DBMS SUPPORT FOR FIBER-REINFORCED COMPOSITE MATERIALS ANALYSIS

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Abstract

The broad scope of this research is the integration of several components of engineering software using a relational database. More specifically, a prototype finite element material property preprocessing system for fiber-reinforced composite materials is described. In this scenario, a materials database is integrated with several software components: a commercially available finite element analysis (FEA) program, ANSYS; a finite element preprocessor, MAZE; and a program for the design of laminated composite materials.

The R:BASE For DOS database management system is used for archival data storage. Components of the system request their data from R:BASE. Where appropriate, output data is placed into the R:BASE database. Interface programs aid in transferring data between the user and the database, and then between the database and the various application programs. This strategy enables the system to control the flow of information and allows the user to run the applications with a minimum of effort.

1 Introduction

Although a vast amount of software is available to solve many complex engineering problems, integration among the packages is often lacking. For example, the required file structure for batch input varies from program to program; therefore, the user must create multiple input files to manipulate the same data with different programs. While there has been some focus on integration with respect to CAD/CAM software, relatively few standard programs exist to generate batch input files from a database. In addition, there is no archival repository in which to store input information in a generic format. The problem is especially apparent in the realm of finite element analysis, where a large volume of input must be provided.

To address the problems of material data input and archival storage in the context of composite materials analysis, a prototype experimental, integrated finite element material property preprocessing system has been developed. The system focuses on the integration of two- and three-dimensional composite materials data with geometry and loading data to create an input file for a finite element analysis package, and is designed to provide simple data transfer among several software packages with a minimum of user interaction. The computational system is composed of several stand alone, task-specific computer programs, some commercial and some written for this application. These programs perform tasks such as composite laminate design, data entry, interface file generation, and finite element analysis. At the core of the system is a database, which provides an archive for fiber-reinforced composite material properties. This paper describes this Computer-Aided Analysis system, detailing the need for such a system and describing each of the components, including the materials database.

2 Composite Material Property Issues

It is readily apparent that, because the analysis system described herein addresses only the generation of material data for input to a FEA program, it cannot be considered a completely integrated finite element analysis system. It does, however, serve a purpose and fulfill a need in the engineering community. Because of analysis and design problems peculiar to the use of composite materials, generating material property values for program input is more difficult than with traditional engineering materials.

First, the complexity of the composite material must be considered. The stiffness or constitutive properties of fiber-matrix composites are usually orthotropic or even anisotropic. This property is inherent to composite materials because of their design and manufacture. The fibers in a unidirectional ply of a fiber-reinforced composite are, by definition, aligned in a single direction; composite laminates are constructed by layering several plies together, rotating each at a specific angle from the others. If a complex laminate is to be designed, often no two coordinate axes share the same material properties.

Furthermore, the composite structure may be manufactured with numerous ply combinations. In this case, a greater amount of material property data has to be generated, because each laminate has a unique set of material properties. Even those laminates that are made from the same composite have different properties, because the on-axis material properties of the composite laminate vary with each change in layup.

For these reasons and others which introduce even further uncertainty, the definition of material properties for a fiber-reinforced composite is very complex, and the process often has to be repeated numerous times for a single structure. In addition, design of structures using composite materials is a relatively new discipline for which few analytical tools exist. Strength properties of the material are often determined through experimentation rather than by calculation. As a result, several different material configurations may actually be analyzed for a particular design scenario to determine the best design.

It is evident, therefore, that there are numerous data collection and usage issue associated with composite materials, particularly in extracting property data for use in a FEA program. The key to designing with composite materials is overcoming these difficulties to obtain complete and accurate data to predict the performance of the composite in a design scenario. To eliminate some of these problems in the areas of data collection, laminate design, and FEA input, an integrated Computer-Aided Analysis system for fiber-reinforced composite materials has been developed. A prototype analysis system, the Composites Database Interface (CDI), is described in this paper.

3 A Computer-Aided Analysis System

The architecture of an integrated Computer-Aided Analysis system for fiber-reinforced composites is described in this section. On a physical level, the purpose of the CDI analysis system that was developed is to automate the input of composite materials data to a finite element analysis system. A secondary purpose is to provide an archive for the storage of composite materials data. A third purpose is to gain insight into the nature and organizational issues of the different types of data that are needed to define composite material properties. Existing technology in finite element analysis and database management is adopted to achieve the required functionality of the integrated system at the physical level.

