(3)) GO TO 9	WBLPR036
	IF (DEV(1). GT. DEV(2). A. DEV(2). LT. DEV(3)) GO TO 10	WBLPR037
C	MINIMUM IS BETWEEN POS(2) AND POS(3)	WBLPR038
	IF (ABS(POS(2)- POS(3)). LT. . 1) GO TO 15	WBLPR039
	POS(1)=POS(2)	WBLPR040
	POS(2)=. 5*(POS(1)+ POS(3))	WBLPR041
	DEL=. 5*DEL	WBLPR042
	GO TO 13	WBLPR043
C	MINIMUM NOT YET REACHED CONTINUE	WBLPR044
8	POS(1)=POS(2)	WBLPR045
	POS(2)=POS(3)	WBLPR046
	POS(3)=POS(3)+ DEL	WBLPR047
	GO TO 13	WBLPR048

C	MINIMUM BETWEEN POS(1) AND POS(2)	WBLPR049
9	IF (ABS(POS(2)-POS(1)). LT. . 1) GO TO 15	WBLPR050
	POS(3)=POS(2)	WBLPR051
	POS(2)=. 5*(POS(1)+ POS(3))	WBLPR052
	DEL=. 5*DEL	WBLPR053
	GO TO 13	WBLPR054
C	MINIMUM BETWEEN POS(1) AND POS(3)	WBLPR055
10	IF (ABS(POS(1)-POS(2)). LT. . 1) GO TO 15	WBLPR056
	DEL=. 4*DEL	WBLPR057
	POS(2)=POS(1)+ DEL	WBLPR058
	POS(3)=POS(2)+ DEL	WBLPR059
	GO TO 13	WBLPR060
C	MINIMUM IS EITHER LESS THAN POS(1) OR BETWEEN POS(1) AND POS(2)	WBLPR061
11	IF (J. EQ. 1) GO TO 12	WBLPR062
	DEL=. 5*DEL	WBLPR063
	POS(3)=POS(2)	WBLPR064
	POS(2)=POS(1)	WBLPR065
	POS(1)=POS(1)- DEL	WBLPR066
	GO TO 13	WBLPR067
C	MINIMUM IS GREATER THAN ZERO.	WBLPR068
12	DEL=- DEL	WBLPR069
	POS(2)=DEL	WBLPR070
	POS(3)=POS(2)+ DEL	WBLPR071
13	CONTINUE	WBLPR072
	DO 14 NT=1,5	WBLPR073
14	PRINT 16, NTRY5,WEIGHT(IWEIGHT)	WBLPR074
15	ALPHA=EXP(- A0(2))	WBLPR075
	PRINT 17, ALPHA,A1(2),POS(2),WEIGHT(IWEIGHT)	WBLPR076
	GAMMA=POS(2)	WBLPR077
	BETA=A1(2)	WBLPR078
	RETURN	WBLPR079
C		WBLPR080
16	FORMAT (1H ,* ITERATION DID NOT CONVERGE AFTER*,I3,* PASSES WITH W	WBLPR081
1	EIGHT*,A10)	WBLPR082
17	FORMAT (1H ,/* ALPHA=*,E13. 7,* BETA=*,E13. 7,* GAMMA=*,E13. 7,* WEIG	WBLPR083
1	HT=*,A10)	WBLPR084
	END	WBLPR085

	SUBROUTINE DEVIA(IFLAG)	DEVIA001
	PARAMETER (NDIM=1500)	DEVIA002
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	DEVIA003
	COMMON /DAT2/ TITLE(8),N,NF,NTRY5,IUNIT	DEVIA004
	REAL LIFE	DEVIA005
	COMMON /TIME LIFE(NDIM),IFL(NDIM)	DEVIA006
	COMMON /DEVI/ X(NDIM),Y(NDIM),POS(3),DEV(3),A0(3),A1(3),W(NDIM)	DEVIA007
	IFLAG=0	DEVIA008
C	FIND STARTING INDEX	DEVIA009
	IF (AMAX1(POS(1),POS(2),POS(3)). LT. LIFE(1)) GO TO 3	DEVIA010
	NFM1=NF- 1	DEVIA011
	DO 1 I=1,NFM1	DEVIA012
1	IF (POS(3). LT. LIFE(I)) GO TO 2	DEVIA013
	IFLAG=1	DEVIA014
	PRINT 8	DEVIA015
	GO TO 7	DEVIA016
2	NI=I	DEVIA017
	GO TO 4	DEVIA018
3	NI=1	DEVIA019
4	DO 6 J=1,3	DEVIA020
	SWEIGHT=0.	DEVIA021
	WXSUM=0.	DEVIA022
	WXSQSUM=0.	DEVIA023
	WXYSUM=0.	DEVIA024
	WYSUM=0.	DEVIA025
	WYSQSUM=0.	DEVIA026
	DO 5 I=NI,NF	DEVIA027
	AL=LIFE(I)- POS(J)	DEVIA028
	X(I)=ALOG(AL)	DEVIA029
	SWEIGHT=SWEIGHT+ W(I)	DEVIA030
	WXSUM=WXSUM+ X(I)*W(I)	DEVIA031

