Report 4134

. SHIP RESEARCH AND DEVELOPMENT CENTER
Bethesda, Maryland 20034

ADDITIONS TO THE NASTRAN USER'S MANUAL AND THEORETICAL MANUAL FOR A THERMOSTRUCTURAL CAPABILITY FOR NASTRAN USING ISOPARAMETRIC FINITE ELEMENTS

Myles M. Hurwitz

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COMPUTATION AND MATHEMATICS DEPARTMENT

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Additions to the NASTRAN User's Manual and Theoretical Manual for a Thermostructural Capability for NASTRAN Using Isoparametric Finite Elements

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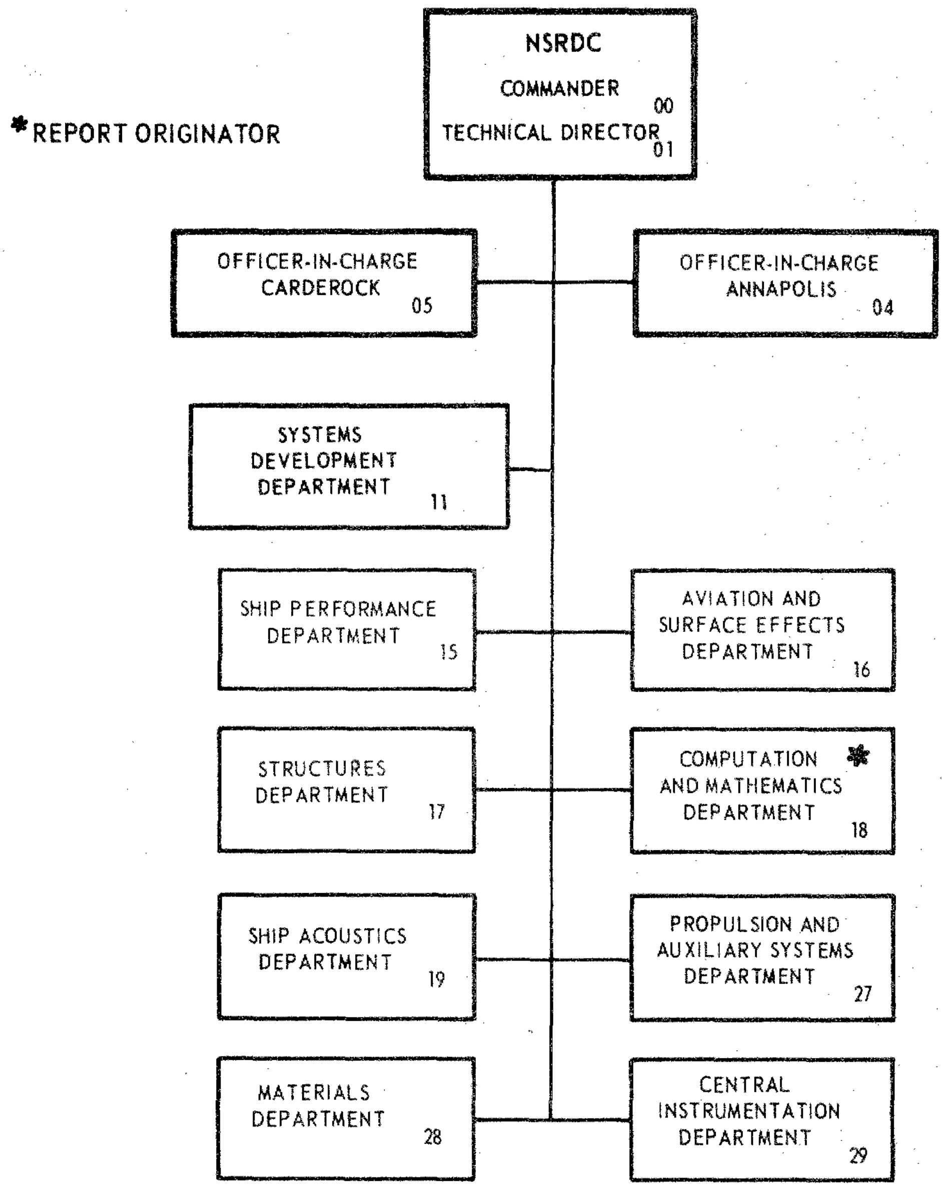

ABSTRACT

This report describes, through additions and modifications to the Level 15.1 NASTRAN User's and Theoretical Manuals, a thermostructural capability for NASTRAN. In addition to this new rigid format, a set of two-dimensional and three-dimensional isoparametric finite elements was added to NASTRAN's finite element library. The thermostructural capability consists of computing a temperature history of the structure, taking account of such thermal conditions as radiation, convection, flux, and heat generation, and then performing a series of structural static analyses, using as part of the static loading the equivalent loads due to the temperature distribution at times selected by the user.

This version of NASTRAN is available for the UNIVAC 1108 and CDC 6000 computers.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

This report describes the thermostructural capability which has been added to the NASTRAN structural analysis program. The report consists of modifications and additions to the Level 15.1.1 NASTRAN User's and Theoretical Manuals. The page numbers on the following pages correspond to the page numbering in those manuals. A brief description and general flow of the new capability are given in Chapter 19 of the Theoretical Manual.

This version of NASTRAN is available for the UNIVAC 1108 and CDC 6000 computers.

USER'S MANUAL ADDITIONS

The material property definition cards are used to define the properties for each of the materials used in the structural model. The MAT1 card is used to define the properties for isotropic materials. The MATS1 card specifies table references for isotropic material properties that are stress dependent. The TABLES1 card defines a tabular stress-strain function for use in Piecewise Linear Analysis. The MATT1 card specifies table references for isotropic material properties that are temperature dependent. The TABLEM1, TABLEM2, TABLEM3, and TABLEM4 cards define four different types of tabular functions for use in generating temperature dependent material properties.

The MAT2 card is used to define the properties for anisotropic materials. The MATT2 card specifies table references for anisotropic material properties that are temperature dependent. This card may reference any of the TABLEM1, TABLEM2, TABLEM3, or TABLEM4 cards.

The MAT3 card is used to define the properties for orthotropic materials used in the modeling of axisymmetric shells. This card may only be referenced by CTRIARG, CTRAPRG and PTORDRG cards. The MATT3 card specifies table references for use in generating temperature dependent properties for this type of material.

The MAT7 card is used to define the properties for isotropic materials for isoparametric elements and for BAR elements in thermal problems. The MATT7 card specifies table references for isotropic material properties that are temperature dependent. This card may reference any of the TABLEM1, TABLEM2, TABLEM3, and TABLEM4 cards.

The MAT8 card is used to define the properties for anisotropic materials for two-dimensional isoparametric elements. The MATT8 card specifies table references for anisotropic material properties that are temperature dependent. This card may reference any of the TABLEM1, TABLEM2, TABLEM3 and TABLEM4 cards.

The MAT9 card is used to define the properties for anisotropic materials for solid isoparametric elements. The MATT9 card specifies table references for anisotropic material properties that are temperature dependent. This card may reference any of the TABLEM1, TABLEM2, TABLEM3, and TABLEM4 cards.

If MATT7, MATT8, or MATT9 cards are used in Rigid Format 14, TRANGE cards must be specified for each referenced table. TRANGE cards will cause the tabular functions specified on TABLEM1, TABLEM2, TABLEM3, and TABLEM4 cards to be changed into step functions to be used in the thermal transient analysis.

The GENEL card is used to define general elements whose properties are defined in terms of deflection influence coefficients and which can be connected between any number of grid points. One of the important uses of the general element is the representation of part of a structure by means of experimentally measured data. No output data is prepared for the general element is the representation of part of a structure by means of experimentally measured data. No output data is prepared for the general element. Detail information on the general element is given in Section 5.7 of the Theoretical Manual.

Dummy elements are provided in order to allow the user to investigate new structural elements with a minimum expenditure of time and money. A dummy element is defined with a CDUMi (i = index of element type, $1 \leq i \geq 9$) card and its properties are defined with the PDUMi card. The ADUMi card is used to define the items on the connection and property cards. Detail instructions for coding dummy element routines are given in Section 6.8.13 of the Programmer's Manual.

1.3.2 Bar Element

The bar element is defined with a CBAR card and its properties (constant over the length) are definedwith PBAR card. The bar element includes extension, torsion, bending in two perpendicular planes and the associated shears. The shear center is assumed to coincide with the elastic axis. Any five of the six forces at either end of the element may be set equal to zero by using the pin flags on the CBAR card. The integers 1 to 6 represent the axial force, shearing force in Plane 1, shearing force in Plane 2, axial torque, moment in Plane 2 and moment in Plane 1 respectively. The structural and nonstructural mass of the bar are lumped at the ends of the element, unless coupled mass is requested with the PARAM card COUPMASS (see Section 3.5.1). Theoretical aspects of the bar element are treated in Section 5.2 of the Theoretical Manual.

1.3.10 Isoparametric Elements

NASTRAN includes six isoparametric elements, two planar elements, two solid elements, and two surface elements. A one dimensional element is also available for use on problems using isoparametric elements. The two planar elements are of the membrane type only. The elements are defined by connection cards as follows:

1. CIS2D4 - planar linear element with four grid points. (quadrilateral)
2. CIS2D8 - planar quadratic element with eight grid points. (quadriparabolic)
3. CIS3D8 - solid linear element with eight grid points.
4. CIS3D20- solid quadratic element with twenty grid points.
5. SURF1 - one-dimensional surface element.
6. SURF4 - linear surface element.
7. SURF8 - quadratic surface element.

Theoretical aspects of these elements are treated in Section 5.13 of the Theoretical Manual.

All the isoparametric elements except the three surface elements may be used as either structural or thermal elements. The user must include an APPISO card to indicate which element to use. As thermal elements, however, they may be used only in Rigid Formats 1 and 14. The three surface elements are dummy elements which are used to conveniently apply thermal boundary surface conditions in Rigid Format 14. Also, SURF4 and SURF8 can be used to apply a uniform static pressure load on a surface of an isoparametric element.

The properties of the IS2D4 and IS2D8 elements are given on PIS2D4 and PIS2D8 cards, respectively. The IS3D8 and IS3D20 elements have no corresponding property cards. Material properties for the planar elements are specified on MAT7 and MAT8 cards. These properties may be made temperature dependent by including MATT7 or MATT8 cards. Material properties for the solid elements are specified on MAT7 or MAT9 cards and may be made temperature dependent by including MATT7 or MATT9 cards. Examination of these cards will show that the isoparametric elements may have isotropic or anisotropic materials and that the thermal as well as structural material properties may be temperature dependent.

Either lumped or consistent mass matrices will be computed for the structural elements and lumped or consistent capacitance matrices will be computed for the thermal elements. Lumped matrices will always be computed unless a PARAM card is presented with parameter COUPMASS specified (see Section 3.5.1). Consistent matrices are usually mandatory.

The element coordinate systems for the planar elements are shown in Figures 13 and 14. Symbols G1, G2. ... refer to the required order of the connected grid points on the connection cards defining the elements. The angle θ for the planar elements is the orientation angle for anisotropic materials. (For solid elements, material coordinate systems must be set up when necessary. For further discussion, see Section 5.13.2.2 of the Theoretical Manual.)

Element stresses at grid points are computed when requested. The following real membrane stresses are output for the solid elements on request:

1. normal stresses in the x-, y-, and z-directions.
2. shear stress on the x-face in the y-direction.
3. shear stress on the y-face in the z-direction.
4. shear stress on the z-face in the x-direction.

The following real membrane stresses are output for the planar elements on request:

1. normal stresses in the x- and y-directions.
2. shear stress on the x-face in the y-direction.

Presently no complex stresses are available.

Also available are the average stresses at the grid points, as well as the maximum element grid point stresses. These represent the normal output from Rigid Format 14. In other rigid formats, a DMAP alter will be required. For further discussion, see Section 3.15 of this manual.

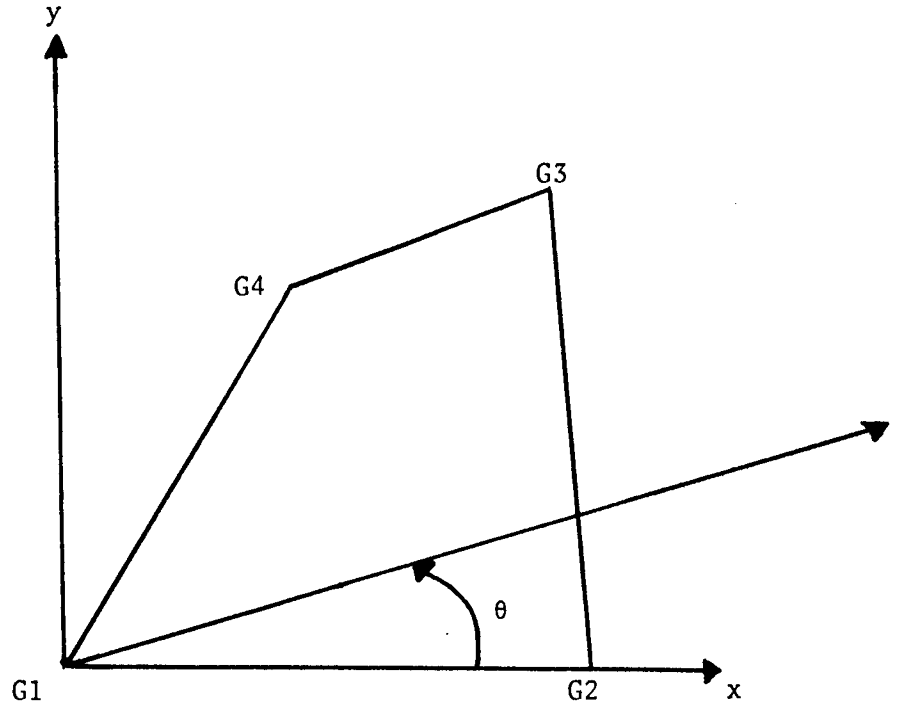


Figure 13 - Planar Quadrilateral Linear Isoparametric Element Coordinate System

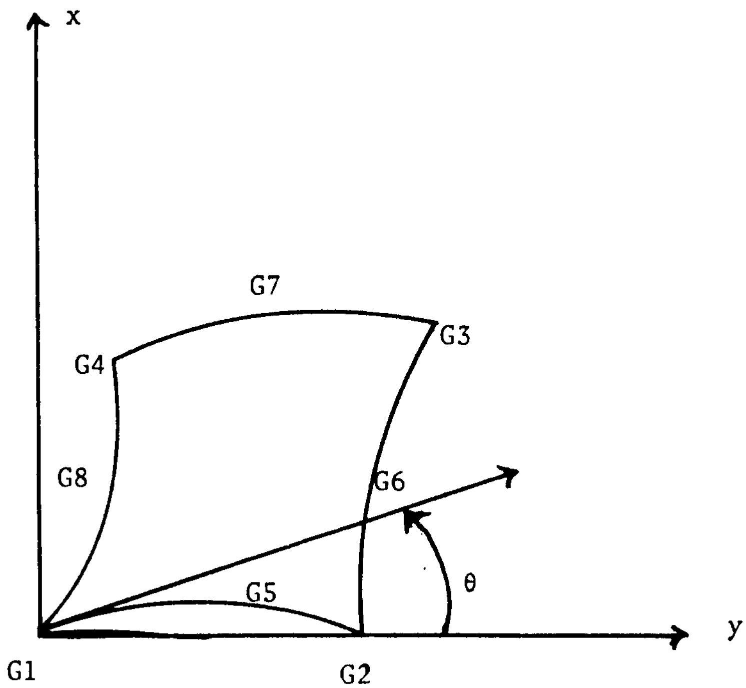


Figure 14 - Planar Quadriparabolic Quadratic
Isoparametric Element Coordinate System

1.5.4 Thermal Transient Loads

NASTRAN includes four types of thermal transient loads. For a full discussion of these loads see Section 19.1.1 of the Theoretical Manual. The RADIAT1 card defines radiation heat exchange between a surface of an isoparametric element and its surroundings in the form

$$Q(t) = HA(T^4 - T_\infty^4)$$

where

- Q is the net rate of radiation heat exchange
- H is the radiation factor
- A is the area of the surface
- T is the temperature of the surface
- T_∞ is the ambient temperature.

H may be temperature dependent and is given on the TABLEH1 card. T_∞ may be time dependent and is given on the TABLET1 card.

The RADIAT2 card defines radiation heat exchange between two isoparametric surfaces in the form

$$Q(t) = HA_1A_2(T_1{}^4 - T_2{}^4)$$

where

- Q is the net rate of radiation heat exchange
- H is the radiation factor
- A_1,A_2 are the areas of the surfaces
- T_1,T_2 are the temperatures of the surfaces.

H may be temperature dependent and is given on the TABLEH1 card.

The CONVEC card defines convective heat exchange between an isoparametric surface element and its surroundings in the form

$$Q(t) = H_c A(T - T_\infty)$$

where

- Q is the heat flow per unit time
- H_c is the film coefficient
- A is the area of the element
- T is the temperature of the surface
- T_∞ is the ambient temperature.

H_c may be time dependent and is given on the TABLHC1 card. T_∞ may be time dependent and is given on the TABLET1 card. (The portion of A(t) defined by $-H_c A T_\infty$ is the load added to the load vector. The portion defined by $H_c A$ is added into the conduction matrix.)

The HGEN card defines internal heat generation for isoparametric elements in the form

$$Q(t) = GV$$

where

Q is the load to be applied

G is the heat generation per unit time for the element

V is the volume of the element.

G may be temperature dependent and is given on the TABLEG1 card.

The HFLUX card defines a boundary heat input per unit area for isoparametric elements in the form

$$Q(t) = qA$$

where

Q is the load to be applied

q is the boundary heat input per unit area

A is the area of the surface.

q may be time dependent and is given on the TABLEQ1 card.

Input Data Card APPISO Isoparametric Element Problem Type Flag

Description: Defines the type of analysis to be performed using isoparametric elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
APPISO	CODE								
APPISO	0								

Field	Contents
CODE	Indicator of type of run: 0 thermal-structural combination; 1 structural only; 2 thermal statics only

Remarks:

1. One and only one APPISO bulk data card must be present when isoparametric elements are used.
2. CODE=0 implies that Rigid Format 14, i.e. thermal transient-structural statics combination, is to be run. Conduction and capacitance matrices will be computed in the thermal portion, and stiffness matrices will be computed in the structural portion. (If only a thermal transient analysis is desired, CODE=0 must be specified.)
3. If CODE=1, then all Rigid Formats except 4, 5, 6, and 14 (presently) may be used because no differential stiffness matrices nor piecewise linear analysis capabilities have been included for isoparametric elements.
4. If CODE=2, only Rigid Format 1 may be used.
5. An APPISO bulk data cord must be present in thermal problems with BAR elements.

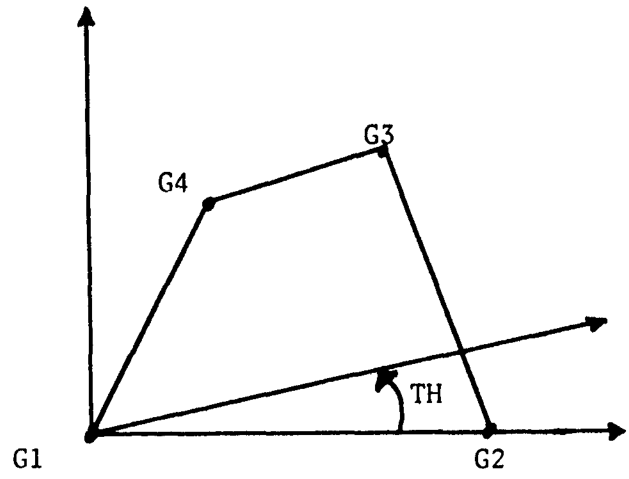
Input Data Card CIS2D4 Quadrilateral isoparametric element connection

Description: Defines a quadrilateral isoparametric membrane element (IS2D4) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CIS2D4	EID	PID	G1	G2	G3	G4	ID1	TH	
CIS2D4	8	2	8	6	1	10			

Field	Contents
EID	Element identification number (Integer >0)
PID	Identification number of a PIS2D4 property card (Integer >0)
G1, G2, G3, G4	Grid point identification numbers of connection points (Integers >0; G1 thru G4 must be unique)
ID1	Reserved for possible later use
TH	Material property orientation angle in degrees (Real) The sketch below gives the sign convention for TH



Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Grid points G1 thru G4 must be ordered as shown above.
3. This element is a planar element, i.e., G1 thru G4 must lie in a plane.
4. Stresses are computed in the element coordinate system.

