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CDA

Cyclic Damage Accumulation Life Prediction System

User and Programmer Manual

Prepared By

Lisa A. Janitor and Richard S. Nelson

United Technologies Corporation
Pratt & Whitney
East Hartford, Connecticut

Under Contract NAS3-23288

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

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CYCLIC DAMAGE ACCUMULATION PROGRAM
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SECTION I

INTRODUCTION

A high temperature, low cycle fatigue life prediction method has been developed by Pratt & Whitney under NASA sponsorship through contract NAS3-23288. This method is known as Cyclic Damage Accumulation (CDA) and is designed to account for the effects on creep-fatigue life of complex loadings such as thermomechanical fatigue, hold periods, waveshapes, mean stresses, multiaxiality, cumulative damage, coatings, and environmental attack. Several features of the model make it practical for application to actual component analysis using modern finite element or boundary element methods. Although it has been developed for use in predicting the crack initiation lifetime of gas turbine engine materials, it can be applied to other materials as well.

In addition to developing the CDA model and its governing equations, the contract activity was expanded to include the writing of a computer program which performs life predictions using it. This report is a combined User Manual and Programmmer Manual for the Cyclic Damage Accumulation (CDA) program. It will describe how to install, run, and modify the CDA program. Section II presents a brief theoretical description of the CDA life prediction model. Section III contains an input description for the program. Section IV gives an output description and examples of the error messages and their causes. Section V describes program flow and algorithms used. Section VI contains information on installation of the code and what changes, if any, may need to be made. Section VII explains how to determine CDA model constants for new materials and what specimen tests are necessary. Section VIII tells how to modify the code to add modes or materials, increase/ decrease the amount of internal storage available, etc. Section IX is a list of references.

Another very significant part of the contract activity was the completion of hundreds of strain-controlled specimen tests on two nickel-base superalloys: cast B1900+Hf and wrought INCO 718. The constitutive behavior of each specimen was recorded and provided the basis for determining the form of the equations required for high temperature life prediction. At the NASA-sponsored workshop for this program, attendees will be provided with a disk which contains not only the FORTRAN source code for the CDA program sections but also several shortened versions of the data from the B1900+Hf database. Appendices A and B show the detailed input and the CDA program output for a TMF test. Appendices C and D list all the specimen data files and the CDA life predictions for them.

SECTION II

THEORETICAL DESCRIPTION

The Cyclic Damage Accumulation life prediction model was first introduced at the end of the base program in 1984 (Moreno et al, 1984). This form of the CDA model was based on continuously cycled isothermal fatigue testing and included several key concepts which made it well suited for use with modern high temperature materials:

1. It used total strain rather than inelastic strain for the basic life prediction. This is especially important for the design of gas turbine engines, since typical components have very small inelastic strains when they are designed for useful lives in the thousands of cycles.

2. It used ratios with respect to reference conditions rather than absolute levels for stresses and other calculated quantities. This helps to reduce the sensitivity to the accuracy of the constitutive modeling.

3. It showed the link between primary creep ductility and basic fatigue capability for B1900+Hf. This required a new term called the primary creep ductility, which can account for the effects of prior loading history. It was shown that these load excursions can set up compliant dislocation structures which can affect subsequent fatigue behavior.

4. It was designed to predict crack initiation, not total failure, with the definition of initiation being the development of of detectable cracks (0.030 in. (0.76 mm.)) at the location being considered.

The option program followed the base program in 1984 and continued until the end of 1988. This activity was designed to take the original model and expand it to include the effects of more complex loadings such as thermomechanical fatigue, cumulative damage, multiaxiality, mean stresses, coatings, and environmental attack (Nelson et al, 1986). As a result, the final CDA model still preserves the key concepts shown above, but it includes several new features to handle more complex situations.

The CDA model is based on the fundamental assumption that an instantaneous damage rate can be calculated and integrated on a cycle-by-cycle basis until a damage of unity is achieved, as follows:

$$1 = \int_0^{N_i} \frac{dD}{dN}\, dN$$

Different rates are calculated simultaneously for whatever modes of damage may apply to a particular material. Currently defined modes in the CDA program include transgranular fatigue (with time-dependent effects), intergranular fatigue, and coating cracking. Environmental effects are also included for the first two substrate modes. For those cycles where the behavior is input, each of these damage rates is calculated for each damage mode active. The damage rates for intermediate cycles are determined by semi-log interpolation between these "defined cycles".

For the transgranular damage mode, the following calculation is the basis of the damage rate:

$$\frac{dD}{dN} = \left(\frac{\Delta\varepsilon_{mech} + \Delta\varepsilon_{tmf} - \Delta\varepsilon_{thrs}}{\Delta\varepsilon_{ref}} \right)^{N1} \times \left(\frac{\Delta\sigma}{\Delta\sigma_{ref}} \right)^{N2} \times 10^{\left(\frac{\sigma_{\max} - \sigma_{\varepsilon_p}}{\sigma_{\max\, ref}} \right)}$$

where:

$\Delta\varepsilon_{mech}$ = total mechanical strain range
$\Delta\varepsilon_{tmf}$ = TMF strain correction (calculated)
$\Delta\varepsilon_{thrs}$ = threshold strain range (constant)
$\Delta\varepsilon_{ref}$ = reference strain range (constant)
$\Delta\sigma$ = stress range
$\Delta\sigma_{ref}$ = reference stress range (f(Temp))
$\sigma_{\max}$ = maximum stress
$\sigma_{\max\, ref}$ = reference maximum stress(f(Temp))
σ_{ε_p} = primary creep stress(f(Temp))
N1, N2 = material constants

The input data is grouped into cycles using the standard "rainflow cycle counting" method based on the reversals of the stress range ratio quantity in the above equation. These individual rates are then summed together and further modified by the time-dependent and environmental factors to give the basic transgranular (mode 1) damage rate:

$$\frac{dD}{dN}_{basic} = \left(\frac{\sum_i \frac{dD}{dN}_i}{X_{nref}} \right) \times F_{timedep} \times F_{envi}$$

The time-dependent factor is based on an Arrhenius function, with its constants tailored to produce the demonstrated frequency effect on basic transgranular fatigue life. Details of its calculation method are provided later in this report.

The current environmental factor is based on an exponential saturation function of the ambient oxygen pressure, which is typical of several reaction-controlled environmental damage mechanisms (Wei, 1986). The factor is given by the following:

$$F_{envi} = (F_{max} - F_{min}) \times \left(1 - e^{-k(\frac{p}{p_{ref}})}\right) + F_{min}$$

The second major damage mode currently active in the CDA model is the intergranular mode. This is based on an integral of an Arrhenius function which is calibrated to data from creep testing, as follows:

$$\frac{dD}{dN}_{inter} = \int \dot{\epsilon} dt$$

Here, $\dot{\epsilon}$ is also defined by an Arrhenius function, but using a different set of constants than the ones used for the time dependent factor. This was found adequate for many components which fail simply from cyclic loadings in the creep regime. The capability of using a third set of Arrhenius constants is also included in the CDA computer program but was not found to be necessary.

The final mode currently active in the program is based on the coating life model from a companion NASA contract (Swanson et al, 1987). It includes a one-dimensional form of the viscoplastic constitutive model developed for PWA 286 overlay coating and calculates life based on tensile hysteretic energy and an effective frequency term. Details of that model are available in the referenced document and related publications.

SECTION III

INPUT DESCRIPTION

General Format of Input Set

The CDA input file consists of one or more sets of specimen data. Input sets can be stacked on top of one another. Blank lines DO NOT need to be inserted between cases, but they may be. There is no limit to the number of sets of data in the input file because the sets are processed (and results output) one at a time.

Each set of data consists of a block of data describing the specimen and one or more cycles of data. The format of the specimen data block and the cycle data follows. Cards are required unless marked "Optional":

```
Card 1
Card 2
Card 3 (optional)
npress Cards 3a  (npress may be 0)
Card 4 (optional)
Card 5
Card 6
Card 7
N sets of the following:
  Card 8
  Card 9
  M Cards 10
```

Specimen Block Data - One set per specimen.

Card 1 - MATERIAL

```
|........|.........|.........|.........|.........|.........|.........|.......
MATERIAL PWA 1455                    PWA286
```

Field	Column(s)	Format	Description
MATERIAL	1-8	A8	Key indicating start of set of data
matid1	10-25	A16	Name of base material; must be found in array MATLS in GETMOD routine.
matid2	34-49	A16	Name of coating material. Blank means specimen is not coated. For coating calculations, matid1 and matid2 must appear in array MATLS in routine CTCONS. matid1 must also appear in array MATLS in GETMOD.

When matid1 and matid2 are read in, any leading or imbedded blanks are removed. For example, if a material is in the MATLS array as PWA1455, matid1 could be PWA 1455 and could appear anywhere in columns 10 - 25.

Card 2 - INITIATION LIFE

```
|........|.........|.........|.........|.........|.........|.......
 INITIATION LIFE   1213
```

Field	Column(s)	Format	Description
INITIATION LIFE	1-16	A16	Key indicating this card contains crack initiation
ICRACK	17-23	I8	Actual crack initiation life recorded for this specimen. Must be left-justified in field.

Card 3 - ENVIRONMENT (OPTIONAL)

```
|........|.........|.........|.........|.........|.........|.......
 ENVIRONMENT       2
```

Field	Column(s)	Format	Description
ENVIRONMENT	1-16	A16	Indicates environmental data is input. Only the first 8 characters are significant.
NPRESS	18-25	I8	Number of cycle number/pressure pairs (cards) input. If this field is 0 or blank, no pressure cards will be read.

Card 3a - PRESSURE INPUT (OPTIONAL, BUT REQUIRED IF NPRESS > 0)

```
|........|.........|.........|.........|.........|.........|.......
  100       10.
```

Field	Column(s)	Format	Description
PCYCLE	1-8	I8	Cycle number at which given partial oxygen pressure begins.
PRESS	9-20	F12.5	Partial oxygen pressure in same units used for PREFCN (psia for PWA 1455).

Note: If environmental data is not input, the environmental factor will be 1.0 for uncoated specimens and F_{min} for coated specimens.

Card 4 - NON-LINEAR DAMAGE CALCULATION (OPTIONAL)

```
|........|.........|.........|.........|.........|.........|.......
NONLIN    ON
```

Field	Column(s)	Format	Description
NONLIN	1-6	A6	Key indicating non-linear card
ONOFF	9-16	A8	Has a value of "ON" or "OFF". Can be placed anywhere in the field. "ON" indicates non-linear damage will be calculated for mode 1.

Card 5 - TEST TYPE AND CONTROL

```
|........|.........|.........|.........|.........|.........|.......
B      S
```

Field	Column(s)	Format	Description
TESTYP	1-7	A7	Test type of this specimen. Only the first character is significant. Must be left-justified. A 'B' in column 1 signifies that multiaxial data must be transformed into uniaxial strains and stresses. Any other letter is ignored.
CONTRL	8	A1	Has a value of 'L' or 'S'. 'L' means this is a load controlled test. 'S' means this is a strain controlled test. This is only used if 'RAW1' or 'RAW2' is an input variable. If CONTRL = 'L', then RAW1 is assumed to be stress. If CONTRL = 'S', then RAW1 is assumed to be strain.

Card 6 - PERIOD AND ISOTHERMAL TEMPERATURE

```
|........|.........|.........|.........|.........|.........|.......
60.0        1200.
```

Field	Column(s)	Format	Description
PERIOD	1-12	F12.5	Cycle period of this specimen in seconds.
ISOTEMP	13-24	F12.5	Isothermal temperature of this specimen in degrees Fahrenheit. For non-isothermal tests, this number is ignored.

Card 7 - NUMBER OF POINTS AND CYCLES

```
|........|.........|.........|.........|.........|.........|.......
100 60
```

Field	Column(s)	Format	Description
M	1-4	I4	Number of points per cycle. Must be the same for all cycles in a set.
N	5-8	I4	Number of cycles in set.

Note: These fields must be left justified.

Cycle Data - N sets for a specimen.

Card 8 - CYCLE NUMBER

```
|........|.........|.........|.........|.........|.........|.......
 CYCLE =        1.
```

Field	Column(s)	Format	Description
CYCLE =	1-8	A8	Key word indicating beginning of a cycle of data.
CYCLENO	11-18	F8.0	Cycle number.

Card 9 - COLUMN HEADINGS

```
|........|.........|.........|.........|.........|.........|.........|.......
    STRESS1     TEMP        TIME        RAW1
```

Field	Column(s)	Format	Description
$head_i$	*	alpha	Column headers identifying types of data input. Allowable values are: 'STRAIN1','STRESS1','STRAIN2', 'STRESS2','TIME','TEMP','RAW1', and 'RAW2'. The order of the headers identifies the order of the data fields on Card 10. 'RAW1' and 'RAW2' can either be strain or stress values. See See the TEST TYPE AND CONTROL CARD (Card 5).

This card is free-formatted with blanks separating the fields. To add more data types (and headers), the following changes must be made:

In RDMAT: 1) increase dimensions of VARS, BNAME, and NAMPOS
2) add new headers to BNAME array
3) increase upper limits on the DO 5 and DO 20 loops.

In LIFE: 1) increase dimension of NAMPOS
2) before reading first cycle of data, insert pointers corresponding to the new data type position in NAMPOS array
3) reference this new data.

Card 10 - STRESS, STRAIN, TIME, AND TEMPERATURE DATA

```
|........|.........|.........|.........|.........|.........|.........|.......
    1 0.961277E+04 0.131192E+04 0.610000E+02 0.326510E-03
```

Field	Column(s)	Format	Description
POINT	2-5	I4	Point number. Not used in the program. Helps when looking at data.
DATA(j,i)	7-18 20-31 33-44 46-57 59-70 72-83	F12.5 " " " " "	Data for variable i for this point j. Can be input in F or E format. There is one value for each variable on this line. The data corresponds to the headers on Card 9. There will be M of these cards following a Card 9 header line.

NOTE: For accurate life predictions for specimen tests, cycle information beyond crack initiation life should not be included. The onset of tensile drop will artificially decrease the damage rate and result in erroneous extrapolated lives.

SECTION IV

OUTPUT DESCRIPTION

Output Files

CDA.OUT FILE

The CDA.OUT file contains information on a cycle by cycle basis. Any CDA error or warning messages are also written to this file. Output for set1 is followed by output for set2, then by output for set3, and so on.

