WL-TM-96-3096

STRUCTURAL INTEGRITY ANALYSIS AND VERIFICATION OF AIRCRAFT STRUCTURES

S. Krishnan, K.L. Boyd

Analytical Services and Materials, Inc.
107 Research Drive
Hampton, Virginia 23666

J.A. Harter

Wright Laboratory
2130 Eight Street, Suite 1
Wright-Patterson AFB, OH 45433-7542

AFGROW User's Manual: Version 3.0.4

Final report for period October, 1994 - July, 1995.

August, 1995

Approved for public release; distribution is unlimited

FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AFB, OHIO 45433-7542

NOTICE

USING GOVERNMENT DRAWINGS, SPECIFICATIONS, OR OTHER DATA INCLUDED IN THIS DOCUMENT FOR ANY PURPOSE OTHER THAN GOVERNMENT PROCUREMENT DOES NOT IN ANY WAY OBLIGATE THE US GOVERENMENT. THE FACT THAT THE GOVERNMENT FORMULATED OR SUPPLIED THE DRAWINGS, SPECIFICATIONS, OR THER DATA DOES NOT LICENSE THE HOLDER OR ANY OTHER PERSON OR CORPORATION; OR CONVEY ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE, OR SELL ANY PATENTED INVENTION THAT MAY RELATE TO THEM.

THIS REPORT IS RELEASABLE TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS). AT NTIS, IT WILL BE AVAILABLE TO THE GENERAL PUBLIC, INCLUDING FOREIGN NATIONS.

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

JOHN S. BROOKS
TEAM LEADER
STRUCTURAL INTEGRITY BRANCH

JAMES A. HARTER
AEROSPACE ENGINEER
STRUCTURAL INTEGRITY BRANCH

JOHN T. ACH
BRANCH CHIEF
STRUCTURAL INTEGRITY BRANCH

IF YOUR ADDRESS HAS CHANGED, IF YOU WISH TO BE REMOVED FROM OUR MAILING LIST, OR IF THE ADDRESSEE IS NO LONGER EMPLOYED BY YOUR ORGANIZATION, PLEASE NOTIFY WL/FIBE, BLDG 65, 2790 D ST., ROOM 504, WRIGHT-PATTERSON AFB OH 45433-7402 TO HELP MAINTAIN A CURRENT MAILING LIST.

Do not return copies of this report unless contractual obligations or notice on a specific document requires its return.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1995	Final 07/01/95--10/3/95

4. TITLE AND SUBTITLE
Structural Integrity Analysis and Verification of Aircraft Structures AFGROW User's Manual: Version 3.0.4

5. FUNDING NUMBERS
C F33615-94-D-3212
PE 62201
PR 2401
TA LE
WU 00

6. AUTHOR(S)
S. Krishnan, K.L. Boyd: Analytical Services and Materials, Inc., J.A. Harter: WL/FIBE

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Analytical Services and Materials, Inc.
107 Research Drive
Hampton VA 23666

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Flight Dynamics Directorate
Wright Laboratory
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7562
POC: J. Brooks, WL/FIBE, (937) 255-6104 x 233

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
WL-TM-96-3096

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution is Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

AFGROW is a workstation-based, graphically interactive computer program for simulation of fatigue crack growth in various structural geometries subject to spectral loading. It is a highly flexible code utilizing standard user-interface objects, such as push-buttons and menus, to create a simple and intuitive environment for the fracture mechanics analyst. The program insulates the user from the complexities of data files and their formats by performing all file creation, retrieval and management tasks. AFGROW is a direct descendent of the computer code, MODGRO, with many changes and new capabilities completely rewritten in C computer language. AFGROW takes the best features of its predecessors and combines them with new ideas into a single, manageable code. Some of the more useful features of AFGROW include the ability to use a material database library for crack growth rate and mechanical property data, an option to approximate stress intensity factor solutions for arbitrary stress fields, and the ability to import stress spectra of virtually any size.

This manual describes the features and capabilities of AFGROW and the use of the Graphical User Interface (GUI) to define problems and perform analyses. The various files used in AFGROW, their naming conventions and file formats are presented. The user-interface, with all menu options and dialogs, is included, as well as instructions on obtaining AFGROW via anonymous file transfer protocol (FTP). The tutorial describes the steps involved in setting up and analyzing an example problem.

14. SUBJECT TERMS	15. NUMBER OF PAGES
AFGROW; MODGRO; fatigue crack growth; fracture mechanics; stress intensity factor; linear elastic fracture mechanics; AFGROW user's manual	66
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

CONTENTS

LIST OF FIGURES

FOREWORD

This user's manual was prepared by Analytical Services & Materials, Inc., Hampton,Virginia, for the Wright Laboratory Structural Integrity Branch, Wright-Patterson Air Force Base, Ohio, under contract F33615-94-D-3212, "Structural Integrity Analysis and Verification for Aircraft Structures." It documents methods and procedures for the use of the fatigue-crack-growth computer program AFGROW. The contract monitor was James A. Harter. The period of performance for this report was October 1994 through July 1995.

The work that contributed to this user's guide (Delivery Order 0001 and 0003) was performed by Analytical Services & Materials, Inc. personnel located at the WL/FIBE Fatigue & Fracture Test Facility, Bldg. 65, Area B, Wright-Patterson AFB, OH. This report was authored by Srinivas Krishnan, James A. Harter and Kevin L. Boyd.

1. INTRODUCTION

AFGROW is a workstation-based, graphically interactive computer program for simulation of fatigue crack growth in common structures subject to spectral loading. It is a highly flexible code that utilizes standard user-interface objects, such as push-buttons and menus, to create a simple and intuitive environment for the fracture mechanics analyst. The program insulates the user from the complexities of data files and their formats by performing all file creation, retrieval and management tasks. The following sections contain descriptions of the various features of AFGROW and instructions on their use.

AFGROW is a direct descendant of the computer code, MODGRO[1], which was created by James Harter in 1986. In its initial form, it consisted of BASIC code running under DOS. The code has since seen many changes and new capabilities, culminating in the creation of AFGROW, which was completely rewritten in C computer language.

Over the years, many crack growth computer codes (CRACKS, CRKGRO, etc.) have been written to analyze fatigue crack propagation. Most successful programs have undergone modifications and have become large and unwieldy. This is largely because the variety of common crack growth problems facing the engineer demands flexibility in solutions and analysis methods. AFGROW takes the best features of many of its predecessors and combines them with some new ideas in a single, manageable code. In this sense, AFGROW represents a significant stage in the evolution of fatigue crack growth programs.

Some of the more useful features of AFGROW include the ability to use a material database library for crack growth rate and mechanical property data, an option to approximate stress intensity factor solutions for arbitrary stress fields, and the ability to import stress spectra of virtually any size.

The stress intensity factor (SIF) calculations in AFGROW are based on the concepts of linear elastic fracture mechanics (LEFM). For most structural configurations these are determined based on closed-form solutions[2,3] built into the code. The exceptions are the user-defined configurations, for which the SIF values for different crack lengths are obtained from an external source and specified by the user.

The workstation-based version of AFGROW (v3.0.4) contains many features that represent a considerable enhancement over the older PC-based version (v2.0). Some of the more significant features include completely upgraded graphical user interface (GUI) with file management capability, visualization and plotting of crack growth in real-time, new beta correction capability, user-defined specimen configurations, updated material property data with extensions to environmental data (including transition from lab air to environment) and modification of SIF solutions due to residual stresses. Version 3.0.4 also includes complete on-line graphical help facilities. This user's manual will contain much of the information included within the on-line help facility, as well as more in-depth information and examples.

The scope of this manual is limited to a description of the features and capabilities available in AFGROW and the use of the GUI to define problems and perform analyses. A more detailed description of the formulation of the equations used and fracture mechanics theory is contained in the MODGRO User's Manual.

The primary development environment for AFGROW has been IRIX 5.2 on a Silicon Graphics Indigo2 workstation. It has also been ported to Solaris 2.3 (Sun) and Linux 1.1 (PC). The AFGROW source code is written in C, using Motif and X11 libraries for the GUI.

A description of the various files used in AFGROW, their naming conventions and file formats, is contained in Chapter 2. The user-interface is described in Chapter 3, with sections describing all the menu options and dialogs. Chapter 4 is a brief tutorial on the use of AFGROW, describing the steps involved in setting up and analyzing an example problem.

Appendix A contains formats of all types of files used by AFGROW. Instructions on how to obtain AFGROW via anonymous ftp are contained in Appendix B.

2. AFGROW FILES

This section describes the different types of files generated or used by AFGROW. In most cases, the user does not need to know the formats of the files. File creation is handled internally in AFGROW. In some instances, the need may arise to generate external files for use by AFGROW, as in the case of large load spectra. For this reason, a detailed description of the file formats is presented in Appendix A.

The external creation of files, using editors or other programs, is not encouraged and should be avoided as far as possible except, as noted above, in cases where large load spectra are required. In these cases, file formats in Appendix A must be adhered to strictly.

2.1 The Application Defaults File

This file, called ***af_def***, controls the appearance of the graphical user-interface. It is used to set the default colors, fonts and certain other attributes of the AFGROW windows. While not essential to the functionality of the program, it is highly advisable to use this file since AFGROW will accept the host system's defaults in its absence, affecting the usability of the program in some cases.

The application defaults file is distributed with the AFGROW binary and must be present on the host machine at run-time. It may reside in any directory provided the appropriate "read"

permissions are set. For example, AFGROW may be installed in a directory called */usr/afgrow* and *af_def* may reside in */usr/afgrow/app_defaults*. Prior to execution of AFGROW, the system must be told where to locate the application defaults file. This is accomplished by typing the following command:

```
setenv XENVIRONMENT /usr/afgrow/app_defaults/af_def
```

Note that the pathname in the above command is for the example cited and will vary according to the location of the application defaults file on the host machine. This command may also be inserted in the user's "*.cshrc*" file (or equivalent) so it is executed automatically, eliminating the need to explicitly invoke it.

2.2 AFGROW Input Files

**.da3* Files

These files contain all information required to define a crack propagation problem, except for spectrum information, which is contained in its own files, and certain control parameters, which will be described later in this section. The user may create a **.da3* file at any time during AFGROW execution by saving the current problem definition to a file. This file may then be opened during any subsequent execution of AFGROW to retrieve that information to the program's problem definition. These operations will be explained in detail in Chapter 3.

The file-naming convention followed in AFGROW requires that input files have a ".da*" extension. The "*" after the "da" refers to the AFGROW version number. For example "*dogbone.da3*" would refer to a file that is compatible with AFGROW version 3.0 or any of

its releases. This is to ensure that errors do not arise due to the use of older files with newer versions of AFGROW.

Input files contain information such as problem title, specimen geometry and dimensions, crack configuration, material properties, retardation information, environment types and locations, etc. Since AFGROW handles both file creation and retrieval, the user does not need to know the file formats. These, however, are presented as a reference in Appendix A.

2.3 AFGROW Spectrum Files

Stress or load spectra in AFGROW are contained in base spectrum files and subspectrum files. These files can be created interactively using AFGROW. However, it may not be practical for the user to create these files manually due to the large size of typical spectra used in fatigue crack growth analyses. In these cases, the user may wish to use an external program that generates the spectrum files. These files are described in Sections 2.3.1 and 2.3.2, and their formats are presented in Appendix A.