Input Data Card CIS2D8 Quadriparabolic isoparametric element connection

Description: Defines a quadriparabolic isoparametric membrane element (IS2D8) of the structural model.

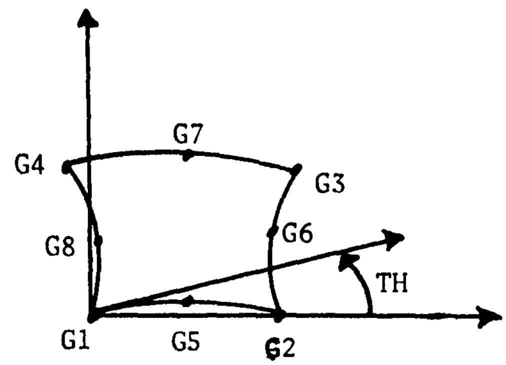
Format and Example:

1	2	3	4	5	6	7	8	9	10
CIS2D8	EID	PID	G1	G2	G3	G4	G5	G6	+abc
CIS2D8	16	2	12	10	15	18	22	3	+A

+abc	G7	G8	ID1	TH					
+A	7	11							

Field	Contents
EID	Element identification number (Integer > 0)
PID	Identification number of a PIS2D8 property card (Integer > 0)
G1, G2, . . .,G8	Grid point identification numbers of connection points (Integers > 0; G1 thru G8 must be unique)
ID1	Number of Gauss quadrature points (ID1=2 or 3--default is 2).

TH — Material property orientation angle in degrees (Real). The sketch below gives the sign convention for TH.



Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Grid points G1 thru G8 must be ordered as shown above.
3. This element is a planar element, i.e., G1 thru G8 must be in a plane.
4. Stresses are computed in the element coordinate system.

Input Data Card CIS3D8 Solid Isoparametric Element Connection

Description: Defines a solid, 8-grid-point isoparametric element (IS3D8) of the structural model without reference to a property card.

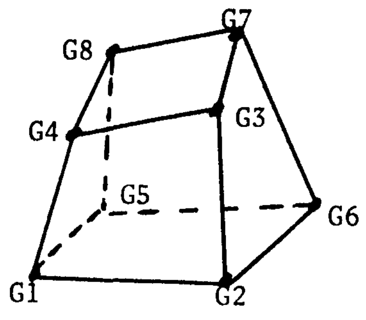
Format and Example:

1	2	3	4	5	6	7	8	9	10
CIS3D8	EID	G1	G2	G3	G4	G5	G6	G7	+abc
CIS3D8	5	8	9	10	11	2	3	4	+A

+abc	G8	ID1	ID2	MID					
+A	5	1		1					

Field	Contents
EID	Element identification number (Integer >0)
G1, G2, G3, . . .G8	Grid point identification numbers of connection points (Integers >0; G1 thru G8 must be unique)
ID1	Coordinate system identification number of the rectangular coordinate system which defines the material axes (Integer >0; 0 means the basic coordinate system). (Not required nor desired for isotropic materials.)

ID2	Reserved for possible later use
MID	Material identification number (Integer > 0)



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Grid points G1 thru G8 must be ordered as shown above, i.e. counterclockwise on opposite face as viewed from face 1 (G1-G4). Also, G1 and G5 must share the same edge.

3. The material property identification number must reference only a MAT7 or MAT9 card.

4. ID1 must refer to a rectangular coordinate system.

5. Stresses are computed in material coordinate system ID1.

Input Data Card CIS3D20 Solid Isoparametric Element Connection

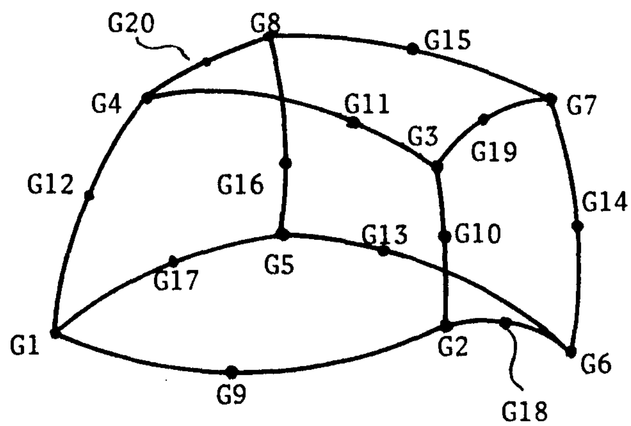
Description: Defines a solid, 20-grid-point isoparametric element (IS3D20) of the structural model without reference to a property card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CIS3D20	EID	G1	G2	G3	G4	G5	G6	G7	+abc
CIS3D20	6	1	2	3	4	5	6	7	+A
+abc	G8	G9	G10	G11	G12	G13	G14	G15	+def
+A	8	9	10	11	12	13	14	15	+B
+def	G16	G17	G18	G19	G20	ID1	ID2	MID	
+B	16	17	18	19	20	2		3	

Field	Contents
EID	Element identification number (Integer >0)
G1, G2, . . .,G20	Grid point identification numbers of connection points (Integers >0; G1 thru G20 must be unique)

ID1	Coordinate system identification number of the rectangular coordinate system which defines the material axes (Integer ≥ 0; 0 means the basic coordinate system). (Not required nor desired for isotropic materials.)
ID2	Number of Gauss quadrature points (ID1=2 or 3--default is 2).
MID	Material identification number (Integer > 0)



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Grid points G1 thru G20 must be ordered as shown above.

3. The material property identification number must reference only a MAT7 or MAT9 card.

4. ID1 must refer to a rectangular coordinate system.

5. Stresses are computed in material coordinate system ID1.

Input Data Card CONVEC Convection Specifications

Description: Specifies convective heat exchange between a surface of an isoparametric element and its surroundings.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CONVEC	TH	TT	HC	TC	S1	S2	S3	S4	+abc
CONVEC		3	.05		9	10	2	6	+A

+abc	S5	S6	S7	S8	S9	S10	S11	S12	+def
+A	21	18	32	ENDT					

(etc.)

Field	Contents
TH	Identification number of a TABLHC1 card (Integer ≥0 or blank)
TT	Identification number of a TABLET1 card (Integer ≥0 or blank)
HC	If TH=0 or blank, HC is the constant value for H for all values of time (Real)

TC	If TT=0 or blank, TC is the constant value for the ambient temperature at all values of time (Real)
Si	Identification numbers of surface elements or two-dimensional isoparametric elements (Integers >0)

Remarks: 1. This card implies the relationship

$$Q = H_c A(T - T_\infty)$$

where Q is the heat flow per unit time due to convection exchange

H_c is the film coefficient, which may be time dependent

A is the area of the surface

T is the temperature of the surface, which is given by the average temperature of the grid points defining the surface.

T_∞ is the ambient temperature, which may be time dependent

2. The term $H_c A$ can be considered a contribution to the conduction (stiffness) matrix, while $-H_c A T_\infty$ can be considered a linear external load. The contribution to the k_{ij} term of the conduction matrix for element Sk is

$$H_c \iint N_i N_j \, dS$$

and the linear external load applied to grid point i is

$$H_c T_\infty \iint N_i \, dS$$

where $N_i N_j$ is the shape function of the surface element applied at grid points i and j.

3. The end of the list is indicated by the BCD string "ENDT" in The field following the last entry. An error is detected if any continuation cards follow the card containing the end-of-list flag "ENDT".

4. In remark 2., if H_c is time-dependent, the program will interrupt the integration process to recompute the contributions to the conduction matrix at each time step. This could be a time-consuming process. Therefore, an option is included whereby no contributions are made to the conduction matrix, but the load applied is computed to be

$$Q = H_c A(T - T_\infty)$$

where T is the temperature at the previous time step. While a much less time-consuming process, this method could cause instabilities in the integration algorithm. This option is implemented by including a PARAM METCON bulk data card, with a value of 1, in the bulk data deck.

Input Data Card HFLUX Boundary Heat Input Specification

Description: Specifies boundary heat input per unit area on a surface of an isoparametric element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
HFLUX	TQ	QC	S1	S2	S3	S4	S5	S6	+abc
HFLUX	3		9	10	2	6	21	18	+A
+abc	S7	S8	S9	S10	S11	S12	S13	S14	+def
+A	32	ENDT							

(etc.)

Field	Contents
TQ	Identification number of a TABLEQ1 card (Integer ≥ 0 or blank)
QC	If TQ=0 or blank, QC is the constant value of q for all time values (Real)
Si	Identification numbers of surface elements or two-dimensional isoparametric elements (Integer >0)

Remarks: 1. This card implies the relationship

$$Q(t) = q(t)A$$

where Q is the total load applied to the surface

q is the boundary heat input per unit area

A is the area of the surface

2. Q will be treated as a linear load applied to the grid points defining the surface. The load applied to grid point i is

$$q(t)\int\int N_i ds$$

where N_i is the shape function for the surface applied at grid point i.

3. The end of the list is indicated by the BCD string "ENDT" in the field following the last entry. An error is detected if any continuation cards follow the card containing the end-of-list flag "ENDT".

BULK DATA DECK

Input Data Card HGEN Internal Heat Generation Specifications

Description: Specifies internal heat generation for isoparametric elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
HGEN	TG	GC	EID1	EID2	EID3	EID4	EID5	EID6	+abc
HGEN	3		9	10	2	6	21	18	+A

+abc	EID7	EID8	EID9	EID10	EID11	EID12	EID13	EID14	+def
+A	32	ENDT							

(etc.)

Field	Contents
TG	Identification number of a TABLEG1 card (Integer $\geq$ 0 or blank)
GC	If TG=0 or blank, GC is the constant value of G for all temperature values (Real)
EIDi	Element identification number of an isoparametric element (Integer $>$ 0)

Remarks: 1. This card implies the relationship

$$Q = GV$$

where Q is the load to be applied

G is the heat generation per unit time for the element which may be temperature dependent

V is the volume of the element

2. The load Q to be applied at grid point i of an element is

$$G(T_i) \iiint N_i \, dxdydz$$

if the element is three-dimensional, or

$$G(T_i) h \iint N_i \, dxdy$$

if the element is two-dimensional,

where N_i is the shape function for the element applied at grid point i

h is the thickness of a two-dimensional element

T_i is the temperature at grid point i

3. The end of the list is indicated by the BCD string "ENDT" in the field following the last entry. An error is detected if any continuation cards follow the card containing the end-of-list flag "ENDT".

Input Data Card MAT7 Material Property Definition

Description: Defines the material properties for linear, temperature-independent, isotropic materials for isoparametric elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT7	MID	E	G	NU	RHO	A	TREF	GE	+abc
MAT7	16	3.+7		0.3	3.2	.4	125.	.1	+A

+abc	K	C							
+A	.31	.60							

Field	Contents
MID	Material identification number (Integer > 0)
E	Young's modules (Real ≥ 0.0 or blank)
G	Shear modulus (Real ≥ 0.0 or blank)
NU	Poisson's ratio (Real or blank)
RHO	Mass density (Real)

A	Thermal expansion coefficient (Real)
TREF	Thermal expansion reference temperature (Real)
GE	Structural element damping coefficient (Real)
K	Conductivity coefficient (Real)
C	Specific heat (Real)

Remarks:

1. The material identification number must be unique for <u>all</u> MAT1, MAT2, MAT3, MAT4, MAT5, MAT7, MAT8, and MAT 9 cards.

2. MAT7 materials may be made temperature dependent by use of the MATT7 card.

3. The continuation card is not required. If it is left out, K and C will be 0.0.

Remarks 4, 5, and 6 apply whenever a structural analysis is to be run. (CODE = 0 or 1 on the APPISO bulk data card.)

4. One of E or G must be positive (i.e., either E > 0.0 or G > 0.0) or both E and G may be > 0.0.

5. If any one of E, G, or NU is blank, it will be computed to satisfy the identity $E = 2(1 + NU)G$; otherwise, values supplied by the user will be used.

6. The mass density RHO will be used to automatically compute mass in a structural dynamics problem. In a thermal transient problem, RHO * C will be used as the coefficient

6. (cont.)

of the temperature derivative with respect to time in the heat flow equation, i.e., RHO*C = capacitance.

Input Data Card MAT8 Material Property Definition

Description: Defines the material properties for linear, temperature-independent, anisotropic materials for two-dimensional isoparametric elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT8	MID	G11	G12	G13	G22	G23	G33	RHO	+abc
MAT8	17	6.2+3			6.2+3		5.1+3	3.2	+A

+abc	A1	A2	A12	TREF	GE	KX	KY	C	
+A	.15			125.	.1	.31	.5	.60	

Field	Contents
MID	Material identification number (Integer >0)
Gij	The 3 x 3 symmetric material property matrix (Real)
RHO	Mass density (Real)
Ai	Thermal expansion coefficient vector (Real)
TREF	Thermal expansion reference temperature (Real)

GE	Structural element damping coefficient (Real)
KX, KY	Conductivity coefficients in the x- and y-directions, respectively (Real)
C	Specific heat (Real)

Remarks:

1. The material identification numbers must be unique for all MAT1, MAT2, MAT3, MAT4, MAT5, MAT7, MAT8, and MAT9 cards.

2. MAT8 materials may be made temperature dependent by use of the MATT8 card.

3. The mass density RHO will be used to automatically compute mass in a structural dynamics problem. In a thermal transient problem, RHO*C will be used as the coefficient of the temperature derivative with respect to time in the heat flow equation, i.e., RHO*C = capacitance.

Input Data Card MAT9 Material Property Definition

Description: Defines the material properties for linear, temperature-independent , anisotropic materials for solid isoparametric elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT9	MID	G11	G12	G13	G14	G15	G16	G22	+abc
MAT9	17	6.2+3						6.2+3	+A
+abc	G23	G24	G25	G26	G33	G34	G35	G36	+def
+A					6.2+3				+B
+def	G44	G45	G46	G55	G56	G66	RHO	A1	+ghi
+B	5.1+3			5.1+3		5.1+3	3.2	.15	+C
+ghi	A2	A3	A12	A23	A31	TREF	GE	KX	+jkl
+C	.15	.15				125.		.31	+D
+jkl	KY	KZ	C						
+D	.5	.22	.60						

Field	Contents
MID	Material identification number (Integer > 0)
Gij	The 6 X 6 symmetric material property matrix (Real)
RHO	Mass density (Real)
Ai	Thermal expansion coefficient vector (Real)
TREF	Thermal expansion reference temperature (Real)
KX, KY, KZ	Conductivity coefficients in the x-, y-, and z-directions, respectively (Real)
C	Specific heat (Real)

Remarks:

1. The material identification numbers must be unique for all MAT1, MAT2, MAT3, MAT4, MAT5, MAT7, MAT8 and MAT9 cards.

2. MAT9 materials may be made temperature dependent by use of the MATT9 card.

3. The mass density RHO will be used to automatically compute mass in a structural dynamics problem. In a thermal transient problem, RHO*C will be used as the coefficient of the temperature derivative with respect to time in the heat flow equation, i.e., RHO*C = capacitance.

Input Data Card MATT7 Material Temperature Dependence

Description: Specifies table references for material properties which are temperature dependent.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MATT7	MID	R1	R2	R3	R4	R5	R6	R7	+abc
MATT7	16	32				18			+A

+abc	R8	R9							
+A		12							

Field	Contents
MID	Material property identification number which matches the identification number on some basic MAT7 card (Integer >0)
Ri	References to table identification numbers (Integers ≥ 0)

Remarks: 1. Blank or zero entries mean no table dependence of the referenced quantity on the basic MAT7 card.

2. TABLEM1, TABLEM2, TABLEM3, or TABLEM4 type tables may be used.

3. If a thermal transient analysis (Rigid Format 14) is being run, the appearance on a MATT7 card of a non-zero Ri for the K and/or C variables (R8, R9) must be accompanied by a TRANGE bulk data card for that Ri.

Input Data Card MATT8 Material Temperature Dependence

Description: Specifies table references for material properties which are temperature dependent.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MATT8	MID	R1	R2	R3	R4	R5	R6	R7	+abc
MATT8	17	32			15			12	+A

+abc	R8	R9	R10	R11	R12	R13	R14	R15	
+A			9			2		8	

Field	Contents
MID	Material property identification number which matches the identification number on some basic MAT8 card (Integer >0)
Ri	References to table identification number (Integer ≥0)

Remarks: 1. Blank or zero entries mean no table dependence of the referenced quantity on the basic MAT8 card.

2. TABLEM1, TABLEM2, TABLEM3, or TABLEM4 type tables may be used.

3. If a thermal transient analysis (Rigid Format 14) is being run, the appearance on a MATT8 card of a non-zero Ri for the KX, KY, and/or C variables (R13, R14, R15) must be accompanied by a TRANGE bulk data card for that Ri.

Input Data Card MATT9 Material Temperature Dependence

Description: Specifies table references for material properties which are temperature dependent.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MATT9	MID	R1	R2	R3	R4	R5	R6	R7	+abc
MATT9	17	32			18			17	+A
+abc	R8	R9	R10	R11	R12	R13	R14	R15	+def
+A				12					+B
+def	R16	R17	R18	R19	R20	R21	R22	R23	+ghi
+B				5			10		+C
+ghi	R24	R25	R26	R27	R28	R29	R30	R31	+jkl
+C	9							11	+D
+jkl	R32	R33	R34						
+D		8							

Field	Contents
MID	Material property identification number which matches the identification number on some basic MAT9 card (Integer >0)
Ri	References to table identification number (Integer ≥0)

Remarks:

1. Blank or zero entries mean no table dependence of the referenced quantity on the basic MAT9 card.

2. TABLEM1, TABLEM2, TABLEM3, TABLEM4 type tables may be used.

3. If a thermal transient analysis (Rigid Format 14) is being run, the appearance on a MATT9 card of a non-zero Ri for the KX, KY, KZ, and/or C variables (R31 through R34) must be accompanied by a TRANGE bulk data card for that Ri.

Input Data Card PIS2D4 Quadrilateral Isoparametric Membrane Property

Description: Used to define the properties of a quadrilateral isoparametric membrane. Referenced by the CIS2D4 card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PIS2D4	PID	MID	T						
PIS2D4	2	1	0.5						

Field	Contents
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Thickness of membrane (Real)

Remarks:

1. All PIS2D4 cards must have unique property identification numbers.
2. The material property identification number must reference only a MAT7 or MAT8 card.

Input Data Card PIS2D8 Quadriparabolic Isoparametric Membrane Property

Description: Used to define the properties of a quadriparabolic isoparametric membrane. Referenced by the CIS2D8 card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PIS2D8	PID	MID	T						
PIS2D8	2	1	0.5						

Field	Contents
PID	Property identification number (Integer >0)
MID	Material identification number (Integer >0)
T	Thickness of membrane (Real)

Remarks:
1. All PIS2D8 cards must have unique property identification members.
2. The material property identification number must reference only a MAT7 or MAT8 card.

Input Data Card PLOAD2 Pressure Load

Description: Defines a uniform static pressure load applied to two-dimensional elements. Only IS2D4, IS2D8, QUAD1, QUAD2, QDMEM, QDPLT, SHEAR, SURF4, SURF8, TRBSC, TRIA1, TRIA2, TRMEM, TRPLT or TWIST elements may have a pressure load applied to them via this card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PLOAD2	SID	P	EID	EID	EID	EID	EID	EID	
PLOAD2	21	-3.6		4	16		2		

Alternate Form

PLOAD2	SID	P	EID1	"THRU"	EID2				
PLOAD2	1	30.4	16	THRU	48				

Field	Contents
SID	Load set identification number (Integer > 0)
P	Pressure value (Real)
EID EID1 EID2	Element identification number (Integer > 0; EID1 < EID2)

Remarks:

1. EID must be 0 or blank for omitted entrys.
2. Load sets must be selected in the Case Control Deck (LOAD=SID) to be used by NASTRAN.
3. At least one positive EID must be present on each PLOAD2 card.
4. If the alternate form is used, all elements EID1 thru EID2 must be two-dimensional
5. The pressure load is computed for each element as if the grid points to which the element is connected were specified on a PLOAD card. The grid point sequence specified on the element connection card is assumed for the purpose of computing pressure loads.
6. All elements referenced must exist.