	WXSQSUM=WXSQSUM+ X(I)**2*W(I)	DEVIA032
	WXYSUM=WXYSUM+ Y(I)*X(I)*W(I)	DEVIA033
	WYSUM=WYSUM+ Y(I)*W(I)	DEVIA034
	WYSQSUM=WYSQSUM+ Y(I)**2*W(I)	DEVIA035
5	CONTINUE	DEVIA036
C	FIND A1 AND A0	DEVIA037
	D=1./((SWEIGHT*WXSQSUM- WXSUM**2)	DEVIA038
	A1(J)=(SWEIGHT*WXYSUM- WYSUM*WXSUM)*D	DEVIA039
	A0(J)=(WYSUM*WXSQSUM- WXYSUM*WXSUM)*D	DEVIA040
	DEV(J)=WYSQSUM- A0(J)*WYSUM- A1(J)*WXYSUM	DEVIA041
6	CONTINUE	DEVIA042
7	RETURN	DEVIA043
C		DEVIA044
8	FORMAT (1H ,* POSITION 3 IS . GE. 2ND GREATEST LIFE. NO FIT CAN BE	DEVIA045
1	MADE FOR THIS WEIGHT. *)	DEVIA046
	END	DEVIA047

	SUBROUTINE PLOTWIB(JP,LIFE)	PLOTW001
	PARAMETER (NDIM=1500)	PLOTW002
	COMMON /RZLT/ ALPHA,BETA,GAMMA	PLOTW003
	DIMENSION AFA(2), BTA(2), GA(2), WGT(3,2)	PLOTW004
	COMMON /DAT/ RANK(NDIM),ARANK(NDIM),IBUFFER(1),ORDER(NDIM)	PLOTW005
	COMMON /DAT2/ TITLE(8),N,NF,NTRY5,IUNIT	PLOTW006
	COMMON /RTLIM/ X2	PLOTW007
	DIMENSION LABELX(6), WEIBSCA(NDIM), LABELY(2), X(2), Y(2)	PLOTW008
	REAL LIFE(NDIM)	PLOTW009
	DATA LABELY/10HPERCENT FA,10HILED /	PLOTW010
	DATA LABELX/10H SHOTS ,10H SECONDS ,10H HOURS ,10H DAYS	PLOTW011
1	,10HOPERATIONS/	PLOTW012
	DATA AFA(1),BTA(1),GA(1)/10H ALPHA= ,10H BETA= ,10H GAMMA=	PLOTW013
1	/	PLOTW014
	DATA WGT(1,1),WGT(2,1),WGT(3,1)/10H WEIGHT IS,10H 1.0,1H /	PLOTW015
	DATA WGT(1,2),WGT(2,2),WGT(3,2)/10H WEIGHT IS,10H 1/VARIANC,1HE/	PLOTW016
	DO 1 I=1,NF	PLOTW017
1	WEIBSCA(I)=ALOG(ALOG(1./ (1.- RANK(I))))	PLOTW018
	DO 2 I=1,NF	PLOTW019
2	IF (LIFE(I). GT. 0.) GO TO 3	PLOTW020
3	NS=I	PLOTW021
	NFF=NF+ 1- NS	PLOTW022
	IF (NS. EQ. 1) GO TO 5	PLOTW023
	DO 4 I=NS,NF	PLOTW024
	K=I+ 1- NS	PLOTW025
	LIFE(K)=LIFE(I)	PLOTW026
4	WEIBSCA(K)=WEIBSCA(I)	PLOTW027
5	L= NFF	PLOTW028
	CALL PLOWB (LIFE,WEIBSCA,L,46,TITLE,80,LABELX(IUNIT),10,LABELY,20)	PLOTW029
	IF (JP. EQ. 0) GO TO 6	PLOTW030
C	DRAW FIT LINE	PLOTW031
	X(1)=0.	PLOTW032
	Y(1)= ALOG(ALPHA)	PLOTW033
	X(2)=X2	PLOTW034
	Y(2)=Y(1)+ BETA*X(2)**2. 302585	PLOTW035
	CALL PLOT (2,X,1,Y,1,46,1)	PLOTW036
	ENCODE (10,7,AFA(2))ALPHA	PLOTW037
	ENCODE (10,7,BTA(2))BETA	PLOTW038
	ENCODE (10,7,GA(2))GAMMA	PLOTW039
	CALL TSP (120,952,20,AFA)	PLOTW040
	CALL TSP (120,968,20,BTA)	PLOTW041
	CALL TSP (120,984,20,GA)	PLOTW042
	CALL TSP (120,1000,21,WGT(1,JP))	PLOTW043
6	RETURN	PLOTW044
C		PLOTW045
7	FORMAT (F10. 4)	PLOTW046
	END	PLOTW047

