

DESIGN PREDICTION FOR LONG TERM STRESS RUPTURE SERVICE  
OF COMPOSITE PRESSURE VESSELS<sup>†</sup>

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SUMMARY

Extensive stress rupture studies on glass composites and Kevlar composites were conducted by the Lawrence Radiation Laboratory beginning in the late 60s and extending to about 8 years in some cases. Some of the data from these studies published over the years were incomplete or were tainted by spurious failures, such as grip slippage. These data have been carefully resurveyed by cognizant staff. Updated verified data sets have been defined for both fiberglass and Kevlar composite strand test specimens. These updated data are analyzed in this report by a convenient form of the bivariate Weibull distribution, to establish a consistent set of design prediction charts that may be used as a conservative basis for predicting the stress rupture life of composite pressure vessels.

The updated glass composite data exhibit an invariant Weibull modulus with lifetime. The data are analyzed in terms of homologous service load (referenced to the observed median strength). The equations relating life, homologous load, and probability are given, and corresponding design prediction charts are presented. A similar approach is taken for Kevlar composites, where the updated strand data do show a turndown tendency at long life accompanied by a corresponding change (increase) of the Weibull modulus. This turndown characteristic is not present in stress rupture test data of Kevlar pressure vessels. A modification of the stress rupture equations is presented to incorporate a latent, but limited, strength drop, and design prediction charts are presented that incorporate such behavior.

The methods presented utilize Cartesian plots of the probability distributions (which are a more natural display for the design engineer), based on median normalized data that are independent of statistical parameters and are readily defined for any set of test data. A technique is shown for estimating the Weibull modulus from each observed value. The design prediction equations and the corresponding design prediction charts can be set up to provide selected levels of conservatism in those regions where data are sparse or unavailable. Design values based on these single-end data should be conservative for multiple-end roving and massive composite structures like those on pressure vessels.

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## INTRODUCTION

The purpose of this report is to provide a useful engineering tool for estimating stress rupture life of S-glass and Kevlar composites subject to long-term tensile stress. The data base is drawn from the extensive 10 year period test program conducted on S-glass and Kevlar single-end composite strands at the Lawrence Livermore National Laboratory (LLNL).

Previously published results of S-glass exhibited a turndown characteristic at long times. This characteristic, when analyzed by a quadratic maximum likelihood method (Ref. 1), produced unrealistic life prediction extrapolation and did not yield realistic and useful long life predictions. The LLNL S-glass data base has recently been subject to a searching re-examination by the cognizant staff (Refs. 2, 3) to eliminate spurious failures such as grip pullouts. These updated data are analyzed here by the Weibull model and tabulated in Appendix A. These data do not exhibit a turndown and are well approximated by invariant Weibull moduli for the life and strength distributions. It should be noted that the stress rupture analysis will produce straight line probability contours on log stress vs log life coordinates if the Weibull moduli for life and strength are invariant with time. The converse is also true.

Convenient analytical methods based on the Weibull model are presented. These methods allow an estimation of the Weibull modulus based on each ranked observation and allow estimation of the population median life based on partial (censored or incomplete) data. The methods of analysis are simple and straightforward, and may be applied in the same fashion to other stress rupture data. The Weibull modulus for S-glass life is  $b = 0.9$ , based on the updated stress rupture data presented. LLNL measurements of S-glass composite strand strength show scatter with a representative coefficient of variation  $CV = 0.48+$ , corresponding with  $m = 24.9$ , which is used in the tabulated data and design prediction. These parameters for S-glass are used to produce the design chart of Figure 1.

The LLNL Kevlar composite strand data (Ref. 2) are presented in Appendix B. These data show a turndown trend. Kevlar spherical vessel data (Ref. 4) do not show this trend. The Weibull model was modified, as discussed later, to incorporate a strength degradation that develops later in time according to a first-order reaction rate (Ref. 5) with a specific time constant. This model predicts that within the time period where degradation is expected, the Weibull modulus for life should show an apparent increase. That is exactly what the Kevlar strand data show, and this modified form is used to construct a rational design chart that includes a partial degradation ( $f = 0.3$ ) with a time constant  $t_c \approx 120,000$  hours. The Weibull modulus for Kevlar composite strand life is also  $b = 0.9$ , while the Weibull modulus for strength is  $m \approx 30$ , reflecting a typically slightly lower scatter ( $CV = 0.04$ ) for Kevlar composite strands than for the S-glass strands. The resulting design chart is shown in Figure 2. Over-plotted on this chart are the pressure vessel data, which do not exhibit the turndown and show greater life at the same homologous load.

Published data for carbon fiber composite strands are very sparse (Ref. 6) and extend to shorter times than the S-glass and Kevlar data. Figure 3 is a preliminary design chart, constructed using the indicated parameters, and should be useful for first-order life estimates of carbon composite pressure vessel stress rupture life.

## DISCUSSION

### The Bivariate Weibull Distribution

An expression for the stress rupture (Ref. 7) of a multifilament strand is given by

$$S = \text{Exp} -H\{R,t\}$$

where  $H$  is a function of the applied load and time. Assuming the function to be separable and of

exponential (power-law) form, it can be expressed as a bivariate form of the well known Weibull distribution function (Ref. 7).

The two-parameter form of the Weibull distribution is given by

$$S = \text{Exp} - \{X/X_0\}^m$$

As a matter of convenience, the function is normalized here to the median value  $X_m$ , or to any other percentile  $S_r$ ,  $X_r$ , which may be appropriate, as in the case of a partial sample where the median has not yet been reached in the experimental program and is unknown:

$$S = \text{Exp} - \{ \ln(1/S_r) (X/X_r)^m \}$$

If the median is known, then  $S_r = 0.5$  and the distribution scale parameter becomes the median. From a design engineer's point of view, this is intuitively more meaningful than the Weibull scale parameter  $X_0$ , which corresponds with the 63% quantile. Forms of the Weibull distribution that use mean normalized data are more awkward because the quantile of the mean value involves a gamma function of the Weibull modulus (shape parameter):

$$S = \text{Exp} - \{ \Gamma(1+1/m)(X/X_{avg}) \}^m$$

The bivariate Weibull form, normalized to median strength and life, is given by

$$S = \text{Exp} - \{ \ln(2) (R_m)^m (t/t_m)^b \}$$

The symbol  $R$  is the homologous load referenced to the median value. This form is used in subsequent discussions for the analysis of the composite stress rupture data.

### From Filaments to Composite Structures

The susceptibility of single filaments to stress rupture is invariably more severe than the susceptibility of multifilament strands for several reasons. The filament surface is totally exposed to the surrounding environment; the access of environmental factors such as moisture, air, or radiation is not impeded; and access remains unimpeded throughout the exposure time. The filament failure under these influences is total, i.e., no load can be transmitted after filament failure. The situation is less severe for the multifilament strand, especially if twist is present. Within a multifilament strand, there is some inhibition of diffusion by geometric effects and by the gradual development of internal concentration gradients. Furthermore, individual filament breaks might not lead to load-carrying reduction because frictional coupling and twist act like the matrix of a composite strand. The composite strand is even less susceptible to individual filament rupture failure because the matrix encapsulates the filaments and can offer considerable protection from diffusion and effects of the environments. Consequently, stress rupture experiments show relatively early failure times and turndown characteristics for single filaments and bare strands as compared with composite strands.

When comparing lifetimes at equal homologous loads, still another factor enters that causes the multifilament strands to exhibit longer life. The prevailing stress within the constituent filaments is reduced because the median strength of a multifilament strand is expected to be less than the median strength of single filaments, and the discrepancy increases as the variability of filament strength increases. At the same homologous load, the average filament stress in massive composites is reduced from the single filament or single-end strand.

For these reasons, it is concluded that using single-end composite strands to establish design charts for massive composites, such as filament-wound pressure vessels, will provide an inherently conservative basis for estimation.

## ANALYTICAL FORMS

### Invariant Weibull Moduli

The median normalized bivariate Weibull equation (Ref. 7) relates load, life, and probability, as shown below:

$$S = \text{Exp} - \left\{ \text{Ln}(2) \left( \frac{\sigma}{\sigma_m} \right)^m \left( \frac{t}{t_m} \right)^b \right\}$$

The equation is the power law form with the underlying linear log-log relation :

$$\left( \frac{\sigma}{\sigma_m} \right)^m \left( \frac{t}{t_m} \right)^b = \frac{\left| \text{Ln} \left( \frac{1}{S} \right) \right|}{\left| \text{Ln}(2) \right|}$$

This relation defines a family of straight lines on log-log coordinates in which the following proportionality holds (where R represents the load fraction of median strength):

$$R^m t^b \propto \frac{\left| \text{Ln} \left( \frac{1}{S} \right) \right|}{\left| \text{Ln}(2) \right|}$$

The preceding relations may be used as shown in the following steps to compute desired combinations of load fraction, R, life, t, and survival probability, S. The shape parameters (Weibull moduli) for strength, m, and for life, b, are determined by analysis of experimental strength and life distributions. For example, the LLNL glass data give  $m = 24.9$  and  $b = 0.9$ . The procedure to construct the probability, load, life design chart follows.

1. Select a reference set of values from the data or design:  $R_r$ ,  $t_r$ , and  $S_r$  (usually  $S_r = 0.5$ ).
2. Select the load and life Weibull moduli  $m$  and  $b$  to give desired conservatism for the design chart.
3. Compute the constant K

$$K = \frac{R_r^m t_r^b \text{Ln}(2)}{\text{Ln} \left( \frac{1}{S_r} \right)}$$

4. Define the general R, t, S relation by

$$R^m t^b = \frac{\left[ K \text{Ln} \left( \frac{1}{S} \right) \right]}{\left[ \text{Ln}(2) \right]}$$

5. Construct the design chart using the log-log form ( $S_r = 0.5$ )

$$\text{Log}(R) = \text{Log}(R_r) - \frac{b}{m} \text{Log}\left(\frac{t}{t_r}\right) + \left(\frac{1}{m}\right) \text{Log}\left[\frac{\text{Ln}\left(\frac{1}{S}\right)}{\text{Ln}(2)}\right]$$

This equation, representing time invariant Weibull moduli for both strength and life, is typified by the glass design chart of Figure 1.

6. Compute life for particular load fraction,  $R$ , and survival probability,  $S$ , by

$$t = \left\{ \frac{K}{R^m} \left[ \frac{\text{Ln}(1/S)}{\text{Ln}(2)} \right] \right\}^{(1/b)}$$

7. Compute load fraction for particular life,  $t$ , and survival probability,  $S$ , by

$$R = \left\{ \frac{K}{t^b} \left[ \frac{\text{Ln}(1/S)}{\text{Ln}(2)} \right] \right\}^{(1/m)}$$

8. Compute the survival probability for particular load fraction,  $R$ , and life,  $t$ , by

$$S = \text{Exp} \left\{ - \frac{R^m t^b}{K} \text{Ln}(2) \right\}$$

### Single Point Estimates for Median Life and Weibull Modulus

The following equations show how the median life may be estimated, when the shape factor,  $m$ , is known, from each early observed failure life at  $t_r$  corresponding with the survival probability,  $S_r$ , where

$S_r = 1 - (r-0.5)/N$  and  $r$  is the rank serial number. The use of  $(r-0.5)$  as the effective rank for computing the corresponding probability is a convenience. Alternative formulations are  $r/N$ ,  $r/(N+1)$ ,  $(r-0.3)/(n+0.4)$ , as well as probabilistic treatments of the "correct" rank assignments. Extensive computer simulations of Weibull distributions (Ref. 8) show that  $(r-0.5)/N$  is an effective and convenient rank assignment. The value of  $S_r$  was taken to be  $1 - (r-0.5)/N$  in the tabulated computations. The median life value is estimated by the following equations (with  $m$  known):

$$S = \text{Exp} \left\{ - \text{Ln}(2) \left( \frac{t}{t_m} \right)^m \right\}$$

$$t_{0.5} = t_m = t_r \left( \frac{\text{Ln}(2)}{\text{Ln}\left(\frac{1}{S_r}\right)} \right)^{\frac{1}{m}}$$

The shape factor may also be estimated from a few early observations, and in this case we take as an interim normalizing value the longest observed life  $t_r$ , corresponding to survivability  $S_r$ , and use the preceding data at lesser life  $t$  having survival probability  $S$  (greater than  $S_r$ ) to estimate the Weibull Modulus by the relation:

$$m = \frac{\text{Ln} \left\{ \frac{\text{Ln} \left( \frac{1}{S} \right)}{\text{Ln} \left( \frac{1}{S_r} \right)} \right\}}{\text{Ln} \left( \frac{t}{t_r} \right)}$$

The two estimators are combined to produce individual median life estimates from each observed value, with  $t_r$  as the normalizing life at survival probability,  $S_r$ , as shown below

$$t_{0.5} = t_r \left\{ \frac{\text{Ln} (2)}{\text{Ln} \left( \frac{1}{S_r} \right)} \right\} \left\{ \frac{\text{Ln} \left( \frac{t}{t_r} \right)}{\text{Ln} \left\{ \frac{\text{Ln} \left( \frac{1}{S} \right)}{\text{Ln} \left( \frac{1}{S_r} \right)} \right\}} \right\}$$

These predictions are tabulated in the data appendices.