Input Data Card RADIAT1   Radiation Specifications

Description: Specifies radiation heat exchange between a surface of an isoparametric element and its surroundings.

Format and Example:

1	2	3	4	5	6	7	8	9	10
RADIAT1	TH	TT	HC	TC	S1	S2	S3	S4	+abc
RADIAT1	3			50.	9	10	2	6	+A

+abc	S5	S6	S7	S8	S9	S10	S11	S12	+def
+A	21	18	32	ENDT					

(etc.)

Field	Contents
TH	Identification number of a TABLEH1 card (Integer ≥0 or blank)
TT	Identification number of a TABLET1 card (Integer ≥0 or blank)
HC	If TH=0 or blank, HC is the constant value of H for all temperature values (Real)
TC	If TT = 0 or blank, TC is the constant value for the ambient temperature at all values of time (Real)

Si	Identification numbers of surface elements or two-dimensional isoparametric elements. (Integers >0)

Remarks: 1. This card implies the relationship

$$Q = HA(T^4 - T_\infty^4)$$

where Q is the net rate of radiation heat exchange between a specified surface and its surroundings

H is the radiation factor, which may be temperature dependent

A is the area of the surface

T is the temperature of the surface, which is given by the average temperature of the grid points defining the surface

T_∞ is the ambient temperature, which may be time dependent

2. Q will be treated as a non-linear load applied to the grid points defining the surface. The load applied to grid point i is

$$H(T_i)(T_i^4 - T_\infty^4)\int\int N_i dS,$$

where N_i is the shape function for the surface applied at grid point i, and T_i is the temperature of grid point i.

3. The end of the list is indicated by the BCD string "ENDT" in the field following the last entry. An error is detected if any continuation cards follow the card containing the end-of-list flag "ENDT".

Input Data Card RADIAT2 Radiation Specifications

Description: Specifies radiation heat exchange between one surface of an isoparametric element and another surface of an isoparametric element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
RADIAT2	TH	HC	S1	S21	S22	S23	S24	S25	+abc
RADIAT2	3		9	10	2	6	21	18	+A
+abc	S26	S27	S28	S29	S210	S211	S212	S213	+def
+A	32	ENDT							

(etc.)

Field	Contents
TH	Identification number of a TABLEH1 card (Integer ≥0 or blank)
HC	If TH = 0 or blank, HC is the constant value of the radiation factor for all temperatures (Real)
S1	Identification number of a surface element or two-dimensional isoparametric element from which the radiation is assumed to be emanating (Integer >0)

S2i | Identification number of a surface element or two-dimensional isoparametric element to which element S1 is assumed to be radiating (Integer > 0)

Remarks: 1. This card implies the relationship

$$Q = HA_1 A_{2i} (T_1^4 - T_{2i}^4)$$

where Q is the net rate of radiation heat exchange between surface S1 and surface S_{2i}

H is the radiation factor, which may be temperature dependent

A_1 is the area of S1

A_{2i} is the area of S_{2i}

T_1 is the temperature of S1, which is given by the average temperature of the grid points defining S1

T_{2i} is the temperature of S_{2i}, which is given by the average temperature of the grid points defining S_{2i}.

2. Q will be treated as a non-linear load applied to the grid points defining the surfaces. The load applied to grid point j of surface S1 is

$$H({T_1}_j^4 - {T_2}_i^4) A_{2i} \iint N_j dS$$

where N_j is the shape function for S1 applied at grid point j. The load applied to grid point j of surface S_{2i} is

$$-H(T_1^4 - {T_{2i}}_j^4) A_1 \iint N_j dS$$

3. The roles of elements S1 and S2i may not be reversed on any other RADIAT2 card.

4. The end of the list is indicated by the BCD string "ENDT" in the field following the last entry. An error is detected if any continuation cards follow the card containing the end-of-list flag "ENDT".

Input Data Card SURF1 One-Dimensional Surface Element.

Description: Defines a one-dimensional surface element of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SURF1	EID	G1	A						
SURF1	3	12	.78						

Field	Contents
EID	Element identification number (Integer > 0)
G1	Grid point identification number (Integer > 0)
A	Area associated with grid point G1 (Real > 0.0)

Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Surface elements contribute no stiffness, mass, or damping properties, nor will any stresses or forces be calculated for them. The only function of SURF1 surface elements is to provide a convenient way of specifying radiation, flux, and convection properties.

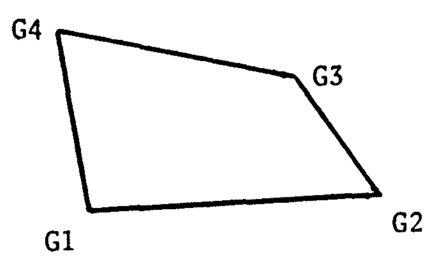
Input Data Card SURF4 Quadrilateral Isoparametric Surface Connection

Description: Defines a quadrilateral isoparametric surface element of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SURF4	EID	G1	G2	G3	G4				
SURF4	3	6	3	1	10				

Field	Contents
EID	Element identification number (Integer >0)
G1, G2, G3, G4	Grid point identification numbers of connection points (Integers >0; G1 thru G4 must be unique)



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Grid points G1 thru G4 must be ordered as shown in the sketch above.

3. Surface elements contribute no stiffness, mass, or damping properties, nor will any stresses or forces be calculated for them. The only function of SURF4 surface elements is to provide a convenient way of specifying radiation, flux, and convection properties and uniform static pressure loads on surfaces of isoparametric elements.

Input Data Card SURF8 Quadriparabolic Isoparametric Surface Element

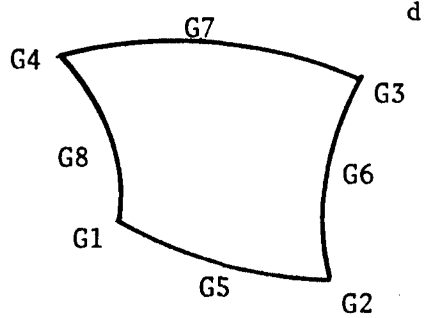
Description: Defines a quadriparabolic isoparametric surface element of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SURF8	EID	G1	G2	G3	G4	G5	G6	G7	+abc
SURF8	3	16	22	3	19	11	8	25	+A

+abc	G8	ID1							
+A	18								

Field	Contents
EID	Element identification number (Integer >0)
G1, G2, . . ., G8	Grid point identification numbers of connection points (Integers >0; G1 thru G8 must be unique)
ID1	Number of Gauss quadrature points (ID1=2 or 3--default is 2).



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Grid points G1 thru G8 must be ordered as shown in the above sketch.

3. Surface elements contribute no stiffness, mass, or damping properties, nor will any stresses or forces be calculated for them. The only function of SURF8 surface elements is to provide a convenient way of specifying radiation, flux, and convection properties and uniform static pressure loads on surfaces of isoparametric surfaces.

Input Data Card TABLEG1 Internal Heat Generation Factor Specification

Description: Defines a tabular function for temperature-dependent internal heat generation factors. Referenced by HGEN bulk data cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLEG1	ID	X	X	X	X	X	X	X	+abc
TABLEG1	3								+A

+abc	T_1	G_1	T_2	G_2	T_3	G_3	T_4	G_4	+def
+A	0.	.75	100.	.82	200.	.9	ENDT		

(etc.)

Field	Contents
ID	Table identification number (Integer > 0)
Ti, Gi	Tabular entries, where Ti is a temperature value (abscissa) and Gi is the internal heat generation factor (ordinate) (Real)

Remarks:

1. The T_i must be in either ascending or descending order but not both.

2. Jumps between two points ($T_i = T_{i+1}$) are allowed, but not at the end points.

3. At least two entries must be present.

4. Any T-G entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.

5. The end of the table is indicated by the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".

6. At temperature T_i, the value of G is G_i. Otherwise, G=f(T), where T is input to the table and G is computed by linear interpolation within the table and linear extrapolation outside the table, using the last two end points at the appropriate table end. At jump points, the average is used.

7. The table ID must be unique with respect to all TABLEH1, TABLHC1, TABLET1, TABLEQ1 and TABLEG1 cards.

Input Data Card TABLEH1   Radiation Factor Table

Description: Defines a tabular function for temperature-dependent radiation factors. Referenced by RADIATI and RADIAT2 bulk data cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLEH1	ID	X	X	X	X	X	X	X	+abc
TABLEH1	3								+A

+abc	T_1	H_1	T_2	H_2	T_3	H_3	T_4	H_4	+def
+A	200	.21	850.	.33	1475.	.61	ENDT		

(etc.)

Field	Contents
ID	Table identification number (Integer >0)
T_i, H_i	Tabular entries, where T_i is a temperature value (abscissa) and H_i is the corresponding radiation factor (ordinate) (Real)

Remarks:

1. The T_i must be in either ascending or descending order but not both.

2. Jumps between two points ($T_i = T_{i+1}$) are allowed, but not at the end points.

3. At least two entries must be present.

4. Any T-H entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.

5. The end of the table is indicated by the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".

6. At temperature T_i, the value of H is H_i. Otherwise, H=f(T), where T is input to the table and H is computed by linear interpolation within the table and linear extrapolation outside the table, using the last two end points at the appropriate table end. At jump points, the average is used.

7. The table ID must be unique with respect to all TABLEH1, TABLHC1, TABLET1, TABLEQ1 and TABLEG1 cards.

Input Data Card TABLEQ1   Boundary Heat Input Value Specification

Description: Defines a tabular function for the time-dependent boundary heat input. Referenced by HFLUX bulk data cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLEQ1	ID	X	X	X	X	X	X	X	+abc
TABLEQ1	ID								+A

+abc	t_1	q_1	t_2	q_2	t_3	q_3	t_4	q_4		+def
+A	0.	.75	100.	1.25	250.	2.10	ENDT			

(etc.)

Field	Contents
ID	Table identification number (Integer > 0)
t_i, q_i	Tabular entries, where t_i is a time value (abscissa) and q_i is the boundary heat input per unit area (ordinate) (Real)

Remarks:

1. The t_i must be in either ascending or descending order but not both.

2. Jumps between two points ($t_i = t_{i+1}$) are allowed, but not at the end points.

3. At least two entries must be present.

4. Any t-q entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.

5. The end of the table is indicated by the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".

6. At temperature t_i, the value of q is q_i. Otherwise, q = f(t), where t is input to the table and q is computed by linear interpolation within the table and linear extrapolation outside the table using the last two end points at the appropriate table end. At jump points, the average is used.

7. The table ID must be unique with respect to all TABLEH1, TABLHC1, TABLET1, TABLEQ1, and TABLEG1 cards.

Input Data Card TABLET1 Ambient Temperature Table

Description: Defines a tabular function for time-dependent ambient temperatures used in convection and radiation calculations. Referenced by CONVEC and RADIAT1 bulk data cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLET1	ID	X	X	X	X	X	X	X	+abc
TABLET1	3								+A

+abc	t_1	$T_{\infty 1}$	t_2	$T_{\infty 2}$	t_3	$T_{\infty 3}$	t_4	$T_{\infty 4}$	+def
+A	0.	1200.	.5	1325.	1.25	1950.	ENDT		

(etc.)

Field	Contents
ID	Table identification number (Integer >0)
t_i, $T_{\infty i}$	Tabular entries, where t_i is a time value (abscissa) and $T_{\infty i}$ is the value of the ambient temperature (ordinate) (Real)

Remarks:

1. The t_i must be in either ascending or descending order but not both.

2. Jumps between two points ($t_i = t_{i+1}$) are allowed, but not at the end points.

3. At least two entries must be present.

4. Any t-T_∞ entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.

5. The end of the table is indicated by the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".

6. At time t_i, the value of T is $T_{\infty i}$. Otherwise, $T_\infty = f(t)$, where t is input to the table and T_∞ is computed by linear interpolation within the table and linear extrapolation outside the table, using the last two end points at the appropriate table end. At jump points, the average is used.

7. The table ID must be unique with respect to all TABLEH1, TABLHC1. TABLET1, TABLEQ1, and TABLEG1 cards.

Input Data Card TABLHC1 Convection Film Coefficient Specification

Description: Defines a tabular function for time-dependent convection film coefficients. Referenced by CONVEC bulk data cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLHC1	ID	X	X	X	X	X	X	X	+abc
TABLHC1	3								+A

+abc	t_1	H_{c_1}	t_2	H_{c_2}	t_3	H_{c_3}	t_4	H_{c_4}	+def
+A	0.	.2	25.	.33	60.	.5	ENDT		

(etc.)

Field	Contents
ID	Table identification number (Integer > 0)
t_1, H_{c_1}	Tabular entries, where t_i is a time value >0; abscissa and H_{c_i} is the corresponding convection film coefficient (ordinate) (Real)

Remarks:

1. The t_i must be in either ascending or descending order but not both.

2. Jumps between two points ($t_i = t_{i+1}$) are allowed, but not at the end points.

3. At least two entries must be present.

4. Any t-H_c entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.

5. The end of the table is indicated by the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".

6. At temperature t_i, the value of H_c is H_{c_i}. Otherwise, $H_c = f(t)$, where t is input to the table and H_c is computed by linear interpolation within the table and linear extrapolation outside the table, using the last two end points at the appropriate table end. At jump points, the average is used.

7. The table ID must be unique with respect to all TABLEH1, TABLHC1, TABLET1, TABLEQ1, and TABLEG1 cards.

Input Data Card **TRANGE** Temperature Range Specifications

Description: Specifies temperature ranges within which temperature-dependent thermal material properties are to remain constant during a thermal transient analysis.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TRANGE	ID	ΔT	T_1	T_2	T_3	T_4	T_5	T_6	+abc
TRANGE	8	5.	100.	200.	300.	400.	500.	600.	+A
+abc	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	+def
+A	700.	800.	ENDT						

(etc.)

Field	Contents
ID	Table identification number (Integer >0)
ΔT	Tolerance (Real ≥ 0.0)
T_i	Temperature values (Real)

Remarks:

1. TRANGE cards will be used during a thermal transient analysis to determine whether a change in element material properties is required.

2. The table identification number ID must match the table identification number on a TABLEM1, TABLEM2, TABLEM3, or TABLEM4 bulk data card which defines a tabular function for a thermal material property KX, KY, KZ, or C on a MAT7, MAT8, or MAT9 bulk data card.

3. If a thermal material property KX, KY, KZ, or C is defined to be temperature dependent (by a non-zero entry in the appropriate field on a MATT7, MATT8, or MATT9 bulk data card), then a TRANGE card specifying the appropriate table identification number must be present.

4. The T_i must be specified in strictly increasing order.

5. At least two T_i's must be specified.

6. The end of the list is indicated by the BCD string "ENDT" in the field following the last entry. An error is detected if any continuation cards follow the card containing the end-of-list flag "ENDT".

7. If the temperature of an element (as given by the average temperature of its grid points) is in the interval $(T_i + \Delta T, T_{i+1} - \Delta T)$, then the temperature range will be considered to be $[T_i, T_{i+1}]$. If the temperature of the element at the previous time step in the transient analysis was not in this range, new material properties for the element will be computed. Otherwise, the same properties will be used.

8. If the temperature of an element is in the range $[T_i - \Delta T, T_i + \Delta T]$, then a determination will be made by NASTRAN as to whether new material properties for the element will be computed. The program will attempt to minimize the number of material property changes. Therefore, the tolerance ΔT gives NASTRAN further leeway in determining material property changes. ΔT may be 0. However, the temperature ranges may not be null intervals.

9. When NASTRAN determines that the temperature of an element lies in a particular interval, the value of the appropriate material property is the average of the values of the material property at the end points of the range.

10. Temperatures less than T_1 are assumed to lie in interval $[T_1, T_2]$ while temperatures greater than T_N are assumed to lie in the interval $[T_{N-1}, T_N]$

restarts. The deletion of operations for each subset is controlled by the restart tables.

If the user wishes to modify the DMAP sequence of a rigid format in some manner not provided for in the available subsets, he can use the ALTER feature described in Section 2. Typical uses are to schedule an EXIT prior to completion, in order to check intermediate output, schedule the printing of a table or matrix for a diganostic purposes, and to delete, or add a functional module to the DMAP sequence. Any DMAP instructions that are added to a rigid format are automatically executed when a restart is performed. The user should be familiar with the rules for DMAP programming, as described in Section 5, prior to making alterations to a rigid format.

The following rigid formats are currently included in NASTRAN:

1. Status Analysis
2. Static Analysis with Inertia Relief
3. Normal Mode Analysis
4. Static Analysis with Differential Stiffness
5. Buckling Analysis
6. Piecewise Linear Analysis
7. Direct Complex Eigenvalue Analysis
8. Direct Frequency and Random Response
9. Direct Transient Response
10. Modal Complex Eigenvalue Analysis
11. Modal Frequency and Random Response
12. Modal Transient Response
13. Normal Modes with Differential Stiffness
14. Thermal Transient - Structural Static Combination

3.1.1 Input File Process

The Input File Processor operates in the Preface prior to the execution of the DMAP operations in the rigid format. A complete description of the operations in the Preface is given in the Programmer's Manual. The main interest here is to indicate the source of data blocks that are created in the Preface and hence appear only as inputs in the

DMAP sequences of the rigid formats. None of the data blocks created by the Input File Processor are checkpointed, as they are always regenerated on restart. The Input File Processor is divided into four parts. The first part (IFP1) processes the Case Control Deck, the second part (IFP) processes the Bulk Data Deck, the third part (IFP3) performs additional processing of the bulk data cards associated with the conical shell element, the fourth part (IFP4) performs additional processing of the bulk data.

2. WTMASS - optional in all rigid formats. The terms of the structural mass matrix are multiplied by the real value of this parameter when they are generated in SMA2. Not recommended for use in hydroelastic problems.

3. IRES - optional in all statics problems (rigid formats 1, 2, 4, 5 and 6). A positive integer value of this parameter will cause the printing of the residual vectors following each execution of SSG3.

4. LFREQ and HFREQ - required in all modal formulations of dynamics problems (rigid formats 10, 11 and 12) unless LMODES is used. The real values of these parameters give the frequency range (LFREQ is lower limit and HFREQ is upper limit) of the modes to be used in the modal formulation.

5. LMODES - required in all modal formulations of dynamic problems (rigid formats 10, 11 and 12) unless LFREQ and HFREQ are used. The integer value of this parameter is the number of lowest modes to be used in the modal formulation.

6. G - optional in the direct formulation of all dynamics problems (rigid formats 7, 8 and 9). The real value of this parameter is used as a uniform structural damping coefficient in the direct formulation of dynamics problems. Not recommended for use in hydroelastic problems.

7. W3 and W4 - optional in the direct formulation of transient response problems. The real values of these parameters are used as pivotal frequencies for uniform structural damping and element structural damping respectively. The parameter W3 should not be used for hydroelastic problems.

8. MODACC - optional in the modal formulation of frequency response and transient response problems. A positive integer value of this parameter causes the Dynamic Data Recovery module to use the mode acceleration method. Not recommended for use in hydroelastic problems.

9. COUPMASS - optional in all rigid formats. A positive integer value of this parameter will cause the generation of coupled mass matrices rather than lumped mass matrices for all bar elements, rod elements, and plate elements that include bending stiffness. This option applies to both structural and nonstructural mass for the following elements: BAR, CONROD, QUAD1, QUAD2, ROD, TRIA1, TRIA2, TUBE. Also, for IS2D4, IS2D8, IS3D8, and IS3D20 elements coupled mass and capacitance matrices will be computed. In Rigid Format 14 coupled capacitance matrices will be computed for BAR elements. Since structural mass is not defined for the following list of elements, the option applies only to the nonstructural mass: QDPLT, TRBSC, TRPLT. A negative value causes the generation of lumped mass and capacitance matrices for all the above elements. (This is the default.) A zero value activates the following parameters described under 10.

