THE GSFC NASTRAN THERMAL ANALYZER NEW CAPABILITIES

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SUMMARY

An overview of four new analysis capabilities, which have been developed and integrated into the GSFC NASTRAN Thermal Analyzer, is given. To broaden the scope of applications, these new additions provide the $\overline{N}TA$ users with the following capabilities of: (1) simulating a thermal louver as a means of the passive thermal control, (2) simulating a fluid loop for transporting energy as a means of the active thermal control, (3) condensing a large-sized finite-element model for an efficient transient thermal analysis, and (4) entering multiple boundary condition sets in a single submission for execution in steady-state thermal analyses.

INTRODUCTION

Four new capabilities have been recently developed and integrated into the GSFC NASTRAN Thermal Analyzer ($\overline{N}TA$), which is a finite-element based general-purpose heat transfer computer program in the NASTRAN system (refs. 1, 2, 3). The $\overline{N}TA$ was originally designed to analyze a large and complex space-borne telescope optical sub-system (refs. 4, 5). The new additions have broadened the scope of engineering application of the $\overline{N}TA$ from component level to system level, so that complete spacecraft, which would generally require passive and/or active thermal controls, can be treated. Also, the manipulative options relating to the operational efficiency of the computer program can become critical when large numbers of elements or grid points are employed in modeling rather than dealing with a problem of a small size. Specifically, the four new capabilities are:

(1) Temperature-dependent emissivity and absorptivity.

(2) One-dimensional thermo-fluid elements.

(3) The condensation of a finite-element thermal model including the non-linear radiative effect.

(4) The entry of multiple boundary condition sets in a single submission for execution.

The purpose of this paper is to provide NASTRAN users with an overview of these new capabilities. Definition, scope, features and limitation of each individual item are given. New elements needed to facilitate functional objectives are introduced. The use of these new elements together with the appropriate solution routines are described. Essential parts of program changes and new elements interfacing with different functional modules in the $\overline{N}TA$ are outlined.

TEMPERATURE-DEPENDENT EMISSIVITY AND ABSORPTIVITY

In the Level 15.5 $\overline{N}TA$, the solution algorithm pertaining to the radiative exchanges is limited to the diffuse-gray case. The programming code is, therefore, sufficient to enter a single constant value for the emissivity, ϵ, and the absorptivity, α, of each surface. As a result, the radiation matrix (the module RMG) is symmetric. These program restrictions have been eliminated by this new capability which permits an independent specification of temperature-dependent emissivity $\epsilon(T)$ and absorptivity $\alpha(T)$. The application of this feature is for transient thermal analysis only. A notable engineering application is to simulate a thermal louver as a means of the passive thermal control.

To accommodate temperature-dependent emissivity and absorptivity through the boundary surface element, HBDY, the RMG module would have to be restructured. Such a rigorous approach would result in a prohibitively large effort, and excessively long computer run times would be required for the following reasons:

(1) The matrices which express the radiation properties are generated in the module RMG which is executed early in the program.

(2) If emissivity and absorptivity are temperature-dependent functions, it would be necessary to execute the RMG module and all subsequent modules up to and including the solution module, TRHT, for each time step.

(3) If radiative heat flow was requested in the output, it would be necessary to execute the data recovery modules after each time step, because $\overline{N}TA$ does not have the ability to store the separate radiation flux matrices $[Q_{ge}]$ for each time step.

Although less flexible than the rigorous approach, an alternative has been adopted to employ the existing general nonlinear capability of NASTRAN (ref. 6). A nonlinear

element, <u>NOLIN5</u>*, has been newly introduced (ref. 7). It allows the emissivity and the absorptivity to be given independently as tabular functions of the radiating surface temperature.

