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ACOUSTICAL MODES OF ARBITRARY VOLUMES USING NASTRAN TRANSIENT HEAT TRANSFER RF9

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SUMMARY

An equivalence between temperature and pressure, heat conduction and 'stiffness', and heat capacity and 'mass' is defined, enabling acoustical modal analysis of arbitrary three-dimensional volumes. The transient heat transfer analysis rigid format in NASTRAN, RF9, has been ALTERed providing the acoustical analysis capability. Examples and ALTERs are included.

INTRODUCTION

A twenty-node isoparametric acoustic finite element model was developed in Reference 1 for analyzing the acoustic mode of irregular shaped cavities. In the present paper,

1. the existence of an identical element in NASTRAN (IHEX2) and,
2. the recognition of the similarity between the acoustical matrices of Reference 1 and the thermal matrices of NASTRAN

have enabled the posing and solution of the acoustics eigenvalue problem for arbitrary three-dimensional cavities bounded by 'hard' acoustic surfaces. A simple modification of the transient heat transfer rigid format RF9 provides the acoustics analysis formulation in NASTRAN.

SIMILARITY OF ACOUSTICAL AND THERMAL MATRICES

Summarizing the finite element formulation of Reference 1, the pressure p in a volume V bounded by a surface S satisfies the three-dimensional wave equation and boundary conditions:

$$\nabla^2 p + (\omega^2/a_0^2)p = 0 \text{ in } V, \text{ and} \tag{1}$$

$$\nabla p \cdot \hat{n} = 0 \text{ on } S, \tag{2}$$

where ω is the frequency of vibration of the acoustical mode, a_0 is the speed of sound, and $\hat{n}$ is the outward normal to S. Representing the volume V by an assemblage of three-dimensional finite elements, the corresponding eigenvalue problem becomes

$$[K - \omega^2 M]\{p\} = 0 \quad , \tag{3}$$

where for the ith element

$$[k]_i = \int_{V_i} [B]_i^T [B]_i dV \quad , \tag{4}$$

$$[m]_i = \int_{V_i} \frac{1}{a_0^2} \lfloor N \rfloor_i^T \lfloor N \rfloor_i \, dV \quad \text{, and} \tag{5}$$

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$$[B]_i = \begin{bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{bmatrix} \lfloor N \rfloor_i \tag{6}$$

The shape function $\lfloor N \rfloor_i$ approximates the pressure within the ith element in terms of the nodal pressures $\{p\}_i$ as

$$p = \lfloor N \rfloor_i \{p\}_i \quad . \tag{7}$$

A comparison with the NASTRAN heat transfer analysis capability (Ref. 2) indicates that,

1. equation (4) is identical to the heat conduction matrix, if the thermal conductivity is unity, and

2. equation (5) is identical to the heat capacity matrix, if the thermal capacity per unit volume is $1/a_0^2$.

The temperature degrees of freedom in the thermal analysis are taken to correspond to the pressure degrees of freedom in the acoustics analysis.

The above correspondence together with the real eigenvalue analysis module (READ) permit the determination of the acoustical modes and frequencies. An ALTER package to be used in HEAT APPROACH RF9 is included in the Appendix.

EXAMPLES

The two examples of Reference 1, shown in Figures 1 and 2, were analyzed using the modified RF9. The results, generally in agreement, are presented in Tables 1 and 2, and Figure 3. It is noted that the missing geometric dimensions in Figure 2 were scaled from the figure of Reference 1.

CONCLUDING REMARKS

With a simple modification, and a 'redefinition' of thermal conductivity and capacity, the transient heat transfer rigid format in NASTRAN has been used to determine the acoustical modes and frequencies of arbitrary volumes. The volume can be modelled by any of the solid elements permitted by RF9. Although only acoustically hard surfaces have been considered in this paper, simple extensions to other boundary conditions are considered to be possible.

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REFERENCES

1 Petyt, M., Lea, J., and Koopmann, G. H., "A Finite Element Method for Determining the Acoustic Modes of Irregular Shaped Cavities," Journal of Sound and Vibration (1976), 45 (4), pp 495-502.

