User's Guide to DEVAR

A Computer Program for Estimating Development Rate as a Function of Temperature

Second Edition

M. J. Dallwitz and J. P. Higgins

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Abstract

DEVAR is a Fortran program for estimating development rate, as a function of temperature, from development times measured under fluctuating or constant temperatures. Fluctuating temperatures may be recorded at given times of day, or the maximum and minimum temperatures may be recorded. The development-rate function to be fitted may be supplied by the user as a Fortran function.

Input to the program is in free format, with the option of fixed format for the temperatures. Various options for input and output are specified by means of control words.

1. Introduction

Development rate, as a function of temperature, is usually estimated from development times measured at constant temperatures. However, there are benefits in using fluctuating temperatures for this purpose.

Firstly, the conditions under which the rate function is determined can be similar to those to which it will be applied. High or low constant temperatures give rises to stresses which may affect the development rate. Extremely high or low constant temperatures can produce 100% mortality, even at temperatures which commonly occur, for short periods, in the field.

Secondly, the equipment requirements may be simpler, because it is only necessary to record the temperatures, not to control them.

DEVAR is a flexible program for estimating the parameters of a development-rate function, from development times measured under fluctuating or constant temperatures. Fluctuating temperatures may be recorded at given times of day, or the maximum and minimum temperatures may be recorded. Maximum-minimum temperatures are interpolated by means of a user-supplied function.

2. The Development-rate Function

Two development-rate functions are supplied with DEVAR. The first is a straight line with threshold. This is defined as

$$r = \begin{cases} b_1(T-b_2) & \text{when } T \geq b_2 \\ 0 & \text{when } T < b_2 \end{cases}$$

where r is the development rate, expressed as percentage per day; b_1 is the percentage development per day per degree above the threshold temperature; b_2 is the threshold temperature; and T is the temperature. The Fortran source code for this function is supplied in the file RATE.FOR.

The second function supplied is

$$\begin{aligned} r_a &= b_1 10^{-v^2(1-b_5+b_5v^2)} \\ u &= (T-b_3)/(b_3-b_2) - c_1 \\ v &= (u + e^{b_4u})/c_2 \\ c_1 &= 1/(1+.28b_4+.72\ln(1+b_4)) \\ c_2 &= 1 + b_4/(1+1.5b_4+.39b_4{}^2) \end{aligned}$$

where r_a is the development rate, expressed as a percentage per day; b_1 is the maximum development rate; b_2 is approximately the temperature ($<b_3$) at which r_a falls to $b_1/10$; b_3 is approximately the temperature at which r_a is a maximum; b_4 controls how sharply r_a approaches 0 at low temperatures; and b_5 controls the asymmetry of r_a. The terms c_1 and c_2 allow the approximate interpretations of b_2 and b_3 given above. The Fortran source code for this function is supplied in the file RATEA.FOR.

The heuristic function r_a is almost linear over a wide range of temperatures, and it approaches 0 fairly sharply at low temperatures, in keeping with experience that a linear function with threshold provides a fairly good approximation to development rates except at high temperatures. If data at low and high temperatures are scarce, it may be difficult to determine accurate values for b_4 and b_5, and the convergence of the iterative fitting procedures (see METHOD, Section 3) may be poor. In that case, it is suggested that these parameters be given the fixed values b_4=6 and b_5=.4 (see PARAMETERS, Section 3). The shape of r_a with these parameter values is shown in Fig. 1.

The user may supply other functions, as described in the file DEVAR.1ST which accompanies the program.

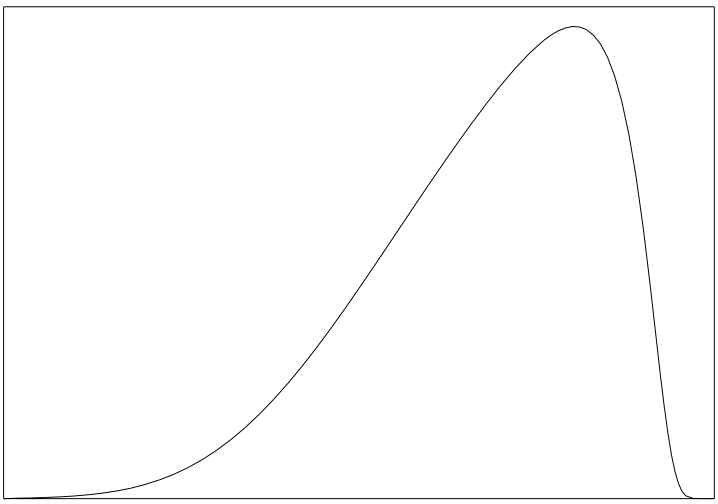

Figure 1. The function r_a with parameters b_4=6 and b_5=.4.

3. General Description of the Data Format

Execution of the program is controlled by *directives*, each of which consists of a *control word* and associated data.

The directives are in free format, that is, the control words and data do not have to be in particular positions in the lines. (However, there is provision for reading the temperatures in fixed format if required.) The data take different forms, depending on the control word, and in some directives may be absent. Control words and data elements are separated by spaces or by the end of a line. In some directives, additional separators such as parentheses may be used. A directive is terminated by the next control word.

Example

```
PERIOD 3.27 DAYS  BEGIN 10:00 AM 25/2/86
TEMPERATURES (MINIMUM 25/2/86) 14 28 16 27 11 31 9 29
```

The control words are PERIOD, BEGIN, and TEMPERATURES. The other words — DAYS, AM, and MINIMUM — are part of the data of the preceding control words.

Control words must be in upper-case letters. They may be abbreviated by leaving off letters from the right. The first letter is sufficient to identify all control words except PARAMETERS, which requires at least the first two letters, to distinguish it from PERIOD. Data words such as AM, PM, NO, and DAYS may also be abbreviated.

An *item* consists of a set of directives describing a single measurement of development time and associated information such as temperatures. Items must be separated by blank lines. (Blank lines may also be used within an item, provided that they do not separate any of the directives BEGIN, END, PERIOD, TEMPERATURES, and WEIGHT.) The directives in an item may appear in any order, except that the TEMPERATURES directive must be the last in the item if the temperatures are in fixed format.

The control words are listed below, with brief descriptions of their purposes. Detailed descriptions of the directives are given in Section 4, in alphabetical order of the control words.

BEGIN specifies the time at which development starts.
END specifies the time at which development is completed.
PERIOD specifies the elapsed time required to complete development.
TEMPERATURES specifies the temperatures.
PARAMETERS specifies initial values for the parameters of the development function.
STEPS specifies the times of day at which fluctuating temperatures are recorded, or are interpolated from maximum/minimum temperatures.
CYCLE specifies the function used to interpolate maximum/minimum temperatures.
WEIGHT specifies item weights to be used in estimating the parameters.
REMOVE specifies items which are not to be used in estimating the parameters.
METHOD specifies the least-squares fitting method to be used.
FORMAT specifies the format of fixed-format temperature data.
HEADING specifies a heading to be placed at the start of each section of the output.
IDENTIFIER specifies identifying text to be placed at the end of an item in the listing.
LISTING specifies whether the input data are to be listed in the output file.
GRAPH specifies whether a graph of the fitted function is to be output.