#### Degradation and Strength Turndown

The possibility of a latent strength reduction, which may appear after a substantial amount of time under sustained load, was addressed by Christensen (Ref. 5). He showed the effect on stress rupture life of degradation that follows first-order chemical reaction rates, with the strength decreasing progressively until failure:

$$\sigma = \sigma_r \text{Exp} (-t/t_c)$$

This idea, with some additional constraints, can be used to make a simple and useful modification of the design charts. One can postulate such degradation, which might be related to moisture effects, and the breakdown of locally susceptible regions in the load-carrying filaments. These locally susceptible regions are finite; after all of them are degraded, the breakdown process will stop. This leads to a fraction,  $f$ , of strength lost in accordance with the time constant,  $t_c$ , of this assumed reaction

$$\sigma = \sigma_r [1 - f (1 - \text{Exp} (-t/t_c))]$$

This fractional strength loss is incorporated into the stress rupture equations as shown below:

$$R = R_r \left( \frac{t_r}{t} \right)^{\frac{b}{m}} \left[ \frac{\text{Ln} \left( \frac{1}{S} \right)}{\text{Ln} (2)} \right]^{\frac{1}{m}} \left\{ 1 - f \left[ 1 - \text{Exp} \left( -\frac{t}{t_c} \right) \right] \right\}$$

The log-log form to be used for plotting the probability contours on the design chart is given by

$$\text{Log} (R) = \text{Log}(R_r) - \frac{b}{m} \text{Log} \left( \frac{t}{t_r} \right) + \left( \frac{1}{m} \right) \text{Log} \left[ \frac{\text{Ln} \left( \frac{1}{S} \right)}{\text{Ln} (2)} \right] + \text{Log} \left\{ 1 - f \left[ 1 - \text{Exp} \left( -\frac{t}{t_c} \right) \right] \right\}$$

This type of design chart is illustrated by the Kevlar composite strand design chart of Figure 2, although the Kevlar vessel data do not exhibit the turndown.

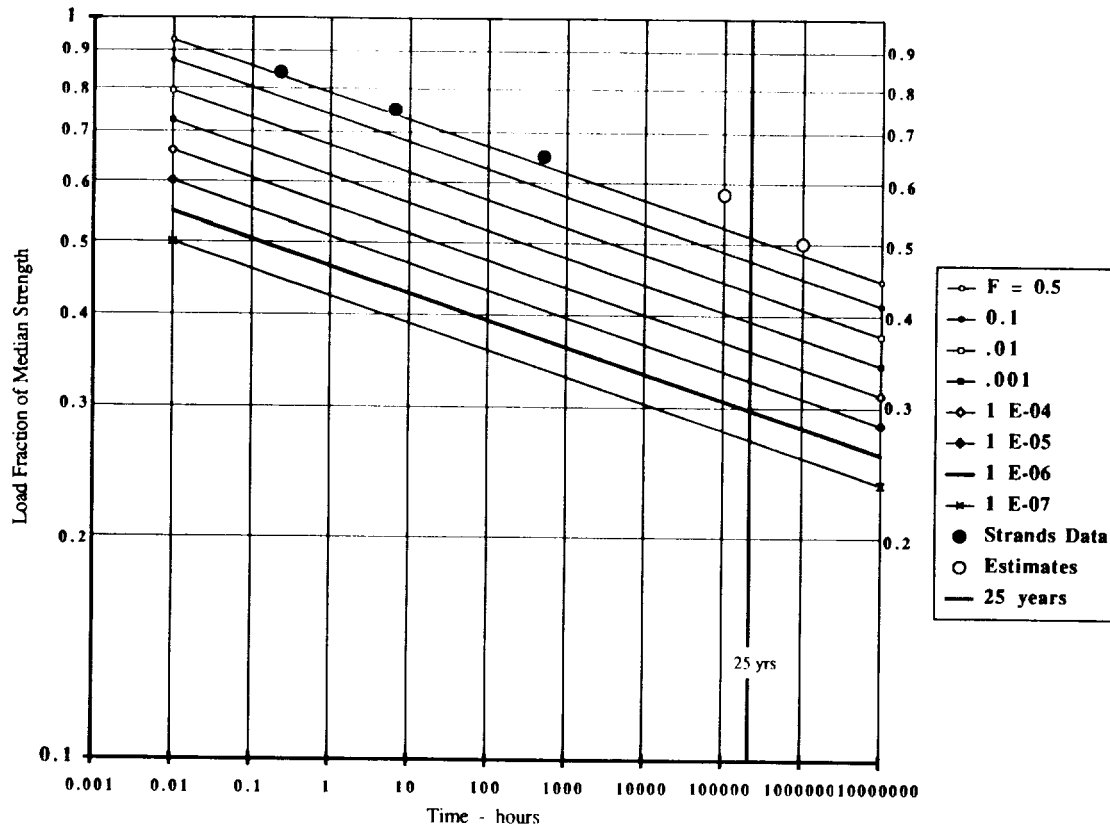


Figure 1. Glass Composite Strand Stress Rupture Design Chart

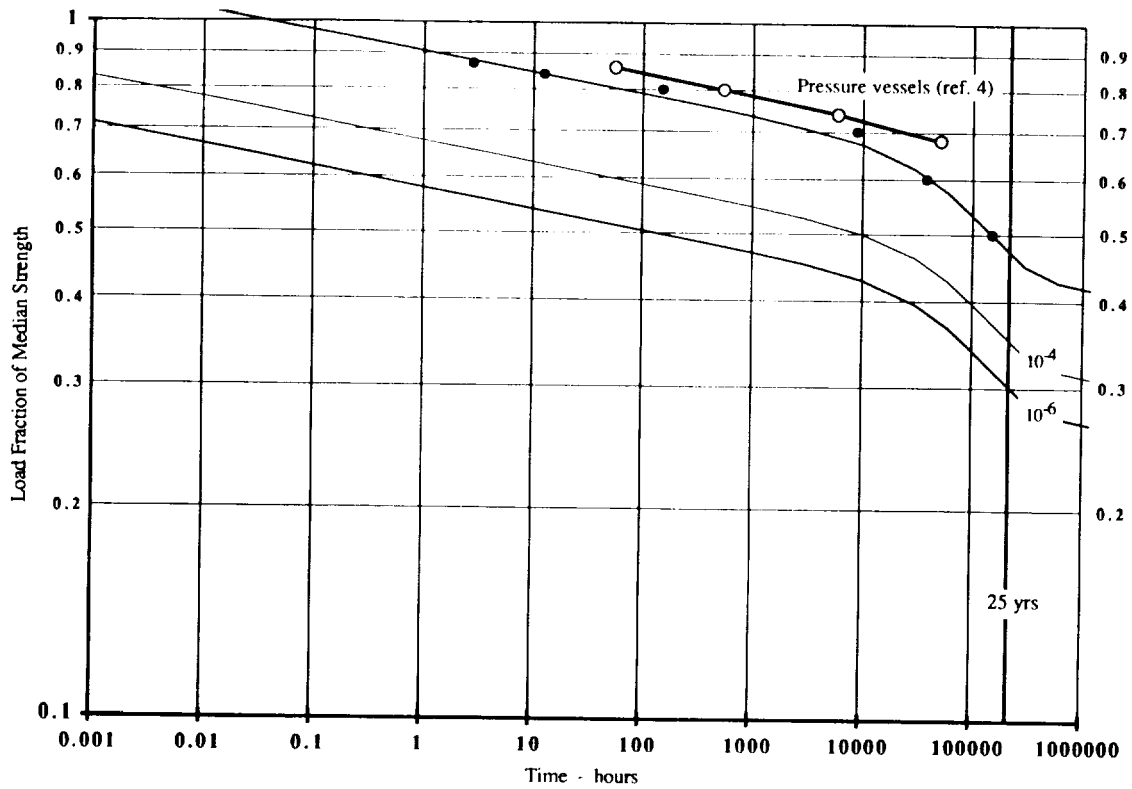


Figure 2. Kevlar Composite Strand Stress Rupture Design Chart with  $m = 30$   $b = 0.9$   $f = 0.3$   $T_c = 120000$  hrs.



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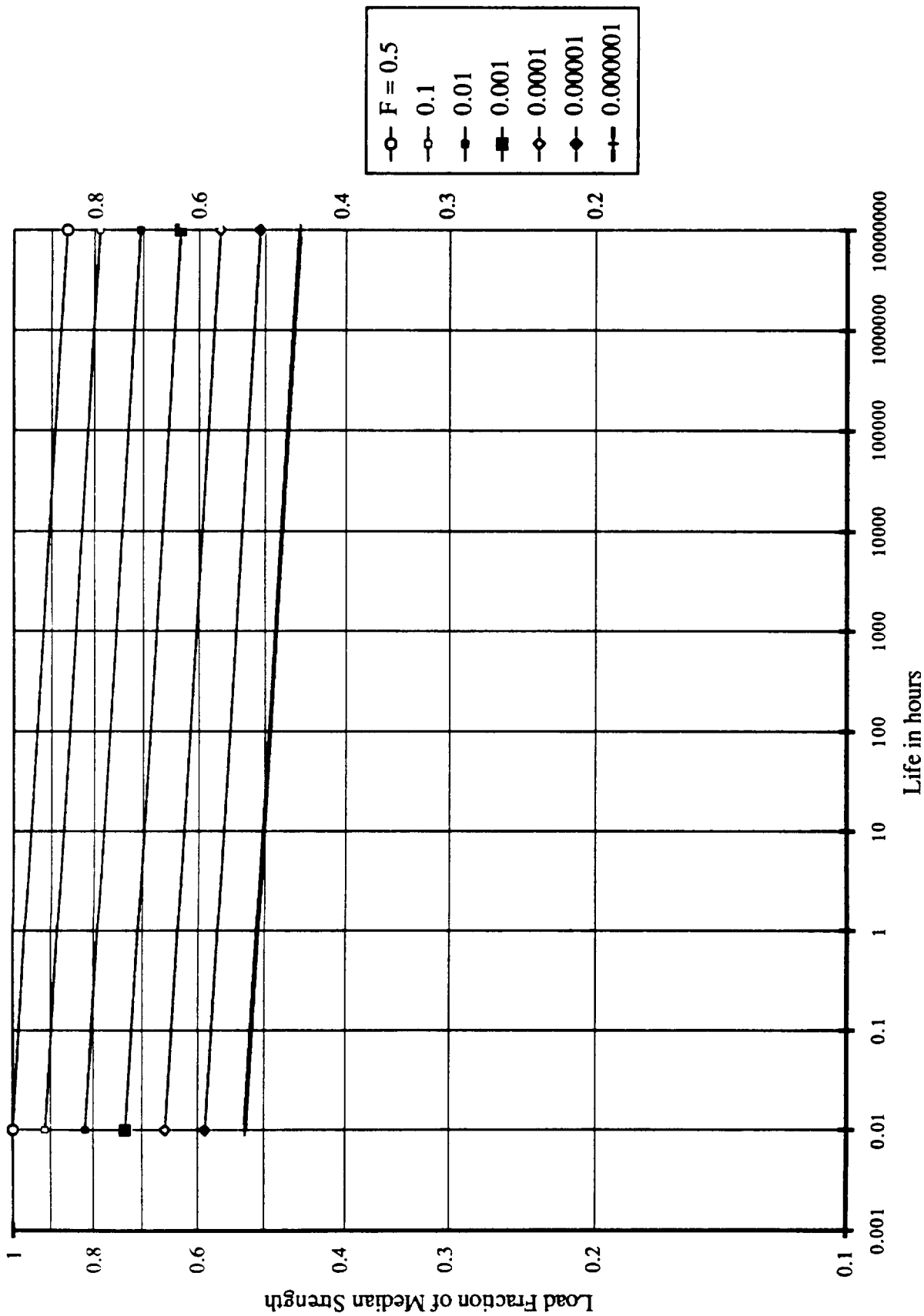


Figure 3. Graphite Composite Stress Rupture Design Chart with  $m = 21$   $b = 0.15$

## CONCLUSIONS

Design charts based on the bivariate form of the Weibull distribution are presented for S-glass composites and Kevlar composites, and for carbon composites in preliminary form. The equations are readily modified to accommodate selected values for the life and strength Weibull moduli in order to determine the most consistent and useful fits to the data.

The methods presented may be applied to any type of stress rupture data that exhibit a consistent power law relation between the Weibull moduli for strength and life. A modification of the linear model is presented and used to accommodate the Kevlar strand data turndown tendency at long life.

The underlying analytical models show that if life and strength are Weibull distributions with invariant moduli (shape factors), then log load vs log life will be linear. Conversely, if the log load vs log life is linear, and either the life distribution or the strength distribution is a Weibull, then the other distribution must also be a Weibull.

The data processing by these methods allows each observation to be used for estimating the Weibull modulus, giving a valuable perspective for engineering approximations that seek a single conservative design reference value. Methods for estimating median life from incomplete data are also shown.

A notable point is the dramatic difference seen in stress rupture life between S-glass and Kevlar composite rupture data on the one hand, and the carbon data on the other hand. The carbon data seem to exhibit very little stress rupture degradation, and therefore offer very high homologous stresses in operation. Such high stress potential (and high performance) may not be a practically usable characteristic. The lower design stresses required for the glass and Kevlar also provide a certain amount of damage tolerance during the service life. In addition, both S-glass and Kevlar are inherently resistant to moderate impact and casual damage. Carbon composites, on the other hand, are notorious for susceptibility to physical damage and abuse. Such susceptibility, coupled with very high operating stresses, could lead to premature or catastrophic failures in cases of casual damage to a carbon composite vessel operating so close to its expected strength.

The design of S-glass and Kevlar pressure vessels is controlled by stress rupture characteristics for long-term service. The design of carbon composite pressure vessels for long term service is controlled by the amount and type of damage in the operating environment. The carbon composite pressure vessels must be protected from environmental damage or designed to resist and tolerate the service environment.

### Acknowledgement

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## SYMBOLS

- S,F Cumulative survival and failure probabilities.
- m Weibull modul (shape factor) for strength; subscript designates median.
- b Weibull modulus for life.
- R Homologous load (referenced to the median strength).
- H, X Function of load and time, and generic variable.
- t Time, life.
- r Subscript for reference value of load and time; also rank number for sorted data.
- f, t<sub>c</sub> Strength fraction lost in first-order degradation reaction, with characteristic time, t<sub>c</sub>.
- σ Stress or strength.

