# FLAPS (Fatigue Life Analysis Programs)— Computer Programs to Predict Cyclic Life Using the Total Strain Version of Strainrange Partitioning and Other Life Prediction Methods

## Users' Manual and Example Problems, Version 1.0

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# Acknowledgments

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# FLAPS PROGRAMS

# FLAPS (FATIGUE LIFE ANALYSIS PROGRAMS)—
## COMPUTER PROGRAMS TO PREDICT CYCLIC LIFE USING THE TOTAL STRAIN VERSION OF STRAINRANGE PARTITIONING AND OTHER LIFE PREDICTION METHODS

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## INTRODUCTION

This manual presents computer programs FLAPS for characterizing and predicting fatigue and creep-fatigue resistance of metallic materials in the high-temperature, long-life regime for isothermal and nonisothermal fatigue. The programs use the Total Strain version of Strainrange Partitioning (TS-SRP), and several other life prediction methods described in this manual. The user should be thoroughly familiar with the TS-SRP and these life prediction methods (Ref. 1-18) before attempting to use any of these programs. Improper understanding can lead to incorrect use of the method and erroneous life predictions. An extensive database has also been developed in a parallel effort. The database is probably the largest source of high-temperature, creep-fatigue test data available in the public domain and can be used with other life-prediction methods as well. This users' manual, software, and database are all in the public domain and can be obtained by contacting the author.

The Compact Disk (CD) accompanying this manual contains executable file for FLAPS program, two datasets required for the example problems in the manual, and the creep-fatigue data in a format compatible with these programs.

## SOFTWARE

The FLAPS program consists of eleven cyclic life prediction and associated computer programs. All these programs are written in FORTRAN 77. The purpose and capability of each program is summarized in Table I.

**Table I. Name, purpose and capabilities of constituents of FLAPS program.**

| No. | Name of Program | Purpose and Capability |
|---|---|---|
| 1. | PMUS | Estimates fatigue resistance of materials. |
| 2. | PLIFE | Predicts cyclic life below creep regime. Incorporates mean stress correction, and multiaxiality. |
| 3. | PNOTCH | Predicts cyclic life of notched components. Performs stress-strain Neuber notch analysis. |
| 4. | PCLIFE | Predicts cyclic life of C-Section components. |
| 5. | PDCA | Predicts cumulative damage life by employing damage curve approach (DCA). Incorporates mission loading history. Incorporates mean stress correction and multiaxiality. |
| 6. | PDLDR | Predicts cumulative damage life by employing double linear damage rule (DLDR). Incorporates mission loading history. Predicts crack nucleation and early growth. Incorporates mean stress correction and multiaxiality. |
| 7. | TABLE | Writes raw experimental data in a user friendly format. |
| 8. | INDATA | Writes data in namelist format for use in FAIL, FLOW and PSRPLIFE programs. |
| 9. | FAIL | Determines generic inelastic strain-range-cyclic relationships and time independent elastic strain-range cyclic relation for PP cycle. |
| 10. | FLOW | Determines time and wave-shape dependent flow relationships. |
| 11. | PSRPLIFE | Predicts cyclic life at critical location of high temperature components. Utilizes – <br>    - Total Strain version of StrainRange Partitioning (TS-SRP) method. <br>    - Raw data from experiments. <br> Performs – <br>    - Isothermal creep-fatigue interaction. <br>    - Thermomechanical fatigue (TMF) life prediction. <br>    - Bithermal characterization. <br>    - Cyclic stress-strain-time-temperature characterization. <br> Incorporates – <br>    - Multiaxiality via triaxiality factor. |

# DATASETS

The data are in six subdirectories under the main directory CFDATA: AGARD, ORNL, COBALT, NICKEL, STAINLES, and PUBLIC. Each subdirectory, with the exception of COBALT, contains several datasets. The COBALT subdirectory contains only one. All data are for fully reversed strain cycles. The entire database contains data for 18 alloys in 38 files. The datasets are too numerous to list here, and the user should consult the README.DOC file in the directory CFDATA for details. A summary of the data is given in Table II. These datasets are especially useful for predicting the cyclic life using the PSRPLIFE (see Table I).

# PROGRAM USAGE

As an example, suppose that an analyst wishes to use a raw (experimental) dataset to predict the life of a particular component by using the FLAPS program. The first step could be to print the appropriate dataset (or sets) in a reader friendly format using TABLE. The next step would be to characterize the failure and flow behavior of the component material using FAIL and FLOW. Life predictions could now be made. The appropriate constants obtained from FAIL and FLOW would be utilized in the program PSRPLIFE. The analyst could now make the desired life prediction(s).

TABLE II.— SUMMARY OF FULLY-REVERSED, HIGH-TEMPERATURE, LOW-CYCLE CREEP-FATIGUE DATA IN DIRECTORY CFDATA

| Alloy | Number of files | Temperature, °C |
|---|---|---|
| René 80 | 2 | 1000 |
| IN-100 | 4 | 650, 732, 760, 900, 925, 1000 |
| MAR M002 | 1 | 750, 850, 950, 1040 |
| Nimonic 90 | 1 | 650, 810, 900 |
| Waspaloy | 2 | 700, 750 |
| René 95 | 1 | 650 |
| Amzirc | 1 | 538 |
| Narloy Z | 1 | 538 |
| TI6AL4V | 1 | 450, 550, |
| 2.25Cr-1Mo | 6 | 316, 371, 427, 482, 538, 593 |
| Hastelloy X | 1 | 750 |
| Haynes 188 | 1 | 316, 760, 316 ↔ 760, 760 ↔ 316 |
| AF2-1DA | 2 | 760 |
| B1900+Hf | 2 | 483,871, 483 ↔ 871, 871 ↔ 483 |
| Inconel 625 | 1 | 650, 815 |
| Inconel 718 | 4 | 650 |
| Inconel 738 | 3 | 750, 850 |
| 304 Stainless steel | 2 | 650 |
| 316 Stainless steel | 2 | 650, 705 |

In discussing the use of these programs, the following convention will be used. Program prompts and output written to the screen will be indicated by the arrow '⇐'. The response, if required, will be indicated by the arrow '⇒'. A program is started by selecting the appropriate number from the main menu. *Please note that alphabetic input to these programs must be in **CAPS**.* The program FLAPS is started by typing the word FLAPS on the command line. The following menu appears:

⇒ **FLAPS**
⇐ THIS PROGRAM PREDICTS THE CYCLIC LIFE, CUMULATIVE DAMAGE

LIFE AND FATIGUE RESISTANCE OF COMPONENTS.
⇐ THE PROGRAM NAMES, THEIR CAPABILITIES AND REQUIRED
INPUTS ARE AS FOLLOWS.

⇐    1. PMUS    -    Estimates Fatigue Resistance of Materials.
    -    Requires Young's Modulus, K, n, % Reduction in
    Area and Ultimate Tensile Strength.

    2. PLIFE    -    Predicts Cyclic Life Below Creep Regime.
    -    Incorporates Mean Stress Correction, and
    Multiaxiality via Triaxiality Factor.
    -    Requires Young's Modulus, Yield Strength and
    Ultimate Tensile Strength.

    3. PNOTCH    -    Predicts Cyclic Life of Notched
    Components.
    -    Performs stress-strain Neuber Notch analysis
    -    Requires Young's Modulus, Yield Strength, Strength-
    Coefficient, K for Monotonic Loading, and
    k for Cyclic Loading.

    4. PCLIFE    -    Predicts Cyclic Life of C-Section
    Components
    -    Employs Method of Universal Slopes.
    -    Requires Young's Modulus, K, n, % Elongation and
    Ultimate Tensile Strength.

    5. PDCA    -    Predicts Cumulative Damage Life.
    -    Employs DAMAGE CURVE APPROACH.
    -    Analyzes Mission Loading History.
    -    Incorporates Mean Stress Correction, and
    Multiaxiality via Triaxiality Factor.
    -    Requires Mission Loading History, Young's Modulus,
    Yield Strength and Ultimate Tensile Strength.

    6. PDLDR    -    Predicts Cumulative Damage Life.
    -    EMPLOYS DOUBLE LINEAR DAMAGE RULE.
    -    Analyzes Mission Loading History.
    -    Predicts Crack Nucleation and Early Growth.
    -    Incorporates Mean Stress Correction, and
    Multiaxiality via Triaxiality Factor.
    -    Requires Mission Loading History, Young's Modulus,
    Yield Strength and Ultimate Tensile Strength.

    7. TABLE    -    Writes raw data in a user friendly
    format

8. INDATA    -    Writes data in namelist format
                  for use in FAIL, FLOW and PSRPLIFE programs.

9. FAIL    -    Determines Four Generic SRP Inelastic
                Strain-Range-Cyclic Relationships and
                Time-Independent Elastic Strain-Range
                Cyclic Relation for PP Cycle.
           -    Utilizes Raw Experimental Data.

10. FLOW    -    Determines Time and Wave-Shape
                 Dependent Flow Relationships.
            -    Utilizes Raw Experimental Data.

11. PSRPLIFE    -    Predicts Cyclic Life at Critical
                     Location of High Temperature Components.
                -    Utilizes Raw Experimental Data.
                -    Total Strain Version of Strainrange Partitioning.
                -    Isothermal Creep-Fatigue Interaction Assessment.
                -    Thermomechanical Fatigue Life Prediction.
                -    Bithermal Characterization.
                -    Cyclic Stress-Strain-Time-Temperature
                     Characterization.
                -    Incorporates Mean Stress Correction, and
                     Multiaxiality via Triaxiality Factor.

⇐ DO YOU WANT THE DESCRIPTION OF PROGRAMS AGAIN? (Y/N)

If the response above is N the following prompt appears. Otherwise, the program presents the description of the programs from PMUS to PSRPLIFE as shown above.

⇐ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:

| | |
|---|---|
| ENTER 1 FOR PMUS | ↑ |
| ENTER 2 FOR PLIFE | **M** |
| ENTER 3 FOR PNOTCH | **A** |
| ENTER 4 FOR PCLIFE | **I** |
| ENTER 5 FOR PDCA | **N** |
| ENTER 6 FOR PDLDR | **-** |
| ENTER 7 FOR TABLE | **M** |
| ENTER 8 FOR INDATA | **E** |
| ENTER 9 FOR FAIL | **N** |
| ENTER 10 FOR FLOW | **U** |
| ENTER 11 FOR PSRPLIFE | ↓ |

⇒ (Enter the appropriate number.)

The user now selects the number of the program that he wishes to run. Depending upon the number entered the control is transferred to the desired program. The program is automatically executed, and after the completion of the execution the control is returned to this main program. The following prompt appears:

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)
⇒ (Enter the desired selection Y or N)

If the selection is Y the main program again presents the list of above 11 choices. The user can make another choice and the above steps are repeated. The following message appears if the answer above is N.

⇐ **** PROGRAM FLAPS FINISHED *****

The above message is an indication of the successful execution and completion of the FLAPS program.

# PMUS

## Program Description

This FORTRAN program estimates the fatigue resistance of materials in the sub-creep range using the method of universal slopes (MUS), Ref. [1]. The universal slopes equation relates the total strain range ($\Delta\varepsilon_t$) to the fatigue life ($N_f$), and is given by

$$\Delta\varepsilon_t = 3.5\frac{\sigma_u}{E}N_f^{-0.12} + D^{0.6}N_f^{-0.6} \tag{1}$$

The total strain range is obtained by adding the elastic and plastic strain range components as functions of life. These functions represent straight lines on the double logarithmic coordinates, having essentially constant ("universal") slopes of –0.12 and –0.6 respectively. Single-cycle strain range intercepts of these lines are related to the tensile properties: the ultimate tensile strength ($\sigma_u$), the modulus of elasticity ($E$), and the true ductility, $D$, determined from the reduction of area in percentage, $R.A.$, by $\ln\left(\dfrac{100}{100 - R.A.}\right)$. $E$ and $\sigma_u$ must adopt the same unit.

The universal slopes equation provides a simple approach to estimate the fatigue resistance of materials because it uses only the static-tensile properties of the material. The original universal slopes equation involves only ductility in the estimation of the plastic line [1]. Muralidharan and Manson [2] modified the plastic line equation by including both tensile strength and ductility. The modified equation gives better prediction of fatigue life, and is written as

$$\Delta\varepsilon_t = 0.266\,D^{0.155}\left[\frac{\sigma_u}{E}\right]^{-0.53}N_f^{-0.56} + 1.17\left[\frac{\sigma_u}{E}\right]^{0.832}N_f^{-0.09} \tag{2}$$

In this program, the fatigue life is calculated using both the original universal slopes equation (Ref. [1]) and the modified equation (Ref. [2]), and the lower value is picked to represent the material's fatigue resistance.

This program also includes the method (10% Rule) developed by Manson and Halford [3] to estimate high-temperature, low-cycle fatigue behavior of materials. The fatigue life obtained from the universal slopes equation is modified by using the creep-rupture properties and is denoted as $N_f'$. The following equation is used to obtain $N_f'$:

$$N_f' = \frac{N_f}{1 + \dfrac{k}{AF}(N_f)^{\frac{m+0.12}{m}}} \tag{3}$$

in which equation:

- $k$: Effective fraction of each cycle for which the material is subjected to the maximum stress. $k$ is often taken to be 0.3.
- $F$: Frequency of stress application.
- $A$: Coefficient characterizing a time intercept of the creep-rupture curve of the material at the test temperature. Here the creep-rupture curve is represented by the equation $\sigma_r = 1.75\sigma_u (t_r / A)^m$. The units of $t_r$, $A$ and $F$ should be consistent. If $t_r$ and $A$ are in minutes, the unit of $F$ should be cycles/minute; if $t_r$ and $A$ are in seconds, the unit of $F$ should be Hz.
- $m$: Slope of log-log creep-rupture line at temperature of interest (negative value).
- $N_f$: Life calculated from the universal slopes equation.

The fatigue behavior of materials can be characterized as follows:

- For the *lower bound* of life use either $10\% N_f$ or $N'_f$, whichever is lower.
- For *average* life use twice the lower bound life.
- For the *upper bound* of life use 10 times of the lower bound life.

**Required Input Data**

- Tensile properties: $E$, $\sigma_u$, $D$ (or Reduction in area, $R.A.$)
- Creep-rupture properties (only for high-temperature, low cycle fatigue): $m$ and $A$
- Total strain range, $\Delta\varepsilon_t$ and $F$.

**Program Output**

The program will output the estimated cyclic life ($N_f$), 10% life, lower bound life, average life and upper bound life.

**Example**

The example below demonstrates how to estimate the fatigue behavior of materials using the program PMUS. The material considered is Inconel [3]. The test temperature is 1500°F, the test frequency ($F$) is 0.017 c/m, the elastic modulus ($E$) is 120000 MPa, the tensile strength ($\sigma_u$) is 170 MPa, the reduction of area is 63.3%, and the creep-rupture properties are $m = -0.15$ and $A = 1.0$ minute.

The program is invoked by selecting "1" from the main menu.

$\Leftarrow$ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
$\Rightarrow$ **1**[*]

---

[*] The bold fonts in the examples in the manual indicate the user input to the program.

$\Leftarrow$ .

   PROGRAM PMUS

   .

   .

The program then asks for tensile properties of the material.

$\Leftarrow$ ENTER MATERIAL CONSTANTS

   .

$\Leftarrow$ ENTER YOUNGS MODULUS:

$\Rightarrow$ **120000**

$\Leftarrow$ ENTER ULTIMATE TENSILE STRENGTH:

$\Rightarrow$ **170**

$\Leftarrow$ ENTER TOTAL STRAIN RANGE:

$\Rightarrow$ **0.01**

$\Leftarrow$ DO YOU KNOW THE DUCTILITY OF MATERIAL? (Y/N)

$\Rightarrow$ **N**

Here if the answer is "Y", the user will be asked to enter the value of *D*. If the answer is "N", the user will be asked to input the % reduction of area and the program will calculate *D* from *R.A.*

$\Leftarrow$ DO YOU KNOW THE REDUCTION IN AREA? (Y/N)

$\Rightarrow$ **Y**

$\Leftarrow$ ENTER REDUCTION IN AREA IN PERCENTAGE:

$\Rightarrow$ **63.3**

If the user does not know the % reduction of area, the program will ask him/her to input the elongation in percentage and then calculate *D* from the elongation.

After entering the tensile properties and the total strange range, the program calculates the fatigue life using both the original universal slopes equation [1] and the modified equation [2]. The lower value is selected as the estimated cyclic life. The program then asks if the damaging effect of exposure to high stress at elevated temperature should be accounted for.

$\Leftarrow$ DO YOU WANT THE LOWER ALTERNATE BOUND ON LIFE USING THE 10%
   RULE? (Y/N)

$\Rightarrow$ **Y**

If the answer is "N", the program will output the estimated cyclic life obtained above. If the answer is "Y", the program will ask for the creep-rupture properties and estimate the bounds of fatigue life using the method developed by Manson and Halford [3].

$\Leftarrow$ ENTER FREQUENCY OF STRESS APPLICATION, OR
   INVERSE OF THE CYCLIC DWELL PERIOD IF DWELL
   TIMES ARE EXPERIENCED (IN CYCLES PER UNIT TIME):

⇒ **0.017**
⇐ ENTER SLOPE OF LOG-LOG STRESS-RUPTURE LINE:
⇒ **-0.15**
⇐ ENTER THE TIME-INTERCEPT FROM STRESS-RUPTURE CURVE:
⇒ **1.0**

The estimated cyclic life, 10% life, lower bound life, average life and upper bound life will be displayed on the screen as follows

CYC. LIFE          10% LIFE      LOWER BOUND LIFE   AVE. LIFE     UPPER BOUND LI FE

0.306300E+04   0.306342E+03    0.344651E+02          0.689302E+02     0.344651E+03

The user can also select to write the results to a file.

⇐ DO YOU WANT THE RESULTS WRITTEN TO A RESULT FILE? (Y/N)
⇒ **Y**

If the answer is "Y", the results will be written to a file "RESULTS.OUT". The program continues and presents the following menu.

⇐ PROGRAM PMUS FINISHED.
   PROGRAM PMUS IS EXITING.
⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

Selecting Y transfers the control back to FLAPS program. The main menu (see page 5) is presented for the user to make from it a choice of the program that is desired to be run. Selection of N terminates the program FLAPS with the following message on screen.

⇐ PROGRAM FLAPS FINISHED.

