NASA Technical Paper 1809

MEGA16 - Computer Program for Analysis and Extrapolation of Stress-Rupture Data

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C. Robert Ensign
Lewis Research Center
Cleveland, Ohio

National Aeronautics
and Space Administration

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Summary

The computerized form of the minimum commitment method of interpolating and extrapolating stress versus time to failure data is a program called MEGA16. This report describes MEGA16, giving examples of its many plots and tabular outputs for a typical set of data. The program assumes a specific model equation and then provides a family of predicted isothermals for any set of data with at least 12 stress-rupture results from three different temperatures spread over reasonable stress and time ranges. It is written in Fortran IV using IBM plotting subroutines, and it runs on an IBM 370 time sharing system.

Introduction

Fundamental to current design practice of ground power turbine equipment is an estimate of a maximum allowable stress at which a particular material can be expected to survive for at least 100 000 hours (11.6 yr) of exposure to a specified temperature. The search for a simple, reliable method of predicting such an estimated stress has been pursued for many years, by many individuals, using many scientific and empirical techniques (refs. 1 and 2). One of the more common approaches involves the use of a time-temperature parameter to extrapolate data from the standard stress-rupture test results. In such a method a model equation relating observed rupture life to temperature and stress is assumed, and its unknown terms are estimated using available test data. Characteristically, the data for a particular material are sparse, cover limited ranges of stress and temperature, or else are collected from a mixture of different heats, product forms, or other manufacturing and testing variables. In addition, the model itself introduces other assumptions and oversimplifications. Nonetheless, a time-temperature parameter is expected to furnish a reasonable estimate of maximum allowable stress at a given life or life at a given stress. This can be used in the design of machine components that are required to operate at high temperatures for extended periods.

The purpose of this paper is to present the computer program, MEGA16 (Manson Ensign Generalized Analysis, Version 16), which has been developed as an objective, fast, and reliable way to use a particular time-temperature method. The method, often referred to as the "minimum commitment method," has been described previously (ref. 3). Results from its application to many sets of data using MEGA16 have been published (ref. 4); they compare favorably with results from other manual and computerized methods. A complete listing of MEGA16 and its subroutines is given in the appendix.

Program Description

General Features

Basically, MEGA16 is a computer program which fits, to one or many sets of input data, a model equation of the form

$$\log t + A\mathcal{P} \log t + \mathcal{P} = \mathcal{G}$$

where $\mathcal{P}$ and $\mathcal{G}$ are temperature and stress functions, each with several coefficients to be determined. MEGA16 produces a series of plots that represent these functions and the stress rupture behavior of the material over the range of input data and to an extrapolated time to failure of up to 100 000 hours.

There are three sections to the main program (fig. 1): The first contains all the general housekeeping (dimensions, constants, etc.) and reading of data and variables associated with a given set of data. The second has the main loop which sets up and solves the equations for each value of an adjustable parameter called A, calculates the predicted values and statistics, prints the tabular results, and plots the curves for that A value. The third section produces other ancillary plots to show the merits of various A values used and the residuals of logarithm of time to failure versus other variables to indicate any trends that may have resulted with the model equation and the given data.

After looping through the various A values selected in the second section of the program (plus an extra A value read in the data) and doing the final plots in the third section, the program then goes on to the next set of data for another material and repeats the whole procedure. Thus a great number of data sets may be handled with one loading of the program.

Published stress-rupture data usually include fewer than 100 specimens for a material. The present form of MEGA16 can handle 200 data points per set; this

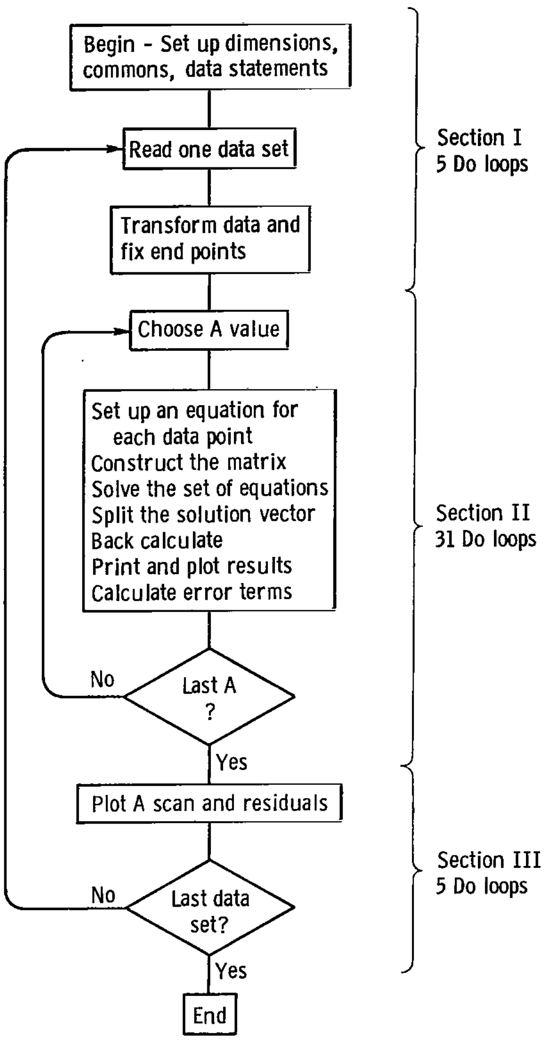


Figure 1. - Flowchart for MEGA16.

value could be increased, if necessary, by appropriate expansion of dimensions. The maximum size of the matrix to be inverted is 200 by 48. For this model equation the 48 dimension could be reduced considerably since there are not as many terms as in other model equations using this same framework. Since MEGA16 has been developed on a computer which has virtual memory, minimal effort was devoted to minimize storage requirements.

Input

Figure 2 is an example, with annotations, of the standard input data format required by MEGA16. The format is not efficient in terms of storage space required, but is has been very convenient for sorting, editing, and changing the constants of the control cards and raw data. It also affords considerable room for expansion or addition of other information, such as creep behavior, tensile strength, or even comments about a particular data point. The first nine lines of every data set give the title, counters, constants, plotting values, and the number of data that follow. Each datum is then given on succeeding lines, with (from left to right) the values for temperature (in deg F), stress (in ksi), hours to failure, and number of times the point is to be weighted, along with other comments or information that will not be read by the program. The data are usually listed in the order of increasing temperature and decreasing stress. Also, all data with the same temperature are grouped together, while data with the same temperature and stress value are grouped in order of increasing life. Of course these formats could be changed to match a given set of data, but we have found it preferable to use a second program which transforms data from another format to this format. At the present, many data sets, for over 30 different materials, are stored on tape in this form, ready to run.

Calculations

The general equation used for MEGA16 (ref. 4) is

$$\log t + A \log t \, \mathcal{P}(T) + \mathcal{P}(T) = \mathcal{G}(\log S) \qquad (1)$$

where

t	time to rupture, hr
A	a constant
$\mathcal{P}(T)$	a function for discrete temperature values
$\mathcal{G}(\log S)$	a stress function
S	σ/σ_o
σ	a given stress value
σ_o	a reference stress, near midrange

The constant A takes on selected values from -0.2 to 0.2 and also can be modified by the following equation:

$$A^* = A\left[1 - \text{AKON}\left(\frac{T - T_{mid}}{T_{mid} + 460}\right)^2\right] \qquad (2)$$

where

T	a given temperature value
T_{mid}	a reference temperature at midrange
AKON	a constant, usually 0, 15, or 30

The temperature function $\mathcal{P}(T)$ is expressed in the form of a station function, which is mathematically similar to a LaGrangian interpolation (see fig. 3 and ref. 3). The stress function is composed of two parts, each of the form

```
33  ASTROLOY        MEGA16
   0     3     0     1
   5     5     3     5     1
1400  1500  1600  1700  1800
1400  1500  1600  1700  1800
1400  1500  1600  1700  1800
1.16  1.632.004
  33    33   99000   -0.15     FTFTFTFTTFTTTFTTT
 100    80    60    50    40    30    20    10   1.0 -1.0
1400101.        12.8       0
1400 86.        59.        0
1400 80.       176.6       0
1400 74.       400.7       0
1400 70.       577.        0
1400 61.      2279.8       0
1400 55.      4063.2       0
1500 75.        30.5       0
1500 64.       142.2       0
1500 56.       351.3       0
1500 52.       712.        0
1500 45.      1228.3       0
1500 39.      2227.4       0
1500 31.      4393.4       0
1600 64.        10.5       0
1600 56.5       28.8       0
1600 46.5      145.8       0    total of NODU values
1600 41.       253.0       0
1600 37.       535.7       0
1600 31.       888.        0
1600 24.5     2899.7       0
1600 19.      6331.        0
1700 41.        11.5       0
1700 33.5       44.2       0
1700 29.       120.9       0
1700 24.       342.7       0
1700 21.       746.7       0
1700 17.5     1768.7       0
1700 14.5     2838.7       0
1800 29.5        6.1       0
1800 20.5       49.3       0
1800 17.       174.        0
1800 14.5      340.7       0
```

```
VARIABLE  NAMES                            FORMAT

TITEL                                      16A4
NF   NP   NG   MK                          16I5
NL   NT   NS   NISO   NXAV                 16I5
CISOT                                      16F5.0
ALOGT=TSTA                                 16F5.0
TSTA                                       16F5.0
SSTA                                       16F5.0
NODU   NODT   CUTOF   AEXT   OPT           2I5,F9.1,F6.3,4X,17L1
CONSTR   (fields 9&10 = ALPHA)             16F5.0
TMP    SIG   AT   WF   BATCH               F5.0,F7.3,F8.2,2F5.0
```

```
COLUMN     VARIABLE       UNITS

  1        temperature    degrees   F
  2        stress         KSI
  3        time           hours
  4        weighting
```

Figure 2. - Typical data set and input format for MEGA16.

$$\mathcal{G}(\log S) = D + E \log S + F S^{\pm\alpha} \tag{3}$$

where

α an integer, usually $+1$ for $\sigma \leq \sigma_o$ and -1 for $\sigma > \sigma_o$

The two parts are connected at a *spline point* where the second derivatives with respect to log S are forced to be equal and will also be continuous if $\alpha = -\alpha$.

The calculations of MEGA16 begin with the expression of each of the input data points in this form of the model equation

$$\log t_i = \mathcal{P}(T)\left[A^* \log t_i + 1\right] + D + E \log\left(\frac{\sigma_i}{\sigma_o}\right) + F_1 \times \left[\frac{(\sigma_i/\sigma_o)^\alpha}{5.30\alpha^2} - \frac{1}{5.30\alpha^2} - \frac{\log(\sigma_i/\sigma_o)}{2.30\alpha}\right] + F_2\left[\frac{(\sigma_i/\sigma_o)^\alpha}{5.30\alpha^2} - \frac{1}{5.30\alpha^2} - \frac{\log(\sigma_i/\sigma_o)}{2.30(-\alpha)}\right] \tag{4}$$

where

F_1 is set equal to 0 for $\sigma > \sigma_o$

F_2 is set equal to 0 $\sigma \leq \sigma_o$

For the number of data used, i = NODU, and the model equation, a matrix of NODU by (NPAR + 1) dimensions is formed and then inverted to provide estimates for the coefficients D, E, F_1, and F_2, as well as the station function values representing the NP discrete temperatures. Figure 4 shows, for a set of data with unevenly spaced test temperatures, an example of this input matrix. The solution, by MEGA16, of this set of equations representing the iron-nickel alloy A-286 (ref. 1) gave these coefficients: $p_i = -2.17,\ -0.81,\ 0.0,\ 1.39,\ 2.64$; $D = 3.79$; $E = -4.33$; $F_1 = 2.25$; and $F_2 = -61.41$. Predicted values of the logarithm of time to rupture are made by MEGA16 using the coefficients with combinations of temperature and stress increments. To provide the predicted isothermals, equation (4) is rewritten as

$$\log t_{est} = \mathcal{G}_{est} + \mathcal{P}_{est} \tag{5}$$

where

$$\mathcal{P}_{est} = p_1 T_1 + p_2 T_2 + \ldots + p_{NP} T_{NP} \tag{6}$$

$$P(T) = p_{n-1}K_{n-1} + p_nK_n + p_{n+1}K_{n+1} + p_{n+2}K_{n+2}$$

where

$$K_{n-1} = \frac{1}{2}\,\frac{(T-T_n)(T-T_{n+1})}{(T_n-T_{n-1})(T_{n+1}-T_{n-1})}$$

$$K_n = \frac{1}{2}\,\frac{(T-T_{n-1})(T-T_{n+1})(T_n-T_{n+2}) + (T-T_{n+1})(T-T_{n+2})(T_n-T_{n-1})}{(T_n-T_{n-1})(T_n-T_{n+1})(T_n-T_{n\pm2})}$$

$$K_{n+1} = \frac{1}{2}\,\frac{(T-T_{n-1})(T-T_n)(T_{n+1}-T_{n+2}) + (T-T_n)(T-T_{n+2})(T_{n+1}-T_{n-1})}{(T_n-T_{n+1})(T_{n+1}-T_{n-1})(T_{n+1}-T_{n+2})}$$

$$K_{n+2} = \frac{1}{2}\,\frac{(T-T_n)(T-T_{n+1})}{(T_n-T_{n+2})(T_{n+1}-T_{n+2})}$$

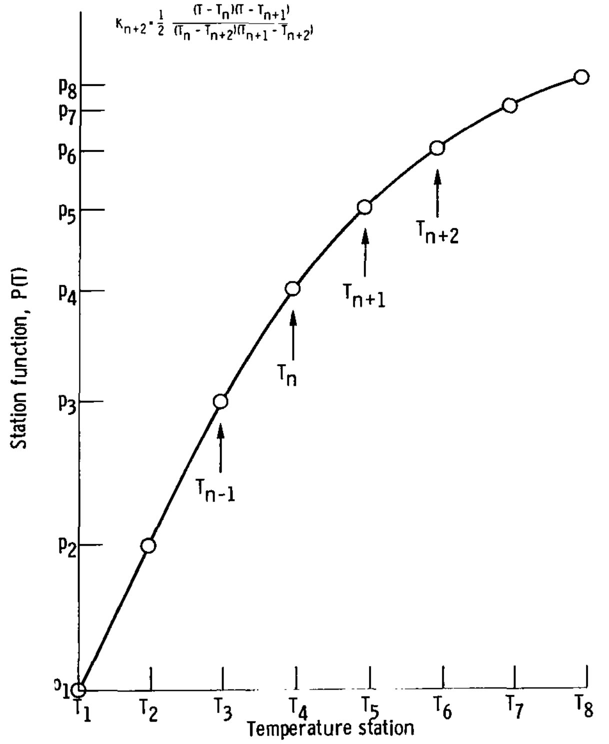


Figure 3. - Idealized temperature function, showing T_i, the discrete values of temperature stations, and corresponding p_i, or station function values.

$$\mathcal{G}_{est} = D + E + \log\left(\frac{\sigma_i}{\sigma_o}\right) + F\left[\frac{(\sigma_i/\sigma_o)^\alpha}{5.30\alpha^2} - \frac{1}{5.30\alpha^2} - \frac{\log(\sigma_i/\sigma_o)}{2.30\alpha}\right] \quad (7)$$

This permits log t_{est} values to be calculated for evenly spaced values of $\log(\sigma_i/\sigma_o)$, which are then plotted versus log stress.

Another important part of the calculation is the estimation of error. The standard deviation of the data used gives an idea of how well the model equation fits over the range of the input variables. It is calculated using

$$\text{Standard deviation} = \sqrt{\frac{\sum_{i=1}^{\text{NODU}} (\log t_i - \log \hat{t}_i)^2}{\text{NODU} - \text{NPAR} - 1}} \quad (8)$$

where

log t_i	logarithm of observed life values
log $\hat{t}_i$	logarithm of predicted life values
NODU	number of data used
NPAR	number of parameters

Output

Figure 5 gives examples of the long and short tabular outputs from a run using the input data from figure 2. Figures 6 shows some of the 16 frames that were plotted on microfiche using an adaptation of an IBM system of plotting (ref. 5). Five plots for each of three *A* values plus the one *A* scan were requested by the series of *F*'s and *T*'s (*F* gives a plot, *T* omits it) in the eighth line of input for this material (fig. 2). The first two *A* values (0 and −0.5) were specified by a statement in the main program of MEGA16, and the third *A*(−0.15) was specified in the data set (also line 8 of fig. 2).

Experience has shown that analysis of a given material is seldom, if ever, completed by the first run of that data set. This, coupled with the fact that constant *A* in the model equation of MEGA16 needs to be optimized, leads to the dual system of selecting trial *A* values; that is, a few values over the range of possible *A* values (−0.2 to 0.2) are set in the beginning of the main program as starting values; 0.1 and −0.05 are useful for a new set of data. A plot of the standard deviation values versus a few *A* values often indicates a U-shaped pattern, pointing to a possible minimum standard deviation at another *A* value. This other *A* value can then be the one read in with the data as the "extra *A*" value (line 8 of fig. 2 and −0.15 above) for succeeding runs. The short form of the tabular output lists only the standard deviation results for specified *A* values and thus is used without any other output as a quick means of finding the best *A* value.