The first line of output for a set of data (assuming no errors) is a line stating whether linear or non-linear damages will be calculated for model damage. Then, for each recorded cycle until failure, the following information is displayed:

Cycle numbers of a pair of adjacent recorded cycles. For the first cycle, NHIGH is 0. Initial damages and basic cycle variables are calculated for this first cycle. For all remaining recorded cycles, two recorded cycles are examined at a time. The information displayed after the NLOW,NHIGH line corresponds to the NHIGH cycle, while that for the NLOW cycle is printed after the previous NLOW, NHIGH line. The following data is shown for each of these cycles:

1) damages for modes 1 and 2
2) lower and upper stress ratio limits for all subcycles (these appear in the order in which they are closed)
3) all basic cycle variables for this cycle (these correspond to the stress ratio loops in the order in which they are printed; for the first cycle, damages are printed first)

If failure occurs before all recorded cycles are processed, the mode in which the material failed, the cycle at which it failed, and the final damages for all modes are written out:

```
FAILED IN MODE    1 AT CYCLE       1293.
FINAL DAMAGES ARE :
DAMAGES  0.10015E+01 0.41521E-01
```

If failure occurs after all recorded cycles are processed, the damages are extrapolated for all modes to determine lives for each mode. For each mode, the mode number, total damage through last recorded cycle, the final damage rate, and the extrapolated lives are displayed. The message that the lives were extrapolated is displayed and the mode with the shortest life is given as the mode at which failure occurred and the cycle at which this happened. Then all extrapolated lives are printed.

```
I,TOTDAM,DDDNBS   1 0.51309E+00 0.19856E-01
  NI(I)        44
I,TOTDAM,DDDNBS   2 0.26935E+00 0.11739E-01
  NI(I)        82
FINAL LIVES WERE EXTRAPOLATED.
FAILURE OCCURRED IN MODE   1 AT CYCLE          44
EXTRAPOLATED LIVES FOR ALL MODES ARE:
EXTRAP. LIVES         44         82
```

Example:

```
NON-LINEAR DAMAGE WILL BE CALCULATED FOR MODE1.
NLOW,NHIGH          1       0
Stress ratio loop closed between      -0.78600 and       0.85518
BCV 0.501768E-020.164118E+01-.234517E-010.501768E-020.966485E+00
BCV 0.664603E-050.508898E-050.508898E-07
DAMAGS(1:2)  0.231517E-03 0.368238E-04
Stress ratio loop closed between      -0.78600 and       0.85383
BCV 0.501628E-020.163982E+01-.247282E-010.501628E-020.966485E+00
BCV 0.659629E-050.501922E-050.501922E-07
NLOW,NHIGH          1       2
DAMAGS(1:2)  0.460874E-03 0.731429E-04
Stress ratio loop closed between      -0.78579 and       0.85248
BCV 0.502020E-020.163827E+01-.259960E-010.502020E-020.966485E+00
BCV 0.664132E-050.508442E-050.508442E-07
NLOW,NHIGH          2       3
DAMAGS(1:2)  0.689966E-03 0.109934E-03
Stress ratio loop closed between      -0.78861 and       0.83441
BCV 0.495822E-020.162302E+01-.429918E-010.495822E-020.966485E+00
BCV 0.624654E-050.455809E-050.455809E-07
NLOW,NHIGH          3       4
DAMAGS(1:2)  0.883051E-03 0.142916E-03
Stress ratio loop closed between      -0.78861 and       0.82824
BCV 0.494600E-020.161685E+01-.487967E-010.494600E-020.966485E+00
BCV 0.614485E-050.442263E-050.442262E-07
          .                   .                    .
          .                   .                    .
          .                   .                    .
          .                   .                    .
NLOW,NHIGH        800     900
DAMAGS(1:2)  0.297444E+00 0.281371E-01
Stress ratio loop closed between       0.13447 and       0.14477
Stress ratio loop closed between      -0.70330 and       0.87890
BCV 0.908000E-050.103073E-01-.691627E+000.908000E-050.488544E-02
BCV 0.158220E+01-.114429E-020.488544E-020.998342E+000.629532E-05
BCV 0.495774E-050.495774E-07
NLOW,NHIGH        900    1000
DAMAGS(1:2)  0.408769E+00 0.316380E-01
Stress ratio loop closed between       0.32032 and       0.32706
Stress ratio loop closed between      -0.81569 and       0.74021
BCV 0.236200E-040.674230E-02-.520175E+000.236200E-040.490668E-02
BCV 0.155590E+01-.131587E+000.490668E-020.998342E+000.525066E-05
BCV 0.343105E-050.343105E-07
NLOW,NHIGH       1000    2000
FAILED IN MODE     1 AT CYCLE        1293.
FINAL DAMAGES ARE :
DAMAGES  0.10015E+01 0.41521E-01
```

DIAG.DAT FILE

The DIAG.DAT file contains information on the following variables: NCYC,EPBAR,DDDNBS,G,ARRH,DAMAGS(1),DAMAGS(2), and DAMAGS(C).

NCYC	-	Cycle number. Information is provided for all recorded cycles and cycles that are powers of 2 until failure. Information is not provided for extrapolated cycles or intermediate cycles.
EPBAR	-	Ep-bar. Calculated by EPRTIO for sigma-ep-max of this cycle.
DDDNBS	-	Linear Damage Rate for Model for this cycle.
G	-	Non-linear Damage Factor. If the NONLIN flag is not set "ON", this is 0.
ARRH	-	Value of Arrhenius equation for Model for this cycle.
DAMAGS(1), DAMAGS(2), DAMAGS(C)	-	Total damages for model, mode2, and coating, respectively, through this cycle.

If more than one set of data is input, sets will be separated by a blank line.

Example:

NCYC	EPBAR	DDDNBS	G	ARRH	DAMAGS(1)	DAMAGS(2)	DAMAGS(C
1	0.966E+00	0.949E-03	0.244E+00	0.109E+01	0.232E-03	0.368E-04	0.000E+0
2	0.966E+00	0.943E-03	0.243E+00	0.109E+01	0.461E-03	0.731E-04	0.000E+0
3	0.966E+00	0.942E-03	0.243E+00	0.109E+01	0.690E-03	0.110E-03	0.000E+0
4	0.966E+00	0.846E-03	0.228E+00	0.109E+01	0.883E-03	0.143E-03	0.000E+0
5	0.966E+00	0.820E-03	0.224E+00	0.110E+01	0.107E-02	0.175E-03	0.000E+0
6	0.966E+00	0.819E-03	0.224E+00	0.110E+01	0.125E-02	0.207E-03	0.000E+0
7	0.966E+00	0.811E-03	0.223E+00	0.110E+01	0.143E-02	0.239E-03	0.000E+0
8	0.966E+00	0.823E-03	0.225E+00	0.110E+01	0.162E-02	0.272E-03	0.000E+0
9	0.966E+00	0.811E-03	0.223E+00	0.110E+01	0.180E-02	0.304E-03	0.000E+0
10	0.966E+00	0.750E-03	0.213E+00	0.110E+01	0.196E-02	0.333E-03	0.000E+0
14	0.966E+00	0.755E-03	0.214E+00	0.110E+01	0.260E-02	0.449E-03	0.000E+0
16	0.966E+00	0.757E-03	0.214E+00	0.110E+01	0.292E-02	0.506E-03	0.000E+0
20	0.966E+00	0.760E-03	0.214E+00	0.110E+01	0.357E-02	0.620E-03	0.000E+0
30	0.966E+00	0.740E-03	0.211E+00	0.110E+01	0.516E-02	0.904E-03	0.000E+0
32	0.966E+00	0.739E-03	0.211E+00	0.110E+01	0.547E-02	0.961E-03	0.000E+0
40	0.966E+00	0.735E-03	0.210E+00	0.110E+01	0.671E-02	0.119E-02	0.000E+0
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

BCV.OUT FILE

The BCV.OUT file contains information on the following variables: CYCNO,SUBC,DELE,STSRNG,STSMAX,EPOSENEG,EPRAT,ARR1, and DDDNBS

CYCNO	-	Cycle number of recorded cycle. Information for recorded cycles less than the failure cycle will be displayed.
SUBC	-	Number of sub-cycles in this cycle.
DELE	-	Maximum strain range in cycle (Basic Cycle Variable)
STSRNG	-	Maximum stress range in cycle (Basic Cycle Variable)
STSMAX	-	Maximum stress ratio value in cycle (Basic Cycle Var.)
EPOSENEG	-	Thermal strain component
EPRAT	-	Ep-ratio
ARR1	-	Arrhenius equation for model.
DDDNBS	-	Linear damage rate for mode 1 for this cycle.

Example:

CYCNO	SUBC	DELE	STSRNG	STSMAX	EPOSENEG	EPRAT	ARR1	DDDNBS
1	1	0.502E-02	0.164E+01	-.235E-01	0.502E-02	0.966E+00	0.665E-05	0.949E-03
2	1	0.502E-02	0.164E+01	-.247E-01	0.502E-02	0.966E+00	0.660E-05	0.943E-03
3	1	0.502E-02	0.164E+01	-.260E-01	0.502E-02	0.966E+00	0.664E-05	0.942E-03
4	1	0.496E-02	0.162E+01	-.430E-01	0.496E-02	0.966E+00	0.625E-05	0.846E-03
5	1	0.495E-02	0.162E+01	-.488E-01	0.495E-02	0.966E+00	0.614E-05	0.820E-03
6	1	0.494E-02	0.162E+01	-.470E-01	0.494E-02	0.966E+00	0.614E-05	0.819E-03
7	1	0.495E-02	0.161E+01	-.512E-01	0.495E-02	0.966E+00	0.615E-05	0.811E-03
8	1	0.494E-02	0.162E+01	-.452E-01	0.494E-02	0.966E+00	0.622E-05	0.823E-03
9	1	0.495E-02	0.161E+01	-.525E-01	0.495E-02	0.966E+00	0.611E-05	0.811E-03
10	1	0.490E-02	0.160E+01	-.624E-01	0.490E-02	0.966E+00	0.587E-05	0.750E-03
14	2	0.494E-02	0.159E+01	-.692E-01	0.494E-02	0.966E+00	0.582E-05	0.755E-03
20	2	0.493E-02	0.158E+01	-.579E-01	0.493E-02	0.966E+00	0.576E-05	0.760E-03
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.

MULT.DIA FILE

The MULT.DIA file contains diagnostic output if the IDIAG flag (hard-coded in MULTAX) is set equal to 1. Initially, it was set equal to 0. The information provided contains the input and transformed strains and stresses for each angle, the uniaxial strains and stresses, angle of failure and material name. For material PWA 1455, normal strain range is also displayed. For INCO 718, the Socie parameter is displayed.

Error Messages

```
ERROR1:    (IN SUBROUTINE LIFE)
  INSUFFICIENT STORAGE IN WORK ARRAY.
  INCREASE THE IWORK PARAMETER IN ILIFE, RE-COMPILE, AND RE-RUN.

ERROR2:    (IN SUBROUTINE RAINFL)
  YOUR DATA HAS EXCEEDED THE ALLOWABLE NUMBER OF LOOPS IN A CYCLE.
  INCREASE THE VALUE FOR ISCTMX IN MAIN, RECOMPILE, AND RERUN.

ERROR3:    (IN SUBROUTINE READ25)
 ERROR READING CYCLE XXXX WITH CYCLE NUMBER XXXXXXXX
 POSSIBLE PROBLEMS: NOT ENOUGH POINTS IN THIS CYCLE OR INPUT FORMAT
 INCORRECT. REMAINDER OF THIS SPECIMEN IS SKIPPED.
 FIX INPUT AND RE-RUN

ERROR4:    (IN SUBROUTINE READ25)
 ERROR READING CYCLE XXXX WITH CYCLE NUMBER XXXXXXXX
 POSSIBLE PROBLEMS: TOO MANY POINTS OR NOT ENOUGH CYCLES.
 REMAINDER OF THIS SPECIMEN IS SKIPPED.
 FIX INPUT AND RE-RUN

ERROR5:    (IN SUBROUTINE READ25)
 UNEXPECTED END OF FILE.
 THERE SHOULD BE XXXX CYCLES, BUT ONLY XXXX CYCLES WERE ENTERED.
 FIX INPUT AND RE-RUN.

ERROR6:    (IN SUBROUTINE READ25)
 UNEXPECTED END OF FILE.
 THERE SHOULD BE XXXX POINTS, BUT ONLY XXXX POINTS WERE ENTERED.
 FIX INPUT AND RE-RUN.'

ERROR7:    (IN SUBROUTINE READ25)
 UNEXPECTED END OF FILE.
 FIX INPUT AND RE-RUN.

ERROR8:    (IN SUBROUTINE GETMOD)
 MATERIAL XXXXXXXXXXXXXXXX NOT FOUND IN MODES DATA.
 CONTACT RESPONSIBLE PROGRAMMER TO CORRECT.
 EXECUTION TERMINATING DUE TO ERROR.

ERROR9:    (IN SUBROUTINE CTCONS)
 MATERIAL XXXXXXXXXXXXXXXX NOT DEFINED IN ROUTINE CTCONS.
 CONTACT RESPONSIBLE PROGRAMMER TO CORRECT.
```

Warning Messages

```
WARN1:      (IN FUNCTION CHRMXS)
 TEMPERATURE OF XXXXXXXX IS LESS THAN OR EQUAL TO
 THE MINIMUM TEMPERATURE OF XXXXX.XX FOR SIGTRF.
 MINIMUM VALUE OF XXXXXXXXXXXX IS ASSUMED.

WARN2:      (IN FUNCTION CHRMXS)
 TEMPERATURE OF XXXXXXXX IS GREATER THAN OR EQUAL TO
 THE MAXIMUM TEMPERATURE OF XXXXXXXX FOR SIGTRF.
 MAXIMUM VALUE OF XXXXXXXXXXXX IS ASSUMED.

WARN3:      (IN FUNCTION SEPREF)
 TEMPERATURE OF XXXXXXXX IS LESS THAN OR EQUAL TO
 THE MINIMUM TEMPERATURE OF XXXXXXXX FOR SGEPRF.
 MINIMUM VALUE OF XXXXXXXXXXXX IS ASSUMED.

WARN4:      (IN FUNCTION SEPREF)
 TEMPERATURE OF XXXXXXXX IS GREATER THAN OR EQUAL TO
 THE MAXIMUM TEMPERATURE OF XXXXXXXX FOR SGEPRF.
 MAXIMUM VALUE OF XXXXXXXXXXXX IS ASSUMED.

WARN5:      (IN FUNCTION FALPHA)
 TEMPERATURE OF XXXXXXXX IS LESS THAN OR EQUAL TO
 THE MINIMUM TEMPERATURE OF XXXXXXXX FOR DALFA.
 MINIMUM VALUE OF XXXXXXXXXXXX IS ASSUMED.

WARN6:      (IN FUNCTION FALPHA)
 TEMPERATURE OF XXXXXXXX IS GREATER THAN OR EQUAL TO'
 THE MAXIMUM TEMPERATURE OF XXXXXXXX FOR DALFA.
 MAXIMUM VALUE OF XXXXXXXXXXXX IS ASSUMED.

WARN7:      (IN FUNCTION FAIL)
 THE TEMPERATURE OF XXXXXXXX IS BELOW THE INTERPOLATION LIMIT OF XXXXXXXX
 SIGF SET TO XXXXXXXXXXXX

WARN8:      (IN FUNCTION FAIL)
 THE TEMPERATURE OF XXXXXXXX IS ABOVE THE INTERPOLATION LIMIT OF XXXXXXXX
 SIGF SET TO XXXXXXXXXXXX

WARN9:      (IN SUBROUTINE PWA286)
 ***************** MXSPLT WAS EXCEEDED ****
```

SECTION V

PROGRAM DESCRIPTION

Description of CDA Subroutines

In CDA FORTRAN:

MAIN	- main routine
OBJFN	- objective function calculation
GETCON	- determine constants for this material
LIFE	- calculate life
RDMAT	- read "header" information for a specimen
RAINFL	- rainflow cycle counting to determine max's & min's in order to find Basic Cycle Variables (BCV's) for a defined cycle
BCVSC	- calculate BCV's for subcycles and major cycle using calculated max's and min's
STNM	- calculate max's and min's of strain terms and stress ratio (sigma / sigma T ref)
READ5	- read cycle information for a specimen
ARRHEN	- calculate integral of Arrhenius equation over a cycle
CHRMXS	- determine characteristic maximum stress (sigma T ref)
SEPREF	- determine sigma Ep reference
FALPHA	- determine delta alpha
EPRTIO	- determine Ep ratio
FAIL	- find sigma f
THRESH	- get delta E threshold
PARSE	- parse input line into words
INTERP	- interpolate damage rates for a given cycle
LININT	- perform linear interpolation between two points
LIMITS	- return the current and next recorded cycle numbers
DAMAGE	- calculate linear damage increment for each mode
GETMOD	- determine which modes should be calculated for this material
MODE1	- calculate mode 1 damage increment (linear)
MODE2	- " " 2 " " "
MODE3	- " " 3 " " "
MODE4	- " " 4 " " "
MODE5	- " " 5 " " "
COMPRS	- remove imbedded blanks from a string
NONLIN	- calculate non-linear damage increment and life fraction
INTSCR	- initialize scratch arrays