Running PMUS for a range of strain range values, a plot of fatigue life versus total strain range can be generated. Figure 1 shows the comparison of estimated and observed fatigue behavior of Inconel at 1500°F. This figure agrees very well with the results presented in Ref. [3].
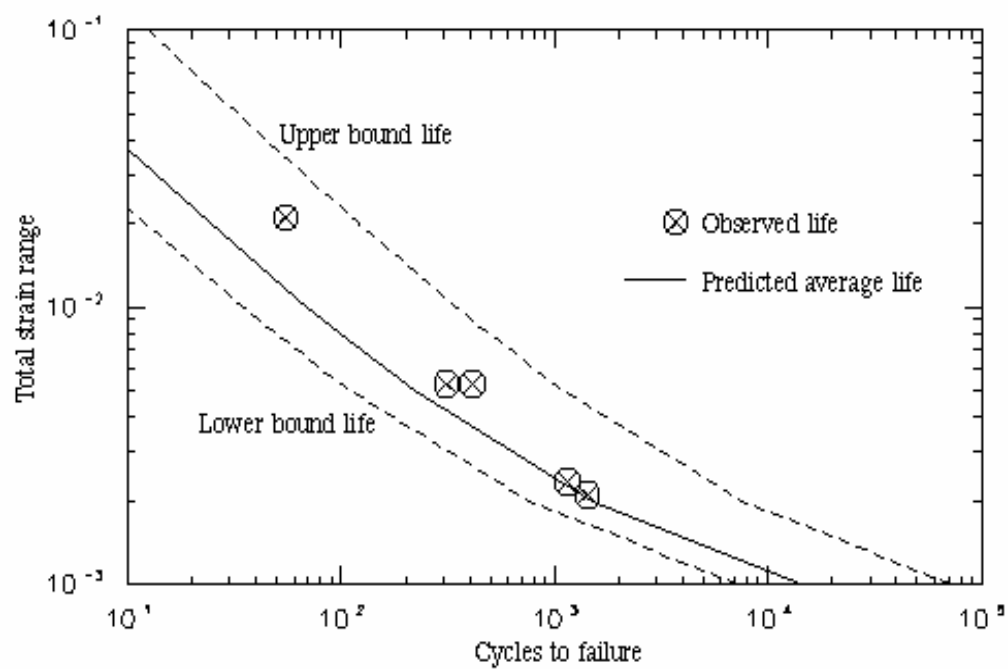
Fig. 1. Comparison of estimated and observed fatigue behavior of Inconel at 1500 °F.

# PLIFE

## Program Description

This FORTRAN program predicts fatigue life below the creep regime for a given total strain range. The method of universal slopes is used to estimate fatigue life and the effects of multiaxial stress state and mean stress are taken into account.

The MUS equation for completely reversed straining takes the following general form

$$\Delta\varepsilon_t = BN_f^b + CN_f^c,\tag{1}$$

where $\Delta\varepsilon_t$ represents the total strain range, $N_f$ represents the fatigue life and $B$, $b$, $C$ and $c$ are material constants to be supplied by the user. If the user cannot prescribe $B$, $b$, $C$ and $c$, their values will be assigned according the original MUS equation, i.e., $B = 3.5\sigma_u / E$, $b = -0.12$, $C = D^{0.6}$ and $c = -0.6$.

The total strain range, which is the sum of the elastic and plastic strain ranges, can be obtained from structural analysis. If the user cannot provide the elastic and plastic strain ranges, the program will calculate them using the stress range and the cyclic stress-strain curve

$$\frac{\Delta\varepsilon_t}{2} = \frac{\Delta\varepsilon_{el}}{2} + \frac{\Delta\varepsilon_{pl}}{2} = \frac{\Delta\sigma}{2E} + \left(\frac{\Delta\sigma}{2K}\right)^{1/n},\tag{2}$$

where $\Delta\sigma$ is the stress range, $K$ is the cyclic strength coefficient and $n$ is the cyclic strain hardening exponent. If the user cannot supply values of $K$ and $n$, the program will estimate them using the ultimate tensile strength, yield strength and ductility.

The mean stress has significant influences on fatigue life in the high-cycle, nominally elastic fatigue regime. The modified Morrow mean stress relation (Halford and Nachtigall [4]; Halford [5]) can be used to obtain the mean stress-corrected fatigue life

$$N_{fm}^{-b} = N_f^{-b} - V_\sigma,\tag{3}$$

where $V_\sigma$ is the ratio of mean stress to alternating stress amplitude and $N_{fm}$ denotes the fatigue life with mean stress modification. For low-cycle fatigue, however, the mean stress may not be sustained due to the presence of cyclic inelastic deformation and consequently, the influence on fatigue life may be washed out. Therefore, this program uses $V_{eff}$ instead of $V$ for mean stress correction, where $V_{eff} = kV_\sigma$ and $k$ is a smooth function which equals one when $\Delta\varepsilon_{pl} = 0$ and rapidly goes to zero as $\Delta\varepsilon_{pl} / \Delta\varepsilon_{el}$ increases. The function $k$ is given by

$$k = \exp\left[-70(\Delta\varepsilon_{pl} / \Delta\varepsilon_{el})^2\right].\tag{4}$$

For the case of multiaxial loading, the Manson-Halford multiaxiality factor, M.F., is used to characterize the multiaxial stress state (Ref. 5[(a),(b)]). To account for the effect of multiaxiality on fatigue life, the plastic line in the MUS equation is displaced downward in strain range by a factor of M.F. (Ref. 5 [(a), (b)]).

**Required Input Data**

- Tensile properties: $E$, $\sigma_y$, $\sigma_u$, $D$ (or $R.A.$)
- Constants for fatigue equation: $B$, $b$, $C$, $c$
- Elastic and plastic strain ranges (or applied stress range)
- Multiaxiality of the stress state: $\sigma_1$, $\sigma_2$, $\sigma_3$
- Mean stress and alternating stress: $\sigma_m$, $\sigma_a$

**Program Output**

The program will output the predicted fatigue life.

**Example**

The example below demonstrates how to use PLIFE. Consider a pressure vessel made of an annealed Inconel 718 [5]. The yield strength is 350 MPa, ultimate tensile strength is 685 MPa, elastic modulus is 205 GPa, reduction of area is 30% and the true ductility ($D$) is 0.357. The vessel experiences an equibiaxial fatigue load with a mean stress of 49 MPa and alternating stress amplitude of 205 MPa. Therefore, the alternating strain amplitude is 0.001 and it is elastic. The constants for the fatigue curve (design curve) are $B = 0.0108$, $b = -0.12$, $C = 0.114$ and $c = -0.6$.

The program is invoked by selecting "2" from the main manual. The following prompt appears on the screen.


$\Leftarrow$ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
$\Rightarrow$ **2**
$\Leftarrow$ .
   PROGRAM PLIFE
   .
   .
The program then asks for tensile properties of the material.

$\Leftarrow$ ENTER MATERIAL CONSTANTS.
   .
$\Leftarrow$ ENTER YOUNGS MODULUS:
$\Rightarrow$ **205000**
$\Leftarrow$ ENTER YIELD STRENGTH:
$\Rightarrow$ **350**
$\Leftarrow$ ENTER ULTIMATE TENSILE STRENGTH:
$\Rightarrow$ **685**

Next, the program asks if the user has values of $B$, $b$, $C$ and $c$ for the for the fatigue equation. If the user does not have these values, $B = 3.5\sigma_u / E$, $b = -0.12$, $C = D^{0.6}$ and $c = -0.6$ will be used according to the original MUS equation.

$\Leftarrow$ DO YOU HAVE VALUES OF CONSTANTS FOR FATIGUE EQUATION? (Y/N)

$\Rightarrow$ **Y**

$\Leftarrow$ ENTER CONSTANT B:

$\Rightarrow$ **0.0108**

$\Leftarrow$ ENTER CONSTANT b:

$\Rightarrow$ **-0.12**

$\Leftarrow$ ENTER CONSTANT C:

$\Rightarrow$ **0.114**

$\Leftarrow$ ENTER CONSTANT c:

$\Rightarrow$ **-0.6**

The program then asks if the user has elastic and plastic strain ranges from structural analysis. If the user does not have these values, the program will calculate them from the applied stress range.

$\Leftarrow$ DO YOU HAVE ELASTIC AND PLASTIC STRAIN RANGES FROM STRUCTURAL
　　ANALYSIS? (Y/N)

$\Rightarrow$ **Y**

$\Leftarrow$ ENTER ELASTIC STRAIN RANGE:
　(Note: the alternating elastic strain amplitude, $\Delta\varepsilon_{el}/2$, should be entered here)

$\Rightarrow$ **0.001**

$\Leftarrow$ ENTER PLASTIC STRAIN RANGE:
　(Note: the alternating plastic strain amplitude, $\Delta\varepsilon_{pl}/2$, should be entered here)

$\Rightarrow$ **0**

After calculating the total strain range, the program will ask the user if the effects of multiaxiality and mean stress should be considered.

$\Leftarrow$ DO YOU HAVE A MULTIAXIAL STRESS SITUTAION? (Y/N)

$\Rightarrow$ **Y**

$\Leftarrow$ ENTER FIRST COMPONENT OF PRINCIPAL STRESS:

$\Rightarrow$ **205**

$\Leftarrow$ ENTER SECOND COMPONENT OF PRINCIPAL STRESS:

$\Rightarrow$ **205**

$\Leftarrow$ ENTER THIRD COMPONENT OF PRINCIPAL STRESS:

$\Rightarrow$ **0**

$\Leftarrow$ DO YOU WANT TO INCLUDE MEAN STRESS CORRECTION? (Y/N)

$\Rightarrow$ **Y**

$\Leftarrow$ ENTER MEAN STRESS:

$\Rightarrow$ **49**

$\Rightarrow$ ENTER ALTERNATING STRESS:
$\Rightarrow$ **205**

The results will be displayed on the screen as follows

*** THE CYCLIC LIFE FOR THE COMPONENT IS ***

  CYC. LIFE     EL. RANGE     PL. RANGE     TOT. RANGE     VSIGN

0.916859E+06   0.100000E-02   0.000000E+00   0.200000E-02   0.239024E+00

$\Leftarrow$ DO YOU WANT THE RESULTS WRITTEN TO A RESULT FILE? (Y/N)

If the response is Y the results will be written to a file named PLIFE.OUT.  A response of N leads to following prompts.

$\Leftarrow$ PROGRAM PLIFE FINISHED.
$\Leftarrow$ PROGRAM PLIFE IS EXITING.
$\Leftarrow$ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

The user may make the desired choice. The response Y will take the user to main menu whereas N will terminate the program FLAPS with the following message.

$\Leftarrow$ PROGRAM FLAPS FINISHED.

It is interesting to note that for this example the predicted cyclic life using PLIFE, $9.17 \times 10^5$, agrees very well with the result presented in Ref. [5], $8.9 \times 10^5$.

# PNOTCH

## Program Description

Engineering structures often contain stress concentrations such as holes or notches, which are the principal sites for the inception of fatigue flaws. In order to predict fatigue life of these structures, the local stress and strain histories at the tip of the notch must be known. This program determines the cyclic stress-strain response at the notch tip region by performing the Neuber analysis (Ref. [6], [7]). According to the Neuber's rule, the actual stress and strain at the notch tip represent a point on a rectangular hyperbola. Since the stress-strain response for the notch tip must coincide with the characteristic cyclic stress-strain behavior of the material, the local (actual) stress $\sigma$ and the local (actual) strain $\varepsilon$ corresponding to a far-field (nominal) stress $S$ can be determined by the intersection of the Neuber hyperbola and the cyclic stress-strain curve. In this program, the monotonic and cyclic stress-strain curves of the material adopt the following forms

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K}\right)^{1/n} \qquad \text{monotonic} \qquad (1)$$

$$\Delta\varepsilon = \frac{\Delta\sigma}{E} + \left(\frac{\Delta\sigma}{K'}\right)^{1/n'} \qquad \text{cyclic} \qquad (2)$$

where $E$ is Young's modulus, $K$ is the monotonic strength coefficient, $n$ is the monotonic strain hardening exponent, $K'$ is the cyclic strength coefficient and $n'$ is the cyclic strain hardening exponent. If $n' = n$, $K' = 2^{1-n} K$.

At high temperature when there is a hold period such that the load on a notched specimen is held constant, the local stress at the notch tip will experience stress relaxation due to creep. This has been taken into account in PNOTCH. During stress relaxation, the local stress and local strain at the notch tip must follow the Neuber hyperbola and the local stress should always remain above or equal to the nominal stress. The creep law employed in this program takes a simple power-law form, $\dot{\varepsilon} = (\sigma / A)^{1/m}$.

## Required Input Data

- Stress intensity factor
- Nominal stress
- Young's modulus and monotonic and cyclic stress-strain curves: $E, n, K, n', K'$
- Creep holding time ($t_r$) for the cycle and constants $m$ and $A$ for the creep law. Note that the unit for $t_r$ must be consistent with the unit of the creep rate.

## Program Output

The results are written to files notch.curve, notch.hyper and notch.values.

- notch.curve: stress-strain curves for loading part and unloading part of each cycle

- notch.hyper: Neuber Hyperbola for loading part and unloading part of each cycle
- notch.values: intersection of the Neuber hyperbola and the stress-strain curve for loading part and unloading part of each cycle

The user can plot the hysteresis loops using the above results.

**Example**

The example below demonstrates how to use PNOTCH. A notched specimen with a stress concentration factor $K_t = 2$ is tested at $1300^\circ$F. The nominal stress is 110 ksi and the hold time is 2 hour (120 minutes). The Young's modulus of the material is 27000 ksi and the stress-strain properties are $K = 259$ ksi, $n = n' = 0.089$ and $K' = 487$ ksi. The constants for the creep law are $m = 0.25$ and $A = 1500$ ksi. With these constants, the creep rate is expressed as in/in/min.

The program is invoked by selecting "3" from the main menu.

$\Leftarrow$ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
$\Rightarrow$ **3**
$\Leftarrow$ .
   PRGRAM PNOTCH
   .
$\Leftarrow$ PROGRAM PREDICTS CYCLIC LIFE OF NOTCHED COMPONENTS.
   .

The program then asks for material properties and loading information.

$\Leftarrow$ ENTER YOUNG MODULUS:
$\Rightarrow$ **27000**
$\Leftarrow$ ENTER STRESS CONCENTRATION FACTOR:
$\Rightarrow$ **2**
$\Leftarrow$ ENTER EXPONENT n FOR MONOTONIC PLASTICITY LAW:
$\Rightarrow$ **0.089**
$\Leftarrow$ ENTER CONSTANT K FOR MONOTONIC LOADING:
$\Rightarrow$ **259**
$\Leftarrow$ ENTER EXPONENT nprime FOR CYCLIC PLASTICITY LAW:
$\Rightarrow$ **0.089**
$\Leftarrow$ ENTER CONSTANT Kprime FOR CYCLIC LOADING:
$\Rightarrow$ **487**
$\Leftarrow$ ENTER APPLIED STRESS VALUE:
$\Rightarrow$ **110**
$\Leftarrow$ ENTER CREEP HOLD TIME FOR THE CYCLE:
$\Rightarrow$ **120**

If the creep hold time is greater than zero, the program will ask about the creep law. The creep law employed in this program takes the simple power-law form. If the user cannot provide the information about the creep law, maximum amount of stress relaxation will be assumed, i.e., the local stress will be relaxed to the value of nominal stress.

⇐ CAN THE CREEP RATE BE DESCRIBED BY A SIMPLE POWER-LAW? (Y/N)
  (program assumes maximum amount of stress relaxation if the answer is "N")
⇒ **Y**
⇐ ENTER THE m POWER:
⇒ **0.25**
⇐ ENTER THE CONSTANT A:
⇒ **1500**
⇐ PROGRAM PNOTCH FINISHED AT CYCLE #4.
  PROGRAM PNOTCH IS EXITING.

After receiving the above information, the program determines the intersection of the Neuber hyperbola and the stress-strain curve and outputs the stress-strain curves and the Neuber hyperbola for loading part and unloading part of each cycle. The results are written to files notch.curve, notch.hyper and notch.values. Figure 2 shows the hysteresis loops for this problem.
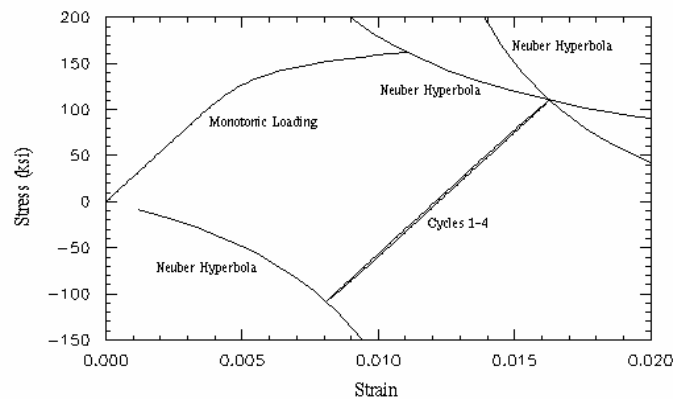


Fig. 2. Hysteresis loops using the Neuber analysis.

The user may continue to run any other program from the main menu by selecting Y or terminate the FLAPS program by selecting N with the following message:

⇐ **** PROGRAM FLAPS FINISHED. ****

# PCLIFE

## Program Description

This FORTRAN program calculates the total strain range versus applied stress and the total strain range versus cyclic life for a C-section component. The Ramberg-Osgood equation

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K}\right)^{1/n}$$
(1)

is used to describe the cyclic stress-strain behavior. The cyclic life is predicted using the method of universal slopes modified for the multiaxial situation.

## Required Input Data

- Material properties: Young's modulus ($E$), ultimate tensile strength ($\sigma_u$), constants in the Ramberg-Osgood relation ($K$, $n$), and % elongation

## Program Output

The outputs are written to files sige_epse.out, deps_nf.out and siga_nf.out, where

- "sige_eps.out" contains $\sigma_1 (= \sigma_a$, applied stress), $\sigma_2$, $\sigma_3$, $\sigma_u$, $\sigma_e$ (effective stress), and $\varepsilon_e$ (strain amplitude)
- "deps_nf.out" contains $\sigma_a (=$ some % of $\sigma_u$), $\varepsilon_e$, $\Delta\varepsilon_t$ (total strain range), $N_f$ (cyclic life), $\log_{10}(N_f)$, and $\log_{10}(\Delta\varepsilon_t)$
- "siga_nf.out" contains $\sigma_u$, $\sigma_a$, $N_f$, $\log_{10}(N_f)$, $\sigma_a / \sigma_u$, and $\ln(N_f)$.