Computer Program Details

MEGA16 consists of a main program of 1300 lines and subroutines totaling 500 lines, including many for documentation. For a typical single set of data on an IBM 370 time sharing system, 15 seconds of central processing time are required, but this drops

Matrix column number				1	2	3	4	5	6	7	8	9
Row	T, °F	σ, ksi	t, hr	log t	k_1	k_2	k_4	k_5	g_1	g_2	g_3	g_4
1	1050	76	81.4	1.911	0.904	0	0	0	1.0	0.321	0	0.041
2		72	97.9	1.991	.900					.297		.036
3		69	210.2	2.323	.834					.279		.032
4		67	523.3	2.719	.864					.266		.029
5	↓	56	12833.6	4.108	.795	↓				.188		.015
6	1100	68	352.1	2.547	.291	0.873				.273		.030
7	1150	65	41.9	1.622	0	.919				.253		.027
8		62	177.7	2.250		.888				.232		.023
9		54	644.4	2.809		.860				.172		.013
10		43	6752.8	3.829		.808				.073		.003
11	↓	38	15460.8	4.189		.791				.020		.0002
12	1200	60	18.9	1.276		0				.218		.020
13		56	154.1	2.188						.188		.015
14		54	385.6	2.586						.172		.013
15		47	839.0	2.924						.112	↓	.006
16		35	6882.4	3.838						-.016	0.0001	0
17	↓	29	17826.5	4.251			↓			-.098	.0044	0
18	1300	40	146.9	2.167			0.892			.042	0	.00086
19	1300	37	335.2	2.525			.874			.008	0	.00003
20	1300	30	1245.7	3.095			.845	↓		-.083	.0032	0
21	1350	30	282.4	2.451			.658	0.329		-.083	.0032	
22	1400	30	49.3	1.693			0	.915		-.083	.0032	
23	1400	22	339.0	2.530			0	.873		-.217	.0202	
24	1400	15	2287.2	3.359	↓	↓	0	.832	↓	-.384	.056	↓

$$k = P(T)[A^{*} \cdot \log t + 1] = P(T) \cdot A \cdot \log t + P(T) \text{ since AKON} = 0$$

$$g_2 = \log(\sigma/\sigma_0) \qquad g_{3,4} = \left[\frac{(\sigma/\sigma_0)^{\alpha}}{\alpha^2(\ln 10)^2} - \frac{1}{\alpha^2(\ln 10)^2} - \frac{\log(\sigma/\sigma_0)}{\alpha \ln 10}\right]$$

Figure 4. - Example of input matrix for MEGA16. Material is A-286 steel (ref. 1). Value of A =-0.05; AKON = 0; spline point = 1.56. Temperature stations are 1050°, 1150°, 1200°, 1300°, and 1400° F.

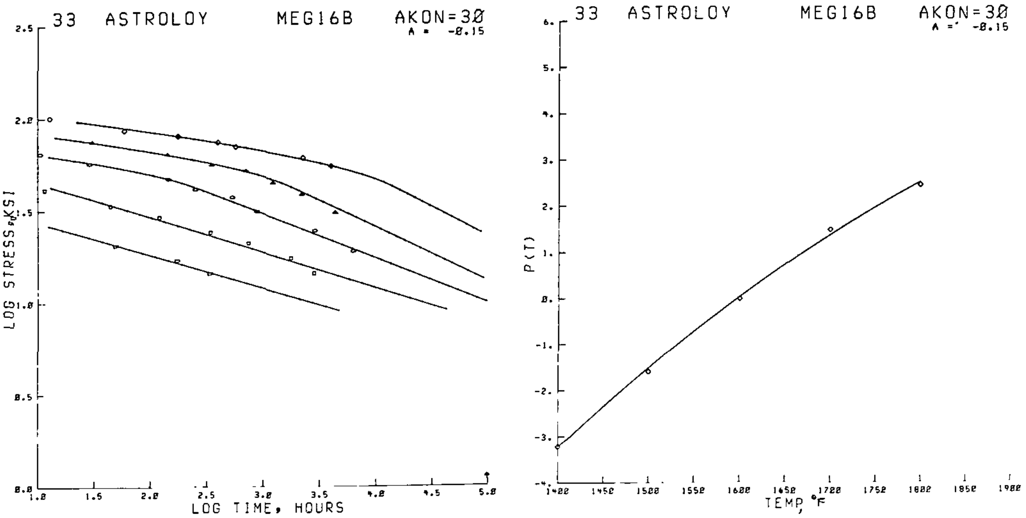
```
 RESULTS FROM MEG16B
            LOGH + A LOGH * P(T) + P(T) = G(SIGMA)
                                                    33  ASTROLOY      MEGA16
 THE VALUES OF  A    =       0.000  -0.050   0.150
S. D. OF DATA USED   =       0.121   0.107   0.079
```

(a) Short printout.

```
 RESULTS FROM MEG16B
            LOGH + A LOGH * P(T) + P(T) = G(SIGMA)
                                                    33  ASTROLOY      MEGA16
G STATIONS
           1.160      1.630      2.004
P STATIONS
         1400.000  1500.000  1600.000  1700.000  1800.000
 G  COEFFICIENTS
           2.373     -4.327     -0.786    -46.084
 P  STATION FUNCTION
          -3.204     -1.582      0.000      1.494      2.460
     DATA USED IN CALCULATION                          THE VALUE OF 'A'  =    -0.150
                   LOG TIME                            TEMP  LOG STRESS    G          P
          OBS         PRED       DIFF      SUM SQ
        1.10721    1.10545   0.00176   0.00000      1400.0    2.00432  -1.71770  -3.20422
        1.77085    1.89317  -0.12232   0.01496      1400.0    1.93450  -0.65844  -3.20422
        2.24699    2.22124   0.02575   0.01563      1400.0    1.90309  -0.21727  -3.20422
        2.60282    2.55466   0.04815   0.01795      1400.0    1.86923   0.23109  -3.20422
        2.76118    2.77860  -0.01742   0.01825      1400.0    1.84510   0.53222  -3.20422
        3.35790    3.27931   0.07858   0.02443      1400.0    1.78533   1.20554  -3.20422
        3.60887    3.60017   0.00870   0.02450      1400.0    1.74036   1.63700  -3.20422
        1.48430    1.42398   0.06032   0.02814      1500.0    1.87506   0.15600  -1.58200
        2.15290    2.10151   0.05139   0.03078      1500.0    1.80618   0.98295  -1.58200
        2.54568    2.57996  -0.03428   0.03196      1500.0    1.74819   1.56691  -1.58200
        2.85248    2.80454   0.04794   0.03425      1500.0    1.71600   1.84101  -1.58200
        3.08930    3.14803  -0.05872   0.03770      1500.0    1.65321   2.26024  -1.58200
        3.34780    3.37789  -0.03009   0.03861      1500.0    1.59106   2.54079  -1.58200
        3.64280    3.72627  -0.08347   0.04557      1500.0    1.49136   2.96600  -1.58200
        1.02119    0.98295   0.03824   0.04704      1600.0    1.80618   0.98295   0.00000
        1.45939    1.53154  -0.07214   0.05224      1600.0    1.75205   1.53154   0.00000
        2.16376    2.17941  -0.01565   0.05249      1600.0    1.66745   2.17941   0.00000
        2.40312    2.44727  -0.04415   0.05444      1600.0    1.61278   2.44727   0.00000
        2.72892    2.63887   0.09005   0.06254      1600.0    1.56820   2.63887   0.00000
        2.94841    2.96600  -0.01759   0.06285      1600.0    1.49136   2.96600   0.00000
        3.46235    3.39594   0.06642   0.06726      1600.0    1.38917   3.39594   0.00000
        3.80147    3.85515  -0.05367   0.07015      1600.0    1.27875   3.85515   0.00000
        1.06070    1.20350  -0.14280   0.09054      1700.0    1.61278   2.44727   1.49449
        1.64542    1.67817  -0.03275   0.09161      1700.0    1.52504   2.82306   1.49449
        2.08243    2.01334   0.06909   0.09638      1700.0    1.46240   3.08840   1.49449
        2.53491    2.44908   0.08583   0.10375      1700.0    1.38021   3.43337   1.49449
        2.87315    2.75423   0.11892   0.11789      1700.0    1.32222   3.67494   1.49449
        3.24765    3.16826   0.07940   0.12419      1700.0    1.24304   4.00272   1.49449
        3.45312    3.59262  -0.13950   0.14365      1700.0    1.16137   4.33868   1.49449
        0.78533    0.81155  -0.02622   0.14434      1800.0    1.46982   3.05707   2.46033
        1.69285    1.71094  -0.01809   0.14467      1800.0    1.31175   3.71840   2.46033
        2.24055    2.16821   0.07234   0.14990      1800.0    1.23045   4.05464   2.46033
        2.53237    2.55450  -0.02212   0.15039      1800.0    1.16137   4.33868   2.46033
                  33  ASTROLOY      MEGA16
                                                     THE VALUE OF 'A'  =    -0.150
S. D. OF RES =   0.079  DOF =   24.0  SUM OF RES =   0.012  AV ABS DEV =   0.057
```

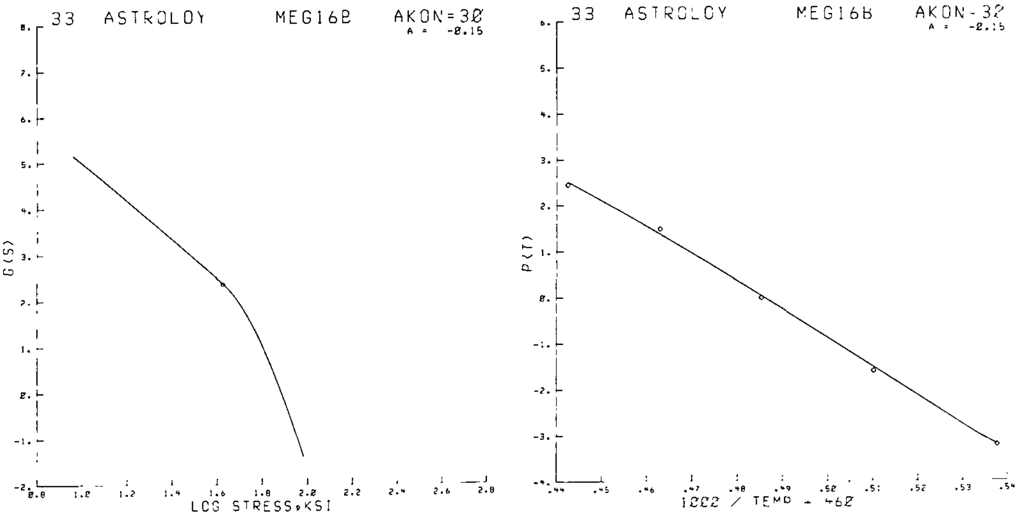
(b) Long printout.

Figure 5. - Example of output from MEGA16.



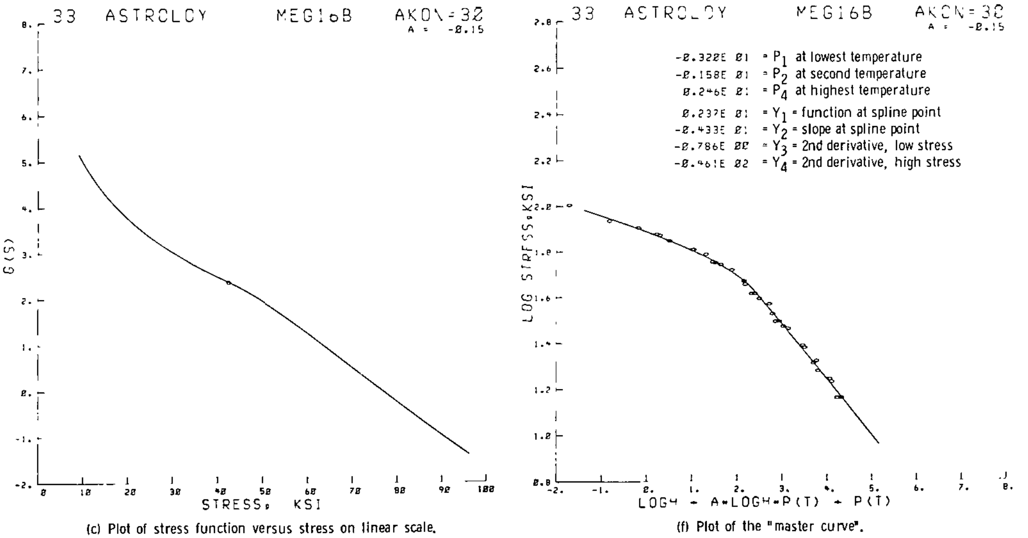
(a) Plot of input data and predicted isothermals.

(d) Plot of temperature function.



(b) Plot of stress function versus log stress.

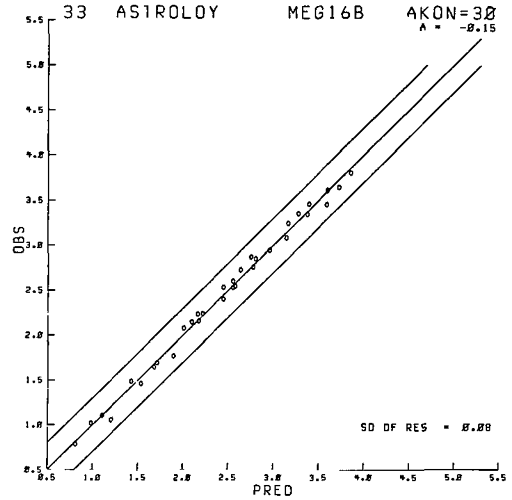
(e) Plot of temperature function versus temperature on a reciprocal scale.



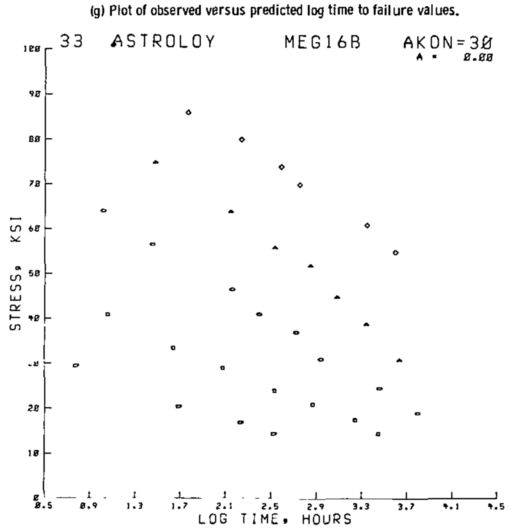
(c) Plot of stress function versus stress on linear scale.

(f) Plot of the "master curve".

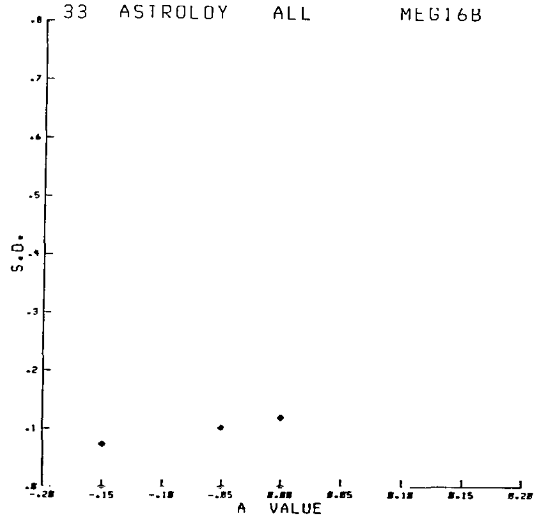
Figure 6. - Sample plots.



(g) Plot of observed versus predicted log time to failure values.



(h) Plot of raw data for preassessment using linear stress scale.



(i) The A scan: observed standard deviation versus selected A value.

Figure 6. - Concluded.

rapidly to about 5 seconds per data set, if many sets are run consecutively after the program is loaded. When run on this virtual memory computer MEGA16 uses approximately 2800 K of eight bit bytes.

Discussion

The question of accuracy, somewhat exemplified by the observed versus predicted plot in each run of MEGA16, has been discussed (refs. 1 to 3), but not really answered. A point not always considered is that the accuracy of a prediction cannot be much better than the precision of the data used to make that prediction. Of course the scatter of a given set of creep-life data depends on many unquantified variables in the general categories of test procedure, metallurgical differences, environment, etc. Estimates of the extent or importance of this scatter are not often presented with creep-life data. Few researchers are inclined to run the expensive replicate tests necessary to given meaningful estimates of the experimental error for various materials and laboratory conditions. To provide a rough estimate of scatter to be found in creep-life experiments, the data analyzed in the development of MEGA16 (ref. 4) were also used to provide the measures of average deviations in table I. Shown are some statistics for the temperature and stress combinations which had three or more repeat tests. Using the usual assumption of a lognormal distribution of time to failure, the last column of this table shows a fairly wide variation in the scatter about the mean log life for various combinations of material temperature and stress. For some materials standard deviations of 0.1 appear to be typical, but for others 0.2 or over are to be expected. Therefore, it is reasonable to assume that the best accuracy to be achieved from a predictive technique will also be somewhere in the range of 0.1 of a decade of the logarithm of the time to rupture, but there will be cases of higher deviation for certain materials and testing conditions.