2.3.1 Base Spectrum Files

**.sp3* Files

Files with a ".sp3" extension contain spectrum information for AFGROW v3.0. A complete spectrum in AFGROW consists of one base spectrum file and one or more subspectrum files, which will be covered in Section 2.3.2. The base spectrum file contains only the spectrum title, a label to be associated with the spectrum, the type of spectrum (blocked or cycle-by-

cycle) and the number of subspectrum files that make up the spectrum. The stress/load values themselves are contained in the subspectrum files. All reference to a particular spectrum in AFGROW is through the base spectrum filename. The program locates the subspectrum files automatically since the subspectrum filenames are derived from the base filename, as described in the next section.

2.3.2 Subspectrum Files

**.sub* Files

The subspectrum files contain the actual stress or load levels and cycle counts that make up the spectrum. Their filenames are based on the filename of the base spectrum file that defines the spectrum. The name of a subspectrum file is made up of the first part of the base spectrum filename, followed by a two digit number indicating the position of that subspectrum file in the spectrum sequence, followed by a ".sub" extension. For example, if the base spectrum filename is ***flight.sp3*** and there are 15 subspectrum files defining the spectrum, then the subspectrum files will be named ***flight01.sub***, ***flight02.sub***, ***flight03.sub*** ..... and so on, ending with ***flight15.sub***.

There may be a maximum of 99 subspectrum files making up a spectrum. Each subspectrum file, in turn, may contain upto 9,999 subspectra, where a subspectrum is a sequence of stress levels. A stress level consists of a maximum stress (load), a minimum stress (load) and a cycle count (unity for a cycle by cycle spectrum, any positive integer for a blocked spectrum). In addition, the size of a subspectrum is limited to a maximum of 1205 stress levels.

Organizing the stress/load spectra as described above facilitates access and management of very large spectra. This method also makes it convenient to rearrange different parts of spectra to represent different loading scenarios.

2.4 Material Database File

matfile.dat

This file contains baseline lab-air material properties for different materials. It serves as a library from which the user may interactively select any material for which tabular crack growth rate data is available. This operation is described in Section 3.4.2.2.2. ***matfile.dat*** is bundled with the AFGROW binary and other related files for distribution and is extracted when AFGROW is installed. The name of this file may not be changed. It may, however, be edited or replaced with another file as required.

The material database file contains blocks of data, each corresponding to a particular material. Each block consists of a material name, 25 sets of **da/dN**, **ΔK** (@ **R** = 0) and **m**, followed by values of the upper and lower limits on **R**, the yield strength and the plane strain fracture toughness of the material, where **R** is the ratio of minimum applied stress to maximum applied stress and **m** is the factor in the Walker Equation that accounts for changing crack growth rates due to shifts in **R**. These variables are explained in greater detail in the MODGRO User's Manual.

There is no restriction on the number of material blocks in ***matfile.dat***. However, the user must bear in mind that this file is the sole source for baseline lab-air material data, and hence is restricted to the materials available in this file when changing materials interactively. The format of ***matfile.dat*** is explained in Appendix A.

2.5 Environment Database Files

*.env Files

AFGROW v3.0 includes the capability to simulate environmental effects on crack growth. Up to six different environments may be applied to different regions of a model (see Section 3.4.2.6 for details).

The code applies "environmental" material property data to determine crack growth rate whenever the crack front is in a region where it is affected by any applied environment. These material property data are contained in a ****.env*** file, whose format is similar to that of matfile.dat, with an additional line that specifies transition criteria for that environment (i.e., at what distance around an environment the effect of that environment is felt and what rules apply for gradually transitioning from baseline lab-air data to environmental data over that distance).

Environment material property files must also be created externally as AFGROW offers no tools to create them.

2.6 User-Input Beta Factor Files

**.bet* Files

These files contain beta factors (stress intensity multiplying factors) for different crack lengths, to be used in place of the closed-form SIF solutions. These files are used when the user selects either of the two user-defined specimen configurations (configuration numbers 1000 and 2000). These configurations are described in the MODGRO User's Manual and should be used when none of the built-in configurations in the model library offer a good approximation of the situation being modeled. AFGROW linearly interpolates between the values in a specified **.bet* file to determine SIF values as the crack front progresses.

2.7 Beta Correction Factor Files

**.sd3* Files

AFGROW has the capability to use beta correction factors to modify the canned SIF solutions to account for dissimilarities between the selected standard configuration and the actual situation being analyzed. These dissimilarities may arise due to various geometric (such as crack growth from an elliptical hole—AFGROW offers solutions only for crack growth from a circular hole) or loading (such as the effect of bending) considerations.

The beta correction factors may either be entered interactively at run-time or they may be read in from a **.sd3* file. The MODGRO User's manual contains more details about how these factors are determined and how they are used.

2.8 Residual Stress Files

**.rs3* Files

These files are used to read in a table of residual stresses as a function of crack length to account for the effect of stresses such as may arise due to interference-fit fasteners or cold-working at a hole. These stresses are required to calculate an effective stress intensity factor, $\mathbf{K}_{eff}$ used in the fatigue crack growth calculations. Residual stress intensity factors are stored as a function of crack length. AFGROW uses superposition to model the effects of a residual stress field on a propagating crack. In this case,

$$\mathbf{K}_{eff} = \sigma_{app}\sqrt{\pi a}\ \beta + \mathbf{K}_{res}$$

As in the case of beta correction Factors, residual stresses may be entered interactively at run-time or read in from a **.rs3* file. Details of their use and file formats are presented in the MODGRO User's Manual and Appendix B respectively.

2.9 AFGROW Output Files

**.of3* Files

AFGROW may be configured to print output to a file during execution. These files will contain crack data printed out at intervals specified by the user, and also a summary of the problem definition.

3. USING AFGROW

This chapter describes the use of AFGROW to simulate fatigue crack growth. The various features and capabilities of the code are explained here, as well as methods and procedures for their use. It also outlines the steps necessary to set up a model using AFGROW.

3.1 Starting AFGROW

To run AFGROW, the user must be running the X Window environment on a UNIX-based graphics workstation. Prior to starting AFGROW, the user must set up attributes such as window colors, fonts, etc., by specifying the application defaults file as described in Section 2.1. AFGROW is then started up by typing:

```
afgrow
```

At this point, two windows will appear on the screen. The larger of these, containing a figure of the cross-section of a plate with a center-crack, is the AFGROW **Display Window**. The other window, containing only text, is the **Status Window**.

The user must first perform a check to ensure that the `setenv` command used to set up the application defaults file was successful. This can be done by simply comparing the colors of the borders of the two windows. These are set up to be different, in the application defaults file. If the colors are identical, the `setenv` command was not successful, and other forms of

the command may be tried (seek help from local system administrator). If the `setenv` command was successful, the user is ready to begin performing analyses using AFGROW.

3.2 The Display Window

As mentioned in the previous section, the larger of the two windows that appear on the screen, upon invoking AFGROW, is the Display Window, shown in Fig. 3.1.

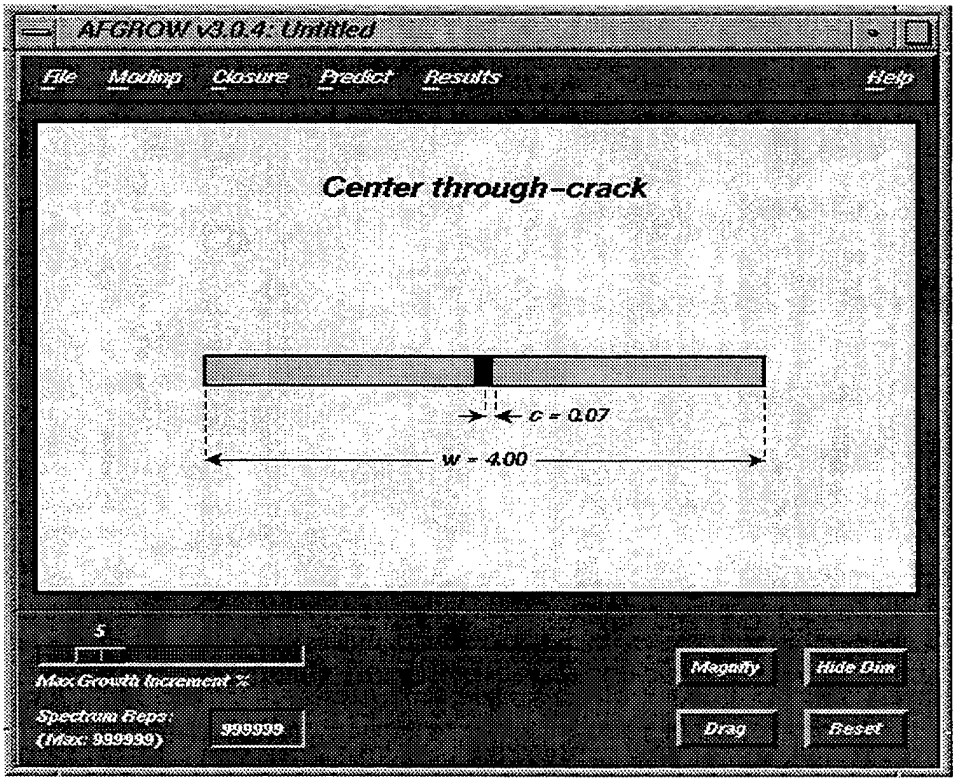

Figure 3.1: The Display Window

At the top of the Display Window is the **Title Bar**, which contains the AFGROW version number and also indicates if an AFGROW input file is currently open or not. If a file is

currently open, the name of the file along with its complete pathname is displayed on the Title Bar.

Located below the Title Bar is the **Menu Bar**, containing six different pull-down menus. These menus contain items needed to perform various tasks and are explained later in this chapter.

The large rectangular area at the center of the Display Window is the **Display Area**. This area is primarily used for displaying a figure of the current specimen configuration (when AFGROW is started up this always defaults to "Center through-crack," with default dimensions as shown). The Display Area is also used to view load or stress spectra graphically.

At the bottom left corner of the Display Window are the **Growth Increment Slider** and the **Spectrum Rep Text Field**. Their functions will become apparent later in this chapter. At the bottom right corner is a cluster of four push-buttons. The **Magnify** and **Drag** buttons are used to manipulate the zoom level and view of the specimen geometry. These are accomplished by clicking on the appropriate button and then, keeping the left mouse button depressed, moving the cursor over the Display Area. These operations are intuitive and the user is aided by bounding boxes that indicate the current zoom level or view into the Display Area. The **Reset** button sets the zoom level and view back to default values. The **Hide Dim** button is used to toggle the specimen dimensions on and off.

3.3 The Status Window

Appearing simultaneously with the Display Window, upon starting up AFGROW, is the Status Window. This is shown in Figure 3.2.