## Example

The C-section component considered here is made of a special alloy with $E = 29500\,\text{ksi}$, $\sigma_y = 120\,\text{ksi}$, $\sigma_u = 150.6\,\text{ksi}$, $K = 196\,\text{ksi}$, $n = 0.0794$ and $elongation = 7\%$. This example shows how to predict cyclic life for this component using PCLIFE. The predicted cyclic life versus applied stress relation is shown in the figure 3. In addition, cyclic lives corresponding to a ±15% variation of material properties, listed in Table 1 are also presented in figure 3.

Table 1

|  | $E$ (ksi) | $\sigma_y$ (ksi) | $\sigma_u$ (ksi) | $K$ (ksi) | $n$ | elongation |
|---|---|---|---|---|---|---|
| +15% | 29500 | 138.0 | 173.2 | 225.4 | 0.0794 | 14% |
| Average | 29500 | 120.0 | 150.6 | 196.0 | 0.0794 | 7% |
| -15% | 29500 | 102.0 | 128.0 | 167.0 | 0.0794 | 3.5% |

The program is invoked by selecting "4" from the main manual.

⇐ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
⇒ **4**
⇐ .
  PROGRAM PCLIFE.
  PROGRAM PREDICTS CYCLIC LIFE OF C-SECTION COMPONENTS.
  .

The user is then asked to input the material properties.

⇐ ENTER YOUNG MODULUS:
⇒ **29500**
⇐ ENTER ULTIMATE TENSILE STRENGTH:
⇒ **150.6**
⇐ ENTER CONSTANT K IN RAMBERG-OSGOOD RELATION:
⇒ **196.0**
⇐ ENTER CONSTANT n IN RAMBERG-OSGOOD RELATION:
⇒ **0.0794**
⇐ ENTER % ELONGATION:
⇒ **7.0**

Based on the above input data, the program calculates the total strain range for each applied stress (some percent of $\sigma_u$) and predicts the corresponding cyclic life. Figure 3 shows the predicted cyclic life versus applied stress.
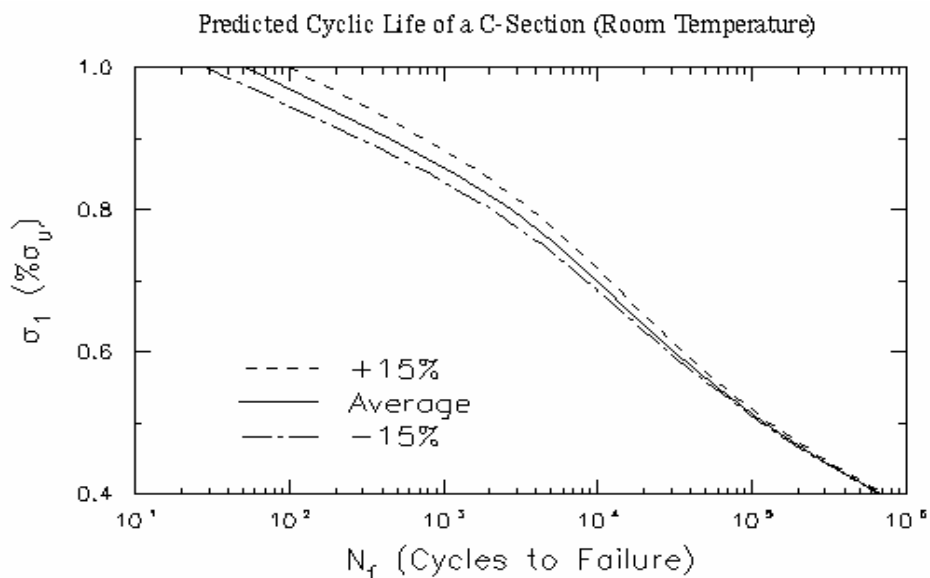


Fig. 3. Predicted cyclic life versus applied stress for the C-section component.

The program continues with the following prompt on the screen.

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

As before choose Y if you wish to run any other program from the main menu or N if you wish to terminate the FLAPS program.

# PDCA

**Program Description**

This FORTRAN program predicts the cumulative damage life of structural component using the damage curve approach (DCA). Development of nonlinear cumulative fatigue damage laws was motivated by the "loading order effect" revealed by extensive laboratory test data. The damage curve approach is a simple empirical damage accumulation equation that recognized two well-established observations. In low-cycle fatigue (LCF), damage in the form of cracking of initially smooth specimens begins very early in the life, whereas in high-cycle fatigue (HCF), cracking damage isn't detectable until very late in life. The transition in behavior is smooth and continuous across the entire range of fatigue lives. Based on a large amount of experimental data for two-level loading, Manson and Halford [8] proposed a damage equation which takes the form of a power-law function of the cycle fraction ($n / N_f$) whose exponent is a function of the ratio of the number of cycles to failure, $N_f$ for the two levels involved in a step change of loading. The DCA concept is that damage accumulation proceeds along the curve associated with the life level at which cycles are applied. Using the proposed damage equation, Manson and Halford derived an equation for DCA analysis

$$\left\{ \left\{ \left\{ \left( n_1 / N_1 \right)^{(N_1/N_2)^{0.4}} + n_2 / N_2 \right\}^{(N_2/N_3)^{0.4}} + n_3 / N_3 \right\}^{(N_3/N_4)^{0.4}} + \ldots + n_{k-1} / N_{k-1} \right\}^{(N_{k-1}/N_k)^{0.4}} + n_k / N_k = 1, \ (1)$$

where $n_i$ represents the number of applied cycles at each loading level in the block having a fatigue life of $N_i$ and the subscripts 1, 2, …, k are the sequence numbers of the loadings as they occur. Therefore, a single equation is provided for use with the damage curve approach. Each loading event provides a fraction of damage until failure is presumed to occur when the damage sum becomes unity. The only constant in the DCA equation is the exponent 0.4 and it has been shown that this constant is not critical. Examination of a series of other values from 0.3 to 0.5 reveals the final results are not greatly altered compared to using the value of 0.4. In this program, the value 0.4 is used in the damage curve equation.

The DCA equation described above has a clear advantage over many other alternative nonlinear damage models, as it is formulated in terms of life level alone. If the user cannot provide the fatigue life for each loading event, the program will call the subroutine PLIFE to estimate it based on the total strain range. PLIFE predicts the fatigue life for a given total strain range using the method of universal slopes with modifications to take into account the effects of multiaxiality and mean stress. The readers are referred to the previous section for details of PLIFE.

**Required Input Data**

- Number of cycles ($n_i$) for each event (strain range) in a mission and number of cycles to failure ($N_i$) for each loading level.

- If $N_i$ is not given for a loading level, its value will be estimated using PLIFE. Additional input data are described in the instructions for PLIFE.

**Program Output**

The program outputs the number of missions to failure and the total number of cycles to failure. These results are displayed on the screen. The program also writes two output files

- ECHO.OUT1: lists all input values for the mission loading cycle.
- RESULT.DCA: contains total cycles for each event, number of missions to failure, and total number of cycles to failure.

**Example**

In Ref. [8], Manson and Halford presented the fatigue test data by Webber and Levy for an aluminum alloy [9]. The loading sequence for each test involves three stress levels with fatigue lives of 51,900, 414,140 and 13,800,000 cycles respectively. The Table 1 below summarizes the test data and the analysis results.

Table 1

| Test No. | $n_1$ | $n_2$ | $n_3$ | Cycles to failure in 1000s | | |
| --- | --- | --- | --- | --- | --- | --- |
| | | | | Exp. | Manson & Halford (DCA) | PDCA prediction |
| 1 | 95 | 5985 | 3420 | 437 | 494 | 497 |
| 2 | 95 | 3990 | 5415 | 871 | 656 | 663 |
| 3 | 95 | 1425 | 7980 | 741 | 1178 | 1180 |
| 4 | 399 | 5985 | 3116 | 363 | 352 | 353 |
| 5 | 399 | 3990 | 5111 | 372 | 437 | 438 |
| 6 | 399 | 1425 | 7676 | 550 | 646 | 646 |
| 7 | 950 | 5985 | 2565 | 275 | 238 | 250 |
| 8 | 950 | 3990 | 4560 | 282 | 289 | 285 |
| 9 | 950 | 1425 | 7125 | 269 | 371 | 371 |

The following demonstrates how to predict cumulative damage life using the program PDCA. Test No. 9 is considered here. The program is invoked by selecting "5" from the main menu.

⇐ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
⇒ **5**
⇐ .
   PROGRAM PDCA
   PROGRAM PREDICTS CUMULATIVE DAMAGE LIFE OF COMPONENTS
   USING THE DAMAGE CURVE APPROACH

.

.

The user is then asked to input the number of events (loading levels) in a mission.

⇐ ENTER TOTAL NUMBER (MAXIMUM 100) OF EVENTS WITH DIFFERENT
   CYCLIC LIVES OR TOTAL STRAIN RANGES) IN THE GIVEN MISSION
   LOADING CYCLE:
⇒ **3**

Next, the user needs to input the number of cycles for each event in a mission and the corresponding fatigue life sequentially. If the number of cycles to failure for an event is not known, the program will estimate its value by calling the subroutine PLIFE.

⇐ ENTER NUMBER OF CYCLES PER BLOCK FOR EVENT NUMBER  1:
⇒ **950**
⇐ DO YOU KNOW THE NUMBER OF CYCLES TO FAILURE FOR EVENT NUMBER
1? (Y/N)
⇒ **Y**
⇐ ENTER CYCLES TO FAILURE FOR EVENT NUMBER  1:
⇒ **51900**
⇐ ENTER NUMBER OF CYCLES PER BLOCK FOR EVENT NUMBER  2:
⇒ **1425**
⇐ DO YOU KNOW THE NUMBER OF CYCLES TO FAILURE FOR EVENT NUMBER
1? (Y/N)
⇒ **Y**
⇐ ENTER CYCLES TO FAILURE FOR EVENT NUMBER  2:
⇒ **414140**
⇐ ENTER NUMBER OF CYCLES PER BLOCK FOR EVENT NUMBER  3:
⇒ **7125**
⇐ DO YOU KNOW THE NUMBER OF CYCLES TO FAILURE FOR EVENT NUMBER
1? (Y/N)
⇒ **Y**
⇐ ENTER CYCLES TO FAILURE FOR EVENT NUMBER  2:
⇒ **13800000**

After the information of all the events (in this case three events) is entered, the program performs cumulative fatigue damage analysis using the damage curve approach and displays the results on the screen as follows

   Total Number of Missions: 39.0
   Total Number of Cycles: 0.371E+06

The results are also written to a file named RESULT.DCA.

RESULT.DCA:

| Event | Total Cycles |
|-------|--------------|
| 1 | 0.371E+05 |
| 2 | 0.556E+05 |
| 3 | 0.278E+06 |

Total Number of Missions:  39.0
Total Number of Cycles:  0.371E+06

The number of cycles to failure for other tests can be evaluated similarly using PDCA. The predicted results for all nine tests are shown in the last column of the above table.

The last message from the program PDCA will be –

⇐ PROGRAM PDCA IS FINISHED.
   PROGRAM PDCA IS EXITING.

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

Select Y if you wish to run any other program, and you will be presented with the main menu. You can select the desired program from this menu. Select N if you do not wish to run a program, and the program FLAPS will terminate with the following on screen message.

⇐ **** PROGRAM FLAPS FINISHED. ****

# PDLDR

**Program Description**

This FORTRAN program predicts the cumulative damage life of structural component using the double linear damage rule (DLDR). As described in the previous section, application of the DCA to a cumulative fatigue damage evaluation of multiple steps in loading events leads to a large number of forward and backward solutions of a power law equation. When damage levels are low, the cumulative errors could overshadow the desired result. This computational disadvantage of the DCA can be circumvented by approximating the curves of the DCA with bi-linear DLDR representations. For the double linear damage rule, Manson and Halford [8 (a) and 8(b)] provided analytical expressions for determining the two phases of life. The procedure involves two steps, each similar to the conventional application of the commonly used linear damage rule (LDR). When the sum of cycle ratios based on Phase I lives (denoted by $N_I$) reaches unity, Phase I is presumed complete, and further loadings are summed as cycle ratios based on Phase II lives (denoted by $N_{II}$). When the sum of cycle ratios based on Phase II lives reaches unity, failure is presumed to occur. It may be convenient to associate Phase I with microcrack initiation and Phase II with microcrack propagation. The equation describing $N_I$ and $N_{II}$ are given as

$$N_I = N \exp(ZN^\phi), \tag{1}$$

$$\phi = \frac{1}{\ln(N_1/N_2)} \ln\left\{\frac{\ln[0.35(N_1/N_2)^{0.25]}}{\ln[1 - 0.65(N_1/N_2)^{0.25}]}\right\}, \tag{2}$$

$$Z = \frac{\ln[0.35(N_1/N_2)^{0.25}]}{N_1^\phi}, \tag{3}$$

$$N_f = N_I + N_{II}. \tag{4}$$

**Required Input Data**

- Number of cycles ($n_i$) for each event (strain range) in a mission and number of cycles to failure ($N_i$) for each loading level.
- Total strain range for each event. The total strain range will not be used in the calculation if the number of cycles to failure is known for the event. If the number of cycles to failure is not known for a loading level, its value will be estimated from the total strain range using PLIFE. Additional input data are described in the instructions for PLIFE.

**Program Output**

The program outputs the number of missions to complete Phase I (crack initiation) and the number of missions to complete Phase II (crack propagation). These results are displayed on the screen. The program also generates the following output files

- ECHO.OUT: lists all input values for the mission loading cycle including event number, total strain range, number of cycles and number of cycles to failure.
- ANBANF.OUT: lists the cycle fractions ($n_i / N_i$) for all events of a mission.
- PRODCT.OUT: outputs the product of $n_i / N_i$ and the number of missions estimated using the LDR for every event.
- NI_NII.OUT: outputs Phase I and Phase II lives for every event.
- LIVES.OUT: outputs Phase I and Phase II damage fractions and number of missions to complete Phase I and Phase II respectively.
- TABLE.OUT: lists all the input data and analysis results in a tabular form.

**Example**

Walcher, et al. [10] studied fatigue failure of the Ti-6Al-4V compressor disk of a small gas-turbine engine. The following Table 1 summarizes the mission loading history and the analysis results using PDLDR.

Table 1

| Event | $\Delta\varepsilon$ (in/in) | $\sigma_{mean}$ (MPa) | Cycles per mission, $n$ | $N_f$ | Phase I life $N_I$ | Phase II life $N_{II}$ | $\dfrac{n}{N_I} \times 10^4$ | $\dfrac{n}{N_{II}} \times 10^4$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.00254 | 695 | 4 | 37180 | 23633 | 13547 | 1.69 | 2.95 |
| 2 | 0.00791 | 394 | 2 | 7200 | 2470 | 4730 | 8.10 | 4.23 |
| 3 | 0.00735 | 359 | 1 | 13650 | 6349 | 7301 | 1.58 | 1.37 |
| 4 | 0.01017 | 268 | 6 | 5550 | 1629 | 3921 | 36.83 | 15.30 |
| 5 | 0.00396 | 616 | 3 | 17400 | 8867 | 8533 | 3.38 | 3.52 |
| 6 | 0.00198 | 727 | 2 | 64000 | 45506 | 18494 | 0.44 | 1.08 |
| 7 | 0.00848 | 172 | 1 | 33000 | 20373 | 12627 | 0.49 | 0.79 |
| 8 | 0.01564 | 62 | 2 | 2500 | 389 | 2111 | 51.41 | 9.47 |
| 9 | 0.01045 | 3 | 1 | 31325 | 19083 | 12242 | 0.52 | 0.82 |
| 10 | 0.00932 | 66 | 1 | 42540 | 27887 | 14653 | 0.36 | 0.68 |
| 11 | 0.01074 | 145 | 1 | 9390 | 3701 | 5689 | 2.70 | 1.76 |
| 12 | 0.01271 | 127 | 1 | 4440 | 1120 | 3320 | 8.93 | 3.01 |
| 13 | 0.01158 | 188 | 1 | 4900 | 1324 | 3576 | 7.55 | 2.80 |
| 14 | 0.00452 | 557 | 2 | 20605 | 11117 | 9488 | 1.80 | 2.11 |

The following demonstrates how to predict the cumulative damage life of the disk using PDLDR. The program is invoked by selecting "6" from the main manual.

$\Leftarrow$ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
$\Rightarrow$ **6**

The user is then asked to input the number of events in a mission and the cycle information for each event.

⇐ ENTER TOTAL NUMBER (MAXIMUM 100) OF EVENTS WITH DIFFERENT
    TOTAL STRAIN RANGES IN THE GIVEN MISSION LOADING CYCLE:
⇒ **14**
⇐ ENTER TOTAL STRAIN RANGE FOR EVENT NUMBER   1:
⇒ **0.00254**
⇐ ENTER NUMBER OF CYCLES PER BLOCK FOR EVENT NUMBER   1:
⇒ **4**
⇐ DO YOU KNOW THE NUMBER OF CYCLES TO FAILURE FOR EVENT NUMBER
    1? (Y/N)
⇒ **Y**

Here the number of cycles to failure for event 1 is known. If the number of cycles to failure for an event is not known, the program will estimate its value by calling the subroutine PLIFE.

⇐ ENTER CYCLES TO FAILURE FOR EVENT NUMBER   1:
⇒ **37180**
.
.
.

After the information of all 14 events is entered, the program performs cumulative fatigue damage analysis using the double linear damage rule and displays the results on the screen as follows

\*\*\* THE NUMBER OF MISSIONS FOR \*\*\*
 \*\*\* CRACK INITIATION IS \*\*\*

      80. MISSIONS


 \*\*\* THE NUMBER OF MISSIONS FOR \*\*\*
  \*\*\* CRACK PROPAGATION IS \*\*\*

      200. MISSIONS

⇐ DO YOU WANT THE RESULTS WRITTEN TO A FILE? (Y/N**)**

If the response above is Y the results will be written to a file named RESULTS.OUT. In addition, the program also generates result files ANBANF.OUT, PRODCT.OUT, NI_NII.OUT, LIVES.OUT and TABLE.OUT. Descriptions of these files are given in the section "Program Output". The results obtained using PDLDR match the results presented in Ref. [8] very well. The execution of PDLDR is completed with the following message:

⇐ PROGRAM PDLDR FINISHED.

PROGRAM DLDR IS EXITING.
⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

Select Y if you want to run any other program. The control is then transferred to the main menu from which the desired program can be selected. Select N if you do not wish to run any other program at this time. The program FLAPS terminates with the following on screen message.

⇐ **** PROGRAM FLAPS FINISHED. *****

# TABLE

**Program Description**

The input datasets to the FORTRAN programs FAIL and FLOW (see Table I) are in NAMELIST format and are difficult to read. TABLE is used to list the data in a reader friendly format.

**Required Input Data**

- Input dataset to be written in a user friendly format.

