Microcomputer Software for Developing and Evaluating Accelerated Life Test Plans

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1. INTRODUCTION

General overview of accelerated life testing

An accelerated life test is an experiment performed to obtain information about the time to failure distribution of some material or product. For example, a researcher may run an accelerated life test to estimate a percentile of this distribution. It is assumed that the time to failure of the material or product is related to the level of some type of stress to which it is exposed and that the material or product is designed to operate under a particular level of stress. As in any other type of experimental situation, there is often a limit to the length of time that is available for a life test. If the material or product is expected to have a long lifetime when operated under design stress conditions, it may be impossible to observe enough failures during a test performed at these conditions to make inferences about the time to failure distribution. In order to make these inferences without increasing the length of the test, a life test can be "accelerated" by running the experiment at higher stress levels. Inference is then made by extrapolating back to the design stress conditions. This type of extrapolation is called extrapolation in stress.

Another type of extrapolation that may be necessary in life testing is extrapolation in time. The limit on available time for the test may mean that few failures are observed at low stress conditions. If one intends to estimate the 100Pth percentile of the time to failure distribution and fewer than 100P% of the units at a certain stress level fail by the end of the test, one would need to extrapolate in time to make the estimate.
With a fixed length of time for testing, the amount of extrapolation in stress that is required and the amount of extrapolation in time that is required are inversely related - if one is decreased, the other is necessarily increased. Since each type of extrapolation is potentially dangerous, it is important to balance these types of extrapolation in designing a test plan. Various test plans have been developed\(^1\) that allow the researcher to balance the risks for a particular testing situation.

In developing these test plans, some simplifying assumptions are made:

- there is a single accelerating stress
- there is a linear relationship between the log of time to failure and an appropriate transformation of the stress variable, and
- the time to failure distribution follows a particular form such as the Weibull or the Lognormal.

To specify a particular testing situation, one must provide values for the following variables:

1. an appropriate transformation for the stress variable,
2. the design stress value and the highest stress value for which the linear relationship between log time to failure and transformed stress may still hold,
3. the percentile of the time to failure distribution that is to be estimated,
4. the number of units available for the test,

---

\(^{1}\) See, for example, Meeker (1984) and Meeker and Hahn (1985)
the assumed form of the time to failure distribution,
guesses of the probabilities of failure at the design and highest
stress values \( p_D \) and \( p_H \), respectively,
guess value for the spread parameter in the time to failure dis-
tribution, and
the length of time available for the test (the censoring time).

Given these values, possible test plans may be developed. A test
plan is specified by the levels of stress at which units are tested and
the particular allocation of experimental units to these levels

Since several types of test plans may be developed, comparisons must
be made between plans. The following are criteria for comparing accel-
erated life test plans:

1. The resulting variance of the estimate of the percentile: this
   variance affects the size of the sample necessary to obtain spec-
   ified accuracy at a desired level of confidence
2. The expected number of failures at each level of stress in the
   experiment if these numbers are too small, the assumptions upon
   which the tests are based may be inaccurate and failures may not
   occur at certain stress levels
3. Robustness to departures from the assumed input values

The basic idea of planning an accelerated life test is to take the
specifications of the testing situation and use these to develop test
plans that may be compared in various ways.
Purpose of ALTPLAN

ALTPLAN is a computer program that is useful in the development and evaluation of accelerated life test plans. ALTPLAN allows the development of several possible plans and provides means of evaluating and comparing these plans according to the criteria mentioned above. ALTPLAN will generate the types of plans presented by Meeker (1984) and Meeker and Hahn (1985) and will also allow the user to modify plans or specify alternative plans.

2. GETTING STARTED

2.1 Preparation of input values

The values of the following variables (described above) are given as input to ALTPLAN (default values are given in parentheses):

1. The type of transformation applied to original stress values (Linear).
2. The design stress value and the highest stress value at which the assumed life-stress relationship can still be expected to hold (Standardized values: 0.000, 1.000)
3. The percentile of the time to failure distribution which is to be estimated at the design stress (0.10).
4. The total number of units available for the test (1000).
5. The assumed form of the time to failure distribution (NONE).
7. The value of the spread parameter in the time to failure distribution (1.000)
8. The censoring time (1.000)
Hardware requirements

ALTPLAN may be run on an IBM PC, AT or XT with at least one disk drive and a minimum of 256K RAM. ALTPLAN requires DOS 2.1 (or later version) and an 8087 Math Coprocessor. An 80-column printer is recommended, but not necessary.