10. CPBAR, CPROD, CPQUAD1, CPQUAD2, CPTRIA1, CPTRIA2, CPTUBE, CPQDPLT, CPTRPLT, CPTRBSC--optional in all rigid formats. These parameters are active only is COUPMASS=0. A positive value will cause the generation of coupled mass matrices for all elements of that particular type as shown by the following table:

Parameter	Element Types
CPBAR	BAR
CPROD	ROD, CONROD
CPQUAD1	QUAD1
CPQUAD2	QUAD2
CPTRIA1	TRIA1
CPTRIA2	TRIA2
CPTUBE	TUBR
CPQDPLT	QDPLT
CPTRBSC	TRBSC

A negative value (the default) for these parameters will cause the general of the lumped mass matrices for these element types.

11. DECOMOPT - optional for **frequency** response problems. The integer value of this parameter is used to control the type of arithmetic used in the decomposition of the dynamic equations. A value of 1 (default) means that double precision, complex arithmetic with partial pivoting will be used. A value of 2 means that double precision, complex arithmetic without pivoting will be used. A value of 4 means that single precision, complex arithmetic without pivoting will be used.

12. OPTION - optional for static analysis. The value HEAT is used to select the heat transfer option for Rigid Format No. 1.

13. BT - required in thermal transient problems in which radiation is being used and temperatures are not specified in ^{o}R or ^{o}K. The usual values for BT are 459.69 and 273.16 for specification in ^{o}F and ^{o}C, respectively.

14. METCON - Optional for Rigid Format 14. A value of 1 will cause the program to make convection contributions only to the load vector. For full details see Remark 4, page 2.4-42c.

3.15 THERMAL TRANSIENT-STRUCTURAL STATICS COMBINATION

3.15.1 DMAP Sequence for Thermal Transient-Structural Statics Combination

RIGID FORMAT 14

```
   N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP  INSTRUCTION
 NO.

  1  BEGIN    NO.14 THERMAL TRANSIENT-STRUCTURAL STATICS - SERIES M $

  2  FILE     LLL=TAPE   $

  3  FILE     QG=APPEND/PGG=APPEND/UGV=APPEND/GM=SAVE/KNN=SAVE    $

  4  PARAM    //C,N,NOP/V,N,IM1=-1 $

  5  PARAM    //C,N,NOP/V,N,IP1=1 $

  6  PARAM    //C,N,NOP/V,N,ICASE=2    $

  7  MODA     /KDD,GMD,KGGXY,GOD/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0.0/C,N,
              0/C,N,0/C,N,0/C,N,0/C,N,0/C,N,0.0/V,N,IFIR=0/V,N,IFIRST=0 $

  8  SAVE     IFIR,IFIRST $

  9  MODA     /CASEXZ,,,/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0/C,N,0/
              C,N,0/C,N,0/C,N,0/C,N,0.0/V,N,IFIR/V,N,IFIRST $

 10  PARAM    //C,N,NOP/V,N,IFOUR=4$

 11  PURGE    MGG,MNN,MFF,MAA/IM1 $

 12  PURGE    SKGGX,SGPST,SMGG,SOGPWG,SKGG,SRG,SYS,SUSET,SOGPST,SGM,SKNN,
              SKFF,SKFS,SKSS,SGO,SKAA,SKOOB,SLOO,SUOO,SKLL,SKLR,SKRR,SLLL,
              SULL,SDM,SPG,SQR,SPO,SPS,SPL,SULV,SUOOV,SRULV,SRUOV,SUGV,SPGG,
              SQG,OPG1,OQG1,OUGV1,OESS1,OEFF1,PUGV1,OESAVG,PLTX2,CASEXY,
              GEOM3X,ESTZ,ECPTZ,GPTTX/IM1  $

 13  GP1      GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL/V,N,LUSET/ C,N,123/
              V,N,NOGPDT $

 14  SAVE     LUSET,NOGPDT$

 15  PURGE    USET,GM,GO,KAA,BAA,MAA,K4AA,PST,KFS,QP,EST/NOGPDT $

 16  CHKPNT   GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL,USET,GM,GO,KAA,BAA,MAA,K4AA,
              PST,KFS,QP,EST $

 17  COND     LBL5,NOGPDT$

 18  GP2      GEOM2,EQEXIN/ECT $

 19  CHKPNT   ECT $

 20  PLTSET   PCDB,EQEXIN,ECT/PLTSETX,PLTPAR,GPSETS,ELSETS/V,N,NSIL/ V,N,
              JUMPPLOT = -1 $
```

N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N

```
DMAP-DMAP  INSTRUCTION
 NO.

 21  SAVE     NSIL,JUMPPLOT $

 22  PRTMSG   PLTSETX//$

 23  CHKPNT   PLTPAR,GPSETS,ELSETS $

 24  SETVAL   //V,N,PLTFLG/C,N,1/V,N,PFILE/C,N,0 $

 25  SAVE     PLTFLG,PFILE $

 26  COND     P1,JUMPPLOT$

 27  PLOT     PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,,/PLOTX1/ V,N,
              NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $

 28  SAVE     JUMPPLOT,PLTFLG,PFILE $

 29  PRTMSG   PLOTX1//$

 30  LABEL    P1 $

 31  GP3      GEOM3,EQEXIN,GEOM2,/BGPDT/SLT,GPTT/C,N,123/V,N,NOGRAV/C,N,123 $

 32  SAVE     NOGRAV   $

 33  PARAM    //C,N,AND/V,N,SKPMGG/V,N,NOGRAV/V,Y,GRDPNT    $

 34  PURGE    SMGG/SKPMGG $

 35  CHKPNT   GPTT,MGG,SMGG,SLT $

 36  TA1,     ,ECT,EPT,BGPDT,SIL,GPTT,CSTM/EST,,GEI,ECPT,GPCT/V,N,LUSET/ C,N,
              123/V,N,NOSIMP=-1/C,N,0/V,N,NOGENL=-1/V,N,GENEL $

 37  SAVE     NOSIMP,NOGENL,GENEL$

 38  PARAM    //C,N,AND/V,N,NOELMT/V,N,NOGENL/V,N,NOSIMP    $

 39  COND     ERROR6,NOELMT    $

 40  PURGE    K4GG,GPST,OGPST,MGG,BGG, K4NN,K4FF,K4AA,MNN,MFF,MAA,BNN,BFF,
              BAA,KGGX/NOSIMP/ OGPST/GENEL$

 41  CHKPNT   EST,ECPT,GPCT,GEI,K4GG,GPST,MGG,BGG,KGGX,OGPST, K4NN,K4FF,K4AA,
              MNN,MFF,MAA,BNN,BFF,BAA $

 42  DPDA     DIT,MPT/DITC,MATTA/V,N,MAT    $

 43  SAVE     MAT    $
```

RIGID FORMAT 14

```
    N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP  INSTRUCTION
 NO.

 44   PARAM     //C,N,NOT/V,N,NOMAT/V,N,MAT    $

 45   EQUIV     DITC,DIT/NOMAT    $

 46   CHKPNT    MATTA  $

 47   COND      LBL110,IM1    $

 48   TABPT     DITC,,,,//  $

 49   LABEL     LBL110    $

 50   INITEM    CASECC,DYNAMICS,EST,ECPT,SIL,MATTA,DIT,EQEXIN/ESTX,ECPTX,
                MATTAB/V,N,SCALAR/V,N,MAT/V,N,STEP/V,N,NOTIC    $

 51   SAVE      SCALAR,MAT,STEP,NOTIC    $

 52   EQUIV     ESTX,EST/NOTIC/ECPTX,ECPT/NOTIC    $

 53   CHKPNT    EST,ECPT,MATTAB $

 54   COND      LBL811,IM1 $

 55   TABPT     ESTX,ECPTX,,,// $

 56   LABEL     LBL811 $

 57   PURGE     MATTA/IM1    $

 58   COND      LABL82,IFIR    $

 59   JUMP      LABL83 $

 60   LABEL     LABL83    $

 61   COND      LABL85,KCON    $

 62   LABEL     LABL82    $

 63   COND      LBL1,NOSIMP$

 64   SMA1      CSTM,MPT,ECPT,GPCT,DIT/KGGX,K4GG,GPST/V,N,NOGENL/ V,N,NOK4GG$

 65   SAVE      NOK4GG$

 66   PURGE     K4NN,K4GG,K4FF,K4AA/NOK4GG$

 67   PURGE     K4GG1,K4GG2,K4GG3,K4GG4/NOK4GG $

 68   CHKPNT    KGGX,GPST,K4GG,K4NN,K4FF,K4AA $
```

N A S T R A N S O U R C E P R O G R A M C O M P I L A T I O N

```
DMAP-DMAP  INSTRUCTION
 NO.

 69  LABEL     LABL85   $

 70  COND      LABL90,IFIR   $

 71  COND      LABL98,KCAP   $

 72  LABEL     LABL90   $

 73  SMA2      CSTM,MPT,ECPT,GPCT,DIT/MGG,BGG/V,Y,WTMASS=1.0/V,N,NOMGG/ V,N,
               NOBGG=-1/V,Y,COUPMASS=-1 $

 74  SAVE      NOMGG,NOBGG$

 75  PURGE     BNN,BFF,BAA,BGG/NOBGG$

 76  JUMP      LABL98 $

 77  LABEL     LABL98   $

 78  EQUIV     KGGX,KGGXY/IM1   $

 79  CHKPNT    MGG,BGG,BNN,BFF,BAA,MNN,MFF,MAA $

 80  LABEL     LBL1 $

 81  EQUIV     KGGX,KGG/NOGENL $

 82  CHKPNT    KGG $

 83  COND      LBL11,NOGENL $

 84  SMA3      GEI,KGGX/KGG/V,N,LUSET/V,N,NOGENL/V,N,NOSIMP $

 85  CHKPNT    KGG $

 86  LABEL     LBL11 $

 87  EQUIV     KGGXY,KGGX/IP1 $

 88  PARAM     //C,N,MPY/V,N,NSKIP/0,N,0/C,N,0 $

 89  COND      LABL91,IFIRST   $

 90  GP4       CASECC,GEOM4,EQEXIN,SIL,GPDT/RG,YS,USET,/V,N,LUSET/V,N,MPCF1=
               -1/V,N,MPCF2=-1/V,N,SINGLE=-1/V,N,OMIT=-1/V,N,REACT=-1/V,N,
               NSKIP/V,N,REPEAT/V,N,NOSET=-1/V,N,NOL/V,N,NOA=-1   $

 91  SAVE      MPCF1,SINGLE,OMIT,NOSET,REACT,MPCF2,NSKIP,REPEAT,NOL,NOA  $

 92  DPD8      EST,DYNAMICS/RAD1,RAD2,CONV,HTGEN,FLUX/V,N,NORAD1/V,N,NORAD2/V,
```

```
        N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP  INSTRUCTION
 NO.
                 N,NOCON/V,N,NOGEN/V,N,NOFLUX $

 93  SAVE        NORAD1,NORAD2,NOCON,NOGEN,NOFLUX $

 94  PURGE       RD2TAB,HTTAB,FLXTAB/IM1/HTGEN/NOGEN/CONVPT,CONTAB,KGGCON,LDCON,
                 KGGSUM/NOCON/ $

 95  CHKPNT      RAD1,RAD2,CONV,HTGEN,FLUX $

 96  LABEL       LABL91    $

 97  COND        LABL73,NOCON    $

 98  COND        LABL81,IFIRST    $

 99  CONV1       GPCT,CONV/CONVPT,CONTAB    $

100  CHKPNT      CONVPT,CONTAB $

101  LABEL       LABL81    $

102  CONV2       GPCT,CONVPT,DIT,CONTAB,CONV/KGGCON,LDCON/V,N,TIME/V,N,LUSET/V,
                 N,STEP    $

103  ADD         KGG,KGGCON/KGGSUM/C,N,(1.0,0.0)/C,N,(1.0,0.0)  $

104  EQUIV       KGGXY,KGG/IP1$

105  EQUIV       KGGSUM,KGG/IM1 $

106  LABEL       LABL73    $

107  PURGE       GM,GMD/MPCF1/GO,KOOB,LOO,UOO,MOOB,MOAB,GOD/OMIT/KFS,PST,QP/
                 SINGLE$

108  EQUIV       KGG,KNN/MPCF1/MGG,MNN/MPCF1/ BGG,BNN/MPCF1/K4GG,K4NN/MPCF1$

109  CHKPNT      GM,RG,GO,KOOB,LOO,UOO,MOOB,MOAB,KFS,QP,USET,GMD,GOD,PST, KNN,
                 MNN,BNN,K4NN $

110  COND        LBL4,GENEL $

111  COND        LBL4,NOSIMP $

112  GPSP        GPL,GPST,USET,SIL/OGPST $

113  OFP         OGPST,,,,,//V,N,CARDNO $

114  SAVE        CARDNO $
```

N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N

```
DMAP-DMAP  INSTRUCTION
 NO.

115  LABEL    LBL4 $

116  COND     LBL2,MPCF1 $

117  COND     LBL220,IFIRST $

118  MCE1     USET,RG/GM $

119  CHKPNT   GM $

120  LABEL    LBL220 $

121  MCE2     USET,GM,KGG,MGG,BGG,K4GG/KNN,MNN,BNN,K4NN $

122  CHKPNT   KNN,MNN,BNN,K4NN $

123  LABEL    LBL2 $

124  EQUIV    KNN,KFF/SINGLE/MNN,MFF/SINGLE/BNN,BFF/SINGLE/K4NN,K4FF/SINGLE$

125  CHKPNT   KFF,MFF,BFF,K4FF $

126  COND     LBL3,SINGLE $

127  SCE1     USET,KNN,MNN,BNN,K4NN/KFF,KFS,KSS,MFF,BFF,K4FF $

128  CHKPNT   KSS $

129  CHKPNT   KFS,KFF,MFF,BFF,K4FF $

130  LABEL    LBL3 $

131  EQUIV    KFF,KAA/OMIT/ MFF,MAA/OMIT/BFF,BAA/OMIT/K4FF,K4AA/OMIT$

132  CHKPNT   KAA,MAA,BAA,K4AA $

133  COND     LBL5,OMIT $

134  SMP1     USET,KFF,MFF,BFF,K4FF/GO,KAA,KOOB,LOO,UOO,MAA,MOOB,MOAB,BAA,
              K4AA $

135  CHKPNT   GO,KAA,MAA,BAA,K4AA $

136  LABEL    LBL5 $

137  EQUIV    KAA,KDD/IM1 $

138  COND     LBL230,NOK4GG $

139  ADD      BAA,K4AA/BDD/C,N,(1.0,0.0)/C,N,(1.0,0.0)    $
```

```
    N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
 DMAP-DMAP INSTRUCTION
  NO.

 140  JUMP     LBL231 $

 141  LABEL    LBL230 $

 142  EQUIV    BAA,BDD/IM1 $

 143  LABEL    LBL231 $

 144  CHKPNT   KDD,BDD $

 145  COND     LBL108,IFIRST   $

 146  DPD      DYNAMICS,GPL,SIL,USET/GPLD,SILD,USETD,,DLT,,,NLFT,TRL,,EQDYN/V,
               N,LUSET/V,N,LUSETD/V,N,NOTFL/V,N,NODLT/V,N,NOPSDL/V,N NOFRL/V,
               N,NONLFT/V,N,NOTRL/V,N,NOEED/C,N,123/V,N,NOUE  $

 147  SAVE     LUSETD,NODLT,NONLFT,NOTRL,NOUE $

 148  PURGE    PNLD/NONLFT$

 149  EQUIV    GO,GOD/NOUE/GM,GMD/NOUE $

 150  COND     LBL221,IM1 $

 151  TABPT    GO,KAA,BAA,CASEXZ,KGG // $

 152  LABEL    LBL221 $

 153  CHKPNT   USETD,EQDYN,DLT,TRL,GOD,GMD,NLFT,PNLD,SILD,GPLD  $

 154  COND     ERROR1,NOTRL$

 155  PARAM    //C,N,ADD/V,N,NEVER/C,N,1/C,N,0 $

 156  PARAM    //C,N,MPY/V,N,REPEATT/C,N,1/C,N,-1 $

 157  JUMP     LBL13 $

 158  LABEL    LBL13$

 159  PURGE    PNLD,OUDV1,OPNL1,OUDV2,OPNL2,XYPLTTA,OPP1,OQP1,OUPV1,OES1,
               OEF1,OPP2,OQP2,OUPV2,OES2,OEF2,PLOTX2,XYPLTT/NEVER $

 160  EQUIV    CASECC,CASEXZ/IM1$

 161  CASE     CASECC,/CASEXX/C,N,TRAN/V,N,REPEATT/V,N,NOLOOP $

 162  SAVE     REPEATT,NOLOOP $

 163  CHKPNT   CASEXX $
```

```
    N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
 DMAP-DMAP  INSTRUCTION
  NO.

 164  DPDC     USETD,KFS,YS,GM/REDUCE,KFSYS/V,N,MPCF1/V,N,SINGLE/V,N,LUSETD/V,
               N,Y$

 165  CHKPNT   REDUCE  $

 166  PURGE    MATTAB,NMATAB,ECPT1,ECPT2/MAT/DLT/NODLT/NLFT/NONLFT/GM/MPCF1/
               YS,KFSYS/Y  $

 167  DPDD     RAD1,RAD2,HTGEN,CASECC,TRL,FLUX/RD1TAB,RD2TAB,HTTAB,TICDAT,
               TSTEPD,FLXTAB/V,N,SCALAR/V,N,NORAD1/V,N,NORAD2/V,N,NOGEN/V,N,
               LUD/V,N,LLOADN/V,N,NLFTP/V,N,NOFLUX $

 168  SAVE     SCALAR,NORAD1,NORAD2,NOGEN,LUD,LLOADN,NLFTP,NOFLUX $

 169  CHKPNT   RD1TAB,RD2TAB,HTTAB,TICDAT,TSTEPD,FLXTAB $

 170  EQUIV    CASEXZ,CASECC/IP1 $

 171  LABEL    LBL108   $

 172  TRDTEMP  DLT,NLFT,DIT,KDD,BDD,REDUCE,LDCON,EST,ECPT,MATTAB,RD1TAB,
               TICDAT,TSTEPD,KFS,GM,USETD,YS,KFSYS/UDVT,  PPT,PNLD,ESTY,ECPTY,
               ECPT1,ECPT2,NMATAB,TEMDAT/V,N,MAT/V,N,SCALAR/V,N,TIME/V,N,STEP/
               V,N,NOCON/V,N,NOGEN/V,N,NORAD1/V,N,NORAD2/V,N,LUSETD/V,N,
               SINGLE/V,N,MPCF1/V,N,LUD/V,N,KCON/V,N,KCAP/V,N,IECPTY/V,N,
               IREPET/V,N,OMEGA/V,Y,EPSCON=0.001/V,N,IGROUP/V,N,ISTEP/V,N,
               NSTEP/V,N,NOUTA/V,N,LLOADN/V,N,NLFTP/V,N,NOFLUX/V,Y,BT$

 173  SAVE     MAT,SCALAR,TIME,STEP,NOCON,NOGEN,NORAD1,NORAD2,LUSETD,SINGLE,
               MPCF1,LUD,KCON,KCAP,IECPTY,IREPET,OMEGA,EPSCON,IGROUP,ISTEP,
               NSTEP,NOUTA,LLOADN,NLFTP,NOFLUX,BT    $

 174  CHKPNT   UDVT,PPT,PNLD,ESTY,IECPTY,ECPT1,ECPT2,NMATAB,TEMDAT $

 175  EQUIV    ESTY,EST/IM1/ECPTY,ECPT/IM1    $

 176  EQUIV    NMATAB,MATTAB/IM1/TEMDAT,TICDAT/IM1 $

 177  EQUIV    EST,ESTY/IP1/ECPT,ECPTY/IP1 $

 178  EQUIV    MATTAB,NMATAB/IP1/TICDAT,TEMDAT/IP1 $

 179  COND     LBL810,IM1 $

 180  TABPT    ESTY,ECPTY,MATTAB,TICDAT,// $

 181  TABPT    NMATAB,TEMDAT,KGG,CASEXZ,// $

 182  LABEL    LBL810 $
```