4. Directives (in Alphabetical Order)

■ *BEGIN*

Description

This directive specifies the time at which development begins.

General form

`BEGIN` *time date*

time must have one of the forms *hh*:*mm* AM, *hh*:*mm* PM, or *hhmm* (24-hour clock); and *date* must have one of the forms *dd*/*mm*/*yyyy* or *dd*/*mm*/*yy*.

Default

None. However, the BEGIN directive may be omitted from an item if the starting time is implied by PERIOD and END directives in the item, or if the PERIOD directive has been specified and the temperature is constant.

Example 1

```
BEGIN 1:35 PM 17/3/1975
```

Example 2

```
BEGIN 1335 17/3/75
```

The two examples are equivalent.

■ *CYCLE*

Description

This directive specifies the shape of the curve which is used to interpolate maximum/minimum temperatures. The interpolated temperatures are calculated as

$$T_t = T_{min} + (T_{max} - T_{min}) c_t$$

where T_t is the interpolated temperature at time of day t, T_{min} and T_{max} are the minimum and the maximum temperatures on either side of t, and c_t is the value of the cycle function at t.

There must be one cycle point corresponding to each time of day specified in the STEPS directive. If the cycle function takes its minimum value at more than one point, the minimum temperatures are associated with the first such point. If the cycle function takes its maximum value at more than one point, the maximum temperatures are associated with the first such point *after* the minimum, or, failing this, the first such point (see Example 2).

The cycle function may be estimated from temperatures measured at fixed times of day (for example, each hour), for several typical days. A simple estimate of the cycle function is given by

$$c_i = \frac{T_i - T_l}{T_u - T_l}$$

where c_i is the cycle point of the ith time of day, T_i is the mean temperature for the ith time of day, T_l is the minimum value of the T_i, and T_u is the maximum value of the T_i.

Alternatively, the points of the cycle may be calculated from some mathematical function (e.g. a sine function) which approximates the actual cycle.

General form

CYCLE $c_1\ c_2 \ldots c_i \ldots$

where c_i is any real number. At most 24 cycle points may be specified.

Default

None. However, once a cycle has been specified, it remains in force from one item to the next until another cycle is specified.

Example 1

```
CYCLE 0.11 0.03 0.0 0.06 0.23 0.46 0.75 0.95 1.0 0.76 0.43 0.24
```

Assuming mimimum and maximum temperatures of 10° and 20°, this would produce the following interpolated temperatures: 11.1 10.3 10 10.6 12.3 14.6 17.5 19.5 20 17.6 14.3 12.4.

Example 2

```
STEPS 6 6 14 14 CYCLE 1 0 0 1
```

These two directives define a square-wave cycle, with the lower temperatures between 0600 hours and 1400 hours, and the higher temperatures for the rest of the day. The minimum temperature is assumed to occur at 0600 hours (2nd step) and the maximum temperature at 1400 hours (4th step).

■ *END*

Description

This directive specifies the time at which development ends.

General form

END *time date*

time must have one of the forms *hh*:*mm* AM, *hh*:*mm* PM, or *hhmm* (24-hour clock); and *date* must have one of the forms *dd*/*mm*/*yyyy* or *dd*/*mm*/*yy*.

Default

None. However, the END directive may be omitted from an item if the starting time is implied by PERIOD and BEGIN directives in the item, or if the PERIOD directive has been specified and the temperature is constant.

Example 1

```
END 9:00 AM 17/3/1975
```

Example 2

```
END 0900 17/3/75
```

The two examples are equivalent.

■ *FORMAT*

Description

This directive specifies the format for the temperature data.

General form

FORMAT $b_1 - e_1 \; b_2 - e_2 \; \ldots b_i - e_i \; \ldots$

where b_i and e_i are integers in the range 1 to 80. b_i and e_i specify respectively the beginning and the end of the ith temperature field on each line. e_i must be greater than or equal to b_i, and b_i must be greater than e_{i-1}. At most 80 fields may be specified. If there are no data following the control word, the format is set to 'free'.

Default

Free format. However, once a format has been specified, it remains in force from one item to the next until another FORMAT directive is used.

Example

```
FORMAT 1-4 5-8 21-24 25-28
```

Four temperatures would be read from each line, from columns 1 to 4, 5 to 8, 21 to 24, and 25 to 28. For another example, see the TEMPERATURES directive.

■ *GRAPH*

Description

This directive specifies whether or not graphical output is to be produced. This output consists of two graphs drawn on the same set of axes. The first is a line graph of the theoretical development rate as predicted by DEVAR, plotted against temperature. The second is a point graph of the observed development rate for each item in the data, plotted against the mean temperature for the item.

It should be noted that, in general, the closeness of the points to the line is not a direct measure of the goodness of fit (except in the case of constant temperatures).

General form

GRAPH f

where f is YES, NO, or absent. 'Absent' is equivalent to YES.

Default

No graph is produced.

Example

```
GRAPH
```

■ *HEADING*

Description

This directive may be used to specify a heading and comments. The first occurrence of the directive specifies a heading, which is formatted (by eliminating excess blanks and filling lines to a preset length), and printed at the start of each section of the output. The second and subsequent occurrences of the directive specify comments, which are formatted and printed immediately.

General form

HEADING $ *text* $

The $ signs that delimit the text must be preceded and followed by blanks (or the start or end of a line). The symbol / in the text, when preceded and followed by blanks, produces a new line in the printed heading or comment. For a heading (i.e. in the first occurrence of the directive), the text must not contain more than 160 characters.

Default

None.

Example

```
HEADING $ DEVELOPMENT OF EGGS
OF B. MICROPLUS / / R. Sutherst and G. Maywald $
```

This would produce the heading

```
DEVELOPMENT OF EGGS OF B. MICROPLUS

R. Sutherst and G. Maywald
```

■ *IDENTIFIER*

Description

This directive may be used to specify an indentifying message for an item. The message is formatted (by eliminating excess blanks and filling lines to a preset length), and printed at the end of the data for the item.

General form

IDENTIFIER $ *text* $

The $ signs that delimit the text must be preceded and followed by blanks (or the start or end of a line). The symbol / in the text, when preceded and followed by blanks, produces a new line in the printed message. The text must not contain more than 160 characters.

Default

None.

Example

```
IDENTIFIER $ Cage 5 / Long grass $
```

This would produce the identifying message

```
Cage 5
Long grass
```

■ *LISTING*

Description

This directive specifies whether or not the input data will be printed on the output file. The directive may be used any number of times. Each directive is effective until the next LISTING directive.

General form

LISTING *f*

where *f* is YES, NO, or absent. 'Absent' is equivalent to YES.

Default

The data are listed.