2. NASTRAN Theoretical Manual, NASA SP-221(05), December 1978.

APPENDIX

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$ ALTER HEAT RF 9 (NASTRAN RELEASE APRIL 1982)
$
ALTER    26,26 $ SET NOMGG=1 BECAUSE OF ERROR IN IHEX2 LOGIC.
EMG      HEST,CSTM,MPT,DIT,GEOM2,/HKELM,HKDICT,DUM1,DUM2,HBELM,HBDICT/
         S,N,NOKGGX/ 1/ S,N,NOBGG $
ALTER    67,67 $ COMPUTE AND PRINT MODES
DPD      DYNAMICS,GPL,HSIL,HUSET/GPLD,HSILD,HUSETD,TFPOOL,HDLT,,,
         HNLFT,HTRL,EED,HEQDYN/HLUSET/S,N,HLUSETD/123/S,N,NODLT/
         123/123/S,N,NONLFT/S,N,NOTRL/S,N,NOEED//S,N,NOUE $
PARAM    //*MPY*/NEIGV/1/-1 $
READ     HKAA,HBAA,,,EED,HUSET,CASECC/LAMA,PHIA,,OEIGS/
         *MODES*/S,N,NEIGV $
OFP      OEIGS,LAMA,,,, // $
SDR1     HUSET,,PHIA,,,HGO,GM,,,,/PHIG,,/1/*REIG* $
SDR2     CASECC,CSTM,MPT,DIT,HEQDYN,HSIL,,,BGPDP,LAMA,,PHIG,
         HEST,,/,,OPHIG,,,PPHIG/*REIG* $
OFP      OPHIG,,,,, // $
PLOT     PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,HEQEXIN,HSIP,,PPHIG,HGPECT,
         /PLOTX3/HNSIL/HLUSEP/JUMPPLOT/PLTFLG/PFILE $
PRTMSG   PLOTX3// $
ENDALTER
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TABLE 1. ACOUSTIC FREQUENCIES OF A RIGHT-ANGLED PARALLELOPIPED (cyc/T)

(a) Symmetric Modes

Mode	Exact Frequency*	Ref. 1	This Paper
1, 0, 0	699	702	680
2, 0, 0	1398	1542	1495
0, 0, 1	1500	1506	1460
1, 0, 1	1655	1664	1613
2, 0, 1	2057	2155	2090
3, 0, 0	2097	2525	2448
3, 0, 1	2579	--	2925

TABLE 1. ACOUSTIC FREQUENCIES OF A RIGHT-ANGLED PARALLELOPIPED (cyc/T) (Contd.)

(b) Antisymmetric Modes

Mode	Exact Frequency*	Ref. 1	This Paper
0, 1, 0	1250	1255	1255
1, 1, 0	1432	1440	1430
2, 1, 0	1876	1988	1952
0, 1, 1	1953	1963	1928
1, 1, 1	2074	2089	2048
2, 1, 1	2401	2499	2440
3, 1, 0	2442	2875	2808
3, 1, 1	2866	3346	3233

$$* \; f_{\ell, m, n} = \frac{a_0}{2} \left[\left(\frac{\ell}{\ell}\right)^2 + \left(\frac{m}{\ell_y}\right)^2 + \left(\frac{n}{\ell_z}\right)^2 \right]^{1/2} , \text{ (Ref. 1)}$$

ℓ_x, ℓ_y, ℓ_z sides of the parallelopiped

TABLE 2. ACOUSTIC FREQUENCIES OF MODEL VAN (cyc/T)

(a) Symmetric Modes

Mode	Ref. 1 Experimental	Ref. 1 Calculated	This Paper
1	606	593	562
2	1174	1150	1104
3	1549	1556	1524
4	1613	1605	1580
5	1817	1829	1751
6	1992	2026	1993

(b) Antisymmetric Modes

Mode	Ref. 1 Experimental	Ref. 1 Calculated	This Paper
1	1220	1168	1118
2	[illegible]	1317	1245
3	1675	1634	1568
4	1996	1956	1940
5	2021	1997	1968
6	2176	2187	2109