Despite the fact that such integrated systems are not new in many domains, their introduction to the realm of composite materials analysis and design has not successfully occurred. This outcome is due in large part to the nature of the materials themselves and the overhead they bring to the development of a successful life-cycle model. The benefits of the system include the ability to generate a laminate in an ad hoc manner, having the material properties both immediately available for formatted FEA input and archived in a materials database.

To integrate the components of the Composites Database Interface, we use an incrementally expandable, or modular, architecture. The system components are embedded in an environment whose function is to facilitate data representation, data transfer, and data manipulation. The functional components of the CDI are described in Section 4.1 below, and the system integration issues are addressed in Section 4.2.

3.1 Functional Components

From a functional point of view, the CDI is composed of the following components:

- Help,
- Data Manipulation,
- Laminate Design,
- Reports/Views, and
- Interface File Generation.

These software components are discussed below and are illustrated in Figure 1. Note that the applications support only the data management aspects of the analysis system; the actual analysis capability is not provided in the CDI. In each component, the necessary program code was written using the R:BASE For DOS application programming language; the CDI, therefore, can be executed only from within the R:BASE DBMS environment. A top level menu-driven user interface allows the user to access the desired component to initiate an appropriate function.

3.1.1 Help Component

The purpose of the CDI Help component, as its name indicates, is to aid the user in executing the remaining CDI components. The Help component provides the user with a collection of help screens describing a variety of CDI topics. Each screen contains descriptive information about a specific CDI function, providing general instructions about how it operates and discussing possible options or command variations. The Help component has no specific data requirements as there is no interaction with the database.

3.1.2 Data Manipulation Component

The function of the Data Manipulation component of the CDI is to provide the user with a simple means of entering, editing, and removing the data in the composite materials database, where it is archived. Two different methods for performing these actions are included in the CDI. The user can either manipulate the data by using on-screen data entry forms developed in R:BASE, or can enter the R:BASE Prompt by Example (PBE) mode directly to perform various tasks. In general, the forms and associated menu system guide the user, in a detailed step-by-step manner, through the data manipulation process, while the PBE mode allows greater freedom but provides less guidance to the user.

Forms are data entry and modification tools that can be developed in R:BASE as part of a database definition. A form corresponds to a specific database table and contains numerous prompts. The data entered on each form corresponds to a single row in the table; each prompt, in turn, corresponds to a particular field of that row. When used for data entry, the fields of a form are initially empty. Data is entered into the form by typing a response to each prompt; a null is entered by leaving the field empty. Once the data has been completely entered into a form and has been determined to be accurate, the user may enter it into the database as a new row in the corresponding table.

Forms can be used in a similar manner to modify data. The user first supplies data indicating which form and row (or rows) of data to be modified. When the form appears on the screen, each field automatically contains the database values for the first applicable row in that table. To change the values in those fields, the user simply types over the current data values, then selects the *Save* action from a menu. The user may also delete database rows by using the appropriate menu options.

The data represented by the collection of data entry forms is the data contained in the materials database. It is the set of data required to support the material property needs of the integrated finite element analysis codes. These needs, which include identification data and material properties for both unidirectional plies and laminated composite materials, are described in various sections of this paper. Were the materials database expanded to support a larger data set, the set of forms could likewise be supplemented.

The alternate means of data entry and modification provided within the Data Manipulation component of the CDI is via direct access to the Prompt By Example (PBE) mode of R:BASE. PBE allows the user to execute R:BASE commands directly, with the aid of screen prompts and context-sensitive informational messages. Possible PBE actions of interest include modifying data, querying the database, using SQL commands, and accessing operating system utilities. Most commonly needed operations can easily be performed using the appropriate PBE options. Certain actions, however, such as modifying the database structure, or haphazardly changing identification codes, should be avoided, as they will lead to inconsistent data within the database and among the CDI programs.

3.1.3 Laminate Design Component

The Laminate component of the CDI allows the user to design both quasi-isotropic and general laminates from the unidirectional ply data stored in the database. The newly generated laminate data, which includes stiffness properties and thermal expansion coefficients, is then stored in the database. As input to this component, the user provides the name of the unidirectional ply and the laminate code or stacking sequence for the layup to be designed.

The laminate code indicates the orientation of each ply in the laminate; a short-hand notation is used to represent repeating layers and planes of symmetry. A quasi-isotropic laminate, by definition, is one having equal ply portions at 0, 45, 90, and -45 degree angles; it is distinguished by equal elastic moduli in the major and minor directions. The laminate data is then generated based upon the material properties of the unidirectional composite. Required ply properties are the elastic and shear moduli, Poisson's ratio, and thermal expansion coefficients.