Example

```
LISTING NO
```

■ *METHOD*

Description

This directive specifies which method is to be used for the least-squares fitting. Method 1 is Powell's algorithm (Powell 1965) (subroutine LSQFUN, adapted by P. J. Ross, CSIRO Division of Soils). Method 2 is the Levenberg-Morrison-Marquardt algorithm (Miller 1981) (subroutine LMM).

In Method 1, the initial parameter accuracies (see directive PARAMETERS) affect both the sizes of the initial steps in the iteration, and the final accuracy of the parameter estimates (i.e. the convergence criterion). In Method 2, the step sizes and the convergence criterion are independent of the specified accuracies, which, in this case, merely indicate which parameters are variable.

General form

METHOD *n*

where *n* is 1 or 2.

Default

Method 2.

Example

```
METHOD 1
```

■ *PARAMETERS*

Description

This directive specifies the initial values of the parameters of the development function, and their approximate accuracies. If an accuracy is specified, the corresponding parameter is variable; that is, it will be adjusted during the least-squares fitting. Otherwise, the parameter is fixed. The number of variable parameters must be less than or equal to the number of items in the least-squares fitting.

If convergence of the fitting procedure is poor, it may be helpful to fix some of the parameters in a preliminary run, and use the values so obtained as the initial values in another run, with all of the parameters variable.

General form

PARAMETERS b_1 (e_1) b_2 (e_2) $\ldots b_i$ (e_i) $\ldots$

where b_i and (e_i) are respectively the initial value and accuracy of the ith parameter. b_i corresponds to B(I) in the Fortran function RATE (see Section 1). If (e_i) is absent, the corresponding parameter is fixed. If (e_i) is present, it may express the accuracy of the corresponding parameter as an absolute value or as a percentage. Absolute and percentage accuracies take the respective forms (a) and (aP), where a is a positive real number. For further information on the significance of the accuracies, see the METHOD directive.

The minimum abbreviation for the control word is PA (to distinguish it from PERIOD).

Default

None.

Example

```
PARAMETERS 40 (20P) 30 (5) 15 (20P) 0.8 0.3
```

■ *PERIOD*

Description

This directive specifies the time required to complete development.

General form

PERIOD d DAYS h HOURS m MINUTES

where d, h and m are real, non-negative numbers.

Default

None. However, the PERIOD directive may be omitted from an item if the development time is implied by BEGIN and END directives in the item.

Example 1

```
PERIOD 20.1 DAYS
```

Example 2

```
P 20 D 2 H 24 M
```

The two examples are equivalent.

■ *REMOVE*

Description

This directive specifies which items are to be excluded from the calculation for the least-squares fitting. The removed items are still included in the calculation of the residual sum of squares, and also appear on any graphical output.

General form

REMOVE $b_1 - e_1\ b_2 - e_2 \ldots b_i - e_i \ldots$

where b_i and e_i are integers specifing respectively the beginning and end of a range of item numbers. e_i must be greater than or equal to b_i, or may be absent. If there are no data following the control word, no items are removed.

Default

All items are included in the least-squares fitting.

Example

```
REMOVE 1 3 7 9-13 16
```

■ *STEPS*

Description

This directive specifies the times of day at which fluctuating temperatures are recorded, or are interpolated from maximum/minimum temperatures.

General form

STEPS $s_1\ s_2 \ldots s_i \ldots$

where the s_i are a non-decreasing sequence of real numbers in the range 0 to 24 inclusive. Each number represents a time of day, in hours. At most 100 steps may be specified.

Default

None. However, once a STEPS directive has been used, the specified times remain in force from one item to the next, until another STEPS directive is used.

Example 1

```
STEPS 1 2 3 4 5 6 7 8 9 10 11 12 13 14
      15 16 17 18 19 20 21 22 23 24
```

Hourly temperatures.

Example 2

```
STEPS 0.1667 2.8333 5.5 6.8333 8.1667 9.5 10.8333 12.1667 13.5
      16.667 18.333 21.5
```

The times increase by $1\frac{1}{3}$ hours between 5:30 AM and 1:30 PM, and by $2\frac{2}{3}$ hours for the rest of the day.

■ *TEMPERATURES*

Description

This directive specifies the temperatures at which the development for an item takes place. The data may be in free or fixed format as indicated by the FORMAT directive current for the item. If the format is fixed then the TEMPERATURES directive must be the last directive in the item, and the temperature data must start on the line after the line which contained the control word TEMPERATURES.

General form (constant temperature)

TEMPERATURES *T*

where *T* is a real number in the range −30 to 60.

General form (fluctuating temperatures, fixed times of day)

TEMPERATURES (*time date*) T_1 T_2 $\ldots T_i \ldots$

where T_i is a real number in the range −30 to 60. *time* must have one of the forms *hh*:*mm* AM, *hh*:*mm* PM, or *hhmm* (24-hour clock); and *date* must have one of the forms *dd*/*mm*/*yyyy* or *dd*/*mm*/*yy*. *time* and *date* are the time and date of the first temperature. *time* must correspond to a time of day specified in the STEPS directive.

General form (fluctuating temperatures, maximum/minimum)

TEMPERATURES (*e date*) T_1 T_2 $\ldots T_i \ldots$

where *e* is MAXIMUM or MINIMUM, and T_i is a real number in the range −30 to 60. *date* must have one of the forms *dd*/*mm*/*yyyy* or *dd*/*mm*/*yy*. *e* specifies whether the first temperature is a maximum or minimum, and *date* specifies the date on which it occurred.

Default

None.

Example 1

```
TEMPERATURE 12.4
```

Example 2

```
FORMAT 7-11 12-16 17-21 22-26 27-31 32-36
      37-41 42-46 47-51 52-56 57-61 62-66
TEMPERATURES (1:00 AM 18/10/80)
181080 10.5 11.8 12.3 12.5 12.4 12.4 12.7 13.7 16.4 18.3 20.5 22.5
       23.9 24.6 24.6 24.6 24.2 22.1 18.8 17.5 16.5 16.2 15.4 15.1
191080 14.7 14.2 14.2 13.8 13.4 13.0 13.3 13.2 13.3 14.0 13.9 14.2
       15.6 17.3 17.9 19.2 20.0 19.4 16.5 14.6 13.5 12.8 12.4 12.1
201080 11.5 11.0 10.9 10.6 10.3 10.3 12.0 13.5 16.0 17.4 17.6 16.7
       18.4 19.7 19.0 20.3 21.1 20.6 19.1 17.4 16.1 14.9 14.4 13.7
211080 13.3 12.8 12.3 12.5 12.9 13.3 13.7 14.1 16.6 18.2 19.4 20.6
       22.1 22.7 23.3 23.7 23.2 22.2 19.0 16.7 15.1 13.7 13.1 13.3
221080 13.3 12.6 11.3 10.5 10.0  9.5 11.2 13.8 15.9 17.4 19.2 21.6
       23.0 23.9 24.6 25.0 24.7 23.0 18.4 15.8 14.9 14.1 13.2 12.4
```

Example 3

```
TEMPERATURES (MAX 25/2/78)
31 18 31 20 28 20 24 15 24 12 22 8 31 14
33 18 25 17 37 18 28 17 37 16 37 15 37 16
36 16 38 13 31 9 23 8 25 16 31 24 23 17
23 17 31 15 32 16 34 17 26 14 30 13 25 14
```

■ *WEIGHT*

Description

This directive specifies the weight to be given to an item in the least-squares fitting, and in the calculation of the residual sum of squares. The weight should generally be proportional to (development time squared)/(variance of development time). If the weight has an integer value *n*, then the effect is the same as if the item appeared *n* times in the data (with weight 1). A weight of 0 causes the item to be ignored in both the least-squares fitting and the calculation of the residual sum of squares (cf. REMOVE). See also Section 5.