N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N

```
DMAP-DMAP INSTRUCTION
 NO.

183  COND     LBL815,IFIRST $

184  MODA     /,,,/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0.0/C,N,0/C,N,0/C,N,0/
              C,N,0/C,N,0/C,N,0.0/V,N,IFIR/V,N,IFIRST $

185  SAVE     IFIR,IFIRST $

186  LABEL    LBL815 $

187  COND     LABL74,IREPET   $

188  COND     LABL95,IECPTY   $

189  REPT     LABL83,500  $

190  JUMP     ERROR4   $

191  LABEL    LABL95   $

192  COND     LBL310,MAT $

193  PARAM    //C,N,AND/V,N,NBOTH/V,N,KCON/V,N,KCAP $

194  COND     LBL310,NBOTH $

195  JUMP     LBL311 $

196  LABEL    LBL310 $

197  EQUIV    KGGXY,KGGX/IM1 $

198  JUMP     LABL97 $

199  LABEL    LBL311 $

200  COND     LABL96,KCON    $

201  SMA1     CSTM,MPT,ECPT1,GPCT,DIT/KGG1,K4GG1,GPST1/V,N,NOGENL/V,N,
              NOK4GG  $

202  SMA1     CSTM,MPT,ECPT2,GPCT,DIT/KGG2,K4GG2,GPST2/V,N,NOGENL/V,N,
              NOK4GG  $

203  ADD      KGG2,KGG1/KGG3/C,N,(1.0,0.0)/C,N,(-1.0,0.0)    $

204  ADD      KGGXY,KGG3/KGG4/C,N,(1.0,0.0)/C,N,(1.0,0.0)    $

205  EQUIV    KGG4,KGGX/IM1    $

206  COND     LABL96,NOK4GG $
```

```
    N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP INSTRUCTION
 NO.

207  ADD      K4GG2,K4GG1/K4GG3/C,N,(1.0,0.0)/C,N,(-1.0,0.0) $

208  ADD      K4GG,K4GG3/K4GG4/C,N,(1.0,0.0)/C,N,(1.0,0.0) $

209  EQUIV    K4GG4,K4GG/IM1 $

210  LABEL    LABL96   $

211  COND     LABL97,KCAP    $

212  SMA2     CSTM,MPT,ECPT1,GPCT,DIT/,BGG1/V,Y,WTMASS/V,N,NOMGG/V,N,NOBGG/V,
              Y,COUPMASS   $

213  SAVE     NOMGG,NOBGG    $

214  SMA2     CSTM,MPT,ECPT2,GPCT,DIT/,BGG2/V,Y,WTMASS/V,N,NOMGG/V,N,NOBGG/V,
              Y,COUPMASS   $

215  SAVE     NOMGG,NOBGG    $

216  ADD      BGG2,BGG1/BGG3/C,N,(1.0,0.0)/C,N,(-1.0,0.0)    $

217  ADD      BGG,BGG3/BGG4/C,N,(1.0,0.0)/C,N,(1.0,0.0)    $

218  EQUIV    BGG4,BGG/IM1    $

219  LABEL    LABL97    $

220  REPT     LABL98,500    $

221  TABPT    DLT,NLFT,BDD,RAD1,RAD2// $

222  TABPT    HTGEN,REDUCE,LDCON,RD1TAB,RD2TAB// $

223  TABPT    HTTAB,TICDAT,TSTEPD,FLUX,FLXTAB//$

224  TABPT    CONVPT,CONTAB,CONV,KGG,//$

225  JUMP     ERROR4     $

226  LABEL    LABL74    $

227  EQUIV    PPT,PDT/NOSET $

228  CHKPNT   UDVT,PDT,PST,PPT,PNLD $

229  VDR      CASEXX,EQDYN,USETD,UDVT,PPT,XYCDB,PNLD/OUDV1,OPNL1/ C,N,
              TRANRESP/C,N,DIRECT/C,N,0/V,N,NOD/V,N,NOP/C,N,0 $

230  SAVE     NOD,NOP $
```

N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N

```
DMAP-DMAP  INSTRUCTION
 NO.

231  CHKPNT   OUDV1,OPNL1 $

232  COND     LBL15,NOD $

233  SDR3     OUDV1,OPNL1,,,,/OUDV2,OPNL2,,,, $

234  OFP      OUDV2,OPNL2,,,,//V,N,CARDNO $

235  SAVE     CARDNO $

236  CHKPNT   OPNL2,OUDV2 $

237  XYTRAN   XYCDB,OUDV2,OPNL2,,,/XYPLTTA/C,N,TRAN/C,N,DSET/V,N,PFILE/ V,N,
              CARDNO $

238  SAVE     PFILE,CARDNO $

239  XYPLOT   XYPLTTA// $

240  LABEL    LBL15 $

241  PARAM    //C,N,AND/V,N,PJUMP/V,N,NOP/V,N,JUMPPLOT $

242  COND     LBL18,PJUMP $

243  EQUIV    UDVT,UPV/NOA $

244  COND     LBL17,NOA $

245  SDR1     USETD,,UDVT,,YS,GOD,GM, ,KFS,KSS,/UPV,,QP/C,N,1/C,N,DYNAMICS  $

246  LABEL    LBL17$

247  CHKPNT   UPV,QP $

248  SDR2     CASEXX,CSTM,MPT,DIT,EQDYN,SILD,,,BGPDT,PPT,QP,UPV,EST,XYCDB/
              OPP1,OQP1,OUPV1,OES1,OEF1,PUGV/C,N,THERMAL   $

249  SDR3     OPP1,OQP1,OUPV1,OES1,OEF1,/ OPP2,OQP2,OUPV2,OES2,OEF2, $

250  CHKPNT   OPP2,OQP2,OUPV2,OES2,OEF2 $

251  OFP      OPP2,OQP2,OUPV2,OEF2,OES2,//V,N,CARDNO $

252  SAVE     CARDNO $

253  COND     P2,JUMPPLOT $

254  PLOT     PLTPAR,GPSETS,ELSETS,CASEXX,BGPDT,EQEXIN,SIL,,PUGV/PLOTX2/ V,N,
              NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $
```

N A S T R A N S O U R C E P R O G R A M C O M P I L A T I O N

```
DMAP-DMAP INSTRUCTION
 NO.

255  SAVE     PFILE $

256  PRTMSG   PLOTX2// $

257  LABEL    P2 $

258  XYTRAN   XYCDB,OPP2,OQP2,OUPV2,OES2,OEF2/XYPLTT/C,N,TRAN/C,N,PSET/ V,N,
              PFILE/V,N,CARDNO $

259  SAVE     PFILE,CARDNO $

260  XYPLOT   XYPLTT// $

261  LABEL    LBL18 $

262  PURGE    SKGGX,SGPST,SMGG,SOGPMG,SKGG,SRG,SYS,SUSET,SOGPST/IFIR $

263  PURGE    SGM,SKNN,SKFF,SKFS,SKSS,SGO,SKAA,SKOOB,SLOO,SUOO,SKLL/IFIR $

264  PURGE    SKLR,SKRR,SLLL,SULL,SDM,SPG,SQR,SPO,SPS,SPL/IFIR $

265  PURGE    SULV,SUOOV,SRULV,SRUOV,SUGV,SPGG,SQG,OPG1,OQG1,OUGV1/IFIR $

266  PURGE    OESG1,OEFF1,PUGV1,OESAVG,PLTX2,CASEXY,GEOM3X,ESTZ,ECPTZ/IFIR $

267  PURGE    GPTTX,GEOM3/IFIR $

268  JUMP     LABL99 $

269  LABEL    LABL99   $

270  RETEMP   CASEXZ,GEOM3,UPV,EQDYN,EQEXIN,SILD,EST,ECPT/CASEXY,GEOM3X,ESTZ,
              ECPTZ/V,N,NSTEP/V,N,AGAIN/V,N,NREC/V,N,NOSUB/V,N,ICASE   $

271  SAVE     NSTEP,AGAIN,NREC,NOSUB,ICASE    $

272  COND     FINIS,NOSUB     $

273  CHKPNT   ESTZ,ECPTZ,CASEXY  $

274  EQUIV    ESTZ,EST/IM1/ECPTZ,ECPT/IM1/CASEXY,CASECC/IM1    $

275  EQUIV    EST,ESTZ/IP1/ECPT,ECPTZ/IP1/CASECC,CASEXY/IP1 $

276  COND     LBL111,IM1    $

277  TABPT    ECPTZ,ESTZ,CASEXY,,,// $

278  LABEL    LBL111  $
```

N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N

DMAP-DMAP NO.	INSTRUCTION	
279	GP3	GEOM3X,EQEXIN,GEOM2,/ ,GPTTX/C,N,123/V,N,NOGRAV/C,N,123 $
280	SAVE	NOGRAV $
281	EQUIV	GPTTX,GPTT/IM1 $
282	CHKPNT	GPTT$
283	COND	LBL201,NOSIMP $
284	COND	LBL909,NOMAT$
285	PARAM	//C,N,SUB/V,N,IDIFF/V,N,ICASE/V,N,IFOUR$
286	COND	LBL909,IDIFF$
287	JUMP	LBL201$
288	LABEL	LBL909$
289	SMA1	CSTM,MPT,ECPT,GPCT,DIT/SKGGX,,SGPST/V,N,NOGENL/V,N,NOK4GG $
290	CHKPNT	SGPST,SKGGX $
291	COND	LBL201,SKPMGG $
292	SMA2	CSTM,MPT,ECPT,GPCT,DIT/SMGG,/V,Y,WTMASS/V,N,NOMGG/V,N,NOBGG/V,Y,COUPMASS $
293	SAVE	NOMGG $
294	CHKPNT	SMGG $
295	COND	LBL201,GRDPNT $
296	COND	ERROR7,NOMGG $
297	GPWG	BGPDT,CSTM,EQEXIN,SMGG/SOGPWG/V,Y,GRDPNT=-1/V,Y,WTMASS $
298	OFP	SOGPWG,,,,,//V,N,CARDNO $
299	SAVE	CARDNO $
300	LABEL	LBL201 $
301	EQUIV	SKGGX,SKGG/NOGENL $
302	CHKPNT	SKGG $
303	COND	LBL211,NOGENL $

N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N

```
DMAP-DMAP  INSTRUCTION
 NO.

304   SMA3      GEI,SKGGX/SKGG/V,N,LUSET/V,N,NOGENL/V,N,NOSIMP  $

305   CHKPNT    SKGG $

306   LABEL     LBL211 $

307   PARAM     //C,N,MPY/V,N,NNSKIP/C,N,0/C,N,0$

308   GP4       CASECC,GEOM4,EQEXIN,SIL,GPDT/SRG,SYS,SUSET,/V,N,LUSET/V,N,
                MPCF1/V,N,MPCF2/V,N,SINGLE/V,N,OMIT/V,N,REACT/V,N,NNSKIP/V,N,
                REPEAT/V,N,NOSET/V,N,NOL/V,N,NOA  $

309   SAVE      MPCF1,MPCF2,SINGLE,OMIT,REACT,NNSKIP,REPEAT,NOSET,NOL,NOA $

310   COND      ERROR8,NOL $

311   PARAM     //C,N,AND/V,N,NOSR/V,N,SINGLE/V,N,REACT  $

312   PURGE     SKRR,SKLR,SQR,SDM/REACT/SGM/MPCF1/SGO,SKOOB,SLOO,SUOO,SPO,
                SUOOV,SRUOV/OMIT/SPS,SKFS,SKSS/SINGLE/SQG/NOSR  $

313   EQUIV     SKGG,SKNN/MPCF1  $

314   CHKPNT    SKRR,SKLR,SQR,SDM,SGM,SGO,SKOOB,SLOO,SUOO,SPO,SUOOV,SQG,SPS,
                SKFS,SKSS,SUSET,SRG,SYS,SRUOV,SKNN  $

315   COND      LBL204,GENEL $

316   GPSP      GPL,SGPST,SUSET,SIL/SOGPST  $

317   OFP       SOGPST,,,,,//V,N,CARDNO  $

318   SAVE      CARDNO $

319   LABEL     LBL204 $

320   COND      LBL213,MPCF2 $

321   MCE1      SUSET,SRG/SGM $

322   CHKPNT    SGM  $

323   MCE2      SUSET,SGM,SKGG,,,/SKNN,,, $

324   CHKPNT    SKNN $

325   LABEL     LBL213 $

326   EQUIV     SKNN,SKFF/SINGLE $
```

```
     N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP INSTRUCTION
 NO.

327  CHKPNT   SKFF  $

328  COND     LBL215,SINGLE $

329  SCE1     SUSET,SKNN,,,/SKFF,SKFS,SKSS,,, $

330  CHKPNT   SKFS,SKSS,SKFF $

331  LABEL    LBL215 $

332  EQUIV    SKFF,SKAA/OMIT $

333  CHKPNT   SKAA $

334  COND     LBL216,OMIT $

335  SMP1     SUSET,SKFF,,,/SGO,SKAA,SKOOB,SLOO,SUOO,,,,, $

336  CHKPNT   SGO,SKAA,SKOOB,SLOO,SUOO $

337  LABEL    LBL216 $

338  EQUIV    SKAA,SKLL/REACT $

339  CHKPNT   SKLL $

340  COND     LB216,REACT $

341  RBMG1    SUSET,SKAA,/SKLL,SKLR,SKRR,,, $

342  CHKPNT   SKLL,SKLR,SKRR $

343  LABEL    LB216 $

344  RBMG2    SKLL/SLLL,SULL  $

345  CHKPNT   SULL,SLLL $

346  COND     LBL217,REACT $

347  RBMG3    SLLL,SULL,SKLR,SKRR/SDM $

348  CHKPNT   SDM  $

349  LABEL    LBL217 $

350  SSG1     SLT,BGPDT,CSTM,SIL,EST,MPT,GPTT,EDT,SMGG,CASECC,DIT/SPG/V,N,
              LUSET/V,N,NNSKIP $

351  CHKPNT   SPG  $
```

```
    N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP INSTRUCTION
 NO.

352   EQUIV      SPG,SPL/NOSET $

353   CHKPNT     SPL $

354   COND       LBL210,NOSET $

355   SSG2       SUSET,SGM,SYS,SKFS,SGO,SDM,SPG/SQR,SPO,SPS,SPL $

356   CHKPNT     SQR,SPO,SPS,SPL $

357   LABEL      LBL210 $

358   SSG3       SLLL,SULL,SKLL,SPL,SLOO,SUOO,SKOOB,SPO/SULV,SUOOV,SRULV,SRUOV/
                 V,N,OMIT/V,Y,IRES=-1/V,N,NSKIP/V,N,EPSI $

359   SAVE       EPSI $

360   CHKPNT     SULV,SUOOV,SRULV,SRUOV $

361   COND       LBL9,IRES $

362   MATGPR     GPL,USET,SIL,SRULV//C,N,L $

363   MATGPR     GPL,USET,SIL,SRUOV//C,N,O $

364   LABEL      LBL9 $

365   SDR1       SUSET,SPG,SULV,SUOOV,SYS,SGO,SGM,SPS,SKFS,SKSS,SQR/SUGV,SPGG,
                 SQG/V,N,NNSKIP/C,N,STATICS $

366   CHKPNT     SUGV,SPGG,SQG $

367   SDR2       CASECC,CSTM,MPT,DIT,EQEXIN,SIL,GPTT,EDT,BGPDT,SPGG,SQG,SUGV,
                 EST,/OPG1,OQG1,OUGV1,OESS1,OEFF1,PUGV1/C,N,STATICS $

368   OFP        OUGV1,OPG1,OQG1,OEFF1,OESS1,//V,N,CARDNO $

369   SAVE       CARDNO $

370   STRSAVG    EQEXIN,OESS1/OESAVG $

371   OFP        OESAVG,,,,,//V,N,CARDNO $

372   SAVE       CARDNO $

373   COND       P22,JUMPPLOT $

374   PLOT       PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,PUGV1,/PLTX2/V,N,
                 NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $
```

```
   N A S T R A N   S O U R C E   P R O G R A M   C O M P I L A T I O N
DMAP-DMAP INSTRUCTION
 NO.

375  SAVE      PFILE $

376  PRTMSG    PLTX2// $

377  LABEL     P22 $

378  COND      FINIS,AGAIN    $

379  REPT      LABL99,100     $

380  FILE      SKGGX=SAVE/SKGG=SAVE/SKNN=SAVE/SKFF=SAVE/SKAA=SAVE/SKLL=SAVE $

381  JUMP      ERROR5    $

382  LABEL     ERROR1$

383  PRTPARM   //C,N,-1/C,N,DIRTRD$

384  LABEL     ERROR4  $

385  PRTPARM   //C,N,-4/C,N,DIRTRD  $

386  LABEL     ERROR5  $

387  PRTPARM   //C,N,-1/C,N,STATICS  $

388  LABEL     ERROR6    $

389  PRTPARM   //C,N,-4/C,N,STATICS    $

390  LABEL     ERROR7    $

391  PRTPARM   //C,N,-3/C,N,STATICS    $

392  LABEL     ERROR8 $

393  PRTPARM   //C,N,-2/C,N,STATICS $

394  LABEL     FINIS$

395  END       $
```

3.15.2 Description of DMAP Operations for Thermal Transient-Structural Statics Combinations

DMAP statements 1-260 are associated with the thermal transient portion of the analysis, while DMAP statements 261-379 are associated with the structural statics portion. Statements 380-395 deal with error conditions. Only selected DMAP statements or sets of statements will be described. Descriptions of other DMAP statements may be found in the Description of Static Analysis, Section 3.2.2 and Direct Transient Response, Section 3.10.2.

4-6. PARAM sets up DMAP parameters for later use.

7. MODA initializes DMAP parameters IFIR and IFIRST. MODA is later used to switch the values of these parameters.

42. DPDA converts temperature-dependent thermal material tables into step functions based on TRANGE bulk data cards and creates a new DIT data block.

50. INITEM modifies the EST and ECPT data blocks by inserting the initial element temperatures as derived from the initial conditions specified on TIC bulk data cards. INITEM also creates data block MATTAB which contains the temperature interval, as derived from TRANGE cards, in which each thermal material property for each element falls.

92. DPDB computes area, surface, and volume integrals required by convection, radiation, and heat generation.

99,102. CONV1, CONV2 compute contributions, due to convection.

164. DPDC creates a matrix which, when premultiplies a load vector, reduces the vector to take account of single point constraints and multi-point constraints.

187.	Go to statement 226 if temperature history is complete.
188, 189.	Go back to statement 60 to recompute all element conductance and/or capacitance matrices if more than half the matrices must be changed.
193, 219.	If less than half the element matrices must be changed, recompute the necessary matrices, compute the net effect of changing these elements, and add the net results into the structure conductance and/or capacitance matrices, as needed.
220.	Go back to statement 77 to reduce the matrices and continue.
270.	RETEMP interrogates case control to determine a time slice selection. If one is found, RETEMP creates TEMP bulk data cards, recreates GEOM3, and sets counters for the next entry to RETEMP.
272.	If no time slice selections exist, go to statement 394.
370.	STRSAVG computes average grid point stresses.
378.	If no more time slice selections exist, as determined by RETEMP, go to statement 394.
379.	Go back to statement 269 to process the next time slice selection.

3.15.4 Case Control and Parameters for Thermal Transient - Structural Statics Combination

The following items relate to subcase definition and data selection for Thermal Transient-Structural Statics Combination.

1. If more than one subcase is defined, the first subcase is assumed to refer to the thermal transient portion of the analysis, and all other subcases are assumed to refer to the structural statics portion. If one or no subcases are defined, the case control data are assumed to refer to the thermal transient portion only, in which case no structural static analysis will be performed.