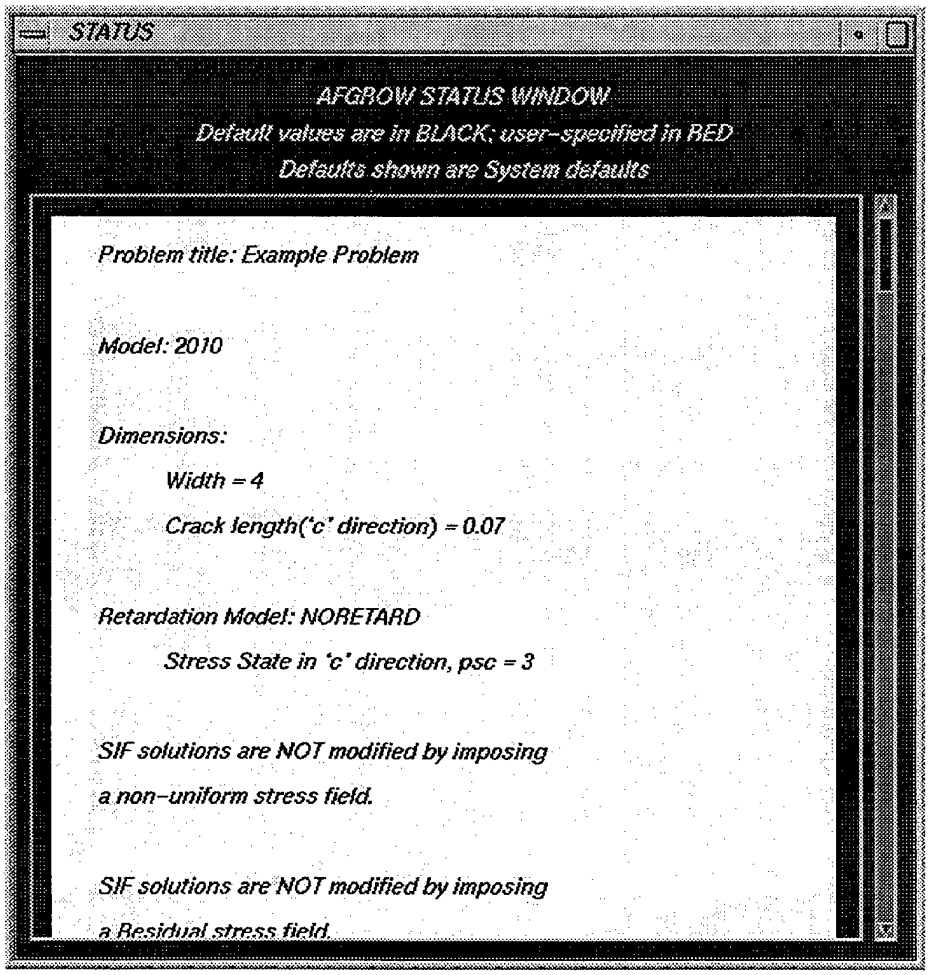

Figure 3.2: The Status Window

The Status Window serves as a tool that allows the user to verify the problem definition at any time during execution. It contains a **Status Area**, on which all the various parameters and options that make up the problem definition are displayed. When AFGROW is first invoked,

it displays the default values assumed by the program. Any changes made by the user are instantly echoed to the Status Window and are color-coded (user-specified in red, defaults in black) to distinguish them from variables that were not changed. Opening an input (***.da3***) file also results in the Status Window being updated, but in this case all the variables appear in black letters to indicate defaults from the file. The Status Area, being larger than the Status Window, is controlled by a scrollbar to move different parts of it into view.

3.4 The Menu/Dialog User-Interface System

All the functions and features of AFGROW are invoked through a system of pull-down menus accessible through the Menu Bar. Each menu contains one or more menu items that either perform actions or lead to pull-right menus that contain more menu items. Most menu actions are accomplished by means of a **Dialog Box** that prompts the user for information necessary to complete that action. This system of menus and dialogs is described in this section.

3.4.1 The FILE Menu

This menu contains menu items necessary to open, close and save AFGROW input files. These items are described in the following subsections.

3.4.1.1 The NEW Menu Item

Clicking on this item closes any input file that is open and resets the problem definition to the system defaults assumed at start-up. *This action will not save the current problem definition*

to any file that is already open. To do so, the user must explicitly choose either SAVE *or* SAVE AS *before choosing* NEW.

3.4.1.2 The OPEN Menu Item

This item is used to open a previously created input file and to read its contents into the problem definition. The model configuration and dimensions are updated on the Display Area and all the new input parameters and variables are displayed on the Status Window.

Choosing this item causes a **File Selection Dialog** (Fig. 3.3) to appear on the screen. This dialog is shown in Figure 3.3.

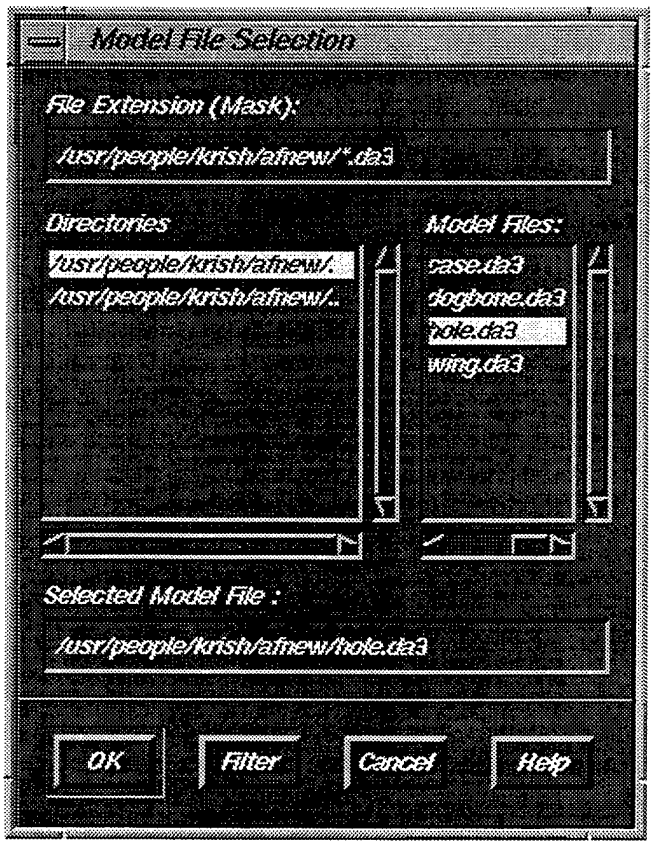

Figure 3.3: The File Selection Dialog

The File Selection Dialog is a standard interface item that is used in all file operations in AFGROW. It contains a tool to navigate through the file system and one that displays files found in the current directory. The user may click on any of these files and then hit the OK button to select that file for opening. At the top of the dialog is a text-field that acts as a filter and is used to control the types of files displayed. The use of this filter is mostly unnecessary and is discouraged since it is already set to display only the appropriate files for the current action.

3.4.1.3 The SAVE Menu Item

Clicking on this item saves the current problem definition to the input file that is currently open or, if no file is open, brings up a File Selection Dialog to select/enter a filename with.

In AFGROW, there is no predefined set of steps to create an input file. The user may choose different options and set variables in anyorder and then save them to a file at any time. AFGROW's system of filling in all variable sets with default values ensures that no information is missing at any time. The user can visually confirm the correctness of the problem definition before saving a file or executing an analysis by looking at the Status Window.

3.4.1.4 The SAVE AS Menu Item

This option allows the user to save the current problem definition to a file other than the one that is currently open. This action is also accomplished by means of a File Selection Dialog.

3.4.1.5 The QUIT Menu Item

Clicking on this item terminates AFGROW. This option does not automatically save the problem definition before exiting. To do so, the user must explicitly use the SAVE or SAVE AS options before quitting.

3.4.2 The MODINP Menu

This menu contains items to perform all the preprocessing functions in AFGROW. The program has been designed so that it has enough information to run an analysis at any time during execution. As previously mentioned, this is accomplished by initially assigning default values to all the options and variables, thus providing a complete problem definition at start-up. The preprocessing items interact with the user so that, while it is possible to turn certain options on or off, they will not allow the user to omit any essential information. This ensures that the problem definition is always complete and valid, and there are no "holes" in the data set.

3.4.2.1 The TITLE Menu Item

The problem title is part of a complete data set. This can be any arbitrary string and is provided for the user to identify problem definitions contained in input files. Clicking on the TITLE menu item calls a **Title Dialog Box** that allows the user to change the problem title.

3.4.2.2 The MATERIAL Submenu

Material properties (the relationship between **da/dN** and **ΔK**) may be specified in AFGROW using two methods; the Walker Equation method or using tabular crack growth rate data. These options are accessible through the MATERIAL submenu.

3.4.2.2.1 The WALKER EQUATION Menu Item

The Walker Equation is a modification of the simpler Paris Equation and is given below:

$$\mathbf{da/dN = C (\Delta K (1 - R)^{(m - 1)})^{p}}$$

where **da/dN** is the crack growth rate, **ΔK** is the Stress Intensity Factor range, **R** is the stress ratio (min. stress / max. stress), and **C**, **m** and **p** are material constants. More details on the Walker Equation can be found in the MODGRO User's Manual.

In AFGROW, Walker Equation data is approximated by entering up to five sets of **C**, **p** and $\mathbf{K_{cut}}$, where $\mathbf{K_{cut}}$ is the cutoff SIF range for that set. Each of these sets represents a straight line segment, $\mathbf{K_{cut}}$ being the maximum **ΔK** value corresponding to that set.

Walker Equation data is entered using the **Walker Equation Dialog Box**, shown in Fig. 3.4.

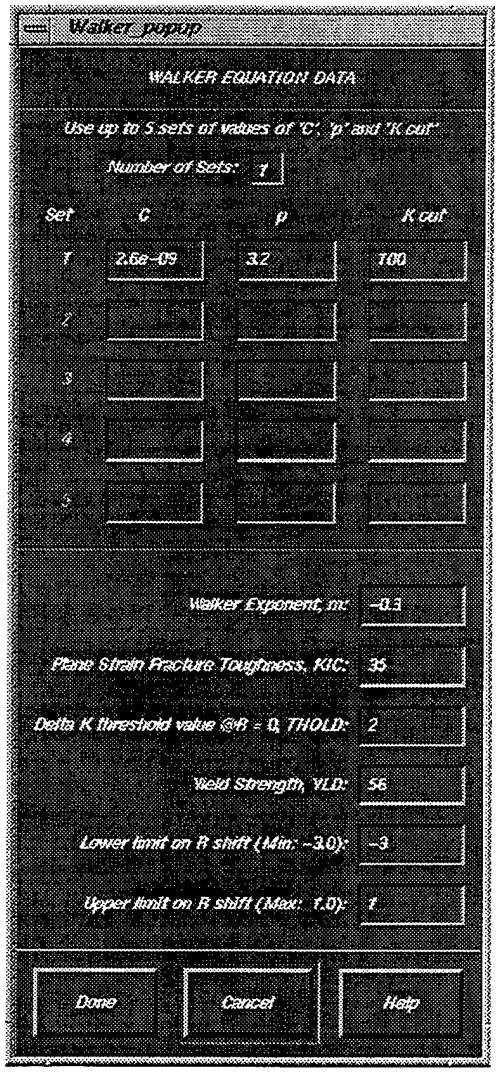

Figure 3.4: The Walker Equation Dialog Box

As is true of most other options, the Walker Equation data is assigned default values by the system unless other values are read in from an input file. These defaults assume that only one set of **C**, **p** and $\mathbf{K}_{cut}$ is used to model Walker Equation data. The text fields corresponding to the other sets are "greyed out", which means that they are disabled and will not accept user input. If the user wishes to use more than one set, the desired number must be entered in the "Number of Sets:" text field followed by a carriage return. This activates the appropriate number of sets, allowing the user to enter the data.