**Program Output**

The output consists of two "pages" because there are too many columns to fit on a single page. Program output is sent to two files for subsequent printing. The program is written assuming that output will be in *portrait* mode. The program can be easily changed to get output, in *landscape* mode if desired.

**Example**

We will illustrate TABLE program by writing the dataset AF21DA.NAS [2] (included in the disk) in a user friendly format as described above. The program is invoked by selecting "7" from the main manual.

⇐ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
⇒ **7**
⇐ .
   PROGRAM TABLE
   THIS PROGRAM WRITES RAW EXPERIMENTAL DATA
   IN A USER FRIENDLY TABULAR FORMAT
    .
The program then proceeds as follows.

⇐ ENTER RAW DATA FILENAME
⇒ **AF21DA.NAS**
⇐ ENTER FILENAME FOR PAGE 1 OF OUTPUT, FILENAME
⇒ **AF21DA.PG1**♦
⇐ ENTER FILENAME FOR PAGE 2 OF OUTPUT, FILENAME
⇒ **AF21DA.PG2**♦
⇐ PROGRAM TABLE FINISHED.
   PROGRAM TABLE IS EXITING.

---

♦ User may assign any other filename.

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y?N)

Select Y if you wish to run a program from the main menu. Select N otherwise. In this case the program terminates with the message.

⇐ **** PROGRAM FLAPS FINISHED. ****

# INDATA

**Program Description**

The program INDATA is used to ease the burden of generating datasets in NAMELIST format for the programs FAIL, FLOW and PSRPLIFE.

**Required Input Data**

- These programs require data from fully reversed tests with a negative value of R. *The program is written to accept stress values in either megapascals (MPa) or kips per square inch (ksi) units. Output is in megapascals.*

**Program Output**

The output consists of the dataset written in the namelist format.

**Example**

As an example, three tests (7, 16, and 52) from the dataset **AF21DA.PWA** [11] located on the CD will be used to generate a dataset named AF21DA.DAT. This example will illustrate the input for a PP cycle (HRSC), a CP strain-hold cycle (THSC), and a PC stress-hold (CCCR) cycle. Procedures for partitioning the hysteresis loop are given in references 12 and 13. The types of cycles accepted by the FAIL, FLOW and PSRPLIFE programs are listed in Table III and are illustrated in figure 4. The program is invoked by selecting "8" from the main menu.

⇐ ENTER THE NUMBER OF PROGRAM NAME YOU WANT TO USE:
⇒ **8**
⇐ .
   PROGRAM INDATA
   THIS PROGRAM WRITES THE DATASET IN NAMELIST FORMAT FOR
   USE WITH FAIL, FLOW AND PSRPLIFE PROGRAMS.
   .
   .

The program is then run using the following steps.

⇐ ENTER FILENAME OF DATASET BEIBG CREATED
⇒ **AF21DA.DAT**
⇐ IS A NEW DATASET BEING CREATED,?   (Y/N)
⇒ **Y**

A new dataset is being created, so the appropriate response is Y (YES). The response here should be N (NO) if a dataset is being created to be appended to an existing dataset. A response of N causes the program to skip the next three prompts and it asks for the units of input stress values.

⇐ A NEW DATASET IS BEING CREATED.
   ENTER NAME OF DATA SOURCE:
⇒ **PWA; NAS3-22387**
⇐ ENTER MATERIAL NAME
⇒ **AF2-1DA**
⇐ ENTER NUMBER OF DATAPOINTS:
⇒ **3**

As mentioned above datasets for three tests are to be entered for this example.

⇐ ARE STRESS UNITS FOR INPUT DATA MPa(M) OR KSI(K)
⇒ **M**

The program is written to accept stress values in either megapascals (MPa) or kips per square inch (ksi) units. Output is in megapascals.

⇐ ENTER SPECIMEN No.
⇒ **7**
⇐ ENTER TEST TYPE
⇒ **HRSC**

The test type HRSC (see figure 4(a)) indicates that the test is isothermal with no time-dependent cyclic strains present in the hysteresis loop. Note that the prompts that follow will vary somewhat depending on the test type.

⇐ ENTER TENSILE TEMP(TTEN)
⇒ **760**
⇐ ENTER COMPRESSION TEMP(TCOMP)
   FOR ISOTHERMAL CASE, ENTER "0" FOR TCOMP
⇒ **0**

For isothermal and bithermal cycles the temperature in the tensile-half of the hysteresis loop is TTEN, and the temperature in the compressive-half of the loop is TCOMP. For all isothermal test a "0" entry for TCOMP reduces the amount of user input. The program then calculates TCOMP, which in this case is 760 °C. For a, thermomechanical cycle, TTEN is the temperature at the tension strain limit of the loop, and TCOMP is the temperature at the compressive strain limit. Both temperatures must be entered. The program assumes that the temperature is in degrees centigrade.

⇐ ENTER CYCLE FREQUENCY, HZ:
⇒ 0.**5**

Note that, for cycles that contain only time-independent inelastic strains (PP cycles), the program calculates the cyclic strain rate assuming a triangular wave form and using the cycle frequency and the total strain range.

⇐ ENTER HALF-LIFE MAX STRESS, MIN STRESS, & STRESS RANGE
  IF ALL THREE VALUES ARE KNOWN, ANY ONE MAY BE
  ENTERED AS "0":
⇒ **1077.9   1130.6   0***

The absolute value of the stresses is entered. If all three values are known, it is only
necessary to enter any two of them. The unknown value must be entered as "0," and the
program will calculate that value, thus reducing user input. If only one value is known, enter
that value in the appropriate sequence with the unknown values entered as "0." Note that the
minimum stress will be compressive in a fully reversed test with a negative value of R. (See
figure 4(a).)

⇐ ENTER % CHANGE (+/-) IS STRESS RANGE FROM
  FIRST TO HALF-LIFE CYCLE:
⇒ **7.7**

Cyclic strain hardening or softening is defined as the percent change in the stress range from
the first to the half-life cycle. Softening is indicated by a negative value. This value is not
used by FAIL or FLOW but is included to better characterize the cyclic mechanical
properties of the alloy.

⇐ ENTER HALF-LIFE STRAINRANGE VALUES - %
  TOTAL, ELASTIC & INELASTIC:
⇒ **1.485   1.150   0**

It is necessary to enter only any two of these values. The remaining value may be entered as
"0," and the program will calculate it.

⇐ ENTER VALUES FOR No, Ni, AND N5:
⇒ **0   0   0**

Because these values were not determined for this test, all three values must be entered as
unknowns. These values define the number of cycles required to produce defined changes in
the cyclic stress-strain hysteresis loop. They are not used by any of the programs but are
recorded to better characterize the cyclic behavior of the alloy. They are defined in reference
14 as follows:

No      Number of cycles to first indication of cracking
Ni      Number of cycles when ratio of maximum tensile to maximum compressive stress
        decreases 10 percent from half-life or stabilized value.
N5      Number of cycles when stress range decreases 5 percent from half-life or  stabilized
        value

---

* If there are more than one input values, they must be separated by a space.

The user can change these definitions if so desired.

⇐ ENTER CYCLES TO FAILURE (NF) AND TOTAL TEST TIME, HRS
   ENTER NEGATIVE VALUE FOR NF IF SPECIMEN DNF:
⇒ **114   0.07**

The program FAIL ignores data from tests where the specimen did not fail (DNF). However, data from DNF tests can be used by FLOW. The definition of failure is left to the user.

⇐ QUIT? Y/N
⇒ **N**

All of the data for specimen 7 have been entered. You are given the choice of quitting or entering data for another test. The appropriate response here is N so that data for the second test can be entered. The following values are for test 16, a tensile hold strain cycle (THSC) test as shown in figure 4(c).

⇐ ENTER SPECIMEN No.
⇒ **16**
⇐ ENTER TEST TYPE:
⇒ **THSC**
⇐ ENTER TENSILE TEMP (TTEN)
⇒ **760**
⇐ ENTER COMPRESSION TEMP (TCOMP)
   FOR TSOTHERMAL CASE, ENTFR"0" FOR TCOMP:
⇒ **0**
⇐ ENTER CYCLE FREQUENCY, HZ:
⇒ **0.033**

This value is determined by the tension hold time of 30 sec and the cyclic strain rate.

⇐ ENTER TEST TYPE
   1= STRAIN HOLD
   2= STRESS HOLD
   3= CONTINUOUS CYCLING
⇒ **1**

Because data for a strain hold test are being entered, the appropriate response is 1. A continuous cycling test is defined as one where the tension-going and/or compression- going strain rates are slow enough to produce time-dependent inelastic strains (see Table III).

⇐ ENTER TEN.-GOING & COMP.-GOING STRAINRATES - %/SEC
   FOR EQUAL RATES, ENTER "0" FOR COMP-GOING RATE:
⇒ **1.2   0**
⇐ ENTER TEN. AND/OR COMP. STRAIN HOLD TIME, SEC:

$\Rightarrow$ **30    0**

Since this is a tensile strain-hold strain cycle, the hold time in compression is zero (see figure 5).

$\Leftarrow$ ENTER HALF-LIFE MAX STRESS, MIN STRESS, & STRESS RANGE
    IF ALL THREE VALUES ARE KNOWN, ANY ONE MAY BE
    ENTERED AS "0":
$\Rightarrow$ **997    1221.8    0**
$\Leftarrow$ ENTER TEN. & COMP. STRESS RELAXATION STRESSES:
$\Rightarrow$ **166.7    0**

This is the amount of stress relaxation during the tensile strain-hold time. There is no compressive stress relaxation during a THSC test, (see figures 4(c) and 5).

$\Leftarrow$ ENTER % CHANGE (+/-) IN STRESS RANGE FROM
    FIRST TO HALF-LIFE CYCLE:
$\Rightarrow$ **5.16**

The specimen experienced cyclic hardening.

$\Leftarrow$ ENTER HALF-LIFE STRAINRANGE VALUES - %
    TOTAL, ELASTIC & INELASTIC STRAINRANGE:
$\Rightarrow$ **1.245    1.007    0**
$\Leftarrow$ ENTER HALF-LIFE VALUES OF INELASTIC STRAINRANGE - %
    EPP, EPC, ECP, FCC:
$\Rightarrow$ **0.145    0    0.093    0**

These are the PP, PC, CP, and CC components of the inelastic strain range. All four values must be entered and must sum up to the inelastic strain range. If they do not, the program will prompt the user to check the input values.

$\Leftarrow$ ENTER VALUES FOR No, Ni, AND N5:
$\Rightarrow$ **0    0    0**
$\Leftarrow$ ENTER CYCLES TO FAILURE (NF) AND TOTAL TEST TIME, HRS
    ENTER NEGATIVE VALUE FOR NF IF SPECIMEN DNF:
$\Rightarrow$ **395    3.52**
$\Leftarrow$ QUIT? Y/N
$\Rightarrow$ **N**

      All of the data for test 16 have been entered, and we now enter the data for test 52. This is a cyclic compressive creep rupture test (CCCR) as shown in figure 4(b).
$\Leftarrow$ ENTER SPECIMEN No. :
$\Rightarrow$ **52**
$\Leftarrow$ ENTER TEST TYPE:

$\Rightarrow$ **CCCR**

$\Leftarrow$ ENTER TENSILE TEMP (TTEN)

$\Rightarrow$ **760**

$\Leftarrow$ ENTER COMPRESSION TEMP (TCOMP)
    FOR ISOTHERMAL CASE, ENTER "0" FOR TCOMP:

$\Rightarrow$ **0**

$\Leftarrow$ ENTER CYCLE FREQUENCY, HZ:

$\Rightarrow$ **1.1E-04**

$\Leftarrow$ ENTER TEST TYPE
    1 = STRAIN HOLD
    2 = STRESS HOLD
    3 = CONTINUOUS CYCLING

$\Rightarrow$ **2**

$\Leftarrow$ ENTER TEN.-GOING & COMP.-GOING STRAINRATES - %/SEC
    FOR EQUAL RATES, ENTER "0" FOR COMP.-GOING RATE:

$\Rightarrow$ **1.2 0**

$\Leftarrow$ ENTER TEN. AND/OR COMP. STRESS HOLD TIME, SEC:

$\Rightarrow$ **0 8760**

There is no tension stress-hold time for this type of cycle (see figure 6).

$\Leftarrow$ ENTER HALF-LIFE MAX STRESS, MIN STRESS, & STRESS RANGE
    IF ALL THREE VALUES ARE KNOWN, ANY ONE MAY BE
    ENTERED AS "0":

$\Rightarrow$ **1092.9   620.6   0**

$\Leftarrow$ ENTER % CHANGE (+/-) IN STRESS RANGE FROM
    FIRST TO HALF-LIFE CYCLE:

$\Rightarrow$ **-2.35**

The specimen experienced cyclic softening.

$\Leftarrow$ ENTER HALF-LIFE STRAINRANGE VALUES - %
    TOTAL, ELASTIC AND INELASTIC:

$\Rightarrow$ **1.200   0.925   0**

$\Leftarrow$ ENTER HALF-LIFE VALUES OF INELASTIC STRAINRANGE - %
    EPP, EPC, ECP, ECC:

$\Rightarrow$ **0.100   0.175   0   0**

$\Leftarrow$ ENTER VALUES FOR No, Ni, AND N5:

$\Rightarrow$ **0  0  0**

$\Leftarrow$ ENTER CYCLES TO FAILURE (NF) AND TOTAL TEST TIME, HRS
    ENTER NEGATIVE VALUE FOR NF IF SPECIMEN DNF:

$\Rightarrow$ **69   18.25**

$\Leftarrow$ QUIT?, Y/N

$\Rightarrow$ **Y**

$\Leftarrow$ PROGRAM INDATA FINISHED.

PROGRAM INDATA IS EXITING.

This completes the data entry for this example. The program displays the following message.

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

If you want to run any other program from the main menu, select Y. Select N otherwise. Program FLAPS then terminates with the following message.
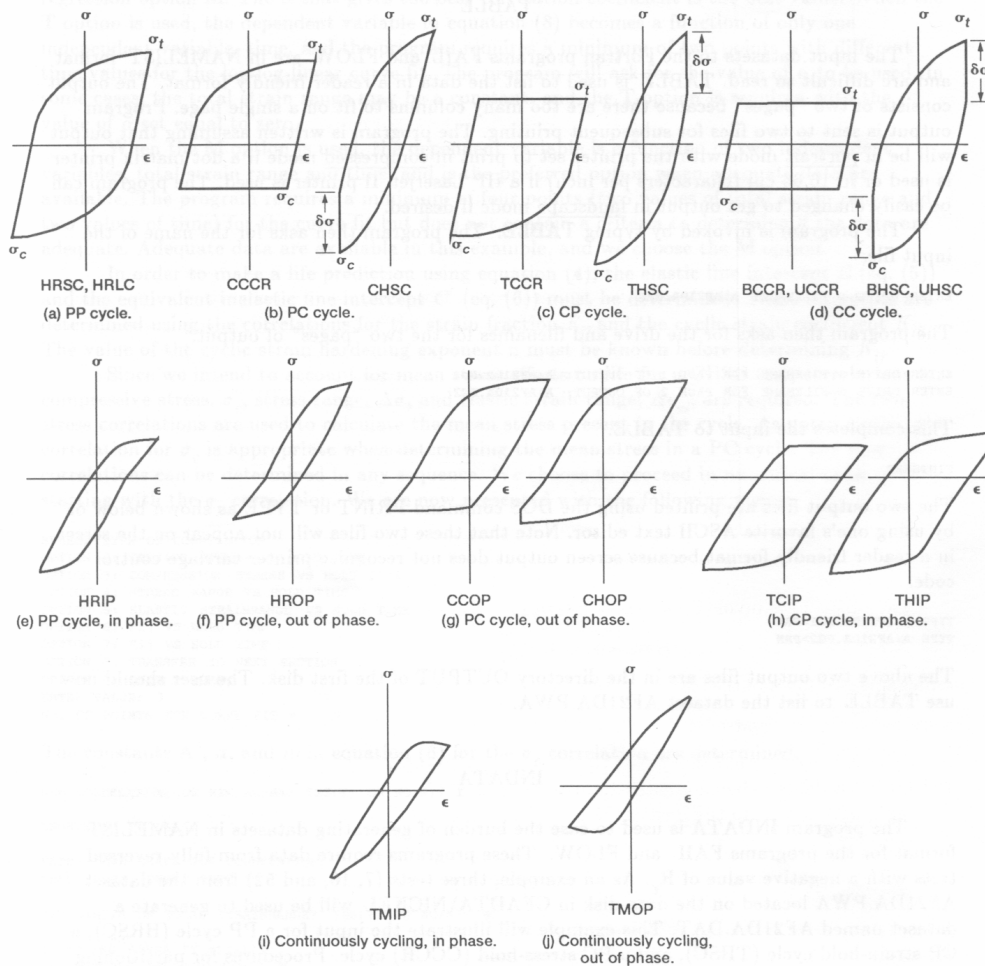
⇐ **** PROGRAM FLAPS FINISHED. ****

**Figure 4. – Generic SRP Hysteresis Loops: isothermal (parts (a)- (d)), bithermal (parts (e) - (h)), and thermomechanical (parts (i) - (j)). (See Table II.)**
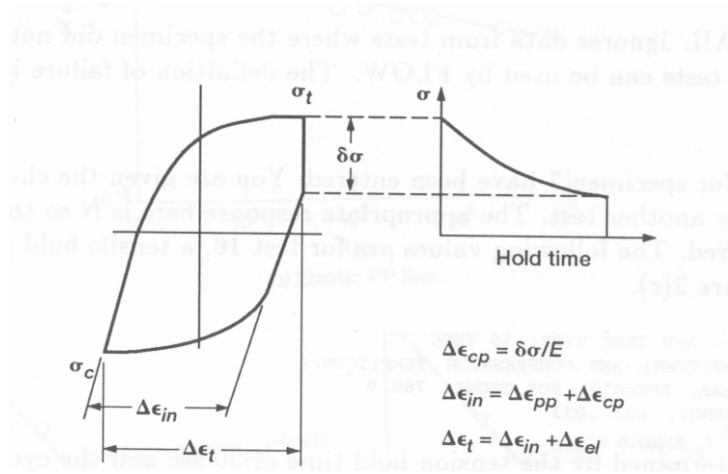
$$\Delta\epsilon_{cp} = \delta\sigma/E$$

$$\Delta\epsilon_{in} = \Delta\epsilon_{pp} + \Delta\epsilon_{cp}$$

$$\Delta\epsilon_t = \Delta\epsilon_{in} + \Delta\epsilon_{el}$$

**Figure 5. - Partitioning of tensile hold strain cycle (THSC).**



$$\Delta\epsilon_t = \Delta\epsilon_{in} + \Delta\epsilon_{el}$$

$$\Delta\epsilon_{in} = \Delta\epsilon_{pp} + \Delta\epsilon_{cp}$$
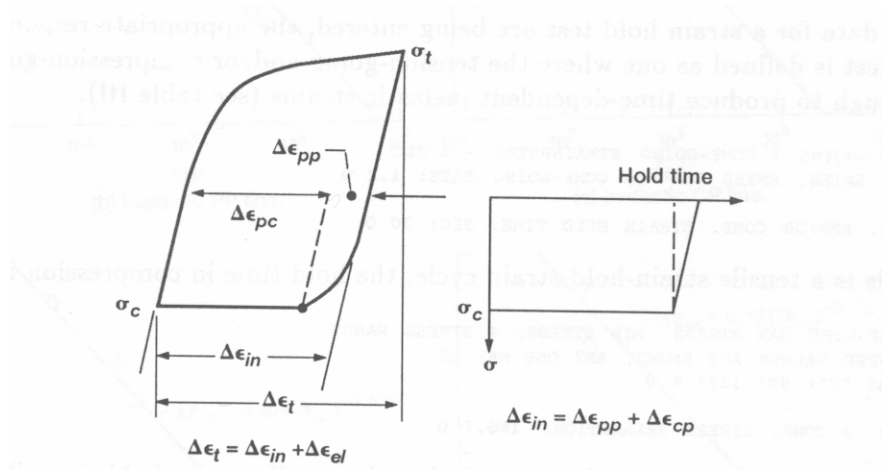
**Figure 6. - Partitioning of compressive cyclic creep rupture cycle (CCCR).**

# FAIL

**Program Description**

This FORTRAN program is used to characterize the *failure* behavior of an alloy as given by the constants in the inelastic strain-range-life relations used by both the Total Strain range version of StrainRange Partitioning (TS-SRP) and the inelastic strain-range-based version of SRP. The equation constants for the elastic strain-range-life relation for pure fatigue or PP cycles are also determined. All equation constants are determined by a log-log linear regression analysis of the appropriate data.