General form

`WEIGHT` *w*

where *w* is a real number greater than or equal to 0.

Default

The weight of each item is 1.

Example

```
WEIGHT 3.5
```

5. Examples

Example 1 – input

```
HEADING $ TEST 1.
          FLEDGING TIME OF CHORTOICETES TERMINIFERA FEMALES $
HEADING $ R. Dallwitz, unpublished data. $

PARAMETERS 0.35 (10P) 20
METHOD 1

CYCLE 0.11 0.03 0 0.06 0.23 0.46 0.75 0.95 1.0 0.76 0.43 0.24
STEPS 0.1666 2.8333 5.5 6.8333 8.1667 9.5 10.8333
12.1667 13.5 16.1667 18.8333 21.5


PERIOD 22 DAYS  BEGIN 2200 1/1/75  WEIGHT 6  IDENT $ CAGE A $
TEMPERATURES (MINIMUM 1/1/75)
      25 44 25 44 25 33 15 37 24 44 25 45 25 46 26 37 26 45
27 47 28 42 25 42 25 43 25 46 26 46 26 46 26 44 26 46 26 46
25 46 25 43 27 35 27 42 28 40

LISTING NO

PERIOD 27 DAYS  BEGIN 2200 1/1/75  WEIGHT 4  IDENT $ CAGE B $
TEMPERATURES (MINIMUM 1/1/75)
      22 45 22 45 23 46 23 37 23 40 23 47 24 43 13 38 23 46
24 47 26 47 25 37 26 46 26 47 28 41 26 45 25 45 26 47 24 48
25 48 25 46 24 48 26 48 25 47 25 45 27 36 27 45 27 42 27 46
26 47

PERIOD 20 DAYS  BEGIN 2200 1/1/75  WEIGHT 9  IDENT $ CAGE E $
TEMPERATURES (MINIMUM 1/1/75)
      28 48 28 48 29 49 31 47 32 50 30 38 30 49 30 43 31 51
30 49 30 49 30 50 30 46 31 53 32 51 31 38 22 39 30 48 32 37
31 40 32 48 30 50 30 50 31 44

PERIOD 26 DAYS  BEGIN 2200 1/1/75  WEIGHT 4  IDENT $ CAGE F $
TEMPERATURES (MINIMUM 1/1/75)
      28 41 28 41 30 38 30 34 26 37 27 36 27 44 28 43 27 44
27 43 28 35 27 47 28 38 27 47 26 46 25 47 26 47 27 46 26 48
27 46 27 33 18 35 26 43 26 31 26 33 27 41 25 42 25 44 27 36

PERIOD 21 DAYS  BEGIN 2200 1/1/75  WEIGHT 3  IDENT $ CAGE G $
TEMPERATURES (MINIMUM 1/1/75)
      31 43 31 43 31 35 34 43 33 40 31 43 30 40 29 47 30 48
31 47 31 46 31 37 31 48 31 42 32 50 30 49 31 51 30 48 31 45
30 48 32 50 32 38 32 38

PERIOD 17 DAYS  BEGIN 2200 1/1/75  WEIGHT 7  IDENT $ CAGE H $
TEMPERATURES (MINIMUM 1/1/75)
      31 59 31 59 31 43 29 39 30 45 33 43 32 39 31 45 28 41
28 48 29 48 30 48 30 48 30 37 29 49 31 42 31 49 29 49 31 50
31 51 31 47 32 52 32 53 32 38

PERIOD 24 DAYS  BEGIN 2200 1/1/75  WEIGHT 8  IDENT $ CAGE I $
TEMPERATURES (MINIMUM 1/1/75)
      23 31 23 31 25 42 27 39 26 39 26 41 27 44 28 31 27 37
27 42 27 42 26 38 26 39 25 39 24 43 25 39 26 39 26 40 29 38
28 34 25 37 25 35 25 43 26 42 26 43 26 42

PERIOD 30 DAYS  BEGIN 2200 1/1/75  WEIGHT 4  IDENT $ CAGE J $
TEMPERATURES (MINIMUM 1/1/75)
      25 37 25 37 24 40 24 40 25 30 24 39 24 27 23 28 23 34
23 30 22 28 24 40 25 38 24 38 24 40 25 42 25 28 25 37 25 40
25 40 24 38 24 39 24 39 24 43 25 38 24 37 24 40 27 37 28 33
```

```
23 36 24 35 23 43 22 33 24 41 24 41 25 32

PERIOD 42 DAYS  BEGIN 2200 1/1/75  WEIGHT 1  IDENT $ CAGE K $
TEMPERATURES (MINIMUM 1/1/75)
      20 27 20 27 19 32 19 32 19 25 19 25 20 28 21 27 20 26
22 31 33 34 21 36 22 36 23 28 22 34 22 26 21 30 20 32 20 29
19 27 20 37 21 36 22 34 22 35 22 38 21 26 21 34 21 39 22 39
22 35 22 36 22 39 22 35 20 32 22 34 25 34 24 31 21 34 22 36
22 34 22 41 22 33 23 40 23 40

PERIOD 64 DAYS  BEGIN 2200 1/1/75  WEIGHT 2  IDENT $ CAGE L $
TEMPERATURES (MINIMUM 1/1/75)
      17 26 17 26 17 30 23 31 17 24 18 25 22 26 19 27 18 23
18 28 20 32 18 35 18 35 19 25 18 33 19 25 17 28 17 28 17 27
16 25 17 37 17 35 20 37 21 37 18 37 19 24 19 33 21 37 20 38
20 35 20 35 20 36 20 39 20 35 22 34 20 35 22 32 22 30 19 33
19 31 19 38 19 38 19 38 20 38 20 32 19 39 20 33 20 40 17 40
20 40 17 43 18 40 18 43 19 42 18 27 16 27 19 39 19 24 18 27
18 37 17 40 18 40 16 31 16 31 16 37 18 30 19 22

PERIOD 43 DAYS  BEGIN 2200 1/1/75  WEIGHT 2  IDENT $ CAGE M $
TEMPERATURES (MINIMUM 1/1/75)
      21 36 21 36 22 40 23 39 23 31 23 38 23 39 24 34 21 35
20 38 21 38 22 37 21 38 22 37 22 38 22 38 22 38 20 35 24 28
24 36 26 33 25 38 22 39 21 39 24 39 25 34 26 28 22 30 22 28
22 35 25 36 22 35 20 34 25 32 26 30 26 30 22 40 22 39 20 34
24 38 25 39 25 38 24 38 25 38 25 38 21 34 20 38 20 38

PERIOD 25 DAYS  BEGIN 2200 1/1/75  WEIGHT 14  IDENT $ CAGE N $
TEMPERATURES (MINIMUM 1/1/75)
      28 41 28 41 24 41 14 43 24 35 25 46 25 46 25 44 28 46
29 46 24 46 24 43 26 34 26 39 29 39 27 42 25 44 24 47 26 48
28 49 26 33 25 34 24 31 26 43 27 48 25 36 24 39 29 40 31 34
29 36 26 48

PERIOD 38 DAYS  BEGIN 2200 1/1/75  WEIGHT 1  IDENT $ CAGE O $
TEMPERATURES (MINIMUM 1/1/75)
      21 39 21 39 21 38 20 36 22 29 22 37 24 34 24 39 21 40
22 40 24 36 22 29 21 28 21 25 21 36 23 37 20 36 18 36 23 32
25 28 25 30 22 38 21 40 18 36 22 39 23 43 24 38 24 39 25 38
24 40 22 44 21 40 20 38 21 36 20 37 22 38 24 38 23 28 23 44
20 45 19 44

PERIOD 20 DAYS  BEGIN 2200 1/1/75  WEIGHT 1  IDENT $ CAGE P $
TEMPERATURES (MINIMUM 1/1/75)
      23 48 23 48 23 48 27 46 28 47 27 47 28 47 27 47 27 46
29 36 29 42 31 41 30 45 27 46 26 45 29 48 31 47 29 35 28 37
30 35 29 45 31 48 28 37 28 43

PERIOD 19 DAYS  BEGIN 2200 1/1/75  WEIGHT 4  IDENT $ CAGE Q $
TEMPERATURES (MINIMUM 1/1/75)
      22 48 22 48 25 46 28 45 28 46 28 47 31 49 28 47 30 38
30 43 32 42 31 45 28 47 27 46 30 48 32 48 30 37 29 38 31 37
30 46 30 46

PERIOD 20 DAYS  BEGIN 2200 1/1/75  WEIGHT 2  IDENT $ CAGE R $
TEMPERATURES (MINIMUM 1/1/75)
      24 48 24 48 28 47 29 48 28 48 28 48 29 48 28 47 30 38
30 43 33 42 31 47 28 47 27 47 30 48 33 48 30 37 29 38 31 37
30 47 33 48 30 40 29 44

PERIOD 18 DAYS  BEGIN 2200 1/1/75  WEIGHT 9  IDENT $ CAGE S $
TEMPERATURES (MINIMUM 1/1/75)
      29 50 29 50 29 52 29 52 29 52 29 52 29 50 30 36 30 43
32 42 31 48 28 50 28 49 30 53 39 52 30 35 29 37 31 35 30 48
31 53

PERIOD 34 DAYS  BEGIN 2200 1/1/75  WEIGHT 11  IDENT $ CAGE T $
```

```
TEMPERATURES (MINIMUM 1/1/75)
      24 42 24 42 25 39 26 39 24 40 25 42 28 33 26 38 29 38
29 42 25 42 24 41 27 42 30 43 25 34 25 31 24 39 26 39 28 44
24 35 23 32 26 36 29 32 29 33 25 40 26 32 18 39 26 44 24 40
29 42 28 45 30 43 27 40 24 41 24 45 24 47 26 46

PERIOD 40 DAYS  BEGIN 2200 1/1/75  WEIGHT 1  IDENT $ CAGE V $
TEMPERATURES (MINIMUM 1/1/75)
      21 36 21 36 18 30 20 39 20 26 17 31 19 35 19 37 21 37
20 30 21 38 21 38 22 35 21 36 20 38 20 38 21 38 21 41 21 40
21 38 21 39 21 38 20 36 22 30 22 36 24 34 24 39 21 40 20 40
22 40 24 35 22 29 21 28 21 25 21 36 23 37 19 28 19 35 23 32
25 28 25 30 22 40 21 40 19 35 22 39 23 40 24 39

PERIOD 45 DAYS  BEGIN 2200 1/1/75  WEIGHT 1  IDENT $ CAGE W $
TEMPERATURES (MINIMUM 1/1/75)
      20 36 20 36 22 38 22 41 22 40 22 38 22 39 22 38 21 36
23 30 23 38 25 34 25 39 22 40 21 40 23 40 25 35 23 30 22 29
22 27 22 36 24 38 20 35 20 35 24 33 26 29 26 31 23 40 23 40
19 35 23 39 24 40 25 39 24 38 25 38 25 38 21 39 20 38 20 38
21 36 17 35 19 36 19 36 20 27 19 39 27 41 27 41

PERIOD 23 DAYS  BEGIN 2200 1/1/75  WEIGHT 4  IDENT $ CAGE X $
TEMPERATURES (MINIMUM 1/1/75)
      26 35 26 35 25 35 25 32 26 45 29 48 25 37 25 43 29 42
31 36 31 38 27 48 25 33 15 46 26 48 28 48 30 47 30 47 31 47
28 48 31 48 25 48 26 49 27 46 26 48 24 47

PERIOD 16 DAYS  BEGIN 2200 1/1/75  WEIGHT 1  IDENT $ CAGE Z $
TEMPERATURES (MINIMUM 1/1/75)
      39 54 39 54 37 50 39 53 41 44 38 47 38 47 38 53 39 52
38 46 39 47 40 48 40 50 40 47 40 51 42 54 41 59 41 59
```