<u>NOLIN5</u> differs from other NASTRAN nonlinear load cards in that a large number of grid points may be involved. An area factor A_i is associated with each grid point. For the emitting surface, the convention is adopted that $A_i > 0$. The sum of the area factors of the grid points associated with the emitting surface is one; hence the average temperature T_{av}, of the emitting surface is

$$T_{av} = \sum_i A_i T_i \qquad (1)$$

Other grid points, assigned to receive the radiation, are given area factors which are negative and are not included in the calculation of T_{av}. The emissivity $\epsilon(T_{av})$ is given as a tabular function of T_{av} by one of the <u>TABLEDi</u> data cards, as is the absorptivity $\alpha(T_{av})$. The rate at which the radiative heat is treated as a nonlinear load at point i is given by

$$N_i = -S\sigma A_i \epsilon(T_{av}) (T_{av} + T_{abs})^4 \qquad (2)$$

where S and A_i are data items and σ, the Stefan-Boltzmann constant, and T_{abs}, a datum temperature in an absolute scale, are rigid format parameters. The following changes have been made to the program:

IFP	New card <u>NOLIN5</u>.
DPD	Add NOLIN5 to subroutine DPD4.
TRHT	Add parameter TABS, SIGMA; add NOLIN5 to subroutine TRDID.
Rigid Format (SOL 9)	Add parameter to TRHT.

ONE-DIMENSIONAL THERMO-FLUID ELEMENTS

A simple but commonly used energy transporting means is the fluid loop consisting of a flowing fluid inside a tube, which may be made to contact a thermally conductive structure. New elements have been developed and added to the $\overline{N}TA$ to allow the effect of an active thermal control to be included in a model.

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*The names of actual $\overline{N}TA$ cards are capitalized and underlined.

The tube to convey the flowing fluid is modeled using the existing TUBE element with modification that allows a tube of uniform wall thickness to have a constant bore and a linearly tapered geometry as well. The convective heat exchange between the fluid and the tube and any heat transferring from the tube to the surroundings are modeled using HBDY elements as shown in Figure 1. The HBDY element has been modified, as is reflected in the PHBDY data card, to accommodate the linear taper.

The developed thermo-fluid elements are available to both the cases of steady-state and transient thermal analyses. For steady-state analysis, a constant flow rate is specified by the user. A new fluid element FTUBE has been introduced. The unusual feature of this element is that it possesses an asymmetric conduction matrix which is characterized by the fluid phenomenon (ref. 8). This element has created a connection CFTUBE and a property PFTUBE data cards. Element routines are needed for IFP, SMA1, SMA2, SDR2, and OFP. This new fluid element can be used in the nonlinear steady-state solution routine, the rigid format APP HEAT, SOL 3.

For transient analysis, a table, TABLEDi, may be provided by the user with a time-dependent flow rate function. In addition to the FTUBE element, the fluid cylinder is also treated as a nonlinear load. A new nonlinear element NFTUBE has been introduced. Both methods can be used in the transient solution routine, the rigid format APP HEAT, SOL 9. These two approaches, the element method and the nonlinear load method, are equivalent and equally simple to apply as far as the user is concerned.

The following changes have been made to the program for this thermo-fluid capability:

IFP	Modify PTUBE, CHBDY; new CFTUBE, PFTUBE, NFTUBE.
GPTA1	New entries for block data.
SMA1, SMA2	FTUBE routine (asymmetric output); fix HBDY type "FTUBE".
SDR2	Compute convected power in FTUBE
OFP	Output SDR2 results.
DPD	Add NFTUBE to subroutine DPD4
TRHT	Add NFTUBE to subroutine TRD1D.

THE CONDENSATION OF A FINITE-ELEMENT THERMAL MODEL

Condensation is the reduction of the number of temperature variables (or the generalized degrees-of-freedom in the NASTRAN system) used for solution efficiency. The OMIT feature of NASTRAN was designed to provide the model condensation. This feature has been extended to the transient thermal analysis, using the rigid format APP HEAT, SOL 9, to include linear and nonlinear boundary conditions. It is accomplished through matrix transfer and partitioning. The computer code has been modified to allow for asymmetric matrix operations. As a result, the restriction used to limit "a grid point which is OMITted may not touch any nonlinear elements" has been removed.