In COATING FORTRAN:

STRCOT - main routine to calculate coating stresses and strains
ETHMIS - calculate thermal mismatch strain
CTCONS - get constants for thermal mismatch strain and coating life model
PWA286 - calculate constitutive behavior of PWA286 overlay coating
SI286 - determine number of subincrements for PWA286
MC286 - calculate temperature dependent material constants for PWA286

In MULTIAXL FORTRAN:

MULTAX - multi-axial main routine
DIRCOS - calculate direction cosines
FAILPL - determines the angle of the FAILure PLane along with other important LCF parameters.
SOCIEP - calculate socie parameter
MAXDE - calculate maximum strain range
HISTRY - transform tension-torsion and torsion-only data into full tensor
SSTMAT - calculate engineering stress and strain transformation matrices
TRNSFM - transform engineering stress and strain vectors from one orientation to another
MATINV - matrix inversion
MATMPY - matrix multiply

Flowchart for LIFE (Chart 1 of 3)

```
Initialization
      |
      V

Read Header Info
      |
      V

Read First Cycle
of Data
      |
      V

    Multi    y     Calculate
   -axial   ----> 1-D Stresses
    Data           and Strains
     ?                  |
                        |
     n|                 |
      |<-----------------
      V

              y     Predict
   Coating  ----> Coating
      ?             Stresses
                       |
     n|                |
      |<----------------
      V

Determine Basic
Cycle Variables
for First Recorded
Cycle
      |
      V

Calculate Linear
Damage
      |
      V

Calculate Non-Linear
Damage
      |
      V

    Failed   y
   (Damage ----------------------
   >= 1.0)                       |
     ?                           |
                                 |
      |                          |
      |                          |
      V                          V

      A                          B
```

Flowchart for LIFE (Chart 2 of 3)

```
                          A                               B
                          |                               |
                         n|                               |
 ----------------------->|                                |
 |                        V                               |
 |                                                        |
 |                      End     y   Extrapolate           |
 |                    of Data  --->    Lives        --->|
 |                        ?                               |
 |                                                        |
 |                       n|                               |
 |                        V                               |
 |               Read Next Cycle                          |
 |               of Data                                  |
 |                        |                               |
 |                        V                               |
 |                     Multi    y    Calculate            |
 |                    -axial  ---->  1-D Stresses         |
 |                     Data          and Strains          |
 |                      ?                 |               |
 |                                        |               |
 |                      n|                |               |
 |                        |<---------------               |
 |                        V                               |
 |                                                        |
 |                              y    Predict              |
 |                   Coating  ---->  Coating              |
 |                       ?           Stresses             |
 |                                        |               |
 |                      n|                |               |
 |                        |<---------------               |
 |                        V                               |
 |                                                        |
 |              Determine Basic                           |
 |              Cycle Variables                           |
 |              for This Recorded                         |
 |              Cycle                                     |
 |                        |                               |
 |                        V                               |
 |                                                        |
 |              Calculate Linear                          |
 |              Damage                                    |
 |                        |                               |
 |          ------------>|                                |
 |          |             V                               |
 |          |                                             |
 |          |          Failed   y                         |
 |          |         (Damage  ----------------------->|
 |          |         >= 1.0)                             |
 |          |            ?                                |
 |          |             |n                              |
 V          V             V                               V

 C          D             E                               F
```

Flowchart for LIFE (Chart 3 of 3)

```
 C        D             E                             F
 |        |             |                             |
 |        |             V                             |
 |        |                                           |
 |        |          Another   n                      |
 |        |          Inter-   ------                  |
 |        |          mediate        |                 |
 |        |          Cycle          |                 |
 |        |             ?           |                 |
 |        |                         |                 |
 |        |            y|           |                 |
 |        |             |           |                 |
 |        |             V           |                 |
 |        |      Interpolate        |                 |
 |        |      Linear Damage      |                 |
 |        |      for Intermediate   |                 |
 |        |      Cycle              |                 |
 |        |             |           |                 |
 |        |             V           |                 |
 |        |      Calculate          |                 |
 |        |      Non-Linear         |                 |
 |        |      Damage for         |                 |
 |        |      Intermediate       |                 |
 |        |      Cycle              |                 |
 |        |             |           |                 |
 |        ---------------           |                 |
 |                                  |                 |
 |                      -------------                 |
 |                      |                             |
 |                      V                             |
 |               Calculate                            |
 |               Non-Linear                           |
 |               Damage for                           |
 |               Defined Cycle                        |
 |                      |                             |
 |                      V                             |
 |                                                    |
 |                    Failed   y                      |
 |                  (Damage  -------------------->    |
 |                  >= 1.0)                           |
 |                     ?                              |
 |                                                    V
 |                     |                            Return
 -----------------------
```

Storage in the WORK and SCRTCH Arrays

The WORK array is used for the storage of most arrays used in CDA. The arrays are passed into routines by indexing their location in the WORK array. The indices are set according to the sizes needed for the arrays. This minimizes the number of changes needed if increased storage is required. The minimum size required for the work array (parameter IWORK in routine LIFE) for a specimen is:

```
IWORK = M * (ICOUNT + 2*NMAT + 4) + N + NDM*4 + 3*NMAT + 1 +
        4 * NLOOPMAX
```

where:

```
M        = number of points in a cycle
ICOUNT   = number of types of data input (STRAIN1,TIME,TEMP,etc.)
NMAT     = number of materials (1 for uncoated, 2 for coated)
N        = number of cycles in specimen
NDM      = number of damage modes for the (base) material
NLOOPMAX = maximum number of subcycles in any cycle
```

A list of the locations of arrays in the WORK array follows:

Index in WORK	Array	Size
idata = 1	DDATA	(M,ICOUNT)
istrnt = idata + m*icount	STRNT	(M+1)
israt = istrnt + m + 1	SRAT	(M+1)
itempt = israt + m + 1	TEMPT	(M+1)
itimet = itempt + m + 1	TIMET	(M+1)
iratio = itimet + m + 1	SRATIO	(M+1)
isgsgt = iratio + m + 1	SGOSGT	(M+1)
ict = isgsgt + m + 1	CDATA	(M*(NMAT-1),2)
icyc = ict + 2*m*(nmat-1)	CYCLE	(N)
imodes = icyc + n	MODES	(NDM)
idr1 = imodes + ndm	DRATE	(NDM+NMAT-1)
idr2 = idr1 + ndm + (nmat-1)	DRATE	(NDM+NMAT-1)
idr = idr2 + ndm + (nmat-1)	DRATE	(NDM+NMAT-1)
ibcv = idr + ndm + (nmat-1)	BCVS	(IWORK-IBCV)

The SCRTCH array is used to hold stacked data in the RAINFL routine. These stacks hold information on all the currently nested loops in the cycle. There are 11 arrays contained in SCRTCH. The size of SCRTCH is initially set to 110 through the ISCTMX parameter. This gives each of these arrays a dimension of 10. These arrays only need to be dimensioned to the maximum number of SIMULTANEOUSLY nested loops in a cycle. This maximum number can be increased by changing the ISCTMX parameter.

ISCTMX = (max. # of simultaneously nested loops) * 11

The arrays stored in SCRTCH and their indices are:

Index in SCRTCH	Array	Size
IRFPOS = 1	RRFPOS	NLPMAX
IRFNEG = IRFPOS + NLPMAX	RRFNEG	"
ISMAX = IRFNEG + NLPMAX	SMAX	"
ISMIN = ISMAX + NLPMAX	SMIN	"
IEMAX = ISMIN + NLPMAX	EMAX	"
IEMIN = IEMAX + NLPMAX	EMIN	"
IEPMAX = IEMIN + NLPMAX	EPMAX	"
IEPMIN = IEPMAX + NLPMAX	EPMIN	"
IENMAX = IEPMIN + NLPMAX	ENMAX	"
IENMIN = IENMAX + NLPMAX	ENMIN	"
ISGTRF = IENMIN + NLPMAX	SGTRFM	"

Calculation of Constants (Material and Temperature Dependent)

A temperature-dependent constant needed at a particular temperature is calculated from a table of values stored in BLOCK DATA. For each constant, there is a set of temperatures and a set of values corresponding to these temperatures. The current maximum number of temperature values is 20 and is the first dimension in all the temperature-dependent constant arrays. The array NVAL contains the number of temperature/constant pairs for the materials. Values not in the table are found by semi-log interpolation if they fall between the maximum and minimum temperatures for this material. If the temperature at which a constant is needed is below the minimum or above the maximum temperature in the table, the constant is set to the respective minimum or maximum value of the constant.

The temperature-dependent constants are:

SIGMAF - (sigma-f) Delta-sigma-ref, calculated in FAIL. Used to determine stress ratio.
SIGTRF - (sigma-T-ref) Characteristic maximum stress, calculated in routine CHRMXS. This accounts for max-stress effects.
SGEPRF - (sigma-ep-ref) Sigma-epsilon-primary-reference, calculated in SEPREF. Accounts for history effects on dislocation networks.
DALFA - (delta-alpha) Calculated in FALPHA. Similar to a thermal expansion coefficient in that it is multiplied by a temperature change to compute a strain. This accounts for TMF effects.

The fixed constants are:

N1 - exponent for strain ratio
N2 - exponent for stress ratio
ETHRES - threshold value for strain range
XNREF - scaling value for life (not independent)
DEREF - scaling value for strain range (not independent)
C1,2,3 - coefficients for epratio (quadratic function)
ARRACN - Arrhenius coefficient (three values, one per mode)
QORCON - Arrhenius Q/R value for temp (three values, one per mode)
ARRBCN - Arrhenius coefficient for stress (three values, one per mode)
C11 - scaling value for Mode 1 Arrhenius function (not independent)
C12 - scaling value for Mode 2 Arrhenius function (not independent)
FMAXCN - maximum environmental damage factor (saturated effect)
FMINCN - minimum environmental damage factor (no effect)
PREFCN - reference partial pressure of oxygen
KCON - combined environmental exponent coefficient (not independent)
BCONO - non-linear damage accumulation reference damage rate
ALPHAO - non-linear damage exponent
DDDNMN - minimum damage rate (corresponds to maximum BETA)

Basic Cycle Variables

For each recorded cycle of data, Basic Cycle Variables are calculated. These BCVs are used in the life prediction model to calculate a damage rate. Some BCVs are calculated for each subcycle in a cycle. Others are only calculated once per cycle.

The BCVs that are calculated for each subcycle are:

delta-strain-total-mechanical
: Maximum strain range in the subcycle. (This BCV is not currently used directly in the mode 1 calculations)

ratioed-stress-range
: Difference of maximum stress ratio and minimum stress ratio in subcycle. The input stress is ratioed by SIGMAF.

max-stress
: The input stress minus the current reference ductility stress is ratioed by SIGTRF, and the maximum of these ratioed stresses in the subcycle is found.

max-delta-strain-adjusted
: The current strain is adjusted to account for TMF effects. The TMF "strain" is added and subtracted from the actual strain. The maximum of these two new strain ranges is used for the BCV.

For each defined cycle there is one value for each of the following:

e-primary-bar
: Accounts for history effects on dislocation networks and their subsequent effect on fatigue life.

Arrhenius function values for modes 1, 2, and 3.
: Accounts for time-dependent effects.

Mode 1 Calculations

Damage rates are calculated from the basic cycle variables for each recorded cycle. In Mode 1, the following is calculated for each subcycle (including major cycle):

$$\frac{dD}{dN}_i = \left(\frac{(BCV(i+4) - \Delta\epsilon_{thrs})}{\Delta\epsilon_{ref}} \right)^{N1} \times BCV(i+2)^{N2} \times 10^{BCV(i+3)}$$

These are summed over all subcycles and the remaining BCVs are figured into the damage rate equation:

$$\frac{dD}{dN}_{basic} = \left(\frac{\sum_i \frac{dD}{dN}_i}{X_{nref}} \times BCV(iepb) + C_{11} \times BCV(iarrh) \right) \times F_{envi}$$

Where iepb is the index of the $\bar{E}_p$ BCV and iarrh is index of the BCV corresponding to the Arrhenius equation for Mode 1. The environmental factor, F_{envi}, that is used for this cycle is found by looping through the PCYCLE array of input pressure cycle numbers. The pressure (and, therefore, the environmental factor, FENVI) for this cycle corresponds to the first cycle in PCYCLE that is less than or equal to the current cycle number. This same method for calculating the environmental factor is used in routine MODE2.

Flowchart for RAINFL (Chart 1 of 2)

```
 Initialization
       |
       V

 Reorder points,
 starting with highest
 stress ratio.
       |
       V

Determine the stress
constants for isothermal
cases.
       |
       V

 Find maximum stress ratio
 within current cycle and
 the maximum value of
 |sigma / sigma ep| of all
 cycles up through this cycle.
       |
       V

 Shift points to begin with
 the max point, and calculate
 the numerator for the maximum
 stress effect term, SGOSGT,
 as follows:
```

$$SGOSGT = \frac{(\sigma - \sigma_{\mathrm{epref}})}{\sigma_{\mathrm{Tref}}}$$

```
       |
       V

 Fill the extra point, "L", to
 end the cycle where it started.
 All values are set equal to the
 first value in the array except
 for the TIMET array, where
 TIMET(L) = TIMET(1) + PERIOD
       |
       V

 Initialize pointers for stress loops.
       |
       V

       A
```

Flowchart for RAINFL (Chart 2 of 2)

```
              A
              |
              V

           DO 70 J = 1, M
------------->|
|             V
|       Update the values of EPLUS
|       and EMINUS using the DETMF
|       value calculated during the
|       last increment (it starts at
|       zero).
|             |
|             V
|       If this is a TMF case,
|       calculate the delta strain
|       correction for thermal
|       cycling.
|             |
|             V
|       Determine if any loops have
|       been closed based on stress
|       ratios.
|             |
|             V
|      If a loop has been closed,
|      calculate BCV's for this loop.
|             |
|             V
|      Determine minimum and maximum
|      values for the current loop.
|             |
|             V
|      If stress reversal is present,
|      reset reference stacks.
--------------|
              V
     70    CONTINUE
              |
              V

        Check for the final loop(s)
        being closed (there may be
        more than one) and calculate
        BCVs of loops closed.
              |
              V

       Calculate dislocation density
       ratio parameter, Ep-bar
              |
              V

       Calculate values of the
       Arrhenius equations for modes 1-3.
              |
              V

       Calculate number of BCVs
              |
              V

           WRITE BCVs
              |
              V

           RETURN
```

Delta Strain Correction for Thermal Cycling

For TMF, a strain correction, DETMF, is calculated at each point in the cycle. This strain correction is added to the strain at that point to find EPLUS and it is subtracted from the strain to find EMINUS. The range over this cycle for EPLUS and EMINUS is calculated and the maximum of these two ranges is stored as a Basic Cycle Variable. DETMF at a point J in the cycle is calculated as:

$$DETMF(J) = \sum_{i=1}^{J} T(i) \times FALPHA(\overline{T(i)})$$

where:

$\overline{T(i)}$ = 0.5 * (T(i+1) + T(i))

T(i) = T(i+1) - T(i)

Arrhenius Equation

The subroutine ARRHEN calculates the Arrhenius equation over a cycle:

$$Arrhenius = A \times \int e^{B \times |sigma| - \frac{Q}{RT}} dt$$

A, B, and Q/R are constants which are material and mode dependent. They are hard-coded in the BLOCK DATA routine in arrays ARRACN, ARRBCN, and QORCON, respectively. The proper constants for this material are stored in ARRA, ARRB, and ARRQOR, respectively, one value in each for each of three modes. T is the temperature in degrees Rankine; the input temperature is converted to degrees Rankine by adding 459.67 in this routine. Sigma is the input stress. The trapezoid rule is used to integrate this function over time. For the last interval, the period is used to determine the final time increment. For the stress and temperature values for the last point the value for the first point in the cycle is used.

