Chapter 1

USING EXPERIMENTAL DESIGNS

The role of experimental design is to estimate the effects of several variables simultaneously. The experimental design then contains a group of experimental runs (Box, Hunter, and Hunter, 1978). Said another way, experimental design is a scientific approach that allows an experimenter to make intentional changes to the inputs of a process or system to identify and observe the reasons for the changes that occur to the response.

Process is defined as some combination of materials, methods, people, environment, and measurement, which used together form a service, produce a product, or complete a task (Schmidt and Launsby, 1989).

In any experiment, the results and conclusions depend to a large extent on the manner in which the data are collected. The primary reason for using any designed experiment is to use data that can provide answers to well thought out questions.

Montgomery (1991) outlines the many disciplines that use experimental design methods. Experimentation is viewed as part of the scientific process where opinions are formed about a process and experiments are performed to generate data from the process. Information from the experiment is then used to establish new opinions, which lead to new experiments, and so on.

In the engineering world, experimental design methods are critical tools that improve the performance of a manufacturing process, which results in:

- improvements in process yields

- reductions in variability and closer conformance to nominal or target requirements

- reductions in development time

- reductions in overall costs.

In engineering design activities, where new products are developed and existing ones improved, experimental design methods provide tools for:

- evaluating and comparing basic design configurations

- evaluating alternative materials

- selecting design parameters so a product will work well under a wide variety of field conditions

- determining key product design parameters that impact a product's performance.

Experimental design is based on three basic principles: replication, randomization, and blocking.

Replication
Replication is a repetition of a basic experimental run. It has two important properties. First, you obtain an estimate of the experimental error that becomes a basic unit of measurement used to determine if observed differences in the data are really statistically different. Second, you use the sample mean to estimate the effect of a factor.

Randomization
Randomization is the basis underlying the use of statistical methods in experimental design. Randomization means that you randomly determine how the experimental material is allocated, and the order in which the individual runs or trials of the experiment will be performed.

Blocking
Blocking is a technique that increases the precision of an experiment. A block is a portion of experimental material that should be more homogeneous than the entire set of material. Blocking involves making comparisons in each block among common conditions in the experiment. Blocking is often necessary to remove the effects of different batches of material, different experimenters, or experiments run on different days.

In some production processes, units are produced in natural chunks or blocks. You want to make sure that these blocks do not bias your estimates of main effects.

Confounding
Confounding is a design technique for arranging a complete factorial experiment in blocks, where the block size is smaller than the number of treatment combinations in one replicate.

To use a statistical approach in designing and analyzing an experiment, it is necessary that everyone involved in the experiment knows exactly what will be studied, and how the data will be collected and analyzed.

Montgomery (1991) cites these tasks for every experiment:

- recognize the problem and write a problem statement
- choose the factors and levels
- select the response variables
- choose the experimental design

- perform the experiments
- analyze the data
- draw conclusions and make recommendations.

This is an important iterative process, because it is where tentative hypotheses are formed and the basis upon which new hypotheses are formed.

Understanding Design Classes

One experimental design will often lead to greater efficiency than other designs in testing hypotheses and making estimates. STATGRAPHICS *Plus* helps you choose the right design and includes designs for these design classes: Screening, Response Surface, Mixture, Multilevel Factorial, Inner/Outer Arrays, Single Factor Categorical, Multi-Factor Categorical, and Variance Component (Hierarchical).

Screening
A Screening design determines the amount of change that occurs in the response variable (defects per unit) when each factor is changed, and if changing the factors together produces results different from changing the factors individually.

Response Surface
Response surface methodology is a process for locating an optimal value in a higher-order model. It utilizes regression, contour plots, and/or a method of steepest ascent/descent.

Mixture
Mixture designs involve experiments where a product is comprised of two or more ingredients or components.

Multilevel Factorial
Multilevel Factorial designs consist of combinations of specific levels of two or more factors, where the number of levels is set by the user. This design class is intended for quantitative factors only and is analyzed as a Response Surface design.

Inner/Outer Arrays Designs
Inner/Outer Arrays designs are a variation on an implementation of Taguchi (Robust) designs. The designs in STATGRAPHICS *Plus* consist of both controllable and uncontrollable noise factors. This design class is intended to determine the combination of factors that reduce the sensitivity to uncontrollable sources of variability.

Single Factor Categorical
Single Factor Categorical designs compare levels of a single nonquantitative variable, with or without blocking factors.

Multi-Factor Categorical
Multi-Factor Categorical designs consist of all combinations of specified levels of two or more factors, where the number is set by the user. The design is intended for nonquantitative factors and is analyzed using ANOVA.

Variance Components (Hierarchical)
Variance Components designs quantify the effects of various factors on the variability of a response. The design consists of nested factors.

Creating Designs

This section summarizes the preliminary steps you perform to create a design. In-depth explanations of the dialog boxes appear in Online Help. The explanations that follow are generic; that is, the process is the same regardless of the design class you are using. *For detailed instructions about creating a certain design, refer to the specific chapter that explains it later in this manual.*

To Create An Experimental Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 1-1.

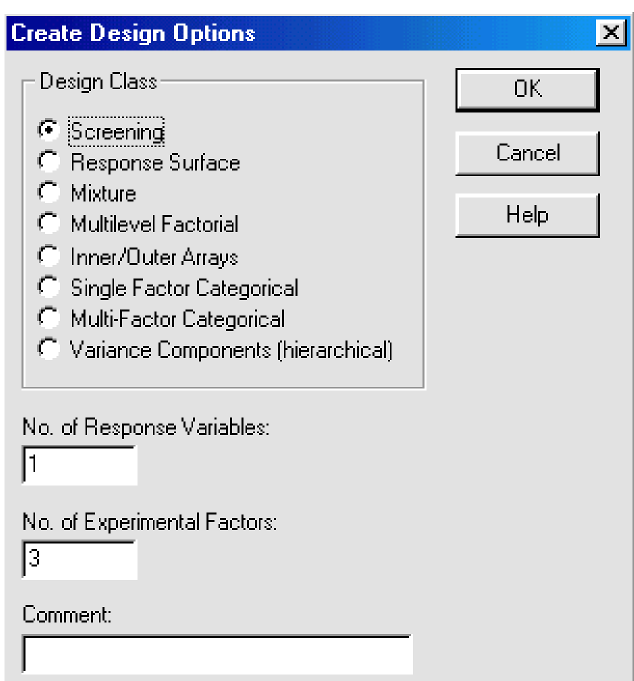


Figure 1-1. Create Design Options Dialog Box

2. Complete the dialog box. You will select a design class and either accept the defaults or enter specific parameters for each of the options on the dialog box.

3. Click OK to display additional Options dialog boxes specific to the design class you are creating.

4. Complete all the applicable dialog boxes, then click OK to display a Design Summary in the Design Attributes window. Before you click OK, you can modify the design you created.

Modifying Designs

If you need to select a different design, redefine the factors or response variables, or make any other changes, you can quickly modify the experimental design without starting over.

Note: Once you enter response data into the DataSheet, the modifications you can make are limited to that particular experimental design.

To Modify An Existing Design

1. Click the right mouse button in the Design Summary pane, then choose Analysis Options... to display the Design Options dialog box.

2. Click the Back... button to redisplay the Design Selection dialog box. You can then select a different design from the list.

3. Continue clicking Back... until you reach the Create Design Options dialog box where you can either create a completely new design or modify the design you are currently working on.

A quick way to return to the Create Design Options dialog box is to click the Return to Input Dialog Box button (the first button on the Attributes window toolbar).

Saving Designs

After you create a design, you must name and save it permanently to the hard disk or to a diskette. STATGRAPHICS *Plus* saves experimental design files as *.sfx files.

To Save Experimental Designs

1. Choose FILE... SAVE AS... SAVE DESIGN FILE AS... from the Menu bar to display the Save Design As dialog box shown in Figure 1-2.

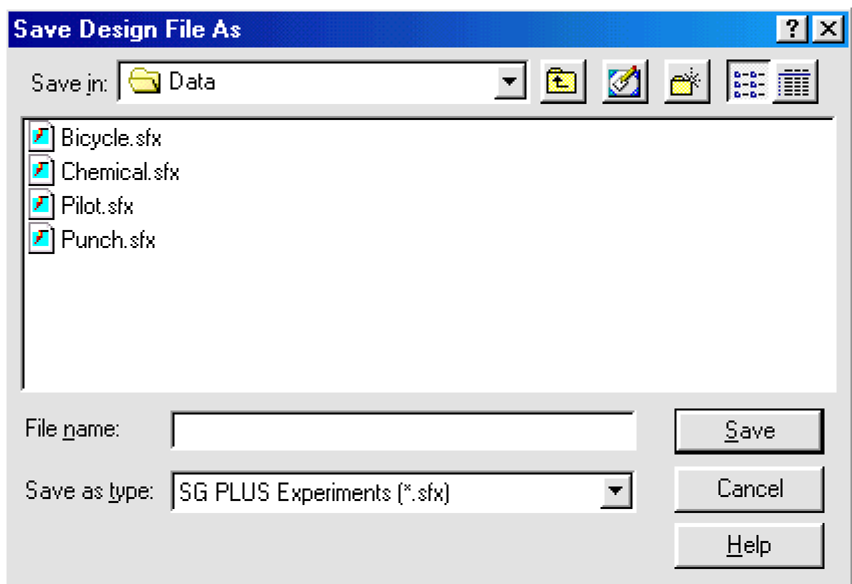


Figure 1-2. Save Design As Dialog Box

2. Type the name for the title of the experimental design and click OK. The program adds the *.sfx extension, saves the file, and displays the Data icon in a Taskbar at the bottom of the Application window.

After the file is saved, the design remains open so you can continue working; the new file name appears on the title bar.

Analyzing Experimental Designs

A primary advantage in using statistical methods to analyze experimental responses is to add objectivity to the decision-making process, which ensures that the results and conclusions will be objective rather than judgmental. Statistical methodologies allow you to measure the likelihood of error in a conclusion or to attach a level of credibility to a statement.

STATGRAPHICS *Plus* contains important statistical methodologies for proving reliability and validity in tabular results. Its graphical capabilities are useful for visualizing the results and presenting them to others.

Before you can analyze a design, you must open the design file.

To Open a Design File

1. Choose SPECIAL... EXPERIMENTAL DESIGN... OPEN DESIGN... from the Menu bar to display the Open Design dialog box shown in Figure 1-3.

2. Choose the design file you want to open, then click Open.

Note: If you created design files in DOS, before you can use them, you must rename them using the file extension .sfx, then bring them into STATGRAPHICS *Plus* for Windows.

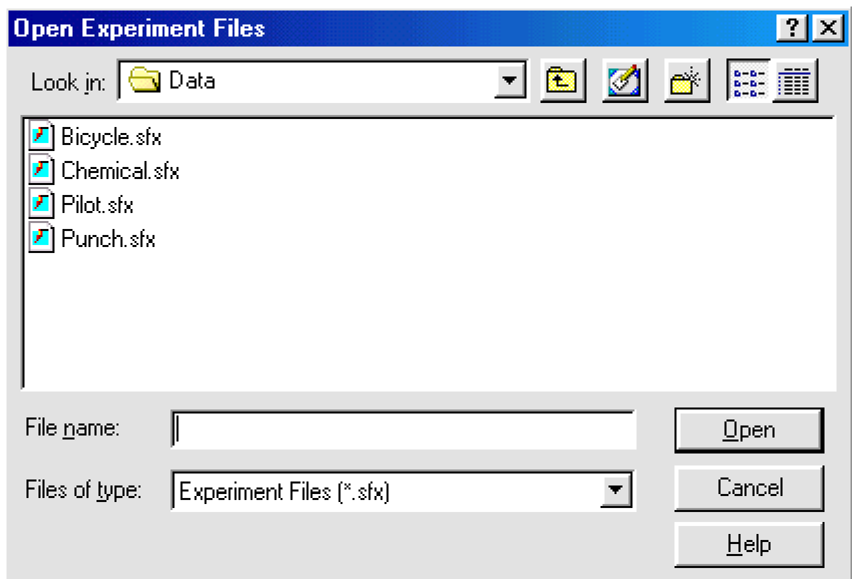


Figure 1-3. Open Design Dialog Box

To Analyze an Experimental Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... ANALYZE DESIGN... from the Menu bar to display the Analyze Design dialog box shown in Figure 1-4.

2. Complete the dialog box by entering the name of the variable that contains the experiment results you want to analyze.

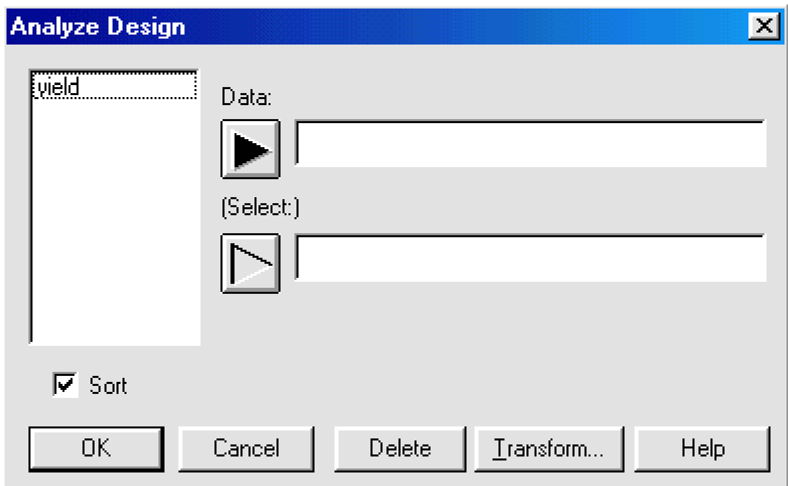


Figure 1-4. Analyze Design Dialog Box

When you click OK, the first tabular option, Analysis Summary, and the first graphical option, which will vary depending on the design, will display in the Analysis window. You can interpret the results, then select other tabular and graphical options.

Because the options are so numerous, depending on the design class and its parameters, it is impossible to document them here. *See Online Help for information about the options.*

References

Box, G. E. P., Hunter, W. G., and Hunter, J. S. 1978. *Statistics for Experimenters*. New York: John Wiley & Sons, Inc.

Cornell, J. A. 1973. Experiments with Mixtures: A Review, *Technometrics*, **15**:437-455.

Cornell, J. A. 1990. *Experiments with Mixtures*, second edition. New York: John Wiley & Sons.

Cornell, J. A. and Piepel, G. F. 1993. *Design and Analysis of Mixture Experiments*. Computer Associates.

Montgomery, D. C. 1991. *Design and Analysis of Experiments*, third edition. New York. John Wiley & Sons.

Schmidt, S. R. and Launsby, R. G. 1989. *Understanding Industrial Designed Experiments*, second edition. Colorado Springs, Colorado: Air Academy Press.

Chapter 2

OPTIMIZING A DESIGN

STATGRAPHICS *Plus* provides a capability to optimize an experiment. Typically, this involves creating a design, then selecting Optimize Design from the Menu bar to determine if there are runs that could be removed from the design before you run the experiment.

Optimize Design is an automated feature that is activated after you create or open a design, with logic to estimate a minimum number of runs (*candidate runs)* for a design. You then use the candidate runs when you analyze the design.

The Optimize Experiment window that displays after you open the design, displays the algorithm used to select the subset of original runs used to reach D-optimality. D-optimality is a criterion that measures the variability of the estimated parameters.

Because D-optimal designs are often used with mixture experiments, the remainder of this chapter uses a Simplex-Centroid design.

To Optimize a Mixture Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box.

2. Choose the Mixture option, enter 3 (change the default) for the No. text box, accept 3 (the default) for the number of components, then enter a comment about the design into the Comment text box (see Figure 2-1).

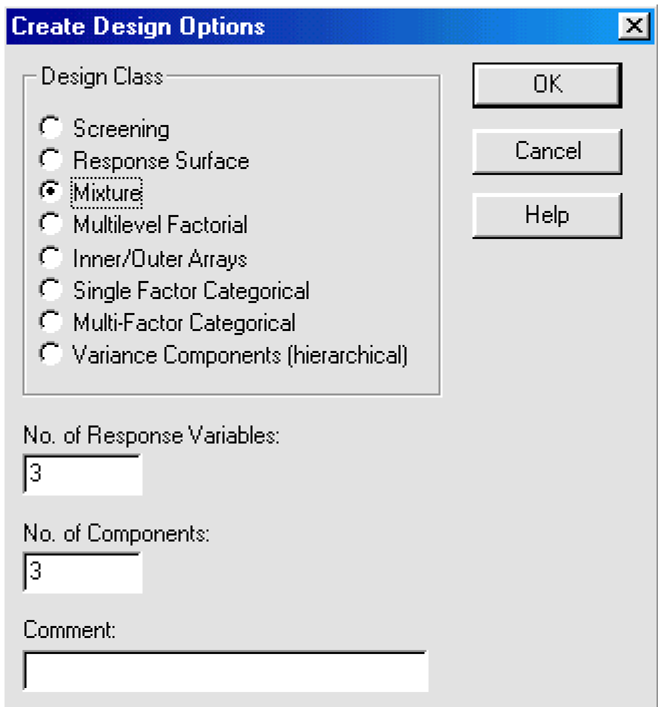


Figure 2-1. Completed Create Design Options Dialog Box

3. Click OK to display the Component Definition Options dialog box shown in Figure 2-2.

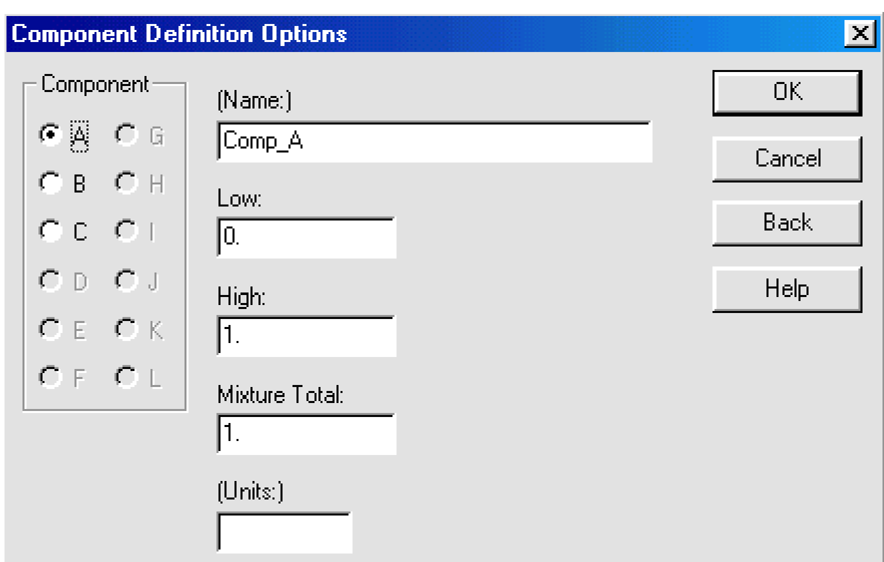


Figure 2-2. Component Definition Options Dialog Box

4. Accept the defaults by clicking OK. The Response Definition Options dialog box displays (see Figure 2-3).

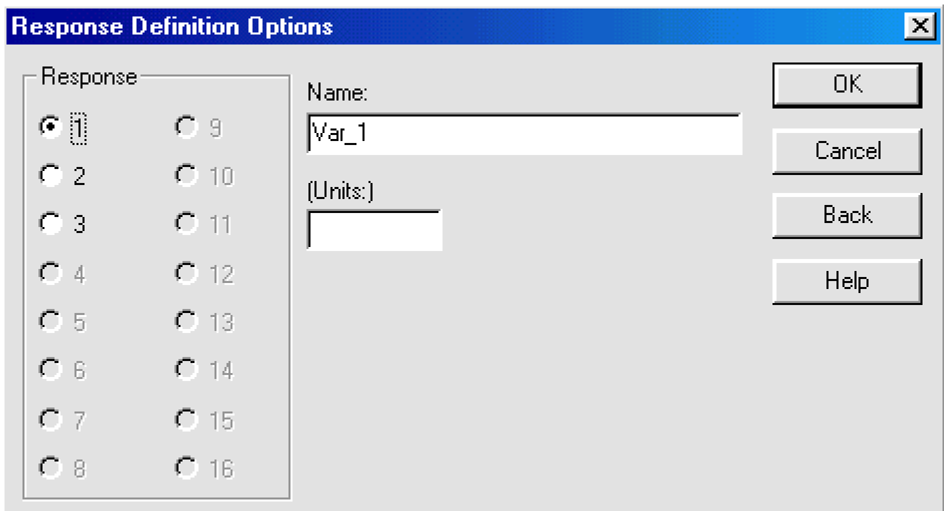


Figure 2-3. Response Definition Options Dialog Box

5. Accept the defaults by clicking OK to display the Mixture Design Selection dialog box (see Figure 2-4).

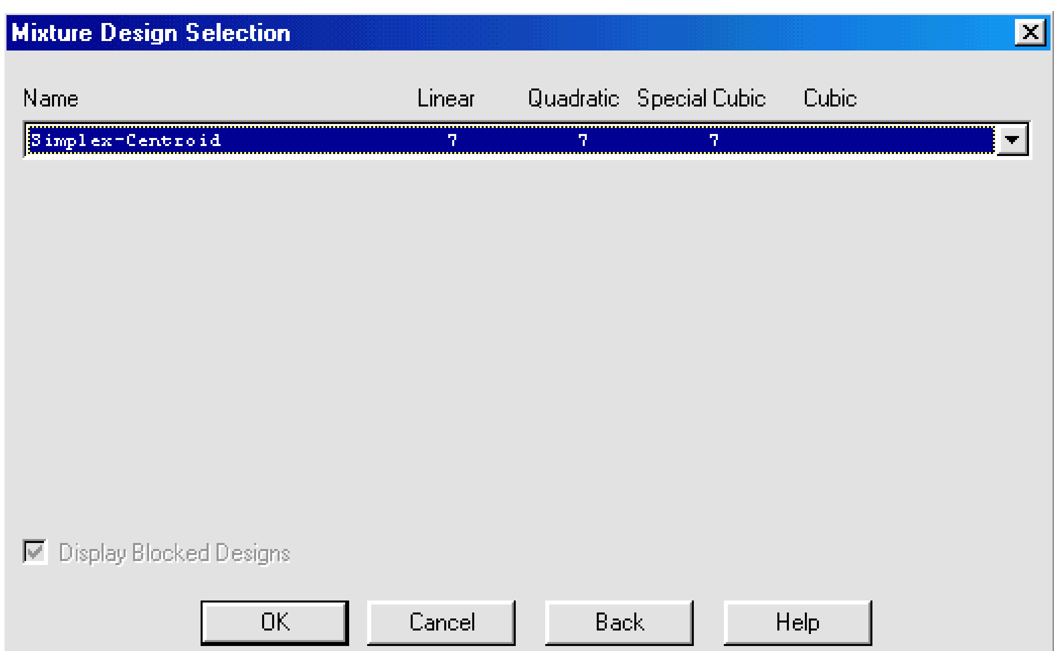


Figure 2-4. Mixture Design Selection Dialog Box

6. Choose the Simplex Centroid design by clicking on it. The 7s that appear for Linear, Quadratic, and Special Cubic are the number of runs for each design.

7. Click OK to display the Mixture Design Options dialog box shown in Figure 2-5. The number of runs (7) also appears on this dialog box.

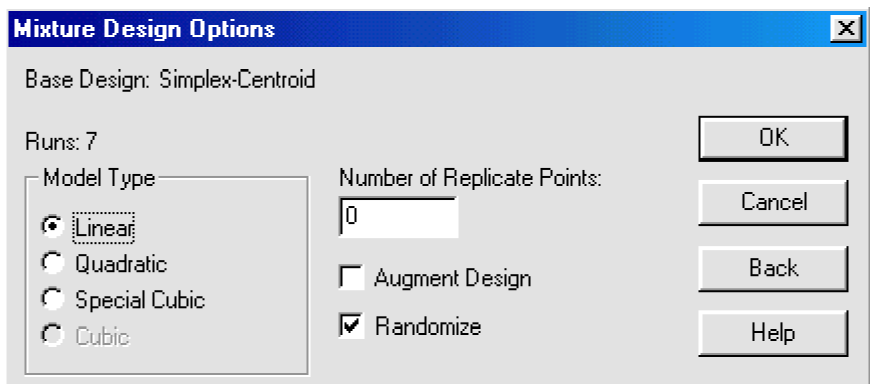


Figure 2-5. Mixture Design Options Dialog Box

8. Complete the dialog box by clicking OK to accept the defaults and to display the Design Summary in the Mixture Design Attributes window (see Figure 2-6). The summary contains information about the design you created.

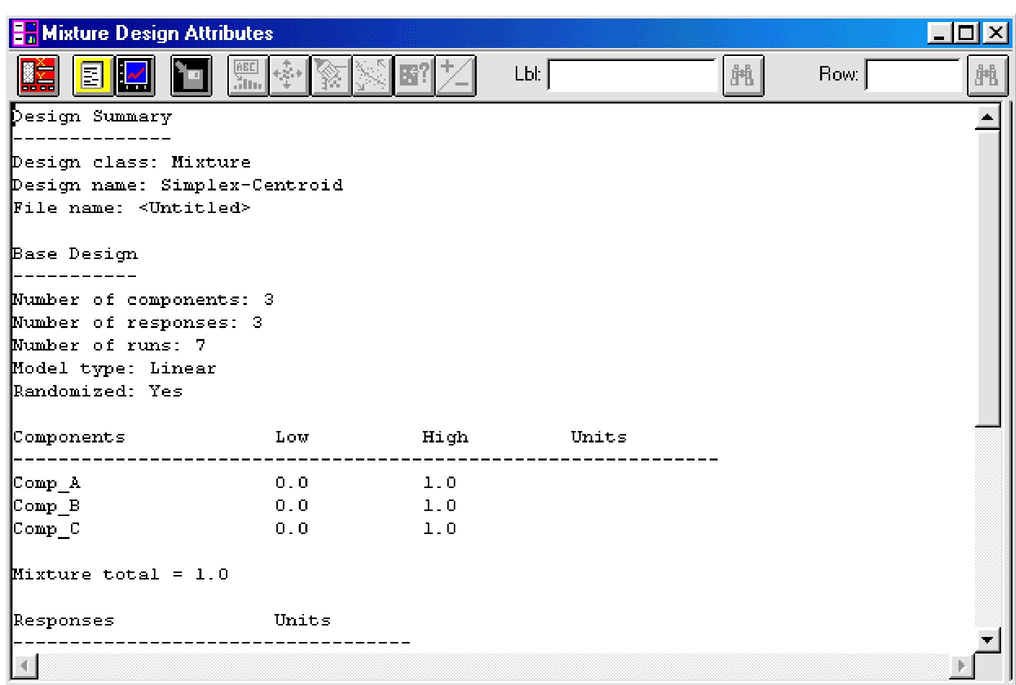


Figure 2-6. Design Summary

9. Choose SPECIAL... EXPERIMENTAL DESIGN... OPTIMIZE DESIGN... from the Menu bar to optimize the design and display the Optimize Experiment window (see Figure 2-7).

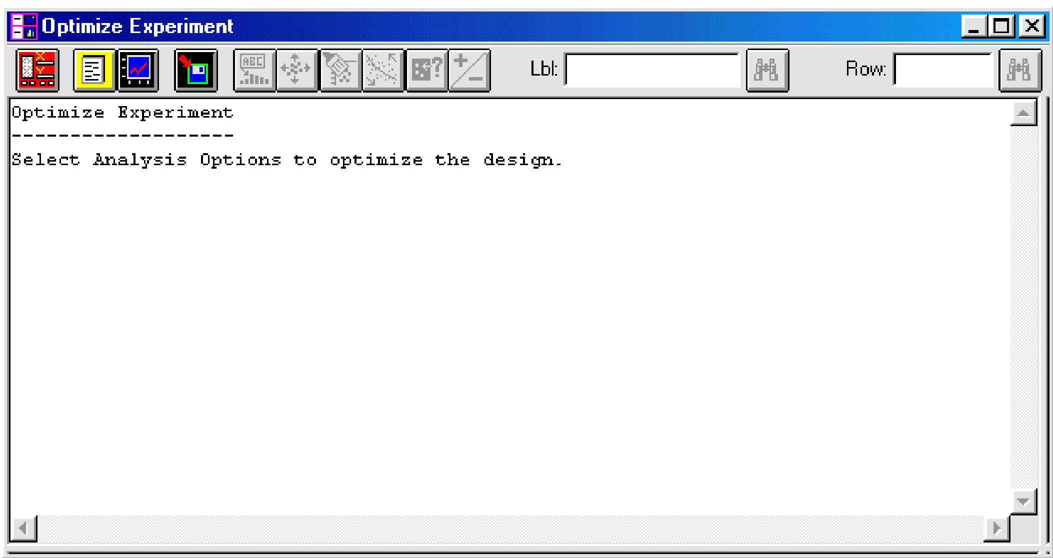


Figure 2-7. Optimize Experiment Window

Note that the next step is to access the Analysis Options dialog box. The dialog box display is dependent on the design class chosen when the design was created. Mixture designs have their own specific dialog box. Other designs share a common dialog box.

To continue with the optimization:

10. Click the right mouse button, then select Analysis Options... from the pop-up menu to display the Optimize Design Options dialog box shown in Figure 2-8 (Figure 2-9).

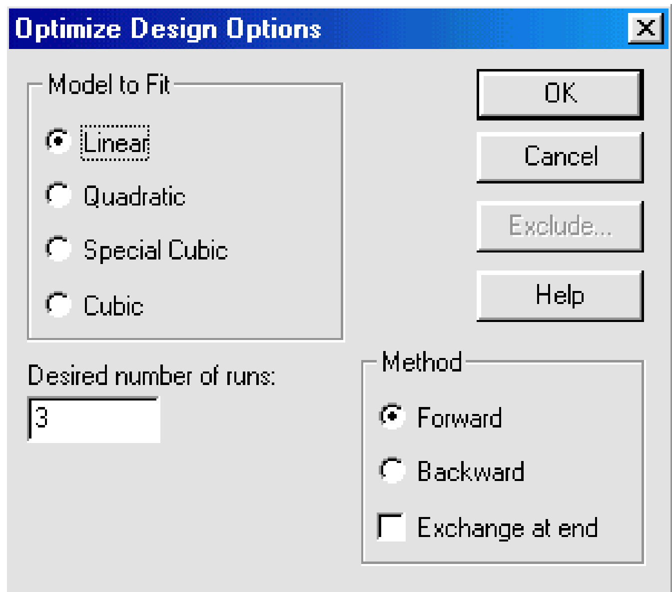


Figure 2-8. Optimize Design Options Dialog Box (Mixture Designs)

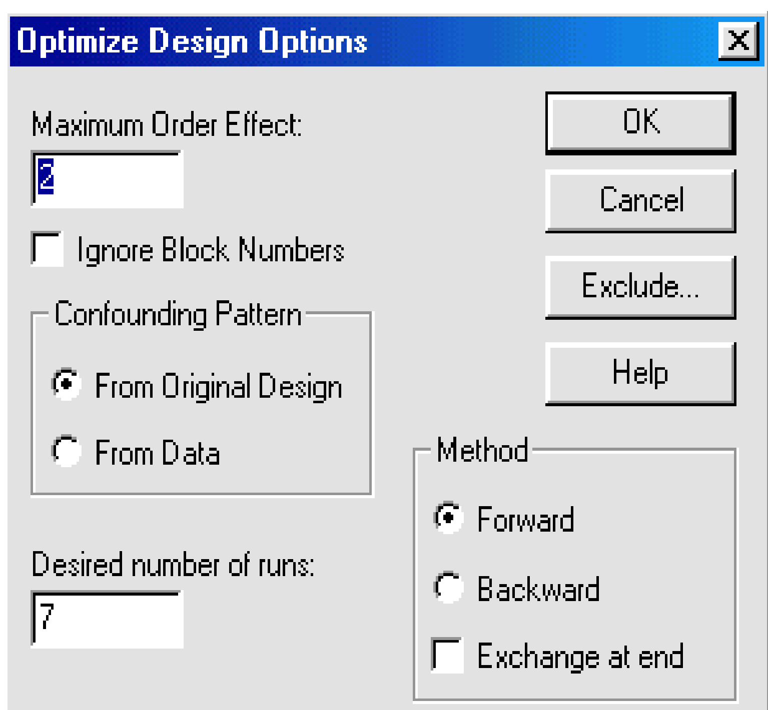


Figure 2-9. Optimize Design Options Dialog Box (Non-Mixture Designs)

11. For this Mixture Designs example, choose another model, enter the number of runs, choose a method, and click OK to display the Optimize Experiment window that contains the Optimization report.

