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VERIFICATION OF FANTASTIC INTEGRATED CODE

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ABSTRACT

FANTASTIC is an acronym for Failure Analysis Nonlinear Thermal and Structural Integrated Code. This program has been developed by Failure Analysis Associates, Palo Alto, California for MSFC in order to improve the accuracy of solid rocket motor nozle analysis. Its first version has been released and received by the Thermal Systems Branch of MSFC. FANTASTIC has three modules:

a. FACT: It is the thermochemical analysis module

b. FAHT: It is the heat transfer analysis module

c. FAST: It is the structural analysis module

All modules have keywords for input of data. Work is in progress for the verification of FAHT module. This is being done by using data for various problems with known solutions as inputs to the FAHT module. The information obtained by running these programs is used to pinpoint problem areas of this code and passed on to the developer for removing bugs from this code. As a result of this procedure, Failure Analysis Associates have revised the first version of the FANTASTIC code and a new improved version has been released and received by the Thermal Systems Branch. Further work to verify the new version is continued:

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1. Introduction

Failure Analsysis Associates, Palo Alto, California has developed an advanced computer code for MSFC to improve the accuracy of the solid rocket motor analysis. The computer code is called "FANTASTIC", an acronym for Failure Analysis Nonlinear Thermal and Structural Integrated Code. The code incorporates a higher order integration scheme for modeling steep temperature and strain gradients. It has a modular design and is intended as a multi-purpose thermostructural analysis code.

FANTASTIC has not been verified before. In order to use this code for the intended purpose outlined above, it is necessary to verify it. The purpose of this report is to give an overview of the procedure followed to verify this code.

2. Procedure

FANTASTIC consists of three modules:

1. FACT: It is the thermochemical analysis module
2. FAHT: It is the heat transfer analysis module
3. FAST: It is the structural analysis module

Because FANTASTIC can be used for a stand-alone thermal or structural analysis, FAHT module was chosen for verification purpose. FAHT module accepts data under numerous keywords. All keywords of FAHT are divided into three blocks:

1. PARAMETER Block: This block is used to provide a title and analysis procedure (i.e., steady or transient etc.) options.

2. MODEL Block: This block is used to provide the details of the model geometry, material, and boundary conditions.

3. INCREMENT Block: This block is used to provide the loading history in the form of various types of incremental loads.

A list of the keywords under each block is given in Table 1. The data must be input as required by the program format.

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2-1 MODEL Geometry

The first requirement in setting up the numerical problem for execution by FAHT is to define the domain of solution. Then this domain is divided into appropriate number of "finite elements". There are various types of elements and an element can have nodes ranging from 2 (link element) to 20 (isoparametric hexahdron element). A list of the names for various types of elements covered by FAHT is given in Table 2. As a general rule more accuracy is obtained by selecting eight noded planar element than four noded planar element for the same curved geometry. In three dimensional problems up to 20 noded elements may be chosen depending upon the geometry. Each node is fixed by a set of coordinates which are input under an appropriate keyword in the MODEL block.

2.2 Material Description

There are a total of 12 FAHT material types. Each material type is defined by a set of properties. For example Type 1 - Thermal: Linear Isotropic material requires three properties namely mass density, specific heat, and thermal conductivity whereas Type 41 - Isothropic three-component charring and decomposing material requires 32 properties to be specified. A list of FAHT material types is given in Table 3.

2.3 Loading Conditions

Loading conditions treated by FAHT include convection, enclosure radiation, lumped heat capacity, and heat sink/source. The convection option is implemented through the keyword *HEATCONVECTIONBC group. The radiant heat exchange option is implemented through the *ENCLOSURERADIATION and *VIEWFACTOR groups. Lumped heat capacity option is implemented via the *LUMPEDHEATCAPACITY group. A volumetric heat sink or source can be defined as a function of time or temperature via the *HEATGENERATION GROUP.

2.4 Boundary Conditions

Boundary conditions for the heat transfer analysis may be specified in terms of prescribed tempersture or heat flux along external boundaries or internal surfaces (e.g., contact resostance or heat flux across gaps between surfaces). This option is implemented via the *TEMPERATUREBC and *HEATFLUXBC groups.

