ECN-C--97-096

PRODETO-COMPUTER PROGRAM
User's manual

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CONTENTS

SUMMARY

Within the EC-funded project PRODETO (JOR3-CT95-0026), computer tools were developed by which the structural reliability of fatigue loaded wind turbine blades can be analysed. The PRODETO software consists of the programs RAINSTAT and FATSTAT and the source code *damage.for* which has to be linked to a commercially available computer program for component reliability analysis. The implementation of the subroutine *damage.for* was done in connection with the code RELIAB01 of CSRconsult, but the structure is such that it can easily be adjusted for other codes.

This manual refers to the following releases:
- RAINSTAT, release 1.3
- FATSTAT, release 1.0
- *damage.for*, release 1.3

1. INTRODUCTION

One of the objectives of the EC-funded JOULE III project "Probabilistic Design Tool" (PRODETO) [1, 2] is the development of a computer code for probabilistic fatigue assessment. This code will be used partly as a probabilistic structural reliability calculation tool for the industry and partly as a safety factors calibration tool for certifying authorities and standards committees. The procedure to calibrate partial safety factors is described in detail in [3] and is depicted in Fig. 1.1. 4 modules can be distinguished, viz. RAINSTAT, FATSTAT, RELIAB, and CALIBRATION.

In the module RAINSTAT the time-series are rainflow counted and the statistical parameters describing the loads are estimated. These parameters are written to an output file such that they can be transferred to an input file for the module RELIAB. Likewise, a lifetime load spectrum based on the rainflow counted results has been made.

The statistical material parameters for fatigue are determined in the module FATSTAT and are written to an output file such that these material parameters can be transferred to an input file of the module RELIAB.

In the module RELIAB the failure probability and the reliability index β are calculated for a number of values of the section modulus W, which is a geometry dependent design parameter. These β-factors are used in the module CALIBRATION to calibrate the partial safety factors. The module RELIAB is based on a commercially available computer code for component reliability analysis to which the limit state function has to be linked.

The PRODETO software consists of programs RAINSTAT and FATSTAT and the source code for the limit state function *damage.for*. In the current version of the limit state function the 2- and 3-parameter Weibull distribution and the Hermite model are optional for describing the load distribution. These models are developed for the flapwise bending moment and are not simply applicable for the edgewise bending moment. A first attempt to consider the edgewise moment is facilitated by the use of the 2-parameter Weibull distribution.

This manual refers to the following releases:
- RAINSTAT, release 1.3
- FATSTAT, release 1.0
- *damage.for*, release 1.3

The theoretical background and the overall structure of these programs is given in [3]. The implementation of the subroutine *damage.for* was done in connection with the code RELIAB01 [4], but the structure is such that it can easily be adjusted for other codes.
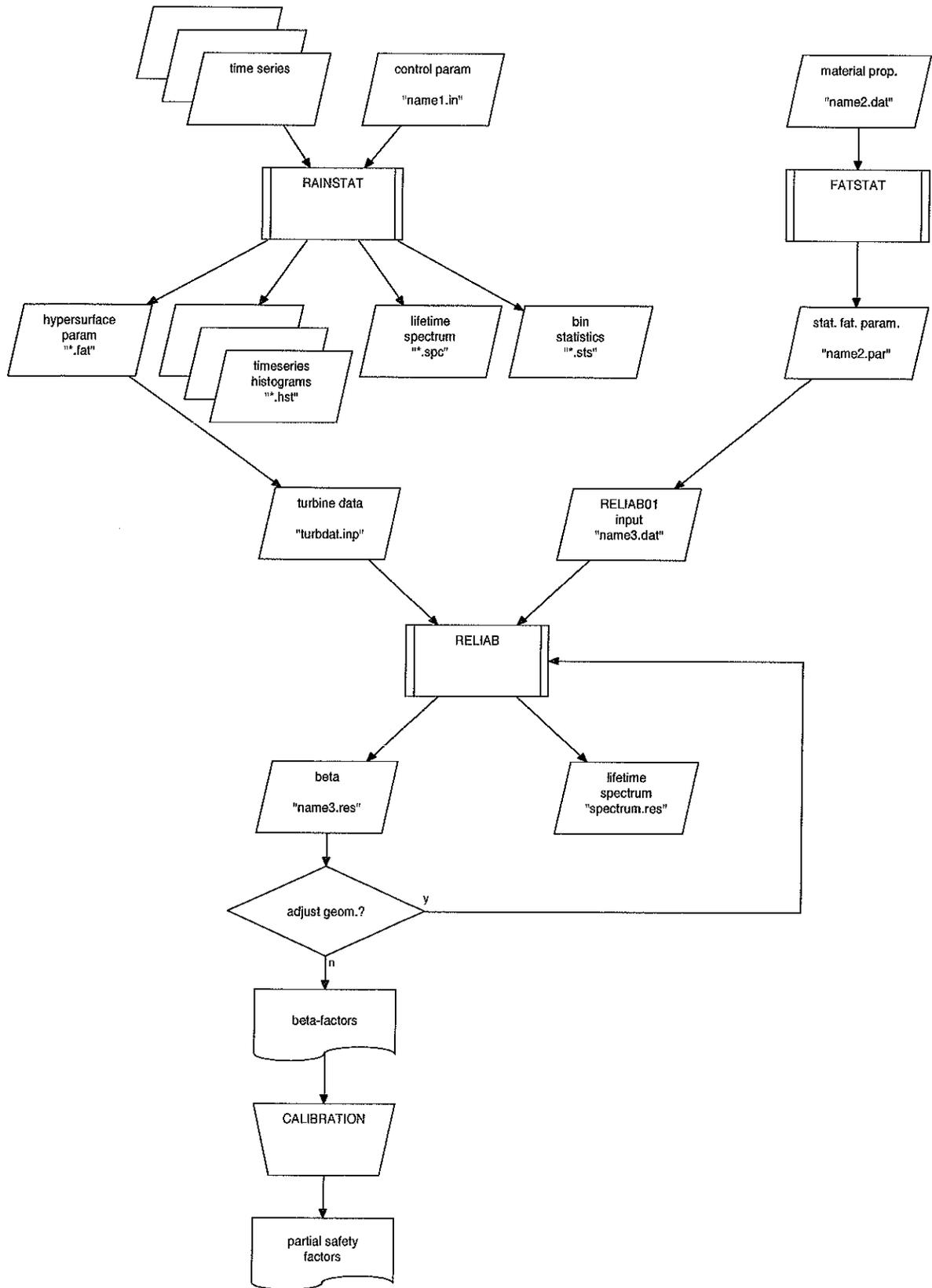
Fig. 1.1 :   *Procedure for calibration of partial safety factors; name1, name2, and name3 are user defined filenames*