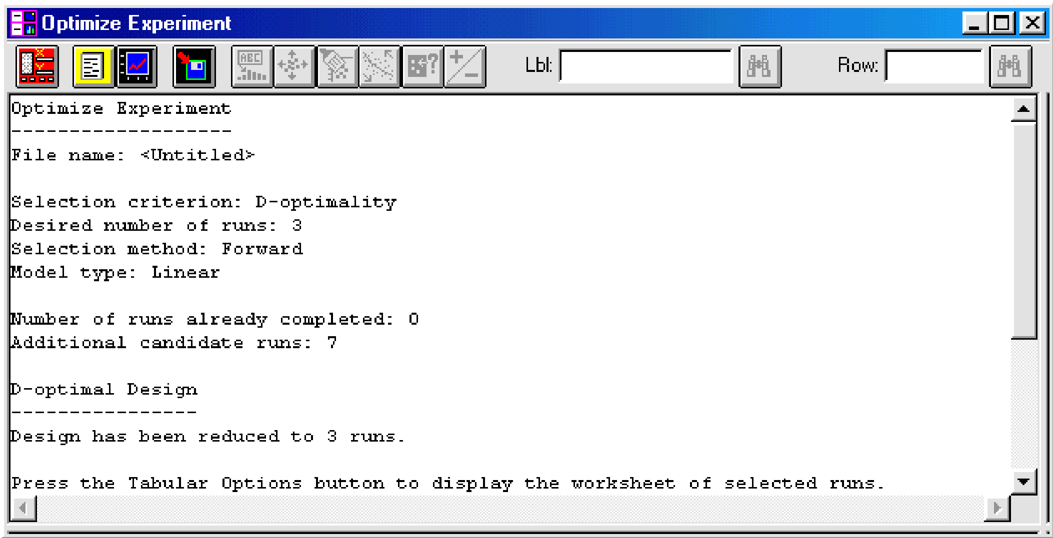


Figure 2-10. Optimize Experiment Window with Optimization Report

When you are satisfied with the optimization, you can use the tabular options to access the worksheet.

12. Click the Tabular Options button on the Analysis toolbar to display the Tabular Options dialog box, select the Worksheet option, then click OK to display the Worksheet (see Figure 2-11).

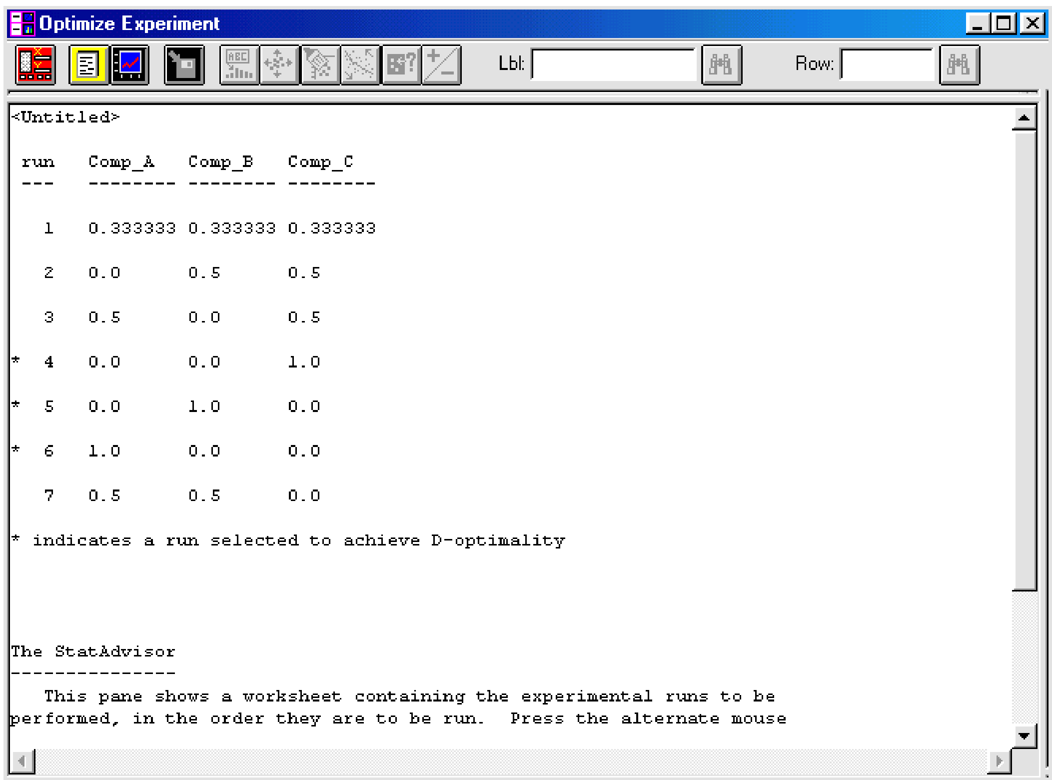


Figure 2-11. Worksheet

Note: Existing runs will not be discarded. For example, if you open the sample experiment file, CHEMICAL.SFX, and select Optimize Design, the existing runs will not be discarded even though there are more runs than would be required if you started the design from the create stage then optimized it.

Chapter 3

USING SCREENING DESIGNS

This chapter presents background information about screening designs, explains how you create a screening design, explains the different types of designs available and how you choose them, and explains how you choose the tabular and graphical options for the design classes.

Screening designs let you set up and analyze the following types of designs:

- two-level and fractional factorial
- mixed-level fractional
- irregular fractional
- Plackett-Burman
- user-specified.

These designs provide a means for reducing experimental time and cost. They are appropriate when some of the variables may have negligible main effects and interactions, or when higher-order interactions are insignificant. In these designs, the number of experimental runs or trials can be reduced by intentionally confounding some of the experimental effects. *See the section, Selecting a Screening Design, later in this chapter for brief descriptions of these designs; see Chapter 1 for detailed information about confounding.*

A screening design determines:

- the amount of change that occurs in the response variable when the level of a factor is changed

- if changing the factors together produces results different from changing the factors individually.

The next section explains how you create a screening design. In-depth explanations about the options on the dialog boxes appear in Online Help.

To Create A Screening Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 3-1.

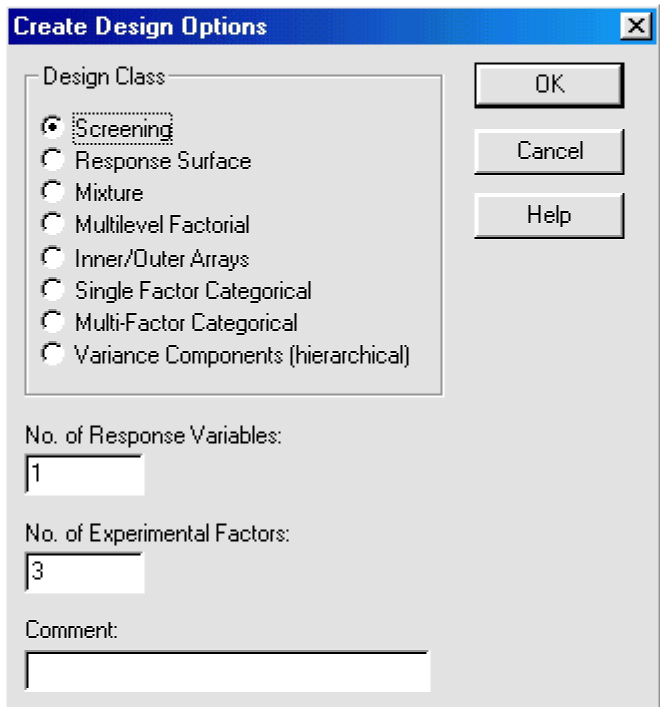


Figure 3-1. Create Design Options Dialog Box (Screening Designs)

2. Complete the dialog box by choosing the Screening design option, entering a number for the response variable(s) and number of experimental factors, then, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Factor Definition Options dialog box shown in Figure 3-2.

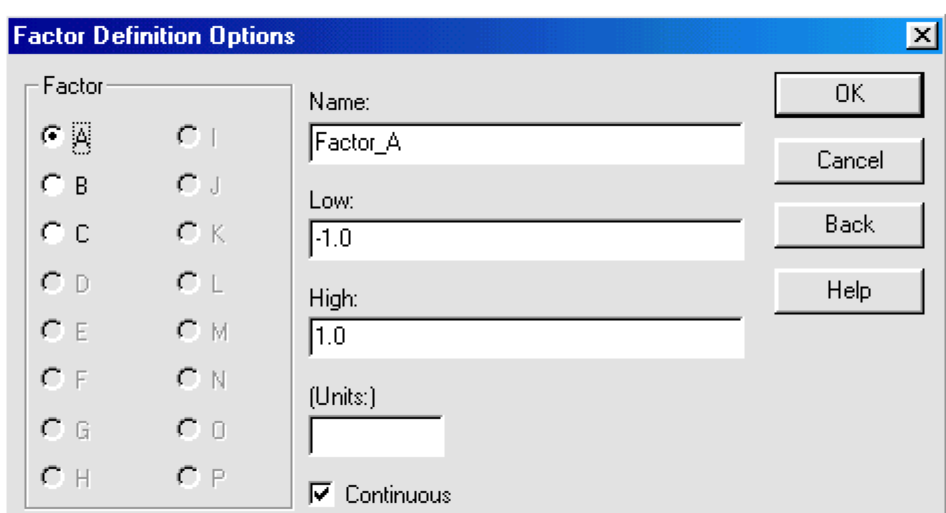


Figure 3-2. Factor Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a factor and entering a name for it, as well as entering the lowest and highest values for the factor in the Low and High text boxes, and, if applicable, entering a value for the units of measure. Then indicate if you want the factor to be Continuous (Quantitative) or Categorical (Qualitative). The default is Continuous (check box marked).

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 3-3.

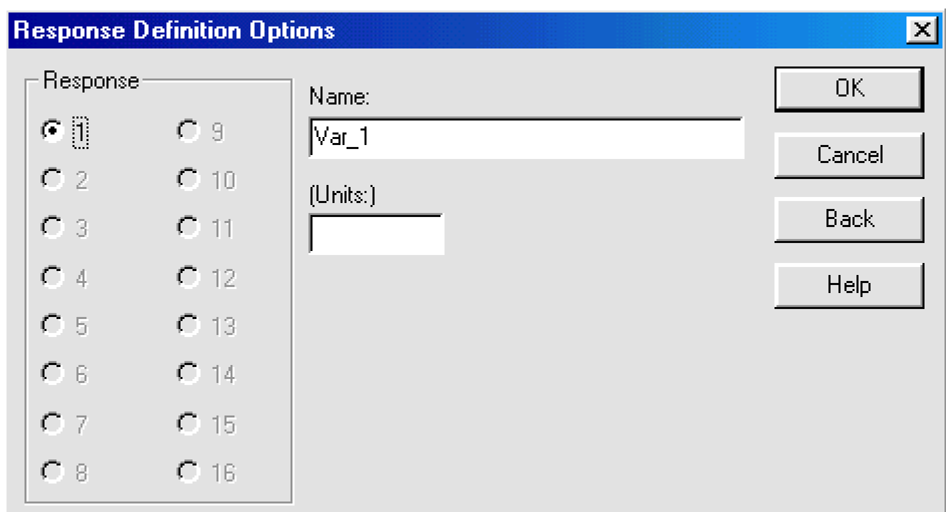


Figure 3-3. Response Definition Options Dialog Box

6. Complete the dialog box by either accepting the defaults or choosing a response variable and defining it by entering a name for it, as well as, if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Screening Design Selection dialog box shown in Figure 3-4.

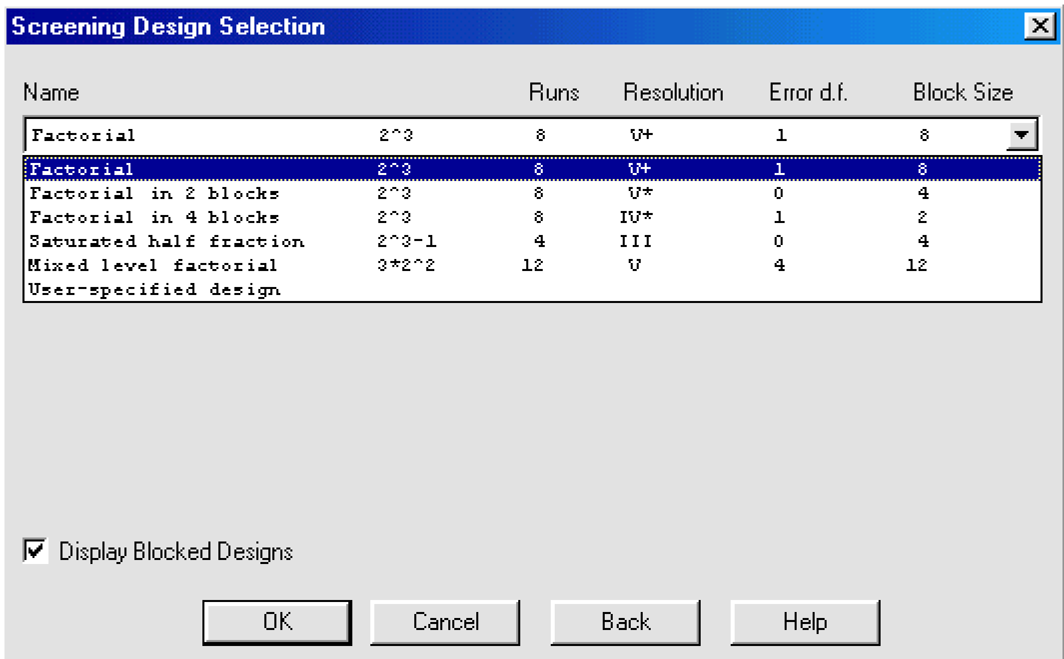


Figure 3-4. Screening Design Selection Dialog Box

8. Indicate if you want the list to include blocked designs by either selecting or deselecting Display Blocked Designs, then choose a design from the list of designs. Displaying Blocked Designs is the default. *For a list of the available designs, see the section, Selecting a Screening Design below.*

Clicking the Back... button redisplays the previous dialog box.

9. Click OK to display the Screening Design Options dialog box shown in Figure 3-5.

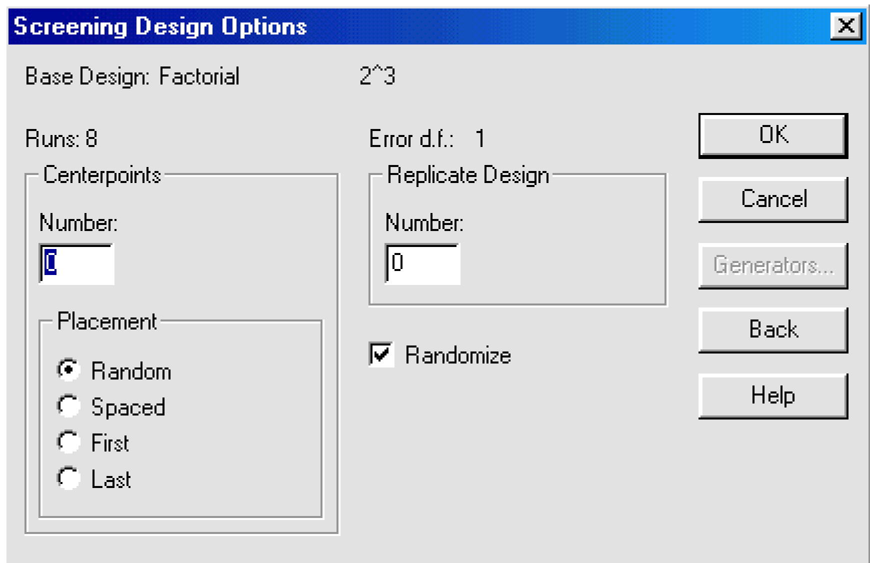


Figure 3-5. Screening Design Options Dialog Box

10. Complete the dialog box. Notice that the dialog box displays the name of the base design, indicates the total number of experimental runs, and the degrees of freedom available for the error. Choose the number of centerpoints that will be used and where they will be placed in the design. If the design will be replicated, enter the number of times, then indicate if the runs should be created in random order by selecting or deselecting the Randomize check box.

If you click OK now, the experimental runs will be placed in the DataSheet and the Design Summary will display in the Design Summary window.

For some design classes, you may be able to press the Generators... button and display the Design Generators dialog box, which lists the design generators used to create the last column(s) of the design matrix. When you click OK, the Screening Design Options dialog box redisplays.

Selecting a Screening Design

STATGRAPHICS *Plus* allows you to set up and analyze highly structured designs and includes predefined designs. You can generate both blocked and unblocked designs. You can also create and analyze your own designs.

Your entries on two dialog boxes determine which designs will display: Create Design and Screening Design Selection. On the first, enter parameters that fit the data you are using; on the latter ensure that the check box for Display

Blocked Designs is either checked or unchecked, then click the Down Arrow to the right of the list on the dialog box, and select a design.

A brief description of the available designs follows; the description also indicates if the design is blocked or unblocked.

- **Two-Level and Fractional Factorial**
  Factorial designs include all combinations of the factor level. Fractional Factorial designs are regular fractions such as 1/2, 1/4, 1/8, and so on or an irregular unbalanced fraction of a complete factorial design.

- **Mixed-Level Factorial**
  Use to study factorial designs based on one or more blocked or unblocked factors that are fixed and where one or more are random.

- **Irregular Saturated Half Fraction**
  Designs of an orthogonal property used to study factorial designs based on half of all combinations of blocked or unblocked factors. Creates a design of resolution III by inundating all the interactions of a full factorial design with additional factors.

- **Plackett-Burman**
  Designs that can be generated in steps of 4 runs, from 4 to 100 runs. The designs have the same number of runs as an equivalent fractional factorial; they are identical to fractional factorials with rows and columns reordered. Those designs of intermediate size are orthogonal.

- **User-Specified Design**
  Designs created by the user that can be blocked or unblocked.

Choosing Tabular Options for a Selected Design Class

Several helpful report options provide additional information about the design you select. However, not all of the options are available for every design class. For example, for Screening Designs, the available tabular options are a Design Summary, a Worksheet, an Alias Structure, and a Correlation Matrix; while for other design classes, the available tabular options are a Design Summary and a Worksheet. Also, a Power Curve graphical option is available for Screening Designs. The four possible tabular options and the graphical option are described next. The descriptions of the options are the same, regardless of the design class you use.

Design Summary

The Design Summary option displays a summary of the design you select (see Figure 3-6). The summary information includes the design class, design name, and file name. Other information about the base design includes the number of experimental factors, blocks, responses, runs, error degrees of freedom, and indicates if the factors were randomized. A table shows the lowest and highest values for each of the factors, and indicates if the factors are Continuous. The name of the response variable is shown.

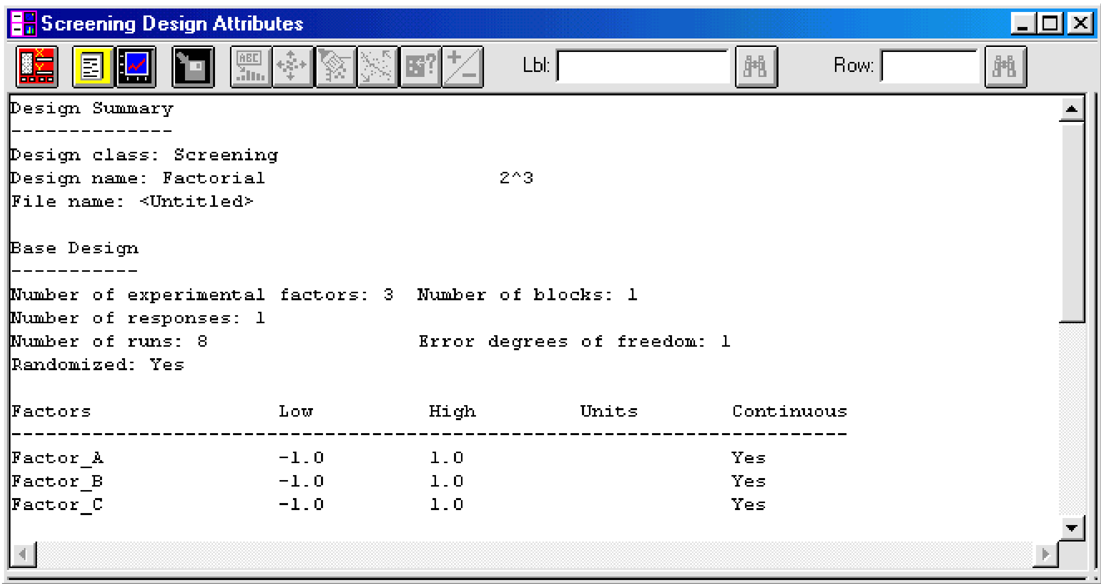


Figure 3-6. Design Summary

Use the *Screening Design Options* dialog box to choose another design. *See Figure 3-4 for an example of this dialog box.*

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 3-7).

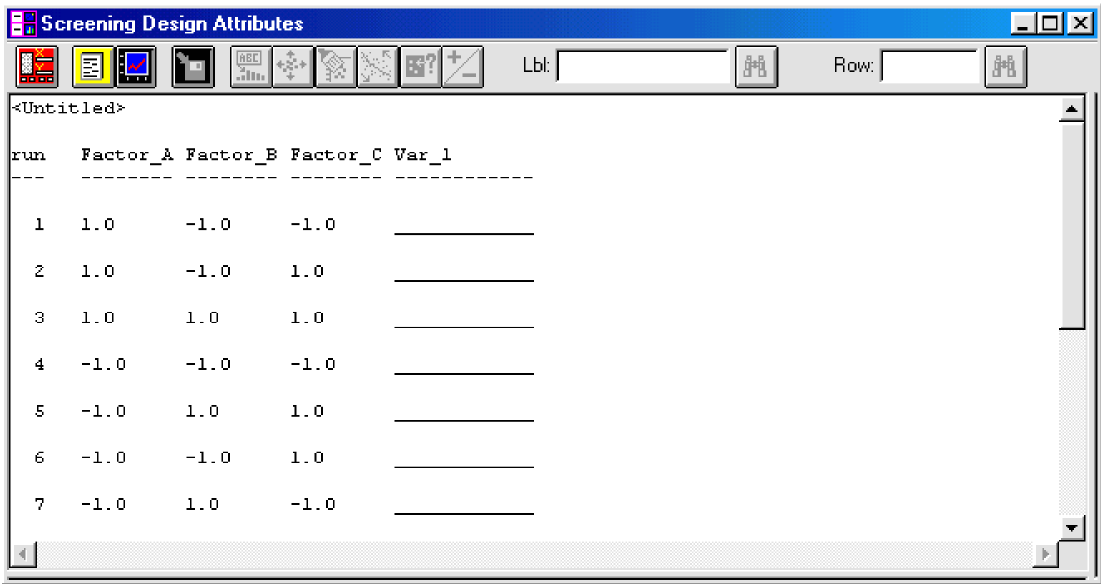


Figure 3-7. Worksheet

Print the Worksheet to record the information, then record the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 3-8).

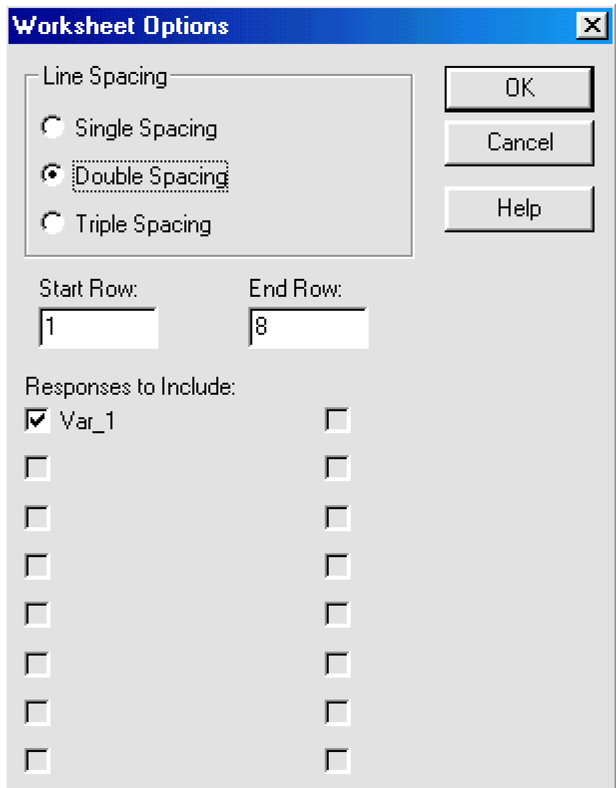


Figure 3-8. Worksheet Options Dialog Box

Alias Structure

The Alias Structure option displays the alias pattern for the design, which shows the main effects, interactions, and any confounding that involves them (see Figure 3-9). If the main effects and interactions are clear of confounding, an appropriate message displays. Confounded effects are joined by a plus sign; for example, A + BC indicates that the main effect, A, is confounded with the two-factor interaction, BC.

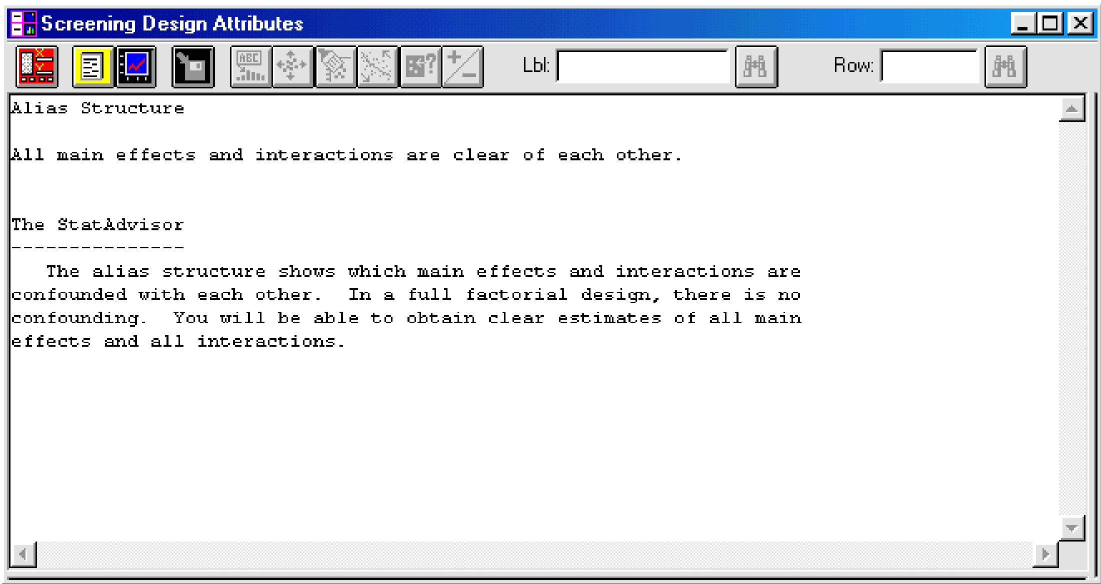


Figure 3-9. Alias Structure

Use the *Alias Structure Options* dialog box to enter a number for the highest-order interaction; these are the highest-order interactions shown in the report (see Figure 3-10). Enter any positive integer, up to the number of factors in the design.

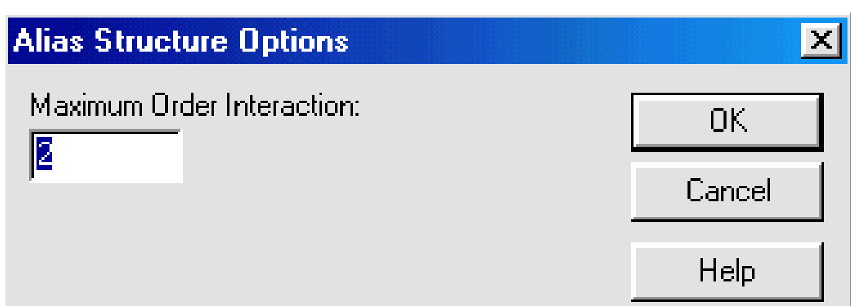


Figure 3-10. Alias Structure Options Dialog Box

Correlation Matrix

The Correlation Matrix option displays a correlation matrix for all the factor and interaction effects, based on the actual design matrix (see Figure 3-11).

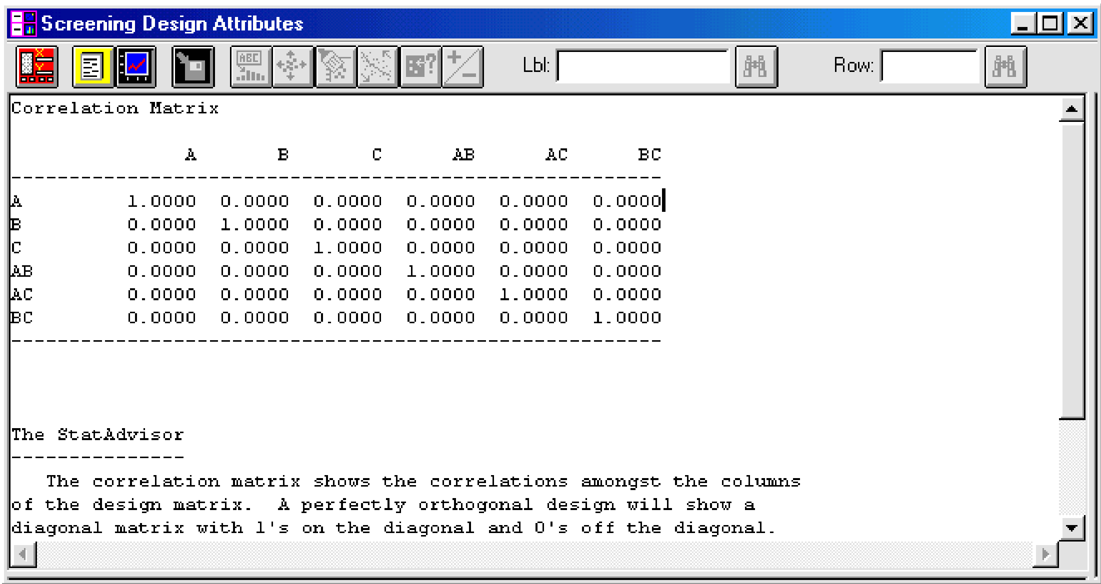


Figure 3-11. Correlation Matrix

Use the *Correlation Matrix Options* dialog box to enter a number that will determine the highest-order effects that will display (see Figure 3-12). Enter a positive integer, up to the number of factors in the design.

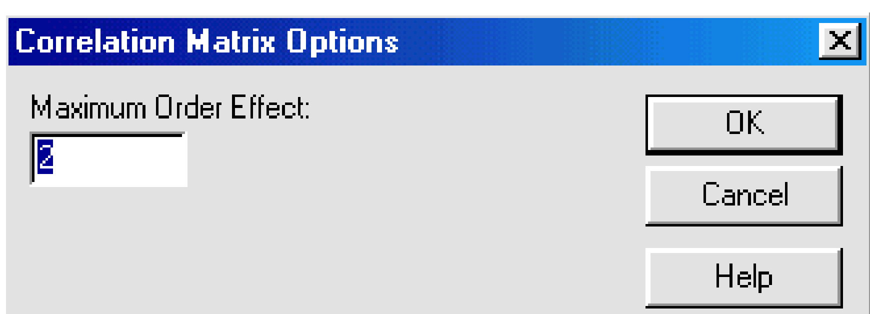


Figure 3-12. Correlation Matrix Options Dialog Box

Choosing Graphical Options for a Selected Design Class

Power Curve

The Power Curve option displays a plot that determines whether or not an experiment can detect effects of the magnitude you expect (see Figure 3-13).

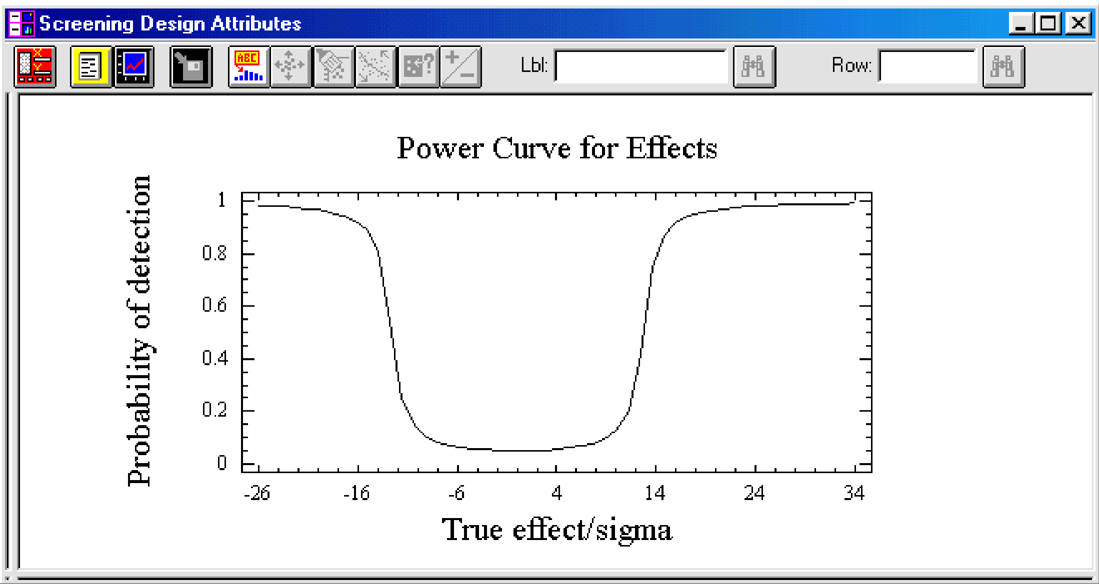


Figure 3-13. Power Curve

Use the *Power Curve Options* dialog box to change the number of degrees of freedom for the error, and to enter a number for the alpha risk (see Figure 3-14). The alpha risk determines the probability of declaring an effect significant when, in fact, it is not.