Starting the program

Before running the program for the first time, an installation procedure must be completed. See appendix B for instructions.

Instructions for starting the program

1. Place ALTPLAN diskette in drive A.
2. If the computer is off, turn it on.
   If the computer is already on, press <CONTROL> <ALT> <DEL> simultaneously to reset the machine.
3. When the A> prompt appears, begin running ALTPLAN by typing:

   A> ALTPLAN

   and the title screen in figure 1 will appear

4. Use ALTPLAN by following the directions given at the bottom of each screen. ALTPLAN is a menu-driven program, meaning that the user controls program operation by making a series of choices from menus. The user may make a selection by typing the single number corresponding to the option and then pressing the <ENTER> key. In most cases, the menu has a default (D) option which

   <ENTER> may be known to some users as <RETURN>. The terminology in this guide will follow the terminology used in IBM documentation.
Figure 1: Title screen

may be selected by simply pressing <ENTER>. The option to leave a program segment and move back up in the menu structure is always option number 1. In many cases it is the default option.

If a printer is available, output on paper may be obtained using the IBM PC print-screen command. To obtain a copy of the screen at a particular time, press <SHIFT> <PRTSC> simultaneously. To begin printing everything that appears on the screen, press <CONTROL> <PRTSC> simultaneously. To stop this printing, press <CONTROL> <PRTSC> again.
3. PROGRAM ORGANIZATION

3.1 Diagrams of the structure of the program

Figure 2: Diagram of the structure of the entire program

Figure 3: Diagram of the Input Module
Plan development module

- Automatic generation of plans
- Modify plans
- Specify plans
- Delete plans

Figure 4: Diagram of the Plan Development Module

Plan evaluation module

- Calculate sample size
- Detailed display
- Sensitivity analysis

Figure 5: Diagram of the Plan Evaluation Module
3.2 Brief description of MAIN menu options

The MAIN menu (shown in figure 6) is the central starting point for all routines. Each option on the main menu has a submenu with which user may choose specific activities. Brief descriptions of the menu options follow

![Main Menu Diagram]

Figure 6: Main menu

1. QUIT - DONE WITH ALTPLAN

   With this option the user may exit from the program. Before exiting, the user will be given a chance to save the current input values and test plans
2 INPUT (OR CHANGE) SPECIFICATIONS OF THE TESTING SITUATION

With this option the user may enter values of the variables that define the testing situation. Values may be entered by typing them in through the keyboard or by reading a file created previously by ALTPLAN. If there are any plans currently in the list of plans, these plans and their corresponding input values may be saved in a disk file. If they are not saved, they are discarded.

3. DEVELOP ACCELERATED LIFE TEST PLANS

In this section of the program the user may develop several types of test plans. Ten types of plans may be generated automatically. The user may modify any plan that has been previously developed or completely specify the stress values and allocations of the plan. There is also an option in this section to delete particular plans from consideration.

4 EVALUATE ACCELERATED LIFE TEST PLANS

As plans are generated in the DEVELOP section, a display of the plans includes the variance of the estimate of the percentile for each plan. More information for evaluation may be generated in this section of the program: a sample size calculation, detailed display of the characteristics of plans, and an analysis of the sensitivity of each type of plan to the assumed failure distribution.
4 DESCRIPTION OF PROGRAM OPTIONS

4.1 Quit - done with ALTPLAN

The screen in figure 7 will be displayed when this option is chosen.

![Quit menu](image)

**Figure 7: Quit menu**

- Selection 1 will allow the user to save the current specifications of the testing situation and all plans that have been developed (but not deleted) with this testing situation. The user will be asked for a file name under which to save the data.

Selection 2 will allow the user to immediately exit from the program.
Input (or change) specifications of testing situation

Specifications of the testing situation must be entered before plans are developed or evaluated. Most of the inputs have default values that need not be changed before plans can be developed. The assumed form of the time to failure distribution and the failure probabilities do not have default values, so they must be entered before any plans may be developed.

Whenever any changes are made in the specifications of the testing situation, the plans developed under the former testing situation cannot be directly compared to the plans which will be developed under the new specifications. The user has the option of saving the plans and the specifications of the testing situation under which they were developed in a disk file before the list of plans is cleared. If saved, this data may be read back into the program at another time.