2. RAINSTAT

2.1 Using the program

In order to generate a rigid basis for determining the first four statistical moments of the load for each combination of the 10-minute mean windspeed, U_{10}, and the turbulence intensity, I_T, second order polynomial surfaces were introduced [3]. Starting with measured or calculated 10-minute time series the program RAINSTAT calculates the parameters for these second order polynomials by which the expected values of the mean and the standard deviation of the first four statistical moments are represented. The parameters of the second order polynomial representing the number of load cycles in the (U_{10}, I_T) space are computed also.

RAINSTAT is a FORTRAN program developed with MS FORTRAN Powerstation 1.0, installed on a Pentium based PC and it consist of the following two parts:
- parsing the initialisation file (*'filename'.in*) and the time series headers
- numerical elaboration of data in time series

The source files for the parser are:
- *pparse.for* - initialisation file and timeseries parsing routines
- *pu.for* - generic low-level i/o and datatypes parser routines

The source files for the numerical elaboration are:
- *prodeto.for* - main program
- *rainflow.for* - rainflow counting routines
- *prdthist.for* - 'low-level' histogram operators
- *prdtstat.for* - statistics generating routines
- *prdtfit.for* - fitting routines

Furthermore the following include files are used in the various source files:
- *params.h* - constants
- *prodetof.h* - initialisation file items
- *rainf.h* - data structures
- *fit.inc* - fit constants
- *puf.f* - parsing constants
- *parsef. h* - parsing keywords
- *rainio.h* - initialisation items

The executable of RAINSTAT is obtained by compiling the above listed source files. The program has to be executed under DOS, where access to the MS FORTRAN Powerstation file *dosxmsf.exe* is required.

The control parameters and the file names of the time series to be analysed are specified in the input file *'filename'.in*, which will be described in detail in section 2.2 together with the structure of the files containing the time-series. The name of the inputfile *'filename'* without the extension *in* has to be specified interactive.

RAINSTAT generates 4 types of output files, which are described in detail in section 2.3

2.2 Description of the input files

2.2.1 Initialisation file format

The initialisation file *'filename'.in* has four major sections, viz. Environment, Turbine, U10ItBin, and Rainflow. These sections are subsequently divided into subsections and/or keyword-value statements. In principle, the order in which the keyword value combinations appear inside the section as well as the order of sections, is free. The parts where this principle does not hold, will be explicitly mentioned. Below the following notation is used:

1. Items in bold face are section and keyword items that are expected to appear in the file

2. Items in italics denote the various (basic) datatypes used to give names, values etc.:

- path	-	quoted string of at most 80 characters
- range	-	integer or real interval formatted as [*integer,integer*] or [*real,real*]
- real	-	positive real value in normal or scientific format
- integer	-	positive integer
- name	-	string of at the most 20 characters
- file name	-	string of at the most 12 characters

Environment

The section **Environment** gives the necessary file paths where the input time series can be found and where the output files containing the histograms, spectra, statistical parameters and fit attributes will be stored. For each missing path a default path name will be selected. Note that of all the given paths, all directories but the last one must already exist.