With the stress function of MEGA16, there is the need for choosing an intermediate value of the logarithm of stress to be used as the spline point. Normally, a value somewhere near the midrange of stress will suffice, but for some data selection of another log stress value will change the fit and give different extrapolations. As an example, some additional calculations were made using the type 316 stainless steel set of data used in reference 4. In that report the location of the spline point for this material had been, for other reasons, selected at a point somewhat distant from the midrange. Figures 7 and 8 show the isothermals and master curves for some of the selected combinations of *A* and spline point locations. Table II gives the resulting standard

TABLE I.—STATISTICS OF REPEAT MEASUREMENTS

TEMP F	STRESS KSI	NO. OF REPEATS	LIFE		LOG LIFE	
			MEAN (a)	C.V. (b)	MEAN (a)	S.D. (c)
			64 1100-O ALUMINUM			
482.	6.0	3	299.67	41.63	2.445	0.212
482.	5.5	3	1274.67	58.67	3.055	0.258
662.	4.0	3	49.17	7.22	1.691	0.031
662.	3.5	4	203.75	14.28	2.306	0.061
752.	3.5	6	13.08	37.86	1.097	0.136
752.	3.0	7	62.71	15.99	1.793	0.070
932.	1.5	3	224.33	26.17	2.340	0.122
						0.127
			75 5454-O ALUMINUM			
662.	14.0	3	81.67	26.67	1.902	0.112
662.	11.0	5	436.00	14.32	2.636	0.063
752.	9.0	7	165.71	13.50	2.216	0.059
842.	7.0	4	96.50	9.48	1.983	0.041
932.	5.0	3	113.00	13.74	2.050	0.060
						0.067
			95 INCO 625			
1200.	70.0	6	46.57	83.72	1.501	0.476
1200.	55.0	3	769.53	69.57	2.781	0.409
1300.	50.0	4	46.67	80.86	1.549	0.382
1300.	45.0	7	246.94	54.79	2.307	0.336
1400.	30.0	5	267.52	69.10	2.326	0.350
1500.	20.0	5	43.18	32.88	1.617	0.139
1500.	17.5	5	87.66	22.75	1.933	0.107
1500.	15.0	9	506.80	73.06	2.601	0.321
1500.	12.5	4	1722.42	53.93	3.171	0.298
1500.	10.0	5	7117.70	34.85	3.834	0.139
1600.	12.0	3	44.00	19.38	1.638	0.082
						0.276
			105 U-500			
1200.	140.0	6	7.53	35.93	0.846	0.192
1200.	100.0	8	1092.57	57.37	2.981	0.239
1500.	60.0	8	17.99	31.58	1.235	0.141
1500.	30.0	6	1060.93	50.99	2.959	0.288
1800.	9.0	3	83.57	59.33	1.849	0.337
						0.239
			104 L-605			
1200.	60.0	8	7.56	38.03	0.851	0.166
1200.	40.0	6	1129.18	30.59	3.035	0.140
1500.	30.0	8	14.45	28.42	1.147	0.111
1500.	17.0	7	1618.47	19.68	3.201	0.092
						0.127
			101 6061-T6 ALUMINUM			
662.	26.0	3	173.00	18.05	2.234	0.076
752.	26.0	3	28.37	133.22	1.163	0.602
752.	21.0	6	76.67	20.27	1.878	0.077
842.	13.0	4	184.38	30.40	2.250	0.134
842.	11.0	3	751.33	22.10	2.869	0.092
932.	13.0	4	19.30	59.09	1.225	0.267
932.	11.0	3	74.33	12.50	1.869	0.056
1112.	4.0	3	133.33	7.09	2.124	0.030
						0.167

[a] $\text{MEAN} = \dfrac{\Sigma x}{n}$

[b] $\text{C.V.} = \dfrac{\sqrt{\text{VAR}}}{\text{MEAN}} \times 100$

[c] $\text{S.D.} = \sqrt{\text{VAR}}$ where $\text{VAR} = \dfrac{\Sigma x^2 - (\Sigma x)^2/n}{n-1}$

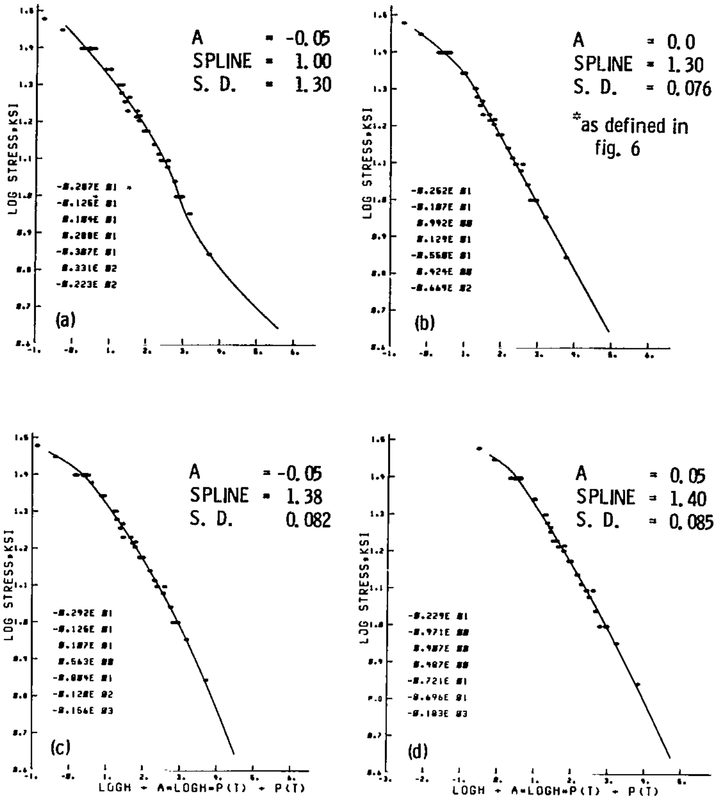


Figure 8. - Results from MEGA16 showing effect of different A values and spline points on shape of master curves. Material, 316 stainless steel.

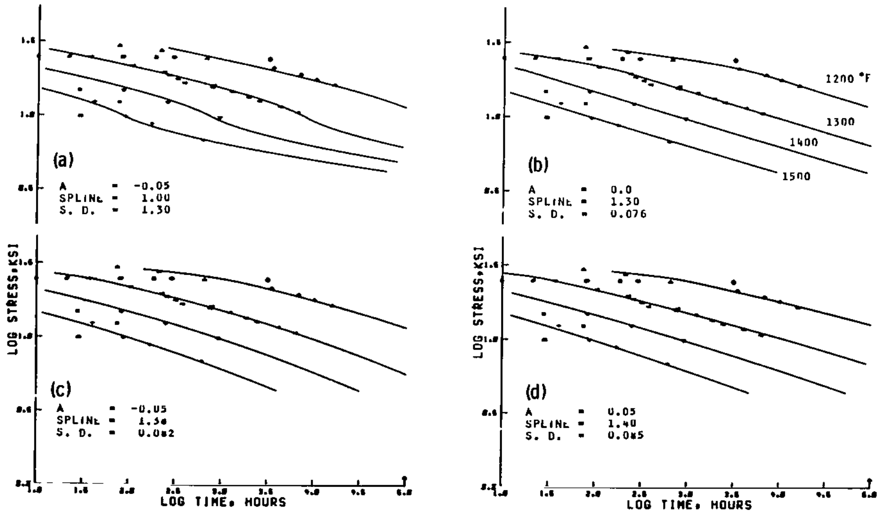


Figure 7. - Results from MEGA16 showing effect of different A values and spline points on shape of predicted isothermals. Material, 316 stainless steel.

TABLE II.—EFFECT OF LOCATION OF SPLINE POINT IN THE STRESS FUNCTION ON THE STANDARD DEVIATION OF PREDICTIONS

[An example using type 316 stainless steel with 38 data and a stress range of 7 to 30 ksi. The program is MEGA16 with AKON = 30.]

Location of spline point	*A* value		
	-0.05	0	0.05
	Standard deviation		
1.0	0.130	0.125	0.125
1.1	0.123	.118	.116
1.2	0.109	.103	.102
1.3	0.082	.076	.076
1.38	0.082	.080	.082
1.4	0.085	.083	.085

deviations for all the combinations. From the table, it appears that a minimum standard deviation exists near 0.076, which is a lower value than that reported in figure 39 of reference 4. Thus, choice of spline point location might be a means of fine tuning the predictions of MEGA16, but from figure 7(a) it is obvious that extreme values of the spine point may give strange predicted isothermals.

Summary of Results

MEGA16 is the outcome of a number of years of study of various forms of the so-called minimum commitment method of analysis of stress-rupture data. Basically, it is a Fortran IV program which fits a specific, yet flexible, model equation to a given family of time-to-failure data. The model includes a discrete temperature function, a two-part stress function, and an adjustable constant, *A*, which affects the extrapolation beyond the range of data. MEGA16 can handle up to 200 data points per set, including the weighting of certain points, if so desired. For each datum it sets up an equation according to the assumed model and some optional locations of the centers of the temperature and stress functions. After it solves the resulting set of equations to determine the coefficients of the terms of the model equation, it predicts the rupture life for each input combination of temperature and stress and predicts the logarithm of the time of evenly spaced values of the logarithm of stress.

MEGA16 produces many different types of plots to depict the response of a particular material. These include (1) the basic predicted time-to-rupture versus stress for specific temperatures, (2) the temperature and stress functions, (3) the time and temperature function versus the logarithm of stress (the master curve), (4) the observed versus predicted log time to failure values, (5) residual plots of the logarithm of time, stress, and temperature, and (6) standard deviation as a function of the parameter *A*. MEGA16 calculates, as an estimate of accuracy, the standard deviation of the observed minus the predicted rupture life.

To be analyzed by MEGA16, the data set representing a material should include test results from at least three different temperatures, each with several levels of stress, and the resulting spread of life values. That set can be run alone or with many other sets of data from other materials to obtain complete analyses, in easy-to-understand graphical form.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, August 28, 1980