Example 1 – output

```
PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:16 ON 10-MAR-92.

TEST 1. FLEDGING TIME OF CHORTOICETES TERMINIFERA FEMALES

R. Dallwitz, unpublished data.

                 PARAMETERS 0.35 (10P) 20
                 METHOD 1

                 CYCLE 0.11 0.03 0 0.06 0.23 0.46 0.75 0.95 1.0 0.76 0.43 0.24
                 STEPS 0.1666 2.8333 5.5 6.8333 8.1667 9.5 10.8333
                 12.1667 13.5 16.1667 18.8333 21.5


                 PERIOD 22 DAYS  BEGIN 2200 1/1/75  WEIGHT 6  IDENT $ CAGE A $
                 TEMPERATURES (MINIMUM 1/1/75)
                       25 44 25 44 25 33 15 37 24 44 25 45 25 46 26 37 26 45
                 27 47 28 42 25 42 25 43 25 46 26 46 26 46 26 44 26 46 26 46
                 25 46 25 43 27 35 27 42 28 40

CAGE A
END OF ITEM   1.
-----------------------------------------------------------------------------

                 LISTING NO
CAGE B
END OF ITEM   2.
-----------------------------------------------------------------------------

*** WARNING - MINIMUM TEMPERATURE EXCEEDS ADJACENT MAXIMUM TEMPERATURE.
    TEMPERATURE NUMBER  21.
CAGE K
```

```
END OF ITEM   9.
------------------------------------------------------------------------------

CAGE Z
END OF ITEM  22.
------------------------------------------------------------------------------


PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:16 ON 10-MAR-92.

TEST 1. FLEDGING TIME OF CHORTOICETES TERMINIFERA FEMALES


ITERATION   0,    2 CALLS OF GIVEF,  F =   209.318
VARIABLES
  .350000


LSQFUN FINAL VALUES OF VARIABLES

ITERATION   1,    6 CALLS OF GIVEF,  F =   124.664
VARIABLES
  .320341


PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:16 ON 10-MAR-92.

TEST 1. FLEDGING TIME OF CHORTOICETES TERMINIFERA FEMALES


PARAMETERS =     .32034  20.00000
                         (FIXED)

RESIDUAL SUM OF SQUARES =   124.6638   ROOT MEAN SUM OF SQUARES = 11.4280
```