Two different models are available for generating laminate stiffness data. Layups may be designed using laminated plate theory, which is the current industry standard, as documented by Tsai in reference [1], or through the STIF3D code, developed at the University of Delaware [2]. Thermal expansion coefficients must be generated using the classical laminated plate model.

Briefly, laminated plate theory is simple to understand and use, and is accurate for balanced, symmetric laminates. The model only generates two-dimensional stiffness data, however; the third dimension properties must be approximated from the available ply and laminate data. STIF3D involves a more complicated three-dimensional theory, thereby generating the entire set of three-dimensional laminate stiffness properties, and is accurate for any laminated composite. STIF3D also requires certain material property approximations on the ply level.

For each new laminate, the shear and elastic moduli, Poisson's ratios, and thermal expansion coefficients can be computed. Where required, valid approximations are presented by the CDI program; the user can accept the suggestions or modify the values as necessary. Note fields are provided in the database to document the various assumptions made by the user.

3.1.4 Reports/Views Component

The Reports/Views component of the CDI provides the user with the capacity to observe the data stored in the database. Data may be viewed on the monitor or hard-copy reports may be generated. By means of menu selections, the user may specify the type and amount of data to be generated, thereby creating custom views and reports.

As with data entry and modification, the data represented by the collection of reports are the data contained in the materials database. Section 4.1.5 and the Appendix provide a description of those data items included in the database. In general, reports may be separated into two categories: identification reports and material property reports. Either category may be generated for both unidirectional and laminated composite materials.

An identification report provides general descriptive data about a composite. For a unidirectional ply, it includes the identification number, as well as the composite, fiber, and matrix names, e.g., `T300/5208`, `T300`, and `N5208`. For a laminated composite, the same report lists the composite name and laminate code, e.g., `T300/5208` and `[0(2)/45/-45]`, in addition to the identification number. For an identification report, the user may elect to report on a single class of composites or to report on all available materials; for example, the user may report on all carbon fiber-reinforced composites (those with the class `CFRP`), or he may view all laminates defined in the database.

Material property reports are more detailed. In addition to the above information, they also include the values of various material properties for the selected plies or laminates, such as elastic and shear moduli, thermal expansion coefficients, Poisson's ratio(s), and density. Material property data may be either individually selected by composite name, or all available composites may be viewed.

3.1.5 Interface File Generation Component

The final functional component of the CDI to be discussed is the Interface File Generation component. This component allows the user to create files of material data suitable for use with either the ANSYS finite element analysis program [3] or with the MAZE preprocessor for the NIKE2D and DYNA2D analysis codes [4].

Recall that a separate file containing the FEA input data must also be developed using a text editor. This file, known as the batch input file, contains the finite element mesh, loading information, and the applicable constitutive relationships for the structure to be analyzed. The integration of the material data file and the batch input file with the analysis code is handled differently for each software package.

First, consider creating an interface file compatible with ANSYS. Figure 2 shows a schematic representation of the data flow for this integration method. When the ANSYS Interface File Generation component of the CDI is executed, the material data for the specified composites is placed into a file known as an ANSYS User file. The User file acts as a library file to the batch input file, which means that, once created, it can be used with multiple batch input files.

The User file is composed of data blocks; each data block contains the appropriate material property definitions for a single material rotated to a specific orientation with respect to the ANSYS coordinate axes. To properly refer to the User file, the user must be sure that the ANSYS batch input file contains specific commands. Along with the finite element data, therefore, calls to the User file are also embedded in the batch input file.

The first step is including a command to identify the name of the User file to the batch input file. Then, for each composite used in the structure to be analyzed, the data block containing the corresponding material definition must be identified. Thus, ANSYS receives the geometry and loading information from the batch file and the materials data from the material data file. In this way, the batch input file and the material data file are used independently to integrate the materials data with ANSYS.

Integration with MAZE is somewhat different because MAZE does not have the ability to reference library files. All of the required data, including materials data, must be contained in one file. Therefore, after the material data file is created by running the MAZE Interface File Generation component of the CDI, it must be appended onto an existing MAZE batch input file with a text editor. Figure 3 shows a schematic representation of the data flow for integration with MAZE. Materials are defined within the CDI by a material number, which must correspond to the material numbering scheme used elsewhere in the batch input file.