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APPENDIX A

S-Glass Composite Strand Data Tables and Plots  
Based on LLNL Data Update

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LLL S-glass

Stress = 479

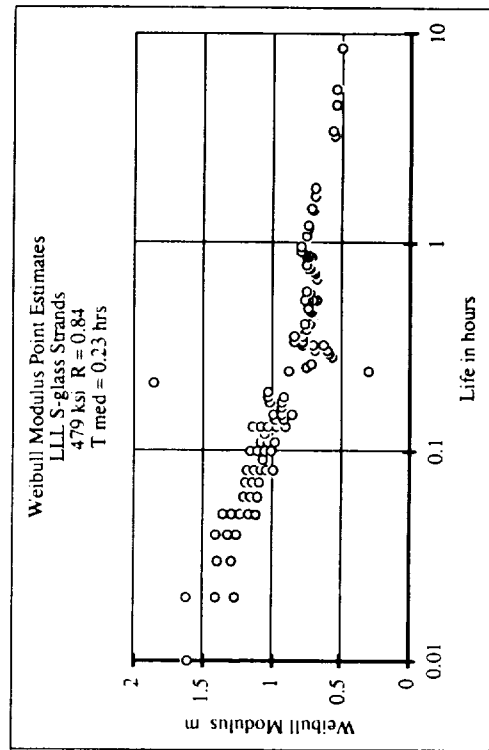
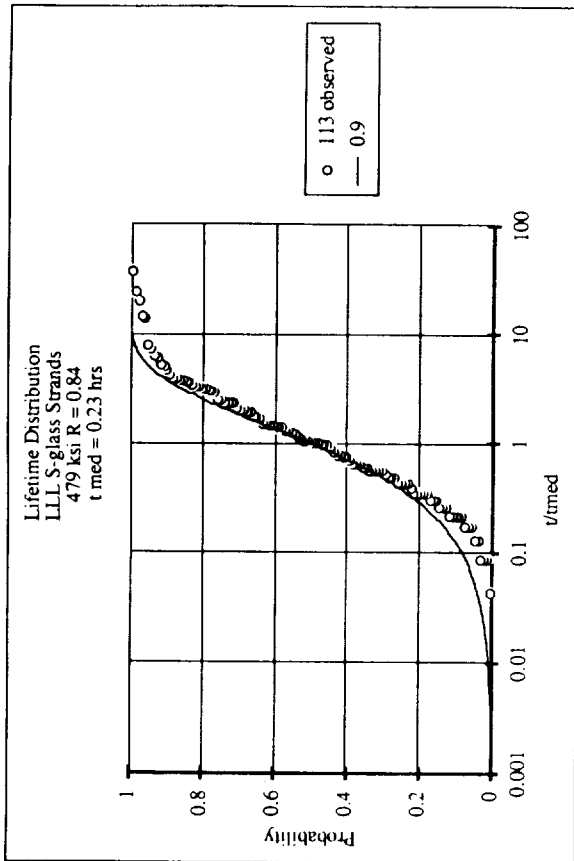
R = 0.84

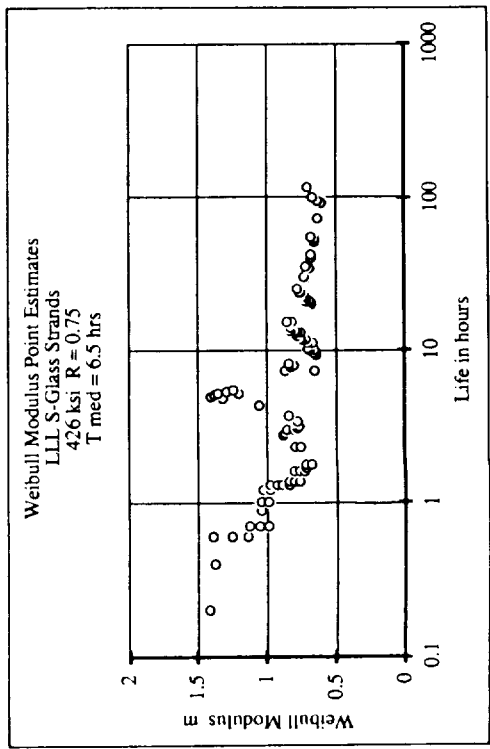
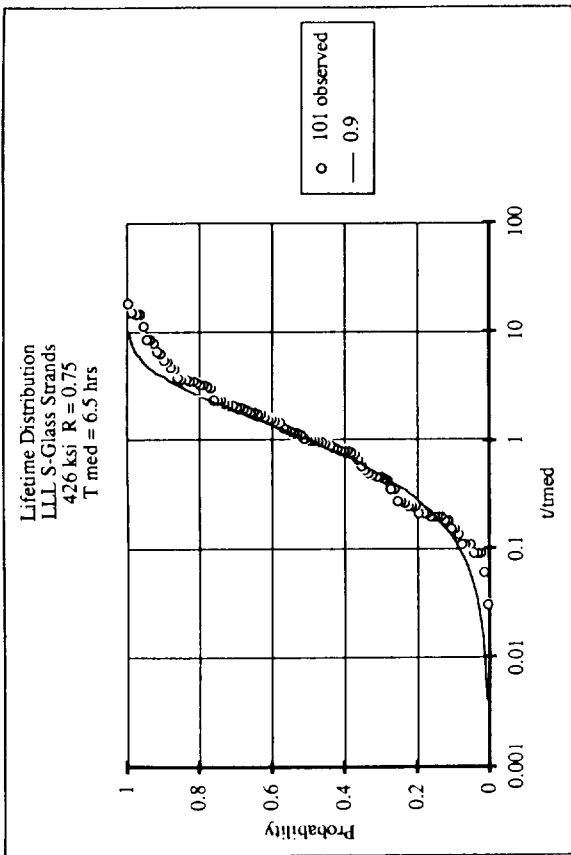
N = 113

Median = 0.23

Specimen type 1 (572) sgl end

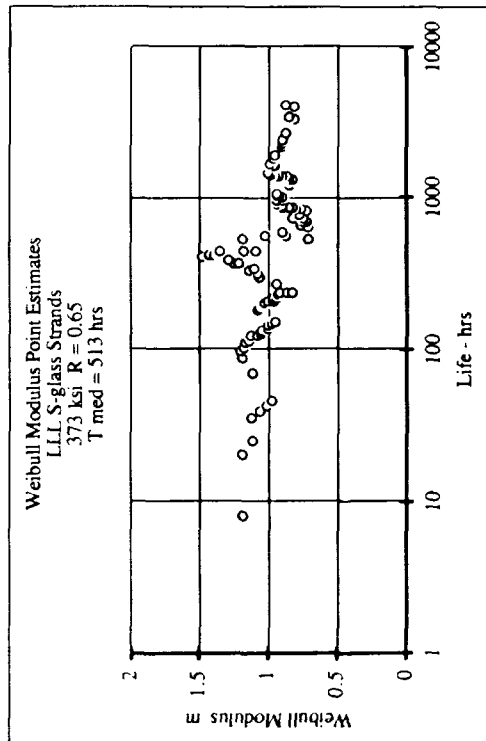
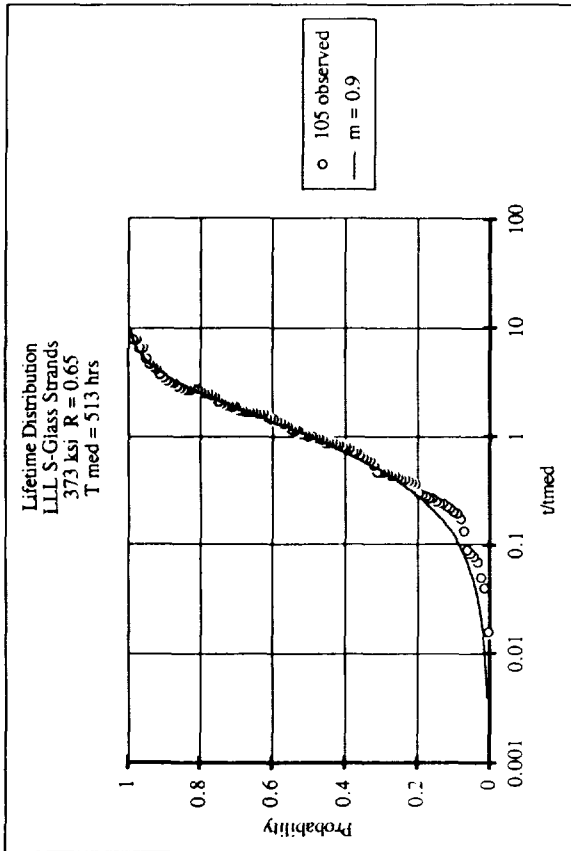
Rank	Life t hrs	Normal $\sqrt{t}$	Prob est F	fit b	Rank r	Life t hrs	Normal $\sqrt{t}$	Prob est F	fit b
1	0.01	0.043	0.004	1.6	58	0.24	1.043	0.509	0.6
2	0.02	0.087	0.013	1.6	59	0.24	1.043	0.518	1.2
3	0.02	0.087	0.022	1.4	60	0.25	1.087	0.527	0.9
4	0.02	0.087	0.031	1.3	61	0.26	1.130	0.535	0.8
5	0.03	0.130	0.040	1.4	62	0.28	1.217	0.544	0.6
6	0.03	0.130	0.049	1.3	63	0.29	1.261	0.553	0.6
7	0.04	0.174	0.058	1.4	64	0.3	1.304	0.562	0.7
8	0.04	0.174	0.066	1.3	65	0.3	1.304	0.571	0.7
9	0.04	0.174	0.075	1.2	66	0.32	1.391	0.580	0.7
10	0.05	0.217	0.084	1.4	67	0.32	1.391	0.588	0.7
11	0.05	0.217	0.093	1.3	68	0.32	1.391	0.597	0.8
12	0.05	0.217	0.102	1.2	69	0.33	1.435	0.606	0.8
13	0.05	0.217	0.111	1.2	70	0.33	1.435	0.615	0.9
14	0.05	0.217	0.119	1.1	71	0.35	1.522	0.624	0.8
15	0.06	0.261	0.128	1.2	72	0.35	1.522	0.633	0.9
16	0.06	0.261	0.137	1.2	73	0.38	1.652	0.642	0.8
17	0.06	0.261	0.146	1.1	74	0.4	1.739	0.650	0.8
18	0.07	0.304	0.155	1.2	75	0.4	1.739	0.659	0.8
19	0.07	0.304	0.164	1.1	76	0.44	1.913	0.668	0.7
20	0.07	0.304	0.173	1.1	77	0.45	1.957	0.677	0.7
21	0.08	0.348	0.181	1.2	78	0.46	2.000	0.686	0.7
22	0.08	0.348	0.190	1.1	79	0.47	2.043	0.695	0.8
23	0.08	0.348	0.199	1.1	80	0.48	2.087	0.704	0.8
24	0.08	0.348	0.208	1.0	81	0.53	2.304	0.712	0.7
25	0.08	0.348	0.217	1.0	82	0.53	2.304	0.720	0.7
26	0.09	0.391	0.226	1.1	83	0.53	2.304	0.730	0.8
27	0.1	0.435	0.235	1.1	84	0.53	2.304	0.739	0.8
28	0.1	0.435	0.243	1.1	85	0.57	2.478	0.748	0.8
29	0.1	0.435	0.252	1.0	86	0.58	2.522	0.757	0.8
30	0.1	0.435	0.261	1.0	87	0.66	2.870	0.765	0.7
31	0.11	0.478	0.270	1.1	88	0.69	3.000	0.774	0.7
32	0.11	0.478	0.279	1.0	89	0.7	3.043	0.783	0.7
33	0.11	0.478	0.288	1.0	90	0.71	3.087	0.792	0.7
34	0.12	0.522	0.296	1.0	91	0.73	3.174	0.801	0.7
35	0.13	0.565	0.305	1.1	92	0.74	3.217	0.810	0.7
36	0.13	0.565	0.314	1.1	93	0.75	3.261	0.819	0.8
37	0.13	0.565	0.323	1.0	94	0.77	3.348	0.827	0.8
38	0.13	0.565	0.332	0.9	95	0.85	3.696	0.836	0.7
39	0.13	0.565	0.341	0.9	96	0.85	3.696	0.845	0.8
40	0.14	0.609	0.350	1.0	97	0.87	3.783	0.854	0.8
41	0.14	0.609	0.358	0.9	98	0.87	3.783	0.863	0.8
42	0.15	0.652	0.367	1.0	99	0.89	3.870	0.872	0.8
43	0.15	0.652	0.376	0.9	100	0.9	3.913	0.881	0.8
44	0.15	0.652	0.385	0.8	101	0.96	4.174	0.889	0.8
45	0.16	0.696	0.394	0.9	102	1.07	4.652	0.898	0.8
46	0.17	0.739	0.403	1.0	103	1.16	5.043	0.907	0.8
47	0.17	0.739	0.412	0.9	104	1.2	5.217	0.916	0.8
48	0.18	0.783	0.420	1.0	105	1.42	6.174	0.925	0.7
49	0.18	0.783	0.429	0.9	106	1.46	6.348	0.934	0.7
50	0.19	0.826	0.438	1.0	107	1.67	7.261	0.942	0.7
51	0.21	0.913	0.447	1.7	108	1.79	7.783	0.951	0.7
52	0.22	0.957	0.456	1.0	109	3.21	13.957	0.960	0.6
53	0.22	0.957	0.465	0.891	110	3.38	14.696	0.969	0.6
54	0.22	0.957	0.473	0.917	111	4.47	19.435	0.978	0.6
55	0.23	1.000	0.482	0.944	112	5.38	23.391	0.987	0.6
56	0.23	1.000	0.491	0.972	113	8.55	37.174	0.996	0.6
57	0.23	1.000	0.500	1.000					





