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USING PAFEC AS A PREPROCESSOR FOR MSC/NASTRAN*

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Abstract: Programs for Automatic Finite Element Calculations (PAFEC) is a general-purpose, three-dimensional, linear and nonlinear finite element program [1]. PAFEC's features include free-format input using engineering keywords, powerful mesh-generating facilities, sophisticated database management procedures, and extensive data validation checks. Presented here is a description of a software interface that permits PAFEC to be used as a preprocessor for MSC/NASTRAN. This user-friendly software, called PAFMSC, frees the stress analyst from the laborious and error-prone procedure of creating and debugging a rigid-format MSC/NASTRAN bulk data deck. By interactively creating and debugging a finite element model with PAFEC, thus taking full advantage of the free-format, engineering-keyword-oriented data structure of PAFEC, the stress analyst can drastically reduce the amount of time spent during model generation. The PAFMSC software will automatically convert a PAFEC data structure into an MSC/NASTRAN bulk data deck. The capabilities and limitations of the PAFMSC software are fully discussed in the following report.

Introduction

Numerous general-purpose programs are currently available to assist engineers during the data preparation phase of a NASTRAN finite element method problem. The goal of these preprocessors is to accept a minimum amount of user data and create the rigid-format input data structure required by the MSC/NASTRAN Bulk Data (NBD), since the NBD is devoid of any sophisticated automatic data generation schemes. Two such sets of software [2,3] developed for the COSMIC/NASTRAN program were presented at the 1982 COSMIC/NASTRAN conference. Many others have been developed. Properly designed preprocessing aids, like these, can greatly reduce the time spent by an engineer in creating the rigid format required by the NBD. If these aids are interactively executed, much correcting and debugging of a finite element model can be accomplished prior to submission of even the first MSC/NASTRAN execution for a new problem. Although most of the available preprocessing aids for MSC/NASTRAN meet their design goals, the authors of this paper prefer to use the free-format data preparation and automatic mesh generation capabilities of the PAFEC suite of finite element computer programs. This paper describes software developed for using PAFEC as a preprocessor for MSC/NASTRAN.

At the National Magnetic Fusion Energy Computing Center (NMFECC), MSC/NASTRAN is leased upon CRAY-1 computer equipment. It is generally executed in a batch processing mode. Serving as interactive front ends to the CRAY-1 machines are several DECsystem-10 computers, called User Service Centers (USCs), that are physically located at individual national laboratories. Within the Oak Ridge National Laboratory (ORNL) USC computer environment, users generally prefer to create data interactively on the user-friendly DECsystem-10s and then to route these data to the CRAY-1 mainframe batch queues for number crunching. Because PAFEC can best be used in an interactive environment, the DECsystem-10s were chosen as the computers upon which to execute PAFEC (although there is a version of PAFEC on the CRAY-1 computers).

The PAFEC suite of program modules is executed as a collection of ten separate phases that create and operate upon a database called the Backing Store (BS) file. Among other capabilities, PAFEC has extensive mesh generation facilities; a free-format, engineering-keyword-oriented, modular data preparation scheme; extremely simple methods to represent repetitive data values; automatic load generation facilities; and a complete graphics software package to display the created finite element data. An optionally available interactive program, the PAFEC Interactive Graphics Suite (PIGS), can be obtained to enhance all the abovementioned capabilities. PAFEC is not simply a preprocessor. Solution sequences exist for linear static and dynamic structural mechanics problems as well as for treating certain classes of nonlinear structural mechanics and heat transfer problems.

On the ORNL DECsystem-10 USC an additional facility has been implemented in the PAFEC control scheme that will automatically invoke the PAFEC-to-MSC/NASTRAN preprocessor for a stress analyst. Mnemonically designated PAFMSC [4], this software contains several subroutines. The main subroutine, called PAFNBD, serves as a controller for the other subroutines. The other subroutines convert the PAFEC BS internal format for the axis systems, nodal points, material properties, element topologies, element properties, and single-point or multipoint constraints into the rigid format of the MSC/NASTRAN NBD. Unique rigid-format continuation card mnemonics are generated as necessary. Upon successful completion of PAFEC PHASE 4, the user's job will have created a disk file, <name>04.NBD, that contains the MSC/NASTRAN NBD (<name> represents the user's PAFEC finite element model job name and 04 is appended to the job name to indicate the file was created in PHASE 4). Thus, the stress analyst can interactively generate, debug, and display a finite element model with PAFEC; convert a model to MSC/NASTRAN rigid-format bulk data using user-friendly software; and then solve the model using MSC/NASTRAN upon one of the larger mainframe computers at the NMFECC.