This feature, however, is not available to the nonlinear steady-state thermal analysis. Since the possible increase of the computer run time expenditure due to the mathematical manipulations would not be justified by the saving that would be realized by a condensed model in the steady-state case.

The program changes made to accommodate this capability have been modifications of MCE2 and SMP1 for asymmetric operations.

THE ENTRY OF MULTIPLE BOUNDARY CONDITION SUBCASES IN ONE EXECUTION

The counterpart of this capability in NASTRAN has been known to its users as the SUBCASE, but this capability was not available to any of the three rigid formats in the $\overline{N}$TA. To loop through several subcases of distinct boundary condition sets is a very desirable feature, especially for a large-sized $\overline{N}$TA model, in which the types of input data card of a problem generally consist of the conduction elements (the connection and property data cards), the boundary surface elements, the material cards, the radiation matrix input cards (RADLST and RADMTX), and different thermal loading cards for specifying boundary conditions. Usually, thermal loadings need only a few cards to describe needed quantities and conditions in steady-state cases, while the rest of cards constitutes the major part of a bulky input deck. This feature has been developed and used to eliminate time-consuming repetitive submissions of bulky input data decks in succession with only changes pertaining to thermal loadings varied from case to case. This multiple entry feature is limited, however, to steady-state thermal analyses using the rigid formats of APP HEAT, SOL 1 and SOL 3. Specifically, a DMAP-ALTER has been added to handle the following loops for

(1) Only thermal loads are changed.

(2) The MPC and SPC constraints are changed.

(3) The boundary surface elements CHBDY are changed.

The required program changes for looping in this rigid format APP HEAT, SOL 3, are summarized as follows:

    Write ALTER

    Fix to IFP1, PARAML for ALTER.

The DMAP-ALTER packet is shown in Figure 2 for reference.

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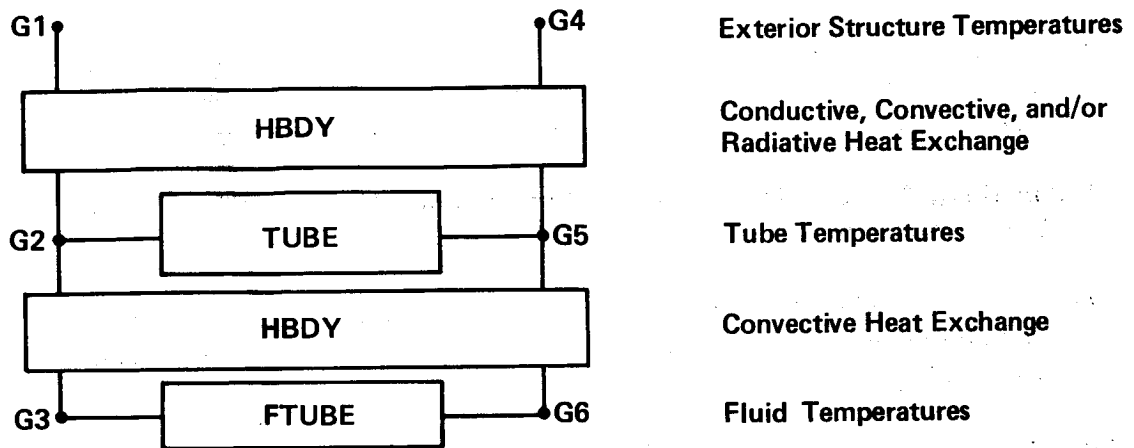   Jan. 1975.