**Required Input Data**

The program will accept data from either isothermal or bithermal tests as listed in Table III.

**Program Output**

The program will generate four output files to determine the four SRP-relations as described below.

**Example**

The life relations to be determined are

$$\Delta \varepsilon_{in} = C_{ij} (N_{ij})^c \tag{1}$$
$$\Delta \varepsilon_{el} = B (N_{pp})^b \tag{2}$$

where *ij = pp, pc, cp, or cc*. The notation used here is the same as that in reference 15.

The user also has the option of determining the time-dependent elastic strain range-life relations for cycles with time-dependent inelastic strains (PC, CP, and CC cycles).

$$\Delta \varepsilon_{el,ij} = B (N_{f0})^b \tag{3}$$

where *B = B(t)* and $N_{f0}$ is the life under theoretical zero mean stress conditions. This option is used when the hold time per cycle is a controlled variable. The elastic line is not used to make life predictions but is used in conjunction with one of the inelastic lines to get a total strainrange versus life relation. This relation is then used for the life prediction.

As recommended in reference 15, data from stress-hold tests are preferred when determining the constants in equation (1) for cycles involving creep (*ij = pc, cp,* and *cc*) because this type of cycle can impart a large amount of cyclic creep damage to the material in a minimum amount of time. The dataset AF21DA.NAS contains this type of data and will be used here. Other types of tests, such as strain-hold, which impart much less cyclic creep

damage can be used, but it may be more difficult to meet the default damage fraction criterion of 0.50 (Ref. 15.) when determining the PC, CP, and CC life relations.

Program FAIL first determines the exponent *b* and intercept *B* for the elastic line (see equation (2)), and the inelastic strain-range-PP life relations (equation (1)). The PC, CP, and CC strain-life relations (equation (1)), are then determined, if adequate data are available in the dataset. The program requires a minimum of two points for the log-log linear regression analysis determining the equation constants. Note that results may be questionable when only a few data points are used in the regression analysis.

This program is invoked by selecting 9 from the main menu, and the following screen prompts occur:

⇐ .
    .
    PROGRAM FAIL
    THIS PROGRAM DETERMINES FAILURE RELATIONS
    USING RAW DATA FROM THE EXPERIMENTS
    THE PROGRAM USES THE SRP-METHOD
    .
    .
⇐ FAIL PROGRAM REQUIRES INPUT DATA IN NAMELIST FORMAT.
    DO YOU HAVE INPUT DATA IN NAMELIST FORMAT? (Y/N)

Because the dataset AF21DA.NAS has the data in namelist format, the response is Y (yes). If you do not have the data in namelist format, select N as your response. The program will then help you in writing the data in namelist format.

⇒ **Y**

⇐ PROGRAM DETERMINES PP CONSTANTS-EXPONENT b- AND
    OTHER SRP RELATIONSHIPS IN TWO STEPS. USER MUST SUPPLY
    THE APPROPRIATE INPUT FILE.

⇐ CALL FAIL TO DETERMINE EXPONENT b FOR ELASTIC LINE.

⇐ ENTER NAME OF THE INPUT FILE:
⇒ **AF21DA.NAS**
⇐ DO YOU WANT TO SEND OUTPUT TO A FILE (F)? (Y/N)
⇒ **Y**

A response of Y permits the creation of a file for program output.

⇐ ENTER THE NAME FOR OUTPUT FILE:
⇒ **AF21DA.B**[*]

This prompt appears if the response to the above prompt was Y.

⇐ DO YOU WANT TO WRITE X, Y DATA FILES FOR OFF-LINE
  PLOTTING, YES(Y) OR NO(N):
⇒ **Y**

This response permits the creation of a file for off-line plotting using appropriate commercially available software.

⇐ ENTER FILENAME FOR OUTPUT:
⇒ **AF21DAXY.B***
⇐ THE DEFAULT VALUE OF MIN INELASTIC STRAIN IS 1.00000E-4
   DO YOU WANT TO CHANGE IT?, YES(Y) OR NO(N):
⇒ **N**

   The default value is the smallest inelastic strain range that can be experimentally determined with satisfactory accuracy. All tests with an inelastic strain range less than the minimum value are rejected with the exception of PP tests. Test data with an inelastic strain range less than the minimum are used to determine the elastic PP failure relation (equation (2)).

⇐ ISOTHERMAL (ISO) OR BITHERMAL (BTH) CYCLES?

A life prediction is to be made for an isothermal test at 760 °C, so the appropriate response is ISO.

⇒ **ISO**
⇐ INPUT ISOTHERMAL TEMP-DEG C:
⇒ **760**
⇐ DO YOU WANT TO USE THE MEAN STRESS CORRECTION OF
  HALFORD & NACHTIGALL ? YES(Y) OR NO(N):
⇒ **N**

This method of accounting for mean stress effects on cyclic life was developed for all alloys and is appropriate in this example. Generally, each alloy should be considered separately when evaluating mean stress effects. The PP line should be determined using data from tests with an R = -1. A small negative mean stress develops for this loading condition and is ignored. *At this stage we want to determine only PP constants so an appropriate response is no (N).*

   The program now displays the number of data points available for each type of SRP cycle.

⇐ NUMBER OF PP POINTS =  9

---

* User may give any other name.

```
NUMBER OF PC POINTS =  6
NUMBER OF CP POINTS =  3
NUMBER OF CC POINTS =  3
```

        CRUNCHING PP DATA
******************************************
⇐ PP CONSTANTS DETERMINED, DO YOU WANT TO CONTINUE?, YES(Y) OR
   NO(N):
⇒ **N**

The response here is no (N) because in the first run we only want to determine the PP
constants**.**

⇐ PP CONSTANTS DETERMINED.

The program FAIL will now be run again to determine the other SRP relations. The
following prompt appears.

⇐ CALL FAIL TO DETERMINE SRP-RELATIONSHIPS.

⇐ ENTER NAME OF INPUT FILE:
⇒ **AF21DA.NAS**
⇐ DO YOU WANT TO SEND OUTPUT TO A FILE?  (Y/N)
⇒ **Y**
⇐ ENTER THE NAME FOR OUTPUT FILE
⇒ **AF21DA.FAL**♦
⇐ DO YOU WANT TO WRITE X, Y DATA FILES FOR OFF-LINE
   PLOTTING, YES(Y) OR NO(N)?
⇒ **Y**
⇐ ENTER FILENAME FOR OUTPUT:
⇒ **AF21DAXY.FAL**♦
⇐ THE DEFAULT VALUE OF MINIMUM INELASTIC STRAIN IS        1.00000E-04
    DO YOU WANT TO CHANGE IT?, YES(Y) OR NO(N):
⇒ **N**
⇐ ISOTHERMAL (ISO) OR BITHERMAL (BTH) CYCLES?
⇒ **ISO**
⇐ INPUT ISOTHERMAL TEMP-DEG C:
⇒ **760**
⇐ DO YOU WANT TO USE THE MEAN STRESS CORRECTION OF
   HALFORD & NACHTIGALL ?, YES(Y) OR NO(N):
⇒ **Y**

---

♦ User may assign any other filename.

We chose the response as yes (Y) now, because we want to include the mean stress effects on cyclic life.

⇐ NUMBER OF PP POINTS =  9
   NUMBER OF PC POINTS =  6
   NUMBER OF CP POINTS =  3
   NUMBER OF CC POINTS =  3

       CRUNCHING PP DATA
**********************************************
⇐ PP CONSTANTS DETERMINED, DO YOU WANT TO CONTINUE?, YES(Y) OR
   NO(N):
⇒ **Y**

The response here is yes (Y) because in this run we want to determine other SRP relations. Note that each type of SRP cycle has more than two points available for determining the constants in equations (1) and (2).

⇐                        CRUNCHING PC DATA
   *************************************************************************

       At this point the program will display the calculated damage fraction for each data point (if it is less than the default value of 0.50) and ask the user if this test is to be included in the analysis. This gives the user the choice of including a test when data are limited or when the damage fraction is sufficiently close to the default value. In this example the damage fraction for each test is ≥0.50. The program now checks again for the minimum number of acceptable data points (two points) required for determining the constants in the $\Delta\varepsilon_{in} - N_{pc}$ relation (equation (1)). Since all the data points have a damage fraction ≥0.50, all six data points are used. If fewer than two points are acceptable, the program skips to the next (CP) Section.

Note that two $\Delta\varepsilon_{in} - N_{ij}$ life relations are determined for each type of cycle (PC, CP, and CC). The first is obtained from a log-log linear regression of the data, as noted earlier. The second relation is obtained by forcing a line through the centroid of the $\Delta\varepsilon_{in} - N_{ij}$ data parallel to the PP inelastic line. This second relation is used in TS-SRP.

⇐ DETERMINE ELASTIC LINE AS A FUNCTION OF HOLD TIME? YES(Y) OR
   NO(N):
⇒ **N**

       This option determines the $\Delta\varepsilon_{in} - N_{f0}$ relation for cycles where the hold time per cycle is a controlled variable. The appropriate response is N because no appropriate time/creep data are available, and there is no way to estimate it from this dataset.

This completes the analysis of the PC data, and the program will now analyze the CP data if sufficient data (number of CP points ≥2) are available.

⇐ CRUNCHING CP DATA
**********************************************************************
The damage fraction for all three tests is ≥0.50, and the constants in the two
$\Delta\varepsilon_{in} - N_{cp}$ relations (equation (1)) are now determined as noted previously.

⇐ DETERMINE ELASTIC LINE AS A FUNCTION OF HOLD TIME ? YES(Y) OR
  NO(N):
⇒ N

The appropriate response here is N because no appropriate time/creep data are available, and there is no way to estimate it from this dataset.

This completes the analysis of the CP data, and the program will now analyze the CC data if sufficient data are available (number of CC points ≥2).

⇐ CRUNCHING CC DATA
**********************************************************************
⇐ CC DAMAGE FRACTION =      0.409904
⇐ DAMAGE FRACTION LESS THAN 0.50. DO YOU WANT
  TO INCLUDE THIS POINT? YES(Y) OR NO(N):
⇒ Y

The damage fraction is fairly close to the desired value of 0.50, and we choose to include it because of the paucity of data CC (three points). The constants in the two $\Delta\varepsilon_{in} - N_{cc}$ relations (equation (1)) are now determined as noted earlier.

⇐ DETERMINE ELASTIC LINE AS A FUNCTION OF HOLD TIME ? YES(Y) OR
  NO(N):
⇒ N

Again, the appropriate response is N because no appropriate time/creep data are available, and there is no way to estimate it from this dataset.

⇐ SRP RELATIONS DETERMINED.
  PROGRAM FAIL FINISHED.
  PROGRAM FAIL IS EXITING.

This completes the session for FAIL program. A plot of the relations determined by FAIL is shown in figure 7. A comparison of the results shown in figure 7 with those shown in figure 7 of reference 15 will reveal small differences in the equation constants. There are two reasons for this: First, the results in reference 15 were obtained on a totally different machine (a mainframe); and second, minor changes have been made in the program.

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

The user may select Y if any other program from the main menu is desired to be run. If the user selects N the program terminates with the following message:

⇐ **** PROGRAM FLAPS FINISHED. ****

Table III. –    TYPES OF CYCLES ACCEPTABLE TO PROGRAMS FAIL, FLOW AND
PSRPLIFE.

| | | |
|---|---|---|
| **Isothermal** | PP Cycle | HRLC High Rate Load Cycle<br>HRSC High Rate Strain Cycle |
| | PC Cycle | CCCR Compressive Cycle Creep Rupture<br>CHSC Compressive Strain-Hold Strain Cycle<br>FSSC Fast-Slow Strain Cycle[a] |
| | CP Cycle | TCCR Tensile Cyclic Creep Rupture<br>THSC Tensile Strain-Hold Cycle<br>SFSC Slow Fast Strain Cycle[a] |
| | CC Cycle | BHSC Balanced Strain-Hold Strain Cycle<br>LRSC Low Rate Strain Cycle |
| **Bithermal** | PP Cycle | HRIP High Rate In-Phase[a]<br>HROP High Rate Out-of-Phase |
| | PC Cycle | CCOP Compressive Cyclic Creep Rupture Out-of-Phase<br>CHOP Compressive Hold Strain Cycle Out-of-Phase |
| | CP Cycle | TCIP Tensile Creep In-Phase<br>THIP Tensile Strain-Hold In-Phase |
| **Thermo-mechanical** | PP Cycle | None |
| | PC Cycle | TMOP Thermomechanical Out-of-Phase[a] |
| | CP Cycle | TMIP Thermomechanical In-Phase[a] |
| | CC Cycle | None |

---

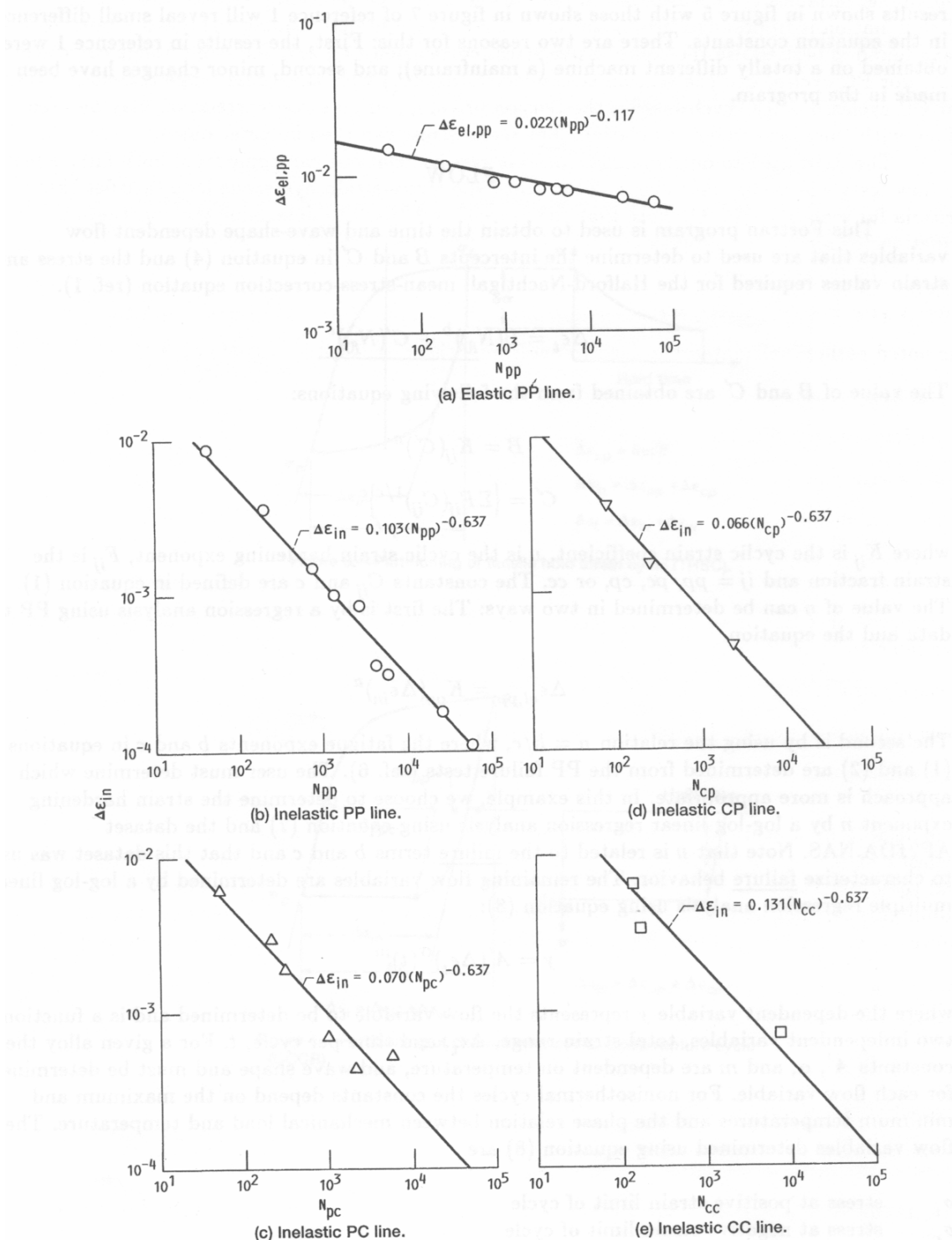[a] These cycles are accepted only by the program flow.

Figure 7. - Plot of results from FAIL and data from Ref. 4. Material,
AF2-1DA; Temperature, 760 °C.