ITEM	OBS. TIME(DAYS)	MEAN TEMP.	STD. DEV.	DEVEL.	OBS. RATE	PRED. RATE	WEIGHT
1	22.000	32.23	6.69	86.70	4.55	3.94	6.00
2	27.000	32.33	7.33	107.31	3.70	3.97	4.00
3	20.000	36.44	6.29	105.31	5.00	5.27	9.00
4	26.000	32.25	5.83	102.15	3.85	3.93	4.00
5	21.000	36.42	5.24	110.49	4.76	5.26	3.00
6	17.000	36.16	5.95	87.98	5.88	5.18	7.00
7	24.000	31.17	4.92	85.87	4.17	3.58	8.00
8	30.000	29.06	4.84	87.12	3.33	2.90	4.00
9	42.000	25.98	4.80	80.73	2.38	1.92	1.00
10	64.000	24.45	5.87	99.25	1.56	1.55	2.00
11	43.000	27.99	4.88	110.06	2.33	2.56	2.00
12	25.000	31.80	6.54	95.04	4.00	3.80	14.00
13	38.000	27.67	5.53	93.60	2.63	2.46	1.00
14	20.000	34.27	6.05	91.39	5.00	4.57	1.00
15	19.000	35.09	5.83	91.82	5.26	4.83	4.00
16	20.000	35.64	5.89	100.20	5.00	5.01	2.00
17	18.000	36.56	6.73	95.51	5.56	5.31	9.00
18	34.000	31.09	5.27	120.97	2.94	3.56	11.00
19	40.000	26.54	5.38	84.49	2.50	2.11	1.00
20	45.000	27.86	5.44	113.71	2.22	2.53	1.00
21	23.000	33.38	6.83	99.03	4.35	4.31	4.00
22	16.000	43.58	4.33	120.87	6.25	7.55	1.00

Example 2 – input

```
HEADING $ TEST 2.
          CHECKS AGAINST INDEPENDENTLY CALCULATED RESULTS $

LISTING NO
PARAMETERS 1 20


IDENT $ CONSTANT TEMPERATURE, 100% DEVELOPMENT $
PERIOD 10 D  TEMP 30

IDENT $ ACTUAL TEMPERATURES, SQUARE WAVE, 100% DEVELOPMENT $
PERIOD 10 D  BEGIN 0000 1/1/80
STEPS 0 16 16 24
TEMP (0000 1/1/80)
 25 25 40 40 25 25 40 40 25 25 40 40 25 25 40 40 25 25 40 40
 25 25 40 40 25 25 40 40 25 25 40 40 25 25 40 40 25 25 40 40

IDENT $ MAX/MIN TEMPERATURES, SQUARE WAVE, 100% DEVELOPMENT $
PERIOD 10 D  BEGIN 0000 2/2/81
CYCLE 0 0 1 1
TEMP (MIN 2/2/81)
 25 40 25 40 25 40 25 40 25 40
 25 40 25 40 25 40 25 40 25 40
 25

IDENT $ ACTUAL TEMPERATURES, SAW TOOTH, 100% DEVELOPMENT $
PERIOD 10 D  BEGIN 0000 1/2/81
STEPS 2 4 14 24
TEMP (0000 1/2/81)
 25 30 35 30 25 30 35 30 25 30 35 30 25 30 35 30 25 30 35 30
 25 30 35 30 25 30 35 30 25 30 35 30 25 30 35 30 25 30 35 30
 25

IDENT $ MAX/MIN TEMPERATURES, SAW TOOTH, 100% DEVELOPMENT $
PERIOD 10 D  BEGIN 0400 1/2/81
STEPS 3 7  CYCLE 0 1
TEMP (MIN 1/2/81)
 25 35 25 35 25 35 25 35 25 35
 25 35 25 35 25 35 25 35 25 35
 25 35

IDENT $ ACTUAL TEMPERATURES, SQUARE WAVE, 2.5% DEVELOPMENT $
PERIOD 0.5 D  BEGIN 0000 1/1/61  WEIGHT 0
STEPS 0 16 16 24
TEMP (0000 1/1/61)
 25 25

IDENT $ ACTUAL TEMPERATURES, SQUARE WAVE, 5% DEVELOPMENT $
PERIOD 0.75 D  BEGIN 0000 1/1/61  WEIGHT 0
TEMP (0000 1/1/61)
 25 25 40 40

IDENT $ ACTUAL TEMPERATURES, SQUARE WAVE, 7.5% DEVELOPMENT $
PERIOD 0.875 D  BEGIN 0000 1/1/61  WEIGHT 0
TEMP (0000 1/1/61)
 25 25 40 40

IDENT $ MAX/MIN TEMPERATURES, SAW-TOOTH, 1.25% DEVELOPMENT $
STEPS 6 18  CYCLE 0 1  WEIGHT 0
PERIOD 0.25 D  BEGIN 0600 2/2/86
TEMPERATURES (MAX 1/2/86)
 40 20 40

IDENT $ MAX/MIN TEMPERATURES, SAW-TOOTH, 5% DEVELOPMENT $
PERIOD 0.5 D  BEGIN 0600 2/2/86  WEIGHT 0
```

```
TEMPERATURES (MAX 1/2/86)
 40 20 40

IDENT $ MAX/MIN TEMPERATURES, SAW-TOOTH, 8.75% DEVELOPMENT $
PERIOD 0.75 D  BEGIN 0600 2/2/86  WEIGHT 0
TEMPERATURES (MAX 1/2/86)
 40 20 40 20
```