Both ANSYS and MAZE encompass three types of finite element analysis: two-dimensional, three-dimensional, and axisymmetric. The current scope of the materials database includes two-dimensional ply data and three-dimensional laminate properties. Recall that much of the laminate data is based upon approximations suggested by the CDI program and either accepted or modified by the user. Where three-dimensional ply properties are required, the composite is assumed to be transversely isotropic; that is, material properties in all planes perpendicular to the composite fiber are assumed equivalent.

The required material properties for finite element analysis of two-dimensional plane structures are as follows: elastic moduli in the X and Y directions, Poisson's ratio in X–Y plane, shear modulus in X–Y plane, thermal expansion coefficients in the X and Y directions, and material density. For axisymmetric structures three dimensions of material properties are required. In addition to the above properties, the elastic modulus and thermal expansion coefficient in the Z direction, and the Poisson's ratios in both the Y–Z and X–Z planes are required. Generic three-dimensional structures, which would require the same data set as axisymmetric structures, are not considered in the CDI because they are not usually created from laminated composites.

3.2 System Integration

The functional components of the CDI are integrated via the R:BASE relational database management system. A brief description of R:BASE is presented in Section 4.2.1 and the related integration issues are addressed in Section 4.2.2.

3.2.1 R:BASE For DOS

R:BASE For DOS, generally referred to as R:BASE, was developed by Microrim, Inc., and is a multi-user relational database management system designed for use on a microcomputer [5]. As R:BASE was created by one of the developers of the RIM DBMS, it retains much of RIM's functionality, supporting the integer, real and double precision data types, which are essential to support engineering applications [6]. In addition, R:BASE enables the user to interactively define database schemas, create custom data entry forms, and generate advanced output reports. The DBMS provides an advanced SQL-based command language and an application programming language. R:BASE is very sophisticated yet simple to use, primarily because of its data entry, manipulation, and report generation functions.

3.2.2 Component Integration

The role of R:BASE in the CDI is two-fold. On one hand, R:BASE is used as a data transfer mechanism. This function of R:BASE facilitates the transfer of data to and from the set of heterogeneous application programs with a minimum of user interaction. As a data transfer mechanism, R:BASE assumes a dynamic role in the evolving analysis process and provides the data required by each application program throughout the process. On the other hand, R:BASE is used as a passive data repository. This capability provides the overall system with a centralized and manageable storage area for capturing the information obtained from the appropriate application programs. The data integrity of the process can thus more easily be monitored, because the information is maintained in one centralized location [7].

To transfer data between independent application programs, one needs to interface the programs; this is done by interfacing each program with R:BASE. Therefore, the data needed by or received from an application program is mapped to a set of appropriate database relations in R:BASE. The collection of all the relations in R:BASE represents the data transmitted between the functional components of the CDI throughout the analysis process. Figure 1 depicts the CDI application programs, the interfaces, the centralized database management system, and the data paths between them. At the present time, relations have been defined to represent the data needed by the FEA programs for two-dimensional and axisymmetric analysis, as described in Section 4.1.5. This data is sufficient to run the remaining application programs as well. Interfaces have been generated for all of the application programs.

To provide the necessary composite materials data in R:BASE to support the prototype, four initial relations have been developed. These relations are designed for supporting identification and material property data for unidirectional plies and laminated composites. A system of identification codes ties the relations together. The appendix includes a detailed description of the database schema, including table and column definitions.

4 Current Status

The Computer-Aided Analysis system described in this paper, the CDI, is currently operational at the level of functionality described above. The system has been fully tested and documented [8]. In addition, the CDI is undergoing upward migration to a workstation environment. With enhancements and modifications, the CDI will be implemented on an Apollo platform. Testing and documentation of this system is also planned.

5 Summary

This paper outlined an approach for merging database technology with finite element analysis applications in the domain of composite material properties. The overall process of analysis and design using composite materials was described and the complexity of the integration process was emphasized. An experimental Computer-Aided Analysis system was described to investigate how to overcome the problems and enhance the integration process.

The overall architecture of a Computer-Aided Analysis system for fiber-reinforced composites using existing technologies was described. The relationship between the analysis system and the external software components of the system was explained in terms of the functionality provided by each component and its data requirements. System integration, which was a key project objective, was achieved by using a database management system. The integration process was described in detail, and finally, the current status of the prototype was indicated.

References

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Appendix: Database Schema

The appendix contains the database schema for the experimental prototype of the Composites Database, as implemented in the R:BASE database management system for the experimental prototype. Each table is documented and the associated columns are enumerated. A brief description is provided for each table and column.