LLL S-glass		Rank	Life t	Normal	Prob est	fit	Rank	Life t	Normal	Prob est	fit
Stress = 426	R = 0.75	r	hrs	$v/med$	F	b	r	hrs	$v/med$	F	b
		1	0.2	0.031	0.005	1.4	52	6.6	1.015	0.510	0.9
		2	0.4	0.062	0.025	1.4	53	7.3	1.123	0.520	1.032
		3	0.6	0.092	0.045	1.4	54	7.4	1.138	0.530	1.065
		4	0.6	0.092	0.035	1.2	55	7.4	1.138	0.540	0.9
		5	0.6	0.092	0.045	1.1	56	7.7	1.185	0.550	0.8
		6	0.7	0.108	0.054	1.1	57	8	1.231	0.559	0.8
		7	0.7	0.108	0.064	1.1	58	8.2	1.262	0.569	0.8
		8	0.7	0.108	0.074	1.0	59	9.2	1.415	0.579	0.6
		9	0.9	0.138	0.084	1.0	60	9.5	1.462	0.589	0.7
		10	1	0.154	0.094	1.0	61	9.9	1.523	0.599	0.7
		11	1	0.154	0.104	1.0	62	10.1	1.554	0.609	0.7
		12	1.2	0.185	0.114	1.0	63	10.4	1.600	0.619	0.7
		13	1.2	0.185	0.124	1.0	64	11.1	1.708	0.629	0.7
		14	1.3	0.200	0.134	1.0	65	11.2	1.723	0.639	0.7
		15	1.3	0.200	0.144	0.9	66	11.6	1.785	0.649	0.7
		16	1.3	0.200	0.153	0.9	67	11.7	1.800	0.658	0.7
		17	1.3	0.200	0.163	0.8	68	12.1	1.862	0.668	0.7
		18	1.4	0.215	0.173	0.8	69	12.3	1.892	0.678	0.8
		19	1.4	0.215	0.183	0.8	70	12.9	1.985	0.688	0.8
		20	1.4	0.215	0.193	0.8	71	13.1	2.015	0.698	0.8
		21	1.6	0.246	0.203	0.8	72	13.4	2.062	0.708	0.8
		22	1.6	0.246	0.213	0.8	73	13.4	2.062	0.718	0.8
		23	1.6	0.246	0.223	0.7	74	13.9	2.138	0.728	0.8
		24	1.7	0.262	0.233	0.7	75	14.8	2.277	0.738	0.8
		25	1.8	0.277	0.243	0.7	76	15.1	2.323	0.748	0.8
		26	1.8	0.277	0.252	0.7	77	15.1	2.323	0.757	0.8
		27	2.3	0.354	0.262	0.8	78	19.5	3.000	0.767	0.7
		28	2.3	0.354	0.272	0.8	79	20.2	3.108	0.777	0.7
		29	2.8	0.431	0.282	0.9	80	20.7	3.185	0.787	0.7
		30	2.9	0.446	0.292	0.9	81	20.9	3.215	0.797	0.7
		31	3	0.462	0.302	0.8	82	21.7	3.338	0.807	0.7
		32	3	0.462	0.312	0.8	83	22.2	3.415	0.817	0.7
		33	3.1	0.477	0.322	0.8	84	22.8	3.508	0.827	0.7
		34	3.2	0.492	0.332	0.8	85	23.5	3.615	0.837	0.7
		35	3.4	0.523	0.342	0.8	86	23.7	3.646	0.847	0.8
		36	3.7	0.569	0.351	0.8	87	24.6	3.785	0.856	0.8
		37	4.3	0.662	0.361	1.1	88	28.8	4.431	0.866	0.7
		38	4.8	0.738	0.371	1.3	89	29.8	4.585	0.876	0.7
		39	5	0.769	0.381	1.4	90	34	5.231	0.886	0.7
		40	5.1	0.785	0.391	1.4	91	34.6	5.323	0.896	0.7
		41	5.2	0.800	0.401	1.4	92	40	6.154	0.906	0.7
		42	5.2	0.800	0.411	1.2	93	42.1	6.477	0.916	0.7
		43	5.4	0.831	0.421	1.3	94	50.3	7.738	0.926	0.6
		44	5.5	0.846	0.431	1.2	95	53.5	8.231	0.936	0.6
		45	5.8	0.892	0.441	1.2	96	55	8.462	0.946	0.7
		46	6	0.923	0.450	0.8	97	72	11.077	0.955	0.6
		47	6.1	0.938	0.460	0.8	98	92.3	14.200	0.965	0.6
		48	6.2	0.954	0.470	0.9	99	92.7	14.262	0.975	0.6
		49	6.4	0.985	0.480	0.9	100	99.3	15.277	0.985	0.7
		50	6.5	1.000	0.490	0.9	101	115.7	17.800	0.995	0.7
		51	6.5	1.000	0.500	1.0					

6091



Rank	Life t	Normal	Prob	est	fit	Rank	Life t	Normal	Prob	est	fit
r	hrs	t/med	F	b	b=0.9	r	hrs	t/med	F	b	b=0.9
1	8	0.016	0.005	1.2	0.004	54	533	1.039	0.510	0.7	1.031
2	20	0.039	0.014	1.2	0.013	55	537	1.047	0.519	1.2	1.062
3	25	0.049	0.024	1.1	0.024	56	563	1.097	0.529	0.9	1.095
4	35	0.068	0.033	1.1	0.035	57	570	1.111	0.538	1.0	1.128
5	39	0.076	0.043	1.1	0.046	58	596	1.162	0.548	0.9	1.162
6	42	0.082	0.052	1.0	0.058	59	643	1.253	0.557	0.7	1.196
7	45	0.088	0.062	1.0	0.071	60	655	1.277	0.567	0.8	1.232
8	69	0.135	0.071	1.1	0.083	61	690	1.345	0.576	0.7	1.268
9	87	0.170	0.081	1.2	0.096	62	707	1.378	0.586	0.7	1.306
10	98	0.191	0.090	1.2	0.110	63	729	1.421	0.595	0.8	1.344
11	103	0.201	0.100	1.2	0.123	64	730	1.423	0.605	0.8	1.383
12	110	0.214	0.110	1.2	0.137	65	770	1.501	0.614	0.8	1.424
13	115	0.224	0.119	1.1	0.151	66	823	1.604	0.624	0.7	1.465
14	123	0.240	0.129	1.1	0.166	67	830	1.618	0.633	0.8	1.508
15	123	0.240	0.138	1.1	0.181	68	842	1.641	0.643	0.8	1.552
16	127	0.248	0.148	1.1	0.196	69	855	1.667	0.652	0.8	1.598
17	135	0.263	0.157	1.0	0.211	70	865	1.686	0.662	0.9	1.644
18	136	0.265	0.167	1.0	0.227	71	866	1.688	0.671	0.9	1.692
19	144	0.281	0.176	1.0	0.243	72	891	1.737	0.681	0.9	1.742
20	149	0.290	0.186	1.0	0.259	73	900	1.754	0.690	0.9	1.794
21	153	0.298	0.195	1.0	0.275	74	945	1.842	0.700	0.9	1.847
22	183	0.357	0.205	1.1	0.292	75	948	1.848	0.710	0.9	1.902
23	190	0.370	0.214	1.1	0.309	76	1004	1.957	0.719	0.9	1.959
24	196	0.382	0.224	1.0	0.327	77	1011	1.971	0.729	0.9	2.018
25	202	0.394	0.233	1.0	0.345	78	1029	2.006	0.738	0.9	2.080
26	206	0.402	0.243	1.0	0.363	79	1063	2.072	0.748	0.9	2.144
27	209	0.407	0.252	1.0	0.381	80	1205	2.349	0.757	0.8	2.210
28	218	0.425	0.262	1.0	0.400	81	1226	2.390	0.767	0.9	2.280
29	222	0.433	0.271	0.9	0.419	82	1297	2.528	0.776	0.8	2.353
30	231	0.450	0.281	0.9	0.438	83	1308	2.550	0.786	0.9	2.429
31	237	0.462	0.290	0.9	0.458	84	1334	2.600	0.795	0.9	2.508
32	238	0.464	0.300	0.9	0.478	85	1374	2.678	0.805	0.9	2.592
33	240	0.468	0.310	0.8	0.498	86	1379	2.688	0.814	0.9	2.681
34	274	0.534	0.319	0.9	0.519	87	1381	2.692	0.824	0.9	2.774
35	305	0.595	0.329	1.1	0.540	88	1391	2.712	0.833	1.0	2.873
36	318	0.620	0.338	1.1	0.562	89	1403	2.735	0.843	1.0	2.978
37	335	0.653	0.348	1.1	0.584	90	1434	2.795	0.852	1.0	3.090
38	341	0.665	0.357	1.1	0.606	91	1467	2.860	0.862	1.0	3.210
39	368	0.717	0.367	1.3	0.629	92	1600	3.119	0.871	1.0	3.339
40	374	0.729	0.376	1.2	0.652	93	1630	3.177	0.881	1.0	3.478
41	391	0.762	0.386	1.3	0.676	94	1648	3.212	0.890	1.0	3.630
42	413	0.805	0.395	1.5	0.700	95	1786	3.481	0.900	1.0	3.796
43	419	0.817	0.405	1.4	0.725	96	1894	3.692	0.910	1.0	3.980
44	426	0.830	0.414	1.4	0.750	97	2152	4.195	0.919	0.9	4.185
45	434	0.846	0.424	1.4	0.775	98	2262	4.409	0.929	0.9	4.417
46	443	0.864	0.433	1.4	0.801	99	2395	4.669	0.938	0.9	4.684
47	444	0.865	0.443	1.2	0.828	100	2673	5.211	0.948	0.9	4.998
48	451	0.879	0.452	1.1	0.855	101	3321	6.474	0.957	0.8	5.377
49	475	0.926	0.462	1.1	0.883	102	3357	6.544	0.967	0.8	5.855
50	499	0.973	0.471	0.911	0.911	103	3996	7.789	0.976	0.8	6.503
51	504	0.982	0.481	0.940	0.940	104	4033	7.862	0.986	0.9	7.497
52	507	0.988	0.490	0.970	0.970	105	4194	8.175	0.995	1.0	9.680
53	513	1.000	0.500	1.000	1.000						



1605

Rank	Life t hrs	Normal $\hat{v}_{norm}$	Prob F	est b	fit b=0.9	est med sample	Med Norm 100000
1	745	0.010	0.0051	1.0	0.004	100811	0.007
2	914	0.012	0.0153	0.8	0.015	108338	0.009
3	2712	0.036	0.0255	0.9	0.026	103955	0.027
4	3384	0.045	0.0357	0.9	0.038	105702	0.034
5	4211	0.055	0.0459	0.8	0.050	106709	0.042
6	5376	0.071	0.0561	0.8	0.063	106753	0.054
7	5400	0.071	0.0663	0.8	0.077	109807	0.054
8	5640	0.074	0.0765	0.7	0.090	112304	0.056
9	6816	0.090	0.0867	0.7	0.104	112145	0.068
10	6984	0.092	0.0969	0.7	0.119	114818	0.070
11	7080	0.093	0.1071	0.6	0.134	117839	0.071
12	9000	0.118	0.1271	0.6	0.164	118907	0.090
13	9096	0.120	0.1471	0.6	0.195	125840	0.091
14	9840	0.129	0.1671	0.5	0.228	131705	0.098
15	14928	0.196	0.1871	0.6	0.261	124906	0.149
16	25968	0.342	0.2071	0.8	0.297	110449	0.260
17	27504	0.362	0.2271	0.7	0.333	114063	0.275
18	27792	0.366	0.2471	0.6	0.371	121063	0.278
19	52176	0.686	0.2671	1.4	0.410	93272	0.522
20	71328	0.938	0.2871	1.4	0.451		0.713
21	76032	1.000	0.3071		0.493	USE	0.760

LLL S-glass

Stress = 332 ksi

R = 58%

N = 98

Normal t = 76032

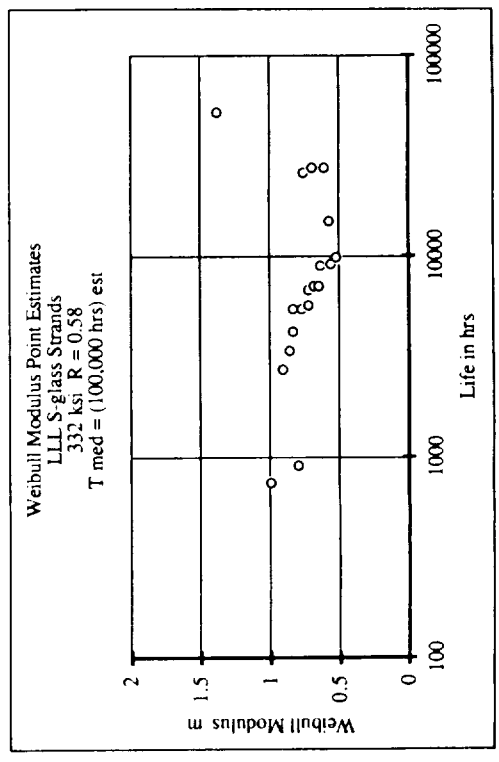
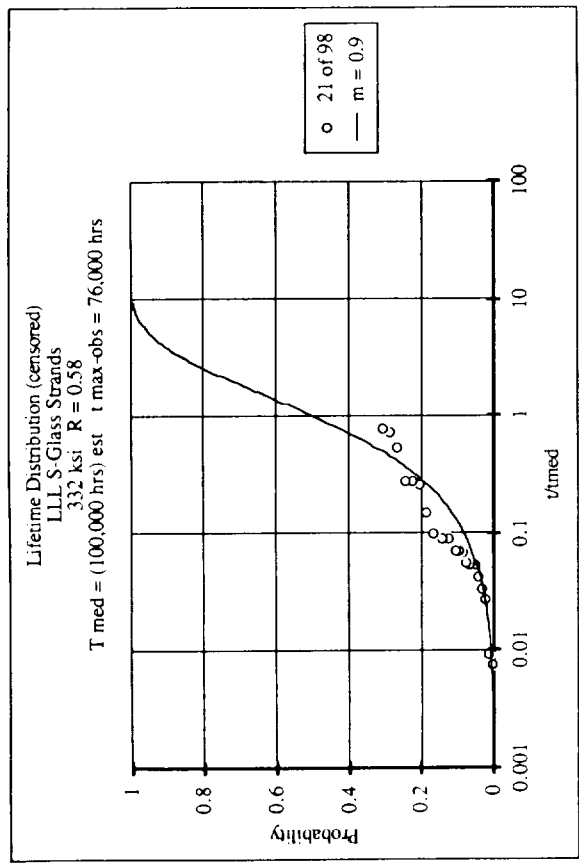
S<sub>norm</sub> = 0.5929