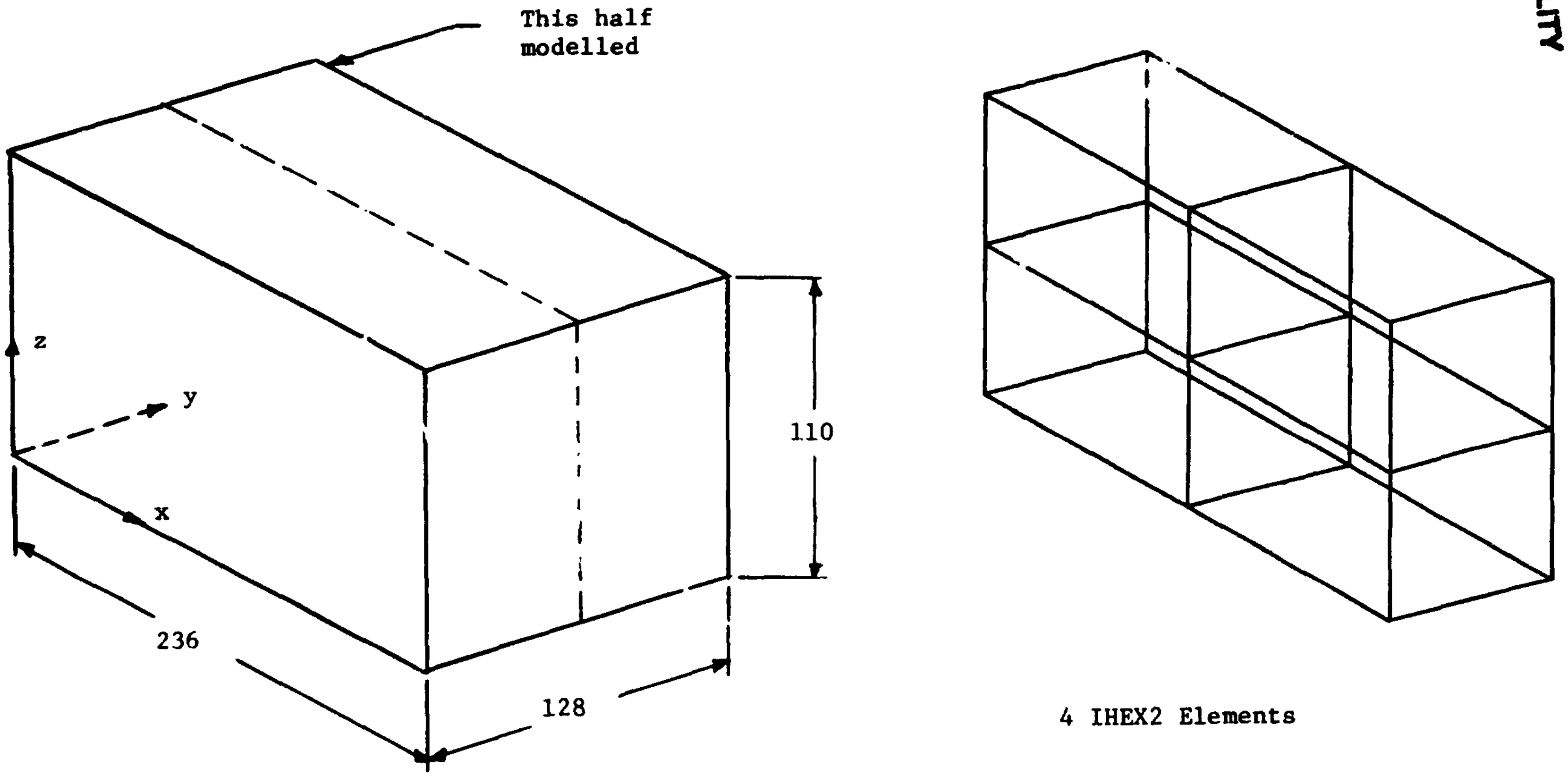

FIGURE 1. DETAILS OF RIGHT-ANGLED PARALLELOPIPED