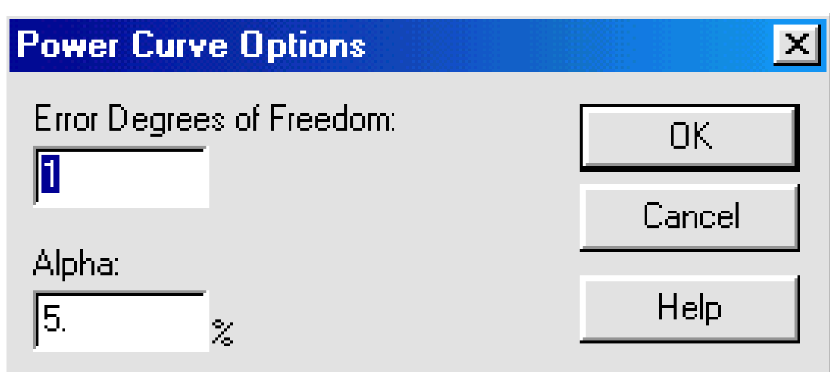


Figure 3-14. Power Curve Options Dialog Box

References

Belsley, D. A., Kuh, E., and Welsch, R. E. 1980. *Regression Diagnostics: Identifying Influential Data and Sources of Colinearity*. New York: John Wiley & Sons, Inc.

Box, G. E. P., Hunter, W. G., and Hunter, J. S. 1978. *Statistics for Experimenters*. New York: John Wiley & Sons, Inc.

Haaland, P. 1989. *Experimental Design in Biotechnology*. New York: Marcel Dekker.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*. 1997. New York: John Wiley & Sons.

Montgomery, D. C. 1991. *Design and Analysis of Experiments*, third edition. New York. John Wiley & Sons.

Schmidt, S. R. and Launsby, R. G. 1989. *Understanding Industrial Designed Experiments*, second edition. Colorado Springs, Colorado: Air Academy Press.

Chapter 4

USING RESPONSE SURFACE DESIGNS

This chapter presents background information about response surface designs, explains how you create a response surface design, explains the different types of designs available and how you choose them, and explains the tabular and graphics options available for the design classes.

Response surface methodology consists of a group of techniques used in the empirical study of relationships between one or more measured responses such as yield, color index, and viscosity, on one hand, and a number of input variables such as time, temperature, pressure, and concentration, on the other (Box, Hunter, and Hunter, 1978).

Montgomery (1997), states that response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for modeling and analysis in applications where a response is influenced by several variables and the objective is to optimize the response.

Montgomery also notes that another objective of RSM is to find a region of the factor space that satisfies the operating specifications. He states that optimum is used in a special way because the initial estimate of the optimum operating conditions will be far away from the actual optimum. In cases such as this, the object is to quickly move to the general area of the optimum.

The *path of steepest ascent* is a technique for moving consecutively along a path of steepest ascent or descent, depending on whether the direction is to be maximized or minimized. The path of steepest ascent is usually a line through the center of the regions.

Experiments conducted along a path of steepest ascent continue until no further increase is observed or until the desired response region is reached. Then a new first-order model can be fitted, a new direction of steepest ascent determined, and if necessary, further experiments conducted in that direction until the process is near the optimum.

To Create A Response Surface Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 4-1.

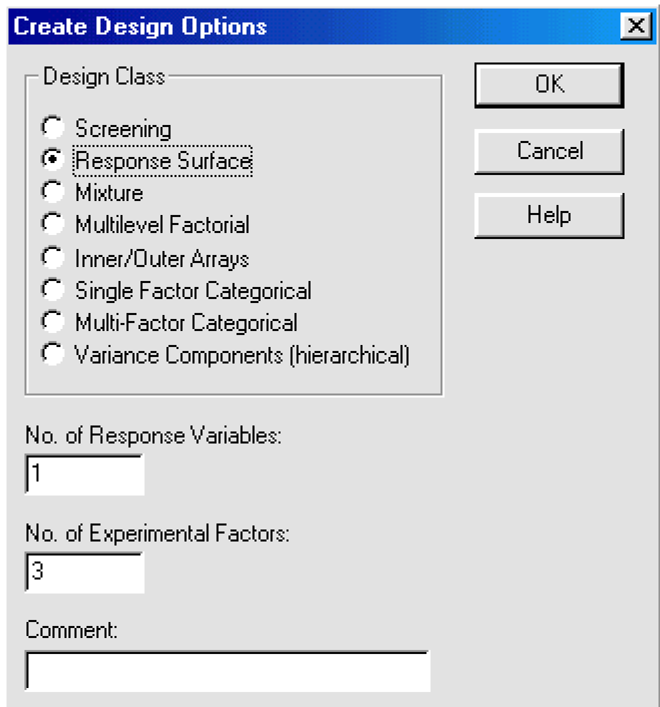


Figure 4-1. Create Design Options Dialog Box (Response Surface Designs)

2. Complete the dialog box by choosing the Response Surface design option, entering a number for the response variable(s) and number of experimental factors, and optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Factor Definition Options dialog box shown in Figure 4-2.

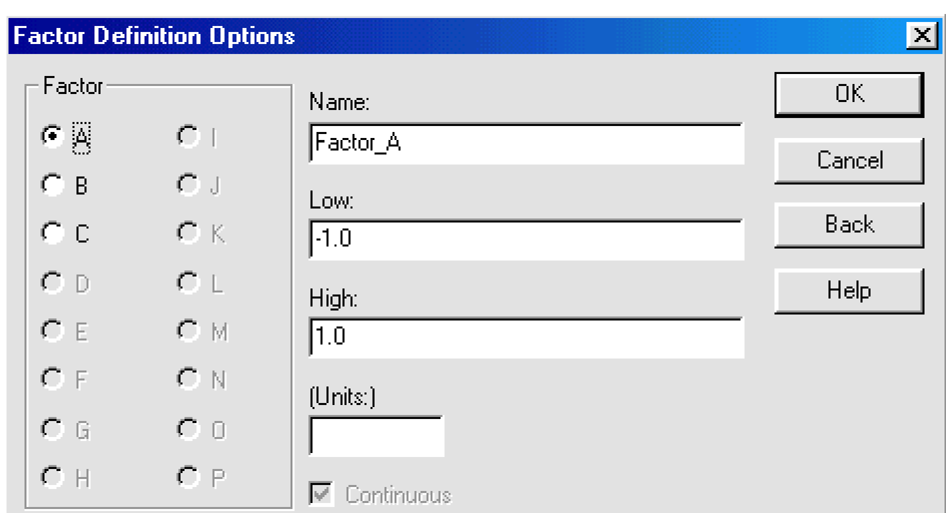


Figure 4-2. Factor Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a factor and entering a name for it, as well as the lowest and highest values for the factor, and, if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 4-3.

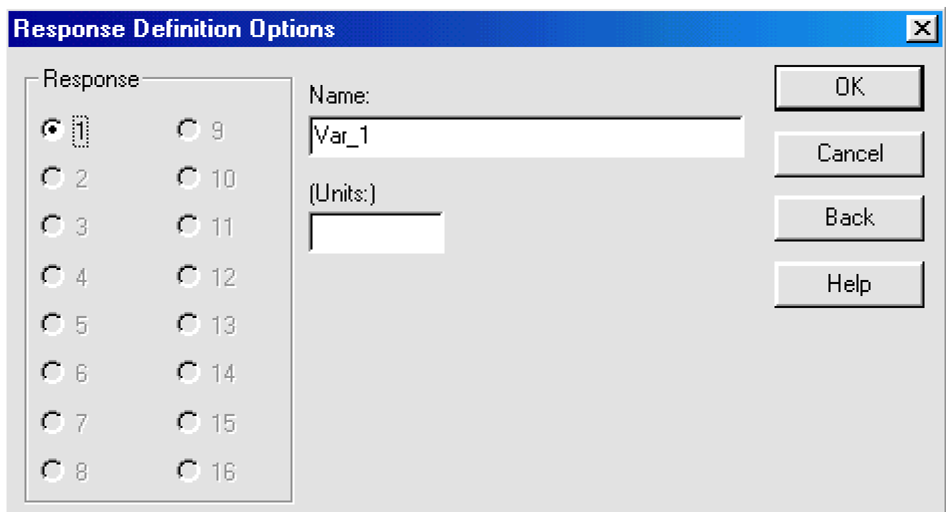


Figure 4-3. Response Definition Options Dialog Box

6. Complete the dialog box by either accepting the defaults or choosing a response variable and defining it by entering a name for it and, if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Response Surface Design Selection dialog box shown in Figure 4-4.

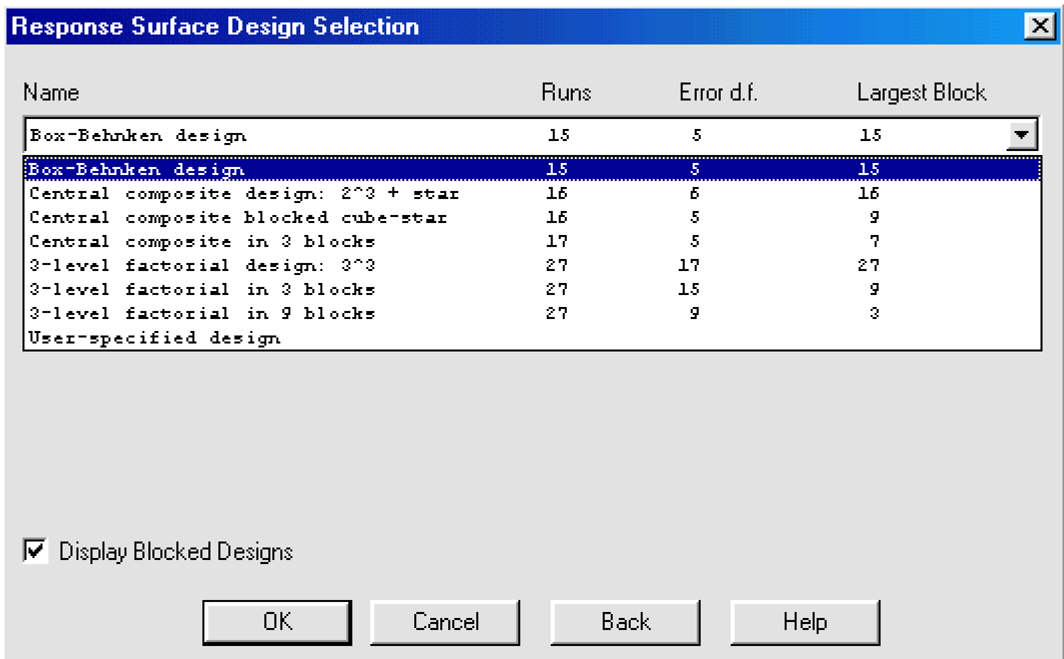


Figure 4-4. Response Surface Design Selection Dialog Box

8. Indicate if you want the list to include blocked designs by either selecting or deselecting Display Blocked Designs, then choose a design from the list of designs. Displaying Blocked Designs is the default. *For a list of the available designs, see the section, Selecting a Response Surface Design, below.*

Clicking the Back... button redisplays the previous dialog box.

9. Click OK to display one of three Design Options dialog boxes: Three-Level, Composite, or a Blocked Composite (see Figures 4-5, 4-6, and 4-7, respectively). The dialog box that displays depends on the design choice.

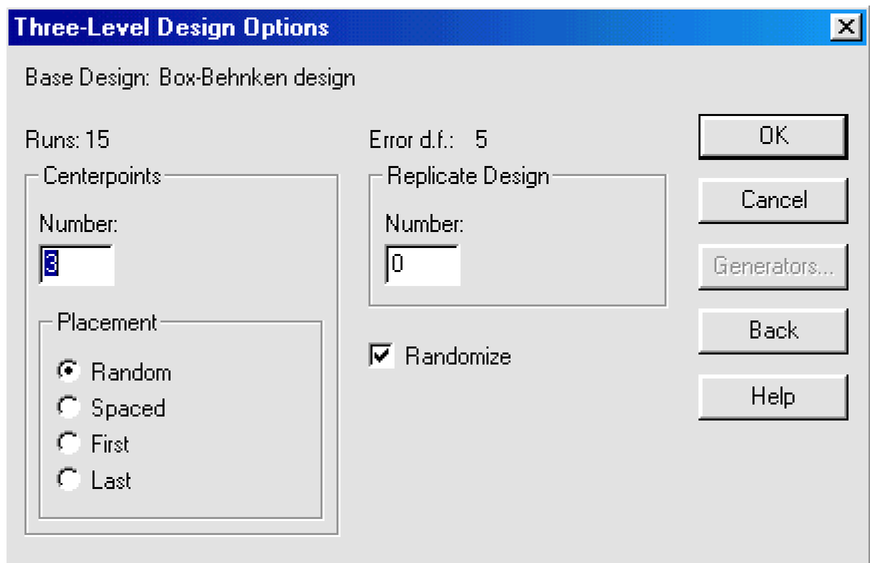


Figure 4-5. Three-Level Design Options Dialog Box

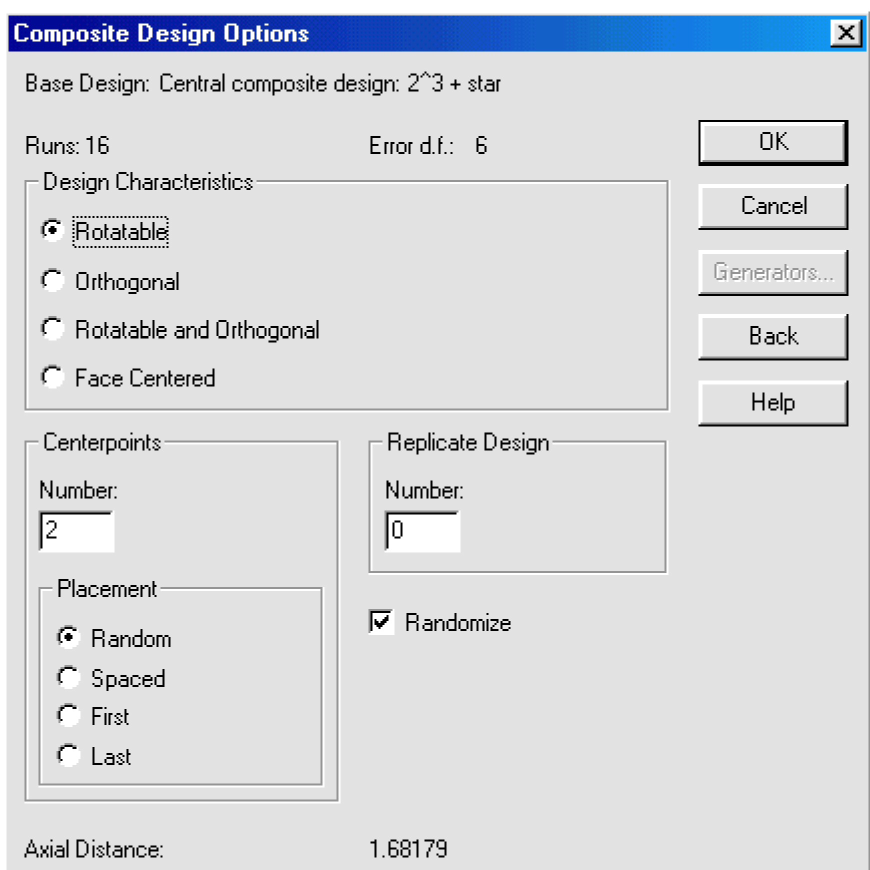


Figure 4-6. Composite Design Options Dialog Box

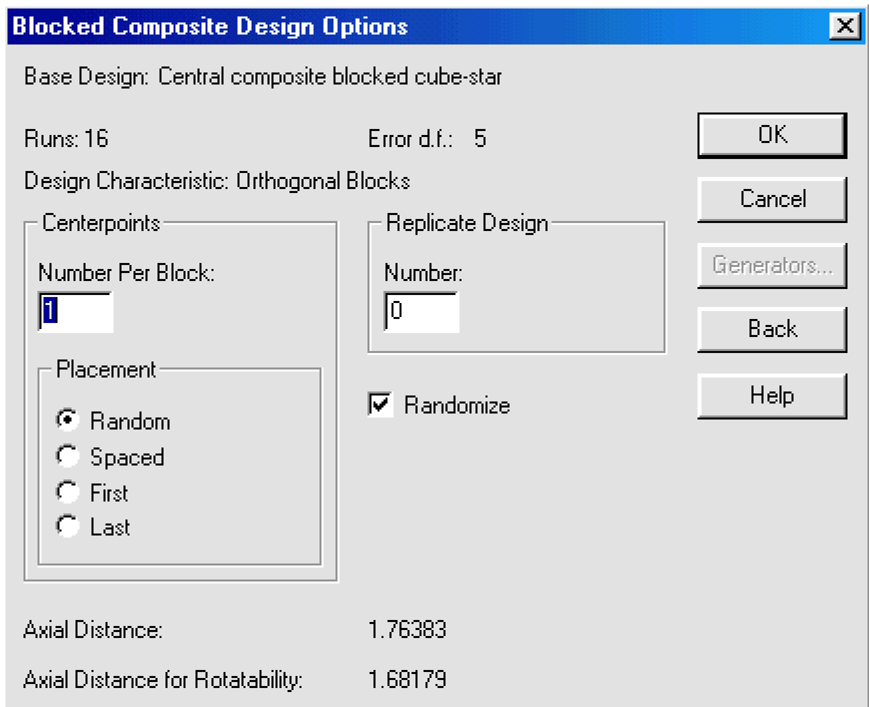


Figure 4-7. Blocked Composite Design Options Dialog Box

10. Complete the dialog box you are using by either accepting the defaults or entering the design characteristics, the number of centerpoints and where they will be placed; indicating if the design will be replicated, and if so, entering the number of times; and indicating if the runs will be created in random order.

If you click OK now, the experimental runs are placed in the Worksheet and the Design Summary displays in the Design Summary window.

Selecting a Response Surface Design

STATGRAPHICS *Plus* allows you to set up and analyze highly structured designs and includes predefined designs. You can generate both blocked and unblocked designs. You can also create and analyze your own designs.

Your entries on two dialog boxes determine which designs will display: Create Design and Response Surface Design Selection. On the first, enter parameters that fit the data you are using; on the latter, ensure that the check box for Display Blocked Designs is either checked or unchecked, then click the Down Arrow to the right of the list on the dialog box, and select a design.

A brief description of the available designs follows; the description also indicates if the design is blocked or unblocked.

- **Three-Level Factorial**
  A design that consists of all combinations of all factor levels. The design is capable of estimating all factors and their interactions. For example, a complete factorial design of three factors, each at three levels, would consist of 3 x 3 x 3 = 27 runs.

- **Central Composite Designs**
  Designs that span a set of quantitative factors with fewer points than a standard factorial multilevel design, without a large loss in efficiency. This major class of designs has two parts: a cube and a star. The cube portion corresponds to a factorial screening design. For example, in a three-factor study, eight points in a central composite design form a cube that corresponds to a 2^3 factorial. The star portion of the design consists of an additional set of points arranged at equal distances from the center of the cube on radii that pass through the centerpoint on each face of the cube. The distance from the center of the cube to one of these points is called the *axial distance* of the star.

  Central composite designs are desirable because of two attributes: orthogonality and rotatability. Orthogonality allows you to measure the desired effects independently of each other. Nonorthogonal designs result in a dependency of effects that is particularly undesirable; that is, some of the factors are correlated. Rotatability implies that you can estimate the response with equal variance regardless of the direction from the center of the design.

- **Box-Behnken Design**
  Uses a selection of corner, face, and central points to span an experimental space with fewer points than a Complete Factorial Design. It is similar in intent to a Central Composite Design, but differs in that no corner or extreme points are used. It has no extended axial points, so it uses only three-level factors. It can be a blocked or unblocked design.
- **Draper-Lin**
  A small central composite design. Rather than a full factorial, the design uses a fractional factorial.

- **User-Specified Design**
  Designs created by the user that can be blocked or unblocked.

Choosing Tabular Options for a Selected Design Class

Several helpful report options provide additional information about the design you select. However, not all of the options are available for every design class. For example, for Response Surface Designs, the available tabular options are the Design Summary, a Worksheet, and a Correlation Matrix, but are not available for other design classes. The three possible tabular options are described next. The descriptions of the options are the same, regardless of the design class option you use.

Design Summary

The Design Summary option displays a summary of the design you select (see Figure 4-8). The summary information includes the design class, design name, and file name. Other information about the base design includes the number of experimental factors, blocks, response variables, centerpoints per block, runs, error degrees of freedom, and indicates if the factors were randomized. A table shows the lowest and highest values for each of the factors. The name of the response variable is also shown.

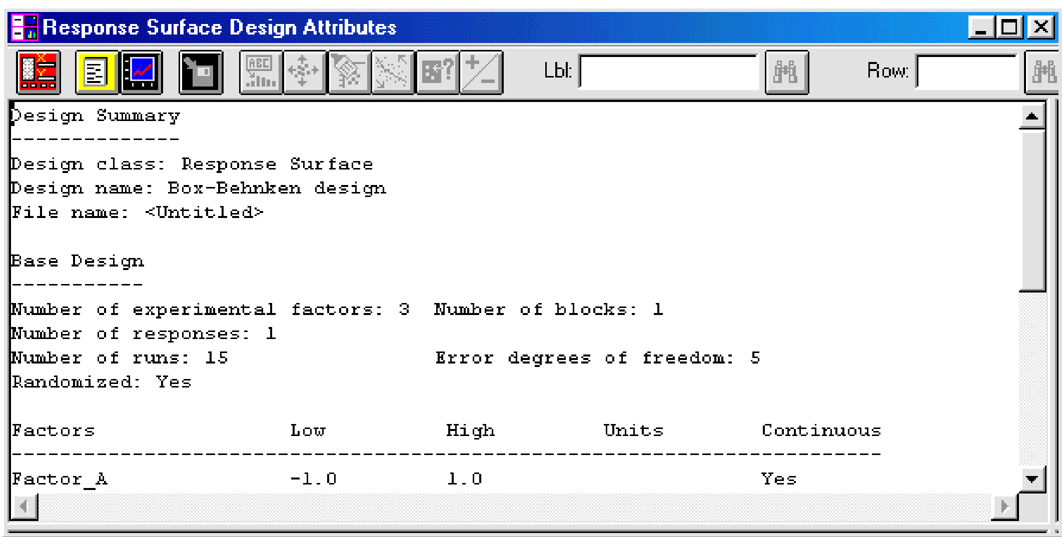


Figure 4-8. Design Summary

Use the *Response Surface Design Selection* dialog box to choose another design.

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 4-9).

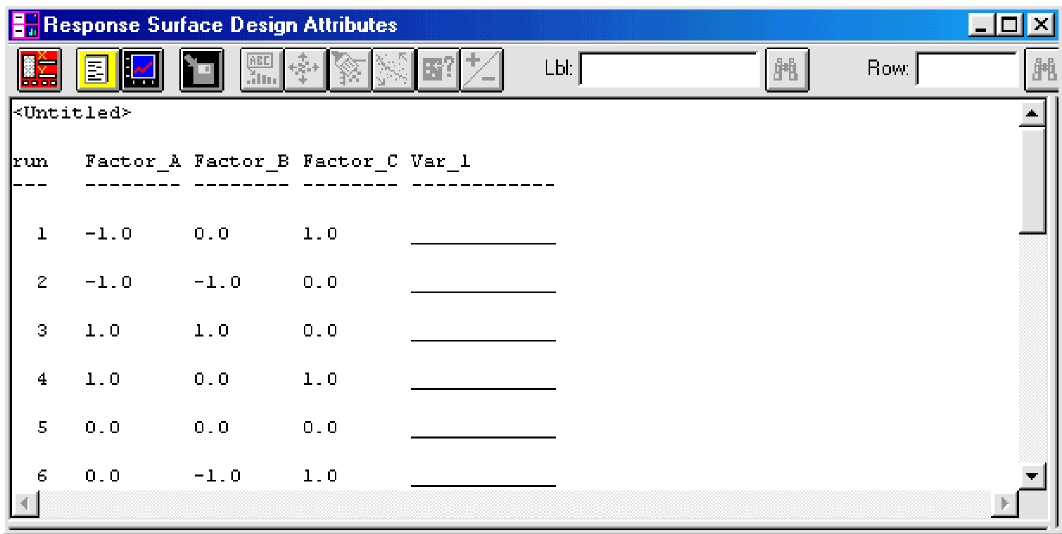


Figure 4-9. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 4-10).

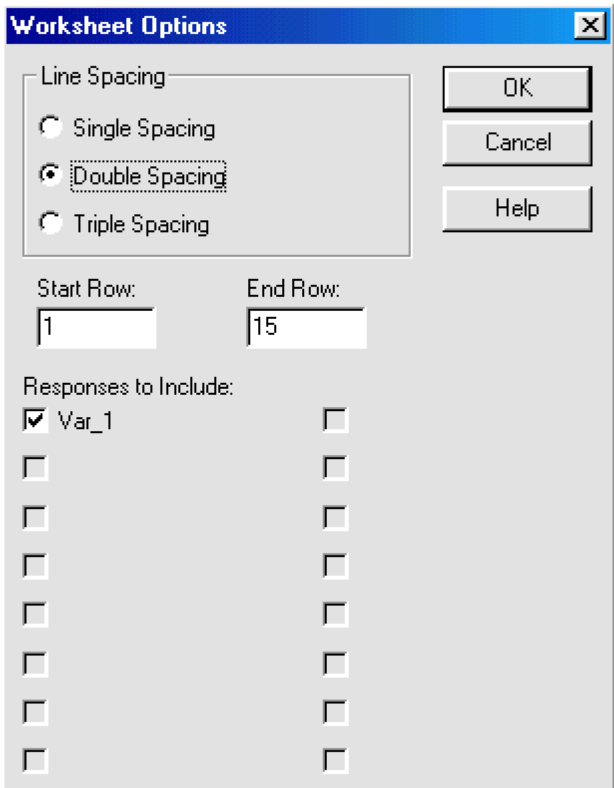
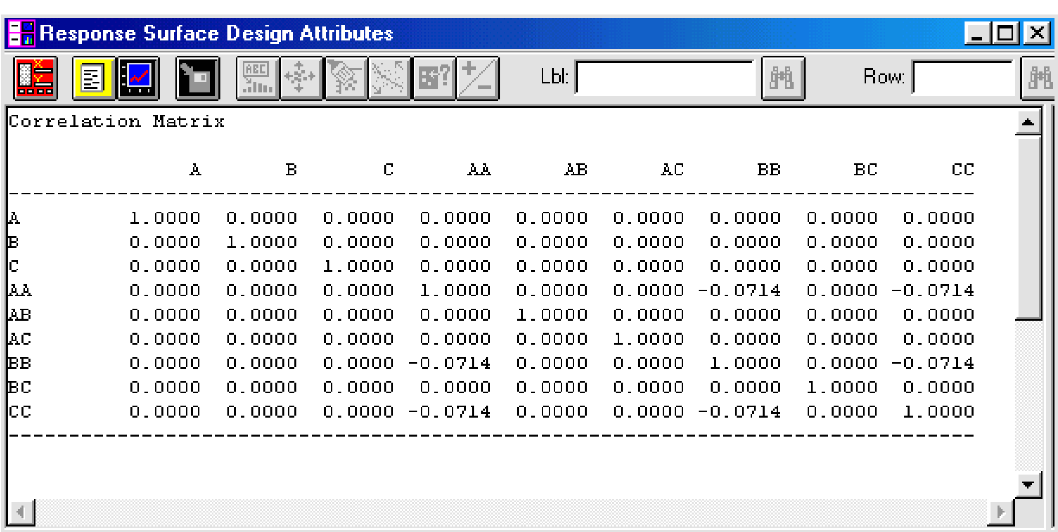


Figure 4-10. Worksheet Options Dialog Box

Correlation Matrix

The Correlation Matrix option displays a correlation matrix for all the effects, based on the actual design matrix (see Figure 4-11).



Correlation Matrix

	A	B	C	AA	AB	AC	BB	BC	CC
A	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AA	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	-0.0714	0.0000	-0.0714
AB	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
AC	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
BB	0.0000	0.0000	0.0000	-0.0714	0.0000	0.0000	1.0000	0.0000	-0.0714
BC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
CC	0.0000	0.0000	0.0000	-0.0714	0.0000	0.0000	-0.0714	0.0000	1.0000

Figure 4-11. Correlation Matrix

Use the *Correlation Matrix Options* dialog box to enter a number that will determine the highest-order effects that will display (see Figure 4-12). Enter a positive integer, up to the number of factors in the design.

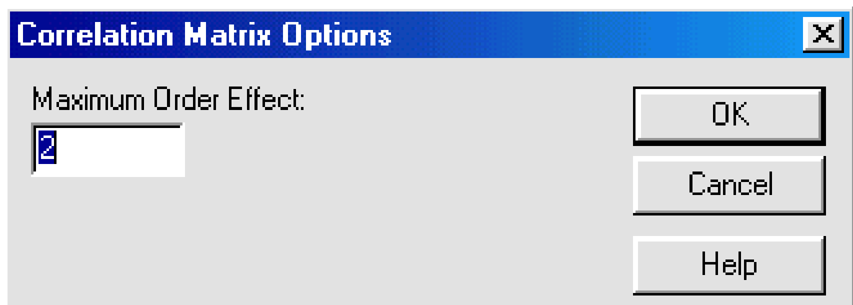


Figure 4-12. Correlation Matrix Options Dialog Box

References

Belsley, D. A., Kuh, E., and Welsch, R. E. 1980. *Regression Diagnostics: Identifying Influential Data and Sources of Colinearity*. New York: John Wiley & Sons, Inc.

Box, G. E. P., Hunter, W. G., and Hunter, J. S. 1978. *Statistics for Experimenters*. New York: John Wiley & Sons, Inc.

Haaland, P. 1989. *Experimental Design in Biotechnology*. New York: Marcel Dekker.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*. 1997. New York: John Wiley & Sons.

Montgomery, D. C. 1991. *Design and Analysis of Experiments*, third edition. New York. John Wiley & Sons.

Schmidt, S. R. and Launsby, R. G. 1989. *Understanding Industrial Designed Experiments*, second edition. Colorado Springs, Colorado: Air Academy Press.

Chapter 5

USING MIXTURE DESIGNS

This chapter presents background information about mixture designs, explains how you create a design, explains the different types of designs available and how to choose them, and explains how you choose tabular options for the design classes.

Mixture designs are usually a special form of response surface designs where two or more formulations, blends, combinations, or components make up a product. Mixture designs are used in industrial situations that involve mixtures that are measured in some type of units, such as volume or weight, that add up to a whole. In addition, mixture designs are usually constructed to estimate linear interactions.

The next section explains how you create a mixture design. In-depth explanations about the options on the dialog boxes appear in Online Help.

To Create a Mixture Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 5-1.

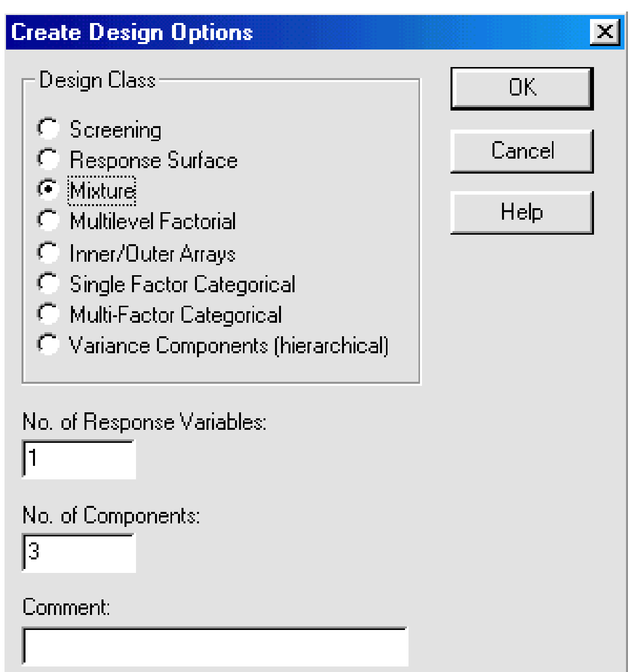


Figure 5-1. Create Design Options Dialog Box (Mixture Designs)

2. Complete the dialog box by choosing the Mixture design option, entering a number for the number of response variable(s) and number of components, then, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Component Definition Options dialog box shown in Figure 5-2.