There are two menus that could appear when the INPUT option on the MAIN menu is chosen. If there are no plans currently in the list of plans, as is the case when the program has just been started, the menu in figure 8 appears.

The second possible menu that could appear when INPUT is chosen on the main menu is similar to the first, but adds another question. If there are plans currently in the list of plans, the user must choose the method of input as above, and must also choose whether to save the current inputs and plans. Thus, the menu in figure 9 is presented.

Selecting to enter input by keyboard (from either menu) will allow the user to type in values for the variables. The menu in figure 10 gives the user the option of changing all the values or just some of the
VALUES Option 1 (ALL) will take the user through the entire input sequence. Option 2 (SOME) leads to the menu in figure 11, allowing the user to choose particular variables to enter.

Selecting to enter input from a file will allow the user to retrieve a file containing input specifications and test plans from diskette. The user will be asked for the name of the file, previously saved by ALTPLAN, that is to be retrieved. There is no facility for listing possible file names.
INPUT (OR CHANGE) SPECIFICATIONS OF TESTING SITUATION

Method of input? / Save current plans? (if any)

1. Enter input by keyboard - first, save current plans
2. Enter input by keyboard - do not save plans (D)
3. Enter input from file - first, save current plans
4. Enter input from file - do not save plans

Enter number of selection or <ENTER> for default (D)
ENTER INPUT BY KEYBOARD

1. Change ALL of the input values (D)
2. Change SOME of the input values

Enter number of selection or <ENTER> for default (D)

Figure 10: An input submenu
4.3 Develop accelerated life test plans

When the user selects this option on the MAIN menu, the menu in figure 12 appears.

- Selection 1 simply takes the user out of the plan development routines and back to the MAIN menu.

Selection 2 leads to the menu in figure 13, allowing the user to generate various types of plans. The types of plans listed in this menu are described in an appendix to this guide.

- Selection 3 allows the user to take a plan that has already been developed and modify it. In the first step, the menu in figure 14 allows the user to modify the stress values in various ways.
all necessary modifications have been made to the stress levels, the user is given the option of modifying the allocations. After the modifications are completed, the plan is evaluated and added to the list of plans. The user is then given the option of modifying another plan.

* Selection 4 allows the user to completely specify the stress values and allocation of a plan. The user must specify the stress values first (Step 1), and then the allocation (Step 2).

Selection 5 allows the user to delete some of the current plans. The user is presented with a list of all current plans and may choose the plans to delete.
GENERATE PLANS AUTOMATICALLY

1. Exit - return to DEVELOP menu (D)
2. Generate all plans, then return to plan menu
3. Statistically Optimum plan
4. 3 Level Best Standard plan
5. Best Compromise plans
6. Equal Expected Number Failing plan
7. 4:2:1 Allocation plans

Enter number of selection or <ENTER> for default (D)
4.4 Evaluate accelerated life test plans

When option 4 on the MAIN menu is chosen, the menu in figure 15 appears.

- Selection 1 simply returns the user to the main menu
- Selection 2 leads to a routine which calculates, for a particular plan, the sample size necessary to have a specified amount of accuracy at a specified level of confidence. The user first chooses the particular plan, then the menu in figure 16 appears, giving the user the option of changing the values used in the sample size formula. After any necessary changes are completed, a display is shown that gives the necessary sample size. The user is then given the option of performing this calculation for another plan.
Selection 3 allows the user to see detailed displays of the characteristics of particular plans. The display follows the form of tables 2 and 10 in the paper of Meeker and Hahn (1985) and includes the following for each stress level:

i) stress value in original and standardized units,

ii) proportional allocation,

iii) number of units allocated,

iv) failure probability, and

v) expected number failing.

Selection 4 allows the user to analyze the sensitivity of the generated plans to the guesses made about the time to failure distri-
CALCULATE NECESSARY SAMPLE SIZE

Make desired changes in current default values

1. Make no (more) changes (D)
2. Value of the spread parameter
3. Percent error in estimate of percentile
4. Probability of staying within percent error

Enter number of selection or <ENTER> for default (D)