Organization

First, a discussion of the most salient features of the model-generating capabilities of PAFEC is presented. (Although PAFEC has complete solution

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capability, this is not discussed here as it is not germane to the subject of this report.) Second, we describe the details of subprogram PAFMSC and its supporting software, as well as the modifications to the PAFEC executive control required to implement the user interface to this software. Finally, an example using this software is presented.

Model Generation with PAFEC

The PAFEC modular data system has many advantages. From the user's standpoint, the finite element data are very easy to input and are intelligible without additional documentation. Additionally, data prepared for other finite element programs can be used as input data by PAFEC with little text-editing manipulation. From the system's standpoint, the data modules are easily scanned to determine the solution sequence and the software required to perform the user's specific finite element task [5].

A PAFEC data module consists of three parts: (1) the module header card, (2) the module contents card, and (3) the free-format numerical data. The module header card and the numerical data are required for every module that the user inputs for a particular finite element problem. (Only those data modules that are needed are entered as data.) The contents card is optional and is used to alter the default definition of certain parts of the data or to change the order of the numerical data located in the third part of the data module. An example of the NODES data module, a fundamental data module, is presented to demonstrate the three parts of the PAFEC modular data:

```
NODES
Z=0.0
NODE        X       Y
   1       0.0     0.0
   2       0.0     1.0
```

The first card represents the module header card, the second card is a constant contents data card, the third card is a contents data card, and the last two cards present the free-format nodal numerical data.

Other data modules can be used to define nodal coordinates; among these are:

NODES — The NODES module can be used to define nodal coordinates in any axis set.

AXES — The AXES module can be used to define different axis sets.

SIMILAR.NODES — Once any number of nodes has been defined, the SIMILAR.NODES module can be used to define other nodes that are similar but perhaps more conveniently located in another axis system.

LINE.NODES — The LINE.NODES module can be used to define any number of nodes to lie upon the same straight line.

ARC.NODES — Similar to the LINE.NODES module, the ARC.NODES module can be used to define any number of nodes to lie upon the same circular arc.

PAFBLOCKS — When used in conjunction with the MESH module, the PAFBLOCKS module will cause two- and three-dimensional blocks of nodes and elements to be generated.

Several data modules are used in the description of finite element topology, types, material properties, and thicknesses. These modules include:

ELEMENTS — The ELEMENTS module describes the element type, properties, group number, and topology for individual elements.

PAFBLOCKS — When used in conjunction with the MESH module, the PAFBLOCKS module will cause two- and three-dimensional blocks of nodes and elements to be generated.

REFERENCE.IN.PAFBLOCKS — The REFERENCE.IN.PAFBLOCKS module permits modification of generated elements within a PAFBLOCK.

PLATES.AND.SHELLS — The PLATES.AND.SHELLS module describes element thicknesses, material number, and other information for membrane, bending, and axisymmetric finite element analysis.

BEAMS — The BEAMS module describes pertinent information for beam elements.

MASSES — The MASSES module is used in dynamic finite element analyses to add mass at nodes.

SPRINGS — The SPRINGS module is used to input simple axial and torsional springs into a finite element analysis.

GROUP.OF.SIMILAR.ELEMENTS — The GROUP.OF.SIMILAR.ELEMENTS module copies selected elements into new elements by simply incrementing element topology. This facility can be used to conveniently describe finite element geometries that contain repetitious sections.

PAFEC examines the data modules describing a structure and the user's control module to determine how many degrees of freedom to permit at each nodal coordinate. To apply constraints at individual or groups of nodes, the following data modules can be used:

RESTRAINTS — The RESTRAINTS module is the most generally used module for describing the degrees of freedon to be constrained. Each row in the data module can be used to describe the constraints at one node, or, if the PLANE and possibly the AXIS entry are used, all the nodes that lie on a line or on a plane can be constrained at once.

ENCASTRE — The ENCASTRE module can be used to constrain all the degrees of freedom for a set of nodes.

SIMPLE.SUPPORTS — The SIMPLE.SUPPORTS module can be used to constrain all the translational degrees of freedom for a set of nodes while leaving the rotational degrees of freedom unchanged.

DISPLACEMENTS.PRESCRIBED

The DISPLACEMENTS.PRESCRIBED module can be used to apply nonzero displacements at certain nodes.

REPEATED.FREEDOMS

The REPEATED.FREEDOMS module is used to constrain two or more nodes to move by an identical amount in a particular direction. This module is useful when slippage is possible at some joint in a structure. When two nodes are arranged to be coincident and therefore to have separate and unrelated degrees of freedom, the REPEATED.FREEDOMS module can be used to define those degrees of freedom that are to be continuous across the joint.