Example 2 – output

```
PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:17 ON 10-MAR-92.


TEST 2. CHECKS AGAINST INDEPENDENTLY CALCULATED RESULTS

                 LISTING NO
CONSTANT TEMPERATURE, 100% DEVELOPMENT
END OF ITEM   1.
------------------------------------------------------------------------------

MAX/MIN TEMPERATURES, SAW-TOOTH, 8.75% DEVELOPMENT
END OF ITEM  11.
------------------------------------------------------------------------------



PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:17 ON 10-MAR-92.

TEST 2. CHECKS AGAINST INDEPENDENTLY CALCULATED RESULTS


PARAMETERS =    1.00000  20.00000
                (FIXED)   (FIXED)

RESIDUAL SUM OF SQUARES =      .0000   ROOT MEAN SUM OF SQUARES =   .0000
```

ITEM	OBS. TIME(DAYS)	MEAN TEMP.	STD. DEV.	DEVEL.	OBS. RATE	PRED. RATE	WEIGHT
1	10.000	30.00	.00	100.00	10.00	10.00	1.00
2	10.000	30.00	7.07	100.00	10.00	10.00	1.00
3	10.000	30.00	7.07	100.00	10.00	10.00	1.00
4	10.000	30.00	3.54	100.00	10.00	10.00	1.00
5	10.000	30.00	5.00	100.00	10.00	10.00	1.00
6	.500	25.00	.01	2.50	200.00	5.00	.00
7	.750	26.67	4.71	5.00	133.33	6.67	.00
8	.875	28.57	6.39	7.50	114.29	8.57	.00
9	.250	25.00	11.18	1.25	400.00	5.00	.00
10	.500	30.00	10.00	5.00	200.00	10.00	.00
11	.750	31.67	10.67	8.75	133.33	11.67	.00

Example 3 – input

```
HEADING $ TEST 3. OVARIAN DEVELOPMENT OF MUSCA VETUSTISSIMA $

HEADING $
Mean times required by nulliparous Musca vetustissima
to complete stage 2 of ovarian development
under constant temperatures in the laboratory
and under fluctuating temperatures in the field. /
Vogt, W.G. and Walker, J.M. (1987). Influences of temperature,
fly size and protein-feeding regime on ovarian development
rates in the Australian bush fly, Musca vetustissima.
Entomol. exp. appl. 44, 101-113 $

LISTING NO
STEPS 1 2 3 4 5 6 7 8 9 10 11 12 13 14
      15 16 17 18 19 20 21 22 23 24

PARAMETERS 3 (1) 9 (2)
METHOD 2


PERIOD 8.608 DAYS WEIGHT 2.78
BEGIN 0800 26/11/85
TEMP (0700 26/11/85)
32.5 32.5 32.5 32.5 32.5 32.5 32.5 9 9 9 9 9 9 9 9 9 9 9 9 9 9
9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
9 9 12 12 15 15 14 15 16.5 16 18 16 14 14 13 13 13 12.5 12
11.5 11 12 12 11 11 11 12 12.5 14 16 17 18 19 19 20 20 20 16
13.5 13 12 11.5 12 12 10.5 9 8 9 9 9 11 15 16 18 18 18.5 20
21 20 17 15 16 16 15 14 14 13 12 12 11.5 11 10 10 10.5 11 13
14 17 19 20 21 22 23 23 23 23 23 20 16 15 15 14 12.5 12 11
11.5 12 10 12 13.5 15 18 19 20.5 21 21 21.5 22 22.5 22.5 20
18 14.5 13.5 13 12.5 12 11 11.5 12 11 11 11.5 13 14 15 15 18
18.5 19 19.5 19.5 18 17 16 14 13 12.5 12 11.5 11 11 11 11.5
12 12 12 13 14 16 17 17 18 18.5 18 19 18 15 13 12 11 11.5 12
12 12 10.5 10 9.5 10 13 14 14.5 17 18 18 20 17 16 17 18 17.5
16 14 13.5 14 14 14 13 13 13 13 13 13 14.5 15 16 17 17 18
18.5 19.5 14 13 15 15 12.5 10 9 10 9.5 10 10 9 8.5 9 9 11.5
15 18 20 20.5 21 22 21.5 21 20 20.5 20 20 15 13 11 10 10.5
10 10 12 12 12 13 14 15 16 16 19 22 22 22 22 22.5 22 22 21
20 20.5 20 19 17.5 18 17 16 16 16.5 16.5 17.5 19 21 22 23
22.5 24

PERIOD 5.167 DAYS WEIGHT 1.0
BEGIN 0800 3/2/86
TEMP (0700 3/2/86)
32.5 32.5 32.5 32.5 32.5 32.5 32.5 5.5 5.5 5.5 5.5 5.5 5.5
5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5
5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 17 20 21.5 22.5 24.5
24.5 24 24 21 19 16 15 15 15 15 15 15 15 15 15 15 15 16 18
21 23 25.5 27 28.5 28.5 29 28.5 28.5 28 25 21 19 15 12 10 11
10 9 9 8 10 16 20 23 25 26 27 27.5 28 28 28 27 26 24 19 18.5
17 16 17 14 12 13 10 8 8 14 19 22 23 24 25 26 27 27 27 27 26
19 17 17 17 16 15 15 15 15 15 15 15 16 18 20 22 23.5 25 26
27 27.5 28 27.5 27 25 18 18.5 17.5 17 17 15.5 15 14 13 11 11
14 20 21.5 24 26.5 29 31 33 33 33 32.5 32.5 31 26 24.5 23 21
23 25 25 23 24 25 25 25 26 28.5 29 31 32 33 32 32

PERIOD 6.254 DAYS WEIGHT 1.72
BEGIN 0800 10/3/86
TEMP (0700 10/3/86)
32.5 32.5 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
9 9 9 9 9 9 9 9 9 14 16 17 18 19.5 20 20 20 20 18 15.5 14 13
11.5 10 10 9 8 7 6.5 6 6 6 12 14 15.5 17 18 18.5 19 19 19 18
```

```
17 14.5 13 11 10 9 8 7 7 7 7 6 6 7 11 14 16 18 19 20.5 21 22
22.5 23 22 18 13 14 12 10 8 7 6 5 5 4 4 5 12.5 15 20 22 24.5
26 26.5 27 27 27 25 20.5 19 17 16.5 12.5 9.5 9 9 8 7 7 6.5 8
13.5 18 21 22 25 27 27.5 28 28 28 27 20 19 13.5 12 11.5 10
10.5 11 9 9 8 8 8.5 13 18 23 27 29 30 30 30 29.5 29 27 24 20
17.5 15.5 15 14 14 10.5 7 10 9 10 12 14 17 18 21 22 23 25
26.5 27 27 27 20 16 15 15 15 15 15 15 15 15 15 14.5 14.5
14.5 17 18 21 22.5 23.5 25 25.5 26 26

TEMP 19 PERIOD 5.8835 DAYS WEIGHT 0

TEMP 25 PERIOD 2.6773 DAYS WEIGHT 5.26

TEMP 27 PERIOD 2.3374 DAYS WEIGHT 10.00

TEMP 28 PERIOD 2.2714 DAYS WEIGHT 6.25

TEMP 29 PERIOD 1.9792 DAYS WEIGHT 5.56

TEMP 32 PERIOD 1.7301 DAYS WEIGHT 5.26

TEMP 38 PERIOD 1.8314 DAYS WEIGHT 0
```