- UNICOMP (Unid, Uniname, Class, Fiber, Matrix, Prodform, Process)

  The UNICOMP relation contains identification and descriptive information concerning unidirectional ply composites.

  - UNID: Unique database identifier of a unidirectional composite
  - UNINAME: Commonly used composite name or identification
  - CLASS: Composite class, typically same as fiber type
  - FIBER: Name of fiber used in the composite
  - MATRIX: Name of matrix used in the composite
  - PRODFORM: Form in which the composite product is available
  - PROCESS: Processing which the composite has undergone

- UNIPROP (Unid, E1, E2, Alp1, Alp2, Nu12, G12, Dens)

  The UNIPROP relation contains material property data about unidirectional ply composites, specifically that which is relevant to finite element analysis.

  - UNID: Unique database identifier of a unidirectional composite
  - E1: Modulus of elasticity in fiber direction, in psi
  - E2: Modulus of elasticity transverse to fiber, in psi
  - ALP1: Coefficient of thermal expansion in fiber direction, in in/in-°C
  - ALP2: Coefficient of thermal expansion transverse to fiber, in in/in-°C
  - NU12: Major Poisson's ratio, unitless quantity
  - G12: Shear modulus of elasticity, in psi
  - DENS: Composite density, in lbf-s^2/in

- LAMINATE (Lamid, Unid, Lamcode)

  The LAMINATE relation contains the information necessary for complete identification of a laminated composite.

  - LAMID: Unique database identifier of a laminated composite
  - UNID: Unidirectional composite used in the laminate
  - LAMCODE: Laminate code indicating ply orientations and thicknesses

- LAMSTIFF (Lamid, Runid, Method, Assump, Ex, Ey, Ez, ExBend, EyBend, Nuxy, Nuyz, Nuxz, Gxy, Gyz, Gxz)

  The LAMSTIFF relation contains material stiffness data about laminated composites necessary to perform finite element analysis. In addition, it contains the data required to uniquely identify a stiffness analysis run.

  - LAMID: Unique database identifier of a laminated composite
  - RUNID: Identifier of stiffness analysis run number
  - METHOD: Method used for generating stiffness properties
  - ASSUMP: Three-dimensional ply/laminate assumptions used in generating laminate stiffness properties
  - EX: Major elastic modulus in X direction (at zero degrees rotation), in psi
  - EY: Minor elastic modulus in Y direction (at ninety degrees rotation), in psi
  - EZ: Elastic modulus in Z direction (through thickness), in psi
  - EXBEND: Bending stiffness around X axis, in psi
  - EYBEND: Bending stiffness around Y axis, in psi
  - NUXY: Major Poisson's ratio for the laminate in X–Y plane, unitless quantity
  - NUYZ: Poisson's ratio for the laminate in Y–Z plane, unitless quantity
  - NUXZ: Poisson's ratio for the laminate in X–Z plane, unitless quantity
  - GXY: Shear modulus of elasticity in X–Y plane, in psi
  - GYZ: Shear modulus of elasticity in Y–Z plane, in psi
  - GXZ: Shear modulus of elasticity in X–Z plane, in psi

- LAMTHERM (Lamid, Alpx, Alpy, Alpxy, Alpz)

  The LAMTHERM relation contains thermal expansion data about laminated composites necessary to perform finite element analysis.

  - LAMID: Unique database identifier of a laminated composite
  - ALPX: Major coefficient of thermal expansion in X direction, in in/in-°C
  - ALPY: Minor coefficient of thermal expansion in Y direction, in in/in-°C
  - ALPXY: Coefficient of thermal expansion at forty-five degrees in X–Y plane, in in/in-°C
  - ALPZ: Coefficient of thermal expansion in Z direction, in in/in-°C