HINGES.AND.SLIDES

The HINGES.AND.SLIDES module is the complement of the REPEATED.FREEDOMS module. Instead of specifying constrained degrees of freedom, this module is used to specify unconstrained degrees of freedom.

LOCAL.DIRECTIONS

The LOCAL.DIRECTIONS module does not describe constraints directly. However, this module can be used to force PAFEC to resolve degrees of freedom in different directions other than the global coordinate axis directions.

GENERALIZED.CONSTRAINTS

The GENERALIZED.CONSTRAINTS module permits writing arbitrary linear functions relating displacements among any number of nodes. Rigid links may be specified with this module.

The PAFMSC Software Interface

The PAFMSC software permits the user to define a finite element model, using the previously discussed modular data dictionary, and then to automatically create a rigid-format, MSC/NASTRAN bulk data deck. Subroutine PAFNBD serves as a controller for several other subroutines, individually discussed below, that are collectively located in the PAFMSC subroutine library. When the user includes the MSC/NASTRAN control directive in a PAFEC control module, then a call to subroutine PAFNBD will be inserted in the PHASE 4 FORTRAN generated for the job. Execution of the PAFNBD subroutine will cause the axis systems, nodal coordinates, material properties, element topologies, element properties, and constrained degrees of freedom to be successively converted from internal PAFEC BS format to MSC/NASTRAN bulk data rigid format. Upon successful completion of the constraint conversion, subroutine PAFNBD returns to the PHASE 4 FORTRAN and normal PAFEC execution.

The PAFMSC software is written in FORTRAN-66 and uses the PAFEC series R09800 subroutines exclusively for accessing the data modules contained in the user's BS file. Therefore, this software is easily implemented in any system where PAFEC has been installed. (A FORTRAN-77 version of the software is being created.) The next several sections discuss the functions of the individual subprograms contained within the PAFMSC software library.

Subroutine PNCOOR

Subroutine PNCOOR performs the processing of axis definitions from PAFEC BS to MSC/NASTRAN format. This subprogram processes each entry of BS module 68 (the internal storage number given to PAFEC axis sets) and writes the appropriate MSC/NASTRAN CORD2R, CORD2C, or CORD2S data cards, depending upon whether the PAFEC coordinate system is rectangular, cylindrical, or spherical, respectively. Unique continuation card mnemonics are generated as necessary.

Subroutine PNNOD

Subroutine PNNOD generates MSC/NASTRAN GRID cards from PAFEC BS module 1 (the internal storage number given to PAFEC global, Cartesian nodal coordinates). All GRID cards are specified in global coordinates. If PAFEC BS module 4 is not empty, then the GRID card will also contain the appropriate output coordinate system designation. Otherwise, the output coordinate system will be the global rectangular coordinate system.

Subroutine PNMAT

Subroutine PNMAT creates MSC/NASTRAN MAT1 data cards from PAFEC BS module 31 (the internal storage number given to the PAFEC materials data). Only isotropic elastic materials are converted, a subprogram PNMAT limitation. Each material in the data module is reformatted and written onto the output file with unique continuation card mnemonics.

Subroutine PNETOP

Subroutine PNETOP processes the element data stored in PAFEC BS modules 17 and 18. Each element definition is processed individually with mappings from PAFEC element types and topologies to MSC/NASTRAN element types and their corresponding topologies. The following element mappings are currently supported.

PAFEC element mnemonic	MSC/NASTRAN element	Element type
30100	CELAS2	Spring
30200	CMASS2	Mass
34000	CLAR	Simple beam
34200	CBAR	Offset beam
34400	CROD	Simple rod
36100	CTRMEM	Triangular membrane
36200	CQDMEM	Quadrilateral membrane
37100	CHEXA	8-node brick
37120	CHEXA	20-node brick
37200	CPENTA	6-node wedge
41320	CTRIA3	Triangular plate
43110	CTRIA6	6-node triangular plate
44100	CTRIA3	Triangular plate
44200	CQUAD4	4-node quadrilateral plate

Unique continuation card mnemonics are generated for each element type requiring a multicard element topology. Also, special processing is required for each PAFEC spring element (number 30100) and mass element (number 30200) since each of these elements may yield as many as six MSC/NASTRAN CELAS2 or CMASS2 element data cards. (Unique element numbers are generated for any newly created elements.)

Subroutine PNPROP

Subroutine PNPROP performs generation of MSC/NASTRAN element property cards. Several PAFEC BS modules are examined and the following mapping is used to create the appropriate MSC/NASTRAN property cards.