The remaining text fields accept values of other variables required to model material properties using the Walker Equation Method. The MODGRO User's Manual contains more information on these variables and how their values are determined.

The dialog will not disappear from the screen and the values will not be accepted unless satisfactory values are present in all text fields. This is a feature, common to all the AFGROW dialogs, intended to protect the user from typographical errors or oversight.

3.4.2.2.2 The TABULAR DATA Menu Item

The second method of characterizing material properties is by using tables of **da/dN** vs. **ΔK** values directly. These tables must be contained in a file called ***matfile.dat***, which is described in Section 2.4. Material selection is done through a **Tabular Data Dialog Box** (Fig. 3.5).

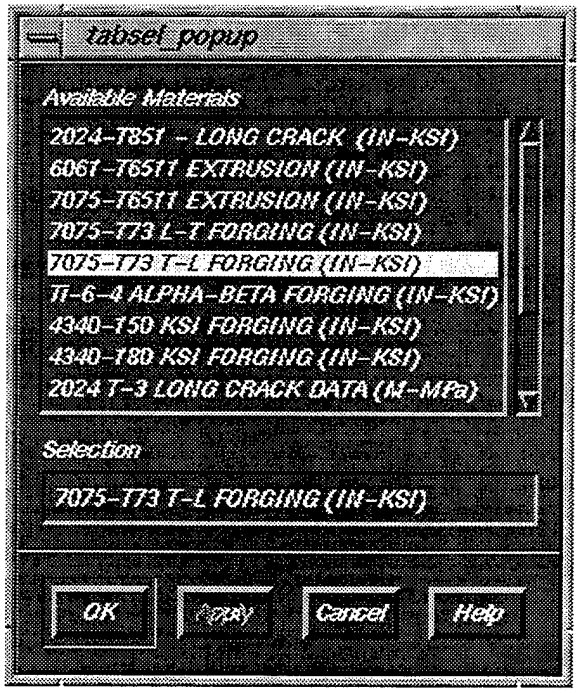

Figure 3.5: The Tabular Data Dialog Box

The dialog displays all the material names found in ***matfile.dat*** in a scrolled window. The user may select one of them by clicking on it and then clicking on the OK button. Clicking on CANCEL causes the dialog to disappear without changing the material name.

3.4.2.3 The MODEL Submenu

This submenu consists of two menu items in a pull-right menu. These are described below.

3.4.2.3.1 The MODEL CONFIGURATION Menu Item

Clicking on this item causes a Model Configuration Dialog Box (Fig. 3.6) to appear on the screen. This dialog consists of a scrolled window that displays iconic representations of the fifteen model configurations currently available in AFGROW. To the right of each of these

icons is a brief description of the corresponding model configuration. To the left is a toggle button that is used to select that configuration. Depressing any toggle button causes any other button that is already depressed to pop out, ensuring that only one configuration is selected.

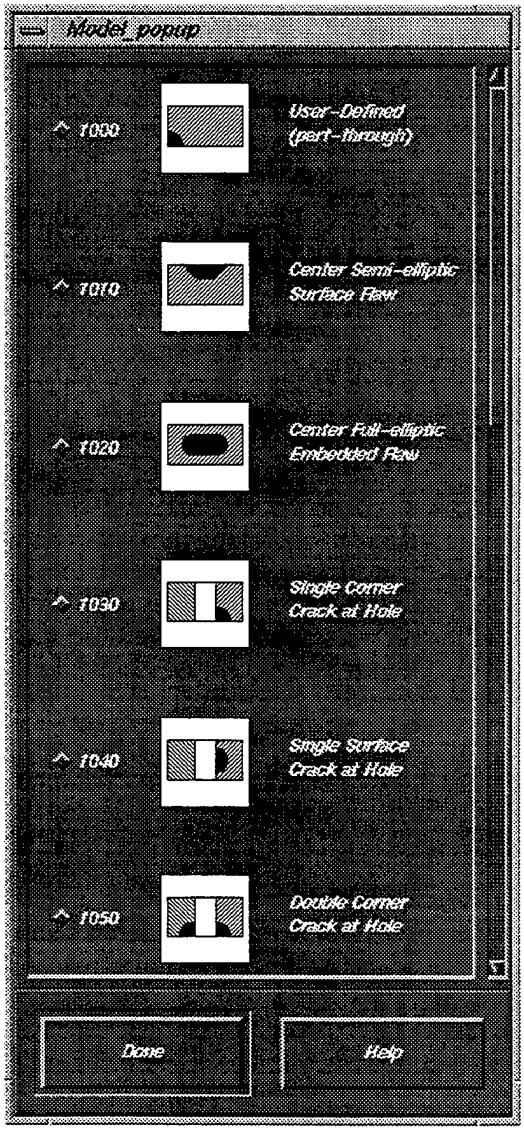

Figure 3.6: The Model Configuration Dialog Box

After selecting the desired configuration, the user must click on the DONE button at the bottom of the dialog to apply that configuration. The Model Configuration Dialog Box disappears simultaneously and, if the model configuration was changed, the **Model Dimensions Dialog Box**, described in the next subsection, appears on the screen. The HELP button brings up the **Help Window**, with information on how to change the model configuration. More information on the online help levels in AFGROW is contained later in this chapter.

3.4.2.3.2 The MODEL DIMENSIONS Menu Item

This action calls the Model Dimensions Dialog Box (Fig. 3.7), which contains several data fields that accept dimensions. Some of the data fields are insensitive since different dimensions are applicable to different model configurations. The user must ensure that values are present in all the active fields before clicking on DONE.

The two toggle buttons near the bottom of the dialog are active only if the current model configuration is 2060 (WOL/CT specimen). These buttons are used to select either Wedge Opening Load or Compact Tension geometry since both of these share a common configuration number. The MODGRO User's Manual contains descriptions of these two geometries and the differences between them.

The dialog automatically checks for validity of data before unmapping itself. This includes checks for unacceptable characters in the data fields as well as checks for impossible

geometries (c > w, etc.). Any discrepancies are reported to the user and require correction before the new dimensions are applied.

This dialog also pops up automatically every time a new specimen geometry is selected using the Model Configuration Dialog.

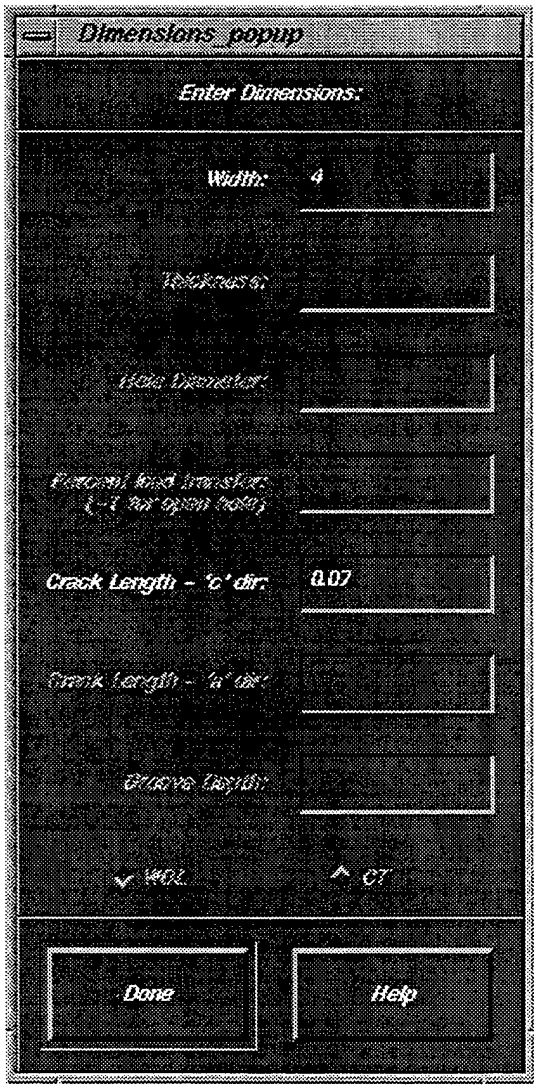

Figure 3.7: The Model Dimensions Dialog

3.4.2.4 The SPECTRUM Submenu

Load spectra used in AFGROW must reside in data files, in a specific format (see Section 2.3, ***AFGROW Spectrum Files***). This submenu contains items used to create, open or view load or stress spectra. These operations are described below.

3.4.2.4.1 The NEW Menu Item

AFGROW allows the user to create stress or load spectra manually, using dialog boxes to key in all the required information. This menu action results in a New Spectrum Dialog (Fig. 3.8) appearing on the screen. This dialog asks for all information necessary to create the base spectrum file.

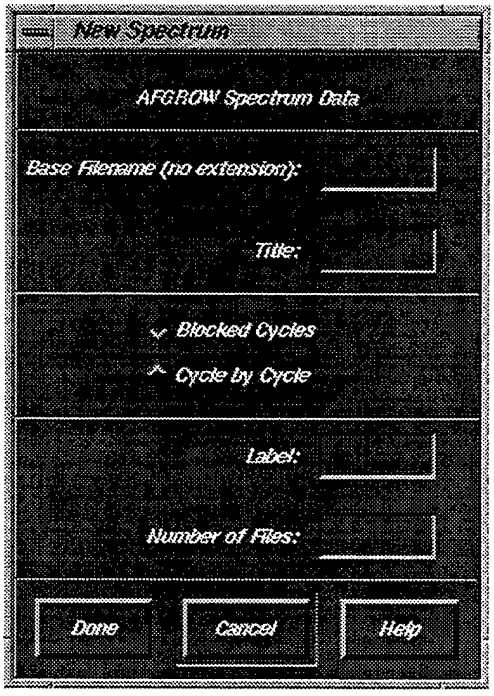

Figure 3.8: The New Spectrum Dialog

The base filename, title, label and number of subspectrum files are entered in the text field boxes. The toggle buttons are used to select the type of spectrum (BLOCKED or CYCLExCYCLE). Clicking on the DONE button makes this dialog unmap itself and a series of dialogs that ask for subspectrum / stress level information appear on the screen.

There are some restrictions on the types of spectra created manually--a maximum of 10 subspectra per file and 25 stress levels per subspectrum are allowed (Note: this still allows large blocked spectra to be created.) To create spectra with more than ten subspectra per file or more than twenty five stress levels per subspectrum, an external spectrum generator must be used.

3.4.2.4.2 The OPEN Menu Item

Spectrum files that have been created previously may be opened with this item. This is accomplished through a File Selection Dialog, similar to the one described in Section 3.4.1.2.

3.4.2.4.3 The VIEW Menu Item

This item is used to view load spectra that have been created or opened. A graphical plot of the stress levels vs. the cycle count is displayed on the Display Area, and a dialog box with only a DONE button appears on the screen. All other user-interface items are made inactive while the user is viewing the spectrum. To quit viewing the spectrum and go back to the main screen, the user must click on the DONE button.