Interpolation of Linear Damage Rates

Linear damage rates are calculated for each requested mode of each of the recorded cycles of data. Linear damage rates are not dependent upon previous cycles and are calculated from BCVs for recorded cycles. (An exception is that the coating damage rate is calculated in a separate routine and is not dependent on BCVs.) For cycles in between two recorded cycles, damage rates are interpolated using semi-log interpolation:

$$dr = (dr2 - dr1) * \frac{(\log(n) - \log(n1))}{(\log(n2) - \log(n1))} + dr1$$

where:

n = cycle to find damage rate at
n1 = recorded cycle 1 for this interval
n2 = recorded cycle 2 for this interval
dr = interpolated damage rate for cycle n
dr1 = calculated damage rate at cycle n1
dr2 = calculated damage rate at cycle n2

Non-linear Damage Calculation

If the NONLIN flag is "ON", non-linear damage will be calculated for mode 1. Non-linear damage is dependent upon the previous cycle's life fraction. The CDA routine NONLIN calculates the non-linear damage increment, DDDNNL. Also calculated in NONLIN are the life fraction used (n/Ni) and the value of the non-linear modifier function for this cycle (G).

$$\frac{dD}{dN}_{non-lin} = \frac{dD}{dN}_{linear} \times G$$

where:

$$\frac{dD}{dN}_{linear} = \frac{1}{N_i}$$

$$D_N = \int_1^N \frac{dD}{dN}_{non-lin} dn$$

$$D_N = \frac{\beta}{\beta + 1} \times \left(\frac{N}{N_i}\right)^{\beta+1} + \left(\frac{N}{N_i}\right) \times \left(\frac{1}{\beta + 1}\right)$$

$$G = \beta \times \left(\frac{N}{N_i}\right)^{\beta} + \left(\frac{1}{\beta + 1}\right)$$

NONLIN solves for $\left(\frac{n}{n_i}\right)$ in the following equation using Newton's method:

$$D_N - \frac{\beta}{\beta + 1} \times \left(\frac{N}{N_i}\right)^{\beta+1} + \left(\frac{N}{N_i}\right) \times \left(\frac{1}{\beta + 1}\right) = 0$$

Calculation of Environmental Factor

For environmental tests, a series of pressures and the cycle numbers at which they start is input. The pressure is treated as a step function. The pressure is considered to be constant from the input cycle number until the cycle before the next input cycle number.

Example:

```
ENVIRONMENT    3
1       100
5       80
10      60
```

The pressure vs. cycle number would look like:

```
pressure

 100 + x---------o
     +           |
  80 +           x----------o
     +                      |
  60 +                      x---------->
     +
     +
     +
     +
     +
     --+---------+----------+----------->
       1         5          10          N
```

This pressure is used to calculate the environmental factor, FENVI. There is one FENVI value calculated for each input pressure. The environmental factor is:

```
FENVI = (FMAX - FMIN) * (1-EXP(KCON*PRESS/PREF)) + FMIN
```

FMAX,FMIN,KCON, and PREF are material-dependent constants set in GETCON. PRESS is the pressure.

If no environment card is entered or NPRESS (number of pressures entered) is zero, then FENVI = 1.0. If the material is coated, FENVI(1) is set equal to FMIN (regardless of the presence of environmental data), and this first value of FENVI is used to multiply the linear damage rates in modes 1 and 2.

There is a limit of 100 of these pressure/cycle number pairs. This can be increased by changing the dimensions of FENVI, PRESS, and PCYCLE at all occurrences. Also, the upper limit of the DO 7 loop in RDMAT would have to be changed.

Extrapolation Beyond Last Recorded Cycle

When a damage rate of 1.0 has not been reached before the end of the recorded cycle data, the damages are extrapolated for each mode. When damage is linear, the life fraction remaining is divided by the last calculated basic damage rate for that mode. This yields the number of cycles remaining. This is added to the last recorded cycle number to determine the predicted life.

Linear:

$$N_i = N_{last} + \frac{1 - D_{last}}{\frac{dD}{dN}_{basic}}$$

When damage is non-linear, the fraction of damage used for each mode is calculated using Newton's method. The predicted life is equal to this fraction divided by the last recorded cycle number.

Non-linear:

Calculate life fraction (lifrac) using Newton's method to solve:

$$\frac{1 - D_{last}}{\frac{dD}{dN}_{basic}} = \sum_{j=N}^{N_i - 1} \left(\beta\left(\frac{j}{N_i}\right) + \frac{1}{\beta + 1} \right)$$

(where N = last recorded cycle)

Then,

$$N_i = \frac{N}{lifrac}$$

Damages for all modes beyond mode 1 are linear. Also, mode 1 is linear if the NONLIN flag is set OFF. The default is OFF.

A life that is calculated to be greater than 1.0E+8 is rounded down to 1.0E+8. This maximum value can be considered to be infinity and follows the standard practice with high cycle life prediction.

Multiaxial Data Transformations

There is a limit of 1000 points per cycle for the multiaxial code. If more than 1000 is needed, the parameter MPTS should be increased in routines MULTAX,SOCIEP,MAXDE,HISTRY, and FAILPL to the number of points. Also, this dimension may be reduced if 1000 points are not needed. This will reduce required memory space.

The multiaxial code transforms the biaxial data into uniaxial data. First, data is transformed into full tensors. The failure plane is then determined from these full tensors by transforming the stresses/strains into 100 different orientations from -90 degrees to +90 degrees.

For material PWA1455, the failure plane is defined as the plane with the highest normal strain range. For material INCO718, the plane with the highest Socie parameter is used (maximum shear strain range plus the normal strain range and normalized mean stress; Socie and Shield, 1984).

Subroutine MULTAX

MULTAX takes stress and strain input, transforms them onto a plane defined by an input normal definition, and then outputs a single stress/strain quantity which depends on the material type.

```
Flowchart:            Initialization
                            |
                            V

                  Store input data in full
                  stress/strain tensors.
                            |
                            V

                 Calculate direction cosines
                 of the normal vector.
                            |
                            V

                 Calculate stress, strain
                 transformation matrices.
                            |
                            V

        Transform stress and strain vectors onto the
        surface plane defined by the surface normal, VNORM.
                            |
                            V

                      Diagnostics.
                            |
                            V

          Determine failure plane orientation.
                            |
                            V

        Calculate equivalent one dimensional stress, strain
        versus time for cycle ICYCLE for CDA digestion.
                            |
                            V
```

Subroutine SOCIEP

SOCIEP calculates SOCIE parameter at maximum shear strain range.

First, the maximum shear strain range and Socie parameter are found by reviewing a full spectrum of slip plane orientations from 90 to -90 degrees. Next, the stress and strain transformation matrices are calculated and the stress and strain vectors are transformed onto the surface plane defined by the surface normal, VNORM. The maximum and minimum shear strains are found and a new $\Delta\gamma_p = (\gamma_{max} - \gamma_{min})/2.0$ is calculated.

If shear strain range for this angle is greater than previous max, then calculate normal strain range and mean stress. We look at mean stress to determine the failure plane if there is more than one plane with the same shear strain range amplitude. If new one is greater, save the new values for SOCANG, SOMAX. If the old mean SO was larger, then we do nothing. If the old mean SO equals the new one, then we look for the angle with the highest normal strain range. If the new shear strain range is greater than the old, then we save the SOCANG, SOMAX, DEMAX, and DGPOLD values.

The Socie parameter is calculated as follows:

$$Socie\ parameter = \hat{\gamma}_p + \hat{\varepsilon}_{np} + \frac{\hat{\sigma}_{no}}{E}$$

where,

$\hat{\gamma}_p$ = max shear strain range

$\hat{\varepsilon}_{np}$ = cyclic normal strain on plane of $\hat{\gamma}_p$

$\frac{\hat{\sigma}_{no}}{E}$ = mean stress acting on the plane of $\hat{\gamma}_p$

E = Young's modulus

The transformed strains and stresses are calculated in the plane of crack initiation.

Subroutine MAXDE

Subroutine MAXDE finds the plane of max normal strain range to use as the failure plane for PWA 1455. The maximum normal strain range is found by reviewing a full spectrum of slip plane orientations from 90 to -90 degrees. The stresses and strains are transformed onto each plane and the maximum normal strain range is calculated. The plane that has the maximum normal strain range is the failure plane. The stresses are transformed onto this plane.

Interaction with Coating Model

The coating model in this program follows the life prediction method developed in a companion NASA contract for anisotropic materials (Swanson et al, 1987). A one-dimensional form of the viscoplastic constitutive model for PWA 286 overlay coating is included for calculation of the actual stresses in the coating. The various model constants are also taken directly from the current versions of those models.

The subroutine which performs these calculations and interfaces with the main CDA routines is called STRCOT. It performs the following:

Flowchart:

Call from LIFE

|
V

Initialization

|
V

Calculate coating strains using:

$$\varepsilon_{coat} = \Delta\alpha \times \Delta T + \varepsilon_{mech}$$

|
V

Calculate coating stresses for current defined cycle by ramping from zero to the first point, then completing three full cycles

|
V

During the third cycle (assumed to be stable), compute the tensile hysteretic energy and the effective frequency terms for the life model

|
V

Compute the coating initiation life and invert it to obtain a damage rate for CDA's use

|
V

Return to LIFE

SECTION VI

INSTALLATION REQUIREMENTS

Installation Requirements

The CDA code is portable and has run on several different PC's with different compilers. It has also been run on Sun workstations and on an IBM mainframe.

A Fortran compiler is required. Memory is dependent upon the array sizes needed for your input files. The parameters IWORK and ISCTMX in MAIN (in CDA.FOR) and the MPTS parameter in routines MULTAX, SOCIEP, MAXDE, HISTRY, and FAILPL (in MULTIAXL.FOR) can be changed to allow the program to fit in your environment. Additionally, if coating or multiaxial processing is not required, this code does not have to be compiled, linked, and loaded.

For running on PC's, the code can be compiled as it is. Once the .OBJ files have been created, they can be linked together as required. For basic life prediction (including TMF and creep-fatigue), only the CDA object code is required. If multiaxial loadings must be considered, the MULTIAXL object code is required in addition to CDA. Also, if coating lives are to be calculated, the COATING object code must be added.

For the mainframe version, the OPEN statements in the MAIN routine must be commented out. The following is a short listing of an EXEC which would execute CDA on an IBM mainframe running VM/CMS:

```
/* */
FNAME:
say 'Enter filename filetype (fm if not 'A') of input file or EXIT.'
pull fn ft fm .
/* default input file type is DATA; default mode is A' */
if fn = ' ' then
  signal FNAME
else if fn = 'EXIT' then
  signal DONE
else do
  if ft = ' ' then
     ft = 'DATA'
  if fm = ' ' then
     fm = 'A'
  end
/* filedefs */
  'FILEDEF 6  DISK OPT     OUT    D (LRECL 132 BLKSIZE 132 '
  'FILEDEF 10 DISK OPT     INPUT  A (LRECL 80  BLKSIZE 80  '
  'FILEDEF 15 DISK BCV     OUT    D (LRECL 80  BLKSIZE 80  '
  'FILEDEF 16 DISK DIAG    DATA   D (LRECL 80  BLKSIZE 80  '
  'FILEDEF 19 DISK MULT    DIAG   D (LRECL 80  BLKSIZE 80  '
  'FILEDEF 25 DISK ' fn ft fm
  'FILEDEF 26 DISK ' fn '  DIAG   D (LRECL 80  BLKSIZE 80  '
  'LOAD CDA MULTIAXL COATING (CLEAR NOAUTO NODUP MAP '
  'START  * '
end
say ' Your output file is ' fn 'DIAG D'
DONE:
exit
```

SECTION VII

DETERMINATION OF CDA CONSTANTS FOR NEW MATERIALS

Recommended Specimen Tests for CDA Constants

As with all life prediction systems, CDA will produce the most accurate life predictions when it is calibrated to data within the regime of interest. It is therefore wise to begin by making estimates of the bounds of parameters such as temperature, strain range and rate, and cycle waveforms which will represent the components to be analyzed with CDA. These will then be used to establish life data at the limits of applicability for CDA, essentially resulting in interpolated lives rather than extrapolated ones. Also, a decision should be made regarding what to define as "initiation life" or "failure life". The specimen tests can then be monitored correctly to provide the desired data (by surface replication, potential drop, load drop, or other suitable means). After the tests, the specimens should be examined to gain understanding of the failure mechanisms and modes (transgranular, intergranular, etc.) which must be modeled for the material in question.

For basic transgranular CDA life prediction, the following matrix of strain controlled specimen tests is recommended as a minimum:

	Strain		Temperature			
Range	R-Ratio	Rate	T1 (Low)	T2	T3	T4 (High)
E1(Low)	-1	fast	X1	X2	X3	X4
E2	-1	fast	X5			X6
E3(High)	-1	fast	X7	X8	X9	X10
E1(Low)	0	fast	X11		X12	
E1(Low)	-inf	fast			X13	
E1(Low)	-1	slow			X14	X15
E3(High)	-1	slow			X16	X17
E3(High)	0	slow			X18	X19
E1(Low)	-1	t-hold			X20	X21
E1(Low)	-1	c-hold				X22
E2	+mean	slow			X23	X24

Determining CDA Constants

Once this matrix of testing is completed, the various CDA constants may be determined as follows:

1. Plot the data from tests X1-X10 based on strain range first, then by stabilized stress range (from half life). Use this to estimate the following constants:

   a. ETHRES - This is the "threshold" strain range below which no significant fatigue damage occurs (appears as asymptote for the life curves).

   b. N1, N2 - The sum of these is the slope for tests which had very little inelasticity; N1 alone is the slope for tests with large inelastic strains. You might start with N1 = N2 = 2.

   c. NREF,DEREF - Pick these in the middle of the data points; they are not independent constants and serve merely as "pivot points" for optimization.

   d. SIGMAF(temp) - Use this to set the curves through your data at the various temperatures. It serves as the main constant for determining life vs. temperature relationships.

2. Next, use the R-ratio tests X11-X13 to set the following:

   a. SIGTRF(temp) - This controls the effect of the maximum cyclic stress on the life prediction.

   b. SGEPRF(temp) - This does two things: first, it serves as a reference point for tests with no maximum stress effect; second, it affects the shape of the primary creep ductility effect.

   c. C1,2,3 - These control the shape of the primary creep ductility function and are set at this time in conjunction with the above two constants. Monotonic primary creep data should be consulted to provide a basis for this function. If no effect is desired or observed in the data, use C1 = 1. and C2 = C3 = 0.

3. Now review the remaining data from the slow rate tests X14-X24 and compare it to the fast rate data to set the following constants:

   a. Arrenhius constants - Use these to set up the basic functional forms required to pick up the data trends. Again, monotonic creep data seems to work best for the mode 2 (intergranular) predictions.

   b. C11, C12 - These are used to scale the Arrhenius parameters inside CDA to predict the data, keeping in mind the different failure modes observed in the actual data.

For TMF predictions, actual TMF tests should be run within the parameters shown in the basic matrix (T1-T3 at E1, for example). The DALFA(temp) constants can then be used to fit this data.

For non-linear damage accumulation, various types of cumulative damage tests can demonstrate the correct values of BCON and ALPHA. Be careful to pick conditions where the same mode is always active. Mixing modes will often result in very little interaction and will lead to confusion.