Appendix—Listing of MEGA16 and its Subroutines

```
C     THIS IS  M E G A 1 6 ----THE MANSON-ENSIGN GENERALIZED ANALYSIS
C     OF STRESS RUPTURE DATA----INCORPORATING THE IDEAS OF MINIMUM
C     COMMITTMENT TO FORM OF EQUATION, THE STATION FUNCTION APPROACH,
C     AND A MODEL EQUATION OF THE FORM
C
C
C             LOGH + (1 + A LOGH)P(T) □ G(S)
C
C                  WHERE  H = TIME
C
C                         P = STATION FUNCTION FOR TEMPERATURE
C
C                         T = TEMP
C
C                         G = STRESS FUNCTION,   D + E LOG S + F S**ALPHA
C
C                         ALPHA = +1 OR -1
C
C                         S = STRESS / REFERENCE STRESS
C
C                         A = A CONSTANT USUALLY BETWEEN -.2 AND +.2
C
C                     OR  A = A(1-ACON(T-TMID/TMID+460))**2
C
C
C
C             A S S U M P T I O N S
C
C
C       FORM OF THE   MODEL  EQUATION
C
C
C       STRESS  AND  TEMPERATURE  ARE THE ONLY
C          INDEPENDENT  VARIABLES
C
C
C       RELATIONSHIPS AMONG  STRESS RUPTURE LIFE,
C          STRESS, AND TEMP  PRESENT IN THE SHORT
C          TIME  OBSERVATIONS  ALSO EXIST IN
C          THE  LONG TIME BEHAVIOR
C
C
C
C
C       CALL  STRUCTURE
C
C                   TUSTR
C                   STACN
C          MEG16B
C                   AMATF   DMFSS
C                           DMLSS
C                   TOPLT   CVFITF  DTRIA
C                                   DSOLVE
C                                   FUNC
C
C
```

```
C     THE SUBROUTINES CALLED BY THIS PROGRAM (MEG16B) ARE
C
C
C  NAME   SOURCE.      PURPOSE
C
C  TUSTR  STUSTR   CONVERTS LOG STRESS VALUE TO STATION FUNCTION FORM
C  STACN  SSTACN   CONVERTS TEMP VALUE TO STATION FUNCTION FORM
C  AMATF  SAMATF   SETS UP THE MATRIX OF STATION FUNCTION EQUATIONS(UMATRX)
C  TOPLT  STOPLT   PREPARES STATION FUNCTION VALUES (XF) FOR PLOTS AND CURVE FITS
C
C
C
C     OTHER SUBROUTINES CALLED ARE
C
C IN     NAME     SOURCE.        PURPOSE
C
C AMATF  DMFSS    SDMF     PREPARES MATRIX, FINDS RANK, AND LINEARLY IND. ROWS
C AMATF  DMLSS    SDML     INVERTS UMATRX TO FIND LEAST SQUARES SOLUTION (XF)
C TOPLT  CVFITF   CRVFF    POLYNOMIAL CURVE FIT -- CROUSE-JORDAN REDUCTION
C CVFITF DTRIA    DCTRIA
C CVFITF DSOLVE   DCSOLV
C CVFITF FUNC     FUNCT
C
C     ADDITIONAL SUBROUTINES CALLED ARE FROM THE IBM PLOTTING PACKAGE
C
C     THESE INCLUDE GPLOT, XAXIS, YAXIS, CHARS, NUMBER, BEGID, TITLE, SCLBAK, ETC.
C
C
C
C  NOMENCLATURE      *****      INPUT VALUES
C
C   TITEL IS THE TITLE FOR A PARTICULAR MATERIAL
C   NF DENOTES THE F COLUMN TO BE OMITTED IN FINAL MATRIX
C   NP DENOTES THE P COLUMN TO BE OMITTED IN FINAL MATRIX
C   NG DENOTES THE G COLUMN TO BE OMITTED IN FINAL MATRIX
C   MK DENOTES THE   COLUMN TO BE USED AS THE DEPENDENT VARIABLE
C   NL IS THE NUMBER OF STATIONS FOR  TIME--NOT USED IN THIS VERSION--SET = NT
C   NT IS THE NUMBER OF STATIONS FOR  TEMP       MAXIMUM = 32
C   NS IS THE NUMBER OF STATIONS FOR  STRESS     MAXIMUM = 16
C   NQ IS THE NUMBER OF STRESS PARAMETERS BEING DETERMINED
C   NCOL IS THE NUMBER OF COLUMNS IN UMATRIX = NUMBER OF BOTH
C     DEPENDENT PLUS INDEPENDENT VARIABLES     MAXIMUM = 48
C   NEV IS THE NUMBER OF EVENLY SPACED LOG TIME VALUES AT
C     WHICH PREDICTIONS ARE MADE
C   NISO IS THE NUMBER OF ISOTHERMALS TO BE PREDICTED
C     WHICH ARE NOT ALSO STATION FUNCTIONS
C   NXAV IS NUMBER OF EXTRA  A  VALUES READ IN  (MAX=1 FOR NOW)
C   CISOT(K)   ARE THE TEMP VALUES OF THE ISOTHERMALS
C   ALOGT      ARE THE LOG TIME STATIONS  (NOT USED IN THIS VERSION)
C   TSTA       ARE THE TEMP STATIONS
C   SSTA       ARE THE LOG STRESS STATIONS
C   NODU  IS THE NUMBER OF INPUT DATA POINTS -- DATA USED
C   NODUW IS THE NUMBER OF DATA USED AFTER WEIGHTING
C   NODP  IS THE NUMBER OF LONG TIME DATA TO BE PREDICTED (NOT IN THIS VERSION)
C   NOEXT  IS THE NUMBER OF DATA ADDED BY THE WEIGHTING
C   CUTOF  IS THE CUTOFF LIFE IN HOURS
C   AEXT  IS THE EXTRA  A  VALUE READ IN WITH DATA
C   OPT     IS THE PLOT OUTPUT OPTION; F (OR 0) MEANS PLOT, T (1) MEANS NO PLOT
C   CONSTR ARE THE VALUES OF CONSTANT STRESS FOR THE
C     ISOSTRESS PLOTS
C   TMP(I)     ARE THE TEMP VALUES OF THE DATA  IN DEGREES FAHREHEIT
C   SIG(I)     ARE THE STRESS VALUES OF THE DATA IN KSI
C   ALS(I)     ARE THE LOG STRESS VALUES
C   AT(I)      ARE THE TIME TO FAILURE VALUES OF THE DATA IN HOURS
C   ALT(I)     ARE THE LOG TIME VALUES
C   WF IS THE NUMBER OF TIMES A POINT IS TO BE WEIGHTED
```

```
C  NOMENCLATURE      *****      CALCULATED VALUES
C
C   PREFIX  W  USUALLY MEANS WEIGHTED VALUE
C   PREFIX  Q  USUALLY MEANS SINGLE PRECISION FOR PLOTTING
C
C   XF       IS THE SOLUTION VECTOR FROM THE INVERSION OF THE SET OF EQUATIONS
C   SFCN(J)  ARE THE STRESS STATION FUNCTION VALUES--THE STRESS FUNCTION
C   TFCN(J)  ARE THE TEMP STATION FUNCTION VALUES--THE TEMP FUNCTION
C
C   STDEV   IS THE STANDARD DEVIATION OF THE RESIDUALS (THE DATA USED)
C   STDL    IS THE STANDARD ERROR OF THE PREDICTED VALUES  =  R M S  VALUE
C   AVARSL  IS THE AVERAGE ABSOLUTE DEVIATION OF THE PREDICTED VALUES
C
C
C  NOTA BENE    MEG16B
C
C    MAXIMUM NUMBER OF INPUT DATA POINTS THIS VERSION CAN TAKE IS 200
C    MAXIMUM SIZE OF MATRIX TO BE INVERTED IS  48 X 48     AMATF,DMFSS
C
      DOUBLE PRECISION SSTA(16),    COEFG(16),   COEFGG(16)
      DOUBLE PRECISION SFCN(16)
      DOUBLE PRECISION ALOGT(32),   COEFP(32),   TSTA(32),    TMPT(32)
      DOUBLE PRECISION DAZERO(48),  DTFIL(64)
      DOUBLE PRECISION ALS(200),    ALT(200),   TRIP(200)
      DOUBLE PRECISION AT(200),     PRDD(200),   PROD(200),   SIG(200)
      DOUBLE PRECISION TMP(200),    WALS(200),   WALT(200),   WTMP(200)
      DOUBLE PRECISION UMATRX(200,48),    VALUA(8),    VALUM(200)
      DOUBLE PRECISION XF,          XPLTT,       TFCN,        XPLTRT
      DOUBLE PRECISION XPLTG,       YPLTG,       SCOEF,       AEXT
      DOUBLE PRECISION TVALP,       YVALU,       YVAL,        YVALG
      DOUBLE PRECISION SDEL,        SVAL,        SVLG
      DOUBLE PRECISION C1,C2,C3,C4,C5,UNKN(11)
C
      DIMENSION QLABX3(1),   QLABX7(1),   QLABY2(1),   QLABY3(1)
      DIMENSION QLABY7(1),   QPX(2),      QPX2(2),     QPXL(2)
      DIMENSION QPXL2(2),    QPXR(2),     QPXR2(2),    QPY(2)
      DIMENSION QPY2(2),     QPYL(2),     QPYL2(2),    QPYR(2)
      DIMENSION QPYR2(2),    QLABX2(3),   QLABXD(4)
      DIMENSION QLABX1(4),   QLABYD(4),   QLABYI(4)
      DIMENSION QABKEY(5),   QADKEY(5),   QAVKEY(5),   QEXKEY(5)
      DIMENSION QRDKEY(5),   QSDKEY(5),   QLABX5(7),   QLABX4(7)
      DIMENSION QLABXC(8),   QLABYC(8),   PSDEV(9),    PSTDEV(9)
      DIMENSION PSTDL(9),    CONSTR(16)
      DIMENSION TITEL(16),   CISOT(32),   PISO(32)
      DIMENSION ALOGP(48),   ALSPE(48),   ALTP(48)
      DIMENSION ALTPE(48),   ALTT(34),    QLABXA(2),   QLABYA(5)
      DIMENSION AZERO(48),   BNONZ(48)
      DIMENSION ALSTRL(64),  PFIL(64),    TFIL(64)
      DIMENSION TRFIL(64)
      DIMENSION RESL(96),    ABRES(200),  GCALC(200),  HOUR(200)
      DIMENSION HOURS(200),  QALS(200),   QALT(200),   QXPL(200)
      DIMENSION QYPL(200),   RES(200),    RESD(200)
      DIMENSION RSDEV(200),  WF(200),     PEST(200)
      DIMENSION AMATRX(48,9),BMATRX(48,9),QVALUA(8)
      DIMENSION QANGLS(16),  QLABX8(3),   PLRESD(200), QLABY4(5)
      DIMENSION QTMPL(200),  QSIGL(200),  QTMP(200)
      DIMENSION ZDEV(200),   PSDZD(9),    XPLTRS(64),  GPLT(64),   ALGTC(64)
      DIMENSION GPLAT(200),  STRL(64),    GLOW(64),    GHIGH(64)
C
      DIMENSION IVGR(7),GRAXV(10),GRAYV(10),KSYM(30)
      DIMENSION GRLEG5(2),GRLEG6(4),XMIS(2),YMIS(2)
      LOGICAL*1 XAXV,YAXV
      DATA XAXV /.TRUE./
      DATA YAXV /.FALSE./
      INTEGER*2 NUMPT/20/
      LOGICAL*1 OPT(17)
```

```
C
      COMMON /ACOMN/ QXPLTT(32),QXPLRT(32),QYPLTT(32),QXPLTG(16),QYPLTG(16)
      COMMON /BCOMN/ XPLTT(32),TFCN(32),XPLTRT(32),XPLTG(16),YPLTG(16)
      COMMON /CCOMN/ XF(48),NP
      COMMON /DCOMN/ D,E,F,G,H,AA
C
C
C  PRINT OUT TODAYS DATE ON EACH PLOT
      INTEGER*2 NDATE
C
      DIMENSION DATES(4)
      DATA NDATE /16/
      DATA DATES(1),DATES(2) / 'DATE',' -- ' /
      DATA DATES(3),DATES(4) / 'MO/D','D/YY' /
      CALL TIME (NDATE,DATES)
      WRITE (7,516) (DATES(I), I=1,4)
C
      DATA QLABX1  / ' LOG',' TIM','E, H','OURS'/
      DATA QLABY1  / ' LOG',' STR','ESS,','KSI '/
      DATA QLABY2  / 'G(S)'                  /
      DATA QLABX2  / 'LOG ','STRE','SS  '       /
      DATA QLABX3  / 'TEMP'                    /
      DATA QLABY3  / 'P(T)'                  /
      DATA QLABY4  / 'RESI','DUAL','S  O','F  L','OG T'                /
      DATA QLABX5  / 'LOGH',' + A','*LOG','H*P(','T) +',' P(T',')   '      /
      DATA QLABX7  / 'PRED'                    /
      DATA QLABY7  / ' OBS'                    /
      DATA QLABX8  / 'STRE','SS, ',' KSI'  /
      DATA QLABX4  / '    ','1000',' / T','EMP ','+ 46','0   ','    '/
      DATA QLABXA / 'A  V','ALUE' /
      DATA QLABYA / 'S.D.',' OF ','PRED','ICTI','ONS ' /
      DATA QLABXD  / 'LOG ','TIME',',A =',' 0  ' /
      DATA QLABYD  / 'LOG ','TIME',',A =',' X  ' /
      DATA QLABXC  / 'LOG ','T, A','=0  ','- LO','G CU','TOFF','    ','    ' /
      DATA QLABYC  / 'LOG ','T, A','=X  ','- LO','G T,',' A=0','    ','    ' /
C
      DATA KSYM /70,66,62,65,68,56,67,61,72,92,78,69,58,63,71,     -
     1  70,66,62,65,92,63,67,61,72,78,69,71,56,143,181 /
      DATA NEV /34/, ALTT / 1.0,1.125,1.25,1.375,1.5, -
     11.625,1.75,1.875,2.0,2.125,2.25,2.375,2.5,2.625,2.75,2.875,3.0,   -
     23.125,3.25,3.375,3.5,3.625,3.75,3.875,4.0,4.125,4.25,4.375,4.5,   -
     34.625,4.69897,4.75,4.875,5.0/
C
C  NOTA BENE
C
C    THE FIRST  A  SHOULD BE ZERO TO INSURE THAT ALL PLOTS HAVE MEANING
C    SET LAK TO AT LEAST 1 LESS THAN DIMENSIONS OF VALUA
C     DATA LAK /5/, VALUA /0.0,-.15,-0.1,-0.05,.15/
      DATA LAK /2/, VALUA /0.00,-0.05/
C
      DATA GRLEG5  /  ' A =','    '/
      DATA QPX  /0.5,5.3/
      DATA QPY  /0.5,5.3/
      DATA QSDKEY  / 'SD O','F RE','S  =','    ','    ' /
      DATA QEXKEY  / 'RMS ','OF P','RED=','    ','    '/
      DATA QAVKEY  / 'AV D','EV P','RED=','    ','    '/
      DATA QABKEY  / 'AB D','EV P','RED=','    ','    '/
      DATA QADKEY  / 'AV A','BS D','EV =','    ','    ' /
      DATA QRDKEY  / 'SD R','EDUC','ED =','    ','    ' /
C
      DATA QPXL  /0.5,4.699/
      DATA QPYL  /0.801,5.0/
      DATA QPXR  /0.801,5.301/
      DATA QPYR  /0.5,5.0/
      DATA QPX2  /2.0,5.0/
      DATA QPY2  /2.0,5.0/
      DATA QPXL2 /2.0,4.699/
      DATA QPYL2 /2.301,5.0/
      DATA QPXR2 /2.301,5.0/
      DATA QPYR2 /2.0,4.699/
```

```
C
C  INITIALIZE--BEGIN WITH A NEW DATA SET
C
 100  DO 105 I=1,200
      TMP(I)=0.0
      SIG(I)=0.0
      AT(I)=0.0
 105  WF(I)=0.0
      DO 106 I=1,9
      PSTDEV(I)=0.0
      PSDEV(I)=0.0
      PSTDL(I)=0.0
 106  PSDZD(I)=0.0
      STDEV = 0.0
      DO 107 J=1,200
      ALT(J) = 0.0
      ALS(J) = 0.0
 107  CONTINUE
      READ (5,410) TITEL
C
C  INPUT--STATION VALUES AND CONSTANTS
C
      READ (5,402) NF,NP,NG,MK
      READ (5,402) NL,NT,NS,NISO,NXAV
      READ (5,400) (CISOT(K),K=1,NISO)
      READ (5,400) (ALOGT(I),I=1,NL)
      READ (5,400) (TSTA(I),I=1,NT)
      READ (5,400) (SSTA(I),I=1,NS)
      READ (5,404) NODU,NODT,CUTOF,AEXT,(OPT(I),I=1,17)
      NCS=8
      READ (5,400) (CONSTR(K),K=1,NCS),ALPHL,ALPHH
C     WRITE (6,515)
      WRITE (7,515)
      WRITE (9,515)
C     WRITE (6,455) TITEL
      WRITE (7,455) TITEL
C     WRITE (7,513)
      WRITE (9,455) TITEL
      WRITE (9,463) (SSTA(I),I=1,NS)
      WRITE (9,467) (TSTA(I),I=1,NT)
C     WRITE (7,477) NF,NP,NG,MK,NL,NT,NS,NISO,NXAV
      KTEST=1
      CUTLOG □ ALOG10(CUTOF)
      CUTHAF □ (CUTLOG+5.0)/2.0
      DO 111 I=1,NS
      QANGLS(I) □ 10.0**SSTA(I)
 111  CONTINUE
      IF (NXAV.NE.1) GO TO 109
      LAK = LAK+NXAV
      VALUA(LAK) = AEXT
 109  NOEXT=0
C
C  INPUT--OBSERVATIONS
C
      DO 115 I=1,NODT
      READ (5,408,END=399,ERR=113) TMP(I),SIG(I),AT(I),WF(I)
      ALT(I)=DLOG10(AT(I))
      ALS(I)=DLOG10(SIG(I))
      GO TO 114
 113  CONTINUE
C
C  WEIGHT DATA
C
 114  IF (NOEXT.GT.0) GO TO 117
      KN = I
      GO TO 118
 117  KN = KN+1
```

```
 118  WTMP(KN) = TMP(I)
      QTMP(KN) = TMP(I)
      WALS(KN) = ALS(I)
      QALS(KN) = ALS(I)
      WALT(KN) = ALT(I)
      QALT(KN) = ALT(I)
      IF (WF(I).LE.1.0) GO TO 116
      KWF = WF(I)-1.0
      DO 112 KK= 1,KWF
      KN = KN+1
      WTMP(KN) = TMP(I)
      WALS(KN) = ALS(I)
      QALS(KN) = ALS(I)
      WALT(KN) = ALT(I)
      NOEXT = NOEXT+1
 112  CONTINUE
 116  IF (I.EQ.1) GO TO 115
      IF (WTMP(I).EQ.WTMP(I-1)) GO TO 115
      KTEST=KTEST+1
 115  CONTINUE
      NODUW □ NODU+NOEXT
      NODTW □ NODT+NOEXT
C
C  CHOOSE AN  A  VALUE