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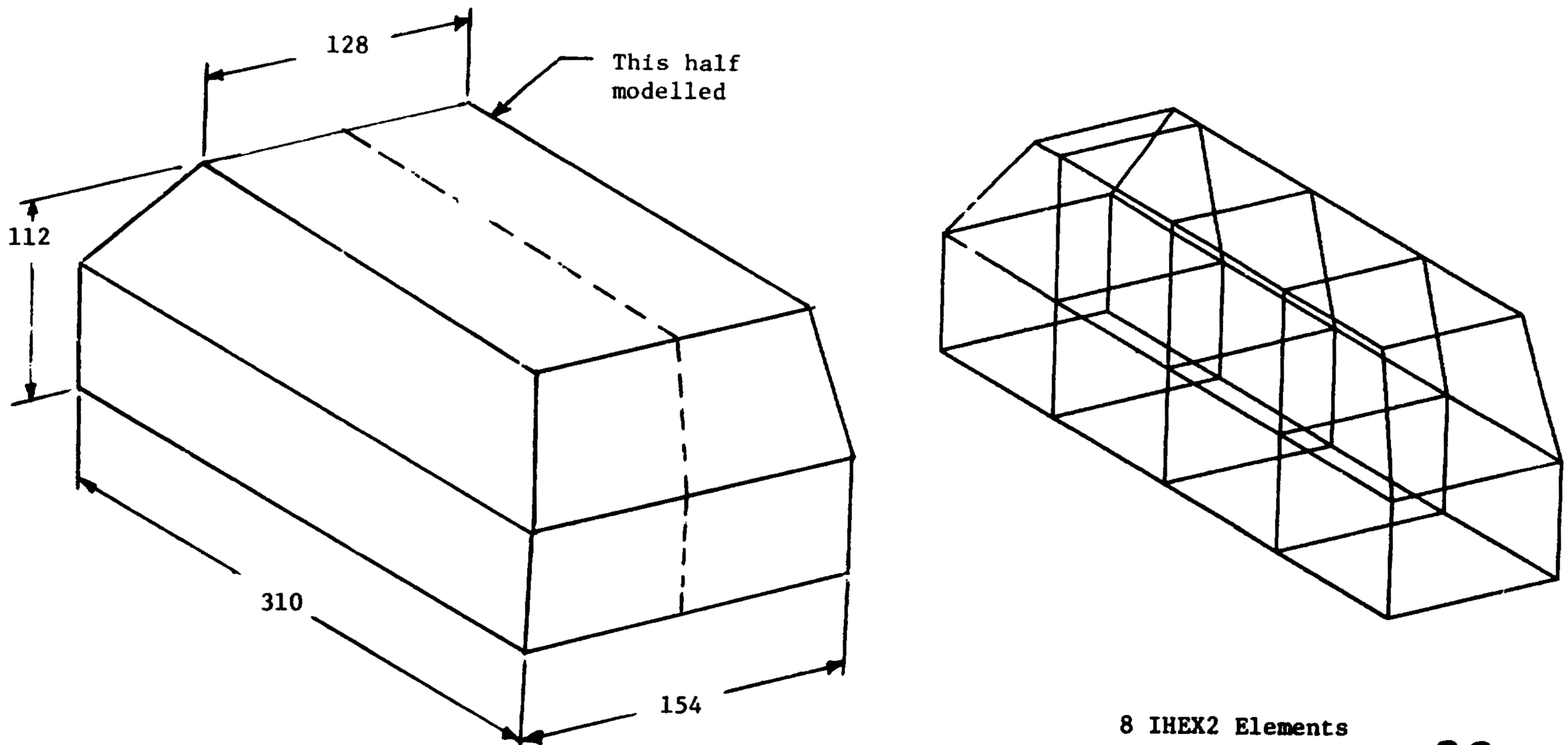