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2.5 Initial Conditions

Initial temperatures may be specified in FAHT at each node. Internal heat generation rates can also be specified as functions of time or temperature.

3. Illustrative Example

Consider a two-dimensional steady state heat transfer in a material with constant thermal conductivity. A schematic showing the boundary conditions is given in Figure 1. The geometry has 32 elements. Each element has four nodes. Thus the total number of nodes is 45. The element type from Table 2 is type number 21, planar quadrilateral. The material type is assumed to be type number 1, thermal: linear isotroic. Therefore, three properties namely mass density, specific heat, and thermal conductivity are required to be specified. This information is given in the material library section of the FAHT user's manual. The input for the implementation of FHAT for this problem under suitable keywords of the PARAMETER block, MODEL block, and the INCREMENT block respectively is given below. Explanations for the input data are also given:

PARAMETER BLOCK

*TITLE

Two Dimensional Steady State Heat Transfer

*TEMPERATURE

This keyword is used because the heat transfer analysis is to be performed in the next time period.

*ENDPARAMETER

This keyword is used to define the end of the PARAMETER block.

MODEL Block

*NODE

This group is used to define nodal coordinates. A node setname must also be defined for a group of nodes.

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NODESET 2

Here NODESET is the name of the node set consisting of all 45 nodes.

1 0.0 0.0

The first number 1, denotes a node which is assigned number 1 with coordinates x = 0.0, y = 0.0. The next two numbers 0.0 and 0.0 denote the x and y coordinates of node 1.

9 2.0 0.0 1

The first number 9, denotes a node which is assigned number 9 with coordinates x = 2.0, y = 0.0. The next two numbers 2.0 and 0.0 denote the x and y coordinates of node 9. The last number 1, denotes the increment for nodes bwetween nodes 1 and 9. The coordinates of nodes 2 through 8 are generated automatically by the build in generator in the code. We can similarly input the coordinates of the remaining nodes as given below.

10	0.0	0.25	
18	2.0	0.25	1
19	0.0	0.50	
27	2.0	0.50	1
28	0.0	0.75	
36	2.0	0.75	1
37	0.0	1.00	
45	2.0	1.00	1

*ELEMENT

This group is used to define element connectivity. Each element must be assigned a unique element number. An element set name must also be defined for each group of elements.

ELSET 21 1

The name of the element set consisting of all 32 elements is ELSET. The number 21 denotes the element type number and the next number 1 denotes the mateiral number for the elements in this set.

1 1 2 11 10 7 1

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The first number 1 denotes an element of the set. The next four numbers 1, 2, 11, and 10 denote that the element is connected by these four nodes. The next two numbers 7 and 1 denote that there are 7 similar elements with increment 1. This data line, therefore, covers input for eight elements 1 through 8. The data for remaining elements is input similarly as below:

9	10	11	20	19	7	1
17	19	20	29	28	7	1
25	28	29	38	37	7	1

*SET

This group is used to define additional node and element sets. Each set must be assigned a unique set name. A node set or an element set may be defined as a list of (node or element) numbers or as a list of (node or element) number ranges.

NODESET 1 1 2

Here NODESET 1 is the name of a node set consisting of nodes 1 through 9. Number 1 denotes that the set-type is node set. (If this number is 2, it would have denoted that the set type is element set). The next number 2 denotes the list tye. Here it means that we are going to input a <u>range</u> of set nodes.

1 9

The number 1 denotes the first node number and number 9 denotes the last node number (range from node 1 through 9).

NODESET 2 1 1

Here NODESET 2 is the name of the node set consisting of nodes 18, 27, 36, and 45. Number 1 denotes the settype (here node set) and the next number 1 denotes that the list type is for a list of node(s) given below.

18 27 36 45

*TEMPERATUREBC

10	383.0
19	707.0
28	924.0
37	1000.0

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Above we have input for specified temperatures at nodes 10, 19, 28, and 37. Another method to input specified temperature boundary condition for a node set is shown below:

NODESET 1 0.0

NODESET 2 0.0

All nodes in NODESET 1 and NODESET 2 have a specified temperature of 0.0.