Figure 16: Values used in the sample size formula

Version 1.0 of ALTPLAN offers an analysis of sensitivity to the assumed form of the distribution. A ratio of variances is calculated for each automatically generated plan in the list of plans. If the assumed distribution is Weibull, \( R(WL/LL) \) is calculated. \( R(WL/LL) \) is the ratio of the variance of a plan generated under a Weibull distribution assumption and evaluated under a Lognormal distribution assumption to the variance of a plan generated and evaluated under the Lognormal distribution assumption. \( R(LW/WW) \) is calculated if the assumed distribution is Lognormal and is defined analogously. The analysis of the sensitivity of plans to the guess values of the failure probabilities is not available.
5. SAMPLE SESSION WITH ALTPLAN

5.1 Getting started

Consider the adhesive-bonded power element example discussed by Meeker and Hahn (1985). Following the list of input values that must be prepared, the values of the variables that specify the testing situation are as follows:

<table>
<thead>
<tr>
<th>Model of life/stress relationship</th>
<th>Arrhenius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest stress value</td>
<td>120 degrees C</td>
</tr>
<tr>
<td>Design stress value</td>
<td>50 degrees C</td>
</tr>
<tr>
<td>Percentile to be estimated</td>
<td>.10</td>
</tr>
<tr>
<td>Sample size</td>
<td>300 units</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumed form of time to failure distribution</th>
<th>Weibull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure probabilities:</td>
<td></td>
</tr>
<tr>
<td>$P_D$</td>
<td>.001</td>
</tr>
<tr>
<td>$P_H$</td>
<td>.900</td>
</tr>
<tr>
<td>Value of spread parameter</td>
<td>1.000</td>
</tr>
<tr>
<td>Censoring time</td>
<td>183 days</td>
</tr>
</tbody>
</table>

The program is started according to the instructions given above and option 2 is chosen on the main menu to enter the specifications of the testing situation.

Entering input values

Figures 17 through 21 show examples of input routine screens. The values specifying the adhesive-bonded power element problem are given as input. Screens not shown are those for entry of sample size, distribution, failure probabilities, and spread parameter.

The routines for entry of the desired stress value form(s) and for entry of censoring time require explanation. Stress values may be given in either their original units (e.g. temperature) or in standardized...
The current (default) model for life/stress relationship is \textit{LINEAR}

\textbf{CHOOSE MODEL FOR LIFE/STRESS RELATIONSHIP}

1. Linear: \[ I = T \]
2. Inverse power law: \[ X = \log(T) \]
3. Arrhenius: \[ Y = -1 / (T + 273) \]

Enter number of selection or \textless\text{ENTER}\textgreater\ for default (D)

Figure 17: Entering life/stress model

units, where standardized design stress is 0.000 and standardized highest stress is 1.000 (see formula in appendix). The user may work exclusively with standardized values, or may choose to use original units for input of stress values and/or see stress values in original units in detailed displays. Since the user will always be shown stress values in standardized units in all displays, the possibilities mentioned above lead to three options for form(s) for input and detailed output of stress values. Figure 18 shows these options. The user makes this choice when entering input values and the choice holds in all routines in the program until it is changed in the input routine.
The current (default) choice of form(s) for stress value input and output is:
INPUT: std OUTPUT: std

CHOOSE STRESS VALUE FORM FOR INPUT AND DETAILED OUTPUT
(std=standardized units, original=original units)

1. INPUT: std OUTPUT: std
2. INPUT: std OUTPUT: original and std
3. INPUT: original OUTPUT: original and std

Enter number of selection or (ENTER) for default (D)
> 2

Figure 18: Entering form(s) for stress values

If option 1 is chosen, the design stress is automatically set to 0.000 and the highest stress is automatically set to 1.000. If option 2 or 3 is chosen, the second step is to enter design and highest stress values in original units.

When censoring time is changed, the user is given the option of having the failure probabilities automatically adjusted. This is a simple way of testing the effects of changing the length of time available for the test. The failure probabilities are adjusted according to the relationship between censoring time and the failure probabilities given by Meeker (1984). After the adjustments are made, the user is given the choice of whether to use the adjusted values or return to the unadjusted values.
Current stress values
  design stress:  0.0000
  highest stress:  1.0000

Type in new value or press ENTER to keep current value
  design stress:  50
  highest stress:  120

Figure 19: Entering stress values

Figure 22 shows the display of the input values.
The current percentile to be estimated is 0.10000

Type in new value or press ENTER to keep current value
Percentile to be estimated:

Figure 20: Entering the percentile to be estimated
The current censoring time is 1.0000

Type in new value or press ENTER to keep current value
Censoring time: 183

Figure 21: Entering the censoring time
5.3 Developing plans

After input values have been entered, it is possible to develop plans. Taking the option to "generate plans automatically" and then the option to "generate all plans" causes the set of plans in figure 23 to be developed. The column headed "V(P)" gives the value of \( n/\sigma^2 \) times the asymptotic variance of the maximum likelihood estimator of the percentile of interest at the design stress. The column headed "Ratio" gives the ratio of V(P) for the particular plan to the value of V(P) for the statistically optimum plan.