- **campaign** *path*

    gives the campaign path name (not used)

    default path: `c:\prodeto\test`

- **data_in** *path*

    gives the path name where the program searches for the time series

    default path : `c:\prodeto\series`

- **data_out** *path*

    gives the path of the main directory in which the program will put the various output files (in subdirectories)

    default path : `c:\prodeto\test`

Turbine

Section **Turbine** gives the necessary turbine characteristics for the use in the calculation of the life cycle total load spectra.

- **availability** *real*

   gives the expected turbine availability percentage over its lifetime

   default : 100.0

- **life_cycle** *real*

   gives the expected turbine life time in years

   default : 20.0

U10ItBin

Section **U10ItBin** defines the 2D windspeed and turbulence intensity bin matrix

- **nu10** *integer*

   gives the number of windspeed classes

   no default

   must be followed by a range definition *range* for each windspeed class in ascending order.

- **nit** *integer*

   gives the number of turbulence intensity classes

   no default

   must be followed by a range definition *range* for each turbulence intensity class in ascending order.

- **bin** *range*

   Subsection describing the windspeed & turbulence intensity bin in more detail. The range consists of the windspeed and turbulence intensity indices respectively in the bin matrix and is used to check the upcoming ranges against the list of range definitions mentioned above. Note that before the first bin description is given these lists must be known, thus **bin** must follow **nu10** and **nit**.

   For each bin interval in which timeseries are found, a bin section should be given. Description for bins in which no time series are found can be omitted.

   * **u10** *range*

      gives the windspeed class range

      no default

   * **it** *range*

      gives the turbulence intensity class range

      no default

   * **series** *integer*

      gives the number of timeseries that fall into the bin given by the class range

      Must be followed by a list of filenames *filename*. The number of files should match the number given above.

- **pserie** *real*

  timebase in minutes of the time series

  default : 10.0

- **weibull_u** *real*

  scale parameter in Weibull distribution

  default : 1.0

- **weibull_k** *real*

  shape parameter in Weibull distribution

  default : 1.0

Rainflow

Section **Rainflow** should give a signal definition section for each signal that will be part of the rainflow count, statistical postprocessing and fitting.

- **signal** *name*

  This named section describes the signal specific parameters for use in the rainflow count algorithm

  * **threshold** *real*

    Value denoting the minimal difference between to subsequent values required before Peak/Valley analysis is carried out.

  * **lin_range**

    Section describing the signal class range division in case of linear range counts.

    ♦ **center**

      the center values of one of the signal classes

    ♦ **step**

      the size of each of the signal classes

  * **log_range**

    Section describing the signal class range division in case of logarithmic range counts.

    ♦ **center**

      the center values of one of the signal classes

    ♦ **step**

      the size of each of the signal classes

  At least one of the lin_range or log_range sections should be present

An example of the initialisation file *'filename'.in* file is given in Annex A.

2.2.2 Time-series

The timeseries files must consist of a header followed by a number of columns with data, where the number of columns has to be equal to the number of signals specified in the header. The first character in a line of the header has to be a #. The header should at least contain a section with a starting line containing

`#      signal`

followed by the signal descriptions

`#      signal_name_quoted-string`

and an end line

`#  #`

The header is expected to end with

`#endheader.`

An example of the time series file is given in Annex B.

2.3 Output files

This section describes the format specification of the following 4 types of output files generated by RAINSTAT:

* Timeseries Histograms (*.hst)
* Cumulative Histogram and Spectrum (*.spc)
* Wind speed & Turbulence Intensity Bin Statistics (*.sts)
* Wind speed & Turbulence Intensity Bin Statistics Fit Attributes (*.fat)

For each signal defined in the rainflow definition section in the initialisation file, a single directory will be created in the user defined data output directory. The directory will be named after the signal alias, the signal name with all non-digits and non-alphabeticals left out. All output files for the signal will be stored in this directory.

Timeseries Histograms

The timeseries histograms contain rainflow counts for each of the time series given in the windspeed & turbulence intensity bin definitions in the initialisation file. For each of the signals given in the rainflow definition in the initialisation file, a single histogram file will be created for each bin, listing the number of counts for each timeseries in which the signal is found. The format of the file is:

* a fourteen line header giving
  1   a title string
  2-11   identification of program and run
  12   the signal name by the keyword-value combination **Signal** name
  13   the windspeed and turbulence intensity classes by the keyword-value combinations **u10** *range* **it** *range*
  14   the word **range** followed by the filenames of the respective timeseries, serving as data column header for the following data part.