	SUBROUTINE PLOWB(X,Y,NPTS,NSYM,LABELZ,NZL,LABELX,NXL,LABELY,NYL)	PLOWB001
	COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XXM,YMX,YMN	PLOWB002
	DIMENSION X(1), Y(1)	PLOWB003
	LIN=-1	PLOWB004
	KSYM=IABS(NSYM)	PLOWB005
	KINC=1	PLOWB006
	MPTS=IABS(NPTS)	PLOWB007
	MZL=IABS(NZL)	PLOWB008
	NXN=IABS(NXL)	PLOWB009
	NYN=IABS(NYL)	PLOWB010
	CALL ADV (1)	PLOWB011
	CALL MAXV (X,KINC,MPTS,ISUB,XXM)	PLOWB012
	YMX=2.0	PLOWB013
	YMN=-10.	PLOWB014
C	THE LOG AXES WILL BE FULL CYCLES.	PLOWB015
	XXM=0.	PLOWB016
	XXM=ALOG10(XXM)	PLOWB017
	IF (YMN.NE.YMX) GO TO 1	PLOWB018
	DYM=.001*ABS(YMX)	PLOWB019
	IF (DYM.EQ.0) DYM=.0001	PLOWB020
	YMN=YMN-DYM	PLOWB021
	YMX=YMX+DYM	PLOWB022
1	CALL ASCL (5,YMN,YMX,MAJY,MINY,KKY)	PLOWB023
	IXL=120	PLOWB024
	IYT=50	PLOWB025
	IXR=980	PLOWB026
	IYB=910	PLOWB027
	CALL FRAME (IXL,IXR,IYT,IYB)	PLOWB028
	CALL DGA (IXL,IXR,IYT,IYB,XXM,XXM,YMX,YMN)	PLOWB029
	CALL WLGLNTM (MAJY)	PLOWB030
	CALL SBLOG	PLOWB031
	CALL SRLIN (MAJY,KKY)	PLOWB032
	CALL EXL	PLOWB033
	IF (NXN.NE.0) CALL DLCH (MAX0(54,IXL+(IXR-IXL-12*NXN)/2),IYB+60,NX	PLOWB034
1	N,LABELX,1)	PLOWB035
	INCX=34	PLOWB036
	IF (NYN.GT.85) INCX=18	PLOWB037
	IF (NYN.NE.0) CALL DLCH (INCX,MIN0(IYB+52,IYB-(IYB-IYT-12*NYN)/2),	PLOWB038
1	NYN,LABELY,1)	PLOWB039
	IF (NZL.NE.0) CALL DLCH (MAX0(54,IXL+(IXR-IXL-12*MZL)/2),10,MZL,LA	PLOWB040
1	BELZ,1)	PLOWB041
	CALL EXH	PLOWB042
C	PLOT POINTS	PLOWB043
	DO 3 NXP=1,MPTS	PLOWB044
	XTWO=X(NXP)	PLOWB045
	YTWO=Y(NXP)	PLOWB046
	XTWO=ALOG10(XTWO)	PLOWB047
	CALL CONVRT (XTWO,NXTWO,XXM,XXM,IXL,IXR)	PLOWB048
	CALL CONVRT (YTWO,NYTWO,YMN,YMX,IYB,IYT)	PLOWB049
	CALL EXL	PLOWB050
	DO 2 I=1,4	PLOWB051
2	CALL PLT (NXTWO,NYTWO,42)	PLOWB052
	CALL EXH	PLOWB053
	NYONE=NYTWO	PLOWB054
	NXONE=NXTWO	PLOWB055
3	CONTINUE	PLOWB056
	RETURN	PLOWB057
	END	PLOWB058
	SUBROUTINE WLGLNTM(NX)	WLGLN001
	COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB	WLGLN002
	DIMENSION XY(4), IXY(4)	WLGLN003
	EQUIVALENCE (XY,XL), (IXY,IXL)	WLGLN004
	DIMENSION ALG(8)	WLGLN005
	COMMON /RTLIM/ X2	WLGLN006
	DATA (ALG(K),K=1,8)/.301029995663981,.477121254719662,.60205999132	WLGLN007
1	7962,.698970004336019,.778151250383644,.845098040014257,.903089986	WLGLN008
2	991944,.954242509439325/	WLGLN009
	DIMENSION HEAD1(2), HEAD2(2)	WLGLN010