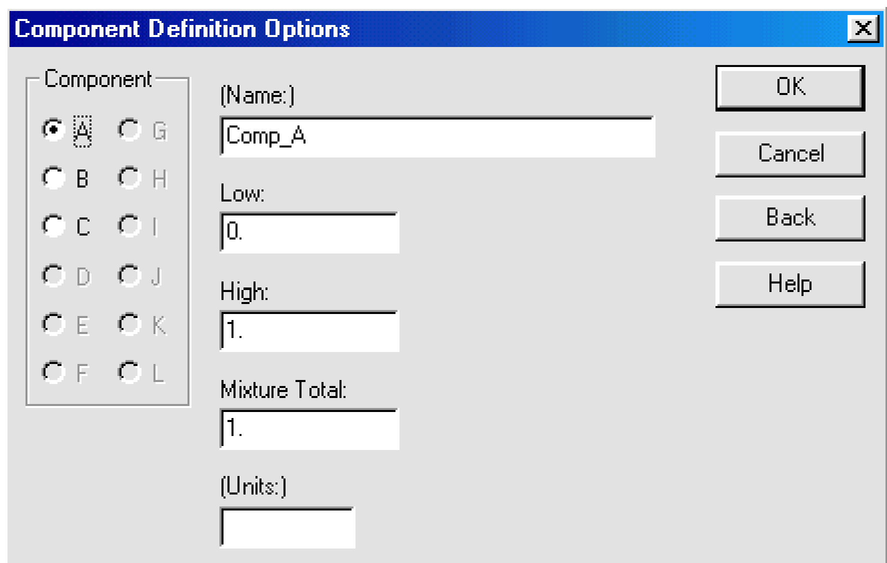


Figure 5-2. Component Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a component and entering a name for it, as well as for the lowest and highest values, and if applicable, entering a value for the mixture total, and the number for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 5-3.

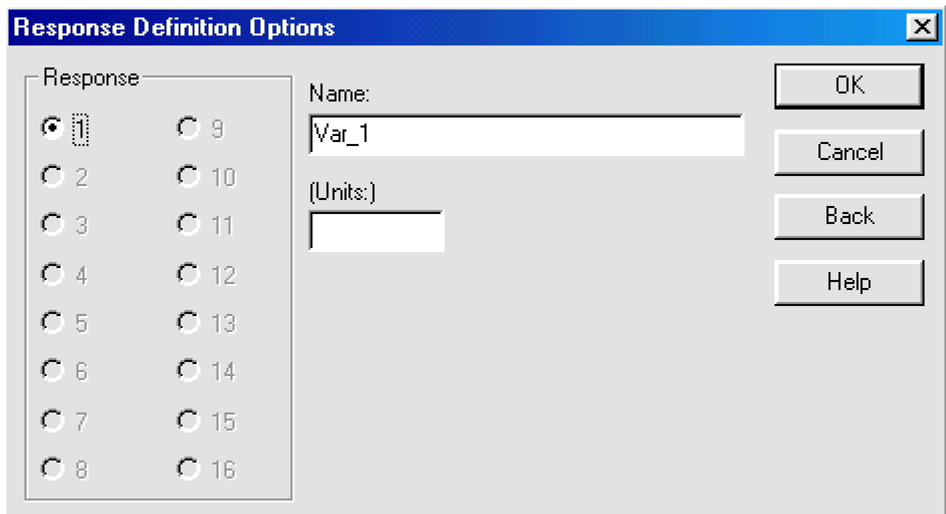


Figure 5-3. Response Definition Options Dialog Box

6. Complete the dialog box by either accepting the defaults or choosing a response variable and defining it by entering a name for it, as well as, and if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Mixture Design Selection dialog box shown in Figure 5-4.

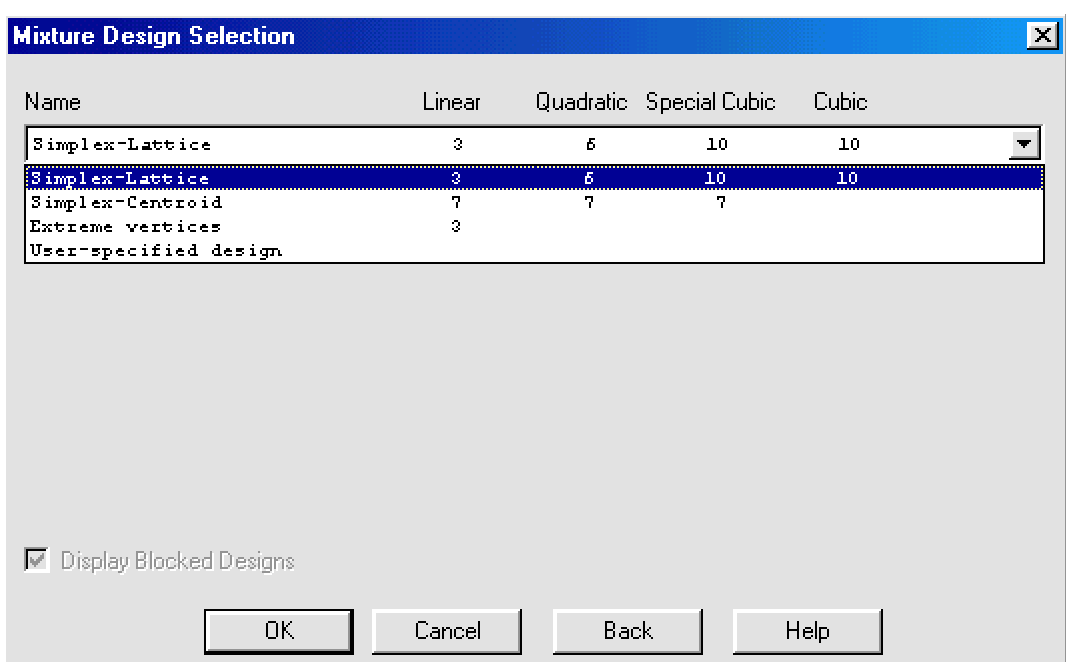


Figure 5-4. Mixture Design Selection Dialog Box

8. Complete the dialog box by either accepting the defaults or choosing a design from the list of design types, entering a value for

   Clicking the Back... button redisplays the previous dialog box.

9. Click OK to display the Mixture Design Options dialog box shown in Figure 5-5.

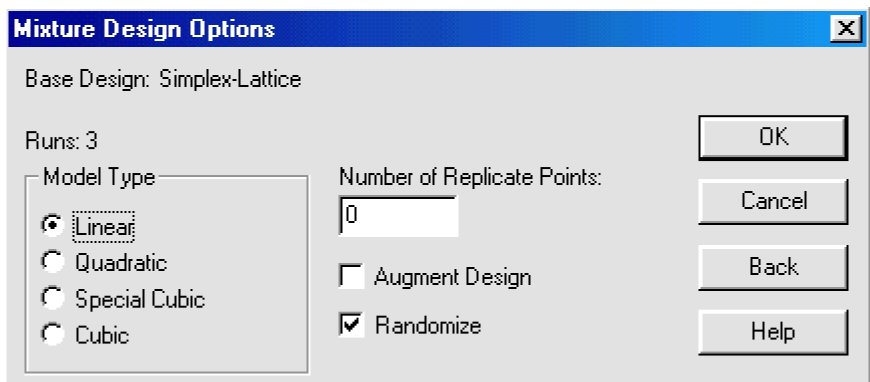


Figure 5-5. Mixture Design Options Dialog Box

10. Complete the dialog box. Notice that the dialog box displays the name of the chosen design and indicates the total number of runs. Choose the type of model you want to analyze when you complete the experimental runs, enter a value for the number of replicate points, then indicate if the design should be augmented and if the experimental runs should be created in random order by selecting or deselecting the Randomize check box.

    If you click OK now, the experimental runs are placed in the DataSheet and the Design Summary displays in the Mixture Design window.

Selecting a Mixture Design

STATGRAPHICS *Plus* allows you to set up and analyze highly structured designs and includes predefined designs. You can also create and analyze your own designs. The model types include linear, quadratic, special cubic, or cubic. Diagnostic statistics and tests within the designs check for a model s utility.

The Mixture Design Selection dialog box lists the available designs. You can also design and create designs of your own choosing. To display a list of available designs, click the Down Arrow to the right of the list. If a simplex design is not available due to the specified constraint, Extreme Vertices and User-Specified Design displays.

- **Simplex-Lattice**
  A design determined by the number of components, q, and the degree, m, of the polynomial model. The design includes all combinations of the components in which the proportions are defined by:

  $x_i = 0, 1/m, 2/m, ..., 1$

  For example, a quadratic, three-component, standard unit design includes the following blends: (1,0,0), (0,1,0), (0,0,1), (1/2, 1/2, 0), (1/2, p, 1/2), (0, 1/2, 1/2).

- **Simplex-Centroid**
  Includes every subset of the components, q, where the proportions are equal for each included component. These subsets consist of pure blends, binary blends, tertiary blends . . . , and the overall centroid.

  For example, a three-component, standard unit design includes the following blends: (1,0,0), (0,1,0), (0,0,1), (1/2, 1/2, 0), (1/2, 0, 1/2), (0, 1/2, 1/2), and the centroid (1/3, 1/3, 1/3).

- **Extreme Vertices**
  A computer-aided design that includes the vertices in a constrained region that does not form a simplex. In a simplex region, the extreme vertices are identical to the vertices found in the simplex-lattice and simplex-centroid designs.

- **User-Specified Design**
  Designs created by the user from data already in a DataSheet.

Choosing Tabular Options for the Selected Design Class

Several helpful report options provide additional information about the design you select. However, not all of the options are available for every design class. For example: Design Summary and Worksheet.

Design Summary

The Design Summary option displays a summary of the design you choose (see Figure 5-6). The summary information includes the design class, design name, and file name. Other information about the base design includes the number of components, response variables, runs, mixture total, and the model type. A table shows the lowest and highest values for each of the components and the name of the response variable.

Use the *Mixture Design Selection* dialog box to choose another mixture design or the *Mixture Design Options* dialog box to make changes to the current design. *See Figure 5-4 and Figure 5-5 for examples of these dialog boxes.*

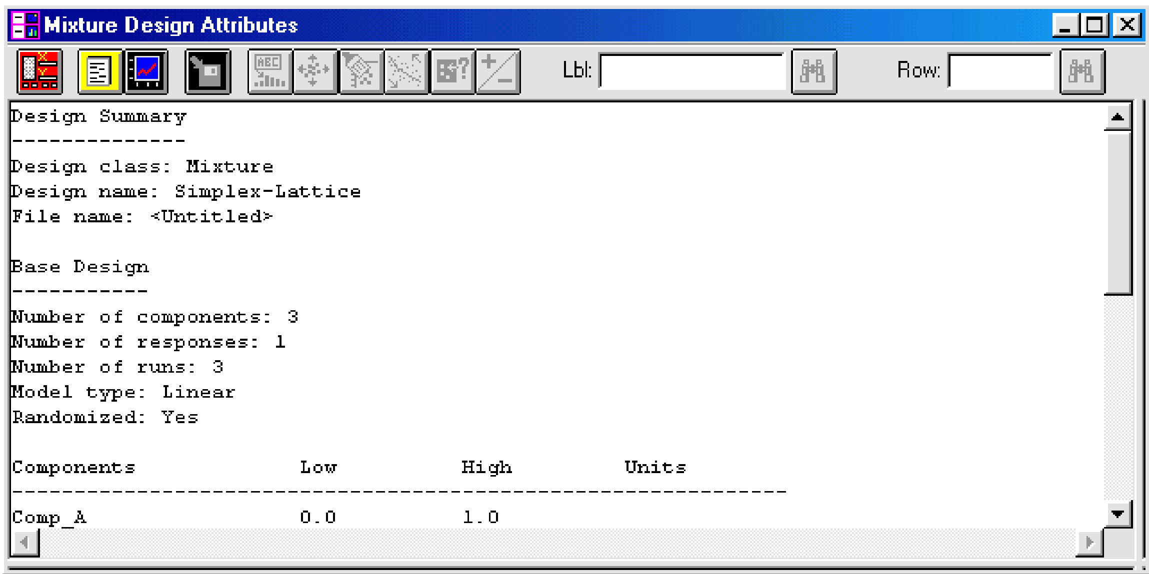


Figure 5-6. Design Summary

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 5-7).

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

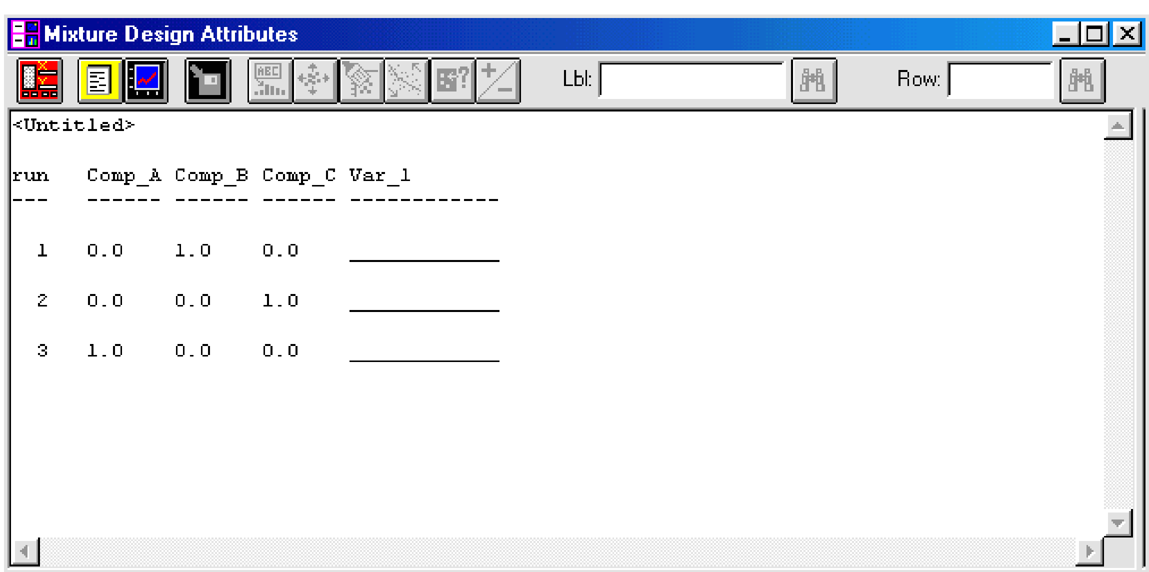


Figure 5-7. Worksheet

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 5-8).

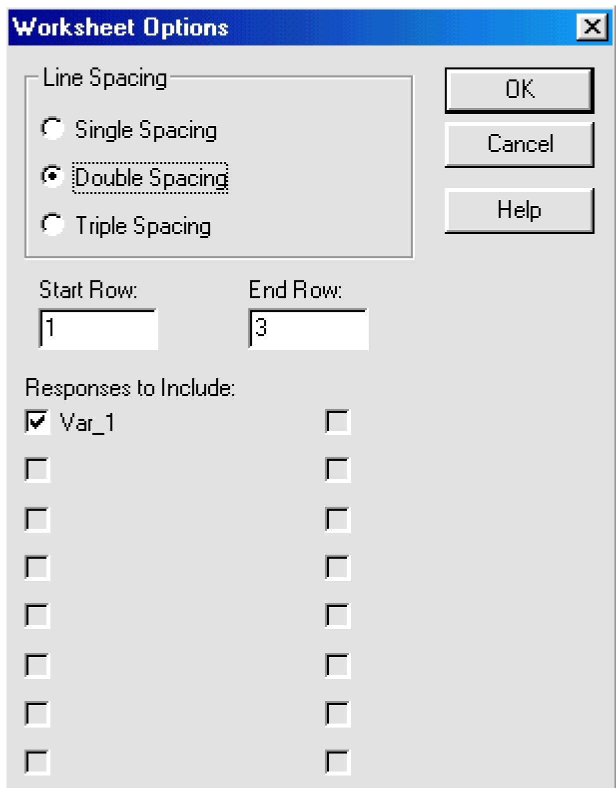


Figure 5-8. Worksheet Options Dialog Box

References

Belsley, D. A., Kuh, E., and Welsch, R. E. 1980. *Regression Diagnostics: Identifying Influential Data and Sources of Colinearity*. New York: John Wiley & Sons, Inc.

Box, G. E. P., Hunter, W. G., and Hunter, J. S. 1978. *Statistics for Experimenters*. New York: John Wiley & Sons, Inc.

Cornell, J. A. 1973 Experiments with Mixtures: A Review, *Technometrics,* **15**:437-455.

Cornell, J. A. 1990. *Experiments with Mixtures*, second edition. New York: John Wiley & Sons.

Cornell, J. A. and Piepel, G. F. 1993. *Design and Analysis of Mixture Experiments*. Computer Associates.

Haaland, P. 1989. *Experimental Design in Biotechnology*. New York: Marcel Dekker.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*. 1997. New York: John Wiley & Sons.

Montgomery, D. C. 1991. *Design and Analysis of Experiments*, third edition. New York. John Wiley & Sons.

Chapter 6

USING MULTILEVEL FACTORIAL DESIGNS

This chapter presents background information about multilevel factorial designs, explains how you create a multilevel factorial design, and how to choose tabular options for the design classes.

The Multilevel Factor design class allows you to create a design that consists of all combinations of specific levels of two or more factors; for example, a two- or three-level factorial design. This design class is intended for quantitative factors only and is analyzed as a response surface design.

To Create a Multilevel Factorial Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 6-1.

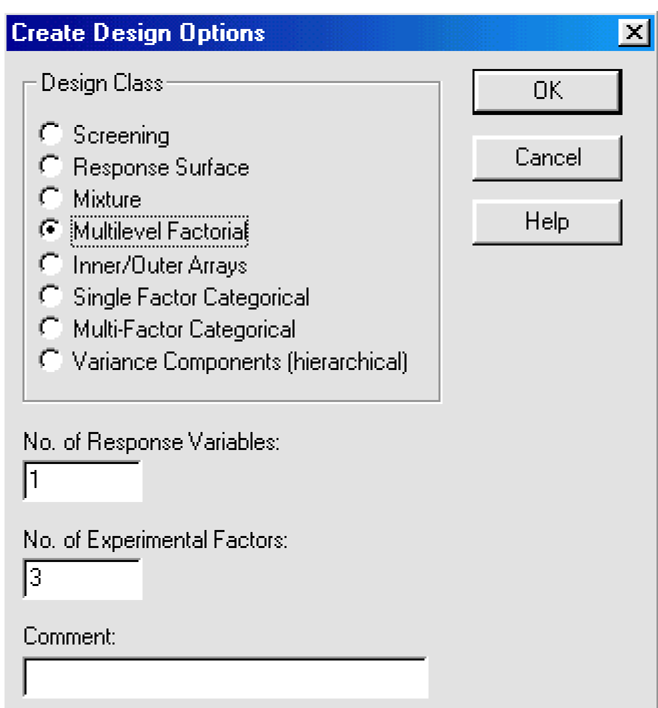


Figure 6-1. Create Design Options Dialog Box (Multilevel Factorial Designs)

2. Complete the dialog box by choosing the Multilevel Factorial design class option, entering a number for the number of response variable(s) and number of experimental factors, then, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Factor Definition Options dialog box shown in Figure 6-2.

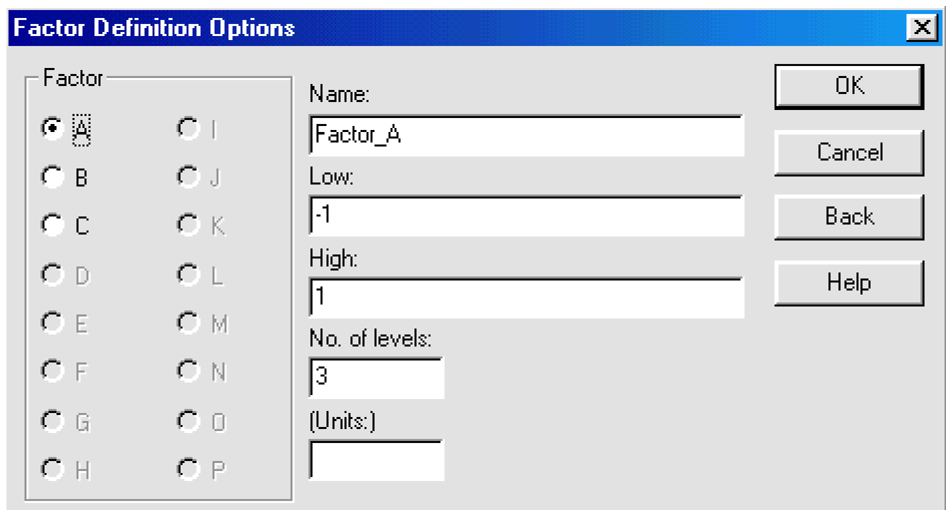


Figure 6-2. Factor Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a factor and entering a name for it, as well as values for the lowest and highest factor, and, if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 6-3.

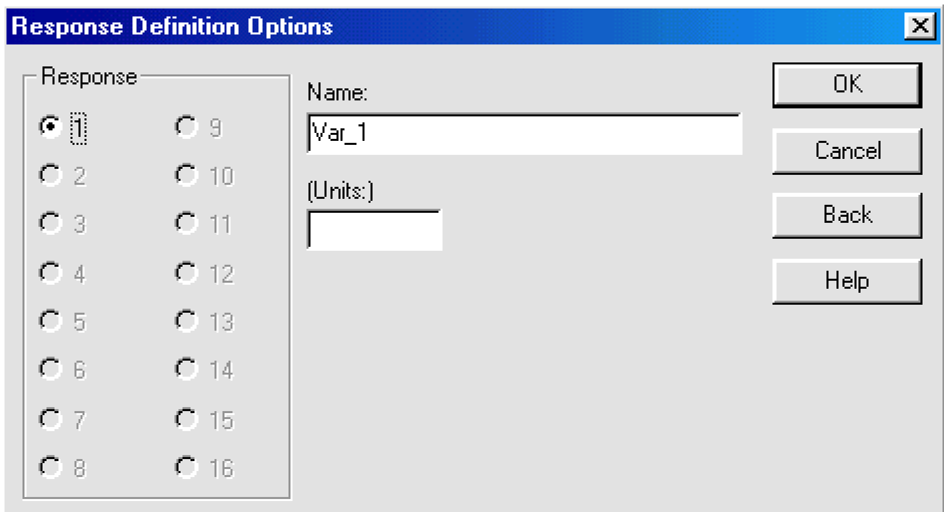


Figure 6-3. Response Definition Options Dialog Box

6. Complete the dialog box by choosing a response variable and defining it by entering a name for it, and, if applicable, entering a value for the units of measure.

Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Multilevel Factorial Design Options dialog box shown in Figure 6-4.

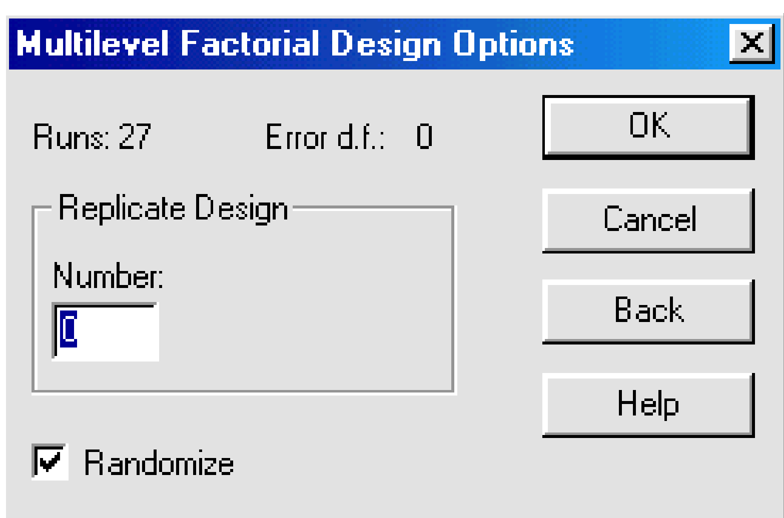


Figure 6-4. Multilevel Factorial Design Options Dialog Box

8. Complete the dialog box by either accepting the defaults or changing the number of times the design will be replicated. The number you enter will determine the number of experimental runs and the degrees of freedom for the design. You can also indicate if the runs will be randomized by selecting or deselecting the check box.

Clicking the Back... button redisplays the previous dialog box.

If you click OK now, the experimental runs will be placed in the DataSheet and the Design Summary will display in the Design Attributes window.

Choosing Tabular Options for a Multilevel Factor Design Class

Several helpful report options are available to describe the design class you choose: Design Summary and Worksheet.

Design Summary

The Design Summary option displays a summary of the design you choose (see Figure 6-5). The summary information includes the design class and file name. Other information about the base design includes the number of experimental factors, blocks, responses, runs, error degrees of freedom, and indicates if the factors were randomized. A table shows the lowest and highest values and the number of levels for each of the factors.

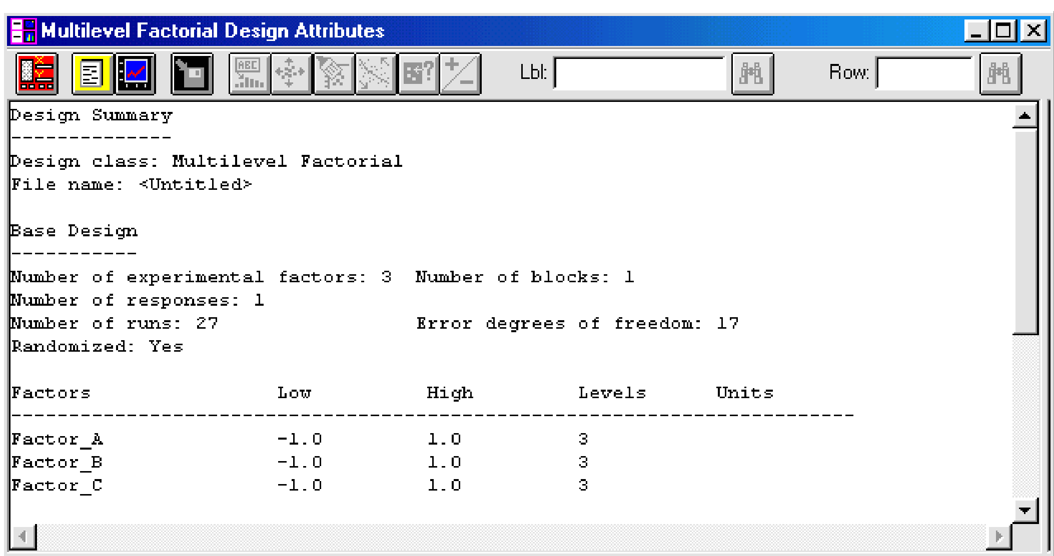
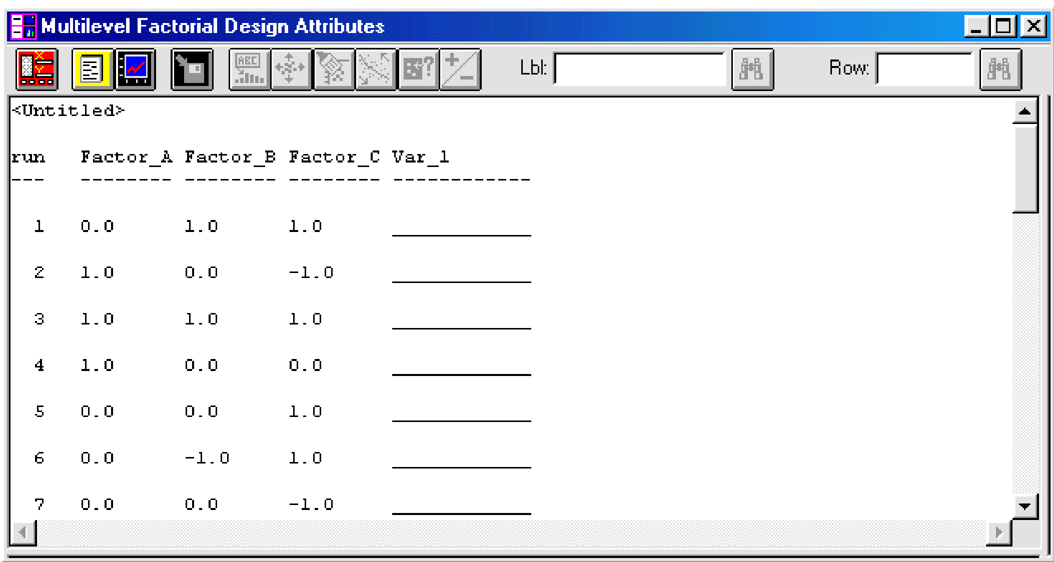


Figure 6-5. Design Summary

Use the *Multilevel Factorial Design Options* dialog box to make changes to the design. *See Figure 6-4 for an example of this dialog box.*

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 6-6).



run	Factor_A	Factor_B	Factor_C	Var_1
1	0.0	1.0	1.0	____________
2	1.0	0.0	-1.0	____________
3	1.0	1.0	1.0	____________
4	1.0	0.0	0.0	____________
5	0.0	0.0	1.0	____________
6	0.0	-1.0	1.0	____________
7	0.0	0.0	-1.0	____________

Figure 6-6. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 6-7).

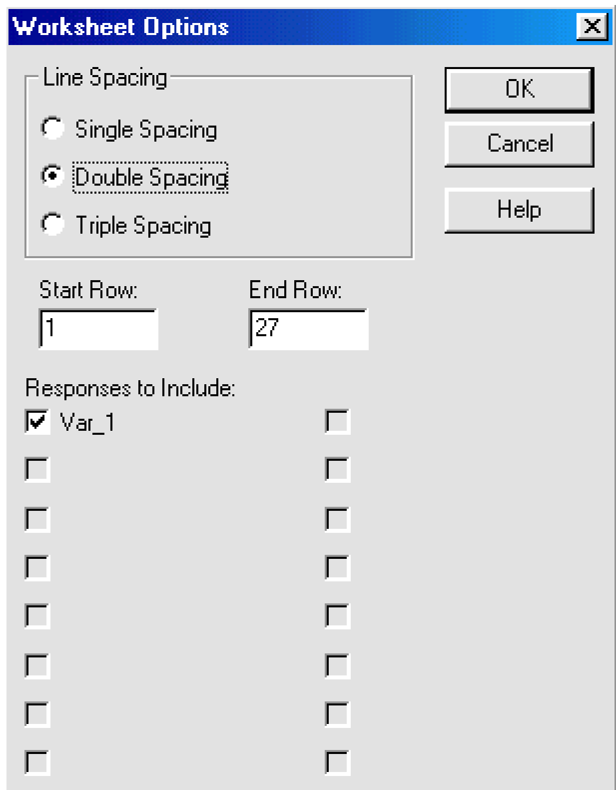


Figure 6-7. Worksheet Options Dialog Box

References

Box, G. E. P., Hunter, W. G., and Hunter, J. S. 1978. *Statistics for Experimenters*. New York: John Wiley & Sons, Inc.

Haaland, P. 1989. *Experimental Design in Biotechnology*. New York: Marcel Dekker.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*. New York: John Wiley & Sons.

Montgomery, D. C. 1991. *Design and Analysis of Experiments*, third edition. New York: John Wiley & Sons.

Schmidt, S. R. and Launsby, R. G. 1989. *Understanding Industrial Designed Experiments*, second edition. Colorado Springs, Colorado: Air Academy Press.

Chapter 7

USING INNER/OUTER ARRAYS DESIGNS

This chapter presents background information about inner/outer arrays designs, explains how you create a design, explains the different types of designs available and how you choose them, and explains how you choose tabular options for the design classes.

The Inner/Outer Arrays Designs Analysis in STATGRAPHICS *Plus* is a variation on an implementation of Taguchi (Robust) designs. The designs in STATGRAPHICS *Plus* consist of both controllable and uncontrollable noise factors. A typical use is to determine the combination of factors that reduce the sensitivity to uncontrollable sources of variability.

Uncontrollable factors, or noise factors, can be external or internal. External sources or *outer noise*, are variations in environmental conditions such as temperature, humidity, vibrations, dust, or human variations in operating a product. Internal sources of noise or *inner noise*, are deviations of the actual characteristics of a product from its nominal settings. These can result from imperfections in a manufacturing process, or from deterioration over time of internal elements and components.

To minimize the effects of noise sources, STATGRAPHICS *Plus* uses a technique of combined arrays design, which incorporates both controllable and uncontrollable noise factors. The combined arrays design must be used with a resolution high enough to estimate all the interactions (usually resolution IV or higher). Montgomery (1997) says that this approach will almost always lead to a dramatic reduction in the size of the experiment . . . and at the same time produces information that is more likely to improve process understanding.

Montgomery (1997) finds Taguchi s theory of robust design to be sound, and says it . . . should be included in the quality improvement process of any organization . In this type of robust design, most American and European engineers focus on system and tolerance design to achieve performance.

It is common in product and process design to base an initial prototype on system design, then use reliability and stability against noise factors, and correct any problems using tolerance design and skip parameter design altogether (Cullen and Hollingum, 1987; Phadke, 1989).

An eight-step process is suggested for conducting a robust design:

1. Identify the main function.

2. Identify the noise factors and testing conditions.

3. Identify the quality characteristics to be observed and the function to be optimized.

4. Identify the control factors and their alternative levels.

5. Design the matrix experiment and define the data analysis procedure.

6. Conduct the matrix experiment.

7. Analyze the data and determine near optimum levels for the control factors.

8. Predict the performance at these levels (Phadke, 1989).

Overall, robust design is a powerful tool that offers simultaneous improvements in quality, cost, and engineering productivity.