C
 121  DO 385 LA=1,LAK
C
C  INITIALIZE ALL THE VECTORS IN COMMON
      DO 119 K=1,48
      XF(K) = 0.0
      XPLTT(K) = 0.0
      TFCN(K) = 0.0
      XPLTG(K) = 0.0
      YPLTG(K) = 0.0
      QXPLTT(K) □ 0.0
      QYPLTT(K) = 0.0
      QXPLTG(K) = 0.0
      QYPLTG(K) □ 0.0
      QXPLRT(K) = 0.0
      XPLTRT(K) = 0.0
 119  CONTINUE
      DO 123 I=1,16
      SFCN(I)=0.0
 123  CONTINUE
      DO 120 I=1,48
      DO 120 J=1,200
 120  UMATRX(J,I)=0.0
C
C  BEGIN PLOT OF ISOTHERMALS
C
      CALL BEGID(1)
      IVGR(1) = 7
      IVGR(2) = 1
      IVGR(3) = 3
      IVGR(4) = 70
      IVGR(5) □ 1
      IVGR(6) = 15
      IVGR(7) = 0
      GRAXV(1) = 10.
      GRAXV(2) = -1.
      GRAXV(3) = 0.
      GRAXV(4) = 1.
      GRAXV(5) □ 5.
      GRAXV(6) = 8.
      GRAXV(7) = 2.
      GRAXV(8) = -1.
      GRAXV(9) = 0.
      GRAXV(10) = 12.
      GRAYV(1) = 10.
```

```
      GRAYV(2) □ -1.
      GRAYV(3) = 90.
      GRAYV(4) = .0
      GRAYV(5) = 2.5
      GRAYV(6) = 5.
      GRAYV(7) = 2.
      GRAYV(8) □ -1.
      GRAYV(9) = 0.
      GRAYV(10) = 12.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IA=1
      DO 140 K=1,KTEST
      IK=0
      DO 130 I=IA,NODTW
      IK=IK+1
      IF (I.EQ.IA) GO TO 125
      IF (WTMP(I).NE.WTMP(I-1)) GO TO 135
 125  QXPL(IK)=WALT(I)
      QYPL(IK)=WALS(I)
 130  CONTINUE
 135  IA=I
      IPLT=IK-1
      IF (K.EQ.KTEST) IPLT=IPLT+1
C
C  PLOT  THE DATA  FOR THE K TH TEMPERATURE
C
      IVGR(2) = IPLT
      IVGR(3) = 3
      IVGR(4) = KSYM(K)
      CALL GPLOT (QXPL,QYPL,IVGR)
 140  CONTINUE
C     WRITE (6,518) (IVGR(I),I=1,7)
C     WRITE (6,501) (GRAXV(I),I=1,10)
C     WRITE (6,501) (GRAYV(I),I=1,10)
C     WRITE (6,519) ((QXPL(I),I=1,6),(QYPL(I),I=1,6))
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,16,20,QLABY1)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,16,20,QLABX1)
C
C  FORM SET OF SIMULTANEOUS EQUATIONS     (UMATRX)
C
      NQ=4
      AKON=0.0
 141  NCOL=NQ+1+NT
      IF (NP.GT.0) NCOL=NCOL-1
C  NOTA BENE    MEG16B
C
C    NUMBER OF UNKNOWNS IS 4 + NT - 1    NUMBER OF COLS IN UMATRX IS  4 + NT
C    THIS USES  S □ STRESS / STRESS MID
C     ALSO  ALPHH = EXPONENT ON S    HIGH STRESS
C           ALPHL = EXPONENT ON S    LOW  STRESS
C
      IF (ALPHH.NE.0.0) GO TO 143
      ALPHH =  -1.0
      ALPHL =   1.0
 143  DO 210 J=1,NODUW
 142  SCOEF=WALT(J)
      YVALG = WALS(J)
      TRIP(J)=((WTMP(J)-TSTA(NP))/(TSTA(NP)+460.))**2
      VALUM(J)□VALUA(LA)*(1.0-AKON*TRIP(J))
 161  CALL TUSTR (SSTA,YVALG,NQ,ALPHL,ALPHH,COEFG)
C     WRITE (7,450) (COEFG(K),K=1,NQ)
```

```
  162   KNT=0
        DO 170 K=1,NT
        IF (WTMP(J).NE.TSTA(K)) GO TO 165
  163   PROD(J)=VALUM(J)*WALT(J)+1.0
        TMPT(K)=PROD(J)
        GO TO 170
  165   TMPT(K)=0.0
        KNT=KNT+1
  170   CONTINUE
  171   IF (KNT.NE.NT) GO TO 190
C
        TVALP □ WTMP(J)
  186   CALL STACN (TSTA,TVALP,NT,TMPT,N)
        PRDD(J)=VALUM(J)*WALT(J)+1.0
  187   DO 193 K=1,NT
  192   TMPT(K) = TMPT(K)*PRDD(J)
  193   CONTINUE
C       WRITE (7,445) (TMPT(K),K=1,NT)
  190   CONTINUE
  194   M=1
        UMATRX(J,M)=SCOEF
        DO 200 I=1,NT
        IF (I.EQ.NP) GO TO 200
        M=M+1
        UMATRX(J,M)=TMPT(I)
  200   CONTINUE
        DO 205 I=1,NQ
        M=M+1
        UMATRX(J,M)=COEFG(I)
  205   CONTINUE
  210   CONTINUE
        IEND=NODUW
  225   KSPARS=0
C
C  SOLVE SET OF SIMULTANEOUS EQUATIONS
C
  226   CALL AMATF (NCOL,IEND,MK,KSPARS,UMATRX)
  227   CALL TOPLT (TSTA,NT,SSTA,NQ,SFCN)
C       WRITE (6,457) VALUA(LA)
        WRITE (9,465) (SFCN(L),L=1,NQ)
        WRITE (9,469) (TFCN(L),L=1,NT)
        C1 = 2.302585092
        C2 = 1.0/(C1*ALPHL)
        C3 = 1.0/(C1*ALPHH)
        C4 □ C2*C2
        C5 = C3*C3
        UNKN(1) = SFCN(1)-C4*SFCN(3)
        UNKN(2) = SFCN(2)-C2*SFCN(3)
        UNKN(3) □ C4*SFCN(3)
        UNKN(4) = SFCN(1)-C5*SFCN(4)
        UNKN(5) = SFCN(2)-C3*SFCN(4)
        UNKN(6) = C5*SFCN(4)
        UNKN(7) = UNKN(2)+C1*ALPHL*UNKN(3)
        UNKN(8) □ UNKN(3)*C1*C1*ALPHL*ALPHL
        UNKN(9) = UNKN(5)+C1*ALPHH*UNKN(6)
        UNKN(10) = UNKN(6)*C1*C1*ALPHH*ALPHH
C       WRITE (7,524) UNKN
        SDEL =  (SSTA(NS)-SSTA(1)+0.2)/50.0
C  ADDING .1 TO GIVE SOME EXTRAPOLATION   18 NOV 76
        STRL(1) = SSTA(1)-0.2
        DO 231 K = 2,50
        STRL(K) □ STRL(K-1) + SDEL
  231   CONTINUE
        KPLT = 0
        DO 232 J □ 1,50
        ALSTRL(J) = 10.0**STRL(J)
        SVAL = 10.0**(STRL(J)-SSTA(2))
        SVLG = DLOG10(SVAL)
        GLOW(J) = SFCN(1)+SFCN(2)*SVLG+SFCN(3)*(C4*SVAL**ALPHL-C4-C2*SVLG)
```

```
      GHIGH(J) = SFCN(1)+SFCN(2)*SVLG+SFCN(4)*(C5*SVAL**ALPHH-C5-C3*SVLG)
      IF (STRL(J).GT.SSTA(2)) GO TO 229
      GPLT(J) = SFCN(1)+SFCN(2)*SVLG+SFCN(3)*(C4*SVAL**ALPHL-C4-C2*SVLG)
      GO TO 228
 229  GPLT(J) = SFCN(1)+SFCN(2)*SVLG+SFCN(4)*(C5*SVAL**ALPHH-C5-C3*SVLG)
 228  KPLT = KPLT + 1
 232  CONTINUE
      KPLOT = 0
      DO 233 J = 1,NODT
      SVAL = 10.0**(WALS(J)-SSTA(2))
      SVLG = DLOG10(SVAL)
      IF (WALS(J).GT.SSTA(2)) GO TO 234
      GPLAT(J) = SFCN(1)+SFCN(2)*SVLG+SFCN(3)*(C4*SVAL**ALPHL-C4-C2*SVLG)
      GO TO 235
 234  GPLAT(J) □ SFCN(1)+SFCN(2)*SVLG+SFCN(4)*(C5*SVAL**ALPHH-C5-C3*SVLG)
 235  KPLOT = KPLOT + 1
 233  CONTINUE
C
C  PLOT THE ISOTHERMALS OF INTEREST THAT ARE NOT SAME AS STATIONS
C
      IF (NISO.EQ.NT) GO TO 214
      DO 211 ISO=1,NISO
      PISO(ISO) □ D+E*CISOT(ISO)+F*CISOT(ISO)**2
      KP = 0
      TRIP(ISO)=((CISOT(ISO)-TSTA(NP))/(TSTA(NP)+460.))**2
      VALUM(ISO)=VALUA(LA)*(1.0-AKON*TRIP(ISO))
      DO 213 IS=1,50
      IF (IS.GT.KPLT) GO TO 213
      ALGTC(IS) = (GPLT(IS)-PISO(ISO))/(1.0+VALUM(ISO)*PISO(ISO))
      IF (ALGTC(IS).LT.1.0.OR.ALGTC(IS).GT.5.0) GO TO 213
      KP = KP+1
      ALSPE (KP) = STRL(IS)
      ALTPE (KP) = ALGTC (IS)
C206  WRITE (7,507) VALUA(LA),CISOT(ISO),ALTT(IS),STRL(IS),ANLO(IS)
 213  CONTINUE
      IVGR(2) □ KP
      IVGR(3) = 2
      IVGR(4) = 0
      CALL GPLOT (ALTPE,ALSPE,IVGR)
 211  CONTINUE
C
C  PLOT THE PREDICTED ISOTHERMALS--LOG STRESS VS LOG TIME
C
 214  PCUT = .05
      IVGR(2) = 1
      IVGR(3) □ 3
      IVGR(4) □ 186
      CALL GPLOT (CUTLOG,PCUT,IVGR)
      DO 265 K=1,NT
      KP=0
      TRIP(K)=((TSTA(K)-TSTA(NP))/(TSTA(NP)+460.))**2
      VALUM(K)=VALUA(LA)*(1.0-AKON*TRIP(K))
      DO 260 I=1,50
      IF (I.GT.KPLT) GO TO 260
      ALGTC(I) = (GPLT(I)-TFCN(K))/(1.0+VALUM(K)*TFCN(K))
      IF (ALGTC(I).LT.1.0.OR.ALGTC(I).GT.5.0) GO TO 260
      KP=KP+1
      ALOGP(KP)=STRL(I)
      ALTP(KP)=ALGTC(I)
C262  WRITE (7,507) VALUA(LA),TSTA(K),ALGTC(I),STRL(I),TFCN(K)
 260  CONTINUE
      CALL INTENS(40)
      IVGR(2) = KP
      IVGR(3) = 0
      CALL GPLOT (ALTP,ALOGP,IVGR)
      CALL INTENS(2)
 265  CONTINUE
C     CALL ENDID(1,0,GRNAM)
      CALL DISPLA(1)
```

```
C
C   END OF ISOTHERMAL PLOT
C
C
C   PLOT  STRESS VS. LOG TIME FOR SELECTED TEMPERATURES
C    SINCE THERE ARE NO PREDICTIONS, USE ONLY A=0
C
 256   IF (OPT(2)) GO TO 261
       IF (VALUA(LA).NE.0.0) GO TO 261
       CALL BEGID(2)
       NUMPT = NODTW
       GRAXV(3) = 0.
       GRAXV(4) = 0.5
       GRAXV(5) = 4.5
       GRAXV(6) = .5
       GRAXV(7) = 2.
       GRAXV(8) = -1.
       GRAXV(9) = 0.
       RMIN = 0.0
       RMAX □ 12.5
       IF (SSTA(3).GT.1.00) RMAX=50.
       IF (SSTA(3).GT.1.70) RMAX=75.
       IF (SSTA(3).GT.1.88) RMAX=100.
       IF (SSTA(3).GT.2.01) RMAX=125.
       IF (SSTA(3).GT.2.10) RMAX=150.
       IF (SSTA(3).GT.2.18) RMAX=200.
       GRAYV(3) = 90.
       GRAYV(4) = RMIN
       GRAYV(5) = RMAX
       GRAYV(6) = 9.
       CALL XAXIS (.9,.6,GRAXV)
       CALL YAXIS (.9,.6,GRAYV)
       IVGR(3) = 3
       CALL TITLE (1,64,25,TITEL)
       CALL CHARS (16,DATES,0.,1.7,9.4,12)
       CALL TITLE (3,12,20,QLABX8)
       CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
       IA=1
       DO 264 K=1,NISO
       IK=0
       DO 263 I=1,NODTW
       IF (WTMP(I).NE.CISOT(K)) GO TO 263
       IK=IK+1
 237   QXPL(IK)=WALT(I)
       QYPL(IK)=SIG(I)
 263   CONTINUE
C
C   PLOT  THE DATA  FOR THE K TH TEMPERATURE
C
       IVGR(2) = IK
       IVGR(4) = KSYM(K)
       CALL GPLOT (QXPL,QYPL,IVGR)
 264   CONTINUE
       CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
       CALL TITLE (4,16,20,QLABX1)
       IVGR(2) = 1
       IVGR(4) = 186
       CALL GPLOT (CUTLOG,PCUT,IVGR)
C      CALL ENDID(2,0,GRNAM)
       CALL DISPLA(1)
C
C   END OF RAW DATA PLOT
C
C   SET UP A TABLE OF LOG G = LOG H VALUES FOR THE CASE OF A=0 ONLY
C
C      WRITE (9,481) (XFILS(II),II=1,49,3)
C      WRITE (9,481) (YFILS(II),II=1,50,3)
```

```
 261  IF (VALUA(LA).NE.0.0) GO TO 251
      DO 266 I=1,50
      DAZERO(I) = GPLAT(I)
      AMATRX(I,LA) = DAZERO(I)
 266  CONTINUE
      GO TO 252
C
C  SET UP A TABLE OF LOG S AND LOG H VALUES FOR THE OTHER A VALUES
C
 251  DO 267 I=1,50
      AMATRX (I,LA) = GPLAT(I)
      BNONZ(I) = GPLAT(I)-ALTT(I)
      BMATRX (I,LA) = BNONZ(I)
 267  CONTINUE
C
C  PLOT THE G  STATION FUNCTION VS LOG STRESS
C
 252  SPLPT = SSTA(2)
      SPLY = SFCN(1)
      SPLX = 10.0**SSTA(2)
      IF (OPT(3)) GO TO 254
      CALL BEGID(3)
      NUMPT = KPLT
      CALL SCLBAK (XAXV,NUMPT,STRL,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) □ XRMAX
      GRAXV(6) = 10.
      CALL SCLBAK (YAXV,NUMPT,GPLT,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(3) = 90.
      GRAYV(4) = YRMIN
      GRAYV(5) = YRMAX
      GRAYV(6) = 10.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) □ KPLT
      IVGR(3) □ 0
      IVGR(4) = 70
      CALL GPLOT (STRL,GPLT,IVGR)
C     WRITE (6,519) ((STRL(I),I=1,6),(GPLT(I),I=1,6))
      IVGR(2) □ 1
      IVGR(3) = 3
      IVGR(4) □ 71
 257  CALL GPLOT (SPLPT,SPLY,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,4,20,QLABY2)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,16,20,QLABY1)
C     CALL ENDID(3,0,GRNAM)
      CALL DISPLA(1)
C
C  PLOT THE G  STATION FUNCTION VS STRESS
C
 254  IF (OPT(4)) GO TO 253
      CALL BEGID(4)
      NUMPT □ KPLT
      CALL SCLBAK (XAXV,NUMPT,ALSTRL,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) = XRMAX
      GRAXV(6) = 10.
      CALL SCLBAK (YAXV,NUMPT,GPLT,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
```

```
      GRAYV(3) = 90.
      GRAYV(4) = YRMIN
      GRAYV(5) = YRMAX
      GRAYV(6) = 10.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = KPLT
      IVGR(3) = 0
      IVGR(4) = 70
 255  CALL GPLOT (ALSTRL,GPLT,IVGR)
C     WRITE (6,519) ((ALSTRL(I),I=1,6),(GPLT(I),I=1,6))
      IVGR(2) = 1
      IVGR(3) = 3
      IVGR(4) = 71
      CALL GPLOT (SPLX,SPLY,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,4,20,QLABY2)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,12,20,QLABX8)
C     CALL ENDID(4,0,GRNAM)
      CALL DISPLA(1)
C
C  PLOT THE P  STATION FUNCTION VS TEMP
C
 253  TFIL(1) = TSTA(1)
      DTFIL(1) = TSTA(1)
      PFIL(1) = TFCN(1)
      TRFIL(1) = 1000./(TSTA(1)+460.)
      TDEL = ( TSTA(NT) - TSTA(1) )/ 30.0
 249  NFIL = 31
      DO 269 I=2,NFIL
      TFIL(I) = TFIL(I-1) + TDEL
      DTFIL(I) = TFIL(I)
      TRFIL(I) = 1000./(TFIL(I)+460.)
 248  PFIL(I) = D+E*TFIL(I)+F*TFIL(I)**2
 269  CONTINUE
C     WRITE (7,487) (TFIL(I),I=1,NFIL)
C     WRITE (7,491) (PFIL(I),I=1,NFIL)
 258  IF (OPT(5)) GO TO 259
      CALL BEGID(5)
      NUMPT = NFIL
      CALL SCLBAK (XAXV,NUMPT,TFIL,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) = XRMAX
      GRAXV(6) = 10.
      CALL SCLBAK (YAXV,NUMPT,PFIL,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(3) = 90.
      GRAYV(4) = YRMIN
      GRAYV(5) = YRMAX
      GRAYV(6) = 10.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = NFIL
      IVGR(3) = 0
      IVGR(4) = 70
      CALL GPLOT (TFIL,PFIL,IVGR)
      IVGR(2) = NT
      IVGR(3) = 3
      IVGR(4) = 70
      CALL GPLOT (QXPLTT,QYPLTT,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,4,20,QLABY3)
```

```
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,4,20,QLABX3)
C     CALL ENDID(5,0,GRNAM)
      CALL DISPLA(1)
C
C  PLOT THE P  STATION FUNCTION VS RECIPROCAL TEMP
C
 259  IF (OPT(6)) GO TO 268
      CALL BEGID(6)
      NUMPT = NFIL
      CALL SCLBAK (XAXV,NUMPT,TRFIL,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) = XRMAX
      GRAXV(6) = 10.
      CALL SCLBAK (YAXV,NUMPT,PFIL,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(3) = 90.
      GRAYV(4) = YRMIN
      GRAYV(5) = YRMAX
      GRAYV(6) = 10.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = NFIL
      IVGR(3) = 0
      IVGR(4) = 70
      CALL GPLOT (TRFIL,PFIL,IVGR)
      IVGR(2) = NT
      IVGR(3) = 3
      IVGR(4) = 70
      CALL GPLOT (QXPLRT,QYPLTT,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,4,20,QLABY3)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,28,20,QLABX4)