PAFEC element mnemonic	MSC/NASTRAN property card
30100	PELAS
34000	PBAR
34200	PBAR
34400	PROD
36100	PTRMEM
36200	PQDMEM
37100	PSOLID
37120	PSOLID
37200	PSOLID
41320	PSHELL
43110	PSHELL
44100	PSHELL
44200	PSHELL

Subroutine PNDOF

Subroutine PNDOF processes constraint data stored in PAFEC BS module 2. Each degree of freedom is examined for constraint codes. Any constrained degree of freedom generates an appropriate MSC/NASTRAN SPC data card. PAFEC REPEATED.FREEDOMS are output as MSC/NASTRAN MPC data cards for the repeated degrees of freedom.

Subroutine PGCMPC

If GENERALIZED.CONSTRAINTS are defined via PAFEC BS module 143, then subroutine PGCMPC generates appropriate MSC/NASTRAN data cards for each generalized constraint. An arbitrary limitation of three independent nodes for any dependent node has been set in subroutine PGCMPC. Unique continuation card mnemonics are generated as necessary.

Integration of the PAFMSC Software Interface into the PAFEC MACRO Dictionary

Minor additions to the PAFEC MACRO dictionary were all that was necessary to completely implement the PAFMSC software into the PAFEC PHASE execution scheme. The PAFEC MACRO dictionary is used by the PAFEC driving program to create FORTRAN and job control information for a particular PAFEC PHASE. Within each PAFEC user data file there exists a control module and possibly several sets of data modules. (The PAFEC control module is analogous to the executive and case control cards of an MSC/NASTRAN data deck.) Based upon the user-specified PAFEC control directives, the PAFEC driver program determines which PHASE and what subroutine within the PHASE should be executed. In order to permit a user-friendly interface between the PAFEC system and the PAFMSC software, a single new control directive, appropriately named MSC/NASTRAN, was added to the PAFEC MACRO dictionary.

PHASE 4 was chosen as the appropriate PHASE to create an MSC/NASTRAN NBD, due to its finite element model generation completeness. The MACRO dictionary was modified to conditionally include a call to subroutine PAFNBD (the driver for the PAFMSC software) in the PHASE 4 FORTRAN, based upon the presence or absence of the MSC/NASTRAN control directive. Similarly, an instruction was inserted to conditionally include the precompiled PAFMSC relocatable object module in the linkage edit step of the PHASE 4 job control. Therefore, to access the PAFMSC software all the user must do is to simply insert the phrase MSC/NASTRAN following the PHASE=4 PAFEC control directive somewhere within his control module. For example, the following few lines represent a valid PAFEC control module that would invoke the PAFMSC software:

```
CONTROL
NAME.ABCD
PHASE=4
MSC/NASTRAN
STOP
CONTROL.END
```

An Illustrative Example

This rather academic example demonstrates most of the capabilities of the PAFMSC software. It is intentionally brief so that a very small MSC/NASTRAN bulk data deck is created. The following listing is a copy of the PAFEC data deck that generates the small three-dimensional plate finite element model shown in Fig. 1.

```
TITLE PAFMSC TEST
CONTROL
SAVE.RESULTS
CONCATENATE.OUTPUT
SAVE.PLOTS
NAME.T
PHASE=4
MSC/NASTRAN
STOP
CONTROL.END
NODES
NODE.NO X.IN     Y.IN     Z.IN
1
2        1.5      0        0.8
3        3.0
4        0        5.0
5        0.75     5        0.4
6        1.5      5.0
PAFBLOCKS
ELEMENT=44200
N1       N2       TOPOLOGY.OF.BLOCK
1        2        1 3 4 6 2 0 0 5
MESH
REFER    SPACING
1        2
2        2 1.5 1
PLATES.AND.SHELLS
MATERIAL          THICKNESS.IN
1                 0.81
MATERIALS
MATERIAL          E         NU        RO
1                 27E6      .27       7.7
RESTRAINTS
NODE     PLANE    DIRECTION
1        2        0
MODES.AND.FREQ
AUTOMATIC.MASTERS           MODES
10                          4
END.OF.DATA
```

After successful execution of PHASE 4 on an ORNL DECsystem-10 computer using the above PAFEC data, a file, T04.NBD, is created containing the MSC/NASTRAN bulk data deck. For completeness this data deck is listed in Fig. 2. All that remains for the user to do is to add an executive and case control deck to the above file, merge this file with the CRAY-1 CCSMOS procedure for executing MSC/NASTRAN at the NMFECC, and then submit the job. (This example was intentionally kept small so that the generated MSC/NASTRAN bulk data deck would be a reasonable size. By changing the spacing data in the MESH module of the PAFEC data deck, significantly more MSC/NASTRAN data cards could be generated.)