	DATA HEAD1/8H XL=XR,.8H YT=YB./	WLGLN011
	DATA HEAD2/9H NO OF X,9H NO OF Y/	WLGLN012
	DATA ITIC/10/,ITIC1/15/	WLGLN013
	CALL WLNLTNM (0,NX)	WLGLN014
	CALL GYA (IYT,IYB,IXR)	WLGLN015
	ITYPE=1	WLGLN016
	IEX=1	WLGLN017
	I1=3*ITYPE-2	WLGLN018
	I2=ITYPE+1	WLGLN019
	X1=XY(I1)	WLGLN020
	X2=XY(I2)	WLGLN021
	IF (X1.NE.X2) GO TO 1	WLGLN022
	PRINT 13, HEAD1(ITYPE)	WLGLN023
	X2=X2+.01	WLGLN024
1	XMIN=AMIN1(X1,X2)	WLGLN025
	XMAX=AMAX1(X1,X2)	WLGLN026
	XMIN=AMIN1(AINT(XMIN),SIGN(AINT(ABS(XMIN)+.999),XMIN))	WLGLN027
	XMAX=AMAX1(AINT(XMAX),SIGN(AINT(ABS(XMAX)+.999),XMAX))	WLGLN028
	X1=XMIN	WLGLN029
	X2=XMAX	WLGLN030
	NY=ABS(X1-X2)	WLGLN031
	IF (NY.LE.25) GO TO 2	WLGLN032
	PRINT 14, HEAD2(ITYPE)	WLGLN033
	RETURN	WLGLN034
2	IF (NY.NE.0) GO TO 3	WLGLN035
	YTT=X1+1.	WLGLN036
	IF (X2.LT.X1) YTT=X1-1.	WLGLN037
	NY=1	WLGLN038
	X1=YTT	WLGLN039
3	IF (XY(I2).GE.XY(I1)) 4,5	WLGLN040
4	IREV=1	WLGLN041
	XY(I1)=X1	WLGLN042
	XY(I2)=X2	WLGLN043
	GO TO 6	WLGLN044
5	IREV=2	WLGLN045
	XY(I1)=X2	WLGLN046
	XY(I2)=X1	WLGLN047
6	ISL=(IXY(I2)-IXY(I1))/NY	WLGLN048
	IYC=IXY(I1)	WLGLN049
	DO 11 I=1,NY	WLGLN050
	DO 10 K=1,8	WLGLN051
	GO TO (7,8), IREV	WLGLN052
7	ICY=ALG(K)*ISL+IYC	WLGLN053
	GO TO 9	WLGLN054
8	ICY=(1.-ALG(K))*ISL+IYC	WLGLN055
9	CALL GYA (IYT,IYB,ICY)	WLGLN056
10	CONTINUE	WLGLN057
	IF (I.EQ.NY) GO TO 12	WLGLN058
	IYC=IXY(I1)+(I*(IXY(I2)-IXY(I1)))/NY	WLGLN059
	CALL GYA (IYT,IYB,IYC)	WLGLN060
11	CONTINUE	WLGLN061
12	RETURN	WLGLN062
C		WLGLN063
C		WLGLN064
13	FORMAT ('0*A10,*IN J530A. UPPER LIMIT INCREASED BY 0.01')	WLGLN065
14	FORMAT ('0*A10,*DECADES EXCEEDS 25 IN J530A. REDUCE RANGE,RESUBMIT')	WLGLN066
1	)	WLGLN067
	END	WLGLN068
	SUBROUTINE WLNLTNM(NX,NY)	WLNLTN001
	COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB	WLNLTN002
	DATA ITIC/10/	WLNLTN003
	COMMON /WSALE/ F(19),ISC(19)	WLNLTN004
	DATA F/5H .01,5H .02,5H .05,5H .1,5H .2,5H .5,5H 1.,5H	WLNLTN005
1	2.,5H 5.,5H 10.,5H 20.,5H 30.,5H 50.,5H 60.,5H 70.,5H 80.	WLNLTN006
2	,5H 90.,5H 95.,5H 99./	WLNLTN007
	DATA ISC/853,804,738,688,639,573,523,473,406,355,301,267,220,200,1	WLNLTN008
1	80,159,134,115,84/	WLNLTN009

```

CALL GYA (IYT,IYB,IXL)
CALL GXA (IXL,IXR,IYB)
NYS=MIN0(NY,128)
DY=FLOAT(IYB-IYT)/NYS
IIXR=IXR-ITIC
NYS=NYS-1
CALL GXA (IXL,IXR,IYT)
DO 1 I=1,NYS
IYS=IYB-I*DY
1 CALL DRV (IXR,IYS,IIXR,IYS)
DO 2 I=1,19
2 CALL GXA (IXL,IXR,ISC(I))
DO 3 I=1,19
3 CALL TSP (80,ISC(I),5,F(I))
RETURN
END