3.4.2.5 The USER-INPUT BETA Submenu

Options under this submenu may be used only when the current specimen configuration is 1000 (User-Defined Part-Through), or 2000 (User-Defined Through-Crack) --the program automatically blocks out any attempt to use them with other configurations. These items are used to create or open User-Input Beta files (***.bet***, see Section 2.6).

3.4.2.5.1 The READ FROM FILE Menu Item

This item allows the user to open a User-Input Beta file using a File Selection Dialog that displays the ***.bet*** files found in the current directory. The dialog is similar to all the other File Selection Dialogs used in AFGROW.

3.4.2.5.2 The CREATE NEW TABLE Menu Item

The user may create Beta Factor tables for the user-defined specimen configurations using this item. This is done through the **User-Input Beta Dialog**, which contains rows of editable text fields in a scrolled window. As in the case of the Walker Equation Dialog, the user must activate or deactivate the required number of rows in the 'a' and 'c' directions before entering the values. The AFGROW User's Manual contains information on how to determine the User-Input Beta factors. The User-Input Beta Dialog is shown in Fig. 3.9.

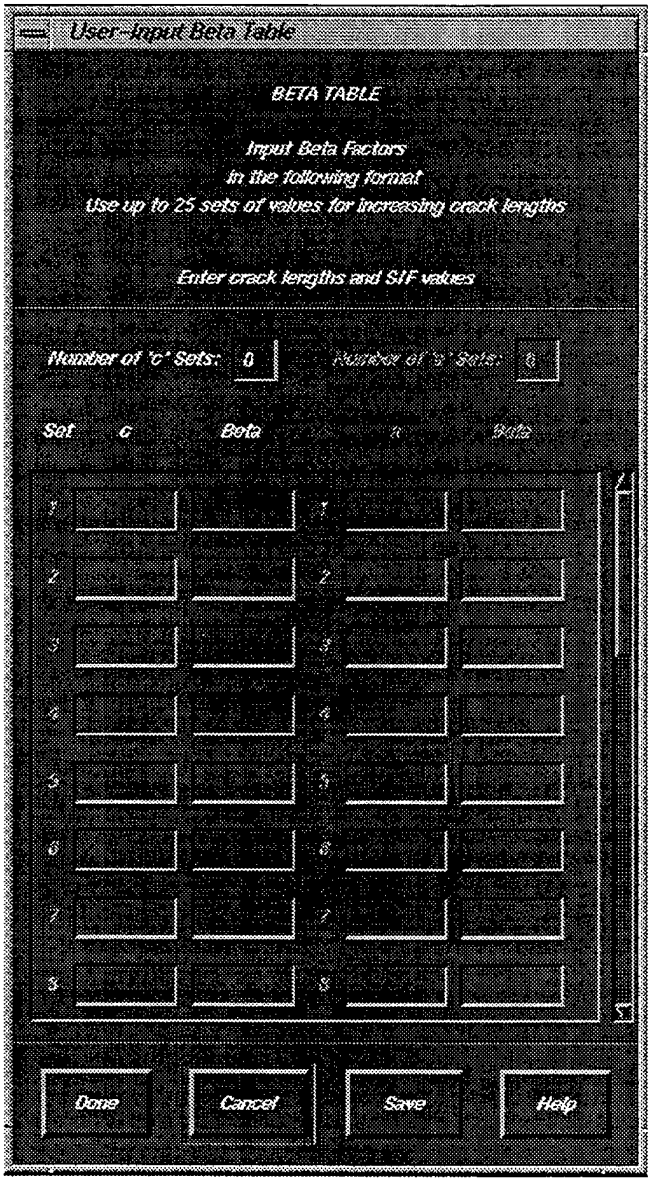

Figure 3.9: The User-Input Beta Dialog

3.4.2.6 The ENVIRONMENT Submenu

AFGROW offers the user the choice of specifying regions on the model subject to different environments. To specify a certain environment, the user must have crack growth rate data for that environment available. Introducing an environment to a region of the model means that crack growth rate data will be read in from a file corresponding to that environment while

the crack front is in the environment. Transition from lab-air to environment and vice versa are also accounted for, using parameters supplied by the user. This is described in detail in the MODGRO User's Manual.

3.4.2.6.1 The ENVIRONMENT ADD Menu Item

An environment is added to the problem definition through this item. The user first has to select an environment to be added, through a File Selection Dialog. This dialog displays all **.env* files found in the current directory. The program searches for environment data for the current specimen material in the selected file and reports errors back to the user. If it finds the required data successfully, an **Environment Dialog** (Fig. 3.10) appears on the screen.

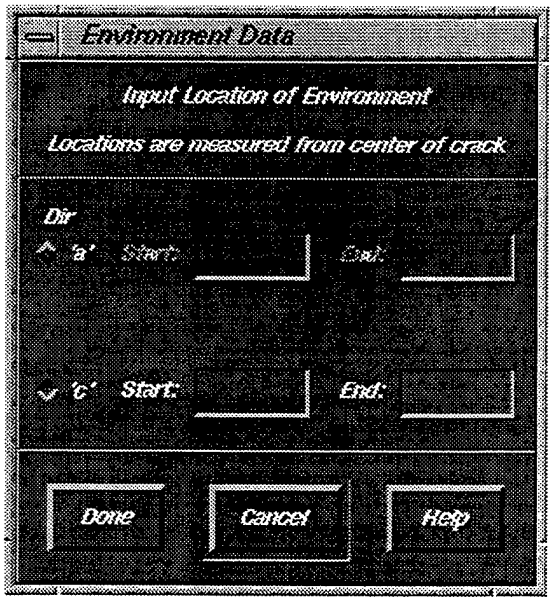

Figure 3.10: The Environment Dialog

The Environment Dialog contains text fields that accept locations of the environment in either the 'a' or the 'c' direction. Only the text fields corresponding to one of these directions is active at any time. The two toggle buttons may be used to activate the appropriate set.

The dialog checks for validity of data and also ensures that environments do not lie outside the problem domain. If the starting and ending locations are found acceptable, they are read into the problem definition. The environment is also displayed as a colored rectangle on the displayed area, with a key indicating the environment name. An example of a model with two environments is shown in Fig. 3.11.

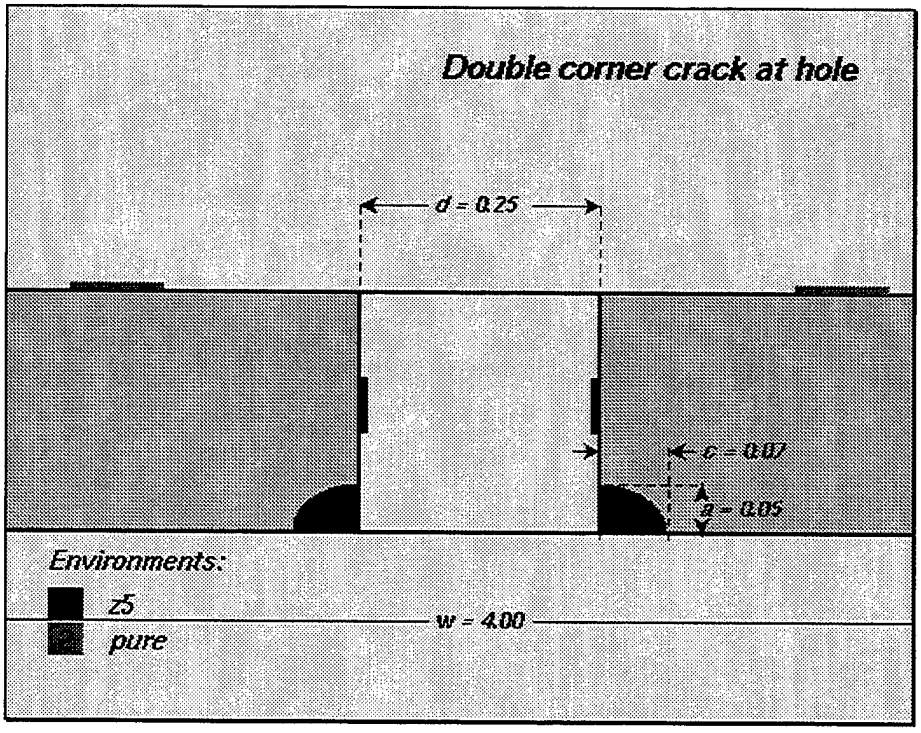

Figure 3.11: Model with Environments

3.4.2.6.2 The ENVIRONMENT DELETE Submenu

This submenu contains six buttons, numbered 1 through 6, that correspond to the environments in the problem definition. A particular environment may be deleted by clicking on the corresponding menu button.

3.4.2.7 The BETA CORRECTION Submenu

The standard SIF solutions used in AFGROW may be modified using tabular **Beta Correction Factors**. These multiplying factors are used to account for differences between the structural configuration being analyzed and the standard solution due to geometric or loading considerations. The MODGRO User's Manual contains a description of the Beta Correction Factors and their derivation.

3.4.2.7.1 The READ FROM FILE Menu Item

This item allows the user to read in a table of Beta Correction Factors from an external file. This operation uses a File Selection Dialog and is similar to the other file-reading options in AFGROW.

3.4.2.7.2 The CREATE TABLE Menu Item

The user may create a table of Beta Correction Factors interactively using this item. Crack lengths and corresponding correction factors are entered into editable text fields in the **Beta Correction Factor Dialog** (Fig. 3.12).

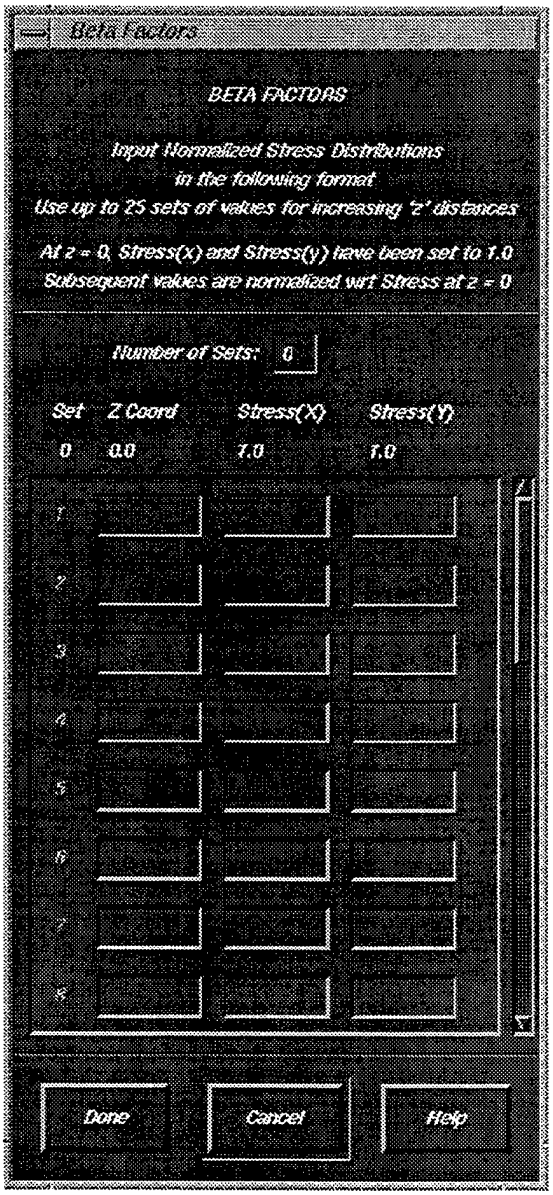

Figure 3.12: The Beta Correction Factor Dialog

A maximum of 25 sets of factors and crack lengths is allowed. The required number of rows of text fields may be activated by entering the appropriate number in the "Number of Sets:" text field.