Finally, the other major types of damage in the CDA model, such as coating, multiaxial, and environmental, will also require data of that sort for accurate calibration. Of course, if the material in question is similar to the nickel-base alloys studied under this contract, you may be able to use the current constants directly or by suitably ratioing them.

In all the above, the actual fitting of constants can be made much easier by using a statistical program or a spreadsheet program which can perform multivariate linear regression. Also, connection to an optimizer program and judicious matching of data sets and constants can produce excellent results for a minimum investment of time.

SECTION VIII

MODIFICATIONS TO CDA CODE

Increasing WORK and SCRTCH arrays

If you have an input case with several points per cycle, several cycles, many subcycles, or many nested subcycles, the dimensions of the WORK and/or SCRTCH arrays may need to be re-dimensioned. Fortunately, the only place this needs to be done is in the LIFE routine unless multiaxial data is also being processed. For multiaxial data, the parameter MPTS must also be increased; this is located in MULTAX, SOCIEP, MAXDE, HISTRY, and FAILPL. WORK is dimensioned to 2000 initially. SCRTCH is dimensioned to 110. Note: increasing these dimensions will increase the amount of memory required.

The minimum size required for the work array (parameter IWORK in routine LIFE) for a specimen is:

```
IWORK = M * (ICOUNT + 2*NMAT + 4) + N + NDM*4 + 3*NMAT + 1 +
        4 * NLOOPMAX
```

where:

```
M        = number of points in a cycle
ICOUNT   = number of types of data input (STRAIN1,TIME,TEMP,etc.)
NMAT     = number of materials (1 for uncoated, 2 for coated)
N        = number of cycles in specimen
NDM      = number of damage modes for the (base) material
NLOOPMAX = maximum number of subcycles in any cycle
```

The size of the SCRTCH array is:

```
ISCTMX = 11 * NLPMAX
```

where:

```
NLPMAX   = maximum number of nested subcycles in any cycle
```

The WORK and SCRTCH arrays are cleared after each specimen is run. If several sets of data are in the same input file, the size of WORK should be large enough to handle the largest case based upon the above criteria. See the section on Storage in WORK and SCRTCH Arrays for information on where the above formulas came from.

Adding and Changing Modes

There are three steps to add a new mode:

1) add a routine to calculate the new mode (dummy routines exist for modes 3 through 5)

2) update routine DAMAGE to call the new routine

3) update the MDS array in the GETMOD routine to "activate" the new mode.

Routine DAMAGE calls the routines to calculate damage rates for desired modes. The MODES array in DAMAGE contains the numbers of the modes to calculate. This array is set in routine GETMOD. The index of the material is MATIND and is also set in GETMOD.

The MDS array in GETMOD is dimensioned (15,2). The first dimension is the maximum number of modes available. The second dimension is the number of materials supported. A '1' in the MDS array says a particular mode will be calculated. A '0' indicates it will not be. For example, a '1' in MDS(i,j) means mode i will be calculated for material j. Currently, the MDS array contains modes for material PWA1455.

If more than 13 new modes are added, some array dimensions must be increased. In LIFE, dimensions of arrays DAMAGS and NI and the upper limit of the DO 7 loop would have to be increased to the number of damage modes PLUS 1. The extra mode is for the coating damage. In GETMOD, the dimension of MODES, first dimension of MDS, and the upper limit of the DO 10 loop would need to be increased to the number of damage modes.

Adding Materials

In CDA.FOR, arrays are dimensioned to hold up to 20 materials. Currently, these arrays hold data for 2 materials (PWA1455 and INCO718). Some arrays are dependent on material only. Others are material and temperature dependent. Arrays depending on material only are:

N10,N20,C110,ALPHA0,BCON0,C120	starting values for N1,N2,C11,ALPHA, BCON, and C12, respectively
ARRACN,QORCON,ARRBCN	Arrhenius equation
FMAXCN,FMINCN,PREFCN,KCON	Environmental constants
C1,C2,C3	used for calculating Ep-bar ratio
NVAL	number of temperature dependent constants for this material
XNREF,DEREF,ETHRES	used in damage calculation
DDDNMN	minimum damage rate for purposes of calculating beta

The above arrays must be updated for the new material constants.

To update a temperature-dependent constant several values need to be entered. Up to 20 temperature/constant pairs can be used to defined the curve for the constant. The constant is stored in it's respective array (listed below). The temperatures are stored in array TABTEM. The number of pairs is entered into the array NVAL. The temperature-dependent arrays have two dimensions. The first corresponds to the temperature; the second, to the material. They are hard-coded to (ntempmax,nmatlmax) where ntempmax is the maximum number of temperature values allowed and nmatlmax is the maximum number of materials allowed. These temperature-dependent constants are:

SIGTRF	- sigma-T-ref	(used in CHRMXS)
SGEPRF	- sigma-Ep-ref	(used in SEPREF)
SIGMAF	- sigma-f	(used in FAIL)
DALFA	- delta-alpha	(used in FALPHA)
TABTEM	- temperatures	(used in all the above)

To add constants for a new material:

1) Add the number of temperatures to the NVAL array at position IMATNEW
2) Add the temperatures to the TABTEM array, in positions TABTEM(i=1,NVAL;IMATNEW).
3) Add the required constants to the SIGTRF, SGEPRF, SIGMAF, and DALFA arrays, using the analogous positions used in step 2.

The position of the constants in the array will be determined in routine GETMOD. The name of the new material must be added to the MATLS array and the index (position of this material's constants in the arrays) must be added to the INDEX array. These two arrays must be increased in size. This set-up of having an index for the material allows aliases for materials. (Example: A material name may be input as INCO718 or IN718.) The name should be added left-justified and without any imbedded blanks. The routine COMPRS will "compress" the material name input to have this format. It's this compressed name that is searched for in the MATLS array in routine GETMOD. Also, array MDS in GETMOD must have it's second dimension increased to the number of materials (not counting aliases; should equal highest number contained in index array), and the modes to be calculated for the new material should be entered into the MDS array. A '1' in MDS(i,j) indicates that mode i will be calculated for material j. A '0' indicates that mode will not be calculated.

Connection to Optimizers

The call to ADS here is only valid if you have ADS (Automated Design Synthesis) optimizer available (Vanderplaats et al, 1983). Pratt and Whitney does not assume responsibility for providing this program. The call to ADS here is only to show how an optimizer could be connected to CDA to optimize material constants. Other optimizers could also be used, including some available for PC's. An objective function is provided, but a different objective function may be used. The X-vector contains the changes to the design variables. This is modified by the optimizer to reduce the objective function value.

SECTION IX

REFERENCES

Moreno, V., Nissley, D. M., and Lin, L. S., 1984, "Creep Fatigue Life Prediction for Engine Hot Section Materials (Isotropic) Second Annual Report," NASA CR-174844.

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Socie, D. F., and Shield, T. W., 1984, "Mean Stress Effects in Biaxial Fatigue of Inconel 718," Transactions of the ASME, Journal of Engineering Materials and Technology, July 1984, Vol. 106, pp.227-232.

Swanson, G. A., Linask, I., Nissley, D. M., Norris, P. P., Meyer, T. G., and Walker, K. P., 1987, "Life Prediction and Constitutive Models for Engine Hot Section Anisotropic Materials Program," NASA CR-179594.

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APPENDIX A

SAMPLE INPUT

The following input file is for Specimen 42B, which was an in-phase TMF test conducted at 1000-1600*F, 0.5% strain range, Re=-1, and 1 CPM. It is included as the second specimen in the disk file 'TMFIN.B19'. The detailed input file, as created by the test rig data acquisition system, is as follows:

```
* * * Top of File * * *
MATERIAL 1455
CRACK INITIATION     370
ENVIRONMENT CODE
TMF    S
    60.00000      0.00000    5
  60   6
  CYCLE =          1.
     STRESS1      TEMP         TIME          RAW1
   1 0.961277E+04 0.131192E+04 0.610000E+02 0.326510E-03
   2 0.129113E+05 0.134929E+04 0.620000E+02 0.662991E-03
   3 0.140108E+05 0.138837E+04 0.630000E+02 0.790106E-03
   4 0.186601E+05 0.142233E+04 0.640000E+02 0.105680E-02
   5 0.243775E+05 0.145359E+04 0.650000E+02 0.135090E-02
   6 0.297493E+05 0.147728E+04 0.660000E+02 0.161013E-02
   7 0.319012E+05 0.150318E+04 0.670000E+02 0.173724E-02
   8 0.367233E+05 0.152491E+04 0.680000E+02 0.196904E-02
   9 0.404616E+05 0.154372E+04 0.690000E+02 0.205378E-02
  10 0.422365E+05 0.156106E+04 0.700000E+02 0.219585E-02
  11 0.465717E+05 0.157548E+04 0.710000E+02 0.241767E-02
  12 0.486136E+05 0.158720E+04 0.720000E+02 0.253233E-02
  13 0.486136E+05 0.159575E+04 0.730000E+02 0.258965E-02
  14 0.498545E+05 0.159966E+04 0.740000E+02 0.254229E-02
  15 0.497131E+05 0.160405E+04 0.750000E+02 0.255476E-02
  16 0.478754E+05 0.159795E+04 0.760000E+02 0.254479E-02
  17 0.468701E+05 0.159282E+04 0.770000E+02 0.251986E-02
  18 0.449538E+05 0.158500E+04 0.780000E+02 0.251488E-02
  19 0.436030E+05 0.157401E+04 0.790000E+02 0.244011E-02
  20 0.412470E+05 0.155984E+04 0.800000E+02 0.224819E-02
  21 0.396134E+05 0.154323E+04 0.810000E+02 0.217590E-02
  22 0.361893E+05 0.152320E+04 0.820000E+02 0.202386E-02
  23 0.309745E+05 0.150220E+04 0.830000E+02 0.180951E-02
  24 0.253356E+05 0.147631E+04 0.840000E+02 0.155279E-02
  25 0.208277E+05 0.145261E+04 0.850000E+02 0.140824E-02
  26 0.148590E+05 0.142623E+04 0.860000E+02 0.113157E-02
  27 0.900019E+04 0.139888E+04 0.870000E+02 0.917220E-03
  28 0.411527E+04 0.136981E+04 0.880000E+02 0.648037E-03
  29 -.240319E+04 0.133586E+04 0.890000E+02 0.348943E-03
  30 -.719386E+04 0.130288E+04 0.900000E+02 0.147054E-03
  31 -.154401E+05 0.126991E+04 0.910000E+02 -.104683E-03
  32 -.208120E+05 0.123766E+04 0.920000E+02 -.468581E-03
  33 -.276289E+05 0.121202E+04 0.930000E+02 -.630589E-03
  34 -.338175E+05 0.118271E+04 0.940000E+02 -.872359E-03
  35 -.409014E+05 0.115633E+04 0.950000E+02 -.119887E-02
  36 -.446397E+05 0.112848E+04 0.960000E+02 -.138829E-02
  37 -.504356E+05 0.110430E+04 0.970000E+02 -.155528E-02
  38 -.566557E+05 0.108207E+04 0.980000E+02 -.176216E-02
  39 -.614621E+05 0.106180E+04 0.990000E+02 -.196903E-02
  40 -.647606E+05 0.104299E+04 0.100000E+03 -.205377E-02
  41 -.680432E+05 0.102907E+04 0.101000E+03 -.218587E-02
  42 -.692999E+05 0.101710E+04 0.102000E+03 -.235536E-02
  43 -.728182E+05 0.100806E+04 0.103000E+03 -.234540E-02
  44 -.735722E+05 0.100171E+04 0.104000E+03 -.247001E-02
  45 -.730539E+05 0.998290E+03 0.105000E+03 -.242017E-02
  46 -.728969E+05 0.100073E+04 0.106000E+03 -.249743E-02
  47 -.718287E+05 0.100391E+04 0.107000E+03 -.245256E-02
```

48	-.715775E+05	0.101441E+04	0.108000E+03	-.235786E-02
49	-.668496E+05	0.102516E+04	0.109000E+03	-.222078E-02
50	-.647134E+05	0.103835E+04	0.110000E+03	-.208368E-02
51	-.583992E+05	0.105471E+04	0.111000E+03	-.206873E-02
52	-.545823E+05	0.107499E+04	0.112000E+03	-.178708E-02
53	-.508754E+05	0.109893E+04	0.113000E+03	-.161262E-02
54	-.455821E+05	0.112384E+04	0.114000E+03	-.152538E-02
55	-.404145E+05	0.114924E+04	0.115000E+03	-.128112E-02
56	-.331735E+05	0.117636E+04	0.116000E+03	-.972055E-03
57	-.261838E+05	0.120445E+04	0.117000E+03	-.762688E-03
58	-.221628E+05	0.123620E+04	0.118000E+03	-.540862E-03
59	-.148747E+05	0.126991E+04	0.119000E+03	-.301586E-03
60	-.709962E+04	0.129702E+04	0.120000E+03	0.523413E-04

CYCLE = 2.

	STRESS1	TEMP	TIME	RAW1
1	0.124086E+04	0.133024E+04	0.121000E+03	0.333988E-03
2	0.714675E+04	0.136077E+04	0.122000E+03	0.680438E-03
3	0.109636E+05	0.139228E+04	0.123000E+03	0.914728E-03
4	0.171522E+05	0.142233E+04	0.124000E+03	0.118142E-02
5	0.232309E+05	0.145164E+04	0.125000E+03	0.138081E-02
6	0.287127E+05	0.147851E+04	0.126000E+03	0.159268E-02
7	0.310530E+05	0.150318E+04	0.127000E+03	0.180453E-02
8	0.360008E+05	0.152418E+04	0.128000E+03	0.199646E-02
9	0.395349E+05	0.154519E+04	0.129000E+03	0.214351E-02
10	0.416553E+05	0.156204E+04	0.130000E+03	0.233293E-02
11	0.460848E+05	0.157719E+04	0.131000E+03	0.239524E-02
12	0.482838E+05	0.158842E+04	0.132000E+03	0.247251E-02
13	0.481738E+05	0.159624E+04	0.133000E+03	0.260710E-02
14	0.498388E+05	0.160064E+04	0.134000E+03	0.260959E-02
15	0.498388E+05	0.160332E+04	0.135000E+03	0.262455E-02
16	0.480482E+05	0.160210E+04	0.136000E+03	0.264199E-02
17	0.486607E+05	0.159453E+04	0.137000E+03	0.259962E-02
18	0.474984E+05	0.158085E+04	0.138000E+03	0.242016E-02
19	0.459120E+05	0.156864E+04	0.139000E+03	0.232296E-02
20	0.422051E+05	0.155765E+04	0.140000E+03	0.230303E-02
21	0.398176E+05	0.154104E+04	0.141000E+03	0.210362E-02
22	0.351840E+05	0.152394E+04	0.142000E+03	0.201639E-02
23	0.294666E+05	0.150171E+04	0.143000E+03	0.178957E-02
24	0.232466E+05	0.147802E+04	0.144000E+03	0.152039E-02
25	0.195711E+05	0.145213E+04	0.145000E+03	0.138580E-02
26	0.136809E+05	0.142599E+04	0.146000E+03	0.113656E-02
27	0.863893E+04	0.139790E+04	0.147000E+03	0.897281E-03
28	0.403674E+04	0.136541E+04	0.148000E+03	0.618127E-03
29	-.289011E+04	0.133415E+04	0.149000E+03	0.304079E-03
30	-.786928E+04	0.130264E+04	0.150000E+03	0.423715E-04
31	-.160370E+05	0.126771E+04	0.151000E+03	-.162009E-03
32	-.215502E+05	0.123766E+04	0.152000E+03	-.393807E-03
33	-.279273E+05	0.121104E+04	0.153000E+03	-.717825E-03
34	-.343986E+05	0.118149E+04	0.154000E+03	-.944640E-03
35	-.412313E+05	0.115706E+04	0.155000E+03	-.113655E-02
36	-.448596E+05	0.112873E+04	0.156000E+03	-.136835E-02
37	-.501215E+05	0.110259E+04	0.157000E+03	-.157522E-02
38	-.560274E+05	0.107914E+04	0.158000E+03	-.174721E-02
39	-.611322E+05	0.105765E+04	0.159000E+03	-.194909E-02
40	-.651532E+05	0.104201E+04	0.160000E+03	-.208119E-02
41	-.686402E+05	0.102833E+04	0.161000E+03	-.218587E-02
42	-.699752E+05	0.101710E+04	0.162000E+03	-.234290E-02
43	-.736351E+05	0.100733E+04	0.163000E+03	-.234290E-02
44	-.742947E+05	0.100342E+04	0.164000E+03	-.245506E-02
45	-.733837E+05	0.100000E+04	0.165000E+03	-.247500E-02
46	-.727869E+05	0.999023E+03	0.166000E+03	-.246254E-02
47	-.714675E+05	0.100391E+04	0.167000E+03	-.244259E-02
48	-.714204E+05	0.101417E+04	0.168000E+03	-.238777E-02
49	-.671480E+05	0.102540E+04	0.169000E+03	-.221828E-02
50	-.644935E+05	0.104128E+04	0.170000E+03	-.218587E-02
51	-.582421E+05	0.105545E+04	0.171000E+03	-.206624E-02
52	-.542368E+05	0.107523E+04	0.172000E+03	-.177462E-02
53	-.508597E+05	0.109795E+04	0.173000E+03	-.159517E-02
54	-.453308E+05	0.112457E+04	0.174000E+03	-.144064E-02
55	-.407915E+05	0.115022E+04	0.175000E+03	-.123625E-02
56	-.335348E+05	0.117733E+04	0.176000E+03	-.105929E-02
57	-.271734E+05	0.120689E+04	0.177000E+03	-.815030E-03
58	-.224769E+05	0.123986E+04	0.178000E+03	-.448641E-03
59	-.154087E+05	0.127064E+04	0.179000E+03	-.201888E-03
60	-.769650E+04	0.129995E+04	0.180000E+03	0.772658E-04

CYCLE = 10.