2. After the first subcase, the subcase number will take on a special meaning. If the second or later subcase number is N, then the N-1st output time step, as indicated on the TSTEP bulk data card selected, will be the time for which the static analysis will be performed.

3. DLOAD or NONLINEAR must be used in the first subcase to define a time-dependent loading condition in addition to any specified thermal loading conditions.

4. TSTEP must be used to select the time-step intervals to be used for integration and for output for the first subcase. The time steps output are those indicated by the skip factors on the selected TSTEP bulk data card and the last time for each specified interval (if that time was not already indicated by the skip factors).

5. A separate subcase must be defined for each static analysis desired, with the subcase number taking on the meaning described in item 2.

6. A static loading condition will automatically be defined for each static subcase by NASTRAN. This condition will consist of the loads induced by the temperature at that time. (This is equivalent to a TEMPERATURE (LOAD) selection.) Additional loads may be defined with a LOAD selection or through grid-point displacements on SPC cards.

7. An SPC set must be selected for each subcase, unless the model is a properly supported free body, or unless all constraints are specified in GRID cards or on Scalar Connection cards.

8. If nonzero initial conditions are desired, IC must be used to select a TIC card set in the Bulk Data Deck. Unlike in other rigid formats, TIC cards should be used for all grid points, not just those on the analysis set.

The following printed output, sorted by point number or element number (SORT2), is available at the selected output time steps of the thermal transient portion of the rigid formats:

1. Temperatures (DISPLACEMENT) and rates of change of temperature with respect to time (VELOCITY) for a list of PHYSICAL points (grid points) or SOLUTION points (independent degrees-of-freedom).

2. Nonzero components of the applied load vector and single point forces of constraint for a list of PHYSICAL points.

3. Nonlinear force vector for a list of SOLUTION points.

The following plotter output is available for the thermal transient portion of the analysis:

1. Undeformed plot of the structural model.

2. X-Y plot of the temperature (component 1) or rate of change of temperature with respect to time of a PHYSICAL or SOLUTION point.

3. X-Y plot of component 1 of the applied load vector or nonlinear force vector.

The following output may be requested for the static analysis portions of the rigid format.

1. Displacements and nonzero components of static loads and single point forces of constraint at selected grid points or scalar points.

2. Forces and stresses in selected elements.

3. Undeformed and deformed plots of the structural model.

The following parameters may be used:

1. GRDPNT - optional - A positive integer value of this parameter will cause the Grid Point Weight Generator to be executed and the resulting weight and balance information to be printed.

2. WTMASS - optional - The terms of the mass matrix are multiplied by the real value of this parameter when they are generated in SMA2.

3. COUPMASS-- optional - A positive integer value of this parameter will cause the generation of coupled mass and capacitance matrices rather than lumped mass and capacitance matrices for the isoparametric elements.

4. IRES - optional - A positive integer value of this parameter will cause the printing of the residual vectors following the execution of SSG3 in the static analysis portion of the rigid format.

5. BT - required if radiation is being used and temperatures are not specified in °R or °K. The usual values for BT are 459.69 and 273.16 for specifications in °F and °C, respectively.

6. METCON - Optional for Rigid Format 14. A value of 1 will cause the program to make convection contributions only to the load vector. For full details see Remark 4, page 2.4-42c.

Some other points to be noted are:

1. The only degree-of-freedom in the thermal transient portion is temperature, which is assumed to be component 1. NASTRAN automatically contrains components 2-6. Therefore, SPC,TIC, etc, specifications should contain only component 1.

2. Permanent constraints placed on a GRDSET card or on GRID cards will be used for the statics portion only and are ignored for the thermal portion.

3. No extra points or direct matrix input are allowed.

4. TEMP, TEMPD, TEMPP1, TEMPP2, TEMPP3, and TEMPRB bulk data cards are not allowed.

5. All OMIT cards will be ignored in the thermal portion.

6. All CONVEC, HFLUX, HGEN, RADIAT1, and RADIAT2 bulk data cards present will be used to compute thermal loads.

7. Element temperatures will always be used to compute temperature-dependent thermal and structural material properties. (This is equivalent to a TEMPERATURE (MATERIAL) case control selection.)

8. In the statics portion, distributed pressure loads specified by the PLOAD2 card can be applied only to elements IS2D4, SURF4, IS2D8, and SURF8.

9. MATT7, MATT8, and MATT9 cards, must be accompanied by corresponding TRANGE cards. See the discussion of the TRANGE bulk data cards.

10. On restart, no rigid format switching from rigid format 14 to any other rigid format or from any other rigid format to rigid format 14 is allowed.

11. Consistency of units, especially for temperature, must be maintained. If the units of thermal material constants are per ^{o}F or per ^{o}R, all temperatures specified, whether through SPC cards, TABLET1 cards, etc., must be in ^{o}F or ^{o}R. Similar rules apply to ^{o}C and ^{o}K. The program makes no conversions for differing units. Therefore, the user is responsible for maintaining consistency. Input and output temperatures will be in the same units for the statics portion of the analysis, so care must be taken that the thermal expansion coefficient vector (on materials cards) is given in the correct units.

12. Time-dependent temperatures may be specified at a grid point by connecting a scalar element from the grid point (degree-of-freedom 1) to ground with a very large "spring" constant, say K_o. Then, using a TLOAD1 bulk data card, specify a load of

$$P(t) = TK_o$$

where T is the desired temperature at time t. If K_o is large enough, any other contributions of conductivity or load at that grid point will essentially be neglected.

13. The only elements presently allowed in rigid format 14 are IS2D4, IS2D8, IS3D8, IS3D20, SURF1, SURF4, SURF8, and BAR.

14. The HEAT parameter option must not be used with rigid format 14.

15. The thermal subcase must always be present, even on restarts. If, on restart, NASTRAN determines that the thermal portion was completed on the previous run and that no changes have been made to the thermal portion, the thermal portion will not be re-executed.

998 *** USER FATAL MESSAGE 998, APPISO CARD REQUIRED

If isoparametric elements are used, the APPISO bulk data card must be present.

999 *** USER FATAL MESSAGE 999, NEITHER TEMP NOR TEMPD BULK DATA CARDS ARE ALLOWED IN A THERMAL ANALYSIS PROBLEM

TEMP and TEMPD bulk data cards are not allowed in Rigid Format 14 (thermal transient analysis) or in Rigid Format 1 (thermal static analysis).

999A *** USER FATAL MESSAGE 999A, EPOINT CARDS, I.E., EXTRA POINTS ARE NOT ALLOWED IN A THERMAL TRANSIENT PROBLRM

999B *** USER FATAL MESSAGE 999B, TEMPP1, TEMPP2, TEMPP3, AND TEMPRB BULK DATA CARDS ARE NOT ALLOWED IN RIGID FORMAT 14

1000 *** USER FATAL MESSAGE 1000, EITHER THERMAL TRANSIENT OR THERMAL STATIC ANALYSIS WAS SELECTED BUT RIGID FORMAT 14 OR 1, RESPECTIVELY, WAS NOT SELECTED

The type of analysis is specified on the APPISO bulk data card. If thermal transient analysis is selected, Rigid Format 14 must be used. If thermal static analysis is selected, Rigid Format 1 must be used.

1000A *** USER FATAL MESSAGE 1000A, HEAT OPTION AND APPISO BULK DATA CARD ARE INCOMPATIBLE.

5151 *** USER FATAL MESSAGE 5151, MATT7 CARD REFERENCES UNDEFINED MAT7 **** CARD

The user should check that all MATT7 cards reference MAT7 cards that exist in the Bulk Data Deck.

5152 *** USER FATAL MESSAGE 5152, MATT8 CARD REFERENCES UNDEFINED MAT8 **** CARD

The user should check that all MATT8 cards reference MAT8 cards that exist in the Bulk Data Deck.

5153 *** USER FATAL MESSAGE 5153, MATT9 CARD REFERENCES UNDEFINED MAT9 **** CARD

The user should check that all MATT9 cards reference MAT9 cards that exist in the Bulk Data Deck.

5154 *** USER FATAL MESSAGE 5154, ELEMENT**** REQUIRES AN APPISO CARD

An APPISO bulk data card is required if isoparametric elements are being used.

5155 *** USER FATAL MESSAGE 5155, COORDINATE SYSTEM **** IS NOT A RECTANGULAR COORDINATE SYSTEM

The material coordinate system for a solid isoparametric element as specified on a CIS3D8 or CIS3D20 bulk data card, must be defined as a rectangular coordinate system.

5156 *** USER FATAL MESSAGE 5156, ELEMENT **** PRODUCES A SINGULAR JACOBEAN

Isoparametric elements require that the determinant of a Jacobean be computed. Check the geometry for the element.

5157 *** USER WARNING MESSAGE 5157, IN MODULE OESAVG THE ELEMENT TYPE IS **** WHILE THE NUMBER OF WORDS ON THE STRESS FILE IS ****
STRESSES WILL BE PRINTED BUT NOT INCLUDED IN THE AVERAGES.

Logic error in module STRSAVG or averaging of stresses of elements with different types of stresses is being attempted.

5158 *** USER WARNING MESSAGE 5158, IN MODULE OESAVG TWO DIFFERENT STRESS COORDINATE OUTPUT SYSTEMS HAVE BEEN SPECIFIED FOR ELEMENTS **** AND **** BUT THESE ELEMENTS HAVE A COMMON GRID POINT.
THE STRESSES FOR THE SECOND ELEMENT WILL NOT BE INCLUDED IN THE AVERAGE

The stress coordinate systems were specified on connection bulk data cards for the elements.

5159 *** USER FATAL MESSAGE 5159, IN MODULE RETEMP THE SUBCASE NUMBER **** IS GREATER THAN THE NUMBER OF OUTPUT TIME STEPS +1, ****.

Subcase numbers after the first subcase in Rigid Format 13 take on special significance. See Section 3.14.4 of the User's Manual.

5160 *** USER FATAL MESSAGE 5160, IN MODULE RETEMP MORE THAN 12 RECORDS EXIST ON GEOM3.

Program logic error.

5161 *** USER FATAL MESSAGE 5161, IN MODULE RETEMP THE NUMBER OF WORDS IN AN EQDYN OR SILD RECORD **** IS NOT CORRECT.
THE NUMBER OF POINTS IN THE P-SET IS ****.

Program logic error.

5162 *** USER FATAL MESSAGE 5162, IN MODULE RETEMP AN SIL NUMBER IN EQDYN IS **** DURING A BINARY SEARCH WE CANNOT FIND IT IN SILD. THE EXTERNAL NUMBER IS ****.

Program logic error.

5163 *** USER WARNING MESSAGE 5163, IN MODULE STRSAVG, OUTPUT DEVICE TYPES FOR ELEMENTS **** AND **** ARE NOT THE SAME;THE OUTPUT DEVICE WILL BE THAT FOR THE FIRST ELEMENT.

Two elements whose stresses are being averaged have different output device types, e.g., print and punch.

5164 *** USER FATAL MESSAGE 5164, IN MODULE STRSAVG, SCALAR INDEX NUMBER **** CANNOT BE FOUND WHEN TRYING TO CONVERT TO THE GRID POINT NUMBER.

Program logic error

5165 *** USER WARNING MESSAGE 5165, THERE ARE NO TEMPERATURE-DEPENDENT MATERIALS IN THIS PROBLEM.

5166 *** USER FATAL MESSAGE 5166, TEMPERATURE-DEPENDENT MATERIAL TABLE **** DOES NOT HAVE A CORRESPONDING TRANGE CARD.

See the remarks for the TRANGE bulk data card.

5167 *** USER FATAL MESSAGE 5167, IN MODULE ****, NOT TRANGE CARDS EXIST.

See the remarks for the TRANGE bulk data card.

5168 *** USER FATAL MESSAGE 5168, IN SUBROUTINE DPDB, THE NUMBER OF ELEMENT ID-S ON A **** CARD IS NONPOSITIVE.

Program logic error

5169 *** USER WARNING MESSAGE 5169, DUPLICATE ELEMENT ID **** ON CARD TYPE ****

TYPE 1 = CONVEC
TYPE 2 = HGEN
TYPE 3 = RADIATI
TYPE 4 = RADIAT2
TYPE 5 = HFLUX

The duplicate ID is ignored.

5170 *** USER WARNING MESSAGE 5170, IN A THERMAL TRANSIENT ANALYSIS, THERE ARE NO RADIAT1, RADIAT2, CONVEC, HGEN or HFLUX CARDS.

5171 *** USER FATAL MESSAGE 5171, ELEMENT ID **** WAS SPECIFIED ON A CONVEC, RADIAT1, RADIAT2, OR HFLUX CARD BUT THE ELEMENT IS EITHER IS3D8 or IS3D20.

Convection and radiation specifications must be made for surfaces, i.e., IS2D4, IS2D8, SURF4, or SURF8, elements, not solids.

5172 *** USER FATAL MESSAGE 5172, ELEMENT ID **** WAS SPECIFIED ON AN HGEN CARD, BUT THE ELEMENT TYPE IS EITHER SURF4 or SURF8.

SURF4 and SURF8 elements are dummy surface elements. Heat generation specifications must be made for only IS2D4, IS2D8, IS3D8, or IS3D20 elements.

5173 *** USER FATAL MESSAGE 5173, SUBROUTINE **** CANNOT FIND ANY IS2D4, IS2D8, IS3D8, IS3D20, SURF4 or SURF8 ELEMENTS ON EST.

Program logic error, or a thermal transient problem does not contain any of these elements.

5175 *** USER FATAL MESSAGE 5175, IN SUBROUTINE DPDB WE CANNOT FIND THE REQUIRED NUMBER OF ELEMENT ID MATCHES OF THE ID-S ON CARD TYPE **** WITH THOSE ON THE SCRATCH FILE.

Check that there exist elements with ID-S that match the ID-S on the **** cards. See message 5169 for the card type correspondence.

5176 *** USER WARNING MESSAGE 5176, ELEMENT ID **** REFERENCE A 8-D ELEMENT BUT THE ID APPEARS ON A CARD TYPE ****. THIS ID WILL BE IGNORED.

CONVEC, RADIAT1, RADIAT2, AND HFLUX may reference only IS2D4, IS2D8, SURF4 or SURF8 elements. See message 2169 for the card type correspondence.

5177 *** USER WARNING MESSAGE 5177, POINT ID ****, COMPONENT ID **** WERE SPECIFIED ON A TIC CARD. THE COMPONENT MUST BE 1 IF THERE ARE NO SCALAR POINTS IN THE PROBLEM AND MUST BE 0 OR 1 IF THERE ARE SCALAR POINTS. THIS TIC WILL BE IGNORED.

In thermal transient problems, the only degree of freedom is temperature which is assumed to be component 1.

5178 *** USER FATAL MESSAGE 5178, NO MATCH ON EQEXIN FOR POINT ID **** ON A TIC CARD.

Obscure program error, or the grid point on a TIC card was not defined on a GRID card.

5179 *** USER FATAL MESSAGE 5179, PIVOT FROM GPCT **** DOES NOT MATCH PIVOT FROM CONVPT.

Program logic error.

5180 *** USER FATAL MESSAGE 5180, SIL **** CANNOT BE FOUND IN GPCT RECORD WITH PIVOT ****.

Program logic error.

5182 *** USER FATAL MESSAGE 5182 SCALAR INDEX NUMBER **** IS EITHER IN BOTH THE D-SET AND S-SET OR IS IN NEITHER.

No thermal multi-point constraints, extra points, or omitted coordinates are used in thermal transient analysis.

5183 *** USER FATAL MESSAGE 5183, IN TRDTEM, THE NUMBER OF DEGREES OF FREEDOM FROM TRL IS **** BUT THE NUMBER OF ROWS OF THE REDUCED LOAD VECTOR IS ****. THESE SHOULD BE EQUAL.

Program logic error.

5184 *** USER FATAL MESSAGE 5184, IN SUBROUTINE **** NOT ENOUGH MATCHES BETWEEN EST AND RADID.

In computing loads as specified on RADIAT1 or RADIAT2 cards, not enough matches were made in finding the element ID-S. At this point, this is probably a program logic error.

5185 *** USER WARNING MESSAGE 5185, IN MODULE TRDTEMP, NOT ENOUGH TIME REMAINS TO COMPLETE THE SOLUTIONS.

See the explanation to message 3045.

5186 *** USER FATAL MESSAGE 5186, IN SUBROUTINE SOLVTI, THE ORDER OF ROW POSITIONS IS NOT STRICTLY INCREASING.

Program logic error.

5187 *** USER FATAL MESSAGE 5187, IN SUBROUTINE SOLVTI, THERE IS A NULL COLUMN IN THE COEFFICIENT MATRIX OF THE THERMAL TRANSIENT ANALYSIS.

The coefficient matrix is singular.

THEORETICAL MANUAL ADDITIONS

5.13 ISOPARAMETRIC ELEMENTS

5.13.1 Introduction

If the shape functions chosen to describe the curvilinear coordinates of a finite element are identical to those used to prescribe the displacement function variation, then the element is termed isoparametric.

This definition and the formulation of the elements in this section are derived and taken from the formulation described in references 1, 2 and 3, and 4. The isoparametric elements in NASTRAN are:

1. IS2D4 - Planar quadrilateral element with zero bending stiffness
2. IS2D8 - Planar quadriparabolic element with zero bending stiffness
3. IS3D8 - Solid linear element
4. IS3D20 - Solid parabolic element

The isoparametric family of elements uses a mapping technique to avoid performing the required numerical integrations on arbitrarily shaped elements. The displacement function is assumed in relation to an element with a simple shape, e.g., rectangle in two dimensions, rectangular parallelepiped in three dimensions. However, the shape of the element is permitted to distort and take another shape, dictated by the same functions that describe the displacement patterns. Figure 1 shows the four available elements and the simple, or parent, element is used.

The grid points of each parent element are defined in a local (ξ, η, ζ) coordinate system. The grid points at the corners have values of $\pm$ 1. The grid points of the curvilinear element are defined in the basic (x, y, z) coordinate system. Each parent element has an assumed displacement function, which is also used to relate the (ξ, η, ζ) coordinates to the (x, y, z) coordinates.