3.4.2.8 The RESIDUAL STRESSES Submenu

AFGROW offers the user the ability to model the effect of residual stresses by reading in a table of residual stresses as a function of crack length. These stresses are used in a Gaussian Integration to determine residual stress intensity factors as a function of crack length. The residual SIFs are linearly interpolated for a given crack length and added to the applied stress intensity to obtain an effective SIF value. At start-up, the default problem definition does not include a table of residual stresses. A residual stress table may be read in from an external file or created interactively. These items are described below.

3.4.2.8.1 The NO RESIDUAL STRESSES Menu Item

The residual stress option may be turned off using this item. Any stress tables that have been read in previously are erased and are not used when calculating the Stress Intensity Factors.

3.4.2.8.2 The READ FROM FILE Menu Item

This item is used to read in residual stresses from a **.rs3* file. This is done interactively using a File Selection Dialog.

3.4.2.8.3 The CREATE TABLE Menu Item

This option allows the user to create a residual stress table interactively, using the **Residual Stress Dialog**. Its appearance and functionality are similar to those of the Beta Correction Factor dialog.

3.4.2.9 The RETARDATION Submenu

AFGROW offers the user a choice of two retardation models, the Willenborg model and the Closure model. The theory and formulation of these models may be found in the MODGRO User's Manual.

The default problem definition does not take retardation into account. The user may specify either of the retardation models using the options in this submenu.

3.4.2.9.1 The NO RETARDATION Menu Item

This item is used to turn the retardation option off. To incorporate a retardation model in the problem definition again, one of the two following options may be used.

3.4.2.9.2 The WILLENBORG MODEL Menu Item

The Modified, Generalized Willenborg retardation model is described in the MODGRO User's Manual. This item calls the **Willenborg Dialog** (Fig. 3.13) that prompts the user for the required parameters.

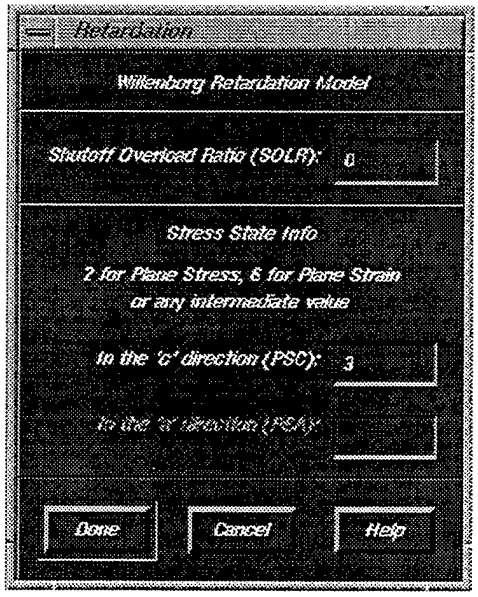

Figure 3.13: The Willenborg Dialog

The Shutoff Overload Ratio (**SOLR**) is the ratio of the overload maximum stress to the subsequent minimum stress required to stop further crack growth. **PSC** and **PSA** are two variables that characterize the state of stress (plane stress or plane strain) in the 'c' and 'a' directions. More on these variables and their determination can be found in the MODGRO User's Manual.

3.4.2.9.3 The CLOSURE MODEL Menu Item

This option utilizes the **Closure Dialog** (Fig. 3.14) to prompt the user for the required information to use the Closure retardation model.

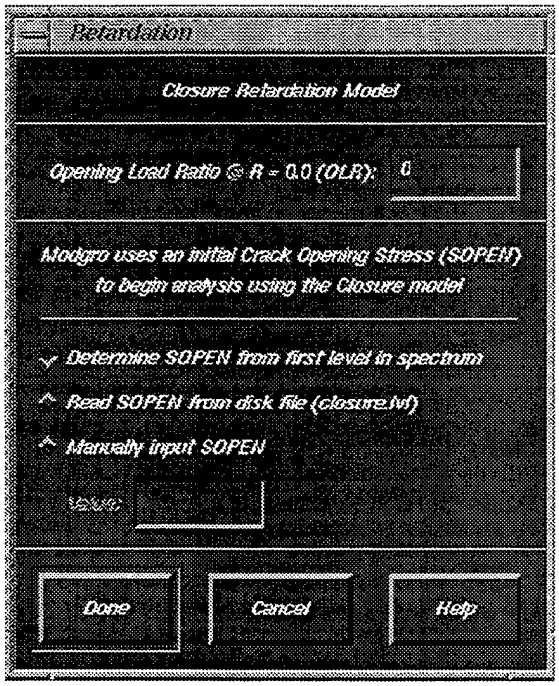

Figure 3.14: The Closure Dialog

A description of the Closure model and its associated variables can be found in the MODGRO User's Manual.

3.4.2.10 The STRESS INFO Menu Item

This item is used to change the Stress Multiplication Factor and Residual Stress Requirement using the **Stress Info Dialog**. This dialog contains two text fields that accepts values for the above two variables.

The Stress Multiplication Factor (SMF) multiplies the stress levels found in the spectrum files to obtain the actual applied stress levels. A normalized spectrum may be used with the SMF to convert the values to the appropriate stresses. For the standard stress intensity models, the

gross section stress is used, except in the case of model no. 2060 (WOL/CT specimen), where the applied point loads are used.

The Residual Strength Stress Requirement (SPCMX) is used for critical crack size determination. A nonzero residual stress value is used to compute a stress intensity at each calculated crack length and defining failure when this value exceeds the applicable fracture toughness. This is useful when the actual load sequence is not certain and provides additional safety in case a high load may occur at any time in service. If a value of zero is used here, then failure occurs any time the applied $\mathbf{K}_{max}$ exceeds the applicable fracture toughness and this stress value in either crack propagation direction. The only exception to this rule is when the failure occurs in the 'a' direction for a part-through flaw, and the crack length 'c' would not fail if considered to be a through-crack. In this case the crack is immediately transitioned to a through-crack and propagation continued. *The value used for* SPCMX *is not multiplied by the Stress Multiplication Factor.*

3.4.3 The PREDICT Menu

This menu contains only one menu item in this version of AFGROW. This is described below.

3.4.3.1 The PREDICT Menu Item

The PREDICT item is used to run a fatigue crack growth prediction on the current problem definition. Before invoking this item, the user must ensure that the problem definition is correct and complete. This is done by checking the data on the Status Window. The user

must also have opened a stress/load spectrum prior to running the analysis. If the problem definition is acceptable and a spectrum is open, the **Predict Dialog** appears on the screen. This dialog is used to set some of the parameters that control the type and frequency of output data generated by the program. The Predict Dialog is shown in Fig. 3.15.

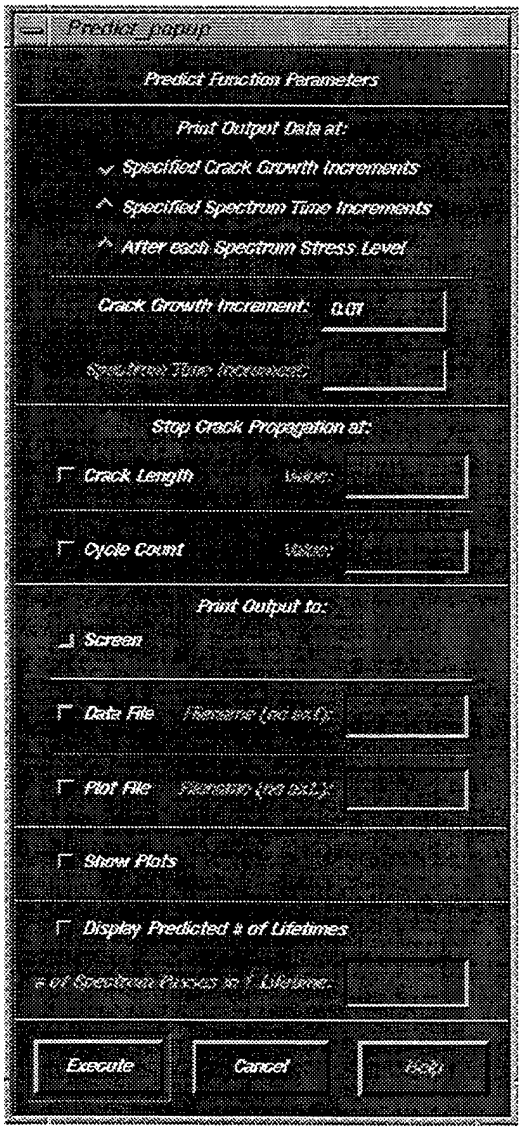

Figure 3.15: The Predict Dialog

At the top of the dialog is a "Radio Box" --a set of toggle buttons from which only one button may be selected. These buttons control how often output data are printed to the screen, or to an output file, and can be set to print at fixed crack length intervals, cycle count intervals or after every stress level in the spectrum. In the case of the first two options, the user must enter the interval in the text fields provided.

Below the radio box are two toggle buttons that can be set to stop crack growth after a certain length or after a certain number of cycles have elapsed. Selecting either of these options require the user to enter a value to stop at in the accompanying text field boxes.

The user may also enable or disable certain types of output. These include printing to the screen, to an output file and to a plot file. In addition, depressing the "Show Plots" button causes a **Plot Window** to come up during the analysis. This window displays real-time plots of **a** vs. **N** and **c** vs. **N** during program execution. The analysis can also be configured to display the predicted number of lifetimes until failure, where a lifetime is a user-specified number of spectrum passes.

Before executing an analysis, two other parameters need to be set, unless the default values are accepted. The controls for these parameters are on the Display Window, on the bottom left corner. The Growth Increment Slider controls the Vroman Integration Interval. This is a percentage of the current crack length after which the Beta Factors are recomputed. Below the slider is the Spectrum Rep Text Field, which is used to control the maximum allowable number of spectrum passes.

After all the required parameters are set, the EXECUTE button may be depressed. At this point, the crack may be seen growing in the Display Window. If the "Show Plots" option was selected, the Plot Window displays graphs of crack lengths vs. cycle count. The Plot Window contains a toggle button to overlay plots. If this is depressed, subsequent plots will be overlaid on the existing ones; else the Plot Window is cleared after each analysis. The color key at the bottom of the Plot Window indicates the order in which the plots were drawn.

Output data is printed to the base window (the window where the AFGROW command was issued from) unless otherwise specified in the Predict Dialog. The same output may also be directed to an output file for future reference.