To Create an Inner/Outer Arrays Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 7-1.

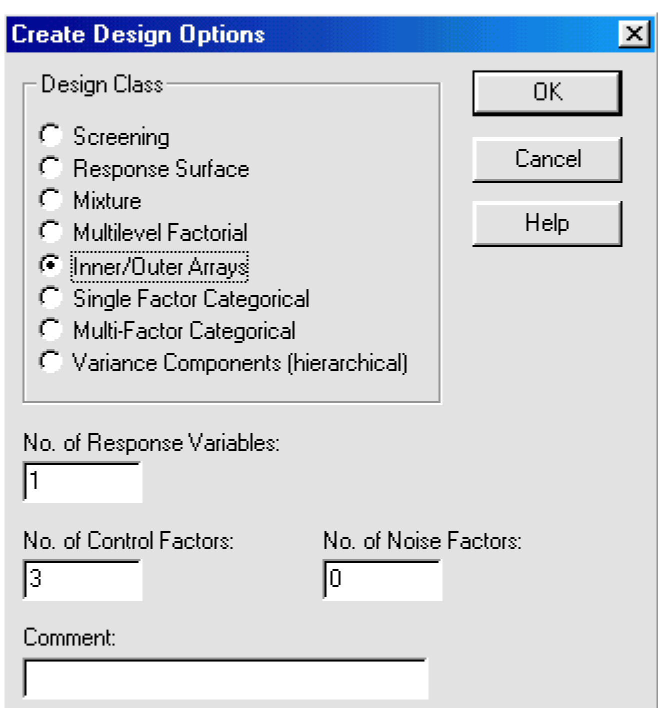


Figure 7-1. Create Design Options Dialog Box (Inner/Outer Arrays Designs)

2. Complete the dialog box by choosing the Inner/Outer Arrays option, entering a number for the number of response variable(s), number of control factors, number of noise factors, and, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Response Definition Options dialog box shown in Figure 7-2.

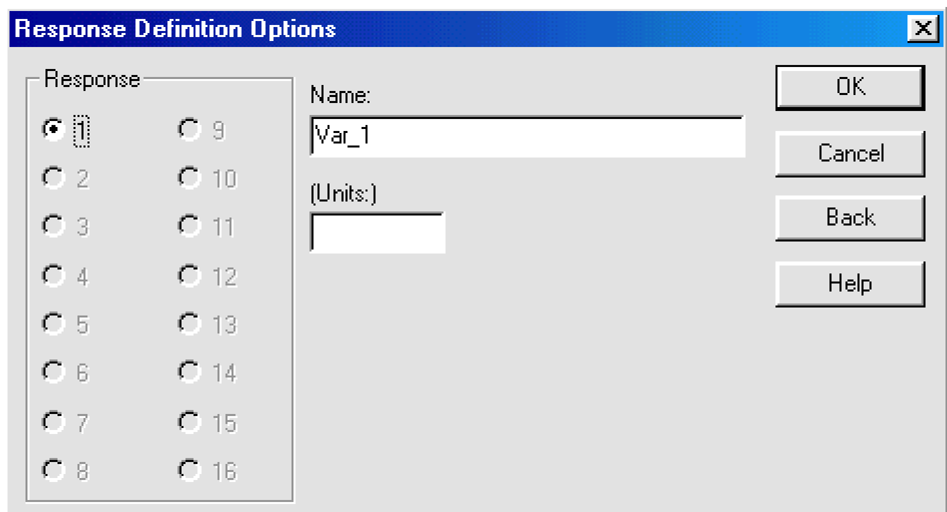


Figure 7-2. Response Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a response variable and defining it by entering a name for it, and, if applicable, entering a value for the units of measure.

Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Inner/Outer Arrays Options dialog box shown in Figure 7-3.

Figure 7-3. Inner/Outer Arrays Options Dialog Box

6. Complete the dialog box. Depending on your earlier choices, you can choose an Inner Array, or if you entered a value for the noise factors, you can also choose an Outer Array. There are 18 available options under each array. Click the Randomize check box if you want the runs randomized.

Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Column Assignments dialog box shown in Figure 7-4.

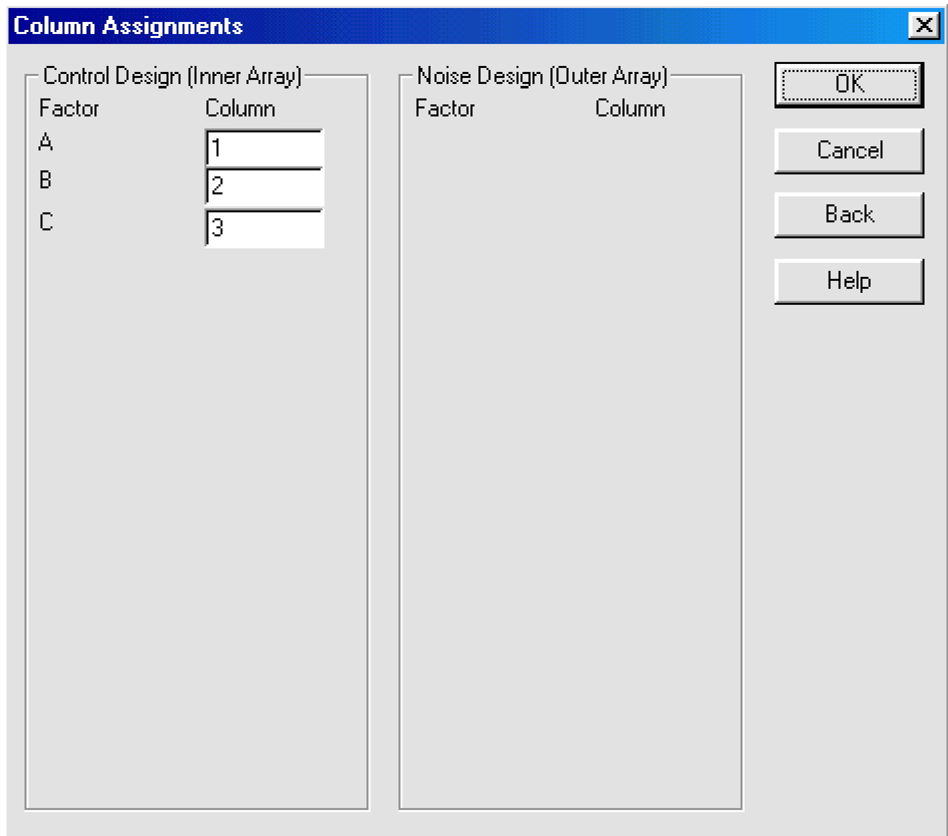


Figure 7-4. Column Assignments Dialog Box

8. Complete the dialog box by entering a number for each factor in the Inner Array.

9. Click OK to display the Control/Noise Factor Definition Options dialog box shown in Figure 7-5.

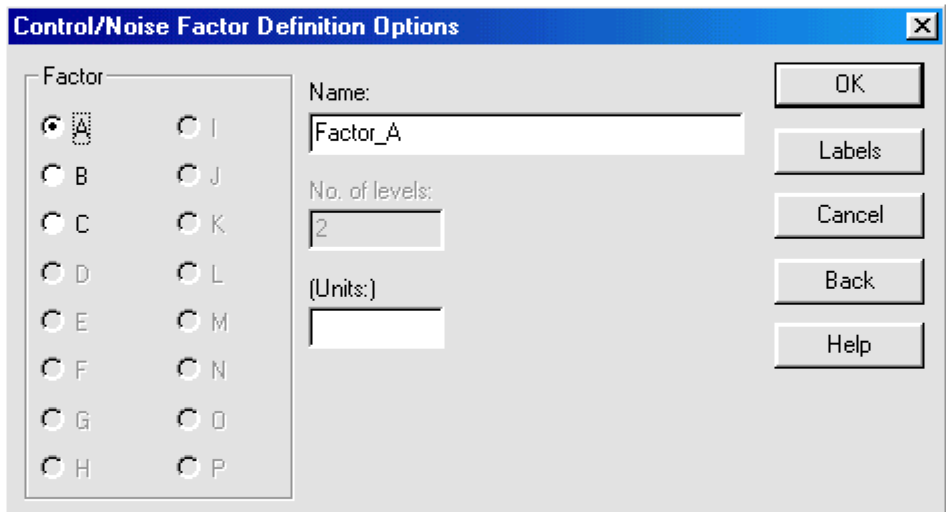


Figure 7-5. Control/Noise Factor Definition Options Dialog Box

10. Complete the dialog box by choosing a factor, entering a name for it, and, optionally, entering a value for the units of measure.

Clicking the Labels... button displays the Factor Levels dialog box (see Figure 7-6), which lets you enter labels for each of the factor levels.

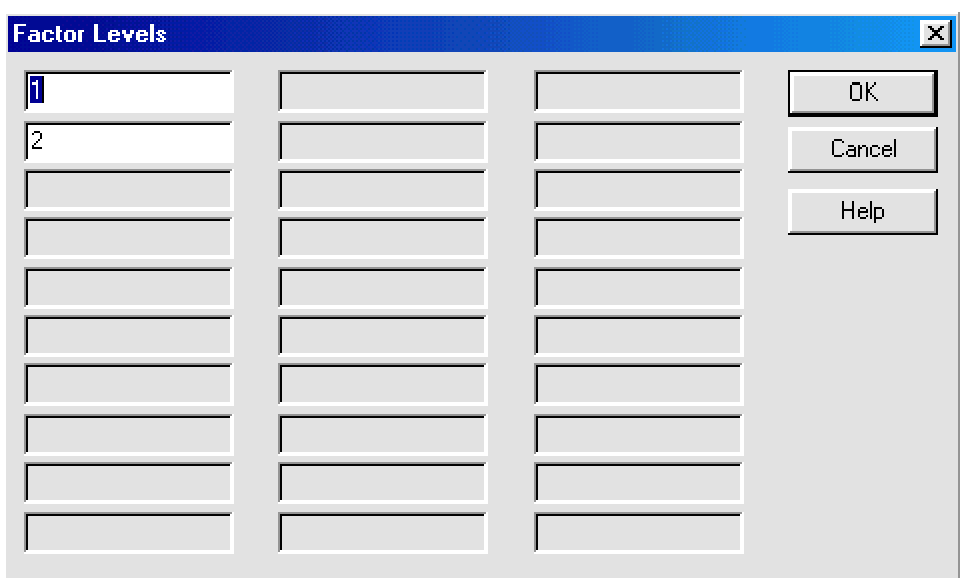


Figure 7-6. Factor Levels Dialog Box

If you click OK now, the experimental runs will be placed in the DataSheet and the Design Summary will display in the Design Attributes window.

Choosing Tabular Options for an Inner/Outer Arrays Design

Several report options are available to describe the Inner/Outer Arrays design: Design Summary and Worksheet.

Design Summary

The Design Summary option displays a summary of the design you choose (see Figure 7-7). The summary information includes the design class, design name, and file name. Other information about the base design includes the number of control factors, noise factors, responses, runs in the inner and outer arrays, and indicates if the factors were randomized. A table shows the number of levels for each of the factors.

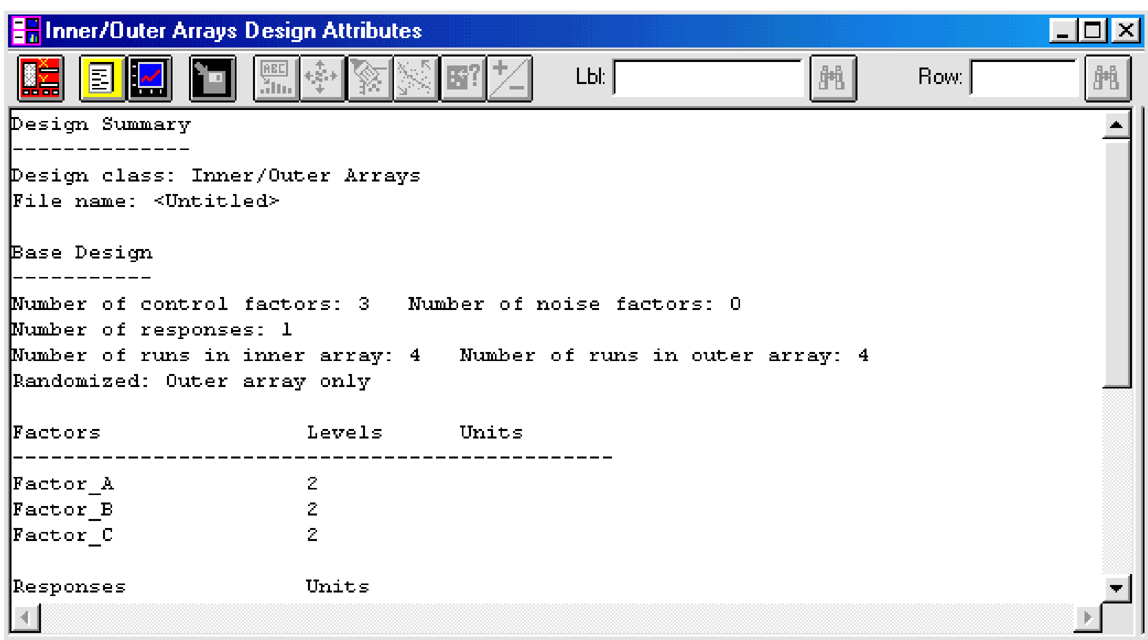


Figure 7-7. Design Summary

Use the *Inner/Outer Arrays Options* dialog box to change the design. *See Figure 7-3 for an example of this dialog box*

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 7-8).

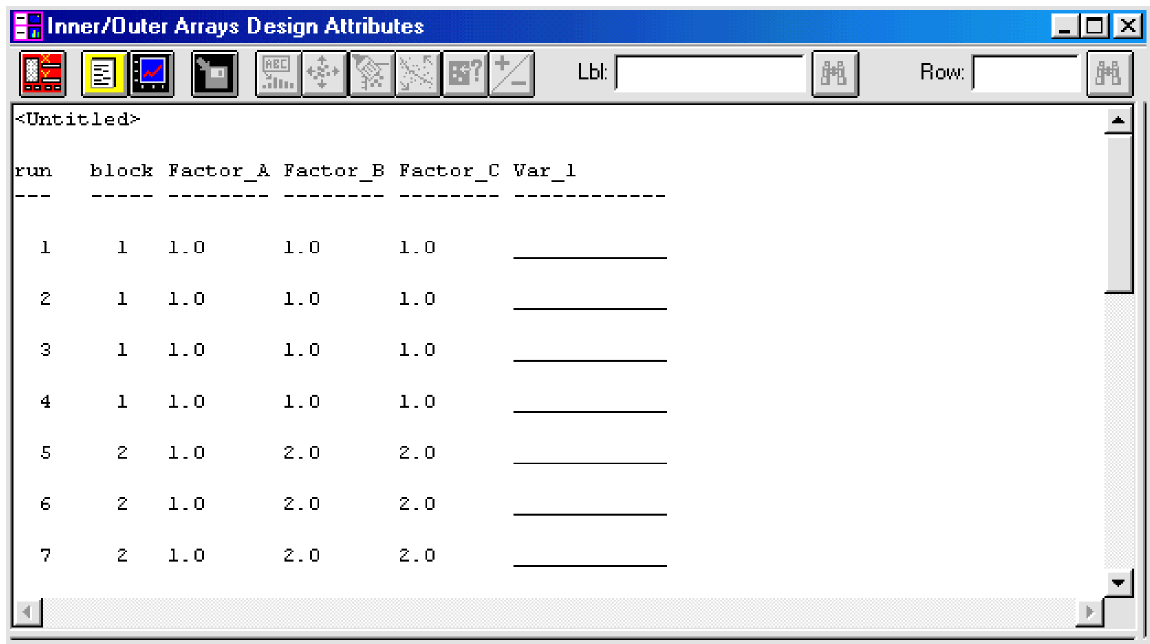


Figure 7-8. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet, enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 7-9).

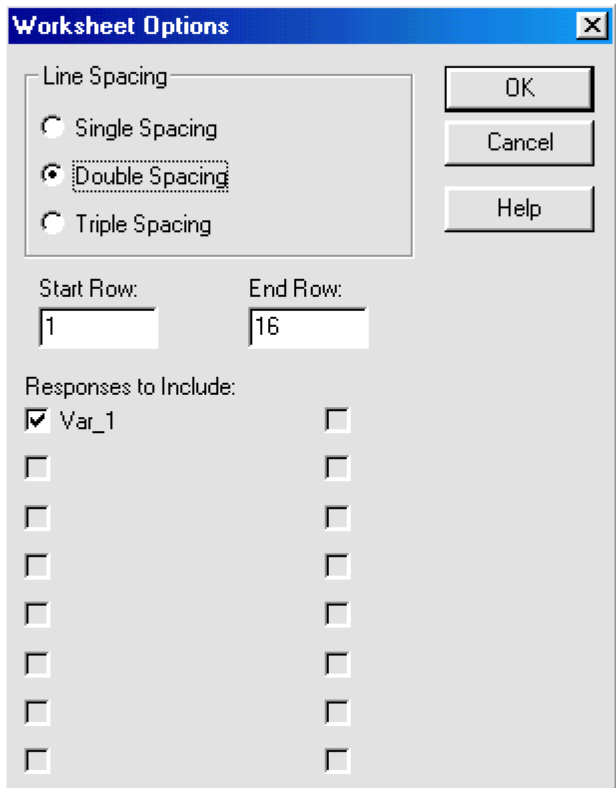


Figure 7-9. Worksheet Options Dialog Box

References

Cullen, J. and Hollingum, J. 1987. *Implementing Total Quality.* New York: Springer-Verlag.

Phadke, S. M. 1989. *Quality Engineering Using Robust Design*. Englewood Cliffs, New Jersey: Prentice Hall.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*, third edition. New York: John Wiley & Sons, Inc.

Pence, G. S. 1993. *Taguchi Methods: A Hands-On Approach*. Massachusetts: Addison-Wesley Publishing Company, Inc.

Chapter 8

USING SINGLE FACTOR CATEGORICAL DESIGNS

This chapter presents background information about single factor categorical designs, explains how you create a design, explains the different types of designs available and how you choose them, and explains how you choose tabular and graphical options for the design classes.

Single factor categorical designs compare levels of a single nonquantitative variable, with or without blocking factors. This type of experiment is the simplest type of experiment because it contains only a single factor of interest. You can analyze these designs as either a multifactor or one-way ANOVA.

In STATGRAPHICS *Plus* you can create seven different types of single factor categorical designs:

- completely randomized with no blocking
- randomized block with one blocking factor
- combinatoric BIB with one blocking factor
- small BIB with one blocking factor
- Latin square with two blocking factors
- Graeco-Latin square with three blocking factors
- hyper-Graeco-Latin square with four blocking factors.

Each of the design types is discussed in the section, Selecting a Single Factor Categorical Design, later in this chapter.

The next section explains how you create a single factor categorical design. In-depth explanations about the options on the dialog boxes appear in Online Help.

To Create a Single Factor Categorical Design

1. Choose SPECIAL... EXPERIMENTAL DESIGNS... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 8-1.

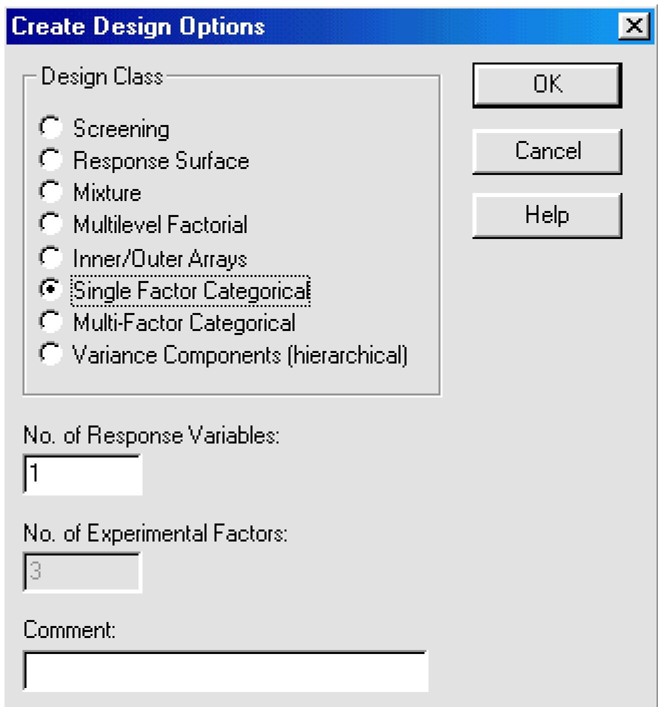


Figure 8-1. Create Design Options Dialog Box (Single Factor Categorical Designs)

2. Complete the dialog box by choosing the Single Factor Categorical design option, entering a number for the response variable(s), then, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Factor Definition Options dialog box shown in Figure 8-2.

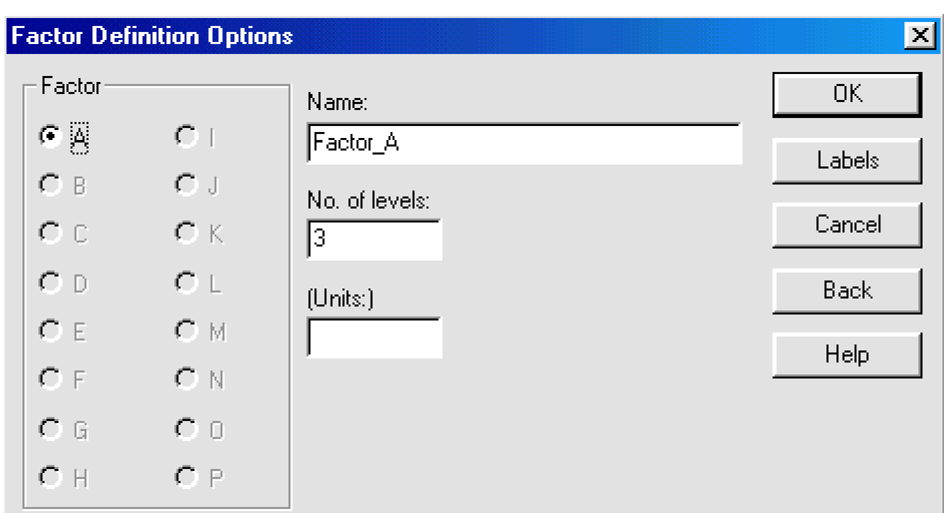


Figure 8-2. Factor Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or entering a name for the factor, as well a value for the number of levels, and, if applicable, the units of measure.

   Clicking the Labels... button displays the Factor Levels dialog box, which you use to enter labels for each of the factor levels.

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 8-3.

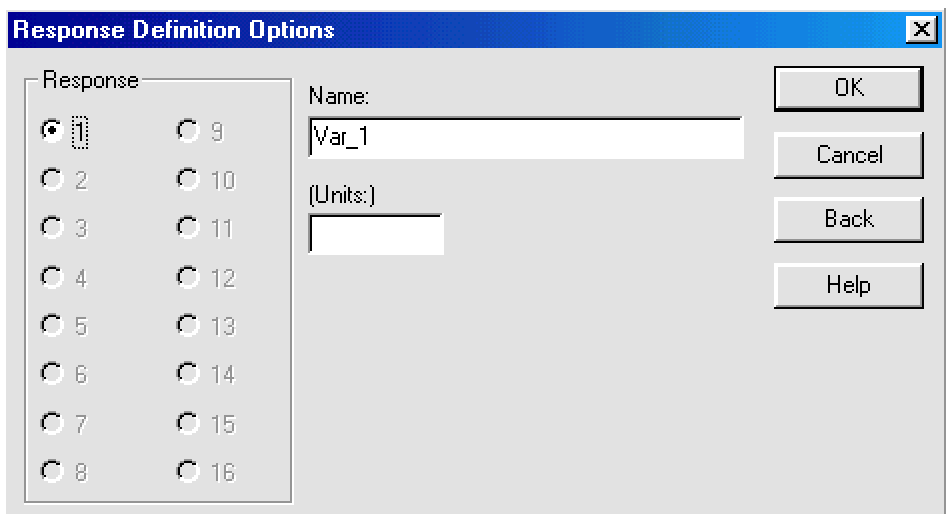


Figure 8-3. Response Definition Options Dialog Box

6. Complete the dialog box by either accepting the defaults or choosing a response variable and defining it by entering a name for it, and if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Single Factor Categorical Design Options dialog box shown in Figure 8-4.

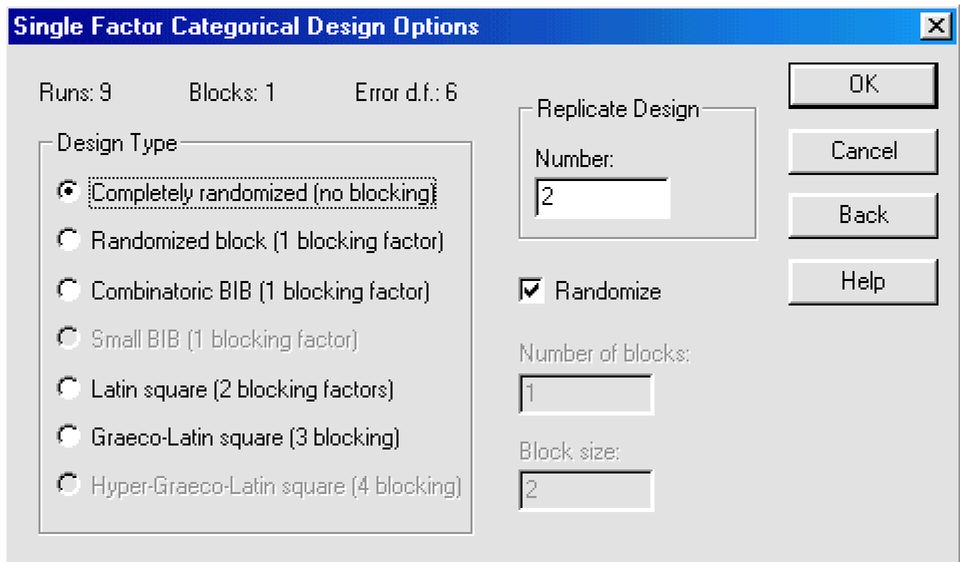


Figure 8-4. Single Factor Categorical Design Options Dialog Box

8. Complete the dialog box by either accepting the defaults or choosing a design from the list of design types, entering a value for the number of times the design will be replicated, and indicating if the design will be randomized. If you are using a blocked design, enter the number and size of the block. *For a list of the available designs, see the section, Selecting a Single-Factor Categorical Design, below.*

Notice that the dialog box displays the number of runs and blocks in the experiment, as well as the error degrees of freedom.

Clicking the Back... button redisplays the previous dialog box.

If you click OK now, the experimental runs will be placed in the DataSheet and the Design Summary will display in the Design Attributes window.

Selecting a Single Factor Categorical Design

The Single Factor Categorical Design Options dialog box provides details about the base design by displaying the number of runs, the number of blocks, error degrees of freedom; and indicating the number of times the design will be replicated, and whether or not the design will be randomized.

The list of designs shown for the Design Type options are briefly described below.

- **Completely Randomized (No Blocking)**
  An experiment in which all treatments are present and all runs are randomly ordered.

- **Randomized Block (One Blocking Factor)**
  A design in which you randomly assign the treatments to be compared with positions in each of several blocks of replications. In a complete block experiment, each block contains all treatments.

- **Combinatoric BIB (One Blocking Factor)**
  This type of design is used when it is not possible to include all factor combinations in every block. However, every factor-level combination occurs an equal number of times and each pair of factors occurs together in an equal number of blocks.

- **Small BIB (One Blocking Factor)**
  A small, balanced, incomplete block (BIB) design that reduces the number of runs required by combinatoric BIB designs.

- **Latin Square (Two Blocking Factors)**
  A Latin square design is an arrangement of the first *n* integers in an *n* by *n* array so every integer appears exactly once in every row and exactly once in every column. In this particular case it is used with two blocking factors. This type of design is useful for reducing two sources of variability.

- **Graeco-Latin Square (Three Blocking Factors)**
  A Graeco-Latin square design is an arrangement of a *k* x *k* pattern that permits the study of *k* treatments simultaneously with three different blocking variables. This type of design is useful for reducing more than two sources of variability.

- **Hyper-Graeco-Latin Square (Four Blocking Factors)**
  A hyper-Graeco-Latin square design is an arrangement that allows the study of *k* treatments with more than three blocking variables. This type of design is useful for reducing more than two sources of variability.

For an example that uses these types of designs, see Box, Hunter, and Hunter (1978).

Choosing Tabular Options for the Selected Design Class

Several report options are available to describe the design you choose: Design Summary and Worksheet. The description of the options are the same, regardless of the design class you use.

Design Summary

The Design Summary option displays a summary of the design you choose (see Figure 8-5). The summary information includes the design class and file name. Other information about the base design includes the number of experimental factors, blocks, responses, runs, error degrees of freedom; and indicates if the runs were randomized. A table shows the number of factor levels.

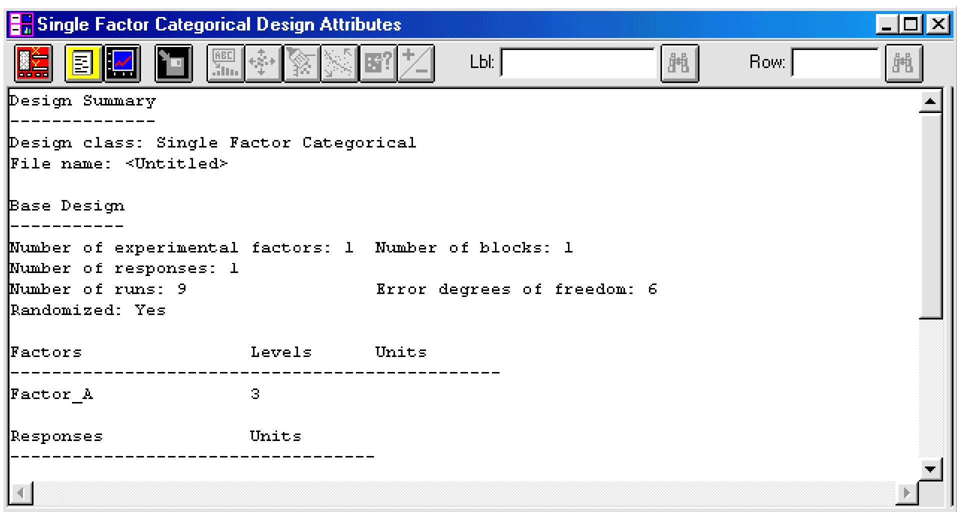


Figure 8-5. Design Summary

Use the *Single-Factor Categorical Design Options* dialog box to choose another design or to make changes to the current design. *See Figure 8-4 for an example of this dialog box.*

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 8-6).

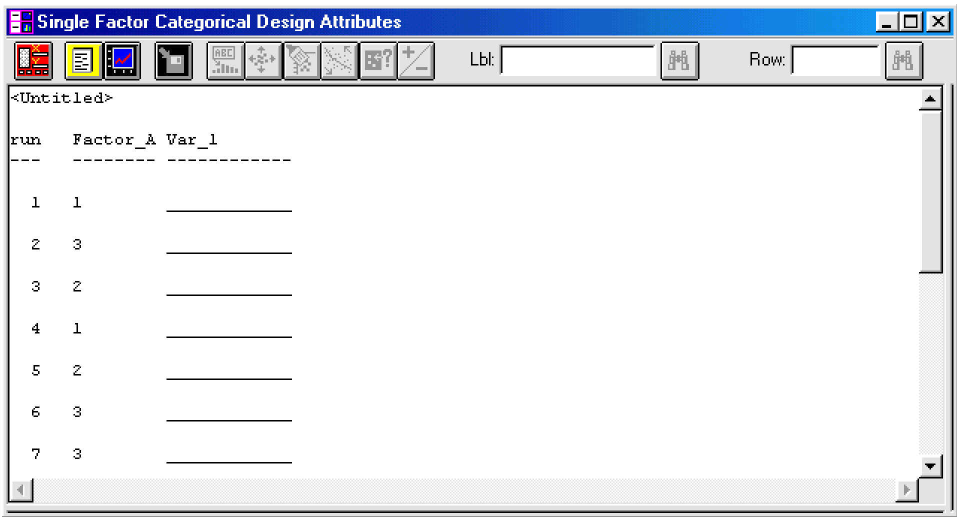


Figure 8-6. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 8-7).