GRID	1		0.000	0.000	0.000	0			
GRID	2		1.500	0.000	0.800	0			
GRID	3		3.000	0.000	0.000	0			
GRID	4		0.000	5.000	0.000	0			
GRID	5		0.750	5.000	0.400	0			
GRID	6		1.500	5.000	0.000	0			
GRID	7		0.000	2.222	-0.000	0			
GRID	8		1.167	2.222	0.622	0			
GRID	9		2.333	2.222	0.000	0			
GRID	10		-0.000	3.889	-0.000	0			
GRID	11		0.917	3.889	0.489	0			
GRID	12		1.833	3.889	0.000	0			
MAT1	12.70E+071.06E+07			2.707.70E+000.00E+00					+MAT001
+MAT001									
SPC	10000	1	123456						
SPC	10000	2	123456						
SPC	10000	3	123456						
SPC	10000	4	6						
SPC	10000	6	6						
SPC	10000	7	6						
SPC	10000	9	6						
SPC	10000	10	6						
SPC	10000	12	6						
CORD2R	1	0	0.0	0.0	0.0	0.0	0.0		1.0+C2R001
+C2R001	1.0	0.0	0.0						
CORD2C	2	0	0.0	0.0	0.0	0.0	0.0		1.0+C2C002
+C2C002	1.0	0.0	0.0						
CORD2S	3	0	0.0	0.0	0.0	0.0	0.0		1.0+C2S003
+C2S003	1.0	0.0	0.0						
CQUAD4	1	1	1	2	8	7			
CQUAD4	2	1	2	3	9	8			
CQUAD4	3	1	7	8	11	10			
CQUAD4	4	1	8	9	12	11			
CQUAD4	5	1	10	11	5	4			
CQUAD4	6	1	11	12	6	5			
PQUAD4	1	1	0.81	1					

Fig. 1. The finite element mesh for the example problem showing the element and nodal numbers.

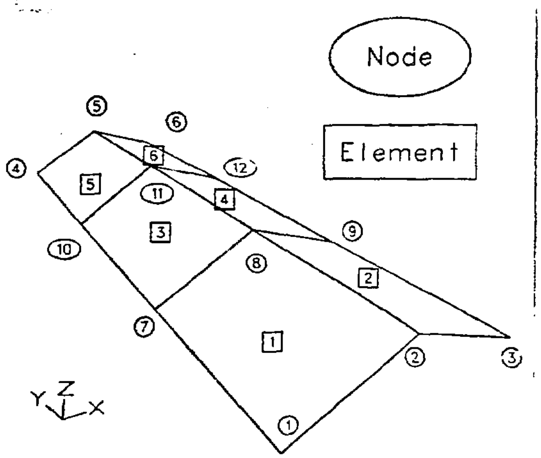

Fig. 2. Reproduction of the MSC/NASTRAN bulk data deck created by the PAFMSC program from the PAFEC data presented in the example problem.

Concluding Remarks

For production problems, using PAFEC and the PAFMSC software as a preprocessor for MSC/NASTRAN eliminates much of the tedious and repetitive typing of the cards necessary for a finite element analysis. This software has been used to preprocess several large magnet structural analysis problems at ORNL and has demonstrated a large reduction in the total number of cards typed by a user for these problems. Future improvements are planned to convert and/or create even more of the data.

References

[1] PAFEC Ltd., PAFEC 75 Systems Reference Manual, Nottingham, England, November 1978.

[2] L. L. Durocher and A. F. Gasper, "An Interactive Review System for NASTRAN," in Proceedings of the Tenth NASTRAN Users' Colloquium, NASA CP-2249, May 1982, pp. 45–64.

[3] E. F. Hirt and G. L. Fox, "Recent Developments of NASTRAN Pre- and Post-Processors: Response Spectrum Analysis (RESPAN) and Interactive Graphics (GIFTS)," in Proceedings of the Tenth NASTRAN Users' Colloquium, NASA CP-2249, May 1982, pp. 18–44.

[4] A similar implementation of this software is called PAFCOS. It converts a PAFEC data base into a COSMIC/NASTRAN NBD. Documentation for the PAFCOS software may be found in: W. H. Gray and T. V. Baudry, "Using PAFEC as a Preprocessor for COSMIC/NASTRAN," in Proceedings of the Eleventh NASTRAN Users' Colloquium (to be published).

[5] PAFEC Ltd., PAFEC For the Engineer, Nottingham, England, Feburary 1981.