3.4.4 The HELP Menu

AFGROW offers online help screens that describe most of the topics presented in this manual. The Help facility is accessible in two ways. For help on a particular dialog and its related functions, the user may click on the HELP button on the dialog. Alternatively, the HELP Menu contains links to all the menus, submenus and items on the menu bar. The desired help screen may be accessed by clicking on the corresponding item.

4. AFGROW TUTORIAL

This chapter illustrates the use of AFGROW by outlining the steps involved in creating an example problem definition. It is assumed that the reader is familiar with the user-interface objects described in Chapter 3.

The example problem consists of a plate with a corner crack at a hole as shown below.

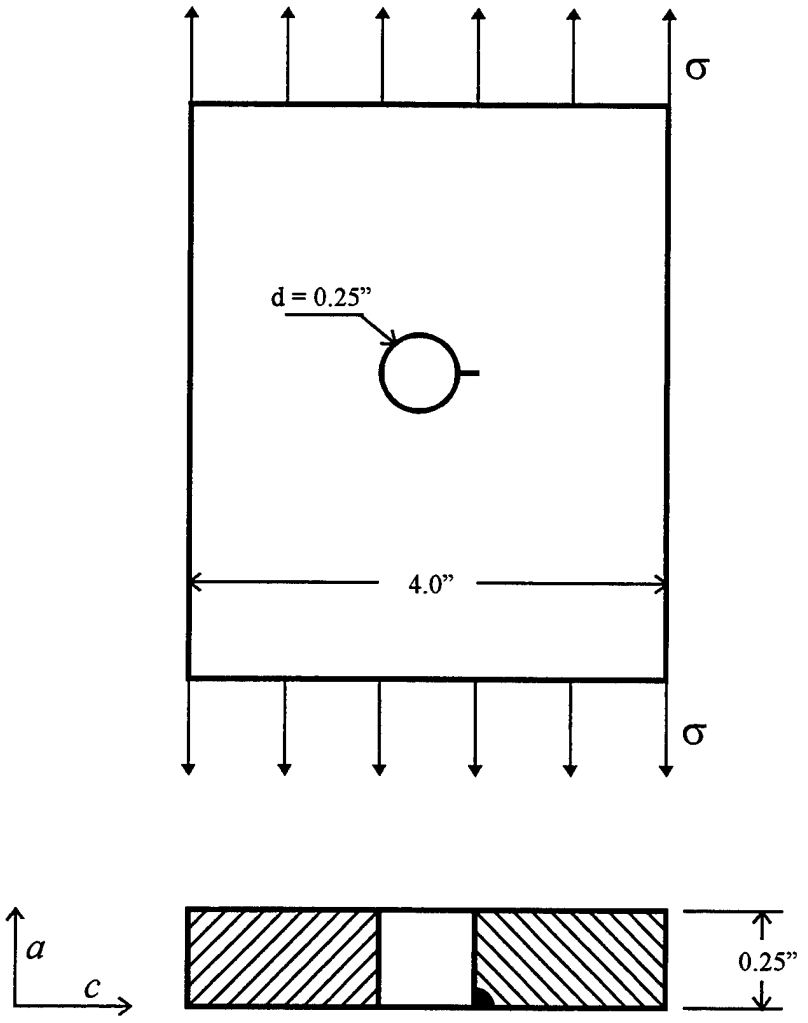

Figure 4.1: Example Problem Geometry

4.1 Problem Definition

The problem definition is as follows:

Specimen geometry:	Corner crack at a hole
Specimen dimensions:	**w** = 4.0", **t** = 0.25", **d** = 0.25"
Initial crack size:	**c** = 0.07", **a** = 0.05"
Material:	7075-T73 L-T Forging from ***matfile.dat***
Spectrum:	14.0 KSI to 0 KSI 1000 cycles
	21.0 KSI to 0 KSI 10 cycles
	14.0 KSI to -0.5 KSI 1000 cycles
Retardation Model:	Willenborg Model, Shutoff Overload Ratio (**SOLR**) = 2.5
Stress State:	**PSC** = 3.0, **PSA** = 4.0
Beta Correction:	None
Residual Stress Table:	None
Environments:	1. from ***case.env*** located from 0.5" to 0.55" from crack origin in 'c' direction.

4.2 Model Creation using AFGROW

Begin by setting up the application defaults in ***af_def*** and starting up AFGROW as described in Chapter 3. You will see the default model configuration on the Display Window and a list of all the default parameters on the Status Window.

It is good practice to start at the top of the MODINP menu and walk downwards in order. Though there are no restrictions on the sequence in which different preprocessing functions are performed, this ensures that the user does not overlook any of the items.

The first item on the MODINP menu is TITLE. Selecting this item results in the Title Dialog Box appearing on the screen. Enter any title of your choice. For example,

```
Tutorial Problem
```

Since the next item is the MATERIAL submenu, you need to determine whether the material has to be changed. This is easily determined by looking at the problem definition in the Status Window. Since this displays the default material (2024-T851 - Long crack), it needs to be changed. Select TABULAR DATA from the submenu. You will see the Tabular Data Dialog on the screen. Select 7075-T73 L-T Forging from the list on the dialog and click on OK. You may confirm that the material has been changed by looking at the Status Window.

Now select CONFIGURATION from the MODEL submenu. You will see the Model Configuration Dialog. Click on the toggle button next to Model 1030 (Single corner crack at hole) and then click on the DONE button. This changes the specimen configuration and draws the new geometry on the Display Window. This is followed by the Model Dimensions Dialog appearing on the screen, since a new model configuration has been selected.

In this case, all the default dimensions are the same as those in our example problem. Hence none of the default values in the Model Dimensions Dialog need to be changed. You may click on Done to dismiss the dialog.

The next item on the menu is the SPECTRUM submenu. Since we need to build the spectrum described in the previous section, select NEW. You will see the Spectrum Dialog. Enter a filename of your choice, without the extension, in the first text field. For example,

```
case
```

Note that this will name the base spectrum file ***case.sp3*** and the subspectrum files ***case01.sub***, ***case02.sub*** (in this example, we will have only one subspectrum file) and so on. The Title and Label may be strings of your choice. Also, select BLOCKED CYCLES by clicking on the corresponding toggle button, since we are creating a blocked spectrum. This spectrum can be contained in one subspectrum file since it is not a large spectrum. Enter "1" in the NUMBER OF FILES text field and click on DONE.

Now you will see a dialog box prompting you for the number of subspectra in the first subspectrum file. This can be 1, 2 or 3, since we have three different stress levels - all three levels can comprise a single subspectrum, each of the three levels may be defined as a separate subspectrum, or they can be grouped to make up two subspectra. For this example, let us choose to have only one subspectrum.

This is followed by another dialog box asking you the number of stress levels in the subspectrum. Enter "3". At this point, a dialog box with three rows of text-fields appears.

You need to input the stress levels and cycle counts in the text fields. Enter the three stress levels from the previous section in the boxes. You may choose to normalize the spectrum and use a Stress Multiplying Factor. In this case, the numbers in the text fields would be:

```
1.0        0.0   1000
1.5        0.0     10
1.0       -0.5   1000
```

Clicking on DONE causes the dialog to disappear and the spectrum files to be created. This action also opens the new spectrum file automatically - you do not need to explicitly open the spectrum you just created.

The USER-INPUT BETA submenu is not required since our current model configuration is not either of the user-defined specimens. You may move on to the ENVIRONMENT submenu.

Select the ADD menu item. You will see a File Selection Dialog displaying all the ***.env*** files in the current directory (see MODGRO User's Manual for details on environment files). You may select any file that contains environmental crack growth rate data for the current material. In this example we select a file called ***case.env*** and click on OK. At this point, the Environment Dialog appears on the screen. The two toggle buttons are used to select the crack growth direction along which the environment is to be added. Select the 'c' direction, enter "0.5" and "0.55" in the START and END text fields respectively, and click DONE. You will see a small colored rectangle on the model in the Display Window and a color key with the environment name below the model.

The next two submenus, BETA CORRECTION and RESIDUAL STRESSES, may be skipped, since we are not using either of these options in this example. Move to the RETARDATION submenu and select WILLENBORG. You will see the Willenborg Dialog on the screen. Let us set the shutoff overload ratio (**SOLR**) to be 3. This means that an overload that is three or more times as much as the subsequent maximum load will stop further crack growth. **PSC** and **PSA** may be set to 3 and 4, respectively. These are just arbitrary values--see the MODGRO User's Manual for an explanation of these variables.

Finally, select the STRESS INFO menu item and set the Stress Multiplication Factor to 14.0 if you created a spectrum with normalized stresses instead of actual stresses. This completes the creation of the problem definition for our example.

4.3 Fatigue Crack Growth Prediction

You are now ready to run an analysis with the model you just created. You might wish to save the definition to a file, using the SAVE option in the FILE menu, before doing so.

Check the value on the Growth Increment Slider on the Display Window. Smaller values are recommended for more accurate predictions. Let us set it at 5%. We will leave the Spectrum Repetitions at the maximum possible (999,999).

Open the PREDICT menu and click on the PREDICT item. This causes the Predict Dialog to appear. Let us leave the output interval at the default and select output to the screen only. Also click on the SHOW PLOTS toggle button and then click EXECUTE.

At this point you will see the Plot Window come up on the screen. You may wish to move this window away from the Display Window, by dragging it with your mouse. Notice the crack growing on the Display Window and the plots on the Plot Window. Output is also printed to the window from which AFGROW was invoked. The output includes crack length(s), cycle count, beta factors, stress ratio, **ΔK** and **da/dN** values at the default interval of 0.01" of crack growth. This is followed by a program execution time report.

You may try out different variations of the above example and compare plots to see the effect of various options. For example, you may turn off the retardation or delete the environment and observe the difference in crack growth rates.

5. REFERENCES

1. Harter, J.A., MODGRO TM AFWAL-TM-88-157-FIBE MODGRO User's Manual v1.2, February, 1988.
2. Newman, J.C., Jr., Raju, I.S., "An Empirical Stress Intensity Factor Equation for the Surface Crack," *Engineering Fracture Mechanics*, Vol. 15, no. 1-2, pp. 185-192, 1981.
3. Hiroshi Tada, Paul C. Paris, George R. Irwin, "Stress Analysis of Cracks Handbook," Del Research Corporation, St. Louis, 1973.

Appendix A

AFGROW File Formats

This appendix contains the formats of all the files used by AFGROW. In most cases, it is possible to create files interactively using AFGROW. Except in the case of material databases, environmental data files and large spectra, external creation of files is discouraged.

Certain types of files have formats that vary according to the problem definition. For this reason, the formats presented here are organized into blocks, with conditional statements, comments and data types italicized, and data sets in bold letters (typewriter font).