*PROPERTY

This group is used to define material properties.

1 1

The first number 1 denotes the material number and the second number 1 denotes the material type (in this example - thermal: linear isotropic). So, three properties namely mass density, specific heat, and thermal conductivity are input in that order as below:

1 1 1

*END MODEL

This keyword is used to define the end of the MODEL block.

*PRINT

This group is used to select the desired printed output printcode 10 is used for printing of temperatures.

NODESET 10

With this input temperatures for all nodes in the set NODESET are printed.

*ENDINCREMENT

This keyword is used to define the end of the INCREMENT block.

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4. CONCLUSIONS

Ten problems with known solutions were used for input of data to FAHT. Based on the runs made and their results, it was found that FAHT needed revision because of bugs in the program. For example, the program was not able to recognize a few keywords for input of data.

The solutions of many problems did not match the known solutions. This indicated that the program needed an overhaul. This information was passed on to the developer, Failure Analysis Associates. Based on these results, the developer has been able to remove bugs and has supplied MSC with a new version of FANTASTIC with workable FAHT module.

TABLE 1 VARIOUS DATA BLOCKS AND KEYWORDS FOR FAHT

PARAMETER Block

*TITLE . . . . . .
*FACT . . . . . .
*TEMPERATURE . . . . . .
*POREPRESSURE . . . . .
*FAST . . . . . .
*TRANSIENT . . . . . .
*NONLINEAR . . . . . .
*ENDPARAMETER . . . . .

MODEL Block

*NODE . . . . . .
*ELEMENT . . . . . .
*SET . . . . . .
*CROSSSECTION . . . . . .
*PROPERTY . . . . . .
*MATERIALDIRECTION .
*TEMPERATUREBC . . . .
*PRESSUREBC . . . . . .
*HEATFLUXBC . . . . . .
*MASSFLUXBC . . . . . .
*INITIALTEMPERATURE .
*INITIALPRESSURE . . . .
*HEATCONVECTIONBC .
*THERMALGAPCONTACT
*LUMPEDHEATCAPACITY
*HEATGENERATION . . .
*NONLINEARHEATBC . . .
*TIMETEMPFUNCTION . .
*ENCLOSURERADIATION .
*VIEWFACTOR . . . . . .
*ENDMODEL . . . . . .

INCREMENT Data Block

*TRANSIENT . . . . . .
*NONLINEAR . . . . . .
*RESTART . . . . . .
*PRINT . . . . . .
*REPORT . . . . . .
*POST . . . . . .
*ENDINCREMENT . . . . . .

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Table 2: FAHT Element Types

Type Number	Element Description	Number of Nodes
11	Link	2
21	Planar quadrilateral	4
22	Planar quadrilateral	8
25	Axisymmetric quadrilateral	4
26	Axisymmetric quadrilateral	8
31	Solid hexahedron	8
32	Solid hexahedron	20
41	2-D planar interface	4
42	2-D planar interface	6
45	Axisymmetric interface	4
46	Axisymmetric interface	6
51	3-D interface	8
52	3-D interface	16

Table 3: FAHT Material Types

Type Number	Material Description	Number of Properties
1	Thermal: linear isotropic	3
2	Thermal: time or temperature dependent isotropic	6
11	Diffusion: linear isotropic	4
12	Diffusion: time or temperature dependent isotropic	8
21	Thermal: linear orthotropic	8
22	Thermal: time or temperature dependent orthotropic	16
31	Diffusion: linear orthotropic	9
32	Diffusion: time or temperature dependent orthotropic	18
41	Isotropic three-component charring and decomposing material	32
42	Isotropic time or temperature dependent three-component charring and decomposing material	
43	Orthotropic three-component charring and decomposing material	
44	Orthotropic time or temperature dependent three-component charring and decomposing material	