- the data part :

S_0	0	...	0
S_0	n_{ij11}	...	n_{ijM1}
S_1	n_{ij11}	...	n_{ijM1}
...	...	...	...
S_{t-1}	n_{ij1t}	...	n_{ijMt}
S_t	n_{ij1t}	...	n_{ijMt}
...	...	...	...
S_{T-1}	n_{ij1T}	...	n_{ijMT}
S_T	n_{ij1T}	...	n_{ijMT}
S_T	0	...	0

For each signal class range $[S_{t-1}, S_t]$, with signal class $t=1,..,T$, two rows of data are appended to the data part containing the counts n_{ijst} of all timeseries $s=1,..,M$, found in bin ij. S_0 is the signal threshold value from the rainflow definition and T is the upper bound of the highest signal class interval for which at least a single count in one of the timeseries is scored. Note that all intermediate ranges are given, even if there is no score in any of the timeseries.

The filenames of these ASCII files are directly adopted from the first 4-characters of the timeseries filename given in the bin definition. Depending on whether linear or logarithmic ranges are counted, the filename is appended by **_lin** or **_log** and has the extension **.hst**.

Cumulative Histogram and Spectrum
For the wind speed & turbulence intensity overall bin matrix, a single cumulative histogram and spectrum file is created for each signal, containing the expected load cycles in each signal class for the overall lifecycle of the turbine. Therefore, for each wind speed bin class interval, an average aggregate histogram is calculated from the histograms created for all turbulence intensity classes. These average histograms are multiplied by a weight factor depending on the turbine availability, turbine lifecycle and the Weibull probability distribution function for the corresponding windspeed class interval. Finally these weighed average histograms are aggregated, giving the cumulative histogram.
The format is :

- a twelve line header part :
  1   a title string
  2-11   identification of program and run
  12   the signal name by the keyword-value combination : **Signal** *name*

- the three-column data part :

$$S_0 \quad 0 \quad H_0 = \sum n_k^*$$

$$S_0 \quad n_1^* \quad H_1 = H_0$$

$$S_1 \quad n_1^* \quad H_1$$

$$\cdots \quad \cdots \quad \cdots$$

$$S_{t-1} \quad n_t^* \quad H_t = H_{t-1} - n_{t-1}^*$$

$$S_t \quad n_t^* \quad H_t$$

$$\cdots \quad \cdots \quad \cdots$$

$$S_{T-1} \quad n_T^* \quad H_T = H_{T-1} - n_{T-1}^*$$

$$S_T \quad n_T^* \quad H_T$$

$$S_T \quad 0 \quad 0$$

where S_0 is the signal threshold value from the rainflow definition.
The cumulative histogram values for each signal class $k=1,2,...T$ are given by :

$$n_k^* = \sum_{i=1}^{N_u} \bar{n}_{ik} W_i$$

where N_u is the number of windspeed classes.
The average histogram values are given by

$$\bar{n}_{ik} = \frac{\sum_{j=1}^{N_I} \sum_{s=1}^{N_{ij}^S} n_{ijsk}}{\sum_{j=1}^{N_I} N_{ij}^S}$$

where N_I is the number of turbulence intensity classes and N_{ij}^S is the number of timeseries in bin ij. W_i is the weighing factor for windspeed class i given by

$$W_i = \left(\frac{T_a}{100}\right) \cdot T_l \cdot 365 \cdot 24 \cdot \frac{60}{m} \cdot \left(F_W(U_i) - F_W(U_{i-1})\right)$$

where T_a is the turbine availability percentage, T_l is the turbine lifecycle in years, m is the timebase of the timeseries in minutes and the Weibull distribution function F_W is given by

$$F_W(x) = 1 - \exp\left(-\left(\frac{x}{u}\right)^k\right)$$

where u and k are the Weibull parameters.
The output filename is **prodetln.spc** or **prodetlg.spc** depending on whether linear or logarithmic ranges are counted.

Windspeed and Turbulence Bin Statistics

For each signal a fixed set of statistical parameters is determined for the aggregated timeseries histograms in each of the windspeed & turbulence intensity bins. For each entry in the windspeed turbulence intensity bin matrix, the next 14 values are determined:

- the estimated values for the 4 classic moments : mean, standard deviation, skewness and kurtosis

- the estimated values for their standard deviation.
- their 6 cross-correlation coefficients.