The 'specify a plan' option is now chosen. Figures 24 and 25 show the process of entering stress values. Figure 26 shows a display of the
ACCELERATED LIFE TEST PLANS ASSUMING A WEIBULL DISTRIBUTION

\[ P = 0.10000 \quad PD = 0.00100 \quad PH = 0.90000 \]

<table>
<thead>
<tr>
<th>Plan Number</th>
<th>Type Code</th>
<th>Stress Levels</th>
<th>Allocation</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20PT</td>
<td>0.682</td>
<td>1.000</td>
<td>0.706</td>
</tr>
<tr>
<td>2</td>
<td>3BS</td>
<td>0.571</td>
<td>0.786</td>
<td>1.000</td>
</tr>
<tr>
<td>3</td>
<td>3BC10</td>
<td>0.663</td>
<td>0.831</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>3BC20</td>
<td>0.638</td>
<td>0.819</td>
<td>1.000</td>
</tr>
<tr>
<td>5</td>
<td>3BEE</td>
<td>0.673</td>
<td>0.837</td>
<td>1.000</td>
</tr>
<tr>
<td>6</td>
<td>3FT100</td>
<td>0.609</td>
<td>0.804</td>
<td>1.000</td>
</tr>
<tr>
<td>7</td>
<td>3FT90</td>
<td>0.548</td>
<td>0.774</td>
<td>1.000</td>
</tr>
<tr>
<td>8</td>
<td>3FT80</td>
<td>0.487</td>
<td>0.744</td>
<td>1.000</td>
</tr>
<tr>
<td>9</td>
<td>3FT70</td>
<td>0.426</td>
<td>0.713</td>
<td>1.000</td>
</tr>
<tr>
<td>10</td>
<td>3FT60</td>
<td>0.365</td>
<td>0.699</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Press ENTER to continue

Figure 23: Display of current plans

The display in figure 29 appears when the "delete plans" option is requested. It shows the automatically generated plans, a modified version of the 3FT100 plan (plan 11 with plan type code M3FT100), and the plan specified above (plan 12 with plan type code USER). Deleting plans 2, 3, 4, and 5 is accomplished by typing those numbers in response to the question. Figure 30 shows the new list of plans.
SPECIFY A PLAN
Step 1: Specify stress values

Enter the number of levels of stress you wish to have in this test plan or press ENTER to have 3 levels

Number of levels: 4

Figure 24: Entering the number of stress levels
ENTER THE STRESS VALUES

Enter 4 stress values in standardized form:

(You may enter these values in any order)

Stress values: .8 .9 1 .7

Figure 25: Specifying stress values
**ABBREVIATED DISPLAY OF PLAN NUMBER 12**

**ASSUMED WEIBULL DISTRIBUTION, P=0.10000 PD=0.00100 PH=0.90000**

<table>
<thead>
<tr>
<th>Stress level number</th>
<th>Stress in original units</th>
<th>Stress in standardized units of test units</th>
<th>Proportion allocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>56.0000</td>
<td>0.000</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>96.0087</td>
<td>0.700</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>105.6736</td>
<td>0.800</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>111.6636</td>
<td>0.900</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>120.0000</td>
<td>1.000</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Press ENTER to continue

**Figure 26: Display of the plan being specified**
SPECIFY A PLAN

Step 2: Specify the allocation

Enter the allocations you wish to have at each stress level in response to the prompts below.

For each level you will be shown the stress value and the initial allocation of zero. Type in the allocation as a number between zero and one.

If you just type ENTER the allocation of zero will stay.