Remaining:

N1 = 50

t1 = 7200 hr

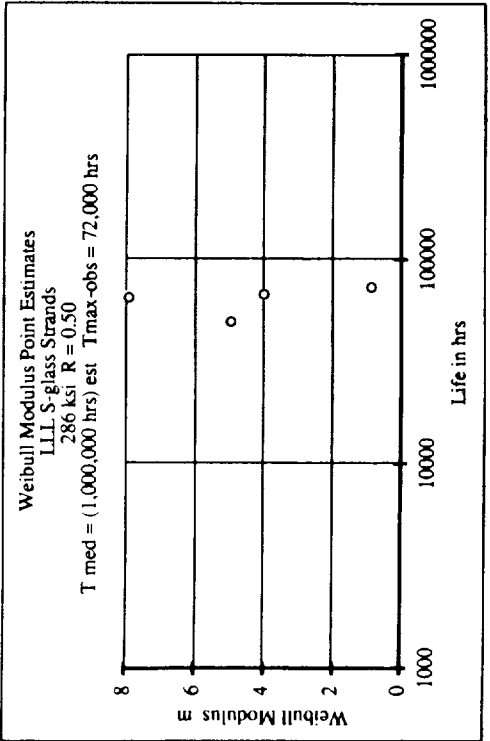
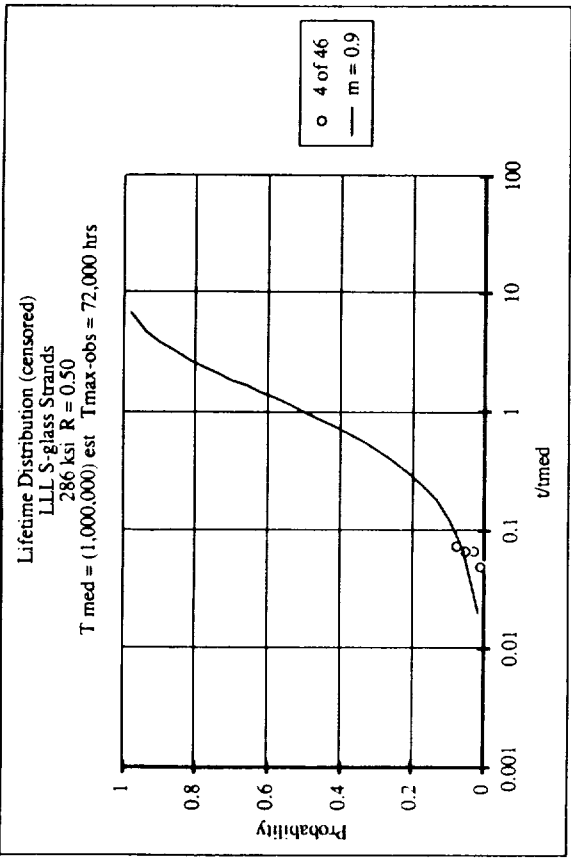
ΔF = 0.02



Rank	Life t hrs	Normal t/μ <sub>norm</sub>	Prob F	est m	est med life	est life 0.9	Life est at 1e-06	med by 1E06	Norm
1	48792	0.672	0.011	5.0	112443	4907270	7514	0.049	
2	65112	0.896	0.033	7.9	95516	1908477	17534	0.065	
3	66600	0.917	0.054	4.0	125193	1092816	4301	0.067	
4	72648	1.000	0.076	0.9		809811	0.26	0.073	

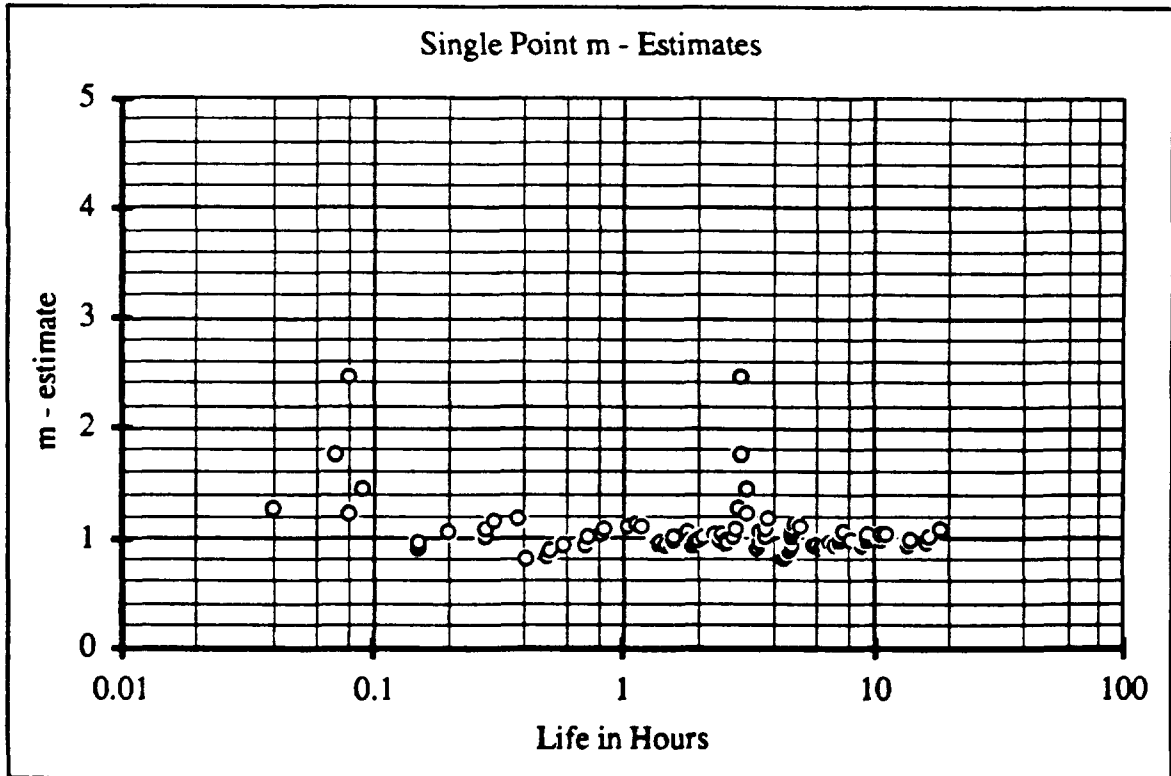
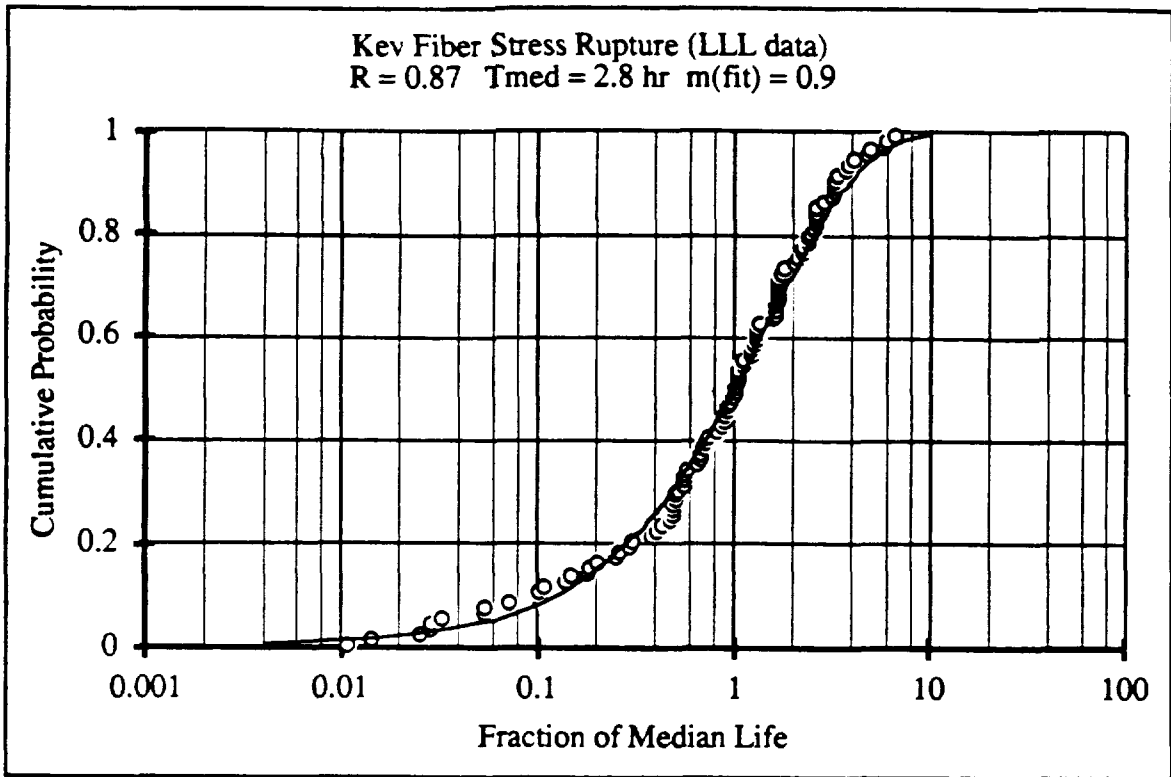
Stress = 286  
 R = 0.5  
 N = 46  
 Normal t = 72648  
 S<sub>norm</sub> = 0.924  
 Type 1 (572)