C     CALL ENDID(6,0,GRNAM)
      CALL DISPLA(1)
C
C  PLOT THE MASTER CURVE   LOG SIGMA VS. THE PARAMETER  G
C
C  NOTA BENE    MEG16B
C
C     IF TEMPERATURE IS NOT A STATION VALUE, USE QUADRATIC CURVE FIT
C     TO INTERPOLATE TEMP FUNCTION IN CALCULATION OF PARAMETER
C
 268  DO 285 I=1,NODT
      DO 270 IT=1,NT
      IY=IT
      IF (WTMP(I).EQ.TSTA(IT)) GO TO 275
 270  CONTINUE
      PEST(I)=D+E*WTMP(I)+F*WTMP(I)**2
      GO TO 280
 275  PEST(I)=TFCN(IY)
      TRIP(I)=((WTMP(I)-TSTA(NP))/(TSTA(NP)+460.))**2
      VALUM(I)=VALUA(LA)*(1.0-AKON*TRIP(I))
 280  GCALC(I)=WALT(I)+PEST(I)*(VALUM(I)*WALT(I)+1.0)
 285  CONTINUE
 286  IF (OPT(7)) GO TO 274
      CALL BEGID(7)
      NUMPT = KPLT
      CALL SCLBAK (XAXV,NUMPT,GPLT,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
```

```
      GRAXV(4) = XRMIN
      GRAXV(5) = XRMAX
      GRAXV(6) = 10.
      CALL SCLBAK (YAXV,NUMPT,STRL,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(3) = 90.
      GRAYV(4) = YRMIN
      GRAYV(5) = YRMAX
      GRAYV(6) = 10.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) □ 1
      IVGR(3) = 3
      IVGR(4) = 156
      SPLY = .6
      CALL GPLOT (SPLY,SPLPT,IVGR)
      IVGR(2) = KPLT
      IVGR(3) = 0
      CALL GPLOT (GPLT,STRL,IVGR)
      IVGR(2) = NODT
      IVGR(3) = 3
      IVGR(4) = 62
      CALL GPLOT (GCALC,QALS,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,16,20,QLABY1)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,28,20,QLABX5)
      CALL NUMBER (2,SFCN(4),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,2.0,15)
      CALL NUMBER (2,SFCN(3),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,2.4,15)
      CALL NUMBER (2,SFCN(2),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,2.8,15)
      CALL NUMBER (2,SFCN(1),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,3.2,15)
      CALL NUMBER (2,QYPLTT(NT),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,3.6,15)
      CALL NUMBER (2,QYPLTT(2),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,4.0,15)
      CALL NUMBER (2,QYPLTT(1),12,3,GRLEG1)
      CALL CHARS (12,GRLEG1,0.,1.1,4.4,15)
C     CALL ENDID(7,0,GRNAM)
      CALL DISPLA(1)
C
 274  IF (OPT(8)) GO TO 281
C
 281  IF (OPT(9)) GO TO 277
C
C  CALCULATE STANDARD DEVIATION OF DATA USED--IN TERMS OF LOG TIME    (STDEV)
C
 277  CONTINUE
      SUMSQ=0.0
      SUMRES=0.0
      SUMAR=0.0
      SUMSQR = 0.0
      SUMZD = 0.0
      SUMZD2 = 0.0
      JR = 1
      WRITE (9,459) VALUA(LA)
      WRITE (9,475)
      DO 325 J=1,NODUW
      YVAL = WALS(J)
 288  CALL TUSTR (SSTA,YVAL,NQ,ALPHL,ALPHH,COEFGG)
C     WRITE (7,450) (COEFGG(KK),KK=1,NS)
      YVALU = WTMP(J)
 321  CALL STACN (TSTA,YVALU,NT,COEFP,N)
```

```
C     WRITE (7,450) (COEFP(KK),KK=1,NT)
      PTRM=COEFP(N-1)*TFCN(N-1)+COEFP(N)*TFCN(N)+COEFP(N+1)*TFCN(N+1)+COEFP-
     1(N+2)*TFCN(N+2)
      TRIP(J)=((WTMP(J)-TSTA(NP))/(TSTA(NP)+460.))**2
      VALUM(J)=VALUA(LA)*(1.0-AKON*TRIP(J))
      HOURS(J)=(GPLAT(J)-PTRM)/(1.0+VALUM(J)*PTRM)
      RES(J)=WALT(J)-HOURS(J)
      SUMSQ=SUMSQ+RES(J)*RES(J)
      SUMRES=SUMRES+RES(J)
      ABRES(J)=DABS(WALT(J)-HOURS(J))
      SUMAR=SUMAR+ABRES(J)
      ZDEV(J) □ WALT(J)*(1.0+VALUM(J)*PTRM)+PTRM-GPLAT(J)
      SUMZD = SUMZD + ZDEV(J)
      SUMZD2 = SUMZD2 + ZDEV(J)*ZDEV(J)
      WRITE (9,489) WALT(J),HOURS(J),RES(J),SUMSQ,WTMP(J),WALS(J),GPLAT(J),PTRM,N
 325  CONTINUE
C
C  NOTA BENE    MEG16B
C
C    NO. OF PARAMETERS FITTED   =  4+NT-1    SINCE TFCN AT ONE TEMP=0
C    NO. OF DEGREES OF FREEDOM  =  NO. OF DATA - (4+NT-1) - 1
C
      NPAR = NT+NQ-1
      NDIV=NODUW-NPAR-1
      IF (NDIV.LT.1) NDIV=1
      DOF=NDIV
      STDEV=SQRT(SUMSQ/DOF)
      SDZD=SQRT(SUMZD2/DOF)
      PSDZD(LA) □ SDZD*2.0
      TOT=NODUW
      AVDEV=SUMAR/TOT
      PSTDEV(LA)=STDEV
C326  WRITE (6,485) STDEV,DOF,SUMRES,AVDEV
C
C  CALCULATE RESIDUALS AND NORMAL DEVIATES  FOR ALL DATA           (RSDEV)
C
      WRITE (9,483) TITEL
      WRITE (9,457) VALUA(LA)
      WRITE (9,485) STDEV,DOF,SUMRES,AVDEV
      SMSQL=0.0
      SMARSL=0.0
      DO 375 J=1,NODTW
      YVALU = WTMP(J)
 351  CALL STACN (TSTA,YVALU,NT,COEFP,N)
      PTRM=COEFP(N-1)*TFCN(N-1)+COEFP(N)*TFCN(N)+COEFP(N+1)*TFCN(N+1)+COEFP-
     1(N+2)*TFCN(N+2)
      TRIP(J)=((WTMP(J)-TSTA(NP))/(TSTA(NP)+460.))**2
      VALUM(J)=VALUA(LA)*(1.0-AKON*TRIP(J))
      HOUR(J)=(GPLAT(J)-PTRM)/(1.0+VALUM(J)*PTRM)
      RESD(J)□WALT(J)-HOUR(J)
      IF (LA.NE.1) GO TO 354
      PLRESD(J) = RESD(J)
 354  RSDEV(J)=RESD(J)/STDEV
 370  CONTINUE
 375  CONTINUE
      WRITE (9,495) WTMP(J).WALS(J),WALT(J),HOUR(J),RESD(J),RSDEV(J)
C     WRITE (6,500) STDL,DENL
C     WRITE (6,505) AVRESL,AVARSL
C
C  PLOT OBSERVED VERSUS PREDICTED VALUES OF LOG TIME TO FAILURE
C
 379  IF (OPT(10)) GO TO 385
      CALL BEGID(10)
      GRAXV(4) □ 0.5
      GRAXV(5) = 5.5
      GRAXV(6) = 10.
      GRAYV(4) = .5
      GRAYV(5) = 5.5
      GRAYV(6) = 10.
```

```
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = NODUW
      IVGR(3) = 3
      IVGR(4) = 63
      CALL GPLOT (HOURS,QALT,IVGR)
      IVGR(2) = 2
      IVGR(3) = 0
      CALL GPLOT (QPX,QPY,IVGR)
      CALL GPLOT (QPXL,QPYL,IVGR)
      CALL GPLOT (QPXR,QPYR,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,4,20,QLABY7)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,4,20,QLABX7)
 380  CALL CHARS (12,QSDKEY,0.,7.,1.4,15)
      CALL NUMBER (4,STDEV,8,2,GRLEG1)
      CALL CHARS (8,GRLEG1,0.,8.4,1.4,15)
C     CALL ENDID(10,0,GRNAM)
      CALL DISPLA(1)
C
C
 385  CONTINUE
C
C  END OF THE LOOP FOR VARIOUS  A  VALUES
C
C  THE NEXT FEW PLOTS WILL EVALUATE THE VARIOUS  A  VALUES USED
C
C
 381  IF (OPT(11)) GO TO 382
C
 382  IF (OPT(12)) GO TO 383
C
 383  IF (OPT(13)) GO TO 384
C
C  PLOT THE  A  SCAN -- S. D. VERSUS  A  VALUES CHOSEN
C
 384  IF (OPT(14)) GO TO 376
      DO 396 I=1,LAK
      QVALUA(I) = VALUK(I)
 396  CONTINUE
      WRITE (7,511) QVALUA
C     WRITE (7,509) PSTDEV,PSTDL
      CALL BEGID(14)
      GRAXV(4) = -.2
      GRAXV(5) □ .2
      GRAXV(6) □ 8.
      GRAYV(4) = 0.0
      GRAYV(5) = .8
      GRAYV(6) = 8.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = LAK
      IVGR(3) = 3
      IVGR(4) = 66
      CALL GPLOT (QVALUA,PSTDEV,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,4,20,QLABYA)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,8,20,QLABXA)
C     CALL ENDID(14,0,GRNAM)
      CALL DISPLA(1)
```

```
C
C     WRITE (7,523) (PSDZD(J),J=1,LAK)
      WRITE (7,502) (PSTDEV(J),J=1,LAK)
C
C  PLOT THE RESIDUALS VERSUS TEMPERATURE
C
 376  IF (OPT(15)) GO TO 377
C
      CALL BEGID(15)
      NUMPT = NODTW
      CALL SCLBAK (XAXV,NUMPT,QTMP,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(1) = 10.
      GRAXV(2) = -1.
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) = XRMAX
      GRAXV(6) = .5
      GRAXV(7) = 2.
      GRAXV(8) = -1.
      GRAXV(9) = 0.
      CALL SCLBAK (YAXV,NUMPT,PLRESD,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(1) = 10.
      GRAYV(2) = -1.
      GRAYV(3) = 90.
      GRAYV(4) = -1.0
      GRAYV(5) = 1.0
      GRAYV(6) = .5
      GRAYV(7) = 2.
      GRAYV(8) = -1.
      GRAYV(9) = 0.
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(1) = 7
      IVGR(2) = NUMPT
      IVGR(3) = 3
      IVGR(4) = 62
      IVGR(5) = 1
      IVGR(6) = 15
      IVGR(7) = 0
      CALL GPLOT (QTMP,PLRESD,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,20,20,QLABY4)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,4,20,QLABX3)
C     CALL ENDID(15,0,GRNAM)
      CALL DISPLA(1)
C
C  PLOT THE RESIDUALS VERSUS LOG STRESS
C
 377  IF (OPT(16)) GO TO 378
C
      CALL BEGID(16)
      NUMPT = NODTW
      CALL SCLBAK (XAXV,NUMPT,QALS,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) = XRMAX
      GRAXV(6) = .5
      CALL SCLBAK (YAXV,NUMPT,PLRESD,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(3) = 90.
      GRAYV(4) = -1.0
      GRAYV(5) = 1.0
```

```
      GRAYV(6) □ .5
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = NUMPT
      IVGR(3) = 3
      IVGR(4) = 62
      CALL GPLOT (QALS,PLRESD,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,20,20,QLABY4)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,12,20,QLABX2)
C     CALL ENDID(16,0,GRNAM)
      CALL DISPLA(1)
C
C  PLOT THE RESIDUALS VERSUS LOG LIFE
C
 378  IF (OPT(17)) GO TO 394
C
      CALL BEGID(17)
      NUMPT □ NODTW
      CALL SCLBAK (XAXV,NUMPT,QALT,XMIS)
      CALL GINTVL (XMIS(1),XMIS(2),10,0,XRMIN,XRMAX)
      GRAXV(3) = 0.
      GRAXV(4) = XRMIN
      GRAXV(5) □ XRMAX
      GRAXV(6) □ .5
      CALL SCLBAK (YAXV,NUMPT,PLRESD,YMIS)
      CALL GINTVL (YMIS(1),YMIS(2),10,1,YRMIN,YRMAX)
      GRAYV(3) □ 90.
      GRAYV(4) □ -1.0
      GRAYV(5) □ 1.0
      GRAYV(6) = .5
      CALL XAXIS (.9,.6,GRAXV)
      CALL YAXIS (.9,.6,GRAYV)
      IVGR(2) = NUMPT
      IVGR(3) = 3
      IVGR(4) = 62
      CALL GPLOT (QALT,PLRESD,IVGR)
      CALL TITLE (1,64,25,TITEL)
      CALL CHARS (16,DATES,0.,1.7,9.4,12)
      CALL TITLE (3,20,20,QLABY4)
      CALL CHARS (8,GRLEG5,0.,8.0,9.5,15)
      CALL NUMBER (4,VALUA(LA),8,2,GRLEG6)
      CALL CHARS (8,GRLEG6,0.,8.5,9.5,15)
      CALL TITLE (4,16,20,QLABX1)
C     CALL ENDID(17,0,GRNAM)
      CALL DISPLA(1)
C
 394  IF (NXAV.NE.1) GO TO 395
      LAK □ LAK-NXAV
C     CALL TERM
 395  GO TO 100
C
C
C
C
C  INPUT  FORMATS
C
 400  FORMAT (16F5.0)
15    IF (K-6) 30,25,20
20    ANS=Z*Z
      ANS=ANS**3
      GO TO 65
25    ANS=Z*Z
      ANS=Z*ANS**2
      GO TO 65
```

```
30    IF (K-4) 45,40,35
35    ANS=Z*Z
      ANS=ANS*ANS
      GO TO 65
40    ANS=Z*Z*Z
      GO TO 65
45    IF (K-2) 60,55,50
50    ANS=Z*Z
      GO TO 65
55    ANS=Z
      GO TO 65
60    ANS=1.
65    FUNC=ANS
      RETURN
C
70    FORMAT (1H0,5X,72HTOO MANY COEFFICIENTS ASKED FOR - ONLY  8  ARE A-
     1VAILABLE YOU CANNOT GET I3)
      END
C...............................................................
 402  FORMAT (16I5)
 404  FORMAT (2I5,F9.1,F6.3,4X,17L1)
 408  FORMAT (F5.0,F7.3,F8.2,F5.0)
 410  FORMAT (16A4)
C
C  OUTPUT FORMATS
C
 455  FORMAT (1H1,50X,18A4)
 457  FORMAT (1H0,50X,22HTHE VALUE OF 'A'  =     ,F7.3)
 459  FORMAT (1H0,5X,25H DATA USED IN CALCULATION,22X,22HTHE VALUE OF 'A' -
     1 =     ,F7.3)
 461  FORMAT (1H0,5X,27H LONG TIME DATA NOT USED     ,20X,22HTHE VALUE OF 'A' -
     1 =     ,F7.3)
 463  FORMAT (1H0,1X,10HG STATIONS/10X,10F10.3/)
 465  FORMAT (1H0,1X,24H G  COEFFICIENTS          /10X,10F10.3/)
 469  FORMAT (1H0,1X,24H P  STATION FUNCTION      /10X,10F10.3/)
 467  FORMAT (1H0,1X,10HP STATIONS/10X,10F10.3)
 471  FORMAT (1H0,5X,3HNO.,5X,11HTEMPERATURE,9X,6HSTRESS,13X,4HTIME,9X,1-
     11HLOG(STRESS),9X,9HLOG(TIME)/)
 475  FORMAT (1H0,20X,8HLOG TIME,22X,6H  TEMP,2X,10HLOG STRESS ,    -
     1 3X,3H G ,7X,3H P  /11X,4H OBS,6X,5H PRED,5X,5H DIFF,5X,6HSUM SQ )
 477  FORMAT (1H0,50HTHE NF,NP,NG,MK,  NL,NT,NS,NISO,NXAV VALUES ARE   ,4I-
     15,5X,5I5)
 481  FORMAT (1X,18F7.3)
 483  FORMAT (1H1,20X,18A4)
 485  FORMAT (1H0,16HS. D. OF RES =  ,F6.3,2X,6HDOF = ,F6.1,2X,14H-
     1SUM OF RES =  ,F6.3,2X,14HAV ABS DEV □  ,F6.3)
 487  FORMAT (1H0,7HTEMP = /10X,10F10.3)
 489  FORMAT (8X,4F10.5,F10.1,3F10.5,I4)
 491  FORMAT (1H0,7HP(T) = /10X,10F10.3)
 495  FORMAT (6X,F10.0,3F12.5,F12.4,F12.3)
 500  FORMAT (1H0,39HSTANDARD ERROR OF PREDICTED VALUES =   ,F7.3,3X,26H-
     1NO. OF DATA PREDICTED =    ,F6.1)
 501  FORMAT (1H0,11F10.4)
 502  FORMAT (1X,'S. D. OF DATA USED   =  ',9F8.3)
 503  FORMAT (1X,'S. D. OF DATA PRED.  =  ',9F8.3)
 504  FORMAT (1H0,1X,'CUTOFF = ',2F11.2,3X,'REDUCED DATA BEGIN AT LIFE = ',  -
     1 F11.2,3X,F6.2,2X,F5.0)
 505  FORMAT (1X,39HAVG. DEVIATION OF PREDICTED VALUES □   ,F7.3,3X,39H-
     1AVG. ABS. DEV. OF PREDICTED VALUES =    ,F7.3)
 506  FORMAT (1H0,1X,'NO. OF DATA USED =',I6,5X,'NO. WEIGHTED =',    -
     1 I6,5X,'NO. PREDICTED =',I6,5X,'D O F  =',F6.0 )
 507  FORMAT (4X,F5.2,F10..0,3X,F8.3,3X,F10.4,2X,F10.4)
 509  FORMAT (5X,9F6.3,2X,9F5.3)
 511  FORMAT (2X,23HTHE VALUES OF  A     =  ,9F8.3)
 513  FORMAT (3X,54HA VALUE    TEMP      LOG TIME       LOG S        STRESS    )
 515  FORMAT (1H1,2X,30HRESULTS FROM MEG16B  (MAY 78)   /  -
     1  15X,39HLOGH + A LOGH * P(T) + P(T) = G(SIGMA)  )
 516  FORMAT (10X,4A4)
 517  FORMAT (2X,12F6.2)
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```
 518  FORMAT (2X,12I6)
 519  FORMAT (2X,12F8.3)
 523  FORMAT (1X,'S. D. OF ZERO DEV.    =   ',9F8.3)
 524  FORMAT (1X,11F9.3)
C
 399  STOP
C
      END
C............................................................
C
      SUBROUTINE TUSTR (XS,X,NS,ALPL,ALPH,COEF)
C
C THIS PROGRAM SETS UP THE STRESS FUNCTION IN TERMS OF