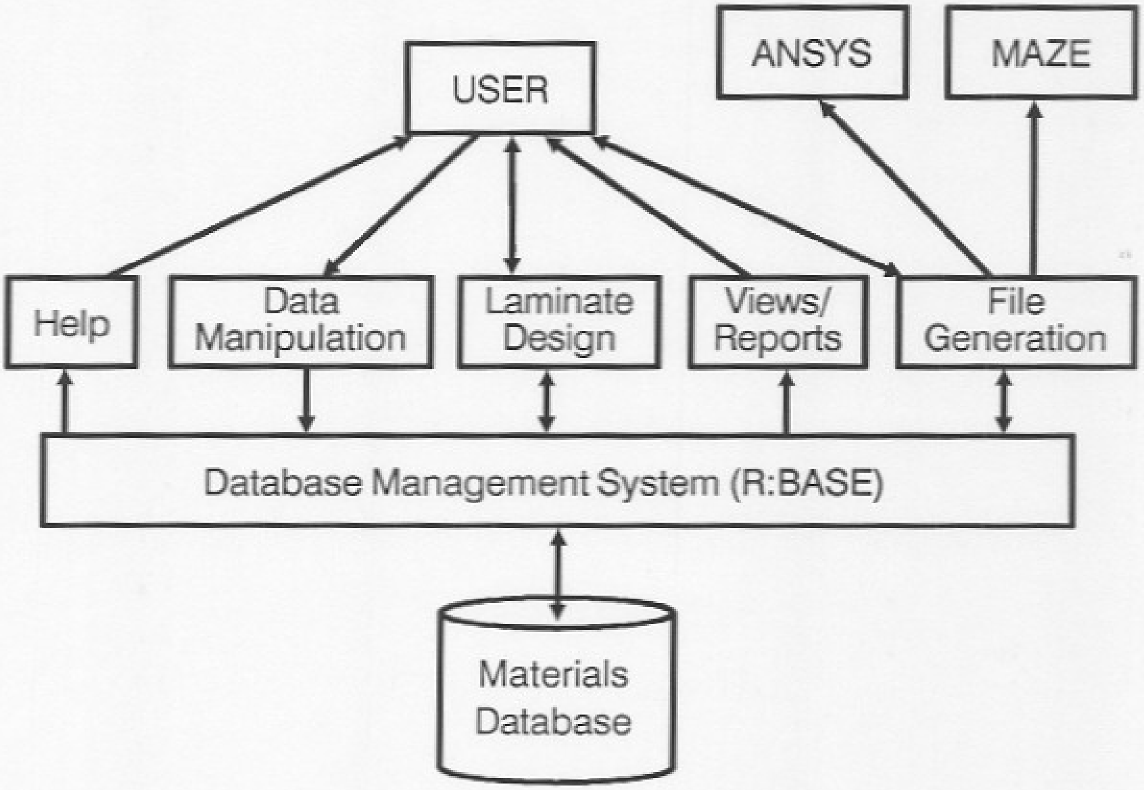

Figure 1: Functional capabilities of CDI

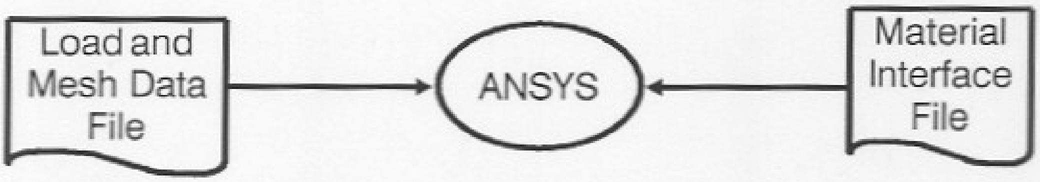

Figure 2: Data flow for ANSYS integration

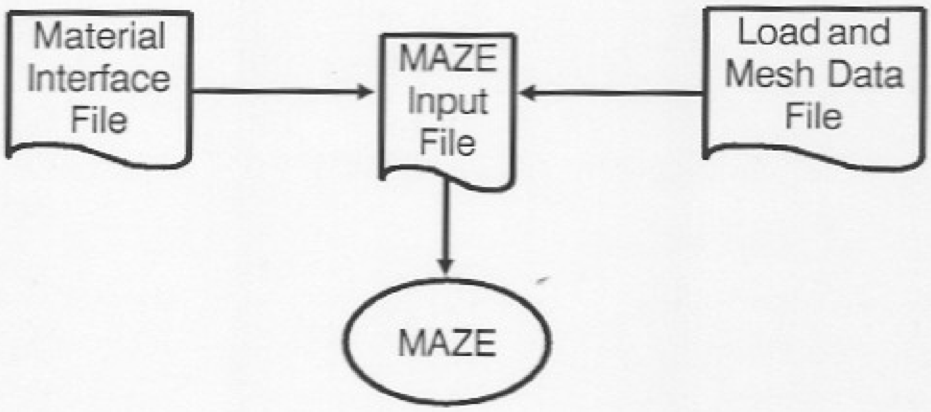

Figure 3: Data flow for MAZE integration