(Use) 1000000 and m = 0.9



**APPENDIX B**

**Kevlar Composite Strand Data Tables and Plots  
Based on Reference 2**

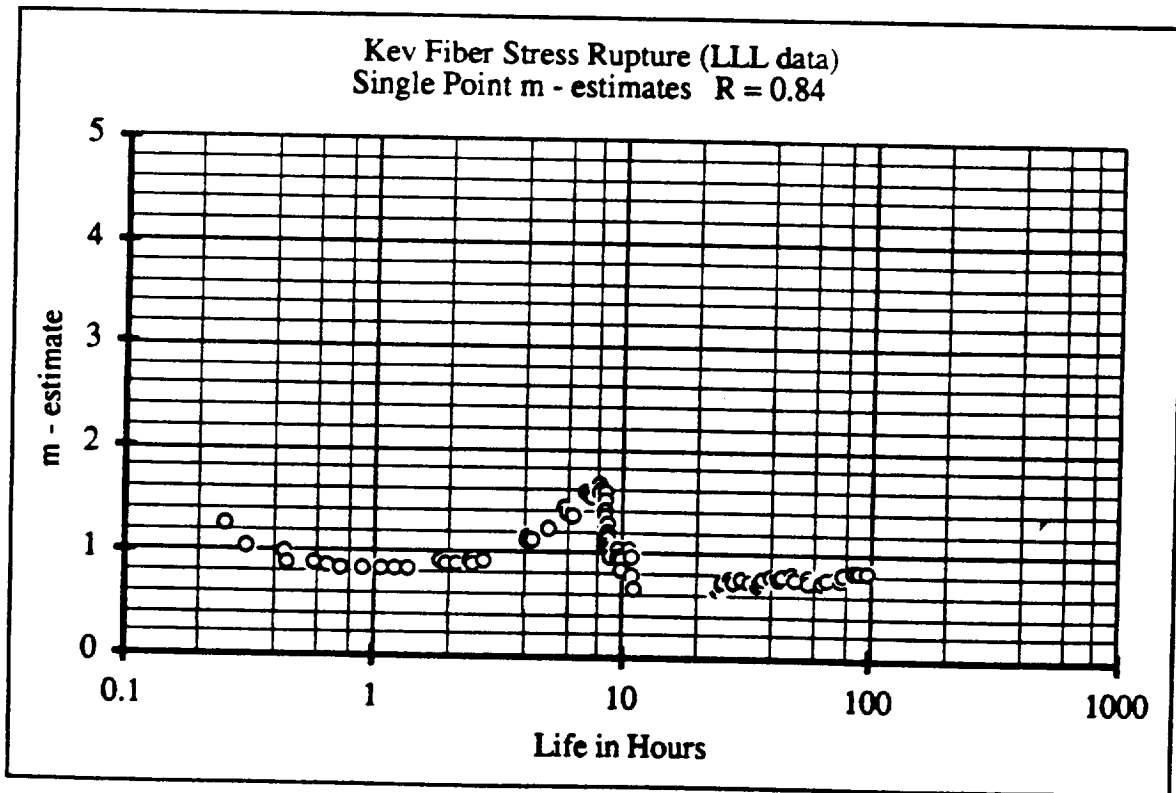
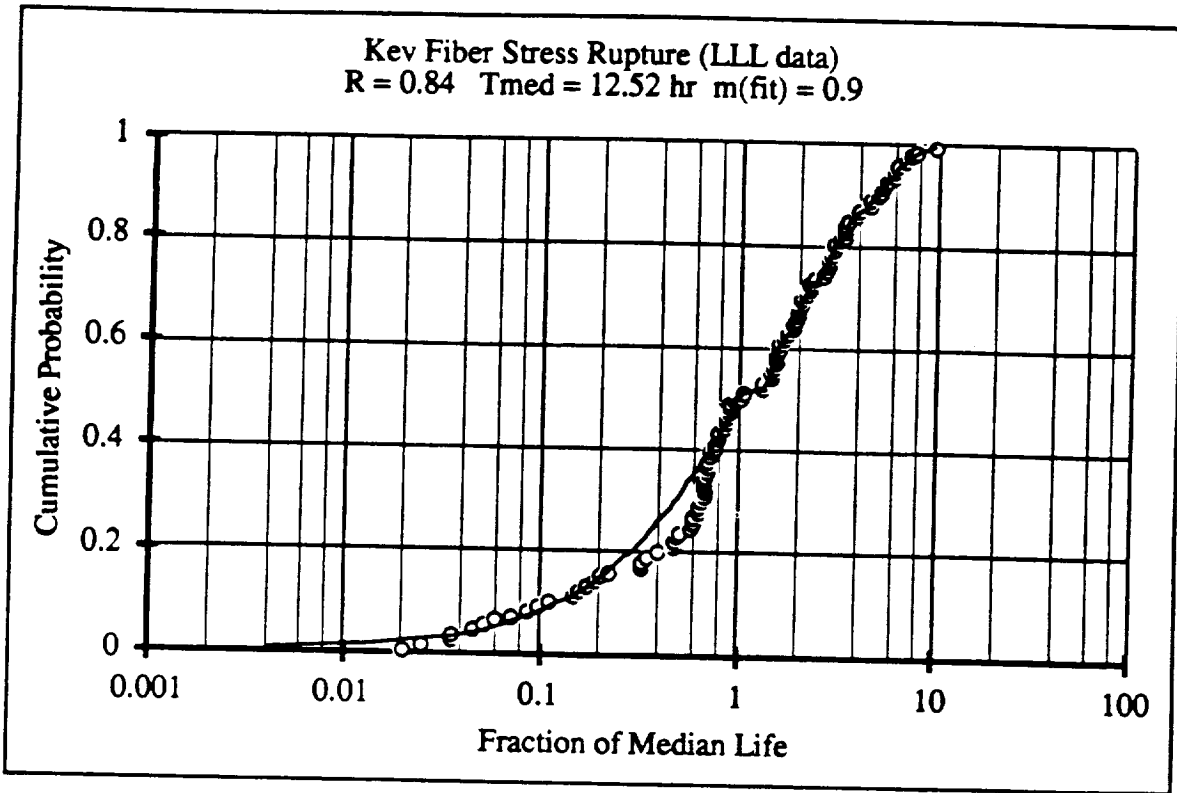


r	Life - hrs	Wmed	F = (r-1/2)/N	1-F	b est	pred/Wmed	r	Life - hrs	Wmed	F = (r-1/2)/N	1-F	b est	pred/Wmed
1	0.03	0.011	0.005	0.995	1.09	0.004	51	2.80	1.002	0.505	0.495	1.29	1.016
2	0.04	0.014	0.015	0.985	0.90	0.014	52	2.89	1.034	0.515	0.485	1.29	1.049
3	0.07	0.025	0.025	0.975	0.90	0.025	53	2.91	1.041	0.525	0.475	1.77	1.083
4	0.08	0.029	0.035	0.965	0.84	0.037	54	2.91	1.041	0.535	0.465	2.47	1.117
5	0.09	0.032	0.045	0.955	0.76	0.049	55	3.10	1.109	0.545	0.455	1.23	1.152
6	0.15	0.054	0.055	0.945	0.73	0.062	56	3.11	1.113	0.555	0.445	1.46	1.188
7	0.15	0.054	0.065	0.935	0.80	0.075	57	3.42	1.224	0.565	0.435	0.91	1.226
8	0.20	0.072	0.075	0.925	0.75	0.088	58	3.47	1.242	0.575	0.425	0.97	1.264
9	0.28	0.100	0.085	0.915	0.78	0.102	59	3.50	1.252	0.585	0.415	1.06	1.303
10	0.28	0.100	0.095	0.905	0.84	0.116	60	3.64	1.302	0.595	0.405	1.00	1.343
11	0.28	0.100	0.105	0.895	0.80	0.131	61	3.67	1.313	0.605	0.395	1.07	1.384
12	0.30	0.107	0.115	0.885	0.78	0.145	62	3.68	1.317	0.615	0.385	1.16	1.427
13	0.38	0.136	0.125	0.875	0.83	0.160	63	3.75	1.342	0.625	0.375	1.18	1.471
14	0.41	0.147	0.135	0.865	0.81	0.176	64	4.39	1.571	0.635	0.365	0.83	1.516
15	0.50	0.179	0.145	0.855	0.86	0.192	65	4.50	1.610	0.645	0.355	0.84	1.562
16	0.51	0.182	0.155	0.845	0.83	0.208	66	4.53	1.621	0.655	0.345	0.89	1.610
17	0.57	0.204	0.165	0.835	0.85	0.224	67	4.53	1.621	0.665	0.335	0.94	1.660
18	0.70	0.250	0.175	0.825	0.93	0.241	68	4.65	1.664	0.675	0.325	0.95	1.711
19	0.72	0.258	0.185	0.815	0.90	0.258	69	4.65	1.664	0.685	0.315	1.00	1.764
20	0.82	0.293	0.195	0.805	0.95	0.275	70	4.69	1.678	0.695	0.305	1.04	1.819
21	0.84	0.301	0.205	0.795	0.92	0.293	71	4.70	1.682	0.705	0.295	1.09	1.876
22	1.05	0.376	0.215	0.785	1.07	0.311	72	4.75	1.699	0.715	0.285	1.12	1.934
23	1.13	0.404	0.225	0.775	1.10	0.329	73	4.84	1.732	0.725	0.275	1.13	1.996
24	1.19	0.426	0.235	0.765	1.11	0.348	74	5.01	1.792	0.735	0.265	1.11	2.059
25	1.32	0.472	0.245	0.755	1.20	0.367	75	5.71	2.043	0.745	0.255	0.95	2.126
26	1.35	0.483	0.255	0.745	1.18	0.386	76	5.92	2.118	0.755	0.245	0.94	2.195
27	1.35	0.483	0.265	0.735	1.12	0.406	77	6.19	2.215	0.765	0.235	0.93	2.268
28	1.36	0.487	0.275	0.725	1.07	0.426	78	6.33	2.265	0.775	0.225	0.94	2.343
29	1.39	0.497	0.285	0.715	1.04	0.446	79	6.59	2.358	0.785	0.215	0.93	2.423
30	1.40	0.501	0.295	0.705	0.99	0.467	80	6.62	2.369	0.795	0.205	0.96	2.506
31	1.48	0.530	0.305	0.695	1.01	0.489	81	6.94	2.483	0.805	0.195	0.94	2.594
32	1.55	0.555	0.315	0.685	1.03	0.510	82	7.16	2.562	0.815	0.185	0.95	2.687
33	1.56	0.558	0.325	0.675	0.97	0.532	83	7.29	2.608	0.825	0.175	0.96	2.786
34	1.57	0.562	0.335	0.665	0.92	0.555	84	7.36	2.633	0.835	0.165	0.99	2.891
35	1.59	0.569	0.345	0.655	0.88	0.578	85	7.38	2.640	0.845	0.155	1.02	3.002
36	1.80	0.644	0.355	0.645	1.04	0.601	86	7.42	2.655	0.855	0.145	1.05	3.122
37	1.85	0.662	0.365	0.635	1.02	0.625	87	8.09	2.894	0.865	0.135	1.00	3.250
38	1.86	0.665	0.375	0.625	0.95	0.649	88	8.88	3.177	0.875	0.125	0.95	3.389
39	1.92	0.687	0.385	0.615	0.94	0.674	89	9.05	3.238	0.885	0.115	0.97	3.541
40	2.00	0.716	0.395	0.605	0.96	0.700	90	9.25	3.309	0.895	0.105	0.99	3.707
41	2.08	0.744	0.405	0.595	0.98	0.725	91	9.26	3.313	0.905	0.095	1.02	3.890
42	2.27	0.812	0.415	0.585	1.23	0.752	92	9.47	3.388	0.915	0.085	1.04	4.095
43	2.38	0.852	0.425	0.575	1.40	0.779	93	10.50	3.757	0.925	0.075	1.00	4.326
44	2.46	0.880	0.435	0.565	1.52	0.806	94	10.57	3.782	0.935	0.065	1.03	4.593
45	2.49	0.891	0.445	0.555	1.41	0.834	95	11.25	4.025	0.945	0.055	1.03	4.906
46	2.61	0.934	0.455	0.545	1.94	0.863	96	13.49	4.826	0.955	0.045	0.95	5.284
47	2.61	0.934	0.465	0.535	1.50	0.892	97	13.78	4.930	0.965	0.035	0.99	5.762
48	2.62	0.937	0.475	0.525	1.13	0.922	98	16.15	5.778	0.975	0.025	0.95	6.408
49	2.74	0.980	0.485	0.515	2.19	0.953	99	16.59	5.936	0.985	0.015	1.01	7.402
50	2.79	0.998	0.495	0.505	0.505	0.984	100	18.16	6.497	0.995	0.005	1.09	9.582

UCID 19849  
440 ksi 0.87  
N = 100  
Med = 2.795

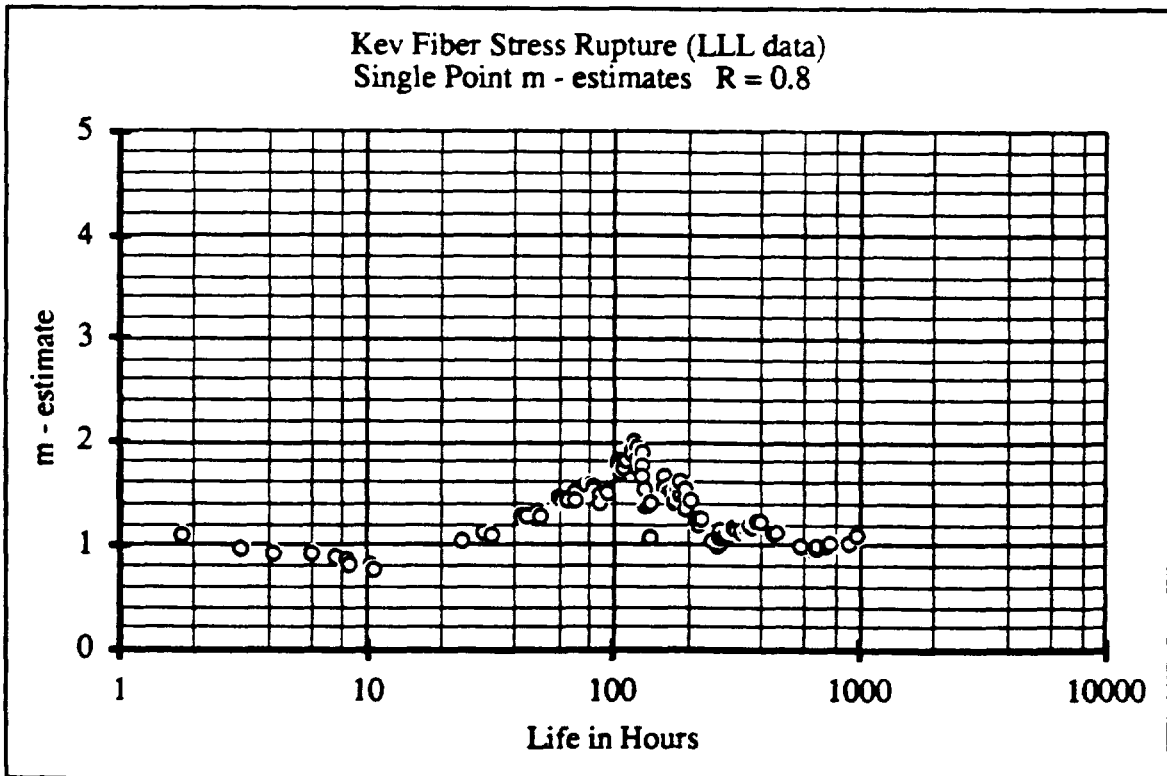
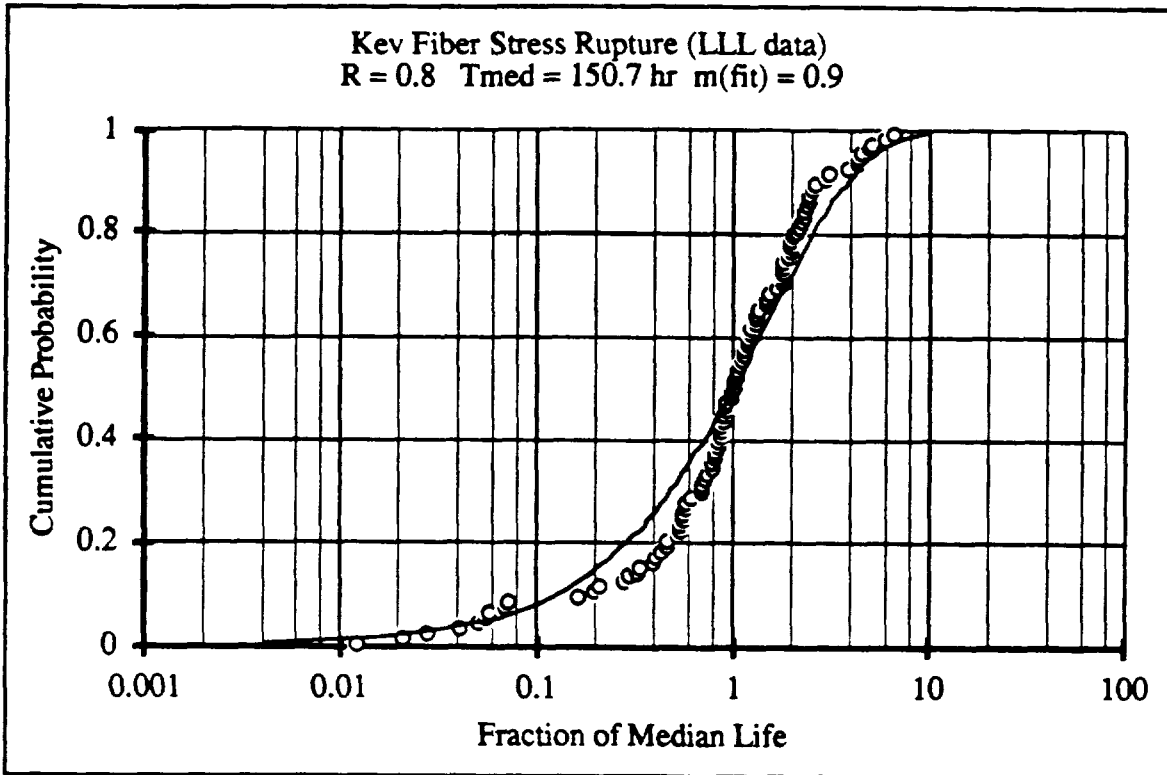
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Med = 2.795