Figure 1. Combination of the $\overline{\text{NT}}$A elements to simulate thermo-fluid effects

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$ THE DMAP-ALTER PACKET TO ALLOW BOUNDARY CONDITION SETS CHANGED IN RF-HEAT,3

$ TO ALLOW TEMP(MATERIAL) TO VARY FROM SUBCASE TO SUBCASE: ALTER 19
$ TO ALLOW SPC OR MPC TO VARY FROM SUBCASE TO SUBCASE: ALTER 31
$ TO ALLOW THERMAL LOAD TO VARY FROM SUBCASE TO SUBCASE: ALTER 58

ALTER 7,7
PLTHBDY   GEOM2,HECT,EPT,HSIL,HEQEXIN,HBGPDT/PECT,PSIL,PEQIN,PBGPDT/
          V,N,NHBDY/V,Y,MESH=NO $
SAVE NHBDY $
EQUIV     HECT,PECT,/NHBDY/HSIL,PSIL/NHBDY/HEQEXIN,PEQIN/NHBDY/HBGPDT,
          PBGPDT/NHBDY $
PLTSET    PCDB,PEQIN,PECT/HPLTSETX,HPLTPAR,HGPSETS,HELSETS/V,N,HNSIL/
          V,N,JUMPPLOT $
ALTER 13,13
PLOT      HPLTPAR,HGPSETS,HELSETS,CASECC,PBGPDT,PEQIN,PSIL,,,,/
          HPLOTX1/HNSIL/HLUSET/JUMPPLOT/V,N,HPLTFLG/V,N,HPFILE $
ALTER 19
SETVAL    //V,N,REPEATT/-1 $
LABEL LOOPTOP
CASE      CASECC,/CASEXX/TRAN/V,N,REPEATT/V,N,NOLOOP $
SAVE REPEATT,NOLOOP $
PARAML    CASEXX//DTI/1/8//V,N,TEMPMATE $
PARAM     //STSR/V,N,TEMPMATE/-10 $
ALTER 32,32
GP4    CASEXX,GEOM4,HEQEXIN,HSIL,HGPDT,, /HRG,    ,HUSET,/HLUSET/
          V,N,HMPCF1/V,N,HMPCF2/V,N,HSINGLE/V,N,HOMIT/V,N,HREACT/
          0/0/V,N,HNOSET/V,N,HNOL/V,N,HNOA $
ALTER 33,33
SAVE HMPCF1,HMPCF2,HSINGLE,HOMIT,HREACT,HNOSET,HNOL,HNOA $
ALTER 37,37
CHKPNT    HGM,HPS,HKFS,HKSS,HUSET,HRG,HKNN,HRNN,HKSF,HRSN    $
ALTER 54
PARAM     //C,N,ADD/V,Y,KSYM/-1/0   $
ALTER 59,59
SSG1      HSLT,HBGPDT,HCSTM,HSIL,HEST,MPT,HGPTT,EDT,,CASEXX,DIT/HPG/
          HLUSET/1 $
ALTER 63,63
SSG2   HUSET,HGM,,,,,HPG/,,HPS,HPF $
ALTER 74,74
SDR2      CASEXX,HCSTM,MPT,DIT,HEQEXIN,,HGPTT,EDT,HBGPDP,HPG,HUG,
          HUGV,HEST,/HOPG1,HOQG1,HOUGV1,HOES1,HOEF1,HPUGV1/STATICS $
ALTER 81,81
PLTSET    PCDB,HEQEXIN,HECT/PSMES,DPLTPAR,DGPSETS,DELSETS/V,N,DSIL/
          V,N,DJ $
SAVE DSIL $
PLOT      DPLTPAR,DGPSETS,DELSETS,CASEXX,HBGPDP,HEQEXIN,HSIP,HPUGV1,,
          HECPT,HOES1/HPLOTX2/DSIL/HLUSEP/JUMPPLOT/V,N,HPLTFLG/
          V,N,HPFILE $
SAVE HPFILE $
ALTER 83
COND FINIS,REPEATT
REPT LOOPTOP,100
JUMP HERROR3 $

$ END OF DMAP-ALTER (53$48)
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Figure 2. The DMAP-ALTER packet for the multiple boundary condition subcases in one execution.