```

```

WLNLN010
WLNLN011
WLNLN012
WLNLN013
WLNLN014
WLNLN015
WLNLN016
WLNLN017
WLNLN018
WLNLN019
WLNLN020
WLNLN021
WLNLN022
WLNLN023
WLNLN024
WLNLN025

```

APPENDIX B

EXAMPLE

In this example, 14 data points from a 40-item sample are given. The lives of the 14 failed units are chosen, within the limits of integer numbers of shots, equal to those derived from a sample of this size having the parameters

$$\alpha = 1000,$$

$$\beta = 0.8,$$

and

$$\gamma = 400.$$

The maximum error is 0.32% for the fit weighted by the variance. The following pages show the input to the program, the printed output, and plots.

```
0000000001111111112222222222333333333344444444445555555555666666666677777777778
123456789012345678901234567890123456789012345678901234567890123456789012345678902
```

SAMPLE WEIBULL FIT

```
40      14      1
599.      1
1689.     1
1870.     1
510.      1
1518.     1
436.      1
2063.     1
2268.     1
701.      1
812.      1
934.      1
1065.     1
1206.     1
1357.     1
```

Program input

SAMPLE WEIBULL FIT

```
NUMBER IN SAMPLE----- 40
NUMBER OF DATA POINTS READ IN----- 14
```

I	LIFE(I)	FAIL
1	599.0	1
2	1689.0	1
3	1870.0	1
4	510.0	1
5	1518.0	1
6	436.0	1
7	2063.0	1
8	2268.0	1
9	701.0	1
10	812.0	1
11	934.0	1
12	1065.0	1
13	1206.0	1
14	1357.0	1

Program output page 1

SAMPLE WEIBULL FIT

I	ORDER(I)	RANK(I)	LIFE(I)
1	1.00000	.01733	436
2	2.00000	.04208	510
3	3.00000	.06683	599
4	4.00000	.09159	701
5	5.00000	.11634	812
6	6.00000	.14109	934
7	7.00000	.16584	1065
8	8.00000	.19060	1206
9	9.00000	.21535	1357
10	10.00000	.24010	1518
11	11.00000	.26485	1689
12	12.00000	.28960	1870
13	13.00000	.31436	2063
14	14.00000	.33911	2268

ALPHA= .9915504E+03 BETA= .7988567E+00 GAMMA= .4004390E+03 WEIGHT=1

ALPHA= .9968374E+03 BETA= .7995921E+00 GAMMA= .4001990E+03 WEIGHT=1/VARIANCE

Program output page 2

SAMPLE WEIBULL FIT

RAW DATA

Film output frame 1

SAMPLE WEIBULL FIT

FITTED DATA

Film output frame 2

SAMPLE WEIBULL FIT

FITTED DATA

Film output frame 3

ALT:286(60)