Together with the information about the number of timeseries read and the total number of load cycles counted, this information is stored in a file. The format of this file is :
- a twelve line file header containing :
  - 1   file title string
  - 2-11 identification of program and run
  - 12   the signal name by a keyword-value combination : **Signal** : *name*
- a data part containing 16 matrices, one for each item given in the following list of items. The string given after each item is the text header line precluding the matrix data values.
  1. number of timeseries counted (integer), 'number of series'
  2. total number of load cycles (real), 'number of load cycles', + fit
  3. mean of load ranges (real), 'mean', + fit
  4. standard deviation of mean of load ranges (real), 'stdev mean', + fit
  5. standard deviation of load ranges (real), 'stdev', + fit
  6. standard deviation of standard deviation of load ranges (real), 'stdev stdev', + fit
  7. skewness of load ranges (real), 'skewness', + fit
  8. standard deviation of skewness of load ranges (real), 'stdev skewness', + fit
  9. kurtosis of load ranges (real), 'kurtosis', + fit
  10. standard deviation of kurtosis of load ranges (real), 'stdev kurtosis', + fit
  11. cross correlation mean - standard deviation (real), ' correlation coefficients moments 1 2',+mean
  12. cross correlation mean - skewness (real), 'moments 1 3',+mean
  13. cross correlation mean - kurtosis (real), 'moments 1 4',+mean
  14. cross correlation standard deviation - skewness (real), 'moments 2 3',+mean
  15. cross correlation standard deviation - kurtosis (real), 'moments 2 4',+mean
  16. cross correlation skewness - kurtosis (real), 'moments 3 4',+mean

The matrices 2 up until 10 are directly followed by a line with their 5 fit attributes from the linear least square fitting using a second order polynomial (see Fit Attributes). The matrices 11 - 16 are followed by the mean value over all windspeed and turbulence intensities (see Fit Attributes). In each matrix, the rows are given by the turbulence intensity classes in ascending order and the columns are given by the windspeed classes in ascending order. The filename is **prodetln.sts** or **prodetlg.sts** depending on whether linear or logarithmic ranges are counted.

Windspeed Turbulence Intensity Bin Statistics Fit Attributes
For each signal the four classical moments estimators and their standard deviations are fitted by the linear least squares fitting method using a second order polynomial. Having two independent coordinates, the windspeed and turbulence intensity, this yields 5 resulting fit attributes. In addition, the matrix containing the total number of load cycles is fitted likewise. The file consists of :
- a twelve line header
  - 1   the title
  - 2-11 identification of program and run
  - 12   the name of the signal : Signal : name

- the data part with 9 x 5 lines of string-comma-value items :

'b(1,1)=',   b(1,1)

...

'b(5,4)=',   b(5,4)

'c(1,1)=',   c(1,1)

...

'c(5,4)=',   c(5,4)

'd(1)=',   d(1)

...

'd(5)=',   d(5)

where
- b(i,j) denotes the ith fit attribute value of the jth classic moment estimator
- c(i,j) denotes the ith fit attribute value of the standard deviation estimator for the jth classic moment
- d(i)   denotes the ith fit attribute value of the total load cycles

The filename is **prodetln.fat** or **prodetlg.fat** depending on whether linear or logarithmic ranges are counted.

3. FATSTAT

3.1 Using the program

For the data points (x_i, y_i) specified in the input file *'filename'.dat* the program FATSTAT performs a linear regression analysis for

$$\log(y) = B_0 + B_1 \log(x) + e$$

The mean values, the standard deviations and the correlation coefficient for B_0 and B_1 as well as the standard deviation of the zero-mean random variable e are written to the output file *'filename'.par*. The name of the input file and the output file *'filename'* has to specified interactive.

FATSTAT is a FORTRAN program developed with MS FORTRAN Powerstation 1.0, installed on a Pentium based PC. The executable is obtained by compiling the source code in the file *fatstat.for*. To run the program the input file *'filename'.dat* has to be prepared. The structure of the input file is described in section 3.2

3.2 Structure of the input data

The format of the input file is given below
- a two line header
  1. an integer N denoting the number of data points present in the data part
  2. comment line
- the data part

$x_1 \ y_1$

. .

. .

$x_N \ y_N$

An example of the input file is given in Annex C

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4. RELIAB

4.1 Using the program

To calculate the failure probability or the safety factor for wind turbine blades under flapwise bending the limit state function $Z=1- D(X)$ or $Z=-\ln D(X)$ described in [3] has to be linked to a computer program that can solve the structural reliability problem

$$P_F = P[Z < 0]$$

The implementation of the limit state function was done in connection with the code RELIAB01 [4]. The source code of the limit state function is given in the standard RELIAB01 file *failel.for* and the file *damage.for*. Furthermore the source code in the standard RELIAB01 file *reliab01.for* was adjusted slightly such that the input file *turbdat.inp* is only read once and to streamline the calculation of the lifetime load spectrum. Because the standard RELIAB01 file *reliab01.for* is compiler dependent, two modified versions are provided; one for the Lahey Fortran compiler and one for the MS Powerstation compiler.

The executable is obtained by linking the modified RELIAB01 files *reliab01.for* and *failel.for* , and the file *damage.for* with the standard object files of RELIAB01.