FIGURE 2. DETAILS OF MODEL VAN

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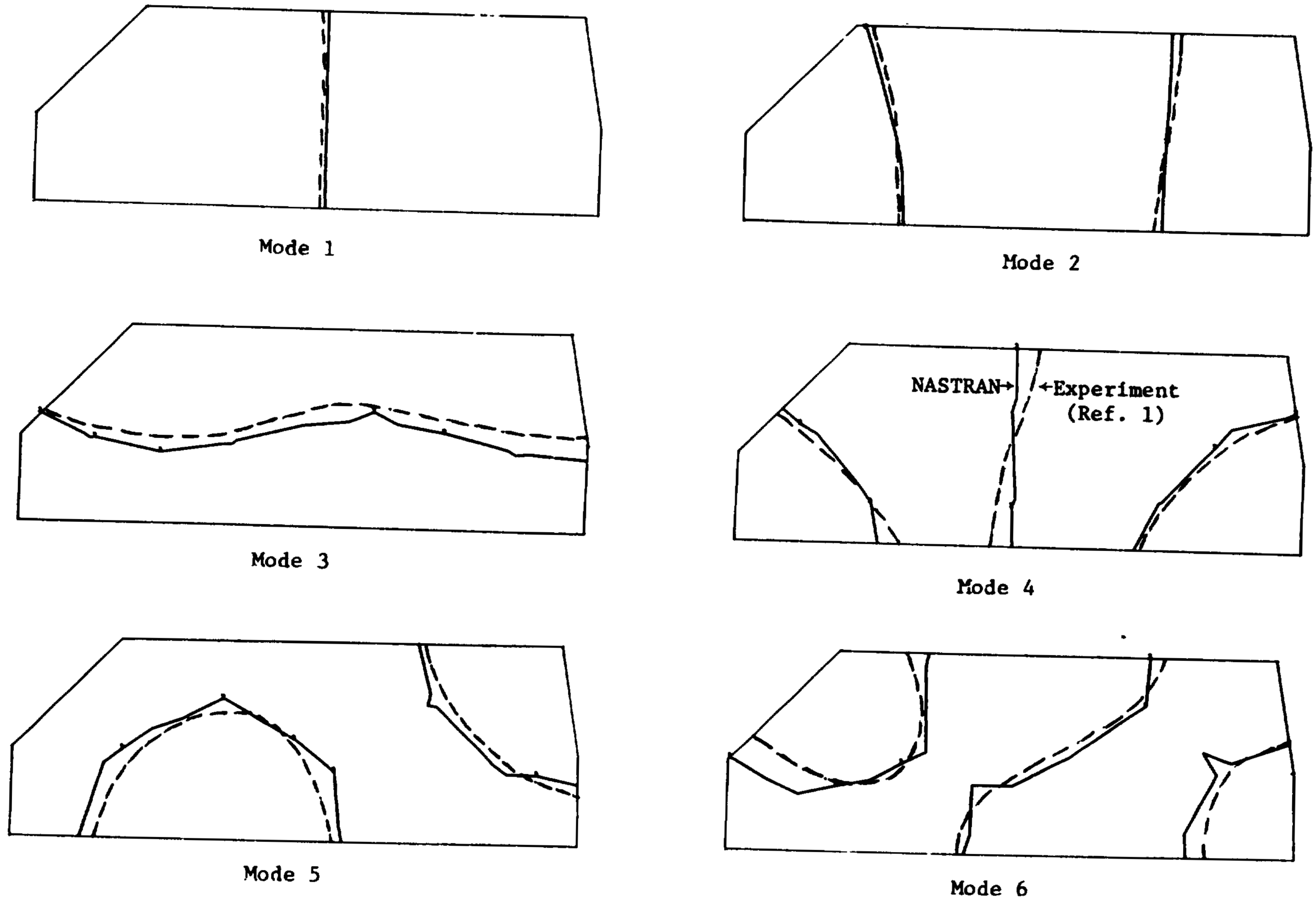

FIGURE 3. SYMMETRIC ACOUSTIC MODES OF MODEL VAN (Figure 2)