C  TWO STRAIGHT LINES MERGED TOGETHER SMOOTHLY
C
C   XS IS  THE VECTOR OF 'STATION VALUES'   ONLY XS(2) IS USED IN THIS VERSION
C   X  IS THE VALUE OF LOG STRESS TO BE EXPRESSED IN TERMS OF THE MODEL EQ.
C   NS  IS THE NUMBER OF STATION VALUES    SET = 3   USUALLY
C   ALPL IS THE EXPONENT FOR THE LOW STRESS REGION
C   ALPH IS THE EXPONENT FOR THE HIGH STRESS REGION
C   COEF IS THE VECTOR OF COEFFICIENTS FOR EACH X VALUE
C
      DOUBLE PRECISION XS,X,COEF,S,SLOG,SSQ,C1,C2,C3
      DIMENSION XS(4),COEF(4)
C     WRITE (7,200) XS
  10  S = 10.0**(X-XS(2))
      SLOG = DLOG10(10.0**X/10.0**XS(2))
      SSQ = S**2
      C1 = 2.302585093
      C2 = 1.0/(C1*ALPL)
      C3 = 1.0/(C1*ALPH)
      IF (X.GT.XS(2)) GO TO 20
C
C  FOR STRESS LT MID STRESS    REGION  1
C
  15  COEF(1) = 1.0
      COEF(2) = SLOG
      COEF(3) = C2*(C2*S**ALPL-C2-SLOG)
      COEF(4) = 0.0
      GO TO 30
C
C  FOR STRESS GT MID STRESS    REGION  2
C
  20  COEF(1) = 1.0
      COEF(2) = SLOG
      COEF(3) = 0.0
      COEF(4) = C3*(C3*S**ALPH-C3-SLOG)
  30  CONTINUE
C     WRITE (7,204) X
C     WRITE (7,201) COEF
C     WRITE (7,203) S,SLOG,SSQ
 200  FORMAT (1X,3F8.4)
 201  FORMAT (10X,5F10.5)
 203  FORMAT (1X,4F9.5)
 204  FORMAT (10X,'   X =   ',F7.4)
      RETURN
      END
C............................................................
C
      SUBROUTINE STACN (X,Y,NS,COEF,N)
C
C  TO EXPRESS A SINGLE VALUE OF A VARIABLE IN TERMS OF DISCRETE 'STATIONS'
C
C    X IS  THE VECTOR OF 'STATION VALUES'
C    Y IS THE VALUE TO BE EXPRESSED IN TERMS OF STATION VALUES
C    NS  IS THE NUMBER OF STATION VALUES
C    COEF IS THE VECTOR OF COEFFICIENTS FOR EACH Y VALUE
C
```

```
C  GIVEN A TABLE OF  DISCRETE  X  VALUES AND ONE VALUE, CALLED  Y ,
C  FIND, FOR THE  Y  VALUE, THE COEFFICIENTS OF A TYPE OF LAGRANGIAN
C  INTERPOLATION EQUATION
C
      DOUBLE PRECISION X,Y,COEF,CA,CB,CC,CD,CE,CF,CH,CJ,CK
      DIMENSION COEF(32),X(32)
C     WRITE (7,205) X
C     WRITE (7,205) Y
    5 CA = 0.0
      CB = 0.0
      CC = 0.0
      CD = 0.0
      CE = 0.0
      CF = 0.0
      CH = 0.0
      CJ = 0.0
      CK = 0.0
      DO 10 K=1,32
   10 COEF(K) = 0.0
   30 DO 20 K= 1,NS
      M=NS-K
C     WRITE (7,206) K,M
      IF (Y.LT.X(2)) GO TO 15
      IF (Y.GE.X(NS-1)) GO TO 16
      IF (Y.GE.X(M)) GO TO 17
   20 CONTINUE
   17 N=M
      CA = Y-X(N-1)
      CB = Y-X(N)
      CC = Y-X(N+1)
      CD = Y-X(N+2)
      CF = X(N  )-X(N+1)
      CE = X(N  )-X(N-1)
      CH = X(N+1)-X(N-1)
      CJ = X(N  )-X(N+2)
      CK = X(N+1)-X(N+2)
   40 COEF(N-1) = (CB*CC)/(CE*CH)*0.5
      COEF(N+2) = (CB*CC)/(CJ*CK)*0.5
      COEF(N  ) = ((CA*CC*CJ)+(CC*CD*CE))/(CE*CF*CJ)*0.5
      COEF(N+1) =-((CA*CB*CK)+(CB*CD*CH))/(CF*CH*CK)*0.5
      GO TO 45
   15 N=2
      GO TO 18
   16 N=NS-1
   18 COEF(N-1) = (X(N)-Y)*(X(N+1)-Y)/((X(N)-X(N-1))*(X(N+1)-X(N-1)))
      COEF(N) = (X(N+1)-Y)*(Y-X(N-1))/((X(N+1)-X(N))*(X(N)-X(N-1)))
      COEF(N+1) = (X(N)-Y)*(Y-X(N-1))/((X(N)-X(N+1))*(X(N+1)-X(N-1)))
   45 CONTINUE
C     WRITE (7,206) N
C     WRITE (6,205) Y
C     WRITE (6,205) (COEF(L),L=1,NS)
  205 FORMAT (1X, 10F10.4)
  206 FORMAT (1X, 3I4)
      RETURN
      END
C.................................................................
```

```
C
      SUBROUTINE AMATF (M,N,MK,KSPARS,U)
C
C
C  MLSS/MFSS PROGRAM BEING USED TO SOLVE THE REDUNDANT EQS
C
C     THE  U  MATRIX MUST BE BROKEN UP INTO THE PROPER MATRICES
C
C    M      IS THE NUMBER OF COLUMNS IN MATRIX
C    N      IS THE NUMBER OF ROWS
C    MK     IS THE COLUMN TO BE USED AS DEPENDENT VARIABLE
C    KS     IS A COUNTER NOT USED IN THIS VERSION
C    U      IS THE MATRIX TO BE INVERTED
C    XF     IS THE SOLUTION VECTOR
C
      DOUBLE PRECISION XF
      DOUBLE PRECISION F(200),AUT(2304),TRAC(200),U(200,48),A(48,200),XXT(48,48)
      COMMON /CCOMN/ XF(48),NP
      DO 5 I=1,48
      DO 5 J=1,200
5     A(I,J)=0.
C
C     READ X
C
      MKM1=MK-1
      MKP1=MK+1
      DO 20 I=1,N
      DO 10 J=1,MKM1
10    A(J,I)=U(I,J)
      DO 15 J=MKP1,M
15    A(J-1,I)=U(I,J)
C     WRITE (6,60) (U(I,J),J=1,M)
      F(I)=-U(I,MK)
20    CONTINUE
      M=M-1
C
C     WRITE (6,60)((A(J,I),J=1,M),I=1,N)
C
C             T
C     FORM XX
C
      DO 25 I=1,M
      DO 25 J=1,M
      XXT(I,J)=0.
      DO 25 K=1,N
25    XXT(I,J)=XXT(I,J)+A(I,K)*A(J,K)
C     DO 7 I=1,M
C   7 WRITE (6,60) (XXT(I,J),J=1,M)
C
C     FORM XF
C
      DO 30 I=1,M
      XF(I)=0.
      DO 30 K=1,N
30    XF(I)=XF(I)+A(I,K)*F(K)
C
C     PREPARE FOR LEAST SQUARES
C
      EPS=1.E-5
      K=0
      DO 35 J=1,M
      DO 35 I=1,J
      K=K+1
35    AUT(K)=XXT(I,J)
      KTOT=K
C     WRITE (6,45) (AUT(K),K=1,KTOT)
  36  CALL  DMFSS (AUT,M,EPS,IRANK,TRAC)
C     WRITE (6,50) IRANK
C     WRITE (6,45) (AUT(K),K=1,KTOT)
```

```
C     COMPUTE           T -1                         T
C              A= (XX )   XF, THE SOLUTION OF  XF - XX A= 0
C
 37   CALL  DMLSS (AUT,M,IRANK,TRAC,0,XF,IER)
C     WRITE (6,50) IER
C     WRITE (6,45) (XF(I),I=1,M)
C
      RETURN
C
40    FORMAT (1H1/5H M=   , I3,3X,4HN=   , I3/1X/2H X/1X)
45    FORMAT (2H F/1X/(8E16.8))
50    FORMAT (I5)
60    FORMAT (2X,10F8.3)
      END
C.....................................................................
C
C        SUBROUTINE DMFSS
C
C        PURPOSE
C           GIVEN A SYMMETRIC POSITIVE SEMI DEFINITE MATRIX ,DMFSS WILL
C           (1) DETERMINE THE RANK AND LINEARLY INDEPENDENT ROWS AND
C               COLUMNS
C           (2) FACTOR A SYMMETRIC SUBMATRIX OF MAXIMAL RANK
C           (3) EXPRESS NONBASIC ROWS IN TERMS OF BASIC ONES,
C               EXPRESS NONBASIC COLUMNS IN TERMS OF BASIC ONES
C               EXPRESS BASIC VARIABLES IN TERMS OF FREE ONES
C           SUBROUTINE DMFSS MAY BE USED AS A PREPARATORY STEP FOR THE
C           CALCULATION OF THE LEAST SQUARES SOLUTION OF MINIMAL
C           LENGTH OF A SYSTEM OF LINEAR EQUATIONS WITH SYMMETRIC
C           POSITIVE SEMI-DEFINITE COEFFICIENT MATRIX
C
C        USAGE
C           CALL DMFSS(A,N,EPS,IRANK,TRAC)
C
C        DESCRIPTION OF PARAMETERS
C           A      - UPPER TRIANGULAR PART OF GIVEN SYMMETRIC SEMI-
C                    DEFINITE MATRIX STORED COLUMNWISE IN COMPRESSED FORM
C                    ON RETURN A CONTAINS THE MATRIX T AND, IF IRANK IS
C                    LESS THAN N, THE MATRICES U AND TU
C                    A MUST BE OF DOUBLE PRECISION
C           N      - DIMENSION OF GIVEN MATRIX A
C           EPS    - TESTVALUE FOR ZERO AFFECTED BY ROUND-OFF NOISE
C           IRANK  - RESULTANT VARIABLE, CONTAINING THE RANK OF GIVEN
C                    MATRIX A IF A IS SEMI-DEFINITE
C                    IRANK = 0 MEANS A HAS NO POSITIVE DIAGONAL ELEMENT
C                              AND/OR EPS IS NOT ABSOLUTELY LESS THAN ONE
C                    IRANK =-1 MEANS DIMENSION N IS NOT POSITIVE
C                    IRANK =-2 MEANS COMPLETE FAILURE, POSSIBLY DUE TO
C                              INADEQUATE RELATIVE TOLERANCE EPS
C           TRAC   - VECTOR OF DIMENSION N CONTAINING THE
C                    SOURCE INDEX OF THE I-TH PIVOT ROW IN ITS I-TH
C                    LOCATION, THIS MEANS THAT TRAC CONTAINS THE
C                    PRODUCT REPRESENTATION OF THE PERMUTATION WHICH
C                    IS APPLIED TO ROWS AND COLUMNS OF A IN TERMS OF
C                    TRANSPOSITIONS
C                    TRAC MUST BE OF DOUBLE PRECISION
C
C        REMARKS
C           EPS MUST BE ABSOLUTELY LESS THAN ONE. A SENSIBLE VALUE IS
C           SOMEWHERE IN BETWEEN 10**(-4) AND 10**(-6)
C           THE ABSOLUTE VALUE OF INPUT PARAMETER EPS IS USED AS
C           RELATIVE TOLERANCE.
C           IN ORDER TO PRESERVE SYMMETRY ONLY PIVOTING ALONG THE
C           DIAGONAL IS BUILT IN.
C           ALL PIVOTELEMENTS MUST BE GREATER THAN THE ABSOLUTE VALUE
C           OF EPS TIMES ORIGINAL DIAGONAL ELEMENT
C           OTHERWISE THEY ARE TREATED AS IF THEY WERE ZERO
C           MATRIX A REMAINS UNCHANGED IF THE RESULTANT VALUE IRANK
C           EQUALS ZERO
```

```
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           THE SQUARE ROOT METHOD WITH DIAGONAL PIVOTING IS USED FOR
C           CALCULATION OF THE RIGHT HAND TRIANGULAR FACTOR.
C           IN CASE OF AN ONLY SEMI-DEFINITE MATRIX THE SUBROUTINE
C           RETURNS THE IRANK X IRANK UPPER TRIANGULAR FACTOR T OF A
C           SUBMATRIX OF MAXIMAL RANK, THE IRANK X (N-IRANK) MATRIX U
C           AND THE (N-IRANK) X (N-IRANK) UPPER TRIANGULAR TU SUCH
C           THAT TRANSPOSE(TU)*TU=I+TRANSPOSE(U)*U
C
C     ..................................................................
C
      SUBROUTINE DMFSS(A,N,EPS,IRANK,TRAC)
C
C
C        DIMENSIONED DUMMY VARIABLES
      DIMENSION A(1),TRAC(1)
      DOUBLE PRECISION SUM,A,TRAC,PIV,HOLD
C
C        TEST OF SPECIFIED DIMENSION
      IF(N)36,36,1
C
C        INITIALIZE TRIANGULAR FACTORIZATION
    1 IRANK=0
      ISUB=0
      KPIV=0
      J=0
      PIV=0.D0
C
C        SEARCH FIRST PIVOT ELEMENT
      DO 3 K=1,N
      J=J+K
      TRAC(K)=A(J)
      IF(A(J)-PIV)3,3,2
    2 PIV=A(J)
      KSUB=J
      KPIV=K
    3 CONTINUE
C
C        START LOOP OVER ALL ROWS OF A
      DO 32 I=1,N
      ISUB=ISUB+I
      IM1=I-1
    4 KMI=KPIV-I
      IF(KMI)35,9,5
C
C        PERFORM PARTIAL COLUMN INTERCHANGE
    5 JI=KSUB-KMI
      IDC=JI-ISUB
      JJ=ISUB-IM1
      DO 6 K=JJ,ISUB
      KK=K+IDC
      HOLD=A(K)
      A(K)=A(KK)
    6 A(KK)=HOLD
C
C        PERFORM PARTIAL ROW INTERCHANGE
      KK=KSUB
      DO 7 K=KPIV,N
      II=KK-KMI
      HOLD=A(KK)
      A(KK)=A(II)
      A(II)=HOLD
    7 KK=KK+K
```

```
C
C        PERFORM REMAINING INTERCHANGE
      JJ=KPIV-1
      II=ISUB
      DO 8 K=I,JJ
      HOLD=A(II)
      A(II)=A(JI)
      A(JI)=HOLD
      II=II+K
    8 JI=JI+1
    9 IF(IRANK)22,10,10
C
C        RECORD INTERCHANGE IN TRANSPOSITION VECTOR
   10 TRAC(KPIV)=TRAC(I)
      TRAC(I)=KPIV
C
C        MODIFY CURRENT PIVOT ROW
      KK=IM1-IRANK
      KMI=ISUB-KK
      PIV=0.D0
      IDC=IRANK+1
      JI=ISUB-1
      JK=KMI
      JJ=ISUB-I
      DO 19 K=I,N
      SUM=0.D0
C
C        BUILD UP SCALAR PRODUCT IF NECESSARY
      IF(KK)13,13,11
   11 DO 12 J=KMI,JI
      SUM=SUM-A(J)*A(JK)
   12 JK=JK+1
   13 JJ=JJ+K
      IF(K-I)14,14,16
   14 SUM=A(ISUB)+SUM
C
C        TEST RADICAND FOR LOSS OF SIGNIFICANCE
      IF(SUM-DABS(A(ISUB)*DBLE(EPS)))20,20,15
   15 A(ISUB)=DSQRT(SUM)
      KPIV=I+1
      GOTO 19
   16 SUM=(A(JK)+SUM)/A(ISUB)
      A(JK)=SUM
C
C        SEARCH FOR NEXT PIVOT ROW
      IF(A(JJ))19,19,17
   17 TRAC(K)=TRAC(K)-SUM*SUM
      HOLD=TRAC(K)/A(JJ)
      IF(PIV-HOLD)18,19,19
   18 PIV=HOLD
      KPIV=K
      KSUB=JJ
   19 JK=JJ+IDC
      GOTO 32
C
C        CALCULATE MATRIX OF DEPENDENCIES U
   20 IF(IRANK)21,21,37
   21 IRANK=-1
      GOTO 4
   22 IRANK=IM1
      II=ISUB-IRANK
      JI=II
      DO 26 K=1,IRANK
      JI=JI-1
      JK=ISUB-1
      JJ=K-1
      DO 26 J=I,N
      IDC=IRANK
      SUM=0.D0
```

```
      KMI=JI
      KK=JK
      IF(JJ)25,25,23
   23 DO 24 L=1,JJ
      IDC=IDC-1
      SUM=SUM-A(KMI)*A(KK)
      KMI=KMI-IDC
   24 KK=KK-1
   25 A(KK)=(SUM+A(KK))/A(KMI)
   26 JK=JK+J
C
C        CALCULATE I+TRANSPOSE(U)*U
      JJ=ISUB-I
      PIV=0.D0
      KK=ISUB-1
      DO 31 K=I,N
      JJ=JJ+K
      IDC=0
      DO 28 J=K,N
      SUM=0.D0
      KMI=JJ+IDC
      DO 27 L=II,KK
      JK=L+IDC
   27 SUM=SUM+A(L)*A(JK)
      A(KMI)=SUM
   28 IDC=IDC+J
      A(JJ)=A(JJ)+1.D0
      TRAC(K)=A(JJ)
C
C        SEARCH NEXT DIAGONAL ELEMENT
      IF(PIV-A(JJ))29,30,30
   29 KPIV=K
      KSUB=JJ
      PIV=A(JJ)
   30 II=II+K
      KK=KK+K
   31 CONTINUE
      GOTO 4
   32 CONTINUE
   33 IF(IRANK)35,34,35
   34 IRANK=N
   35 RETURN
C
C        ERROR RETURNS
C
C        RETURN IN CASE OF ILLEGAL DIMENSION
   36 IRANK=-1
      RETURN
C
C        INSTABLE FACTORIZATION OF I+TRANSPOSE(U)*U
   37 IRANK=-2
      RETURN
      END
C.......................................................................
C
C        SUBROUTINE DMLSS
C
C        PURPOSE
C           SUBROUTINE DMLSS IS THE SECOND STEP IN THE PROCEDURE FOR
C           CALCULATING THE LEAST SQUARES SOLUTION OF MINIMAL LENGTH
C           OF A SYSTEM OF SIMULTANEOUS LINEAR EQUATIONS WITH SYMMETRIC
C           POSITIVE SEMI-DEFINITE COEFFICIENT MATRIX.
C
C        USAGE
C           CALL DMLSS(A,N,IRANK,TRAC,INC,RHS,IER)
C
```

```
C        DESCRIPTION OF PARAMETERS
C           A      - COEFFICIENT MATRIX IN FACTORED FORM AS GENERATED
C                    BY SUBROUTINE MFSS FROM INITIALLY GIVEN SYMMETRIC
C                    COEFFICIENT MATRIX A STORED IN N*(N+1)/2 LOCATIONS
C                    A REMAINS UNCHANGED
C                    A MUST BE OF DOUBLE PRECISION