To run the program two input files have to be prepared, viz. the standard RELIAB01 input file *'filename'.dat* and the input file *turbdat.inp* with turbine relevant data. The structure of the input file *'filename'.dat* is described in detail in the RELIAB01 user's manual. A relevant example of this input file is given in Annex D. The structure of the input file *turbdat.inp* is given section 4.2.

The results of the reliability analysis are written to the output file *'filename'.res* and the calculated Cumulative Distribution Function (CDF) and the Probability Density Function (PDF) of the load range are written to *spectrum.res*. The name of the standard RELIAB01 input file and output file *filename* has to specified interactive.

4.2 Structure of the input data

The structure of the input file *turbdat.inp* is given below

1: comment
2: comment
3: comment
4: integer   specifying the kind of transformation to be used

          10 : Hermite transformation with Y = ln(X)
          11 : Hermite transformation with Y = log(X)
          12 : Hermite transformation with Y = X
          2   : 3-parameter Weibull distribution
          3   : 2-parameter Weibull distribution
          12, 2, or 3 has to be specified in case the lin_range option was used in the section Rainflow of the initialisation file of the program RAINSTAT.
          11 has to be specified in case the log_range option was used in the section Rainflow of the initialisation file of the program RAINSTAT.
          10 can be used in case the rainflow counting of the time series is done for ln(X), the natural logarithm of the load range.

5: comment

6:	real	specifying the modulus of elasticity [Pa]
7:	comment	
8:	real	specifying the design lifetime in years
9:	comment	
10:	integer	specifying the maximum number of load range increments
11:	comment	
12:	real	specifying the maximum load range [Nm] range to be considered
13:	comment	
14:	real	[load ranges in input files] / [Nm], so if the load ranges in the time series are given in [kNm] this factor should be 1000.
15:	comment	
16:	integer	specifying number of wind speed bins
17:	comment	
18:	real real	specifying the minimum and maximum wind speed [m/s] to be considered
19:	comment	
20:	integer	specifying the number of turbulence intensity bins
21:	comment	
22:	real real	specifying minimum and maximum turbulence intensity [%] to be considered
23:	comment	
24:	comment	
25;	comment	
26:	real real	specifying the mean value [%] and the coefficient of variation in the log-normal distribution of the turbulence intensity
27:	comment	
28:	comment	
29:	real real	specifying the slope parameter and the scale parameter in the Weibull distribution for the 10-minute mean windspeed
30:	comment	
31:	'text', real	$b_{0,1}$
.	.	.
.	.	.
75:	'text', real	d_4

The comment lines are skipped when this file is read. For detailed information about lines 31-75, in which the parameters of the hypersurfaces are specified, one is referred to the example of this input file given in Annex E

REFERENCES

[1]   JOULE-III project proposal, *Development of a design tool for structural reliability analyses of wind turbine components.*

[2]   JOULE-III work programme (JOR3-CT95-0026), *Development of a design tool for structural reliability analyses of wind turbine components.*

[3]   H. Braam, K.O. Ronold, and C.J. Christensen, *PRODETO Computer program - Theory and Program Structure*, ECN-C--97-093, To be published

[4]   RELIAB01 Version 2.11 December 1995, CSRconsult, Denmark

ANNEX A : EXAMPLE OF RAINSTAT INPUT FILE

```
Environment
    campaign 'c:\' ! not used
    data_out 'c:\prdtpgm\rainstat\example\results' ! path for the spectra
      and histograms
    data_in 'c:\prdtpgm\t_series' ! path where the data files can be
      found


Turbine
    availability 100.0
    life_cycle 20.0


U10ItBin

  nu10 11

    [0,2]
    [2,4]
    [4,6]
    [6,8]
    [8,10]
    [10,12]
    [12,14]
    [14,16]
    [16,18]
    [18,20]
    [20,22]

  nit 10

    [0,2]
    [2,4]
    [4,6]
    [6,8]
    [8,10]
    [10,12]
    [12,14]
    [14,16]
    [16,18]
    [18,20]

  pserie 10.0
  weibull_u 9.5912229 ! 8.5 / wortel(pi)/2
  weibull_k 2.0

bin [3,4]
    u10 [4,6]
    it [6,8]
    series 2
        4_d53.txt
        4_d717.txt

  bin [4,6]
    u10 [6,8]
    it [10,12]
    series 2
        6_f308.txt
        6_f676.txt

  bin [6,5]
    u10 [10,12]
    it [8,10]
    series 2
        10_e363.txt
        10_e369.txt

  bin [8,8]
    u10 [14,16]
```

```
      it [14,16]
      series 2
        14_h163.txt
        14_h421.txt

bin [9,6]
      u10 [16,18]
      it [10,12]
      series 2
        16_f182.txt
        16_f320.txt

  bin [11,8]
      u10 [20,22]
      it [14,16]
      series 2
        20_h439.txt
        20_h441.txt


Rainflow

   signal 'klap 4[kNm]'

      threshold 0.0
      lin_range
         center 5.0
         step 10.0

   signal 'zwaai 6[kNm]'

      threshold 0.0
      lin_range
         center 10.0
         step 20.0

   signal 'torsie as[kNm]'

      threshold 0.0
      lin_range
         center 10.0
         step 20.0

   signal 'buig 1006[kNm]'

      threshold 0.0
      lin_range
         center 10.0
         step 20.0
```