more



r	Life - hrs	$\hat{v}med$	$F = (r-1/2)/N$	S = 1-F	b est	b=0.9 pred	UCID 19849 424.8 ksi 0.84 N = 103 Med = 12.52	r	Life - hrs	$\hat{v}med$	$F = (r-1/2)/N$	1-F	b est	pred $\hat{v}med$
1	0.25	0.020	0.005	0.995	1.27	0.004		51	11.13	0.889	0.490	0.510		0.969
2	0.31	0.025	0.015	0.985	1.04	0.014		52	12.52	1.000	0.500	0.500		1.000
3	0.44	0.035	0.024	0.976	1.00	0.024		53	12.94	1.034	0.510	0.490		1.031
4	0.45	0.036	0.034	0.966	0.90	0.036		54	16.42	1.312	0.519	0.481		1.064
5	0.57	0.046	0.044	0.956	0.89	0.046		55	16.47	1.315	0.529	0.471		1.097
6	0.65	0.052	0.053	0.947	0.86	0.060		56	17.68	1.412	0.539	0.461		1.130
7	0.73	0.058	0.063	0.937	0.83	0.072		57	17.79	1.421	0.549	0.451		1.165
8	0.89	0.071	0.073	0.927	0.84	0.085		58	18.45	1.474	0.558	0.442		1.200
9	1.06	0.085	0.083	0.917	0.84	0.099		59	18.95	1.514	0.568	0.432		1.237
10	1.22	0.097	0.092	0.908	0.85	0.112		60	19.07	1.523	0.578	0.422		1.274
11	1.37	0.109	0.102	0.898	0.84	0.126		61	19.40	1.550	0.587	0.413		1.312
12	1.83	0.146	0.112	0.888	0.92	0.140		62	19.62	1.567	0.597	0.403		1.352
13	1.96	0.157	0.121	0.879	0.91	0.155		63	19.86	1.586	0.607	0.393		1.392
14	2.15	0.172	0.131	0.869	0.91	0.170		64	20.76	1.658	0.617	0.383		1.433
15	2.40	0.192	0.141	0.859	0.92	0.185		65	21.38	1.708	0.626	0.374		1.476
16	2.51	0.200	0.150	0.850	0.90	0.200		66	23.03	1.839	0.636	0.364		1.520
17	2.77	0.221	0.160	0.840	0.91	0.216		67	23.10	1.845	0.646	0.354	0.66	1.565
18	4.05	0.323	0.170	0.830	1.16	0.232		68	23.83	1.903	0.655	0.345	0.67	1.612
19	4.07	0.325	0.180	0.820	1.12	0.248		69	24.46	1.954	0.665	0.335	0.68	1.660
20	4.34	0.347	0.189	0.811	1.13	0.265		70	24.81	1.982	0.675	0.325	0.71	1.710
21	4.98	0.398	0.199	0.801	1.24	0.282		71	25.15	2.009	0.684	0.316	0.73	1.761
22	5.86	0.468	0.209	0.791	1.43	0.299		72	25.18	2.011	0.694	0.306	0.77	1.814
23	5.90	0.471	0.218	0.782	1.37	0.317		73	26.96	2.153	0.704	0.296	0.75	1.869
24	6.18	0.494	0.228	0.772	1.39	0.335		74	27.53	2.199	0.714	0.286	0.75	1.926
25	6.30	0.503	0.238	0.762	1.36	0.353		75	27.86	2.225	0.723	0.277	0.77	1.985
26	7.14	0.570	0.248	0.752	1.59	0.372		76	29.89	2.387	0.733	0.267	0.74	2.047
27	7.32	0.585	0.257	0.743	1.58	0.391		77	32.55	2.600	0.743	0.257	0.70	2.110
28	7.45	0.595	0.267	0.733	1.55	0.410		78	33.95	2.712	0.752	0.248	0.70	2.177
29	7.92	0.633	0.277	0.723	1.66	0.429		79	34.51	2.756	0.762	0.238	0.72	2.246
30	7.99	0.638	0.286	0.714	1.60	0.449		80	34.74	2.775	0.772	0.228	0.74	2.319
31	8.22	0.657	0.296	0.704	1.62	0.470		81	35.63	2.846	0.782	0.218	0.75	2.395
32	8.35	0.667	0.306	0.694	1.58	0.490		82	36.84	2.942	0.791	0.209	0.76	2.475
33	8.38	0.669	0.316	0.684	1.50	0.511		83	36.97	2.953	0.801	0.199	0.78	2.558
34	8.39	0.670	0.325	0.675	1.42	0.533		84	39.17	3.129	0.811	0.189	0.77	2.647
35	8.45	0.675	0.335	0.665	1.35	0.555		85	41.54	3.318	0.820	0.180	0.76	2.740
36	8.53	0.681	0.345	0.655	1.29	0.577		86	42.32	3.380	0.830	0.170	0.77	2.838
37	8.55	0.683	0.354	0.646	1.21	0.600		87	42.53	3.397	0.840	0.160	0.79	2.943
38	8.64	0.690	0.364	0.636	1.15	0.623		88	43.61	3.483	0.850	0.150	0.81	3.055
39	8.68	0.693	0.374	0.626	1.07	0.646		89	48.54	3.877	0.859	0.141	0.77	3.175
40	8.92	0.712	0.383	0.617	1.06	0.670		90	49.02	3.915	0.869	0.131	0.79	3.304
41	8.93	0.713	0.393	0.607	0.97	0.695		91	55.20	4.409	0.879	0.121	0.75	3.443
42	9.45	0.755	0.403	0.597	1.05	0.720		92	55.99	4.472	0.888	0.112	0.77	3.595
43	9.57	0.764	0.413	0.587	0.98	0.745		93	61.37	4.902	0.898	0.102	0.75	3.761
44	9.80	0.783	0.422	0.578	0.95	0.771		94	63.17	5.046	0.908	0.092	0.76	3.944
45	9.83	0.785	0.432	0.568	0.84	0.798		95	66.48	5.310	0.917	0.083	0.77	4.149
46	10.60	0.847	0.442	0.558	1.04	0.825		96	67.06	5.356	0.927	0.073	0.79	4.381
47	10.82	0.864	0.451	0.549	0.98	0.853		97	74.01	5.911	0.937	0.063	0.78	4.648
48	10.83	0.865	0.461	0.539	0.79	0.881		98	74.61	5.959	0.947	0.053	0.81	4.961
49	11.03	0.881	0.471	0.529	0.67	0.910		99	76.46	6.107	0.956	0.044	0.83	5.340
50	11.12	0.888	0.481	0.519	0.519	0.939		100	84.26	6.730	0.966	0.034	0.83	5.819
								101	89.87	7.178	0.976	0.024	0.85	6.465
								102	97.37	7.777	0.985	0.015	0.88	7.460
								103	119.09	9.512	0.995	0.005	0.91	9.641

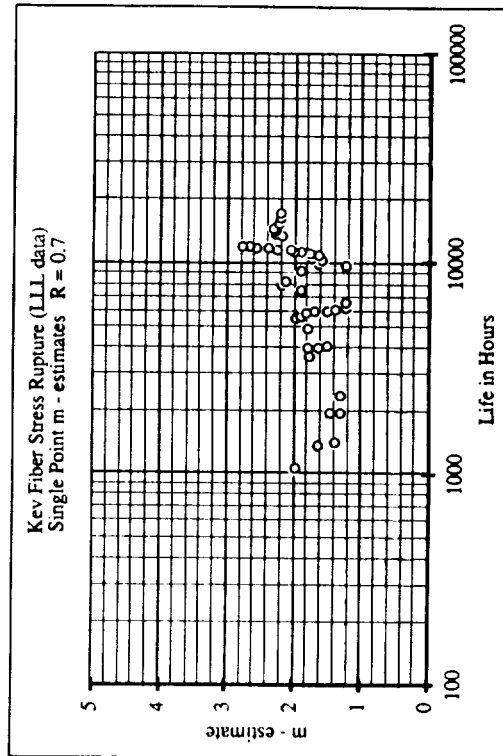
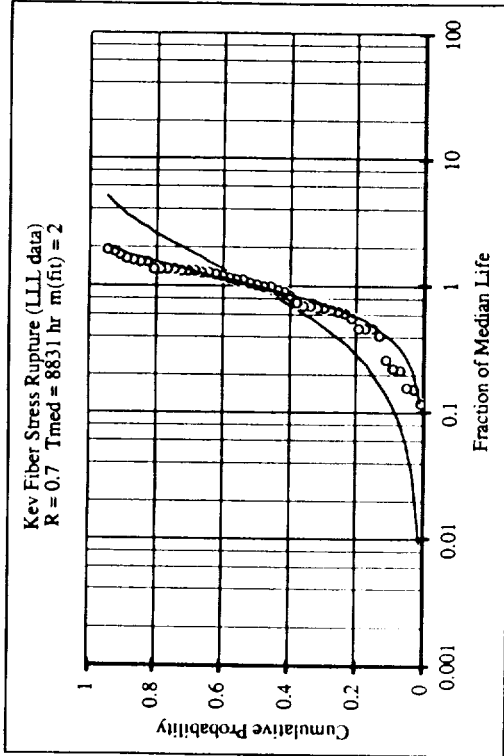
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r	Life - hrs	$\hat{m}$ med	F = $(r-1/2)/N$	S = 1-F	m = 0.9 fit	UCID 19849 404.6 ksi 0.8 N = 100 Med = 150.7 hr	r	Life - hrs	$\hat{m}$ med	F = $(r-1/2)/N$	S = 1-F	b est	b=0.9 pred
1	1.80	0.012	0.005	0.995	1.11	0.004	51	152.20	1.010	0.505	0.495		1.016
2	3.10	0.021	0.015	0.985	0.99	0.014	52	152.80	1.014	0.515	0.485	1.57	1.049
3	4.20	0.028	0.025	0.975	0.92	0.025	53	157.70	1.046	0.525	0.475	1.66	1.083
4	6.00	0.040	0.035	0.965	0.90	0.037	54	160.00	1.062	0.535	0.465	1.52	1.117
5	7.50	0.050	0.045	0.955	0.86	0.049	55	163.60	1.086	0.545	0.455	1.48	1.152
6	8.20	0.054	0.055	0.945	0.81	0.062	56	166.90	1.107	0.555	0.445	1.41	1.188
7	8.50	0.056	0.065	0.935	0.81	0.075	57	170.50	1.131	0.565	0.435	1.44	1.226
8	10.30	0.068	0.075	0.925	0.77	0.102	58	174.90	1.161	0.575	0.425	1.41	1.264
9	10.60	0.070	0.085	0.915	1.06	0.116	59	177.70	1.179	0.585	0.415	1.44	1.303
10	24.20	0.161	0.095	0.905	1.13	0.131	60	179.20	1.189	0.595	0.405	1.53	1.343
11	29.60	0.196	0.105	0.895	1.11	0.145	61	183.60	1.218	0.605	0.395	1.48	1.384
12	31.70	0.210	0.115	0.885	1.29	0.160	62	183.80	1.220	0.615	0.385	1.41	1.427
13	41.90	0.278	0.125	0.875	1.27	0.176	63	194.30	1.289	0.625	0.375	1.37	1.471
14	44.10	0.293	0.135	0.865	1.34	0.192	64	195.10	1.295	0.635	0.365	1.45	1.516
15	49.50	0.328	0.145	0.855	1.28	0.208	65	195.30	1.296	0.645	0.355	1.55	1.562
16	50.10	0.332	0.155	0.845	1.45	0.224	66	202.60	1.344	0.655	0.345	1.45	1.610
17	59.70	0.396	0.165	0.835	1.44	0.241	67	220.20	1.461	0.665	0.335	1.20	1.660
18	61.70	0.409	0.175	0.825	1.44	0.258	68	221.30	1.468	0.675	0.325	1.26	1.711
19	64.40	0.427	0.185	0.815	1.51	0.275	69	227.20	1.508	0.685	0.315	1.24	1.764
20	69.70	0.463	0.195	0.805	1.44	0.293	70	251.00	1.666	0.695	0.305	1.06	1.819
21	70.00	0.464	0.205	0.795	1.59	0.311	71	266.50	1.768	0.705	0.295	0.99	1.876
22	77.80	0.516	0.215	0.785	1.60	0.329	72	267.90	1.778	0.715	0.285	1.03	1.934
23	80.50	0.534	0.225	0.775	1.57	0.348	73	269.20	1.786	0.725	0.275	1.07	1.996
24	82.30	0.546	0.235	0.765	1.53	0.367	74	270.40	1.794	0.735	0.265	1.11	2.059
25	83.50	0.554	0.245	0.755	1.47	0.386	75	272.50	1.808	0.745	0.255	1.15	2.126
26	84.20	0.559	0.255	0.745	1.48	0.406	76	285.90	1.897	0.755	0.245	1.11	2.195
27	87.10	0.578	0.265	0.735	1.41	0.426	77	292.60	1.942	0.765	0.235	1.11	2.268
28	87.30	0.579	0.275	0.725	1.51	0.446	78	295.10	1.958	0.775	0.225	1.14	2.343
29	93.20	0.618	0.285	0.715	1.82	0.467	79	301.10	1.998	0.785	0.215	1.15	2.423
30	103.40	0.686	0.295	0.705	1.70	0.489	80	304.30	2.019	0.795	0.205	1.18	2.506
31	104.60	0.694	0.305	0.695	1.74	0.510	81	316.80	2.102	0.805	0.195	1.15	2.594
32	105.50	0.700	0.315	0.685	1.82	0.532	82	329.80	2.188	0.815	0.185	1.14	2.687
33	108.80	0.722	0.325	0.675	1.74	0.555	83	334.10	2.217	0.825	0.175	1.16	2.786
34	112.60	0.747	0.335	0.665	1.82	0.578	84	346.20	2.297	0.835	0.165	1.15	2.891
35	116.80	0.775	0.345	0.655	1.94	0.601	85	351.20	2.330	0.845	0.155	1.17	3.002
36	118.00	0.783	0.355	0.645	2.00	0.625	86	353.30	2.344	0.855	0.145	1.20	3.122
37	122.00	0.810	0.365	0.635	1.95	0.649	87	369.30	2.451	0.865	0.135	1.18	3.250
38	123.50	0.820	0.375	0.625	1.85	0.674	88	372.30	2.470	0.875	0.125	1.21	3.389
39	124.40	0.825	0.385	0.615	1.75	0.700	89	381.30	2.530	0.885	0.115	1.23	3.541
40	125.40	0.832	0.395	0.605	1.78	0.725	90	393.50	2.611	0.895	0.105	1.23	3.707
41	129.50	0.859	0.405	0.595	1.91	0.752	91	451.30	2.995	0.905	0.095	1.11	3.890
42	130.40	0.865	0.415	0.585	1.66	0.779	92	461.50	3.062	0.915	0.085	1.13	4.095
43	131.60	0.873	0.425	0.575	1.53	0.806	93	574.20	3.810	0.925	0.075	0.99	4.326
44	132.80	0.881	0.435	0.565	1.37	0.834	94	653.30	4.335	0.935	0.065	0.94	4.593
45	133.80	0.888	0.445	0.555	1.39	0.863	95	663.00	4.399	0.945	0.055	1.00	4.906
46	137.00	0.909	0.455	0.545	1.42	0.892	96	669.80	4.445	0.955	0.045	1.00	5.284
47	140.20	0.930	0.465	0.535	1.09	0.922	97	739.70	4.908	0.965	0.035	0.99	5.762
48	140.90	0.935	0.475	0.525	1.09	0.953	98	759.60	5.040	0.975	0.025	1.03	6.408
49	148.50	0.985	0.485	0.515	0.984		99	894.70	5.937	0.985	0.015	1.01	7.402
50	149.20	0.990	0.495	0.505			100	974.90	6.469	0.995	0.005	1.09	9.582