# FLOW

## Program Description

The program FLOW is used to characterize the *flow* behavior (the constitutive response) of an alloy as by the constants in the flow equations used by TS-SRP.

## Required Input Data

The program will require appropriate failure and flow datasets.

## Program Output

The program will generate four output files to determine the flow behavior of the material.

## Example and Description

This FORTRAN program is used to obtain the time and wave-shape dependent flow variables that are used to determine the intercepts B and C' in equation (1) and the stress and strain values required for the Halford-Nachtigall mean-stress-correction equation (Ref. 15).

$$\Delta \varepsilon_t = B\,(N_{f0})^b + C'\,(N_{f0})^c \tag{1}$$

The value of B and C' are obtained from the following equations:

$$B = K_{ij}\,(C')^n \tag{2}$$

$$C' = \left\{ \sum F_{ij}\,(C_{ij})^{1/c} \right\}^c \tag{3}$$

where $K_{ij}$ is the cyclic strain coefficient (elastic strain range at $\Delta \varepsilon_{in} = 1.0$), $n$ is the cyclic strain hardening exponent, $F_{ij}$, is the strain fraction and $ij = pp, pc, cp,$ or $cc$. The constants $C_{ij}$ and $c$ are defined in equation (1) of the FAIL section. The value of $n$ can be determined in two ways: The first, is by a regression analysis using PP test data and the equation

$$\Delta \varepsilon_{el,pp} = K_{pp}\,(\Delta \varepsilon_{in})^n \tag{4}$$

The second is by using the relation $n = b/c$, where the fatigue exponents $b$ and $c$ (see equations (1) and (2) of the FAIL section) are determined from the PP failure tests (Ref. 13). The user must determine which approach is more appropriate. In this example, we choose to determine the strain hardening exponent $n$ by a log-log linear regression analysis using equation (4) and the dataset AF21DA.NAS. Note that $n$ is related to the failure terms $b$ and $c$ and that this dataset was used to characterize failure behavior. The remaining flow variables are determined by a log-log linear multiple regression analysis using equation (5):

$$y = A'(\Delta\varepsilon_t)^\alpha (t)^m \tag{5}$$

where the dependent variable represents the flow variable to be determined and is a function of two independent variables, total strain range, $\Delta\varepsilon_t$, and time per cycle, $t$. For a given alloy the constants $A'$, $\alpha$, and $m$ are dependent on temperature, and wave shape and must be determined for each flow variable (see Ref. [16]). For nonisothermal cycles the constants depend on the maximum and minimum temperatures and the phase relation between mechanical load and temperature. The flow variables determined using equation (5) are:

| | |
|---|---|
| $\sigma_t$ | stress at positive strain limit of cycle |
| $\sigma_c$ | stress at negative strain limit of cycle |
| $\Delta\sigma$ | stress range, $\sigma_t + \sigma_c$ |
| $\Delta\varepsilon_{el}$ | elastic strain range |
| $F_{ij}$ | strain fraction, |
| $K_{ij}$ | cyclic strain coefficient |

The variables $K_{ij}$ and $F_{ij}$ are used to determine the intercepts $B$ and $C'$ in equation (1), and the remaining variables are used to determine the Halford-Nachtigall mean-stress correction. A word of explanation is in order regarding the correlations used in determining the mean stress. We have found it best to use the compressive stress correlation ($\sigma_c$) and the stress range correlation ($\Delta\sigma$) for PC cycles, and the tension stress correlation ($\sigma_t$) with the stress range correlation ($\Delta\sigma$) for CP cycles. For CC cycles either the tension or compression stress correlation may be used along with the stress range correlation. The mean stress can then be determined.

The data used to determine the mean-stress correlations can come from both failure tests and flow tests where the specimen is cycled until the stress-strain hysteretic loop satisfies the criteria for stability (Ref. 15). Note that the type of cycle used to determine the constants in equation (5) must be appropriate to the duty cycle to be predicted.

The program is invoked by selecting option 10 in the main menu. The following screen prompts occur:

⇐ .
   PROGRAM FLOW
   THIS PROGRAM DETERMINES FLOW RELATIONS
   USING RAW DATA FROM THE EXPERIMENTS
   THE PROGRAM USES THE SRP-METHOD
   .
   .
⇐ FLOW PROGRAM REQUIRES INPUT DATA IN NAMELIST FORMAT.
   DO YOU HAVE INPUT DATA IN NAMELIST FORMAT? (Y/N)

Because the dataset AF21DA.NAS has the data in namelist format, the response is Y (yes). If you do not have the data in namelist format, select N as your response. The program will then help you in writing the data in namelist format.

$\Rightarrow$ **Y**

$\Leftarrow$ .

   PROGRAM WILL FIRST DETERMINE THE
   STRAIN HARDENING EXPONENT, n
   USER MUST SUPPLY THE PERTINENT INPUT FILE.
   .

$\Leftarrow$ ENTER INPUT FILE NAME:
$\Rightarrow$ **AF21DA.NAS**

As noted earlier, this dataset is used to determine the value of $n$ in equation (4).

$\Leftarrow$ SEND OUTPUT TO A FILE, YES(Y) OR NO(N)?
$\Rightarrow$ **Y**

This response Y permits the creation of a file for output.

$\Leftarrow$ ENTER FILE NAME FOR OUTPUT:
$\Rightarrow$ **AF21DA.N**$^\blacklozenge$

This prompt appears only if the response to the previous prompt was Y.

$\Leftarrow$ DO YOU WANT TO WRITE X-Y DATA FILES FOR OFF-LINE
   PLOTTING? YES(Y) OR NO (N):
$\Rightarrow$ **Y**

A response of Y permits a file to be created for off-line plotting using appropriate commercially available software.

$\Leftarrow$ ENTER FILENAME FOR OUTPUT:
$\Rightarrow$ **AF21DAXY.N**$^\blacklozenge$

This response appears if the response to the previous prompt was Y.

$\Leftarrow$ THE DEFAULT VALUE OF MINIMUM INELASTIC S.R. IS     1.00000E-04
   DO YOU WANT TO CHANGE IT? YES(Y) OR NO (N):
$\Rightarrow$ **N**

The default value will not be changed. Note that three flow variables involve the inelastic strain range. They are the cyclic strain hardening exponent $n$, the strain fraction $F_{ij}$, and the cyclic strain coefficient $K_{ij}$. If a test has an inelastic strain range value less than the minimum, it is not used to determine the equation constants for these three flow variables. However, such a test can be used to determine the stress and elastic strain range correlations.

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$^\blacklozenge$ User may choose any other name.

⇐ ENTER TYPE OF DATA FOR ANALYSIS
   1 = FLOW DATA ONLY
   2 = FAILURE DATA ONLY
   3 = FLOW AND FAILURE DATA

The user has the option of using data from flow tests only, failure tests only, or both. This dataset contains only failure data, so the appropriate response is 2.

⇒ **2**
⇐ ISOTHERMAL(ISO) OR BITHERMAL (BTH)
   OR THERMOMECHANICAL (TMF) CYCLES?
⇒ **ISO**

Life predictions are to be made for isothermal data at 760 $^{\circ}$C, so the appropriate response is ISO.

⇐ INPUT ISOTHEMAL TEMP:
⇒ **760**

The program now displays the number of data points available for each type of SRP cycle.

⇐ BCCR - NOT PROGRAMMED FOR THIS CYCLE TYPE
   BCCR - NOT PROGRAMMED FOR THIS CYCLE TYPE
   BCCR - NOT PROGRAMMED FOR THIS CYCLE TYPE
   NUMBER OF PP POINTS =    9
   NUMBER OF PC POINTS =    6
   NUMBER OF CP POINTS =    3
   NUMBER OF CC POINTS =    0
 PAUSE: NUMBER OF DATA POINTS FOR CURVE FITTING
 Enter 'go' to continue.

⇐ ANALYZE PP DATA ?, YES(Y) OR NO(N):
⇒ **Y**

The value of the cyclic strain hardening exponent *n* in equation (4) is to be determined from the PP test data.

⇐ CRUNCHINC PP DATA
⇐ EXPONENT n DETERMINED.

The constants in equation (4) are now determined and shown in figure 8. Two output files have been created: The first, AF21DA.N, contains the correlation for the strain hardening coefficient. The second, AF21DAXY.N contains the same information but in an X-Y format for plotting.
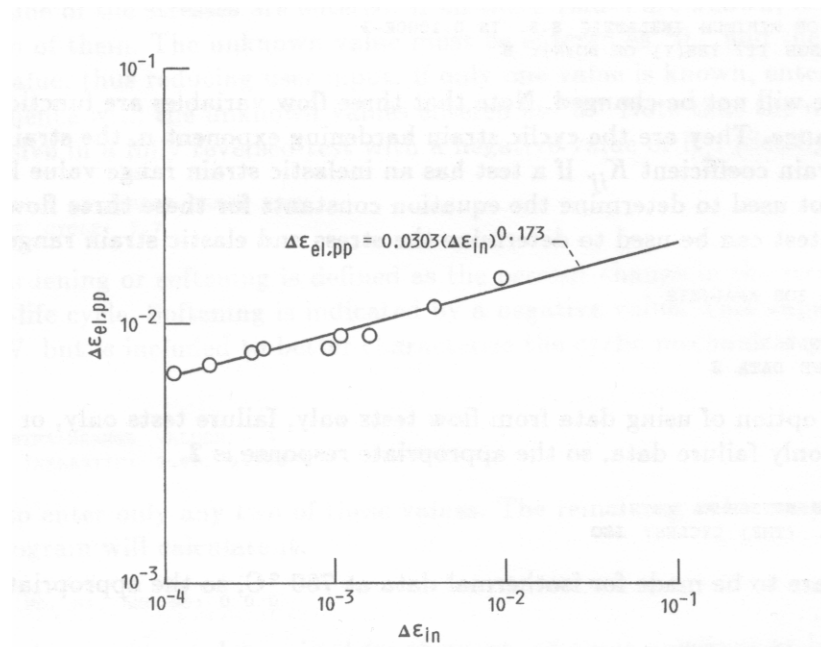
**Figure 8. - Comparison of results from program FLOW with the data from Ref. 12. Material, AF2-1DA; temperature, 760 °C.**

The remaining flow correlations are determined using the dataset AF21DA.PWA, which features strain-hold test data. This is necessary because we intend to predict the life of a compressive strain-hold (CHSC) cycle. The following prompts appear:

$\Leftarrow$ .
   PROGRAM WILL NOW DETERMINE CONSTANTS
   APRIME, m, alpha IN THE FLOW EQUATION.
   USER MUST SUPPLY THE PERTINENT INPUT FILE.
   .
$\Leftarrow$ ENTER INPUT FILE NAME:
$\Rightarrow$ **AF21DA.PWA**
$\Leftarrow$ SEND OUTPUT TO A FILE, YES(Y) OR NO(N))?
$\Rightarrow$ **Y**
$\Leftarrow$ ENTER FILENAME FOR OUTPUT:
$\Rightarrow$ **AF21DA.FLO**[*]
$\Leftarrow$ DO YOU WANT TO WRITE X-Y DATA FILES FOR OFF-LINE
   PLOTTING YES(Y) OR NO(N):
$\Rightarrow$ **Y**
$\Leftarrow$ ENTER FILENAME FOR OUTPUT:
$\Rightarrow$ **AF21DAXY.FLO**[*]
$\Leftarrow$ THE DEFAULT VALUE OF MINIMUM INELASTIC S.R. IS        1.00000E-04
   DO YOU WANT TO CHANGE IT? YES(Y) OR NO(N):
$\Rightarrow$ **N**
$\Leftarrow$ SELECT TYPE OF DATA FOR ANALYSIS
   1 = FLOW DATA ONLY
   2 = FATLURE DATA ONLY
   3 = FLOW AND FAILURE DATA
$\Rightarrow$ **2**

This dataset contains only failure data for the strain-hold tests.

$\Leftarrow$ ISOTHERMAL (ISO) OR BITHERPLAL (BTH)
   OR THERMOMECHANICAL (TMF) CYCLES?
$\Rightarrow$ **ISO**

We intend to predict the life of an isothermal cycle, so ISO is the appropriate response.

$\Leftarrow$ INPUT ISOTHERMAL TEMP:
$\Rightarrow$ **760**

The program now displays the number of data points available for each type of SRP cycle. Note that a limited number of cycle types are built into the program at this time. The user can easily modify the program to accept other cycle types. If a test cycle is of a type not coded

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[*] Any other file name may be chosen.

into the program, it will be rejected. In this case three tensile creep extension ratcheting (TCER) tests are rejected. A TCER cycle is a tension stress-hold cycle with a fixed hold time per cycle, and the maximum strain limit is not controlled. A list of the cycle types coded into the program is given in Table III.

$\Leftarrow$ BCCR - NOT PROGRAMMED FOR THIS CYCLE
  BCCR - NOT PROCFA14MED FOR THIS CYCLE
  TCER - NOT PROGRAMMED FOR THIS CYCLE TYPE
  TCER - NOT PROGRAMMED FOR THIS CYCLE TYPE
  TCER - NOT PROGRAMMED FOR THIS CYCLE TYPE
  NUMBER OF PP POINTS =      8
  NUMBER OF PC POINTS =     12
  NUMBER OF CP POINTS =     12
  NUMBER OF CC POINTS =      3
PAUSE: NUMBER OF DATA POINTS FOR CURVE FITTING
Enter 'go' to continue.

$\Leftarrow$ ANALYZE PP DATA ? YES(Y) OR NO(N):
$\Rightarrow$ **N**

The appropriate response here is N because the cyclic strain hardening exponent $n$ has already been determined.

$\Leftarrow$ ANALYZE PC DATA, YES(Y) OR NO(N)?
$\Rightarrow$ **Y**
$\Leftarrow$ CRUNCHING PC DATA:
$\Leftarrow$ ENTER WAVE SHAPE FOR CORRELATION,
  CHSC, CCCR, FSSC:
$\Rightarrow$ **CHSC**

For isothermal conditions, three cyclic wave shapes are currently built into the program for PC cycles: CHSC, CCCR, and FSSC (see Table II). Since we intend to predict the life of a compressive strain-hold test, **CHSC** is the appropriate choice.

$\Leftarrow$ SET LIMITS ON TOTAL STRAINRANGE?, YES(Y) OR NO(N):
$\Rightarrow$ **N**

There are occasions where a good correlation is not obtained over the entire span of the data as measured by the total strain range (Ref. 17). This option gives the user the opportunity to limit data to tests within a specified maximum and minimum total strain range. For this example there is no need to set limits on the total strain range.

$\Leftarrow$ DETERMINE ALPHA BY TRIAL(T)
  OR MULTIPLE REGRESSION (M) :
$\Rightarrow$ **M**

As noted earlier, three constants in equation (5) are to be determined by a log-log multiple linear regression analysis. When the span of the total strain range data are limited either by choice or by circumstances, a better curve fit can usually be determined if the value of $\alpha$ is estimated by trial and error using the T option rather than by the log-log linear multiple regression option M. The $\alpha$ that gives the best correlation coefficient is the best value. When the T option is used, the dependent variable in equation (5) becomes a function of only one independent variable, time, and the program requires a minimum of two points with different time values for the log-log linear curve fit. The program will ask for the value of $\alpha$ to be used. In some cases, the total strain range may be a constant, and the T option is required with the value of $\alpha$ set equal to zero.

When the M option is used, the dependent variable is a function of two independent variables, total strain range and time, and is the preferred option when adequate data are available. The program requires a minimum of four points (two values of total strain range and two values of time) for the curve fit but does not contain criteria to determine if the data are adequate. Adequate data are available in this example, and we choose the M option.

In order to make a life prediction using equation (1), the elastic line intercept $B$ (equation (2)) and the equivalent inelastic line intercept $C'$ (equation (3)) must be determined. These intercepts are determined using the correlations for the strain fraction $F_{ij}$ and the cyclic strain coefficient $K_{ij}$. The value of the cyclic strain hardening exponent $n$ must be known before determining $K_{ij}$.

Since we intend to account for mean stress effects on life for a CHSC test, correlations for compressive stress, $\sigma_c$, stress range, $\Delta\sigma$, and elastic strain range, $\Delta\varepsilon_{el}$, are required. The two stress correlations are used to calculate the mean stress present, in the cycle. As noted earlier, the correlation for $\sigma_c$ is appropriate when determining the mean stress in a PC cycle. The flow correlations can be determined in any sequence. We choose to proceed in numerical order starting with the $\sigma_c$ correlation. We are now presented with the following menu:

$\Leftarrow$ SELECT TYPE OF CORRELATTON
    OPTION 2: TENSION STRESS VS HOLD TIME
    OPTION 3: COMPRESSION STRESS VS HOLD TIME
    OPTION 4: STRESS RANGE VS HOLD TIME
    OPTION 5: ELASTIC STRAINRANGE VS HOLD TIME
    OPTION 6: $F_{ij}$ VS HOLD TIME
    OPTION 7: $K_{ij}$ VS HOLD TIME
    OPTION 8: TRANSFERTO NEXT SECTION
    OPTION 9: QUIT PROGRAM
$\Leftarrow$ ENTER VALUE:
$\Rightarrow$ **3**
No. OF   POINTS FOR CURVE FIT =    9

The constants A', $\alpha$, and $m$ in equation (3) for the $\sigma_c$ correlation are determined.

$\Leftarrow$ NEW PC CORRELATION OR NEW ALPHA? YES(Y) OR NO(N):
$\Rightarrow$ **Y**
$\Leftarrow$ CRUNCHING PC DATA:
$\Leftarrow$ ENTER WAVE SHAPE FOR CORRELATION,
   CHSC, CCCR, FSSC:
$\Rightarrow$ **CHSC**
$\Leftarrow$ SET LIMITS ON TOTAL STRAINRANGE? YES(Y) OR NO(N):
$\Rightarrow$ **N**
$\Leftarrow$ DETERMINE ALPHA BY TRIAL(T)
   OR MULTIPLE REGRESSION(M)?
$\Rightarrow$ **M**

The program presents the menu for the next correlation.

$\Leftarrow$ SELECT TYPE OF CORRELATION
   OPTION 2: TENSION STRESS VS HOLD TIME
   OPTION 3: COMPRESSION STRESS VS HOLD TIME
   OPTION 4: STRESS RANGE VS HOLD TIME
   OPTION 5: ELASTIC STRAINRANGE VS HOLD TIME
   OPTION 6: $F_{ij}$ VS HOLD TI14E
   OPTION 7: $K_{ij}$ VS HOLD TIME
   OPTION 8: TRANSFER TO NEXT SECTION
   OPTION 9: QUIT PROGRAM
$\Leftarrow$ ENTER VALUE:
$\Rightarrow$ **4**
$\Leftarrow$ No. OF POINTS FOR CURVE FIT =    9

The constants A', $\alpha$, and *m* in equation (5) are now determined for $\Delta\sigma$, correlation.