Stress level 1
Standardized stress value = 0.700 Allocation = 0.000
New allocation: .5

Stress level 2
Standardized stress value = 0.800 Allocation = 0.000
New allocation: .2

Figure 27: Entering the allocation
ABBREVIATED DISPLAY OF PLAN NUMBER 12

ASSUMED WEIBULL DISTRIBUTION, P=0.10000  PD=0.00100  PH=0.90000

<table>
<thead>
<tr>
<th>Stress level number</th>
<th>Stress in units</th>
<th>Proportion of test units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50.0000</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>96.0087</td>
<td>0.700 0.50</td>
</tr>
<tr>
<td>2</td>
<td>103.6736</td>
<td>0.800 0.20</td>
</tr>
<tr>
<td>3</td>
<td>111.6636</td>
<td>0.900 0.20</td>
</tr>
<tr>
<td>4</td>
<td>120.0000</td>
<td>1.000 0.10</td>
</tr>
</tbody>
</table>

The plan has now been specified. It will be evaluated and added to the set of plans already generated.

Press ENTER to continue

Figure 28: The completed plan
### ACCELERATED LIFE TEST PLANS ASSUMING A WEIBULL DISTRIBUTION

**P=0.10000**  
**PD=0.00100**  
**PH=0.90000**

<table>
<thead>
<tr>
<th>Plan Number</th>
<th>Type</th>
<th>Stress Levels</th>
<th>Allocation</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20PT</td>
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<td>0.663</td>
<td>0.831</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>3BC20</td>
<td>0.638</td>
<td>0.819</td>
<td>1.000</td>
</tr>
<tr>
<td>5</td>
<td>3BEE</td>
<td>0.673</td>
<td>0.837</td>
<td>1.000</td>
</tr>
<tr>
<td>6</td>
<td>3FT100</td>
<td>0.609</td>
<td>0.804</td>
<td>1.000</td>
</tr>
<tr>
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<td>0.548</td>
<td>0.774</td>
<td>1.000</td>
</tr>
<tr>
<td>8</td>
<td>3FT80</td>
<td>0.487</td>
<td>0.744</td>
<td>1.000</td>
</tr>
<tr>
<td>9</td>
<td>3FT70</td>
<td>0.426</td>
<td>0.713</td>
<td>1.000</td>
</tr>
<tr>
<td>10</td>
<td>3FT60</td>
<td>0.365</td>
<td>0.699</td>
<td>1.000</td>
</tr>
<tr>
<td>11</td>
<td>M3FT100</td>
<td>0.500</td>
<td>0.804</td>
<td>1.000</td>
</tr>
<tr>
<td>12</td>
<td>USER</td>
<td>0.700 (2 more)</td>
<td>1.000</td>
<td>0.500 (2 more)</td>
</tr>
</tbody>
</table>

Enter the numbers of the plans you wish to delete, separated by spaces: 2 3 4 5

*Figure 29: Before plans are deleted*
## ACCELERATED LIFE TEST PLANS ASSUMING A WEIBULL DISTRIBUTION

\[
\begin{array}{llllllll}
\text{Plan} & \text{Type} & \text{Stress Levels} & \text{Allocation} & \text{Precision} \\
\text{Number} & \text{Code} & \text{Low} & \text{Middle} & \text{High} & \text{Low} & \text{Middle} & \text{High} & \text{V(P)} & \text{Ratio} \\
1 & 20FT & 0.682 & 1.000 & 0.706 & 0.294 & 126 & 1.000 \\
6 & 3FT100 & 0.609 & 0.804 & 1.000 & 0.571 & 0.286 & 0.143 & 146 & 1.218 \\
7 & 3FT90 & 0.548 & 0.774 & 1.000 & 0.571 & 0.286 & 0.143 & 150 & 1.246 \\
8 & 3FT80 & 0.487 & 0.744 & 1.000 & 0.571 & 0.286 & 0.143 & 159 & 1.324 \\
9 & 3FT70 & 0.426 & 0.713 & 1.000 & 0.571 & 0.286 & 0.143 & 172 & 1.431 \\
10 & 3FT60 & 0.365 & 0.689 & 1.000 & 0.571 & 0.286 & 0.143 & 184 & 1.554 \\
11 & M3FT100 & 0.500 & 0.804 & 1.000 & 0.571 & 0.286 & 0.143 & 163 & 1.361 \\
17 & WRE & 0.706 & 1.000 & 0.500 & 0.100 & 178 & 1.482 \\
\end{array}
\]