A-1 AFGROW Model File (**.da3*)

BLOCK 1:

`Title, **title**` *String*

BLOCK 2:

`Model Configuration No., **modnum**` *Integer*

BLOCK 3:

If **modnum** *= 2060(WOL/CT Specimen)*

`WOL/CT Flag, **wct**` *Integer (***0** *if WOL,* **1** *if CT)*

BLOCK 4:

`Initial Crack Length`

`in`c' direction, **ci**` *Double-Precision*

BLOCK 5:

If **modnum** *< 2000 (part-through crack)*

Initial Crack Length

in`a' direction, **ai** *Double-Precision*

BLOCK 6:

If **modnum** *< 2000 (part-through crack) or* **modnum** *== 2060 (WOL/CT Specimen)*

Thickness of Specimen, **t** *Double-Precision*

BLOCK 7:

Specimen Width, **w** *Double-Precision*

BLOCK 8:

If **modnum** *= 1030, 1040, 1050, 1060, 2020 or 2030*

Diameter of Hole, **d** *Double-Precision*

% Load transfer at

Hole, **ltrans** *Double-Precision*

BLOCK 9:

If **modnum** *= 2060 (WOL/CT Specimen)*

Groove Depth, **g** *Double-Precision*

BLOCK 10:

If **modnum** *= 1000 or 2000 (User-defined Specimens)*

Length of Beta Factor

Table (`c' direction),

n_userbeta_c *Integer*

c_length[1], beta_c[1] *Double Precision*

. . . . .

*(**n_userbeta_c** sets of crack lengths and Beta Factors)*

. . . . .

c_length[n], beta_c[n]

BLOCK 11:

*If **modnum** = 1000 (User-defined, Part-through crack)*

Length of Beta Factor

Table (`a' direction),

n_userbeta_a *Integer*

a_length[1], beta_a[1] *Double Precision*

. . . . .

*(**n_userbeta_a** sets of crack lengths and Beta Factors)*

. . . . .

a_length[n], beta_a[n]

BLOCK 12:

Environment check, ***Envs*** *String*

*If **Envs** =* "NOENVS"

No environments, do nothing

*Else if **Envs** =* "ENVS"

Number of Environments,

numenv *Integer, max. 6*

dir[1], start[1], *Integer, Double Precision,*

end[1], trans[1], *Double, Double*

a[1], b[1], c[1], filename[1] *Double, Double, Double, String*

. . . . .

*(**numenv** sets)*

. . . . .

dir[numenv], start[numenv],

end[numenv], trans[numenv],

a[numenv], b[numenv], c[numenv], filename[numenv]

where:

dir[i] = *Environment Direction (0 for 'a', 1 for 'c')*

start[i] = *Distance of start of environment from crack origin*

end[i] = *Distance of end of environment from crack origin*

trans[i] = *Transition distance*

a[i], b[i], c[i] = *Coefficients of transition polynomial*

filename[i] = *Name of environment database file*

BLOCK 13:

Retardation Model, **retard_mod** *String*

If **retard_mod** = "NORETARD"

No retardation, do nothing

Else if **retard_mod** = "WILLENBORG"

Shutoff Overload Ratio, **SOLR** *Double Precision*

Else if **retard_mod** = "CLOSURE"

Opening load Ratio, **OLR** *Double Precision*

BLOCK 14:

Stress State in `c' dir, **PSC** *Double Precision*

If **modnum** < *2000 (part-through crack)*

Stress State in `a' dir, **PSA** *Double Precision*

BLOCK 15:

Beta Correction check, **Betacor** *String*

If **Betacor** = "NOKMOD"

do nothing, no Beta Correction

Else if **Betacor** = "KMOD"

Length of Beta correction
table in `c' direction,
nbetacor_c *Integer*

c_length[1], stress_c[1], *Double Precision*
betacor_c[1]

. . . . .

*(***nbetacor_c** *sets of crack lengths and Beta Correction Factors)*

. . . . .

c_length[n], stress_c[n],
betacor_c[n]

If **modnum** *< 2000,*

Length of Beta correction
table in `a' direction,
nbetacor_a *Integer*

a_length[1], stress_a[1], *Double Precision*
betacor_a[1]

. . . . .

*(***nbetacor_a** *sets of crack lengths and Beta Correction Factors)*

. . . . .

a_length[n], stress_a[n],
betacor_a[n]

BLOCK 16:

Residual Stress check, **Resid** *String*

If **Resid** = "NOKRES"

do nothing, no Residual Stress table

Else if **Resid** = "KRES"

Length of Residual Stress
table in `c' direction,
nres_c *Integer*

c_length[1], rstress_c[1], *Double Precision*
resid_c[1]

. . . . .

*(**nres_c** sets of crack lengths and Beta Correction Factors)*

. . . . .

c_length[n], rstress_c[n],

resid_c[n]

If **modnum** *< 2000,*

Length of Residual Stress

table in `a' direction,

nres_a *Integer*

a_length[1], rstress_a[1], *Double Precision*

resid_a[1]

. . . . .

*(**nres_a** sets of crack lengths and Beta Correction Factors)*

. . . . .

a_length[n], rstress_a[n],

resid_a[n]

BLOCK 17:

Material check, **Mat** *String*

If **Mat** = "TABULAR"

Material Name, **mat_name** *String*

rate[1], delta_k[1], m[1] *Double Precision*

. . . . .

*(25 sets of **da/dN**, **ΔK** and **m**)*

. . . . .

rate[25], delta_k[25], m[25]

Critical SIF, Lower limit on R-shift,

Upper limit on R-shift, Yield Stress

kic, rlo, rhi, yield *Double Precision*

Else if **Mat** = "NOTABULAR" *(Walker Equation Method)*

Number of Walker segments,

nseg *Integer*

wc[1], n[1], kcut[1] *Double Precision*

. . . . .

(25 sets of Walker parameters)

. . . . .

wc[25], n[25], kcut[25]

m, threshold *Double Precision*

Critical SIF, Lower limit on R-shift,

Upper limit on R-shift, Yield Stress

kic, rlo, rhi, yield *Double Precision*

BLOCK 18:

Stress Multiplication Factor,

SMF *Double Precision*

Residual Stress Requirement,

SPCMX *Double Precision*

A-2 Base Spectrum File (**.sp3*)

BLOCK 1:

Spectrum Title, ***Title***	*String*
Spectrum Label, ***Label***	*String*
Spectrum Type, ***Type***	*String*
Number of files, ***files***	*Integer*

A-3 Subspectrum File (**.sub*)

BLOCK 1:

Subspectrum number, Number of Stress levels

sub_num, num_levels	*Integer*
max[1], min[1], num_cycles[1]	*Double, Double, Integer*

. . . . .

*(**num_levels** sets of max. stress, min. stress and number of cycles)*

. . . . .

max[n], min[n], num_cycles[n]

A-4 Material data File (*matfile.dat*)

BLOCK 1:

Material Name, ***mat_name***	*String*
rate[1], delta_k[1], m[1]	*Double Precision*

. . . . .

(25 sets of da/dN, ΔK and m)

. . . . .

rate[25], delta_k[25], m[25]

Lower limit on R-shift,

Upper limit on R-shift,

Critical SIF, Yield Stress

rlo, rhi, kic, yield *Double Precision*

A-5 Environment data File (*.*env*)

BLOCK 1:

Material Name, ***mat_name*** *String*

rate[1], delta_k[1], m[1] *Double Precision*

. . . . .

(25 sets of da/dN, ΔK and m)

. . . . .

rate[25], delta_k[25], m[25]

Transition distance, coefficient a, coeff b, coeff c

dist, a, b, c *Double Precision*

Lower limit on R-shift,

Upper limit on R-shift,

Critical SIF, Yield Stress

rlo, rhi, kic, yield *Double Precision*

A-6 User-Input Beta Factor File (*.*bet*)

BLOCK 1:

Length of Beta Factor

Table (`c' direction),

n_userbeta_c *Integer*

c_length[1], beta_c[1] *Double Precision*

. . . . .

*(**n_userbeta_c** sets of crack lengths and Beta Factors)*

. . . . .

c_length[n], beta_c[n]

BLOCK 2:

If **modnum** *= 1000 (User-defined, Part-through crack)*

Length of Beta Factor

Table (`a' direction),

n_userbeta_a *Integer*

a_length[1], beta_a[1] *Double Precision*

. . . . .

*(**n_userbeta_a** sets of crack lengths and Beta Factors)*

. . . . .

a_length[n], beta_a[n]

A-7 Beta Correction Factor File (*.*sd3*)

BLOCK 1:

Length of Beta correction

table in `c' direction,

nbetacor_c *Integer*

c_length[1], stress_c[1], *Double Precision*

betacor_c[1]

. . . . .

*(**nbetacor_c** sets of crack lengths and Beta Correction Factors)*

. . . . .

c_length[n], stress_c[n],

betacor_c[n]

If **modnum** *< 2000,*

Length of Beta correction

table in `a' direction,

nbetacor_a *Integer*

a_length[1], stress_a[1], *Double Precision*

betacor_a[1]

. . . . .

*(**nbetacor_a** sets of crack lengths and Beta Correction Factors)*

. . . . .

a_length[n], stress_a[n],

betacor_a[n]

A-8 Residual Stress File (*.rs3)

BLOCK 1:

Length of Residual Stress
table in `c' direction,

nres_c *Integer*

c_length[1], rstress_c[1], *Double Precision*
resid_c[1]

. . . . .

*(**nres_c** sets of crack lengths and Beta Correction Factors)*

. . . . .

c_length[n], rstress_c[n],
resid_c[n]

If **modnum** *< 2000,*

Length of Residual Stress
table in `a' direction,

nres_a *Integer*

a_length[1], rstress_a[1], *Double Precision*
resid_a[1]

. . . . .

*(**nres_a** sets of crack lengths and Beta Correction Factors)*

. . . . .

a_length[n], rstress_a[n],
resid_a[n]

Appendix B

Obtaining AFGROW

The AFGROW executable code may be obtained via anonymous ftp using the following procedure:

1. Connect to our anonymous ftp site by typing

   ```
   ftp fibec.flight.wpafb.af.mil
   ```

2. You will be prompted for a login name. Type

   ```
   anonymous
   ```

3. At the password prompt, type in your complete email address in the form *userid@hostname.domain*. For example,

   ```
   afgrow-user@somemachine.somewhere.somedomain
   ```

4. At this point you will see a message telling you that you have been successfully connected. Change directories to the AFGROW directory by typing in

   ```
   cd pub/afgrow
   ```

5. This directory contains AFGROW binaries for IRIX (SGI), SunOS (SUN), HP-UX (HP), IBM RS6000 (AIX) and Linux. These files are contained in compressed archive files named ***afgrow.sgi.tar.Z***, ***afgrow.solaris.tar.Z***, ***afgrow.hp.tar.Z***, ***afgrow.ibm.tar.Z*** and ***afgrow.linux.tar.Z***, respectively. Each archive file contains the appropriate binary and the other files necessary to execute the code.

6. Set the transfer mode to binary. This step is very important and is performed by simply typing

   ```
   bin
   ```

7. Transfer the files to your machine. Remember that the files will be placed in the directory you were in when you began the procedure. Type in the following command:

```
get afgrow.sgi.tar.Z (or appropriate archive file)
```

8. After each of the above two commands you will see messages telling you that the transfer was successful. At this point, type

```
bye
```

This gets you out of ftp and back to your machine.

9. Now you need to uncompress the archive file and extract its contents. Type

```
uncompress afgrow.sgi.tar.Z
tar xvf afgrow.sgi.tar
```

This will extract several files and place them in the current directory. These include a material database file, ***matfile.dat***, an application defaults file, ***af_def***, and several example input and spectrum files.

10. Make sure that file permissions are set correctly by typing

```
chmod 755 afgrow
```