$\Leftarrow$ NEW PC CORRELATION OR NEW ALPHA? YES(Y) OR NO(N):
$\Rightarrow$ **Y**

Input to the program continues in the above manner determining the constants for the correlations for $\Delta\varepsilon_{el}$, and $F_{pc}$. The last correlation is for $K_{pc}$.

$\Leftarrow$ CRUNCHING PC DATA:
$\Leftarrow$ ENTER WAVE SHAPE FOR CORRELATION,
   CHSC, CCCR,FSSC:
$\Rightarrow$ **CHSC**
$\Leftarrow$ SET LIMITS ON TOTAL STRAINRANGE? YES(Y) OR NO(N):
$\Rightarrow$ **N**
$\Leftarrow$ DETERMINE ALPHA BY TRIAL(T)
   OR MULTIPLE REGRESSION(M)?
$\Rightarrow$ **M**

Nominally, $K_{ij}$ is not a function of total strain range, and the T option is appropriate with the value of $\alpha$ set equal to zero. For some alloys the value of $K_{ij}$ may be a weak function of total strain range, and the M option would be appropriate. In this example we choose to use the M option.

&#8656; SELECT TYPE OF CORRELATION
   OPTION 2: TENSION STRESS VS HOLD TIME
   OPTION 3: COMPRESS10N STRESS VS HOLD TIME
   OPTION 4: STRESS RANCE VS HOLD TIME
   OPTION 5: ELASTIC STRAINRANGE VS HOLD TIME
   OPTION 6: $F_{ij}$ VS HOLD TIME
   OPTION 7: $K_{ij}$ VS HOLD TIME
   OPTION 8: TRANSFER TO NEXT SECTION
   OPTION 9, QUIT PROGRAM
&#8656; ENTER VALUE:
&#8658; **7**
&#8656; No. OF POINTS FOR CURVE FIT =    8

The constants A', $\alpha$, and $m$ in equation (5) for the $K_{ij}$ are now determined. Note that one data point has been rejected because the inelastic strain range is less than the default value of EMIN.

&#8656; NEW PC CORRELATION OR NEW ALPHA? YES (Y) , NO (N) :
&#8658; **N**

All of the necessary PC correlations have been determined. A response of N terminates analysis of the PC data, and we now have the option of correlating the CP data.

&#8656; ANALYZE CP DATA? YES(Y) OR NO(N):
&#8658; **Y**
.
.
The CP data can be analyzed in a similar manner, and the proper wave shape for this example is THSC because the data in reference 18 are from strain-hold tests. The screen prompts will be identical to those shown above.

&#8656; ANALYZE CC DATA? YES(Y) OR NO (N):
&#8658; **N**

The CC flow correlations cannot be determined because of insufficient data (three points and only one hold-time value), so the appropriate response is N.

&#8656; FLOW RELATIONS DETERMINED.
   PROGRAM FLOW FINISHED.
   PROGRAM FLOW IS EXITING.

Note that the program will accept only balanced CC cycles where the hold times (BHSC) or straining rates (LRSC) are equal in both tension and compression. These balanced cycles generally contain only PP and CC $(\Delta\varepsilon_{pp} + \Delta\varepsilon_{cc})$ inelastic strain components. Any PC or CP $((\Delta\varepsilon_{pc}, \Delta\varepsilon_{cp})$ inelastic strain range component present will usually be small and can be ignored. Procedures for analyzing cycles containing unbalanced hold time and/or inelastic strains are not fully developed at this time.

This completes the session for FLOW program. Four output files have been generated during this session: The files, AF21DA.N and AF21DA.FLO, respectively contain the value of exponent $n$, flow correlations and the data used to determine them in a reader friendly format. The other two files, AF21DAXY.N and AF21DAXY.FLO, contain these same data but in an X-Y format suitable for plotting.

Plots of the relations determined by FLOW and their representation of the data are shown in figures 9 to 13. As with the failure relations, the constants in these figures differ slightly from those shown in figures 9, 11, 13, 15, and 17 of reference 15 for reasons cited earlier. Our experience has shown that equation (5) generally gives satisfactory correlations for all flow variables with the exception of $F_{ij}$. The $F_{ij}$ correlation typically has the most scatter and the lowest correlation coefficient, probably because equation (5) does not model $F_{ij}$ as well as it models the other flow variables.

The final prompt from the program is:

⇐ DO YOU WANT TO RUN ANY OTHER PROGRAM? (Y/N)

A selection of Y will return you to the main menu where you can select the desired program. Selecting N will terminate the program FLAPS with the following message:
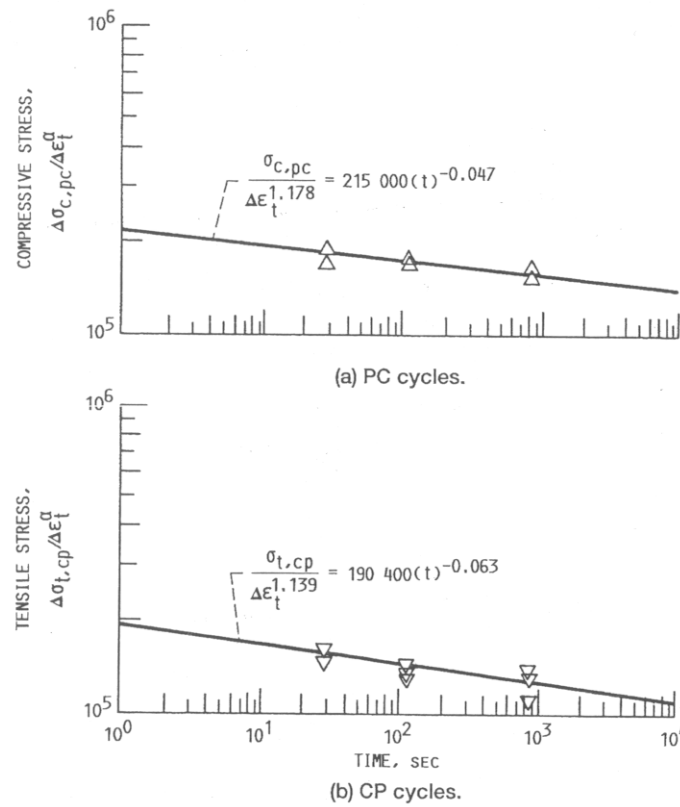
⇐ **** PROGRAM FLAPS FINISHED. ****

**Figure 9. - Plot of results from FLOW and the data from Ref. 12. Plot shows the relation between stress, normalized by total strain range, and hold-time for strain hold PC and CP cycles. Material, AF2-1DA; temperature, 760 °C.**
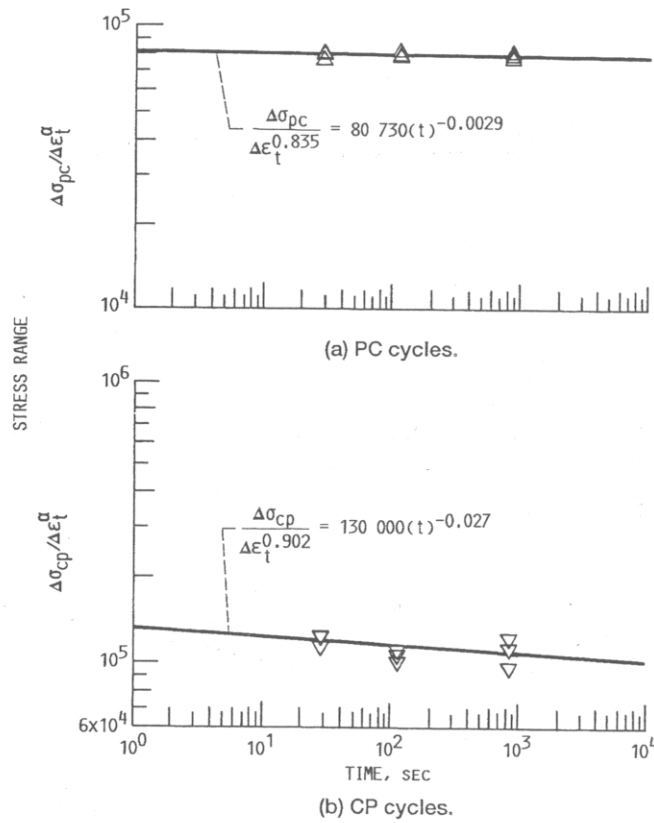
**Figure 10. - Plot of results from FLOW and the data from Ref. 12. Plot shows the relation between stress range, normalized by total strain range, and hold-time for strain hold PC and CP cycles. Material, AF2-1DA; temperature, 760 $^{o}$C.**
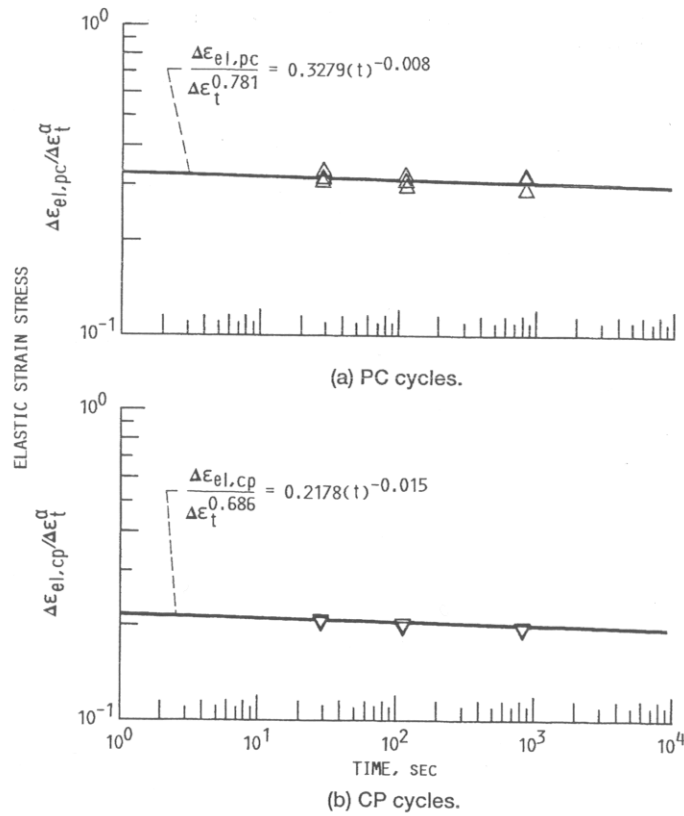
**Figure 11. - Plot of results from FLOW and the data from Ref. 12. Plot shows the relation between elastic strain range, normalized by total strain range, and hold time for strain-hold PC and CP cycles. Material, AF2-1DA; temperature, 760 °C.**
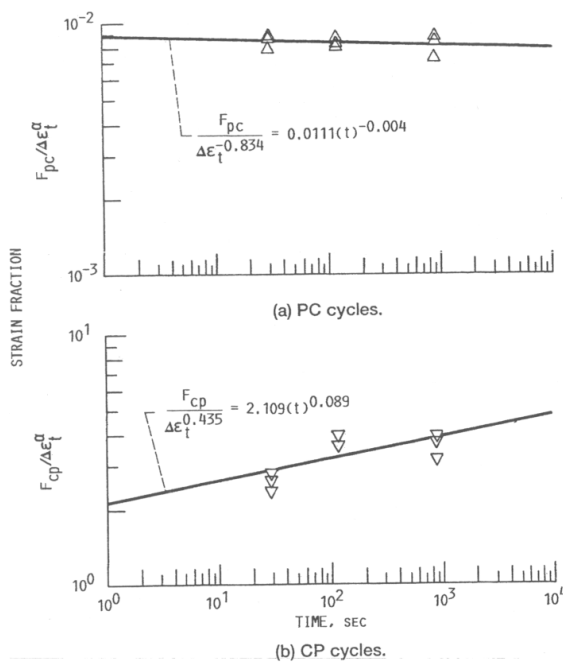
**Figure 12. - Plot of results from FLOW and the data from Ref. 12. Plot shows the relation between strain fraction, normalized by total strain range, and hold time for strain-hold PC and CP cycles. Material, AF2-1DA; temperature, 760 °C.**
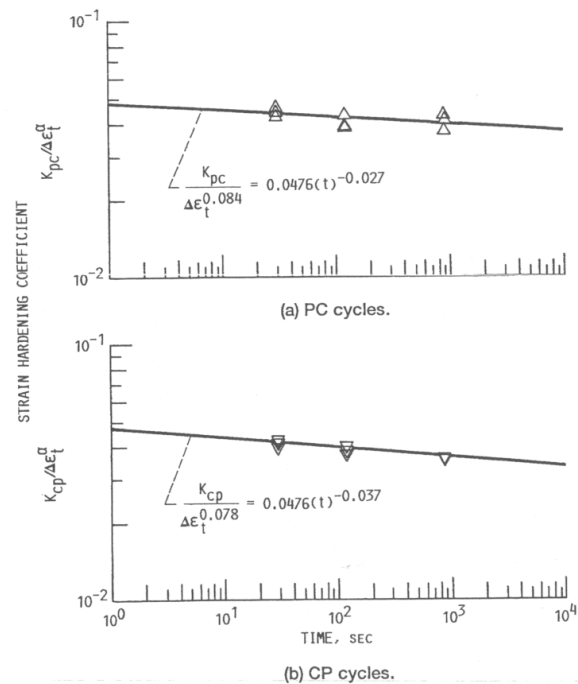


**Figure 13. - Plot of results from FLOW and the data from Ref. 12. Plot shows the relation between strain coefficient, normalized by total strain range, and hold time for strain-hold PC and CP cycles. Material, AF2-1DA; temperature, 760 °C.**

# PSRPLIFE

**Program Description**

This program is used to predict cyclic life using information generated by the programs FAIL and FLOW. Note that PSRPLIFE is written for the case where the cycle to be predicted contains time-independent PP strain and one type of time-dependent strain (PC, CP, or CC). Procedures have not been developed at this time for predicting the life of a cycle containing an unbalanced inelastic strain component (PP + CC + {PC or CP}).

**Required Input Data**

The program will require appropriate failure, flow and other cyclic test datasets for which the cyclic life is to be ascertained.

**Program Output**

The program will generate several output files depending upon the choices made by the user. These may contain the output files as mentioned earlier in FAIL and FLOW programs. The files containing the predicted life may also be generated if the user desires to do so.

**Example and Description**

As an example of how this program is used, the life of a PC test (test 243 from Ref. 18), for the nickel-based alloy AF2-1DA subjected to an isothermal (760 $^\circ$C) compressive strain hold cycle (CHSC), will be predicted. In order to predict the life of this or any other cycle (in this case for the alloy AF2-1DA**),** the constants for the appropriate failure and flow relations must be determined. The PSRPLIFE is written to automatically determine these constants by calling the programs FAIL and FLOW. Because detailed explanations for various steps in the FAIL and FLOW program have been already described in the preceding sections, these will not be repeated here. The user is referred to preceding sections should an explanation for a particular step be required. The user must supply the appropriate input datasets. The failure and flow relations needed in this prediction are obtained from two datasets, which contain the isothermal (760 $^\circ$C) test results. These data were also used in reference 15. One dataset, AF21DA.NAS (Ref. 4), features stress-hold creep-fatigue test data and will be used to determine the generic SRP failure relations. The second dataset, AF21DA.PWA (Ref. 11), features strain-hold creep-fatigue test data and will be used to determine the flow relations

The program is invoked by selecting option 11 from the main menu. The program responds by presenting the following menu:

$\Leftarrow$ PROGRAM PSRPLIFE
.
.

.

⇐ THE PROGRAM REQUIRES INPUT DATA IN NAMELIST FORMAT.
  DO YOU HAVE INPUT DATA IN NAMELIST FORMAT?   (Y/N)

⇒ **Y**

⇐ ENTER TEST DETAILS.

  .

  .

⇐ ENTER SPECIMEN NUMBER

⇒ **243**

⇐ ENTER TOTAL STRAIN RANGE

⇒ **0.0085**

⇐ ENTER HOLD TIME IN SECONDS

⇒ **300**

⇐ ENTER CYCLE TYPE – PC, CP OR CC?

⇒ **PC**

⇐ PROGRAM WILL CALL SUBROUTINE FAIL TWICE TO DETERMINE
  FOUR SRP RELATIONSHIPS. USER MUST SUPPLY THE
  APPROPRIATE INPUT FILE BELOW.

  CALL FAIL TO DETERMINE EXPONENT b FOR ELASTIC LINE.

⇐ ENTER NAME OF INPUT FILE:

⇒ **AF21DA.NAS**

⇐ DO YOU WANT TO SEND OUTPUT TO A FILE?  (Y/N)

⇒ **Y**

⇐ ENTER THE NAME FOR OUTPUT FILE:

⇒ **AF21DA.B**

⇐ DO YOU WANT  TO WRITE X,Y DATA FILES FOR OFF-LINE
  PLOTTING , YES(Y) OR NO(N)?

⇒ **Y**

⇐ ENTER FILENAME FOR OUTPUT:

⇒ **AF21DAXY.B***

⇐ THE DEFAULT VALUE OF MIN INELASTIC STRAIN IS      1.00000E-4
  DO YOU WANT TO CHANGE IT?, YES(Y) OR NO(N):

⇒ **N**

⇐ ISOTHERMAL (ISO) OR BITHERMAL (BTH) CYCLES? ISO

⇒ **ISO**

⇐ INPUT ISOTHERMAL TEMP-DEG C:

⇒ **760**

⇐ DO YOU WANT TO USE THE MEAN STRESS CORRECTION OF
  HALFORD & NACHTIGALL ? YES(Y) OR NO(N):

⇒ **N**

---

* User may give any other name.

The program now displays the number of data points available for each type of SRP cycle.

⇐ NUMBER OF PP POINTS =  9
   NUMBER OF PC POINTS =  6
   NUMBER OF CP POINTS =  3
   NUMBER OF CC POINTS =  3

      CRUNCHING PP DATA
*****************************************
⇐ PP CONSTANTS DETERMINED, DO YOU WANT TO CONTINUE?, YES(Y) OR NO(N):
⇒ N

The response here is no (N) because in the first run we only want to determine the PP constants.

⇐ PP-CONSTANTS DETERMINED.

The program FAIL will now be run again to determine the SRP relations. The following prompt appears.