Example 3 – output

```
PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:19 ON 10-MAR-92.


TEST 3. OVARIAN DEVELOPMENT OF MUSCA VETUSTISSIMA

Mean times required by nulliparous Musca vetustissima to complete stage 2 of
ovarian development under constant temperatures in the laboratory and under
fluctuating temperatures in the field.
Vogt, W.G. and Walker, J.M. (1987). Influences of temperature, fly size and
protein-feeding regime on ovarian development rates in the Australian bush
fly, Musca vetustissima. Entomol. exp. appl. 44, 101-113

                 LISTING NO
END OF ITEM   1.
------------------------------------------------------------------------------

END OF ITEM  10.
------------------------------------------------------------------------------


PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:19 ON 10-MAR-92.

TEST 3. OVARIAN DEVELOPMENT OF MUSCA VETUSTISSIMA


NONLINEAR LEAST SQUARES BY LEVENBERG ALGORITHM. LMM VERSION DATED 30 DEC 1982.

STARTING POINT:
P( 1)   3.00000     P( 2)   9.00000
                     INITIAL SUMSQ=   580.923

ITS=  1
NITER=  1 EPS=   .500000     SUMSQ=   80.8302     PRED SUMSQ=   138.694
P( 1)   2.64473     P( 2)   9.65242

ITS=  2
NITER=  1 EPS=   .200000     SUMSQ=   31.9273     PRED SUMSQ=   46.5067
P( 1)   2.34064     P( 2)   8.41916
```

```
ITS=  3
NITER=  1 EPS=   .800000E-01 SUMSQ=   28.7888     PRED SUMSQ=   28.8841
P( 1)   2.28174     P( 2)   8.01394

ITS=  4
NITER=  1 EPS=   .320000E-01 SUMSQ=   28.7684     PRED SUMSQ=   28.7749
P( 1)   2.27905     P( 2)   7.98771

              EVIDENCE OF CONVERGENCE

ITS=  5
NITER=  1 EPS=   .128000E-01 SUMSQ=   28.7674     PRED SUMSQ=   28.7684
P( 1)   2.27871     P( 2)   7.98549


              PARAMETER ESTIMATES (APPROX.S.E.)
        1           2.27871       ( .9587E-01)
        2           7.98549       ( .5489    )

              CORRELATIONS OF PARAMETER ESTIMATES

    1     1.00000

    2      .85340     1.00000

STANDARD DEVIATION OF RESIDUALS =  2.1896


PROGRAM DEVAR, REVISED 10-MAR-92.  RUN AT 18:19 ON 10-MAR-92.

TEST 3. OVARIAN DEVELOPMENT OF MUSCA VETUSTISSIMA


PARAMETERS =    2.27871   7.98549


RESIDUAL SUM OF SQUARES =    28.7674   ROOT MEAN SUM OF SQUARES =  5.9966
```

ITEM	OBS. TIME(DAYS)	MEAN TEMP.	STD. DEV.	DEVEL.	OBS. RATE	PRED. RATE	WEIGHT
1	8.608	13.26	5.23	103.37	11.62	12.01	2.78
2	5.167	16.75	8.60	110.25	19.35	21.34	1.00
3	6.254	13.56	6.48	83.33	15.99	13.32	1.72
4	5.884	19.00	.00	147.67	17.00	25.10	.00
5	2.677	25.00	.00	103.80	37.35	38.77	5.26
6	2.337	27.00	.00	101.28	42.78	43.33	10.00
7	2.271	28.00	.00	103.59	44.03	45.61	6.25
8	1.979	29.00	.00	94.78	50.53	47.89	5.56
9	1.730	32.00	.00	94.67	57.80	54.72	5.26
10	1.831	38.00	.00	125.26	54.60	68.39	.00

6. Theory

The development rate of insects is usually assumed to be representable as a function

$$r(T;b_1,b_2,\ldots b_n) \tag{1}$$

where T is the temperature, and $b_1,b_2,\ldots b_n$ are coefficients that determine the form of the function, within limits imposed by the algebraic expression chosen to represent the function. Two of the most popular functions are the linear function with threshold

$$b_1(T-b_2)_+ \tag{2}$$

(equivalent to day-degrees), and the logistic function

$$\frac{b_1}{1+e^{(T-b_2)/b_3}}\ . \tag{3}$$

The coefficients b_i have usually been determined by measuring the development time at various constant temperatures, and choosing the b_i so that the function r gives the best fit to the measured rates. That is, the b_i are chosen to minimize

$$\sum_{i=1}^{m} w_i' \Big(\frac{100}{p_i} - r(T_i;b_1,\ldots b_n) \Big)^2 \tag{4}$$

where T_i are the temperatures, p_i is the measured development time at T_i , and w_i' is a weight. The factor 100 is included because rates are conventionally expressed in percent per unit time (usually per day). As the p_i typically have a wide range of values, suitable w_i' also tend to have a wide range, and (4) can be put into a more convenient form by setting

$$w_i' = p_i^2 w_i$$

whereupon (4) becomes

$$\sum_{i=1}^{m} w_i (100 - p_i r(T_i;b_1,\ldots b_n))^2\ . \tag{5}$$

In this expression, $p_i r(T_i;b_1,\ldots b_n)$ is the percentage development which the rate function predicts should have taken place in the period p_i. This should be as close as possible to the observed percentage development, 100 . The problem defined by (4) or (5) can be solved using readily available least-squares routines.

Once the rate function has been determined, it is usually applied to calculating development times in fluctuating-temperature regimes, that is, where the temperature $T(t)$ is a function of time. It is assumed that the amount of development between times t_1 and t_2 is given by

$$\int_{t_1}^{t_2} r(T(t);b_1,..b_n)\,dt\ . \tag{6}$$

The problem of determining the b_i can readily be generalized to the fluctuating-temperature case. (5) becomes

$$\sum_{i=1}^{m} w_i \Big(100 - \int_{t_b}^{t_e} r(T_i(t);b_1,\ldots b_n)\,dt \Big)^2 \tag{7}$$

where t_b and t_e are the times of the beginning and end of development. The minimization of (7) presents no more difficulty than that of (5), except for the evaluation of the integral. In general, this must be evaluated numerically for each set of b_i selected by the minimization routine. (DEVAR uses the trapezoidal rule for the integrations.)

6. References

Miller, A. J. (1981). LMM — a subroutine for unconstrained non-linear least-squares fitting. *CSIRO Aust. Div. Mathematics and Statistics Consulting Rep.* No. VT 81/23.

Powell, M. J. D. (1965). A method for minimizing a sum of squares of non-linear functions without calculating derivatives. *Comp. J.* **7**, 303.