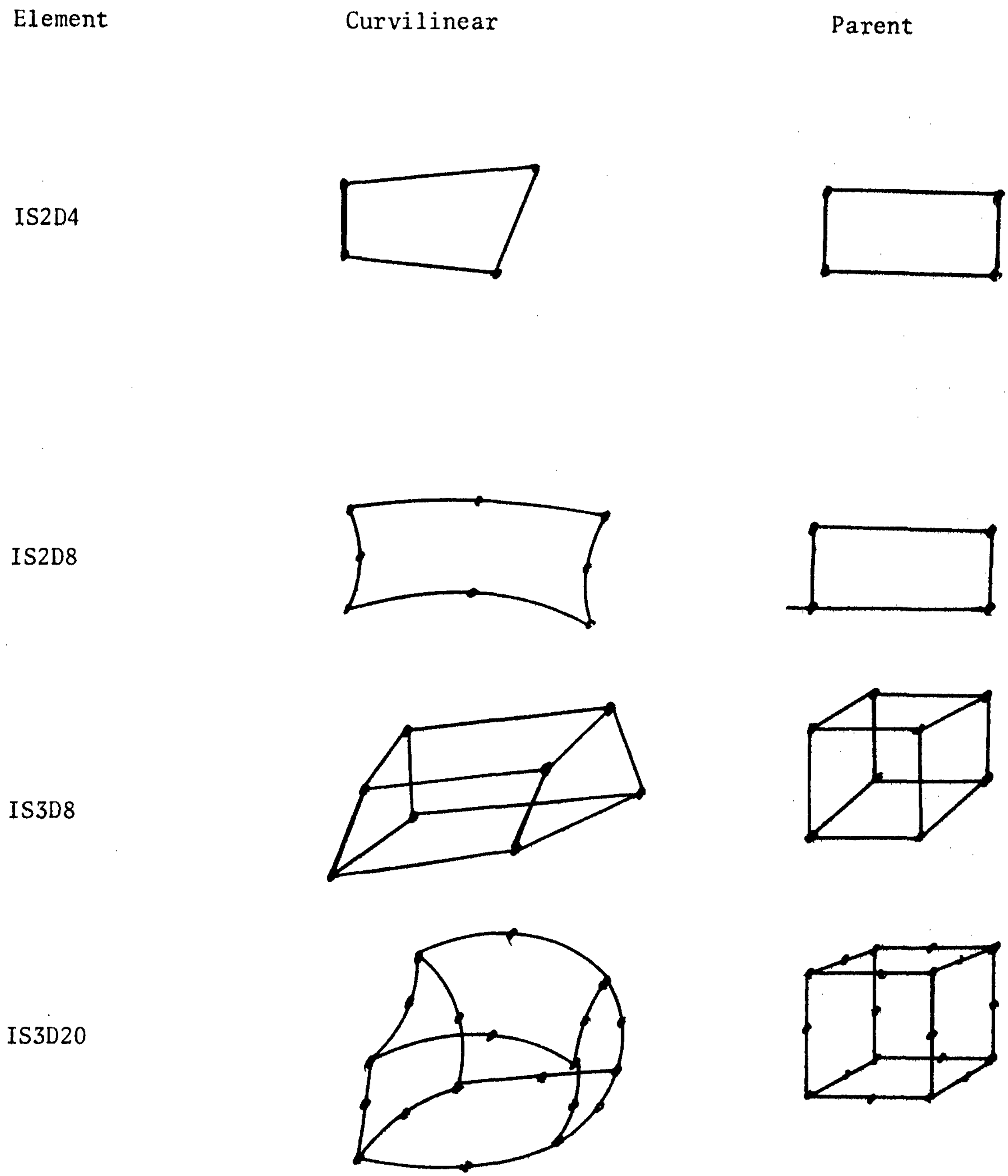


Figure 1. Isoparametric Elements and Their Associated Parent Elements

5.13.2 Structural Elements

5.13.2.1 Planar Elements

Consider the planar elements in Figures 2a and 2b below. (The order of the grid point numbering is required.)

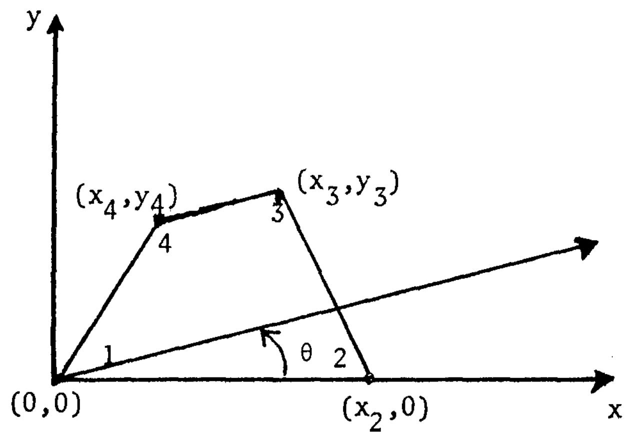


Figure 2a. IS2D4 Element

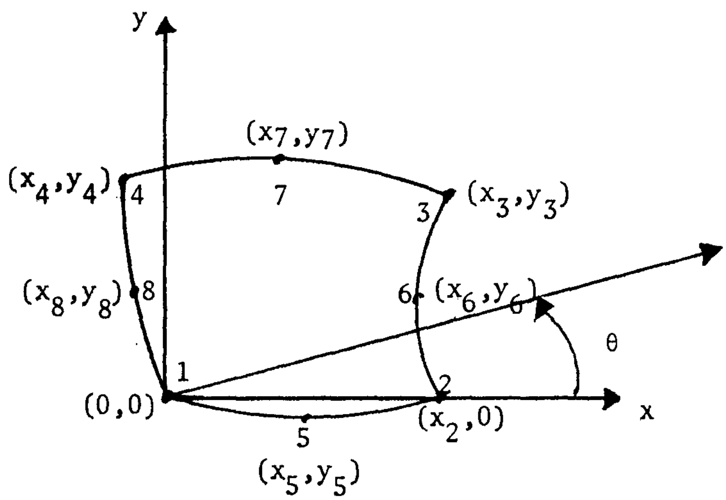


Figure 2b. IS2D8 Element

These elements have a thermal, as well as structural, capability and may have anisotropic thermal and structural temperature-dependent material properties.

For the thermal and structural elements, lumped or consistent capacitance and mass matrices, respectively, may be computed.

Let u and v be the components of displacement in the element coordinate system, parallel to the x- and y-directions of the element coordinate system, respectively. The in-plane displacements of all the grid points of the element are represented by the vector

$$\{u_e\} = \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ \cdot \\ \cdot \\ \cdot \\ u_n \\ v_n \end{Bmatrix} \qquad (1)$$

where n= 4 or 8 depending on the element. If $[K_{ee}]$ is the associated stiffness matrix, then

$$[K_{ee}]\{u_e\}=\{f_e\} \qquad (2)$$

where $\{f_e\}$ is the vector of in-plane forces.

$[K_{ee}]$ is derived as follows:

Assume that the displacement function is given by

$$\{u\}=[N]\ \{u_e\} \qquad (3)$$

where {u} is the vector of in-plane displacements and [N] is the shape matrix. The shape matrix [N] may be given as $[N] = [IN_1, IN_2, \ldots IN_n]$ where I is the 2x2 identity matrix. The N_i are defined as follows:

IS2D4

$$N_i = \frac{1}{4}(1+\xi\xi_i)(1+\eta\eta_i) \qquad (4)$$

IS2D8

(i) Corner grid points $\quad N_i = \frac{1}{4}(1+\xi\xi_i)(1+\eta\eta_i)(\xi\xi_i+\eta\eta_i-1)$

(ii) $\xi=\pm1,\ \eta=0$ $\quad N_j = \frac{1}{2}(1+\xi\xi_j)(1-\eta^2)$

(iii) $\xi=0,\ \eta=\pm1$ $\quad N_k = \frac{1}{2}(1-\xi^2)(1+\eta\eta_k)$

(5)

where i, j, k take on values of the grid point numbers.

The membrane strains are given by:

$$\{\varepsilon\} = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} u_x \\ v_y \\ u_y + v_x \end{Bmatrix}$$

$$\begin{bmatrix} N_{1x} & 0 & N_{2x} & 0 & \cdots\cdots\cdots & N_{nx} & 0 \\ 0 & N_{1y} & 0 & N_{2y} & \cdots\cdots\cdots & 0 & N_{ny} \\ N_{1y} & N_{1x} & N_{2y} & N_{2x} & \cdots\cdots\cdots & N_{ny} & N_{nx} \end{bmatrix} \{u_e\} \qquad (6)$$

where the x and y subscripts refer to partial derivatives of $N_1, \ldots,$ N_n with respect to the x-and y-directions of the element coordinate system. Note that these partial derivatives cannot be directly obtained since the N_i functions are functions of the (ξ, η) coordinate system. Therefore, we must define the Jacobean [J] as follows:

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = \begin{bmatrix} N_1 & N_2 & \ldots & N_n & 0 & 0 \ldots 0 \\ 0 & 0 & \ldots & 0 & N_1 & N_2 \ldots N_n \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \\ y_1 \\ y_2 \\ \vdots \\ y_n \end{Bmatrix} \qquad (7)$$

$$[J] = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} \end{bmatrix} = \begin{bmatrix} N_{1\xi} & N_{2\xi} & \cdots & N_{n\xi} \\ N_{1\eta} & N_{2\eta} & \cdots & N_{n\eta} \end{bmatrix} \begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ \vdots & \vdots \\ x_n & y_n \end{bmatrix} \qquad (8)$$

Now, the necessary partial derivatives may be obtained as follows:

$$\begin{Bmatrix} N_{i\xi} \\ N_{i\eta} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} \end{Bmatrix} \begin{Bmatrix} N_{ix} \\ N_{iy} \end{Bmatrix} \tag{9}$$

or

$$\begin{Bmatrix} N_{i\xi} \\ N_{i\eta} \end{Bmatrix} = [J] \begin{Bmatrix} N_{ix} \\ N_{iy} \end{Bmatrix} \tag{10}$$

So

$$\begin{Bmatrix} N_{ix} \\ N_{iy} \end{Bmatrix} = [J]^{-1} \begin{Bmatrix} N_{i\xi} \\ N_{i\eta} \end{Bmatrix} \tag{11}$$

If we now rewrite (6) as

$$\{\varepsilon\} = [B]\{u_e\}$$

then the usual energy considerations yield the stiffness matrix

$$[K_{ee}] = t\int_{-1}^{1} \int_{-1}^{1} [B]^T [G_e][B] \det[J]\, d\xi d\eta \tag{12}$$

where

t is the element thickness

G_e is the material properties matrix

det [J] is the determinant of the Jacobean.

(It can be shown that det [J] $d\xi d\eta = dx dy$).

In NASTRAN the $[G_e]$ matrix may be anisotropic so that the only restriction is that it be symmetric. In the case of isotropy,

$$[G_e] = \begin{bmatrix} \frac{E}{1-\nu^2} & \frac{\nu E}{1-\nu^2} & 0 \\ \frac{\nu E}{1-\nu^2} & \frac{E}{1-\nu^2} & 0 \\ 0 & 0 & G \end{bmatrix} \qquad (13)$$

where the shear modulus G is $G = E/2(1+\nu)$.

If anisotropic materials are used, the user specifies them with respect to a particular orientation, which does not necessarily correspond to the principal axes. The angle θ (see figures 2a and 2b) is an input parameter. The properties matrix in the material coordinate system is transformed into the element coordinate system by

$$[G_E] = [U]^T [G_m] [U]$$

where

$$[U] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \cos\theta\sin\theta \\ \sin^2\theta & \cos^2\theta & -\cos\theta\sin\theta \\ -2\cos\theta\sin\theta & 2\cos\theta\sin\theta & \cos^2\theta-\sin^2\theta \end{bmatrix} \qquad (14)$$

is the transformation matrix for the rotation of strain components.

The integration specified in equation (12) is performed numerically using Gaussian quadrature. The stiffness matrix is approximated by

$$K_{ee} \doteq t \sum_{\ell=1}^{p} \sum_{m=1}^{p} A_\ell A_m [f(\xi_\ell, \eta_m)] \qquad (15)$$

where

A is the coefficient used in the quadrature and depends on the number of quadrature points

p is the number of quadrature points

$f = [B]^T [G_e][B] \det[J]$

The number of quadrature points p used for the IS2D4 element is 2 for IS2D8, 2 or 3. The number p may vary. As p increases, theoretically, the solution improves. However, running times increase rapidly as p increases. The values of p used for these elements appear to be very satisfactory.

Finally, the stiffness matrix is transformed from the local element coordinate system to the global coordinate system of the grid points. If this transformation is given by

$$\{u_e\} = [T]\{u_g\}, \qquad (16)$$

then

$$\{K_{GG}\} = [T]^T [K_{ee}][T] \qquad (17)$$

The consistent mass matrix for these planar elements is given by

$$[M_{ee}] = t\int_{-1}^{1} \int_{-1}^{1} [N]^T \rho [N] \det [J] d\xi d\eta \quad (18)$$

where ρ is the mass density. The appropriate transformation gives $[M_{GG}]$.

The lumped mass matrix is formed by distributing the mass proportionately among the grid points of the element. This matrix is diagonal. The total mass for an element is ρV, where V is the element volume, so that the mass applied to grid point i is

$$\frac{\int N_i^2}{\sum_{j=1}^{n} \int N_j^2} \rho t \int_{-1}^{1} \int_{-1}^{1} \det[J] d\xi d\eta . \quad (19)$$

A load vector is produced by the thermal expansion of an element. The thermal strain vector is

$$\{\varepsilon_t\} = \begin{Bmatrix} \varepsilon_{xt} \\ \varepsilon_{yt} \\ \gamma_t \end{Bmatrix} = \{\alpha_m\}(t_i - T_0) \quad (20)$$

where $\{\alpha_m\}$ is the thermal expansion coefficient vector and t_i is the temperature at element grid point i, and T_0 is the reference temperature.

Then,

$$\{\sigma_t\} = [G_e]\{\varepsilon_t\} = [G_e]\{\alpha_m\}(t_i - T_0) . \quad (21)$$

So, the load is

$$\{P_e\}^i = t[\int_{-1}^{1} \int_{-1}^{1} [B]^T \det[J] d\xi d\eta] \; [G_e]\{\alpha_m\}(t_i - T_0) \quad (22)$$

Transformation to global coordinates

$$\{P_G\} = [T]^T \{P_e\} \quad (23)$$

completes the calculation.

After the grid point displacements have been computed, element stresses are computed as follows:

$$\{u_e\}=[T]\ \{u_g\} \tag{24}$$

$$\{\varepsilon\}=[B]\{u_e\} \tag{25}$$

$$\{\sigma\}=[G_M]\{\varepsilon-\varepsilon_t\} \tag{26}$$

or

$$\{\sigma\}=[G_M][B][T]\{u_g\}-[G_M]\{\alpha_m\}(t_i - T_0) \tag{27}$$

By evaluating [B] at the gauss quadrature points, stresses are computed at these gauss points. Grid point stresses are computed by extrapolating from the gauss points. This method appears to be superior to computing grid point stresses directly. Also, the number of gauss quadrature points used in computing the mass matrix is one more than that used in computing the stiffness matrix.

5.13.2.2 Solid Elements

The two solid elements in NASTRAN are the IS3D8 and IS3D20 elements, which are connected to 8 and 20 grid points, respectively. The sides of the IS3D8 element are linear; the sides of the IS3D20 element are parabolic. An IS3D8 element is shown in Figure 3.

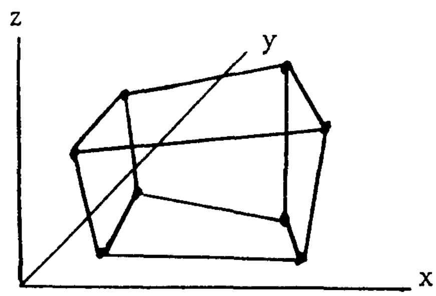


Figure 3. IS3D8 Element

Many details in the derivations below are very similar to those for the planar elements and will not be repeated.

If anisotropic material properties are to be specified for a solid element, the user supplies a coordinate system number which refers to a rectangular material coordinate system. The element geometry is then transformed into this material coordinate system, in which all calculations are made until the final conversion to the global coordinate system.

Let u, v, w be the components of displacement in the material coordinate system, parallel to the x-, y-, z-axes of that system, respectively. Then the displacements of the grid points of the element are represented by the vector

$$\{u_e\} = \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ u_2 \\ v_2 \\ w_2 \\ \vdots \\ u_n \\ v_n \\ w_n \end{Bmatrix} \qquad (1)$$

where n is 8 or 20, depending on the type of element. The shape functions N_i are as follows:

<u>IS3D8</u>

$$N_i=\frac{1}{8}(1+\xi\xi_i)(1+\eta\eta_i)(1+\zeta\zeta_i) \quad (2)$$

<u>IS3D20</u>

(i) Corner grid points $\quad N_i=\frac{1}{8}(1+\xi\xi_i)(1+\eta\eta_i)(1+\zeta\zeta_i)(\xi\xi_i+\eta\eta_i+\zeta\zeta_i-2)$

(ii) $\xi_j=0 \quad N_j=\frac{1}{4}(1-\xi^2)(1+\eta\eta_j)(1+\zeta\zeta_j)$ (3)

(iii) $\eta_k=0 \quad N_k=\frac{1}{4}(1+\xi\xi_k)(1-\eta^2)(1+\zeta\zeta_k)$

(iv) $\zeta_\ell=0 \quad N_\ell=\frac{1}{4}(1+\xi\xi_\ell)(1+\eta\eta_\ell)(1-\zeta^2)$

The shape matrix [N] may be represented as

$$[N]=[IN_1,\ IN_2,\ldots IN_n] \quad (4)$$

where I is the 3X3 identity matrix. Then the displacement function is given by

$$\{u\}=[N]\{u_e\}$$

The strains are given by

$$\{\varepsilon\}=\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{Bmatrix}=\begin{Bmatrix}u_x\\ v_y\\ w_z\\ u_y+v_x\\ v_z+w_y\\ w_x+u_z\end{Bmatrix}=[B]\{u_e\} \quad (5)$$

where

$$[B]=\begin{bmatrix} N_{1x} & 0 & 0 & --- & N_{nx} & 0 & 0 \\ 0 & N_{1y} & 0 & --- & 0 & N_{ny} & 0 \\ 0 & 0 & N_{1z} & --- & 0 & 0 & N_{nz} \\ N_{1y} & N_{1x} & 0 & --- & N_{ny} & N_{nx} & 0 \\ 0 & N_{1z} & N_{1y} & --- & 0 & N_{nz} & N_{ny} \\ N_{1z} & 0 & N_{1x} & --- & N_{nz} & 0 & N_{nx} \end{bmatrix} \quad (6)$$

The Jacobean [J] becomes

$$[J]=\begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} & \frac{\partial z}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} & \frac{\partial z}{\partial \eta} \\ \frac{\partial x}{\partial \zeta} & \frac{\partial y}{\partial \zeta} & \frac{\partial z}{\partial \zeta} \end{bmatrix} = \begin{bmatrix} N_{1\xi} --- N_{n\xi} \\ N_{1\eta} --- N_{n\eta} \\ N_{1\zeta} --- N_{n\zeta} \end{bmatrix} \begin{bmatrix} x_1 & y_1 & z_1 \\ \vdots & \vdots & \vdots \\ x_n & y_n & z_n \end{bmatrix} \quad (7)$$

The stiffness matrix $[K_{ee}]$ then becomes

$$[K_{ee}]=\int_{-1}^{1}\int_{-1}^{1}\int_{-1}^{1} [B]^T[G_m][B]\det[J]\,d\xi\, d\eta\, d\zeta \quad (8)$$

where $[G_m]$ is the material properties matrix which, in the case of isotropy, is:

$$[G_m] = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1 & \frac{\nu}{1-\nu} & \frac{\nu}{1-\nu} & 0 & 0 & 0 \\ & 1 & \frac{\nu}{1-\nu} & 0 & 0 & 0 \\ & & 1 & 0 & 0 & 0 \\ & & & \frac{(1-2\nu)}{2(1-\nu)} & 0 & 0 \\ & \text{symmetric} & & & \frac{(1-2\nu)}{2(1-\nu)} & 0 \\ & & & & & \frac{1-2\nu}{2(1-\nu)} \end{bmatrix} \quad (9)$$

The approximation for the integration is

$$[K_{ee}] \doteq \sum_{\ell=1}^{p} \sum_{m=1}^{p} \sum_{n=1}^{p} A_\ell A_m A_n [f(\xi_\ell, \eta_m, \zeta_n)] \tag{10}$$

For IS3D8 elements p=2, for IS3D20 elements p=3. Finally, if [T] is a transformation matrix from the material coordinate system to the global coordinate system, then

$$[K_{GG}] = [T]^T [K_{ee}] [T] \tag{11}$$

The consistent mass matrix is given by

$$[M_{ee}] = \rho \int_{-1}^{1} \int_{-1}^{1} \int_{-1}^{1} [N]^T [N] \det[J] d\xi d\eta d\zeta \tag{12}$$

The lumped mass matrix is

$$[M_{ee}] = \rho \int_{-1}^{1} \int_{-1}^{1} \int_{-1}^{1} \det[J] d\xi d\eta d\zeta \tag{13}$$

and the mass associated with grid point i is

$$\frac{\int N_i^2}{\sum_{j=1}^{n} \int N_j^2} \rho \int_{-1}^{1} \int_{-1}^{1} \int_{-1}^{1} \det[J] d\xi d\eta d\zeta$$

The load vector due to thermal expansion is

$$\{P_e^i\} = [\int_{-1}^{1} \int_{-1}^{1} \int_{-1}^{1} [B]^T d\xi d\eta d\zeta] [G_m] \{\alpha_m\} (t_i - T_0) \tag{14}$$

For completeness, the element stresses are, again,

$$\{\sigma\} = [G_m][B][T]\{u_g\} - [G_m]\{\alpha_m\}(t_i - T_0)$$

Grid point stresses are computed by first computing stresses at gauss quadrature points and then extrapolating to the grid points.