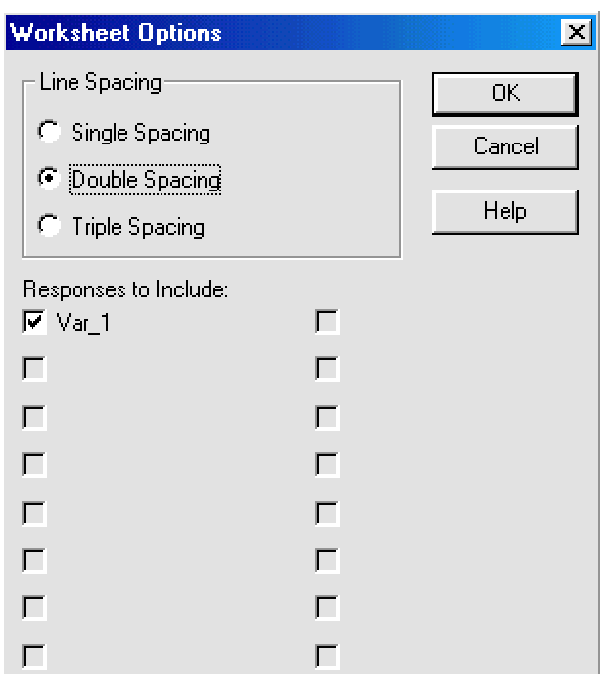


Figure 8-7. Worksheet Options Dialog Box

Chapter 9

USING MULTI-FACTOR CATEGORICAL DESIGNS

This chapter presents background information about the Multi-Factor Categorical design, explains how you create this type of design, and explains how you choose the tabular options for the design class.

Multi-factor categorical designs consist of all combinations of levels for two or more factors, where you set the number of levels. The analysis is intended for nonquantitative factors and is analyzed using ANOVA.

The next section explains how you create a Multi-Factor Categorical design. In-depth explanations about the options on the dialog boxes appear in Online Help.

To Create a Multi-Factor Categorical Design

1. Choose SPECIAL... EXPERIMENTAL DESIGNS... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 9-1.

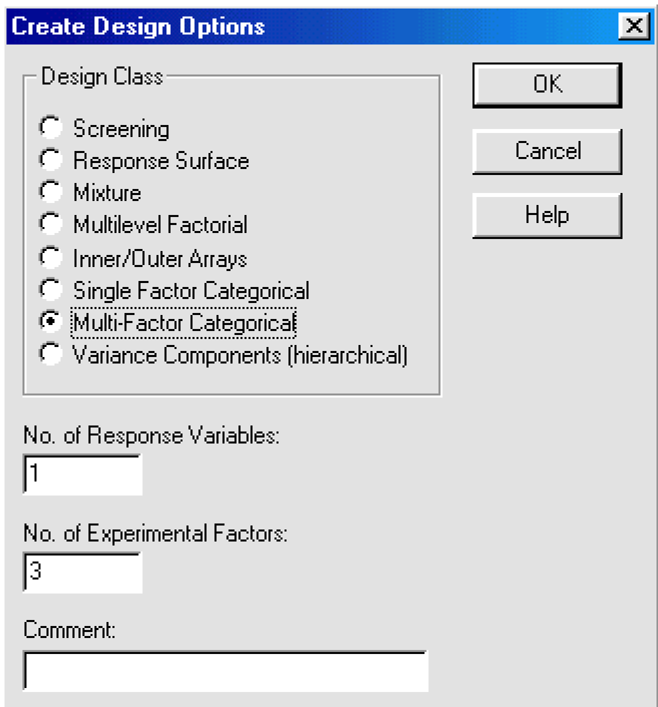


Figure 9-1. Create Design Options Dialog Box (Multi-Factor Categorical Designs)

2. Complete the dialog box by choosing the Multi-Factor Categorical design class option, entering a number for the number of response variable(s) and number of experimental factors, then, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Factor Definition Options dialog box shown in Figure 9-2.

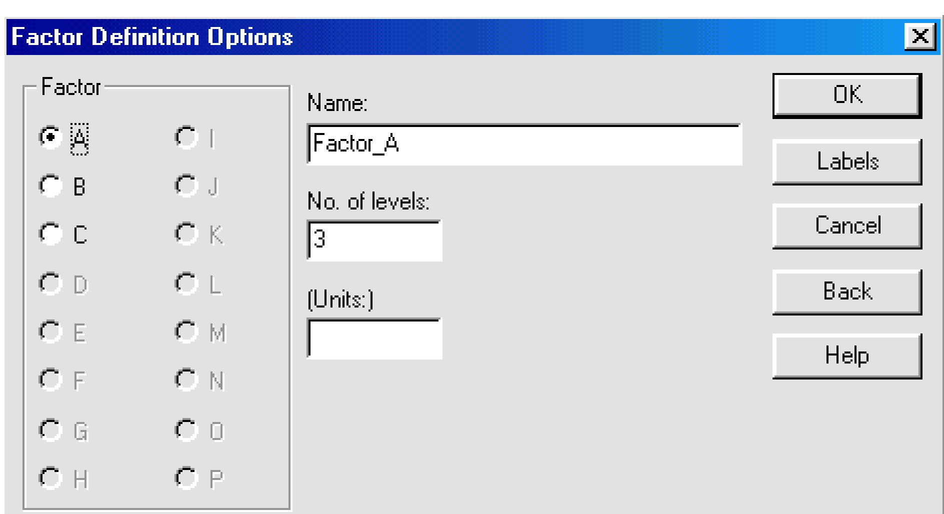


Figure 9-2. Factor Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a factor and entering a name for it, as well as a value for the number of levels, and, if applicable, the number of units of measure.

   Clicking the Labels... button displays the Factor Levels dialog box, which you use to enter labels for each of the factor levels.

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 9-3.

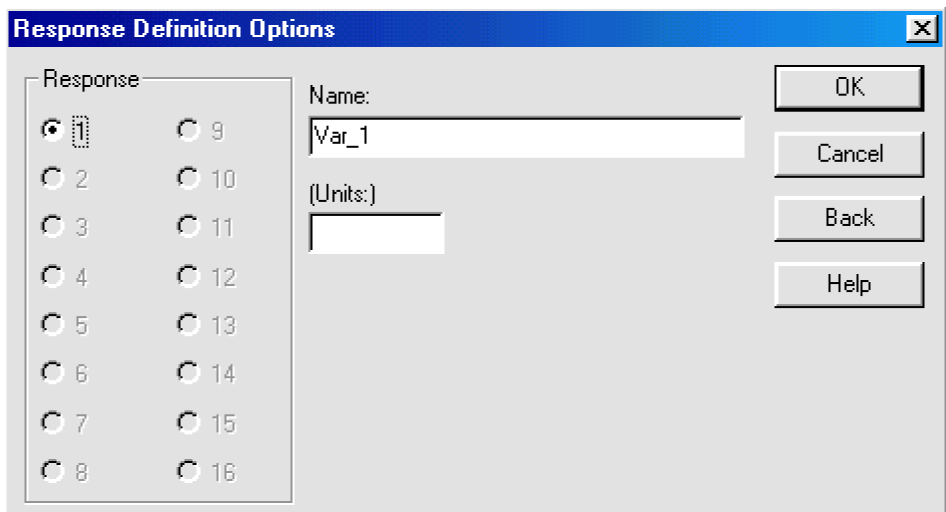


Figure 9-3. Response Definition Options Dialog Box

6. Complete the dialog box by either accepting the defaults or choosing a response variable, and defining it by entering a name for it, and, if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Multi-Factor Categorical Design Options dialog box shown in Figure 9-4.

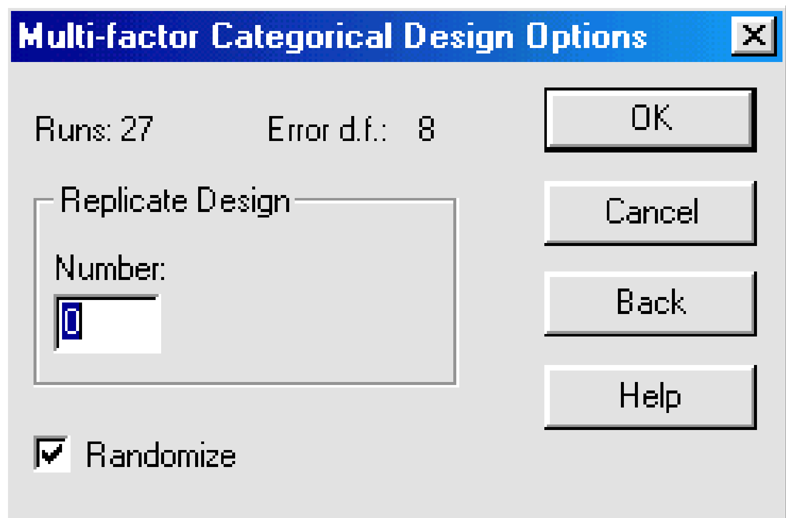


Figure 9-4. Multi-Factor Categorical Design Options Dialog Box

8. Complete the dialog box by either accepting the defaults or changing the number of times the design will be replicated. The number you enter will determine the number of experimental runs and the degrees of freedom for the design. You can also indicate if the runs will be randomized by selecting or deselecting the check box.

Clicking the Back... button redisplays the previous dialog box.

If you click OK now, the experimental runs will be placed in the DataSheet and the Design Summary will display in the Design Attributes window.

Choosing Tabular Options for a Multi-Factor Categorical Design

Several report options are available to describe the multi-factor categorical design you choose: Design Summary and Worksheet.

Design Summary

The Design Summary option displays a summary of the design you choose (see Figure 9-5). The summary information includes the design class and file name. Other information about the base design includes the number of experimental factors, responses, runs, error degrees of freedom, and indicates if the runs were randomized. A table shows the number of levels for each of the factors.

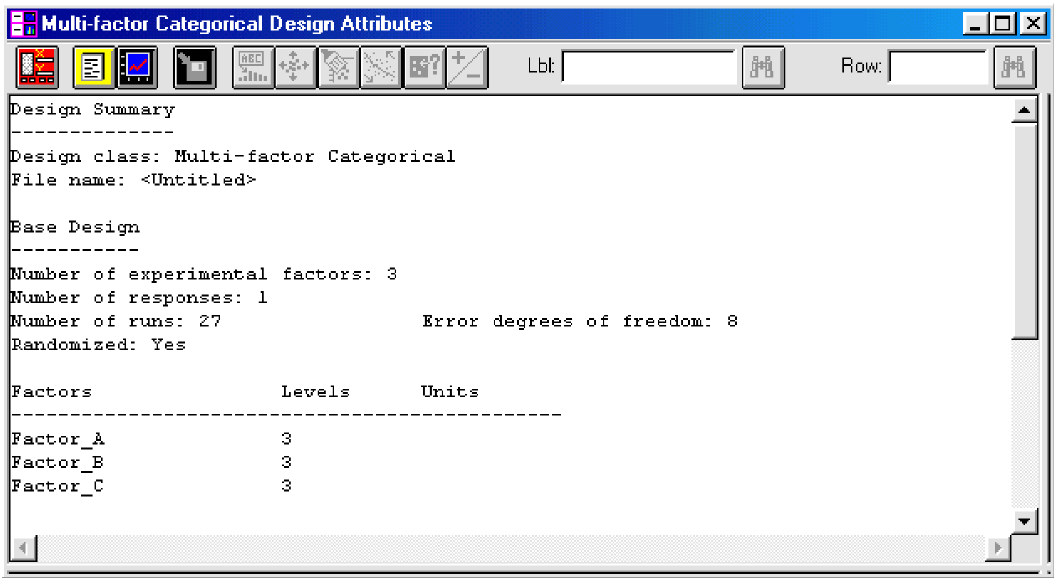


Figure 9-5. Design Summary

Use the *Multi-Factor Categorical Design Options* dialog box to make changes to the design. *See Figure 9-4 for an example of this dialog box.*

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 9-6).

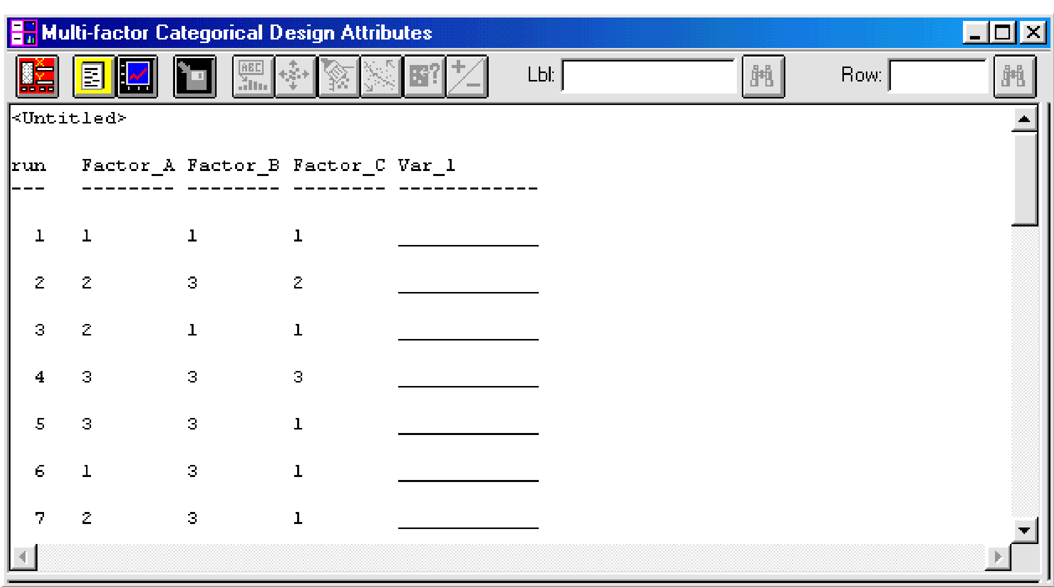


Figure 9-6. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 9-7).

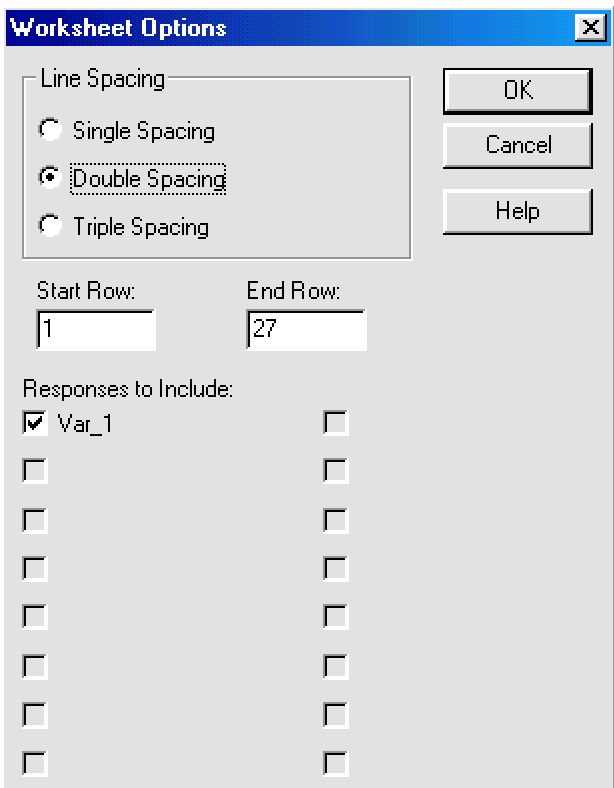


Figure 9-7. Worksheet Options Dialog Box

Chapter 10

USING VARIANCE COMPONENTS (HIERARCHICAL) DESIGNS

This chapter presents background information about the Variance Components (Hierarchical) design, explains how you create this type of design, and explains how you choose tabular options for the design class.

Variance Components (Hierarchical) designs consist of nested factors. The analysis is intended for quantifying the effects of various factors on the variability of the response variable(s). It is analyzed as a Variance Components analysis.

The next section explains how you create a Variance Components (Hierarchical) design. In-depth explanations about the options on the dialog boxes appear in Online Help.

To Create a Variance Components (Hierarchical) Design

1. Choose SPECIAL... EXPERIMENTAL DESIGNS... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 10-1.

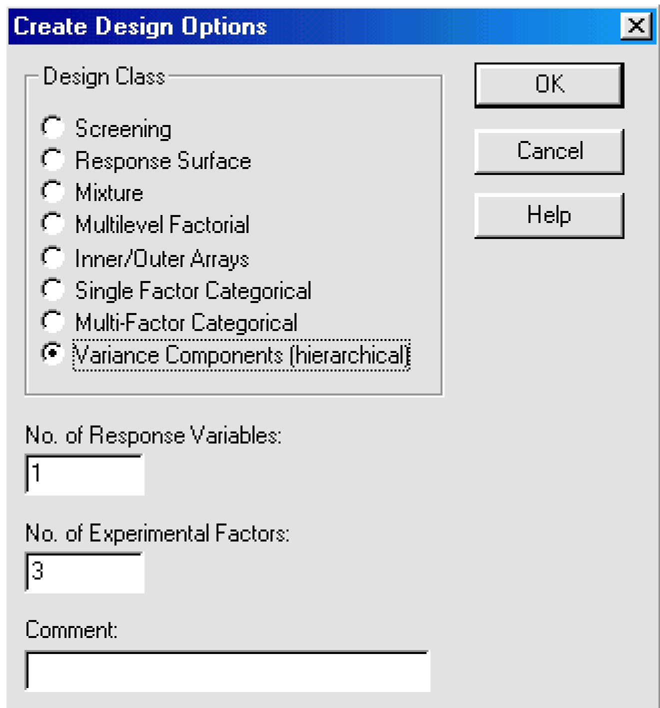


Figure 10-1. Create Design Options Dialog Box (Variance Components Designs)

2. Complete the dialog box by choosing the Variance Components (Hierarchical) design option, entering a number for the response variable(s) and number of experimental factors, then, optionally, entering a descriptive comment that will identify the design.

3. Click OK to display the Factor Definition Options dialog box shown in Figure 10-2.

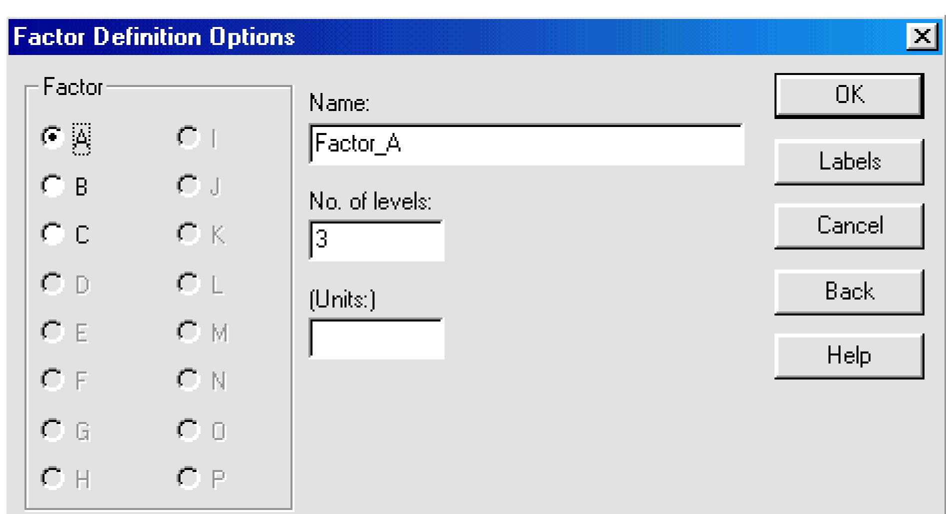


Figure 10-2. Factor Definition Options Dialog Box

4. Complete the dialog box by either accepting the defaults or choosing a factor and entering a name for it, as well as a value for the number of levels, and, if applicable, a value for the number of units.

   Clicking the Labels... button displays the Factor Levels dialog box, which you use to enter labels for each factor level.

   Clicking the Back... button redisplays the previous dialog box.

5. Click OK to display the Response Definition Options dialog box shown in Figure 10-3.

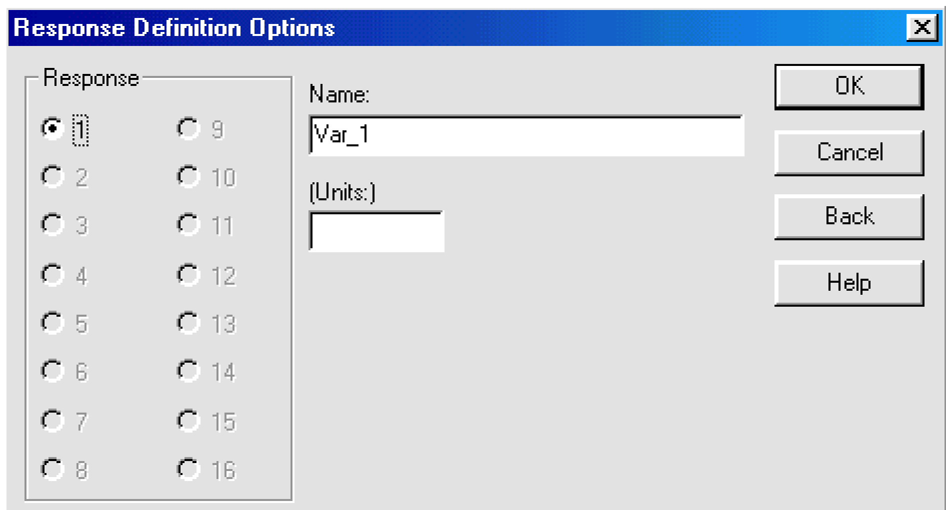


Figure 10-3. Response Definition Options Dialog Box

6. Complete the dialog box by either accepting the defaults or choosing a response variable and defining it by entering a name for it, and, if applicable, entering a value for the units of measure.

   Clicking the Back... button redisplays the previous dialog box.

7. Click OK to display the Variance Components Design Options dialog box shown in Figure 10-4.

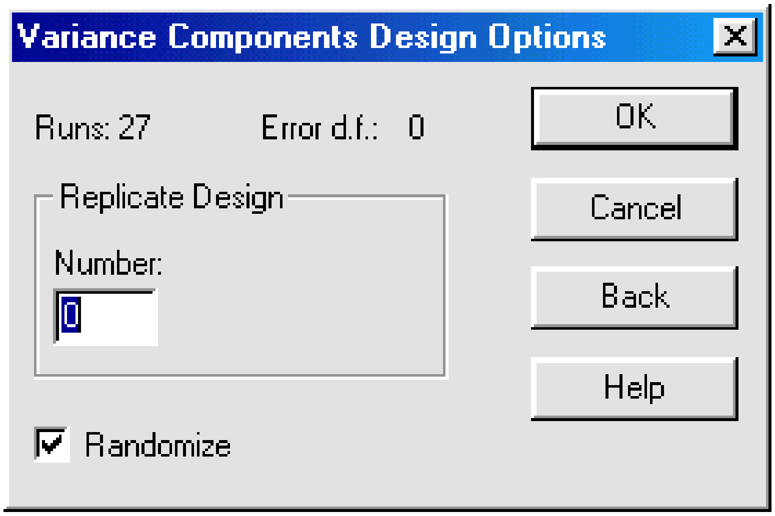


Figure 10-4. Variance Components Design Options Dialog Box

8. Complete the dialog box by either accepting the defaults or changing the number of times the design will be replicated. The number you enter will determine the number of experimental runs and the degrees of freedom for the design. You can also indicate if the runs will be randomized by selecting or deselecting the check box.

Clicking the Back... button redisplays the previous dialog box.

If you click OK now, the experimental runs will be placed in the DataSheet and the Design Summary will display in the Design Attributes window.

Choosing Tabular Options for a Variance Components (Hierarchical) Design

Several report options are available to explain the design you choose: Design Summary and Worksheet.

Design Summary

The Design Summary option displays a summary of the design you choose (see Figure 10-5). The summary information includes the design class and file name. Other information about the base design includes the number of experimental factors, blocks, responses, runs, and indicates if the factors were randomized. A table shows the number of levels for each of the factors.

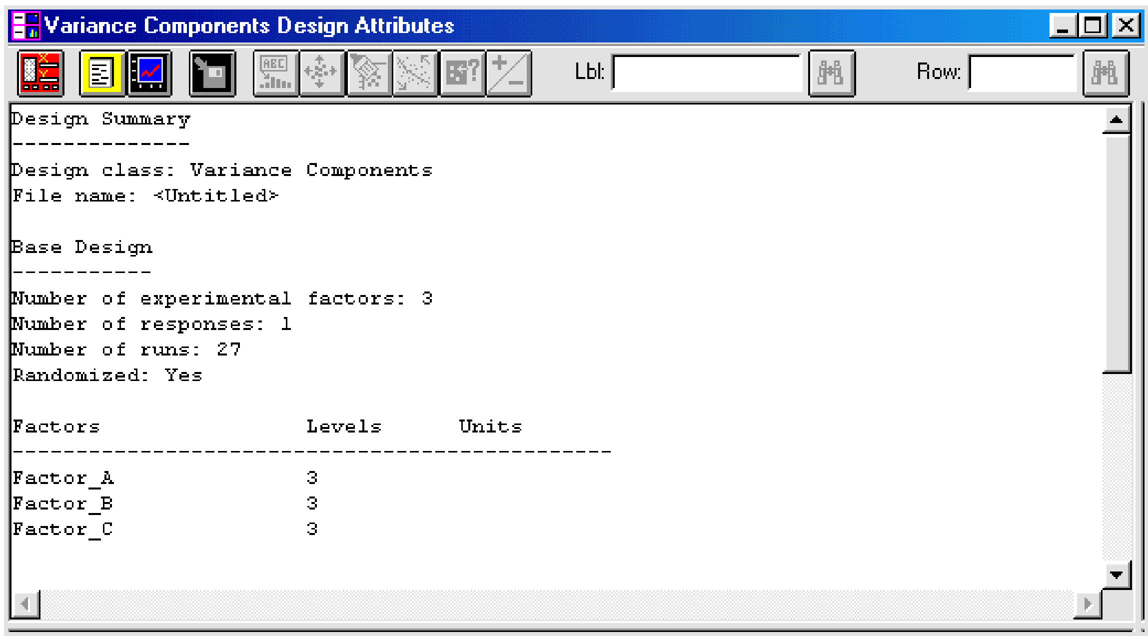


Figure 10-5. Design Summary

Use the *Variance Components Design Options* dialog box to choose another design or to make changes to the current design. *See Figure 10-4 for an example of this dialog box.*

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 10-6).

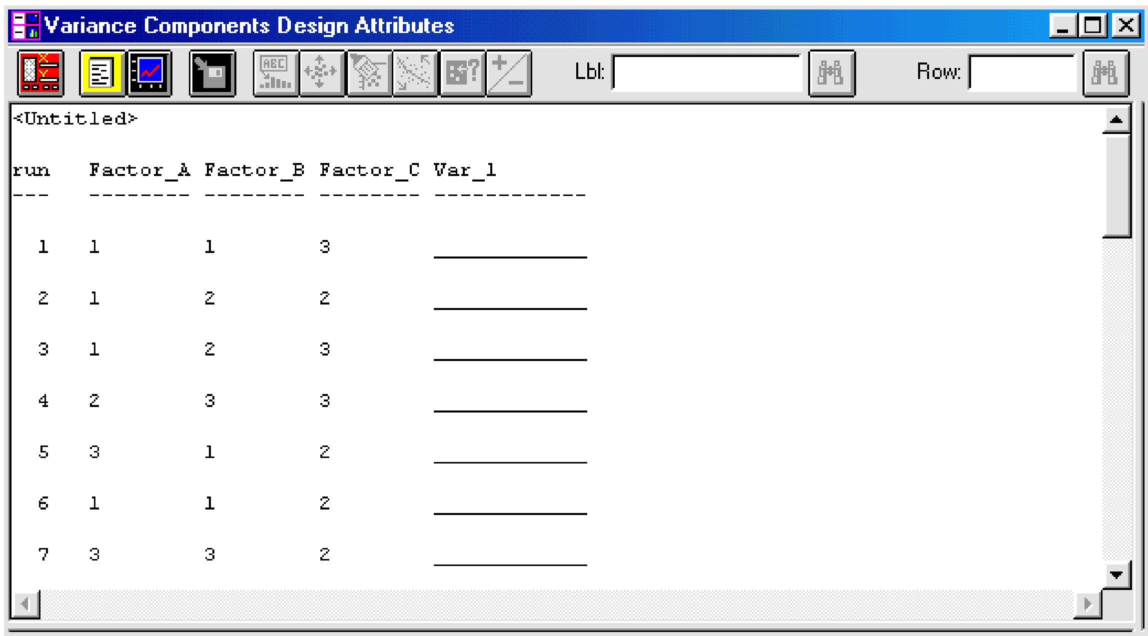


Figure 10-6. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 10-7).

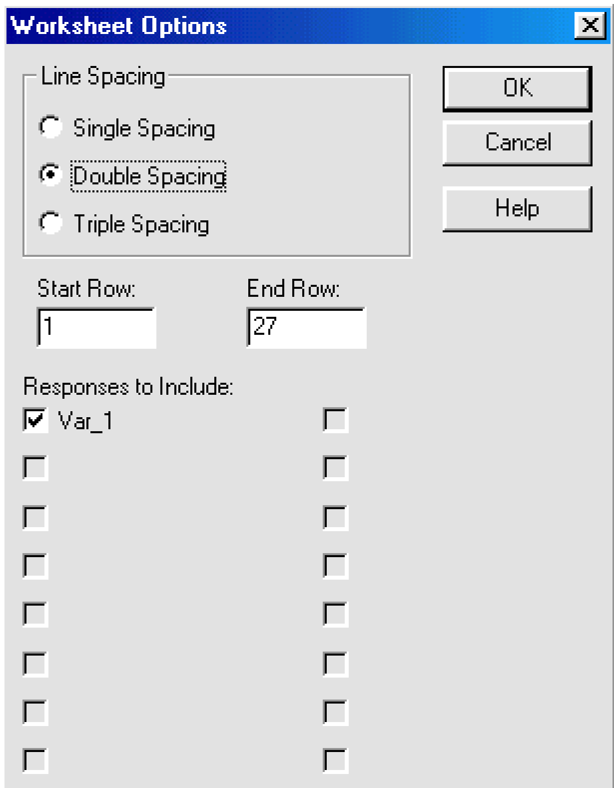


Figure 10-7. Worksheet Options Dialog Box

Chapter 11

USING MULTIPLE RESPONSE OPTIMIZATION

This chapter explains a function that determines the combination of experimental factors that simultaneously optimize several response variables. The goal of the function is to maximize a desirability function and can be used after you analyze two or more design components. Several of the Analyze Design windows must be open to use this function. If an Analyze Design window is minimized to a Taskbar, the program will not recognize the analysis.

The remainder of this chapter provides step-by-step instructions for creating a Response Surface design with two response variables, then applying the Multiple Response Optimization function to determine the experimental run at which maximum desirability is achieved.

To Create the Response Surface Designs

1. Choose SPECIAL... EXPERIMENTAL DESIGN... CREATE DESIGN... from the Menu bar to display the Create Design Options dialog box shown in Figure 11-1.

2. Complete the dialog box by choosing the Response Surface design option, entering ***2*** for the number of response variables, accepting the default in the No. of Experimental Factors dialog box, and, optionally, entering a comment about the design in the Comments text box.