Press ENTER to continue

---

**Figure 30:** After plans are deleted

### 5.4 Evaluating the plans

The plans developed in the previous section may be evaluated by choosing the "evaluate plans" option on the main menu. Figure 31 shows the display generated when the sample size calculation is requested for plan 6 and figure 32 shows the detailed display of plan 6.
SAMPLE SIZE DETERMINATION

Percentile to be estimated: 0.10000
Value of the spread parameter: 1.0000
Percent error in estimate of percentile: 100.00
Probability of staying within percent error: 0.9500
Distribution of time to failure: WEIBULL

Test plan used:

<table>
<thead>
<tr>
<th>Plan</th>
<th>Type</th>
<th>Stress Levels</th>
<th>Allocation</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>Low</td>
<td>0.609</td>
<td>0.049</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>Middle</td>
<td>1.000</td>
<td>0.571</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>High</td>
<td>0.206</td>
<td>0.143</td>
</tr>
</tbody>
</table>

REQUIRED TOTAL SAMPLE SIZE: 1169

Press ENTER to continue

Figure 31: Sample size determination
**Figure 32: Detailed display of a plan**

Exiting from the program

user may request that the plans developed during this session be saved before exiting from the program. As shown in figure 33, the user will be asked for a filename.
5.6 Remarks about the sample session

This sample session is a short example of how ALTPLAN may be used. Various options concerning data entry, plan development, and plan evaluation have not been shown. These options may be explored while running the program by making the appropriate menu selections.
ACKNOWLEDGEMENT

Program code for generation and evaluation of test plans was provided by Dr. William Q. Meeker. I would like to acknowledge this contribution and express my appreciation for the technical support and encouragement he provided to me during this project.
Appendix A

DESCRIPTION OF TYPES OF ACCELERATED LIFE TESTS

The **2 level statistically optimum** plan (2OPT) minimizes the variance of the estimate of the percentile.

- The **3 level best standard** plan (3BS) has 3 equally spaced stress levels with equal allocations. Subject to this restriction, the lowest stress value is chosen to minimize the variance of the estimate of the percentile.

- The **best compromise** plans (3BC10 and 3BC20) put a specified proportion of the test units (.10 and .20, respectively) at the middle stress level, which is chosen as halfway between the low and high stress levels. Subject to these restrictions, the low and high stress levels are chosen to minimize the variance of the estimate of the percentile.

The **best equal expected number failing** plan (3BEE) is like a best compromise plan except that the allocations are chosen so that at each stress level, the expected number of units failing is the same.

- The **optimized 4:2:1 allocation** plan (3FT100) has three stress levels with a 4:2:1 allocation of test units to the low, middle and high stress levels, respectively. The low and middle test stresses are chosen to minimize the variance of the estimate of the percentile, with the middle stress as close as possible to halfway be-
between the low and high stresses subject to the restriction that the probability of failure at the middle stress be at least twice the percentile that is to be estimated (i.e., \( p_M \geq 2p \)).

- The **adjusted 4:2:1 allocation** plans (3FT90, 3FT80, 3FT70, 3FT60) are obtained from the optimized 4:2:1 plan by reducing the low stress value to 0.90, 0.80, 0.70, 0.60 times the value of the low stress value in the optimum plan. The middle stress level is adjusted to be as close as possible to halfway between the low and high stress values subject again to the restriction that \( p_M \geq 2p \).

- The **modified** plans (any plan type code beginning with M) are those obtained by modifying one of the plans described above.

- The **user-specified** plans have plan type code USER.
Appendix B

INITIAL INSTALLATION OF ALTPLAN

This version of ALTPLAN uses extended screen control. In order to run the program, two special files must be on the diskette used to boot the system. The procedure described below will accomplish this. For more information, see the section on "Configuration commands, particularly the "device" configuration command, in the DOS reference manual.

1. Put DOS 2.1 (or a later version) diskette in Drive A and boot the system.
2. Put an empty diskette in Drive B.
3. Format the diskette in Drive B with the command:
   A> format b:/s
4. Copy a file from the DOS diskette with the command:
   A> copy a:ansi.sys b:
5. Remove the DOS diskette and place the ALTPLAN diskette in Drive A.
6. Copy the ALTPLAN files onto the new diskette with the commands:
   A> copy a:ALTPLAN.EXE b:
   A> copy a:config.sys b:
   The CONFIG.SYS file consists of one line:
   DEVICE=ANSI.SYS
7. Now the new ALTPLAN diskette (the one in drive B) can be used to boot the system and to run ALTPLAN. Follow the instructions in the section in this guide on starting the program.
Appendix C

SUMMARY OF PROGRAM LIMITATIONS

ALTPLAN will allow up to 50 plans to be developed with up to 10 levels of stress for each plan. The program will terminate with errors if the user attempts to develop more than 50 plans.