ANNEX B : EXAMPLE OF INPUT FILE WITH TIME SERIES

```
#    version labelfilestat:1.00
#    Mean 10.488525
#    Turbulence 0.096048
#    scanrate [scan/sec]   32.000000
#    Signal properties [ name,mean,stdev,max,min]
#    'Wind speed 1[m/s]'   10.48853 1.007399 13.38558 7.629511
#    'Wind direction[deg]'   120.4339 5.157219 139.8387 101.9586
#    'Elec. Power[kW]' 382.4995 56.39359 589.1701 230.2562
#    'rotor speed[rpm]'   1501.011 1.012702 1505.859 1495.605
#    'Zwaai 4[kNm]' 39.34211 74.57184 180.3818 -116.36
#    'klap 4[kNm]'  -216.458 22.00143 -121.203 -302.79
#    'zwaai 5[kNm]' 89.60764 79.96023 251.96   -60.3182
#    'zwaai 6[kNm]' 32.27715 76.61144 182.4546 -127.861
#    'torsie as[kNm]' 150.1567 23.1822  237.78   83.01196
#    'buig 1006[kNm]'  -22.1063 53.57703 133.9511 -191.004
#    'buig 90° -1006[kNm]'   5.433668 54.80707 172.4315 -144.199
#    #
#    data class: Unknown
#    turbine mode:  Production 2
#    rotorspeed: high speed
#    wind mode:  Unknown
#ENDHEADER
9.976      113.253   302.14    1501.465 -71.305   -165.492 197.583   35.392    121.938   -15.146   -8.5
9.976      113.774   297.584   1500      -80.627   -175.827 202.244   38.09     118.656   -27.161   -13.793
9.976      114.643   296.572   1501.465 -83.734   -184.685 199.137   35.392    115.373   -49.553   -19.087
9.976      114.643   298.09    1501.465 -89.949   -190.59  197.583   36.741    113.497   -63.753   -33.523
9.976      114.991   298.597   1500      -85.288   -189.113 186.708   47.535    112.09    -76.314   -53.252
10.008     117.076   296.572   1501.465 -80.627   -183.208 172.725   55.63     113.028   -77.952   -67.207
10.087     117.597   295.053   1500      -72.859   -186.161 152.528   70.471    115.373   -79.044   -73.462
```

ANNEX C : EXAMPLE OF FATSTAT INPUT FILE

```
33
eps_a           N
4.89180E-03     10
3.91680E-03     430
3.37647E-03     4600
2.74488E-03     89800
3.39088E-03     4200
2.33183E-03     768700
2.71126E-03     35100
2.71126E-03     31300
2.16853E-03     1841500
3.38367E-03     2640
2.70646E-03     6200
2.71126E-03     46300
1.88996E-03     136300
1.63300E-03     1.1E+07
2.16853E-03     2685200
2.02924E-03     779200
2.03405E-03     602100
2.03405E-03     567900
1.88996E-03     4286000
2.43509E-03     125770
3.41249E-03     445
2.52827E-03     2000
2.52827E-03     3810
2.52827E-03     3940
2.21224E-03     46700
2.21224E-03     112000
2.21224E-03     198000
1.89620E-03     61000
1.89620E-03     93600
1.89620E-03     111000
1.89620E-03     391000
1.58017E-03     596000
1.58017E-03     1310000
```

ANNEX D : EXAMPLE OF STANDARD RELIAB01 INPUT FILE

```
*********************************************************************
* File: MSM_lg.DAT                                                  *
*        Input file to RELIAB01                                     *
*                                                                   *
* CSR ApS - April 1994                                              *
*********************************************************************

$CONTROL

* Comment.
  PRODETO: Measurements, Hermite
*--
* Type of reliability analysis.
1
*--
* Number of fixed parameters,
* Number of stochastic variables.
1, 8
*--
* Number of correlated variables.
* Perform d(beta)/d(rho) 0/1
* Number of parameter studies
6, 0, 0
*--
* Output parameter.
2

$END

********
$FIXED

* Parname
* Number of fixed parameters,
* Value,
* Comment.
W, 1, 0.002, Geometry factor [m^3]

$END

********
$STOCHAS

* Varname
* Number of stochastic variable,
* Type of distribution,
* Statistical parameters,
* Comment.
U1,      1, 2, 0.0, 1.0, normal
U2,      2, 2, 0.0, 1.0, normal
U3,      3, 2, 0.0, 1.0, normal
U4,      4, 2, 0.0, 1.0, normal
logK,    5, 2, -12.372, 0.513, logk
m,       6, 2, 7.912, 0.247, m
e,       7, 2, 0.0, 0.396, residu
F_model, 8, 0, 1.0, Model uncertainty

$END

********
$CORRELA

* Type of input.
1
*--
* Correlations.
1.
0.0, 1.
```

```
-0.017033, -0.011039, 1.0
0.0052083,  0.0, 0.072672, 1.0
0.0, 0.0, 0.0, 0.0, 1.0
0.0, 0.0, 0.0, 0.0, -0.996, 1.0
```