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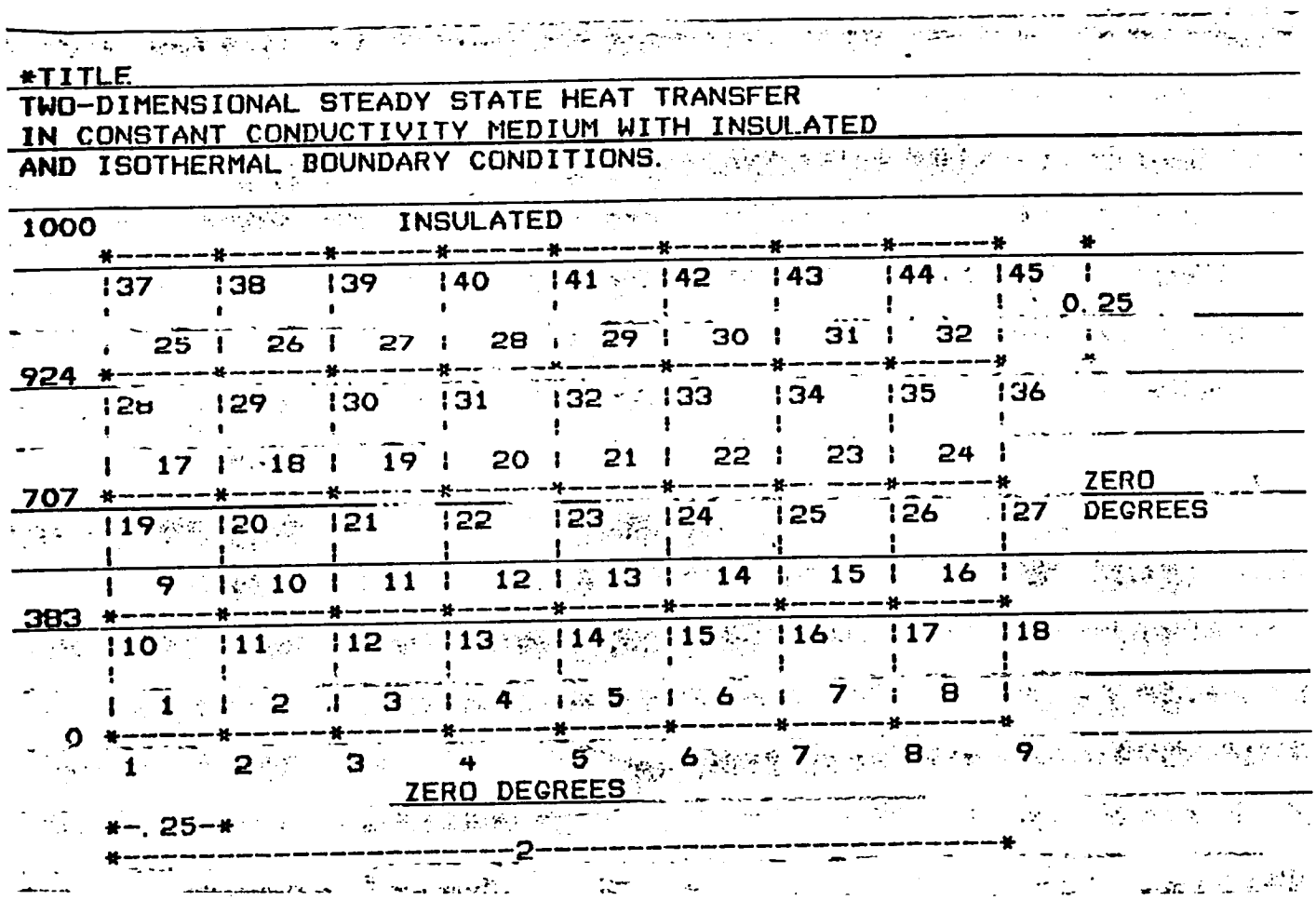

FIGURE 1 MODEL GEOMETRY SHOWINGS NODES (*), NODE NUMBERS 1 THROUGH 45, ELEMENTS 1 THROUGH 32, AND BOUNDARY CONDITIONS