⇐ CALL FAIL TO DETERMINE SRP-RELATIONSHIPS.
⇐ ENTER NAME OF INPUT FILE:
⇒ AF21DA.NAS
⇐ DO YOU WANT TO SEND OUTPUT TO A FILE?  (Y/N)
⇒ Y
⇐ ENTER THE NAME FOR OUTPUT FILE
⇒ AF21DA.FAL♦
⇐ DO YOU WANT TO WRITE X, Y DATA FILES FOR OFF-LINE PLOTTING, YES(Y) OR NO(N)?
⇒ Y
⇐ ENTER FILENAME FOR OUTPUT:
⇒ AF21DAXY.FAL♦
⇐ THE DEFAULT VALUE OF MINIMUM INELASTIC STRAIN IS        1.00000E-04 DO YOU WANT TO CHANGE IT?, YES(Y) OR NO(N):
⇒ N
⇐ ISOTHERMAL (ISO) OR BITHERMAL (BTH) CYCLES?
⇒ ISO
⇐ INPUT ISOTHERMAL TEMP-DEG C:
⇒ 760
⇐ DO YOU WANT TO USE THE MEAN STRESS CORRECTION OF

---

♦ The filename is arbitrary.

HALFORD & NACHTIGALL ?, YES(Y) OR NO(N):

$\Rightarrow$ **Y**

We chose the response as yes (Y) now, because we want to include the mean stress effects on cyclic life.

$\Leftarrow$ NUMBER OF PP POINTS =  9
   NUMBER OF PC POINTS =  6
   NUMBER OF CP POINTS =  3
   NUMBER OF CC POINTS =  3

     CRUNCHING PP DATA
\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

$\Leftarrow$ PP CONSTANTS DETERMINED, DO YOU WANT TO CONTINUE?, YES(Y) OR
   NO(N):

$\Rightarrow$ **Y**

The response here is yes (Y) because in this run we want to determine other SRP relations. Note that each type of SRP cycle has more than two points available for determining the constants in equations (1) and (2) of FAIL section.

$\Leftarrow$                       CRUNCHING PC DATA
   \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

$\Leftarrow$ DETERMINE ELASTIC LINE AS A FUNCTION OF HOLD TIME? YES(Y) OR
   NO(N):

$\Rightarrow$ **N**

$\Leftarrow$                       CRUNCHING CP DATA
   \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

$\Leftarrow$ DETERMINE ELASTIC LINE AS A FUNCTION OF HOLD TIME ? YES(Y) OR
   NO(N):

$\Rightarrow$ **N**

     This completes the analysis of the CP data, and the program will now analyze the CC data if sufficient data are available (number of CC points $\geq 2$).

$\Leftarrow$                       CRUNCHING CC DATA
   \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

$\Leftarrow$ CC DAMAGE FRACTION =      0.409904
$\Leftarrow$ DAMAGE FRACTION LESS THAN 0.50. DO YOU WANT
   TO INCLUDE THIS POINT? YES(Y) OR NO(N):

$\Rightarrow$ **Y**

The damage fraction is fairly close to the desired value of 0.50, and we choose to include it because of the paucity of data CC (three points). The constants in the two $\Delta\varepsilon_{in} - N_{cc}$ relations (equation (1) of FAIL section) are now determined as noted earlier.

$\Leftarrow$ DETERMINE ELASTIC LINE AS A FUNCTION OF HOLD TIME ? YES(Y) OR NO(N):

$\Rightarrow$ **N**

$\Leftarrow$ SRP RELATIONS DETERMINED.
PROGRAM FAIL FINISHED.
\*\*\*\*\*\*\*\*\*\*\*\*\*\*

$\Leftarrow$ PROGRAM WILL CALL SUBROUTINE FLOW TO DETERMINE
THE STRAIN HARDENING EXPONENT, n.
USER MUST SUPPLY THE PERTINENT INPUT FILE.

$\Leftarrow$ ENTER INPUT FILE NAME:

$\Rightarrow$ **AF21DA.NAS**

$\Leftarrow$ SEND OUTPUT TO A FILE, YES(Y) OR NO(N)?

$\Rightarrow$ **Y**

This response permits the creation of a file for output.

$\Leftarrow$ ENTER FILE NAME FOR OUTPUT:

$\Rightarrow$ **AF21DA.N**$^\blacklozenge$

$\Leftarrow$ DO YOU WANT TO WRITE X-Y DATA FILES FOR OFF-LINE
PLOTTING? YES(Y) OR NO (N):

$\Rightarrow$ **Y**

A response of Y permits a file to be created for off-line plotting using appropriate commercially available software.

$\Leftarrow$ ENTER FILENAME FOR OUTPUT:

$\Rightarrow$ **AF21DAXY.N**$^\blacklozenge$

This response appears if the response to the previous prompt was Y.

$\Leftarrow$ THE DEFAULT VALUE OF MINIMUM INELASTIC S.R. IS     1.00000E-04
DO YOU WANT TO CHANGE IT? YES(Y) OR NO (N):

$\Rightarrow$ **N**

$\Leftarrow$ ENTER TYPE OF DATA FOR ANALYSIS
1 = FLOW DATA ONLY
2 = FAILURE DATA ONLY

---

$^\blacklozenge$ User may assign any other filename.

3 = FLOW AND FAILURE DATA

The user has the option of using data from flow tests only, failure tests only, or both. This dataset contains only failure data, so the appropriate response is 2.

$\Rightarrow$ **2**
$\Leftarrow$ ISOTHERMAL(TSO) OR BITHERMAL (BTH)
    OR THERMOMECHANICAL (TMF) CYCLES?
$\Rightarrow$ **ISO**

Life predictions are to be made for isothermal data at 760 $^{\circ}$C, so the appropriate response is ISO.

$\Leftarrow$ INPUT ISOTHEMAL TEMP:
$\Rightarrow$ **760**

The program now displays the number of data points available for each type of SRP cycle.

$\Leftarrow$ BCCR - NOT PROGRAMMED FOR THIS CYCLE TYPE
    BCCR - NOT PROGRAMMED FOR THIS CYCLE TYPE
    BCCR - NOT PROGRAMMED FOR THIS CYCLE TYPE
    NUMBER OF PP POINTS =    9
    NUMBER OF PC POINTS =    6
    NUMBER OF CP POINTS =    3
    NUMBER OF CC POINTS =    0
 PAUSE: NUMBER OF DATA POINTS FOR CURVE FITTING
 Enter 'go' to continue.

$\Leftarrow$ ANALYZE PP DATA ?, YES(Y) OR NO(N):
$\Rightarrow$ **Y**

The value of the cyclic strain hardening exponent $n$ in equation (4) of FLOW section is to be determined from the PP test data.

$\Leftarrow$ CRUNCHING PP DATA
$\Leftarrow$ EXPONENT n DETERMINED.
  .

The constants in equation (4) of FLOW section are now determined and are shown in figure 8. Two output files have been created: The first, AF21DA.N, contains the correlation for the strain hardening coefficient. The second, AF21DAXY.N, contains the same information but in an X-Y format for plotting.

      The remaining flow correlations are determined using the dataset AF21DA.PWA, which features strain-hold test data. This is necessary because we intend to predict the life of a compressive strain-hold (CHSC) cycle. The following prompts appear:

⇐ PROGRAM WILL NOW DETERMINE CONSTANTS
   APRIME, m, alpha IN THE FLOW EQUATION.
   USER MUST SUPPLY THE PERTINENT INPUT FILE.
⇐ ENTER INPUT FILE NAME:
⇒ **AF21DA.PWA**
⇐ SEND OUTPUT TO A FILE, YES(Y) OR NO(N))?
⇒ **N**
⇐ ENTER FILENAME FOR OUTPUT:
⇒ **AF21DA.FLO\***
⇐ DO YOU WANT TO WRITE X-Y DATA FILES FOR OFF-LINE
   PLOTTING YES(Y) OR NO(N):
⇒ **Y**
⇐ ENTER FILENAME FOR OUTPUT:
⇒ **AF21DAXY.FLO\***
⇐ THE DEFAULT VALUE OF MINIMUM INELASTIC S.R. IS          1.00000E-04
   DO YOU WANT TO CHANCE IT? YES(Y) OR NO(N):
⇒ **N**
⇐ SELECT TYPE OF DATA FOR ANALYSIS
   1 = FLOW DATA ONLY
   2 = FATLURE DATA ONLY
   3 = FLOW AND FAILURE DATA
⇒ **2**

This dataset contains only failure data for the strain-hold tests.

⇐ ISOTHERMAL (ISO) OR BITHERMAL (BTH)
   OR THERMOMECHANICAL (TMF) CYCLES?
⇒ **ISO**

We intend to predict the life of an isothermal cycle, so ISO is the appropriate response.

⇐ INPUT ISOTHERMAL TEMP:
⇒ **760**

The program now displays the number of data points available for each type of SRP cycle.

⇐ BCCR - NOT PROGRAMMED FOR THIS CYCLE
   BCCR - NOT PROCFA14MED FOR THIS CYCLE
   TCER - NOT PROGRAMMED FOR THIS CYCLE TYPE
   TCER - NOT PROGRAMMED FOR THIS CYCLE TYPE
   TCER - NOT PROGRAMMED FOR THIS CYCLE TYPE
   NUMBER OF PP POINTS =        8

---

* Any other file name may be chosen.

```
     NUMBER OF PC POINTS =     12
     NUMBER OF CP POINTS =     12
     NUMBER OF CC POINTS =      3
```
PAUSE: NUMBER OF DATA POINTS FOR CURVE FITTING
Enter 'go' to continue.


$\Leftarrow$ ANALYZE PP DATA ? YES(Y) OR NO(N):
$\Rightarrow$ **N**


The appropriate response here is N because the cyclic strain hardening exponent has already been determined.


$\Leftarrow$ ANALYZE PC DATA, YES(Y) OR NO(N)?
$\Rightarrow$ **Y**


The appropriate response here is Y because the life of a PC cycle is being determined.


$\Leftarrow$ CRUNCHING PC DATA:
$\Leftarrow$ ENTER WAVE SHAPE FOR CORRELATION,
  CHSC, CCCR, FSSC:
$\Rightarrow$ **CHSC**


For isothermal conditions, three cyclic wave shapes are currently built into the program for PC cycles: CHSC, CCCR, and FSSC (see Table III). Since we intend to predict the life of a compressive strain-hold test, **CHSC** is the appropriate choice.


$\Leftarrow$ SET LIMITS ON TOTAL STRAINRANGE?, YES(Y) OR NO(N):
$\Rightarrow$ **N**


There are occasions where a good correlation is not obtained over the entire span of the data as measured by the total strain range (Ref. 17). This option gives the user the opportunity to limit data to tests within a specified maximum and minimum total strain range. For this example there is no need to set limits on the total strain range.


$\Leftarrow$ DETERMINE ALPHA BY TRIAL(T)
  OR MULTIPLE REGRESSION (M) :
$\Rightarrow$ **M**
$\Leftarrow$ SELECT TYPE OF CORRELATTON
  OPTION 2: TENSION STRESS VS HOLD TIME
  OPTION 3: COMPRESSION STRESS VS HOLD TIME
  OPTION 4: STRESS RANGE VS HOLD TIME
  OPTION 5: ELASTIC STRAINRANGE VS HOLD TIME
  OPTION 6: $F_{ij}$ VS HOLD TIME
  OPTION 7: $K_{ij}$ VS HOLD TIME
  OPTION 8: TRANSFERTO NEXT SECTION
  OPTION 9: QUIT PROGRAM

⇐ ENTER VALUE:
⇒ **3**
No. OF   POINTS FOR CURVE FIT =      9

The constants A', $\alpha$, and *m* (see equation (5) of FLOW section) for the $\sigma_c$ correlation are determined.

⇐ NEW PC CORRELATION OR NEW ALPHA? YES(Y) OR NO(N):
⇒ **Y**
⇐ CRUNCHING PC DATA:
⇐ ENTER WAVE SHAPE FOR CORRELATION,
   CHSC, CCCR, FSSC:
⇒ **CHSC**
⇐ SET LIMITS ON TOTAL STRAINRANGE? YES(Y) OR NO(N):
⇒ **N**
⇐ DETERMINE ALPHA BY TRIAL(T)
   OR MULTIPLE REGRESSION(M)?
⇒ **M**

The program presents the menu for the next correlation.

⇐ SELECT TYPE OF CORRELATION
   OPTION 2: TENSION STRESS VS HOLD TIME
   OPTION 3: COMPRESSION STRESS VS HOLD TIME
   OPTION 4: STRESS RANGE VS HOLD TIME
   OPTION 5: ELASTIC STRAINRANGE VS HOLD TIME
   OPTION 6: $F_{ij}$ VS HOLD TI14E
   OPTION 7: $K_{ij}$ VS HOLD TIME
   OPTION 8: TRANSFER TO NEXT SECTION
   OPTION 9: QUIT PROGRAM
⇐ ENTER VALUE:
⇒ **4**
⇐ No. OF POINTS FOR CURVE FIT =      9

The constants A', $\alpha$, and *m* are now determined for $\Delta\sigma$, correlation.

⇐ NEW PC CORRELATION OR NEW ALPHA? YES(Y) OR NO(N):
⇒ **Y**

Input to the program continues in the above manner determining the constants for the correlations for $\Delta\varepsilon_{el}$, and $F_{pc}$. The last correlation is for $K_{pc}$.

⇐ CRUNCHING PC DATA:
⇐ ENTER WAVE SHAPE FOR CORRELATION,
   CHSC, CCCR,FSSC:

$\Rightarrow$ **CHSC**
$\Leftarrow$ SET LIMITS ON TOTAL STRAINRANGE? YES(Y) OR NO(N):
$\Rightarrow$ **N**
$\Leftarrow$ DETERMINE ALPHA BY TRIAL(T)
   OR MULTIPLE REGRESSION(M)?
$\Rightarrow$ **M**

Nominally, $K_{ij}$ is not a function of total strain range, and the T option is appropriate with the value of $\alpha$ set equal to zero. For some alloys the value of $K_{ij}$ may be a weak function of total strain range, and the M option would be appropriate. In this example we choose to use the M option.

$\Leftarrow$ SELECT TYPE OF CORRELATION
   OPTION 2: TENSION STRESS VS HOLD TIME
   OPTION 3: COMPRESS10N STRESS VS HOLD TIME
   OPTION 4: STRESS RANCE VS HOLD TIME
   OPTION 5: ELASTIC STRAINRANGE VS HOLD TIME
   OPTION 6: $F_{ij}$ VS HOLD TIME
   OPTION 7: $K_{ij}$ VS HOLD TIME
   OPTION 8: TRANSFER TO NEXT SECTION
   OPTION 9, QUIT PROGRAM
$\Leftarrow$ ENTER VALUE:
$\Rightarrow$ **7**
$\Leftarrow$ No. OF POINTS FOR CURVE FIT =     8

The constants A', $\alpha$, and $m$ (see equation (8) of FLOW section) for the $K_{ij}$ are now determined. Note that one data point has been rejected because the inelastic strain range is less than the default value of EMIN.

$\Leftarrow$ NEW PC CORRELATION OR NEW ALPHA? YES (Y) , NO (N) :
$\Rightarrow$ **N**

All of the necessary PC correlations have been determined. A response of N terminates analysis of the PC data, and we now have the option of correlating the CP data.

$\Leftarrow$ ANALYZE CP DATA? YES(Y) OR NO(N): Y
$\Rightarrow$ **N**
$\Leftarrow$ ANALYZE CC DATA? YES(Y) OR NO (N):
$\Rightarrow$ **N**

The response for the above two cases is N because we are determining the life of a PC cycle.

$\Leftarrow$ FLOW RELATIONS DETERMINED.
   PROGRAM FLOW FINISHED.
   PROGRAM FLOW IS EXITING.

The program prints the following values:

$\Leftarrow$
specimen number:    243
total strain range:    0.008500
cycle type:    PC
FIJ =   0.577843E+00
KIJ =   0.273515E-01
CPRIME =    0.803573E-01

THE CYCLIC LIFE WITHOUT MEAN STYRESS IS
NF0 = 0.125709E+04

$\Leftarrow$ DO YOU WANT PREDICTED LIFE WRITTEN TO A FILE
YES(Y)/NO(N)?
$\Rightarrow$ **Y**

The following prompt appears only if the response above was Y.

$\Leftarrow$ ENTER OUTPUT FILE NAME FOR PREDICTED CYCLIC LIFE
$\Rightarrow$ **PREDICT**♦

The program will account for mean stress effects, if required, by presenting the following prompts.

$\Leftarrow$ CORRECT FOR MEAN STRESS EFFECTS, (Y/N)
$\Rightarrow$ **Y**

The response is Y because we want to include mean stress effects.  The program prints the following values:

$\Leftarrow$

specimen number:    243
ELAS =   0.758225E-02
EIN =  0.917754E-03
K =    0.358601E+00
SMEAN =     0.143945E+03
SAMP =     0.739486E+03
V =    0.194656E+00

THE CYCLIC LIFE WITH MEAN STYRESS IS
Nfm = 0.966910E+03

---

♦ The file name is arbitrary.

The program will now ask if more life predictions are to be made.

$\Leftarrow$ MORE PREDICTIONS,  (Y/N)?
$\Rightarrow$ **N**

The response above is N because we do not want to make any more life predictions.

This finishes the program PSRPLIFE. The life of a PC cycle has been determined. The program outputs the life of a PC cycle without mean stress correction as 1257 and that with mean stress correction as 967 cycles. The negligibly small difference between these predicted lives and those listed in reference 13 is due to minor changes made to the programs and use of different computing platforms.

$\Leftarrow$ DO YOU WANT TO RUN ANY OTHER PROGRAM?  (Y/N)
$\Rightarrow$ **N**

The response above is N because at this time we do not wish to run any other program. This finishes the program FLAPS. The following message appears on the screen:

$\Leftarrow$         **** PROGRAM FLAPS FINISHED. ****

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**13. ABSTRACT** *(Maximum 200 words)*

This manual presents computer programs FLAPS for characterizing and predicting fatigue and creep-fatigue resistance of metallic materials in the high-temperature, long-life regime for isothermal and nonisothermal fatigue. The programs use the Total Strain version of Strainrange Partitioning (TS-SRP), and several other life prediction methods described in this manual. The user should be thoroughly familiar with the TS-SRP and these life prediction methods before attempting to use any of these programs. Improper understanding can lead to incorrect use of the method and erroneous life predictions. An extensive database has also been developed in a parallel effort. The database is probably the largest source of high-temperature, creep-fatigue test data available in the public domain and can be used with other life-prediction methods as well. This users' manual, software, and database are all in the public domain and can be obtained by contacting the author. The Compact Disk (CD) accompanying this manual contains an executable file for the FLAPS program, two datasets required for the example problems in the manual, and the creep-fatigue data in a format compatible with these programs.

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