	STRESS1	TEMP	TIME	RAW1
1	-.361264E+04	0.133464E+04	0.601000E+03	0.403776E-03
2	0.328279E+04	0.136297E+04	0.602000E+03	0.660498E-03
3	0.774362E+04	0.139301E+04	0.603000E+03	0.842447E-03
4	0.141678E+05	0.142184E+04	0.604000E+03	0.113158E-02
5	0.205607E+05	0.145164E+04	0.605000E+03	0.129358E-02
6	0.261838E+05	0.147631E+04	0.606000E+03	0.161013E-02
7	0.280058E+05	0.150318E+04	0.607000E+03	0.184192E-02
8	0.333149E+05	0.152491E+04	0.608000E+03	0.193664E-02
9	0.368018E+05	0.154372E+04	0.609000E+03	0.217591E-02
10	0.389694E+05	0.156204E+04	0.610000E+03	0.223822E-02
11	0.434303E+05	0.157719E+04	0.611000E+03	0.241767E-02
12	0.457392E+05	0.158745E+04	0.612000E+03	0.242515E-02
13	0.457549E+05	0.159551E+04	0.613000E+03	0.254728E-02
14	0.472785E+05	0.160137E+04	0.614000E+03	0.253980E-02
15	0.475926E+05	0.160357E+04	0.615000E+03	0.255974E-02
16	0.457863E+05	0.160186E+04	0.616000E+03	0.261956E-02
17	0.461005E+05	0.159209E+04	0.617000E+03	0.249494E-02
18	0.442313E+05	0.158280E+04	0.618000E+03	0.241767E-02
19	0.429590E+05	0.157206E+04	0.619000E+03	0.244011E-02
20	0.401318E+05	0.156009E+04	0.620000E+03	0.231050E-02
21	0.386396E+05	0.154323E+04	0.621000E+03	0.216593E-02
22	0.351997E+05	0.152418E+04	0.622000E+03	0.201389E-02
23	0.304090E+05	0.149927E+04	0.623000E+03	0.179456E-02
24	0.242675E+05	0.147631E+04	0.624000E+03	0.160264E-02
25	0.200580E+05	0.145042E+04	0.625000E+03	0.133596E-02
26	0.138223E+05	0.142599E+04	0.626000E+03	0.115650E-02
27	0.838761E+04	0.139814E+04	0.627000E+03	0.867371E-03
28	0.359694E+04	0.136639E+04	0.628000E+03	0.665484E-03
29	-.353411E+04	0.133464E+04	0.629000E+03	0.366390E-03
30	-.843474E+04	0.130264E+04	0.630000E+03	0.548338E-04
31	-.167752E+05	0.126673E+04	0.631000E+03	-.129607E-03
32	-.224926E+05	0.123937E+04	0.632000E+03	-.396300E-03
33	-.292624E+05	0.121226E+04	0.633000E+03	-.648036E-03
34	-.354353E+05	0.118393E+04	0.634000E+03	-.902269E-03
35	-.419695E+05	0.115584E+04	0.635000E+03	-.113157E-02
36	-.457549E+05	0.112824E+04	0.636000E+03	-.144063E-02
37	-.512367E+05	0.110259E+04	0.637000E+03	-.156027E-02
38	-.574724E+05	0.107865E+04	0.638000E+03	-.174471E-02
39	-.627186E+05	0.105960E+04	0.639000E+03	-.199146E-02
40	-.662841E+05	0.104323E+04	0.640000E+03	-.207621E-02
41	-.696455E+05	0.102687E+04	0.641000E+03	-.223572E-02
42	-.712476E+05	0.101685E+04	0.642000E+03	-.235536E-02
43	-.750016E+05	0.100806E+04	0.643000E+03	-.234290E-02
44	-.757084E+05	0.100318E+04	0.644000E+03	-.248247E-02
45	-.752215E+05	0.998779E+03	0.645000E+03	-.250990E-02
46	-.746717E+05	0.100073E+04	0.646000E+03	-.241020E-02
47	-.731639E+05	0.100635E+04	0.647000E+03	-.245755E-02
48	-.727869E+05	0.101172E+04	0.648000E+03	-.236783E-02
49	-.687502E+05	0.102467E+04	0.649000E+03	-.227312E-02
50	-.666611E+05	0.103908E+04	0.650000E+03	-.208867E-02
51	-.605196E+05	0.105740E+04	0.651000E+03	-.195906E-02
52	-.559803E+05	0.107670E+04	0.652000E+03	-.188927E-02
53	-.524462E+05	0.109893E+04	0.653000E+03	-.163505E-02
54	-.469644E+05	0.112115E+04	0.654000E+03	-.148550E-02
55	-.427863E+05	0.114851E+04	0.655000E+03	-.120884E-02
56	-.357652E+05	0.117929E+04	0.656000E+03	-.100446E-02
57	-.282257E+05	0.120640E+04	0.657000E+03	-.822508E-03
58	-.238120E+05	0.123571E+04	0.658000E+03	-.548339E-03
59	-.183145E+05	0.126746E+04	0.659000E+03	-.221828E-03
60	-.120160E+05	0.130166E+04	0.660000E+03	0.224319E-04

CYCLE = 30.

	STRESS1	TEMP	TIME	RAW1
1	-.353411E+04	0.133366E+04	0.180100E+04	0.393806E-03
2	0.309431E+04	0.136199E+04	0.180200E+04	0.660498E-03
3	0.725670E+04	0.139130E+04	0.180300E+04	0.937160E-03
4	0.131469E+05	0.142306E+04	0.180400E+04	0.113158E-02
5	0.199638E+05	0.145286E+04	0.180500E+04	0.132349E-02
6	0.256341E+05	0.147826E+04	0.180600E+04	0.162010E-02
7	0.276917E+05	0.150342E+04	0.180700E+04	0.172976E-02
8	0.330950E+05	0.152467E+04	0.180800E+04	0.192667E-02
9	0.365976E+05	0.154543E+04	0.180900E+04	0.208369E-02
10	0.384982E+05	0.156082E+04	0.181000E+04	0.220831E-02
11	0.428648E+05	0.157743E+04	0.181100E+04	0.234041E-02

12	0.453622E+05	0.158867E+04	0.181200E+04	0.253233E-02
13	0.455507E+05	0.159648E+04	0.181300E+04	0.251239E-02
14	0.473570E+05	0.160210E+04	0.181400E+04	0.258217E-02
15	0.476712E+05	0.160308E+04	0.181500E+04	0.259464E-02
16	0.458649E+05	0.159795E+04	0.181600E+04	0.263202E-02
17	0.451423E+05	0.159282E+04	0.181700E+04	0.259962E-02
18	0.429747E+05	0.158793E+04	0.181800E+04	0.251737E-02
19	0.426135E+05	0.157377E+04	0.181900E+04	0.236035E-02
20	0.400061E+05	0.155545E+04	0.182000E+04	0.231300E-02
21	0.373516E+05	0.153933E+04	0.182100E+04	0.205377E-02
22	0.325609E+05	0.152320E+04	0.182200E+04	0.196903E-02
23	0.270634E+05	0.150415E+04	0.182300E+04	0.176963E-02
24	0.214088E+05	0.147802E+04	0.182400E+04	0.153534E-02
25	0.180004E+05	0.145237E+04	0.182500E+04	0.131352E-02
26	0.117961E+05	0.142526E+04	0.182600E+04	0.105929E-02
27	0.640851E+04	0.139668E+04	0.182700E+04	0.857402E-03
28	0.158642E+04	0.136712E+04	0.182800E+04	0.563293E-03
29	-.526189E+04	0.133561E+04	0.182900E+04	0.396299E-03
30	-.962848E+04	0.130142E+04	0.183000E+04	0.972054E-04
31	-.179376E+05	0.126771E+04	0.183100E+04	-.189426E-03
32	-.235293E+05	0.123742E+04	0.183200E+04	-.468581E-03
33	-.302677E+05	0.121104E+04	0.183300E+04	-.735271E-03
34	-.366448E+05	0.118222E+04	0.183400E+04	-.939654E-03
35	-.433517E+05	0.115340E+04	0.183500E+04	-.118391E-02
36	-.475455E+05	0.112702E+04	0.183600E+04	-.144313E-02
37	-.534043E+05	0.110186E+04	0.183700E+04	-.161261E-02
38	-.598599E+05	0.107841E+04	0.183800E+04	-.179955E-02
39	-.651375E+05	0.106131E+04	0.183900E+04	-.196405E-02
40	-.686087E+05	0.104275E+04	0.184000E+04	-.209615E-02
41	-.722372E+05	0.102882E+04	0.184100E+04	-.218338E-02
42	-.732737E+05	0.101661E+04	0.184200E+04	-.237032E-02
43	-.774362E+05	0.100830E+04	0.184300E+04	-.240522E-02
44	-.780017E+05	0.100220E+04	0.184400E+04	-.247998E-02
45	-.772320E+05	0.999511E+03	0.184500E+04	-.249743E-02
46	-.767137E+05	0.999511E+03	0.184600E+04	-.242017E-02
47	-.753315E+05	0.100464E+04	0.184700E+04	-.240521E-02
48	-.753000E+05	0.101417E+04	0.184800E+04	-.237780E-02
49	-.701795E+05	0.102443E+04	0.184900E+04	-.232546E-02
50	-.679020E+05	0.103981E+04	0.185000E+04	-.218338E-02
51	-.613992E+05	0.105642E+04	0.185100E+04	-.206873E-02
52	-.568913E+05	0.107572E+04	0.185200E+04	-.189177E-02
53	-.533886E+05	0.109819E+04	0.185300E+04	-.161012E-02
54	-.480324E+05	0.112164E+04	0.185400E+04	-.148052E-02
55	-.438858E+05	0.114827E+04	0.185500E+04	-.124124E-02
56	-.370374E+05	0.117855E+04	0.185600E+04	-.106677E-02
57	-.303148E+05	0.120640E+04	0.185700E+04	-.775150E-03
58	-.265451E+05	0.123669E+04	0.185800E+04	-.510952E-03
59	-.207963E+05	0.126942E+04	0.185900E+04	-.269183E-03
60	-.149689E+05	0.130142E+04	0.186000E+04	-.373868E-04

CYCLE = 100.

	STRESS1	TEMP	TIME	RAW1
1	-.199481E+04	0.133171E+04	0.600100E+04	0.411253E-03
2	0.449224E+04	0.136199E+04	0.600200E+04	0.570770E-03
3	0.892166E+04	0.139375E+04	0.600300E+04	0.937160E-03
4	0.155972E+05	0.142281E+04	0.600400E+04	0.105929E-02
5	0.221471E+05	0.145066E+04	0.600500E+04	0.142318E-02
6	0.272833E+05	0.147826E+04	0.600600E+04	0.156526E-02
7	0.297336E+05	0.150244E+04	0.600700E+04	0.179456E-02
8	0.344929E+05	0.152638E+04	0.600800E+04	0.191420E-02
9	0.383254E+05	0.154543E+04	0.600900E+04	0.211859E-02
10	0.403988E+05	0.156180E+04	0.601000E+04	0.221080E-02
11	0.449696E+05	0.157670E+04	0.601100E+04	0.244758E-02
12	0.472157E+05	0.158867E+04	0.601200E+04	0.243263E-02
13	0.473413E+05	0.159599E+04	0.601300E+04	0.249245E-02
14	0.490220E+05	0.160186E+04	0.601400E+04	0.253731E-02
15	0.493833E+05	0.160357E+04	0.601500E+04	0.265944E-02
16	0.477654E+05	0.160088E+04	0.601600E+04	0.258965E-02
17	0.483623E+05	0.159380E+04	0.601700E+04	0.251488E-02
18	0.472628E+05	0.158085E+04	0.601800E+04	0.248995E-02
19	0.453151E+05	0.156839E+04	0.601900E+04	0.233293E-02
20	0.414983E+05	0.156009E+04	0.602000E+04	0.219834E-02
21	0.394563E+05	0.154226E+04	0.602100E+04	0.205128E-02
22	0.351369E+05	0.152272E+04	0.602200E+04	0.195657E-02
23	0.294038E+05	0.150147E+04	0.602300E+04	0.171480E-02
24	0.234351E+05	0.147826E+04	0.602400E+04	0.153534E-02

25	0.199795E+05	0.145384E+04	0.602500E+04	0.135590E-02
26	0.142935E+05	0.142501E+04	0.602600E+04	0.113905E-02
27	0.884312E+04	0.139643E+04	0.602700E+04	0.904758E-03
28	0.414669E+04	0.136590E+04	0.602800E+04	0.610650E-03
29	-.351840E+04	0.133464E+04	0.602900E+04	0.371375E-03
30	-.830908E+04	0.130215E+04	0.603000E+04	0.124622E-03
31	-.165867E+05	0.126746E+04	0.603100E+04	-.134592E-03
32	-.218015E+05	0.123864E+04	0.603200E+04	-.428701E-03
33	-.285556E+05	0.120982E+04	0.603300E+04	-.667976E-03
34	-.349170E+05	0.118173E+04	0.603400E+04	-.904761E-03
35	-.422208E+05	0.115388E+04	0.603500E+04	-.114154E-02
36	-.460691E+05	0.112775E+04	0.603600E+04	-.144562E-02
37	-.519121E+05	0.110210E+04	0.603700E+04	-.164252E-02
38	-.580379E+05	0.107914E+04	0.603800E+04	-.178958E-02
39	-.637239E+05	0.105813E+04	0.603900E+04	-.193663E-02
40	-.677292E+05	0.104226E+04	0.604000E+04	-.214599E-02
41	-.708862E+05	0.103029E+04	0.604100E+04	-.225815E-02
42	-.715617E+05	0.101563E+04	0.604200E+04	-.235038E-02
43	-.754885E+05	0.100684E+04	0.604300E+04	-.234041E-02
44	-.762267E+05	0.100147E+04	0.604400E+04	-.239773E-02
45	-.758969E+05	0.100024E+04	0.604500E+04	-.250740E-02
46	-.752057E+05	0.100147E+04	0.604600E+04	-.243761E-02
47	-.736979E+05	0.100391E+04	0.604700E+04	-.244509E-02
48	-.738236E+05	0.101295E+04	0.604800E+04	-.237780E-02
49	-.693785E+05	0.102491E+04	0.604900E+04	-.224819E-02
50	-.675407E+05	0.104055E+04	0.605000E+04	-.215846E-02
51	-.607081E+05	0.105716E+04	0.605100E+04	-.205378E-02
52	-.565457E+05	0.107523E+04	0.605200E+04	-.180453E-02
53	-.529802E+05	0.109722E+04	0.605300E+04	-.158271E-02
54	-.475926E+05	0.112457E+04	0.605400E+04	-.151292E-02
55	-.429276E+05	0.115022E+04	0.605500E+04	-.125370E-02
56	-.348384E+05	0.117880E+04	0.605600E+04	-.101692E-02
57	-.278174E+05	0.120762E+04	0.605700E+04	-.732780E-03
58	-.234665E+05	0.123766E+04	0.605800E+04	-.523415E-03
59	-.167909E+05	0.126771E+04	0.605900E+04	-.186933E-03
60	-.103510E+05	0.129946E+04	0.606000E+04	0.199395E-04

CYCLE = 300.