Also, the number of gauss quadrature points used in computing the mass matrix is one more than that used in computing the stiffness matrix.

5.13.3 Thermal Elements

The differential equation governing the behavior of the temperature u is

$$\frac{\partial}{\partial x}(k_x \frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(k_y\frac{\partial u}{\partial y})+\frac{\partial}{\partial z}(k_z\frac{\partial u}{\partial z})+G-C\frac{\partial u}{\partial t} =0 \qquad (1)$$

where

k_x, k_y, k_z	are the anisotropic conductivity coefficients
G	is the rate of heat generation or external heat input, and
C	is the capacitance

In addition to specified temperatures on the boundaries, another boundary condition might take the form

$$k_x\frac{\partial u}{\partial x} \ell_x+k_y\frac{\partial u}{\partial y} \ell_y +k_z \frac{\partial u}{\partial z} \ell_z+q+H_c(u-u_a)=0 \qquad (2)$$

where

ℓ_x, ℓ_y, ℓ_z	are the direction cosines of the outward normal to the boundary surface
q	is the heat flux per unit of surface
H_c	is the film coefficient for convection, and
u_a	is the ambient temperature for convection

If k_x, k_y, k_z are equal and q and α are zero, then equation (2) reduces to a condition applicable to non-conducting boundaries

$$\frac{\partial u}{\partial \eta} =0 \qquad (3)$$

By applying Euler's theorem in the calculus of variations, equation (1) will be satisfied, subject to boundary condition (2), if and only if the functional

$$X\equiv\iiint [\frac{1}{2}\{k_x(\frac{\partial u}{\partial x})^2+k_y(\frac{\partial u}{\partial y})^2+k_z(\frac{\partial u}{\partial z})^2\}-(G-C\frac{\partial u}{\partial t})u]dxdydz \qquad (4)$$

is minimized and if the boundary conditions (2) are satisfied.

Zienkiewicz[1] states that boundary conditions (2) may be taken into account by modifying equation (4) as follows:

$$X=\iiint \left[\frac{1}{2}\left\{k_x\left(\frac{\partial u}{\partial x}\right)^2+k_y\left(\frac{\partial u}{\partial y}\right)^2+k_z\left(\frac{\partial u}{\partial z}\right)^2-\left(G-C\frac{\partial u}{\partial t}\right)u\right]dxdydz$$

$$+\int_B (q-H_c u_a)udS+\int_B \frac{1}{2}H_c u^2 dS \qquad (4')$$

where the last two integrals are surface integrals taken over the boundary on which conditions (2) are applied. (We will not be too careful about the placement of the thermal coefficients H_c, α, k_x, ..., etc. since these parameters are considered to be constant within an element.)

Now assume, as in previous sections, that, for any element,

$$u=[N]\{u_e\} \qquad (5)$$

where now,

$$[N]=[N_1,\ N_2,\ \ldots,\ N_n],$$

$$\{u_e\}=\begin{Bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{Bmatrix},\ \text{and}$$

n is the number of grid points associated with the element then

$$u=[N_1,\ N_2,\ \ldots,N_n]\begin{Bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{Bmatrix} \qquad (6)$$

We now want to minimize the functional X with respect to all u_i's in the problem. We can do this by evaluating the contributions to each differential, $\frac{\partial X}{\partial u_i}$, from each element, adding, and equating to zero. If the contribution to X from an element is X_e, then, differentiating equation (4')

$$\frac{\partial X_e}{\partial u_i} = \iiint [k_x \frac{\partial u}{\partial x} \frac{\partial}{\partial u_i}(\frac{\partial u}{\partial x}) + k_y \frac{\partial u}{\partial y} \frac{\partial}{\partial u_i}(\frac{\partial u}{\partial y}) + k_z \frac{\partial u}{\partial z} \frac{\partial}{\partial u_i}(\frac{\partial u}{\partial z})$$

$$-(G - C\frac{\partial u}{\partial t}) \frac{\partial u}{\partial u_i}] \, dxdydz \qquad (7)$$

$$+\int_B (q - H_c u_a) \frac{\partial u}{\partial u_i} dS + \int_B H_c u \frac{\partial u}{\partial u_i} dS$$

Now, substituting equation (6) into equation (7), we obtain

$$\frac{\partial X_e}{\partial u_i} = \iiint \{k_x N_{ix} [N_{1x}, \ldots, N_{nx}] + k_y N_{iy} [N_{1y}, \ldots, N_{ny}] + k_z N_{iz} [N_{1z}, \ldots, N_{nz}]\}$$

$$dxdydz \{u_e\}$$

$$-\iiint C N_i dxdydz + \iiint C N_i [N_1, \ldots N_n] dxdydz \frac{\partial u_e}{\partial t} \qquad (8)$$

$$+\int_B (q - H_c u_a) N_i dS + \int_B H_c N_i [N_1, \ldots, N_n] dS \{u_e\}$$

If all the contributions from an element are denoted by

$$\{\frac{\partial X}{\partial u}\}_e = \left\{ \begin{array}{c} \frac{\partial X_e}{\partial u_1} \\ \vdots \\ \frac{\partial X_e}{\partial u_n} \end{array} \right\} \qquad (9)$$

then the notation can be reformulated to

$$\{\frac{\partial X}{\partial u}\}_e = [K_{ee}]\{u_e\} + [B_{ee}] \{\frac{\partial u_e}{\partial t}\} + \{P_e\} \qquad (10)$$

where

$[K_{ee}]$ is the element conductivity (stiffness) matrix
$[B_{ee}]$ is the element capacitance (damping) matrix, and
$\{P_e\}$ is the vector of element loads.

Equating equation (10) to 0 and performing some manipulation yields, for the entire problem,

$$[B]\{\dot{u}\}+[K]\{u\} = -\{P\} \tag{11}$$

Then,

$$K_{ij}=\Sigma\int\int\int(k_x N_{ix} N_{jx}+k_y N_{iy} N_{jy}+k_z N_{iz} N_{jz})dxdydz+\Sigma\int_B H_c N_i N_j dS \tag{12}$$

$$B_{ij}=\Sigma\int\int\int C N_i N_j dxdydz \tag{13}$$

and

$$P_i=-\Sigma\int\int\int C N_i dxdydz+\Sigma\int_B (q-H_c u_a) N_i dS \tag{14}$$

where the summation covers the contributions from each element. Finally, the matrices and vectors are assembled in exactly the same way as in the structural problem.

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19. THERMAL TRANSIENT - STRUCTURAL STATICS COMBINATION

Thermal transient - Structural Statics Combination, Rigid Format 14, is a combination of the analyses contained in Direct Transient Analysis, Rigid Format 9, with modifications, and Static Analysis, Rigid Format 1. In the transient analysis portion, the temperature history of the structure is computed, taking account of such thermal conditions as radiation, convection, flux, and heat generation. Then, a series of static analyses will be performed using, as part of the static loading the equivalent loads due to the temperature distribution at times selected by the user.

The finite elements allowed to be used in Rigid Format 14 are the isoparametric elements IS3D4, IS3D8, IS3D8, and IS3D20, the surface elements SURF1, SURF4, and SURF8, and the BAR element. These elements may have anisotropic, temperature-dependent material properties in both the thermal and structural analyses. Therefore, in the thermal transient analysis, element conductence and capacitance matrices may be recomputed. Recomputation of element matrices will also be performed if convection is specified.

A very simplified flow diagram of Rigid Format 14 is given in Figure 1.

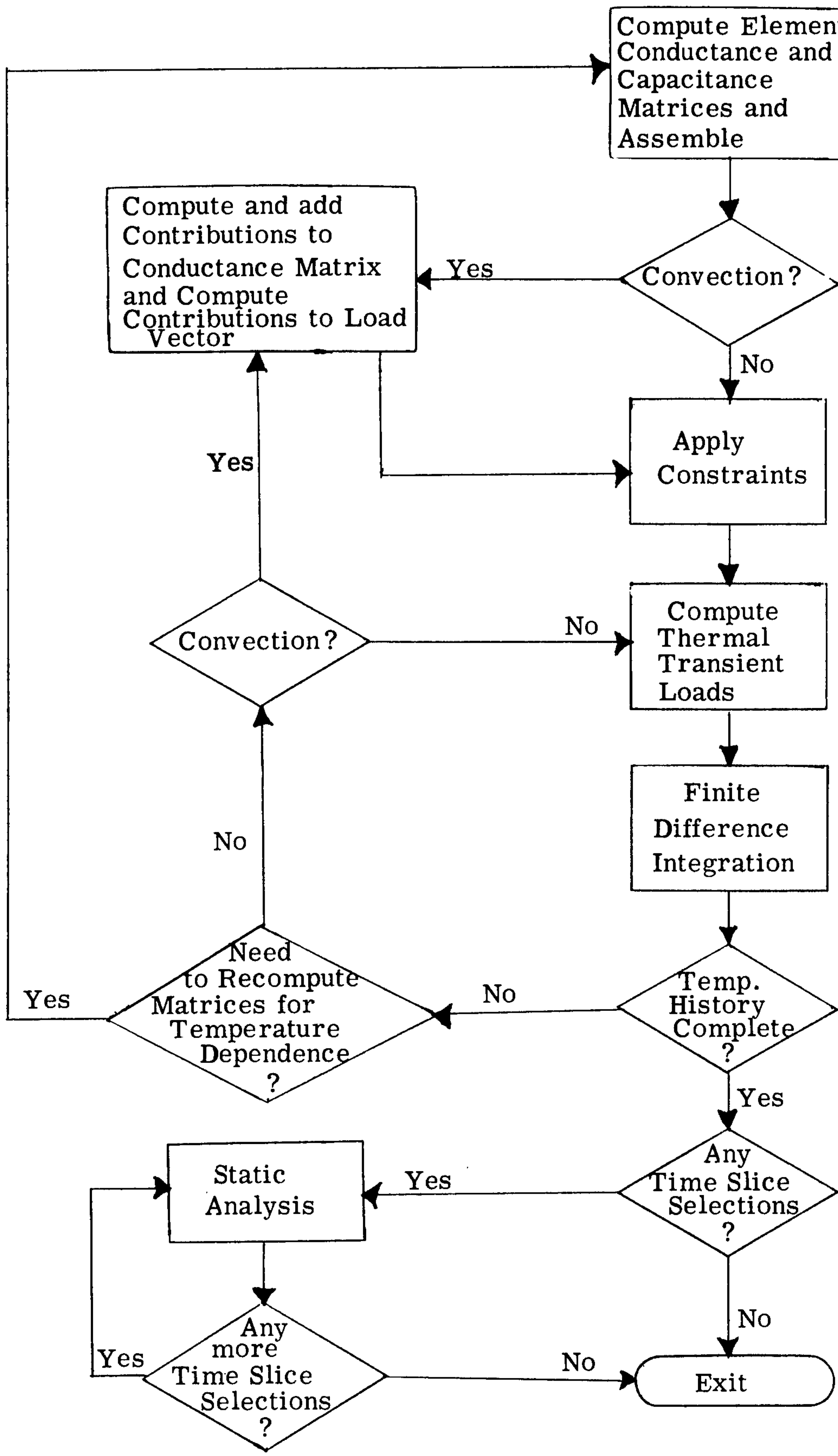

Figure 1. Simplified Flow Diagram for Rigid Format 14

19.1 THERMAL TRANSIENT ANALYSIS

In thermal transient analysis, the governing differential equation is a first order equation rather than the second order equation governing the structural problem. Before the integration algorithm is described, the thermal transient loads will be described.

19.1.1 Thermal Transient Loads

The following types of loading are available in a thermal transient analysis:

1. Transient loads of the types discussed in Section 11.1
2. Nonlinear loads of the types discussed in Section 11.2
3. Convection from a surface to its surroundings
4. Radiation from a surface to its surroundings
5. Radiation from one surface to another surface
6. Internal heat generation
7. Heat flux

Of the new types of loading, convection, heat generation, and heat flux were discussed in Section 5.13.3. An expansion of those remarks, as well as a discussion of the radiation loads, will be presented here. (Equations (12) (13), and (14) in Section 5.13.3 include convection, heat generation, and heat flux.)

<u>Convection</u> loads are given by

$$Q=H_c A(T-T_\infty) \tag{1}$$

where

- Q is the heat flow per unit time due to convection exchange
- H_c is the film coefficient, which may be time dependent
- A is the area of the surface
- T is the temperature of the surface
- T_∞ is the ambient temperature

Contributions of

$$H_c \int\int N_i N_j dS \tag{2}$$

are made to the (i,j)th entry of the conduction matrix for the element. The contribution to the transient load vector from each grid point defining the surface is

$$H_c T_\infty \int\int N_i dS \tag{3}$$

where N_i and N_j make up the element shape matrix [N]. (See Section 5.13.2.1.) (The integrals in equations (2) and (3) are surface integrals, as are $\iint ds$ integrals in equations (8), (10), and (12).) Internal heat generation loads are given by

$$Q=GV \tag{4}$$

where

Q is the load to be applied

G is the heat generation per unit time, which may be temperature dependent, and

V is the element volume

For solid elements, the contribution from each grid point of the element is

$$G(T_i)\iiint N_i dxdydz \tag{5}$$

while for planar elements, the contribution is

$$G(T_i)h\iint N_i dxdy \tag{6}$$

where h is the element thickness and T_i is the temperature of grid point i. Loads due to heat flux are given by

$$Q=qA \tag{7}$$

where

Q is the load to be applied

q is the heat flux coefficient, which may be time dependent, and

A is the area

The contribution to the load vector from each grid point defining the surface is

$$\iint q(t)N_i dS \tag{8}$$

The load due to radiation from a surface to its surroundings is

$$Q=HA(T^4-T_\infty^4) \tag{9}$$

where

Q is the net rate of radiation heat exchange between a specified surface and its surroundings

H is the radiation factor, which may be temperature dependent

A is the area of the surface

T is the temperature of the surface, and

T_∞ is the ambient temperature, which may be time dependent.

The contribution to the load vector from a grid point defining the surface is

$$-H(T_i)(T_i^4-T_\infty^4)\iint N_i dS \tag{10}$$

where T_i is the temperature of grid point i.

For radiation between two surfaces,

$$Q=HA_1A_2(T_1^4-T_2^4) \tag{11}$$

where

Q is the net rate of radiation heat exchange between surfaces S_1 and S_2

H is the radiation factor, which may be temperature dependent

A_1,A_2 are the areas of S_1 and S_2, respectively, and

T_1,T_2 are the temperatures of S_1 and S_2, respectively.

The contribution to the load vector from a grid point defining surface S_1 is

$$-H(T_i)(T_{1_i}^4-T_2^4)A_2\iint N_i dS \tag{12}$$

and, from surface S_2, the contribution is

$$H(T_{2_i})(T_1^4-T_{2_i}^4)A_1\iint N_i dS \tag{13}$$

(In equations (2), (3), (8), (10), (12) and (13), the surface integral $S=\iint dS$ is computed as follows.

$$S=\iint\sqrt{EG-F^2}\,d\xi d\eta \tag{14}$$

$$E=\left(\frac{\partial x}{\partial\xi}\right)^2+\left(\frac{\partial y}{\partial\xi}\right)^2+\left(\frac{\partial z}{\partial\xi}\right)^2 \tag{15}$$

$$F=\frac{\partial x}{\partial\xi}\ \frac{\partial x}{\partial\eta}+\frac{\partial y}{\partial\xi}\ \frac{\partial y}{\partial\eta}+\frac{\partial z}{\partial\xi}\ \frac{\partial z}{\partial\eta} \tag{16}$$

$$G=\left(\frac{\partial x}{\partial\eta}\right)^2+\left(\frac{\partial y}{\partial\eta}\right)^2+\left(\frac{\partial z}{\partial\eta}\right)^2 \tag{17}$$

and

$$\begin{bmatrix} \frac{\partial x}{\partial\xi} & \frac{\partial y}{\partial\xi} & \frac{\partial z}{\partial\xi} \\ \\ \frac{\partial x}{\partial\eta} & \frac{\partial y}{\partial\eta} & \frac{\partial z}{\partial\eta} \end{bmatrix} = \begin{bmatrix} \frac{dN_1}{d\xi} & \cdots & \frac{dN_n}{d\xi} \\ \\ \frac{dN_1}{d\eta} & \cdots & \frac{dN_n}{d\eta} \end{bmatrix} \begin{bmatrix} x_1 & y_1 & z_1 \\ \vdots & \vdots & \vdots \\ \\ x_n & y_n & z_n \end{bmatrix} \tag{18}$$

(Notation is the same as in Section 5.13.3)

19.1.2 Integration Algorithm

The system of differential equations to be solved is

$$[B\frac{d}{dt}+K]\{u\}=\{P\} \tag{1}$$

Although the coefficient matrices [B] and [K] may be functions of time t and of the solution vector {u}, it is assumed that they vary slowly so that they can be considered constant during any one time step. The load vector {P} may be the sum of a time dependent load $\{P_T\}$ and a non-linear load $\{P_N\}$.

The solution algorithm begins with initial conditions prescribed at time t_0, and computes the solution at prescribed times t_i, i=1, 2, 3,. . ..

If at time t_i, i=0, 1, 2, . . ., the solution $\{u_i\}$ is prescribed or has been previously computed, the algorithm proceeds to compute the solution $\{u_{i+1}\}$ at the following time t_{i+1}. For the time increment $\Delta t_i = t_{i+1} - t_i$, the solution of Equation (1) is

$$\{u_{i+1}\} = \int_{t_i}^{t_{i+1}} \{P\}dt + \exp(-\Delta t[B^{-1}K])\{u_i\} \ . \quad (2)$$

This is the value of the solution to be approximated.

The Approximation of the Solution {u}

Since the load vector is the sum of a time dependent load $\{P_T\}$ that can be computed at t_i and t_{i+1}, and a non-linear load that is computed only at t_i, the integral in Equation (2) is approximated by

$$\Delta t\{ \tfrac{1}{2}(P_{T_i} + P_{T_{i+1}}) + P_{N_i}\} \ . \quad (3)$$

The matrix in exponential form from Equation (2) in a series expansion,

$$[I] - \Delta t[B^{-1}K] + \frac{(\Delta t)^2}{2!}[B^{-1}K]^2 - \frac{(\Delta t)^3}{3!}[B^{-1}K]^3 + \cdots, \quad (4)$$

is equal, up to terms of order $(\Delta t)^2$, to the expression

$$[B + \frac{\Delta t}{2}K]^{-1}[B - \frac{\Delta t}{2}K] = [I + \frac{\Delta t}{2}B^{-1}K]^{-1}[I - \frac{\Delta t}{2}B^{-1}K]$$
$$= [I] - \Delta t[B^{-1}K] + \frac{(\Delta t)^2}{2}[B^{-1}K]^2 - \frac{(\Delta t)^3}{4}[B^{-1}K]^3 + \cdots. \quad (5)$$

Thus an approximate solution in the form of the solution of a system of linear algebraic equations is given by

$$[B + \frac{\Delta t}{2}K]\{u_{i+1}\} = [B - \frac{\Delta t}{2}K]\{u_i\} + [B + \frac{\Delta t}{2}K]\{\tfrac{1}{2}(P_{T_i} + P_{T_{i+1}}) + P_{N_i}\}\Delta t \quad (6)$$

This linear system is solved by a symmetric decomposition and forward-backward substitution.

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13. ABSTRACT

This report describes, through additions and modifications to the Level 15.1 NASTRAN User's and Theoretical Manuals, a thermostructural capability for NASTRAN. In addition to this new rigid format, a set of two-dimensional and three-dimensional isoparametric finite elements was added to NASTRAN's finite element library. The thermostructural capability consists of computing a temperature history of the structure, taking account of such thermal conditions as radiation, convection, flux, and heat generation, and then performing a series of structural static analyses, using as part of the static loading the equivalent loads due to the temperature distribution at times selected by the user.

This version of NASTRAN is available for the UNIVAC 1108 and CDC 6000 computers.