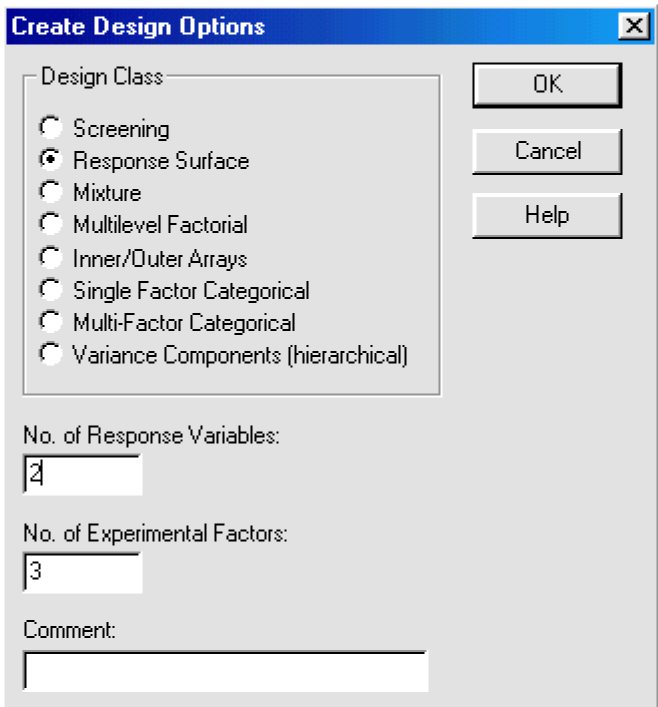


Figure 11-1. Create Design Options Dialog Box (Multiple Response Optimization)

3. Click OK to display the Factor Definition Options dialog box shown in Figure 11-2.

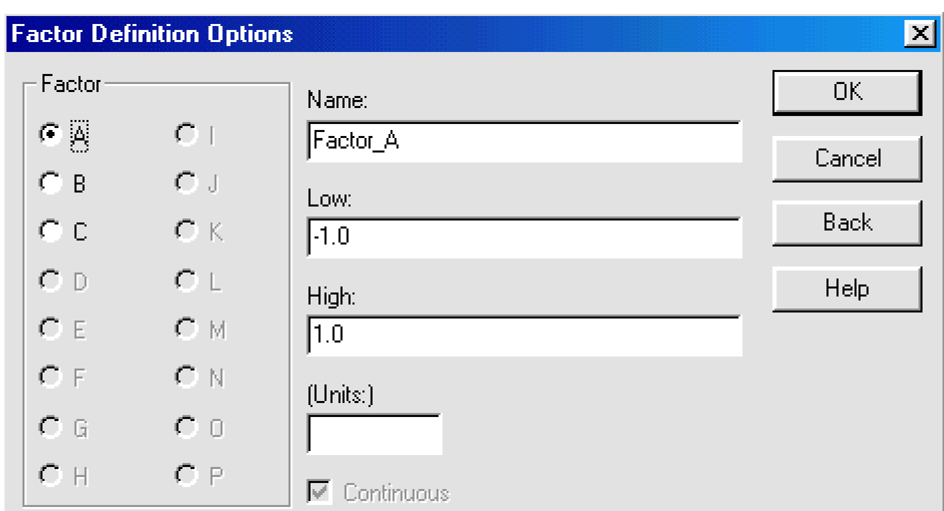


Figure 11-2. Factor Definition Options Dialog Box

4. Complete the dialog box by accepting all the defaults.

5. Click OK to display the Response Definition Options dialog box shown in Figure 11-3.

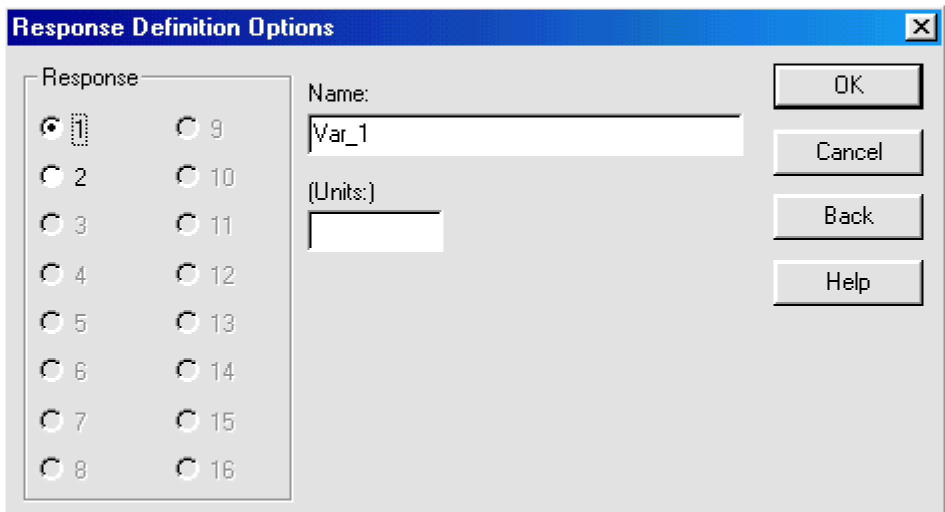


Figure 11-3. Response Definition Options Dialog Box

6. Complete the dialog box by accepting all the defaults.

7. Click OK to display the Response Surface Design Selection dialog box shown in Figure 11-4.

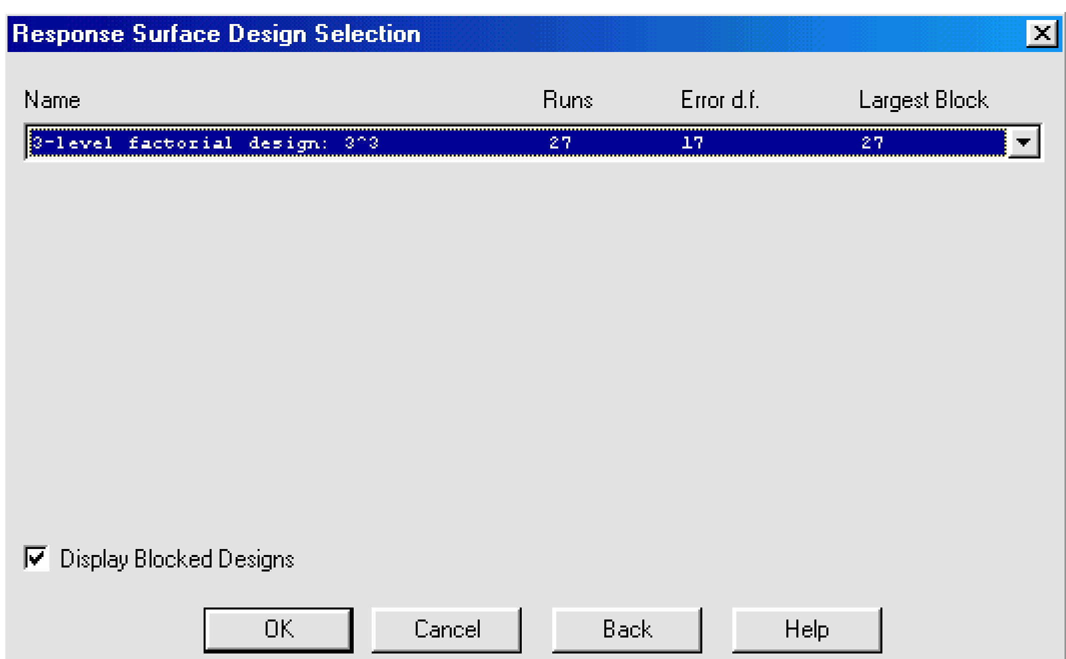


Figure 11-4. Response Surface Design Selection Dialog Box

8. Click the arrow on the right side of the design options and choose the 3-Level Factorial Design (3^3), and accept the other default.

9. Click OK to display the Three-Level Design Options dialog box shown in Figure 11-5.

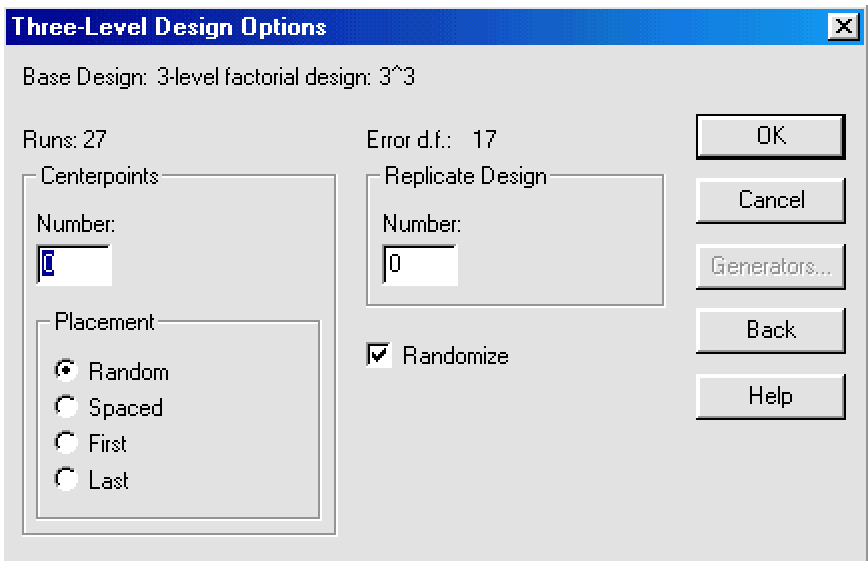


Figure 11-5. Three-Level Design Options Dialog Box

10. Complete the dialog box by accepting all the defaults. Notice that the dialog box provides information about the design you chose.

11. Click OK to place the experimental runs in the DataSheet and the Design Summary in the Design Attributes window shown in Figure 11-6.

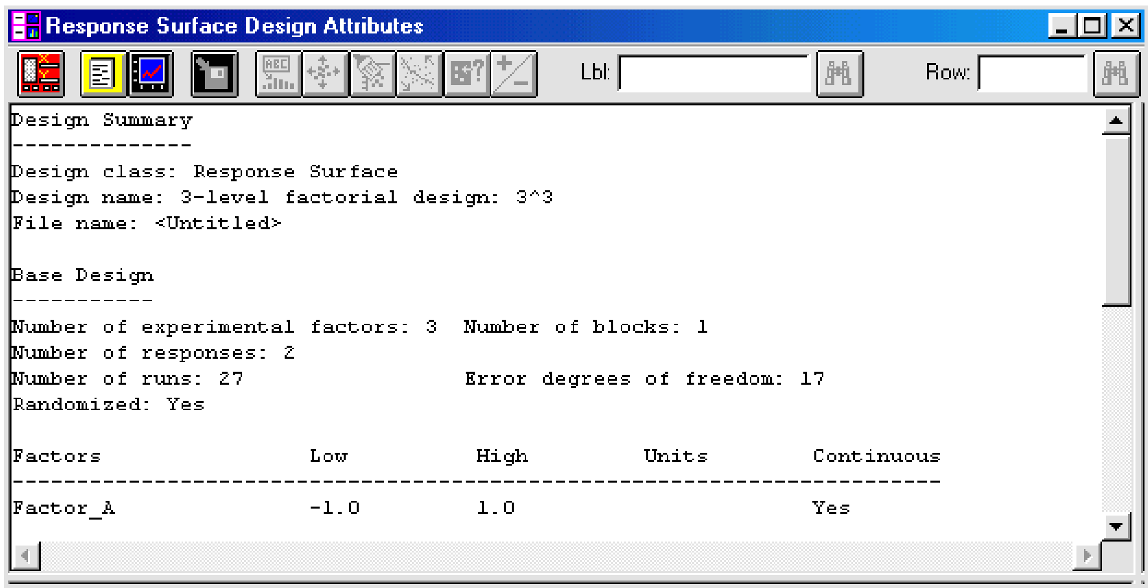


Figure 11-6. Design Summary

12. Click the Tabular Options button on the Analysis toolbar to display the Tabular Options dialog box, then select the Worksheet option and click OK to display the Worksheet in the second text pane of the Design window (see Figure 11-7).

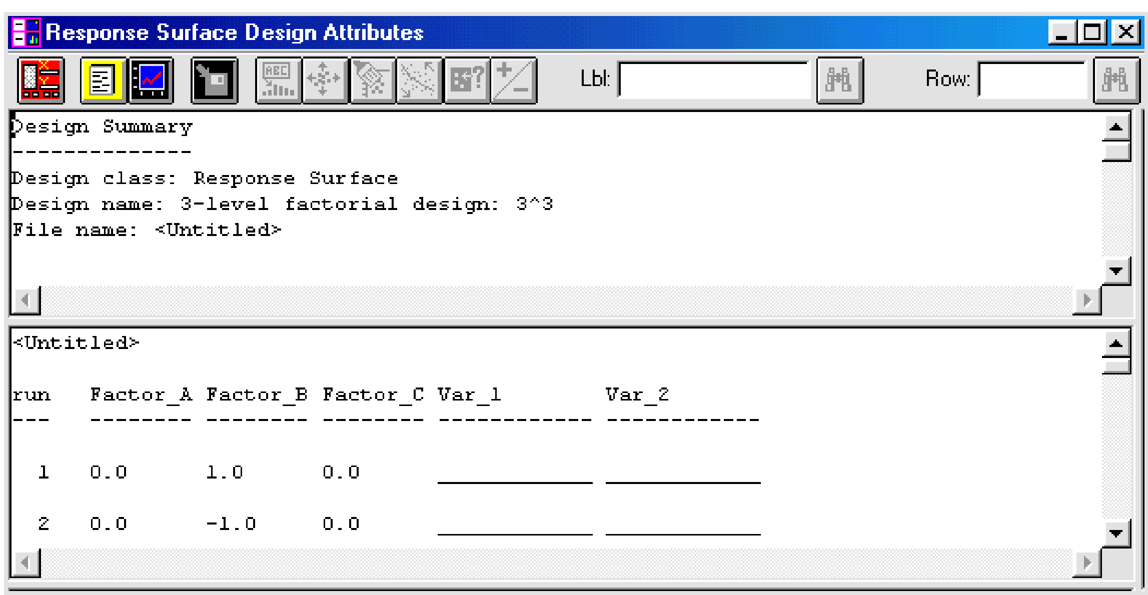


Figure 11-7. Worksheet

13. Maximize the Worksheet, print it, then enter the values for Var_1 into the blank spaces provided.

14. Restore the DataSheet, enter the values for Var_1 into the appropriate column of the DataSheet.

15. Choose SPECIAL... EXPERIMENTAL DESIGN... ANALYZE DESIGN... from the Menu bar to display the Analyze Design dialog box shown in Figure 11-8.

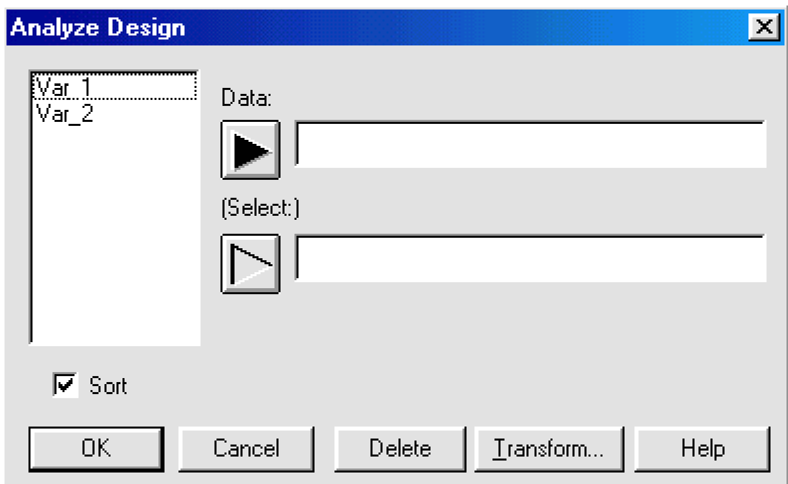


Figure 11-8. Analyze Design Dialog Box

16. Enter ***Var_1*** into the Data text box, then click OK to display the Analysis Summary and the Pareto Chart in the Analysis window shown in Figure 11-9.

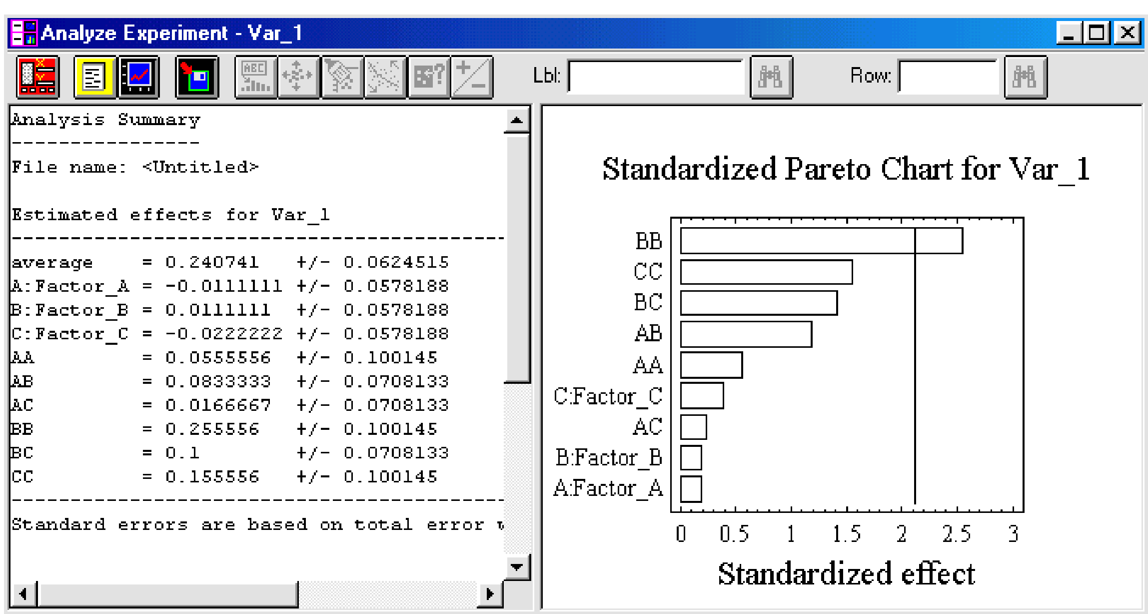


Figure 11-9. Analysis Summary and Pareto Chart in Analysis Window

17. Enter the values for Var_2 into the blank spaces on the Worksheet you printed.

18. Repeat Steps 14, 15, and 16, using Var_2. Leave both of the Analysis windows open.

To Use the Multiple Response Optimization Function

1. Choose SPECIAL... EXPERIMENTAL DESIGN... MULTIPLE RESPONSE OPTIMIZATION from the Menu bar to display the Multiple Response Optimization dialog box.

2. Enter Var_1 and Var_2 into the Responses text box (see Figure Figure 11-10).

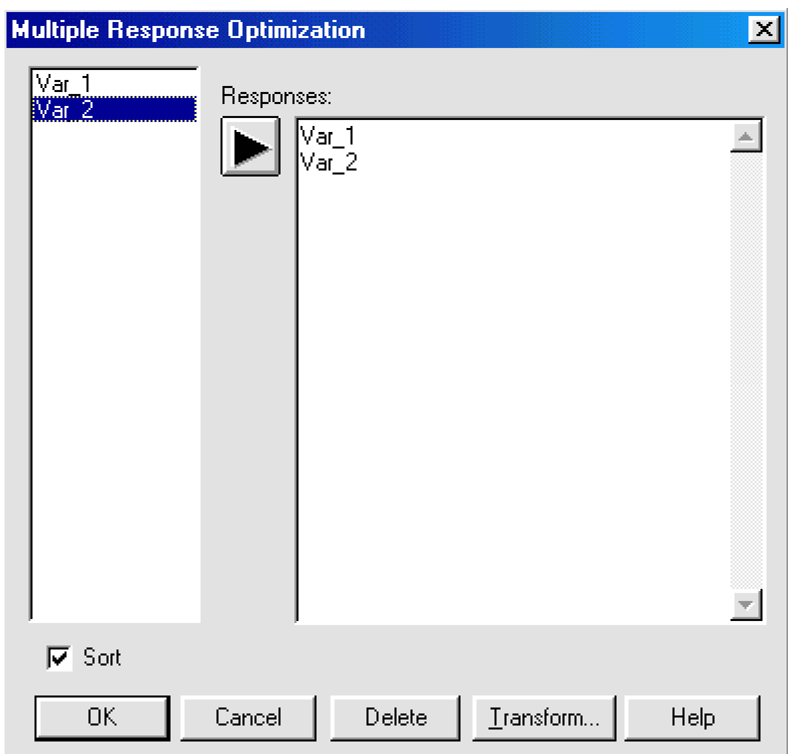


Figure 11-10. Completed Multiple Response Optimization Dialog Box

3. Click OK to display the Multiple Response Optimization window shown in Figure 11-11.

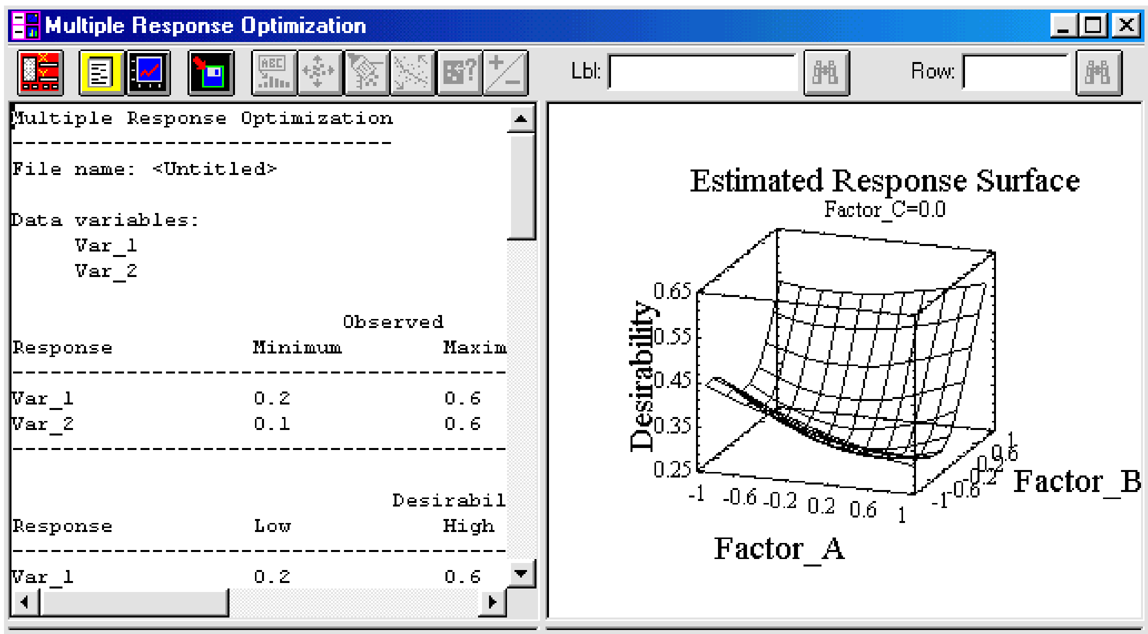


Figure 11-11. Multiple Response Optimization Window

4. Click the Tabular Options button on the Analysis toolbar to display the Tabular Options dialog box, which contains two options: Analysis Summary and Optimize Desirability.

5. Choose the latter option, click OK, then maximize the second pane (see Figure 11-12).

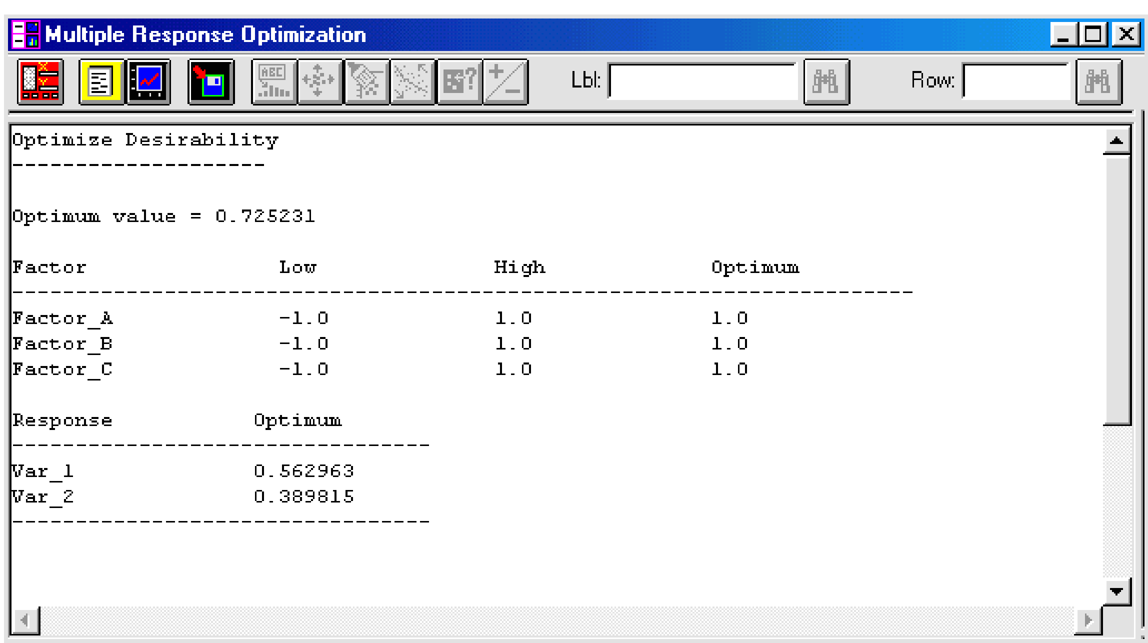


Figure 11-12. Optimize Desirability in Analysis Window

To Further Refine the Optimization

1. Place the mouse pointer on the Optimize Desirability pane, click the right button, then the left on Analysis Options... to display the Multiple Response Optimization Options dialog box shown in Figure 11-13. This dialog box lets you further refine the optimization.

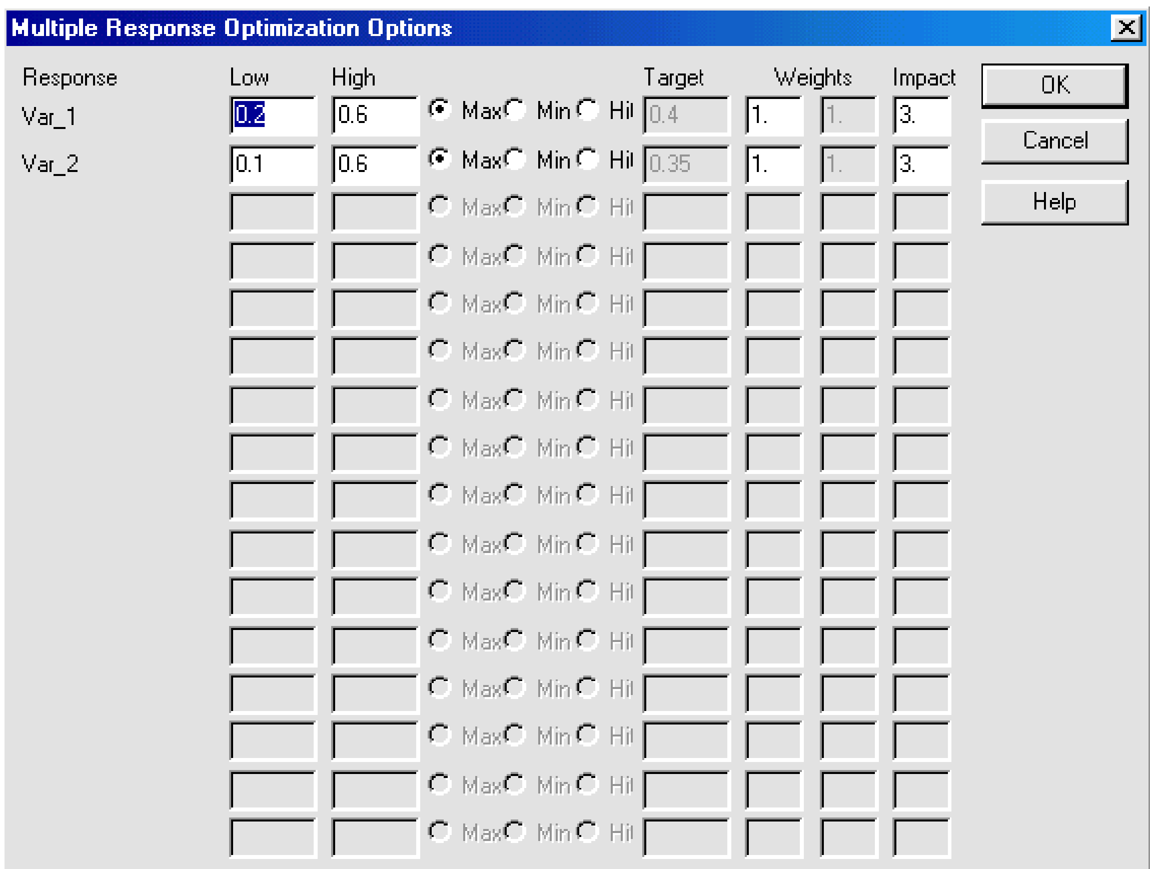


Figure 11-13. Multiple Response Optimization Options Dialog Box

2. Click OK, then place the mouse pointer on the Optimize Desirability pane, click the right button, then the left on Pane Options... to display the Optimize Response Options dialog box shown in Figure 11-14.

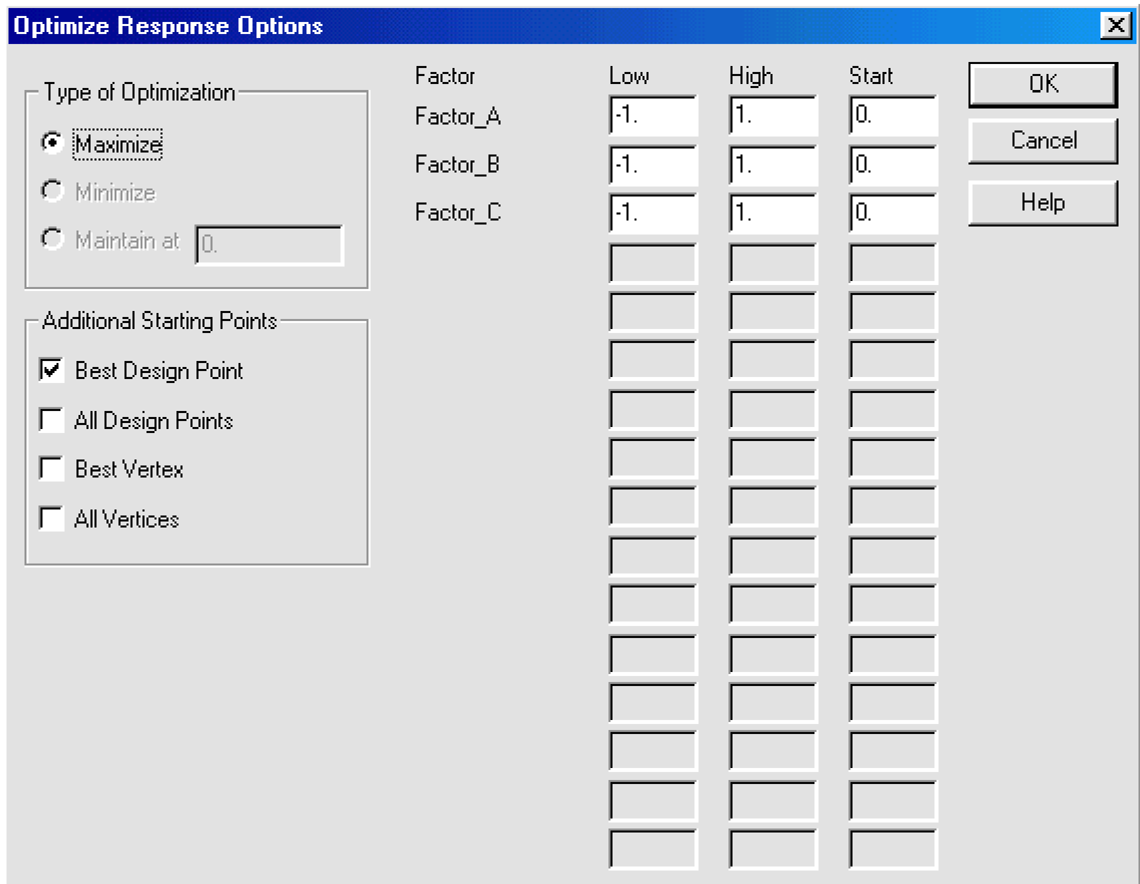


Figure 11-14. Optimize Response Options Dialog Box

This dialog box lets you choose the type of optimization, and set additional starting points for the optimization process.

To Create Plots for the Optimization

1. Click the Graphical Options button on the Analysis toolbar to display the Graphical Options dialog box. The options include two Response plots so you can display both a Response Surface Plot and a Contour Plot simultaneously, as well as Overlaid Contour plots.

Use Pane... options for the Response plots to display the Response Plot Options dialog box shown in Figure 11-15.

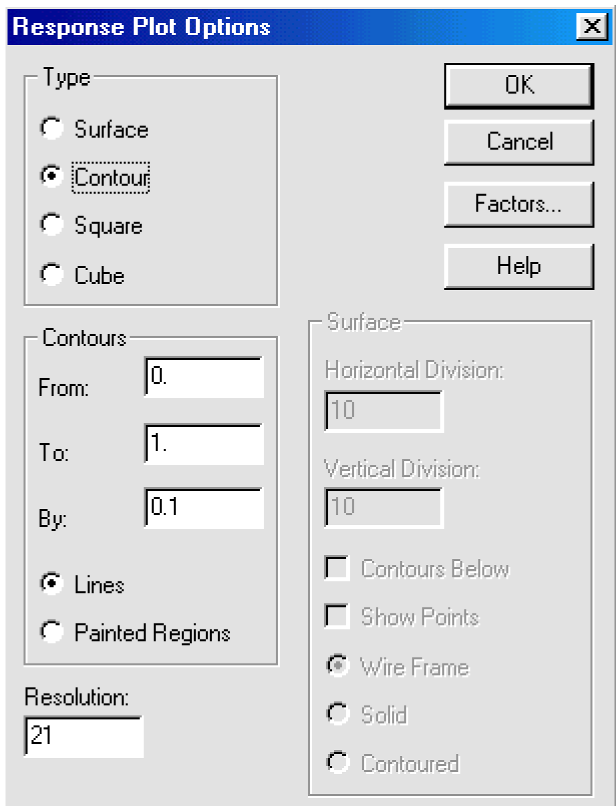


Figure 11-15. Response Plot Options Dialog Box

Use Pane... options for the Overlaid Contour Plots to display the Response Plot Factors dialog box shown in Figure 11-16.