$END

****
$RELIAB1

* Type of reliability method (FORM, SORM, and Simulation).
2, 0, 0
*--
* Type of failure element.
1

$END

****
$FORM

* Accuracy parameter.
1.D-6
*--
* Number of variables to perform sensitivity analysis for.
* Number of parameters to perform sensitivity analysis for.
* Max number of iterations in FORM
0, 0, 50

$END

****
$SIM
* Number of trials
1000
*--
* Reduction of failure element evaluations.
1

$END

ANNEX E : EXAMPLE OF RELIAB INPUT FILE TURBDAT.INP

```
* K_TRANS  = 1k FOR HERMITE TRANSFORMATION (k=0:Y=LN(X); k=1:Y=LOG(X); k=2:Y=X)
* K_TRANS  = 2   FOR 3-PARAMETER WEIBULL DISTRIBUTION
* K_TRANS  = 3   FOR 2-PARAMETER WEIBULL DISTRIBUTION
11
* E_mod : MODULUS OF ELASTICITY [Pa]
20.1E+09
*T_life : LIFETIME [YEARS]
20.0
* N_L : NUMBER OF LOAD RANGE INCREMENTS
300
* X_max : MAXIMUM LOAD RANGE [Nm]
3000000.
* DIM_FAC = [dimension of X in input files]/[Nm]
1000.
* N_i : NUMBER OF MEAN WIND SPEED INCREMENTS
8
* MINIMUM AND MAXIMUM MEAN WIND SPEED [m/s]
4.0,20.0
* N_j :  NUMBER OF TURBULENCE INTENSITY INCREMENTS
6
* MINIMUM AND MAXIMUM TURBULENCE INTENSITY [%]
8.0,20.0
* WIND CLIMATE PARAMETERS
* TURBULENCE INTENSITY IS LOGNORMAL DISTRIBUTED
* MEAN VALUE [%] AND COEFICIENT OF VARIATION (SIGMA/MU) [-] OF I_T
12.41,0.25
*10-MINUTE MEAN WIND SPEED IS WEIBULL DISTRIBUTED
*SLOPE PARAMETER AND SCALE PARAMETER OF WEIBULL DISTRIBUTION
2.0,9.591
* COEFFICIENTS FOR HYPERSURFACES IN (U_10,I_T) SPACE
'b(0,1)=',    1.6857
'b(1,1)=',   -.33823E-01
'b(2,1)=',    .16773E-02
'b(3,1)=',   -.41810E-02
'b(4,1)=',    .17780E-03
'b(0,2)=',    .45209
'b(1,2)=',   -.12703E-01
'b(2,2)=',    .61487E-03
'b(3,2)=',   -.50112E-02
'b(4,2)=',    .16584E-03
'b(0,3)=',   -.90886
'b(1,3)=',    .13056
'b(2,3)=',   -.52478E-02
'b(3,3)=',    .52320E-01
'b(4,3)=',   -.17722E-02
'b(0,4)=',    .35633
'b(1,4)=',    .10930
'b(2,4)=',   -.36137E-02
'b(3,4)=',    .79553E-01
'b(4,4)=',   -.23597E-02
'c(0,1)=',    .54090E-01
'c(1,1)=',   -.27100E-02
'c(2,1)=',    .10611E-03
'c(3,1)=',   -.52614E-02
'c(4,1)=',    .21263E-03
'c(0,2)=',    .32574E-01
'c(1,2)=',   -.14569E-02
'c(2,2)=',    .43128E-04
'c(3,2)=',   -.29652E-02
'c(4,2)=',    .12042E-03
'c(0,3)=',    .24670
'c(1,3)=',   -.67290E-02
'c(2,3)=',    .26581E-03
'c(3,3)=',   -.29617E-01
'c(4,3)=',    .11375E-02
'c(0,4)=',    .65681E-01
'c(1,4)=',   -.40634E-02
'c(2,4)=',    .43156E-04
'c(3,4)=',   -.15689E-02
'c(4,4)=',    .12634E-03
'd(0)='  -186.11
'd(1)='   61.721
'd(2)='  -.70743
'd(3)='   54.684
'd(4)='  -1.6306
```