C           N      - DIMENSION OF COEFFICIENT MATRIX
C           IRANK  - RANK OF COEFFICIENT MATRIX, CALCULATED BY MEANS OF
C                    SUBROUTINE DMFSS
C           TRAC   - VECTOR OF DIMENSION N CONTAINING THE
C                    SUBSCRIPTS OF PIVOT ROWS AND COLUMNS, I.E. THE
C                    PRODUCT REPRESENTATION IN TRANSPOSITIONS OF THE
C                    PERMUTATION WHICH WAS APPLIED TO ROWS AND COLUMNS
C                    OF A IN THE FACTORIZATION PROCESS
C                    TRAC IS A RESULTANT ARRAY OF SUBROUTINE MFSS
C                    TRAC MUST BE OF DOUBLE PRECISION
C           INC    - INPUT VARIABLE WHICH SHOULD CONTAIN THE VALUE ZERO
C                    IF THE SYSTEM OF SIMULTANEOUS EQUATIONS IS KNOWN
C                    TO BE COMPATIBLE AND A NONZERO VALUE OTHERWISE
C           RHS    - VECTOR OF DIMENSION N CONTAINING THE RIGHT HAND SIDE
C                    ON RETURN RHS CONTAINS THE MINIMAL LENGTH SOLUTION
C                    RHS MUST BE OF DOUBLE PRECISION
C           IER    - RESULTANT ERROR PARAMETER
C                    IER □ 0 MEANS NO ERRORS
C                    IER =-1 MEANS N AND/OR IRANK IS NOT POSITIVE AND/OR
C                            IRANK IS GREATER THAN N
C                    IER = 1 MEANS THE FACTORIZATION CONTAINED IN A HAS
C                            ZERO DIVISORS AND/OR TRAC CONTAINS
C                            VALUES OUTSIDE THE FEASIBLE RANGE 1 UP TO N
C
C        REMARKS
C           THE MINIMAL LENGTH SOLUTION IS PRODUCED IN THE STORAGE
C           LOCATIONS OCCUPIED BY THE RIGHT HAND SIDE.
C           SUBROUTINE DMLSS DOES TAKE CARE OF THE PERMUTATION
C           WHICH WAS APPLIED TO ROWS AND COLUMNS OF A.
C           OPERATION IS BYPASSED IN CASE OF A NON POSITIVE VALUE
C           OF IRANK
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           LET T, U, TU BE THE COMPONENTS OF THE FACTORIZATION OF A,
C           AND LET THE RIGHT HAND SIDE BE PARTITIONED INTO A FIRST
C           PART X1 OF DIMENSION IRANK AND A SECOND PART X2 OF DIMENSION
C           N-IRANK. THEN THE FOLLOWING OPERATIONS ARE APPLIED IN
C           SEQUENCE
C           (1) INTERCHANGE RIGHT HAND SIDE
C           (2) X1 □ X1 + U * X2
C           (3) X2 =-TRANSPOSE(U) * X1
C           (4) X2 □ INVERSE(TU) * INVERSE(TRANSPOSE(TU)) * X2
C           (5) X1 □ X1 + U * X2
C           (6) X1 = INVERSE(T) * INVERSE(TRANSPOSE(T)) * X1
C           (7) X2 =-TRANSPOSE(U) * X1
C           (8) X2 = INVERSE(TU) * INVERSE(TRANSPOSE(TU)) * X2
C           (9) X1 = X1 + U * X2
C           (10)X2 □ TRANSPOSE(U) * X1
C           (11) REINTERCHANGE CALCULATED SOLUTION
C           IF THE SYSTEM OF SIMULTANEOUS LINEAR EQUATIONS IS SPECIFIED
C           TO BE COMPATIBLE THEN STEPS (2), (3), (4) AND (5) ARE
C           CANCELLED.
C           IF THE COEFFICIENT MATRIX HAS RANK N, THEN THE ONLY STEPS
C           PERFORMED ARE (1), (6) AND (11).
C
C     ..............................................................
```

```
C
      SUBROUTINE DMLSS(A,N,IRANK,TRAC,INC,RHS,IER)
C
C
C        DIMENSIONED DUMMY VARIABLES
      DIMENSION A(1),TRAC(1),RHS(1)
      DOUBLE PRECISION SUM,A,RHS,TRAC,HOLD
C
C        TEST OF SPECIFIED DIMENSIONS
      IDEF=N-IRANK
      IF(N)33,33,1
    1 IF(IRANK)33,33,2
    2 IF(IDEF)33,3,3
C
C        CALCULATE AUXILIARY VALUES
    3 ITE=IRANK*(IRANK+1)/2
      IX2=IRANK+1
      NP1=N+1
      IER=0
C
C        INTERCHANGE RIGHT HAND SIDE
      JJ=1
      II=1
    4 DO 6 I=1,N
      J=TRAC(II)
      IF(J)31,31,5
    5 HOLD=RHS(II)
      RHS(II)=RHS(J)
      RHS(J)=HOLD
    6 II=II+JJ
      IF(JJ)32,7,7
C
C        PERFORM STEP 2 IF NECESSARY
    7 ISW=1
      IF(INC*IDEF)8,28,8
C
C        CALCULATE X1 = X1 + U * X2
    8 ISTA=ITE
      DO 10 I=1,IRANK
      ISTA=ISTA+1
      JJ=ISTA
      SUM=0.D0
      DO 9 J=IX2,N
      SUM=SUM+A(JJ)*RHS(J)
    9 JJ=JJ+J
   10 RHS(I)=RHS(I)+SUM
      GOTO(11,28,11),ISW
C
C        CALCULATE X2 = TRANSPOSE(U) * X1
   11 ISTA=ITE
      DO 15 I=IX2,N
      JJ=ISTA
      SUM=0.D0
      DO 12 J=1,IRANK
      JJ=JJ+1
   12 SUM=SUM+A(JJ)*RHS(J)
      GOTO(13,13,14),ISW
   13 SUM=-SUM
   14 RHS(I)=SUM
   15 ISTA=ISTA+I
      GOTO(16,29,30),ISW
C
C        INITIALIZE STEP (4) OR STEP (8)
   16 ISTA=IX2
      IEND=N
      JJ=ITE+ISTA
C
C        DIVISION OF X1 BY TRANSPOSE OF TRIANGULAR MATRIX
   17 SUM=0.D0
      DO 20 I=ISTA,IEND
```

```
      IF(A(JJ))18,31,18
   18 RHS(I)=(RHS(I)-SUM)/A(JJ)
      IF(I-IEND)19,21,21
   19 JJ=JJ+ISTA
      SUM=0.D0
      DO 20 J=ISTA,I
      SUM=SUM+A(JJ)*RHS(J)
   20 JJ=JJ+1
C
C         DIVISION OF X1 BY TRIANGULAR MATRIX
   21 SUM=0.D0
      II=IEND
      DO 24 I=ISTA,IEND
      RHS(II)=(RHS(II)-SUM)/A(JJ)
      IF(II-ISTA)25,25,22
   22 KK=JJ-1
      SUM=0.D0
      DO 23 J=II,IEND
      SUM=SUM+A(KK)*RHS(J)
   23 KK=KK+J
      JJ=JJ-II
   24 II=II-1
   25 IF(IDEF)26,30,26
   26 GOTO(27,11,8),ISW
C
C         PERFORM STEP (5)
   27 ISW=2
      GOTO 8
C
C         PERFORM STEP (6)
   28 ISTA=1
      IEND=IRANK
      JJ=1
      ISW=2
      GOTO 17
C
C         PERFORM STEP (8)
   29 ISW=3
      GOTO 16
C
C         REINTERCHANGE CALCULATED SOLUTION
   30 II=N
      JJ=-1
      GOTO 4
C
C         ERROR RETURN IN CASE OF ZERO DIVISOR
   31 IER=1
   32 RETURN
C
C         ERROR RETURN IN CASE OF ILLEGAL DIMENSION
   33 IER=-1
      RETURN
      END
C
C.............................................................
C
      SUBROUTINE TOPLT (TP,NT,ALOGS,NQ,GS)
C
C  THIS PROGRAM SPLITS THE XF VECTOR INTO TEMPERATURE AND
C   STRESS COMPONENTS  FOR PLOTTING AND CURVE FITTING
C
      DOUBLE PRECISION XF,TP,ALOGS,GS,X,Y,XX,YY,P
      DOUBLE PRECISION XPLTT,TFCN,XPLTRT,XPLTG,YPLTG
      DIMENSION TP(32),ALOGS(16),P(7),X(32),Y(48),CISOT(32),XX(16),YY(48),GS(16)
      COMMON /ACOMN/ QXPLTT(32),QXPLRT(32),QYPLTT(32),QXPLTG(16),QYPLTG(16)
      COMMON /BCOMN/ XPLTT(32),TFCN(32),XPLTRT(32),XPLTG(16),YPLTG(16)
      COMMON /CCOMN/ XF(48),NP
      COMMON /DCOMN/ D,E,F,G,H,AA
```

```
C
C   TEMPERATURE COMPONENT
C
    5   DO 10 I=1,16
        X(I)=0.0
        Y(I)=0.0
   10   GS(I)=0.0
        K=1
        NTM1 □ NT-1
        DO 25 I=1,NTM1
        IF (K.EQ.NP) GO TO 20
   15   Y(K) = XF(I)
        X(K)=TP(K)
        K=K+1
        GO TO 25
   20   Y(K)=0.0
        X(K)=TP(K)
        K=K+1
        IF (I.EQ.NT) GO TO 25
        GO TO 15
   25   CONTINUE
        DO 30 I=1,NT
        XPLTT(I)=X(I)
        XPLTRT(I)=1000./(X(I)+460.)
        TFCN(I)=Y(I)
        QXPLTT(I) □ XPLTT(I)
        QYPLTT(I) □ TFCN(I)
        QXPLRT(I) = XPLTRT(I)
   30   CONTINUE
        NB=2
        CALL CVFITF (X,Y,NB,NT,P,0)
        D=P(1)
        E=P(2)
        F=P(3)
C
C   STRESS COMPONENT
C
   35   NTM2P=NT
        NQMQ=NTM2P+NQ-1
        K=0
        DO 40 I=NTM2P,NQM2
        K=K+1
        GS(K)=-XF(I)
   40   CONTINUE
        RETURN
        END
C...................................................................
C
        SUBROUTINE CVFITF (XP,YP,NBIG,NSMALL,P,IPL)
C
C   THIS IS A GENERAL CURVE FITTING SUBROUTINE
        DIMENSION LAB(1), KKK(9), LABH(9),LABX(1),LABY(1)
        DIMENSION X(100),Y(100),YCALC(100),DELY(100),ERRATA(100),D(8)
        DIMENSION A(8,8),P(7),CC(7),XP(100),YP(100),TITLE(6),FMTW(7),PK(1),KPL(14)
        DATA NINC,XNINC/100,99./
        DATA LABX /'  X '/
        DATA LABY /'F(X)'    /
        DATA LAB(3)/4H    /
        DATA KKK/3,999,2,0,0,0,0,-1,0/
C
C
C   NOTA BENE    CVFITF
C
C     XP ARRAY CANNOT BE LARGER THAN 100
C     YP ARRAY CANNOT BE LARGER THAN 100
C        I.E. NSMALL CANNOT EXCEED 100
C     NBIG CANNOT BE GREATER THAN 6
C
```

```
C      P □ OUTPUT ARRAY OF COEFFICIENTS WHERE P(1) IS THE CONSTANT
C          TERM, P(2) IS THE COEFFICIENT OF THE FIRST DEGREE TERM AND
C          P(3) IS THE COEFICIENT OF THE SECOND DEGREE TERM, ETC.
C     XP = INPUT ARRAY INDEPENDENT VARIABLE
C     YP = INPUT  ARRAY DEPENDENT VARIABLE
C   NBIG = DEGREE OF POLYNOMIAL TO BE ESTIMATED
C NSMALL = NUMBER OF OBSERVATIONS (NO. PAIRS OF DATA PROVIDED)
C    IPL = CVFIT OUTPUT CONTROL
C            0  FOR NO OUTPUT
C            1 FOR DATA OUTPUT
C            2 FOR DATA AND PLOT OUTPUT
C
C DETNUM= VARIATION DUE TO REGRESSION
C DETDEN= TOTAL VARIATION
C    DEV= VARIANCE
C   DVTN= STD. DEVIATION
C  DETRM= COEFFICIENT OF DETERMINATION
C  CORRL= CORRELATION COEFFICIENT
C ERRATA= RELATIVE ERROR
C   DELY= RESIDUAL ERROR
C    ERS= RELATIVE VARIANCE
C    ERA= RELATIVE STD. DEVIATION
C
      DATA PK(1),KPL(1),KPL(2)/1.0,64,2/
      DOUBLE PRECISION A,D,CC,XMAXX,XP,YP,X,P,Y
 1    IF (NSMALL.GT.100) GO TO 65
      KN=NBIG
 2    IF (KN.GT.6) GO TO 75
      NBIG □ NBIG+1
 4    SN=NSMALL
      D(NBIG+1)=0.
 3    DO 5 I=1,NSMALL
      X(I)=XP(I)
      Y(I)=YP(I)
 5    D(NBIG+1)=D(NBIG+1)+Y(I)**2
      XMAXX=X(1)
      DO 15 I=2,NSMALL
      IF (XMAXX-DABS(X(I))) 10,15,15
  10  XMAXX=DABS(X(I))
  15  CONTINUE
C
C  NORMALIZE THE INDEPENDENT VARIABLE TO THE INTERVAL -1.,+1.
C
      DO 20 I=1,NSMALL
  20  X(I)=X(I)/XMAXX
C
C  SET UP THE MATRIX OF COEFFICIENTS
C
      DO 25 I=1,NBIG
      DO 25 J=1,NBIG
  21  A(I,J)=0.
      DO 25 K=1,NSMALL
  22  FI=FUNC(I,X(K))
  23  FJ=FUNC(J,X(K))
  24  A(I,J)=A(I,J)+FI*FJ
25    CONTINUE
C
      DO 30 I=1,NBIG
      D(I)=0.
      DO 30 K=1,NSMALL
      FI=FUNC(I,X(K))
      D(I)=D(I)+Y(K)*FI
  30  CONTINUE
C
      CALL DTRIA (A,NBIG,D,DET)
      CALL DSOLVE (A,NBIG,CC)
      XXAXX=1./XMAXX
      DETNUM=0.
      DO 35 J=1,NBIG
```

```
      P(J)=CC(J)
      DETNUM=DETNUM+CC(J)*D(J)
   35 P(J)=P(J)*FUNC(J,XXAXX)
      IF (IPL.EQ.0) RETURN
C
C  COMPUTE Y-CALC,DELTA-Y,AND STANDARD DEVIATION
C
      DETNUM=DETNUM-SUMYSQ
      DETDEN=D(NBIG+1)-SUMYSQ
      DETRM=DETNUM/DETDEN
      CORRL=SQRT(ABS(DETRM))
      CN=NBIG
      ENDIV=SN-CN-1.
      POLREG=DETNUM/ENDIV
      TOTREG=DETDEN/ENDIV
      ERS=0.
      DEV=0.
      DO 45 I=1,NSMALL
      X(I)=XP(I)
      K□NSMALL+I
      Y(K)=0.
      DO 40 J=1,NBIG
      FJ=FUNC(J,X(I))
   40 Y(K)=Y(K)+P(J)*FJ
C
      DELY(I)=Y(I)-Y(K)
      ERRATA(I)=DELY(I)/Y(K)
      ERS=ERS+ERRATA(I)**2
   45 DEV=DEV+DELY(I)*DELY(I)
      DEV=DEV/ENDIV
      IF (ENDIV.GT.0.0) GO TO 50
      DVTN=1.000
      GO TO 55
   50 DVTN=SQRT(DEV)
   55 ERS=ERS/SN
      ERA=SQRT(ERS)
C
C     WRITE (7,85) LABX,LABY
      DO 60 I=1,NSMALL
      K=NSMALL+I
   60 WRITE (7,90) X(I),Y(I),Y(K),DELY(I),ERRATA(I)
C     WRITE (7,95) KN
C   61 WRITE (7,100) (P(I),I=1,NBIG)
C     WRITE (7,105) DEV,DVTN,DETRM,CORRL,ERS,ERA
C     WRITE (7,110) DET
C
      IF (IPL.LT.2) RETURN
C
      RETURN
 65   WRITE (6,115) NSMALL
 75   WRITE (6,125) NBIG
      STOP
C
85    FORMAT (1X,3A4,12X,2A4,10X,12HCALC FUNC.   ,6X,10H DEVIATION,8X,1-
     15H RELATIVE ERROR)
90    FORMAT (5G18.8)
95    FORMAT (41H THE REGRESSION EQUATION FOR THE ABOVE IS/43H  Y = A(0)-
     1 + SUM OF (( A(J) * X**J )), J=1,I1)
100   FORMAT (7G18.8)
105   FORMAT (1X,2X,14H THE VARIANCE=G15.7,20H STANDARD DEVIATION=G15.7-
     1/3X,14HDETERMINATION=G15.7,8X,12HCORRELATION=G15.7/1X,2X,14H PCT -
     2VARIANCE=G15.7,20H STD. PCT DEVIATION=G15.7)
110   FORMAT (13H0DETERMINANT=G14.6//)
115   FORMAT (43H0ONLY 100 DATA POINTS ALLOWED, YOUR NSMALL=I13,1H.)
120   FORMAT (6H0NBIG=2A4,2X,7HNSMALL=2A4)
125   FORMAT (1X,2X,20H**POLYNOMIAL DEGREE=I5,11H IS TOO BIG)
      END
```

```
C...........................................................
C
      SUBROUTINE DTRIA (B,NR,C,DET)
C
C
      DIMENSION A(8,8), C(8), B(8,8)
      DOUBLE PRECISION A,B,C
      KM1=NR
      K=NR+1
      DO 5 I=1,KM1
      DO 5 J=1,KM1
5     A(I,J)=B(I,J)
      DO 10 I=1,KM1
10    A(I,K)=C(I)
      DO 15 N=2,K
15    A(1,N)=A(1,N)/A(1,1)
      DO 40 J=2,K
      M=0
      L=J-1
      DO 40 I=2,KM1
      M=M+1
      IF (M-L) 25,25,20
20    M=L
25    DO 30 N=1,M
30    A(I,J)=A(I,J)-A(N,J)*A(I,N)
      IF (I-J) 35,40,40
35    A(I,J)=A(I,J)/A(I,I)
40    CONTINUE
      DET=1.0
      DO 45 I=1,KM1
      DET=DET*A(I,I)
      DO 45 J=1,K
45    B(I,J)=A(I,J)
      B(KM1,KM1)=1.0
      RETURN
      END
C...........................................................
C
      SUBROUTINE DSOLVE (A,M,X)
      DIMENSION A(8,8), X(7)
      DOUBLE PRECISION A,X
      MP1=M+1
      MM1=M-1
      DO 10 K=1,MM1
      MMK=M-K
      MMKP1=MMK+1
1     X(M)=A(M,MP1)/A(M,M)
      SUM=0.
      DO 5 I=MMKP1,M
5     SUM=SUM+A(MMK,I)*X(I)
10    X(MMK)=A(MMK,MP1)-SUM
      RETURN
      END
C...........................................................
C
      FUNCTION FUNC (I,X)
      DOUBLE PRECISION X,Z,ANS
      Z=X
      K=I
      IF (K-8) 15,10,5
5     WRITE (6,70) K
      STOP
10    ANS=ALOG10(Z)
      GO TO 65
```

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