	STRESS1	TEMP	TIME	RAW1
1	-.229324E+04	0.133146E+04	0.180010E+05	0.326510E-03
2	0.408386E+04	0.136053E+04	0.180020E+05	0.615634E-03
3	0.793211E+04	0.139399E+04	0.180030E+05	0.929683E-03
4	0.145605E+05	0.142404E+04	0.180040E+05	0.120635E-02
5	0.210319E+05	0.145286E+04	0.180050E+05	0.142069E-02
6	0.268278E+05	0.147973E+04	0.180060E+05	0.151541E-02
7	0.291525E+05	0.150318E+04	0.180070E+05	0.174970E-02
8	0.341002E+05	0.152540E+04	0.180080E+05	0.200642E-02
9	0.377914E+05	0.154568E+04	0.180090E+05	0.209865E-02
10	0.400218E+05	0.156326E+04	0.180100E+05	0.229056E-02
11	0.447182E+05	0.157645E+04	0.180110E+05	0.245755E-02
12	0.470900E+05	0.158793E+04	0.180120E+05	0.247251E-02
13	0.471686E+05	0.159673E+04	0.180130E+05	0.249993E-02
14	0.488021E+05	0.160137E+04	0.180140E+05	0.263451E-02
15	0.489592E+05	0.160283E+04	0.180150E+05	0.264199E-02
16	0.474042E+05	0.159917E+04	0.180160E+05	0.253232E-02
17	0.468387E+05	0.158989E+04	0.180170E+05	0.256722E-02
18	0.446397E+05	0.158232E+04	0.180180E+05	0.241767E-02
19	0.429590E+05	0.157059E+04	0.180190E+05	0.232545E-02
20	0.395977E+05	0.155984E+04	0.180200E+05	0.231549E-02
21	0.384825E+05	0.154421E+04	0.180210E+05	0.207371E-02
22	0.354353E+05	0.152272E+04	0.180220E+05	0.189924E-02
23	0.306132E+05	0.149756E+04	0.180230E+05	0.169237E-02
24	0.241576E+05	0.147386E+04	0.180240E+05	0.154781E-02
25	0.201994E+05	0.144993E+04	0.180250E+05	0.136088E-02
26	0.135710E+05	0.142306E+04	0.180260E+05	0.108172E-02
27	0.777504E+04	0.139717E+04	0.180270E+05	0.817522E-03
28	0.306289E+04	0.136663E+04	0.180280E+05	0.578248E-03
29	-.397391E+04	0.133293E+04	0.180290E+05	0.376360E-03
30	-.903161E+04	0.129751E+04	0.180300E+05	0.224319E-04
31	-.181575E+05	0.126698E+04	0.180310E+05	-.249245E-03
32	-.237021E+05	0.123913E+04	0.180320E+05	-.493505E-03
33	-.304090E+05	0.120884E+04	0.180330E+05	-.675453E-03
34	-.368018E+05	0.118051E+04	0.180340E+05	-.984519E-03
35	-.438858E+05	0.115413E+04	0.180350E+05	-.121631E-02
36	-.479225E+05	0.112677E+04	0.180360E+05	-.145808E-02
37	-.536556E+05	0.110186E+04	0.180370E+05	-.162009E-02

38	-.597029E+05	0.107914E+04	0.180380E+05	-.178958E-02
39	-.649333E+05	0.105911E+04	0.180390E+05	-.194411E-02
40	-.683889E+05	0.104226E+04	0.180400E+05	-.215098E-02
41	-.717816E+05	0.102589E+04	0.180410E+05	-.227809E-02
42	-.731639E+05	0.101612E+04	0.180420E+05	-.237530E-02
43	-.773106E+05	0.100684E+04	0.180430E+05	-.240522E-02
44	-.778602E+05	0.100073E+04	0.180440E+05	-.247500E-02
45	-.774362E+05	0.998534E+03	0.180450E+05	-.246005E-02
46	-.772634E+05	0.100098E+04	0.180460E+05	-.242764E-02
47	-.760854E+05	0.100562E+04	0.180470E+05	-.235037E-02
48	-.755199E+05	0.101441E+04	0.180480E+05	-.229305E-02
49	-.706192E+05	0.102589E+04	0.180490E+05	-.227062E-02
50	-.684202E+05	0.104104E+04	0.180500E+05	-.218089E-02
51	-.615563E+05	0.105618E+04	0.180510E+05	-.198399E-02
52	-.576138E+05	0.107596E+04	0.180520E+05	-.187930E-02
53	-.538284E+05	0.109941E+04	0.180530E+05	-.165250E-02
54	-.478754E+05	0.112677E+04	0.180540E+05	-.144562E-02
55	-.428491E+05	0.114998E+04	0.180550E+05	-.122878E-02
56	-.351997E+05	0.118051E+04	0.180560E+05	-.987010E-03
57	-.279430E+05	0.121177E+04	0.180570E+05	-.765180E-03
58	-.216130E+05	0.123864E+04	0.180580E+05	-.491013E-03
59	-.144506E+05	0.126698E+04	0.180590E+05	-.206873E-03
60	-.790069E+04	0.129507E+04	0.180600E+05	0.797582E-04

* * * End of File * * *

APPENDIX B

SAMPLE OUTPUT

The input file for Specimen 42B shown in Appendix A will generate the following output files from the CDA program (IBM FORTRAN-77, 3090 CPU):

File 'CDA.OUT' : This is the main output file containing information generated during the rainflow cycle counting evaluation of each defined cycle. This particular file contains three different warnings that some of the temperature data falls below the minimum defined temperature for the CDA constants. The end of the file contains the final life predictions with information concerning which mode produced the lowest life. Note that lives are shown for both modes, since the last defined cycle is lower than the life prediction, requiring extrapolation to determine the final life prediction.

```
* * * Top of File * * *
 ONLY LINEAR DAMAGES WILL BE CALCULATED.
 NLOW,NHIGH         1        0
 WARN7: THE TEMPERATURE OF    998.29 IS BELOW THE INTERPOLATION LIMIT OF  1000.00
 SIGF SET TO 185000.00000
 WARN3: TEMPERATURE OF    998.29 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
 MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
 WARN1: TEMPERATURE OF    998.29 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR SIGTRF.
 MINIMUM VALUE OF  0.65884E+05 IS ASSUMED.
 WARN3: TEMPERATURE OF    998.29 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
 MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
 WARN5: TEMPERATURE OF    999.51 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR DALFA.
 MINIMUM VALUE OF  0.00000E+00 IS ASSUMED.
 Stress ratio loop closed between      -0.39775 and       0.79973
 BCV 0.508708E-020.119748E+01-.849445E-010.634642E-020.127269E+01
 BCV 0.334663E-040.247453E-040.247453E-06
 DAMAGS(1:2)   0.115178E-02 0.179057E-03
 WARN7: THE TEMPERATURE OF    999.02 IS BELOW THE INTERPOLATION LIMIT OF  1000.00
 SIGF SET TO 185000.00000
 WARN3: TEMPERATURE OF    999.02 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
 MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
 WARN1: TEMPERATURE OF    999.02 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR SIGTRF.
 MINIMUM VALUE OF  0.65884E+05 IS ASSUMED.
 WARN3: TEMPERATURE OF    999.02 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
 MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
 WARN5: TEMPERATURE OF    999.51 IS LESS THAN
 THE MINIMUM TEMPERATURE OF  1000.00 FOR DALFA.
 MINIMUM VALUE OF  0.00000E+00 IS ASSUMED.
 Stress ratio loop closed between      -0.38659 and      -0.38646
 Stress ratio loop closed between      -0.40173 and       0.79916
 BCV 0.000000E+000.131249E-03-.200062E+010.000000E+000.511699E-02
 BCV 0.120089E+01-.837929E-010.640143E-020.128979E+010.347775E-04
 BCV 0.264835E-040.264835E-06
 NLOW,NHIGH         1        2
 DAMAGS(1:2)   0.233821E-02 0.370691E-03
 WARN7: THE TEMPERATURE OF    998.78 IS BELOW THE INTERPOLATION LIMIT OF  1000.00
 SIGF SET TO 185000.00000
```

```
WARN3: TEMPERATURE OF   998.78 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN1: TEMPERATURE OF   998.78 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SIGTRF.
MINIMUM VALUE OF  0.65884E+05 IS ASSUMED.
WARN3: TEMPERATURE OF   998.78 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN5: TEMPERATURE OF   999.75 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR DALFA.
MINIMUM VALUE OF  0.00000E+00 IS ASSUMED.
Stress ratio loop closed between     -0.40936 and      0.76399
BCV 0.512946E-020.117335E+01-.117179E+000.641271E-020.132399E+01
BCV 0.272525E-040.178826E-040.178826E-06
NLOW,NHIGH        2      10
DAMAGS(1:2)  0.107718E-01 0.156092E-02
WARN7: THE TEMPERATURE OF   999.51 IS BELOW THE INTERPOLATION LIMIT OF  1000.00
SIGF SET TO 185000.00000
WARN3: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN7: THE TEMPERATURE OF   999.51 IS BELOW THE INTERPOLATION LIMIT OF  1000.00
SIGF SET TO 185000.00000
WARN3: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN1: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SIGTRF.
MINIMUM VALUE OF  0.65884E+05 IS ASSUMED.
WARN3: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN1: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SIGTRF.
MINIMUM VALUE OF  0.65884E+05 IS ASSUMED.
WARN3: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN5: TEMPERATURE OF   999.51 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR DALFA.
MINIMUM VALUE OF  0.00000E+00 IS ASSUMED.
Stress ratio loop closed between     -0.40759 and     -0.40738
Stress ratio loop closed between     -0.42172 and      0.76359
BCV 0.000000E+000.208080E-03-.205922E+010.000000E+000.512945E-02
BCV 0.118532E+01-.116459E+000.639323E-020.138089E+010.262976E-04
BCV 0.171913E-040.171913E-06
NLOW,NHIGH       10      30
DAMAGS(1:2)  0.302717E-01 0.408741E-02
Stress ratio loop closed between     -0.39955 and     -0.39852
Stress ratio loop closed between     -0.41210 and      0.79274
BCV 0.000000E+000.103152E-02-.203773E+010.000000E+000.516684E-02
BCV 0.120483E+01-.903631E-010.645865E-020.138089E+010.326190E-04
BCV 0.240402E-040.240402E-06
NLOW,NHIGH       30     100
DAMAGS(1:2)  0.104587E+00 0.148942E-01
WARN7: THE TEMPERATURE OF   998.53 IS BELOW THE INTERPOLATION LIMIT OF  1000.00
SIGF SET TO 185000.00000
WARN3: TEMPERATURE OF   998.53 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN1: TEMPERATURE OF   998.53 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SIGTRF.
MINIMUM VALUE OF  0.65884E+05 IS ASSUMED.
WARN3: TEMPERATURE OF   998.53 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR SGEPRF.
MINIMUM VALUE OF  0.61000E+05 IS ASSUMED.
WARN5: TEMPERATURE OF   999.63 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR DALFA.
MINIMUM VALUE OF  0.00000E+00 IS ASSUMED.
WARN5: TEMPERATURE OF   999.76 IS LESS THAN
THE MINIMUM TEMPERATURE OF  1000.00 FOR DALFA.
MINIMUM VALUE OF  0.00000E+00 IS ASSUMED.
Stress ratio loop closed between     -0.42090 and      0.78336
BCV 0.511699E-020.120425E+01-.974358E-010.640509E-020.138089E+01
```

```
BCV 0.301031E-040.212735E-040.212735E-06
NLOW,NHIGH        100      300
DAMAGS(1:2)   0.322359E+00 0.473135E-01
I,TOTDAM,DDDNBS    1 0.32236E+00 0.10632E-02
  NI(I)        937
I,TOTDAM,DDDNBS    2 0.47313E-01 0.15394E-03
  NI(I)       6488
FINAL LIVES WERE EXTRAPOLATED.
FAILURE OCCURRED IN MODE    1 AT CYCLE          937
EXTRAPOLATED LIVES FOR ALL MODES ARE:
EXTRAP. LIVES          937        6488
OBJ IN MAIN  0.00000E+00    ILOOP =     0
* * * End of File * * *
```

File 'BCV.OUT' : This file lists the basic cycle variables (BCV's) for the major cycle of each defined cycle. It also lists the current value of the damage rate for Mode 1. This file is formatted for direct input to plotting programs.

* * * Top of File * * *

CYCNO	SUBC	DELE	STSRNG	STSMAX	EPOSENEG	EPRAT	ARR1	DDDNBS
1	1	0.509E-02	0.120E+01	-.849E-01	0.635E-02	0.127E+01	0.335E-04	0.115E-02
2	2	0.512E-02	0.120E+01	-.838E-01	0.640E-02	0.129E+01	0.348E-04	0.119E-02
10	1	0.513E-02	0.117E+01	-.117E+00	0.641E-02	0.132E+01	0.273E-04	0.994E-03
30	2	0.513E-02	0.119E+01	-.116E+00	0.639E-02	0.138E+01	0.263E-04	0.963E-03
100	2	0.517E-02	0.120E+01	-.904E-01	0.646E-02	0.138E+01	0.326E-04	0.113E-02
300	1	0.512E-02	0.120E+01	-.974E-01	0.641E-02	0.138E+01	0.301E-04	0.106E-02

* * * End of File * * *

File 'DIAG.DAT': This file is designed to provide information regarding the evolution of the first three damage modes. It lists the major components of the damage rate for mode 1 as well as the current level of damage for modes 1-3. Note that additional cycles are included at logarithmic intervals (every 2X).