UCID 19849  
354 kn 0.7  
N = 49  
Med = 8831 hr



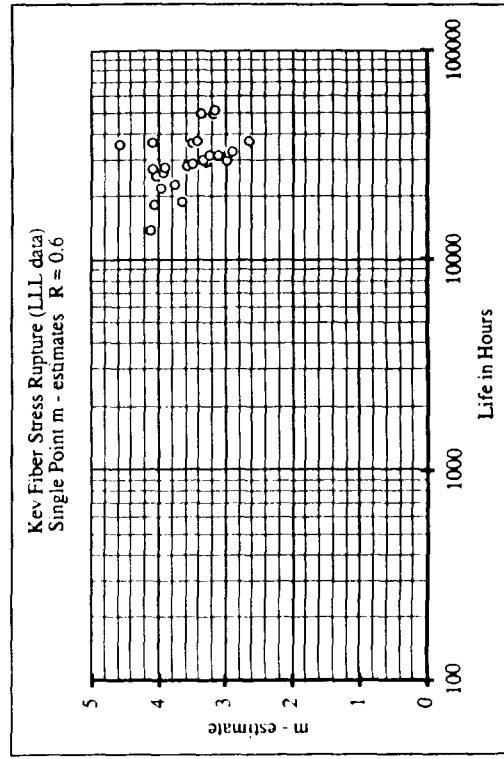
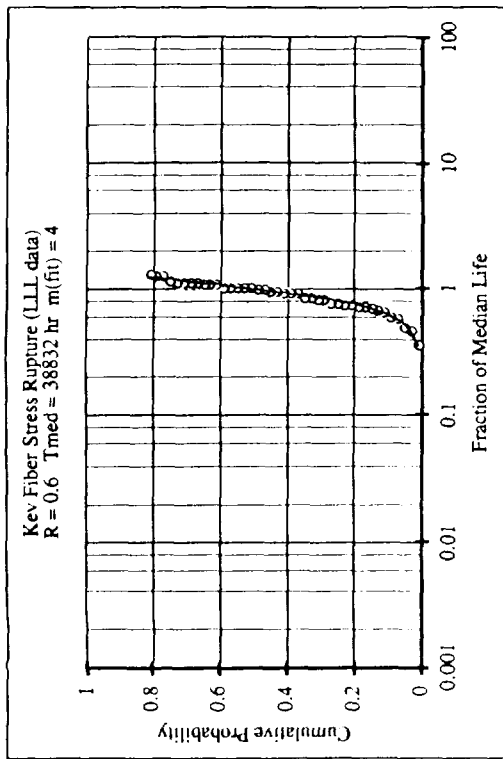
r	Life - hrs	$V_{med}$	$F = (r-1/2)/N$	$S = 1-F$	med	m = 0.9 fit	m = 1.5	m = 2
1	1051	0.119	0.010	0.990	1.96	0.009	0.060	0.122
2	1337	0.151	0.031	0.969	1.64	0.032	0.109	0.212
3	1389	0.157	0.051	0.949	1.40	0.057	0.158	0.275
4	1921	0.218	0.071	0.929	1.47	0.083	0.203	0.327
5	1942	0.220	0.092	0.908	1.30	0.112	0.244	0.373
6	2322	0.263	0.112	0.888	1.32	0.141	0.284	0.414
7	3629	0.411	0.133	0.867	1.78	0.172	0.323	0.453
8	4006	0.454	0.153	0.847	1.81	0.204	0.360	0.490
9	4012	0.454	0.173	0.827	1.64	0.238	0.398	0.524
10	4063	0.460	0.194	0.806	1.50	0.273	0.434	0.558
11	4921	0.557	0.214	0.786	1.81	0.309	0.470	0.590
12	5445	0.617	0.235	0.765	1.97	0.347	0.507	0.621
13	5620	0.636	0.255	0.745	1.89	0.386	0.543	0.652
14	5817	0.659	0.276	0.724	1.83	0.427	0.579	0.682
15	5905	0.669	0.296	0.704	1.69	0.469	0.615	0.711
16	5956	0.674	0.316	0.684	1.52	0.513	0.651	0.741
17	6068	0.687	0.337	0.663	1.40	0.559	0.688	0.770
18	6121	0.693	0.357	0.643	1.23	0.606	0.725	0.798
19	6473	0.733	0.378	0.622	1.22	0.656	0.762	0.827
20	7501	0.849	0.398	0.602	1.91	0.707	0.800	0.856
21	7886	0.893	0.418	0.582	2.17	0.761	0.839	0.884
22	8108	0.918	0.439	0.561	2.13	0.817	0.878	0.913
23	8546	0.968	0.459	0.541	0.936	0.875	0.918	0.942
24	8666	0.981	0.480	0.520	1.000	0.936	0.958	0.971
25	8831	1.000	0.500	0.500	1.90	1.000	1.000	1.000
26	9106	1.031	0.520	0.480	1.22	1.067	1.043	1.030
27	9711	1.100	0.541	0.459	1.22	1.137	1.086	1.060
28	9836	1.110	0.561	0.439	1.65	1.211	1.131	1.090
29	10205	1.156	0.582	0.418	1.58	1.290	1.178	1.121
30	10396	1.177	0.602	0.398	1.74	1.372	1.225	1.153
31	10661	1.230	0.622	0.378	1.64	1.459	1.275	1.185
32	11026	1.249	0.643	0.357	1.78	1.552	1.327	1.219
33	11214	1.270	0.663	0.337	1.89	1.651	1.380	1.253
34	11362	1.287	0.684	0.316	2.01	1.757	1.437	1.289
35	11604	1.314	0.704	0.296	2.06	1.870	1.496	1.325
36	11608	1.314	0.724	0.276	2.27	1.993	1.558	1.364
37	11745	1.330	0.745	0.255	2.38	2.125	1.624	1.404
38	11762	1.332	0.765	0.235	2.57	2.270	1.694	1.446
39	11895	1.347	0.786	0.214	2.68	2.429	1.769	1.491
40	12044	1.364	0.806	0.194	2.78	2.605	1.850	1.538
41	13520	1.531	0.827	0.173	2.18	2.801	1.939	1.590
42	13670	1.548	0.847	0.153	2.28	3.025	2.057	1.646
43	14110	1.598	0.867	0.133	2.28	3.282	2.147	1.707
44	14496	1.641	0.888	0.112	2.32	3.585	2.272	1.776
45	15395	1.743	0.908	0.092	2.23	3.952	2.419	1.856
46	16179	1.832	0.929	0.071	2.21	4.417	2.599	1.951
47	17092	1.935	0.949	0.051	2.21	5.047	2.831	2.072

1615

UCID 19849  
303.5 ksi 0.6  
N = 50  
Med = 38832 hr

r	Life - hrs	Wmed	F = (r-1/2)/N	S = 1-F	b est	b = 4 fit
1	13872	0.357	0.010	0.990	4.11	0.347
2	18024	0.464	0.030	0.970	4.07	0.458
3	19008	0.489	0.050	0.950	3.64	0.522
4	21960	0.566	0.070	0.930	3.96	0.569
5	22872	0.589	0.090	0.910	3.77	0.607
6	25008	0.644	0.110	0.890	4.05	0.640
7	25848	0.666	0.130	0.870	3.94	0.670
8	27216	0.701	0.150	0.850	4.08	0.696
9	27744	0.714	0.170	0.830	3.91	0.720
10	27840	0.717	0.190	0.810	3.58	0.743
11	28512	0.734	0.210	0.790	3.49	0.764
12	28896	0.744	0.230	0.770	3.30	0.784
13	29832	0.768	0.250	0.750	3.34	0.803
14	29832	0.768	0.270	0.730	2.99	0.821
15	31224	0.804	0.290	0.710	3.23	0.838
16	31752	0.818	0.310	0.690	3.10	0.855
17	32232	0.830	0.330	0.670	2.94	0.872
18	32976	0.849	0.350	0.650	2.91	0.888
19	35544	0.915	0.370	0.630	4.58	0.904
20	35760	0.921	0.390	0.610	4.10	0.919
21	35928	0.925	0.410	0.590	3.51	0.934
22	36528	0.941	0.430	0.570	3.43	0.949
23	36720	0.946	0.450	0.550	2.65	0.964
24	38592	0.994	0.470	0.530	0.978	0.978
25	38592	0.994	0.490	0.510	0.993	0.993
26	39072	1.006	0.510	0.490	1.007	1.007
27	39240	1.011	0.530	0.470	1.022	1.022
28	39576	1.019	0.550	0.450	1.036	1.036
29	39744	1.023	0.570	0.430	1.050	1.050
30	39744	1.023	0.590	0.410	1.065	1.065
31	41592	1.071	0.610	0.390	1.094	1.094
32	41760	1.075	0.630	0.370	1.109	1.109
33	41760	1.075	0.650	0.350	1.125	1.125
34	42600	1.097	0.670	0.330	1.140	1.140
35	42600	1.097	0.690	0.310	1.156	1.156
36	42960	1.106	0.710	0.290	1.172	1.172
37	43176	1.112	0.730	0.270	1.189	1.189
38	44664	1.150	0.750	0.250	1.207	1.207
39	49176	1.266	0.770	0.230	3.18	1.225
40	49440	1.273	0.790	0.210	3.36	1.244
41	51192	1.318	0.810	0.190		

repeat\*  
repeat\*  
repeat\*  
repeat\*



UCID 19849	r	Life - hrs	t/t4	F = (r-1/2)/N	S = 1-p	m est	Est Median	t/med	m fit	m =
252 ksi 0.5	1	31344	0.475	0.010	0.990	2.65	154536	0.209	0.244	3.000
N = 50	2	32376	0.490	0.030	0.970	1.22	420866	0.216	0.353	
r=4 life = 66024	3	58056	0.879	0.050	0.950	2.70	152386	0.387	0.420	
	4	66024	1.000	0.070	0.930			0.440	0.471	

(150,000)