Available models of life/stress relationship are Linear, Inverse power law and Arrhenius.

- Available distributions of time to failure are Weibull and Lognormal.

Limitations on input values follow:

<table>
<thead>
<tr>
<th>Variable</th>
<th>default</th>
<th>minimum</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD</td>
<td>NONE</td>
<td>.00001</td>
<td>P</td>
</tr>
<tr>
<td>PH</td>
<td>NONE</td>
<td>.00001</td>
<td>&lt; 1.000</td>
</tr>
<tr>
<td>Percentile (P)</td>
<td>.10</td>
<td>.00001</td>
<td>&lt; 1.000</td>
</tr>
<tr>
<td>sample size</td>
<td>1000</td>
<td>1</td>
<td>1,000,000</td>
</tr>
<tr>
<td>spread parameter</td>
<td>1</td>
<td>&gt; 0</td>
<td>1,000,000</td>
</tr>
<tr>
<td>censoring time</td>
<td>1</td>
<td>&gt; 0</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

Stress values:

<table>
<thead>
<tr>
<th>standardized units</th>
<th>-10.00</th>
<th>10.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>original units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear model</td>
<td>-1,000,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Inverse power law</td>
<td>&gt; 0</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Arrhenius</td>
<td>&gt; -273</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>
NOTE: Errors may occur in plan evaluation even when $p_D$ and $p_H$ are within the given limits. If a message such as "EPLAN ERROR" or "POWELD ERROR" flashes across the screen, the values of $p_D$ and $p_H$ may be the problem.
Appendix D

AREAS FOR POSSIBLE IMPROVEMENT

1. Sensitivity analysis: sensitivity to misspecified failure probabilities.
2. Help screens put an option on each menu for HELP with the other menu options
3. Evaluate plans for a vector of percentiles - determine the plan by the first entry in the vector
4. Add an initial module for testing at a single stress condition
5. Develop a batch version of the program for experienced users or provide an option to reduce the number of menu selections that must be made
6. Provide for the output of a data collection sheet for a particular plan
7. Provide a listing of files saved previously by ALTPLAN.
Appendix E

STATISTICAL REFERENCES AND COMPUTATIONAL FORMULAS

REFERENCES


COMPUTATIONAL FORMULAS

1. Transformations

   Linear             \( X = T \)

   Inverse power law  \( X = \log(T) \)

   Arrhenius          \( X = -1 / (T + 273) \)

where \( X = \) transformed stress

\( T = \) stress value in original units
2. Standardization

\[ Z = \frac{(X - X_D)}{(X_H - X_D)} \]

where \( Z \) = standardized stress value

\( X \) = transformed stress value

\( X_D \) = transformed design stress value

\( X_H \) = transformed highest stress value

3. Variance ratio

\[ R = \frac{V(P)}{V} \]

where \( V(P) \) = Variance of the estimate of the 100Pth percentile for the plan under consideration

\( V \) = Variance of the estimate of the 100Pth percentile for the statistically optimum plan

See Meeker (1984) for formulae to compute \( V(P) \) as a function of the percentile to be estimated, the stress levels, and the proportional allocation.
4 Alternative parameterization

The testing situation has been specified in terms of $p_D$ and $p_H$ for input to ALTPLAN. An alternate parameterization uses a standardized (log) censoring time, $a$, and the standardized slope, $b$. Let $\tilde{F}(z) = F(z; 0, 1)$ be the standardized cdf of the assumed location-scale distribution. Then $\tilde{F}^{-1}(p)$ denotes the 100Pth quantile of the distribution.

Then,

$$p_D = \tilde{F}(a)$$

$$p_H = \tilde{F}(a-b)$$

$$a = \tilde{F}^{-1}(p_D)$$

$$b = a - \tilde{F}^{-1}(p_H)$$

5. Sample size determination

$$N = Z^2 \sigma^2 V / [\log(1+\gamma)]^2$$

where $Z = z_{(1-\alpha/2)}$

$\sigma = $ value of the spread parameter

$V = $ Variance of the estimate of the percentile

$\gamma = $ percent error / 100