* * * Top of File * * *

NCYC	EPBAR	DDDNBS	G	ARRH	DAMAGS(1)	DAMAGS(2)	DAMAGS(C)
1	0.127E+01	0.115E-02	0.000E+00	0.151E+01	0.115E-02	0.179E-03	0.000E+00
2	0.129E+01	0.119E-02	0.000E+00	0.152E+01	0.234E-02	0.371E-03	0.000E+00
4	0.132E+01	0.110E-02	0.000E+00	0.147E+01	0.458E-02	0.711E-03	0.000E+00
8	0.132E+01	0.102E-02	0.000E+00	0.147E+01	0.877E-02	0.130E-02	0.000E+00
10	0.132E+01	0.994E-03	0.000E+00	0.147E+01	0.108E-01	0.156E-02	0.000E+00
16	0.138E+01	0.981E-03	0.000E+00	0.147E+01	0.167E-01	0.233E-02	0.000E+00
30	0.138E+01	0.963E-03	0.000E+00	0.147E+01	0.303E-01	0.409E-02	0.000E+00
32	0.138E+01	0.972E-03	0.000E+00	0.151E+01	0.322E-01	0.434E-02	0.000E+00
64	0.138E+01	0.107E-02	0.000E+00	0.151E+01	0.650E-01	0.893E-02	0.000E+00
100	0.138E+01	0.113E-02	0.000E+00	0.151E+01	0.105E+00	0.149E-01	0.000E+00
128	0.138E+01	0.111E-02	0.000E+00	0.149E+01	0.136E+00	0.197E-01	0.000E+00
256	0.138E+01	0.107E-02	0.000E+00	0.149E+01	0.275E+00	0.405E-01	0.000E+00
300	0.138E+01	0.106E-02	0.000E+00	0.149E+01	0.322E+00	0.473E-01	0.000E+00

* * * End of File * * *

APPENDIX C

LIST OF FORTRAN SOURCE AND SAMPLE INPUT DATA FILES ON WORKSHOP DISK

FORTRAN SOURCE FILES (file ext .FOR)

Filename	Description of File
CDA	Main CDA program; includes all required routines for basic life predictions (isothermal, TMF, environmental)
MULTIAXL	Performs calculations required for handling multiaxial loadings; must be linked to 'CDA.OBJ'.
COATING	Predicts both the constitutive behavior and the resulting life of overlay coating; must be linked to 'CDA.OBJ'.

DATA FILES OF SPECIMEN TESTS OF CAST B1900+Hf MATERIAL (file ext .B19)

BASELINE ISOTHERMAL TESTS, CONTINUOUSLY CYCLED

Filename	Spec	Ninit	Nominal Test Conditions
1000FAST	17D	7405	1000F, 0.50%, Re=-1, 10 CPM
	22A	5120	1000F, 0.50%, Re=0, 10 CPM
	50A	133	1000F, 1.00%, Re=-1, 5 CPM
1200FAST	17C	418	1200F, 0.80%, Re=-1, 10 CPM
1600FAST	24D	1295	1600F, 0.50%, Re=-1, 10 CPM
1600SLOW	51A	499	1600F, 0.50%, Re=-1, 0.5 CPM
	31B	49	1600F, 0.80%, Re=-1, 0.625 CPM
1600RRAT	22D	1606	1600F, 0.50%, Re=0, 10 CPM
	24A	1313	1600F, 0.50%, Re=+1/3, 10 CPM
	27D	4365	1600F, 0.50%, Re=-inf, 10 CPM
1800FAST	53A	308	1800F, 0.50%, Re=-1, 10 CPM
1800SLOW	30B	325	1800F, 0.50%, Re=-1, 1 CPM
	29B	44	1800F, 0.80%, Re=-1, 0.625 CPM

THERMOMECHANICAL TESTS: UNCOATED & PWA 286 COATED; VARIOUS CYCLE TYPES

Filename	Spec	Ninit	Nominal Test Conditions
TMFIN	128B	5127	1000-1600F, 0.4%, Re=-1, 1 CPM, In-phase
	42B	370	1000-1600F, 0.5%, Re=-1, 1 CPM, In-phase
TMFOUT	122A	2116	1000-1600F, 0.4%, Re=-1, 1 CPM, Out-of-phase
	105D	993	1000-1600F, 0.5%, Re=-1, 1 CPM, Out-of-phase
TMFMEAN	109C	177	1000-1600F, +30+/-50 Ksi, 1 CPM, Out-of-phase
	111B	5611	1000-1600F, -10+/-50 Ksi, 1 CPM, Out-of-phase
TMFCOAT	120A*	3700	1000-1600F, 0.4%, Re=-1, 1 CPM, Out-of-phase
	113A*	1495	1000-1600F, 0.5%, Re=-1, 1 CPM, Out-of-phase
	120D*	10012	1000-1600F, 0.4%, Re=-1, 1 CPM, In-phase
	113D*	1450	1000-1600F, 0.4%, Re=-1, 1 CPM, CW Elliptical
	119C*	11125	1000-1600F, 0.4%, Re=-1, 1 CPM, CCW Elliptical
	119B*	577	1000-1800F, 0.5%, Re=-1, 1 CPM, Out-of-phase
	120C*	2338	1000-1600F, 0.4%, Re=-1, 1 CPM, 1 min Tmax hld, Out
	113C*	742	1000-1600F, 0.5%, Re=-1, 1 CPM, "LC" Dogleg

* All specimens in this group were coated with PWA 286 overlay

MULTIAXIAL TESTS (ALL ARE FULLY REVERSED LOADINGS)

Filename	Spec	Ninit	Nominal Test Conditions
1600MAX	212	2337	1600F, e1=0.5%, 10 CPM, torsion only
	226	5811	1600F, e1=0.5%, 10 CPM, in-phase, gamma=1.5
	216	1313	1600F, e1=0.5%, 10 CPM, out-of-phase, gamma=1.5
	207	327	1600F, e1=0.5%, 1 CPM, out-of-phase, gamma=1.5

ENVIRONMENTAL AND MEAN STRESS TESTS

Filename	Spec	Ninit	Nominal Test Conditions
ENVI	111C	674	1600F, 0.5%, Re=-1, 1 CPM, 75 psia O2
	112A	460	1800F, 0.4%, Re=-1, 1.25 CPM, 75 psia O2
	136D	900	1600F, 0.5%, Re=-1, 10 CPM, 1 min Thold, 75 psia O2
1800MEAN	126B	76	1800F, 0.4%, 12.5 CPM, +21 Ksi mean stress
	135D	1692	1800F, 0.4%, 12.5 CPM, +13 Ksi mean stress

APPENDIX D

LIFE PREDICTION RESULTS FOR SAMPLE INPUT DATA FILES ON WORKSHOP DISK

Shown below are the actual life predictions generated by the CDA program for each of the sample input files included on the CDA workshop disk. These are from the 'CDA.OUT' file, with the information on the defined cycles deleted to save space.

```
*****  Results from input file:  1000FAST.B19   ***********************

 I,TOTDAM,DDDNBS    1 0.90794E+00 0.13323E-03
   NI(I)       7690
 I,TOTDAM,DDDNBS    2 0.39569E-09 0.66358E-13
   NI(I) 100000000
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE         7690
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        7690 100000000

 I,TOTDAM,DDDNBS    1 0.84340E+00 0.15787E-03
   NI(I)       5991
 I,TOTDAM,DDDNBS    2 0.10036E-06 0.20844E-10
   NI(I) 100000000
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE         5991
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        5991 100000000

 FAILED IN MODE     1 AT CYCLE         92.
 FINAL DAMAGES ARE :
 DAMAGES   0.10078E+01 0.25332E-07

*****  Results from input file:  1200FAST.B19   ***********************

 I,TOTDAM,DDDNBS    1 0.84524E+00 0.22073E-02
   NI(I)        416
 I,TOTDAM,DDDNBS    2 0.18483E-04 0.48629E-07
   NI(I)  20563904
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE          416
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES         416  20563904

*****  Results from input file:  1600FAST.B19   ***********************

 FAILED IN MODE     1 AT CYCLE       1294.
 FINAL DAMAGES ARE :
 DAMAGES   0.10004E+01 0.42388E-01

*****  Results from input file:  1600SLOW.B19   ***********************

 I,TOTDAM,DDDNBS    1 0.60339E+00 0.14823E-02
   NI(I)        667
 I,TOTDAM,DDDNBS    2 0.12480E+00 0.29126E-03
   NI(I)       3404
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE          667
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES         667      3404

 I,TOTDAM,DDDNBS    1 0.52425E+00 0.13127E-01
   NI(I)         76
 I,TOTDAM,DDDNBS    2 0.23425E+00 0.59454E-02
   NI(I)        168
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE           76
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES          76       168
```

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***** Results from input file: 1600RRAT.B19   ************************

 FAILED IN MODE     1 AT CYCLE        923.
 FINAL DAMAGES ARE :
 DAMAGES  0.10007E+01 0.52034E+00

 FAILED IN MODE     2 AT CYCLE        558.
 FINAL DAMAGES ARE :
 DAMAGES  0.84905E+00 0.10007E+01

 FAILED IN MODE     1 AT CYCLE       2454.
 FINAL DAMAGES ARE :
 DAMAGES  0.10003E+01 0.46801E+00

***** Results from input file: 1800FAST.B19   ************************

 I,TOTDAM,DDDNBS    1 0.89896E+00 0.31693E-02
   NI(I)        327
 I,TOTDAM,DDDNBS    2 0.30632E+00 0.10013E-02
   NI(I)        988
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE         327
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES          327        988

***** Results from input file: 1800SLOW.B19   ************************

 FAILED IN MODE     2 AT CYCLE        208.
 FINAL DAMAGES ARE :
 DAMAGES  0.93642E+00 0.10002E+01

 I,TOTDAM,DDDNBS    1 0.90377E+00 0.23557E-01
   NI(I)         44
 I,TOTDAM,DDDNBS    2 0.74115E+00 0.19247E-01
   NI(I)         53
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE          44
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES           44         53

***** Results from input file: TMFIN.B19      ************************

 FAILED IN MODE     1 AT CYCLE       3498.
 FINAL DAMAGES ARE :
 DAMAGES  0.10002E+01 0.94306E-01

 I,TOTDAM,DDDNBS    1 0.32236E+00 0.10632E-02
   NI(I)        937
 I,TOTDAM,DDDNBS    2 0.47313E-01 0.15394E-03
   NI(I)       6488
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE         937
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES          937       6488

***** Results from input file: TMFOUT.B19     ************************

 I,TOTDAM,DDDNBS    1 0.77120E+00 0.31633E-03
   NI(I)       2823
 I,TOTDAM,DDDNBS    2 0.11027E-01 0.12008E-05
   NI(I)     825709
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE        2823
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES         2823     825709

 I,TOTDAM,DDDNBS    1 0.48611E+00 0.83366E-03
   NI(I)       1116
 I,TOTDAM,DDDNBS    2 0.96616E-02 0.86095E-05
   NI(I)     115528
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE    1 AT CYCLE        1116
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES         1116     115528
```

```
*****  Results from input file:  TMFCOAT.B19     ***********************

 I,TOTDAM,DDDNBS    1 0.52186E+00 0.11694E-03
   NI(I)       7788
 I,TOTDAM,DDDNBS    2 0.12913E-01 0.22573E-05
   NI(I)     440978
 I,TOTDAM,DDDNBS    3 0.35530E+00 0.97403E-04
   NI(I)      10318
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE         7788
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        7788    440978      10318

 I,TOTDAM,DDDNBS    1 0.91460E+00 0.74115E-03
   NI(I)       1515
 I,TOTDAM,DDDNBS    2 0.44032E-01 0.28290E-04
   NI(I)      35192
 I,TOTDAM,DDDNBS    3 0.33820E+00 0.24024E-03
   NI(I)       4154
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE         1515
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        1515     35192       4154

 FAILED IN MODE     1 AT CYCLE        5444.
 FINAL DAMAGES ARE :
 DAMAGES   0.10002E+01 0.16824E+00 0.47735E+00

 I,TOTDAM,DDDNBS    1 0.12676E+00 0.86731E-04
   NI(I)      11468
 I,TOTDAM,DDDNBS    2 0.22544E-02 0.65807E-06
   NI(I)    1517559
 I,TOTDAM,DDDNBS    3 0.38670E+00 0.27451E-03
   NI(I)       3634
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   3 AT CYCLE         3634
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES       11468   1517559       3634

 FAILED IN MODE     3 AT CYCLE        6775.
 FINAL DAMAGES ARE :
 DAMAGES   0.62182E+00 0.18447E-01 0.10000E+01

 FAILED IN MODE     1 AT CYCLE         376.
 FINAL DAMAGES ARE :
 DAMAGES   0.10016E+01 0.16615E+00 0.67568E-01

 I,TOTDAM,DDDNBS    1 0.72050E+00 0.23365E-03
   NI(I)       3496
 I,TOTDAM,DDDNBS    2 0.91672E-01 0.16909E-04
   NI(I)      56017
 I,TOTDAM,DDDNBS    3 0.34073E+00 0.15078E-03
   NI(I)       6672
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE         3496
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        3496     56017       6672

 I,TOTDAM,DDDNBS    1 0.41722E+00 0.53214E-03
   NI(I)       1795
 I,TOTDAM,DDDNBS    2 0.24867E-01 0.17312E-04
   NI(I)      57025
 I,TOTDAM,DDDNBS    3 0.19151E+00 0.26304E-03
   NI(I)       3773
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE         1795
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        1795     57025       3773
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*****  Results from input file:  TMFMEAN.B19    ***********************

 FAILED IN MODE    2 AT CYCLE         61.
 FINAL DAMAGES ARE :
 DAMAGES  0.49222E+00 0.10064E+01

 FAILED IN MODE    1 AT CYCLE       2773.
 FINAL DAMAGES ARE :
 DAMAGES  0.10002E+01 0.10062E+00

*****  Results from input file:  1600MAX.B19    ***********************

 I,TOTDAM,DDDNBS    1 0.89291E+00 0.43840E-03
   NI(I)       2244
 I,TOTDAM,DDDNBS    2 0.13997E-01 0.67678E-05
   NI(I)     147689
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE          2244
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        2244    147689

 FAILED IN MODE    1 AT CYCLE       2200.
 FINAL DAMAGES ARE :
 DAMAGES  0.10002E+01 0.32392E-01

 FAILED IN MODE    1 AT CYCLE        901.
 FINAL DAMAGES ARE :
 DAMAGES  0.10001E+01 0.15398E+00

 I,TOTDAM,DDDNBS    1 0.30627E+00 0.99757E-03
   NI(I)        995
 I,TOTDAM,DDDNBS    2 0.48995E-01 0.16086E-03
   NI(I)       6211
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE           995
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES         995      6211

*****  Results from input file:  ENVI.B19       ***********************

 FAILED IN MODE    1 AT CYCLE        237.
 FINAL DAMAGES ARE :
 DAMAGES  0.10022E+01 0.22967E+00

 FAILED IN MODE    2 AT CYCLE        153.
 FINAL DAMAGES ARE :
 DAMAGES  0.84230E+00 0.10025E+01

 FAILED IN MODE    1 AT CYCLE        322.
 FINAL DAMAGES ARE :
 DAMAGES  0.10020E+01 0.20285E+00

*****  Results from input file:  1800MEAN.B19   ***********************

 I,TOTDAM,DDDNBS    1 0.10992E+00 0.14890E-02
   NI(I)        673
 I,TOTDAM,DDDNBS    2 0.27801E+00 0.42252E-02
   NI(I)        246
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   2 AT CYCLE           246
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES         673       246

 I,TOTDAM,DDDNBS    1 0.98635E+00 0.64627E-03
   NI(I)       1521
 I,TOTDAM,DDDNBS    2 0.97927E+00 0.63337E-03
   NI(I)       1532
 FINAL LIVES WERE EXTRAPOLATED.
 FAILURE OCCURRED IN MODE   1 AT CYCLE          1521
 EXTRAPOLATED LIVES FOR ALL MODES ARE:
 EXTRAP. LIVES        1521      1532
```