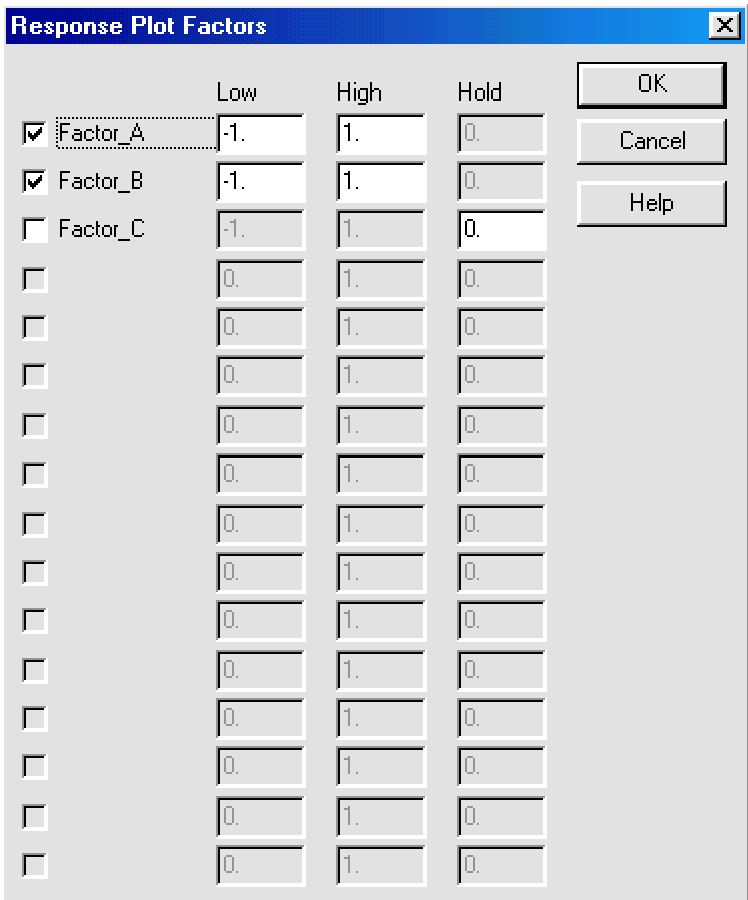


Figure 11-16. Response Plot Factors Dialog Box

For additional information about Response Surface Plots, see the Chapter 8, Using Basic Plots, Using the Response Surface Plots Analysis, in the *User Manual.* You can also find the information in Online Help.

Chapter 12

AUGMENTING DESIGNS

In experimental design, it is usually most effective to estimate the effects of several variables simultaneously when each design contains a certain set of experimental runs. You will not necessarily use a new design for each iteration of experimentation.

Problems arise when it is not clear how you should change an unsatisfactory hypothesis, or when a hypothesis appears satisfactory, but you feel you need further confirmation. Many times the solution is to add more data. To do this, you choose a new experimental design or attach additional experimental runs through augmentation.

The design you choose depends on the hypothesis you are currently using. The design should allow you to explore areas for which you lack information, and should add greater significance to the study. For example, you may want to augment a design to:

- clear main effects so the effects of certain interactions are not confounded
- obtain results that are more conclusive
- remove (collapse) a factor that does not have a significant effect on the response
- add star points to a design to create a central composite design for estimating quadratic terms.

STATGRAPHICS *Plus* provides capabilities that allow you to add experimental runs to an existing design. The program adds the runs to the original design (the base set of runs), and typically places the added runs in a new block.

Before you begin the augmentation, open STATGRAPHICS *Plus*, then open a design file.

To Open a Design File

1. Choose SPECIAL... EXPERIMENTAL DESIGN... OPEN DESIGN... from the Menu bar to display the Open Experiment Files dialog box.

2. Enter the name of the design file into the File Name text box to load the data.

Using Augment Design Actions

The remainder of this section explains each of the augment actions, takes you through the steps required for augmenting a design, and details the available tabular and graphical options. In-depth explanations of the options on the dialog boxes appear in Online Help.

Depending on the action you choose and the design you are using, the program may display options dialog boxes for you to complete. For example, when you choose the Replicate Design action and click OK, the Replicate Design dialog box displays, which you use to enter the number of complete replicates you want to add to the original design.

If the action does not require you to complete more dialog boxes, the design is augmented and the results displayed in the Design Attributes window. The following actions are available from the Augment Design menu: Replicate Design, Add a Fraction, Collapse Design, Clear Main Effects, Clear a Factor, and Add Star Points. The type of design you are using determines the action you use.

Replicate Design
This action replicates an entire design, including its centerpoints and block structure. When you replicate a design, each replicate is placed in its own block. If you are using a User-Specified design, all the runs in the design will be replicated.

To Replicate a Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... AUGMENT DESIGN... from the Menu bar to display the Augment Design dialog box shown in Figure 12-1.

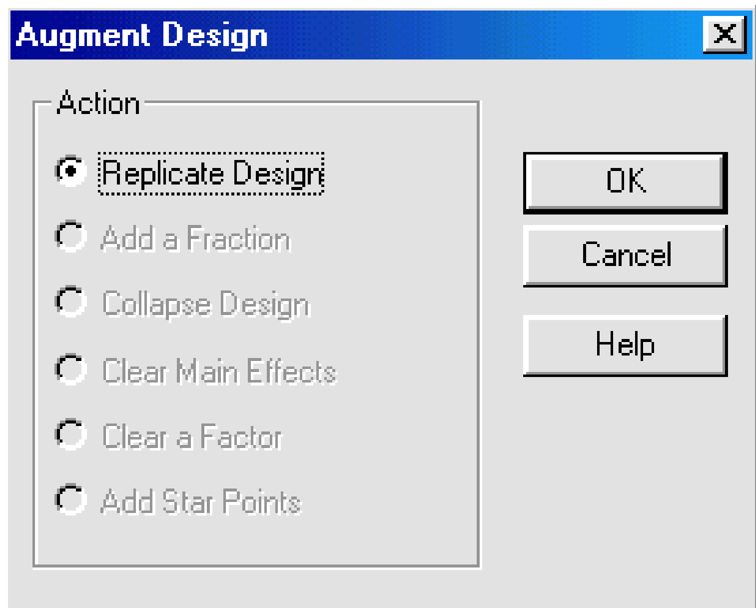


Figure 12-1. Augment Design Dialog Box

2. Choose the Replicate Design option, then click OK to display the Replicate Design dialog box shown in Figure 12-2.

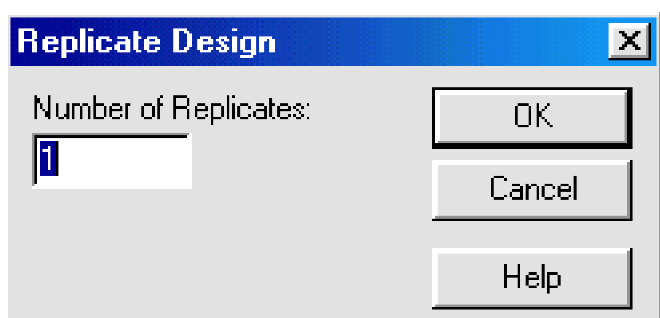


Figure 12-2. Replicate Design Dialog Box

3. Enter a positive integer into the Number of Replicates text box to indicate the number of times the design will be replicated.

4. Click OK to display the Design Summary in the Design Attributes window. *See the section, Choosing Tabular Options, later in this chapter for a description of a Design Summary.*

Add a Fraction

This action adds a fraction to the design, which removes all confounding of main effects from second-order interactions in a resolution III design. The new runs are added to the design in a way that clears the main effects from confounding and produces a resolution IV design.

To Add a Fraction to a Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... AUGMENT DESIGN... from the Menu bar to display the Augment Design dialog box.

2. Choose the Add a Fraction option, then click OK to perform the augmentation and display the results in the Design Summary in the Design Attributes window. *See the section, Choosing Tabular Options, later in this chapter for a description of a Design Summary.*

Collapse Design

This action removes a single factor from a factorial design. The design that results is less fractioned, and may be a replicate of the original design.

To Collapse a Design

1. Choose SPECIAL... EXPERIMENTAL DESIGN... AUGMENT DESIGN... from the Menu bar to display the Augment Design dialog box.

2. Choose the Collapse Design option, then click OK to display the Collapse Design dialog box shown in Figure 12-3.

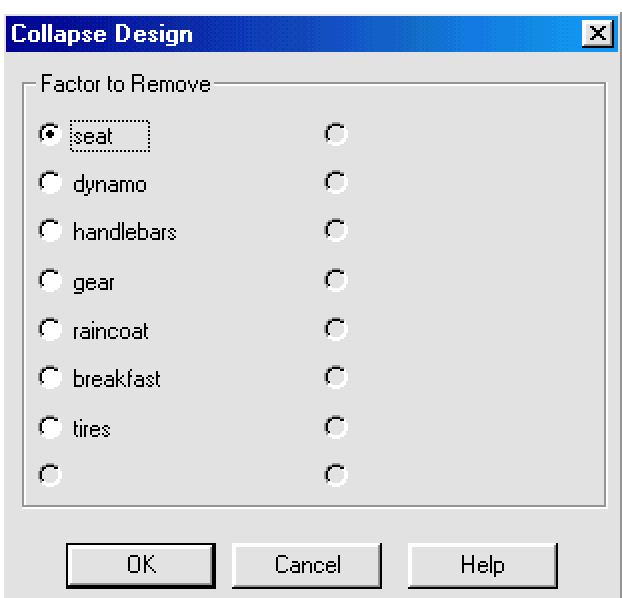


Figure 12-3. Collapse Design Dialog Box

3. Complete the dialog box by choosing one of the listed factors.

4. Click OK to remove the factor from the design and display the results in the Design Summary in the Design Attributes window. *See the section,* *Choosing Tabular Options, later in this chapter for a description of a Design Summary.*

Clear Main Effects

This action is similar to the Foldover Design action in that it removes confounding of all main effects from second-order interactions in a resolution III design. The difference is that this action always produces a resolution IV design.

The Clear Main Effects action does not allow you to add a new factor. If the original design was unblocked, the additional runs are added in a new block. If the original design was a blocked design, the additional runs follow the same block structure, which doubles the number of blocks.

To Clear Main Effects

1. Choose SPECIAL... EXPERIMENTAL DESIGN... AUGMENT DESIGN... from the Menu bar to display the Augment Design dialog box.
2. Choose the Clear Main Effects option, then click OK to add the additional run in a new block and display results in the Design Summary in the Design Attributes window. *See the section, Choosing Tabular Options, later in this chapter for a description of a Design Summary.*

Clear a Factor

This action clears all confounding of a factor with other effects; that is, all the interactions that include that factor. When you clear a factor, the main effect and its interactions appear without confounding. The program adds runs that contain reversed factor levels (for the factor you select), and unchanged factor levels for all the other factors, which doubles the number of runs in the design.

To Clear a Factor

1. Choose SPECIAL... EXPERIMENTAL DESIGN... AUGMENT DESIGN... from the Menu bar to display the Augment Design dialog box.

2. Choose the Clear a Factor option, then click OK to display the dialog box shown in Figure 12-4.

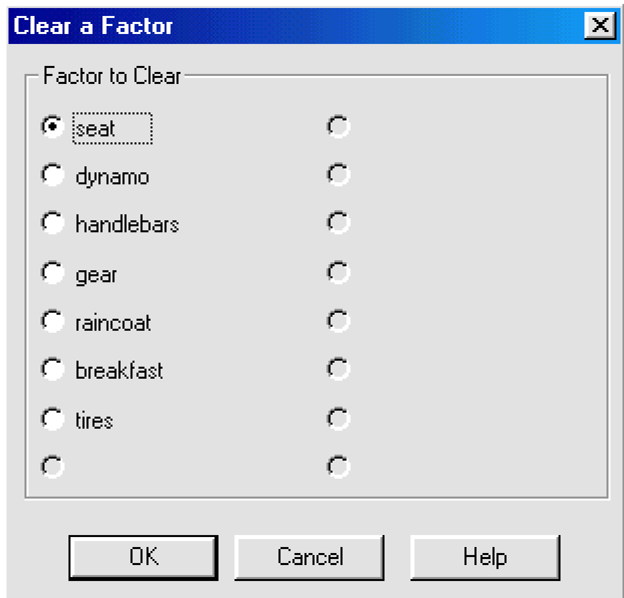


Figure 12-4. Clear a Factor Dialog Box

3. Complete the dialog box by choosing one of the listed factors.

4. Click OK to add the additional runs to the design, clear the factor from the design, and display the results in the Design Summary in the Design Attributes window. *See the section, Choosing Tabular Options, later in this chapter for a description of a Design Summary.*

Add Star Points

This action adds star points to a Screening design to create a central composite design. The program calculates the axial distance, based on the number of star points and the number of base points in the base design, and creates a design that is orthogonally blocked.

To Add Star Points

1. Choose SPECIAL... EXPERIMENTAL DESIGN... AUGMENT DESIGN... from the Menu bar to display the Augment Design dialog box.

2. Choose the Add Star Points option, then click OK to add the runs to the design and display the results in the Design Summary in the Design Attributes window. *See the section, Choosing Tabular Options, later in this chapter for a description of a Design Summary.*

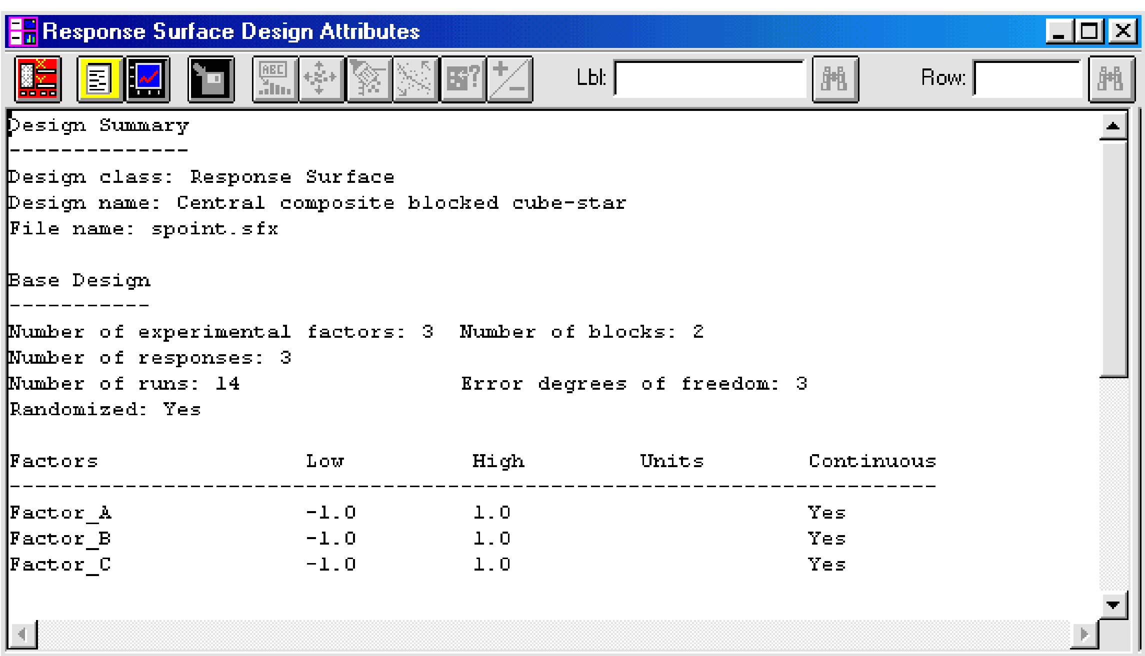
Choosing Tabular Options for Augmenting a Design

Several report options are available to describe the results of the augmentation. Not all of the options are available for every design class. For example, if you are augmenting a Mixture design, the Alias Structure tabular option is not available, while for another design class it might be.

The tabular options that always display are described next. The descriptions of the options are the same, regardless of the design class you use.

Design Summary

The Design Summary option displays a summary of the augmented design (see Figure 12-5). The summary information includes the design class, design name, file name, and any comments you entered on the Create Design dialog box. Other information about the base design includes the number of experimental factors, blocks, response variables, centerpoints per block, runs, and the error degrees of freedom. Tables at the bottom of the summary display information about the factors and responses.

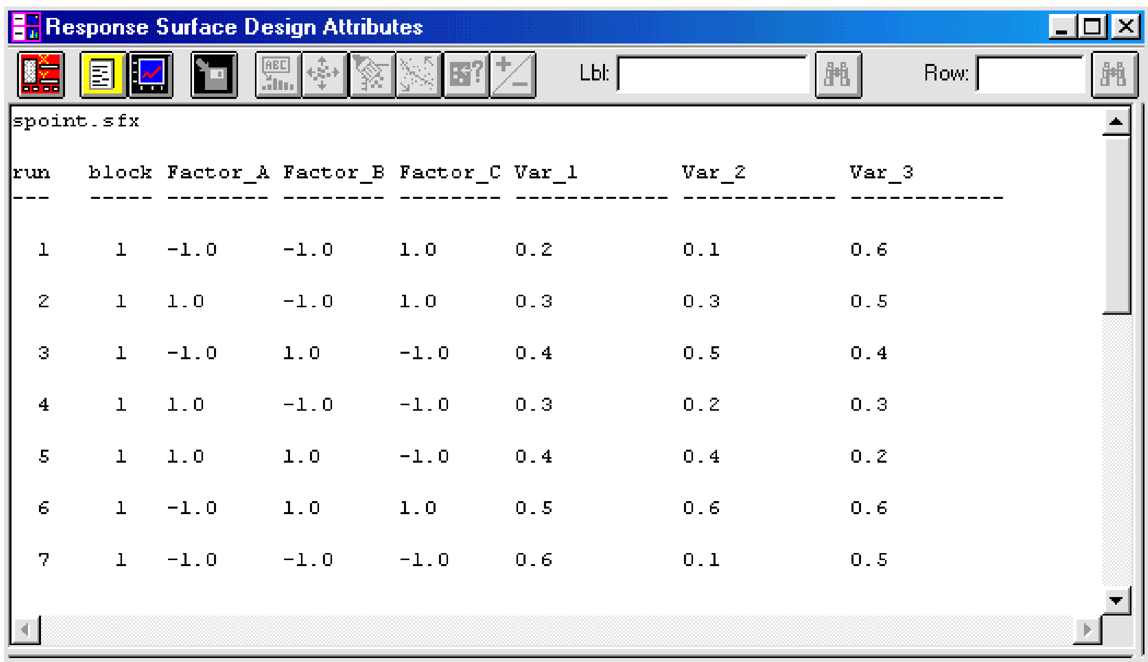



```
Design Summary
--------------
Design class: Response Surface
Design name: Central composite blocked cube-star
File name: spoint.sfx

Base Design
-----------
Number of experimental factors: 3  Number of blocks: 2
Number of responses: 3
Number of runs: 14                 Error degrees of freedom: 3
Randomized: Yes

Factors                Low         High        Units        Continuous
-----------------------------------------------------------------------
Factor_A               -1.0        1.0                      Yes
Factor_B               -1.0        1.0                      Yes
Factor_C               -1.0        1.0                      Yes
```

Figure 12-5. Design Summary

Worksheet

The Worksheet option displays a Worksheet that contains the experimental runs that will be performed, as well as the order in which you should run them (see Figure 12-6).



spoint.sfx

run	block	Factor_A	Factor_B	Factor_C	Var_1	Var_2	Var_3
1	1	-1.0	-1.0	1.0	0.2	0.1	0.6
2	1	1.0	-1.0	1.0	0.3	0.3	0.5
3	1	-1.0	1.0	-1.0	0.4	0.5	0.4
4	1	1.0	-1.0	-1.0	0.3	0.2	0.3
5	1	1.0	1.0	-1.0	0.4	0.4	0.2
6	1	-1.0	1.0	1.0	0.5	0.6	0.6
7	1	-1.0	-1.0	-1.0	0.6	0.1	0.5

Figure 12-6. Worksheet

Print the Worksheet to record the information, then write or type in the values for the responses in the blank spaces provided. Restore the DataSheet and enter the values into the appropriate column(s) of the DataSheet, then analyze the design.

Use the *Worksheet Options* dialog box to choose the spacing between the runs for the Worksheet, to enter values for the starting and ending rows, and to choose the response variables that will be included (see Figure 12-7).

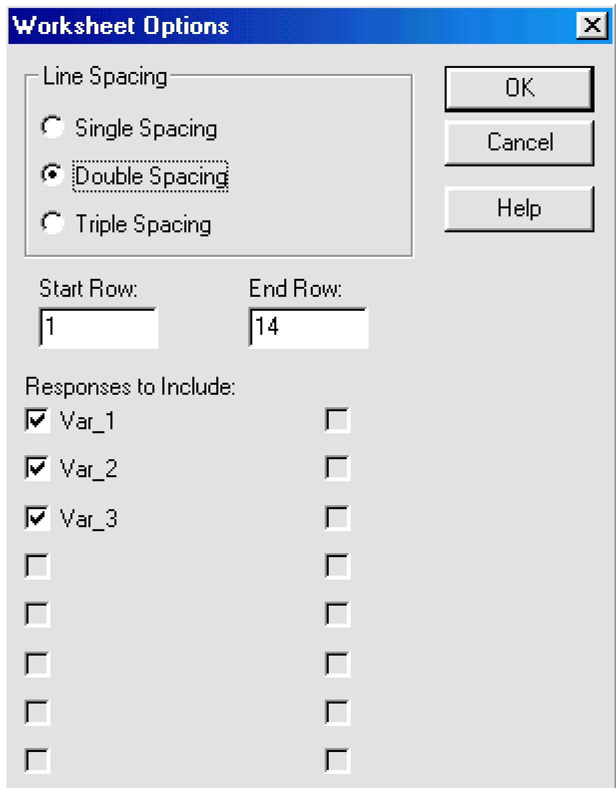


Figure 12-7. Worksheet Options Dialog Box

Alias Structure
Note: This option is not available for Mixture designs.

The Alias Structure option creates the alias pattern for the design (see Figure 12-8). The alias pattern shows the main effects, interactions, and any confounding that involves the main effects and interactions.

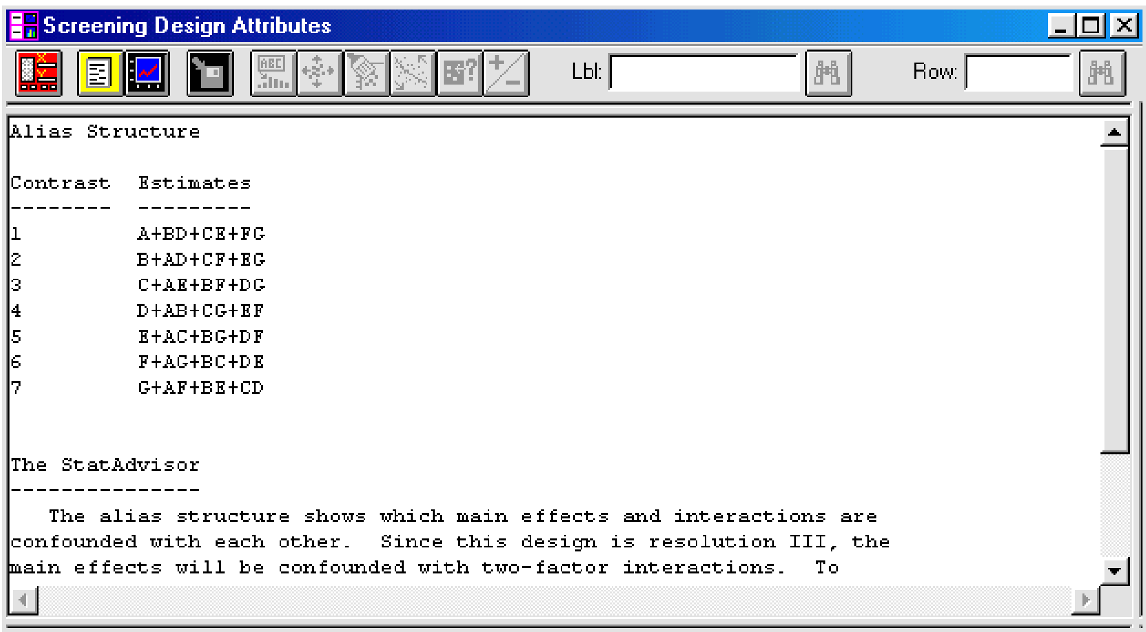


Figure 12-8. Alias Structure

If main effects and second-order interactions are clear of confounding, an appropriate message displays. Confounded effects are joined by a plus sign; for example, A + BC indicates that the main effect, A, is confounded with the two-factor interaction, BC.

Use the *Alias Structure Options* dialog box to enter a number for the highest-order interaction; these are the highest-order interactions shown in the report (see Figure 12-9). Enter any poisitive integer, up to the number of factors in the design.

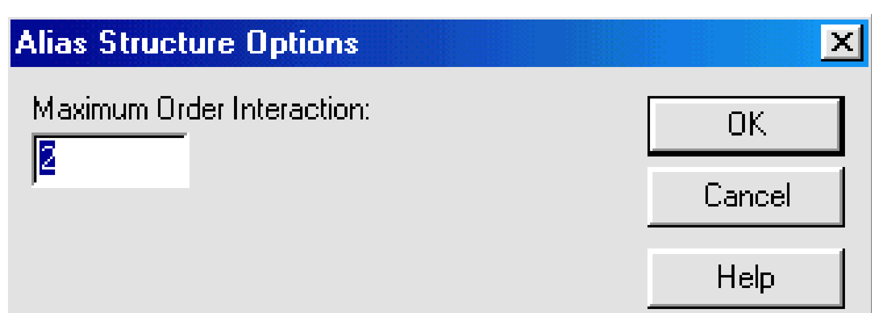
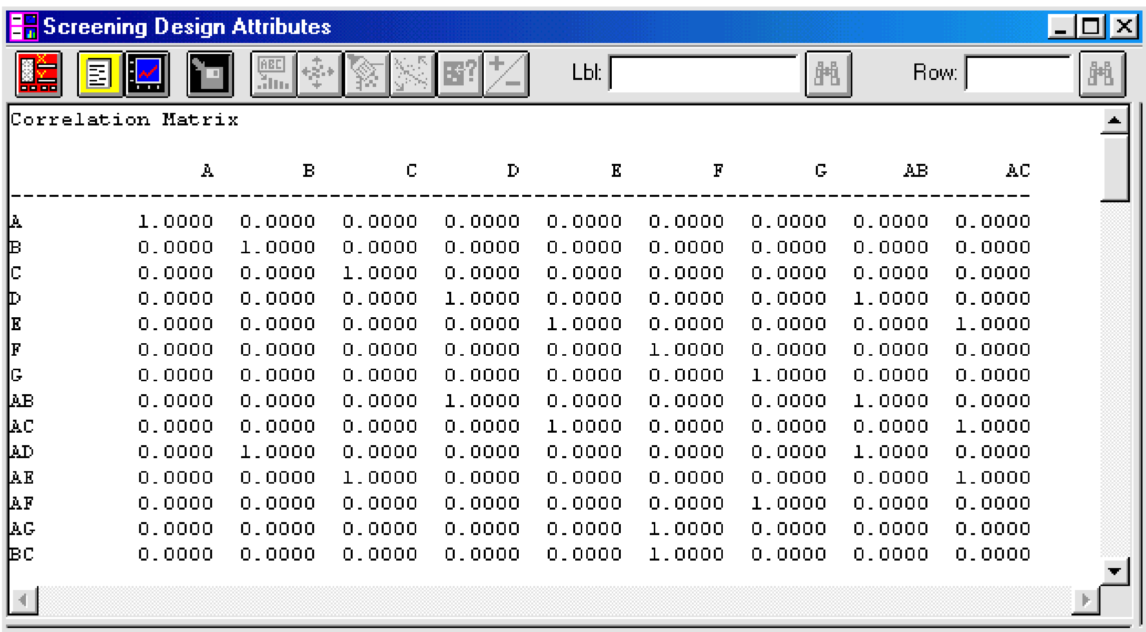


Figure 12-9. Alias Structure Options Dialog Box

Correlation Matrix
The Correlation Matrix option displays a correlation matrix for all the factor and interaction effects, based on the actual design matrix (see Figure 12-10).



	A	B	C	D	E	F	G	AB	AC
A	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
E	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
F	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
AB	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
AC	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
AD	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
AE	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
AF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
AG	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
BC	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000

Figure 12-10. Correlation Matrix

Use the *Correlation Matrix Options* dialog box to enter a number that will determine the highest-order effects that will display (see Figure 12-11). Enter a positive integer, up to the number of factors in the design.

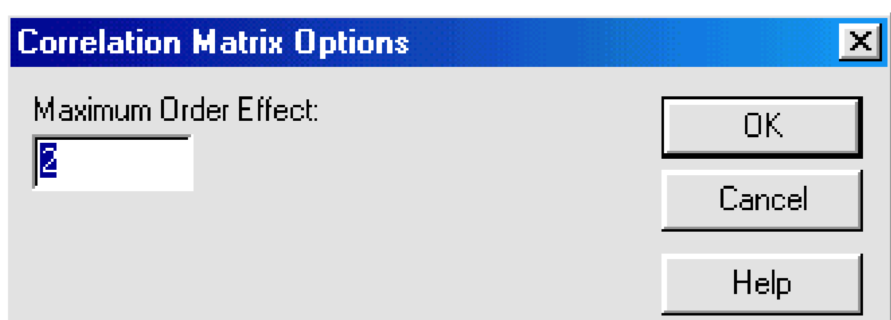


Figure 12-11. Correlation Matrix Options Dialog Box

Choosing Graphical Options for Augmenting a Design

Note: This action is available only for Screening designs.

The Power Curve option creates a plot that determines whether or not an experiment can detect effects of the magnitude you expect (see Figure 12-12).

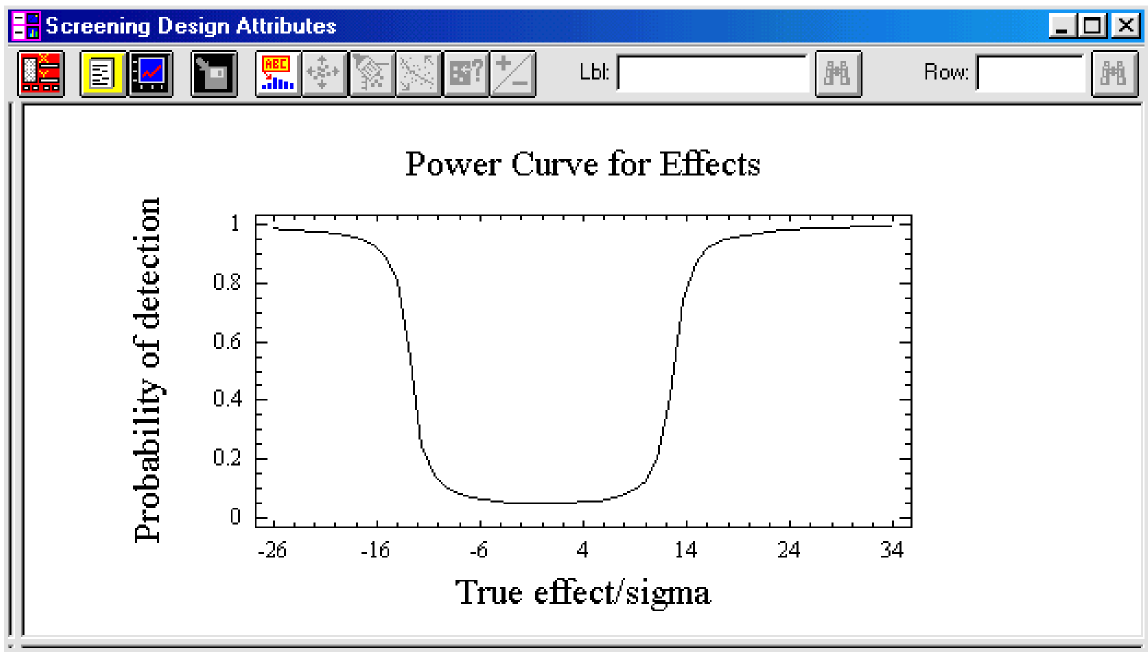


Figure 12-12. Power Curve

Use the *Power Curve Options* dialog box to change the number of degrees of freedom for the error, and to enter a number for the alpha risk (see Figure 12-13). The alpha risk determines the probability of declaring an effect significant when, in fact, it is not.

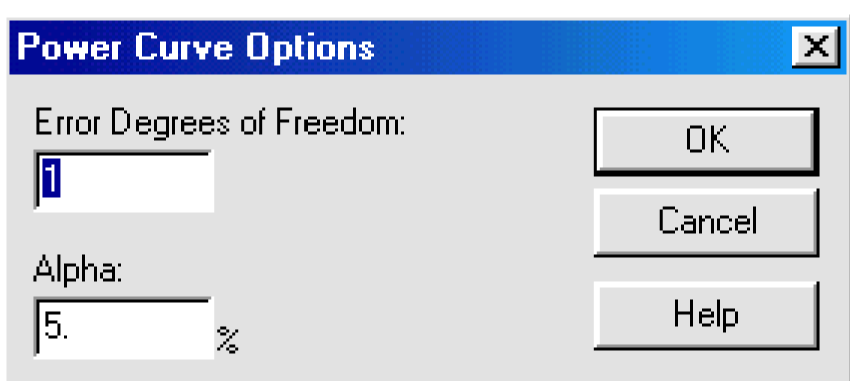


Figure 12-13. Power Curve Options Dialog Box

References

Box, G. E. P., Hunter, W. G., and Hunter, J. S. 1978. *Statistics for Experimenters*. New York: Wiley.